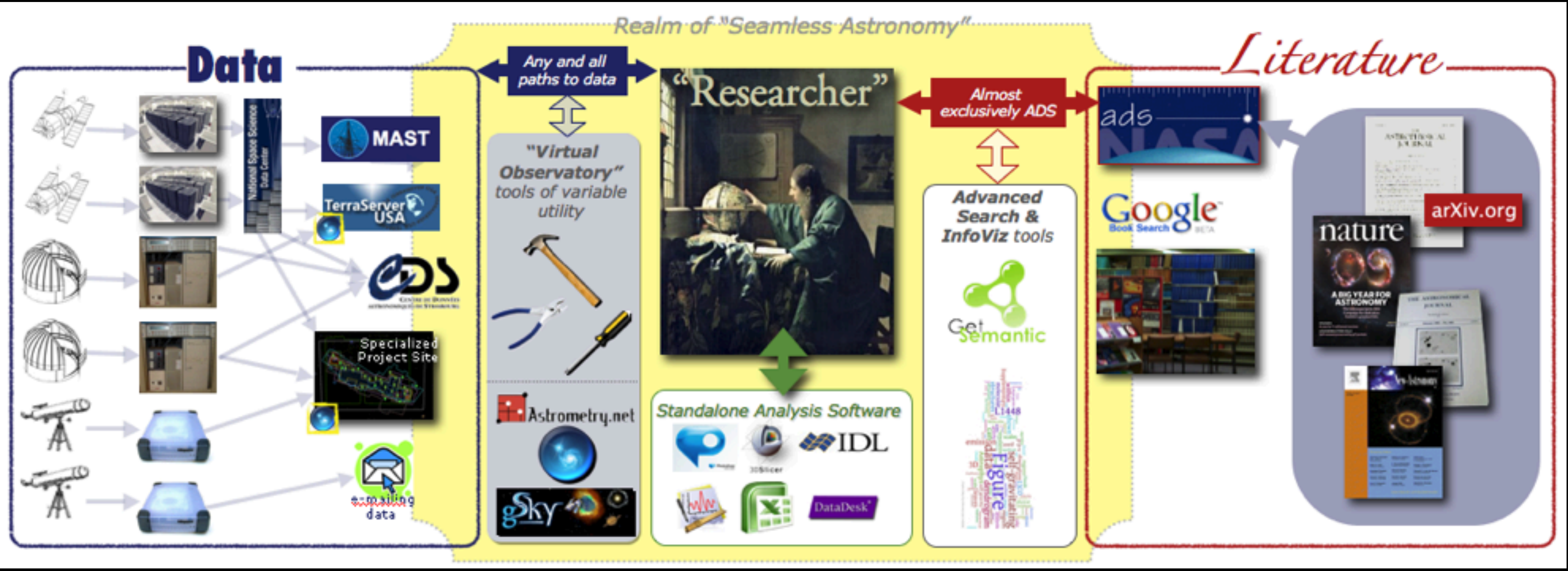
Evermore
Seamless Astronomy

Alyssa A. Goodman

Harvard-Smithsonian Center for Astrophysics

with Alberto Accomazzi, Douglas Burke, Gus Muench & Michael Kurtz (Harvard-Smithsonian CfA); Eli Bressert (U. Exeter); Tim Clark (Massachusetts General Hospital/Harvard Medical School); Chris Borgman (UCLA); **Jonathan Fay** & **Curtis Wong** (Microsoft Research)

Realm of Seamless Astronomy



3500 years of Observing

Stonehenge, 1500 BC

Ptolemy in Alexandria, 100 AD

Observatory Tower, Lincolnshire, UK, c. 1300

Galileo, 1600

The "Scientific Revolution"

Reber's Radio Telescope, 1937

NASA/Explorer 7 (Space-based Observing) 1959

"The Internet"

Long-distance remote-control/ "robotic" telescopes 1990s

"Virtual Observatories" 21st century

What can today's Astronomer's "Research" look like?

Research

In my *Astronomy* research, I am primarily interested in how the gas in galaxies constantly re-arranges itself over huge time spans to constantly form new stars. I have also had a long-standing interest in data *visualization*, and in improving the use of *computers* in all aspects of scientific research. I teach a course at Harvard called "The Art of Numbers," and I am very involved in the WorldWide Telescope Project, which brings astronomical data to everyone through an interface that demonstrates data delivery for the 21st Century of "e-Science."

COMPLETE
The COordinated Molecular Probe

Star Formation Taste Tests
A community of theorists, numericists, and

Astronomical Medicine

WorldWide Telescope

Visualization

Science for Everyone

http://www.cfa.harvard.edu/~agoodman/

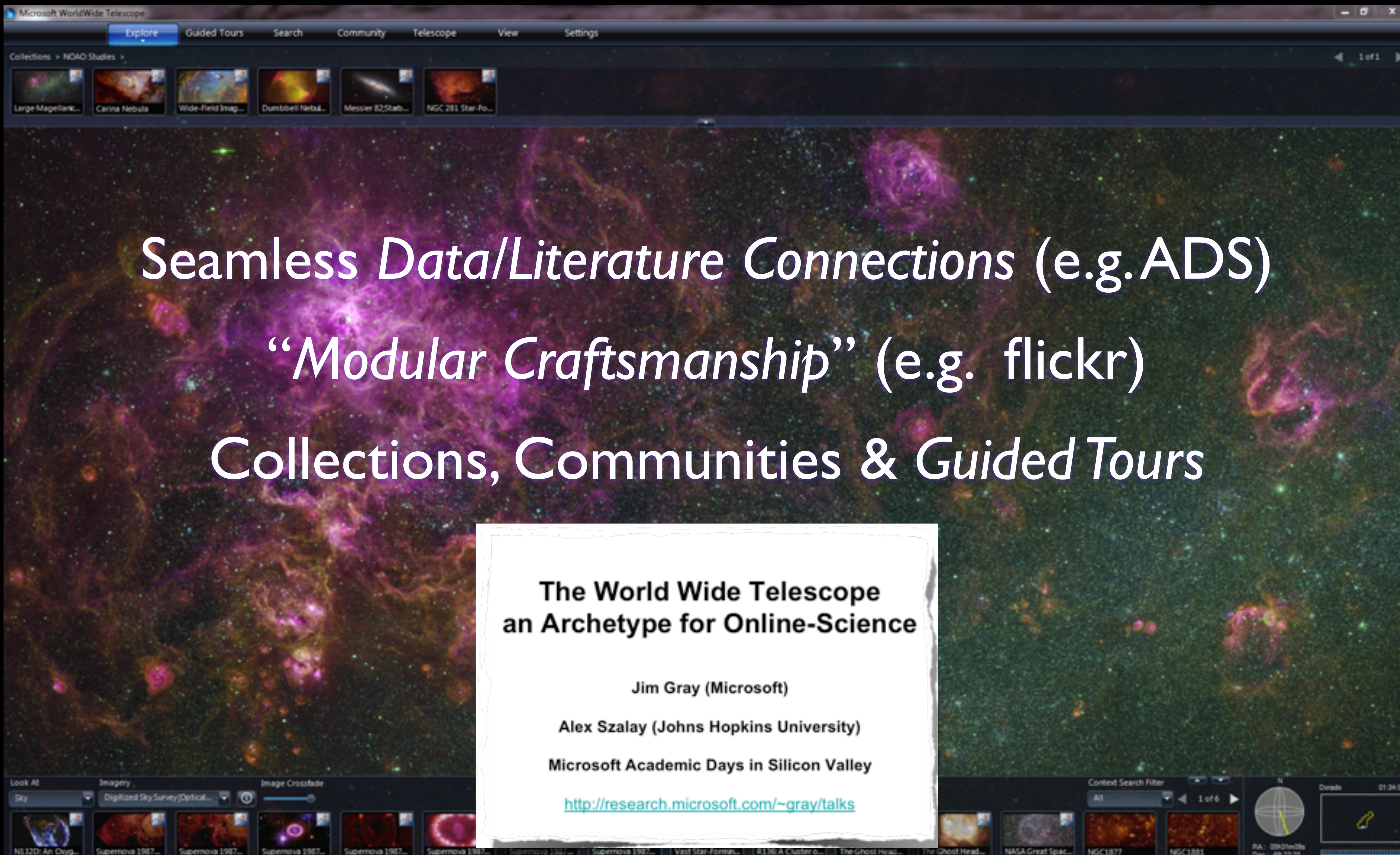
Publishing

Data | Simulation

WorldWide Telescope

e-Science Tools | Viz

WorldWide Telescope: a UIS from Microsoft Research [UIS=Universe Information System]



Seamless *Data/Literature Connections* (e.g. ADS)

"*Modular Craftsmanship*" (e.g. flickr)

Collections, Communities & *Guided Tours*

The World Wide Telescope an Archetype for Online-Science

Jim Gray (Microsoft)

Alex Szalay (Johns Hopkins University)

Microsoft Academic Days in Silicon Valley

http://research.microsoft.com/~gray/talks

Created by Curtis Wong and Jonathan Fay at MSR; AG is "Academic Partner" on the WWT Project

The (US) Backstory

2001 ················ 2008 (2010)

Science New

$10 Million N

ScienceDaily (Oc
its users the worl
research institutio
starting an ambiti
universe online.

NVO

. . . the Universe at your fingertips

See Also: (NVO), headed by astronomer Alex

NVO senior personnel:
Charles Alcock, University of Pennsylvania Kirk B rne, Astro
Tim Cornwell, NSF National Radio Astronomy Ob atory
Optical Astronomy Observatory Giuseppina Fabbia , Smit
Observatory Alyssa Goodman, Harvard University ***Jim Gray,***
Hanisch, Space Telescope Science Institute George Helou, N
Analysis Center Stephen Kent, Fermilab Carl Kesselman, Uni
Miron Livny, University of Wisconsin, Madison Carol Lonsd
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About Funding

Proposals and Awards

Proposal and Award Policies and Procedures Guide
Introduction
Proposal Preparation and

VAO

VIRTUAL ASTRONOMICAL OBSERVATORY

SEARCH
NSF Web Site

ICS | ABOUT

Print

Management and Operation of the Virtual Astronomical Observatory

CONTACTS

Name	Email
Nigel Sharp	nsharp@nsf.gov
Eileen D. Friel	efriel@nsf.gov

NSF

NASA

PROGRAM GUIDELINES

Solicitation 08-537

Please be advised that the NSF Proposal & Award Policies & Procedur (PAPPG) includes revised guidelines to implement the mentoring pro the America COMPETES Act (ACA) (Pub. L. No. 110-69, Aug. 9, 2007.) specified in the ACA, each proposal that requests funding to support postdoctoral researchers must include a description of the mentoring that will be provided for such individuals. Proposals that do not comp this requirement will be returned without review (see the PAPP Guide Grant Proposal Guide Chapter II for further information about the implementation of this new requirement).

2001 ················ 2008 (2010)

NVO

. . . the Universe at your fingertips

VAO

VIRTUAL ASTRONOMICAL OBSERVATORY

and meanwhile...

+ IVOA

RVO

AstroGrid

Aus-VO

VObs.it

vo-i

CVO

SVO
Spanish Virtual Observatory

BRAVO

IVOA

ArVO
Armenian Virtual Observatory

NVO
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China-VO

EURO VO

JVO

HVO
Hungarian Virtual Observatory

GERMAN ASTROPHYSICAL
GAVO
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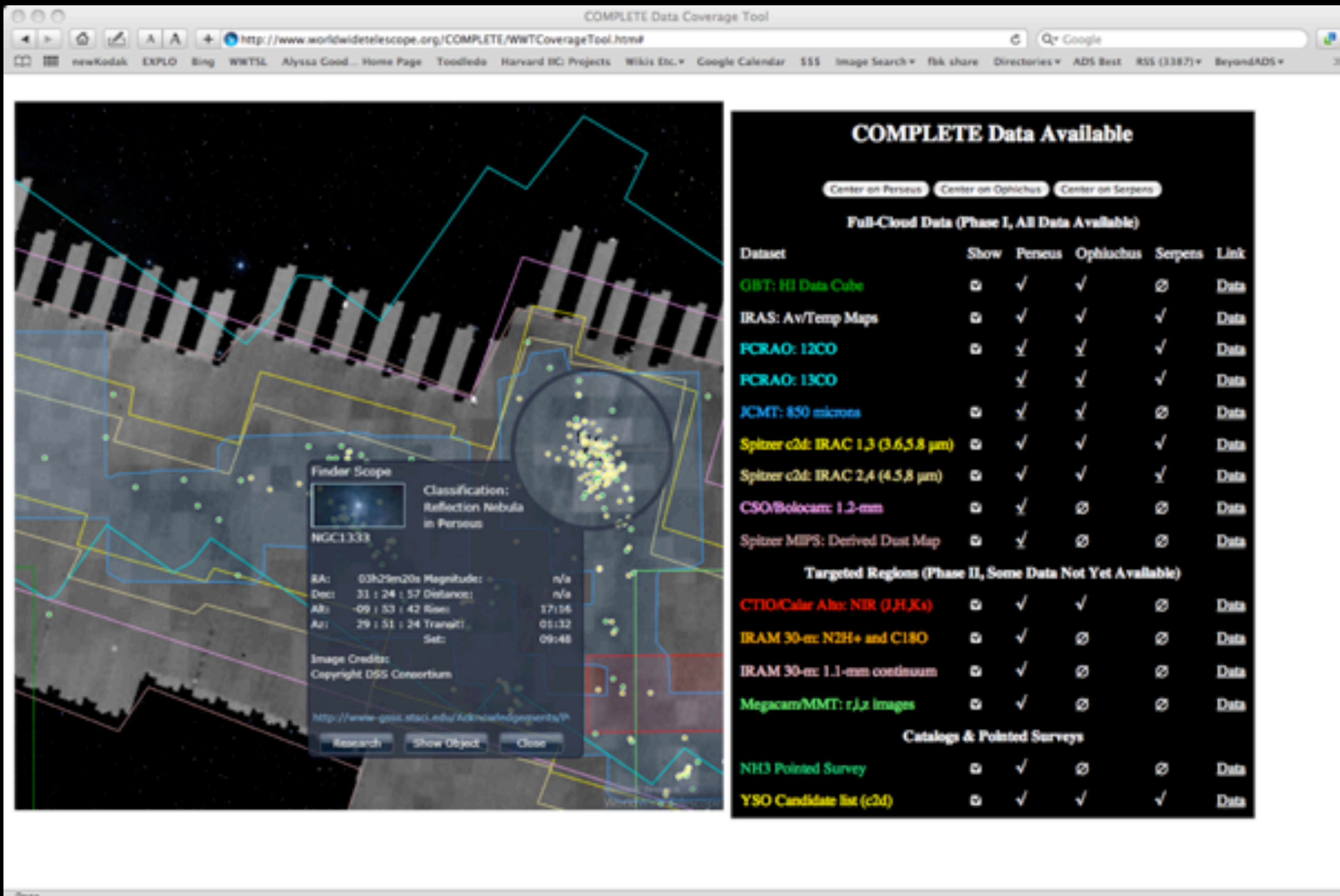
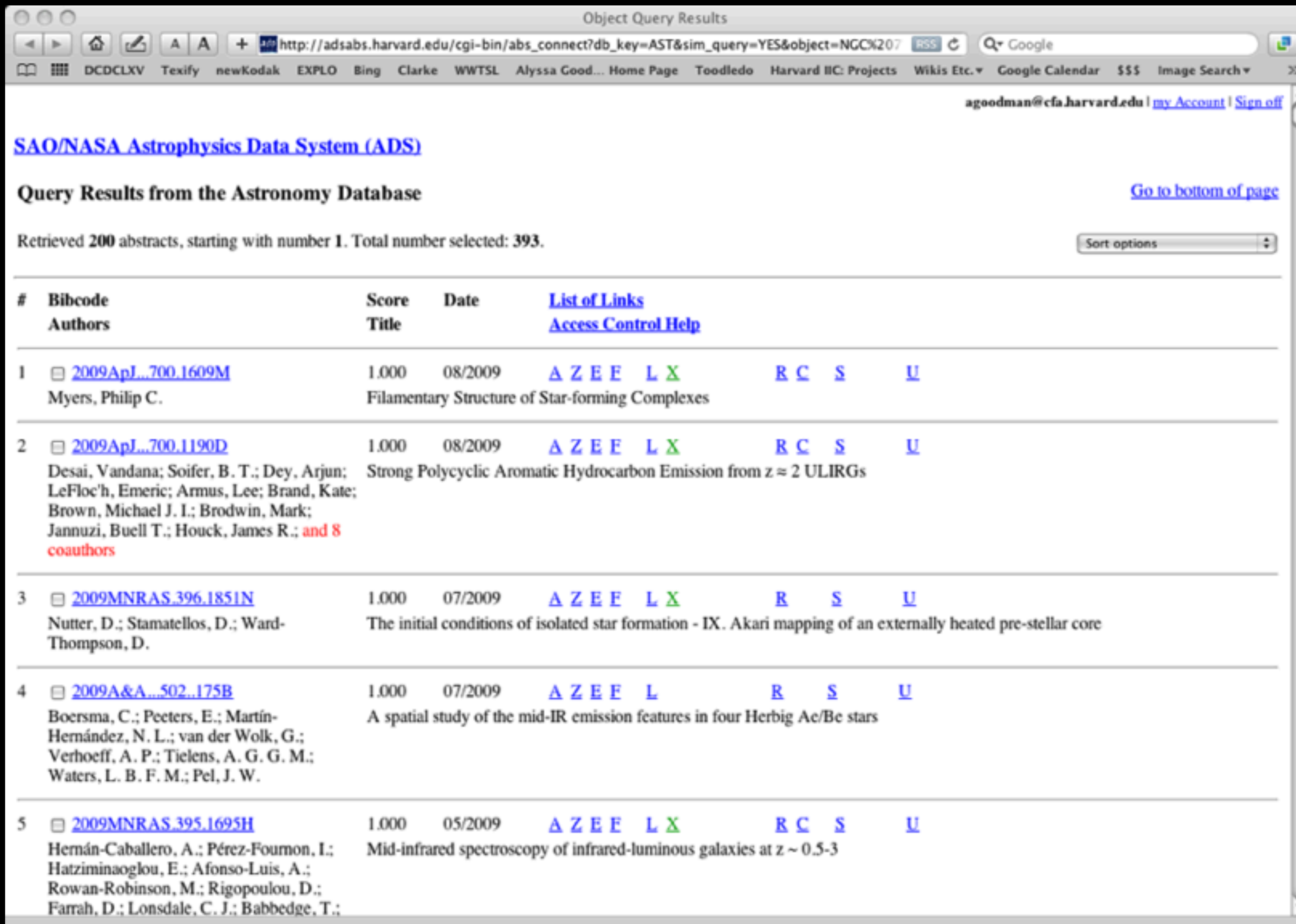
VO France

What/where are/is "Data"?



What/where is literature?



Object Query Results

http://adsabs.harvard.edu/cgi-bin/abs_connect?db_key=AST&sim_query=YES&object=NGC%207

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SAO/NASA Astrophysics Data System (ADS)

Query Results from the Astronomy Database

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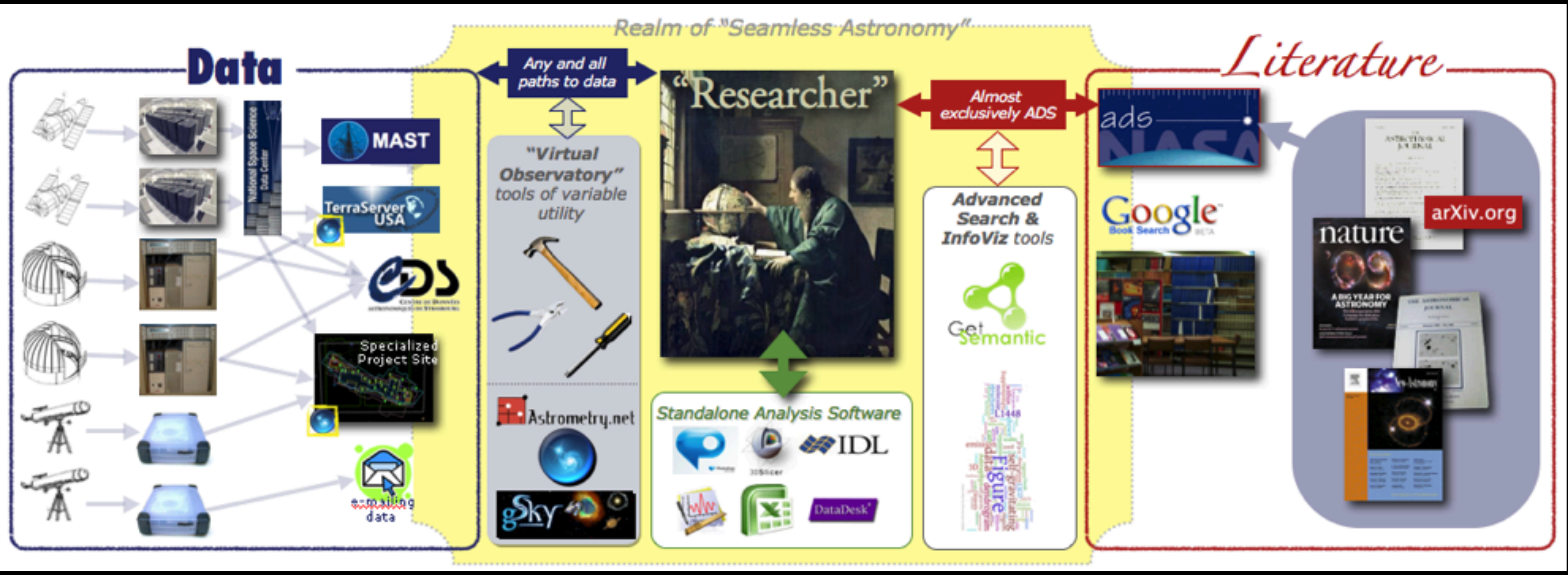
Sort options

#	Bibcode / Authors	Score / Title	Date	List of Links / Access Control Help
1	2009ApJ...700.1609M Myers, Philip C.	1.000 Filamentary Structure of Star-forming Complexes	08/2009	A Z E F L X R C S U
2	2009ApJ...700.1190D Desai, Vandana; Soifer, B. T.; Dey, Arjun; LeFloc'h, Emeric; Armus, Lee; Brand, Kate; Brown, Michael J. I.; Brodwin, Mark; Jannuzi, Buell T.; Houck, James R.; and 8 coauthors	1.000 Strong Polycyclic Aromatic Hydrocarbon Emission from $z \approx 2$ ULIRGs	08/2009	A Z E F L X R C S U
3	2009MNRAS.396.1851N Nutter, D.; Stamatellos, D.; Ward-Thompson, D.	1.000 The initial conditions of isolated star formation - IX. Akari mapping of an externally heated pre-stellar core	07/2009	A Z E F L X R S U
4	2009A&A...502..175B Boersma, C.; Peeters, E.; Martín-Hernández, N. L.; van der Wolk, G.; Verhoeff, A. P.; Tielens, A. G. G. M.; Waters, L. B. F. M.; Pel, J. W.	1.000 A spatial study of the mid-IR emission features in four Herbig Ae/Be stars	07/2009	A Z E F L R S U
5	2009MNRAS.395.1695H Hernán-Caballero, A.; Pérez-Fournon, I.; Hatziminaoglou, E.; Afonso-Luis, A.; Rowan-Robinson, M.; Rigopoulou, D.; Farrah, D.; Lonsdale, C. J.; Babbedge, T.;	1.000 Mid-infrared spectroscopy of infrared-luminous galaxies at $z \sim 0.5$-3	05/2009	A Z E F L X R C S U

Seamless Astronomy



But, that was 2009...

Realm of "Seamless Astronomy"
2010
Evermore
Seamless
Astronomy
Data
"Researcher"
Advanced Search & InfoViz tools
GetSemantic
arXiv.org
nature
A BIG YEAR FOR ASTRONOMY
ASTROPHYSICAL JOURNAL
THE ASTRONOMICAL JOURNAL
Astrometry.net
Sky
Literature
Standalone Analysis Software
IDL
3DSlicer
DataDesk

This simple argument, first made at the 2009 WWT session at AAS, seems to be working:

"Astronomy research tools should work as seamlessly as travel research tools."

"Astronomy research tools should work as seamlessly as travel research tools."

When the concept of a **"Virtual Observatory" (VO)** was first discussed by future-looking astronomers in the mid-1990s, all thoughts were about **distributed data** and a **common system** to access it. But, information access on today's web primarily works in the **reverse**: **distributed tools** accessing **common data centers**. Capability and ease-of-use improvements to the web typically now come in the form of **nesting, aggregating or connecting tools.** Think **kayak.com**, iGoogle, or Bing Maps. In the "Seamless Astronomy" view to be discussed, today's "VO" should be thought of as the **ever-improving set** of **data archives, tools, interconnections,** and **standards** that strive to make astronomical research as "seamless" as travel research. The good news is that the cutting-edge of the astronomical research environment is moving rapidly in this seamless direction. The most savvy institutions are beginning to realize that the original VO model of data distributed on thousands of individual researchers' desktop hard drives is not a sustainable model, and that they need to offer **data hosting, archiving, and stewardship** services the way libraries offer such services for printed matter. **Software tools** are becoming much more **interoperable** thanks to protocols for message-passing such as "**SAMP**." And, the improved speed of **web applications** is to some extent removing platform-dependence as an obstacle to programmers and users alike. The bad news is that **most astronomers are largely unaware** of the tools that this new nirvana offers, and instead still conduct online research in the same way they did a decade ago. In this talk, I will focus in particular on how our recent work on connecting Microsoft's **WorldWide Telescope** program to other commonly-used astronomical research tools--most notably literature searching tools--has made the astronomical research environment more seamless. More generally, I will emphasize and demonstrate that an **ever-increasing diversity of tools** allow researchers to carry out a particular research task, so that the **important research** for the future lies in figuring out **how to make the tools, their interconnections, and their connections to data and literature resources useful and well-known to the astronomical community.**

(Abstract of the *Evermore Seamless Astronomy* presentation by A. Goodman at the Microsoft External Research Symposium, April 2010.)

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Date: March 23, 2010 12:19:23 AM EDT
To: Alyssa Goodman

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for Alyssa Goodman
Tue Mar 23 00:19:23 2010
Astronomy database

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Astronomical Journal
Astronomy & Astrophysics
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Astrophysical Journal

GOODMAN, ALYSSA - Citations: 3310 (total 4002)

2010NewA...15..444K: Karatas,+: New intrinsic-colour calibration for uvby-beta photometry
2010MNRAS.403.1054D: Dabringhausen,+: Mass loss and expansion of ultra compact dwarf galaxies through gas expul... stellar evolution for top-heavy ste... mass functions
2010ApJ...713..269F: Federrath,+... Collapse and Accretion in Turbul... Clouds: Implementation and Com... Sink Particles in AMR and SPH
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2010ApJ...712.1137K: Kauffmann...

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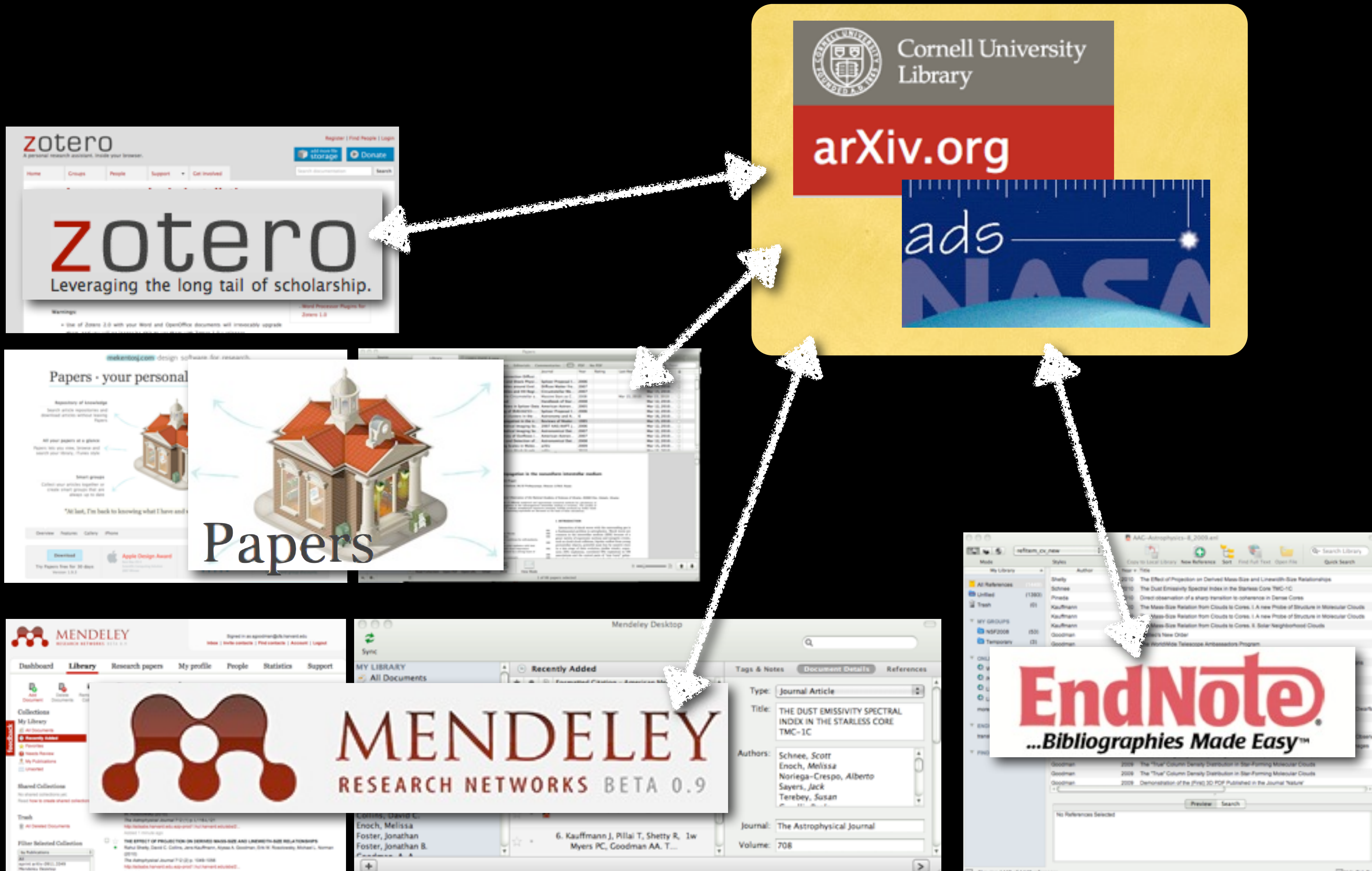
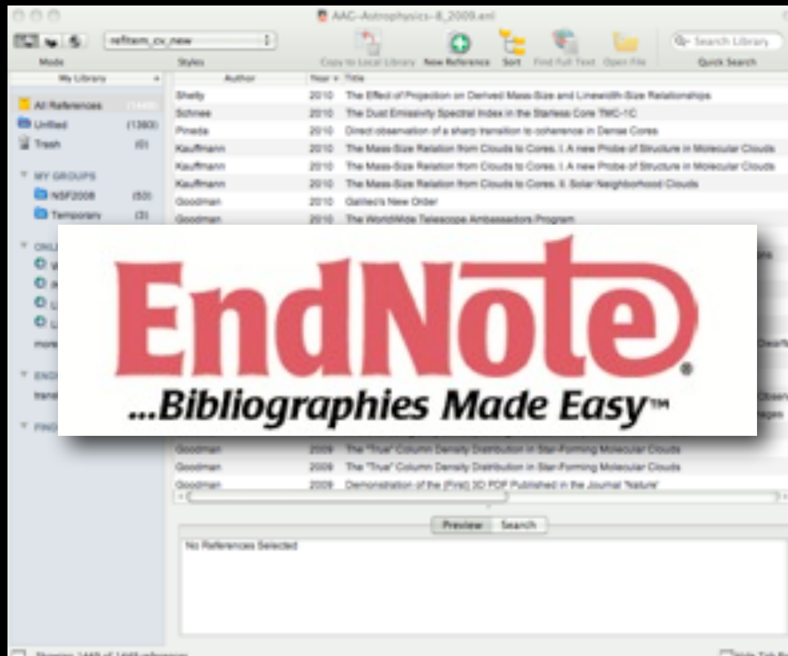
Astronomers can see parallels...

Literature Handling: *Diverse Apps*, *Common Data*



What fraction of astronomy researchers know about these tools?



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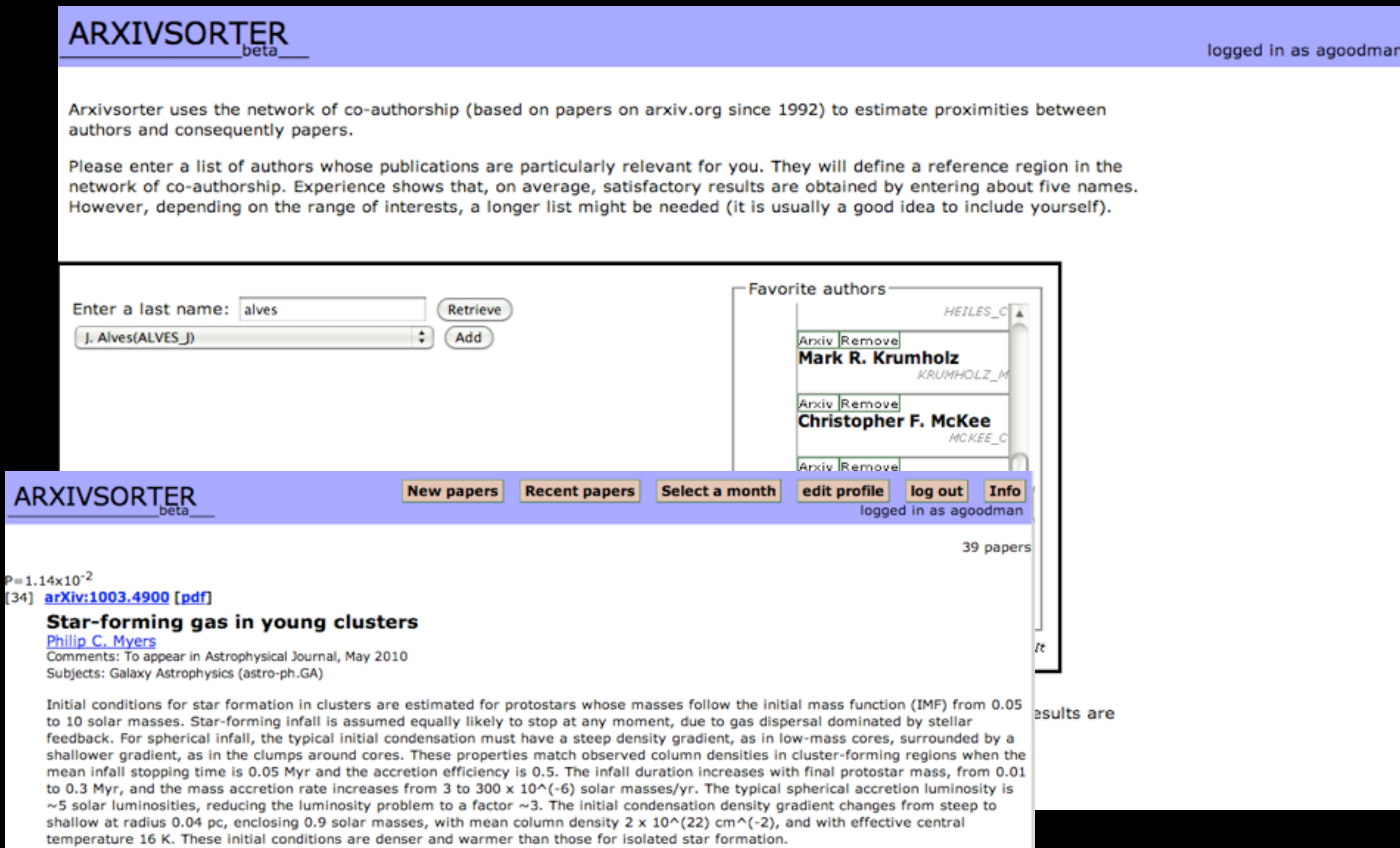

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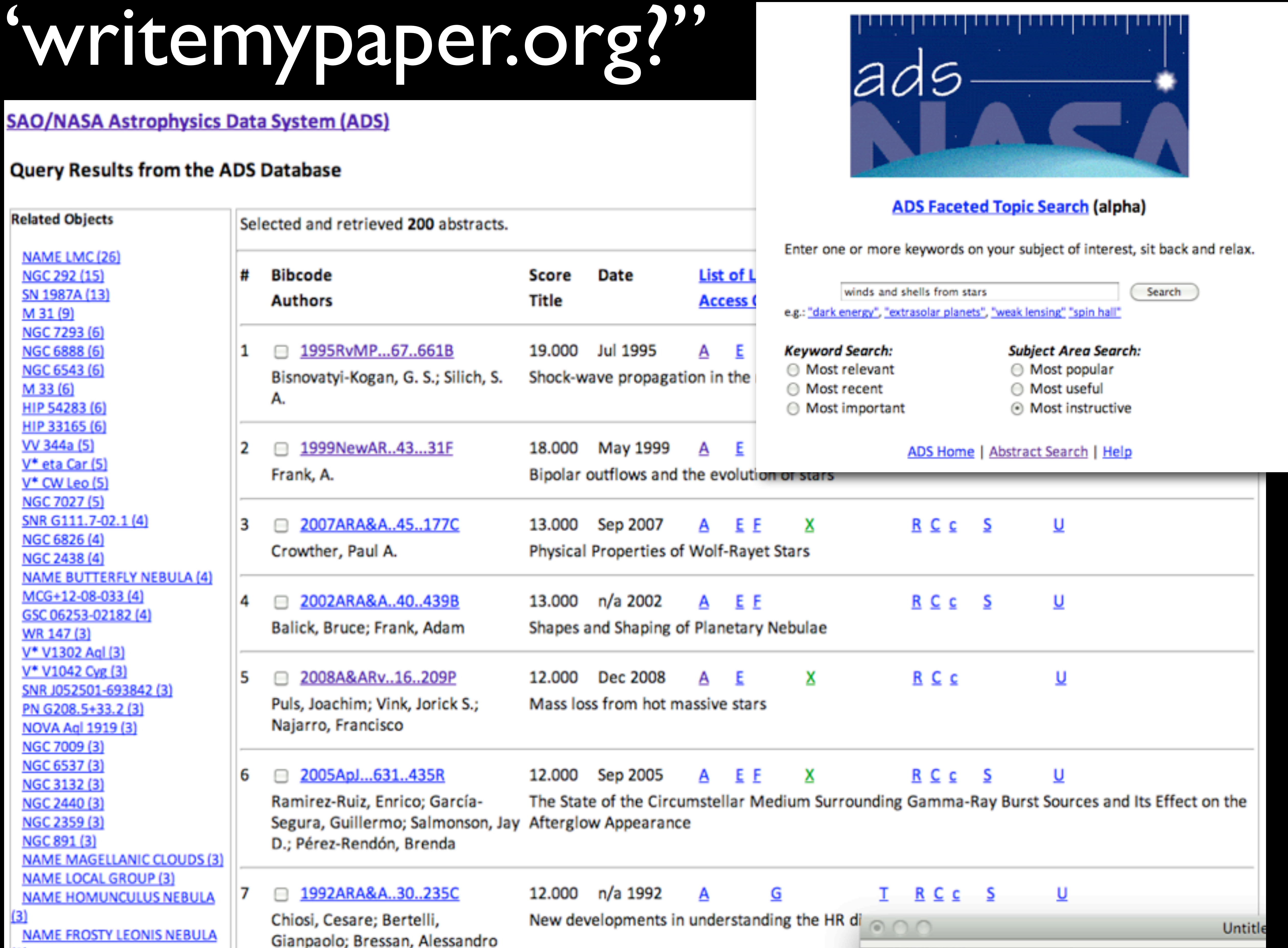

This page generated using ADS faceted Search, as developed by Michael Kurtz, Alberto Accomazzi & Jonathan Fay


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in Cepheus
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Distance: n/a
Rise: Circumpolar
Transit: Circumpolar
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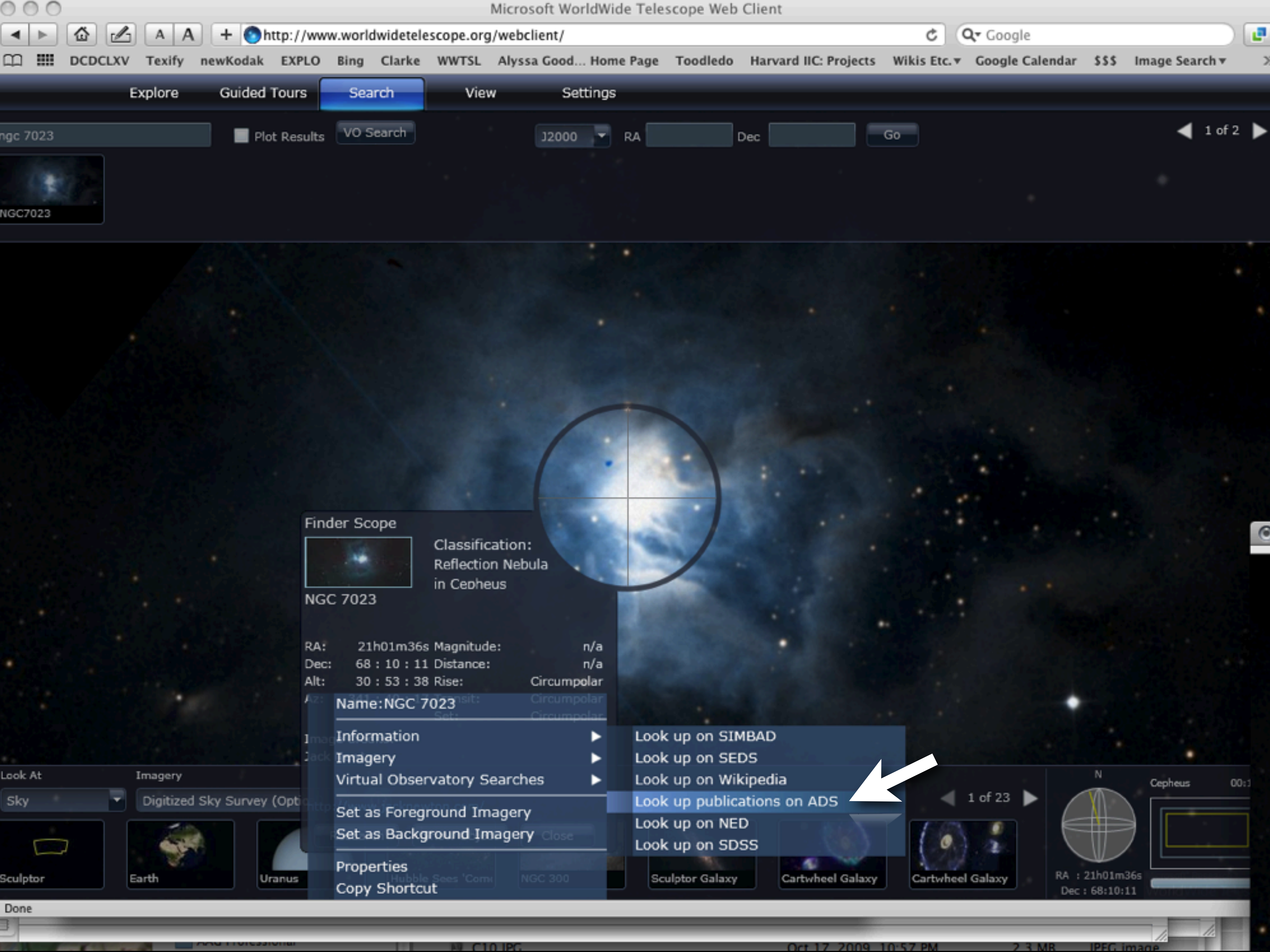
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Object Query Results

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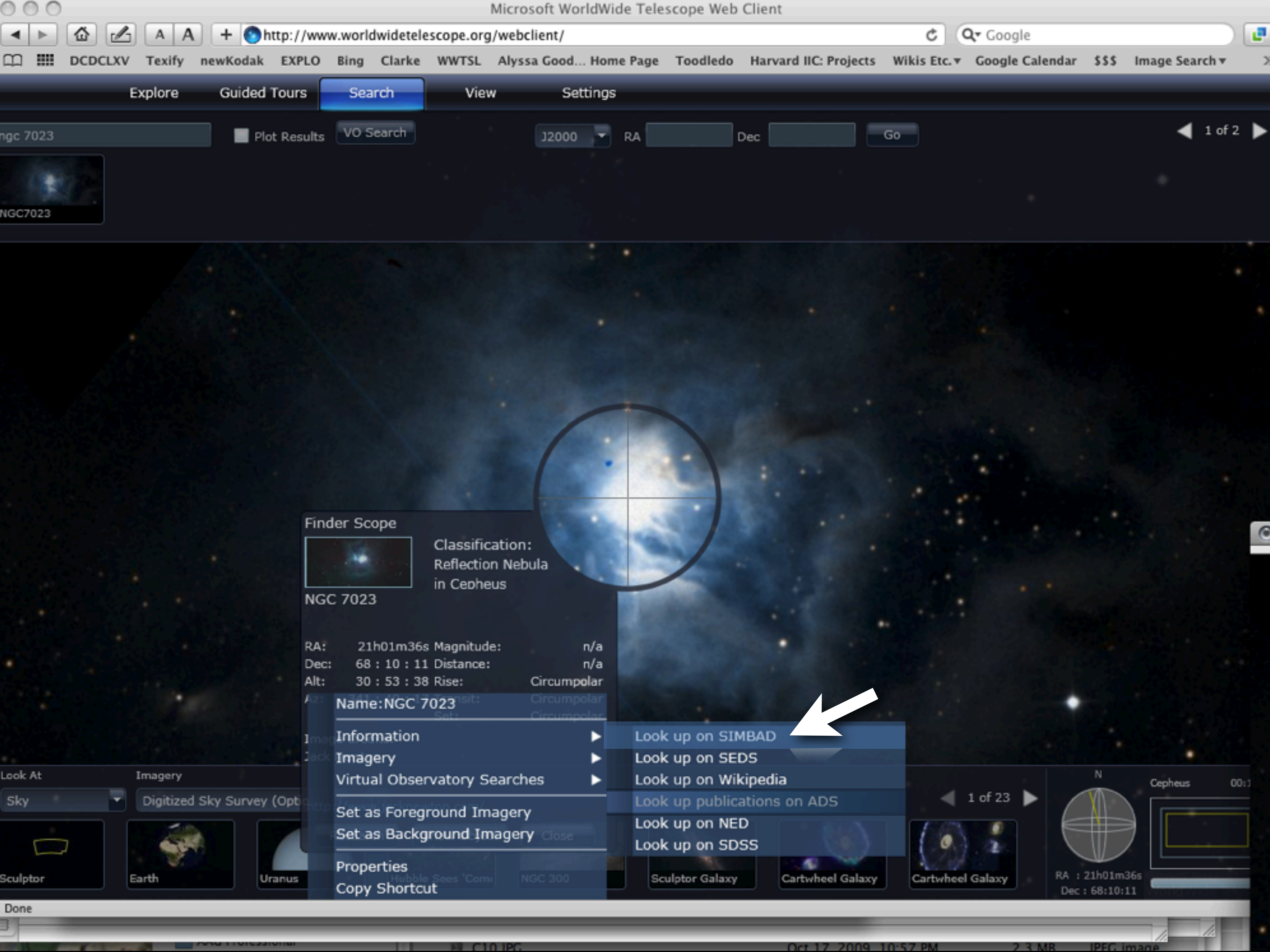
5	2009MNRAS.395.1695H Hernán-Caballero, A.; Pérez-Fournon, I.; Hatziminaoglou, E.; Afonso-Luis, A.; Rowan-Robinson, M.; Rigopoulou, D.; Farrah, D.; Lonsdale, C. J.; Babbedge, T.;	1.000 Mid-infrared spectroscopy of infrared-luminous galaxies at $z \sim 0.5$-3	05/2009	A Z E F L X R C S U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SIMBAD query result

http://simbad.u-strasbg.fr/simbad/sim-id?Ident=NGC+7023&jsessionid=B8F7CD92574727FFC

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Simbad VizieR Aladin Catalogs Dictionary Biblio Tutorials Developers

SIMBAD query result

other query modes : Identifier query | Coordinate query | Criteria query | Bibliography query | Basic query | Script submission | Output options | Help

Object query : NGC 7023 — C.D.S. - SIMBAD4 rel 1.132 - 2009.10.23CEST21:59:31

Available data Basic data | Identifiers | Plot & images | Bibliography | Measurements | External archives | Notes

Basic data :

NGC 7023 -- Open (galactic) Cluster

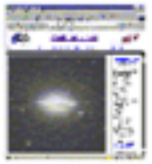
query around with radius 2 arcmin

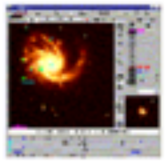
Other object types:	Cl* (C,Cl,[BDB2003]) ,OpC (OCISM) ,HII (LBN) ,V* (AAVSO) ,IR (IRAS)
ICRS coord. (ep=2000) :	21 01 36.9 +68 09 48 (-) [- - -] D -
FK5 coord. (ep=2000 eq=2000) :	21 01 36.9 +68 09 48 (-) [- - -] D -
	104.0616 +14.1926 (-) [- - -] D -
Fluxes (1) :	B 7.20 [-] D -

Identifiers (11) :

NGC 7023	IRAS 20599+6755	LBN 487	[BDB2003] G104.06+14.19
C 2059+679	IRAS F20599+6755	OCISM 50	AAVSO 2044+67
Cl VDB 139	LBN 104.08+14.21	OCl 235	

Plots and Images — plot around — radius 10 arcmin — Aladin previewer — Aladin applet

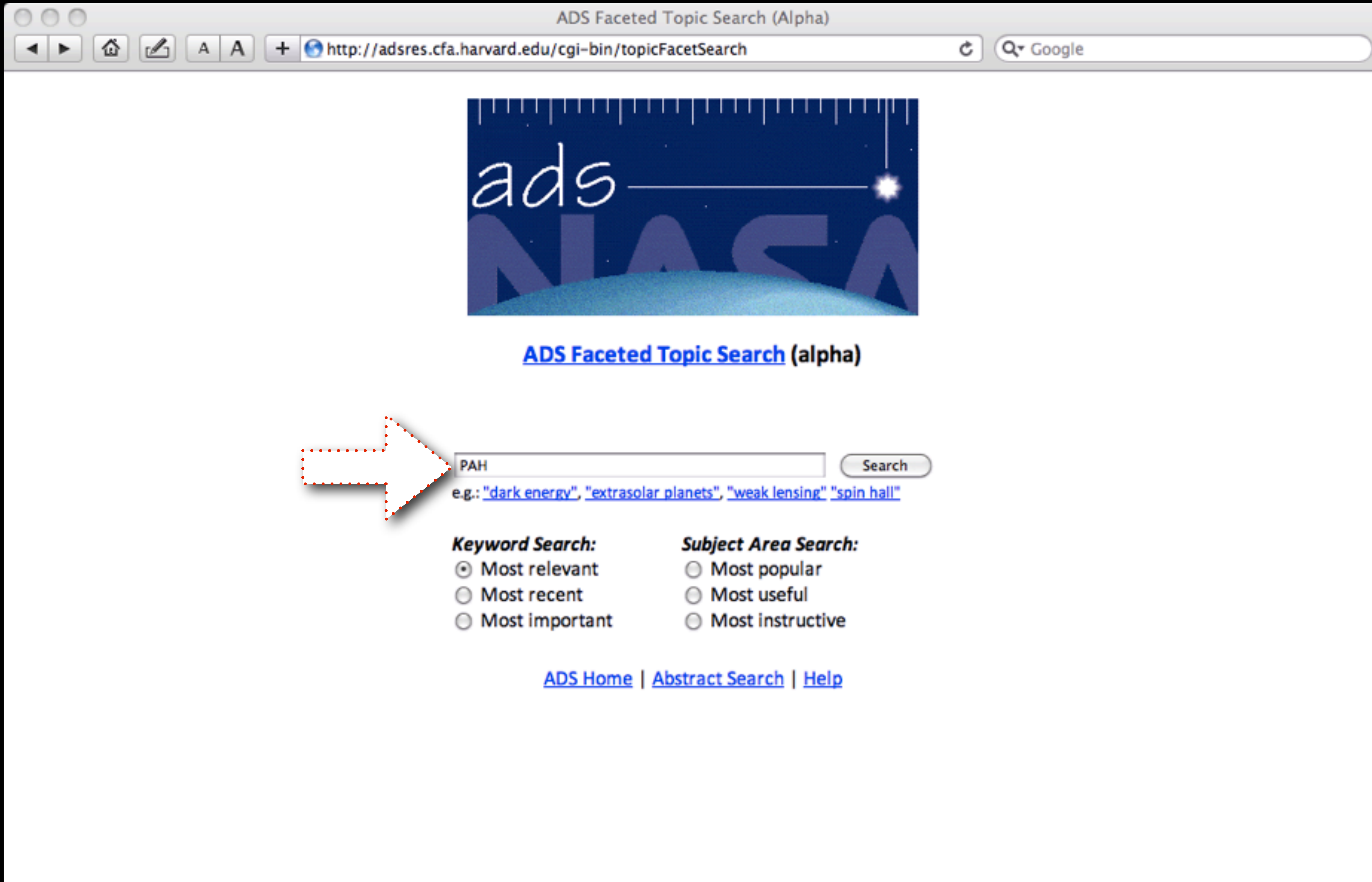




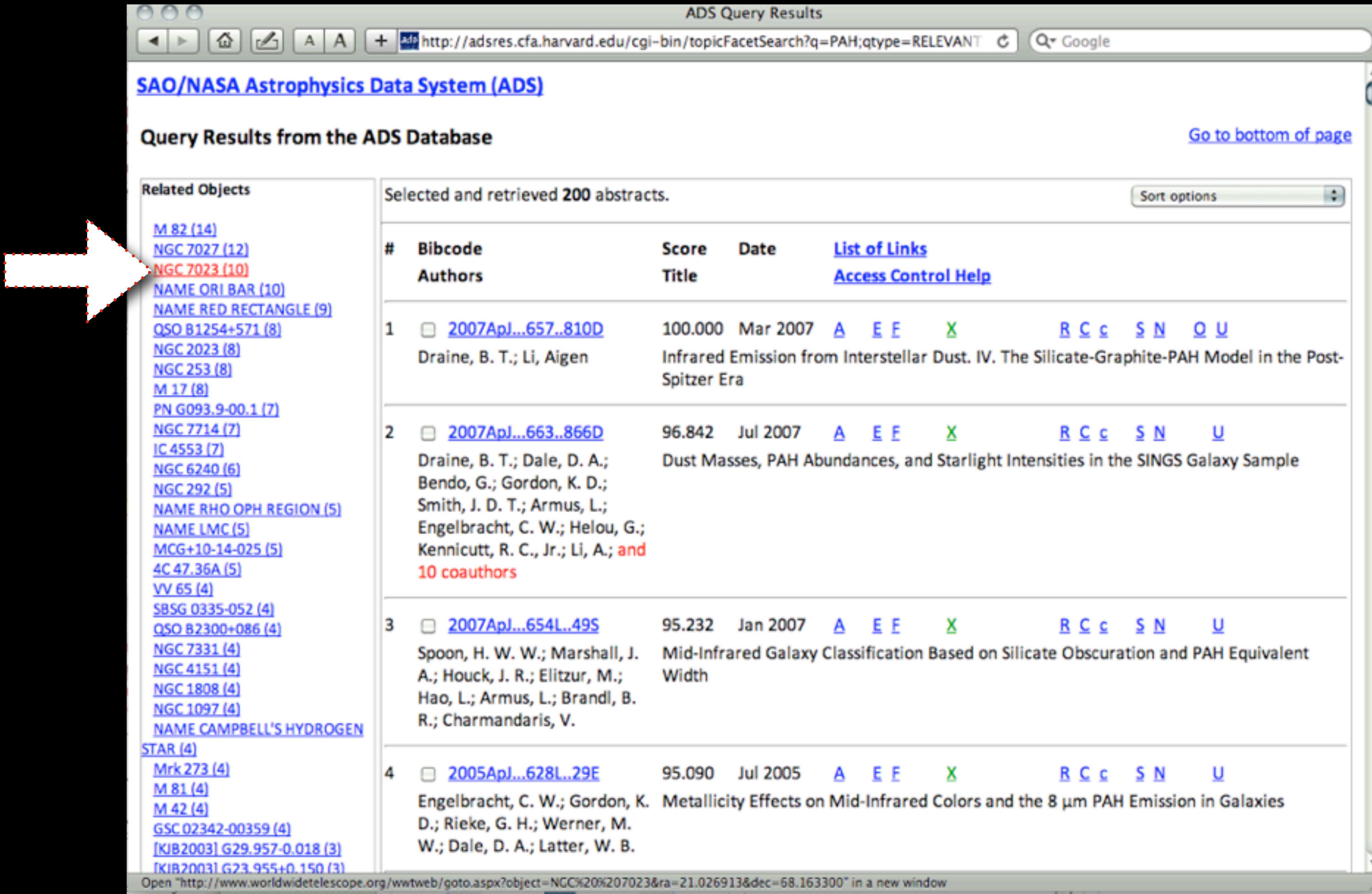
References (371 between 1983 and 2009)

Simbad bibliographic survey began in 1950 for stars (at least bright stars) and in 1983 for all other objects (outside the solar system).

display — reference summary — from: 1983 to: 2009

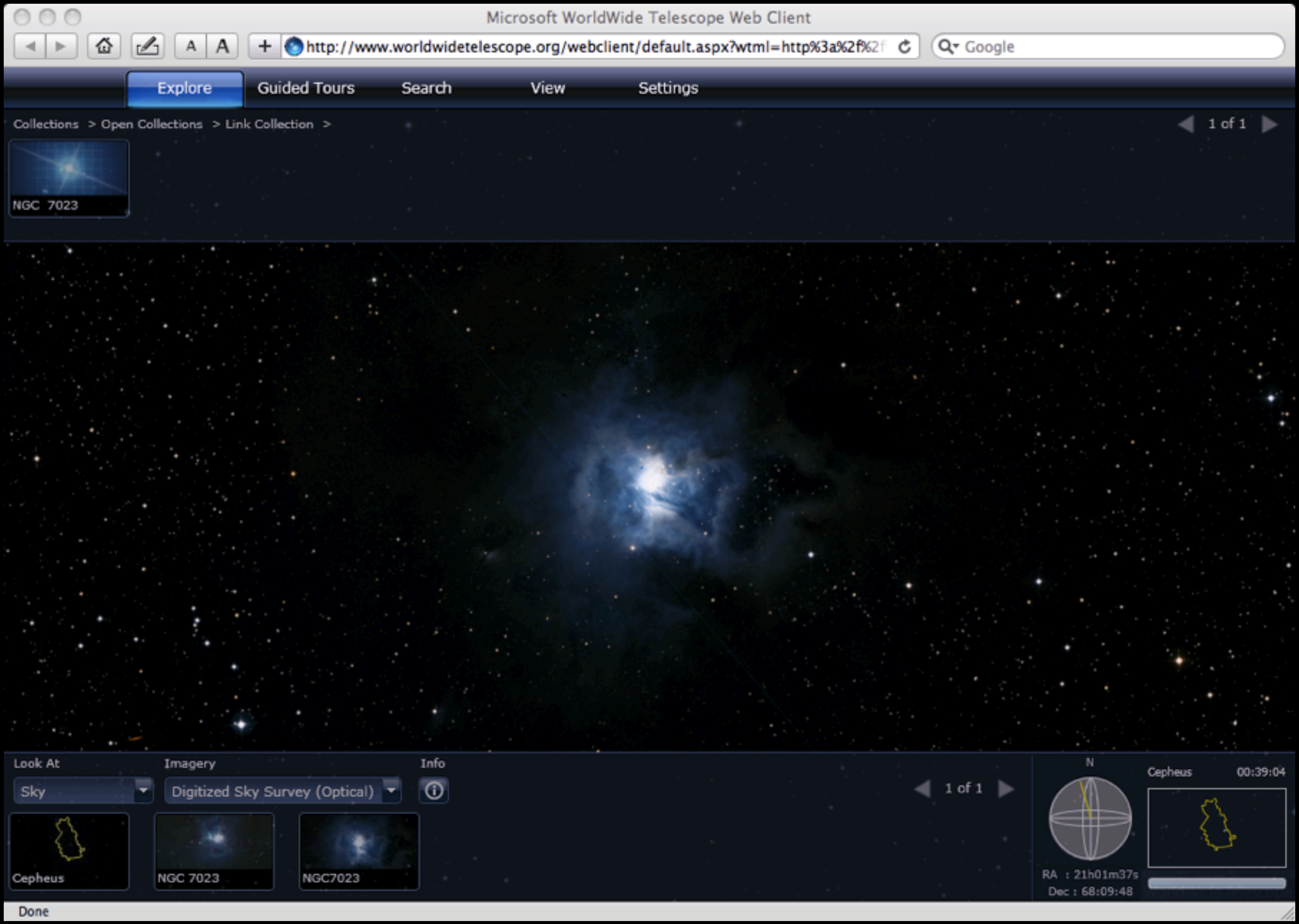


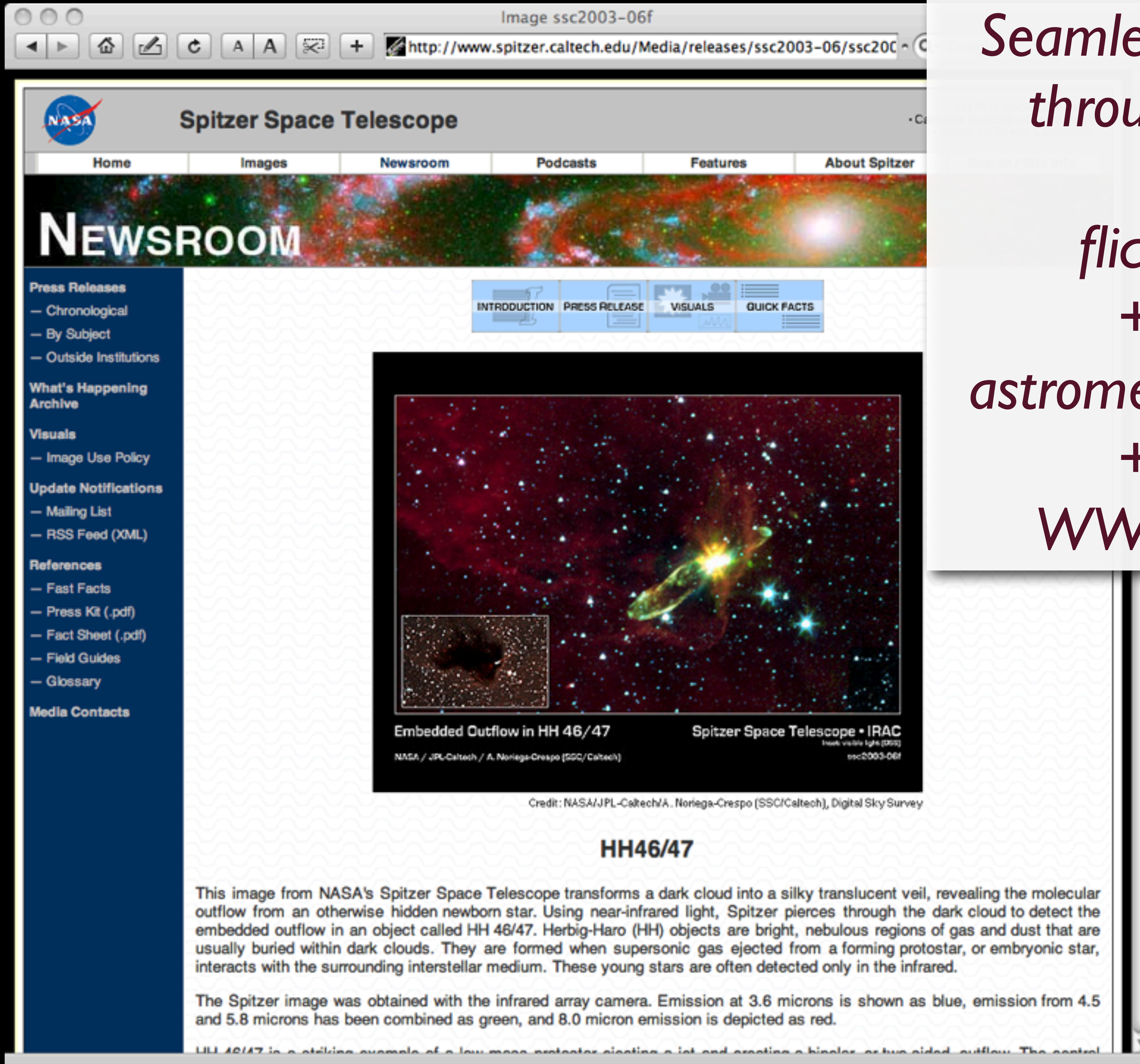
"alpha" Faceted Topic Search in ADS (courtesy of Michael Kurtz & Alberto Accomazzi)



list of objects with links to WWT browser
(thanks to ADS team & Jonathan Fay)

And now we got to NGC 7023 by using the literature as a filter.





Seamlessness through...

flickr

+

astrometry.net

+

WWT !?

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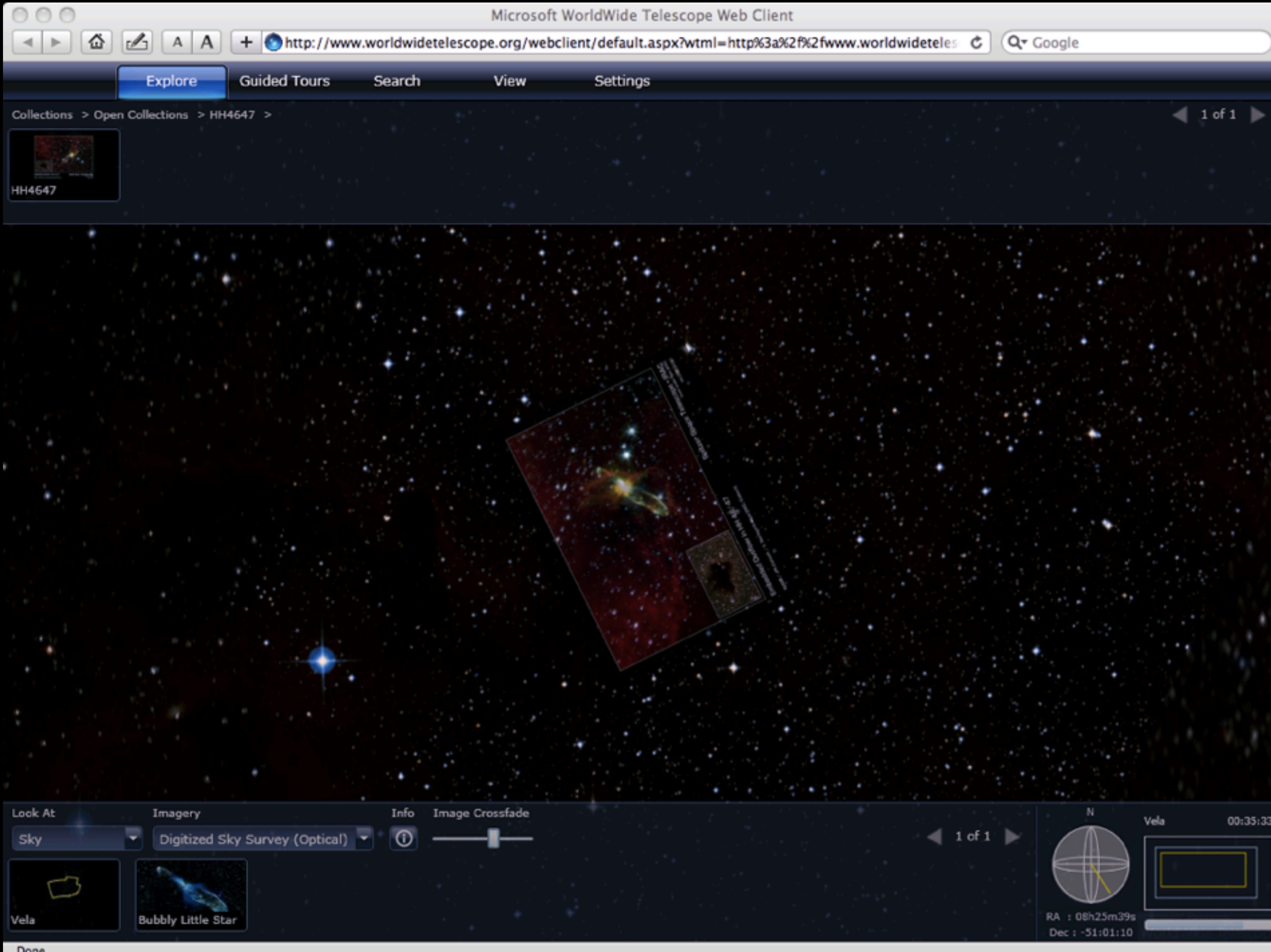
Microsoft WorldWide Telescope Web Client
http://www.worldwidetelescope.org/webclient/default.aspx?wtml=http%3a%2f%2fwww.worldwidetele
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1 of 1
HH4647
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1 of 1
Vela
Bubbly Little Star
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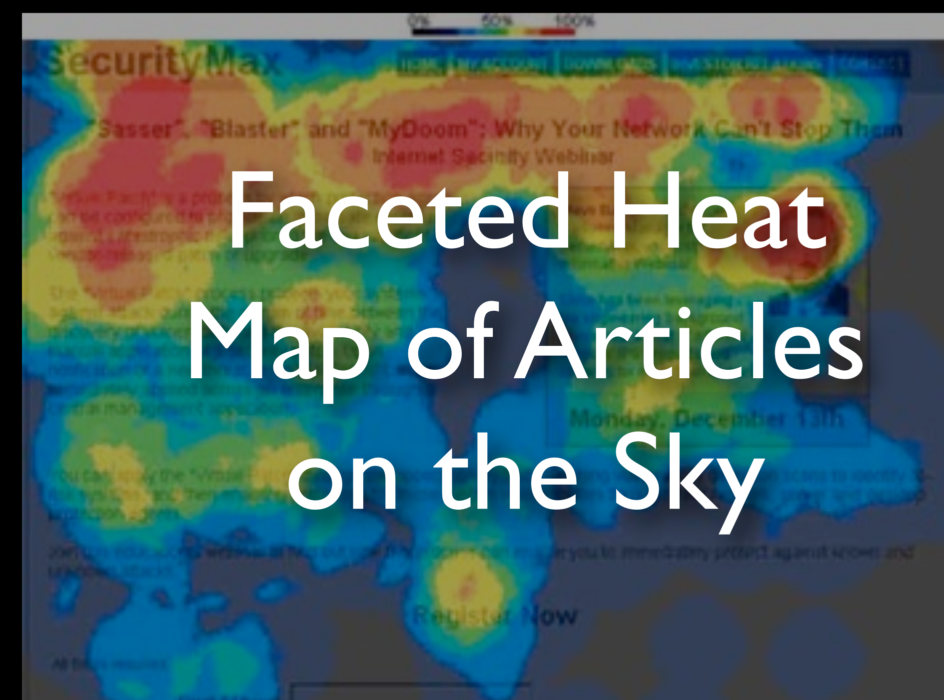
Vela
00:35:33
RA : 08h25m39s
Dec : -51:01:10
Done

Coming Soon from ADS
(I hope!)



The future is here... data *IN* articles

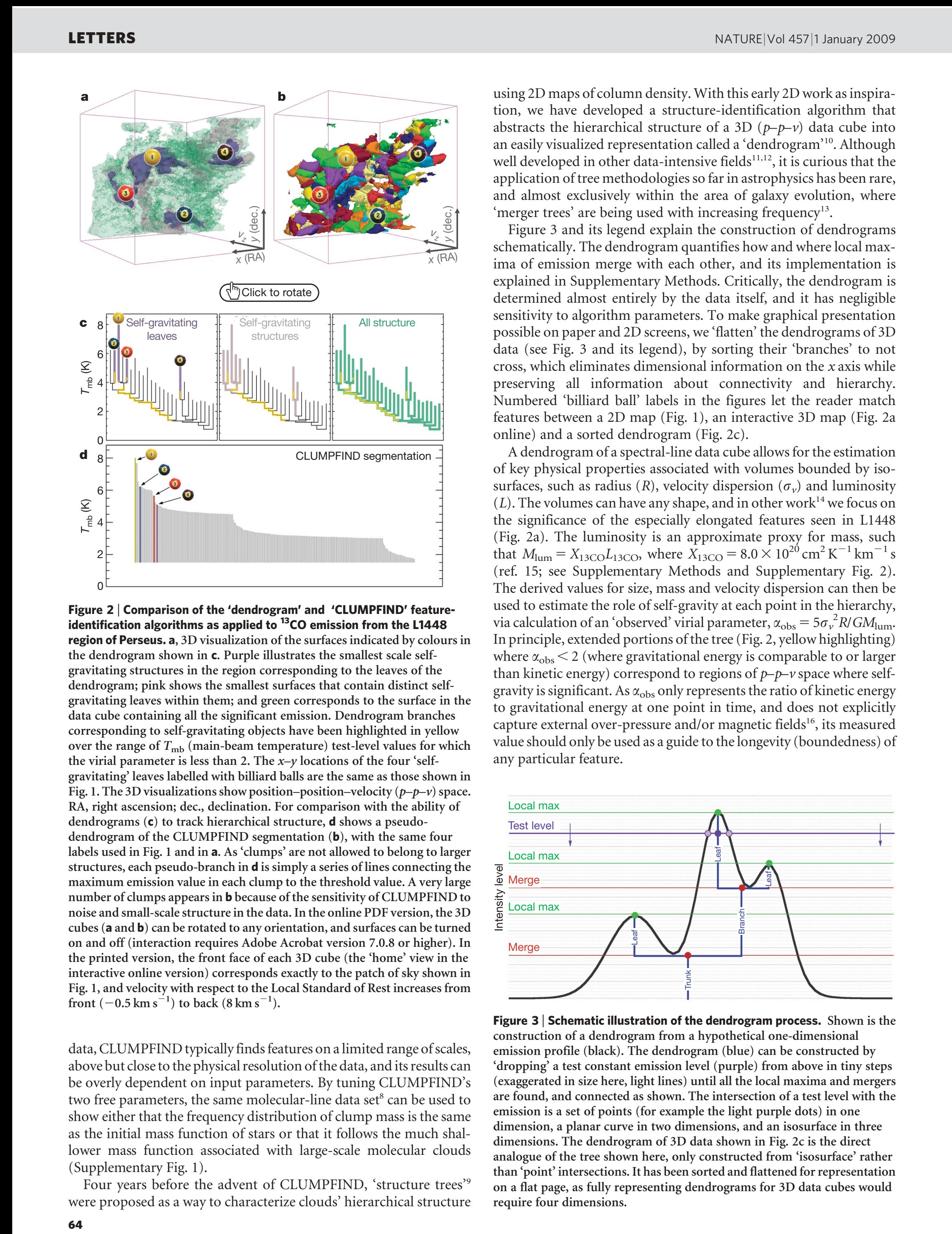


Figure 2 | Comparison of the 'dendrogram' and 'CLUMPFIND' feature-identification algorithms as applied to ^{13}CO emission from the L1448 region of Perseus. a, 3D visualization of the surfaces indicated by colours in the dendrogram shown in **c**. Purple illustrates the smallest scale self-gravitating structures in the region corresponding to the leaves of the dendrogram; pink shows the smallest surfaces that contain distinct self-gravitating leaves within them; and green corresponds to the surface in the data cube containing all the significant emission. Dendrogram branches corresponding to self-gravitating objects have been highlighted in yellow over the range of T_{mb} (main-beam temperature) test-level values for which the virial parameter is less than 2. The *x*–*y* locations of the four 'self-gravitating' leaves labelled with billiard balls are the same as those shown in Fig. 1. The 3D visualizations show position–position–velocity (*p*–*p*–*v*) space. RA, right ascension; dec., declination. For comparison with the ability of dendrograms (**c**) to track hierarchical structure, **d** shows a pseudo-dendrogram of the CLUMPFIND segmentation (**b**), with the same four labels used in Fig. 1 and in **a**. As 'clumps' are not allowed to belong to larger structures, each pseudo-branch in **d** is simply a series of lines connecting the maximum emission value in each clump to the threshold value. A very large number of clumps appears in **b** because of the sensitivity of CLUMPFIND to noise and small-scale structure in the data. In the online PDF version, the 3D cubes (**a** and **b**) can be rotated to any orientation, and surfaces can be turned on and off (interaction requires Adobe Acrobat version 7.0.8 or higher). In the printed version, the front face of each 3D cube (the 'home' view in the interactive online version) corresponds exactly to the patch of sky shown in Fig. 1, and velocity with respect to the Local Standard of Rest increases from front ($-0.5\ km\ s^{-1}$) to back ($8\ km\ s^{-1}$).

data, CLUMPFIND typically finds features on a limited range of scales, above but close to the physical resolution of the data, and its results can be overly dependent on input parameters. By tuning CLUMPFIND's two free parameters, the same molecular-line data set[8] can be used to show either that the frequency distribution of clump mass is the same as the initial mass function of stars or that it follows the much shallower mass function associated with large-scale molecular clouds (Supplementary Fig. 1).

Four years before the advent of CLUMPFIND, 'structure trees'[9] were proposed as a way to characterize clouds' hierarchical structure using 2D maps of column density. With this early 2D work as inspiration, we have developed a structure-identification algorithm that abstracts the hierarchical structure of a 3D (*p*–*p*–*v*) data cube into an easily visualized representation called a 'dendrogram'[10]. Although well developed in other data-intensive fields[11,12], it is curious that the application of tree methodologies so far in astrophysics has been rare, and almost exclusively within the area of galaxy evolution, where 'merger trees' are being used with increasing frequency[13].

Figure 3 and its legend explain the construction of dendrograms schematically. The dendrogram quantifies how and where local maxima of emission merge with each other, and its implementation is explained in Supplementary Methods. Critically, the dendrogram is determined almost entirely by the data itself, and it has negligible sensitivity to algorithm parameters. To make graphical presentation possible on paper and 2D screens, we 'flatten' the dendrograms of 3D data (see Fig. 3 and its legend), by sorting their 'branches' to not cross, which eliminates dimensional information on the *x* axis while preserving all information about connectivity and hierarchy. Numbered 'billiard ball' labels in the figures let the reader match features between a 2D map (Fig. 1), an interactive 3D map (Fig. 2a online) and a sorted dendrogram (Fig. 2c).

A dendrogram of a spectral-line data cube allows for the estimation of key physical properties associated with volumes bounded by isosurfaces, such as radius (R), velocity dispersion (σ_v) and luminosity (L). The volumes can have any shape, and in other work[14] we focus on the significance of the especially elongated features seen in L1448 (Fig. 2a). The luminosity is an approximate proxy for mass, such that $M_{lum} = X_{13CO}L_{13CO}$, where $X_{13CO} = 8.0 \times 10^{20}\ cm^2\ K^{-1}\ km^{-1}\ s$ (ref. 15; see Supplementary Methods and Supplementary Fig. 2). The derived values for size, mass and velocity dispersion can then be used to estimate the role of self-gravity at each point in the hierarchy, via calculation of an 'observed' virial parameter, $\alpha_{obs} = 5\sigma_v^2 R/GM_{lum}$. In principle, extended portions of the tree (Fig. 2, yellow highlighting) where $\alpha_{obs} < 2$ (where gravitational energy is comparable to or larger than kinetic energy) correspond to regions of *p*–*p*–*v* space where self-gravity is significant. As α_{obs} only represents the ratio of kinetic energy to gravitational energy at one point in time, and does not explicitly capture external over-pressure and/or magnetic fields[16], its measured value should only be used as a guide to the longevity (boundedness) of any particular feature.

Figure 3 | Schematic illustration of the dendrogram process. Shown is the construction of a dendrogram from a hypothetical one-dimensional emission profile (black). The dendrogram (blue) can be constructed by 'dropping' a test constant emission level (purple) from above in tiny steps (exaggerated in size here, light lines) until all the local maxima and mergers are found, and connected as shown. The intersection of a test level with the emission is a set of points (for example the light purple dots) in one dimension, a planar curve in two dimensions, and an isosurface in three dimensions. The dendrogram of 3D data shown in Fig. 2c is the direct analogue of the tree shown here, only constructed from 'isosurface' rather than 'point' intersections. It has been sorted and flattened for representation on a flat page, as fully representing dendrograms for 3D data cubes would require four dimensions.

Note: This work came from the "AstroMed" project am.iic.harvard.edu

Goodman et al. *Nature*, 2009


Explore
Guided Tours
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Wide-Field Imag...
Dumbbell Nebul...
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NGC 281 Star-Fo...
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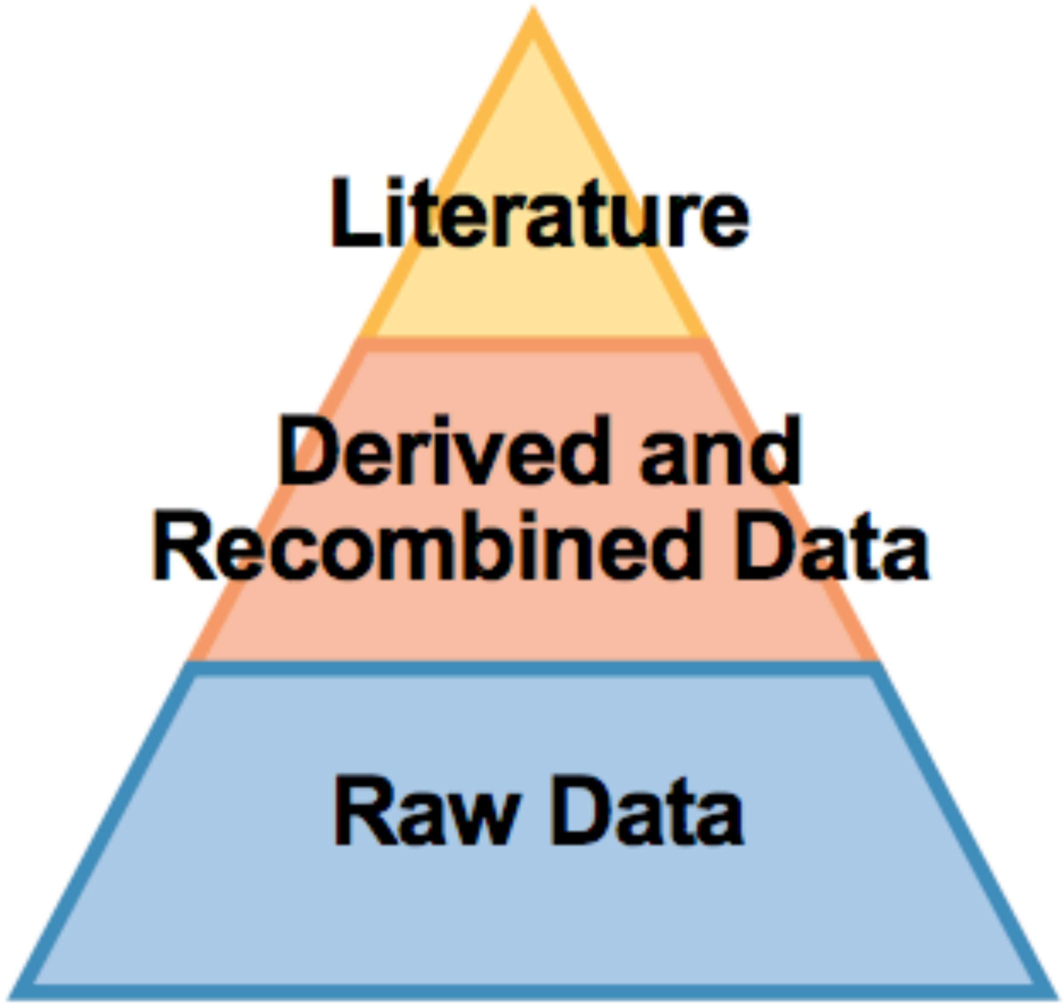
"New Data"
WWT/ADS/SIMBAD/VAO
WWT as API
"Your Data"
"My Data"
3D PDF
Imagery
Image Crossfade
Digitized Sky Survey (Optical...
Context Search Filter
All

Jim Gray (& Alex Szalay) had it right (in 2004)

All Scientific Data Online

- Many disciplines overlap and use data from other sciences
- Internet can unify all literature and data
- Go from literature to computation to data back to literature
- Information at your fingertips for everyone-everywhere



- Increase Scientific Information Velocity
- Huge increase in Science Productivity

Jim Gray (& Alex Szalay) had it right (in 2004)

The World Wide Telescope an Archetype for Online-Science

Jim Gray (Microsoft)

Alex Szalay (Johns Hopkins University)

Microsoft Academic Days in Silicon Valley

http://research.microsoft.com/~gray/talks

All Scientific Data Online

- Many disciplines overlap and use data from other sciences
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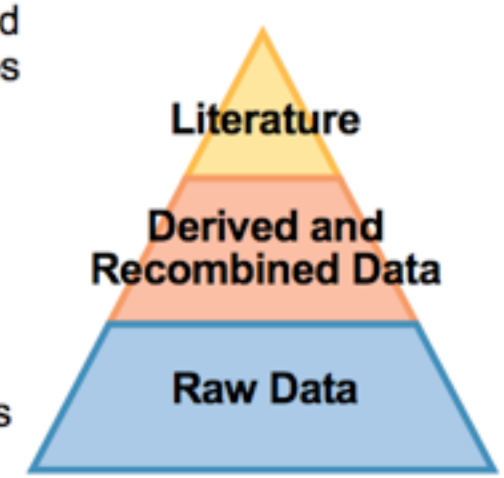
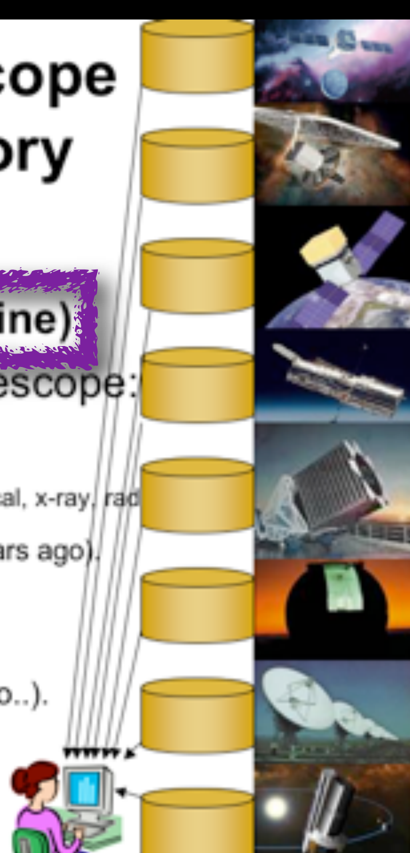


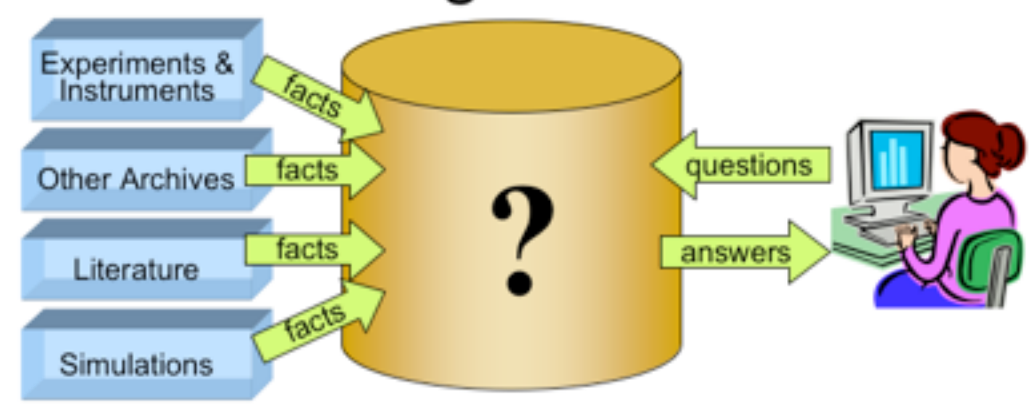
World Wide Telescope Virtual Observatory

http://www.ivoa.net/

- Premise:
  - **Most data is (or could be online)**
- The Internet is the world's best telescope:
  - It has data on every part of the sky
  - In every measured spectral band: optical, x-ray, rad
  - As deep as the best instruments (2 years ago).
  - It is up when you are up. The "seeing" is always great (no working at night, no clouds no moons no..).
  - It's a smart telescope: links objects and data to literature on them.



The Big Picture



The Big Problems

- Data ingest
- Managing a petabyte
- Common schema
- How to organize it?
- How to reorganize it
- How to coexist with others

- Query and Vis tools
- Support/training
- Performance
  - Execute queries in a minute
  - Batch query scheduling

8

How do we increase the fraction of astronomy researchers who know about these tools?

WIKIBOOKS
Open books for an open world

User Groups
(CfA now has one)

YouTube

+Suggestions?!

User Groups
(CfA now has one)

WIKIBOOKS
Open books for an open world

ASTROBETTER
Tips and Tricks for Professional Astronomers

.astronomy

YouTube

my experiment

How do we increase the number of people who create and interlink new tools?

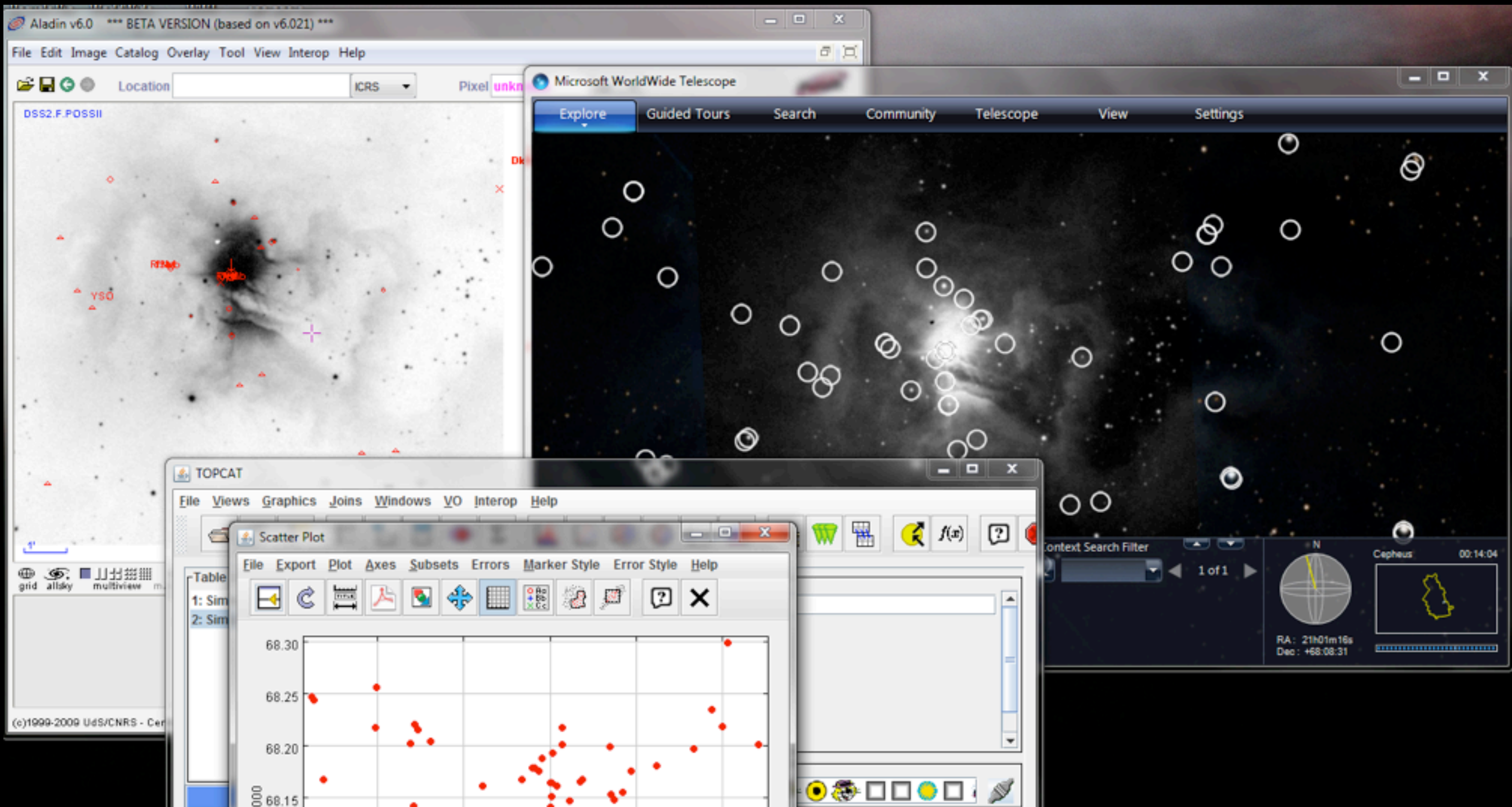
Kiva model proposed here in 2009...

Now being implemented through VAO "Associates" and WWT Partners.

How do we organize such diverse tools, so as to make them interoperably useful?....

"SAMP" is a great technical start, but offers a very significant user interface challenge.

SAMP



Aladin v6.0 *** BETA VERSION (based on v6.021) ***
File Edit Image Catalog Overlay Tool View Interop Help
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(c)1999-2009 UdS/CNRS - Cer
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TOPCAT
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Table
Scatter Plot
File Export Plot Axes Subsets Errors Marker Style Error Style Help
68.30
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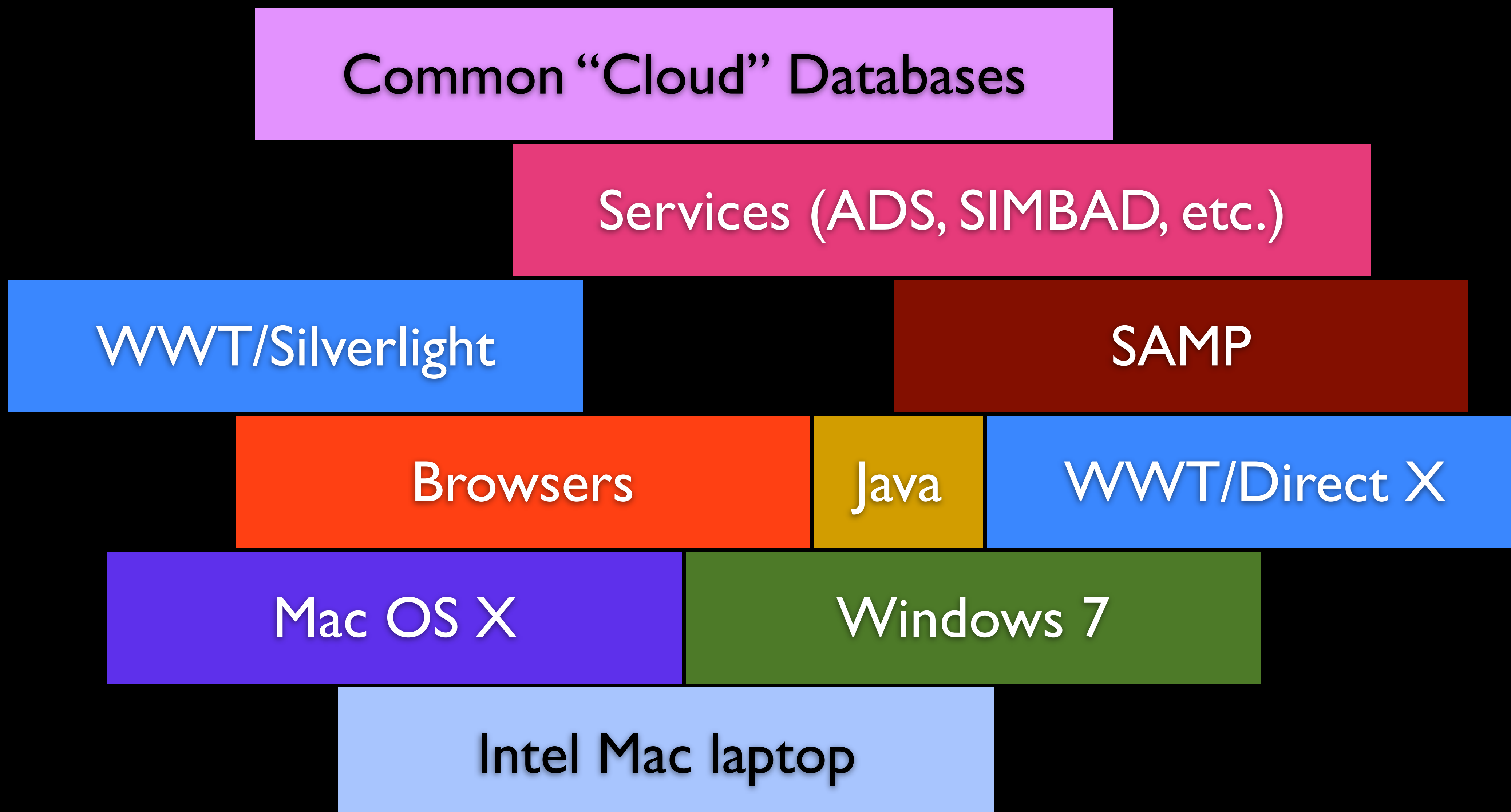
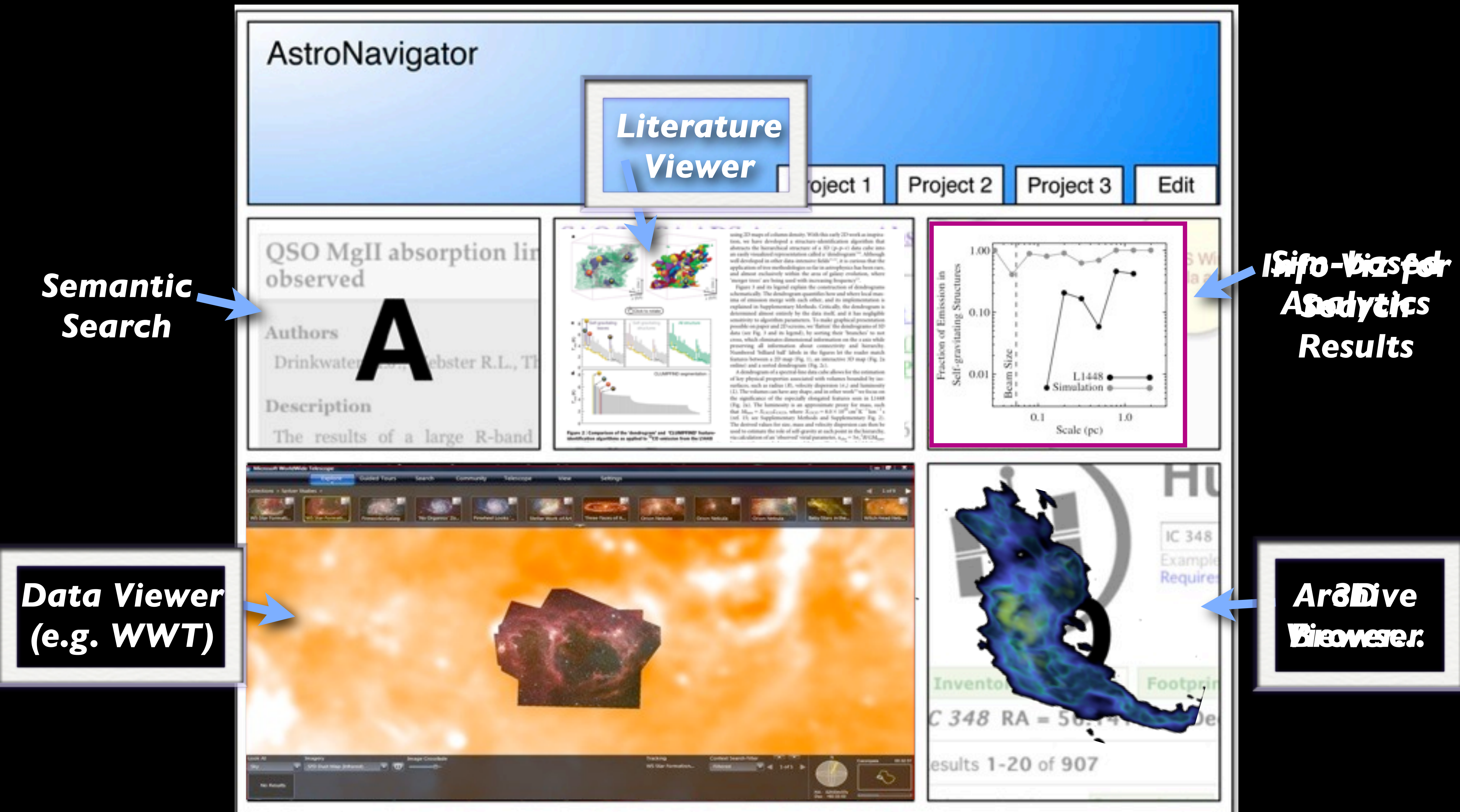
68.15

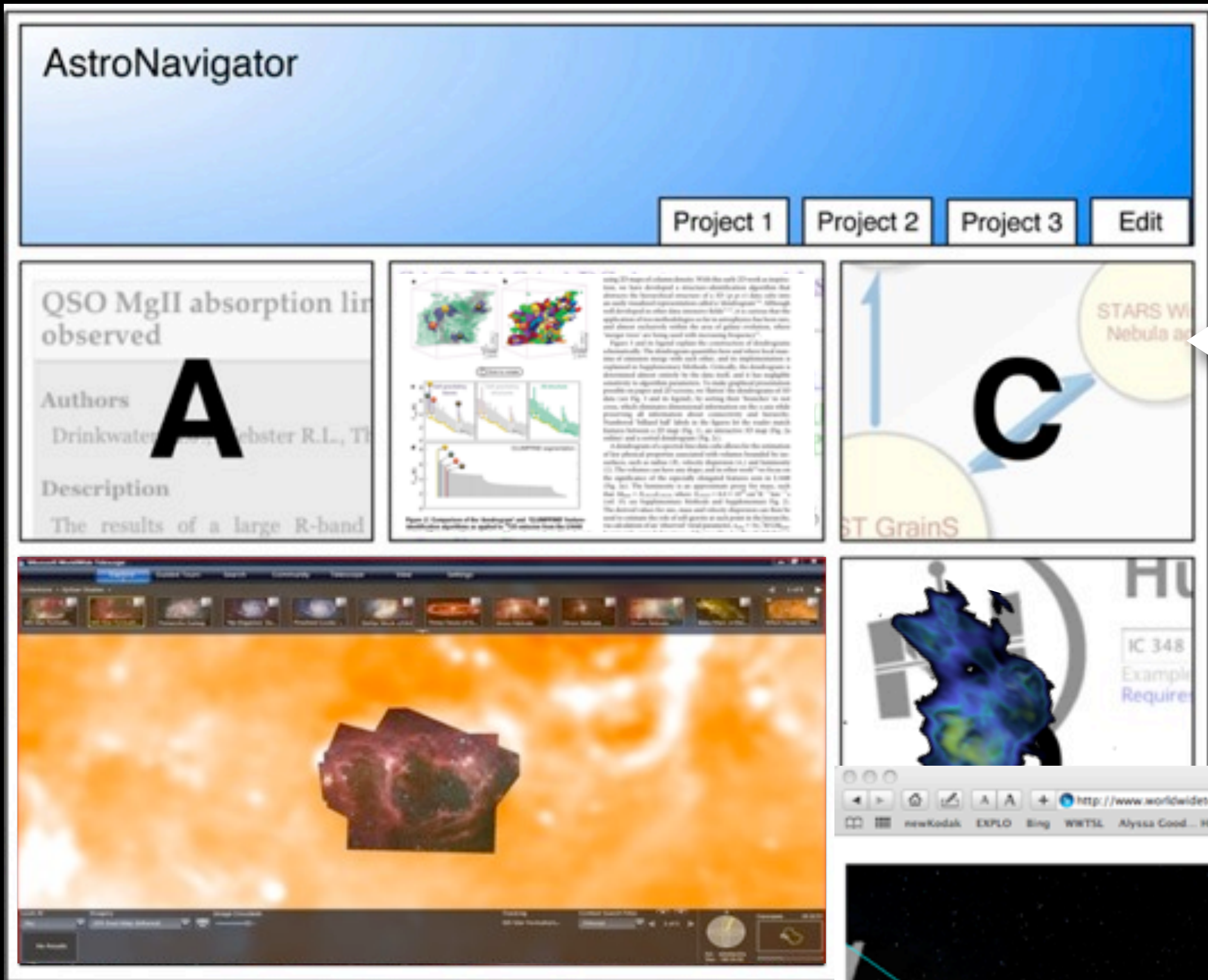
Think about the "modules" needed to make this work...but do the details matter, to your research, if the system works seamlessly?



Seamless Astronomy

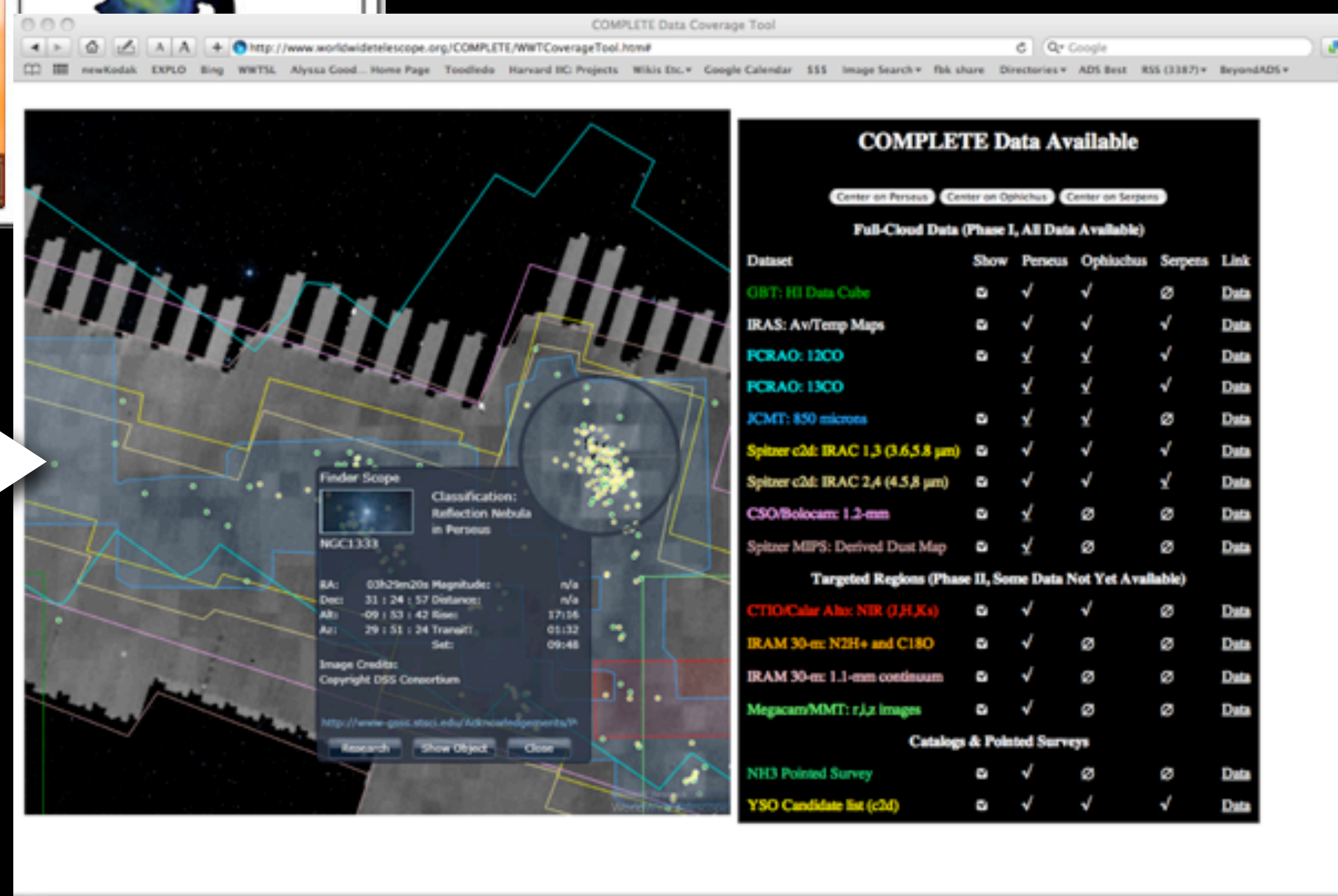


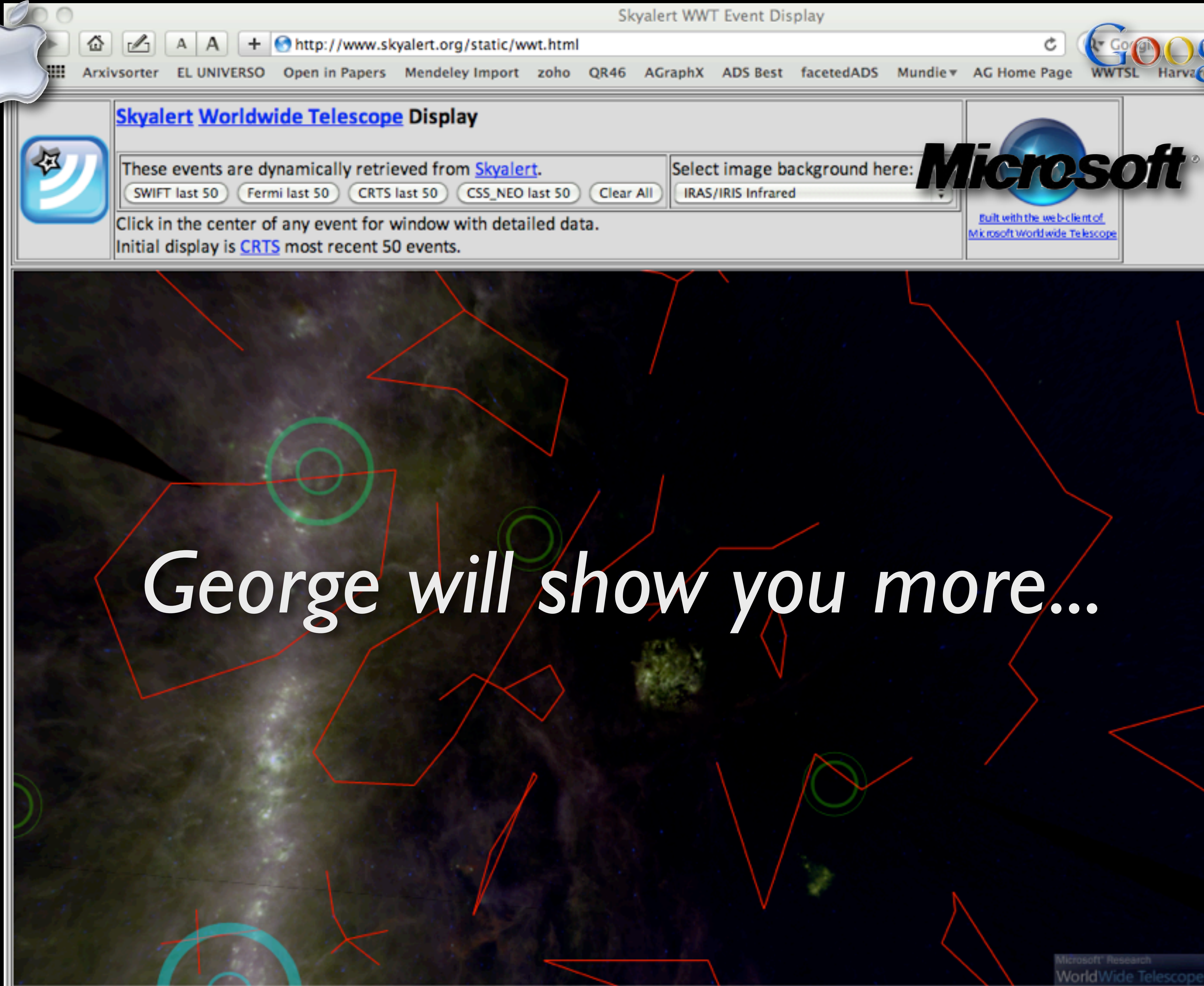
Mockup based on work of Eli Bressert, excerpted from NASA AISRP proposal by Goodman, Muench, Christian, Conti, Kurtz, Burke, Accomazzi, McGuinness, Hendler & Wong, 2008



Fiction
(for now)

Fact
(right now)





George will show you more...

http://www.skyalert.org/static/wwt.html

Evermore Seamless Astronomy

Alyssa A. Goodman
Harvard-Smithsonian Center for Astrophysics

with Alberto Accomazzi, Douglas Burke, Gus Muench & Michael Kurtz (Harvard-Smithsonian CfA); Eli Bressert (U. Exeter); Tim Clark (Massachusetts General Hospital/Harvard Medical School); Chris Borgman (UCLA); **Jonathan Fay** & **Curtis Wong** (Microsoft Research)