Global Scientific Data Sharing and Big Data Knowledge discovery

Czech Virtual Observatory and COST action Big Sky Earth

Petr Škoda
Astronomical Institute of the Czech Academy of Sciences

Supported by grant COST LD-15113 of the Czech Ministry of Education Youth and Sports
And COST Action TD1403 Big Sky Earth

RDA Meets Czech Researchers
Prague, Czech Republic, 27th October 2017
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.

- We acknowledge namely materials of B.Hanish, G. Djorgovski, G. Longo, T. Hey and M. Breddels, D Vinkovic, P. Baumann, A Nina and presentations from AI2016 in Sorrento.
Outline of the Talk

- Data Avalanche in astronomy
- Virtual Observatory
- Astroinformatics
- Big Sky Earth
- Transfer of technology
- CZVO
  - Be stars discovery in LAMOST surveys
  - Ondrejov Southern Photometry Survey
- Future
Dark Energy Camera (DECam)

~0.4 PB/yr

74 chips – 570 Mpixels - 4m Cerro Tololo
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
Cherenkov Telescope Array

- 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

27 PB/year in archive
SKA

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
LOFAR network

<table>
<thead>
<tr>
<th></th>
<th>LOFAR</th>
<th>SKA</th>
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<tbody>
<tr>
<td>Raw Telescope</td>
<td>112 PB/yr</td>
<td>60 EB/yr</td>
</tr>
<tr>
<td>Archive Rate</td>
<td>6 PB/yr</td>
<td>100 PB/yr</td>
</tr>
</tbody>
</table>
Data Avalanche

Moore law for chips – doubling 1.5 year

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

=====> Processing to data

---

![Graph showing exponential growth in numbers per night over years, with a note T_2 < 18 mths 1990-2000.](image)
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”

Start of VO – early 2000
Space-Time-Coordinate Data Model
Technology of VO

Unified data format– VOTable, UCD (semantics)

Web services (WS)

VOregistry – 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 interoperability – SAMP

Allows develop applications as bricks
sending VOTABLES (catalogue-spectra-images)
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
Simple Spectra Access Protocol

Spectral Data Model

Simple Spectra Access Protocol

Version 1.04
IVOA Recommendation Feb 01, 2008

This version:
http://www.ivoa.net/Documents/REC/SA/SA-20080201.html
Latest version:
http://www.ivoa.net/Documents/latest/SA.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 0.90, September 2006
Version 0.95, May 2006
Version 0.51, October 2005
Version 0.90, May 2005

Editors:
D.Tody, M. Dolejsky

Authors:
D.Tody, M. Dolejsky, J. McDowell, F. Bonnarel, T. Budavari, H. Holszko, A. Mico, P. Csicska, J. Salgado,
P. Skoda, R. Thompson, F. Valdés, and the data access layer working group.

IVOA Spectral Data Model

Version 1.03
IVOA Recommendation 2007-10-29

This version (Recommendation Rev 1):
Latest version:
http://www.ivoa.net/Documents/latest/SpectrumDM.html
Previous versions:

Editors:
Jonathan McDowell, Doug Tody.

Contributors:
# SSAP Parameters

## 4.1.1 Mandatory Query Parameters

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

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Sample value</th>
<th>Physical unit</th>
<th>Datatype</th>
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<tbody>
<tr>
<td>POS</td>
<td>52,-27.8</td>
<td>degrees; defaults to ICRS</td>
<td>string</td>
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<tr>
<td>SIZE</td>
<td>0.05</td>
<td>degrees</td>
<td>double</td>
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<tr>
<td>BAND</td>
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## 4.1.2 Recommended and Optional Query Parameters

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<th>Unit</th>
<th>Req</th>
<th>Datatype</th>
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<td>degrees</td>
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<td>SPECTR</td>
<td>2000</td>
<td>λ/dλ</td>
<td>REC</td>
<td>double</td>
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<td>SPATRES</td>
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<td>TIMERES</td>
<td>31536000 (=1yr)</td>
<td>seconds</td>
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<td>double</td>
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<td>TARGETCLASS</td>
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SPLAT-VO
(Starlink, Heidelberg, Ondrejov)
VOspec (ESAC)
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

(With thanks to Jim Gray)

From T. Hey, AI2010

T. S. Kuhn – Structure of Scientific Revolutions
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 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
Astroinformatics
From Big Data to understanding the Universe at Large

http://eas.unige.ch/EWASS2017/session.jsp?id=S14
Need for a new science: Astroinformatics

Knowledge Discovery in Databases

Data Gathering (e.g., from sensor networks, telescopes...)

→ Data Farming:
  - Storage/Archiving
  - Indexing, Searchability
  - Data Fusion, Interoperability, ontologies, etc.

→ Data Mining (or Knowledge Discovery in Databases):
  - Pattern or correlation search
  - Clustering analysis, automated classification
  - Outlier / anomaly searches
  - Hyperdimensional visualization

→ Data understanding
  - Computer aided understanding
  - KDD
  - Etc.

→ New Knowledge

Database technologies

Key mathematical issues

Ongoing research

Longo 2009
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*
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
A Key Challenge: Visualising Multidimensional Data Spaces

- Hyperdimensional structures (clusters, correlations, etc.) may be present in many complex data sets, whose dimensionality may be $D \sim 10^2 - 10^4$, 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 $\sim 3 - 12(?)$ dimensions

What good are the data if we cannot effectively extract knowledge from them?
Visualization of Big Data
Big Data Era in Sky and Earth Observation – TD 1403 COST action

P. Škoda
Czech Representative in MC
The era of Big Data has arrived!

Example: images + time = surface movements

**sentinel-1A**

Launch date: 3. April 2014

up to 2.4 TB/day of imaging radar data for 7 years (fully open and free data access policy)

**Applications:** Oceans and ice, Changing lands, Emergency response

Part of the **European Earth Observation Programme Copernicus:** the most ambitious Earth observation programme to date: 30 satellites: peta-bytes now: zetta-bytes in a decade
Remote sensing – Big Data
Machine Learning

Precise farming
Forestry
Ore mining
Water resources monitoring
Automatic classification of terrain
Resistance of buildings (Aquilla)
Mobile network structure – disasters
Customized product for every user
Ionospheric variations and natural disasters predictions

**Earthquake**

Kraljevo (43.74 N, 20.69 E), November 3, 2010

**Cyclon**

Nina 2016
computing resources, digital curation, numerical methods, knowledge discovery in big data sets, machine learning
Impact

Big Data is not just bigger, it is different!

Success in research will depend on the ability to mine knowledge from that data.

And some of the most interesting science probably hasn’t even been imagined!
From Sky Surveys to Neurobiology

- Using the data analytics tools based on ML, developed for the analysis of sky surveys, to design a better diagnostics for autism

- Feature importance using random forests =>

- Next: correlate with MRI scans

(with R. Adolphs et al.)

J. Bunn, CD³
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.
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
Czech VO – CZVO (not in IVOA)

after 2006
(IAU Prague)

Support of FP{6,7}
EURO-VO, COSADIE, AIDA

Asterics (GAVO)

MEYS CR (MŠMT)
CSF (GAČR)
BT and MT at Faculties of IT astroinformatics and VO

- FIT VUT Brno
  - 2011 1 BT (Random Forests in Astronomy)
  - 1 PhD – Wavelets Dimensionality Reduction (pending)

- VŠB-TU Ostrava
  - 2013+2015 1 BT + 1 MT - SPLAT-VO

- FIT ČVUT (8 BT+5 MT)
  - 2012 2 BT (VO-Korel+SSA proxy)
  - 2013 2 BT (OSPS Image + Catalogue Server)
  - 2014 2 BT (Random Forests + SOM)
  - 2015 1 BT (VO-Cloud)
    - 2 MT (Clustering OSPS + Deep Learning)
  - 2016 2 MT (Semisupervised learning + Outlier finding)
  - 2017 1 MT (VO Cloud) + 1 BT (deep learning) + 1 PhD (VO light curve)
VO Services of CZVO

Welcome to ASU CAS Data Center.

In addition to the services listed below, on this site you probably can access numerous tables using TAP or form-based ADQL.

Please check out our site help.

The early stages of development of this archive in years 2013-2015 was supported by grant 13-08195S of Czech Science Foundation.

Its current extended version has been funded by grants COST LD-15113 (spectra and light curves) and INGO LG-15010 (images and photometry) of Czech Ministry of Education Youth and Sport.

Services Available

By Title | By Subject | By Author

- CCD700 Spectra Web Interface
- DK154 Lightcurves Web Interface
- DK154 Ondrejov RAW observations SIAP
- DK154 Ondrejov REDUCED observations SIAP
- DK154 SCS for observed objects
- HEROS Public Spectra Web Interface
- LAMOST DR1 Spectra Web Interface
- LAMOST DR3 Spectra Web Interface
- LAMOST PILOT Spectra Web Interface
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 ??????
## CCD700 Spectra Web Interface

### Parameters
- Object standard name: ['psiper']

### Result
Matched: 44

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</tbody>
</table>
Spectra in SPLAT-VO - query
Spectra in VO – direct access plot

![Spectrogram](image-url)
Spectra in SPLAT-VO - DataLink
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
SOM Worker example
VO-CLOUD spectra visualisation
Be Candidates Found
Yet Unknown Be Star (UCAC ...)

Graph 1: 
- Y-axis: Flux
- X-axis: Wavelength [Ångströms]
- Data points showing fluctuations in flux across different wavelengths.

Graph 2: 
- Y-axis: Flux
- X-axis: Wavelength [Ångströms]
- Data points showing notable peaks and troughs in flux at specific wavelengths.
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 on sky **ALADIN, X-MATCH CDS**

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

- Very similar methodology in e.g. Mass spectrography
- DNA analysis – search for patterns
Danish 1.54m at La Silla robotized in Summer 2012
Danish 1.54m Telescope
Reduced OSPS image + bintable photometry in 2nd extension
# SIAP – Raw images query

**DK154 Ondrejov RAW observations SIAP**

Observations captured by ASU CAS facility by DK154 telescope

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<tr>
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<th>ngc 330</th>
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<tr>
<td>Image covers Rol</td>
</tr>
<tr>
<td>Rol covers image</td>
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<tr>
<td>The given position is shown on image</td>
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Relation of Image and specified Region of Interest.

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<tr>
<th>Band [m]</th>
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<tr>
<td>ALL</td>
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<tr>
<td>Wavelength (range of interest or symbolic bandpass names)</td>
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<table>
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<tr>
<th>Minimum Date</th>
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<tr>
<td>MM/DD/YYYY</td>
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<td>Minimum date (if empty, returns everything until Maximum date)</td>
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OSPS SIAP in Aladin (DSS in back)
OSPS Image coverage (footprints)
Data Cubes = Scientific Data Structure

IVOA N-Dimensional Cube Model
Version 1.0
IVOA Working Draft 20150320

This version:
WD-CubeDM-1.0-20140930
Previous version(s):

Editor(s):
Mark Cresiello-Dittmar

Authors:
Doug Tody, Francois Bommarito, Omar Laurino, Mireille Louys, Arnold Rots, Jose Enrique Ruiz, Jesus Salgado, and the IVOA Data Model Working Group.
Time Series Cube Data Model
Version 1.1

IVOA Note 2017-02-05

Working group
Time domain interest group

This version
http://www.ivoa.net/documents/cubeDM/20170205

Latest version
http://www.ivoa.net/documents/cubeDM

Previous versions

Author(s)
Jiří Nádvorník, Petr Škoda, Dave Morris, Pavel Tvrdík

Editor(s)
Jiří Nádvorník
OSPS Light curves in SPLAT-VO using Sparse Cube DM
OSPS Light curves – plot (customized)
Conclusions

- Machine learning on Big Data archives may identify new interesting objects yet unknown
- Global Data Federation from Multiple fields
- Crucial is interactive visualization
- Future science will be multidisciplinary
- Wide collaboration of experts and informaticians
- Education of new expert – Data Scientist
- Transfer of technology – commercial interest
- $X$-Informatics $\leftarrow$ Philosophia (love of wisdom)
- VO-like technology helps in every step