Archival Science with the ESAC Science Archives and Virtual Observatory

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OUTLINE

- Introduction to the ESAC Science Archives
- What UV data is available in the Astronomical ESAC Science Archives
- Introduction to the Virtual Observatory (VO)
- What UV data is available in the VO
- How to access all this data
- Archival Science and a few examples
- Summary

Introduction: The European Space Astronomy Centre (ESAC)

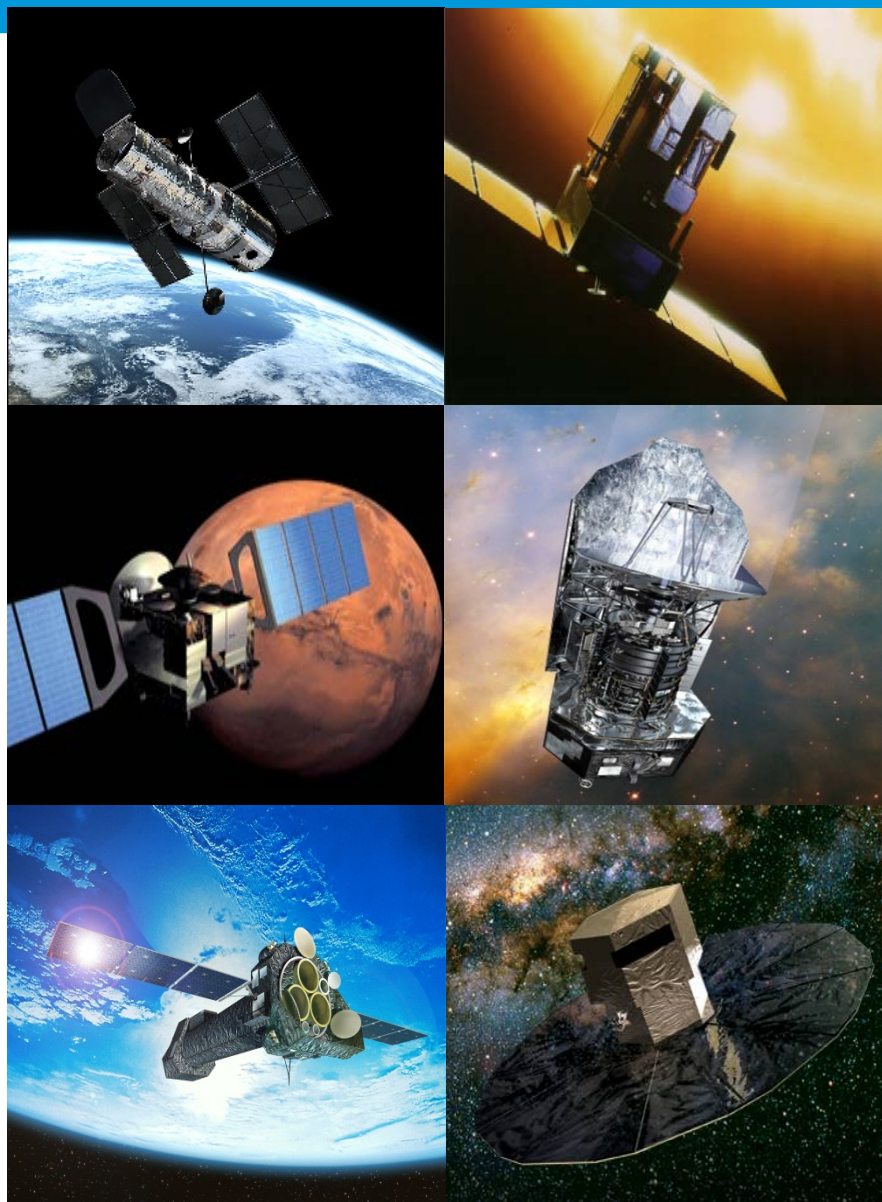
- ESAC is the ESA centre that hosts the Science Operations Centre (SOC) for ESA's astronomy, heliospheric and planetary missions
- Other Activities:
  - Science Archives
  - Tracking of satellites

- Located in Villanueva de la Cañada, close to Madrid (Spain).
- Since June 2009, ESAC is formally a new ESA Establishment.

Introduction: The ESAC Science Archives

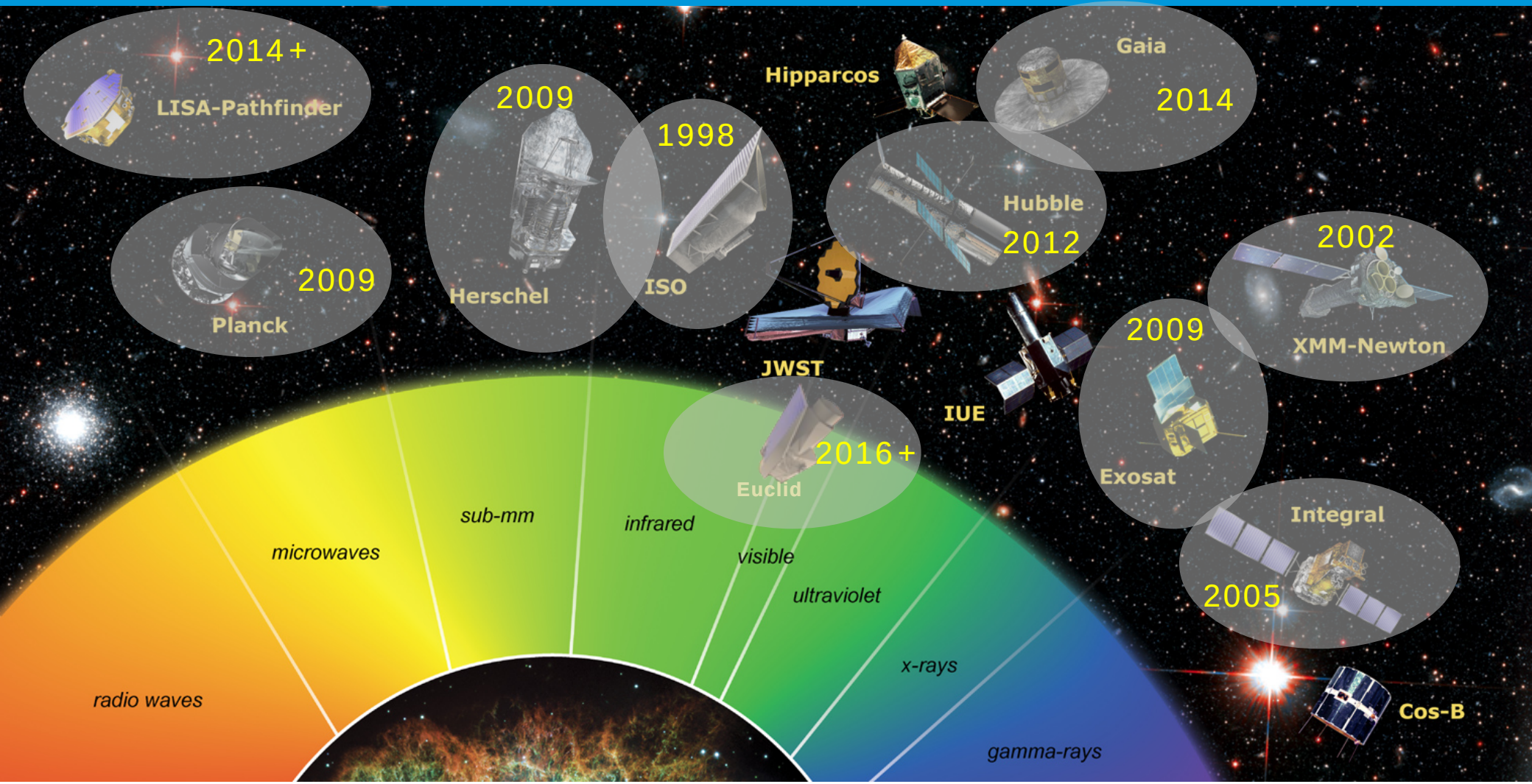
http://archives.esac.esa.int

- Different missions:
  - Astronomy, Planetary, Solar System, …
- Different types of data:
  - Raw data, calibrated processed data, high level data products, …
- Different Users:
  - Scientific Community (public access)
  - PI team and observers (controlled access)
  - Science Operations Team (privileged access)
- Common Architecture and Look and Feel:
  - Better corporate image for ESA



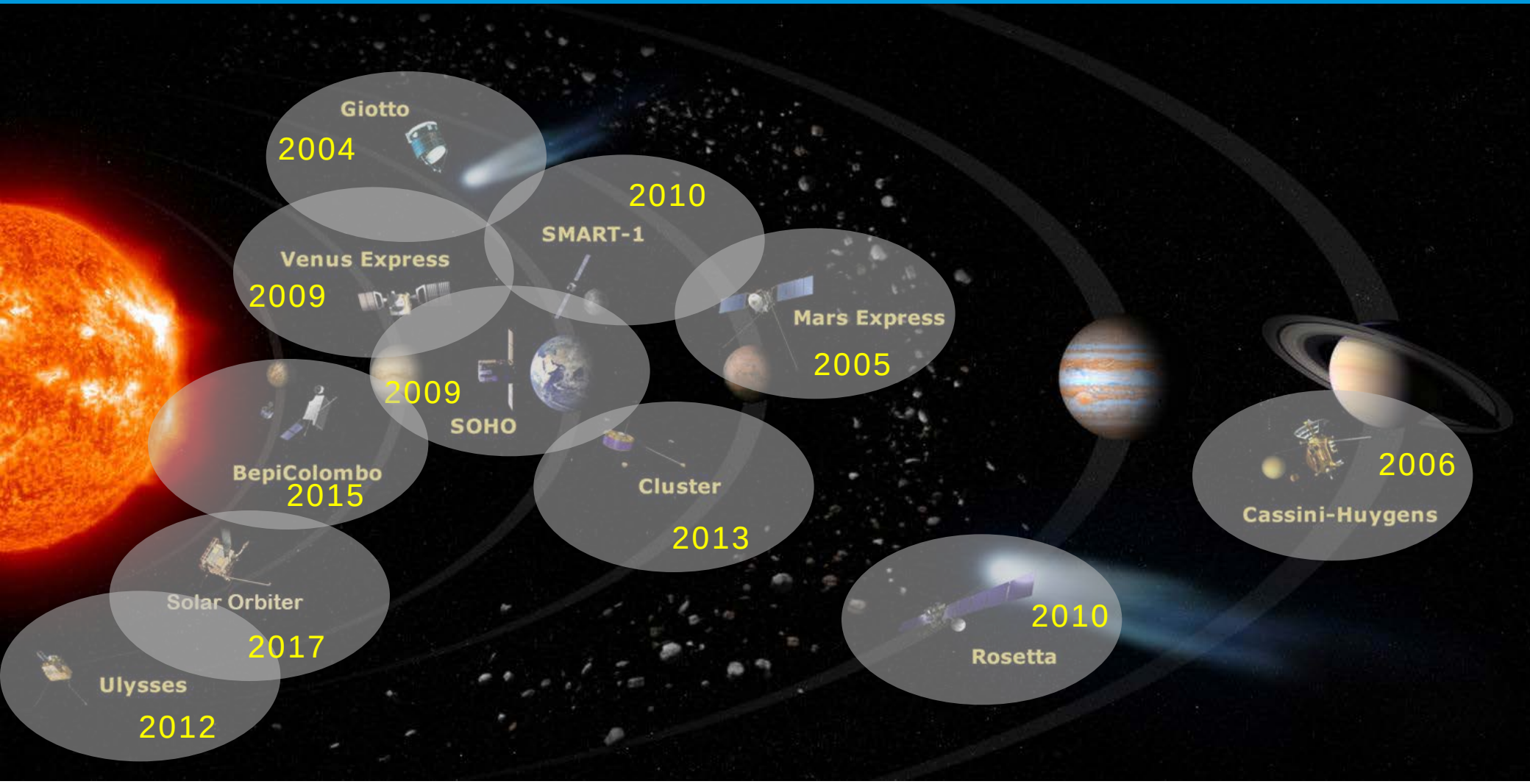
ESAC Science Archives – Astronomy

http://archives.esac.esa.int



ESAC Science Archives – Planetary & Solar System

http://archives.esac.esa.int



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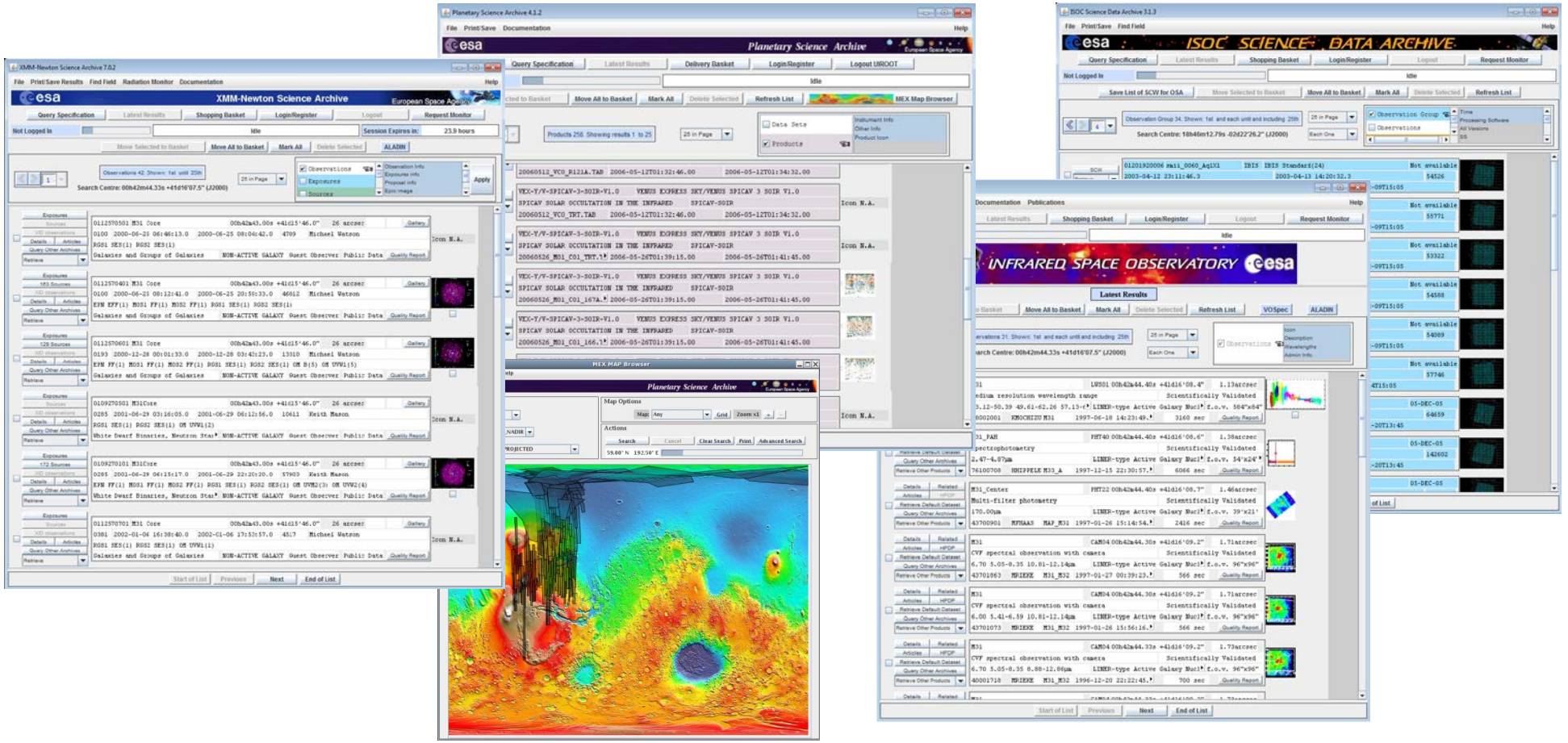
- Archives have gone through 3 generations of updates:
  - 1st Gen (1998): Small apps (Java applets; Web couldn't support user reqs).



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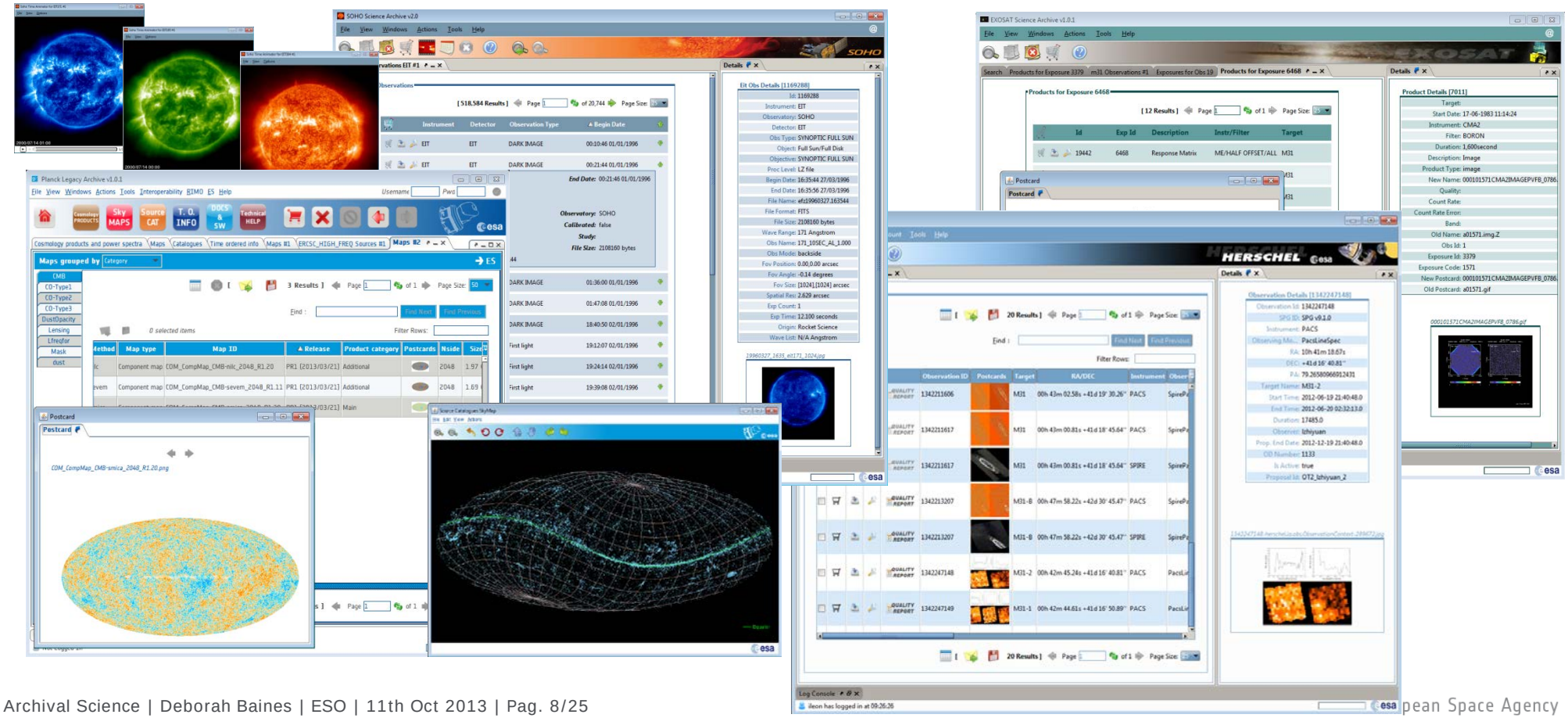

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  - 1st Gen (1998): Small apps (Java applets; Web couldn't support user reqs).
  - 2nd Gen (2006): Desktop application (Java webstart; User friendly UI).
  - 3rd Gen (2013): Web-based (Google Web Toolkit; User friendly; tablets & mobiles).
  - An ESA Multi-Mission Archive interface is also in development

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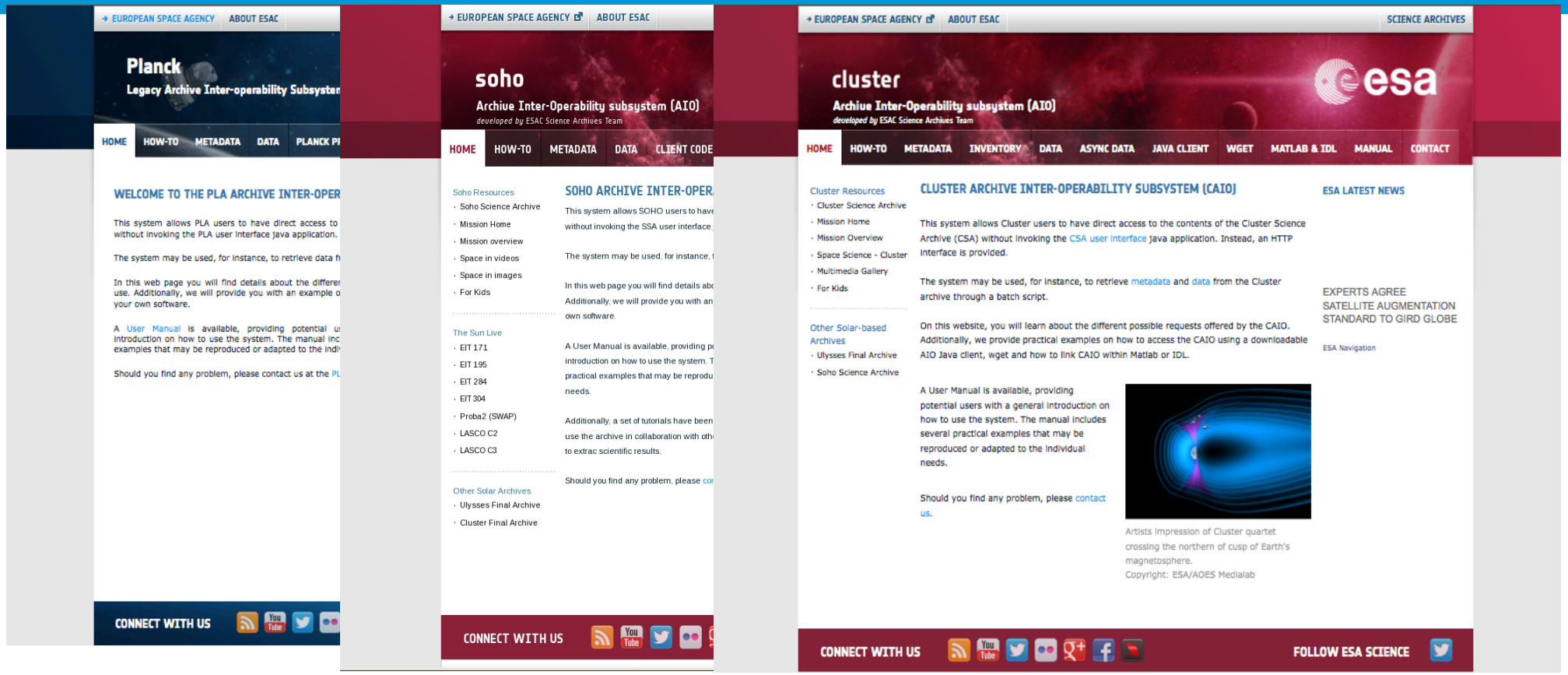
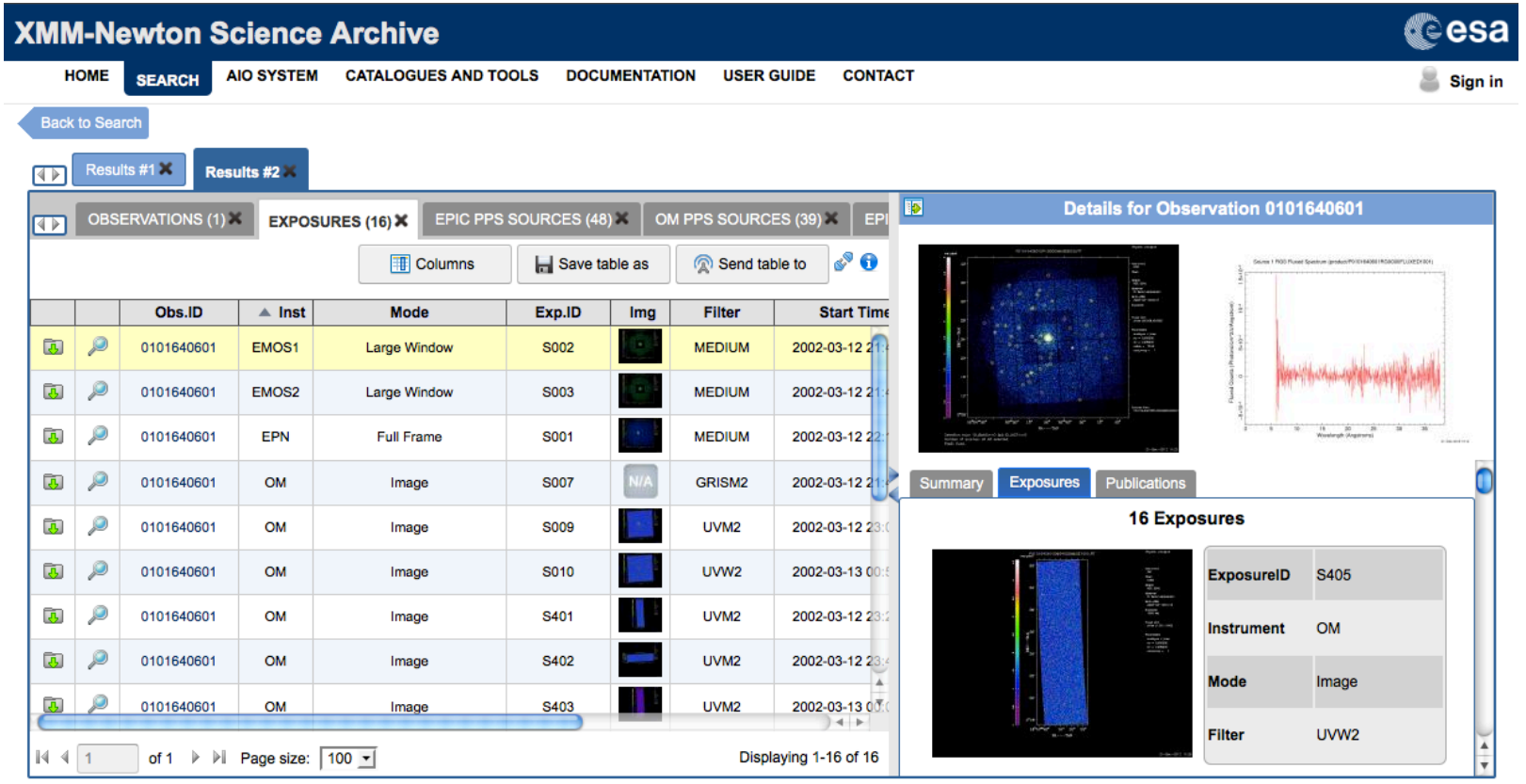


- Archives can also be directly accessed without launching the User Interface: Archive Inter-Operability (AIO). Complementary way to access content via http access, and batch scripts can be run.

Ultraviolet Data in the ESAC Astronomical Science Archives

XMM-Newton Science Archive:

- Optical/UV Monitor telescope (170 – 650 nm, 6 broad band filters, 3 in UV)
- OM Source catalogue.



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Ultraviolet Data in the ESAC Astronomical Science Archives

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- OM Source catalogue.

ESA Hubble Science Archive:

- Moved to ESAC in June 2012 due to the closure of the Space Telescope European Coordinating Facility (ST-ECF), where the archive was previously located.
- 9 instruments in UV range:
  - **Active:** ACS (Advanced Camera for Surveys, ~120 to 1000 nm)
  - COS (Cosmic Origins Spectrograph, ~115 to 320 nm)
  - STIS (Space Telescope Imaging Spectrograph, ~115 to 1000 nm)
  - WFC3 (Wide Field Camera 3, ~200 to 1700 nm)
  - **Legacy**: FOC (Faint Object Camera, ~120 to 550 nm)
  - FOS (Faint Object Spectrograph, ~115 to 850 nm)
  - GHRS (Goddard High Resolution Spectrograph, ~105 to 300 nm)
  - WFPC & WFPC2 (Wide Field Planetary Cameras 1 & 2, ~115 to 1000 nm)

ESAC Astronomical Science Archives Data

Other wavelengths:

- **Planck Legacy Archive** (Microwaves, 30 to 857 GHz; Includes Sky maps, catalogues, cosmology products)
- **Herschel Science Archive** (Far-IR & Sub-mm, 55 to 672 um; Includes images, photometry, spectra and catalogues)
- **ISO Data Archive** (IR, 2.5 to 240 um; Includes images, photometry, spectra and catalogues)
- **ESA Hubble Science Archive** (UV, Optical and near-IR, 105 to 2500 nm; Includes images, spectra, astrometric and photometric data)
- **XMM-Newton Science Archive** (X-ray, 0.15 to 15 keV; Includes images, spectra, light curves and catalogues)
- **EXOSAT Science Archive** (X-ray, 0.05 to 50 keV; Includes images, spectra, light curves and Slew Survey catalogue)
- **INTEGRAL Science Data Archive** (Gamma-ray & X-ray, 15 keV to 10 MeV; Includes images, spectra, light curves and catalogues. Source monitoring in the X-ray, 3-35 keV, and optical V-band, 550 nm).

The Virtual Observatory
http://www.ivoa.net

- **The Virtual Observatory (VO) is the vision that astronomical datasets and other resources should work as a seamless whole.**
  - Many projects and data centres worldwide are working towards this goal.
  - The VO allows astronomers to interrogate multiple data centres in a seamless and transparent way and to utilise astronomical data.
  - Provides analysis and visualization tools within that system.
  - Provides access to science ready data.
  - Gives data centres a standard framework for publishing and delivering services using their data.

- Requires everyone to speak the same language:

  VO standards and protocols defined and adopted within the IVOA (International Virtual Observatory Alliance)

- **Ultimate Goal: Aid the work of astronomers and foster new science**

Ultraviolet Data in the VO

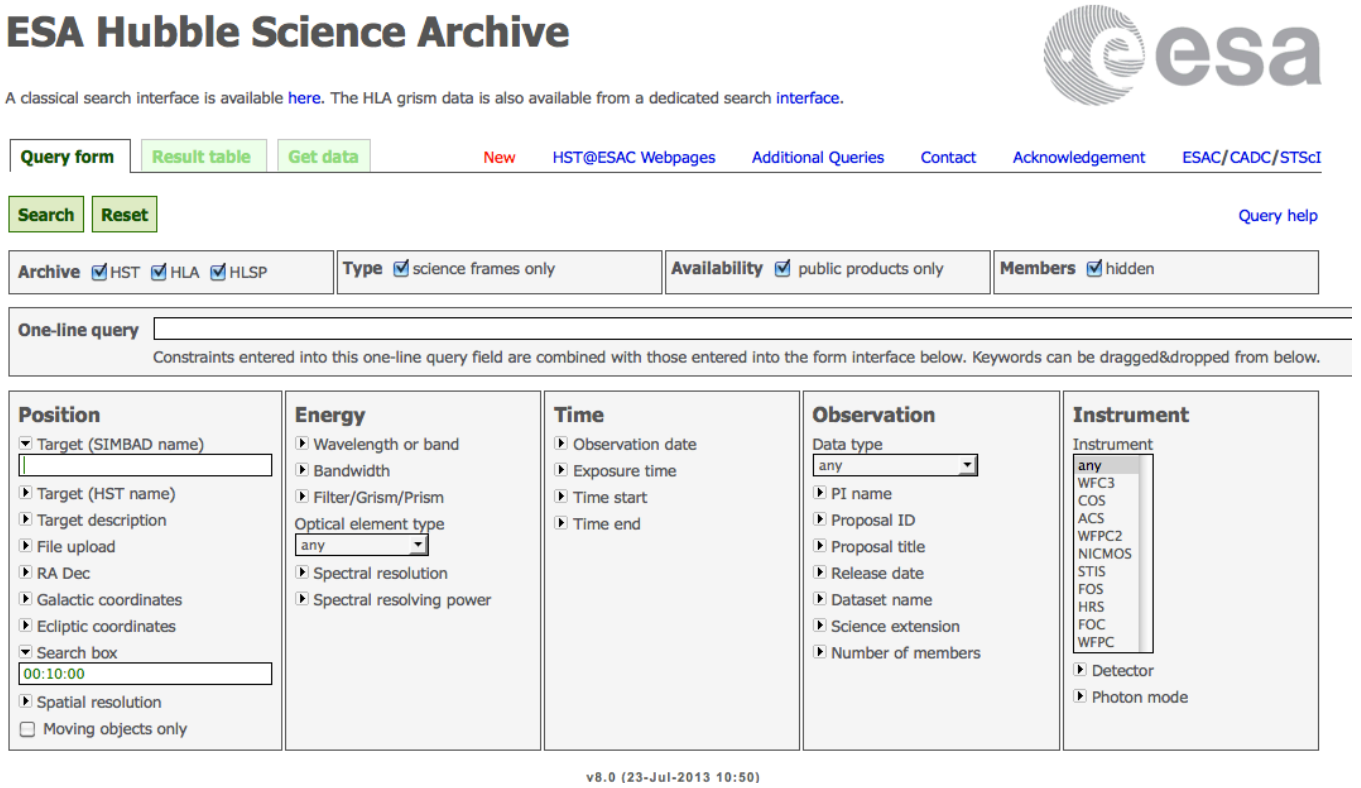
- **Images**:
  - Extreme Ultraviolet Explorer (Heasarc)
  - GALEX (STScI, Heasarc & MAST)
  - HST (MAST & ST-ECF -> ESAC)
  - Ultraviolet Imaging Telescope (UIT) on ASTRO-1 mission (MAST)
  - XMM-Newton OM (ESAC & MAST) …… (~100 services covering all wavelengths)
- **Spectra**:
  - Extreme Ultraviolet Explorer Merged Spectra (STScI)
  - Far Ultraviolet Spectroscopic Explorer (STScI & Obs Paris)
  - Galaxy Evolution Explorer (STScI)
  - HST STIS, FOS & GHRS (STScI & ST-ECF -> ESAC)
  - Hopkins Ultraviolet Telescope (STScI)
  - IUE, highly processed, newly extracted (INES) (STScI & CAB)
  - ESO Spectrum service: incs UVES (ESO) …… (~55 services covering all λs).
- **Catalogues**:
  - Source catalogues: GALEX-DR5 AIS & MIS, EUVE, UIT, XMMOMSUSS, Hubble Deep Field …
  - Observation logs: HST, IUE, FUSE, HUT, EUVE, XMM-Newton …
  - Over 230 covering all wavelengths (not including VizieR). Including VizieR -> 11500+ !

How to access all this data

In the ESAC Science Archives:

http://archives.esac.esa.int

- XSA: http://archives.esac.esa.int/xsa
- HST: http://archives.esac.esa.int/hst



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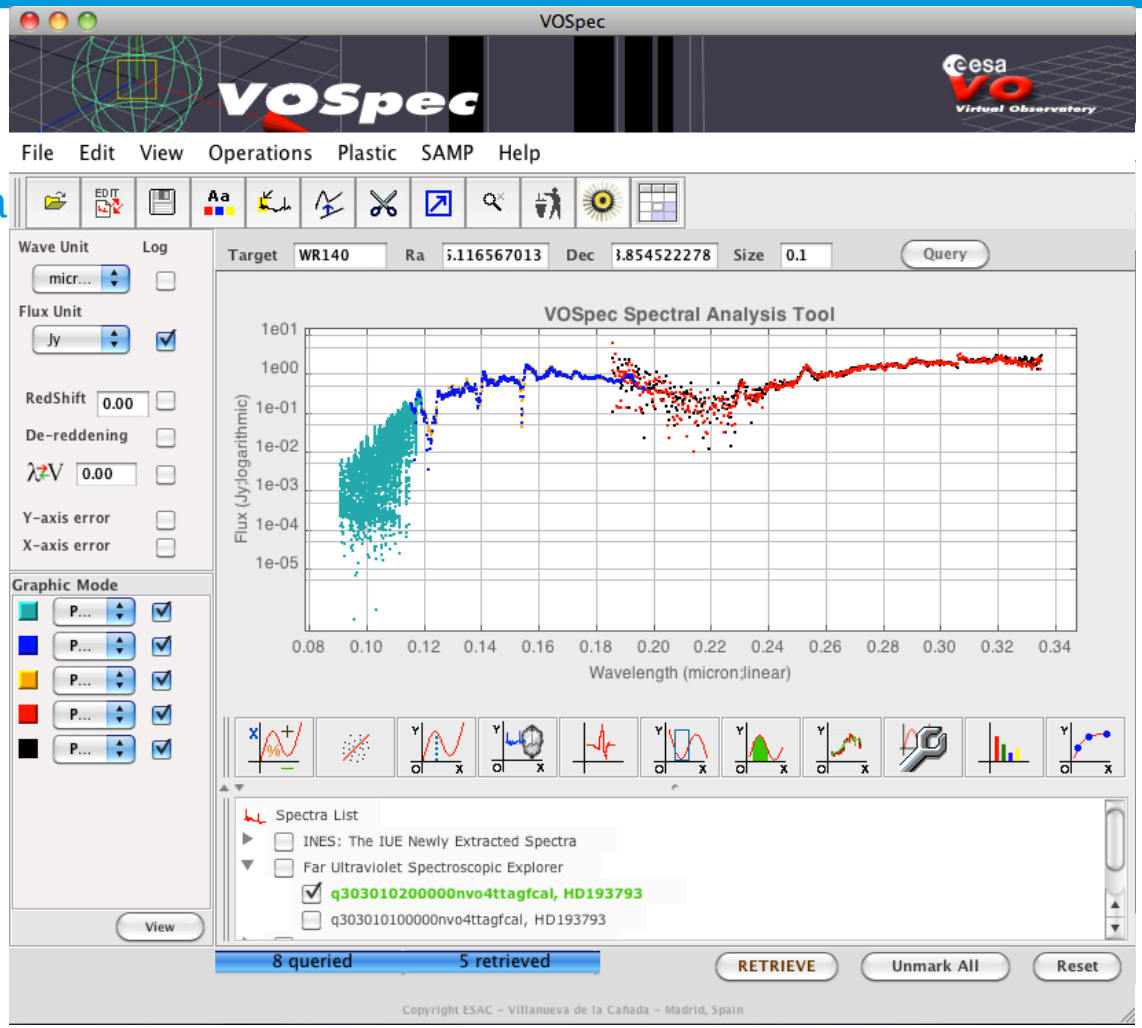
- HST: http://archives.esac.esa.int/hst

In the VO:

- Aladin – interactive software sky atlas to visualise images and superimpose catalogues.
- TOPCAT – interactive graphical viewer and editor for tabular data.
- VOSpec – Multi-wavelength spectral analysis tool.
- All other tools: e.g. IRAF etc.
see IVOA and Euro-VO web pages.



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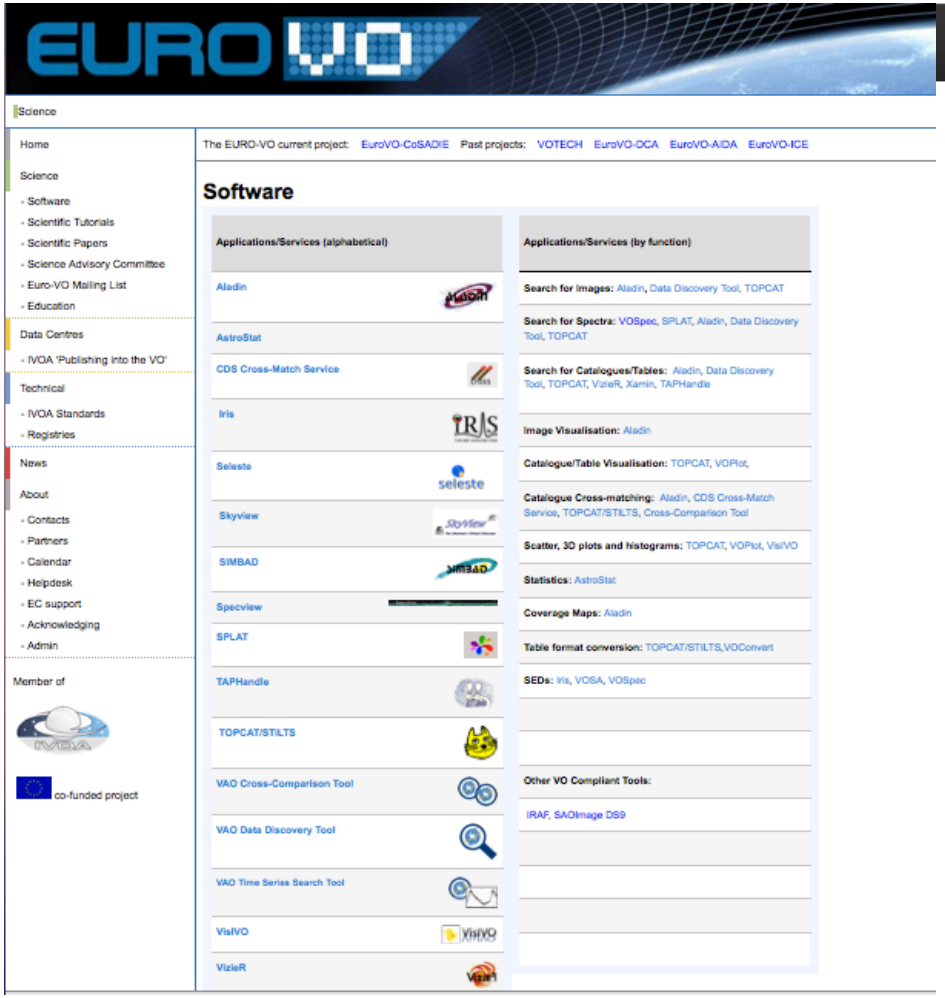
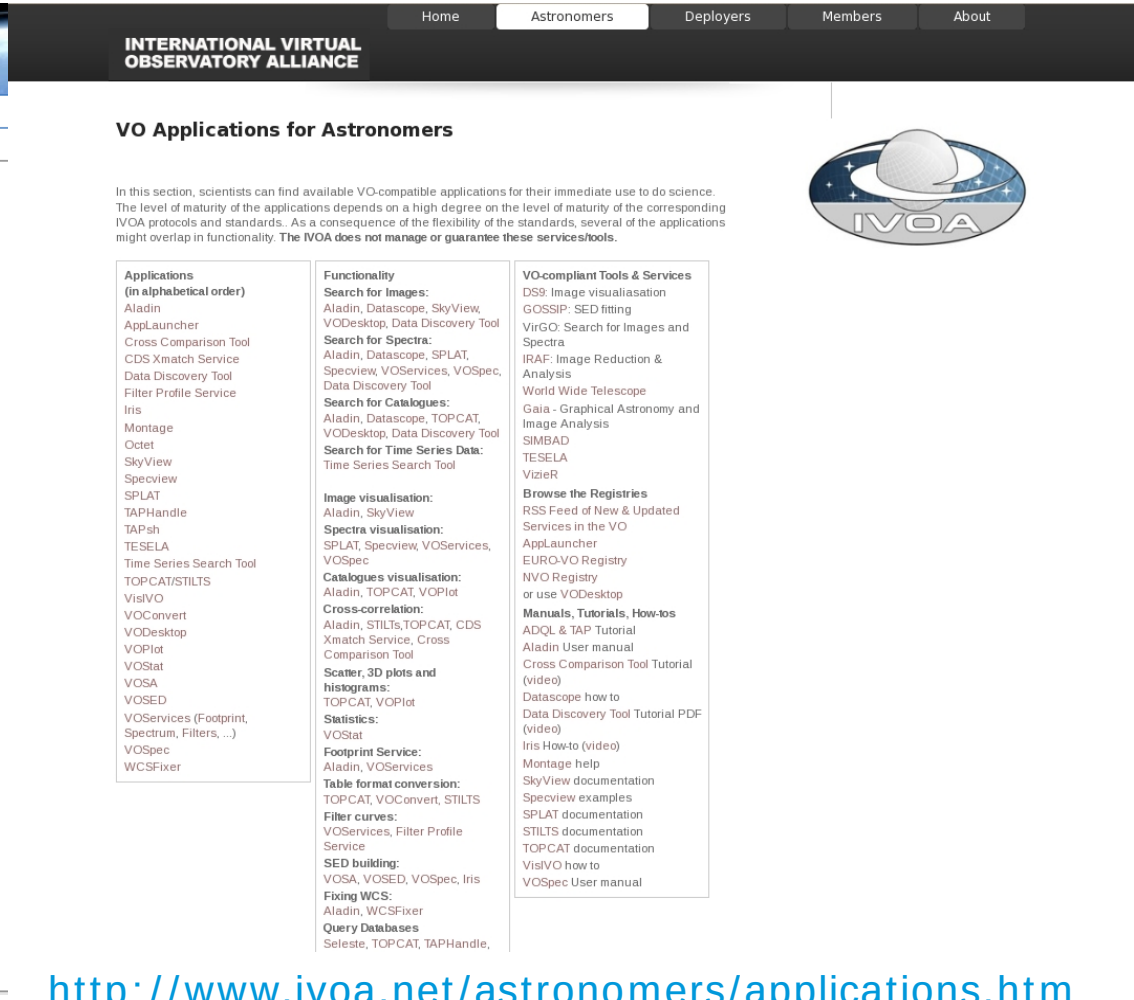


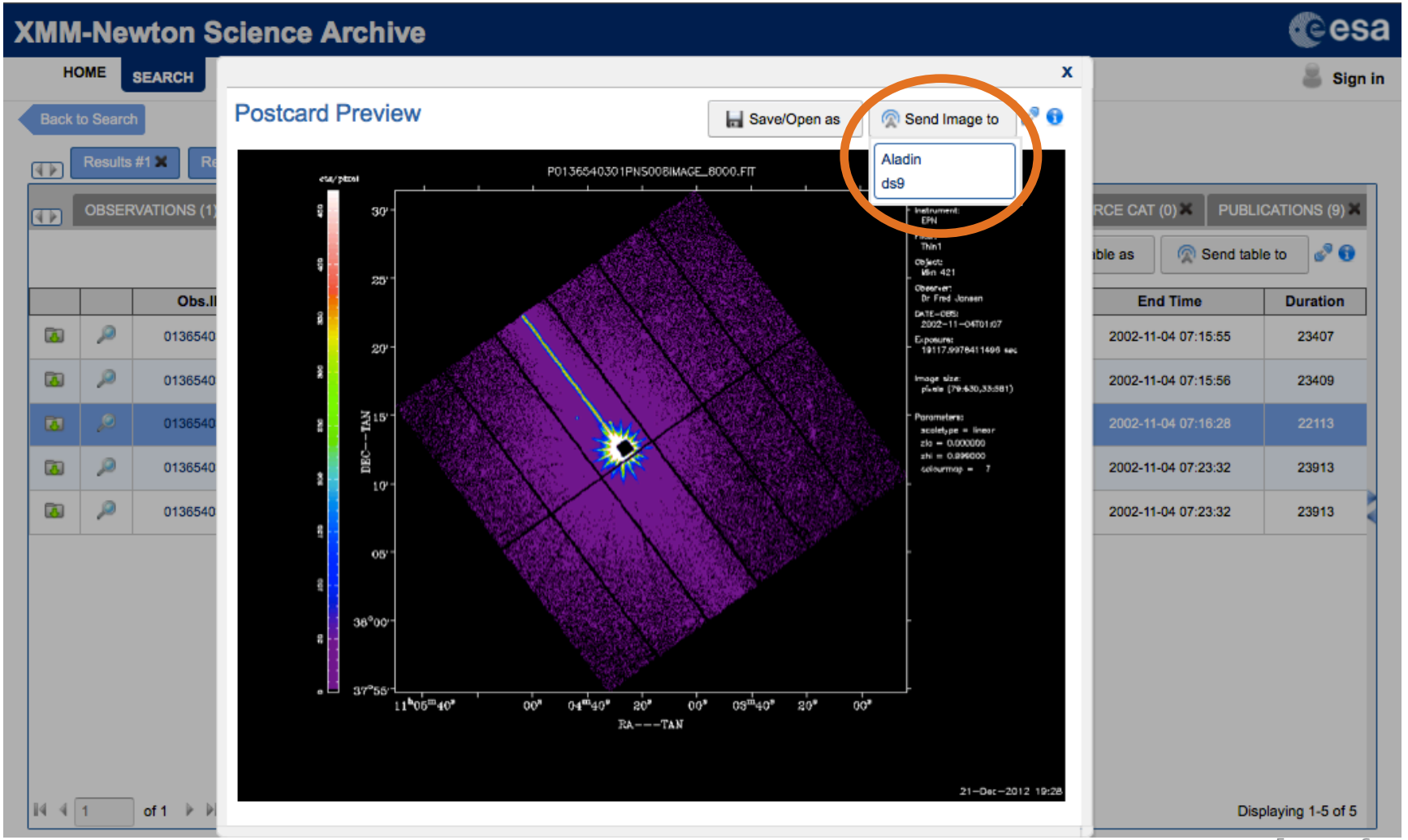
http://www.euro-vo.org/?q=science/software



http://www.ivoa.net/astronomers/applications.htm

Interoperable Tools

- Simple Application Messaging Protocol (SAMP):



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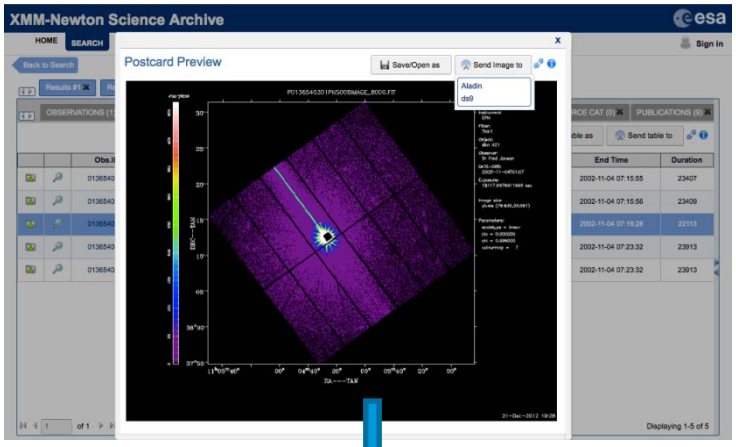
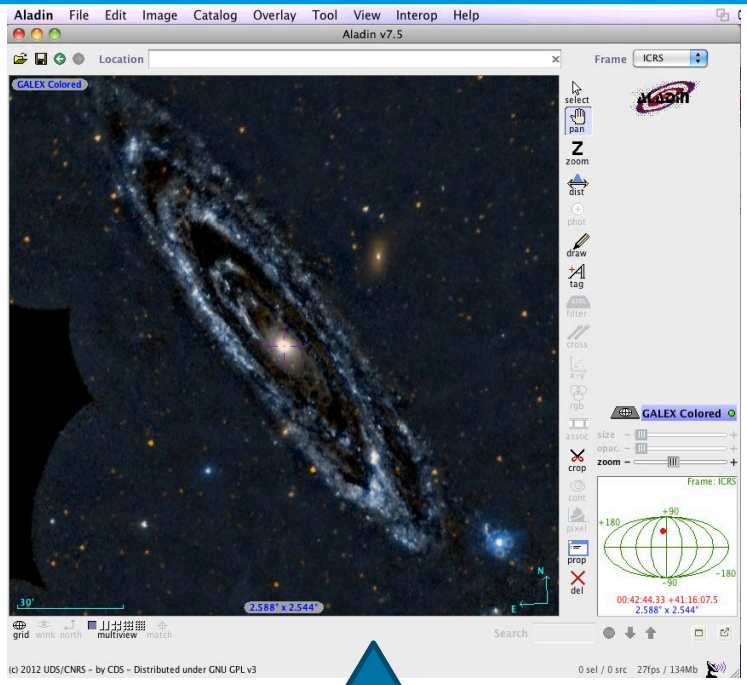
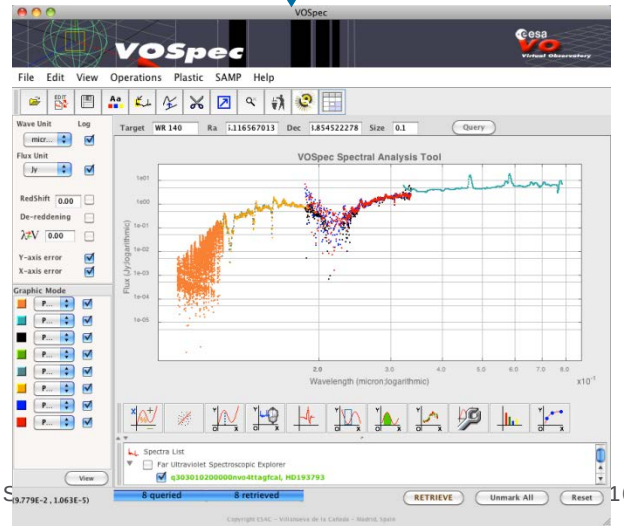
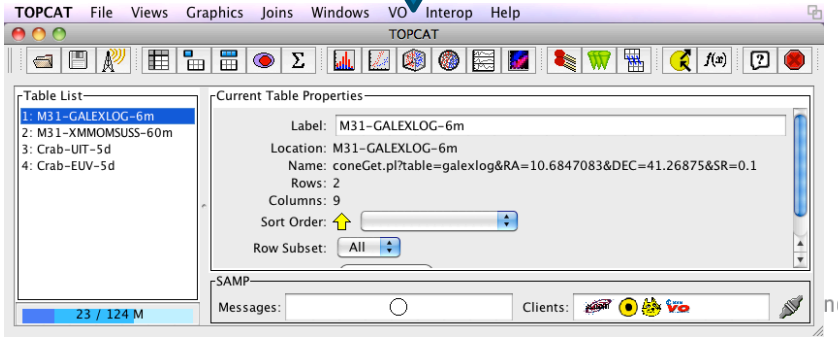
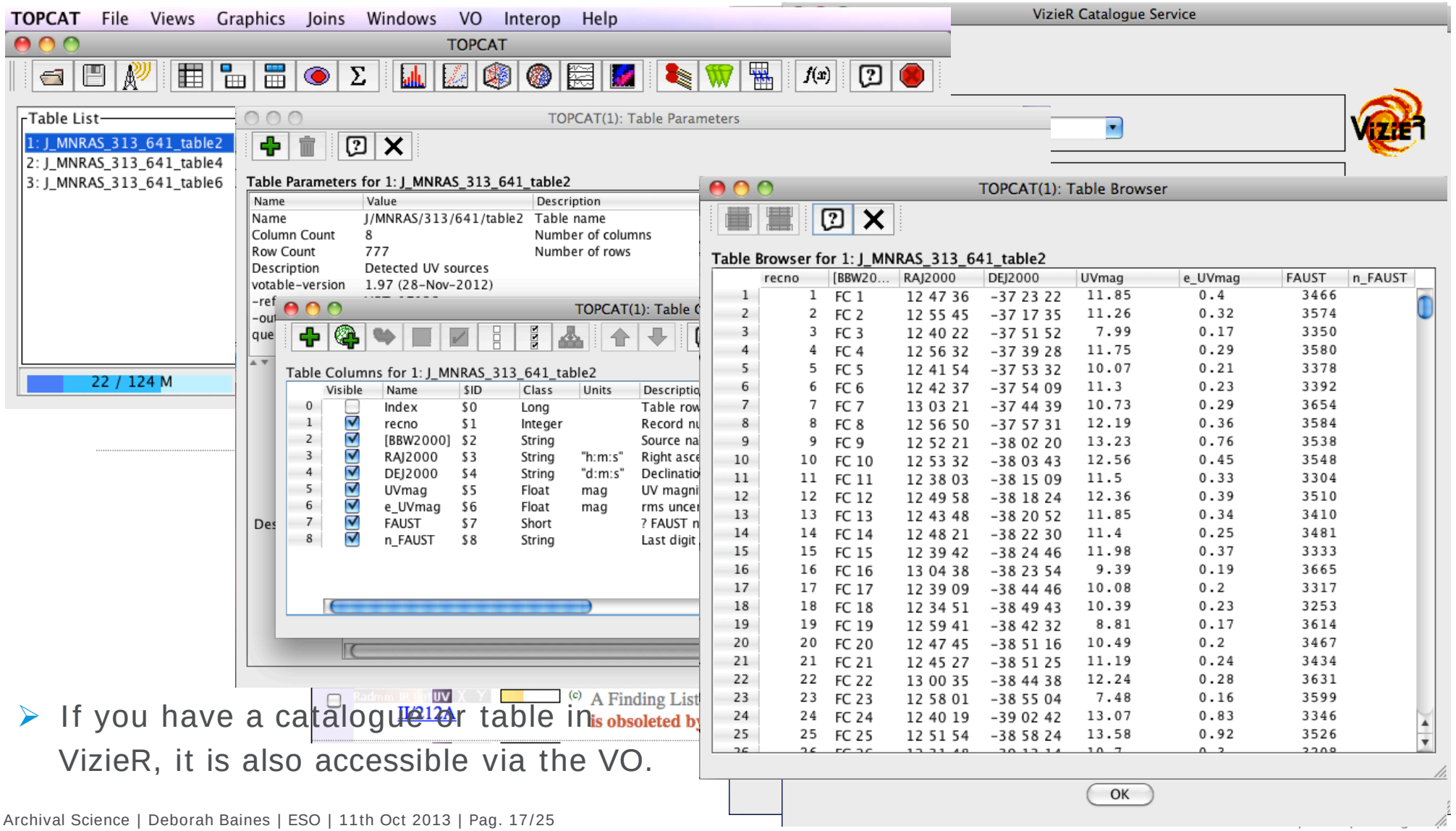








VizieR catalogues in the VO



- If you have a catalogue or table in VizieR, it is also accessible via the VO.

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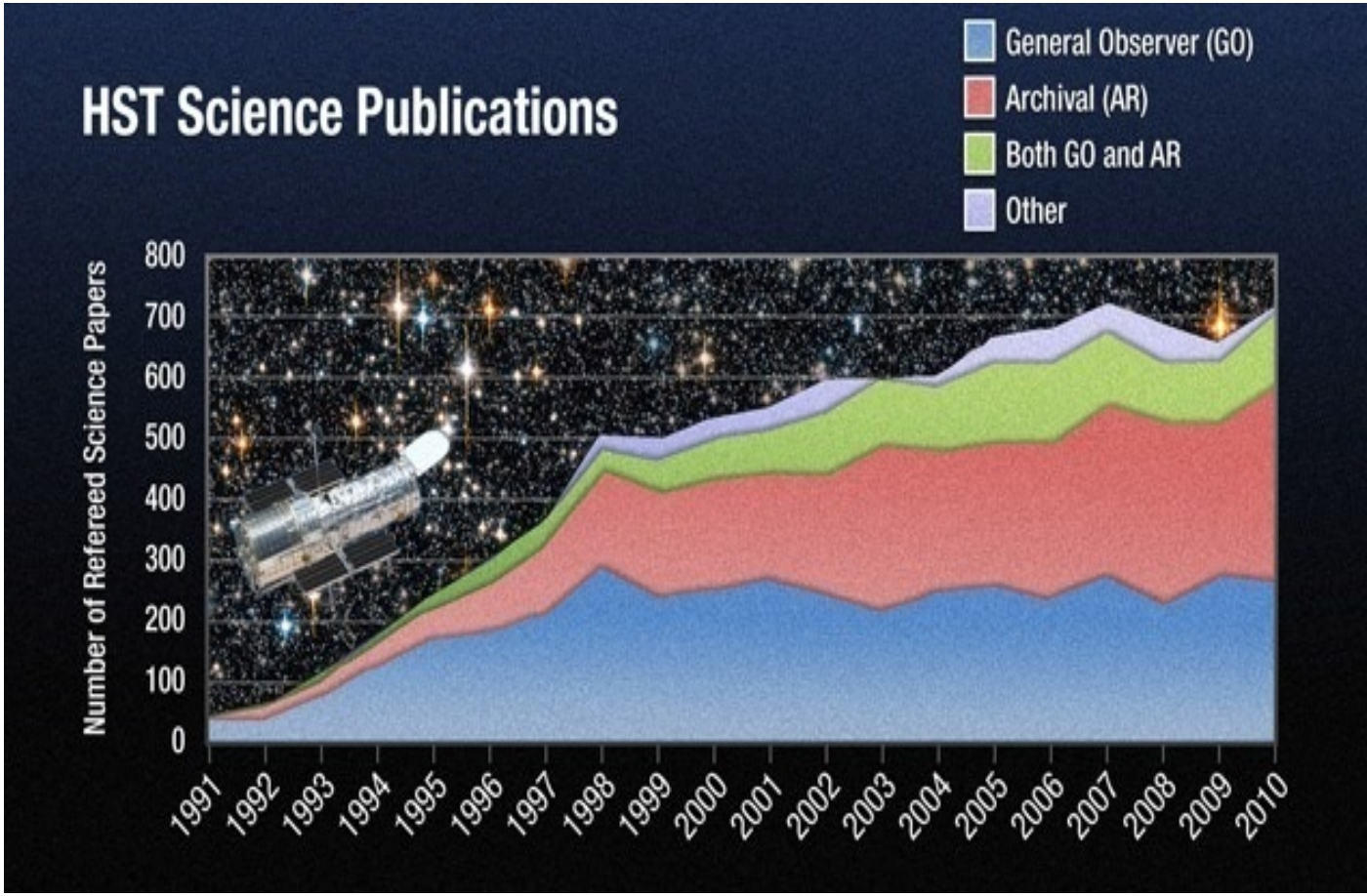
Archival Science

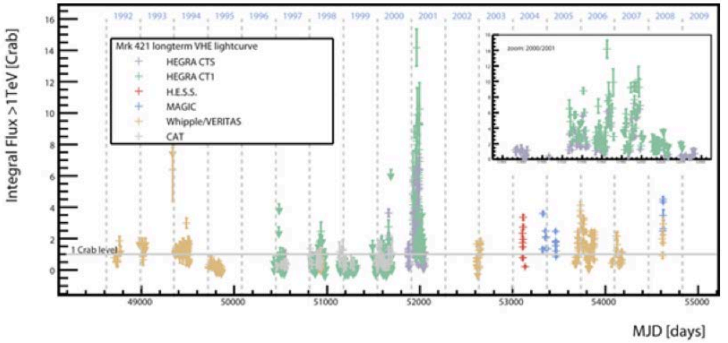
- Image from the HST 10,000 science publications press release in June 2011, showing the number of archival papers (AR) increasing whilst General Observer (GO) papers are around the same number from 1997 to 2010:

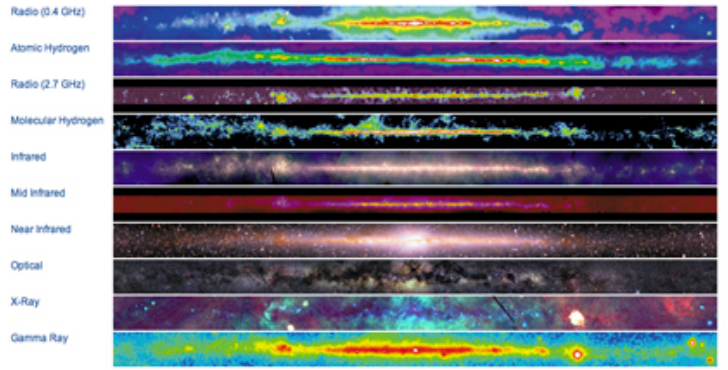
- One reason for the surge -> the telescope's longevity. Hubble has amassed almost 23 years of data, and astronomers are finding new uses for the data. Projects not imagined when observations were taken.



Archival Science

- What kind of science can you do with archival data that you can't, for example, with a short-term observing program?
  - Long-term variability of objects (XMM-Newton science data from 2000 to present, HST science data from 1990 to present, …).
  - Statistical and correlative studies: obtain data on a large sample of the same types of sources.
  - Multi-wavelength studies using archival data from a number of missions, telescopes and catalogues.
  - Management of large archives for the discovery of rare objects (particularly a VO example).
  - Citizen science: e.g. Galaxy Zoo using SDSS images and Hubble Space telescope images (from the CANDELS survey) to classify galaxies.
  - …

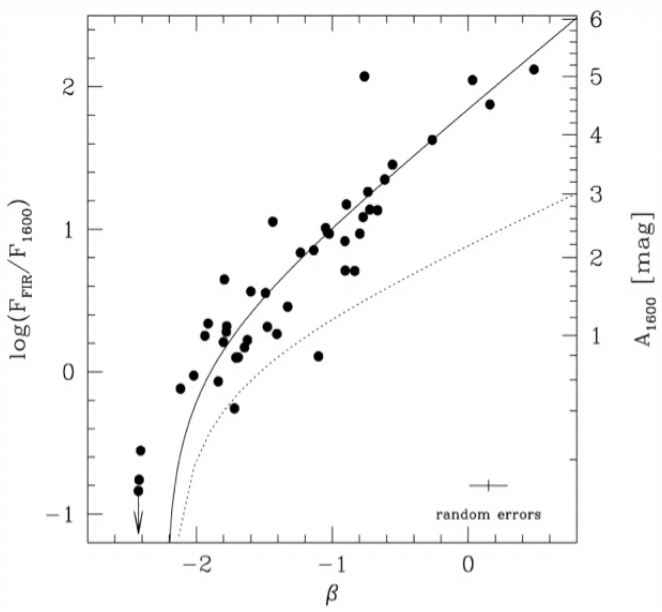




Archival Science Examples (HST)

Dust Absorption and the Ultraviolet Luminosity Density at z≈3 as Calibrated by Local Starburst Galaxies **Meurer, G. R., Heckman, T. M. & Calzetti, D. (1999) ApJ, 521, 64**

- Highly cited HST Archival science paper (over 490).
- Uses archival data from HST (UV fluxes), IUE (UV fluxes) and IRAS (FIR fluxes).
- Paper refines a technique to measure the absorption-corrected UV luminosity of starburst galaxies using rest-frame UV quantities alone and apply it to Lyman-limit U dropouts at z≈3 found in the Hubble Deep Field.
- Method is based on an observed correlation between the ratio of far-IR (FIR) to UV fluxes with spectral slope β (a UV colour).
- A fit to this relation allows the UV flux absorbed by dust and reprocessed to the FIR to be calculated, and the dust-free UV luminosity to be determined.
- Summary: demonstrate the close correspondence between local starbursts and high-z Lyman-limit systems, and that there may be a mass-metallicity relationship out to z≈3.

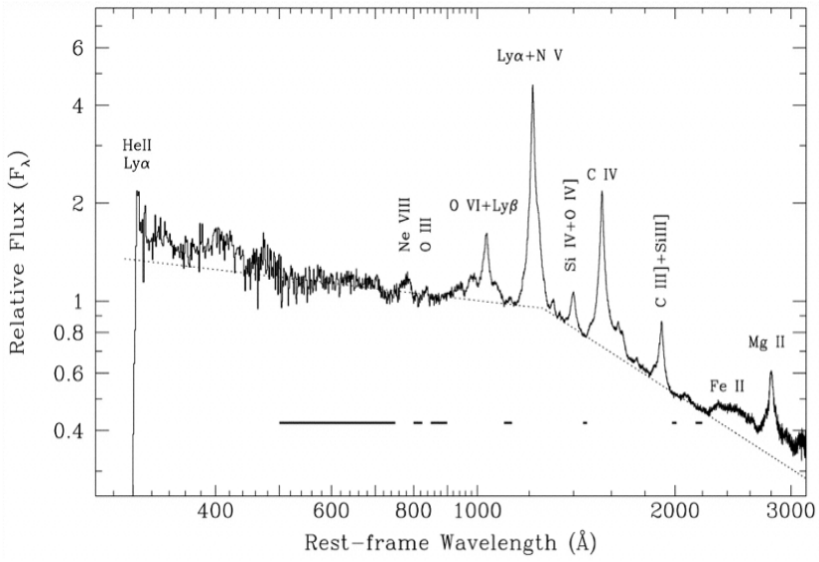


Ratio of FIR to UV fluxes at 1600 Å compared to UV spectral slope β for UV-selected starburst galaxies.

Archival Science Examples (HST)

The Rest-Frame Extreme-Ultraviolet Spectral Properties of Quasi-Stellar Objects
Telfer, R. C. et.al. (2002) ApJ, 565, 773

- Highly cited HST Archival science paper (over 320).
- Use a sample of 332 HST spectra of 184 QSOs with z > 0.33 to study the typical UV spectral properties of QSOs.
- Sample is twice as large as previous work with a better spectral coverage in the extreme-UV.
- The overall composite continuum can be described by a power law, between 500 to 1200 Å.
- Summary: Find no evidence for evolution of a power law index with redshift for either radio-loud or radio-quiet QSOs.
- Summary: Find marginal evidence for a trend toward harder EUV spectra with increasing luminosity for radio-loud QSOs.



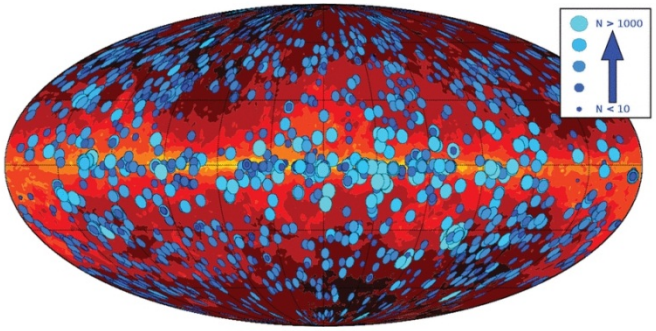
Overall mean composite QSO spectrum in 1 Å bins with some prominent emission lines marked. Dotted line shows best-fit power law continuum (excluding below 500 Å).

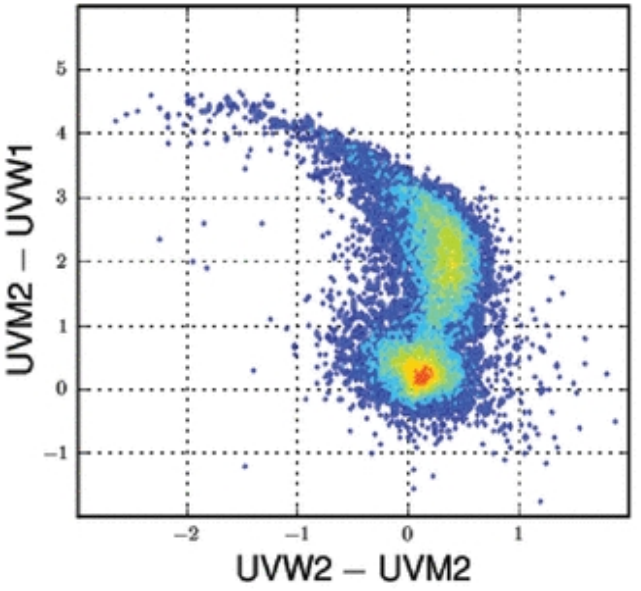
Archival Science Examples (XMM-Newton)

XMMOMSUSS – XMM-Newton Optical Monitor Serendipitous UV Source Survey Catalogue

Page, M. J. et.al. (2012) MNRAS, 426, 903

- Contains source detections from 2,417 XMM OM observations in up to 3 broad band UV filters, between February 2000 and March 2007.
- All data publicly available in the Archive since May 2007.
- Net sky area, 29 – 54 deg^2, depending on UV filter.
- Content: filter-dependent source positions, magnitudes and fluxes. Also profile diagnostics and variability statistics.
- Contains 624,049 unique objects (753,578 UV source detections above 3-sigma). More than 10% of sources visited more than once using the same filter.
- ~1.0 arcsec positional accuracy of catalogue detections.
- Rich in early-type stars and star-forming galaxies out to z~0.8.





Summary

- There are currently 7 ESAC Astronomical Science Archives with data from microwaves to gamma-rays.
- The ESAC Science archives hold UV data in the XMM-Newton Science Archive and ESA Hubble Science Archive.
- Many of the large data centres have published UV data in the Virtual Observatory, including HST, GALEX, FUSE, IUE, EUVE, XMM-Newton data …
- VizieR catalogues are also available in the Virtual Observatory.
- The older the mission, the more important Archival data becomes.
- Archival data particularly good for studying long-term variability of objects, large statistical and correlative studies, multi-wavelength studies, discovery of rare objects, …
- Very valuable science can (and is being) done with Archival data.

Come and visit us...

http://archives.esac.esa.int

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