Optical Spectroscopy with the Technology of Virtual Observatory

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8th Serbian Conference on Spectral Line Shapes in Astrophysics
Invited Lecture, 7-th June 2011, Divčibare, Serbia

Credits

- The presentation is based on many different sources – mainly the on-line published slides from IVOA meetings, slides or pictures found on internet.
- We acknowledge namely materials of E. Solano, D. De Young, F. Le Petit, B.Hanish, C.R. Blanco, E. Hatsiminaoglou, T.Hey

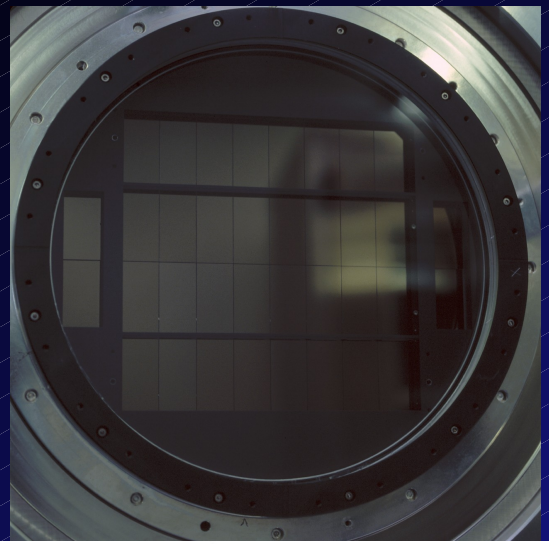
Outline of the Talk

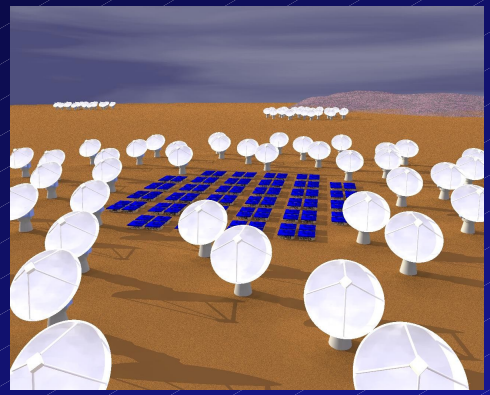
- VO – the hidden revolution in astronomy
- Data Avalanche in astronomy
- History of VO
- Basic principles of technology
- VO Tools for spectroscopy
- Theory in VO (model spectra, SEDs)
- VO Science
- Astroinformatics

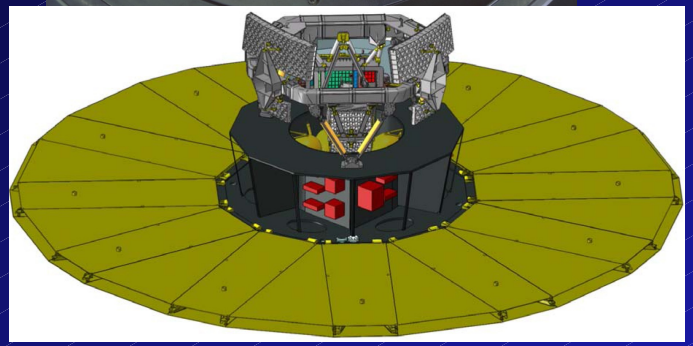
VO – The Hidden Revolution in Astronomy

- VO is the radical change of the paradigma of the work of the scientists – effectiveness !!!
- VO is there but hidden under the hood (Aladin, Vizier, Simbad, NED, MAST, ADS.....
- Everyday question (what, where, format, units)
- Scientists are conservative (don't like change)
  - The fear of buzzword VO (multispec, large scale)
- IT literacy – obligatory in near future (scripts...)

Data Avalanche







Large Scale Data

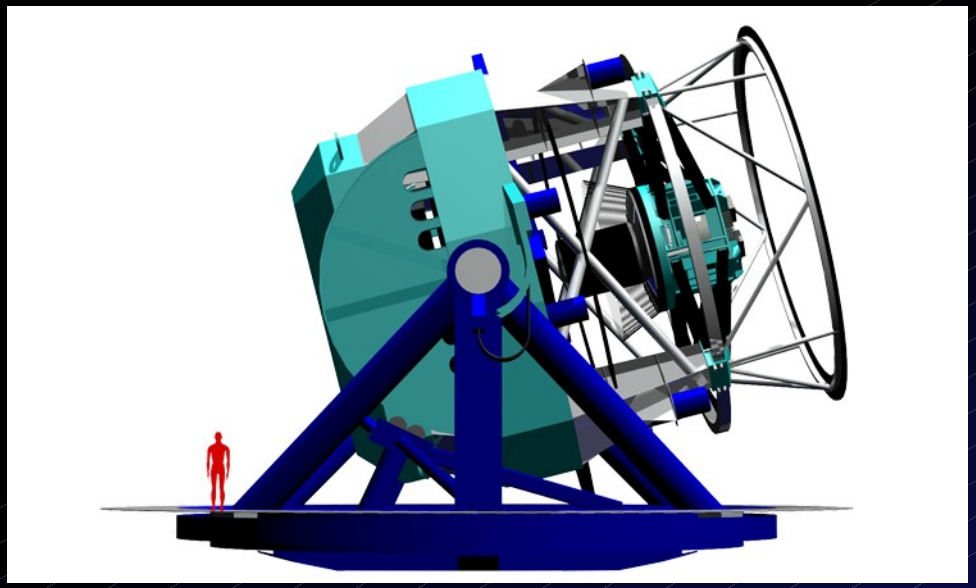
- *Huge surveys*:100 million sources at < 3000 sources per night ⇒> 100 years to identify them
- *Huge data collections*: download and data analysis on desktop problematic/impossible.
- Example: downloading Sloan Digital Sky Survey (SDSS) DR6 data:
  - images (10 Terabytes) ⇒~ 3 months at 10 Mbps
  - catalogues (2 Terabytes) ⇒~ 3 weeks
  - on DVDs ⇒~ 2,100 of them
- And *data analysis*?? (similar size for MACHO, 2MASS etc)

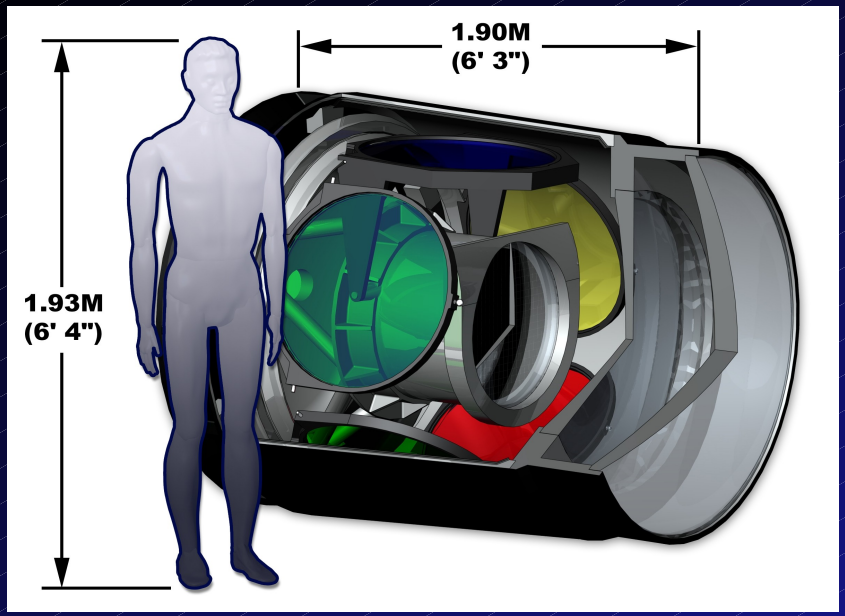
CD Sea

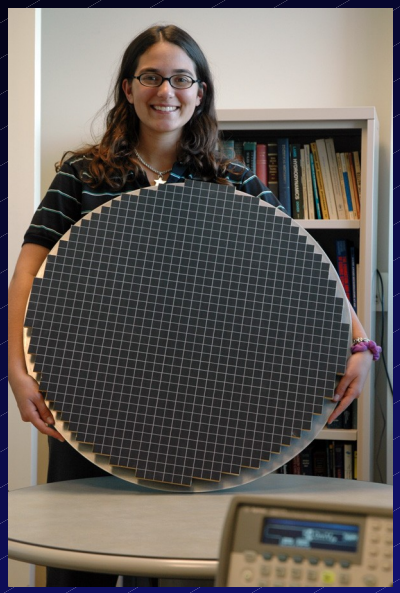
600 000 CD = 372 TB (CD 650MB)
600 000 DVD = 2.5 PB (DVD=4.5GB)

Bruce Monro
Kilmington UK

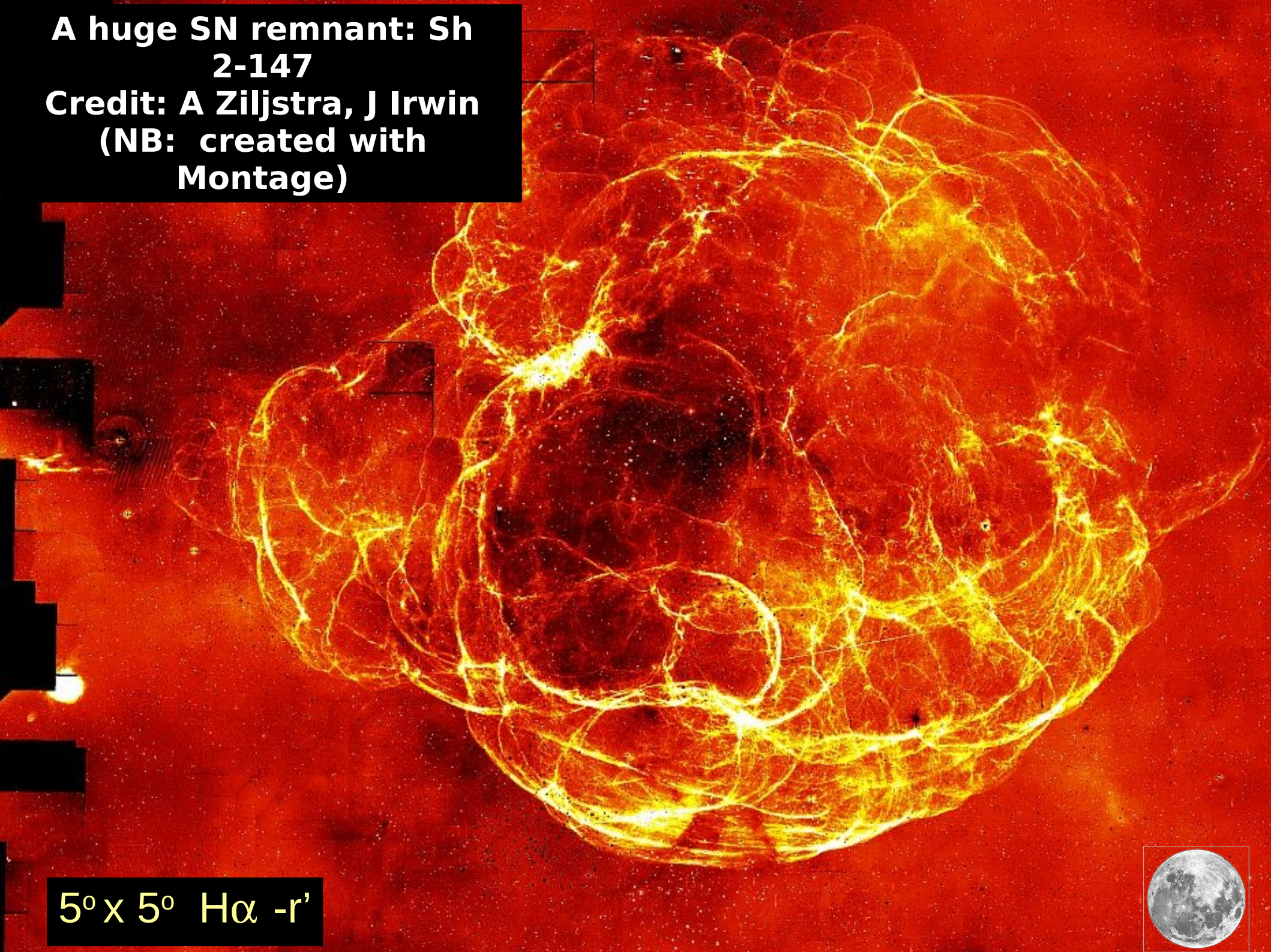
LSST (8.4m)







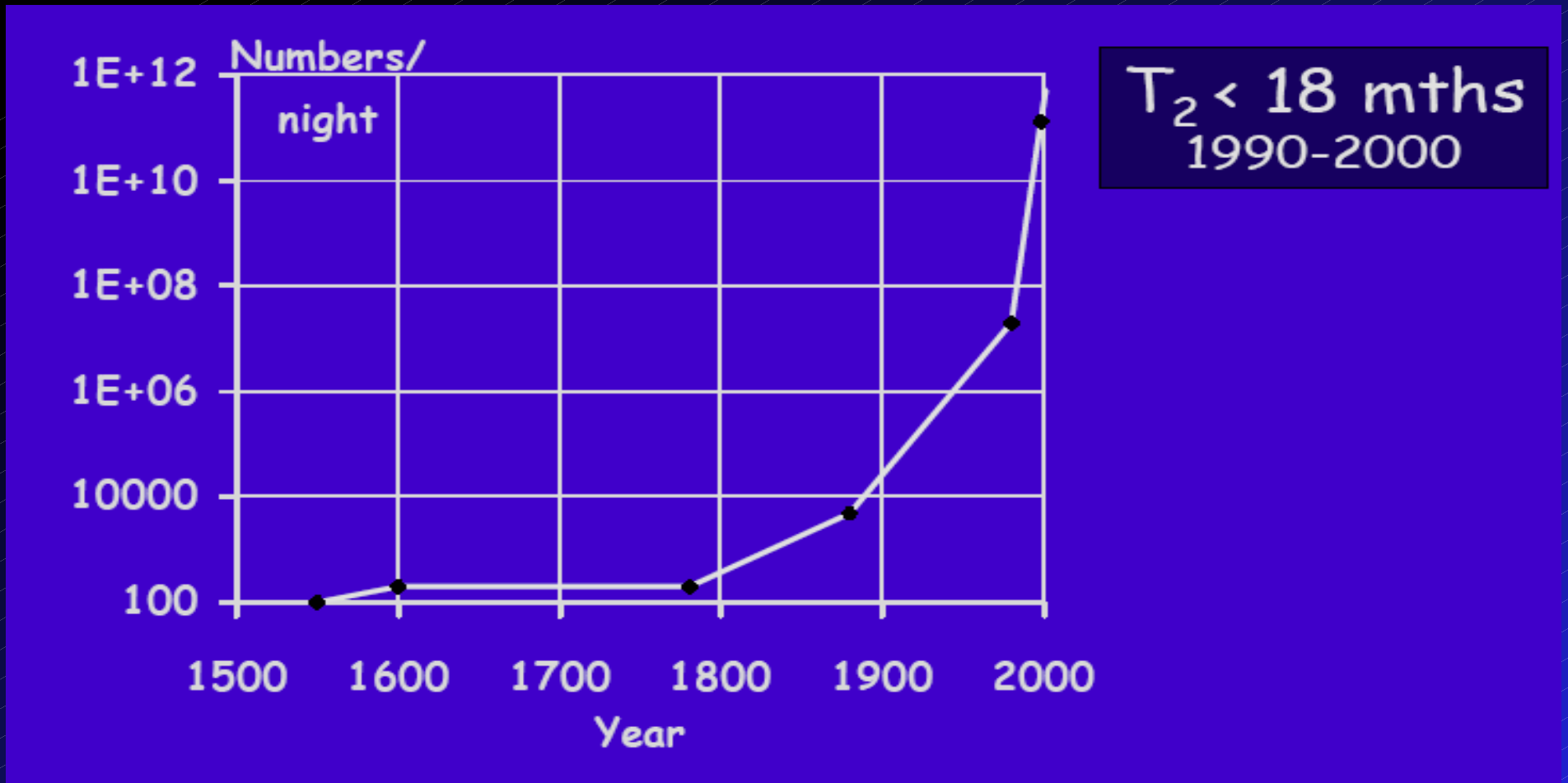
200 CCD 4kx4k,
32 channels (6400)
3.2 Gpix every 20 sec
64cm diameter
3.5 deg FOV
30 TB/night
2 TFLOPS
detection of changes
within 60sec


A huge SN remnant: Sh 2-147
Credit: A Ziljstra, J Irwin (NB: created with Montage)
5° x 5° Hα -r'

Data Avalanche

Moore law for chips –doubling 1.5 year

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



History of VO

Success of IUE/HST archives

idea of the VO - end 2000

Federation of archives (MAST, NED)

- unified IF, data format for transport

Huge data – distributed processing

GRID - started in HEP (accelerator science)

Multispectral research : radio---gamma

- Virtual Universe (UK), AstroVirTel (ESO)

Data for SDSS, SIMBAD, NED – key research

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"

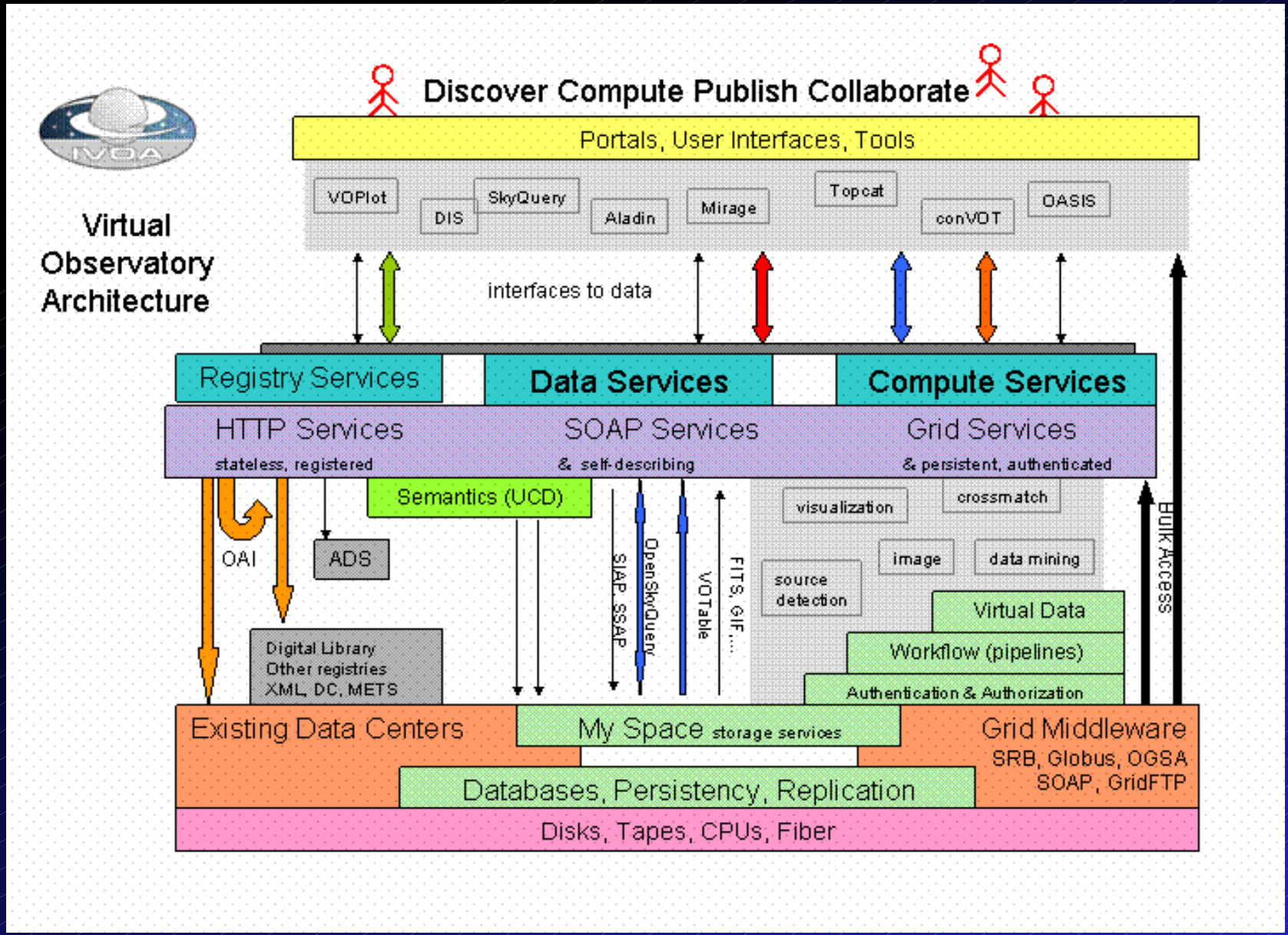
IVOA


Astro Grid
ArVO
American Virtual Observatory
Aus-VO
BRAVO
China-VO
CVO
esa
France
ESO
IVOA
GERMAN ASTROPHYSICAL
GAVO
VIRTUAL OBSERVATORY
EURO VO
HVO
Hungarian Virtual Observatory
JVO
NOVA
RVO
SVO
vo-i
VAO
VIRTUAL ASTRONOMICAL OBSERVATORY
VObs.it

Analogy between VO and WWW

- Linking HYPERTEXT/DATA among servers
- Synergy effect of GLOBAL NET (Gopher,WAIS)
- Powerfull SEARCH (VERONICA – GOOGLE)
- DISTRIBUTED but CENTRAL Steering Organisation (W3C/IVOA)
- Recommendations = „Obligatory“ Standards
- Astronomers in forefront of development
- Scepticism (usefullness for my field ???)
- Steep Growth – average user can use it without knowledge of principles (effectivity, habits)

Architecture of VO



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)

VOTable

```
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<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)

Technology of VO

ADQL (Astronomical Data Query Language)

XMATCH, REGION (2 catalogues - shifted)

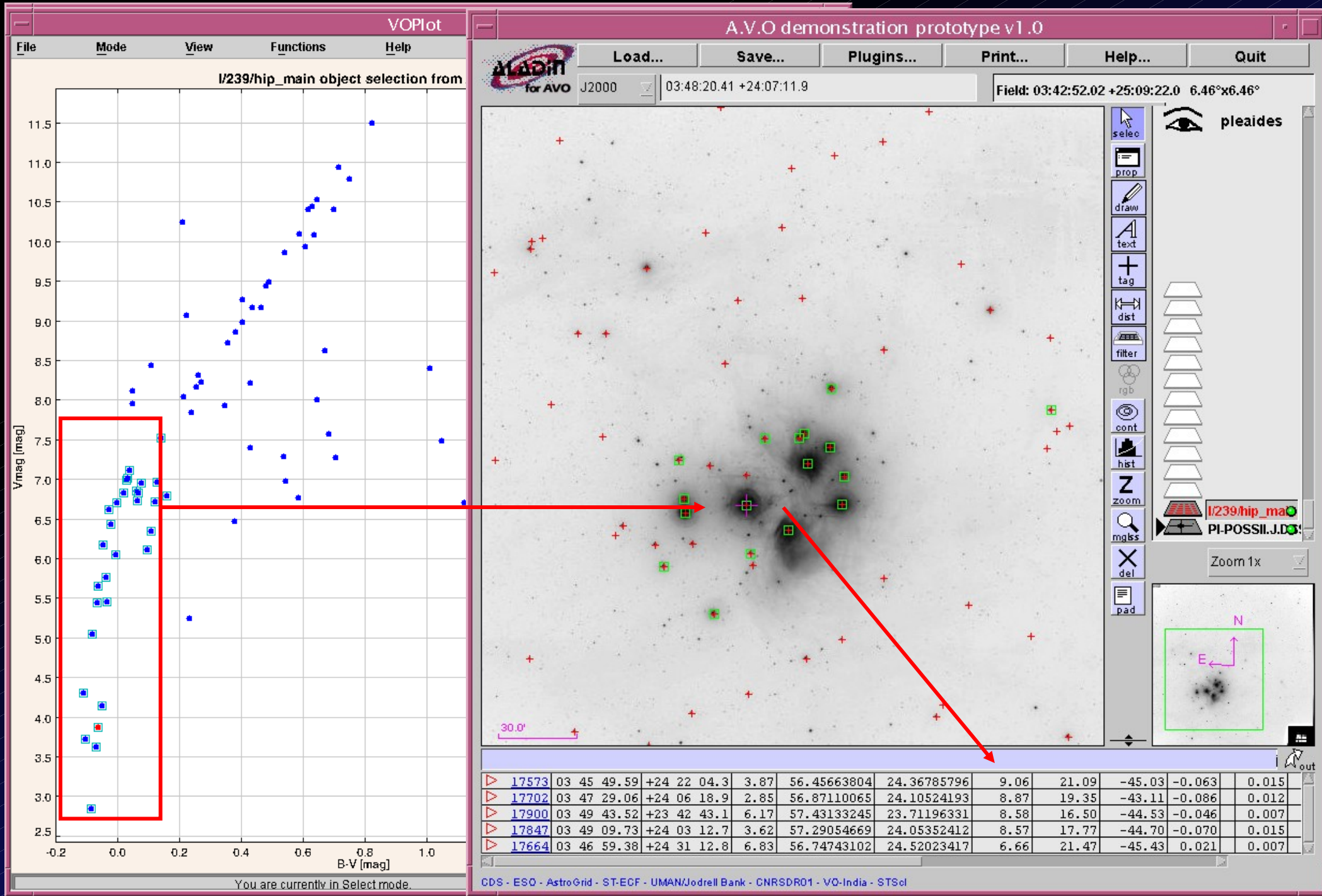
Application interoperabilty – PLASTIC, SAMP

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

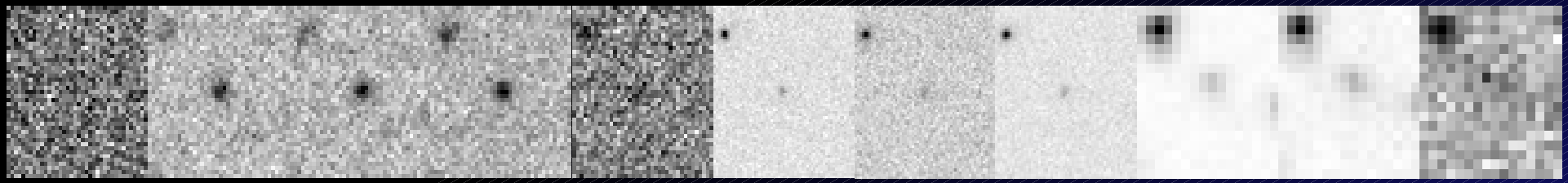
Commercial interest (GoogleSky, MS WWT)

Planetariums, Outreach (Stellarium)

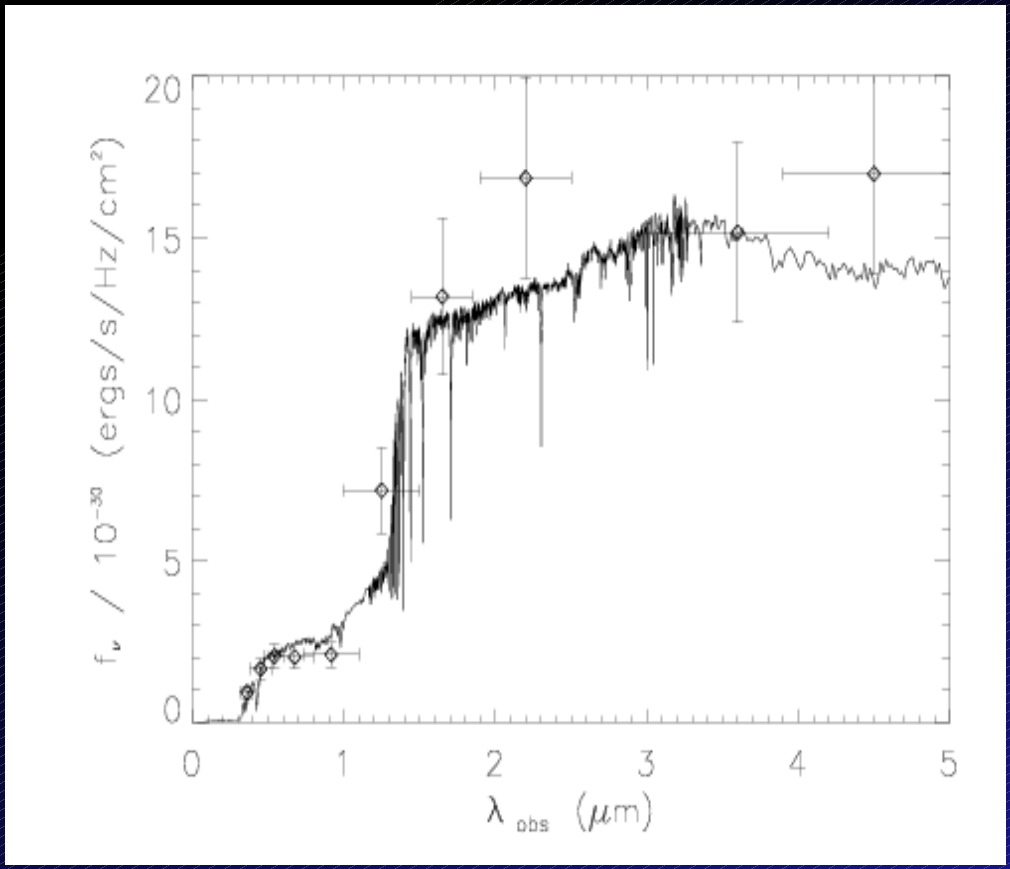
Colour-magnitude diagram



SED from photometry



U B V R I J H Ks 3.6μm 4.5 μm 5.8 μm



zphot = 2.52
Age = 500 Myr
Stellar mass = 9.9e10^9 M_{sun}
Reduced chi-sq = 1.04
SFR current = 0.79 M_{sun} yr^{-1}

Where we need huge spectra collections ?

Many objects (automatic classification by fitting many models)

HR diagrams of stellar clusters

Many spectra of one object (time series)

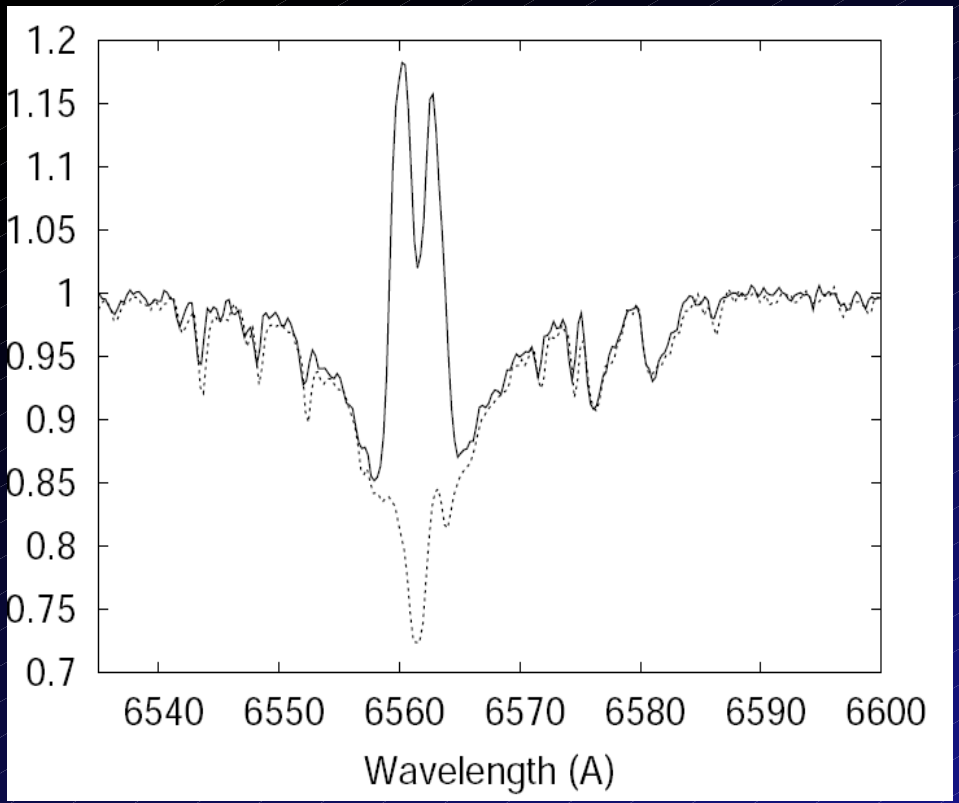
Changes of Line Profiles in Time

Blind comparison of different exposures

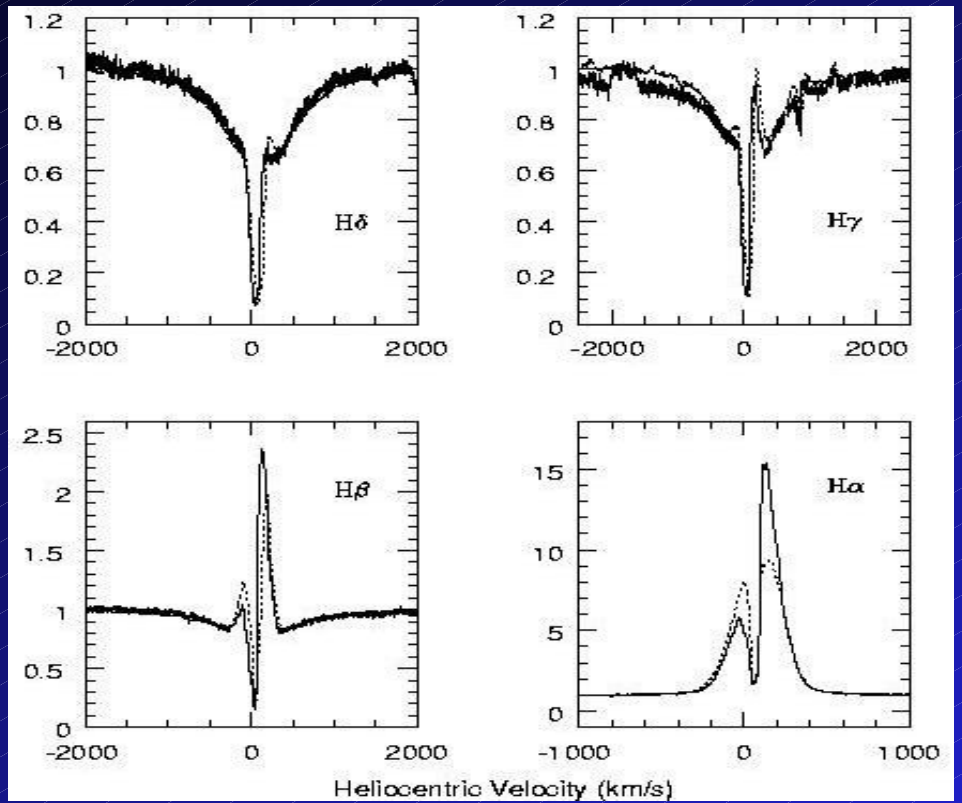
Emission/absorption, shell phases

Time evolution of object – mass transfer,

V/R variations

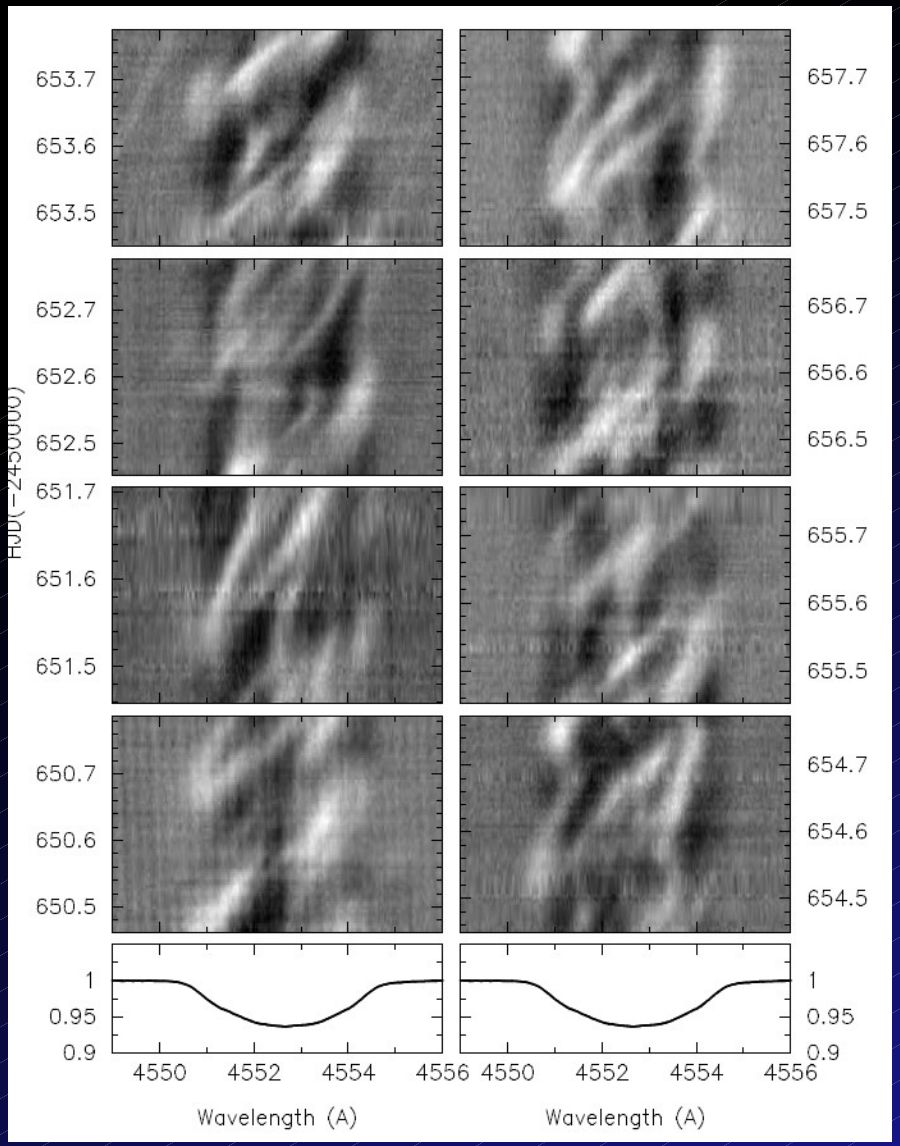


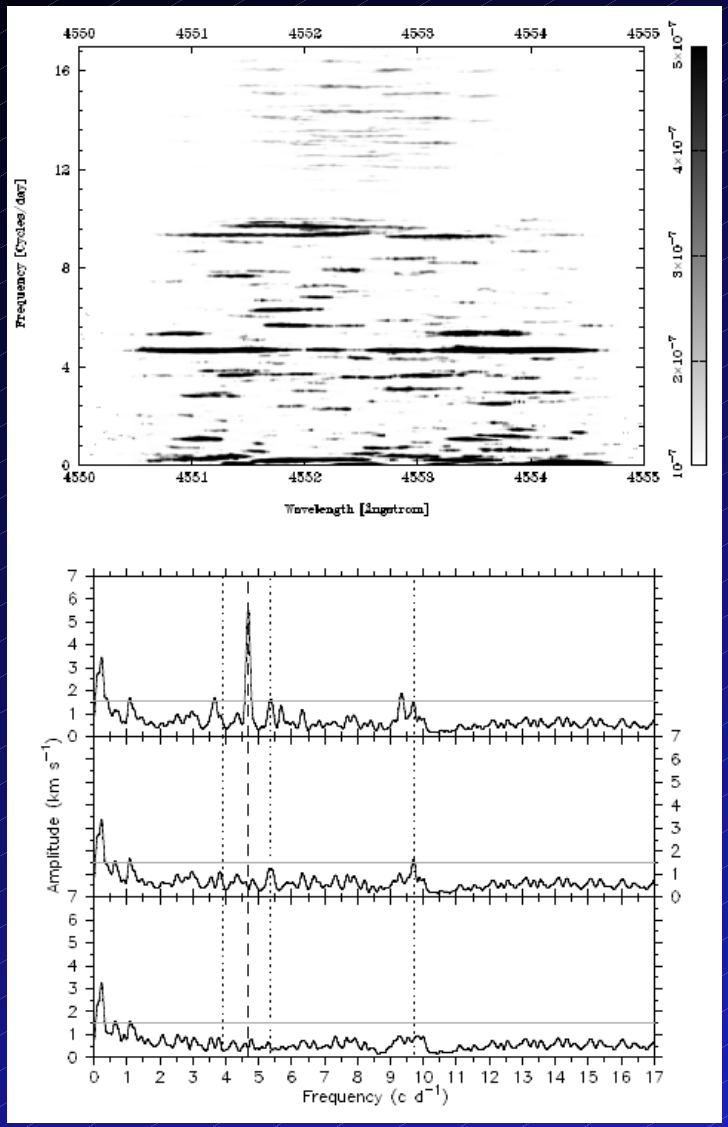
HD6226 : Slechta and Skoda 2004



Borges et al. 2008

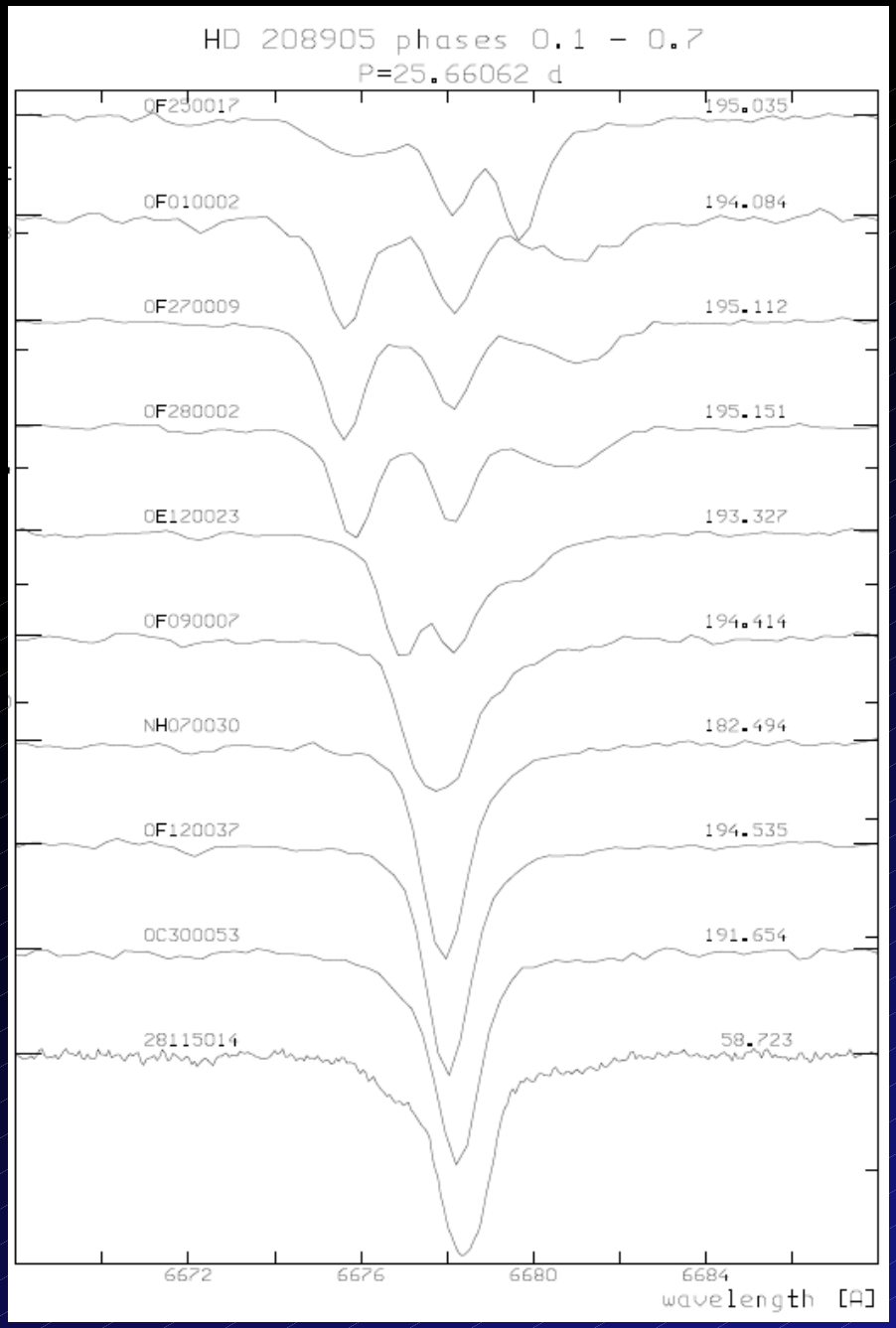
Periodogram of Line Profile NRP

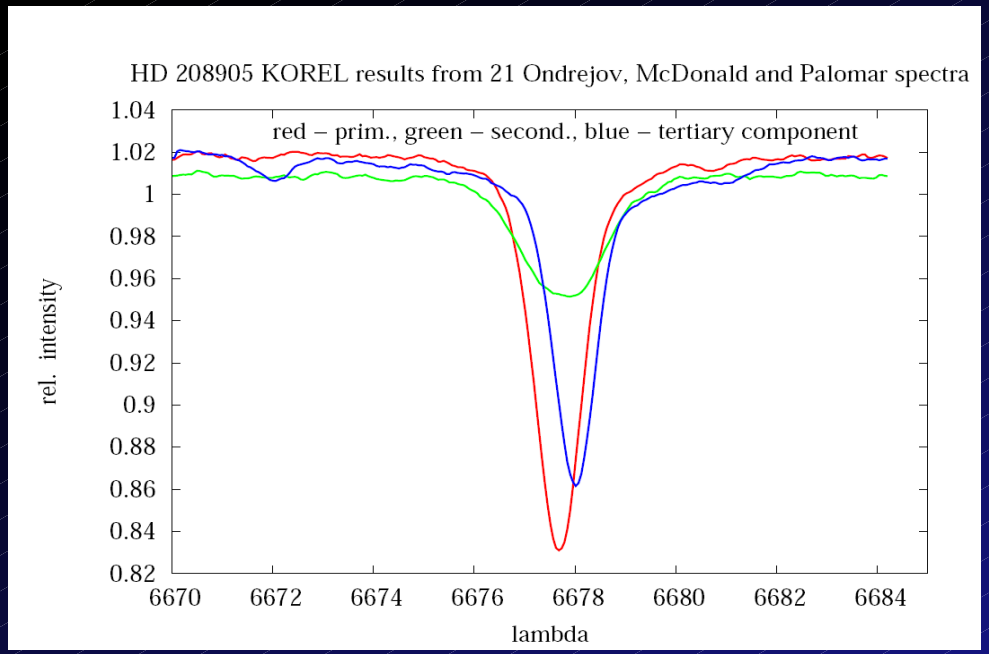


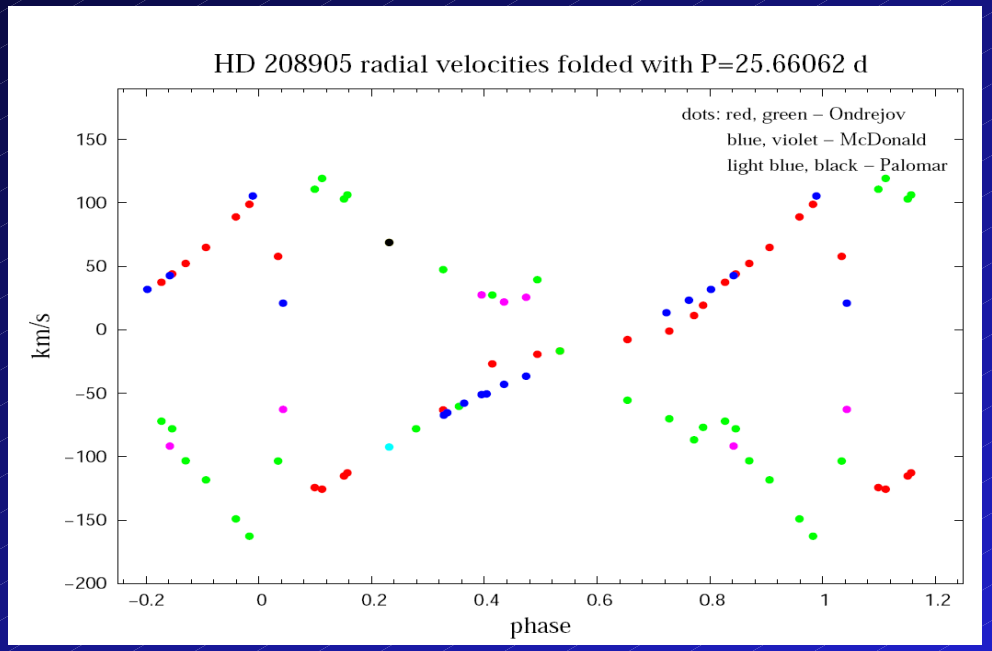


Lambda Sco: Uytterhoeven 2004

Spectra Disentangling in Fourier Space - KOREL

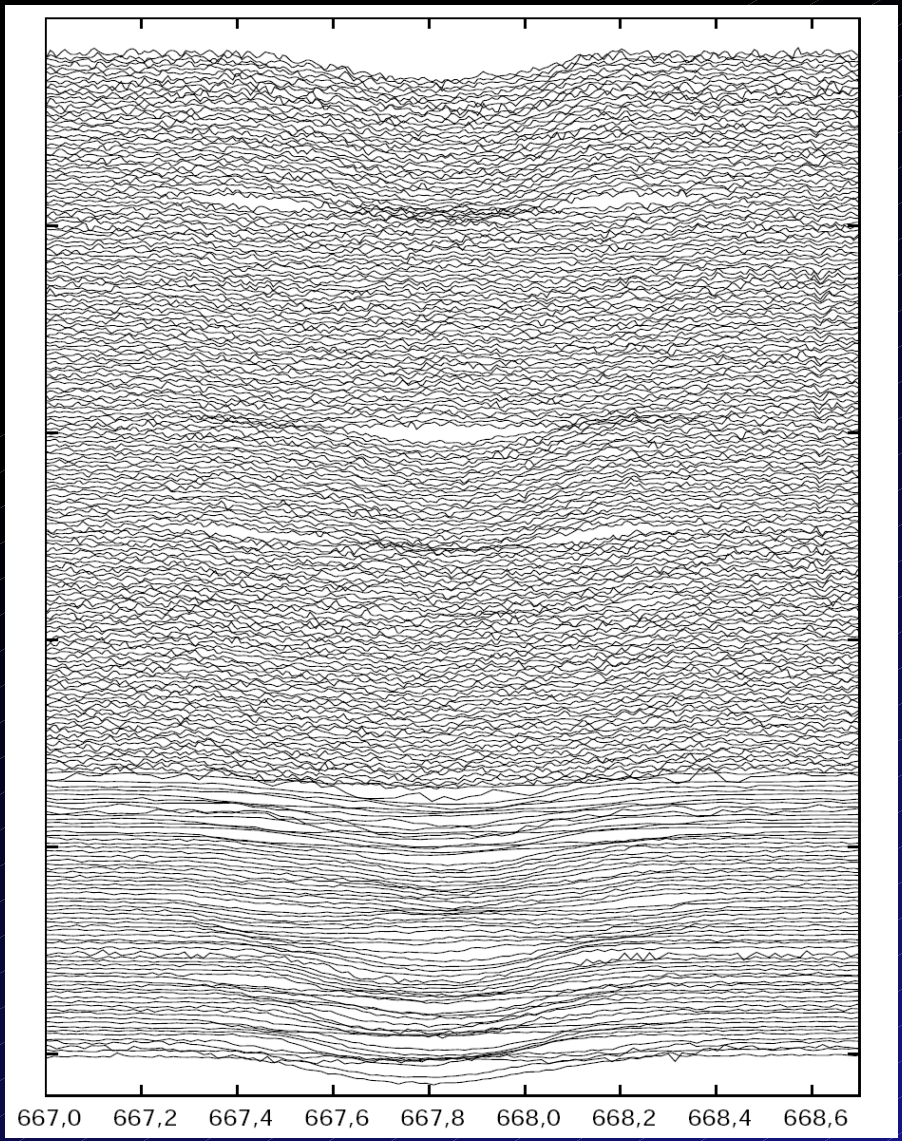


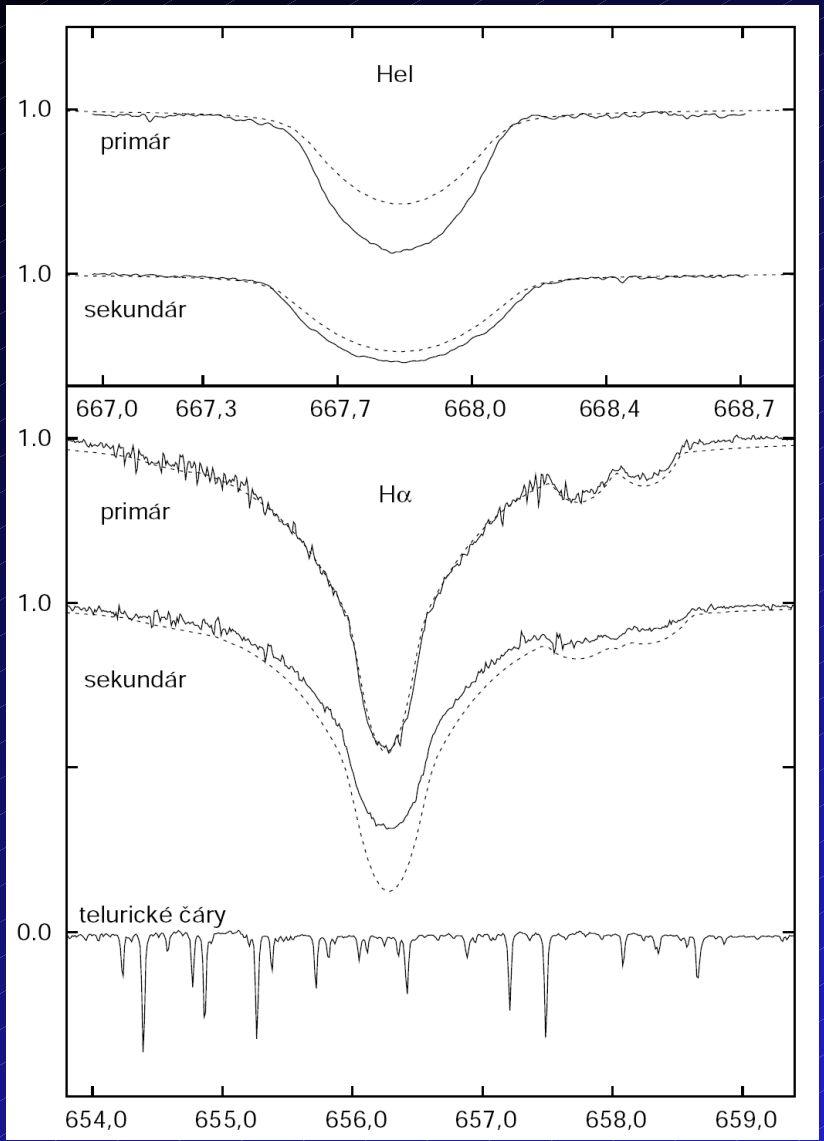




HD208905: Koubsky et al. 2006

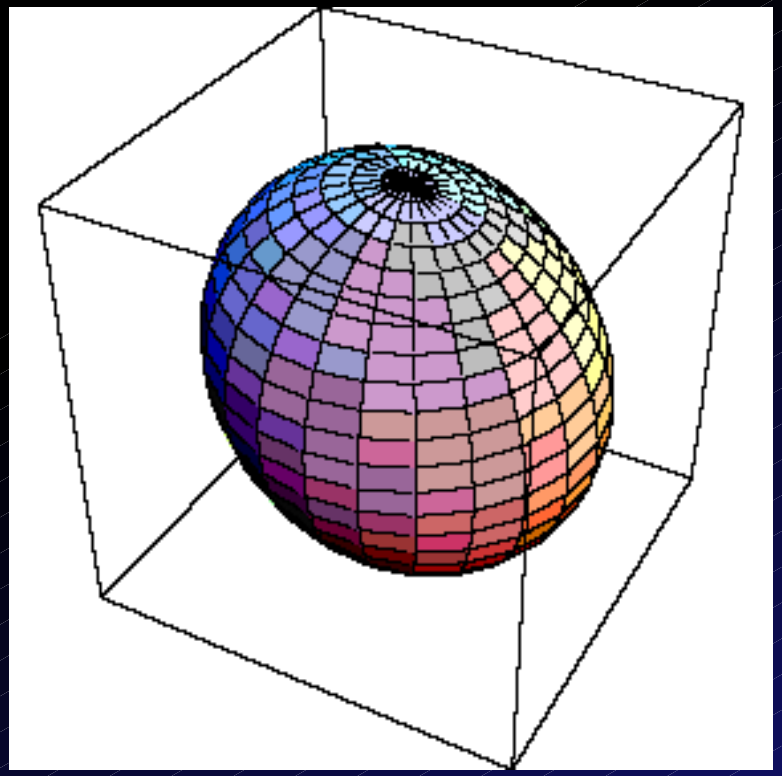
Many spectra overploted to find cuts

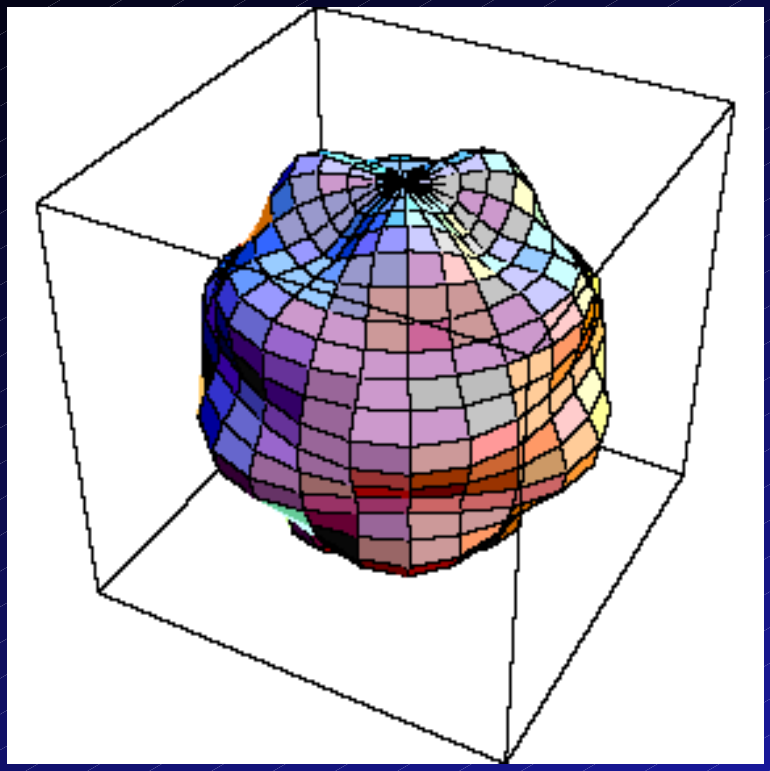




V436 Per Janík 2003

Non Radial Pulsation



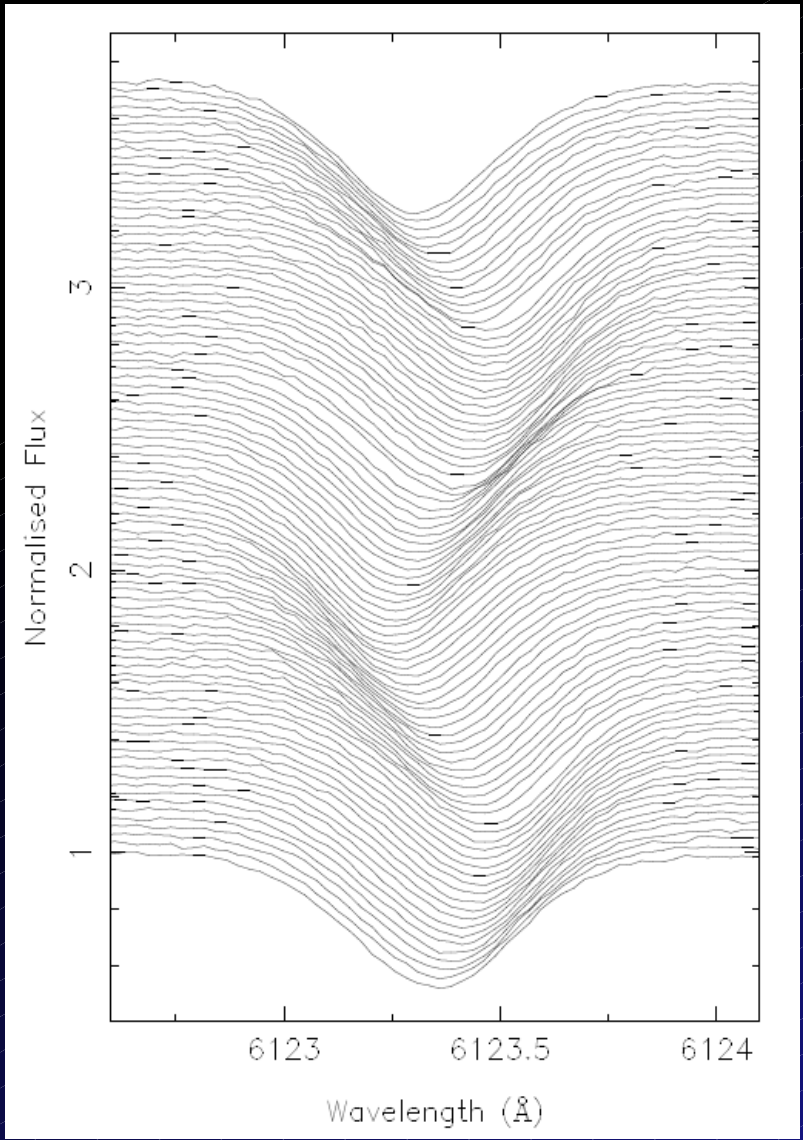


$\ell = 2, m=1$

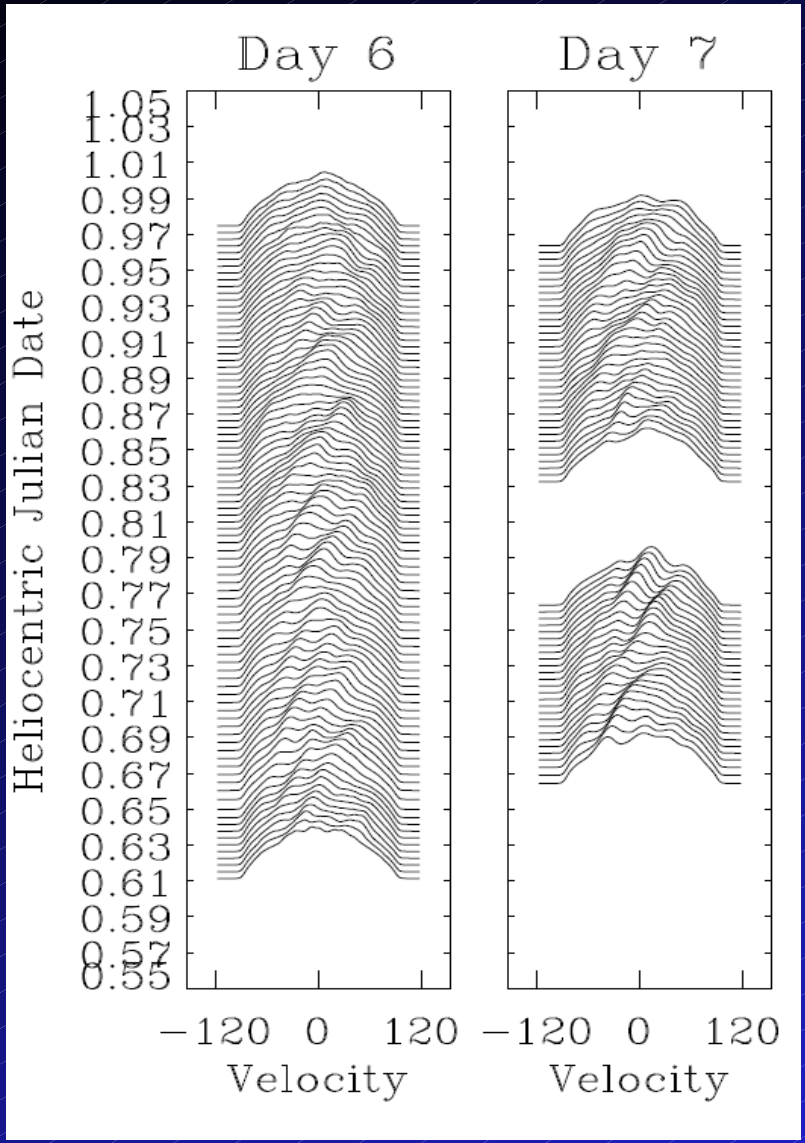
$\ell = 8, m=3$

Tim Bedding

Measured Pulsations



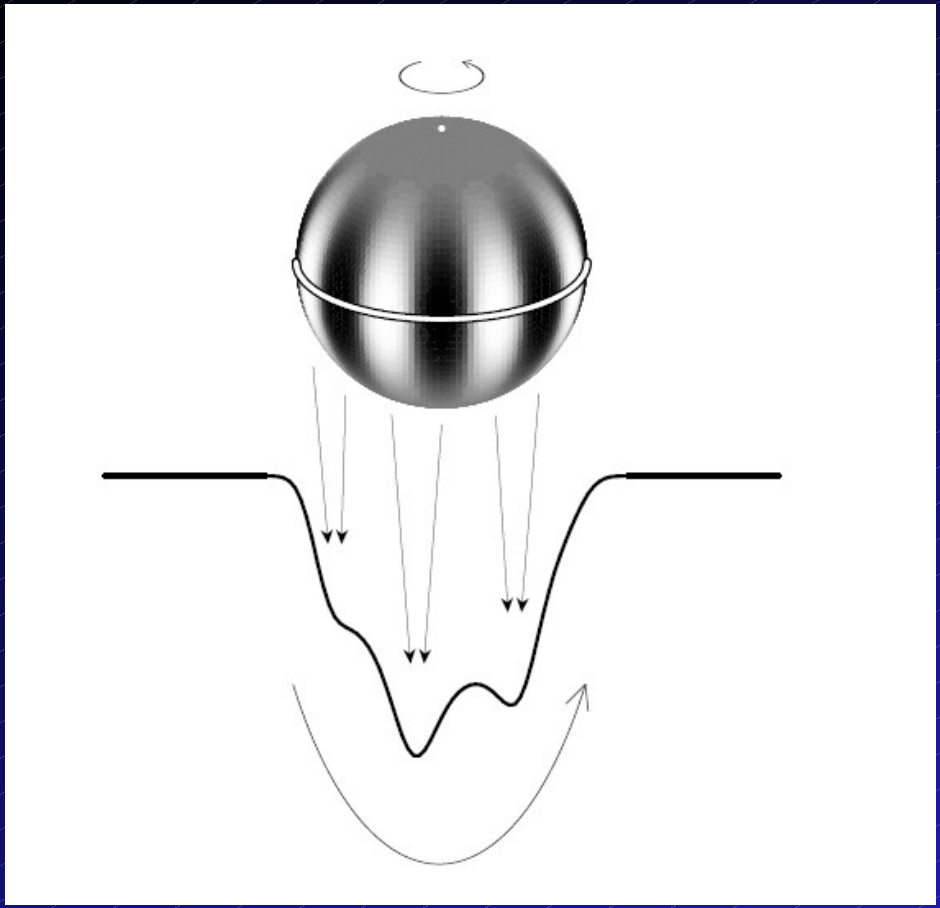
Rho Pup – del Sct type



Eps Cep - del Sct type

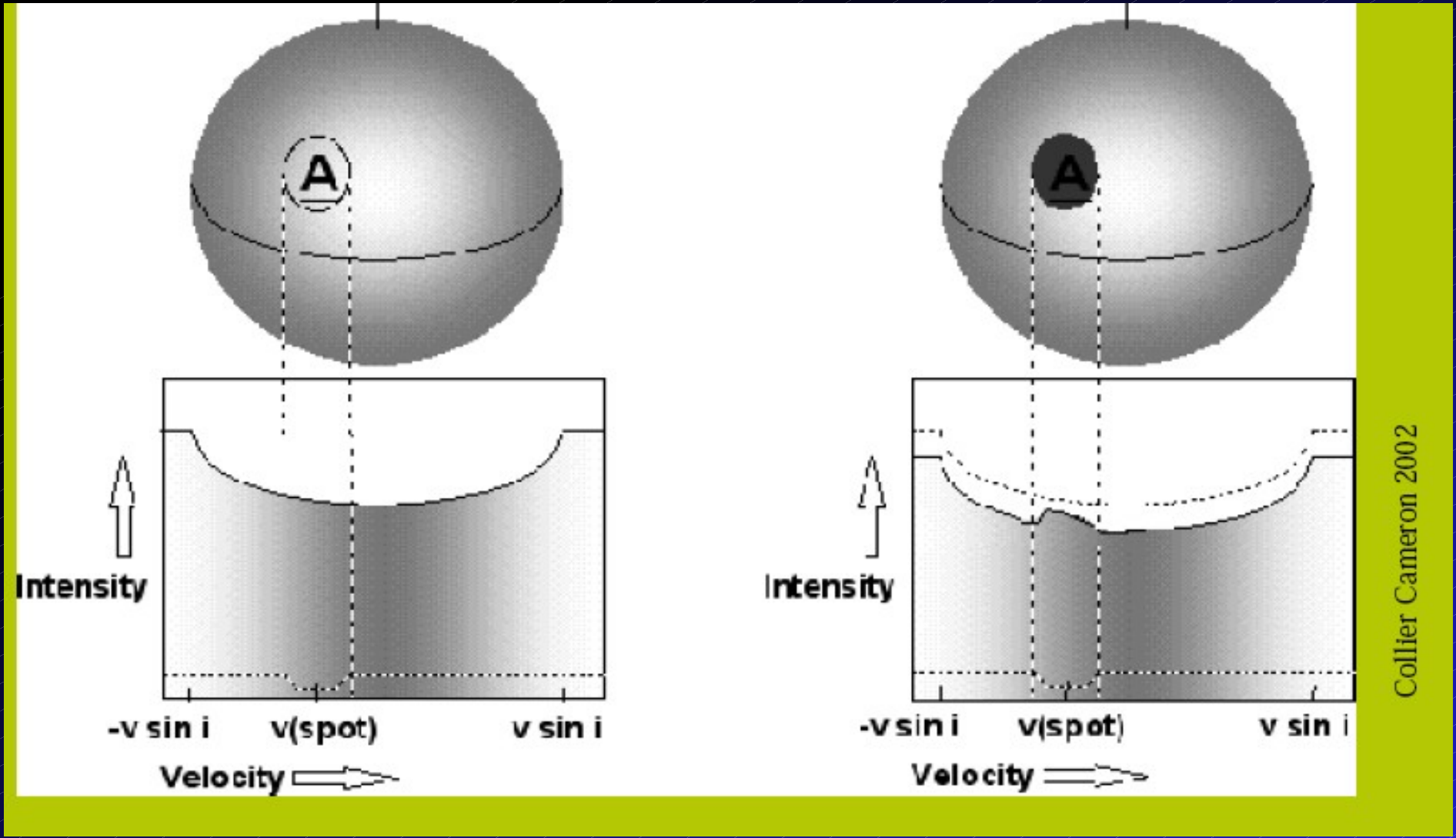
Doppler Imaging - NRP

Vogt & Penrod -80s
Zet Oph

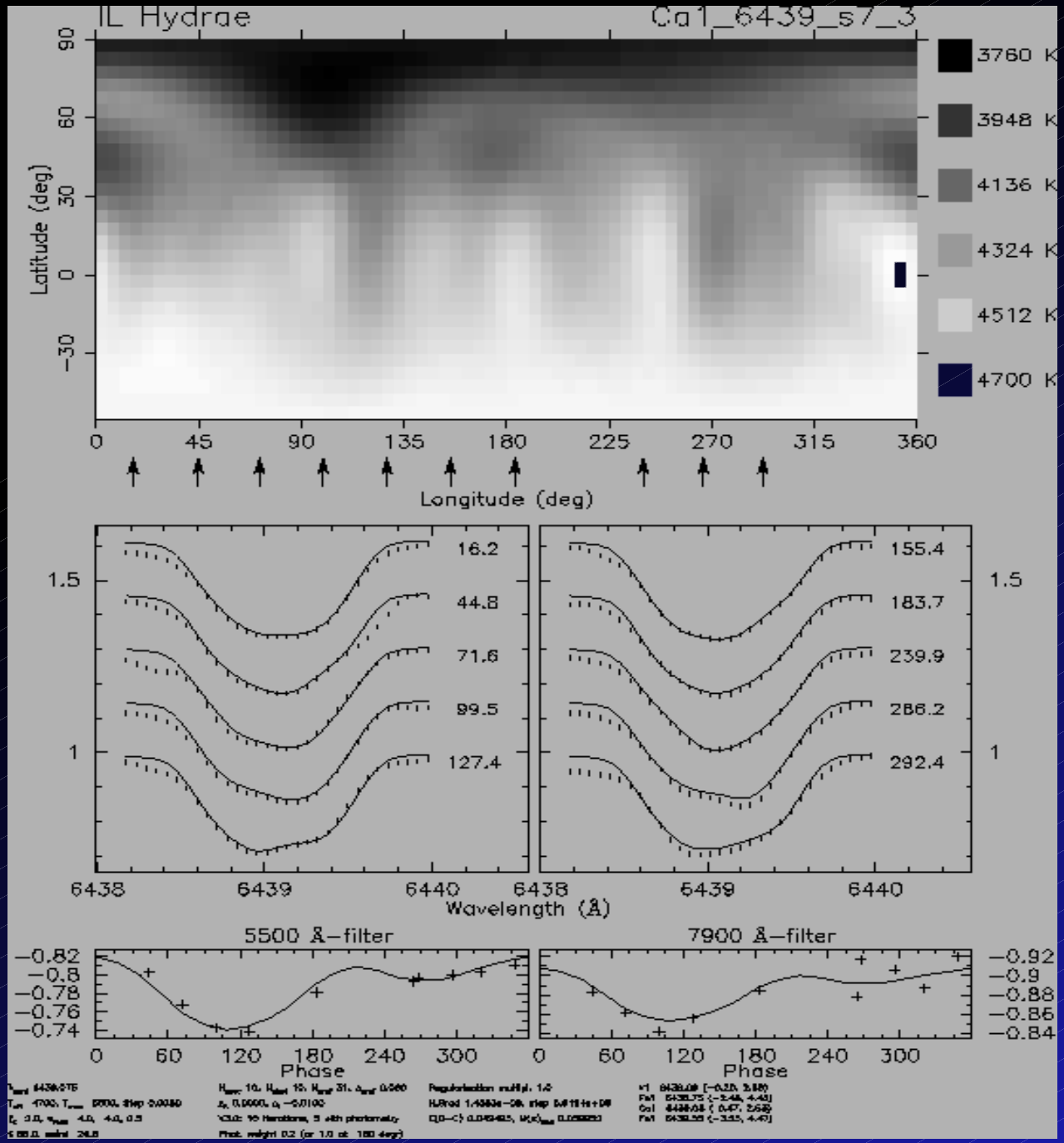


Doppler Imaging

From LPV due to rotation
stellar Spots - darker, brighter – chemical patch



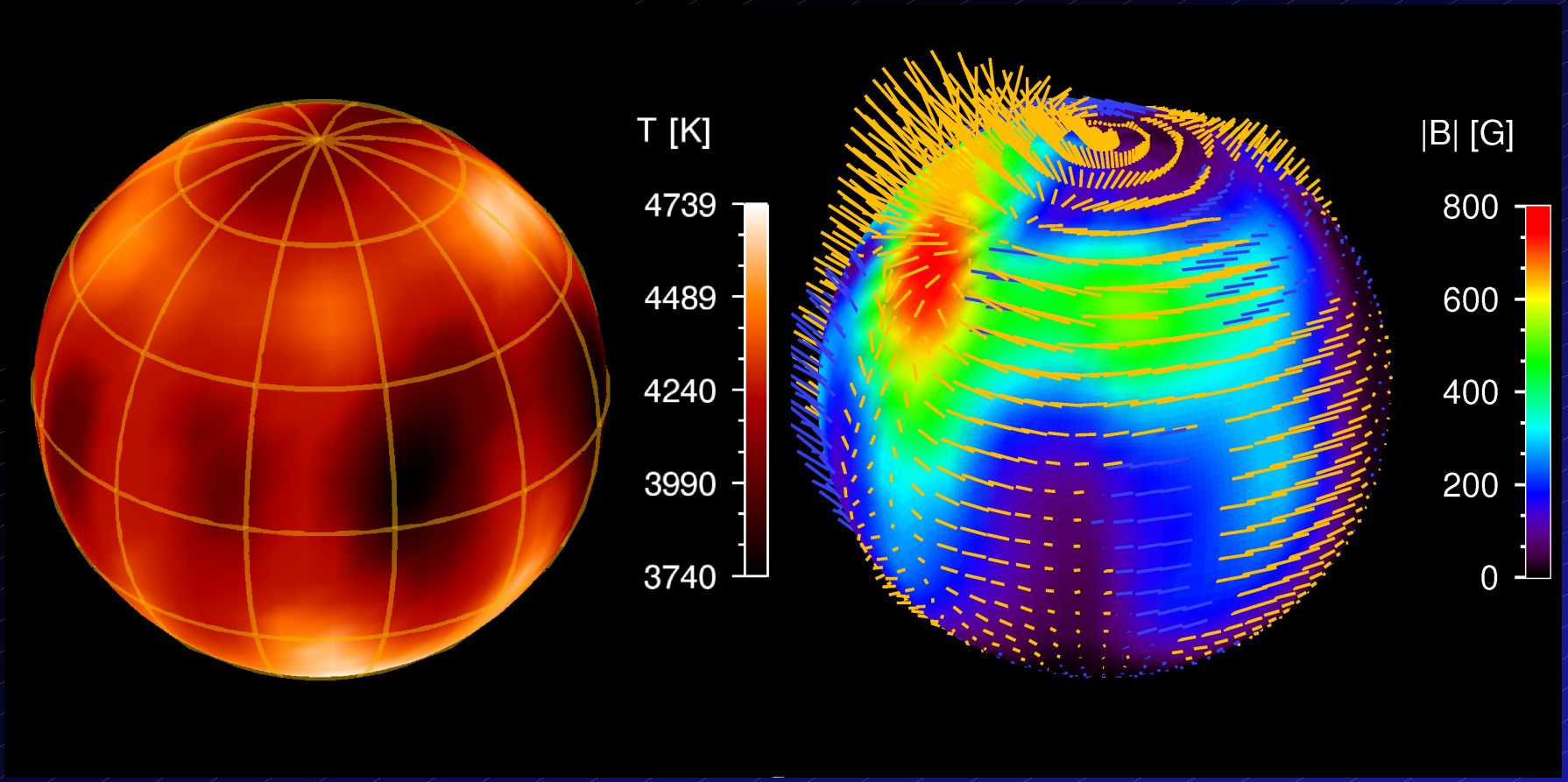
Doppler Imaging



Different elements

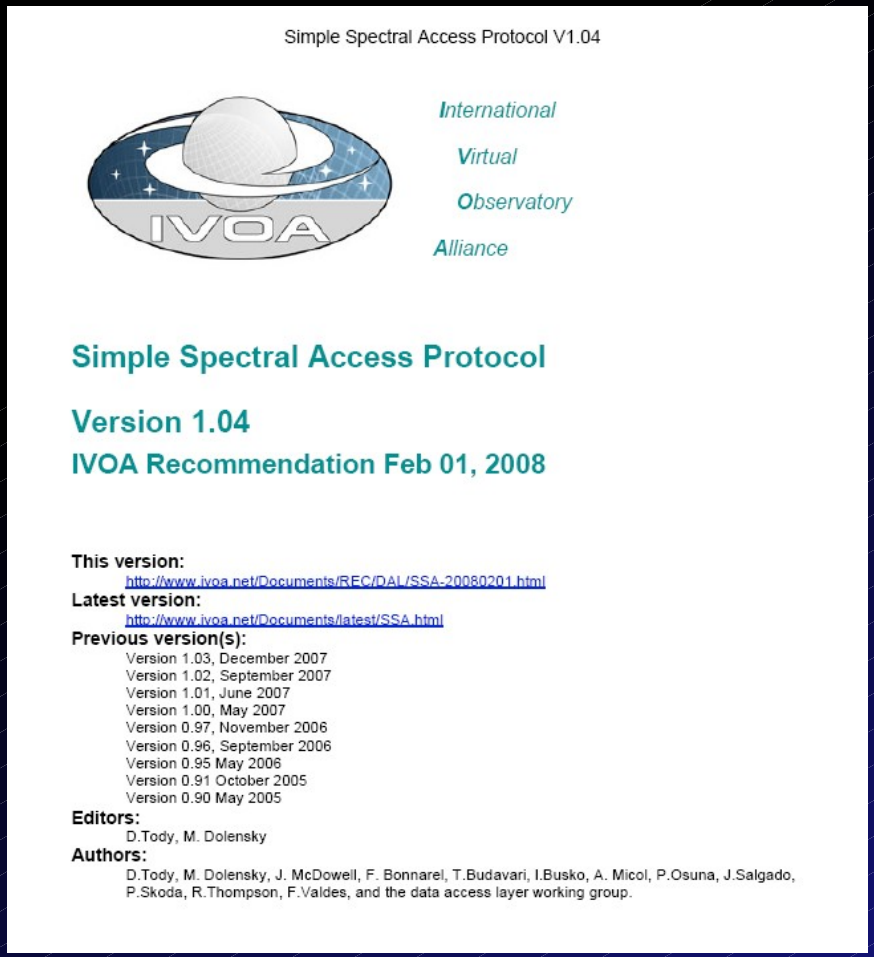
temperature distribution

Zeeman Doppler Imaging



II Peg, Strassmeier 2007

Simple Spectra Access Protocol
Spectral Data Model



Simple Spectral Access Protocol V1.04

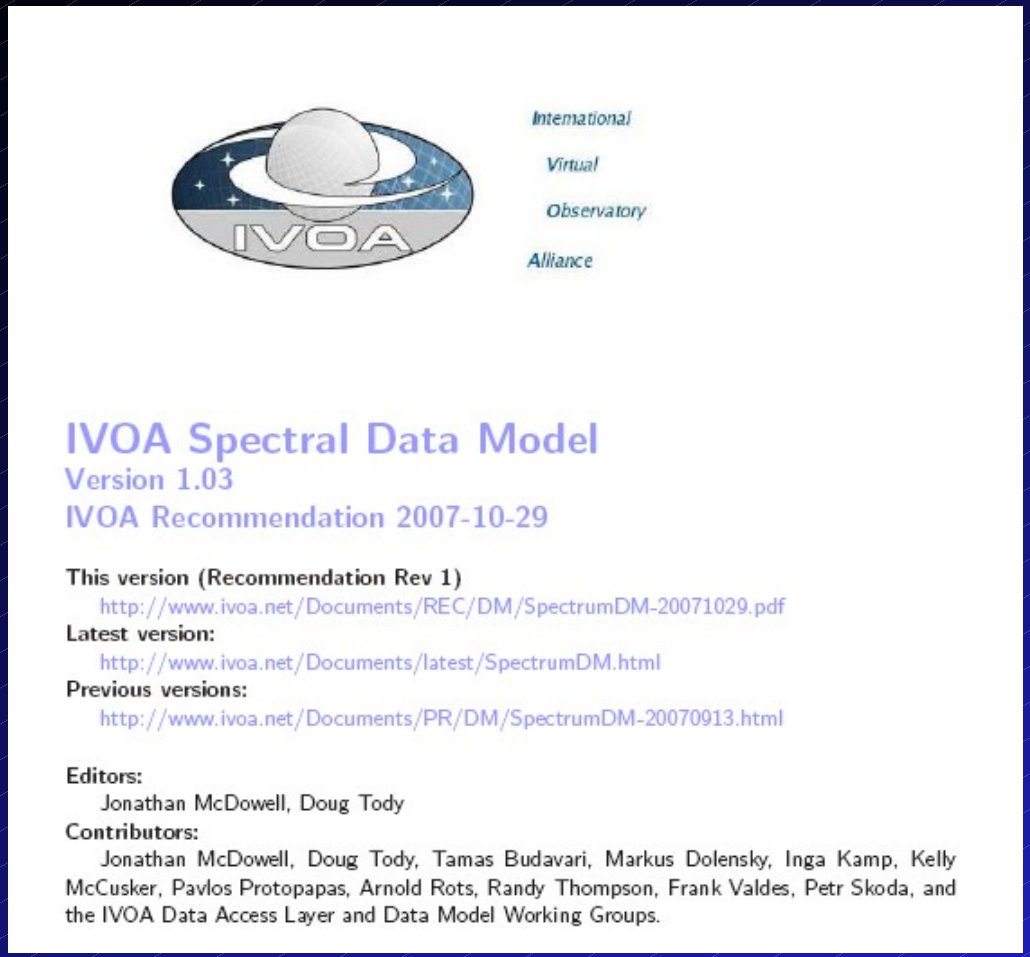
International Virtual Observatory Alliance

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:
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Contributors:
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SSAP Parameters

4.1.1 Mandatory Query Parameters

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

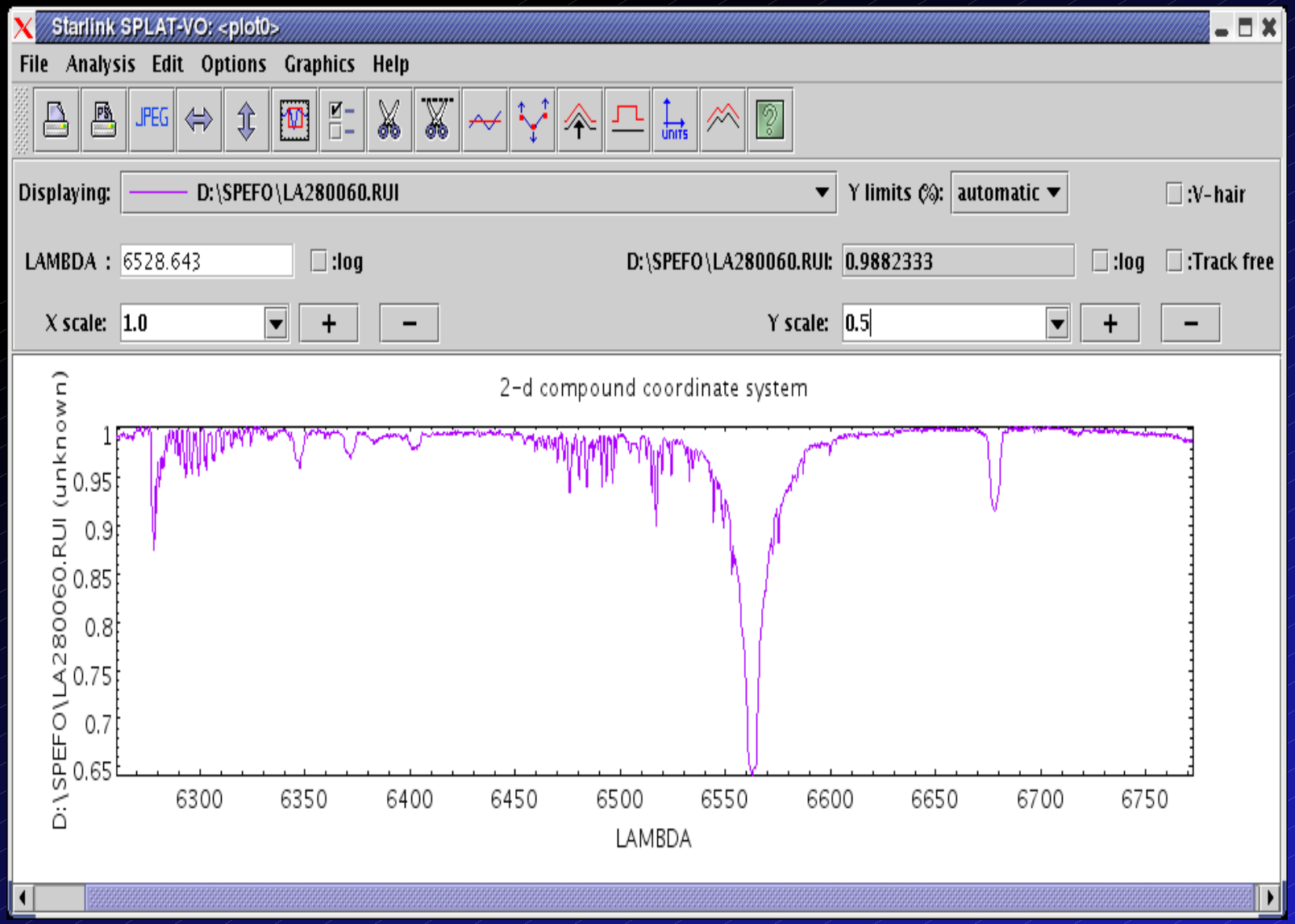
Parameter	*Sample value*	*Physical unit*	*Datatype*
POS	52,-27.8	degrees; defaults to ICRS	string
SIZE	0.05	degrees	double
BAND	2.7E-7/0.13	meters	string
TIME	1998-05-21/1999	ISO 8601 UTC	string
FORMAT	votable	-	string

4.1.2 Recommended and Optional Query Parameters

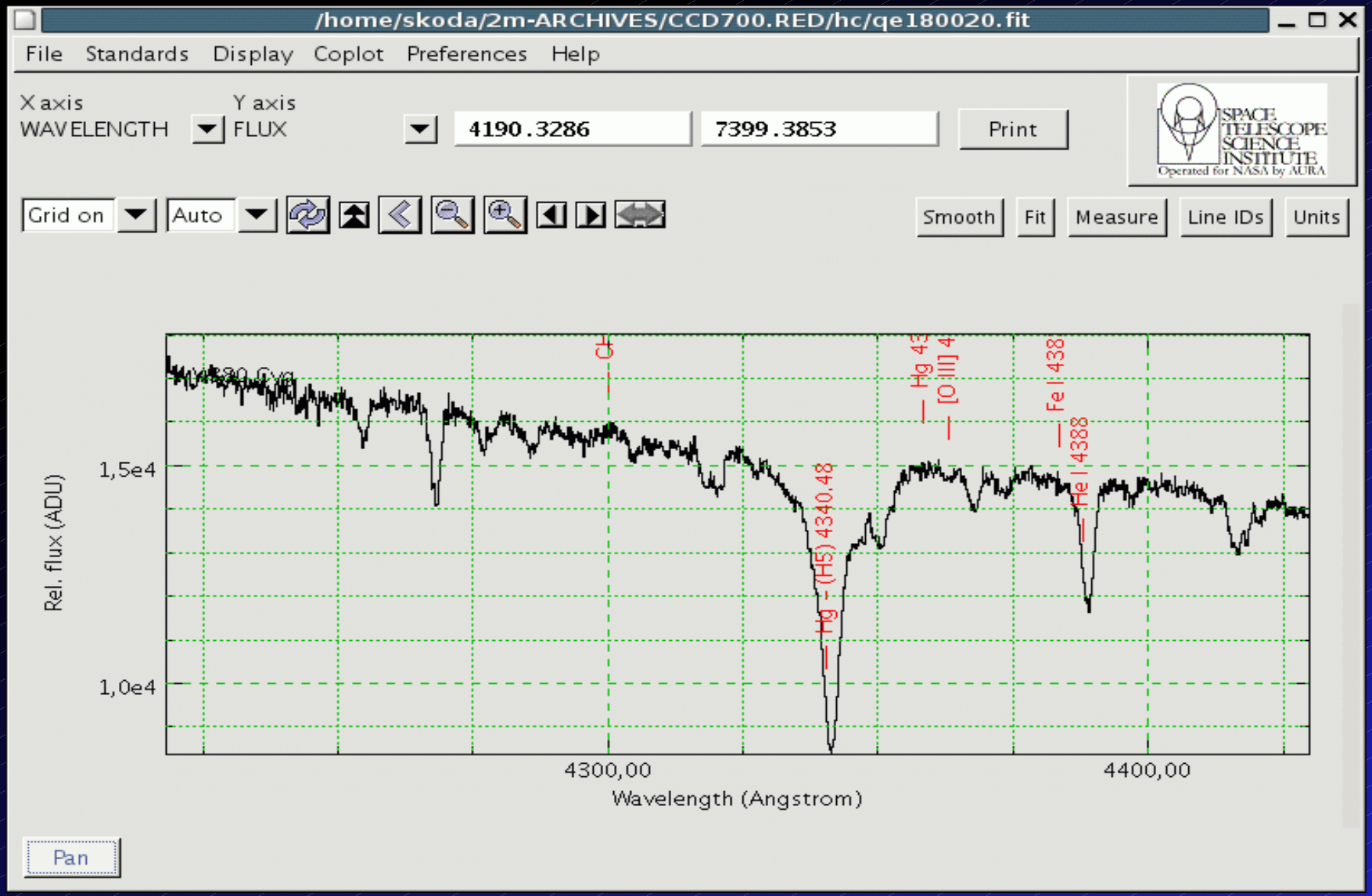
Parameter	Sample value	Unit	Req	Datatype
APERTURE	0.00028 (=1°)	degrees	OPT	double
SPECRP	2000	λ/dλ	REC	double
SPATRES	0.05	degrees	REC	double
TIMERES	31536000 (=1yr)	seconds	OPT	double
SNR	5.0	dimensionless	OPT	double
REDSHIFT	1.3/3.0	dimensionless	OPT	string
VARAMPL	0.77	dimensionless	OPT	string
TARGETNAME	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

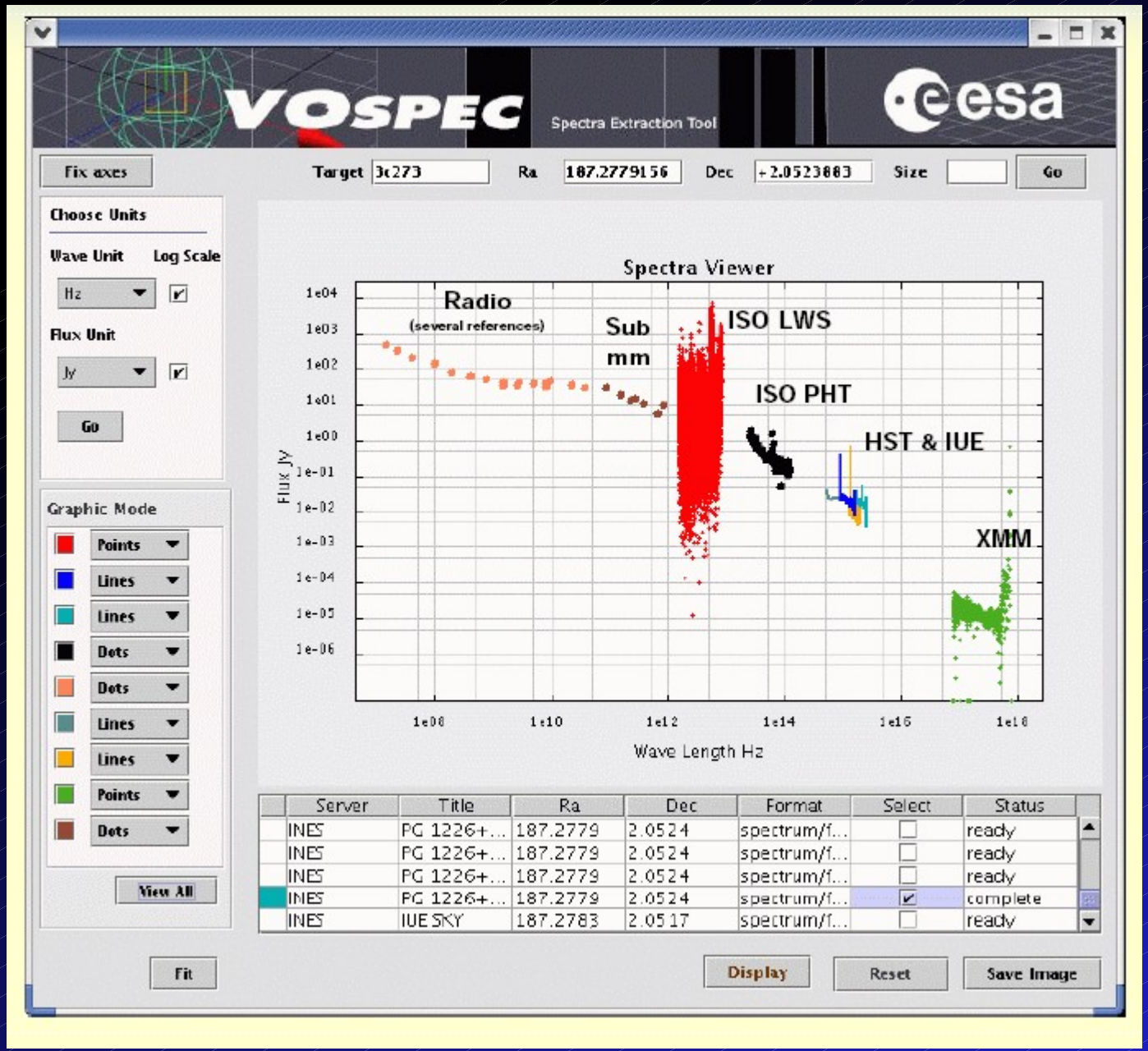
SPLAT-VO (Starlink, JAC)



SpecView (STScI)



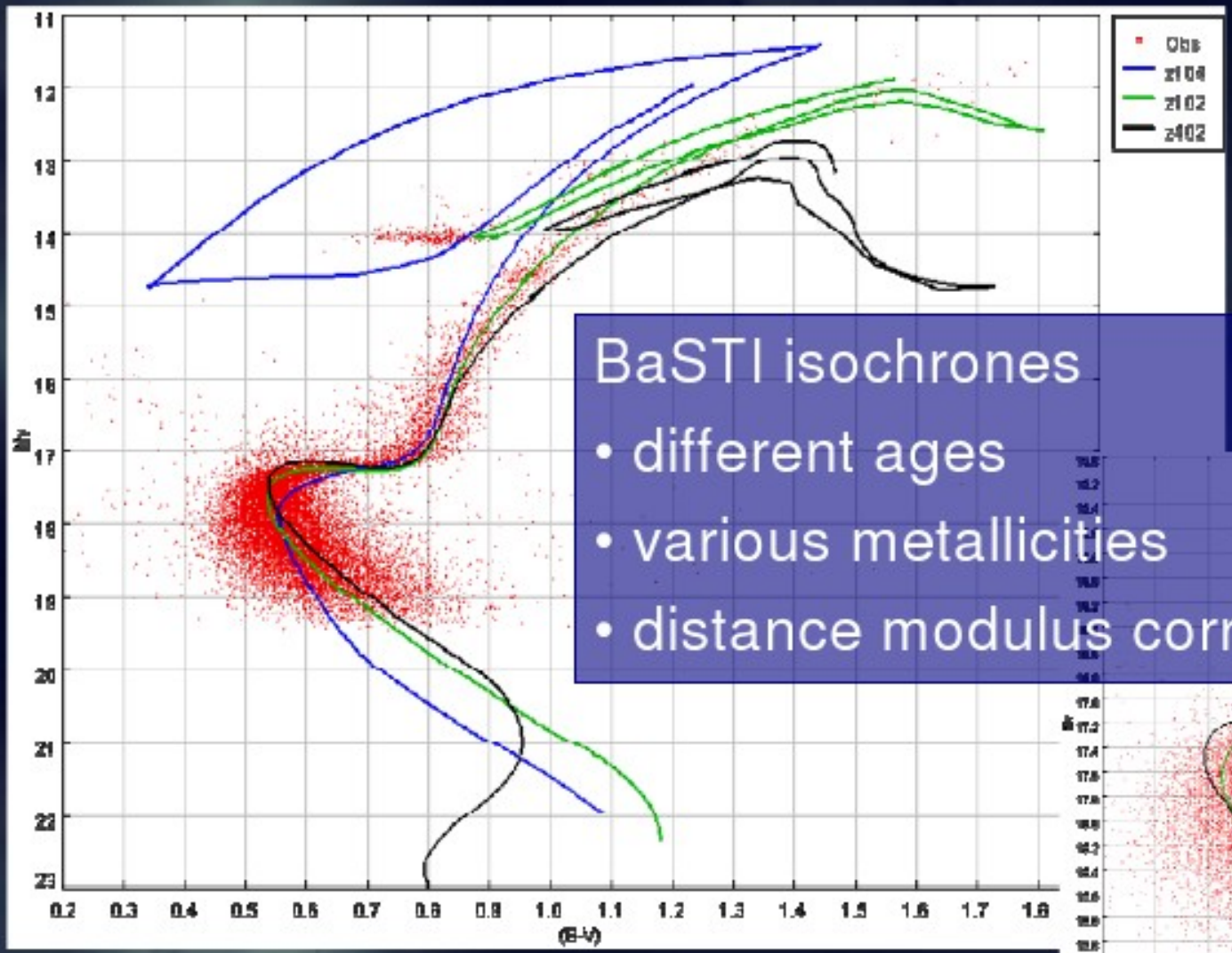
VOspec (ESAC)


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

Theory VO (TVO)

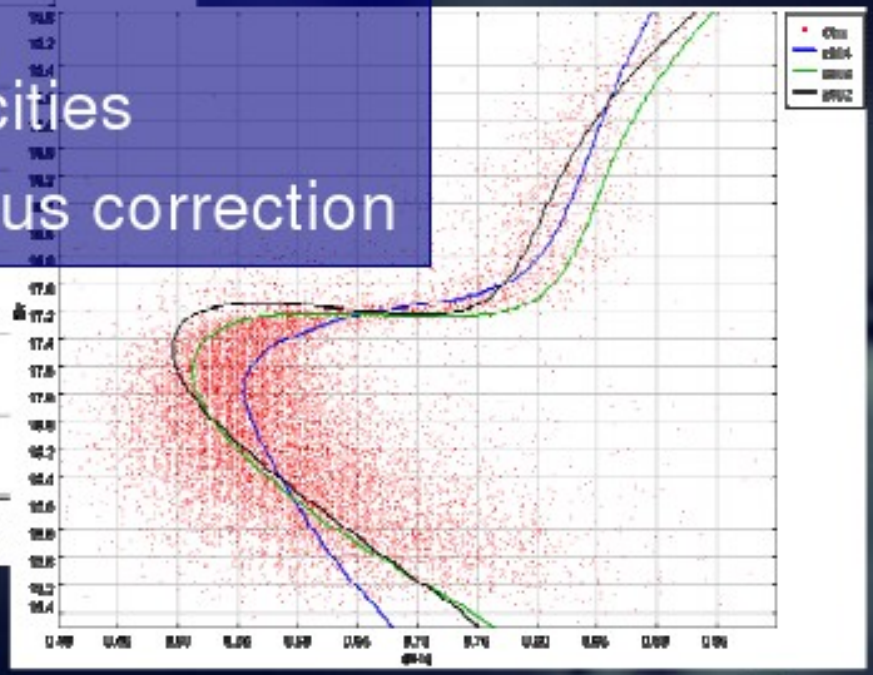
- Methods of VO (parameters in DB, SQL...) for study of results of simulations , catalogues of simulated objects like SDSS...(PCA)
- Browsing of simulation space along different axes – parameters, regions...
- Evolutionary tracks, Photo Dissociation Regions – VAMDC
- Formation of artificial galaxies, clusters – N body models (Millenium Run 10 billions, 25TB)
- Theoretical Spectra (GAVO – Rauch, GRID)

BaSTI Isochrones



step 1
metallicity

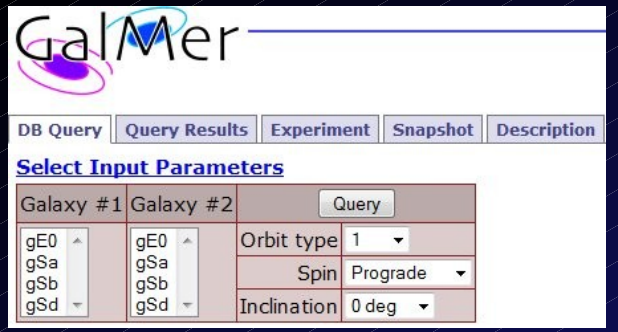
BaSTI isochrones
- different ages
- various metallicities
- distance modulus correction

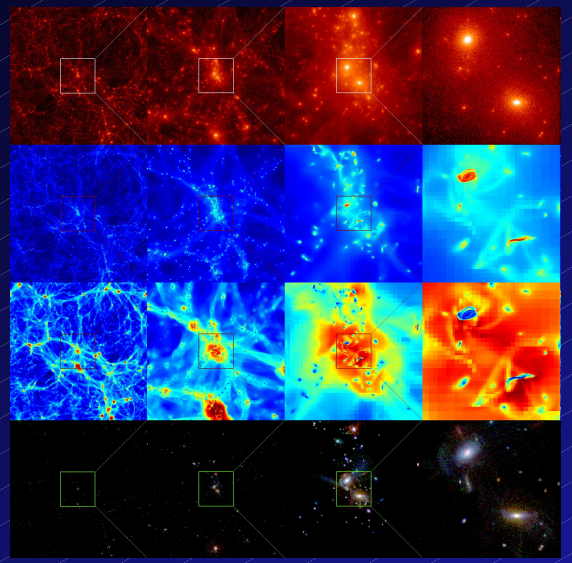


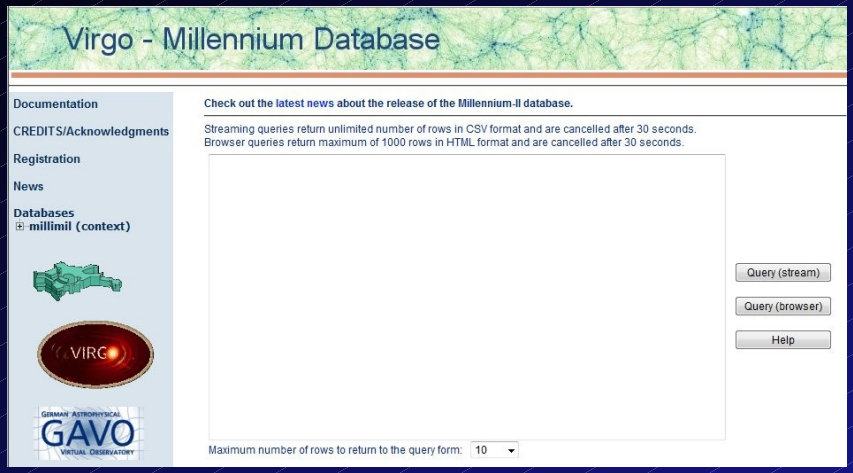
z = 0.01 (α-enh) ; 0.008 (scaled solar)

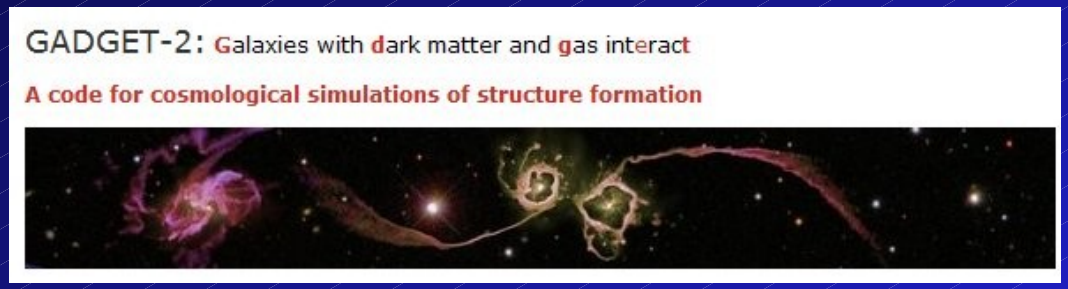
Using SimDB/SimDAP

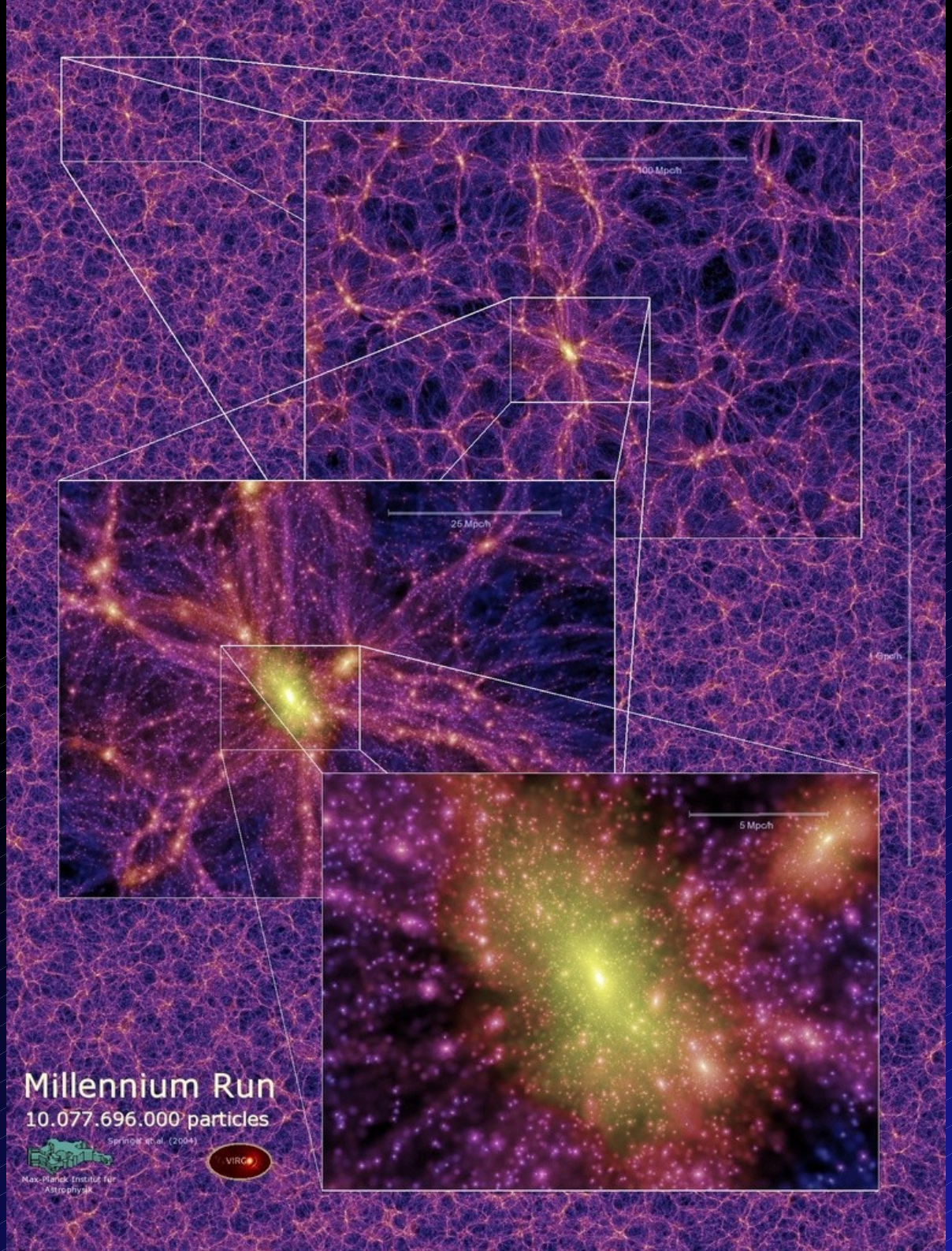
- Cosmological simulations
  - Prototypes for GalMER, Horizon
- PDR simulations
  - test implementation of Meudon PDR code
- Isochrones/evolutionary tracks
  - BaTSI
- Visualization tools
  - VisIVO







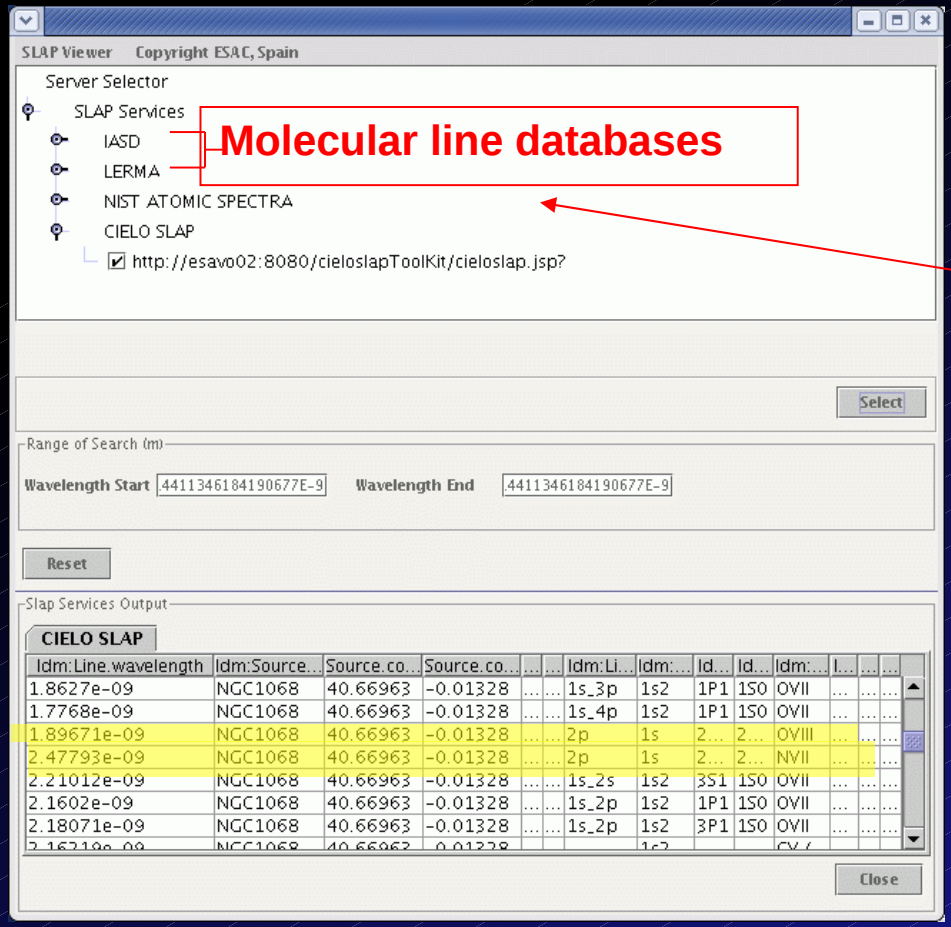


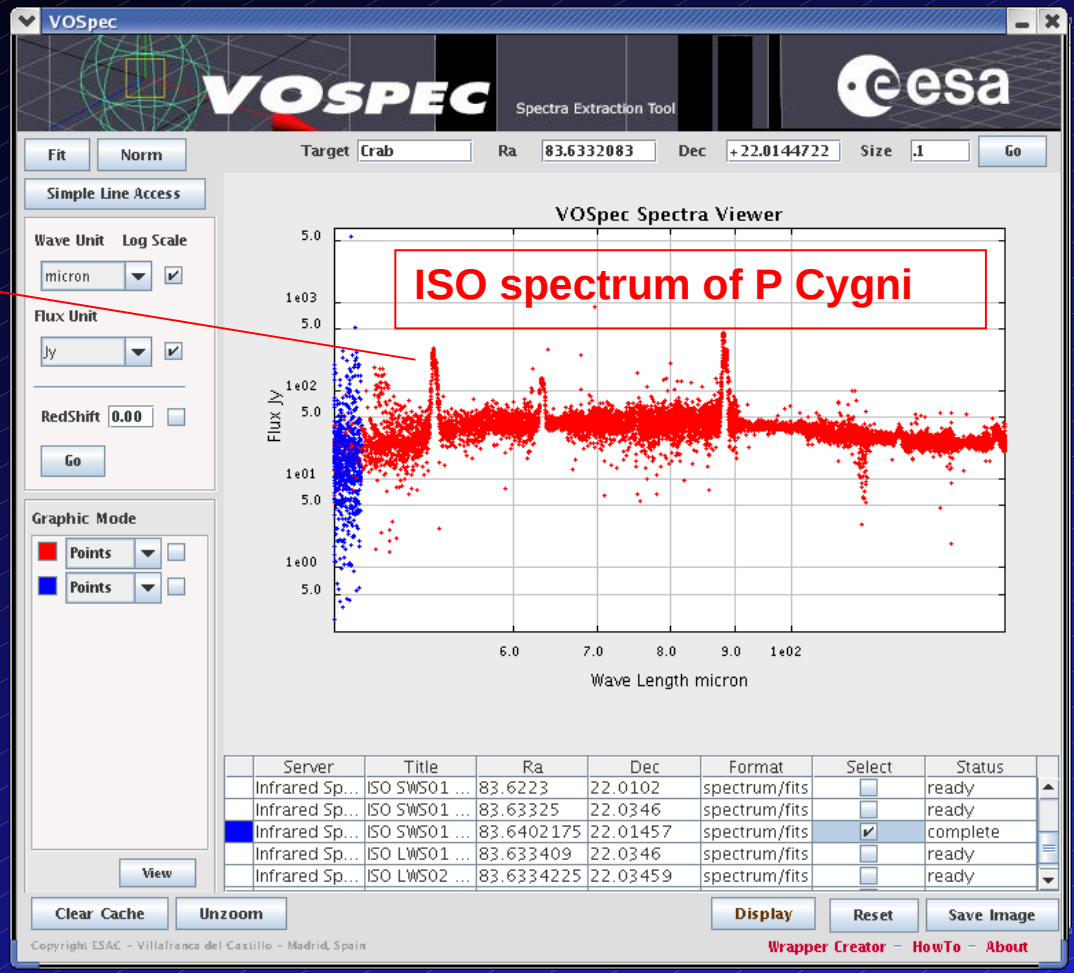


Millenium Run

- 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

CIELO VO – line catalogue SLAP



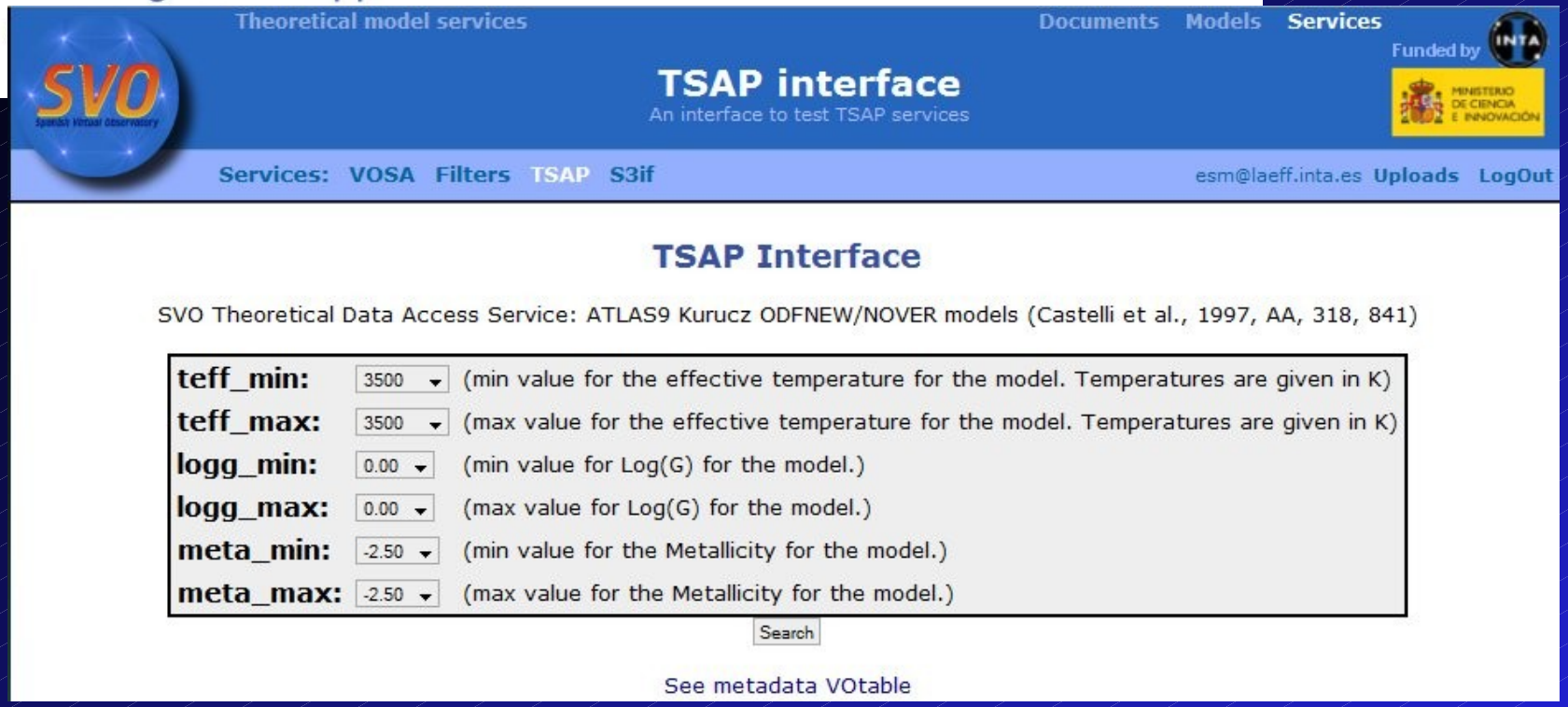


(IVOA Line Data Model: Dubernet, Osuna et al., in preparation)
(Simple Line Access Protocol: Salgado et al., in preparation)

Access protocols in VO: TSAP

Theoretical models in the VO

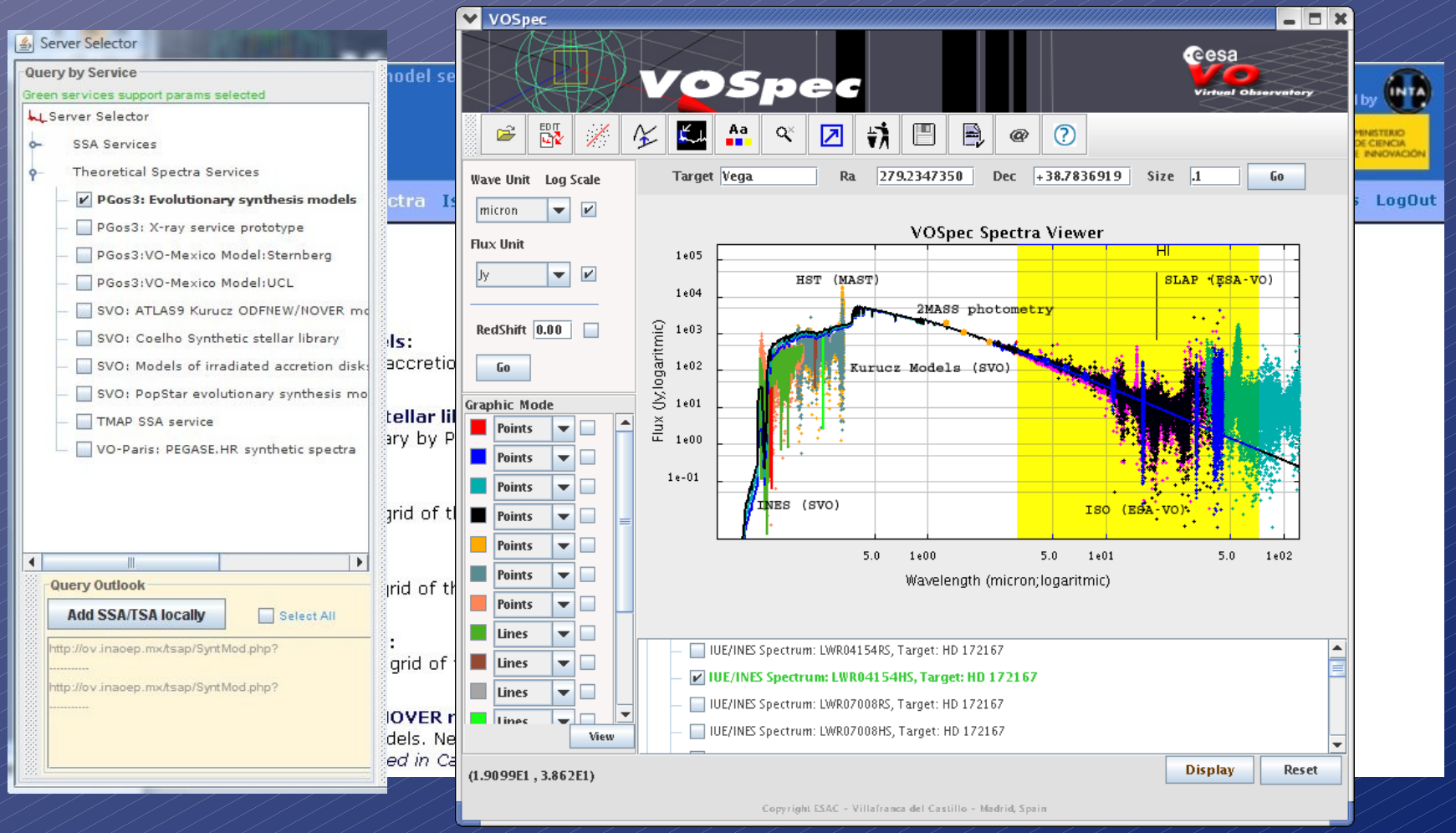
- **Theoretical spectra: TSAP**
  - Included in the SSAP standard (use case for theoretical spectra)
  - A simple protocol.
  - Dialog server-application.



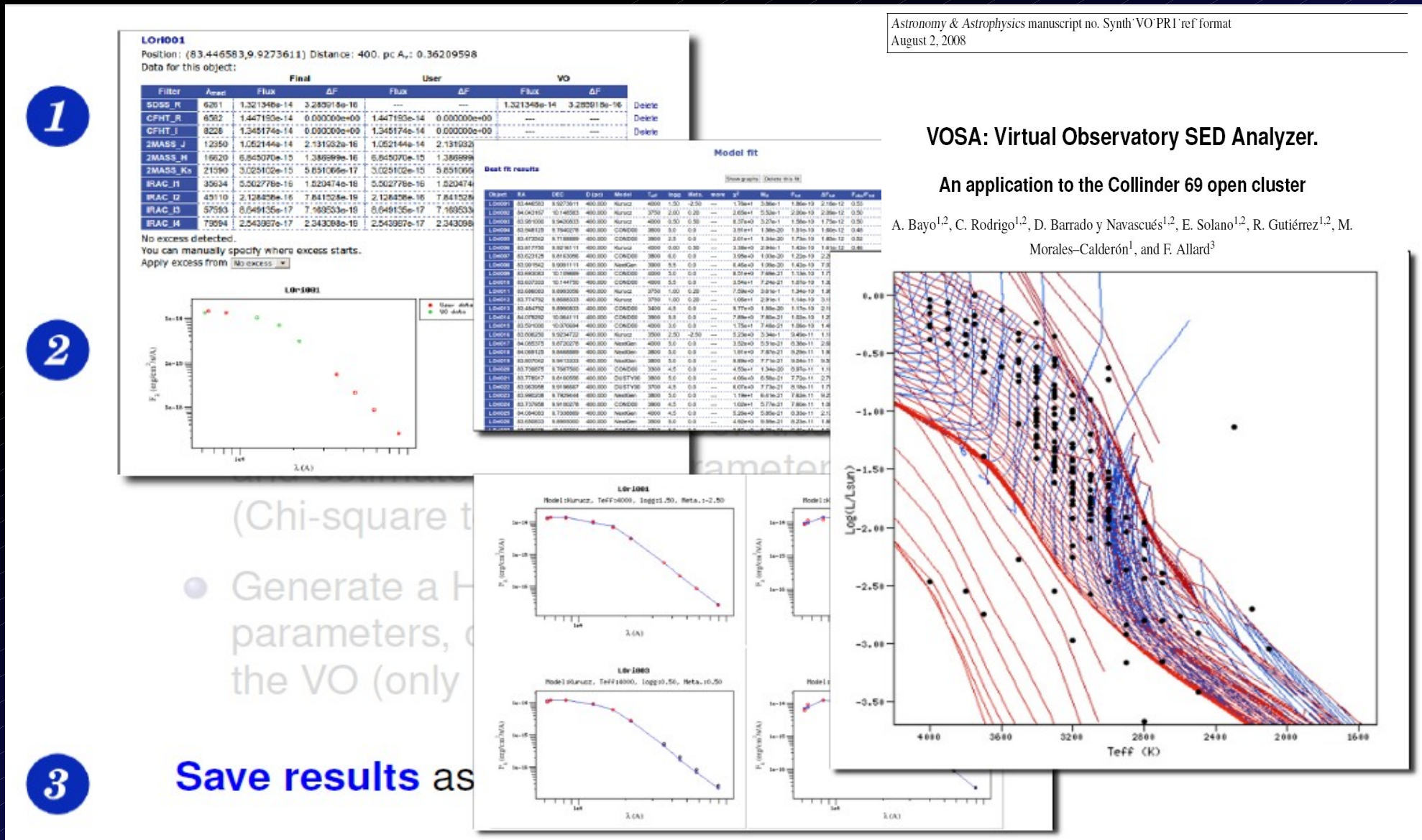
Archives, Theory, VO-Science, DataMining, E&O

Simple Spectral Access Protocol V1.04

Appendix A: Theoretical Spectral Access Use Case



VO SED Analyzer (VOSA)



SED Science

A search for new hot subdwarf stars by means of Virtual Observatory tools

R. Oreiro[1], C. Rodríguez-López[2,3], E. Solano[4], A. Ulla[3], R. Østensen[5], and M. García-Torres[6]

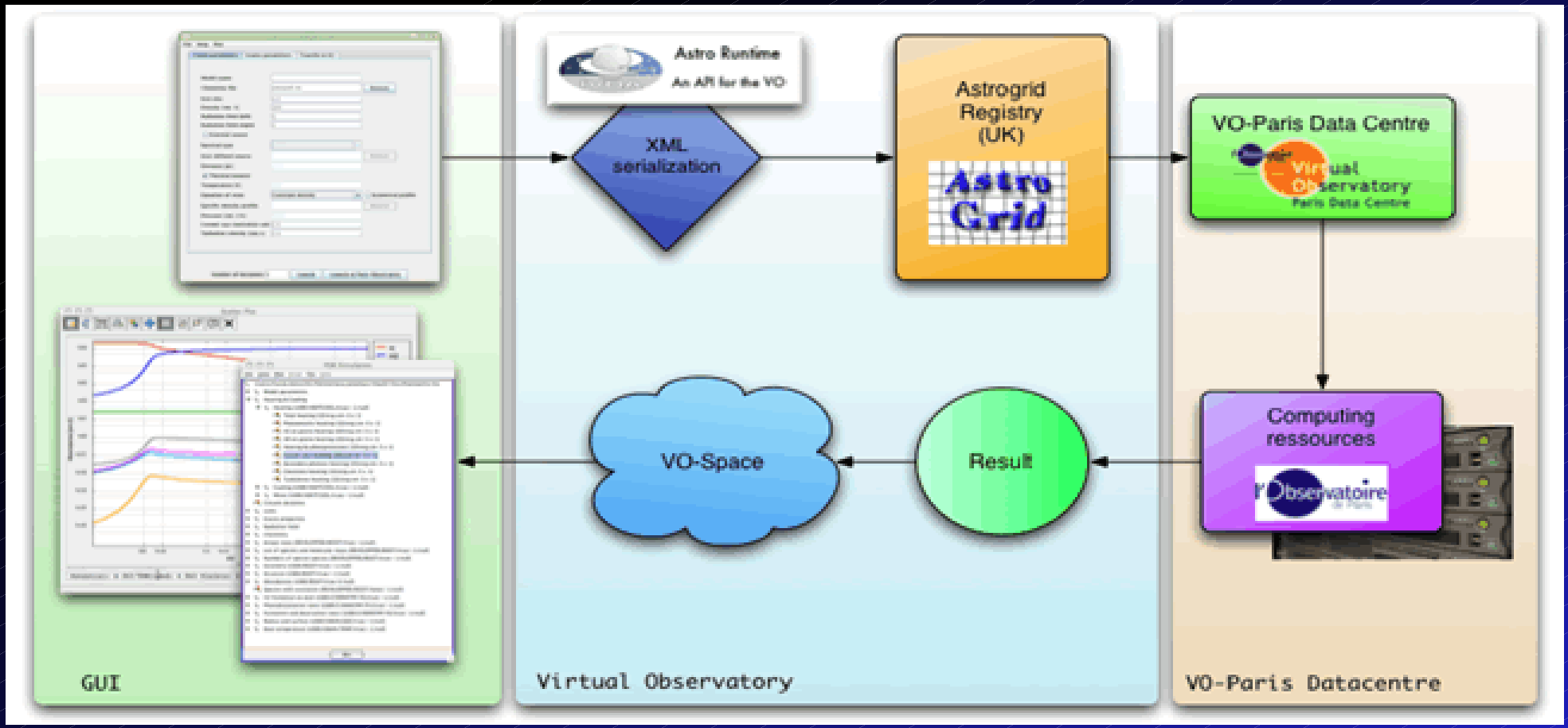
Identification of blue high proper motion objects in the Tycho-2 and 2MASS catalogues using Virtual Observatory tools

F. M. Jiménez-Esteban[1,2,3], J. A. Caballero[4], and E. Solano[1,2]

SEDs = priority science case for US VAO (NSF funded)

SED building in an automatic way (filter services, zero points)
VO Photometry Standard

PDR VO-infrasctructure



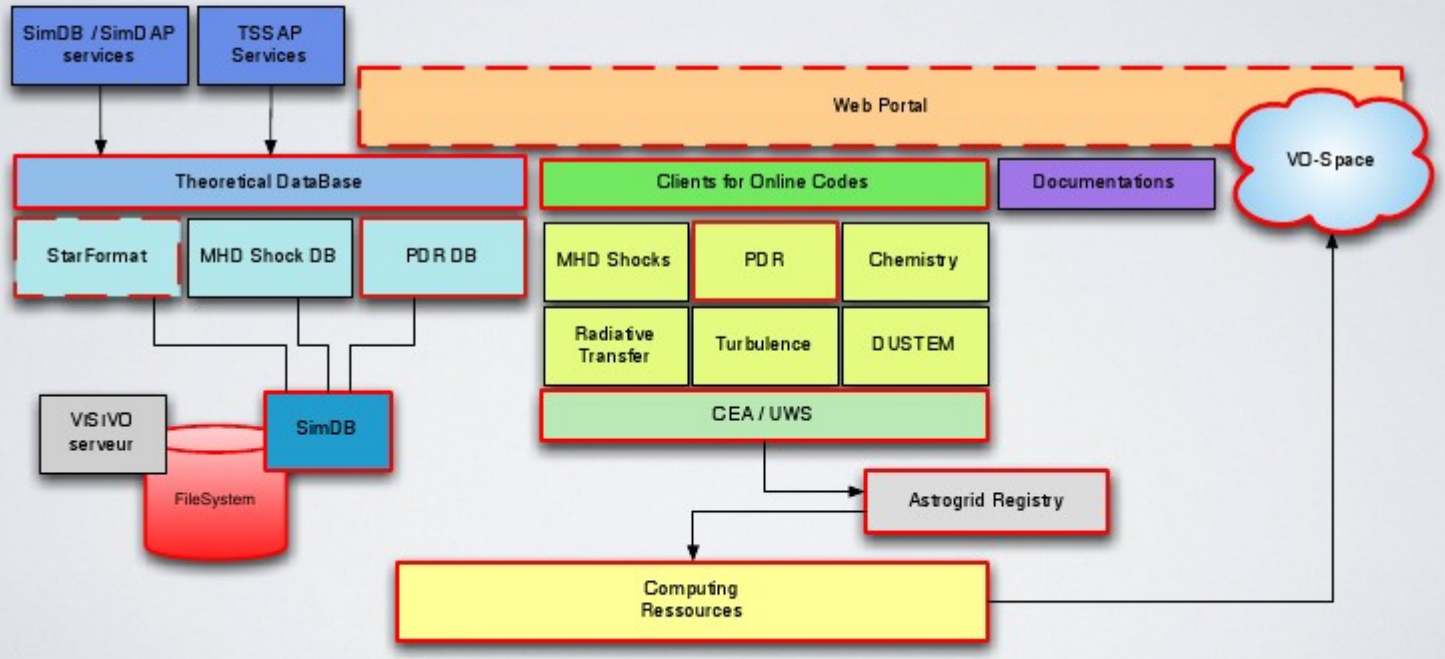
ISM platform

Interstellar Medium Platform

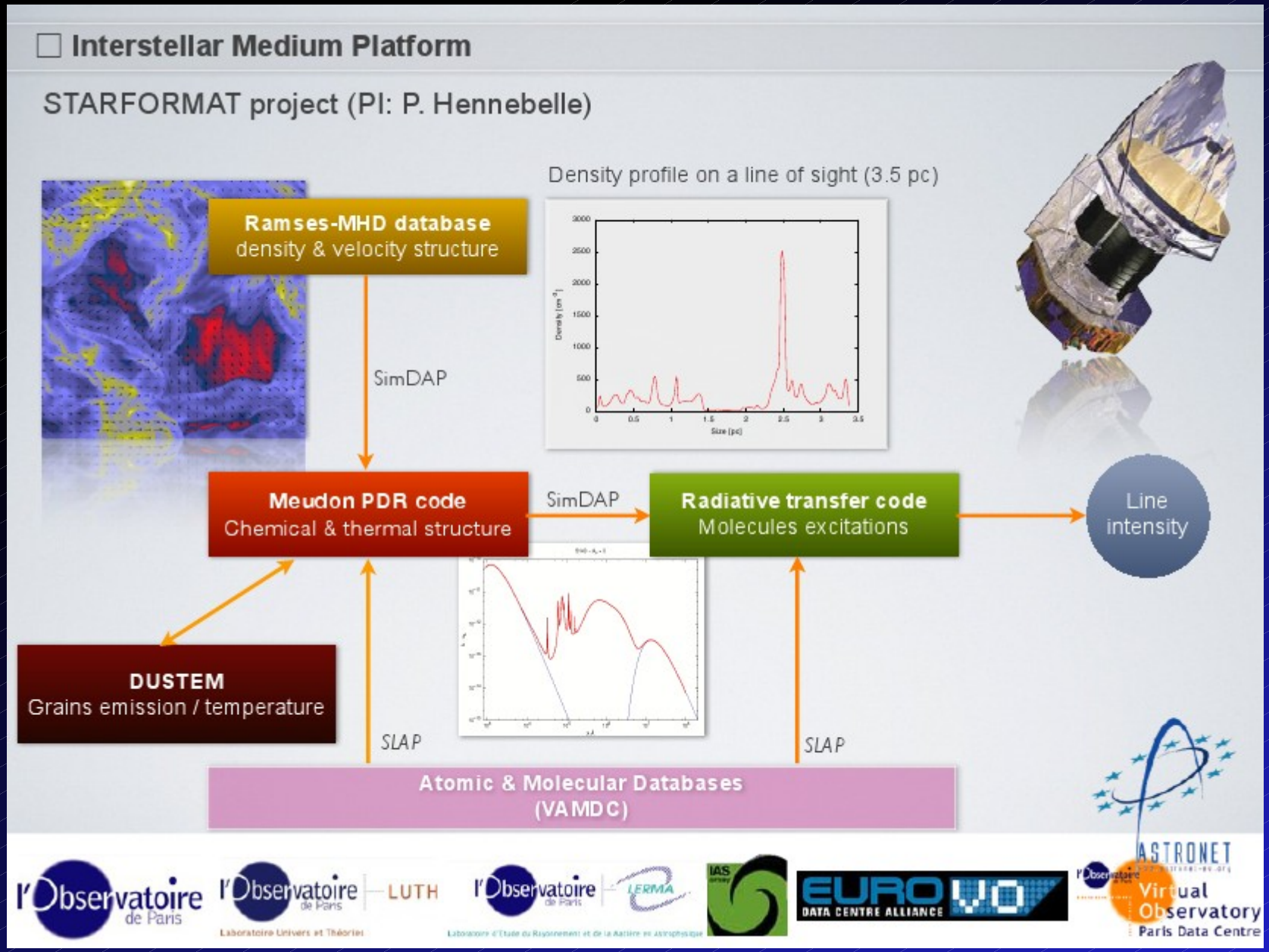
Bring together expertise in modeling / simulation of the ISM

Provide theoretical services about ISM

Codes - Databases - Tools & services



Complex join of TVO bricks



VO Science

- 31 (9) new obscured type 2 QSO (Padovani 2004)
- Brown dwarfs (about 20 candidates)
- Brightest (WD?) Albus-1 (Cabalero et al. 2008)
- Widest CPM binaries
- AGB to PNe - 100 new (200) with VO
- SED (Spectrum Energy Distribution)
- Bolometric magnitude
- VOEvent – robotic telescopes (GRB, transits,)
- Outreach , Education (MS WWT, GoogleSky)

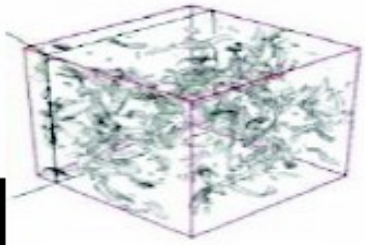
Astroinformatics

- Analogy – Bioinformatics (Genome analysis with GRIDS, ATB)
- e-Science in Astronomy - using informatics (computer science)
- Data mining, Knowledge discovery - VO-NEURAL, DAME
- Clustering
- Classification
- Supervised learning (Neural Networks, SVM)
- Examples
  - Photometric RedShift
  - Searching for QSO (light curves, MOS)
  - Automatic Light curves classification (GAIA, LSST)
- Very NEW – emerging discipline

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

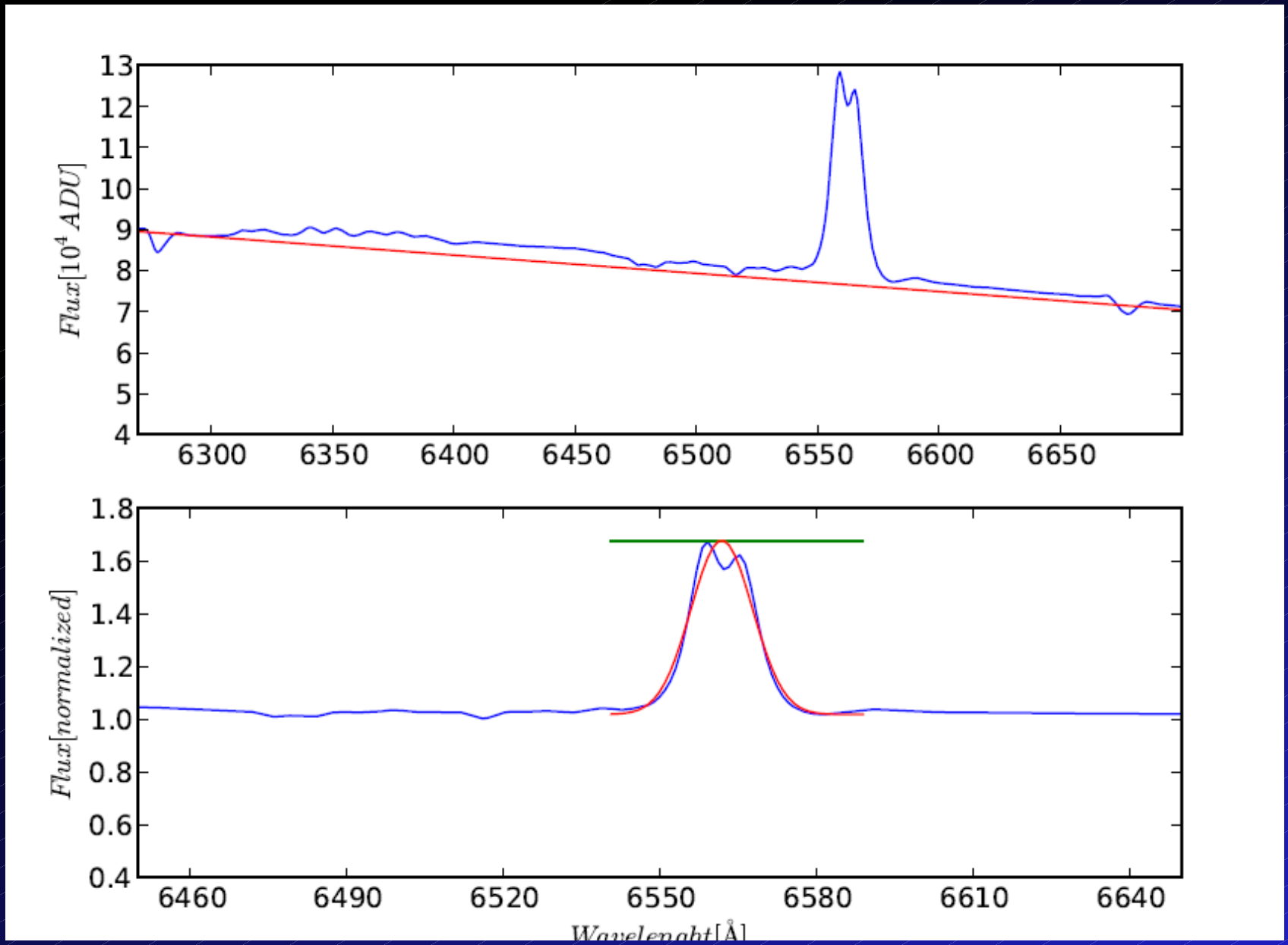
$$\left(\frac{\dot{a}}{a}\right)^2 = \frac{4\pi G\rho}{3} - K\frac{c^2}{a^2}$$



(With thanks to Jim Gray)

From T. Hey, AI2010

Feature extraction (emission)



Be Star Candidate #1 in SEGUE

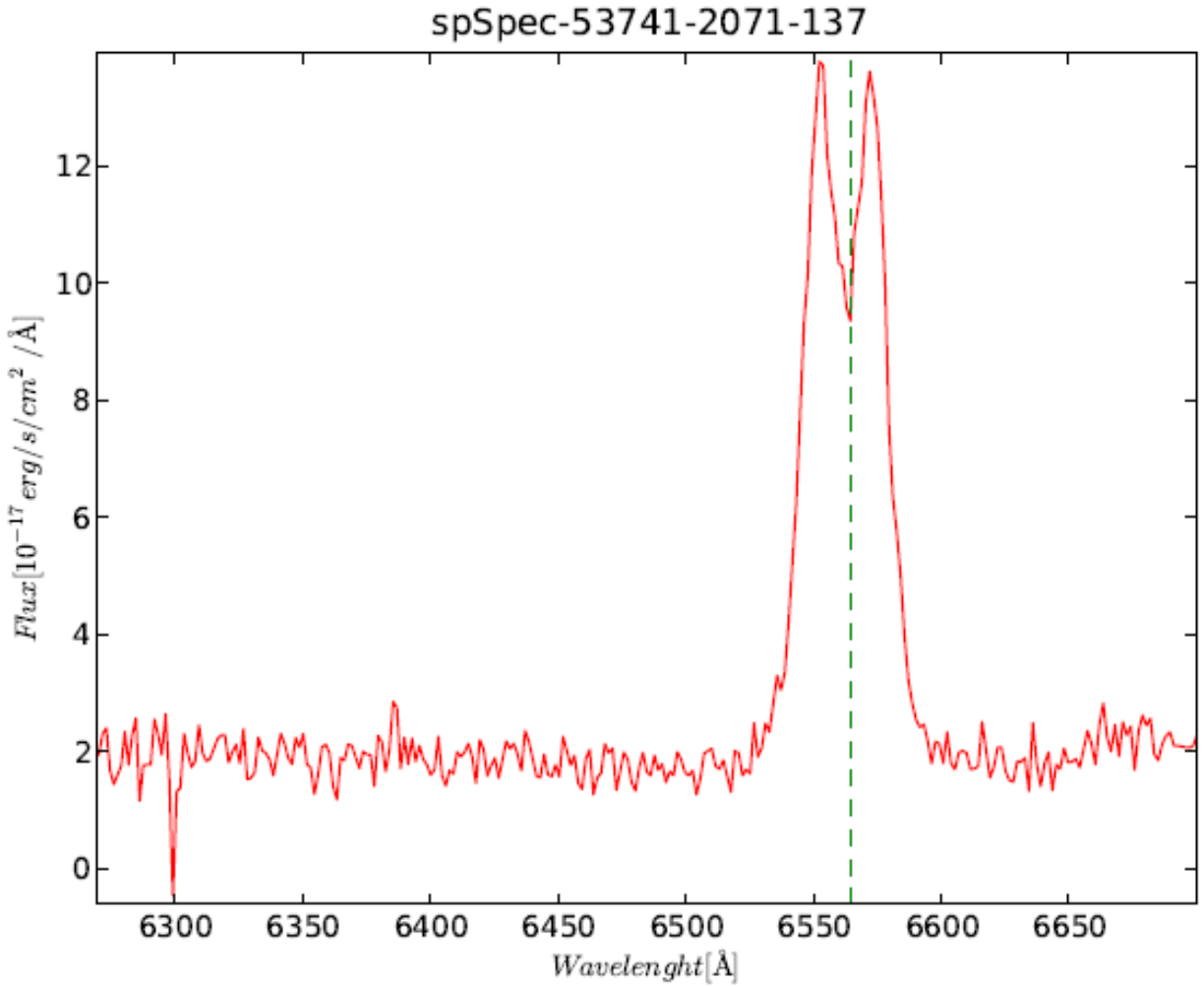


Figure 3.11: Example 1: SDSS J035747.16-063850.7

Be Star Candidate #3 in SEGUE

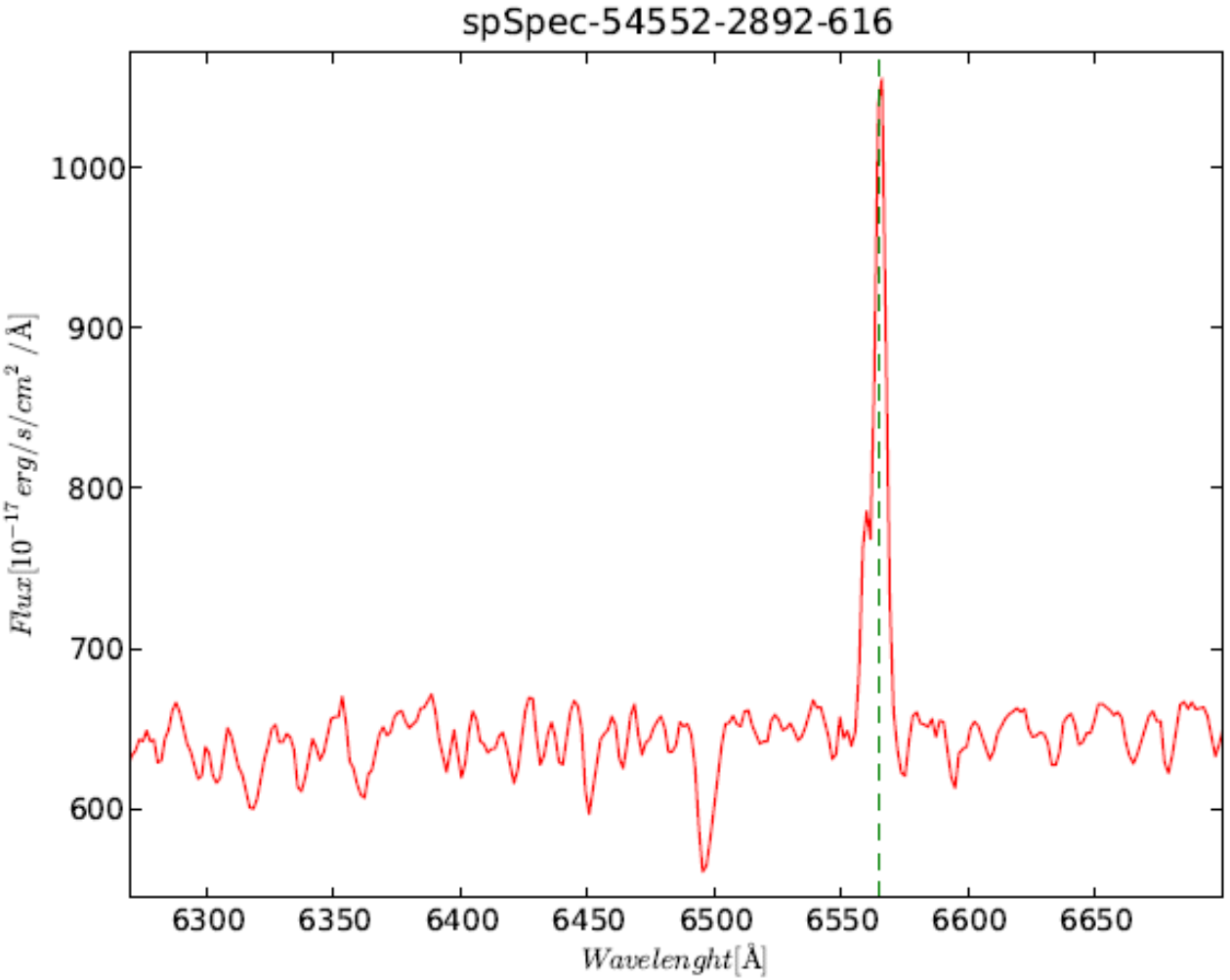
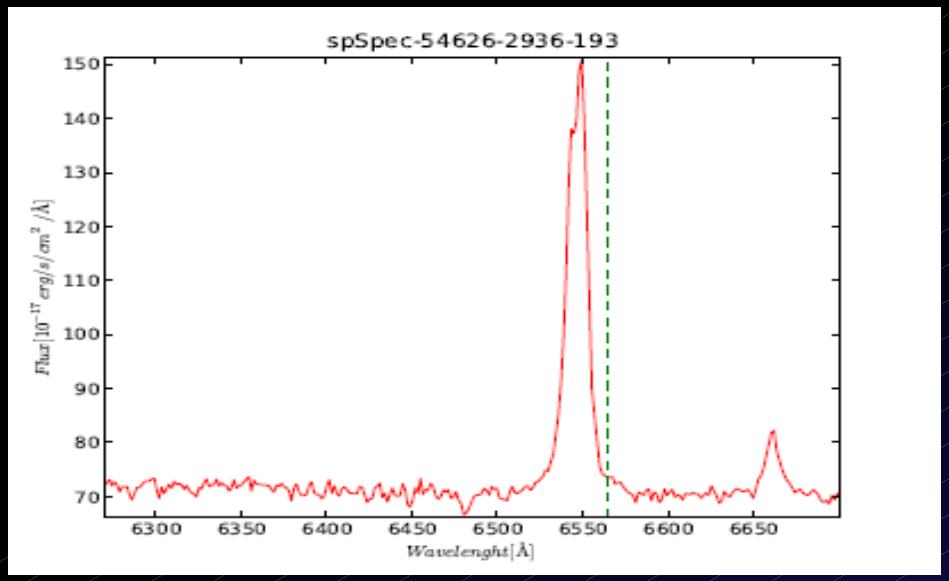
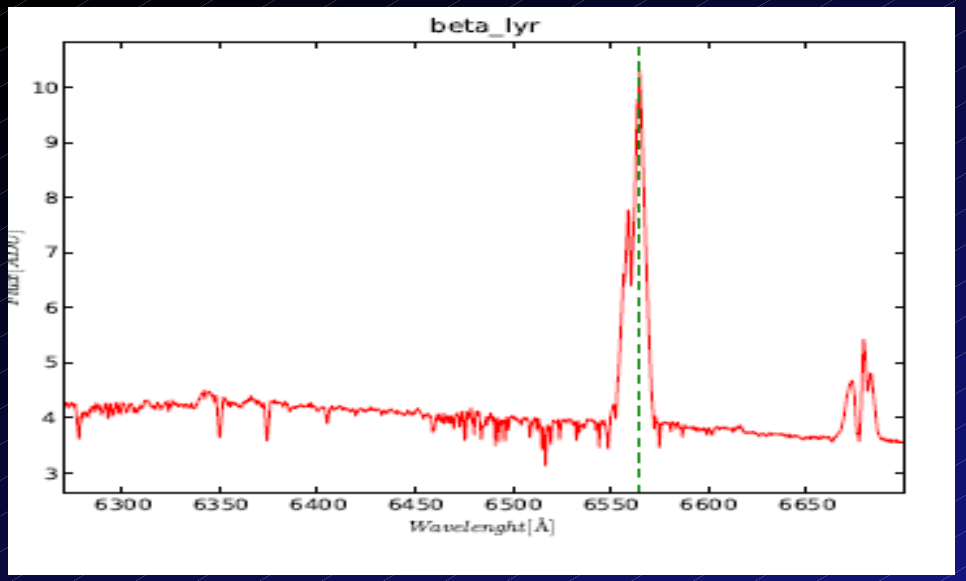
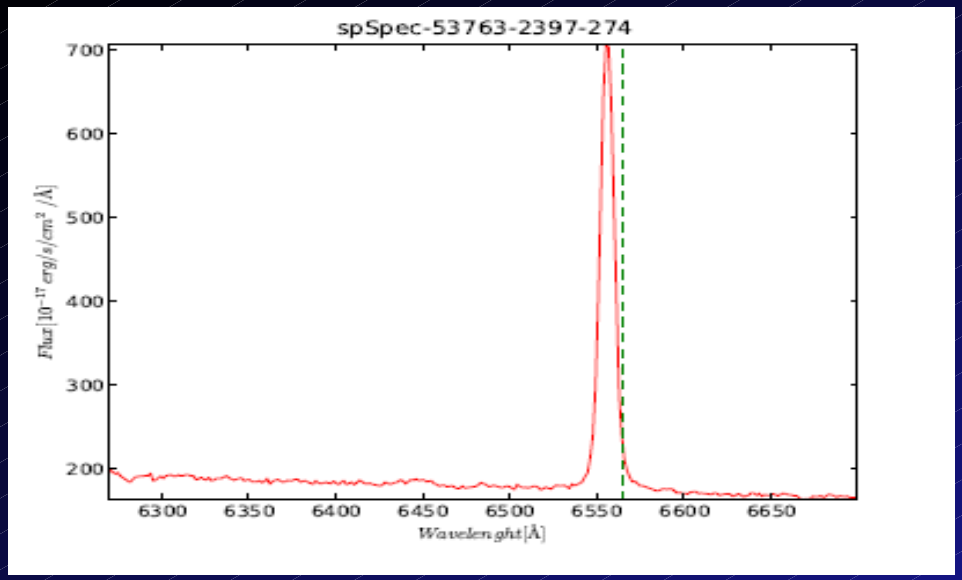


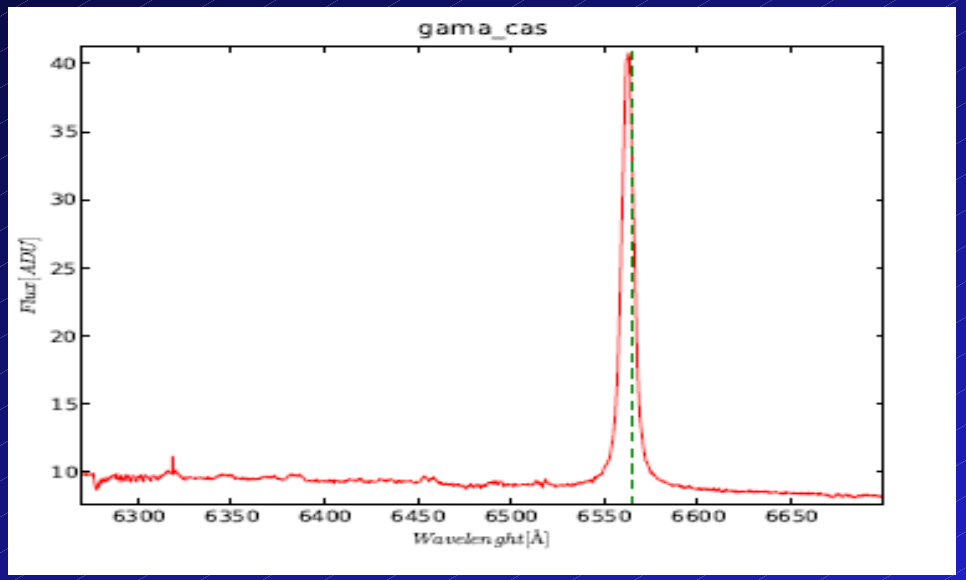
Figure 3.13: Example 3: SDSS J120729.12+003659.8

Candidates – Similarity !









Conclusions

VO is not „virtual“ – its a REAL instrument

Yields new discoveries (panspectral, rare obj.)

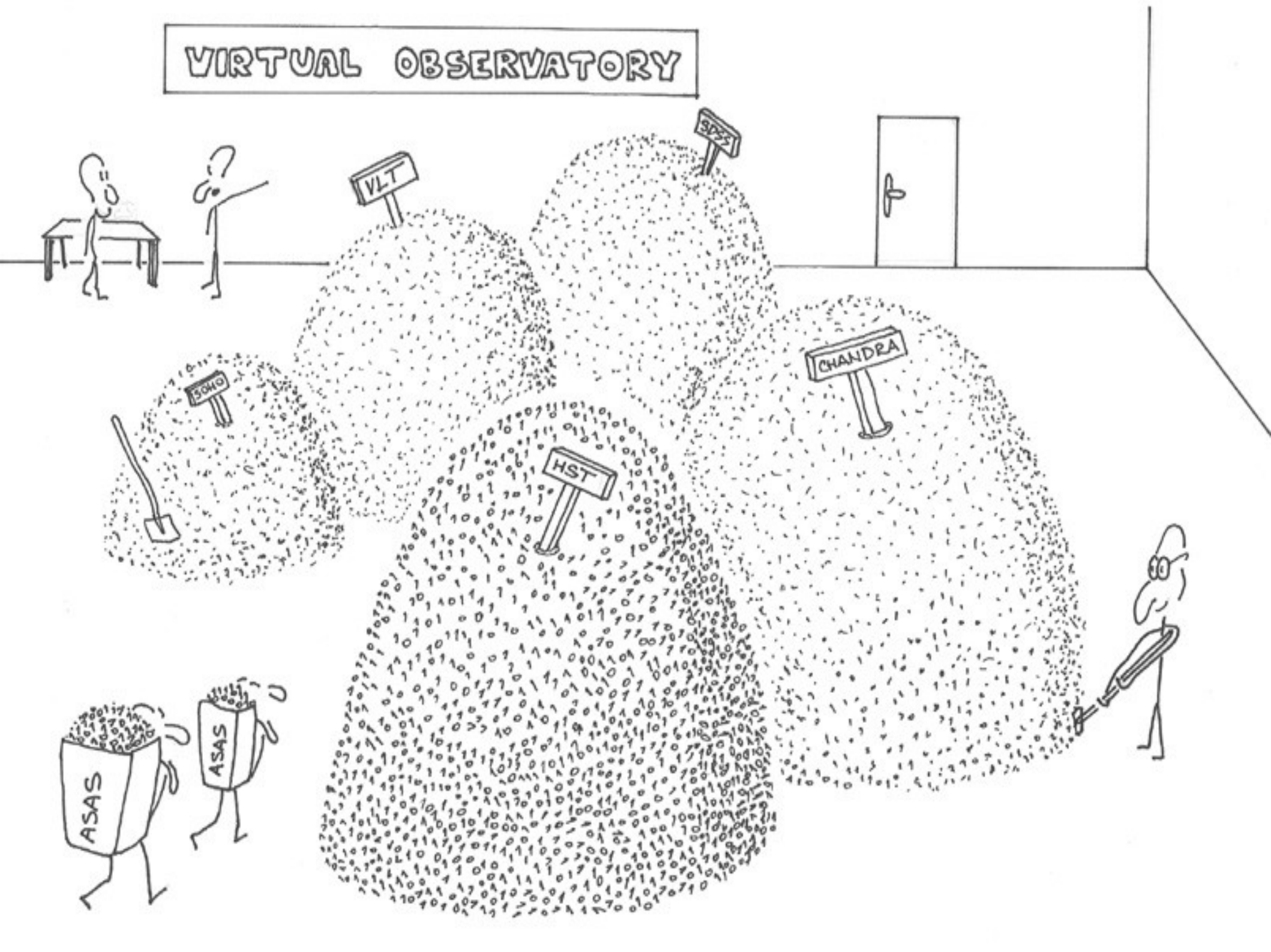
Doing spectroscopy in VO can speed up the spectra discovery and analysis

Tools are already here or will come soon

Power of joining bricks (spatial+spectral+time) inf.

Astroinformatics – extraction of knowledge

e-Science in astronomy, VO=harness of AI


VIRTUAL OBSERVATORY
VLT
SDSS
SOHO
HST
CHANDRA
ASAS
ASAS

VO Basics (tutorial by P. Skoda)

- VOTable (Metadata - UCD, data FITS,ASCII..)
- VO Registry – where, what, how - harvesting
- Protocols (not theory)
  - Conesearch (search in circle with given radius)
  - SIA (transfer of image given dimension, resampling)
  - SSA (spectrum of target, pos., spec. range, time...)
  - TAP (new – query of multiple tables and services)
  - SLAP (atom. and molecular transitions, oscil. str.,)
- ADQL (VOQL) – like SQL (query tables)
- CEA (jobs – VOSPACE) WS, GRID

Practical Examples and Tutorials

EURO-VO Scientific Tutorials

http://www.euro-vo.org/pub/fc/workflows.html

VO Schools EURO-VO - 2009,2010,2011

http://cds.u-strasbg.fr/twikiAIDA/bin/view/EuroVOAIDA/VOSchool09/WebHome

http://cds.u-strasbg.fr/twikiAIDA/bin/view/EuroVOAIDA/VOSchool10/WebHome

http://www.eurovo-ice.eu/twiki/bin/view/EuroVOICE/ICESchool

AIDA WP5 pages - VO in Education and Outreach

http://cds.u-strasbg.fr/twikiAIDA/bin/view/EuroVOAIDA/WP5WorkProgrammeUsecases