

Exploiting Virtual Observatory and Information Technology: Techniques for Astronomy

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Lecture #1 Goal:
Explore the emerging
new distributed data
resources, and
mechanisms to
(remotely) analyse that
data

Course Overview

- Lecture One: VO: Virtual Observatory overview, the technology (grids), science drivers, VO standards, VO Projects
- Lecture Two: Data: databases, science archives, federating data, registries, xml. Science: hunting for brown dwarfs
- Lecture Three: Applications: workflows, data analysis systems, theory services. Science: photometric redshifts
- Lecture Four: SQL: data mining with SDSS DR3, open sky query, Sloan Web Services [Richard McMahon]
- Lecture Five: Demonstrations of VO Tools: I: apps
- Lecture Six: Demonstrations of VO Tools: II: workflows
- Lecture Seven: Radio/sub-mm I: ALMA, SKA, eVLA, eMerlin; challenges and solutions [John Richer]
- Lecture Eight: Radio/sub-mm II: applications and pipelines, analysis algorithms [John Richer]

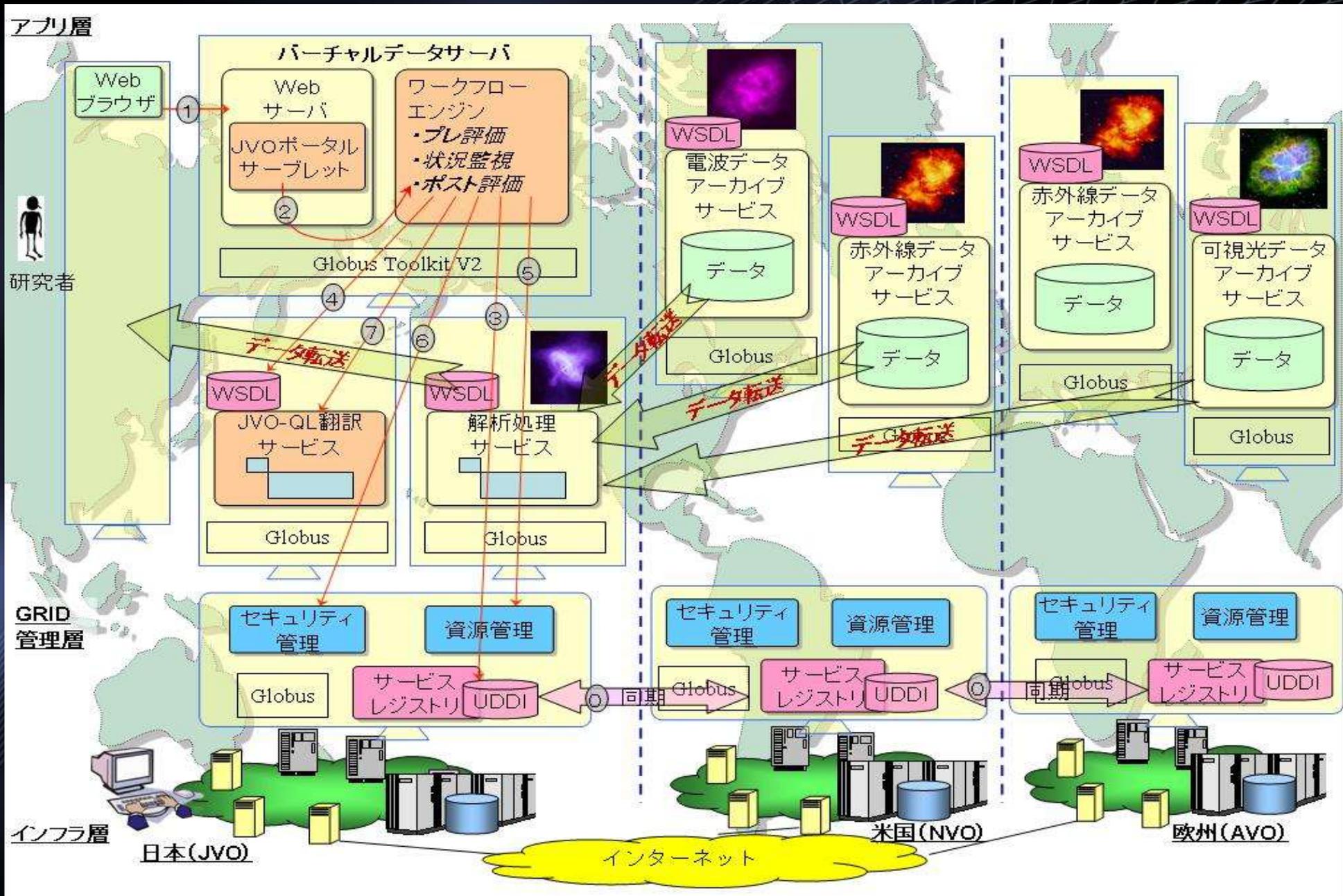
Summary: Lecture #1

- Introduction and Background
- Virtual Observatories
 - Science Drivers
 - Technological Drivers
- Distributed Computing
 - Networks
 - The Grid
- Supporting Computational Technologies
 - Web Services
 - Grid Services
- VO Technologies
 - VO Standards

Introduction and Background

- This course is *not* about programming per se,
- It is about:
 - Locating data and information resources
 - Discovering newly emerging Virtual Observatory Systems
 - Learning use of these systems
 - Moving on to use these systems in your science
 - ... and then possibly doing some of your own development
- This lecture introduces the Virtual Observatories
 - Following lectures explore the use of these facilities

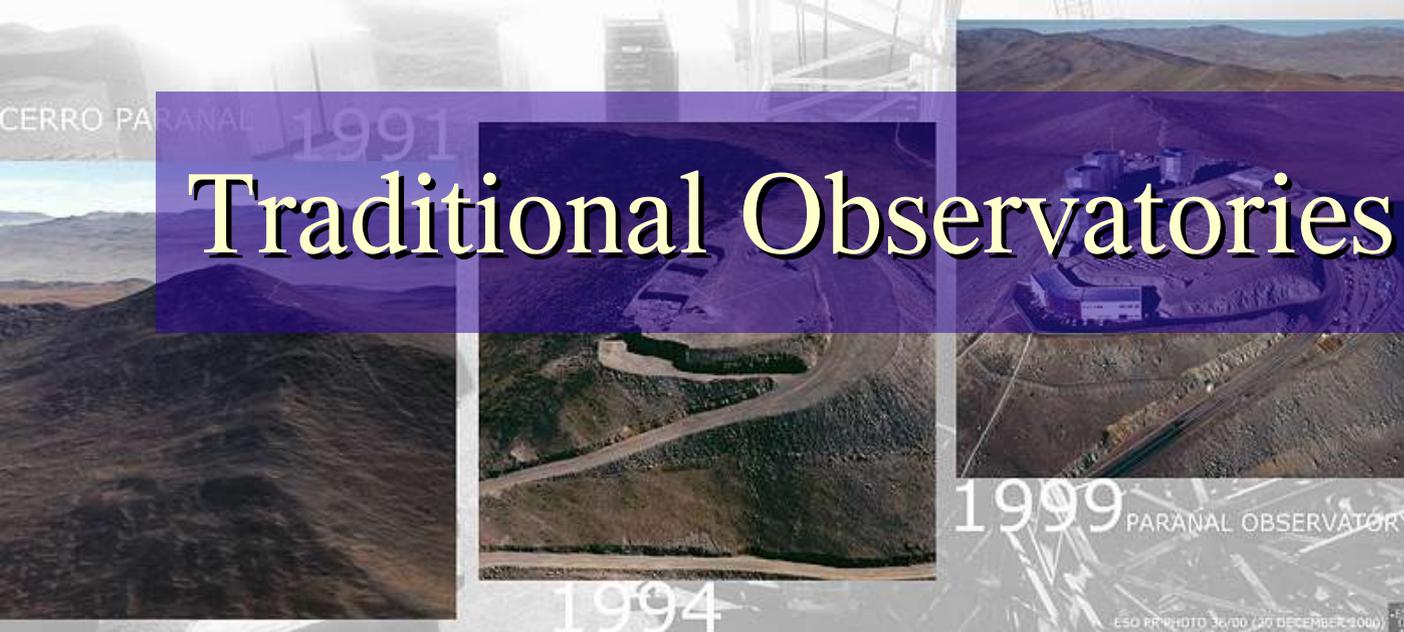
But first ... VO in a nutshell ...



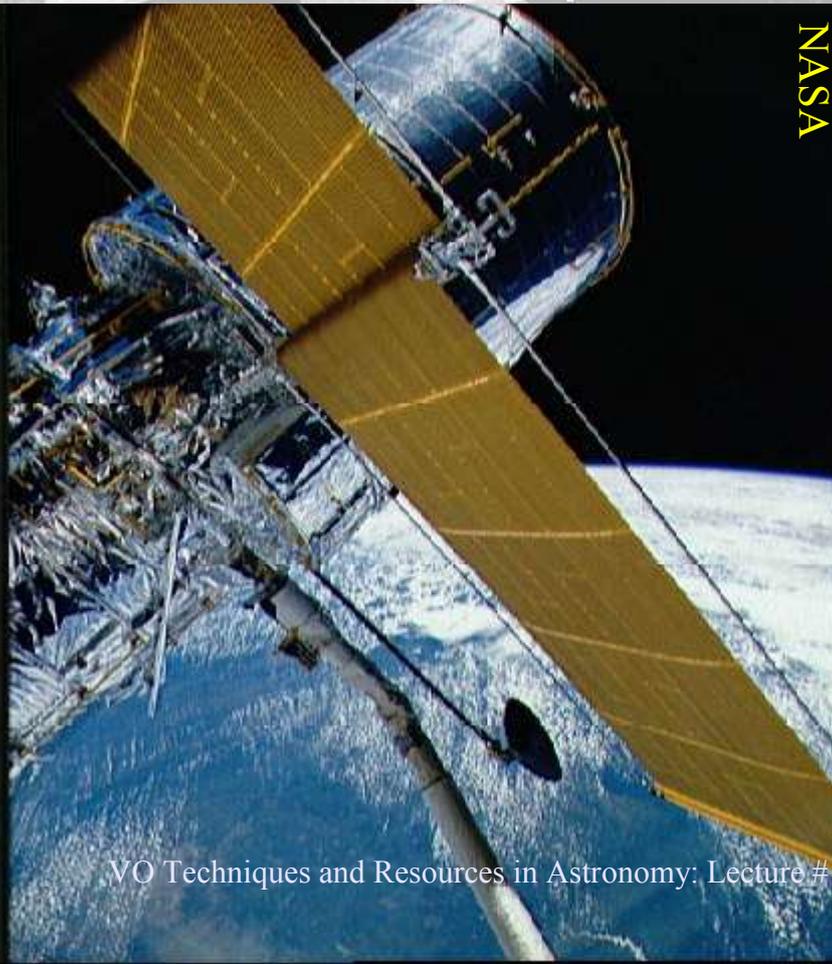
Virtual Observatories: Overview

From WHY to HOW and WITH WHAT

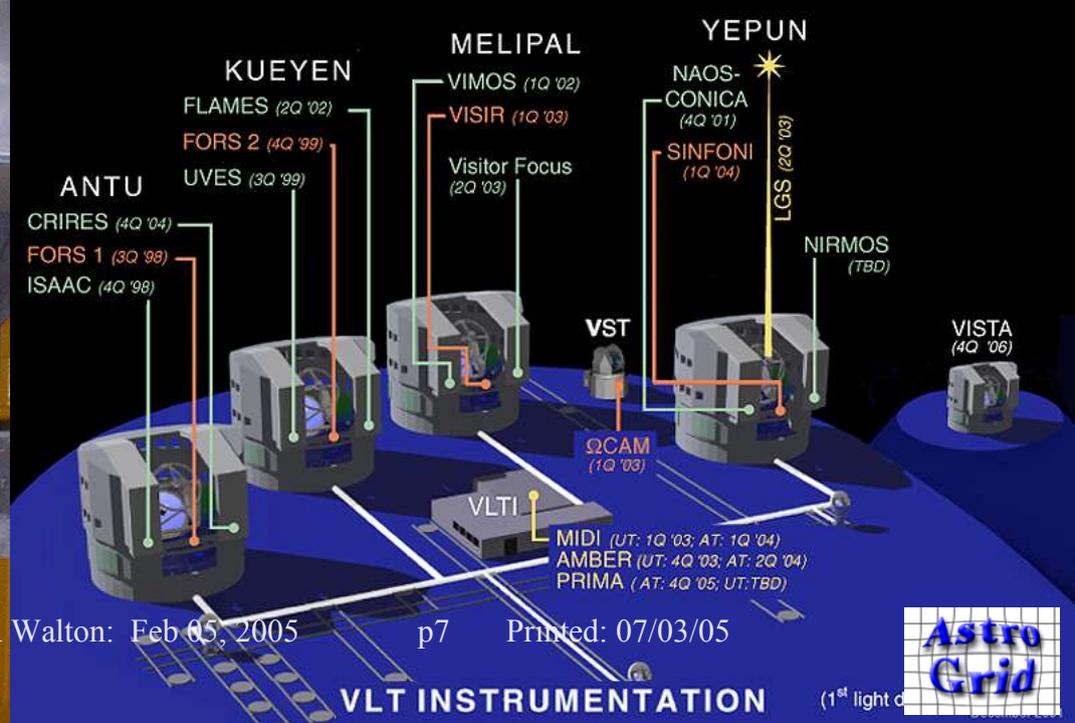
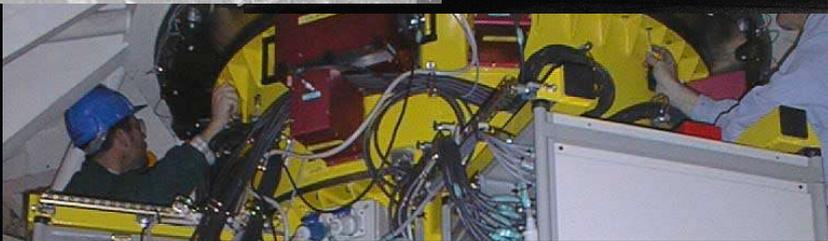
Traditional Observatories



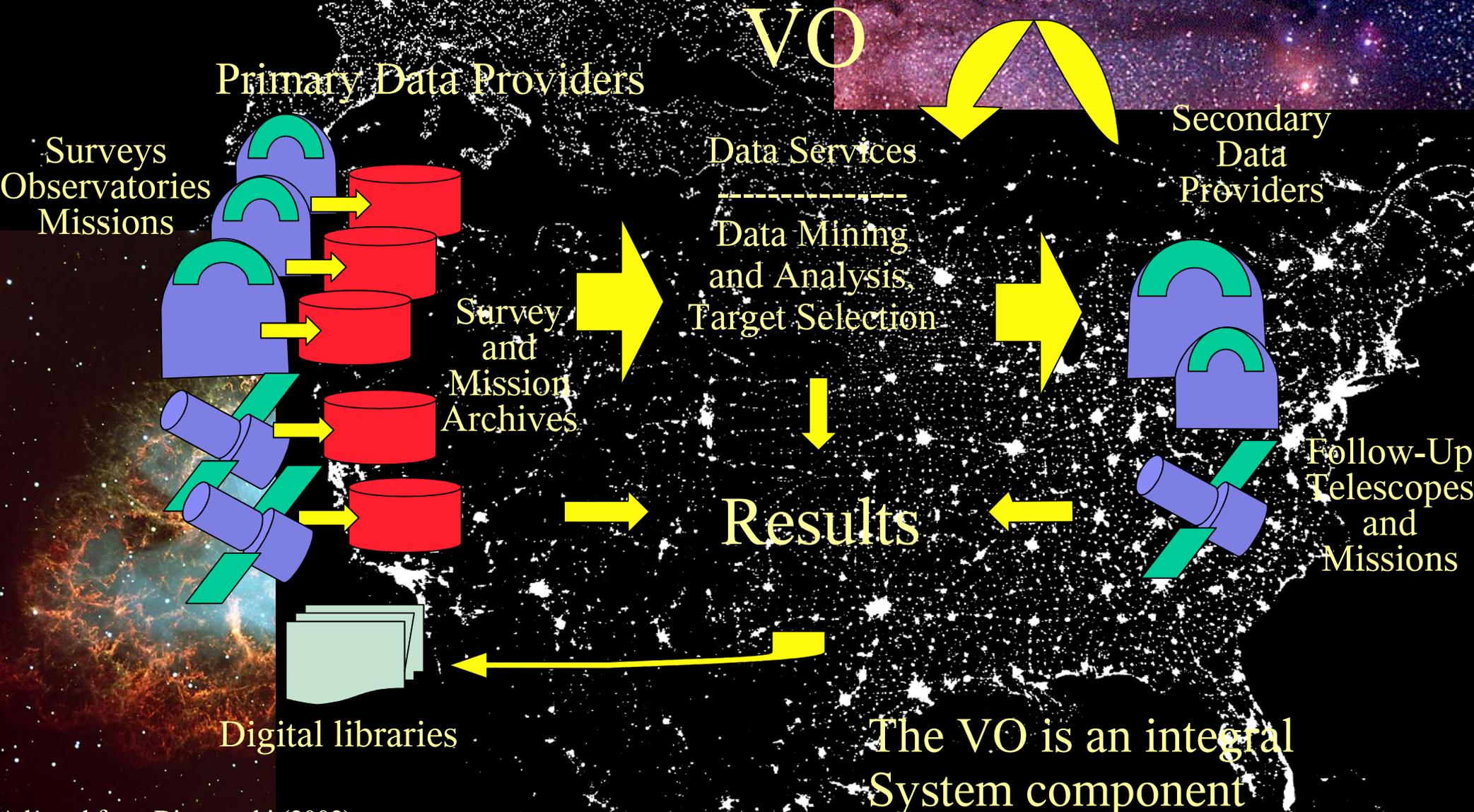
Images from ESO



NASA



The New Scientific Method: enabled by the Virtual Observatories



Science Drivers for a VO

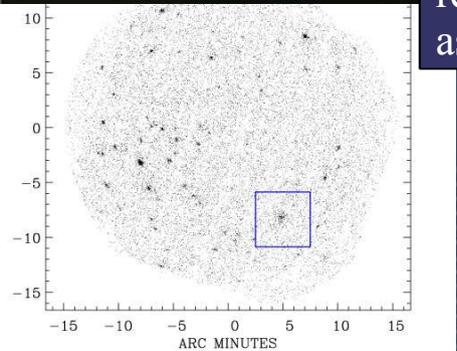
- Enable new science
 - Perhaps through doing things that weren't thought of before
 - By making possible science that was impossible to do before
 - e.g. High precision cosmology, where mass data handling is required
 - By making it easier to what is currently hard to do
 - Thus giving the researcher – you – more time for interpretation of results
- All VO projects list a number of key use cases

New Science from VO's: Cosmology

DEFLECTION OF LIGHT RAYS CROSSING THE UNIVERSE, EMITTED BY DISTANT GALAXIES



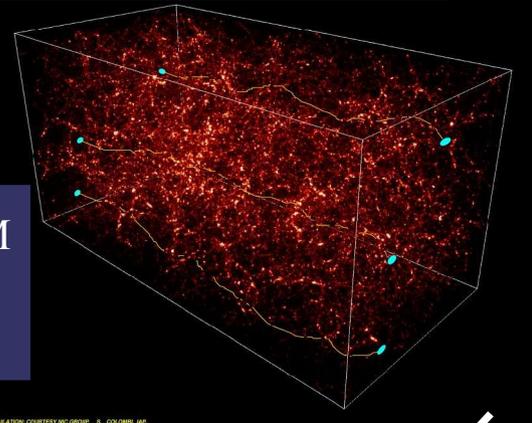
NASA



Multiple large image sources: registration & association

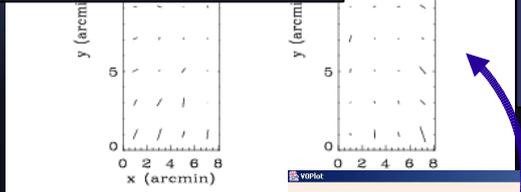
Automatic cluster finding techniques

Multi-TB Λ CDM models, e.g. Millennium Sim

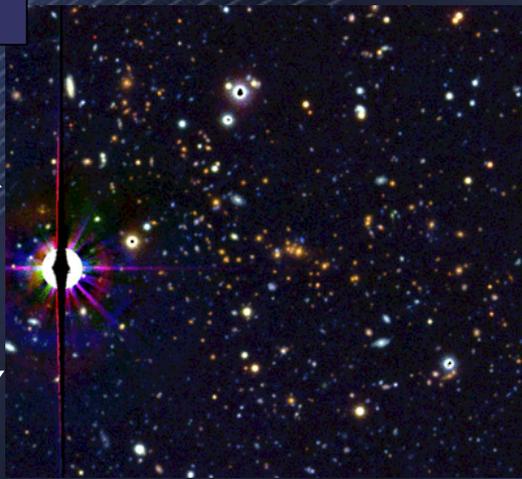


SIMULATION: COURTESY MCG GROUP, S. COLOMBI, IAP

Generate Shear Maps c.f. CDM models > DM distribution with redshift

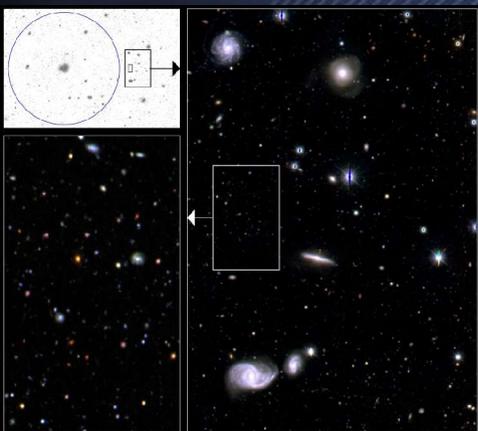


Remove star correlate gal with z

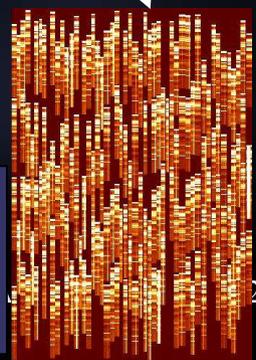


X-ray cluster: Chandra X-ray (Mullis) overlaid on a deep BRI image (Clowe & Luppino).

Figure 7. Example of astrometric... the Wide Field Camera on WHT.

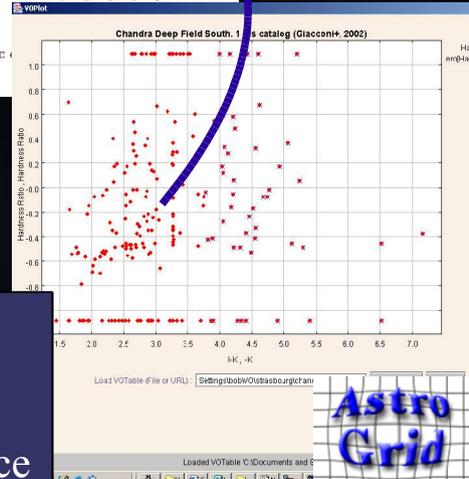


Probing the Universe - Wide-field imaging at CFHT with the CFH12K camera
Images by J.-C. Cullinane (CFHT), © 2000 CFHT



Source ID from multiplexed spectral data

Colour-Colour relationships classification in multi-phase space



ESO

resources in Astro

2005

Astro Grid

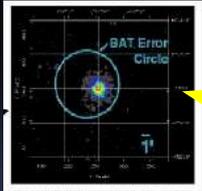
SWIFT satellite observes gamma ray burst

Gamma Ray Bursts

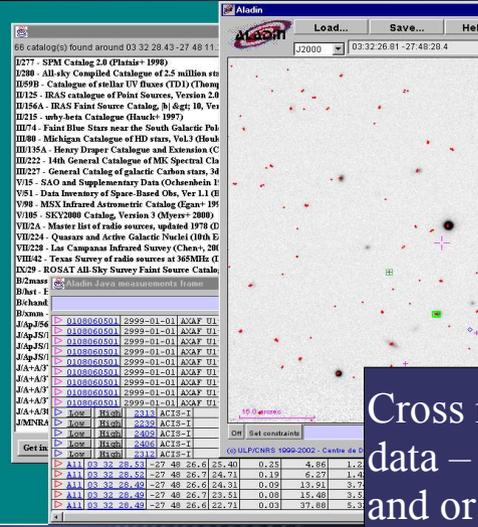
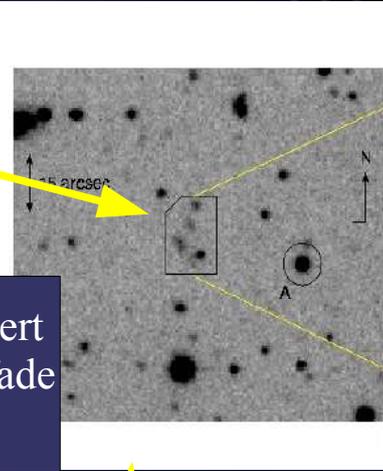
Image from ESO



Interaction with observatory pipelines



Localise GRB alert in minutes – as fade rapidly.

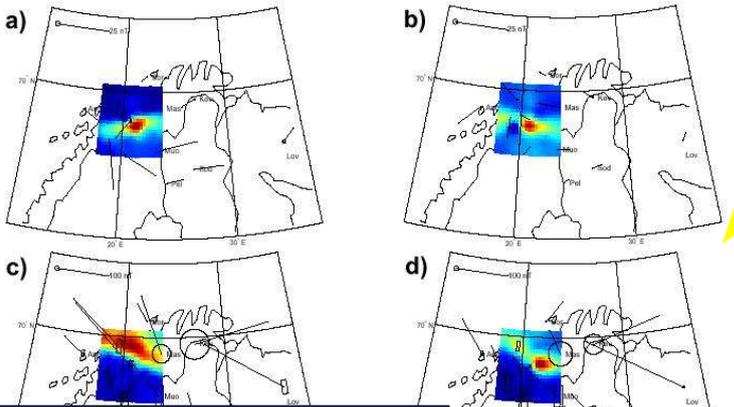
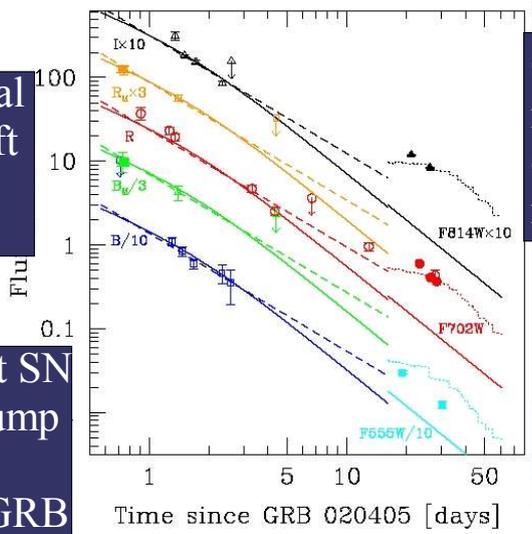


Cross reference multi-λ data – ID pre-cursor and or environment

Large computational photometric redshift calcs on multi-λ > gives distance

Compare against SN light curves – bump shows evidence for a SN in the GRB (Price et al, 2002)

Collate data from multiple telescopes over months - meta data issues



Reprocessing of ionospheric STP data change coords from earth to celestial



D. Ducros, ESA

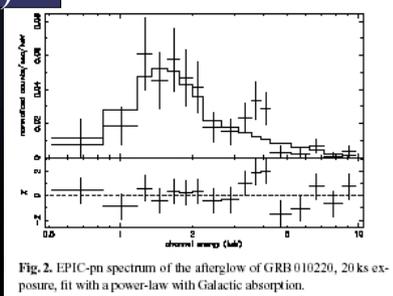


Fig. 2. EPIC-pu spectrum of the afterglow of GRB 010220, 20 ks exposure, fit with a power-law with Galactic absorption.

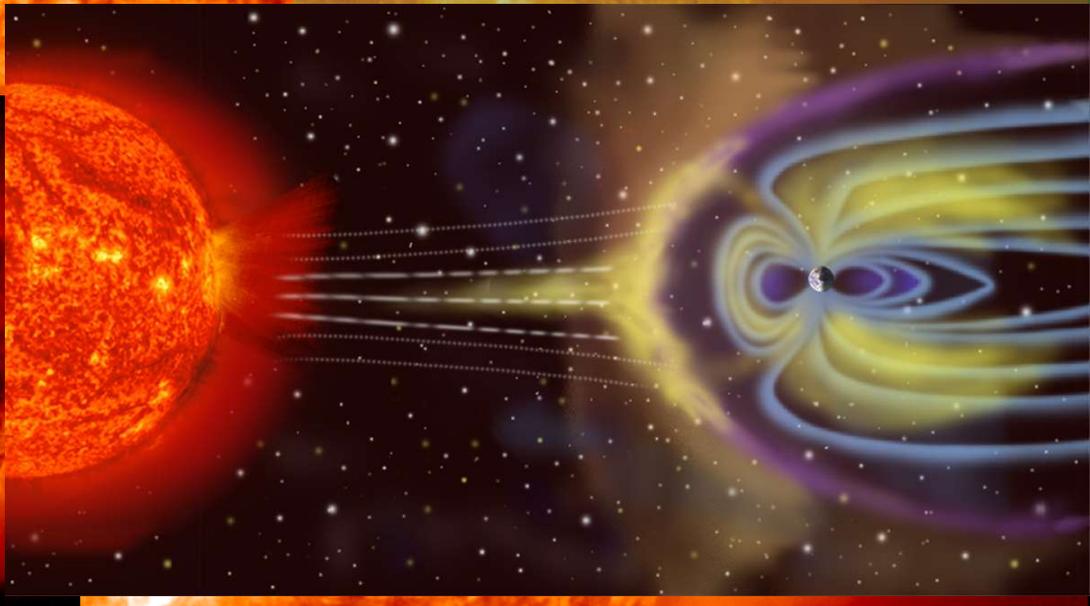
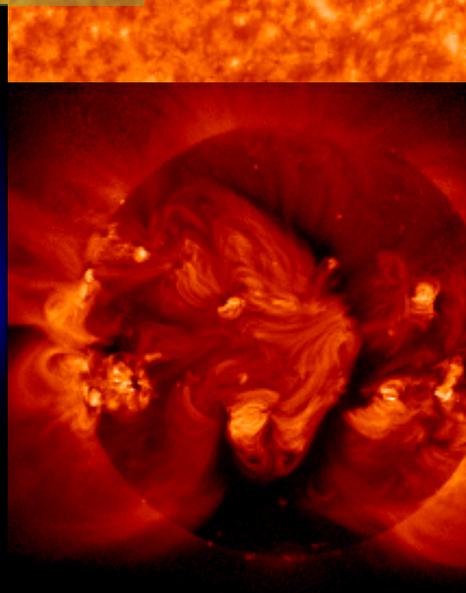
Image + IRIS data

New & Improved Science from VO's: Space Weather

What happens to the Earth's magnetosphere during a coronal mass ejection ?

Event imaged by space based solar observatory

Effect detected later by satellites and ground radar



2002/03/12 07:00

SOHO/EIT - EUV

Yohkoh - Xray

NASA: Living With a Star - <http://lws.gsfc.nasa.gov>

The Need for Virtual Observatories: Managing Technological Change



- The massive **Growth of Data**
 - Number + size of telescopes
 - Optical: ESO's 4x8m VLT, 2x8m Gemini
 - X-ray: XMM-Newton
 - sub-mm: ALMA
 - Increase in **size and multiplex** capabilities of instrumentation:
 - Infra-Red: VISTA > 100 GB/nights
 - Radio: e-Merlin > data rates ~320 Gbps
 - **All sky at 0.1 arcsec – 100 TB**

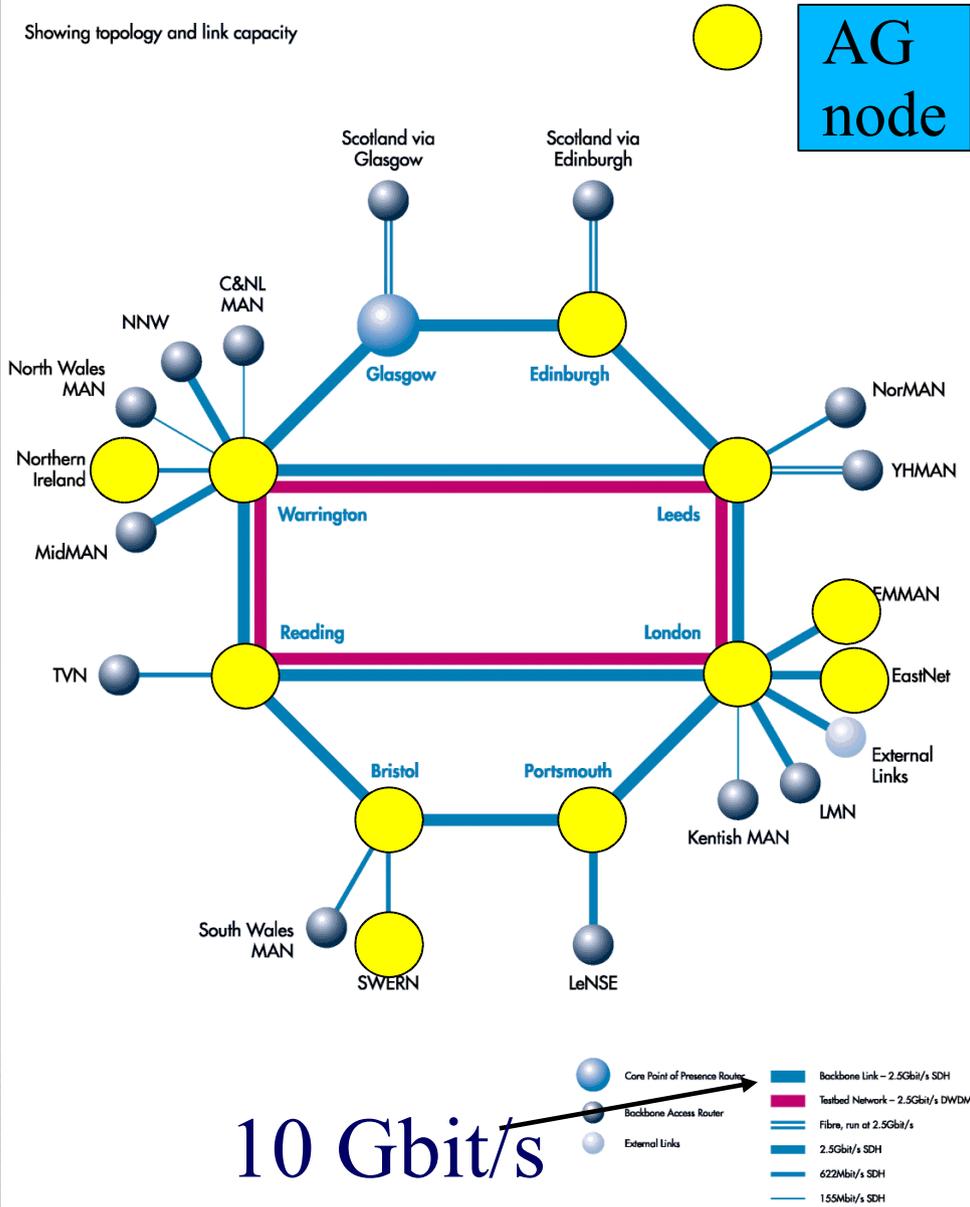


New Computational Opportunities

Creating a distributed system with Grids and Web Services

The JANET Backbone

Showing topology and link capacity



10 Gbit/s



Fast Global Networks

BBCi CATEGORIES TV RADIO COMMU

Low Graphics version | Change edition

BBC NEWS UK EDITION

>1 Gbit/sec

- News Front Page
- World
- UK
- England
- Northern Ireland
- Scotland
- Wales
- Business
- Politics
- Health
- Education
- Science/Nature

Technology

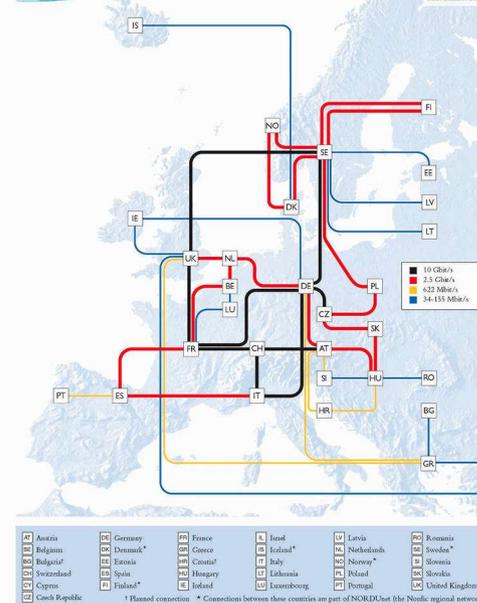
Last Updated: Thursday, 6 March, 2003, 13:56 GMT



Net speed record smashed

A quantity of data equivalent to a DVD-quality movie is transmitted across the Atlantic in less than 30 seconds.

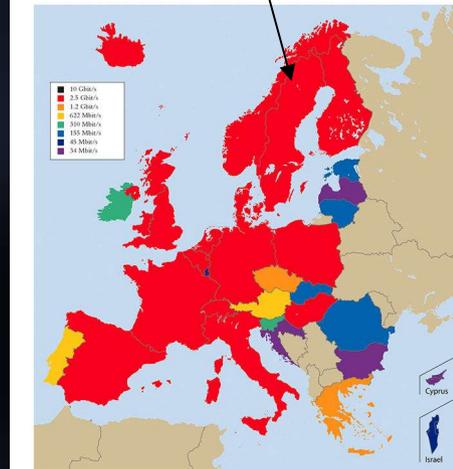
- Grid plan for high speed net
- Scientists develop net jambuster



Multi-Gigabit pan-European Research Network Backbone topology February 2002



2.5Gbit/s



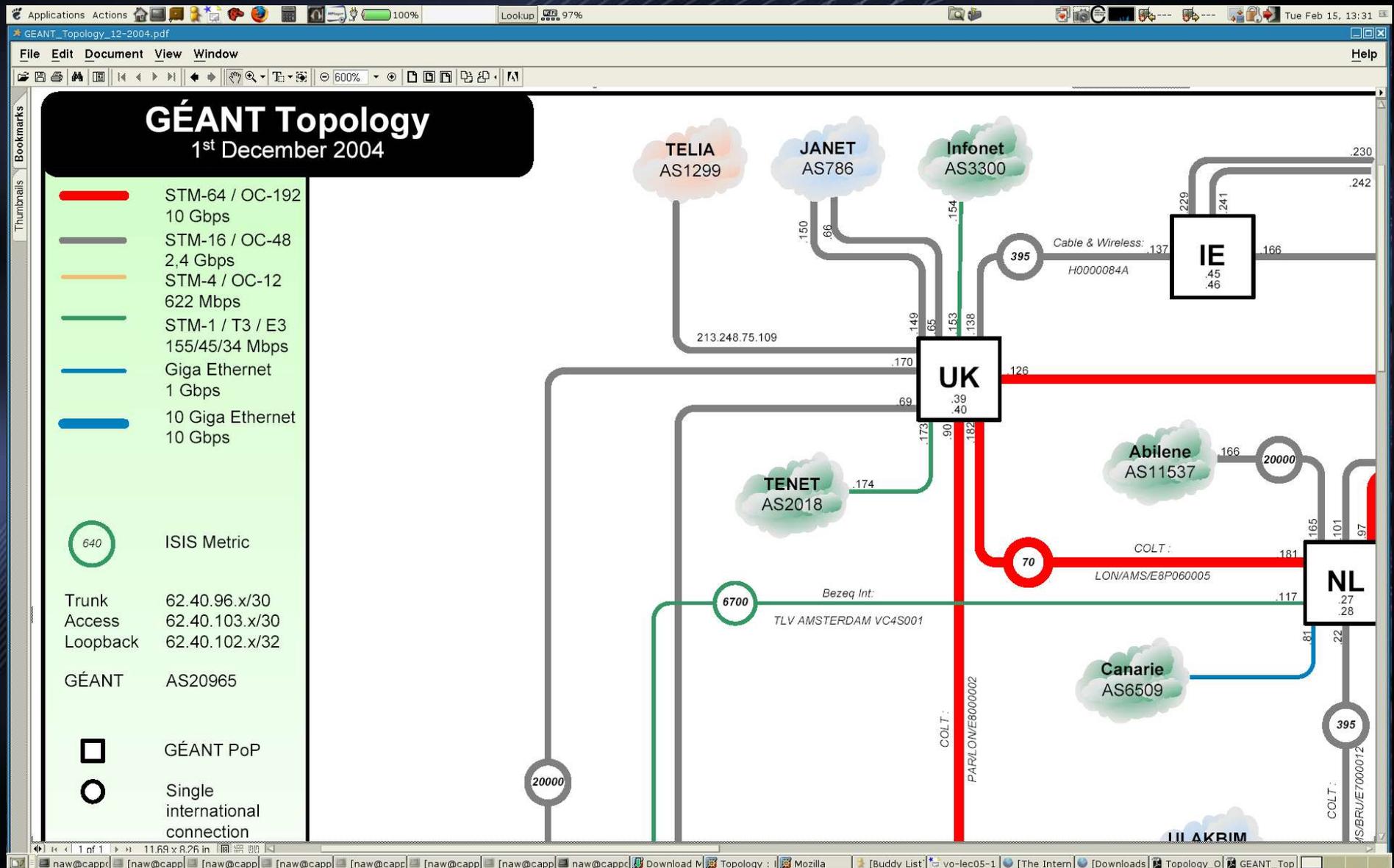
Backbone Access Speeds



Geant2 / SuperJanet 5/ UKLight

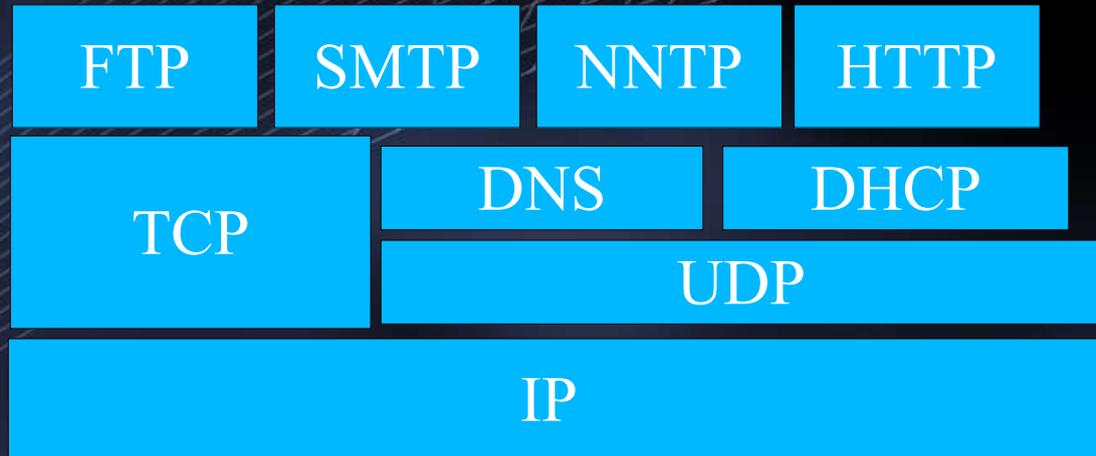
Networks are getting faster, with more cover

New technologies: Lambda-wave optical systems



The Internet/ The WWW

Internet core protocols



WWW core protocols



Web services and Grid services add layers of protocols to these

The Grid

www.globus.org
www.ggf.org

Grid Guru's, Ian Foster / Carl Kesselman:

"A computational Grid is a hardware and software infrastructure that provides **dependable, consistent, pervasive** and **inexpensive** access to high-end computational capabilities."

- The Grid creates a virtual platform for computation and data manipulation
- c.f. The Internet, a virtual platform for information

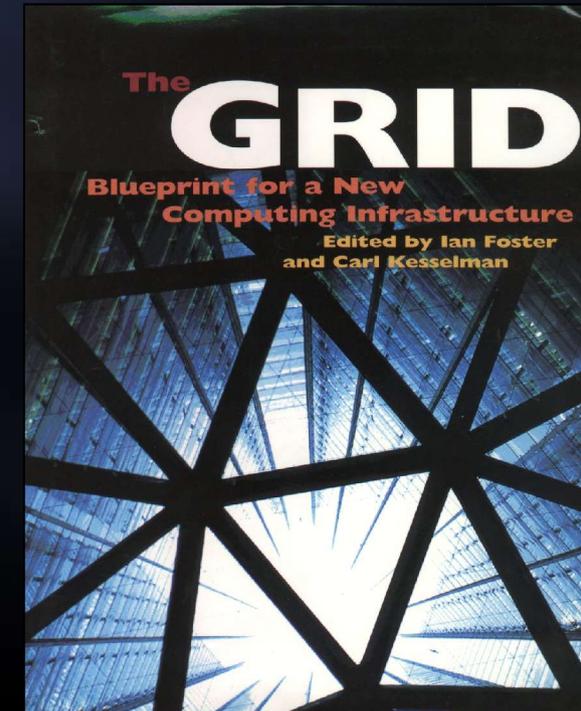
Early history dates to the 1980's

1990s: PVM, MPI, OpenMP: support parallel machines

1995: 1st Grid: I-Way at SC95

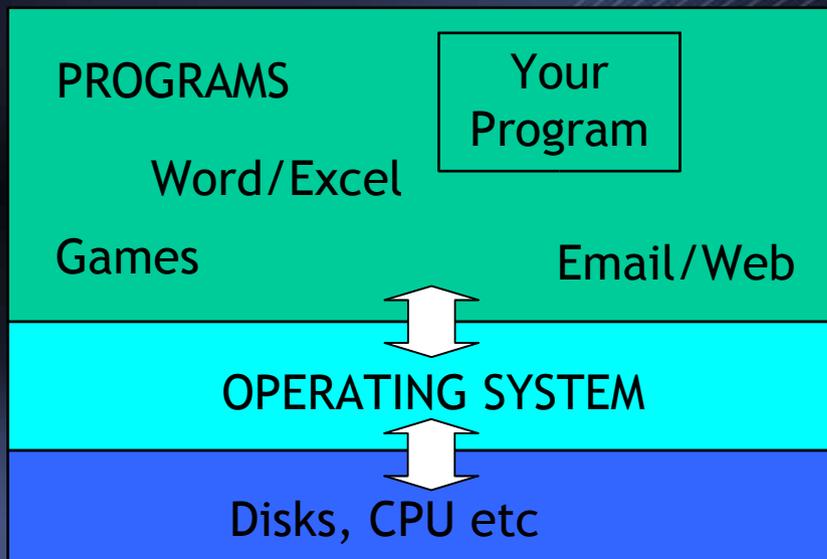
Late 1990s: Globus, Legion, Condor, SRB

Late 1990s: Grid Forum -> Global Grid Forum

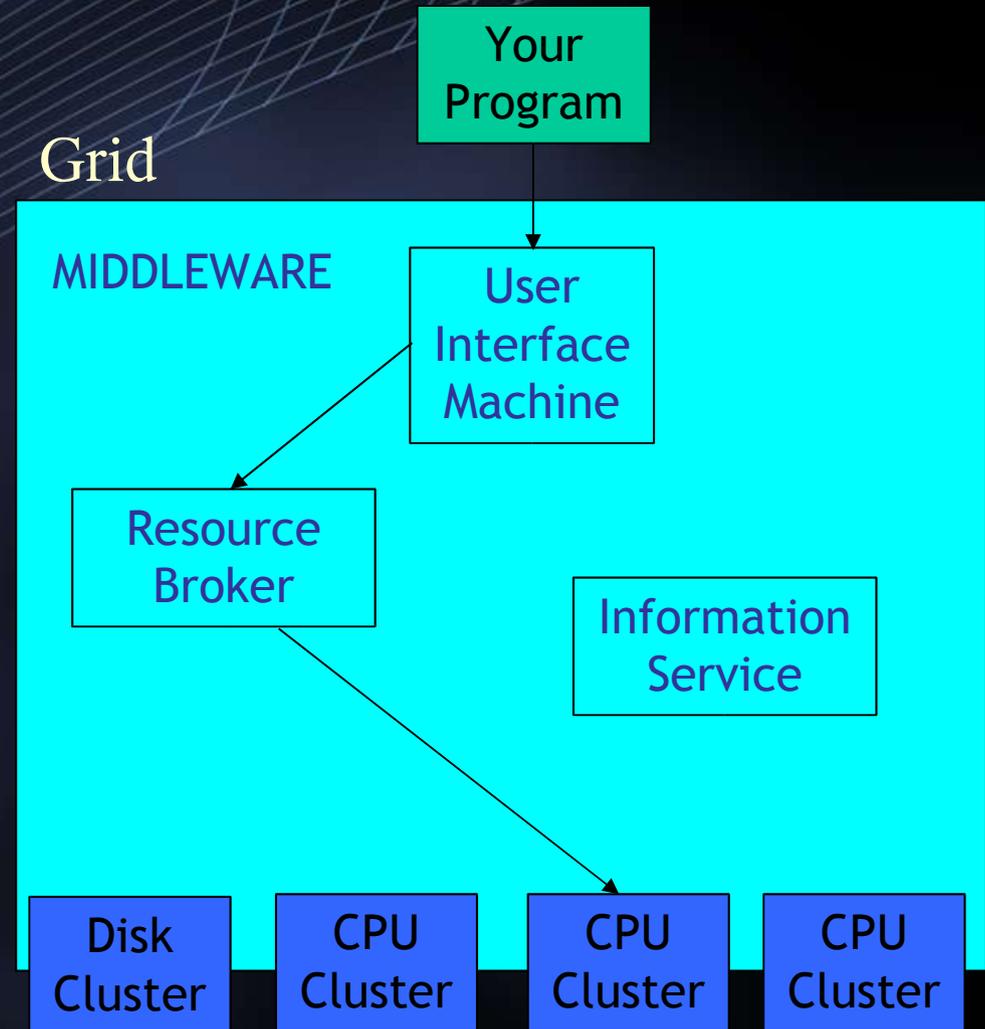


What is the Grid?:

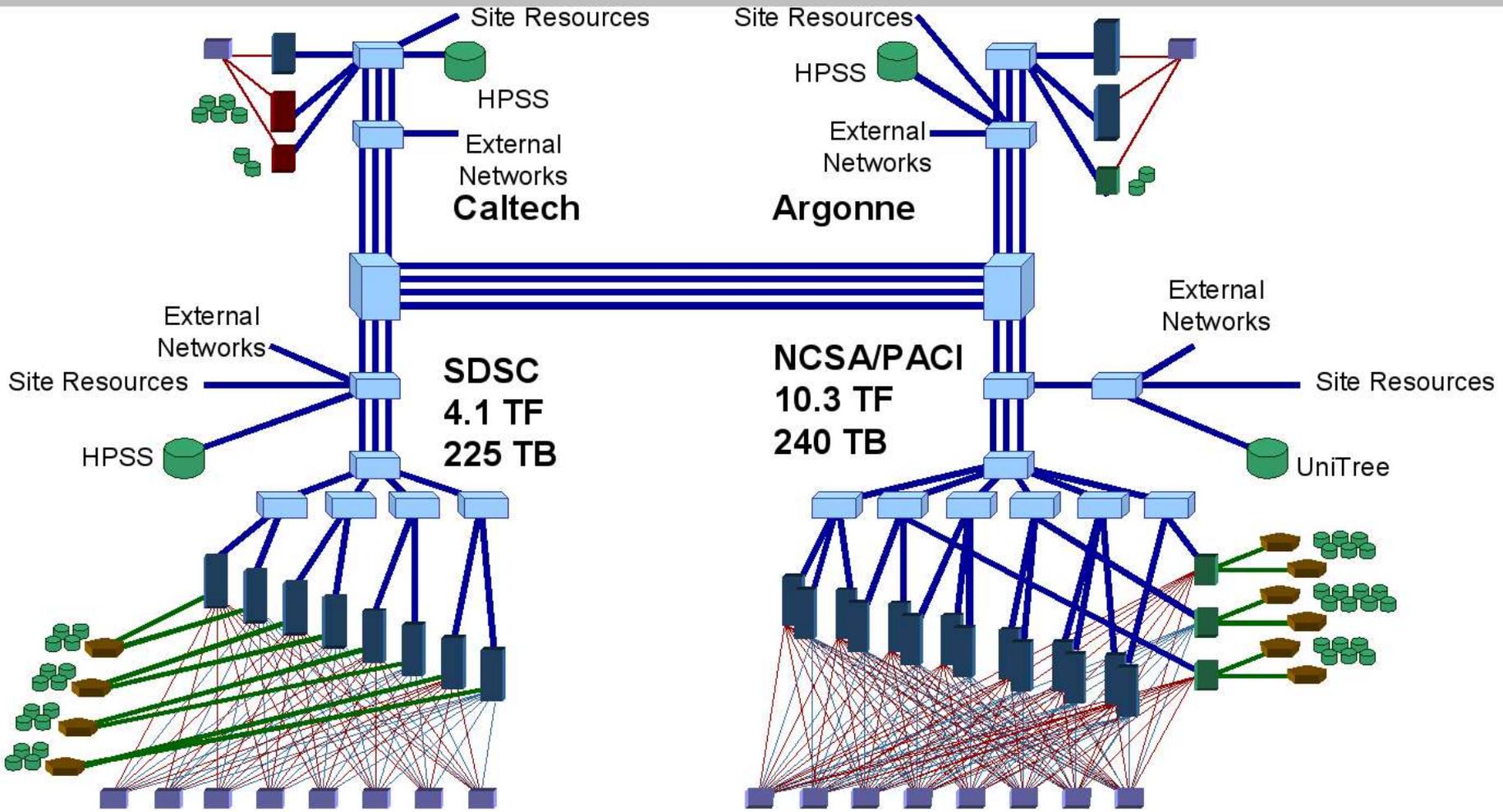
A single PC



Grid



Overview of Distributed TeraGrid Resources



NVO Summer School Sept 2004



Web Services

- Service Orientated Architectures
 - An application architecture within which all functions are defined as independent services with well-defined invocable interfaces which can be called in defined sequences to form scientific processes.
- Core
 - SOAP: simple object access protocol
 - WSDL: web services description language
- Implementations: Apache/AXIS, MS/ .NET (Open Source Mono), Python, Perl, PHP
- WS-I*, WSRF standards: state, security, addressing, management, asynchronous transactions

SOAP/WSDL

SOAP: a lightweight protocol for exchange of information in a decentralized, distributed environment. It is an XML based protocol that consists of three parts: an envelope that defines a framework for describing what is in a message and how to process it, a set of encoding rules for expressing instances of application-defined datatypes, and a convention for representing remote procedure calls and responses.

WSDL is an XML format for describing network services as a set of endpoints operating on messages containing either document-oriented or procedure-oriented information. The operations and messages are described abstractly, and then bound to a concrete network protocol and message format to define an endpoint. Related concrete endpoints are combined into abstract endpoints (services). WSDL is extensible to allow description of endpoints and their messages regardless of what message formats or network protocols are used to communicate, however, the only bindings described in this document describe how to use WSDL in conjunction with SOAP 1.1, HTTP GET/POST, and MIME.

Source: W3C

Grid Services

- Web services handle:
 - Service Description
 - Service Implementation
 - Service Publishing, Discovery and Binding
 - Service Invocation and Execution
 - Stateless services
- Grid services add another layer
 - Secure file transport
 - Programme execution
 - Monitoring services
 - Adds state: allows asynchronous operations
- Open Grid Services Architecture:

Grid/Web Services: Links

- Java: <http://java.sun.com/webservices/index.jsp>
 - Axis (SOAP implementation): <http://ws.apache.org/axis/>
 - Globus (GT4, Apr 05): <http://www-unix.globus.org/toolkit/>
- C#: <http://msdn.microsoft.com/vcsharp/>
 - Mono: <http://www.mono-project.com/about/index.html>
 - .Net: <http://www.microsoft.com/net/>
 - WSRF .NET: <http://www.cs.virginia.edu/~gsw2c/wsrf.net.html>
- Perl
 - SOAP::Lite <http://www.soaplite.com/>
 - WSRF::Lite <http://www.sve.man.ac.uk/Research/AtoZ/ILCT>
- Standards
 - WSRF <http://www-106.ibm.com/developerworks/library/ws-resource/>
 - SOAP <http://www.w3.org/TR/soap/>

Grid Services: Links

- Globus and OGSA: <http://www.globus.org/ogsa>
- Globus and WSRF: <http://www.globus.org/wsrf>
- OMII: <http://www.omii.ac.uk>
- EGEE: <http://public.eu-egee.org/>
 - gLite <http://glite.web.cern.ch/glite/>

Astro-RG @ Global Grid Forum interfacing with the grid community

The image shows a screenshot of a web browser displaying the GridForge website. The browser window title is "GridForge: Project Summary - Astro RG - Mozilla". The address bar shows the URL "https://forge.gridforum.org/projects/astro-rg/". The page content includes a navigation menu on the left with links like "ABOUT GGF", "GET INVOLVED", "NEWS & EVENTS", "CONTACT", "DOCUMENTS", "NEXT GGF", and "AREAS & GROUPS". The main content area displays the "Project Summary - Astro RG" page, which includes the following information:

- Project:** Astro RG
- Project Summary - Astro RG**
- Astronomical Grid Community (astro-rg)**
- Research Group Information:**
 - Working Group:** [Nicholas Walton](#), [Reagan Moore](#)
 - Chair(s):** [Nicholas Walton](#), [Reagan Moore](#)
 - Secretary:** [Guy Rixon](#)
 - Email list:** astro-rg@gridforum.org ([subscribe](#))
 - Email list archive:** ([by thread](#)) or ([by date](#))
- Research Group Charter:**

The Astronomy Research Group explores issues related to the use of Grid technology in support of astronomical data collections and data analysis pipelines. The Astronomy Research Group is supported by the International Virtual Observatory Alliance, a partnership of Virtual Observatory (IVOA) projects from across the globe. The term VO references Virtual Observatories, rather than Virtual Organizations. However, a Virtual Observatory is a Virtual Organization of diverse, distributed partners.
- Project Admins (5):**
 - [Guy Rixon](#)
 - [Masatoshi Ohishi](#)
 - [Nicholas Walton](#)
 - [Reagan W. Moore](#)
 - [Steve Crumb](#)
- Members (13)**
[\[View All Project Members\]](#)

The browser window also shows a search bar with "Projects" selected and a "GO" button. The page is logged in as "Nicholas Walton" with links for "Advanced Search", "Help", and "Logout".

<http://forge.gridforum.org/projects/astro-rg>

VO Technologies

High level interoperability protocols
coupled with Grid Technologies

IVOA: Enabling Interoperability

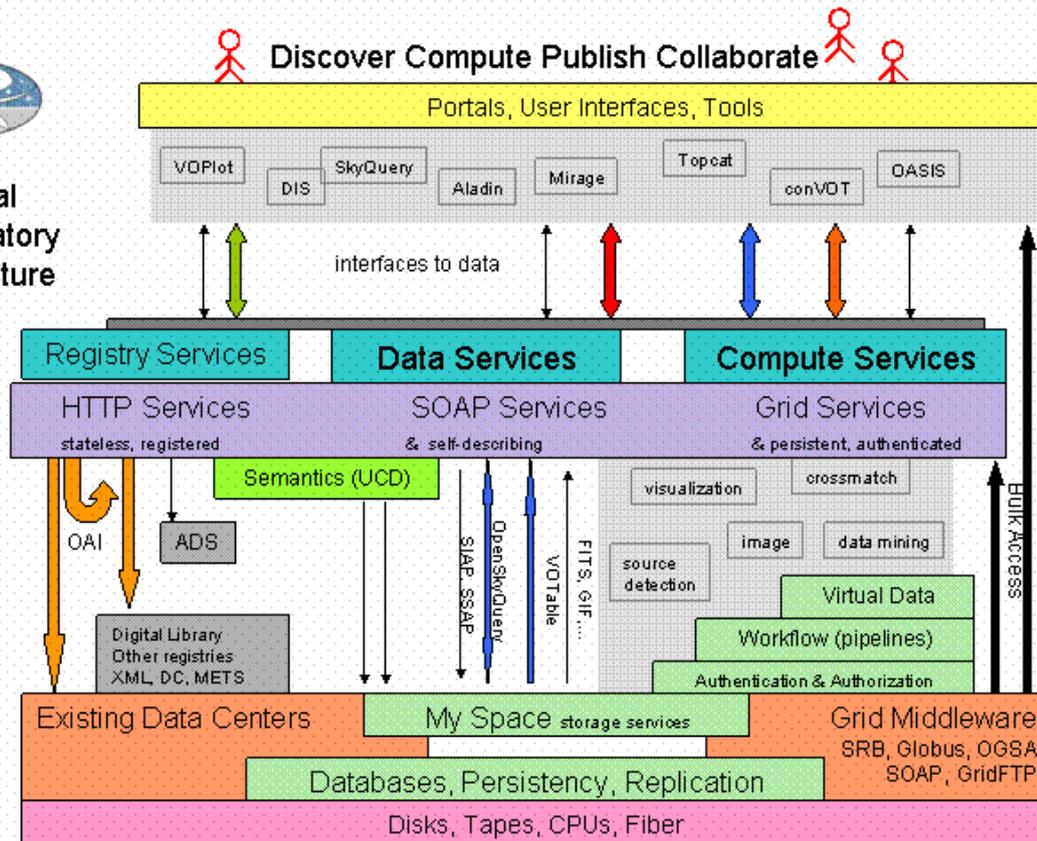
- The International Virtual Observatory Alliance
<http://www.ivoa.net>
- A global partnership
- Projects represent major global astronomy data providers, e.g. ESO, STScI, NAOJ
- Multi-wavelength
- Multi-site



IVOA Architecture Analysis



Virtual
Observatory
Architecture



Analysis of a VO:

- Multi-layer
- Complex
- User interfaces thru a portal
- Astro-apps interface to a VO abstraction layer
- Lower level middleware provided by the 'grid' world
 - e.g. SRB
- Hardware at bottom layer

IVOA has working groups to address 'astro' specific 'boxes'

Ref: IVOA Architecture Overview: Williams et al, 2004

IVOA Note 2004-06-14:

<http://www.ivoa.net/Documents/Notes/IVOArch/IVOArch-20040615.html>

IVOA Working Groups: <http://www.ivoa.net/forum>

- Registry:
 - how to 'register' resources: concept of VOResources
- Data Access Layer
 - Standards for remote data access: e.g. SIAP, SSA
- Data Model
 - Standards for the actual data: e.g. XML'ing of FITS
- VO Query Language
 - Standards for 'astro' database access: e.g. Openskyquery, 'circle'
- Unified Content Descriptors
 - Standards for common ways of describing data: metadata
- VOTable
 - XML representation of tabular data
- Grid & Web Services
 - Interfaces to Grid and Web Service stds: e.g. 'Heartbeat'

IVOA: Interest Groups

Aim: issues of importance across working groups

- Applications
 - Interfacing new and legacy apps (e.g. Iraf) to the VO
- RadioVO
 - Issues relevant to 'Radio': e.g. The UV plane, interferometry
- Theory
 - Simulations, mass scale compute
- Data Curation & Preservation
 - Linkages to the Digital Libraries world, a-ph, ADS
- Architecture
 - Fitting it all together
- Networks
- Semantics

Virtual Observatories

A brief tour: specific examples of use in later lectures

UK-VO: AstroGrid <http://www.astrogrid.org>

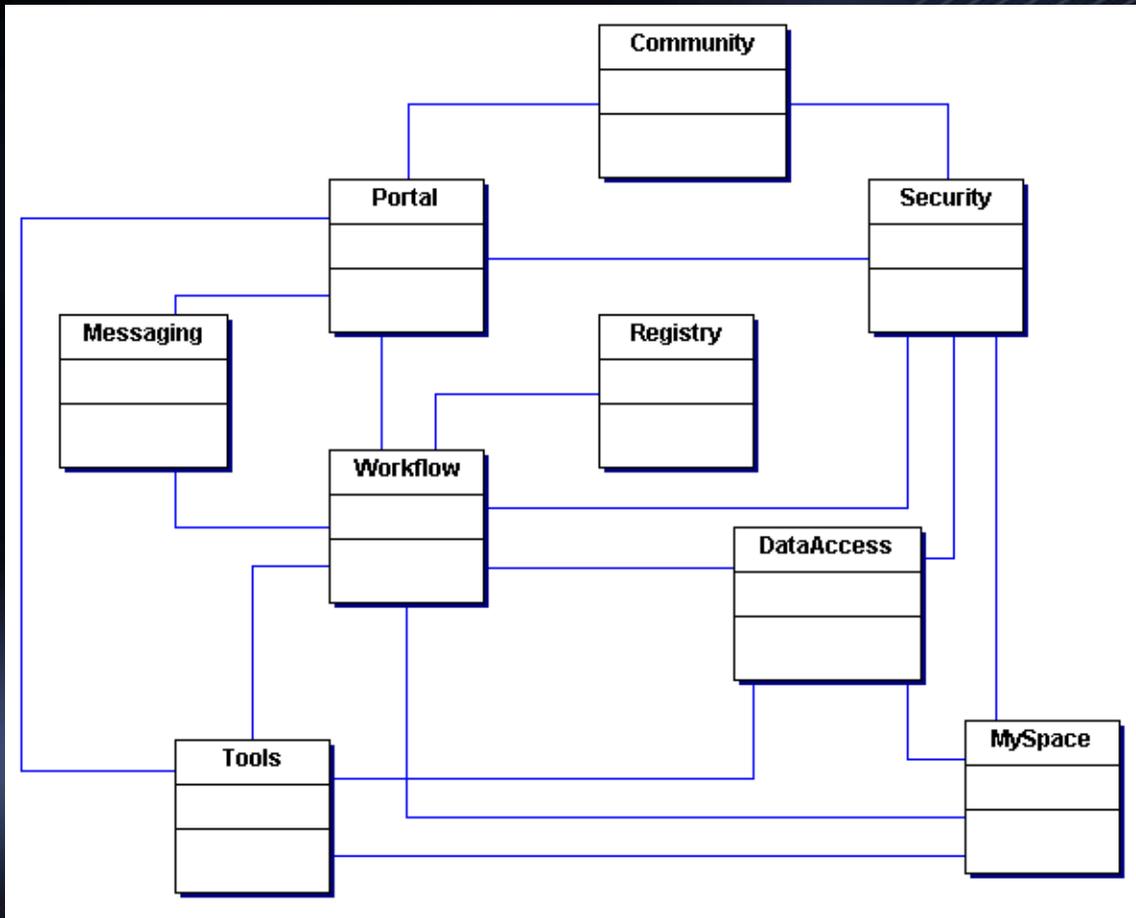
- Web Services based system
- Linkages to main UK data providers
- VO interoperability with external VO's/ Data Providers

The screenshot shows the AstroGrid Portal search interface. At the top, there are navigation buttons: Home, MySpace, Resources, Queries, Workflows, Jobs, Help, and Logout. Below this is a 'Resource browser' section with a 'Search for:' field. The search criteria are organized into 'General Constraints' and 'Wavelength' sections. The 'General Constraints' section includes fields for Resource name, Resource publisher, Resource title, and Description, each with a dropdown menu for the constraint type (string, elais, etc.). The 'Wavelength' section includes a dropdown menu for the wavelength type (EUV, Gamma R, Infrared, Millimeter, Optical, Radio, UV). Below the search fields, there are radio buttons for 'and' and 'or' constraints. A 'Search by:' section at the bottom provides a legend for the constraint types. The main content area displays the search results for the query 'elais', showing a list of resources with their titles and descriptions. The first result is 'Title: ELAIS: final band-merged catalogue (Rowan-Robinson+, 2004) - Final ELAIS Catalogue'. The description of this resource is: 'The catalog represents the final band-merged European Large-Area ISO Survey (ELAIS) Catalogue at 6.7, 15, 90 and 175{mu}m, and the associated data at U, g', r', i', z, J, H, K and 20cm. Details about the origin of the survey, the observations, data reduction and optical identification are described in the paper. In addition to fluxes in the radio, infrared and optical passbands, spectroscopic redshifts are tabulated, where available. For the N1 and N2 areas, the Isaac Newton Telescope ugriz Wide Field Survey permits photometric redshifts to be estimated for galaxies and quasars.' The search results also include a table with columns for 'curation', 'table/column', and 'xml'.

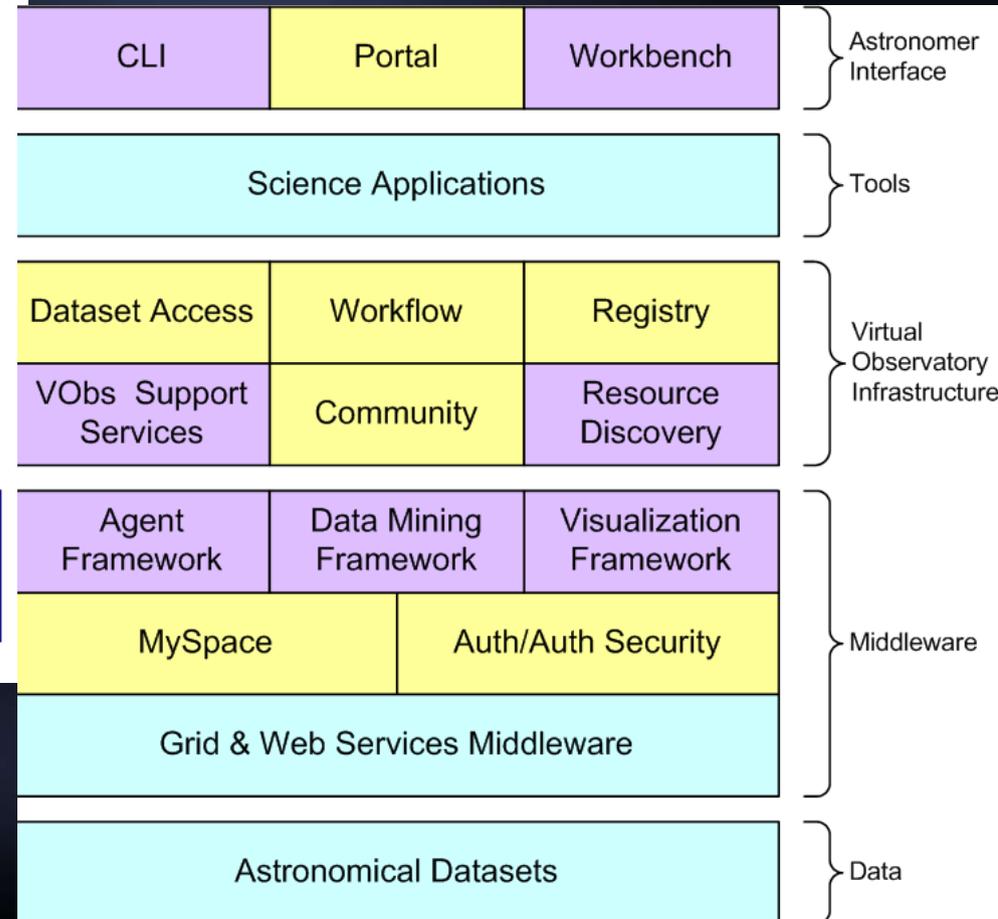
The screenshot shows the AstroGrid user interface. At the top, there are navigation buttons: Home, Task, MySpace, Profile, Admin, Logout, Help, and PPARC. Below this is a 'Welcome to AstroGrid' banner with the user's name 'Kona Andrews' Home Page'. The main content area is divided into several sections: 'Help', 'Recent jobs', and 'Examples'. The 'Help' section includes a 'Hint' button, a 'Glossary' section, and a 'FAQ & Cookbook' section. The 'Recent jobs' section displays a table of recent jobs with columns for Name, Time submitted, Status, and Job ID. The 'Examples' section includes links for 'Example cone search', 'Example catalogue search', 'Example data extraction', and 'Example workflow construction'. The bottom of the page features a footer with the text '© AstroGrid 2004'.

Name	Time submitted	Status	[more] Job ID
ADASS paper plots	2004-09-13 10:13am	Completed55667315
Brown dwarfs	2004-09-13 10:13am	Running1791494912
XMATCH with USNOB	2004-09-13 10:13am	Error1229106770
XMATCH with WF-CAM	2004-09-13 10:13am	Running048010803
Job for Brian	2004-09-13 10:13am	Completed32143444
Big X-ray job	2004-09-13 10:13am	Running23360710

VO Architecture: AstroGrid



Layer diagramme



Legend

- Existing Component
- AstroGrid-2 Component
- External Component

Component based system

US-VO: NVO <http://www.us-vo.org>

- Partnership of major data/ compute centres in the USA:
 - IPAC, NASA-HESARC, NASA-JPL, NRAO, NOAO, SDSS, SAO, STScI
 - SDSC, NCSA, Pittsburgh
 - Globus, MS
- Webservices based
- Initially tools
 - Now moving to an architecture

The screenshot shows the US National Virtual Observatory (NVO) website. The browser window title is "US-VO Website - Mozilla Firefox". The address bar shows "http://www.us-vo.org/". The website header features the NVO logo and the text "US National Virtual Observatory". Below the header is a navigation menu with links: Home, Registry, Tools, Data Access, Publish, Education, Software Library, Grid Computing, Architecture, and Contact Us. The main content area is titled "NVO - Facilitating Scientific Discovery" and contains a paragraph about NVO's objective and a list of services. The left sidebar has sections for News, About, Community, and Documents. The right sidebar has sections for Team and IVOA. The footer of the browser window shows "Done".

US National Virtual Observatory

Home Registry Tools Data Access Publish Education Software Library Grid Computing Architecture Contact Us

News

[NVO at the AAS, January 2005](#)
[VO Science Session at San Diego AAS Meeting](#)
[NVO News Archive](#)

About

[What is the NVO? Who is Involved?](#)
[Science Objectives](#)
[NVO in Use](#)

Community

[NVO Meetings](#)
[International VO Alliance](#)
[NVO Summer School](#)

Documents

Recent NVO Documents:
[How to Publish to the NVO](#)
[Quarterly Report, October-December 2004](#)
[NVO-TeraGrid First Year Results](#)

NVO - Facilitating Scientific Discovery

NVO's objective is to enable new science by greatly enhancing access to data and computing resources. In conjunction with the January 2005 meeting of the American Astronomical Society, NVO is releasing a first set of software tools and applications that make it easy to locate, retrieve, and analyze data from archives and catalogs worldwide.

- [The NVO Registry Portal at STScI](#) finds source catalogs, observation logs, image archives, and other astronomical resources registered with the NVO.
- [NVO DataScope](#) helps you discover and explore astronomical data from repositories around the world.
- [OpenSkyQuery](#) lets you cross-match your data with numerous catalogs.
- [NVO Spectrum Services](#) allow you to search, plot, and retrieve Sloan, 2dF, and other spectra.
- [The Web-Enabled Source Identification with Cross-Matching \(WESIX\)](#) package lets you upload images to SExtractor and cross-correlate the objects found with selected survey catalogs.
- [How to publish your data collections to the NVO](#) provides software libraries and sample code of VO Services for people who want to write their

Team

[NVO Team Meeting](#)
25-26 April 2005
LSST Observatory, Tucson, AZ

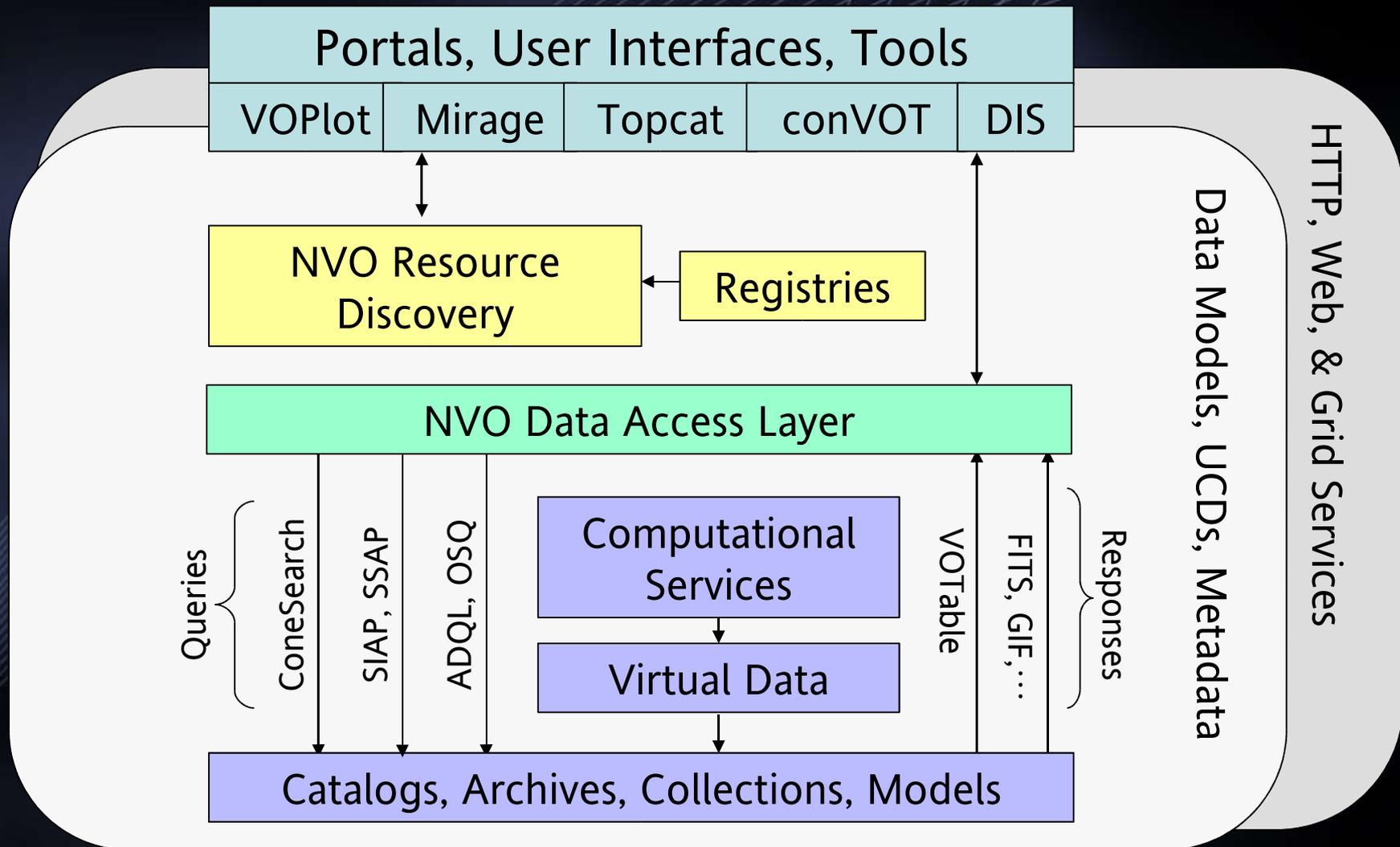
IVOA

IVOA Interop Workshop, Kyoto (16-20 May)
Detailed information will soon be available at the [JVO](#) web site.

DataScope

Find images and catalog objects

US-VO: Architecture



Euro-VO: AVO <http://www.euro-vo.org>

- AVO: study programme
- Partners
 - ESO, AstroGrid, ESA/ECF, JBO, CDS, Terapix
- Main outputs
 - Technology Assessments
 - Demo products (to be discussed in a later lecture)
- AVO leads into a larger Euro-VO project
 - Links data centres and missions with technology development & operations

The screenshot shows the AVO website with the following content:

- Navigation Menu:**
 - Virtual Observa
 - [Introduction](#)
 - [Overview](#)
 - [Q & A](#)
 - [Movie](#)
 - About the AVO
 - [Introduction](#)
 - [Partners](#)
 - [EC support](#)
 - [Acknowledgin](#)
 - Further Reading
 - [Articles](#)
 - [Presentations](#)
 - [The IVO Allianc](#)
 - [AVO Internal Si](#)
 - [Images](#)
 - [Links](#)
 - [Contacts](#)
 - [Search](#)
 - [Home](#)

- News Items:**
- Euro-VO Workshop 2005**
27 June - 1 July, 2005 The EURO-VO Project announces a workshop on VO technologies and standards explicitly designed for data centres and large projects to acquire the knowledge and experience necessary to allow them to become "publishers" in the VO. In tutorials and lectures, participants will be instructed in the use of VO analysis tools, libraries and the existing web service infrastructure to build VO compliant services. The application deadline is **1 March 2005**.
[Workshop Page >](#)
- AVO Demo 2005**
January 25-26, 2005 The final demo of the AVO project - "Toward the EuroVO" - has been held at ESAC, Villafranca del Castillo, Spain. The demo showcased new workflow techniques and focus on two scientific scenarios, i.e., the evolution of AGB stars to Planetary Nebulae and Star Formation Histories in Galaxies.
[Event Page >](#)
- VO-TECH Kick-off Meeting**
November 18-19, 2004 The kick-off meeting of the new EC FP6 VO-TECH project has been

Footer: Ioa logo, AN EC RTD PROJECT 2002-2004, European Southern Observatory • European Space Agency • UK ASTROGRID Consortium • Centre de Données astronomique de Strasbourg • TERAPIX • Jodrell Bank Observatory

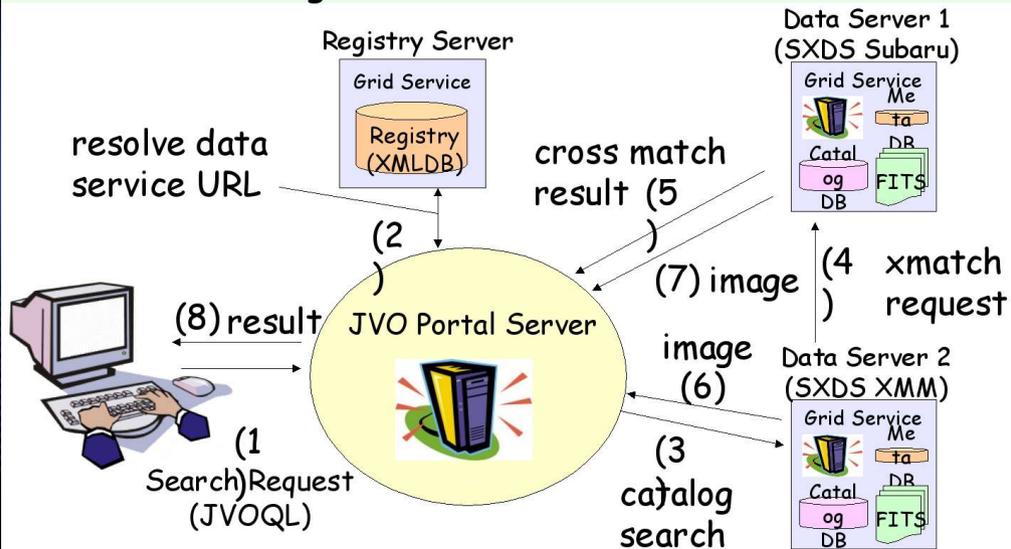
Japan-VO: JVO <http://jvo.nao.ac.jp>

• Partners

- NAOJ, JAXA, ICRR, Ochanomizu U, Osaka U, Titech, Fujitsu
- Data from Suburu, Astro-F, Nobeyama, Alma
- 1st JVO prototype based on Globus Toolkit 2 – 'grid'
- 2nd JVO prototype based on GT3 – grid services, improved performance

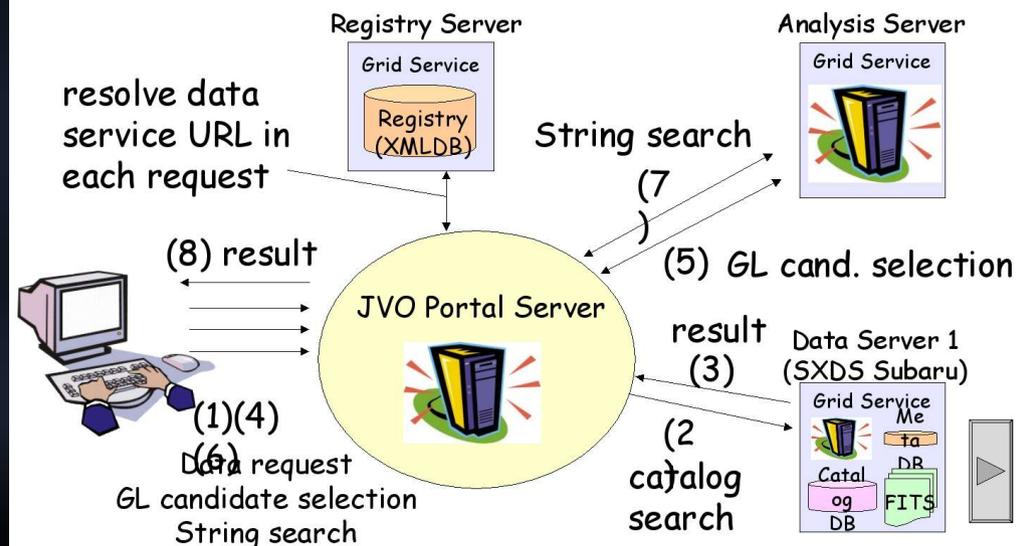
Demo 1: Cross match & Image request

Cross match of the optical and X-ray catalogs of SXDS and image retrievals.

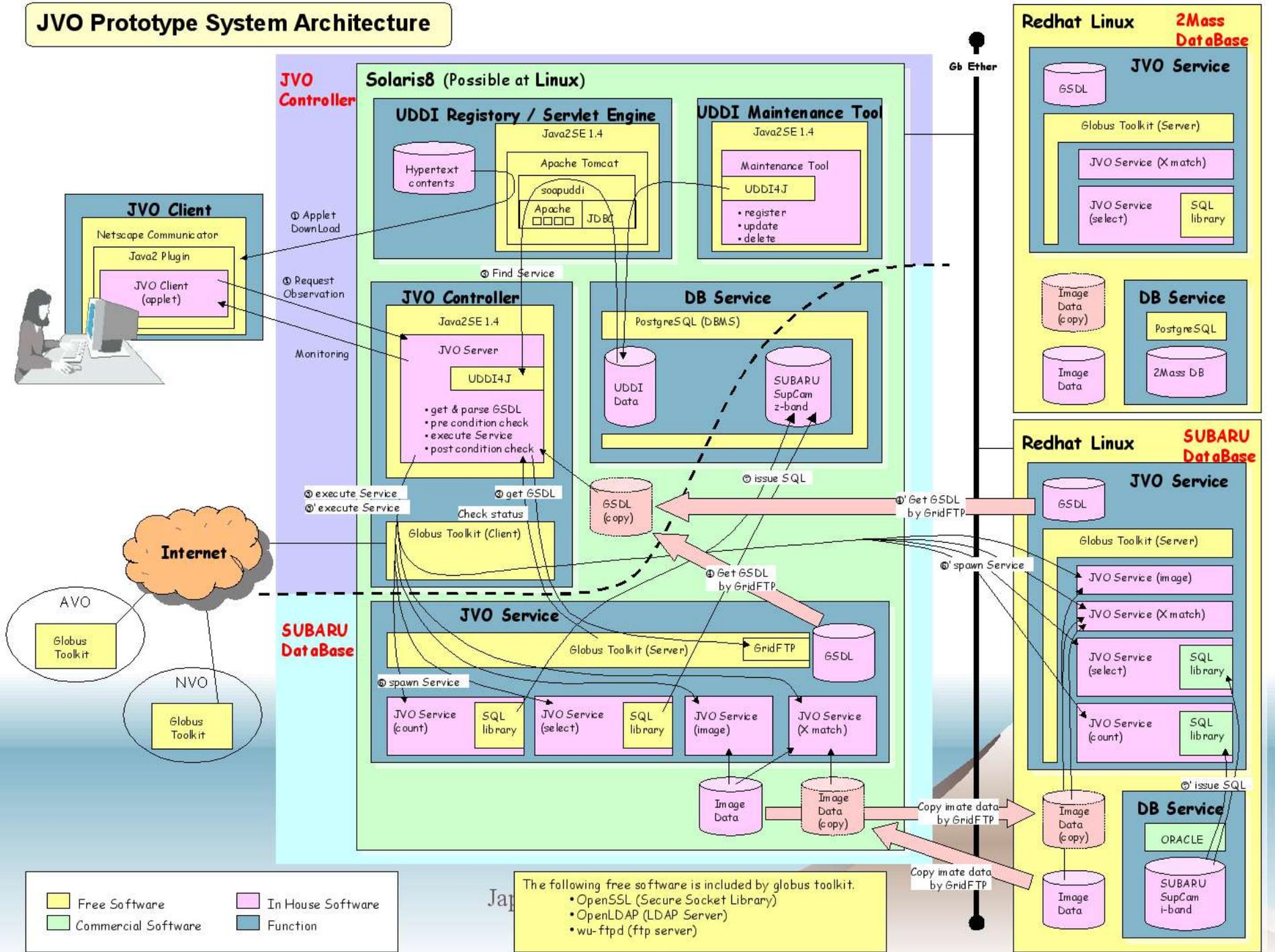


Demo 2: Cosmic String Search

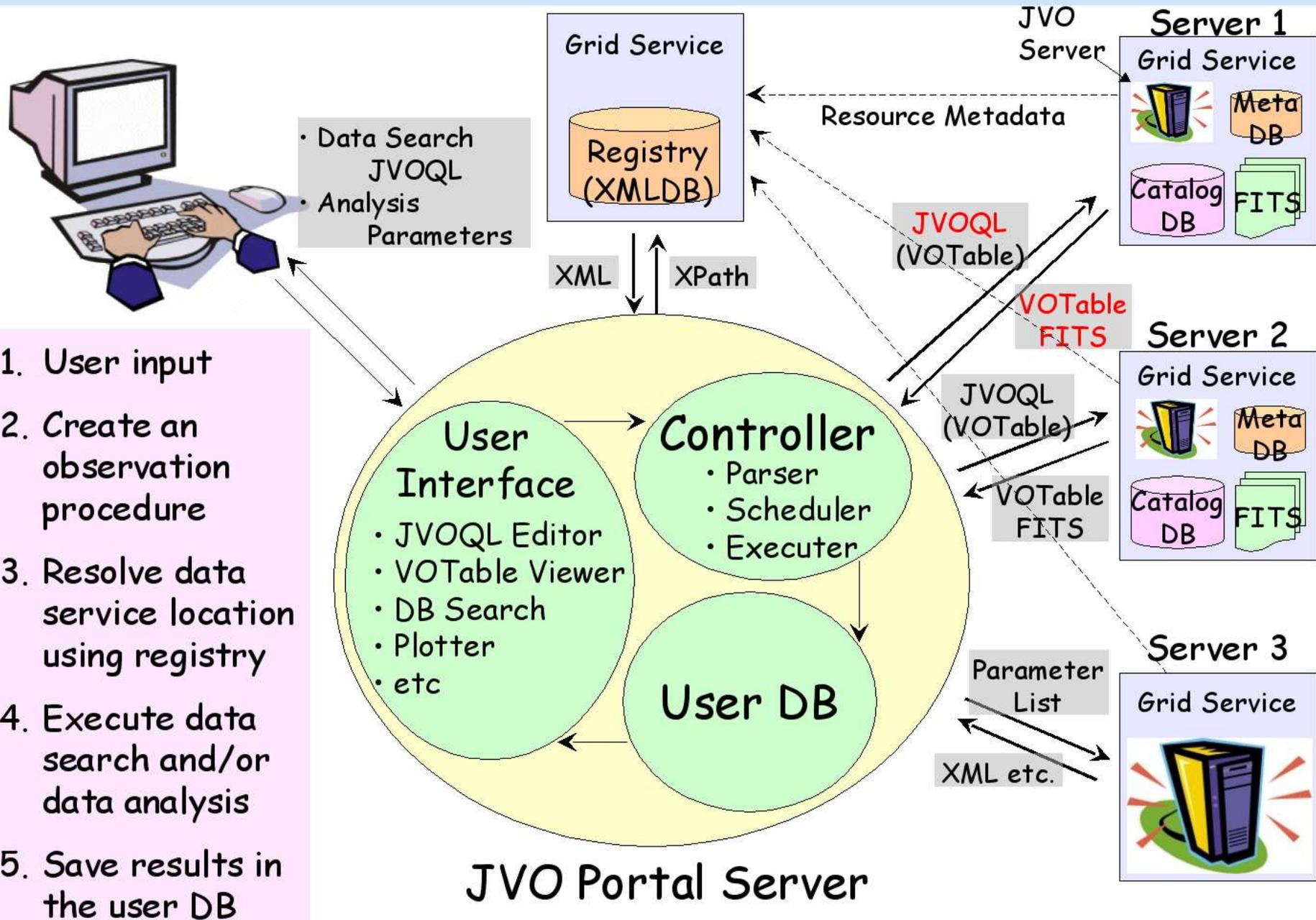
Data request to the SXDS optical catalog, GL candidate selection, String search by pattern recognition.



JVO Prototype System Architecture



Architecture of JVO Proto 2

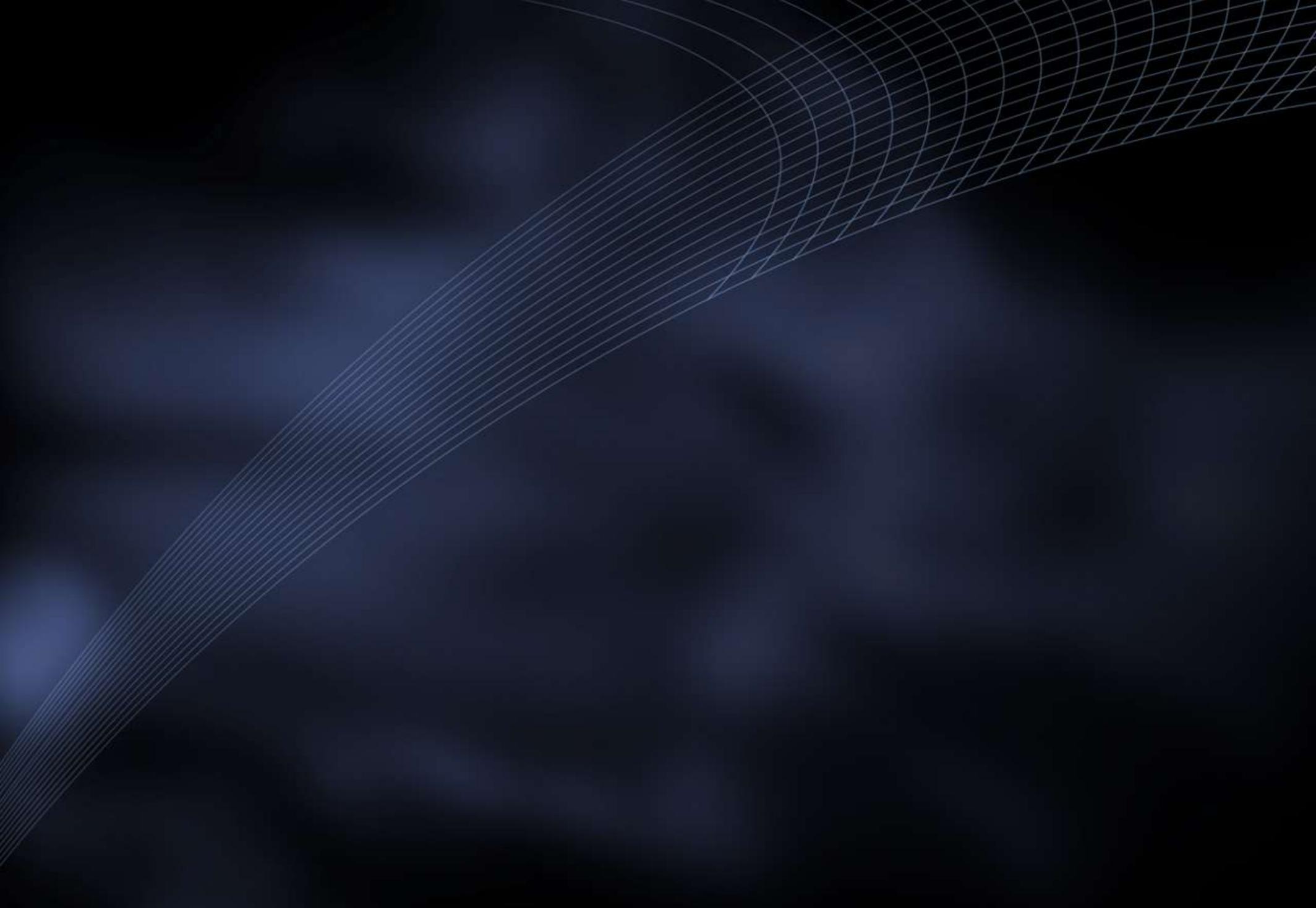


Other VO projects

- Aus-VO (Australia): <http://www.aus-vo.org>
- CVO: <http://www2.cadc-ccda.hia-ihp.nrc-cnrc.gc.ca/cvo/>
- China-VO: <http://www.china-vo.org>
- Draco (Italy): <http://www.as.oat.ts.astro.it/draco/>
- GAVO (Germany): <http://www.g-vo.org/>
- HVO (Hungary): <http://hvo.elte.hu/en/>
- KVO (Korea): <http://kvo.kao.re.kr/>
- RVO (Russia): <http://www.inasan.rssi.ru/eng/rvo/>
- SVO (Spain): <http://laeff.esa.es/svo/>
- VO-France: <http://www.france-vo.org/>
- VO-India: <http://vo.iucaa.ernet.in/~voi/>

Lecture 1: Acknowledgements

- 'Grid' diagramme on Slide 19 Adapted from S. Lloyd, see http://www.gridpp.ac.uk/talks/Inaugural_Lecture.ppt
- Some material on Slide 20 adapted from M. Graham, see NVO Summer School: <http://www.us-vo.org/summer-school/proceedings/presentations/WSTechnology.ppt>
- Teragrid graphic on slide 21 from Roy Williams, see <http://www.us-vo.org/summer-school/proceedings/presentations/Grid.ppt>
- The graphic on slide 36 due to Bob Hanisch, see <http://www.us-vo.org/summer-school/proceedings/presentations/Introduction.ppt>
- The graphics on Slides 5 and 39 are due to Masatoshi Ohishi of the JVO project
- The graphic on Slides 38 & 40 due to Yuji Shirasaki of the JVO project



SOAP Example

Request:

```
<soap:Envelope xmlns:xsi=http://www.w3.org/2001/XMLSchema-instance xmlns:xsd=http://www.w3.org/2001/XMLSchema
  xmlns:soap="http://schemas.xmlsoap.org/soap/envelope/">
  <soap:Body>
    <ComovingLineOfSight xmlns="http://skyservice.pha.jhu.edu">
      <z>float</z>
      <hubble>float</hubble>
      <omega>float</omega>
      <lambda>float</lambda>
    </ComovingLineOfSight>
  </soap:Body>
</soap:Envelope>
```

Response:

```
<soap:Envelope xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
  xmlns:xsd="http://www.w3.org/2001/XMLSchema"
  xmlns:soap="http://schemas.xmlsoap.org/soap/envelope/">
  <soap:Body>
    <ComovingLineOfSightResponse xmlns="http://skyservice.pha.jhu.edu">
      <ComovingLineOfSightResult>float</ComovingLineOfSightResult>
    </ComovingLineOfSightResponse>
  </soap:Body>
</soap:Envelope>
```

WSDL Example

```
<definitions>
  <import>*
  <types>
    <schema></schema>*
  </types>
  <message>*
    <part></part>*
  </message>
  <portType>*
    <operation>*
      <input></input>
      <output></output>
      <fault></fault>*
    </operation>
  </portType>
  <binding>*
    <operation>*
      <input></input>
      <output></output>
    </operation>
  </binding>
  <service>*
    <port></port>*
  </service>
</definitions>
```

- include other WSDLs
- define datatypes used in <message> elements
- model data exchanged
- a subset of operations supported for an endpoint
 - define input and output messages
- concrete protocol and data format specification for a <portType> element
- identifies actual endpoint for WS