

Interoperability tools for the Virtual Observatory

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ABSTRACT

Interoperability is one of the key issues in the current efforts to build the Virtual Observatory. We present here some of the tools which already contribute to the efficient exchange of information between archives, databases, and journals.

Keywords: interoperability, Virtual Observatory, astrophysics, information systems

1. INTRODUCTION

Interoperability has been identified as one of the crucial issues of the emerging Virtual Observatory at an international level (for an introduction to the concept of the Virtual Observatory, see Brunner et al. 2001³).

The challenge is to provide the scientific community with an integrated access to a wide variety of information, databases and services, not only heterogeneous by their origins (observatory archives, electronic publications, national or international services) but also diverse in nature: bibliography, images, data tables, spectra, etc.

Solutions for interoperability imply a strong coordination of all data producers and archive managers, so that common protocols and standards can be discussed, decided, and implemented.

At a basic level, interoperability requires the ability for a database system to *understand a query* formulated by another complementary database, to *process it unambiguously*, and to *transfer the results* back to the querying system so that it can be used for building an integrated response to a user.

Let us give some examples of these different steps:

- *to understand the query*: this implies that the query syntax is correct. Most of the past efforts (see e.g., Astrobrowse, section 3.2.1) have been devoted to the management of queries by position because most of the databases share an approach by equatorial coordinates. The ASU protocol (Ochsenbein et al. 1998¹⁸) described in section 2.3 is an example of a coordinated effort to standardize query formulation for submission to Web servers.
- *to process a query unambiguously* it is important to ensure that potentially interoperable systems share the same assumptions (e.g. : equatorial coordinates are expressed in the J2000 system). At a first level, this can start with very simple agreed upon data description; a striking example is the bibcode: this 19-character code (Schmitz et al. 1995²²) describes unambiguously a reference to a paper published in a journal or book within the astronomy and astrophysics scientific community. As a second step, it becomes essential that interoperable databases and services share common *data dictionary* parameters; this is the main driver for the GLU project which will be described in section 3.1. For instance, the GLU system will keep the knowledge about the coordinate system used by each service, and will provide the coordinate translation from the query, when appropriate.
- *transfer the results for further use* implies in principle a symbolic –as well as a physical– description of all retrieved data items. In practice most systems simply deliver a status code (or a number of records) and the corresponding records (or an access to these records on a remote site).

It is part of the future challenge of the Virtual Observatory to be able to go much further in this direction, and reach a point where all data elements would be rigorously described so that they can be used within classification algorithms, for example, as a step of knowledge extraction.

2. PROTOCOLS AND STANDARDS

The first step towards interoperability is the development of common protocols and standards for the astronomical information services. As shown, e.g. by Egret et al. (2000⁵), the history of coordinated development of astronomical information services demonstrates that coordinating spirit is not out of reach in a small community such as astronomy, largely sheltered from commercial influence.

In this section we give some examples of this coordinated effort which constitute some of the keys for the Virtual Observatory of the future: a standard format (FITS); a standard descriptor (bibcode); and a proposed syntax for web queries (ASU).

Finally we present AstroRes, a proposed data description for XML.

2.1. FITS data and image format

The Flexible Image Transport System (FITS) for astronomy (Wells et al. 1981²³) is a commonly agreed system to encode both a definition of the data and the data itself in a machine independent way. It is a clear and unambiguous standard for stating how geometric information in an astronomical image should be represented.

The advantage of using a standard format for transport of astronomical images was soon realized and most major observatories implemented it as the prime format for data exchange. Subsequently, the FITS format was recommended by International Astronomical Union as the standard format for interchange of image data between all observatories.

The extension of the FITS format to table and catalogue data resulted from the work of a Task Force appointed under IAU recommendation, and is described by Grosbøl et al. (1988¹⁰) and Harten et al. (1988¹⁴). The more recent adoption of the World Coordinate System (WCS) standard (Calabretta and Greisen 2000⁴) is a necessary tool for all kinds of astrometric cross-matching of images and catalogues.

While FITS is 'the' reference format for astronomical image description, it is certainly less successful to describe data tables, where simpler robust systems are frequently preferred.

One of them is the ReadMe file system implemented by Ochsenbein (1994¹⁷) and used by the astronomical data centers around the world. This file description is also used by the VizieR catalogue database, and for the description of data tables associated to all major astronomical journals. Similarly to FITS, it uses a header file to describe the data, but the main data file is simply coded in ASCII, without any overhead. The header is easily understandable by the human, as well as by the computer.

2.2. Reference code

Handling references to the literature is a very common, and often confusing, task. The astronomers have adopted a very simple system, the *bibcode*, to describe unambiguously a reference to a paper published in a journal or book within the astronomy and astrophysics scientific community. This 19-character code (Schmitz et al. 1995²²) contains enough information (and redundancy) to allow an immediate identification of a reference.

Example: 2000ApJS...131...335R is the *bibcode* for a paper²¹ published in the year 2000, in the *Astrophys. Journal Suppl.* (ApJS), vol. 131, p. 335. The final letter (R) is the initial letter of the name of the first author (Rutledge).

The fact that major databases (NED, SIMBAD, ...), abstract service (ADS), and electronic publishers (Journals of the American Astronomical Society, *Astronomy & Astrophysics*, ...), all members of the *Urania** collaboration, share the same system has been a very powerful help for a rapid development of interoperability between abstract services, journals and databases.

2.3. Astronomical Standardized URL

The Astronomical Standardized URL (ASU[†], Ochsenbein et al. 1998¹⁸) results from discussions between several institutes (CDS, ESO, ESA, CADC, OAT), for proposing a common syntax for on-line Web queries (generally using the GET method for specifying query parameters directly in the URL).

The basic concept of ASU is a standardized way of specifying query parameters such as:

- catalogues: `-source=catalog_designation,`

*<http://www.aas.org/Urania/>

†<http://vizier.u-strasbg.fr/doc/asu.html>

- target positions: `-c=name_or_position`,
- and radius: `rm=radius_in_arcmin`,
- output format: `-mime=type`,
- and general constraints on parameters: `column_name=constraint`.

Example: To get the X-rays sources from the Rosat All-Sky Bright Source Catalogue around M31, you can use the following URL: <http://vizier.u-strasbg.fr/cgi-bin/VizieR?-source=1RXS&-c=M31,rm=20&-out.all>

ASU is currently used within a number of archives and catalogue services, generally in parallel with other, more sophisticated, or more system-dependent query mechanisms.

2.4. XML AstroRes

The Extensible Markup Language (XML) is a developing standard in which the description of the data (the metadata) is included with the actual data in a single electronic document.

XML is an ideal support for developing new standards for accessing and understanding tabular data, particularly for handling the responses from queries to on-line catalogue services. If such responses are encoded in XML using agreed upon tags and attributes, it becomes possible to both display the data in clearly formatted tables and use the data in other applications (such as generating graphical overlays of object positions on survey images).

XML-encoded tables can also provide the basis for the next generation of data discovery and integration tools (Astrobrowse, ISAIA, see below). A certain number of initiatives are under way to develop a general frame for XML in astronomy (see, e.g., XML for Astronomy at NASA/GSFC²⁵ and XML resources at NASA/ADC²⁶).

Some developments tackle well defined questions for implementing operational tools. For instance ALADIN (section 4.2) is fully XML compatible. The AstroRes standard, developed as the result of a collaboration between scientists from CDS, ESO, Univ. Illinois, STScI and GSFC provides a first standard data description for astronomical tabular outputs. The detailed definitions of XML AstroRes tags and attributes, including examples and the proposed Data Description Document, are available on-line[‡] (Ochsenbein et al. 2000¹⁹).

3. ASTRONOMICAL DATA DICTIONARIES

With a large number of on-line services giving access to data or information, it is clear that tools giving coordinated access to several (or even many) distributed services are needed. This was, for instance, the concern expressed by NASA through the Astrobrowse project (Heikkila et al. 1999¹⁵).

In this section we will first describe a tool for managing a “metadata” dictionary of astronomy information services (GLU); then we will show how the existence of such a metadatabase can be used for building efficient search and discovery tools.

3.1. The CDS GLU

The CDS (Centre de Données astronomiques de Strasbourg) has developed GLU[§] (Générateur de Liens Uniformes, i.e. Uniform Link Generator; Fernique et al. 1998⁷) as a tool for managing remote links in a context of distributed heterogeneous services.

First developed for ensuring efficient interoperability of the several services existing at CDS (VIZIER, SIMBAD, ALADIN, bibliography, etc.; see Genova et al. 2001⁸), this tool has also been designed for maintaining addresses (URLs) and query syntax, and for storing a view of the conceptual data model of distributed services (ADS, NED, observatory archives, journals, etc.).

A key element of the system is the “GLU dictionary” maintained by the data providers contributing to the system, and distributed to all sites of a given domain. This dictionary contains knowledge (meta-data) about the participating services (URLs, syntax and semantics of input fields, descriptions, etc.), so that it is possible to generate automatically a correct query for submission to a remote database.

The service provider (data center, archive manager, or webmaster of an astronomical institute) can use GLU for coding a query, taking benefit of the easy update of the system: knowing which service to call, and which answer to expect from this

[‡]<http://vizier.u-strasbg.fr/doc/astrores.htx>

[§]<http://simbad.u-strasbg.fr/glu/glu.htx>

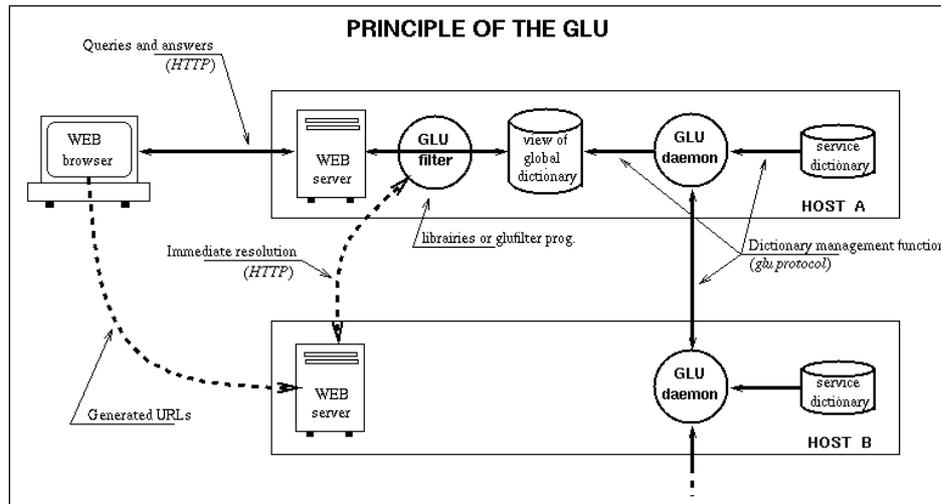


Figure 1. A scheme of the GLU principles.

service, the programmer does not have to worry about the precise address of the remote service at a given time, nor of the detailed syntax of the query (expected format of the equatorial coordinates, etc.). The system includes a mechanism to share and maintain the distributed dictionary, similarly to what is done for name services on the Internet.

3.2. New search and discovery tools

The example of GLU demonstrates the usefulness of storing into a database the knowledge about information services (their address, purpose, domain of coverage, query syntax, etc.). In a second step, such a database can be queried when the challenge is to provide information about whom is providing what, for a given object, region of the sky, or domain of interest.

Several projects are working to provide prototype solutions, based on the concept of a *data access layer* where general queries are translated into the multiple specific query languages of individual services. We will present in this section *AstroBrowse* and *AstroGlu*. Other examples are *AMASE*[¶] at NASA/ADC, or *Querator*, described by Pierfederici et al. in this conference.

3.2.1. Astrobrowse

Astrobrowse is a project that began within the United States astrophysics community, primarily within NASA data centers, for developing a user agent which significantly streamlines the process of locating astronomical data on the web. Several prototype implementations are already available^{||}. With any of these prototypes, a user can already query thousands of resources without having to deal with out-of-date URLs, or spend time figuring out how to use each resource's unique input formats. Given a user's selection of web-based astronomical databases and an object name or coordinates, *Astrobrowse* will send queries to all databases identified as containing potentially relevant data. It provides links to these resources and allows the user to browse results from each query. *Astrobrowse* does not recognize, however, when a query yields a null result, nor does it integrate query results into a common format to enable intercomparison.

3.2.2. AstroGLU

Consider the following scenario: we have a data item I (for example an author's name, the position or name of an astronomical object, a bibliographical reference, etc.), and we would like to know more about it, but we do not know a priori which service S to contact, and what are the different data types D which can be received in response. This scenario is typical of a scientist exploring new domains as part of a research procedure.

[¶]<http://amase.gsfc.nasa.gov/>

^{||}<http://heasarc.gsfc.nasa.gov/ab/>

The GLU dictionary can actually be used for helping to solve this question: the dictionary can be considered as a reference directory, storing the knowledge about all services accepting data item I as input, for retrieving data D_1 or D_2 . For example, we can easily obtain from such a dictionary the list of all services accepting an author's name as input; information which can be accessed, in return, may be an abstract (service ADS), a preprint (LANL/astro-ph), the author's address (RGO e-mail directory) or personal Web page (StarHeads), etc.

Based on such a system, it becomes possible to create automatically a simple interface guiding the user towards any of the services described in the dictionary.

This idea has been developed as a prototype discovery tool, under the name of AstroGLU** (Egret et al. 1998⁶). The aim of this tool is to help the users find their way among several dozens (for the moment) of possible actions or services. A number of compromises have to be taken between providing the user with the full information (which would be too abundant and thus unusable), and preparing digest lists (which implies hiding some amount of auxiliary information and making somewhat subjective selections).

A resulting issue is the fact that the system puts on the same line services which have very different quantitative or qualitative characteristics. AstroGLU has no efficient ways yet to provide the user with a hierarchy of services, as a gastronomic guide would do for restaurants. Qualification of relevant datasets and services, on the basis of well-established science requirements, will be a necessary step of the Virtual Observatory.

4. TOWARDS AN INTEGRATION OF DISTRIBUTED DATA AND INFORMATION SERVICES

To go further, one needs to be able to integrate the result of queries provided by heterogeneous services.

In this section we will first present working examples of data integration –the SIMBAD or NED name resolvers, and the ALADIN interactive sky atlas. Then we will describe the ISAIA project of an integrated system able to display the results of complex heterogeneous queries.

4.1. Name resolvers

A name resolver is a basic example of interoperability: it is a simple program which sends the name of an astronomical object to the SIMBAD or NED databases, and receives in return the position of the object on the sky (or an error message when the name is not known from the database). Such programs have been made available, even before the advent of the web, as simple and robust client/server routines.

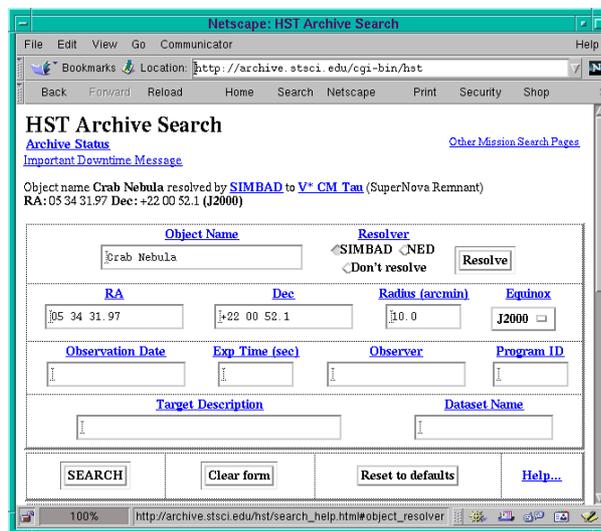


Figure 2. An example of SIMBAD/NED name resolver in the Hubble Space Telescope archive system at STScI.

** <http://simbad.u-strasbg.fr/glu/cgi-bin/astroglu.pl>

NED and SIMBAD name resolvers are now used throughout the community, integrated into most of the astronomical on-line archives and databases (Fig. 2).

4.2. The example of ALADIN

The ALADIN interactive sky atlas developed by the CDS in Strasbourg is a powerful prototype of data integrators.

ALADIN has been primarily developed for the identification of astronomical sources through visual analysis of reference sky images (Bonnarel et al. 2000a¹). ALADIN fully benefits from the environment of CDS databases and services (SIMBAD reference database, VizieR catalogue service, etc.), and is designed as a multi-purpose service for use by the astronomical community worldwide.

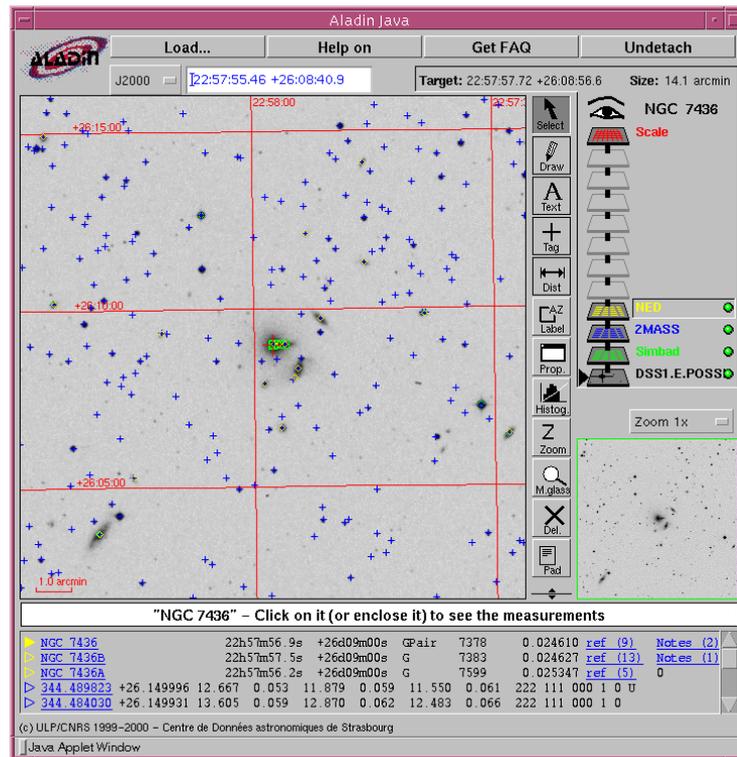


Figure 3. Example of ALADIN window, with an image centered on NGC 7436, and objects from SIMBAD, NED and 2MASS marked by symbols.

The system, proposed as a Java applet (see Figure 3), allows the user to visualize digitized images of a part of the sky, to superimpose entries from the CDS astronomical catalogues and tables, and to interactively access related data and information from the SIMBAD, NED, VizieR, or other archives for all known objects in the field.

ALADIN is particularly useful for multi-spectral cross-identifications of astronomical sources, observation preparation and quality control of new data sets (by comparison with standard catalogues covering the same region of sky).

Data integration is made possible through the use of the GLU data dictionary, and of the ASU protocol. Input and output formats are gradually migrated to the AstroRes XML format (section 2.4), as soon as it is implemented in the remote services.

4.3. ISAIA

ISAIA (Integrated System for Archival Information Access^{††}; Hanisch 2000a,¹² 2000b¹³) is a project to build an interoperability layer (middleware) for providing access to distributed space science data resources via common query protocols and metadata standards.

^{††}<http://heasarc.gsfc.nasa.gov/isaia/>

The key objective of the project is to develop an interdisciplinary data location and integration service for space sciences. Building upon existing data services and communications protocols, this service will allow users to transparently query a large variety of distributed heterogeneous Web-based resources (catalogues, data, computational resources, bibliographic references, etc.) from a single interface. The service will collect responses from various resources and integrate them in a seamless fashion for display and manipulation by the user.

Because the scope of ISAIA is intended to span the space sciences – astrophysics, planetary science, solar physics, and space physics – it is necessary to find a way to standardize the descriptions of data attributes that are needed in order to formulate queries. The ISAIA approach is based on the concept of *profiles*. Profiles map generic concepts and terms onto mission or dataset specific attributes. Users may make general queries across multiple disciplines by using the generic terms of the highest level profile, or make more specific queries within subdisciplines using terms from more detailed subprofiles.

The profiles play three critical and interconnected roles:

1. They identify appropriate resources (catalogues, mission datasets, bibliographic databases): the *resource profile*
2. They enable generic queries to be mapped unambiguously onto resource-specific queries: the *query profile*
3. They enable query responses to be tagged by content type and integrated into a common presentation format: the *response profile*

The resource, query, and response profiles are all aspects of a common database of resource attributes. Current plans call for these profiles to be expressed using XML (eXtensible Markup Language, an emerging standard which allows embedding of logical markup tags within a document) and to be maintained as a distributed database using the CDS GLU facility.

The profile concept is critical to a distributed data service where one cannot expect data providers to modify their internal systems or services to accommodate some externally imposed standard. The profiles act as a thin, lightweight interface between the distributed service and the existing specific services. Ideally the service-specific profile implementations are maintained in a fully distributed fashion, with each data or service provider running a GLU daemon in which that site's services are fully described and updated as necessary. Static services or services with insufficient staff resources to maintain a local GLU implementation can still be included, however, as long as their profiles are included elsewhere in the distributed resource database. The profile concept is not unique to space science, but would apply equally well to any distributed data service in which a common user interface is desired to locate information in related yet traditionally separate disciplines.

5. MULTI-WAVELENGTH CROSS-IDENTIFICATION

A key science driver for interoperability in the context of the Virtual Observatory is the ability to perform multi-wavelength cross-identification at a massive scale, using reference surveys, and the wealth of observational data already collected in our disciplinary field.

5.1. Scientific motivations

One of the very first scientific motivations for the Virtual Observatory is to develop new tools for an efficient multi-wavelength approach, providing a global view of the complete energy distribution of the astronomical objects. This approach should encompass, e.g., the ability to select and retrieve objects according to the particular shape of their spectrum.

Because of the massive data volumes, it is not feasible for remote users to download a significant fraction of these data. Interoperable data-mining services should therefore be developed, so that the user can seamlessly issue joint queries to multiple distributed databases (see e.g. Lawrence 2001¹⁶).

5.2. The example of X-ray and optical cross-identification

Recent works have shown the power of cross-identifying X-ray and optical catalogues (see Rutledge et al. 2000²¹). As an example of a result of such a general cross-identification process, Guillout et al. (1999¹¹) have reported the detection of a late-type stellar population in the direction of the Gould Belt among stars found by cross-correlating the ROSAT All-Sky Survey with the Tycho catalogue.

Among the many projects under way, we would like to mention the ClassX project proposed by T. Mc Glynn. Conceived as a prototype of the Virtual Observatory, ClassX ('Classifying the High Energy Universe') has been recently approved by NASA. The goal is to build an automated classifier for X-ray sources and to use it to try to distinguish the physical classes of all known X-ray objects. Massive datasets from the HEASARC, ST-MAST, and Chandra archives along with information from VizieR, 2MASS, FIRST and other systems will all be needed within this effort.

5.3. ESO/CDS data mining project

The Centre de Données astronomiques de Strasbourg (CDS) has been focusing in the recent years on new developments for the cross-identification of objects from large surveys. SIMBAD provides the identification of objects published in the literature, or from reference catalogues; the VizieR catalogue browser can be used to browse through the survey result catalogues, and to compare them to other catalogues and published tables; the ALADIN sky atlas allows the user to overlay survey catalogues on images of the sky, together with SIMBAD, NED, and catalogues and published tables from VizieR (Bonnarel et al. 2000b²).

ESO and CDS have been developing data-mining tools in order to allow users to access and combine the information stored in the forms of catalogues at CDS, and catalogues and data at ESO (prototype ‘ESO-CDS data mining project’; Ortiz et al. 1999²⁰). The idea is that remote users can either submit their own data “tables” (as ASCII files) for comparison, or extract information from either ESO or CDS to cross correlate by position in the sky or by any of the parameters provided by the data catalogues. An important point has been the development of knowledge structures with the purpose of facilitating the description of the data to provide highly flexible data-mining options.

Two knowledge detection structures were developed: one for *astronomical object types*, and the other for *column content*.

- The structure for object type resembles the structure used in SIMBAD, with a four level hierarchy; the source to assign object types to the catalogues and tables is the standardized description file (ReadMe file) developed at CDS and shared now by other data centers and journals.
- The structure related to column content was fully developed for this project. It contains 35 main categories and has a four level hierarchy. Categories such as Photometry, Positions, Spectroscopy, Time and Physical Quantities are amongst the most populated.

A *Unified Content Descriptor* (UCD) has been assigned to each of the columns in each of the tables accessed with VizieR. For that, we developed an automatic UCD assignation procedure based on column name, column units, and column description.

The effort of unifying column description or object types, although not directly visible to the end user, is critical for the rigorous data organization and description which will pave the way to new Virtual Observatory applications in the domain of data mining and knowledge extraction.

6. FINAL REMARKS: THE ASTROPHYSICAL VIRTUAL OBSERVATORY

Interoperability is one of the major challenges of the Virtual Observatory. The new paradigm of a federation of astronomical archives (see Williams 2001²⁴), as opposed to a central master database, imposes novel approaches. We want to build a *semantic web*, where each service can feed data to another service, and interactively perform multiple steps on the user’s behalf, so that only a small valuable piece of knowledge comes out and is presented to the scientist.

An Interoperability Working Group, chaired by Françoise Genova has been appointed by the European OPTICON network (Gilmore 2001⁹), recognizing the essential scientific and practical benefits resulting from cost-effective tools and standards for improving access to, and exchange and usage of, data archives and astronomical information services. The goals of this working group, to which international partners are associated, is to study the practical tools required for enhanced interoperability between distributed heterogeneous services, providing scientists with transparent navigational tools.

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