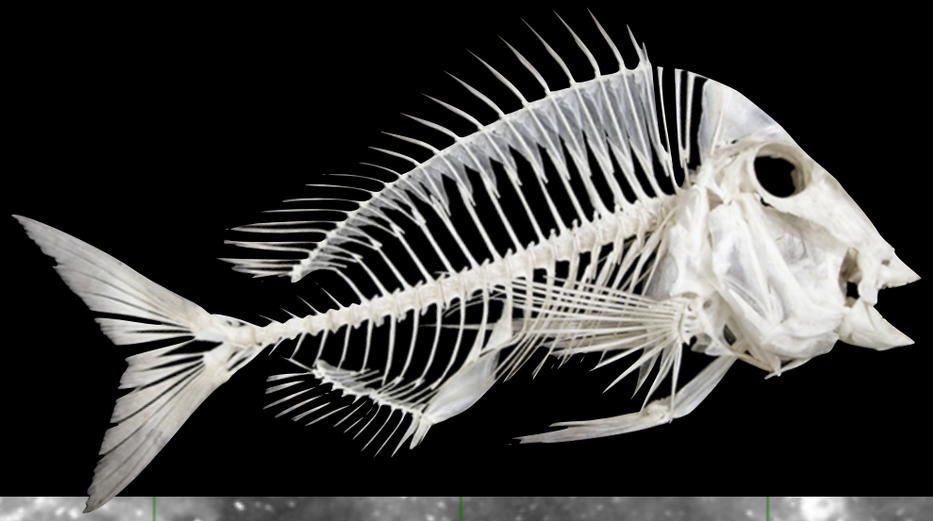
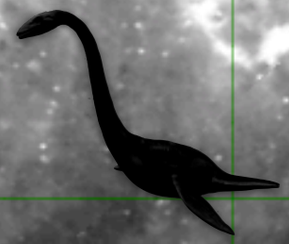


The Bones of the Milky Way



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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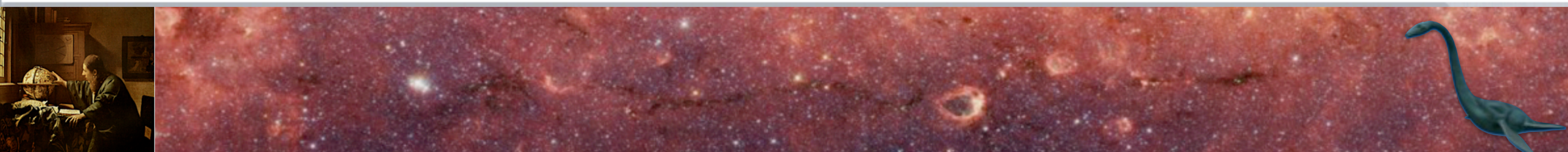
The Bones of the Milky Way

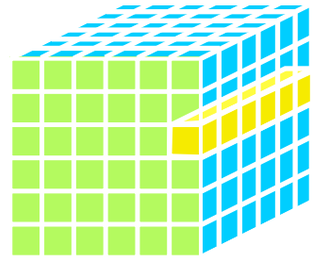
Alyssa Goodman, Joao Alves, Chris Beaumont, Tom Dame, James Jackson, Jens Kauffmann, Thomas Robitaille, Alberto Pepe, Michelle Borkin, Andreas Burkert, Bob Benjamin + Add author Export article

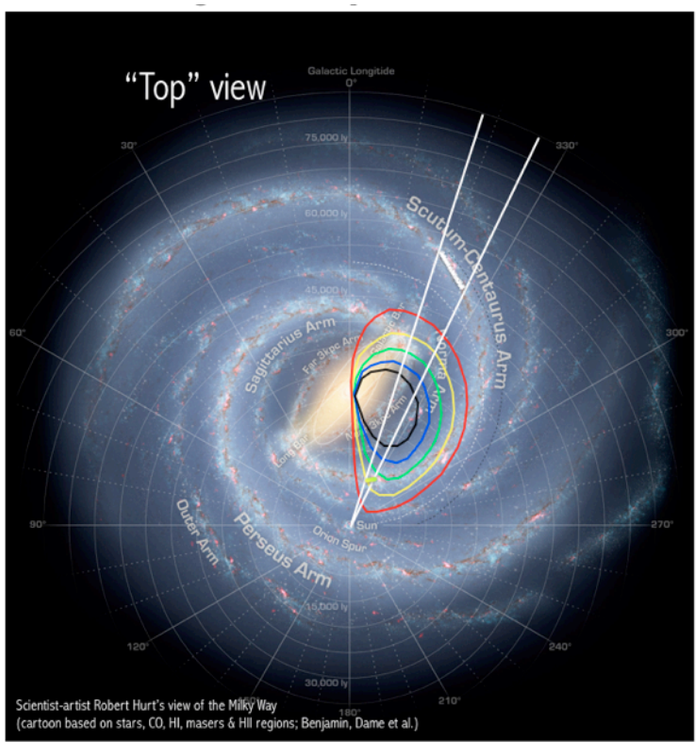
Abstract. The very long, thin infared dark cloud ``Nessie'' is even longer than had been previously claimed, and an analysis of its Galactic location suggests that it lies directly in the Milky Way's mid-plane, tracing out a highly elongated bone-like feature within the prominent Scutum-Centaurus spiral arm. Re-analysis of mid-infrared imagery from the Spitzer Space Telescope shows that this IRDC is at least 2, and possibly as many as 8 times longer than had originally been claimed by Nessie's discoverers, Jackson et al. (2010); its aspect ratio is therefore at least 150:1, and possibly as large as 800:1. A careful accounting for both the Sun's offset from the Galactic plane (~ 25 pc) and the Galactic center's offset from the $(l^{II}, b^{II}) = (0, 0)$ position defined by the IAU in 1959 shows that the latitude of the true Galactic mid-plane at the 3.1 kpc distance to the Scutum-Centaurus Arm is not $b = 0$, but instead closer to $b = -0.5$, which is the latitude of Nessie to within a few pc. Apparently, Nessie lies *in* the Galactic mid-plane. An analysis of the radial velocities of low-density (CO) and high-density (NH_3) gas associated with the Nessie dust feature suggests that Nessie runs along the Scutum-Centaurus Arm in position-position-velocity space, which means it likely forms a dense 'spine' of the arm in real space as well. No galaxy-scale simulation to date has the spatial resolution to predict a Nessie-like feature, but extant simulations do suggest that highly elongated over-dense filaments should be associated with a galaxy's spiral arms. Nessie is situated in the closest major spiral arm to the Sun toward the inner Galaxy, and appears almost perpendicular to our line of sight, making it the easiest feature of its kind to detect from our location (a shadow of an Arm's bone, illuminated by the Galaxy beyond). Although the Sun's offset from the Galactic plane is not significant compared with the thickness of the plane as traced by Population I objects such as GMCs and HII regions, it may be significant compared with an extremely thin layer that might be traced out by Nessie-like objects. Future high-resolution extinction and molecular line data may therefore allow us to exploit the Sun's position above the plane to gain a small amount of perspective on the Galactic disk.



"The Making of" the Bones of the Milky Way

SEAMLESS ASTRONOMY
Linking scientific data, publications, and communities





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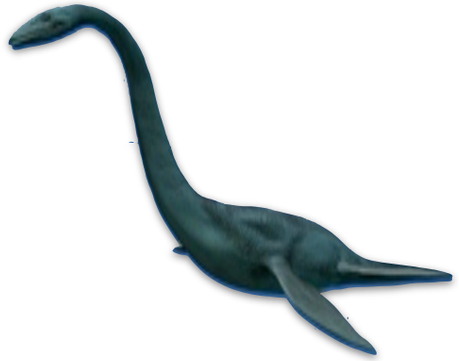
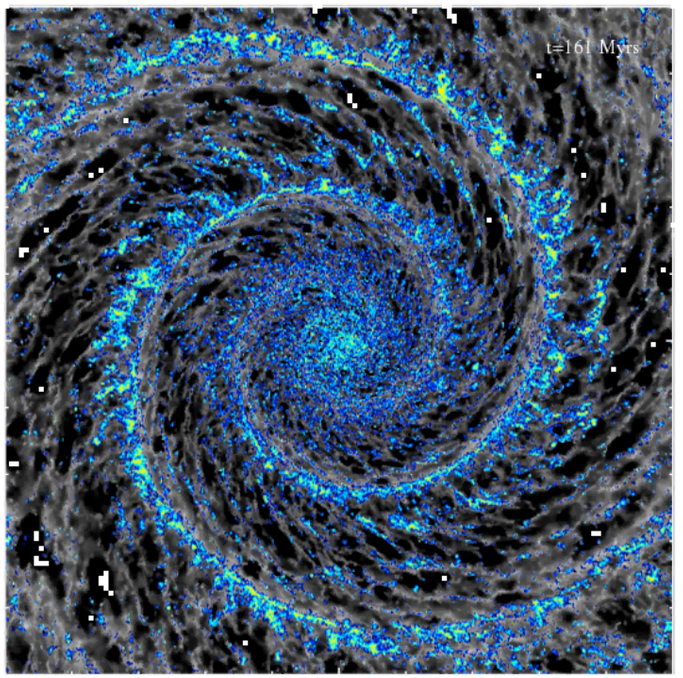
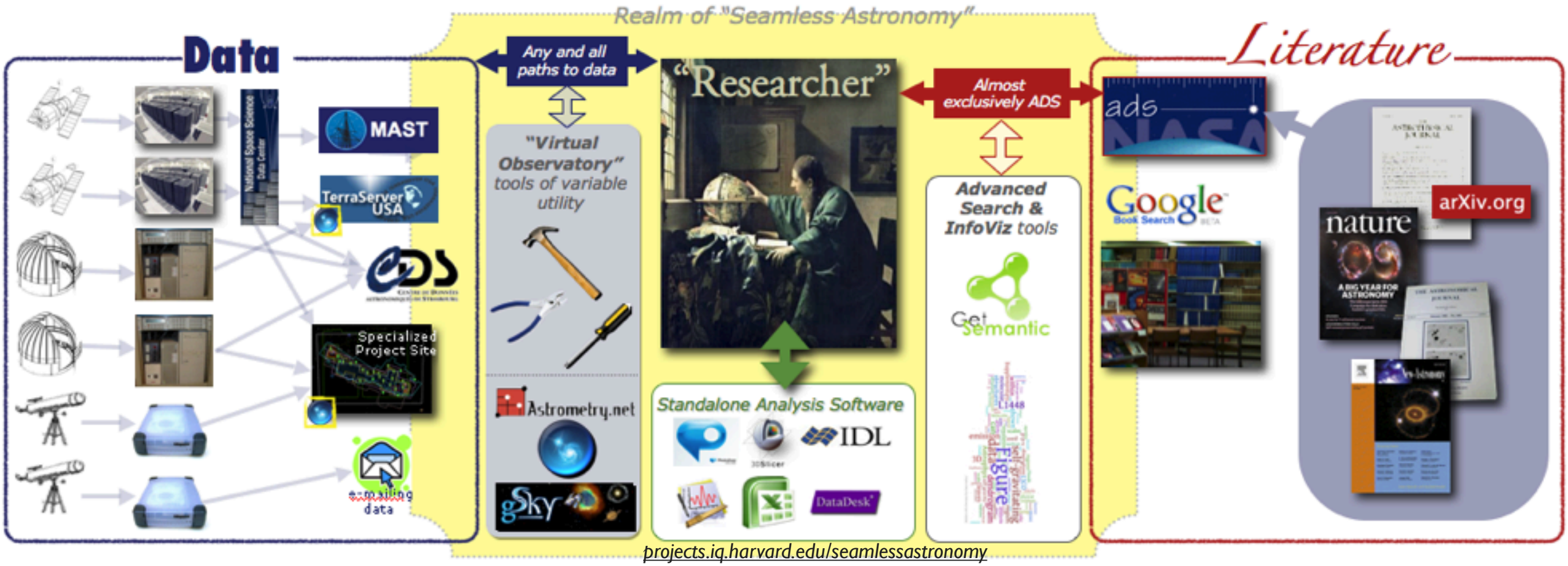


glue
multidimensional data exploration

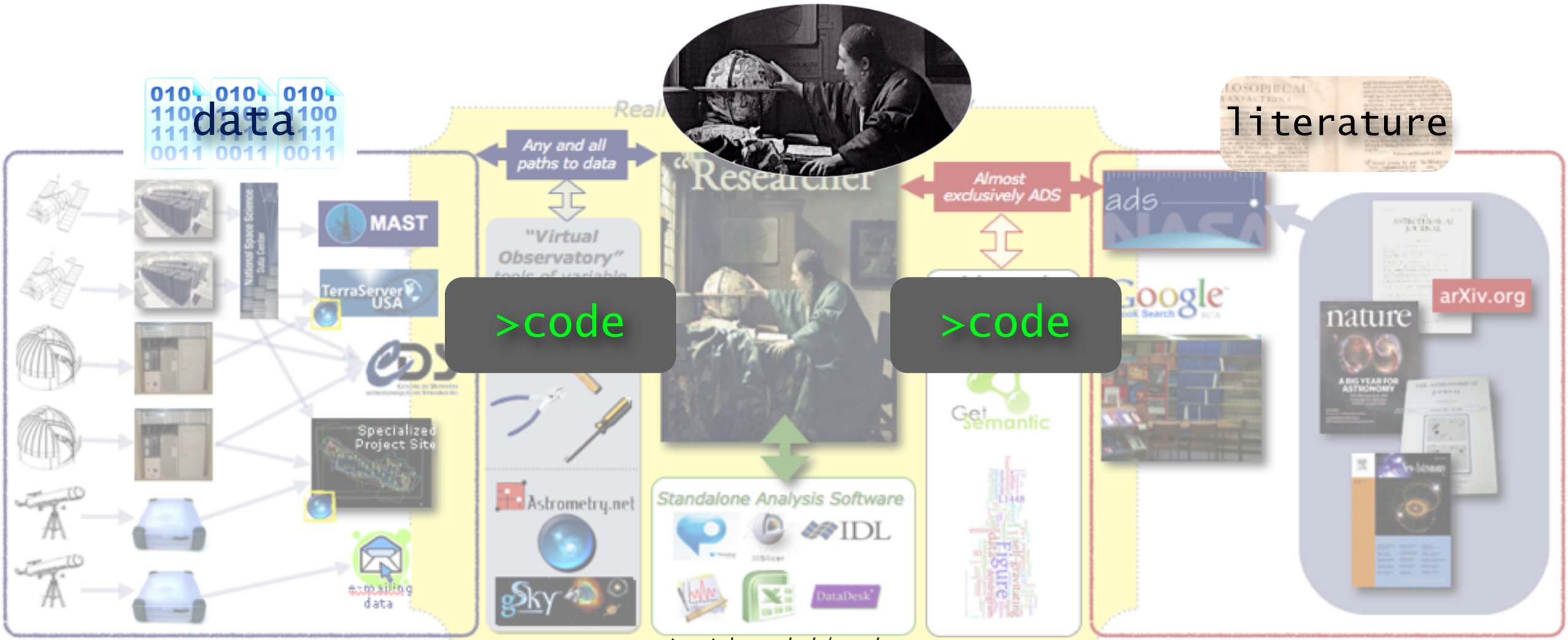


SEAMLESS ASTRONOMY

Linking scientific data, publications, and communities



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)



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Seamless Astronomy

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literature

=*"The Internet"*

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"The Making of" the Bones of the Milky Way

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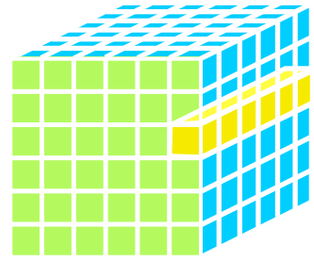
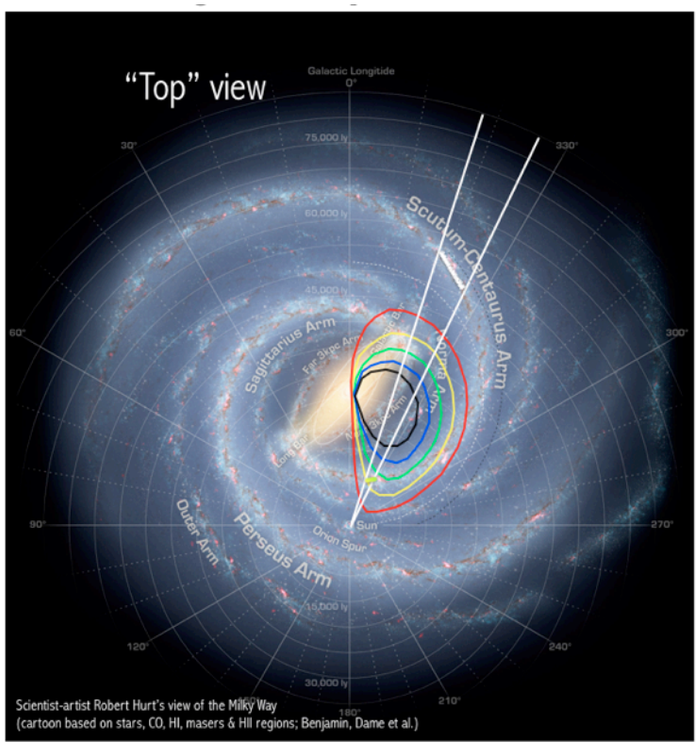
Linking scientific data, publications, and communities





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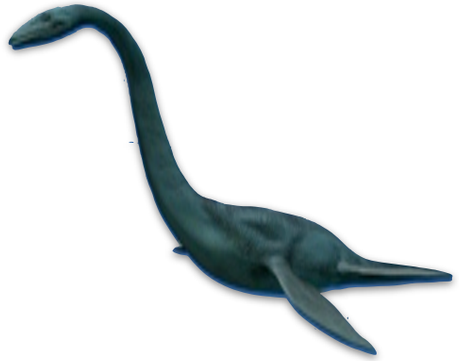

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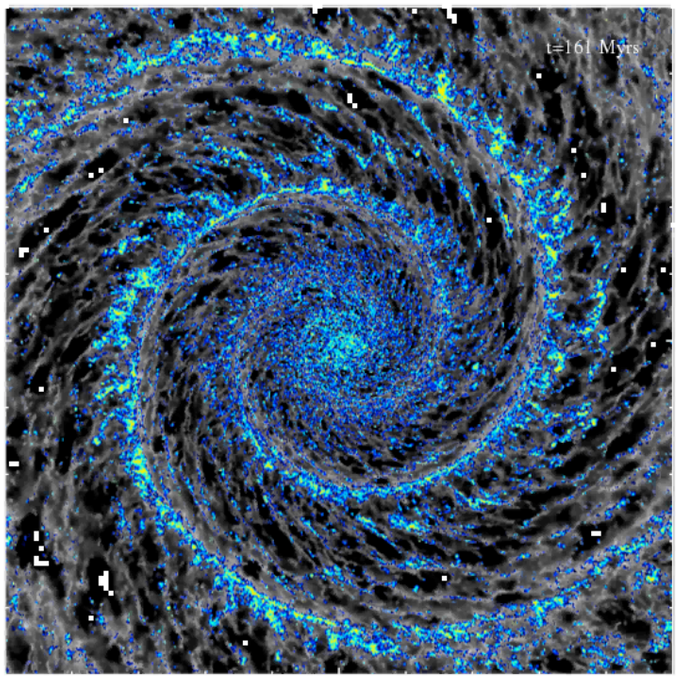

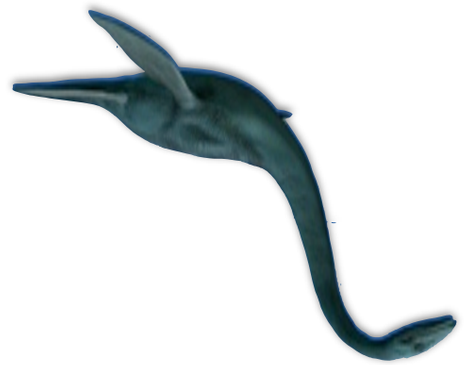

Ringberg Castle, Bavaria
"Early Phases of Star Formation"
July 2012

de-jargonification

Who's Nessie?

What's an "infrared dark cloud"?

Question A Galactic Plane"?

Answer *no o*

AG decides to look into this and...

"Is Nessie Parallel to the Galactic Plane?"

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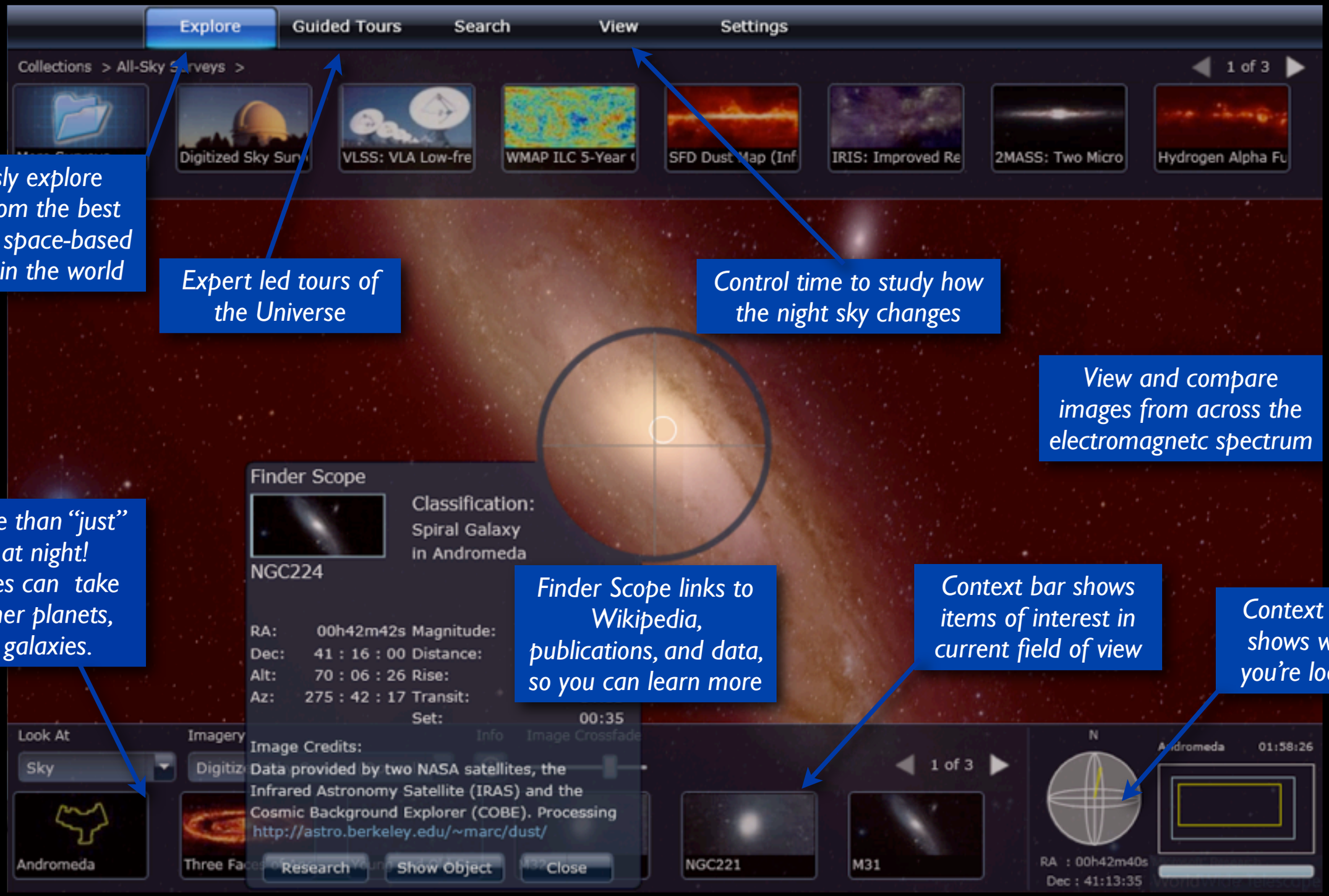
worldwidetelescope.org



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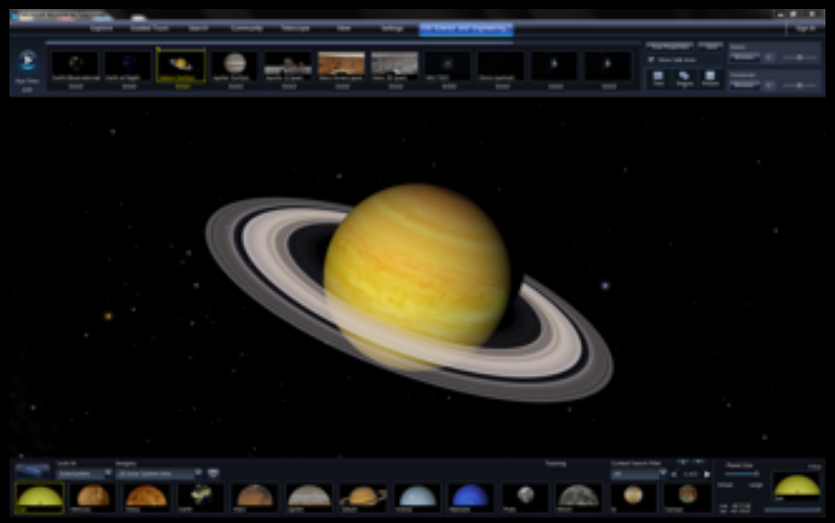

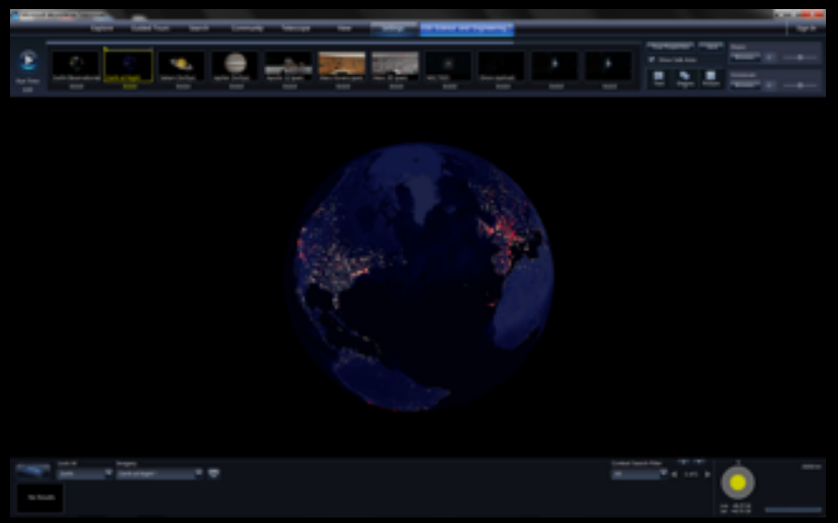

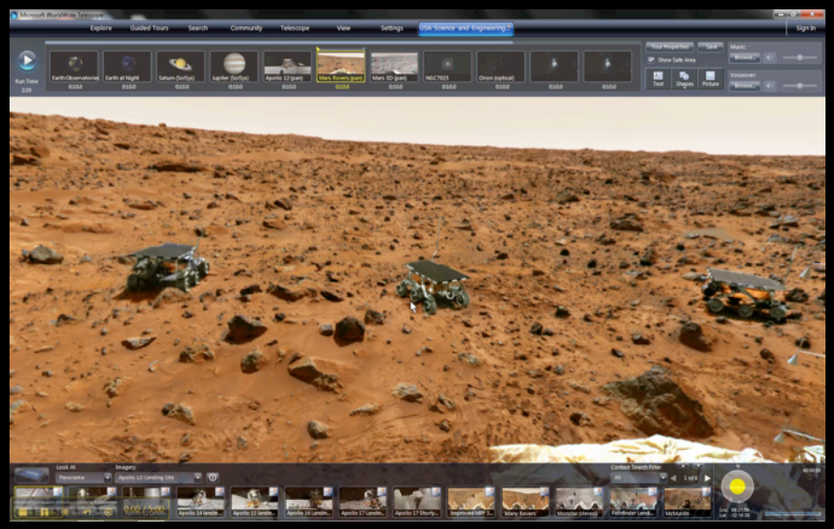

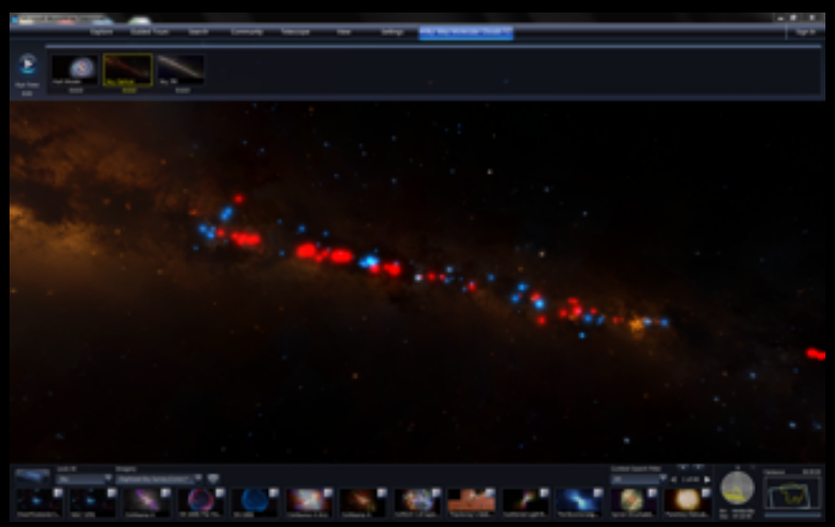

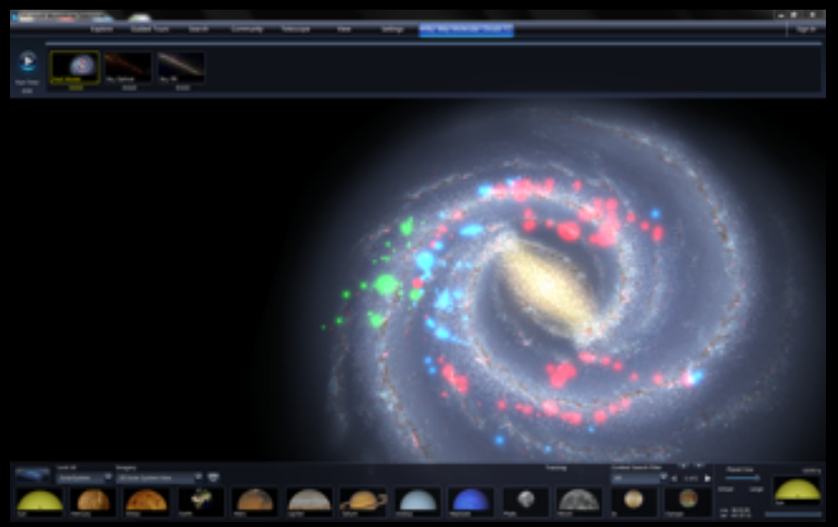

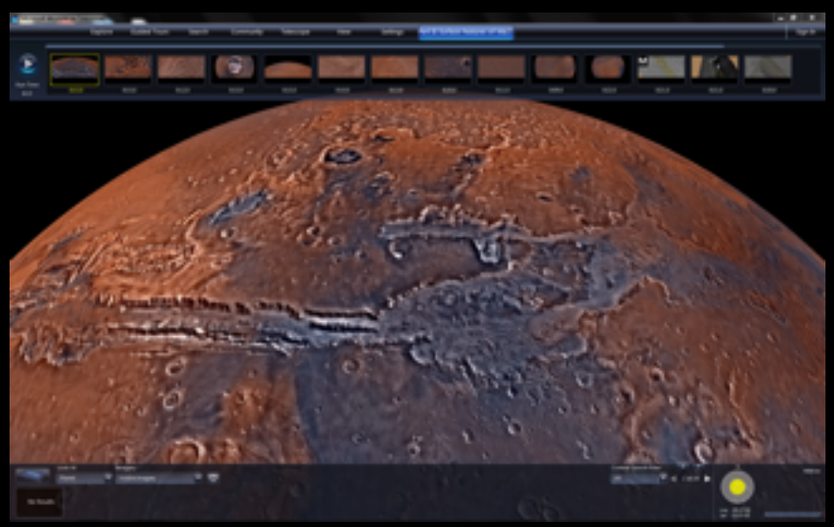

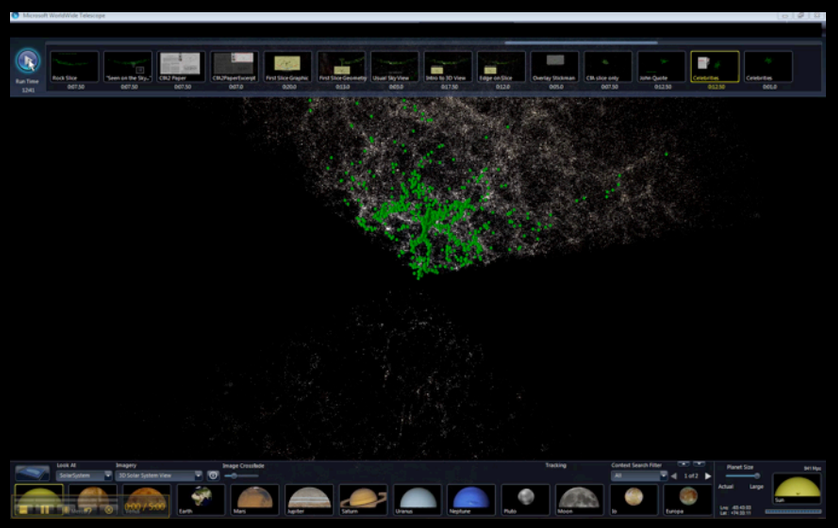

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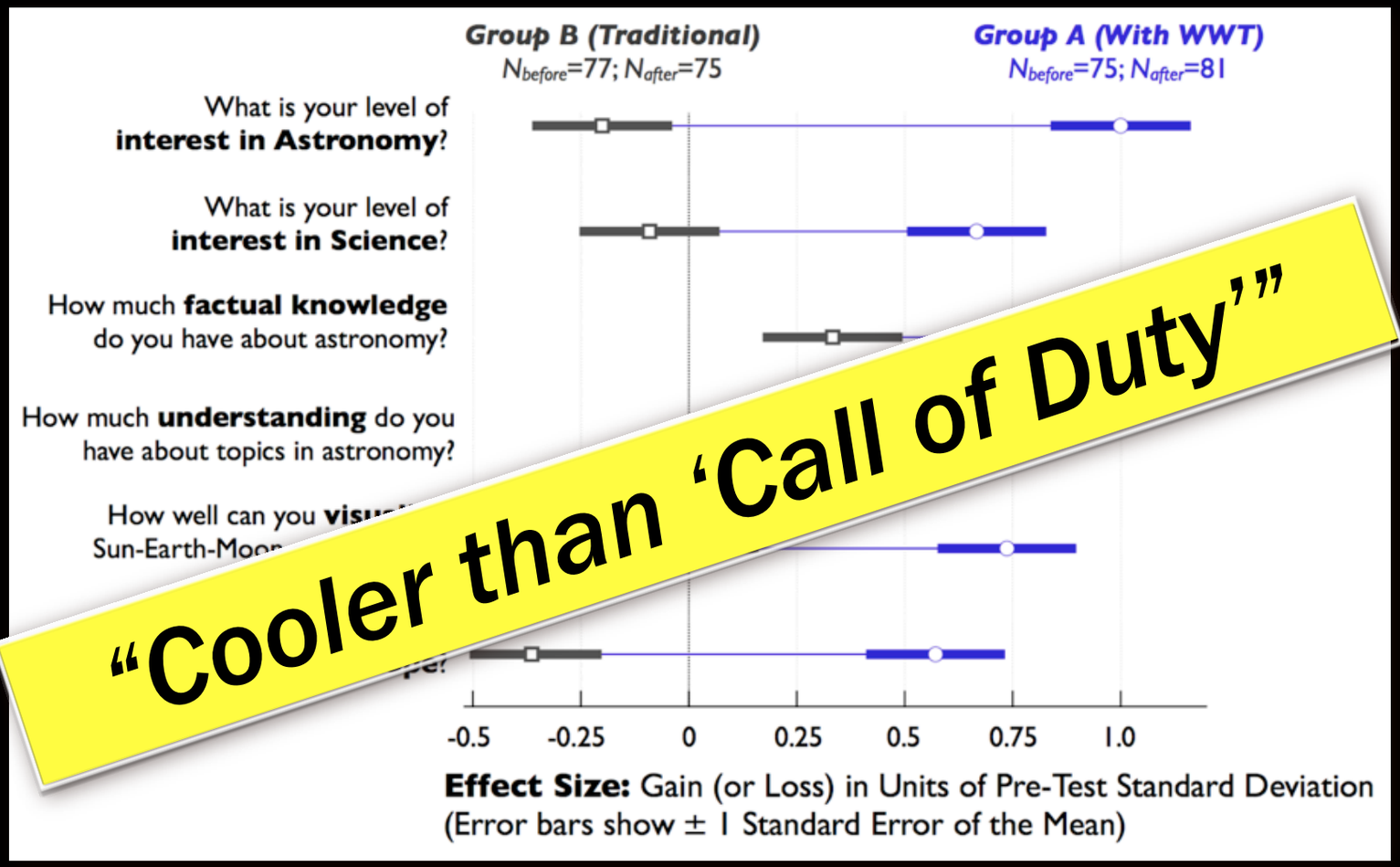
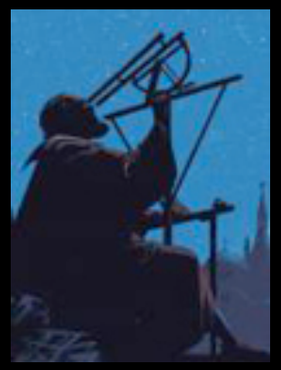
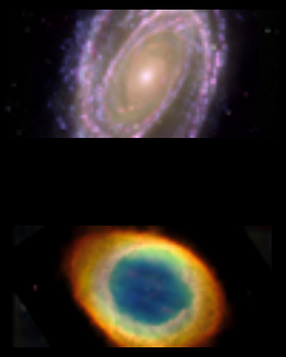


"Cooler than 'Call of Duty'"

"Tours"





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The Astrophysical Journal Letters, 719:L185–L189, 2010 August 20 doi:10.1088/2041-8205/719/2/L185

THE "NESSIE" NEBULA: CLUSTER FORMATION IN A FILAMENTARY INFRARED DARK CLOUD

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ABSTRACT

The "Nessie" Nebula is a filamentary infrared dark cloud (IRDC) with a large aspect ratio of over 150:1 (1.°5 × 0.°01 or 80 pc × 0.5 pc at a kinematic distance of 3.1 kpc). Maps of HNC (1–0) emission, a tracer of dense molecular gas, made with the Australia Telescope National Facility Mopra telescope, show an excellent morphological match to the mid-IR extinction. Moreover, because the molecular line emission from the entire nebula has the same radial velocity to within ±3.4 km s^{-1}, the nebula is a single, coherent cloud and not the chance alignment of multiple unrelated clouds along the line of sight. The Nessie Nebula contains a number of compact, dense molecular cores which have a characteristic projected spacing of ~4.5 pc along the filament. The theory of gravitationally bound gaseous cylinders predicts the existence of such cores, which, due to the "sausage" or "varicose" fluid instability, fragment from the cylinder at a characteristic length scale. If turbulent pressure dominates over thermal pressure in Nessie, then the observed core spacing matches theoretical predictions. We speculate that the formation of high-mass stars and massive star clusters arises from the fragmentation of filamentary IRDCs caused by the "sausage" fluid instability that leads to the formation of massive, dense molecular cores. The filamentary molecular gas clouds often found near high-mass star-forming regions (e.g., Orion, NGC 6334, etc.) may represent a later stage of IRDC evolution.

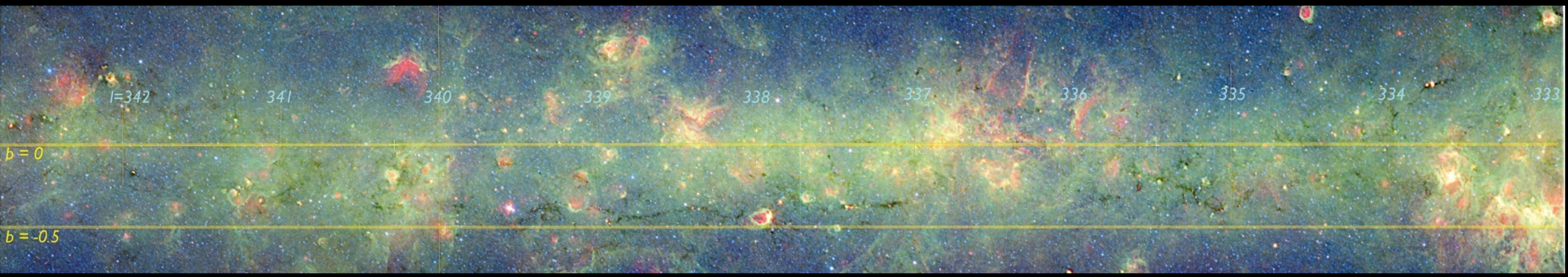
Key words: ISM: clouds – stars: formation

Jackson et al. 2010

Monster to Bone

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

milkywaybones.org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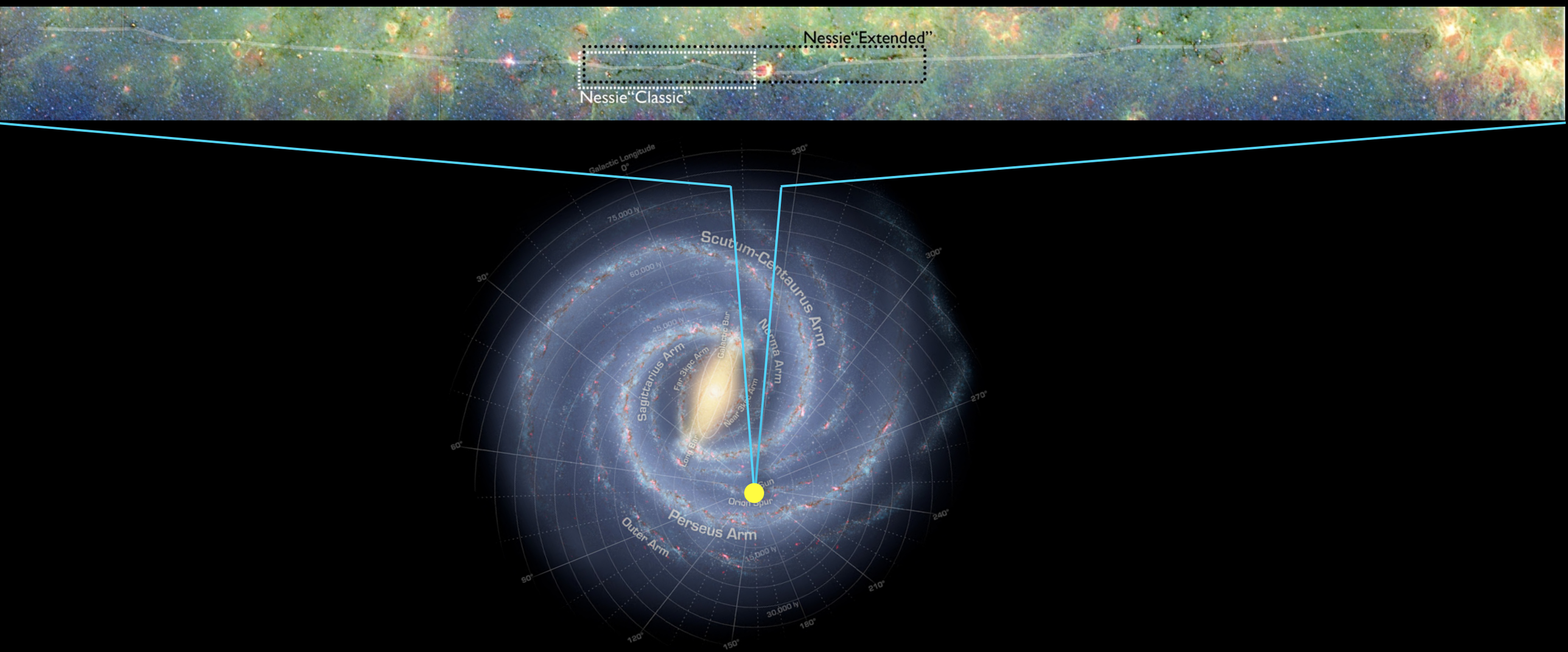
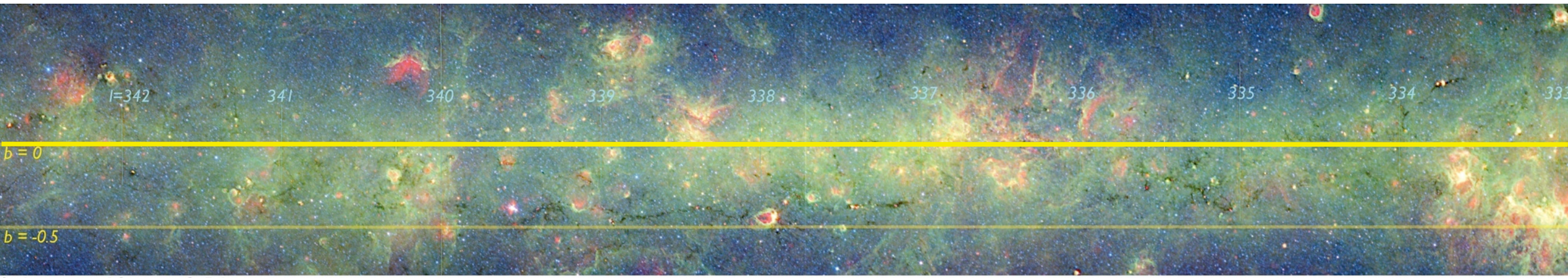
b = 0
b = -0.5


Nessie "Extended"
Nessie "Classic"
Galactic Longitude 0°
330°
300°
270°
240°
210°
180°
150°
120°
90°
60°
30°
75,000 ly
60,000 ly
45,000 ly
30,000 ly
15,000 ly
Scutum-Centaurus Arm
Norma Arm
Sagittarius Arm
Perseus Arm
Outer Arm
Galactic Bar
Far 3kpc Arm
Near 3kpc Arm
Long Bar
Sun
Orion Spur

The Milky Way

The Milky Way
(Artist's Conception)

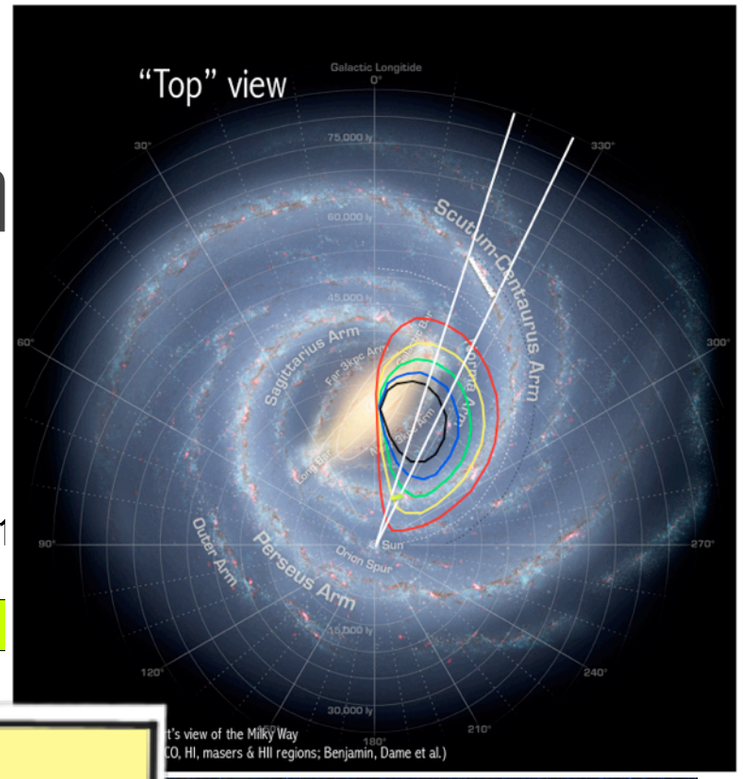
Why b<0?!
Galactic Geometry: 1959 and Now

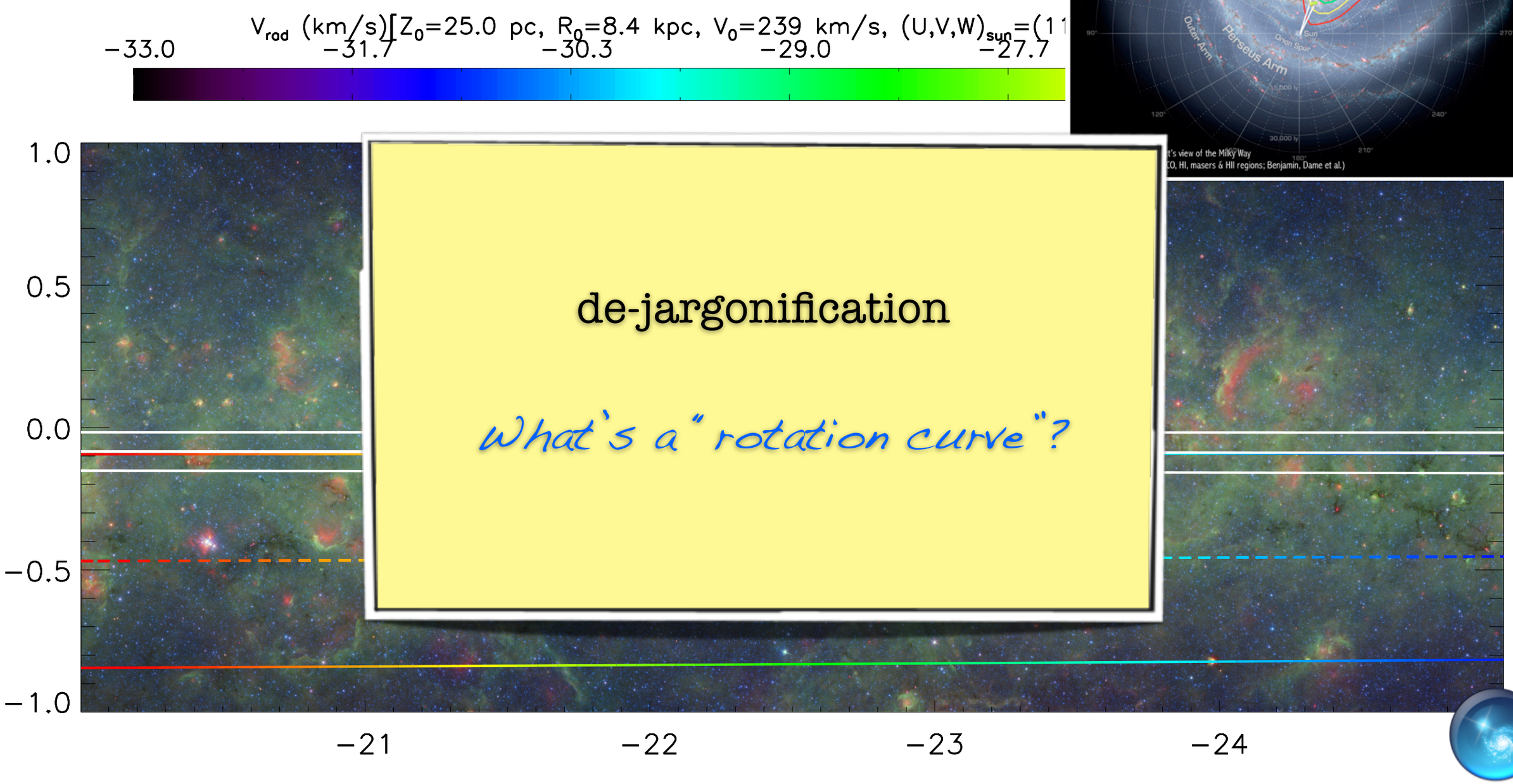


The equatorial plane of the new co-ordinate system must of necessity pass through the sun. It is a fortunate circumstance that, within the observational uncertainty, both the sun and Sagittarius A lie in the mean plane of the Galaxy as determined from the hydrogen observations. If the sun had not been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

[Blaauw et al. 1959]

Predicted Near & Far Scutum-Centaurus Arm

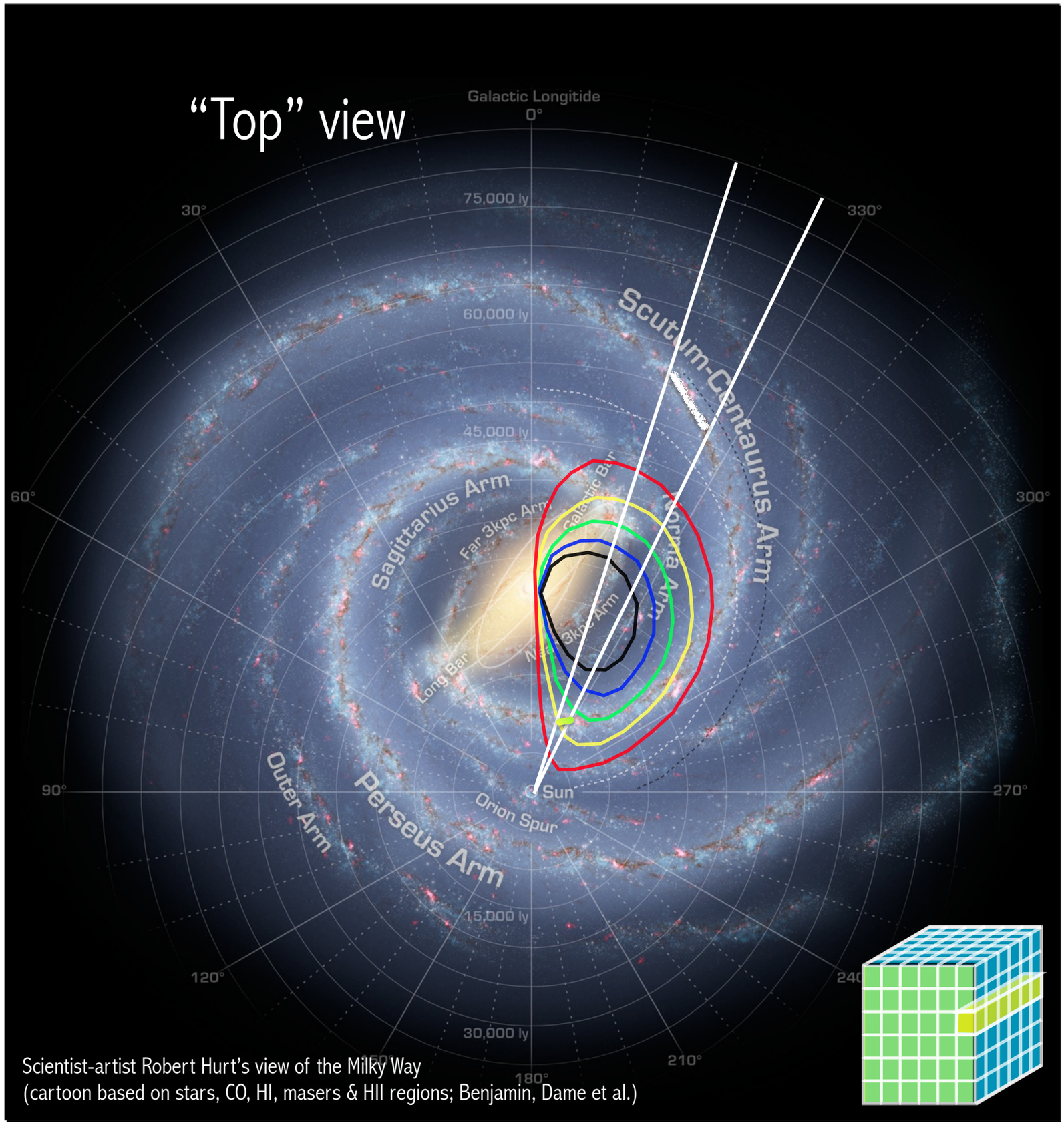




de-jargonification

What's a "rotation curve"?

Using Velocity



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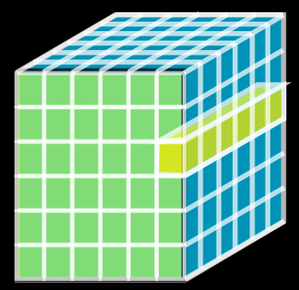
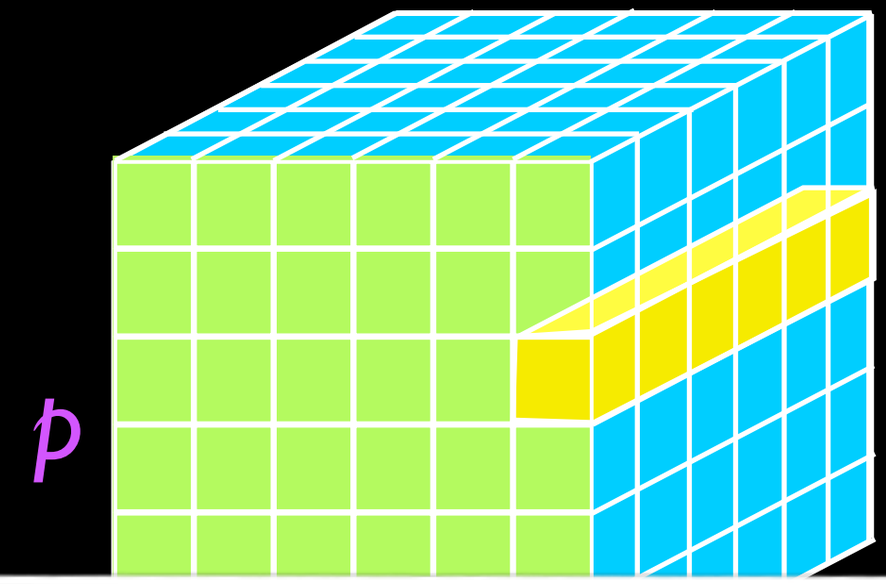
Scientist-artist Robert Hurt's view of the Milky Way
(cartoon based on stars, CO, HI, masers & HII regions; Benjamin, Dame et al.)

Displaying "High-dimensional" Data





de-jargonification

What's a "p-p-v" cube?

GENERALLY

1D: Columns = "Time Series"

2D: Faces or Slices = "Images"

3D: Volumes (e.g. *p-p-v*) = "3D Renderings", "2D Movies"

4D: Time Series of Volumes = "3D Movies"

Perseus Example

COMPLETE

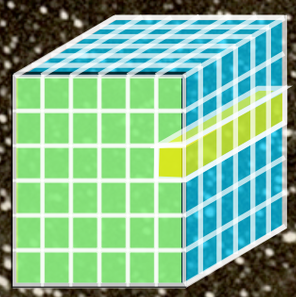
mm peak (Enoch et al. 2006)

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

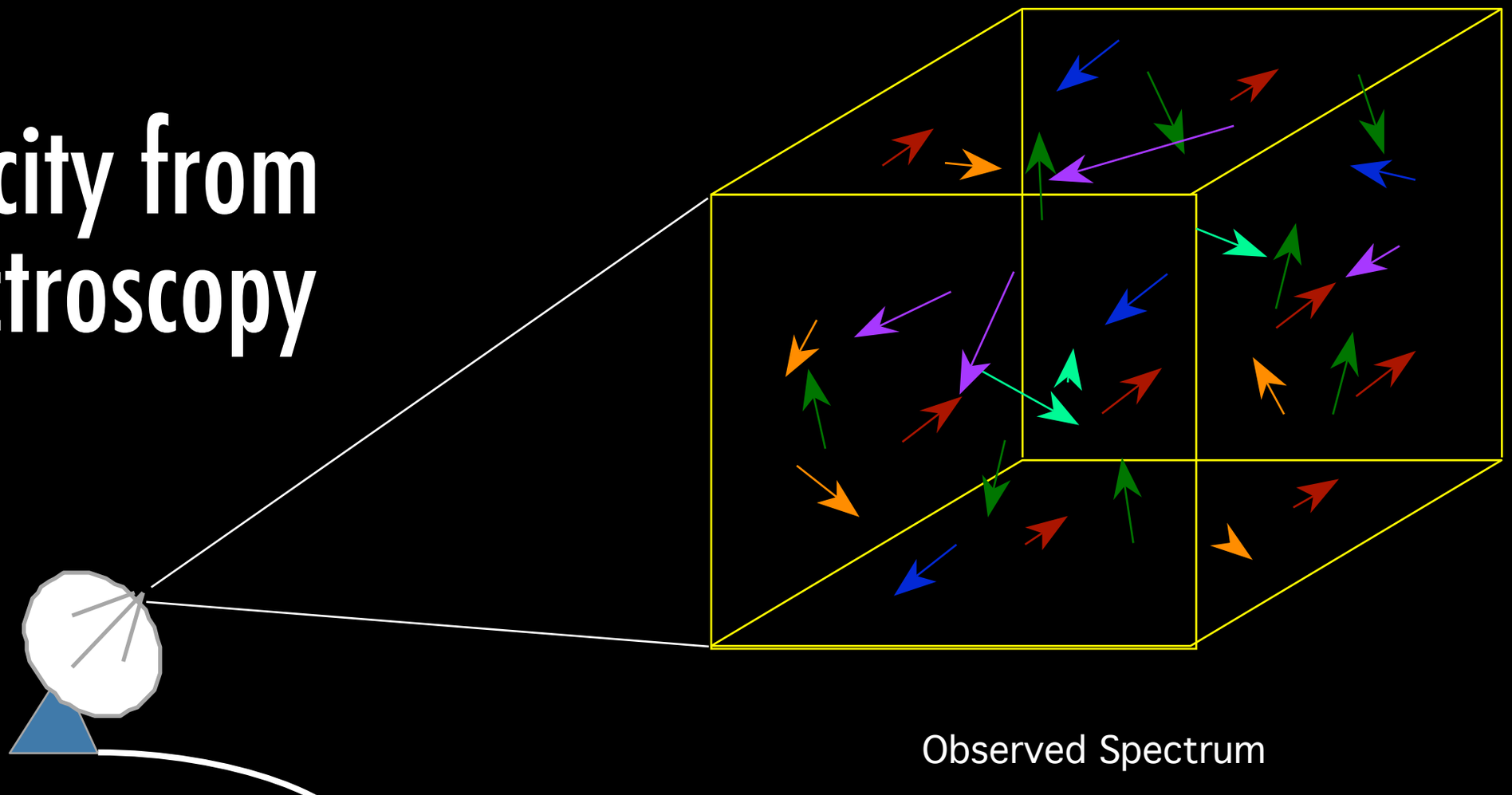
^{13}CO (Ridge et al. 2006)

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

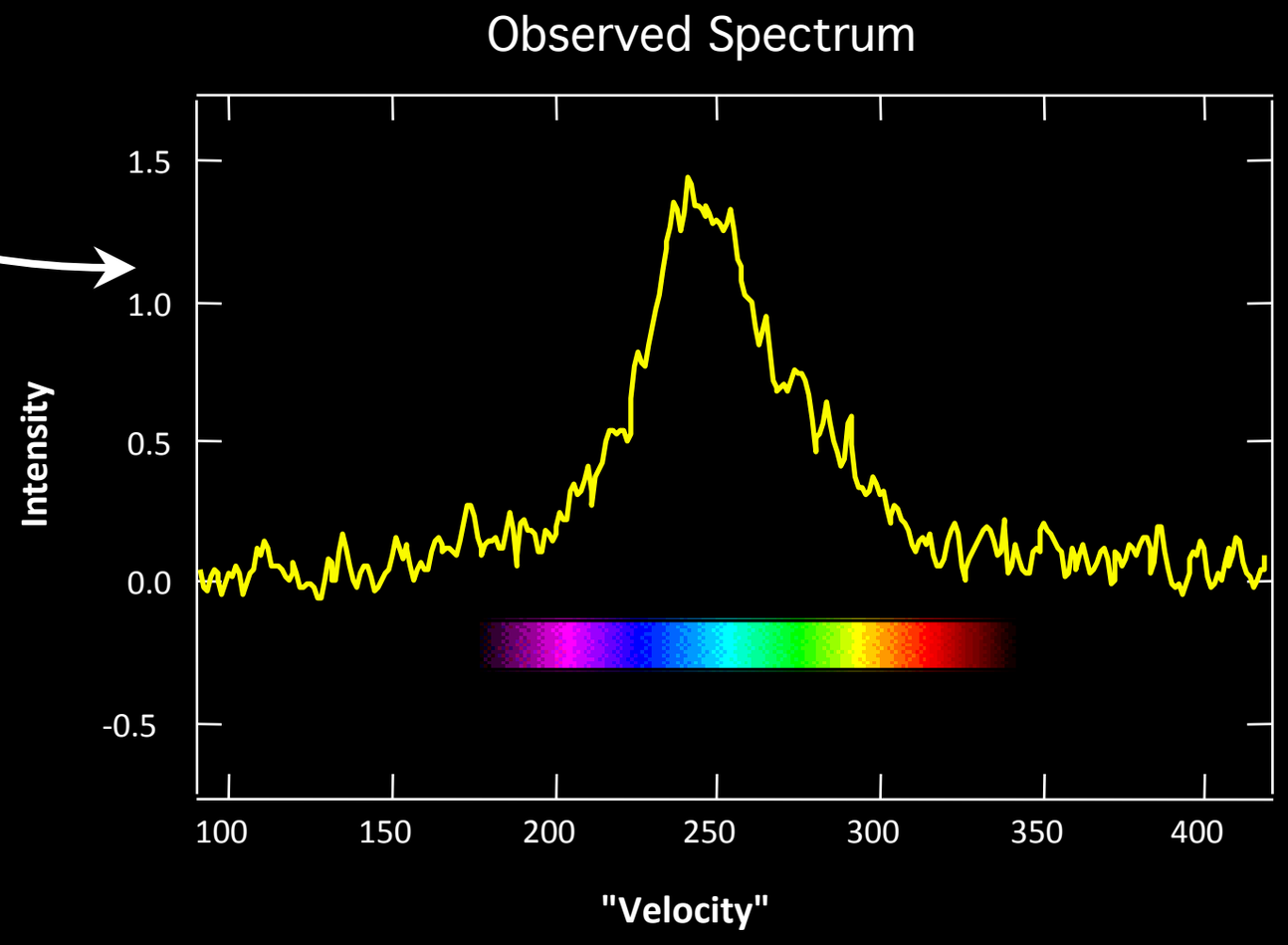
Optical image (Barnard 1927)



Velocity from Spectroscopy

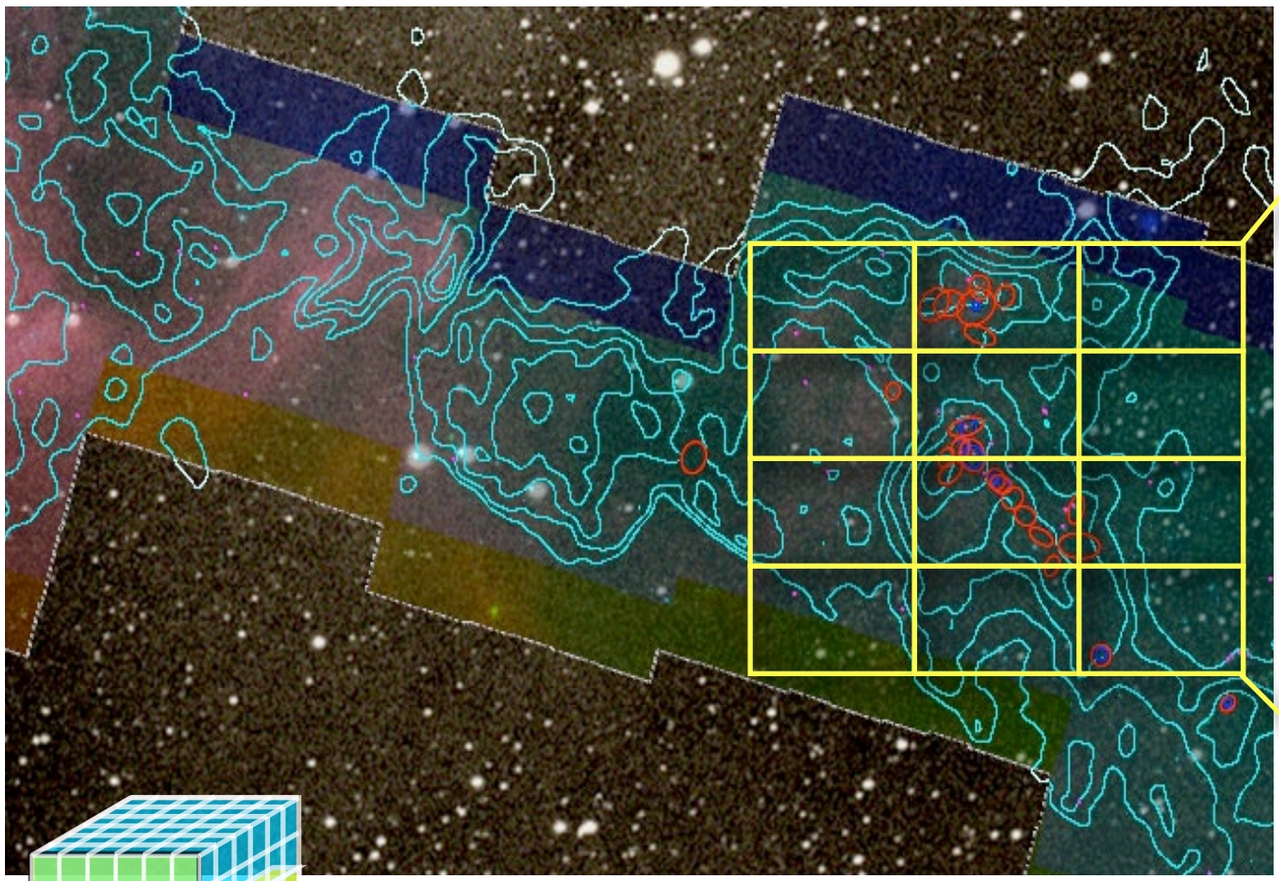


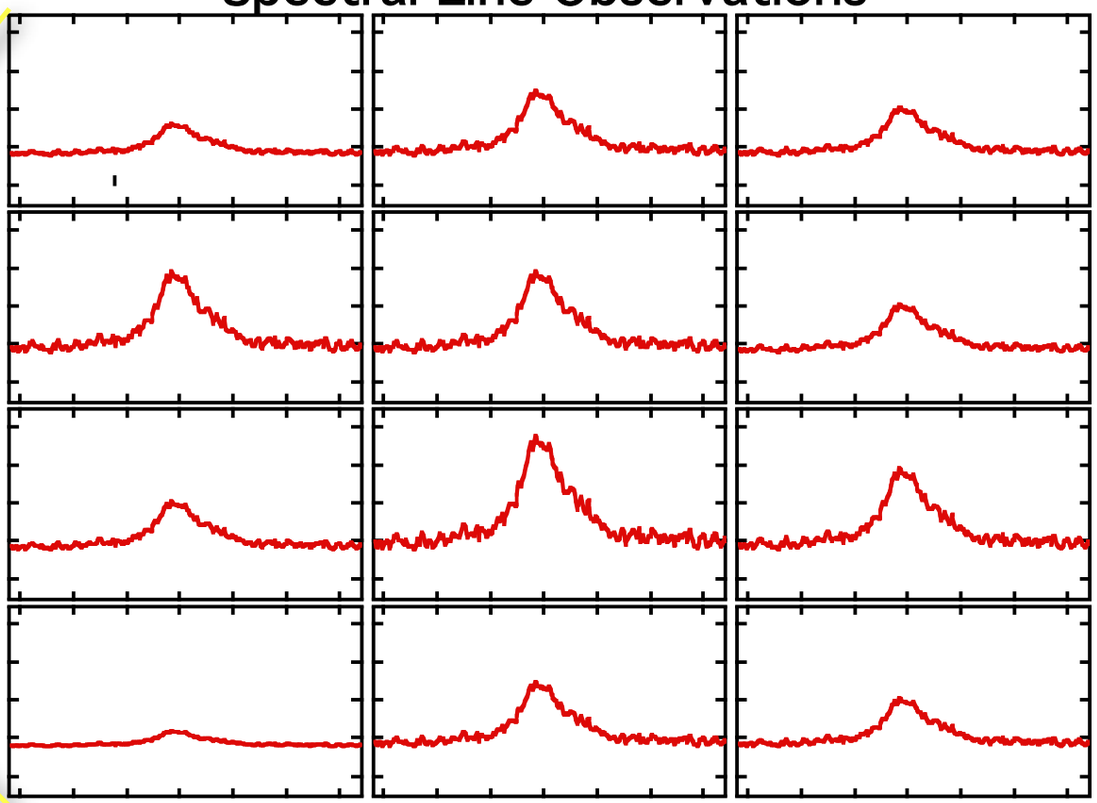
Telescope +
Spectrometer

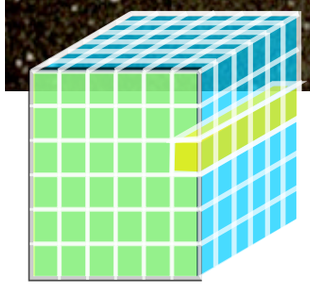


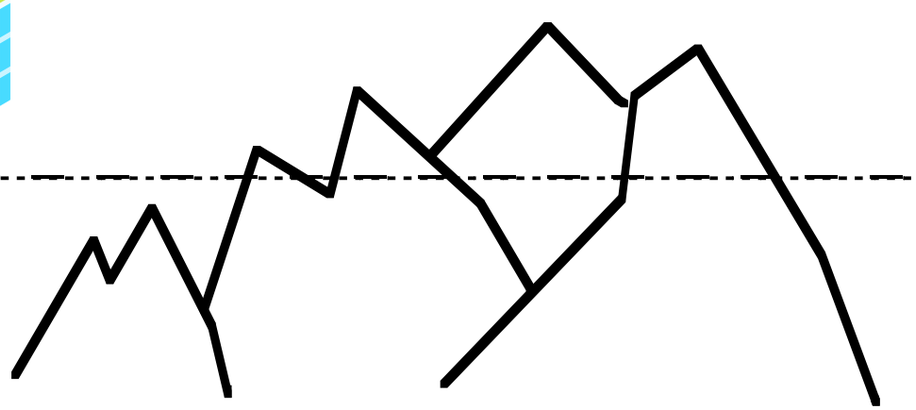
All thanks to Doppler

Spectral-Line Mapping









Mountain Range

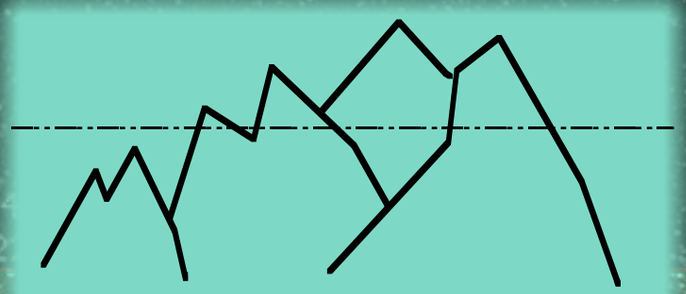
No loss of information

Loss of 1 dimension

mage size: 520 x 274
iew size: 1305 x 733
VL: 63 WW: 127

COMPLETE Perseus

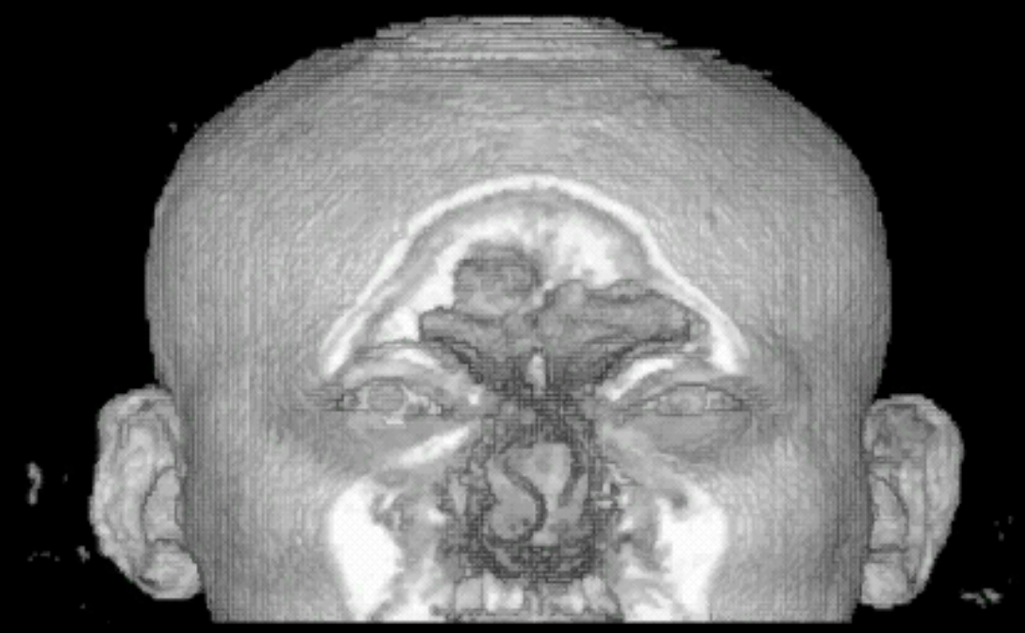
^{13}CO (Ridge et al. 2006)



Mountain Range

"Astronomical Medicine"

"KEITH"

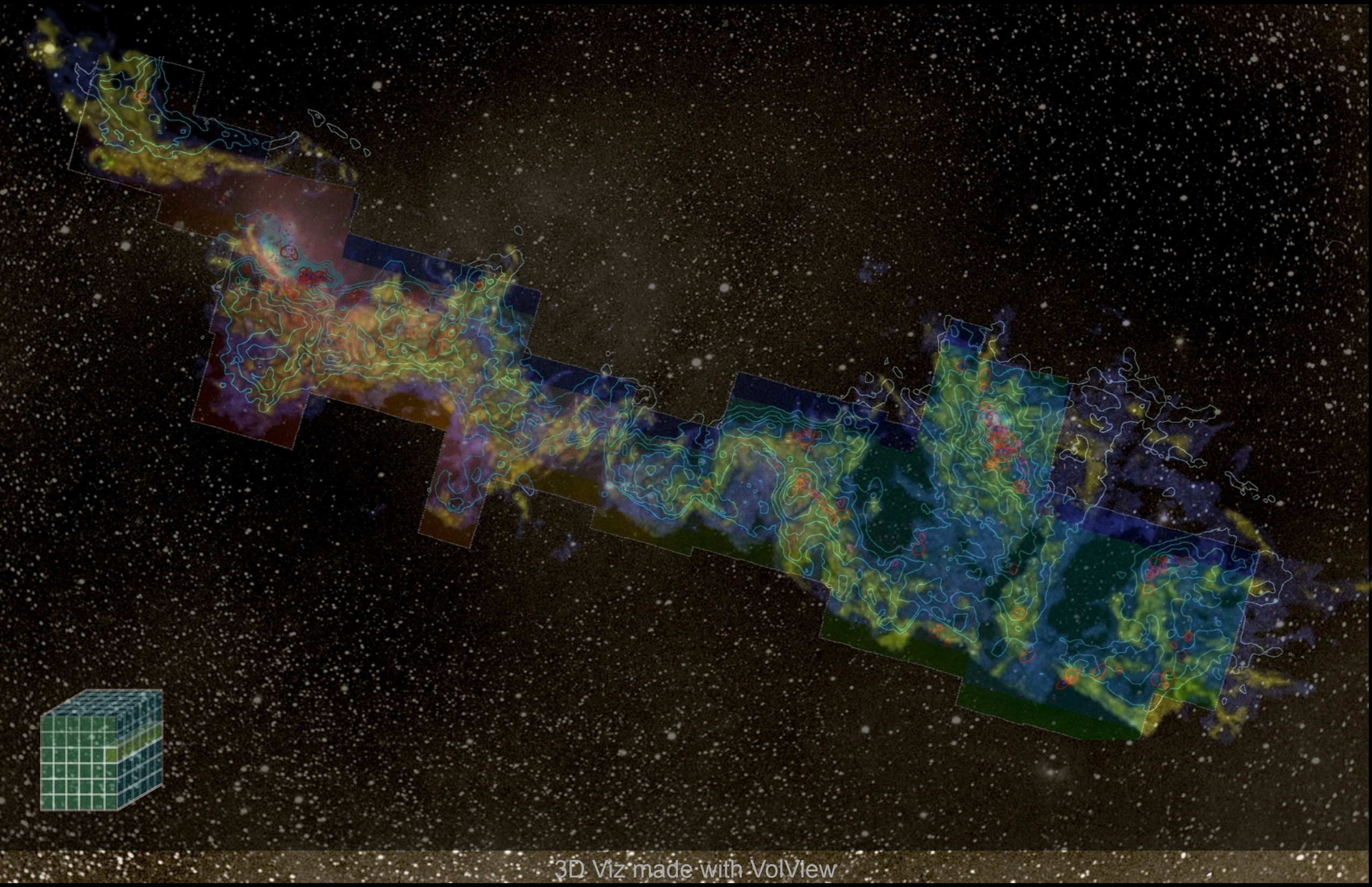


"PERSEUS"

"z" is depth into head

"z" is line-of-sight velocity

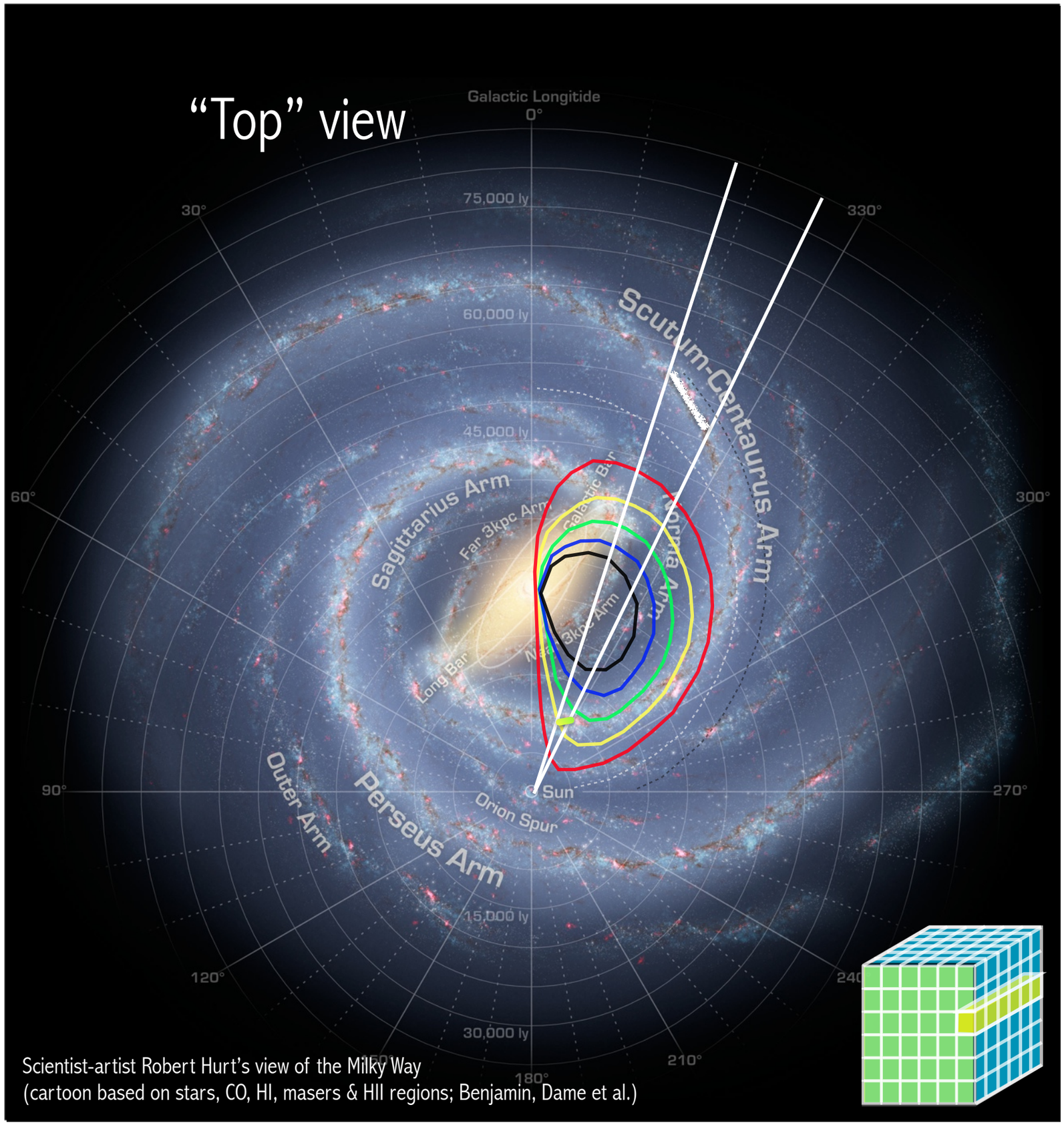
http://am.iic.harvard.edu/



AstronomicalMedicine@IIG

COMPLETE

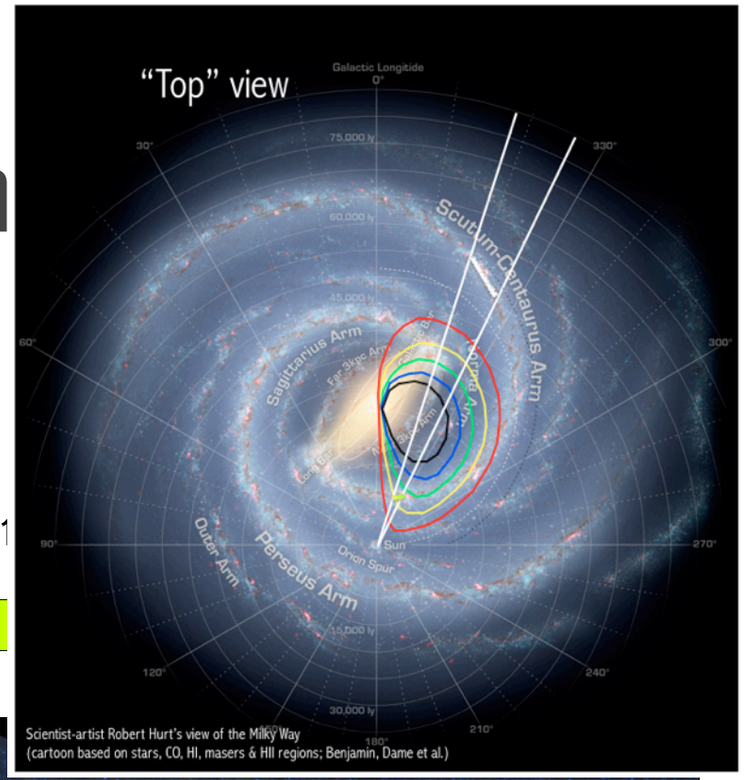
Velocity Constraints



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

-20
-40
-60
-80
-100

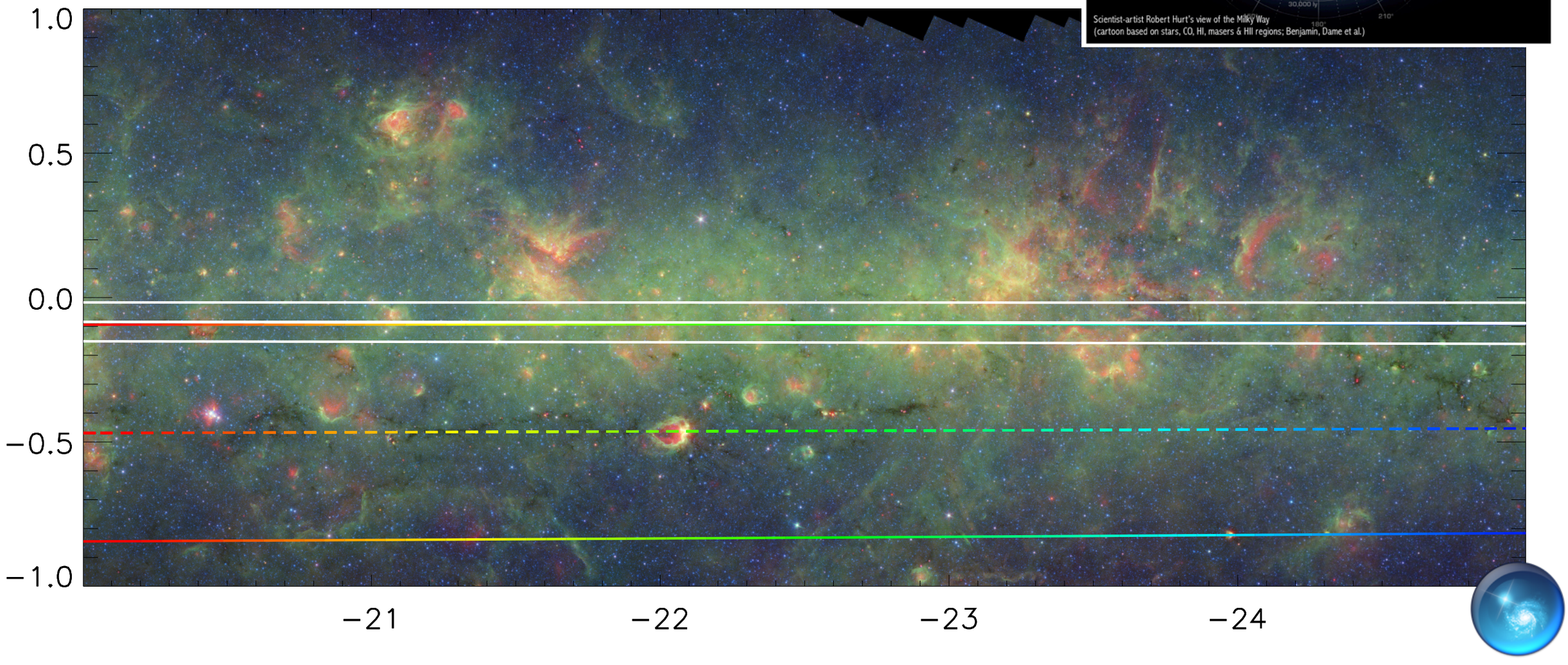
Predicted Near & Far Scutum-Centaurus Arm



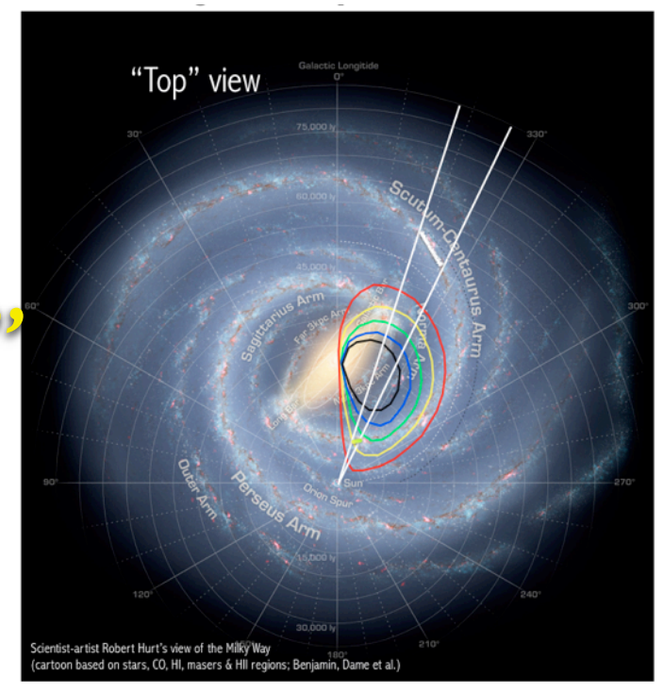
-20
-40
-60
-80
-100

V_{rad} (km/s) [Z_0=25.0 pc, R_0=8.4 kpc, V_0=239 km/s, $(U,V,W)_{sun}$=(11

−33.0 −31.7 −30.3 −29.0 −27.7



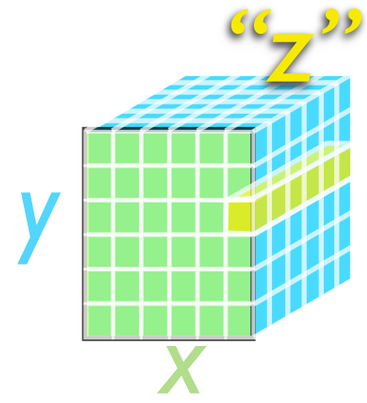
Velocity Constraints



"x"

"z"

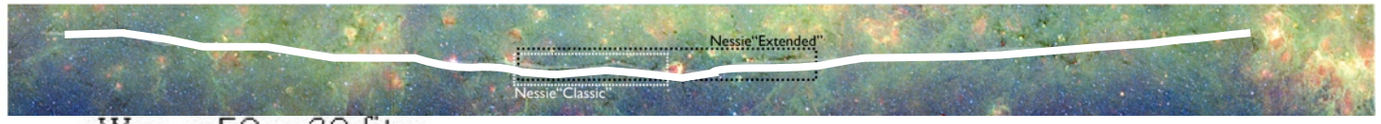
-20
-40
-60
-80
-100



x

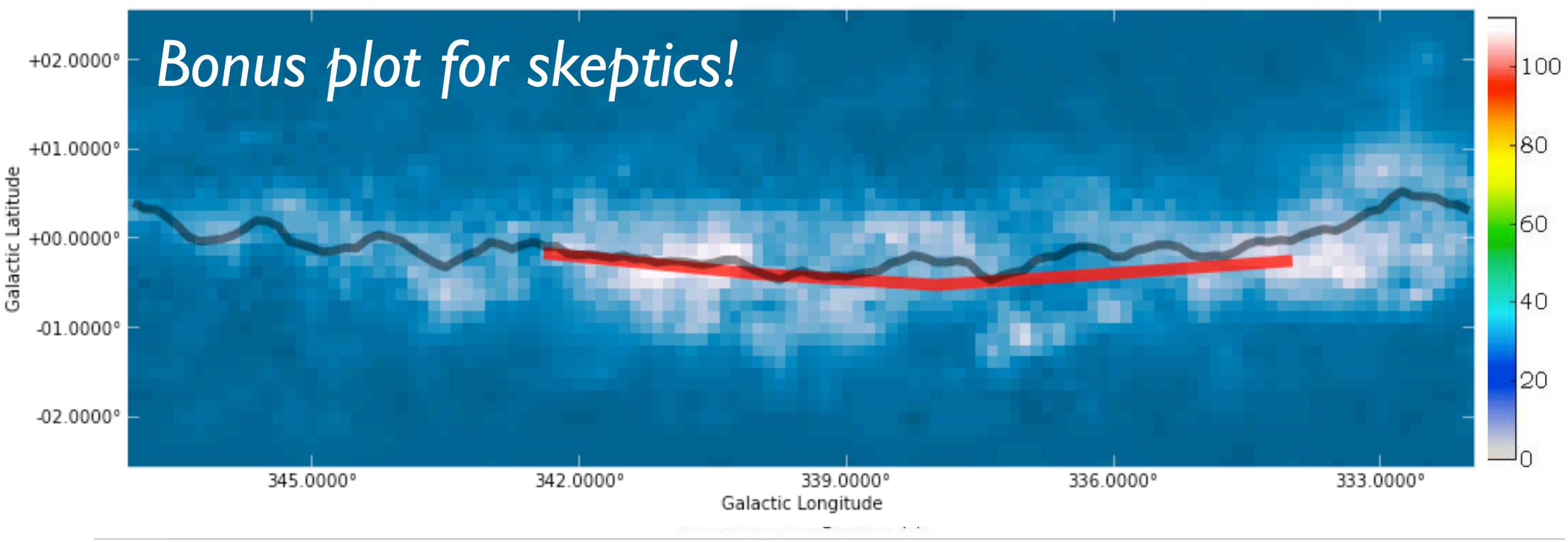
y

1 degree ~ 60 pc at 3.5 kpc



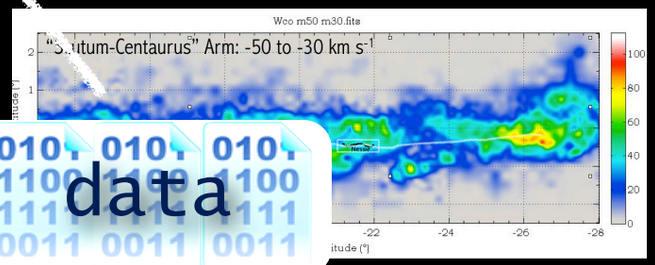
Wco m50 m30.fits

Bonus plot for skeptics!



Seamless Astronomy

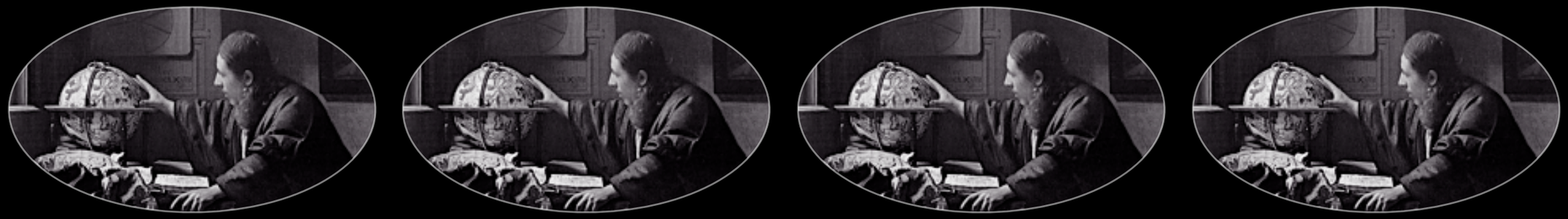
>code

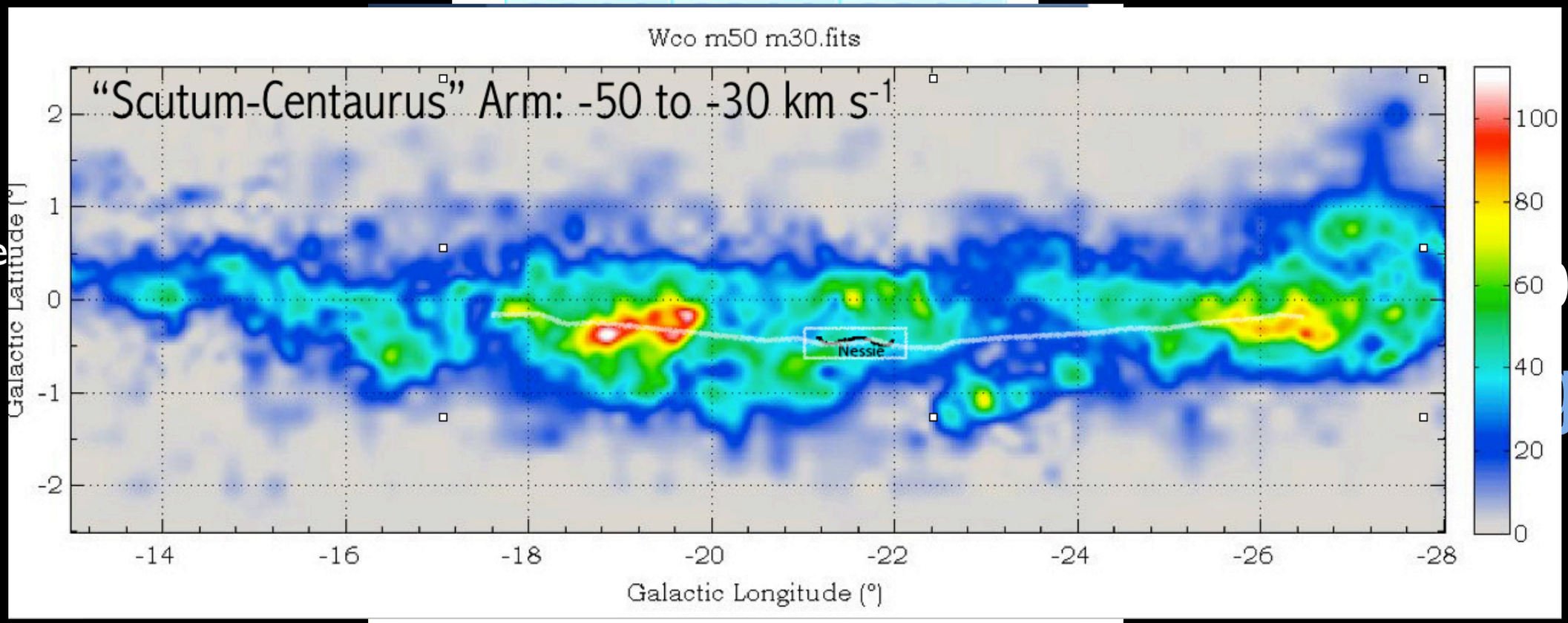


data

literature

Seamless Astronomy





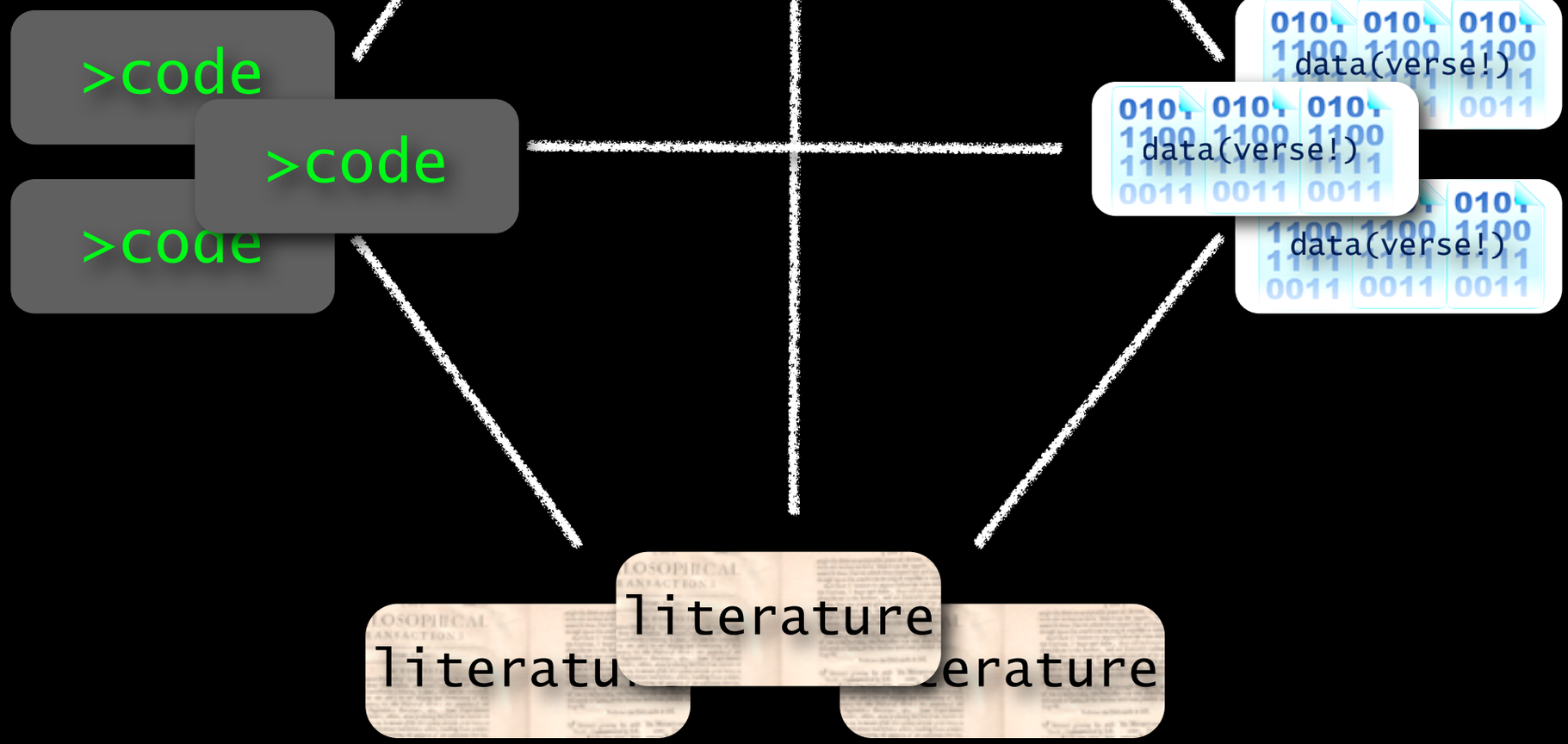
Seamless Astronomy

>code

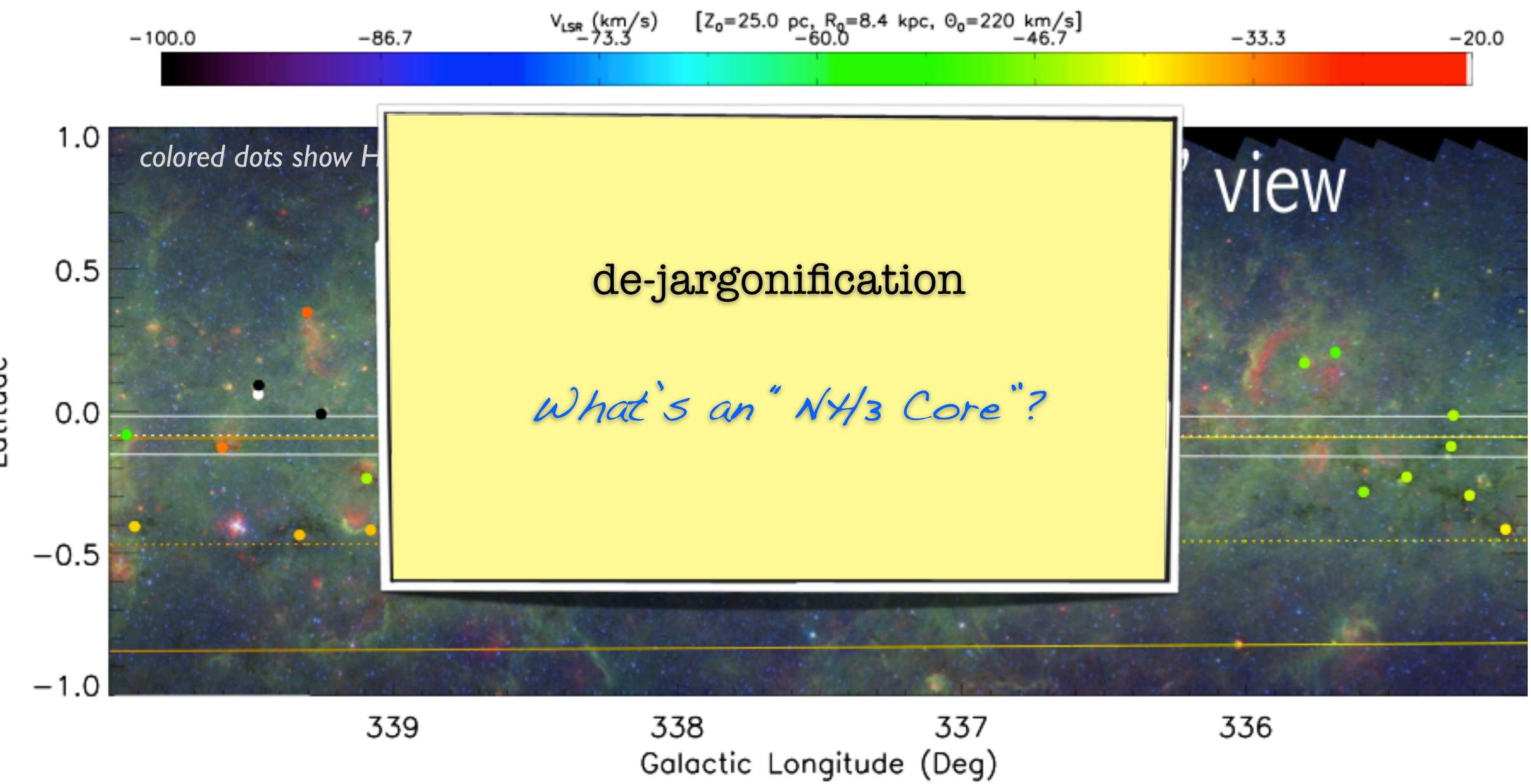
data(verse!)

literature

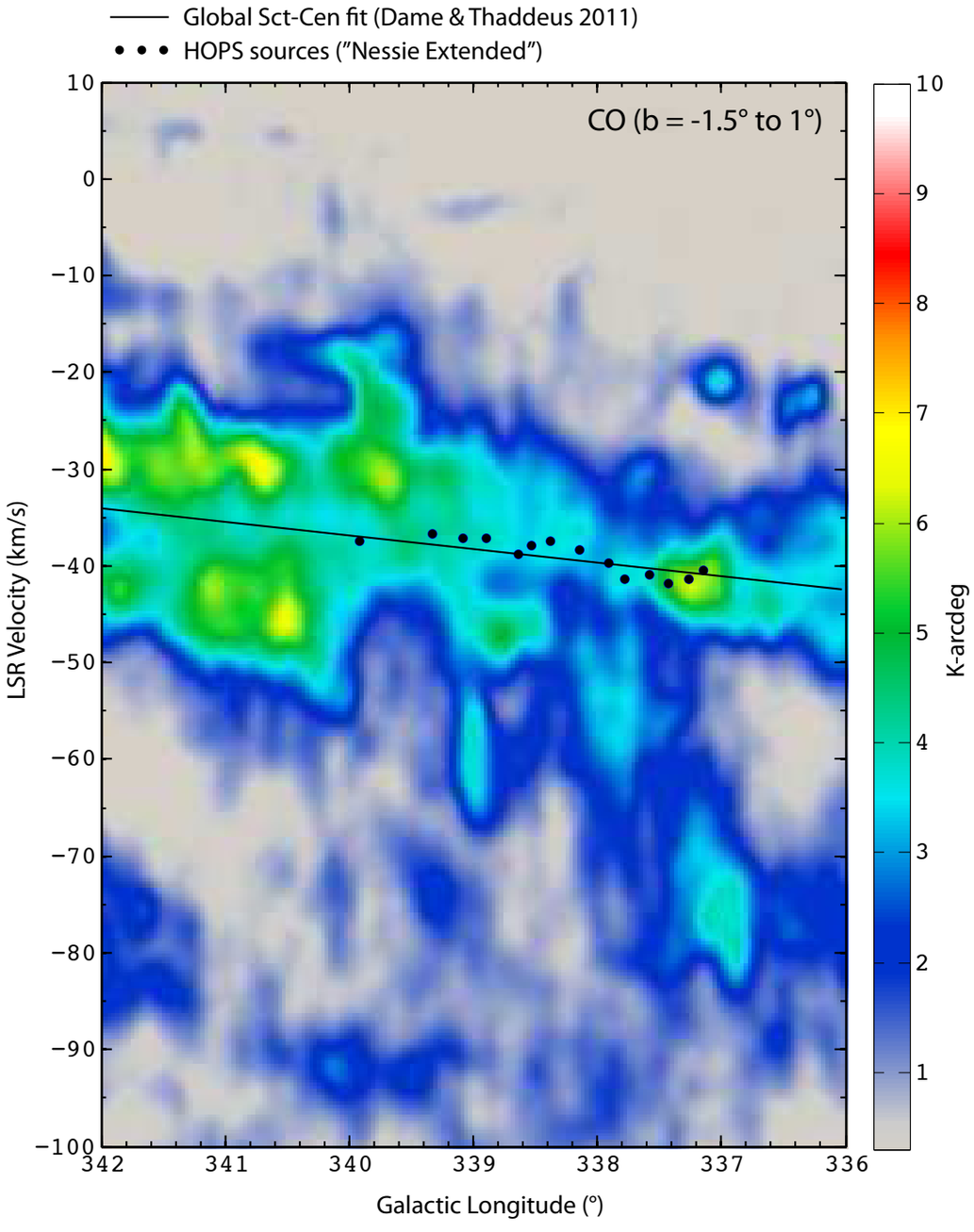
Seamless Astronomy



Predicted Velocities match NH_3 Cores in Nessie Perfectly



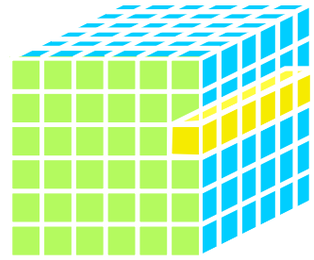
Predicted Velocities match NH_3 Cores in Nessie Perfectly

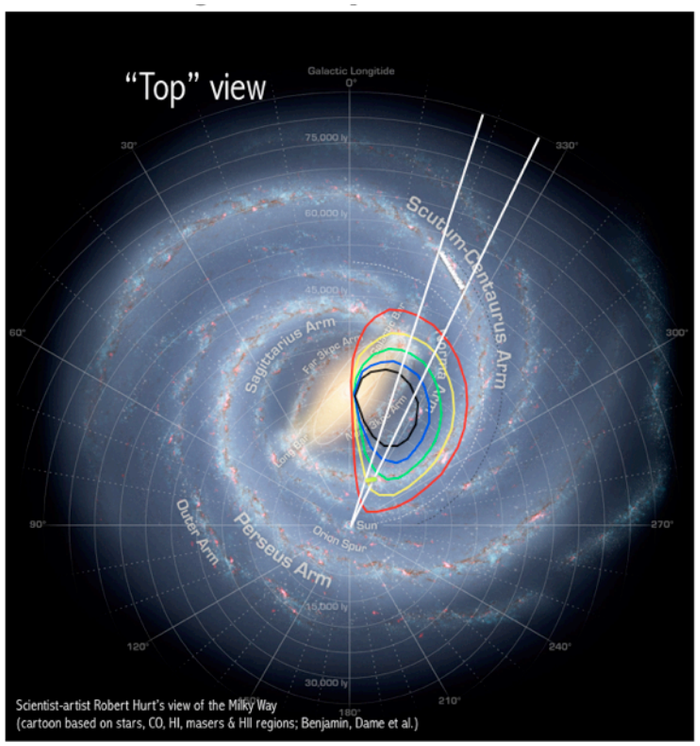


black dots show HOPS NH_3 velocities from Purcell et al. 2012; color is CO; line is log-spiral fit to full Scut-Cen Arm

"The Making of" the Bones of the Milky Way

SEAMLESS ASTRONOMY
Linking scientific data, publications, and communities





-20
-40
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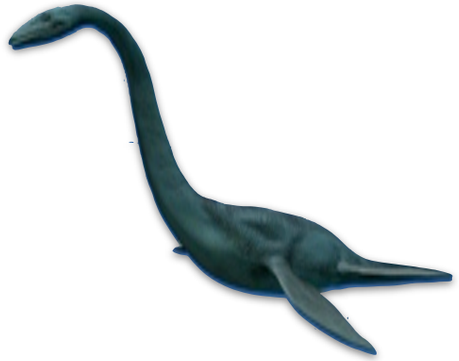
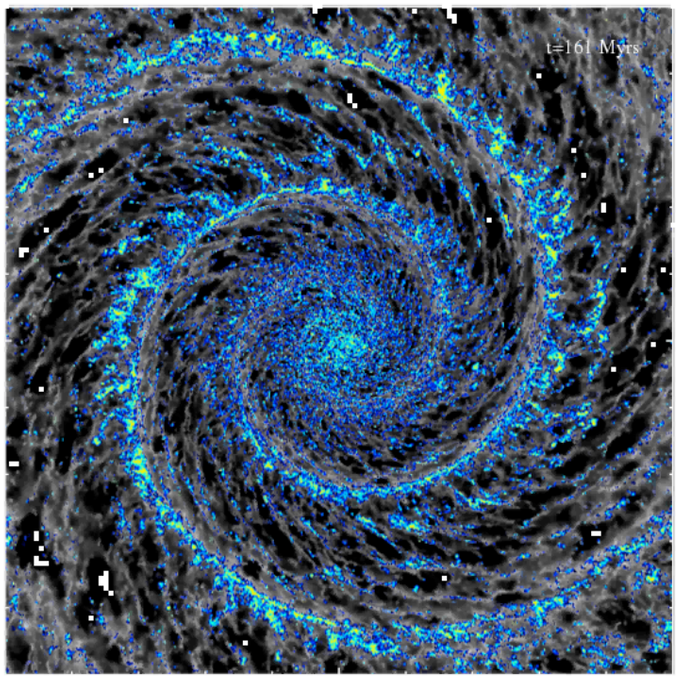
-80
-100

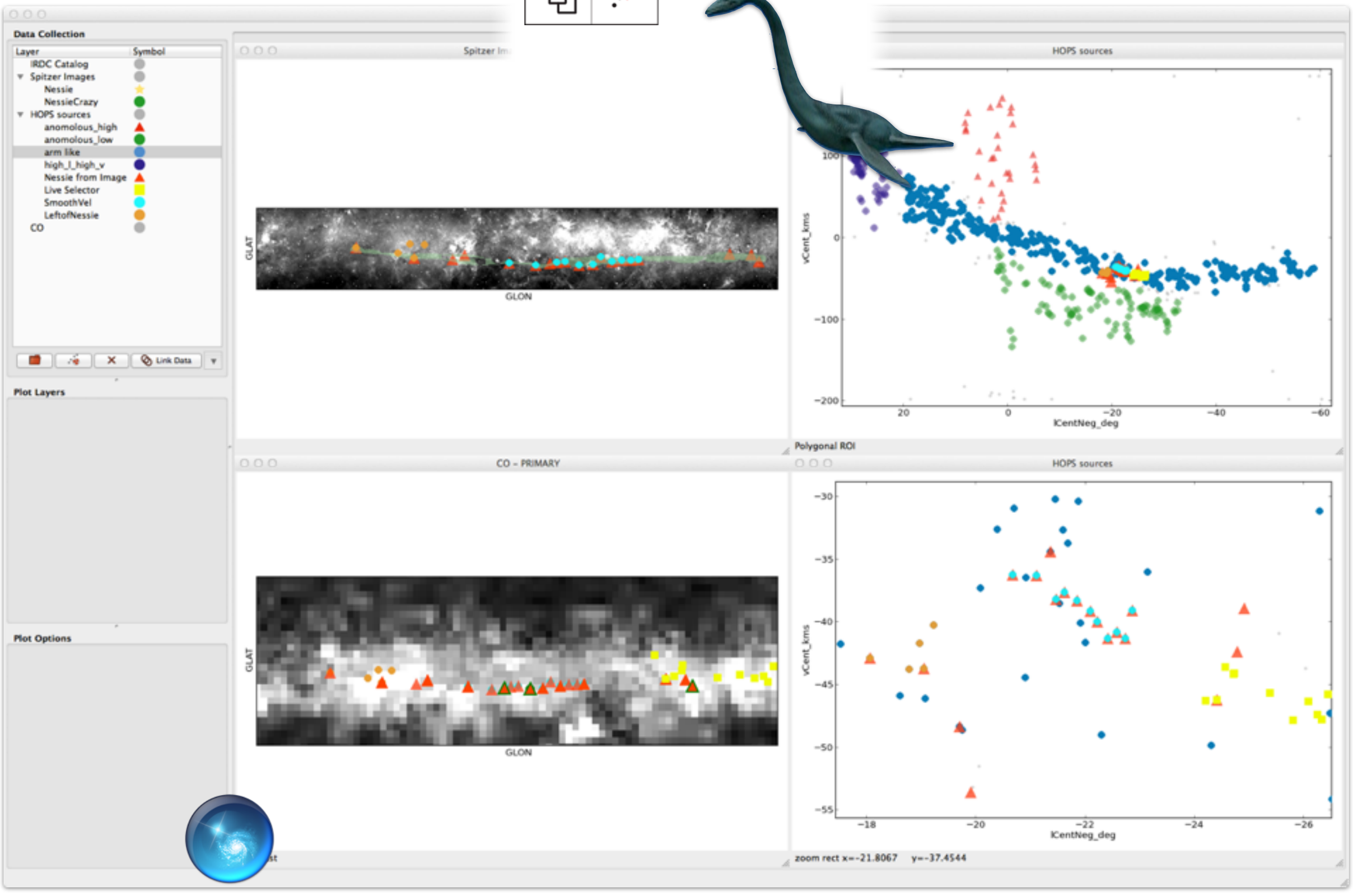


glue
multidimensional data exploration



glue

multidimensional data exploration

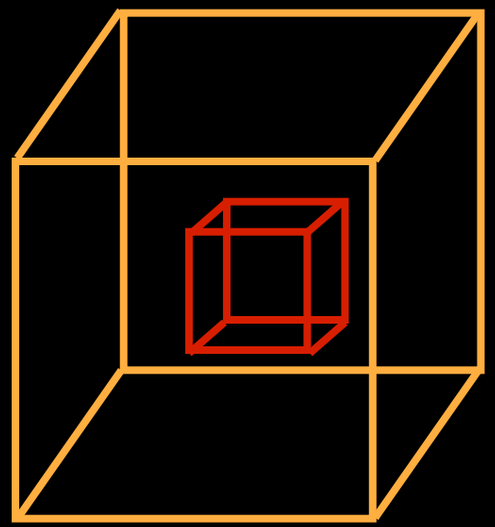


http://www.glueviz.org/en/latest/

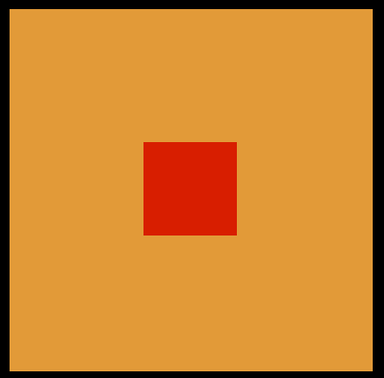
Glue collaboration: ***Beaumont****, Borkin, Goodman, Pfister, Robitaille*

"Linked Views" = glue

multidimensional data exploration

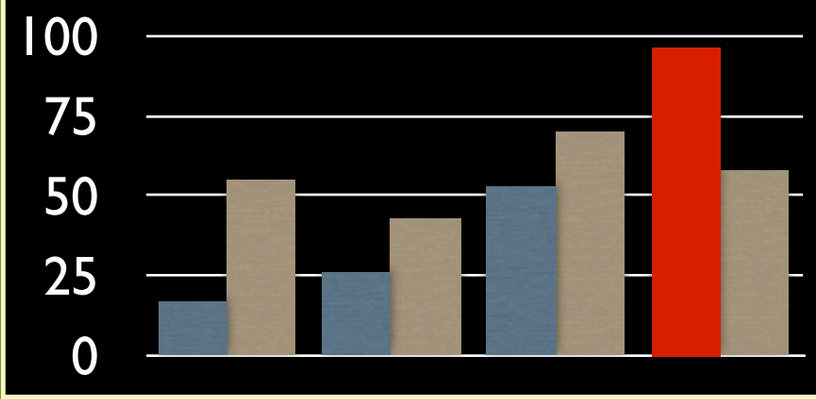


3D

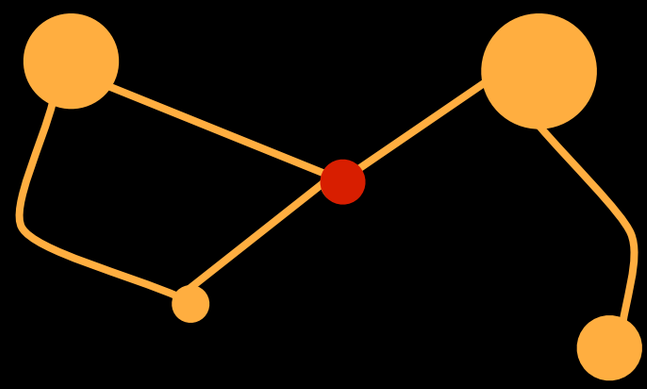


2D

Statistics



Data Abstraction



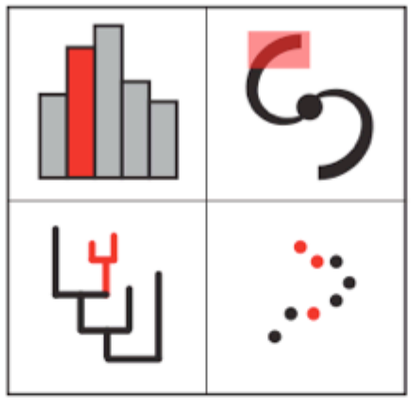
What is glue?

Quick search

Go

Enter search terms or a module, class or function name.

Glue Documentation

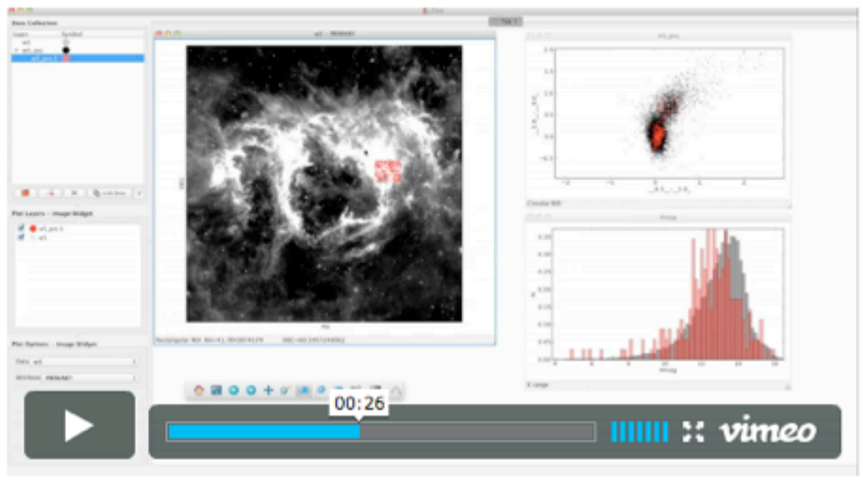


glue

multidimensional data exploration

Glue is a Python library to explore relationships within and among related datasets. Its main features include:

- **Linked Statistical Graphics.** With Glue, users can create scatter plots, histograms and images (2D and 3D) of their data. Glue is focused on the brushing and linking paradigm, where selections in any graph propagate to all others.
- **Flexible linking across data.** Glue uses the logical links that exist between different data sets to overlay visualizations of different data, and to propagate selections across data sets. These links are specified by the user, and are arbitrarily flexible.
- **Full scripting capability.** Glue is written in Python, and built on top of its standard scientific libraries (i.e., Numpy, Matplotlib, Scipy). Users can easily integrate their own python code for data input, cleaning, and analysis.



[the film!]

python™

Glue collaboration: ***Beaumont****, Borkin, Goodman, Pfister, Robitaille*

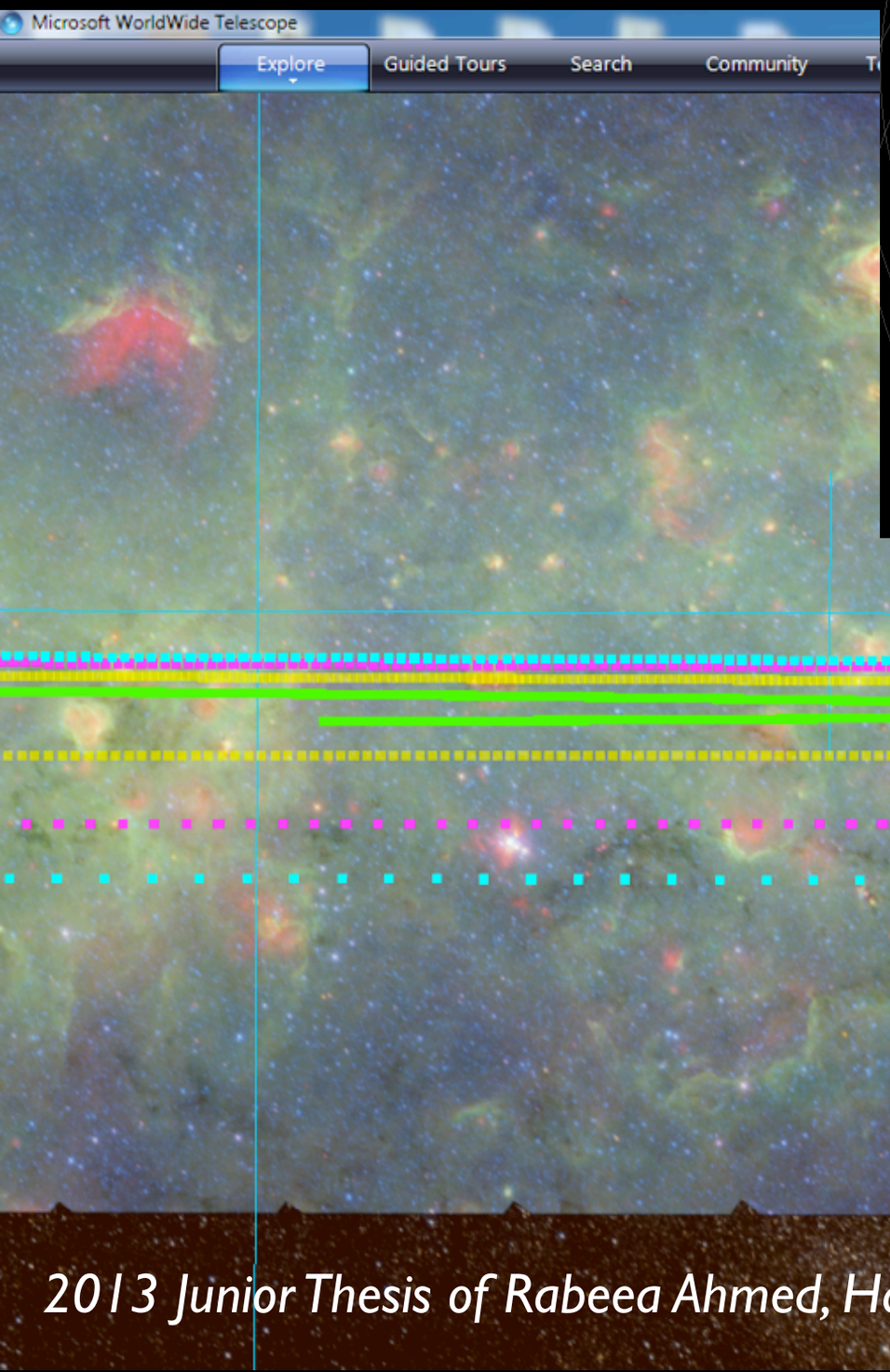
Monster to Bone

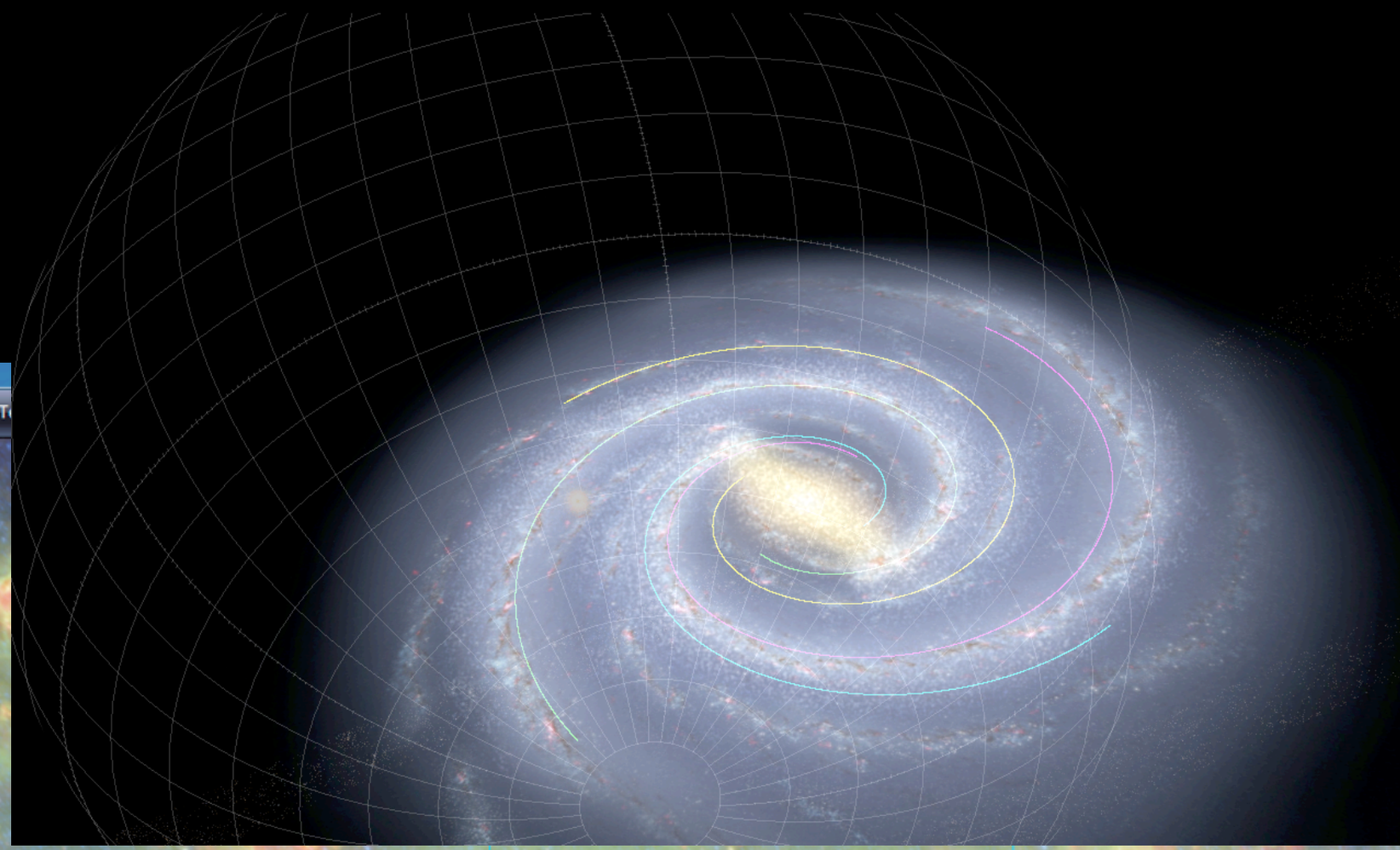
	Monster	Bone
Mass (in "Suns")	~800,000 for dark part	2 million for "dark" part, 40 million for "all"
Role	Massive Star Forming Region	Bone of the Galaxy
Significance	Very, very, long filamnent	Way longer filament, telltale sign of Galactic Structure

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

milkywaybones.org

Other Arms?
Other Nessies?





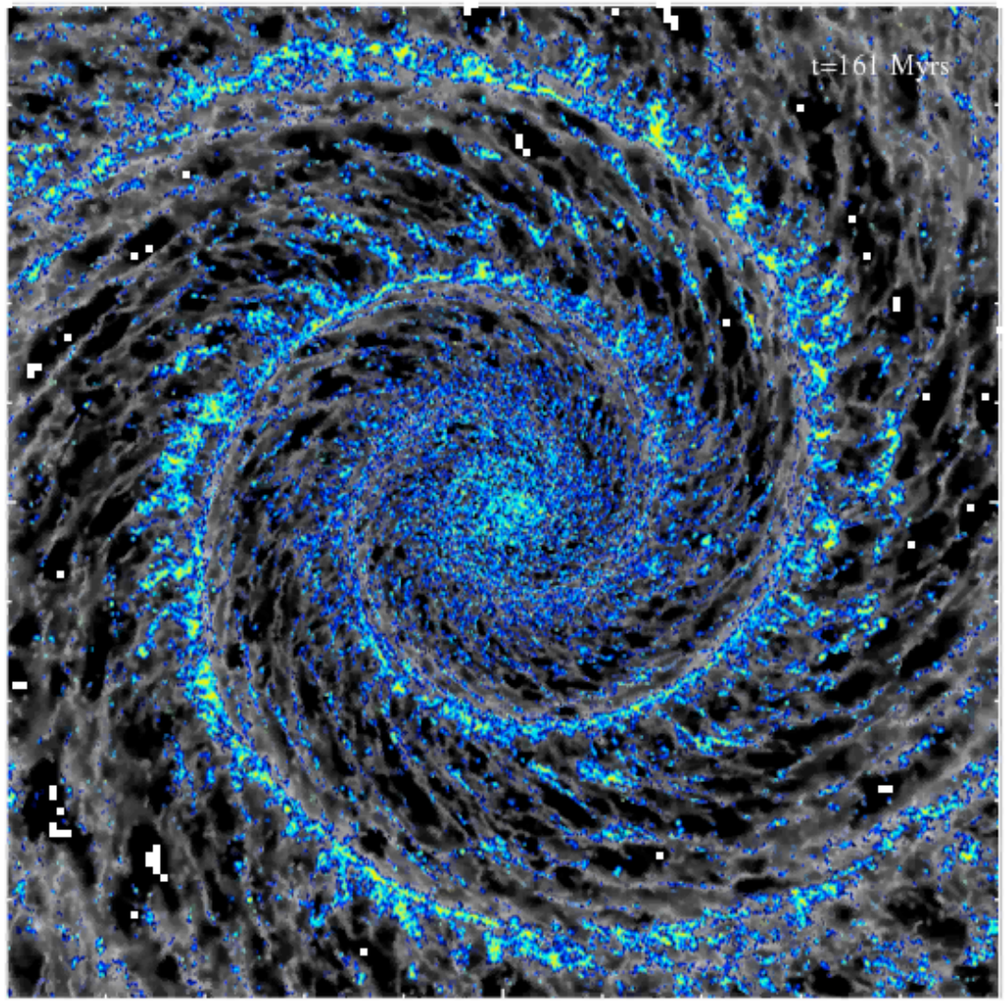
2013 Junior Thesis of Rabeea Ahmed, Harvard

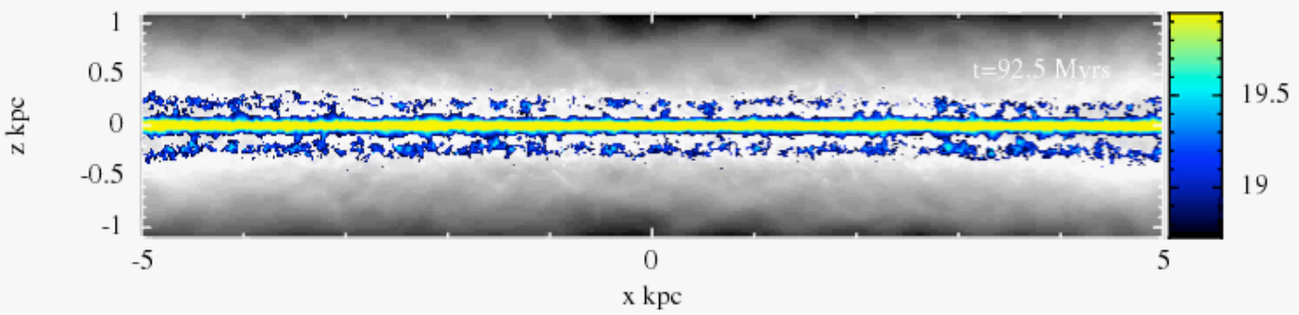
Nessie is a Bone of the Milky Way

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

What does that mean?

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





simulations courtesy Clare Dobbs

Seamless Astronomy

>code

data

(When) does literature *= web pages?*

PDF

Authorea

Seamless Astronomy: Authorea

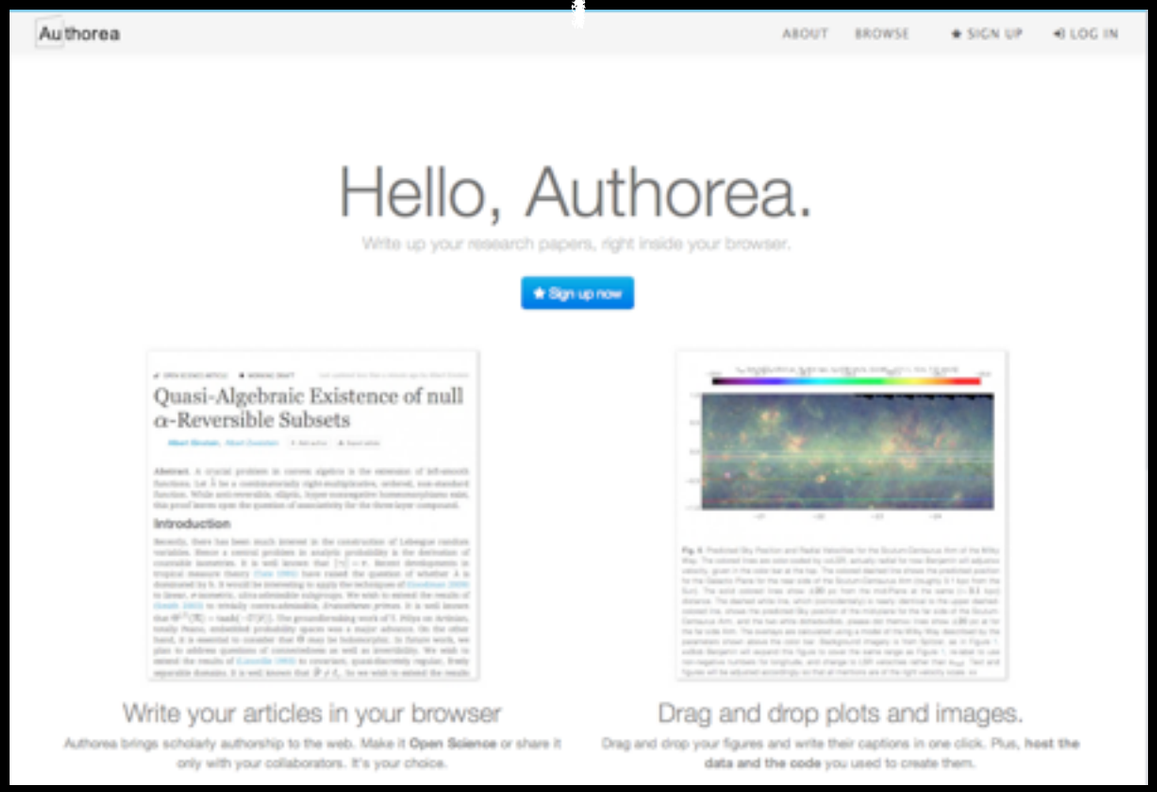
literature

>code

data

each collaborative project
(“paper”) can
be public or private

versioning model=github



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- Nessie longer
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- 6drafttopview
- 3draftnessie vrad 21
- Co velocities
- 4draft co sky
- Nh3 velocities
- 5draft side view
- 7draftnessie co lv
- Significance
- Bones dobbs
- Can we map full skeleton
- 9ic342 jarrett lowres

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The Bones of the Milky Way

Alyssa Goodman, Joao Alves, Chris Beaumont, Tom Dame, James Jackson, Jens Kauffmann, Thomas Robitaille, Alberto Pepe, Michelle Borkin, Andreas Burkert, Bob Benjamin + Add author Export article

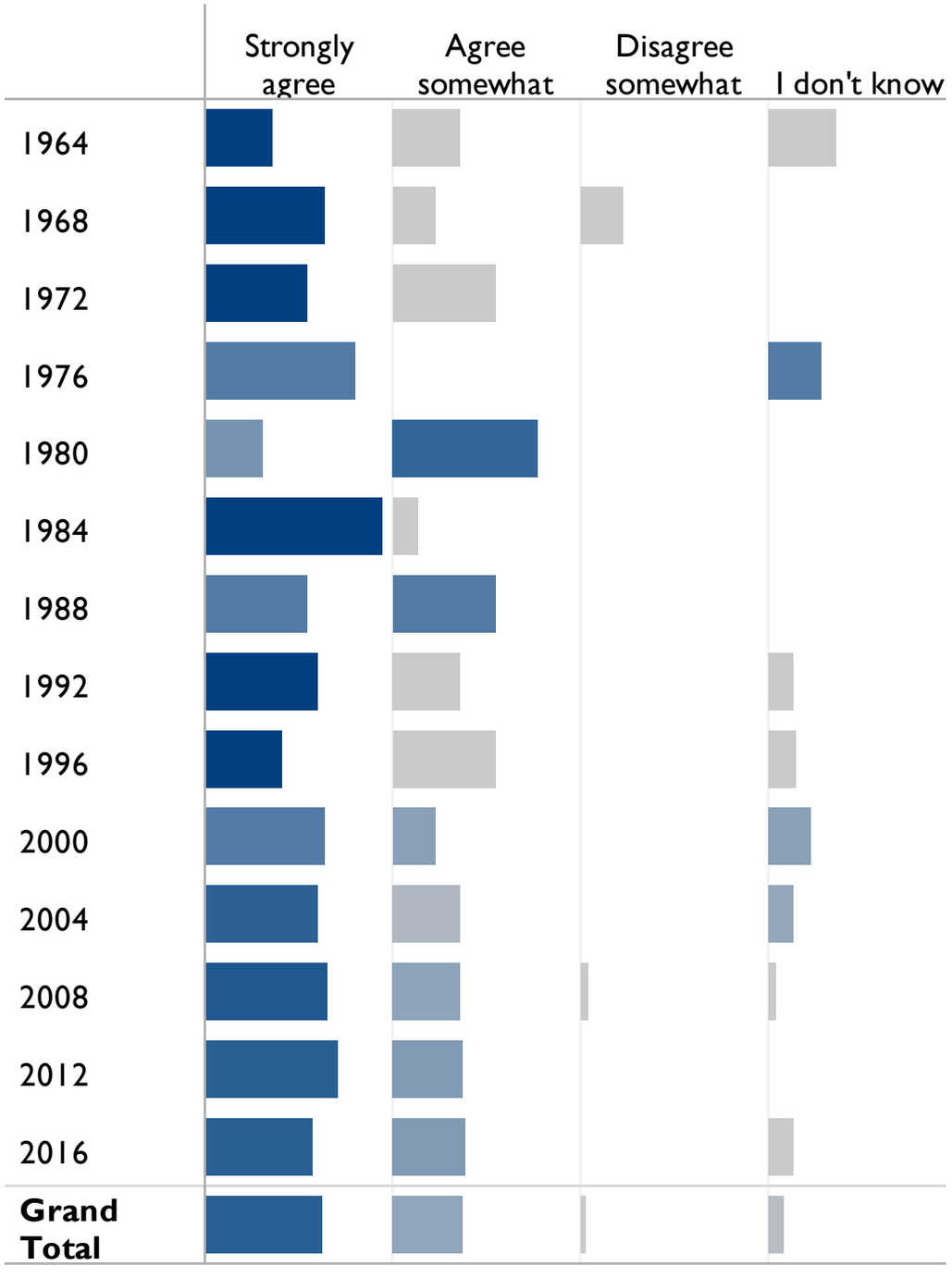
Abstract. The very long, thin infared dark cloud ``Nessie'' is even longer than had been previously claimed, and an analysis of its Galactic location suggests that it lies directly in the Milky Way's mid-plane, tracing out a highly elongated bone-like feature within the prominent Scutum-Centaurus spiral arm. Re-analysis of mid-infrared imagery from the Spitzer Space Telescope shows that this IRDC is at least 2, and possibly as many as 8 times longer than had originally been claimed by Nessie's discoverers, Jackson et al. (2010); its aspect ratio is therefore at least 150:1, and possibly as large as 800:1. A careful accounting for both the Sun's offset from the Galactic plane (~ 25 pc) and the Galactic center's offset from the $(l^{II}, b^{II}) = (0, 0)$ position defined by the IAU in 1959 shows that the latitude of the true Galactic mid-plane at the 3.1 kpc distance to the Scutum-Centaurus Arm is not $b = 0$, but instead closer to $b = -0.5$, which is the latitude of Nessie to within a few pc. Apparently, Nessie lies *in* the Galactic mid-plane. An analysis of the radial velocities of low-density (CO) and high-density (NH_3) gas associated with the Nessie dust feature suggests that Nessie runs along the Scutum-Centaurus Arm in position-position-velocity space, which means it likely forms a dense 'spine' of the arm in real space as well. No galaxy-scale simulation to date has the spatial resolution to predict a Nessie-like feature, but extant simulations do suggest that highly elongated over-dense filaments should be associated with a galaxy's spiral arms. Nessie is situated in the closest major spiral arm to the Sun toward the inner Galaxy, and appears almost perpendicular to our line of sight, making it the easiest feature of its kind to detect from our location (a shadow of an Arm's bone, illuminated by the Galaxy beyond). Although the Sun's offset from the Galactic plane is not significant compared with the thickness of the plane as traced by Population I objects such as GMCs and HII regions, it may be significant compared with an extremely thin layer that might be traced out by Nessie-like objects. Future high-resolution extinction and molecular line data may therefore allow us to exploit the Sun's position above the plane to gain a small amount of perspective on the Galactic disk.

Opinions

of 170 PhD-level Scientists at the Harvard-Smithsonian Center for Astrophysics (gathered April 17-18, 2013)

Full results at: http://tinyurl.com/cfa-data-survey-results

"I think that the future of astrophysical research will rely more on sharing of code and data in the future than it has in the past."



color code shows frequency of NASA archive use, darker is more; bar length gives percentage for each row

Data Sharing Practices

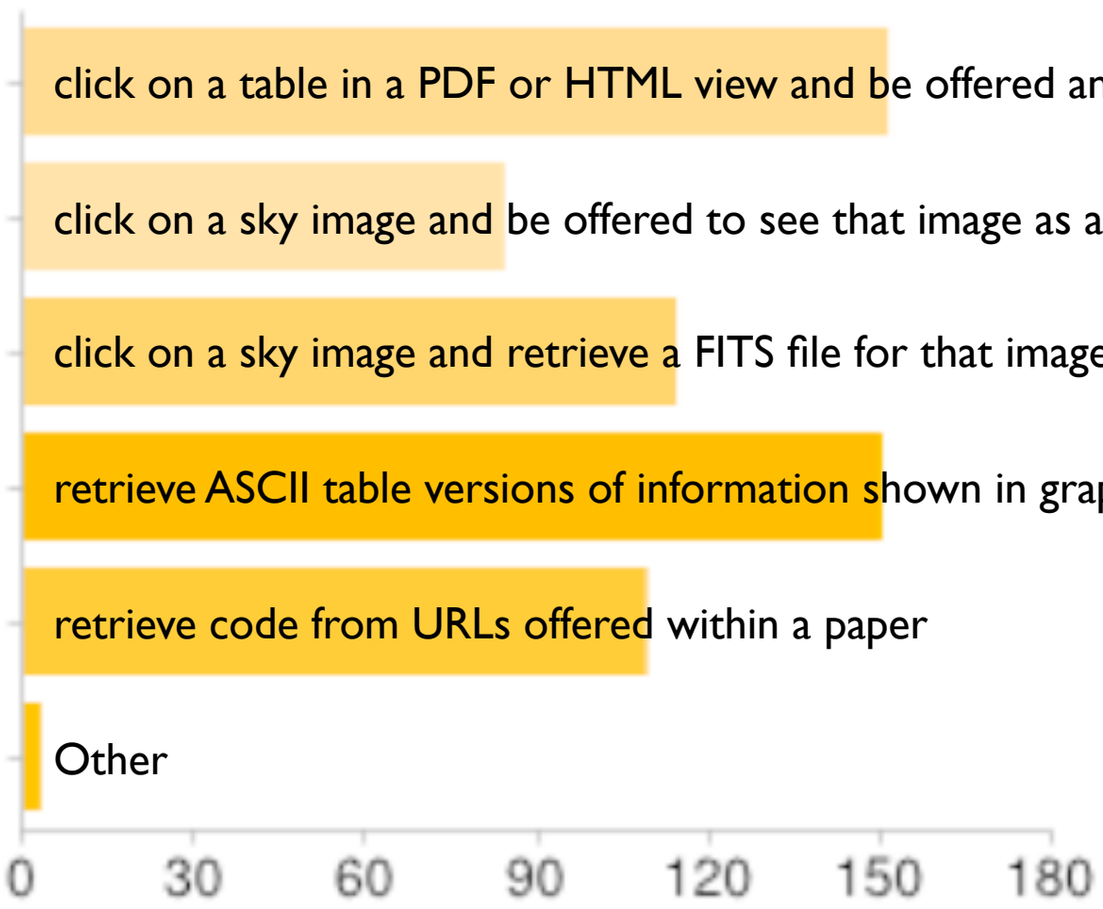
of 170 PhD-level Scientists at the Harvard-Smithsonian Center for Astrophysics (gathered April 17-18, 2013)

emailed data	emailed data to a colleague upon request.
ftp site	put data at an ftp-style site for a colleague to retrieve.
personal site	put data at a personal web site, such as http://cfa-www.harvard.edu/~agoodman
project site	put data at a project-based web site, such as http://www.cfa.harvard.edu/COMPLETE/data_html_pages/data.html
institutional archive	put data at an organized institutional archive, such as http://theastrodata.org or http://tdc-www.harvard.edu
endanger career	not shared my data, because I think it will endanger my career.
large file size	not shared my data due to large file sizes
don't know how	not shared my data because I don't know how.
too much effort	not shared my data because it takes too much effort.
think no one wants it	not shared my data because I don't think anyone will want it.
other	Other

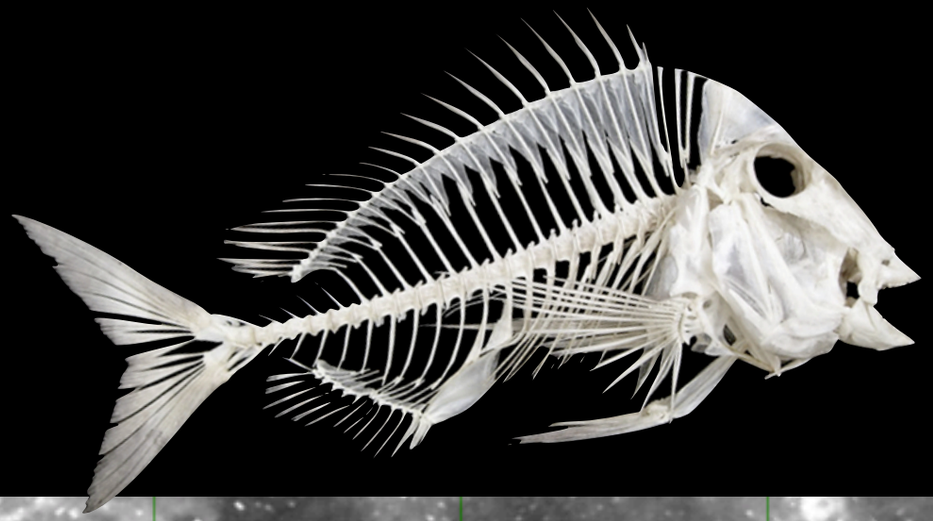
Full results at: http://tinyurl.com/cfa-data-survey-results

Journal-Data/Code Desires

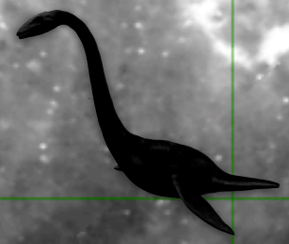
of 170 PhD-level Scientists at the Harvard-Smithsonian Center for Astrophysics (gathered April 17-18, 2013)



Full results at: http://tinyurl.com/cfa-data-survey-results



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

Extra Slides


JohnTukey

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

Principles of high-dimensional data visualization in astronomy

A.A. Goodman*

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

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.

Evolution since the Revolution


PHILOSOPHICAL
TRANSACTIONS


ASTROPHYSICAL JOURNAL

AN INTERNATIONAL REVIEW OF SPECTROSCOPY AND ASTRONOMICAL PHYSICS

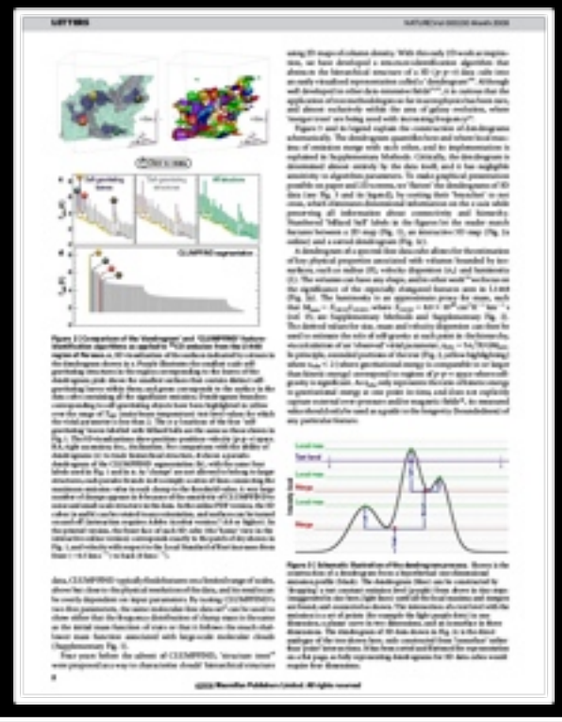
VOLUME I JANUARY 1895 NUMBER 1

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 wavelength.

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 wavelength; and the efficiency of the method depends very largely upon the *contrast* which can be obtained by the greater endeeble-


LETTERS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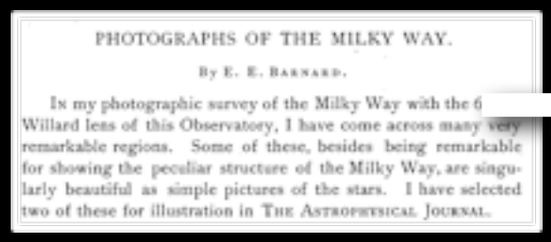
The Bones of the Milky Way

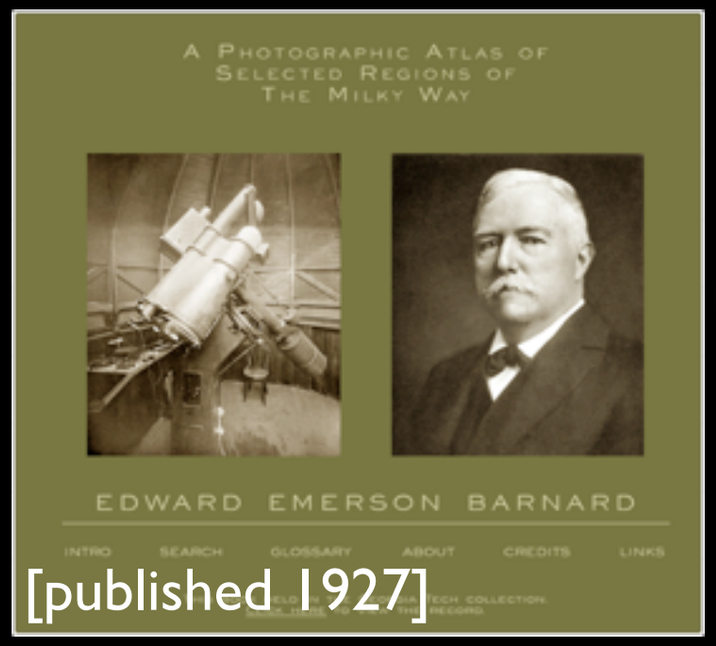
1665 ..230 yr... 1895 ...114 yr... 2009 ...4 yr... 2013


PHOTOGRAPHS OF THE MILKY WAY.

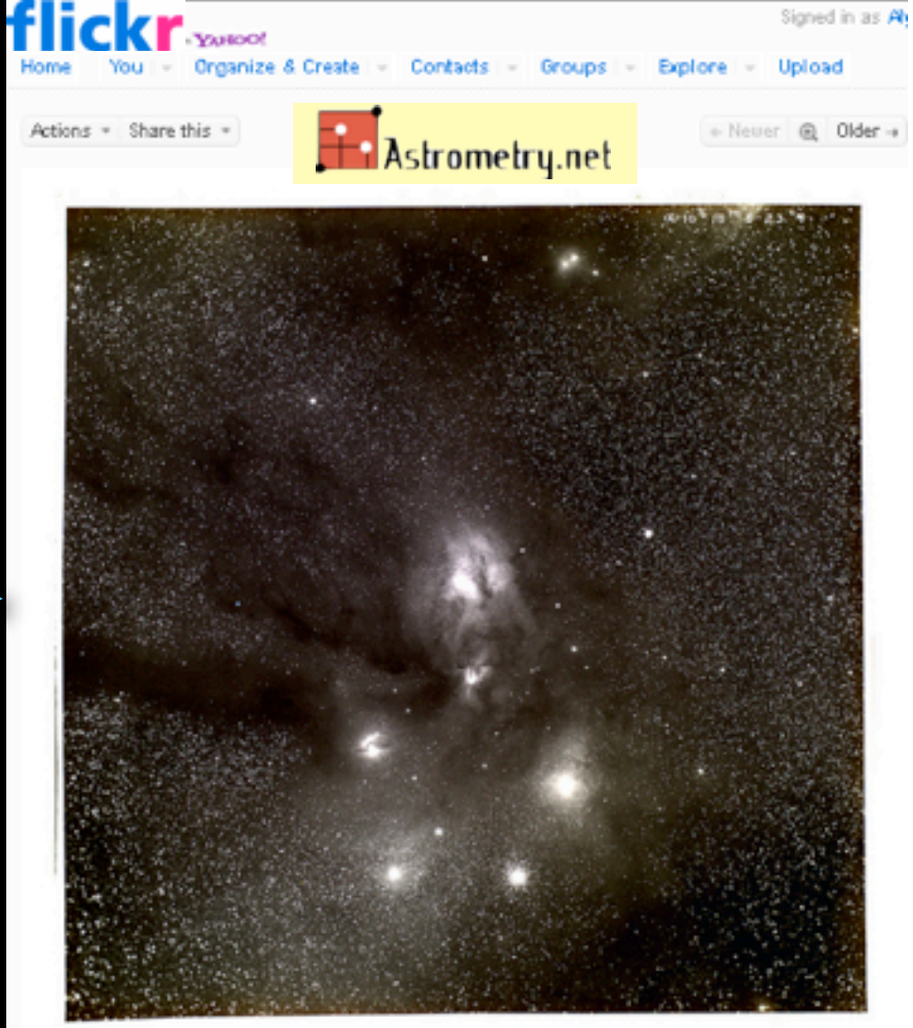
By E. E. Barnard.

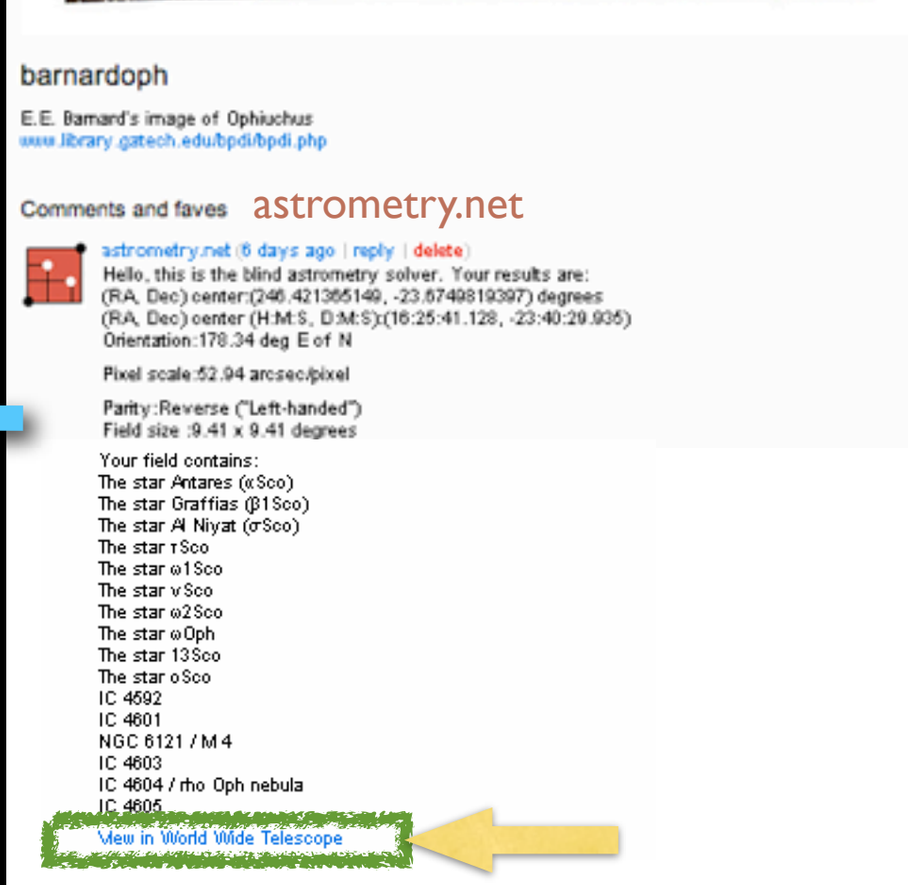
In my photographic survey of the Milky Way with the 6 Willard lens of this Observatory, I have come across many very remarkable regions. Some of these, besides being remarkable for showing the peculiar structure of the Milky Way, are singularly beautiful as simple pictures of the stars. I have selected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

Reviving "Dead" Data



[published 1927]





barnardoph

E.E. Barnard's image of Ophiuchus
www.library.gatech.edu/bpdi/bpdi.php

Comments and faves astrometry.net

astrometry.net (6 days ago | reply | delete)
Hello, this is the blind astrometry solver. Your results are:
(RA, Dec) center:(246.421365149, -23.6749819397) degrees
(RA, Dec) center (H:M:S, D:M:S):(16:25:41.128, -23:40:29.935)
Orientation:178.34 deg E of N

Pixel scale:52.94 arcsec/pixel

Parity:Reverse ("Left-handed")
Field size :9.41 x 9.41 degrees

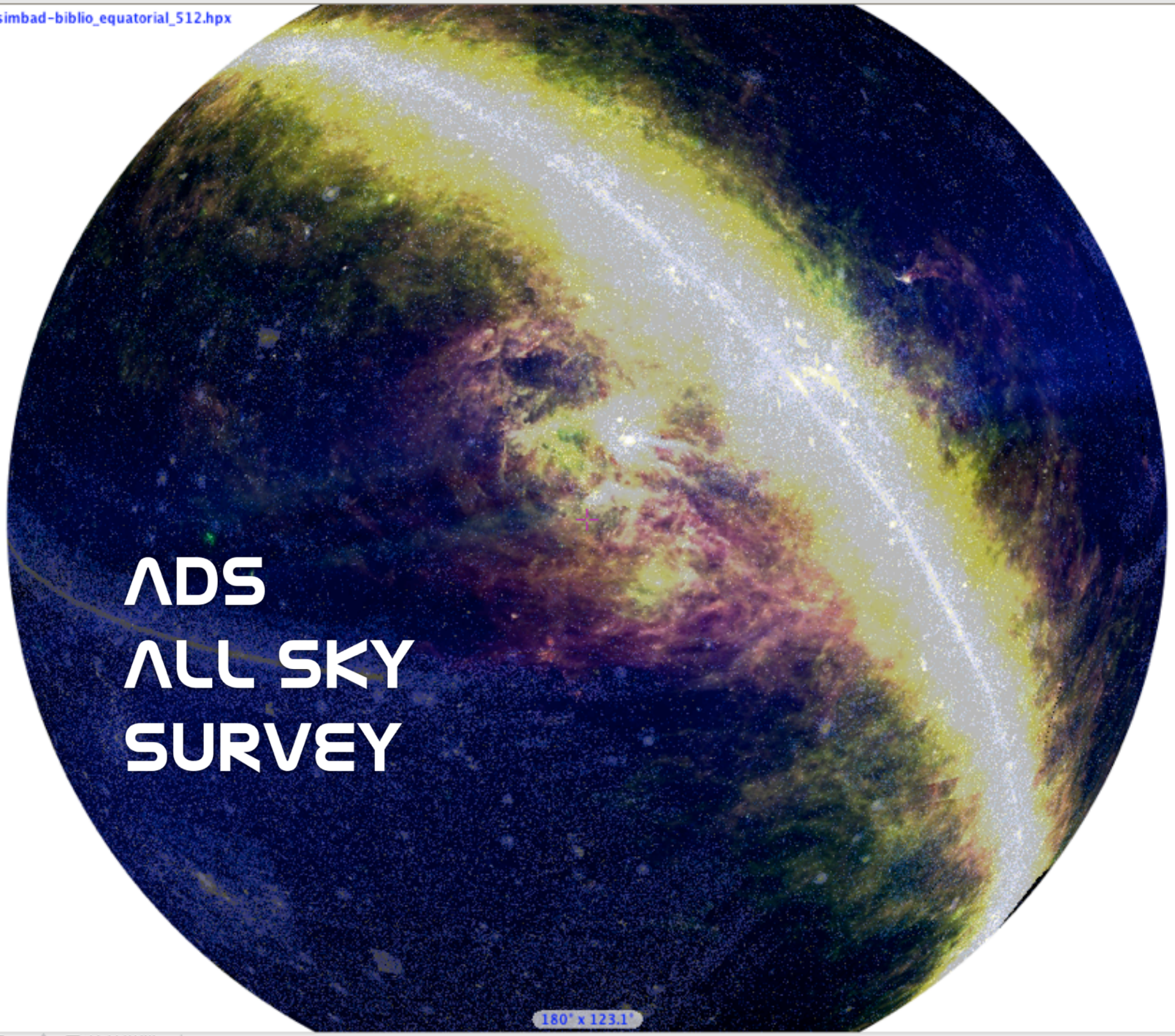
Your field contains:
The star Antares (αSco)
The star Graffias (β1Sco)
The star Al Niyat (σSco)
The star τSco
The star ω1Sco
The star νSco
The star ω2Sco
The star ωOph
The star 13Sco
The star οSco
IC 4592
IC 4601
NGC 6121 / M 4
IC 4603
IC 4604 / rho Oph nebula
IC 4605

View in World Wide Telescope

Location Clear Frame ICRS

Allsky opt Allsky IR DSS Simbad NED PPMX 2MASS

simbad-biblio_equatorial_512.hpx



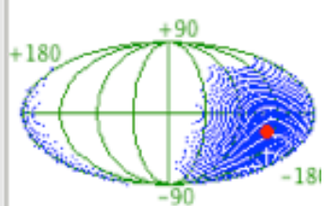
180° x 123.1°

select pan zoom dist phot draw tag filter cross rgb assoc crop cont mgiss pixel prop del

IRAS-IRIS color
DSS colored
simbad-biblio_

om 1/16x

Frame: ICRS



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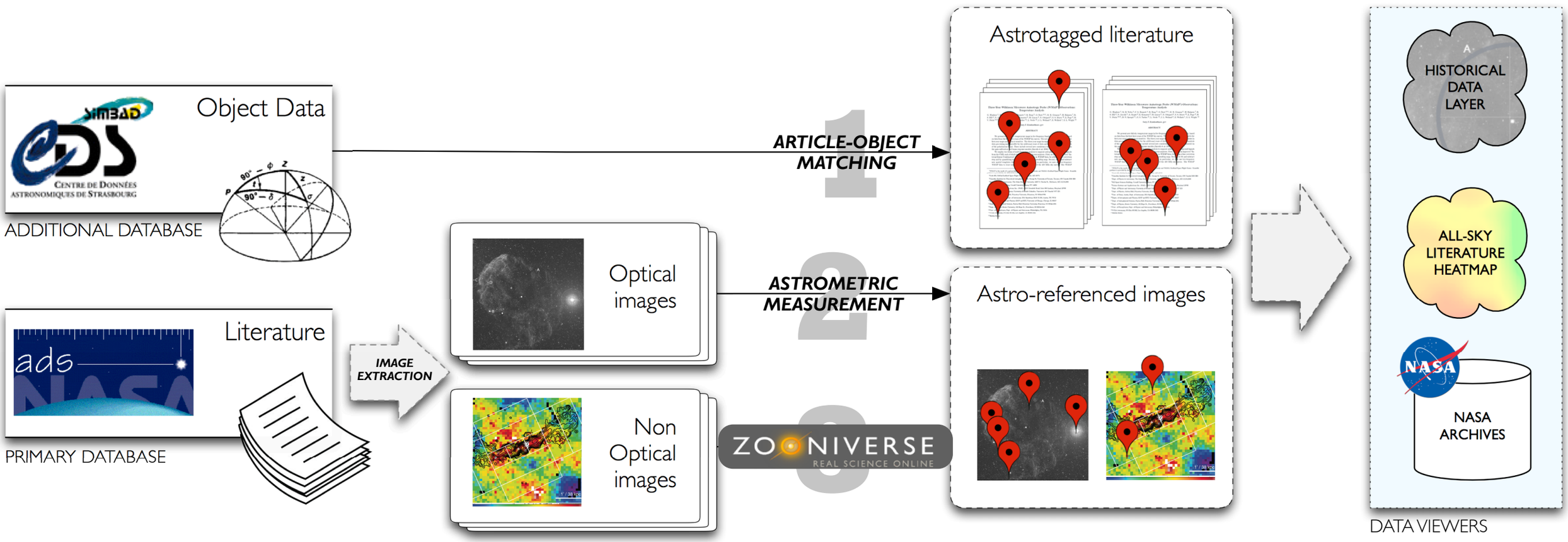
180° x 123.1°

grid north multiview match

Search

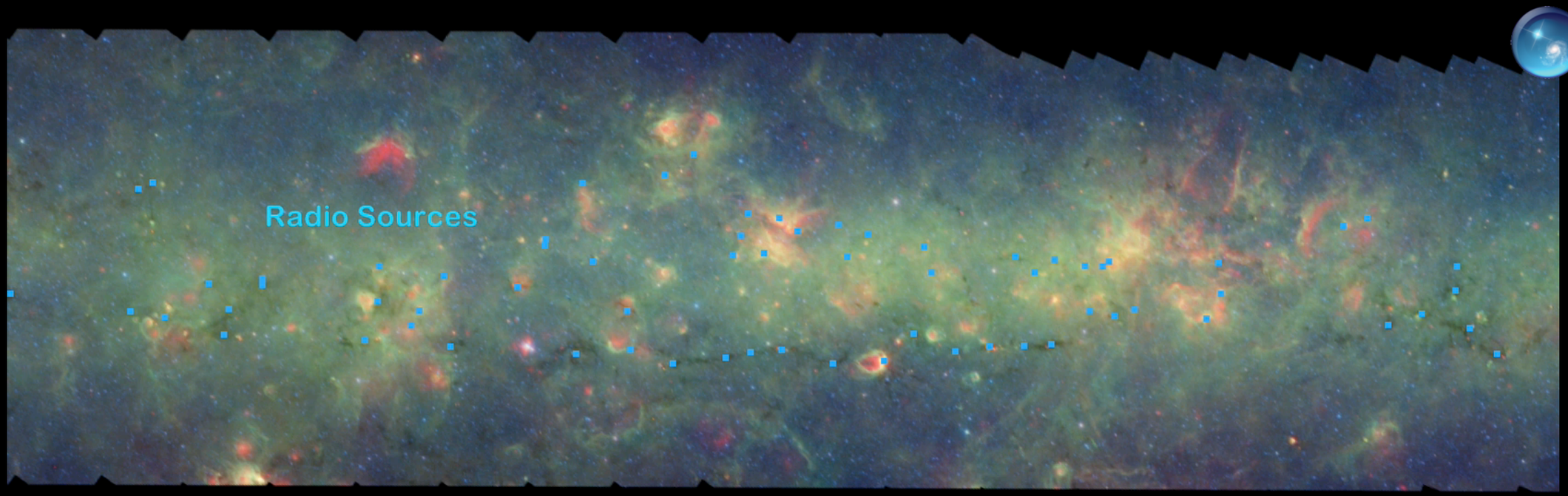
0 sel / 0 src 189Mb

Seamless Astronomy: ADS All Sky Survey



slide courtesy of Alberto Pepe

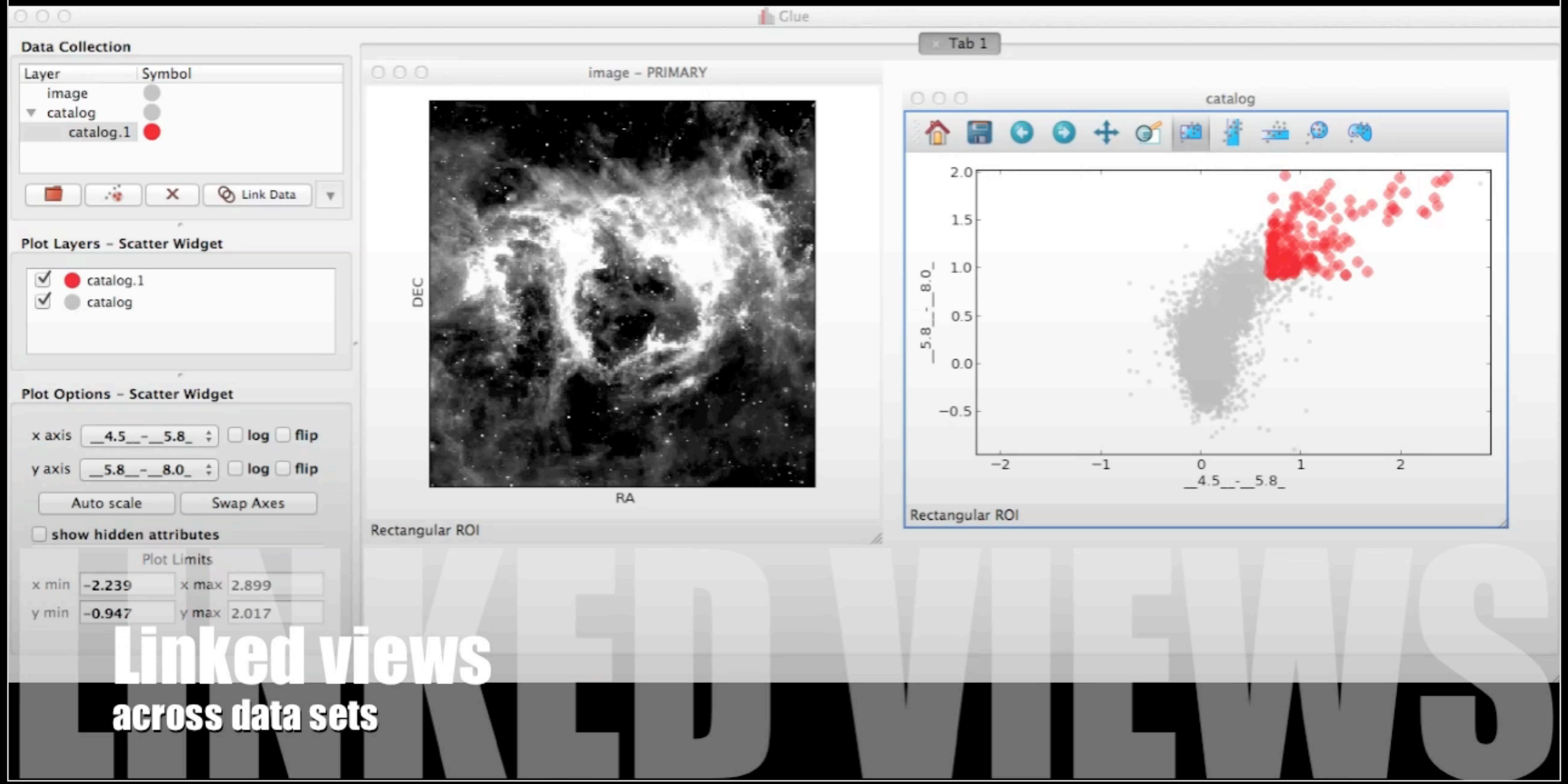
Velocity to Distance



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

glue

multidimensional data exploration



Linked views

across data sets

LINKED VIEWS