Stellar Spectroscopy with Virtual Observatory

Petr Škoda

Astronomical Institute of the Czech Academy of Sciences, Ondřejov

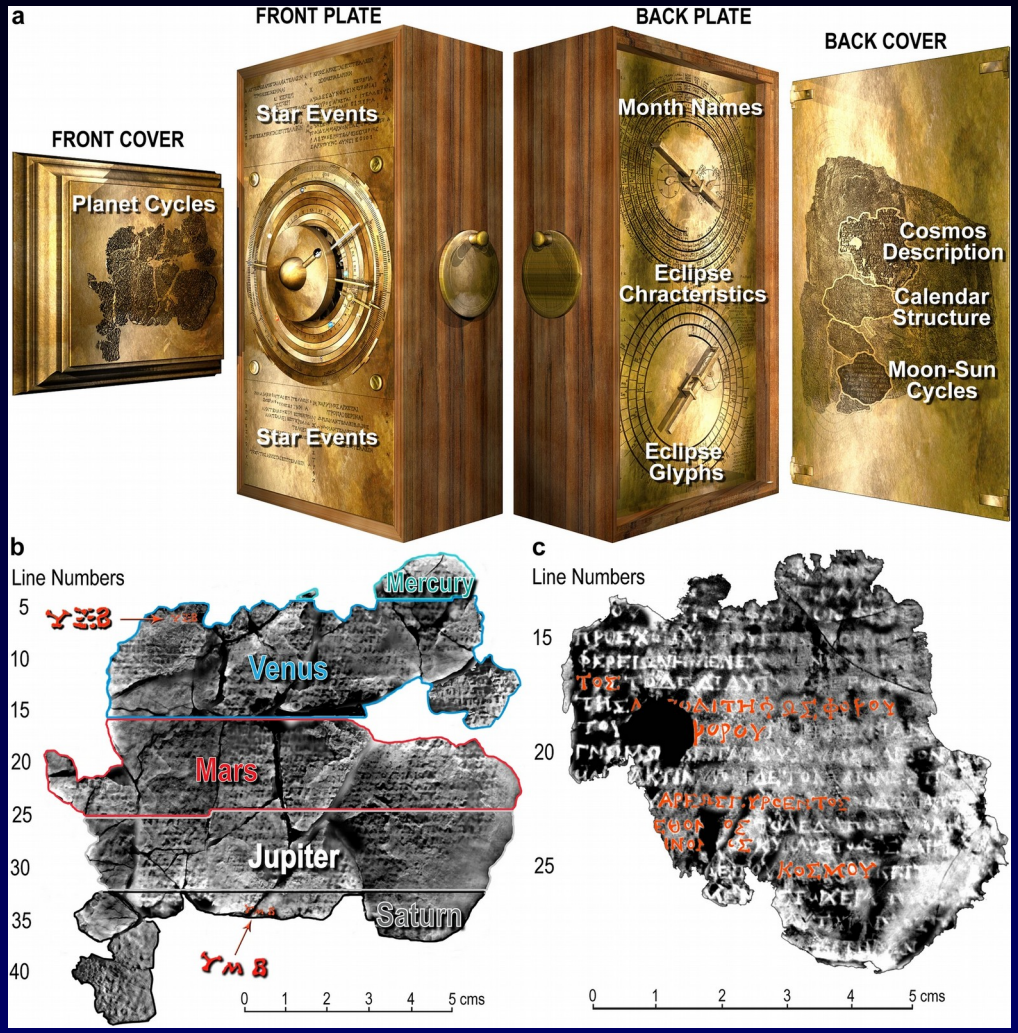
Faculty of Information Technology, Czech Technical University in Prague

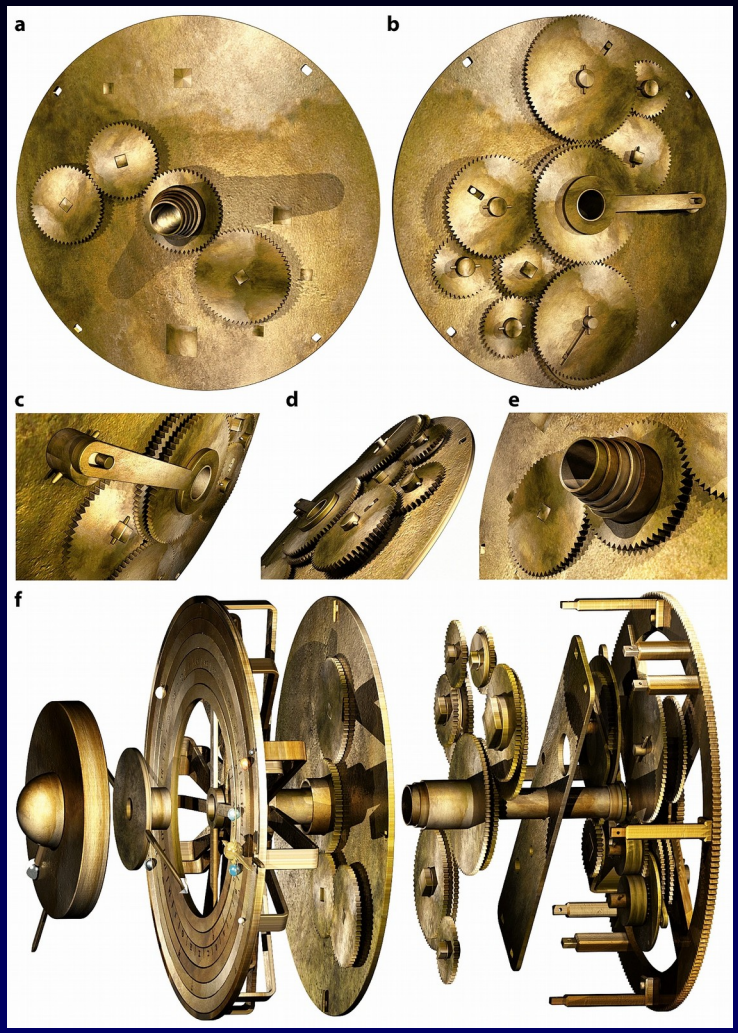
Lecture at workshop on observational techniques,
AI Ondrejov, 16st September 2021

Credits

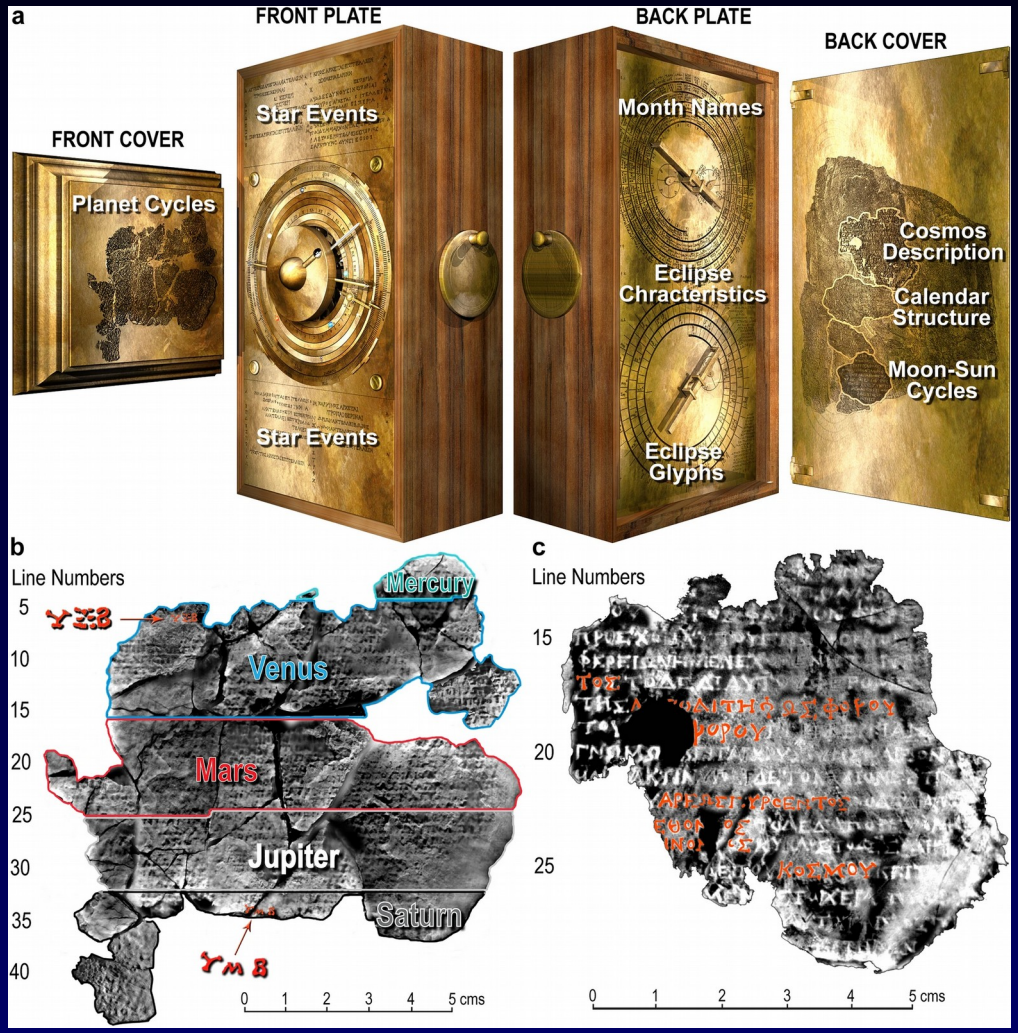
The presentation is based on many different sources – mainly the on-line published slides from IVOA meetings, slides from Astroinformatics and COST meetings or pictures found on Internet.

Astronomy - the leader of technology



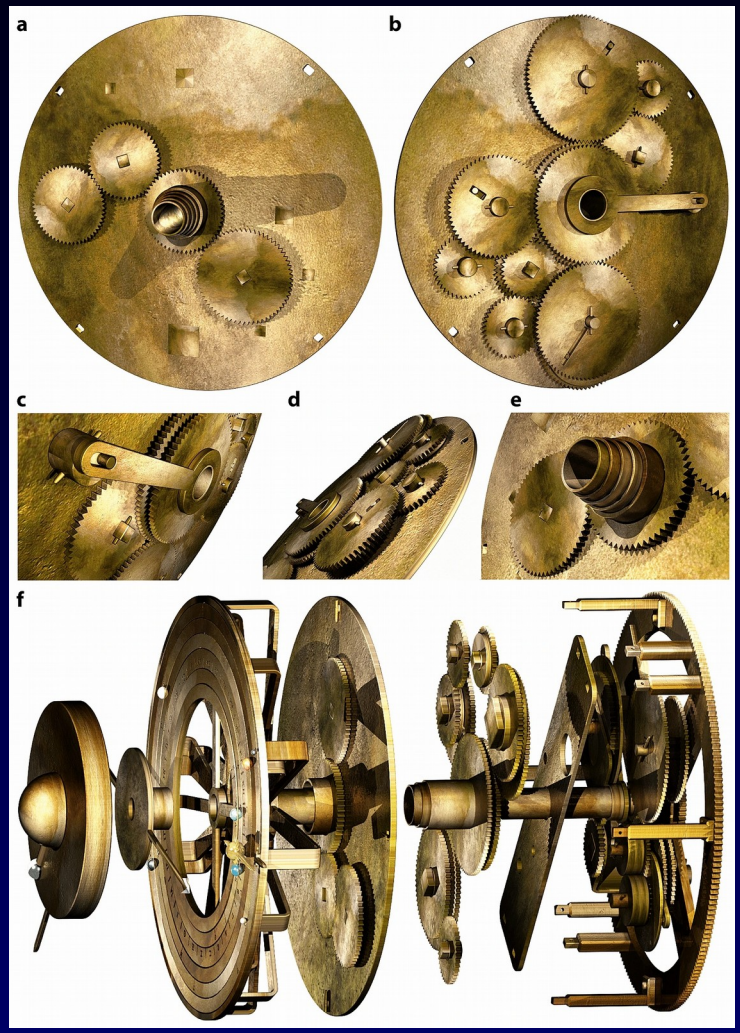


Astronomy - the leader of technology



Antikythera mechanism 150-100 BC

.



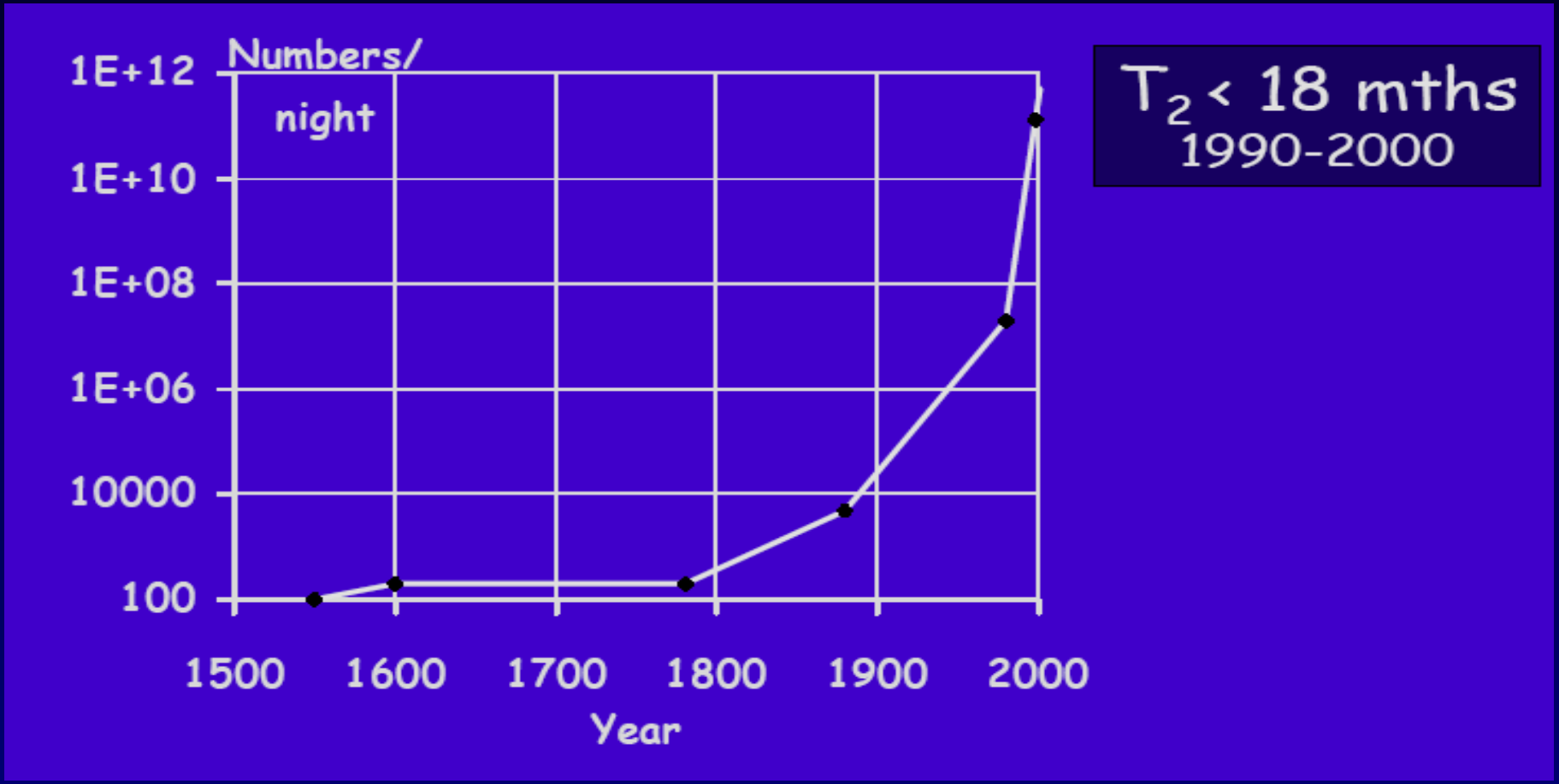
Freth et al. Nature Sci. Rep. 11, 5821 (2021)

Data Avalanche

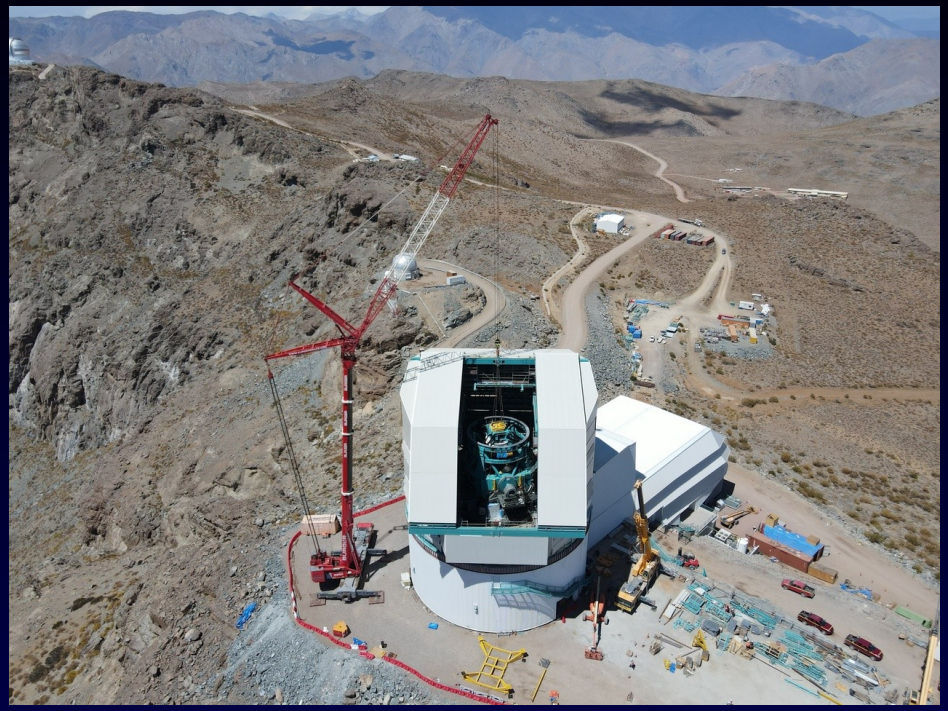
Moore law for chips –doubling 1.5 year

Data in astronomy – doubling < 1 yr ! (9 month current)

100 PB today, 100 TB/night

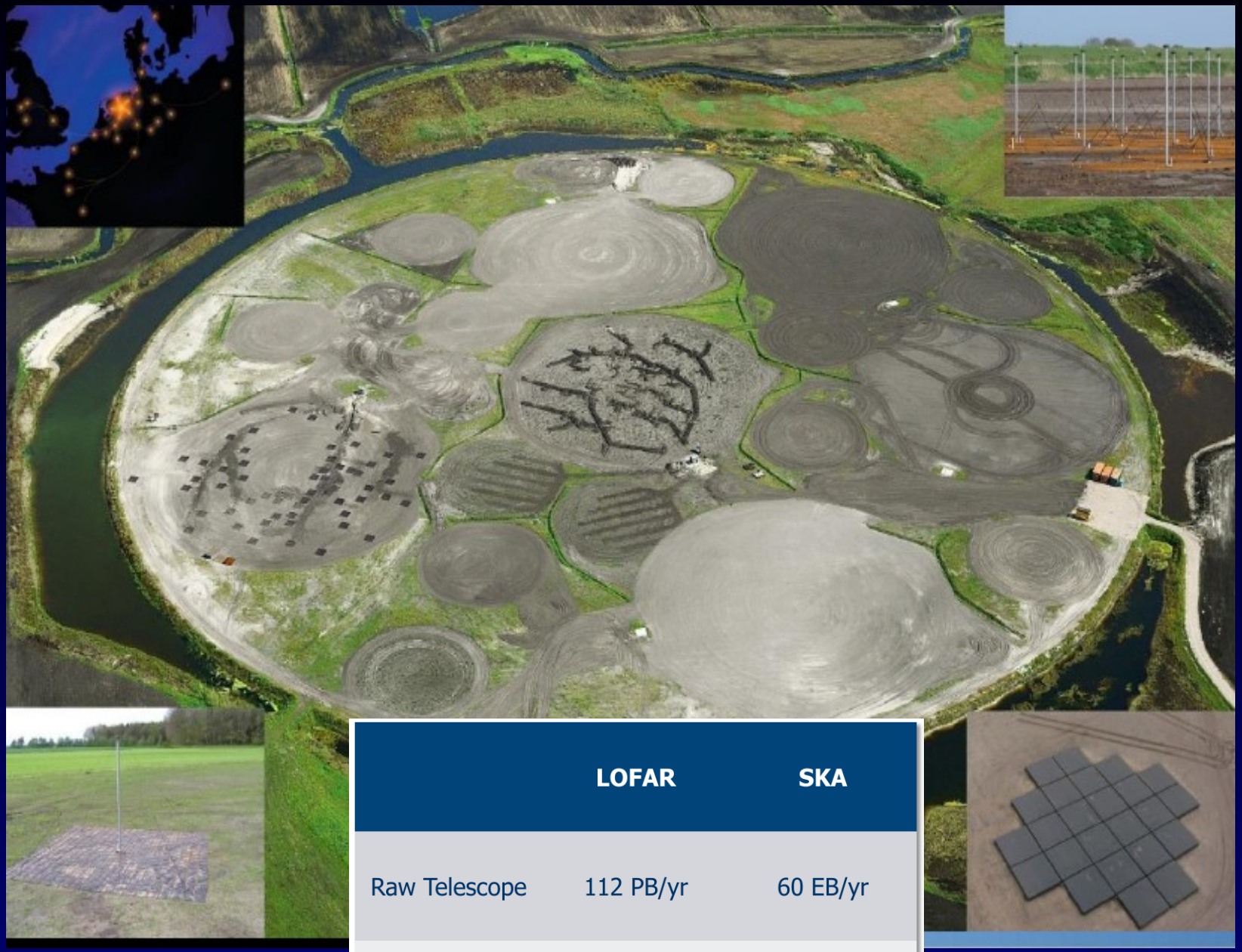


LSST – Vera C. Rubin Observatory



201 CCD 4kx4k,
3.2 Gpix every 15 sec
3.5 deg FOV (64cm)
20 TB/day=6 PB/yr RAW
1.5 PB catalogue !!!
detection of changes 60s!
10 million allerts/night !
38 billion objects x 1000
32 tril. meas. -5 PB table

LOFAR network



	LOFAR	SKA
Raw Telescope	112 PB/yr	60 EB/yr
Archive Rate	6 PB/yr	100 PB/yr

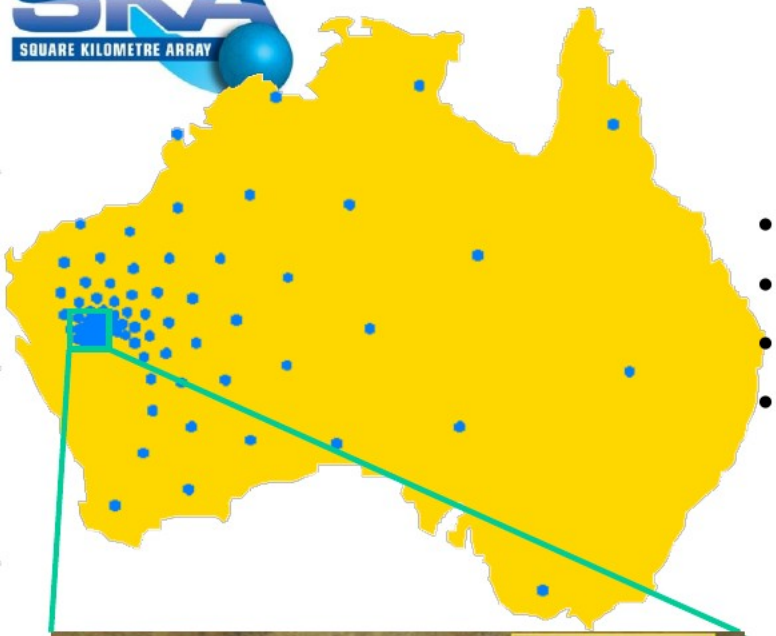
SKA

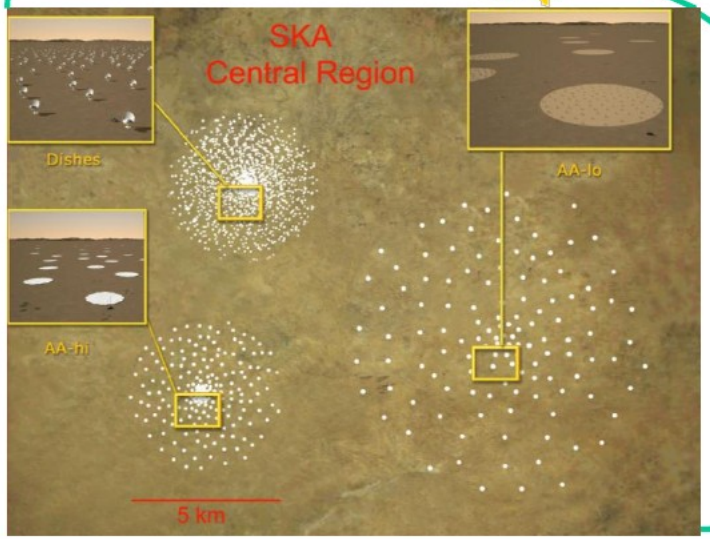
SKA
SQUARE KILOMETRE ARRAY

UNIVERSITY OF CAMBRIDGE

also a Continental sized Radio Telescope

- Need a radio-quiet site
- Very low population density
- Large amount of space
- Possible sites (decision 2012)
  - Western Australia
  - Karoo Desert RSA





SKA

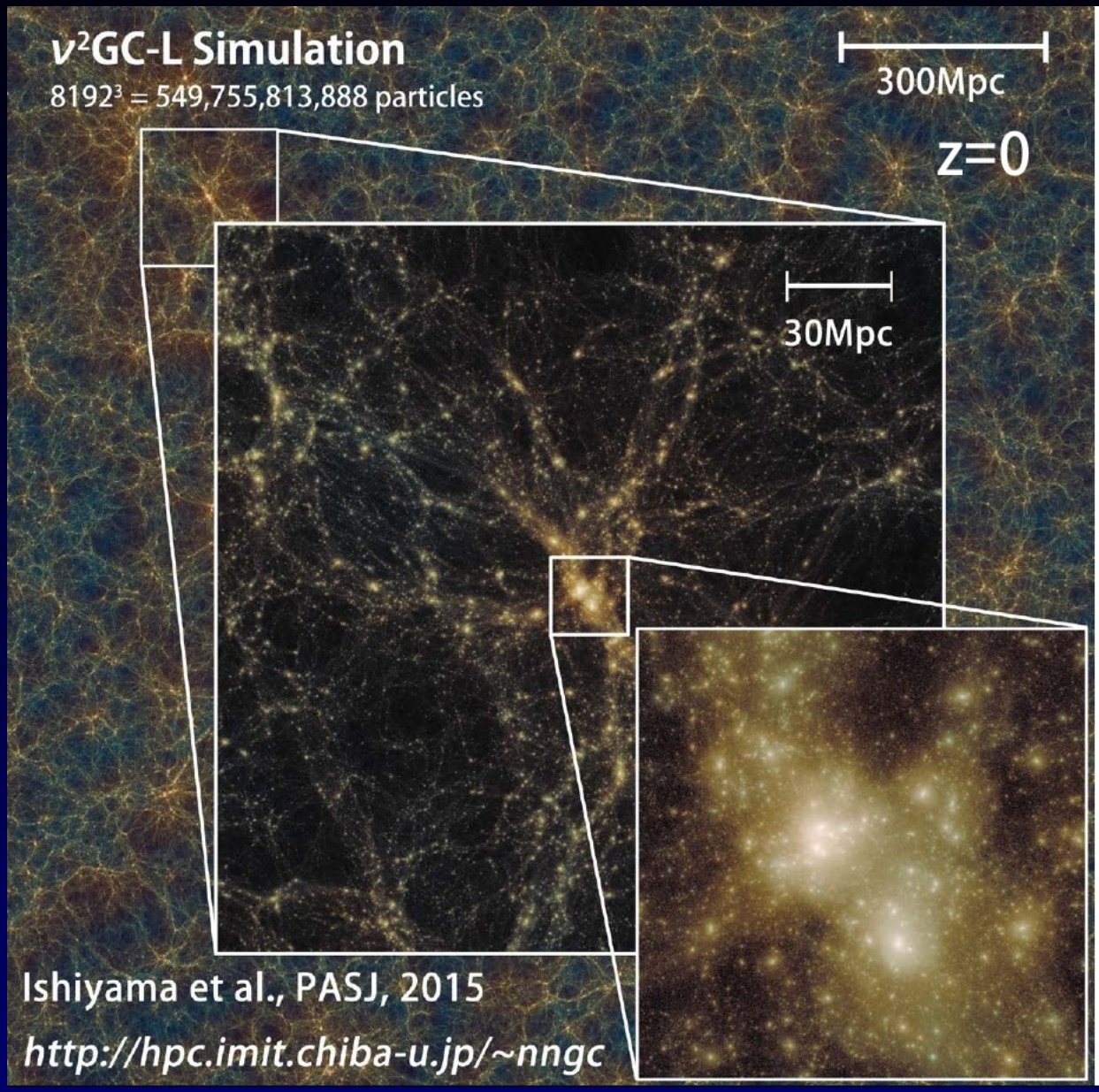
SKA

SKA Archive Volumes

- ~0.5 – 10 PB/day of image data
- Source count ~10^6 sources per square degree
- ~10^{10} sources in the accessible SKA sky, 10^4 numbers/record
- ~1 PB for the catalogued data

100 Pbytes – 3 EBytes / year of fully processed data

Simulation of Universe



$N = 8192^3 = 549,755,813,888$

$L = 1.12$ Gpc/h
$m = 2.2 \times 10^8$ Msun/h

Planck Cosmology

11x larger volume,
4x better mass res,
compared to
Millennium Run
(Springel+ 2005)

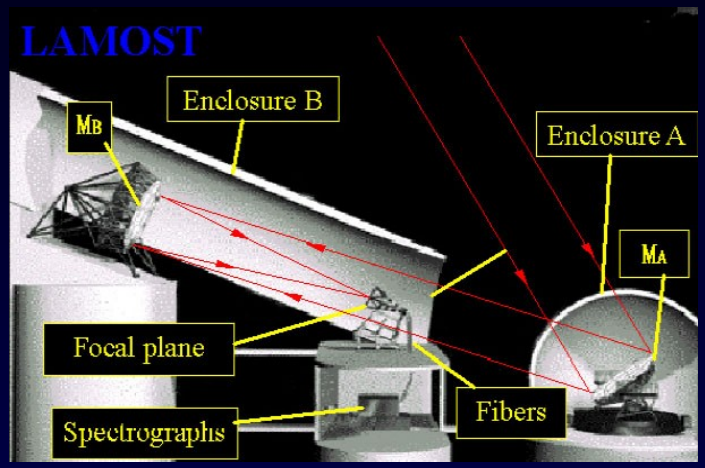
- $N = 2160^3$
- $L = 0.5$ Gpc/h
- $m = 8.6 \times 10^8$ Msun/h
- WMAP1 (σ_8=0.9)

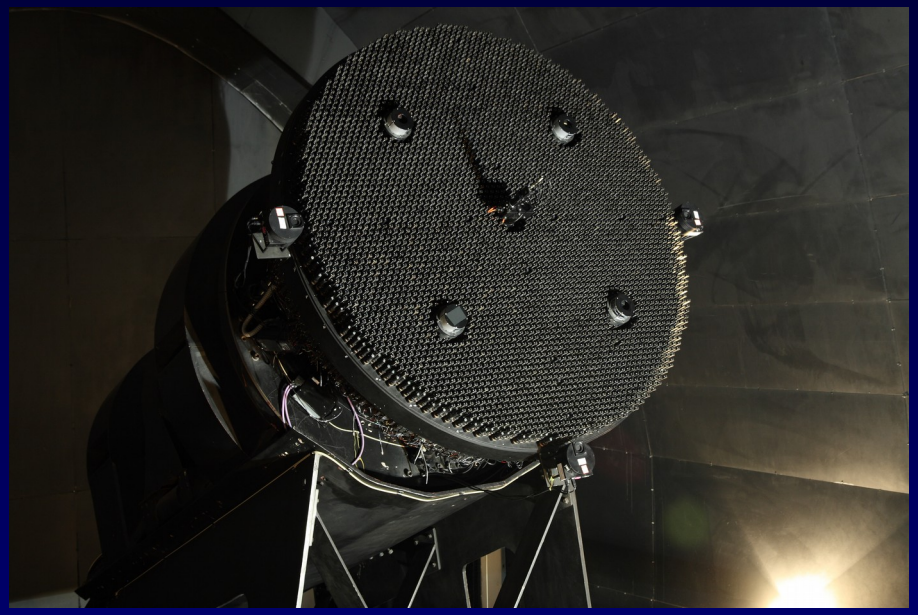
~ 100 hours on
131,072 CPU cores
of K computer

Data size : ~1PB

LAMOST (Guoshoujing)

- Xinglong, China
- 4 m mirror (30 deg meridian)
- 4000 fibres





LAMOST Spectral Surveys

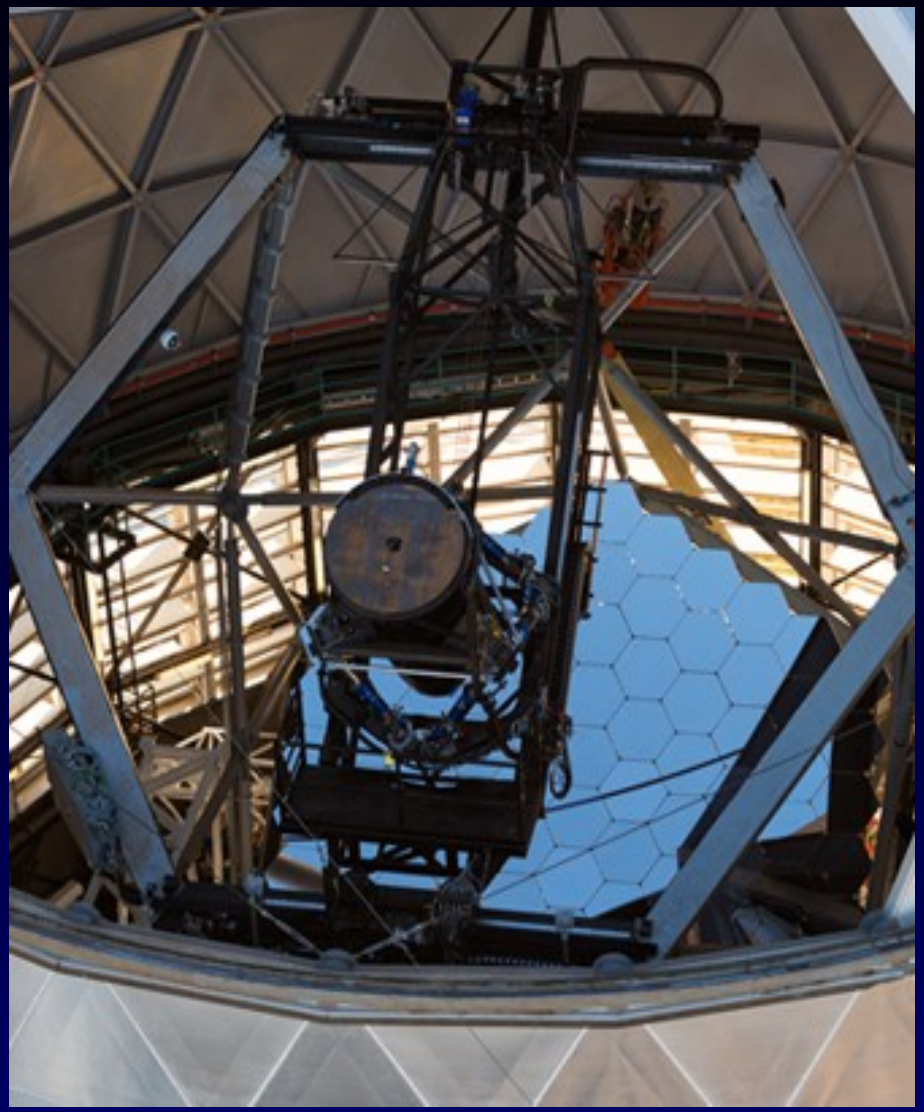
DR1 (end 2013) **2 204 860** spectra
1 085 404 stars classified by pipeline
DR2 (beg 2015) **4 132 782** spectra
3 779 674 stars
307 000 unknown!

DR5 (half 2017) **9 017 844** spectra
DR6 (half 2018) + 739 006
+ 249 591 low res.
+ 3 508 695 mid res.

Each fibre – 2 motors
double arm 33mm circle

Fibre collects light from
3.3 arcsec circle on sky

Hobby Eberly Telescope (HET)



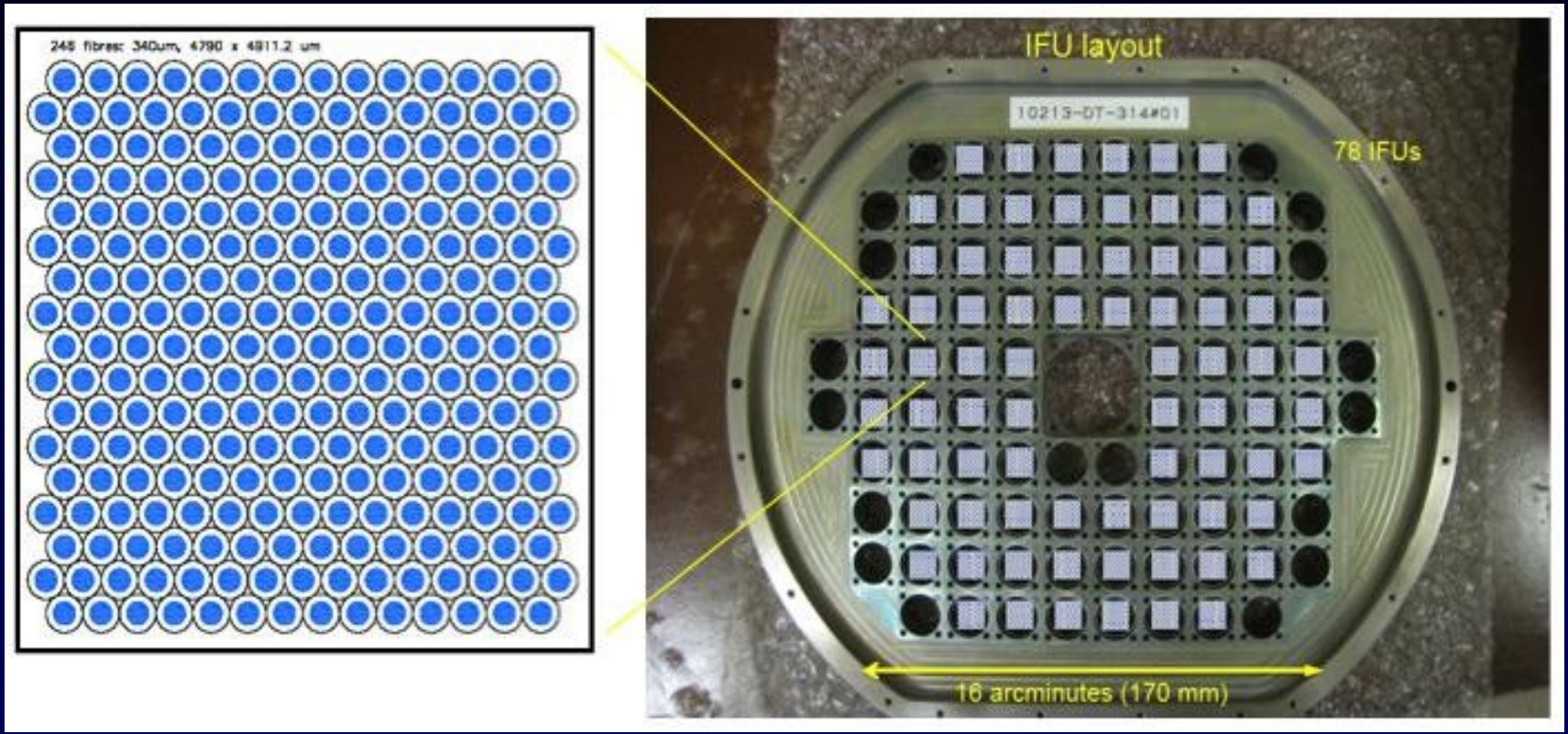
Mc Donald Observatory Texas

Equiv diameter 9.5m (11m)

Fixed in position during observation - only primary tracker

HETDEX Survey

In theory 34944 spectra every 20min !



VIRUS 78 IFU = 156 spectrographs
IFU= 448 fibers
34944 fibers , FOV 22 arcmin, 3500-5500 A, R=800
1 million spectra of galaxies (only part - statistic hits)

Virtual Observatory : Key Definitions

- *"The Virtual Observatory will be a system that allows astronomers to interrogate multiple data centers in a seamless and transparent way, which provides new powerful analysis and visualization tools within that system, and which gives data centers a standard framework for publishing and delivering services using their data".*

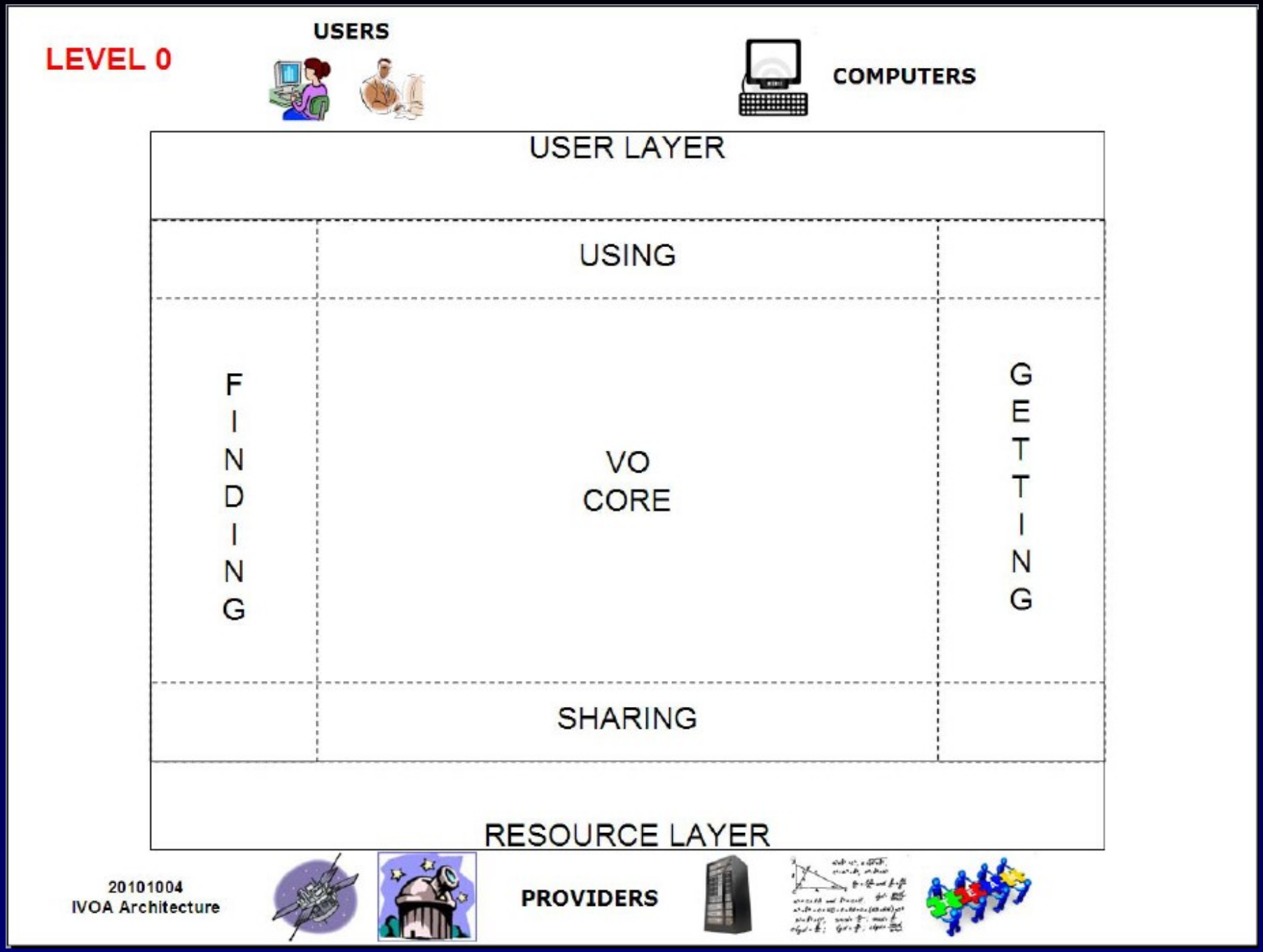
- Standardization of data and metadata, and of data exchange methods.

- Registry, listing available services and what can be done with them.

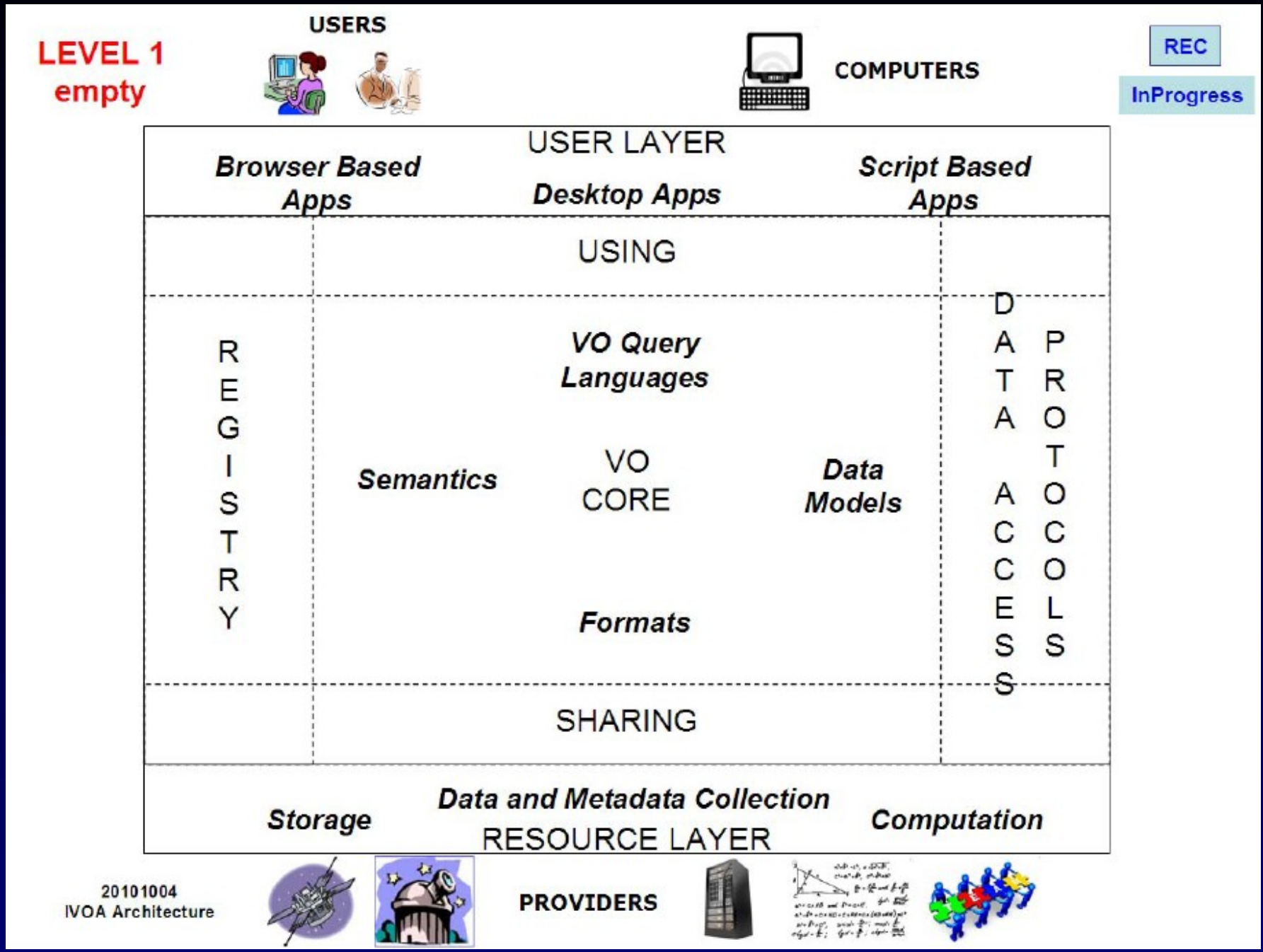
R.J.Hanisch, P.J.Quinn, in "IVOA – Guidelines for participation"

IVOA (established 2002)

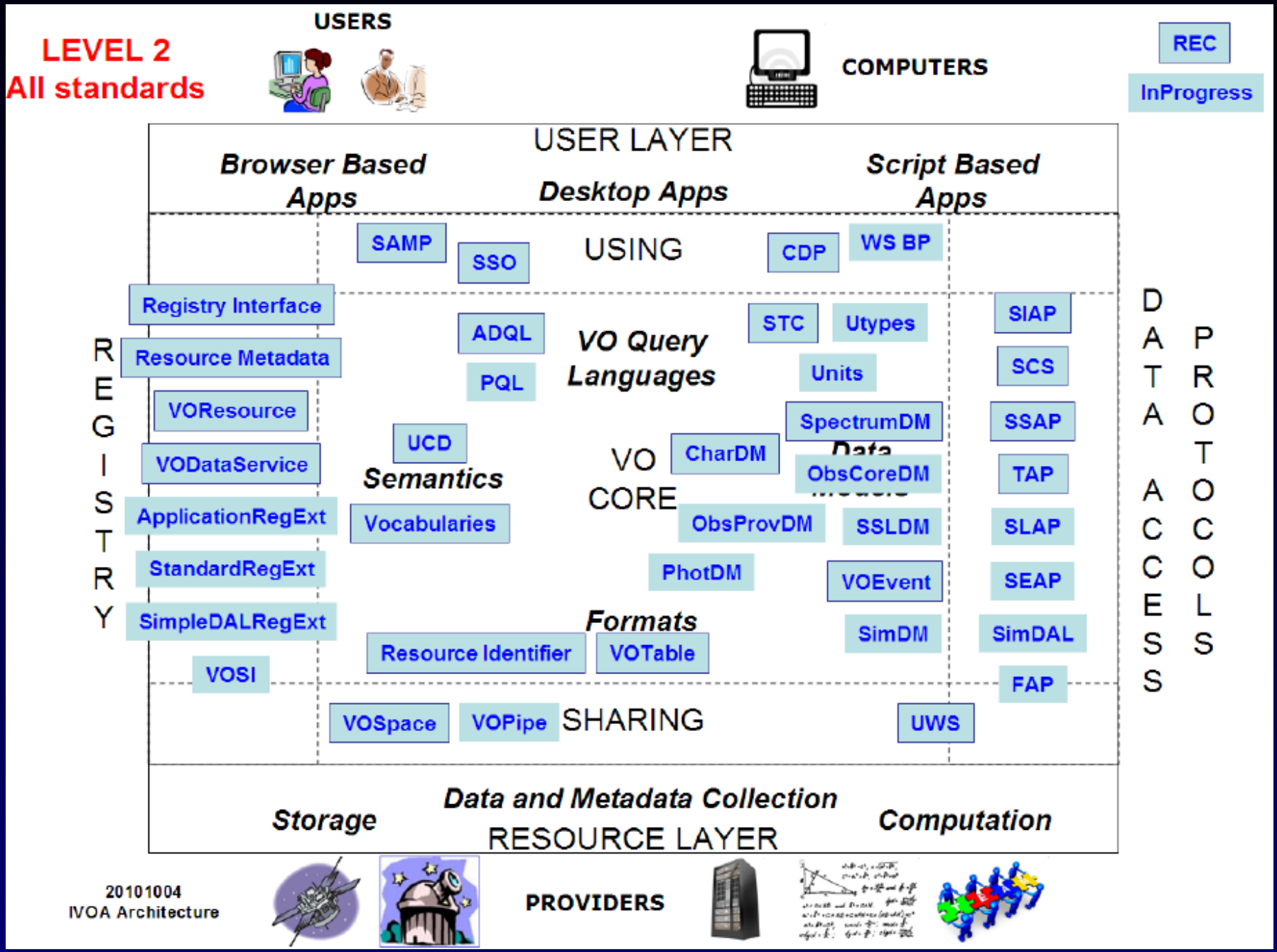
Ecosystem of VO – level 0



Ecosystem of VO – level 1



Ecosystem of VO – level 2



Big Data handling

VO Space	Moving big tables across (load only results)
SSO	Authentication, authorization, groups and consortia
UWS	Universal worker service (job synch, asynch)
PDL	Parameter Description Language
SIM-DB	Simulations, theory data

Technology of VO

Unified data format– VOTable, UCD (Vizier)

Transparent transport (unit conversion)

Web services (WS)

VOregistry (DNS like) Google for data+WS protocols

- ConeSearch (searching in circle on sky)
- SIAP (Simple Image Access Protocol)
- SSAP(Simple Spectral Access Protocol)
- SLAP(Simple Line Access Protocol) - VAMDC
- TAP (Table Access Protocol) – query e.g. whole SDSS
- VOEVENT (transients, robotic telescopes,Sun)
- datacubes, DATALINK on-the-fly data processing

Technology of VO

ADQL (Astronomical Data Query Language)

- XMATCH, REGION (2 catalogues – shifted)

Application interoperabilty – SAMP

- Allows develop applications as bricks
- sending VOTABLES (catalogue-spectra-images)

Science Portals

ESASky

https://sky.esa.int/

ESO Archive Science Portal

https://archive.eso.org/scienceportal/home

IRSA IPAC archive (Firefly)

https://irsa.ipac.caltech.edu/irsaviewer/

FITS standard

>30 years, separation of metadata (human readable and data)

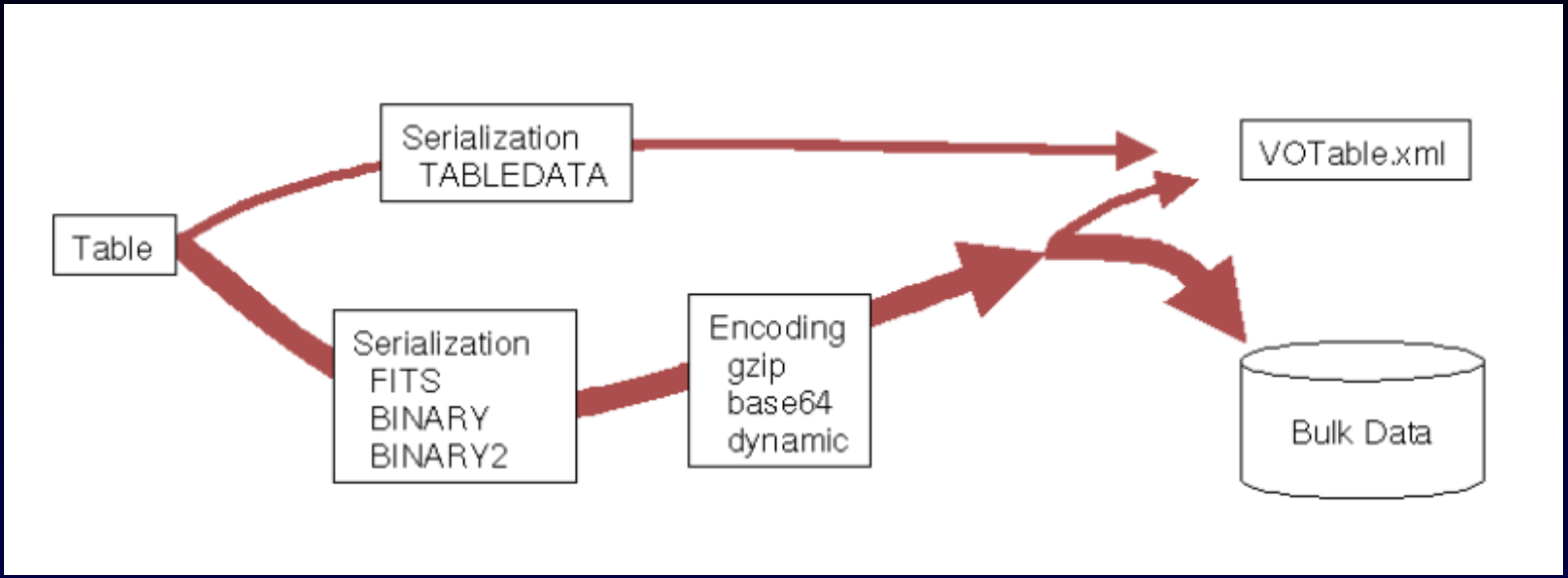
```
SIMPLE  =                    T / file does conform to FITS standard
BITPIX  =                   16 / number of bits per data pixel
NAXIS   =                    2 / number of data axes
NAXIS1  =                 2048 / length of data axis 1
NAXIS2  =                 2048 / length of data axis 2
EXTEND  =                    T / FITS dataset may contain extensions
COMMENT   FITS (Flexible Image Transport System) format is defined in 'Astronomy
COMMENT   and Astrophysics', volume 376, page 359; bibcode: 2001A&A...376..359H
BZERO   =                32768
BSCALE  =                    1 / REAL=TAPE*BSCALE+BZERO
ORIGIN  = 'PESO    '           / AsU AV CR Ondrejov
OBSERVAT= 'ONDREJOV'           / Name of observatory (IRAF style)
LATITUDE=             49.91056 / Telescope latitude  (degrees), +49:54:38.0
LONGITUD=             14.78361 / Telescope longitud  (degrees), +14:47:01.0
HEIGHT  =                  528 / Height above sea level [m].
TELESCOP= 'ZEISS-2m'           / 2m Ondrejov observatory telescope
GAIN    =                    2 / Electrons per ADU
READNOIS=                   10 / Readout noise in electrons per pix
TELSYST = 'COUDE   '           / Telescope setup - COUDE or CASSegrain
INSTRUME= 'OES     '           / Coude echelle spectrograph
CAMERA  = 'VERSARRAY 2048B'    / Camera head name
DETECTOR= 'EEV 2048x2048'      / Name of the detector
CHIPID  = 'EEV 42-40-1-368'    / Name of CCD chip
```

VOTable Example

```
<?xml version="1.0"?>
<VOTABLE version="1.3" xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
 xmlns="http://www.ivoa.net/xml/VOTable/v1.3"
 xmlns:stc="http://www.ivoa.net/xml/STC/v1.30" >
  <RESOURCE name="myFavouriteGalaxies">
    <TABLE name="results">
      <DESCRIPTION>Velocities and Distance estimations</DESCRIPTION>
      <GROUP utype="stc:CatalogEntryLocation">
        <PARAM name="href" datatype="char" arraysize="*"
               utype="stc:AstroCoordSystem.href" value="ivo://STClib/CoordSys#UTC-ICRS-TOPO"/>
        <PARAM name="URI" datatype="char" arraysize="*"
               utype="stc:DataModel.URI" value="http://www.ivoa.net/xml/STC/stc-v1.30.xsd"/>
        <FIELDref utype="stc:AstroCoords.Position2D.Value2.C1" ref="col1"/>
        <FIELDref utype="stc:AstroCoords.Position2D.Value2.C2" ref="col2"/>
      </GROUP>
      <PARAM name="Telescope" datatype="float" ucd="phys.size;instr.tel"
             unit="m" value="3.6"/>
      <FIELD name="RA"   ID="col1" ucd="pos.eq.ra;meta.main"
             datatype="float" width="6" precision="2" unit="deg"/>
      <FIELD name="Dec"  ID="col2" ucd="pos.eq.dec;meta.main"
             datatype="float" width="6" precision="2" unit="deg"/>
      <FIELD name="Name" ID="col3" ucd="meta.id;meta.main"
             datatype="char" arraysize="8*"/>
      <FIELD name="RVel" ID="col4" ucd="spect.dopplerVeloc" datatype="int"
             width="5" unit="km/s"/>
      <FIELD name="e_RVel" ID="col5" ucd="stat.error;spect.dopplerVeloc"
             datatype="int" width="3" unit="km/s"/>
      <FIELD name="R" ID="col6" ucd="pos.distance;pos.heliocentric"
             datatype="float" width="4" precision="1" unit="Mpc">
        <DESCRIPTION>Distance of Galaxy, assuming H=75km/s/Mpc</DESCRIPTION>
      </FIELD>
      <DATA>
        <TABLEDATA>
        <TR>
          <TD>010.68</TD><TD>+41.27</TD><TD>N 224</TD><TD>-297</TD><TD>5</TD><TD>0.7</TD>
        </TR>
        <TR>
          <TD>287.43</TD><TD>-63.85</TD><TD>N 6744</TD><TD>839</TD><TD>6</TD><TD>10.4</TD>
        </TR>
        <TR>
          <TD>023.48</TD><TD>+30.66</TD><TD>N 598</TD><TD>-182</TD><TD>3</TD><TD>0.7</TD>
        </TR>
        </TABLEDATA>
      </DATA>
    </TABLE>
  </RESOURCE>
</VOTABLE>
```

- Header with metadata first
- Unknown end
- BIG DATA transfer
- Links to streams...
- Live pre-processing URLs
- On-the-fly creation of data

VOTable Serialization




```
<RESOURCE>
 <PARAM name="EPOCH" datatype="float" value="1999.987">
  <DESCRIPTION> Original Epoch of the coordinates</DESCRIPTION>
 </PARAM>
 <PARAM name="TELESCOP" datatype="char" arraysize="*" value="VTel" />
 <INFO name="HISTORY">
   The very first Virtual Telescope observation made in 2002
 </INFO>
 <TABLE>
  <FIELD  (insert field metadata here) />
  <DATA><FITS extnum="2">
   <STREAM encoding="gzip" href="ftp://archive.cacr.caltech.edu/myfile.fit.gz"/>
  </FITS></DATA>
 </TABLE>
</RESOURCE>
```

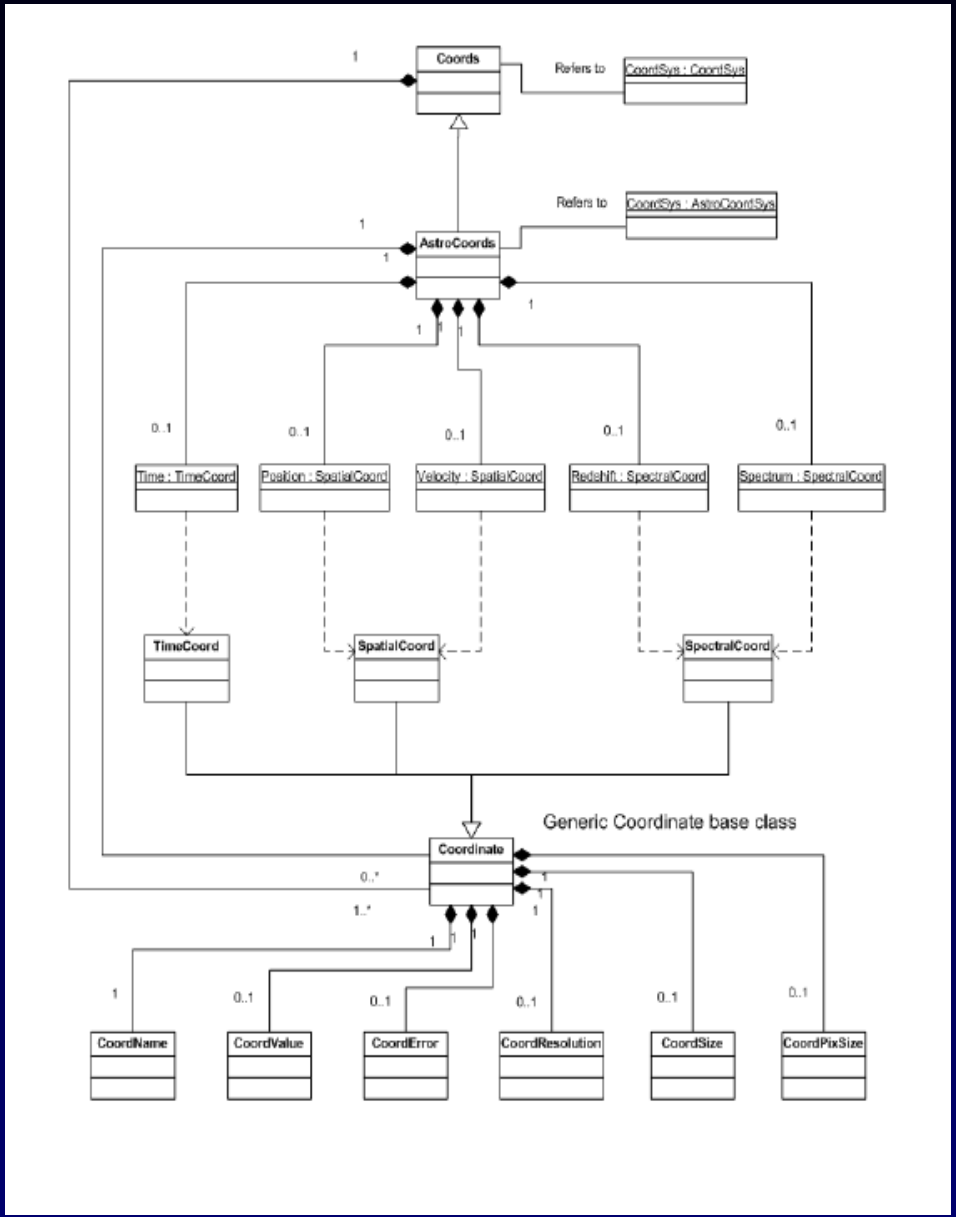
Universal Content Descriptors

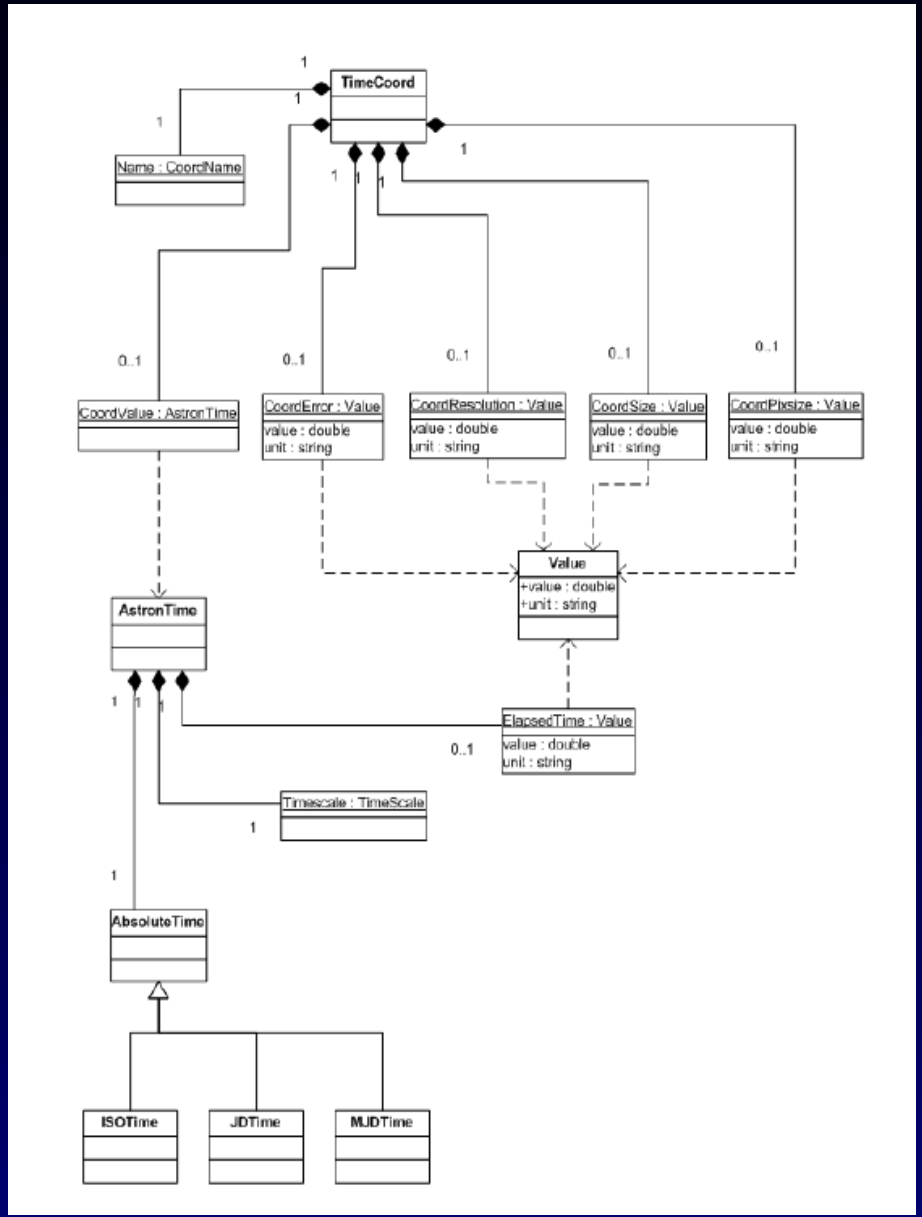
S	em.IR	Infrared part of the spectrum
S	em.IR.J	Infrared between 1.0 and 1.5 micron
S	em.IR.H	Infrared between 1.5 and 2 micron
S	em.IR.K	Infrared between 2 and 3 micron
S	em.IR.3-4um	Infrared between 3 and 4 micron
S	em.IR.4-8um	Infrared between 4 and 8 micron
S	em.IR.8-15um	Infrared between 8 and 15 micron
S	em.IR.15-30um	Infrared between 15 and 30 micron
S	em.IR.30-60um	Infrared between 30 and 60 micron
S	em.IR.60-100um	Infrared between 60 and 100 micron

S	pos.eq	Equatorial coordinates
Q	pos.eq.dec	Declination in equatorial coordinates
Q	pos.eq.ha	Hour-angle
Q	pos.eq.ra	Right ascension in equatorial coordinates
Q	pos.eq.spd	South polar distance in equatorial coordinates
S	pos.errorEllipse	Positional error ellipse
Q	pos.frame	Reference frame used for positions (FK5, ICRS,..)
S	pos.galactic	Galactic coordinates
Q	pos.galactic.lat	Latitude in galactic coordinates
Q	pos.galactic.lon	Longitude in galactic coordinates

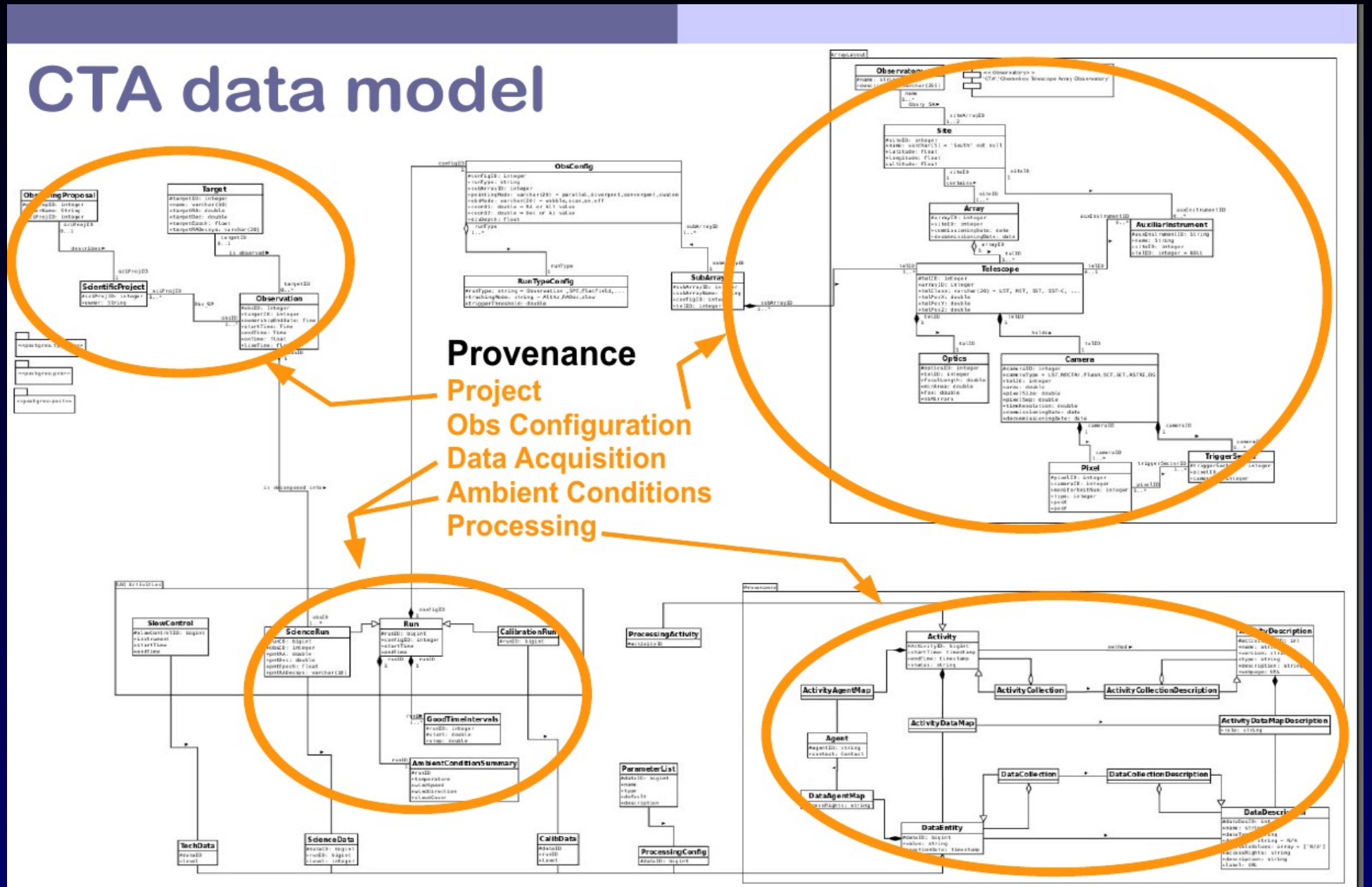
P	stat.stdev	Standard deviation
S	stat.uncalib	Qualifier of a generic incalibrated quantity
Q	stat.value	Miscellaneous statistical value
P	stat.variance	Variance
P	stat.weight	Statistical weight
Q	time	Time, generic quantity in units of time or date
Q	time.age	Age
Q	time.creation	Creation time/date (of dataset, file, catalogue,...)
Q	time.crossing	Crossing time
Q	time.duration	Interval of time describing the duration of a generic event or phenomenon
Q	time.end	End time/date of a generic event

Space-Time-Coordinate Data Model





Cherenkov Telescope Array Data Model



VO Registry – XML

```
<validationLevel validatedBy="ivo://archive.stsci.edu/nvoregistry">2</validationLevel>
<title>Hubble Space Telescope Spectra</title>
<shortName>HST Spectra</shortName>
<identifier>ivo://mast.stsci/ssap/hst</identifier>
▼<curation>
  <publisher>MAST</publisher>
  ▼<creator>
    <name>MAST</name>
  </creator>
  <version>1.0</version>
  ▼<contact>
    <name>Archive Branch, STScI</name>
    <email>archive@stsci.edu</email>
  </contact>
</curation>
▼<content>
  <subject>UV</subject>
  <subject>Optical</subject>
  <subject>and Infrared Astronomy</subject>
  ▼<description>
    Spectra from the following HST instruments are available: GHRS (processed by CADC), FOS (processed by ECF), and STIS (1st
    order). Service is still under development. Links point to new (but incomplete) VO-compatible FITS files created by MAST staff.
  </description>
  <referenceURL>http://archive.stsci.edu/</referenceURL>
  <type>Archive</type>
  <contentLevel>Research</contentLevel>
</content>
▼<capability standardID="ivo://ivoa.net/std/SSA" xsi:type="ssa:SimpleSpectralAccess">
  ▼<interface role="std" version="0.5" xsi:type="vs:ParamHTTP">
    <accessURL use="base">http://archive.stsci.edu/ssap/search.php?id=HST&</accessURL>
    <queryType>GET</queryType>
  </interface>
  <complianceLevel>query</complianceLevel>
  <dataSource>pointed</dataSource>
  <creationType>archival</creationType>
  <maxSearchRadius>360.0</maxSearchRadius>
  <maxRecords>10000</maxRecords>
  <defaultMaxRecords>10000</defaultMaxRecords>
  <maxAperture>180.0</maxAperture>
  <maxFileSize>1000000000</maxFileSize>
</capability>
▼<coverage>
  ▼<STCResourceProfile xmlns="http://www.ivoa.net/xml/STC/stc-v1.30.xsd">
    <AstroCoordSystem id="mast.stsci_ssap_hstUTC-FK5-TOPO" xlink:href="ivo://STClib/CoordSys#UTC-FK5-TOPO" xlink:type="simple"/>
    ▼<AstroCoords coord_system_id="mast.stsci_ssap_hstUTC-FK5-TOPO">
      ▼<Position1D>
        <Size pos_unit="arcsec">0.0500000007450581</Size>
      </Position1D>
    </AstroCoords>
  </STCResourceProfile>
  <waveband>UV</waveband>
  <waveband>Optical</waveband>
</coverage>
</ri:Resource>
```

Simple Spectra Access Protocol
Spectral Data Model

International
Virtual
Observatory
Alliance

Simple Spectral Access Protocol

Version 1.04

IVOA Recommendation Feb 01, 2008

This version:
http://www.ivoa.net/Documents/REC/DAL/SSA-20080201.html
Latest version:
http://www.ivoa.net/Documents/latest/SSA.html
Previous version(s):
Version 1.03, December 2007
Version 1.02, September 2007
Version 1.01, June 2007
Version 1.00, May 2007
Version 0.97, November 2006
Version 0.96, September 2006
Version 0.95 May 2006
Version 0.91 October 2005
Version 0.90 May 2005
Editors:
D.Tody, M. Dolensky
Authors:
D.Tody, M. Dolensky, J. McDowell, F. Bonnarel, T.Budavari, I.Busko, A. Micol, P.Osuna, J.Salgado, P.Skoda, R.Thompson, F.Valdes, and the data access layer working group.

International
Virtual
Observatory
Alliance

IVOA Spectral Data Model

Version 1.03

IVOA Recommendation 2007-10-29

This version (Recommendation Rev 1)
http://www.ivoa.net/Documents/REC/DM/SpectrumDM-20071029.pdf
Latest version:
http://www.ivoa.net/Documents/latest/SpectrumDM.html
Previous versions:
http://www.ivoa.net/Documents/PR/DM/SpectrumDM-20070913.html

Editors:
Jonathan McDowell, Doug Tody
Contributors:
Jonathan McDowell, Doug Tody, Tamas Budavari, Markus Dolensky, Inga Kamp, Kelly McCusker, Pavlos Protopapas, Arnold Rots, Randy Thompson, Frank Valdes, Petr Skoda, and the IVOA Data Access Layer and Data Model Working Groups.

SSAP Parameters

4.1.1 Mandatory Query Parameters

The following parameters **must** be implemented by a compliant service:

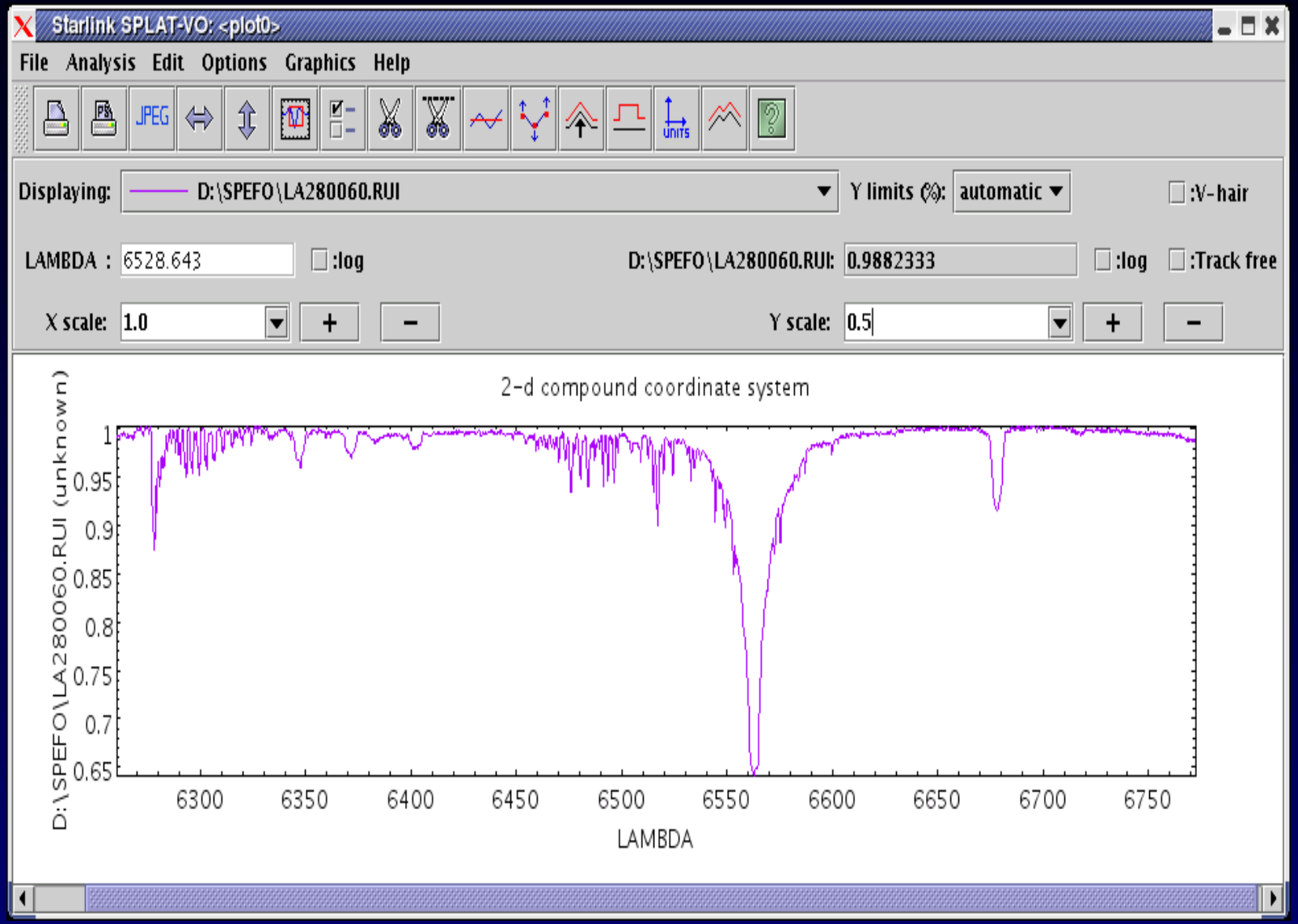
Parameter	*Sample value*	*Physical unit*	*Datatype*
POS	52,-27.8	degrees; defaults to ICRS	string
SIZE	0.05	degrees	double
BAND	2.7E-7/0.13	meters	string
TIME	1998-05-21/1999	ISO 8601 UTC	string
FORMAT	votable	-	string

4.1.2 Recommended and Optional Query Parameters

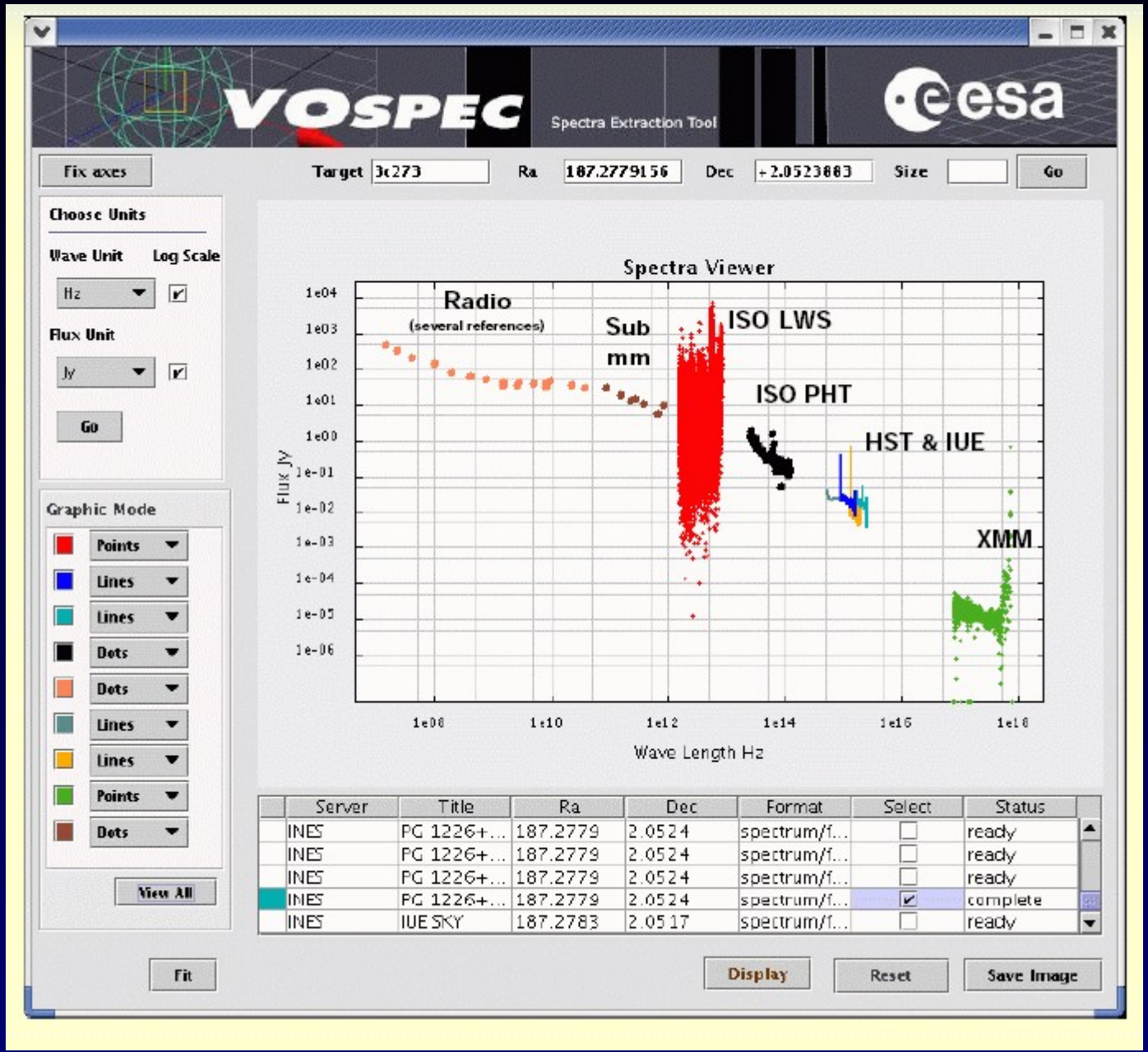
Parameter	Sample value	Unit	Req	Datatype
APERTURE	0.00028 (=1")	degrees	OPT	double
SPECRP	2000	λ/dλ	REC	double
SPATRES	0.05	degrees	REC	double
TIMERES	31536000 (=1yr)	seconds	OPT	double
SNR	5.0	dimensionless	OPT	double
REDSHIFT	1.3/3.0	dimensionless	OPT	string
VARAMPL	0.77	dimensionless	OPT	string
TARGETNAME	mars		OPT	string
TARGETCLASS	star		OPT	string
FLUXCALIB	relative		OPT	string
WAVECALIB	absolute		OPT	string
PUBDID	ADS/col#R5983		REC	string
CREATORDID	ivo://auth/col#R1234		REC	string
COLLECTION	SDSS-DR5		REC	string
TOP	20	dimensionless	REC	int
MAXREC	5000		REC	string
MTIME	2005-01-01/2006-01-01	ISO 8601	REC	string
COMPRESS	true		REC	boolean
RUNID			REC	string

The spatial, spectral, and time resolution of the data may all be used as query constraints

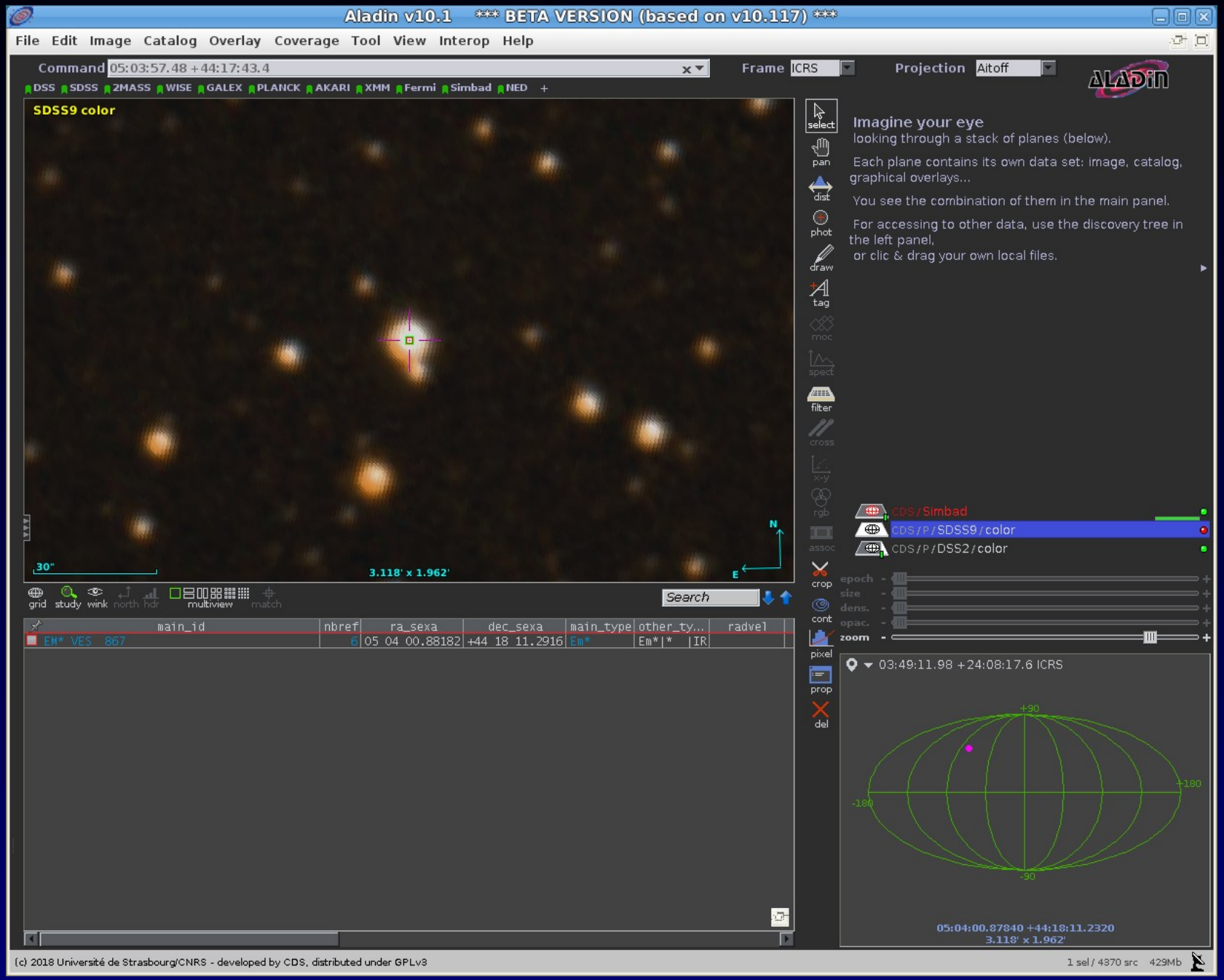
SPLAT-VO
(Starlink, Heidelberg, Ondrejov)



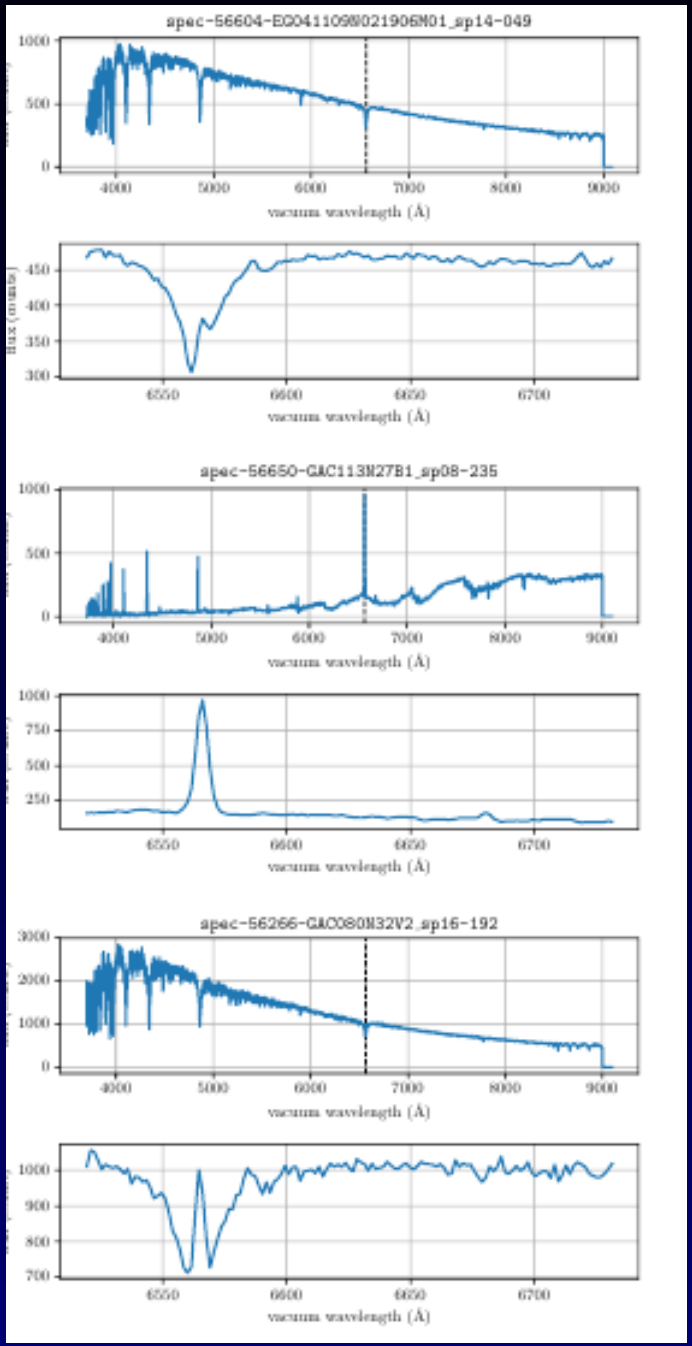
VOspec (ESAC)

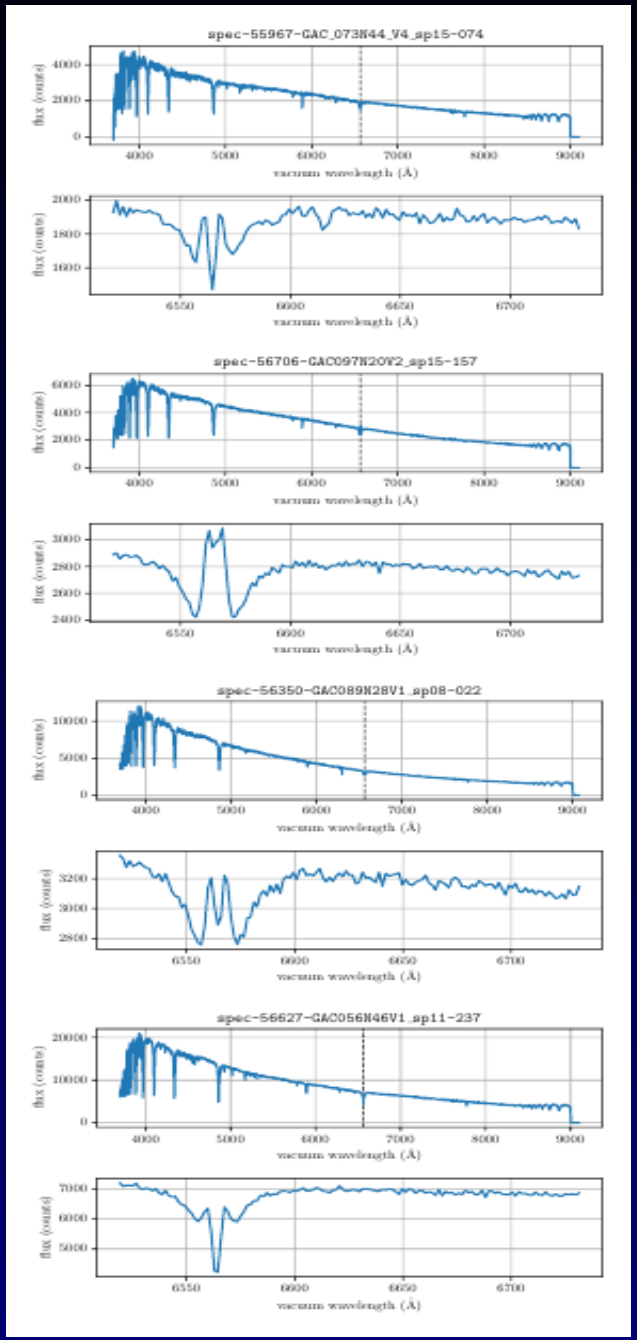

VOSPEC
Spectra Extraction Tool
esa
Fix axes
Target 3c273
Ra 187.2779156
Dec +2.0523883
Size
Go
Choose Units
Wave Unit
Log Scale
Hz
Flux Unit
Jy
Go
Graphic Mode
Points
Lines
Lines
Dots
Dots
Lines
Lines
Points
Dots
View All
Spectra Viewer
Radio
(several references)
Sub
mm
ISO LWS
ISO PHT
HST & IUE
XMM
Flux Jy
1e04
1e03
1e02
1e01
1e00
1e-01
1e-02
1e-03
1e-04
1e-05
1e-06
1e08
1e10
1e12
1e14
1e16
1e18
Wave Length Hz
Server
Title
Ra
Dec
Format
Select
Status
INES PG 1226+... 187.2779 2.0524 spectrum/f... ready
INES PG 1226+... 187.2779 2.0524 spectrum/f... ready
INES PG 1226+... 187.2779 2.0524 spectrum/f... ready
INES PG 1226+... 187.2779 2.0524 spectrum/f... complete
INES IUE SKY 187.2783 2.0517 spectrum/f... ready
Fit
Display
Reset
Save Image

Aladin- HIPS

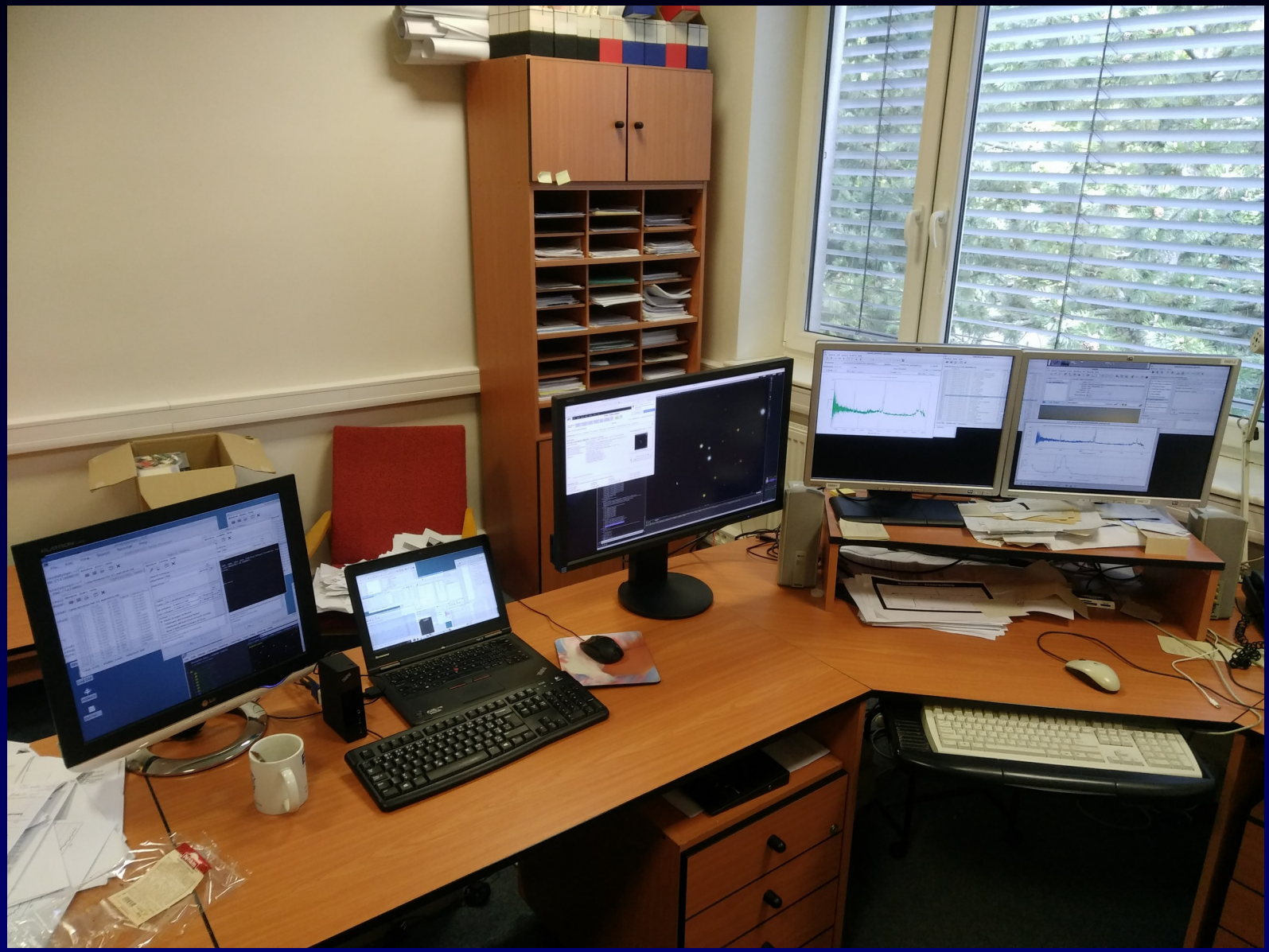

Aladin v10.1 *** BETA VERSION (based on v10.117) ***
File Edit Image Catalog Overlay Coverage Tool View Interop Help
Command 05:03:57.48 +44:17:43.4
Frame ICRS
Projection Aitoff
DSS SDSS 2MASS WISE GALEX PLANCK AKARI XMM Fermi Simbad NED
SDSS9 color
Imagine your eye
looking through a stack of planes (below).
Each plane contains its own data set: image, catalog, graphical overlays...
You see the combination of them in the main panel.
For accessing to other data, use the discovery tree in the left panel,
or clic & drag your own local files.
CDS/Simbad
CDS/P/SDSS9/color
CDS/P/DSS2/color
main_id nbref ra_sexa dec_sexa main_type other_ty... radvel
EM* VES 867 6 05 04 00.88182 +44 18 11.2916 Em* Em*|* |IR
03:49:11.98 +24:08:17.6 ICRS
05:04:00.87840 +44:18:11.2320
3.118' x 1.962'
(c) 2018 Université de Strasbourg/CNRS - developed by CDS, distributed under GPLv3

Single-peak & Double-peak Candidates

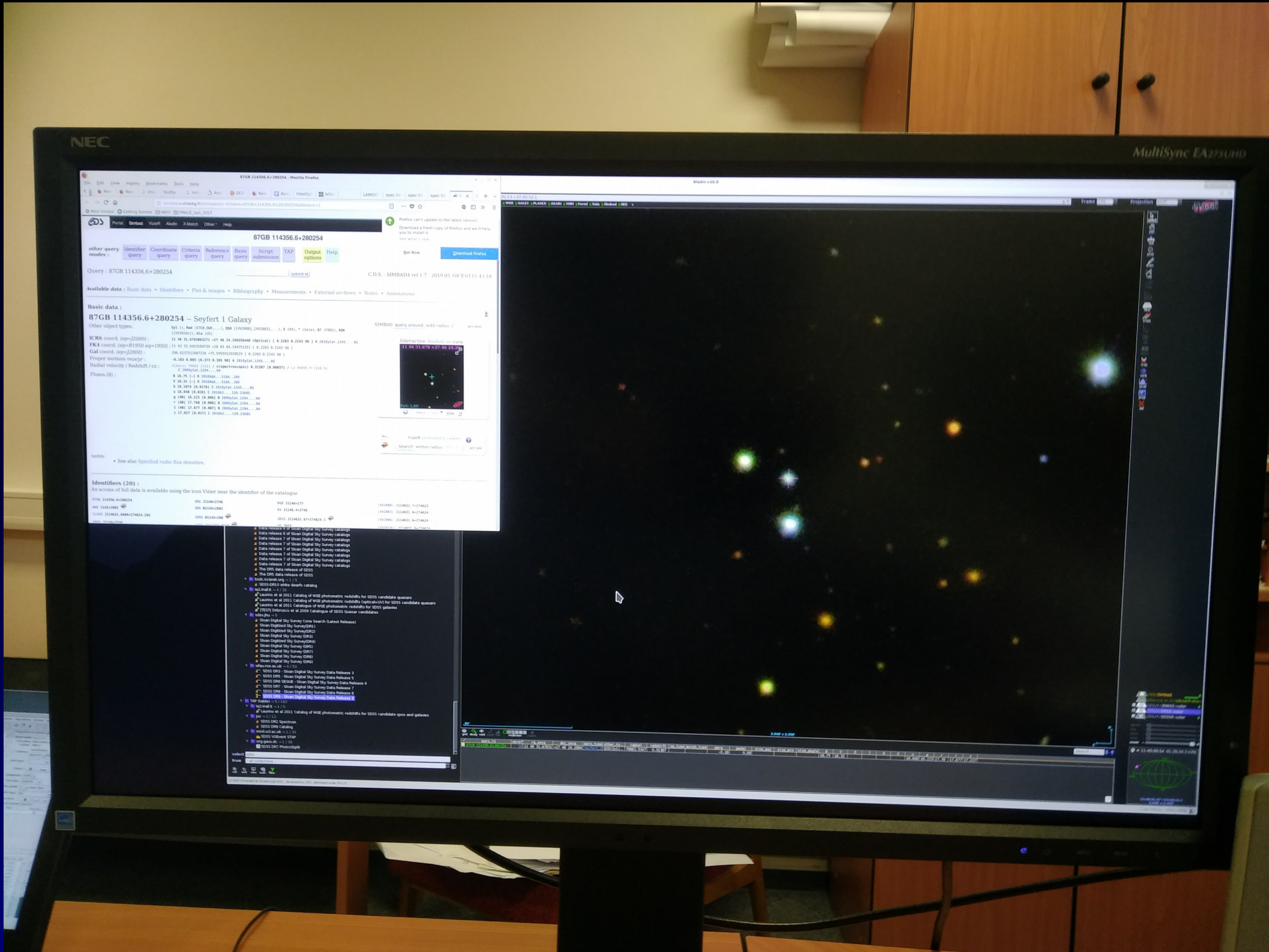




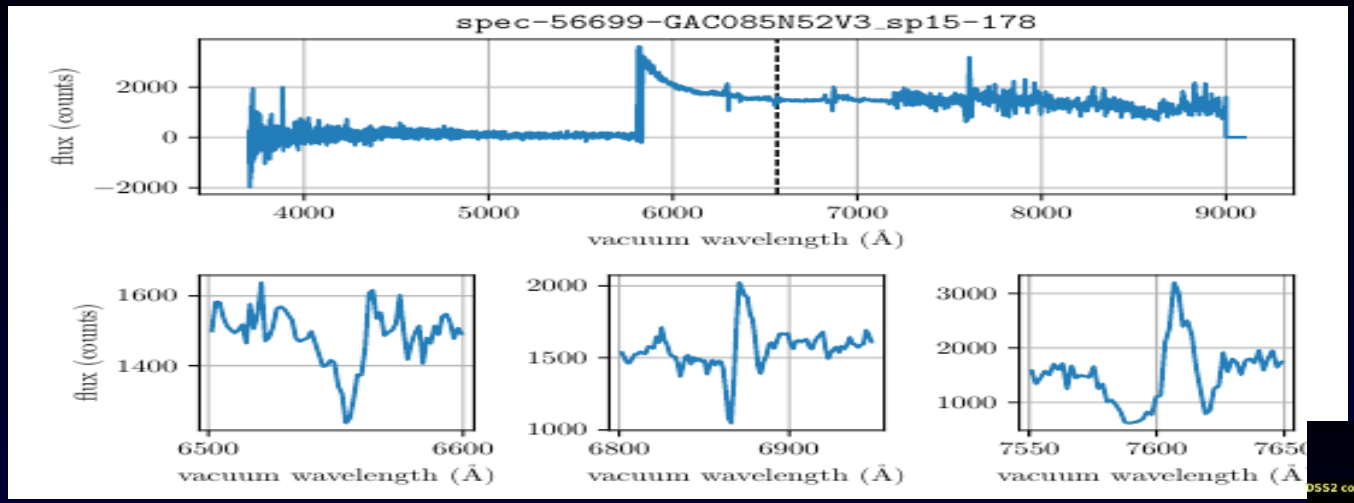
Analysis

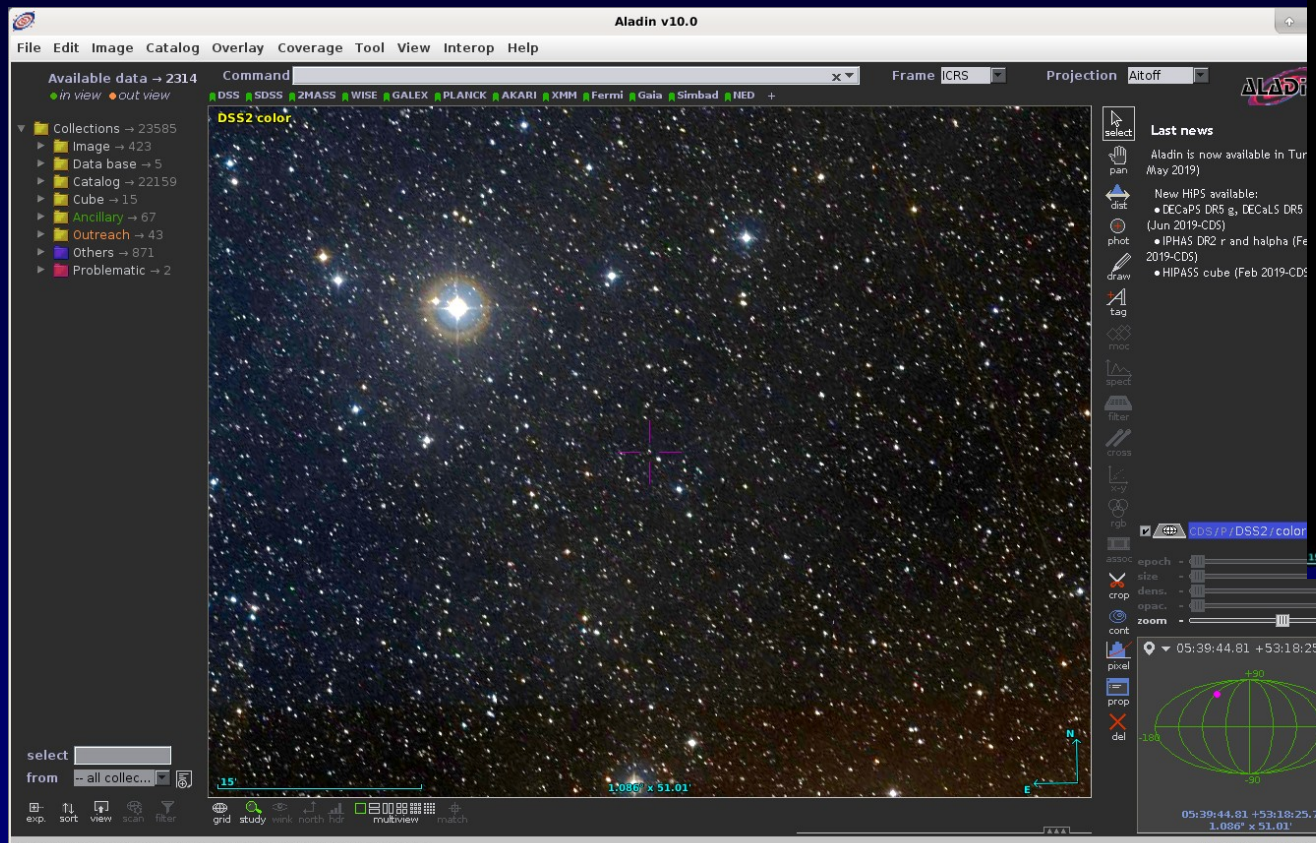


Starlink SPLAT-VO: <plot2203>
TOPCAT(2): Table Browser
TOPCAT
TOPCAT(2): Activation Actions
Xpdf: spec-56716-HD114322N280318M_sp08-042.pdf
HP LP2065
68691
66612


NEC
MultiSync EA275UHD
87GB 114356.6+280254
Basic data :
87GB 114356.6+280254 -- Seyfert 1 Galaxy
Identifiers (20) :

Visual Verification of Object with Disk



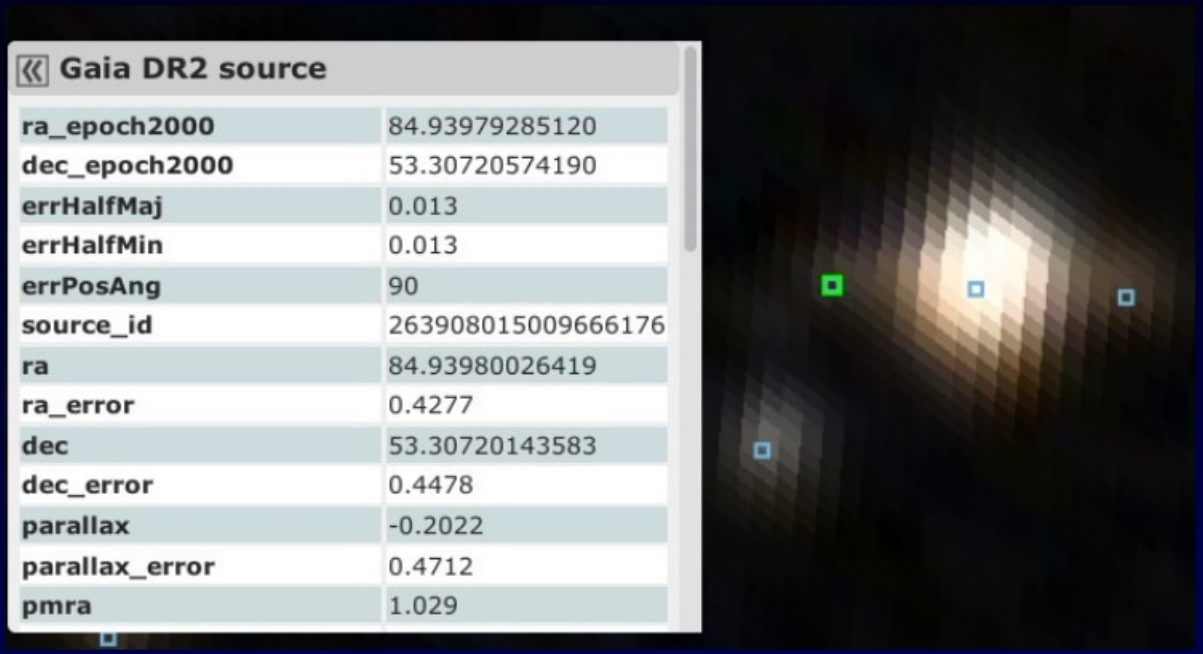


Gravitational lensing ???

6.7 arcsec from center star – absolute symmetry, no time evolution

PanSTARRS-1 Archive 2011-2014

Gaia DR2 source	
ra_epoch2000	84.93979285120
dec_epoch2000	53.30720574190
errHalfMaj	0.013
errHalfMin	0.013
errPosAng	90
source_id	263908015009666176
ra	84.93980026419
ra_error	0.4277
dec	53.30720143583
dec_error	0.4478
parallax	-0.2022
parallax_error	0.4712
pmra	1.029



1st lens – Twin QSO 0957+561 A+B
1979 2.1m Kitt Peak

6 arcsec distance

Tutorial of VO

https://hendhd.github.io/ivoa_newcomers/

https://www.canfar.net/storage/list/pdowler/ivoa/virtual2021a

Thank You