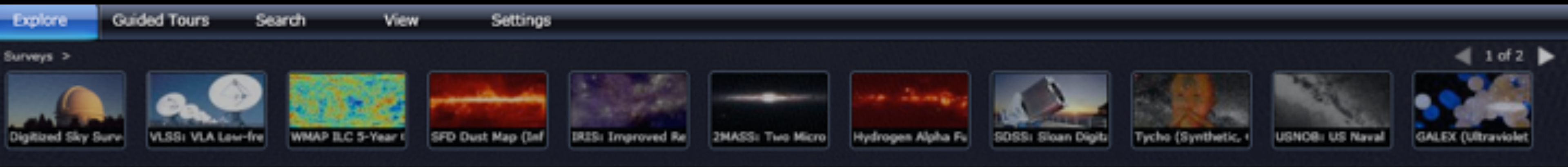


The Future of Astronomy

Alyssa A. Goodman
Harvard-Smithsonian Center for Astrophysics
Initiative in Innovative Computing at Harvard
WGBH Scholar-in-Residence

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

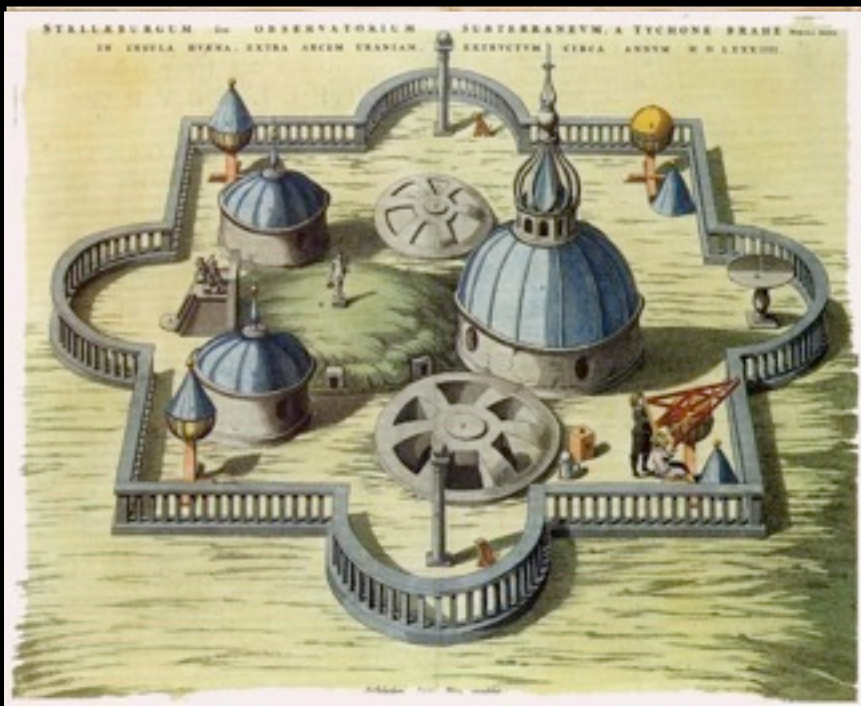
NASA/Explorer 7 (Space-based Observing) 1959

"The Internet"

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

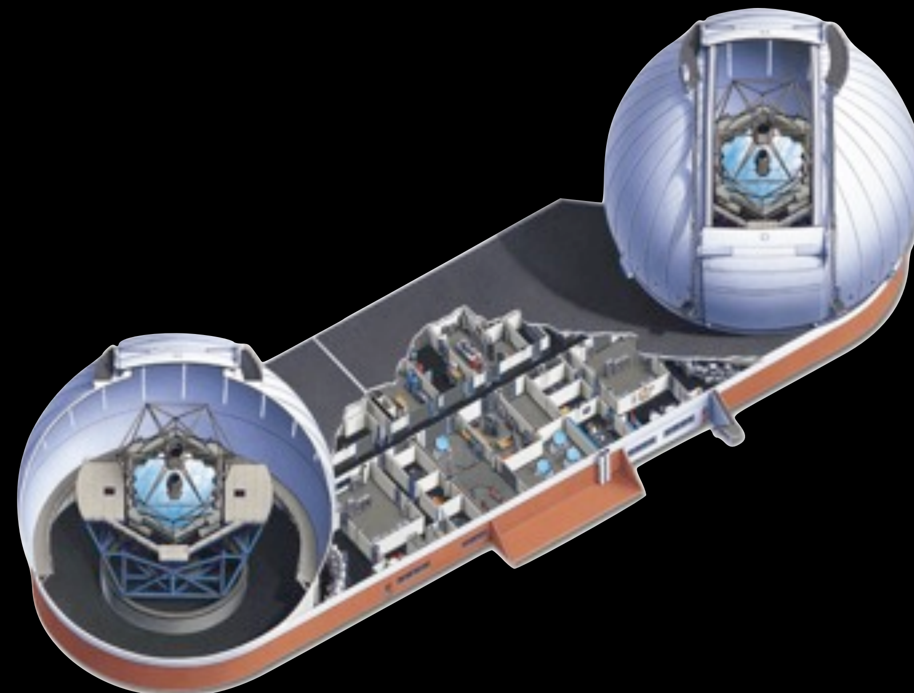
"Virtual Observatories" 21st century

Uraniborg / Stjerneborg (Tycho Brahe, 1576 / 1581)



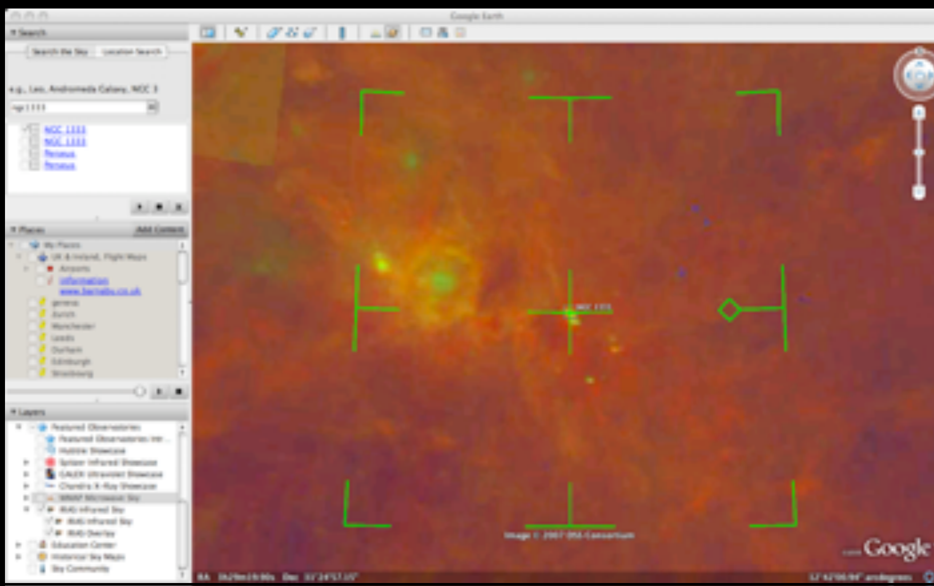
Galileo: c. 1609

W.H. Keck Observatory (1995+)



Full-sky virtual astronomy: c. 2023?

“One Earth, One Sky”



WWT 2001

WWT Today

VIEWPOINT

The World-Wide Telescope

Alexander Szalay,[1] Jim Gray[2]

All astronomy data and literature will soon be online and accessible via the Internet. The community is building the Virtual Observatory, an organization of this worldwide data into a coherent whole that can be accessed by anyone, in any form, from anywhere. The resulting system will dramatically improve our ability to do multi-spectral and temporal studies that integrate data from multiple instruments. The Virtual Observatory data also provide a wonderful base for teaching astronomy, scientific discovery, and computational science.

Hubble Space Telescope (HST) (1), the Chandra X-Ray Observatory (2), the Sloan Digital Sky Survey (SDSS) (3), the Two Mi-

spectral surveys. Together, they house an order of magnitude more data than any single instrument. In addition, all the astronomy literature is online and is cross-indexed with the observations (6, 7).

Why is it necessary to study the sky in such detail? Celestial objects radiate energy over an

Fig. 1. Telescope area doubles every 25 years, whereas telescope CCD pixels double every 2 years. This rate seems to be accelerating. It implies a yearly data doubling. Huge advances in storage, computing, and communications technologies have enabled the Internet and will enable the Virtual Observatory.

[1]The Johns Hopkins University, Baltimore, MD 21218, USA. [2]Microsoft Bay Area Research Center, San Francisco, CA, USA.

Microsoft Research

quick demo of WWT

“WWT as a Preview of 21st Century e-Research in Astronomy”

(based on American Astronomical Society Meeting presentation, Long Beach, CA, 2009)

--OR--

Group chose this one, so I’ve added these slides next...

“Astronomical Data and Information Visualization”

(based on American Astronomical Society Meeting , Washington, DC, 2010)

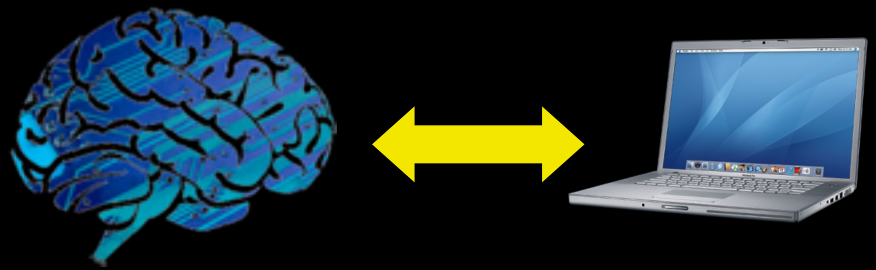
Astronomical Data and Information Visualization

Alyssa A. Goodman
Harvard-Smithsonian Center for Astrophysics
Initiative in Innovative Computing at Harvard
WGBH Scholar-in-Residence

Relative Strengths

Pattern Recognition
Creativity

Calculations



Data Reduction

Data Display

Context (e.g. journals + online data)

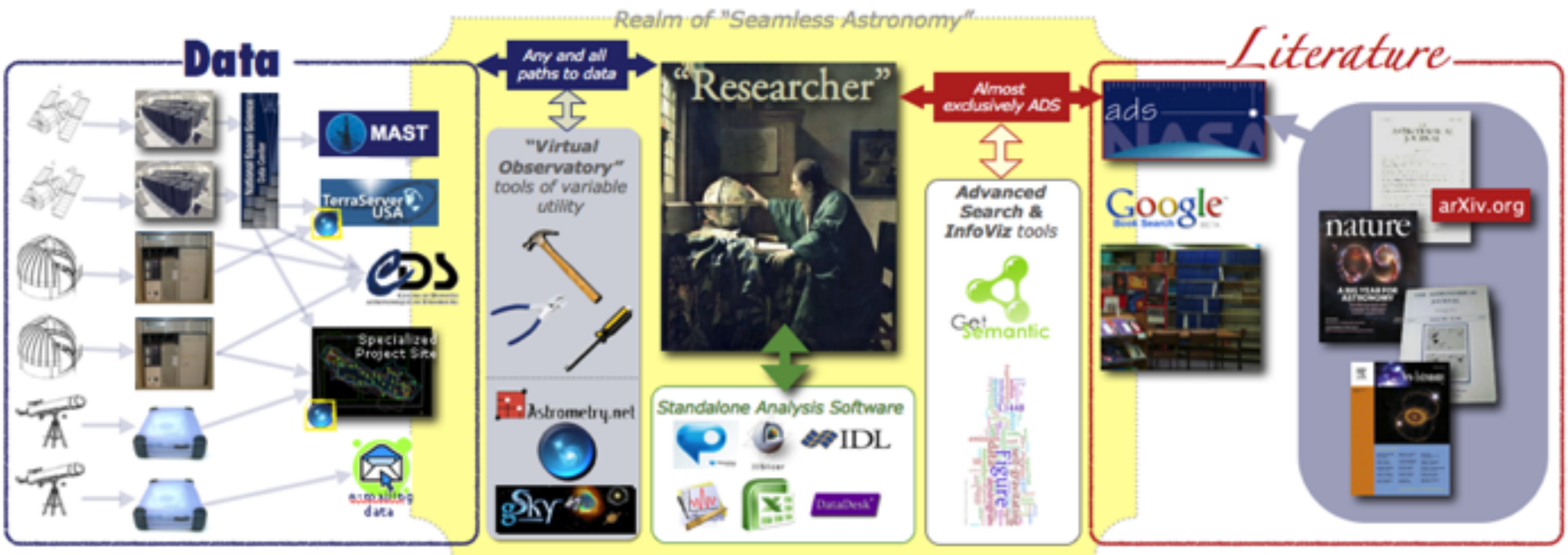
Simulation Design

Statistics Design

Data Exploration (Visualization)

Seamless Astronomy

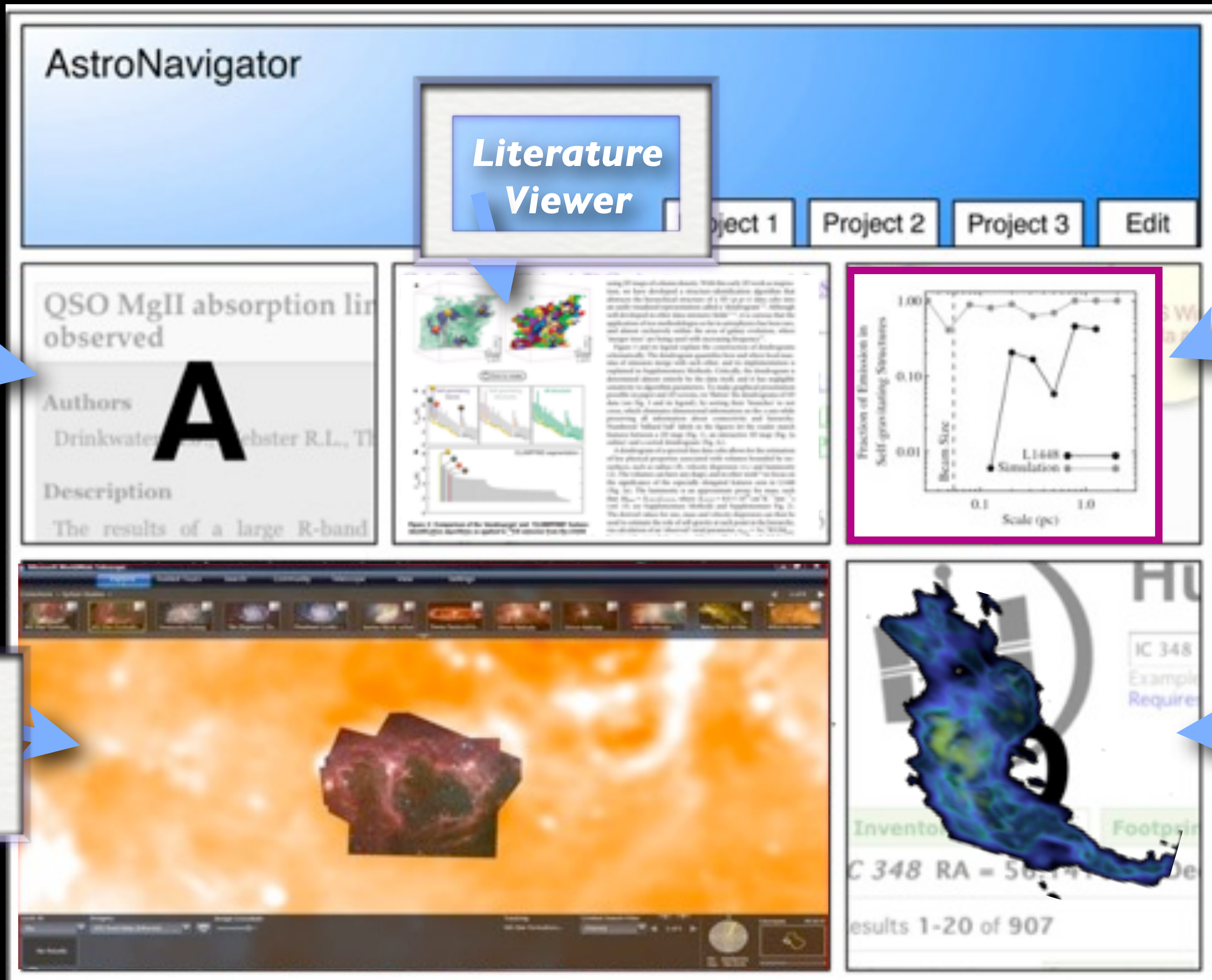
www.cfa.harvard.edu/~agoodman and worldwidetelescope.org



"Seamless Astronomy" is collaboration amongst many researchers at CfA, MSR, Princeton, STScI, NYU, RPI, and UCLA, and it is supported by NASA, NSF and Microsoft External Research.

Seamless Astronomy

Semantic Search



Info-Vis for Analytics

Sifted Search Results

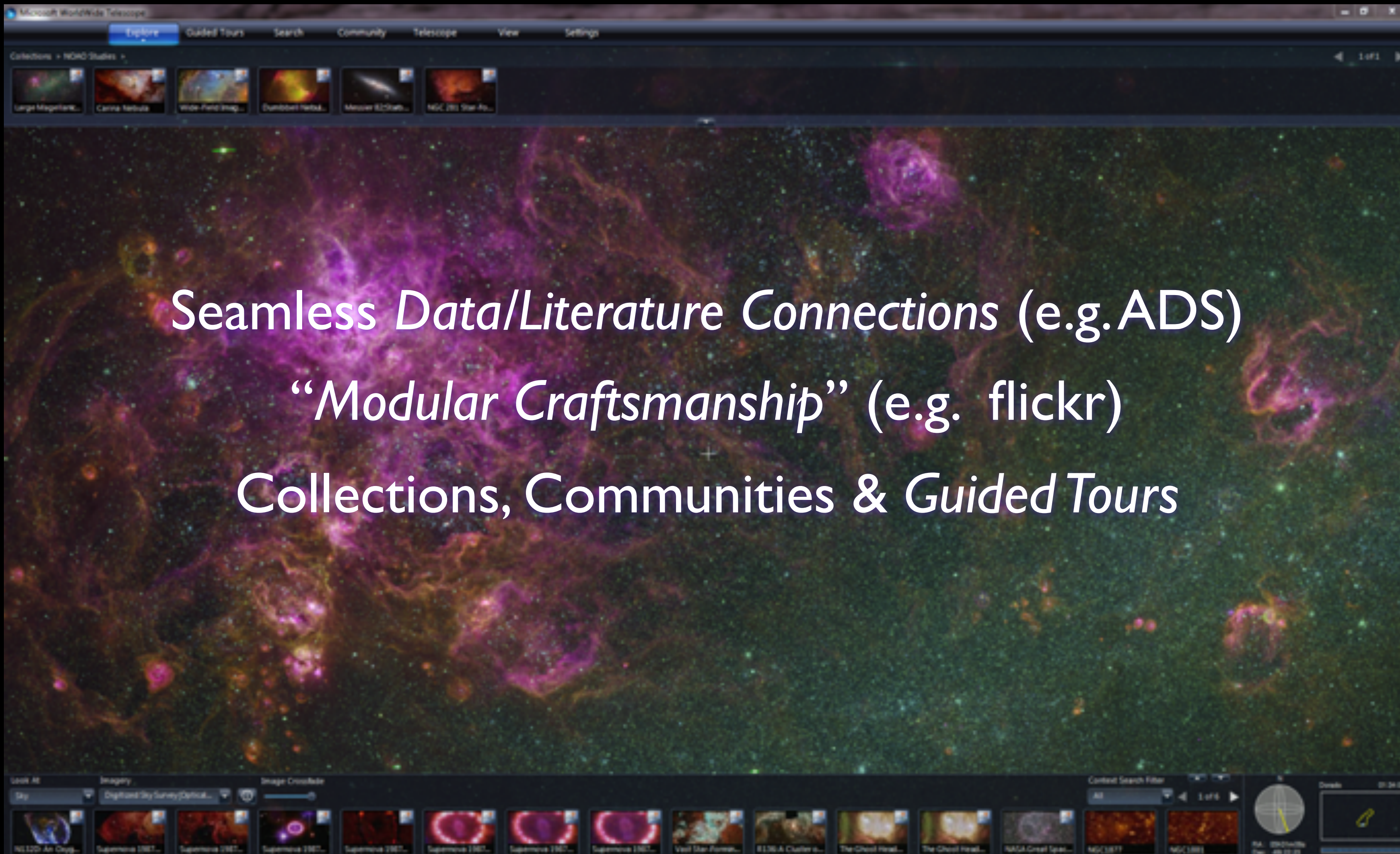
Data Viewer (e.g. WWT)

Archive Browser

3D Viewer

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

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



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


Explore
Guided Tours
Search
View
Settings
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Plot Results
VO Search
J2000
RA
Dec
Go
1 of 2
NGC7023
Finder Scope
Classification:
Reflection Nebula
in Cepheus
NGC 7023
RA: 21h01m36s
Dec: 68 : 10 : 11
Alt: 30 : 55 : 38
Az: 341 : 36 : 56
Magnitude: n/a
Distance: n/a
Rise: Circumpolar
Transit: Circumpolar
Set: Circumpolar
Image Credits:
Jack Newton
http://www.jacknewton.com/
Research
Show Object
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Imagery
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1 of 23
Sculptor
Earth
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Sculptor Galaxy
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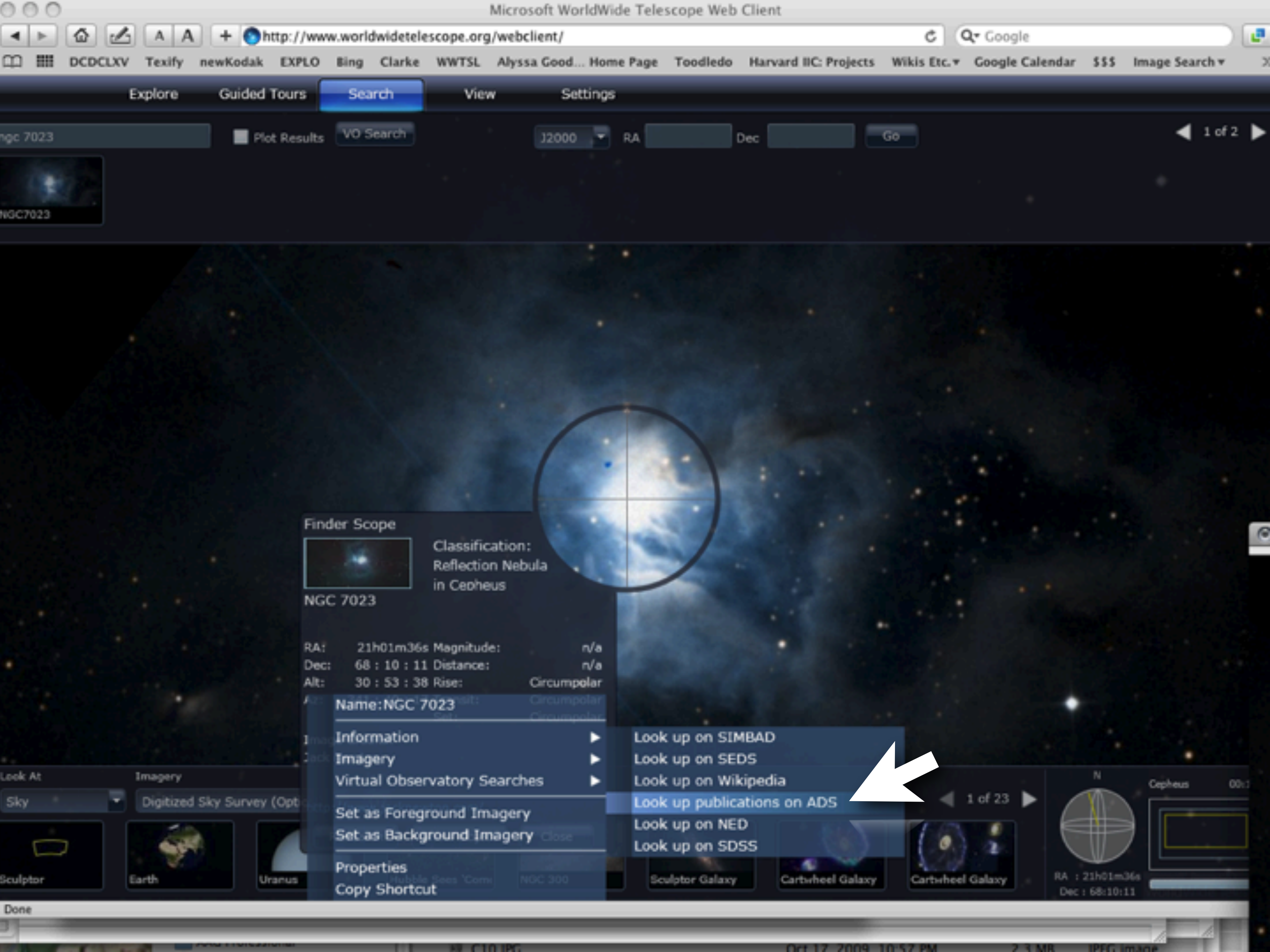
Microsoft WorldWide Telescope Web Client
http://www.worldwidetelescope.org/webclient/
Google
DCDCLXV Texify newKodak EXPLO Bing Clarke WWTSL Alyssa Good... Home Page Toodledo Harvard IIC: Projects Wikis Etc. Google Calendar $$$ Image Search
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1 of 2
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Reflection Nebula
in Cepheus
NGC 7023
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Dec: 68 : 10 : 11 Distance: n/a
Alt: 30 : 53 : 38 Rise: Circumpolar
Name:NGC 7023
Information
Imagery
Virtual Observatory Searches
Set as Foreground Imagery
Set as Background Imagery
Properties
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Look up on SEDS
Look up on Wikipedia
Look up publications on ADS
Look up on NED
Look up on SDSS
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Cartwheel Galaxy
Cartwheel Galaxy
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Cepheus
RA : 21h01m36s
Dec : 68:10:11
Done

Object Query Results

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

DCDCLXV Texify newKodak EXPLO Bing Clarke WWTSL Alyssa Good... Home Page Toodledo Harvard IIC: Projects Wikis Etc. Google Calendar $$$ Image Search

agoodman@cfa.harvard.edu | my Account | Sign off

SAO/NASA Astrophysics Data System (ADS)

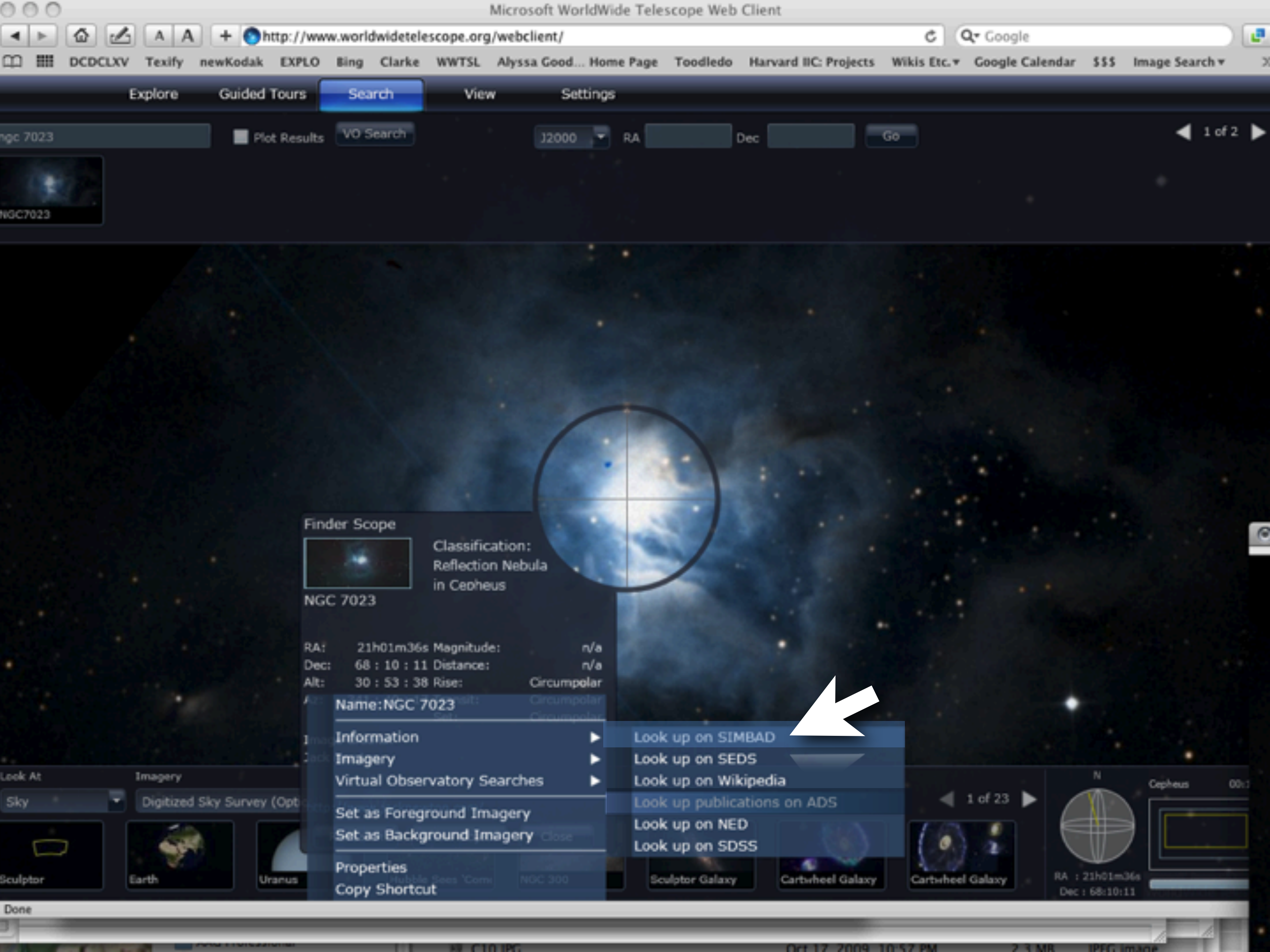
Query Results from the Astronomy Database

Go to bottom of page

Retrieved **200** abstracts, starting with number **1**. Total number selected: **393**.

Sort options

#	Bibcode / Authors	Score	Date / Title	List of Links / Access Control Help
1	2009ApJ...700.1609M Myers, Philip C.	1.000	08/2009 Filamentary Structure of Star-forming Complexes	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	08/2009 Strong Polycyclic Aromatic Hydrocarbon Emission from $z \approx 2$ ULIRGs	A Z E F L X R C S U
3	2009MNRAS.396.1851N Nutter, D.; Stamatellos, D.; Ward-Thompson, D.	1.000	07/2009 The initial conditions of isolated star formation - IX. Akari mapping of an externally heated pre-stellar core	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	07/2009 A spatial study of the mid-IR emission features in four Herbig Ae/Be stars	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	05/2009 Mid-infrared spectroscopy of infrared-luminous galaxies at $z \sim 0.5$-3	A Z E F L X R C S U


Microsoft WorldWide Telescope Web Client
http://www.worldwidetelescope.org/webclient/
Explore
Guided Tours
Search
View
Settings
ngc 7023
Plot Results
VO Search
J2000
RA
Dec
Go
1 of 2
NGC7023
Finder Scope
Classification:
Reflection Nebula
in Cepheus
NGC 7023
RA: 21h01m36s
Magnitude: n/a
Dec: 68 : 10 : 11
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Alt: 30 : 53 : 38
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Set as Background Imagery
Properties
Copy Shortcut
Look up on SIMBAD
Look up on SEDS
Look up on Wikipedia
Look up publications on ADS
Look up on NED
Look up on SDSS
Look At
Sky
Imagery
Digitized Sky Survey (Opt
Sculptor
Earth
Uranus
Sculptor Galaxy
Cartwheel Galaxy
Cartwheel Galaxy
1 of 23
Cepheus
Done

SIMBAD query result

http://simbad.u-strasbg.fr/simbad/sim-id?ident=NGC+7023&jsessionid=88F7CD92574727FFC

DCDCLXV Texify newKodak EXPLO Bing Clarke WWTSL Alyssa Good... Home Page Toodledo Harvard IIC: Projects Wikis Etc. Google Calendar $$$ Image Search

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) :

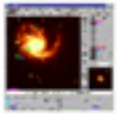
NGC 7023	IRAS 20599+6755	LBN 487	[BDB2003] G104.06+14.19
C 2059+679	IRAS F20599+6755	OCISM 50	AAVSO 2044+67
Cl VDB 139	LBN 104.08+14.21	OCl 235	

Plots and Images

plot around radius 10 arcmin

Aladin previewer

Aladin applet

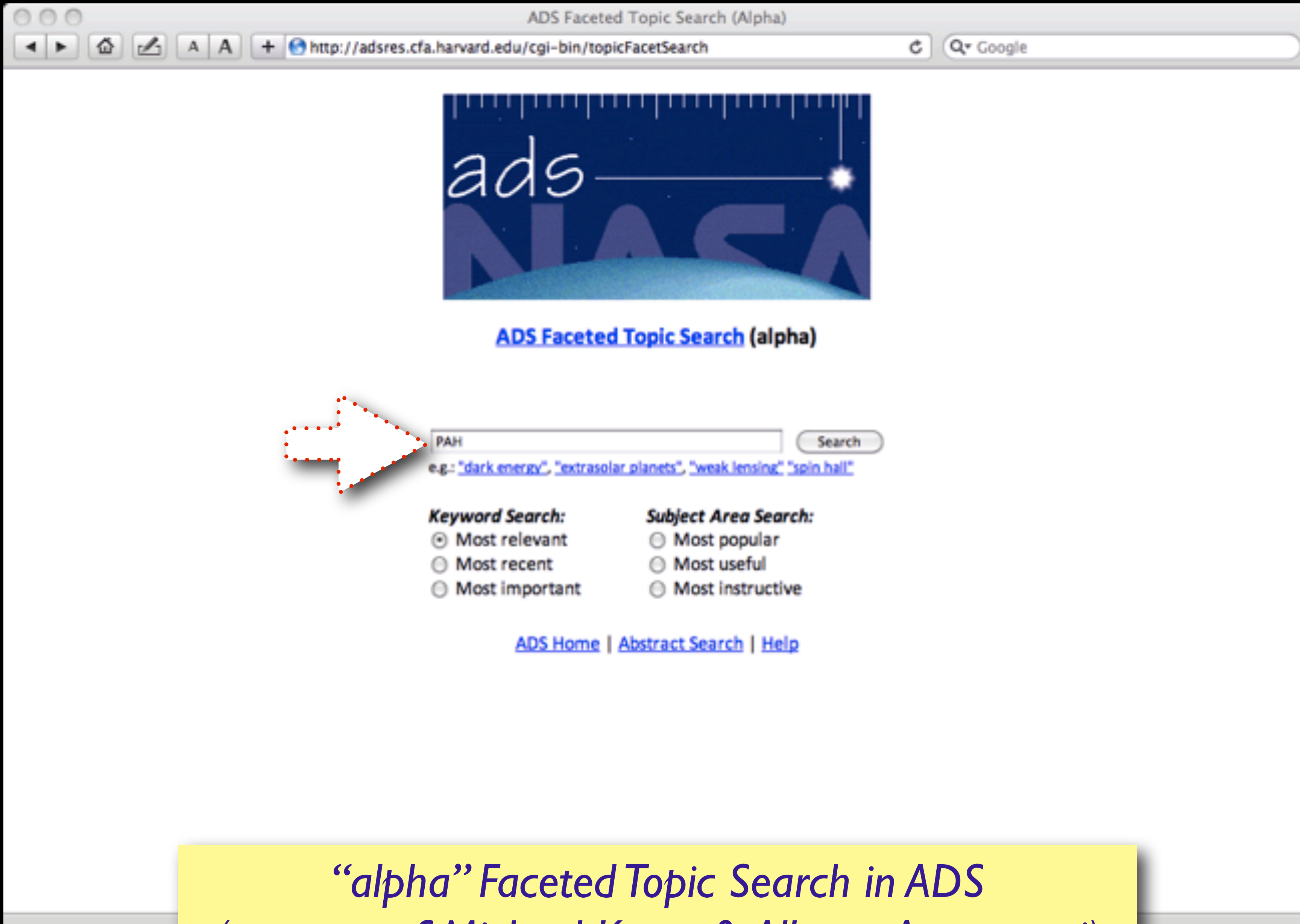


References (371 between 1983 and 2009)

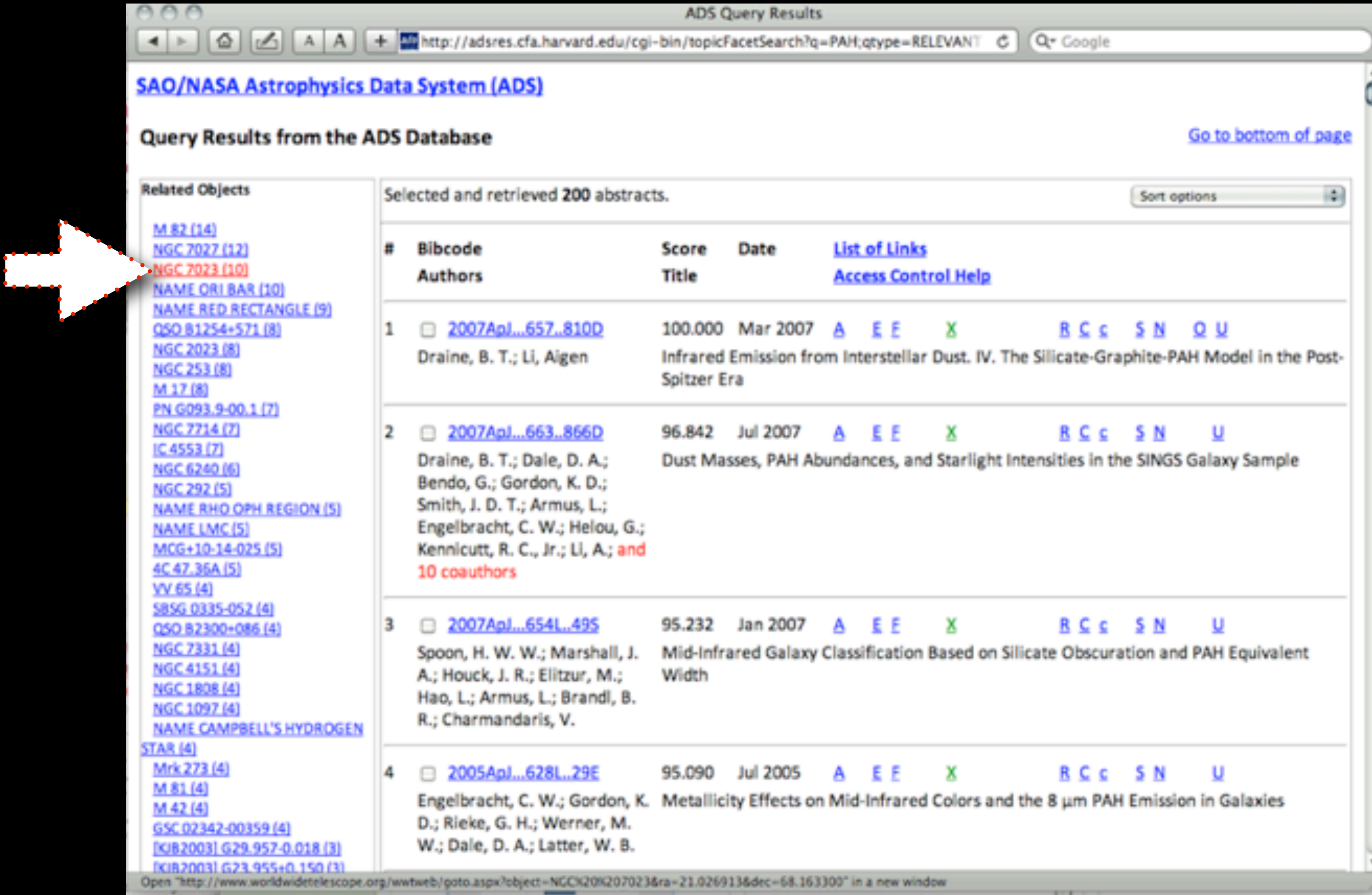
Simbad bibliographic survey began in 1950 for stars (at least bright stars) and in 1983 for all other objects (outside the solar system).

display reference summary

from: 1983 to: 2009

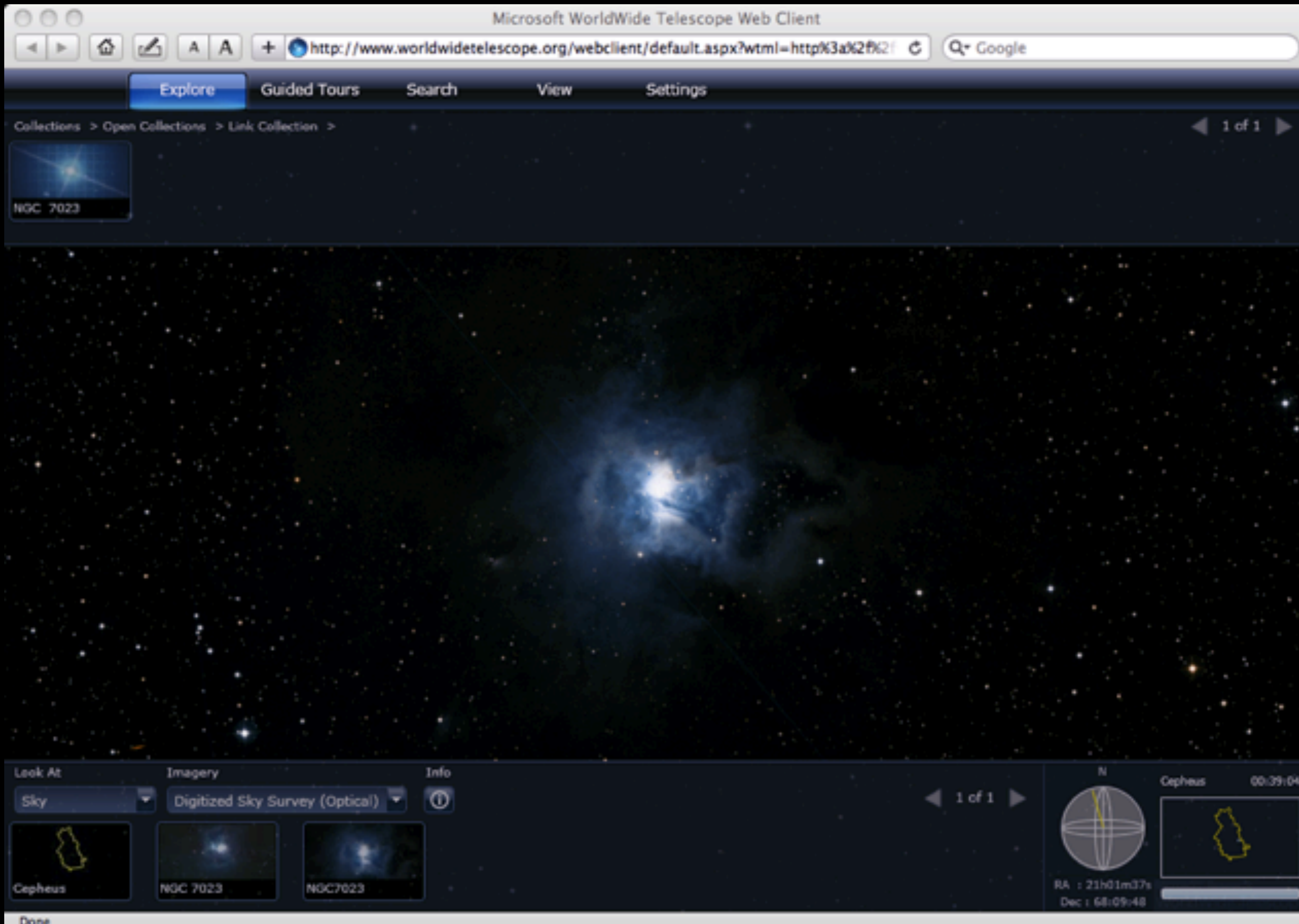


"alpha" Faceted Topic Search in ADS
(courtesy of Michael Kurtz & Alberto Accomazzi)



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...

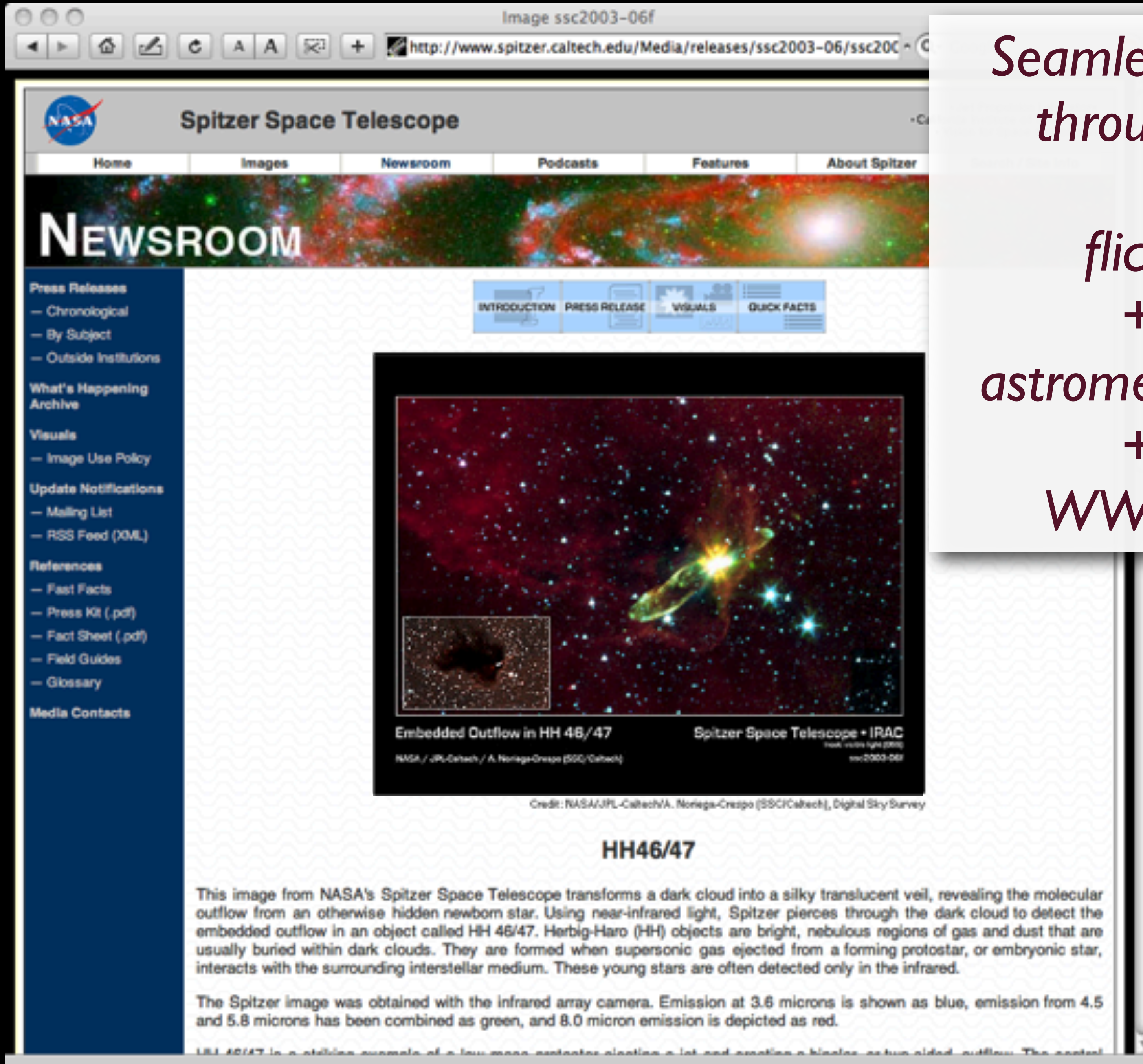
flickr

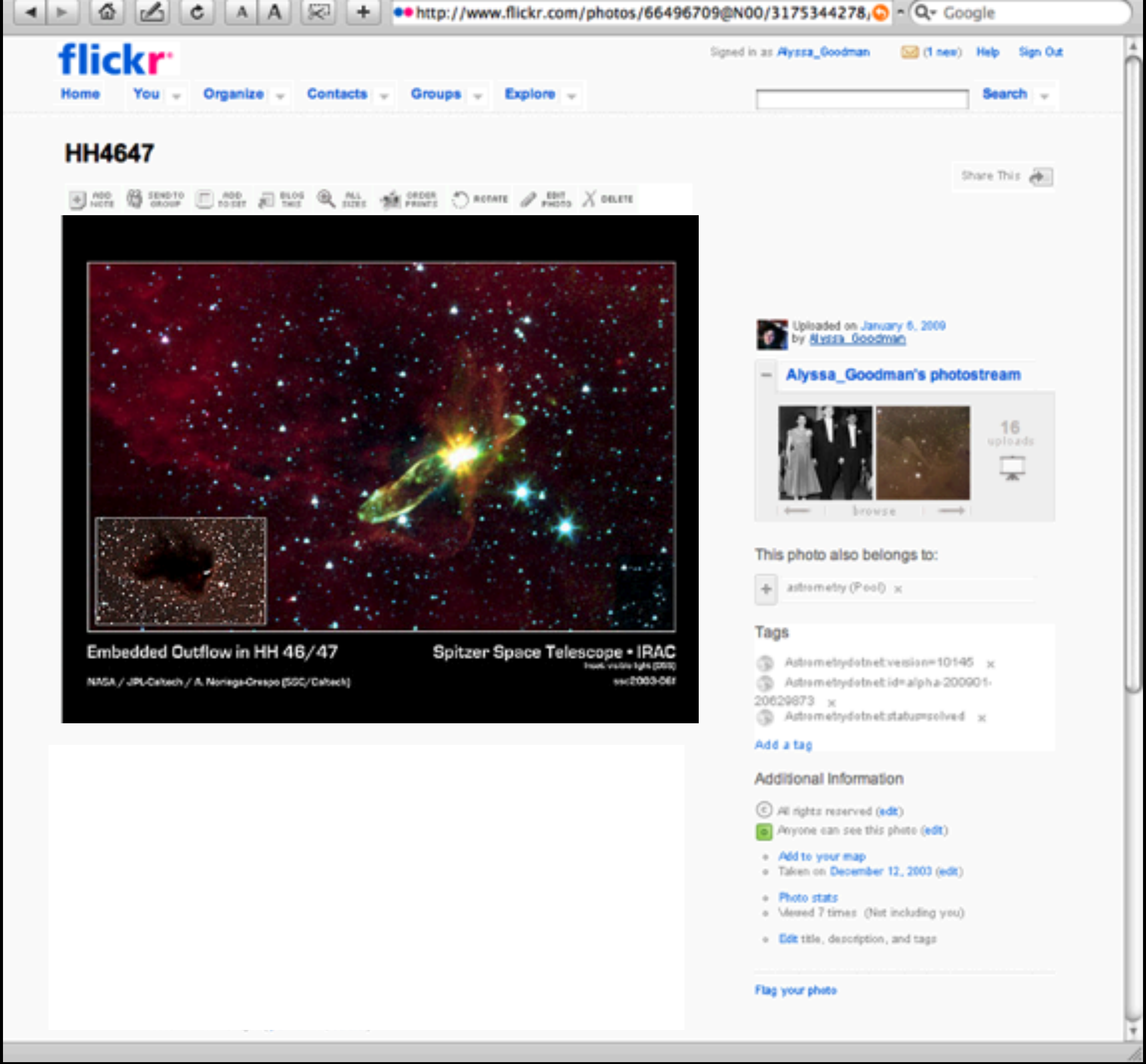
+

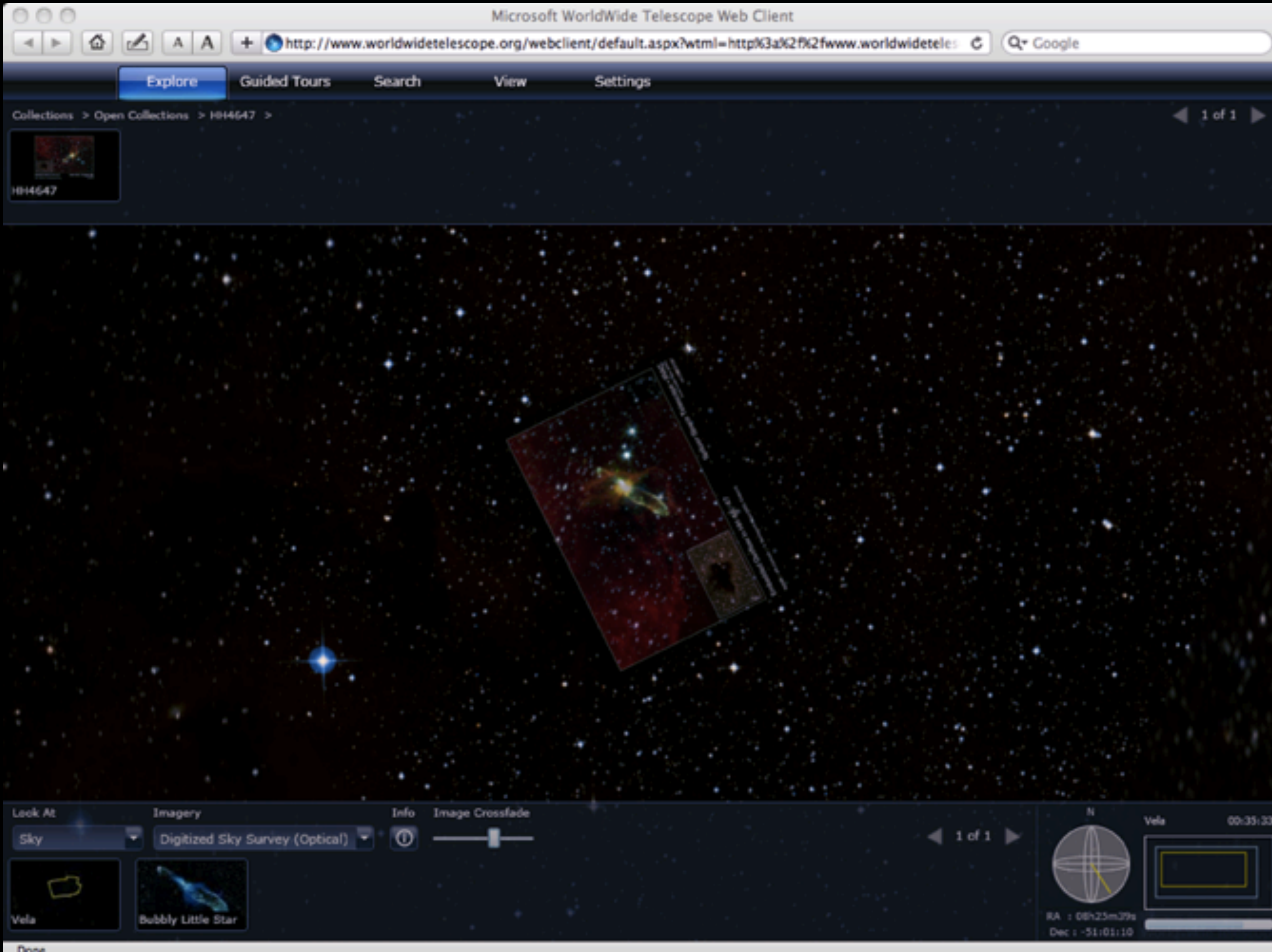
astrometry.net

+

WWT !?




http://www.flickr.com/photos/66496709@N00/3175344278/
Google
flickr
Signed in as Alyssa_Goodman (1 new) Help Sign Out
Home You Organize Contacts Groups Explore
Search
HH4647
Share This
ADD NOTE SEND TO GROUP ADD TO SET BLOG THIS ALL SIZES ORDER PRINTS ROTATE EDIT PHOTO DELETE
Embedded Outflow in HH 46/47
Spitzer Space Telescope • IRAC
NASA / JPL-Caltech / A. Noriega-Crespo (SSC/Caltech)
ssc2003-06f
Uploaded on January 6, 2009
by Alyssa_Goodman
Alyssa_Goodman's photostream
16 uploads
browse
This photo also belongs to:
astrometry (Pool)
Tags
Astrometrydotnet:version=10145
Astrometrydotnet:id=alpha-20090120629873
Astrometrydotnet:status=solved
Add a tag
Additional Information
All rights reserved (edit)
Anyone can see this photo (edit)
Add to your map
Taken on December 12, 2003 (edit)
Photo stats
Viewed 7 times (Not including you)
Edit title, description, and tags
Flag your photo


Microsoft WorldWide Telescope Web Client
http://www.worldwidetelescope.org/webclient/default.aspx?wtml=http%3a%2f%2fwww.worldwidetele
Google
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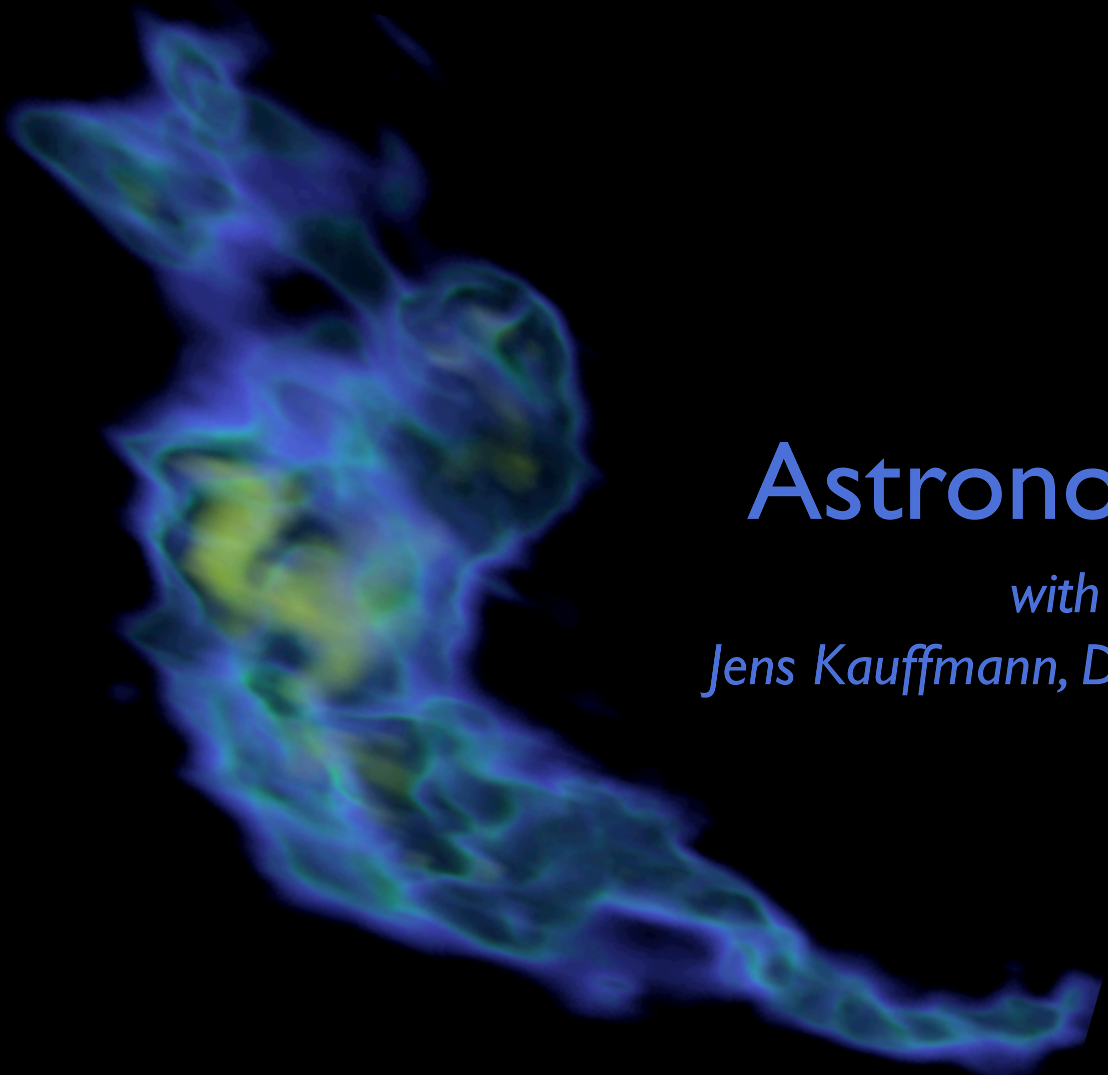
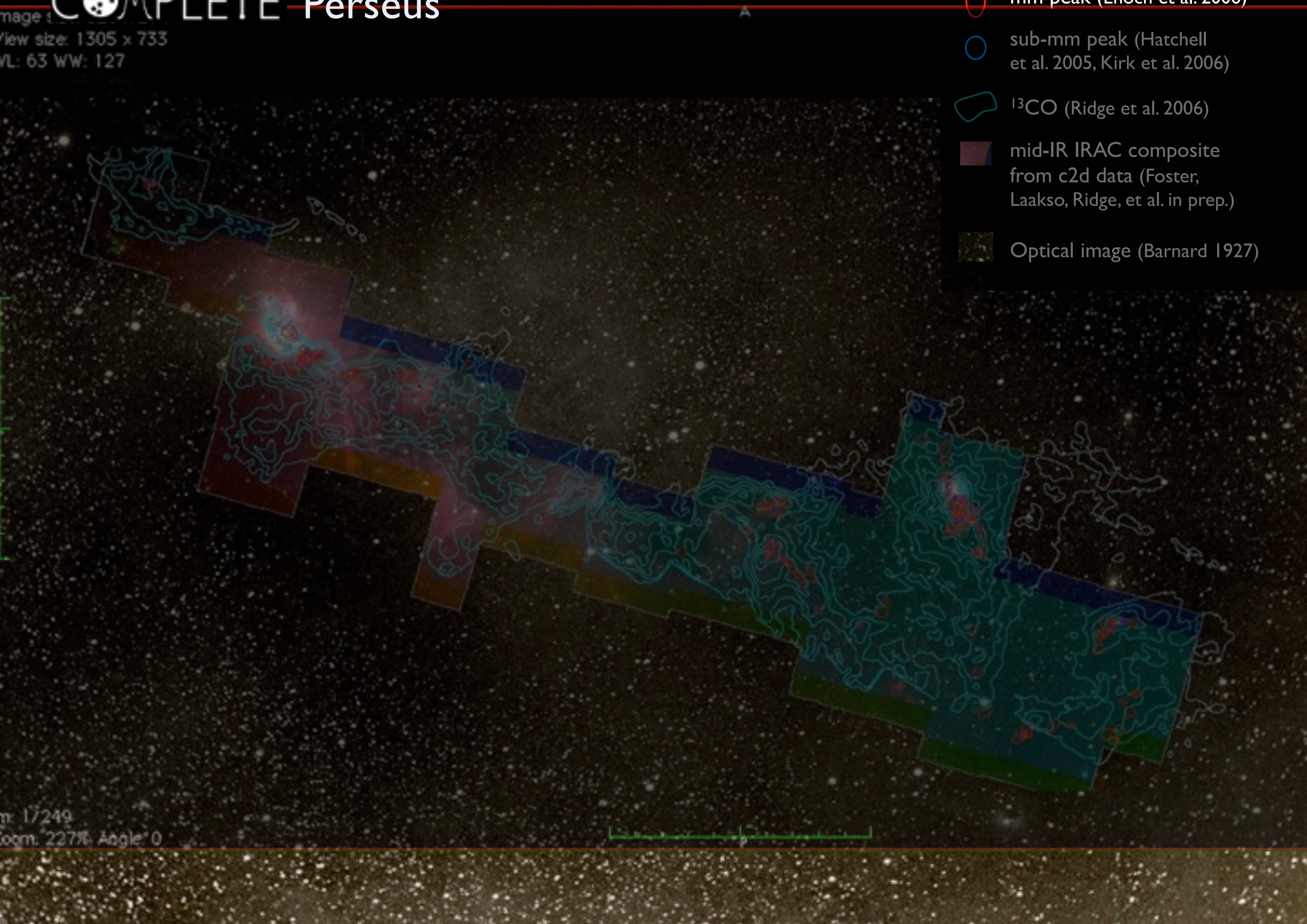


Astronomical Medicine

with Michael Halle, Michelle Borkin,
Jens Kauffmann, Douglas Alan, Erik Rosolowsky &
Nick Holliman

COMPLETE Perseus



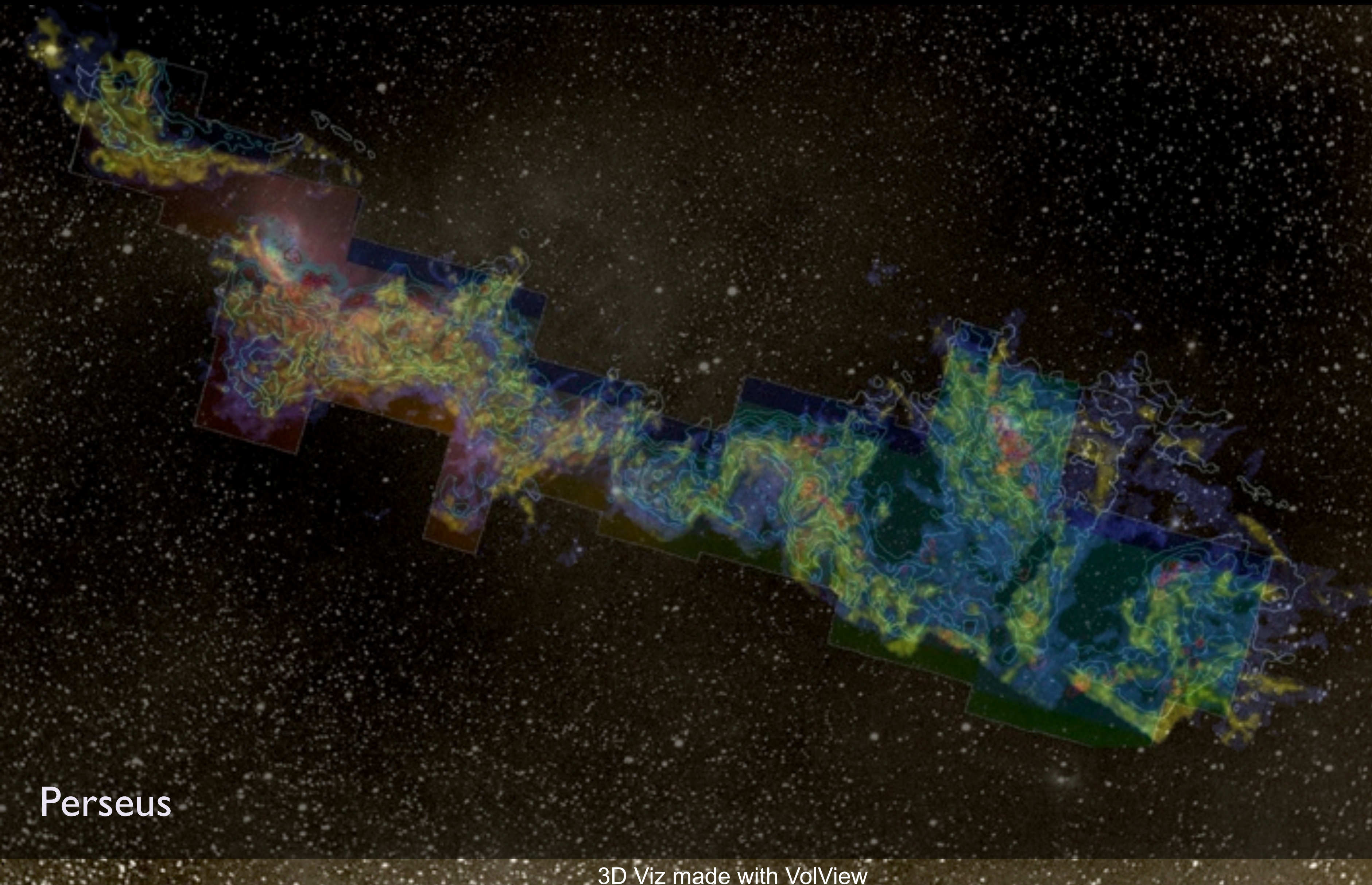
mm peak (Enoch et al. 2006)

sub-mm peak (Hatchell et al. 2005, Kirk et al. 2006)

^{13}CO (Ridge et al. 2006)

mid-IR IRAC composite from c2d data (Foster, Laakso, Ridge, et al. in prep.)

Optical image (Barnard 1927)



AstronomicalMedicine@ IIC COMPLETE

3D PDF (demo)

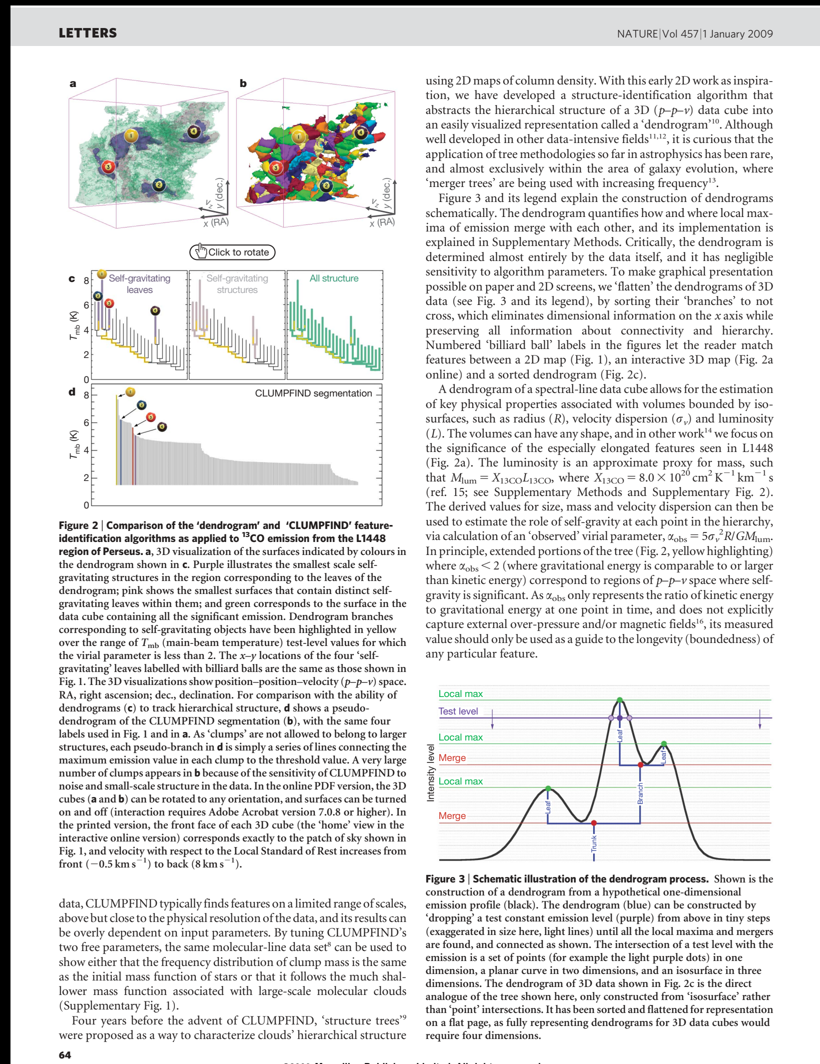


Figure 2 | Comparison of the 'dendrogram' and 'CLUMPFIND' feature-identification algorithms as applied to ^{13}CO emission from the L1448 region of Perseus. a, 3D visualization of the surfaces indicated by colours in the dendrogram shown in **c**. Purple illustrates the smallest scale self-gravitating 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).

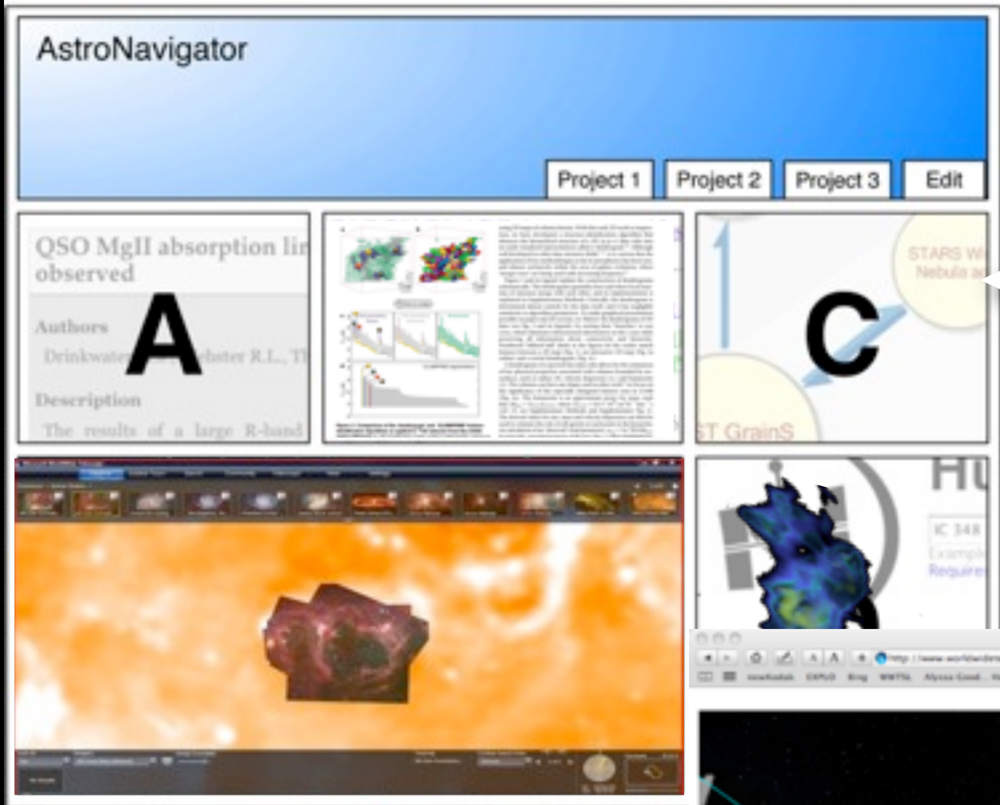
Four years before the advent of CLUMPFIND, 'structure trees'[9] were proposed as a way to characterize clouds' hierarchical structure using 2D maps of column density. With this early 2D work as inspiration, we have developed a structure-identification algorithm that abstracts the hierarchical structure 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, $\alpha_{obs} = 5\sigma_v^2R/GM_{lum}$. 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.

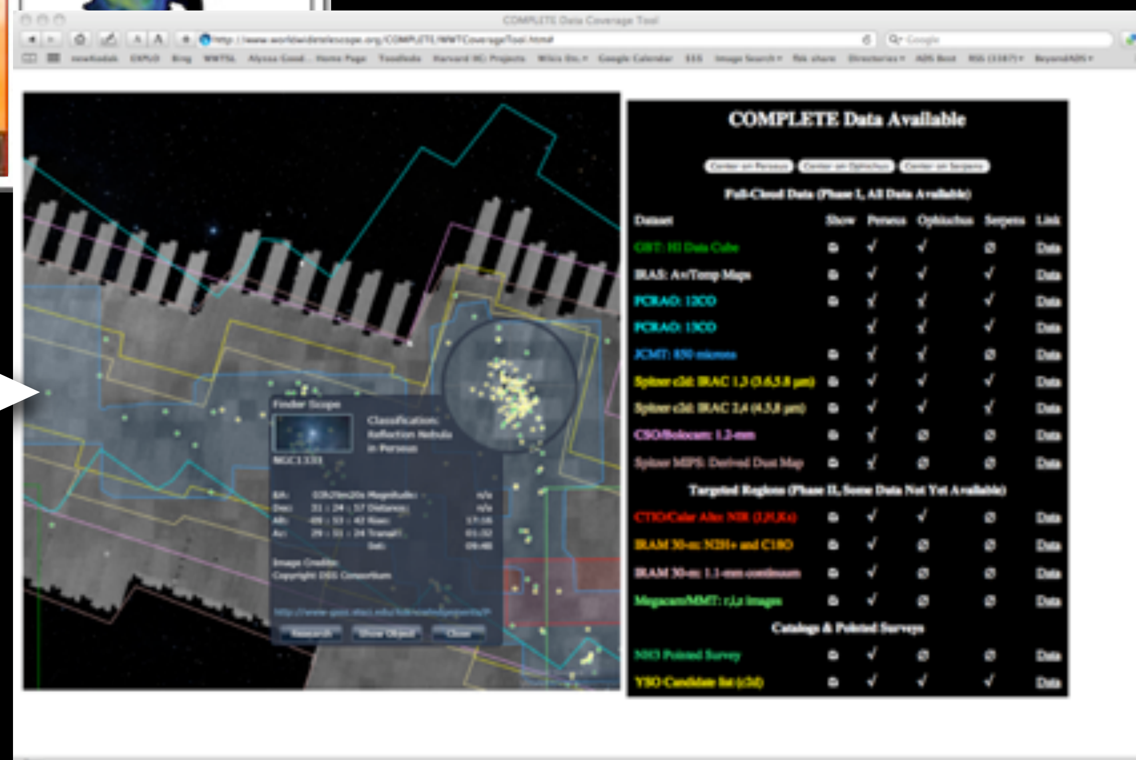
Figure 3 | Schematic illustration of the dendrogram process. Shown is the construction of a dendrogram from a hypothetical one-dimensional emission profile (black). The dendrogram (blue) can be constructed by 'dropping' a test constant emission level (purple) from above in tiny steps (exaggerated in 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.

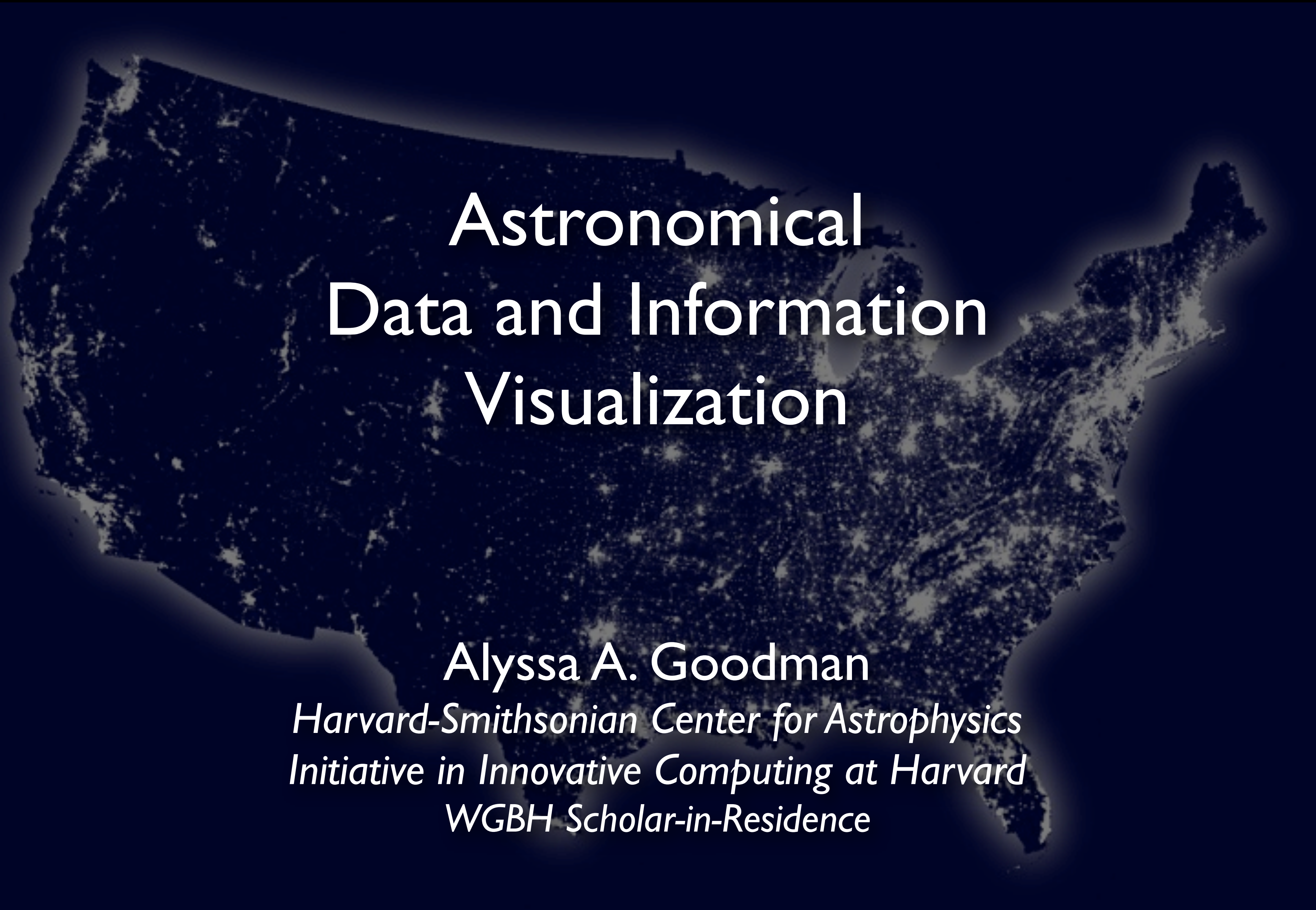
Goodman et al. *Nature*, 2009



Fiction
(for now)

Fact
(right now)





Astronomical Data and Information Visualization

Alyssa A. Goodman

Harvard-Smithsonian Center for Astrophysics

Initiative in Innovative Computing at Harvard

WGBH Scholar-in-Residence

Astronomical
Data and Information
Visualization

Organization, Anarchy, or
Organized Anarchy?


Sea
www.cfa.harvard.edu
telescope.org
Data
Literature
MAST
TerraServer USA
Specialized Project Site
Any and all paths to data
"Virtual Observatory" tools of variable utility
Astrometry.net
Standalone Analysis Software
IDL
Almost exclusively ADS
Advanced Search & InfoViz tools
ads
Google
arXiv.org
nature