Challenges and Scientific Requirements for Visualization in the VO

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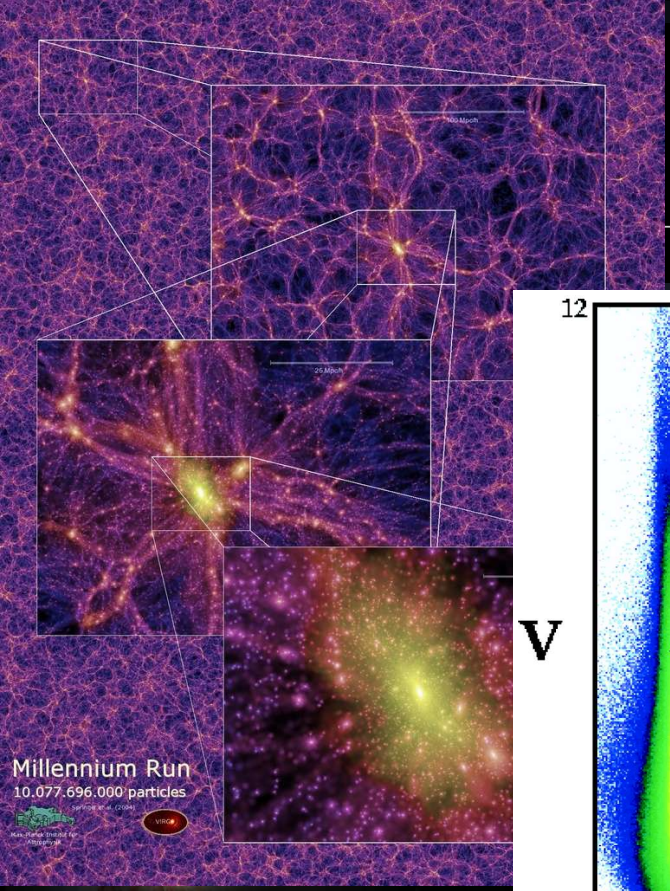
Turning point into the VO era

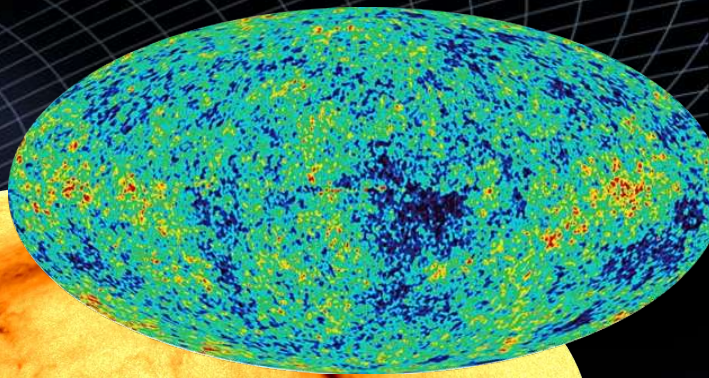
- Essential for imminent data volumes and rates
- Multi- λ science requires
  - Data from different telescopes
  - Analysis tools
  - on-line services
  - archived information

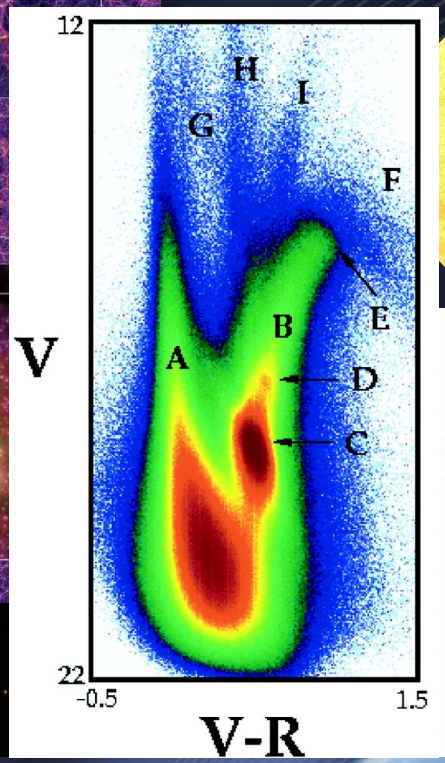
  to be *readily compatible*
- VO = framework for interoperable systems
- VO Vision: *All Astronomy resources as if they were on your desktop*

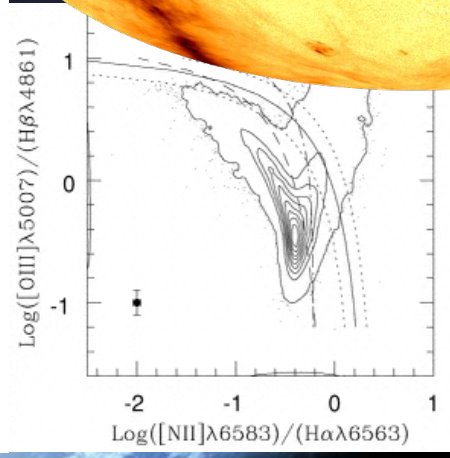
Visualization of :

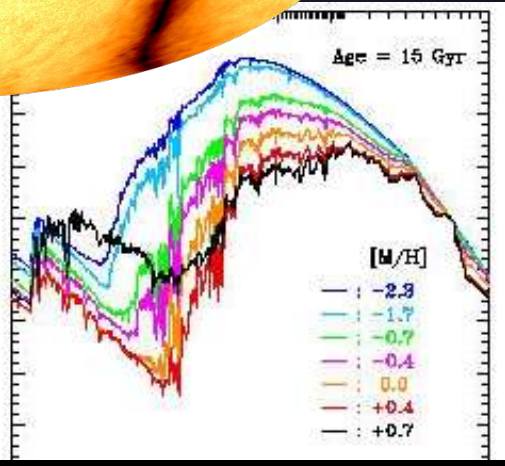
- Images (multi-band, mosaics, cutouts, FT)
- Catalogues
- Spectra
- Spatial Information
  - Sky regions, slits, FoV, etc.
- Simulation data – many kinds
- Multi-d data sets
  - Data cubes, irregularly spaced data
  - Plots, multi-d cluster analysis and correlations

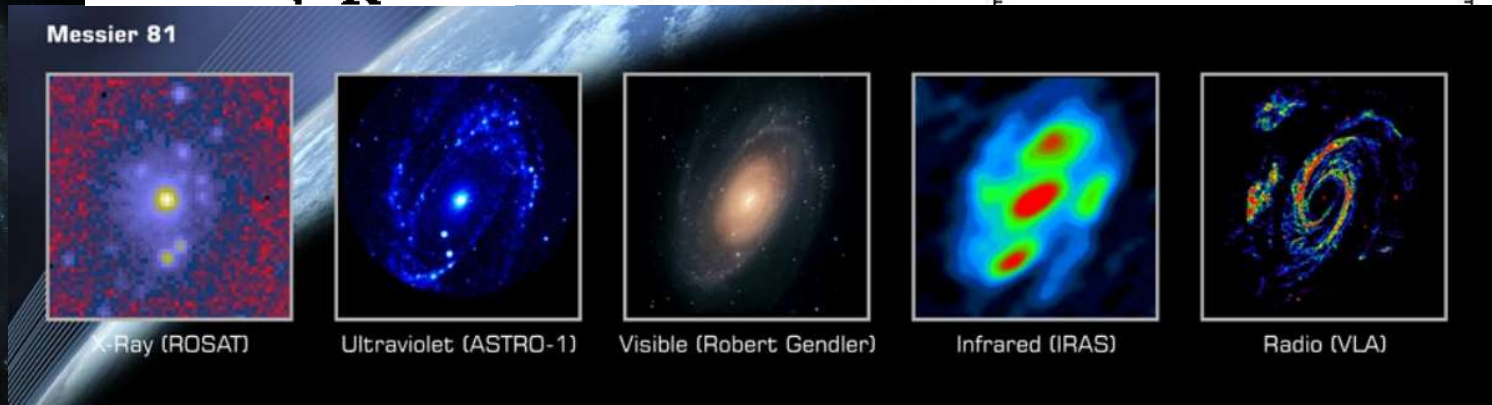

Millennium Run
10.077.696.000 particles




12
22
-0.5
1.5
V
V-R
H
I
G
F
E
B
A
D
C


Log([OIII]λ5007)/(Hβλ4861)
Log([NII]λ6583)/(Hαλ6563)
1
0
-1
-2
-1
0
1


Age = 15 Gyr
[M/H]
-2.3
-1.7
-0.7
-0.4
0.0
+0.4
+0.7


Messier 81
X-Ray (ROSAT)
Ultraviolet (ASTRO-1)
Visible (Robert Gendler)
Infrared (IRAS)
Radio (VLA)

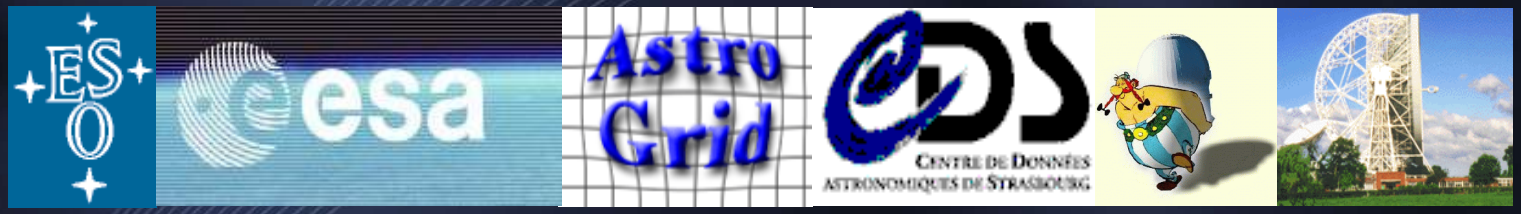
Visualization requirements drawn from

- AVO demo experience
  - Implementing prototypes, doing science
- Science Reference Mission
  - Science capabilities for VO – AVO SWG
- *NVO, AstroGrid Science use cases*

AVO

ASTROPHYSICAL VIRTUAL OBSERVATORY

- R&D on scientific requirements and technology for building a VO



- Phase-A, 2001-2004/5
- Driven by strategy of scientific VO demonstrations

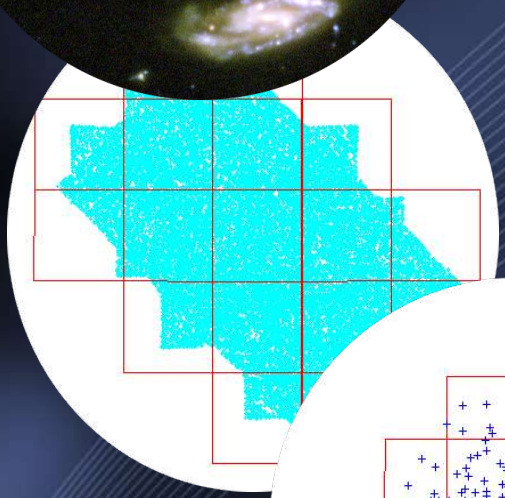
'First Science' (Jan 2004)

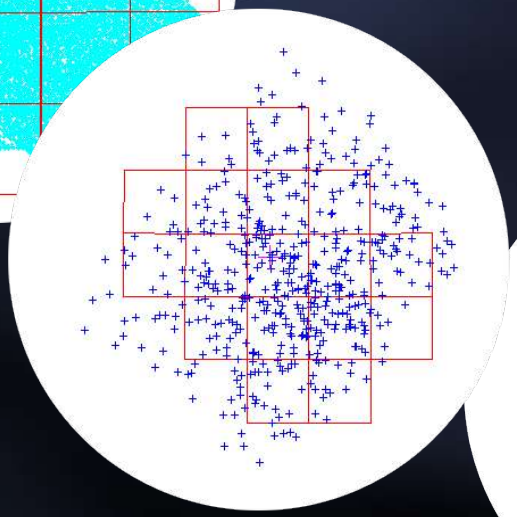
- Prototype VO tools for science
  - *Aladin & CDS services, AstroGrid*
  - *Using distributed information*
- Enabled by real gains in standards for:
  - Data access
  - Manipulating image and catalogue data
  - Remote calculations

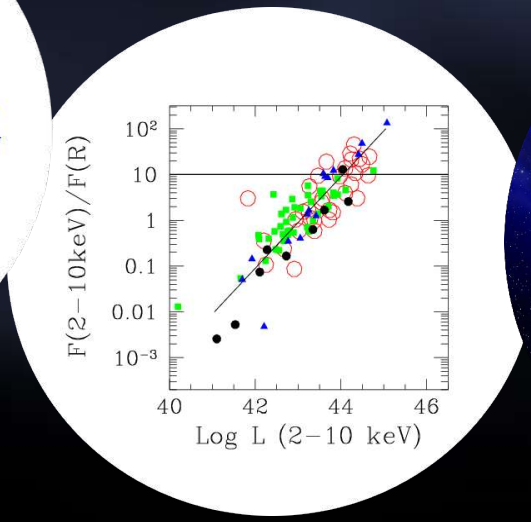
Discovery of QSO 2s with VO tools

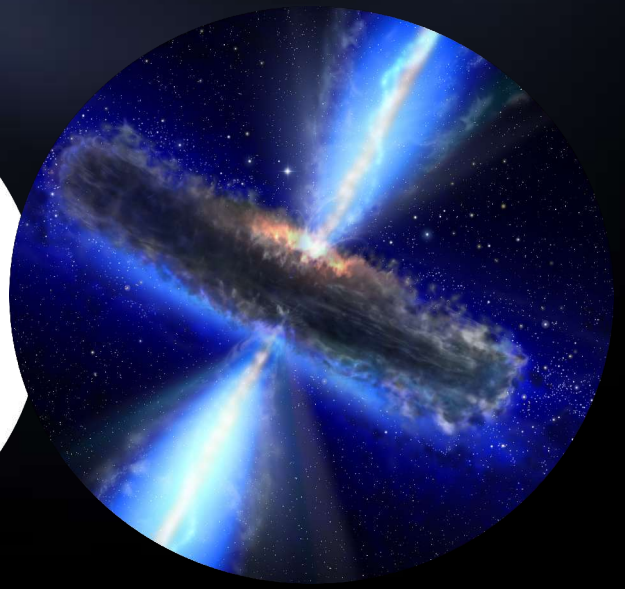
- GOODS Optical ACS data & catalogues
- Chandra X-ray catalogues
- Select absorbed X-ray sources
- Cross-match X-ray and optical
- Apply empirical estimator for Lx
- Check against spectroscopy

$Lx>10^{44}$: QSO 2



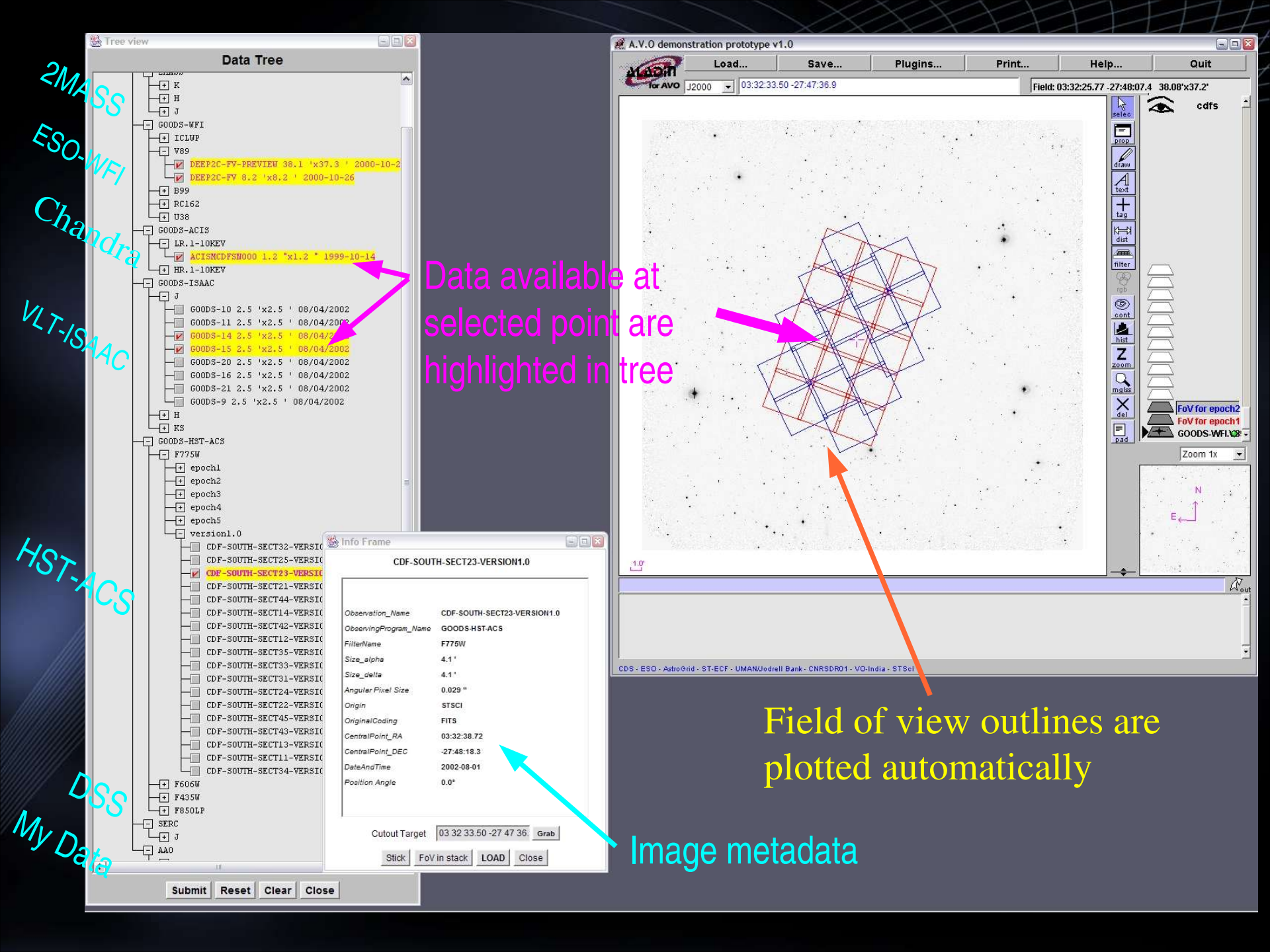






Visualization aspects

- Data from many sources
  - Visualize data outline before download
- GOODS images ~ 100 GB
  - Getting to the pixels
  - Handling large images
  - Making cutouts
- Catalogue - Image – Spectra
  - Filtering catalogues for display and selection
  - Interoperating visualization tools


2MASS
ESO-WFI
Chandra
VLT-ISAAC
HST-ACS
DSS
My Data
Tree view
Data Tree
K
H
J
GOODS-WFI
ICLWP
V89
DEEP2C-FV-PREVIEW 38.1 'x37.3 ' 2000-10-2
DEEP2C-FV 8.2 'x8.2 ' 2000-10-26
B99
RC162
U38
GOODS-ACIS
LR.1-10KEV
ACISMCDFSN000 1.2 "x1.2 " 1999-10-14
HR.1-10KEV
GOODS-ISAAC
J
GOODS-10 2.5 'x2.5 ' 08/04/2002
GOODS-11 2.5 'x2.5 ' 08/04/2002
GOODS-14 2.5 'x2.5 ' 08/04/2002
GOODS-15 2.5 'x2.5 ' 08/04/2002
GOODS-20 2.5 'x2.5 ' 08/04/2002
GOODS-16 2.5 'x2.5 ' 08/04/2002
GOODS-21 2.5 'x2.5 ' 08/04/2002
GOODS-9 2.5 'x2.5 ' 08/04/2002
H
KS
GOODS-HST-ACS
F775W
epoch1
epoch2
epoch3
epoch4
epoch5
version1.0
CDF-SOUTH-SECT23-VERSION1.0
F606W
F435W
F850LP
SERC
J
AAO
Submit
Reset
Clear
Close
Info Frame
CDF-SOUTH-SECT23-VERSION1.0
Observation_Name CDF-SOUTH-SECT23-VERSION1.0
ObservingProgram_Name GOODS-HST-ACS
FilterName F775W
Size_alpha 4.1 '
Size_delta 4.1 '
Angular Pixel Size 0.029 "
Origin STSCI
OriginalCoding FITS
CentralPoint_RA 03:32:38.72
CentralPoint_DEC -27:48:18.3
DateAndTime 2002-08-01
Position Angle 0.0°
Cutout Target 03 32 33.50 -27 47 36.
Grab
Stick
FoV in stack
LOAD
Close
Data available at selected point are highlighted in tree
A.V.O demonstration prototype v1.0
Load...
Save...
Plugins...
Print...
Help...
Quit
J2000
03:32:33.50 -27:47:36.9
Field: 03:32:25.77 -27:48:07.4 38.08'x37.2'
cdfs
FoV for epoch2
FoV for epoch1
GOODS-WFI
Zoom 1x
CDS - ESO - AstroGrid - ST-ECF - UMAN/Jodrell Bank - CNRSDR01 - VO-India - STScI
Field of view outlines are plotted automatically
Image metadata

Data Tree

- Scalable data access
  - Interoperability of large archives to small data sets
- Image metadata – FOV browsing
- Access to any image available by URL
  - Automatic generation of image data set description in XML
- Efficiently get to the relevant pixels

Catalogues

- Manipulation
- X-match
- Visualization

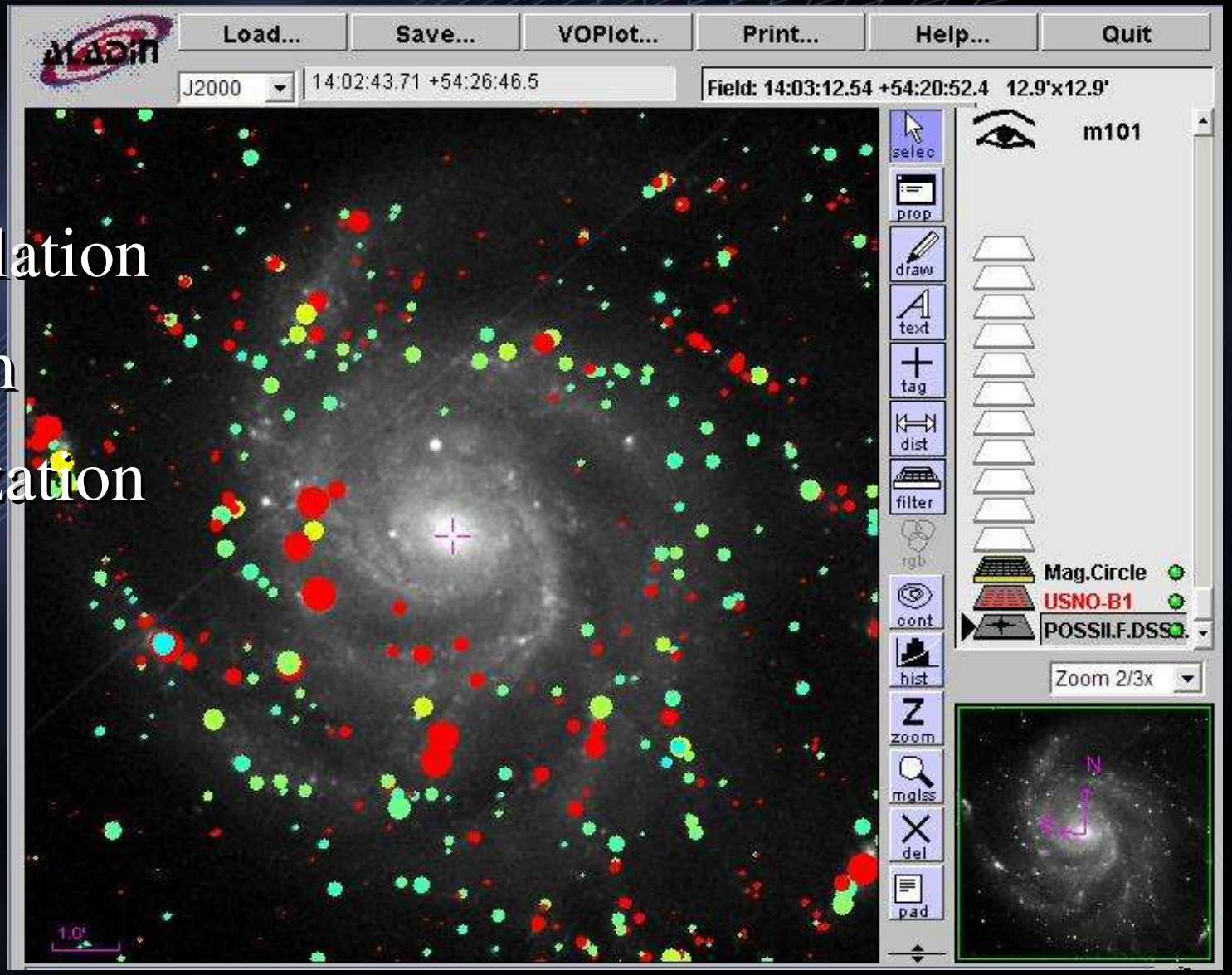


Image Cutout Tool

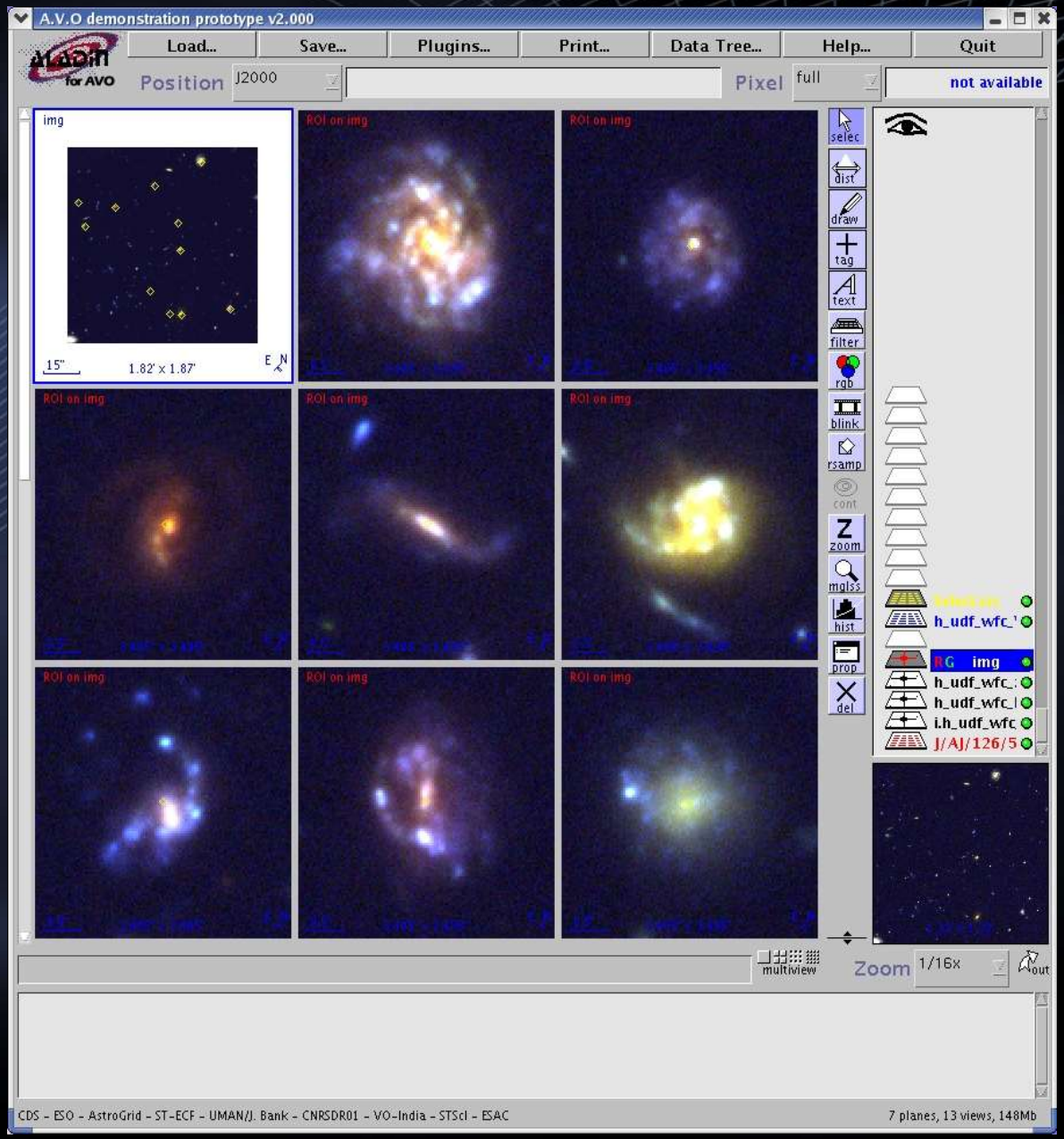
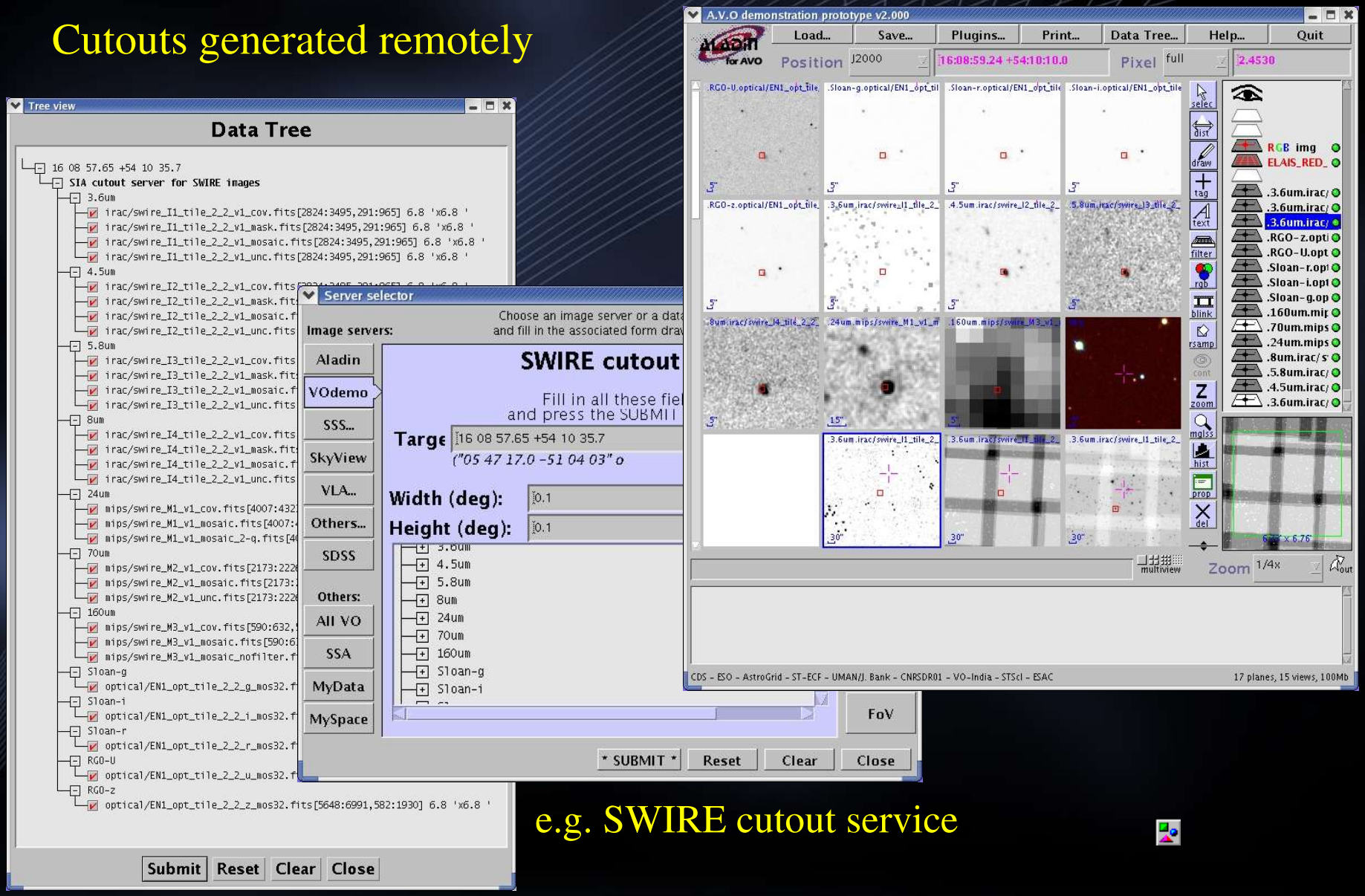
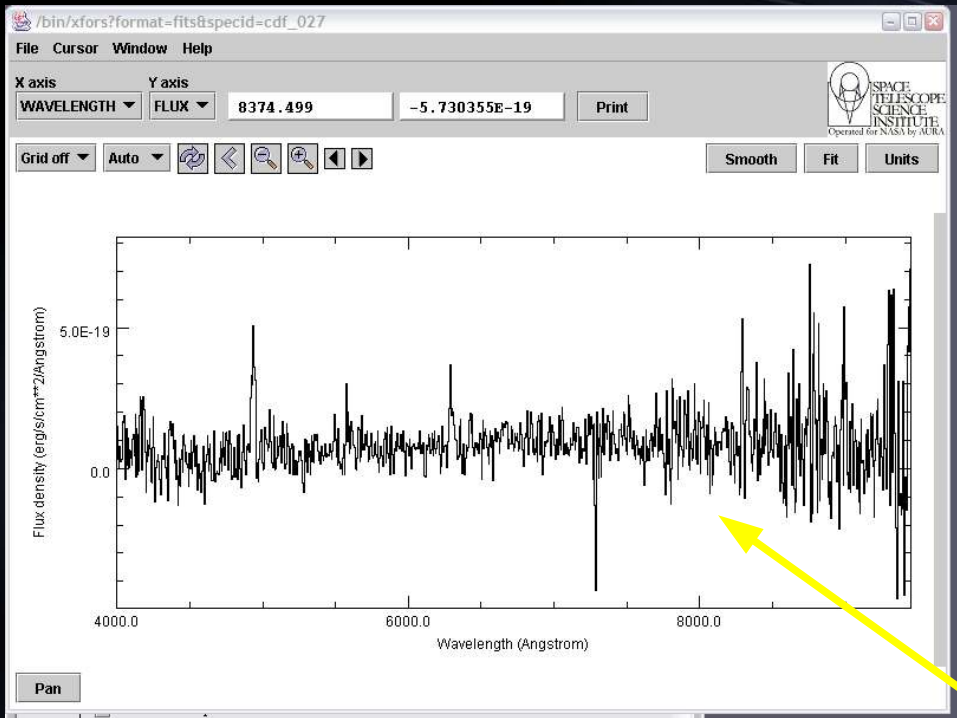


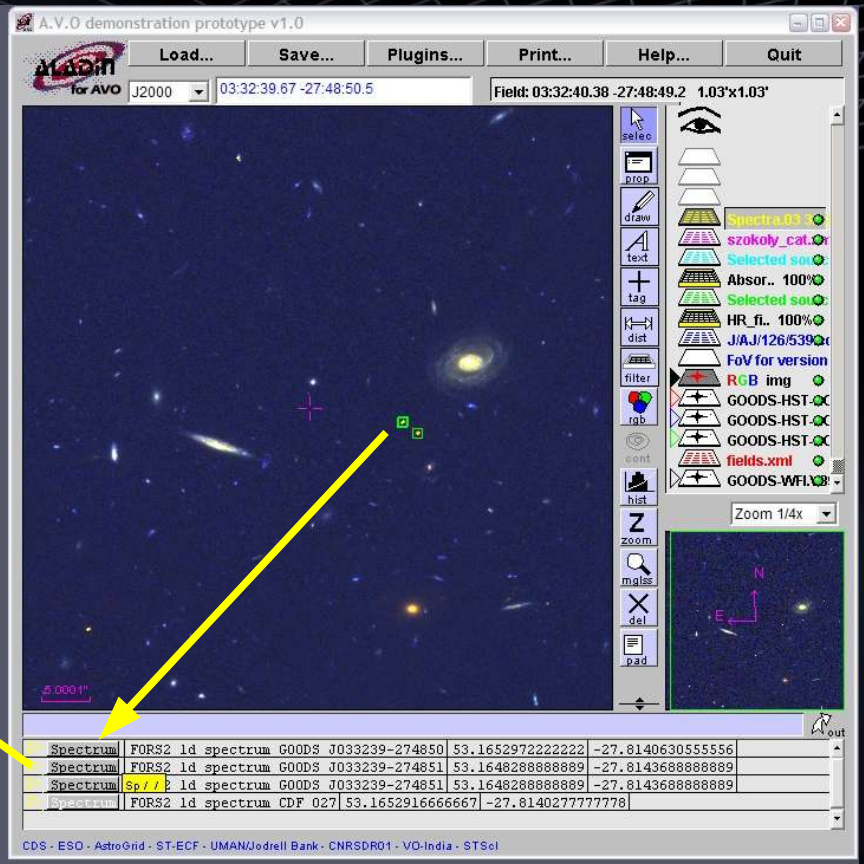
Image Cutout *Services*

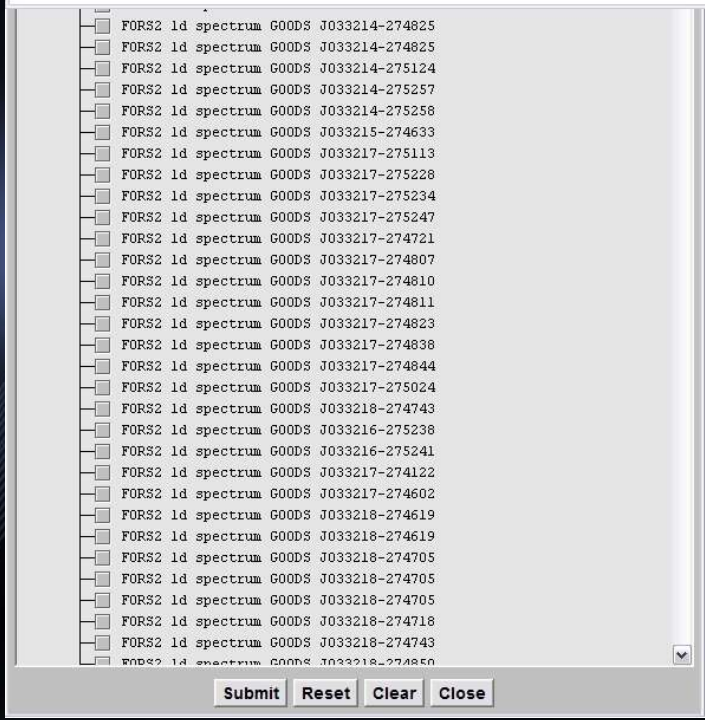
Cutouts generated remotely



e.g. SWIRE cutout service





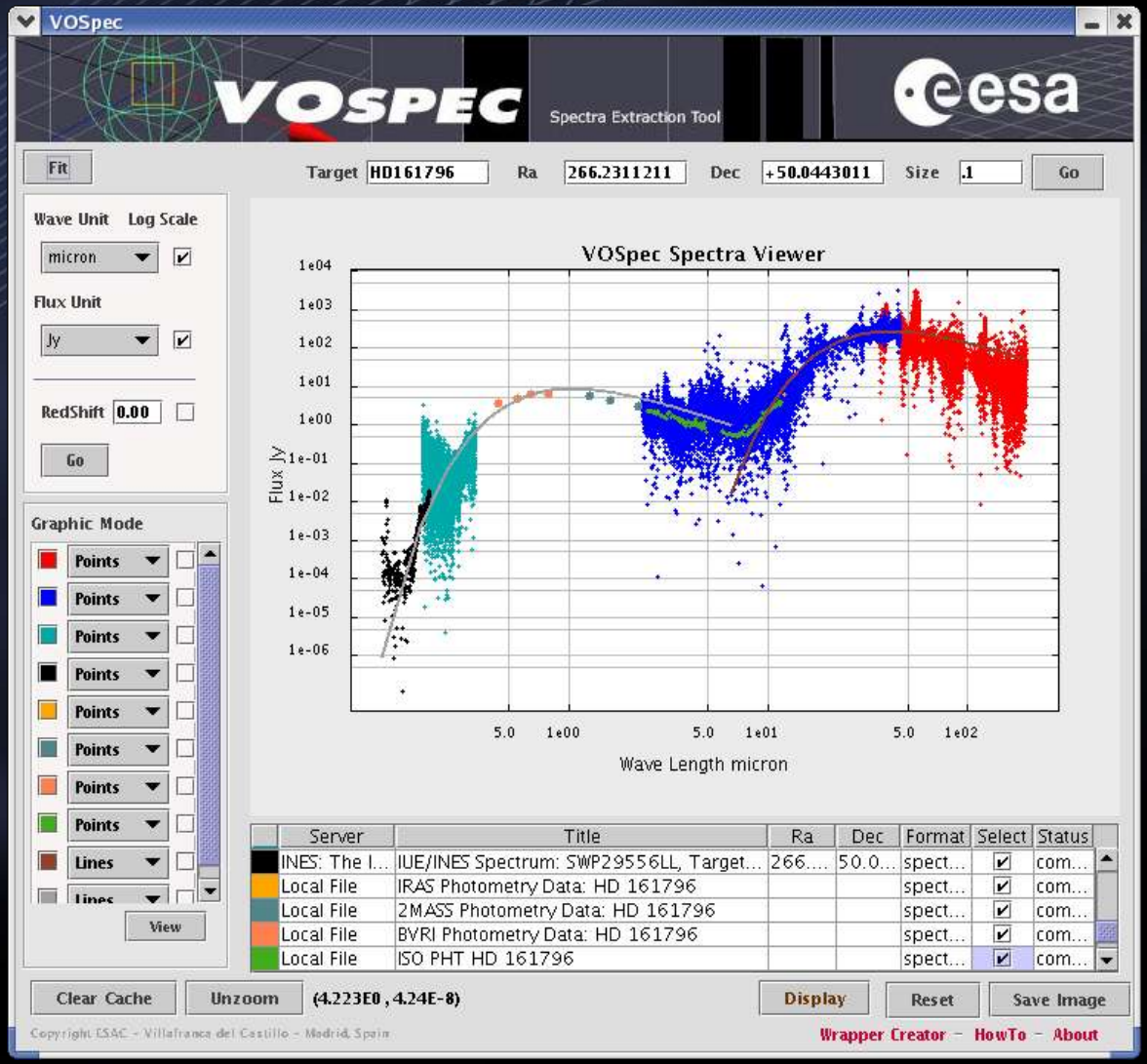


Simple Spectrum Access

Image / Spectrum / Catalog interoperability

Multi-archive spectra

- SSA servers
- Registry
- Unit interop.



AVO demo visualization – what did we learn?

- Simple metadata goes a long way
  - data tree, fov browsing, units
- Cutout and image servers provide useable access to large data sets
  - but still limited because downloading for vizualisation – need remote visualization
- Interactions between VO visualization tools is relatively easy (Java)

- SIA, SSA good start for data access
  - More detail about data needed
    - Raw, science ready etc.
- Scientific metadata needed to maintain data integrity

AVO Science Reference Mission

- Circumstellar disks: from pre-Main Sequence stars to stars harbouring planets
- Intermediate Velocity Clouds
- Which Star will go Supernova next?
- Initial Mass Function within 1kpc: Planetary to Stellar Masses
- Initial Mass Function for Massive Stars
- Contributions of Low and Intermediate Mass Stars to the ISM
- Galaxy Formation and Evolution from z=10 to 0.1
- Build-up of Supermassive Black Holes
- Formation and Evolution of Galaxy Clusters
- Correlation of CMB, radio/mm and optical/NIR Galaxy Surveys

Galaxy Formation and Evolution from z=10 to 0.1

- When did the 1st objects form?
- What are the progenitors of present day massive ellipticals?
- How many massive galaxies at z>1,2,4?
- How do SF and galaxy stellar mass densities evolve?

→ Required data

- Deep Multi-wave surveys (GOODS, COSMOS)
- HST+ACS bviz imaging
- SLOAN
- Optical spectroscopy
- MERLIN, GMRT, VLA, ATCA radio
- Chandra and XMM-Newton X-ray
- Spitzer mid-IR
- Future sub-mm
- GALEX UV imaging

"Only now, and only with through the VO, are the datasets large enough, and the tools mature enough that Galaxy Formation and Evolution can be examined in a meaningful way."

VO steps

- Extract sample from data
  - Perform Sextractor type photometry
    - Cross correlate with images, catalogues, spectra. *Crucial that output results are scientifically useable and reliable* Matching of PSF, consisitent photometric apertures, treatment of noise, and upper limits
      - Sanity checks like stellar colours
        - Output multi-band catalogue, and colour-colour diagrams
      - Visualize output colour-colour space
    - Photometric z from SEDs (Template SED libraries, extinction curves etc.)
    - Physical Parameters – L, E(B-V), SFR, M/L $\in$ stellar mass
  - Comparison with star formation scenarios and synthetic spectra
  - Morphological analysis
    - Stack images at same wavelength, or spectra at different redshifts
      - Build average spectra for specific object classes
        - Angular clustering analysis
  - Comparison with mock catalogues from theoretical simulations

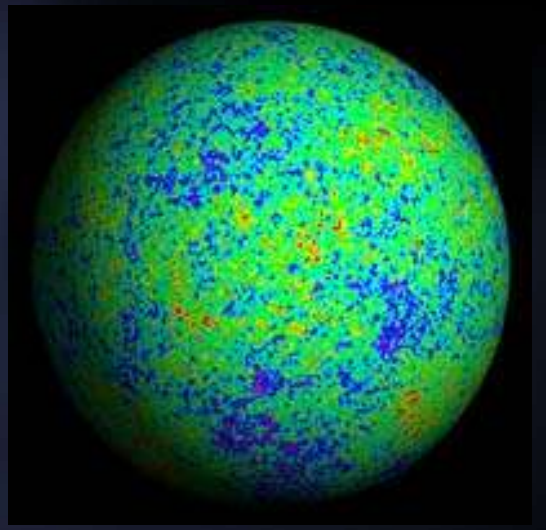
Visualization aspects

- Visualization of results at each step
  - Very wide range of data
- Non-local data – remote visualisation ?
- Colour-colour space “tool”

  “We strongly suggest to make colour-colour diagrams clickable on individual plotted objects or to have the possibility to mouse select regions of plots”
  - Sophisticated multi-d plotter for astronomy?

Correlation of CMB, radio/mm and optical//NIR Galaxy Surveys

- Integrated Sachs-Wolfe Effect
- *CMB fluctuations from passage through time varying gravitataional potential*
- Sunyaev-Zel'dovich Effect
- *Inverse compton scattering of photons by plasma in the hot intra-cluster medium*



- Required data
- WMAP
- Planck
- radio/IR surveys
- X-ray/optical cluster data

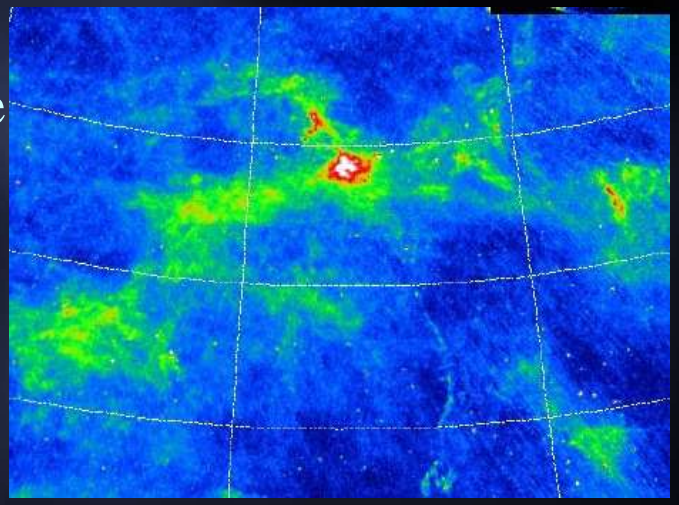
Study of full-sky maps from federated archives to disentagle various cosmological and astrophysical effects

Visualization aspects

- Visualization of all-sky maps
  - HEALPix spherical partition
- Visualization of multi- cluster data
- Deprojection algorithms to study morphology in survey data

Intermediate Velocity Clouds

- What is the origin of neutral gas clouds moving with unexpected velocities in the galaxy ?



- Required data
  - All sky far-IR surveys DIRBE
  - IAR, HIPASS 21cm
  - SHASSA H

- VO Steps

  Identify regions of excess HI or H
  To detect IR IVC, remove foreground using HI
  Check contamination by warm ISM
  Classify dust rich/poor IVCs
  Analyse spatial distribution

Visualization aspects

- All sky map comparisions at different wavelengths and resolutions
- Source extraction/segmentation for extended sources
- Spectral data cube manipulator

Common requirements

- Visual browsing of data and distributed information
- Visualizing heterogeneous data
  - Combining Multi-wavelength data taking into account different:
    - Units
    - coverage
    - resoultions/PSF, observing technique

Common requirements (cont.)

- Multi-wave cutouts of individual sources
- Generate and visualize SEDs from image, and spectral and catalogue data
  - Taking into account different
    - Beams/apertures (extended sources)
    - Backgrounds
    - Photometric systems
- Time axis:
  - Light-curves
  - Multi-epoch imaging

Common requirements (cont.)

- Compare observations with models
  - Virtual observations of models
  - Projection of models to observed parameter space
  - Spectral fitting/classification
  - Colour-colour visualization Tool
  - Astronomy functionality alongside visualization
    - Reproject data, correct for extinction, calulate luminosities etc.
    - Visualization requirements ∈ Analysis requirements

Implications of Visualization requirements

- Robustness of
  - Astrometry across all data types
  - data count/flux conservation(?)
  - Error propagation
    - And all the scientific metadata that is required for that, not to mention the scientific computing involved