ESO - ALMA

Ondřejov ARC node

Proposed by

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1. Introduction

According to the European ARC status, the primary goal of the network of cooperating ARC nodes is to provide professional service and face-to-face support to the community of ALMA users. To accomplish this objective the task is distributed (under coordination of the core ARC at ESO) among the nodes according to three main principles: 1. match between user's requirements and the node expertise, 2. user's geographical locality, and 3. capacity of the nodes. We propose to create a new ARC node in Ondřejov with the aim to extend the European ARC network functionality in all the mentioned aspects:

We will provide a unique scientific and technical support in the fields of solar radio physics, galactic/extragalactic and relativistic astrophysics, and laboratory measurements of molecular spectral lines. These research areas, all belonging to the main ALMA scientific objectives, are not yet covered, or are covered only partially, with other existing EU ARC nodes. In the field of laboratory molecular spectroscopy, we plan to collaborate with Cologne/CDMS catalogue.

Regarding the lack of any ARC node eastwards from the axis Onsala-Bologna, the Ondřejov node will provide regional support not only to Czech ALMA users but to applicants from other countries of the Central and Eastern European region, e.g. Poland, Slovakia, Hungary etc., that are not ESO members yet.

The proposed Ondřejov ARC node will offer all necessary infrastructure and will create several dedicated scientific and technical working positions. It will thus increase the total capacity of the network of European ARC nodes.

The proposed node is to be formed as a consortium of several collaborating institutions, including mainly the Astronomical Institute of the Academy of Sciences of the Czech Republic (AI ASCR) in Ondřejov and the Institute of Chemical Technology (ICT) in Prague. Further we plan to cooperate closely with the Charles University in Prague, the Masaryk University in Brno and others. The node will be located in Ondřejov, Czech Republic.

2. Our expertise

The Astronomical Institute, Academy of Sciences of the Czech Republic and all scientific or academic institutions involved in the proposed ARC node in Ondřejov have long experience in ALMA-related research fields which guarantees the functionality of the node.

We can provide a unique expert support particularly in the following areas:

1. **Solar radio spectroscopy & MHD and radiative-transfer numerical simulations**
2. **Dense regions in galaxies**
3. **Software development and parallel data processing**
4. **Laboratory microwave molecular spectroscopy**

Our competence in the above mentioned fields is shared among the cooperating institutions as follows:

Astronomical Institute of the Academy of Sciences of the Czech Republic (AI ASCR), Ondřejov is the largest professional institution in the field of astronomy and astrophysics in the Czech Republic providing unique - on the national level - facilities for observational and theoretical work. It consists of four scientific departments covering the areas of solar/stellar physics, interplanetary matter and galaxies and planetary systems. The institute has been involved in organization of several conferences and workshops; in 2006 it supported and co-organized the 26th General Assembly of the IAU in Prague. The institute has expertise relevant to the proposed project - services for the ALMA user community, including training/development – and can cover the areas 1, 2 and 3.

Institute of Chemical Technology, Prague (ICT) is the largest university in the Czech Republic oriented to all fields of chemistry with a huge laboratory and technology background. Laboratory of the high resolution molecular spectroscopy, which is a joint venture with the J. Heyrovský Institute of Physical Chemistry of the Academy of Sciences of the Czech Republic, provides outstanding experimental facilities for the microwave spectroscopy as well as deep theoretical experiences in molecular quantum mechanics. The expertise relevant to the proposed project is the area 4.

Expert areas:

Solar radio spectroscopy & MHD and radiative transfer numerical simulations

Solar radio spectroscopy has a long tradition in our institute. It is regularly carried out at the AI ASCR in Ondřejov since 1967 (the second location in Europe, after Tübingen/Weissenau, 1966). Currently we are operating two radio spectrographs in the dm/cm wavelength range covering the total frequency band 0.8 – 4.5 GHz. We provide the radio data to the whole solar community (see http://www.asu.cas.cz/~radio). The core of our work is in the solar radio spectra interpretation and modelling. We have developed several numerical models of particle acceleration in solar flares connected with their micro-wave and X-ray emissions. We would like to point out, that the physics of particle acceleration in the solar flares is one of the proposed scientific ALMA goals (section 4.1.1 in the S*cience with ALMA* document), not yet covered by any of existing ARC nodes.

Non-LTE radiative transfer. The RT group at AI ASCR have developed the non-LTE codes for radiative transfer in both solar and stellar atmospheres and winds. The non-LTE approach will be in particular important for correct interpretation of ALMA observations of the solar atmospheric structures and processes.

Physics of solar prominences & filaments. Another ALMA scientific goal (*Science with ALMA*, sect. 4.1.2). We have developed MHD and RT models of solar prominences/filaments. They have to be tested in the wavelength range of ALMA.

Plasma astrophysics. We have a long-lasting experience in plasma astrophysics. We have developed several 2D and 3D MHD and kinetic (PIC) codes for simulation of various processes in the astrophysical plasma. We found efficient acceleration processes connected with the magnetic field reconnection and dynamic magnetic traps. We recognized and simulated the radio emission of the flare-ejected plasmoids. We have experience with non-thermal radio generation mechanisms, in particular the plasma emission.

Dense regions in galaxies

Galaxy evolution in clusters and groups. The working group of physics of galaxies at the AI ASCR has an extensive experience with numerical simulations of galaxies evolving in groups and clusters. Restricted N-body codes in combination with genetic algorithms, and tree/SPH codes are used in simulations of

galaxies in groups orbiting through the hot and diluted medium in clusters. Using the IRAM 30m telescope at Pico Veleta, Spain, we observe the effects of the galaxy environment. We search for CO emission in the high density bow-shock regions in the front sides, as well as in the tails of galaxies in the Virgo cluster or in other galaxy clusters.

Triggered star formation. We have studied HI distribution in the Milky Way using the Leiden-Dwingeloo survey. More than 500 expanding shells have been discovered. Complementary observations with the Effelsberg radio telescope show more detailed substructures. The observations of the triggered star formation in expanding shells are compared to simulations with SPH and AMR codes. The external triggers like the transition of a spiral density wave or galaxy versus galaxy collision are also considered.

Protoplanetary disks. With AMR-type codes, we perform radiation hydrodynamics models of layered protoplanetary disks. The dead-zone breaks to rings promoting the accumulation of solid particles leading to planet formation.

Galactic center and AGN's. The working group in relativistic astrophysics of AI ASCR have contributed to the discussion of mechanisms that resolves the issue of Sgr A* flares origin as well as the role of stellar winds in their formation. By means of HST, high-sensitivity VLT and NTT spectroscopy as well as CFHT/OASIS, CAHA/PMAS and VLT/VIMOS spectrographs, we study kinematics, sizes and physical properties of narrow-line regions (NLR) in active galaxies.

Software development - parallel data processing

We have developed the software for processing and analysis of the data observed by our present radiospectrographs. We have experience with programming of graphical user interfaces (GUIs) in C++ (using Qt library) and IDL (IDLWidgets). We perform parallel (MPI-based) algorithms running on distributed computer architectures (clusters) implemented in C/C++ and Fortran applicable to various astrophysical problems. Code X-SPEC able to analyze the SED and spectral lines in the X-ray domain has been devised. (Magneto)hydrodynamical codes based on finite-difference and SPH schemes, tree codes, genetic algorithms and other numerical tools are used to our scientific work. Several public codes like ZEUS or GADGET have been used and adapted for our purposes.

Laboratory microwave molecular spectroscopy

Laboratory of the high resolution microwave spectroscopy of small molecules focused to hyperfine effects. The high resolution molecular spectroscopy has a long tradition in the Czech Republic. The Prague high resolution molecular spectroscopy group is an organizer of a prestigious biennial conference since 1970 which is now the leading conference in Europe in the field (http://www.chem.uni-wuppertal.de/conference). Today a centerpiece of Prague laboratory is a high resolution microwave system covering the spectral region from 10 to 750 GHz continuously. It is expected that the ALMA spectra will include many unidentified line belonging also to stable molecules.

Spectroscopy of unstable transient molecular species. There is many molecular species whose molecular microwave spectra were not measured so far such as molecular fragments, radicals and ions or other transient molecules. The Prague laboratory has experiences in studies of unknown radicals, to obtain the microwave spectra and molecular constants for the first time. Transition lines of unknown molecular species can constitute a major part from the unidentified lines in the ALMA spectra of interstellar molecular clouds.

Theoretical detailed analyses of molecular energies. Besides the standard molecular parameters theoretical analyses of the high resolution spectra allow one also to derive precise values of energy levels. These detailed analyses often require difficult measurements of forbidden transitions and other expertise in the theory of the molecular quantum mechanics. The knowledge of energies makes possible a derivation of precise molecular partition functions, temperature dependences of transition intensities and other quantities useful for studies of physical properties of interstellar molecular clouds.

Transition (dipole) moment measurements. The molecular transition moments for rotational transitions is a crucial quantity for an analytical evaluation of the line intensities measured in the interstellar medium. The Prague laboratory has built up a special set-up to measure molecular Stark effect. These data can be evaluated to determine very precise values of the dipole moment.

Besides the individual contributions of the single institutions which are to participate in the Ondřejov ARC node we expect also synergy effects upgrading the long-lasting bilateral cooperation between our institutions. We are also open to collaborate with other institutions.

3. Planned activities

3.1 Science

With respect to our expertise and in accordance with the declared ALMA scientific objectives we plan to carry out ALMA-based scientific projects mainly in the areas adduced below. In all of these fields we offer scientific support to the whole ALMA user community.

3.1.1 Structure of the solar chromosphere and transition region

Under the quiet solar conditions ALMA primarily will observe the chromosphere and transition region. With its high spatial resolution up to 0.1" it will provide new insights into the fine structure of these layers and enable studies of physical processes that are not only relevant for the Sun, but also for other areas of space physics.

3.1.2 Solar super-granular convection – joint studies with GREGOR

GREGOR is the new 1.5m solar telescope assembled on Tenerife, Spain, by the German consortium of the Kiepenheuer Institute for Solar Physics, the Astrophysical Institute Potsdam (AIP), the Universitäts-Sternwarte Göttingen and other national and international partners (including AI ASCR Ondřejov). Both ALMA and GREGOR are capable of observing the solar chromosphere with high angular resolution. Simultaneous observations of the Sun in optical and mm/sub-mm wavelengths with ALMA and GREGOR allow to study super-granular cells at chromospheric levels, and to investigate their coupling to the transition region and hot corona.

3.1.3 Structure and formation of solar prominences/filaments

There are only a limited number of studies of solar prominences and filaments in the radio domain. In particular, the central cooler parts of prominences are opaque in the mm wavelengths and thus the ALMA observations could provide a unique diagnostics of the temperature structure of prominences/filaments. The theoretical studies will be performed in order to predict the brightness temperatures observable by ALMA. Simultaneous observations (campaigns) with optical and space UV instruments will be proposed.

3.1.4 Non-thermal radio emission of solar flares

Non-thermal radio radiation in the frequency range 70 - 900 GHz emitted in solar flares is generated by highly energetic electrons. The millimetre and sub-mm radiation arises from gyro-synchrotron and/or inverse Compton emission – hence, the radio emission with a frequency of 250 GHz to be generated by the gyro-synchrotron mechanism requires electron energy of 10 MeV in active regions with a typical magnetic field of 500 G, for instance. Thus, this radiation is of great interest in order to study highly energetic processes during solar flares. In a solar flare, both electrons and ions are accelerated up to energies of 100 MeV within time scales of a few seconds. It is still an open question in which way such highly energetic particles are produced within such a short time. We plan to simulate magnetic reconnection in highly-filamented, extremely thin current sheets using combined MHD-kinetic model whose results would be possible to relate to the ALMA observations. The understanding of such processes is important for the whole field of high energy astrophysics. We propose joint observations with Brazilian Decimetric Array (INPE, Brazil).

3.1.5 Environmentally induced star formation in cluster galaxies

The molecular phase represents the component of the interstellar medium (ISM) that participates in the process of star formation. With ALMA, we shall observe the molecular content of galaxies experiencing effects of the cluster environment. Both global molecular imaging and detailed high-resolution studies of bright galaxies could bring interesting results on triggered formation of super star clusters. These observations should focus on the star formation (SF) history of cluster galaxies that are influenced by the effects of the cluster environment, especially SF induced by the ram pressure compression of the ISM forming a bow-shock at the windward side of the disk and in the inner disk region, SF induced by the material that is re-accreted to the disk after the stripping event, and SF in molecular clouds forming in the tails of the stripped neutral ISM.

3.1.6 Triggered star formation in the local and distant Universe

The expanding cold HI shells in the Milky Way and nearby galaxies are places where the stellar feedback leads to triggered star formation. The "collect and collapse" scenario creates cold high-density regions, where the star formation process will be observed with ALMA. There, in cold high density regions new molecules will be detected. The high angular-resolution observations with ALMA of star and planetary disk formation will be confronted with our numerical models. The star-forming regions in high-z galaxies will be examined with the view of deriving a high-z initial mass function. We will test the stellar masses as a function of their environments and chemical compositions of the ISM.

3.1.7 SGR A* and central star clusters in galaxies

We intend to contribute to the discussion of mechanisms of Sgr A* flares origin as well as the role of stellar winds in their formation. Our analyses take these special and general relativistic effects into account by using the concept of a transfer functions. So far we have been employing NIR/X-ray data for which future ALMA observations will provide essential addition in its spectral bands. High-z star forming galaxies will be observed in order to resolve the central stellar cluster and to discover the growth-rates of the central black holes.

3.1.8 A search for new molecular species from various interstellar areas in the ALMA microwave spectra observations. Precise laboratory measurements of stable or unstable molecular species give predictions of spectral frequencies. This will be supplemented by calculation methods which will be used also for tests of the molecular stability. This research will be organized in collaboration with the Universities in Wuppertal and Cologne. High-resolution microwave spectroscopy and high level quantum mechanical interpretations are keys to unambiguously interpret microwave spectra from various astronomical sources as cold dark clouds and the diffuse interstellar medium. The search for more and more complex species in space is one of the crucial science drivers for ALMA. Mm and sub-mm astronomy will provide detailed tools for answers to the key questions in astrochemistry: What is the life-cycle of matter in inter- and circumstellar environments and how does this affects the formation and death of stars? With the increasing spectral and spatial resolution of ALMA the chemistry of hot cores and circumstellar discs can be unraveled, where complex species such as ethers, sugars, acids and alcohols are formed and destroyed. Isotopic fractionation can be used to understand the coldest places in the universe.

3.2 Development

With respect to our skills and the needs of the ALMA community we are capable to contribute to the developmental tasks in the following areas:

3.2.1 Molecular spectral lines databases

High quality spectra measured in the Prague laboratory will be analyzed to obtain quantities which are needed for the interpretation of ALMA observations. As a result, line lists, intensities, Einstein coefficients and partition functions of astrophysically relevant molecules studied in the Prague laboratory will be prepared for international databases of the spectroscopic data (e.g. CDMS – Cologne database for molecular spectroscopy, HITRAN – database of the Harvard Smithsonian Institute etc.).

3.2.2 User software testing and development

We would like to contribute to the development of the user software, in particular the SW for manipulation with the solar data. Starting with gaining expertise in the CASA software package (the workshop of the German ARC node in Bonn) we are ready to test the CASA SW later, and eventually we also plan to add new functions/modules to the CASA SW package. Because of our experience with the implementation of parallel/MPI codes in C/C++ we would like to focus our activities onto the parallel data processing. Having deep experience with the (non-LTE) radiative transfer codes we are capable to contribute also by SW modules for transformation of brightness temperature to real physical quantities in the radio (in particular solar) sources.

3.3 User support

We are ready to provide support to the community of ALMA users in all areas of our expertise. In particular:

- Scientific support in the field of solar and galactic radio/millimeter observations
- Preparation and submission of proposals to ALMA
- Data storage and processing (reduction)
- Interpretation of observations
- Numerical modelling of the observed processes
- Interstellar molecular line identification
- Data analysis using the CASA package. We are interested in getting deep expertise in the CASA software subsequently up to the level of developers
- Training of new users in the CASA software usage
- Organization of workshops to introduce the ALMA project to the central European astronomical community
- Promoting the ALMA possibilities among astronomy communities of Central and Eastern Europe, including the public outreach.

Besides the face-to-face contact support on-place we plan to create an on-line help desk (www interface) covering issues of areas of our particular expertise.

4. ARC node location, funding, and communications with other nodes

The proposed Ondřejov ARC node will be located in Ondřejov, Czech Republic, the seat of the Astronomical Institute of the Academy of Sciences of the Czech Republic. The address is Fričova 298, 251 65 Ondřejov, Czech Republic.

All necessary funding of the node will be provided directly by the Astronomical Institute, however additional resources like grants, EC funding etc. will be searched as well.

We plan to be in a permanent contact with the European ARC located at ESO Headquarters in Garching near München. We are ready to consider all their instructions and recommendations. If necessary, we will set up channels for direct communication with other ARC nodes.

5. Capacities and resources

To accomplish the tasks related to the functionality of an ARC node, we possess, or plan to acquire, the following resources:

5.1 Infrastructure

Astronomical Institute of ASCR, Ondřejov

The AI ASCR is provided with all the necessary infrastructure to host an ARC node. We will have sufficient hosting offices and accommodation capacities for the ALMA users to whom the face-to-face support should

be provided. Besides the standard UNIX/Linux workstations we are equipped with a computer cluster consisting of 24 nodes interconnected by the fast InfiniBand fabric. The cluster represents 80 64-bit AMD Opteron CPU cores @2.6GHz in total, with 160GB of distributed DDR2 RAM and 6.4TB HDD capacity (including 5.2TB in the parallel PVFS2 filesystem). The system is further supplemented with the special graphical node dedicated to data visualisation using IDL routines. The computer center of the department of Galaxies and Planetary Systems further provides large storage capacities and an interesting parallel computing power of 64-bit CPUs.
Moreover, we plan to substantially increase our capacities by constructing a new **E2S center – Center of excellence for ESO and ESA astronomy activities in the Czech Republic**, of which the Ondřejov ARC node will be an integral part. Concerning the node, new offices (at least two rooms), an advanced data center and computer laboratory (equipped with large data storages of 100 TB and both distributed and shared-memory powerful computer systems of 1000 – 1500 CPU cores), as well as ESO public outreach center and other facilities, are planned in the proposal of the E2S center. In the frame of this project we further plan to upgrade our internet connections. The E2S project is now being submitted to the EC-funded national operational programme "Research and Development for Innovations".

Institute of Chemical Technology, Prague
The laboratory of high resolution molecular spectroscopy of the ICT is equipped with a microwave high resolution spectrometer fully covering the spectral range from 10 to 750 GHz. The microwave system is integrated with a special Stark and radical cells that provide measurements of the molecular dipole moments and molecular radicals, respectively. A multireflection cell allowing measurements of very weak transitions is under construction. The laboratory is equipped with adequate computer facilities and has access to necessary quantum chemistry programs. New laboratory is in preparation within E2S center.

5.2 Human resources

Astronomical Institute, ASCR, Ondřejov. From the very beginning of the ARC node operation we plan to allocate three members of our research staff – M. Karlický (leading senior scientist) and M. Bárta together with P. Jáchym (junior researchers) – for the node functions. The technical support of the ARC node (computers, data storage, internet connection to other ARC nodes) will be provided by J. Polach who is an expert in it. With further development of the ARC node, new PhD students and post-docs will be hired, as well as other specialists. For the newly built E2S center we will allocate two additional positions dedicated to the ARC node.

ICT, Prague. Besides the laboratory staff members (Š. Urban – leading senior scientist and P. Kania – junior researcher) we want to employ L. Kolesniková (junior researcher specialized to the radical studies) and T. Uhlíková (junior researcher specialized to the quantum chemistry calculations) plus more 2-3 students.

6. Preparation of experts for the Ondřejov ARC node

In order to fully match the operational standards of the European ARC nodes before the completion of ALMA in 2012, we plan to send several young scientists to long-term stays at existing ARC nodes (in the frame of post-doc fellowship or visiting programs) and directly participate in the CSV program in Chile. We have already started with this intention: currently P. Jáchym, future junior scientist in the Ondřejov node, has applied for ESO ALMA fellowships to Chile and IRAM ARC node in Grenoble, and started to negotiate a possible cooperation with the IRAM ARC node. During these long-term stays, our delegates should become experts in the fields of millimeter interferometry, data reduction techniques, and face-to-face support, and after their return provide theoretical and technical user support at the professional level of the European ARC nodes.

Planned time schedule of long-term training stays:
2009 – P. Jáchym, galactic interferometry, he applied for post-doc positions in Chile and at IRAM ARC node He is already at IRAM ALMA node for 6 months stay training.
2010 – M. Krause, stellar interferometry.

2011 – M. Bárta, solar interferometry, he is already involved in the first tests using CASA.
2011 – L. Nová, high dispersion molecular spectroscopy.

We ask ARC representatives to support these applications.

Together with the long-term stays at abroad institutions we aim to acquire experience in workshops and schools connected to sub-mm/mm interferometry and data reduction (e.g. CASA Tutorial in Garching, May 2009). Further, we are in personal contact with experts in the field of interferometric solar observations and data reduction (K. Shibasaki, Nobeyama Solar Radioheliograph, Japan; T. Bastian, NRAO, USA; A. Altyntsev, Solar Radioheliograph, Irkutsk, Russia; H. Sawant, project of Brazilian Solar dm-Array; Y. Yan, project of Chinese Solar Radioheliograph) . In February 2009, M. Karlický visited Nobeyama for this purpose.

Finally, M. Bárta, M. Krause, and P. Jáchym are proposed to participate in the CASA testing and training project in Europe.

7. Conclusions

The proposed new Ondřejov ARC node (www.asu.cas.cz/alma) will extend the functionality of the European ARC network in several aspects: It will provide services to the whole ALMA community in expert areas which are declared as the ALMA scientific objectives but have not yet been sufficiently covered by existing European nodes (solar radio physics, dense regions and triggered star formation, laboratory microwave molecular spectroscopy).
It will serve as a regional center for countries of the Central and Eastern Europe (recent EU members and prospective ESO members), including the Czech Republic, which are not at this moment served by any existing EU ARC node.
Finally, it will increase the total capacity of the ARC network by adding a new expertise, infrastructure and manpower. Last but not least, the direct participation of the Czech Republic in the network of the European ALMA Regional Center nodes will open up new perspectives for Czech astronomical research in the field of sub-mm/mm observations.

In Ondřejov, March 2009

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