Seamless Astronomy, Sea Monsters & the Milky Way


The Astronomer, Vermeer


"Nessie", Spitzer Space Telescope

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

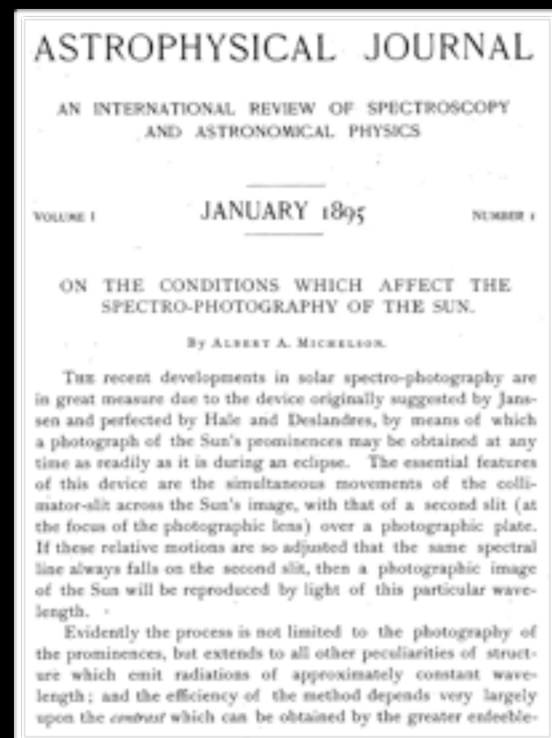
"The Internet"

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

NVO IVOA gSky

"Virtual Observatories" 21st century

Evolution since the Revolution



ASTROPHYSICAL JOURNAL

AN INTERNATIONAL REVIEW OF SPECTROSCOPY AND ASTRONOMICAL PHYSICS

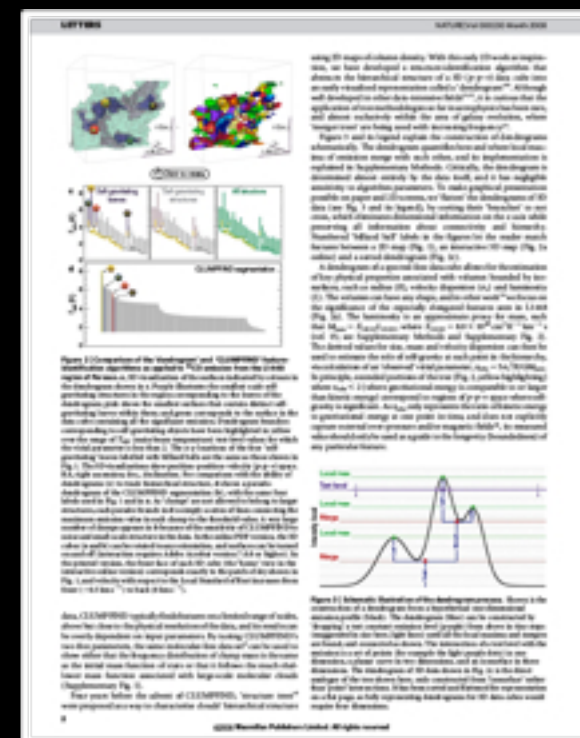
VOLUME I — JANUARY 1895 — NUMBER 1

ON THE CONDITIONS WHICH AFFECT THE SPECTRO-PHOTOGRAPHY OF THE SUN.

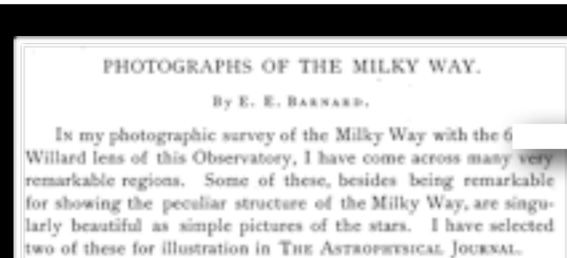
By Albert A. Michelson.

The recent developments in solar spectro-photography are in great measure due to the device originally suggested by Janssen and perfected by Hale and Deslandres, by means of which a photograph of the Sun's prominences may be obtained at any time as readily as it is during an eclipse. The essential features of this device are the simultaneous movements of the collimator-slit across the Sun's image, with that of a second slit (at the focus of the photographic lens) over a photographic plate. If these relative motions are so adjusted that the same spectral line always falls on the second slit, then a photographic image of the Sun will be reproduced by light of this particular wave-length.

Evidently the process is not limited to the photography of the prominences, but extends to all other peculiarities of structure which emit radiations of approximately constant wave-length; and the efficiency of the method depends very largely upon the *contrast* which can be obtained by the greater enfeeble-



1665 ..230 yr... 1895 ...114 yr... 2009 ...4 yr... 2013



PHOTOGRAPHS OF THE MILKY WAY.

By E. E. Barnard.

In my photographic survey of the Milky Way with the 6 Willard lens of this Observatory, I have come across many very remarkable regions. Some of these, besides being remarkable for showing the peculiar structure of the Milky Way, are singularly beautiful as simple pictures of the stars. I have selected two of these for illustration in The Astrophysical Journal.

ads NASA → flickr from YAHOO! Astrometry.net →

Evolution since the Revolution

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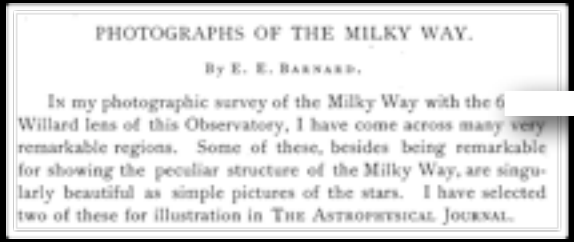

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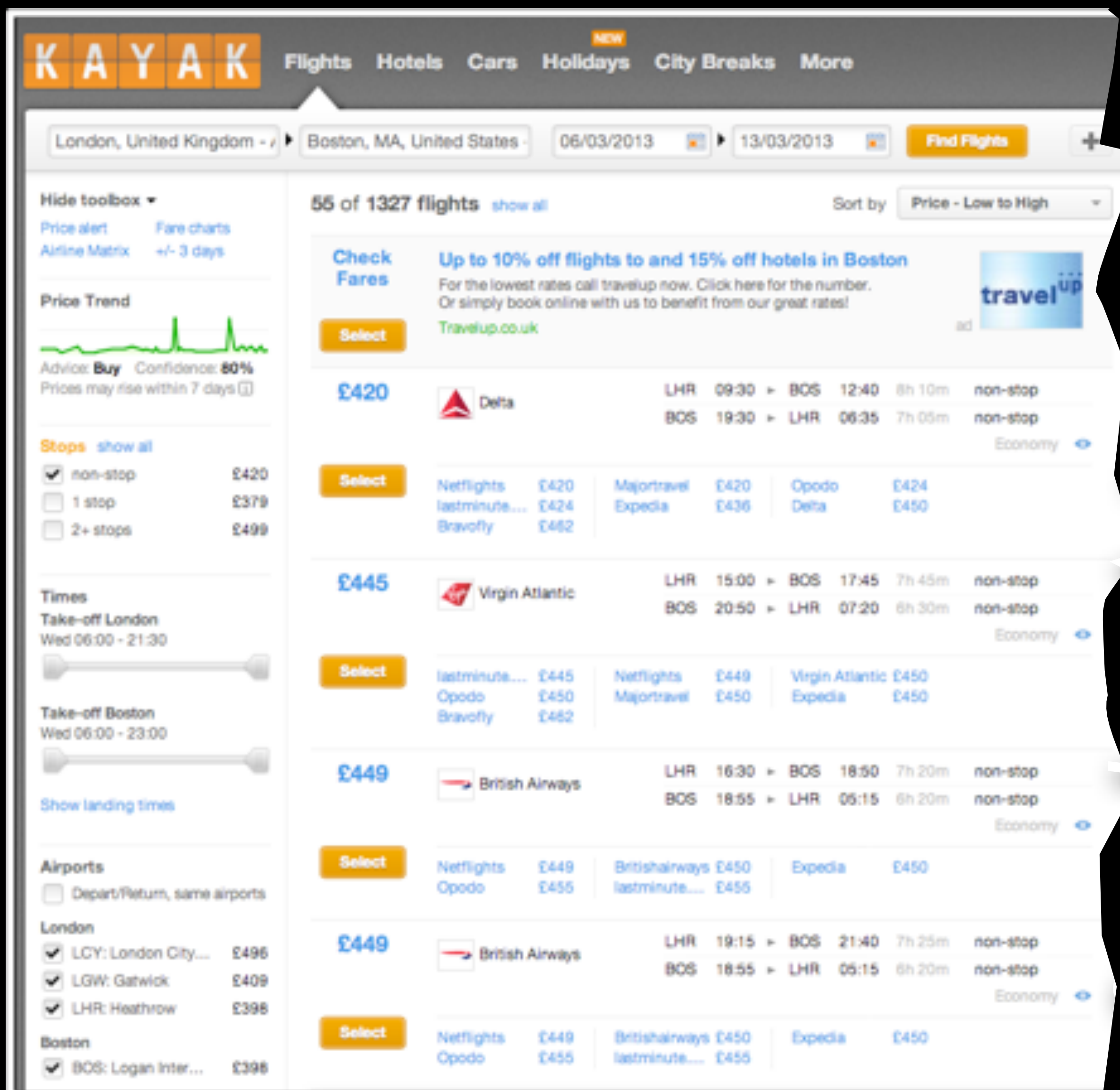
ads NASA → flickr from YAHOO! Astrometry.net →

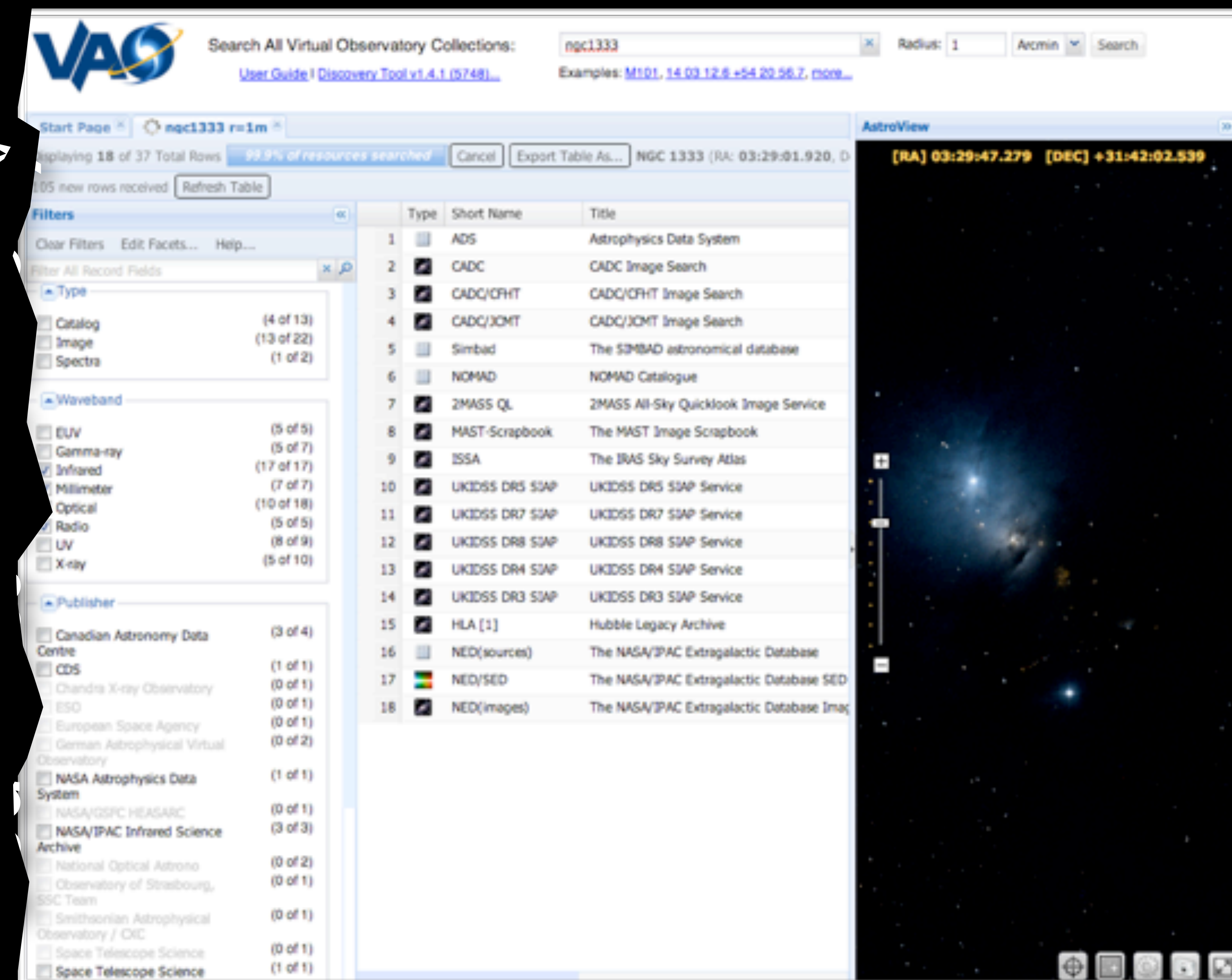
[demo]

2009

Real Life

"Science"

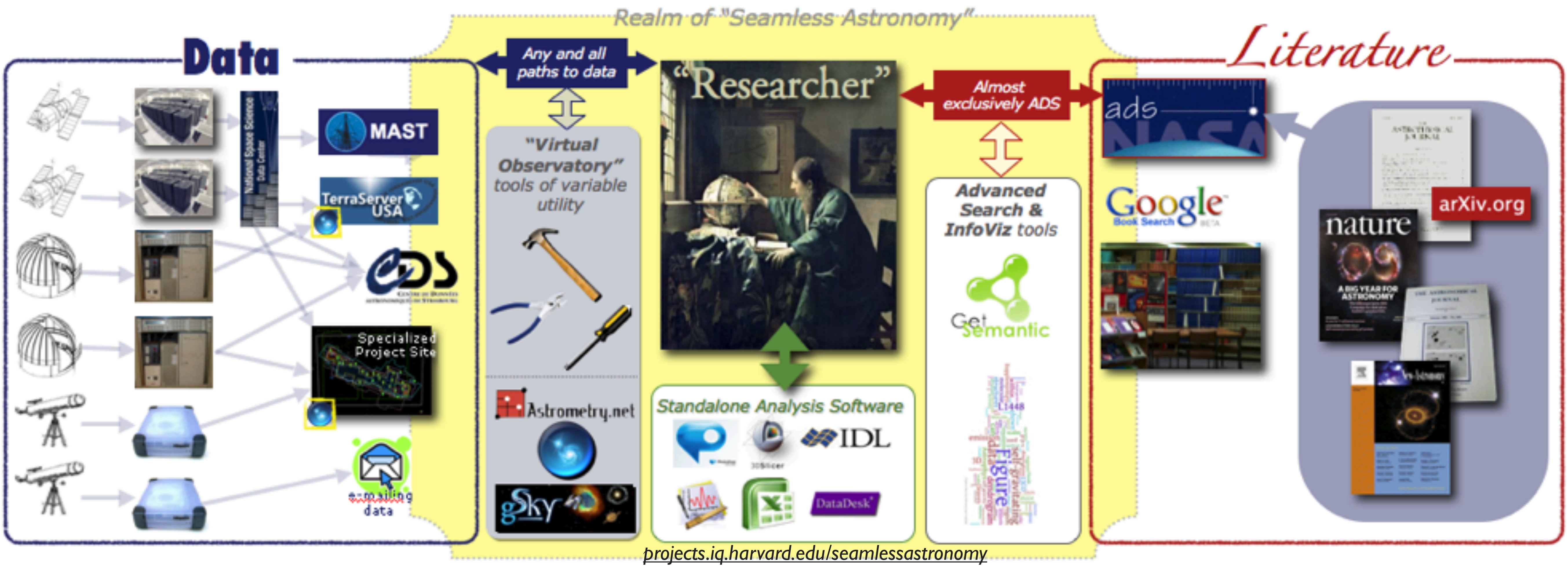




KAYAK

VAO Data Discovery Tool

Seamless Astronomy



Alberto Accomazzi, Christopher Beaumont, Douglas Burke, Raffaele D'Abrusco, Rahul Davé, Christopher Erdmann, Pepi Fabbiano, Alyssa Goodman, Edwin Henneken, Jay Luker, Gus Muench, Michael Kurtz, Max Lu, Victoria Mittelbach, Alberto Pepe, Arnold Rots, Patricia Udomprasert (Harvard-Smithsonian CfA); Mercé Crosas (Harvard Institute for Quantitative Social Science); Christine Borgman (UCLA); Jonathan Fay & Curtis Wong (Microsoft Research); Alberto Conti (Space Telescope Science Institute)

Smithsonian Microsoft Research

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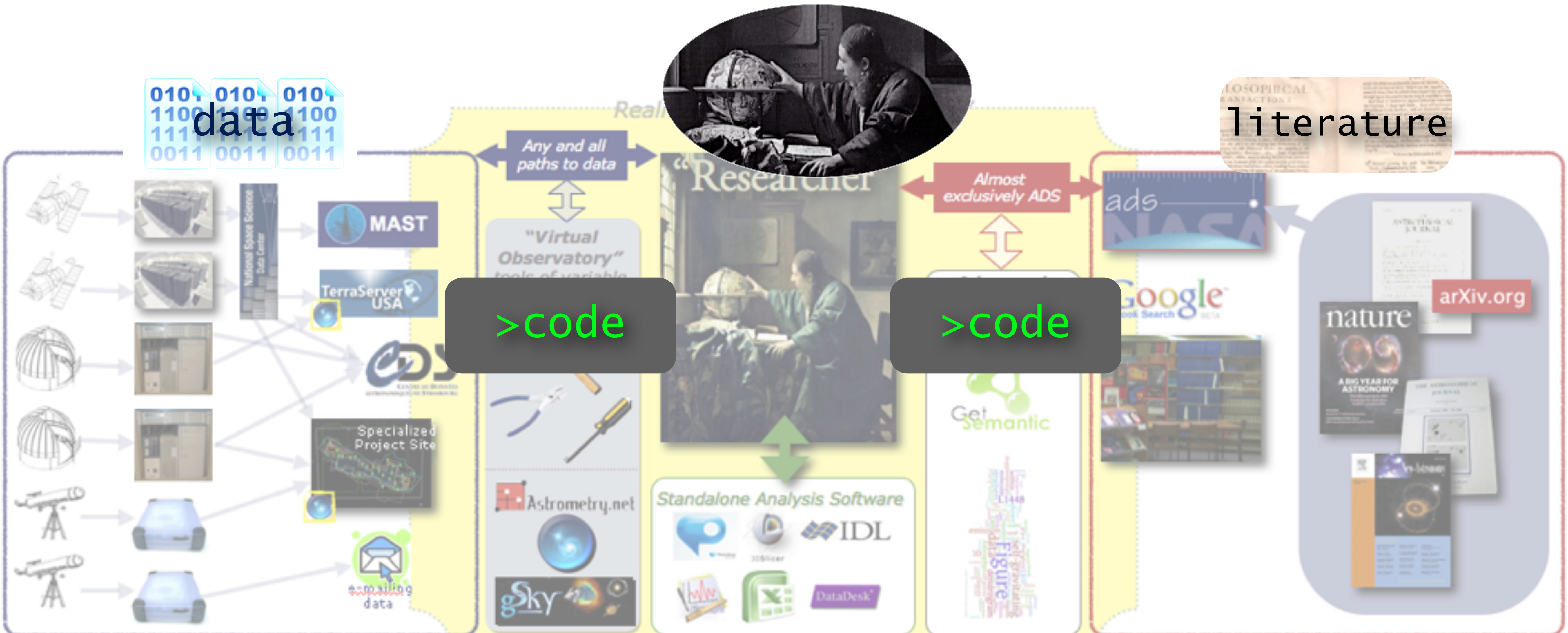

projects.iq.harvard.edu/seamlessastronomy

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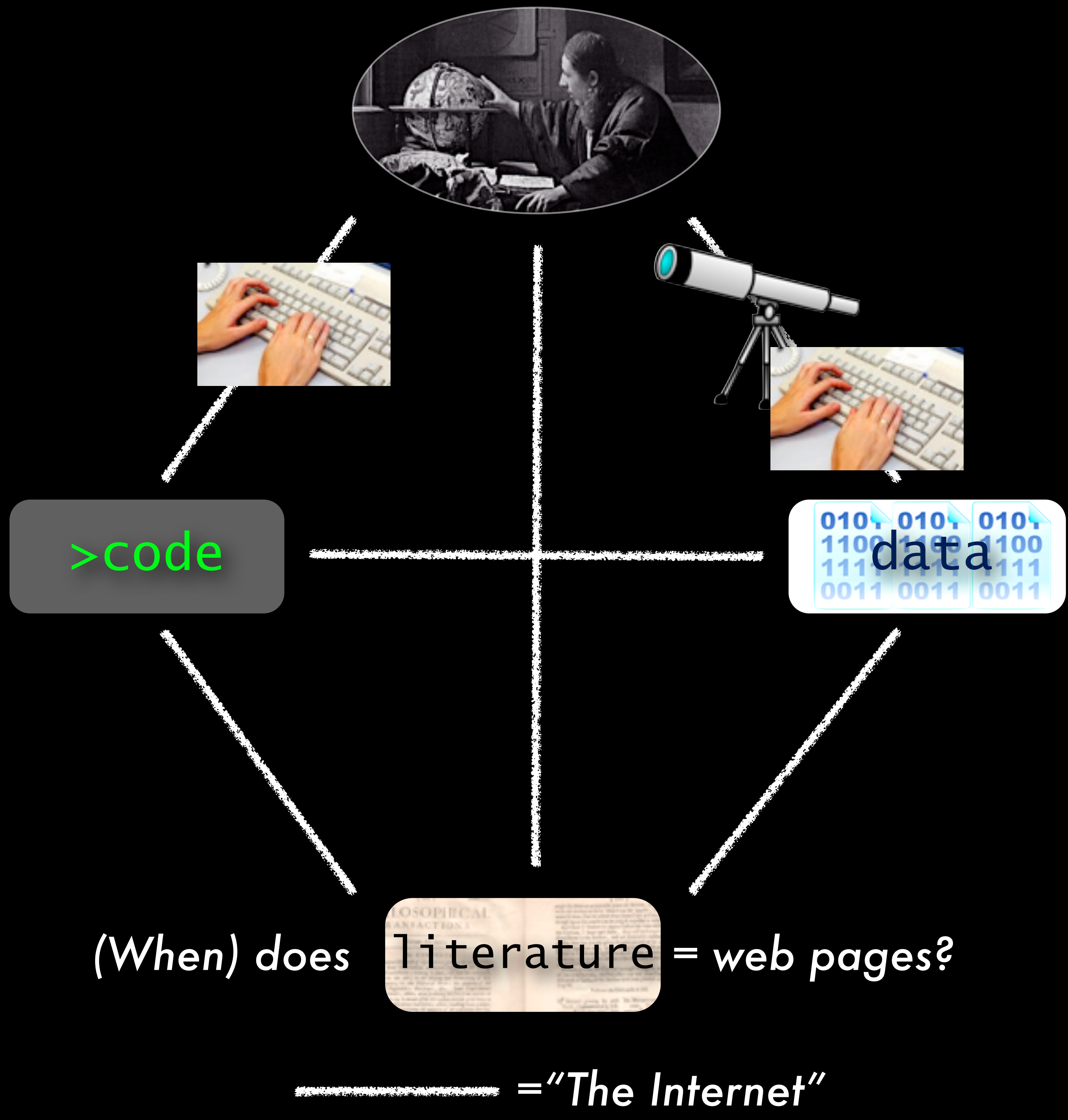

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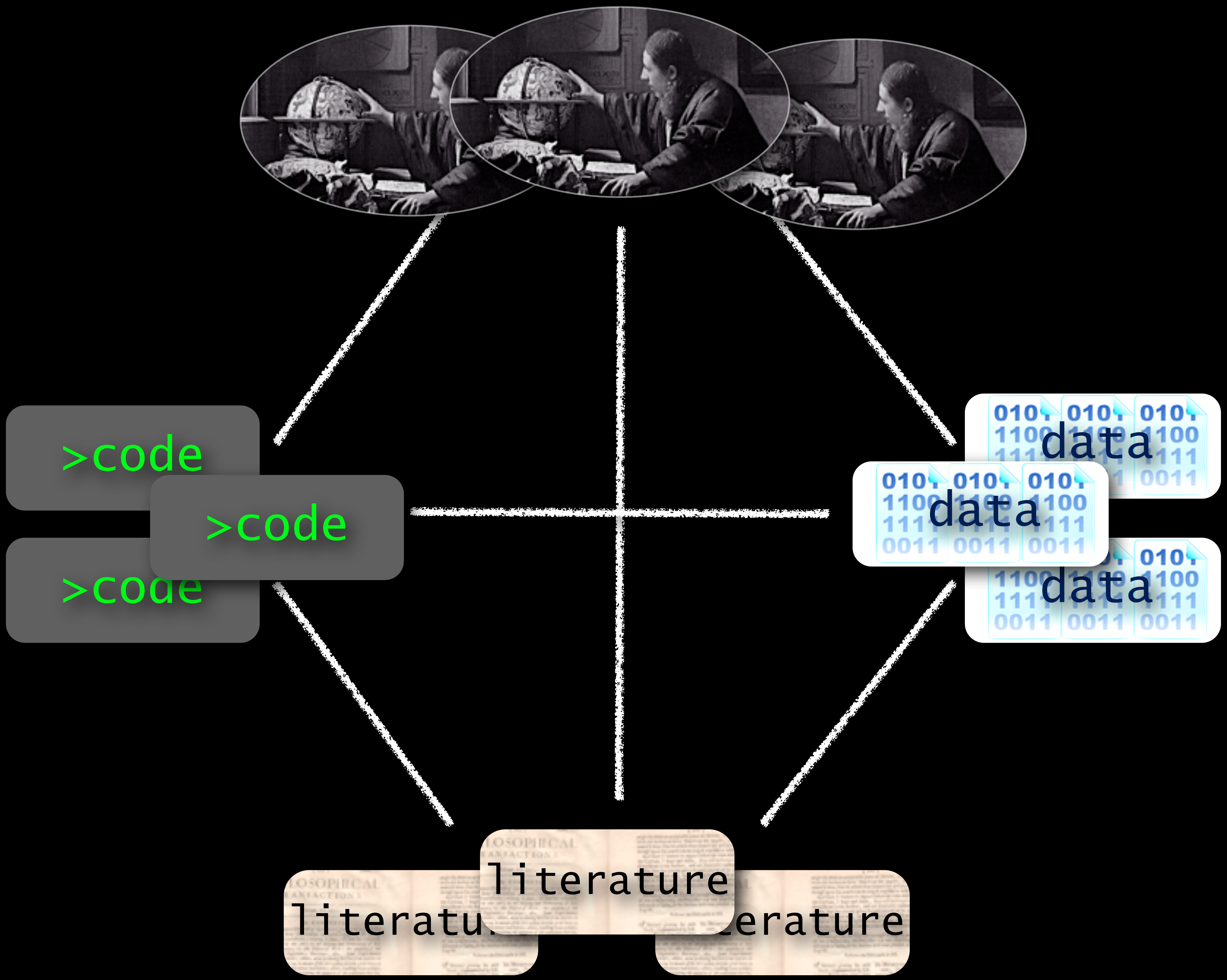

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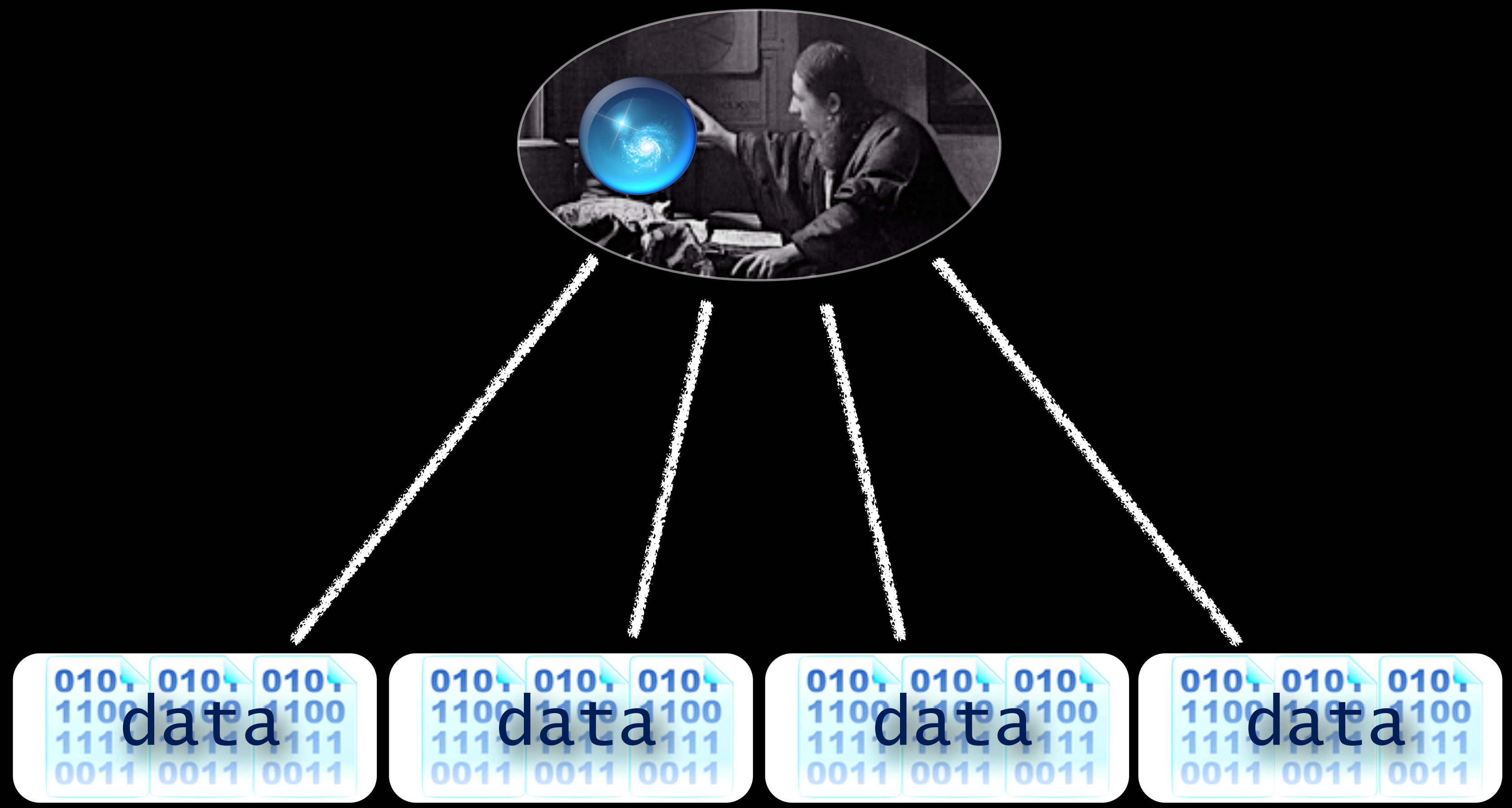
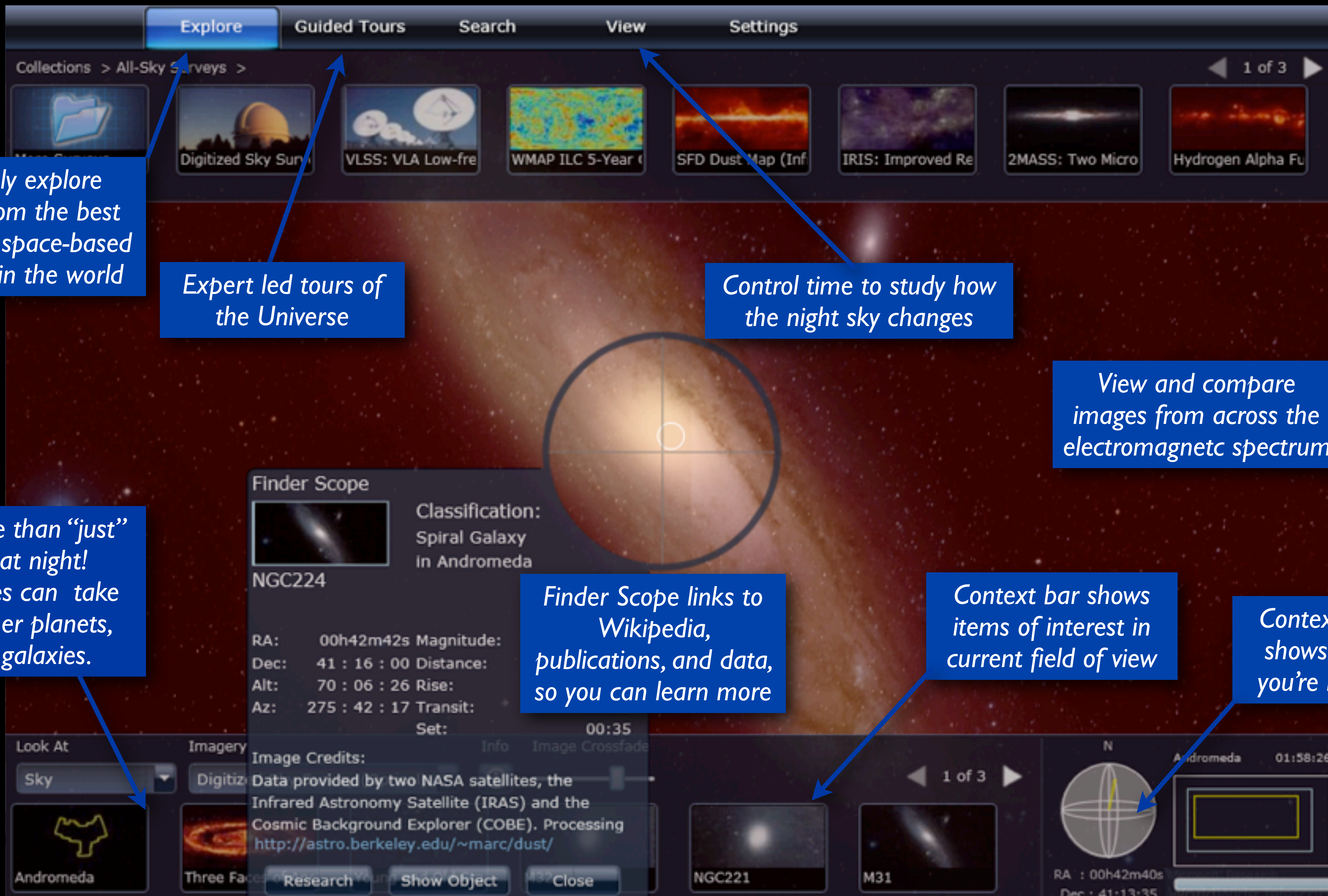


A "Virtual Observatory"

Best Instantiation: WorldWide Telescope
est. 2008

Microsoft® Research WorldWide Telescope

worldwidetelescope.org



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[demo]

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Best Instantiation: ADS
est. 1994*

[demo]

*see Kurtz et al. 2000 for full history

Seamless Astronomy

Better(!):
ADS Labs
est. 2011

[demo]

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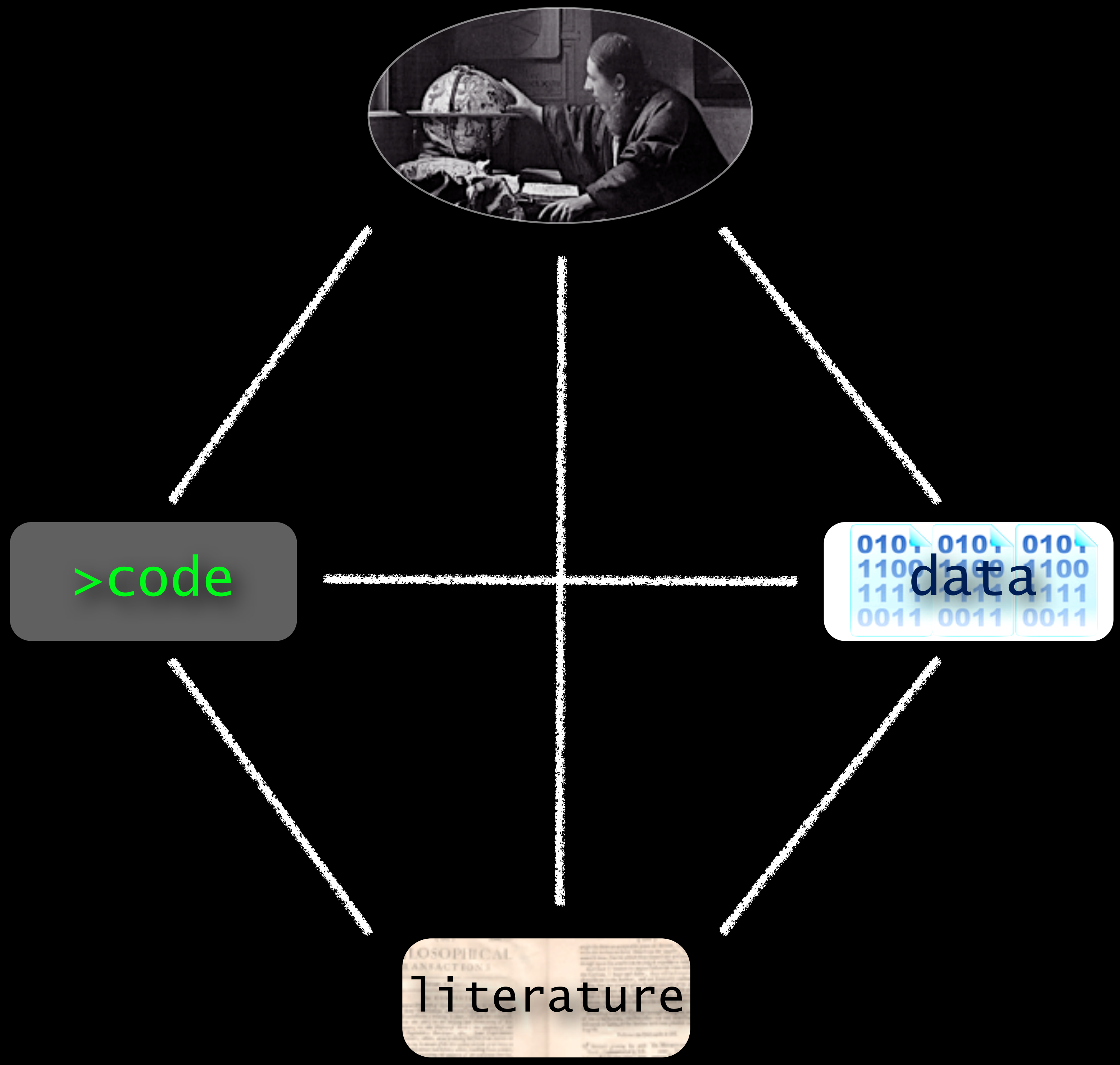

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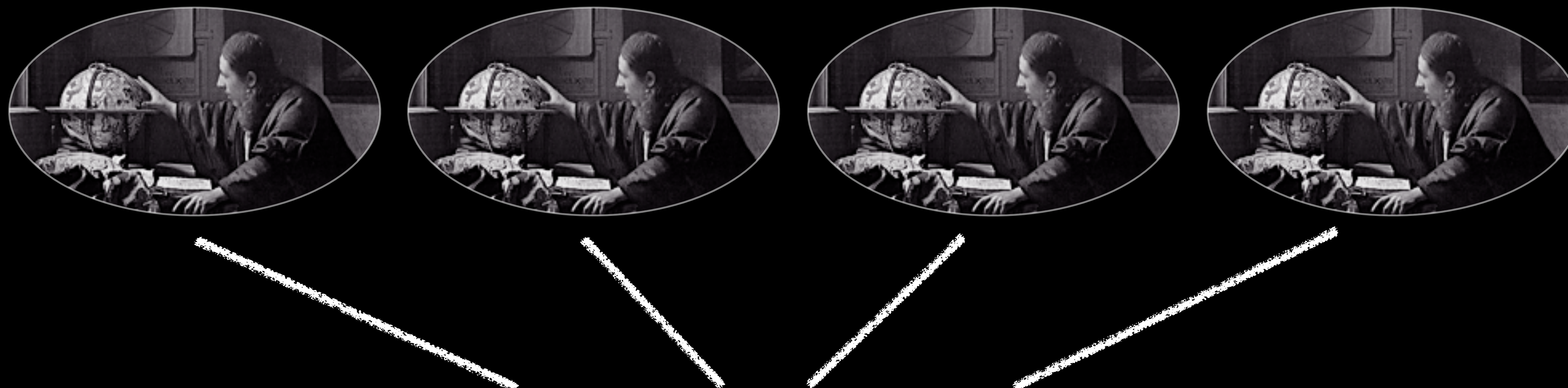

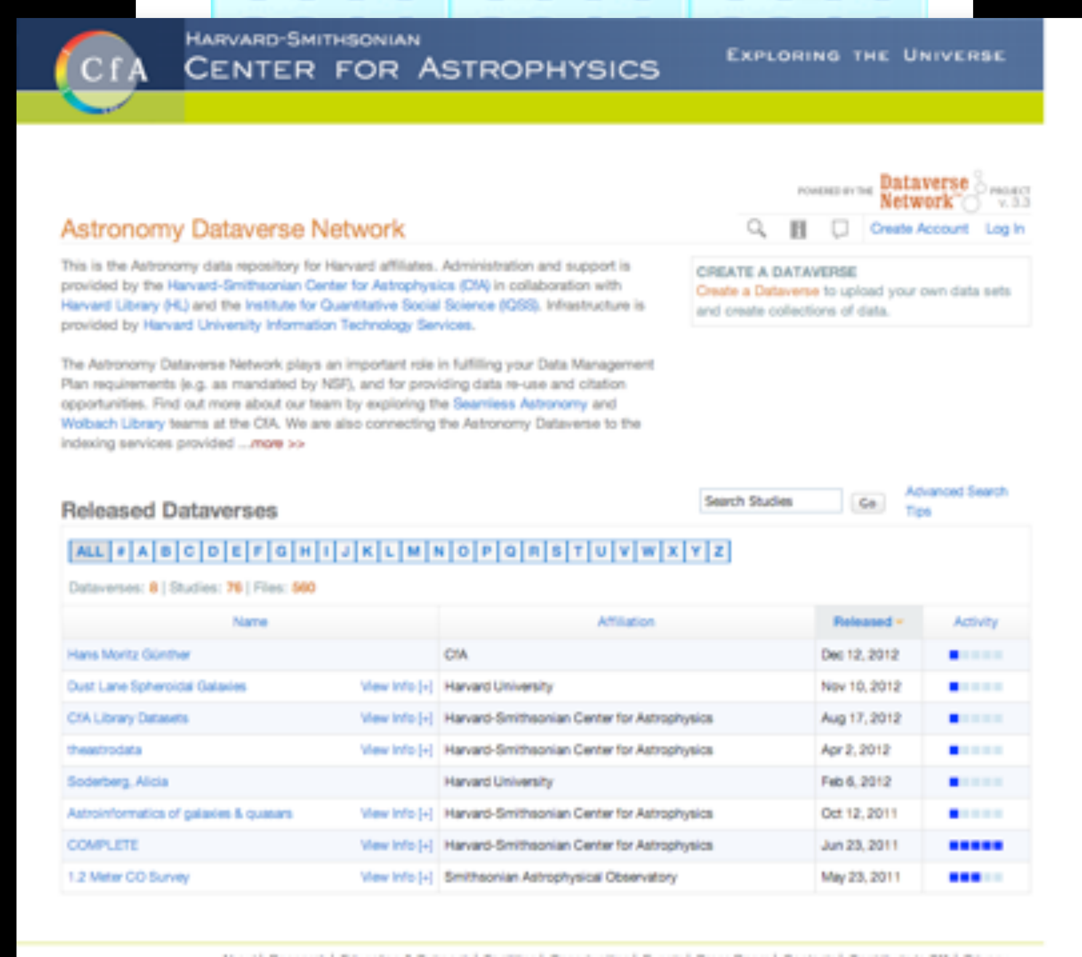

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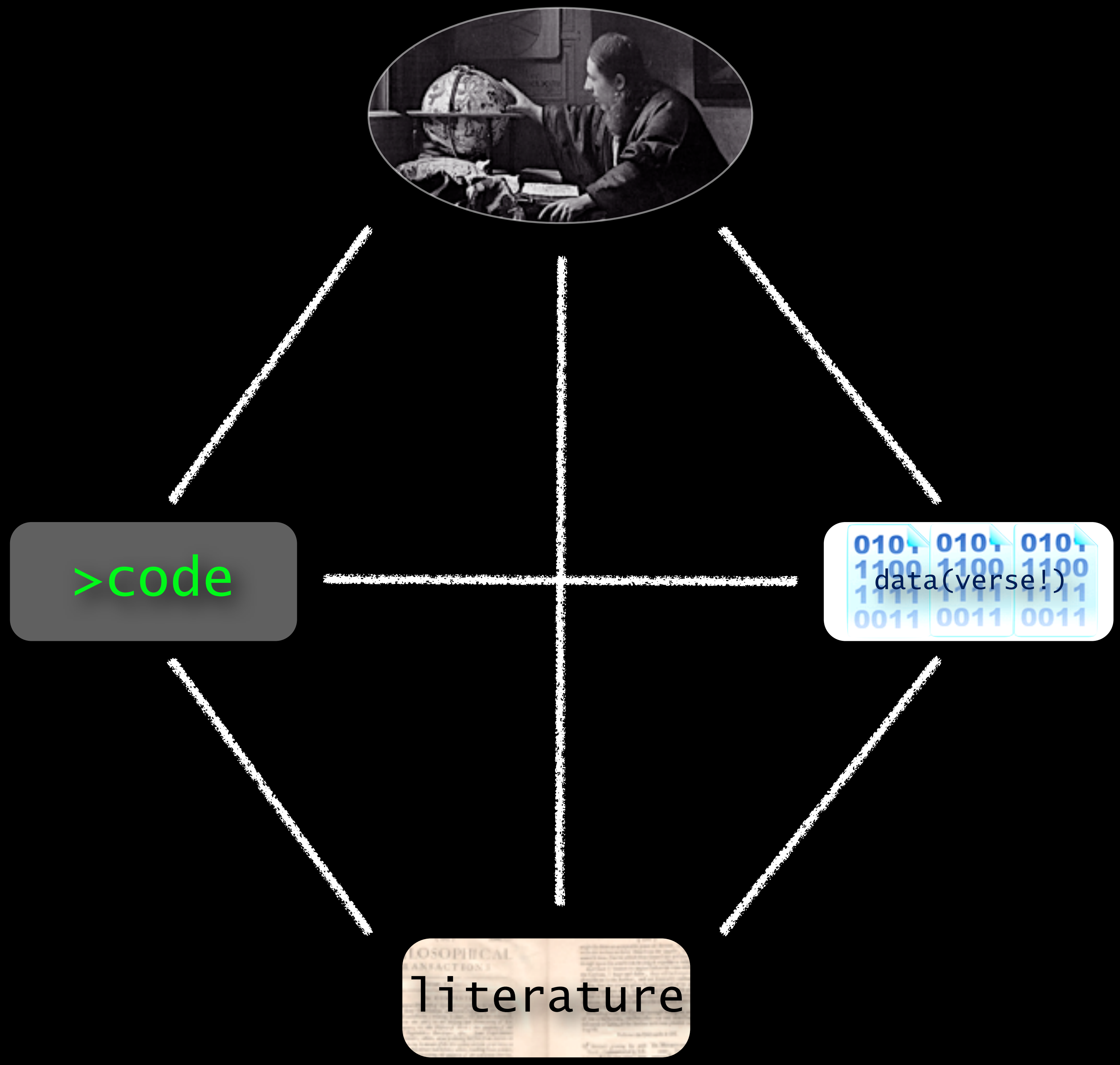

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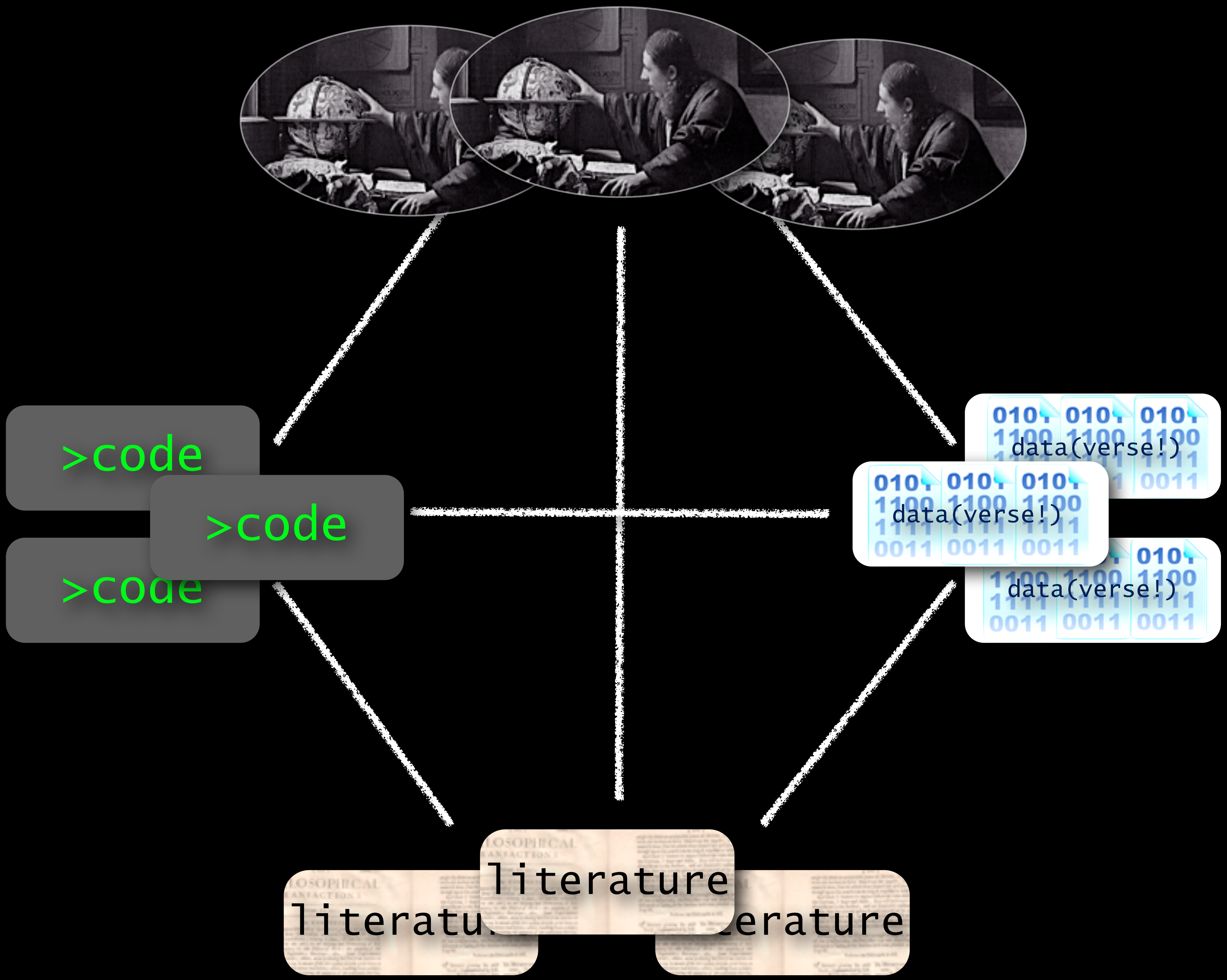
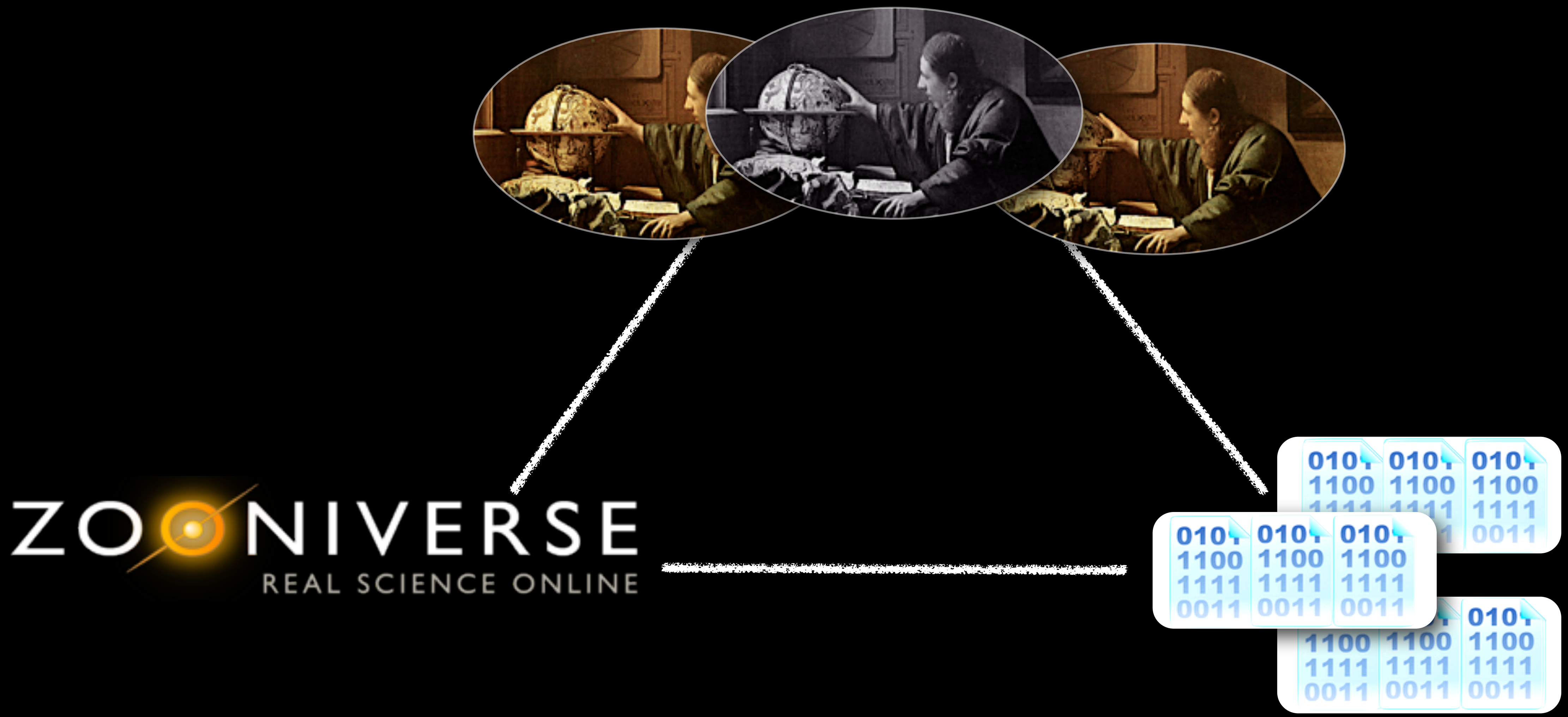
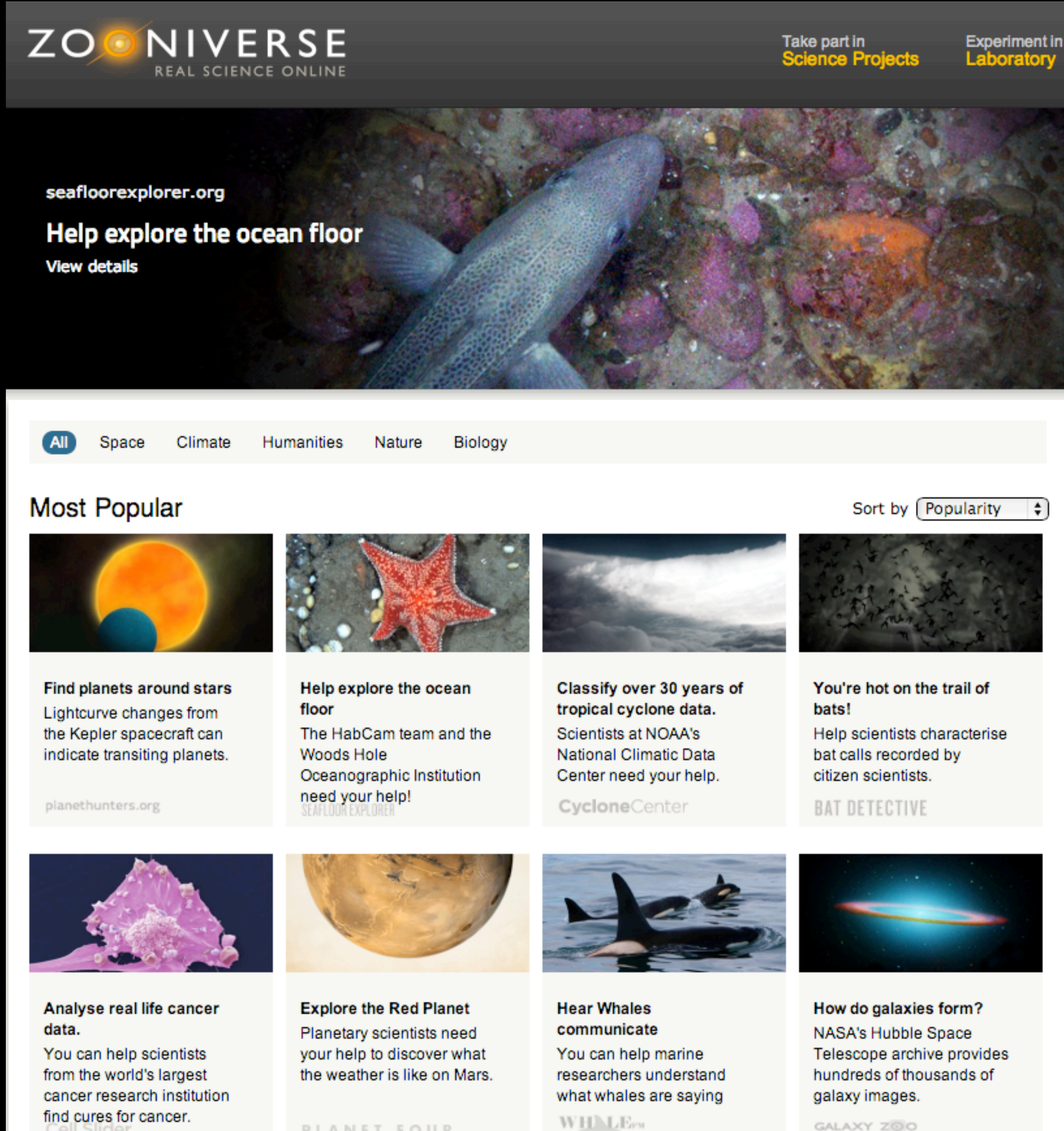


Seamless Astronomy: Citizen Science



Zooniverse team at Oxford: Chris Lintott, Rob Simpson, Brooke Simmons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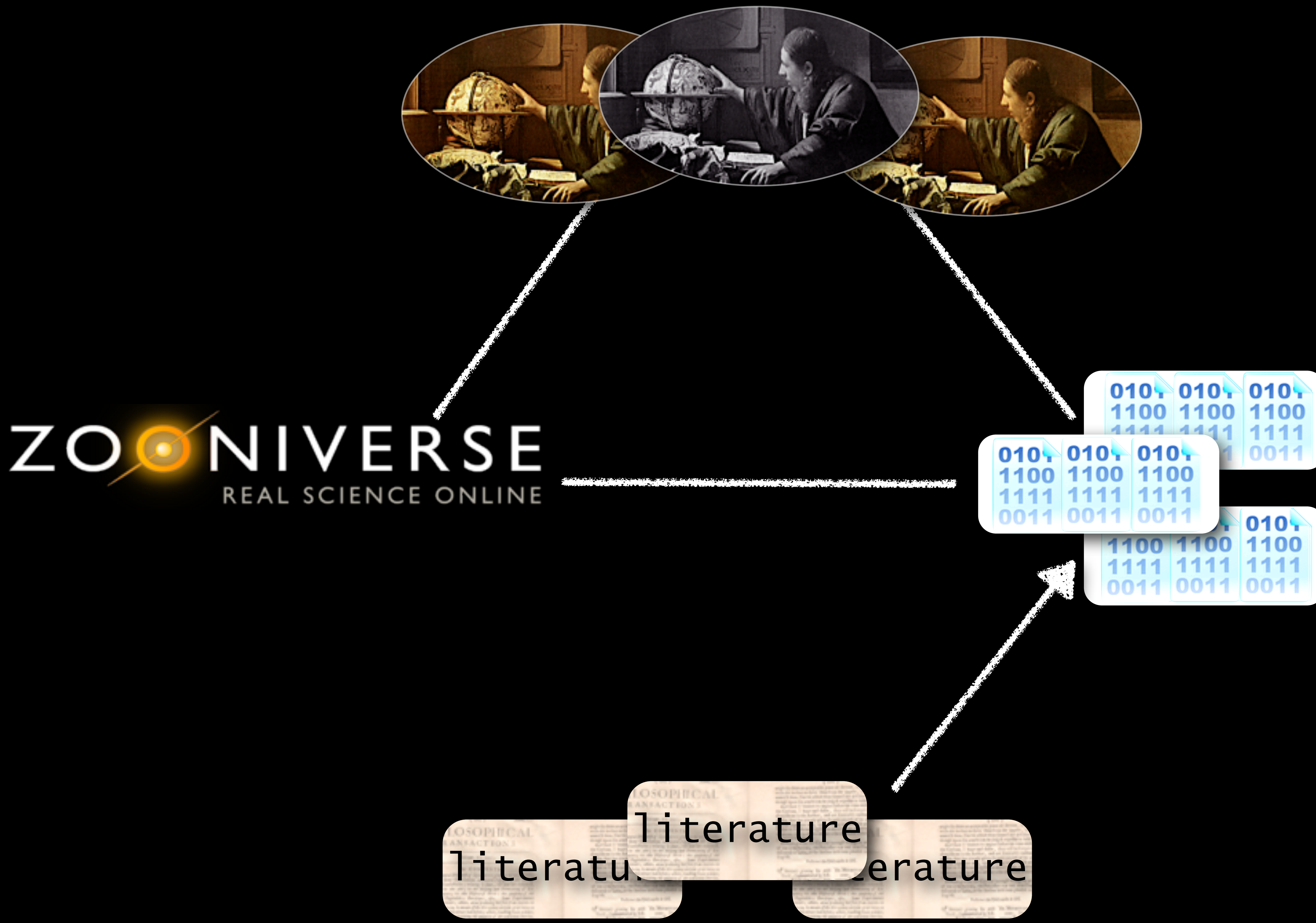
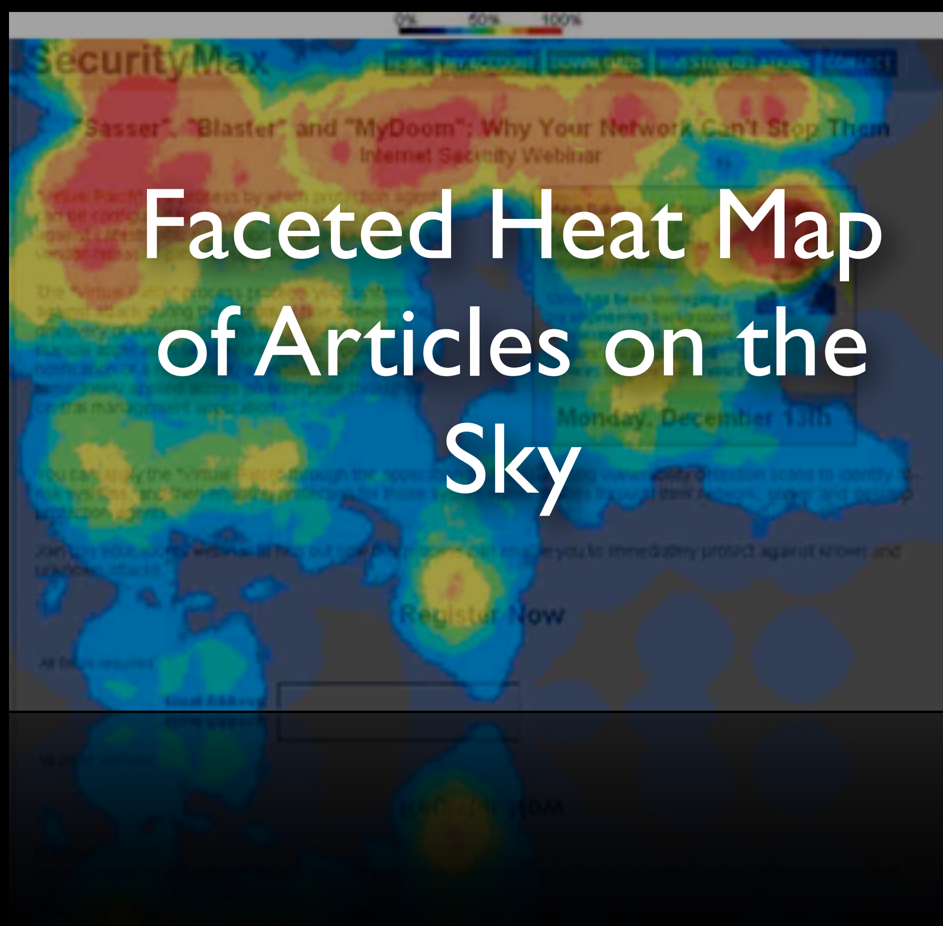


ADSASS particpants include: ADS, CDS, STScI, NYU/astrometry.net, Microsoft Research & Zooniverse

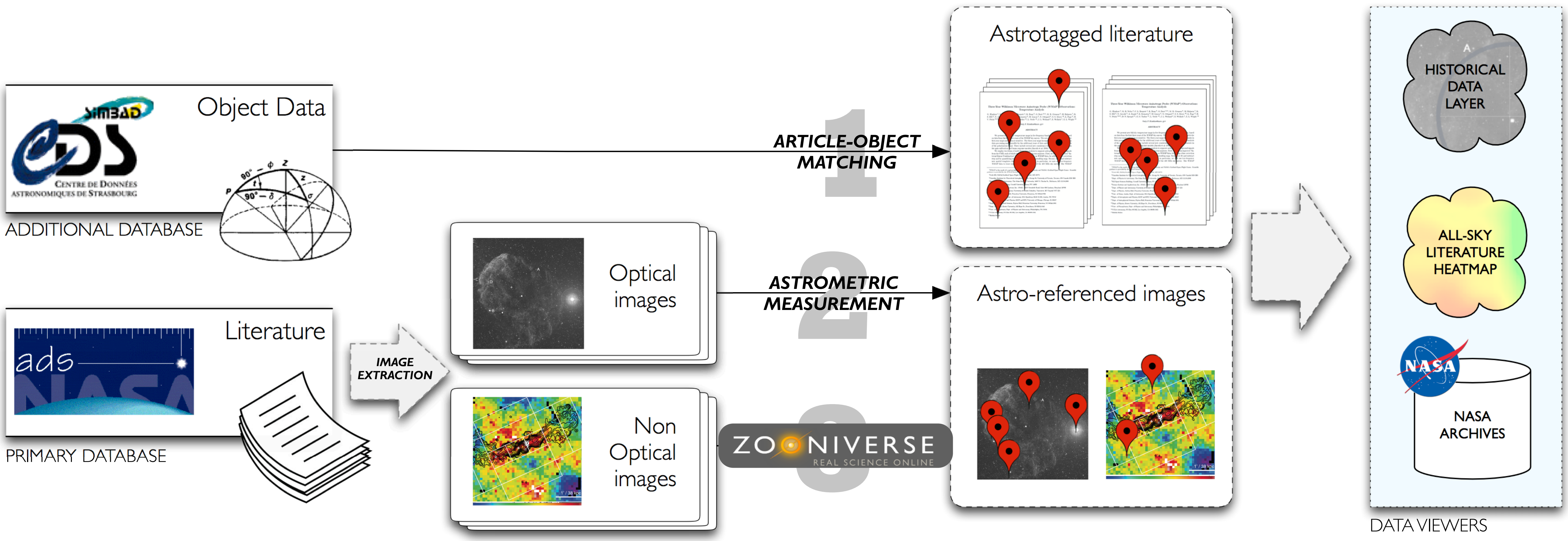
Seamless Astronomy: ADS All Sky Survey



ADS-CDS-Seamless-MSR collaboration

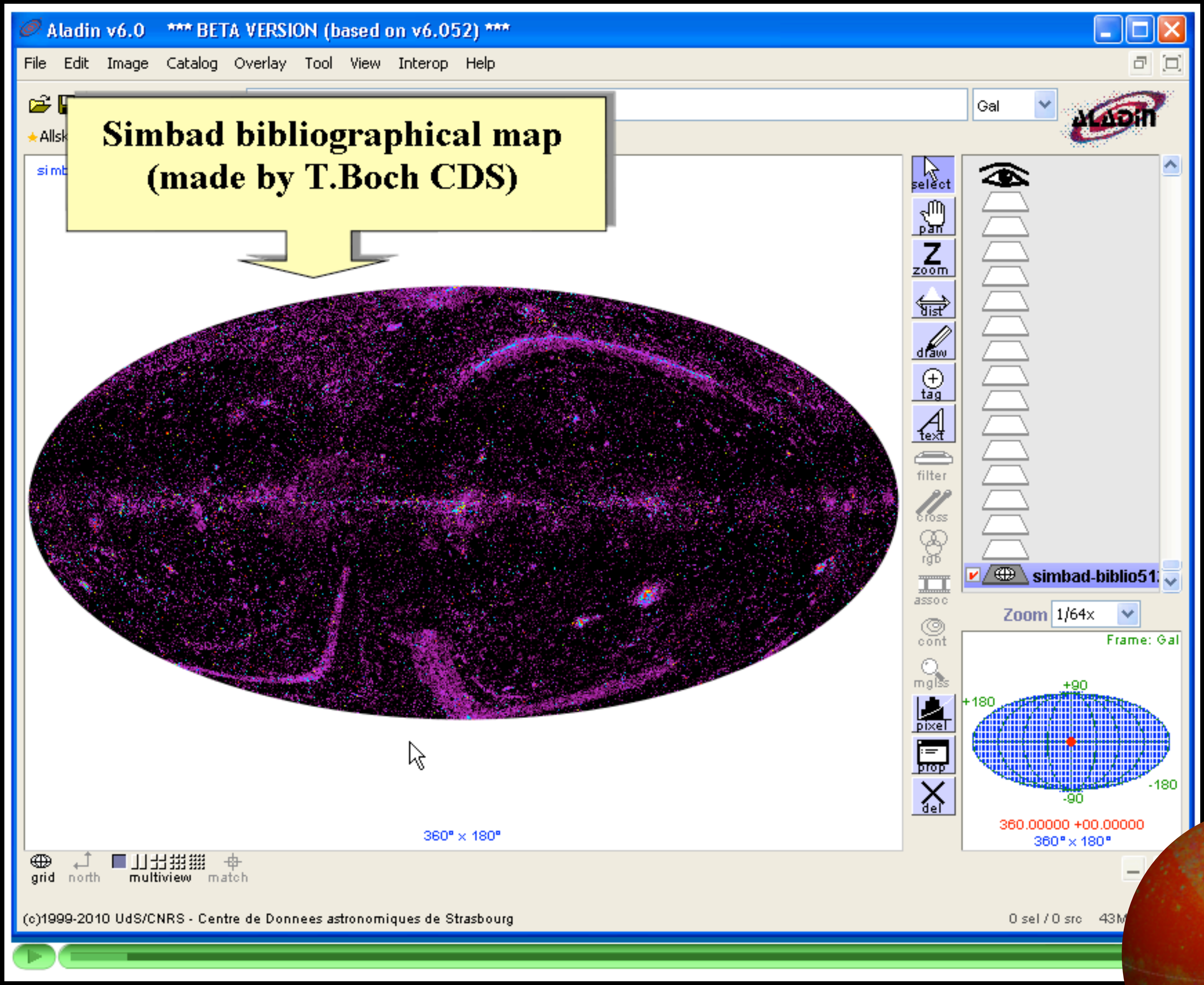
ADS-Seamless-astrometry.net-MSR-Zooniverse collaboration

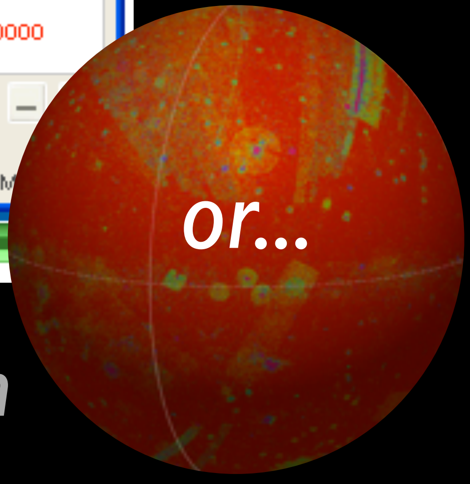
Seamless Astronomy: ADS All Sky Survey



slide courtesy of Alberto Pepe

Prototype of Articles on the Sky (2010)





with thanks to CDS/Pierre Fernique/Thomas Boch

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Draft version October 18, 2010
Preprint typeset using LaTeX style emulateapj v. 11/10/09

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

Nick Indriolo[3], Geoffrey A. Blake[4], Miwa Goto[5], Tomonori Usuda[6], Takeshi Oka[7], T. R. Geballe[8], Brian D. Fields[3,9] Benjamin J. McCall[3,9,10]

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.

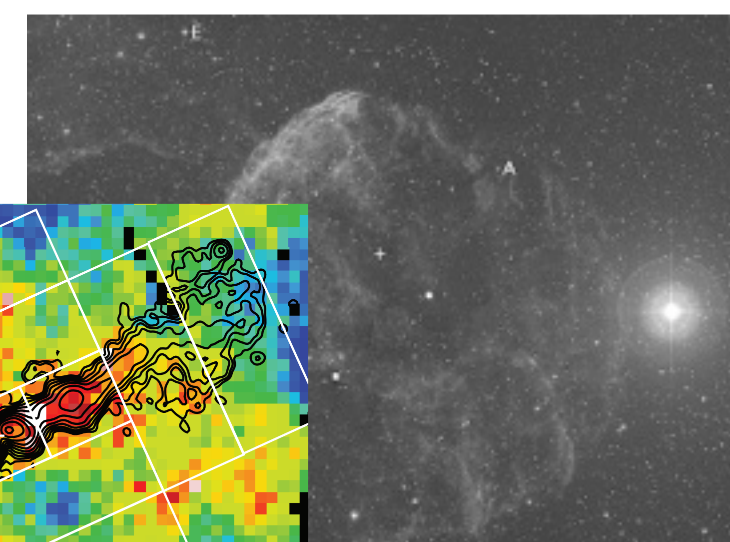
IC 443 is an intermediate age remnant (about 30,000 yr; Chevalier 1999) located in the Galactic anti-center region $(l, b) \approx (189°, +3°)$ at a distance of about 1.5 kpc in the Gem OB1 association (Welsh & Sallmen 2003), and is a particularly well-studied SNR. Figure 1 shows the red image of IC 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 $\alpha = 06^{\rm h}17^{\rm m}08.4^{\rm s}$, $\delta = +22°36'39.4''$ 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 data 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.
[3] Department of Astronomy, University of Illinois at Urbana-Champaign, Urbana, IL 61801
[4] Division of Geological and Planetary Sciences and Division of Chemistry and Chemical Engineering, MS 150-21, California Institute of Technology, Pasadena, CA 91125
[5] Max-Planck-Institut für Astronomie, Königstuhl 17, Heidelberg D-69117, Germany
[6] Subaru Telescope, 650 North A'ohoku Place, Hilo, HI 96720
[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
Candidate New and Extended Outflow Locations

				Mass ($M_\odot$)	Momentum ($M_\odot$ km s^{-1})	Kinetic Energy (10^{42} erg)	Driving Source Candidate(s)
[illegible]	[illegible]	[illegible]	[illegible]	0.05	0.19	6.93	L1448-IRS1
CPOC 2	[illegible]	[illegible]	[illegible]	0.36	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



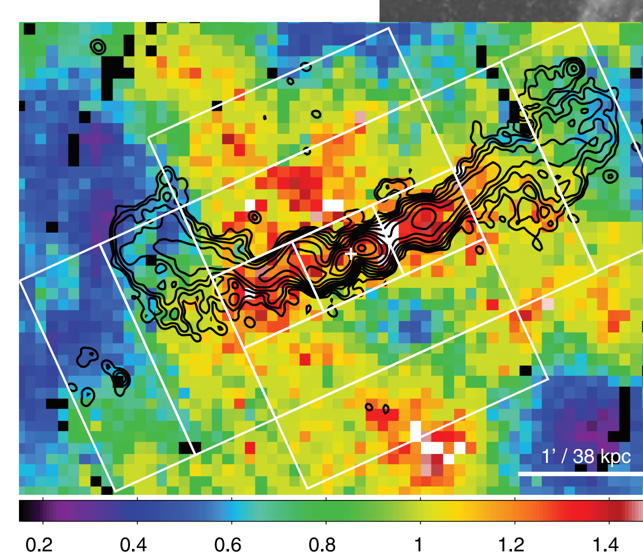
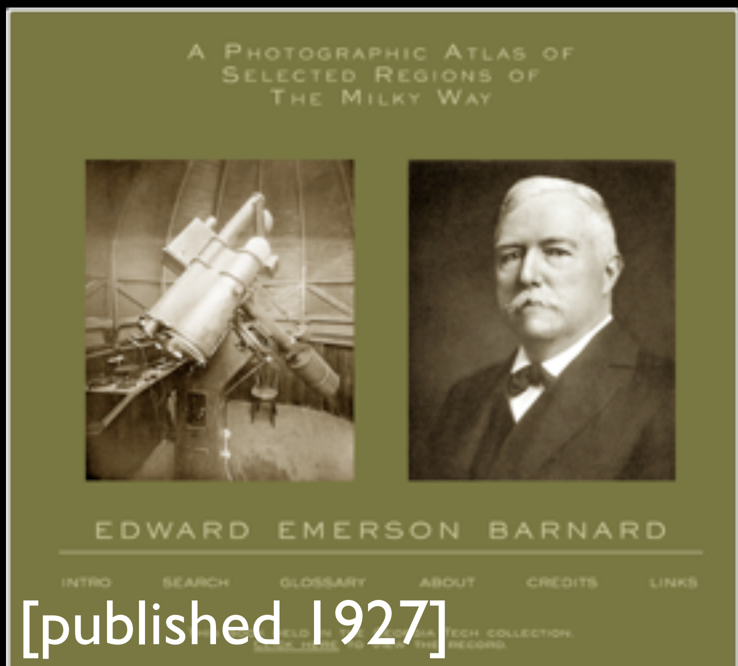
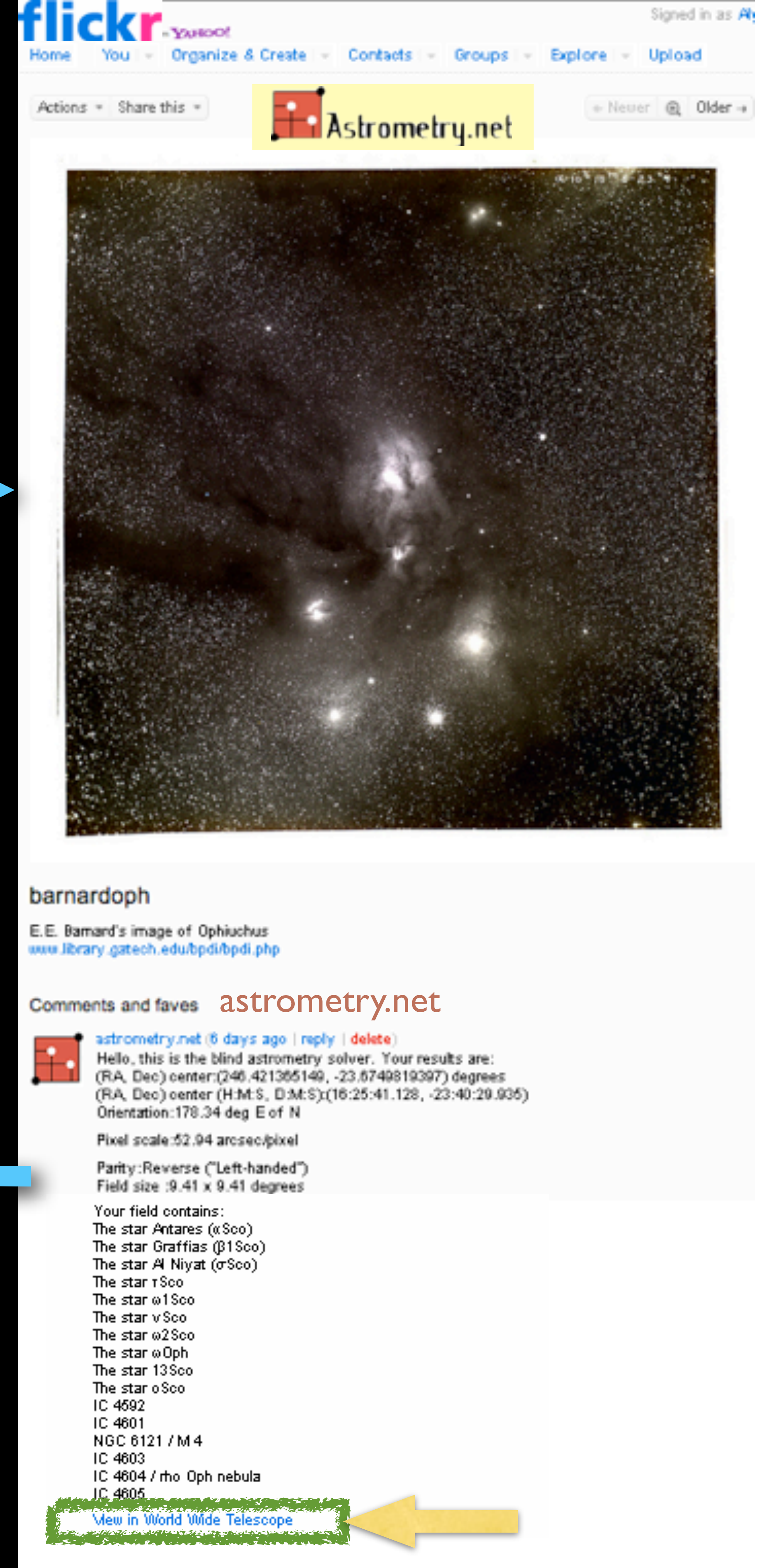


Figure 3. Abundance map of the core of AWM 4, with GMRT 610-MI contours overlaid. Rectangular regions were used to examine the variati in abundance across and along the jet. The white cross marks the positi of the radio core.

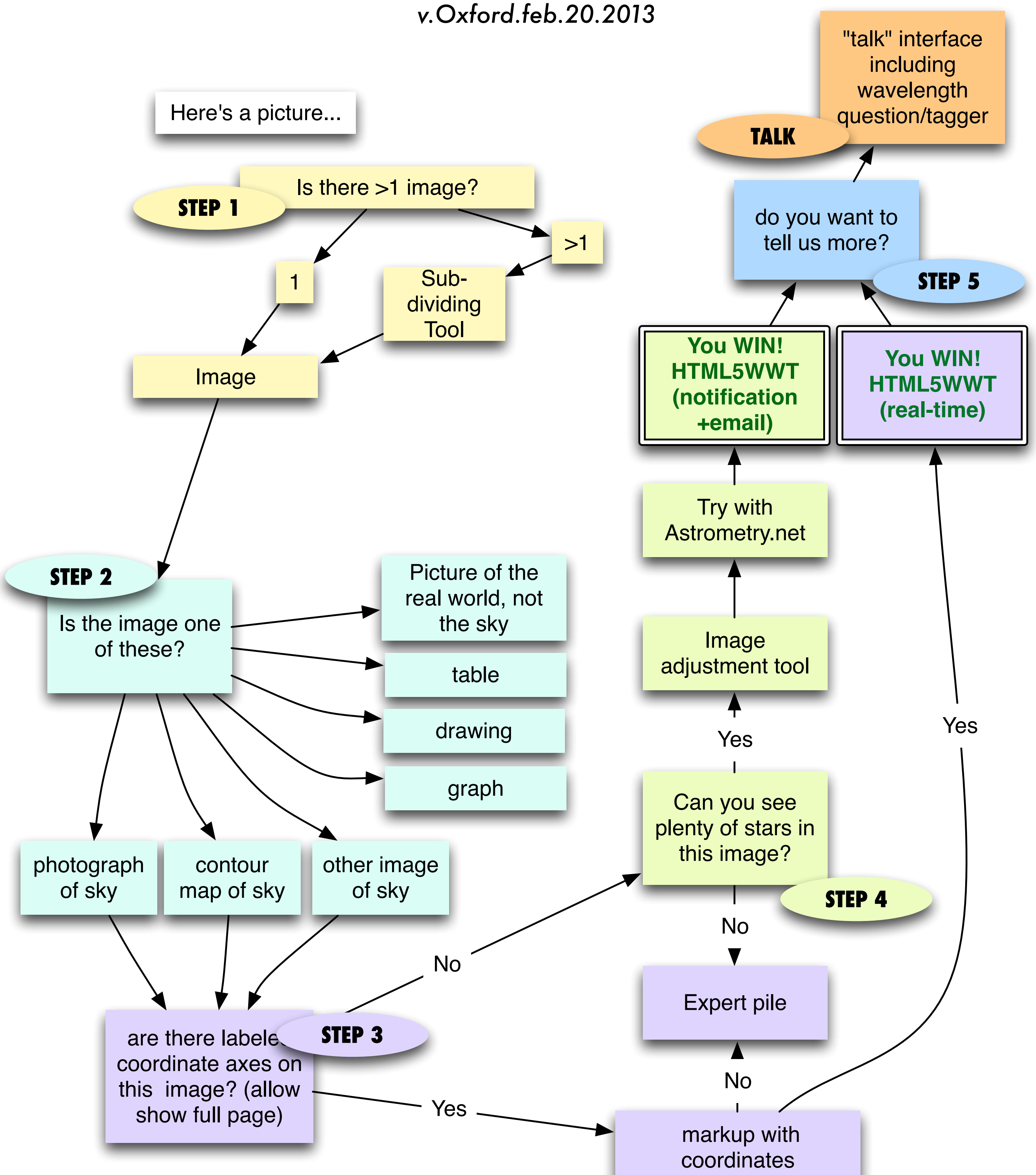
Reviving "Dead" Data

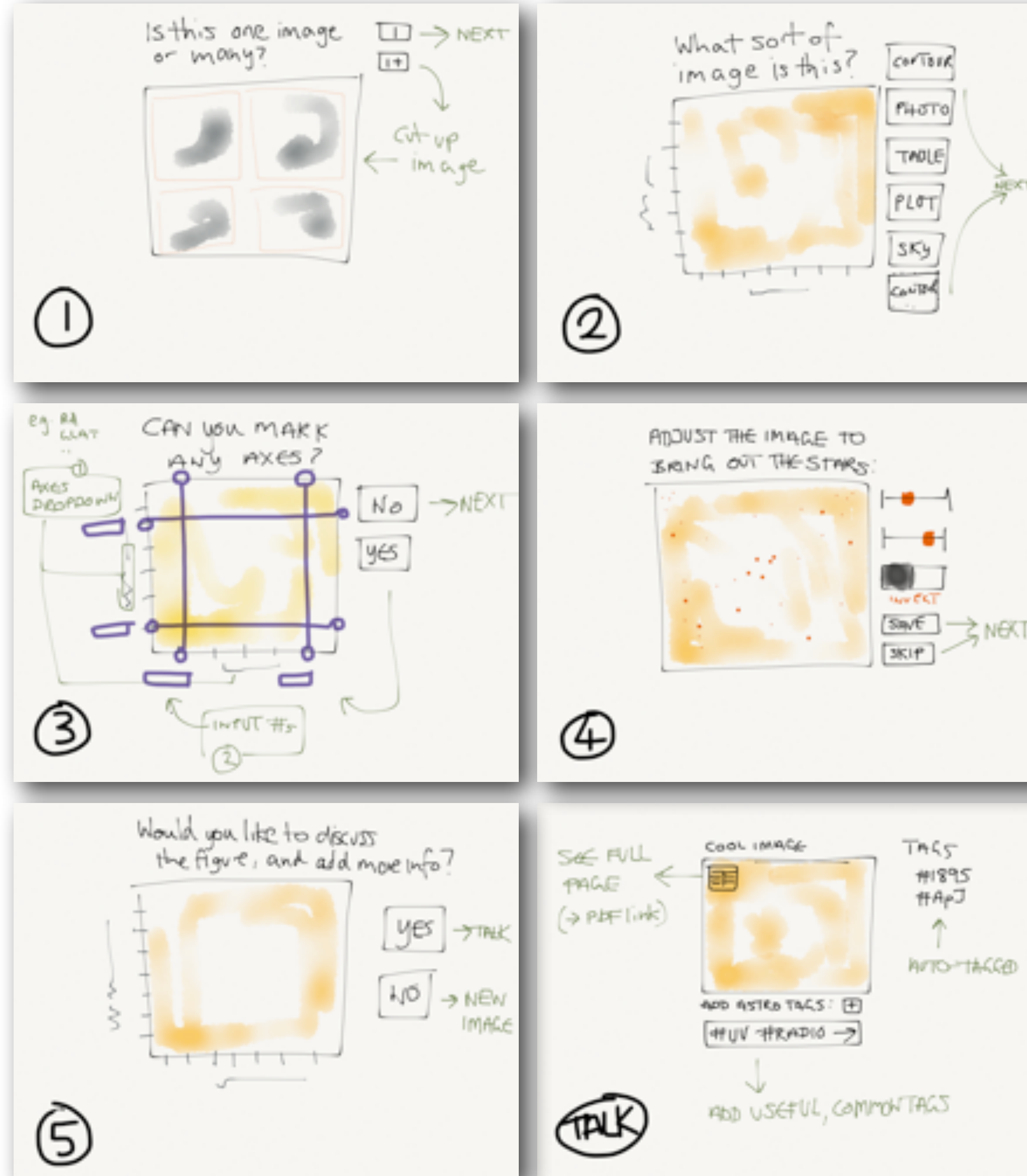




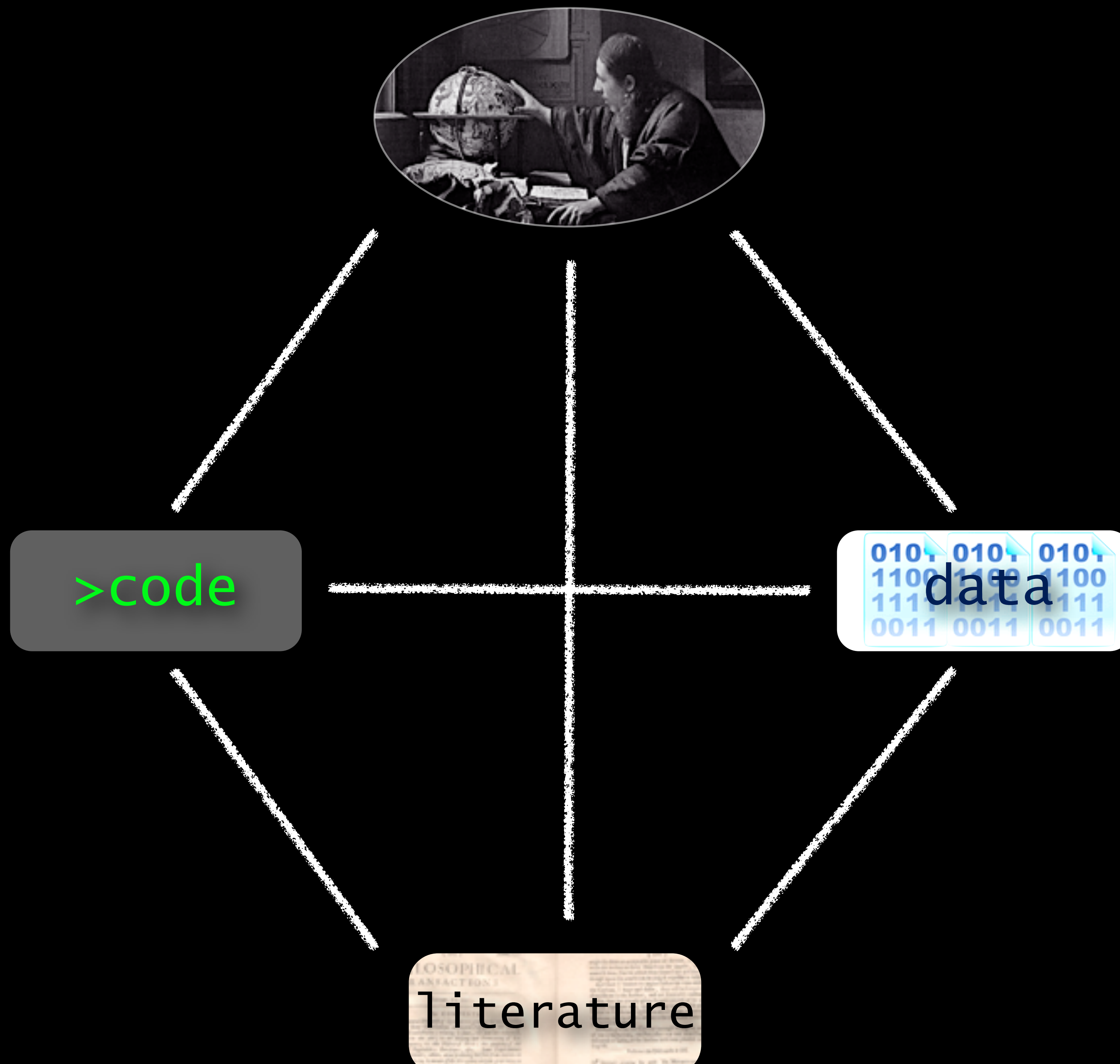
Coming Soon!

Workflow for **Old Astronomy**
(the ADS All Sky Survey Zooniverse Project)
v.Oxford.feb.20.2013

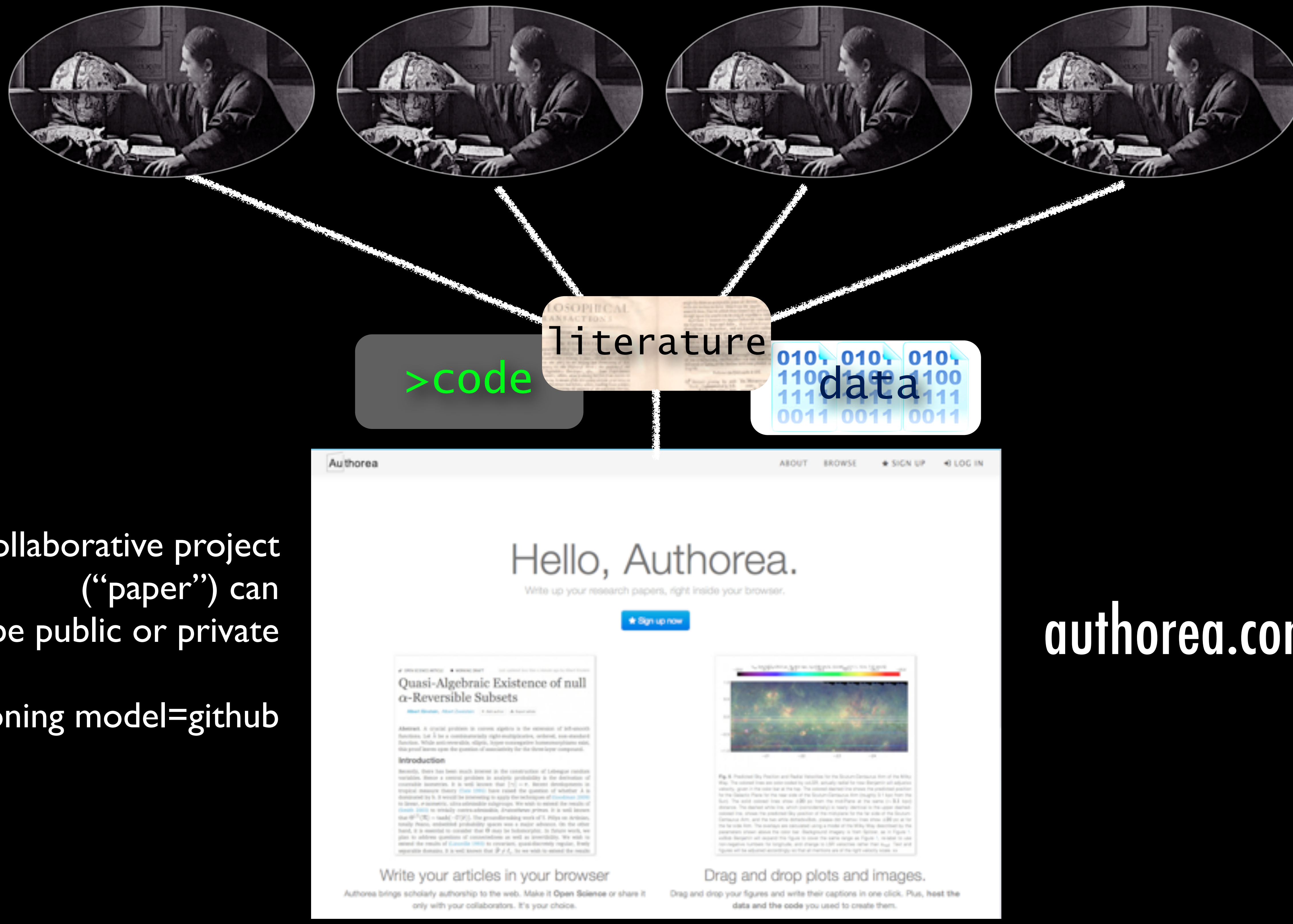




Seamless Astronomy



Seamless Astronomy: Authorea



each collaborative project ("paper") can be public or private

versioning model=github

authorea.com

milkywaybones.org

Released to the public January 2013,
at American Astronomical Society
Press Conference,
Long Beach, California

Press Conference Slides–*Verbatim*

The Bones of the Milky Way

Alyssa A. Goodman (Harvard-Smithsonian Center for Astrophysics)

with collaborators at (alphabetically by insitution):

Boston University: James Jackson

Caltech: Jens Kauffmann

Harvard - Smithsonian: Christopher Beaumont, Michelle A. Borkin, Thomas M. Dame

Max Planck Insitute for Astronomy: Thomas Robitaille

U. Munich: Andreas Burkert

U. Vienna: Joao F. Alves

U. Wisconsin: Robert A. Benjamin

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Sea Monster to Skeletal Shadow

Peculiar dust cloud named "Nessie" much larger than thought.

Nessie more important as "bone" than sea monster.

Sun's height above Plane may make full Milky Way skeleton mappable.

Who, What, and Where is "Nessie"?

"Is Nessie Parallel to the Galactic Plane?"

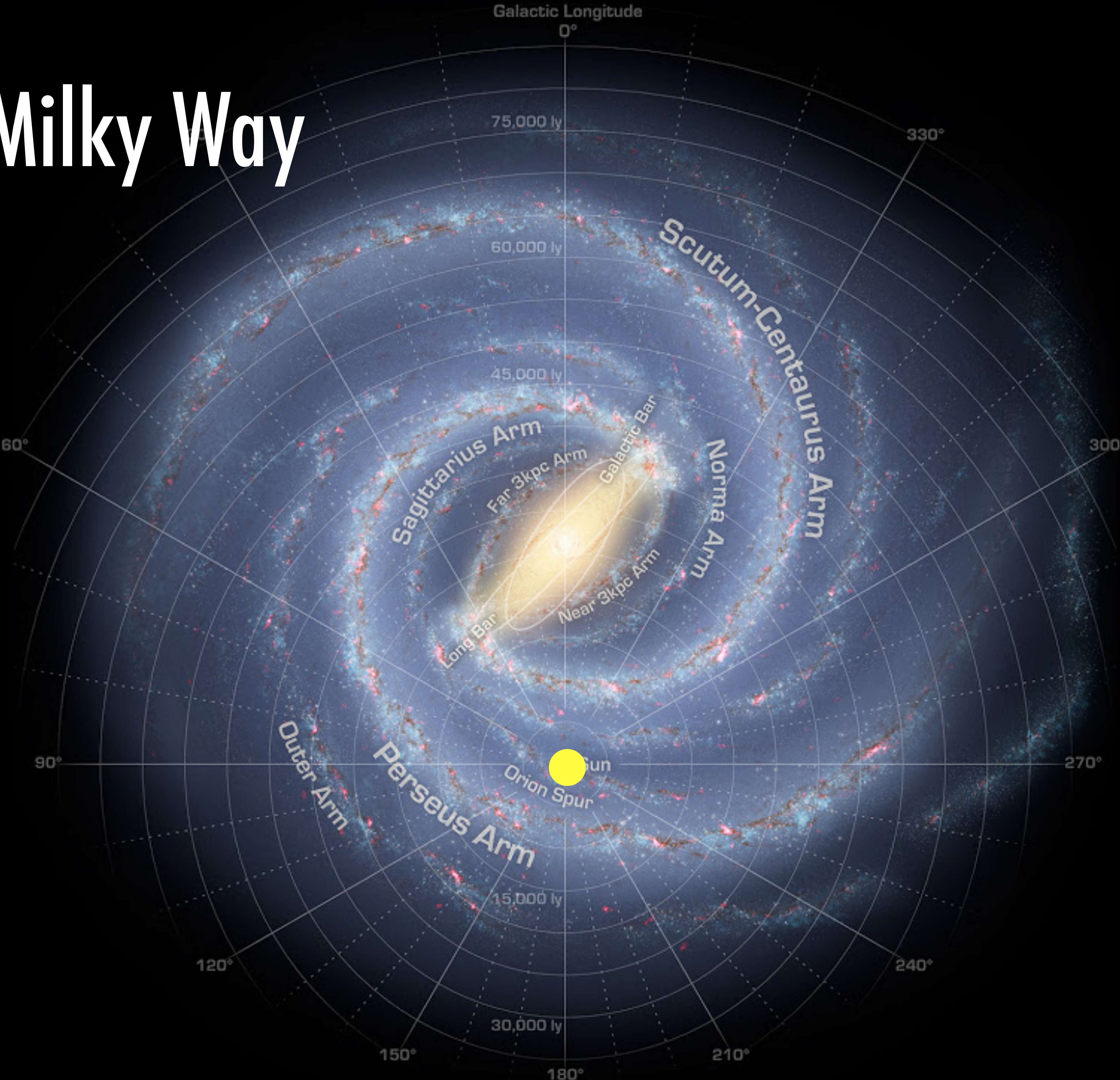
The Milky Way

The Milky Way
(Artist's Conception)

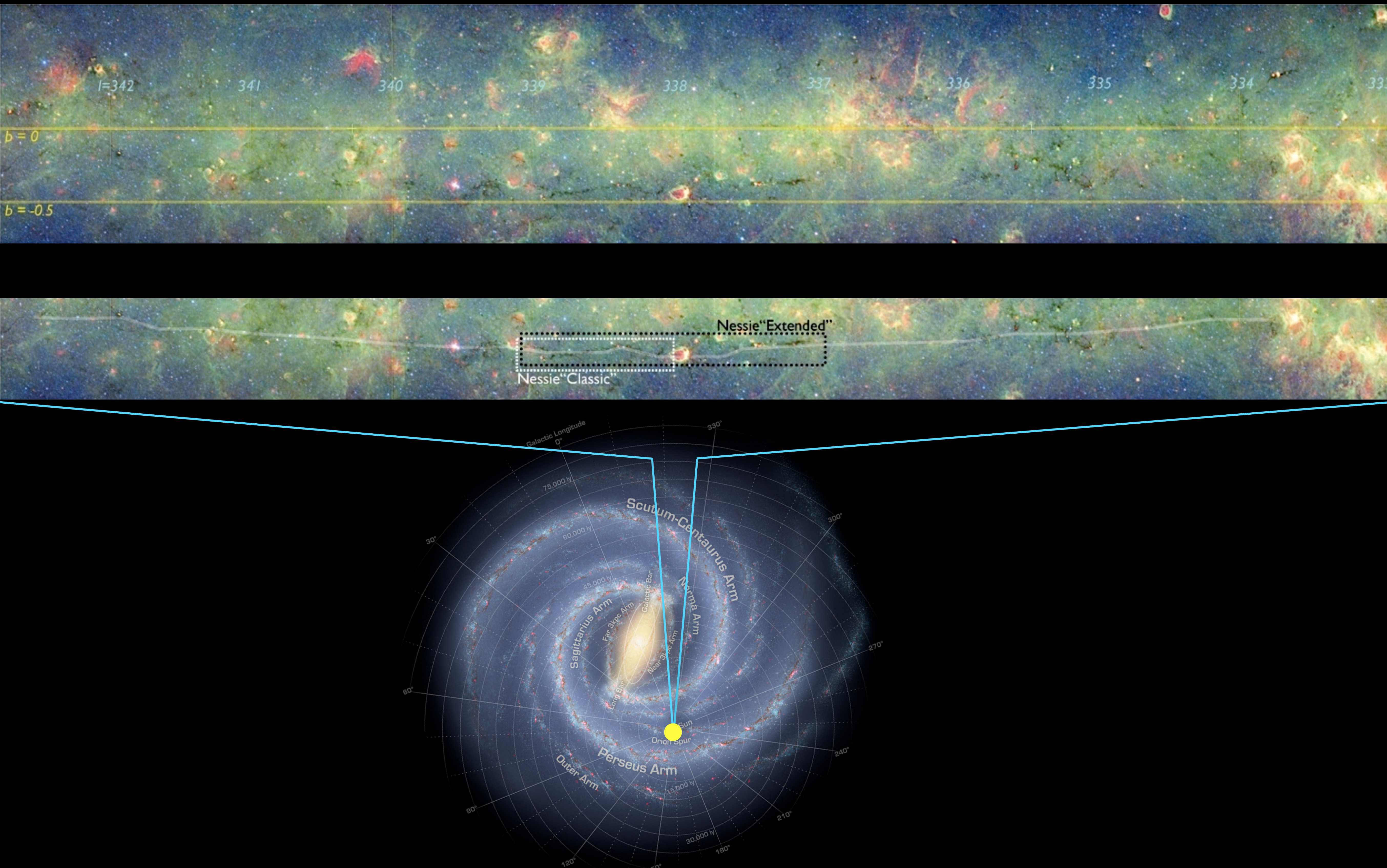
Who, What, and Where is "Nessie"?

"Is Nessie Parallel to the Galactic Plane?"

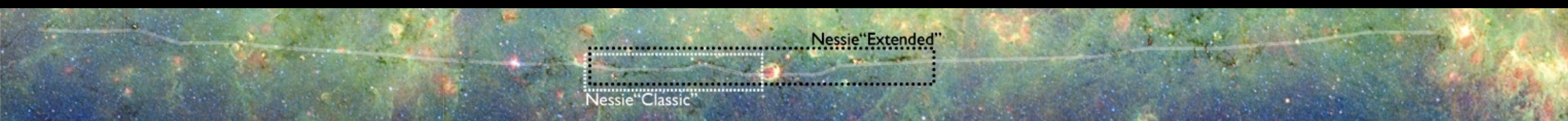
The Milky Way



Alyssa Goodman, Harvard-Smithsonian CfA, The Bones of the Milky Way, milkywaybones.org



Alyssa Goodman, Harvard-Smithsonian CfA, The Bones of the Milky Way, milkywaybones.org

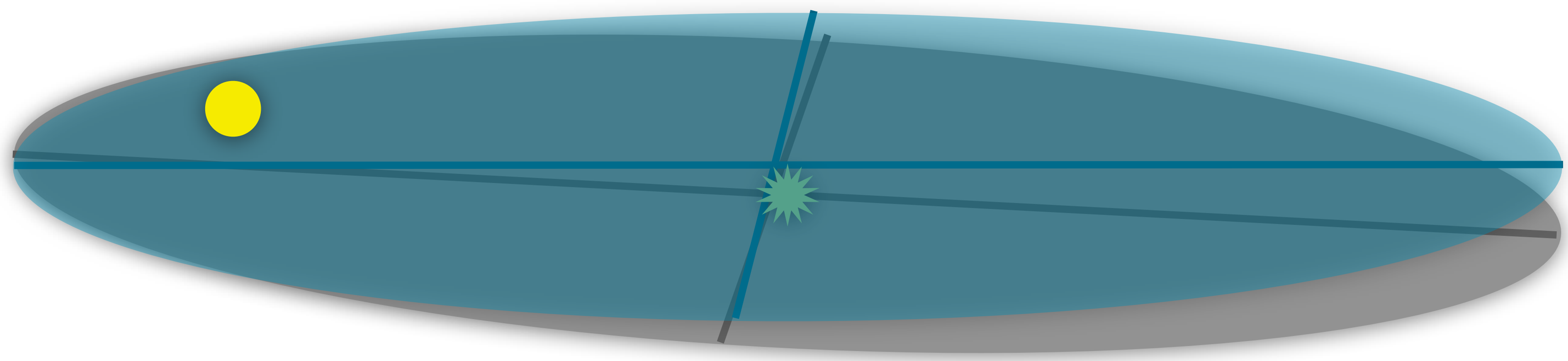


Just "Nessie Extended"...
~500 light years long & 1.5 light years thick.
300:1 axial ratio.

Why is it 0.5 degrees below b=0? Is it in the plane, or not?

Where are we?

"IAU Milky Way", est. 1959



True Milky Way, modern

> The equatorial plane of the new co-ordinate system must of necessity pass through the sun. It is a fortunate circumstance that, within the observational uncertainty, both the sun and Sagittarius A lie in the mean plane of the Galaxy as determined from the hydrogen observations. If the sun had not been so placed, points in the mean plane would not lie on the galactic equator.
>
> *[Blaauw et al. 1959]*

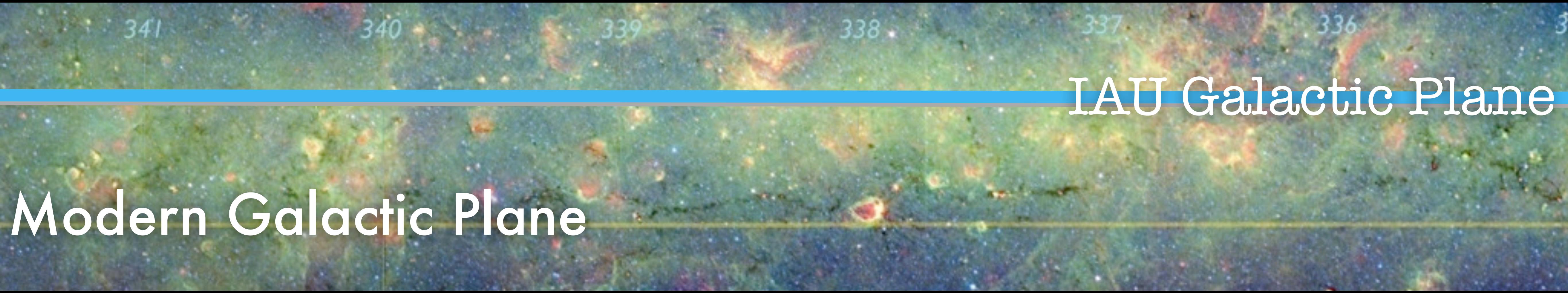
Sun is ~75 light years "above" the IAU Milky Way Plane

\+

Galactic Center is ~20 light years offset from the IAU Milky Way Center

=

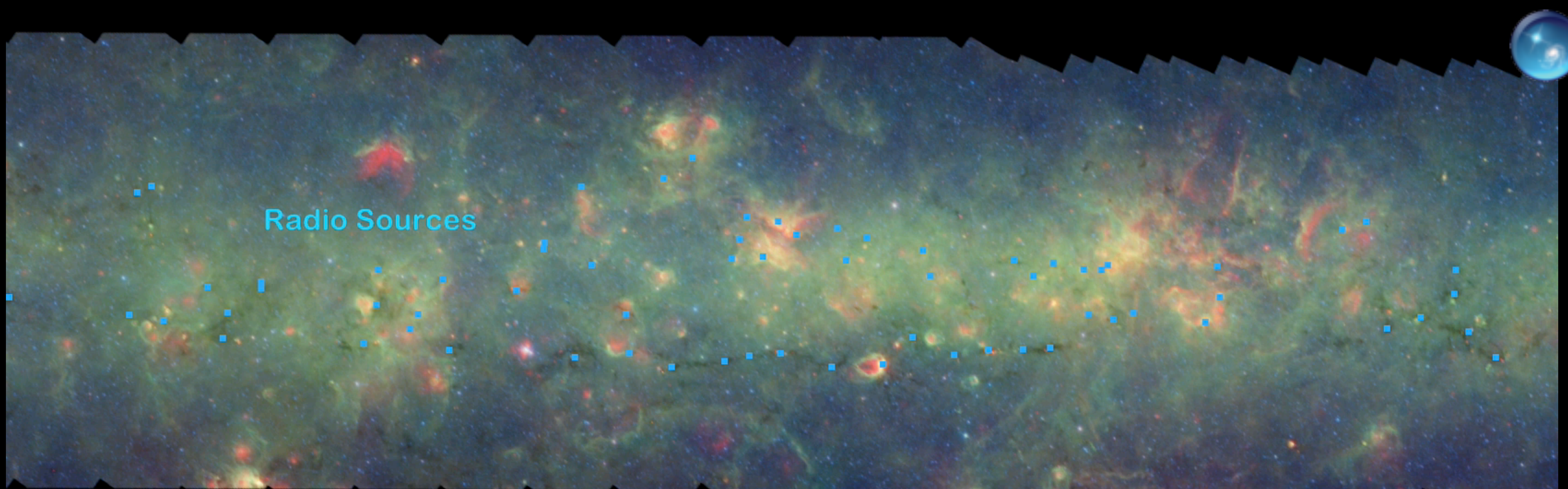
The Galactic Plane is not exactly where you'd think it is when you look at the sky, and...



Yes, Nessie is EXACTLY in the Galactic Plane!

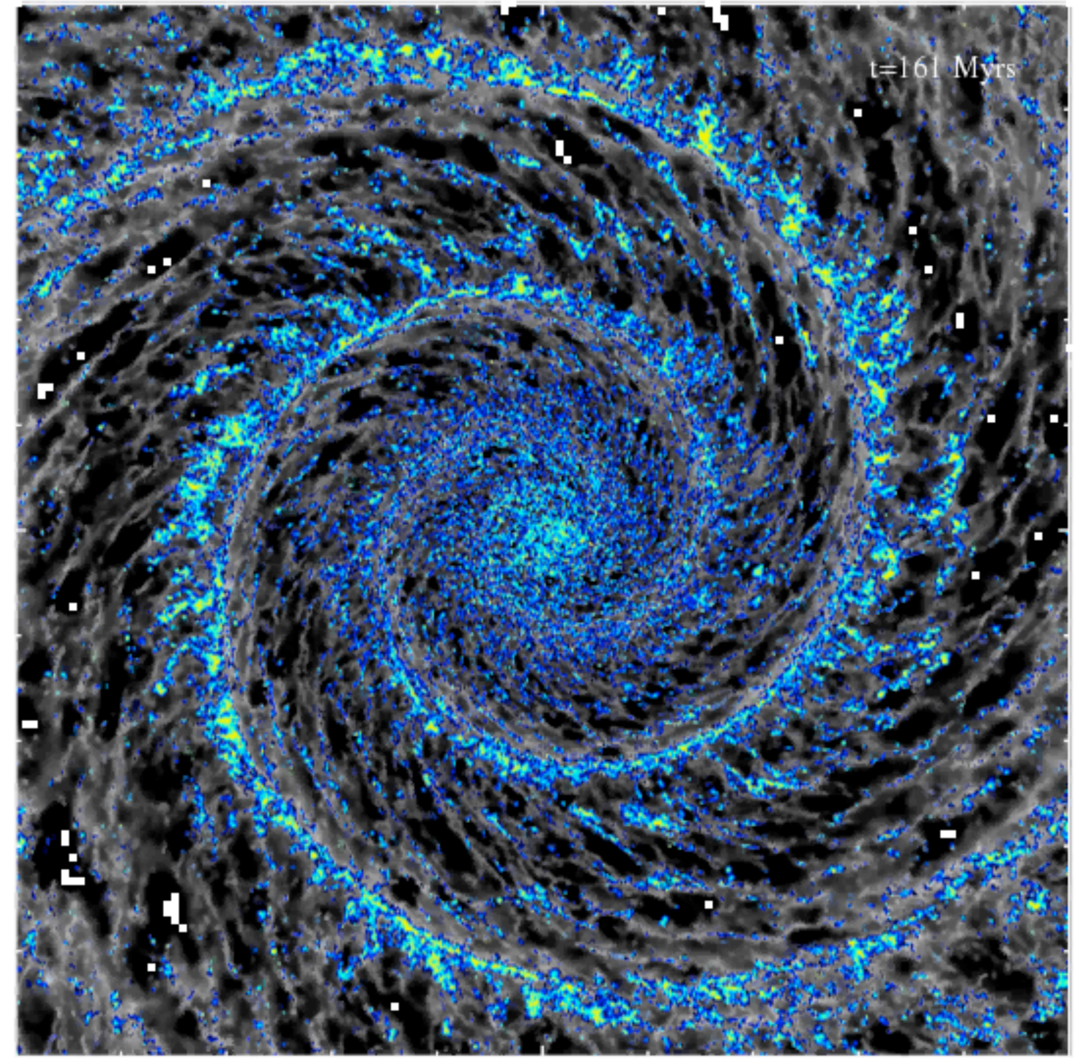
What about its distance?

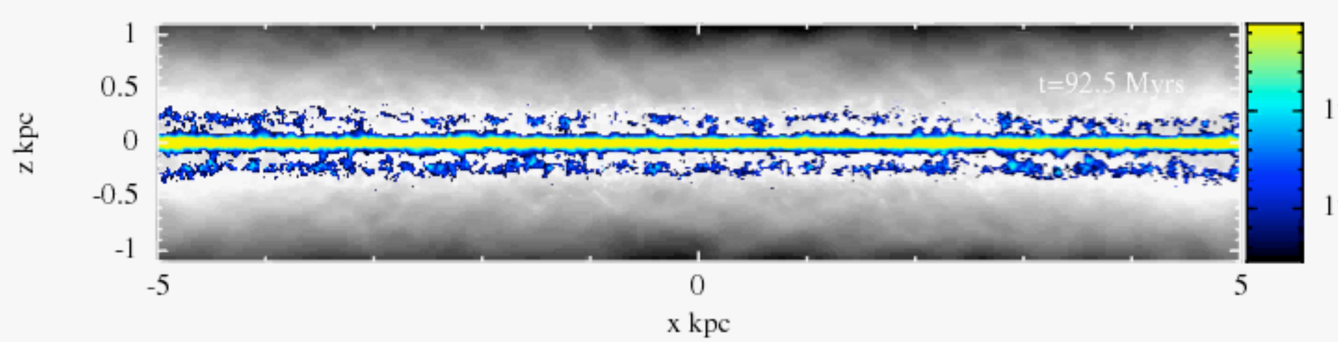
Velocity to Distance



A full 3D skeleton?

(flipped) image of IC342 from Jarrett et al. 2012; WISE Enhanced Resolution Galaxy Atlas





simulations courtesy Clare Dobbs

Monster to Bone

There could be ~1000 more of these to find...a full skeleton perhaps?

The Bones of the Milky Way: Credits

Seamless Astronomy-style tools used in this project

SEAMLESS ASTRONOMY

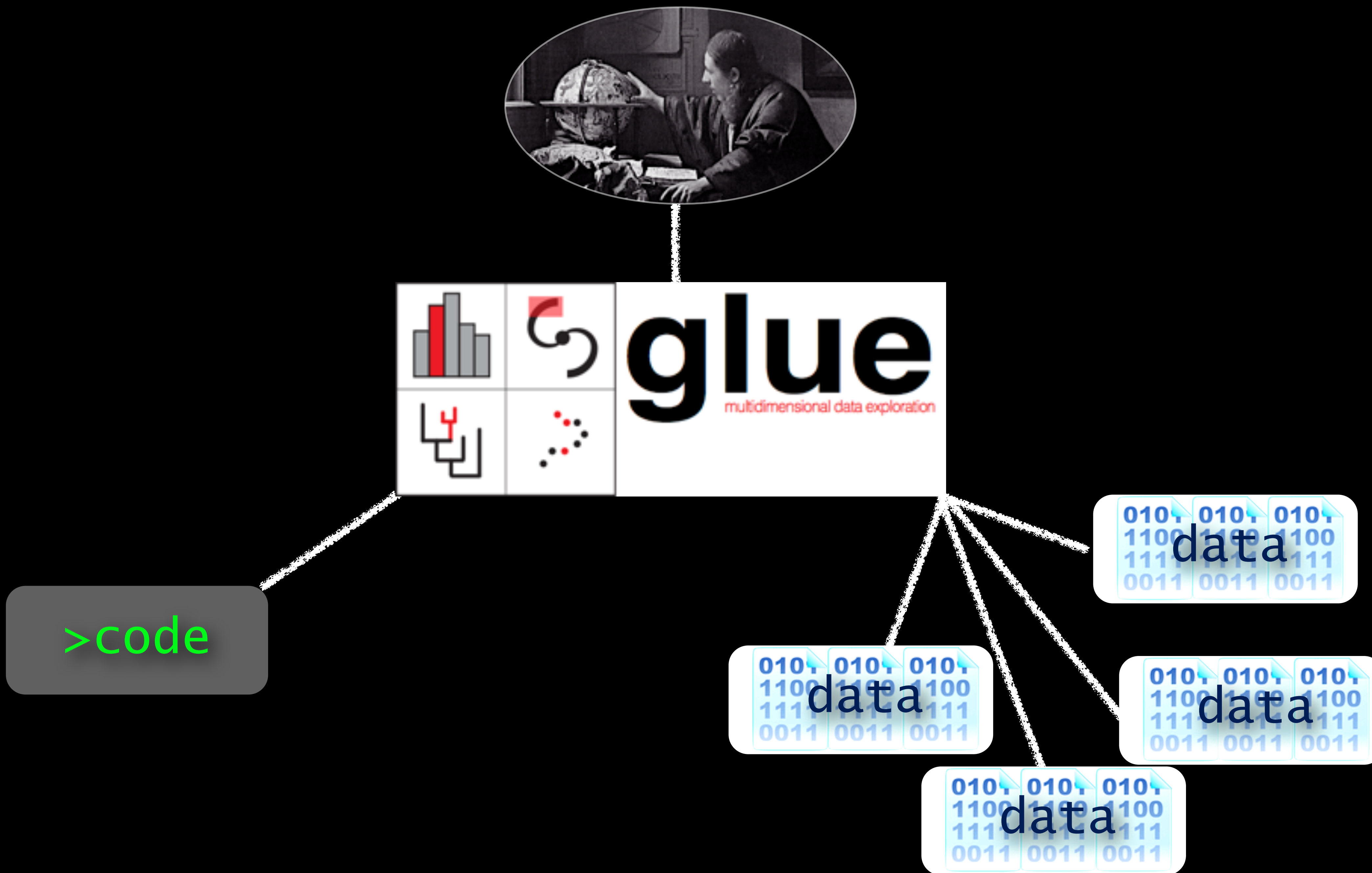
authorea.com (open publishing)
theastrodata.org (open data)
glueviz.org (open source tools)
universe3d.org (collaborative data)
worldwidetelescope.org (universe information system)
virtual observatory standards (international online information-sharing systems)

Supported by

Microsoft Research, NSF, NASA, VE RI TAS, Smithsonian

Alyssa Goodman, m:617-230-7080; url: milkywaybones.org

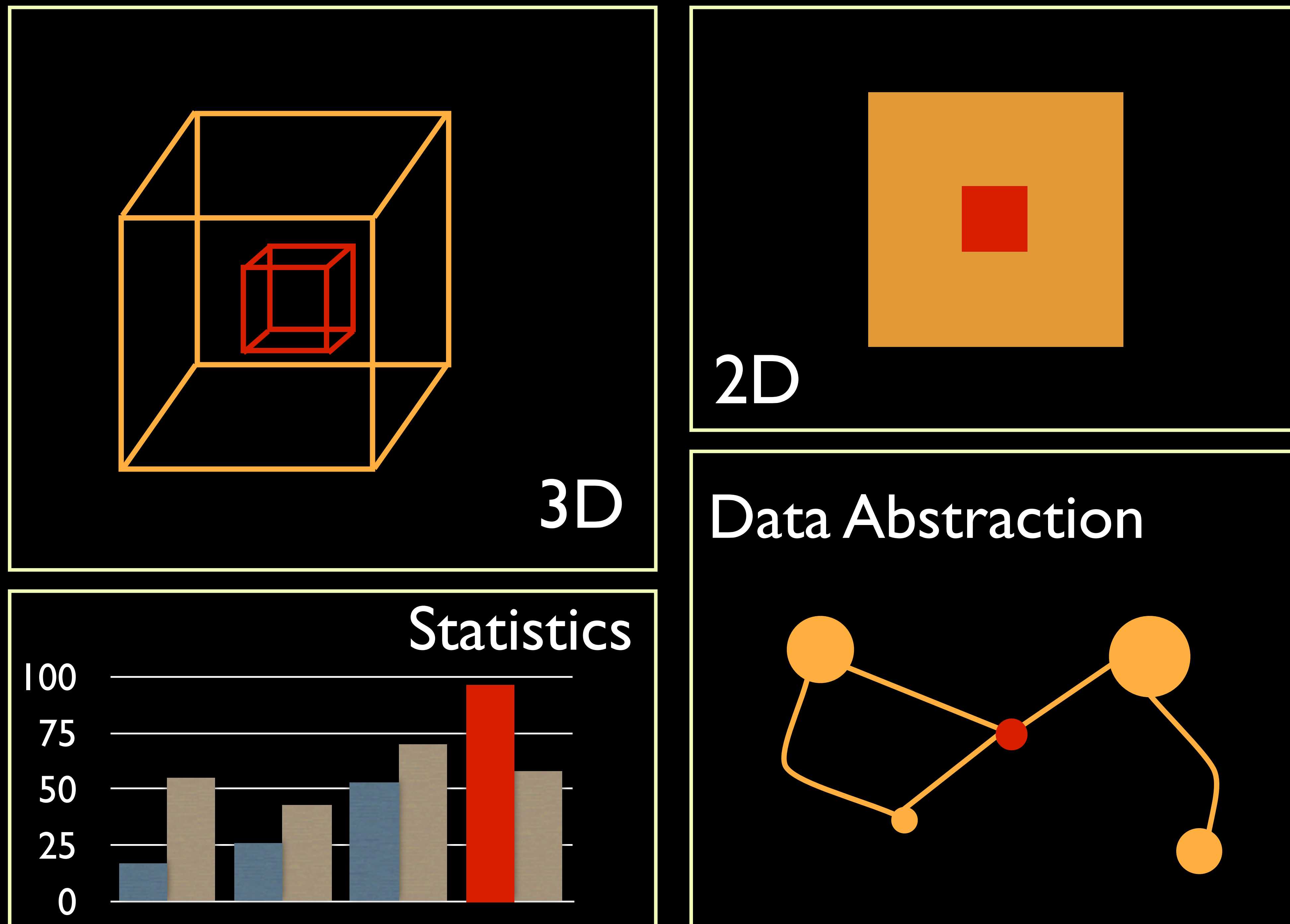
Seamless Astronomy: Data Visualization

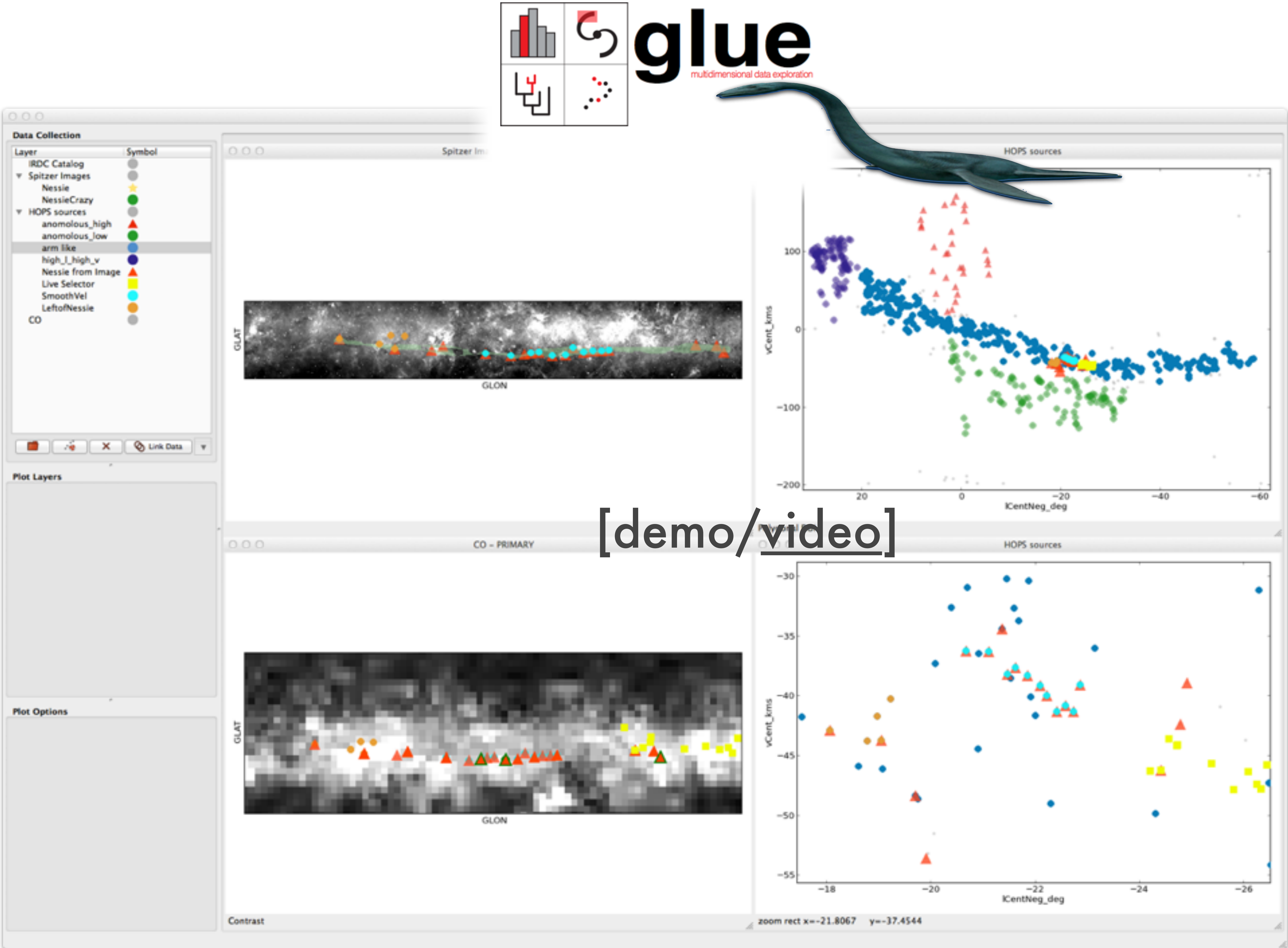


Glue collaboration (see *glueviz.org*): Chris **Beaumont**, lead & Alyssa **Goodman** (Harvard-CfA);
Michelle **Borkin** & Hanspeter **Pfister** (Harvard-SEAS/CS) and Thomas **Robitaille** (MPIA Heidelberg)

“Linked Views”= glue

multidimensional data exploration

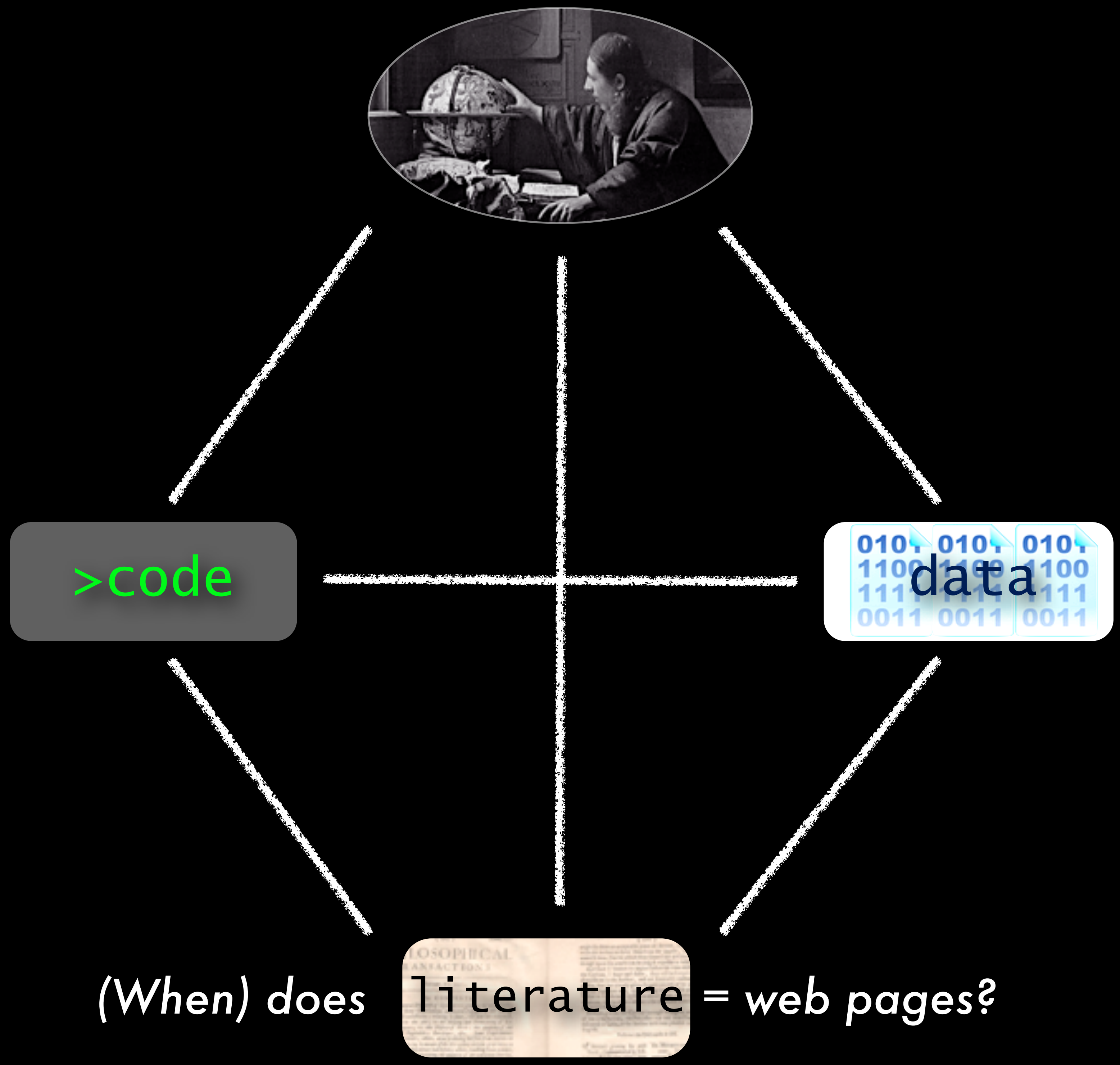




[demo/video]

http://www.glueviz.org/en/latest/ *Glue collaboration:* ***Beaumont****, Borkin, Goodman, Pfister, Robitaille*

Seamless Astronomy



(When) does literature = web pages?

Seamless Astronomy, Sea Monsters & the Milky Way

The Astronomer, Vermeer

"Nessie", Spitzer Space Telescope

Alyssa A. Goodman

Harvard-Smithsonian Center for Astrophysics

What does "Publication-Quality" Graphics Mean in an Interactive 3D World?

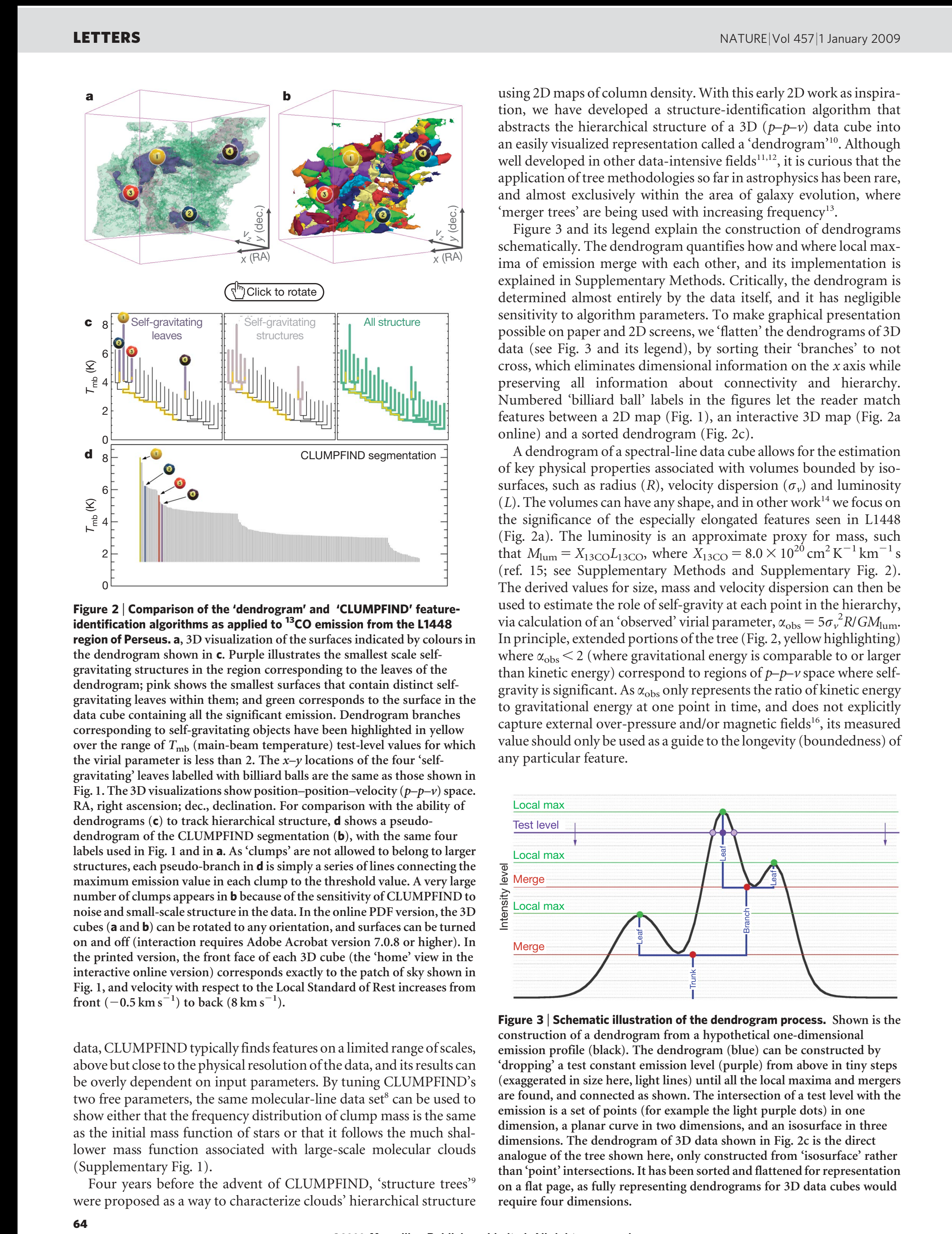


Figure 2 | Comparison of the 'dendrogram' and 'CLUMPFIND' feature-identification algorithms as applied to ^{13}CO emission from the L1448 region of Perseus. a, 3D visualization of the surfaces indicated by colours in the dendrogram shown in **c**. Purple illustrates the smallest scale self-gravitating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

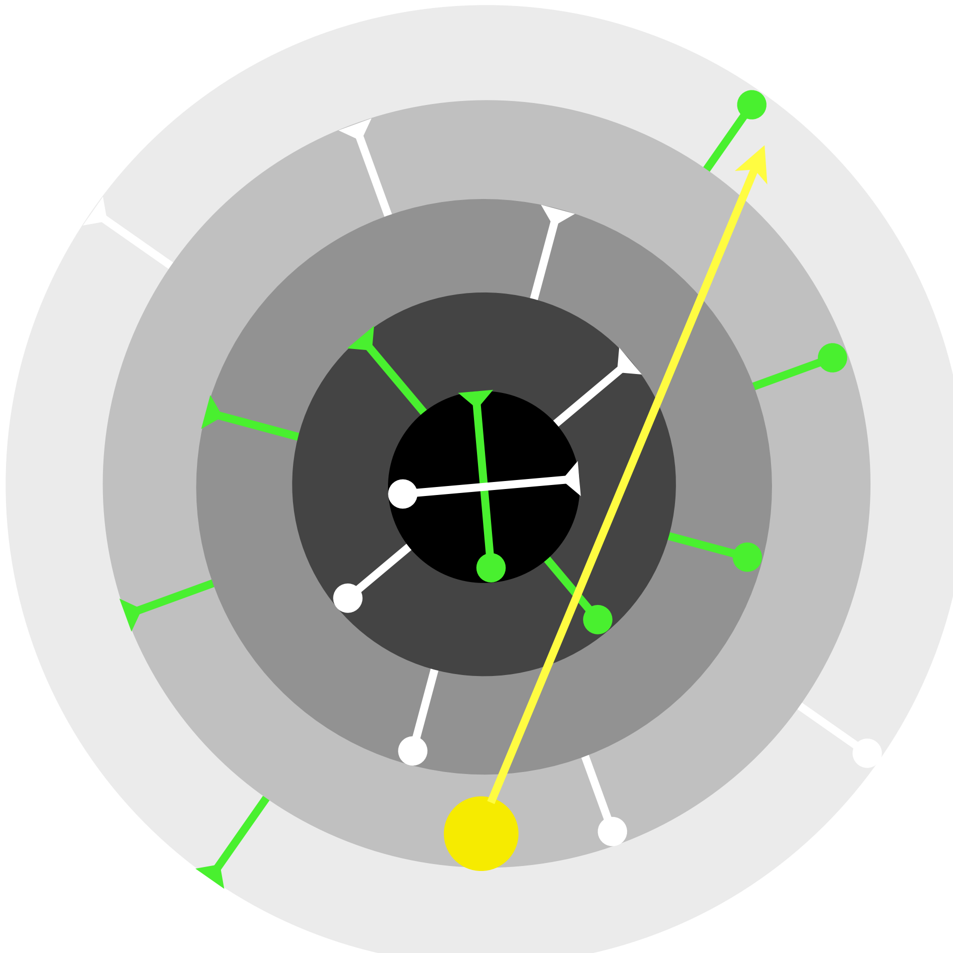
Figure 3 and its legend explain the construction of dendrograms schematically. The dendrogram quantifies how and where local maxima of emission merge with each other, and its implementation is explained in Supplementary Methods. Critically, the dendrogram is determined almost entirely by the data itself,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

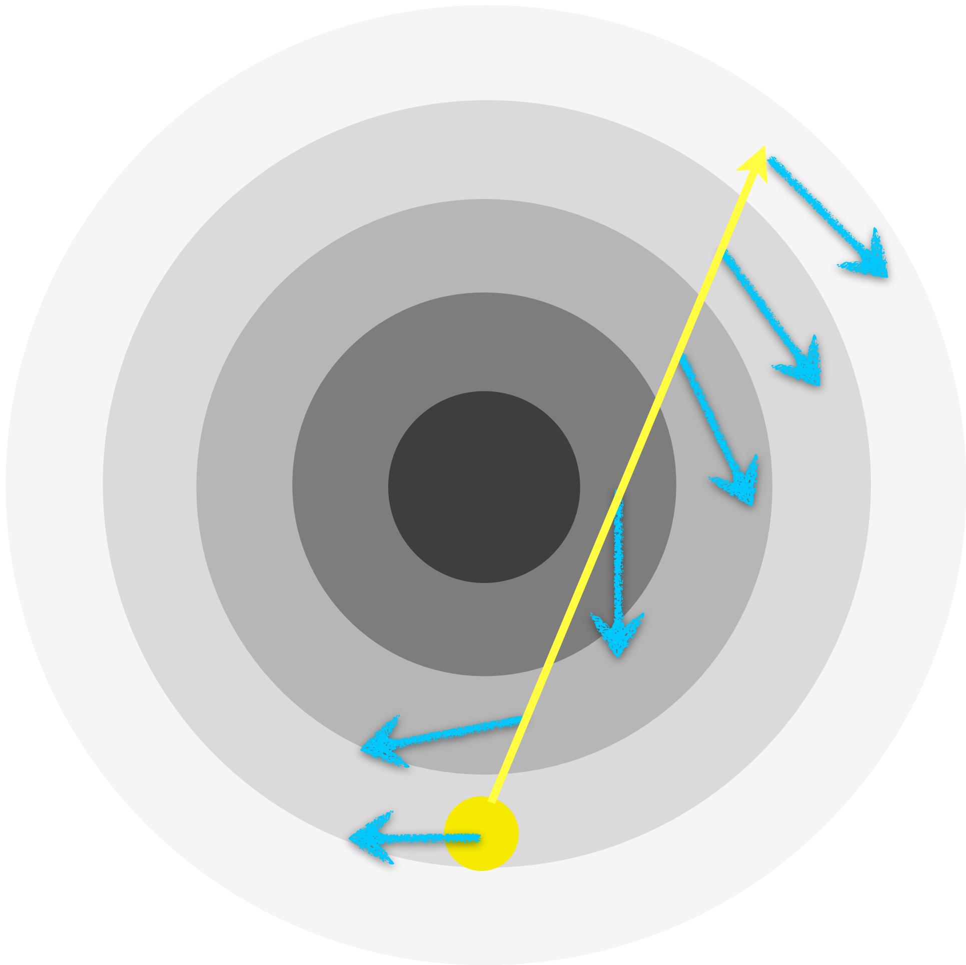
A dendrogram of a spectral-line data cube allows for the estimation of key physical properties associated with volumes bounded by isosurfaces, such as radius (R), velocity dispersion (σ_v) and luminosity (L). The volumes can have any shape, and in other work[14] we focus on the significance of the especially 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.

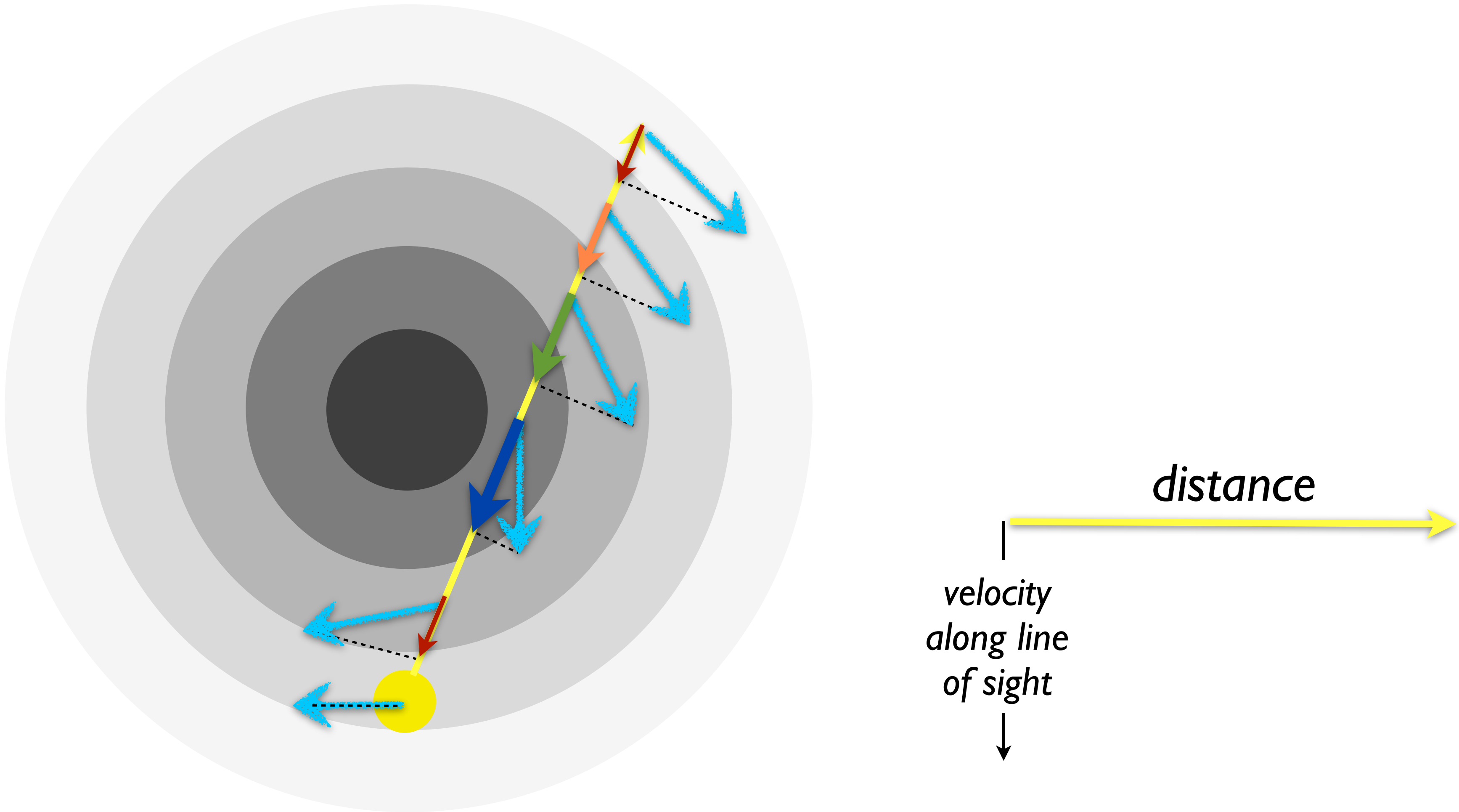
Figure 3 | Schematic illustration of the dendrogram process. Shown is the construction of a dendrogram from a hypothetical one-dimensional emission profile (black). The dendrogram (blue) can be constructed by 'dropping' a test constant emission level (purple) from above in tiny steps (exaggerated in 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, Rosolowsky, Borkin, Foster, Halle, Kauffmann & Pineda, **Nature**, 2009*

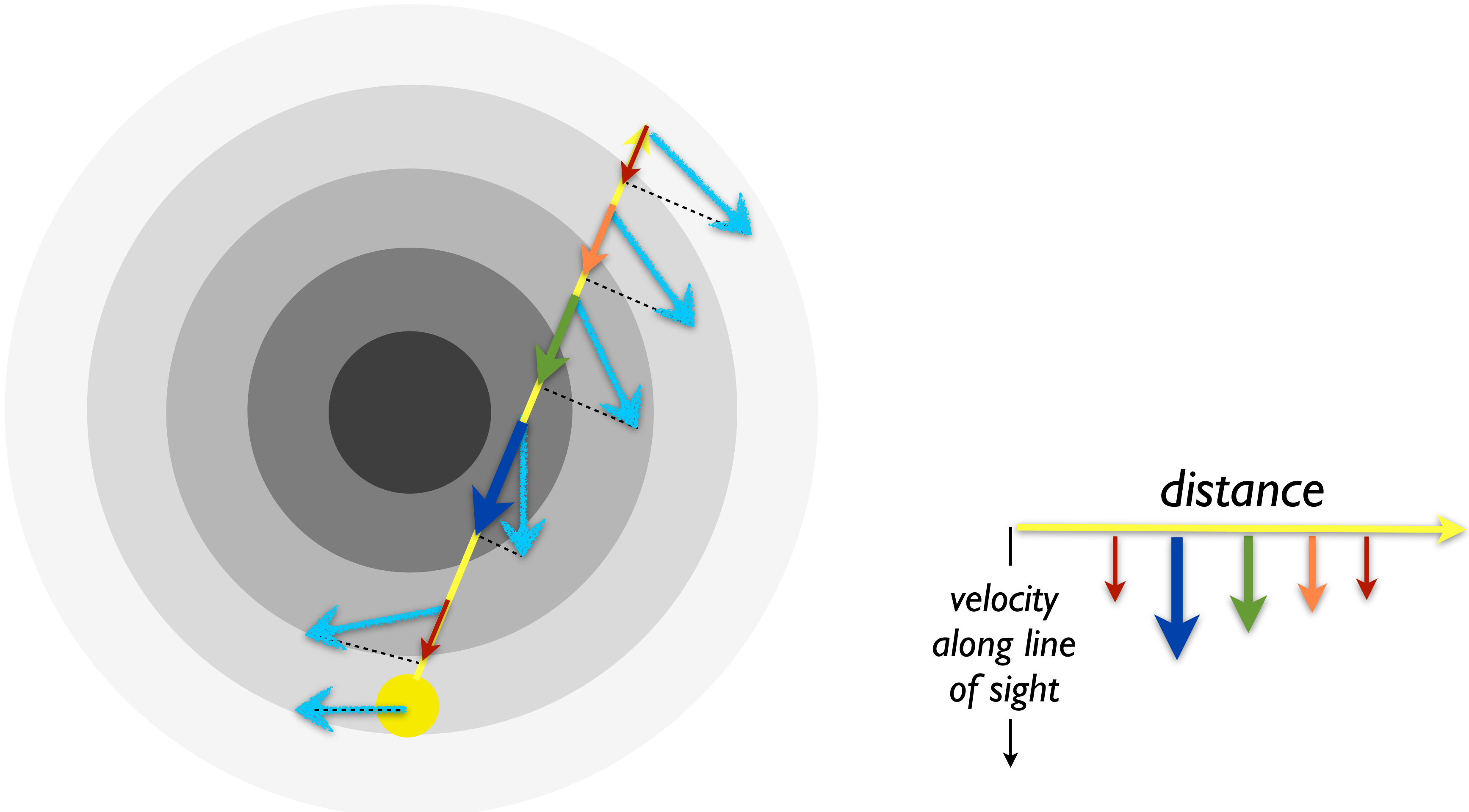
A Spiral Galaxy Observed from its Outskirts...





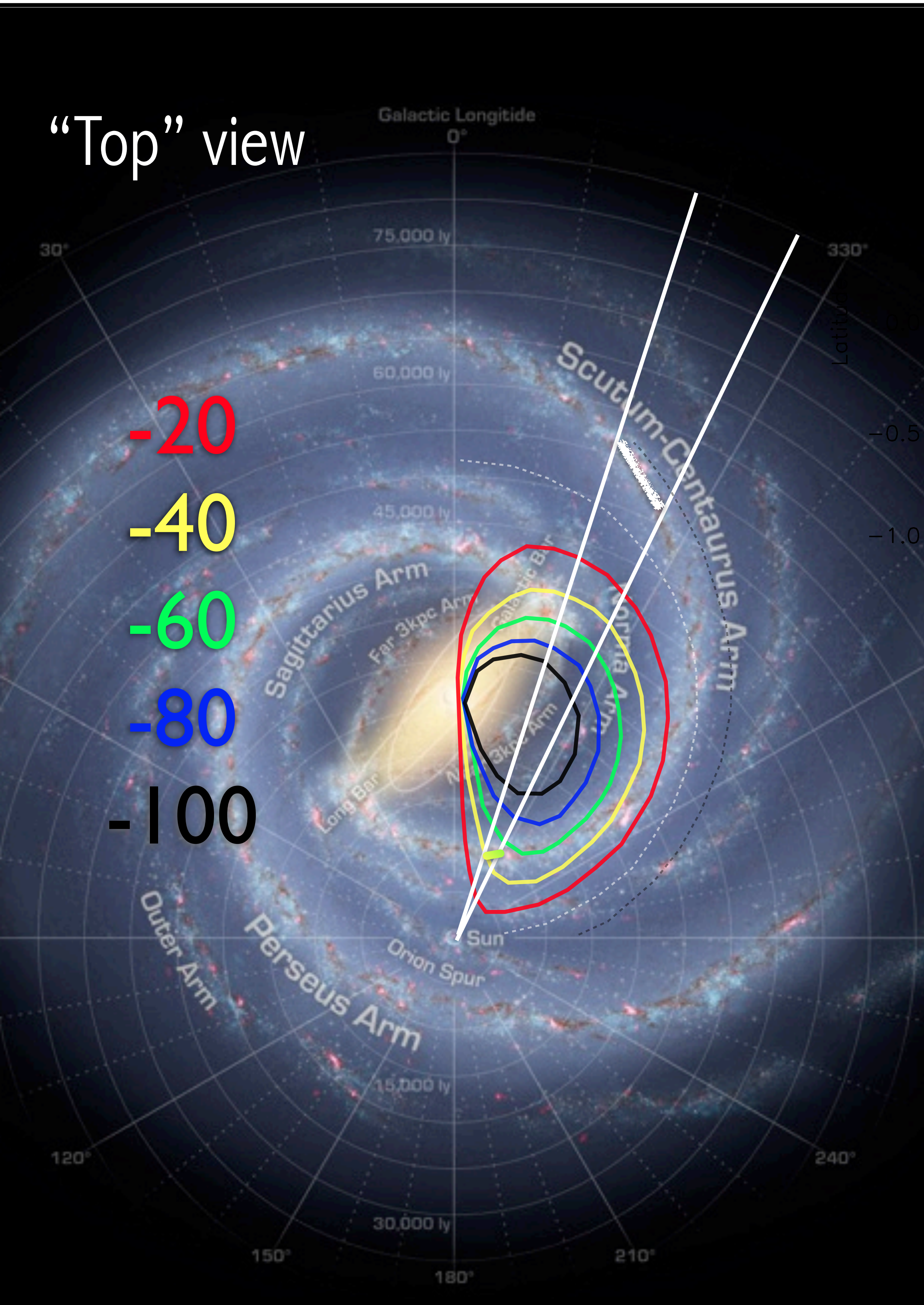


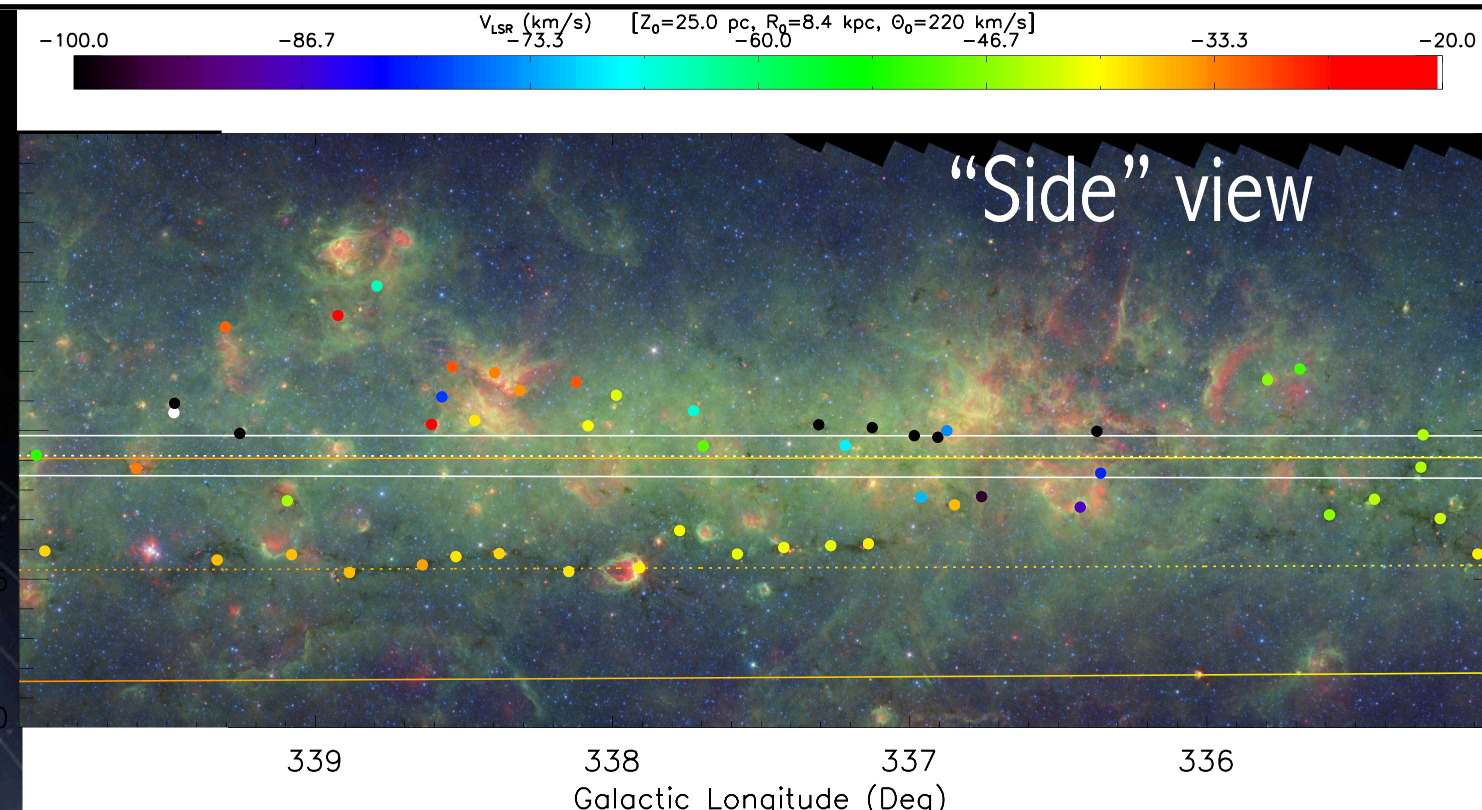
distance
velocity
along line
of sight



distance
velocity
along line
of sight

Using Velocity Constraints

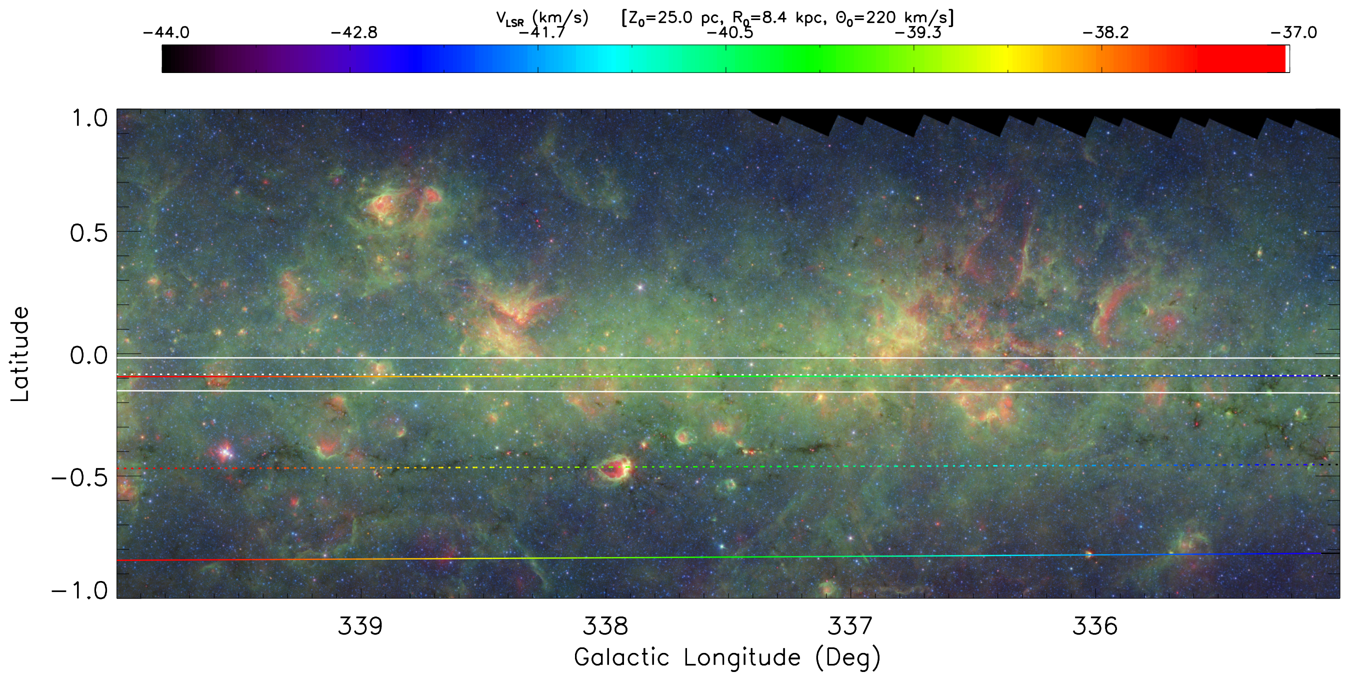




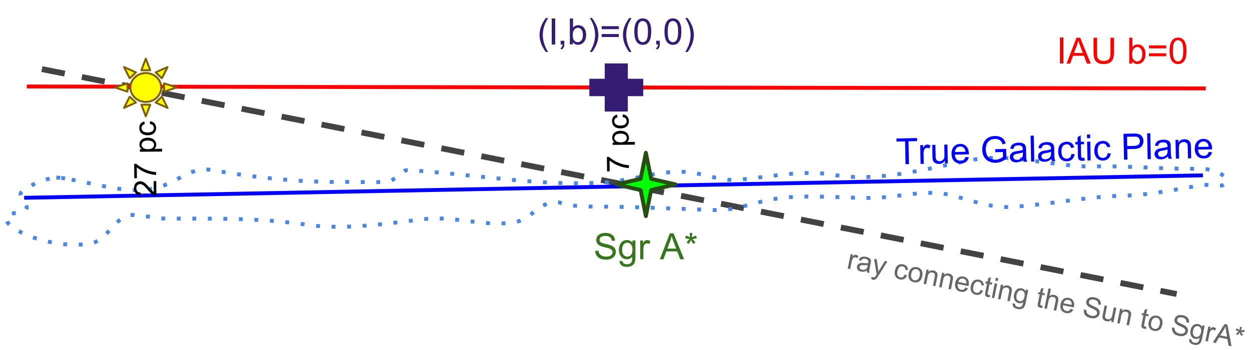
Left: Scientist-artist Robert Hurt's view of the Milky Way
(cartoon based on stars, CO, HI, masers & HII regions; Benjamin, Dame et al.)

Where is "Nessie," in 3D?

How close to "in" the plane?

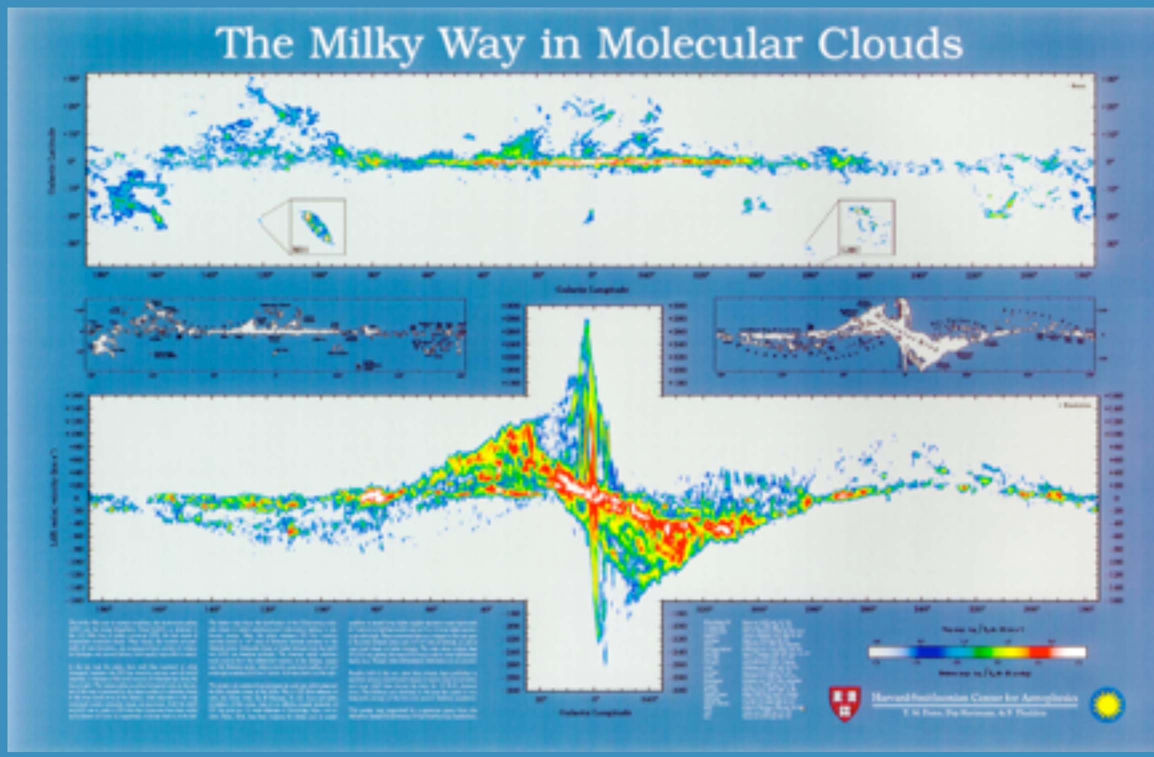


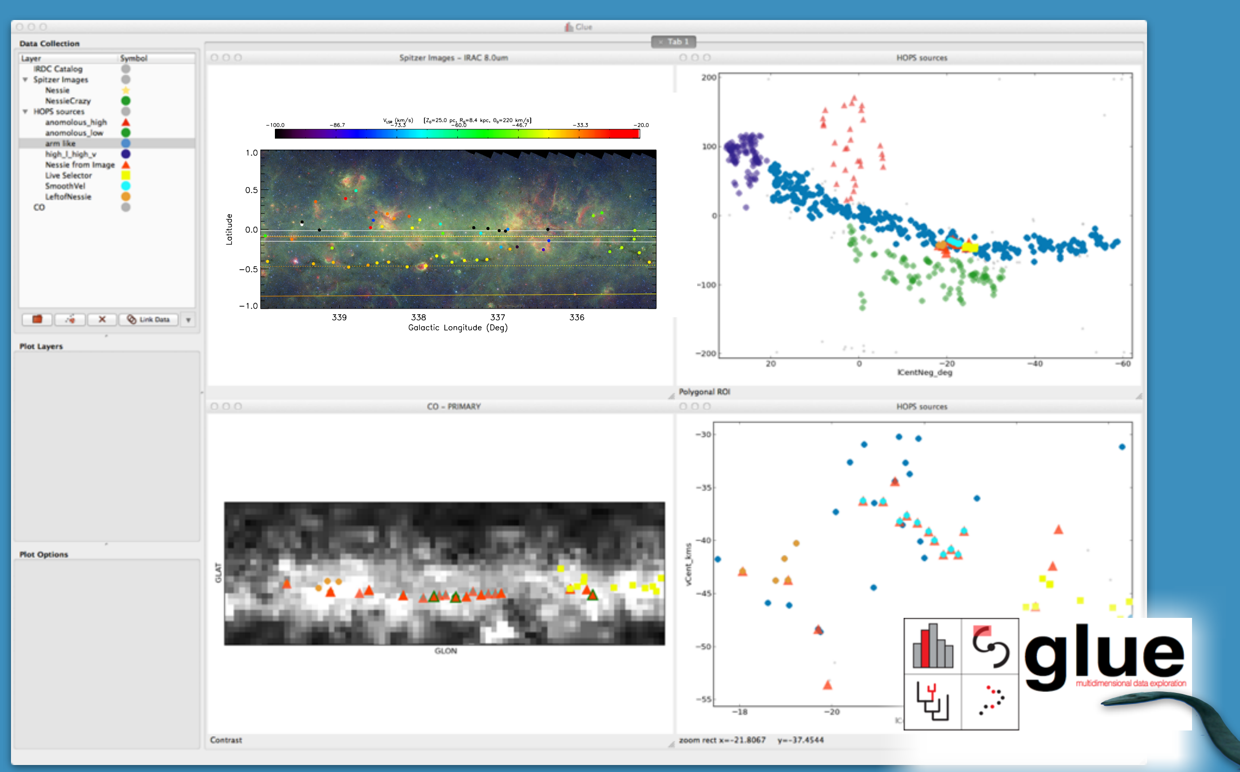
Drawing is schematic--NOT to scale



Notes:
IAU b=0 set from HI, which is uncertain by ~0.1 degrees
tilt of red w.r.t. blue would be (20/8400)*180/pi=0.13 degrees

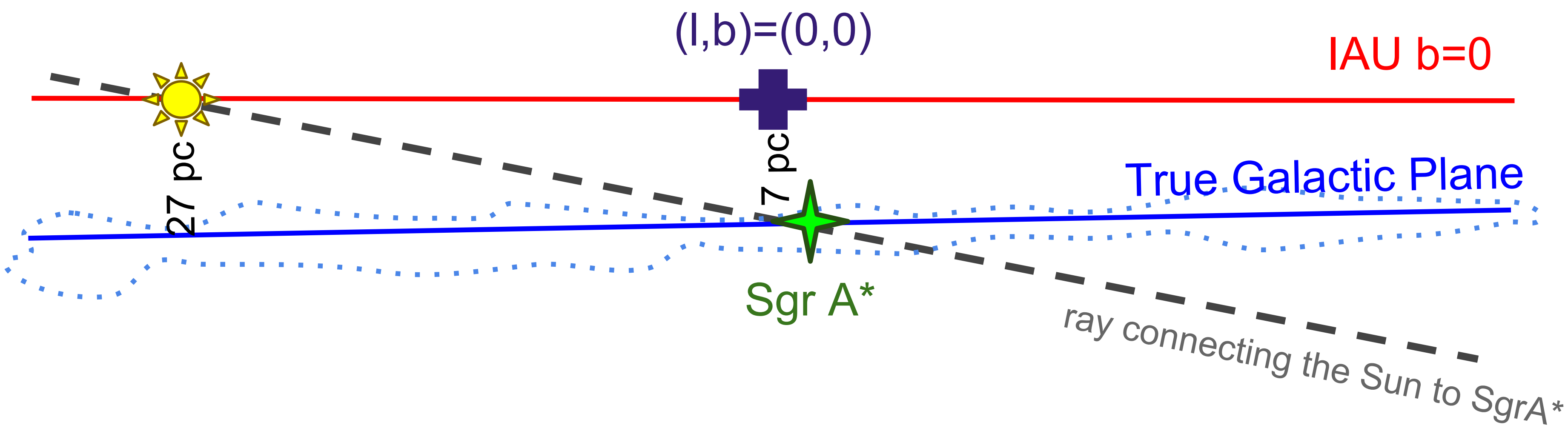
At what distance & inclination to l.o.s?





"Advanced" Galactic Geometry

Drawing is schematic--NOT to scale



Notes:
IAU b=0 set from HI, which is uncertain by ~0.1 degrees
tilt of red w.r.t. blue would be (20/8400)*180/pi=0.13 degrees