

# CDS and the VO

# Virtual Observatory

- Framework for interoperable and efficient access to astronomical data and services
- e-Science for Astronomy
- Based on global standards
  - co-ordination via IVOA



# Vision

- Archives and databases form a ‘digital sky’
- New possibilities via data discovery, efficient data access and interoperability

Driven by:

- Exploding data rates
- Multi- $\lambda$  science



# CDS involvement

- Development of VO standards
- Leadership roles in IVOA, EuroVO, VOFrance
- VO science tools and services
- VO science
- Science tutorials, outreach/education
- Assisting the Data Centre community to publish to the VO

# CDS approach to VO

- Participate fully in VO development of standards -- it helps the CDS services
- As a major content provider we need to be involved
- Careful implementation of VO in CDS services alongside other access modes
- Use VO to foster innovation and collaboration

# Projects



- European co-ordination

- **AVO** (FP5)
- **VO**Tech (FP6)
- **DCA** (FP6)
- **AIDA** (FP7)
- **ICE** (FP7)

# IVOA

- **Leadership roles:**

**Genova** - Chair 2006-7, Vice-Chair 2005-6, DCP IG Vice chair 2004-7,  
Comm. Standards and Processes 2007-

**Ochsenbein** - VOTable Chair 2003-9

**Allen** - Applications IG/WG Chair 2005-8, Comm. Science Priorities 2009-  
Newsletter Editor, Secretary 2009-

**Derriere** - Semantics WG Chair 2008-

**Schaaff** - Grid and Web Services WG Vice Chair 2011-

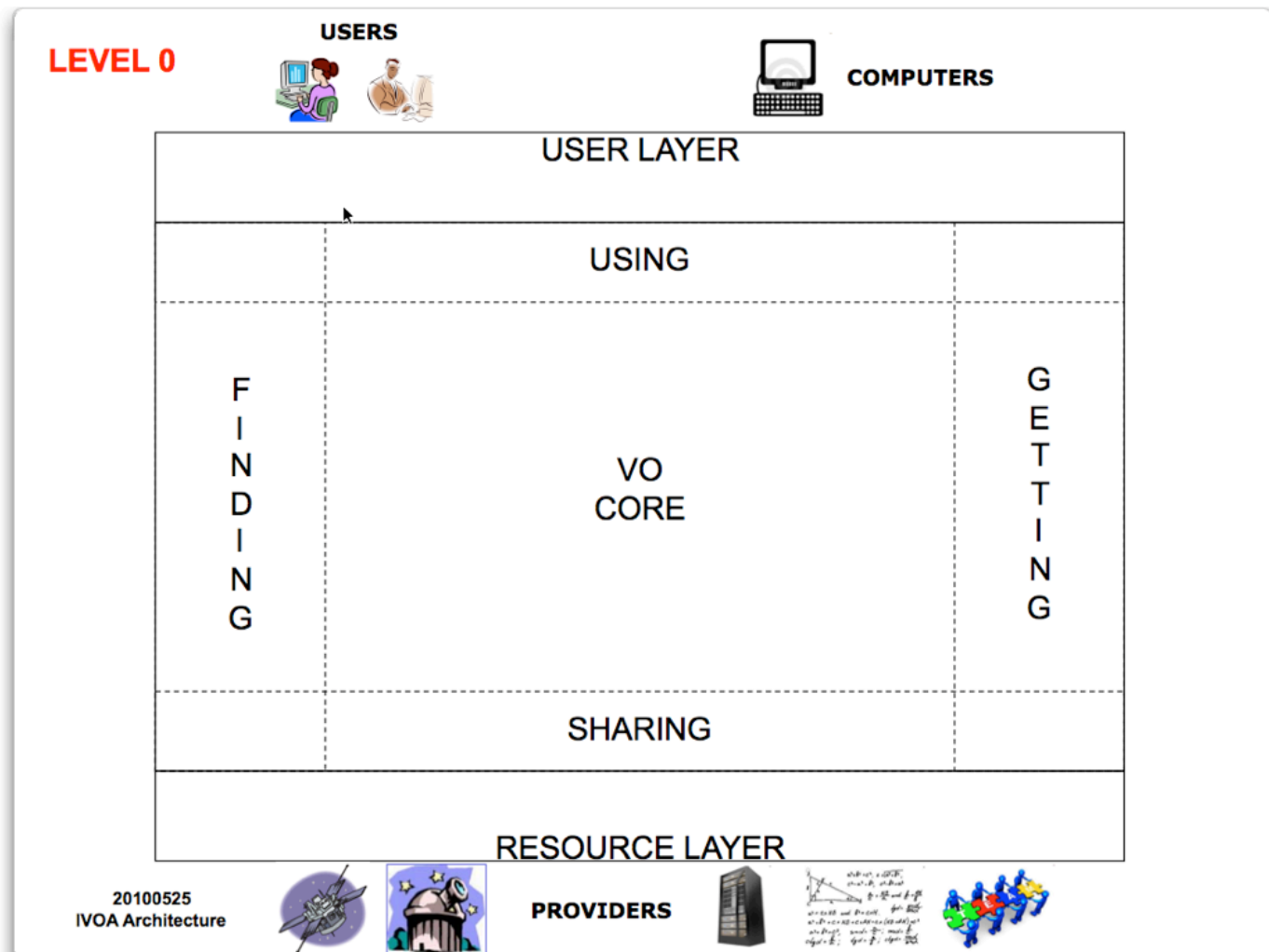
**Preite-Martinez (INAF)** - Semantics WG Chair 2005-8

**Louys (LSIIT)** - Data Models WG Chair 2007-11

**Wozniak (Obs. Strasbg.)** - Theory WG Chair 2008-11

# IVOA - Architecture

Multi-level structure for understanding each component of the VO



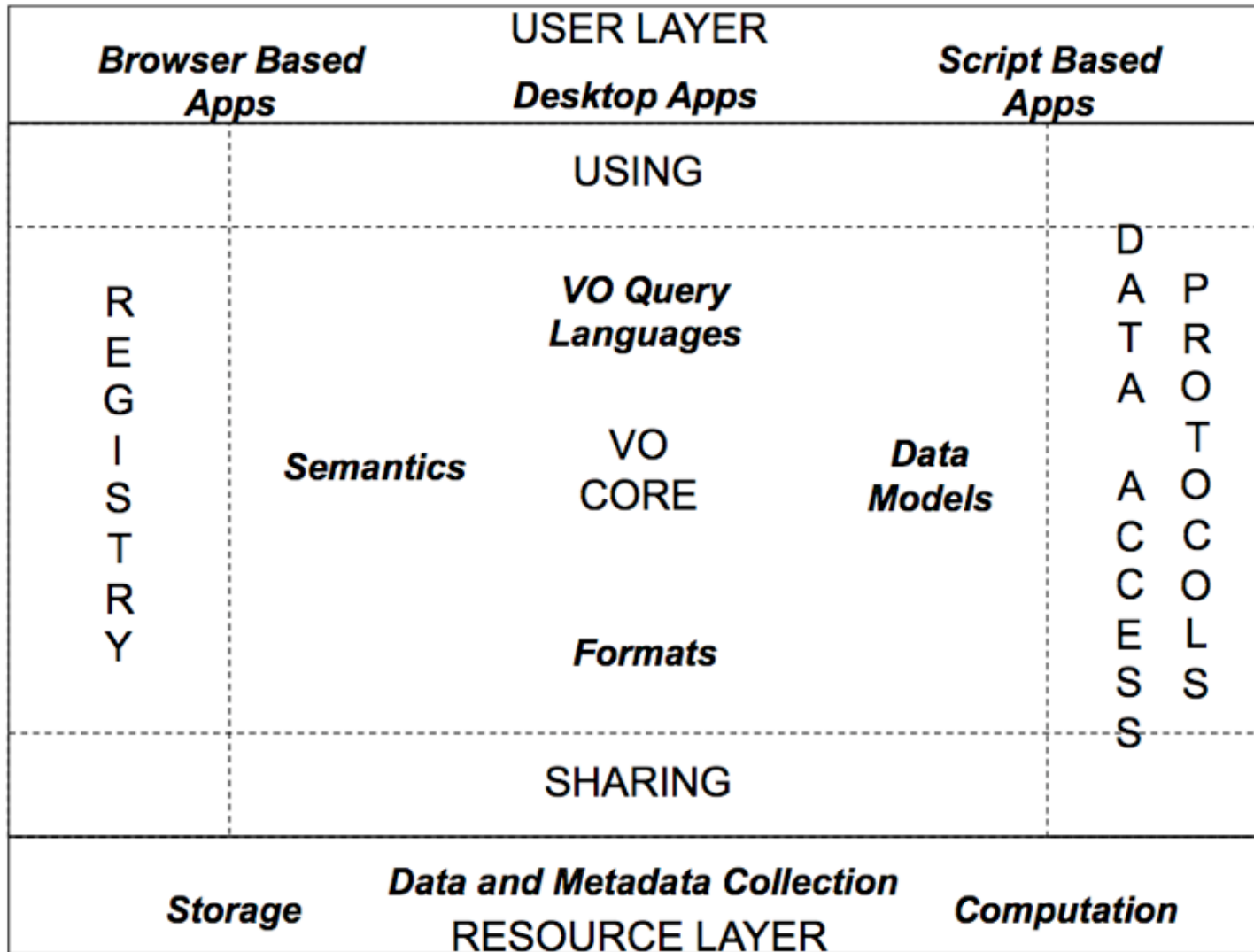


**LEVEL 1**

**USERS**



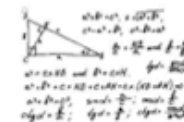
**COMPUTERS**



20100525  
IVOA Architecture



**PROVIDERS**



**LEVEL 2**

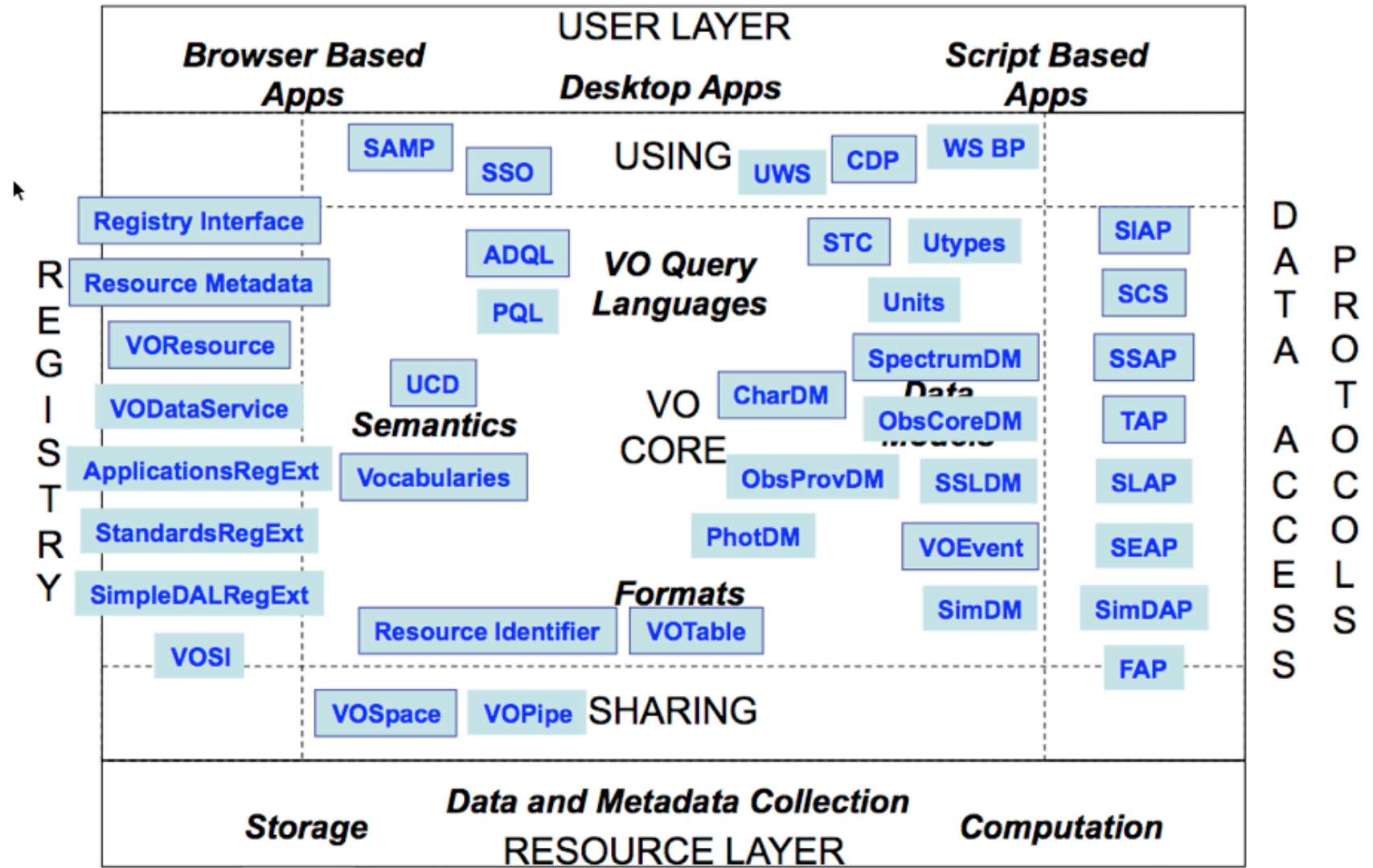
**USERS**



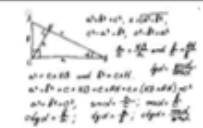
**COMPUTERS**

**REC**

**InProgress**



**PROVIDERS**



# Specific CDS contributions to IVOA standards

- VOTable
- Data Access Layer
  - Simple Spectral Access (SSA), Simple Image Access (SIA), Table Access Protocol (TAP)
- Data models: Characterisation, ObsTAP
- Applications: SAMP
- GWS:VOSpace 2.0, Basic Profiles

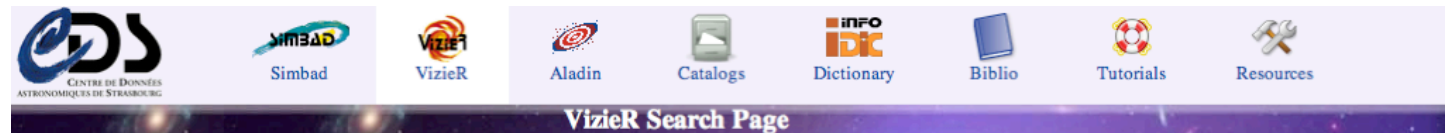
*see the list of IVOA standards 'signed' by CDS members*

- One important aspect of CDS participation: *testing implementations alongside of standards development*
  - ensures relevant and useable standards
- Examples:
  - VOSpace reference implementation and toolkit
  - UWS toolkit
  - VOTable parser
  - DMs/Characterisation in Aladin image server
  - Aladin SAMP

# VO in CDS services

- VO Compliance in services
  - VO access alongside existing modes (Vizier example to follow)
- VO interoperability of tools (SAMP)
- Innovation (e.g. CDS Portal, Healpix techniques)

# VO standards used in VizieR web page interface



**Simple Target** **List Of Targets**

Target Name (resolved by [Sesame](#)) or Position:  J2000  2  arcmin

Radius  Box size

2MASS All-Sky Catalog of Point Sources (Cutri+ 2003) [ReadMe+ftp](#) [Similar Catalogs](#)

1.II/246/out [Post annotation](#)  
The Point Source catalogue of 470,992,970 sources. Please [acknowledge the usage of the 2MASS All-Sky Survey](#); see also the [2MASS Pages](#). (470992970 rows)

**Simple Constraint** **List Of Constraints**

Query by **Constraints** applied on Columns (Output Order:  +  -)

Show	Sort	Column	Constraint	Explain (UCD)
<input checked="" type="checkbox"/>	<input type="radio"/>	RAJ2000	<input type="text"/> deg	(ra) Right ascension (J2000) ( <a href="#">pos.eq.ra:meta.main</a> )
<input checked="" type="checkbox"/>	<input type="radio"/>	DEJ2000	<input type="text"/> deg	(dec) Declination (J2000) (dec) ( <a href="#">pos.eq.dec:meta.main</a> )
<input type="checkbox"/>	<input type="radio"/>	errMaj	<input type="text"/> arcsec	(err_maj) Major axis of position error ellipse ( <a href="#">stat.error</a> )
<input type="checkbox"/>	<input type="radio"/>	errMin	<input type="text"/> arcsec	(err_min) Minor axis of position error ellipse ( <a href="#">stat.error</a> )
<input type="checkbox"/>	<input type="radio"/>	errPA	<input type="text"/> deg	[0,180] (err_ang) Position angle of error ellipse major axis (E of N) ( <a href="#">stat.error</a> )
<input checked="" type="checkbox"/>	<input type="radio"/>	2MASS	<input type="text"/> (char)	(designation) Source designation ( <a href="#">Note 1</a> ) ( <a href="#">meta.id:meta.main</a> )
<input checked="" type="checkbox"/>	<input type="radio"/>	Jmag	<input type="text"/> mag	<sup>(n)</sup> (j_m) J selected default magnitude ( <a href="#">Note 2</a> ) ( <a href="#">phot.mag:em_IR_J</a> )
<input type="checkbox"/>	<input type="radio"/>	Jcmsig	<input type="text"/> mag	<sup>(n)</sup> (j_cmsig) J default magnitude uncertainty ( <a href="#">Note 3</a> ) ( <a href="#">stat.error:phot.mag</a> )
<input checked="" type="checkbox"/>	<input type="radio"/>	e_Jmag	<input type="text"/> mag	<sup>(n)</sup> (j_msigcom) J total magnitude uncertainty ( <a href="#">Note 4</a> ) ( <a href="#">stat.error:phot.mag:em_IR_J</a> )
<input type="checkbox"/>	<input type="radio"/>	Jsnr	<input type="text"/> mag	<sup>(n)</sup> (j_snr) J Signal-to-noise ratio ( <a href="#">stat.snr</a> )
<input checked="" type="checkbox"/>	<input type="radio"/>	Hmag	<input type="text"/> mag	<sup>(n)</sup> (h_m) H selected default magnitude ( <a href="#">Note 2</a> ) ( <a href="#">phot.mag:em_IR_H</a> )

VOTable

UCDs

**Search Criteria** [Save in CDSportal](#)

Keywords

2mass  
Tables  
II/246  
..out  
VII/233  
..XSC  
II/241

**Preferences**  
max: unlimited

VOTable

All columns

**Compute**

Distance

Distance (x,y)

Galactic

J2000

B1950

Ecl. J2000

default

Sort by Distance

No sort

**Position in:**

Sexagesimal

Decimal °

**Mirrors**

CDS, France

# VizieR catalogues described in the Registry

The screenshot shows a web browser window with the URL <http://registry.euro-vo.org/result.jsp?searchMethod=XPathQLSearch&select=%23ResourceType%23%3D%27Cat> and a search term "meganerdruns". The page header features the EURO-VO logo and the text "AIDA Astronomical Infrastructure for Data Access". Below the header, there are navigation links for "The Euro-VO projects: VOTECH EuroVO-DCA EuroVO-AIDA".

The left sidebar contains a "EURO-VO Registry" menu with the following items: Search Resources, Resource, Organisation, Authority, Data Collection, Service, Registry, Table Service, Data Service, **Catalog Service**, **Catalog Service (CDS)**, Cone Search (CS), Open Sky Node (OSN), Simple Image Access (SIAP), Proto Spectral Access (PSAP), Simple Spectral Access (SSAP), Simple Line Access (SLAP), and Theoretical Spectral Access (TSAP). Below the menu are sections for "Insert Resources", "Update Resources", "Validate Resources", and "EURO-VO Registry Resource Details". At the bottom of the sidebar, it says "Member of" with the IVOA logo and "Powered by" with the eesa Vo Virtual Observatory logo.

The main content area is titled "Search Results" and shows a list of catalogues. The first result is "Results of obs with the 6-inch transit circle (Hammond+ 1927-1982) [I/100A]". It includes the IVOA identifier "ivo://CDS.VizieR/I/100A" and a description: "This catalog is a compilation of seven catalogs of positions derived from observations with the six-inch transit circle of the U. S. Naval Observatory. The observations were obtained between 1911 and 1971 and were published in the catalogs: W210, W025, W150, W250, W350, W450, and W550. Proper motions and, in most catalogs, spectral types were added from other sources." It was published by CDS on 1997-12-09T10:25:36 and last updated on 1997-12-09T10:25:36.

The second result is "Occultation Double-Star Observations (Evans 1983) [I/110]". It includes the IVOA identifier "ivo://CDS.VizieR/I/110" and a description: "This catalog contains data on 224 double stars observed photoelectrically during lunar occultations. The author cites the advantages of this method of double star detection as increased resolution, accuracy of the vector separations of roughly one-half arcsecond or better, and the opportunity to make photometric determinations of the magnitude differences between components. The vector separation is the true separation projected along a line perpendicular to the actual lunar limb. The catalog is a compilation of twelve years of observations from the literature (through roughly 1980). It is divided into three files. The first file, data1.dat, contains information on stars brighter than visual magnitude 6.7. The second, data2.dat, lists SAO catalog stars fainter than magnitude 6.7. The third file, data3.dat, contains data on faint stars with no SAO number. For these stars, data on their magnitudes or spectral types may be absent. In many cases there are multiple records per star, reflecting separate observations. The records are arranged by SAO number or other identifier, and contain visual magnitudes, spectral type, observing run number, a subjective grade of the probability of being double, the vector separation with computed error, position angle, and the lunar limb slope and its error. It also includes the magnitude difference between the components in (somewhat arbitrarily assigned) blue and red band passes. In the case of a triple star, the run number is repeated and the data for the triple given with magnitude differences from the brightest star." It was published by CDS on 1997-12-09T10:31:28 and last updated on 1997-12-09T10:31:28.

The third result is "Lowell Proper Motion Survey - Southern Hemisphere (Giclas+ 1978) [I/112]". It includes the IVOA identifier "ivo://CDS.VizieR/I/112" and a description: "This catalog contains a summary of the Lowell Proper Motion Survey for the southern hemisphere as completed to mid-1978. The catalog gives the position, motion, magnitude, and color of 2758 stars from the Lowell program." It was published by CDS on 1997-12-09T10:33:22 and last updated on 1997-12-09T10:33:22.

The fourth result is "Parallaxes and Proper Motions near SGP (Murray+ 1986) [I/129]". It includes the IVOA identifier "ivo://CDS.VizieR/I/129" and a description: "The catalog contains 6125 stars brighter than B-17.5, V-17.0 in the south galactic cap. The data have been obtained using the UK Schmidt telescope between 1975 and 1981. The plates were measured on the GALAXY machine at RGO. External errors of the parallaxes range between +/-0.012 and +/-0.017 arcsec according to magnitude. Internal proper motion errors range from +/-0.006 and +/-0.008 arcsec. In addition to the positions, proper motions, and parallaxes, the photometric data include B and V." It was published by CDS on 1997-12-09T10:48:39 and last updated on 1997-12-09T10:48:39.

# VizieR catalogues accessible via VOExplorer

VO Explorer - CDFS tables

Contents of CDFS tables - 53 resources

Publisher	IVOA-ID	Flag...	Title	Valida...
CDS	ivo://CDS.VizieR/J/Ap/682/985		FIREWORKS photometry of GOODS CDF-S (Wuyts...	ⓘ
CDS	ivo://CDS.VizieR/J/MNRAS/371...		GOODS ELAIS-N1 24um flux densities (Rodighier...	ⓘ
CDS	ivo://CDS.VizieR/J/Ap/697/13...		GOODS Ks-selected multiwavelength compilation...	ⓘ
CDS	ivo://CDS.VizieR/J/Ap/666/863		GOODS MIPS early-type galaxies (Van Der Wel+,...	ⓘ
CDS	ivo://CDS.VizieR/VII/246		GOODS Morphological Catalog (Bundy+, 2005)	ⓘ
CDS	ivo://CDS.VizieR/J/Ap/650/148		GOODS blue early-type galaxies (Lee+, 2006)	ⓘ
CDS	ivo://CDS.VizieR/II/261		GOODS initial results (Giavalisco+, 2004)	ⓘ
CDS	ivo://CDS.VizieR/J/A+A/504/751		GOODS-MUSIC catalog updated version (Santini+...	ⓘ
CDS	ivo://CDS.VizieR/J/A+A/449/951		GOODS-MUSIC sample: multicolour catalog (Grazi...	ⓘ
CDS	ivo://CDS.VizieR/J/Ap/689/687		GOODS-N spectroscopic survey (Barger+, 2008)	ⓘ
CDS	ivo://CDS.VizieR/J/A+A/454/423		GOODS-South Field VLT/FORS2 redshifts. II. (Van...	ⓘ
CDS	ivo://CDS.VizieR/J/A+A/478/83		GOODS-South Field VLT/FORS2 redshifts. III. (Van...	ⓘ
CDS	ivo://CDS.VizieR/J/A+A/434/53		GOODS-South Field redshifts (Vanzella+, 2005)	ⓘ
CDS	ivo://CDS.VizieR/J/Ap/653/10...		Galaxies at 1.4 <- z <- 3.0 in GOODS-North Field...	ⓘ
CDS	ivo://CDS.VizieR/J/Ap/600/L155		Gravitational lens in GOODS ACS fields (Fassnacht...	ⓘ
CDS	ivo://CDS.VizieR/J/A/127/3137		Hawaii redshifts in the ACS-GOODS region (Cowie...	ⓘ
CDS	ivo://CDS.VizieR/J/Ap/606/L25		Hubble Ultra Deep Parallel Fields (Bouwens+, 20...	ⓘ
CDS	ivo://CDS.VizieR/J/Ap/677/169		H(alpha) galaxies at z=0.84 (Villar+, 2008)	ⓘ

Information Table Metadata

### GOODS MIPS early-type galaxies (Van Der Wel+,...

Short Name JApJ666/863 IVOA-ID ivo://CDS.VizieR/J/ApJ/666/863  
Resource Type CatalogService Created 2009-12-18 Validated ⓘ by ivo://CDS.VizieR

Content Type catalog Subject galaxies, redshifts Level research  
We select galaxies with spectroscopic redshifts and early-type morphologies from Hubble Space Telescope Advanced Camera for Surveys (ACS) imaging from the Great Observatories Origin Deep Survey (GOODS; Giavalisco et al., 2004ApJ...600L..93G, Cat. 261>) in the Chandra Deep Field-South (CDF-S) and the Hubble Deep Field-North (HDF-N).  
[Further Information...](#)

Source Reference [2007ApJ...666..863V \(bibcode\)](#)

Footprint Service <http://cdsarc.u-strasbg.fr/viz-bin/w/Footprint?-gal&-z&&-s&sqrt&catid=16660863>  
Waveband Coverage optical, infrared  
[Show Table Metadata](#)

Service Rights public  
This resource describes an **Service**  
Interface Type Web Form Access URL <http://vizier.u-strasbg.fr/cgi-bin/VizieR-2?-source=JApJ/666/863>

This resource describes an **Service**  
Interface Type Http Query Access URL <http://vizier.u-strasbg.fr/viz-bin/votable/-dtd/-A?-source=JApJ/666/863>  
Query Type get Result Type text/xml+votable

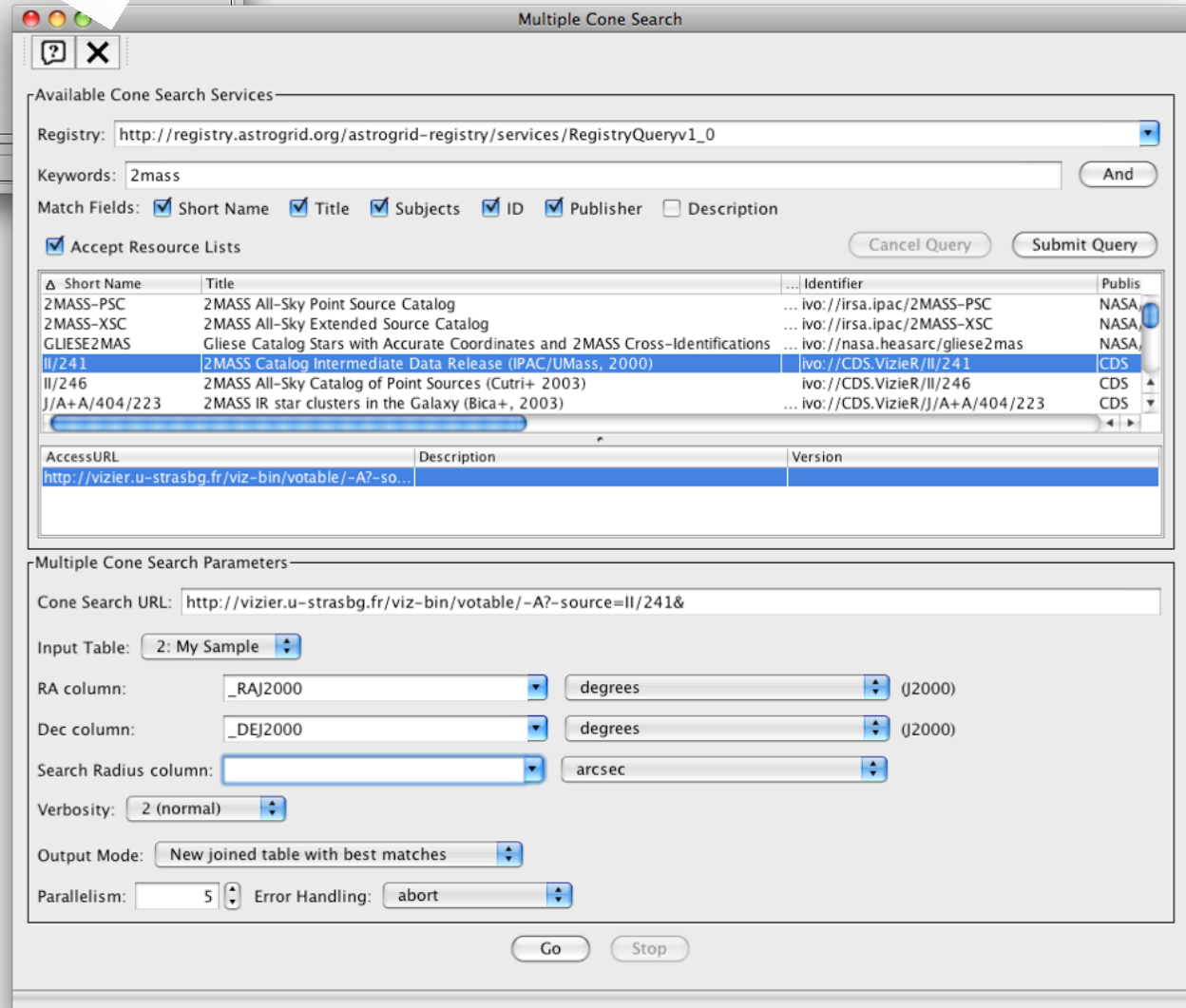
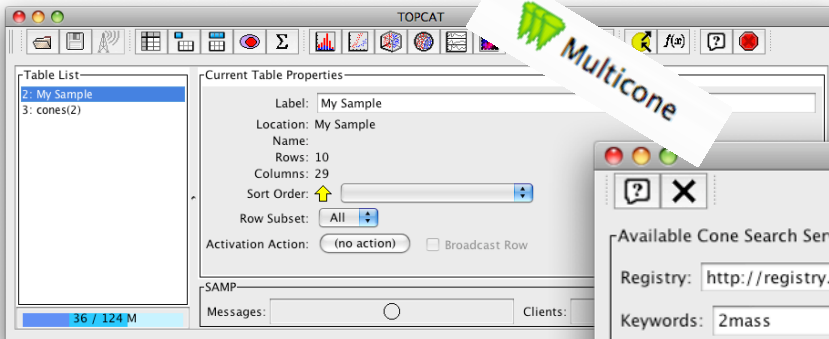
This resource describes a **Catalog cone search service**  
Verbose Parameter supported Maximum Search Radius 180.0 Maximum Results Returned 9999  
[Test Query](#) RA 0.0 Dec 90.0 SR 0.1

Interface Type Http Query Role std Access URL <http://vizier.u-strasbg.fr/viz-bin/votable/-A?-source=JApJ/666/863&>  
Query Type get Result Type text/xml+votable

Actions: Position Query, Multi Query, Web interface, Download...

About: Selection: CatalogService, Further Info, Publication, Email Curator





My Sample of objects

Find 2MASS from VizieR in registry

Cone Search for each object

Table Browser for 4: cones(2)

	DEJ2000	Jmag	e_Jmag	Hmag	e_Hmag	Kmag	e_Kmag	rd_flg	bl_flg	cc_flg	extd_flg	mp_flg	ld_opt	Separation
1	54.3489	13.356	0.045	12.486	0.075	12.282	0.051	222	111	000	0	0		0.00184
2	69.6799	9.617		9.058	0.087	8.376	0.11	022	011	000	0	0		0.00085
3	40.86525	8.97	0.062	7.712	0.03	8.108	0.046	212	101	000	1	0	U	0.00087
4	39.06329	10.55	0.057	9.845	0.069	9.505	0.045	222	111	000	1	0		0.00062
5	69.81249	11.537	0.062	10.694	0.061	10.397	0.053	222	111	000	1	0	U	0.00062



Interactive Sky Atlas

Images

Catalogues

VO Access

All Sky

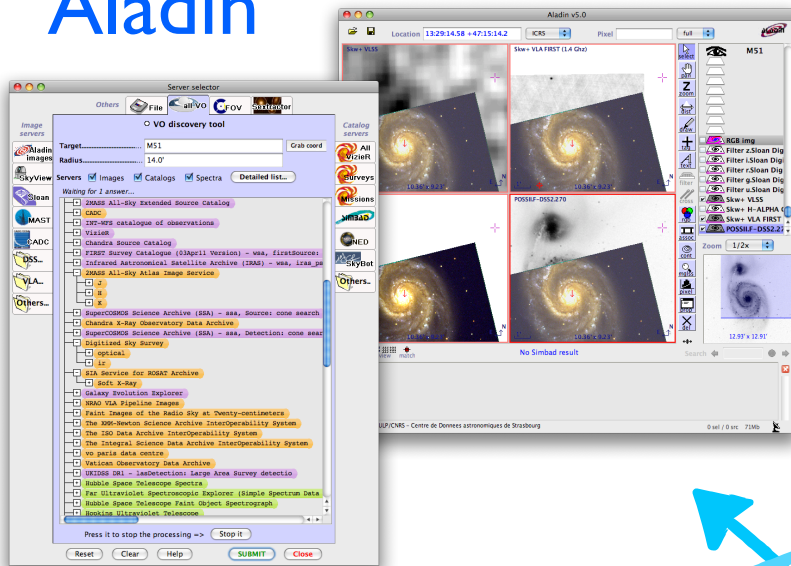
Scripting

and more...

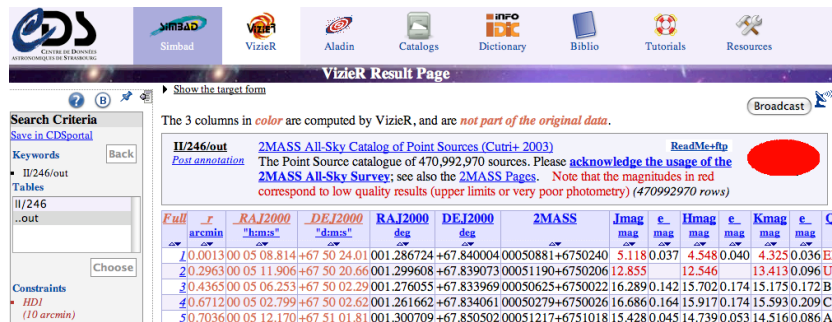
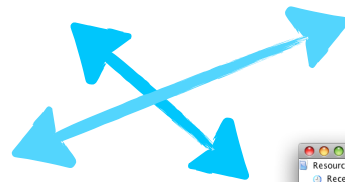
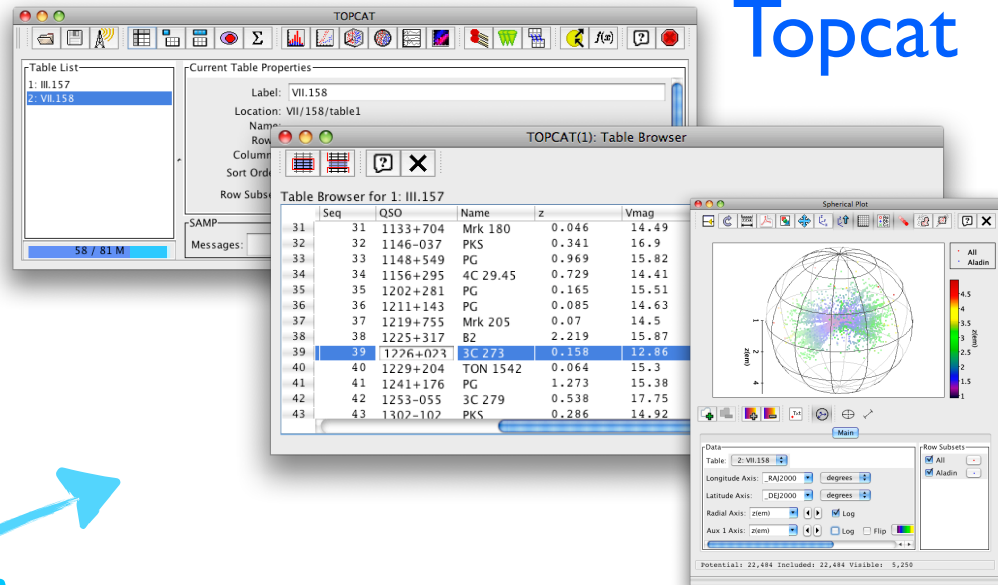
The screenshot displays the ALADIN v7.0 web interface. The main window is titled "Aladin v7.0" and shows a multi-panel view of the Antennae Galaxies (NGC 4038-4039). The top-left panel shows a color image of the galaxies. The top-middle panel shows a contour plot of the galaxies. The top-right panel shows a 2MASS image. The bottom-left panel shows a 2MASS image in a different band. The bottom-middle panel shows a 2MASS image in a different band. The bottom-right panel shows an RGB image. A "VO discovery tool" dialog box is open in the foreground, showing a search for "ngc 4039" with a radius of "14'". The dialog box lists various data sources and filters, including "Chandra X-Ray Observatory Data Archive", "The XMM-Newton Science Archive Interoperability System", "ESO science Archive Image Service", "BandPass: BB#B/123", "BandPass: BB#I/203", "BandPass: BB#Rc/162", "BandPass: BB#U/50", "BandPass: BB#V/89", "ST-ECF Hubble Legacy Archive Images", and "Multimission Archive at STScI (MAST)". The dialog box also has a "Stop it" button and a "SUBMIT" button. In the background, there is a "Server selector" window showing various servers like "Allsky", "all-vo", "FOV", "SExtractor", and "Watch". On the right side, there is a "Catalog servers" panel with various icons and a "1/8x" zoom level. At the top right, there is a logo for "all-vo".

# SAMP tool interoperability

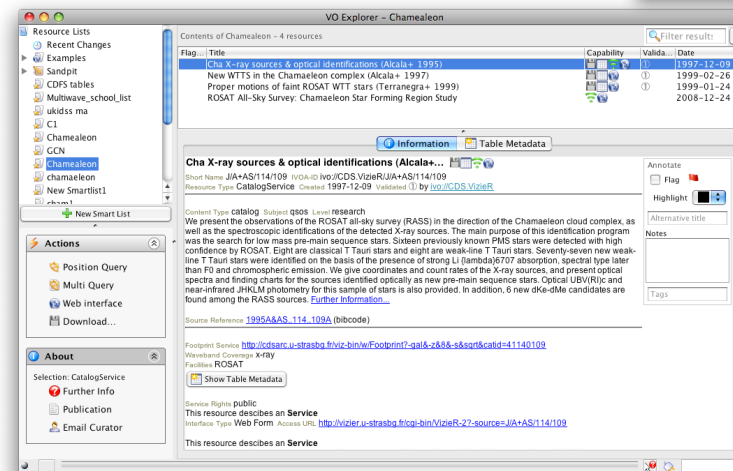
Aladin



Topcat



Web pages (VizieR)



VO Desktop

# Innovation: CDS Portal



The screenshot shows the CDS Portal interface for NGC 4039. The browser address bar displays the URL <http://cdsportal.u-strasbg.fr/#NGC%204039>. The page header includes the CDS logo and navigation links for Simbad, VizieR, Aladin, Catalogs, Dictionary, Biblio, Tutorials, and Resources. The main content area is titled "CDS Portal" and includes a search bar with "Target: NGC 4039" and a "GO" button. Below the search bar, the J2000 position for NGC 4039 is given as 12 01 53.7 -18 53 08. The "Object identifiers, measurements and bibliography for NGC 4039" section lists key information: Object type: Galaxy in Pair of Galaxies; Morphological type: Sc; 1014 bibliographic references; 359 objects within 2'; and links to display maps. A histogram on the right shows the number of bibliographic references for NGC 4039 from 1950 to 2011. The "Images for NGC 4039" section includes a table of Aladin images and a color image of the galaxy. The "Catalogues for NGC 4039" section lists 4 catalogues with the keyword and 146 catalogues around NGC 4039.

Portal [My data](#) [Login](#) [Preferences](#) [Register](#)

Target:

J2000 position for NGC 4039: 12 01 53.7 -18 53 08

### Object identifiers, measurements and bibliography for NGC 4039

- Object type: Galaxy in Pair of Galaxies
- Morphological type: Sc
- [More SIMBAD data for NGC 4039](#)
- [1014 bibliographic references](#)
- [359 objects within 2'](#)
- [Display map around NGC 4039](#)
- [Display SimPlay interactive map around NGC 4039](#)
- [Related objects in bibliography:](#)

Number of bibliographic references for NGC 4039

### Images for NGC 4039

- [Display region in Aladin \(Web Start\)](#)

Survey	Band	$\lambda$ ( $\mu\text{m}$ )	Size	Epoch	Resolution	Download
DENIS	I	0.79	12.5' x 12.4'	1996-03-30	0.9" / pixel	<a href="#">FITS</a>
DENIS	J	1.23	12.6' x 12.7'	1996-03-30	0.9" / pixel	<a href="#">FITS</a>
DENIS	K	2.16	12.6' x 12.7'	1996-03-30	0.9" / pixel	<a href="#">FITS</a>
2MASS	K	2.16	8.5' x 17.0'	1999-03-20	0.9" / pixel	<a href="#">FITS</a>
2MASS	H	1.65	8.5' x 17.0'	1999-03-20	0.9" / pixel	<a href="#">FITS</a>
2MASS	J	1.24	8.5' x 17.0'	1999-03-20	0.9" / pixel	<a href="#">FITS</a>
AAO	R	0.63	12.9' x 12.9'	1996-02-26	1.0" / pixel	<a href="#">JPEG</a> <a href="#">FITS</a>
SERC	I	0.80	12.9' x 12.9'	1996-05-25	1.0" / pixel	<a href="#">JPEG</a> <a href="#">FITS</a>

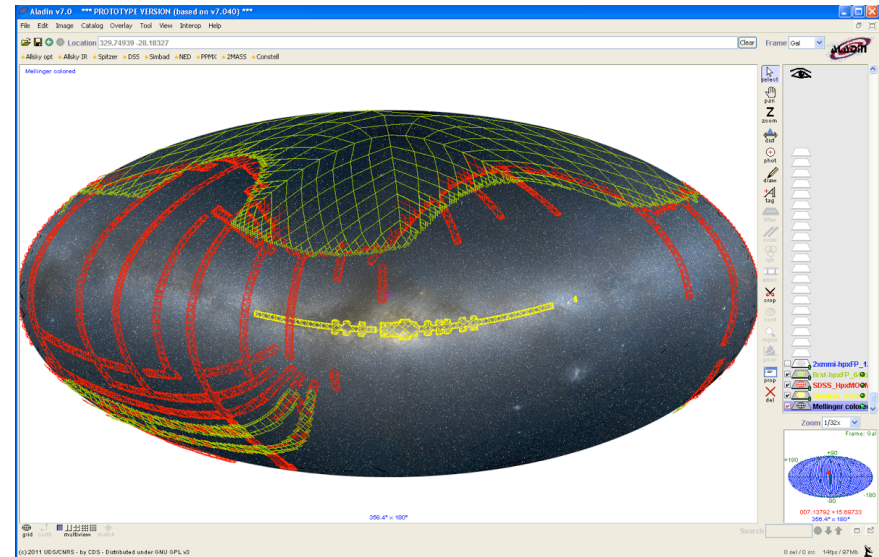
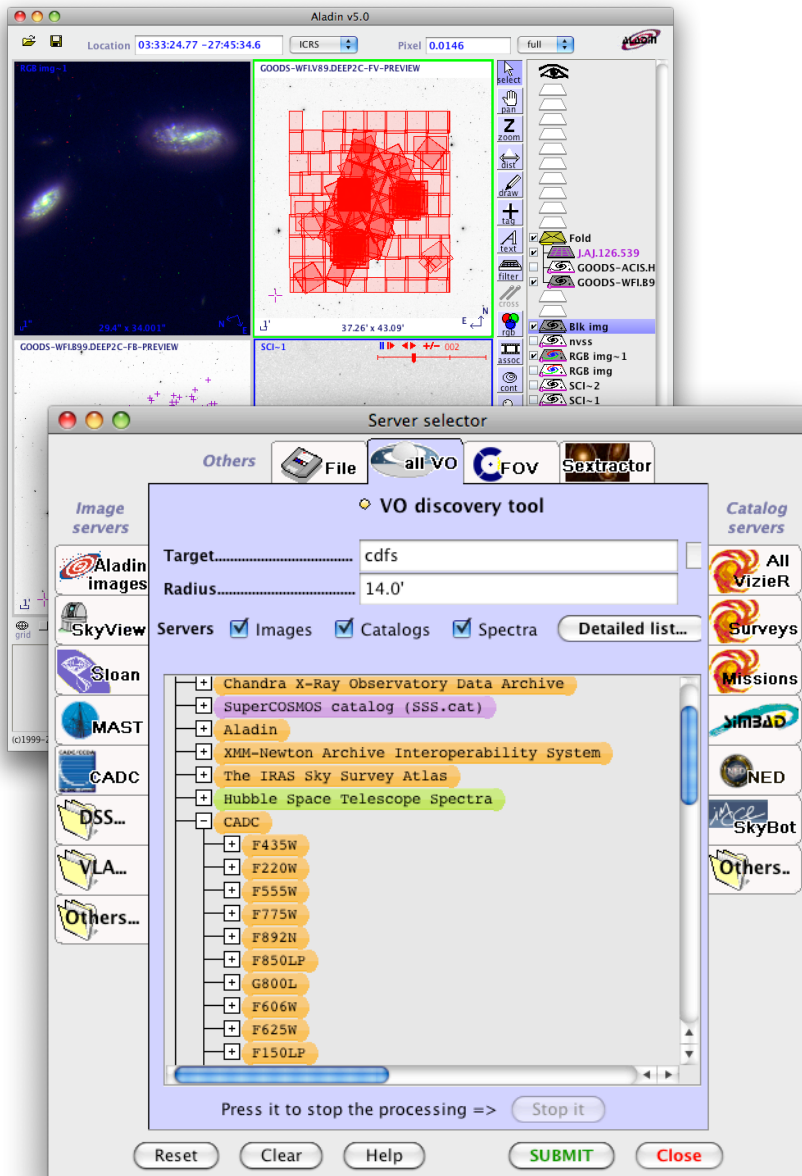
[Display color image](#)

### Catalogues for NGC 4039

- [4 catalogues with 'NGC 4039' keyword](#)
- [146 catalogues around NGC 4039:](#)

Name	Description	Local density	Wavelength	Popularity	Coverage map
<a href="#">I/297 Query</a>	NOMAD Catalog (Zacharias+ 2005) <a href="#">[ReadMe]</a>	53	optical,IR	77	
<a href="#">J/A+A/443... Query</a>	NGC 4038/4039 broad and /narrow band photometry (Mengel+, 2005) <a href="#">[ReadMe]</a>	51	optical	27	
<a href="#">I/284 Query</a>	The USNO-B1.0 Catalog (Monet+ 2003) <a href="#">[ReadMe]</a>	51	optical	89	
<a href="#">I/305 Query</a>	The Guide Star Catalog, Version 2.3.2 (GSC2.3) (STScI, 2006) <a href="#">[ReadMe]</a>	49	optical	74	

# Innovations driving VO ideas



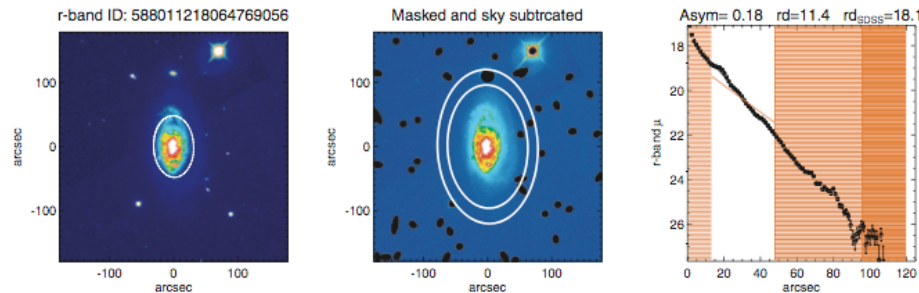
## Data Access Layer concepts

- SIA services :
  - Discovery phase ---> aladin metadata tree
  - AccessData phase : full retrieval , cutout, resampling, ----> and now :Healpix multiresolution access mode
- DataLink service :
  - relates the « discovered » obsid to data links such as
    - Access data modes
    - Provenance information
    - Etc ....

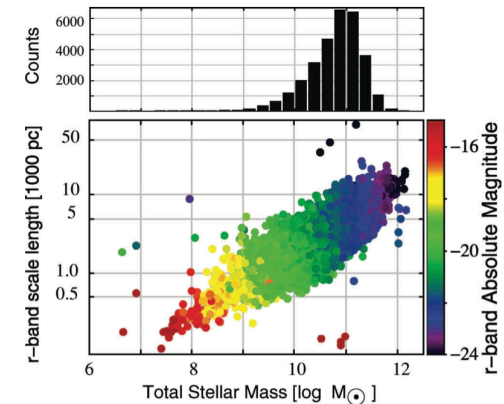
# VO Science

e.g. Euro-VO Research Initiative

- SDSS, Skyview, Aladin, Topcat, IDL/GDL, VOSpace + Cluster System at CDS



×30374 →



Freeman law of galaxy disks confirmed for large sample out to  $z=0.3$

# Scalelength of disc galaxies

Kambiz Fathi,<sup>1,2\*</sup> Mark Allen,<sup>3</sup> Thomas Boch,<sup>3</sup> Evanthia Hatziminaoglou<sup>4</sup>  
and Reynier F. Peletier<sup>5</sup>

<sup>1</sup>Stockholm Observatory, Department of Astronomy, Stockholm University, AlbaNova Center, 106 91 Stockholm, Sweden  
<sup>2</sup>Oskar Klein Centre for Cosmoparticle Physics, Stockholm University, 106 91 Stockholm, Sweden  
<sup>3</sup>Observatoire de Strasbourg, UMR 7550, Strasbourg 67000, France  
<sup>4</sup>European Southern Observatory, Karl-Schwarzschild-Str. 2, 85748 Garching bei München, Germany  
<sup>5</sup>Kapteyn Astronomical Institute, Postbus 800, 9700 AV Groningen, the Netherlands

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## ABSTRACT

We have derived disc scalelengths for 30 374 non-interacting disc galaxies in all five Sloan Digital Sky Survey (SDSS) bands. Virtual Observatory methods and tools were used to define, retrieve and analyse the images for this unprecedentedly large sample classified as disc/spiral galaxies in the LEDA catalogue. Cross-correlation of the SDSS sample with the LEDA catalogue allowed us to investigate the variation of the scalelengths for different types of disc/spiral galaxies. We further investigate asymmetry, concentration and central velocity dispersion as indicators of morphological type, and are able to assess how the scalelength varies with respect to galaxy type. We note, however, that the concentration and asymmetry parameters have to be used with caution when investigating type dependence of structural parameters in galaxies. Here, we present the scalelength derivation method and numerous tests that we have carried out to investigate the reliability of our results. The derived disc scalelength is 3.79 kpc, with an rms dispersion of 2.05 kpc, and this is a typical value irrespective of passband and galaxy morphology. Separating the derived scalelengths for scalelengths presented here are representative for a typical galaxy mass of  $10^{10.8,0.24} M_{\odot}$ , and the rms dispersion is larger for more massive galaxies. The average  $r$ -band scalelengths for different galaxy masses, the  $r$ -band scalelength is  $1.52 \pm 0.65$  kpc for galaxies with total stellar mass  $10^{12} M_{\odot}$  and  $5.73 \pm 1.94$  kpc for galaxies with total stellar mass between  $10^{11}$  and  $10^{12} M_{\odot}$ . Distributions and typical trends of scalelengths have also been derived in all the other SDSS bands with linear relations that indicate the relation that connect scalelengths in one passband to another. Such transformations could be used to test the results of forthcoming cosmological simulations of galaxy formation and evolution of the Hubble sequence.

**Key words:** galaxies: structure.

## 1 INTRODUCTION

The exponential scalelength of a galaxy disc is one of the most fundamental parameters to determine its morphological structure as well as to model its dynamics, and the fact that the light distributions are exponential makes it possible to constrain the formation mechanisms (Freeman 1970). The scalelength determines how the stars are distributed throughout a disc, and can be used to derive its mass distribution, assuming a specific M/L ratio. Ultimately, this mass distribution is the primary constraint for determining the formation scenario (e.g. Lin & Pringle 1987; Dutton 2009, and references therein), which dictates the galaxy's evolution. As the

galaxy evolves, substructures such as bulges, pseudo-bulges, bars, rings and spiral arms may build up, and this will then considerably change the morphology of the host discs (Combes & Elmegreen 1993; Elmegreen et al. 2005; Bournaud, Elmegreen & Elmegreen 2007). The scalelength value is intimately connected to the circular velocity of the galaxy halo, which in turn relates closely to the angular momentum of the halo in which the disc is formed (Dalcanton, Spergel & Summers 1997; Mo, Mao & White 1998). Up to the last few years, cosmological simulations were limited to rather low resolution, were discs and spheroids were barely resolved, and generally limited to high redshifts, so reproducing realistic disc scalelengths for modern galaxies was clearly out of reach. The current simulations reach resolutions that allow resolving the discs from high redshift down to redshift zero, and subtle mechanisms changing the disc masses and scalelengths can be studied

\*kambiz@astro.su.se  
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# REVISITING THE SCALE LENGTH- $\mu_0$ PLANE AND THE FREEMAN LAW IN THE LOCAL UNIVERSE

KAMBIZ FATHI  
AND  
OSKAR KLEIN CENTRE FOR COSMOPARTICLE PHYSICS, STOCKHOLM UNIVERSITY, 106 91 STOCKHOLM, SWEDEN  
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## ABSTRACT

We have used Virtual Observatory technology to analyze the disk scale length  $r_d$  and central surface brightness  $\mu_0$  for a sample of 29,955 bright disk galaxies from the Sloan Digital Sky Survey. We use the results in the  $r$  band and revisit the relation between these parameters and the galaxy morphology, and find the average value  $(\mu_0) = 20.2 \pm 0.7$  mag arcsec<sup>-2</sup>. We confirm that late-type spirals populate the lower left corner of the  $r_d$ - $\mu_0$  plane and that the early and intermediate spirals are mixed in this diagram, with disk ellipticals at the top left corner. We further investigate the Freeman Law and confirm that it indeed defines an upper limit for  $\mu_0$  in bright disk galaxies with  $r_{mag} < 17.0$ , and that disks in late-type spirals ( $T \geq 6$ ) have fainter central surface brightness. Our results are based on a volume-corrected sample of galaxies in the local universe ( $z < 0.3$ ) that is two orders of magnitude larger than any sample previously studied and deliver statistically significant implications that provide a comprehensive test bed for future theoretical studies and numerical simulations of galaxy formation and evolution.

**Key words:** galaxies: evolution – galaxies: formation – galaxies: structure  
*Online-only material:* color figures

## 1. INTRODUCTION

The current mainstream galaxy formation paradigm states that galaxy disks form within dark matter halos and that there is an intimate relation between the scale length  $r_d$  of the disk and that of the halo. The mass distribution of the disk is entirely set by the  $r_d$  and, for example, in the exponential case, 60% of its total mass is confined within two scale lengths and 90% within four scale lengths. Moreover, the angular momentum of the disk is set by  $r_d$  and the mass distribution of its host halo, and the fact that the angular momentum vectors are aligned suggests that there is a physical relation between the two. During the formation process, galaxy mergers and associated star formation and feedback processes play a crucial role in the resulting structure, however, the observed sizes of disks suggest that the combination of these physical processes indicate that galactic disks have not lost much of the original angular momentum acquired from cosmological torques (e.g., White & Rees 1978; Fall & Efstathiou 1980). The hierarchical and infall models predict comparable  $r_d$ s and in a cold collapse scenario (Vand 1959) since angular momentum is conserved, immediately after the collapse the gas is supported by rotation so that it quickly collects in the region where a disk forms with substantially higher rotation velocity than the halo is to form. A large  $r_d$  disk forms when the disk mass is smaller than the halo mass over the disk region, and vice versa: a small  $r_d$  disk forms when the mass of the disk dominates the mass of the halo in any part of the disk. The self-gravitating disk will also modify the shape of the rotation curve near the center of a galaxy (Gelato & Sommer-Larsen 1999) and the disk is then set to undergo secular evolution. The natural implication of this scenario is that the  $r_d$  dictates the life of a disk, and consequently, is a prime factor which determines the position of a galaxy on the Hubble sequence.

One prominent indicator for a smooth transition from spiral toward S0 and disk ellipticals is provided by the  $r_d$ - $\mu_0$  diagram, where  $\mu_0$  is the central surface brightness of the disk, where spirals and S0s are mixed and disk ellipticals populate

the upper left corner of this diagram (Kent 1985; Scorza & Bender 1995). Another instructive relation is the Freeman Law (Freeman 1970) which relates  $\mu_0$  to the galaxy morphological type. Although, some studies have found that the Freeman Law is an artifact due to selection effects (e.g., Disney 1976; Bothun 1981; Scorza & van den Bosch 1998), recent work has shown that proper consideration of selection effects can be combined with kinematic studies to explore an evolutionary sequence (e.g., van der Kruit 1987, 2002; de Jong 1996; Koda et al. 2000).

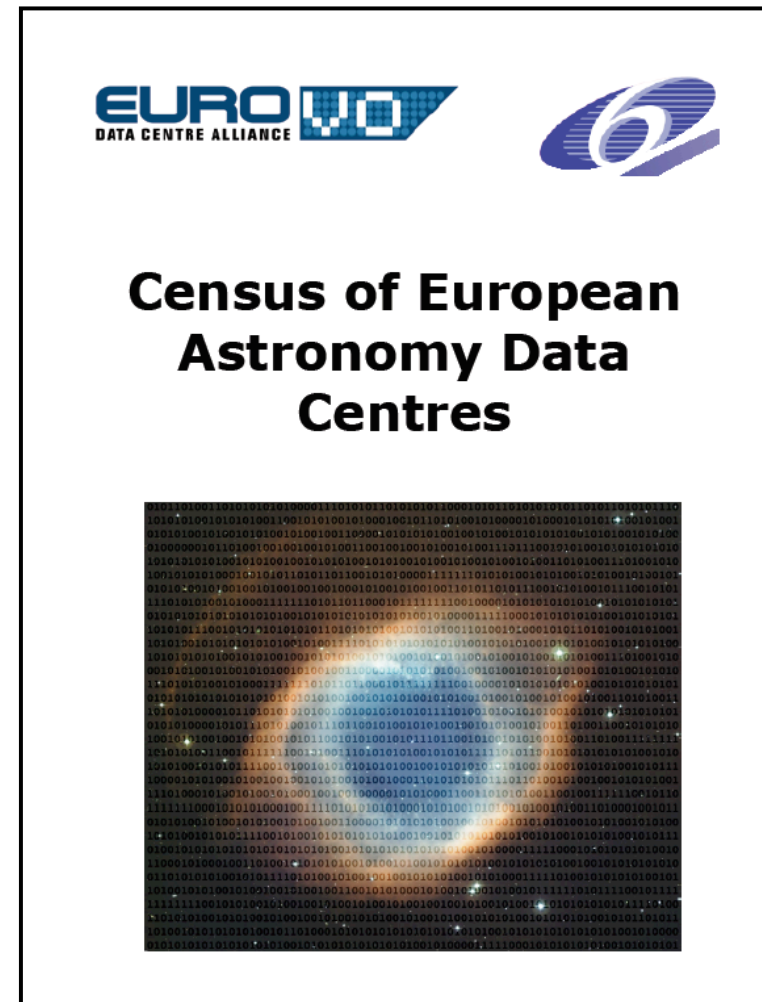
In the comparison between theory and observations, two issues complicate matters. On the theory side, mapping between initial halo angular momentum and  $r_d$  is not trivial, partly due to the fact that commonly the initial specific angular momentum distribution of the visible and dark component favors disks that are more centrally concentrated than exponential (e.g., de Jong & Lacey 2000; van den Bosch 2001). Observationally, comprehensive samples have yet not been studied, and the mixture of different species such as low and high surface brightness galaxies complicate the measurements of disk parameters (McGaugh et al. 1995; Graham & de Blok 2001).

Here, we analyze the  $r_d$  and  $\mu_0$  from an unprecedentedly large sample of bright disk galaxies in the nearby universe ( $z < 0.3$ ) using the Sloan Digital Sky Survey (SDSS) Data Release 6 (York et al. 2000; Adelman-McCarthy et al. 2008). As detailed in Fathi et al. (2010, hereafter F10), both parameters were robustly determined for 30,374 galaxies in the  $r$  band (only 29,955 used here as described in Section 2), whereas in other SDSS bands, the derived parameters are valid only for subsets of this sample. In the  $g$ ,  $i$ , and  $z$  bands ( $\approx 27,000$ – $30,000$  galaxies), the sample sizes are comparable to the one presented here. In the  $u$  band,  $r_d$  and  $\mu_0$  were robustly derived for a few hundred objects and therefore, not considered here. Throughout this Letter, unless otherwise stated, we use disk parameters in the  $r$  band and investigate the two relations mentioned above, in order to provide a comprehensive test bed for forthcoming galaxy formation and evolution.

# Assisting VO uptake

*CDS contributions to Data Centre Alliance project*

- Workshop tutorials
- Scientific rationale
- SAADA (w/L. Michel)
- UCD tools
- Census





# Census summary

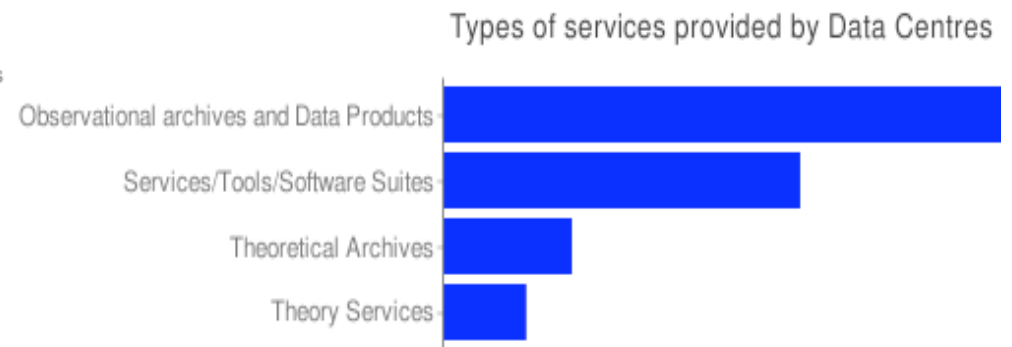
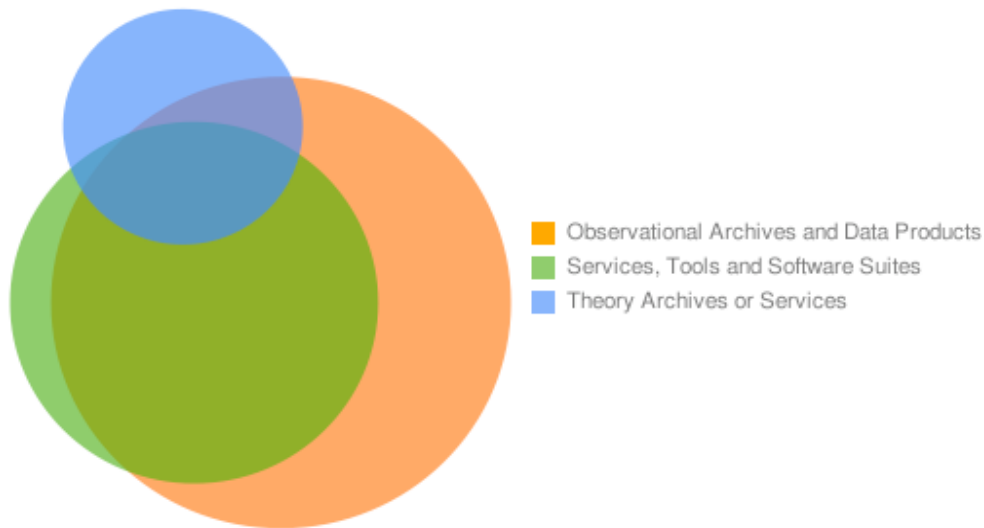
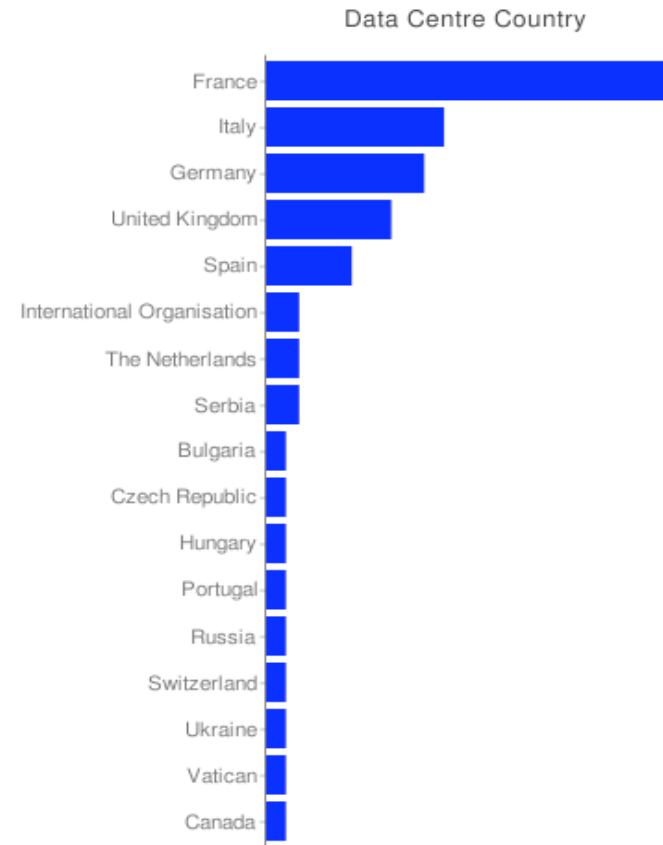
68 Data Centres

134 Observational Archives

66 'Service/Tool/Software Suite'

24 Theory Archives

8 Theory Services



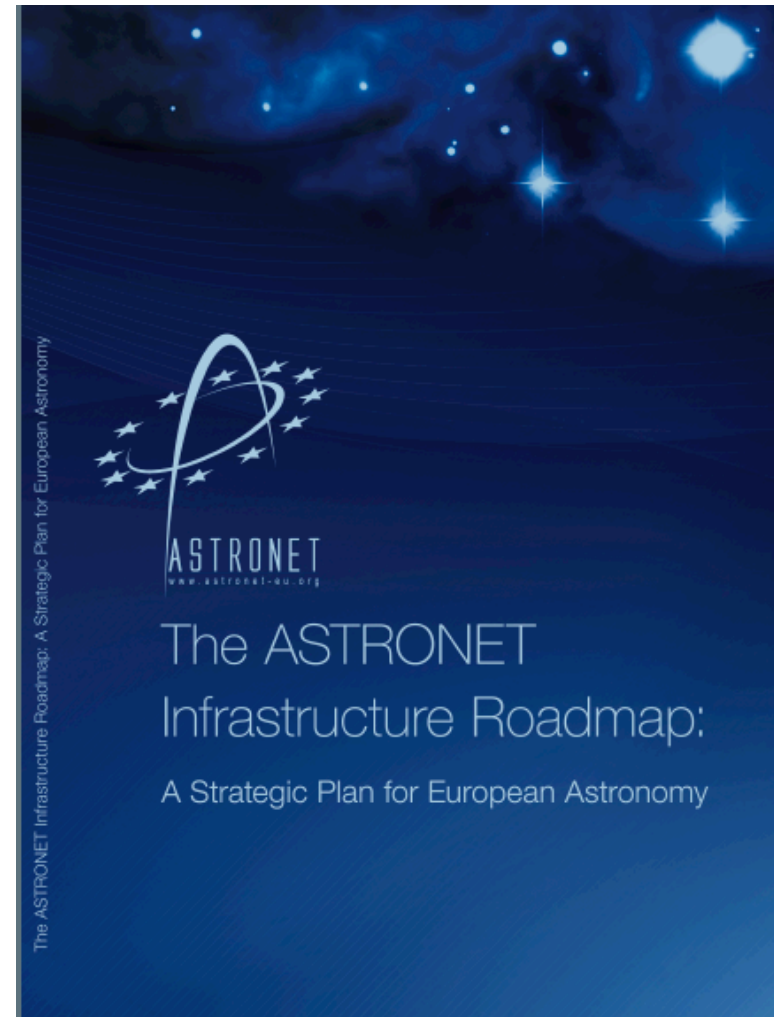
Diversity in terms of 'scale, content and function'

# Implications for VO

- Maintain coordination of VO developments with Data Centres
- Ensure VO publishing is not significantly more difficult than web publishing
- Accommodate diversity
- Increase emphasis on 'Science ready data'
- The census identifies Data Centres who will lead up-take of VO as Euro-VO moves into operational phase

# VO as Infrastructure

- VO in the ASTRONET Infrastructure roadmap
- recommendations for VO compliance
- community validation of VO approach



Panel D members: Allen, Padovani