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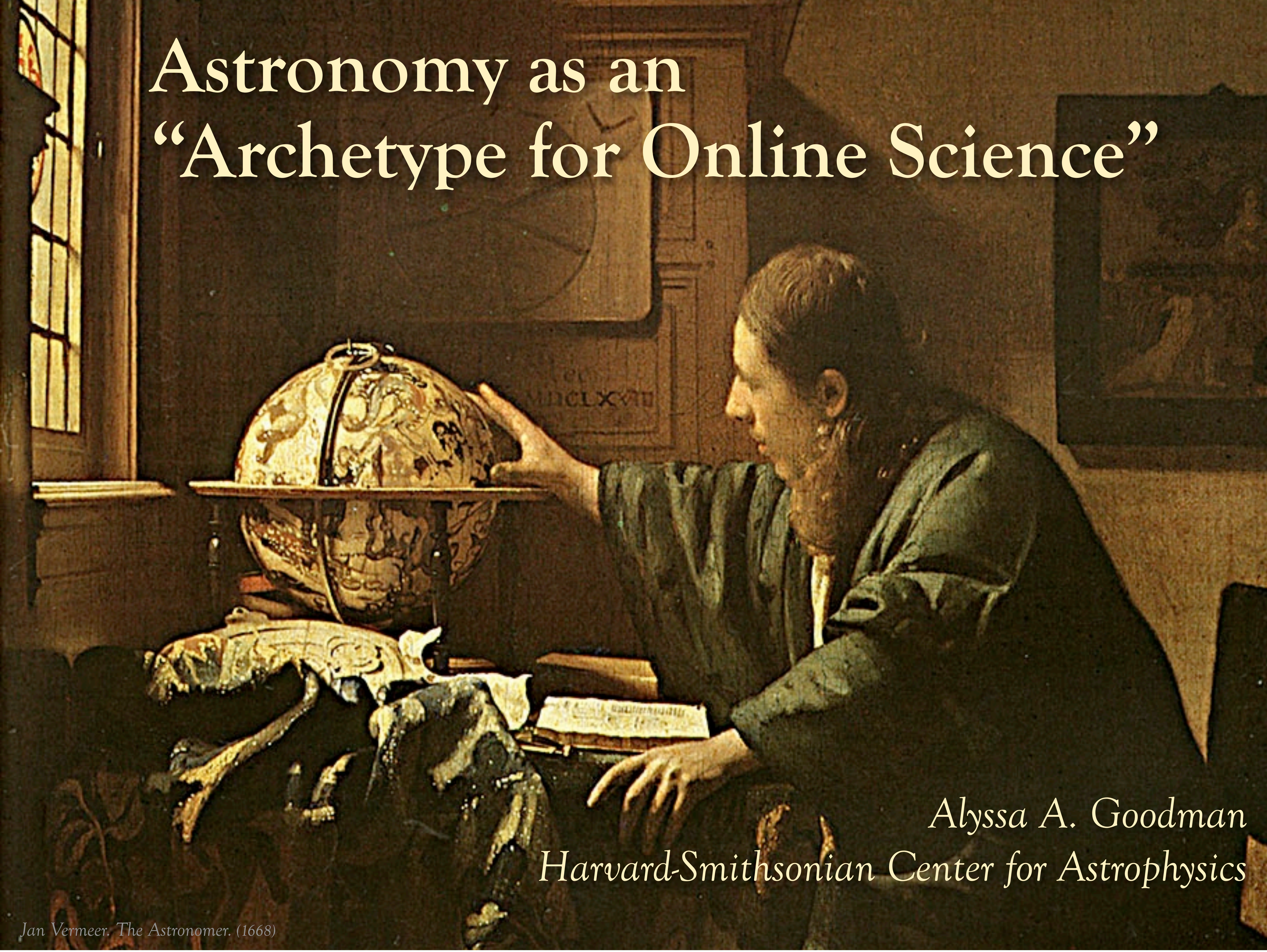
Astronomy as an “Archetype for Online Science”



Jan Vermeer. The Astronomer. (1668)

Alyssa A. Goodman
Harvard-Smithsonian Center for Astrophysics

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

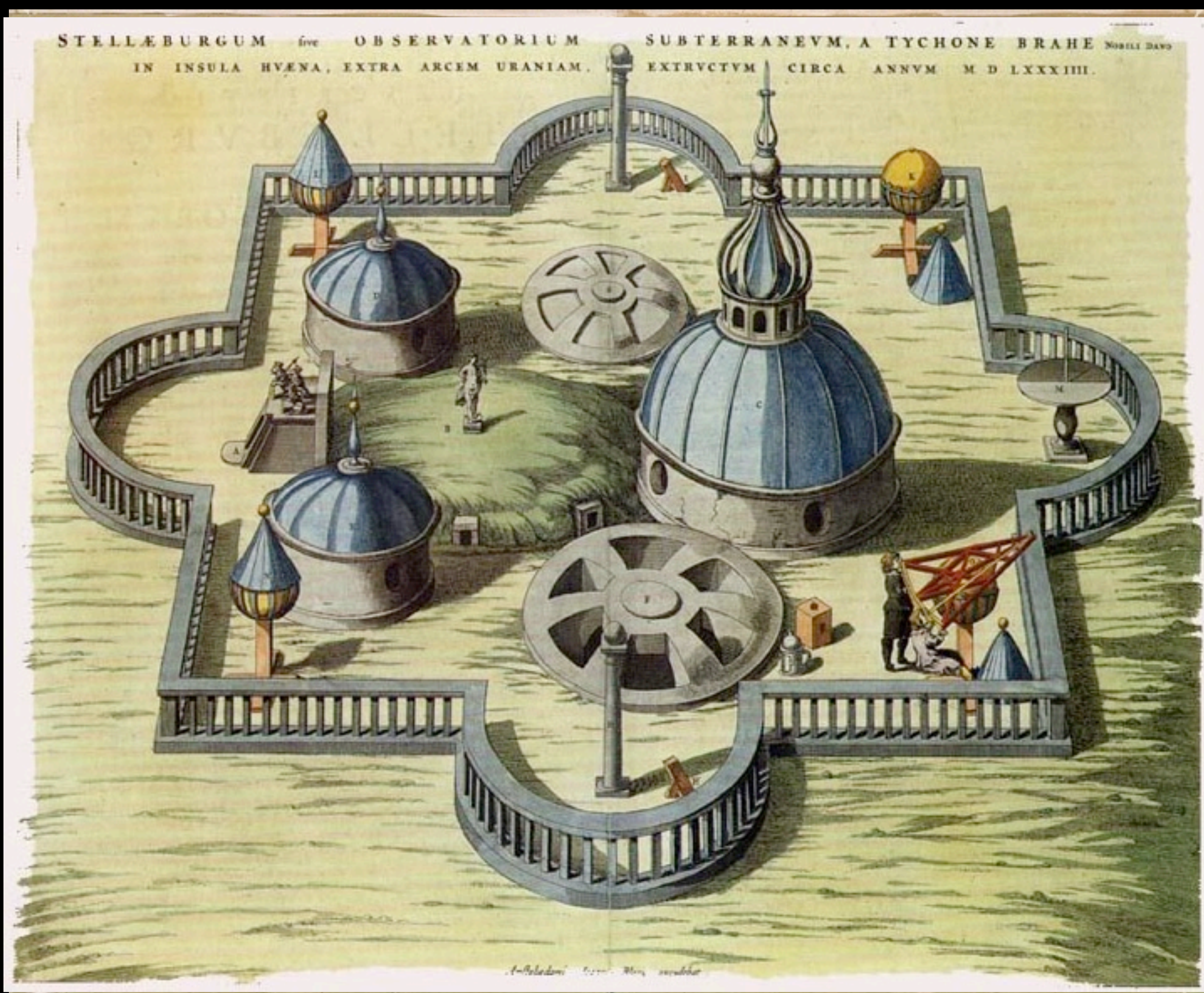
"The Internet"

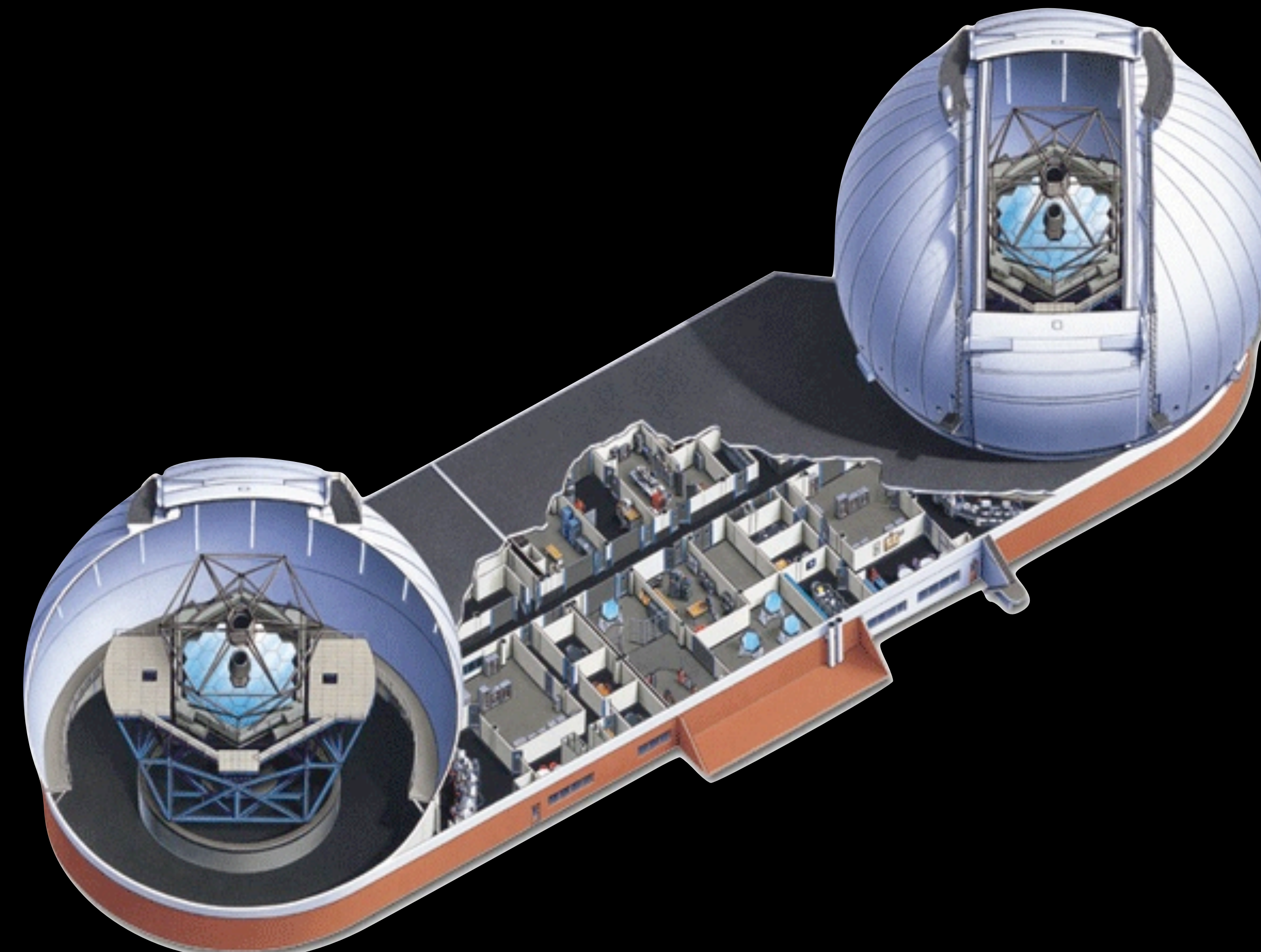
Long-distance remote-control/ "robotic" telescopes 1990s

"Virtual Observatories" 21st century

Stjerneborg / Uraniborg
(Tycho Brahe, 1581 / 1576)

W.H. Keck Observatory
(1995+)





Galileo: 1610

Full-sky virtual astronomy:
c. 2023?

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Observatory Tower, Lincolnshire, UK, c. 1300

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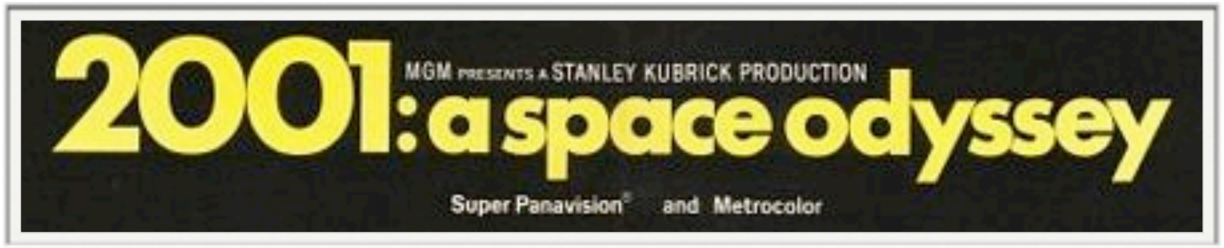
RVO
Astro Grid
Aus-VO
VObs.it
vo-i
CVO
SVO
Spanish Virtual Observatory
BRAVO
ArVO
Armenian Virtual Observatory
NVO
NATIONAL VIRTUAL OBSERVATORY
IVOA
China-VO
EURO VO
JVO
HVO
Hungarian Virtual Observatory
GERMAN ASTROPHYSICAL GAVO VIRTUAL OBSERVATORY
France



The World-Wide Telescope, an Archetype for Online Science

Jim Gray
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Gray@Microsoft.com

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The Johns Hopkins University
Szalay@jhu.edu

Abstract: Most scientific data will never be directly examined by scientists; rather it will be put into online databases where it will be analyzed and summarized by computer programs. Scientists increasingly see their instruments through online scientific archives and analysis tools, rather than examining the raw data. Today this analysis is primarily driven by scientists asking queries, but scientific archives are becoming active databases that self-organize and recognize interesting and anomalous facts as data arrives. In some fields, data from many different archives can be cross-correlated to produce new insights. Astronomy presents an excellent example of these trends; and, federating Astronomy archives presents interesting challenges for computer scientists.

Introduction

Computational Science is a new branch of most disciplines. A thousand years ago, science was primarily *empirical*. Over the last 500 years each discipline has grown a *theoretical* component. Theoretical models often motivate experiments and generalize our understanding. Today most disciplines have both empirical and theoretical branches. In the last 50 years, most disciplines have grown a third, *computational* branch (e.g. empirical, theoretical, and computational ecology, or physics, or linguistics.)

statistics among sets of data points in a metric space. Pair-algorithms on N points scale as N^2. If the data increase a thousand fold, the work and time can grow by a factor of a million. Many clustering algorithms scale even worse. These algorithms are infeasible for terabyte-scale datasets.

The new online science needs new data mining algorithms that use near-linear processing, storage, and bandwidth, and that can be executed in parallel. Unlike current algorithms that give exact answers, these algorithms will likely be heuristic and give approximate answers [Connolly, Szapudi].

Astronomy as an Archetype for Online Science

Astronomy exemplifies these phenomena. For thousands of years astronomy was primary empirical with few theoretical models. Theoretical astronomy began with Kepler is now co-equal with observation. Astronomy was early to adopt computational techniques to model stellar and galactic formation and celestial mechanics. Today, simulation is an important part of the field – producing new science, and solidifying our grasp of existing theories.

Astronomers are building telescopes that produce terabytes of data each year -- soon terabytes per night. In the old

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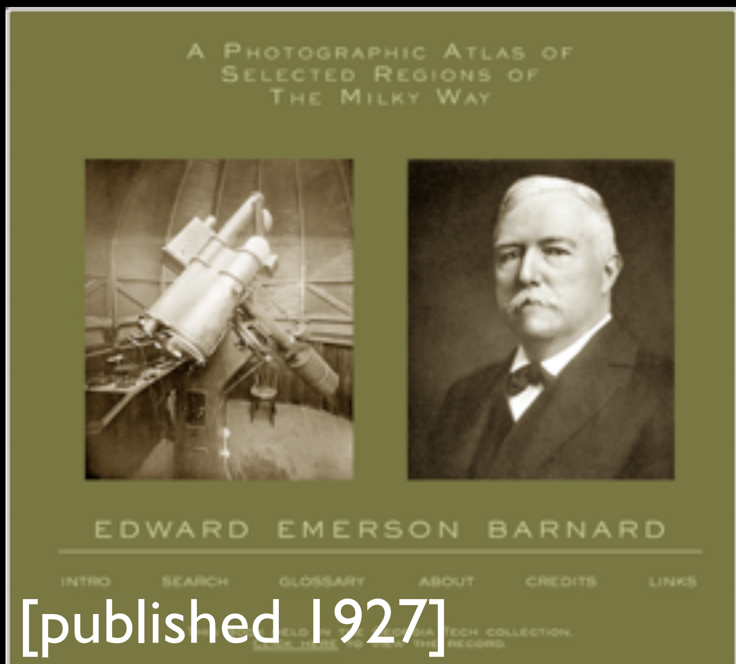
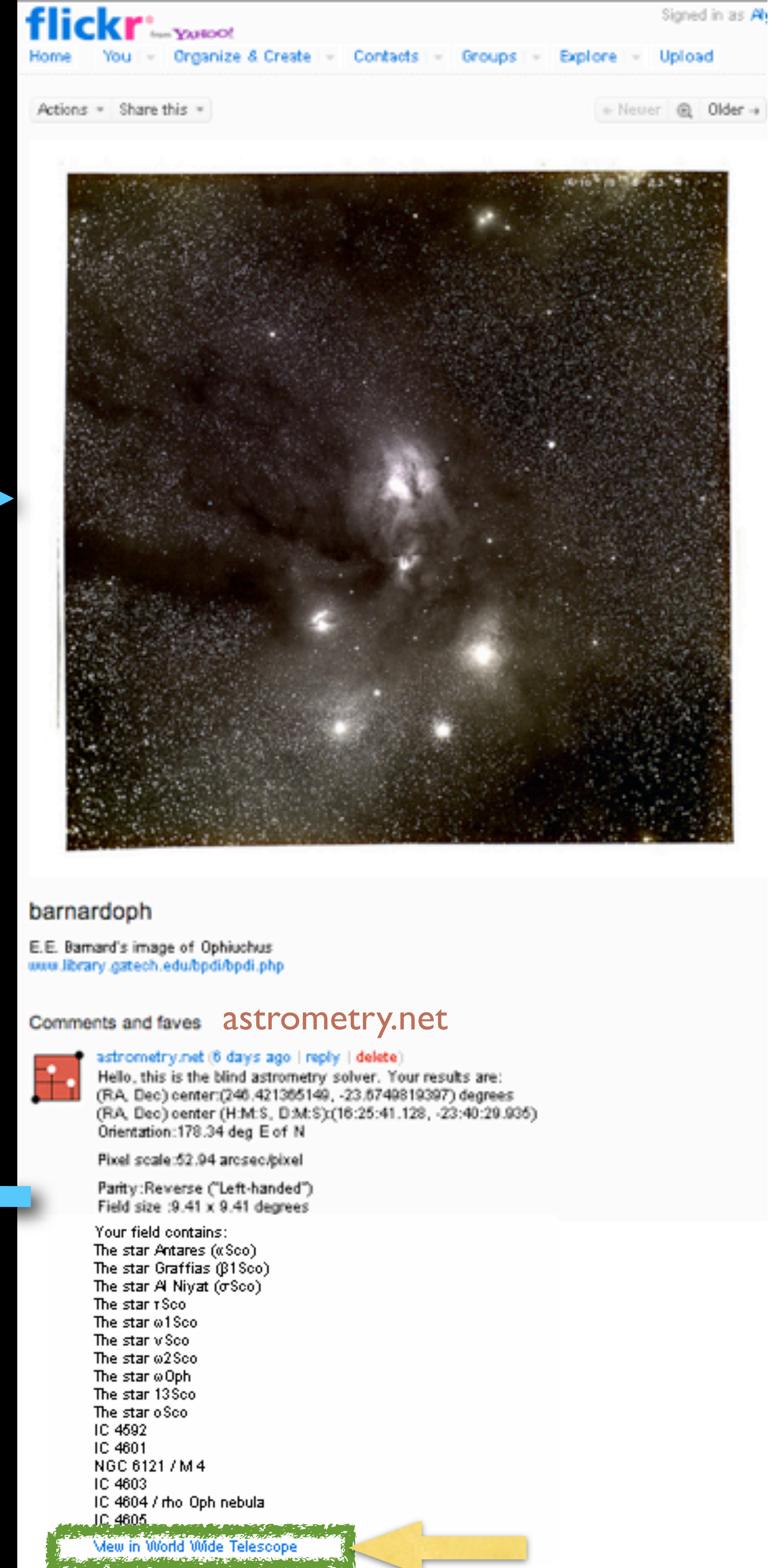
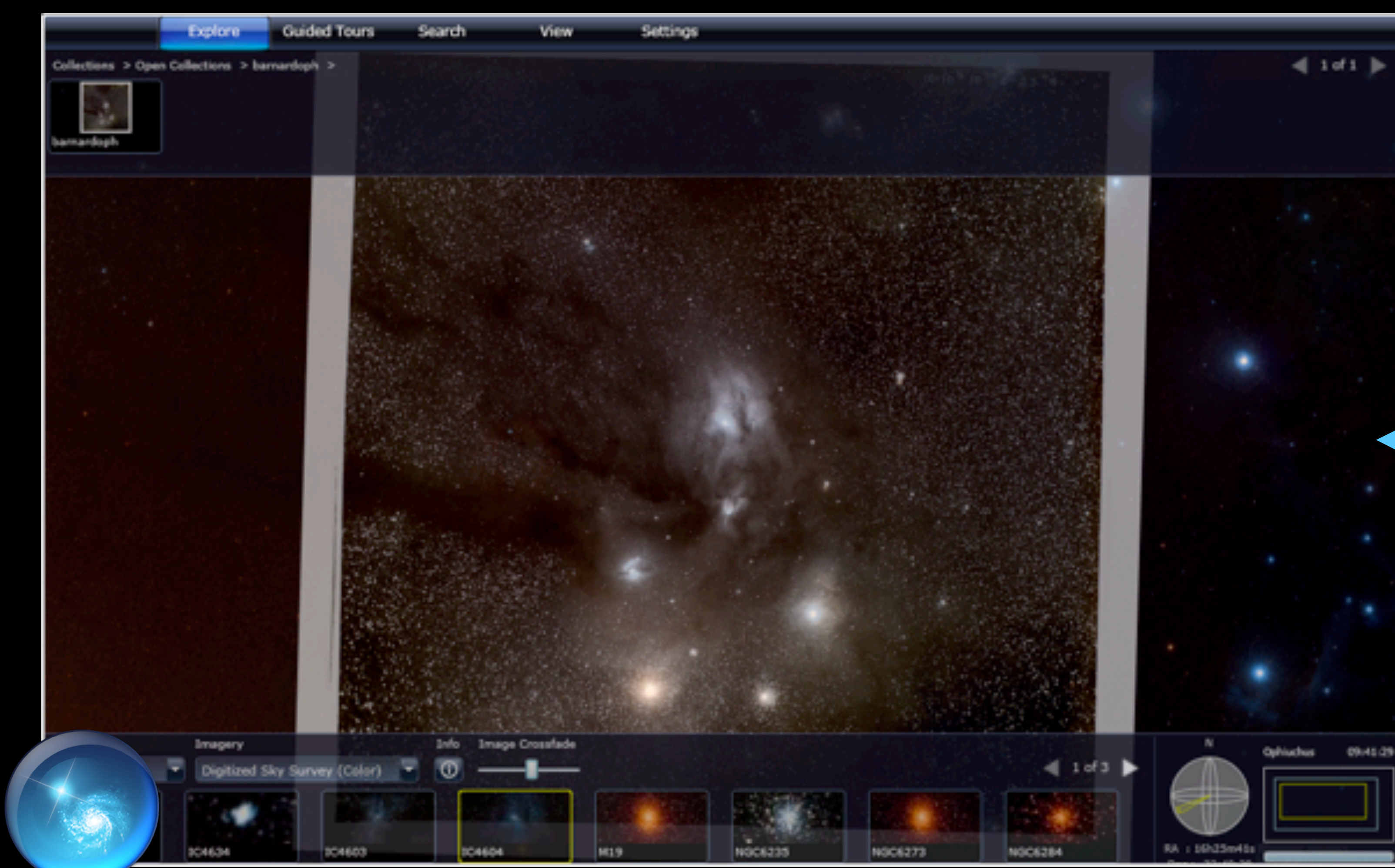
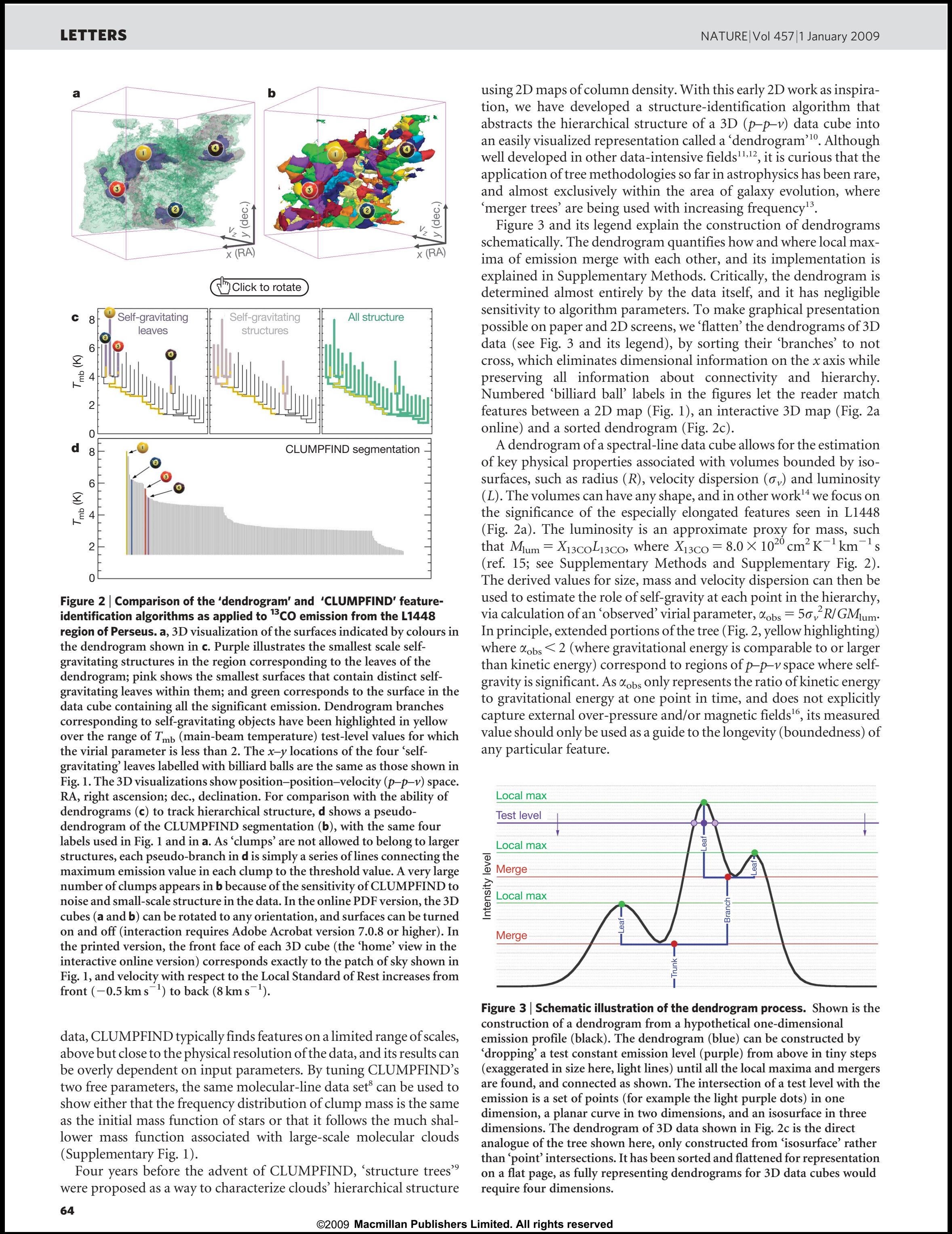






Data in *Literature*

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



NATURE|Vol 457|1 January 2009

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].

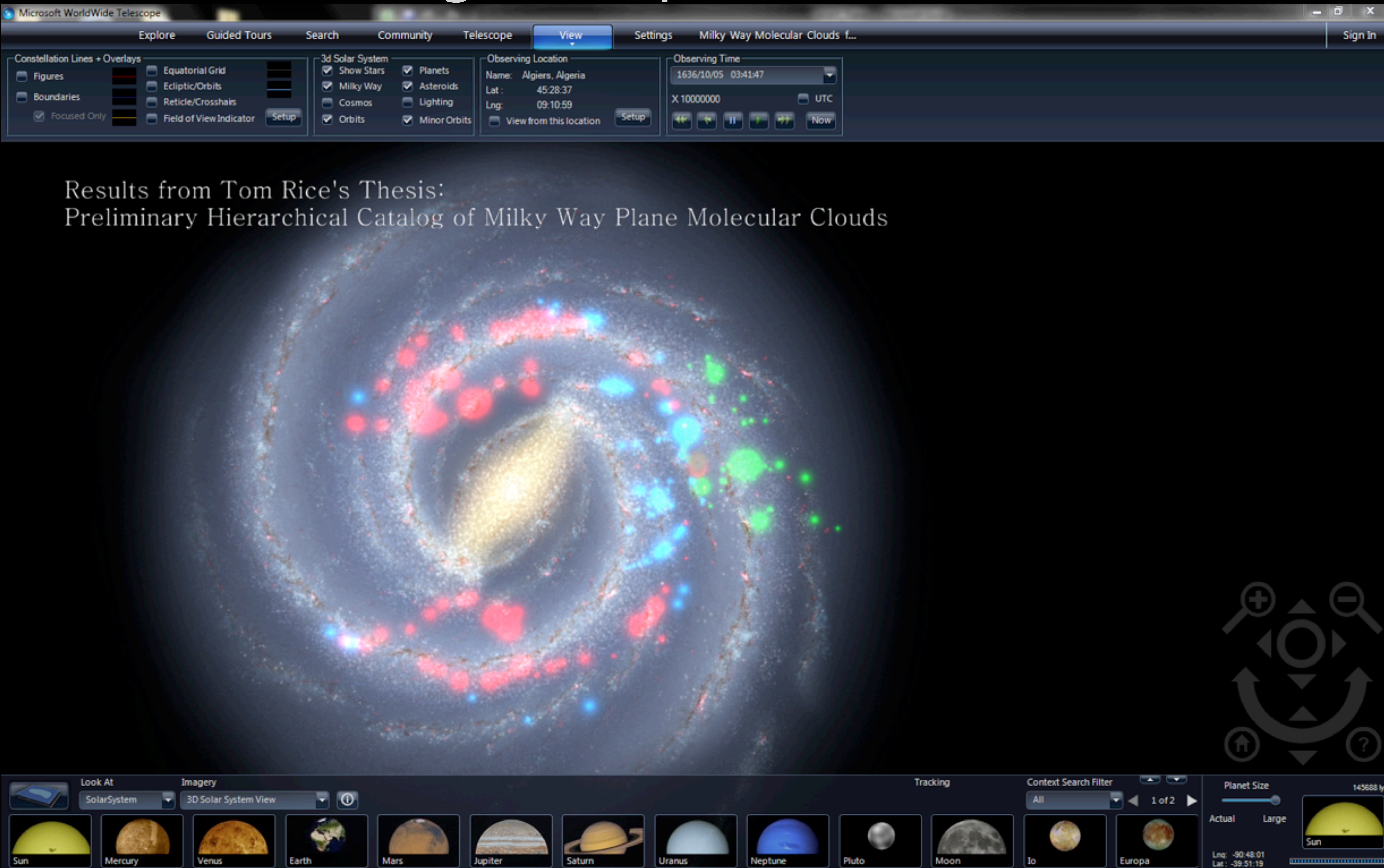
Figure 3 and its legend explain the construction of dendrograms schematically. The dendrogram quantifies how and where local maxima of emission merge with each other, and its implementation is explained in Supplementary Methods. Critically, the dendrogram is determined almost entirely by the data itself, 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.

Goodman et al. *Nature*, 2009

Winning a Hoopes Prize in 2012



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What is Universe3D.org?

The intention of Universe3D.org is to host links to web content that enable the enhancement of our three-dimensional view of the Universe.

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- People

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- Announcements
- Help

Toolbox

- What links here
- Related changes
- Upload file
- Special pages
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- Permanent link

Recently added Dataset

SLOAN Digital Sky Survey The Sloan Digital Sky Survey or SDSS is a major multi-filter imaging and spectroscopic redshift survey using a dedicated 2.5-m wide-angle optical telescope at Apache Point Observatory in New Mexico, United States. The main galaxy sample has a median redshift of z = 0.1; there are redshifts for luminous red galaxies as far as z = 0.7, and for quasars as far as z = 5; and the imaging survey has been involved in the detection of quasars beyond a redshift z = 6.

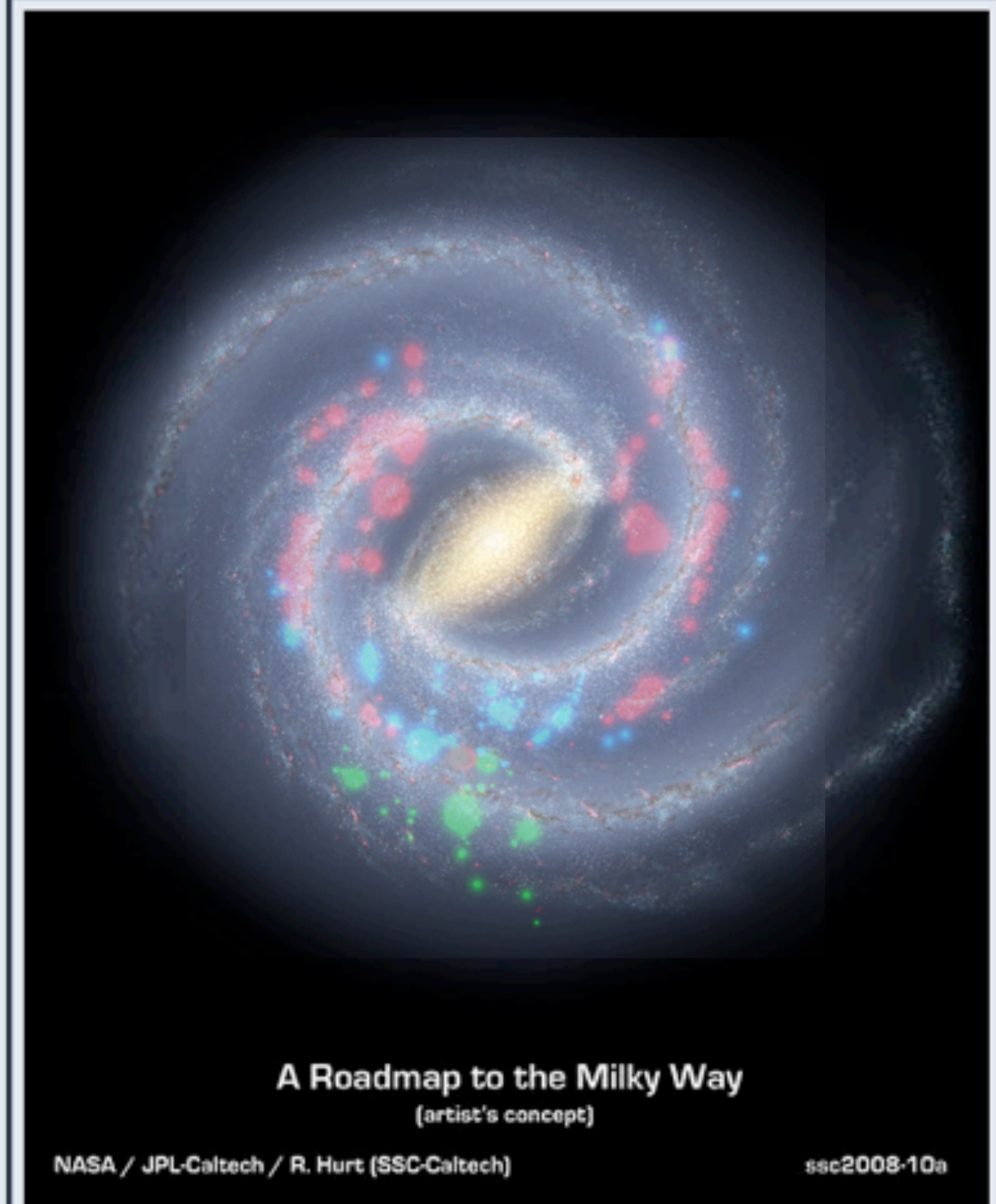
Astronomy News

- *June 26, 2012:* Astronomers use supercomputer to explore role of dark matter in galaxy formation
- *June 25, 2012:* Moon to pass by Mars tonight
- *June 24, 2012:* Astronomers find planets so close they 'see' each other in night sky
- *June 14, 2012:* Huge Asteroid to fly by Earth
- *June 13, 2012:* Astronomers may have discovered the oldest galaxy in the Universe
- *June 5, 2012:* Last Transit of Venus for the 21st century

Announcements

- *July 05, 2012:* Website moved to the URL universe3d.org!
- *June 11, 2012:* Website moved to MediaWiki!
- *December 5, 2011:* Site established!
  To make good on Alyssa Goodman's promise at the "Milky Way 2011" meeing held in Rome this past September, the site "universe3d.org" has been established. By 2012, it will be populated with links to existing data

The Milky Way



SEAMLESS ASTRONOMY

Linking scientific data, publications, and communities

ABOUT PROJECTS PEOPLE RESOURCES DATAVERSE

SEAMLESS ASTRONOMY

About

The **Seamless Astronomy Group** at the **Harvard-Smithsonian Center for Astrophysics** brings together astronomers, computer scientists, information scientists, librarians and visualization experts involved in the development of tools and systems to study and enable the next generation of **online astronomical research**.

Current projects include research on the development of systems that seamlessly integrate scientific data and literature, the semantic interlinking and annotation of scientific resources, the study of the impact of social media and networking sites on scientific dissemination, and the analysis and visualization of astronomical research communities. Visit our project page to find out more.

SHARE

Latest Announcements

Introducing the Astronomy Dataverse

Latest Feed Items

@rahuldave there is a writeboard with my notes... More at next #seamlessastronomy next week.

Thanks to @astrobites and @astroknight06 for great summary http://t.co/jWWFT0CD of our High-D Data Viz work! #ivoa #seamlessastronomy

SEAMLESS ASTRONOMY

Projects

ADS Labs

ADS All-SKy Survey (ADSASS)

ADS All Sky Survey

can be found on this conference paper.

Astronomy Dataverse

Astronomy Dataverse

hosted by Harvard University and managed by the Institute for Quantitative Social Science (IQSS), as a project-based repository for the storage, access, and citation of reduced astronomical data. We have interviewed a set of 10 astronomers about their needs, and the prototype CfA Dataverse is now online.

WorldWide Telescope

High-D Visualization

high-dimensional data, and the integration of WorldWide Telescope into research and teaching paradigms.

Social Networks

Collaboration Networks

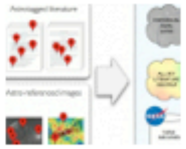
Data Citation

Semantic Search

SEAMLESS ASTRONOMY

Projects

ADS Labs



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WorldWide Telescope

High-D Visualization

high-dimensional data, and the integration of WorldWide Telescope into research and teaching paradigms.

Study of the impact of social media and networking sites on scientific dissemination

Social Networks

Astronomers, and more broadly, the scientific community, are increasingly using blogging, micro-blogging and other social media for both discovering and disseminating scientific knowledge. We are exploring several avenues for studying the impact of Twitter and other social networking sites on scientific readership.

Collaboration Networks

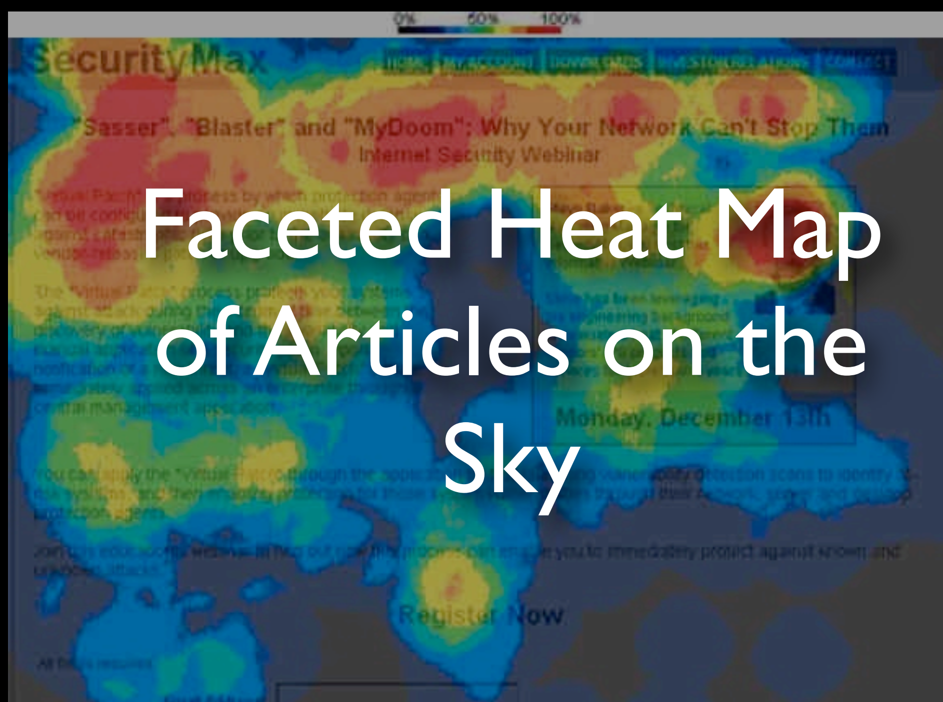
Data Citation

Semantic description and annotation of scientific resources

RDF store and facets, and links to semantic ADS.

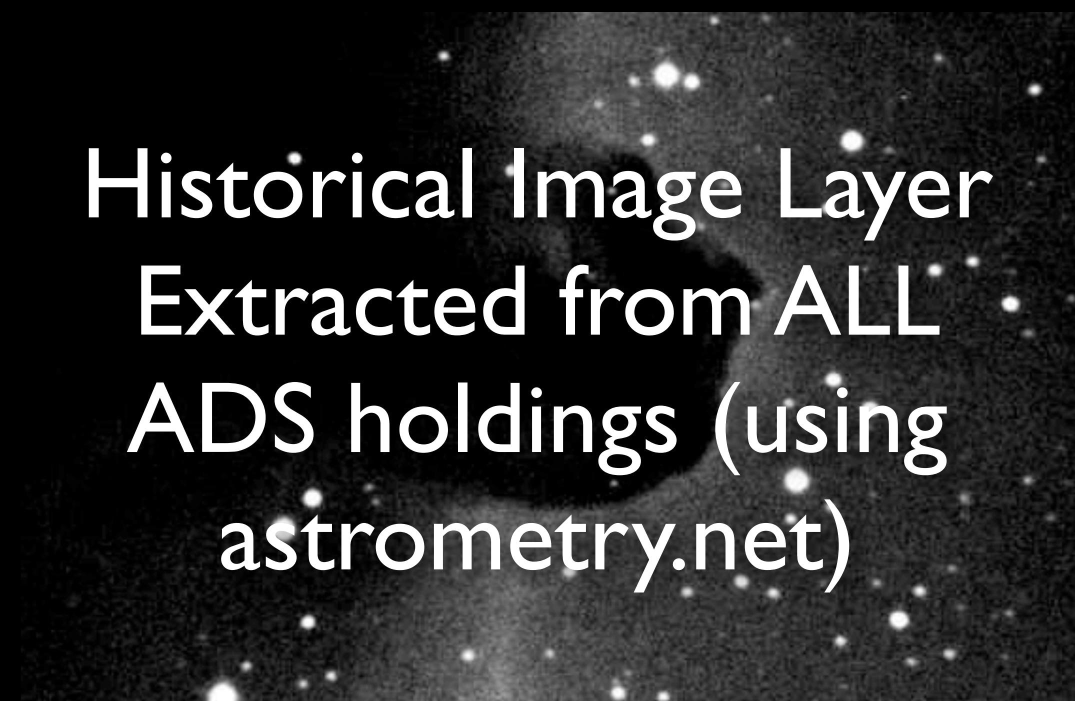
Semantic Search

ADS All Sky Survey



Faceted Heat Map of Articles on the Sky

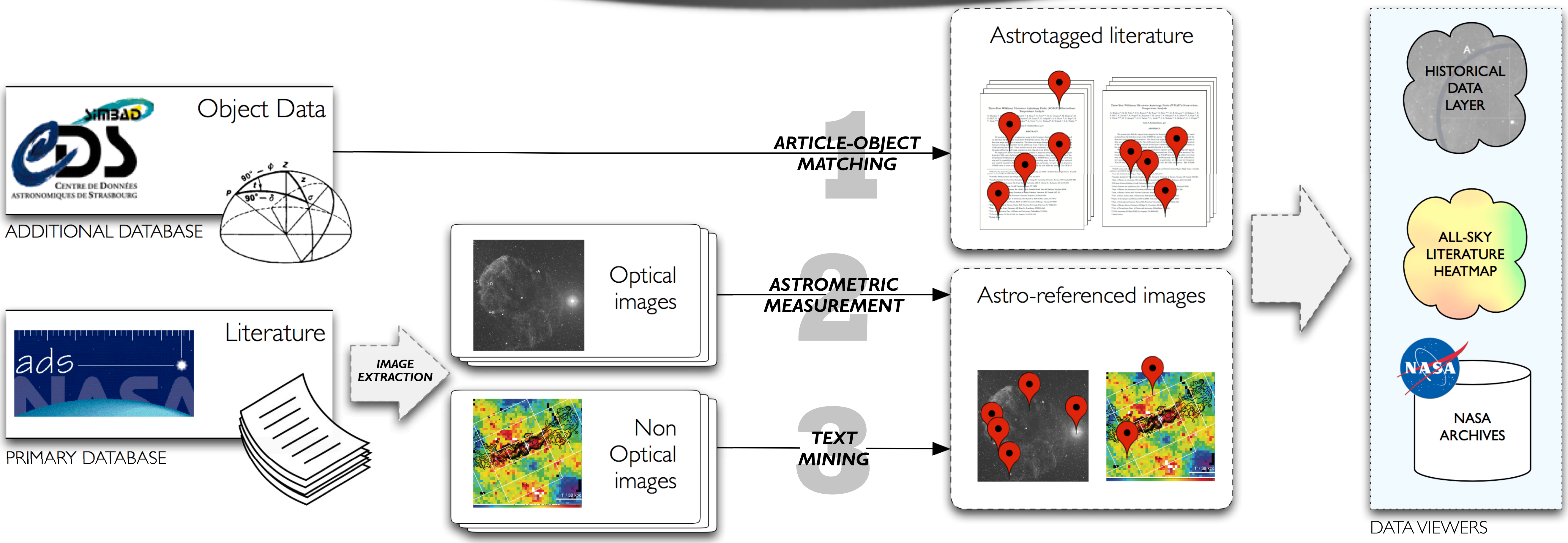
ADS-CDS-Seamless collaboration

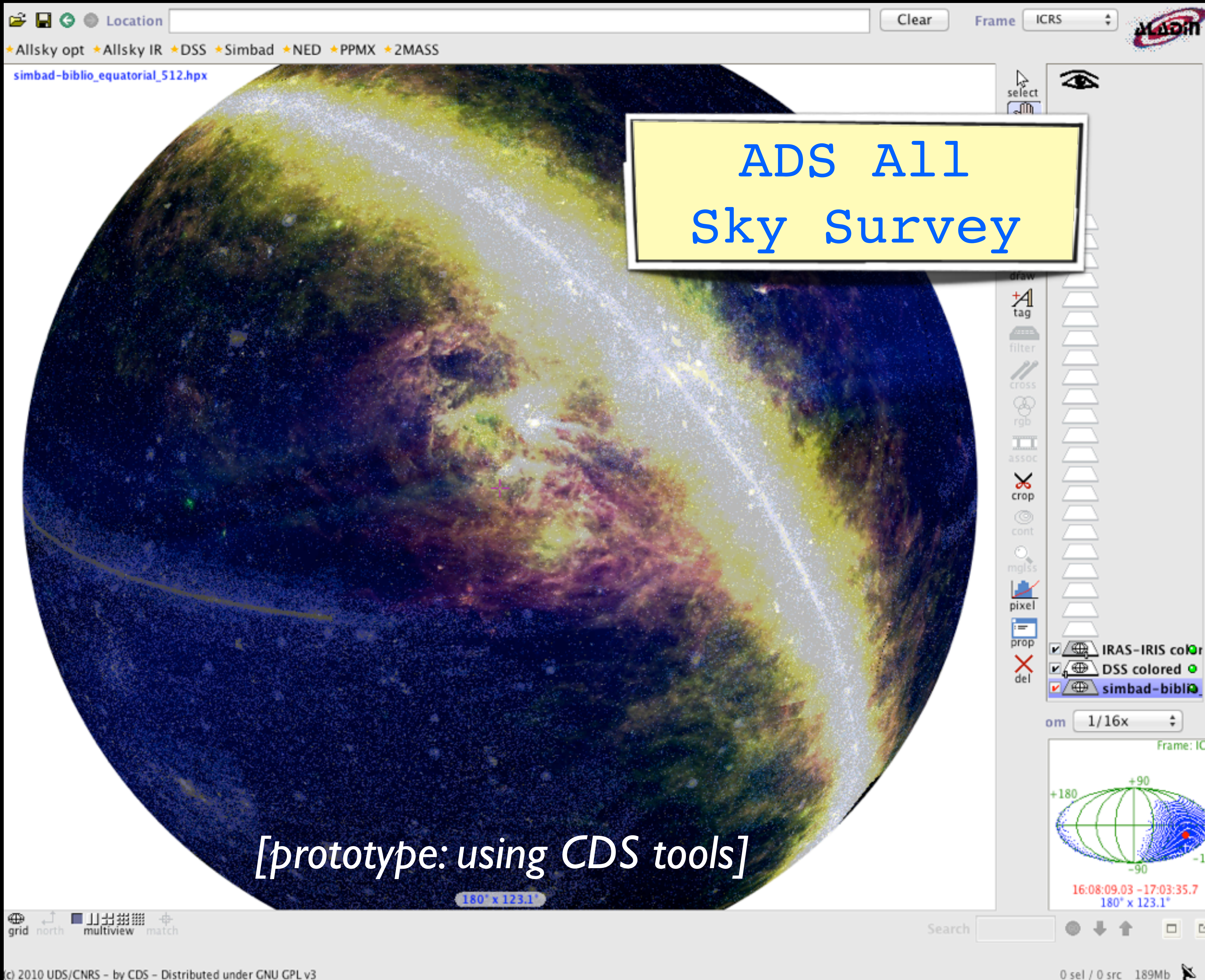


Historical Image Layer Extracted from ALL ADS holdings (using astrometry.net)

ADS-Seamless-astrometry.net collaboration

ADS All Sky Survey

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180° x 123.1°
select
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cont
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pixel
prop
del
IRAS-IRIS color
DSS colored
simbad-biblio
1/16x
Frame: ICRS
+90
+180
-90
16:08:09.03 -17:03:35.7
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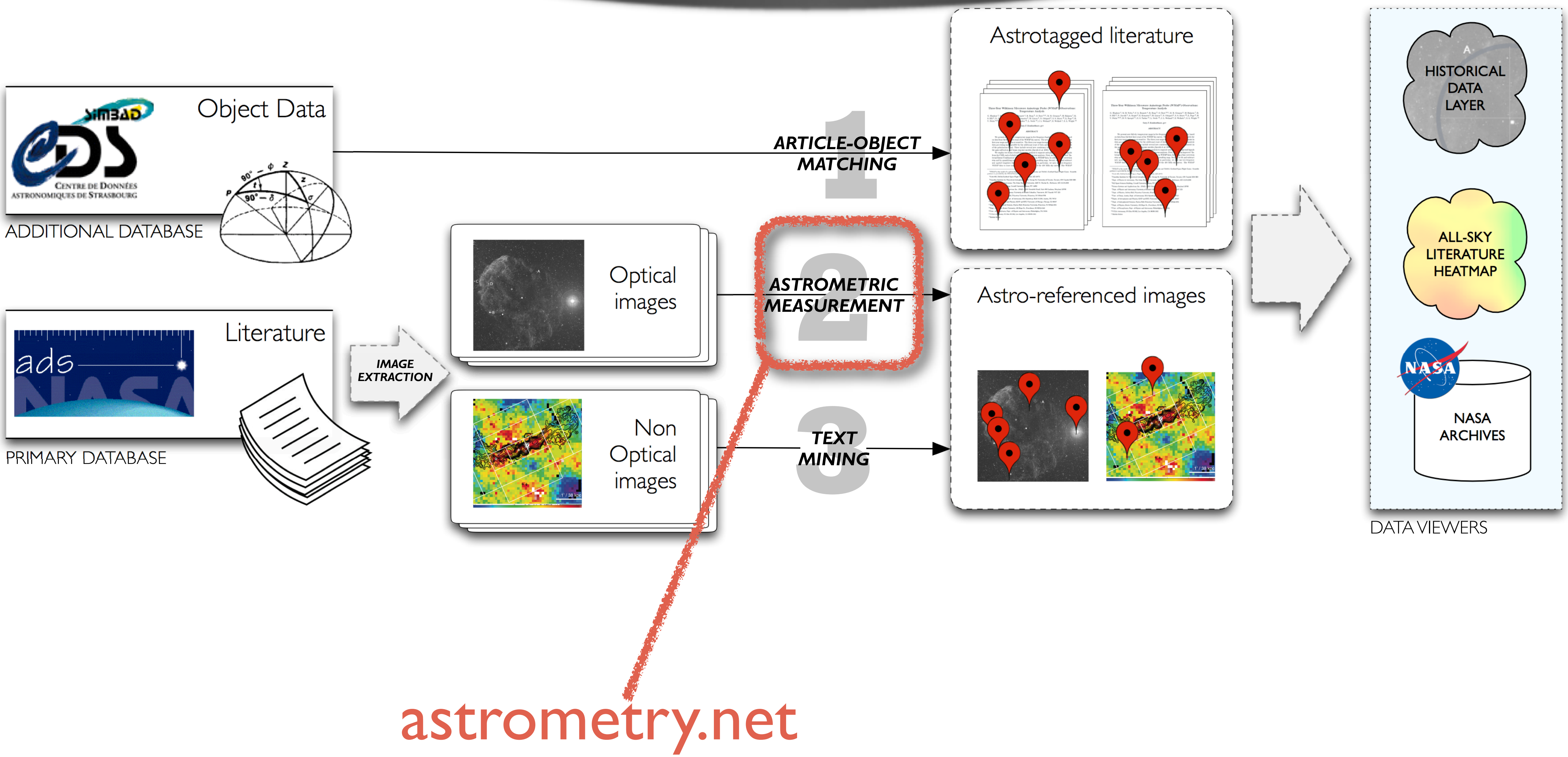
ADS All Sky Survey



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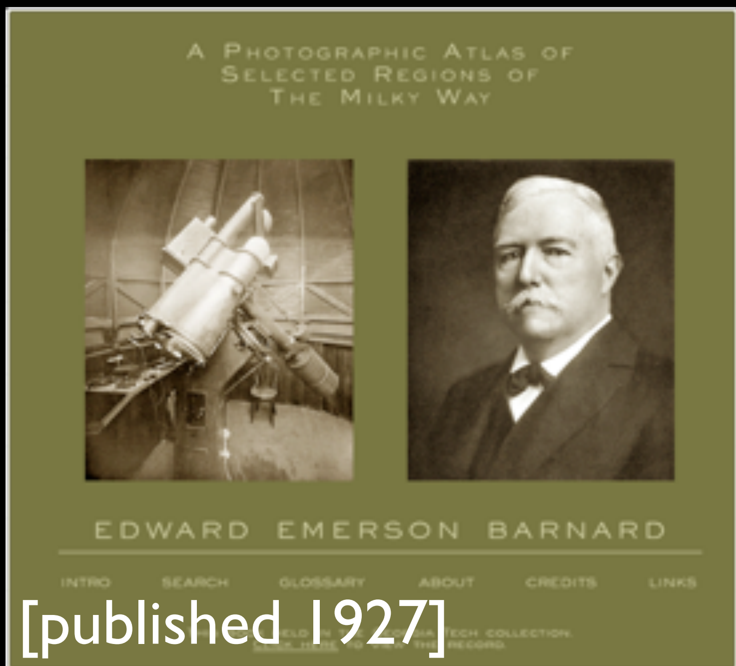
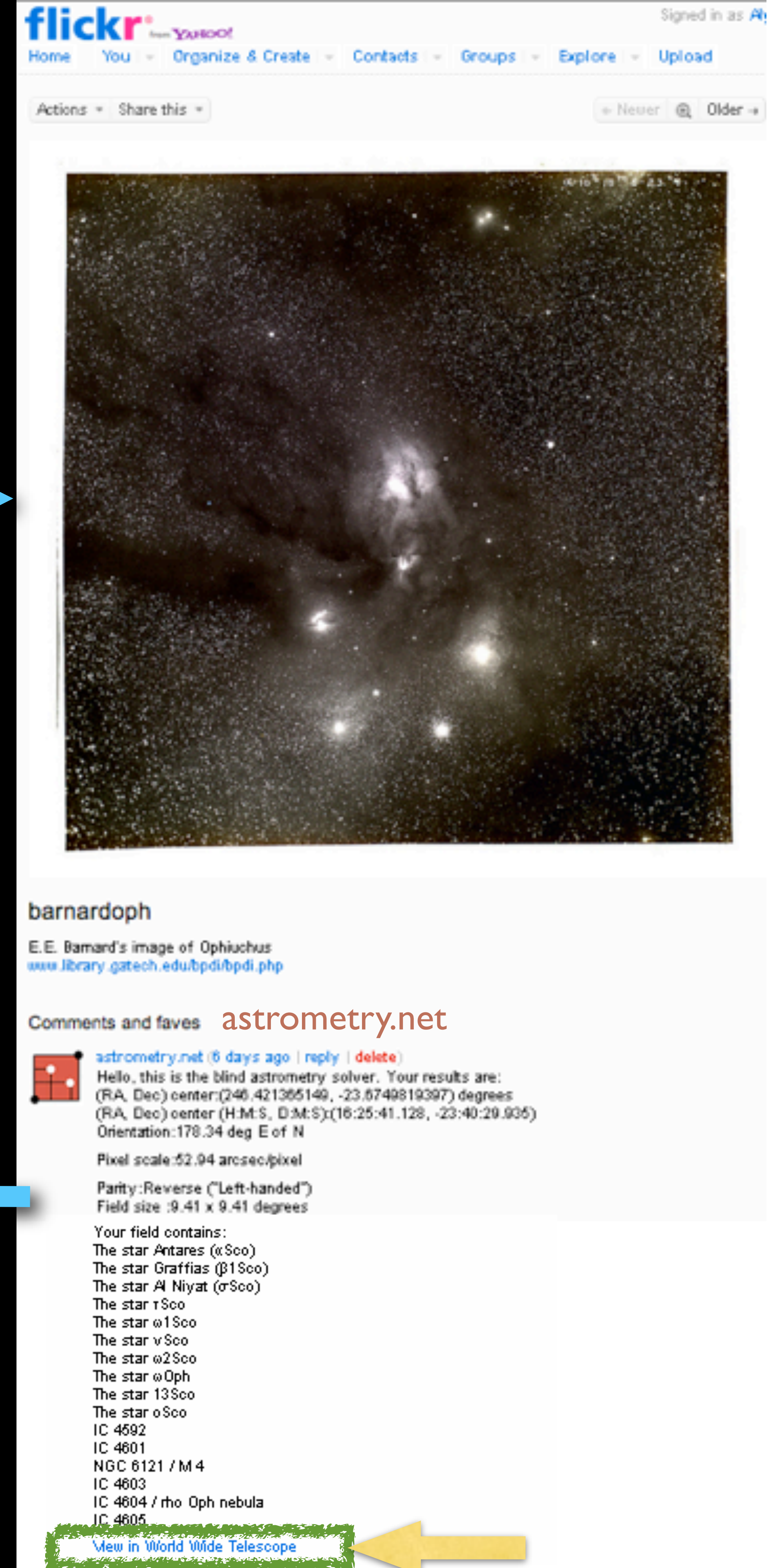
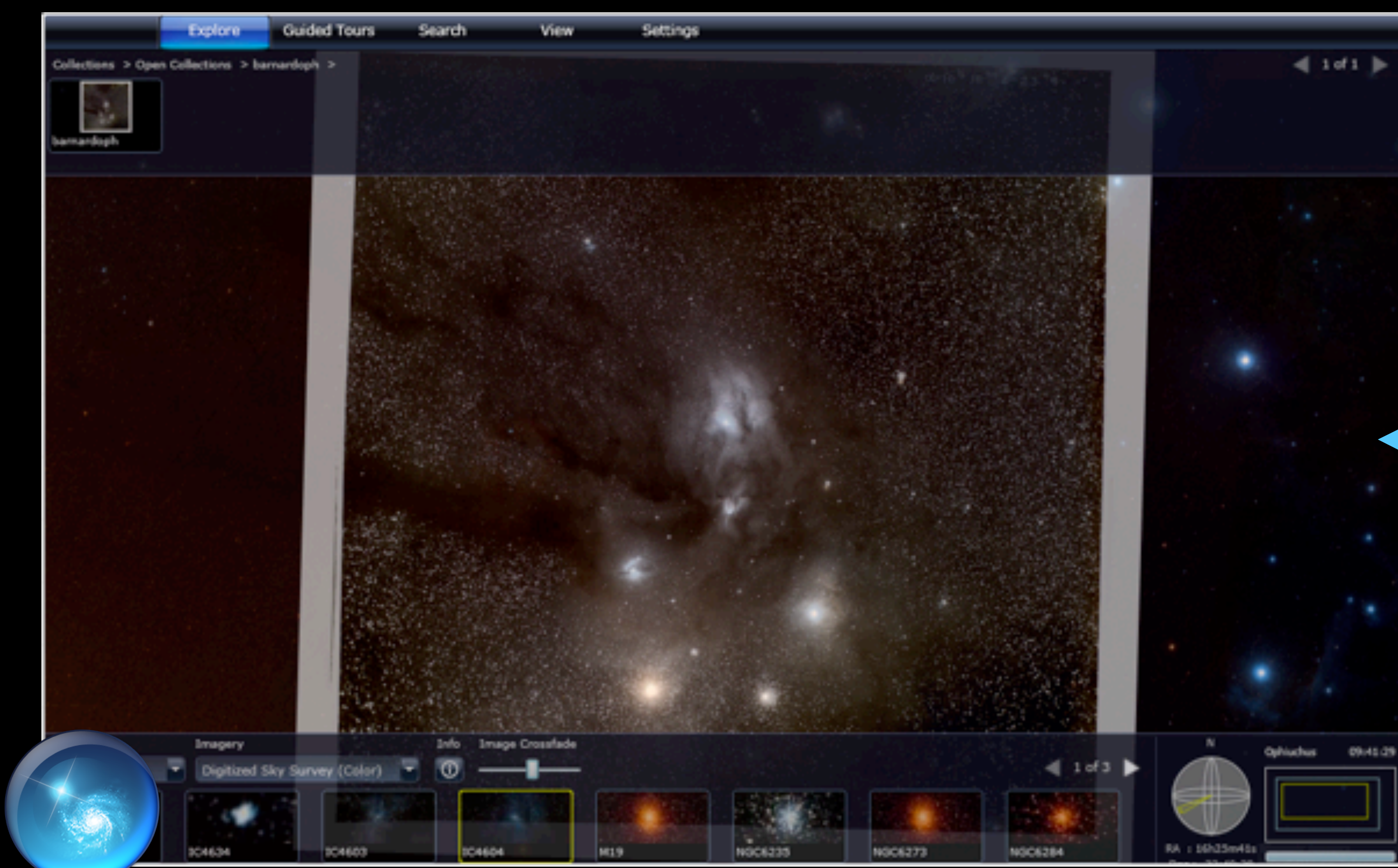
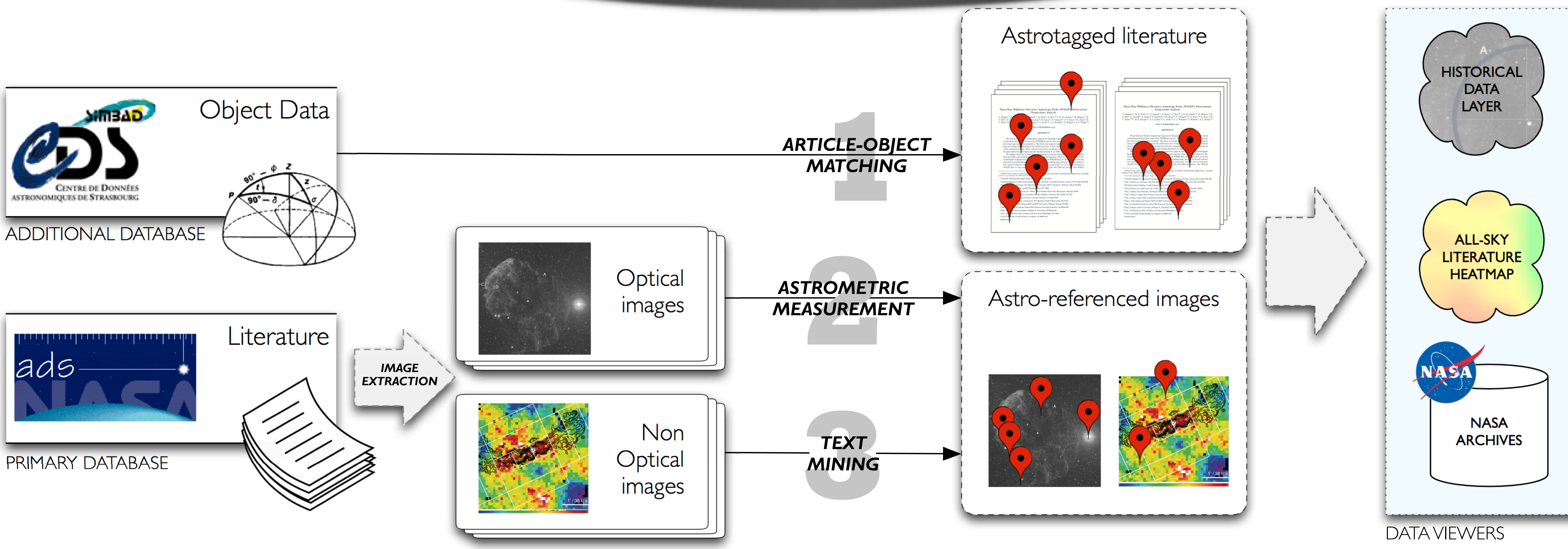






ADS All Sky Survey



>1 Million Articles, like this one

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INVESTIGATING THE COSMIC-RAY IONIZATION RATE NEAR THE SUPERNOVA REMNANT IC 443 THROUGH H_3^+ OBSERVATIONS[1,2]

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Draft version October 18, 2010

ABSTRACT

Observational and theoretical evidence suggests that high-energy Galactic cosmic rays are primarily accelerated by supernova remnants. If also true for low-energy cosmic rays, the ionization rate near a supernova remnant should be higher than in the general Galactic interstellar medium (ISM). We have searched for H_3^+ absorption features in 6 sight lines which pass through molecular material near IC 443—a well-studied case of a supernova remnant interacting with its surrounding molecular material—for the purpose of inferring the cosmic-ray ionization rate in the region. In 2 of the sight lines (toward ALS 8828 and HD 254577) we find large H_3^+ column densities, $N(H_3^+) \approx 3 \times 10^{14}$ cm^{-2}, and deduce ionization rates of $\zeta_2 \approx 2 \times 10^{-15}$ s^{-1}, about 5 times larger than inferred toward average diffuse molecular cloud sight lines. However, the 3σ upper limits found for the other 4 sight lines are consistent with typical Galactic values. This wide range of ionization rates is likely the result of particle acceleration and propagation effects, which predict that the cosmic-ray spectrum and thus ionization rate should vary in and around the remnant. While we cannot determine if the H_3^+ absorption arises in post-shock (interior) or pre-shock (exterior) gas, the large inferred ionization rates suggest that IC 443 is in fact accelerating a large population of low-energy cosmic rays. Still, it is unclear whether this population can propagate far enough into the ISM to account for the ionization rate inferred in diffuse Galactic sight lines.

Subject headings: astrochemistry – cosmic rays – ISM: supernova remnants

1. INTRODUCTION

As cosmic rays propagate through the interstellar medium (ISM) they interact with the ambient material. These interactions include excitation and ionization of atoms and molecules, spallation of nuclei, excitation of nuclear states, and the production of neutral pions (π^0) which decay into gamma-rays. Evidence suggests that Galactic cosmic rays are primarily accelerated by supernova remnants (SNRs) through the process of diffusive shock acceleration (e.g. Drury 1983; Blandford & Eichler 1987), so interstellar clouds in close proximity to an SNR should provide a prime "laboratory" for studying these interactions. IC 443 represents such a case, as portions of the SNR shock are known to be interacting with the neighboring molecular clouds.

IC 443 is an intermediate age remnant (about 30,000 yr; Chevalier 1999) located in the Galactic anti-center region $(l, b) \approx (189°, +3°)$ at a distance of about 1.5 kpc in the Gem OB1 association (Welsh & Sallmen 2003), and is a particularly well-studied SNR. Figure 1 shows the red image of IC 443 taken during the Second Palomar Observatory Sky Survey. The remnant is composed of subshells A and B; shell A is to the NE—its center at $\alpha = 06^h17^m08.4^s$, $\delta = +22°36'39.4''$ J2000.0 is marked by the cross—while shell B is to the SW. Adopting a distance of 1.5 kpc, the radii of subshells A and B are about 7 pc and 11 pc, respectively. Between the subshells is a darker lane that runs across the remnant from the NW to SE. This is a molecular cloud which has been mapped in ^{12}CO emission (Cornett et al. 1977; Dickman et al. 1992; Zhang et al. 2009), and is known to be in the foreground because it absorbs X-rays emitted by the hot remnant interior (Troja et al. 2006). Aside from this quiescent foreground cloud, observations of the $J = 1 \rightarrow 0$ line of ^{12}CO also show shocked molecular material coincident with IC 443 (DeNoyer 1979; Huang et al. 1986; Dickman et al. 1992; Wang & Scoville 1992). These shocked molecular clumps first identified by DeNoyer (1979) and Huang et al. (1986) in CO have also been observed in several atomic and small molecular species (e.g. White et al. 1987; Burton et al. 1988; van Dishoeck et al. 1993; White 1994; Snell et al. 2005), and are thought to be the result of the expanding SNR interacting with the surrounding ISM. While many of the shocked clumps are coincident with the quiescent gas, it

[1] Some of the presented herein were obtained at the W.M. Keck Observatory, which is operated as a scientific partnership among the California Institute of Technology, the University of California and the National Aeronautics and Space Administration. The Observatory was made possible by the generous financial support of the W.M. Keck Foundation.
[2] Based in part on data collected at Subaru Telescope, which is operated by the National Astronomical Observatory of Japan.
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[5] Max-Planck-Institut für Astronomie, Königstuhl 17, Heidelberg D-69117, Germany
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[7] Department of Astronomy and Astrophysics and Department of Chemistry, University of Chicago, Chicago, IL 60637
[8] Gemini Observatory, 670 North A'ohoku Place, Hilo, HI 96720
[9] Department of Physics, University of Illinois at Urbana-Champaign, Urbana, IL 61801
[10] Department of Chemistry, University of Illinois at Urbana-Champaign, Urbana, IL 61801

Table 1
...didate New and Extended Outflow Locations

					Momentum ($M_\odot$ km s^{-1})	Kinetic Energy (10^{42} erg)	Driving Source Candidate(s)
					0.19	6.93	L1448-IRS1
					0.88	21.68	L1448-IRS1
CPOC 3	03:24:30	30:50:00	10 × 5	0.02	0.08	2.93	L1448-IRS3
CPOC 4	03:24:54	30:43:10	4 × 4	0.01	0.04	2.10	Multiple in L1448
CPOC 5	03:25:39	30:28:20	7 × 5	0.02	0.05	1.32	SSTc2dJ032519.52+303424.2
CPOC 6	03:27:55	31:19:50	4 × 3	0.02	0.03	0.36	Multiple NGC 1333, near HH 338
CPOC 7	03:28:00	31:03:40	15 × 12	0.29	1.79	112.00	SSTc2dJ032834.49+310051.1
CPOC 8	03:28:32	30:28:20	8 × 11	0.11	0.28	7.17	Near HH 750 and HH 743, SSTc2dJ032835.03+302009.9 or SSTc2dJ032906.05+303039.2
CPOC 9	03:28:28	31:13:20	8 × 8	0.26	0.56	12.63	SSTc2dJ032832.56+311105.1 or SSTc2dJ032837.09+311330.8
CPOC 10	03:28:27	31:23:20	8 × 8	0.24	0.42	7.50	SSTc2dJ032844.09+312052.7
CPOC 11	03:28:40	31:07:10	8 × 6	0.11	0.27	7.01	STTc2dJ032834.53+310705.5
CPOC 12	03:28:43	31:07:30	8 × 7	0.19	0.97	52.02	SSTc2dJ032843.24+311042.7
CPOC 13	03:28:50	31:27:10	6 × 8	0.31	0.80	21.00	Multiple in NGC 1333
CPOC 14	03:28:57	30:50:20	6 × 5	0.03	0.05	0.73	SSTc2dJ032850.62+304244.7 or SSTc2dJ032852.17+304505.5
CPOC 15	03:29:07	30:45:50	7 × 5	0.19	0.80	32.82	SSTc2dJ032850.62+304244.7 or SSTc2dJ032852.17+304505.5
CPOC 16	03:29:30	31:07:10	6 × 6	0.04	0.10	2.40	HH 18A, multiple in NGC 1333
CPOC 17	03:29:41	31:17:30	9 × 13	3.20	8.49	235.28	Near HH 497, HH 336, multiple in NGC 1333
CPOC 18	03:29:41	31:27:10	5 × 6	0.08	0.21	6.35	HH 764, multiple in NGC 1333
CPOC 19	03:29:27	31:34:00	9 × 7	0.19	0.59	19.31	IRAS 03262+3123
CPOC 20	03:30:06	31:27:10	5 × 4	0.04	0.08	1.73	Multiple NGC 1333
CPOC 21	03:30:11	31:14:00	8 × 5	0.05	0.13	3.45	HH 767, SSTc2dJ033024.08+311404.4

N	Identifier	Otype	ICRS (J2000) RA	ICRS (J2000) DEC	Sp type	#ref 1850 - 2011	#notes
1	* zet Per	V*	03 54 07.9215	+31 53 01.088	B1Ib	706	1
2	CCDM J03554+3103A	**	03 55 23.0773	+31 02 45.014	O9.5IIIe-B0Ve	720	0
3	NAME ELNATH	*i*	05 26 17.5134	+28 36 26.820	B7III	287	1
4	* zet Tau	Be*	05 37 38.6858	+21 08 33.177	B2IV	592	0
5	Ass Gem OB 1-	As*	06 09.8	+21 35	~	118	0
6	TYC 1877-287-1	*	06 16 13.3409	+22 45 48.634	sdO	9	0
7	HD 254577	*	06 17 54.3853	+22 24 32.928	B0.5II-III	30	0
8	HD 43582	V*	06 18 00.3459	+22 39 29.995	B0IIIn	21	0
9	IC 443	SNR	06 18 02.7	+22 39 36	S	729	2
10	HD 254755	*	06 18 31.7741	+22 40 45.125	O9Vp	33	0

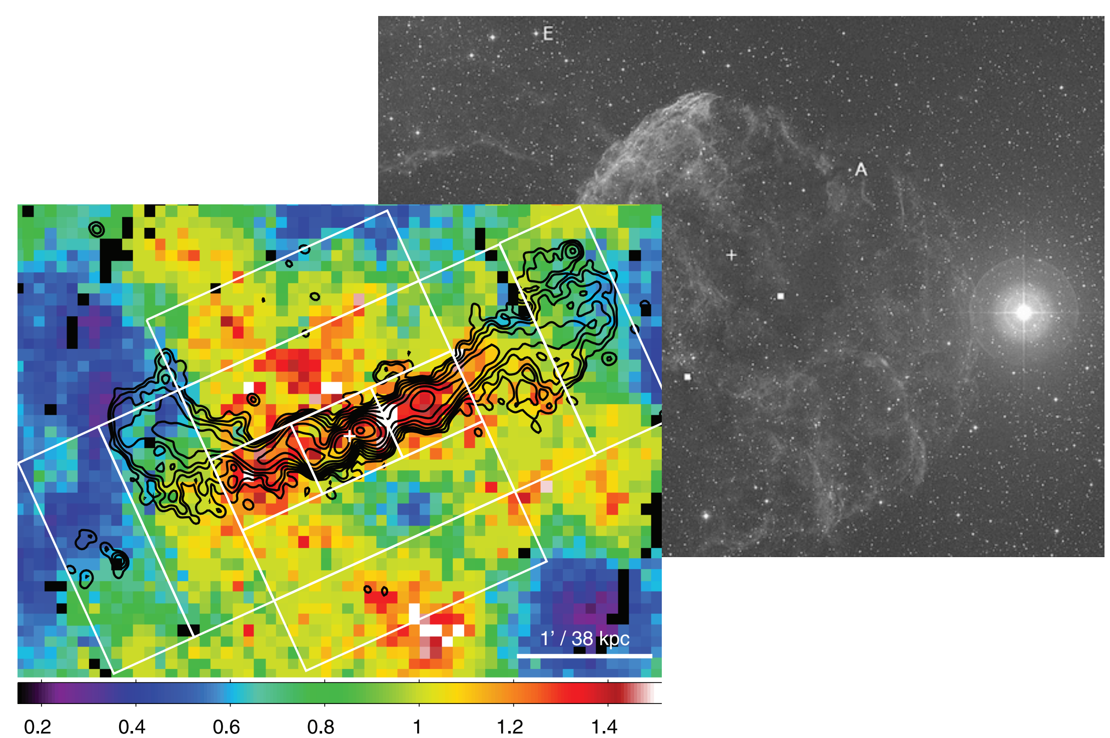
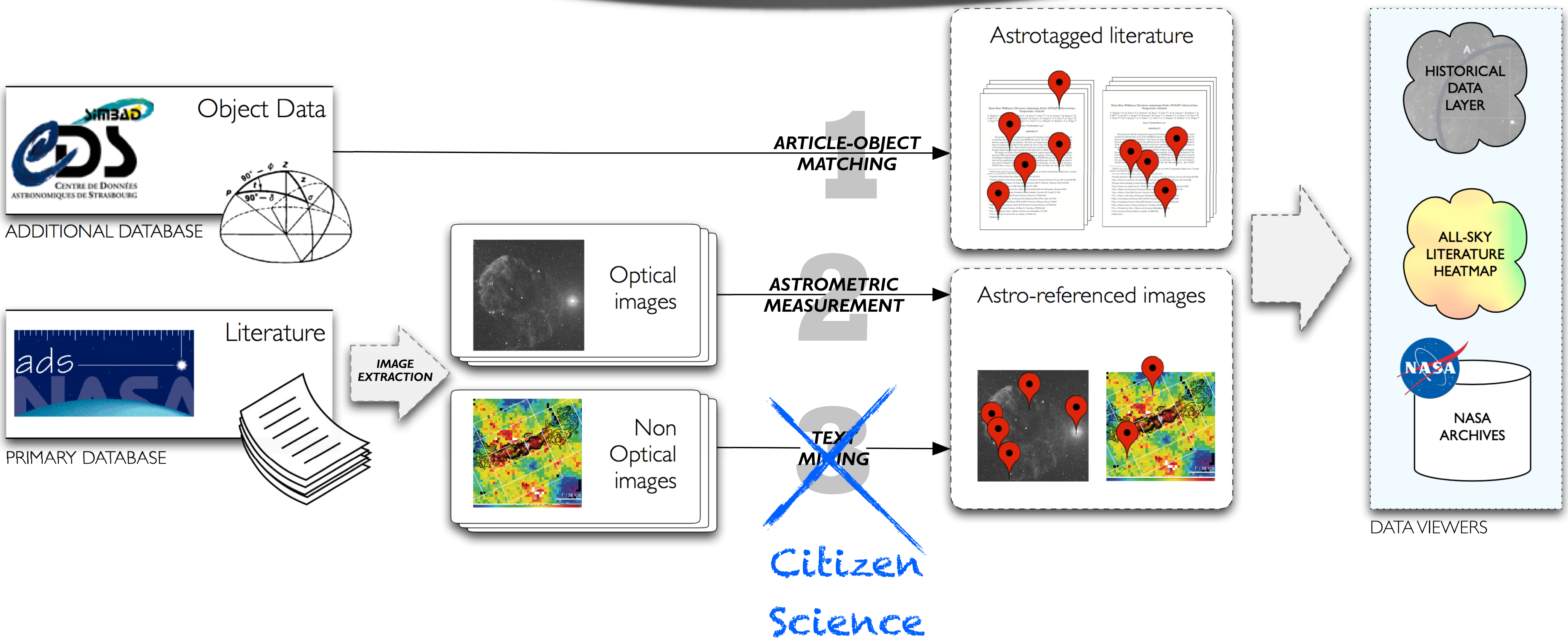


Figure 3. Abundance map of the core of AWM 4, with GMRT 610-MI contours overlaid. Rectangular regions were used to examine the variati in abundance across and along the jet. The white cross marks the positi of the radio core.

ADS All Sky Survey



pilogue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...just like SOLAR STORMWATCH
THE MILKY WAY PROJECT
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The Milky Way Project aims to sort and measure our galaxy, the Milky Way. Initially we're asking you to help us find and draw bubbles in beautiful infrared data from the Spitzer Space Telescope.
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SEAMLESS ASTRONOMY

Projects

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ADS All Sky Survey

ADS All-SKy Survey (ADSASS)

can be found on this conference paper.

Astronomy Dataverse

Astronomy Dataverse

hosted by Harvard University and managed by the Institute for Quantitative Social Science (IQSS), as a project-based repository for the storage, access, and citation of reduced astronomical data. We have interviewed a set of 10 astronomers about their needs, and the prototype CfA Dataverse is now online.

WorldWide Telescope

High-D Visualization

high-dimensional data, and the integration of WorldWide Telescope into research and teaching paradigms.

Social Networks

Study of the impact of social media and networking sites on scientific dissemination

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Collaboration Networks

Data Citation

Semantic description and annotation of scientific resources

RDF store and facets, and links to semantic ADS.

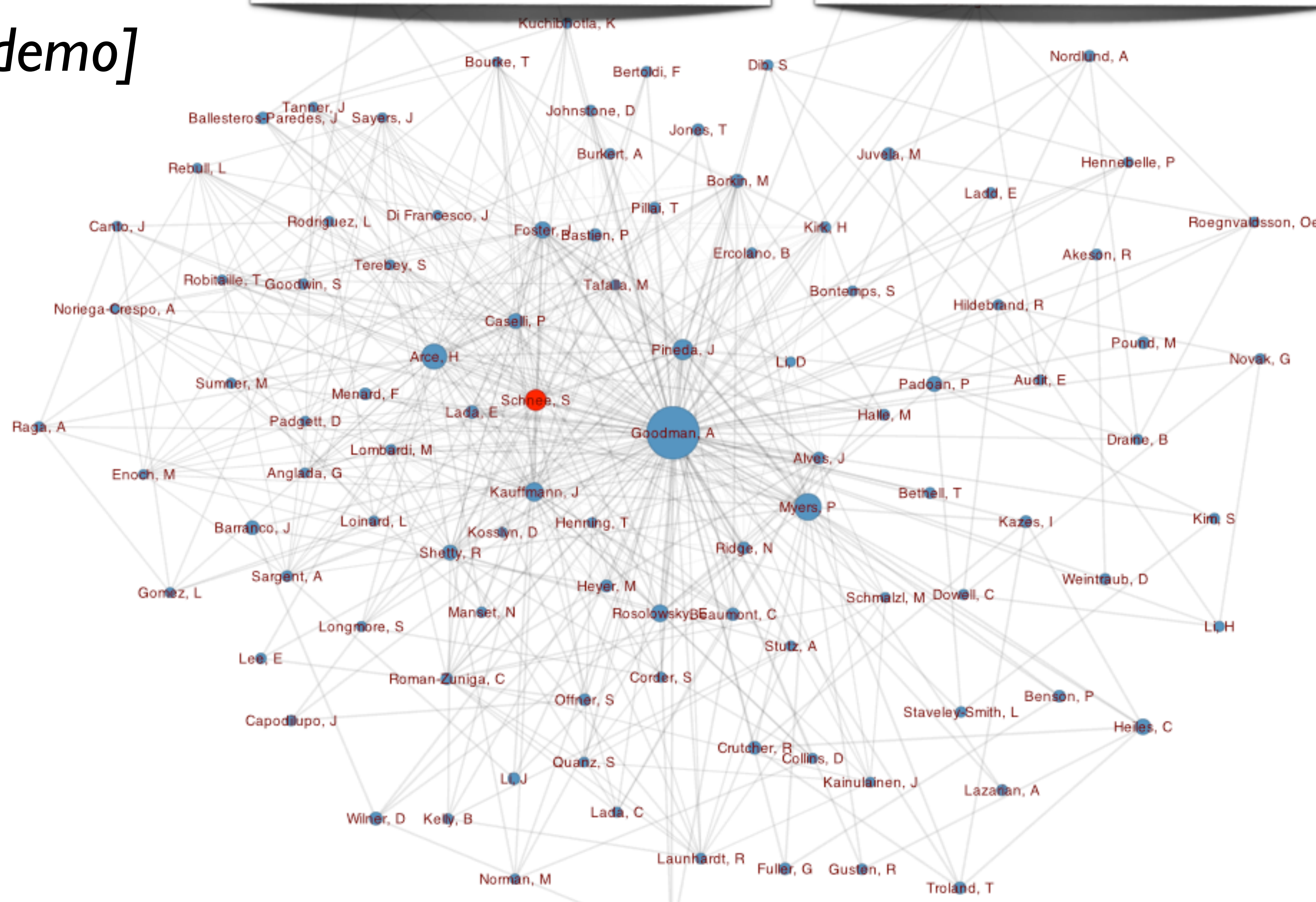
Semantic Search

Semantic Web

ADS Labs

Collaboration Networks

[demo]



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Projects

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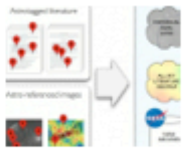

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Semantic Web

Semantic Search

Archetypes in a Dataverse

Astronomy Dataverse

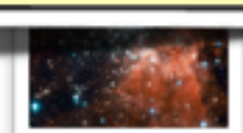
&

Data Citation

Asteroid You have small data sets ou'd like to see stay in reliable orbits.

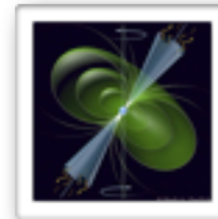
Protostar You're young and eager to become a full-grown star, so you want to share all the data you can, and embed links to it in your publications.

Main-sequence Star 've been at this for a while, so you have data history and a good future. You'd like pload important data to go with "old" ers now, and more in the future.



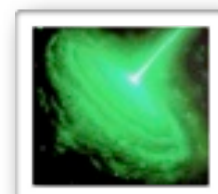
luster You collect things in catalogs and lists, and you want to group the catalogs for the greater good.

Supernova Your disks are EXPLODING with data, and you don't know what to do with it. You want to permalink vast data sets directly to papers, and more...



Pulsar You really like it when things *change*. Time-domain astronomy is your thing, and you want online identifiers that understand time.

Galaxy You love everything, but you're organized. You make and collect Surveys you don't want to lose, and you want people to find them from far away.



Quasar Your energy is nearly unlimited, so you suck up (mine) and spit out as much data as you can find. And you like to share in showy ways.

The Dataverse Network® Project

Black Hole You suck down any and all data, with unbridled appetite. Dataverse is *NOT* for you.

Coming soon to **PLoS one**... *Pepe et al. 2012*

Data handling, archiving, and citing in astronomy

Alberto Pepe[1,2,*], August Muench[1], Christopher Erdmann[1], Mercè Crosas[2], Alyssa Goodman[1]
1 Harvard-Smithsonian Center for Astrophysics, Cambridge, MA, USA
2 Institute for Quantitative Social Science, Harvard University, Cambridge, MA, USA
* E-mail: apepe@cfa.harvard.edu

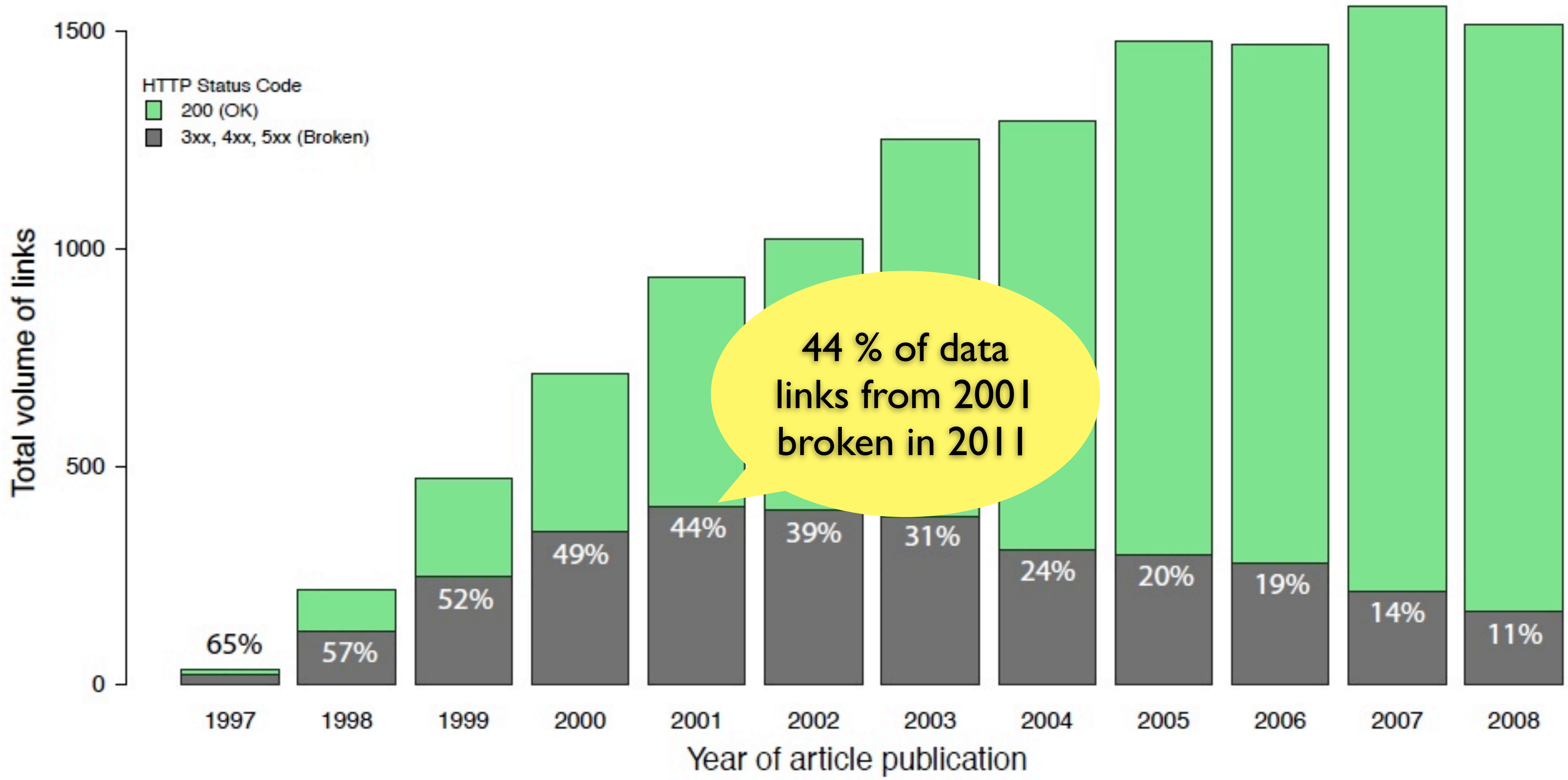


Figure 1. Volume of potential data links in astronomy publications. Total volume of external links in all articles published between 1997 and 2008 in the four main astronomy journals, color coded by HTTP status code. Green bars represent accessible links (200), grey bars represent broken links. .

Pepe et al. 2012

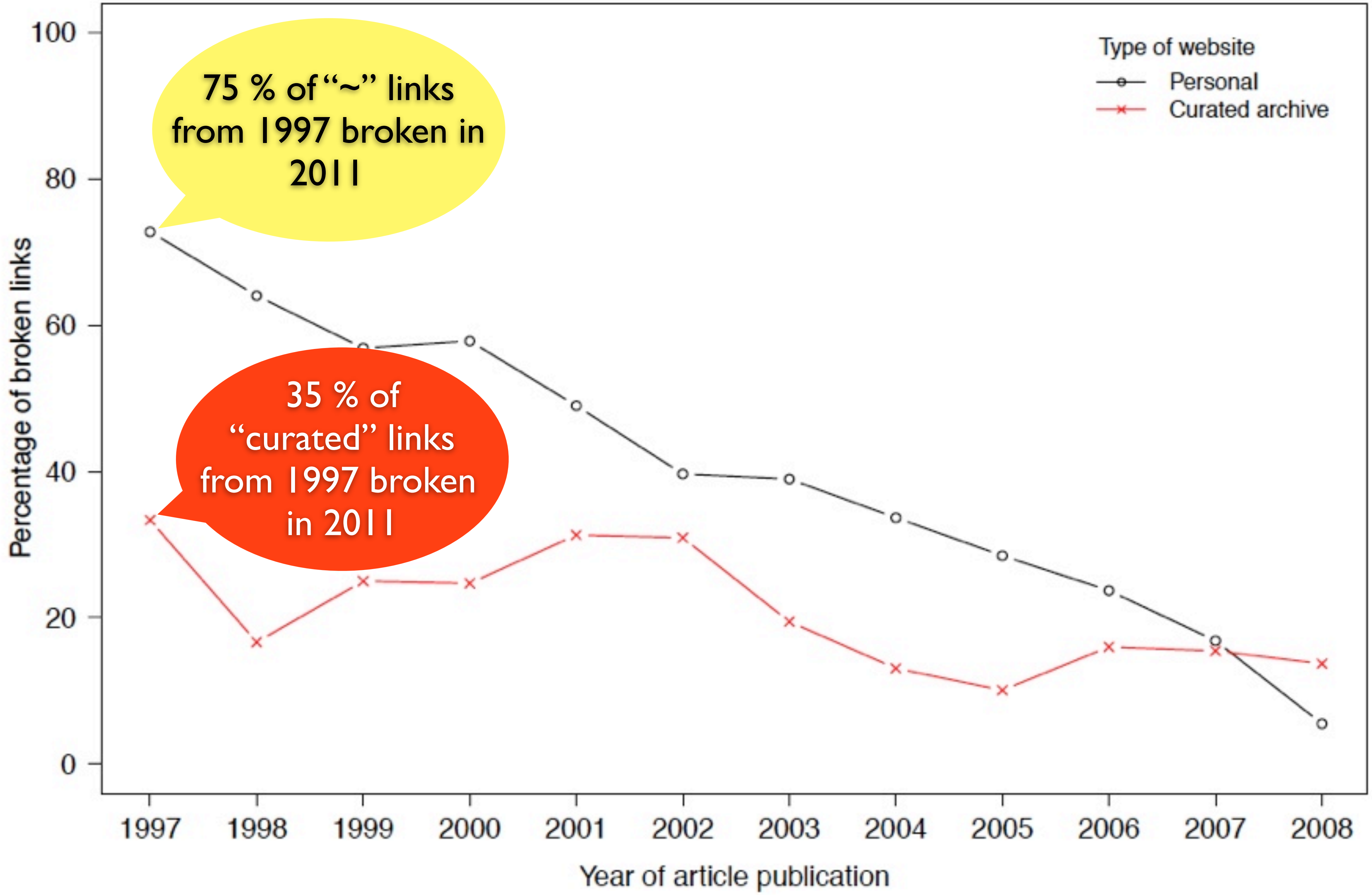


Figure 2. Percentage of broken links in astronomy publications according to type of website. Percentages of broken external links in all articles published between 1997 and 2008 in the four main astronomy journals. Black circles represent links to personal websites (link values contain the tilde symbol, ˜), while red crosses represent links to curated archives such as governmental and institutional repositories.

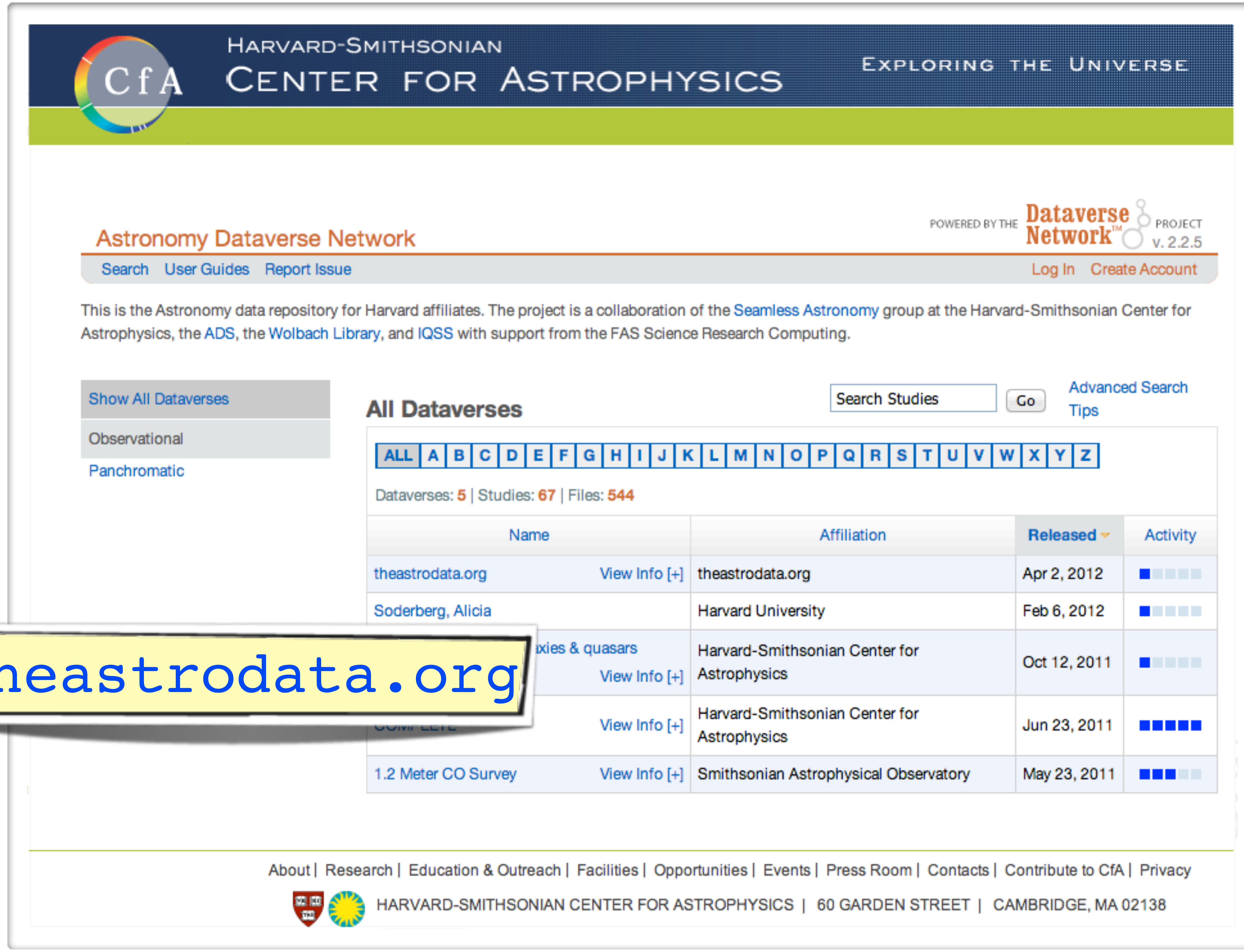
Pepe et al. 2012

Data Citation

&

Astronomy Dataverse

theastrodata.org



SEAMLESS ASTRONOMY

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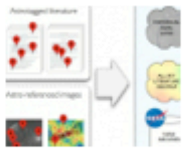
ADS All-SKy Survey (ADSASS)



The ADS All-Sky Survey (ADSASS) is an ongoing effort aimed at turning the NASA As… lite… rep… in… ob… dis… dat… tyi… …ata …l data, …. The …ASS …by …nation can be found on this conference paper.

Astronomy Dataverse

Astronomy Dataverse

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WorldWide Telescope

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High-D Visualization

Viz-e-L…

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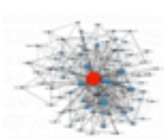
Networ… …s



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RDF store and facets, and links to semantic ADS.

Semantic Web

Astron. Nachr. / AN **333**, No. 5/6, 505 – 514 (2012) / **DOI** 10.1002/asna.201211705

Principles of high-dimensional data visualization in astronomy

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Harvard-Smithsonian Center for Astrophysics, Cambridge, MA, USA

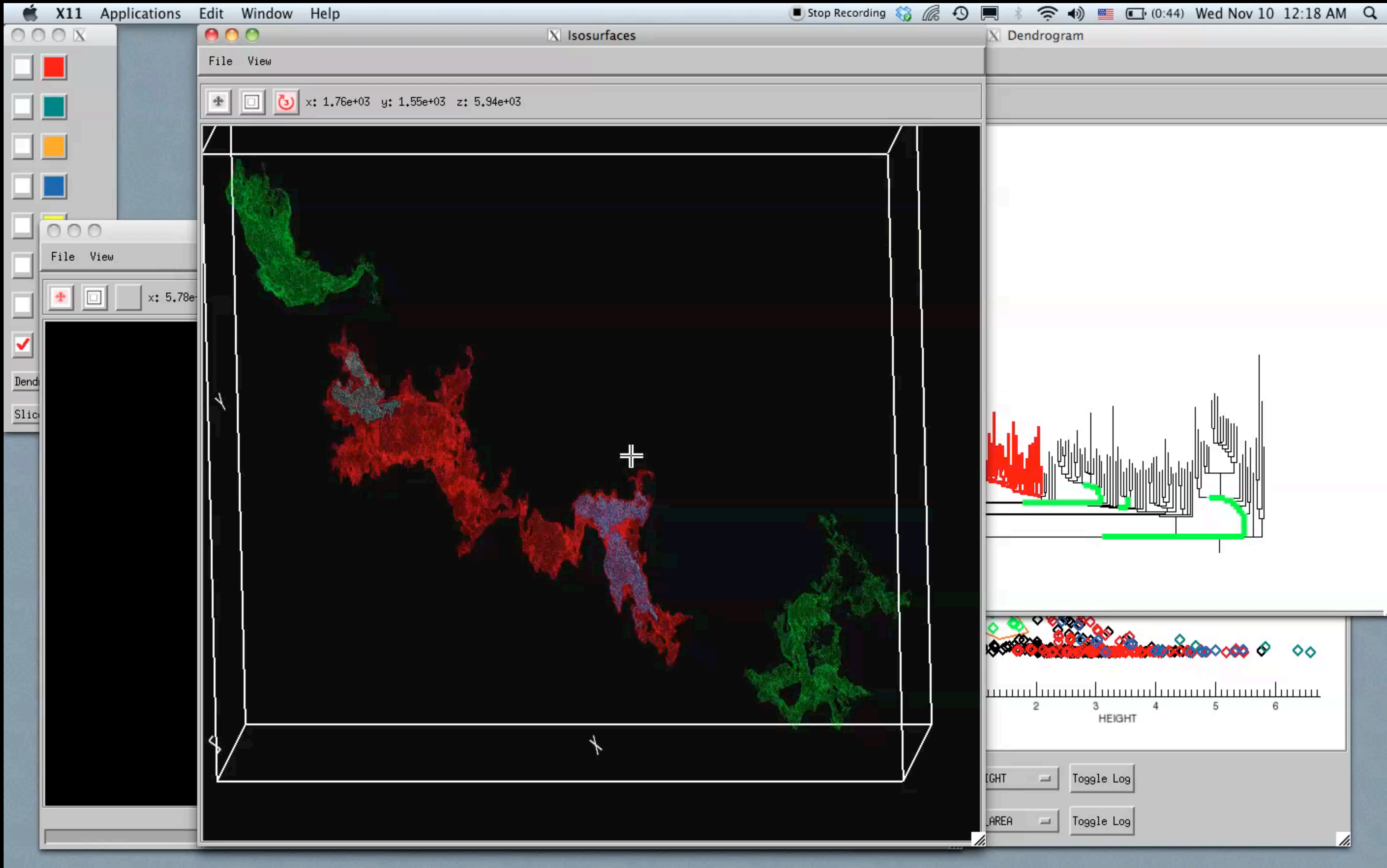
High-D Visualization

Received 2012 May 3, accepted 2012 May 4
Published online 2012 Jun 15

Key words cosmology: large-scale structure – ISM: clouds – methods: data analysis – techniques: image processing – techniques: radial velocities

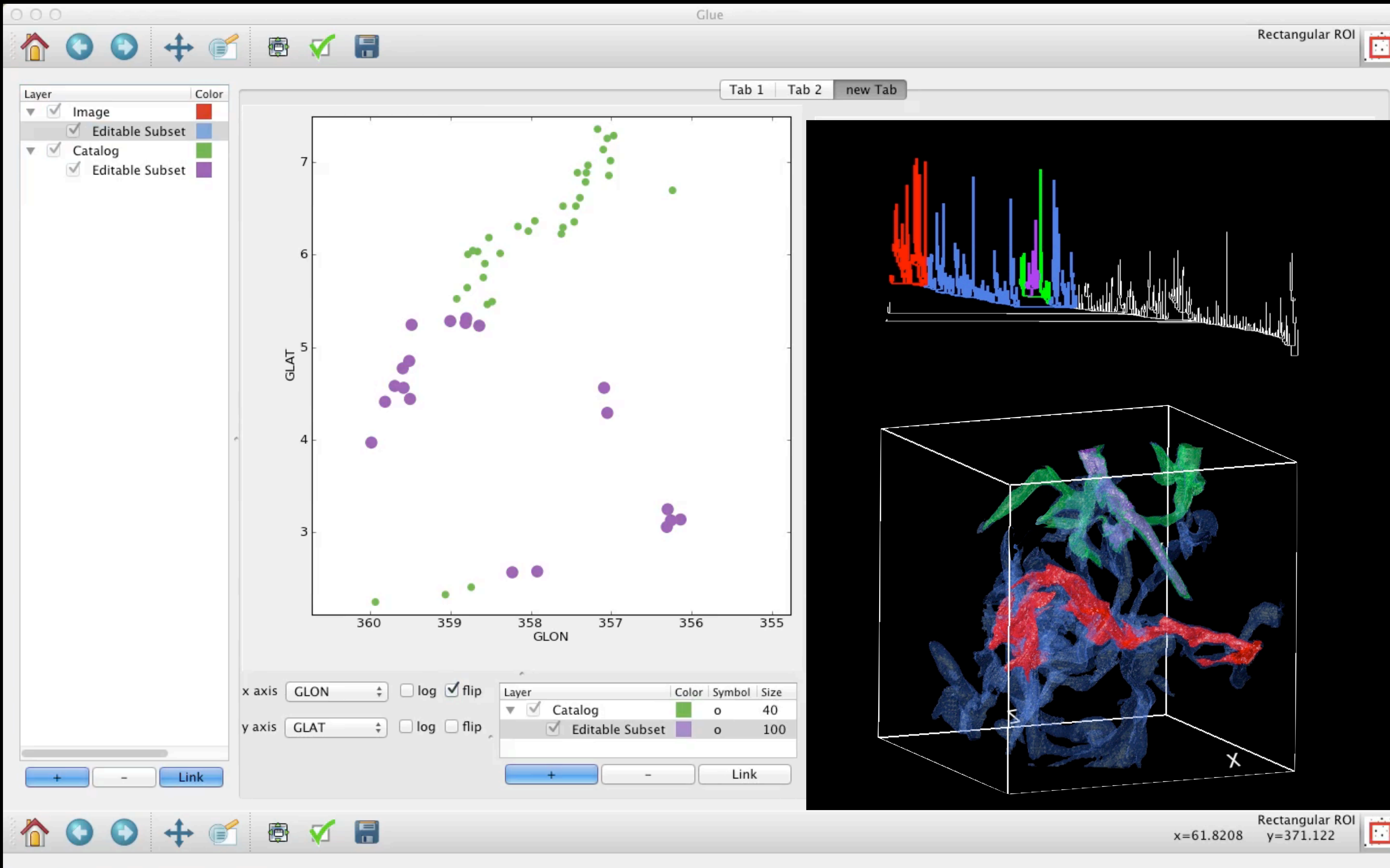
Astronomical researchers often think of analysis and visualization as separate tasks. In the case of high-dimensional data sets, though, interactive *exploratory data visualization* can give far more insight than an approach where data processing and statistical analysis are followed, rather than accompanied, by visualization. This paper attempts to charts a course toward "linked view" systems, where multiple views of high-dimensional data sets update live as a researcher selects, highlights, or otherwise manipulates, one of several open views. For example, imagine a researcher looking at a 3D volume visualization of simulated or observed data, and simultaneously viewing statistical displays of the data set's properties (such as an x-y plot of temperature vs. velocity, or a histogram of vorticities). Then, imagine that when the researcher selects an interesting group of points in any one of these displays, that the same points become a highlighted subset in all other open displays. Selections can be graphical or algorithmic, and they can be combined, and saved. For tabular (ASCII) data, this kind of analysis has long been possible, even though it has been under-used in astronomy. The bigger issue for astronomy and other "high-dimensional" fields, though, is that no extant system allows for full integration of images and data cubes within a linked-view environment. The paper concludes its history and analysis of the present situation with suggestions that look toward cooperatively-developed open-source modular software as a way to create an evolving, flexible, high-dimensional, linked-view visualization environment useful in astrophysical research.

Exemplar: Linked Dendrogram Views in IDL



Video & implementation: Christopher Beaumont, CfA/UHawaii;
inspired by AstroMed work of Douglas Alan, Michelle Borkin, AG, Michael Halle, Erik Rosolowsky

Glue



Current linked view work by Beaumont, Borkin, Goodman, Pfister & Robitaille

Value of "Linked Views" from Harvard Undergrad Thesis* Work

on "A Hierarchical Catalog of Molecular Clouds in the Milky Way"

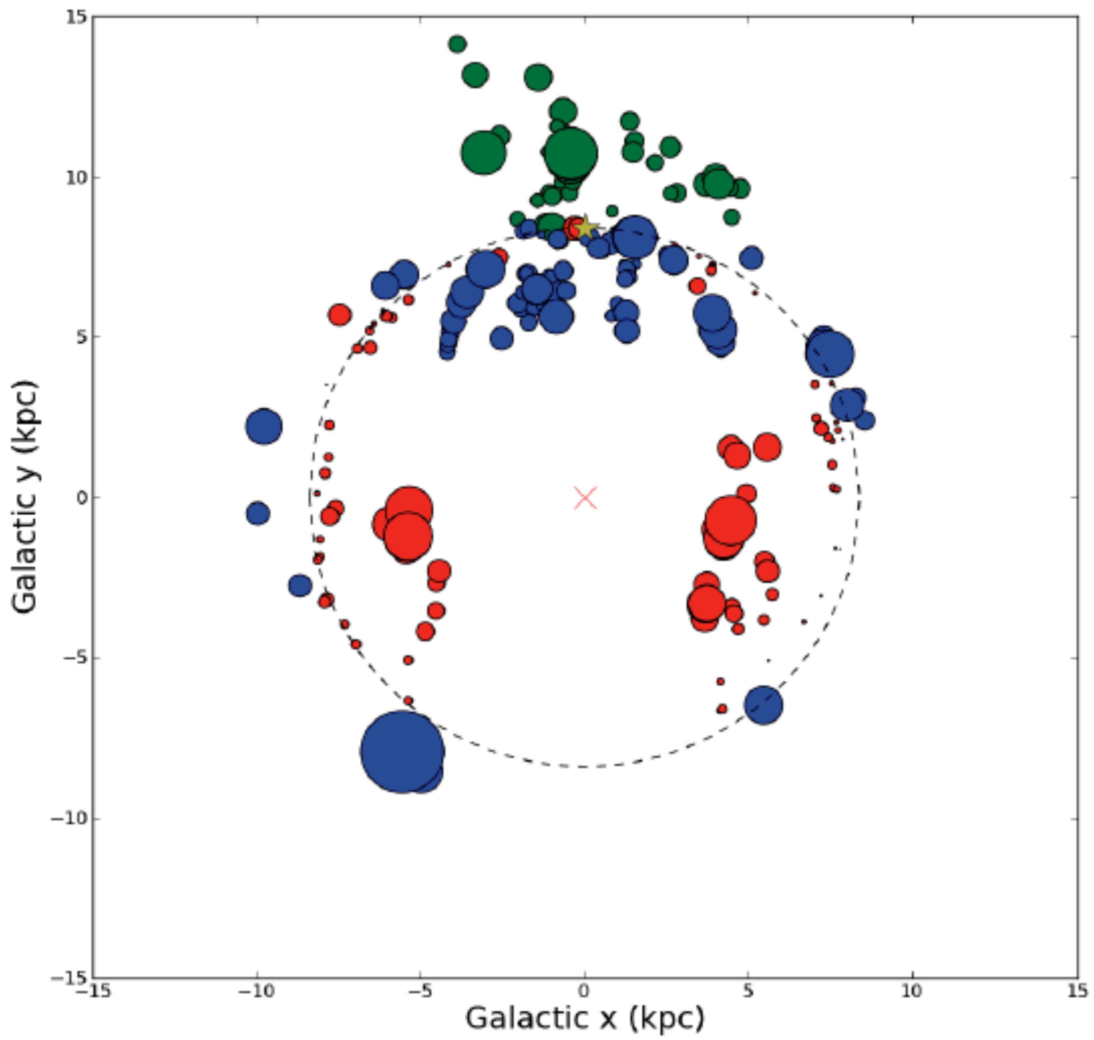
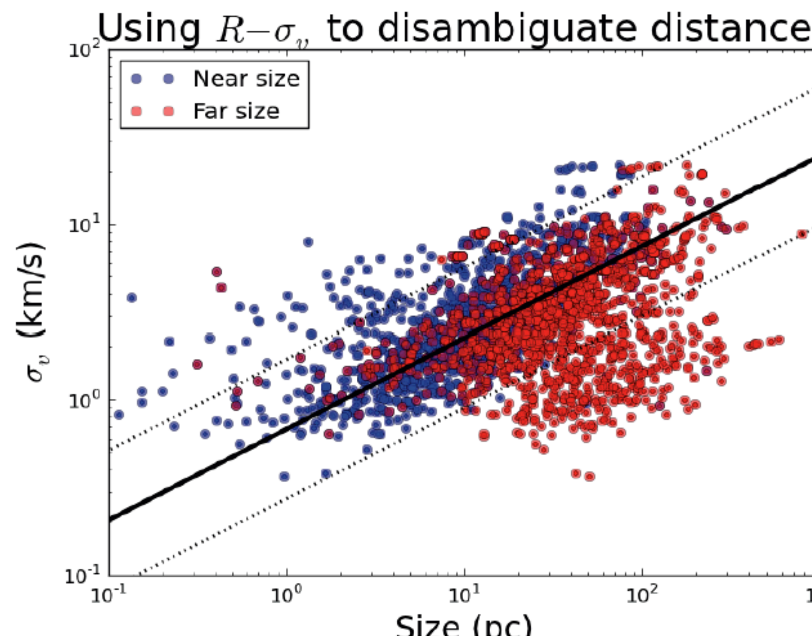


Fig. 8.— All of the "bound clouds" identified in our catalog, plotted face-on in Galactocentric X, Y coordinates. The Sun is located at the yellow star in the upper center. Green: Outer Galaxy; Blue: Near Distance or single-distance solution; Red: Far distance.



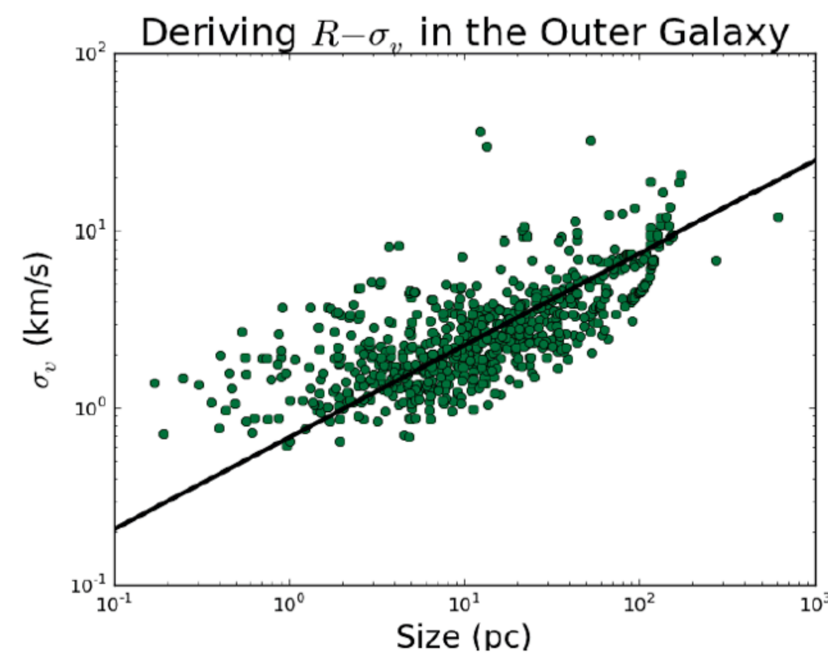
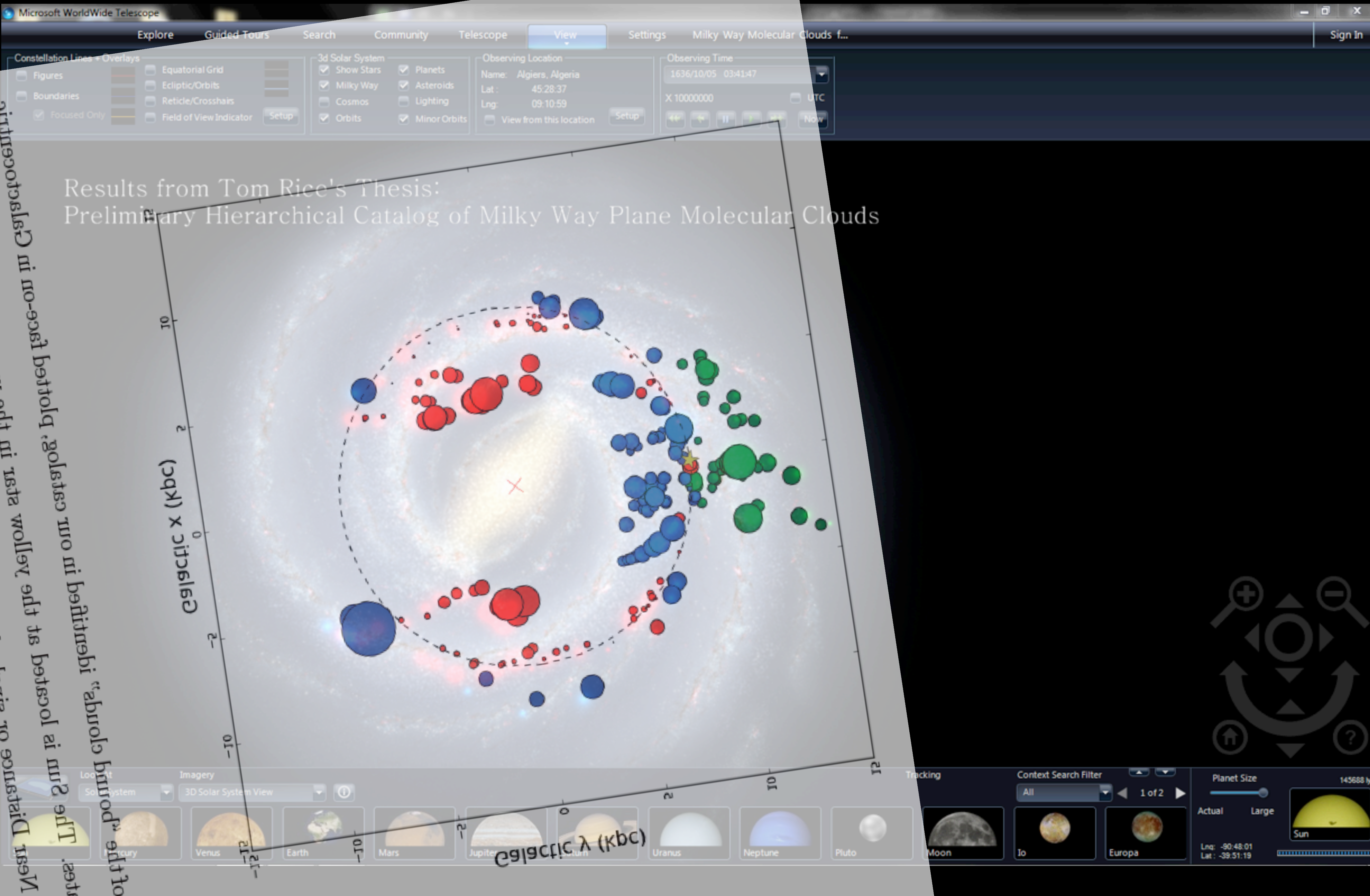


Fig. 5.— The size-linewidth relationship for clouds in the Outer Galaxy. We obtained a fit of $\sigma_v = 0.68\sigma_R^0.52$.

**thesis of Tom Rice, '12, awarded Hoopes Prize*

Value of “Linked Views” from Harvard Undergrad Thesis* Work



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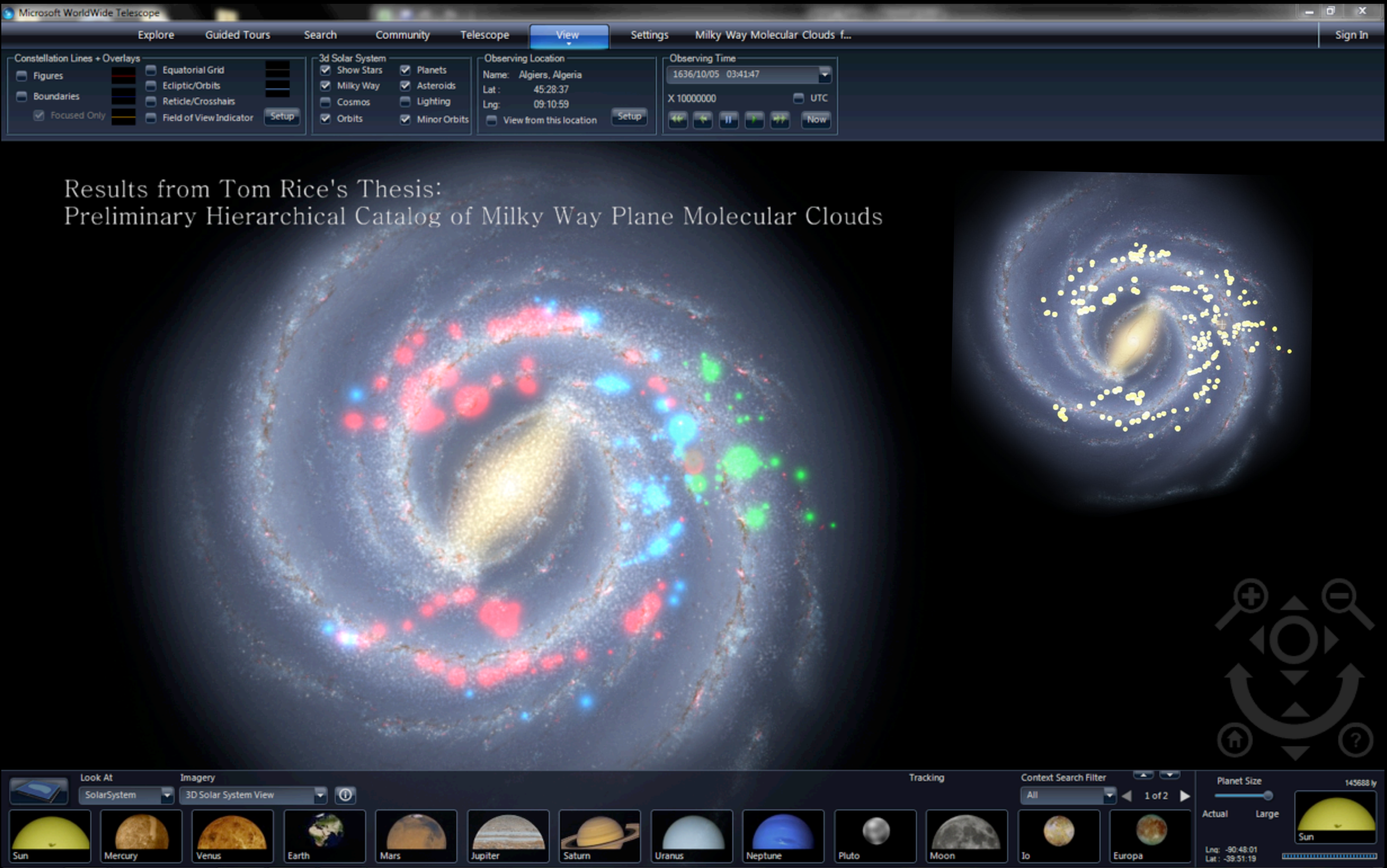

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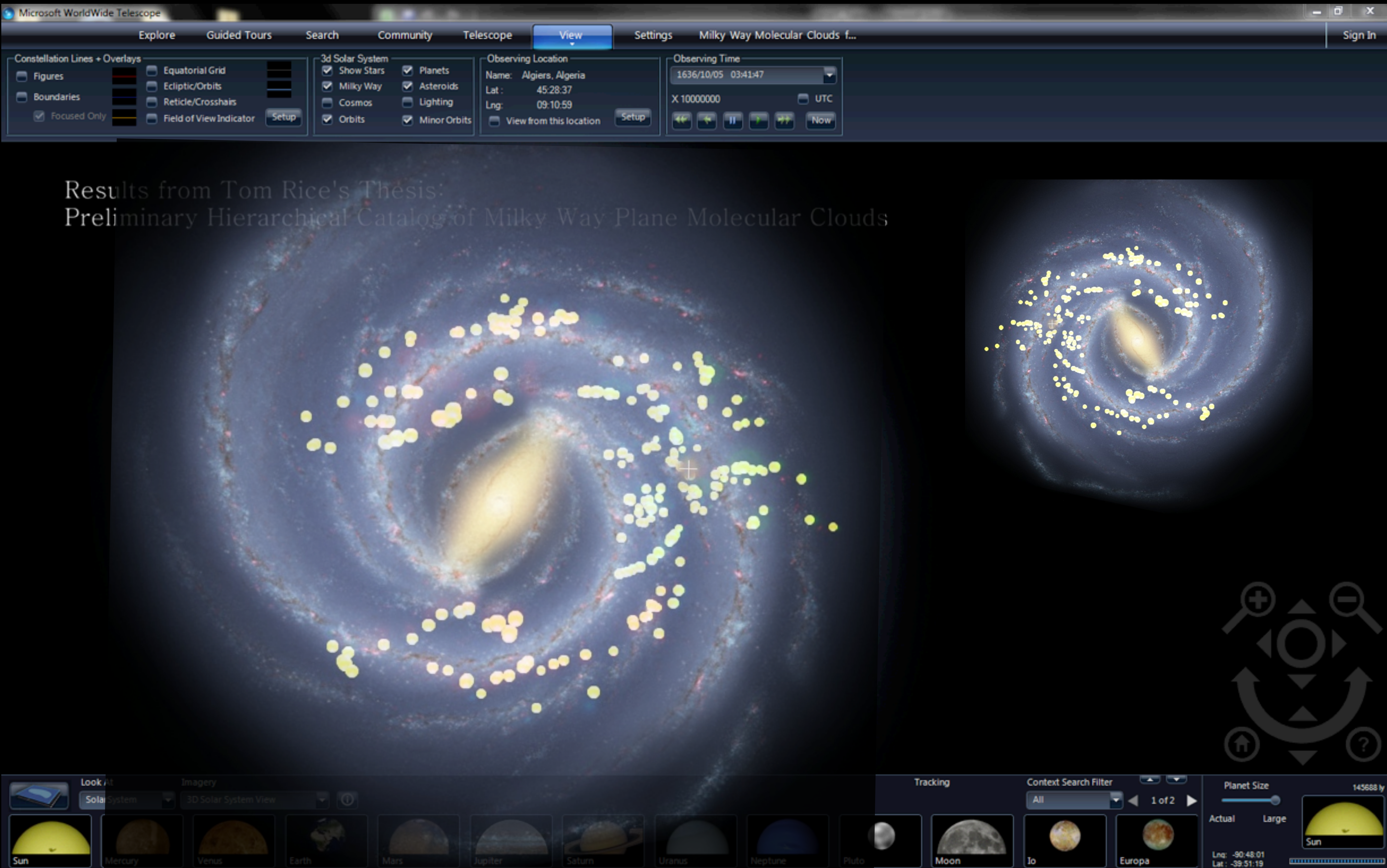

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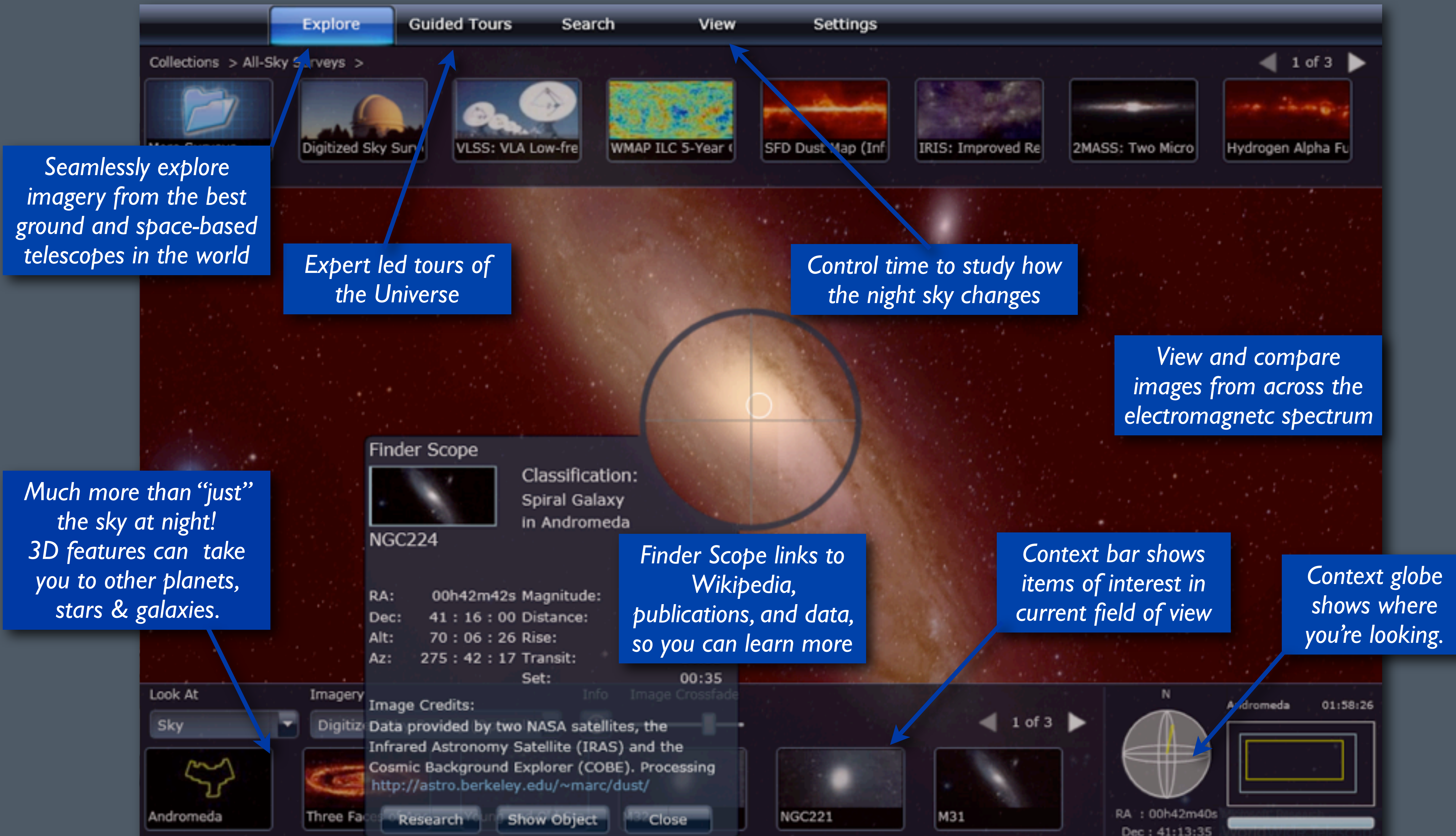

The WorldWide Telescope Ambassadors Program

Alyssa **Goodman** & Patricia **Udomprasert**
Harvard-Smithsonian Center for Astrophysics

Curtis Wong & Jonathan Fay
Microsoft Research

Gains in Student Interest and Understanding

("Traditional Way" vs "WWT Way")