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The Virtual Observatory: an Overview

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- Astronomy in the XXI century
- The Virtual Observatory (VO)
- The VO in Europe: the EURO-VO project
- Data centres in the VO era
- VO science

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The way Astronomy works

- Telescopes (ground- and space-based, covering the full electromagnetic spectrum) ⇒ Observatories
- Instruments (telescope/band dependent) ⇒ Observatories/Consortia
- Data analysis software (instrument dependent) ⇒ Observatories/Consortia/Researchers
- *Active* Archives ⇒ Observatories/Agencies
- Publications ⇒ Journals
- Data curation (metadata + tables & catalogues) ⇒ Data curators
- … and Public Outreach ⇒ Observatories/Agencies

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The Good News

- Observational data normally stored in *astronomical archives*, freely available *on-line* after ~ 1 year
- Results published in academic journals, all *available on-line* (full content in general freely available after ~ 3 years)
- One *single entry point for journals*: ADS
- Two-way links between most archives and publications
- Data curators (object metadata + catalogues) *on-line*; some links to archives and publications
- Analysis software available from Observatories/Archives *on-line*
- Press release and outreach material (pictures, movies) *on-line*

The "less Good" News

- Different astronomical archives have *widely different access/search interfaces and standards/conventions*; serving mainly raw data
- Widely specialized, *complex analysis software* for various sub-branches; steep learning curve, but multi-wavelength now the norm
- Publication - Archive links point to *raw, unprocessed data*
- Object *metadata not homogeneously defined*; links with archives and publications not complete
- Press release and *outreach material disconnected*
- *Information avalanche*

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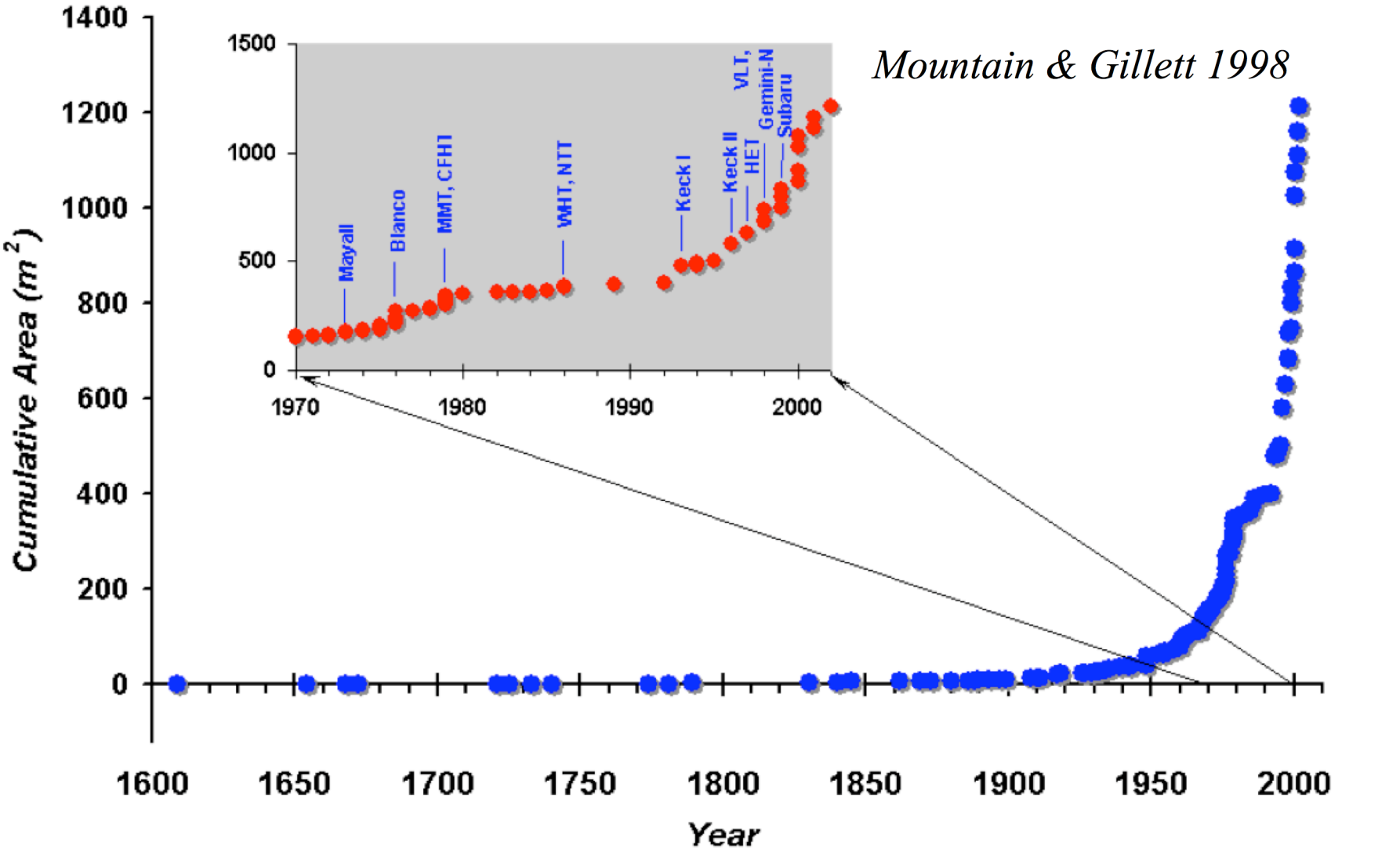
Telescope Collective Area Increase



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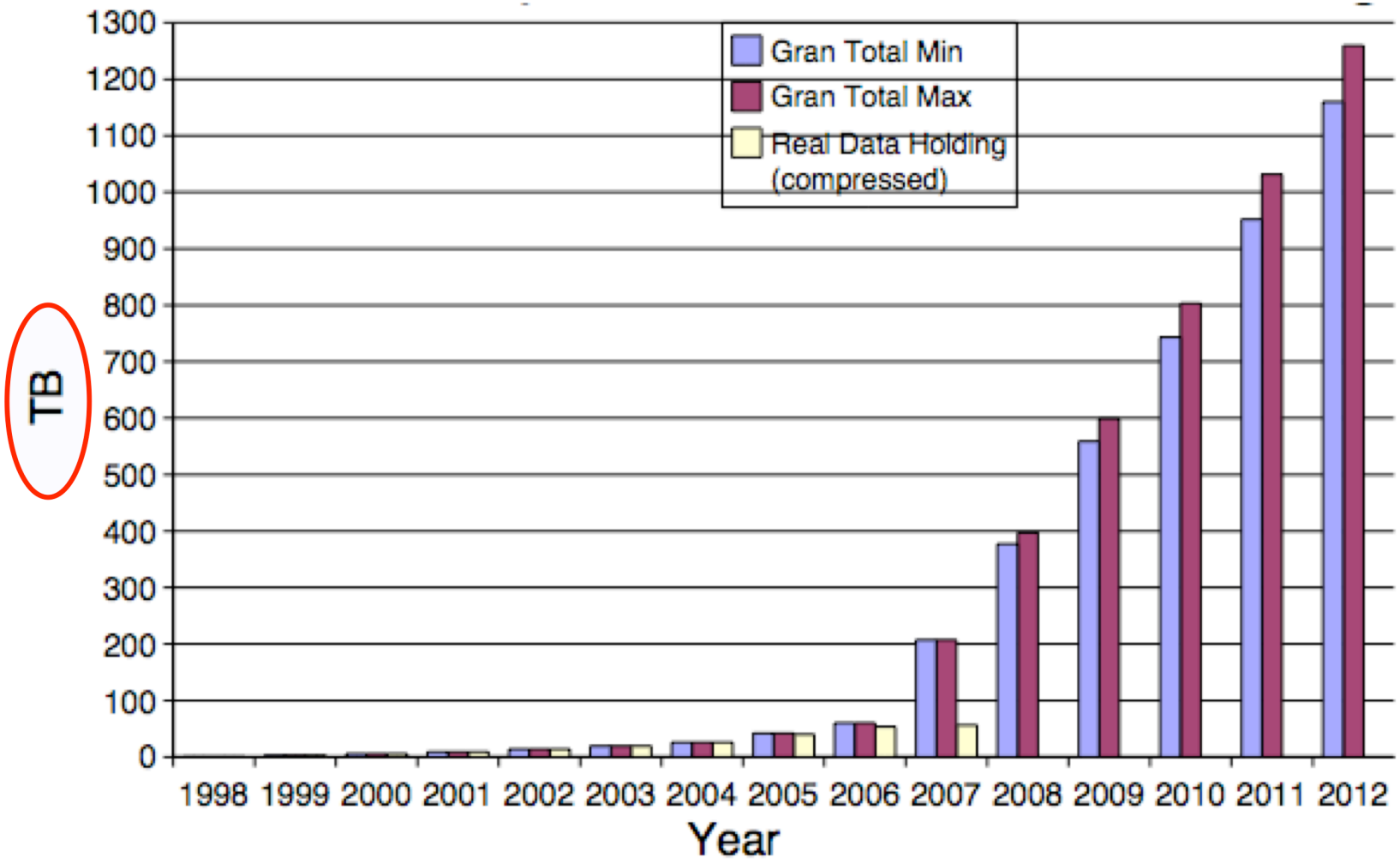
ESO Archive Growth



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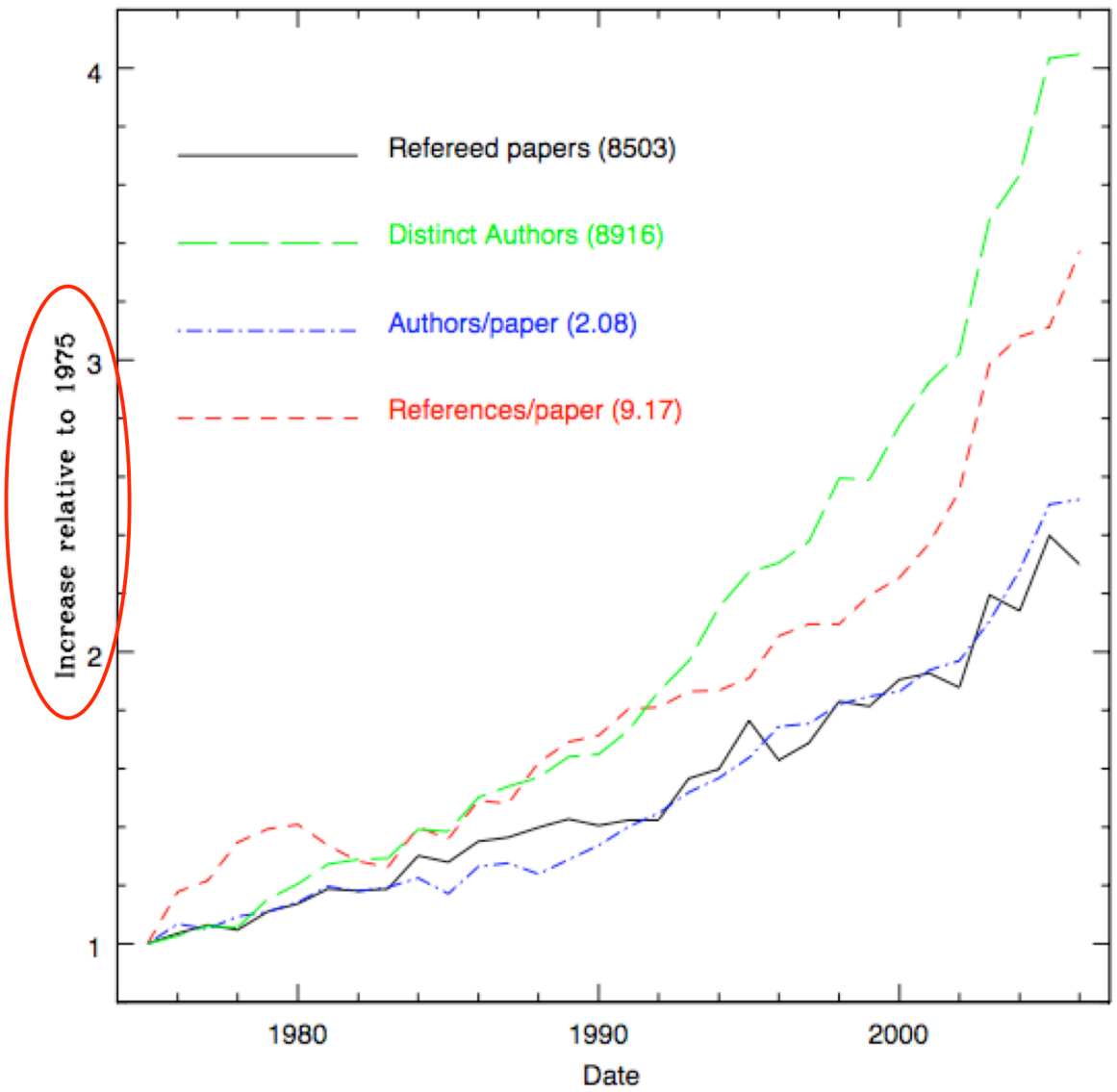
Astronomical Publication Growth



White 2007

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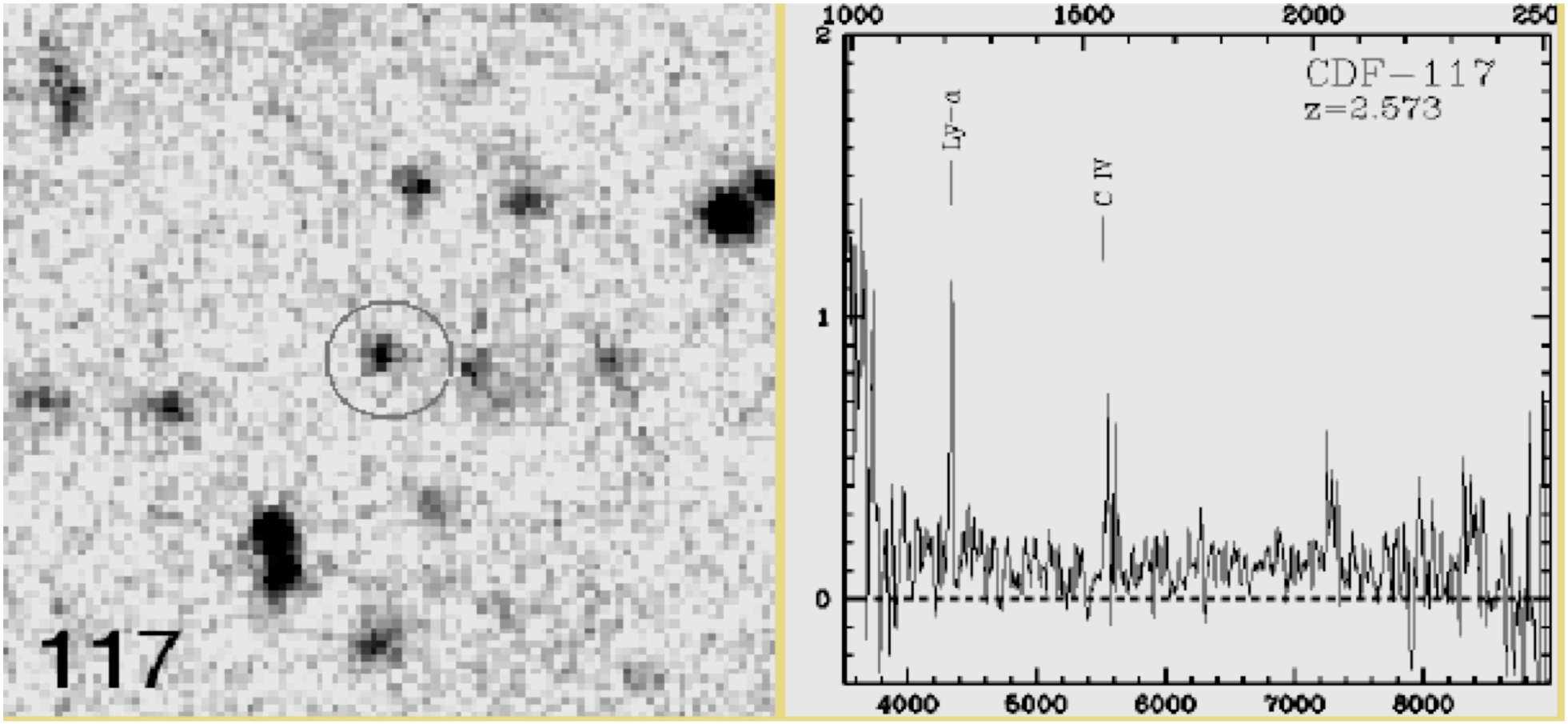
Information Avalanche

- *Huge surveys*: 100 million sources at < 3000 sources per night ⇒ > 100 years to identify them
- *Ever fainter sources* routinely surpassing the identification limits of 8 - 10m telescopes [R ≈ 25]
- *Huge data collections*: download and data analysis on desktop problematic/impossible. Example: downloading Sloan Digital Sky Survey (SDSS) DR6 data:
  - ✓ images (10 Terabytes) ⇒ ~ 3 months at 10 Mbps (ESO's speed)
  - ✓ catalogues (2 Terabytes) ⇒ ~ 3 weeks
  - ✓ on DVDs ⇒ ~ 2,100 of them
- And *data analysis*?? (similar size for MACHO, 2MASS etc …)



R ~ 25.5, VLT/FORS2, t_{exp} ~ 2.5 hrs (Szokoly et al. 2004)

courtesy of P. Quinn

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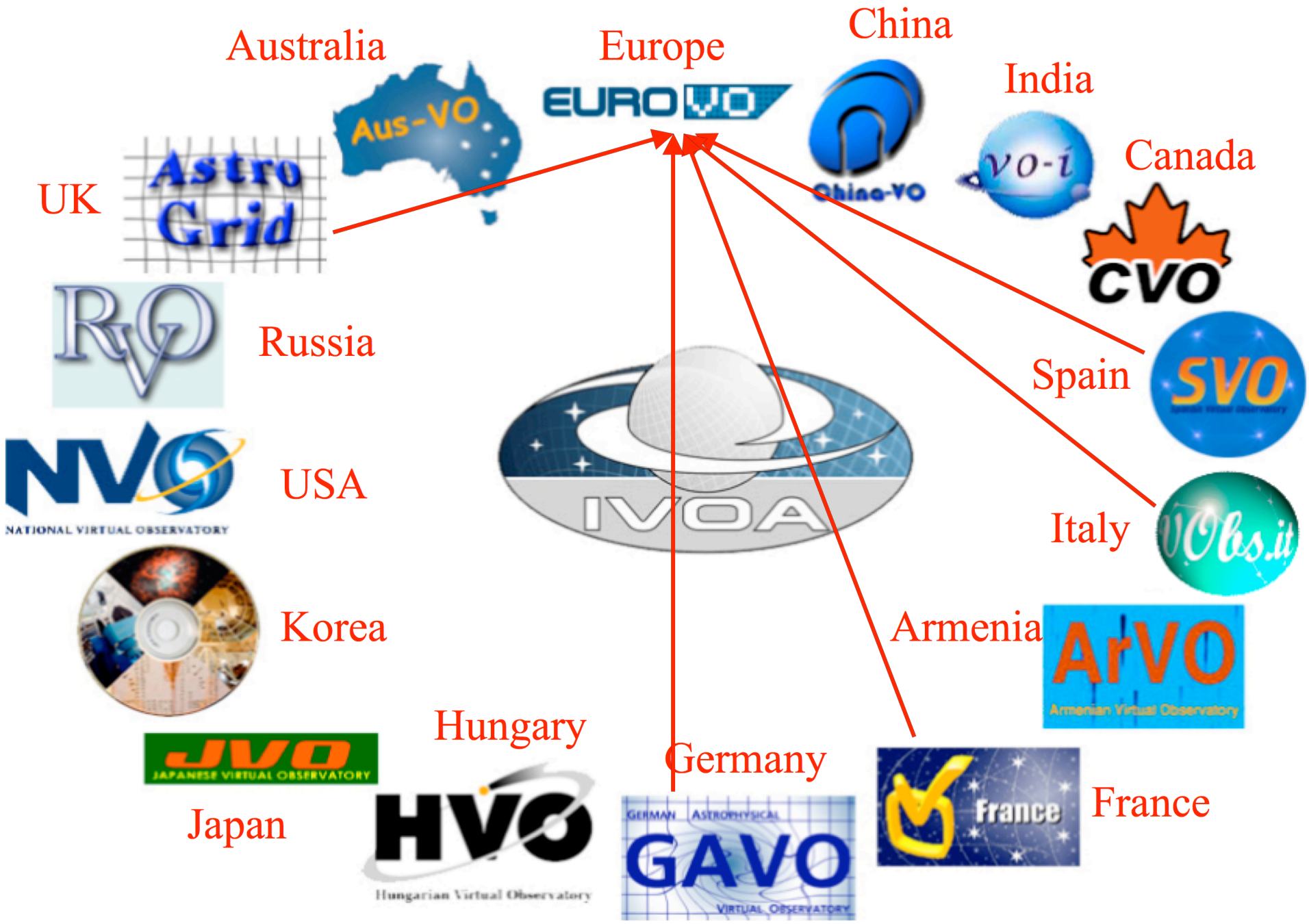
The Virtual Observatory

- The Virtual Observatory (VO) is an innovative, still evolving, system to:
  - take advantage of astronomical data explosion (e.g., use statistical identification to diminish need for a spectrum ⇒ multi-wavelength, *multi-dimensional* analysis)
  - allow astronomers to interrogate multiple data centres in a seamless and transparent way and to utilize at best astronomical data
  - permit remote computing and data analysis
  - foster *new science*
- Web: all documents inside PC; *VO: all astronomical databases inside PC*
- VO ⇒ democratization of astronomy!
- All of the above requires the various players to speak the same language ⇒ *VO standards and protocols defined and adopted within the IVOA (International Virtual Observatory Alliance), which includes 16 projects world-wide*

16 Member Organizations



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The IVOA: http://ivoa.net

- 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*
- Works by telecons, "TWiki" pages, and bi-annual meetings (last one in Trieste [May 2008])
- Needs: standardization of data and metadata, data exchange methods, and list of available services
- Structure:
  - ✓ IVOA Executive Board includes representatives from all VO projects
  - ✓ Working and Interest Groups

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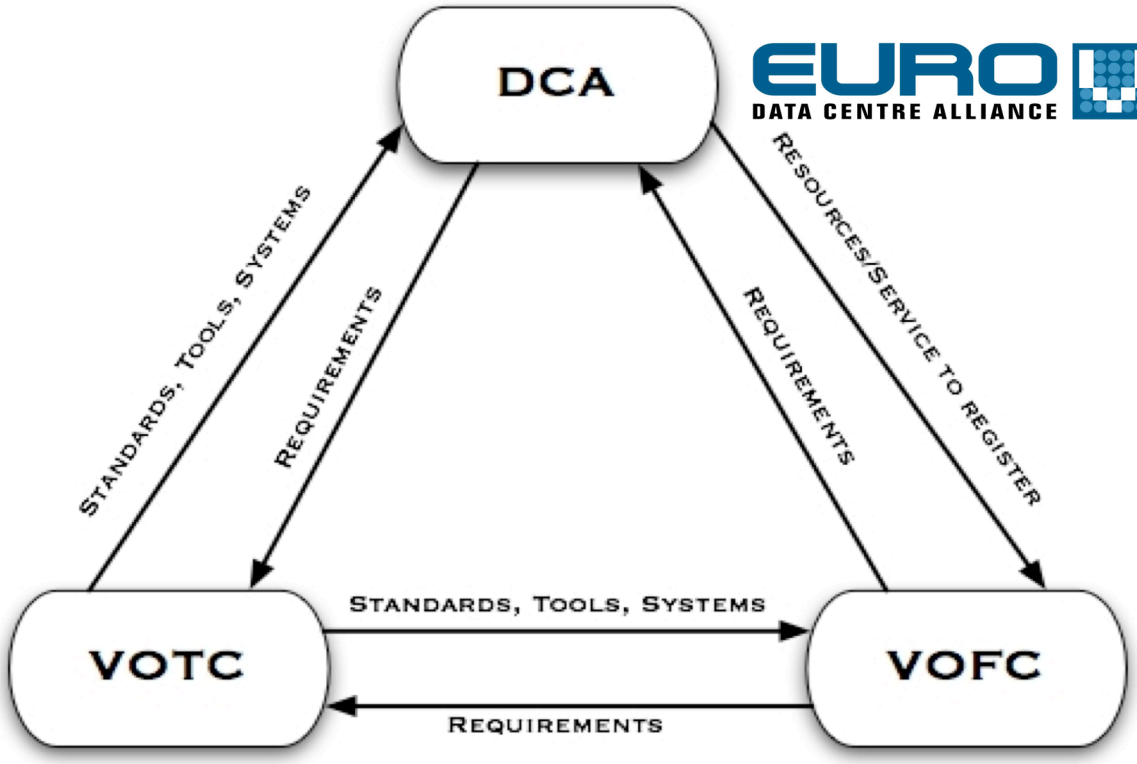
The European View: the EURO-VO
http://www.euro-vo.org

- Successor to the Astrophysical Virtual Observatory (AVO), which was a 5 M€, Phase A study (2001 - 2004/5) on the scientific requirements and technology for building the VO in Europe, *50%* funded by European Community (Fifth Framework Programme [FP5])
- Includes 8 partners: ESO, European Space Agency (ESA), plus six national nodes: INAF (Italy), INSU (France), INTA (Spain), NOVA (Netherlands), PPARC (UK), and RDS (Germany)
- Has three components: Data Centre Alliance, Technology Centre, Facility Centre
- Partly funded by the EC but substantial (~ 50%) partner support

EURO VO

EURO VO DATA CENTRE ALLIANCE



EURO VO TECHNOLOGY CENTRE

EURO VO FACILITY CENTRE

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Some EURO-VO Activities

- Data Centre Alliance (DCA):
  - Community Workshop for astronomers *Astronomical Spectroscopy and the VO* (March 2007 at European Space Astronomy Centre [ESAC], Madrid)
  - *EURO-VO Workshop on how to publish data in the VO* for developers (June 2007 at ESAC)
  - *EURO-VO Workshop on how to publish data in the VO* for developers (June 23 - 27 2008 at ESO)
- Facility Centre (FC), located at ESO, co-managed by ESO & ESA. Main activities:
  - 1st EURO-VO Technical Workshop (June 2005 at ESO)
  - Selection of EURO-VO Science Advisory Committee; held first 4 meetings
  - EURO-VO Web pages
  - EURO-VO Research Initiative
  - Participation to conferences, workshops, and schools

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The EURO-VO Project: Future

- The EURO-VO proposal "Astronomical Infrastructure for Data Access (AIDA)" submitted to the EC first Framework Programme 7 (FP7) Infrastructure call INFRA-2007-1.2.1 "Scientific Digital Repositories" has been selected for funding (2.7 M€); same partners as the EURO-VO
- Project started Feb. 1, 2008. This ensures continuation of European-wide VO activities at least until 2010
- AIDA is a combination of DCA, VOTC, and FC activities
- AIDA aims at unifying the digital data collection of European astronomy, integrating their access mechanisms with evolving e-technologies and enhancing the science extracted from these data-sets
- *VO is moving worldwide from development to operations*

Data Centres in the VO Era

- The VO needs data ⇒ astronomical data centres lie at its foundation
- The VO is more than a system: also a "frame of mind"
  ⇒ modern access to better data
- The VO is "convenient" for data centres as well. Various reasons:
  1. old technology has hard time keeping up with current data volume and complexity
  2. broadens user base
  3. exposes highly processed data in a direct way through VO protocols

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VO-compliant Archives

The VO cannot (and does not) dictate how to manage an archive

- The VO requires data centres to have a "VO layer" to:
  - ✓ "translate" any locally defined parameter to the standard (IVOA compliant) ones (e.g., RA can be called in many different ways)
  - ✓ hide any observatory/telescope/instrument specific detail and work in astronomical units: e.g., *wavelength range/band* (not grism or filter name), *spectral resolution, signal-to-noise ratio, field of view, limiting magnitude* ⇒ provide the right meta-data (data about data)
- The VO will work at best with high level "science-ready" data ⇒ data centres should make an effort to provide such data

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• The European Organisation for Astronomical Research in the Southern Hemisphere
• Intergovernmental organisation (founded 1962) to 'establish and operate an astronomical observatory in the southern hemisphere, equipped with powerful instruments, with the aim of furthering and organizing collaboration in astronomy…'.
• Three observational sites, all in Chile: *1 - 4m class telescopes* (La Silla), *Very Large Telescopes* [VLT, 4x8m] (Paranal), *APEX* (in operation) and *ALMA* (giant array of 12-m submm antennas under construction) (Llano de Chajnantor, San Pedro de Atacama)
• 13 European member states (including Finland as of 2004) + agreement with Chile

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A data centre's perspective: ESO

- ESO operates one of the largest astronomical archives in the world
- ESO is committed to becoming a key provider of data and resources in the Virtual Observatory:
  - Founding member of IVOA
  - Lead partner of Astrophysical Virtual Observatory
  - Lead partner of EURO-VO
- To this aim, ESO has created (Nov. 2004) the Virtual Observatory Systems Dept. (17 people) to manage ESO's VO activities but especially with the goal of turning its archive into a powerful scientific resource for the ESO and world-wide community

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High-level VO Work on the ESO Archive

1. Build a "VO layer"
2. Improve archive interface
3. Collect/derive/create meta-data: allow "smart" queries
4. Create highly processed ("science-ready") data: very important for VO users
5. Collect, validate, and publish into archive (according to detailed guidelines) highly processed community data [paradigm change]
6. Same from Large Programs and upcoming ESO Public Surveys (VST [2.6m mirror, 1 sq. deg. optical camera] & Vista [4m mirror, 0.6 sq. deg. IR camera] survey telescopes) [*required* to provide their data products to the ESO archive]

Similar work is going on in many data centres around the world: e.g., ESAC, MAST, CADC

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Science and the Virtual Observatory

The ultimate goal of the VO is to facilitate the work of astronomers and foster new *science*.

This is done *directly* by:

- allowing easier/better access to (ever larger amounts of) data
- providing new/improved research tools (more later)

And *indirectly* by:

- motivating data centres to:
  1. agree on common standards (esp. for information exchange)
  2. provide homogeneous meta-data (data about data) and quality flags
  3. produce and/or collect science-ready data

Indirect ways not easily linkable to the VO!

(e.g., data - papers links; but also Aladin!)

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A selection of VO-based astronomical papers

- List of VO-based papers at http://www.euro-vo.org/pub/fc/papers.html
- Papers which make "heavy" use of VO tools and services
- Lower limit to papers which are VO-related
- Selected (almost randomly) *recent* results to show diversity of problems which can be tackled with VO tools:
  1. *Using VO tools to investigate distant radio starburst hosting obscured AGN in the HDF(N) region,* Richards et al., A&A, 472, 805 (2007)
  2. *Albus 1: a very bright White Dwarf candidate*, Caballero & Solano, ApJ, 665, L151 (2007)
  3. *Flare productivity of newly-emerged paired and isolated solar active regions,* Dalla, Fletcher, & Walton, A&A, 468, 1103 (2007)
  4. *Radio-loud Narrow-Line Type 1 Quasars,* Komossa et al., AJ, 132, 531 (2006)
  5. *Luminous AGB stars in nearby galaxies. A study using VO tools,* Tsalmantza et al., A&A, 447, 89 (2006)

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VO Research Initiatives

- Call for Proposals issued April 2008 by EURO-VO project, through the ESO/ESA managed Facility Centre
- Aimed at supporting astronomical projects driven by the VO concept and making use of VO tools and applications
- Deadline: June 15
- Selected teams will receive scientific support and technical contact points to complete their projects
- Similar initiatives carried out by NVO (USA)

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Summary

- Astronomy has changed and grown considerably
- Some work is required to integrate and make interoperable the various components ⇒ the Virtual Observatory
- Goal: all astronomical databases "one click away"
  ⇒ democratization of Astronomy!
- The Virtual Observatory is an international effort (with very strong European initiatives), which requires involvement at the project but also at the *data centre* level
- The final goal is **Science**
- How to use VO tools for research coming up next …