NAVO: NASA Data in the Virtual Observatory

Thomas McGlynn, Alan Smale (NASA/GSFC), Richard White, Thomas Donaldson, Alessandra Aloisi (STScI/MAST), Joseph Mazzarella, Rick Ebert (NED/IPAC, Caltech), David Imel, G. Bruce Berriman (IPAC, Caltech), Harry Teplitz, Steve Groom and Vandana Desai (IRSA/IPAC, Caltech)

1. Introduction

In October 2014, NASA launched the NASA Virtual Astronomical Observatories, NAVO, to maintain Virtual Observatory assets inherited from the US Virtual Astronomical Observatory (VAO) and to provide coordinated and comprehensive access to NASA's astronomical data holdings. During its first year, NAVO has established standards for access to mission datasets and the NAVO archives have begun implementation of these standards for the major NASA astronomy data holdings. This paper describes the access to mission data that will be supported at NAVO archives, the scope of the NAVO archives and the implementation of new capabilities during the past year. Feedback from the community is welcome to assess our priorities and schedule. Funded NAVO institutions include IRSA, MAST, NED and the HEASARC but all NASA archives are represented in NAVO discussions. All NAVO capabilities are based upon the maturing standards developed in the International Virtual Observatory Alliance (IVOA).

NASA archive holdings include a myriad critical astronomical resources spanning all observed wavelengths. Individually the NASA archives have been major players in the development of community standards to ensure easy access and maximum use of these data. The goal of NAVO is to ensure comprehensive and consistent publishing of NASA resources through the virtual observatory.

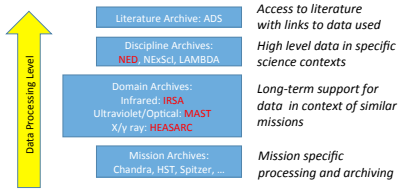

Figure 1. Organization of NASA archives
(Funded NAVO activities)

Mission data is initially processed by the mission team but is then typically sent to one of the domain archives for general user access. Several archives provide access to high-level data with specific science interests in extragalactic, planetary or cosmological astronomy. The ADS has a unique role providing easy access to the literature and also many links back to underlying data. Within the NAVO collaboration, the NASA archives use VO protocols to provide comprehensive access to NASA's data holdings.

2. NASA Data Holdings

NASA archives NASA mission datasets, mirrors archives from non-US space missions and also holds key ground data sets. Providing standard interfaces to these diverse holdings is the central goal for NAVO. Table 1 summarizes the major holdings in various categories. Each mission is given only once though many, e.g., Hubble or Swift fit into multiple categories. Figure 2 illustrates the tremendous science scope of the NAVO holdings ranging over the entire spectrum and over many orders of magnitude in resolution.

Table 1. Major NASA archive holdings

Class	Missions & Datasets (Active in **bold**)
Radio	VLA-FIRST
Microwave	ACT, BLAST, BOLOCAM,COBE, **Planck**, SPT, WMAP
Infrared/Ground	2MASS, DENIS
Infrared/Space	AKARI, **Herschel**, IRAS, IRTS, ISO, **Spitzer**, SWAS,
Optical	DSS/GSC, EPOCh, **Hubble (ACS, COS,** FOC, FOS, GHRS, HSP, **NICMOS, STIS, WFCS,** WF/PC[12]), **KEPLER/K2,** PTF, PPMXL
Ultraviolet	BEFS, EUVE, FUSE, GALEX, HUT, IMAPS, IUE, TUES, UIT, WUPPE
X ray	Ariel V, AGILE, ASCA, BeppoSAX, BBXRT, **Chandra,** Copernicus, Einstein, EXOSAT, GINGA, HEAO-1, MAXI, ROSAT, RXTE, **Suzaku**, **Swift**, **XMM-Newton**
γ ray	Compton, COS-B, **Fermi,** Vela 5B
Literature	**Astrophysics Data System**
Extragalactic Objects	**NASA Extragalactic Database**
Exoplanets	**NExScI**

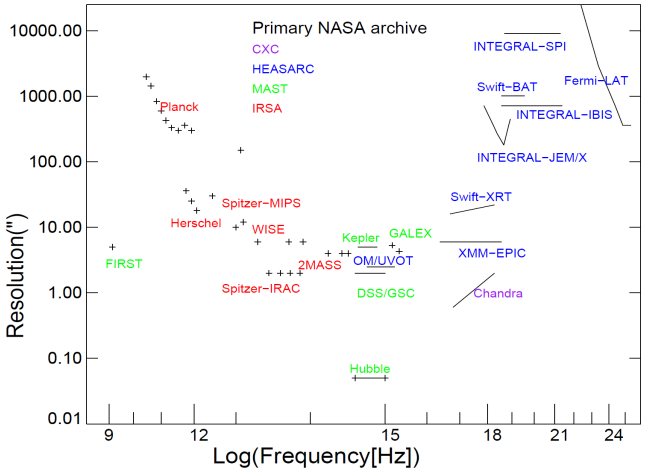

Figure 2. Distribution of selected NAVO holdings in frequency and resolution. The frequency scale is stretched to help distinguish infrared and optical datasets.

3. Standard Access to NASA Archives

The central thrust of the NAVO effort is to use existing VO protocols to provide uniform access to NASA archive data. Figure 3 illustrates how VO protocols are combined to provide an integrated interface to NASA data holdings. The 'simple' VO standards: cone search, image access and spectral access provide easily invoked, position-based queries for catalog information, and the primary image and spectral products for missions. By the end of FY 2017 this model should be implemented for all significant NASA holdings.

Complex catalog queries are supported using the VO table access protocol (TAP) which allows sophisticated queries of individual tables and also supports cross-correlations among tables in a given mission. TAP also allows for geometric constraints and a common framework for geometric queries is being developed.

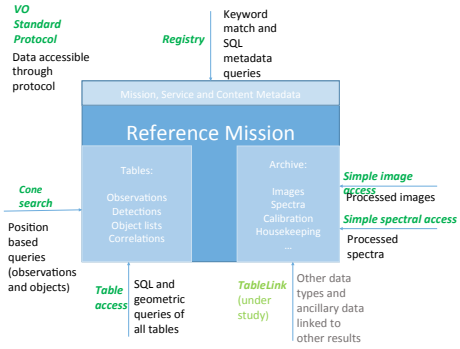

Figure 3. A VO mission data model

During NAVO's first year a major effort has been started to provide the complete suite of TAP, Cone, SIA and SSA services at all NAVO archives. Major new TAP capabilities have been developed at IRSA and MAST, and the HEASARC has begun to release new observation based data services. The VO registry hosted at MAST has been upgraded to be able to handle complex SQL (or more precisely ADQL) structured queries.

The TableLink protocol recently approved by the IVOA is being studied to see if it can be used to provide standardized access to the often complex datasets. TableLink allows printing to not just individual files, but to a complete file structure.

Users can discover the existence of resources through the VO registry capabilities. All current VO services are registered and in future years NAVO will be making sure that these entries provide comprehensive and consistent descriptions of NASA resources

4. How can you use NAVO?

Table 2 shows the archive access capabilities you can already use and the release dates for additional functionality. These services are fully integrated into the underlying archive environments and updates to missions tables and data are reflected in the VO interfaces immediately.

Table 2. Available and scheduled NAVO capabilities

Query	HEASARC	IRSA	MAST	NED
Simple Positional Queries	✓	✓	✓	✓
Complex SQL Queries	✓	✓	Late 2015	2017
Images	Surveys now; Observations Late 2015	✓	✓	✓
Spectra	Early 2016	2016	✓	SEDs now; Data 2019

In addition to implementing this consistent and comprehensive interface to NASA data, NAVO is developing standardized metadata for NASA missions; looking at using VO standards for cloud data, time series and events; understanding how the community can effectively query very large databases; and ensuring that new VO standards support the needs of our community. These areas and implementation of enhanced VO protocols dominate the NAVO schedule after 2016. NAVO supports one of the VO registries at MAST that allows any provider to publish new resources and all scientists to discover existing capabilities. We also continually monitor VO sites to ensure robust services.

You can access NAVO's resources through existing VO tools like Aladin for images, TOPCAT for tables, IRIS with NED's SED services for spectral data and through VO-aware archives like the HEASARC's Xamin. Or you can build your own tools to access them: VO protocols mostly use simple, synchronous Web queries. To get detailed information about the access points for specific missions and examples of how to access NAVO services try our NAVO summary pages at:

http://heasarc.gsfc.nasa.gov/vo/summary

Similar pages – each describing all of the NAVO services -- will soon be available at all NAVO archives.

NAVO is an ongoing effort and we hope to respond to the needs of our community. Please contact any of the authors if you have needs or suggestions for how we can increase the usefulness of NASA's astronomy data.