# Astroinformatics - Extracting New Knowledge about Universe

# in the Epoch of Petabyte-Scaled Archives

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Supported by grant COST LD-15113 of the
Czech Ministry of Education Youth and Sports

Python BootCamp
IAG, University Sao Paulo , Brazil
16th February 2017

# Credits

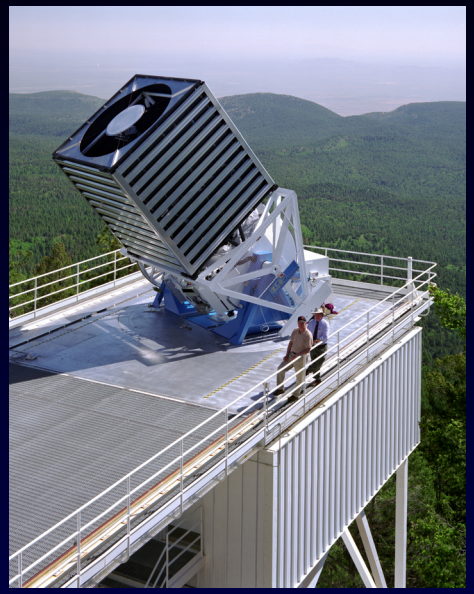
- The presentation is based on many different sources – mainly the on-line published slides from IVOA meetings, slides from Astroinformatics workshops or pictures found on Internet.
- We acknowledge namely materials of E. Solano, E. Hatsiminaoglu, B.Hanish, G. Djorgovski, G. Longo, T. Hey, F. Le Petit, M. Breddels and presentations from AI2016 in Sorrento

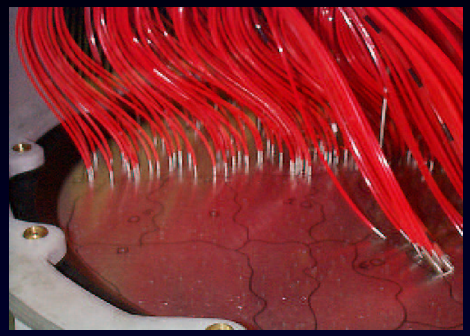
# Outline of the Talk

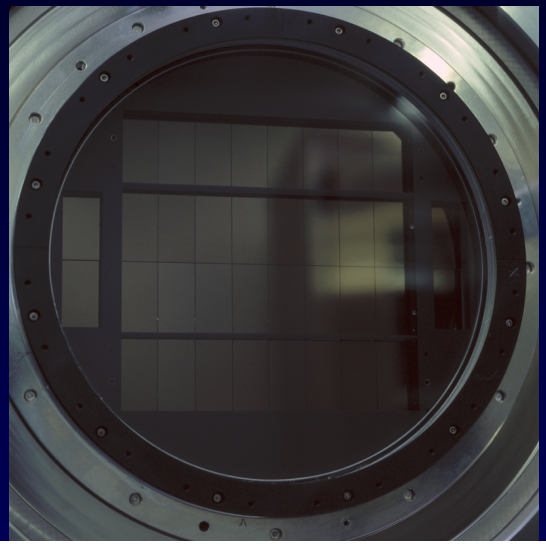
- Data Avalanche in astronomy
- Virtual Observatory
- Astroinformatics
- Visualizations
- Transfer of technology
- Citizen Science

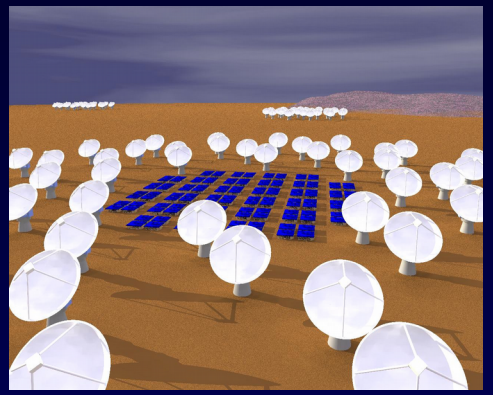
- Examples  of our projects

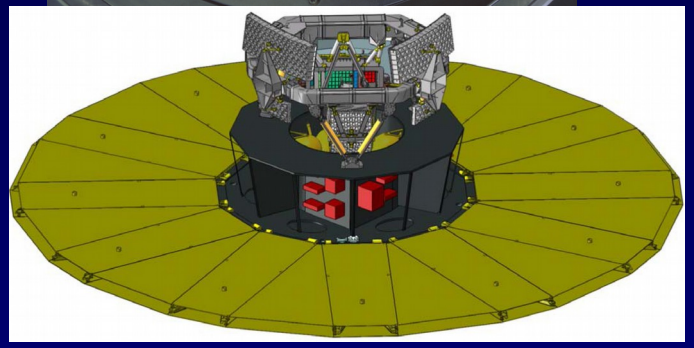
# Data Avalanche





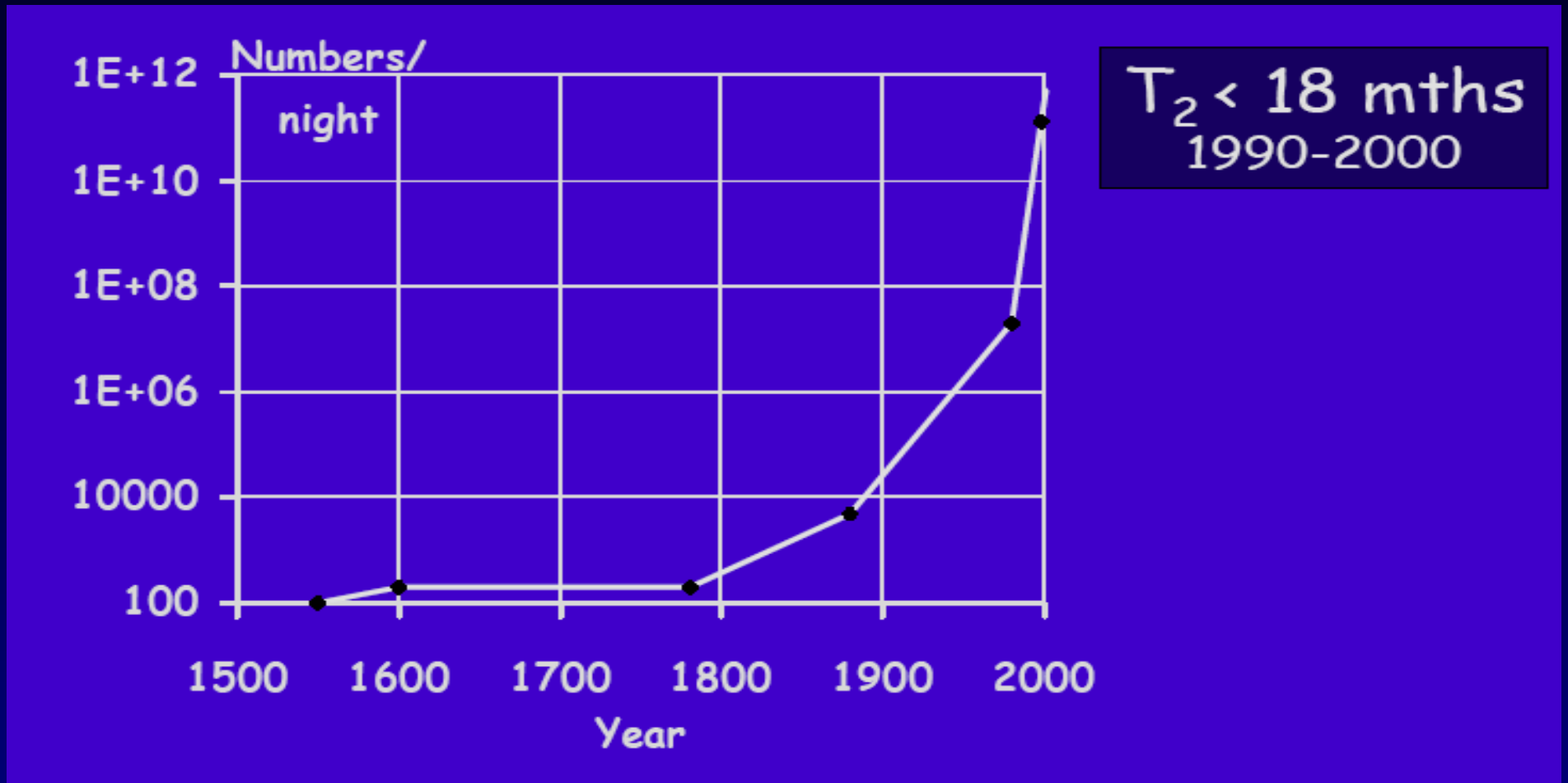




# Data Avalanche

Moore law for chips –doubling 1.5 year

Data in astronomy – doubling < 1 yr ! (1000/10 yr)



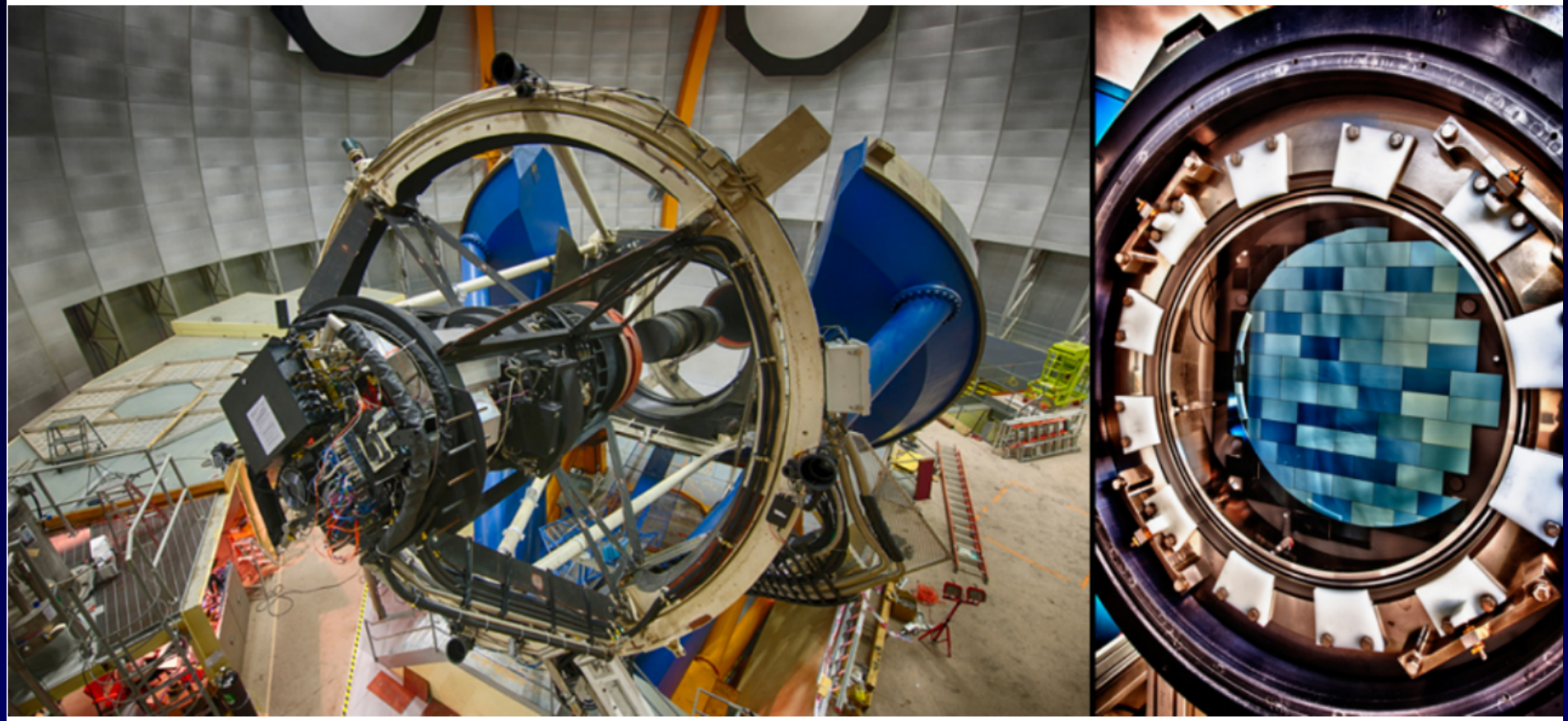
# CD Sea

600 000 CD = 372 TB  (CD 650MB)
600 000 DVD = 2.5 PB (DVD=4.5GB)

Bruce Monro
Kilmington UK

# Dark Energy Survey Camera

Dark Energy Camera (DECam)

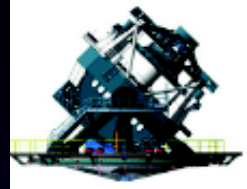


~0.4 PB/yr

# Large Synoptic Survey Telescope


201 CCD 4kx4k,
3.2 Gpix every 20 sec
3.5 deg FOV (64cm)
20 TB/day=6 PB/yr RAW
1.5 PB catalogue !!!
detection of changes 60s!

38 billion objects x 1000
32 tril. meas. -5 PB table



# LSST: Data Volume

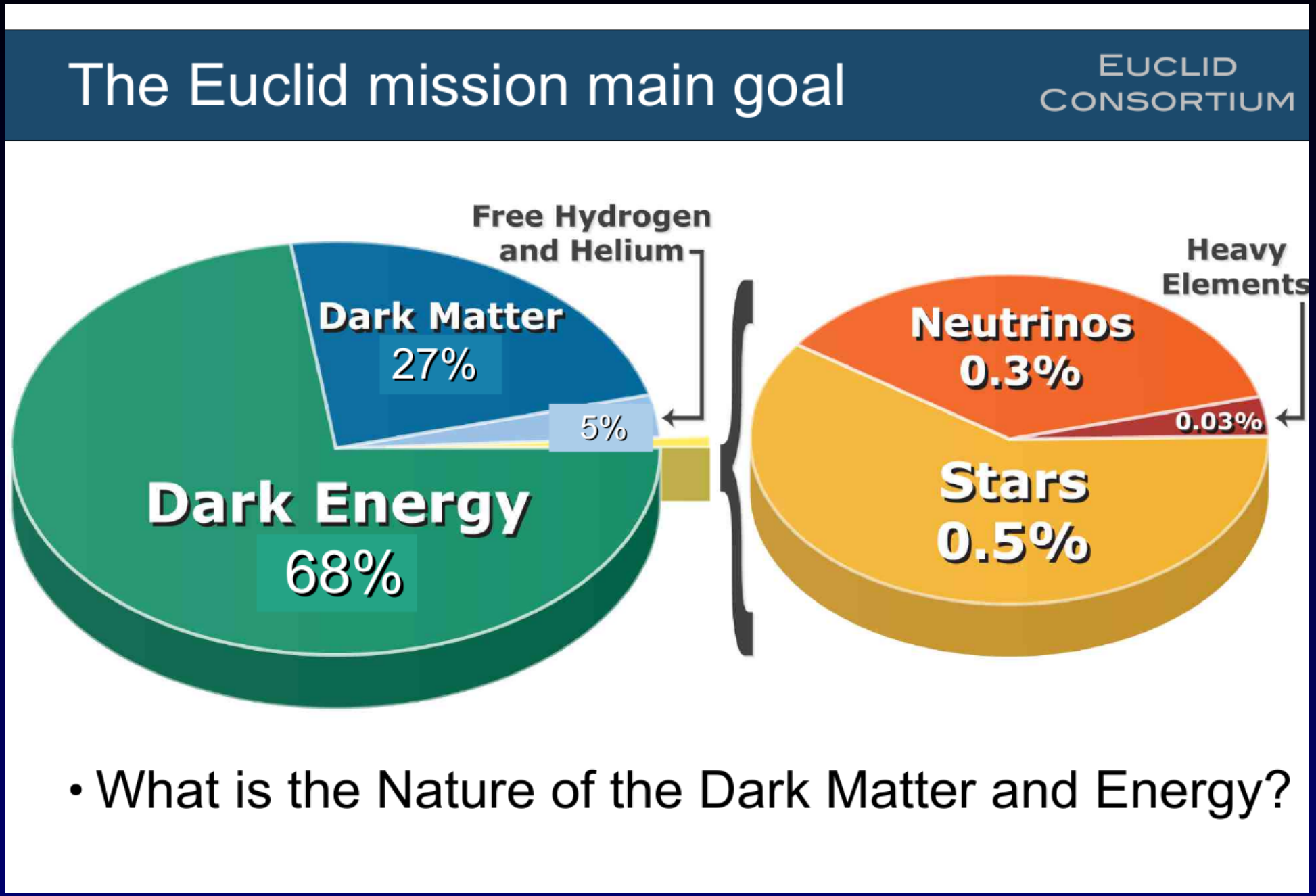
- One 6.4-gigabyte image every ~17 seconds
- ~1000 visits (two back-to-back images), per night
- 15 terabytes of raw scientific image data / night

- 8.4 terapixel image (movie) of the sky to ~27.5 mag in 6 bands

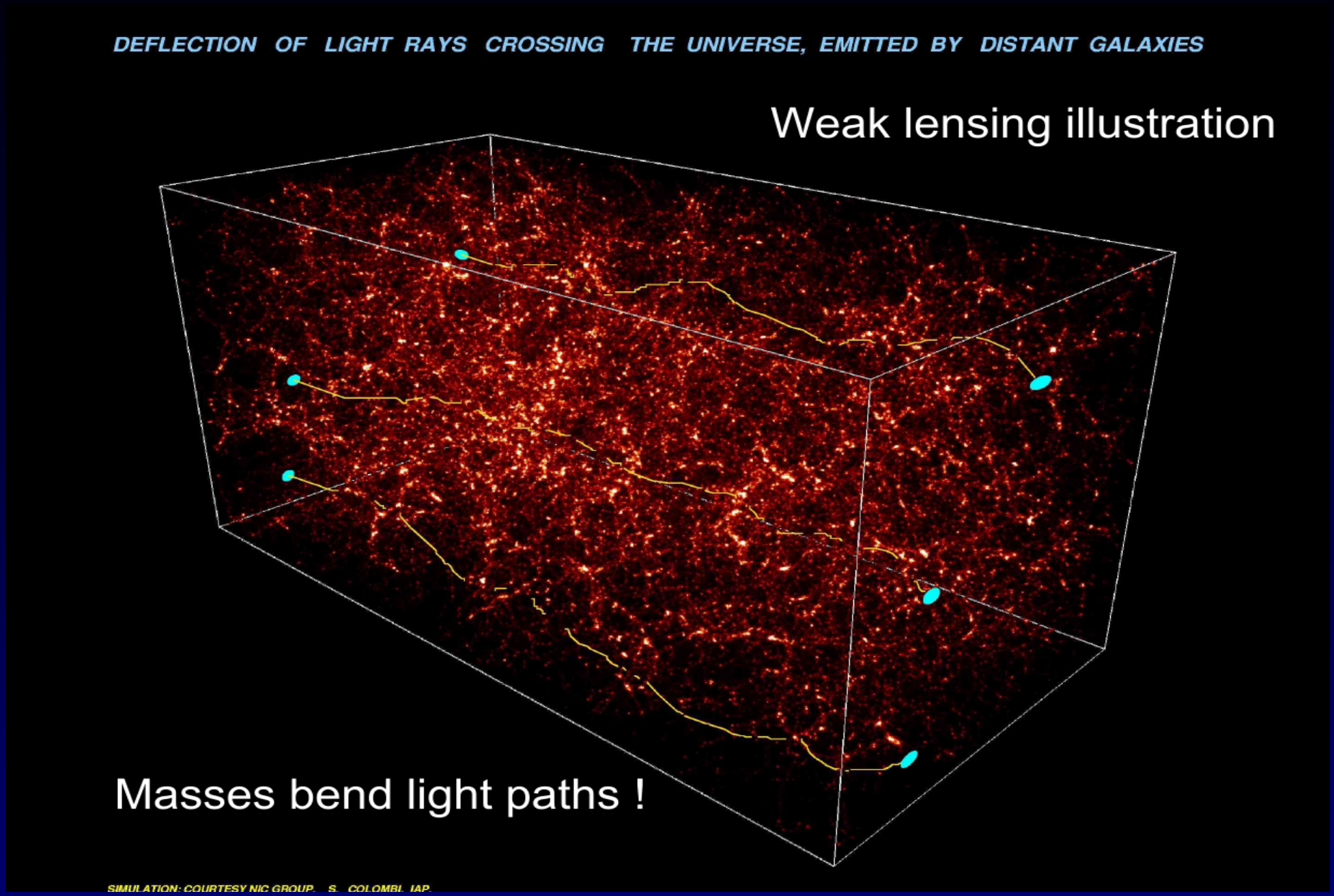
- A catalog of ~38 billion observed objects (24B galaxies, 14B stars)
- A catalog of ~32 trillion photometric measurements

- ~2000 events per observation (includes variables+asteroids)
- ~2 million events per night, for 10 years
- Requirement: Process & transmit alerts within 60 seconds

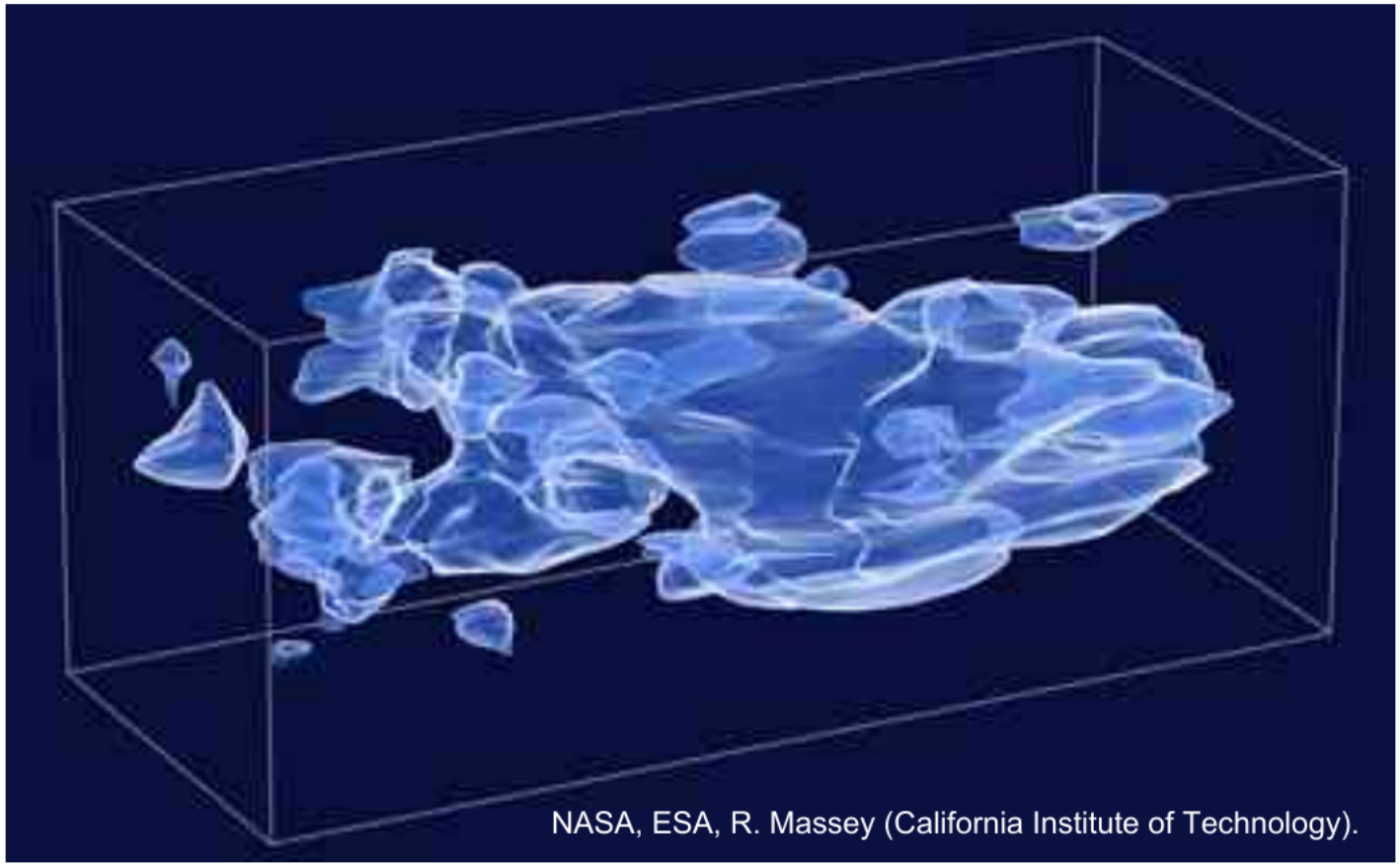
# Project EUCLID



# EUCLID principles



# Euclid Data Archive




| | 2021 | 2022 | 2023 | 2024 | 2025 | 2026 | 2027 |
|---|---|---|---|---|---|---|---|
| Storage (PB) | 15 | 30 | 50 | 60 | 75 | 90 | 90 |
| Computing (kilo cores / year) | 2.5 | 5 | 8.5 | 12 | 16 | 20 | 21 |

Numbers from Christophe Dabin @ tk1

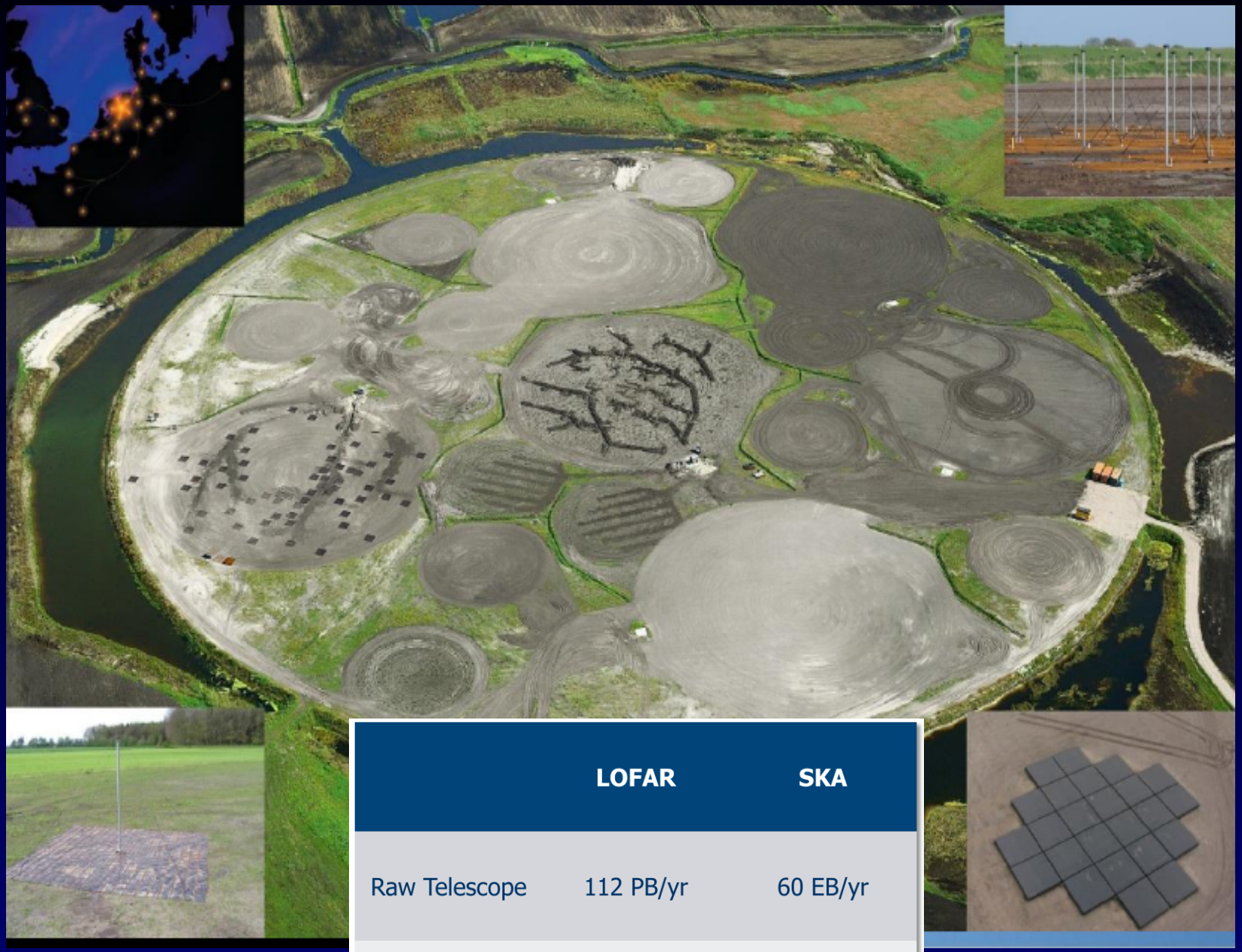
# Atacama Large Milimeter Array
# ALMA

64 antennas 12m
Chajnator 5000m
Chile
2008-2013

it is spectrograph
as well as ...

0.5-2 PB/yr RAW

# LOFAR network



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

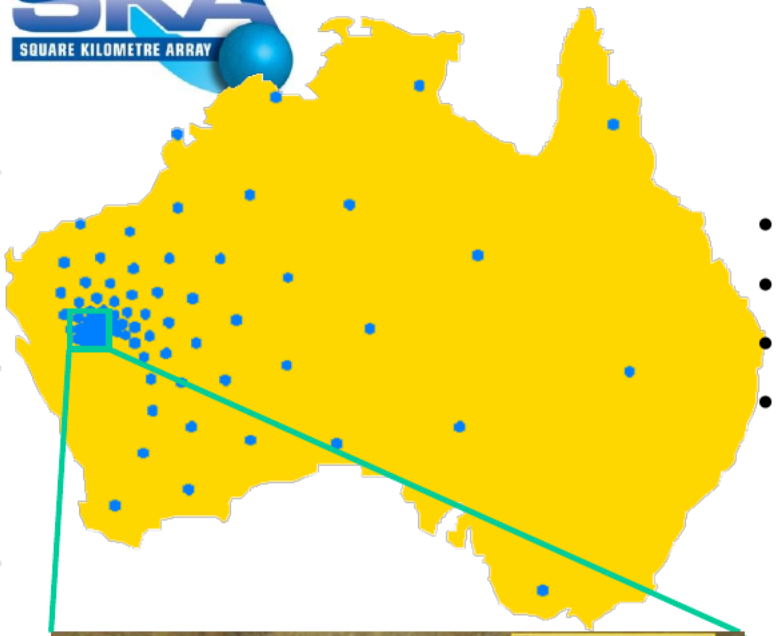
# SKA

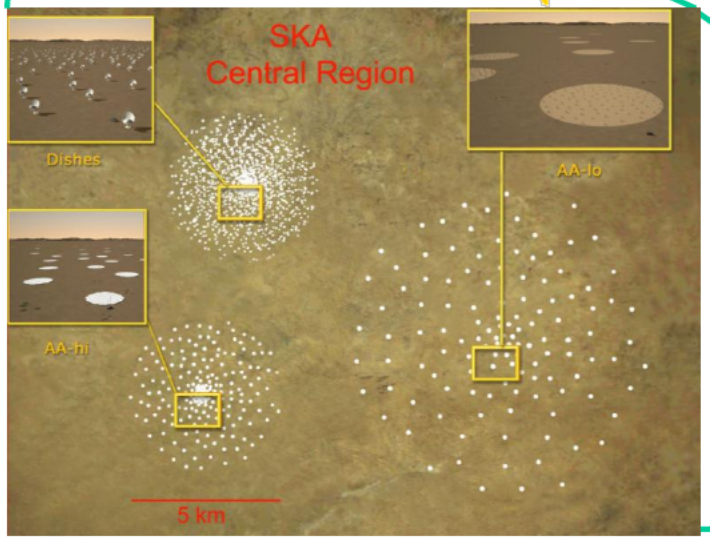
SKA SQUARE KILOMETRE ARRAY

UNIVERSITY OF CAMBRIDGE

## also a Continental sized Radio Telescope

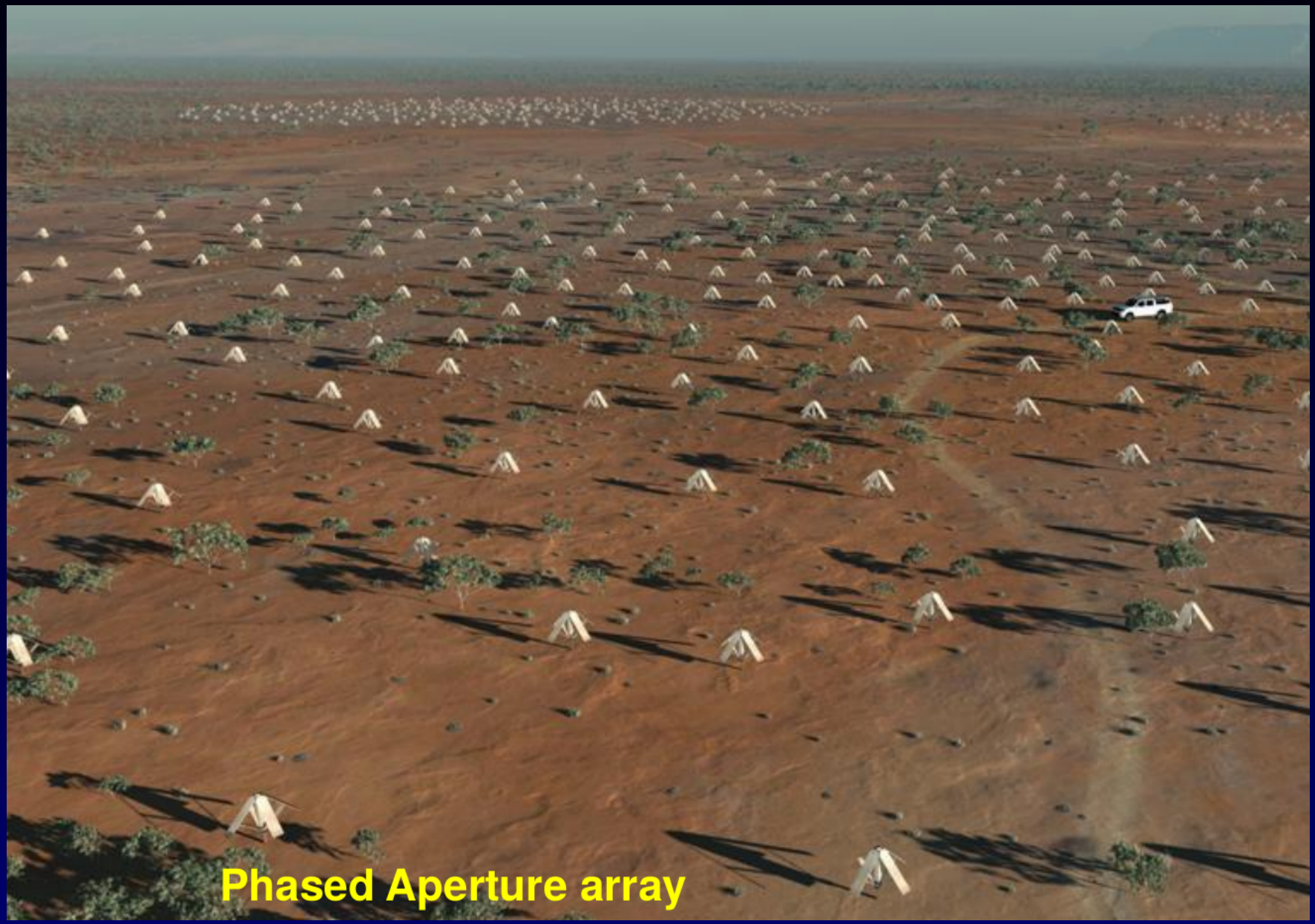
- Need a radio-quiet site
- Very low population density
- Large amount of space
- Possible sites (decision 2012)
  - Western Australia
  - Karoo Desert RSA



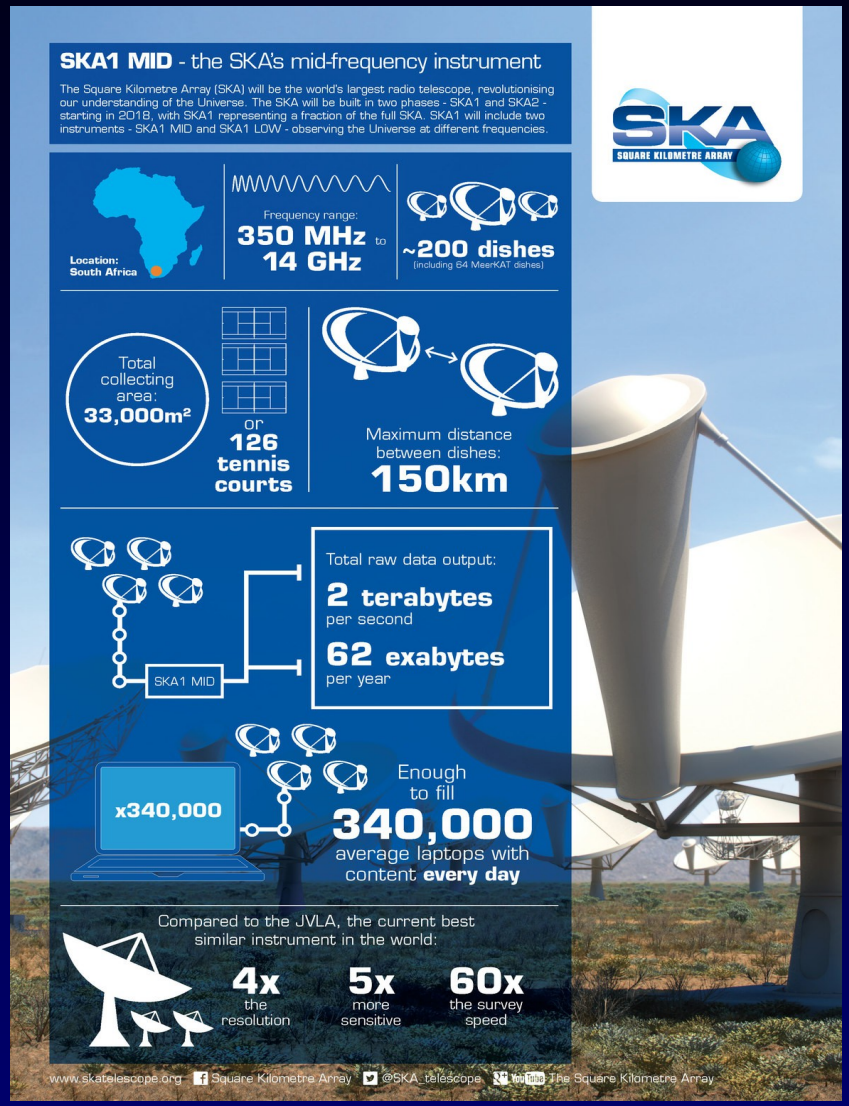


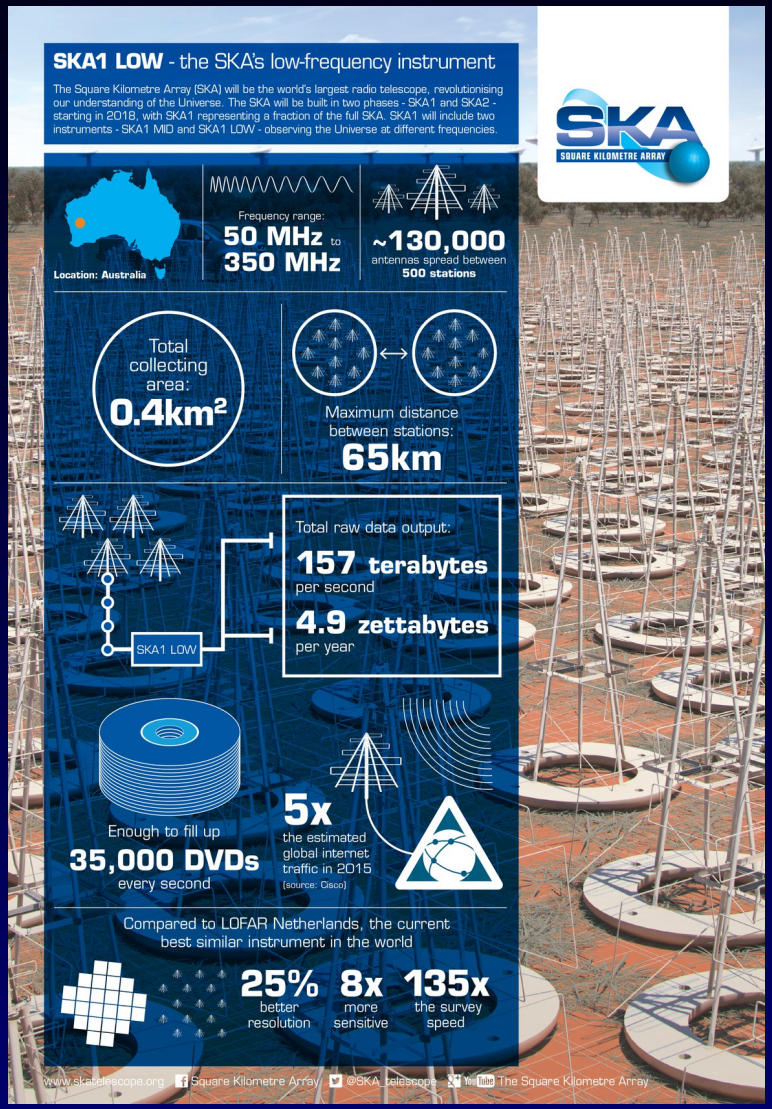

# SKA

# SKA



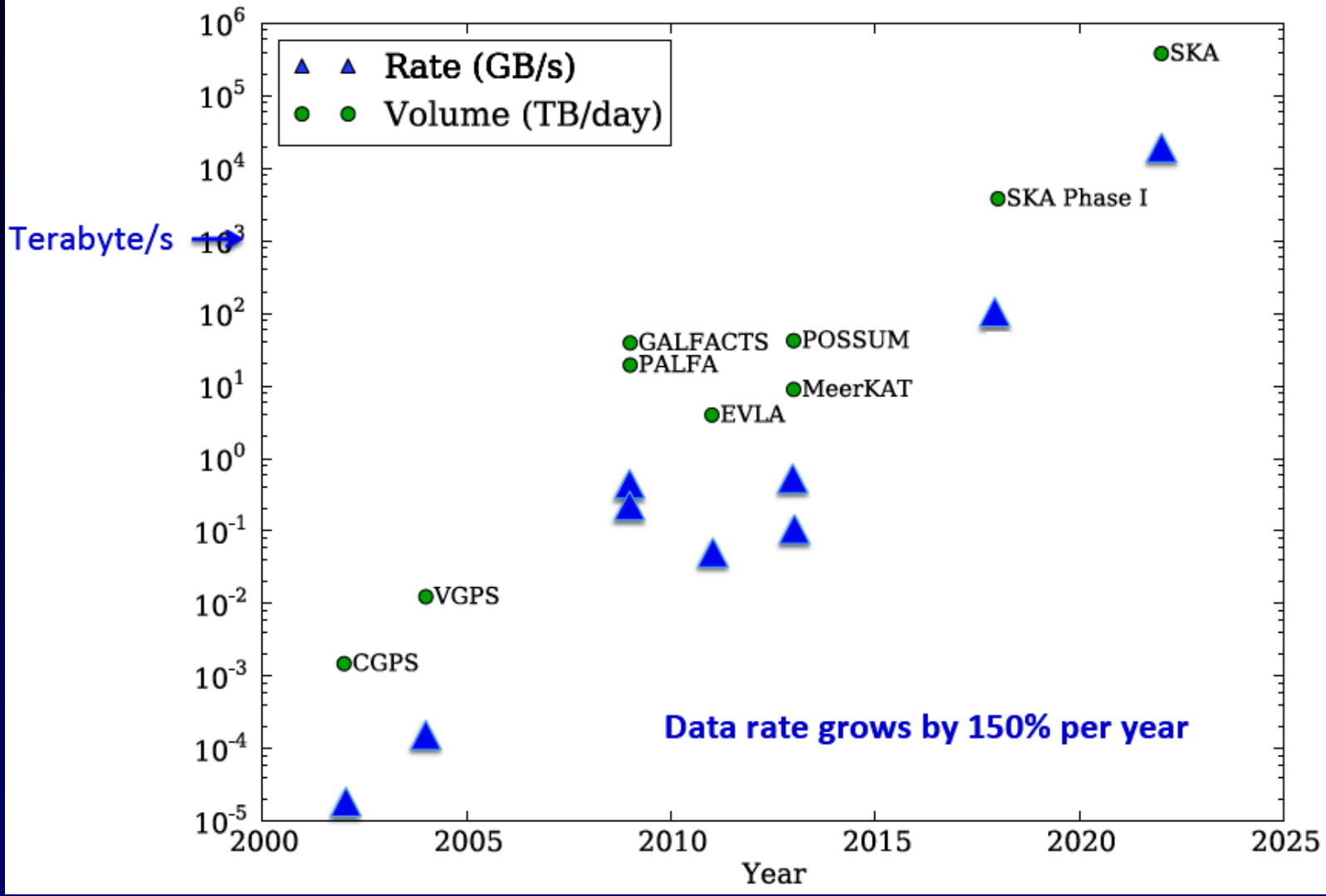
# Square Kilometer Array
# SKA



# Cyber SKA

## Survey Raw Data Rates **out of Correlator**



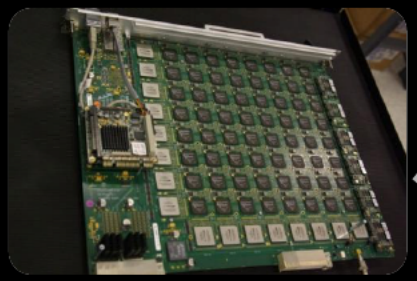

R. Taylor 2013

# SKA Data Challenge

LOFAR ASTRON

**Antennas**

**Digital Signal Processing (DSP)**



To Process is HPC
2020: 100 PBytes/day
2028: 10,000 PBytes/day

Over 10's to 1000's kms

Transfer antennas to DSP
2020: 20,000 PBytes/day
2028: 200,000 PBytes/day

Over 10's to 1000's kms

**HPC Processing**
**2020: 300 PFlop**
**2028: 30 EFlop**

**High Performance Computing Facility (HPC)**

# 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

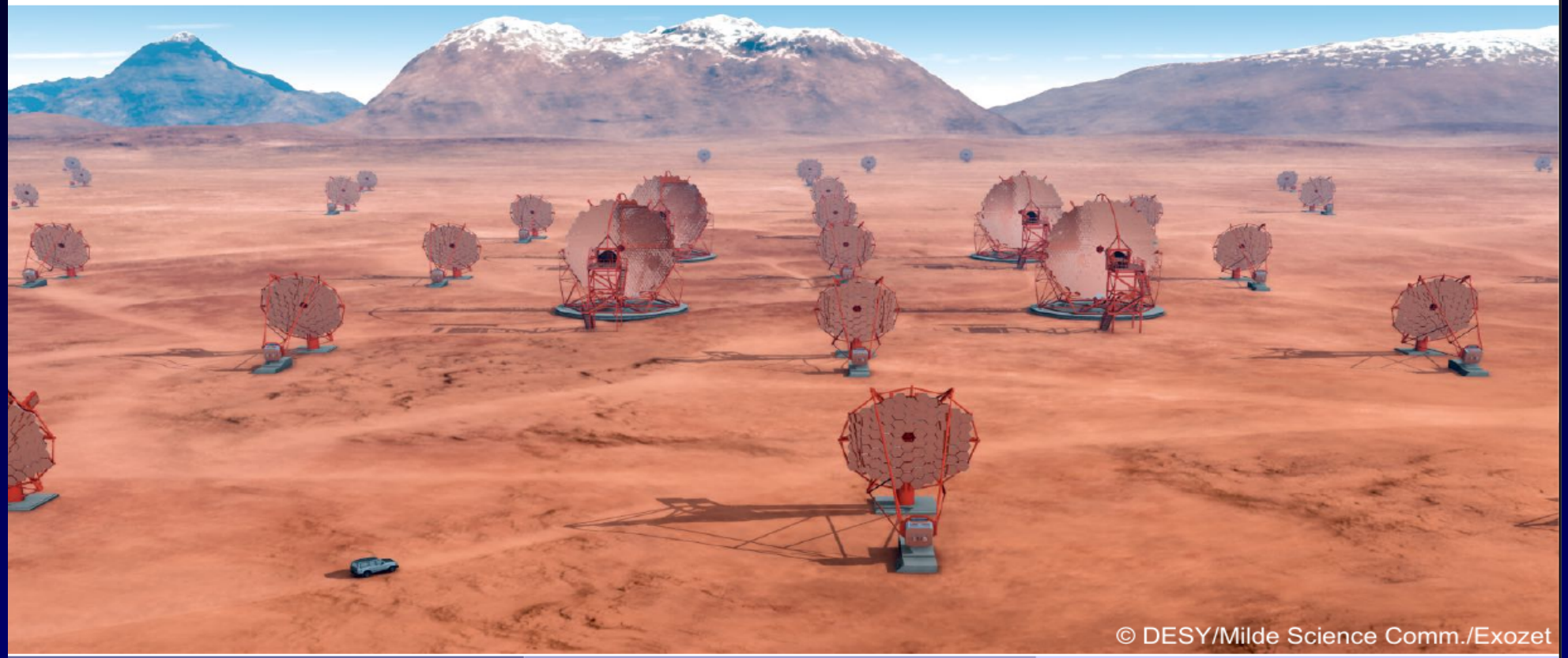
**100 Pbytes – 3 EBytes / year of fully processed data**

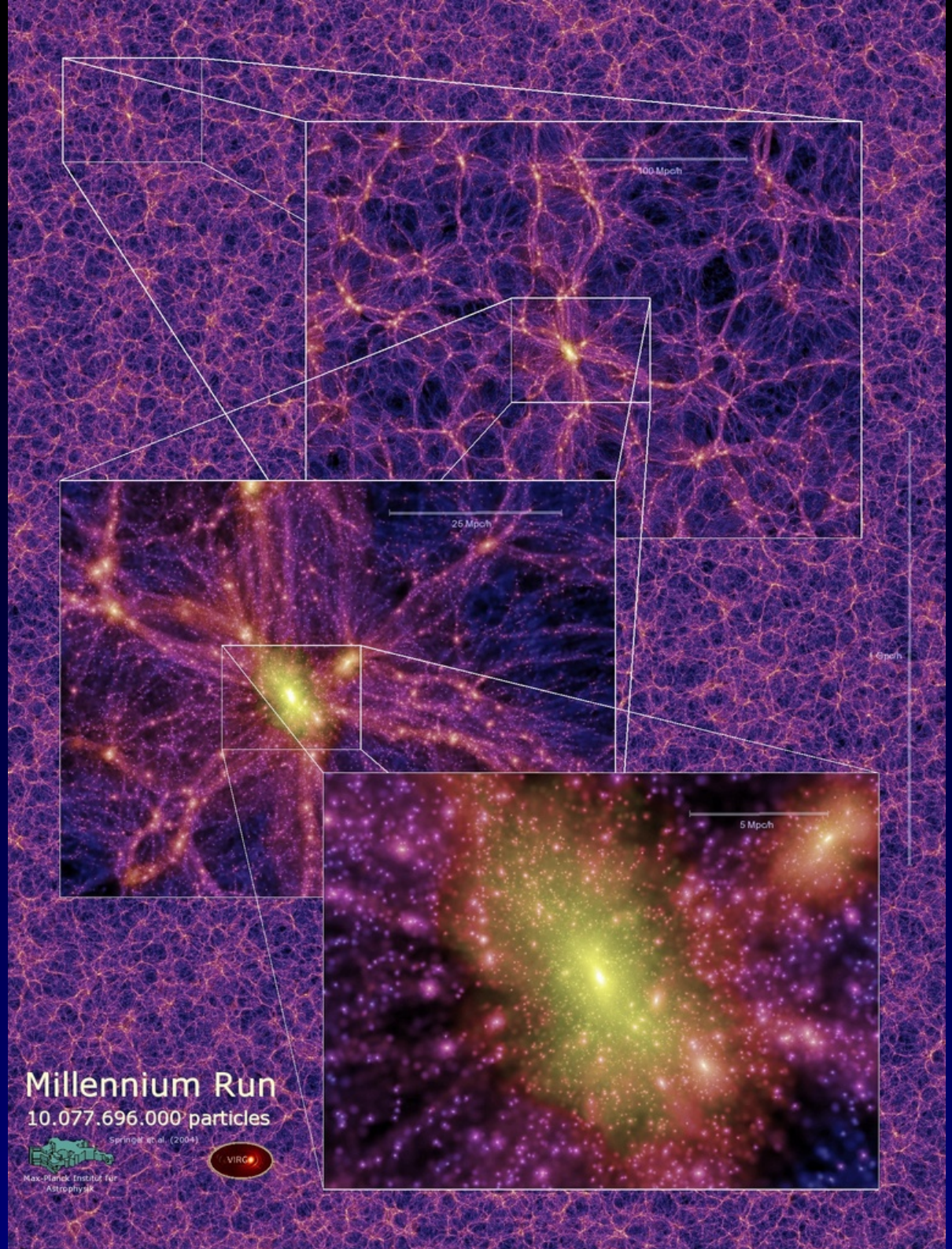
# Cherenkov Telescope Array



cta
cherenkov telescope array
Observatory

- Two arrays of **100 (South)** et **20 (North)** telescopes
- July 2015: sites selection, Chile (ESO) and La Palma
- 2016: pre-production phase
- 2018-2013: production phase
- Observatory **open** to the community






# Millenium Run

- 10^10 particles
- Several Gpc to
- 10 kpc
- Cube 2 billion ly
- One month MPSSC
- 25 TB
- Evolution of 20 mil galaxies
- Evolution merger tree

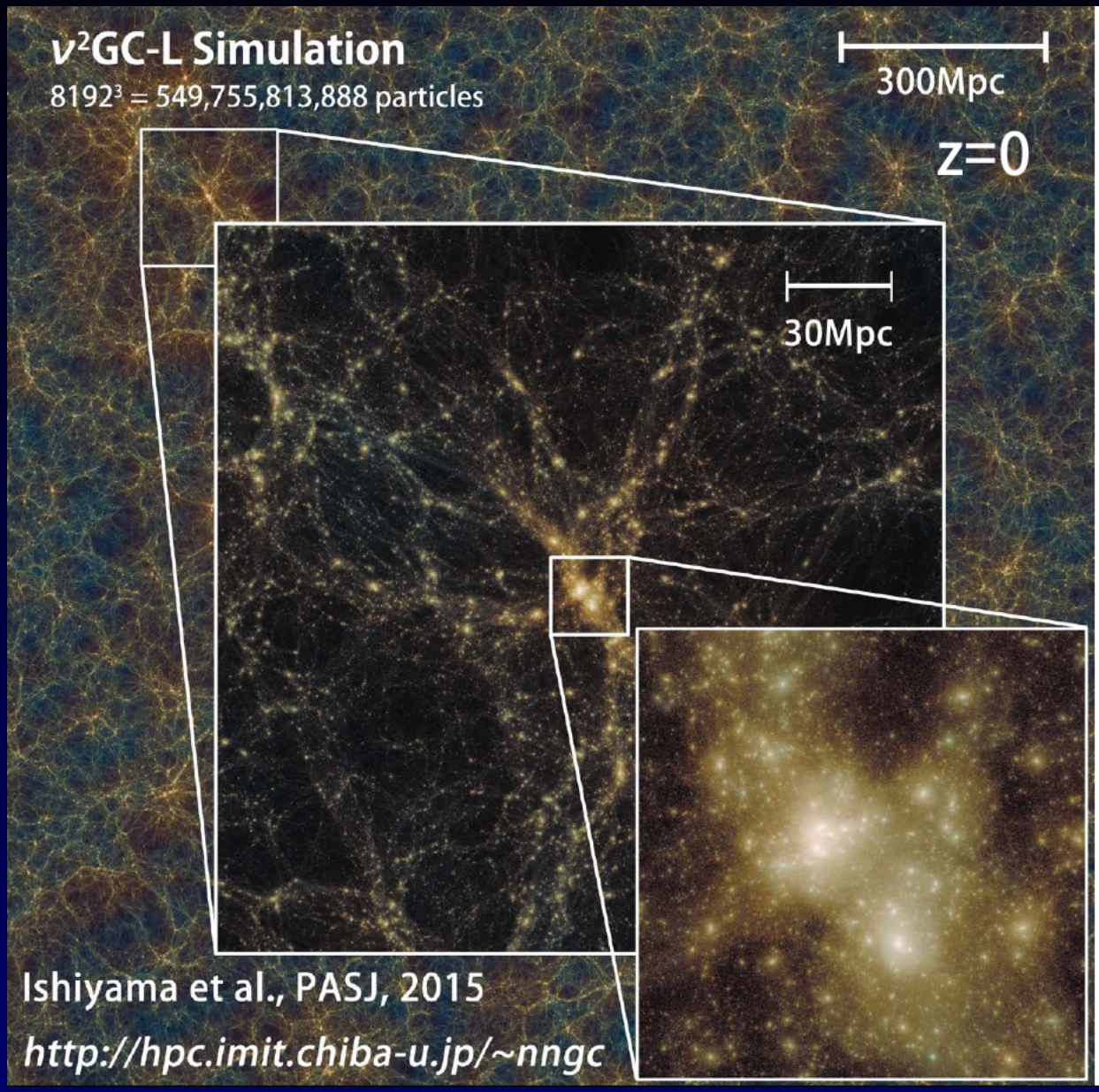
# Simulation of the Universe

World's fifth fastest supercomputer

## K computer

- SPARC64™ VIIIfx, 2.0GHz octcore (128Gflops / CPU)
  - Total 82944 nodes (663552 CPU core), 10.6 Pflops peak spped
- 16 GB memory / core, Total 1.3PB memory
- 6D torus network

# Simulation of Universe




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

L = 1.12 Gpc/h
m = 2.2 x $10^8$ 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 x $10^8$ Msun/h
- WMAP1 ($\sigma_8$=0.9)

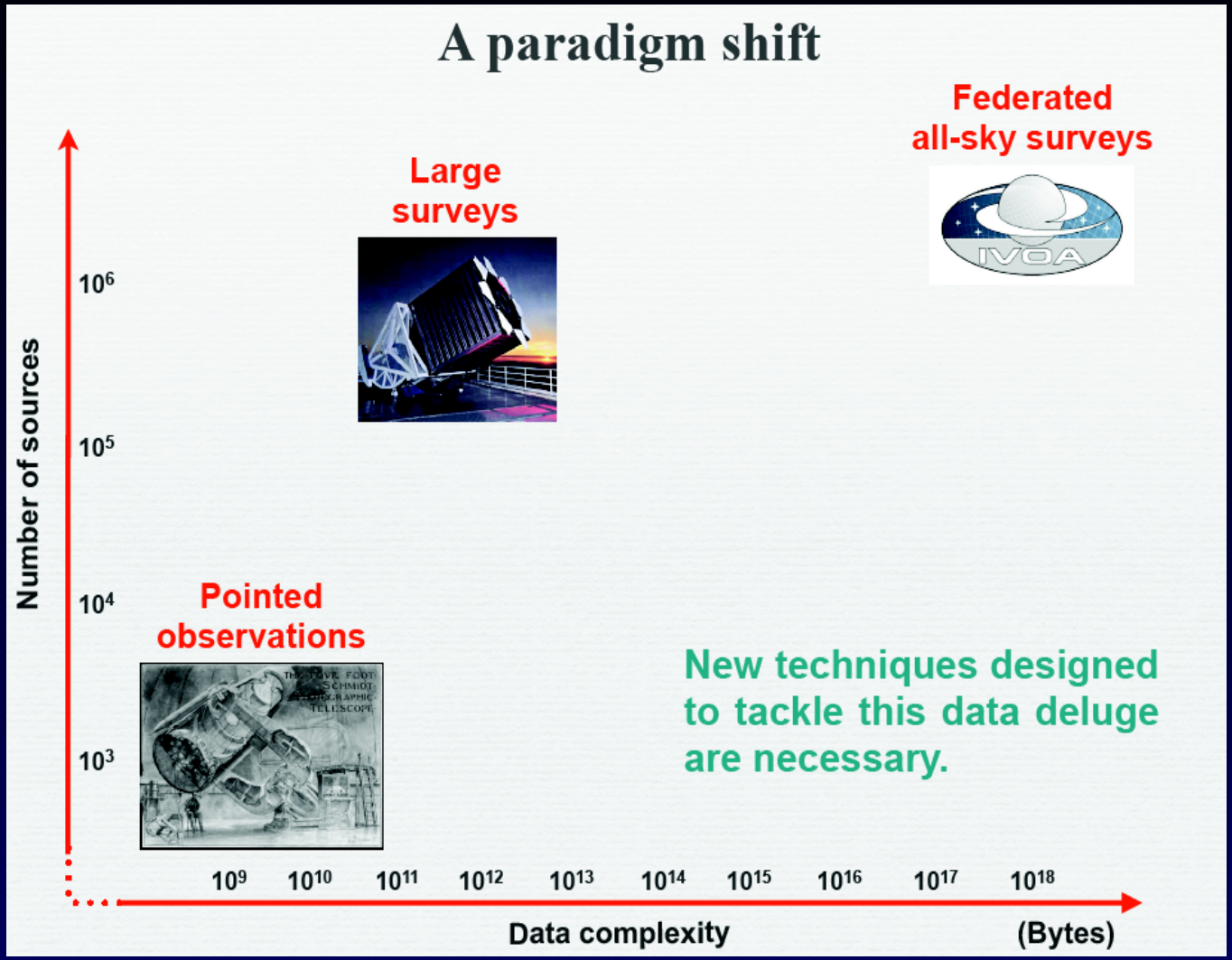
~ 100 hours on
131,072 CPU cores
of K computer

Data size : ~1PB

# Problem of 1PB Data Transfer

## Data transfer

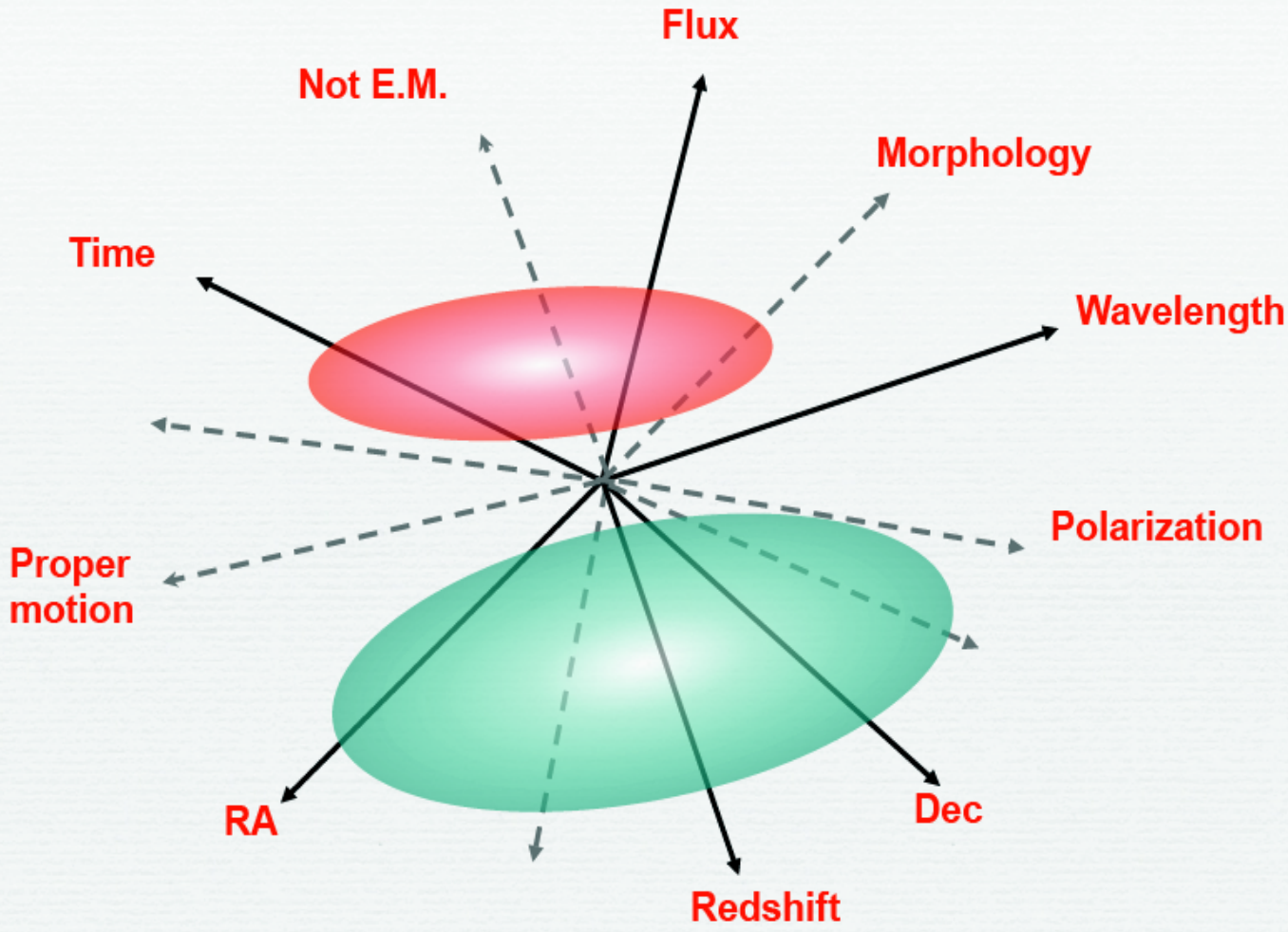
- If 100 Mb/s network is available
  - ~10TB / day
  - ~100 days / 1PB
- Typically, effective speed is less than 10Mb/s
  - < 1TB / day
  - > 3 years / 1PB ……
- **Delivery by car**
  - **3 days / 1PB**
    - From Kobe to Chiba
      (from Kyoto to Tokyo + 100km , ~600km journey)




D'Abrusco 2010

Data analysis at storage place
Move processing = not data !

# A growing parameter space




**Most discoveries were made in small regions of subspaces or along some of these axes**

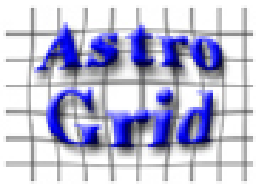
D'Abrusco 2010

# 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


Astro
Grid


ArVO
American Virtual Observatory


Aus-VO


BRAVO


China-VO


CVO


esa


France


IVOA


ESO


GERMAN ASTROPHYSICAL
GAVO
VIRTUAL OBSERVATORY


EURO VO


HVO
Hungarian Virtual Observatory


JVO


NOVA


RVO

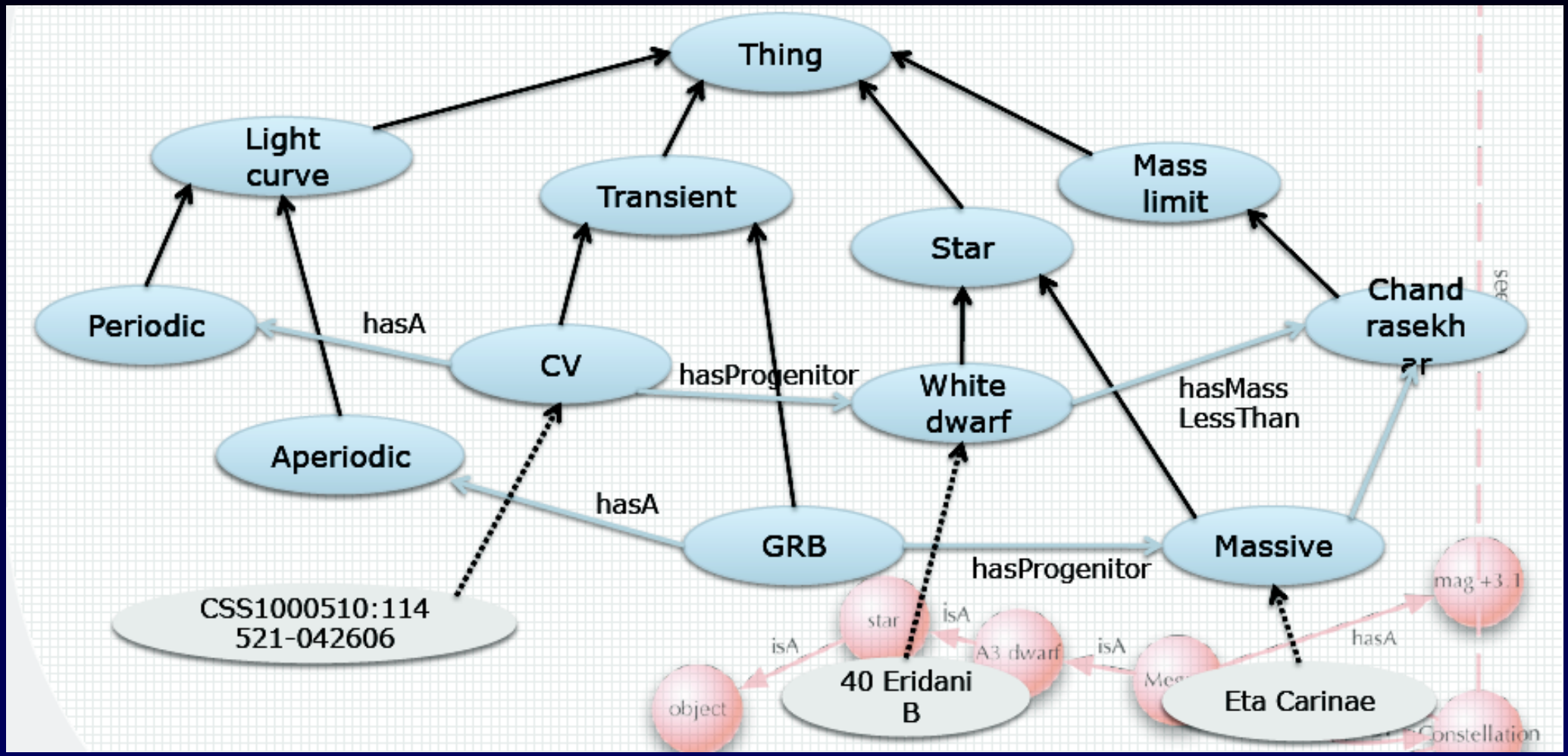

SVO


vo-i


VAO
VIRTUAL ASTRONOMICAL OBSERVATORY


VObs.it

# Ontologies in Astronomy

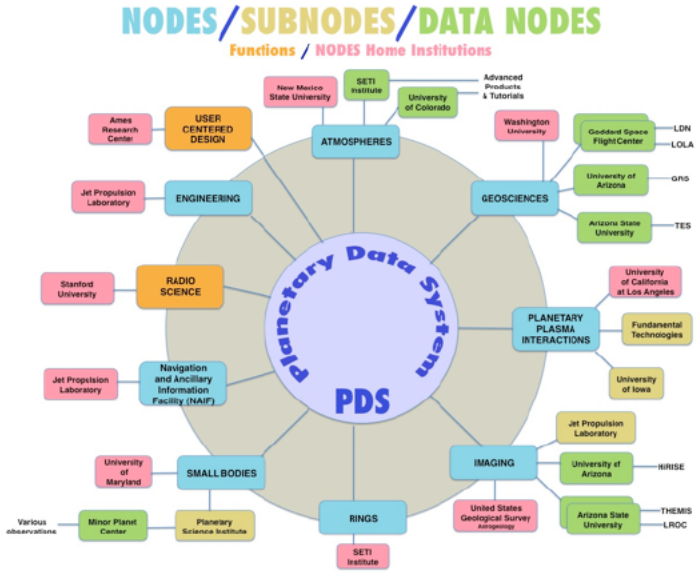



SKOS, RDF standards, search with understanding (not return QSO as binary star)

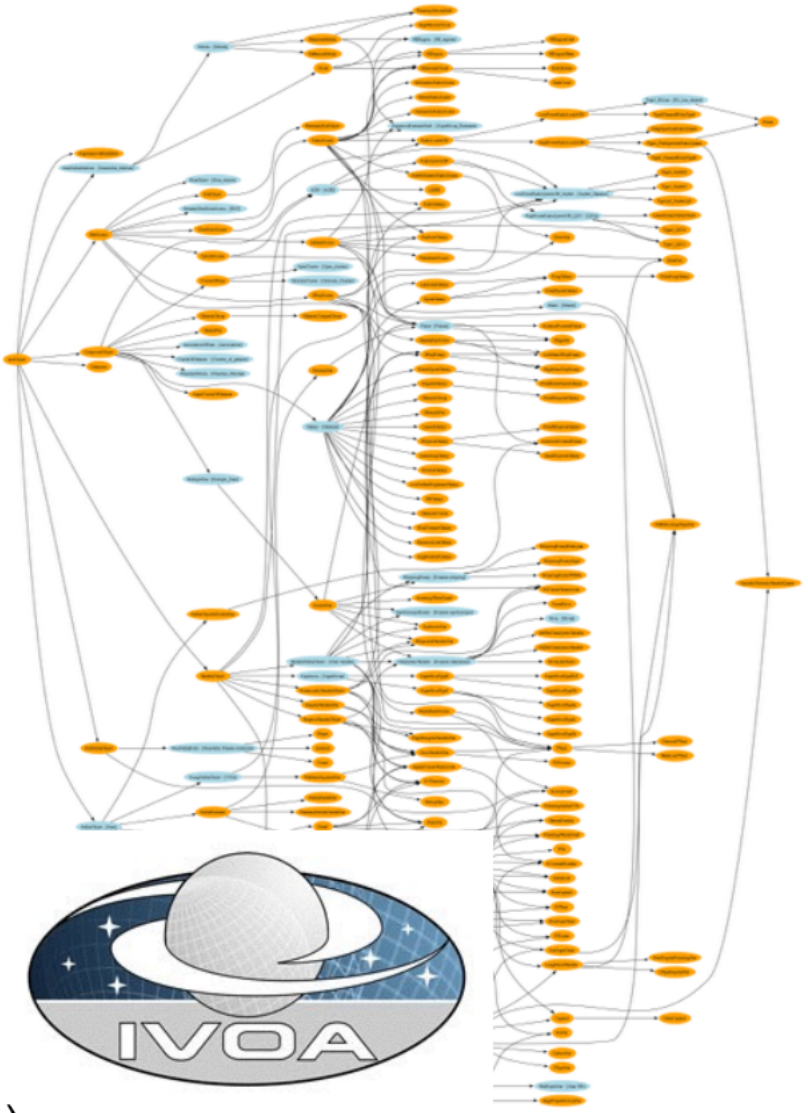
From Graham, M. AI2010

# Ontologies

## Ontologies




***PDS***
***Steve Hughes***
***Dan Crichton***




PDS -> Earth Science (NASA)

Astronomical Objects

# Technology of VO

Unified data format– VOTable, UCD (Vizier)

Transparent transport (unit conversion)

Web services (WS) e-commerce, B2B, J2EE, .Net

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)
- TAP (Table Access Protocol)
- VOEVENT (transients, robotic telescopes,Sun)
- more – datacubes, on-the-fly data generation....

# Technology of VO

ADQL (Astronomical Data Query Language)

- XMATCH, REGION (2 catalogues - shifted)

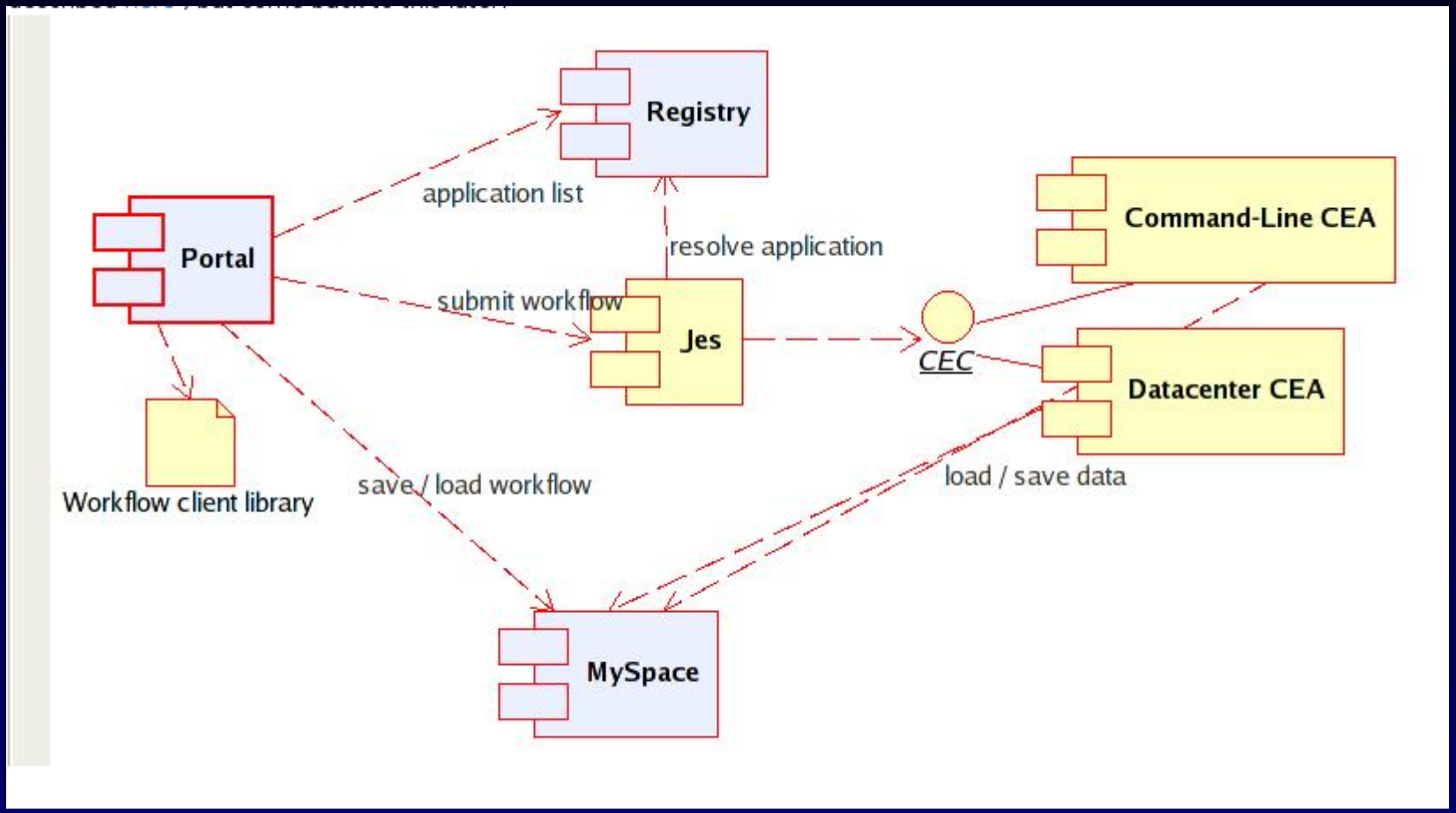
Application interoperabilty – (PLASTIC), SAMP

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

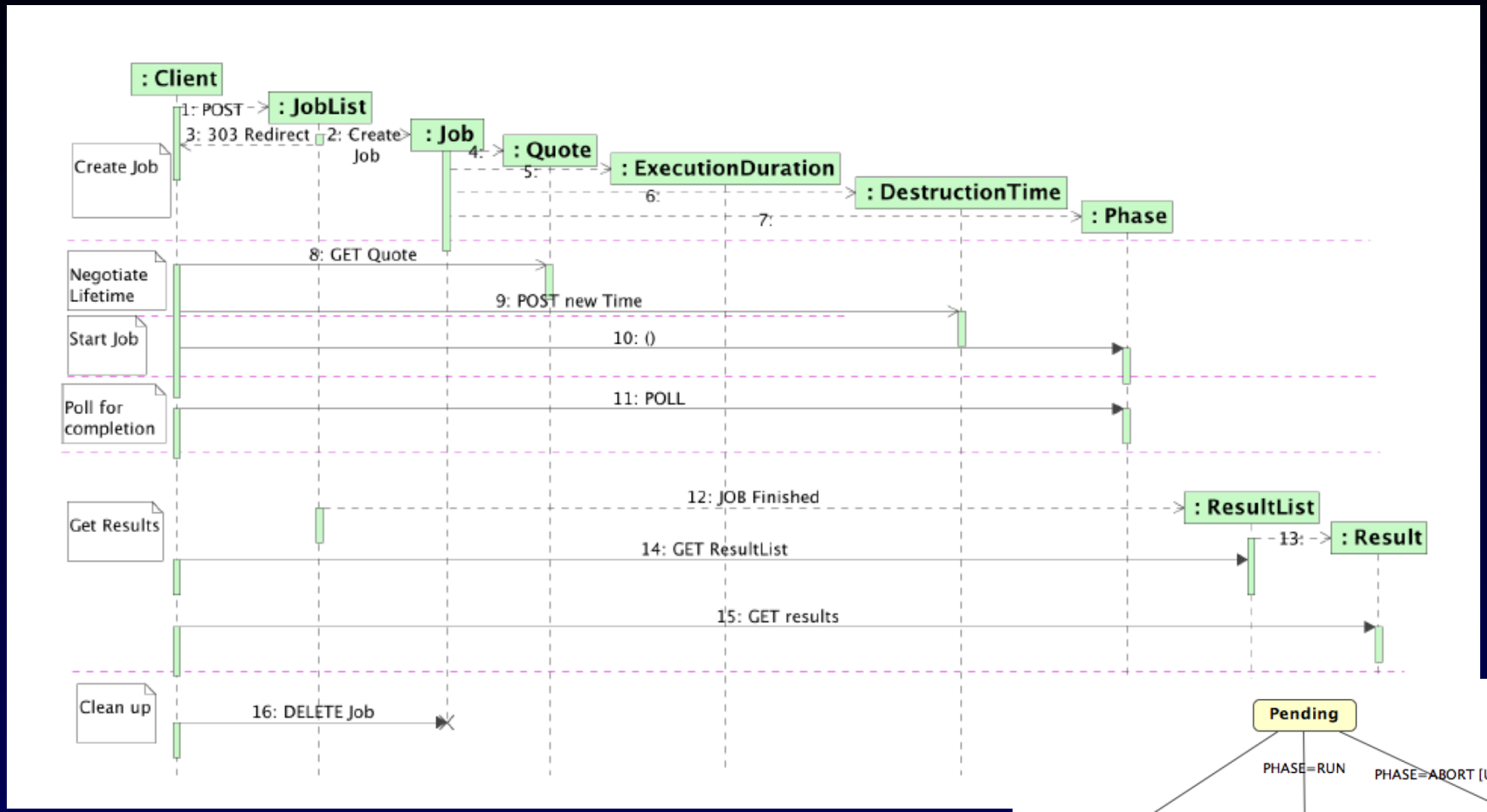
Commercial interest (GoogleSky, MS WWT)

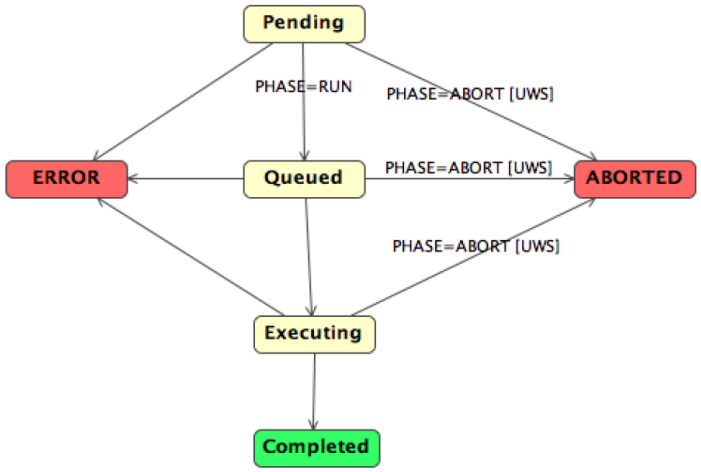
# Workflows - Astrogrid

Running remote services – e.g. Sextractor, CASJobs, AstroNeural MLP....

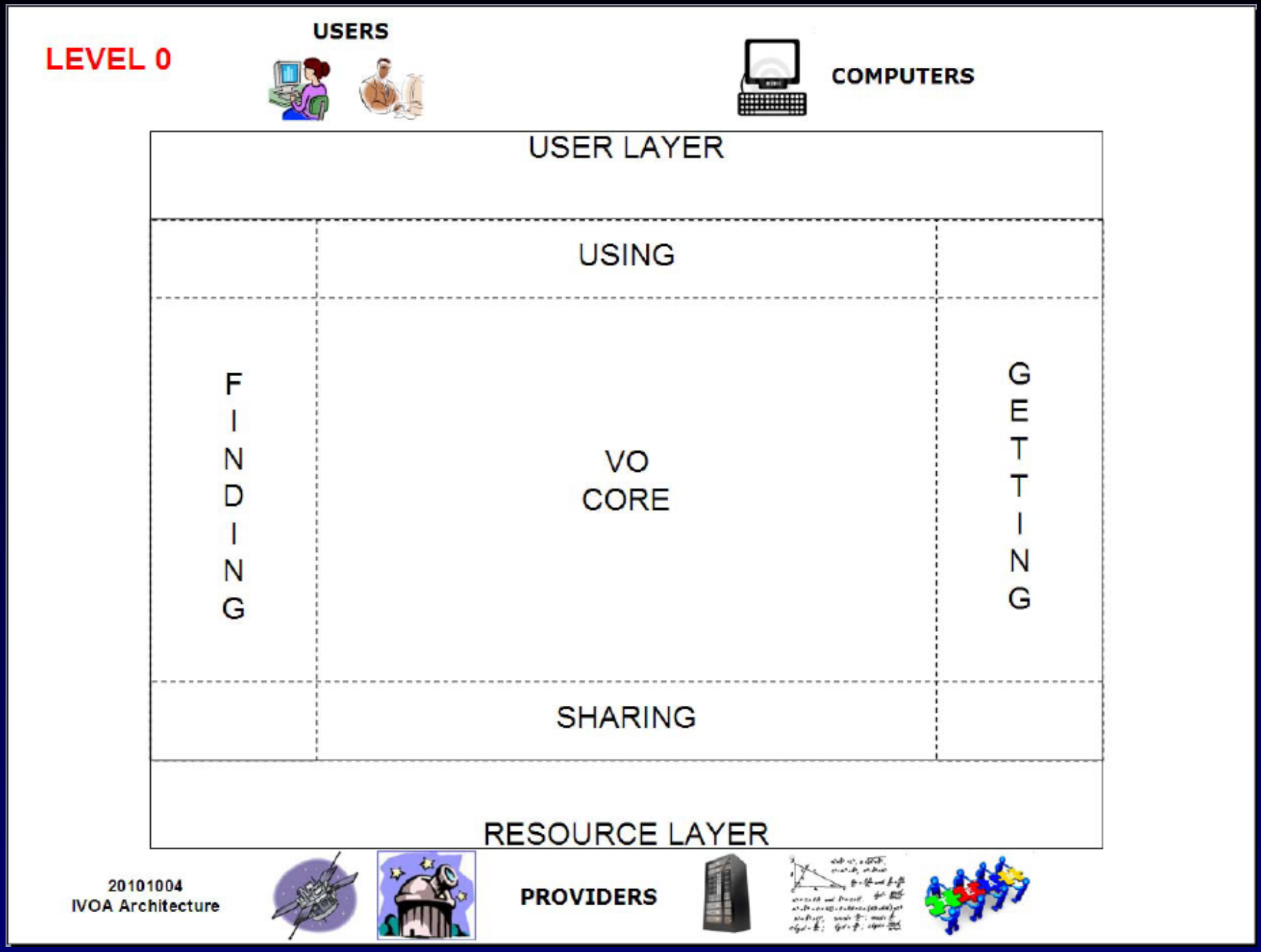


# IVOA Universal Worker Service (UWS)

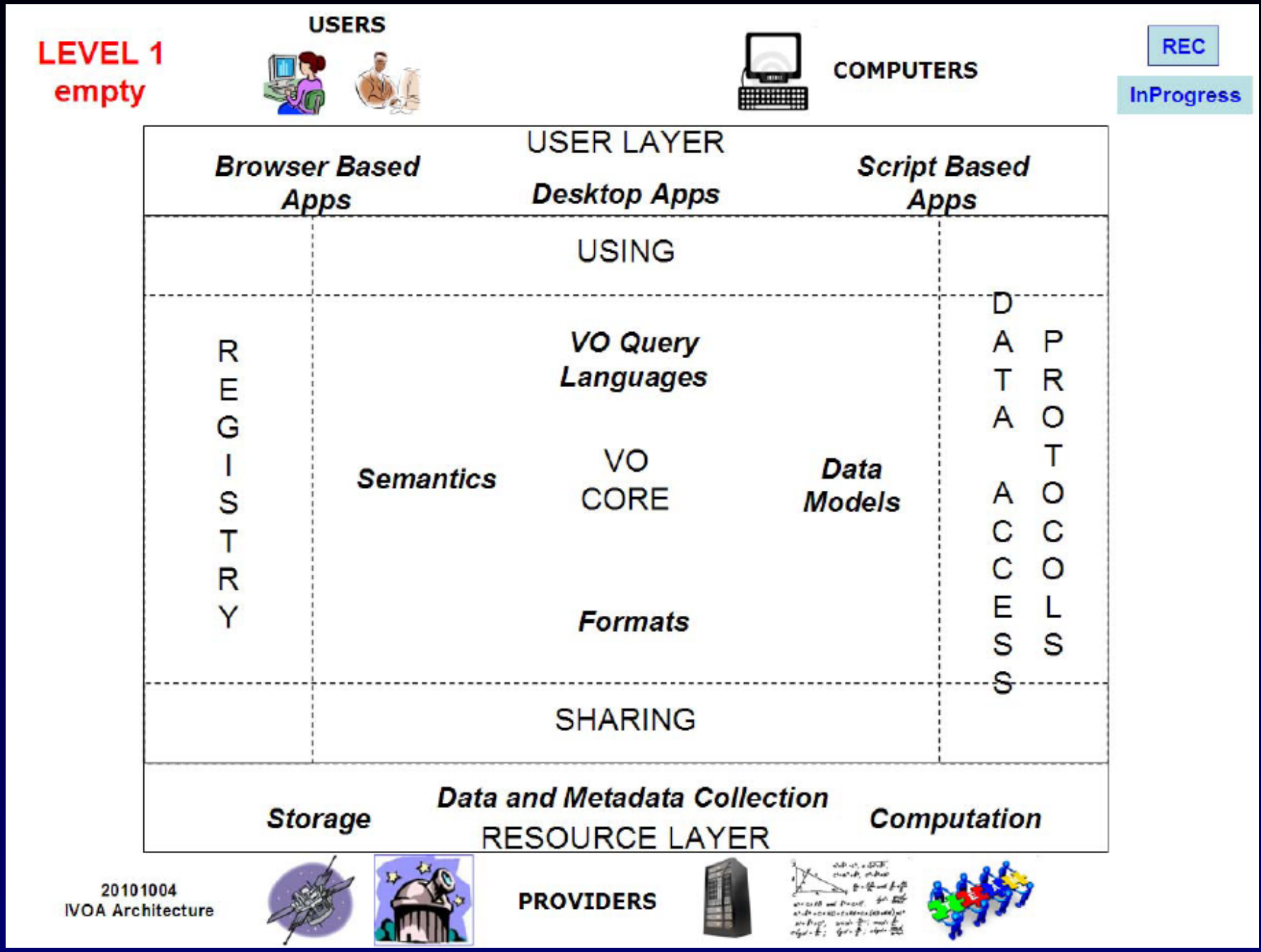


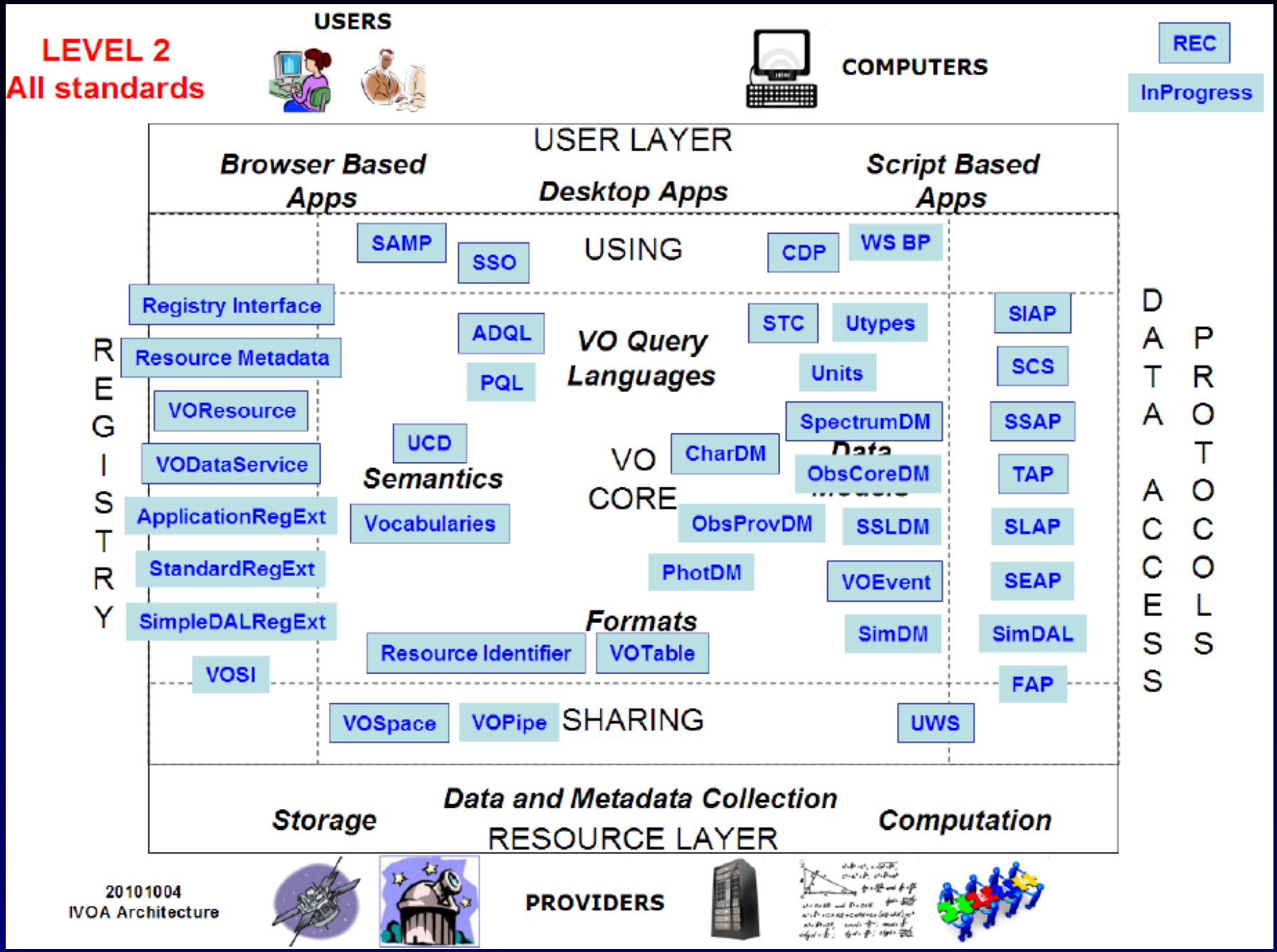
# Ecosystem of VO – level 0



# Ecosystem of VO – level 1



# Ecosystem of VO – level 2



# FITS standard

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

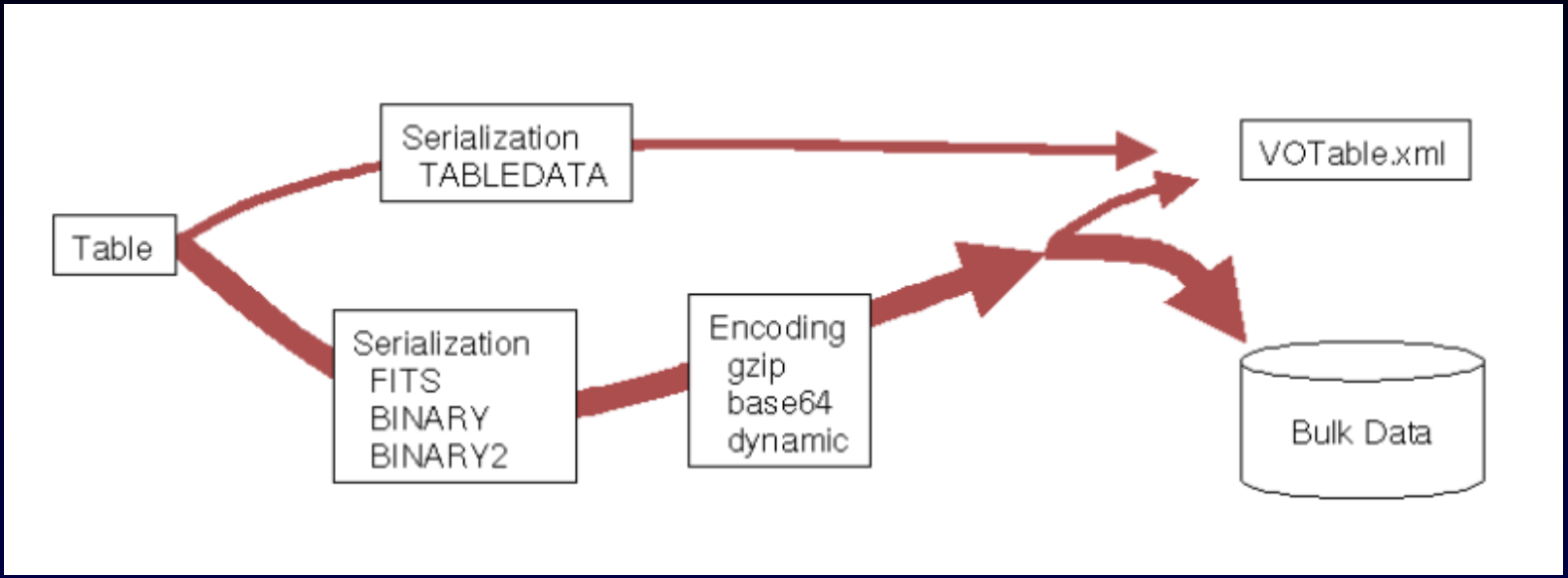
```
SIMPLE  =                    T / file does conform to FITS standard
BITPIX  =                   16 / number of bits per data pixel
NAXIS   =                    2 / number of data axes
NAXIS1  =                 2048 / length of data axis 1
NAXIS2  =                 2048 / length of data axis 2
EXTEND  =                    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

```
<TABLE name="SpectroLog">
<FIELD name="Target" ucd="meta.id" datatype="char" arraysize="30*"/>
<FIELD name="Instr" ucd="instr.setup" datatype="char" arraysize="5*"/>
<FIELD name="Dur" ucd="time.expo" datatype="int" width="5" unit="s"/>
<FIELD name="Spectrum" ucd="meta.ref.url" datatype="float" arraysize="*"
      unit="mW/m2/nm" type="location">
<DESCRIPTION>Spectrum absolutely calibrated</DESCRIPTION>
<LINK type="location"
      href="http://ivoa.spectr/server?obsno="/>
</FIELD>
<DATA><TABLEDATA>
<TR><TD>NGC6543</TD><TD>SWS06</TD><TD>2028</TD><TD>01301903</
TD></TR>
<TR><TD>NGC6543</TD><TD>SWS07</TD><TD>2544</TD><TD>01302004</
TD></TR>
</TABLEDATA></DATA>
</TABLE>
```

Serialization (metadata first, end of data unknown, tree structure)

# 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 |

# Characterization

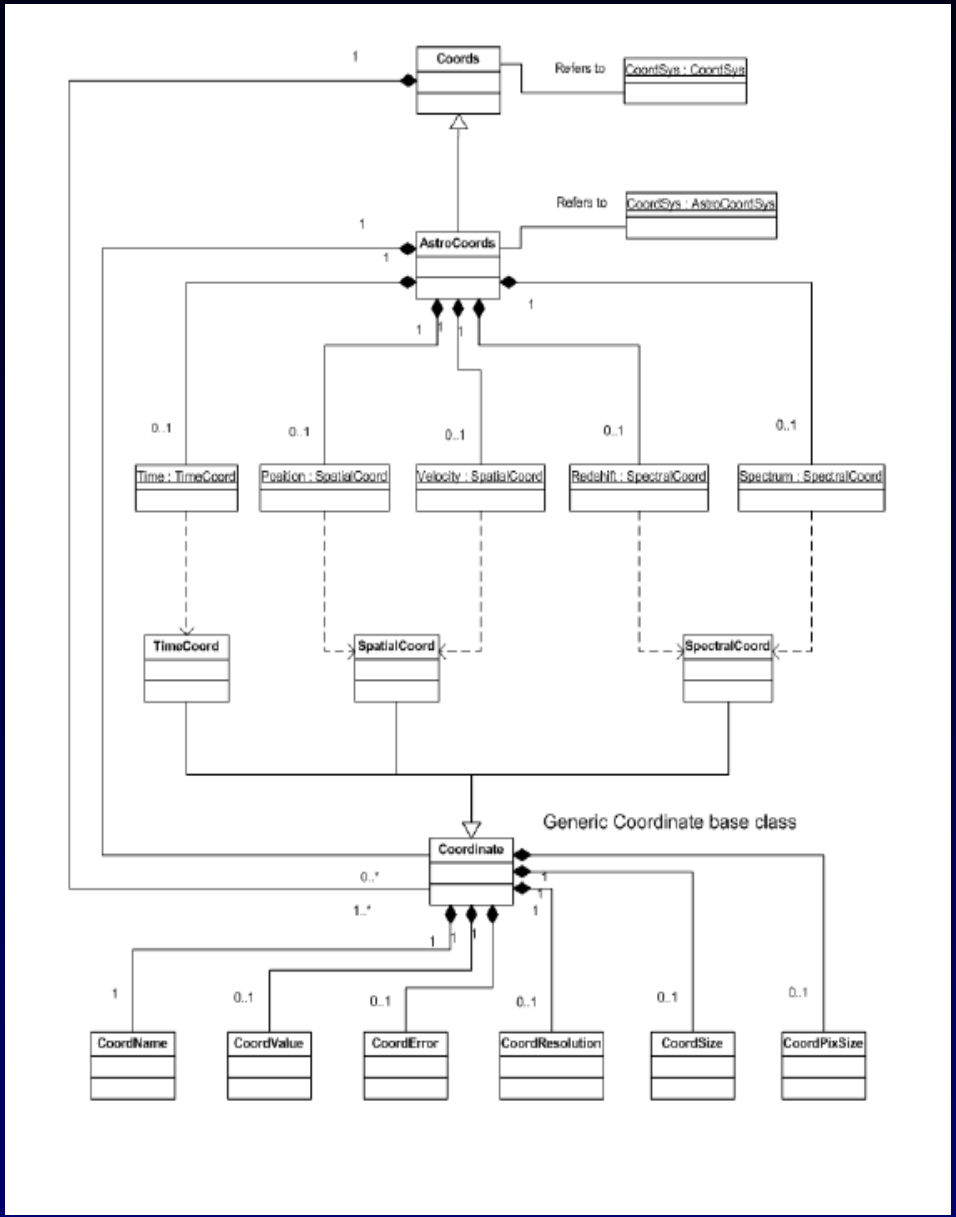
Curation – long time preservation issues (digital libraries)

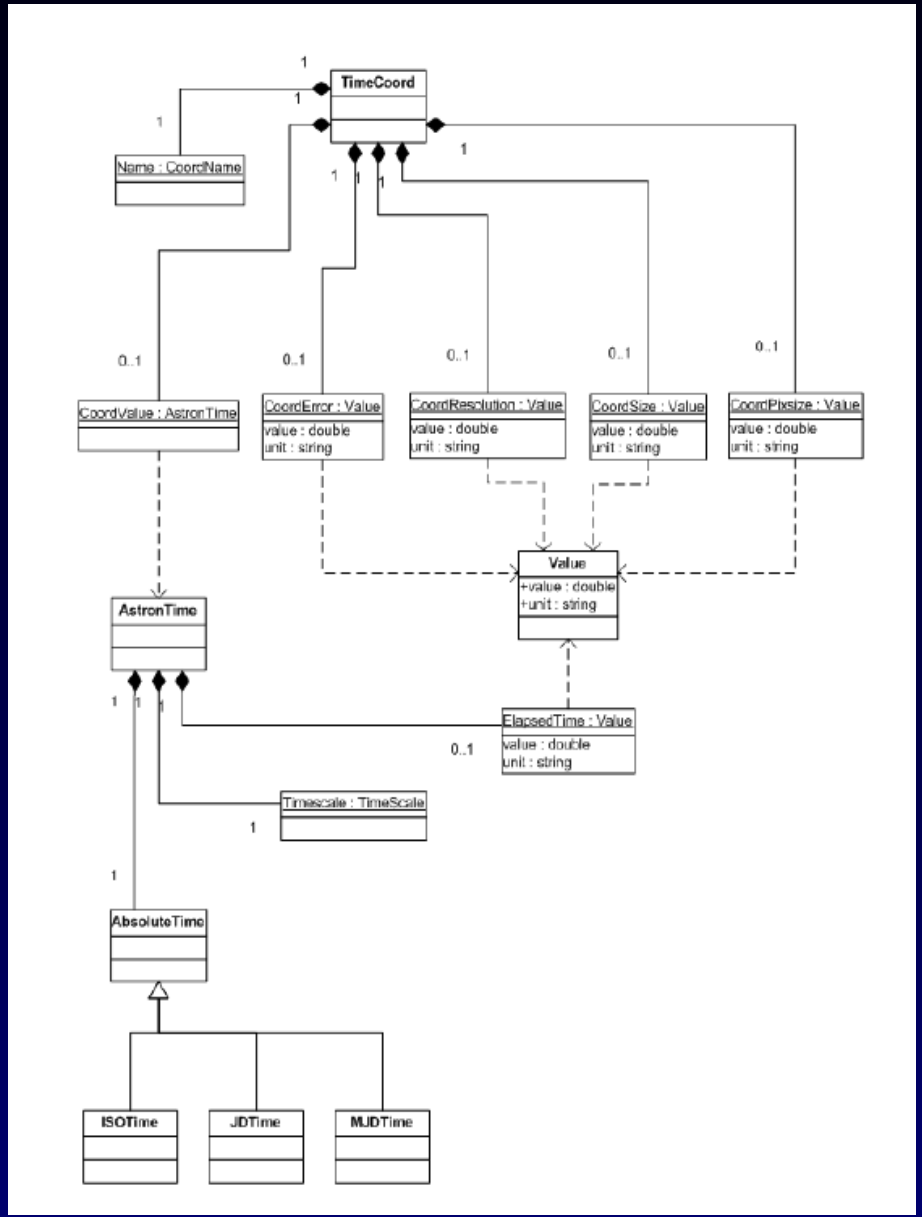
Provenance (how was processed, links to other products)

Characterization level 1 (spatial, spectral, temporal, polarization, location, coverage, porosity – SUB-CUBE)

Characterization level 2 (distorsion in images, spectra with nonlinear resolution …..)

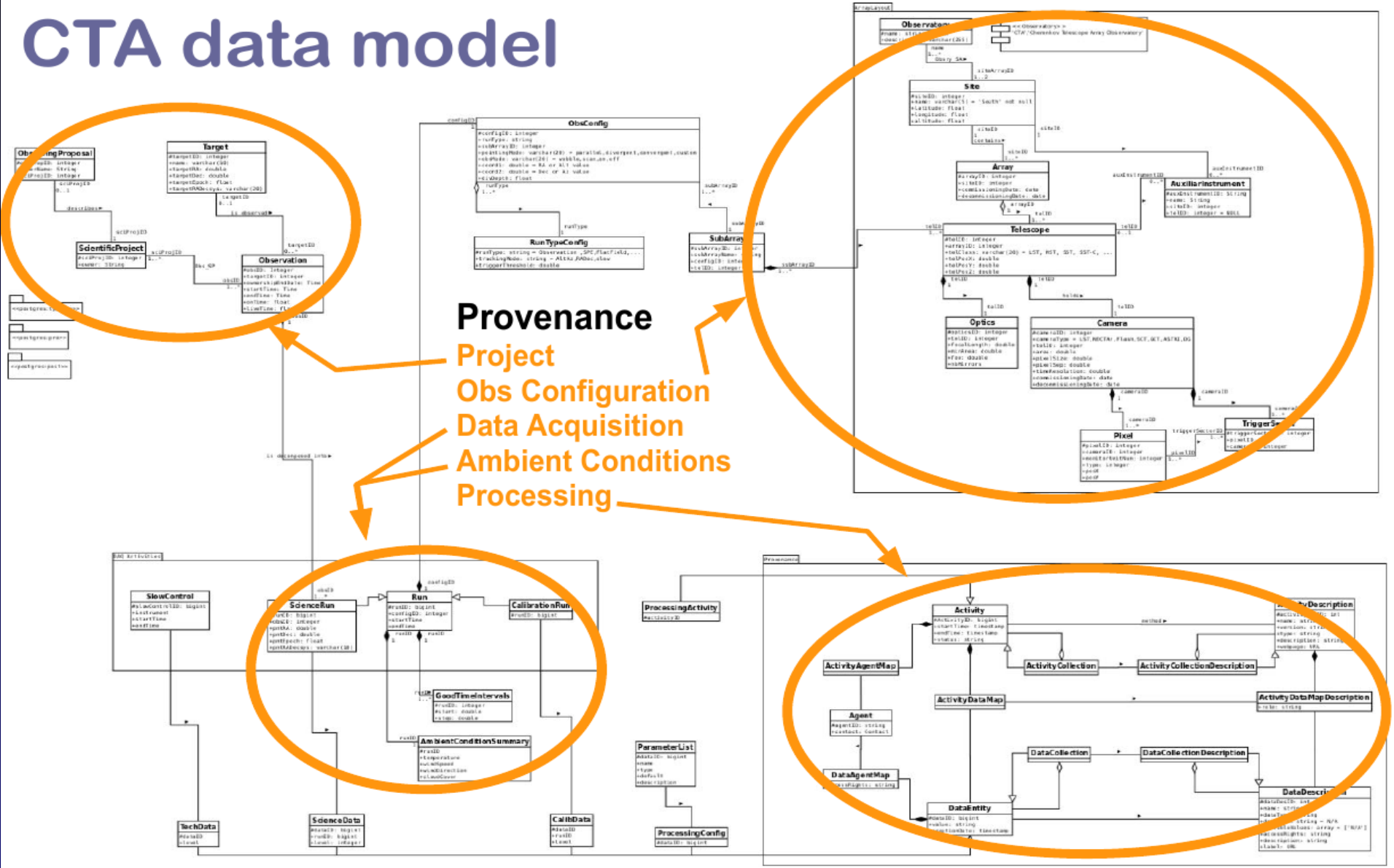
# Space-Time-Coordinate Data Model



# Cherenkov Telescope Array Data Model

## CTA data model



# 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

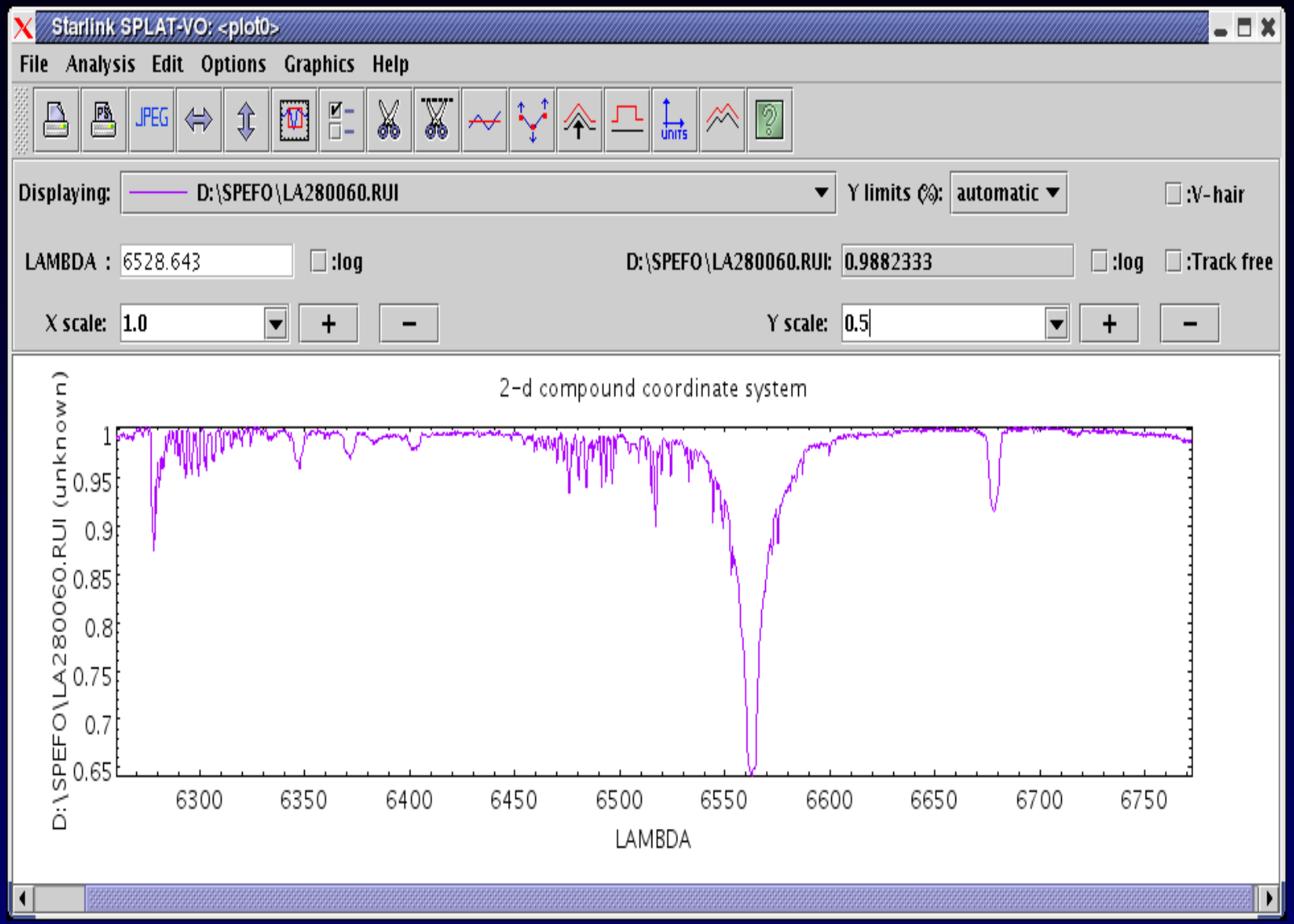
| Parameter | Sample value | Unit | Req | Datatype |
|---|---|---|---|---|
| APERTURE | 0.00028 (=1") | degrees | OPT | double |
| SPECRP | 2000 | λ/dλ | REC | double |
| SPATRES | 0.05 | degrees | REC | double |
| TIMERES | 31536000 (=1yr) | seconds | OPT | double |
| | | | | |
| SNR | 5.0 | dimensionless | 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

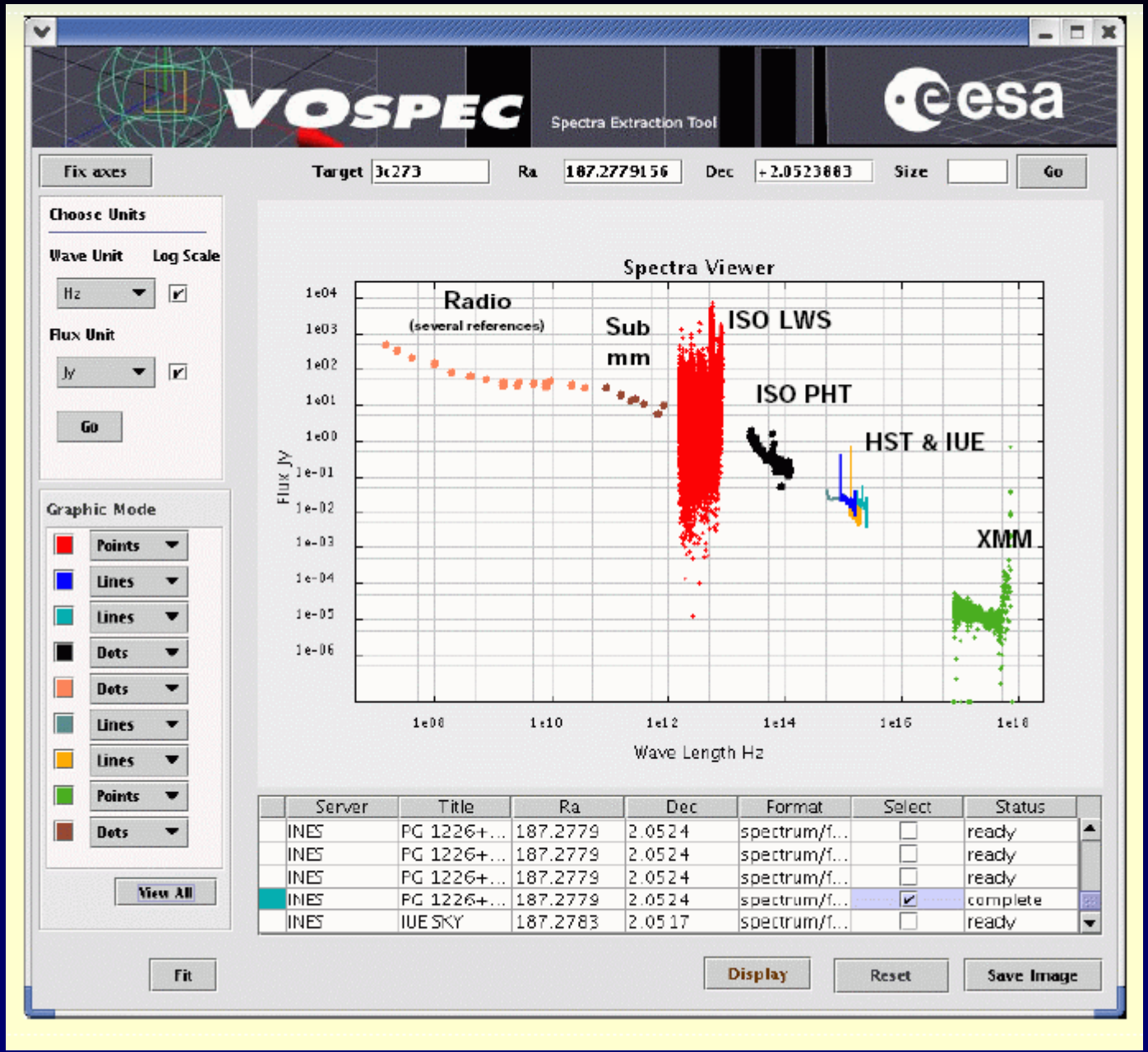
# Big Data handling

| | |
|---|---|
| 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 |

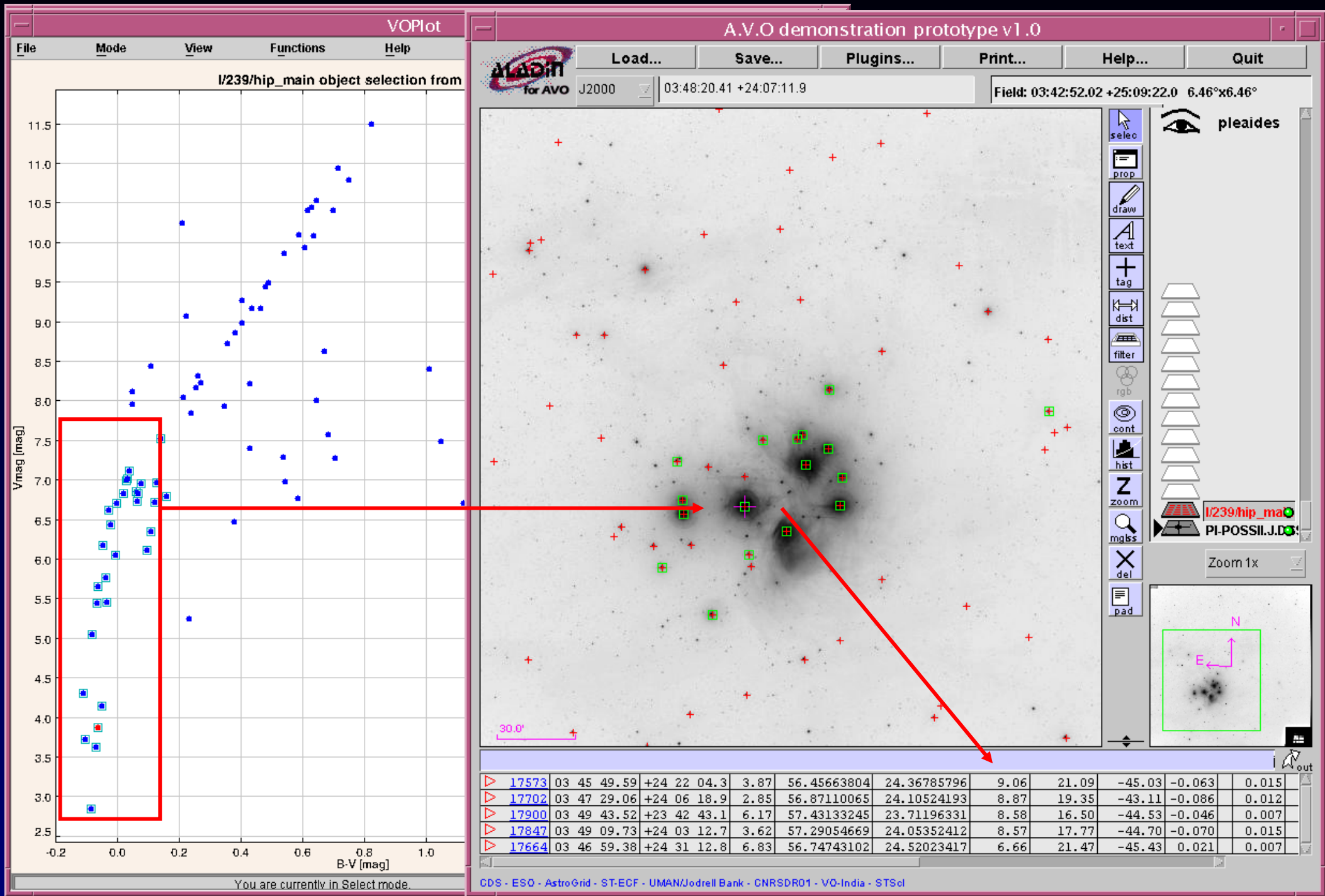
# SPLAT-VO (Starlink, JAC)



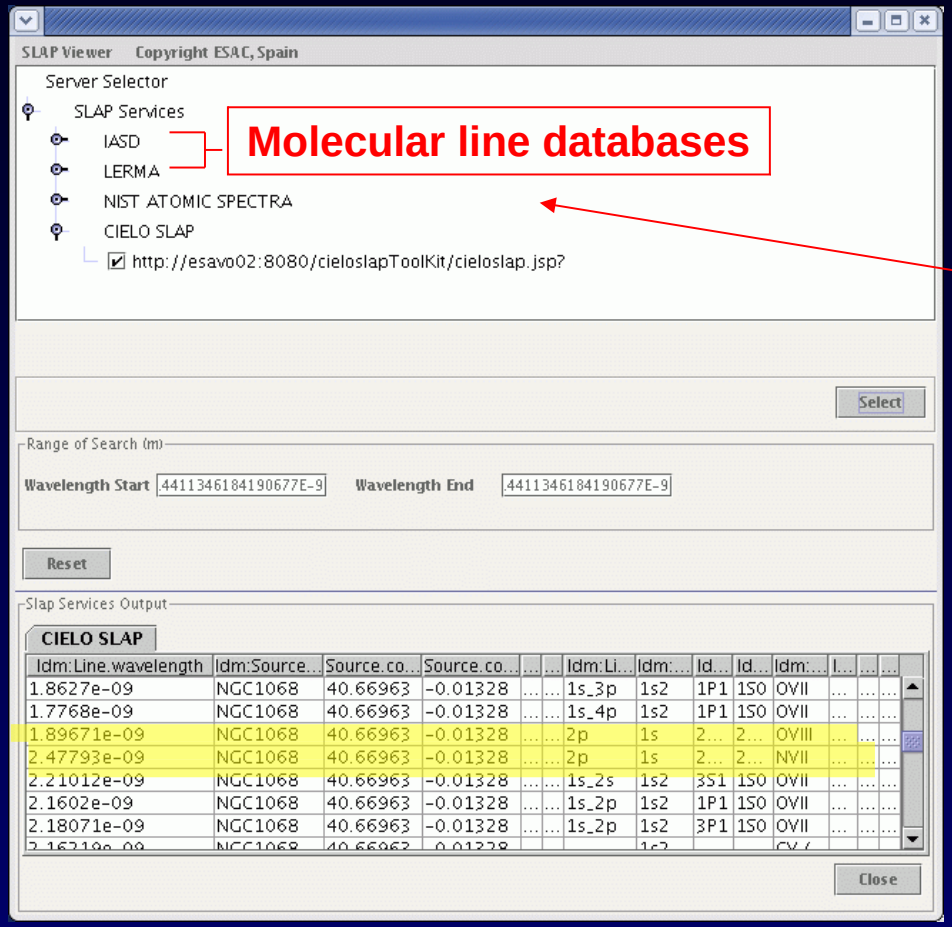
# VOspec (ESAC)

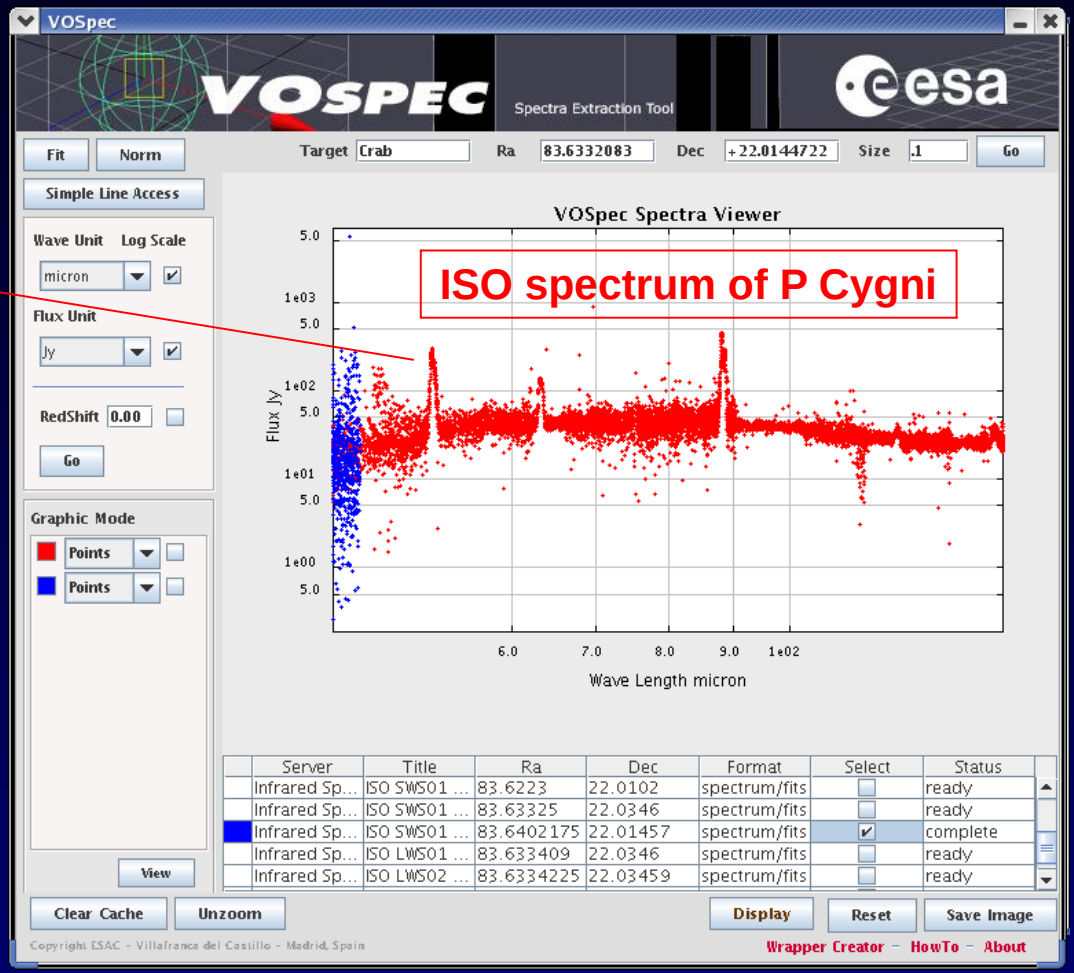

VOSPEC
Spectra Extraction Tool
esa
Fix axes
Target 3c273
Ra 187.2779156
Dec +2.0523883
Size
Go
Choose Units
Wave Unit
Log Scale
Hz
Flux Unit
Jy
Go
Graphic Mode
Points
Lines
Lines
Dots
Dots
Lines
Lines
Points
Dots
View All
Spectra Viewer
Radio
(several references)
Sub
mm
ISO LWS
ISO PHT
HST & IUE
XMM
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

# Colour-magnitude diagram



# CIELO VO – line catalogue SLAP




(IVOA Line Data Model: Dubernet, Osuna et al., in preparation)
(Simple Line Access Protocol: Salgado et al., in preparation)

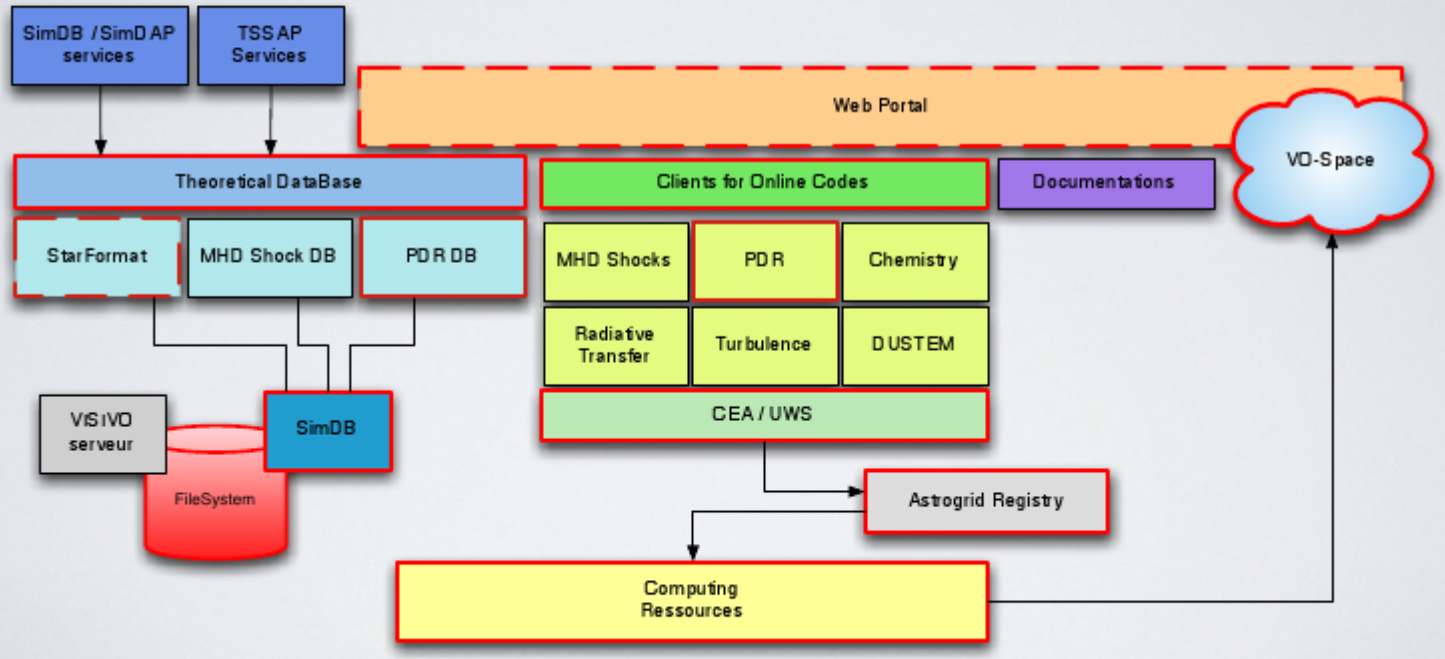
# ISM platform

## Interstellar Medium Platform

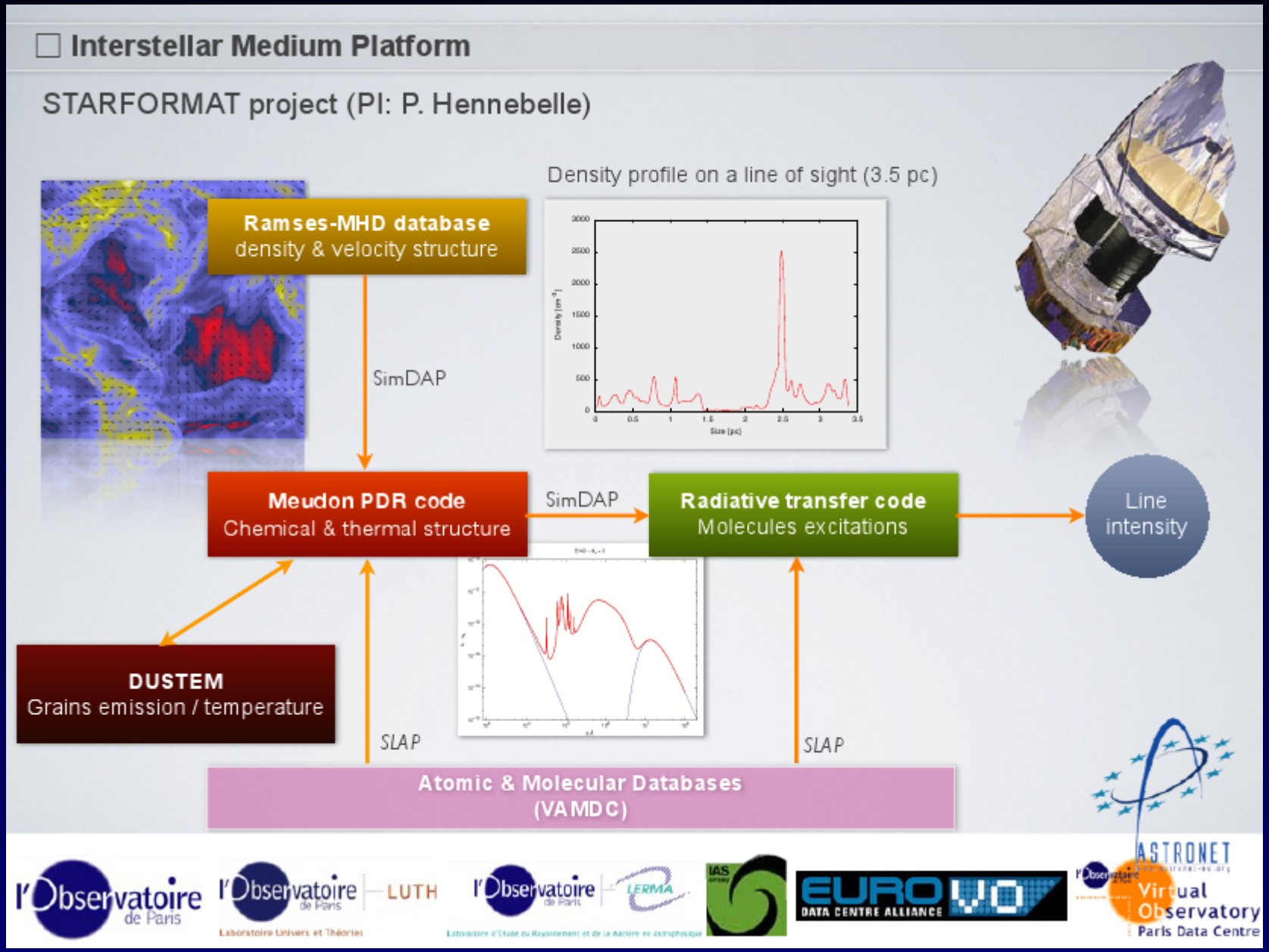
Bring together expertise in modeling / simulation of the ISM

Provide theoretical services about ISM

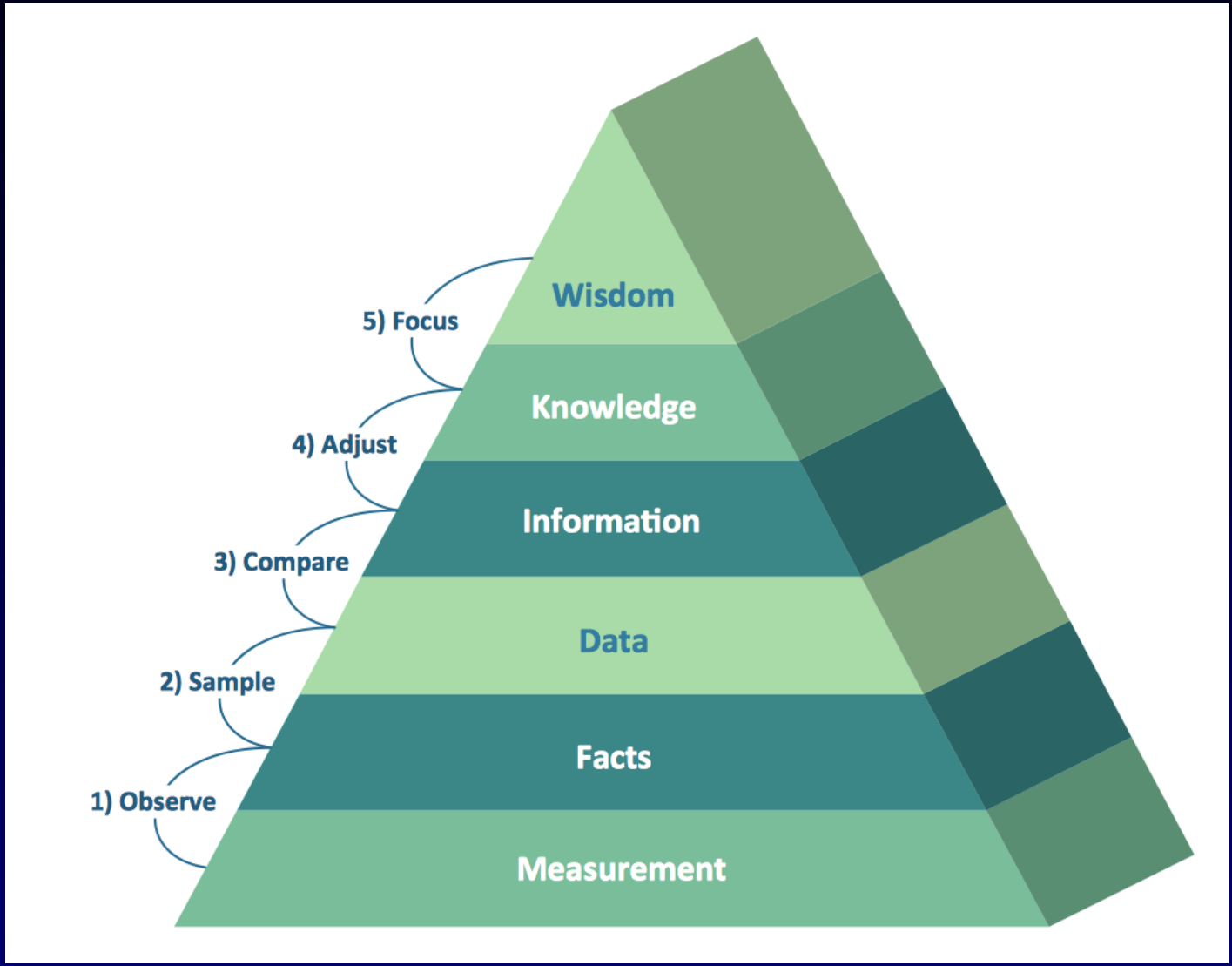
### Codes - Databases - Tools & services



# Complex join of TVO bricks



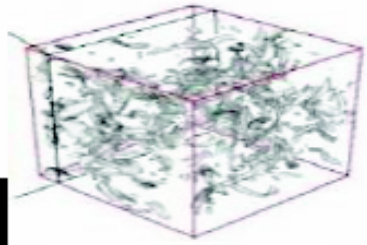
# Data-Knowledge-Wisdom Pyramid

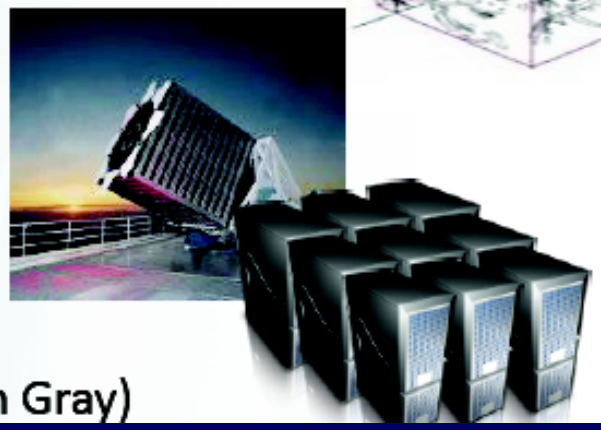


# Emergence of a Fourth Research Paradigm

1. Thousand years ago – **Experimental Science**
   - Description of natural phenomena
2. Last few hundred years – **Theoretical Science**
   - Newton's Laws, Maxwell's Equations…
3. Last few decades – **Computational Science**
   - Simulation of complex phenomena
4. Today – **Data-Intensive Science**
   - Scientists overwhelmed with data sets from many different sources
     - Data captured by instruments
     - Data generated by simulations
     - Data generated by sensor networks
   - ➢ eScience is the set of tools and technologies to support data federation and collaboration
     - For analysis and data mining
     - For data visualization and exploration
     - For scholarly communication and dissemination

$$\left(\frac{\dot{a}}{a}\right)^2 = \frac{4\pi G\rho}{3} - \mathrm{K}\frac{c^2}{a^2}$$

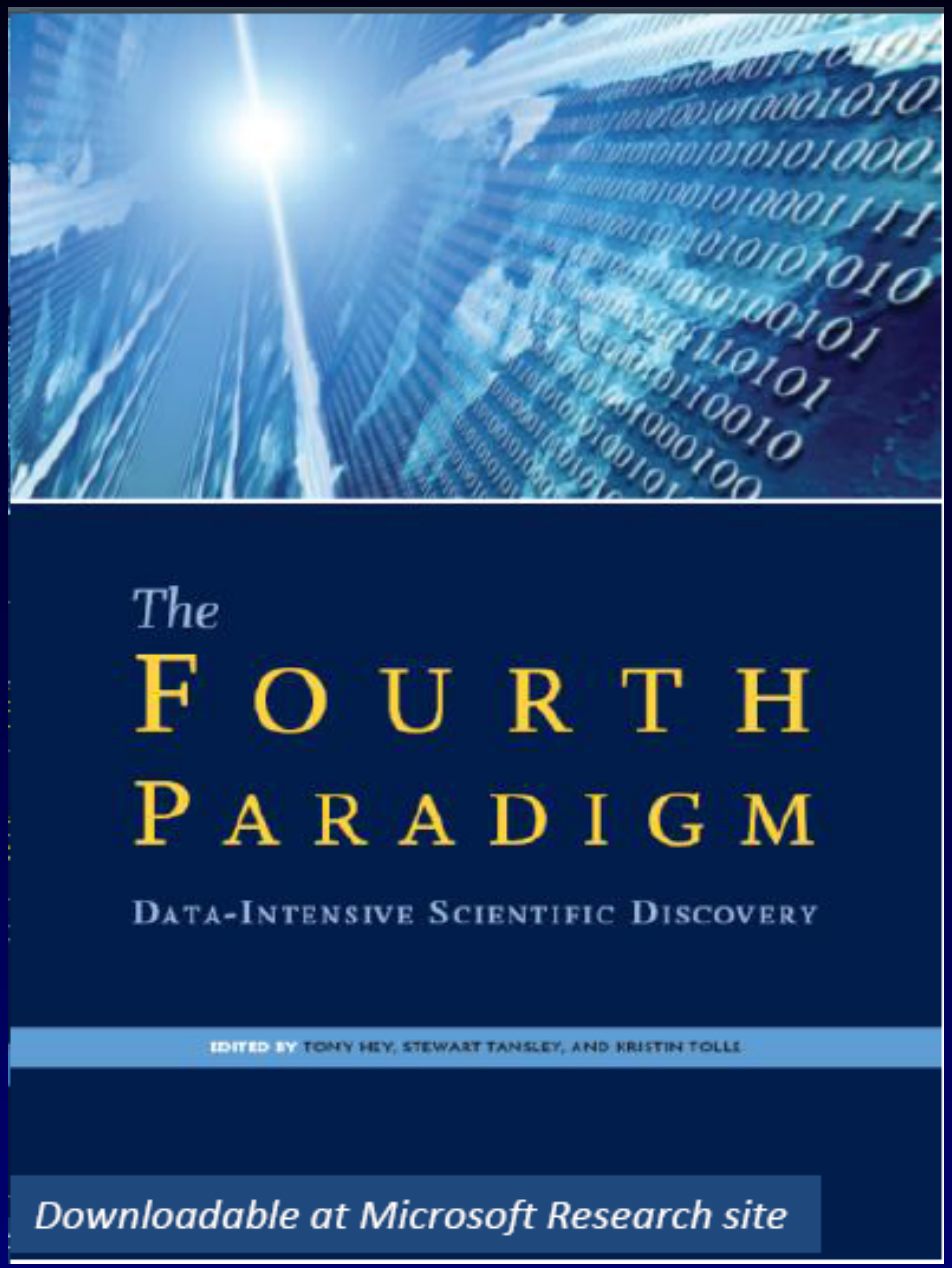




(With thanks to Jim Gray)

From T. Hey, AI2010

# X-informatics

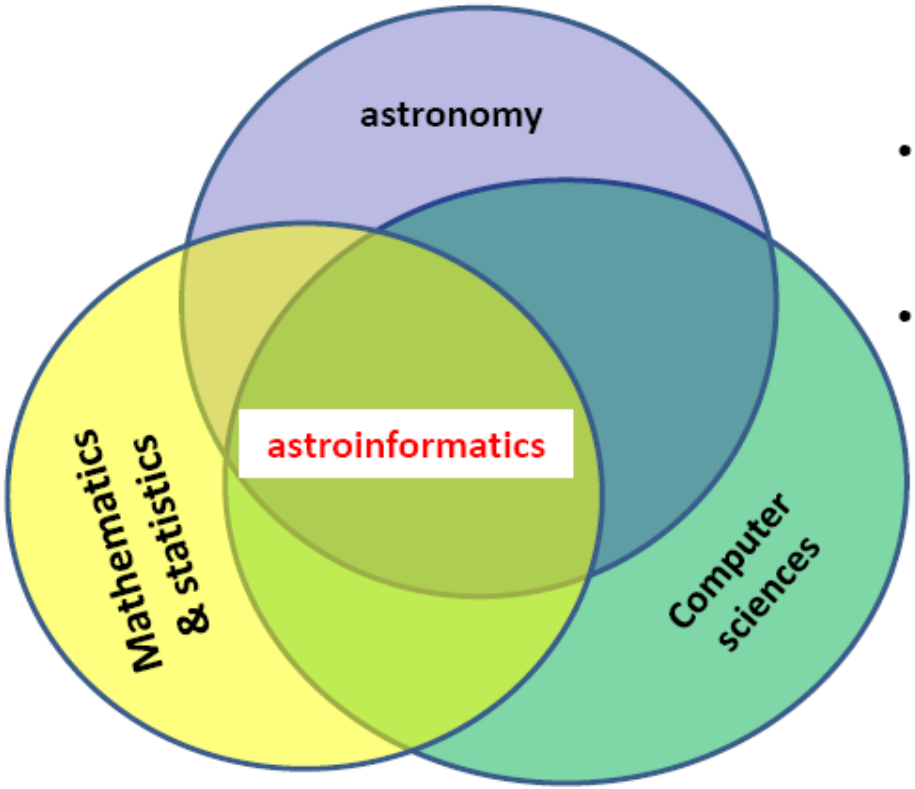



Changing methodology of the Science

Synergy between different worlds

Sociological aspects (net-based research communities)

# Experimental astronomy has become a three players game




- **astronomy**: problems, data, understanding of the data structure and biases
- **mathematics**: evaluation of the data, falsification/validation of theories/models, etc
- **computer science**: implementation of infrastructures, databases, middleware, scalable tools, etc

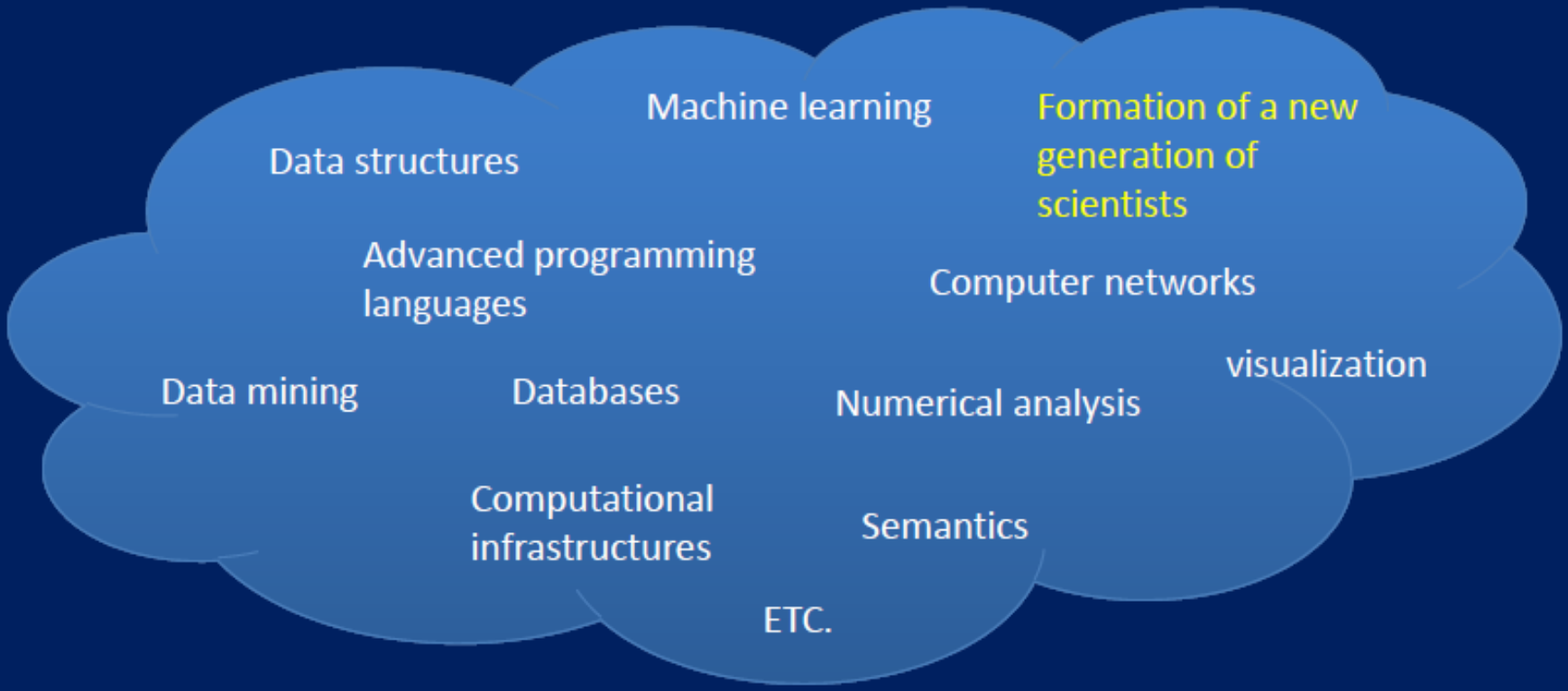
- **Astroinformatics: AAS n. 215, Washington, December 2009,** chairperson: K. Borne
- **Astroinformatics 2010: Caltech (USA) June 16-19 2010;**co-chairpersons: S.G. Djorgovski, G. Longo
- **Astroinformatics 2011: UNINA – Sorrento,** co-chairpersons: S.G. Djorgovski, G. Longo

Longo 2010

# Astroinformatics

- Analogy – Bioinformatics (Genome analysis with GRIDS, ATB)
- e-Science in Astronomy
- Data mining, Knowledge discovery - VO-NEURAL, DAME
- Examples
  - Photometric RedShift
  - Searching for QSO (light curves, MOS)
  - Automatic Light curves classification (GAIA, LSST)
- New ways of scholar communication (VR, 2nd Life, U-Science)
- BIG data problems, GPUs, NoSQL DB, visualization,
- Very NEW – emerging discipline

# A new discipline in the making: AstroInformatics




Very lively Community - AstroInformatics International Conferences

2010 – Pasadena
2011 – Napoli
2012 – Redmond (Microsoft)
2013 – South Africa

Join us on Astroinformatics page on Facebook

IVOA – IG on KDD WIKI

# Data Driven Science

## What is Fundamentally New Here?

- The ***information volumes and rates*** grow exponentially

➡ ***Most data will never be seen by humans***

- A great increase in the data ***information content***

➡ ***Data driven vs. hypothesis driven science***

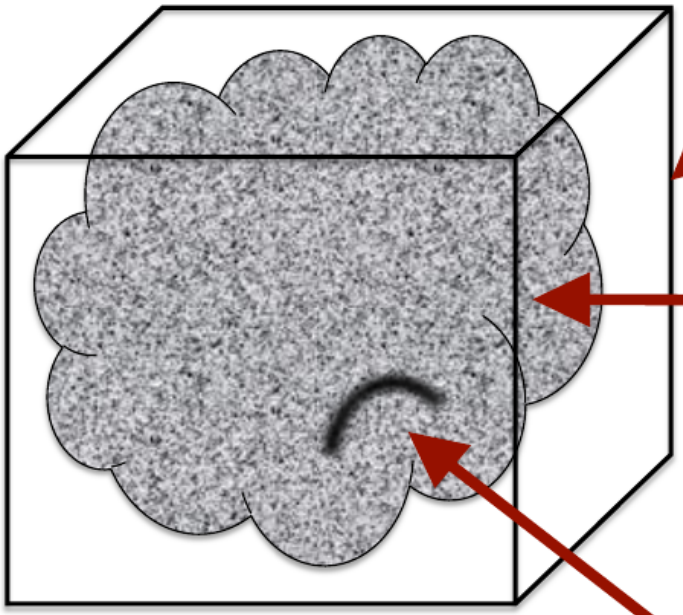
- A great increase in the ***information complexity***

➡ ***There are patterns in the data that cannot be comprehended by humans directly***

Djorgovski

# Hidden Patterns in Data

## Pattern or structure (Correlations, Clustering, Outliers, etc.) Discovery in High-Dimensional Parameter Spaces



D >> 3 parameter space hypercube

High-D data cloud: mostly noise, of an arbitrary distribution

But in some corner of some sub-D projection of this data space, there is ***something ≠ noise***

# Visualization in Machine Learning

## A Key Challenge: Visualisating Multidimensional Data Spaces

- Hyperdimensional structures (clusters, correlations, etc.) may be present in many complex data sets, whose dimensionality may be D ~ $10^2$ – $10^4$, or higher
- It is a matter of ***data understanding***, choosing the right data mining algorithms, and interpreting the results
- We are biologically limited to perceiving up to ~ 3 - 12(?) dimensions

**What good are the data if we cannot effectively extract knowledge from them?**

Djorgovski

# Scientific Communities

"The co-authorship network of scientists represents a prototype of complex evolving networks. In addition, it offers one of the most extensive database to date on social networks."[a]

[a]Barabàsi et al., "Evolution of the social network of scientific collaborations"

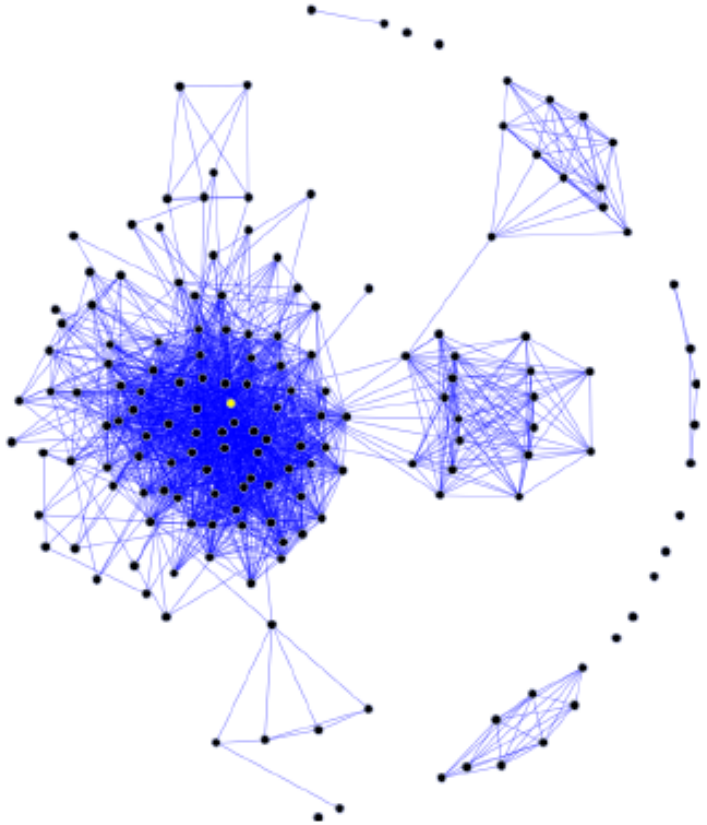
"Social scientists have long recognized the importance of boundary-spanning individuals in diffusing knowledge (Allen 1977; Tushman 1977), and recently, several papers have rigorously demonstrated that technological knowledge diffuses primarily through social relations, not through publications."[a]

[a]Sorenson, and Singh, "Science, Social Networks and Spillovers"

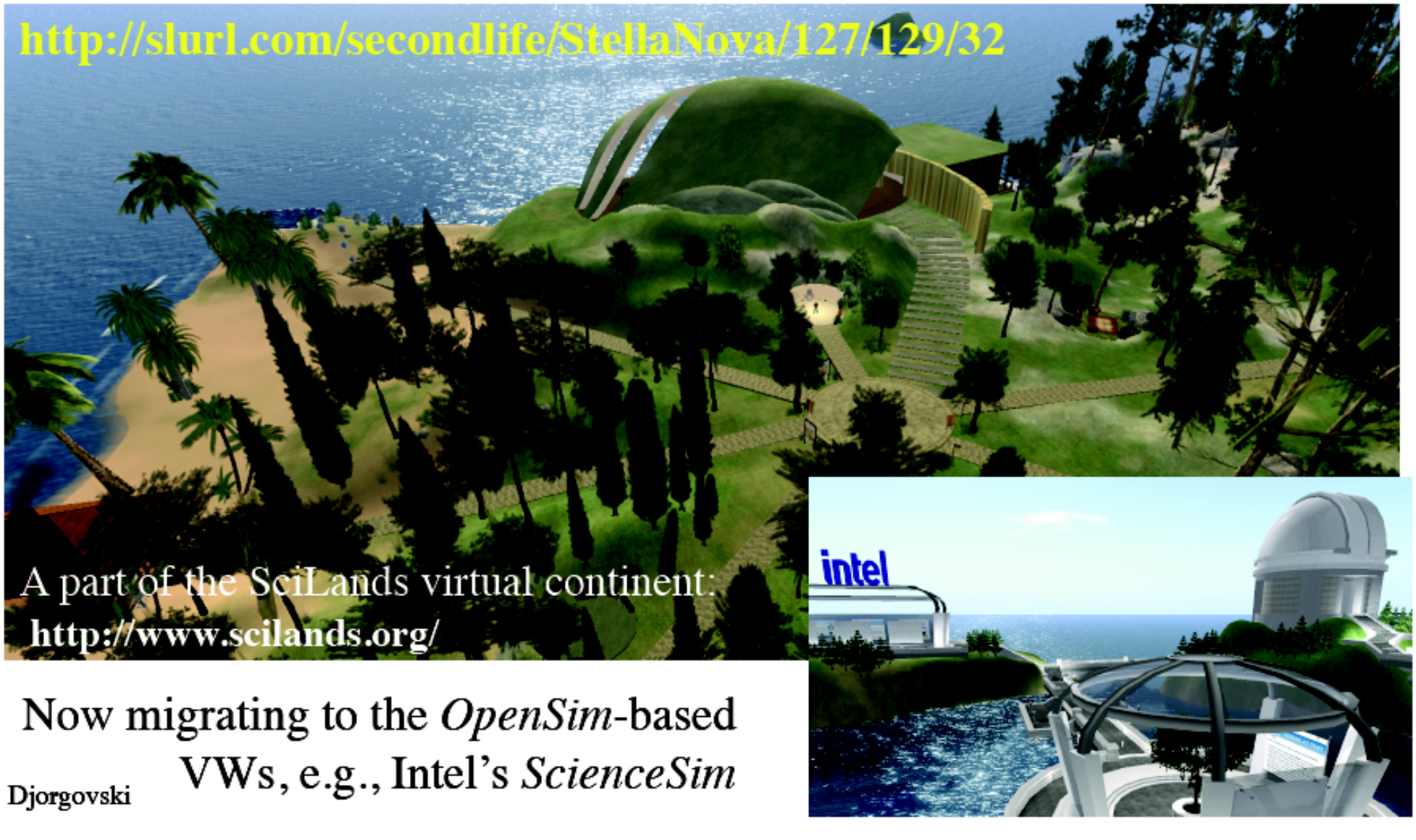
From O. Laurino - AI2010

## Motivations of a social networking IT platform for science

- The importance of boundary-spanning individuals in social networks might be what X-informatics is all about;
- we break scientific *cliques* and create new, unexpected, effective links across the science community's network;
- an effective scientific social network platform may be an effective step towards *seamless astronomy*. Seamless not only in terms of data and applications access, but also in terms of social interactions between people in the scientific network.



# Virtual Worlds (2nd Life for Science)

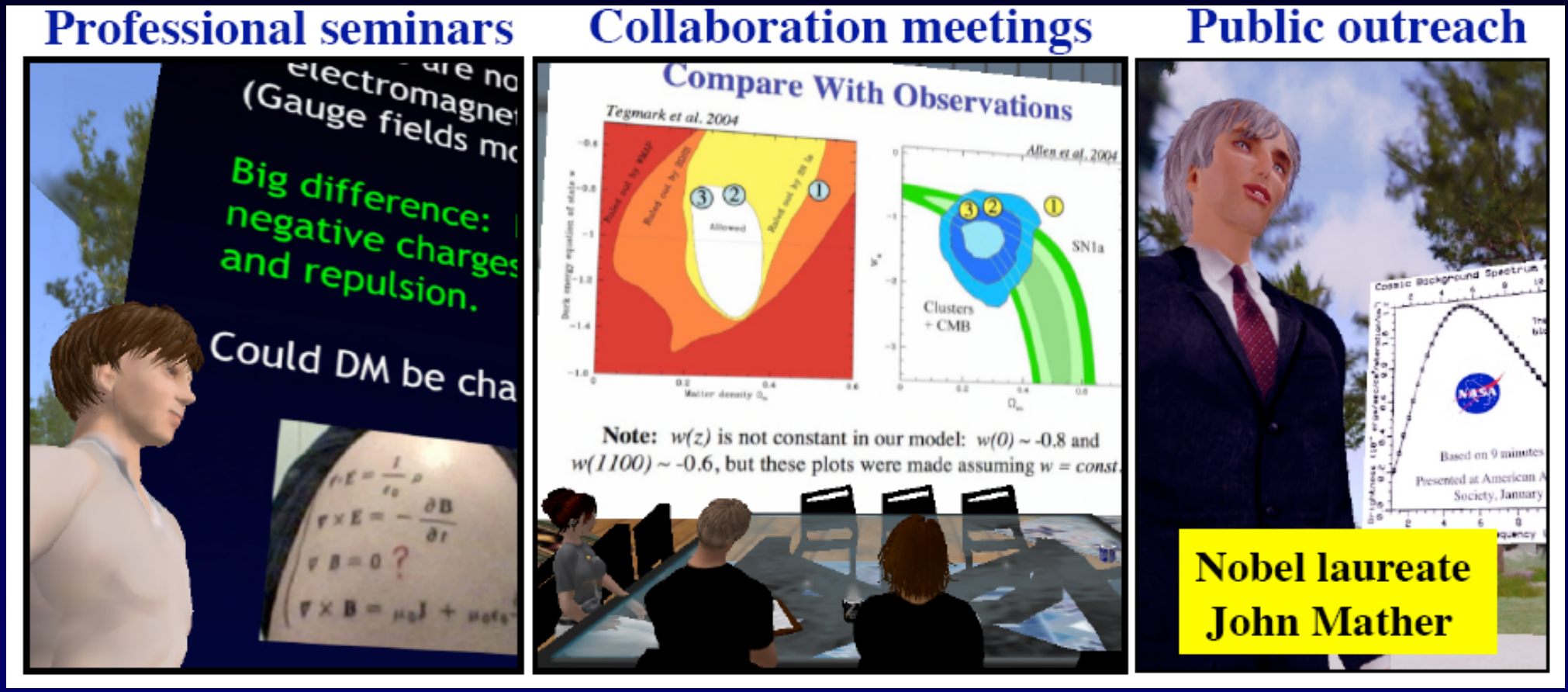


# Virtual Conferences

Virtual conferences at zero cost

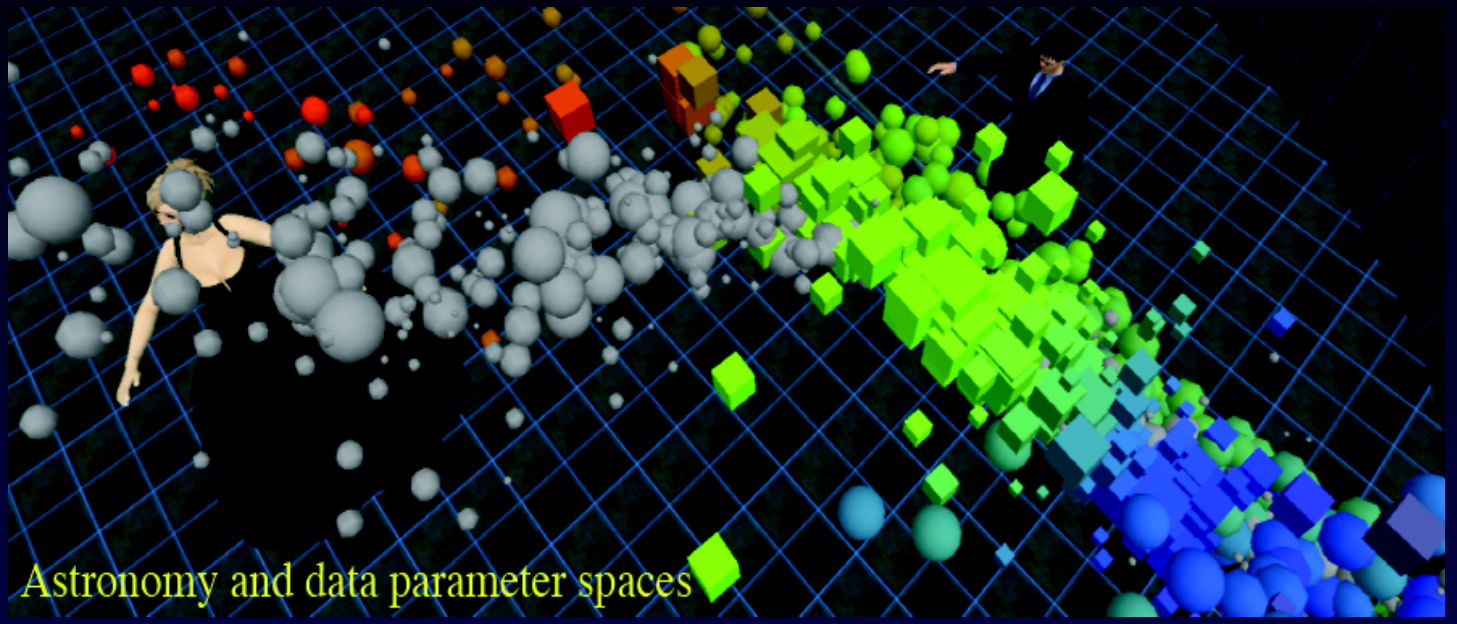
Problem with time zones

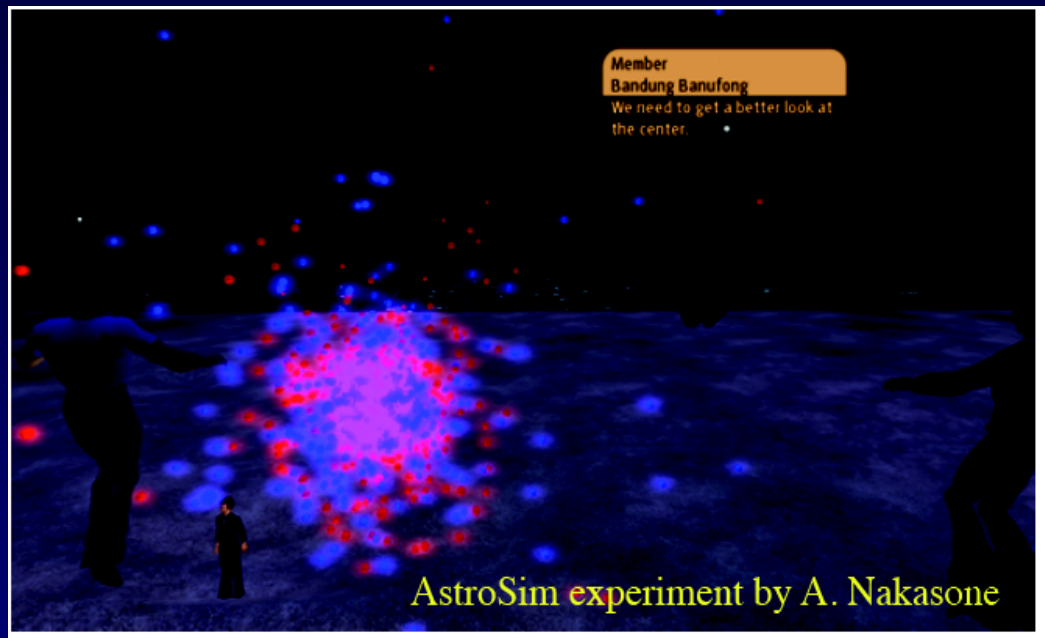
Outreach, education




From Djorgovski - AI2010

# Immersive VR Experiments



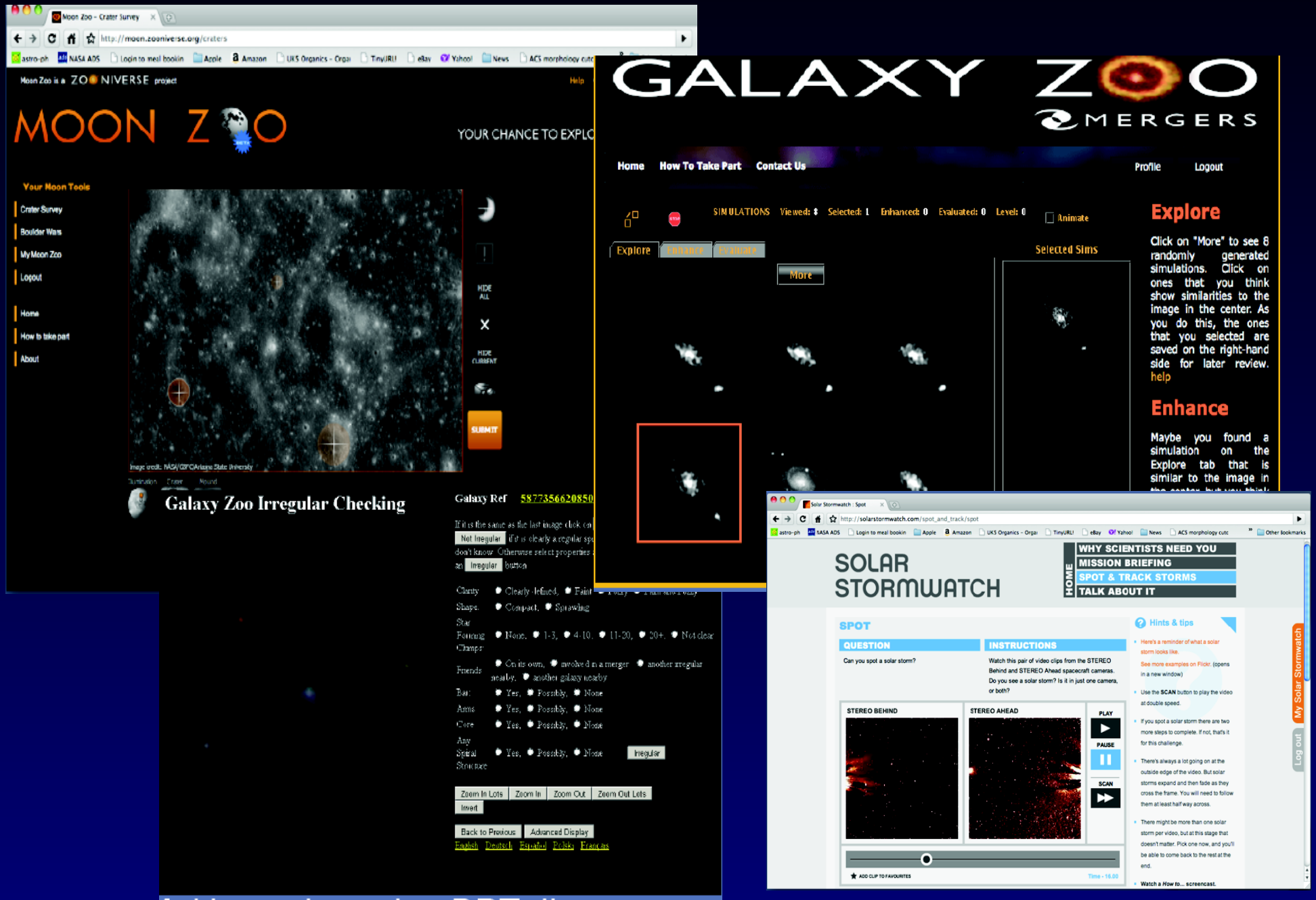




Scientists immersed in, and interacting with, numerical simulations of star clusters

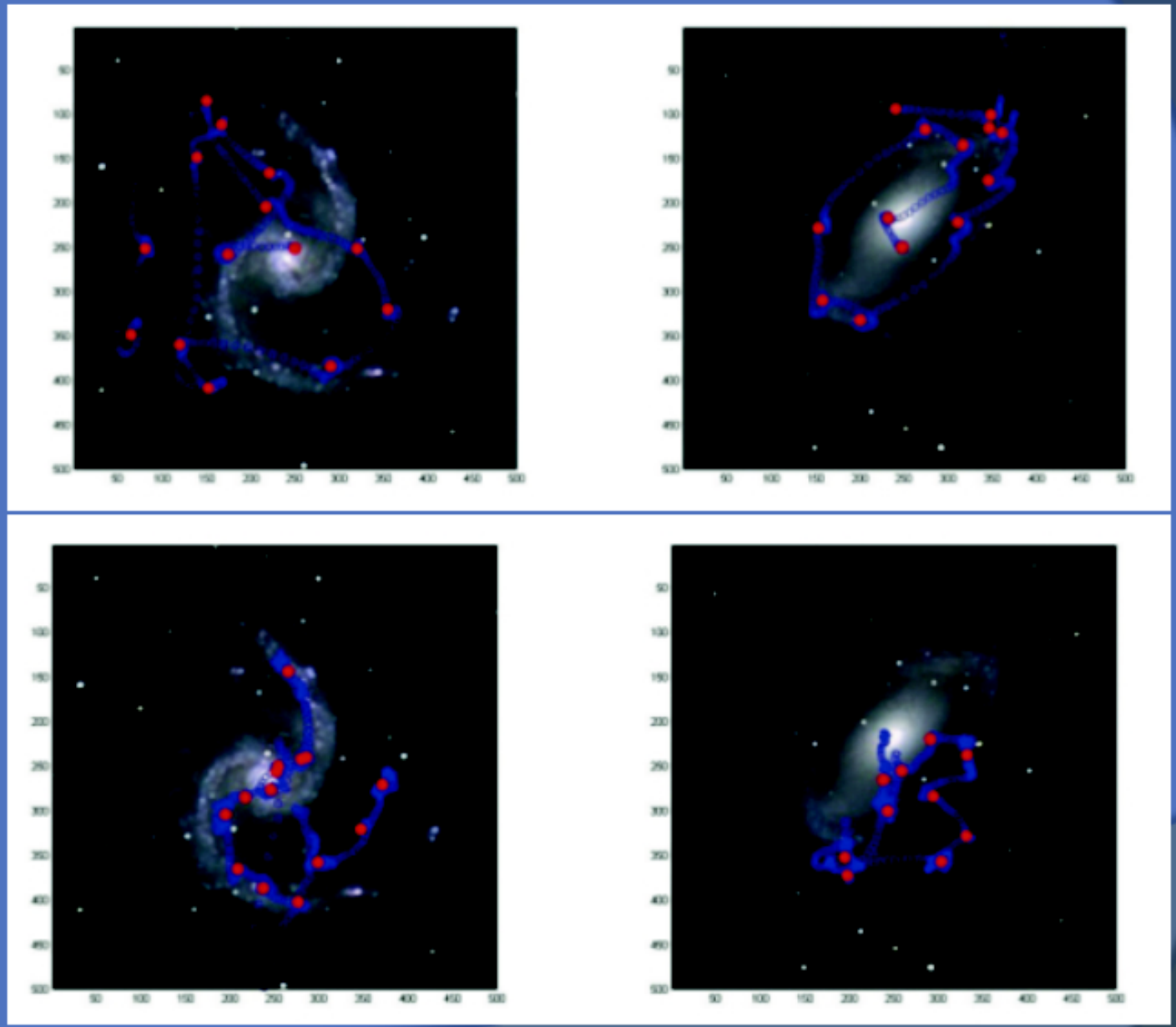
# Citizen Science - Galaxy ZOO


> 20 Science papers published so far

# Examples ZOOniverse



# Expert vs Non-expert Classifier

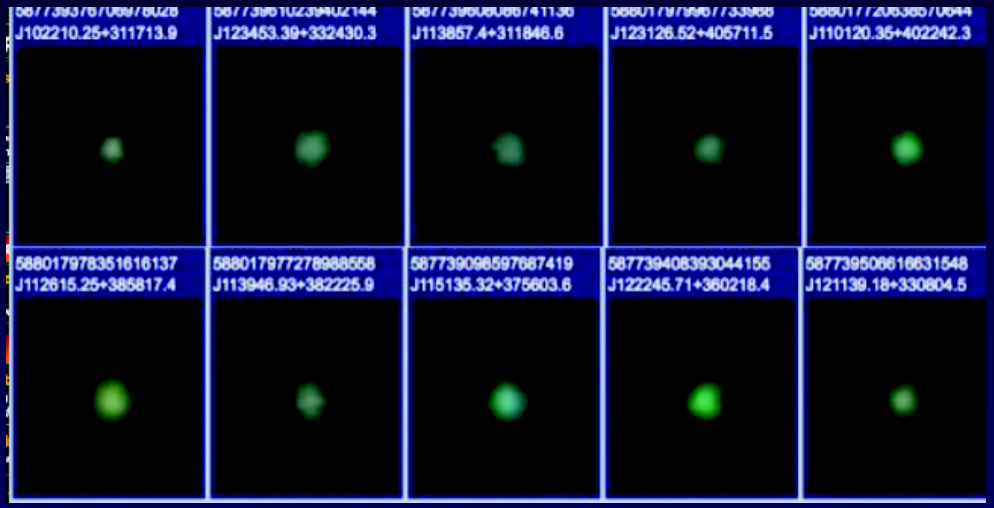


# Citizen Science x Expert Science

Verified by human – training sets

Independent answers=estimate of error

Serendipitious discovery




Galactic Peas

Scale - complexity

# Knowledge Discovery in U-Science

Known knowns :
Primary task. Data reduction by science team.

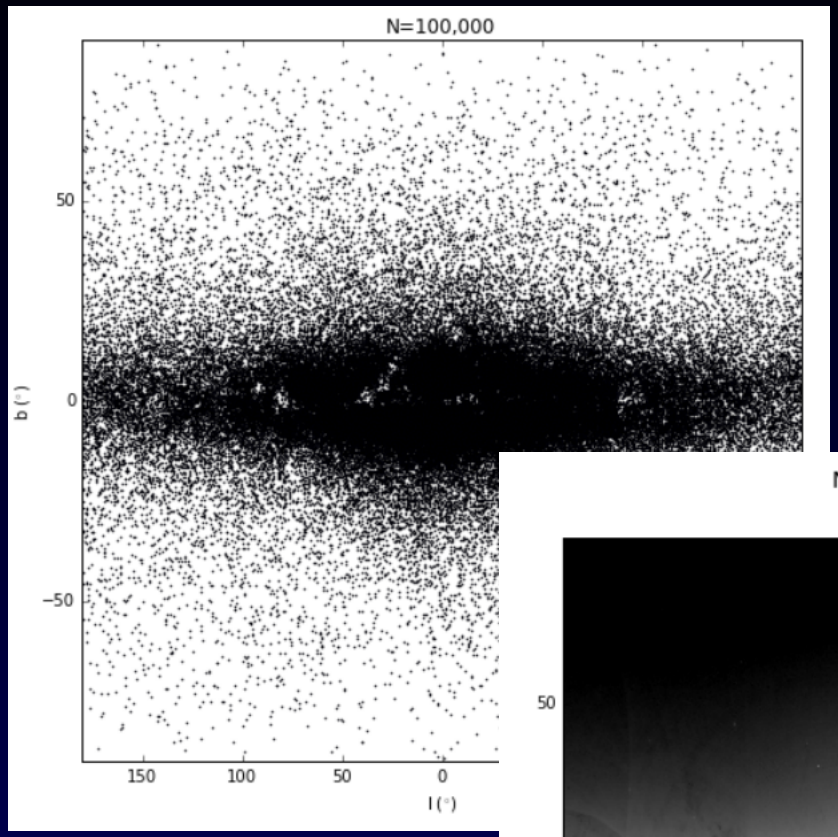
Known unknowns :
Related to primary task. Results funneled to specific researchers.

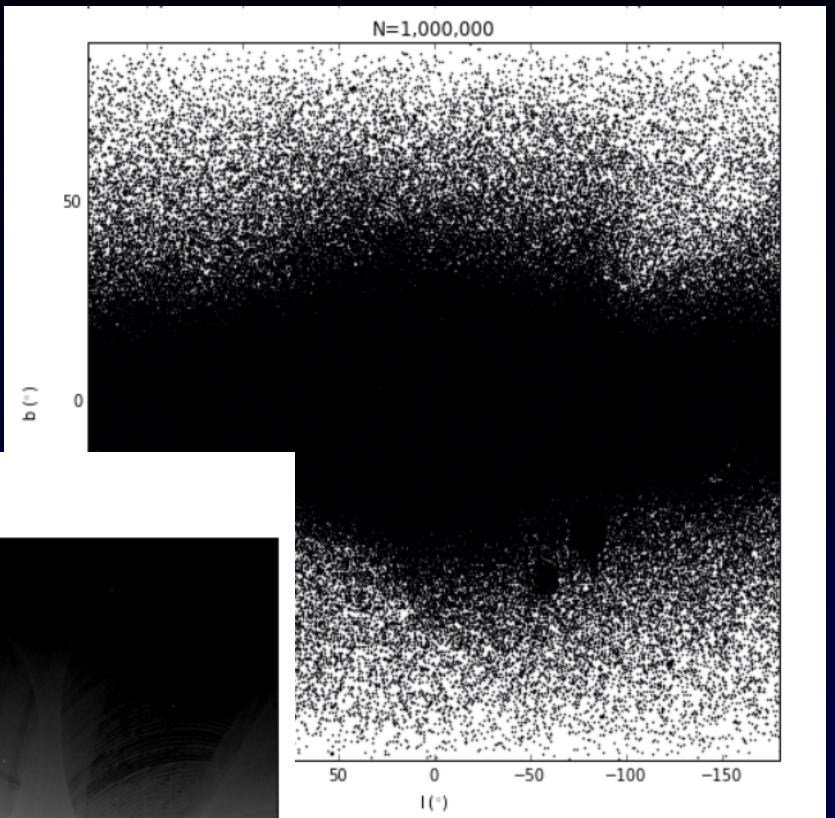
Unknown unknowns :
Serendipity. Currently rely on forum moderators to filter.

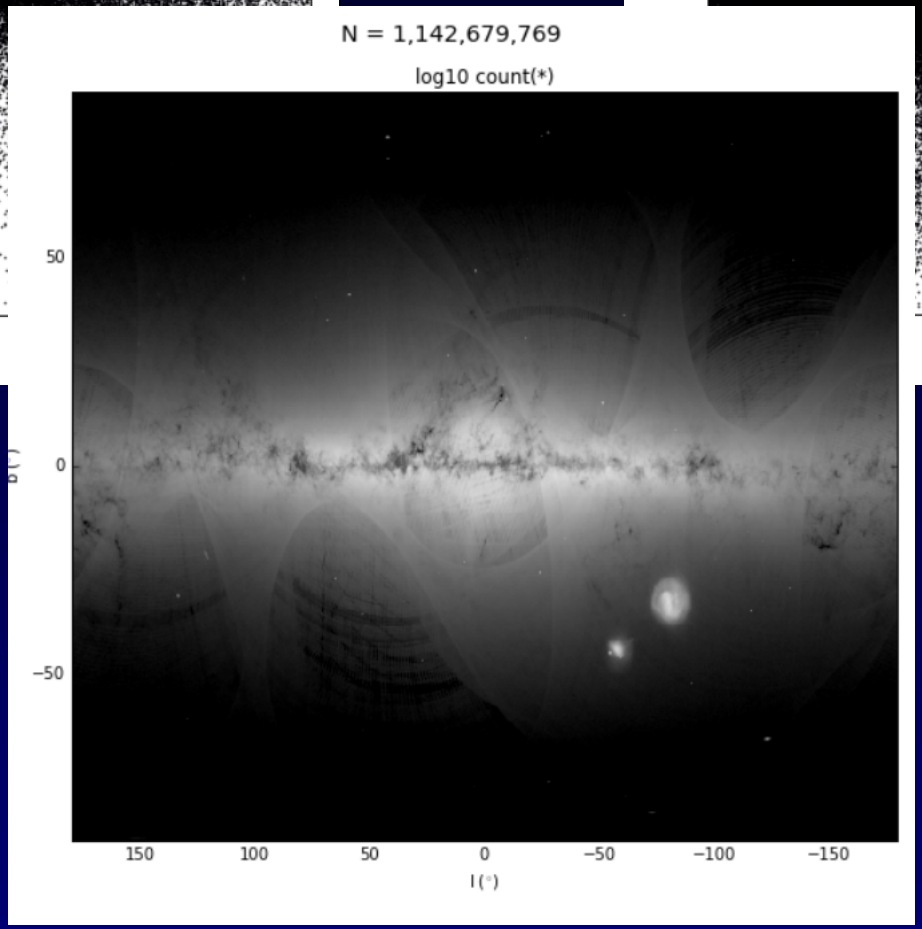
Hanny van Arkel - Voorwerp

Light echo of quasar?

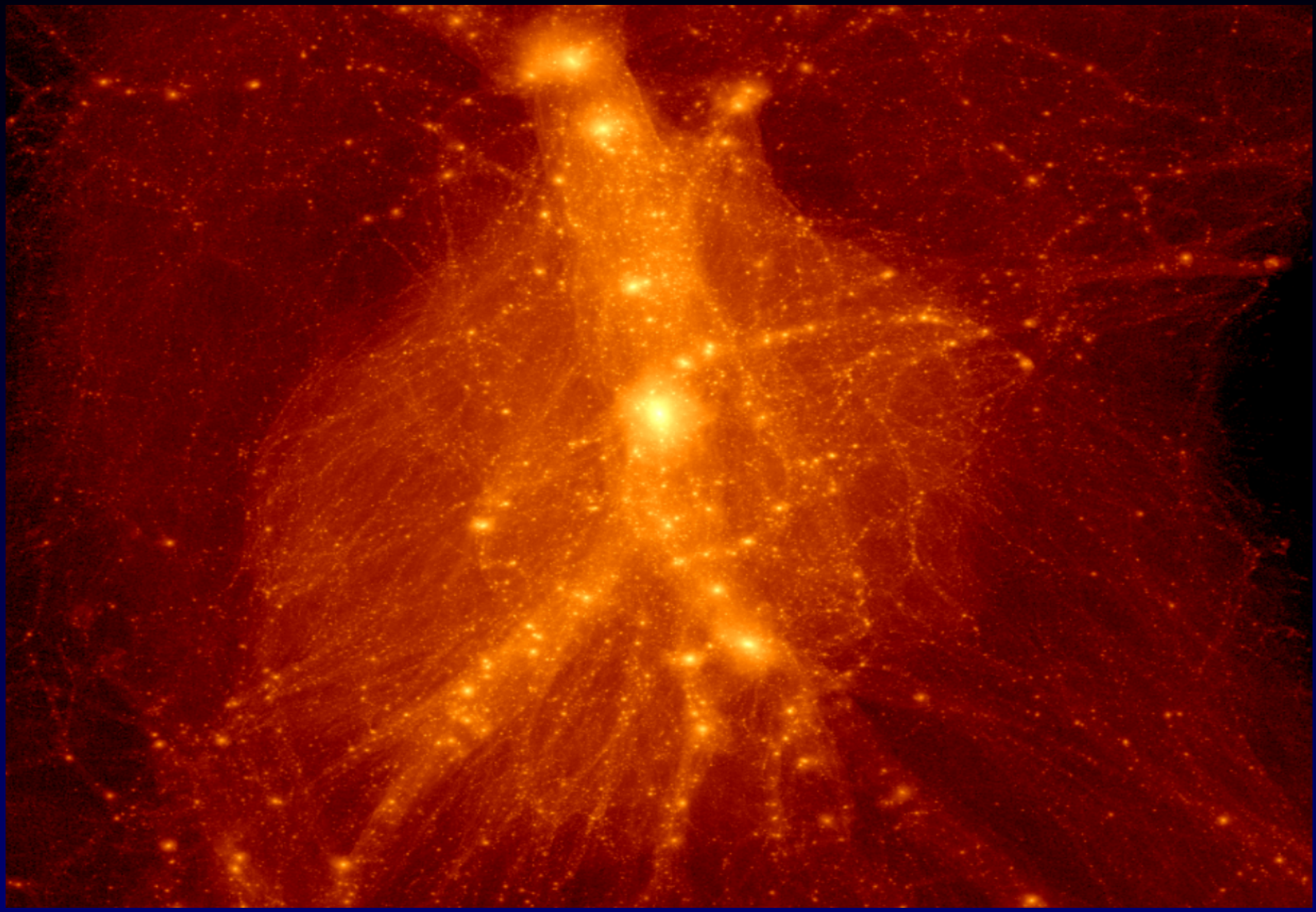
# Visualization of 1 B points – Gaia DR1



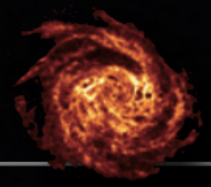



# Visualization of Big Data

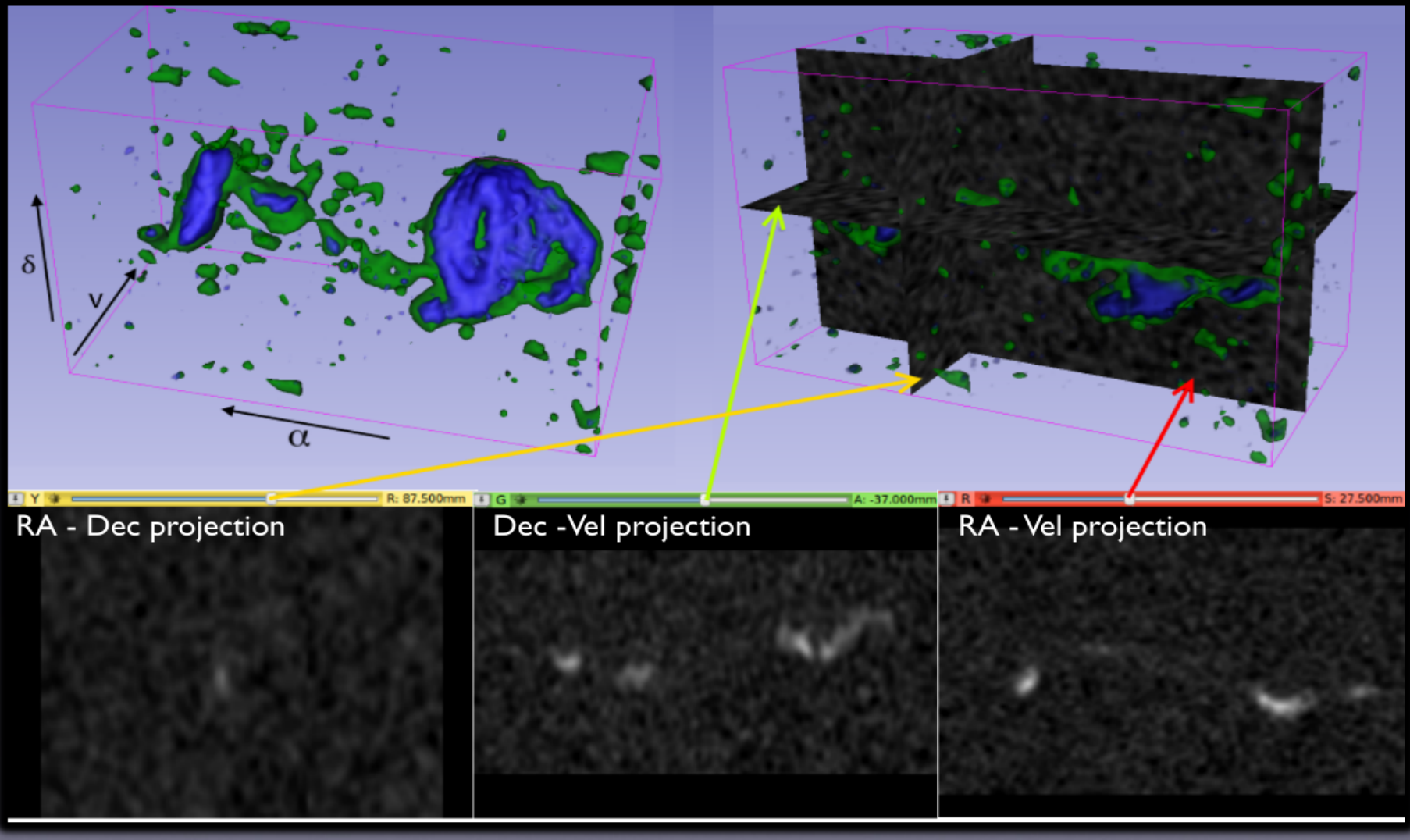


# Visualization of Big Data

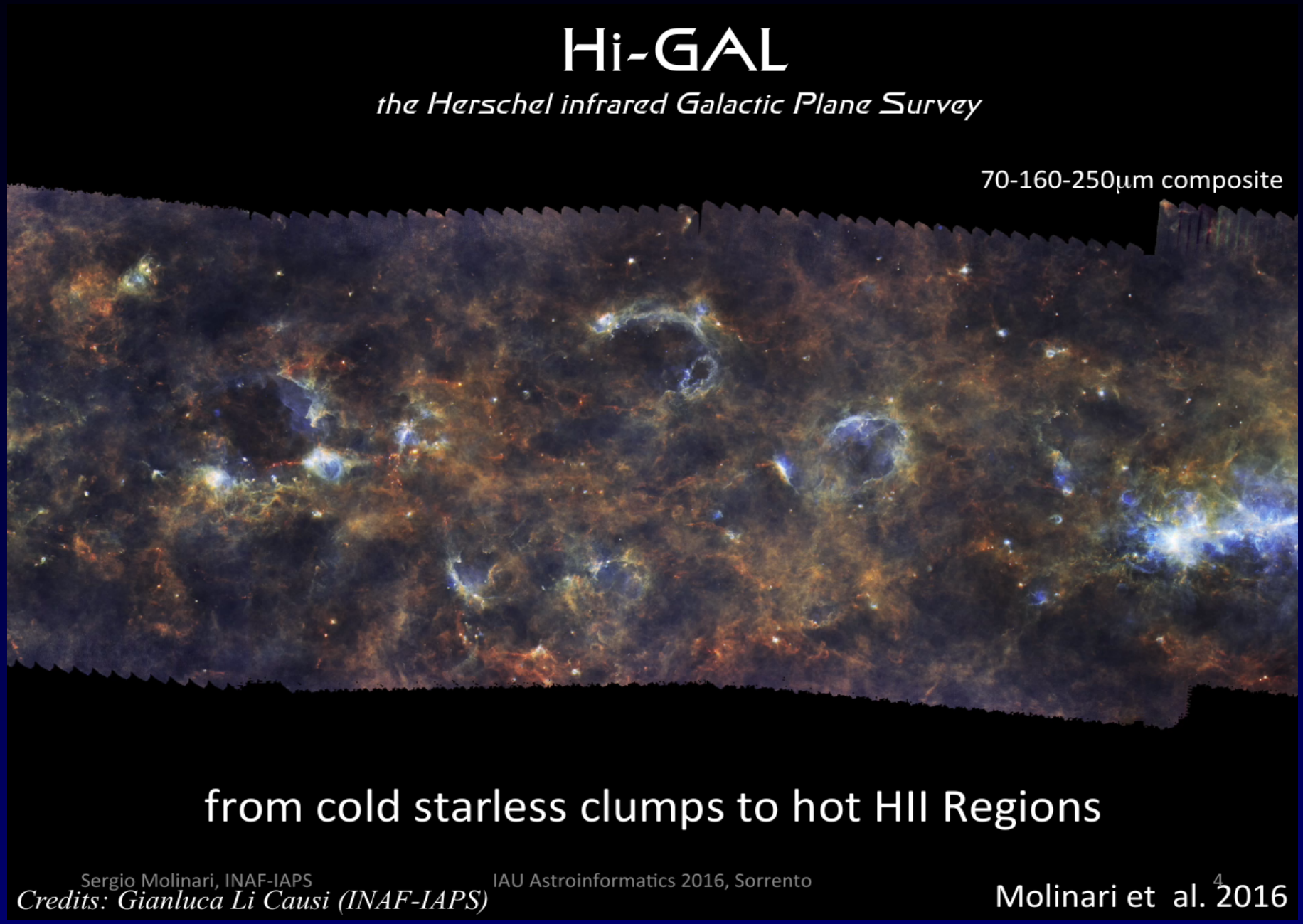
# Visualization of Radio Data Cubes



3D Slicer provides full linked views, not just slices



# Star Forming Regions in Galaxy



# CAVE2 Monash University AU

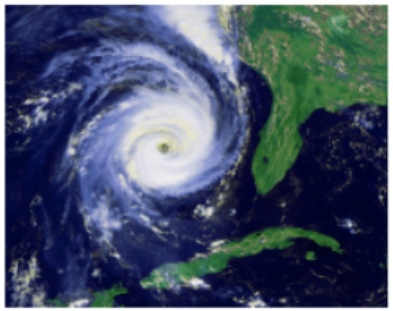
8m diameter, 330 deg FOV , 80x LCD 46“  1366x768 Stereo + head tracking ……

# From Astronomy to Earth Sciences

GRACE
AQUA

## From Observations to Applications

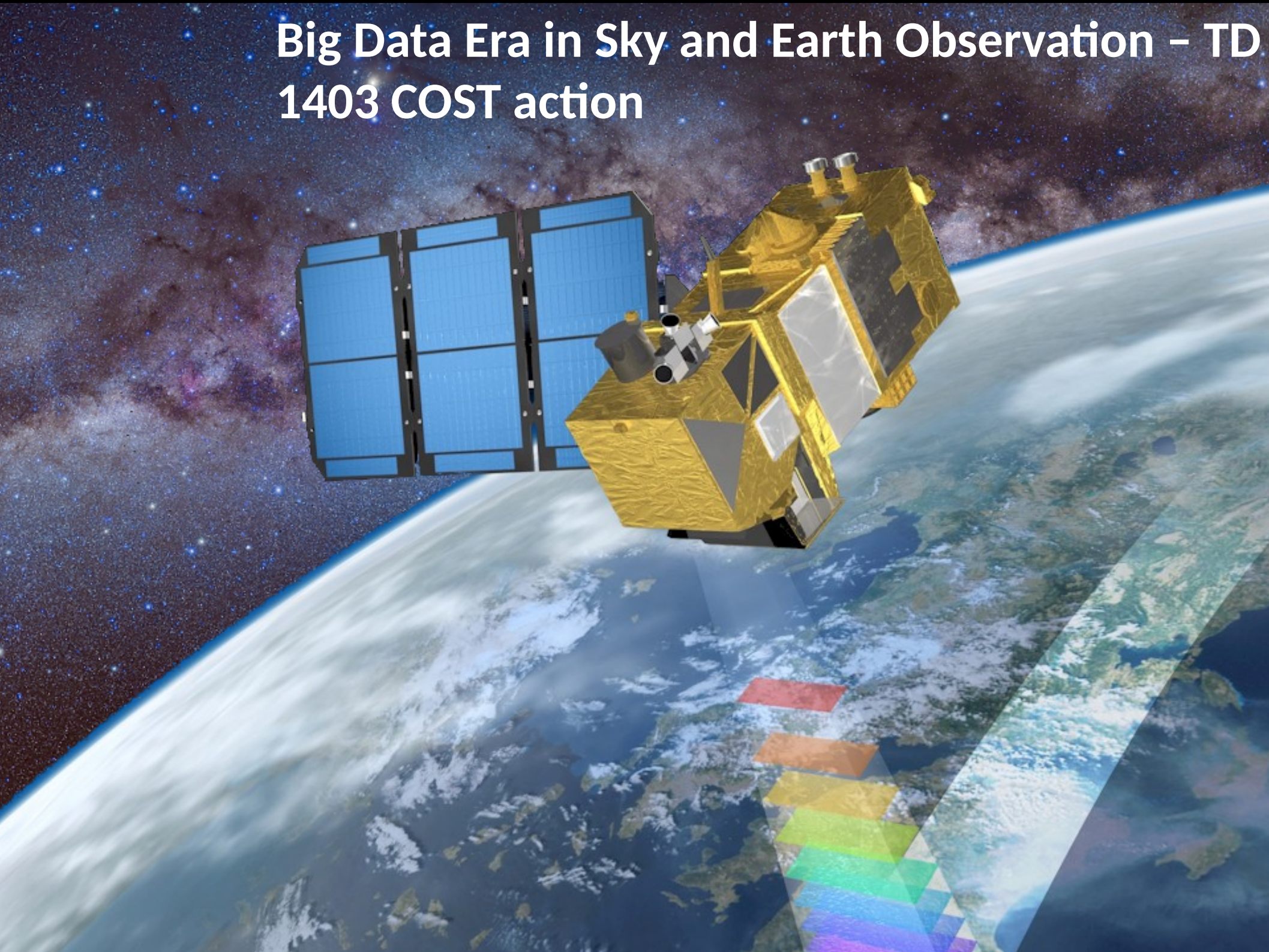
**Satellite Measurements**



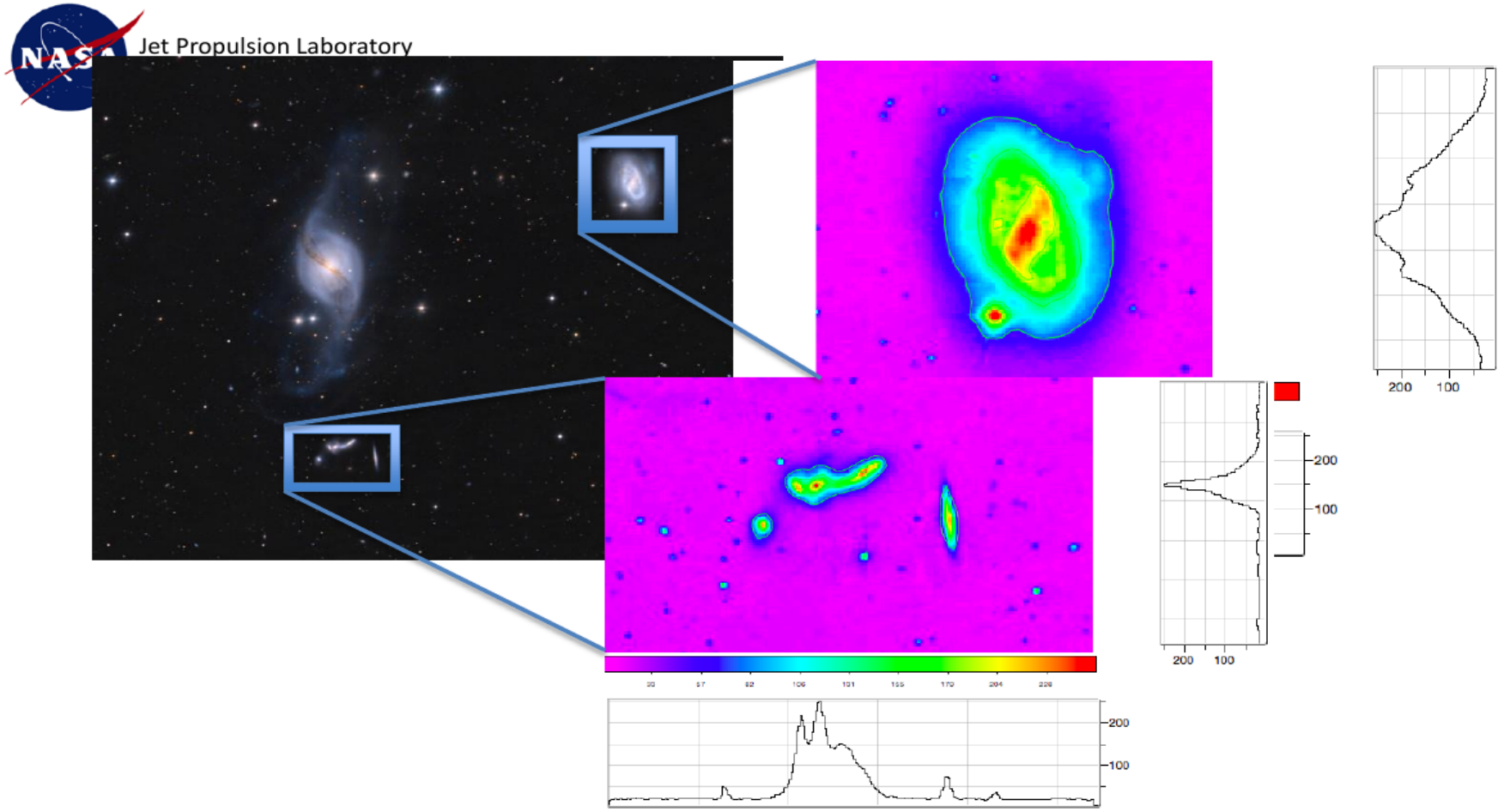
**Satellite Products**


**Environmental Applications**

# Big Data Era in Sky and Earth Observation – TD 1403 COST action

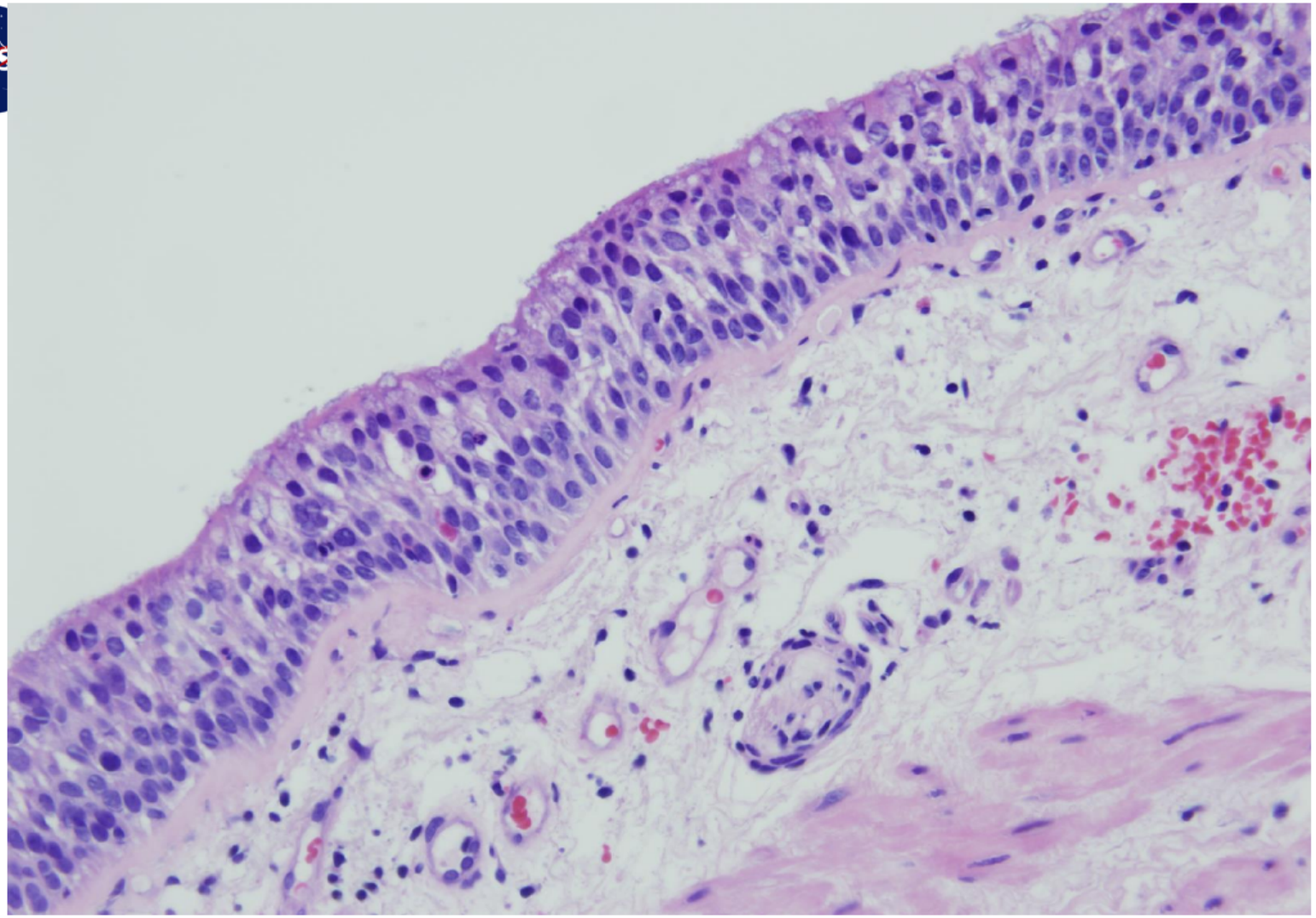


# Finding Galaxies by Shape NASA




Description: Detecting objects from astronomical measurements by evaluating light measurements in pixels using intelligent software algorithms.
Image Credit: Catalina Sky Survey (CSS), of the Lunar and Planetary Laboratory, University of Arizona, and Catalina Realtime Transient Survey (CRTS), Center for Data-Driven Discovery, Caltech.

# Finding Cancer Signatures NASA



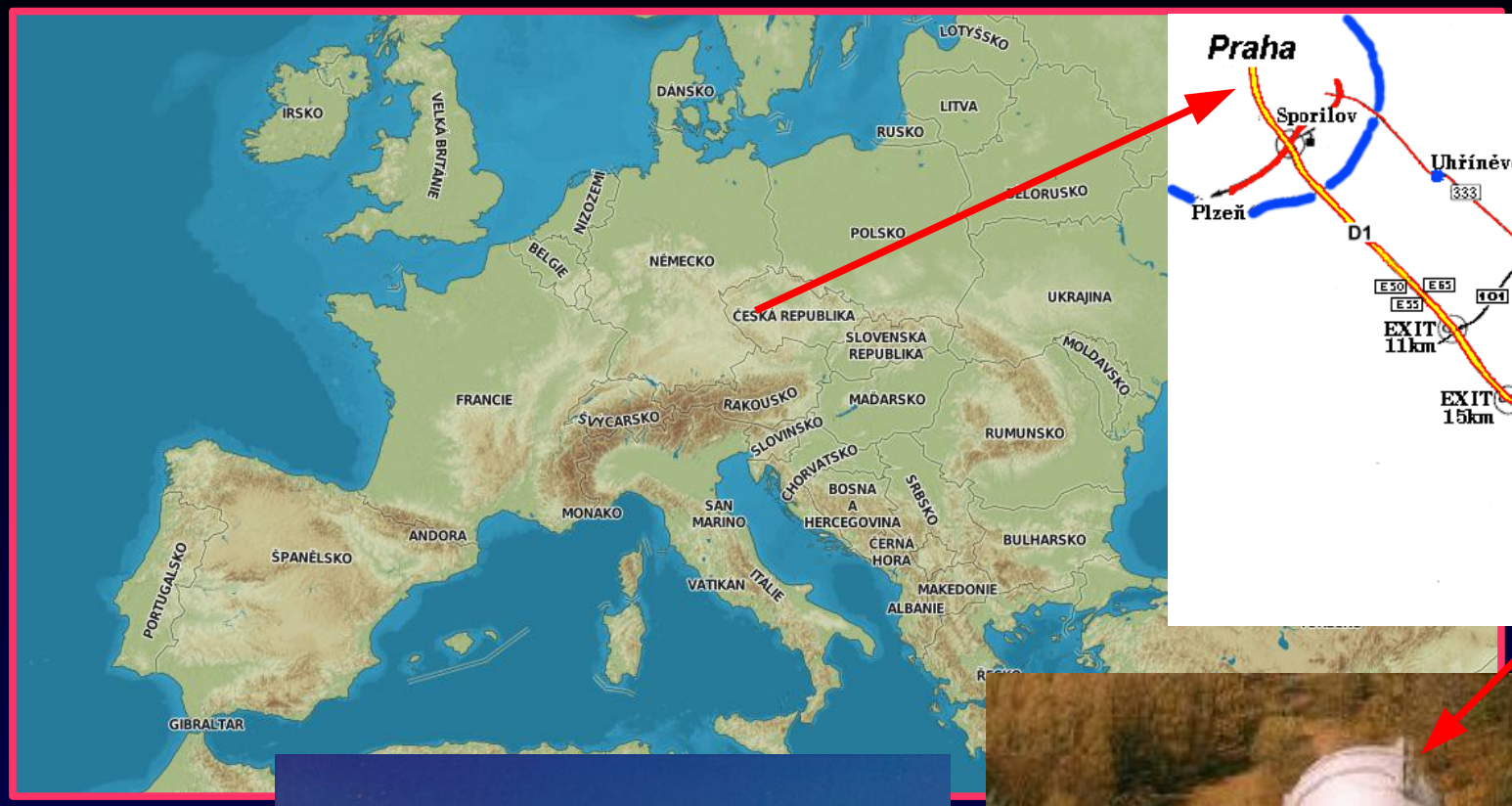
Description: Detecting objects from oncology images using intelligent software algorithms transferred to and from space science.
Image Credit: EDRN Lung Specimen Pathology image example, University of Colorado

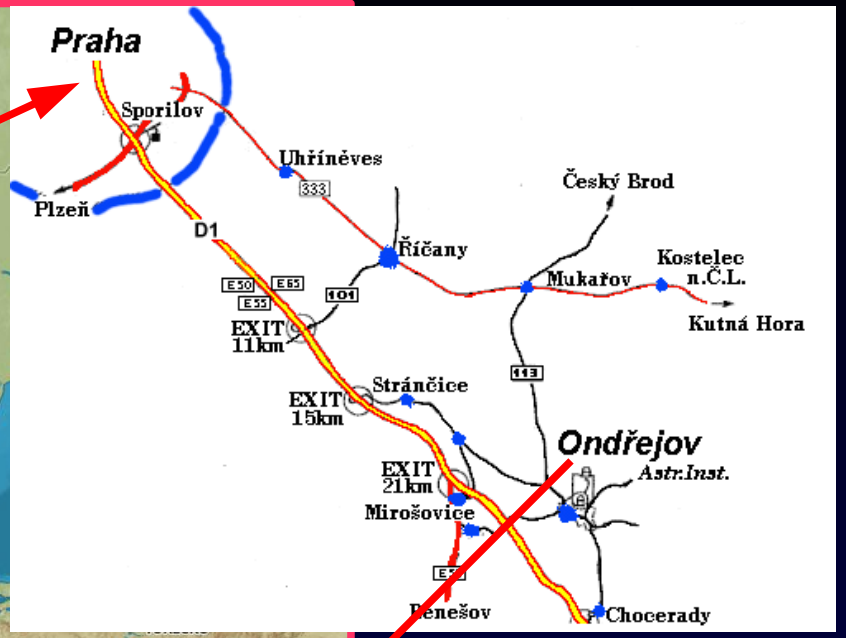
# Challenges of (Astro)informatics

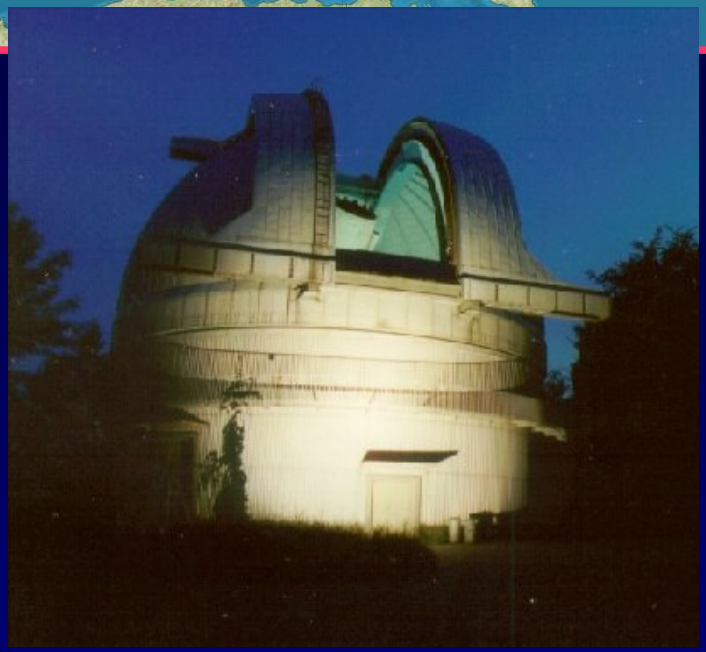
Big Data 3(5)xV

- Complex
- Missing values
- Censoring
- Upper limits
- Parallelization (Massive - GPU – new algorithms)
- Queries in PB table
- Visualization of many dimensions
- Stream processing
- Non- Gaussian Statistics, PDF

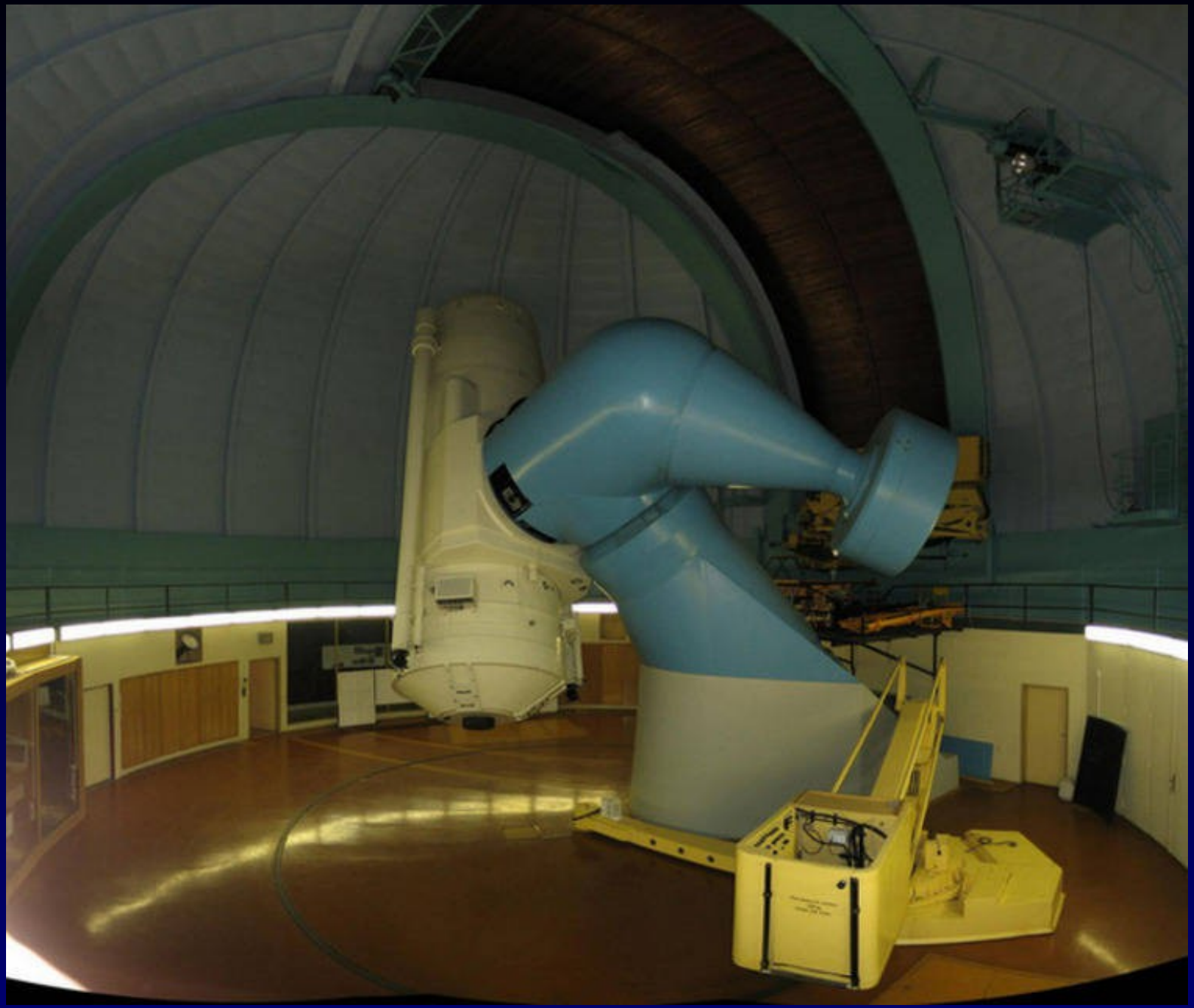
# Ondřejov observatory



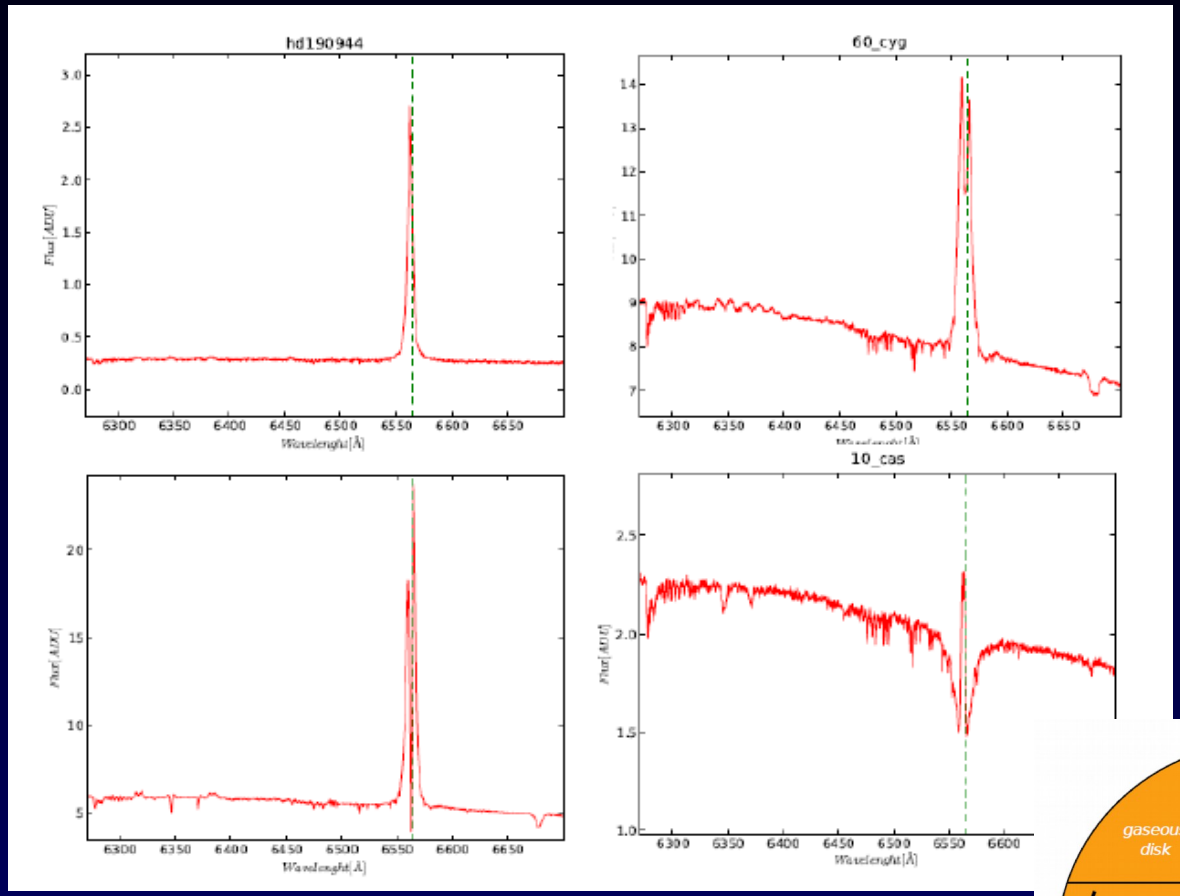



# Ondřejov 2m Perek Telescope (1967)



# Machine Learning of Spectra

Use case:  ML of spectra profile  of Halpha line (Be stars)

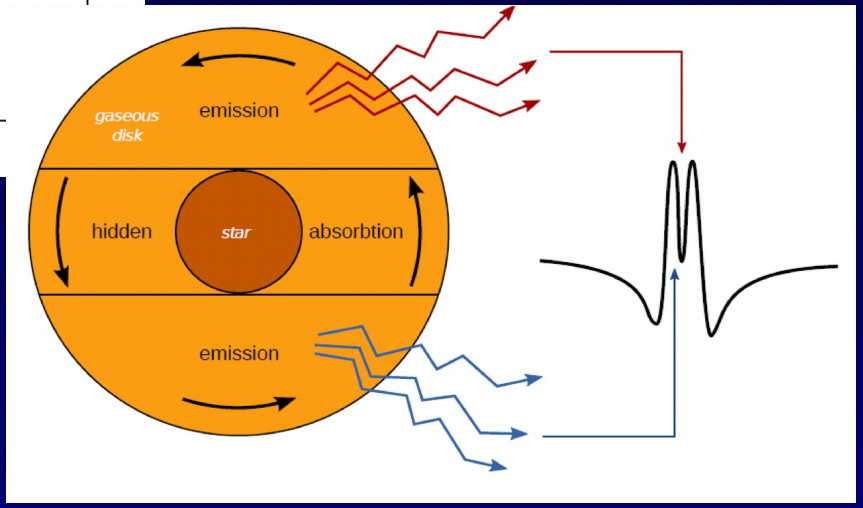



Be stars

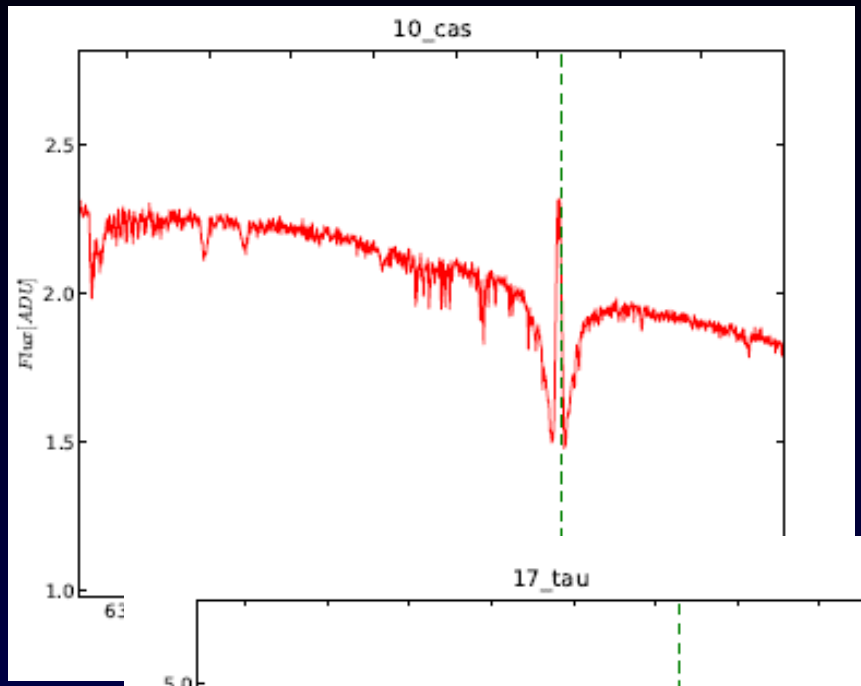
Disk or envelope

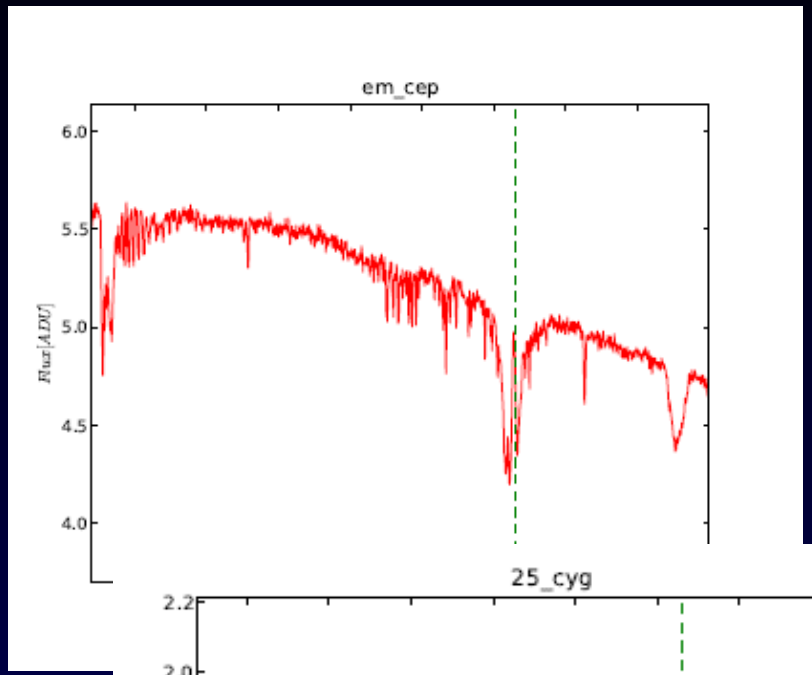
Rotates, Hot

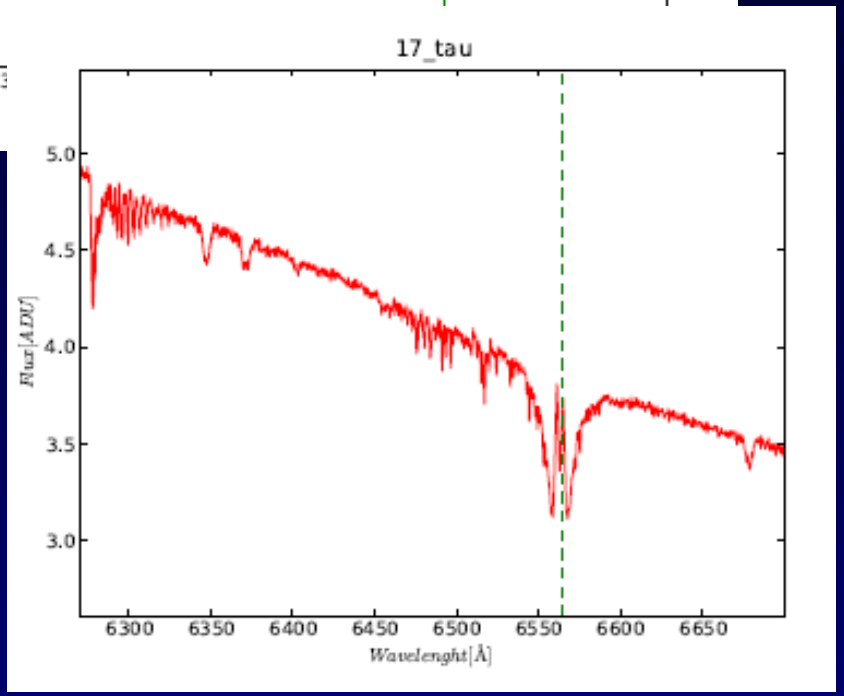
Origin ?????

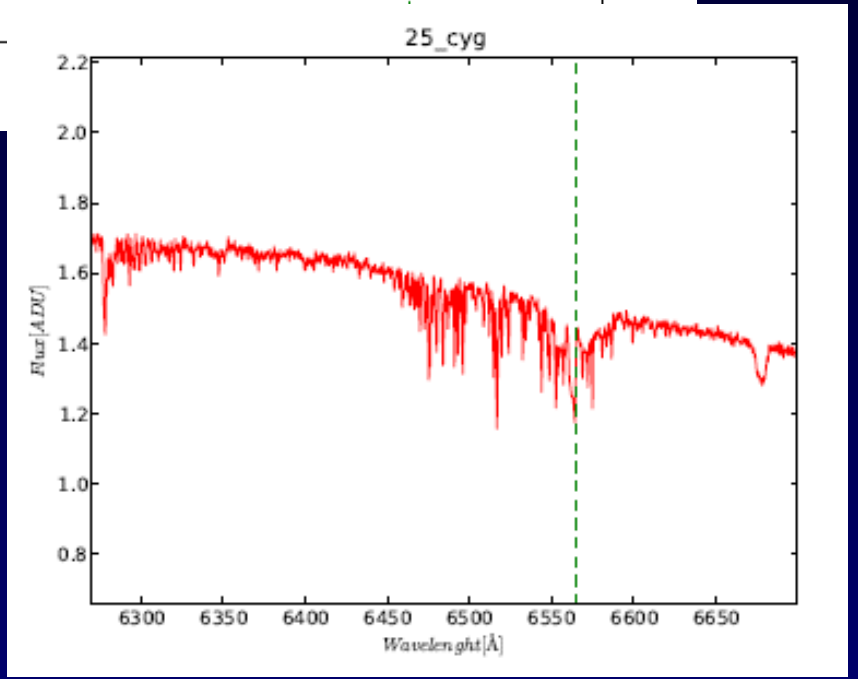


# Be Stars : Emission in absorption



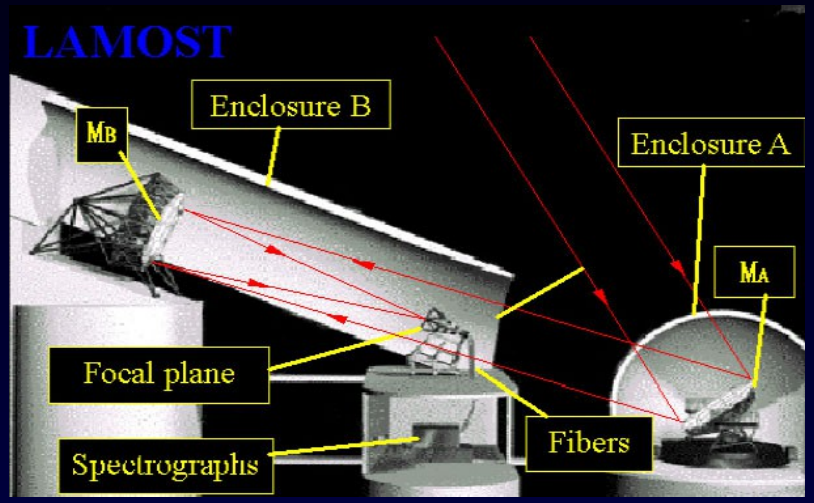



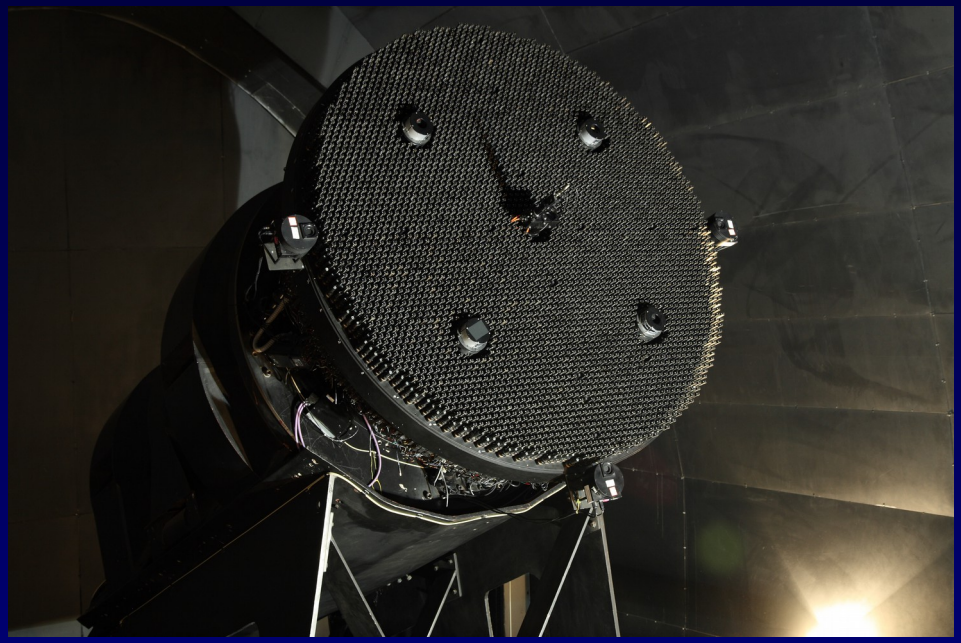



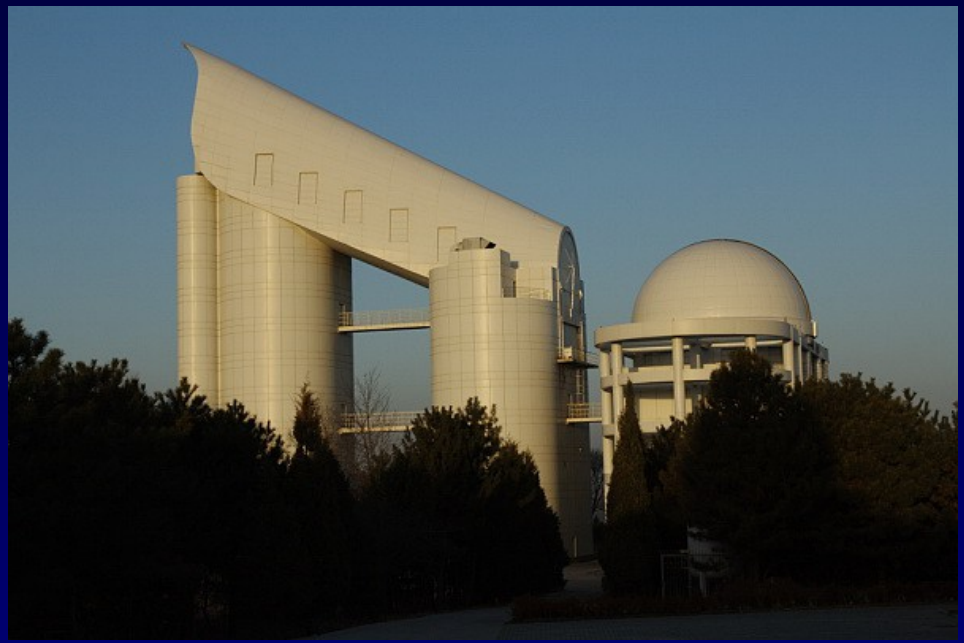



# LAMOST (Guoshoujing)

Xinglong- China
4m mirror (30 deg meridian)
4000  fibers
10 mil spectra / 5 yr
Automatic RV-z





# LAMOST Spectral Surveys

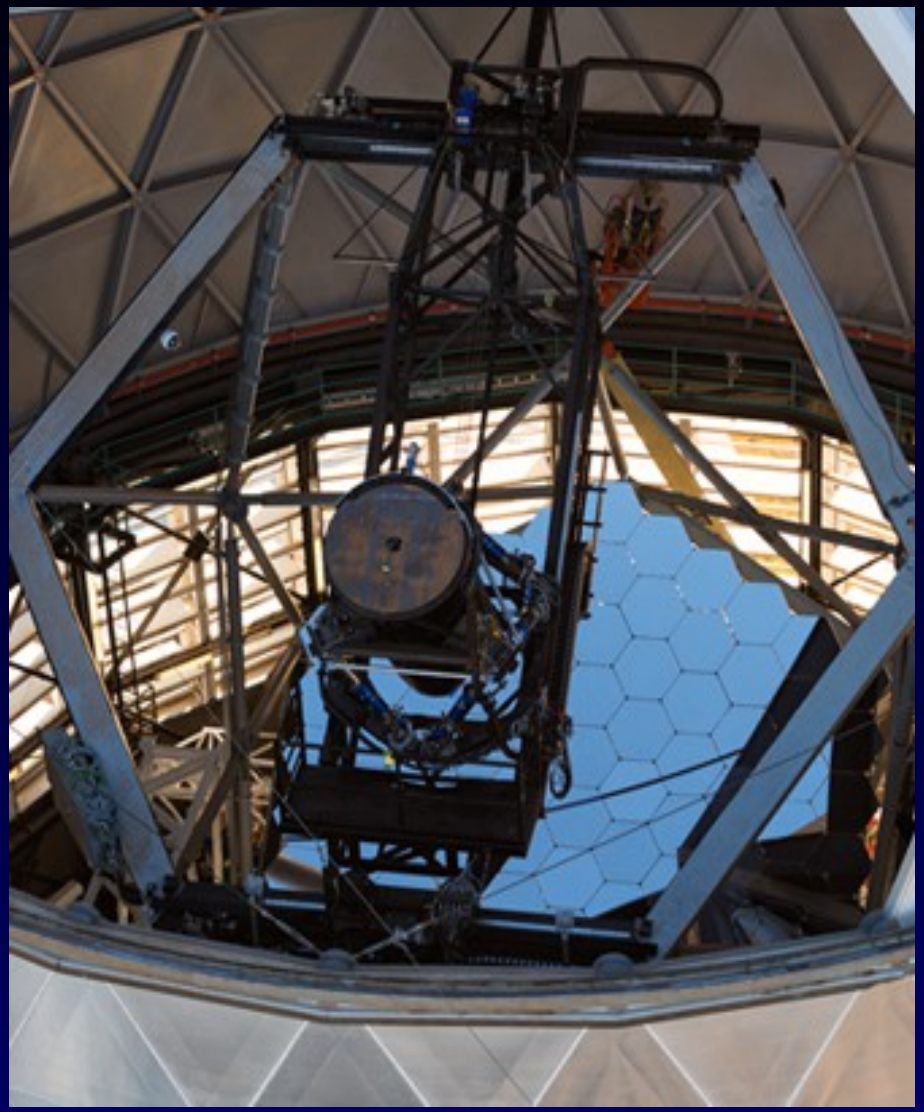
DR1 (end 2013) **2 204 860** spectra
1 085 404 stars

DR3 (half 2015) **5 755 126** spectra
DR4 (Feb 2016) **+ 741 522**

Each Fiber – 2 motors
double arm 33mm circle

Fibre collects light from
3.3 arcsec circle on sky

# Hobby Eberly Telescope (HET)



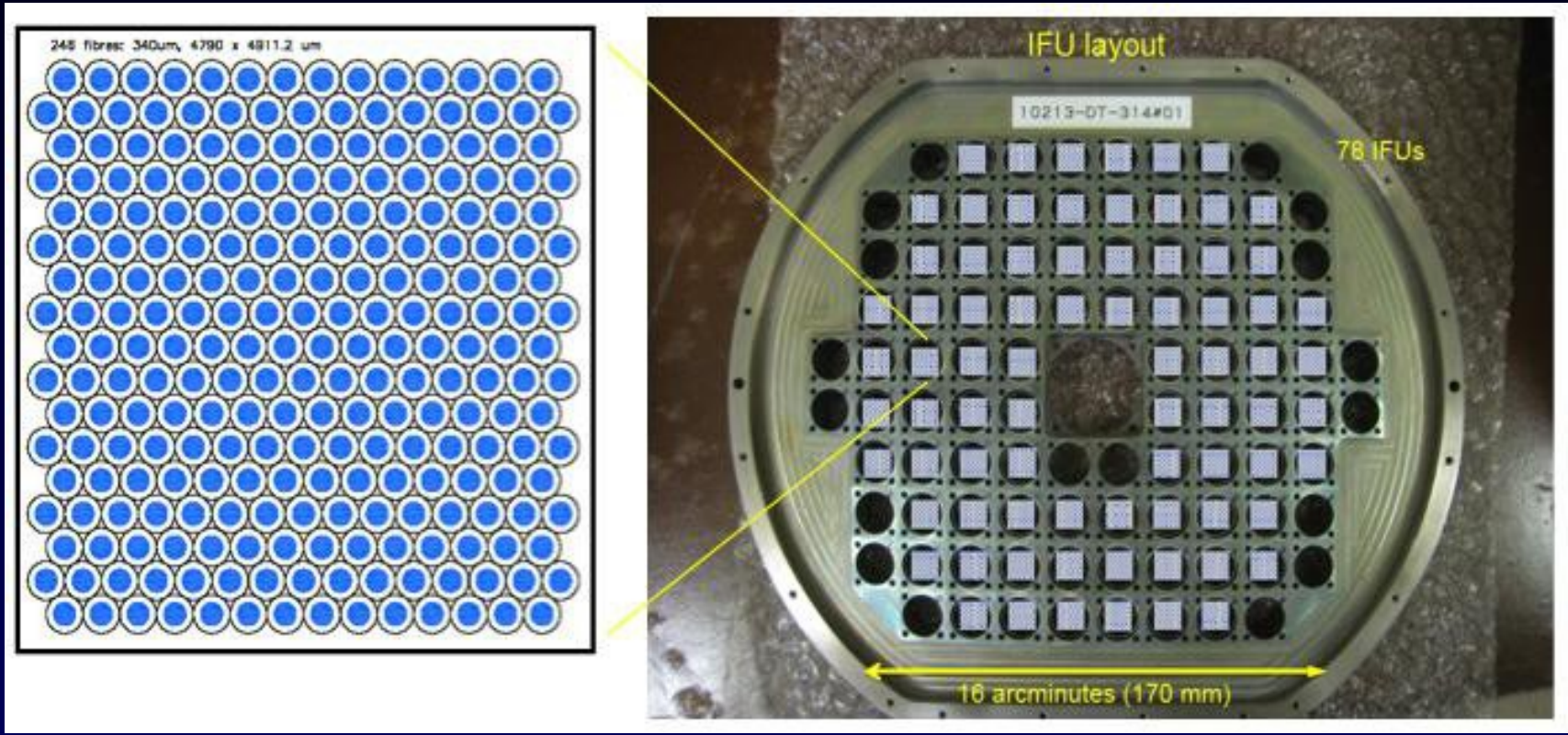
Mc Donald Observatory Texas

Equiv diameter 9.5m (11m)

Fixed in position during observation - only primary tracker

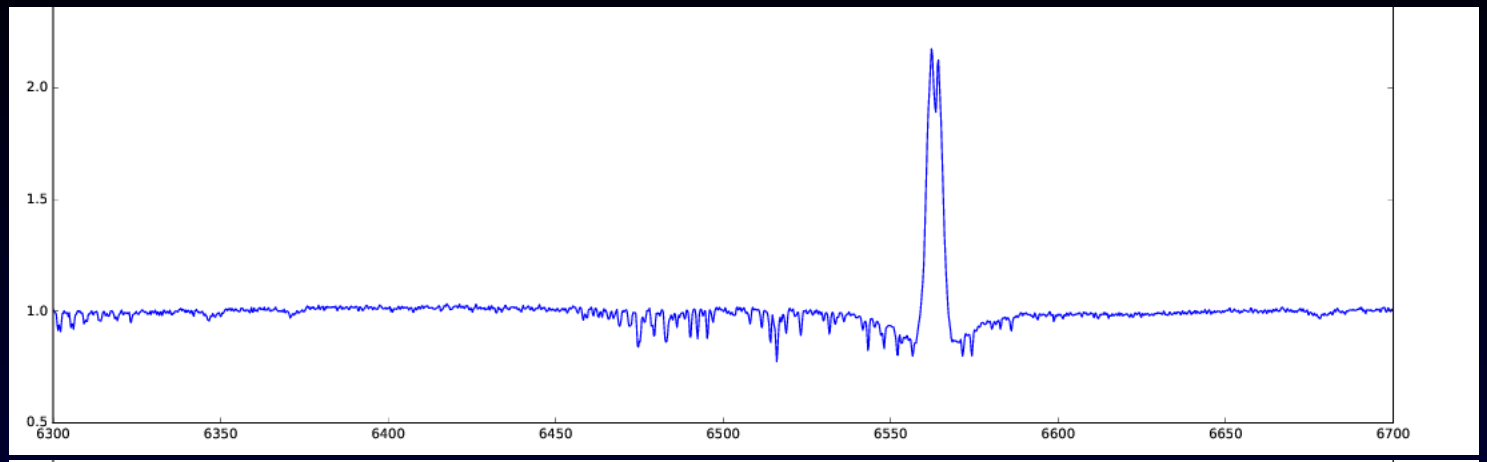
# HETDEX Survey

In theory 34944 spectra every 20min !

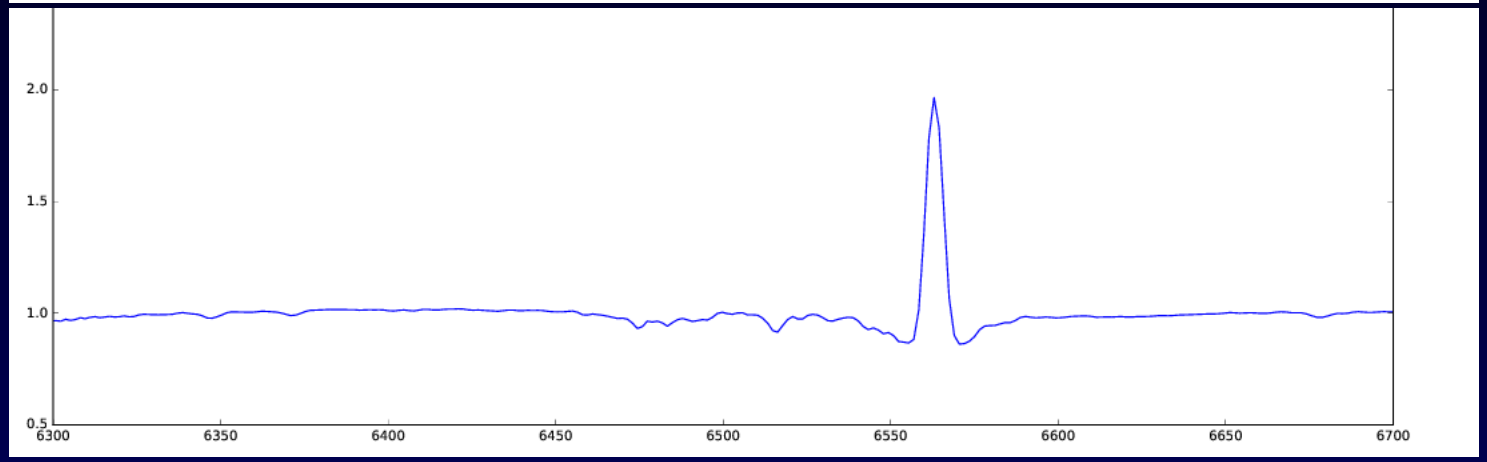



VIRUS 78 IFU = 156 spectrographs
IFU= 448 fibers
34944 fibers , FOV 22 arcmin, 3500-5500 A, R=800
1 million spectra of galaxies (only part - statistic hits)

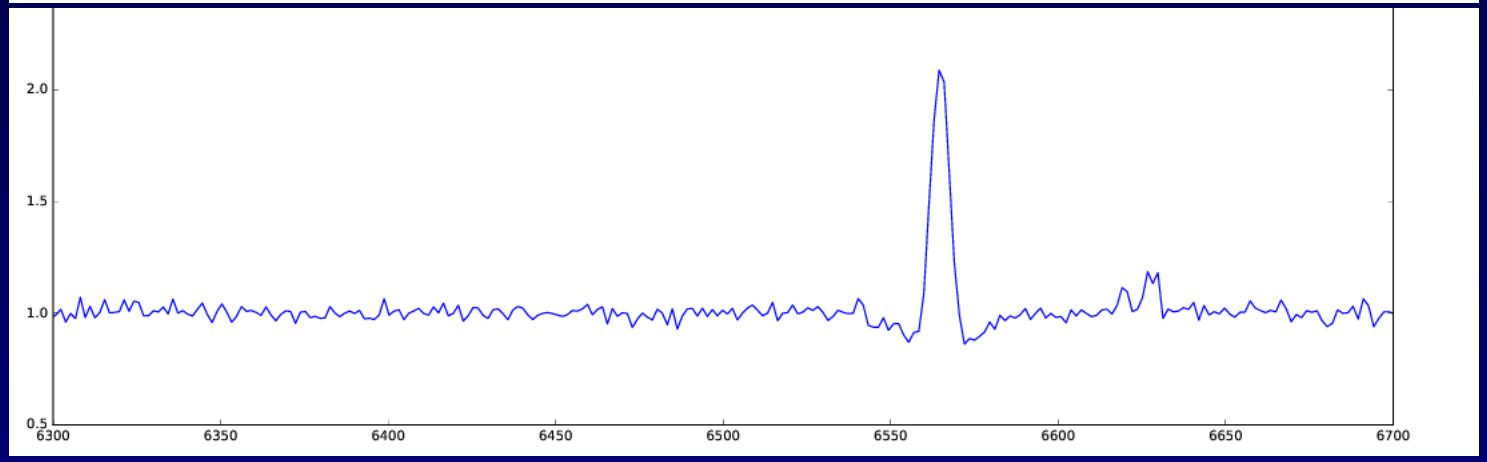
# Resolution Degradation




OND R=13000

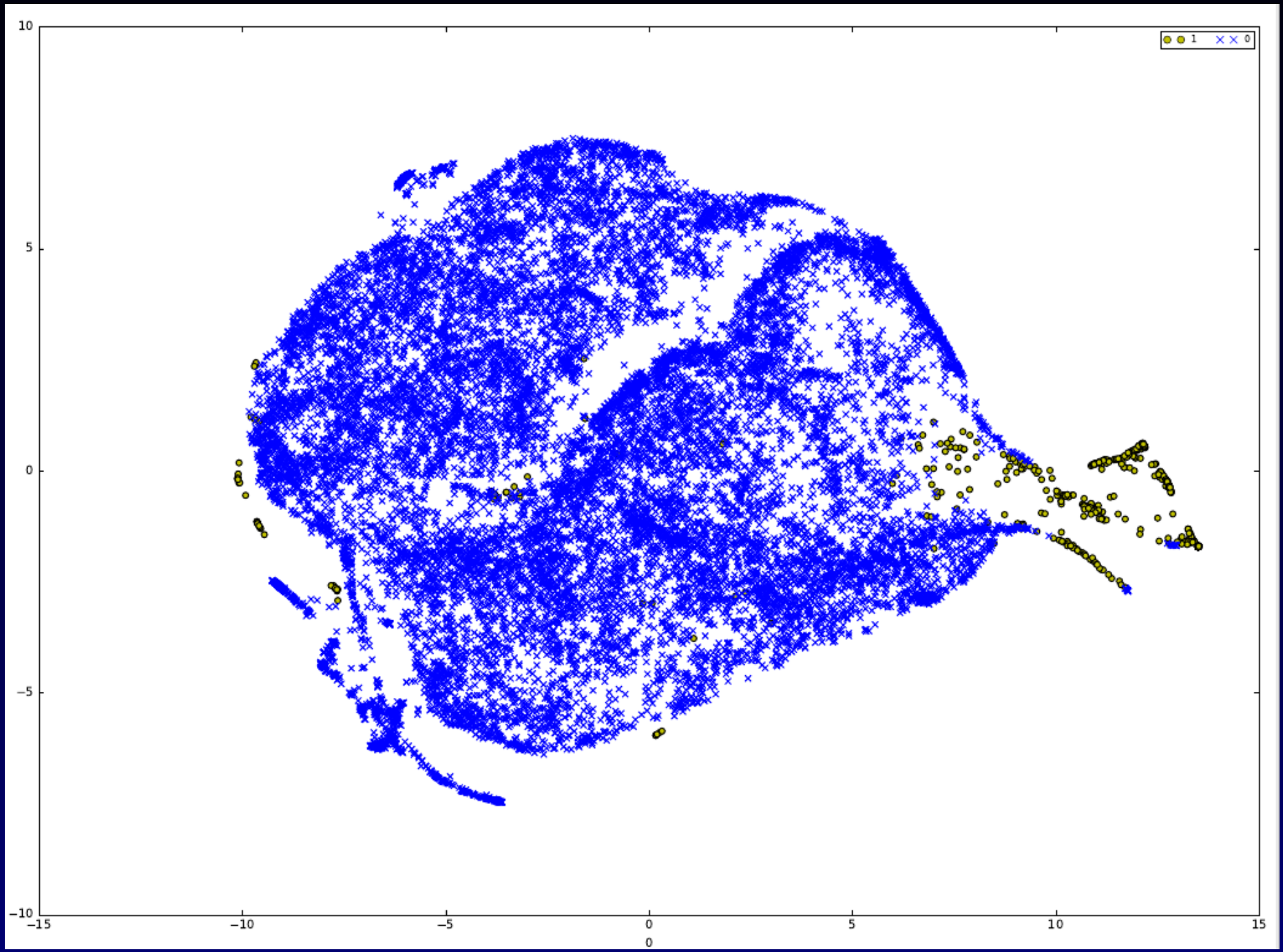



OND R=1800




LAMOST

# LAMOST TSNE Structure



# Semi-Supervised Training

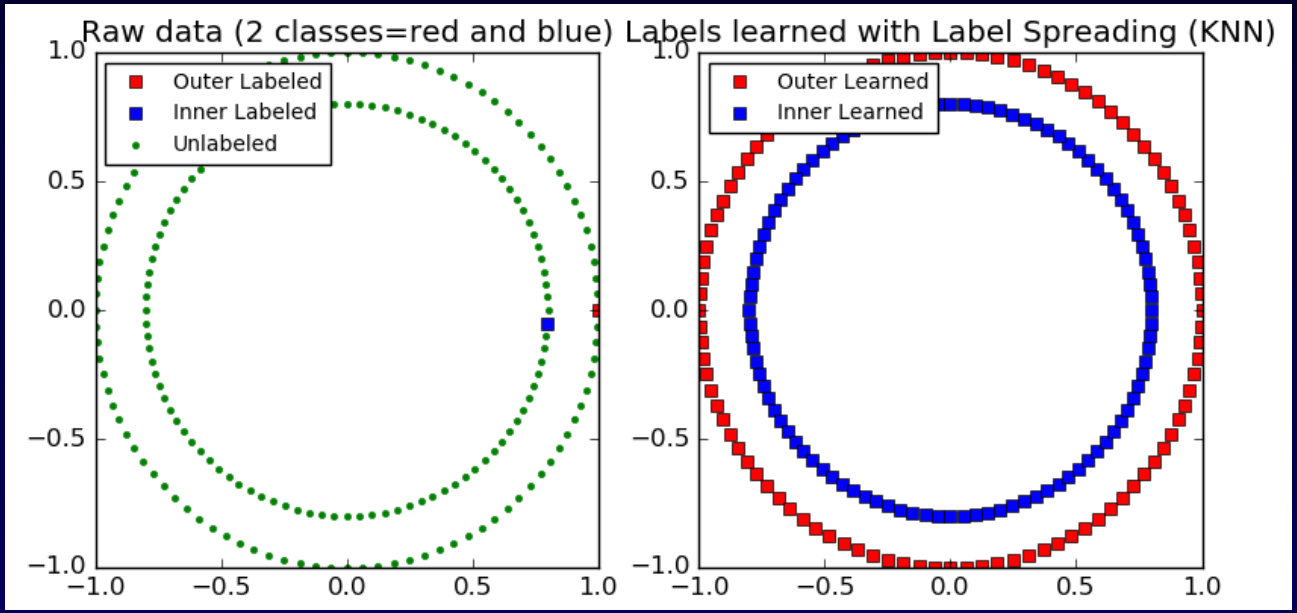
Not supervised (even if not Domain Adaptation)

- sample of labelled data - about 1600
- unlabelled (LAMOST) - HDFS limit to 1,048,576 (2^20)

Graph methods:

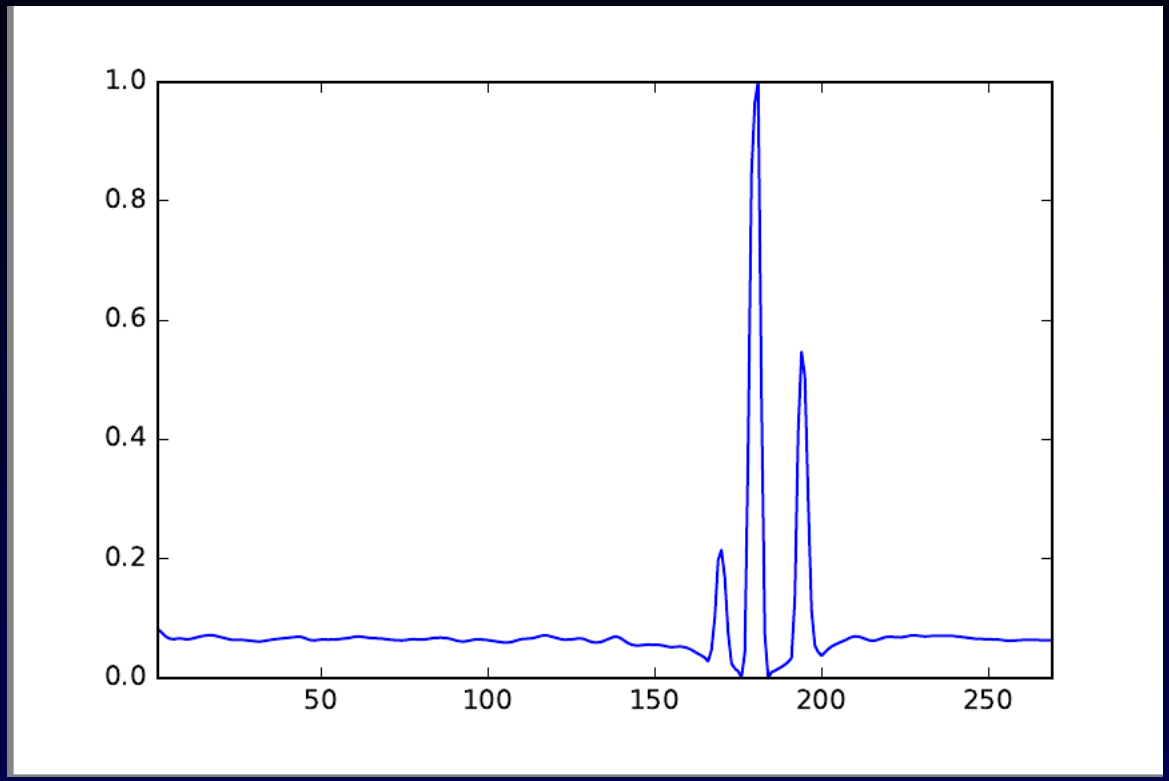
Label spreading

Label propagation

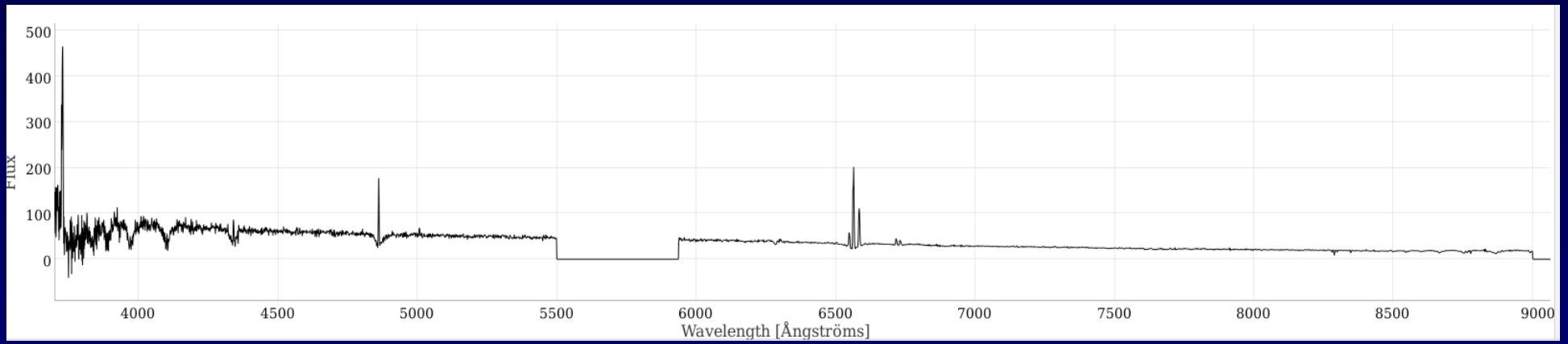



Spark on HDFS - National cloud MetaCentrum

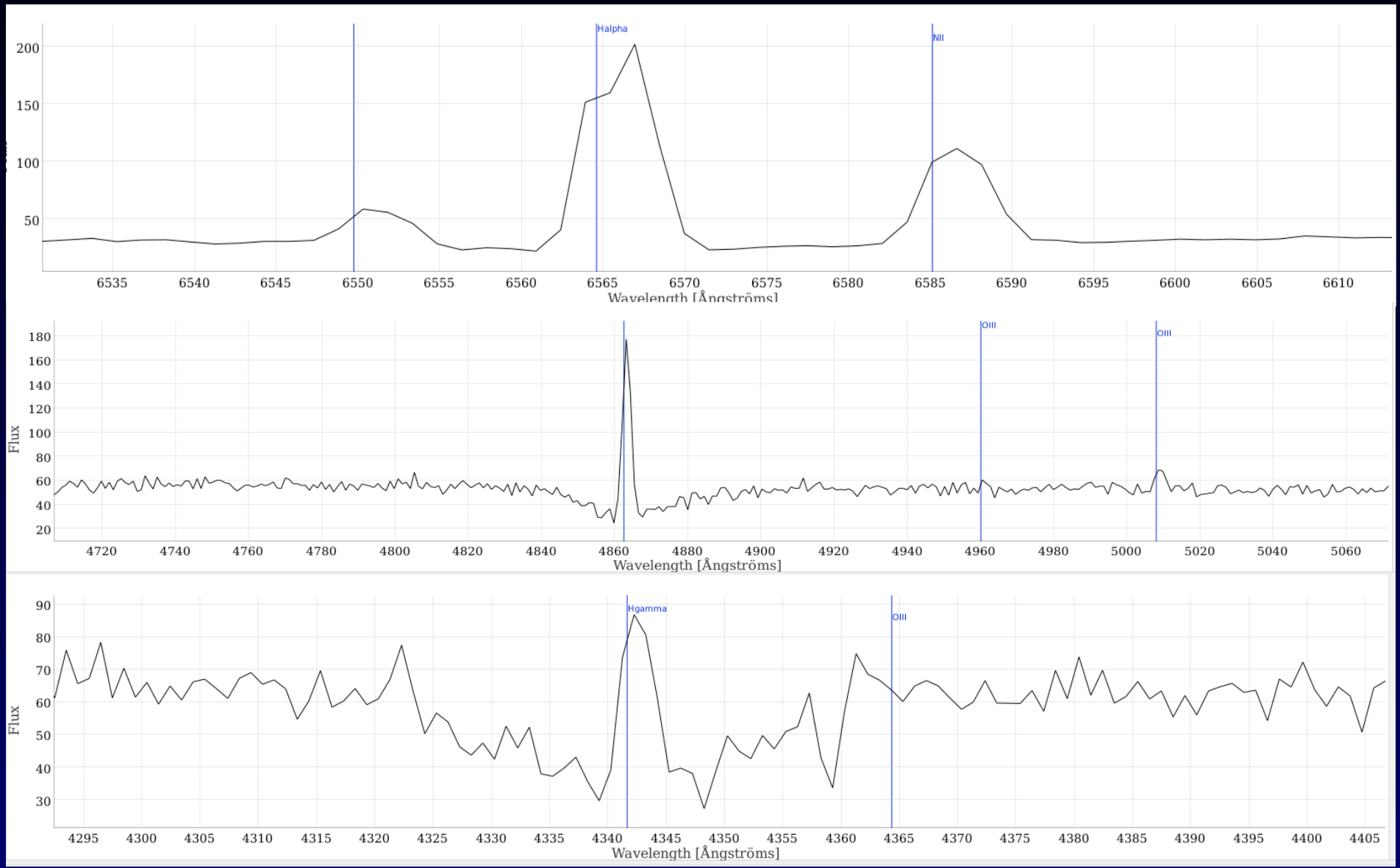
# Be Candidates – Semi Supervised ML




Palička 2016



# Be Candidates Found



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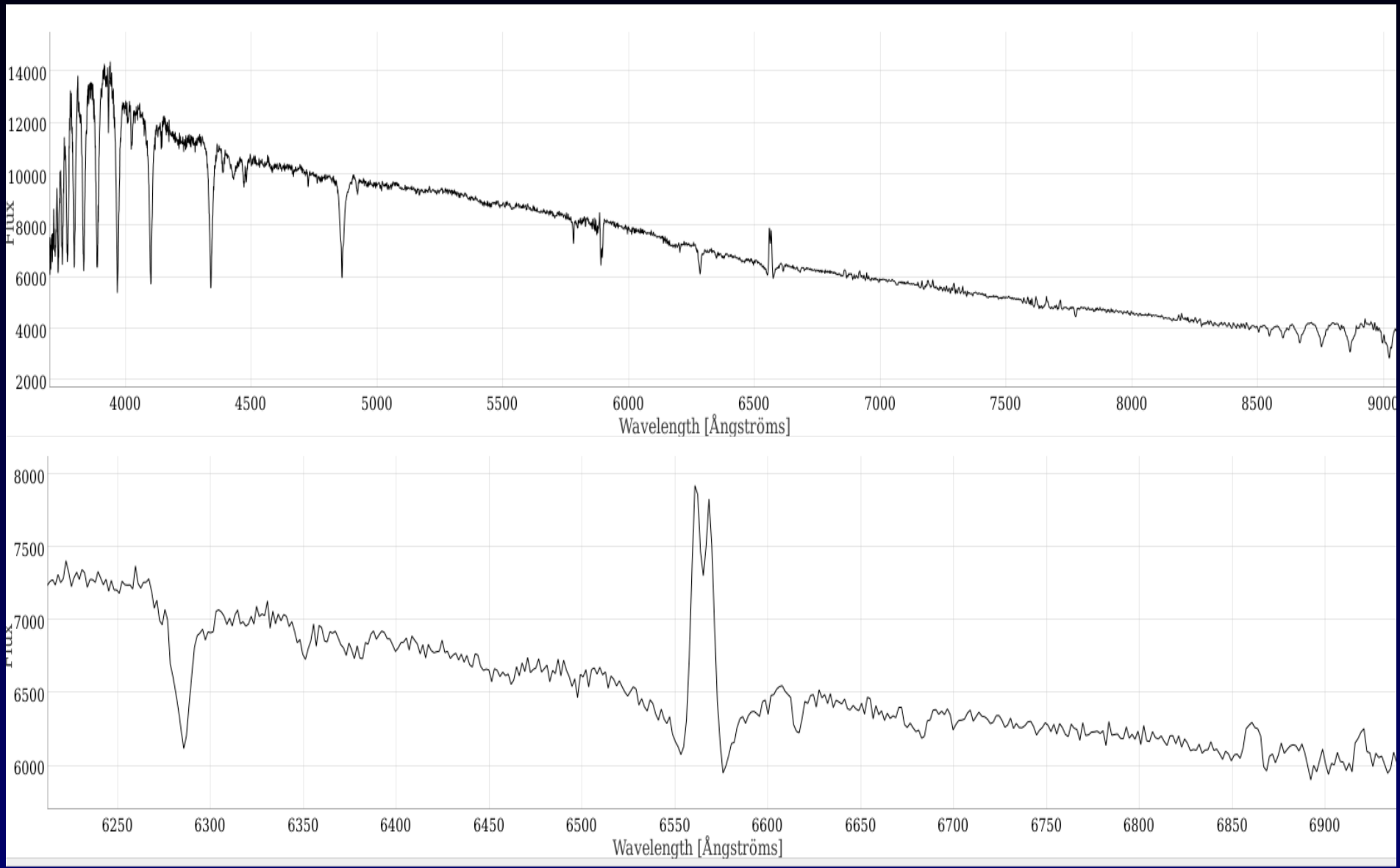

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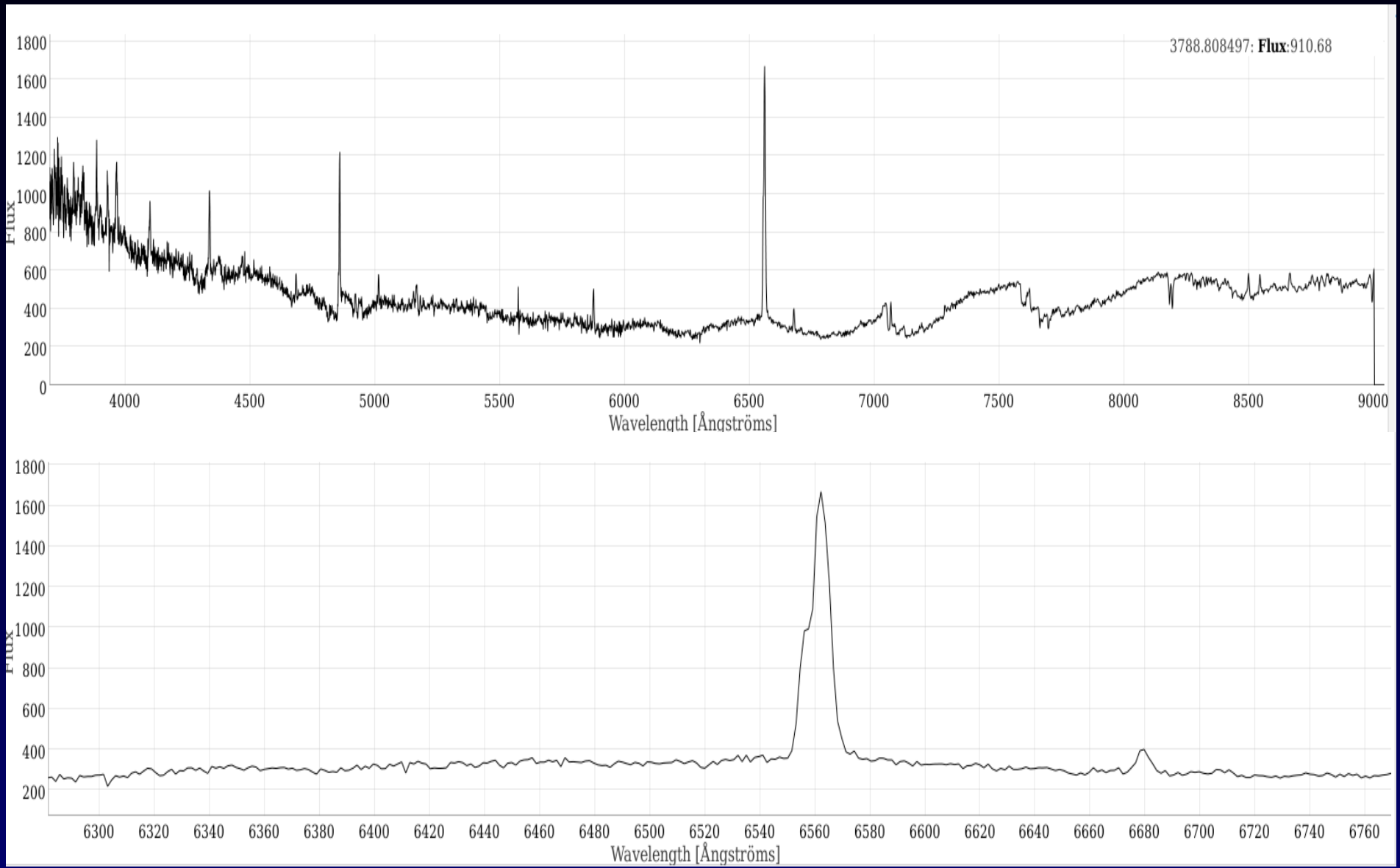

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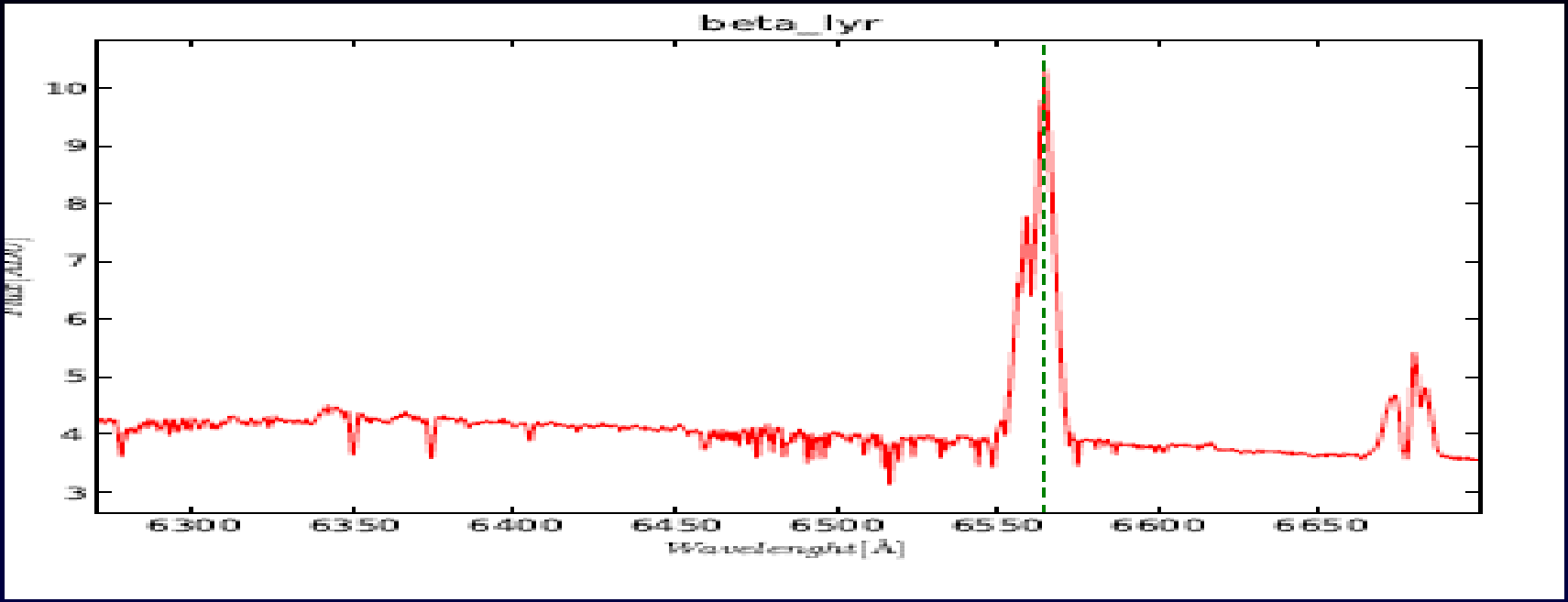
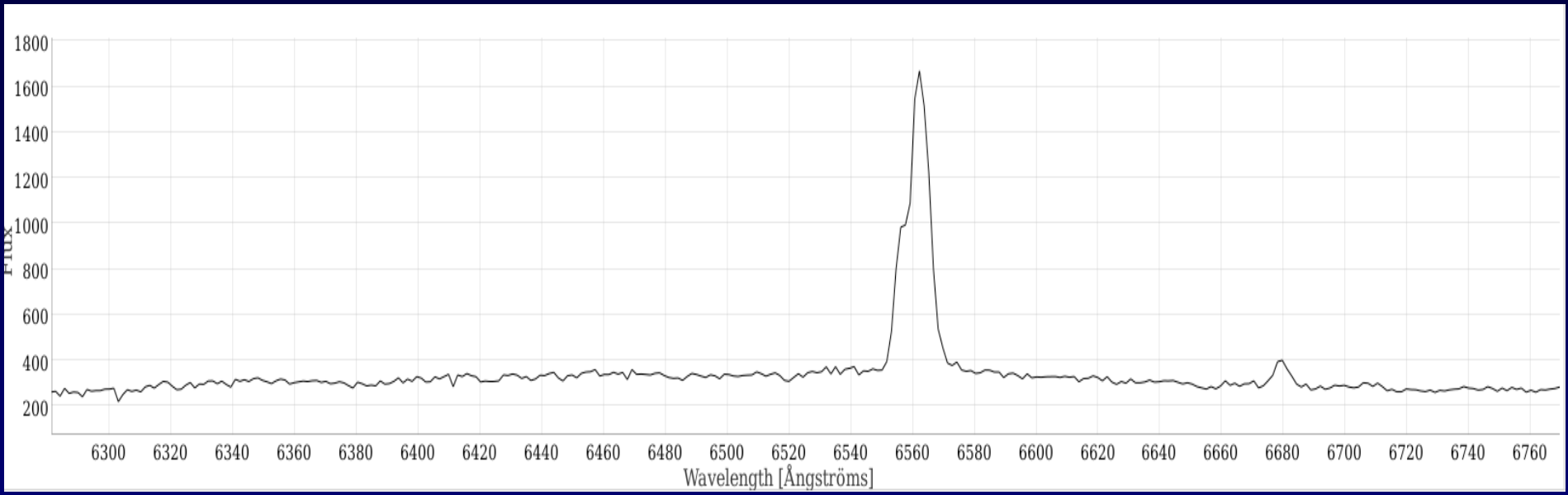
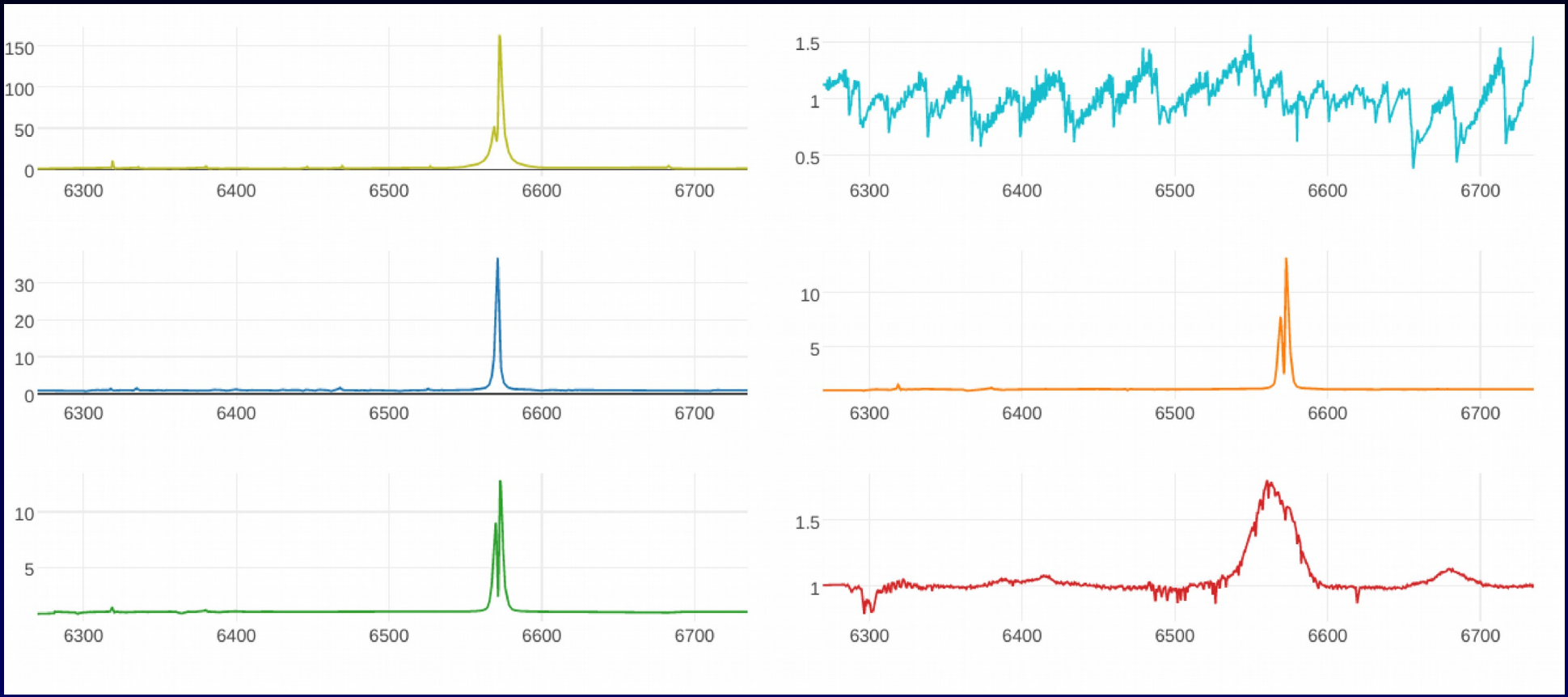


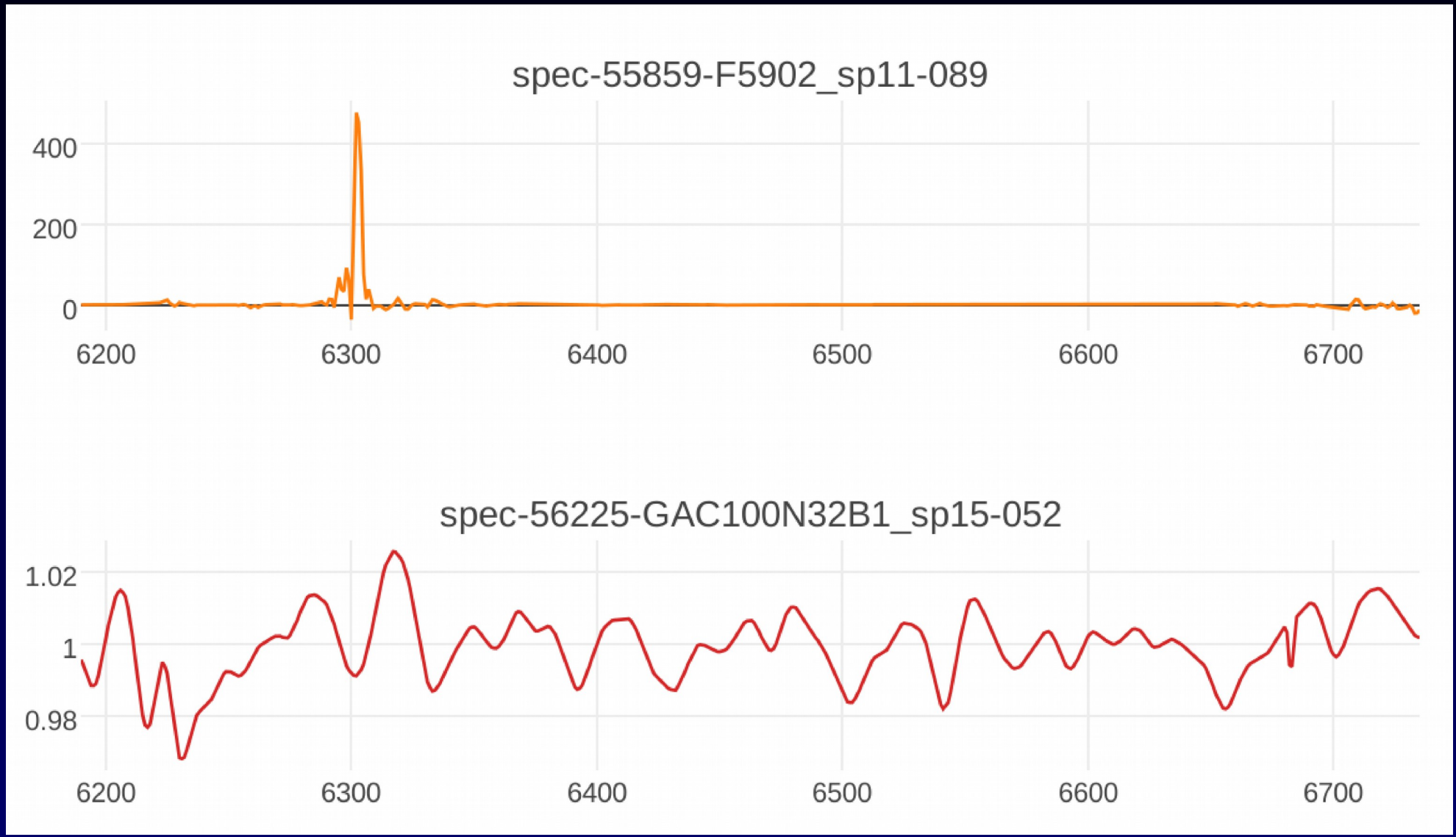
# CCD700 Outliers

Unsupervised learning – Local Outlier Factor - LOF

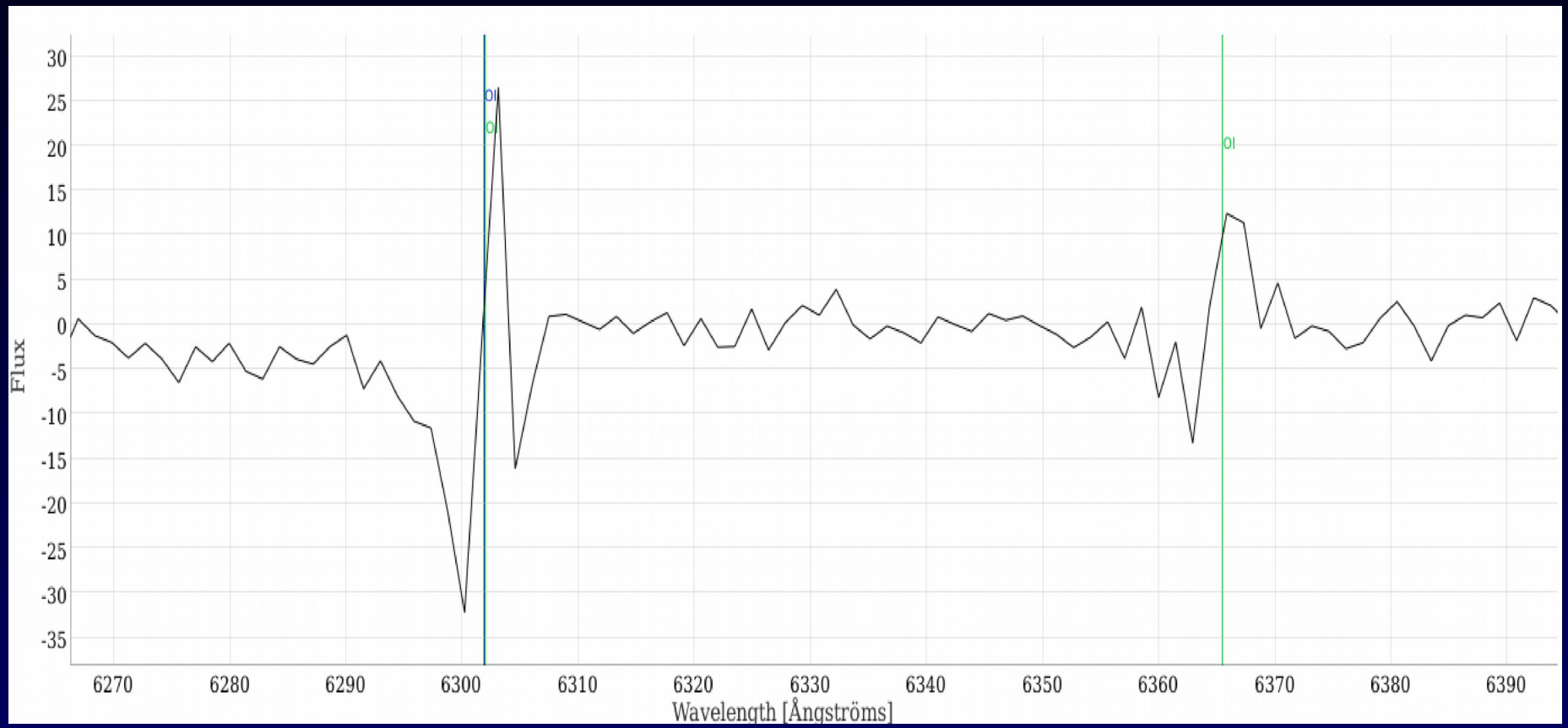



Shakurova 2016

# LAMOST Outliers



# LAMOST Be star - outlier



# Concept of scientific „CLOUD“

ITERATIVE REPEATING of SAME computation (workflow)

Global non-linear optimization (Korel)

Synthetic spectra (various elements, wavelength-ranges)

Machine Learning (almost all methods)

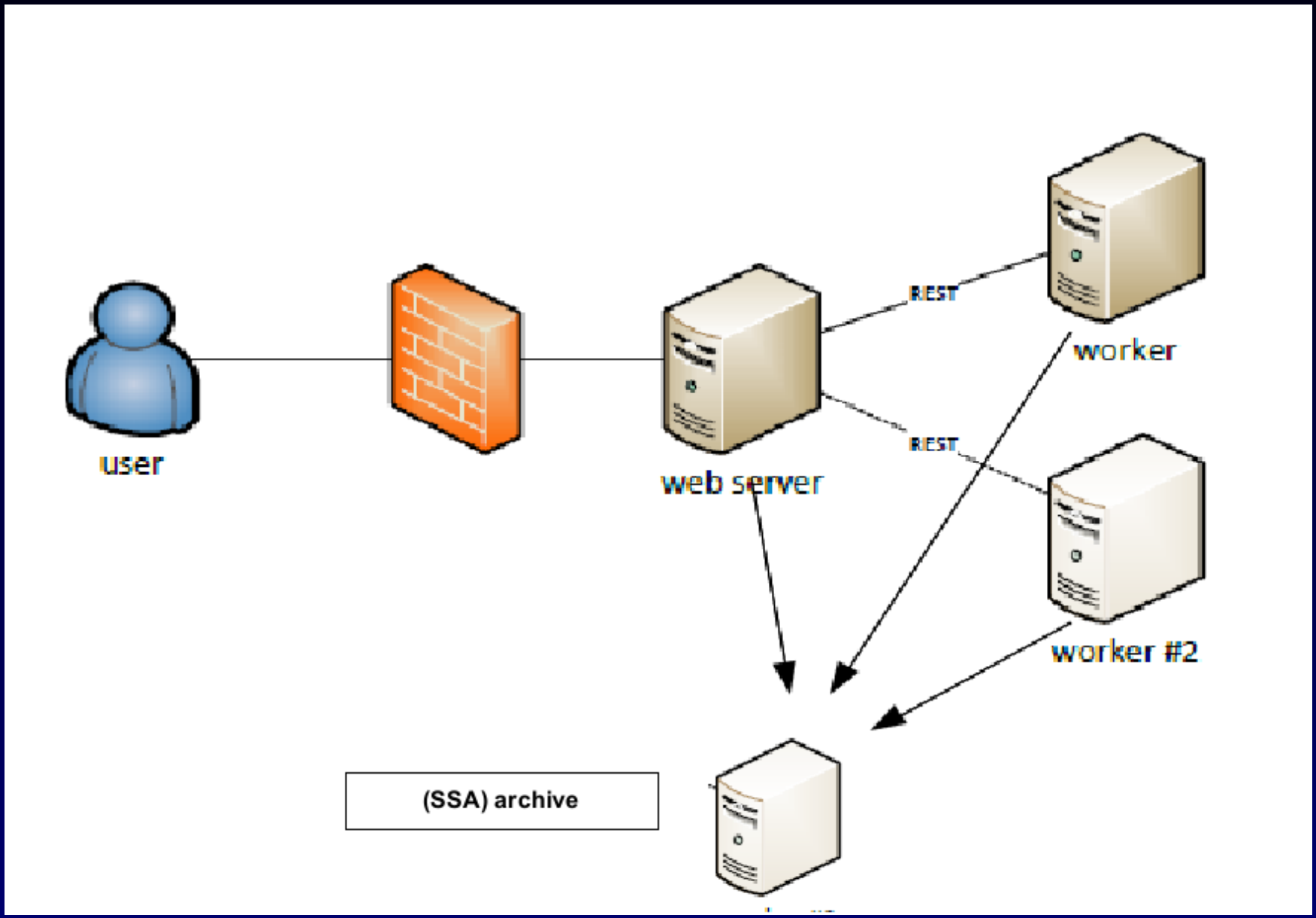
LARGE stable INPUT data + small changing PARAMS

Many runs on SAME data (tuning required)

Graphics visualization from postprocessed output (text) files

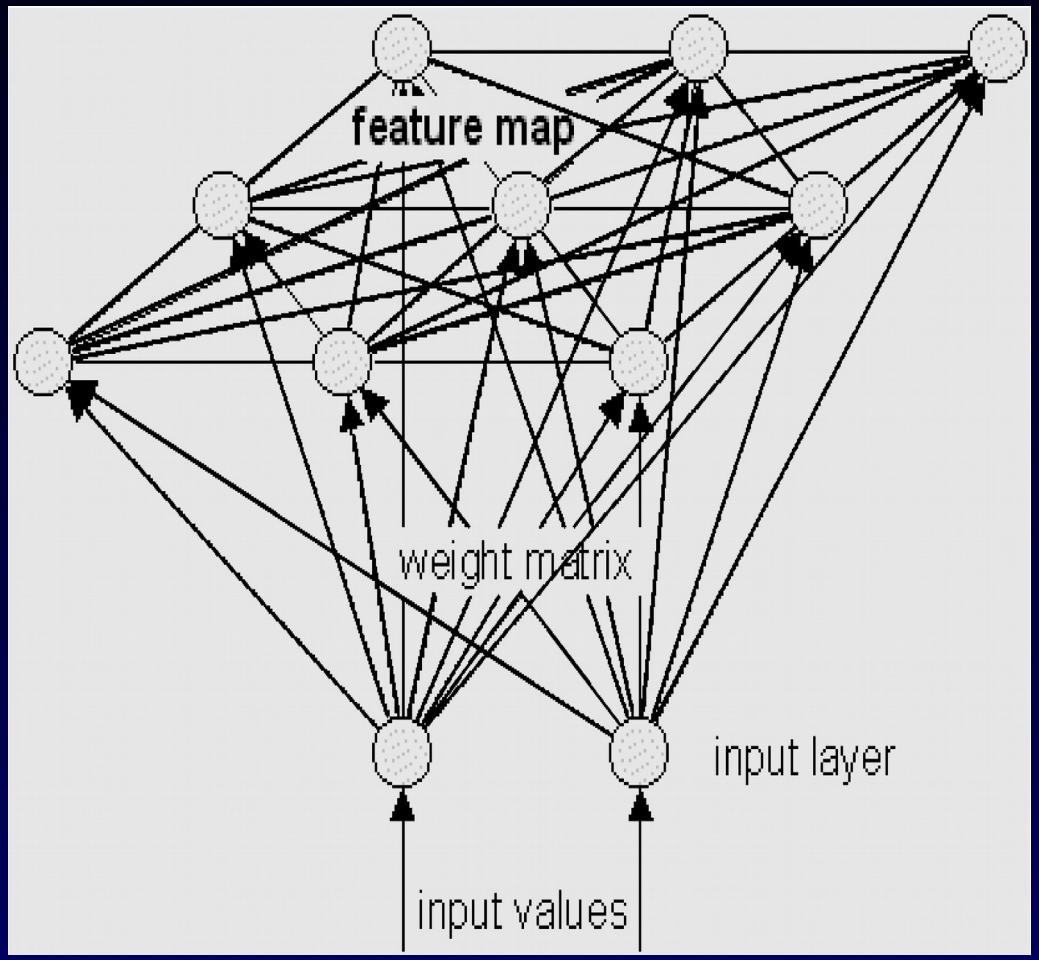
Using WWW browser - supercomputing in PDA/mobil

# Machine Learning of BIG Archive



# Principles of SOM

Self-Organizing = Kohonen map




Association (activation) map

How many vectors activate every neuron

Unified Distance Matrix (U-matrix)

Every neuron= sum of distances to neighbours

The higher = more unique (outlier)

# Machine Learning of Spectra
# SW view

ML does not produce new data – same spectra in groups

Results the same size as input (+ small overhead)

Tracing visual shape from ML results

- Solf-Organizing maps – finding outliers
- Easy trace shape from neuron - clickable maps
- Visualisation of many spectra in web – dygraph (JS)

# Virtual Observatory inside

- OND 2m archive on SSAP protocol (spectra access)
- LAMOST DR1 on SSAP (using DaCHS)
- Preprocessing (rectify, cutout) – DataLink on server
- SAMP (send spectra to SPLAT-VO - view details)
- Visualization of results

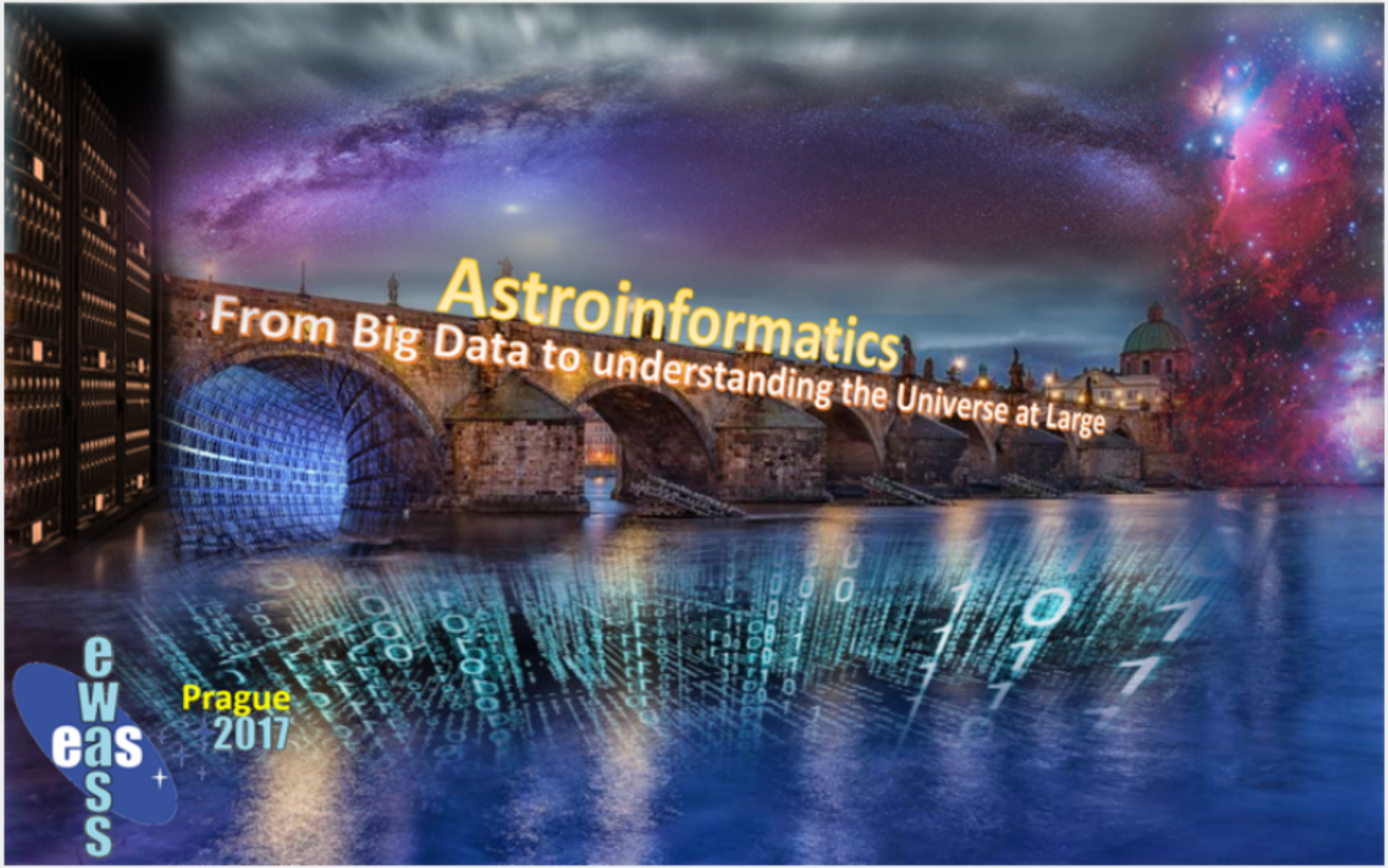
- VO-CLOUD – cloud engine based on UWS REST jobs
- Cross-matching (ADQL, TAP, TOPCAT, TAPhandle, pyVO, Vizier )

# Conclusions

- Machine learning on big spectra archives may identify new interesting objects yet unknown
- Crucial is interactive visualization of candidates
- VO technology helps in every step
- Future astronomy will be multidisciplinary
- Wide collaboration of experts and informaticians

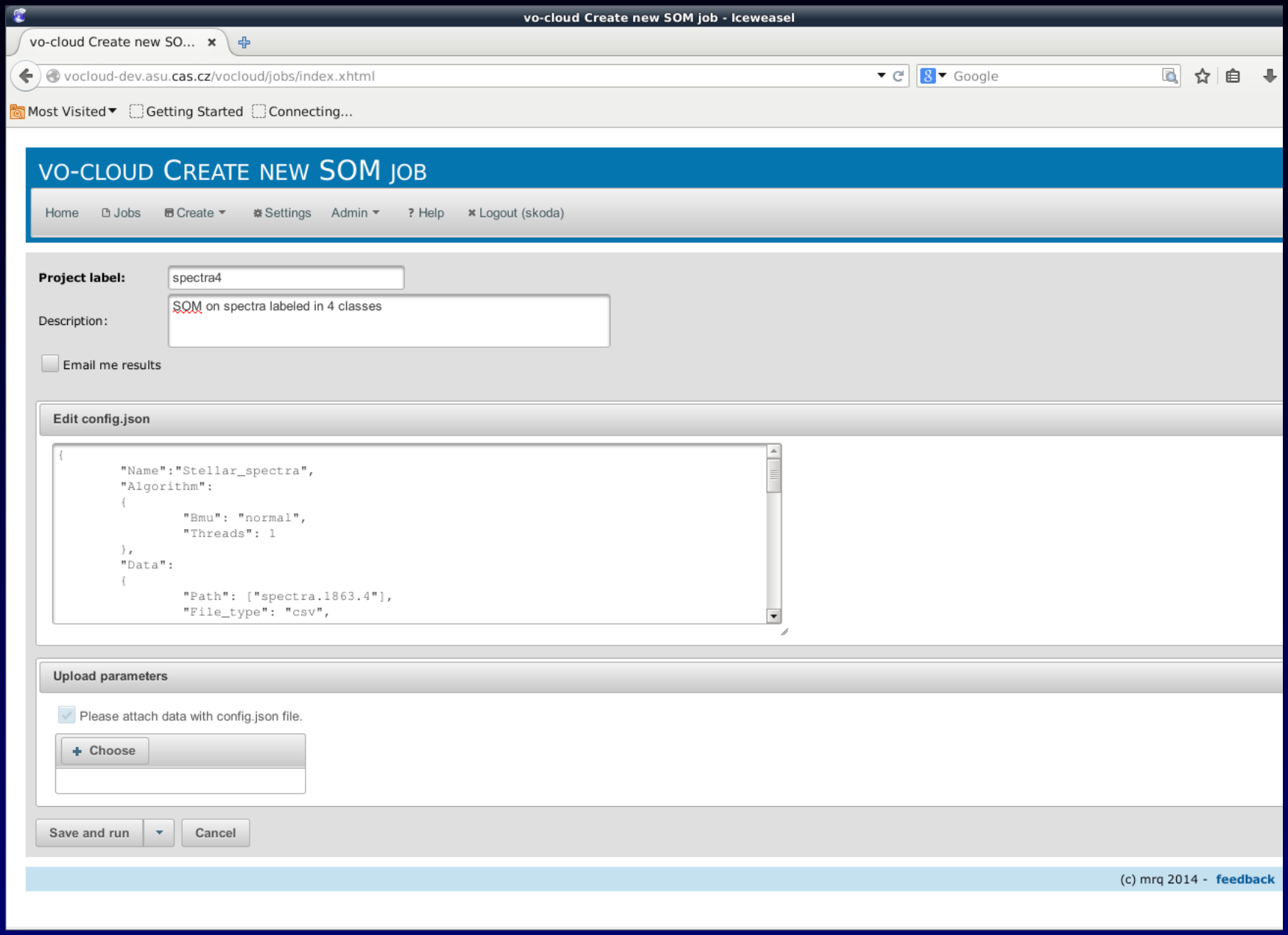
Symposium S14

29 – 30 June 2017

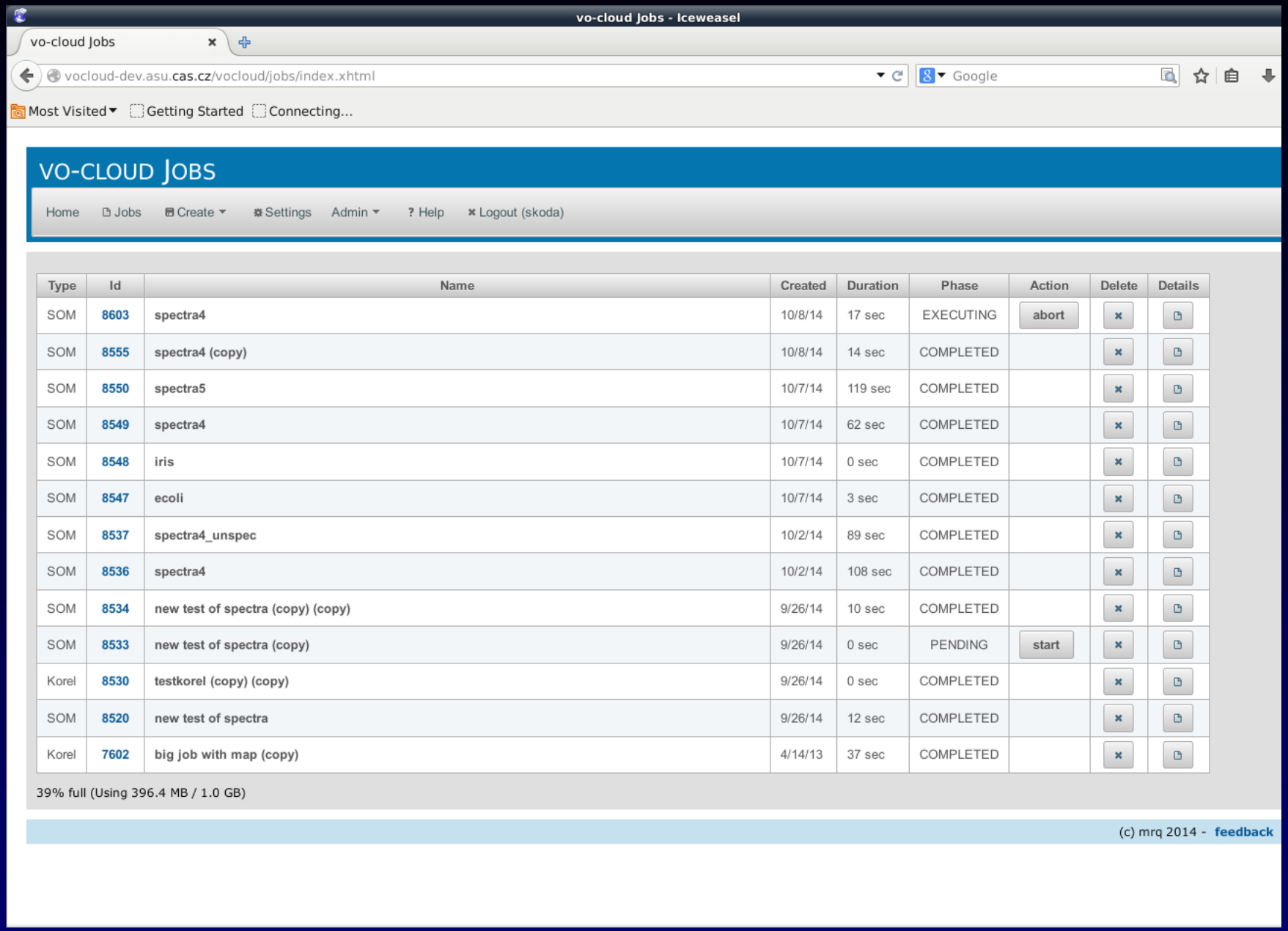



http://eas.unige.ch/EWASS2017/session.jsp?id=S14

# DEMO – create job

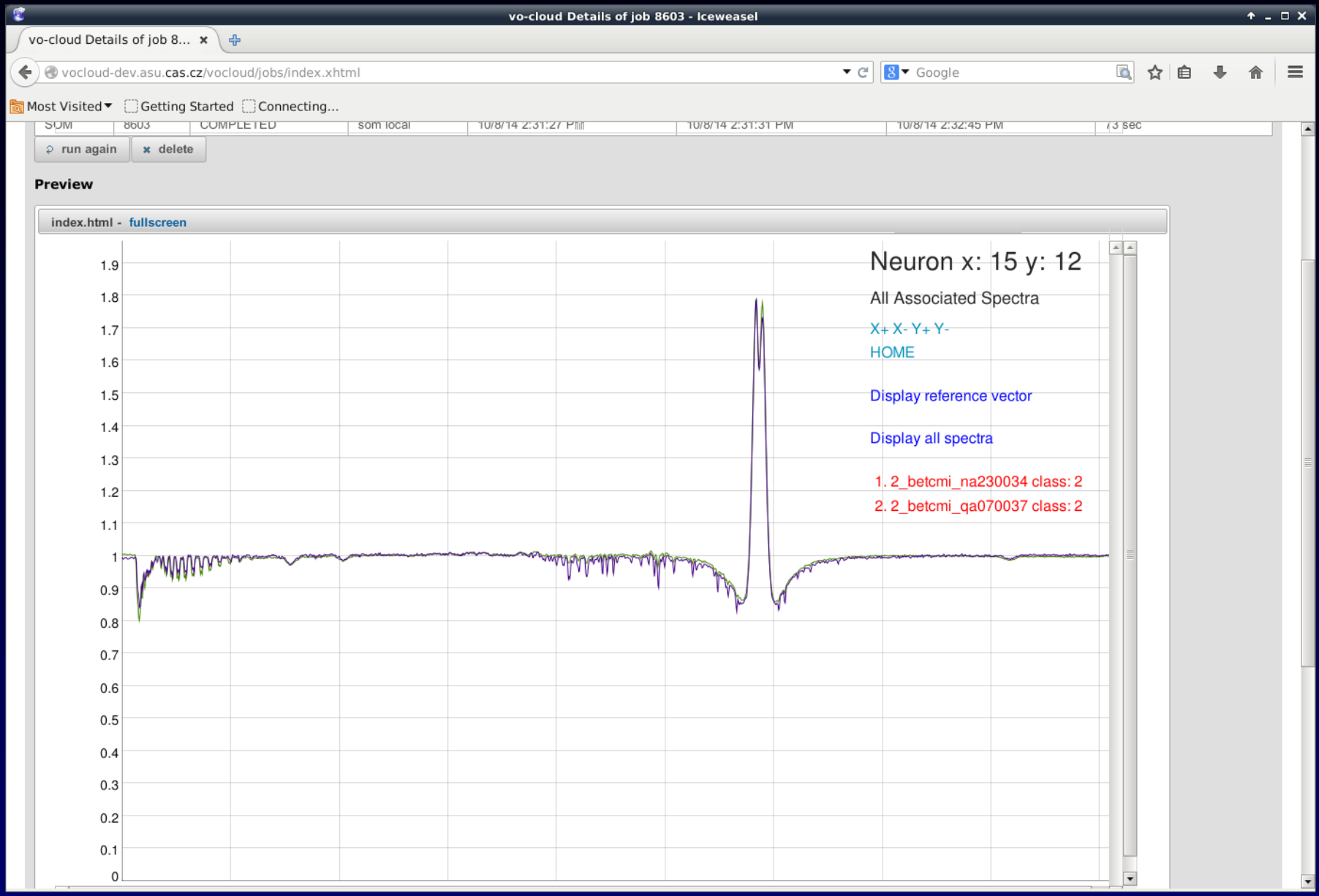


# DEMO – Job is running




| Type | Id | Name | Created | Duration | Phase | Action | Delete | Details |
|---|---|---|---|---|---|---|---|---|
| SOM | 8603 | spectra4 | 10/8/14 | 17 sec | EXECUTING | abort | × | |
| SOM | 8555 | spectra4 (copy) | 10/8/14 | 14 sec | COMPLETED | | × | |
| SOM | 8550 | spectra5 | 10/7/14 | 119 sec | COMPLETED | | × | |
| SOM | 8549 | spectra4 | 10/7/14 | 62 sec | COMPLETED | | × | |
| SOM | 8548 | iris | 10/7/14 | 0 sec | COMPLETED | | × | |
| SOM | 8547 | ecoli | 10/7/14 | 3 sec | COMPLETED | | × | |
| SOM | 8537 | spectra4_unspec | 10/2/14 | 89 sec | COMPLETED | | × | |
| SOM | 8536 | spectra4 | 10/2/14 | 108 sec | COMPLETED | | × | |
| SOM | 8534 | new test of spectra (copy) (copy) | 9/26/14 | 10 sec | COMPLETED | | × | |
| SOM | 8533 | new test of spectra (copy) | 9/26/14 | 0 sec | PENDING | start | × | |
| Korel | 8530 | testkorel (copy) (copy) | 9/26/14 | 0 sec | COMPLETED | | × | |
| SOM | 8520 | new test of spectra | 9/26/14 | 12 sec | COMPLETED | | × | |
| Korel | 7602 | big job with map (copy) | 4/14/13 | 37 sec | COMPLETED | | × | |

# DEMO


vo-cloud Details of job 8603 - Iceweasel
vo-cloud Details of job 8...
vocloud-dev.asu.cas.cz/vocloud/jobs/index.xhtml
Google
Most Visited
Getting Started
Connecting...
SOM
8603
COMPLETED
som local
10/8/14 2:31:27 PM
10/8/14 2:31:31 PM
10/8/14 2:32:45 PM
73 sec
run again
delete
Preview
index.html - fullscreen
Neuron x: 15 y: 12
All Associated Spectra
X+ X- Y+ Y-
HOME
Display reference vector
Display all spectra
1. 2_betcmi_na230034 class: 2
2. 2_betcmi_qa070037 class: 2
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0