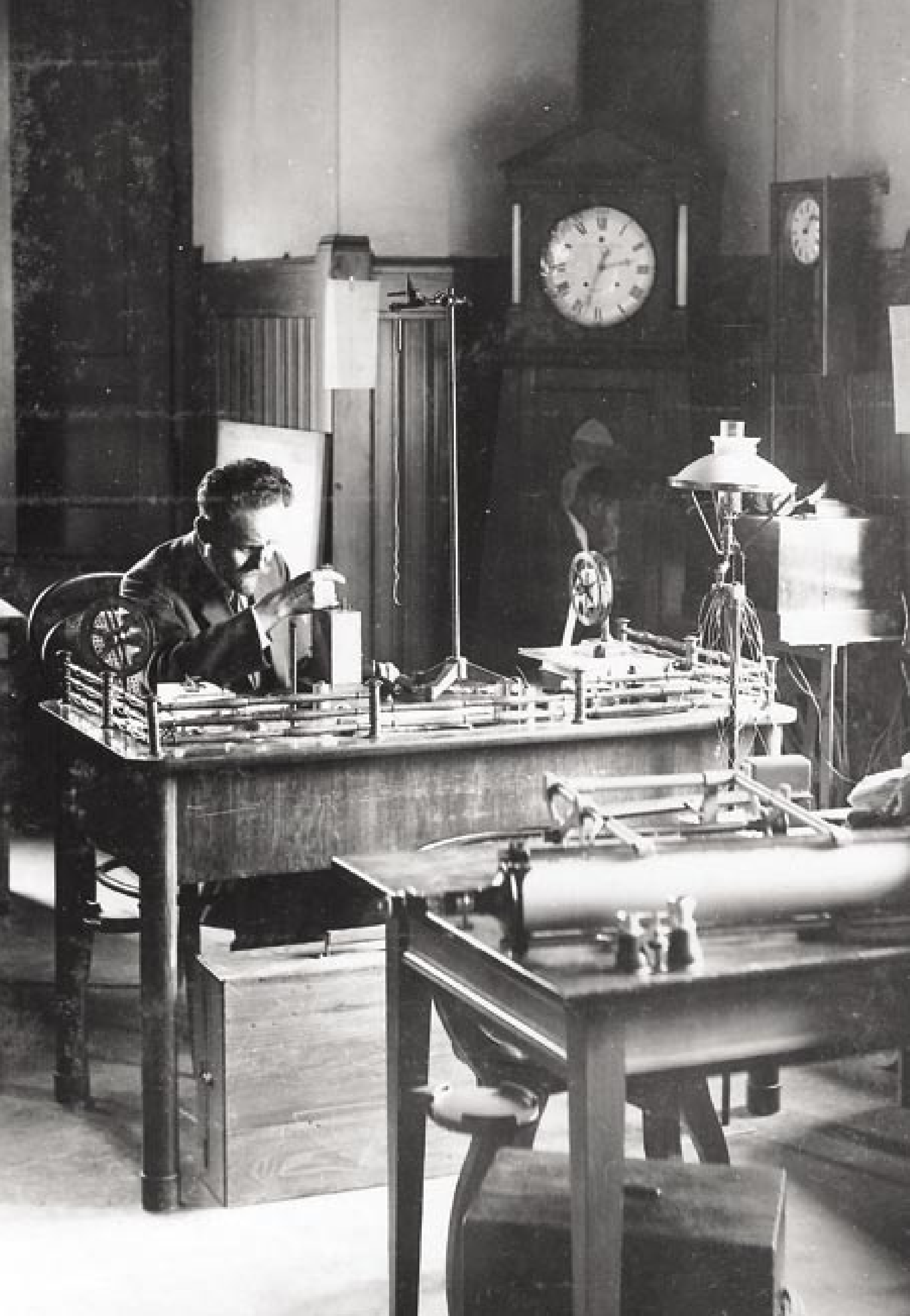
Activity Report 2020

Astronomical Institute / Academy of Sciences of the Czech Republic



Astronomical Institute
of the Czech Academy of Sciences

ACTIVITY REPORT 2020

asu Astronomical Institute
of the Czech Academy
of Sciences

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Left: A photograph from the Institute's historical archives. The Central dome (1914) is among the oldest buildings of the Ondřejov Observatory. It was designed by Josef Fanta, one of the most prominent representatives of Czech Art Nouveau architecture.

FOREWORD

The Astronomical Institute of the Czech Academy of Sciences is a Public Research Institution engaged in professional scientific research in the fields of astronomy, astrophysics and space sciences, as well as in broad public outreach activities that have been pursued at the site of the Ondřejov Observatory as well as in frequent educational events in the capital city of Prague and around the state. Our scientists lead projects and supervise in several doctoral programmes that are accredited by the Ministry of Education, Youth and Sports of the Czech Republic to teach university students to pursue original exploration in astronomy and astrophysics, theoretical physics, and plasma physics.

The Institute is among the oldest scientific institutions in the country. It is the direct successor of the Observatory of the Jesuit College, located in the tower of the Clementinum in Prague, where scientific observations started in 1722. Visitors interested in history of science can tour one of the largest European building complexes occupying two hectares near Charles Bridge. Astronomical Tower offers a beautiful view of the Old Town area just next to Johannes Kepler's house (currently a museum), along with the Baroque Library that still keeps the precious Vyšehrad Codex. In the Meridian Hall, time keeping measurements were carried out till the 19th century and two wall quadrants and unique instruments remain on display to date.

Along a parallel line of history, in 1898, a private observatory owned by Josef Jan Frič was founded in Ondřejov village, 35 km southeast of Prague. In 1928 this small observatory was donated to the state and the Prague University, and then gradually expanded to its current state of the largest professional observatory in the country. The two establishments merged in 1953 within the State Astronomical Observatory to create the Astronomical Institute, since then belonging to the Academy of Sciences. Individual visitors and organized groups are welcome to visit the historical site of the Ondřejov Observatory.

– Vladimír Karas,
the Director of the Astronomical
Institute, *in the Ondřejov*
Observatory, 1st July 2020

Left: The solar radiotelescope and a decorative sculpture in the Observatory Arboretum.

The Institute and modern astronomy in the Czech Republic

Nowadays, the Institute emerges as a modern public organization involved in a rich set of international projects across Europe and worldwide. On the national level the Institute carries out the major part of research in astronomy and astrophysics in the Czech Republic. During the recent two decades the international collaboration of the Institute has been greatly expanded and it currently represents a significant part of its research activities, including a close cooperation with the European Southern Observatory (ESO), the European Space Agency (ESA), the International Astronomical Union (IAU) and other important bodies where we are full members. The Institute represents the Czech astronomical community in the European professional journal of Astronomy and Astrophysics.

Centuries ago, astronomy was the first of classical sciences that had developed an observational basis to verify and, eventually, falsify our theories about the processes shaping cosmic bodies and the Universe as a whole. To this end, the development of highly sophisticated instrumentation has been crucial, as this allows astronomers to carry out precise observations and quantify and record results. However, along with the empirical approach, equally important has been the tight relationship with mathematics that provides the basis for deeper understanding of the origin and evolution of cosmic systems. Astronomy was the first to develop and employ procedures that are now routinely accepted by other branches of science as well as in engineering and technology.

Modern astronomy combines the cutting-edge technology of innovative engineering solutions for highly complex optical systems and space devices with the popular culture and citizen science, where the general public is engaged in research. The Institute contributes actively to all these roles especially through its international involvement in European Southern Observatory and European Space Agency, but also on the national level by cooperating with the Czech Astronomical Society and coordinating the Czech National Committee on Astronomy.

Through the involvement in ESO, the Czech Republic has joined the ambitious project of European Extremely Large Telescope (E-ELT). With the main mirror consisting of 1000 segments, in total 42 metres across, the instrument will collect almost 20 times more light than any current telescope and it will be able to resolve 17 times sharper images than the Hubble Space Telescope. The shape of the mirror surface has to be extremely precise with the roughness less than 10 nanometers. Once the construction of E-ELT is completed, it will have a major impact on our understanding of the Universe, including the most distant objects and the processes shaping the evolution of the Cosmos. During all phases – the design, construction, operation, as well as data reduction and interpretation – astronomy requires highly trained professionals with deep knowledge, technical skills, and maximum dedication and enthusiasm.

Students of astronomy are trained in mathematical methods, theoretical and experimental physics, computing and informatics, as well as modern technology. They have to be; otherwise a continuous flood of discoveries would quickly fade away. However, discover-

A new building of ASU in Prague.

ies in astronomy cannot be planned. In fact, nowhere in science any attempt of perfect planning of next steps has ever worked. Instead, serendipity is what defines future directions for those who are prepared to recognize newly emerging opportunities. The discovery of cosmic microwave background radiation is a clear-cut example of an incidental finding which shaped our view of the cosmic history by supporting the hypothesis of the Big Bang.

Understanding how the Universe functions and evolves, what is our role in it, what will be the future of stars, of our Sun, and of the Solar System is clearly the main motivation for the endless effort of astronomers. It also motivates new generations to learn and creates an enormous interest of general public. But does the basic research in astronomy also provide some kind of direct benefit to the society? In this context the issue of technical innovations and corporate spin-offs has become a fashionable topic of discussions. The Institute oversees the Czech largest involvement in the ESA's scientific space mission of Solar Orbiter that was launched in 2020.

Astronomy for every day

Numerous practical applications of the "blue-sky" astronomy research exist and are very well known: Communication methods of today owe a lot to radio astronomy research that had started several decades ago and helped to develop techniques of transmitting, compressing, detecting and decoding weak signals. Besides other applications this laid basis to the modern wireless technology.

The construction of ever bigger telescopes and ever more sensitive detectors is motivated by an unending hunt for photons from the most distant galaxies, quasars and other faint objects. Clearly this is useful and relevant in numerous other areas of technology development far away from astronomy. Astronomers realized the importance of charge-coupled devices (CCD) for imaging and these detectors are now present in all digital cameras. Likewise, active optics has been greatly improved in recent years in order to achieve amazingly sharp images and removing the degrading effect of atmosphere; the same technique is now employed in other areas of image processing.

X-ray astronomy has been pursued in order to reveal dense compact stars and black holes because the gas becomes enormously accelerated and heated by overwhelming gravitational attraction of these bodies, and so it radiates much of its energy in the form of high-energy radiation, X-rays and gamma-rays. However, the wavelength of this radiation is so short that ordinary telescopes that are suitable for much longer wavelengths of optical light cannot focus it. Astronomers have mastered techniques of X-ray imaging as well as high-dispersion studies of grating spectra. This knowledge is useful in a variety of applications ranging from medicine to security.

One could continue endlessly discussing everyday applications of astronomical research. However, the few above-given examples should help us to understand that, indeed, basic research in astronomy creates valuable knowledge and experience.

Motivated by curiosity, fundamental research is equally useful as the search for solutions to specific problems: not only that the basic science provided foundations to all electronics including computers, transportation including rockets and satellites, communication technology including the Internet, and so on, but even more importantly it creates deep cultural connections and gives us a broad perspective about the Cosmos which surrounds us. Indeed, Heinrich Hertz did not discover electromagnetic waves with the aim of constructing radio; instead, it was the beauty of theoretical physics, which describes electromagnetism in terms of Maxwell's equations, that captivated him. Firm observational evidence in the form of data acquired by ground based telescopes and detectors on-board satellites are essential for the astronomical research, as well as the whole science, as without them the purely speculative approach risks losing its directions.

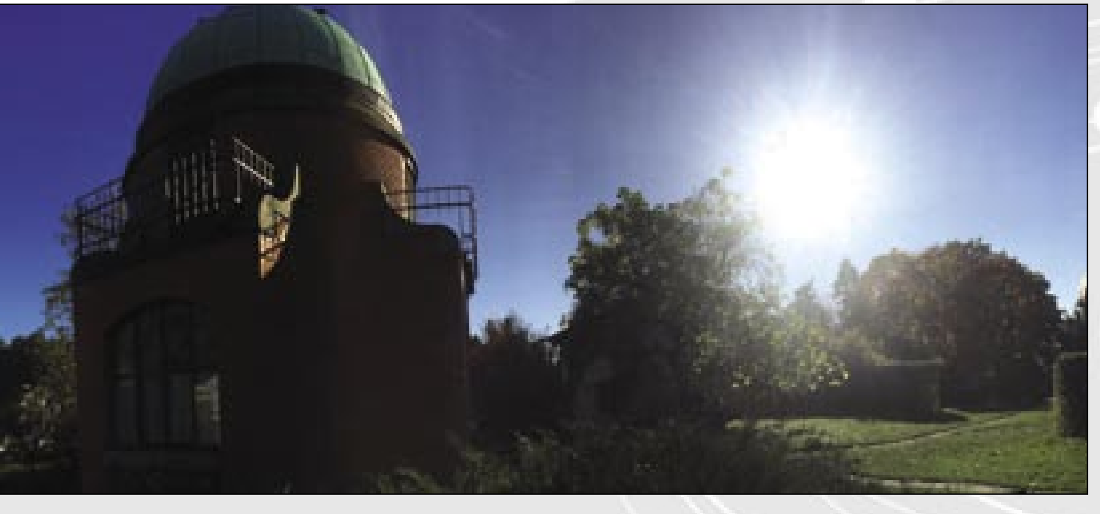
At the Astronomical Institute we participate in the effort to reveal fundamental facts about our Universe and its diverse constituents including our Sun and billions of other suns in the Milky Way and distant galaxies, planets and small bodies of the Solar System, as well as enigmatic black holes and neutron stars. We do it because we recognize these topics as immensely important and also because we are confident that our research, like any other high-quality basic research, is equally useful for our society as the search for direct solutions to practical tasks of everyday life.

Participation in international projects

The Institute scientists have continued to collaborate in numerous ongoing international projects that are financed by the Czech Ministry of Education, Youth and Sports, the Czech Science Foundation, the European Union and other bodies and agencies. Recently, several large-scale EU FP7 and FP9 grants were successfully completed. In 2019 the Astronomical Institute hosted a number of celebrations remembering the 100th anniversary of the International Astronomical Union. Among the outcome of these activities and panel discussions the formulation of the roadmap for Czech astronomy has been particularly useful for our research field.

While celebrating its 125th anniversary in 2015, The Czech Academy of Sciences formulated and implemented a visionary New Strategy "AV21". The Astronomical Institute contributes to this ambitious endeavour in the area of space missions (aimed to support the participation of Czech scientists and industry), cosmic hazards (namely, by studying risks from near-Earth objects and exploring potentially dangerous asteroids), and the space weather (the impact of Solar activity on life of individuals and the entire civilization of the Earth). We wish to work further towards expanding the astrophysics subjects to include more of our essential research areas, in particular, the technologically demanding Space Exploration, as well as the synergic overlap with Astroparticle Physics that appears so highly relevant to address fundamental open questions of today.

The afternoon sun shines above the historical domes of the Ondřejov Observatory.



II

OUR MISSION

Research in Astronomy and Astrophysics has a long and internationally recognized tradition in the Czech Republic, formerly Czechoslovakia. The Astronomical Institute of the Academy of Sciences of the Czech Republic (the "Institute", abbreviated as ASU hereafter) is the largest scientific institution in the field, also involved in educational activities and supervision of students in the country. The Institute is traditionally active in solar physics, stellar and galactic astrophysics, and studies of interplanetary matter. Four Science Departments represent active research directions. These are led by Senior Research Scientists.

The Astronomical Institute of the Academy of Sciences of the Czech Republic is the foremost Public Research Organisation (veřejná výzkumná instituce – v. v. i.) in the field. Its major part is located in the village of Ondřejov southeast of Prague, where it operates the largest Czech optical telescope and a variety of other instruments. Part of the Institute is placed in a detached section Prague. While the Organizational Structure of the Institute has been stabilized since the major reorganization in the early 1990s and an update in 2005, there exists a procedure involving the Director and the Institute Council which allows for modifications to be considered in case it might turn out to be desirable and substantiated. Two new working groups have recently been established to pursue exoplanetary research and to develop radio astronomical techniques.

The Institute is one of the oldest scientific institutions in the Czech lands, and it is a modern scientific institution. As a direct successor of Prague Clementinum, the Ondřejov Observatory was originally established by Doctor J. J. Frič as a private observatory situated near the village of Ondřejov back in 1898. Since then it has been gradually developed to its current role as a significant player in the Czech scientific environment.

Left: An aerial view of the dome of the Perek 2m Telescope (left) and the Stellar Department building (right) at the Ondřejov Observatory. (© Jaroslav Horák)

The Institute profile, its research activities and basic results and financial operation are described in Annual Reports, which have a structure defined by legal requirements, and in Activity Reports published bi-annually (English Edition). Further information can be found in Annual Reports of the Academy of Sciences (available in both Czech and English Editions). Finally, the Institute has a renewed website (http://www.asu.cas.cz), which is also dedicated to the general public and youth.

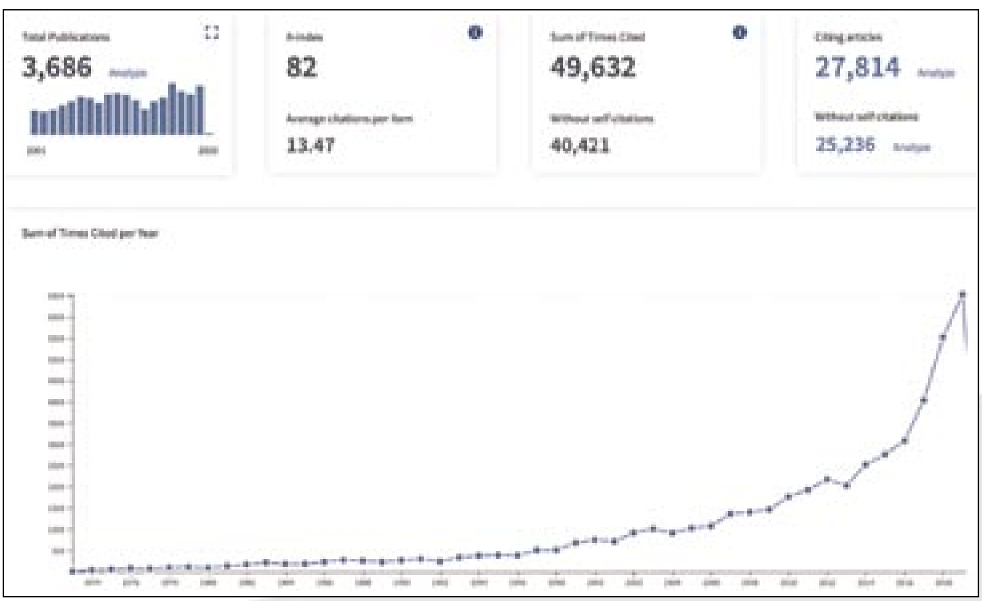
In four Science Departments (Teams) the research staff of the Astronomical Institute is primarily engaged in solar physics, stellar physics, meteors and asteroids, and galaxies and extragalactic objects. As the main academic institute in the field of Astronomy and Astrophysics in the Czech Republic, we examine the objects and the effects from the immediate vicinity of the Earth to the remote Universe. A variety of instruments is in daily use at the Observatory for different kinds of investigations and observational programmes, suitably selected for the local conditions. The Institute operates the largest telescope in the Czech Republic – the Perek 2m Telescope. The other instruments are mainly devoted to photometry of asteroids multichannel spectroscopy for monitoring solar flares, solar patrol service programme and solar radio monitoring, a photographic zenith telescope, a robotic telescope for recording the optical counterparts of gamma-ray bursts within the network, and automated cameras to track bolides.

Steadily growing impact of scientific publications of the Institute's researchers can be seen in the bottom figure. Let us note that for Phase I of this Evaluation (bibliometrics) we selected only a fraction of relevant publications where the role of our scientists is clearly demonstrated by their leading position on the list of authors. However, our scientists frequently join large consortia, where the Institute contributes in cooperation with many other international institutions. This is particularly important in preparations for space missions (e.g. White Papers on proposed satellites, often with hundreds of co-authors). In these cases, the authorship is less visible, nevertheless, such activities are also highly important for the future development of Astronomy and its technological basis.

A strong aspect of the Institute performance is its extensive international collaboration. Regardless of the difficulties in establishing international contacts before 1989, the Institute is now internationally recognized as the leading research organization in the field of Astronomy and Astrophysics. Since the General Assembly of the **International Astronomical Union** (IAU) in Prague in 2006, the Institute has organised numerous international meetings and symposia. In particular, in a close cooperation with the **European Astronomical Society**, European Week of Astronomy and Space Science was held in Prague 2017.

In 2008 the Czech Republic became a regular member of the **European Space Agency** (ESA). This membership was a successful ending of long-lasting negotiations with ESA representatives and preparation on the Czech side. During that preparatory period scientists of the Institute helped with organizational matters

Numbers of yearly citations (since 1973) to scientific papers published by the authors with the Institute affiliation. The steadily growing tendency demonstrates an increasing international impact of the astronomers working in the Institute. (source: Web of Science)



The building of Cosmic Laboratory hosts the headquarters of the Astronomical Institute at the site of the Ondřejov Observatory.

related to space research. Since then the Institute has been playing a visible role in the space research in the Czech Republic which helps us to build long term strategic partnerships between industry and academia. The Institute continues to have representatives in the national Board for Space Activities, in the Board of Directors and Supervisory Board of the Czech Space Office, in the Czech PRODEX Board, in the Board of Space Activities of the Czech Academy of Sciences and in the Coordination Board of the Ministry of Transportation. The ESA membership has opened new broad possibilities especially in the field of space-related sciences.

Within the **European Southern Observatory** (ESO), where the Czech Republic has been a regular member since 2007, new opportunities for observations with the largest telescopes emerge and ongoing individual programmes are submitted and carried out at Paranal and La Silla sites. As described in a separate section dedicated to large infrastructures, an Atacama Large Millimeter/submillimeter Array Regional Centre (ARC) has been situated in the Ondřejov Observatory. The Institute has signed an agreement on the usage of the Danish 1.5m telescope for asteroid research and stellar photometry. Moreover, the Institute also takes an active role in promoting all aspects of ESO membership in the Czech Republic, scientific as well as industrial.

The materials presented in this report provide an update of the corresponding material submitted for the previous five-year evaluation period and they maintain similar structure in order to facilitate an easier comparison of the progress achieved in ASU. The current report was written during the developing state of COVID-19 medical emergency; the period covered here does not include important changes in the society that we have to anticipate in the future.

Research directions investigated by the Institute over the past five years (2014–2019)

The scientific life of the Institute is organized within four Departments. These are equivalent to Teams for purposes of the present Evaluation:

Department of Solar Physics

Team #1 **(the Head Mgr. Miroslav Bárta, Ph.D.)** focuses on processes in both active and quiet solar atmosphere. Active processes affect the entire outer space including the Earth and its immediate environment (i.e. the space weather). At the Ondřejov Observatory, a long-term systematic study of the Sun in optical and radio wavelengths of electromagnetic radiation is carried out, and these observations are supplemented with the data gained thanks to the international cooperation from satellites providing information on solar radiation in the ultraviolet, X-ray and gamma-ray bands of the spectrum. Solar flares and prominences, structure and dynamics of the solar atmosphere and heliosphere, and space weather are examined. Processes in solar flares and prominences are numerically modelled with the particular emphasis on the magnetic reconnection and the particle acceleration mechanisms. Regions of the Sun at different altitudes are studied in order to understand the interaction between the motion of plasma and the magnetic field. The dynamic phenomena of the solar wind are monitored, especially the formation and propagation of coronal mass ejections and their associated magnetic clouds, as well as the interaction of the solar wind with the Solar System objects.

Department of Stellar Physics

Team #2 **(the Head Mgr. Brankica Kubátová, Ph.D.)** studies stars, especially stellar winds and outflows, double and multiple stars, with the emphasis on their evolution, interaction and mass exchange in close systems. The research mainly concerns the class of hot stars (especially the spectral class B). These are highly luminous bodies, often showing the presence of a circumstellar disc of accreted material. The formation and physical characteristics of accretion disks are not yet satisfactorily explained. Their research is divided into a practical study of stellar spectra and a theoretical investigation of atmospheres and stellar winds using sophisticated numerical simulations. The studied spectra are acquired by the 2m telescope in Ondřejov and at other observatories thanks to the international cooperation (mainly in the framework of our membership in ESO, and elsewhere within the collaboration). The Department also deals with the study of white dwarfs, their classification and determination of the basic physical parameters of the acquired spectra. More recently a new working group on exoplanetary research has been established. There is also an ongoing research of galactic and extragalactic cosmic sources of high-energy radiation in visible light and in the field of high-energy radiation, namely, flashes of gamma radiation and their optical afterglows.

Department of the Interplanetary Matter

Team #3 **(the Head RNDr. Pavel Spurný, CSc.)** conducts the research of the small objects of the Solar System, namely, meteoroids and asteroids. The department studies the interaction of the interplanetary objects of various sizes with the Earth's atmosphere, observes meteors and works on the theoretical interpretation of observations. The Team contributes and employs the European Fireball Network which was founded by the Astronomical Institute and continues to be organized by the Team. It also cooperates in similar activities connected with bolides observations worldwide. All of these activities generate highly visible results – the so-called Meteorites with genealogy. The observed data are used for the study of the physical processes during the meteoroid penetration into the Earth's atmosphere, which includes radiation, ionization, and fragmentation. The physical characteristics and the chemical composition of various types of meteoroids are determined, as well as their origin and distribution in the Solar System, their relationship to comets, asteroids and meteorites. Furthermore, we study non-gravitational processes in small asteroids, binary systems and paired asteroids, and asteroids in excited (non-principal) rotation states. We also observe so-called Near-Earth Asteroids and their source regions.

Department of Galaxies and Planetary Systems

Team #4 **(the Head Mgr. Richard Wűnsch, Ph.D.)** studies the evolution of isolated galaxies, galaxies in groups and clusters, the formation of stars and stellar systems. The Team explores the dynamics of the Milky Way galactic system – Magellanic Cloud, also free gas blown from galaxies due to their movement in the environment and spatially resolved spectroscopy of galactic nuclei. Observations in radio, infrared, ultraviolet, and X-ray bands are compared with the results of analytical models and computer simulations of gravitational and magnetohydrodynamic processes. The Team scientists are devoted to physics of compact objects (neutron stars and black holes) and study processes taking place in their vicinity. On the theory side, within the framework of the General Theory of Relativity the characteristics of compact objects are analysed and modelled, in particular, the nuclei of the active galaxies, neutron stars and microquasars. The modelling of multiwavelength characteristics of the produced electromagnetic signal is performed for spectra, polarization and temporal variability. Furthermore, as another research line, part of the Team studies the rotation of the Earth, the orientation of its axis in space and the gravitational field.

Further details about the scientific and educational activities of our Teams are given in the separate sections that describe the Departments and Working groups active in the Institute. Let us note that the definitions of the four Teams and their Working groups agree with the official structure of the Institute, as listed in its organization chart.

A steadily growing impact of scientific publications of the Institute's researchers is seen in Figure on p. 12. Let us note that for Phase I of this Evaluation (bibliometrics) we selected only a fraction of relevant publications where the role of our scientists is clearly demonstrated by their leading position on the list of authors. However, our scientists frequently join large consortia, where the Institute contributes in cooperation with many other international institutions. This is particularly important in preparations for space missions (e.g. White Papers on proposed satellites, often with hundreds of co-authors). In these cases, the authorship is less visible, nevertheless, such activities are also highly important for the future development of Astronomy and its technological basis.

Let us note at this point that already in 2011 ESA approved the Solar Orbiter (M2-class satellite mission by ESA) and the work on the satellite construction started. ASU scientists and technicians participated in three international consortia to build the scientific payload instruments METI S (UV coronagraph), STIX (hard X-ray telescope) and RPW (in situ radio plasma-wave detector). At the end of 2019 the instruments were successfully delivered, tested and integrated in the satellite and the launch has been scheduled for February 2020.

The above-mentioned Science Departments – Teams are further sub-divided into ten Working Groups in total, where the actual research activities are carried out: see the Organizational Structure of the Institute. The Director establishes working Groups following a discussion in the Institute Council. Each of the Working Groups is led by a distinguished senior researcher with a supervision and management record. A more thorough exposition of scientific activities and results are thus given in the description of the individual Teams elsewhere.

ESO has established one of European ALMA (Atacama Large Millimeter/submillimeter Array) nodes in Ondřejov, which provides the expertise mainly for the solar physics community. The Institute proposed a new ALMA-CZ Research Infrastructure in 2014, and it is currently at a promising stage of negotiations for funding. The European ARC (ALMA Regional Centre) has been formed as a coordinated distributed network of seven nodes centred around ESO. One of the nodes is hosted at the Astronomical Institute of the Academy of Sciences in Ondřejov. The Czech node provides services namely in ALMA-related research in solar physics and laboratory millimetre spectroscopy. In these areas it serves the ALMA user community in the Czech Republic and entire region of Central and Eastern Europe. In the solar research with ALMA this expertise is unique even on the European scale. Partly it also serves international community from Brazil and Chile (ALMA location). The services provided to the users range from help with proposal preparation (Phase I), negotiation of technical details of the project with the observatory (Phase II), data reduction and imaging (QA2) up to help with data analysis and interpretation. At the same moment the Czech node helps with further development of ALMA in commissioning of the new solar observing mode. In fulfilling its tasks, the Czech node closely collaborates with ESO, partner nodes in Europe, ARCs at NRAO and NAOJ, Joint ALMA Observatory (JAO) and also with academic institutions in the Czech Republic.

The European Fireball Network (EN) was established in former Czechoslovakia in 1963 and its current updated version represents the longest continuously operational fireball network in the World. It consists of four closely cooperating parts – Czech, German, Slovak and Dutch. The centre of EN is located in Ondřejov and the Institute coordinates all its activities. The most developed part operated directly by the Institute consists of fourteen stations in the Czech Republic, three in Slovakia and one in Austria and Germany. This core of the network was completely modernized in the last 6 years and equipped with new instruments for a complex study of bright meteors. Except fully automated digital photographic cameras for direct and spectral observations of fireballs (DAFO and SDAFO) we also use supplementary video arrays which provide us with additional information about dynamics, fragmentation and spectral types. For a detailed fragmentation study we developed a unique system called Fireball

Intelligent Positioning System (FIPS). This system consists of a low-resolution high-sensitivity all-sky video camera, which monitors the sky and recognizes moving objects, and a high-resolution tracking camera with the field of view of 15°, which is able to reach any position in the sky in about one second and then track the fireball according to the instructions from the all-sky video. The fireball fragmentation can be therefore observed in high resolution starting about two seconds after the fireball beginning. We significantly participated in developments of all these sophisticated instruments. This experiment enables us to study fireballs to such an extent, precision and complexness as never before. Within the scope of this experiment, we closely cooperate with our colleagues in Comenius University in Bratislava, and with several amateur groups active in Poland, Slovenia, Croatia, Austria and Hungary. We have continued to use the double station video observations of faint meteors. Our goal in this research has been not only to monitor the activity of known meteor showers but also to look for unexpected events. In case of predicted outbursts or enhanced activity we promptly adjust our observational programme. For this purpose, we use an automatic double station MAIA camera as well as original manual video cameras.

Furthermore, we study rotational properties of asteroid pairs. Recently, we measured 35 pairs with our technique of time-resolved photometry. Most data were taken with the 1m telescope at Wise Observatory, Israel, and the 1.54m Danish telescope at La Silla, Chile. We derived their primary spin and mass, and we found a strong correlation between the square of primary spin frequency and the mass ratio. Also, the 0.65m Ondřejov photometric telescope has been refurbished and it is remotely controlled and works in a semi-automatic mode. It is used for photometry of asteroids in the vicinity of the Earth and in their source regions in the asteroid main belt. It serves as a supplementary instrument for the 1.54m Danish telescope at ESO's La Silla station, within our project on non-gravitational processes in asteroids.

The Solar Activity Monitoring and Forecasting unit (see the website http://www.asu.cas.cz/~sunwatch/) provides regular solar observations in the white light and the Hα line. It uses three small full-disc telescopes for drawings, white light, and Hα and two 20cm telescopes for imaging of active regions in the photosphere and Hα chromosphere. The results are shared within the International Space Environment Service (ISES) as a part of the Regional warning Centre Prague (station No. 31516), and the Solar influences Data Centre (SIDC) in Brussels. In addition to solar observations, the unit collects all the accessible data on the actual state of solar activity. Daily and weekly forecasts are compiled. Apart from the scientific usage, these are presented on the Czech Television as a part of daily weather forecasts. The solar-activity forecast, made in Ondřejov since 1978, is a national service and represents an integral part of the international space weather programme.

The Teams of the Institute at the Ondřejov site as well as abroad pursue other important programmes. These include an active involvement in the recently established EAST (European Association for Solar Observations) Organization as well as an active participation in a large solar project GREGOR, the largest European solar telescope, where the Institute takes part under a bilateral agreement with the Leibniz Institute for Astrophysics. This has opened an opportunity for the Czech solar community to obtain the leading-edge data. The 1.5m solar reflector, located at Observatorio del Teide, Tenerife, was developed and built under the leadership of the Kiepenheuer Institute for Solar Physics in Freiburg with the Leibniz Institute for Astrophysics Potsdam, the Institute for Astrophysics Göttingen, and the Max Planck Institute for Solar System Research in Göttingen as German partners and with the Instituto de Astrofísica de Canarias and the Astronomical Institute of the Czech Academy of Sciences as international partners. The participation of ASU in this project enabled our scientists to join the large infrastructure consortium of the upcoming EST Solar telescope.

The Zeiss Photographic Zenith Tube (PZT) has been operated and controlled remotely in a fully automatic mode. PZT is used for monitoring non-polar and non-tidal deflections of the local vertical caused by the changes of mass distribution in near and distant surroundings. To obtain the full vector of gravity, we complete our observations of the direction of the local vertical with the observations of the gravitational acceleration performed at nearby located absolute and superconducting gravimeters of the Geodetic Observatory Pecný. Thanks to the achieved accuracy of PZT observations, our instrument can also serve as a reference station for the new mobile zenith cameras developed recently over the world.

Among very frequent domestic cooperation agreements we can select the following examples:

- Agreement on scientific collaboration and joint accreditation of doctoral programme in Theoretical Physics, Astronomy and Astrophysics with Charles University (the Faculty of Mathematics and Physics)
- Agreement on a scientific collaboration and joint accreditation of doctoral programme in Theoretical Physics and Astrophysics with Masaryk University in Brno (the Faculty of Science)
- Agreement with Research Institute of Geodesy, Topography and Cartography (Public Research Institution) in Zdiby about mutual cooperation in Geodesy, Astronomy and Astrophysics
- Agreement with the Czech Technical University in Prague about cooperation in experimental cosmic research
- Agreement with the Institute of Atmosphere Physics (Public Research Institution) in Prague on shared use of supercomputing resources
- Partnership with ESERO Consortium – ESA Education Office in the Czech Republic

In addition to formal agreements, as an example of (one of many) successful scientific results obtained in an informal cooperation of our researchers, we mention the Press Release from the Gemini observational programme carried out by one of our Teams, which has been included among Science Highlights and elected by the Institute Council as among five important published results (see below).

The above-mentioned agreements and ongoing supervision of students prove that the Institute has established strong links with universities, namely those in Prague, Brno, Opava, Ústí nad Labem, Plzeň, and Liberec. The Ph.D. programme is based on accreditations approved by the Ministry of Education, Youth and Sports (MŠMT) and mutual agreements about collaboration with Charles University, Masaryk University in Brno, and others. Scientists are involved in teaching on the level of Master ("magister") and

Ph.D. ("doctoral") programmes. The Institute has four Full Professors, as well as Associate Professors (Docent) and Doctors of Science (DrSc., DSc) who serve in Doctoral Boards, State Examination Committees, Science Councils, and other relevant bodies.

In the frame of the state accreditation system the Institute's scientists supervise PhD students who take part in the ongoing research projects. After defending their Theses many of these students find postdoctoral positions at top research institutions abroad, thanks to extensive international contacts of the Institute's leading scientists. The Institute runs a postdoctoral programme which is open to all qualified international applicants (currently, several Czech and foreign researchers work at the Institute and some of them became staff members). The Institute has been successful in attracting doctoral grants and Centres of Excellence funded by the Grant Agency of the Czech Republic (previously Center for Theoretical Astrophysics, followed by Albert Einstein Center for Gravitation and Astrophysics). This has enabled additional funding to our PhD programme. The Institute provides the summer practice and field trips for undergraduate students from schools in Prague, Brno, as well as from abroad.

International cooperation

International collaboration of the Institute has been traditionally very broad, as is reflected by the position of Director's Deputy for International Relations in the Institute Management scheme. Natural focus of the cooperation goes toward European countries and institutions, which however reach far beyond the traditional definition of Europe (for example the European Southern Observatory is located in Chile and includes several Southern American countries). Furthermore, special projects cover joint research work of the Institute astronomers with U.S. scientists (e.g. the scientific participation in Space Research performed within NASA programmes or a continued research done jointly with collaborators at Massachusetts Institute of Technology or the Smithsonian Center for Astrophysics). More recently a promising opportunity has emerged within the Czech Academy and the Chinese Academy of Sciences mutual cooperation scheme; currently we closely cooperate on the Phase A / B of new polarimetry missions.

In addition to the existing inter-academy agreements, the Institute has established a frequent international cooperation and declared Memoranda of Understanding with relevant institutions and societies active in Astronomy and Astrophysics worldwide. As an example, these include:

- Astronomical Institute of the Slovak Academy of Sciences
- Max-Planck-Institut für Astronomie in Heidelberg
- European Southern Observatory
- Hvar Observatory of the University of Zagreb
- Faculty of Mathematics of the University of Belgrade
- Fachhochschule Nordwestschweiz in Windisch
- Institut für Physik in Graz
- Shanghai Astronomical Observatory
- Niels Bohr Institute in Copenhagen
- National Astronomical Observatory of Japan
- Leibnitz-Institut für Astrophysik in Potsdam
- Physikalische Institute der Universität zu Köln (Cologne)
- Center for Theoretical Physics of the Polish Academy of Sciences in Warsaw

HR policy of the Institute

The Career Code of the Czech Academy of Sciences regulates the position of the academically educated workers, whereas the corresponding labour laws regulate the commencement, changes and the termination of the employment. The Career Code is carefully observed at the Institute.

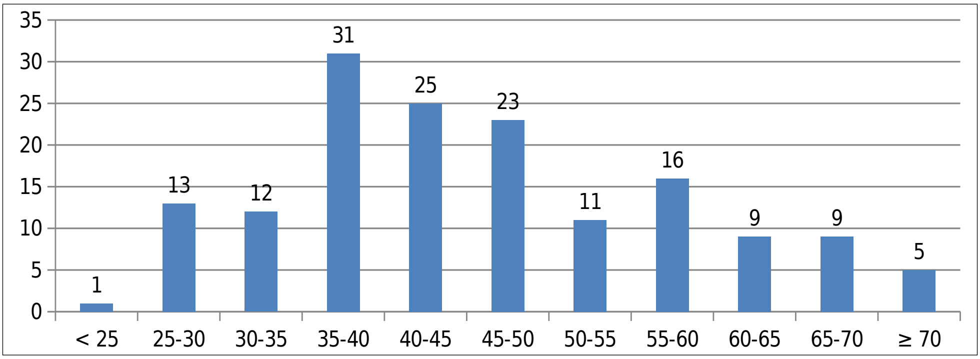
The workers are recruited on the basis of the tender announced by the Director of the Institute of the Academy of Sciences of the Czech Republic. The recruiting procedure is regulated by article 51 of the Articles of Association of the Academy of Sciences of the Czech Republic. Job performance, creative activity and the results of workers are evaluated regularly. In the evaluation of the workers, no discrimination on the grounds of sex, age, origin, religion, political views etc. must be present. The workers are, on the basis of evaluation results in attestations placed in the qualification grade. The evaluation result is decisive for the further career progression and the wage of the worker. The worker may be attested at the request of the manager or on his/her own motion.

Workers' remuneration is regulated by the Internal Wage Regulation in which wage categories for each qualification grade are specified. Workers shall comply with the Code of Ethics for researchers of the Czech Academy of Sciences.

The Institute provides conditions for the professional development. Workers are asked to participate, according to their possibilities, in education of students and public which is the main means of increase of the level of knowledge and its spread. Teaching is considered an important activity of the Institute workers.

The Institute Qualification Grades for the academically educated workers are defined as follows:

1. Research assistant – a worker with a completed university degree
2. Graduate student – a worker studying Ph.D.
3. Postdoctoral fellow – a worker who has acquired Ph.D., Dr. or the equivalent (hereinafter "Ph.D."). Ph.D. usually works under the leadership of experienced research workers and publishes his/her results both independently and within a creative team. As Ph.D. one can be categorized for 5 years the longest after he/she defends his/her Ph.D. degree.
4. Associate scientist/scholar – a worker who is not categorized within the higher qualification grade 5 or 6 after five years from his/her Ph.D. degree completion have expired.
5. Scientist/scholar – a worker who had been granted CSc. degree, academic degree Ph.D. He/she works independently, performs exacting and difficult tasks in his/her scientific field. He/she regularly publishes scientific papers in both domestic and foreign review magazines and he/she usually is an investigator of grant or programme projects.
6. Senior scientist/scholar – a worker fulfilling qualification grade 5 requirements. In addition, he/she is also a leading scientific person who significantly takes part in the development of the specific scientific field in the international measure. Subject to the approval of the Czech Academy Coordination Committee. Senior workers may acquire an Emeritus Scientist status as an appreciation of lifelong successful scientific work and merits of development of the Institute or in the field of science.



Age structure of the Institute (related to 31st December 2019).

The evaluation (Attestation) of individual scientists takes place regularly at the Institute to ensure a high standard of research. The principal criterion is the number and the value of publications in refereed and impacted journals, as well as educational and management activities for the Institute. The general aim of these attestations is: to increase the level of scientific activities of the Institute; to create the base for conceptual or rational personal policy of the Institute; to compare the results of the activities of workers within the qualification grade; to encourage the workers to a systematic professional growth; to provide the workers a regular opportunity for self-reflection.

The subject of the evaluation at the Attestation shall exclusively be a scientific, professional or a pedagogical activity of a worker. The regular attestations do not apply to: the Director of the Institute, who is appointed to the function on the basis of a tender and whose activity is evaluated by the Academic Council of the Academy of Sciences of the Czech Republic in different context or deadlines; Visiting researchers who are employees of other domestic or foreign institutes; Emeritus scientist workers of the Academy of Sciences of the Czech Republic; Under the decision of the Director, also researchers – retiree who are appointed for the maximum period of one year.

The evaluation during the Attestation is carried out by the Attestation Commission appointed by the Director of the Institute (article 23 sub. 2 of the Articles of Association of the Academy of Sciences of the Czech Republic appendix) after the discussion in the Council of the Institute (article 11 b) of the Articles of Association of the Academy of Sciences of the Czech Republic appendix). The Attestation Commission has got at least five members and at least one third of them must not include the employees from the relevant institute.

The Attestation Commission takes actions on a yearly basis (it may take actions more often if needed). It is possible to establish more Attestation Commissions at the institutes that would coordinate their actions.

The Director provides the Regulation (available in writing in Czech and English language versions) which has to be approved by the Institute Council. As the Attestation outcome, researchers are placed into categories defined by the mentioned Carrier System. The top category of leading scientists requires the approval of a special committee of the Academy of Sciences – currently about 20 %

of our researchers belong to this category and most of them have the degree Doctor of Sciences (DSc), which can be considered as an equivalent of Research Professor.

Finally, let us note in addition to the above-mentioned Academy and Institute-wide regulations, professional astronomers belong to the world-wide International Astronomical Union (IAU). The membership of this institution (which celebrated the 100th anniversary in 2019) assumes the adherence to the IAU Code of Conduct, where the ethics policy and the anti-harassment procedures are carefully drafted and agreed.

Following a continued discussion in the Institute Council the Director's office prepares the materials towards the application for HR Award. The questionnaires will be initiated in autumn 2020 with the aim of completing the procedure within a period of one year. This will add another layer of proper management of human resources above the current practices.

Strengths and weaknesses of the Institute

Strengths, weaknesses and opportunities go hand in hand. Based on the long-term performance of the Institute, several groups are increasingly involved in new space research projects by ESA. The Institute scientists are members of international consortia (Co-Investigators, Lead Scientists, Members of the Advisory Boards) of Gaia, Solar Orbiter, Proba 3, BeppiColombo, and several other missions (namely, new large missions of Juice and Athena in future). It is worth noting that currently, despite their scientific potential, our gradual involvement in ESA space missions suffers from the lack of competitive companies and qualified industry for space sector in the Czech Republic. In such circumstances the Institute decided in 2013 to take over the responsibility by employing several engineers with prior expertise in space industry. Since then the development continues well under the Institute management. Nevertheless, the Institute's attempts to hire new technical personnel for space research are risky and the future funding is uncertain.

Within ESO, new opportunities emerge for observations with the most advanced telescopes. The Institute has signed a trilateral agreement with ESO and Copenhagen University to support the programme of asteroid research and for stellar photometry. ESO has established one of European ALMA nodes in Ondřejov (see elsewhere for details). Other opportunities lie in our active involvement in large solar ground-based projects GREGOR and EST.

IT services are satisfactory and up-to-date. There is an obvious need of continued upgrade of the system, and our network managers take care of the central servers, their performances, connectivity and upgrade. The network capabilities of the Ondřejov Observatory have strongly increased since the Institute, in a close collaboration with CESNET, received a direct optical connection to Prague with the speed of 10 Gbit/sec. Since 2012 the Institute has been covered by EDUROAM wireless authentication system.

Permanent access to our Observatory and computational facilities (the Perek 2m Telescope, the 0.65m Photometric telescope, the Solar spectrograph HSFA2, solar radio telescopes, solar patrol, the Photographic Zenith Tube, bolide cameras, and computer clusters) enable us to perform long-term observational projects, such as asteroid photometry, high-resolution spectroscopy of bright stars, observations of fireballs, spectroscopic observations of flares and prominences, solar radio spectra analysis, and monitoring of solar activity, as well as the related data analyses. These prove to be scientifically productive. An additional technology, beyond our direct capability, is obtained by means of large international facilities and collaborations.

Light and radio-signal pollution represents a risk for future observing conditions at the Ondřejov Observatory. This will not improve in the forthcoming years. The Institute does not plan new large experiments on its Observatory campus, but rather intends to keep running currently used ones and upgrade them in a sensible manner. The observational programmes have been selected so that the light/radio pollution does not have a significant impact on them.

In summary, apart from a variety of external difficulties related to the situation of basic research in the Czech Republic, the Institute in its current status represents a well-established and productive research facility.

The publication rate in respected international journals such as Astronomy & Astrophysics (of which the Czech Republic is a full member), The Astrophysical Journal (USA), Solar Physics, Icarus and others is satisfactory and continuously growing. The Institute's scientists have also published papers in the prestigious journals Nature and Science. Naturally, there are differences among individual researchers, which the internal Evaluation procedure (individual Attestations) addresses. The Institute has extraordinary pedagogical and public outreach activities. Its gradually increasing involvement in collaborations within ERA is quite evident. The Institute is the leading organization in the field of astronomy and astrophysics in the Czech Republic. The future of the Institute is guaranteed by a continuous inflow of young professionals, but this will strongly depend on the national funding policy for research. On the side of the Institute management, an active policy of educating the young generation and procedures for hiring new perspective scientists are established and applied, as well as the rules of a gender balance that have been adopted in agreement with the national and EU legislation.

Putting this in a mathematical language, apart from the role of "boundary and initial conditions", strengths and weaknesses of the Institute are determined by the strengths and weaknesses of its Teams. A very detailed exposition of these topics can be found in the following chapters that describe individual Departments.

Assessment of the strategy plan of the Institute for the period of 2015–2019

The government institutional support for basic research in the Czech Republic is not stable: there exist risks that creative young scientists will not be able to come back and will be forced to stay abroad or move outside the Academy. In the wake of COVID-19 emergency we can expect a very turbulent period where programmes of basic science will face delays and cancellations.

On one hand, ASU scientists have been highly active in proposing and successful in obtaining research grants from the Czech Science Foundation, relevant government agencies, as well as the EU FP7 and Horizon 2020. On the other hand, the activity within the ERC programme still needs to be expanded. Overall, a significant and growing fraction of grant funding with respect to institutional resources poses a risk factor.

The Astronomical Institute is an integral part of the Czech Academy of Sciences, and our scientists frequently serve in Academy Boards and Advisory Committees. Unlike the problematic situation in the 1990s (funding-induced reduction of the number of employees from 246 in 1989 down to 117 in 1995, consequences of which are still visible in the age structure of the Institute, see the plot on p. 21), there is no more a lack of young scientists. Teams are above the minimum critical mass, nevertheless, in the long term some working groups may struggle to maintain their viable operation.

Female researchers are under-represented among the scientific staff of some groups but the balance is improving, and it is generally more favourable than in many other Czech institutions.

The Ondřejov Observatory continues to be the main site of the Astronomical Institute. In 2011 a newly constructed building was opened in Prague. With its status of the capital city, government offices and two major universities, Prague is a natural cultural, administrative and technological centre of the country. The location well within the city but also in an excellent reach of Ondřejov is what makes the Prague site an essential and integral part of the Astronomical Institute. Nowadays, the Prague site serves as an important hub along with Ondřejov. Despite its significant reduction at the beginning of the 1990s the renewed workplace in Prague proves to be an essential link, where researchers meet with students and small scientific meetings are organized. Students come to consult with supervisors, often as a part of their diploma and doctoral theses. The Director, the Council, and the Supervisory Board of the Institute hold their business meetings both in Prague and Ondřejov.

The Institute is fully involved in an international collaboration. The fragmentation of research topics might be considered as a partial risk, while on the other hand the diversification has its clear advantages in the fast-changing environment of current science. Despite the above-mentioned prevailing uneasy situation of maintaining positions in research in the country and in Europe in general, the Institute management makes all effort to support the essential directions. For example, it has been decided to search actively for new personnel with the expertise in science fields of radio interferometry (ESO's future ALMA programme) and space research (ESA's future JUICE and ATHENA large missions).

Strategy plan of the Institute as a whole for the period of 2020–2024

Being very active in several ESO and ESA programmes, the Institute aims to obtain an external support from a variety of relevant sources to participate in maintaining and building large European facilities, as well as contributing in ESA space science missions and the related scientific projects.

During the past years, the Institute management took great care of modernizing and robotizing almost all currently used instruments at the Ondřejov Observatory and within the distributed fireball networks. This was mainly financed thanks to a special programme of the Academy of Sciences for the maintenance of expensive instruments. However, as said elsewhere, due to the decreasing quality of observing conditions, the Institute does not rely on building or purchasing any significant instruments for its main site in Ondřejov.

Concerning the Space Programmes, the participation in ESA projects will provide to the Institute and its scientists a direct access to a new technology. The participation in the development of scientific instruments increases the competitiveness in the space area, which then enables the Institute to be accepted as a reliable partner in scientific consortia. On the other hand it must be accepted that the participation in space projects is a long-lasting and expensive adventure which does not necessarily provide an immediate output. In terms of Research, Development and Innovation Information System of the Czech Republic the H/W results of these activities will be submitted at the end of the implementation phase as functional specimens. The Astronomical Institute is among the most active institutions to support the technological advancement in Space research in the Czech Republic. We expect that scientific results in a form of papers in scientific journals will follow during the observational phase of the related space missions for which the Institute management also actively seeks financial support.

Considering all these attributes it was decided that, to even enhance the international reputation of the Czech space physics school, our participation in crucial space projects is important and necessary. To support an ever-increasing amount of space activities the development teams at the Institute continue to be extended and the Institute invests substantial resources into required laboratory instrumentation. Since the very beginning all the space H/W activities at the Institute have been supported and financed since the very beginning by the ESA PRODEX programme, whereas the scientific personnel is supported by the institutional resources. The activity of the Institute in the field of Space projects is fully within the scope of a newly formulated Czech *National Space Plan*, as approved jointly by the Ministry of Education, Youth and Sports (MŠMT) and the Ministry of Transportation (MD) of the Czech Republic.

Concerning the ground-based programmes, our scientists will continue taking an active role in proposing and performing the observational explorations in Chilean sites of ESO, including the Very Large Telescope (VLT), ALMA (Atacama Large Millimeter/submillimeter Array), and E-ELT in more distant future. ALMA, as the new cutting-edge observational facility for astrophysics, is constructed and operated in the worldwide international cooperation. To ensure an efficient scientific return and support the excellence in research, the main partners in the ALMA consortium – ESO (Europe), NRAO (U.S.) and NAOJ (Japan) – have decided to form a user-support infrastructure, a network of three ALMA Regional Centers – ARCs, located at the respective organizations. In connection with an increasing science data flow and number of projects to be served, the Czech node of the EU ARC will have to increase its capacity. To accomplish this task a project has been submitted by the Institute to the open call of the Ministry of Education of the Czech Republic for the support of building and operating Research Infrastructures in 2014. As a result of the international peer-review process the project was unanimously recommended for financing (the expected start date was 2016) and the Czech node of the European ARC is listed in the updated Roadmap of Research Infrastructures in the Czech Republic.

Topics on Space programmes and Hazards from Near-Earth Asteroids and risks from Cosmic Weather have been pursued within the Strategy "Strategie AV21" of the Czech Academy of Sciences.

In this context, the Institute involvement in EST collaboration will continue to build a 4-metre class solar telescope located in the Canary Islands to specialize in high spatial and temporal resolution using instruments that can efficiently produce two-dimensional spectral information about our Sun. Furthermore, we plan to continue and further enhance our studies of physical properties of asteroids. To this end we intend to utilize primarily the telescope on La Silla, whereas supporting data will be taken in Ondřejov. We plan to observe asteroids that are potential targets for robotic or human missions that are under preparation. Our photometric observations will provide key data, such as their rotational period and spin state, absolute magnitude and shape elongation. We plan to collaborate with researchers utilizing asteroid astrometry data taken by the Gaia satellite.

We plan to increase the number of our own fireball stations equipped with the modern Digital Autonomous Fireball Observatories (DAFO) and make thus fireball observations still more efficient and accurate. We also plan to extend the observations by adding all-sky digital bolide spectrographs, which are just being developed, and place them at several bolide stations together with DAFOs. One of the goals will be to determine the physical properties of meteoroids from individual meteor showers, in particular meteor showers with parent bodies classified as asteroids.

The Institute will continue as an active player in the scientific life of the international astronomical community. Following a highly successful organization of many conferences with international participation in the past (Notably, the General Assembly of the International Astronomical Union in Prague, and various smaller symposia and workshops), the organization of the European Week of Astronomy and Space Science was a great success in Prague in 2017.

The Institute will also remain active at different levels of education in collaboration with universities and the regional government in Prague and Central Bohemia. We successfully negotiated an update of the Agreements with the Faculty of Mathematics and Physics of Charles University and the Faculty of Natural Sciences of Masaryk University in Brno about the joint accredited programmes of doctoral (Ph. D.) studies.

We consider our productive and active researchers to be the main strength of the Institute as a whole. There is an excellent mixture of scientists of all ages. International visitors and temporary staff from around the world supplement stable long-term employees. The Institute management and the Director personally are deeply engaged in all aspects of education and supervision of our younger colleagues, as well as a sensible policy towards postdoctoral fellows.

The historical part of the original Observatory continues to serve for public education, organising tours and field trips, whereas the modern scientific research is performed at more recent and modernised facilities of the Ondřejov Observatory, as well as in an extensive international cooperation.

New offices in the city of Prague improve the direct contact with universities to further extend teaching of the young generation and the public outreach.

Research for practice

The Institute pays due attention to the issues of transfer of knowledge and technologies and follows the state-of-the-art guidelines of the Czech Government and the Czech Academy of Sciences. In 2015 the Director introduced internal norms that regulate the approach of scientific, technical and administrative staff towards the intellectual properties (the text of these norms is available on the Institute Intranet). Also, the Director appointed a position of Secretary for Applications and Knowledge Transfer, who systematically oversees relevant aspects with the field of Institute activities and identifies potential issues. ASU thus has in place internal mechanisms for identification and administration of intellectual property, both the copyrighted and industrial property, created at the Institute. Thanks to these mechanisms, the Institute can identify and assess the research results with application potential in a timely manner. Moreover, the Institute participates in the successful programme of knowledge and technology transfer education which is organized by CeTTAV (Center for Transfer of Technologies of the Czech Academy of Sciences) and funded from the programmes of the Czech Ministry of Education, Youth and Sports.

The main fields of research with the application potential at the Astronomical Institute, in which the transfer of knowledge and technologies to the Czech society and industry occurs are:

- Monitoring and forecasting of space phenomena with a direct and potentially damaging impact for the Earth and to society, such as Space Weather and Geomagnetic Activity caused by the activity of the Sun, or the Near-Earth Objects and the space debris.
- Close collaboration with the Czech aerospace industries on the development and manufacturing of hardware and software components for space missions.
- Development and maintenance of databases of the observed data and software for the calibration and analysis of these data, which are often accessible by the general public under the Open Access licence policies.
- Public outreach and education for a wide range of age groups.

During the evaluation period the main results with the application potential concerned the work of our engineers towards the development of three instruments for the upcoming satellite mission of Solar Orbiter. The devices were successfully delivered and tested at the end of 2019.

Leading the Strategy AV21 Academy of Sciences programme "Space for Mankind"

The Astronomical Institute coordinates the inter-institutional research programme Space for Mankind within the aims of the Strategy AV21 to strengthen the cooperation between the scientific community and the technical teams in the development and testing of new technologies for Space research. This includes especially the spacecraft instruments for direct exploration of space surroundings around the Earth, exploration of the

Sun and planets in the Solar System, and for astronomical observations, which are the key elements for deeper understanding of the physical nature of matter. The focus is also given to find synergies between different institutes of the Czech Academy of Sciences and to transfer the achieved technologies to applied physics and to support the related industrial innovations.

The main goals of the programme are:

- to increase the involvement and cooperation between the institutes of the AS CR in Space research
- to bring new knowledge about the Earth ionosphere and magnetosphere, the Sun, the Solar System and distant Universe based on space observations
- to share the experience achieved during the development of scientific instruments for space explorations
- to strengthen connections between the AS CR and industry
- to inform the public about the exploration of near and distant Universe, popularise Space research in relation to the society

The programme currently includes 11 institutes across the Czech Academy of Sciences that collaborate on 11 different research topics. The Astronomical Institute is the coordinating institute and the topics of the programme being solved at ASU include mainly the study of hot and energetic Universe via X-ray astronomy, Solar physics, gravitational astronomy, exoplanet research, the Earth observation, ground-based observation of the Universe and collaboration with other institutes in the programme.

The programme supports successful Czech involvement in space programmes by the European Space Agency (ESA) that include:

- Solar Orbiter – this European space mission to the Sun was successfully launched in February 2020. The spacecraft has 10 scientific instruments onboard with 3 having a hardware and/or software contribution from ASU
- JUICE – a mission to the icy moons of the Jupiter to be launched in 2022. The power supply of one scientific instrument was developed at ASU
- ATHENA (Advanced Telescope for High Energy Astronomy) – a large X-ray observatory to study hot and energetic Universe. In 2019 the Czech team led by ASU joined the instrumentation consortium of the main scientific instrument X-IFU (X-ray Integral Field Unit)
- eXTP (enhanced X-ray Timing and Polarimetry) – an X-ray Chinese–European space mission with an expected role of ESA, the Czech team led by ASU will develop Collimator and Detector Frames for the innovative scientific instrument LAD (Large Area Detector)
- PLATO – a mission to study exoplanets with the goal to discover an exoplanet with the surrounding conditions similar to the Earth
- LISA (Laser Interferometer Space Antenna) – a space-based gravitational-wave observatory

Among the successful activities of the programme belong the involvement in new space projects (ATHENA, eXTP, PLATO, LISA, etc.), the organisation of expert conferences (10 years of the Czech Republic in ESA, SWARM workshop), lectures at the Academy of Sciences and in the Parliament of the Czech Republic, and public outreach activities (an exhibition Ad Infinitum at the AS CR, exhibitions at several science festivals including the production of a 1:4 model of the ATHENA satellite or an artistic model of a black hole or a gravitational wave simulator).

Regional cooperation within the Czech Republic

In addition to numerous scientific and educational programmes, the Institute forms partnerships with regional institutions in the Czech Republic, in particular, the Central Bohemian Region and the Region of Prague, where the Institute operates its premises, and also other regions where instruments are located and Areas of Dark Sky are introduced. The Astronomical Institute is the founding member of the Central Bohemian Innovation Centre, which promotes a technically challenging scientific technology to businesses located within the region.

Cooperation with universities and student supervision

The Astronomical Institute of the Czech Academy of Sciences is a non-university research institute. Supervision and teaching of students is organized jointly with universities in several programmes specialized in Astronomy, Astrophysics and Cosmic Physics within the accreditation by the Ministry of Education, Youth and Sports of the Czech Republic. Our researchers also lead students individually at universities abroad.

The Institute provides Ph.D. education, which is formally bound to Czech universities in the form of common Accreditation. The Astronomical Institute, as the largest astronomical institution in Czech Republic regarding the academic staff, instrumental equipment and the library services, supports both pedagogical and research activities of all Czech and several foreign universities active in astronomy and astrophysics and related fields. Joint Accreditation for Ph.D. supervision have been acquired in cooperation with the Faculty of Mathematics and Physics of Charles University and with the Faculty of Science of Masaryk University in Brno.

On the basis of Agreement with the faculty of Mathematics and Physics of Charles University, Prague, the Institute participates in undergraduate study programmes of Astronomy, Astrophysics, and Plasma Physics. In particular, the Institute, along with the faculties, is responsible for the recognized and accredited undergraduate Study Programme in Theoretical Physics, Astronomy and Astrophysics. Students from other universities, especially the Czech and Slovak Republics and also from elsewhere are supervised by researchers of the Institute.

Many researchers of our permanent staff supervise students, teach at universities as external lecturers and they take part in examinations and committees of study programmes. The Institute also yields its facilities for practical training of university students at all levels and for research by university students and staff. On the other hand, the cooperation with universities helps to find and properly prepare new researchers for the Institute and the astronomical community in general. To track a proper record of educational supervising, an electronic Astronomy Student Information System (ASIS) was developed at the Institute in 2012 an has been operated here since then.

The Institute is active in teaching at high-school level. The observatory is a common destination for excursions and field trips organized by regional high-schools to enhance teaching in physics by practical experience. For motivated and gifted students long-term stays and the involvement in research work are enabled at the Institute, in particular, in the framework of Open Science initiative. Topics and supervision are provided for students participating in the competition called High-School Professional Activity. With the aim of continued education of high-school teachers, the Institute takes part in the Czech ESERO – ESA Education Office.

Lecture courses are listed in the relevant sections of our four Teams. These include examples of individual lectures as well as regular full-term courses that are included within the accredited programmes.

Overview of lectures, seminars and courses

ASU researchers deliver lectures and supervise students as external collaborators at various universities. Joint accreditation in the field of Astronomy, Astrophysics and Space Physics includes the Faculty of Mathematics and Physics at Charles University, the Faculty of Natural Sciences at Masaryk University in Brno, and the Faculty of Natural Sciences at Jan Evangelista Purkyně University in Ústí na Labem. Individual collaboration then includes several other research universities in the Czech Republic and abroad.

The Institute has accreditation agreements about Ph.D. supervision with the Faculty of Mathematics and Physics (Charles University), the Faculty of Natural Sciences (Masaryk University) in Brno, and the Faculty of Natural Sciences (University of Jan Evangelista Purkyně) in Ústí nad Labem.

Albert Einstein Center for Gravitation and Astrophysics

During five years of the existence of the Albert Einstein Center for Gravitation and Astrophysics – a project carried out in cooperation with the Faculty of Mathematics and Physics (Charles University, Prague) and the Institute of Physics (Silesian University in Opava), was funded within the scheme of Centres of Excellence supported by the Czech Science Foundation – the project members followed the plan completed successfully in 2017. They obtained valuable results in General Relativity as well as closely related fields, as is common in mainly theoretical research. Traditional topics in relativistic astrophysics and cosmology were explored.

A significant part of the research activity was devoted to astrophysical processes around black holes, for example, to the problems of accretion disks, jets and the influence of strong external magnetic fields. Black holes interacting with binary systems were studied, or black holes surrounded by ring or toroidal structures. We also studied generalized black holes, when gravity interacts with electromagnetic fields described by non-linear electrodynamics, and analyzed large polytropic spheres in spacetimes with cosmological constant. We studied molecular clouds and the structure of galaxies. Last but not least we investigated the current problems of gravitational lensing, which is applied more and more often in various parts of astronomy and astrophysics. The research activity of the Center, however, was much broader than just applied astrophysics and astronomy. For example, conservation laws were formulated and expressed explicitly in the linearized theory of gravitation, in massive gravity and in a large class of Horndeski's theories; geometrical properties were discovered in theories of gravity in higher dimensions; members of the collaboration analysed properties of various radiative spacetimes such as gyratons in a general dimension, or scalar fields in the framework of the Robinson–Trautman class. We succeeded in separating equations for fields on the background of boost-rotation symmetric radiative spacetimes representing accelerating black holes; studied theoretical aspects of black hole physics, in particular, the near-horizon regions of extremal black holes and Meissner effect of expulsion of stationary magnetic fields; analysed the influence of strongly gravitating sources on the black holes interior, etc. New results were also obtained in numerical relativity.

V. Karas acted as PI on the side of the Astronomical Institute. Numerous research papers were published and 17 students defended their Ph.D. theses in the course of this collaboration, which continues till today, albeit informally or the basis of different funding.

Research services: library, database, collections and others

On its sites in Ondřejov and Prague the Institute maintains the Library of astronomical literature. Our collection contains specialized monographies and professional journals (both printed and electronic), as well as historical prints. The Library is accessible to scientists and general public, and it cooperates with other libraries to provide interlibrary exchange services.

Subject fields include: astronomy and astrophysics; physics; mathematics; computer science; engineering.

Holdings of the Library: The total amount includes 82 600 items, including 15 000 books and 67 000 journal items (many of them are available unbroken from the first volume).

Staff: two librarians (university degree), one employee for printing and high-school connection.

Professional journals available

- On-line access to the journals from Springer and Elsevier Publishing Houses with a wide selection of scientific titles in astronomy and astrophysics. The library is a member of the National Consorcium for both Publishers. Their annual average rate is 811 600 CZK.
- On-line access to other scientific journals: Astronomical Journal, Astophysical Journal, Astronomy and Astrophysics, Meteoritics, Monthly Notices of the R.A.S., etc. The annual average budget for these journals is 710 000 CZK.

Library databases and publication records

- In the Library we maintain the database for the publication of our research articles (EPCA). All the articles, proceedings papers, books and other materials are collected in the database.
- Full access to the Web of Knowledge (including the Web of Science and the Citation Index) as well as Scopus and several other database systems is ensured to the researchers connected to the Institute network.

Monographies

- The majority of books are purchased in a printed version. The annual average budget is 170 000 CZK, whereas electronic versions are also often available.

- Proceedings of the International Astronomical Union Symposium are available online. Selected book series are available via Springer Consortium.

Services for researchers.

- Our Library functions as other typical scientific libraries – we provide our scientists with book acquisition, loans, manage on-line access to science journals in physics and astronomy, we provide research and print materials for conferences.
- We provide papers and articles from other libraries in Czech, and we obtain articles from abroad – this is a very popular and desired service for scientists. The Library serves as the centre of information for astronomy and astrophysics in the whole country – about 30 libraries from the Czech Republic ask us for various information materials per year.

Science databases and services

The Institute has a tradition in publishing astronomical data. The public archive of more than 16 000 spectra of mainly Be and similar emission-line stars – secured by the Reticon 1872F successor of photographic plates – was established in the late 1990s as one among the first ten web-based archives of ground-based observatories worldwide. Despite its proprietary data format based on in-home developed spectra analysis package (SPEFO) we receive numerous requests for data and assistance with their use.

The archive of 1000 HEROS echelle spectrograph exposures, secured in the years 2000–2003 during the time of HEROS attachment to Ondřejov 2m Telescope, was published in the framework of the Czech Virtual Observatory (supported by EURO-VO FP6 project). This also served as the reference testbed for the development of several VO standards for post-processing of astronomical spectra. In the recent decade a real archiving challenge was the publication of the growing archive of more than 15 thousand spectra being obtained by several CCD cameras in Coude 700mm focus of 2m Telescope.

The established data policy requests a restricted access to recent results (younger than one year), which required the implementation of the basic authentication mechanism in the main VO tools like SPLAT-VO, Aladin and Topcat. Currently the data flow is fully automated – every newly reduced spectrum is imported in database and published in VO archive within 10 min after putting it in a given directory.

The Institute makes also publicly available as a cloud service the Fourier disentangling code KOREL integrated with a web-based visualization and a distributed framework of parallel computing nodes running on a cluster of servers. As of end of 2014 there are 146 registered users of whom 75 have actively computed in total more than 900 jobs.

Another type of archives is the Ondřejov Southern Photometry Survey (OSPS) delivering using VO SIAP protocol the previews and metadata of about 180 thousand images obtained in a remote observing mode by Danish 1.54m telescope in Chile by several groups of Czech astronomers (described further below in more detail), as well as other products currently in proprietary period. There has also been published a manually created catalogue of white dwarfs observed at the 74inch Mt Stromlo observatory by WD group of the department.

An extensive archive of all-sky images was collected by the Czech part of the European Fireball Network during more than five decades and it is maintained in the Ondřejov Observatory.

Other publicly available archive and services are available, albeit not yet in a VO-compatible format. For example, a broad variety of optical spectra and images (catalogues of prominences, flare catalogues, slit images of spectra obtained by Multichannel Flare Spectrograph and Horizontal Spectrograph) as well as everyday optical images of the Sun in white light and Hα and radiograms of solar radio data events are maintained and offered to the community. Furthermore, in the branch of geodesy, various models of the gravitational field and related SW and databases are developed and published.

In addition to the above-mentioned Institute-wide activities, a lot of editorial work proceeds via Teams and individual scientists of the Institute, for example the publication of conference proceedings and the work in editorial boards and advisory panels of professional journals, such as Solar Physics, Classical and Quantum Gravity.

Administration of research infrastructures

Atacama Large Millimeter / submillimeter Array – participation of the Czech Republic (ARC-CZ)

The Large Research Infrastructure EU-ARC.CZ (Atacama Large Millimeter/submillimeter Array – participation of the Czech Republic) forms the access point to the largest ground-based astronomical observatory for users from the Czech Republic and the region of central and eastern Europe. As one of the nodes of the European ALMA Regional Center (EU ARC), it provides support to users during the complete lifetime of observing projects from proposal preparation, preparation of the Phase 2 material, delivery of the calibrated science products to users, and, if required, additional data reduction support, advice regarding observing strategies and help with ALMA archival research. Together with the face-to-face support, the node is also active in the quality assurance of ALMA data, in assisting with science verification and the ongoing Extension and Optimization of Capabilities (EOC) effort, and in building and developing the European and local ALMA community. EU-ARC.CZ is the only node in Europe with expertise in solar radio observations. It processes solar projects from all European observers and it has played a key role in the development and CSV of solar regime of ALMA observations. The node also organizes community days, workshops, university lectures and seminars.

The Astronomical Institute of the Czech Academy of Sciences strongly supports the activities of the LRI at several levels. From providing facilities and infrastructure (buildings, energy and communications), the necessary equipment and services (including hardware and software maintenance), to covering part of the staff costs of the LRI expert team (key staff) from their institutional resources. The Astronomical Institute also allows EU-ARC.CZ to use its economic and technical department to ensure the operation of the infrastructure administratively. For its service and development activities, the LRI uses the HPC computer cluster OASA built in 2016 at the Institute. The cluster will be modernized in 2020 based on a support that the LRI obtained from the OP RDE programme within the call No. 02_18_046, Research Infrastructures II. The operation of the infrastructure is supervised by an international Advisory Board which was established in 2016 as an independent external body.

Since ALMA has been offering regular observing cycles for the past seven years, its user community has reached certain maturity. At the same time, ALMA almost reached its planned technical and observational capabilities and capacities. Therefore, the nature of the user support provided by the LRI and the entire EU ARC network is beginning to somewhat change and move towards a greater focus on scientific support. The LRI plans to evolve, similarly to other nodes of the European ALMA network, into more general centers of expertise of millimeter and radio interferometry that would focus not only on ALMA, but also on other modern or emerging radio interferometric observatories, such as SKA or LOFAR (Low-Frequency Array). A specific objective of the future development of the LRI could be the cooperation with the Institute of Nuclear Physics and Atmospheric Physics of the AS CR to build a new station of the LOFAR Observatory in the Czech Republic. In addition to the "classical" astrophysical observations, this project would also propose an innovative use of this instrument to study processes in atmospheric discharges using a dedicated hardware. The LOFAR project is listed on the European ESFRI road map and the extension of its network to the Czech Republic would bring a significant improvement from the perspective of the instrument itself (existing stations cover mainly north-west Europe), but also socio-economic benefits for the Czech Republic. The preliminary negotiations with the LOFAR consortium show their interest in building a station in the Czech Republic. Investment funds from the planned programme OP JAK (within a dedicated call for large research infrastructures) could in principle be used to modernize the LRI towards a wider Expert Center of millimeter and radio interferometry support and to implement the ambitious project of the LOFAR expansion.

In conclusion, the Czech node of the European ALMA Regional Center has been granted financial support from the Ministry of Education, Youth and Sports of the Czech Republic until 2022. The continuation of the project beyond this period is open and will be decided based on a large international peer-review of large research infrastructures which will take place in 2021. ASU strongly supports the operation of the Czech ALMA node. In the foreseen future, the Czech node infrastructure plans to evolve, similarly to other nodes of the European ALMA network, into a more general Center of expertise of millimeter and radio interferometry that would focus not only on ALMA, but also on other modern or emerging radio interferometric observatories. A specific objective of the future development could be building of a station of the LOFAR Observatory in the Czech Republic, in collaboration with the Institute of Nuclear Physics and Atmospheric Physics of the Czech Academy of Sciences.

European Solar Telescope – participation of the Czech Republic (EST-CZ)

The Astronomical Institute of the Czech Academy of Sciences has been hosting a new research infrastructure called "European Solar Telescope – participation of the Czech Republic (EST-CZ)" since January 2019. EST-CZ can be understood as a national node

Open Days at the Ondřejov Observatory.

of the research infrastructure EST that is a project of a 4-metre class solar telescope to be installed in the Canary Islands. The EST is currently in its preparatory phase with the first light expected in 2027 at the earliest.

The EST's main research goal is to observe the Sun. The Sun is the only star that can be studied in high resolution. We can study fundamental interactions between plasma, magnetic field, and radiation in the solar atmosphere. Although we are not able to spatially resolve the intrinsic scales of these magneto-hydrodynamic processes yet, the magnetic Sun forms the basis of our knowledge of the cosmic magnetic field. With the EST we will improve the resolution and enhance our understanding of fundamental science.

We expect a close cooperation in drafting observing proposals for ALMA and EST once the EST is commissioned.

Outreach activities and research popularization

The astronomy popularization is an integral part of the Institute's activities and its level exceeds the average within the Academy. A full-time position of a manager of public relations (PR) has been established to maintain a useful and visible impact on general public, especially the young generation. Press releases are regularly prepared and our press manager coordinates a close cooperation with scientific sections of newspapers, magazines and the relevant programmes in TV and on the radio. The Czech Astronomical Society uses the Institute premises to promote astronomy to interested laypeople. The Astronomical Institute takes its responsibility in preservation of our cultural heritage connected with astronomy and cosmology, its mediation to the public as well as spreading of the astronomical knowledge.

Astronomy, the "oldest science", has become a firm part of our culture and society and all staff members and students have an opportunity for training in outreach activities. In the area of popularization of astronomy, we take advantage of the history of the Ondřejov Observatory lasting for more than 120 years. The Institute takes a conscientious care of this national cultural, scientific and architectonic heritage. Part of the Observatory site is open to the public during most of the year as the Museum, historical domes, and the Arboretum. This is a unique site not only at the national level but it also attracts visits and tours from abroad.

We hold special Open Days (attendance of almost 10 000 during the Evaluation period). In the years of 2015–2019 we invited the public to 175 events on the Astronomical Institute website. The most important events in the public domain include: European Week of Astronomy and Space Sciences in Prague in 2017 and two related exhibitions, astronaut Andrew Feustel's tour of the Czech Republic in 2019 and regular participation in the Science Fair every year. On the Internet, a section of the Institute's web site (http://www.asu.cas.cz) is oriented towards the general public and a part of it is focused on children and young people. Our Facebook page has been maintained since 2013 and today it is the most watched Facebook page of all institutes of the Academy of Sciences (https://www.facebook.com/AstronomickyUstav).

We organize exhibitions and public events at the site of the Ondřejov Observatory, in Prague and elsewhere. Astronomers frequently attend science programmes and discussions on radio channels to present opinions and news in the field. We participate in the annual European Scientists Night, support talented youths (Astronomical Olympiad and student research works, field trips, collaboration with the local elementary and high school, etc.). The Czech Astronomical Society (http://www.astro.cz) website is operated in the Institute network and reaches wide audience of amateur astronomers. Each year a set of most important discoveries published by our astronomers are selected by the Institute Council; their highlights are summarized for the informed public in Czech language.

A specific activity is a collaboration on the preservation of dark night sky environment against light pollution. The Institute conducts expert activities in this field and also explaines problems of light pollution to the public. In collaboration with the Wroclaw University and other four Czech and Polish institutions, the Institute promotes Jizera Dark Sky Area that is dedicated to the protection of dark night sky and is the first cross-border area of that kind in the world.

While many educational activities proceed directly through individual teams and their scientists (and these are mentioned in their reports elsewhere in the Evaluation materials), the Institute management takes an active role to oversee the Institute-wide projects: organizing individual and group public visits (25 thousand visitors during the Evaluation period) and taking part in joint educational activities with the Academy of Sciences (a formal Agreement and a continued cooperation with the Centre of Administration and Operations), a variety of Foundations (e.g., ESERO, to educate high-school teachers about Space Research in Europe), Institutes, City of Prague and Ondřejov.

Publishing activity concerning scientific books and periodicals

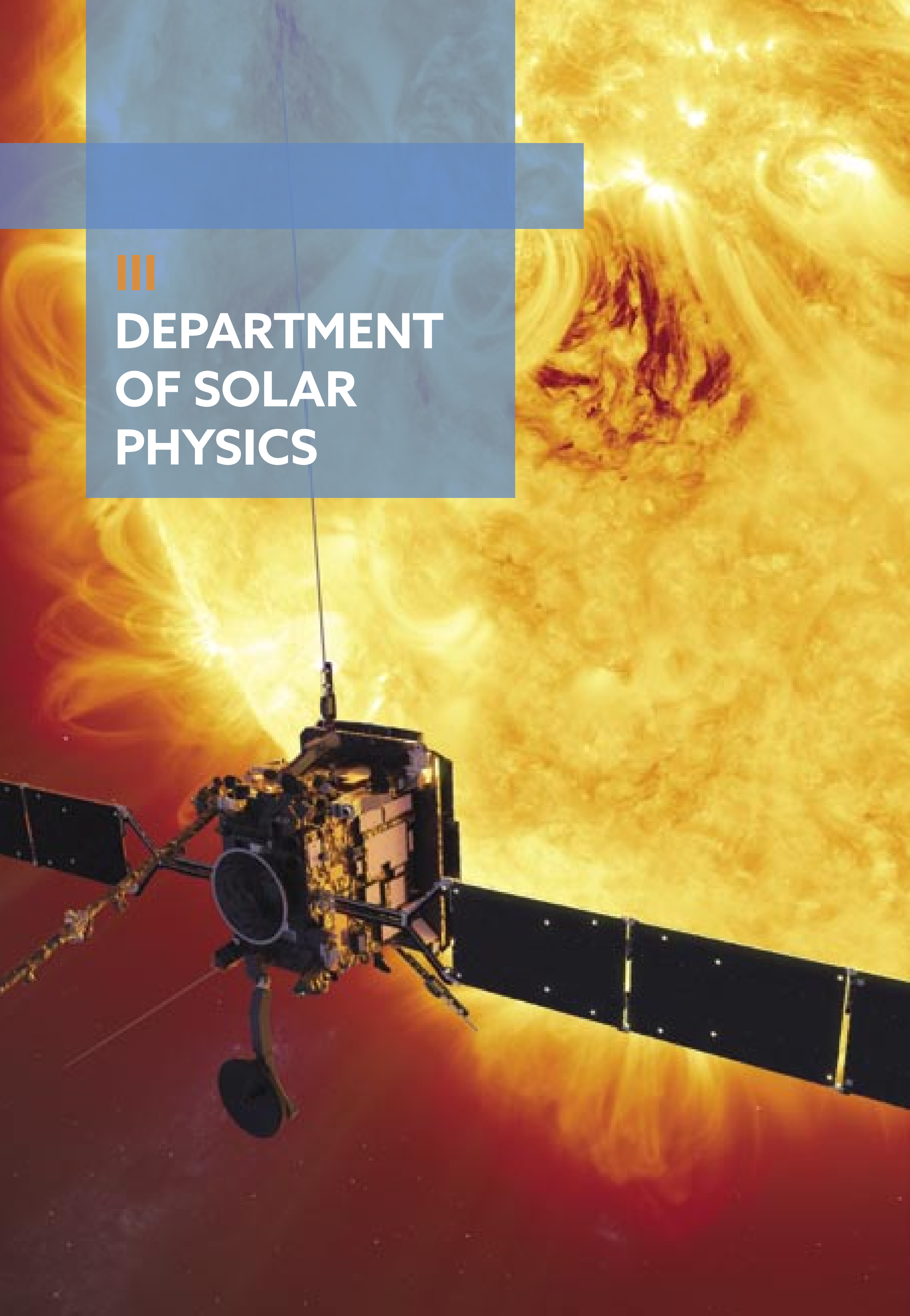
On behalf of the whole Czech astronomical community, the Institute contributes to the operation of the international astronomical journal Astronomy and Astrophysics, where Dr. Jiří Kubát represents the Czech Republic and serves as a member of the Board of Directors. The journal is a community non-commercial project of European astronomers (the impact factor exceeds 5). The journal is financially supported by sponsoring countries, who contribute to the budget proportionally to their economic strength. The journal is not owned by its publisher and the publisher is selected by the Board of Directors for a limited time period. Publishing in this journal is free of charge for astronomers working in institutions located in sponsoring countries, including the Czech Republic. Once accepted, papers are sent to a language editor, who suggests language improvements. This is a significant help for authors, who are not native English speakers (a common case in institutes in the Czech Republic). The journal supports the open access policy. In addition, all papers are in open access starting one year after the publication date.

ALMA ARC All-Hands Meeting took place for the first time in the Czech Republic (in the Conference Center of the Czech Academy of Sciences in Liblice). The annual meeting of the European ALMA network staff was also attended by the ALMA Observatory director general Sean Dougherty and heads of the partner ALMA centers in North America and East Asia, Anthony Remijan and Hiroshi Nagai, respectively. In 2017, the LRI coordinated the preparation of the Special Section 20 "Science with ALMA: Discoveries, Priorities and User Support" at the large international conference EWASS 2017 (European Week of Astronomy and Space Sciences) held in Prague. More than 100 participants attended the session which presented both the latest scientific discoveries from ALMA as well as the future development of the interferometer and the European user support system, including the operation of the Czech node of the European ALMA network.

*A distinguished Czech astronomer doc. Luboš Perek (*1919 †2020). From 1968 to 1975, Perek served as Director of the Astronomical Institute of the Czechoslovak Academy of Sciences. In 1975 he was appointed Director of the United Nations Office for Outer Space Affairs. Perek served as General Secretary of the International Astronomical Union (IAU) from 1967 to 1970, and he participated enthusiastically in the IAU's centenary celebration event in Prague 2019.*

The European Space Astronomy Center (ESAC) in Madrid initiated a series of workshops with James Web Space Telescope (JWST) experts to train researchers from ESA member states on JWST proposal planning tools, resources and documentation so they can share their knowledge with other scientists all across Europe. The selected institutions were asked to organize JWST workshops in the ESA participating countries to support the preparation of proposals for the JWST Cycle 1.

III DEPARTMENT OF SOLAR PHYSICS



The Head of the Department: Dr. Miroslav Bárta

The research in the Department of Solar Physics is targeted to the Sun, our nearest star. The proximity of the Sun has two essential aspects: First, it is a unique lab for studying many processes in astrophysical plasma, its interaction with the (self-generated) magnetic fields and with electromagnetic radiation, from quite a nearby. Second, the Sun is critically important for the life on Earth and – albeit the energy flux that it supplies to our planet is rather steady on long-term time scales – the Sun yet exhibits its variability and activity. The processes of solar activity play now – as our civilization becomes more dependent on sensitive technologies – a bigger role and, hence, our understanding to their dynamics has even practical impacts. The same is true for a realistic estimation of a long-term variability of the solar activity on the climate change on the Earth.

Solar physics is nowadays quite a developed and wide research field and a team of the size of that ours, obviously, cannot cover it in full completeness. We therefore focus on four particular topics and this is also reflected by the internal structure of the Department, which is composed of four, however mutually closely collaborating, working groups.

Working group Physics of solar flares and prominences: The group concentrates on the research of the most remarkable solar-activity phenomena: flares, eruptions, and prominences. The goal is to provide coherent understanding of modern observations in terms of the underlying physical processes (actual configuration of magnetized plasma and its dynamics, flare energy release and deposition, formation & transfer of radiation in non-equilibrium plasma, etc.). The methods and tools used for accomplishing this objective include analytic and advanced numerical (HPC) modelling, numerical calculations of the radiative transfer, and a multi-spectral analysis of the observed data, including those acquired by our own instruments. In order to have a statistically broader ensemble of flaring activity, the possibility to search for its specific spectral manifestations at other stars is researched, too.

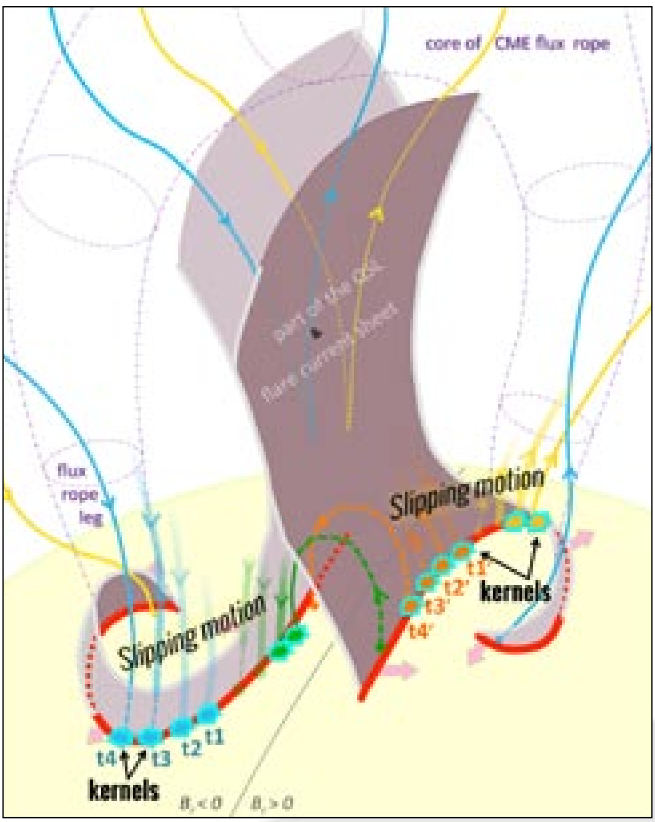
Working group Structure and dynamics of the solar atmosphere: The research of this group is targeted namely at detailed structure of the solar photosphere and lower chromosphere and its relation to the processes of (magneto-)convection. Since the magnetic fields play a key role in the solar variability, the attention is paid to magnetic elements of all sizes from micro-flux-tubes to large sunspots. The research

At the end of 2019 the Solar Orbiter was assembled and the scientific instruments were integrated in the satellite with the launch date in February 2020, executed successfully as planned. This has been the most significant participation of Czech scientists and industry over the entire new era of ESA's space scientific missions (© ESA/NASA).

methods involve high-resolution optical imaging, including major international instruments like GREGOR and (prepared) European Solar Telescope/EST (see section Participation in large cooperations for details), advanced spectro-polarimetric inversions providing the magnetic field maps, and dynamic-features tracking, including (local) helioseismology. The group is also responsible for the operation of our Solar Patrol Service.

Working group Solar radio astronomy: Radio-astronomical methods play increasing role in the modern astrophysical research. In the solar-physics context, especially small/multi-scale plasma processes of primary energy release and particle acceleration in flares are inherently related to the radio emission – the radio waves are their first messengers. The group namely aims at understanding modern radio data (including that from our own instrumentation) by means of advanced HPC plasma simulations (Particle-in-Cell/PIC, multi-scale MHD). Part of the WG, integrated in the Czech EU ARC node, plays a significant role (Europe leaders) in the development of the Solar ALMA Observing Mode and provides a unique support to the solar science observations with ALMA in the entire Europe (see Participation in large cooperations). Furthermore, a more practical impact of the intensive solar radio bursts to the systems of satellite navigation and radio communication is studied in an international collaboration.

Slipping of reconnected-line foot-points detected by moving kernels (Dudík et al., 2017).



Working group Heliosphere and Space weather: Disturbances propagate from the active Sun through the Heliosphere, the environment filled by the solar wind particles and magnetic fields. Eventually, they reach the vicinity of the Earth and cause the so-called space-weather effects with an impact on our civilization. Research in this field is the subject of our last WG. It focuses namely on analytical modelling of propagating magnetic clouds and advanced HPC simulations of kinetic-scale processes in the solar wind. Moreover, it participates in HW/SW development for space missions oriented to solar/heliospheric research (e.g. Solar Orbiter, JUICE – see Participation in large cooperations). In collaboration with the other WGs of the Department, the group also contributes to the research of space-weather effects to technologies, e.g., studies of geo-magnetically induced currents (GICs) at the electric power grids.

Research activity and characterisation of the main scientific results

The research activities of the Department can be – by their nature – grouped into three main clusters: (i) Basic research of the physical processes at the Sun and in the Heliosphere, (ii) Research with a more direct impact to applications, and, (iii) Observations & development activities in the scientific instrumentation, including services for the large international projects and infrastructures.

In line with the central mission of the Astronomical Institute, this type of activity is clearly the dominant one. In the period of 2014–2019, the staff of the Department made remarkable headway in researching many particular open questions in solar & heliospheric physics. Here we try to describe the main landmarks in more detail and insert them into a broader context.

Scientific results

True 3D nature of solar eruptions: Slipping magnetic reconnection revealed in modern observations

Magnetic reconnection is a key process for energy release in flares (and likely also for many other "explosive" phenomena at the Sun and in the Universe in general). Not only its energetic aspects are important in the solar context, but its role in restructuring the topology of the magnetic field as well. For example, it is essential for the ultimate release of the erupting filaments, which finally propagate as CMEs or magnetic clouds though the entire heliosphere, from the Sun. Many numerical models of the large-scale magnetic reconnection – until recently – have stayed with the 2D (or 2.5D – including all three components of vector quantities) geometries. This approach, is actually, not so bad as the flare geometry usually has "an invariant" direction along the polarity-inversion line (PIL) and for the price of ignoring the "edge effects" and structuring along the PIL it provides much better computational resolution. However, we live in the 3D nature and thus the 3D aspects – especially when handling the eruption as a whole – are absolutely essential. The Paris–Meudon group (Aulanier et al., 2012) developed a fully 3D model of eruption in the zero plasma beta approximation. Many 3D-reconnection effects like the line slipping, predicted by earlier theoretical studies (e.g. Priest & Pontin, 2008), were shown essential in this flux-eruption model. The model also brought our deeper insight into the magnetic-topology change, between the erupting flux-rope, flare-loop arcades, and over-laying magnetic field lines. However, a question remained open, whether this model is really applicable for solar eruptions and (eruptive) flares. In collaboration with French colleagues, a group from our Department (Dudík et al., ApJ, 2017; Sobotka et al., A&A, 2016; Zemanová et al., ApJ, 2019) with a careful analysis of data – unabmbiguously showed the presence or model-predicted features (line slipping traced by the bright-points motions in the flare ribbons, expansion/contraction of loops at the flux-rope flanks, dynamics of the 'J'-shaped ribbon hooks, etc.) in the real high-resolution observations of eruptive flares. The observational evidences for the 3D slipping reconnection model found by our analysis range from the signatures seen in the chromosphere by GREGOR up to the hot-corona EUV lines observed by SDO/AIA. The amazing agreement found between the model and in-depth analysed observational data is important as it confirms that we are on the way to understanding the physics of solar eruptions.

Fragmented reconnection in solar flares: Multi-scale aspects of the particle acceleration

In addition to the 3D nature of magnetic reconnection in solar eruptions and flares, its multi-scale character is important, too. In our previous studies (Bárta et al., 2011, Karlický & Bárta, 2011, etc.) we researched the spontaneous cascading fragmentation of the current layer in the solar flare into plasmoids, interleaved by smaller-scale current sheets. Resulting "fractal current sheet" (anticipated by Shibata & Tanuma, 2001) has consequences for so called fragmented energy release and particle acceleration. In collaboration with MPS Göttingen (Zhou et al., ApJ 2015, 2016) we researched particle acceleration in such a fragmented current layer (the result of our multi-scale high-resolution MHD simulations) for the first time, using the Test-Particle (TP) approach. The effects of particle drifts (curvature, gradient) in the turbulent magnetic field, and the resistive acceleration in multiple small-scale dissipation regions, were studied separately in two consecutive papers. It was found that the Fermi-like drift acceleration in the rapidly varying magnetic fields of the fragmented CS has a bigger impact on the total energy gain for a bulk of the TP electrons, however, the (rare) particles with the highest velocities gained their energies in the DC acceleration in the multiple dissipative regions. Our Team contributed with the high-resolution MHD model results that were used as an underlying field for the TP simulations. The result is essential for understanding how the particles are accelerated in flares. Namely, the fragmented nature of the flare current sheet can be – exactly through the particle acceleration processes – imprinted to the radio data received by our sensitive and high-cadence radio spectrographs (Observing infrastructures below) and compared with the model.

Accelerated particles in flares: Mystery of energy deposition scenarios

Fraction of the particles accelerated in the current layer in the solar corona propagates downwards, towards the Sun, reaching finally the denser layers of the solar atmosphere. Here, their energy is deposited and eventually thermalised. The question, however, persists, how this process actually runs, what are, e.g., the heights of the energy deposition and, consequently, what are the radiation signatures of those processes in the observed spectrum. The process is very complex with mutual bi-directional dependencies between population of the accelerated particles at a given height, temperature and density structure (including, e.g., generated shock waves) in the location of the energy deposit, and the radiation field. Using the combined approach of radiative-hydrodynamics (RHD), including the non-LTE radiative transfer, and particle-energy deposition calculations carried out in the FLARIX code, the (bit unexpected) height distribution of the energy deposition was found, together with its consequent radiation manifestation in the form of visible-continuum enhancement. This enhancement in higher layers was confirmed by the off-limb observation of the solar flare (Heinzel et al., ApJ, 2017). After the continuum enhancement was revealed in the UV (Heinzel and Kleint, 2014) and later also in the optical and IR radiation (Kleint et al., ApJ, 2016), this result represents a solid explanation based on the advanced combined physical modelling. The significance of the result exceeds the field of solar physics and it is relevant for the manifestation of flaring activity at stars, too. A possible connection between solar and stellar flares on the ground of similarity in continuum enhancements has started to be studied also observationally by our Team (see Observing infrastructures below). So far the stellar flares are characterized mostly by their light curves, but, in fact, explosive phenomena with quite different underlying physics may exhibit similar radiation-flux dynamics. On the other hand, the enhancement in particular spectral domains can help to distinguish between the flare-type and a different activity going on the star.

Non-Maxwellian solar plasma and its signatures in the emitted spectrum

As it was mentioned in the paragraph above, the transport of energetic particles from the corona to denser layers, where they are eventually thermalised, is a complex process and for quite some time the particle velocity distribution function is far from the Maxwellian equilibrium. Moreover, the (frequent) presence of turbulence and waves results in the secondary, local, energisation of particles. There are other statistics, which can describe the energy distribution function in this non-equilibrium state better – both on theoretical grounds (e.g., Tsallis entropy generalisation for non-equilibrium systems) and because of a better agreement with observations. One of them is the so called kappa-distribution. The radiation calculations based on the assumption of non-Maxwellian plasmas fit the observed spectral features better, yet with a smaller number of free parameters (density plus two parameters of kappa-distribution vs. multiple two-parametric gaussians in the multi-thermal description). A group in our Department made a big progress in studying the kappa-distribution present in the solar atmosphere not only in such non-equilibrium situations like solar flares, but also during say, "standard" processes leading to the quasi-continuous heating of the solar corona. Above all, the freely available software package & database KAPPA was developed in the Department (Dzifčáková et al., ApJSS, 2015). The SW enables calculations of optically thin spectral lines for non-equilibrium distributions, namely the kappa-type, and this way it represents a generalization of the well-known package CHIANTI, where similar calculations are provided for the Maxwellian equilibrium plasmas. Using the KAPPA package and comparing the modelled spectra produced by this tool with the observed ones, the presence and parameters of the kappa distribution was found in a variety of situations in the solar atmosphere – flares, transient coronal loops, transition region (Dudík et al. ApJ, 2017, Sol. Phys, 2017; Dzifčáková et al. ApJ, 2018). Hence, the results of this group showed the omnipresence of the non-Maxwellian plasmas in the solar atmosphere, surprisingly even under "quiet" conditions.

Radiative transfer – a key to decipher the information in spectroscopic & spectro-polarimetric measurements

While the above described research is focused on departures from the thermodynamic equilibrium of plasmas, similar effects are important for the radiation field, too. The significance of the so-called non-LTE approach for a correct interpretation of continuum enhancements in the flaring solar atmosphere under bombardment of energized particles has been already mentioned above. But there are many other situations, where the radiation is not in local equilibrium with the medium it propagates through and this effect strongly influences the shape of spectrum of the outgoing radiation, which we finally receive by our instruments. And vice versa – should we be able to decipher the information contained in the (multi-wavelength) spectroscopic measurements and reveal the structure of the medium, in which the radiation is formed (and/or through which it is transmitted) via spectroscopic and spectro-polarimetric (SP) inversions, the (Stokes) spectrum formation calculations frequently need to involve also the non-LTE physics. This issue represents a long-term research topic within our Team. In the recent period we achieved significant headway namely in the three following directions of this research:

i) Full 3D Non-LTE radiative transfer (RT) of the polarized light (full Stokes vector),
ii) Extension of our non-LTE models/codes to new spectral lines available from the modern spacecrafts,
iii) Applications of spectro-polarimetric inversions (both LTE and non-LTE) to modern high-resolution data – from both ground-based and space-born instruments. In the following paragraphs, we present a few illustrative result examples for all four sub-topics.

Probing structure of the chromosphere and transition region by magnetically-sensitive spectral lines

Modern spectro-polarimeters allow us to probe density, velocity, temperature, and – via the Zeeman and Hanle effects on the polarized light – also the magnetic structure of the solar atmosphere. As it has been already written, in order to make use of the spectro-polarimetric information for revealing the 3D maps of plasma parameters, the influence of the distribution and gradients of those parameters onto the (Stokes) spectrum formation under general non-LTE conditions must be understood. Our Team members significantly contributed to this knowledge by the 3D non-LTE Stokes RT code PORTA and its application to the (i) MHD-modelled solar atmosphere (chromosphere + transition region) for magnetically sensitive Lyman-α line (Štěpán et al., ApJ, 2015), and, (ii) An easily controlled 'toy-model' of the structure of the solar atmosphere, which enabled to study the influence of gradients of temperature or velocity field to the polarization signal in the chromospheric Ca II (8542 Å) line. The first result has a direct application for comparison of the MHD model with the measurements of the CLASP (Lyman-α spectro-polarimeter onboard a rocket) instrument, the latter contribution shows that the inhomogeneities in plasma structure may effectively mask the influence of the magnetic field on the polarized-light signal. This has general relevance for the SP methodology.

Solar plasma diagnostics using Mg II lines observed from space

As an example of the recent development in our RT expert group targeted at the extension of the non-LTE radiative transfer and spectrum formation calculations to new spectral windows, an inclusion of spectral lines invisible from the Earth into our codes can be adduced. The importance of this upgrade is clear, if we take into account that many space-born devices oriented at high-dispersion solar spectroscopy were launched during (or shortly before) the period (e.g. IRIS, SDO/AIA) and their new high-quality data call for interpretation. The newly extended non-LTE RT code was applied to Mg II line observed from the IRIS instrument. First (Liu et al., Sol. Phys., 2015), the X-class flare was studied using the IRIS slit-scanning mode and by means of fitting the non-LTE calculated Mg II profiles (strongly enhanced by the flare) in bright kernels in the flare ribbons with the observations, the structure of the solar atmosphere and its dynamics in those kernels was revealed. The position, structure and time evolution of the Mg II kernels were also compared with the hard X-ray emission brightening – this is again important for the research of the yet open question of the flare particle-beams energy deposition. Another application of the extended non-LTE spectrum formation code aimed at the cool flare loops, again observed by IRIS in the Mg II line (Mikula et al., ApJ, 2017). Such loops are expected (by models) to be present at other flaring stars, too, and the Mg II line analysis can represent a sensitive indicator for distinguishing the solar-like flares from the other sudden-brightening events at the star. The non-LTE inversion of the line revealed plasma in a highly dynamical state even in those cool loops.

High-resolution SP inversions and white-light flares

For the sake of illustration of the third aspect of the continuing development in our RT calculations and line inversions – their applications to the newly emerging issues induced by modern, high-resolution data – a couple of examples are presented. As the first one, let us adduce a new light that the high-resolution SP inversions have shed at the above discussed issue of the energy deposition, heating, and continuum-emission enhancement in the flaring solar atmosphere. Namely, the polarization signal reveals the magnetic structure of the observed region, which provides very important context information, e.g., for possible trajectories of the bombarding particle beams, propagation of shocks, etc. Our Team studied an example of the white-light flare with the so-far unprecedentedly high spatial and spectro-polarimetric resolution (Jurčák et al., A&A, 2018) and used the SP inversions for the detailed investigation of heating of the flaring solar atmosphere structured by the magnetic field.

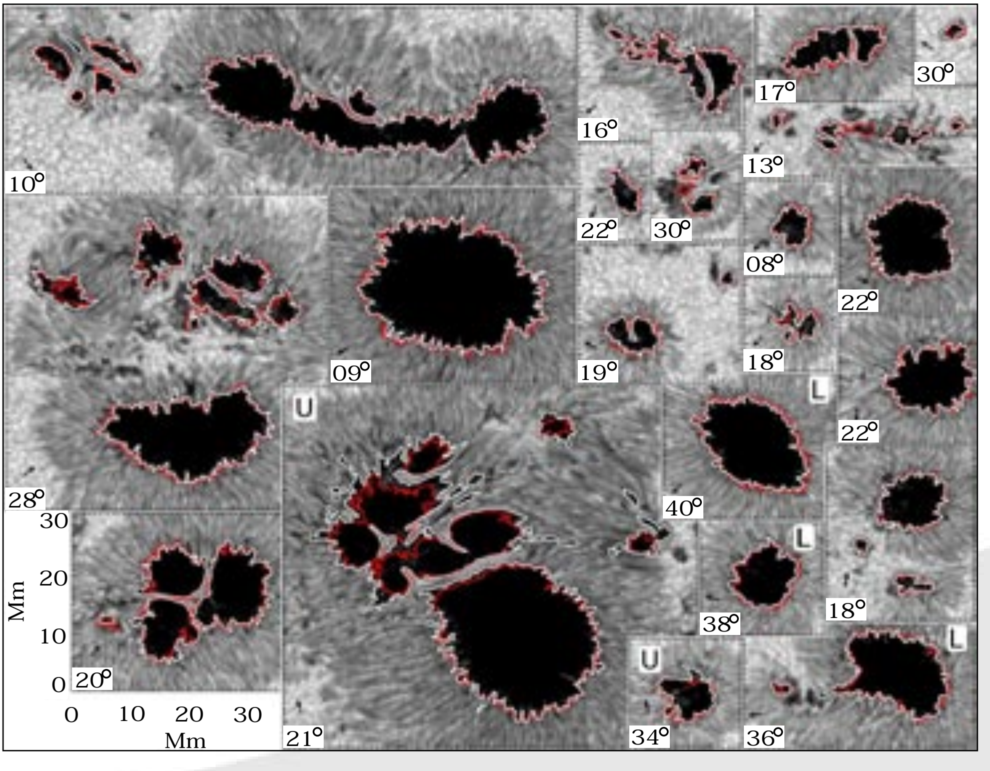
Estimation of the chromospheric heating by acoustic waves

Another example, where the SP inversions with high time cadence revealed the structure of the 'quiet' solar atmosphere and its wave-dominated dynamics, is the study of the chromospheric heating by propagating acoustic waves (Sobotka et al., ApJ, 2016). Having the quite complete information on the atmospheric structure at different height levels, including its time evolution, the authors were able to calculate the wave-energy flux and its decrease with the height ascribed to its thermalisation. The high-resolution (in all spatial, temporal and SP domains) allowed for the first really qualified estimation of the share of the waves to the heating of the upper chromosphere and shed light on the long-term debate on the solar atmosphere heating.

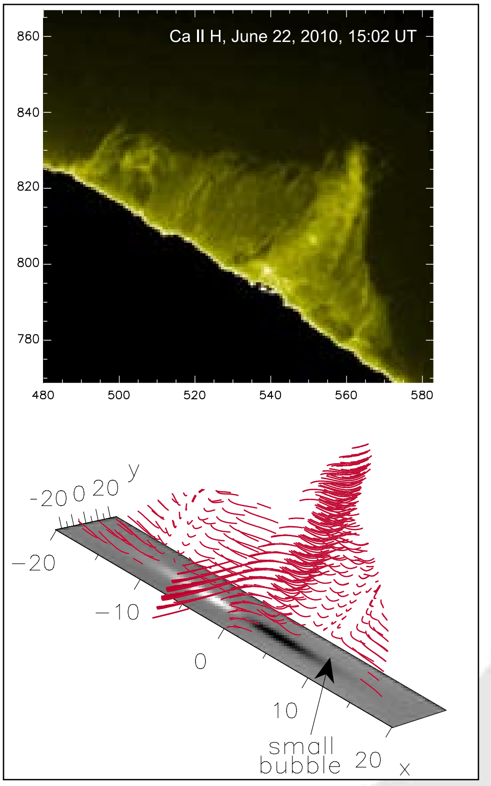
Umbra/penumbra border line in sunspots: Do we see a sharp transition between two magneto-convection regimes?

The sharp border line (a sudden drop of intensity) between umbra and penumbra visible in the white-light images of the sunspots is remarkable. There were several attempts to relate the position of this boundary to the magnetic field properties – e.g., to its magnitude or inclination. In the paper by Jurčák et al. (A&A, 2015) it was convincingly shown, that after some transition period of time, during which the penumbra is being formed, the emission-intensity drop line corresponds quite exactly to the boundary between the regions, where the strength of the vertical component of the magnetic field is higher than a critical value ~1.8 kGauss (umbra), and where it is less. The critical value for Bver is quite a universal constant for all sunspots and this division between umbra and penumbra based on Bver value is nowadays frequently referred as Jurcak's criterion in the literature. Its validity

The umbra/penumbra boundary (shown with white contours) corresponds universally to the level Bver=1850 Gauss (red contour). Only unsteady, still developing magnetic elements exhibit some differences (Jurčák et al, 2018).



was later extended to smaller magnetic elements, too (Jurčák et al., A&A, 2017) – it was shown that pores, whose vertical component does not reach the critical value, are unstable and are consecutively "consumed" by the evolving penumbra. On the other hand, the pores, which have (an internal) region where the Bver is super-critical, evolve eventually into the "standard" sunspot with umbra and penumbra. This universal empirical rule seems to have a deep physical background: Modern MHD simulations of sunspots show that the critical value of the vertical component of the magnetic field separates two distinct regimes of magnetoconvection. This way our result contributed significantly to understanding physics of sunspots and pores and related the notoriously known but so far a bit mysterious border line between umbra and penumbra to the deeper underlying physics. The work on the relation between MHD simulations and high-resolution observations of sunspots continued with a study of the relation between the magnetic field and the temperature in the sunspot penumbrae – such a comparison of the model prediction with the data obtained by SP inversions (Sobotka & Rezaei, Sol. Phys., 2017), was also done for the first time.



The observed fine structure of solar prominence compared with the WPFS model (Gunár et al., 2018).

Fine structure of prominences: Non-LTE calculations and predictions for ALMA observations

Both the modern high-resolution images on one side, and the difficulties with fitting the observed spectra of prominences to their older compact models on the other side, led to a change of the paradigm in the recent past years and a new picture of the prominence as a cloud of thinner threads of cool material deposited in many local magnetic dips emerged. The prominence modelling and non-LTE calculations of the prominence spectral line formation belong to the traditional research topics in our Department. Its recent development takes advantage of the opportunity, which is offered by the modern multi-threaded prominence models based on searching of magnetic dips in the non-linear extrapolations of the photospheric magnetic fields to the upper atmosphere. In an international collaboration with the University of St. Andrews (providing the NLFF extrapolated magnetic field) a new 3D Whole-Prominence Fine Structure (WPFS) model was developed, based on the filling the extrapolated magnetic structure by plasma in (magneto-)hydrostatic equilibrium (Gunár & Mackay, A&A, 2016). The temperature and density prominence structures in the WPFS model correspond well to those inferred by the non-LTE "inversions" of really observed prominences. It was shown that – consistently with the model assumptions – the plasma beta is low enough almost everywhere, with exception of the most dense parts of the threads. Our modelling continued by the extension of the 3D density & temperature map in the prominence to its expected (ideal) sky-brightness maps as it could be seen in the millimeter wavelength domain continuum (Gunár et al., ApJ, 2016). The result was very important in view of starting solar observations with ALMA (Spring 2017), and the predictions made by the model were later actually confirmed by ALMA prominence observations. Since our Team is deeply involved in the Solar ALMA ObsMode development and has been participating (as the European ARC leader) in the Commissioning and Science Verification of solar observations with ALMA (see details below in the ALMA-specific section), the result was also used as a reference use-case for prominences in the Development Study Report: Solar Research with ALMA delivered to ESO. Because of an immediate application of the result for coming ALMA observations, we extended our study of prominence appearance in ALMA images by atmospheric and instrumental effects at the ALMA observing site. To that end, we used Hα image of the prominence with a medium resolution (~1") comparable with the expected ALMA Band 3 images in compact array configurations, re-calculated it (ideally) into a brightness map at 3 mm using the relation between Hα total intensity and brightness temperature (derived by Heinzel & Jejcic, 2009), and calculated the simulated interferometric visibilities of that map, degraded by the instrumental and (Earth) atmospheric effects. The simulated visibilites were finally processed (IFT+clean) in the standard SW package CASA in order to get the prominence maps as ALMA would see it. These results have a significant impact on the world-wide adopted procedures for the solar ALMA data processing.

Oscillations and (quasi-) periodic processes in the solar atmosphere

Oscillations and waves are omnipresent in the entire solar atmosphere. Since their (quasi)periods depend on the parameters of the medium in which they propagate, their analysis has quite a big diagnostic potential. In analogy with similar usage of the waves generated during earthquakes and propagating through the body of the Earth, we speak about helioseismology (propagation in the photosphere and sub-photospheric layers) or coronal (loop) seismology (probing structures in the solar corona). These modern methods are being developed and applied to selected research problems also in our Department in the last couple of years. A few examples of the recent results follow right now.

Helioseismologic inversions for investigation of the large-scale flow structure at the Sun

Our Team members use the time-distance (local) helioseismology method for the investigation of large-scale flows in and under the solar photosphere. Namely, the super-granular flows are one of the long-term research topics of one of our WGs. Earlier they were studied with a more traditional method, like feature tracking, nowadays the research is extended by the usage of the modern ones, right that based on the local helioseismology. Nevertheless, as the results reached in this field showed (Švanda, A&A, 2015), the method based on the time-distance helioseismologic inversions are far from providing unique solutions, i.e., the flow structures: Many different flow structures can result in the same measured signal. The result is of much more general relevance – it shows the possible weak points of the method and warns against using it blindly. In an international collaboration the method was also used for studying the flows at even larger scale: Meridional circulation and differential rotation of the Sun as a whole. In order to validate the recent helioseismologic methods, their results were compared with those obtained by a more traditional feature (Coherent Structures) tracking (Roudier et. al., A&A, 2018). It was shown that within the uncertainties the result of both methods is the same. This cross-validation is an important outcome because the new method can also study weak variations of the flows on a much shorter timescale.

Flare-generated pulsations as a unique diagnostic tool for physics inside

Many types of (quasi-)periodic oscillations are detected in solar coronal loops, in particular being driven by the dynamic processes running in the solar eruptions and flares. One of such processes is the cascading fragmentation of the flare current sheet (CS) inherently connected with the formation of plasmoids and their subsequent motions and mutual interactions. Since the plasmoids sizes in the flare current sheet occupy (as expected by the model, e.g., Bárta et al., 2011) all range of dimensions from a few tens of the dissipation scale up to a few thousands of kilometers, also their dynamic times vary from very sub-second scales (oscillations during merging of small-scale plasmoids) up to minutes (travel time of large-scale plasmoid along the flare CS). In order to investigate the dynamics of plasmoids as possible drivers of observed pulsations, we studied the interaction of a large-scale plasmoid with a flare-loop arcade (Jelínek et al., ApJ, 2017) using an MHD numerical model. It was found that "a fall" of plasmoid to the arcade loop-top leads to several periods of system oscillations, until the plasmoid merges into the loop system. Such oscillations could have observable signatures in, e.g., the position of the loop-top HXR source and the modulation of its signal, or in the dynamics of the separation of flare ribbons.

Plasmoids of smaller sizes, closer to the dissipation scale, and their mutual coalescence have a direct connection with the rate of magnetic energy converted in the reconnection and thus with the injection of accelerated particles into the flare volume. Such injected beams can be detected by quite sensitive radio spectrum measurements. And exactly such expected quasi-periodic broad-band radio pulsations at the sub-second timescale were observed with our instruments in the GHz frequency range. We studied this radio-detected signatures of small-scale fragmented energy release in a broader context of multi-wavelength observations – multiple plasma (presumably reconnection) jets were also found in the EUV data (Meszárosová et al., A&A, 2016). The result supports the fragmented 'multi-site reconnection' paradigm for solar flares.

The (quasi-)periodic modulation of the injection of accelerated particle beams represents one possible source of the observed pulsations. Another one are already above mentioned oscillation eigenmodes of the loops or interacting arcade/plasmoid system. Nevertheless, other possibilities need to be investigated. To that end, we (Karlický & Jelínek, A&A, 2016) simulated (and estimated possible outcome in form of detectable pulsations) a process, where thermal shock – generated by an impulsive bombardment of the dense layers by energetic particles – propagates along the flare loop with several reflections at the photosphere (thermal shock bouncing). The result shows that this process can explain so far mysterious time-scales of pulsations observed in some flares.

Because of the expertise of our group in the topic of oscillations of magnetic structures in the solar corona, we were invited to the international collaborative paper that broadly reviews this general plasma-physics phenomenon across many environments (corona, heliosphere, planetary magnetospheres; Nakariakov et al., Space Science Reviews, 2016).

Oscillations and rotation-like periodic motions in solar prominences

Also solar prominences exhibit a periodic type of motions. Mostly they are detected by measuring the Doppler velocities in prominence spectra (also by our instrumentation – see below). However, some weak quasi-periodic motions observed this way may represent a false detection and are in fact induced by the (Earth) atmospheric turbulence effects in the air mass above the telescope. In order to estimate the fraction of false-detected periods, we performed two-site simultaneous observations of the prominence oscillations in collaboration with University of Wroclaw (Zapiór et al., Sol. Phys., 2016). The mutual distance of the two telescopes (feeding the spectrographs) cancels the atmospheric effects and it was shown that actually only few detected periods are inherently related to the prominence dynamics. The results have a more general impact as a warning for searching blindly for the (quasi-)periods in the single-telescope data without estimating the influence of atmospheric and instrumental defects on the observed data.

A careful analysis of prominence observations has revealed another type of an "optical illusion" – the appearance of some prominences in the form of "tornadoes". In order to track a real 3D motion of identifiable plasma blobs in the prominence volume, we helped (in an international collaboration) to extend the 2D velocity information in the image plane by the third component of their velocities measured spectroscopically by the Doppler shifts. Assuming that the blobs "fall" along the magnetic field lines, the 3D magnetic structure of the prominence was revealed. It was shown that the circular/helical motions of the blobs are quite frequently a mere illusion (Schmieder et al., A&A, 2017), so a "tornado" is a misleading name in this context.

Kinetic-scale plasma processes at the Sun seen in high-resolution radio spectra

Diagnostically significant solar radio emission (i.e., radio bursts) at metric and decimetric wavelength range is inherently connected with the kinetic-scale plasma processes like instabilities of non-Maxwellian particle distribution functions (beam-type, loss-cone, temperature-anisotropy, etc.). One of the many types of solar radio bursts, the spectacular "zebra pattern" (along with the Sun it is also observed in the magnetosphere of Jupiter or in the Crab nebula), can be used for quite an exact estimation of coronal density and magnetic field in its source. The proposed diagnostics is based on the widely accepted emission mechanism for zebras – so called double-resonance instability of the upper-hybrid (UH) waves (Zheleznyakov & Zlotnik, 1975). This instability generates waves with frequencies in a series of harmonic resonances – each one than represents one zebra stripe in the spectrum. The open question remains, how to ascribe a harmonic number to the given observed stripe. This uncertainty has so far prevented the accurate usage of zebra observations for inferring the plasma parameters inside the source. Using analytical calculations and Particle-In-Cell (PIC) plasma simulations of the UH instability, the method for this identification was presented for the first time (Karlický & Yasnov, A&A, 2016).

In another paper (Karlický, ApJ, 2015) we studied confinement of hot electrons by self-generated thermal front at the plasma kinetic scale. Using the PIC simulation it was found that the thermal discontinuity suppresses significantly the electron flux from the hot to the cold region. At the same moment, the thermal front moves and this process can manifest itself by a characteristic signature in the radio spectra. An example of such signature found in our radio data was presented. The result also shed light on the so far mysterious long-duration HXR sources, whose hot-electron contents had been supposed to dissolve much faster.

Kinetic-scale plasma processes in the solar wind: Models and in-situ measurements

Thanks to the availability of the in-situ measurements (nowadays also by Solar Parker Probe and Solar Orbiter), the solar wind is a perfect laboratory of dilute, turbulent, magnetized plasmas and a test-bed for our theoretical and modelling approaches to such environment, which have much broader relevance in plasma physics and its applications (e.g. in controlled fusion). In this field, our group contributed namely by

i) Analytical calculation of the generalized plasma dispersion tensor under presence of specific distribution functions, and
ii) Hybrid simulations of plasma instabilities and turbulence in the solar wind.

The first result (Vandas & Hellinger, Phys. of Plasmas, 2015) represents a significant extension of analytical dispersion-tensor calculations done so far for simpler particle distribution functions by the ring-type particle distribution, frequently found in the solar wind. The result is important for analytical calculations of possible plasma instabilities that may result from the presence of ring-type distributions in plasmas.

The latter contribution – thanks to the "mezzo-scale" applicability of hybrid simulations – provided a bridge between various concepts of plasma descriptions and this way enabled their cross-validation. As an illustration of this fruitful approach, the verification of the specific Hall-MHD approximation to the turbulence based on a new form of the von Karman–Howarth equation using a concurrent description by the fluid and hybrid approximations in their common domain, can be adduced (Hellinger et al., ApJL, 2018). The newly verified von Karman–Howarth fluid approximation can be now used on a more extended range of scales with much less computing resources than fully kinetic or hybrid approaches. In another paper, the hybrid code was used for the extension of the plasma-kinetic analytical description of the fire-hose instability in the solar wind to its non-linear regime (Matteini et al., ApJ, 2015). And as a final example of such useful bridging across the scales, let us adduce the hybrid simulation of the mirror instability running on the background of the developed multi-scale turbulence in the solar wind (Hellinger et al., ApJ, 2017). The simulation found that the mirror instability is not suppressed by turbulence and its structures can coexists on top of it. Since the process contains both ion-kinetic and hydrodynamic scales (it spans from the ion skin depth to the turbulent-cascade energy input scale, taking into account the solar-wind expansion in the co-moving reference frame), only the specific hybrid approach used in the paper was able to treat all involved processes self-consistently. The result is important for understanding the modern in-situ measurements of the solar wind parameters.

Closer to applications

Albeit the mass-center of the activities carried out at the Institute is by its foundation in the science and basic research, some results obtained in the field of solar physics, namely the influence of solar activity on the Earth and our civilization, are closer to applications. In the following paragraphs, we briefly describe three illustrative examples reached during the last five years.

How frequent are the harmful solar eruptions?

Solar eruptions and flares can have a significant and multi-channel impact on the Earth, namely on our modern sensitive technologies. The means of their influence range from a collision of a magnetized cloud/ejected CME with the Earth's magnetosphere, leading to geomagnetic storms and geomagnetically-induced currents (GICs), through an interaction of energetic particles and radiation with the upper atmosphere, up to enhanced radio noise interfering with our communication or navigation devices. As our civilization becomes more dependent on technologies, expected damages caused by a possible major solar event increase rapidly. Indeed, in 1859 the famous Carrington event (among other remarkable effects) damaged a few telegraph lines (there were not so many such lines at those times) but if an event of such magnitude appeared nowadays, they say that our civilization would be practically switched off for more than three months and the damages would hardly be possible to be enumerated in money. Naturally, a question arises, how frequent are the major events like that in 1859. Since historical written records are quite short in order to make a statistic solely from solar events, a plausible way out is to increase the statistical ensemble by taking into account many Sun-like stars. These so called 'solar-stellar connection' studies started to appear in the last decade. Their number increases because of (i) the practical motivation mentioned in this paragraph, and (ii) the means of detection of flares at other stars increased in the past few years thanks to the space missions oriented namely on the popular research of exoplanets. Our group does not stay behind the development and we have published (mostly in an international collaboration) a bunch of papers on this topic. In order to use other stars as a part of an ensemble for statistical scaling of the magnitude of solar events, one has to study the similarities and differences between the Sun and other stars carefully. Švanda and Karlický (ApJ, 2016) studied an ensemble of flaring A-type stars recorded by the Kepler exoplanet mission. By methods of the statistical correlation between the flare energetic spectrum and the (non-)presence of stellar coronae they studied the relation between the coronae and the flaring activity. They speculate that the flares at the stars, which have hot coronae, contribute to their (corona) maintenance. In the following paper (Balona, Švanda & Karlický, MNRAS 2016) the authors studied a broader range of stars from A to M spectral type, again using the Kepler-mission archive. They found a correlation between the flaring activity and the star rotation rate as well as between the presence of star-spots and the flares. These correlations strongly indicate that the flares at stars – defined phenomenologically as a sudden rise of light curves (in specific spectral channels) followed by a slower decrease – are, in fact, of similar nature as the solar flares; that their common underlying physics is a sudden release of stored magnetic energy. In order to bring further evidence for qualitatively the same – just up-scaled in magnitude – background mechanism of stellar and solar flares, we study the enhancements in specific ranges of spectral continua as it has already been described above (Heinzel et al., ApJ 847, 2017). Such broad-band observational features are more robust and more likely to be detectable also at the (remote) stars, where we lack the spatial resolution. Specifically, there is a practical question, whether we can have – in principle – a super-flare at our Sun, i.e., whether the detected stellar superflares are just up-scaled solar-like flares. To that end we contributed to the discussion by a paper Can Flare Loops Contribute to the White-light Emission of Stellar Superflares (Heinzel & Shibata, ApJ 859, 2018). As it has already been claimed: Clarification of the similarities/differences between phenomena of solar and stellar flares is essential for using the stellar data as an extension of solar flare statistics and, consequently, making qualified estimation of major solar event probability of occurrence (magnitude vs. typical period of recurrence).

Can even middle-magnitude events lead to cumulative damages in power grids?

Large solar eruptions (when hitting the Earth) are undoubtedly harmful for our infrastructure namely to the power grids by the action of the above mentioned GICs. But what about the cumulative effect of middle-magnitude events? This question was addressed by Výbošťková & Švanda (arXiv:1709.08485, in Czech), who statistically studied the failure rates in the main Czech power transmission system operated by the Czech national operator ČEPS vs. the space-weather effetcs. They showed that the effects of solar activity on the failure rate in the back-bone power grid cannot be excluded even for our central-European country (i.e. rather far from the geomagnetic pole). Namely, the middle-size geomagnetic events (substorms) may lead to unnoticed partial damage or performance worsening of the power-grid devices (e.g., transformers), which may than fail later, during the next overload. In this direction, M. Švanda also made a study Risks of solar flares for the nuclear power plants operated by the Czech Energetic Company (ČEZ), at the request of the Czech Energetic Company (2016).

Direct influence of solar radio bursts to GNSS systems

Solar flares and eruptions do not affect our technologies only by the best-known GICs, but via many other channels. One of them is also quite a known effect of a highly dynamic variability of the total electron content (TEC) in the Earth ionosphere due to ionizing radiation (plus particles and atmospheric currents) enhancements during the flares. The TEC variability has a direct effect on the global navigation satellite systems (GNSS; specifically e.g., GPS, Galileo, GloNass, etc.) as it inserts hardly-predictable time delays for the radio (L-Band) signal travelling from the satellite to the navigation receiver. Much less it is known that even the solar radio emission can reach such high spectral flux density that it interferes the GNSS radio communication, and the satellite navigation is not just inaccurate (like in case of the TEC irregularities), but – in extreme cases – even completely impossible. One such case of a major flare was studied in an international cooperation (namely with DLR) and the results published as a paper Solar Radio Burst Events on 6th September 2017 and Its Impact on GNSS Signal Frequencies (Sato et al., Space Weather 17, 2019). Our group contributed by the in Europe unique measurements of solar radio spectra of that event; the figure of our spectrum was selected for the front page of the SW journal issue. Our radio spectrographs (see below) operate exactly in the L-Band, where the GNSS communications runs, too.

Solar activity forecasting

Last but not least in this direction, our Department operates the Solar Patrol Service (in more detail described below). This service – among other activities – works as a national reference for predictions of the solar activity and the related space-weather effects. We provide this forecasts to the TV (presented daily on the Czech Television as a part of the weather forecast) and radio broadcasting, press agency, and for approximately 50 Czech and international users (radio communications, radio amateurs, ISES, SIDC, and others). At the same moment, the service is involved in international networks (details below).

Observing (and computing) infrastructures

Our Team operates (and further developes) several in-house observing (and computing) facilities and in addition to that, it is involved in the development and operation/services for a couple of major international infrastructures and projects. Let us start with a brief description of the recent development in our local infrastructures.

Solar Patrol Service

Solar Patrol – as already mentioned – works as a national service for monitoring and forecasting of the solar activity & space weather. It works in the frame of the International Space Environment Service (ISES) and its Regional Warning Center (RWC) Prague. At the same moment it is involved into Sunspot index and long-term Solar Observation (SILSO) and CV-Helios international networks for monitoring and classification of the solar magnetic activity manifested by sunspots, and for the activity forecasting. The patrol operates three small full-disc refractors for drawings, white light, and Hα, and two 20cm refractors for imaging of active regions in the photosphere and Hα chromosphere. An upgrade of cameras and steps towards better automation of the telescope control were undertaken during the past few years. The time of low solar activity around the minimum was also used by our operator for digitization of the archive of our older paper records, not only from Ondrejov but also from a series of observing stations on the territory of the Czech Republic and Slovakia. The web interface for the forecasts and monitoring was completely rebuilt, too. In 2019 we started negotiations on a possible incorporation of our SPS into the Solar Weather Expert Service Centre (S-ESC) working in the frame of the ESA's Space Situational Awareness (ESA SSA) programme oriented to space weather; the negotiations are underway. At the end of 2019, our SPS also undertook steps towards the inclusion into Flare scoreboard – NASA operated validation programme for solar flare forecasting. More details on instrumentation, activities, observation records etc., can be found at the SPS web site http://www.asu.cas.cz/~sunwatch.

Solar optical spectroscopy labs

The department currently operates two solar spectroscopic labs:

1) HSFA2 – the 0.5m horizontal solar telescope equipped with a large multichannel slit spectrograph observing in five spectral regions simultaneously: Ca II H, Hβ, Na I D and He I D3, Hα, and Ca II 854.2 nm. The spectrograph is used for our research in solar flares and prominences; during the last years namely the observing programme targeted at the research of prominence 3D structure and oscillations was run (see the published results above). The device is also often utilized in coordinated campaigns with other European space and ground-based instruments. A major upgrade of cameras to higher resolution & cadence was carried out at the end of 2019. The details on instrumentation and the data archives are available at http://www.asu.cas.cz/~sos/.
2) In 2018, two low-dispersion spectrographs Ocean HR4000 in near UV and visible channels were installed in the no more used laboratory of historical Multi-channel Flare Spectrograph (MFS; Valníček, Švestka et al., 1959). They are fed by the still operating original MFS telescope and heliostat. The goal of the research is to mimic observations of the Sun as a star – quite a significant part of the solar surface is selected around the active region and model-predicted (already mentioned Heinzel et al., 2017) specific enhancement in continua is searched in the spatially-integrated signal from that area. Such a robust detection technique could be used for searching of this feature in stellar flares, too.

Enhanced solar radio spectrographs – from RT5 to OSCARS

The group has (already for decades) been operating three radio instruments for solar research – radiometer RT3 @3GHz with time cadence of 1 ms, and two radio spectrographs (RT4 and RT5), each composed of 256 frequency channels spanning over the ranges 0.8 – 2.0 GHz (RT5) and 2.0 – 5.0 GHz (RT4), fed by 10m (RT5) and 3m (RT4) parabolic dishes. The spectrographs are unique instruments in the European time zone and observed frequency range, and provide results used in many of our research publications (see Basic research above) as well as for the direct application in the GNSS interference of solar bursts (as mentioned in Applications). The data archive and the details on instrumentation can be found at http://www.asu.cas.cz/~radio/. Motivated by our research interest in the multi-scale fragmented magnetic reconnection, whose model predicts radio-burst sub-structures at short time scales, and also by the above mentioned new practical application of our measurements in the GNSS interference research, we decided to upgrade our channel-sweeping spectrograph RT5 with (practically usable) time resolution 10 ms and the channel width of 4 MHz to a fully digitized FFT-based device. The new spectrograph (Ondrejov Solar hi-Cadence Automated Radio Spectrograph – OSCARS) was designed in collaboration with the Faculty of Electrical Engineering TU Prague (details in Puričer, Kovář, & Bárta, Electronics 8, 2019) and its main advantage is that it provides higher spectral (1 MHz) and temporal (1 ms) resolutions with yet better sensitivity and S/N ratio. The new spectrograph is currently (since September 2019) cross-tested with the existing older RT5 device and later it shall replace it. A similar upgrade is envisaged for the higher-frequency RT4 spectrograph, too.

HPC cluster OASA, solar data servers

Our numerical simulations and ALMA data processing demanded a new computer cluster OASA, basically replacing the old one (OCAS) built in 2005–2007. Although it represents an all-institute HPC infrastructure, used by all its departments, the main share

in its building (project design, execution, and management) was done by the Dept. of Solar Physics. The cluster started serving our community in January 2017. We also operate three larger servers for processing, archiving, and publishing (via web interface) our own data.

It is hard to omit our participation in big international infrastructures in this section completely – let us mention it at least briefly; below we give details about our most significant collaboration programmes.

ALMA

Solar physics, together with galactic & extragalactic astrophysics, represents a key research topic and expertise of our involvement in the European ALMA Regional Center (EU ARC), one of the three world centers of the international ARC infrastructure serving to support the science operations and further development of the ALMA observatory. Our main contribution in this area in the period of 2015–2019 includes

i) Development of the Solar ALMA Observing Mode, its commissioning and science verification (our Institute was the leader of the European consortium of the ESO project Solar Research with ALMA, carried out in 2014–2017),
ii) User support for all European solar science observations with ALMA (from proposal preparation to data processing), and
iii) World-wide coordination and maintenance of the solar ALMA data reduction (QA2) procedures & documentation shared at http://wikis.alma.cl.

RT5 radiotelescope is currently in the process of a significant modernization of its electronics. Once completed and tested during 2020 the upgraded technological set-up will allow to execute a new observation strategy.

Our activities in this field shall be described in detail below. In 2015 our participation in the project was institutionalized at the national level by acknowledging the status (and corresponding support) of Large Research Infrastructures to our ARC node by the Czech Government. Together with EST (see below) it is one of the two LRIs that ASI operates among total 48 LRIs in Czechia (https://www.vyzkumne-infrastruktury.cz/en/physic/eu-arc-cz/).

Large European solar optical telescopes – GREGOR & EST

Our participation in the GREGOR project (1.5m solar telescope in the Canaries, built and operated by a consortium of German research institutions + ASI (CZ) + IAC (Spain); early science started in 2014) through the agreement with Leibnitz Institute for Astrophysics (AIP) in Potsdam continued during the last five years namely by its exclusive usage, guaranteed by our direct partnership with the project. Our Team members participated in many observing campaigns and the high-quality data acquired by the telescope contributed to the key results of our Team and were used in many of our publications (see above). Success of the spectro-polarimetric methods in revealing the detailed structure of the solar photosphere and chromosphere (incl. mag. fields) with the large instruments led to even larger international projects of giant solar telescopes. In Europe, a consortium of 18 countries (European Association for Solar Telescopes, Czechia represented by ASI belongs to 14 founding members) has made an agreement on constructing and operating the 4m European Solar Telescope (EST). Its construction is currently in the advanced preparatory phase and first light is expected in 2027. At the European level, the consortium will be institutionalized as ERIC (European Research Infrastructure Consortium), at the national scale our participation is covered by the LRI EST-CZ (https://www.vyzkumne-infrastruktury.cz/en/physic/est-cz/).

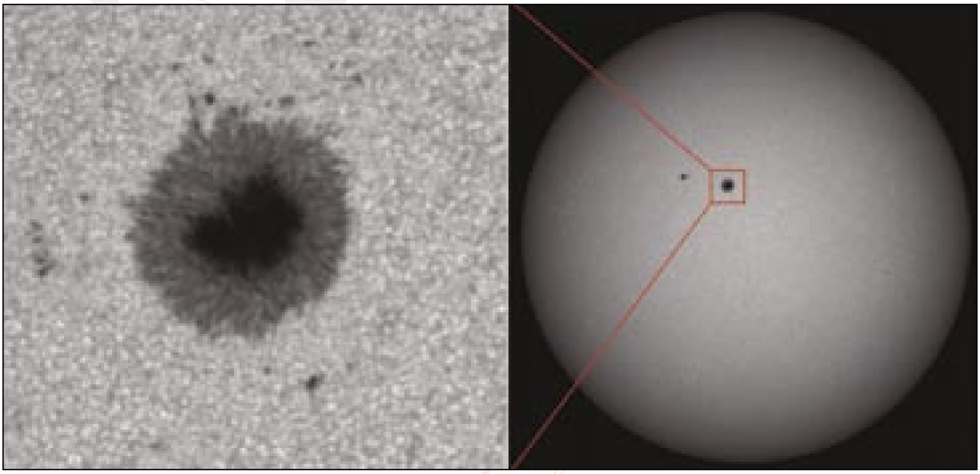
Space missions for solar & heliospheric research

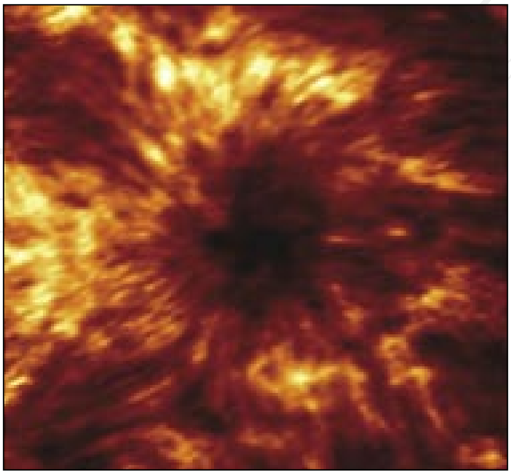
At the beginning of 2020 a long-term international endeavour finished with its 'grand final' – a successful launch of the ESA/NASA space mission Solar Orbiter. Our Department was directly involved in the development of HW and SW parts for three of total 10 scientific instruments onboard (METIS, STIX, and RPW). The development goes on for the JUICE and Proba-3 ESA missions, where our Department participates, too.

Cooperation within international research area

As it can already be seen from the presented results, our research is far from being carried out solitarily – actually, the opposite is true and our Department is naturally involved in many bi-lateral and network-type collaborations. Starting in the national context, we continued our traditional collaboration namely with solar-physics oriented teams at Czech universities – the Faculty of Mathematics & Physics of Charles Universityin Prague, the Faculty of Science of University of South Bohemia in České Budějovice (Budweis), and the Faculty of Science – Jan Evangelista Purkyně University in Ústí nad Labem. The collaboration has a form of common research projects (grants), external teaching at the universities, supervising students (bachelor, master, and PhD theses, student projects), organizing joint seminars, etc. In the recent period we also started a co-operation with the Faculty of Science of Masaryk University in Brno (bachelor project applied to solar ALMA observations) and extended our already existing collaboration with the Faculty of Electrical Engineering – TU Prague (design and development of the FFT-based digital radio spectrograph, a closer collaboration with their plasma-physics group). In the field of FEM solver for the multiscale MHD equations we have initiated a cooperation with the Mathematical Inst. of the Czech Academy of Sciences and the Faculty of Electrical Engineering at the University of Western Bohemia in Pilsen. Our Solar Patrol Service renewed the collaboration with regional (public) observatories and well-equipped amateur astronomers in monitoring of the solar (namely sunspot) activity. Such a network (Fotosferex) existed before, but in the later 1990s its activity diminished and the network disappeared. Along with, e.g., the improvement of the sunspot statistics, the collaborative network has a big educational and popularization impact. In the frame of the Institute activities we also contribute as for the effort to map and shape the local research area in the Region of Central Bohemia – we participate in activities organised to that end by the Central-Bohemian Innovation Center (https://s-ic.cz/en/), namely contributing to the regional RIS3 strategy documents and the Innovation Atlas.

Thanks to the continuing internationalization of the European research space, also our involvement in the cooperation at the trans-national level increases. During the past five years, we have continued fruitful collaborations with a number of foreign partners at universities and science institutes: Leibnitz Institute for Astrophysics (AIP) Potsdam, MPS Gottingen, KIS Freiburg, MPA Garching, and Potsdam University in Germany, Observatoire de Paris–Meudon, Inst. d'Astrophysique Spatiale Paris, IRAP Toulouse, and Obs. Midi Pyrenees in France, Harvard–Smithsonian Center for Astrophysics, SSL Berkeley, and Lone Star College Houston in the USA, Universities of Cambridge, Dundee, and St. Andrews in the UK, Tor Vergata University Rome and Florence University in Italy, IAA Granada and IAC Tenerife in Spain, Sternberg Astronomical Inst. Moscow and ISTP Irkutsk in Russia, Wroclaw University and Space Research Centre in Poland, ISSI Bern and University of Applied Sciences and Arts Windisch in Switzerland, Astron. Inst. of the Slovak Academy of Sciences and Comenius University in Bratislava in Slovakia, IGAM Graz in Austria, Royal Observatory of Belgium, National Inst. for space Research in Brazil, NAOJ Tokyo and Kyoto University in Japan, and Rosseland Center for Solar Physics at the Oslo University in Norway. A new collaboration was started with the Center for Astrophysics at the Technical University Berlin (Germany), University of Warwick (UK), Pulkovo Observatory in St. Petersburg (Russia) and National Astronomical Observatories of China in Beijing. Our cooperation with Uni Oslo has been newly extended to the solar ALMA observations domain: the Oslo group has started activities in the advanced solar data post-processing (self-cal, simulations), the procedure built on top of our calibration, imaging, and QA2 routines.





Top: A photo of the Sun (on the right hand side) with a large sunspot in its centre. The detail of this sunspot is in the top left panel.

Bottom left: Solar ALMA Observations are the key program of the Ondřejov Regional Centre. In a color coded image we show a large sunspot seen by ALMA for the first time.

In the period of 2015–19 we were involved in two large EC-funded research networks (Marie Curie-Sklodowska RTNs):

i) RadioSUN – a network of institutes from EU countries and companies co-operating with the selected universities and institutes in Russia and China on the topic of solar radio astrophysics in 2012–2016, and
ii) SolarNet – a consortium of 35 mostly European institutions, universities & companies formed in order to promote, coordinate and scientifically utilize high-resolution solar observations and to help to develop corresponding observing facilities (https://solarnet-project.eu). The project started in 2019 and shall continue till end of 2022. The current SolarNet H2020 project is a follow-up of the SolarNet FP7 network running in 2014–17, our involvement in the new SolarNet increased significantly.

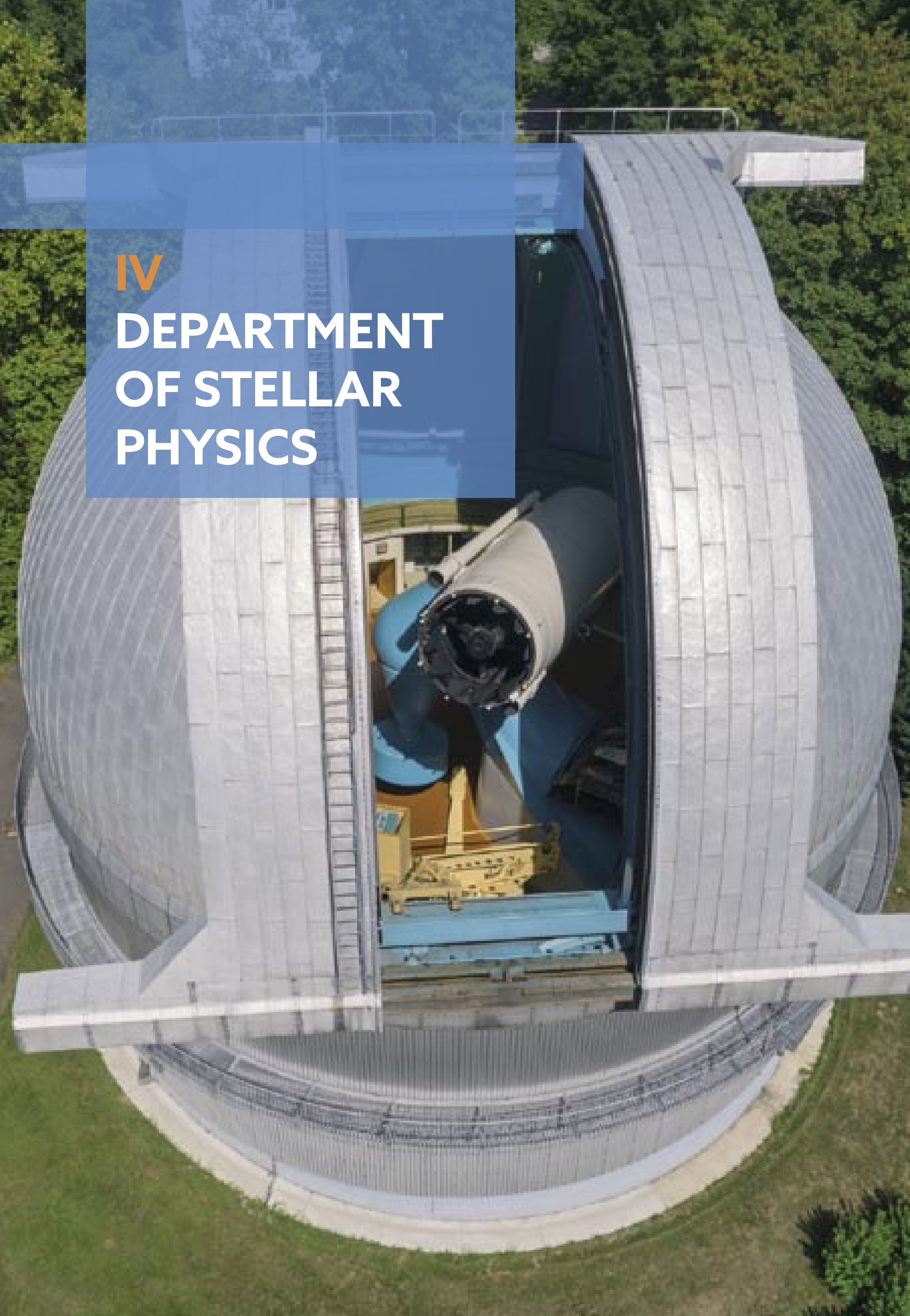
As already mentioned: We are naturally involved in the pan-European structures like ESA – namely through our contributions to the mentioned space-mission development (ESA-PRODEX programme), ESO – being the unique European expert center for the solar ALMA observations and data processing in the frame of the EU ARC network (details shall follow), and the

EAST (European Association for Solar Telescopes) – being the EST consortium member (more below).

We (co)organized two bigger (~100 participants) international events during the evaluated period and a couple of smaller workshops and meetings – the details are given in a specific sub-section below. And even our "local" regular weekly seminar (http://wave.asu.cas.cz/solsem) has an international dimension – it is integrated into the bi-weekly organized network of European Solar-Physics Online Seminars – ESPOS (https://folk.uio.no/tiago/espos/).

A view of the ALMA radiotelescopes at the high-altitude site in the Atacama desert (© ESO)

IV
DEPARTMENT OF STELLAR PHYSICS



The Head of the Department:
Dr. Brankica Kubátová

The research of the Department of Stellar Physics can be characterised by its dominant focus on studies of hot stars. More specifically, the long-term almost exclusive focus on Be and shell stars in binary systems was successfully extended to studies of hot massive stars at their different evolutionary stages, which now represent the main research topics of the Team of the Stellar department. The main characteristics of hot massive stars is the outflow of matter. These stellar winds can be relatively steady at or near the main sequence, but in later stellar evolutionary stages this picture changes dramatically and the outflows become more violent and irregular. Particularly, the research includes studies of luminous, hot massive B and Otype stars, and massive stars in transition phases (i.e. Wolf–Rayet (WR) stars, Luminous Blue Variables (LBVs), Blue Supergiants (BSGs), B[e] supergiants (B[e]SGs), Yellow Hypergiants (YHGs), and Red Supergiants (RSGs)). The studied objects can be either single or in binary or multiple systems. Furthermore, the Team is involved in observational and theoretical investigations of the chemistry and dynamics of the circumstellar material of evolved massive stars. The research of massive stars is complemented by studies of low-mass stars in late evolutionary stages, namely white dwarfs, subdwarfs, cataclysmic variables, and recently also RR Lyrae stars. Theoretical studies in modelling stellar atmospheres with a natural focus on hot massive stars are also a part of the Team's research. These studies include full NLTE (i.e. without the assumption of the local thermodynamic equilibrium) model atmospheres as well as NLTE models of stellar winds. The Team is also involved in astroinformatics research in order to develop new methods and tools to deal with the exponentially increasing amount of data in astronomy. Besides the massive star research, the Team focus was also extended by the research field of exoplanets, namely by measuring radial velocities of exoplanet candidates and detecting and characterizing exoplanet atmospheres. Observations of γ-ray bursts are an independent research direction.

The Team operates the largest optical instrument in the Czech Republic, the Perek 2m Telescope equipped with single order and echelle spectrographs, and a recently installed photometric camera. This Telescope is mainly used for observations of stars and stellar systems including those with exoplanets. These objects are studied by Team members, often in an international collaboration.

Left: An aerial view of the Perek 2m Telescope for optical spectroscopy of hot stars and exoplanetary research programmes. The Telescope has been upgraded recently by adding unique state-of-the-art fibre optics. (© Jaroslav Horák)

Other telescopes available for observations are the D50 telescope and the BART robotic telescope, both devoted mainly to observations of γray burst afterglows. Because the Czech Republic is an ESO member state, Team members can apply for observing time with all ESO facilities, and they also have access to facilities at Gemini Observatory via durable international collaborations. Data acquired with these facilities provide an imperative pillar for the Team's research. Moreover, Team members take part in scientific and payload consortia for the development of new ground-based (SCORPIO, PLATOSpec) and space facilities (PLATO), which will provide valuable data for essential future research and discoveries of the Team.

The Team is organized in three scientific working groups, namely Physics of Hot Stars, Extrasolar Planet Research, and High Energy Astrophysics.

Research activity and characterisation of the main scientific results

Working group Physics of Hot Stars

Research results. The main results of this group concern theoretical and observational studies of massive hot stars, subdwarfs, and white dwarfs, theory and modelling of stellar atmospheres, winds, stellar ejecta, chemistry in circumstellar material, and transfer of radiation. Furthermore, the group is also focused on the research and education in data-oriented astronomy, i.e., astroinformatics. It is characterised by several complementing research directions. All citations refer to papers where Team members were involved.

Stellar atmospheres, stellar winds, and their modelling

Theoretical studies in this research field are mainly targeted at the development of sophisticated codes for stellar atmospheres and wind modelling and investigations of physical mechanisms which govern different processes in stars and their surroundings. One of the main goals of the theoretical study of the research led by J. Kubát is to provide improved mass-loss rates of massive hot stars using their own developed sophisticated stellar atmosphere and wind codes including 3D phenomena (such as non-sphericity and wind inhomogeneities, i.e., wind clumping). Furthermore, the research activities are focused on the development of codes which are able to calculate emergent spectra in different wavebands and which can be directly compared with observations. Based on such comparison reliable values of stellar and wind parameters can be derived, in particular the mass-loss rates of massive stars in different evolutionary phases and different metallicity. The proper value of mass-loss rate is one of the main ingredients for stellar evolution modelling.

The group continued to work on the development of a hydrodynamic NLTE wind model code. This unique code enables the construction of a spherically symmetric wind model including a consistent calculation of the hydrodynamic structure based on the actual radiation force acting on wind matter, without a necessity to use unnecessary approximations (force multipliers). The most important steps of the code development were described in several papers (Krtička & Kubát 2017, A&A 606, A31; 2018, A&A 612, A20, and references therein). The code also allows external irradiation of the

The fourth working group in the Stellar Department, named "Operation and Development of the 2m Telescope", is a mainly technological unit; its task is to maintain the Perek 2m Telescope at the Ondřejov Observatory.

wind. Using this code it was analysed how strongly Xray radiation from the secondary influences the wind of the primary in high-mass Xray binaries (Krtička et al. 2015, A&A 579, A111; 2018, A&A 620, A150). Winds of high gravity stars were also analysed, namely of subdwarfs (Krtička et al. 2016, A&A 593, A101) and central stars of planetary nebulae (Krtička et al., 2020, A&A 635, A173). This work was led by and done in a close cooperation with colleagues from Masaryk University Brno. In a broader team, two specific subwarfs (HD 49798 and BD+18 2647) were studied in detail with the help of our models (Krtička et al. 2019, A&A 631, A75) using the data obtained during awarded observing time at the European Southern Observatory (ESO) spectrograph UVES@UT2.

The group also started a major update of their static spherically symmetric NLTE model atmosphere code by its transfer to modern versions of Fortran, which enabled a significant improvement in the code performance. Recently, the group members succeeded to implement approximate treatment of atmospheric inhomogeneities and published the first results (Kubát & Kubátová 2019, ASPCS 519, 45). In a study of the effects of proper treatment of Rayleigh scattering in plane-parallel model atmosphere calculations it was found that it influences emergent radiation (Fišák et al. 2016, A&A 590, A95). The group members participated in several review papers, concerning X-ray influence on stellar winds (Krtička et al. 2016, AdSpR 58, 710) and structure of inhomogeneous winds (Oskinova et al. 2016, JQSRT 183, 100).

In addition to developing their own codes, the group members are also experienced in using similar stellar atmospheres and wind codes (e.g., TLUSTY, SYNSPEC, PoWR, and CMFGEN) as well as the stellar evolution codes (e.g., MESA) for analysing different types of stars. The important contribution of this type of research is a prediction of spectral appearance and spectral classification of the metal-poor (0.02 $Z_\odot$) chemically homogeneously evolving stars. It was found that a detection of a very hot star without almost any metal lines but with strong He II emission lines consistent with a very early O type giant or supergiant will point to a strong candidate for a star resulting from chemically homogeneous evolution (Kubátová et al., 2019, A&A 623, A8). The synthetic spectra were computed using the Potsdam Wolf–Rayet (PoWR) atmosphere code while the stellar evolutionary sequences of low-metallicity ($Z \sim 0.02\ Z_\odot$), fast-rotating massive star were computed using the Bonn evolutionary code (Szécsi et al. 2015, A&A 581, A15). Furthermore, stellar evolution and cluster hydrodynamics simulations were combined for the first time in a novel way to study the formation of globular clusters. This allowed drawing of an unprecedentedly complex picture on how and why supergiants can be responsible for abundance anomalies that we observe in globular clusters today (Szécsi & Wünsch 2019, ApJ 871, 20).

We started a web-service to make stellar spectral analysis and atmospheric parameter inference for hot evolved stars available to a larger community. The service is a web interface to the classical NLTE model atmosphere code TLUSTY. Even though all procedures are public and well documented, such calculations are complex tasks from theory through informatics, which require tailored expertise. This is a major reason why some astronomers try to avoid such studies. With the framework provided by Astroserver (https://astroserver.org/) this procedure can be used on

Named after doc. Luboš Perek in 2012, recently refurbished 2m Telescope was reopened to full operation and presented to the Academy community in spring 2020 by Dr. Miroslav Šlechta (photographed on the left during the speech at the press conference).

a user platform to produce publication-grade results with relatively little user personal efforts. The interface is also intended to help observers to quickly process spectra, as well as students to take their first step in quantitative stellar spectroscopy and learn spectroscopy with the TLUSTY code (Németh 2019, ASPCS 519, 117). The service, in its current form, is most suitable to fit hot subdwarf spectra, which is also reflected by the published results (e.g. Lei et al. 2018, ApJ 868, 70; Schindewolf et al. 2018, A&A 620, A36; Luo et al. 2019, ApJ 881, 7, Lei et al. 2019, ApJ 881, 135). A procedure for binary spectral disentangling was added to the service in 2019, which is heavily used in our hot subdwarf research. Future developments will extend the capabilities of the web-service to fit all types of stellar spectra.

Massive stars in short-lived transition phases

One more expertise of the group is the research of massive stars in short-lived transition phases. These phases are divided into several stellar classes: WR stars, LBVs, BSGs, B[e]SGs, YHGs, and RSGs. During all these phases, the stars display signs for highly dynamic atmospheres and envelopes, and expel large amount of material, often in a series of eruptions. The ejected material accumulates in either circumstellar disks, shells, unipolar, bipolar or multi-polar nebulae. The research of massive stars in transition phases led by M. Kraus is focused on developing suitable methods to derive mass-loss values of these types of stars and to investigate the chemical evolution, structure and dynamics of the ejected material. The knowledge of the amount of mass a star loses within each phase of its life is of utmost importance for reliable predictions of the evolution and final fate of massive stars. Moreover, members of the group investigate physical mechanism(s) that can lead to enhanced mass-loss and trigger eruptions, as well as they analyse the chemical composition, the 3D structure and dynamics of ejecta to uncover the mass-loss history of massive stars in transition.

The group combines results from theoretical models with information derived from observations. Optical, infrared and radio data are collected from 2 to 12 metre telescopes, utilizing facilities at GEMINI North and South, ESO's Very Large Telescopes, APEX Telescope, Nordic Optical Telescope, Gran Telescopio de Canarias, Southern African Large Telescope, 2.2m MPI Telescope, 2.15m CASLEO Telescope, and our Perek 2m Telescope. These data are supplemented with images from space missions such as the Spitzer Space Telescope, the Wide-field Infrared Survey Explorer, as well as with photometric data and light curves from various ground-based surveys (e.g., AAVSO, ASAS). In the past five years a number of objects in the various categories in the Galaxy, the Large and Small Magellanic Clouds (LMC, SMC), M31, and M33, were analysed. Here the most important results are highlighted.

New ongoing eruptions for two LBVs in the Magellanic Clouds were identified. The stellar parameters that were derived for the stars before and during eruptions imply a drastic increase in luminosity during outburst. Such a behaviour is not expected for a regular LBV S Dor cycle and imply that both stars experience an eruption accompanied by large mass-loss (Campagnolo et al. 2018, A&A 613, A33). The variability of Romano's star in the nearby galaxy M33, which is an object in transition from an LBV to a WR star, was also followed and its current mass-loss rate was derived, which was found to be higher than ever before, with a highly increased outflow velocity (Maryeva et al. 2018, A&A 617, A51; 2019, Galaxies 7, 79). This star is surrounded by a compact but asymmetric envelope of ionized gas, a clear witness of prior intense mass-loss (Maryeva et al. 2020, A&A 635, A201).

Based on optical and infrared spectroscopic and imaging data of a large sample of B[e]SGs, we discovered emission from molecules (TiO, CO, and SiO) arising in the close vicinity of the hot stars (Kraus et al. 2015, ApJ 800, L20; 2016, A&A 593, A112; Muratore et al. 2015, AJ 149, 13) and found that all objects are surrounded by a unique combination of multiple rings of atomic and molecular gas and dust (Aret et al. 2016, MNRAS 456, 1424; Maravelias et al. 2018, MNRAS 480, 320; Torres et al. 2018, A&A, 612, A113). These rings can be clumpy or smooth, and are found to be stable in case of single stars, for which we propose that planets or minor bodies might have formed in the disks, creating gaps and stabilizing the adjacent rings (Kraus et al. 2017, AJ, 154, 186). For B[e]SGs in binary systems, the rings are typically circumbinary and display high variability. We also performed a census of B[e]SGs and defined clear classification criteria for B[e]SGs in order to distinguish them from LBVs as well as from massive pre-main sequence stars (Kraus 2019, Galaxies, 7, 83). These criteria are based on specific emission features in the optical and near-infrared spectra, and on the disjoint loci of the objects in certain infrared color-color diagrams. The established criteria were used to classify a number of objects in our Galaxy and galaxies of the Local Group (Kourniotis et al. 2018, MNRAS 480, 3706; Condori et al. 2019, MNRAS 488, 1090; Arias et al. 2018, PASP 130, 114201, Kraus et al. 2020, MNRAS, 493, 4308).

The systematic photometric and spectroscopic monitoring of Galactic YHGs resulted in the discovery of a new outburst in one of them (Kraus et al. 2019, MNRAS 483, 3792). The detailed analysis revealed an enhanced photospheric pulsation activity prior to the outburst. A decrease in the time intervals between outbursts was also noted, which was interpreted as indication for an imminent major eruption. These studies further suggest that YHGs might evolve into B[e]SGs, linking these two phases (Aret et al. 2017, ASPCS 508, 239; Aret et al. 2017, ASPCS 510, 162).

Pulsation activity has also been investigated in a sample of BSGs. These objects display strong photometric and spectroscopic variability. A periodic variability in their winds was found, which correlates with previously identified variability periods (Haucke et al. 2018, A&A, 614, A91). The results suggest that radial pulsation modes might be responsible for the wind variability in the mid/late B-type stars. These radial modes might be identified with strange modes, which are known to facilitate (enhanced) mass loss. Hence the observed wind variabilities were interpreted as due to pulsation-triggered mass-loss (Kraus et al. 2015, A&A, 581, A75).

Massive stars are mostly born in double or multiple systems, and merging of two objects is a common phenomenon, altering the subsequent evolution of the merger remnant from single star evolution. Two merger remnants were discovered and analysed (Gvaramadze et al. 2019, MNRAS, 482, 4408). One of them is identified as a high-velocity runaway O star with an associated horseshoe-shaped infrared nebula. The derived high stellar rotation speed can be best explained by a rejuvenated and spun-up binary product. The other object is the likely remnant of a super-Chandrasekhar mass merger of two carbon–oxygen white dwarfs. It was proposed that this object will produce a low-mass neutron star in the near future, accompanied by a high-energy transient and a fast-evolving supernova (Gvaramadze et al. 2019, Nature 569, 684).

Based on Perek 2m observations the group participated in an analysis of several delta Scuti stars in eclipsing binaries, which led to the determination of their effective temperature, surface gravity, and metallicity (Kahraman Aliçavuş et al. 2017, MNRAS 470, 915; 2017, AIPC 1815, 080013). The group also used the data from the Perek 2m Telescope for a preliminary analysis of the quasi-WR star HD 45166 (Doležalová et al. 2019, ASPCS 519, 197). Furthermore, using the Perek 2m Telescope, we participated in an international campaign of the observation of bright Wolf–Rayet stars in Cygnus. It resulted in an international study of the variability of the star WR 134 (Aldoretta et al. 2016, MNRAS 460, 3407).

Subdwarfs and white dwarfs

White dwarfs are inevitably crucial objects to understand Galactic archaeology, stellar evolution, and supernovae, through which stellar astronomy is connected to cosmology. The research activity revolving around the late stages of stellar evolution in the group was led by A. Kawka and S. Vennes. With a particular focus on white dwarfs and hot subdwarfs, they developed and applied both observational and theoretical methods in their work.

The most significant scientific output in the research direction of white dwarfs was the discovery of the first bound remnant of a failed Type Ia supernova (Iax) event (Vennes et al. 2017, Science 357, 680). The intensive observational campaign and interpretation lasted for two years on world-class telescopes, including the 2.4m Hiltner Telescope at the MDM Observatory (USA), the 4.2m William Herschel Telescope at La Palma (Spain), and the 8.2m Gemini-North Telescope (USA). The object has a metal dominated atmosphere, therefore the analysis required new spectroscopic tools, that were developed within by S. Vennes and A. Kawka.

Another significant output was the review paper of hot subdwarf binary populations (Kawka et al. 2015, MNRAS 450, 3514), where a thorough analysis based on collected literature data on all known hot subdwarf binaries was performed. Beyond the review, the paper discussed six new binaries that were characterized for the first time using new measurements with MPG/FEROS as well as archival data. The study presented the companion mass distribution, which is important for the fine-tuning of the future binary evolution models.

The close, super-Chandrasekhar double degenerate system NLTT 12758 consists of two CO white dwarfs of similar masses and ages, and one of the two components is highly magnetic. The magnetic white dwarf spins around its axis with a period of 23 minutes and they orbit around each other with a period of 1.15 days. Although the components of NLTT 12758 will not merge over a Hubble time, systems with very similar initial parameters will come into contact and merge thus undergoing either an accretion induced collapse to become a rapidly spinning neutron star (an isolated milisecond pulsar) or a Type Ia supernova explosion. The paper discusses the atmospheric, kinematic and evolutionary properties of the system (Kawka et al. 2017, MNRAS, 466, 1127). Spectroscopic observations obtained by XSHOOTER@UT3 at the ESO were used to analyse a cool metallic white dwarf NLTT 19868. Using a model atmosphere analysis its parameters together with metal abundances were derived (Kawka et al. 2016, MNRAS 458, 325).

Hot subdwarfs form a substantial fraction of low mass stars that experience an intermediate core helium-burning evolutionary phase before they become white dwarfs. They are at a major intersection on the evolutionary crossroad from the giant branch to the white dwarf sequence, at the hot end of the horizontal branch. These compact stars overwhelm white dwarfs in magnitude limited samples and dominate the Galactic disk populations of underluminous blue stars. Unlike white dwarfs, hot subdwarfs have more complex structures and peculiarities that require more sophisticated models, such as NLTE spectral synthesis.

The research focused on the spectroscopic investigations of hot subdwarfs using TLUSTY NLTE model atmospheres with a goal to process all available spectra and derive atmospheric parameters free of large systematics. The procedure must also include the analysis of composite binary spectra, due to the large binary fraction of hot subdwarfs. Extensions to process atmospheric chemical stratification and radiative interactions in close and compact binaries are underway. The former is important to derive an accurate luminosity function and mass distribution of hot subdwarfs, while the latter is necessary to be able to provide reliable stellar surface boundary conditions for seismic models. Gaia kinematic data brought the necessary precision to calibrate the luminosity function and discover extremely peculiar objects that overlap with hot subdwarfs in the HRD (Vennes et al. 2017, Science 357, 680). This allowed us to develop automated tools we currently need to work with large data sets, such as SDSS and LAMOST spectra (e.g.: Luo et al. 2019, ApJ 881, 7; Lei et al. 2020, ApJ 889, 117). The methods, tools, and know-how acquired in these studies may prove essential in the near future when large spectroscopic surveys will collect massive data sets.

Be and shell stars

Be stars are Btype main sequence stars that show or showed sometimes in their recorded history emission lines, dominantly the hydrogen Hα line. Studies of this type of stars were dominating the group output in the past. Although most of the active researchers in this field are retired now, their research continues. Several studies of individual Be stars were performed.

A successful observing ESO proposal (spectrograph SINFONI@UT4) led to proper identification which component of the binary Be star 1 Del is the emission-line object (Kubát et al. 2016, A&A 587, A22). The pulsating Be star β CMi, possibly in a binary system, was reanalysed with a conclusion that its binary period can not be confirmed (Harmanec et al. 2019, ApJ 875, 13). An analysis of photometric and spectroscopic observations of the binary system with a Be star, namely HD 81357, led to a determination of the period (33.77 d), the mass ratio $M_1/M_2 = 10$, and a discovery that its low-mass secondary has to fill its Roche-lobe (Koubský et al. 2019, A&A 629, A105). Consequently, this system probably belongs to the family of stripped envelope stars.

Large data archives – Astroinformatics

The part of the group is involved in large data archives research and Astroinformatics, i.e., applications of machine learning and big data analysis in astronomy, including the Virtual Observatory (VO). This research is led by P. Škoda, V. Votruba (until the end of 2018), and several students from the Faculty of Information Technology of the Czech Technical University in Prague, the Faculty of Science of Masaryk University, Brno and the Technical University in Ostrava. The key research goals were divided into several main directions:

- Development of methods for finding Be stars using machine learning in millions of light curves, which were also incorporated in the pipeline of Gaia variability pipeline in the framework of Gaia CU7 (used in a number of papers of Gaia collaboration where V. Votruba and P. Koubský were co-authors, e.g. Holl et al. 2018, A&A 618, A30)
- Discovery of new emission line stars in big spectral surveys SDSS and LAMOST using deep learning and domain adaptation.
- Development of cloud-based infrastructure for machine learning of astronomical spectra.
- Development and implementation of standards of International Virtual Observatory Alliance, development of VO-compatible applications, setup of VO-compatible archives (Perek 2m Telescope spectra CCD700 based on SSAP protocol), remotely controlled DK154 (Danish 1.54m telescope at ESO) photometry telescope archive based on SIAP, SCS, and newly developed time-series protocol.

One of the main achievements are a definition of a new International Virtual Observatory Alliance (IVOA) standard for time series based on spare data cubes, which was presented at several IVOA Interoperability workshops and published as IVOA note (Nádvorník et al. 2017, IVOA Note 2017-12-15), and a modification of a widely used SPLATVO code for work with this standard (Šaloun et al. 2016, Springer Advances in Intelligent Systems and Computing 427, 373).

The members of the group participated in grants of the Czech Science Foundation, together with the Faculty of Mathematics and Physics of Charles University in Prague and Technical University Ostrava. One of the results of this collaboration is the chapter about Big Data in complex systems, namely astronomy (Pokorný et al. 2015, Springer Studies in Big Data 9, 29). A subsequent project covering the research in Astroinformatics was the COST LD grant of the Ministry of Education, Youth and Sports led by P. Škoda. Results were presented at several Astronomical Data Analysis Software & Systems (ADASS) conferences (Škoda et al. 2017, ASPCS 512, 689; 2019, ASPCS 521, 402) and IVOA workshops as well as at a conference Astroinformatics 2016 (Škoda et al. 2017, IAUS 325, 180).

Working group Extrasolar Planet Research

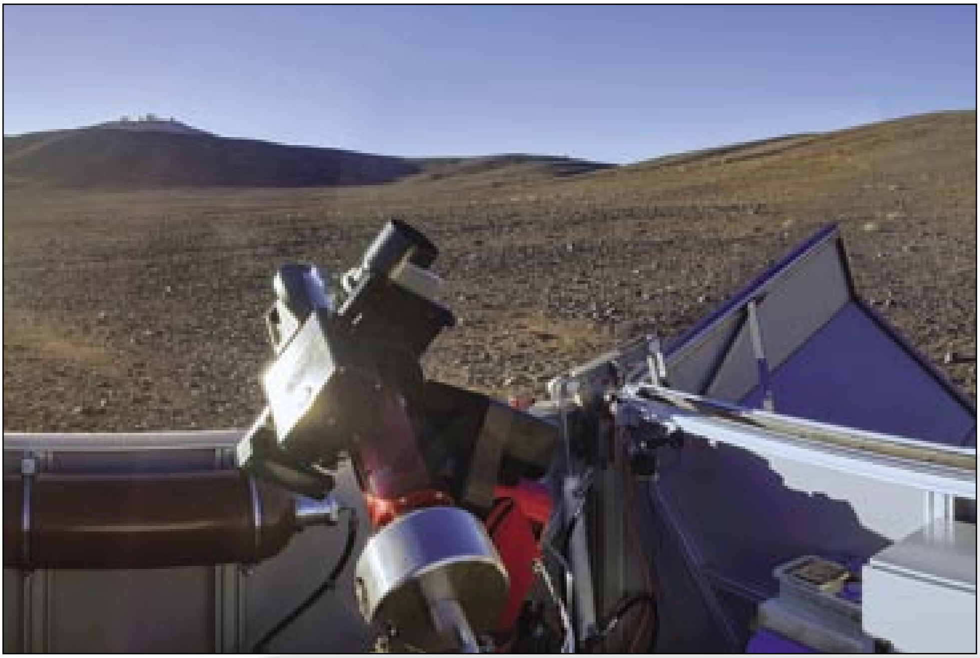
Research results. The main results of this group concern radial velocities measurement and detection and characterization of exoplanet atmospheres, as well as studies of various types of pulsating stars, e.g. δ Sct or RR Lyrae variables. The members of the group are also engaged in space research activities and ground-based instrumentation.

Extrasolar planets

The working group was officially established in May 2018. However, the first research results led by the members of the group had been obtained earlier. Observations of a stellar flare on the planet host HD 189733 during a primary transit based on observations obtained using UVES@UT2 at the ESO were analysed in collaboration with the Hamburg Observatory (Klocová et al. 2017, A&A 607, A66). The analysis showed that the activity of an exoplanet host star can affect cores of a wide range of optical lines and must be taken into account when studying exoplanetary atmospheres.

The group had two main foci of research. The first topic was precise measurements of radial velocities for the characterization of exoplanetary systems. Basically, spectroscopic measurements are used to characterize and validate newly reported exoplanet candidates. This topic includes instrumentation and space mission participation. The first highlight was in the field of instrumentation, i.e., the resumption of operation of the Ondřejov Echelle Spectrograph (OES) for exoplanetary research (Kabáth et al. 2020, PASP 132, 035002). In the frame of the joint project with the Tautenburg observatory the characterization of the frequency of planets around A type stars from Kepler field was described (Sabotta et al. 2019, MNRAS 489, 2069). The Kepler-410 system was analysed in a collaboration led by colleagues from Slovakia (Gajdoš et al. 2019, MNRAS, 484,

The fully robotic FRAM telescope was installed at the Paranal observatory in 2019. Four 8m VLT telescopes of the European Southern Observatory are seen in the background. (© Martin Jelínek)



4352). Radial velocities from three observatories (including observations using the OES spectrograph) were used, however, transit timing variations were not accompanied by radial velocity variations. In an international collaboration led by the group the first Transiting Exoplanet Survey Satellite (TESS) brown dwarf was confirmed using data from several observatories including the OES spectrograph at the Perek 2m Telescope, which contributed with a significant number of data points. The brown dwarf TOI-503b is physically extremely interesting as it sits directly in the Brown Dwarf desert (Šubjak et al. 2020, AJ, 159, 4).

The group also led and published the first time detection of a δ Scuti like pulsator with a peculiar chemical composition caused by a magnetic field that is bound in a binary system with a red dwarf companion (Skarka et al. 2019, MNRAS, 487, 4230). It is the first detection of such an object. The data set was mainly obtained with Perek 2m Telescope.

The second topic is the characterization of exoplanetary atmospheres, which is currently a hot topic of modern astronomy. An independent detection of sodium in two gas giant planets was reported (Žák et al. 2019, AJ 158, 120). Furthermore, the use of 2m class telescopes for the exoplanetary atmospheres research was evaluated (Kabáth et al. 2019, PASP 131, 085001).

RR Lyrae stars

The study of RR Lyrae strars in our Team started in November 2017, when a new member of the group M. Skarka was employed. Since that time several papers about RR Lyrae stars have been published.

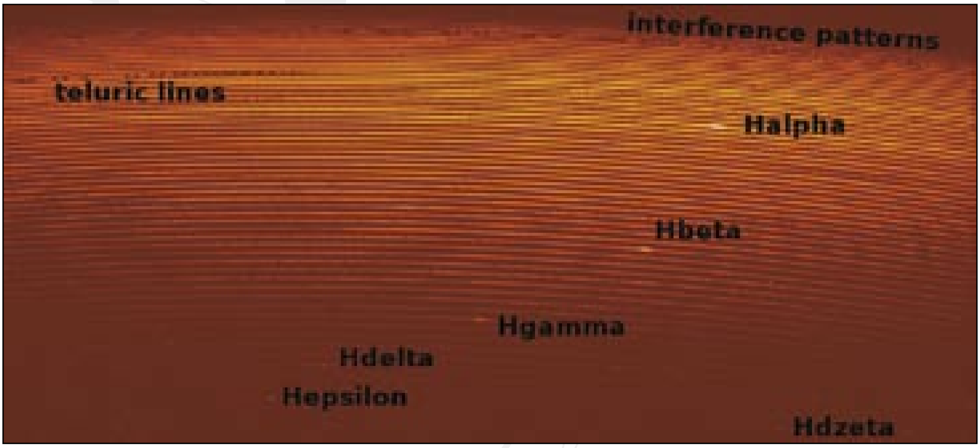
The most important result is the discovery of long-term cyclic period variations in pulsation period of RR Lyrae stars (Skarka et al. 2018, MNRAS, 474, 824). Such variations can easily be interpreted as the consequence of binarity via the Light-Travel Time Effect. This study revealed an alternative way that produces similar behaviour. We also identified new binary candidates with an RR Lyrae component which are extremely rare (Prudil et. al 2019, MNRAS 487, L1). In another paper, it was showed that the automatic routines are not suitable for the preprocessing of the Kepler/K2 data of RR Lyrae stars and a new estimation of the incidence rate of Blazhko stars was estimated.

The last two papers dealt with the Oosterhoff dichotomy of RR Lyrae stars in the Galactic bulge (Prudil et al. 2019, MNRAS, 484, 4833 and MNRAS, 487, 3270; M. Skarka participated on the analysis and helped with the revision). All the work was performed in cooperation with colleagues from the Konkoly Observatory in Budapest and with the Astronomisches Rechen-Institut, Zentrum für Astronomie der Universität Heidelberg.

Working group High Energy Astrophysics

Research results. The main results of this group concern the multi-spectral analysis of gamma-ray bursts (GRB), other types of celestial high energy sources including various types of Xray binaries and cataclysmic variables (CV). The members of the group are also engaged in a related space-based and ground-based instrumentation.

To obtain the necessary high-energy observational data, the group was involved in a high-energy satellite research, and also maintains collaboration with a future ground-based facility bound to observe gamma-rays



The echellogram of the eruptive star AD Leo, spectral type M4.5Ve and magnitude V=9.4 mag. The spectrograph depicts short spectral orders and it has recently been used for precise measurements of radial velocities.

from surface – Čerenkov Telescope Array (CTA), which is being built at two sites, La Palma and Paranal. CTA now counts with three robotic telescopes FRAM built and operated in collaboration between the Institute of Physics of the Academy of Sciences of the Czech Republic and the group of High Energy Astrophysics. The group has also been operating two relatively small robotic telescopes on the ground of the Ondřejov Observatory since 2000 (25cm) and 2004 (50cm). The role of these telescopes is to complement high energy observations with original optical data for both GRB and CV. These objectives complement well, as the GRBs require a small amount of rapid-response time, while CVs occupy a long-term programme.

The GRB observations are typically promptly reported through the Gamma-ray Coordinates Network (GCN). During the past five years, more than a dozen such Circulars were issued with successful minute-timescale responses of robotic telescopes to the satellite GRB triggers. The summary of GRB observations obtained by the BOOTES-system in collaboration with Spain was elaborated in form of a large article, which includes 71 GRB follow-ups providing optical afterglow detections in 23 cases (Jelínek et al. 2016, Advances in Astronomy 2016, 192846). The analysis of seven faintest γray burst afterglows detected by the 50cm telescope in Ondřejov was recently presented as well (Jelínek et al. 2019, AN 340, 622).

We also presented studies of the long-term activity of various types of binary Xray sources (systems with an accreting compact object): the intermediate polar GK Per (Šimon 2015, A&A 575, A65); the accreting neutron star Her X1 (Šimon 2015, AJ 150, 3); the polar AM Her (Šimon 2016, Ap&SS 361, 235; Šimon 2016, MNRAS 463, 1342); a very luminous nova-like binary QU Car (Šimon 2017, AN 338, 696); the post-nova X Ser (Šimon 2018, A&A 614, 141) and a dwarf nova DT Oct (Šimon & Edelmann 2019, AstBu 74, 490).

The group also invested a considerable effort into the observations of DG CVn, which resulted in two related studies (Caballero-García et al. 2015, MNRAS 452, 4195; Šimon 2017, Rev. Mex. Astron. Astrophys. 53, 59). An important part of the group's work is the operation, improvements and maintenance of the robotic telescope instrumentation. For one of the devices, this effort was recently summarized and presented by Štrobl et al. (2019, AN 340, 633).

The group also specializes at the study of archival photographic images, both direct and spectral, and participates actively in the rescue of valuable old observations stored in the archives of various observatories on glass photographic plates and negatives. Archival data are used to monitor the long-term behaviour of high-energy radiation sources and to follow and interpret their physical nature. This enables to study the activity of such sources on very long-time scales. These data were applied, e.g., in analyses a blazar OJ 287 (Valtonen et al. 2016, ApJ 819, L37; 2019, ApJ 882, 88; Dey et al. 2018, ApJ 866, 11).

The group also contributed to the efforts of detecting gravitational waves by observing with local telescopes (Abbott et al. 2016, ApJS 225, 8, Abbott et al. 2016, ApJ 826, L13).

In a research led by R. Hudec the group also participated in the design and development of new innovative space experiments with an emphasis on Xray optics, telescopes, and monitors (e.g., Hudec et al. 2017, SPIE 10569, Hudec et al. 2017, SPIE 10563). The group is also involved in data analyses related to ESA Gaia satellite (e.g., Šimon et al. 2017, Experimental Astronomy 44, 129). The group is also involved in the design of astrophysical payloads on nano and cube satellites (e.g., Tichý et al. 2015, Baltic Astronomy 24, 242, Remisova & Hudec 2017, SPIE 10562, 105620U).

A composite image of the nearby starburst galaxy, Messier 82 (M82) taken with Mark2 3200 camera using u′, g′, r′ and z′ collar filters. The camera is also a proper device for monitoring of optical counterparts of γ-ray bursts object which are the subject of research of the High Energy Astrophysics working group

The group regularly organizes international conferences and workshops (AXRO and IBWS), and participates in the organization of large international conferences such as SPIE Europe, Frascati workshop on Multispectral behaviour of cosmic high-energy sources, and international conferences on Frontier objects in astrophysics.

Working group Operation and Development of the Perek 2m Telescope

The main task of this working group concerns the maintenance and upgrading of the Perek 2m Telescope in Ondřejov. The Perek 2m Telescope installed in Ondřejov is the main instrument for stellar and since recently also for exoplanetary research in the Czech Republic. The Telescope is equipped with single order and echelle spectrographs, both placed in the coudé focus. The single order spectrograph can be used in the first and second spectral orders with a resolving power of 12 000 in the Hα spectral region (first order) while the echelle spectrograph has a resolving power of 40 000 around the Hα line. The single order spectrograph displays 47.5 nm in the first and 23.8 nm in the second spectral order. Both spectrographs are equipped with CCD chips cooled by liquid nitrogen.

The single order spectrograph operates in the first and second spectral orders. The first order is used in the red part of the spectrum, from 5100 to 8900 Å. The second order is used in the blue part, between 4000 and 5100 Å. For the light dispersion we use the Bausch & Lomb grating with 833 gr/mm. The resolving power is 12 000 in the Hα spectral region (around 6563 Å). For the detection of light, we use the CCD chip PyLoN 2048x512BX, E2V 42-10 BX, pixel size 13.5 μm, cooled by liquid nitrogen to −115 °C. The spectrograph is used mainly to study hot stars. The main advantage is that it depicts a wide interval of wavelengths (475 Å in the Hα spectral region) with uniform S/N.

The resolving power of the Ondřejov Echelle Spectrograph (OES) spectrograph is 40 000 in the Hα spectral region. It depicts a lot of short spectral orders. One order covers 85 Å (in the near UV region) up to 120 Å (in the near IR region). The spectrograph is equipped with two dispersion elements. The first dispersion element: grating, 55 gr/mm, blaze angle 69 deg, made by Richardson Grating Laboratories; the second dispersion element: equilateral prism, apical angle 55 deg, glass Schott LF5, made by "Vývojová optická dílna" Turnov (now TopTec Turnov), a part of the Institute of the Plasma Physics of the Czech Academy of Sciences. The light is depicted on the CCD chip Versarray 2048B, EEV 2048x2048, EEV 42-10-1-36B, pixel size 13.5 μm, cooled by liquid nitrogen to −110 °C. As the spectrograph depicts short spectral orders, it is used mainly for a precise measurement of radial velocities. It can also be used for studying narrow lines profiles because the continuum can be detected just around narrow lines. For a safe operation of the Telescope the meteorological station is used to follow humidity while an all sky camera is used to monitor clouds. The operation, service works, and upgrades of the Telescope are carried out by three technicians who also serve as night assistants.

During the last five years, the group performed upgrades of the Telescope concerning the reliability and safety of the operation and also the optical configuration and efficiency of the Telescope. The diesel backup power supply for elimination of a possible electricity blackout was installed in 2015. It allows an independent closing the dome shutter during an electricity failure to prevent effects of storms or any other weather calamities. The power supply also serves for the permanent operation of the CCD chips which should not be under-cooled.

In 2016, a regular maintenance operation, a recoating of the main mirror was done in the company 4HJena engineering, which inherited the equipments from the company Carl-Zeiss Jena, who finished building the Telescope in 1967. However, during the works in the 4HJena engineering company, a part of the mirror was damaged. The company succeeded to fix the problem and the mirror can be used again, however, the effective surface of the mirror was reduced by about 6 % of the total mirror area. Despite this, the Telescope was successfully put back into operation in 2017.

The most significant and fundamental upgrade of the Telescope during the last decades was performed by the group in 2019. The optical configuration was completely changed, which led to an increased efficiency of the optical system. Previously, the light was reflected to the coudé spectrograph with a system of mirrors. However, the reflecting surfaces slowly degenerate with time and it leads to an exponential decrease of the total efficiency. The main part of the upgrade was putting the optical fibers from the primary focus to the coudé room, where the spectrographs are placed. As a result, only one reflecting surface (i.e., the 2m primary mirror) is present instead of four mirrors, which was before. With this upgrade of the Telescope, a higher efficiency and extension of the observational limits were achieved. The possibility of observing fainter objects broaden the number of observing programmes which can be performed with the Perek 2m Telescope.

Besides the upgrade of the optics of spectrographs, in addition, the field of view in the primary focus is used and a photometric Mark2 3200 camera (Moravian Instrument) for direct imaging is installed there now. One example of the image taken with this camera is shown in Fig. on p. 75. The diameter of the field of view is 7 arcmin. Currently, the photometric camera is equipped with u, g, r, i, and z collar filters corresponding to Sloan sky survey. It can be also equipped with narrow-band filters, for instance for investigation of planetary nebulae. The camera is also a proper device for monitoring of optical counterparts of γ-ray bursts object which are the subject of research of the High Energy Astrophysics working group, which is a part of the Team.

The Perek 2m Telescope served as an observing tool for a number of projects, led partly by local scientists and partly by colleagues from collaborating institutes. Projects led by local scientists were mentioned in the parts devoted to working groups of Physics of Hot Stars and Extrasolar Planet Research. Here we mention projects led by scientists outside the Team. As the Telescope can offer observations which span over longer time intervals, it was mainly used for studies of binary stars and multiple stellar systems. The long-term observations are essential for this type of projects and are done mostly in collaboration with colleagues from the Team, who serve as observational astronomers and also provide their experience in data processing and analysis.

There is a number of binary and multiple stellar systems observed using the Perek 2m Telescope. Observations obtained with the Perek 2m Telescope contributed to the studies of an eclipsing binary BD+36°331 (Kıran et al. 2016, A&A 587, A127), a triple system V746 Cas (Harmanec et al. 2018, A&A 609, A5), triple systems V348 And and V572 Per (Zasche et al. 2019, AJ 158, 95), triple systems V773 Cas, QS Aql, and BR In (Zasche et al. 2017, AJ 153,36), and a quadruple system ξ Tau (Nemravová et al. 2016, A&A 594, A55). Some members of the enigmatic class of B[e] stars we observed as well, namely MWC 728 (Miroshnichenko et al. 2015, ApJ 809, 129), HD 50138 (Jeřábková et al. 2016, A&A 586, A116), and several B[e] candidates (Arias et al. 2018, PASP, 130, 114201). Archival spectra from the Perek 2m Telescope were used to supplement interferometric analysis of the eclipsing interacting binary β Lyr (Mourard et al. 2018, A&A 618, A112).

A panoramic photograph of the historical part of the Ondřejov Observatory, which was established in 1898.

Cooperation within international research area

POEMS (Physics of Extreme Massive Stars)

The Team takes part in the European Union's Framework Programme for Research and Innovation Horizon 2020 project "Physics of Extreme Massive Stars – POEMS" in the frame of the Marie Skłodowska-Curie RISE action (Grant Agreement No. 823734, 2019–2022). The PI of the project is the Team member M. Kraus. Within this action, which started in January 2019, our Team extended and deepened its existing cooperations with researchers from

1) Universidad Nacional de La Plata, Argentina,
2) Observatório Nacional, Rio de Janeiro, Brazil,
3) Universidad de Valparaíso, Chile, and
4) Tartu Observatory, Estonia

and initiated new cooperations with

researchers from
5) University of Göttingen, Germany,
6) Royal Observatory of Belgium,
7) University of Leeds, UK,
8) Shamakhy Astrophysical Observatory, Azerbaijan, and
9) Pontificia Universidad Católica de Valparaíso, Chile.

These cooperations comprise the common investigation of the research outlined in that project via exchange and training of researchers at all levels of experience. The cooperations are (and will become more) evident from common publications with all involved institutes. In the frame of the POEMS project, the Team members of the working group Physics of hot stars, together with their partners from Universidad Nacional de La Plata, organized a Summer School on "Pulsations along Stellar Evolution", held in La Plata, Argentina, 11th–22nd November 2019, and gave lectures and practical courses.

GAČR (Czech Science Foundation)/DFG international project

Between the years 2017–2019, a Team member P. Kabáth was responsible for the international GACR/DFG grant 17-01752J "Tautenburg and Ondřejov programme for measuring radial velocities of transiting planetary systems". The main aim of the grant was a joint follow-up of TESS planetary candidates with Tautenburg Observatory in Germany. The Team members cooperated with Prof. A. P. Hatzes and E. Guenther from Tautenburg observatory on a radial velocity follow-up of exoplanets.

Australian National University Canberra

The Team members A. Kawka and S. Vennes developed a very efficient informal research network across the globe.

This network includes observers as well as theorists. A close collaboration was maintained with the research group of dr. L. Ferrario at the Australian National University on magnetic white dwarfs.

Institut für Physik und Astronomie, Universität Potsdam

The Team has also a long-term cooperation with the Institut for Physics and Astronomy, University Potsdam (Germany). This informal collaboration with members of the team of Prof. W.-R. Hamann and his successor Prof. S. Geier resulted in a number of publications in the evaluated period (e.g. Kubátová et al. 2019, A&A 623, A8; Vos et al. 2019, MNRAS 482, 4592) and in collaboration on student education in the form of observational practise at the Perek 2 m Telescope in Ondřejov.

Matematički fakultet, Univezitet u Beogradu

Based on an agreement between the Astronomical Institute and the Faculty of Mathematics, University of Belgrade (Serbia), every year a summer internship of students from the faculty takes place in Ondřejov, often at the Perek 2m Telescope. Moreover, we also collaborate scientifically in the field of radiation transfer.

Institute of Astronomy, Bulgarian Academy of Sciences

Based on an agreement between the Czech and the Bulgarian Academy of Sciences we continued a collaboration with the Institute of Astronomy in Sofia. Both institutes operate very similar 2m telescopes (both produced by Carl Zeiss Jena), which enable an efficient exchange of observational experience and also scientific data.

Per aspera ad astra simul

The Team member P. Kabáth was the PI of an ERASMUS+ programme "Per aspera ad astra simul" which is a partnership of Czech, Slovak, and Spanish institutions. Team members were conducting joint programmes with the Observatory at Skalnaté Pleso, Slovakia, in collaboration with Drs. M. Vaňko and J. Budaj.

PLATOSPec

In 2018, the project PLATOSPec was founded. PLATOSPec will be a new state of the art spectrograph for 1.5m telescope at ESO La Silla, Chile. PLATOSpec is a partnership of the Astronomical Institute Ondřejov led by P. Kabáth as a PI, Thueringer Landessterwarte Tautenburg (Germany), and Universidad Catolica de Chile, Valparaíso (Chile). The project is now almost fully funded thanks to a grant obtained from the Czech Academy of Sciences. The telescope should be refurbished in 2021.

KESPRINT

The KESPRINT is an international consortium collaborating on the follow-up and characterization of exoplanets. The KESPRINT members work at more than a dozen institutes around the world. The KESPRINT consortium is one of the most productive teams in the field of exoplanetary science. The consortium jointly applies for telescope time and it possesses resources to detect, characterize and describe new exoplanets detected by the space mission CoRoT, Kepler/K2, TESS and in the future PLATO. Our Team contributes with the Perek 2m Telescope time and OES observations. The latest discovery led by a PhD student of our Team is a "First transiting brown dwarf from TESS space mission" (Šubjak et al. 2020, AJ, 159, 4).

Laboratório Nacional de Astrofísica, Brazil

An official agreement about the collaboration of the Team of ASU and Laboratório Nacional de Astrofísica (LNA), Itajuba, Brazil was signed on 25th October 2016. Within this collaboration the technological expertise of opticians from LNA contributed to the Telescope refurbishment as well as to the adjustment of OPERA package for OES echelle reduction and its optimization.

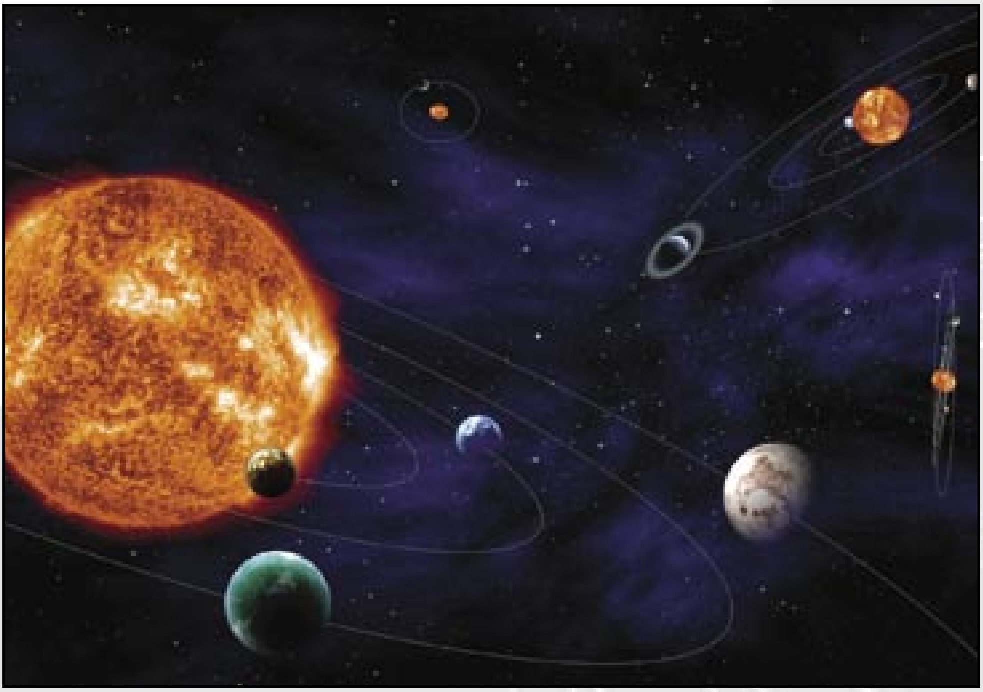
BOOTES

The Team has been collaborating with the Spanish Institute of Astrophysics of Andalucia (IAA-CSIC) on the development and deployment of the robotic telescope network BOOTES for twenty years. Since 2004, the robotic telescope BART effort has been extended to Institute of Physics robotic system FRAM, to support the high energy particle Pierre Auger Observatory in Argentina. This collaboration led to our Team being invited to the Cherenkov Telescope Array in 2019. The responsible person for this collaboration is M. Jelínek.

ESA/PLATO

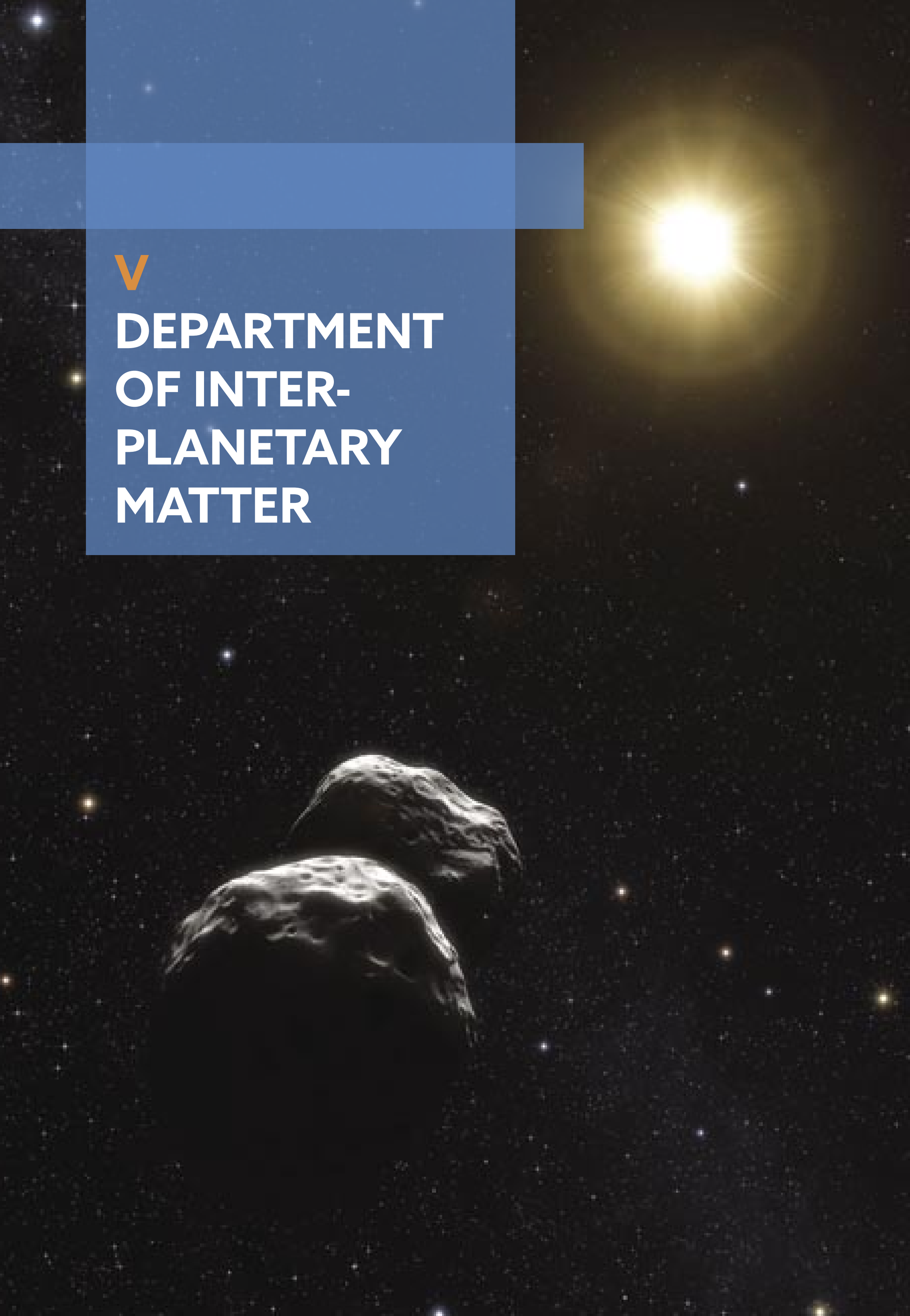
In 2019, the Czech Republic officially joined an ESA PLATO Space Mission Consortium with P. Kabáth becoming a PLATO Science Board Member. P. Kabáth coordinates the Czech contribution which is the transport containers for the cameras. PLATO should be launched in 2026.

The PLATO mission will assemble the first catalogue of confirmed and planets characterised by density, composition, and evolutionary age, including planets in the habitable zone of their host stars. (© ESA, C. Carreau)



V

DEPARTMENT OF INTER-PLANETARY MATTER



The Head of the Department:
Dr. Pavel Spurný

The Department of Interplanetary Matter studies minor bodies of the Solar System, in particular meteoroids and asteroids. The attention is devoted to the study of the interactions of interplanetary bodies of different size with the Earth's atmosphere. Photometric studies of Near-Earth Asteroids are also performed. The Department consists of two working groups.

The Group of Meteor Physics observes meteors in the optical region, analyses the observed data by own methods and procedures (continuously improved) and performs theoretical interpretations of the observations. The basic observational system is the European Fireball Network (EN) which was established in the former Czechoslovakia in 1963 and it is the longest continuously operational fireball network in the world. The center of the EN is located in Ondřejov and all its activity is coordinated by the Astronomical Institute of CAS. At present the core of the EN, which is the most developed network for complex fireball observations and based on our sophisticated instruments, consists of 14 stations in the Czech Republic, 3 in Slovakia and one in Austria and Germany. In scope of this experiment (EN) we closely cooperate with colleagues from Slovakia (ASU SAV, Comenius University), Germany (Tautenburg, Augsburg, Munster), and from the Netherlands (Dutch Meteor Society). We also cooperate with several amateur groups active in Poland, Slovenia, Croatia, Austria and Hungary. Starting in 2014, all Czech, Slovak, and Austrian stations have been gradually significantly modernized and equipped with a new very sophisticated instrument for optical observation of fireballs the Digital Autonomous Fireball Observatory (DAFO). An excellent performance of DAFO was proven by the observations of Taurids in 2015 (see below). We also significantly enlarged our network. Three new stations equipped with DAFO have been established in Czechia and two in Slovakia since 2015. Moreover, a spectral version of the observatory (SDAFO) was developed and since 2016 SDAFO has been gradually installed at eight Czech, one Slovak, and one German stations. Therefore, complementary spectral data are now available for almost all bright fireballs observed by DAFO. The digitization of the network required building of powerful central servers in Ondřejov and developing a new database and software for searching fireballs in a large number of images, measuring fireballs and reference stars, and computing fireball trajectories and other parameters. All this work was done by our Group. To achieve the best possible precision and reliability, we prefer manual or semi-automatic procedures to automatic "pipelines".

Left: An artist's impression of the asteroid (234) Barbara. (© ESO/L. Calçada)

Fireball observations by DAFO were supplemented by continuous video observations. Batteries of 13 video cameras covering the whole sky were created at Ondřejov and Kunžak stations and individual video cameras were installed at some other stations. Video cameras enable imaging of individual fragments and measurement of speeds for fireballs with low angular velocities (especially the very distant ones), where speed measurement is difficult on DAFO. For an even more detailed observation of fireball fragmentation, high-resolution cameras (FIPS) on fast moving mounts were developed and installed at Ondřejov and Kunžak. The cameras follow fireballs according to the instructions from the all-sky video system. We significantly participated in the development of all mentioned instruments – DAFO, SDAFO and FIPS. All this was possible mainly thanks to big financial support called Praemium Academiae given by CAS (2013–2018) and by the EXPRO grant given by GAČR (2019).

Television cameras are used in the double station (Ondřejov and Kunžak) video observation programme for the observation of faint meteors and their spectra. Besides the automatic MAIA cameras, manually operated video cameras are used during special campaigns. The cameras were modernized and improved in the recent period. The analogue camera was replaced by a digital DMK23G445 GigE monochromatic camera with the resolution of 1280x960 pixels. For the detection of fainter meteors, long focal Canon *F*/2, *f* = 135 mm lens was purchased. Dedicated software for camera control, observation planning and video capture was also prepared. The observational data are used to study physical processes during the penetration of small meteoroids into planetary atmospheres, including ablation, deceleration, radiation, fragmentation and chemical composition.

The Asteroid Group focuses on physical studies of asteroids in the Solar System. We study properties of small asteroids, binary asteroid systems, paired and clustered asteroids, and asteroids in excited (non-principal) rotation states, and their formation and evolutionary processes. We also observe so called Near-Earth

The Žďár nad Sázavou fireball. Section from an all-sky image taken by DAFO at Veselí nad Moravou.

Asteroids (NEAs; also NEOs – Near Earth Objects) and their source regions. NEAs are a part of the asteroid population, which represents an impact hazard for the Earth. Precise astrometry allows a determination of the orbits of NEOs and therefore to calculate their potential risk for the Earth. There is a number of observatories across the world which collaborate with us on the project. Our two main observational instruments are the 1.54m Danish telescope at the European Southern Observatory, La Silla, Chile and the 0.65m telescope at Ondřejov. The observations on the 1.54m telescope at La Silla are run within our collaboration project with the Danish colleagues at the Niels Bohr Institute, Copenhagen University. The collaboration with the other observatories across the world provides us with data from a number of their instruments that allow us to get a substantially more thorough understanding of the studied objects.

Research activity and characterisation of the main scientific results

Group of Meteor Physics

The analyses of important individual bolides leading to meteorite falls

The Group of Meteor Physics is a world leading group in observations of bright bolides and interpretation of bolide data. A special category are the instrumentally observed meteorite falls. The scientific value of the data increases when both bolide and the corresponding meteorites can be analysed. The number of instrumentally observed meteorite falls has continued to increase in the recent years also thanks to our observations and/or computations. At the moment, there are about 35 instrumentally observed falls worldwide. The number became somewhat blurred since there are cases where some instrumental data about the bolide exist but the data or the involved analyses are poor and the results are therefore not very reliable. In any case, our group participated in the analyses of more than half of these cases and we believe that our results belong to the most reliable ones. It is especially true for the cases when the bolide was observed by our own dedicated EN cameras and radiometers. In the period of 2015–2019, meteorites Stubenberg, Hradec Králové, and Renchen were recovered on the basis of our observations and analyses. Without our computation of the meteorite strewn field, these meteorites would remain hidden in the fields and forests of the central European landscape. The same case was the Žďár nad Sázavou meteorite, which fell at the end of 2014 and where very detailed data enabled us to analyse the atmospheric flight thoroughly. The final paper was accepted in December 2019 and published at the beginning of 2020. The analysis of the Križevci meteorite fall of 2011 was published in 2015. We also determined the trajectory and orbit of the Ejby meteorite, which fell in 2016 in Denmark. Casual records were combined with our radiometric curve. Finally, the fall of the carbonaceous meteorite Maribo (2009, also Denmark) was reanalysed and modelled using three fragmentation models.

There were about two dozen of meteorite dropping bolides observed by EN cameras in 2015–2019, where we initiated of performed by ourselves unsuccessful meteorite searches. These were mostly smaller events with a limited number of expected fragments on the ground. Although meteorites were not recovered, the atmospheric fragmentation was studied in detail. A paper about strengths of ordinary chondritic meteoroids, based on both recovered and unrecovered meteorite falls, was prepared and submitted for publication.

Among the papers already published on the topic of meteorite falls, the most important follow hereafter.

The instrumentally recorded fall of the Križevci meteorite, Croatia, 4th February 2011

By Borovička J., Spurný P., Šegon D., Andreić Ž., Kac J., Korlević K., Atanackov J., Kladnik G., Mucke H., Vida D., Novoselnik F., Meteoritics & Planetary Science 50, 1244–1259 (2015). The Križevci fall was the 19th instrumentally recorded meteorite fall in history. All available camera records were analysed to obtain reliable atmospheric trajectory, orbit, and initial mass. Moreover, the radiometric light curve from Martinsberg enabled us to model the meteoroid atmospheric fragmentation. It was shown that the recovered meteorite was the only sizeable fragment that reached the ground. This work added a valuable piece among a still rare class of meteorites with known orbits.

All final analysis and the paper writing was done by the members of our Team. The photograph and radiometric record from the camera in Martinsberg, operated by our Team in collaboration with Austrian colleagues, was very important to characterise the bolide. The co-authors from Croatia and Slovenia provided their camera records. The Croatian team recovered the meteorite.

Atmospheric trajectory and heliocentric orbit of the Ejby meteorite fall in Denmark on 6th February 2016

By Spurný P., Borovička J., Baumgarten G., Haack H., Heinlein D., Sørensen A.N., Planetary and Space Science 143, 192–198 (2017). The Ejby meteorite fall occurred in the Copenhagen suburbs of Denmark on 6th February 2016 and raised the attention of many inhabitants in large areas of NW Europe. We collected available casual optical records and combined them with our own radiometric records. Thanks to our rich experience with the analysis of these data, we were able to reliably describe this extraordinary bolide and bring a complete picture about its atmospheric trajectory and fragmentation, photometry and heliocentric orbit.

All analysis work and the vast majority of the paper writing was done by the members of our Team. German and Danish colleagues provided us with casual optical records, calibration of the video record and wind profile model. Danish colleagues also collected the meteorites.

The Maribo CM2 meteorite fall: Survival of weak material at high entry speed

By Borovička J., Popova O., Spurný P., Meteoritics & Planetary Science 54, 1024–1041 (2019). The recovery of the rare carbonaceous Maribo meteorite was a surprising and very important event. By analysing the available bolide data we confirmed the high entry speed of 28 km/s which we had previously derived and it also corresponds well to values derived by other authors. We also refined the trajectory and orbit. To explain how such fragile material can survive high entry speed, we applied three different fragmentation models to our radiometric light curves. We found that internal cracks, which weaken ordinary chondrites, are not important for carbonaceous chondrites. Although carbonaceous chondrites are intrinsically weaker, both types therefore reach similar fragmentation strengths.

The radiometric light curves were obtained by our Team. We computed the bolide trajectory and orbit and applied one of the fragmentation models. O. Popova applied the other two models and contributed, together with us, to the interpretation of the results.

The Žďár nad Sázavou meteorite fall: Fireball trajectory, photometry, dynamics, fragmentation, orbit, and meteorite recovery

By Spurný P., Borovička J., Shrbený L.. Meteoritics & Planetary Science 55, 376–401 (2020). The main exceptionality of this case consists in a detailed analysis of a high number of high-resolution instrumental records (both photographic and radiometric) taken by our automated cameras (both digital and analog) in the Czech part of the EN. Thanks to our experience how to analyse such an unusually large amount of high quality data from dedicated instruments, we were able to obtain detailed, reliable, and precise results concerning the atmospheric trajectory, photometry, dynamics, and heliocentric orbit of the Žd'ár bolide. On top of that, we described in detail its fragmentation scenario and predicted impact area for all sizes of meteorites. The reality exactly confirmed our predictions because all meteorites were found in the predicted areas and their masses correspond well to the predicted ones. This is the best proof of a correct interpretation of our observations. The Žd'ár nad Sázavou bolide and meteorite fall was the first fall recorded by the newly modernised Czech part of the EN and validated the correctness of this modernisation of our instrumental facilities and their background as well. The Žďár nad Sázavou meteorite fall belongs to the most reliably, accurately, and thoroughly described meteorite falls in history.

Physical properties and composition of meteoroids; their ablation, radiation, and fragmentation in the atmosphere

Revealing the structure and composition of meteoroids from meteor observations is in fact the main goal of the group. Although meteorites provide the "ground truth", their delivery is possible only from meteoroids, which are large enough and strong enough so that their part can survive the atmospheric passage. Bolide observations provide data on meteoroids, which are large but too fragile or have too high entry speed to drop meteorites. Observations of fainter meteors provide information about smaller meteoroids (less than one centimetre). Small meteoroids can, generally, have different sources than large ones.

Physical properties are studied on the basis of observed light curves, decelerations and morphologies (presence of wakes and individual fragments) of meteors. Further information is extracted from meteor spectra, which are also used to reveal chemical composition of meteoroids. Almost all used data are from our own instruments. Also the reduction methods and the fragmentation models used to fit the data were developed by our group.

The actual topics of the last five years ranged from a unique individual superbolide, over stream meteoroids of common origin (the Taurids) to a general study of small meteoroids.

A special attention was devoted to peculiar iron meteoroids. The most important papers published as of March 2020 follow.

The 7th January 2015 superbolide over Romania and structural diversity of meter-sized asteroids

By Borovička J., Spurný P., Grigore V., Svoreň J., Planetary and Space Science 143, 147–158 (2017). The trajectory, orbit, and atmospheric fragmentation behaviour of a very bright superbolide over central Romania were determined using the data from two bolide cameras in Slovakia, one in Czechia (both photographic and radiometric records) and five carefully calibrated casual video records from Romania. The bolide was so bright that it was detected from the orbit by the US Government sensors. The reported speed was, however, found to be wrong. The orbit was asteroidal but the fragmentation pattern was found very untypical. The meteoroid resisted until the dynamic pressure of 1 MPa but then disrupted completely. We concluded the meteoroid represented a new type of asteroidal material not contained in meteorite collections.

All analysis and the paper writing was done by the members of our Team. The photographs and radiometric records from the cameras in Stará Lesná, which are a part of our network and are operated in collaboration with Slovakian colleagues, were very important to characterize the bolide. The co-author from Romania provided calibration photos for the casual video records.

Radiation of molecules in Benešov bolide spectra & The CaO orange system in meteor spectra

By Borovička J., Berezhnoy A.A., Icarus 278, 248–265 (2016) and Berezhnoy A.A., Borovička J., Santos J., Rivas-Silva J.F., Sandoval L., Stolyarov A.V., Palma A., Planetary and Space Science 151, 27–32 (2018), respectively. The photographic spectrum of the Benešov superbolide obtained at the Ondřejov Observatory in 1991 is still unique in many aspects. It is the only spectrum produced by a meter-class meteoroid. In the first paper we concentrated on the analysis of molecular radiations. The spectra of CaO, AlO, and MgO observed in Benešov were not detected in any other meteor spectrum. We compared the intensities of these bands with FeO along the trajectory and compared them with theoretical calculations. Non-equilibrium effects, e.g. the difference between rotational and vibrational temperature of AlO, were found. CaO and FeO could not be analysed in detail, because their molecular constants, especially transition probabilities, are not well known. The second paper was devoted specially to the analysis of CaO electronic transitions and the comparison of synthetic spectrum with the Benešov spectrum.

The Benešov spectrum was obtained by our Team. J. Borovička extracted and calibrated the molecular spectra and computed rotational and vibrational temperatures of AlO. A. Berezhnoy provided theoretical calculations of molecular band intensities and organized the work on the second paper. Other authors of the second paper contributed with a theoretical investigation of CaO molecular states.

Catalogue of representative meteor spectra & Properties of small meteoroids studied by meteor video observations

By Vojáček V., Borovička J., Koten P., Spurný P., Štork R., Astronomy and Astrophysics 580, A67 (31 pp.) (2015)

An iron fireball (left) and its spectrum (right) captured by a SDAFO.

and Vojáček V., Borovička J., Koten P., Spurný P., Štork R., Astronomy and Astrophysics 621, id. A68 (21 pp.) (2019), respectively. The catalogue of representative meteor spectra provided the first database of low-resolution spectra of relatively faint meteors. It was based on our decade-long video observations. Spectra were divided into spectral types and compared with orbital types. The effect of velocity on line intensities was pointed out. The catalogue was well received by the community and serves as a valuable source of information for meteoritical works.

A combination of spectral and orbital properties of small meteoroids with the modelling of their erosion in the atmosphere provided a unique insight into the population of small debris of the Solar System. We showed that physical properties are influenced by both the origin and the evolution of the orbit. Iron meteoroids on cometary orbits were found, supporting the idea of large-scale mixing in the early Solar System. Early ablation of sodium was typical for bodies with small grains. Bodies depleted in sodium were generally stronger and lacked the finest grains.

All work was done entirely by the members of our Team, including observation, analysis, and modelling by our own methods.

Ablation of small iron meteoroids – First results; Small iron meteoroids. Observation and modelling of meteor light curves & The properties of cm-sized iron meteoroids

By Čapek D, Borovička J., Planetary and Space Science 143, 159–163 (2017); Čapek D., Koten P., Borovička J., Vojáček V., Spurný P., Štork R., Astronomy and Astrophysics 625, id. A106 (17 pp.) (2019) and Vojáček V., Borovička J., Spurný P., Čapek D., Planetary and Space Science 182, id. 104882 (7 pp.) (2020), respectively. Iron meteoroids can be distinguished by the presence of iron lines and by the absence of usually bright lines of Na, Mg, Ca in their spectra. We first studied a population of faint iron meteors characterized also by low beginning heights and often unusual light curves with a rapid increase of the brightness near the beginning. We developed three numerical models of their ablation based on three different physical processes. We found that the scenario of immediate removal of liquid iron from the meteoroid surface as droplets with a Nukiyama–Tanasawa size distribution is able to reproduce the data. Dedicated video observations of faint iron meteoroids were performed and the model was applied to 60 meteors. The model was able to adequately describe most of the light curves. For an individual meteor, the model allowed us to estimate the initial mass, mean drop size, and luminous efficiency. The fact that the mass and luminous efficiency can be estimated independently is a unique property of the model.

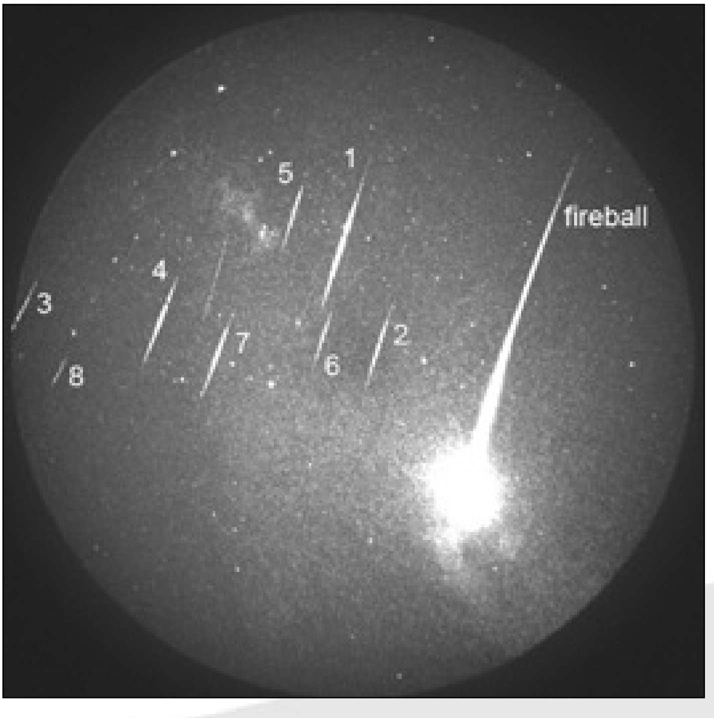
Then we collected fireballs with iron spectra observed by the newly developed Spectral Digital Autonomous Fireball Observatories. A sample of 9 iron meteoroids with diameters about 1–4 cm was studied. The orbits were asteroidal and similar to those of small iron meteoroids. Surprisingly, using classical methods of fireball classification, these fireballs were classified, at least formally, as fragile bodies comparable in strength to cometary meteoroids. The ablation model for small meteoroids was not directly applicable. The erosion model was able to fit the light curves by manually adjusting erosion parameters. To describe the sudden drop at the end of the light curve, it was necessary to progressively increase the erosion coefficient and decrease droplet masses along the trajectory. All this work was done entirely by the members of our Team.

September epsilon Perseid cluster as a result of orbital fragmentation

By Koten P., Čapek D., Spurný P., Vaubaillon J., Popek M., Shrbený L., Astronomy & Astrophysics 600, id. A74 (5 pp.) (2017). A bright fireball was observed above the Czech Republic on 9th September 2016. Moreover, the video cameras at two separate stations recorded additional eight fainter meteors flying on parallel atmospheric trajectories within less than 2 seconds (see the figure below). All the meteors belong to the September epsilon Perseid meteor shower. The observed group of meteors was interpreted as the result of the orbital fragmentation of a bigger meteoroid. The fragmentation happened no earlier than 2 or 3 days before the encounter with the Earth at a distance smaller than 0.08 AU from the Earth. In the past, such clusters were occasionally observed among very active meteor showers. As the September epsilon Perseid shower is not such a case, the result is exceptional.

Four of six authors including the

The epsilon Perseid cluster.

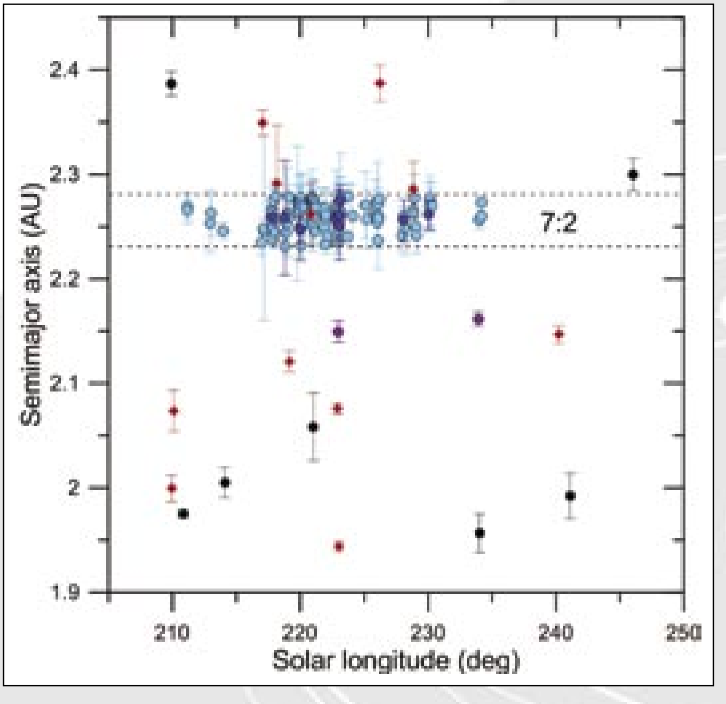


corresponding author are members of our Team. M.Popek (IAP CAS) provided us with one video record and J. Vaubaillon (France) participated in the modelling of the orbital fragmentation.

Physical properties of Taurid meteoroids of various sizes

By Borovička J., Spurný P., Planetary and Space Science 182, id. 104849 (8 pp.) (2020). The origin of the Taurid complex is still debated. In addition to comet 2P/Encke, various asteroids were proposed to be members of the complex and thus possible parent bodies of Taurid meteoroids. Previous work suggested that meteorite dropping fireballs can be encountered among Taurids. We used a well-defined orbital sample of 16 Taurid fireballs with detailed radiometric light curves and modelled their atmospheric fragmentation. The sample represented meteoroids of initial masses from 8 g to 650 kg (diameters 1–70 cm). It was found that the majority of Taurid material has a very low strength of less than 0.01 MPa and a density less than 1000 kg/m³. Stronger material up to 0.3 MPa is present as well and forms small inclusions in large bodies or exists as small (cm-sized) separate bodies. These properties strongly suggest a cometary origin of Taurids. The reported strong fireballs were most probably interlopers of a different origin. This work was done entirely by the members of our Team.

Plot of semimajor axes vs. solar longitude for 2015 Taurid fireballs showing tight clustering of most orbits in the 7:2 resonance with Jupiter.



Orbital studies

Besides the information about their atmospheric behaviour, our instruments also provide data on heliocentric orbits of all observed fireballs and meteors. Some of our work is devoted primarily to orbital studies. It concerns the extraordinary activity of meteor showers, some regular meteor showers, as well as individual meteors of special interest. In the evaluated period we published fundamental papers on a fireball on the Earth-bound orbit, the first of its kind, and about the discovery and detailed description of a new branch of Taurid meteoroid stream.

Impact detections of temporarily captured natural satellites

By Clark D.L., Spurný, P., Wiegert P., Brown P., Borovička J., Tagliaferri E., Shrbený L., The Astronomical Journal 151, id. 135, (15 pp.) (2016). Based on the observation of a unique bolide on 13th January 2014 by the cameras of our fireball network, it was proved that it is the first such case in the world where the meteoroid before its collision with the Earth has been temporarily captured as a natural satellite of the Earth (Minimoon). This exceptional result was possible to achieve only thanks to very precise data. Such accuracy is crucial for reliable backward integration of the meteoroid orbit and the recognition of its exceptional history.

This is common work of our Team and the team from University of Western Ontario (UWO). The instrumental data on the bolide and its analysis were obtained by our Team. Backward integration was performed by the UWO team. Both teams interpreted the results and contributed to their parts of the text.

Discovery of a new branch of the Taurid meteoroid stream as a real source of potentially hazardous bodies

By Spurný P., Borovička J., Mucke H., Svoreň J., Astronomy and Astrophysics 605, id. A68 (25 pp.) (2017). Based on an accurate analysis of 144 Taurid fireballs captured in 2015 by our fireball network we discovered that this enhanced activity of fireballs was caused by a well-defined orbital structure of bodies belonging to the Taurid complex. We proved that it also contains large bodies up to at least hundreds of meters. It is for the first time when the real source of potentially hazardous bodies that can cause a regional or even continental disaster on Earth was identified and described.

The vast majority of used records, all analysis and the paper writing were done by the members of our Team. The contribution of Slovak and Austrian colleagues consists only in the use of photographic and radiometric records for some Taurid fireballs from one camera in Austria and one in Slovakia, which are parts of our network and are operated in collaboration with these colleagues of ours. The paper was chosen for the official press release of the A&A journal.

On the age and formation mechanism of the core of the Quadrantid meteoroid stream

By Abedin A., Spurný P., Wiegert P., Pokorný P., Borovička J., Brown P., Icarus 261, 100–117 (2015). The Quadrantid meteor shower is among the strongest annual meteor showers and it is unusual by its very short duration around maximum activity, its recent onset and unusual parent body, asteroid 2003 EH1. For the first time we used data on high precision photographic Quadrantids, equivalent to gram–kilogram size, to constrain the age of the core of the stream. According to our results, from the backward integrations, the most likely age of the Quadrantids is between 200 and 300 years.

This is common work of our Team and the team from University of Western Ontario ((UWO). The instrumental data on the used Quadrantids fireballs and their analysis were performed by our Team. Backward integration was performed by the UWO team. Both teams participated in the interpretation of the results and the contribution to their parts of the text.

September epsilon Perseids observed by the Czech Fireball Network

By Shrbený L., Spurný P., Astronomy & Astrophysics 629, A137 (2019). We presented 25 photographic fireballs belonging to the September epsilon Perseid (SPE) meteor shower observed by the Czech part of the European Fireball Network in 2013–2017. An exceptionally high activity of bright photographic fireballs was observed in 2013, while a lower activity, but still higher than in other years, was observed in the period of 2015–2017. Physical properties of these SPE fireballs were studied and compared to other meteor showers. Corrected geocentric radiant of the 2013 outburst fireballs was determined and can be used for the confirmation of future outbursts in 2026 and 2030, as predicted by another team. On the basis of determined heliocentric orbits the parent body of the shower is an unknown long-period comet on retrograde orbit with an orbital period of the order of a thousand years. This work was done entirely by the members of our Team.

Activity profile, mass distribution index, radiants, and orbits of the 2018 Draconid meteor shower outburst

By Koten P., Borovička J., Vojáček V., Spurný P., Štork R., Shrbený L., Janout P., Fliegel K., Páta P., Vítek S., Planetary and Space Science 182, id. 104871 (9 pp.) (2020). Following the successful observation and analysis of the 2011 Draconid meteor shower outburst, another such event was predicted by theoretical modellers for 8th October 2018. Using a variety of video and photographic cameras covering a broad range of magnitudes, the outburst was successfully observed by us. The main peak was found at 23:07.5 ± 0:05 UT, in a good agreement with other reports as well as with the predictions. Two other sub-peaks or enhancements of the activity were detected later in the night. The maximum flux of meteoroids was 0.033 ± 0.007 meteoroids km^{-2} h^{-1} [$M_V > +6.5$], equivalent to ZHR = 140 ± 30 which is higher than the majority of the models predicted. The analysis of radiants, mass distribution index evolution and the comparison with other experiments suggest that the later activity was probably caused by the mixture of different trails of the stream which were more dispersed. The flux of the meteoroids was three to four times smaller in comparison with the 2011 Draconid outburst. Heliocentric orbits of individual meteoroids were also reported. This result was obtained mostly by the members of our Team. The co-authors from Czech Technical University participated in the development of the MAIA cameras.

Meteoroid orbits from video meteors. The case of Geminid stream

By Hajduková M., Koten P., Kornoš L., Tóth J., Planetary and Space Science 143, 89–98 (2017). In this work common with Comenius University in Bratislava, we studied the orbits of Geminids and showed that in most video databases (except ours) the initial speed of meteors is systematically underestimated.

Books and reviews

The expertise of the Team members is reflected by invitations of theirs to present lectures and to contribute to books. Part of the invitations was related to the Chelyabinsk superbolide of 2013 (the largest asteroid impact of the last century). Our Team contributed significantly to the description of that event. J. Borovička was invited to present a lecture about Chelyabinsk during the IAU General Assembly in 2015 and at the Erice (Italy) international school in 2017. The first lecture was published in the proceedings of the IAU (Borovička J.: The Chelyabinsk event. In: Astronomy in Focus, Volume 1, Focus Meeting 9, Ed.: P. Benvenuti, Proceedings of the International Astronomical Union, Volume 11, Issue A29A , 247–252, 2016) and the second lecture was published as a chapter in a book (Borovička J.: The trajectory, structure and origin of the Chelyabinsk impactor. In: Hypersonic Meteoroid Entry Physics, Eds.: G. Colonna, M. Capitelli, and A. Laricchiuta, IOP Series in Plasma Physics, IOP Publishing, Bristol, UK, pp. 2-1 – 2-11, 2019). We also published a catalogue of video records related to the Chelyabinsk event (Borovička J., Shrbený L., Kalenda P., Loskutov N., Brown P., Spurný P., Cooke W., Blaauw R., Moser D.E., Kingery A.: A catalogue of video records of the 2013 Chelyabinsk superbolide. Astronomy and Astrophysics 585, A90, 2016).

J. Borovička was also invited by the editors of the book Asteroids IV to contribute the chapter about meteorite falls (Borovička J., Spurný P., Brown P.: Small Near-Earth Asteroids as a Source of Meteorites, in: Asteroids IV, Eds.: P. Michel, F.E. DeMeo, W.F. Bottke. The University of Arizona Press, pp. 257–280, 2015). Asteroids IV is the fourth in a series of books about asteroids published nearly in a ten-year period and summarizing the achievements in the field during the last decade. The most important part of the chapter is the summary and evaluation of the 22 instrumentally observed meteorite falls known at that time. The most interesting cases were discussed in the context of structure and origin of asteroids.

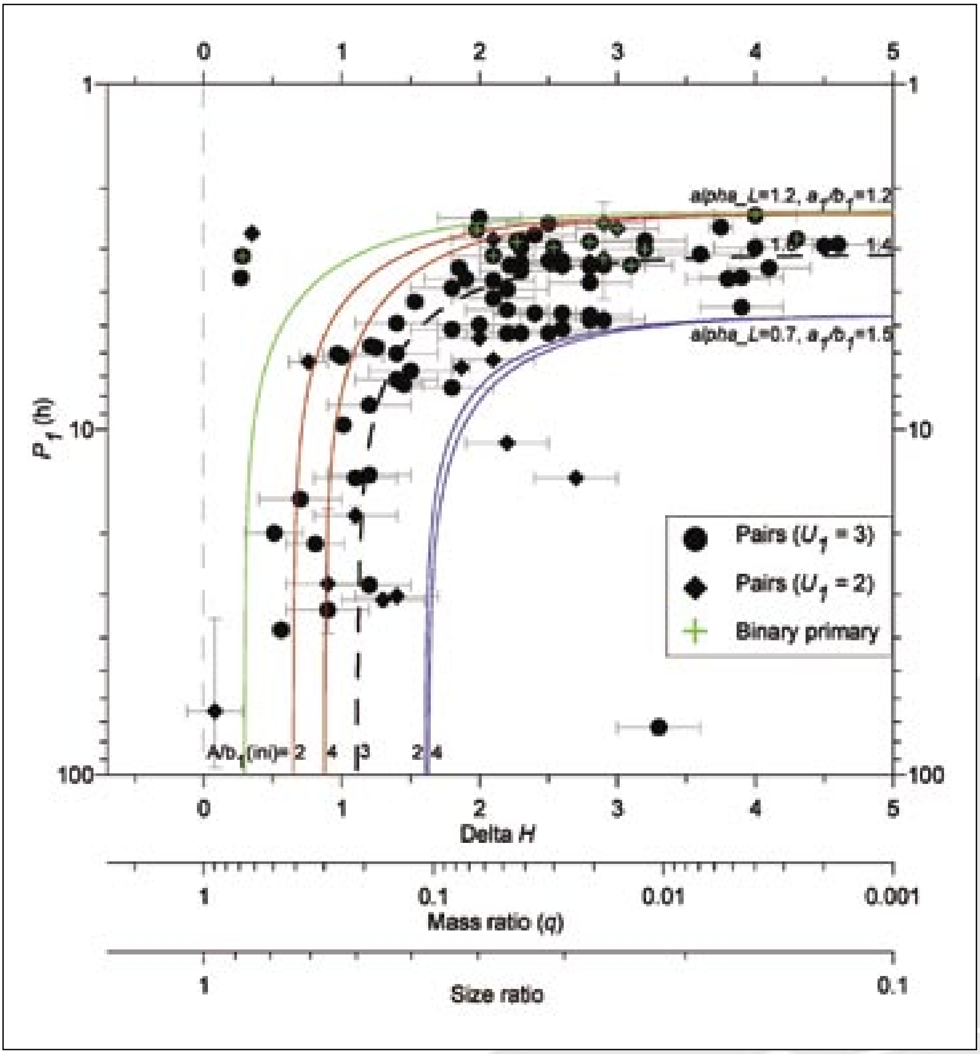
Two of the three authors are members of our Team and they contributed together more than 80 % of the text as well as the three tables compiling the data about the instrumentally observed meteorite falls.

Finally, and most importantly, we significantly contributed to the book Meteoroids published by Cambridge University Press. The book was a project of the IAU Commission F1 'Meteors, Meteorites, and Interplanetary Dust' led by G. Ryabova. The purpose of the book was to present the current status of knowledge and to serve as the main reference in the field for the next 10 – 15 years. The members of our Team contributed to three of twelve chapters, two of them as leading authors: see Meteoroids: Sources of Meteors on Earth and Beyond, Eds.: G.O. Ryabova, D.J. Asher, M.D. Campbell-Brown, Cambridge University Press, Cambridge, UK (2019).

Group of Asteroids

Formation and evolution of asteroids by rotational fission

A predominant formation and evolution mechanism of small (km-sized and smaller) asteroids appears to be the process of rotational fission. The knowledge of the mechanism and its outcomes is important for understanding how small asteroids, both in the main belt and in the near-Earth space, were created and what their properties are. In the series of papers, we studied physical and dynamical properties of asteroids



Primary rotation periods vs mass ratios of asteroid pairs. More than 90% of asteroid pairs are within the upper and lower limits (green and blue curves) predicted by the theory of rotational fission. (Pravec et al., 2019)

formed by this process and placed constraints to the rotational fission theory. Our studies reached from constraining the thermal YORP effect, which appears to be a mechanism spinning up asteroids to their critical spin frequencies at which they fission, over determining properties of asteroid pairs, which are couples of asteroids orbiting on highly similar heliocentric orbits that escaped each other very recently, to studies of young asteroid clusters (mini-families) that appear to be largely formed by rotational fission as well. We determined several key characteristics of the spin-fission pairs and systems, such as their ages (ranging from ~10^4 to a few 10^6 yrs), sizes, spins and shapes. We found that while the basic theory of rotational fission explains most of the observed properties of the asteroid systems, there are certain features that indicate more complexity of the process, calling for developing a more advanced theory.

Among them, the most interesting are the following ones:
1) The primaries of some asteroid pairs are actually binary systems (having satellites), so those pairs are actually systems with one escaped and one bound secondaries.
2) A few percent of asteroid pairs have high size ratios that were unpredicted by the basic theory, which indicates a presence of some additional source of energy.
3) Some asteroid clusters were formed by cascade disruptions, with two or more fission events over the past 10^6 yrs or so.

Overall, we found that spin-fission asteroid systems are a complex population and its thorough understanding will require further detailed studies, which should give us a better knowledge of small asteroids, including the potentially dangerous ones in the near-Earth space.

The Team contributed to publications in several key points. They identified/discovered many of the studied asteroid pairs and some of the asteroid clusters, obtained or organized photometric observations of the objects, determined their spin periods and sizes, determined or constrained their ages, interpreted (together with other co-authors) the obtained data and compared them to predictions from the rotation fission theory. Their contributions to the individual papers ranged from 10 to 80 %.

See also:

- Pravec P., Fatka P., Vokrouhlický D., Scheeres D.J., Kušnirák P., Hornoch K., Galád A., et al., Asteroid clusters similar to asteroid pairs. Icarus, 304, 110–126 (2018)
- Pravec P., Fatka P., Vokrouhlický D., Scheirich P., Ďurech J., Scheeres D.J., Kušnirák P., Hornoch K., Galád A., Pray D.P., Krugly Yu.N., Burkhonov O., Ehgamberdiev Sh.A., Pollock J., Moskovitz N., Thirouin A., Ortiz J.L., Morales N., Husárik M., Inasaridze R.Ya., Oey J., Polishook D., Hanuš J., Kučáková H., et al., Asteroid pairs: A complex picture. Icarus, 333, 429–463 (2019)
- Fatka P., Pravec P., Vokrouhlický D., Cascade disruptions in asteroid clusters. Icarus, 338, 113554, 11 pp (2020)
- Vokrouhlický D., Pravec P., Ďurech J., Bolin B., Jedicke R., Kušnirák P., Galád A., Hornoch K., et al., The young Datura asteroid family. Spins, shapes, and population estimate. Astronomy and Astrophysics 598, A91, 19 pp (2017)
- Vokrouhlický D., Pravec P., Ďurech J., Hornoch K., Kušnirák P., Galád A., Vraštil J., Kučáková H., et al., Detailed Analysis of the Asteroid Pair (6070) Rheinland and (54827) 2001 NQ8. Astronomical Journal, 153:270, 17 pp (2017)
- Vokrouhlický D., Ďurech J., Pravec P., Kušnirák P., Hornoch K., et al., The Schulhof family: Solving the age puzzle. Astronomical Journal, 151:56, 12 pp (2016)
- Žižka J., Galád A., Vokrouhlický D., Pravec P., Kušnirák P., Hornoch K., Asteroids 87887 – 415992: the youngest known asteroid pair? Astronomy and Astrophysics 595, A20, 11 pp (2016)
- Ďurech J., Vokrouhlický D., Pravec P., Hanuš J., Farnocchia D., Krugly Yu.N., Ayvazian V.R., Fatka P., Chiorny V.G., Gaftonyuk N., Galád A., Groom R., Hornoch K., Inasaridze R.Y., Kučáková H., Kušnirák P., et al., YORP and Yarkovsky effects in asteroids (1685) Toro, (2100) Ra-Shalom, (3103) Eger, and (161989) Cacus. Astronomy and Astrophysics 609, A86, 10 pp (2018)

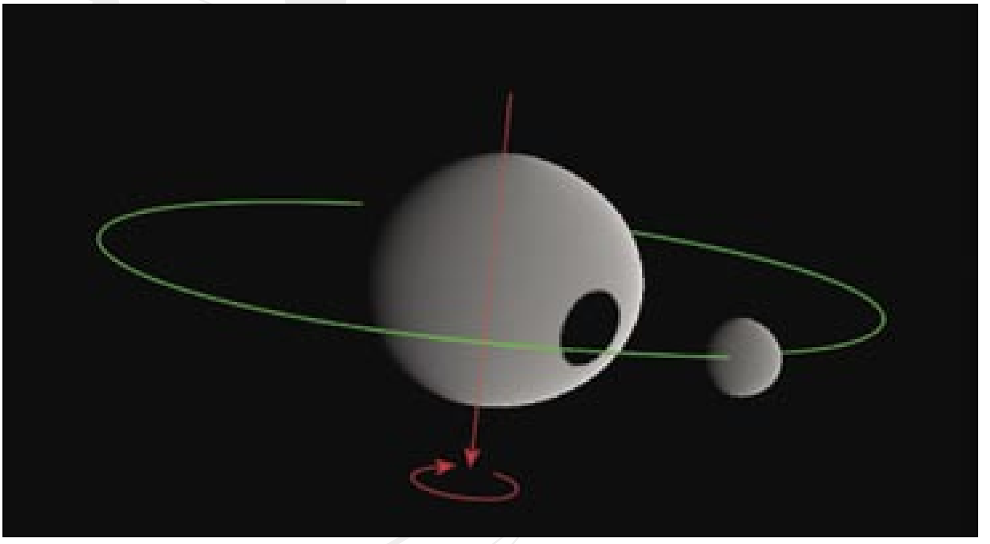
An artist's impression of the interstellar asteroid 1I/'Oumuamua. (© ESO)

- Moskovitz N.A., Fatka P., et al., A common origin for dynamically associated near-Earth asteroid pairs. Icarus 333 165–176 (2019)

Interstellar asteroid in an excited spin state

The discovery of the first interstellar object 1I/'Oumuamua in October 2017 provided a unique opportunity to study a planetesimal born in another planetary system. We collected and analysed its photometric measurements that were taken with large telescopes in the world after its discovery from 25th to 30th October 2017. We found that the object is not in a basic spin state with minimum rotational energy, but it is in an excited spin state, showing two periods (rotation and precession). While the origin of the state is unknown, it appears to be an original excitation from its creation in its mother star's system or an outcome of the process of its ejection from the system. We also obtained a constraint on its extremely elongated (cigar-like) or flattened (pancake-like) shape, with a lower limit on the longest-to-shortest axis ratio of 5:1. This extreme shape suggests that the body has a rigid internal structure with non-zero cohesion. In addition, we found that the object exhibits a variable colour over its surface as it rotates, within a range that is broadly consistent with Solar System asteroids, such as the P- and D-type asteroids, Jupiter Trojans and dynamically excited Kuiper belt objects. These characteristics are unique and not seen in small Solar System bodies, making 1I/'Oumuamua an extremely interesting but puzzling object.

P. Pravec made the key analysis of the photometric data and found out that the interstellar asteroid is in an excited spin state, and constrained its shape. He also contributed to the interpretation of the data in terms of damping timescale estimation. His contribution represented about 30 % of the work on this publication.



A model of the binary near-Earth asteroid (175706) 1996 FG3. (Scheirich et al., 2015)

See Fraser W.C., Pravec P., Fitzsimmons A., Lacerda P., Bannister M.T., Snodgrass C., Smolić I., The tumbling rotational state of 1I/'Oumuamua. Nature Astronomy 2, 383–386 (2018).

Binary asteroids, their spin, shape and orbit properties

Binary asteroids, i.e., systems of two bodies orbiting each other, are frequent among small (km-sized and smaller) asteroids in the main belt as well as in the near-Earth space. They are interesting both scientifically, as they reveal some key asteroid properties and formation mechanisms, as well as for the planetary safety as diverting a dangerous binary asteroid would pose more challenge than single asteroids. In the four papers, we continued our long-term investigations of binary asteroids. We focused on describing rotation and shape properties of the secondaries of a sample of 46 binary asteroids, on constraining a long-term evolution of the so-far best described orbit of a binary near-Earth asteroid, on determining properties of the main-belt binary asteroid Isberga by combining photometric, spectroscopic and interferometry data, and on physical modelling of the unusual triple (i.e., having two satellites) near-Earth asteroid (153591) from a combination of radar and photometric observations. We compared our data with theories of binary asteroid dynamics. In particular, we found that secondaries of close binary asteroid systems are in 1:1 spin orbit resonance, while those on more distant, wider orbits have asynchronous rotations, which agrees with predictions from the theories of binary asteroid dynamics, and we also found that their elongations are limited to axis ratios ≤ 1.5 which appears to be due to their dynamical or structural stability requirements. As for the binary near-Earth asteroid (175706), we found that its mutual orbit did not evolve during the 17 years of our observations, suggesting that it is in a state of equilibrium between the thermal BYORP effect acting on the mutual orbit and tides between the binary system components. For the binary main-belt asteroid Isberga, we found that it is a typical representative of binary asteroids. As for the triple asteroid (153591), we found that while the inner satellite is in the 1:1 synchronous rotation, the outer one is asynchronous, and we determined bulk densities of the three components of the triple asteroid that are consistent with its primitive material composition suggested by its B taxonomic type. Overall, these studies further advanced our knowledge of binary asteroids and they also suggested ways how we can obtain a more thorough understanding of them with further observations in the future.

The Team contributed to the publications in several key points. They discovered several new binary asteroids, obtained or organized photometric observations of the studied objects, determined their spins and estimated shapes, determined their mutual orbits, interpreted (together with other co-authors) the obtained data and compared them to predictions from theories of binary asteroid dynamics. Their contributions to the individual papers ranged from 10 to 70 %.

See also:

- Pravec P., Scheirich P., Kušnirák P., Hornoch K., Galád A., et al., Binary asteroid population. 3. Secondary rotations and elongations. Icarus, 267, 267–295 (2016)
- Scheirich P., Pravec P., Jacobson S.A., Ďurech J., Kušnirák P., Hornoch K., et al., The binary near-Earth Asteroid (175706) 1996 FG3 — An observational constraint on its orbital evolution. Icarus, 245, 56–63 (2015)
- Carry B., Matter A., Scheirich P., Pravec P., et al., The small binary asteroid (939) Isberga. Icarus, 248, 516–525 (2015)
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Support to the NASA DART and ESA Hera space missions to (65803) Didymos

The NASA DART (Double Asteroid Redirection Test) and ESA Hera missions to the binary asteroid (65803) Didymos, which we discovered with photometric and radar observations (Pravec et al., IAU Circular 8244, 2003), are key space missions in the field of planetary safety against asteroid impacts. DART will be the first space experiment to demonstrate the asteroid impact hazard mitigation by using a kinetic impactor to deflect an asteroid in 2022, and Hera will provide a detailed characterisation of outcomes of the exmeriment during its stay around the binary asteroid a few years later. In these papers, we described the proposed missions, their rationales and expected outcomes, and we also gave basic data on their target, the binary asteroid Didymos. We also outlined the important role of further detailed ground-based observations of Didymos in the years before as well as after the DART impact (which will happen in September–October 2022) that are necessary for both the preparation of the missions and the determination of outcomes of the deflection experiment.

P. Pravec and P. Scheirich (in Michel et al. 2016) contributed with analyses of ground-based photometric data obtained for the binary asteroid Didymos for the preparation of the space missions and with planning further observations that are necessary for ensuring the success of the missions.

Their contributions to the papers were about 5 to 10 %. P. Pravec became a member of the DART Investigation Team, a co-chair of the Hera Working Group 2 on Remote Observations, and a Data Analysis Coordinator of the joint DART-Hera Remote Observations Working Group.

See also:

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- Cheng A.F., Rivkin A.S., Michel P., Atchison J., Barnouin O., Benner L., Chabot N.L., Ernst C., Fahnestock E.G., Kueppers M., Pravec P., et al., AIDA DART asteroid deflection test: Planetary defense and science objectives. Planetary and Space Science, 157, 104–115 (2018)
- Hirabayashi M., Davis A.B., Fahnestock E.G., Richardson D.C., Michel P., Cheng A.F., Rivkin A.S., Scheeres D.J., Chesley S.R., Yu Y., Naidu S.P., Schwartz S.R., Benner L.A.M., Pravec P., et al., Assessing possible mutual orbit period change by shape deformation of Didymos after a kinetic impact in the NASA-led Double Asteroid Redirection Test. Advances in Space Research, 63, 2515–2534 (2019)

Cooperation within international research area

The European Fireball Network, the main project of the Group of Meteor Physics, has been an international project since its beginning in the 1960s. While the centre is in Ondřejov, stations are spread on the territory of several countries. Currently, we have mutual agreements with institutions or organizations in Slovakia, Austria, Germany, and the Netherlands. The agreements define the conditions of camera operation, data flow, and publication of results. In addition, we cooperate on a case to case basis with institutions, organisation or individuals (amateur astronomers) in other countries, e.g. Hungary, Slovenia, Croatia, Romania, Poland, Denmark, or Switzerland. The cooperation concerns important fireballs recorded also by other cameras than our own or by casual videos (from security or dashboard cameras), which need to be calibrated. Examples of such collaboration published in this period include the Križevci and Ejby meteorite falls or the Romanian superbolide of

The president of the Czech Academy of Sciences prof. Eva Zažímalová visited the site of the Ondřejov Observatory in 2020 to discuss the performance, results, investment plans and the overall outlook of the Astronomical Institute. Dr. Petr Pravec introduces the observational programme that he leads at the Ondřejov 65 cm telescope.

2015. There were also collaborations on bolides, which led to unsuccessful meteorite searches.

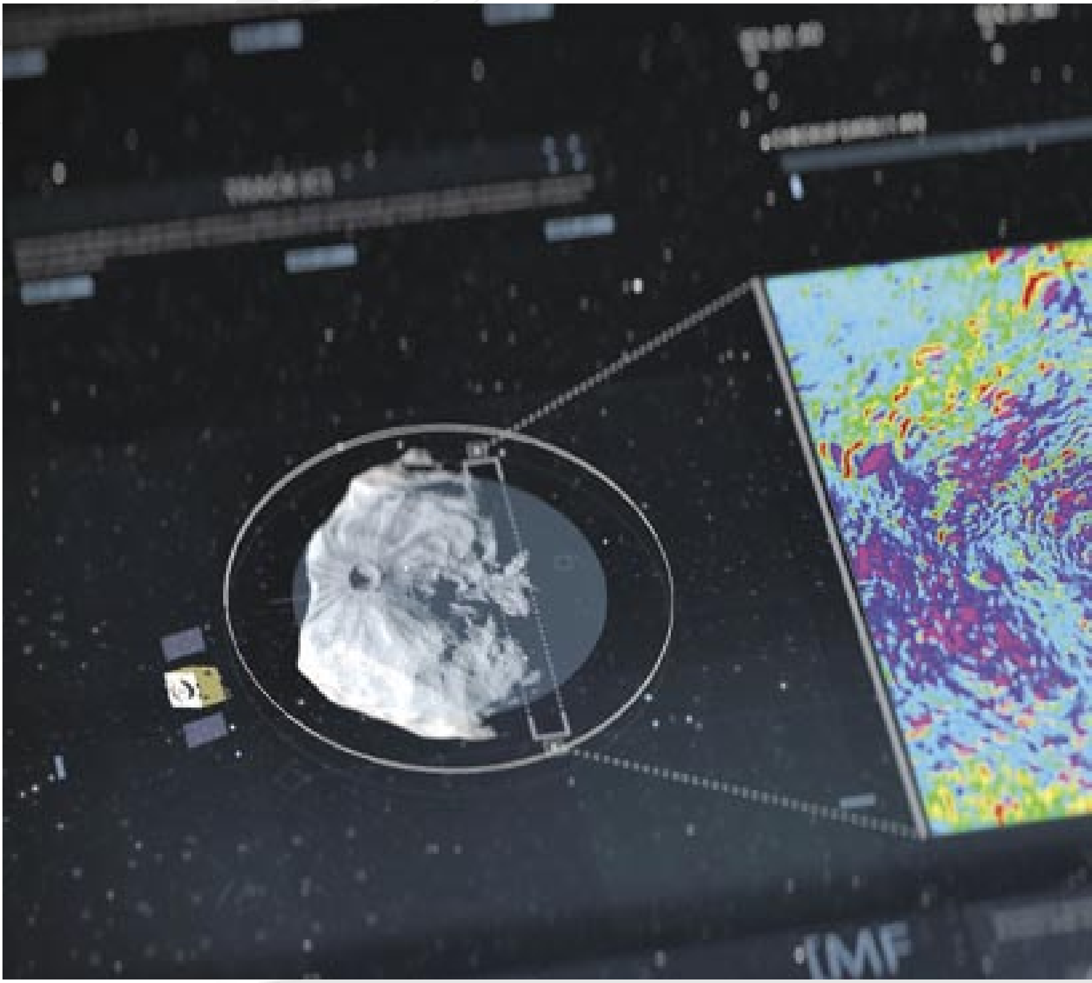
On a more theoretical level, there is a long-term collaboration with O. Popova (the Russian Academy of Sciences) and A. Berezhnoy (the Sternberg Astronomical Institute, Moscow). Both have been visiting the Ondřejov Observatory for medium-length stays supported from our grants. O. Popova is an expert on meteor physics and fragmentation, A. Berezhnoy is an expert in astrochemistry. This cooperation led to several common publications, as it can be seen in the previous section.

Another long-term collaboration is with the Meteor Physics Group at the University of Western Ontario, Canada. This group is a leading group in meteor science in North America. They appreciate the quality of our data and performed analyses, especially backward orbital integrations, which are outside our expertise. The results published in this period deal with a temporarily captured satellite and the Quadrantid meteoroid stream.

The main international co-operator of P. Koten remains Jeremie Vaubaillon (Observatoire de Paris, IMCCE, France). The cooperation was also supported by the Mobility project provided by the Ministry of Education, Youth, and Sports which was solved within the years 2016–2017. J. Vaubaillon is an expert on the modelling of the meteor streams evolution. He successfully predicted several meteor shower outbursts in recent years. The cooperation with him allows us to connect both our experimental and his theoretical approaches of meteor studies. Other co-operators are Slovakian colleagues M. Hajduková and J. Tóth.

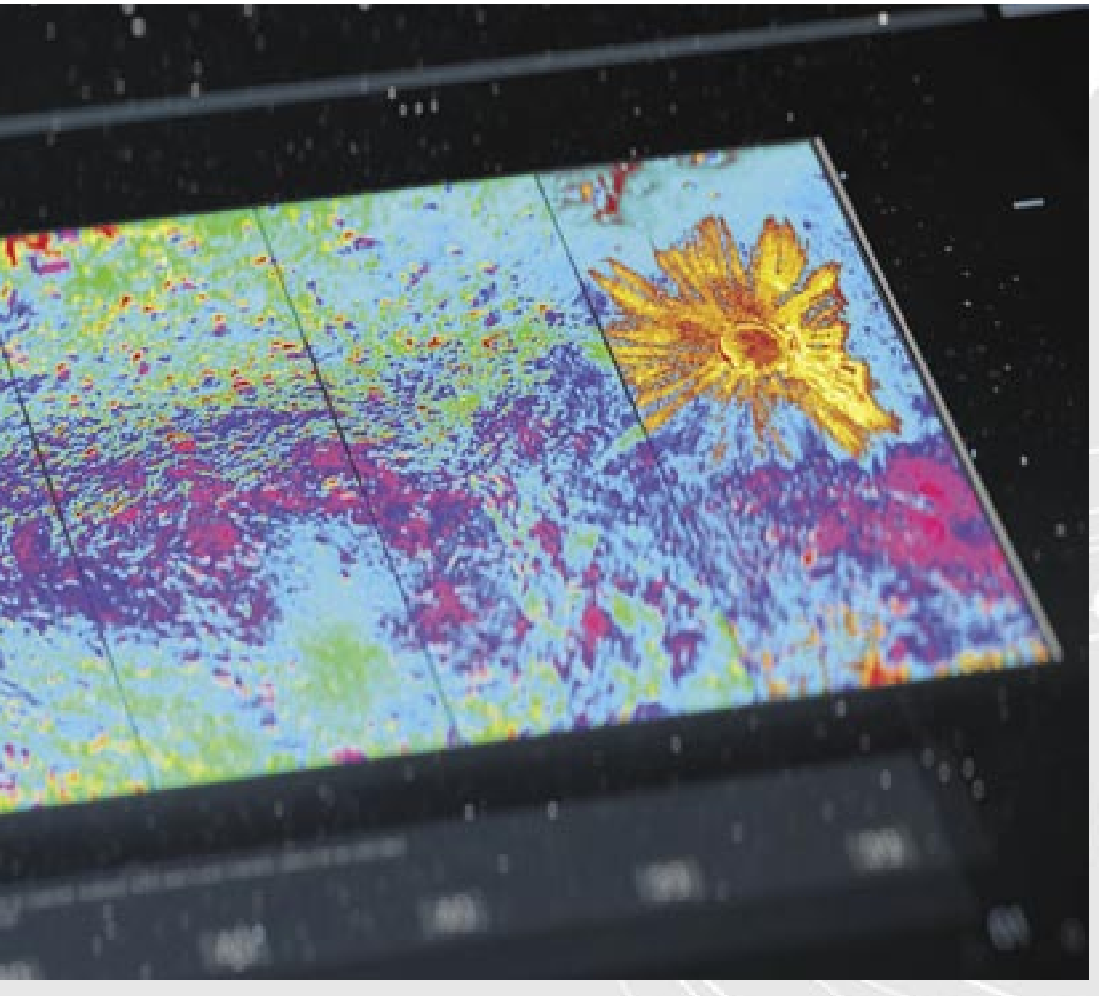
Two members of our Team organised and led an international team of authors to prepare a chapter in the book Meteoroids: Sources of Meteors on Earth and Beyond (see the previous section).

In the research of asteroids, we have a great long-term collaboration with several research teams working on the asteroid research in the world. The collaboration is largely informal, focused on coordinating observations with a variety of observational techniques by the individual teams, sharing the obtained data, and performing their joint analyses, modelling and interpretations. It led to a number of results and scientific papers as outlined above. Our most significant collaboration was with the Niels Bohr Institute (NBI) of the Copenhagen University in Denmark on a joint use of the Danish 1.54m telescope at the La Silla station of the European Southern Observatory in Chile. Within our agreement with NBI, we used the telescope for our physical

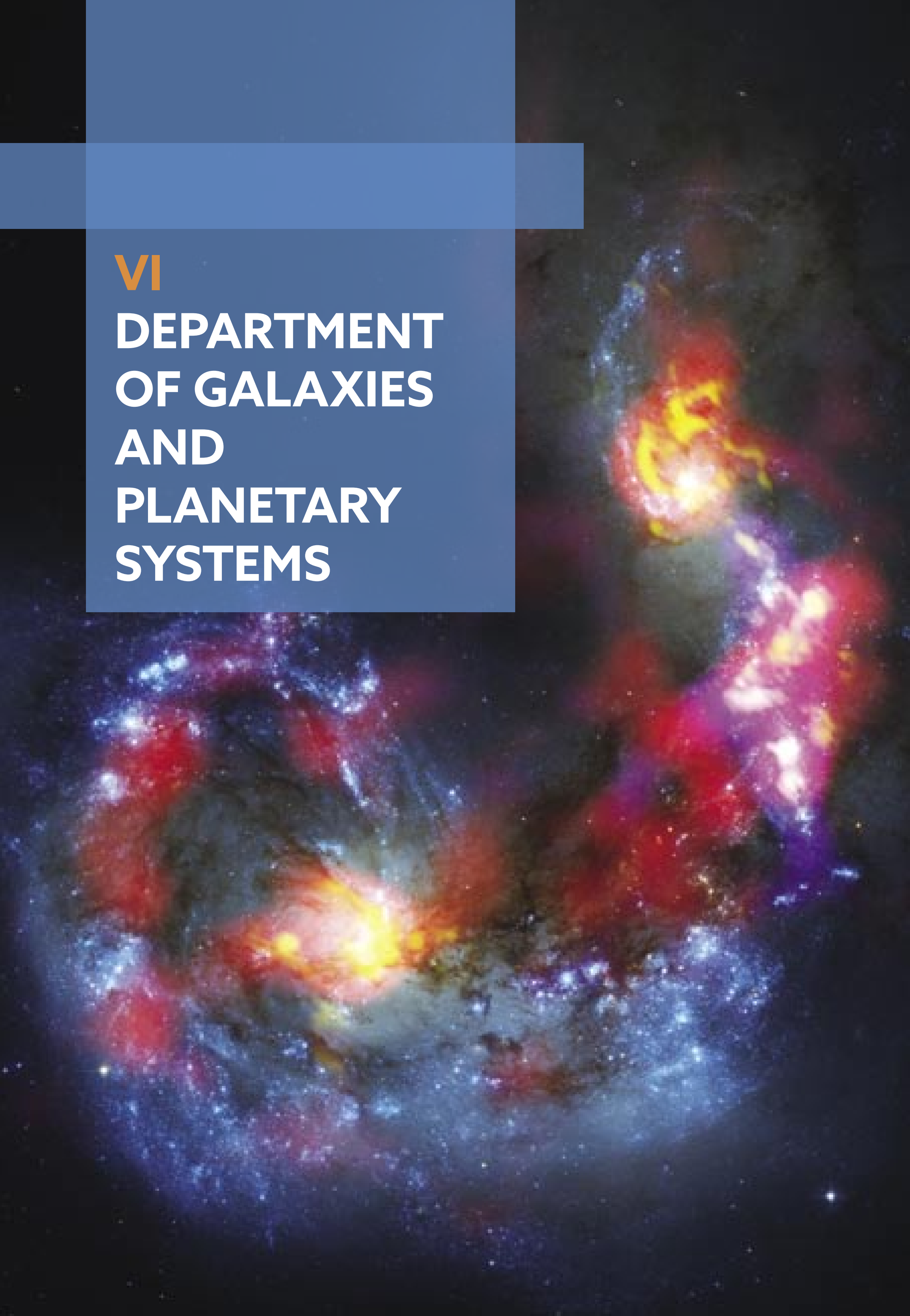


studies of asteroids on 30 % of nights during 2015–2019. The photometric data we obtained with the telescope were used in about half of our published papers during the given period. On the national level, we had a great collaboration with the team led by prof. David Vokrouhlický from Charles University, Prague. In that collaboration we focused on thorough studies of formation and evolution of asteroids by the rotational fission process (see the number of papers above). Petr Pravec and Petr Scheirich were also involved in the Asteroid Impact & Deflection Assessment (AIDA) mission that are two space mission to the binary asteroid (65803) Didymos, one by NASA called DART (Double Asteroid Re-direction Test) and one by ESA called Hera. Petr Pravec co-chaired the Hera Working Group 2 on Remote Observations of the mission target Didymos. Most recently we have also been involved in the preparation of the proposed NASA Janus space mission to two binary near-Earth asteroids (35107) 1991 VH and (175706) 1996 FG3, which we also discovered here from Ondřejov.

A visualisation of the surface of Didymos' smaller companion Didymoon scanned by Hera. (© ESA)



VI
DEPARTMENT OF GALAXIES AND PLANETARY SYSTEMS



The Head of the Department:
Dr. Richard Wünsch

The Team of the Department of Galaxies and Planetary Systems of the Astronomical Institute of the Czech Academy of Sciences (ASU) – consists of the following three research groups: Physics of galaxies, Relativistic astrophysics and Planetary systems. The research of the Team focuses on the areas of star formation and stellar clusters, evolution of galaxies in groups and clusters, super-massive black holes in active galactic nuclei as well as the one in the center of the Milky Way and stellar-mass black holes in X-ray binary systems in our Galaxy. Another active theme is traditionally Earth's rotation and its gravity field, and precise astrometry. The details about the research activities of individual groups are given below and in the next section. Some activities are joint collaborations of more than one of our research groups.

Left: Antennae Galaxies composite of ALMA and Hubble observations (© ALMA: ESO/NAOJ/NRAO. Visible light image: the NASA/ESA Hubble Space Telescope)

Researchers from our Team are also involved in two large programmes: Strategy AV21 – Space for Mankind (J. Svoboda from our Team is the coordinator), and the Czech ALMA node (P. Jáchym from our Team is the coordinator).

Physics of galaxies. The research of this group focuses mainly on the study of the formation and evolution of galaxies, structures in the interstellar medium and formation of massive star clusters. The project to study "Green Pea" galaxies was performed in collaboration with the Relativistic astrophysics group. The project on Gould's Belt using the data of the GAIA satellite is performed together with astrometrists of the Planetary systems group. The group is led by Jan Palouš.

Relativistic astrophysics. The mission of the group is to explore – by theoretical approaches, numerical modelling, and data interpretation – physical processes near accreting stellar-mass black holes in binary systems and super-massive black holes in active galactic nuclei, as well as the Milky Way's under-luminous core. Both archival and newly obtained data are employed (X-ray, near-infrared, optical, and submillimeter spectral bands) in collaboration with our partners abroad. We also participate in preparations of future missions, especially preparations of their scientific programmes. A recent research activity of the group concerns modelling of gravitational waves from compact objects inspiraling into super-massive black holes. The group is led by Vladimír Karas.

Planetary systems. The missions of the group are the research in dynamics of the Earth's rotation, its gravity field, orbital analysis of space missions, and astrometry with Zeiss Photographic Zenith Tube in Ondřejov. The group of Planetary Systems consists of two

A multiwavelength study of galaxy ESO137-001; combination of mm radio (ALMA), Hα (VLT/MUSE) and optical (HST).

parts led by Cyril Ron in Prague, while Aleš Bezděk, Jaroslav Klokočník and Jan Sebera work in Ondřejov.

Additional information, including links to web pages of individual groups can be found at http://www.asu.cas.cz/en/departments/galaxies-department.

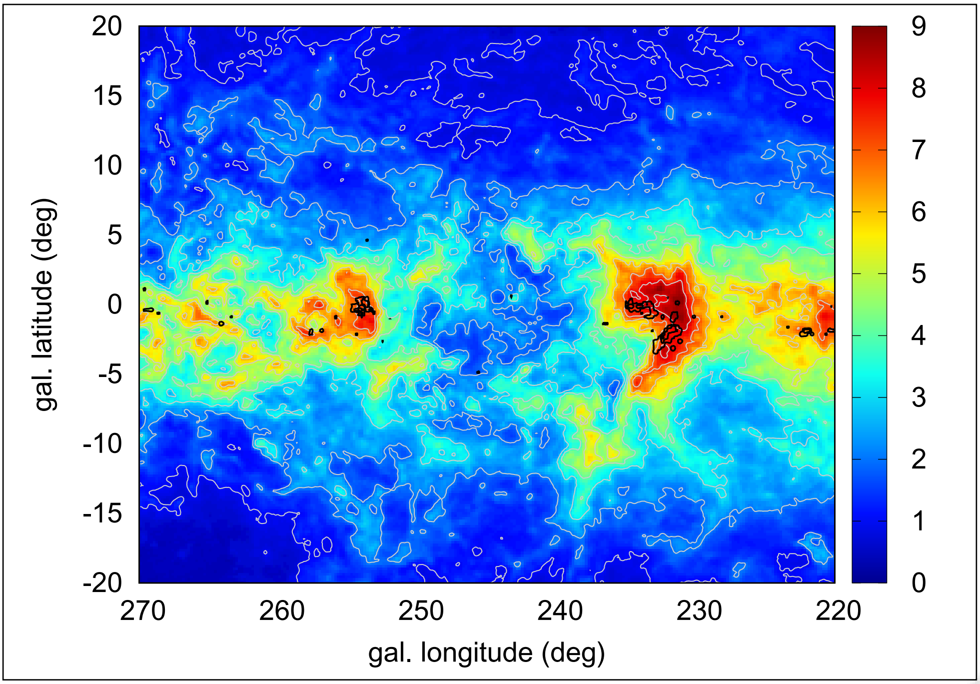
Research activity and characterisation of the main scientific results

Galaxy formation and evolution

One of the key challenges in galaxy evolution theory is to understand the star formation history of galaxies – in particular, how star formation is triggered and how it can be suddenly quenched. The environmental effects in galaxy clusters and groups are thought to play an important role, especially ram pressure stripping (RPS) of the interstellar medium as galaxies move through the surrounding intracluster medium. Other mechanisms include gravitational interactions between galaxies and the tidal influence of the cluster potential.

In recent years numerous cluster galaxies with jellyfish-like ‚tails' of stripped gas have been diskovered. These are multiphase systems, many of them containing young stars. RPS thus not only quenches star formation in galaxies, but can initiate new star formation in the striped gas. Jáchym et al. (2017, ApJ, 839, 114) showed for the first time that tails of jellyfish galaxies may be dominated by cold molecular components. In the Coma galaxy D100, IRAM 30m observations revealed large amounts of molecular gas that exceed the mass of ionized hot and warm phases together. The molecular-to-ionized gas mass ratio is elevated due to excitation and heating from shocks induced by ram pressure. With ALMA, the first high-resolution map of the cold molecular gas distribution in a jellyfish galaxy was obtained (Jáchym et al. 2019, ApJ, 883, 145). The ALMA observations also displayed CO filaments oriented in the direction of the tail that are likely young molecular features formed in situ.

Besides gas clouds clearly connected with cluster galaxies, there are others, more mysterious: certain HI clouds



One of the largest supershells in the Milky Way – GS242–03+37 – extends through the whole thickness of the Galactic disk. Young star forming regions are found in its walls. An observation taken in 21cm neutral hydrogen line (© HI4PI survey).

in Virgo are isolated, optically dark, and with high velocity widths suggestive of rotation. We have explored a variety of possible origins of dark neutral gas structures. Köppen et al. (2018, MNRAS, 479, 4367) describe how to analytically calculate the effects of ram pressure stripping. In Taylor et al. (2020, AJ, in press) we demonstrated that ram pressure is the most likely mechanism to explain a population of short gas tails we diskovered elsewhere in the Virgo cluster. The research into smaller, detached clouds is ongoing. In Taylor et al. (2016, MNRAS, 461, 3001) we showed that harassment has difficulties in producing features with similar isolation and velocity, while if the clouds are gravitationally bound by dark matter – essentially galaxies in their own right – then they could survive the tidal effects of the cluster for several gigayears. We are now beginning to incorporate the effects of the intra-cluster medium and ram pressure stripping into these simulations to see how this will affect our conclusions.

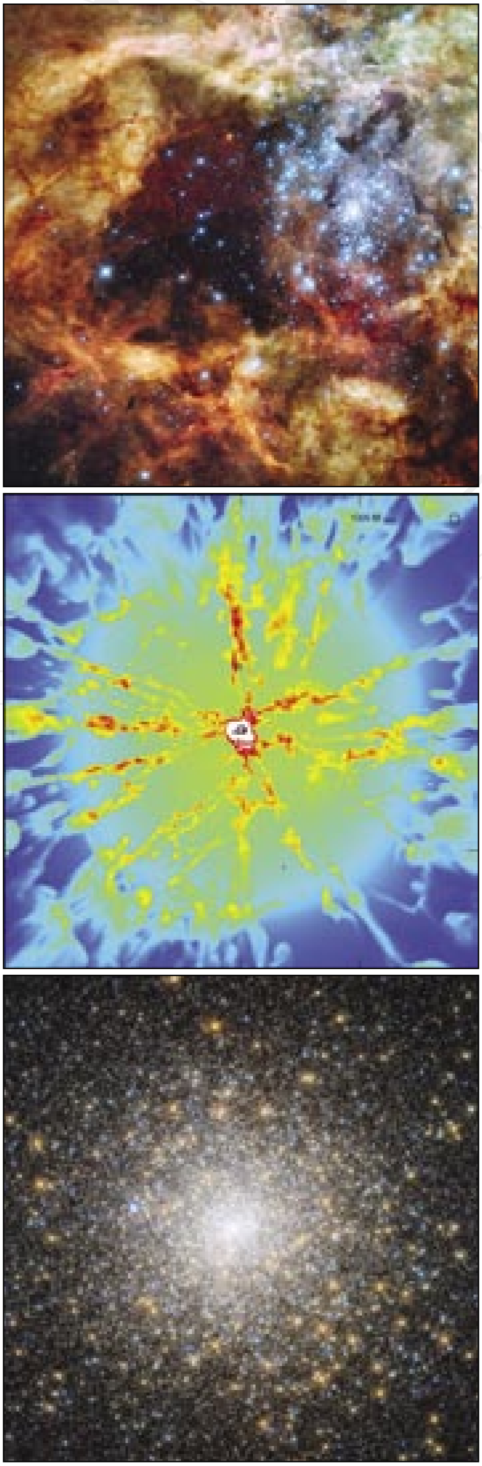
Structures in the interstellar medium

HI shells and supershells belong to the most striking structures in the distribution of the interstellar medium in galaxies. The majority of them are created by the energetic activities of massive stars, mostly by supernovae explosions combined with intense radiation and stellar winds, but there are structures of unknown origins, where the stellar origin is not probable. The role of HI shells is not straightforward: walls of these structures expand into the neighbouring interstellar medium destroying existing molecular clouds and therefore decreasing the star formation in their vicinity, but also sweeping the surrounding material into dense sheets, promoting creation of new clumps and clouds and thus increasing the star formation. We study expanding shells both observationally and theoretically in the following papers.

Ehlerová & Palouš (2016, A&A 587, 5) created a catalogue of HI shells in the outer Milky Way and explored the correlation between HI shell walls and the presence of molecular clouds observed in CO line. Zychová & Ehlerová (2016, A&A 595, 49) analysed a system of two colliding interstellar bubbles. A mostly theoretical work of Dinnbier et al. (2017, MNRAS 466, 4423), that studies gravitational fragmentation of shells, diskovers a new type of instability and explores its impact on star formation in shell walls. Ehlerová & Palouš (2018, A&A 619, 101) analysed in detail one of the largest supershells in our Galaxy (GS242–03+37) and by that studied the effect of large shells on their surroundings.

Massive star clusters

Young massive star clusters are rare: there are only about ten young star clusters more massive than 10^4 Solar masses in our Galaxy, and clusters with masses higher than 10^5 Solar masses have been found only in external galaxies. However, they were much more common in the early Universe, at the peak of the cosmic star formation rate, when a significant fraction of all existing stars was formed. The understanding how star formation proceeded at that time, whether it was qualitatively different than nowadays, is interesting by itself, however, it also impacts



Top: R136 in the Large Magellanic Cloud (the most massive young star cluster in the Local group). Credit: NASA, ESA (HST). Middle: RHD simulation with secondary star formation in a young massive cluster (Wünsch et al., 2017). Bottom: Galactic globular cluster M15. (© NASA, ESA, HST) other fields, e.g. cosmology, formation of galaxies and origin of chemical elements in the Universe. Among many open questions, a particularly interesting one is how globular clusters were formed. It has been found that globular clusters (very old massive star clusters found typically in galactic halos) consist of several populations of stars which differ in their chemical composition. Moreover, spectroscopy of red giants in globular clusters has revealed very unusual chemical patterns that are not observed in any other known objects.

We develop, in collaboration with INAOE in Puebla (Mexico), a model of rapidly cooling shocked stellar winds that aims to address the question of the origin of multiple stellar populations in globular clusters. The model and its implementation using the radiation-hydrodynamic code is described in Wünsch et al. (2017, ApJ 835, 60). Additional aspects of this model (e.g. theory of self-shielding of dense clumps) is described in Palouš et al. (2017, IAUS316, 251) and Wünsch et al. (2017, IAUS316, 294). The impact of supernovae on the secondary star formation and on the formation and destruction of dust by them is studied in a series Martínez González et al. (2017, ApJ 843, 95; 2018, ApJ 866, 40; 2019, ApJ 887, 198). In Tenorio Tagle et al. (2019, ApJ 879, 58) we explore the relation between the star formation efficiency and the properties of multiple stellar populations in globular clusters. Further, we describe an alternative model of the formation of multiple stellar populations in the shell created by the exploding Population III star in Recchi et al. (2017, Ap&SS 362, 183).

Green pea galaxies

Green pea galaxies are highly star forming compact dwarf galaxies typically observed at moderate redshift $z = 0.2 - 0.3$, with a relatively high fraction of leaking ionising radiation. They are thought to be the equivalents of high-redshift starburst galaxies that may be responsible for the re-ionisation of the Universe. In Izotov, Orlitová et al. (2016, Nature 529, 178) we report a detection of a significant Lyman continuum escape, and demonstrate the conditions under which the ionizing radiation can leak. In Orlitová et al. (2018, A&A 616, A60) we report a diskovery of peculiar double-peaked Lyman alpha line profiles at Green pea galaxies that are difficult to be reproduced by models.

Gould's Belt

Gould's Belt is a system of young stars within 1 kpc from the Sun. The origin and evolution of the young stars is explored with the astrometric data provided by GAIA astrometric satellite. The main question is the origin of nearby OB associations, how they are connected to nearby molecular clouds, and how their recent formation is connected to the structure of the Milky Way. This research is performed in collaboration with C. Ron of the Planetary Systems Group. A review paper Palouš & Ehlerová, "Gould's Belt: Local Large-Scale Structure in the Milky Way" was published in the Handbook of Supernovae (ISBN 978-3-319-21845-8, Springer International Publishing AG, 2017 p. 2301). Recently we published a paper Palouš, Ehlerová & Ron, 2019, "Gould's Belt: As Seen in Gaia DR2" (2019, ASPC, 519, 169).

Modelling X-ray spectral, timing and polarisation properties of AGN and XRBs

The X-ray spectral, timing and polarisation properties of the radiation coming from close vicinity of black holes in AGN and XRBs enable us to probe the effects of strong gravity, to learn about the black-hole properties, its mass and spin, and to study accretion processes. We investigate the properties of thermal radiation emitted by the accretion disk, Comptonization of this radiation in the hot corona above, that is responsible for the primary X-ray radiation, as well as the re-processing of the primary X-rays that fall back onto the accretion disk. These on one hand increase the disk temperature and on the other hand produce the disk-reflection spectrum with its distinct features as the soft excess (in 0.3–1 keV), the fluorescent iron K alpha spectral line (around 6.4 keV) and the Comptonized hump (above 10 keV).

We develope numerical codes that can be used to model different components of these systems – the black hole, accretion disk and corona (or hot inner accretion flow) and study their properties in spectral, timing and polarisation domains. We have created a library for computing the photon trajectories in the curved space-time of a black hole with arbitrary mass and spin, SIM5 (Astrophysics Source Code Library, record ascl:1811.011). We have developed a package of numerical codes named "KY" to model the accretion disk emission, i.e. both the thermal disk radiation as well as the re-processed reflection spectra from black-hole accretion disks (e.g. Dovčiak & Done 2016, AN, 337, 441; Kammoun et al. 2019, MNRAS 485, 239). Further we have developed new codes to model the X-ray and UV/optical (thermal) reverberation, KYNREVERB (e.g. Caballero-Garcia et al. 2018, MNRAS, 480, 2650; Kammoun et al. 2019, ApJL, 879, L24). Both of these numerical packages can be used within the XSPEC, a widely used platform for fitting X-ray observational data. To model the primary X-ray radiation and properties of the corona, we have developed a brand new numerical code, MONK (Zhang et al. 2019). In the future we want to use this code to produce XSPEC table models to fit the spectral, timing and polarisation properties of the corona. After extensive tests and use with data, we provide our codes and tables to the astrophysical community at our Institute projects web page (see e.g. https://projects.asu.cas.cz/stronggravity/kyn).

Polarization in AGN, XRBs and Sgr A*

Recently, the X-ray polarisation astronomy got a new incentive as new X-ray missions with a polarimeter on board have been approved – the NASA's IXPE mission to be launched in 2021 and the Chinese eXTP mission with an expected launch in 2027. Members of our Team joined these efforts in multiple ways – by our research contribution to their scientific programme, by co-organizing the mission preparations as collaborators, participating in the scientific consortium structure as science topical working group chair (in the IXPE mission), and by arranging a hardware contribution of the Czech Republic, thus becoming a member of a hardware consortium (in the eXTP mission).

We have used our models to predict the polarisation for different systems emitting X-ray radiation – we have computed time variations of the polarization signal from AGN due to cloud obscurations (Marin & Dovčiak, 2015, A&A, 573, A60), polarization of reflection nebulae in the Galactic center (Marin et al., 2015, A&A, 576, A19), polarized scattered fluxes by the exoplanet HD 189733b (Marin & Grosso, 2017, ApJ, 835, 283), contribution of parsec-scale material on to the polarized X-ray spectrum of type 1 Seyfert galaxies (Marin et al., 2018, MNRAS, 478, 950) and we have predicted the X-ray polarization of type 2 Seyfert galaxies (Marin et al. 2018, MNRAS, 473, 1286). We have also modelled optical and UV polarization of AGNs originating in either uniform-density or clumpy regions (Marin et al., 2015, A&A, 577, A66).

AGN spectral states

We study similarities of accretion processes between black holes of largely different mass, stellar-mass black holes in X-ray binaries and supermassive black holes in galactic nuclei. While stellar-mass X-ray binaries are known to change their accretion properties within several weeks to months, the supermassive black holes are much larger and thus less variable. There are, however, similarities between these two distinct classes of black holes, such as the presence of accretion disk and also the presence of a relativistic highly-collimated outflow, the so called jet, in some sources.

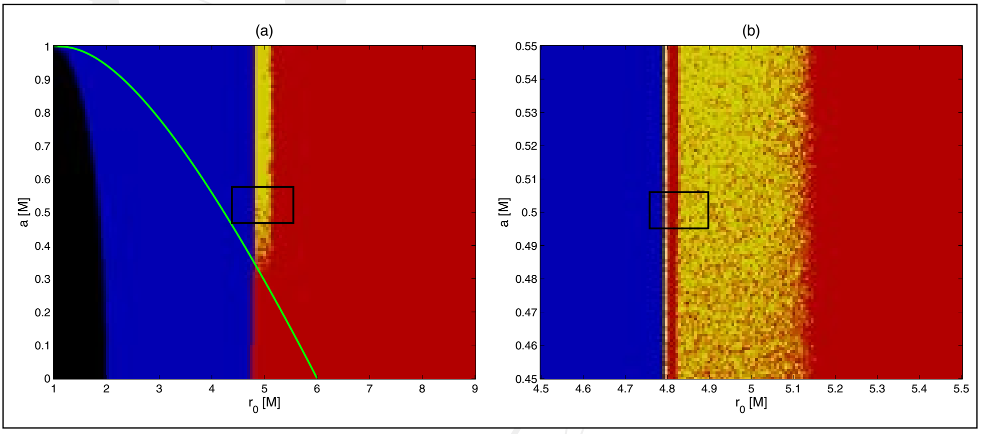
In a recently published paper (Svoboda et al., 2017, A&A, 603, A127), we performed the largest study of AGN spectral states using the entire archive of X-ray and optical/UV sources detected by XMM-Newton in its first ~15 years of operations to address one of the fundamental problems in modern astrophysics: does accretion onto black holes scale solely, or primarily with mass? This unprecedented parent sample allowed us to extract the largest and best-quality sample for this kind of studies with a population of ~1 500 galaxies hosting an accreting super-massive black hole with high-quality simultaneous optical and X-ray data. Our study provides an observational support to the hypothesis that accretion onto super-massive black hole works in a similar way as the stellar-mass black holes in X-ray binaries, and that XRB and AGN follow similar evolutionary paths.

Since 2019, there has been a junior team led by J. Svoboda to address the AGN spectral states in more detail. Namely, we will focus on AGN with known radio morphology from sensitive radio observations to see whether the jet launching mechanism is closely related to the accretion state and evolves similarly as for X-ray binaries.

Quasi-periodic oscillations

Accreting black holes in binary systems often exhibit quasi-periodic oscillations (QPOs) of the observed X-rays. Sometimes the frequency of these oscillations is very high (in kilohertz range) and they occur at two distinct peaks. QPO properties differ from source to source, however, it appears that they keep a fixed frequency ratio of small rational numbers. The exact origin of this phenomenon is still not very clear. High frequencies of QPOs roughly correspond to orbital frequencies of the matter in close vicinity of the central black hole, moreover, they roughly inversely scale with its mass what likely suggests a relativistic origin of this phenomenon.

Our group is involved in examining the stability and oscillation properties of the accretion flows under various conditions (see e.g. Miranda et al. 2015, MNRAS 446, 240). In collaboration with the Institute of Physics at Silesian University in Opava (IP SU), we developed a finite-element code to explore possible modes of thick accretion disks (tori) with constant angular momentum distributions. This represents a complementary case to thin accre-



Magnetic fields extract rotational energy from the black hole back and convert it to the outflowing Poynting flux and to kinetic energy of accelerated plasma flows. Such outflows are indeed observed, but the regions where they originate from remain below resolution capabilities of present-day techniques. In our recent work we have proposed that the conditions in the ergosphere can lead to magnetic reconnection and chaotic motion occurring in the strong gravitational field of a rotating black hole (figure from Kopáček & Karas, 2018, ApJ, 853, 53).

tion disks with nearly Keplerian angular momentum distributions. Currently, we work on an extension of the code to include fully general angular-momentum distributions to adopt a variety of other types of accretion flows and their geometries. In collaboration with IP SU, we develope a model based on oscillation modes of thick accretion tori (see Török et al., 2016 ApJ, 833, 273).

MHD simulations of wind in High-mass X-ray binary systems

High-mass X-ray binary systems (HMXBs) are interacting binaries in which a compact companion, either a neutron star or a black hole, orbits a massive early-type star, typically an OB supergiant. This type of stars is characterized by an enhanced mass-loss rate of the order of ~10^{-6} Solar masses per year. The compact companion is immersed in the stellar wind and accretes material from it, giving rise to a strong X-ray flux. The wind of the massive star is severely disrupted by the gravity and photo-ionization of the companion and its accretion flow. We have developed a code for three-dimensional time-dependent radiation hydrodynamic simulations of stellar winds in interacting binaries to improve models of high-mass X-ray binaries and to explore the properties of circumstellar matter (Čechura & Hadrava, 2015, A&A 575, A5). We have also developed a new method of interpreting Doppler tomograms of observed XRB spectra that is based on a comparison with synthetic Dopplerograms calculated from radiation-hydrodynamic models of the circumstellar matter in the binary system. We have applied this method to the optical spectra of Cyg X-1 obtained mainly by the Perek 2m Telescope of the Astronomical Institute in Ondřejov. We found that our model with the assumed parameters fits well the observations in both high/soft and low/hard states of the object.

Magnetic fields around black holes

The electromagnetic field is governed by Maxwell's equations. These are the first-order differential equations for the electric and magnetic intensity vectors. When expressed in the equivalent, and perhaps more elegant tensorial formalism, the mutually coupled equations for the field intensities can be unified in terms of the electromagnetic field tensor, comprising both the electric and the magnetic field components in a single quantity. In the astrophysical context, coupling with plasma is essential. In the context of black holes, effects of strong gravity also have to be taken into account. Near rotating compact objects, neutron stars and black holes, the field lines are wildly deformed by rapidly moving plasma and strong gravitational fields. Studying the effects of strong gravity is a traditional direction with interesting results achieved also in a broader collaboration with our colleagues at universities within the frame of Albert Einstein Center in Prague. We address questions whether rotating black holes power relativistic jets. How the particles are accelerated near the event horizon? Is the motion regular or chaotic? Compelling answers may be beyond our reach yet for some time. However, the group of Karas, Kopáček, Suková, Araudo et al. contributed to the field by publishing a series of related papers (ApJ, MNRAS, A&A, CQG, etc.) over the evaluation period. The adopted approach turns out to be particularly useful in the framework of the theory of relativity.

Gravitational wave modelling

In 2017 a junior team led by G. Loukes-Gerakopoulos started a new direction of research by modelling sources of gravitational waves and computing the respective waveforms. In particular, we focus on Extreme Mass Ratio Inspirals (EMRIs), which are binary systems consisting of a primary super-massive black hole (SMBH) and a secondary stellar-mass compact object. In these binaries, the comparably lighter compact object can be viewed as moving in the gravitational field of the primary, where it slowly spirals towards the central black hole. The degradation of the orbit is caused by the loss of energy and angular momentum due to gravitational radiation reaction. Such processes are predicted to routinely occur in the centers of galaxies, where the compact objects enter inspirals around the heavy central black holes due to complicated many-body dynamics of the surrounding dense stellar clusters.

Gravitational waves from EMRIs are promising sources for the space-based gravitational-wave detector LISA (Laser Interferometer Space Antenna). LISA is the L3 mission of ESA in its Cosmic Vision science programme currently scheduled for launch in the early 2030s. The EMRI signals detected by LISA will allow us to map the spacetimes around SMBHs. In return, this will also allow us to test whether the gravitational fields of SMBHs are well described by Einstein's General Relativity or not. The current consensus is that gravitational waveform template banks are necessary in order to be able both to detect and interpret the received signal.

In the source modelling we concentrate mainly on the inclusion of astrophysical effects modifying the simplest EMRI models, namely effects due to the finite size of the secondary objects or external gravitational perturbations. In both cases, we employ tools traditionally developed in the fields of dynamical astronomy and non-linear dynamics ranging from Poincaré sections to canonical perturbation theory. For calculating the GW fluxes and the waveforms we use a time domain Teukolsky solver called Teukode developed by our collaborators at the University of Jena, and tools from the Black Hole Perturbation Toolkit.

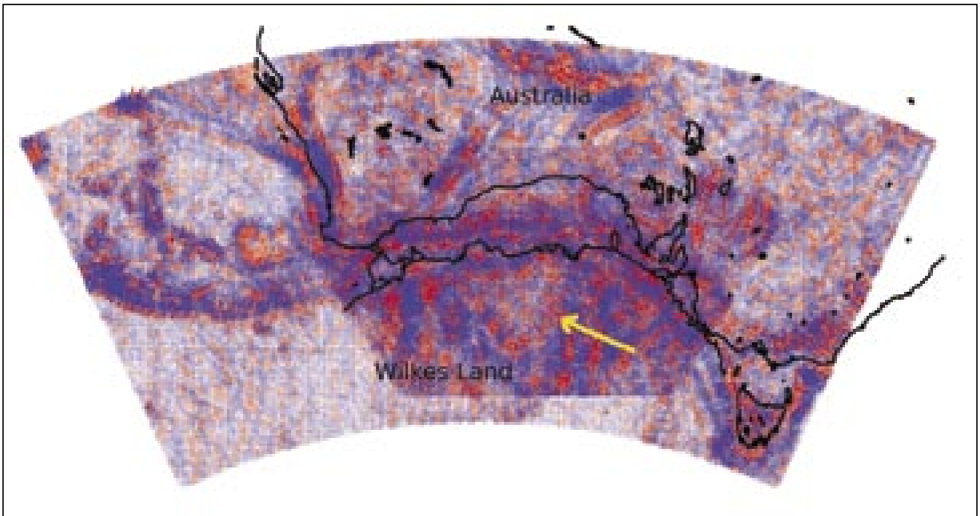
Multiphase environment of Centaurus A

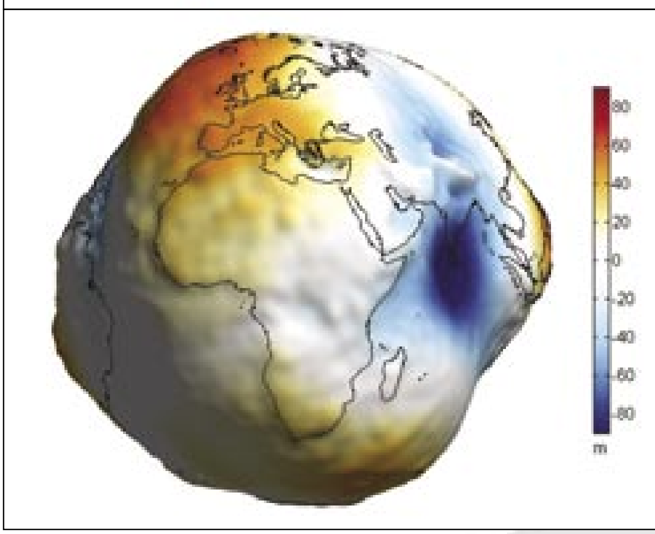
We studied the combined high resolution ALMA and Chandra images of the central 500 pc of the Centaurus A galaxy. Our aim was to study the multi-phase gas distribution in the close vicinity of the central supermassive black hole. We perform CLOUDY simulations of the photoionized gas and dust illuminated by the broadband Centaurus A continuum to examine what physical processes are responsible for multi-phase gas equilibrium. We conclude that the hot X-ray emitting plasma cannot coexist with the dusty gas at temperatures of 100 K in a pressure equilibrium. The natural consequence of this result is that the cold CO emitting gas has to be shielded from the X-ray emission. We build a 3D model and by projection we calculate the emissivity maps and match them to the observed images of the source. This study helps to determine the 3D spatial distribution of the circumnuclear gas under the conditions of thermal equilibrium. This work is currently being completed, where Borkar, Boorman, & Karas are involved, in collaboration with colleagues from Nicolaus Copernicus Astronomical Center and the Center for Theoretical Physics of the Polish Academy of Sciences in Warsaw, Inter University Centre for Astronomy and Astrophysics in Pune, and Instituto di Radioastronomia, Instituto Nazionale di AstroFisica in Bologna.

Satellite geodesy and gravity field

Geo-applications of high-resolution gravity field models – a new method to detect and study causative underground bodies of various origin (trenches, volcanoes, lakes, river valleys, paleolakes, impact craters, etc) according to their fine density variations have been implemented, the results were published in a series of impacted papers (see below). We published a monograph with Springer: Gravitational Atlas of Antarctica (Klokočník et al., 2017, Arab. J. Geosci, 10, 199). The gravity aspects (gravity anomalies, the Marussi tensor of the second derivatives, gravity invariants, strike angles and virtual deformations) were computed and plotted for Antarctica. These gravity aspects (descriptors), which are derived from the top quality global static comprehensive high-resolution gravity field models, provide much more complete but complex information about the density variations beneath the Earth's surface or ice than only the traditional gravity anomalies.

At least 2 candidates for subglacial volcanoes, 3 for subglacial lakes and 1 for a lake basin near the Lake Vostok in East Antarctica have been diskovered (Klokočník et al., 2016, Ann. Geophys., 59, 5). Our analyses independently supported the opinion that Wilkes Land in East Antarctica contains a huge impact crater (a crater basin with a mascon like on the Moon) which affected the geological past of the Earth (~250 mil. yrs ago) similarly as the proven impact crater Chicxulub on Yucatan (~65 mil. yrs old) (Klokočník et al., 2018, Polar Sci, 17, 59). We also studied (with the gravity aspects) paleolakes on Sahara and confirmed their existence known or diskovered/suggested before wholly independently by geologists. We added a diskovery of one such paleolake





Top: Virtual deformations showing internal tensions (blue compression, red dilatation) derived from the gravity field model EIGEN 6C4 for Wilkes Land, East Antarctica, showing a huge impact crater – originally Antarctica and Australia were connected (Klokočník et al., 2018, Planets and Space, 70, 135).

Left: Geoid heights derived from the gravity field (Bezděk & Sebera, 2013, Comp. Geosci., 56, 127)

along the Egyptian–Libyan border, under deep layers of sand. This land was still habitable 5000 to 7000 years ago. Now only few oases remain. We correlated the gravity signal with the possible position and shape of two other paleolakes and/or river system in Egypt (Klokočník et al., 2017, Arab. J. Geosci, 10, 199). The hypothetical impact structure in the Saginaw Bay (MI, USA) has been tested as well (Klokočník et al., 2019, JGLR, 45, 12).

The time-variable gravity field from satellite GPS orbits. We continued the development and implementation of our original inversion method of the precise GPS orbital data into time-variable gravity fields (so-called monthly gravity solutions). Within the framework of recent Earth missions dedicated to observe the time-varying gravity (CHAMP, GRACE, GRACE-FO, GOCE, Swarm), a special attention is paid to the processing of non-gravitational forces measured by on-board accelerometers. We contributed to this topic especially within the ESA Swarm mission (Bezděk et al., Adv. Space Res. 2017, 59, 2512; dtto 2018, 62, 317). We also studied other small, but nowadays important perturbative accelerations, those due to the general theory of relativity (Bezděk and Letko, 2019, JAG, 161, 270) and due to ocean tides (Štěpánek et al., 2016, AGG, 13, 27). Finally, based on our long-term expertise and good results in this research area (Bezděk et al., 2016, GJI, 205, 1665; da Encarnacao et al., 2016, Planets & Space, 68, 127), our working group was invited to be one of the five international academic members of an ESA-organized consortium named "Multi-approach gravity field models from Swarm GPS data".

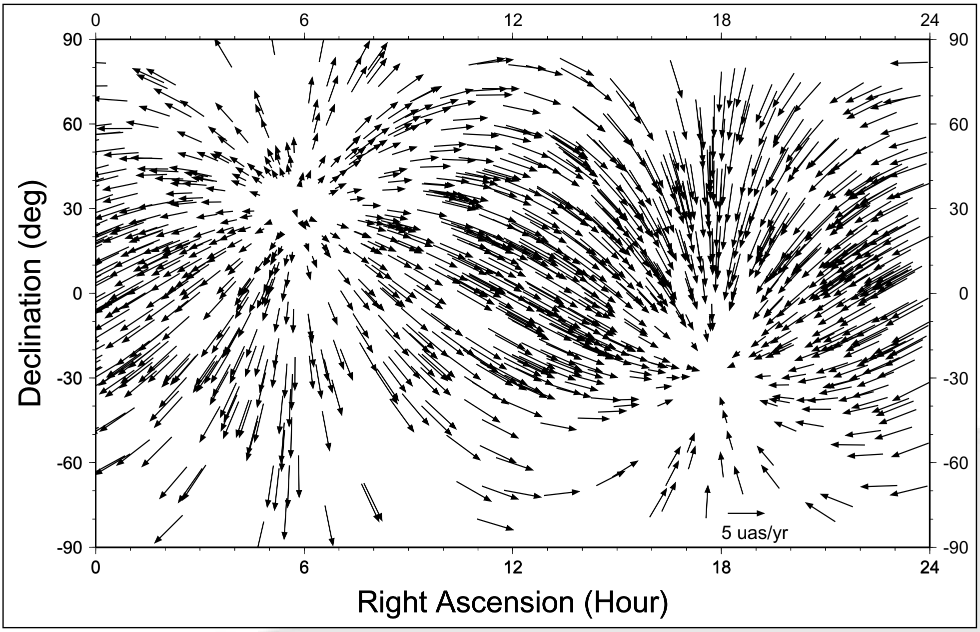
For gravity fields, we developed original routines for the spheroidal harmonic representations that were used

1) to update a high-resolution gravity model EGM2008 over the oceans where new data come from satellite altimetry every year (Sebera et al., 2016, Icarus, 272, 70), and
2) to model a gravity field of small bodies – the OSIRIS-REx target Bennu with the oblate harmonics, and Castalia with the prolate spheroidal harmonics. Our group also started new topics related to geomagnetism, for which we derived a global magnetic susceptibility map for geologic/tectonic interpretations based on satellite-only data (Sebera et al., 2019, Surv. Geophys., 40, 1229).

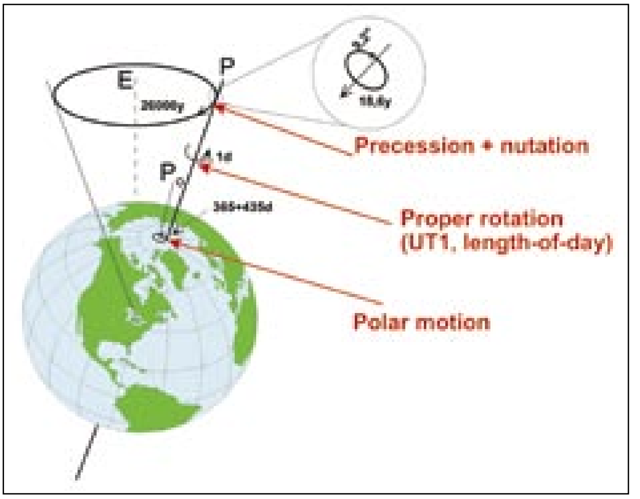
Global geodynamics, Earth's rotation and galactic aberration

The Prague part of the group continued studying the effects of the geophysical fluids (atmosphere, ocean, continental hydrology) and geomagnetism on Earth's rotation. It consists in studying movements of the Earth's spin axis in space (nutation) and in the Earth's body (polar motion). These motions were modelled using the integration of Liouville equations in Brzezinski's broad-band form. Newly we added an impulse-like excitation

An aberration proper motion field of extragalactic sources for an aberration constant of 5.8 μas/yr (McMillan et al., 2019, A&A, 630, A93).



Earth's rotation is described by Earth orientation parameters (Vondrák, 2018, IAG Symp., 147, 203).



due to the geomagnetic jerks, the sudden changes of geomagnetic field, with the common use of excitations by the atmosphere and the ocean. It was demonstrated that the inclusion of the excitation by geomagnetic jerks, in addition to the atmospheric and the oceanic excitation, improves the agreement between the integrated and the observed Earth orientation parameters substantially (Vondrák & Ron, 2015, Serb. AJ, 191, 59). Based on these results a new method for determining periods and quality factors of the eigenmodes of free core nutation (Vondrák & Ron, 2017, A&A, 604, A56) and of Chandler wobble in polar motion (Vondrák et al., 2017, Adv. Space Res., 59, 1395), free from the geophysical effects, has been proposed.

Galactic aberration. An alternative method to detect the secular aberration drift induced by the Solar System acceleration due to the attraction to the Galaxy centre was proposed by Titov&Krásná (2018, A&A, 610, A36). This method is free of the individual radio source proper motion caused by the intrinsic structure variation. They developed a procedure to estimate the scale factor directly from a very long baseline interferometry (VLBI) data analysis in a source-wise mode within a global solution. This approach splits the systematic dipole effect and uncorrelated motions on the level of observational parameters. H. Krásná as a member of the IVS (VLBI Service for geodesy & astrometry) working group on Galactic aberration (WG8) further contributed to the Galactic aberration research as published in MacMillan et al. (2019, A&A, 630, A93). The findings of the WG8 were used by the IAU ICRF3 working group in the generation of the 3rd realization of the International Celestial Reference Frame (ICRF3).

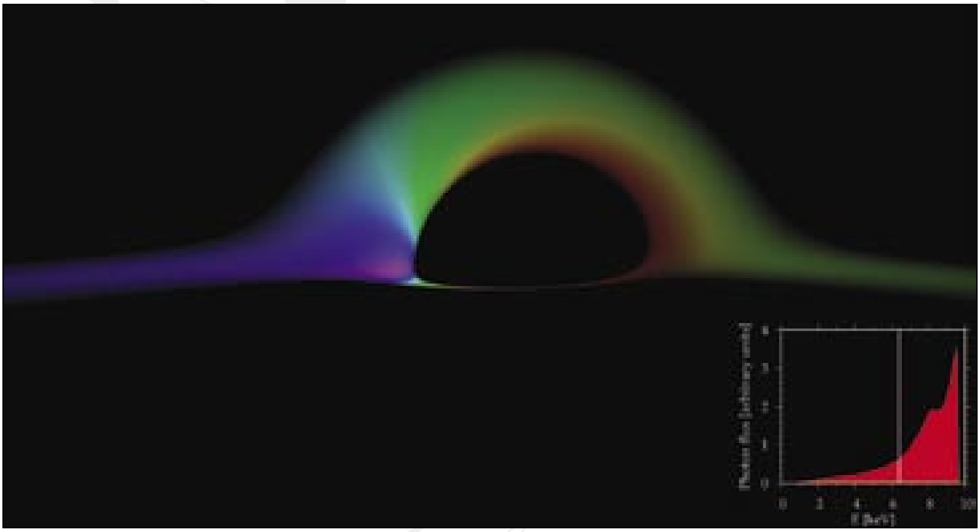
Cooperation within international research area

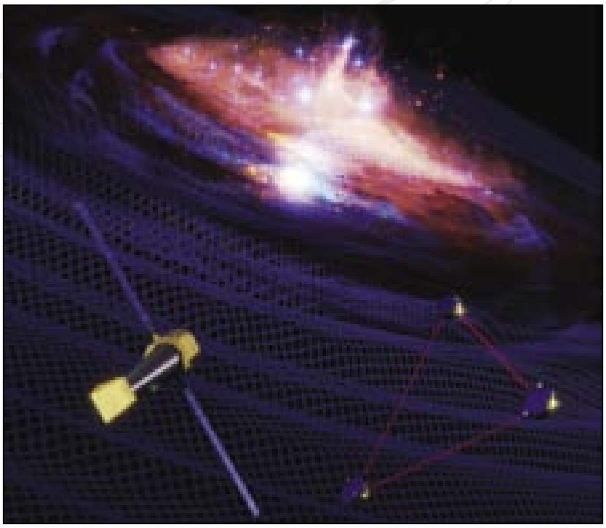
Strategy AV21 – Space for Mankind

The research programme Space for Mankind of the Strategy AV 21 aims to strengthen the cooperation between the scientific community and the technical teams in development and testing of new technologies for space research. There are three research teams in the Galaxies and Planetary System department:

- Hot and Energetic Universe – beyond the possibilities of ground-based laboratories
- Earth observation
- Gravitational Universe

The Hot and Energetic Universe group is involved in a large mission





Top: Simulations of the frequency shift of radiation coming from a deep gravitational field of the closest neighbourhood of a black hole and corresponding spectral line profile in an offset (© M. Dovčiak, ASU).

Left: The large ESA missions ATHENA and LISA will reveal secrets of the Energetic and Gravitational Universe. The goal of the Strategy AV21 – Space for Mankind is a successful Czech involvement in these large European space projects. (Credits: R.Buscicchio, based on content from NASA, ESA, IFCA, and Athena Community Office)

of the European Space Agency (ESA) ATHENA (Advanced Telescope for High Energy Astronomy). The ASU team participates in the Athena Science Advisory Team. Michal Dovčiak is a co-chair of the working group "Closest environments around supermassive balck holes". In 2019, the team also joined the instrumentation consortium of the main ATHENA scientific instrument X-IFU (X-ray Integral Field Unit). Jiří Svoboda became a member of the X-IFU Science Advisory Team and leads the Czech instrumentation team in collaboration with the Institute of Atmospheric Physics. The Czech contribution to the X-IFU detector will be the Remote Terminal Unit, an important electronic component to control the temperature in the central part of the detector and commanding other electronic and mechanical units. The team is also involved in the X-ray Chinese–European space mission eXTP (enhanced X-ray Timing and Polarimetry). The Czech team led by ASU will develop Collimator and Detector Frames for the innovative scientific instrument LAD (Large Area Detector).

The Earth Observation team is devoted mainly to two space missions, GRACE and Swarm and conducted related activities focused on remote sensing of the Earth. They organized ESA Swarm Data Quality Workshop and Copernicus workshop to learn from experts how to use the data collected from these missions.

The Gravitational Universe team is involved in the consortium of the LISA (Laser Interferometer Space Antenna) mission, which is the space-based gravitational-wave observatory planned by ESA. The ultimate goal of this group is to get involved in the scientific simulations as well as to agree on providing a hardware contribution to the spacecraft.

Czech node of the European ALMA Regional Center – Large Research Infrastructure EU-ARC.CZ

ASU hosts one of the nodes of the European ALMA Regional Center network, the Czech ALMA node. Since 2016 the node has been running as a national Large Research Infrastructure (LRI) EU-ARC.CZ supported by the Ministry of Education, Youth and Sports of the Czech Republic. The staff of the node works on the base of an interdepartmental (together with Team 1 at the Department of Solar physics) collaboration with international researchers and postdocs. The Head of the node (P. Jáchym who is also the PI of the LRI project), together with one researcher and a postdoc are members of the GPS dept. They focus mainly on user support activities, but also on observations and research in extragalactic areas. Among the main support activities are Phases 1 and 2 of the preparation of observing proposals, quality assurance (QA) analysis of acquired ALMA data, further analysis of delivered data when required by PIs of observing projects, face-to-face consultations, participation in ALMA software testing and end-to-end testing, and educational activities. During the QA, the LRI staff assess whether the acquired observing data meet the parameters required in the projects (especially the spatial and spectral resolution and sensitivity). To do this, they perform either a full manual data reduction or Weblog Reviewing for pipeline calibrated projects. To process the data, the LRI uses the HPC computer cluster OASA in Ondřejov.

Our team members of the node also participate in ALMA development – in collaboration with the central node of the European ALMA network at ESO, they developed the Imaging Script Generator code for automatic creation of a script template for imaging interferometric data using CASA software. This tool became a standard part of the software toolbox (CASA extension) used by the ARC staff. To extend the ALMA user base in the Czech Republic as well as in the neighboring countries, the node team organizes workshops, seminars and conferences. E.g., in April 2017, a "Joint Pre-Cycle 5 ALMA workshop" was organized together with the Toruń Astronomical Center at Nicolaus Copernicus University, Poland. We also coordinated the preparation of the Special Section 20 "Science with ALMA: Diskoveries, Priorities and User Support" at the large international conference EWASS 2017 held in Prague in June 2017. Within the EU ARC network, in 2018 the node co-organised with ESO the annual all-hands meeting which took place for the first time in the Czech Republic. In 2019, our node member participated as Technical secretary at the ALMA Proposal Review Committee meeting.

ALMA node

The Team members who are also members of the Czech ALMA node (i.e. the Large Research Infrastructure EU-ARC.CZ) cooperate with other nodes of the European ALMA Regional Center (ARC), including the main node in ESO. For example, they participated in the development of the Imaging Script Generator, a code that automatically creates a script template for imaging interferometric ALMA data using CASA software. It became a standard part of the software toolbox (CASA extension) used by the ARC staff. The node members also cooperate with the German center Bonn–Cologne in the field of millimeter Very Large Baseline Interferometry or with the French IRAM center in the field of scientific data processing. Prof. A. Eckart (Univ. Cologne and Max-Planck-Institut fuer Radioastronomy, Bonn) and dr. E. Hatziminaoglou (ESO) and dr. M. Zwaan (ESO) are members of the international Advisory Board of the Czech ALMA node project.

Arecibo observatory, 300m single dish radiotelescope

Team members working on the origin of dark neutral gas structures use Arecibo

data from the projects AGES and WAVES. AGES was a 2700 hour project mapping 200 square degrees of sky covering different galaxy environments. WAVES is an ongoing project to map an additional 50 square degrees in the Virgo cluster. Team members have access to unpublished data from both surveys and collaborate with the Observatory staff on data reduction and analysis.

ESA Swarm DISC consortium

Multi-approach gravity field models from Swarm GPS data: a consortium of five international academic organizations led by TU Delft producing the official monthly gravity fields for the Swarm mission. The European Space Agency (ESA), through the Swarm Data, Innovation and Science Cluster (DISC), supports teams from ASU, University of Bern, TU Delft, TU Graz, and the Ohio State University to provide monthly gravity field models representing Earth's gravity field variations. The monthly models are distributed on a quarterly basis at ESA's Earth Swarm Data Access and at the International Centre for Global Earth Models (ICGEM). The consortium started its work in 2017, currently it is foreseen to support the work of the consortium in supplying the Swarm gravity fields until 2021 (http://jgte.github.io/gswarm).

ALMA antennas observing the Milky Way's center. (© P. Horálek/ESO)

SILCC (SImulating Life Cycle of Clouds) collaboration

This is an international collaboration to advance numerical simulations so that they can capture the full matter cycle in the interstellar medium of galaxies. The core SILCC team is led by S Walch (Cologne University) and consists of 7 people from Cologne University, Heidelberg University, Max Planck Institute for Astrophysics in Garching, Leibnitz institute for Astrophysics in Potsdam and ASU. R. Wünsch (from our Team) is a member of the core SILCC team and is responsible for the development of the self-gravity and radiation transport modules. These are key parts of the simulation code, together with the chemical network and supernova explosions developed by other Team members. SILCC simulations have been run on the largest supercomputers in Europe, e.g. more than 100 mil. core hours have been awarded to the project on the SuperMUC supercomputer in Garching. This collaboration resulted in several highly cited papers, e.g. Walch el al. (2015, MNRAS 454, 238), Girichidis et al. (2016, MNRAS 456, 3432) and Wünsch et al. (2018, MNRAS 475, 3393).

Instituto Nacional de Astrofísica, Óptica y Electrónica (INAOE), Puebla, Mexico

We have a fruitful long lasting collaboration with the researchers of the INAOE. Prof. G. Tenorio-Tagle and dr. S. Silich has visited ASU several times and we participated in Guillermo Haro workshops in Mexico. S. Martínez González worked as a postdoc at ASU for almost 3 years. The collaboration still continues, we work on common projects focussing on formation and evolution of star clusters and star formation in galaxies.

National Institute of Geophysics, Geodesy and Geography of Bulgarian Academy of Sciences

A common project of this institute and ASU: "Periodical and impulse variations of geodetic series" – 2014–2016; Ron, Vondrák, Chapanov (BAS) – resulted in 3 papers in Acta Geodynamica et Geomaterialia in the period of 2015–2017.

Tel Aviv University

Cooperation between ASU and Tel Aviv University (Prof. L. Eppelbaum) about tectonophysics from satellite data (GOCE); mutual visits and publications. (2015–2016).

STRONG GRAVITY – European FP7 collaborative project

During 2013–2017 our Team coordinated (Dr. Michal Dovčiak) the international research project STRONG GRAVITY funded by the EU in the 7th Framework Programme for Space research that was the only one in this field coordinated by an institution from the Czech Republic. It was a collaborative project of 30 scientists from 7 prominent European institutions: ASU, the Czech Republic; University Roma Tre, Italy; CNRS, France; University of Cambridge, the UK; CSIC, Spain; University of Cologne, Germany; Nicolaus Copernicus Astronomical Center, Poland. This project was oriented towards the legacy of the cornerstone XMM-Newton X-ray satellite mission of the European Space Agency (ESA) in synergy with relevant data in other spectral domains that were covered by ground-based infrared and radio interferometric techniques at the European Southern Observatory (ESO) and elsewhere. We analysed and interpreted multi-wavelength spectral and fast timing information on accreting black holes in compact binaries, in cores of active galactic nuclei, as well as other galaxies exhibiting a low level of activity due to an intermittent supply of gas from the cosmic environment or by switching to a radiatively inefficient regime.

University of Crete

We have been collaborating with the University of Crete (prof. Iossif Papadakis) since 2011. The main common research topic is AGN variability where our Team (Bursa, Caballero-Garcia, Dovčiak, Karas, Pecháček, Svoboda, Zhang) contributes with theoretical and numerical modelling of variability of black-hole accretion disks (hot spot modelling, X-ray and thermal reverberation modelling) while the team at the University of Crete contributes with observational data reduction, statistical analysis and fitting the data with our numerical models. This collaboration has been supported several times by bilateral Czech and Greek governmental mobility agreements.

University Roma Tre

Our Team and the team of prof. Giorgio Matt at University Roma Tre have been collaborating fruitfully on the topic of spectroscopy and polarimetry of AGNs for more than two decades. Our Team contributes mainly with theoretical and numerical modelling of black hole systems while our partners contribute mainly by data reduction and analysis as well as by theoretical modelling. Our collaboration has also led us to common work on a larger international scale in many X-ray mission proposals (two of them accepted for funding, the ESA L2 mission, Athena, and NASA SMEX mission, IXPE). The collaboration includes mutual visits of young researchers of both teams in partner institutions.

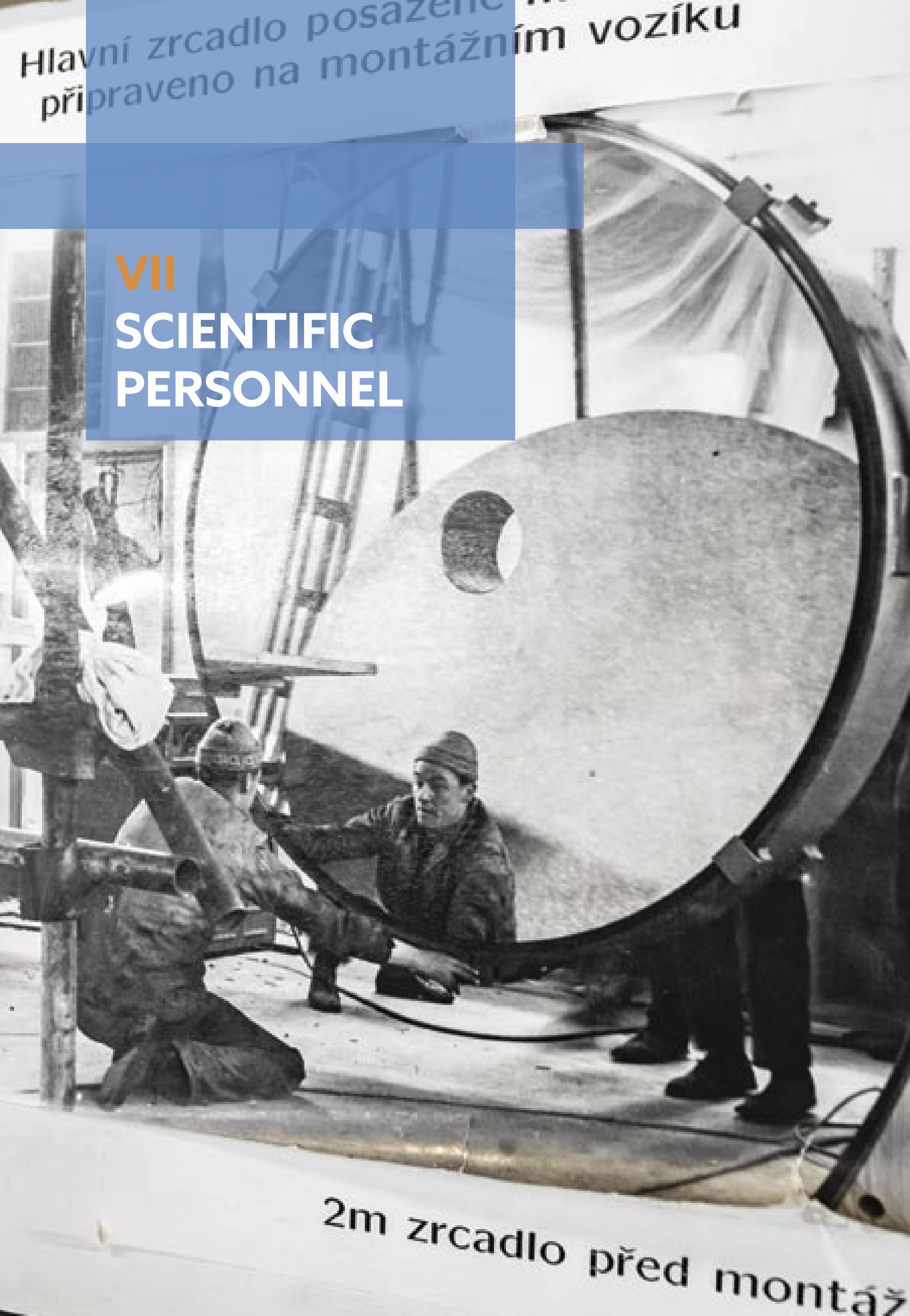
Shanghai Astronomical Observatory

The cooperation between ASU and Shanghai Astronomical Observatory (prof. W. Yu) concerns the research of timing in X-ray binaries and AGNs (e.g. tidal disruption events – TDE) and the collaboration on scientific preparations of the Chinese eXTP space mission with a large European contribution. Our Team provides mainly numerical modelling while our partner contributes with data analysis. Our collaboration is also supported by the Ministry of Education, Youth and Sports through a project of "Czech–Chinese collaboration on the new X-ray mission eXTP: Spectral modelling and data analysis".

N. Copernicus Astronomical Centre and Center for Theroretical Physics of the Polish Academy of Science (CAMK/CFT – PAN)

The collaboration between ASU and CAMK-PAN (prof. Agata Różańska, prof. Marek Abramowicz), and CFT-PAN (prof. Bożena Czerny, dr. Agnieszka Janiuk) has already been continuing for more than a decade and it has been supported by several bilateral projects co-funded by both Academies. We study the inner accretion flow in X-ray binaries and AGN. In XRBs we study the yet unexplained phenomenon of QPOs (Quasi-periodic oscillations). In this collaboration we provide especially our experience in General Relativistic simulations while our partner contributes with their experience in radiative transfer.

VII
SCIENTIFIC PERSONNEL



The Institute organisation scheme, science departments and working groups (last updated on 31st December 2019)

Management of the Institute

Director	prof. RNDr. Vladimír Karas, DrSc.
Deputy director – Science secretary	RNDr. Jiří Borovička, CSc.
Deputy director – International relations	RNDr. Michal Dovčiak, Ph.D.

Secretariat

Assistant to the Director	Ms. Daniela Pivová
Public outreach	Mr. Pavel Suchan
International projects	Ing. Iva Tužinská
Information technology	Ing. Petr Ryšavý

Science Departments

Solar Physics	Mgr. Miroslav Bárta, Ph.D.
Stellar Physics	Mgr. Brankica Kubátová, Ph.D.
Interplanetary Matter	RNDr. Pavel Spurný, CSc.
Galaxies and Planetary Systems	Mgr. Richard Wünsch, Ph.D.

Technical and Economy Administration

Ms. Libuše Kronusová

Support Committees

Space Programmes Management	RNDr. Jiří Svoboda, Ph.D.
Library	Mgr. Radka Svašková
Mechanical Workshop	Mr. Jiří Zeman
Detached premises in Prague	Mgr. Michal Bursa, Ph.D.
Applications and Knowledge Transfer	Mgr. Stanislav Gunár, Ph.D.

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Left: A photo from the Institute's historical archives – setting the 2m mirror of the Perek telescope in the Ondřejov Observatory more than five decades ago.

Scientific personnel

Solar Physics Department

Head of the Department:
Mgr. Miroslav Bárta, Ph.D.

Working group of physics of solar flares and prominences

Leader of the working group:
doc. RNDr. Elena Dzifčáková, DSc.

Dudík Jaroslav, doc. RNDr., Ph.D.
Fárník František, RNDr., CSc.
Gunár Stanislav, RNDr., Ph.D.
Heinzel Petr, prof. RNDr., DrSc.
Kašparová Jana, Mgr., Ph.D.
Kotrč Pavel, RNDr., CSc.
Mészárosová Hana, Ing., Ph.D.
Nickeler Dieter, Ph.D.
Varady Michal, doc. RNDr., Ph.D.
Zapiór Maciej, Ph.D.
Zemanová Alena, Ph.D.

Working group of structure and dynamics of solar atmosphere

Leader of the working group:
Mgr. Jan Jurčák, Ph.D.

Ambrož Pavel, RNDr., CSc.
Švanda Michal, doc., Ph.D.
Štěpán Jiří, Ph.D.

Working group of heliosphere research

Leader of the working group:
RNDr. Marek Vandas, DrSc.

Hellinger Petr, Dr.
Laifr Jaroslav, Ing., Dr.
Šimberová Stanislava, Ing., CSc.
Štverák Štěpán, Ing., Dr.

Working group of solar radioastronomy

Leader of the working group:
Mgr. Miroslav Bárta, Ph.D.

Jiřička Karel, Ing., CSc.
Karlický Marian, prof. RNDr., DrSc.
Koval Artem, Ing., Ph.D.
Liu Wenjuan, Ph.D.
Motorina Galina, Ph.D.
Skála Jan, Ph.D.

Stellar Physics Department

Head of the Department:
Mgr. Brankica Kubátová, Ph.D.

Working group of physics of hot stars

Leader of the working group:
Michaela Kraus, Ph.D.

Koubský Pavel, RNDr., CSc.
Kubát Jiří, doc. RNDr., CSc.
Kubátová Brankica, Ph.D.
Liimets Tiina, Ph.D.
Mareva Olga, Ph.D.
Németh Péter, Ph.D.
Škoda Petr, RNDr., CSc.
Pavlík Václav, RNDr., Ph.D.

Working group of high energy physics

Leader of the working group:
Mgr., Martin Jelínek, Ph.D.

René Hudec, doc. RNDr. CSc.
Šimon Vojtěch, RNDr., Ph.D.

Working group of exoplanet research

Leader of the working group:
Dipl. phys. Petr Kabáth, Dr. rer. nat.

Klocová Tereza, Ph.D.
Skarka Marek, Ph.D.

Working group of operation and development of 2m telescope

Leader of the working group:
RNDr. Miroslav Šlechta, Ph.D.

Members of the group are the telescope technicians and observers

Department of Interplanetary Matter

Head of the Department:
RNDr. Pavel Spurný, CSc.

Working group of meteor physics

Leader of the working group:
RNDr. Jiří Borovička, CSc.

Čapek David, RNDr., Ph.D.
Koten Pavel, Ph.D.
Shrbený Lukáš, Ph.D.
Spurný Pavel, RNDr., CSc.
Štork Rostislav, RNDr., Ph.D.
Vojáček Vlastimil, Ph.D.

Working group of asteroid research

Leader of the working group:
Mgr. Petr Pravec, Ph.D.

Fatka Petr, Ph.D.
Kučáková Hana, Ph.D.
Scheirich Petr, Ph.D.

Department of galaxies and planetary systems

Head of the Department:
Mgr. Richard Wünsch, Ph.D.

Working group of physics of galaxies

Leader of the working group:
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Barna Barnabás, Ph.D.
Deshev Boris, Ph.D.
Ehlerová Soňa, RNDr., Ph.D.
Franeck Annika, Ph.D.
Jáchym Pavel, Ph.D.
Jungwiert Bruno, RNDr., Ph.D.
Kourniotis Michalis, Ph.D.
Orlitová Ivana, Mgr. Ph.D.
Taylor Rhys, Ph.D.
Wünsch Richard, Mgr., Ph.D.

Working group of relativistic astrophysics

Leader of the working group:
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Boorman Peter, Ph.D.
Borkar Abhijeet Pramod, Ph.D.
Bursa Michal, Mgr., Ph.D.
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A coelostat powering the FICUS solar broadband slit-free spectrograph. This instrument was developed to study the relationship between solar and stellar eruptions. Currently, it is located in Dr. Boris Valníček's laboratory.

Front cover: The comet Neowise attracted a lot of attention when it appeared above the solar radiotelescopes of the Ondřejov Observatory in summer 2020 (© Vlastimil Vojáček).

*Front inside cover: Prof. František Nušl (*1867 †1951) on a historical photograph at the astronomical observatory in Ondřejov, where he was the first director (1918–1937). He was also one of the founders of the Czech Astronomical Society (and its president in 1922–1948) and also a Vice-President of the International Astronomical Union (1928–1935).*

Back inside cover: The domes of the Mayer 65cm Telescope and the Perek 2m Telescope at the site of Ondřejov Observatory.

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