Real Astronomy from Virtual Observatories

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About this presentation

• What is a Virtual Observatory?
• How much data is there?
• How does it work?
• Examples of VO-enabled research
• Education and public outreach
• Conclusions
What’s a “Virtual” Observatory?

• First, a “real” observatory:
  – Telescope (optical, infrared, ultraviolet, radio, x-ray)
  – Detectors, instruments (cameras, spectrographs, photometers)
  – Site (ground, space)
  – Computers (telescope control, instrument control, data acquisition, data processing, data storage)
  – Astronomers, technicians, engineers, support staff, …
What’s a “Virtual” Observatory?

- “Virtual” observatory
  - “Telescope” → digital data accessible on the Internet
  - “Detectors, instruments” → computer programs
  - “Site” → the user’s desktop
  - Computers (telescope control, instrument control, data acquisition, data processing, data storage)
  - Astronomers, technicians, engineers, support staff, …
The Virtual Observatory...

- Provides “observers” with access to all archived astronomical data as if it were stored on the local computer
- Provides tools to locate and retrieve data of interest, regardless of where it is stored
- Provides tools to compare data from different real telescopes and instruments
- Provides computational services and data management services on a supercomputer scale
Threads of the VO Fabric

Multiwavelength astrophysics

Archival Research

Survey astronomy

Temporal astronomy

Moore's Law

Digital detectors

The Internet

Data Standards
Data integration

Cas A supernova remnant
optical (HST)
Data integration

Cas A supernova remnant

radio (VLA)
Data integration

Cas A supernova remnant

x-ray (Chandra)
Data integration
Data integration
Toward a “new astronomy”

- Past: Observations of small, carefully selected samples (often with a priori prejudices) of objects in one or a few wavelength bands.
Toward a “new astronomy”

Future: Multi-wavelength data for millions of objects, allowing us to:

- Discover significant patterns from the analysis of statistically rich and unbiased image/catalog databases
- Understand complex astrophysical systems via confrontation between data and sophisticated numerical simulation
Toward a “new astronomy”

- Discovering new phenomena and patterns in these datasets will require simultaneous access to multi-wavelength archives, advanced visualization and statistical analysis tools.
How much data is there?
Bits, bytes, and pixels

- **Bit**: Smallest amount of information a computer stores; 0 or 1
- **Byte**: 8 bits
- **Pixel**: Smallest element of an image (typically 2 bytes per color or filter)
- **All sky**: $4\pi$ steradians, or 40,000 square degrees
  - 500 billion pixels, or 4 Terabytes, for sky survey at 1 arcsec resolution
The language of “lots”

- One: $1 \times 10^0$
- Kilo: $1,000 \times 10^3$
- Mega (million): $1,000,000 \times 10^6$ (floppy disk, 1.5 MB; digital camera, 6 Mpix; HST image, 10-40 MB; LofC, 21 Mbooks; CDROM, 600 MB)
- Giga (billion): $1,000,000,000 \times 10^9$ (computer disk, 80 GB; NASA budget, 15 G$)
- Tera (trillion): $1,000,000,000,000 \times 10^{12}$ (HST archive, 30 TB; US budget, 2.8 T$; US national debt, 9.1 T$)
- Peta (quadrillion): $1,000,000,000,000,000 \times 10^{15}$ (all-sky surveys in the time domain)
- Exa (quintillion): $1,000,000,000,000,000,000 \times 10^{18}$
The total area of astronomical telescopes in m², and CCDs measured in Gigapixels, over the last 25 years. The number of pixels and the data doubles every year.

The amount of data now available in on- and near-line data archives in the US.

Anticipated growth rate of 10s to 100s of TB/year!
More and more pixels

PanSTARRS
1.4 Gpixel camera

LSST
3.2 Gpixel camera
How does it work?
How Do You Build a Virtual Observatory?

• Good news: do not have to invent everything from scratch
  – Build on existing data archives, on-line catalogs
  – Exploit advances in computer and networking technology
  – Utilize new “grid” technologies for high performance computing

• But there are challenges:
  – “Metadata” standards
  – Data quality and completeness
  – Cross-correlation of TB-scale databases at different locations
  – Visualization of large parameter spaces
Find all radio-loud, early type galaxies with $0.4 < z < 0.7$ that lie within 2’ of extended x-ray emission, please!
Find all radio-loud, early type galaxies with $0.4 < z < 0.7$ that lie within 2’ of extended x-ray emission, please!

There are 125,852 galaxies which satisfy these criteria. What now?

The Virtual Observatory concept
The Virtual Observatory in action
QuickTime® and a Sorenson Video decompressor are needed to see this picture.
Why not just use Google?

- Very little astronomical data is text-based
- Text-based searches are unstructured
- Need to “get inside” data archives and databases to find the actual measurements and their uncertainties
- Google just leads you to web sites; the VO finds data and delivers it
Without VO

archive 1

archive 2

archive 3

service 1

service 2

service 3

survey 1

survey 2

survey 3

n services, n interfaces
With VO

$n$ services, “1” interface

- archive 1
- archive 2
- archive 3
- service 1
- service 2
- service 3
- survey 1
- survey 2
- survey 3
VO-enabled research
Enabling new science

• Structure and evolution of the universe
  – Proper statistical comparison between local and distant samples
  – Cluster surveys as tracer of large-scale structures
  – Automated detection of arc-shaped objects to locate gravitational lenses
Enabling new science

• A fully digital Galaxy
  – Star catalogs (stellar evolution, stellar dynamics)
  – Interstellar medium
  – Role of close encounters and influence on star formation
  – Comparison with theoretical models and simulations
Enabling new science

- Rare and exotic objects
  - Very high redshift quasars
  - Brown dwarfs
  - Time-variable objects, transient events: distant supernovae and microlensing
  - Dark matter in the galactic halo
  - Variable stars
  - Asteroids
Enabling new science

- **Census of active galactic nuclei**
  - Systematic searches for black holes
  - Panchromatic approach to circumvent obscuration problems
- **Search for extra-solar planets**
  - Search for planet transits in much larger data samples (Large Synoptic Survey Telescope), bolstered by supporting astrometric data
- **Theoretical astrophysics**
  - Globular cluster modeling
  - Galaxy mergers
  - Evolution of large-scale structure
Current VO-based research

- Studies of merging galaxies
- Automated supernova detection
- Environments of starburst galaxies and relationship of starbursts with active galaxies
- Quasar discovery and analysis
- Search for clusters of galaxies and distance estimation
- Structure of the Milky Way halo
- Infrared properties of radio galaxies
- Super star clusters in nearby galaxies
Education & public outreach

• The Virtual Observatory can enable broad public access to panchromatic images and digital movies of the changing sky

• The compelling nature of these images can be used to capture public interest and advance science literacy
  – Students can “take” and analyze data using software developed for web browsers
  – Superb resource for designing hands-on curriculum modules
Welcome to the National Virtual Observatory!

The NVO is a revolutionary new astronomy project. NVO partners are developing a set of online tools to link all the world's astronomy data together, giving people all over the world easy access to data from many different instruments, at all wavelengths of the electromagnetic spectrum from radio to gamma rays.

This site is a gateway to education and public outreach resources from the NVO. Rather than creating new materials from scratch, the NVO team partners with existing educational programs so that astronomical data can be used by students, teachers, and the public.

Click one of the buttons above to find out how the NVO and its education and outreach partners can help you. To find out more about how the NVO is, click one of the links on the left. To search the site or contact the NVO outreach staff, use one of the links below.

M81 image courtesy of Jonathan Irwin, DSS2
To sum up...
The Virtual Observatory and astronomy

• VO relies on data collected and archived from real observatories.
• VO enables research that cannot be done with one telescope or instrument.
• VO provides a computational framework that supports research questions that are now difficult, if not impossible, to carry out.
• For less than 1% of the cost of building new telescopes, the VO allows astronomers, educators, and the public to explore, synthesize, and learn. Adds value to all observational facilities.
“... I think this is likely to change astronomy as we know it.”
— A. Szalay (JHU)

http://us-vo.org/