The basics of Astronomical Virtual Observatories

Graduate Course by

Ana I. Gómez de Castro

- Which are the astronomers needs?
- Which are the requirements for these scientific purposes?
- The astronomical data. Definition of standards.
- The origin of the Astronomical Virtual Observatory.
- Associated mathematical problems.

1.Which are the astronomers needs?

- Astronomers run observing programs in **three basic modes**:
  - Observing objects associated with an ***astronomical problem***, for instance, planetary nebulae, galaxy formation, cosmology, stellar evolution, solar system,…
  - Observing objects with a certain ***instrument*** (or in a specific wavelength range), for instance, infrared astronomy, radioastronomy, high energy astronomy….
  - Running ***surveys***. The whole sky is observed to determine three parameters for each detected source (α,δ) and flux at a given wavelength range (or velocity).

- In the past, most of the astronomers used to specialize in the use of one observational technique and apply it to work in one or few related astronomical problems.

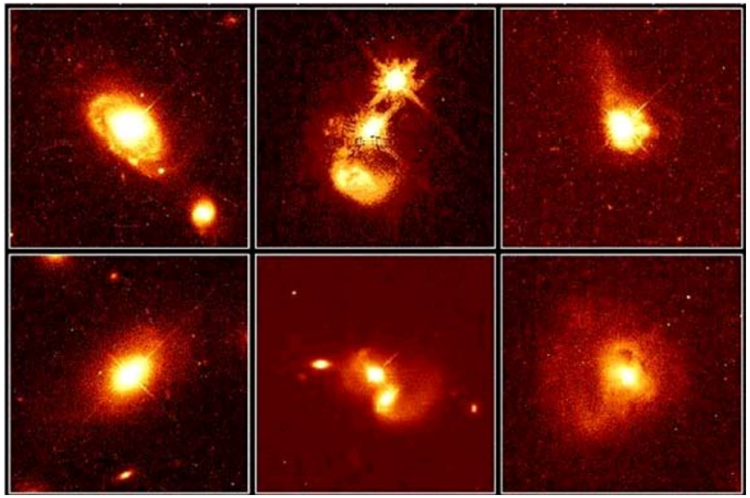
  This was a NEED since there were not standard, world-wide procedures for data analysis and each instrument is somewhat dPdM ("de su Padre y de su Madre") !!

  The advent of space astronomy in the late seventies required the definition of standard procedures for the analysis of all the data from the same mission (e.g. telescope + instrument +???). This extended to ground based astronomy and has become a requirement for the new generations of astronomers.

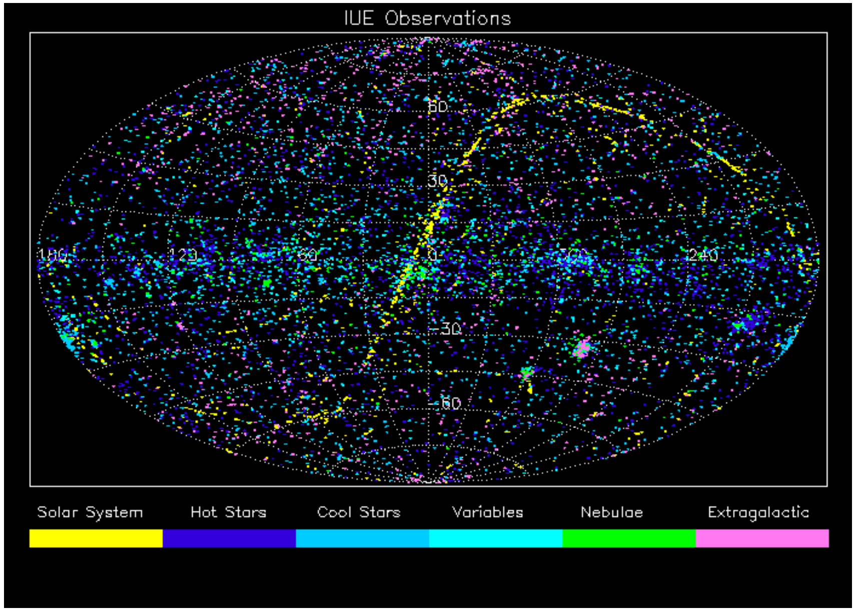
- In addition to this standardization, *all the professionals agree in maintaining simultaneously the possibility of direct handling on the original data* for obvious reasons which are at the very base of the scientific method.

The observing modes:

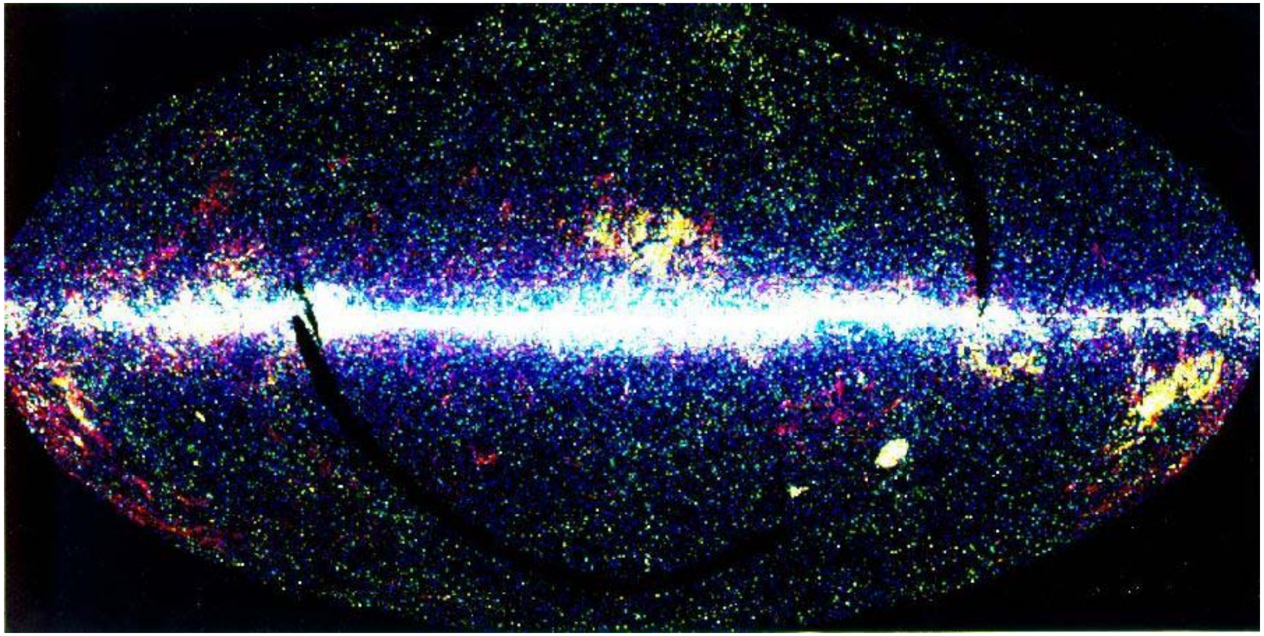
Mode 1: By type of astronomical object: QSO's



Mode 2: By observational mode- UV astronomy

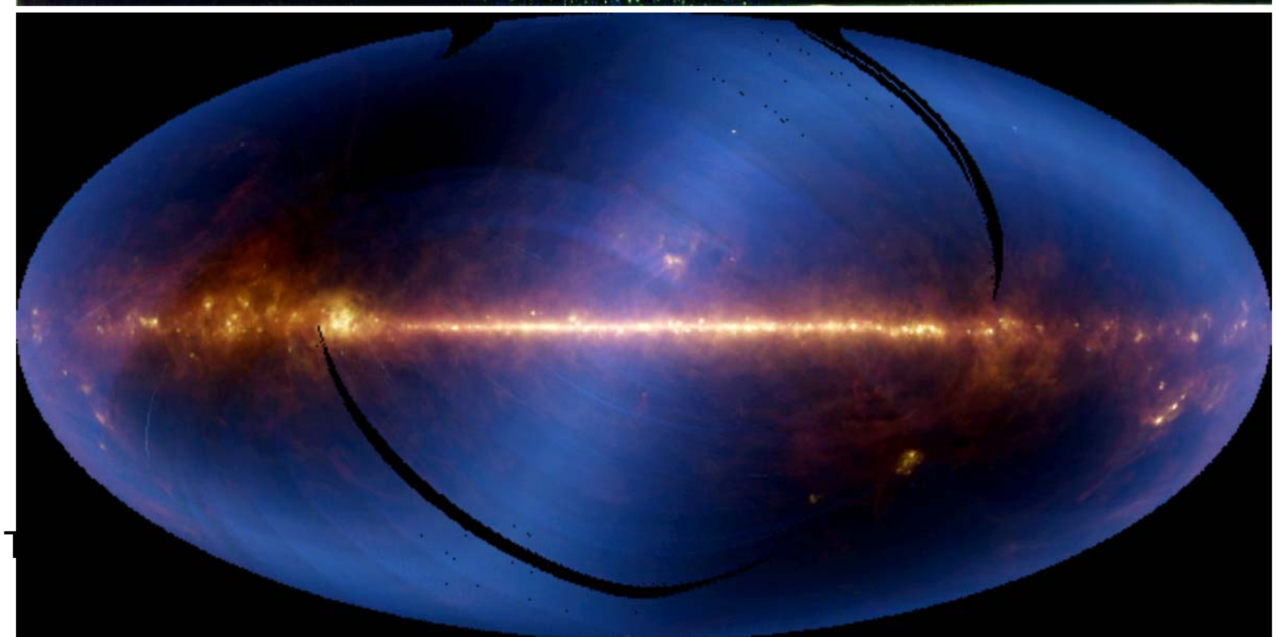


3. Surveys: the Infrared Astronomical Satellite (IRAS) survey



Point-like sources:

Sources are color coded by their infrared colors. Blue sources are cool stars within our Galaxy, which show an obvious concentration to the galactic plane and center. Yellow-green sources are galaxies which are basically uniformly distributed across the sky, but show an enhancement along a great circle above the galactic plane. This enhancement is caused by galaxies in the Local Supercluster. Reddish sources, the infrared cirrus, are extremely cold material close to us in our own Galaxy. Black areas were not surveyed by IRAS.



All sky survey:

The colors represent infrared emission detected in three of the telescope's four wavelength bands (blue is 12 microns; green is 60 microns, and red is 100 microns). Hotter material appears blue or white while the cooler material appears red. The hazy, horizontal S-shaped feature that crosses the image is faint heat emitted by dust in the plane of the solar system.

- The increasing **sophistication of astronomical instrumentation** is forcing the existence of a new class of astronomers/engineers fully devoted to design, development and calibration.

  The technology is developing so rapidly that requires a full-time dedication. This pace favours strongly specialization so “Renaissance men” who develop instruments and carry out simultaneously astronomical research are becoming “rare species”.

- Observatories are also requiring the astronomers to prove that they have fully exploited all the data **available** prior to award them with observing time.

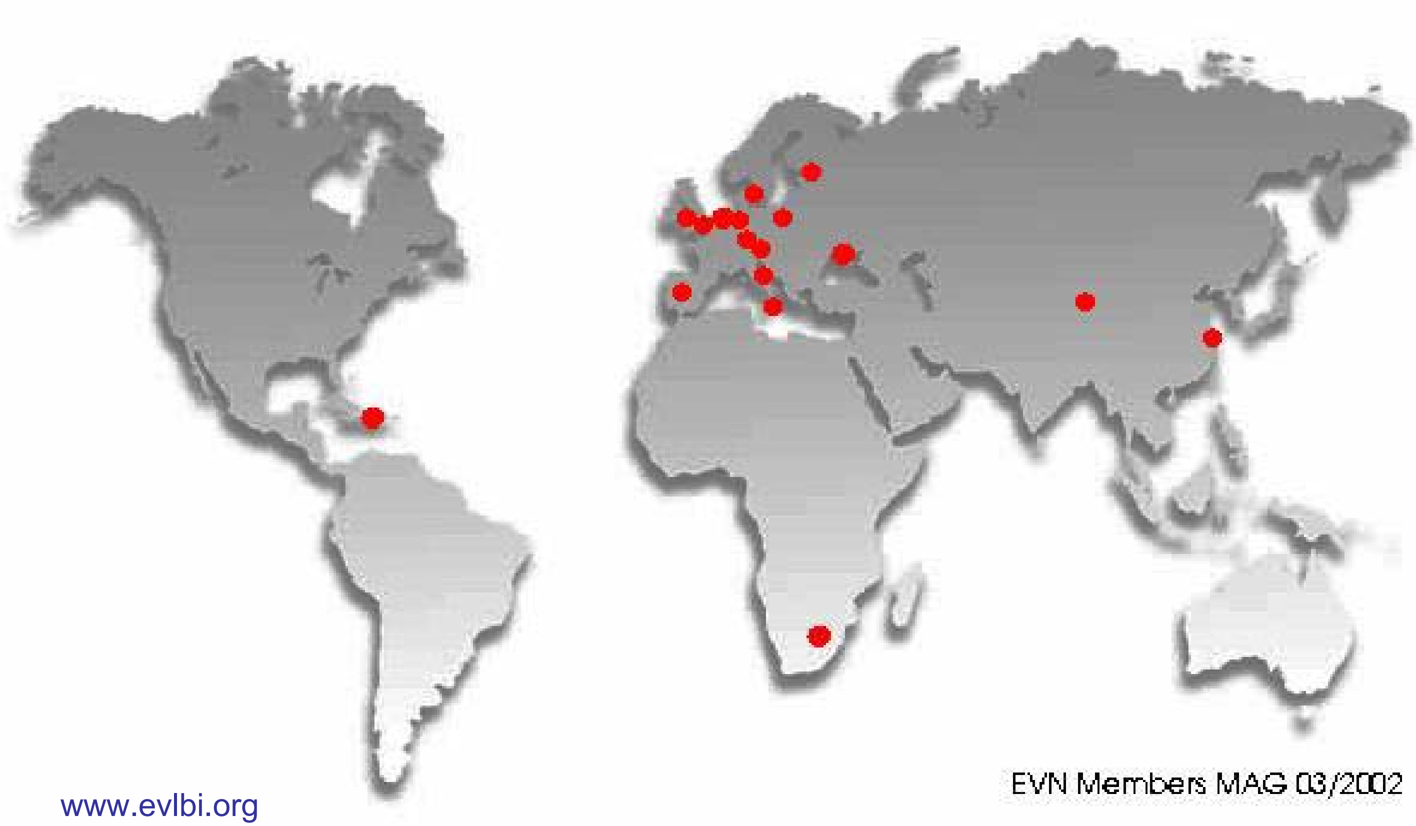
  The **high oversubscription rates** of the large observatories are forcing the astronomers to publish fast the results (this requires a rapid data processing) and to exploit the best they can the resources available in Archives and in the Web (small observatories are closing and the financial support is becoming concentrated in few large-scale facilities *all over the planet*).

- A **new way of carrying out astronomical research is emerging**. Astronomers pick-up a physical problem (which may be associated to one or many objects) and search for all the observational information related with it. They are not constraint by the wavelength range or the technique (imaging, spectroscopy…) and they are often interested in searching for any possible signature of time variability.

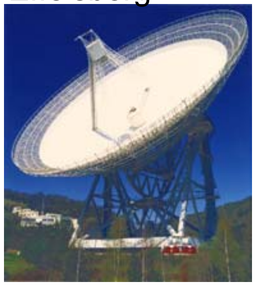
  (In fact, the rationale for the applications for observing time have change in the last 20 years significantly. In the 80’s rationale based on completing samples, obtaining more data on a object to “get further insight in its nature” were very usual. Now, the physics background has to be clearly spelled out.)

Example of the technological sophistication of modern astronomy

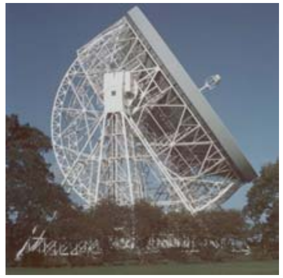
The European V.L.B.I. Network (EVN) is an interferometric array of radio telescopes spread throughout Europe and beyond, The EVN members operate 18 individual antennae, which include some of the world's largest and most sensitive radio telescopes. The EVN observes for 3 periods per year known as "VLBI sessions". Each of these sessions are approximately 3-4 weeks long and typically involve 3-4 different observing frequencies. The EVN scheduler ensures that all telescopes follow the same observing schedule. After each observing programme is completed, the VLBI friends at each EVN telescope provide feedback on the status of the observations and deposit logs and other ancillary data on the EVN Server maintained in Bologna, Italy.



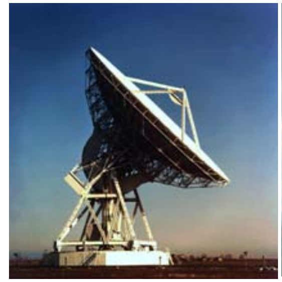
www.evlbi.org



Effelsberg



Lovell



Medicina

Robledo

Yebes

- As the EVN telescopes observe the same cosmic radio source simultaneously, the data are recorded on high capacity magnetic tapes together with a high precision time signal from atomic clocks. They are later replayed and combined at the "correlator".

- In addition to "EVN-only" observations, the EVN array often links-up with MERLIN, an interferometer network of telescopes distributed around the southern half of the UK. In this extended mode, the coverage of the EVN-MERLIN array ranges from a few tens to many thousands of kilometers. The EVN-MERLIN array is thus sensitive to a wide range of radio structures from the arcsecond scale to the milliarcsecond scale.

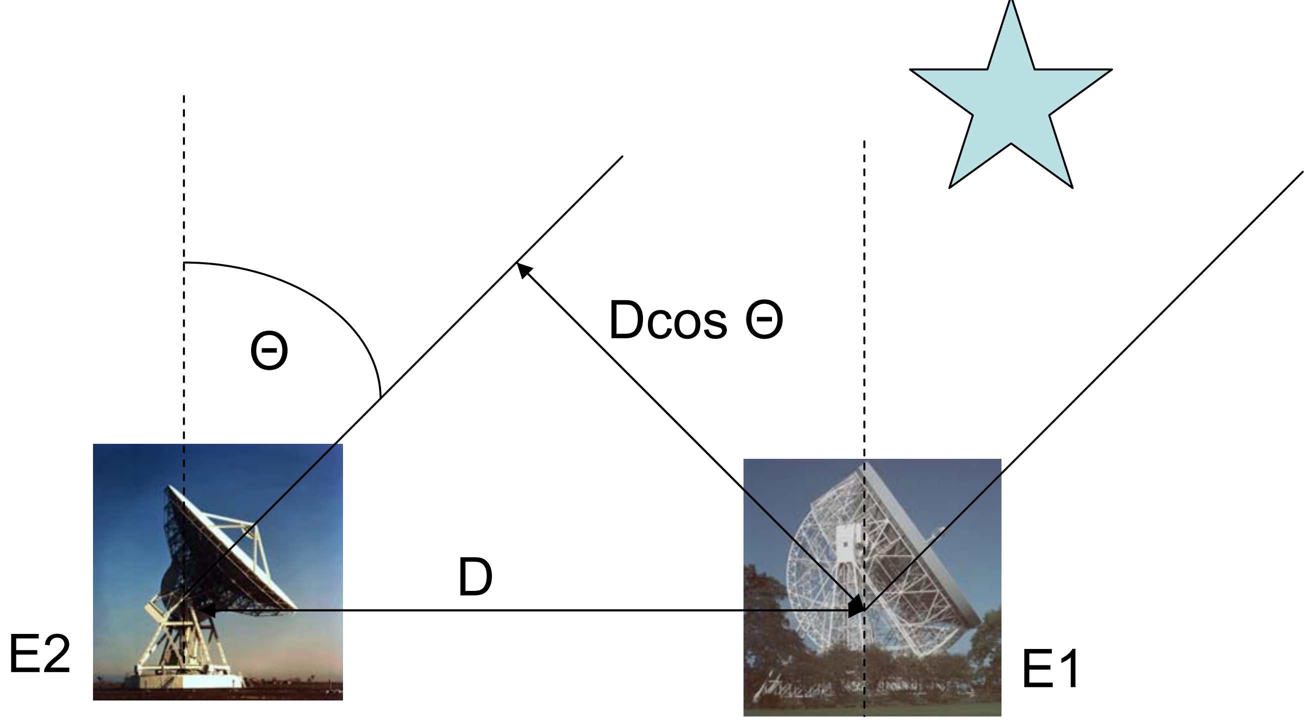
- The EVN also observes simultaneously with the US VLBA, so-called "global VLBI", obtaining sub-milliarcsecond resolution at frequencies higher than 5 GHz.

- The EVN also participates in Space VLBI observations as part of a ground array of radio telescopes observing simultaneously with the Japanese HALCA satellite. High resolution radio images made with the EVN and HALCA are available.

Westerbrok

Arecibo

Onsala



Radio-interferometry measures the spatial structure of an astronomical image in the Fourier space. The signal received simultaneously in two receivers, E1 and E2, is multiplied in the correlator making use of the atomic time signal recorded simultaneously with the radioflux. The product of both signals produces an interferometric pattern because of the delay which has a geometric component (Dcos Θ) plus other components related with the motion of the Earth Crust or the propagation of the radiosignal through the atmosphere. In the very simplest approach of considering monochromatic signals, the measurement can be roughly considered to be:

$\mathbf{E1} = \mathbf{E0}\cos(\mathbf{kr}-\omega t)$ $\mathbf{E2} = \mathbf{E0}\cos[\mathbf{k}(\mathbf{r}+D\mathrm{sen}\Theta)-\omega t]$

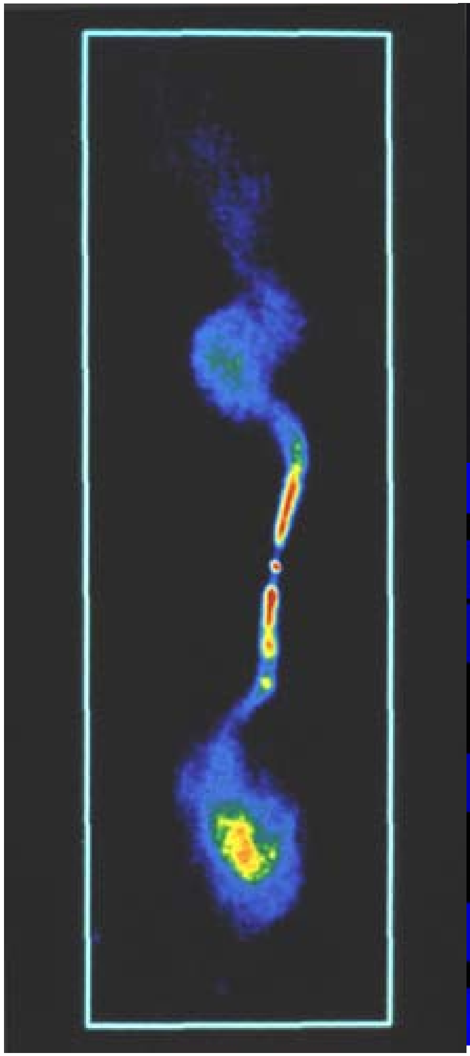
$P(t) = \mathbf{E1}{*}\mathbf{E2} = E0^2\,\{\cos^2(\mathbf{kr}-\omega\, t)\cos(kD\mathrm{sen}\Theta) + 0.5\sin 2(\mathbf{kr}-\omega t)\sin(kD\mathrm{sen}\Theta)\}$

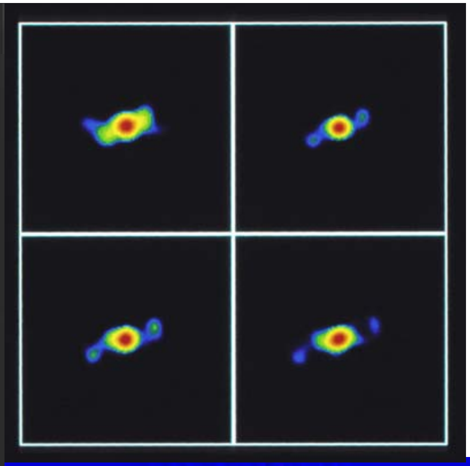
- So, $\Delta P(\varsigma) = \int_t^{t+\varsigma} P(t)dt \propto \cos\left(\frac{2\pi D\sin\theta}{\lambda}\right) = \mathrm{Re}\left(e^{i\frac{2\pi D\sin\theta}{\lambda}}\right)$ with $\zeta \gg 2\pi/\omega$

Fourier Transform of F(x), $f(v) = \int F(x)\exp(i2\pi xv)dx$

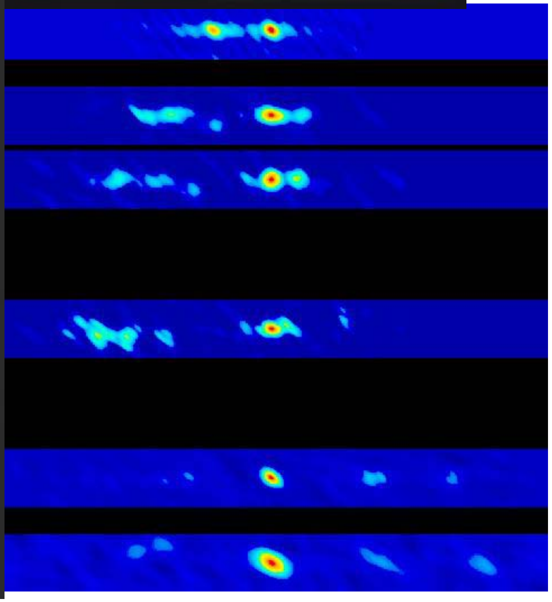
Image reconstruction from VLA data:

VLA radio image of dual radio jets emerging from opposite sides of the nucleus of a large elliptical galaxy whose optical dimensions are about 1/10th the radio features. The redshift of the galaxy is 5400 km/s; the distance is 350 million light-years. The radio jets expand to form diffuse radio lobes outside of the galaxy halo. The interpretation is that the jets delineate the channels through which energy flows from the nucleus to power the outer radio source lobes





SS433 is an object known as an X-ray binary. X-ray binaries are systems of a "normal" star in orbit around a very dense massive compact object, a black hole or neutron star. In these systems there is frequently matter transfer from the normal star onto the compact object. This interaction of matter with the intense gravitational field of the black hole or neutron star causes the matter to heat up and produce X-rays, hence the name X-ray binary. SS433 is special because it is one of the few in this class to also exhibit jets of material ejected at speeds close to the speed of light on opposite sides of the system. This images shows four radio images of radio/x-ray star SS 433 made with the VLA in January, February, March, and April 1981.



A time ordered sequence of images of the microquasar GRO J1655-10, with earlier times at the top and later times underneath. This sequence covers a month in the life of the microquasar, as imaged by the VLBA. GRO J1655-40 is a binary system in which the outer envelope of the normal star is overflowing onto its black hole companion. The accreting matter swirls into a rapidly rotating disk as it falls towards the black hole; near the center, some of this matter is "squirted out" perpendicular to the disk, at relativistic speeds (i.e, speeds approaching the speed of light). The radio emission associated with these relativistic jets is what we see here. The intrinsic speed of these jets is about 90% of the speed of light.

How would professional astronomers like to access the Astronomical Archives?

1. **With only one single interface (and grammatical) to access all the astronomical Archives.**

2. **It has to include some obvious tools like:**
   - Determination of the Spectral Energy Distribution (SED) for any given source.
   - Classification of the objects: spectral, morphological, etc..
   - Cross-correlation among catalogues or images to identify counterparts in all the wavelength ranges, even those no catalogued (new generation telescopes ought to produce detect new objects which are not included in the classical catalogues).
   - Non-monocromatic light-curves analysis.
   - Automated determination of relevant astronomical parameters such as rotation velocities, redshifts, metallicities, proper motions, …
   - Comparison with theoretical models (often simulations) and statistical tools to analyze the quality of the fitting. Archives of numerical simulations.

3. MOST IMPORTANT: ACCURACY AND **HANDY INFORMATION ON UNCERTAINTIES AND METHODS** which allows the proper use of the information by the non expert in this particular instrumentation.

4. This tool must be easy to implement in any platform.

5. Connected to bibliographic services in the web and to proposal preparation systems: simulators, etc….

6. Unsupervised procedures which produce continuously updated catalogues with the basic parameters of the astronomical objects based on the data in the Archives.

……….

The most relevant physical characteristics:

- Radial velocity
- Rotation velocity
- Distances (parallax)
- Angular velocities in the plane of the sky (proper motions)
- Orbital motions (in galactic sources)
- Characteristic variability scales: from flares to pulsations
- Spectral type (stars)
- Surface gravity (stars)
- Chemical composition
- Density (or density structure)
- Temperature (or temperature structure)
- Magnetic fields
- Underlying stellar population (galaxies)
- Rotation curve (galaxies)
- Spatial structure (from galaxies or nebulae to the surface of the stars)

could be derived directly from the world-wide Archive entries using unsupervised but *scientifically certified procedures*.

2nd. order calculations which involve models still under debate should not be included. Notice that a fair fraction of the astronomers work is devoted to the design, revision and update of the methods to determine the important physical variables.

2. Which are the requirements for these scientific purposes?

- **Technical:**
  Communications technology that warrants rapid and secure access to a world-wide distributed network of ARCHIVES. GRID technology.
- **Scientific:**
  Definition of standards for astrometry, photometry, spectroscopy and polarimetry. Criteria for the certification of the data quality. Methods to compute physical magnitudes from data.
- **Technical/Scientific:**
  Definition of the portable data formats (FITS: URL:fits.gsfc.nasa.gov). Definition of standard procedures for user-designed searches based on standard scientific programming languages (C, Fortran) which allows user designed searches, processing of the Archive data and storing of final results in a handy scientific format. It is also useful an interface with the standard software packages for the analysis and reduction of astronomical data (IRAF, MIDAS…) , data searches and download.
- **Political:**
  Which Archives are going to be allowed to join the consortium?. Who and how decides the functionalities to be implemented in AVO?….

3. The astronomical data.

The most abstract representation of astronomical data (***AD***) are vectors:

***AD* =** $(\alpha,\delta,F_1,F_2,\ldots.F_N,t)$, with dimension N+3, where N depends on the source

with, α: right ascension
δ: declination
} Spherical polar coordinates in the equatorial absolute system as defined by the *International Celestial Reference System* (ICRS)

F_i: the flux integrated within a wavelength range $\Delta\lambda_i$ (this integration may or may not weight equally all the points within the interval $\Delta\lambda_i$)

t : the time and date at which the magnitudes are measured (*Universal Time 1* (UT1) or *Terrestrial Dynamical Time* (TDT) are the most often used time systems, dates are given in *Julian dates (JD))*.

Several vectors correspond to the same astronomical object since:

The properties (coordinates and fluxes) may change with time.

Objects may be extended and so they are not represented by a single (α,δ)

Therefore, only three basic physical magnitudes are measured:

1. Angles.
   The accurate measurement of the coordinates is related with the precision of the reference system. The standard defined by the *International Astronomical Union* (IAU) is the *International Celestial Reference System* or ICRS

2. Time.
   The accurate measurement of time is related with the precise definition of the time scale more convenient for the analysis of the given astronomical source. Astronomers work with three (two) basic time scales: *Terrestrial Time* (TT), the *Barycentric Dynamical Time* (TDB) and the *Universal Time* (UT).

   Dates are given in *Julian Dates*.

3. Flux or energy detected by unit time and by unit surface oriented in a given direction in a certain wavelength range.

   Accurate flux measurements requires a good definition of photometric standards, which will have to be different for different spectral ranges.

   Also spectro-photometric standards are required.

   (*The atmosphere is a difficult to solve problem when high accuracy is required. The highest accuracy can only be achieved from the space.)*
   Polarized and unpolarized standards are required for the calibration of polarization measurements.

3.1 The International Celestial Reference System

Rationale:

The fundamental planes, equator and ecliptic, define the astronomical equatorial (absolute) reference system of coordinates (α,δ). However these planes are variable. Some of these variations can be easily modeled as the secular precession of the Earth rotation axis around the ecliptic pole or the chandlerian period but some are not, like seasonal variations of the rotation axis or unpredictable variations associated to geodynamical processes. As a result, the very definition of these planes is problematic for high precision work.

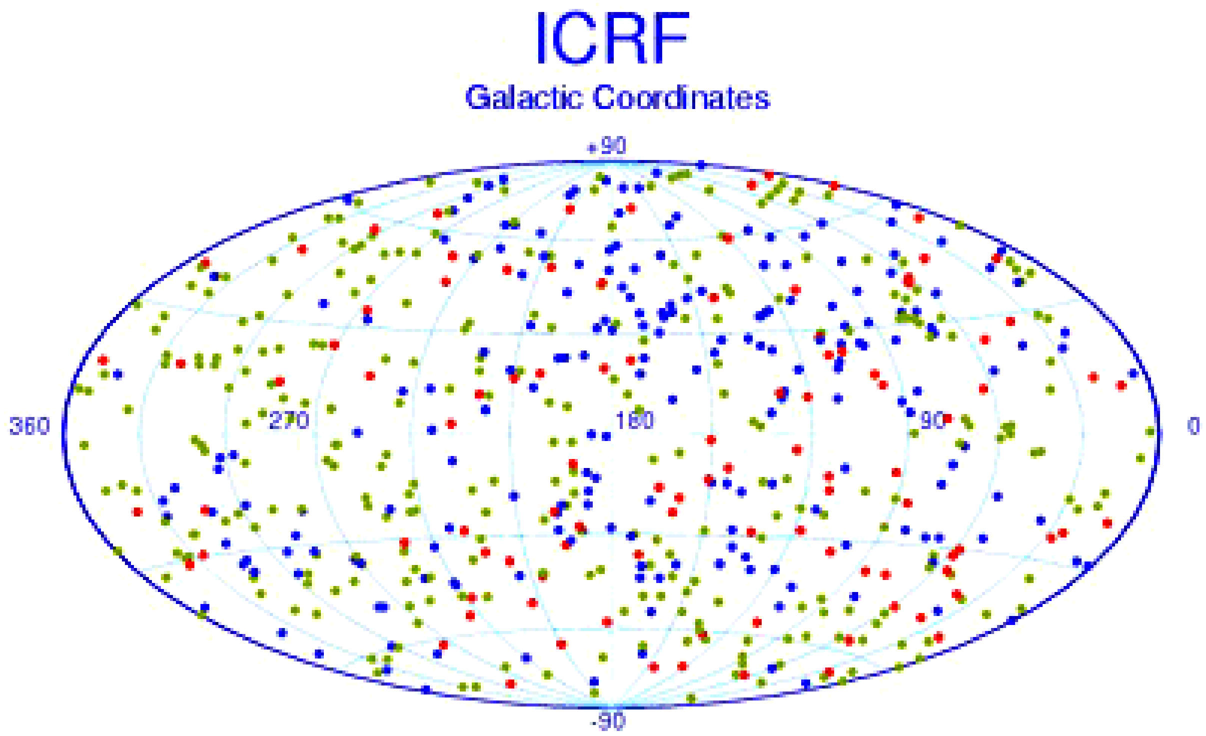
The ICRS is a means of realizing a space-fixed (quasi-inertial) coordinate system on the sky by defining a set of fiducial objects, specifying the precise coordinates for each one, and providing standard models and algorithms that allow these coordinates to be transformed into observable quantities for any epoch.

For this purpose both a *reference system* and a *reference frame* have to be defined:

A *reference system* is the complete specification of how a celestial coordinate system is to be formed. It defines the origin and fundamental planes (or axes) of the coordinate system. It also specifies all of the constants, models, and algorithms used to transform between observable quantities and reference data that conform to the system.

A *reference frame* consists of a set of identifiable fiducial points on the sky along with their coordinates, which serves as the practical realization of a reference system.

Most commonly, a reference frame consists of a catalogue of precise positions (and motions, if measurable) of stars or extragalactic objects as seen from the solar system barycenter at a specific epoch (now usually "J2000.0", which is 12h TT on 1 January 2000). The ICRS is materialized by precise equatorial coordinates of extragalactic radio sources observed in Very Long Baseline Interferometry (VLBI) programmes.



The ICRF contains J2000.0 VLBI coordinates of 608 extragalactic radio sources evenly distributed on the sky. The radio positions are based upon a general solution for all applicable dual-frequency Mark III VLBI data available through the middle of 1995. Because of different observing histories and astrometric suitability, the source positions estimated from the VLBI data analysis are of varying quality. Thus the objects in ICRF are classified in three categories:

- Defining sources: 212 high-astrometric-quality objects, as far as the period of observations analyzed to build the frame is concerned. They define the ICRF axes.

- Candidate: 294 sources, some have insufficient observations or duration of observation to be defining, while others with many observations may have larger than expected differences in position between catalogue. They are likely to climb up to the former category in the future.

- Other: 102 sources with identified excessive position variation, either linear or random. They are included for the sake of densifying the frame or because they have contributed to the optical frame ties.

Official and commonly used source designations, physical characteristics and position time series plots and values are provided for the 608 ICRF objects. In addition complete information for an individual source, can also be obtained.

The ICRS is described in http://hpiers.obspm.fr/webiers/results/icrf/Icrs.html

Equator/Pole of ICRS

The VLBI analysis which permits to calculate radio source coordinates also provide corrections to the conventional IAU models for precession and nutation, thus leading to the accurate estimation of the shift of the mean pole at J2000.0 relative to its conventional position, to which the pole of ICRS is attached. One can estimate that the pole at J2000.0 is shifted from the ICRS pole by 17.1 mas in the direction 12h and by 5.1 mas in the direction 18h.

The pole of ICRS is also consistent with that of FK5. Using the Hipparcos catalogue which includes all the FK5 stars, Mignard and Froeschle(1997) have derived the FK5 pole in ICRF with an uncertainty of a few mas. Assuming that the error in the precession rate is absorbed by the proper motions of stars, the uncertainty in the FK5 pole position relative to the mean pole at J2000.0 can be estimated to ± 50 mas. The ICRS celestial pole is consistent with that of FK5 within the uncertainty of the latter.

Origin of right ascensions of ICRS

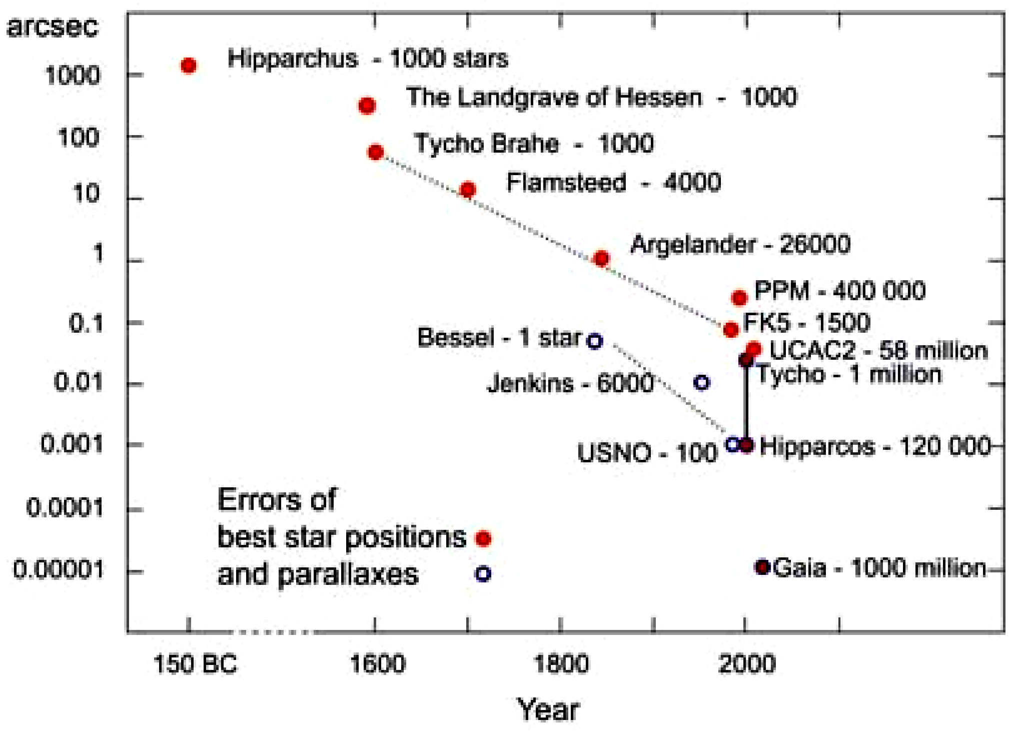
The Ox axis of ICRS was implicitly defined in the initial realization of the IERS celestial reference frame (Arias et al., 1988) by adopting the mean J2000.0 right ascensions of 23 radio sources in a group of VLBI catalogues. These catalogues were compiled by fixing the right ascension of the quasar 3C273B to the usual conventional FK5 value (Hazard et al., 1971).

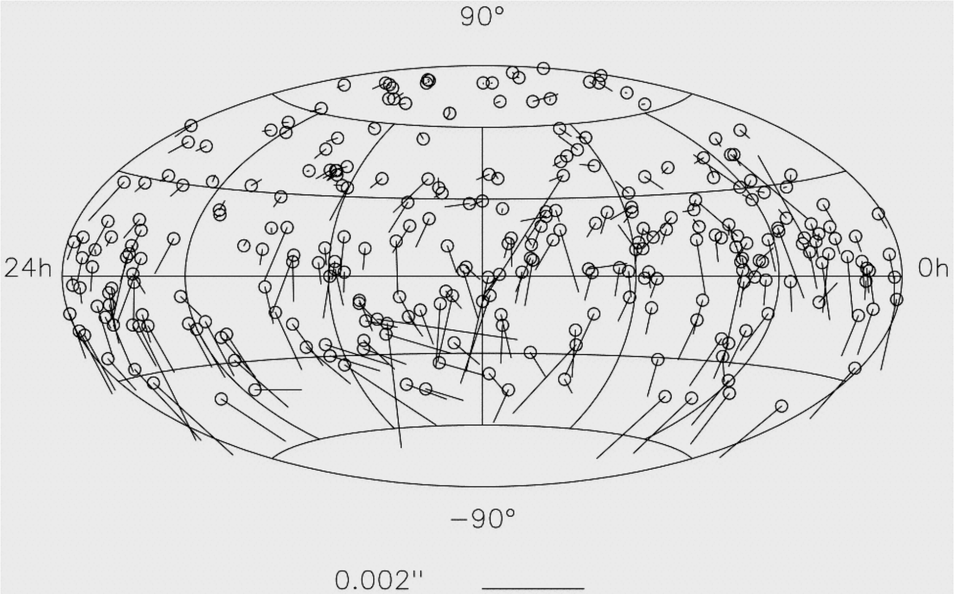
According to Mignard and Froeschle1997) the FK5 origin of right ascensions is offset from the ICRS one by -22.9 mas. Considering the mean epoch of 1955 for the proper motions in right ascension, the uncertainty in the FK5 origin of right ascensions can be estimated in ±100 mas (Morrison et al., 1990, Lindegren et al., 1995). Comparing VLBI and LLR Earth orientation and terrestrial reference frames, Folkner et al. (1994) estimated the frame tie between the IERS celestial system and the planetary ephemeris, showing that the Ox axis of ICRS is offset from the mean equinox at J2000.0 by 78 ±10 mas .

Note: The positions of solar system objects can also be used to define a reference frame. A reference frame defined by the ephemeredes of one or more solar system bodies is called a *dynamical reference frame*. Because the ephemeredes used incorporate the theories of motion of the Earth as well as that of the other solar system bodies, dynamical reference frames embody in a very fundamental way the moving equator and ecliptic, hence the equinox. They have therefore been used to properly align star catalogue reference frames (the star positions were systematically adjusted) on the basis of simultaneous observations of stars and planets. However, dynamical reference frames are not very practical for establishing a coordinate system for day-to-day astronomical observations. The ICRS does not involve a dynamical reference frame.

Building reference systems from astronomical catalogues….

Any two objects in the catalogue, any pair of coordinates or directions (α, δ), define a unique spherical coordinate system on the sky - a reference frame. A modern astrometric catalogue contains data on a large number of objects (N), so the coordinate system is vastly over determined. The quality of the reference frame defined by a catalogue depends on the extent to which the coordinates of all possible pairs of objects ($\sim N^2/2$) serve to define the identical equator and right ascension origin, within the expected random errors.





Comparison between GFSC and JPL sources

- Typically, every catalogue contains *systematic errors*, that is, errors in position that are similar in direction. Systematic errors mean that the reference frame is warped, or is effectively different for different classes of objects. Obviously, minimizing systematic errors when a catalogue is constructed is as important (if not more so) than minimizing the random errors.

- To be useful, a reference frame must be implemented at the time of actual observations, and this requires the computation of the geocentric coordinates of the catalogue objects at arbitrary dates and times. The accuracy of the *proper motions* of the objects is an essential factor in this computation. Because the tabulated proper motions are never perfect (even if assumed zero), any celestial reference frame deteriorates with time. Moreover, systematic errors in the proper motions can produce time-dependent warping and spurious rotations in the frame. Therefore, the accuracy and consistency of the proper motions are critical to the overall quality, utility, and longevity of reference frames defined by stars. For this reason the ICRF is based in very distant radiosources with basically undetectable proper motions.

A brief history about how the ICRS was built…

- The "1991 IAU Resolution on reference frames" (passed by the 21st IAU General Assembly) recommended that an IAU working group establish a list of extragalactic radio sources that would be "candidates for primary sources defining the new conventional reference frame."

- The construction and implementation of the ICRS was authorized and supported by the International Astronomical Union (IAU). Resolution B2, passed by the 23rd General Assembly of the IAU in August 1997, states that,

  1. *from 1 January 1998, the IAU celestial reference system shall be the International Celestial Reference System (ICRS) as specified in the 1991 IAU Resolution on reference frames and as defined by the International Earth Rotation Service (IERS);*
  2. *the corresponding fundamental reference frame shall be the International Celestial Reference Frame (ICRF) constructed by the IAU Working Group on Reference Frames;*
  3. *the Hipparcos Catalogue shall be the primary realization of the ICRS at optical wavelengths;*
  4. *the IERS should take appropriate measures, in conjunction with the IAU Working Group on Reference Frames, to maintain the ICRF and its ties to the reference frames at other wavelengths.*

- At the subsequent IAU General Assembly in 2000, restricted the number of Hipparcos stars that would be considered part of the optical realization of the ICRS. The relevant part of this resolution states that

  1. *all stars flagged C, G, O, V and X in the Hipparcos Catalogue should be excluded from the optical realization of the ICRS. This modified Hipparcos frame be labelled the Hipparcos Celestial Reference Frame (HCRF). This change eliminated about 15% of the stars in the Hipparcos catalogue, leaving those with well determined linear proper motions.*
  2. *The IAU 2000A precession-nutation model was defined, as well as the Celestial Intermediate Pole, the Celestial Ephemeris Origin, and other quantities that, together, specify how the orientation of the Earth is to be computed.*
  3. *Other related resolutions dealt with time scales and relativity.*

3.2 The Terrestrial Time (TT)

Definition: Terrestrial Time (TT) is a time scale established by the International Astronomical Union (IAU) to serve as the independent argument for apparent geocentric ephemeredes of solar system bodies. That is, TT is used for the prediction or recording of the positions of celestial bodies as measured by an observer on Earth. It is the successor to Ephemeris Time (ET), but is based on the SI second. It applies to clocks at sea-level, and for practical purposes it is tied to Atomic Time TAI through the formula $TT = TAI + 32.^{s}184$.

Ephemeris Time (ET) is an astronomical time scale defined by the orbital motions of the earth, moon, and planets. The earth does not rotate with uniform speed, so the solar day is an imprecise unit of time. Ephemeris time is calculated from the positions of the sun and moon relative to the earth, assuming that Newton's laws are perfectly obeyed. It is used to calculate the future positions of the sun and the planets. By convention, the standard seasonal year is taken to be A.D. 1900 and to contain 31,556,925.9747 sec of ephemeris time. In 1984 ephemeris time was renamed terrestrial dynamical time (TDT or TT).

Atomic Time (TAI), with the unit of duration the *System International (SI) second* defined as the duration of 9,192,631,770 cycles of radiation corresponding to the transition between two hyperfine levels of the ground state of cesium 133. TAI is the International Atomic Time scale, a statistical timescale based on a large number of atomic clocks.

3.3 The Barycentric Dynamic Time

Barycentric Dynamic Time (TDB) is the independent argument of ephemeredes and dynamical theories that are referred to the *solar system barycenter*. TDB varies from TT only by periodic variations. TDB differs from TT by an amount which cycles back and forth by between 1 and 2 milliseconds due to relativistic effects. It is a consequence of the TT clock being on the Earth rather than in empty space: the ellipticity of the Earth's orbit means that the TT clock's speed and gravitational potential vary slightly during the course of the year, and as a consequence its rate as seen from an outside observer varies due to transverse Doppler effect and gravitational redshift. By definition, TDB and TT differ only by periodic terms, and the main effect is a sinusoidal variation of amplitude; the largest lunar and planetary terms are nearly two orders of magnitude smaller.

- The variation is negligible for most purposes, but unless taken into account would swamp long-term analysis of pulse arrival times from the millisecond pulsars.
- For most purposes, the distinction between TT and TDB is of no practical importance. For example to predict the Earth's position and velocity.

3.4 The Coordinated Universal Time

Universal Time (UT) is counted from 0 hours at midnight, with unit of duration the *mean solar day*, defined to be as uniform as possible despite variations in the rotation of the Earth.

UT0 is the rotational time of a particular place of observation. It is observed as the diurnal motion of stars or extraterrestrial radio sources.

UT1 is computed by correcting UT0 for the effect of polar motion on the longitude of the observing site. It varies from uniformity because of the irregularities in the Earth's rotation. In astronomical usage, UT often refers to UT1.

Coordinated Universal Time (UTC) differs from TAI by an integral number of seconds. UTC is kept within 0.9 seconds of UT1 by the introduction of one-second steps to UTC, the ***"leap second"*.** To date these steps have always been positive.

[In the most common civil usage, UT refers to UTC which is the basis for the worldwide system of civil time. This time scale is kept by time laboratories around the world and is determined using highly precise atomic clocks. The International Bureau of Weights and Measures makes use of data from the timing laboratories to provide the international standard UTC which is accurate to approximately a nanosecond (billionth of a second) per day. The length of a UTC second is defined in terms of an atomic transition is not directly related to any astronomical phenomena. UTC is the time distributed by standard radio stations that broadcast time, such as RNE. It can also be obtained readily from the Global Positioning System (GPS) satellites. The difference between UTC and UT1 is made available electronically and broadcast so that navigators can obtain UT1.]

The leap second:

Civil time (UTC) is occasionally adjusted by one second increments to ensure that the difference between a uniform time scale defined by atomic clocks does not differ from the Earth's rotational time by more than 0.9 seconds.

Rationale: The Earth is constantly undergoing a deceleration caused by the braking action of the tides. Through the use of ancient observations of eclipses, it is possible to determine the average deceleration of the Earth to be roughly 1.4 milliseconds per day per century. This deceleration causes the Earth's rotational time to slow with respect to the atomic clock time. After 500 days, the difference between the Earth rotation time (UT1) and the atomic time (UTC) would be 1 second. Instead of allowing this to happen, the leap second is inserted to bring the two times closer together.

Investigations of topocentric solar-system phenomena such as occultations and eclipses require solar time as well as dynamical time. TT/TDB is all that is required in order to compute the geocentric circumstances, but if horizon coordinates or geocentric parallax are to be tackled UT is also needed.

Dynamical time is the independent variable in the theories which describe the motions of bodies in the solar system. When you use published formulae which model the position of the Earth in its orbit, for example, or look up the Moon's position in a precomputed ephemeris, the date and time you use must be in terms of one of the dynamical timescales. If UT is used directly the results will be about 1 minute out (in the present era).

It is not hard to see why such timescales are necessary. UTC would clearly be unsuitable as the argument of an ephemeris because of leap seconds. A solar-system ephemeris based on UT1 or sidereal time would somehow have to include the unpredictable variations of the Earth's rotation. TAI would work, but eventually the ephemeris and the ensemble of atomic clocks would drift apart. In effect, the ephemeris *is* a clock and the hands are the motions of the bodies of the solar system.

A brief RECENT history of the "second"….

In a first step, the second was defined in terms of the rotation of the Earth as 1/86,400 of a mean solar day, *1900 January 0 at12 hours mean solar time*

In 1956, the International Committee for Weights and Measures, defined the second in terms of the period of revolution of the Earth around the Sun for a particular epoch, because by then it had become recognized that the Earth's rotation was not sufficiently uniform as a standard of time.

The Earth's motion was described in Newcomb's *Tables of the Sun*, which provides a formula for the motion of the Sun at the epoch 1900 based on astronomical observations made during the eighteenth and nineteenth centuries. The *ephemeris second* thus defined is "*the fraction 1/31,556,925.9747 of the tropical year for 1900 January 0 at12 hours ephemeris time.*" Ephemeris Time (ET) was defined as the measure of time that brings the observed positions of the celestial bodies into accord with the Newtonian dynamical theory of motion.

In 1960, this definition was ratified by the 11th General Conference on Weights and Measures.

In the following several years of work, two astronomers at the USNO and two astronomers at the National Physical Laboratory (Teddington, England) determined the relationship between the frequency of the cesium atom (the standard of time) and the ephemeris second. They determined the orbital motion of the Moon about the Earth, from which the apparent motion of the Sun could be inferred, in terms of time as measured by an atomic clock.

In 1967 the Thirteenth General Conference on Weights and Measures defined the **second** of atomic time in the International System of Units (SI) as "*the duration of 9,192,631,770 periods of the radiation corresponding to the transition between the two hyperfine levels of the ground state of the cesium 133 atom".* The second thus defined is equivalent to the ephemeris second.

The **International Earth Rotation Service (IERS)**, monitors the Earth's rotation. Part of its mission involves the determination of UT1.

3.5 The standards for flux calibration:

Standards have to fulfill two basic conditions:

1. They have to be bright sources (to avoid spending too much observing time in calibration-related observations) but not too bright!. As a consequence they are instrument/telescope/wavelength dependent. For instance, White Dwarfs are taken as standards for the UV range but will never be used in the optical range.

2. They cannot be variable. As a consequence they also depend on the sensitivity of the instrument.

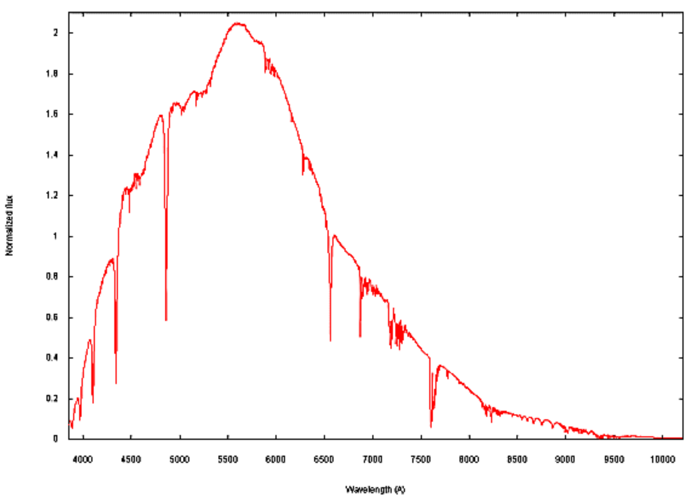
There is a web site that collects information on *Standard Objects For Astronomy* (SOFA) (URL:sofa.astro.utoledo.edu/SOFA/) according to different observing techniques (Photometry, Spectroscopy, Polarimetry, Interferometry…) and wavelength domains (gamma, X-ray, UV, visible, IR, radio).

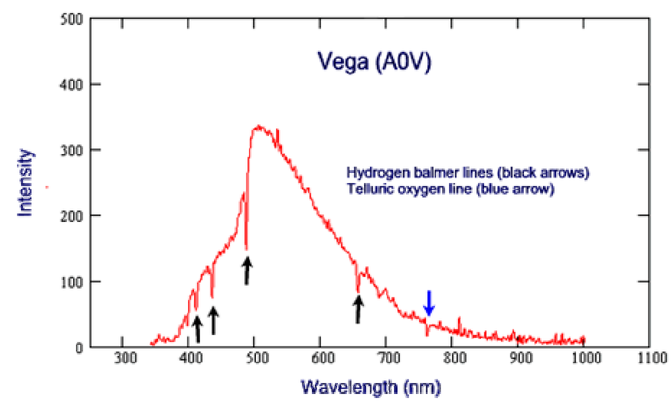
PRIMARY STANDARD: VEGA

The magnitude scale is defined such that,

$$m_1 - m_2 = -2.5 \log (F_1/F_2)$$ where m_1 and m_2 are magnitudes and F_1 and F_2 are fluxes

- The zero point of the magnitude scale has to be set by the definition of standard stars.
- Vega (α Lyrae) is the primary standard, *e.g.* by definition its magnitude should be 0.00 at all wavelengths.
- At λ=5556 Å, F=3.44x10^{-9} erg/s/cm^2/Å (Hayes,D.S. 1985, in *Calibration of Fundamental Stellar Quantities*, IAU Symp. 111) or F=3.6x10^{-9} erg/s/cm^2/Å (Rydgren *et al.* 1984, US Naval Obs. Pub. XXV, Pt. 1).
- By definition, the mean B-V colours of 11 Vega-like stars (spectral type A0) are zero.





a) Catalogues of photometric standard stars

There are many catalogues of photometric standard stars. A catalogue of primary standards for a given photometric system is usually published when the system is defined. For widely used systems further catalogues of `secondary' standards will often be compiled by making observations calibrated with the original primary standards.

- **Johnson-Morgan system (optical range)**
  - The primary standards for the Johnson-Morgan system are listed in various places, including the original publications. These standards are often too bright (and too few in number) for modern instrumentation and programmes, and catalogues of fainter (and more numerous) secondary standards are often more useful. Some suitable catalogues of secondary standards are: Johnson and Morgan1953 (ApJ,117,313), Landolt 1973 (AJ,78), Landolt 1983 (AJ 88), Landolt 1992 (AJ 104), Christian *et al*. 1985 (PASP 97), Graham 1982 (PASP 94) and Menzies *et al*.1991 (MNRAS,248). Landolt's catalogues are the most widely used

    (see URL:www.noao.edu/wiyn/obsprog/images/tableA.html)

  - Keck also uses this standards (V=11.5-16.0), this implies that any uncertainty in the flux calibration is greatly amplified when very weak sources, at the magnitude limit of the telescope, are observed. For this reason, new weaker standards are going to be defined for the 10m telescopes generation (as for instance the GTC).

THE ASTROPHYSICAL JOURNAL

AN INTERNATIONAL REVIEW OF SPECTROSCOPY AND ASTRONOMICAL PHYSICS

VOLUME 117 MAY 1953 NUMBER 3

FUNDAMENTAL STELLAR PHOTOMETRY FOR STANDARDS OF SPECTRAL TYPE ON THE REVISED SYSTEM OF THE YERKES SPECTRAL *ATLAS**

H. L. JOHNSON AND W. W. MORGAN
Yerkes and McDonald Observatories

Received November 29, 1952

ABSTRACT

A system of photoelectric photometry is outlined which utilizes the revised zero point of the visual magnitude scale of the North Polar Sequence and which returns to the original definition for the zero point of color indices in terms of main-sequence stars of class A0; the interval A0–gK0 is 1 mag. The revised Yerkes *Atlas* system (MK) of spectral classification is taken as standard. The latter is described briefly, and a list of standard stars is included.

Magnitudes and color indices from measures in three wave-length bands are given for stars selected by spectral type and luminosity class to be representative of the principal regions of the H-R diagram. A few white dwarfs are also included.

A standard main sequence is defined for the new color–absolute magnitude diagram by the use of stars of large parallax, together with the galactic clusters NGC 2362, the Pleiades, the Ursa Major nucleus, and Praesepe. A standard main sequence is also defined for the relationship between the two systems of color index.

A purely photometric method for determining spectral types and space reddening for B stars in galactic clusters is described.

TERMINOLOGY

y. Deflection through yellow filter, corrected for sky.
b. Deflection through blue filter, corrected for sky.
u. Deflection through ultraviolet filter, corrected for sky.
C_y. Observed blue-yellow color index, reduced to outside the earth's atmosphere.
C_u. Observed ultraviolet-blue color index, reduced to outside the earth's atmosphere.
V. Observed magnitude through yellow filter, reduced to outside the earth's atmosphere. This is approximately equivalent to the photovisual magnitude on the International System.
B. Observed magnitude through blue filter, reduced to outside the earth's atmosphere and including a zero-point correction to satisfy the condition

$$B - V = 0$$

for main-sequence stars of class A0 on the MK system.
U. Observed magnitude through ultraviolet filter, reduced to outside the earth's atmosphere and including a zero-point correction to satisfy the condition

$$U - B = 0$$

for main-sequence stars of class A0 on the MK system.

* *Contributions from the McDonald Observatory, University of Texas,* No. 216.

TABLE I. *UBV* photoelectric magnitudes and color indices for selected area stars.

Star	α(1975)	δ(1975)	V	B − V	U − B	n	m	Mean errors V	Mean errors B − V	Mean errors U − B	BSD	Type	Note
92- 263	$0^h54^m23^s$	+0°28′11″	10.79	$+1^m05$	$+0^m86$	15	7	0^m023	0^m008	0^m027	445	G5	
92- 276	0 55 10	+0 33 46	12.04	+0.63	+0.08	13	6	0.020	0.014	0.019	457	G0	
92- 282	0 55 30	+0 30 22	12.96	+0.32	−0.04	13	7	0.029	0.027	0.022	462	G:	
92- 288	0 56 00	+0 28 41	11.62	+0.86	+0.48	11	6	0.015	0.012	0.021	476	G3	
92- 336	0 53 45	+0 39 21	8.06	+0.98	+0.82	4	2	0.019	0.003	0.011	435	G8	
92- 342	0 53 53	+0 35 07	11.62	+0.44	−0.04	11	6	0.014	0.011	0.013	441	F8	
92- 348	0 54 13	+0 36 28	12.11	+0.59	+0.05	11	6	0.019	0.021	0.026	443	G0	
92- 364	0 55 36	+0 35 55	11.67	+0.60	−0.03	13	6	0.018	0.015	0.012	465	G0	
92- 433	0 55 37	+0 52 36	11.65	+0.66	+0.12	7	4	0.011	0.015	0.016	466	G2	
92- 507	0 55 34	+0 57 51	11.33	+0.94	+0.68	7	4	0.010	0.011	0.024	463	G0	
92- 508	0 55 34	+1 01 28	11.67	+0.54	−0.04	9	5	0.011	0.011	0.016	464	F5	
92- 510	0 55 51	+0 58 54	9.97	+1.07	+1.03	1	1	···	···	···	473	G5	
93- 12	1 51 39	+0 06 32	11.18	+0.42	+0.01	2	1	0.006	0.012	0.007	197	F4	
93- 24	1 52 46	+0 03 19	10.18	+0.68	+0.15	2	1	0.004	0.001	0.002	216	G3p	
93- 30	1 53 09	+0 02 50	11.47	+0.55	0.00	2	1	0.001	0.006	0.008	224	G2	
93- 35	1 53 40	+0 06 14	11.75	+0.53	+0.02	2	1	0.012	0.001	0.013	231	G0	
93- 37	1 53 43	+0 05 00	9.46	+0.44	+0.02	2	1	0.002	0.006	0.006	233	F2	
93- 101	1 52 01	+0 15 02	9.72	+0.65	+0.14	2	1	0.005	0.009	0.001	201	G2p	
93- 103	1 52 04	+0 15 53	8.81	+1.18	+1.16	2	1	0.001	0.001	0.000	203	G8	
93- 179	1 51 07	+0 25 06	11.07	+0.63	+0.14	8	4	0.012	0.016	0.010	475	G2	
93- 180	1 51 10	+0 24 55	11.24	+0.65	+0.07	9	4	0.009	0.007	0.014	447	G2	
93- 241	1 54 02	+0 29 12	9.39	+0.85	+0.42	6	3	0.014	0.006	0.010	541	G2	
93- 312	1 52 57	+0 39 00	12.00	+0.59	+0.05	15	8	0.015	0.019	0.010	507	G2	
93- 317	1 53 21	+0 35 40	11.55	+0.50	−0.04	15	8	0.018	0.026	0.015	519	F8	
93- 326	1 53 33	+0 39 44	9.56	+0.45	−0.03	9	4	0.011	0.006	0.010	527	F6	
93- 332	1 53 46	+0 32 52	9.79	+0.51	−0.02	6	3	0.012	0.013	0.015	534	F8	
93- 333	1 53 48	+0 38 24	12.00	+0.84	+0.46	17	9	0.019	0.016	0.030	535	G5	
93- 350	1 54 41	+0 39 05	10.26	+0.47	−0.06	8	4	0.014	0.017	0.007	562	F5	
93- 351	1 54 43	+0 39 54	10.93	+0.59	+0.08	6	3	0.012	0.009	0.014	563	F6	
93- 375	1 51 01	+0 44 53	10.69	+0.45	0.00	2	1	0.008	0.006	0.003	474	F6	
93- 395	1 52 27	+0 50 19	11.64	+0.67	+0.09	7	4	0.014	0.008	0.018	503	G2	
93- 405	1 53 03	+0 47 58	12.19	+0.50	−0.03	9	5	0.018	0.017	0.021	511	G0p	
93- 407	1 53 20	+0 46 28	11.96	+0.87	+0.58	19	9	0.020	0.017	0.027	518	G3	
93- 417	1 53 44	+0 45 34	11.92	+0.75	+0.25	17	8	0.022	0.013	0.026	532	G1	
93- 422	1 54 03	+0 51 47	12.11	+0.60	+0.08	2	1	0.013	0.006	0.015	543	G0	
93- 424	1 54 09	+0 49 23	11.62	+1.08	+0.95	14	6	0.010	0.017	0.034	548	K2	
93- 484	1 51 54	+0 53 00	12.26	+0.50	−0.03	13	7	0.019	0.021	0.029	489	G3	
93- 488	1 52 15	+0 53 32	12.16	+0.57	+0.04	1	1	···	···	···	497	G2	
93- 503	1 53 10	+0 52 10	12.60	+0.65	+0.12	13	7	0.020	0.019	0.025	513	G5	
93- 554	1 51 20	+1 08 03	8.52	+0.39	−0.03	4	2	0.018	0.014	0.016	479	F0	
93- 555	1 51 24	+1 05 18	10.69	+0.79	+0.25	2	1	0.009	0.008	0.004	480	G2p	
94- 6	2 52 08	−0 05 08	9.54	+1.08	+0.85	4	2	0.028	0.013	0.013	210	G6	1
94- 11	2 52 21	−0 02 50	9.12	+1.05	+0.77	4	2	0.013	0.008	0.028	216	G5	
94- 32	2 53 30	−0 09 01	6.52	+1.05	+0.88	7	4	0.007	0.009	0.016	229	G4	
94- 86	2 56 43	−0 10 43	11.52	+0.77	+0.33	4	2	0.018	0.017	0.011	281	G1	
94- 90	2 56 59	−0 07 32	11.89	+0.66	+0.09	4	2	0.016	0.024	0.022	285	G1	
94- 155	2 56 47	+0 04 41	11.67	+0.50	+0.02	4	2	0.008	0.014	0.014	282	G0	
94- 163	2 57 06	+0 02 37	12.35	+0.60	+0.08	6	3	0.023	0.016	0.027	286	F9	
94- 168	2 52 13	+0 15 39	11.82	+1.03	+0.76	8	3	0.024	0.011	0.046	213	K2	2
94- 171	2 52 22	+0 11 13	12.65	+0.82	+0.27	4	2	0.031	0.019	0.034	217	G5	
94- 188	2 53 00	+0 13 22	11.77	+1.02	+0.85	4	2	0.009	0.008	0.027	225	G5	
94- 228	2 55 08	+0 14 02	10.49	+0.41	−0.02	1	1	···	···	···	257	F2p	
94- 236	2 55 36	+0 13 52	10.48	+1.23	+1.20	3	2	0.020	0.004	0.008	262	K3	
94- 242	2 56 05	+0 12 38	11.73	+0.30	+0.08	10	5	0.014	0.008	0.005	268	A5	
94- 251	2 56 30	+0 10 04	11.21	+1.21	+1.24	11	6	0.010	0.008	0.033	278	K2	
94- 293	2 53 57	+0 20 14	7.02	+1.13	+1.12	7	4	0.014	0.011	0.015	470	G5	
94- 296	2 54 03	+0 22 11	12.26	+0.74	+0.24	11	6	0.017	0.024	0.031	476	G3	
94- 297	2 54 05	+0 22 02	12.08	+0.75	+0.27	9	5	0.019	0.014	0.016	477	G5	
94- 300	2 54 18	+0 23 45	11.53	+1.10	+1.01	11	5	0.016	0.015	0.028	484	K2	
94- 305	2 54 39	+0 24 55	8.89	+1.42	+1.60	7	4	0.014	0.009	0.039	490	K5	
94- 308	2 54 57	+0 25 16	8.74	+0.50	0.00	7	4	0.010	0.008	0.010	498	F7p	
94- 319	2 55 54	+0 20 54	6.62	+0.32	+0.04	7	4	0.009	0.005	0.008	514	F0	
94- 328	2 56 22	+0 27 56	10.05	+0.74	+0.28	2	1	0.008	0.004	0.006	530	G3	
94- 342	2 57 12	+0 20 16	9.03	+1.00	+0.73	7	4	0.019	0.010	0.018	544	K0	
94- 392	2 54 49	+0 28 46	11.04	+0.68	+0.14	1	1	···	···	···	494	G1	
94- 394	2 54 57	+0 29 09	12.26	+0.55	−0.04	11	5	0.019	0.022	0.026	499		

- **Strömgren system (optical range)**
  - Grønbech and Olsen 1976 (A&AS 25), Grønbech, Olsen and Strömgren (A&AS 26) and references therein.

- ***JHKLM* system (infrared range)**
  - For catalogues of standards in the *JHKLM* system see http://www.starlink.rl.ac.uk/star/docs/sc6.htx/node10.html#IRSYS
  - As for the original Johnson-Morgan system, the zero point of the *JHKLM* system is defined so that an unreddened A0 star has the same magnitude in all colours: $J = H = K = L = M$ ($= U = B = V$). The standard star used is also Vega (β Lyræ).

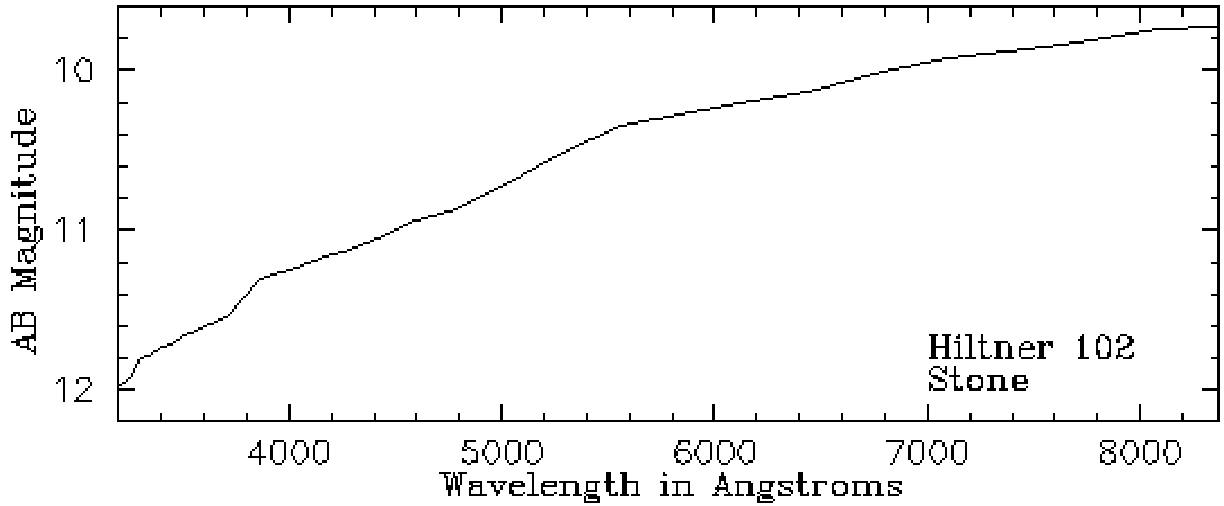
- **UV photometry**
  - The system is based on the TD1 satellite UV fluxes, by Thompson et al. (*Scientific Research Council*, 1978); magnitudes and standard errors are derived from absolute fluxes by means of the calibration by Hayes & Latham (A. J. 197, 593, 1975).
  - Wavelengths: 274.0 nm (effective width 310*Å*), *236.5 nm* (effective width *330Å*), *196.5 nm* (effective width *330Å*), and *156.5 nm* (effective width *330Å*).

b) Catalogues of spectrophotometric standard stars

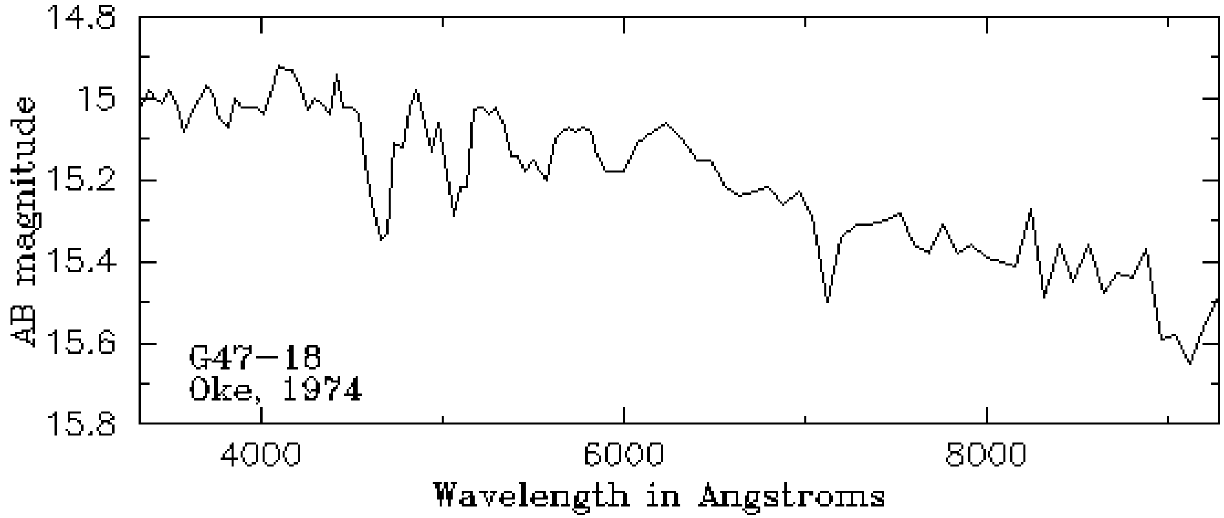
•**Spectrophotometric standards (optical range):**

•There are many lists of standards (often provided in the observatories web pages).

•As an example: this is a part of a Technical Note from the ING-telescopes compiled primarily for observers requiring a quick-reference list of stars.
(URL:http://www.ing.iac.es/Astronomy/instruments/pfip/pfip_flux_stand.html)
"*The list is based on Strom's (1977) list of spectrophotometric standards for use with the Kitt Peak telescopes and is intended both for use at the telescope and for reference when planning observations. The aim here has been to maintain essentially the same style of presentation as Strom, but enhance the usefulness for today's observers by: providing new, more accurate positions; checking the proper motions; adding a few extra standards; and by pointing out a number of minor errors and inconsistencies in Strom's and other related papers. Most of the 59 stars discussed come from the Kitt Peak list. Nine other standards have been included: 5 faint stars measured by Filippenko and Greenstein (1984), and 4 bright stars by Oke and Gunn (1983) who give flux magnitudes to 12,000Å…*"



Stone, R.P.S., 1977. Astrophys. J., 218, 767.



Oke, J.B., 1974. Astrophys. J. Supp. Ser. 27, 21

•**Spectrophotometric standards (UV range):**

- •Most of the information is gathered at the MAST (*Multimission Archive at the Space Telescope*: archive.stsci.edu) which contains all the archives on the UV missions.
- •The only mission currently working in the UV range (from 120nm to 320nm) is the *Hubble Space Telescope* (HST): Bohlin et al. (ApJS, 73, 413, 1990) discuss the UV calibration of HST standards from IUE data.
- •The basic data for the UV and optical spectrophotometric standards is held in the database CALOBS at StSci (URL: http://kahuna.stsci.edu/instruments/observatory/cdbs/calobs.html) there are spectra available for 23 stars in this **white dwarf flux system.** Turnshek et al. (AJ, 99, 1243, 1990) list the calibration targets and provide finding charts.
- •The conversion of the IUE, HST FOS and optical spectra into standard star spectra on the white dwarf primary spectrophotometric scale (Bohlin, Colina & Finlay, AJ, 110, 1316, 1995) is described by Bohlin (Proceedings of STScI HST Calibration Workshop, eds. A. Koratkar & C. Leitherer, p. 49, 1994) and Bohlin (AJ, 111, 1743, 1996).
- •The data for the 23 stars in the white dwarf spectrophotometric system and a further 7 stars with IUE and model fluxes (indicated by an M in the last column of the table below) are provided in the CALOBS web page (fits files). The ABMag/flux conversion has been made using the formula ABMAG = -2.5 alog10(Fv) - 48.59 (Hamuy et al., PASP, 104, 533, 1992), where Fv is in ergs/cm/cm/s/Hz.

Star Name	α (hhmmss.ss)	δ (±ddmmss.s)	Spec. Type	STMAG[1] (5460A)	Model opt. spectra
HR153	00 36 58.30	+53 53 48.9	B2 IV	3.63	M
BPM16274	00 50 03.18	-52 08 17.4	DA2	14.36	M
GD 50	03 48 50.06	-00 58 30.4	DA2	14.05	
Hz4	03 55 21.70	+09 47 18.7	DA4	14.45	
LB227	04 09 28.76	+17 07 54.4	DA4	15.24	
Hz2	04 12 43.51	+11 51 50.4	DA3	14.02	
HR1996	05 45 59.92	-32 18 23.4	O9 V	5.15	M
HD 49798	06 48 04.64	-44 18 59.3	O6	8.31	M
HD 60753	07 33 27.26	-50 35 03.7	B3 IV	6.60	M
BD+75d325	08 10 49.31	+74 57 57.5	O5p	9.51	
AGK+81266	09 21 19.06	+81 43 28.6	sdO	11.88	
GD 108	10 00 47.33	-07 33 31.2	sdB	13.57	
Feige 34	10 39 36.71	+43 06 10.1	DO	11.12	
HD 93521	10 48 23.51	+37 34 12.8	O9 Vp	6.95	
HR4554	11 53 49.83	+53 41 41.1	A0 V	2.59	M
Hz21	12 13 56.42	+32 56 30.8	DO2	14.67	
Hz44	13 23 35.37	+36 08 00.0	sdO	11.68	
GRW705824	13 38 51.77	+70 17 08.5	DA3	12.80	
HR5191	13 47 32.44	+49 18 48.0	B3 V	1.83	M
BD+332642	15 51 59.86	+32 56 54.8	B2 IV	10.73	
Vega	18 36 56.33	+38 47 01.1	A0 V	-0.01	
LDS749B	21 32 15.75	+00 15 13.6	DB4	14.71	
BD+284211	21 51 11.07	+28 51 51.8	Op	10.47	
G93-48	21 52 25.33	+02 23 24.3	DA3	12.74	
NGC7293St	22 29 38.46	-20 50 13.3	Hot	13.48	
Feige 110	23 19 58.39	-05 09 56.1	DOp	11.80	

[1] STMAG = -2.5 log10(F(λ)) - 21.10 where F(λ) is in ergs/cm/cm/s/A.

c) Catalogues of polarimetric standard stars

- Two kind of standard stars are required:
  - Unpolarized standards: to remove systematic polarization effects introduced by the instrumental set-up.
  - Polarized standards: to relate the polarization direction to an absolute reference frame, namely the ICRS.

- List of standards may be found for:

  - The UV/optical range:
    The most comprehensive review and collection of data is in the *Wisconsin Ultraviolet Photo Polarimeter Instrument* (WUPPE) web page (URL:www.sal.wisc.edu/WUPPE/polcats/wuppol.html)
    There is also further information in Turnshek et al 1990 (AJ **99** 1243) from HST work.

  - The infrared range:
    A comprehensive collection including both polarized and unpolarized standards may be found in the *United Kingdown InfraRed Telescope* (UKIRT) web page
    (URL: http://www.jach.hawaii.edu/JACpublic/UKIRT/instruments/irpol/irpol_stds.html)

UNPOLARIZED STANDARD STARS (optical/UV)

Star Name	α(2000)	δ(2000)	V	Spectral Type
HD 432	00 09 10.69	+59 08 59.2	2.2	F2 IV
HD 12021(1)	01 57 56.14	-02 05 57.7	8.85	A0
HD 10476	01 42 29.76	+20 16 06.6	5.2	K1 V
HD 14069(1)	02 16 45.19	+07 41 10.7	8.99	A0
HD 20630	03 19 21.70	+03 22 12.7	4.8	G5 V
EGGR 247(1)	05 05 30.61	+52 49 51.9	11.79	DAw (White Dwarf)
HD 38393	05 44 27.79	-22 26 54.2	3.6	F6 V
HD 39587	05 54 22.98	+20 16 34.2	4.4	G0 V
HD 43834	06 10 14.47	-74 45 11.0	5.09	G6 V
HD 61421	07 39 18.11	+05 13 30.0	0.3	F5 IV
HD 100623	11 34 29.49	-32 49 52.8	6.0	K0 V
HD 102870	11 50 41.72	+01 45 53.0	3.6	F8 V
GJ 3753(1)	12 50 05	+55 06.0	12.32	DA
HD 114710	13 11 52.39	+27 52 41.4	4.3	G0 V
HD 115617	13 18 24.3	-18 18 40.3	4.8	G6 V
BD +33 2642(1)	15 51 59.89	+32 56 54.32	10.81	B2IV (PN)
HD 154417	17 05 16.82	+00 42 09.2	6.0	F8 V
36 Oph A	17 15 20.98	-26 36 10.2	4.3	K1 V (Double star)
HD 156384	17 18 57.18	-34 59 23.3	5.0	F7V
HD 165908	18 07 01.54	+30 33 43.7	5.06	F7V
HD 185395	19 36 27.1	+50 13 10	4.5	F4 V
HD 188512	19 55 18.79	+06 24 24.3	3.7	G8 IV
HD 198149	20 45 17.38	+61 50 19.6	3.4	K0 IV
WD 2148+286(1)	21 51 11.02	+28 51 50.4	10.54	Op (White Dwarf)
HD 209100	22 03 21.66	-56 47 0.9.5	4.64	K5 IV
HD 210027	22 07 00.67	+25 20 42.4	3.8	F5 V
HD 212311(1)	22 21 58.59	+56 31 52.7	8.12	AA0
HD 216956	22 57 39.04	-29 37 20.1	1.2	A3 V

(1) from URL:chinadoll.as.arizona.edu/~schmidt/spol/polstds.html

POLARIZED STANDARDS (optical/UV)

TABLE III. *HST* polarimetric calibration targets—polarized stars.

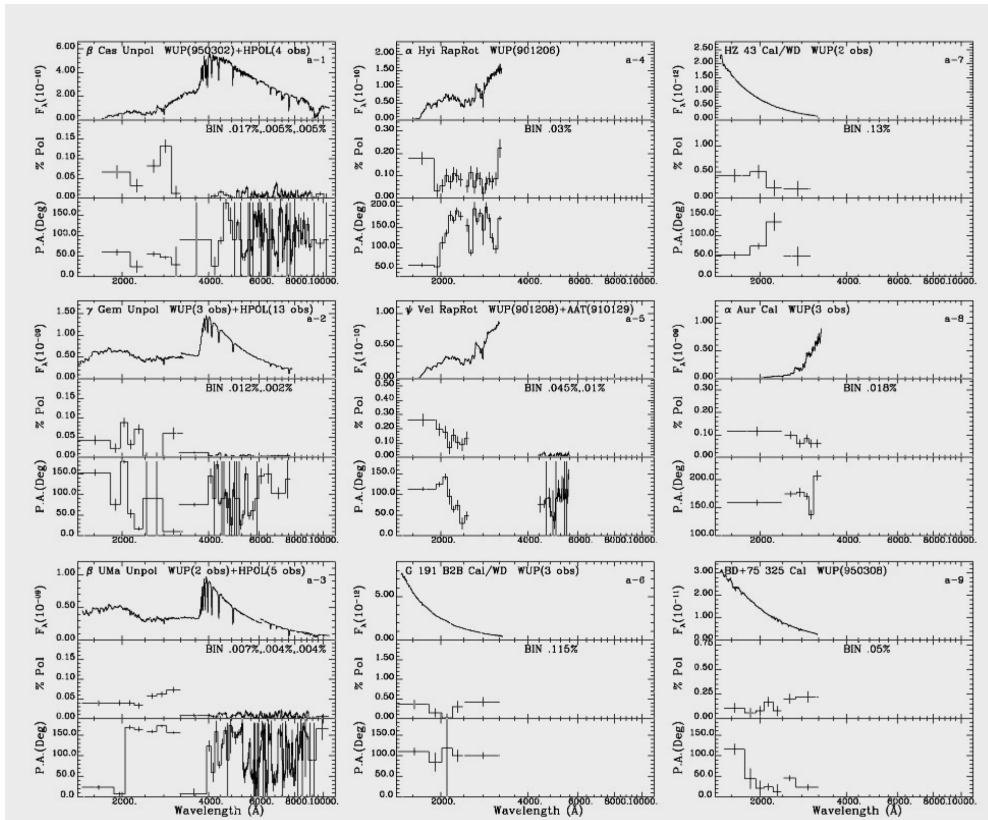
Name	α (2000)			δ (2000)			V	$B-V$	Spectral Type	$\%P_V(Err)^a$	$\theta_V{}^b$	N^c
BD+64° 106	0^h	57^m	$36^s.71$	+64°	51′	35″.1	10.34	+0.69	B1V	5.65(.053)	96°.8	2
BD+59° 389	2	02	42.06	+60	15	26.5	9.07	+1.01	F0Ib	6.69(.027)	98.2	4
HD19820	3	14	05.35	+59	33	47.7	7.11	+0.51	O9IV	4.81(.047)	114.9	4
HD25443	4	06	08.07	+62	06	07.0	6.78	+0.29	B0III	5.13(.061)	134.2	1
BD+25° 727	4	44	24.90	+25	31	42.7	9.50	+0.72	A2III	4.27(.012)	33.8	1
HD251204	6	05	05.67	+23	23	38.9	10.28	+0.28	B0IV	4.04(.066)	147	1
HD298383	9	22	29.76	−52	28	57.4	9.68	+0.88	A0Ib	5.23(.009)	148.6	12
HD110984	12	46	44.91	−61	11	11.7	8.95	+0.44	B0IV	5.70(.007)	91.6	20
HD111579	12	51	03.61	−61	14	37.8	9.50	+0.78	B2Ib/II	6.46(.014)	103.1	6
HD126593	14	28	51.06	−60	32	24.8	8.50	+0.49	B0.5IV	5.02(.012)	75.2	6
o Sco	16	20	38.20	−24	10	10.3	4.57	+0.84	A5II	4.17(.008)	32.9	6
HD154445	17	05	32.24	−0	53	31.7	5.61	+0.12	B1V	3.80(.075)	88.03	4[d]
HD155197	17	10	15.62	−4	50	03.1	9.20		A0	4.38(.030)	103.2	4
HD161056	17	43	47.03	−7	04	46.2	6.32	+0.36	B1.5V	4.035(.038)	67.01	4[d]
HD204827	21	28	57.70	+58	44	24.0	7.93	+0.82	B0V	5.36(.025)	58.6	5

[a] $\%P_V(Err)$ is the percent polarization in the V filter with the uncertainty in parentheses.
[b] θ_V is the equatorial position angle in the V filter.
[c] Number of observations by Tapia or Schmidt
[d] Possibly variable

(from Turnshek et al 1990, AJ 99, 1243)

It is difficult to find non-variable polarized standards. For instance, HD204827 is known to be variable (see Bastien et al 1988: AJ, 95, 900).

- WUPPE and Optical data (1400A -11000A) for unpolarized sources including unpolarized standards (Bet Cas, Gam Gem, Bet UMa), rapid rotators (Alpha Hyi, Psi Vel), white dwarfs and flux calibration (G191B2B, HZ43, Alpha Aur, BD+75 325) targets



(from URL:www.sal.wisc.edu/WUPPE/Atlas/atlas01.html)

3. The origin of the IVO (AVO).

At the origin of the AVO, there were a set of services demanded by the national astronomical communities to gather, cross-identify, catalogue and provide easy access to all kinds of astronomical data.

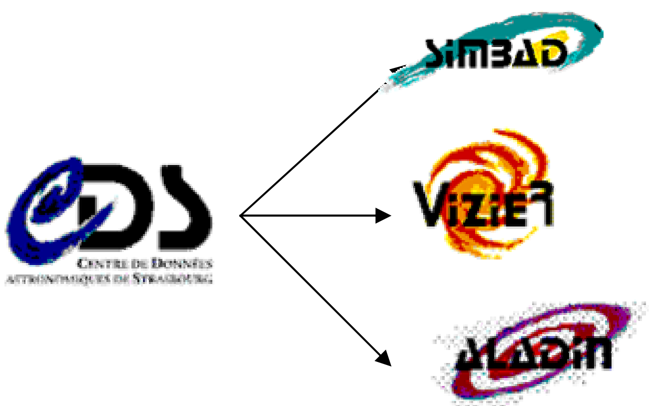
The services were related with:

- On-line catalogues of astronomical sources
- Cross-identification services
- Compilations of measured properties for different type of sources
- Bibliographic services to access information on a given astronomical object and/or the work on a certain issue
- Web access to publications and calibration data
- Data Archives

Some services were developed in various countries simultaneously and, at the end, those most demanded by the community have become leading contributors to AVO. This is just a short summary of the most useful for usual astrophysics research.

The Centre de Données astronomiques de Strasbourg (CDS)

The Strasbourg astronomical Data Center (CDS) is a data center dedicated to the collection and worldwide distribution of astronomical data and related information. The CDS hosts the SIMBAD astronomical database, the world reference database for the identification of astronomical objects.
URL: cdsweb.u-strasbg.fr



Search by astronomical sources	http://simbad.u-strasbg.fr/sim-fid.pl
Search catalogues	http://vizier.u-strasbg.fr/viz-bin/VizieR
Search Sky plates	http://aladin.u-strasbg.fr/aladin.gml

SIMBAD: Query by identifier, coordinates or reference code

other query modes	Query by identifier	Query by coordinates	Query by reference code	Query by list (file)	Query by parameters

1. Enter an identifier, coordinates or a reference code:

Examples:
sirius, M 31, 12 30 45 +10 20, 1996A&A.305.33K
How to write an identifier can be found in the dictionary of nomenclature.
UAI format can also be used (Ex: uai 1230+08 Object-type)

a. For identifiers you can choose to query : only this object

b. For coordinate and around object queries, define a radius : 10 arc min

c. For coordinate queries, define the input system : FK5 epoch : 2000 equinox : 2000

SUBMIT CLEAR

2. Optional output options :

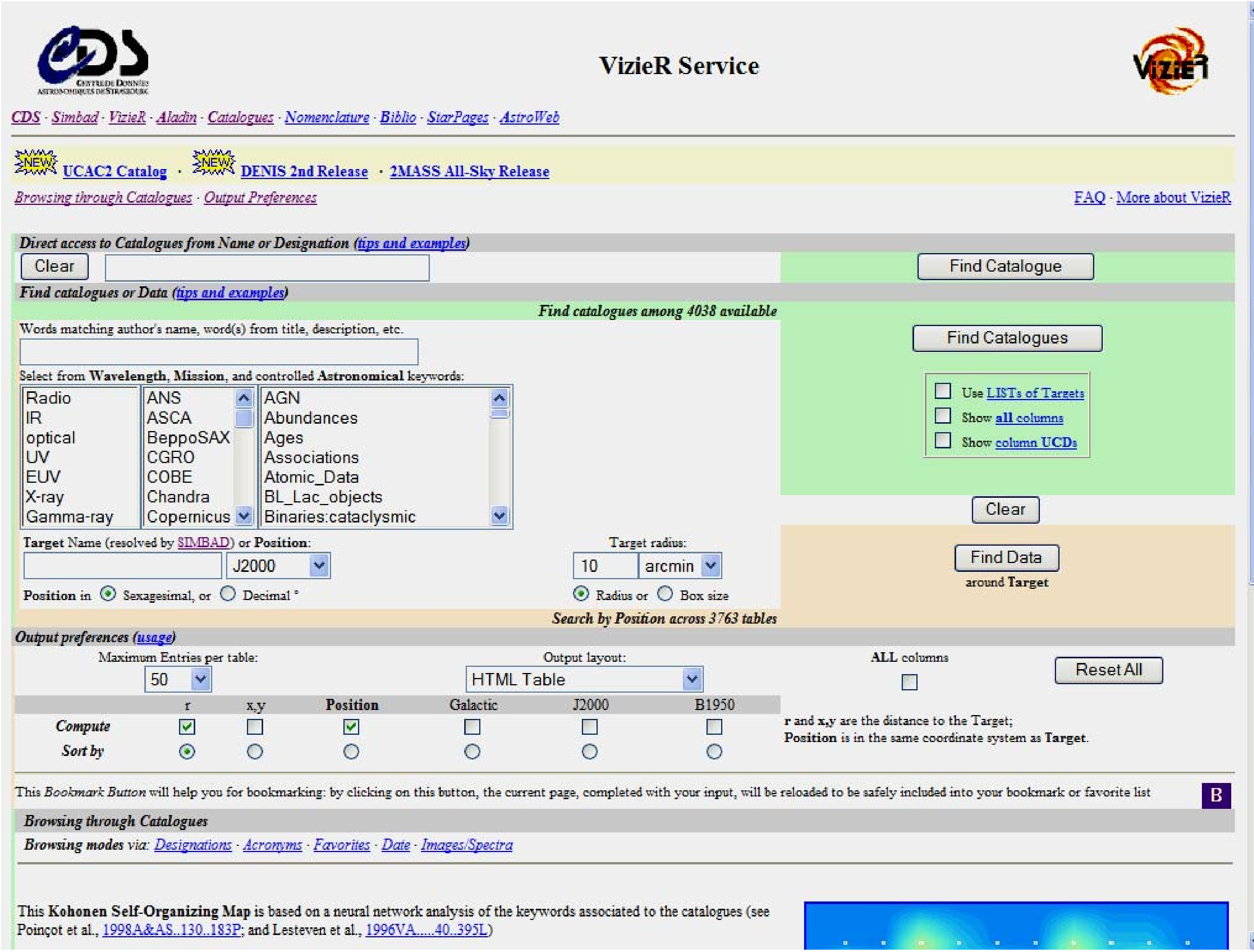
a. Lists should contain all objects.

b. ☑ **measurements** # of measurements

c. ☐ **bibliography** **from** 1983 **to** 2004

d. Display coordinates

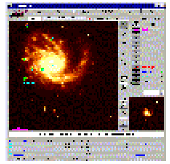
	1st frame :	2nd frame :	3rd frame :
Coordinate system :	FK5	FK4	Galactic
Equinox :	2000.0	1950.0	2000.0
Epoch :	2000.0	1950.0	2000.0


VizieR Service
CDS · Simbad · VizieR · Aladin · Catalogues · Nomenclature · Biblio · StarPages · AstroWeb
NEW UCAC2 Catalog · NEW DENIS 2nd Release · 2MASS All-Sky Release
Browsing through Catalogues · Output Preferences
FAQ · More about VizieR
Direct access to Catalogues from Name or Designation (tips and examples)
Clear
Find Catalogue
Find catalogues or Data (tips and examples)
Find catalogues among 4038 available
Words matching author's name, word(s) from title, description, etc.
Find Catalogues
Select from Wavelength, Mission, and controlled Astronomical keywords:
Radio
IR
optical
UV
EUV
X-ray
Gamma-ray
ANS
ASCA
BeppoSAX
CGRO
COBE
Chandra
Copernicus
AGN
Abundances
Ages
Associations
Atomic_Data
BL_Lac_objects
Binaries:cataclysmic
Use LISTs of Targets
Show all columns
Show column UCDs
Clear
Target Name (resolved by SIMBAD) or Position:
J2000
Target radius:
10
arcmin
Find Data
around Target
Position in Sexagesimal, or Decimal °
Radius or Box size
Search by Position across 3763 tables
Output preferences (usage)
Maximum Entries per table:
50
Output layout:
HTML Table
ALL columns
Reset All
r
x,y
Position
Galactic
J2000
B1950
Compute
Sort by
r and x,y are the distance to the Target;
Position is in the same coordinate system as Target.
This Bookmark Button will help you for bookmarking: by clicking on this button, the current page, completed with your input, will be reloaded to be safely included into your bookmark or favorite list
B
Browsing through Catalogues
Browsing modes via: Designations · Acronyms · Favorites · Date · Images/Spectra
This Kohonen Self-Organizing Map is based on a neural network analysis of the keywords associated to the catalogues (see Poinçot et al., 1998A&AS..130..183P; and Lesteven et al., 1996VA.....40..395L)

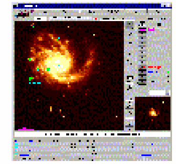
The Aladin Interactive Sky Atlas

CDS · Simbad · VizieR · Aladin · Catalogues · Nomenclature · Biblio · StarPages · AstroWeb

en français



Launch ***Aladin applet*** *(Fr - US - Jp - Ru - In - UK - Ca)**



Install ***Aladin*** *on your machine*

Jump to ***Aladin previewer***

New: Science case tutorial - February 2004
Aladin tutorials dedicated to specific science cases
New: Aladin manual 2nd release - February 2004
describing Aladin version 2
New: How to provide my data in Aladin - February 2004

Description

Aladin is an interactive software sky atlas allowing the user to visualize digitized images of any part of the sky, to superimpose entries from astronomical catalogs or personal user data files, 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).
The *Aladin interactive atlas* is available in three modes: a simple previewer, a Java applet interface and a Java Standalone interface.
The CDS provides the images of the Two Micron All Sky Survey (2MASS) from the University of Massachusetts and IPAC (JPL/ Caltech), the images of the Space Telescopes Science Institute Digital Sky Survey (DSS-I, DSS-II), with complete sky coverage, as well as an ensemble of higher resolution images (ESO-R and SERC plates) digitized at the MAMA facility in Paris. These latter images are intended for studies of crowded regions of the southern sky, such as the southern Galactic Plane.
Additionally *Aladin Java* allows one to access other archive images such as HST, SUPERCosmos, FIRST, NVSS, Merlin, XMM-Newton, Chandra, and all images provided by SkyView (HEASARC).

Access to the service

Aladin applet (Fr - US - Jp - Ru - In - UK - Ca)* - *in your browser without any installation (394KB - java 1.1.4 compatible)*
Aladin Standalone - *Install Aladin java on your machine*
Aladin previewer - *access to images only*
How to use Aladin applet for your own data/image servers

Documentation

The Aladin Java FAQ
The Aladin Java Manual (9Mb)
"How to provide my data in Aladin" manual
The Aladin **science case** tutorial
The Aladin Java **filter** manual

Snapshots

M20 - *Composed RGB image for Trifid Nebula and filters*
ACO1060 - *the Aladin Java interface around ACO1060*
NGC4038 - *DENIS data in Aladin Java*

Some Aladin figures

5.5TB magnetic disks for the Aladin image server containing:
. **250** Schmidt plates digitized by the Paris MAMA
. **671** CD-ROMs for the DSS-I and II (STScI)

CDS · Simbad · VizieR · Aladin · Catalogues · Nomenclature · Biblio · StarPages · AstroWeb

Catalogues and files available at CDS

Catalogues and files available at CDS

Version of 28-Feb-2004

- B. Copies of external databases, regularly updated. (14 catalogues)
- I. Astrometric Data (246 catalogues)
- II. Photometric Data (226 catalogues)
- III. Spectroscopic Data (198 catalogues)
- IV. Cross-Identifications (21 catalogues)
- V. Combined data (100 catalogues)
- VI. Miscellaneous (92 catalogues)
- VII. Non-stellar Objects (204 catalogues)
- VIII. Radio and Far-IR data (73 catalogues)
- IX. High-Energy data (24 catalogues)
- Tables from *Astronomy and Astrophysics* (1217 catalogues)
- Tables from *Astronomy and Astrophysics Supplement Series* (1167 catalogues)
- Tables from *Astronomical Journal* (755 catalogues)
- Tables from *Astronomicheskii Zhurnal (Russian)* (78 catalogues)
- Tables from *Astrophysical Journal* (402 catalogues)
- Tables from *Astrophysical Journal Supplement Series* (480 catalogues)
- Tables from *Monthly Notices of the Royal Astronomical Society* (307 catalogues)
- Tables from *Publications of the Astronomical Society of the Pacific* (108 catalogues)
- Tables from *Pis'ma v Astronomicheskii Zhurnal (Astronomy Letters)* (69 catalogues)
- Tables from *publications from other journals* (182 catalogues)

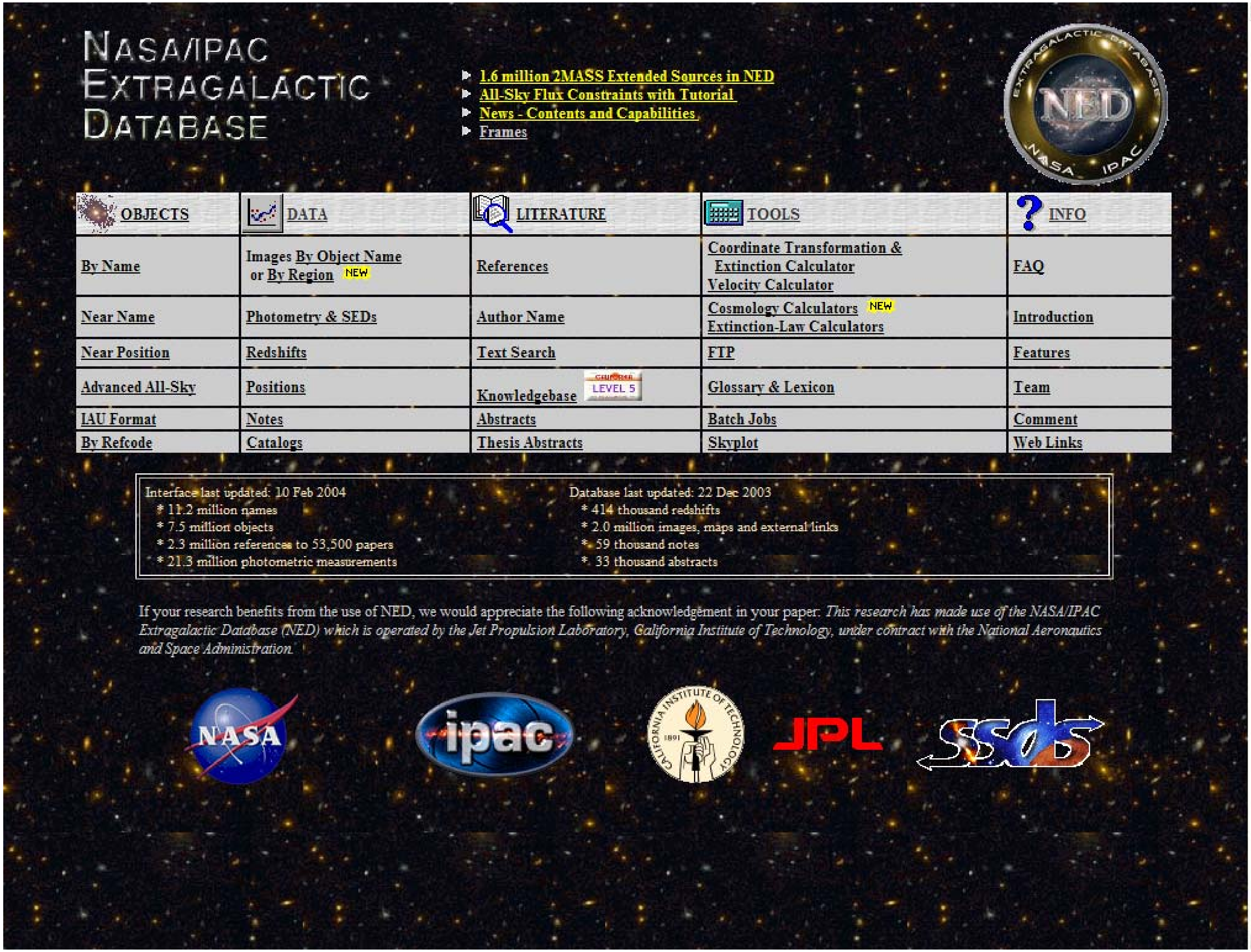
- Catalogues ordered by their *Usual Name* (942 catalogues)

- Catalogues with *Additional Material*

THE NASA/IPAC EXTRAGALACTIC DATA BASE (NED)

NED is built around a master list of *extragalactic* objects for which cross-identifications of names have been established, accurate positions and redshifts entered to the extent possible, and some basic data collected.
Bibliographic references relevant to individual objects have been compiled, and abstracts of extragalactic interest are kept on line.
Detailed and referenced photometry, position, and redshift data, have been taken from large compilations and from the literature. NED also includes images for over 773,000 extragalactic objects from 2MASS, from the literature, and from the Digitized Sky Survey.

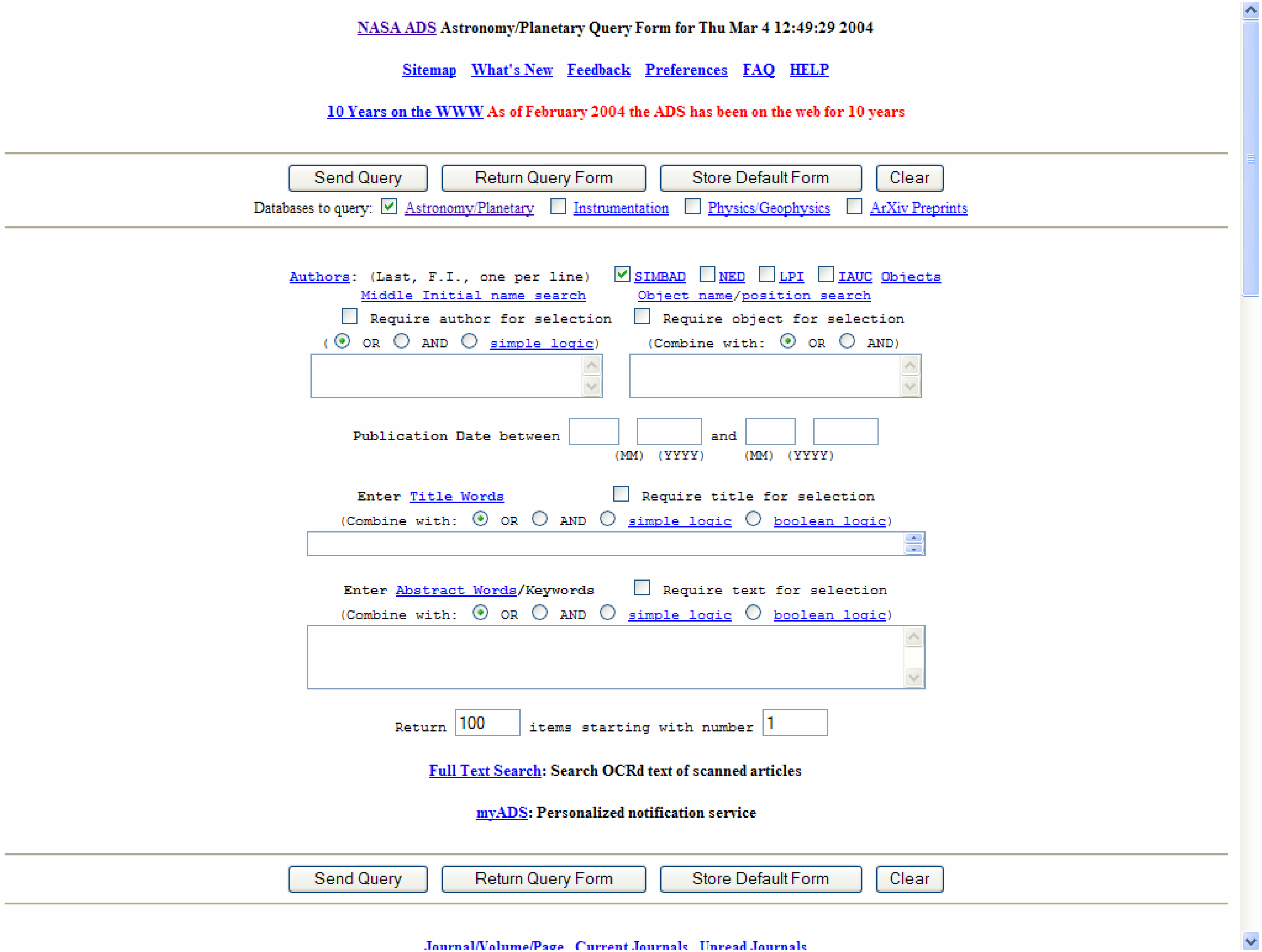
NED is an extragalactic database. Data and references for Galactic objects may be retrieved from SIMBAD (Set of Identifications, Measurements, and Bibliography for Astronomical Data), maintained by Centre de Données Astronomiques de Strasbourg, France.
Similarly, solar system and planetary data (e.g. for Mars or for Halley's Comet) may be retrieved from NASA's Planetary Data System (PDS) at JPL.


NASA/IPAC EXTRAGALACTIC DATABASE
1.6 million 2MASS Extended Sources in NED
All-Sky Flux Constraints with Tutorial
News - Contents and Capabilities
Frames
NED
EXTRAGALACTIC DATABASE NASA IPAC
OBJECTS
DATA
LITERATURE
TOOLS
INFO
By Name
Images By Object Name or By Region NEW
References
Coordinate Transformation & Extinction Calculator
Velocity Calculator
FAQ
Near Name
Photometry & SEDs
Author Name
Cosmology Calculators NEW
Extinction-Law Calculators
Introduction
Near Position
Redshifts
Text Search
FTP
Features
Advanced All-Sky
Positions
Knowledgebase
LEVEL 5
Glossary & Lexicon
Team
IAU Format
Notes
Abstracts
Batch Jobs
Comment
By Refcode
Catalogs
Thesis Abstracts
Skyplot
Web Links
Interface last updated: 10 Feb 2004
* 11.2 million names
* 7.5 million objects
* 2.3 million references to 53,500 papers
* 21.3 million photometric measurements
Database last updated: 22 Dec 2003
* 414 thousand redshifts
* 2.0 million images, maps and external links
* 59 thousand notes
* 33 thousand abstracts
If your research benefits from the use of NED, we would appreciate the following acknowledgement in your paper: This research has made use of the NASA/IPAC Extragalactic Database (NED) which is operated by the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration.
NASA
ipac
CALIFORNIA INSTITUTE OF TECHNOLOGY
1891
JPL
ssds

The Astrophysics Data System (ADS)

The Astrophysics Data System (ADS) is a NASA-funded project which maintains four bibliographic databases containing more than 3.6 million records: Astronomy and Astrophysics, Instrumentation, Physics and Geophysics, and preprints in Astronomy. The main body of data in the ADS consists of bibliographic records, which are searchable through our Abstract Service query forms, and full-text scans of much of the astronomical literature which can be browsed though our Browse interface.

URL:adswww.harvard.edu


NASA ADS Astronomy/Planetary Query Form for Thu Mar 4 12:49:29 2004

Sitemap What's New Feedback Preferences FAQ HELP

10 Years on the WWW As of February 2004 the ADS has been on the web for 10 years

Send Query | Return Query Form | Store Default Form | Clear

Databases to query: [x] Astronomy/Planetary [ ] Instrumentation [ ] Physics/Geophysics [ ] ArXiv Preprints

Authors: (Last, F.I., one per line) [x] SIMBAD [ ] NED [ ] LPI [ ] IAUC Objects

Middle Initial name search — Object name/position search

[ ] Require author for selection — [ ] Require object for selection

((•) OR ( ) AND ( ) simple logic) — (Combine with: (•) OR ( ) AND)

Publication Date between (MM) (YYYY) and (MM) (YYYY)

Enter Title Words [ ] Require title for selection

(Combine with: (•) OR ( ) AND ( ) simple logic ( ) boolean logic)

Enter Abstract Words/Keywords [ ] Require text for selection

(Combine with: (•) OR ( ) AND ( ) simple logic ( ) boolean logic)

Return 100 items starting with number 1

Full Text Search: Search OCRd text of scanned articles

myADS: Personalized notification service

Send Query | Return Query Form | Store Default Form | Clear

Journal/Volume/Page Current Journals Unread Journals

es.arXiv.org e-Print archive mirror

Automated e-print archives [physics] [Search] [Form Interface] [Help]

17 Jan 2004: Endorsement system introduced.
15 Sep 2003: Announcement of New Quantitative Biology archive.
For more info, see cumulative "What's New" pages.
Robots Beware: indiscriminate automated downloads from this site are *not* permitted.

Physics

- Astrophysics (**astro-ph** new, recent, abs, find)
- Condensed Matter (**cond-mat** new, recent, abs, find)
  includes: Disordered Systems and Neural Networks; Materials Science; Mesoscopic Systems and Quantum Hall Effect; Other; Soft Condensed Matter; Statistical Mechanics; Strongly Correlated Electrons; Superconductivity
- General Relativity and Quantum Cosmology (**gr-qc** new, recent, abs, find)
- High Energy Physics - Experiment (**hep-ex** new, recent, abs, find)
- High Energy Physics - Lattice (**hep-lat** new, recent, abs, find)
- High Energy Physics - Phenomenology (**hep-ph** new, recent, abs, find)
- High Energy Physics - Theory (**hep-th** new, recent, abs, find)
- Mathematical Physics (**math-ph** new, recent, abs, find)
- Nuclear Experiment (**nucl-ex** new, recent, abs, find)
- Nuclear Theory (**nucl-th** new, recent, abs, find)
- Physics (**physics** new, recent, abs, find)
  includes (see detailed description): Accelerator Physics; Atmospheric and Oceanic Physics; Atomic Physics; Atomic and Molecular Clusters; Biological Physics; Chemical Physics; Classical Physics; Computational Physics; Data Analysis, Statistics and Probability; Fluid Dynamics; General Physics; Geophysics; History of Physics; Instrumentation and Detectors; Medical Physics; Optics; Physics Education; Physics and Society; Plasma Physics; Popular Physics; Space Physics
- Quantum Physics (**quant-ph** new, recent, abs, find)

Mathematics

- Mathematics (**math** new, recent, abs, find)
  includes (see detailed description): Algebraic Geometry; Algebraic Topology; Analysis of PDEs; Category Theory; Classical Analysis and ODEs; Combinatorics; Commutative Algebra; Complex Variables; Differential Geometry; Dynamical Systems; Functional Analysis; General Mathematics; General Topology; Geometric Topology; Group Theory; History and Overview; K-Theory and Homology; Logic; Mathematical Physics; Metric Geometry; Number Theory; Numerical Analysis; Operator Algebras; Optimization and Control; Probability Theory; Quantum Algebra; Representation Theory; Rings and Algebras; Spectral Theory; Symplectic Geometry

Nonlinear Sciences

- Nonlinear Sciences (**nlin** new, recent, abs, find)
  includes (see detailed description): Adaptation and Self-Organizing Systems; Cellular Automata and Lattice Gases; Chaotic Dynamics; Exactly Solvable and Integrable Systems; Pattern Formation and Solitons

NASA Science Archive Research Centers

HEARSAC
(High Energy Astrophysics)
URL:hearsac.gsfc.nasa.gov

Host data from far UV to Gamma rays space missions.

It also contains tools and software for data analysis

MAST
(UV-NearIR data)
URL:Archive.stsci.edu

Host HST and IUE data plus data from UV and Far UV missions.

There are some tools for searching all the Archives simultaneously.

IRSA-IPAC
(Infrared Science)
URLwww.ipac.caltech.edu

The InfraRed Science Archive (IRSA) and the Infrared Processing and Analysis Center (IPAC) are located together

The **NATIONAL SPACE SCIENCE DATA CENTER** provides further information on space missions. URL: nssdc.gsfc.nasa.gov

The **PLANETARY DATA SYSTEM** (PDS) archives and distributes information from NASA's planetary mission, astronomical observations and laboratory measurements.URL:pds.jpl.nasa.gov

HEASARC Archives, Software & Tools

---Archives & Software---

HEASARC Resources/Education

---Resources/Education---

HEASARC

High Energy Astrophysics
Science Archive Research Center

HEASARC | Observatories | Archive | Software | Tools | Help/FAQ | Education & Outreach

HEASARC Services
Information
What's New
Links
Calibration
Images
Site Map

Dedicated Support Facilities
ASCA
Astro-E2
BeppoSAX
CGRO
Chandra
EUVE
HETE-2
Integral
ROSAT
RXTE
Swift
XMM-Newton

Other NASA Archive Services
ADS
IRSA
LAMBDA
MAST
NED
NSSDC
Spitzer

Other Services
CDS
Hipparcos
ISO
Preprints

Search the HEASARC site: enter text

The HEASARC is an archive of astronomy data from extreme ultraviolet, X-ray, and gamma-ray observatories. On this site, you'll find archival data, multi-mission software and analysis tools, information about current and past observatory missions, and information for educators and the public.

- More about the HEASARC
- Frequently Asked Questions

Latest News

- *Imagine News:* Giant Black Hole Rips Apart Unlucky Star In Cosmic Reality Show (23 Feb)
- New Browse: version 7 released (30 Jan)
- *Imagine News:* A Neutron Star Emerges As A Rare Magnetic Emerald (28 Jan)
- NVO service hosted by HEASARC: Search 12 Data Archives with one click! (21 Jan)

More News

Latest Gamma-Ray Bursts

GRB040228: GCN Circ archive: HETE
GRB040223: GCN Circ archive: INTEGRAL, x-ray, optical, radio, near-IR

Gamma-ray burst Coordinates Network Circulars Archive

HEASARC Picture of the Week

Astronomy Picture of the Day

Browse the Archive

Education & Public Outreach

- StarChild (Grades K-8: general astronomy)
- Imagine the Universe (Grades 7-12: high-energy astronomy)
- X-ray and Gamma-ray images of celestial objects

...and more

Is my favorite object an X-ray, gamma-ray, or EUV source? enter source name

Frequency Regime: X-Ray Submit

This file was last modified on Thursday, 26-Feb-2004 10:45:13 EST

Curator: Karen Smale

Information | What's New | Links | Calibration | Images | Site Map || Dedicated Support Facilities: ASCA | ASTRO-E2 | BeppoSAX | CGRO | Chandra | EUVE | HETE-2 | Integral | ROSAT | RXTE | Swift | XMM-Newton || Other NASA Archives: ADS | IRSA | LAMBDA | MAST | NED | NSSDC | Spitzer || Other Archives: CDS | Hipparcos | ISO | Preprints

HEASARC Home | Observatories | Archive | Software | Tools | Help/FAQ | Education & Outreach

MAST Multimission Archive at Space Telescope

- About MAST
- MAST Search Toolbox
- VizieR/MAST Cross Correlation Search
- MAST Scrapbook
- MAST Coplotter
- What's New
- FAQ
- High-Level Science Products
- Software
- FITS
- Related Sites
- MAST and the VO
- Acknowledgments

The Multimission Archive at STScI supports a variety of astronomical data archives, with the primary focus on scientifically related data sets in the optical, ultraviolet, and near-infrared parts of the spectrum. MAST provides search tools and retrieval support for the following missions:

Missions				Catalogs & Surveys
HST	ASTRO	ORFEUS	Copernicus	GALEX
FUSE	HUT	BEFS	ROSAT	SDSS
IUE	UIT	IMAPS		GSC
EUVE	WUPPE	TUES		DSS
				VLA-FIRST

NSSDC Legacy Missions

December 30, 2003 The **HST Ultra Deep Field (UDF)** Data Products are currently planned for release March 9, 2004. Please check the UDF web site for more information. There is also a form asking for users to indicate interest in getting the UDF Raw observations on DVDs.

ACS WFC images from the GOODS program corresponding to the UDF field are now available via anonymous ftp. These images have the same orientation and pixel scale as the final UDF images (see the README file for details).

Quick Target Search and/or Mission Search

Enter Target name (or Coordinates): [ ]

Resolver: (•) SIMBAD ( ) NED

and/or Band/Data Type(s):

	X-Ray	Extreme UV	Far UV	Near UV	Optical	Near IR	Radio
Images	☐	☐	☐	☐	☐	☐	☐
Spectra	☐	☐	☐	☐	☐	☐	
Other			☐	☐	☐	☐	

Search | Reset | Help


ipac
Infrared Processing and Analysis Center
NASA's Infrared Astrophysics Data Center
NASA
About IPAC
Missions & Programs
Research
Data
Cool Cosmos
Headlines
New Images from the Spitzer Space Telescope
Spitzer Featured Image
Spitzer Science Center
Michelson Science Center
Staff Directory
Seminars/Talks
Visitor Information
Job Opportunities
Staff Pages
IR/NASA Links
Feedback
JPL
Missions & Programs
OPERATIONAL
Spitzer Space Telescope · GALEX · 2MASS · KI · PTI
IN DEVELOPMENT
Herschel · Planck
UNDER DESIGN
WISE · SIM · TPF
PAST
ISO · WIRE · MSX · IRAS
Science Research
SWIRE · SINGS · FLS · VPL · ISO Key Project on Normal Galaxies
Data & Documents
ARCHIVES
IRSA · NED · 2MASS · ISO Archive · External Sites
PLANNING TOOLS
SPOT · IRSKY · Coordinate Conversion · External Sites
ANALYSIS PACKAGES & TOOLS
SKYVIEW · IRAS/HIRES · IRAS/SCANPI · ISO Analysis · Web Infrared Tool Shed · Montage · External Sites
DOCUMENTS
Spitzer Reserved Observations Catalog · 2MASS Explanatory Supplement · IRAS Explanatory Supplement · IRAS/FSC
Education & Outreach
Cool Cosmos · 2MASS Public Outreach and Education · GALEX Education · Glossary

Welcome to the

National Space Science Data Center

NASA Goddard Space Flight Center
Greenbelt, MD 20771, USA

Services

General

- NSSDC User Survey
- Obtaining Data from NSSDC

Education & Public Outreach

- General Public Page
- Space Science Education Page

Discipline-specific Services

- Astrophysics
- Space Physics
- Solar Physics
- Planetary/Lunar Sciences
- Earth Sciences

Multidisciplinary Services

Data and directory services

- Master Catalog
- Anonymous FTP Site
- Order CD-ROMs and Videotapes

Photographic resources

Overview

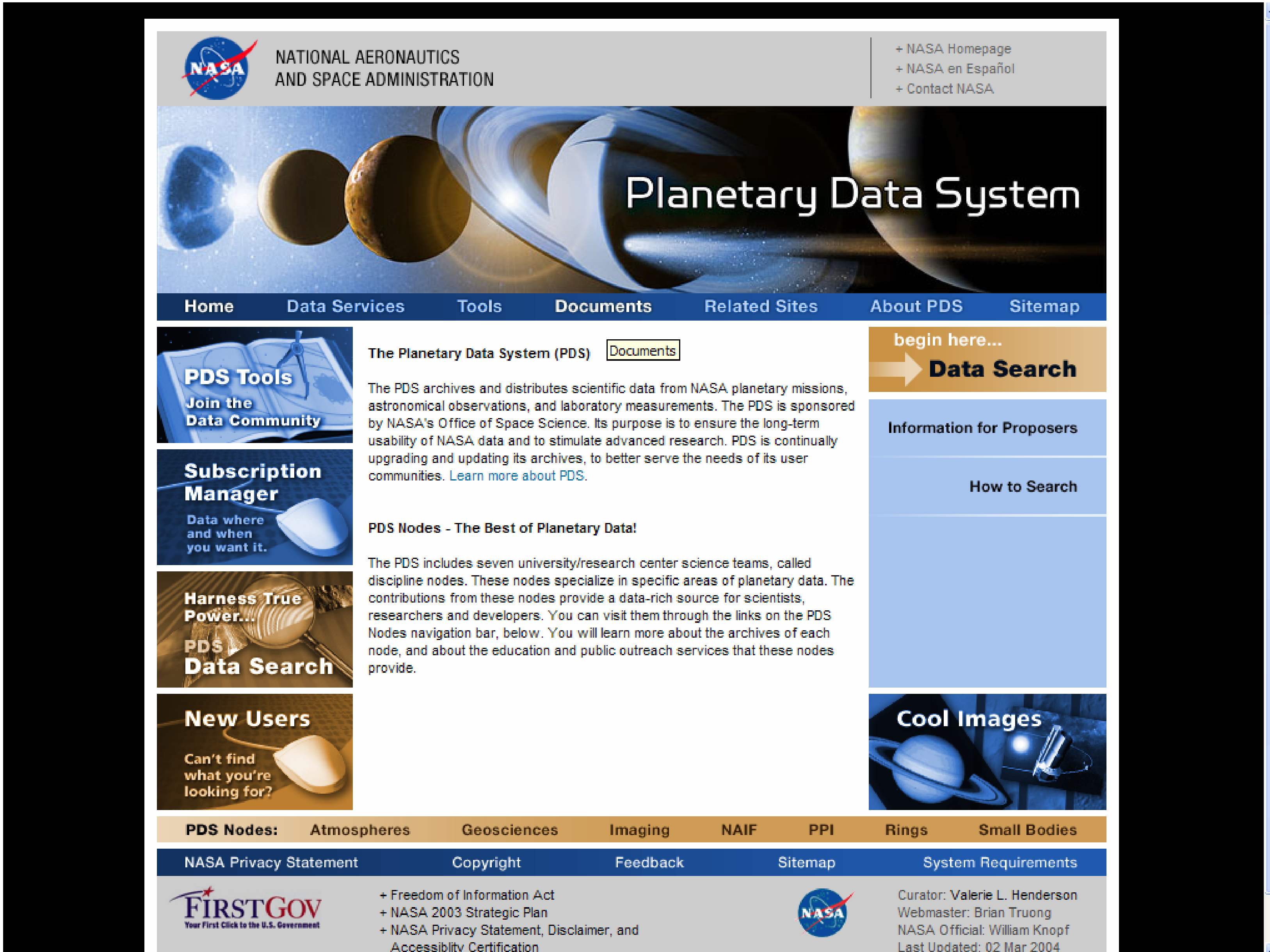
- NSSDC Charter
- About NSSDC

Publications

- NSSDC Newsletter
- SPACEWARN Bulletin
- NSSDC Annual Reports
  - 2002 HTML or PDF
  - 2001
  - 2000
  - 1999
  - 1998
- NSSDC Archive Plan, 2003-2006
  HTML or PDF

General Information

- Frequently Asked Questions (FAQs)
- Search
- Feedback
- Help Desk


NATIONAL AERONAUTICS
AND SPACE ADMINISTRATION
+ NASA Homepage
+ NASA en Español
+ Contact NASA
Planetary Data System
Home
Data Services
Tools
Documents
Related Sites
About PDS
Sitemap
PDS Tools
Join the Data Community
Subscription Manager
Data where and when you want it.
Harness True Power...
PDS Data Search
New Users
Can't find what you're looking for?
The Planetary Data System (PDS)
Documents
The PDS archives and distributes scientific data from NASA planetary missions, astronomical observations, and laboratory measurements. The PDS is sponsored by NASA's Office of Space Science. Its purpose is to ensure the long-term usability of NASA data and to stimulate advanced research. PDS is continually upgrading and updating its archives, to better serve the needs of its user communities. Learn more about PDS.
PDS Nodes - The Best of Planetary Data!
The PDS includes seven university/research center science teams, called discipline nodes. These nodes specialize in specific areas of planetary data. The contributions from these nodes provide a data-rich source for scientists, researchers and developers. You can visit them through the links on the PDS Nodes navigation bar, below. You will learn more about the archives of each node, and about the education and public outreach services that these nodes provide.
begin here...
Data Search
Information for Proposers
How to Search
Cool Images
PDS Nodes: Atmospheres Geosciences Imaging NAIF PPI Rings Small Bodies
NASA Privacy Statement
Copyright
Feedback
Sitemap
System Requirements
FIRSTGOV
Your First Click to the U.S. Government
+ Freedom of Information Act
+ NASA 2003 Strategic Plan
+ NASA Privacy Statement, Disclaimer, and Accessiblity Certification
Curator: Valerie L. Henderson
Webmaster: Brian Truong
NASA Official: William Knopf
Last Updated: 02 Mar 2004

THE ASTROPHYSICAL VIRTUAL OBSERVATORY (AVO)

The Astrophysical Virtual Observatory Project (AVO) will conduct a research and demonstration programme on the scientific requirements and technologies necessary to build a Virtual Observatory (VO) for European astronomy.
URL:www.euro-vo.org

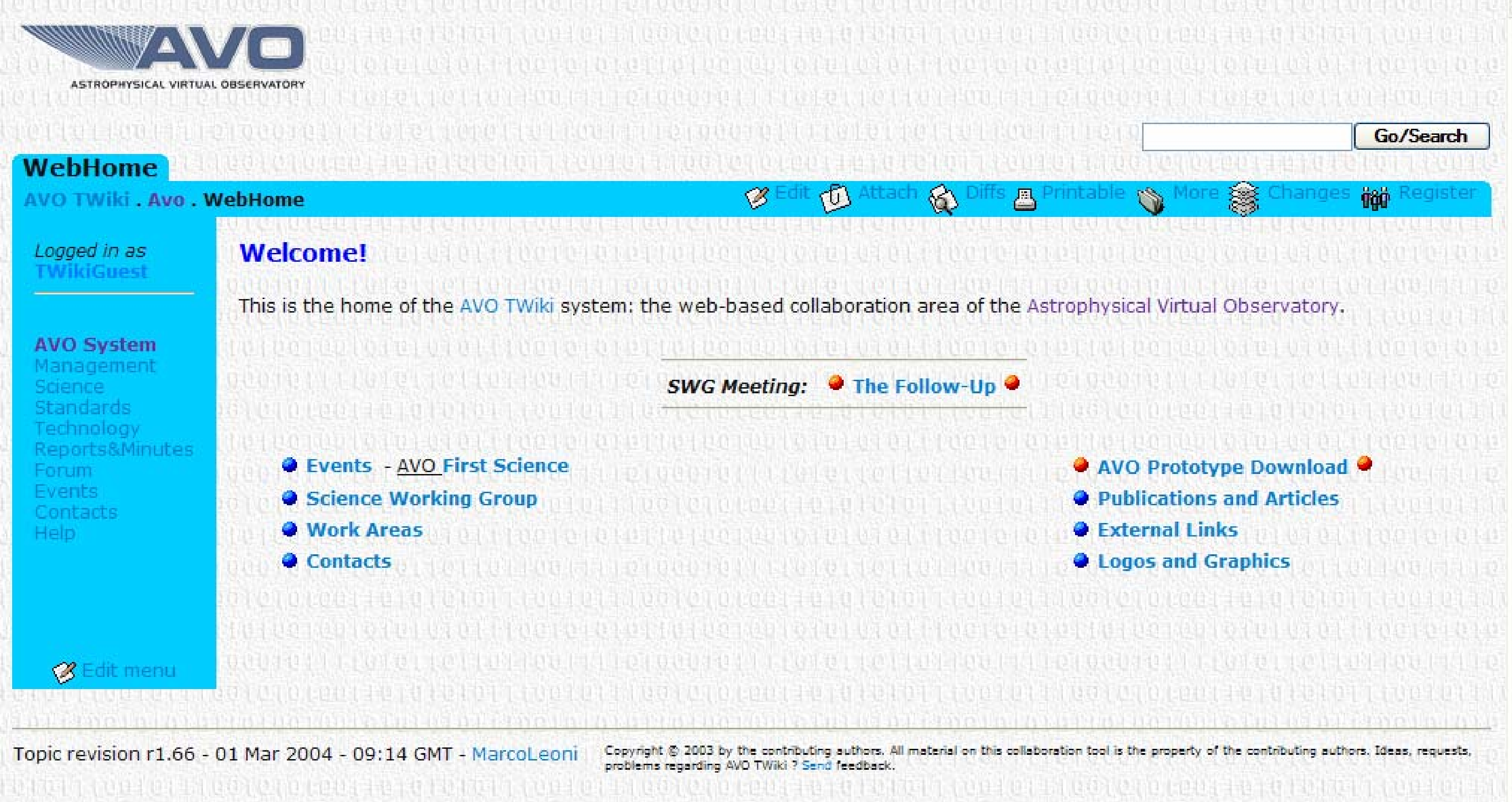
The AVO has been jointly funded by the European Commission (under FP5 - Fifth Framework Programme) with six European organisations participating in a three year Phase-A work programme, valued at 5 million Euro. The partner organisations are:

- the European Southern Observatory (ESO) in Munich, Germany
- the European Space Agency (ESA)
- AstroGrid (funded by PPARC as part of the UK's E-Science programme)
- the CNRS-supported Centre de Données Astronomiques de Strasbourg (CDS)
- the University Louis Pasteur in Strasbourg, France
- the CNRS-supported TERAPIX astronomical data centre at the Institut d'Astrophysique in Paris, France
- the Jodrell Bank Observatory of the Victoria University of Manchester, UK.

The Phase A program will focus its effort in the following areas:

- **Science:** A detailed description of the science requirements for the AVO will be constructed, following the experience gained in a smaller-scale science demonstration program called ASTROVIRTEL (Accessing Astronomical Archives as Virtual Telescopes).
- **Interoperability: The** difficult issue of data and archive interoperability will be addressed by new standards definitions for astronomical data and trial programmes of "joins" between specific target archives within the project team.
- **Technology: The** necessary GRID and database technologies will be assessed and tested for use a full AVO implementation.

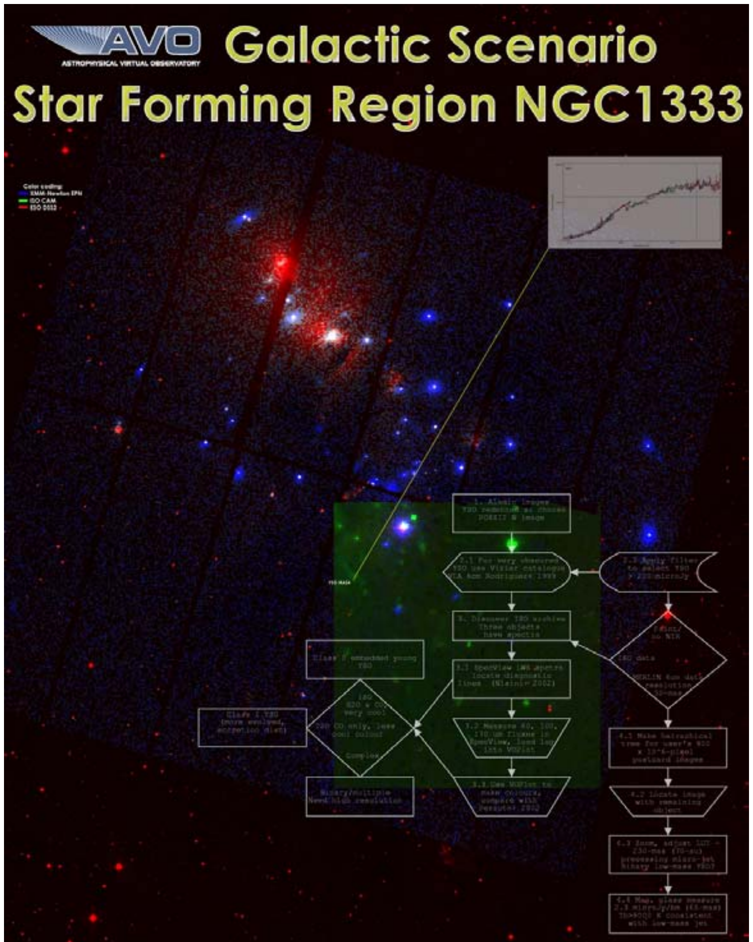
The AVO project is currently working in conjunction with other international VO efforts in the United States and Asia-Pacific region. This is part of an International Virtual Observatory Alliance to define essential new data standards so that the VO concept can have a global dimension. The AVO partners will join with all astronomical data centres in Europe to put forward an FP6 IST (Sixth Framework Programme - Information Society Technologies Programme) Integrated Project proposal *to make a European VO fully operational by the end of 2007.*

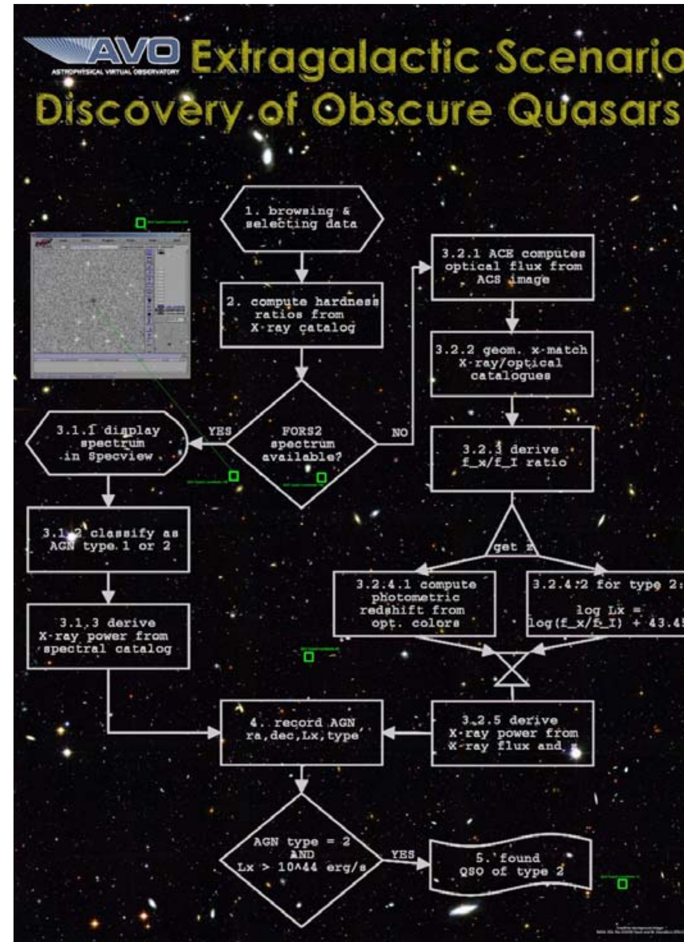


The scientific work is concentrated in three aspects:

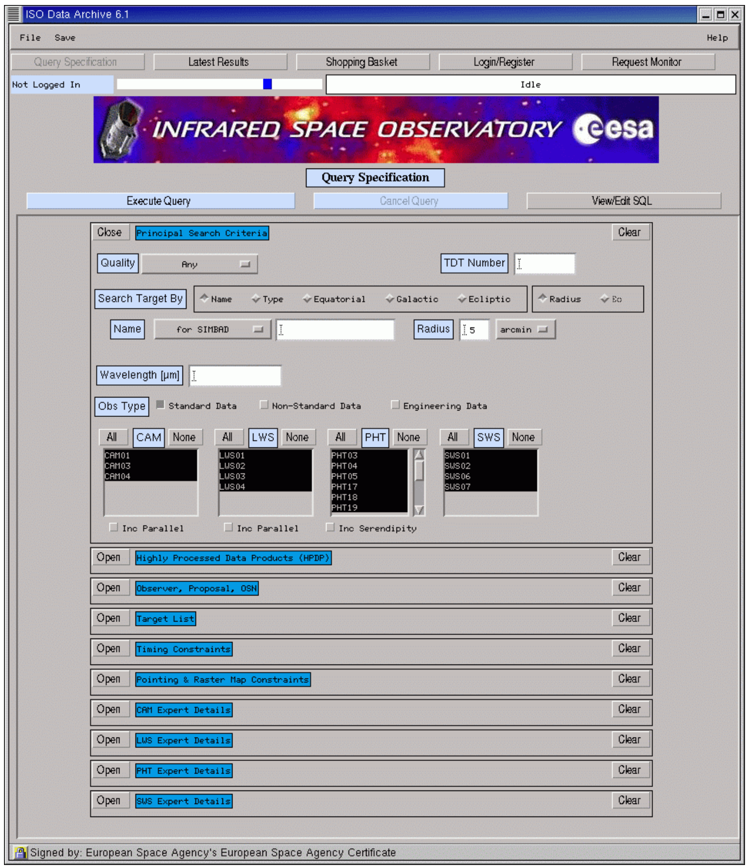
- *Defining the science goals against which the AVO scientific impact can be measured*
- *Defining the scientific requirements for the implementation of the AVO.*
- *Pilot implementation of selected AVO science projects.*
  - *A galactic scenario for AVO demo*
  - *An extra galactic scenario for AVO demo*

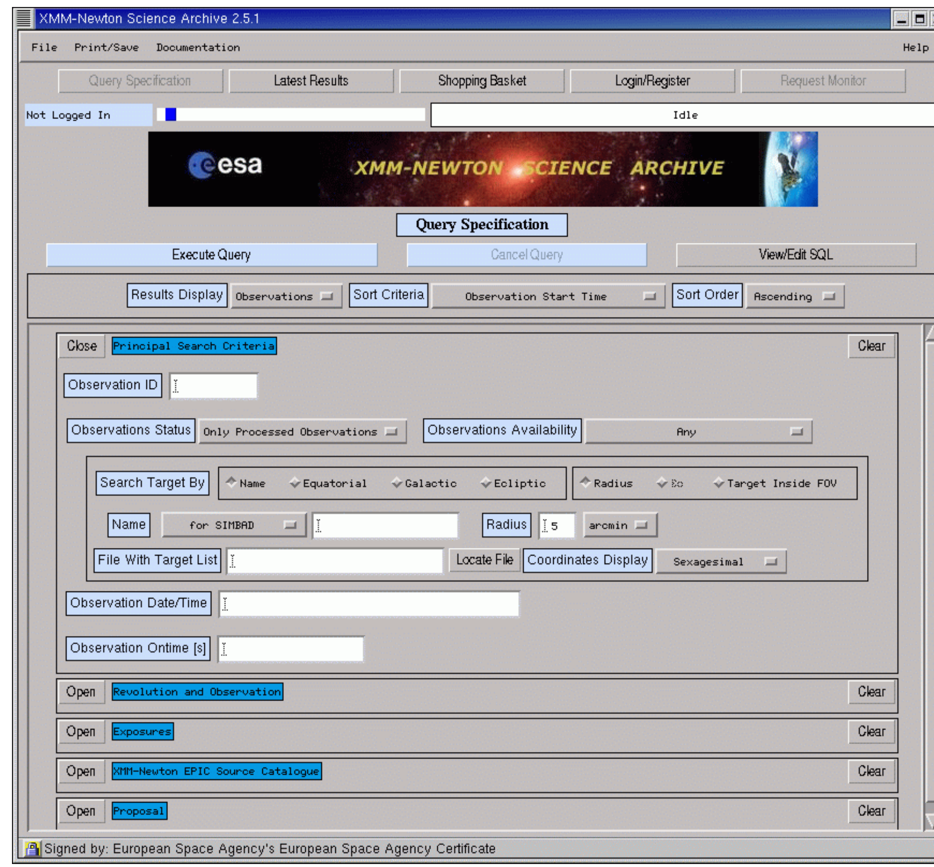
AVO DEMOS (2004)





THE ESA ARCHIVES
(now accessible through the AVO interface)





GALACTIC SCENARIO: Milky Way Star-Forming Regions

Rationale:

VOs can help develop more systematic diagnostics for classifying Young Stellar Objects (YSOs) and for relating the evolution of SFR as a whole to a well defined set of observables which can be used as a diagnostic to establish the age and mass of YSOs (and henceforth, to study the pre-main sequence evolution).

The scenario which we will build here is restricted to providing examples of what could be done, with the emphasis on new tools and data recently released to AVO (spectral tools, ISO, XMM) so we can't provide a complete answer, but hopefully suggest some scientifically useful applications of the capabilities.

Steps:

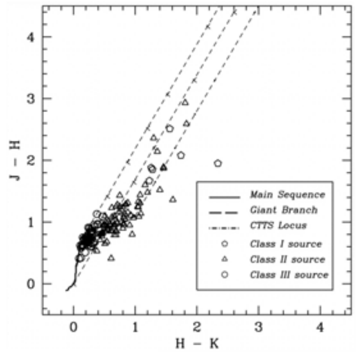
1st. Go to www.eurovo.org/twiki/bin/view/Avo/SwgDownload#Installation_in_3_Steps and download the files. Install the prototype.

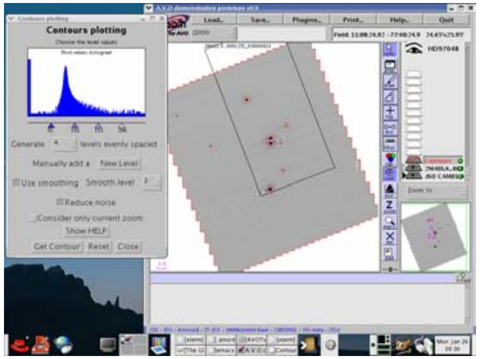
2nd Follow the instructions for the Chamaleon case.

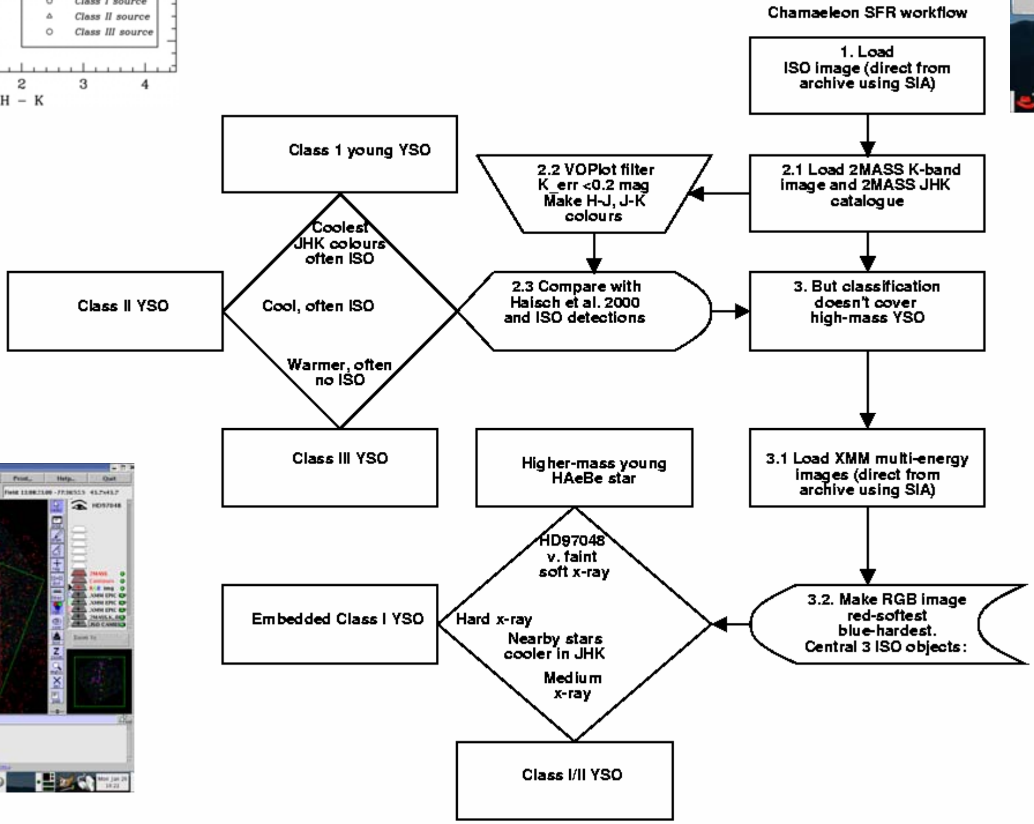
(URL:. www.euro-vo.org/twiki/bin/view/Avo/Spare)

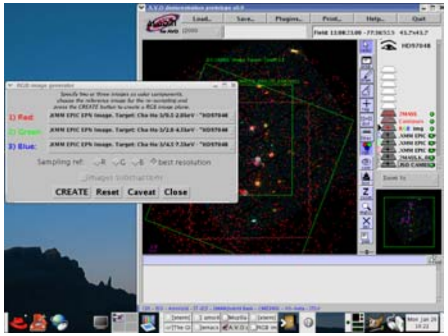
3rd. Inspect by yourselves the NGC1333 case.

- Target HD97048 -- Case from -- AnitaRichards - 26 Jan 2004
- Default search radius unless specified
- Load > VOdemo tab
  - SIA server for ISO Images (direct from the ISO Archive)
    - Load ISO CAM01 SE
- Load > Aladin tab, tree view
  - Load 2MASS K image covering central stars
- Main window
  - Select ISO image and make contours (default settings)
- Load > Surveys in Vizier
  - Load 2MASS
- Make sure contours and catalogue are higher in stack, use zoom window to shift 2MASS field of view to select region with ISO contours (2/3 magnification).
  - Note about a dozen ISO sources (YSO, HH objects etc.)
  - Select all 2MASS catalogue sources in view
- Plugins > VOPlot (developed by VO India)
  - Functions menu in VOPlot
    - VOPlot Create Filters (to exclude points if Kmag error > 0.2)
      - Name Kaccurate, expression $19<0.2
    - Create New Columns to make colours
      - Name J-H, expression $3-$4, units mag
      - Name H-K, expression $4-$5
  - Select Y-axis J-H, X-axis H-K, Filter Kaccurate and Plot
- In main Aladin window,
  - Select and/or hover over HD97048 and other 2 central ISO/2MASS objects
  - Note positions in VOPlot
  - Compare with JHK colour-colour regions Haisch et al. 2000 AJ 120 1396 fig 8a: *high resolution* or *page-sized*
    - HD97048 probably Class II, other objects II and I or II
  - VOPlot Mode
    - Clear all Selections
    - Select
    - Use cursor (drag from top left) to select various regions in VOPlot colour-colour plot, e.g. Class III have [J-H]<1.6 and [H-K]<0.4
    - Note distribution in Aladin image, e.g. Class III not ISO-bright
- Central 3 objects
  - All bright at K-band and ISO 7 um
  - HD97048 maybe more evolved, later class?
  - Or evolving faster - higher mass?
- Load > VOdemo tab
  - SIA Server for XMM-Newton Archive
  - Load EPN images 0.5-2.0, 2.0-4.5, 4.5-7.5 keV
- Make X-ray RGB image
- Zoom in on central objects
  - HD97048 faint very soft
    - suggests high-mass evolved YSO
  - Two objects above have bluer=harder X-ray colours
    - suggests early, embedded YSO
  - Other objects with redder=softer X-ray colours
    - suggests low-mass T Tauri stars


J − H
H − K
Main Sequence
Giant Branch
CTTS Locus
Class I source
Class II source
Class III source


Contours plotting


Chamaeleon SFR workflow
1. Load ISO image (direct from archive using SIA)
2.1 Load 2MASS K-band image and 2MASS JHK catalogue
2.2 VOPlot filter K_err <0.2 mag Make H-J, J-K colours
2.3 Compare with Haisch et al. 2000 and ISO detections
3. But classification doesn't cover high-mass YSO
3.1 Load XMM multi-energy images (direct from archive using SIA)
3.2. Make RGB image red-softest blue-hardest. Central 3 ISO objects:
Class 1 young YSO
Coolest JHK colours often ISO
Cool, often ISO
Warmer, often no ISO
Class II YSO
Class III YSO
Higher-mass young HAeBe star
HD97048 v. faint soft x-ray
Hard x-ray
Nearby stars cooler in JHK
Medium x-ray
Embedded Class I YSO
Class I/II YSO


CREATE Reset Caveat Close

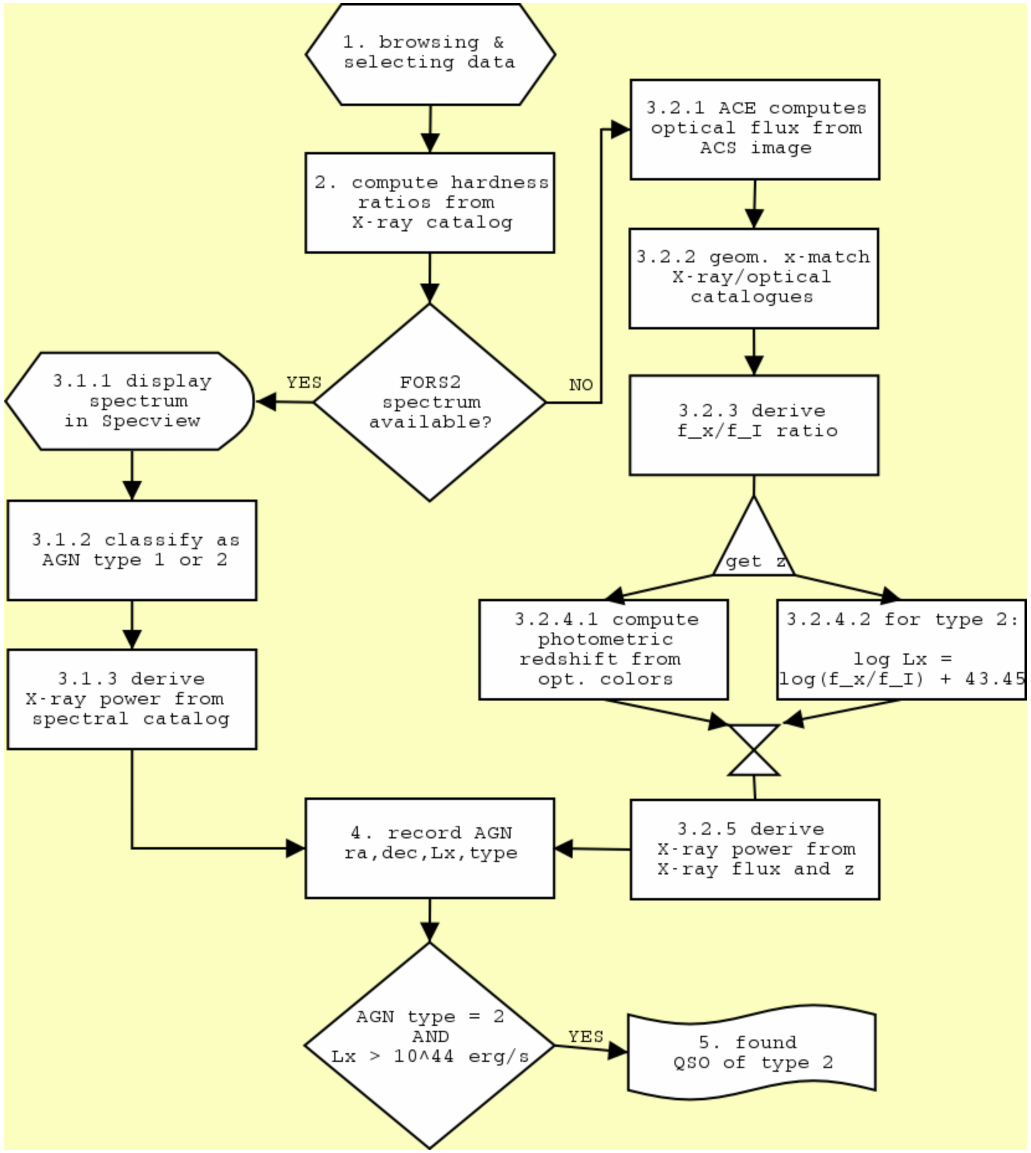
EXTRAGALACTIC SCENARIO: Obscured Quasars

Rationale:

The unified model for active galactic nuclei (AGN) is widely accepted. The physics of black hole, accretion disk, jet, and obscuring torus is convolved with the geometry of the viewing angle and can explain most of the apparent disparate properties (and nomenclature) of active galaxies (the use of the word "torus" here is generic for the obscuring region). Type 1 sources are those in which we have an unimpeded view of the central regions and therefore exhibit the straight physics of AGN with no absorption. Type 2 objects arise when the view is obscured by the torus. While many examples of local, and therefore relatively low-power, type 2 AGN are known (Seyfert 2s), it has been debated if their high-power counterparts, type 2 QSO, exist. If so, they are expected to make a significant fraction of the X-ray background. These sources are heavily reddened and therefore fall through the "standard" (optical) methods of quasar selection. The hard X-rays, however, are thought to be able to penetrate the torus. Type 2 QSO, therefore, should have narrow, if any, permitted lines, powerful hard X-ray emission, and a high equivalent width Fe K line

Steps:

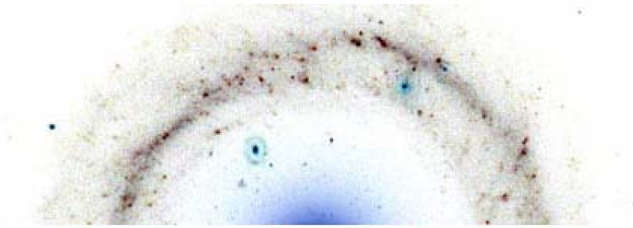
Follow the instructions for the Extragalactic case.
(URL:. www.euro-vo.org/twiki/bin/view/Avo/ExtragalacticScenario)


1. browsing & selecting data
2. compute hardness ratios from X-ray catalog
FORS2 spectrum available?
YES
NO
3.1.1 display spectrum in Specview
3.1.2 classify as AGN type 1 or 2
3.1.3 derive X-ray power from spectral catalog
3.2.1 ACE computes optical flux from ACS image
3.2.2 geom. x-match X-ray/optical catalogues
3.2.3 derive f_x/f_I ratio
get z
3.2.4.1 compute photometric redshift from opt. colors
3.2.4.2 for type 2:
log Lx = log(f_x/f_I) + 43.45
3.2.5 derive X-ray power from X-ray flux and z
4. record AGN ra,dec,Lx,type
AGN type = 2 AND Lx > 10^44 erg/s
YES
5. found QSO of type 2

International Virtual Observatory Alliance Partners May 2003
http://www.ivoa.net

Project	URL
AstroGrid (UK)	http://www.astrogrid.org
Australian Virtual Observatory	http://avo.atnf.csiro.au
Astrophysical Virtual Observatory (EU)	http://www.euro-vo.org
Virtual Observatory of China	http://www.china-vo.org
Canadian Virtual Observatory	http://services.cadc-ccda.hia-iha.nrc-cnrc.gc.ca/cvo/
German Astrophysical Virtual Observatory	http://www.g-vo.org/
Italian Data Grid for Astronomical Research	http://wwwas.oat.ts.astro.it/idgar/IDGAR-home.htm
Japanese Virtual Observatory	http://jvo.nao.ac.jp/
Korean Virtual Observatory	http://kvo.kao.re.kr/
National Virtual Observatory (USA)	http://us-vo.org/
Russian Virtual Observatory	http://www.inasan.rssi.ru/eng/rvo/
Virtual Observatory of India	http://vo.iucaa.ernet.in/~voi/

NATIONAL VIRTUAL OBSERVATORY



PROJECT

[Standards]
[Software & Services]
[Metadata] (NCSA)
[Publications]
[Prototypes]
[Internal]
[Logos]

ABOUT NVO

What is the NVO?
Science Objectives

COMMUNITY

Discussion Lists
International VO
Other Links
IVOA Events Page

PEOPLE

Contact Us
Personnel

US National Virtual Observatory

The National Virtual Observatory collaboration aims to create standards for astronomical data collections that will be used by the wide astronomical community. In this way we will make data easier to use, easier to find, and easier to join with other data. A second thrust is exploring the use of high-performance computing resources for discovery in astronomy. (more)

Recent News

The 2003 NVO External Advisory Committee Report

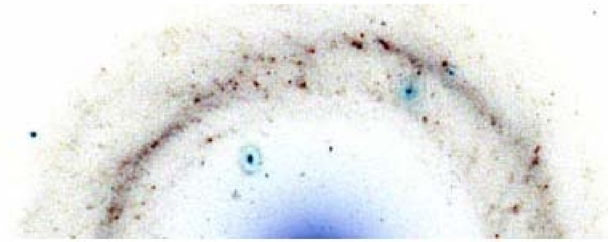
The NVO Advisory Committee met for the second time on December 11-12, 2003 , at Johns Hopkins University in Baltimore . Committee members in attendance included Gerry Gilmore, John Huchra, Sid Karin, Rob Kennicutt, Carl Lagoze, Paul Messina, Eve Ostriker, and Sidney Wolff. Presentations were made by key members of the NVO team.

The Advisory Committee was very positively impressed by the continued progress made by the NVO team, and made several recommendations for the future development of the project. To see more, read the report.

Latest NVO News

- The 2003 NVO External Advisory Committee Report
- The 2003 NVO Annual Report
- The NVO Data Inventory Service
- Virtual Observatory Prototype Produces Surprise Discovery Early demo project identifies new brown dwarf
- NVO External Advisory Committee Report
- Science Prototypes at the AAS
- First year Annual Report Released
- Simple Image Access Prototype Specification
- The International Virtual

NVO
NATIONAL VIRTUAL OBSERVATORY



NSF

PROJECT

Standards
Software & Services
Metadata (NCSA)
Publications
Prototypes
Internal
Logos

ABOUT NVO

What is the NVO?
Science Objectives

COMMUNITY

Discussion Lists
International VO
Other Links
IVOA Events Page

PEOPLE

Contact Us
Personnel

Prototypes

Now one year into development, the National Virtual Observatory Project is presenting several science prototypes at the January 2003 meeting of the American Astronomical Society. Our goal in showing these prototypes is to demonstrate that interesting and efficient research can be done by building upon just a few new data exchange and data access protocols and standards. Furthermore, we use these prototypes to validate and steer the course for technology development within the project - the NVO technologies are responsive to science needs. The three prototypes we have implemented thus far are

- A gamma-ray burst event follow-up service
- A brown dwarf candidate search service
- A galaxy morphology analysis service

These new standards for astronomical data access, publishing, discovery, and interoperability are being developed in cooperatively with the astronomy and computer science communities, building upon advanced information technologies. The emphasis is on maximum return for minimal change in procedure - from either providers or consumers of data.

The NVO Project is working closely with similar development efforts worldwide. We have jointly formed the International Virtual Observatory Alliance, bringing together the leaders from all such efforts, and have agreed upon on common roadmap for development and interoperability. Our goal is to build upon the national initiatives to bring about a truly international facility, bringing the world's foremost astronomical information services and data collections to the fingertips of astronomers, educators, and students everywhere.

Latest NVO News

- The 2003 NVO External Advisory Committee Report
- The 2003 NVO Annual Report
- The NVO Data Inventory Service
- Virtual Observatory Prototype Produces Surprise Discovery
  Early demo project identifies new brown dwarf
- NVO External Advisory Committee Report
- Science Prototypes at the AAS
- First year Annual Report Released
- Simple Image Access Prototype Specification
- The International Virtual Observatory Alliance: A Mission and Roadmap Statement
- VOTable Feature

Gamma-Ray Burst Follow-Up Service Science Prototype

Rationale:

Rapid collection of multi-wavelength imaging, catalogue and observation data following an interesting transient event is essential. This service can also be used as a general tool to quickly access all data available on any patch of sky for any science use.

Data Resources

Multi-wavelength data from any number of sites (currently 13 different sites) sampling energies from X-ray to radio, and including images, object lists, and catalogues of observations.

What the VO Brings

Integration and organization of a variety of data sources into an easily comprehensible information set. Scalability to an arbitrary number of data providers. Integrates data with multiple data visualization services.

URL: http://www.us-vo.org/prototypes/gammarayburst.html

Brown Dwarf Search Science Prototype:

Rationale:

The search for brown dwarfs has been revolutionized by the latest deep sky surveys. A key attribute to discovering brown dwarfs is the federation of many surveys over different wavelengths. Such matching of catalogues is currently laborious and time consuming. This matching problem is generic to many areas of astrophysics.

Data Resources

Sloan Digital Sky Survey (SDSS) Early Data Release (15 million objects)

2-Micron All Sky Survey (2MASS) 2nd Incremental Point Source Catalog (162 million objects)

What the VO Brings

Real-Time Cross Matching of Large Catalogs. Today, doing the matching of these two large datasets is user-intensive and is replicated by many different users. Also, the correlation of these two datasets can take years of CPU time if not done correctly. The NVO brings two key aspects to this problem. First, it removes the need for the user to download large data to their machine, making direct use of distributed data. Second, the matching algorithm used here is computationally efficient and designed to give answers in minutes rather than hours; results can be returned to the user in real-time.

URL: www.us-vo.org/prototypes/browndwarf.html

IVOA Mission and Roadmap 2002-2005

- **Mission**: To facilitate the international coordination and collaboration necessary for the development and deployment of the tools, systems and organizational structures necessary to enable the international utilization of astronomical archives as an integrated and interoperating virtual observatory.

January 2002	Initiate international dialog on interoperability. OPTICON Interoperability Working Group meeting, Strasbourg. Discussion and revision of draft VO Table standard
April 15, 2002	Reach agreement on VOTable 1.0.
June 10-14, 2002	Formation of IVOA
January 2003	Coordinated initial science demonstrations by IVOA members
January 2003	IVOA agreement on initial suite of interoperability standards and tools
May 2003	Working Published Web Services
August 2003	Coordinated intermediate science demonstrations which include international data access and exchange at IAU General Assembly
October 2003	Astronomical Query Language v. 1.0 definition.
January 2004	Coordinated intermediate science demonstrations, including incorporation of grid-based computing and data storage technologies
May 2004	Resource Discovery 1.0
July 2004	VO development roadmap for 2005+
October 2004	Compound Web Services and Ontology Service 1.0
January 2005	Coordinated complex science demonstrations

5. Associated mathematical problems

There are two basic branches of mathematics involved in the development and operation of Virtual Observatories (VOs):

1. Operatiional (or Operations) Research (OR):

   OR is related with the optimization of the processes related with the management of the Archives Networks.

2. Statistics

   Statistics is related with the analysis of the large data volume and its interpretation to derive the degree of reliability of a given scientific assumption/model.

Statistical methods are often included in undergraduate programs so in this course emphasis will be made on OR.

A short primer to OR

5.1 The historical introduction.
5.2 Definition of OR
5.3 Methods and models in OR.
5.4 Classic problems in OR with application to V.O.
5.5 An example: The automated operations of a large telescope.
5.6 Some exercises.

5.1 A brief history of OR

OR was born from the formulation in mathematical language and the application of the scientific method to logistic and management problems.

Two examples of the early works:

How can you remove the largest possible amount of material from a store with the minimal effort?

This problem was analyzed by F.W. Taylor in 1885 who is the recognized pioneer of the management science

Which are the main characteristics of the traffic through the telephone lines?

A.K. Erlang developed a mathematical model to explain this process in 1917 marking the origin of the formalization of queuing problems.

…BUT ….

OR was really born during the II World War…

In 1934 the British Army created a Committee to apply the recent scientific and technologic advances against German air attacks. Some experiments were run during military manoeuvres involving both radar information on the location of two airplanes and the information broadcasted by the planes themselves.

This is a *complex problem* with *many different inter-related components*, with *different properties* undergoing variable *environmental conditions*. The concept of *system* was introduced. A.P.Rowe proposed to name the analysis of these experiments as *operational research*, introducing for the first time the modern terminology.

After the II World War, the Ministry of Commerce of UK created research teams to apply the same methods.

In 1946 the project RAND (Research AND Development) was created in USA. RAND became the RAND corporation and collaborated actively with the Department of Mathematics of the Princetown University.

In 1952, the American operative research society, ORSA, was created.

In 1962, the Sociedad Española de Estadística, Investigación Operativa e Informática was founded.

5.2 Definition of OR

OR is the application of the scientific method to complex problems in the management and direction of large systems of men, machines, materials, and money in the Industry, Commerce, Administration and Defence. Typically, a scientific model of the system is built taking into account risks and random factors, to predict and compare the results of the different possible decisions, strategies or controls. The objective is to assist the responsible in the decision process in a scientific manner.

Notice that two basic terms are introduced:

System as the ensemble of elements with some given properties which are inter-related and submitted to the influence of some external conditions.

Scientific (mathematical) model which is the translation to mathematical language of the system and the problem to be analyzed. In OR this model ought to take into account the reactions of the system to the various possible decisions and an estimate of *goodness of the solution.*

5.3 Methods and models in OR

The key difference between the OR models and other mathematical models is the possibility of introducing changes in the system state to take into account the decision making process.

The key elements in an OR model are:

- Variables
- Parameters
- Functional relations among variables
- Constraints to the variables
- Objective function

There are different types of variables:

- Control variables which are defined to describe the problem.
- State variables which define the state of the problem.
- Output variables.

The uncertainty is modeled in two basic different manners depending on the problem:

- Through random variables making use of statistical tools to build stochastic models.
- Through the theory of fuzzy sets to model non-random uncertainties.

The decision-making process:

There are two basic kinds of problems:

Problems in a certainty environment:

In many cases the system can be described by a single mathematical function, **f(x),** where **x** represents a given state of the system (**xєX,** the set of all posible states of the system) and **f(x)** is a well defined function from **X** in **IR**. The decision problem consist in finding the **x** which minimizes **f(x):**

$$\min_{x \in X} f(x)$$

The solution of the problem is trivial if **X** is finite and small. There are technical difficulties when **X** is large because the computational time to find out the solution increases significantly with the number of possible states and some approximate solutions, heuristics, are searched for.

Problems in an uncertainty environment:

Typical cases are problems when the consequences of a given decision are uncertain, or when they can be valued in a very different manners. This type of problems are very complex even if the number of possible solutions is small. In this case, decision tables are made to assist the decision-maker.

Decission-making Table

	Context 1	…….	Context i	…….	Context n
State 1	U_{11}	…….	U_{1i}	…….	U_{1n}
. .					
State i	U_{i1}	…….	U_{ii}	……..	U_{in}
. .					
State m	U_{m1}	…….	U_{mi}	……..	U_{mn}

Context or environment where the decision is made.
State of the system

5.4 Classic problems in OR with application to the VO

1. Production planning or resource allocation problems:

   (or how to obtain the maximum benefit from a limited amount of well defined resources)

   An example could be how to obtain the total amount of data required in a retrieval request to VO in a minimum amount of time and with a minimal number of consults to the distributed grid of Archives.

2. Sequencing and scheduling problems

   A classy example is the sequencing and optimal scheduling of the observations of a telescope.

3. Stock problems

   An example could be the definition of mirror Archives. The largest amount of mirrors provides a larger stock and, ideally, data retrieval and VO consultation would be optimal. However, this implies a huge cost in computer memory and human resources. Mirroring is efficient for heavily consulted archives. OR analyzes the trade-off between cost-efficiency and optimal support to the community.

4. Queuing problems

   It is a related problem. If many users are working with VO simultaneously, they will make a queue. OR analyses the trade-off between the number of queues and the VO users satisfaction?

5.5 An example: The automated operations of a large telescope.

Rationale

Automatic Operations and Scheduling (AOS) are defined to get the largest scientific profit from the high operational costs of the large astronomical facilities. This condition is better fulfilled by AOS than by the operations run in the traditional manner because:

- AOS can get full advantage of the variations of the weather conditions.
- AOS allow defining, in a uniform manner, calibration sequences and Uniform Data Archives (UDA) for ground telescopes. UDAs are available already for several space missions (IRAS, IUE, ROSAT, HST, ISO...) and they have proved to be very valuable for scientific research, in fact, there is a growing community astronomers carrying out research based on Archive Data.
- The complexity of the operations of the 10 m. generation telescopes, as well as the development of sophisticated instruments, requires a well trained scientific staff which presumably would stay in the telescope operations team. This staff can supervise and run the relevant quality controls on the AOS.
- From the point of view of the astronomer, AOS provides a fair chance to see his/her observing program carried out (and in the optimal conditions of airmass, seeing, transparency…). The observatories usually assign more observing time than the actually available. In the traditional observing scheduling, this was translated into having a good or bad observing run and, maybe, having to resubmit the scientific project for the next year.

AOS can be cleanly treated as a mathematical problem and henceforth, mathematical tools can be adequately designed to optimize the performance of the facilities, whichever the Astronomical Community understands as optimization.

- The scheduling problem has an inherent computational complexity: the number of solutions grows exponentially with the number of targets and there is no algorithm that can avoid the explicit or implicit enumeration of all the solutions.

  [The computational complexity is a rigorous mathematical discipline that shows how most of the optimization problems can be grouped into classes such that all of the problems in the same class are of similar complexity; the NP-hard problems are the most important class.]

- Some interesting applications of new mathematical tools and artificial intelligence to the scheduling and related problems may be found:
  - in the JPL web page (URL: www-aig.jpl.nasa.gov)
  - in some conference proceedings as, *e.g.,* Dasgupta & Michalewicz (1997).
  - In Johnston and Adorf (1994), where the program developed for the scheduling of the HST, is described. This program is based on neural networks and, by now, is widely extended in the community and modified versions have been applied to other telescopes, included ground based telescopes as the VLT (Giannone et al 2000).
  - Recent developments in the application of automated modes to telescope scheduling and operation (from small robotic telescopes to telescopes larger than the Earth as the VSOP-VLBI Mission) are summarized in the proceedings of some recent conferences (see e.g. Ford, 1998; Manset, Veillet and Crabtree, 2000).

The mathematical model

Let us consider N astronomical targets to be scheduled; the observation of each target is translated into a sequence of telescope and instrument commands defined by the astronomer, e.g. field acquisition, pointing, instrument set-up (positioning of filter wheels, gratings...), calibration or a set of repeated observations.

Each target $j \in \{ 1,2, \ldots , N \}$ is characterized by:

- A priority $q \in Q = \{ 1,2,\ldots,q \}$, which is assigned by the CAT following an anticipated scientific return. This parameter reflects the scientific relevance of the observation; the more important, the smaller q is assigned. The set Q is linearly ordered and can be supposed without any loss of a generality that the maximum allowed value is $q=4$.

- The right ascension, $\alpha(j)$, and declination, $\delta(j)$ of the target j

- A time length $\tau(j)$ including telescope manoeuvring, instrumental set-up, calibration and exposure times.

Target	Right Ascension	Declination	Q	τ(time required to carry out the observation)
S(1)	α(1)	δ(1)	q(1)	τ(1)
S(2)	α(2)	δ(2)	q(2)	τ(2)
S(3)	α(3)	δ(3)	q(3)	τ(3)
. . . .	. . . .	. . . .	. . . .	. . . .
S(N)	α(N)	δ(N)	q(N)	τ(N)

PROCEDURE:

1st. *Define a weighting function* that assigns to each priority a given weight.

$$q_i \xrightarrow{f(q)} f(q_i)$$

$$\begin{pmatrix} 1 \\ 2 \\ 3 \\ 4 \end{pmatrix} \xrightarrow{f(q)} \begin{pmatrix} f(1) \\ f(2) \\ f(3) \\ f(4) \end{pmatrix}$$

f(q)	q=1	q=2	q=3	q=4
High pass-band Policy	1	0.4	0.3	0.1
Step Policy	1	0.9	0.2	0.1
Low pass-band Policy	1	0.8	0.7	0.1

2nd. *Define the scheduling problem*.

Given a total available time **T**, several scheduling problems can be stated depending on the hypothesis of the model and on the criteria of the telescope manager. A basic scheduling problem is stated when the objective is to maximize the total weight of the targets scheduled along the horizon time **T**.

3rd. *Define the objective function* to maximize,

$$F = \sum_{i=1}^{i=Ns} f(q(S_i))$$

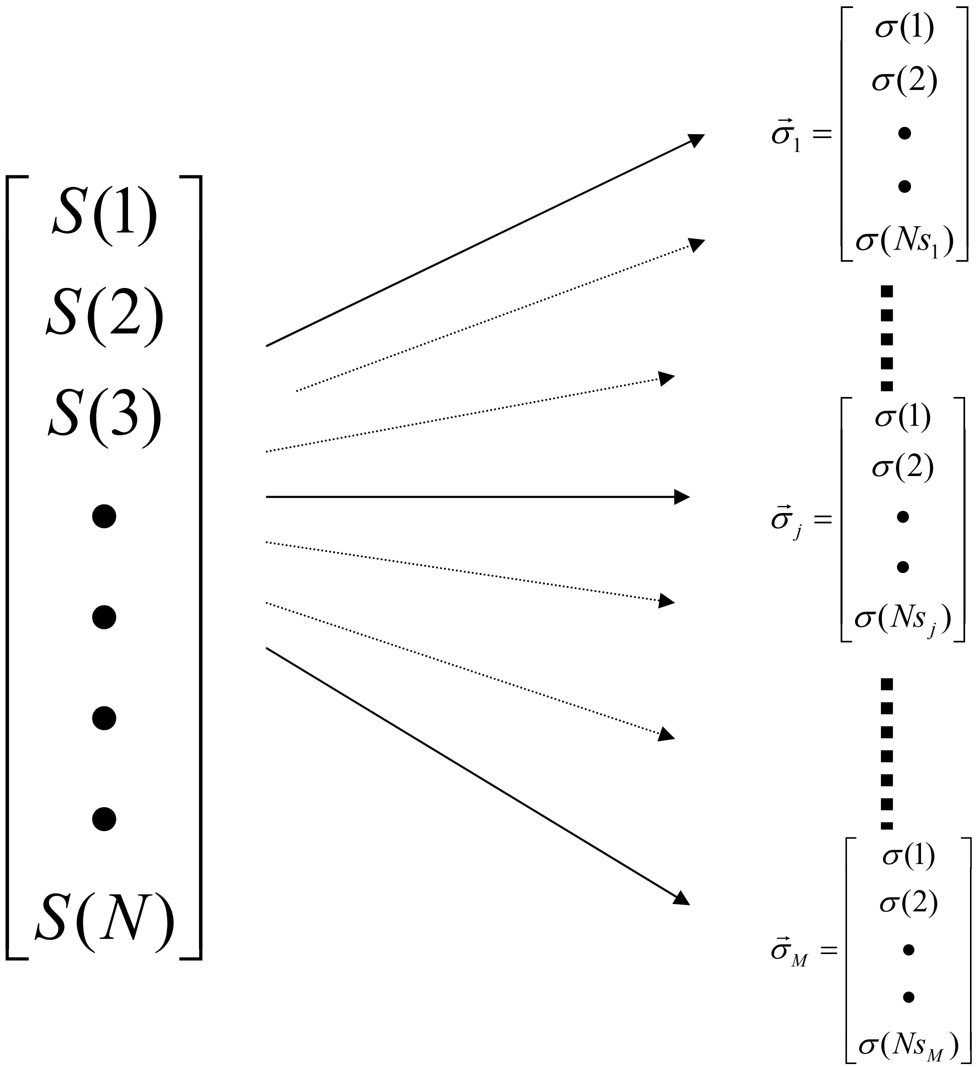
with: - S(i) the i-th target scheduled
- Ns is the total number of targets scheduled (Ns ≤ N) which can be observed in the horizon time **T**.

This basic scheduling problem can be stated as a permutation problem in the sense that the optimal solution can be characterized as a permutation (S(1),…,S(Ns)) of the targets. Such permutation identifies the order in which the targets must be consecutively performed, i.e. target S(i+1) follows to target S(i) (although some time delay can exists between the observation of two consecutive targets, it will be neglected). Consequently, the decision variable will only consider the order in which the targets are observed. Given a horizon time T and an arrangement of the N targets:

S = (S(1), S(2), …., S(N))

a valid solution for the basic scheduling problem, characterized by the Ns scheduled observations:

σ = (σ(1), σ(2), …. , σ(Ns))



where:

σ(i) Є {S(1), S(2)…S(N)}

and,

$$\sum_{k=1}^{k=Ns_i} \tau(\sigma(k)) \leq T, \forall i$$

As a permutation problem, every arrangement of observations **σ** contains a feasible scheduling and the optimization problem looks for the optimum solution among them.

The decision variable is the number of scheduled targets Ns and their order, which will be characterized by the vector:

$\boldsymbol{\sigma}_i = (\sigma(1), \sigma(2), \ldots, \sigma(Ns_i))$

The objective function F, is constructed for each vector $\boldsymbol{\sigma}_i$.

There are many possible objective functions, a generic example which takes into account that several observations may correspond to the same observing program and which weights aspect that the total number of observed objects or the total exposure time could be:

$$F = \left(\sum_{k=1,Ns} f(\sigma(k)) \right) \cdot Ns^p \cdot G(j)$$

where, for each scheduling vector, $\boldsymbol{\sigma}_j$, the number of actual observations carried out is also weighted (with a weighting factor "p", and a function G(j) is introduced to favour those scheduling vectors which include targets/observations from the same scientific program.

The permutation problem:

- The problem is then reduced to determine all the possible vectors, $\boldsymbol{\sigma}_i$, and compute F(i) to determine the scheduling vector with the maximum value of F.

- If the number of observations is large, the complete enumeration of all the feasible solutions is impossible or too much time consuming. As a consequence, good approximate solutions have to be found, **heuristics**, without enumerating all the solutions.

- I will discuss two basic types of heuristics:
  - **Neighbourhood search methods**
  - **Genetic algorithms**

    Some well-known meta-heuristics, such as simulated annealing, tabu search, genetic algorithms or neural networks have been proposed to circumvent the local-optimum problem of the NSMs (see e.g. Reeves 1993- Modern Heuristic Techniques for Combinatorial Problems, Oxford: Blackwell Scientific Pub.)

Neighbourhood Search Methods (NSM)

Simple improvement

The new permutation $\boldsymbol{\sigma}_i$ is derived changing the elements S(j1) and S(j2):

$\boldsymbol{\sigma}_i$= (S(1),…., S(j1-1), S(j2), S(j1+1), …., S(j2-1), S(j1), S(j2+1),…., S(Ns_i))

The process continues until any couple j1,j2 є { 1, … ,N } does not improve the actual permutation.

2-opt Exchange improvement

In the previous heuristic, two elements of the permutation are interchanged, the other elements are in the same position. In this heuristic, however, given two elements, the second is placed after the first one, and all intermediate elements are delayed one position.

$\boldsymbol{\sigma}_i$= (S(1),…., S(j1-1), S(j1), S(j2), S(j1+1), …., S(j2-1), S(j2+1),…., S(Ns_i))

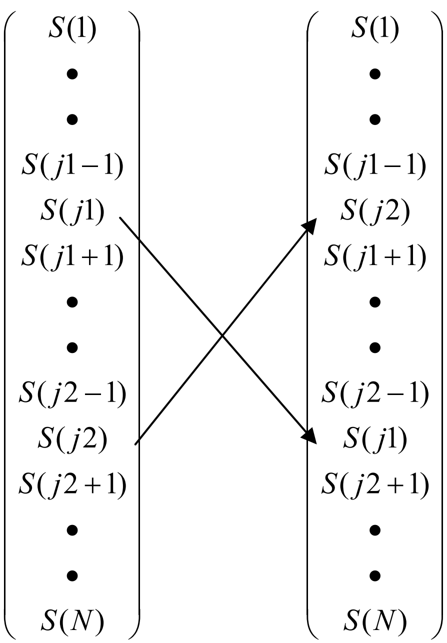
Lin-Kernighan algorithm

In this heuristic, some major changes are introduced in the permutation σ '.

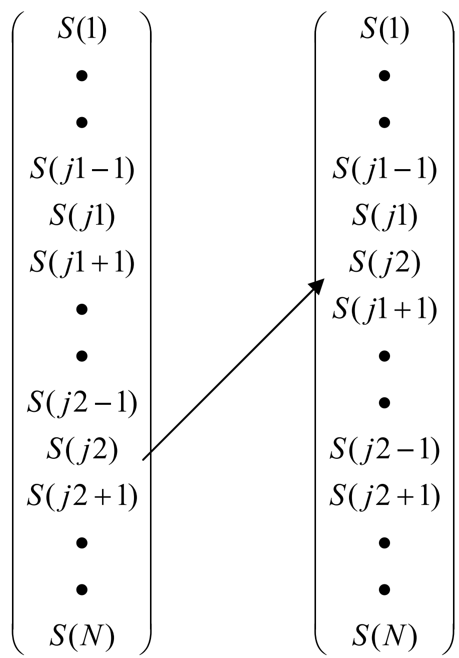
$\boldsymbol{\sigma}_i$= (S(1),…., S(j1-1), S(j2), S(j2-1), …., S(j1+1), S(j1), S(j2+1),…., S(Ns_i))

Neighbourhood Search Methods (NSM)

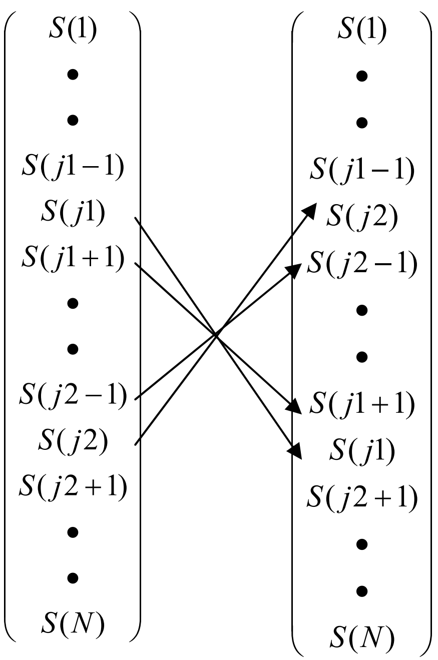
Simple improvement



2-Opt exchange improvement



Lin-Kernighan algorithm



Genetic Algorithms

- The name genetic algorithm originates from the analogy between the representation of a complex structure by means of a vector of components and the genetic structure of a chromosome and its genes. In selective breeding of plants or animals, offspring are sought which have certain desirable characteristics that are determined at the genetic level by the way the parent's chromosomes combine. In a similar way, in seeking better solutions to complex problems, we often combine pieces of existing solutions. It is expected that following *natural rules*, a set of solutions can be combined so that better ones are obtained (Holland, 1975).

- The natural rules of GAs are ***selection*** of the best individuals of population, ***crossover*** between two selected individuals to produce two new ones, the sons, which will replace their parents and ***mutation***, which arbitrarily changes some characteristics of some individuals. Associated with these rules, three mathematical operators are defined:
  - Selection operator determines the individuals to be chosen for mating.
  - Crossover operator determines the manner in which the sons are generated from the parents.
  - Mutation operator alters some the characteristics of some (very few) individuals from the population.

$$\begin{pmatrix} S(1) \\ \bullet \\ \bullet \\ S(j1-1) \\ S(j1) \\ S(j1+1) \\ \bullet \\ \bullet \\ S(j2-1) \\ S(j2) \\ S(j2+1) \\ \bullet \\ \bullet \\ S(N) \end{pmatrix}$$

A whole generation of vectors $\boldsymbol{\sigma}_i$ is built containing M vectors.

Selection Operator

A probability p_i of being selected is asigned to each one of the vectors $\boldsymbol{\sigma}_i$ of the population.

The probability is defined:

$$p_i = \frac{F_i}{\sum_{i=1}^{i=M} F_i}$$

Crossover Operator

The M individuals are classified into M/2 Couples. New individuals are defined from the mixing of the original ones, e.g.,

PARENTS

$$\sigma_i = (\sigma_i(1),\ldots,\sigma_i(j1),\ldots,\sigma_i(j2),\ldots\sigma_i(Ns_i))$$

$$\sigma_j = (\sigma_j(1),\ldots,\sigma_j(j1),\ldots,\sigma_j(j2),\ldots\sigma_j(Ns_j))$$

CHILDREN

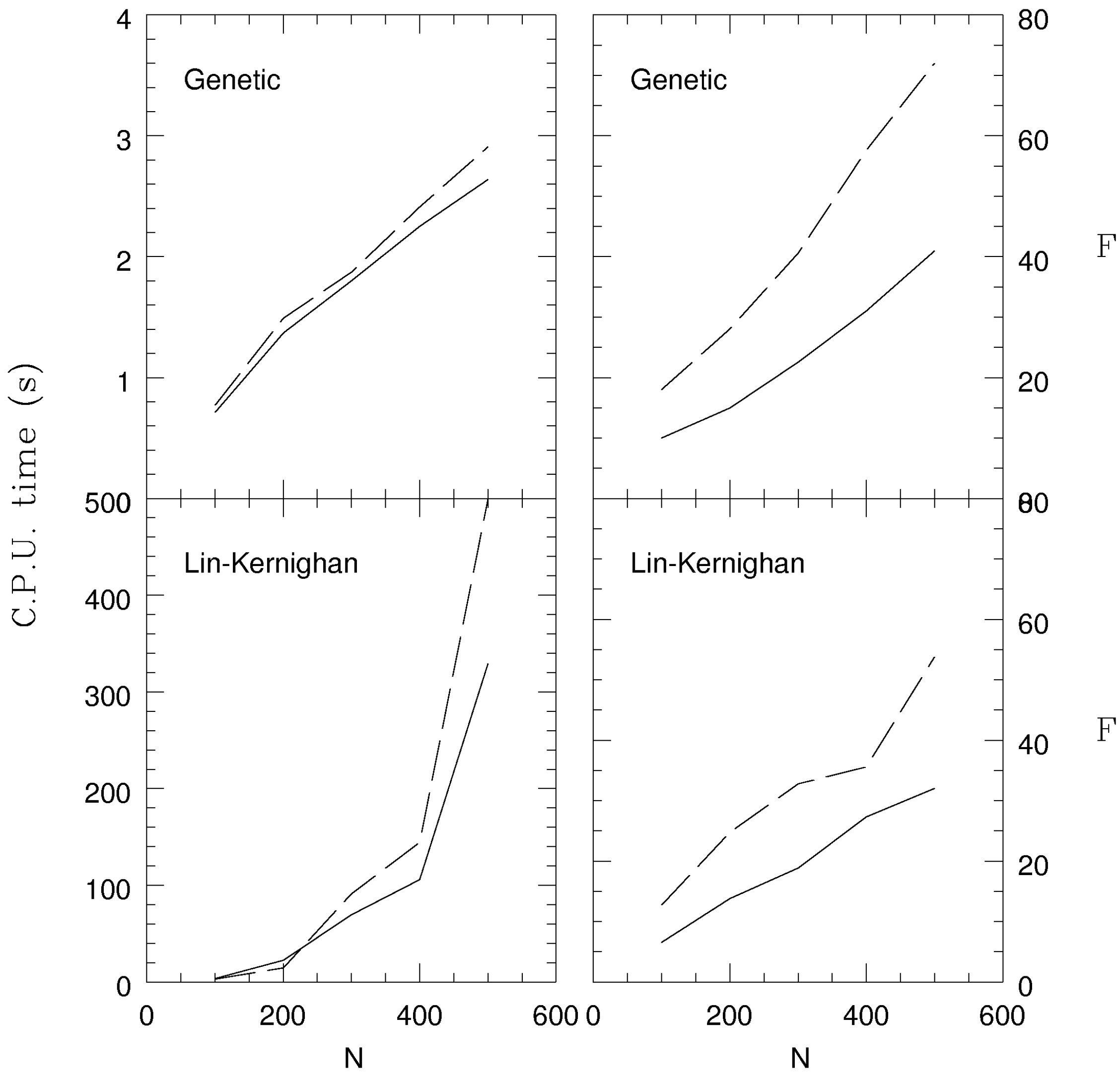
$$\sigma_k = (\sigma_i(1),\ldots,\sigma_i(j1),\ldots,\sigma_j(j2),\ldots\sigma_j(Ns_k))$$

$$\sigma_l = (\sigma_j(1),\ldots,\sigma_j(j1),\ldots,\sigma_i(j2),\ldots\sigma_i(Ns_l))$$

This cycle is iterated several times.

Mutation Operator

The new offspring may suffer mutations with a given probability, p_m. Mutations may be the permutation of two elements.

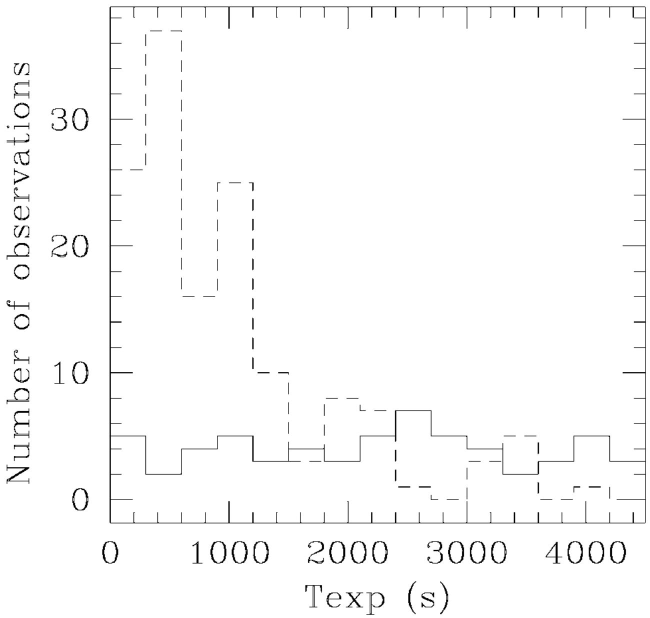


Scaling of the computer performance with the number of observations, N for the Lin-Kernighan and the genetic algorithms. The C.P.U. time and the objective function F are shown in the left and right panels respectively. The results are shown for two oversubscription factors: 1.5 (dashed) and 3 (solid).

APPLICACION TO A LIST OF OBSERVATIONS

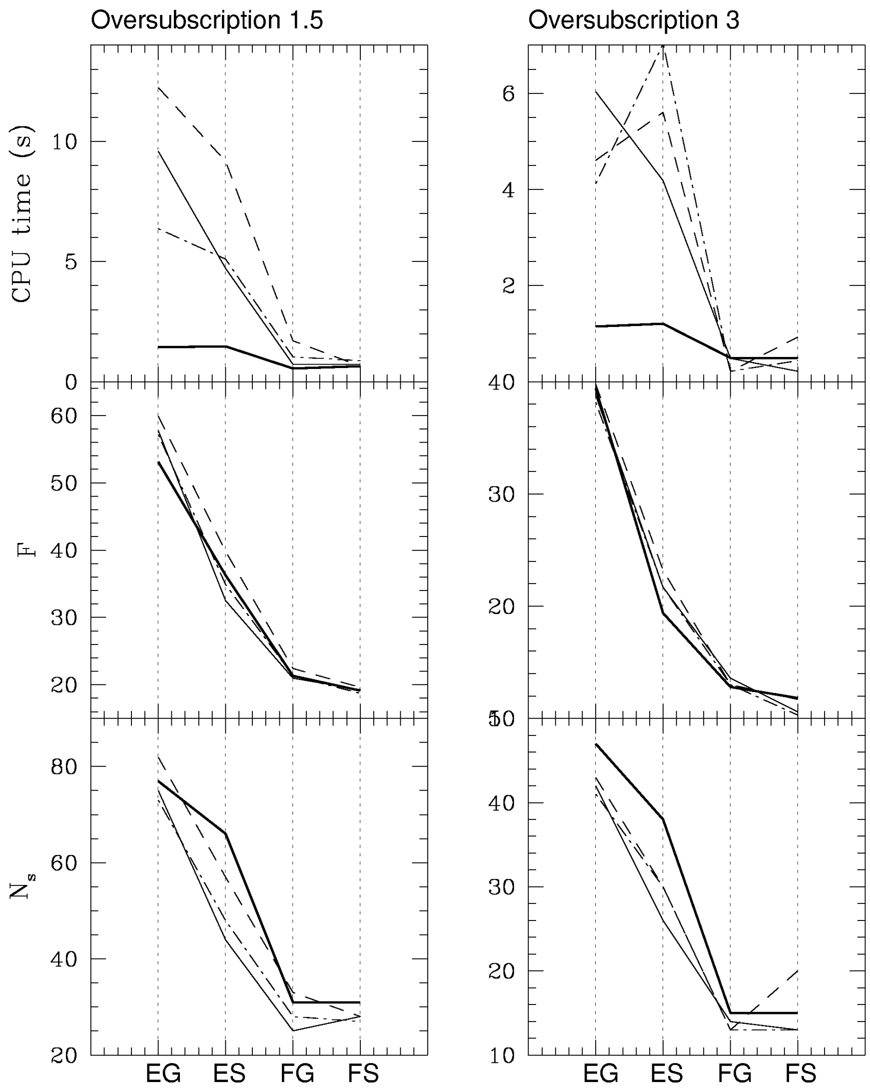
The sample has been selected from the *Infrared Space Observatory* (ISO) targets list. Two test data files have been made:

- An *exponential distribution* (ED) test list. 140 observations have been selected at random from the original ISO list. The histogram of the distribution of the observations by exposure times is exponential-like, e.g., the number of targets which require short exposure times is significantly larger than the number of targets with small exposure times.
- A *flat distribution (FD)* test list has been obtaine after some manipulation of the original ISO file; only 60 targets are included.

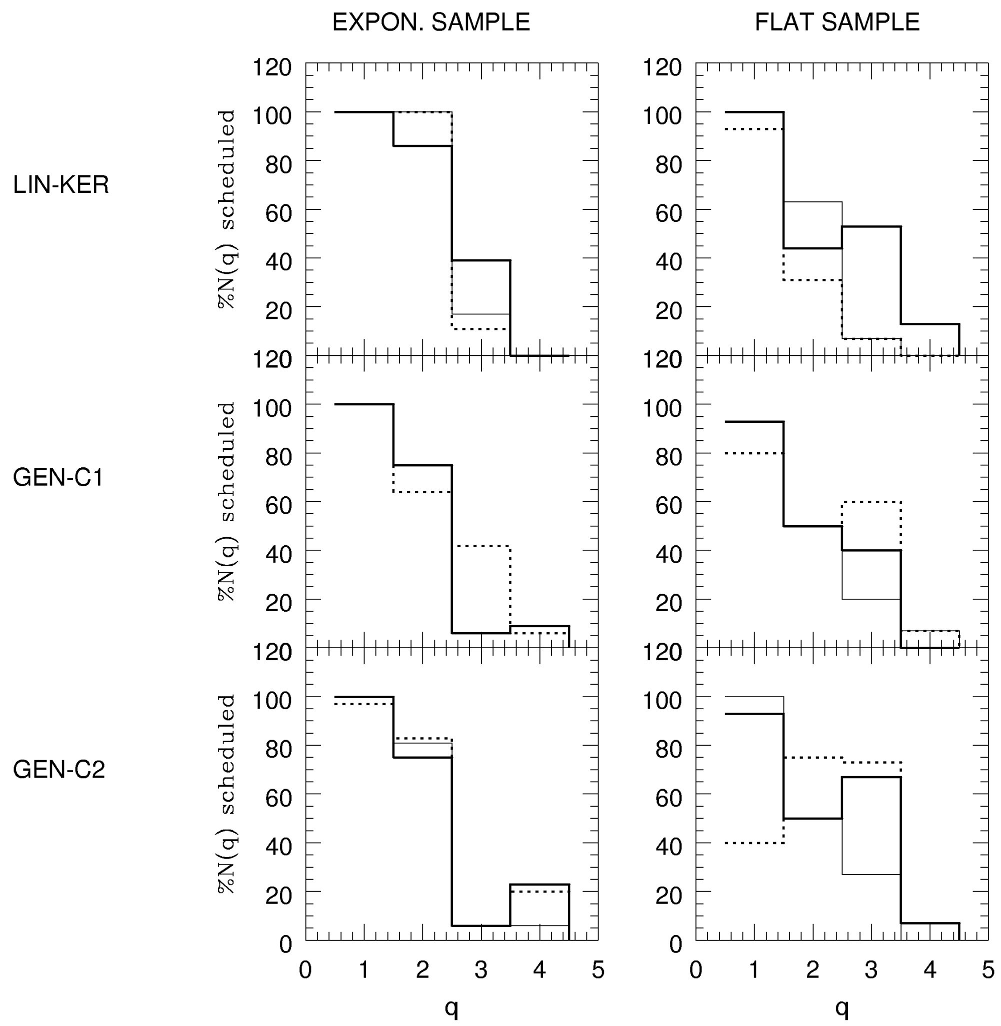


The quality factors, q(i), has been assigned by hand to these two lists. Two types of criteria have been followed:

•*Grey policy:* (G) assigns q=1,2,3 and 4 to each quarter of targets in the list
•*Standard policy*: (S) assigns q=1,2,3 and 4 to the 10%, 60%, 20% and 10% of the targets



Summary of some computational experiences. The results for three neighbourhood search methods (simple, 2-opt and Lin-Kernighan) as well as for the genetic algorithms are plotted with thin, dot-dashed, dashed and thick lines respectively. EG, ES, FG and FS stand for data files with exponential (E) or flat (F) distributions and grey (G) or standard (S) policies.



Effect of the scientific policies in the finally scheduled observations. The three policies used for the simulation are *high passband*, *step* and *low passband* and the corresponding results are marked with thick, thin and dotted lines respectively.

INPUT SAMPLE	ALGORITHM	POLICY	F	Ns	n(q=1)	n(q=2)	n(q=3)	n(q=4)
EXPONENTIAL	Lin-Kernighan	High Passband	**51.6**	**80**	35	31	14	0
		Step	**68.6**	**77**	35	35	6	0
		Low PassBand	**66.6**	**75**	35	35	4	0
	Genetic	High Passband	**46.7**	**67**	35	27	2	3
		Step	**60.0**	**67**	35	27	2	3
		Low Passband	**64.1**	**75**	35	23	15	2
FLAT	Lin-Kernighan	High Passband	**20.4**	**32**	15	7	8	2
		Step	**24.2**	**26**	15	10	1	0
		Low Passband	**24.6**	**31**	14	5	9	3
	Genetic	High Passband	**19.0**	**28**	14	8	6	0
		Step	**21.9**	**26**	14	8	3	1
		Low Passband	**24.8**	**30**	12	8	9	1

IN SUMMARY:

- The neighbourhood search algorithms and the genetic algorithms deal with the optimization problem in different manners and this shows in the results. For large size problems, genetic algorithms are by far the best. However, for small size problems, neighbourhood search algorithms are efficient to search for the local maximum of F closest to the initial solution; this property depends strongly on a ``a priori'' good knowledge of the problem. The **genetic algorithms are clearly superior** if there is not such a knowledge of the main constraints in the scheduling of the observations. Moreover, genetic algorithms are rapid enough to allow a fast re-organization of the scheduling queues that can be as rapid as the variations of the weather conditions (few seconds).

- To take advantage of the automatic scheduling, **it is important to have a small degree of oversubscription** in the final allocated time **and a large number of observations with short exposure times** for instance, the SNAPSHOT proposals for the Hubble Space Telescope.

- **The only way to ensure that first class projects are carried out is by introducing directly constraints in the scheduling programme** since the heuristics do not guarantee that they are scheduled instead of more convenient projects.

- The algorithms are sensitive to the scientific policy by means of the definition of the function F and also by the assignment of priorities to the projects. Also the way in which the CATs qualify the observing proposals is relevant. Currently, CATs qualify the proposals in very different manners depending on the European Facility.

6. TRABAJOS DE CURSO

1. Determine, for a given star, the three components of the velocity in the L.S.R. from the radial velocity and proper motion extracted from SIMBAD (compare the different values in SIMBAD, VIZIER and the literature and provide a critical interpretation of the discrepancies if any exist)
2. Determine the Spectral Energy Distribution for a given source (from radio to X-ray) making use of the data in SIMBAD and VIZIER.
3. Search the Web sites of the main European Observatories for information on the photometric and spectrophotometric standards.
4. Make a scientific project which is feasible and takes full advantange of the Virtual Observatories capabilities (use the AVO demo if feasible).