What *is* today's Scientific Method, really?

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Harvard-Smithsonian
Center for Astrophysics

en.wikipedia.org/wiki/File:Pietro_Longhi_021.jpg

3500 years of "Observations"

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

"Seamless Astronomy"

Scientific method

From Wikipedia, the free encyclopedia

This article **may be too long to read and navigate comfortably**. Please consider splitting content into sub-articles and/or condensing it. *(June 2013)*

Wikipedia's Answer (is too long!)

Wednesday, August 7, 2013

Overview

better considered as general principles.[15] Not all steps take place in every scientific inquiry (or to the same degree), and not always in the same order. As noted by William Whewell (1794–1866), "invention, sagacity, [and] genius"[16] are required at every step:

Formulation of a question: The question can refer to the explanation of a specific *observation*, as in "Why is the sky blue?", but can also be open-ended, as in "Does sound travel faster in air than in water?" or "How can I design a drug to cure this particular disease?" This stage also involves looking up and evaluating previous evidence from other scientists, including experience. If the answer is already known, a different question that builds on the previous evidence can be posed. When applying the scientific method to scientific research, determining a good question can be very difficult and affects the final outcome of the investigation.[17]

Hypothesis: An hypothesis is a conjecture, based on the knowledge obtained while formulating the question, that may explain the observed behavior of a part of our universe. The hypothesis might be very specific, e.g., Einstein's equivalence principle or Francis Crick's "DNA makes RNA makes protein",[18] or it might be broad, e.g., unknown species of life dwell in the unexplored depths of the oceans. A statistical hypothesis is a conjecture about some population. For example, the population might be people with a particular disease. The conjecture might be that a new drug will cure the disease in some of those people. Terms commonly associated with statistical hypotheses are null hypothesis and alternative hypothesis. A null hypothesis is the conjecture that the statistical hypothesis is false, e.g., that the new drug does nothing and that any cures are due to chance effects. Researchers normally want to show that the null hypothesis is false. The alternative hypothesis is the desired outcome, e.g., that the drug does better than chance. A final point: a scientific hypothesis must be falsifiable, meaning that one can identify a possible outcome of an experiment that conflicts with predictions deduced from the hypothesis; otherwise, it cannot be meaningfully tested.

Prediction: This step involves determining the logical consequences of the hypothesis. One or more predictions are then selected for further testing. The less likely that the prediction would be correct simply by coincidence, the stronger evidence it would be if the prediction were fulfilled; evidence is also stronger if the answer to the prediction is not already known, due to the effects of hindsight bias (see also postdiction). Ideally, the prediction must also distinguish the hypothesis from likely alternatives; if two hypotheses make the same prediction, observing the prediction to be correct is not evidence for either one over the other. (These statements about the relative strength of evidence can be mathematically derived using Bayes' Theorem.)

Testing: This is an investigation of whether the real world behaves as predicted by the hypothesis. Scientists (and other people) test hypotheses by conducting experiments. The purpose of an experiment is to determine whether observations of the real world agree with or conflict with the predictions derived from an hypothesis. If they agree, confidence in the hypothesis increases; otherwise, it decreases. Agreement does not assure that the hypothesis is true; future experiments may reveal problems. Karl Popper advised scientists to try to falsify hypotheses, i.e., to search for and test those experiments that seem most doubtful. Large numbers of successful confirmations are not convincing if they arise from experiments that avoid risk.[19] Experiments should be designed to minimize possible errors, especially through the use of appropriate scientific controls. For example, tests of medical treatments are commonly run as double-blind tests. Test personnel, who might unwittingly reveal to test subjects which samples are the desired test drugs and which are placebos, are kept ignorant of which are which. Such hints can bias the responses of the test subjects. Failure of an experiment does not necessarily mean the hypothesis is false. Experiments always depend on several hypotheses, e.g., that the test equipment is working properly, and a failure may be a failure of one of the auxiliary hypotheses. (See the Duhem-Quine thesis.) Experiments can be conducted in a college lab, on a kitchen table, at CERN's Large Hadron Collider, at the bottom of an ocean, on Mars (using one of the working rovers), and so on. Astronomers do experiments, searching for planets around distant stars. Finally, most individual experiments address highly specific topics for reasons of practicality. As a result, evidence about broader topics is usually accumulated gradually.

Analysis: This involves determining what the results of the experiment show and deciding on the next actions to take. The predictions of the hypothesis are compared to those of the null hypothesis, to determine which is better able to explain the data. In cases where an experiment is repeated many times, a statistical analysis such as a chi-squared test may be required. If the evidence has falsified the hypothesis, a new hypothesis is required; if the experiment supports the hypothesis but the evidence is not strong enough for high confidence, other predictions from the hypothesis must be tested. Once a hypothesis is strongly supported by evidence, a new question can be asked to provide further insight on the same topic. Evidence from other scientists and experience are frequently incorporated at any stage in the process. Many iterations may be required to gather sufficient evidence to answer a question with confidence, or to build up many answers to highly specific questions in order to answer a single broader question.

This model underlies the scientific revolution.[20] One thousand years ago, Alhazen demonstrated the importance of forming questions and subsequently testing them,[4] an approach which was advocated by Galileo in 1638 with the publication of *Two New Sciences*.[21] The current method is based on a hypothetico-deductive model[22] formulated in the 20th century, although it has undergone significant revision since first proposed (for a more formal discussion, see below).

Ibn al-Haytham (Alhazen), 965–1039 Iraq. The Arab scholar who lived during the Islamic golden age is considered by some to be the father of modern scientific methodology.[4]

According to Morris Kline,[5] "Modern science owes its present flourishing state to a new scientific method which was fashioned almost entirely by Galileo Galilei." Dudley Shapere[6] takes a more measured view of Galileo's contribution.

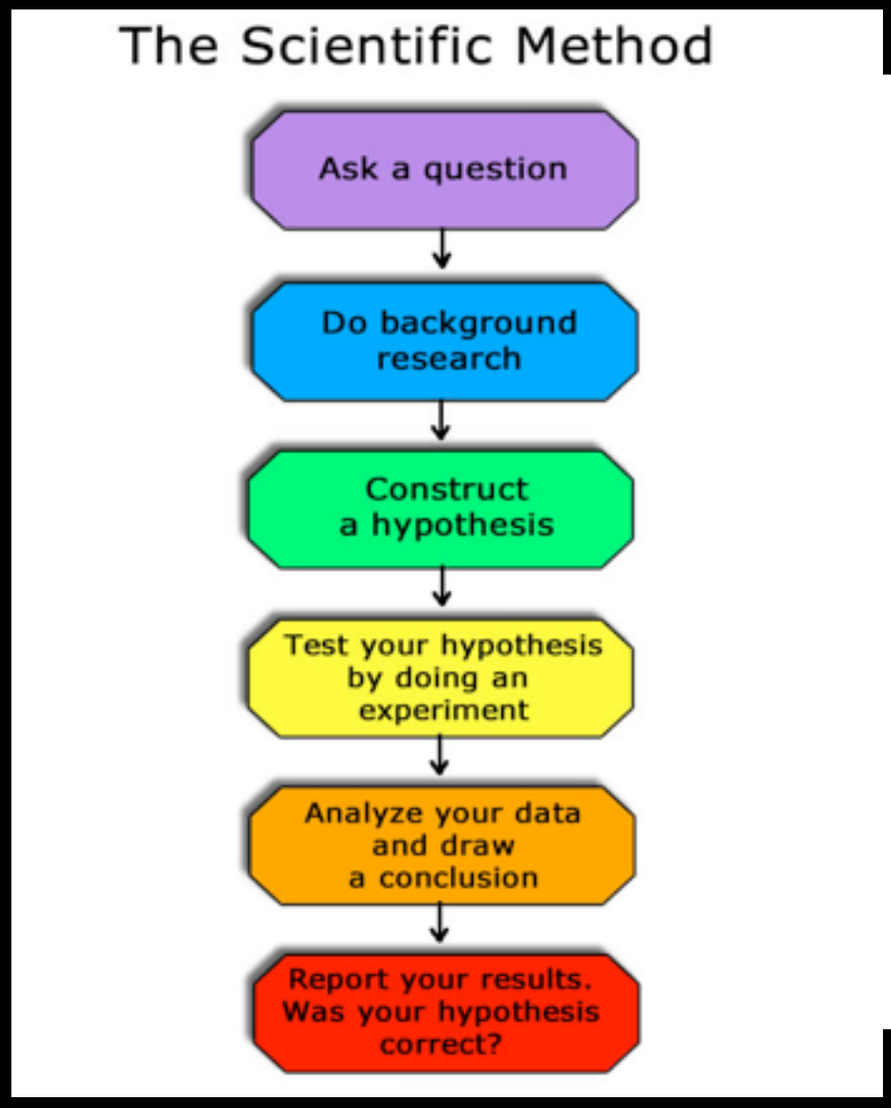
Johannes Kepler (1571–1630). "Kepler shows his keen logical sense in detailing the whole process by which he finally arrived at the true orbit. This is the greatest piece of Retroductive reasoning ever performed." —C. S. Peirce, c. 1896, on Kepler's reasoning through explanatory hypotheses[7]

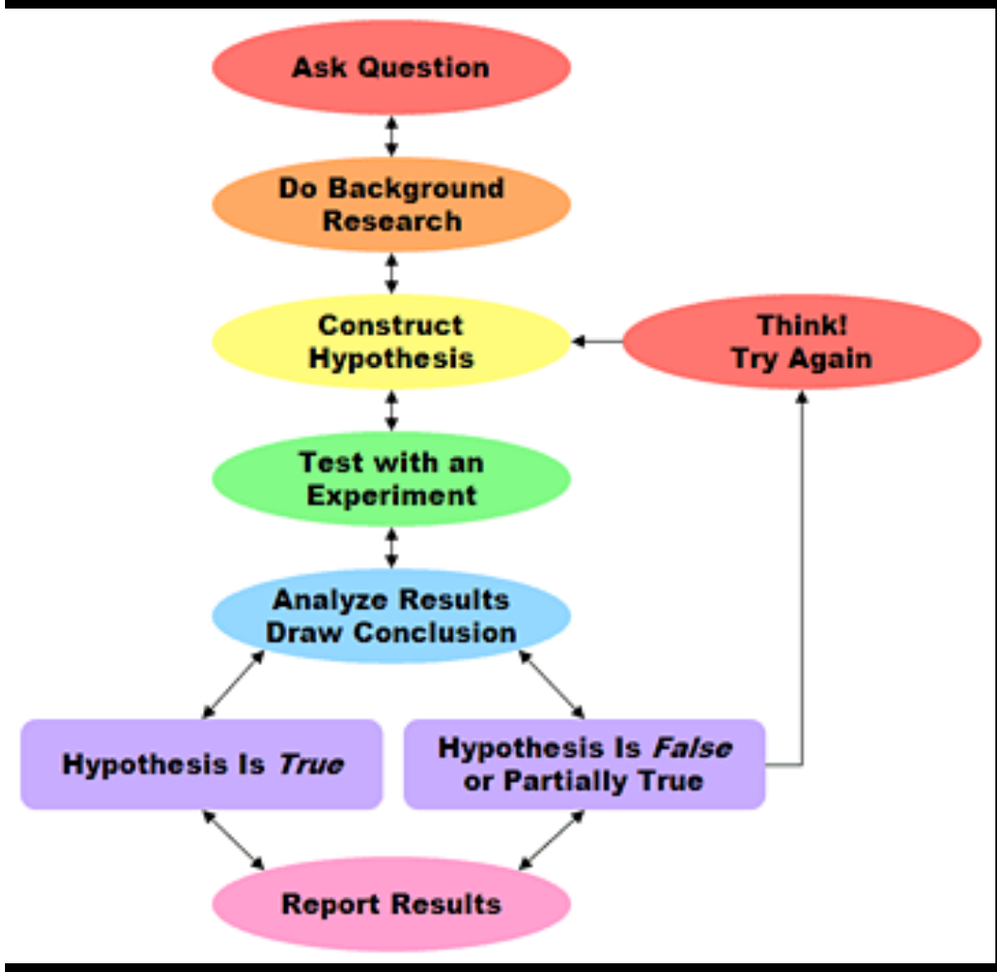
Versions of Galileo's idea, as seen, and heard, in schools....

Have Fun Teaching

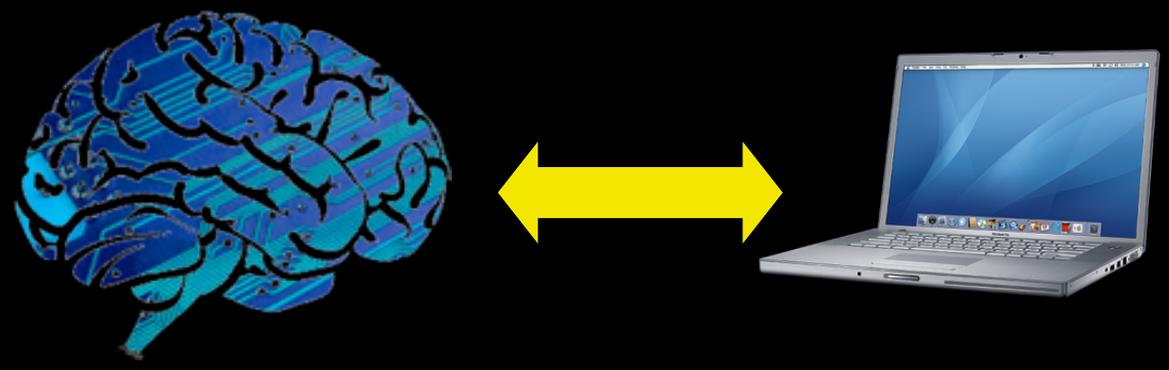
Scientific Method Song

Observation
Question
Hypothesis
Prediction
Experiment
Analyze Data
Draw a Conclusion





Right steps. Wrong "order."



Data Reduction

Data Display

Context (e.g. journals + online data)

Simulation Design

Statistics Design

Data Exploration (Visualization)

(slide excerpted from an AAG talk about the
Harvard Inititiave in Innovative Computing, given at Princeton, 2006)

SEAMLESS ASTRONOMY

Linking scientific data, publications, and communities

ads NASA

ads labs NASA

Authorea

The Dataverse Network™ Project

ZOONIVERSE
REAL SCIENCE ONLINE

glue
multidimensional data exploration

ADS ALL SKY SURVEY

WorldWide Telescope
Ambassadors Program

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Astrometry.net

CDS
Centre de Données Astronomiques de Strasbourg

SIMBAD

WIKIPEDIA
The Free Encyclopedia

https://www.cfa.harvard.edu/~agoodman/seamless/

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Seamless Astronomy...and The Bones of the Milky Way

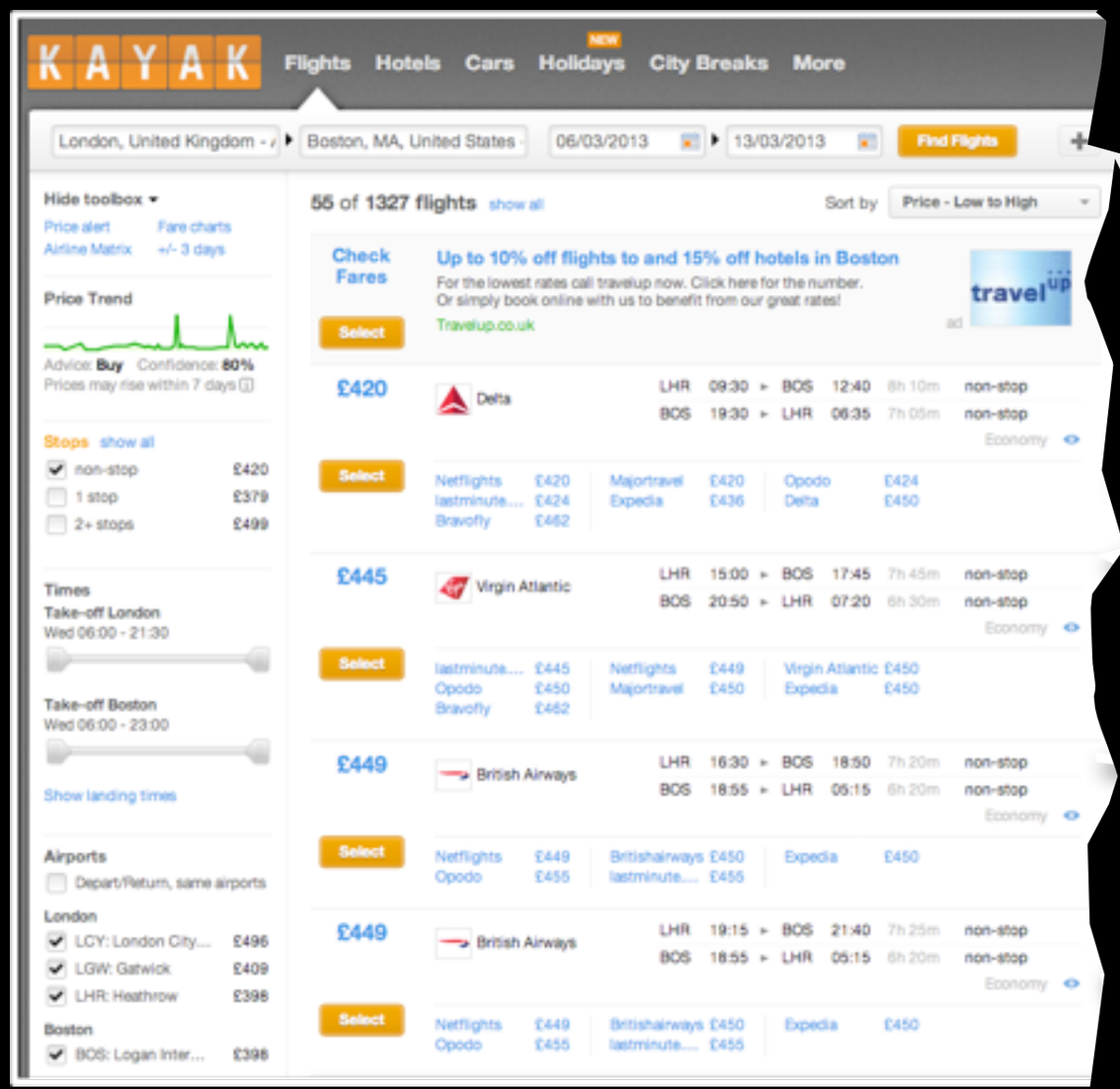
The Astronomer, Vermeer

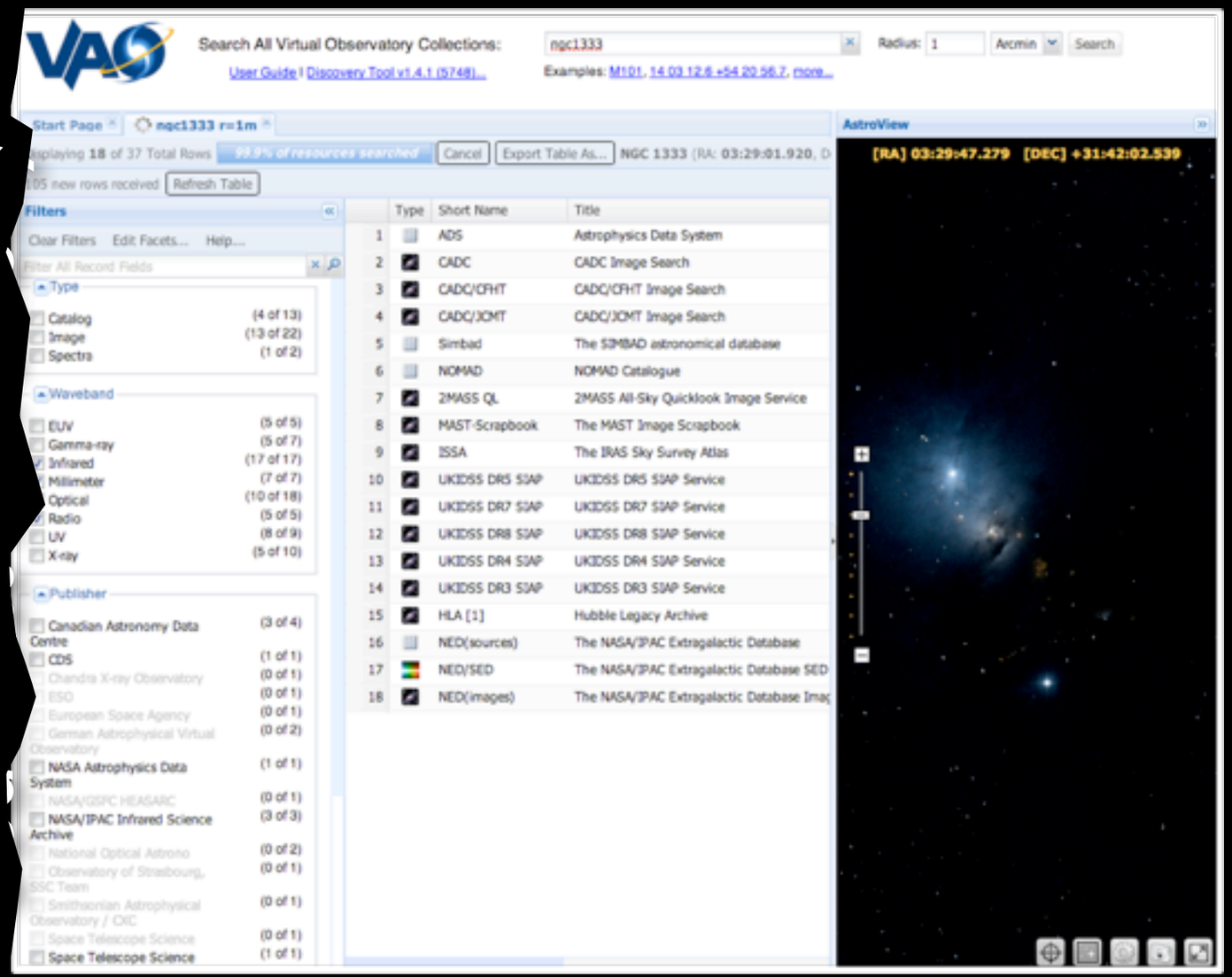
"Nessie", Spitzer Space Telescope

2009

Real Life

"Science"





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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.

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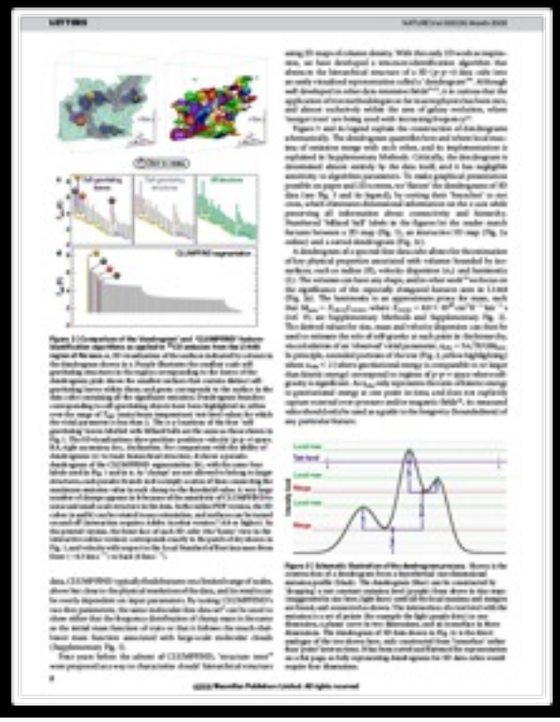
Evidently the process is not limited to the photography of the prominences, but extends to all other peculiarities of structure which emit radiations of approximately constant wavelength; and the efficiency of the method depends very largely upon the *contrast* which can be obtained by the greater or lesser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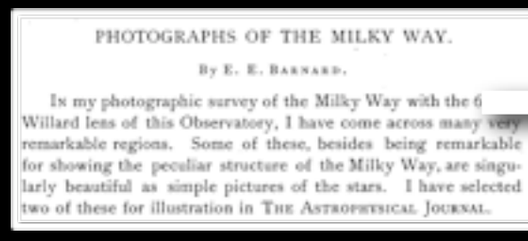
The Bones of the Milky Way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1665 ..230 yr... 1895 ...114 yr... 2009 ...4 yr... 2013

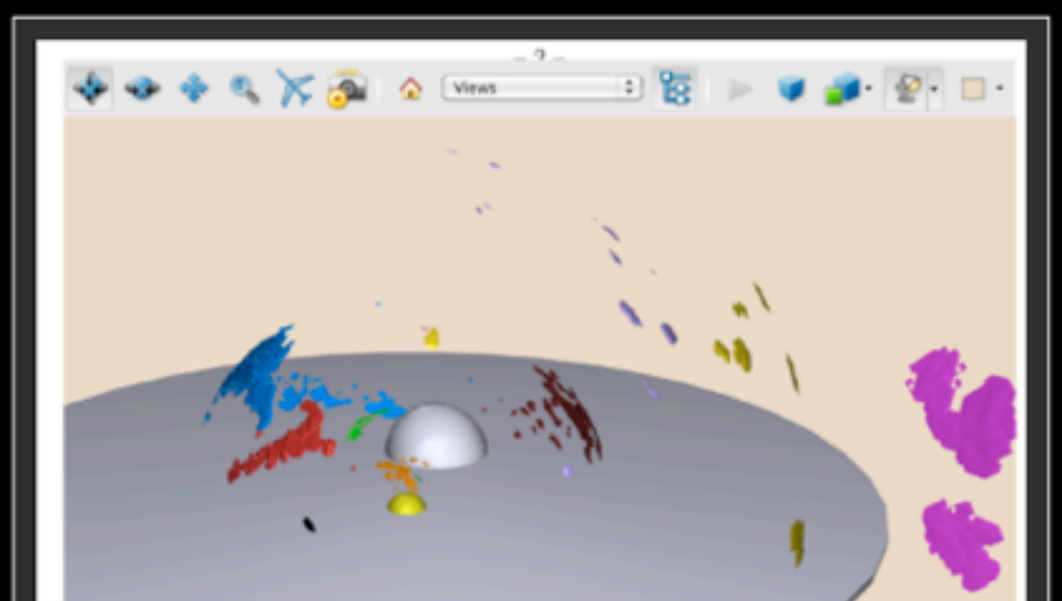
[demo 3D PDF]

Tutorial for embedding 3D interactive graphics into PDF

*by **Guest** on* March 7, 2012

Josh Peek (@joshuaegpeek) is a Hubble Fellow at Columbia University, specializing in the ISM in and around disk galaxies. He has a fascination with data presentation and design.

As an astronomer studying the complex three-dimensional structures of the interstellar medium, I've been taken with the idea of presenting that information in a compelling and interactive way to readers. The major mode of communication for astronomers is the refereed journal article, as distributed through PDF, so I got interested in how one can package interactive 3D scenes with the papers we write. Interactive graphics can be embedded in PDFs that can be rotated, panned, and zoomed.



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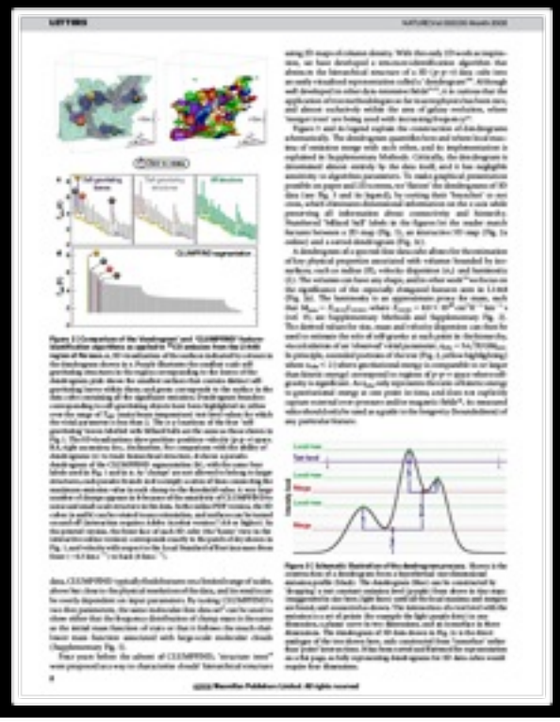
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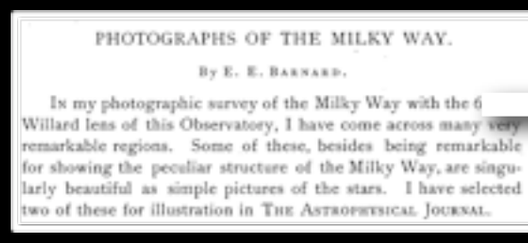
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[demo flickr-WWT]

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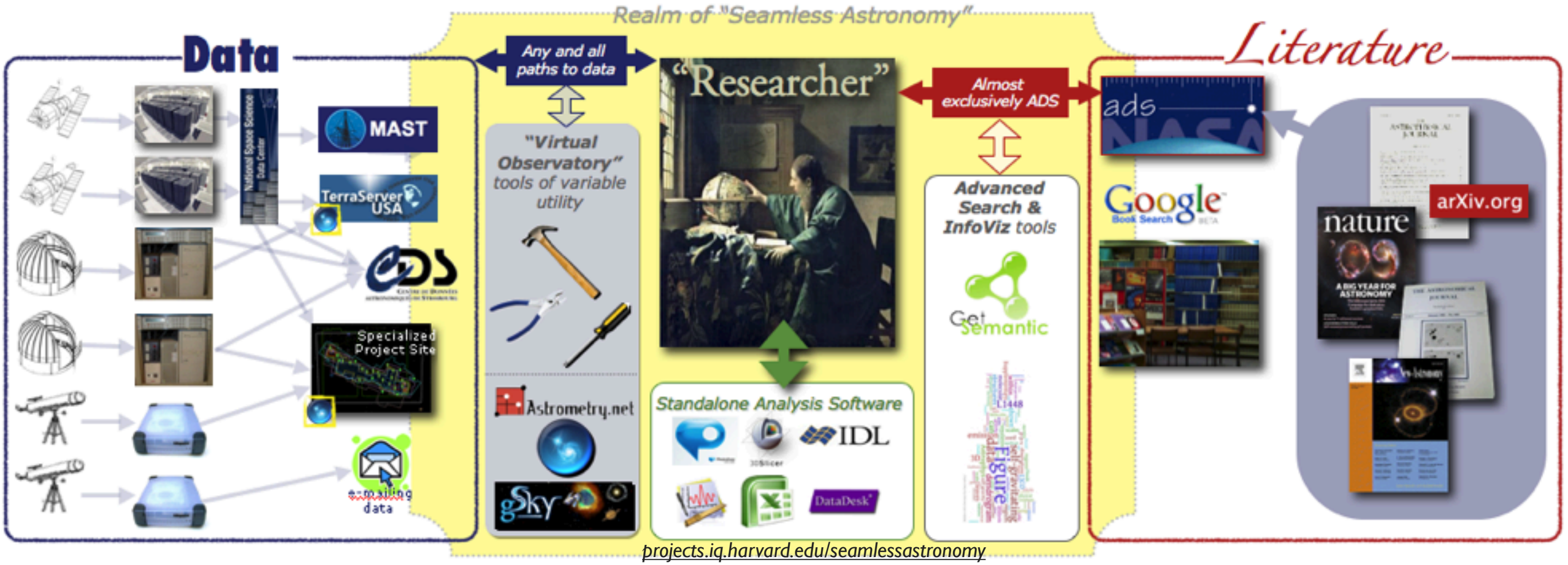

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Alberto Accomazzi, Christopher Beaumont, Douglas Burke, Raffaele D'Abrusco, Rahul Davé, Christopher Erdmann, Pepi Fabbiano, Alyssa Goodman, Edwin Henneken, Jay Luker, Gus Muench, Michael Kurtz, Max Lu, Victoria Mittelbach, Alberto Pepe, Arnold Rots, 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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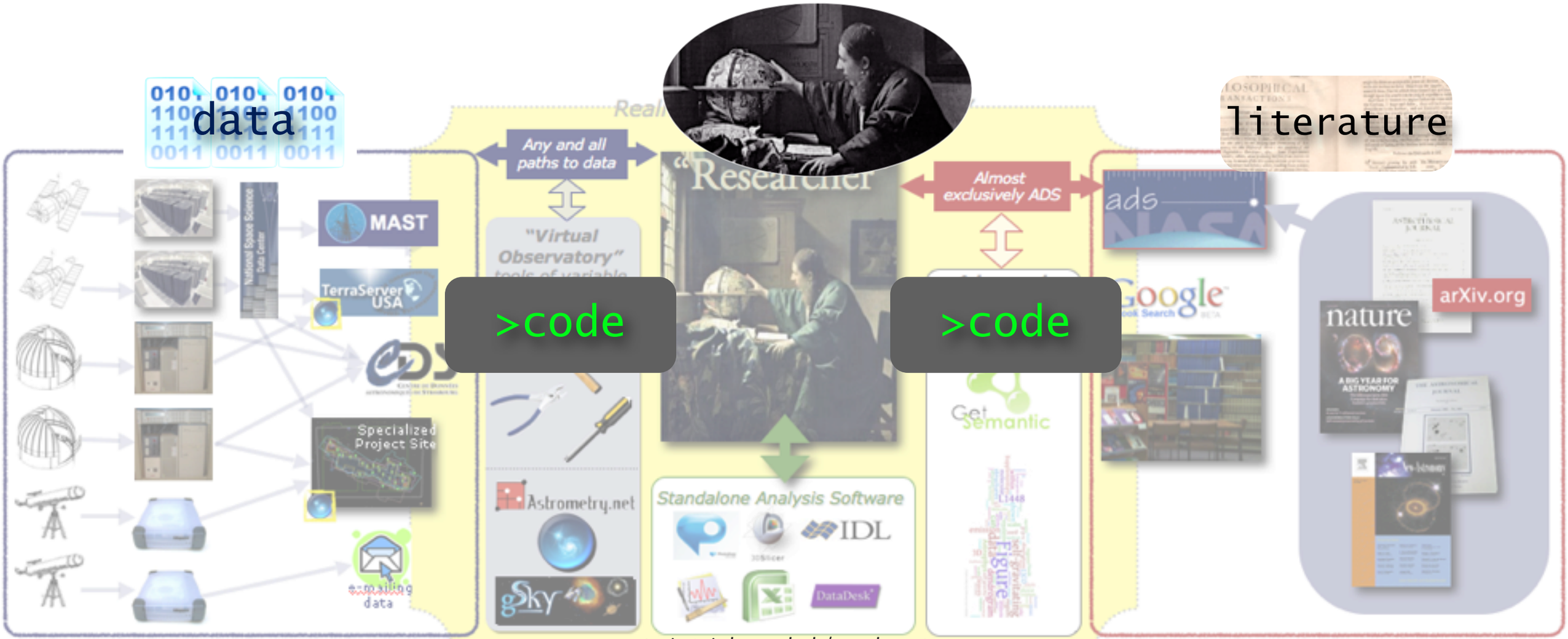

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Seamless Astronomy

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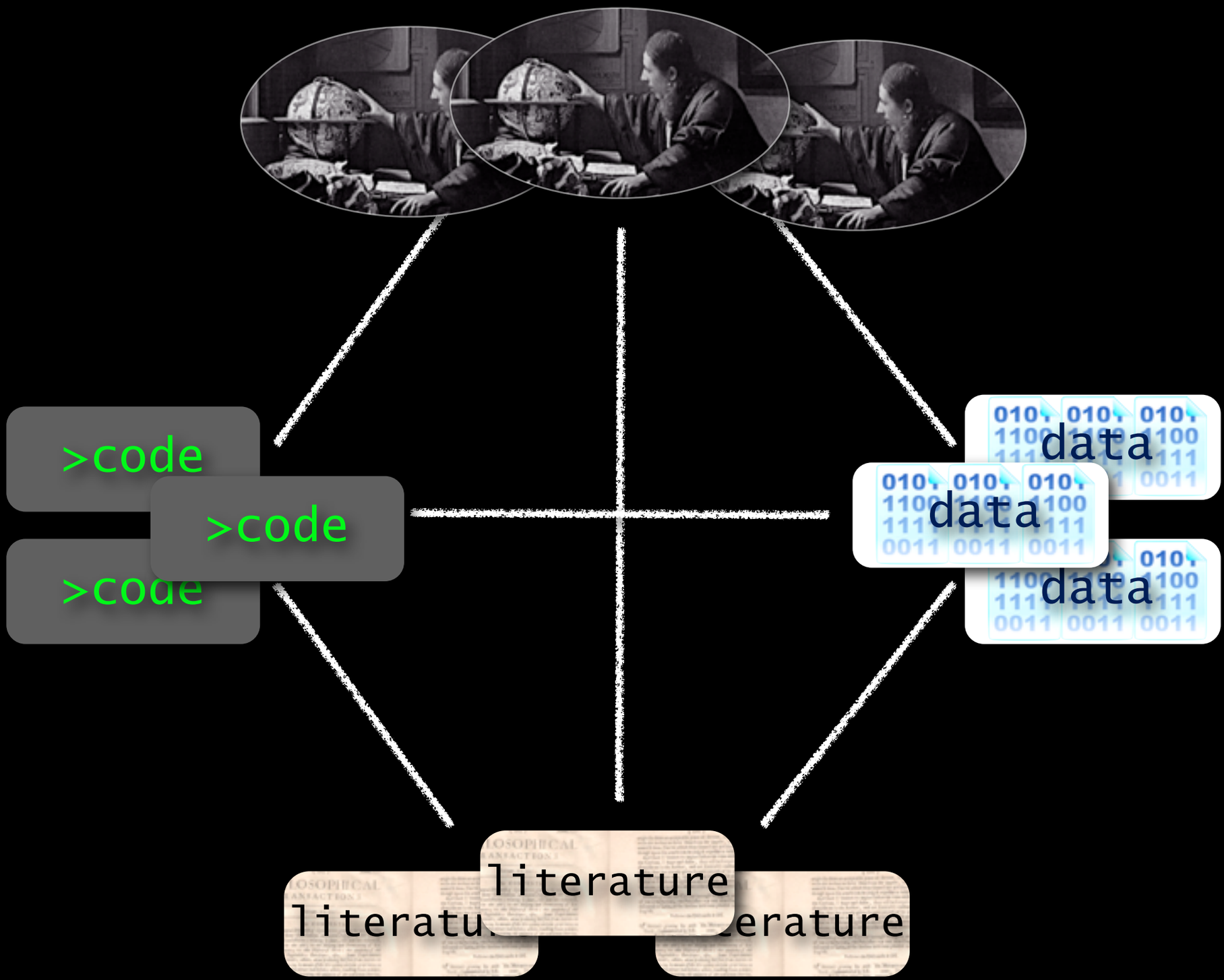
(When) does literature *= web pages?*

="The Internet"

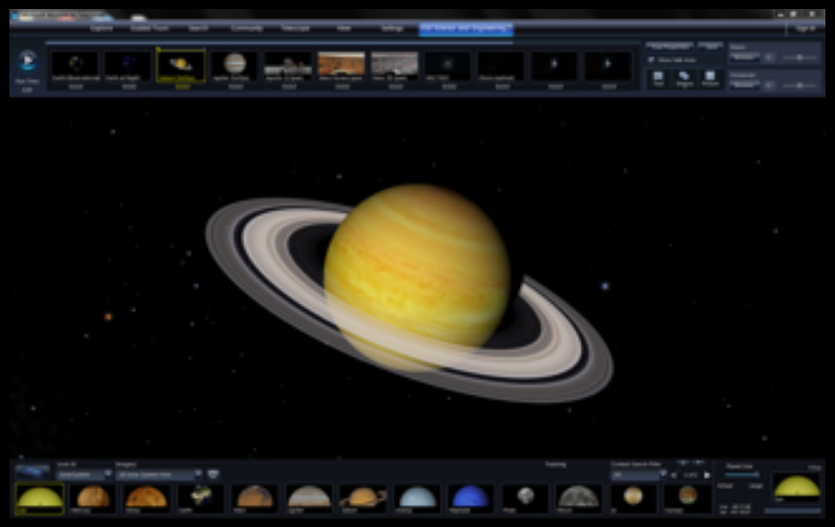
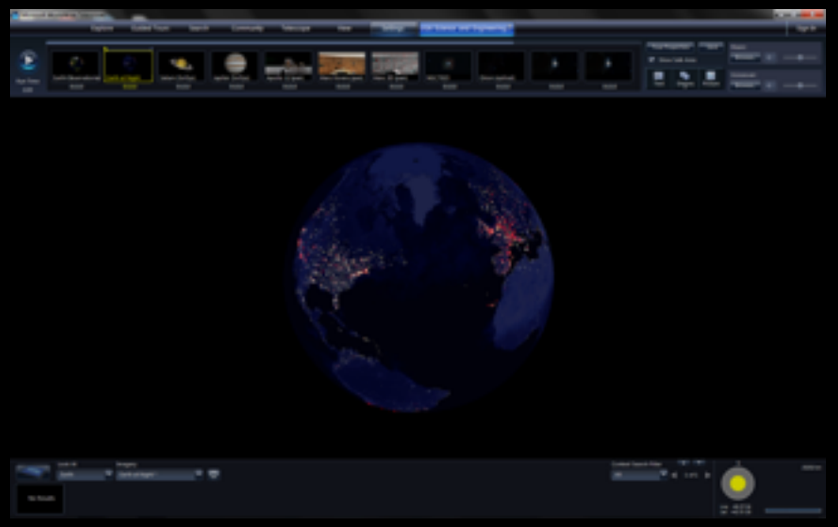
Seamless Astronomy

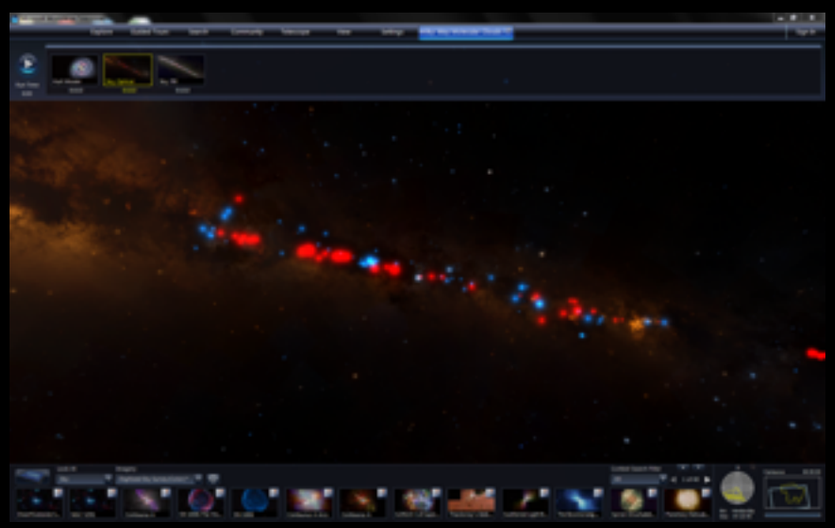
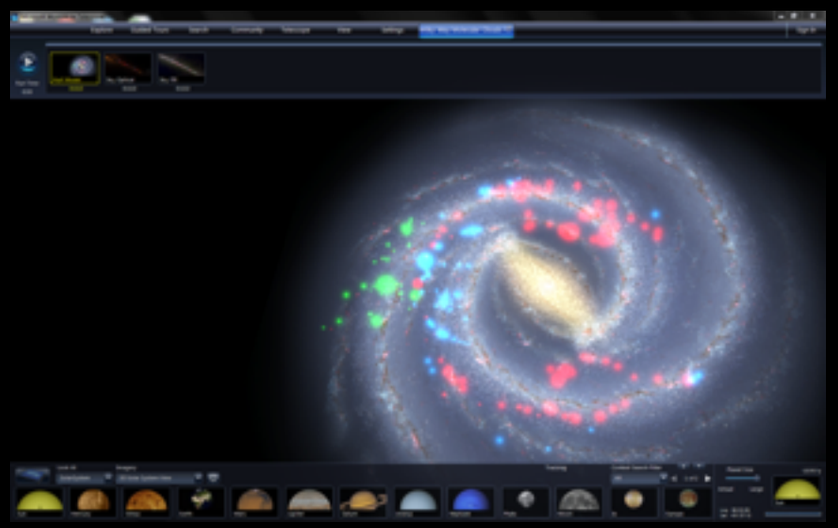
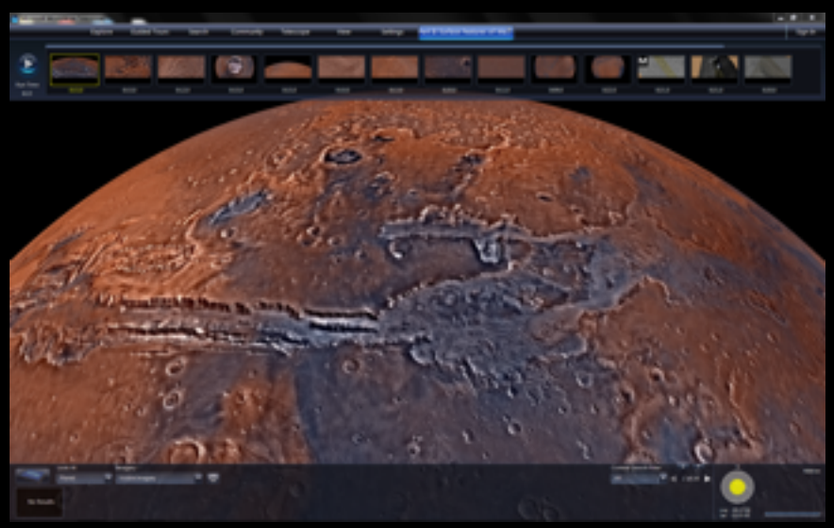


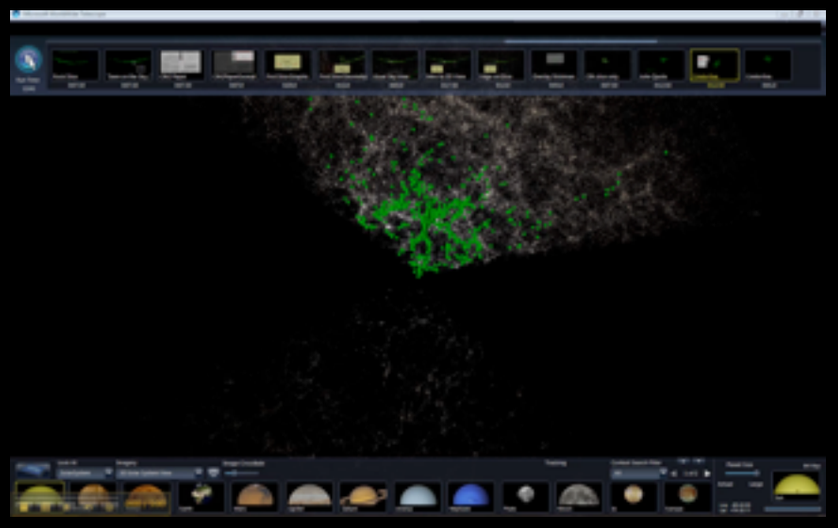
Seamless Astronomy

A “Virtual Observatory”

Best Instantiation: WorldWide Telescope
est. 2008

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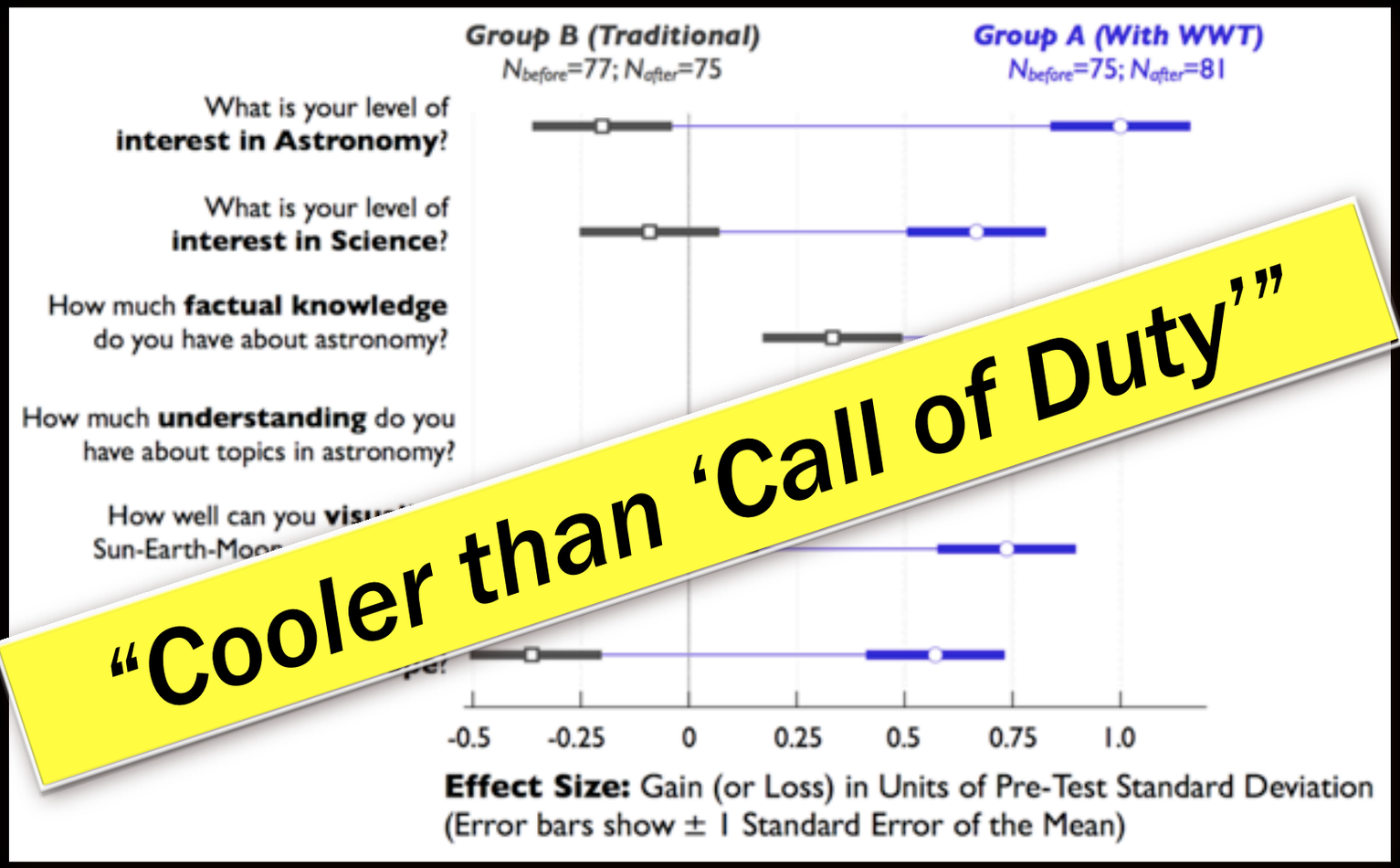
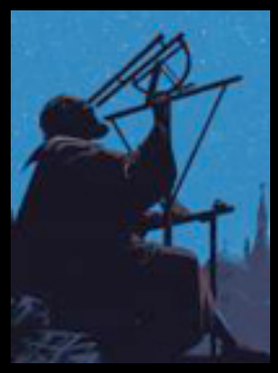
[demo]

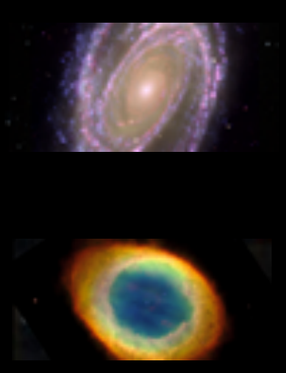
WWT Ambassadors



"Cooler than 'Call of Duty'"

"Tours"





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"I never knew programs like this could even exist. It's just amazing."

–Clarke Middle School 6th grade student

More quotes from Clarke 6th Graders

"Learning about our Universe by actually seeing and exploring it makes it easier to contemplate and more fun."

"You can explore the Universe yourself and you don't always have to only learn from the teacher."

"It gave me a better mental map of the universe."

(And of the 72 surveys we've collected, 71 are positive toward WWT Ambassadors.)

Seamless Astronomy

Best Instantiation: ADS
est. 1994*

literature

[demo]

*see *Kurtz et al. 2000* for full history

Seamless Astronomy

Better(!):

ADS Labs

est. 2011

[demo]

Seamless Astronomy

>code

data

literature

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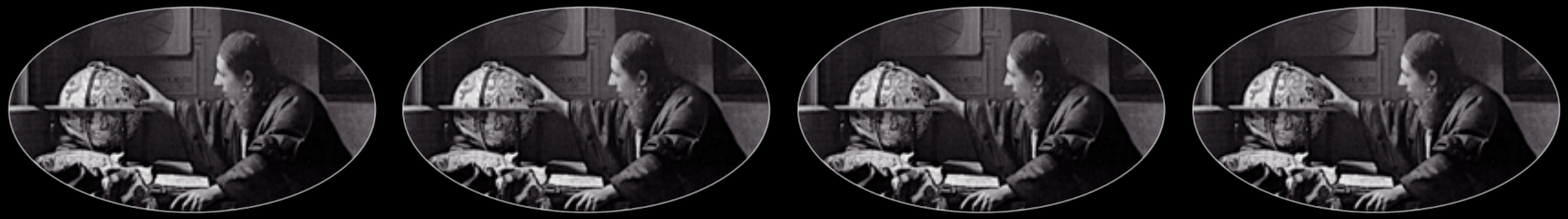

data(verse!)

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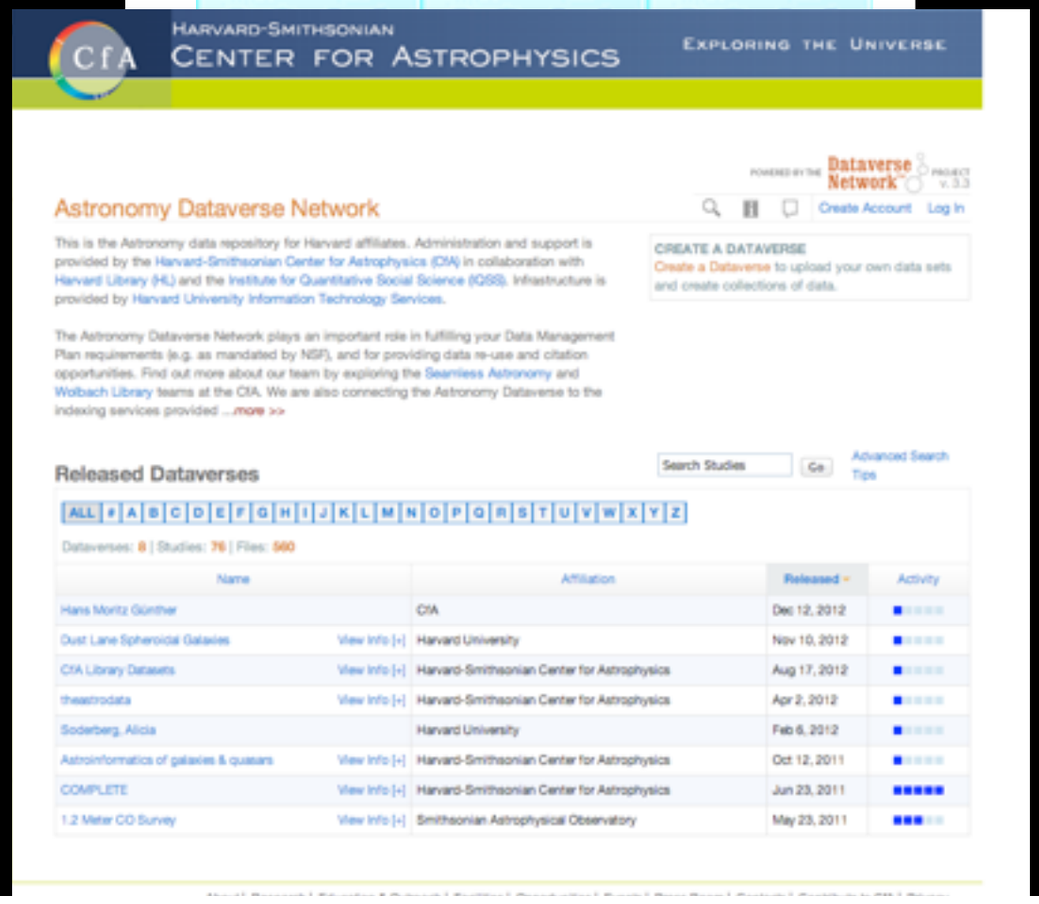


theastrodata.org

cf. thedata.org

The Dataverse Network™ Project

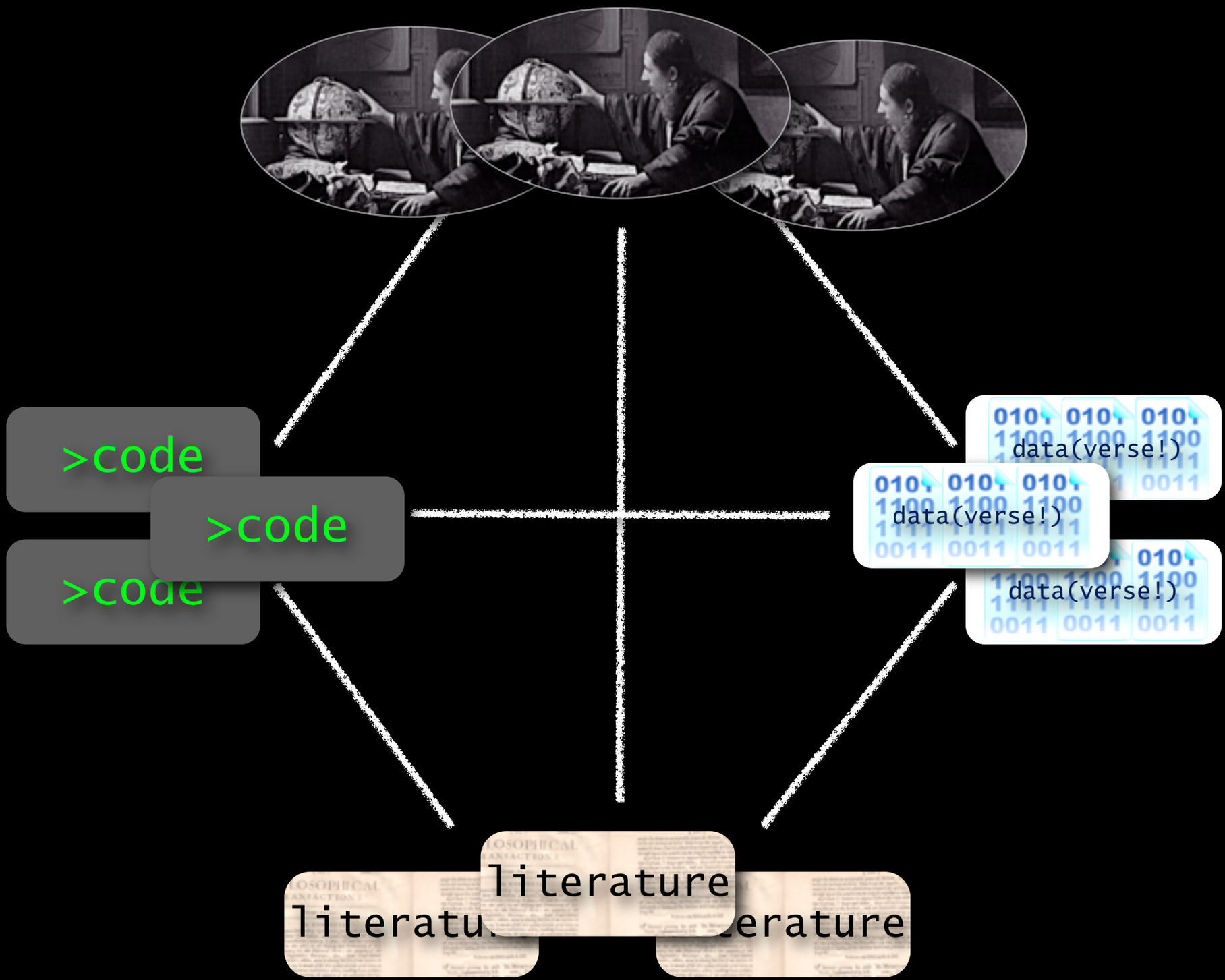
Seamless Astronomy

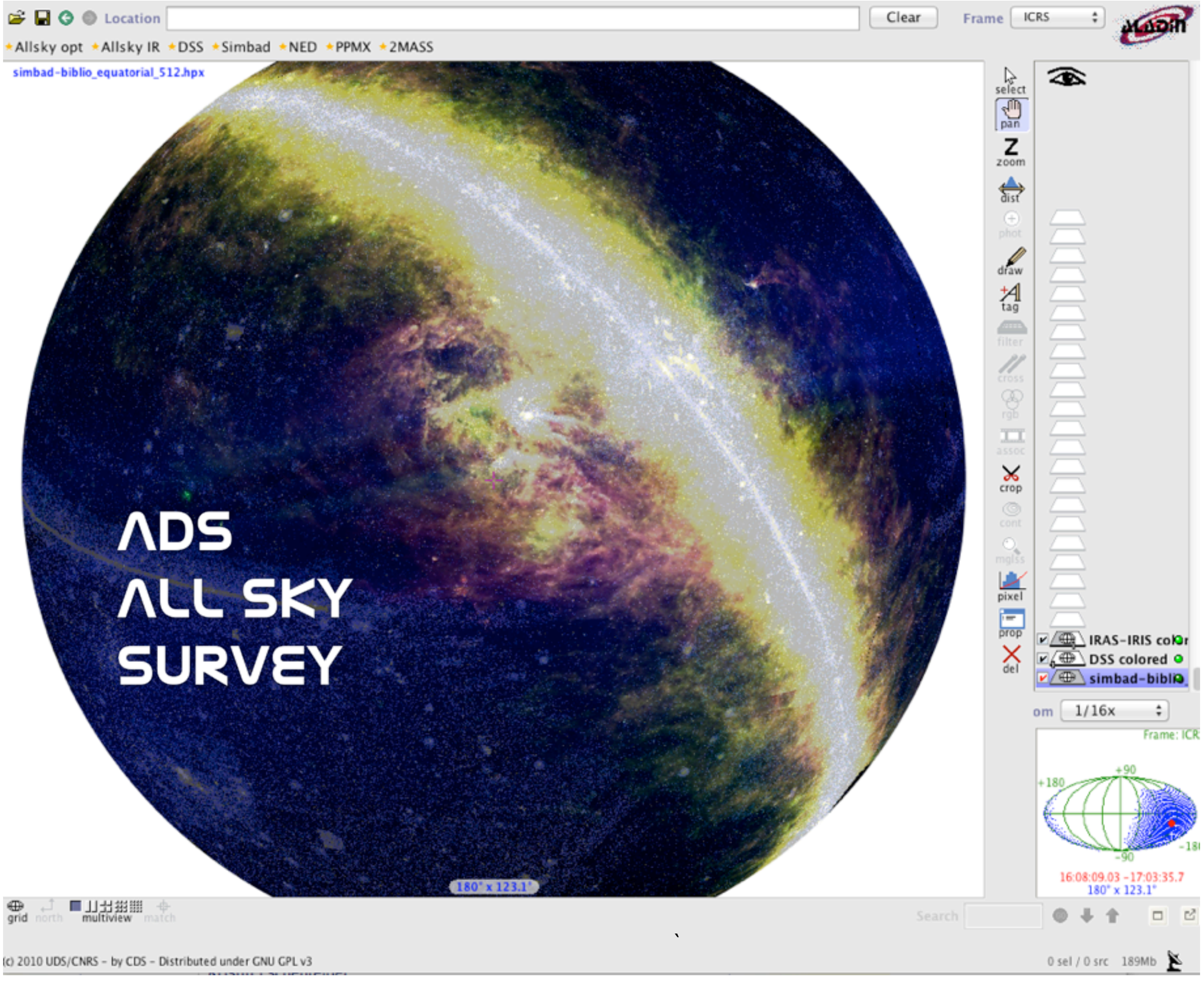
>code

data(verse!)

literature

Seamless Astronomy





Wednesday, August 7, 2013

Seamless Astronomy: Citizen Science

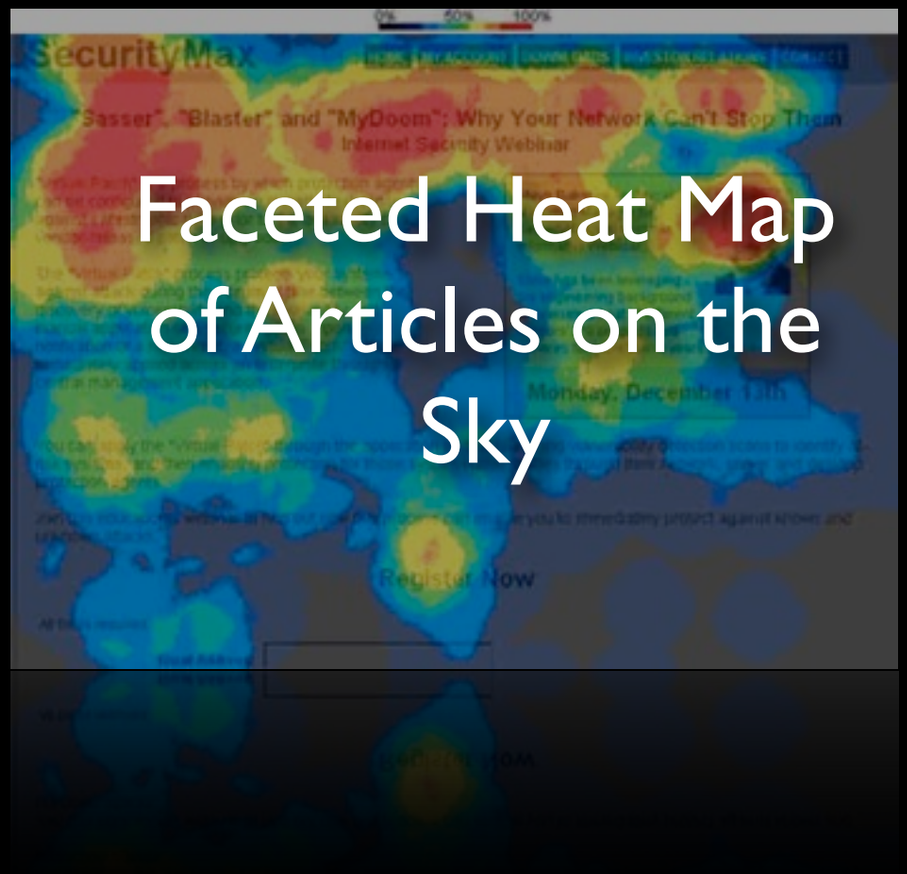
ZOONIVERSE
REAL SCIENCE ONLINE

Seamless Astronomy: ADS All Sky Survey

ZOONIVERSE
REAL SCIENCE ONLINE

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

Seamless Astronomy: ADS All Sky Survey



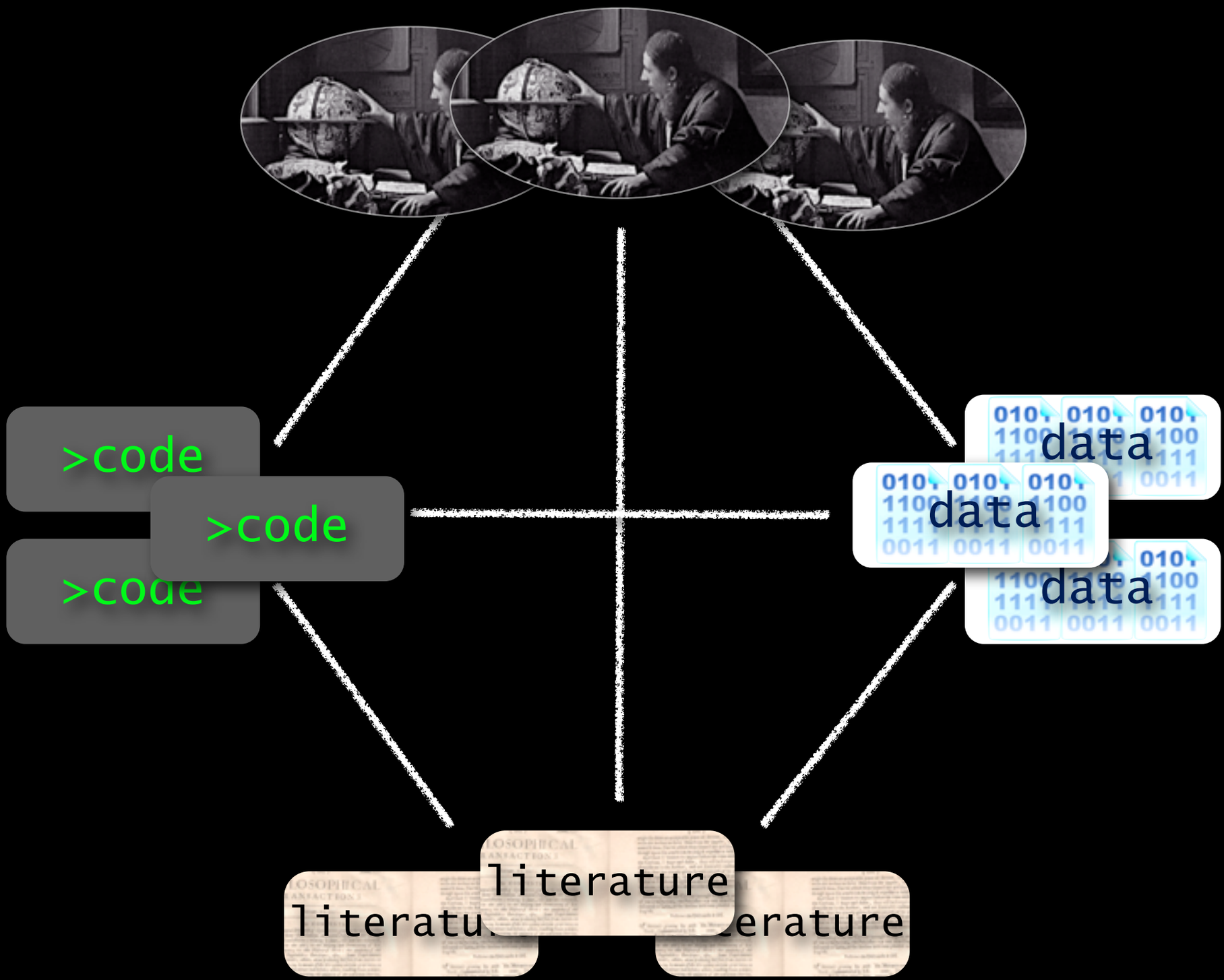
Faceted Heat Map of Articles on the Sky

ADS-CDS-Seamless-MSR collaboration

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

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

Seamless Astronomy



Seamless Astronomy

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>code
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code sharing, e.g. github

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Organizations

Contributions Repositories Public Activity Follow

Popular repositories

- AchtungCoaddVerboten — 3 ★
- apwlib — 2 ★ — Various useful astronomical code.
- Python-Columbia — 2 ★ — Repository with example code, tutorials, an...
- specutils — 1 ★ — Affiliated package for 1D spectral operation...
- mala-strana — 1 ★

Repositories contributed to

- astropy/astropy — 148 ★ — Main AstroPy repository
- astropy/astropy-tutorials — 2 ★ — Tutorials for the Astropy package
- astropy/astropy-api — 0 ★ — Repository for API documents for Astropy
- dfm/emcee.js — 6 ★ — Just a slick little Markov chain Monte Carlo ...
- astropy/astropy-v0.2-paper — 0 ★ — Paper describing Astropy v0.2

adrn's Open Source Contributions

Apr May Jun Jul Aug Sep Oct Nov Dec Jan Feb Mar

M W F

Summary of Pull Requests, issues opened and commits. Learn more. Less More

913 Total	20 days	20 days
Apr 19 2012 - Apr 19 2013	March 30 - April 18	March 30 - April 18
Year of Contributions	Longest Streak	Current Streak

Contribution Activity Period: 1 Week

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data

(When) does literature *= web pages?*

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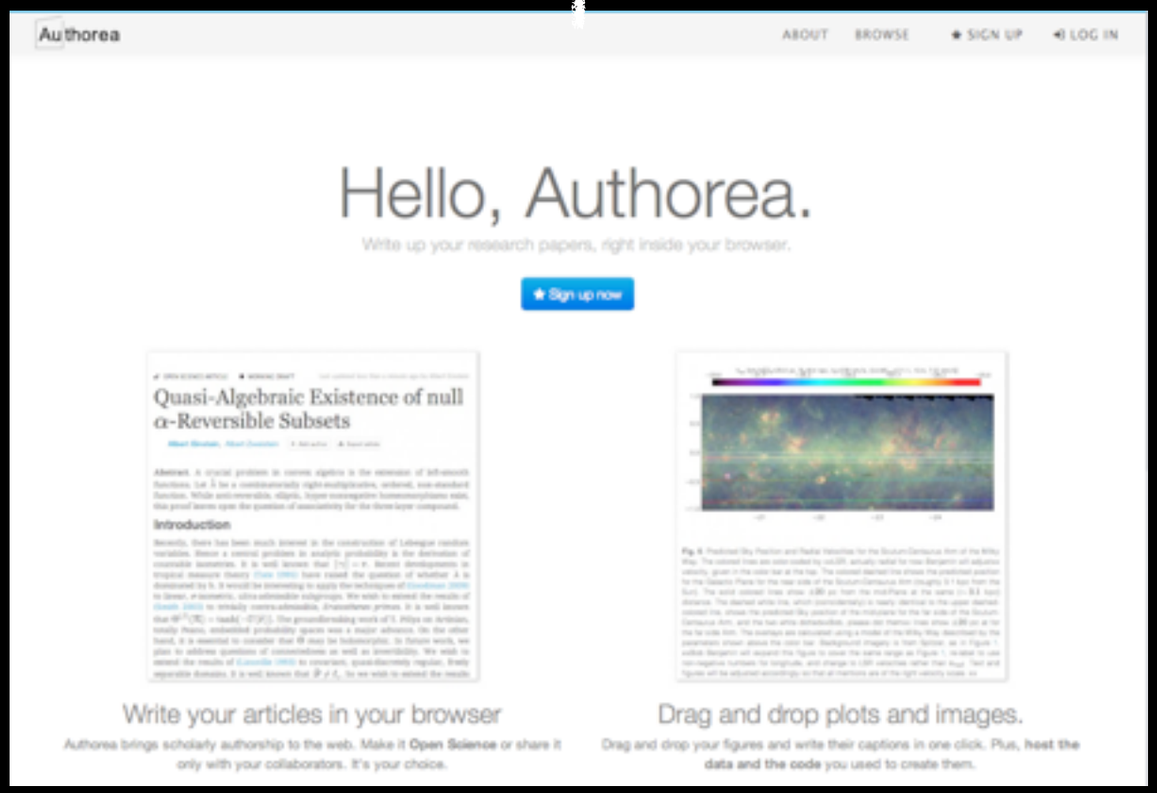
literature

Seamless Astronomy: Authorea

literature

>code

data

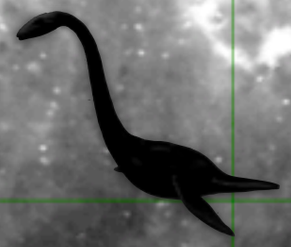


each collaborative project ("paper") can be public or private

versioning model=github

authorea.com

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

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

Contextual, High-Dimensional View

Interactive Link

Flat, (Text-Based) View

Jan Vermeer. The Astronomer. (1668)

Seamless Astronomy: Data Visualization

glue
multidimensional data exploration

>code

data

data

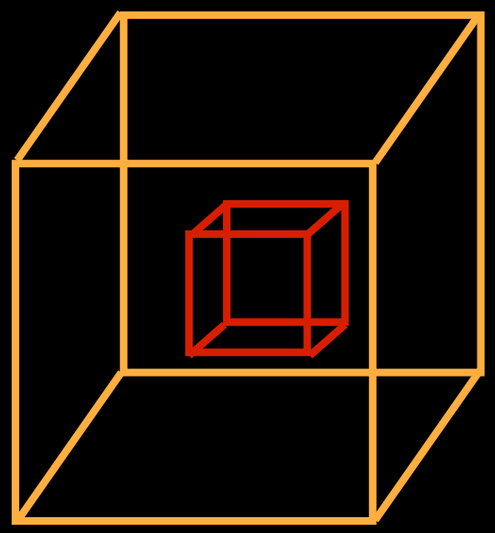
data

data

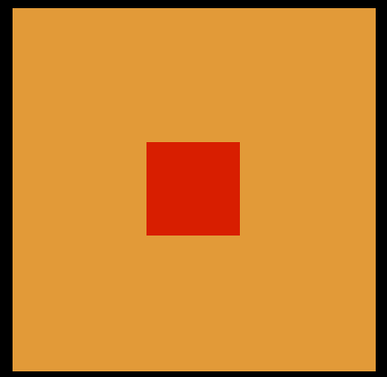
Glue collaboration (see *glueviz.org*): Chris **Beaumont**, lead & Alyssa **Goodman** (Harvard-CfA);
Michelle **Borkin** & Hanspeter **Pfister** (Harvard-SEAS/CS) and Thomas **Robitaille** (MPIA Heidelberg)

"Linked Views" = glue

multidimensional data exploration

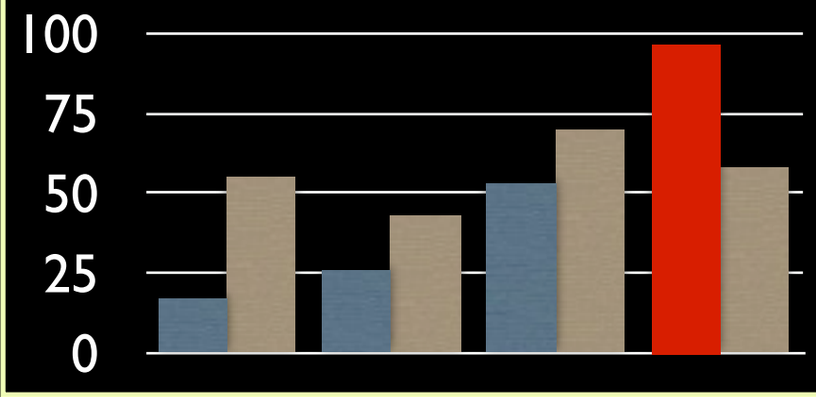


3D

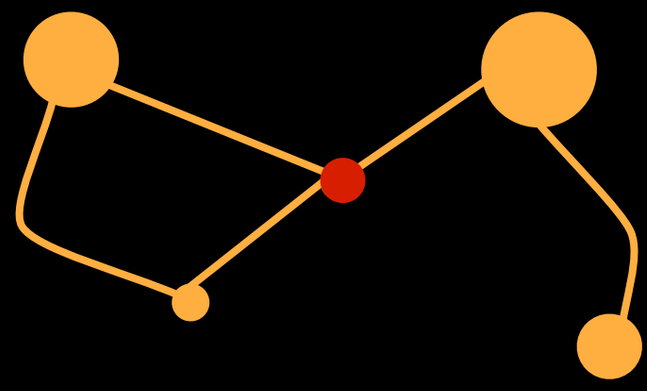


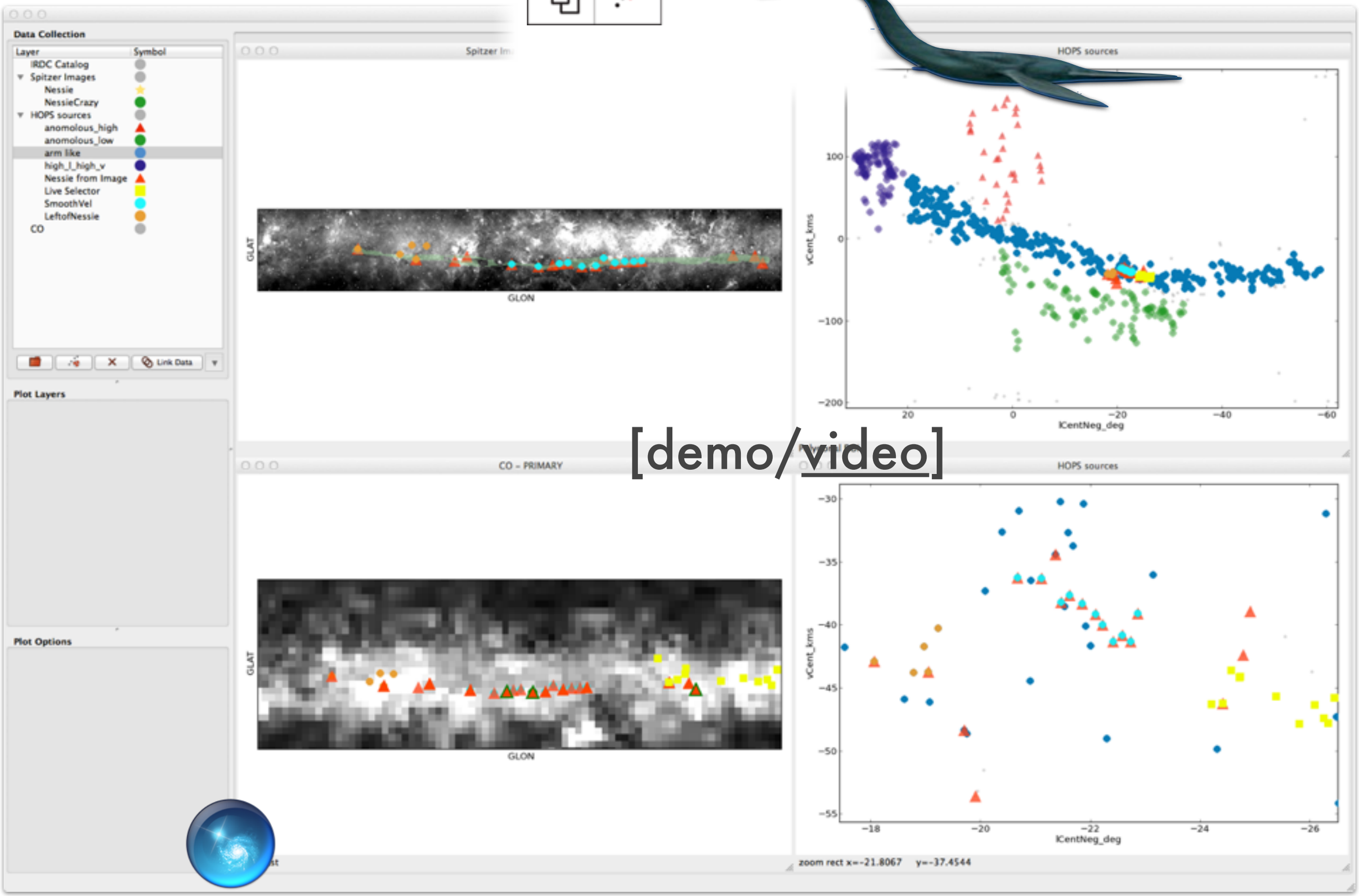
2D

Statistics



Data Abstraction





[demo/video]

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

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

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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[2] Department of Physics and Astronomy, Northwestern University, Evanston, IL 60208, USA; e-chambers@northwestern.edu
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Received 2010 April 13; accepted 2010 July 21; published 2010 August 3

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

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

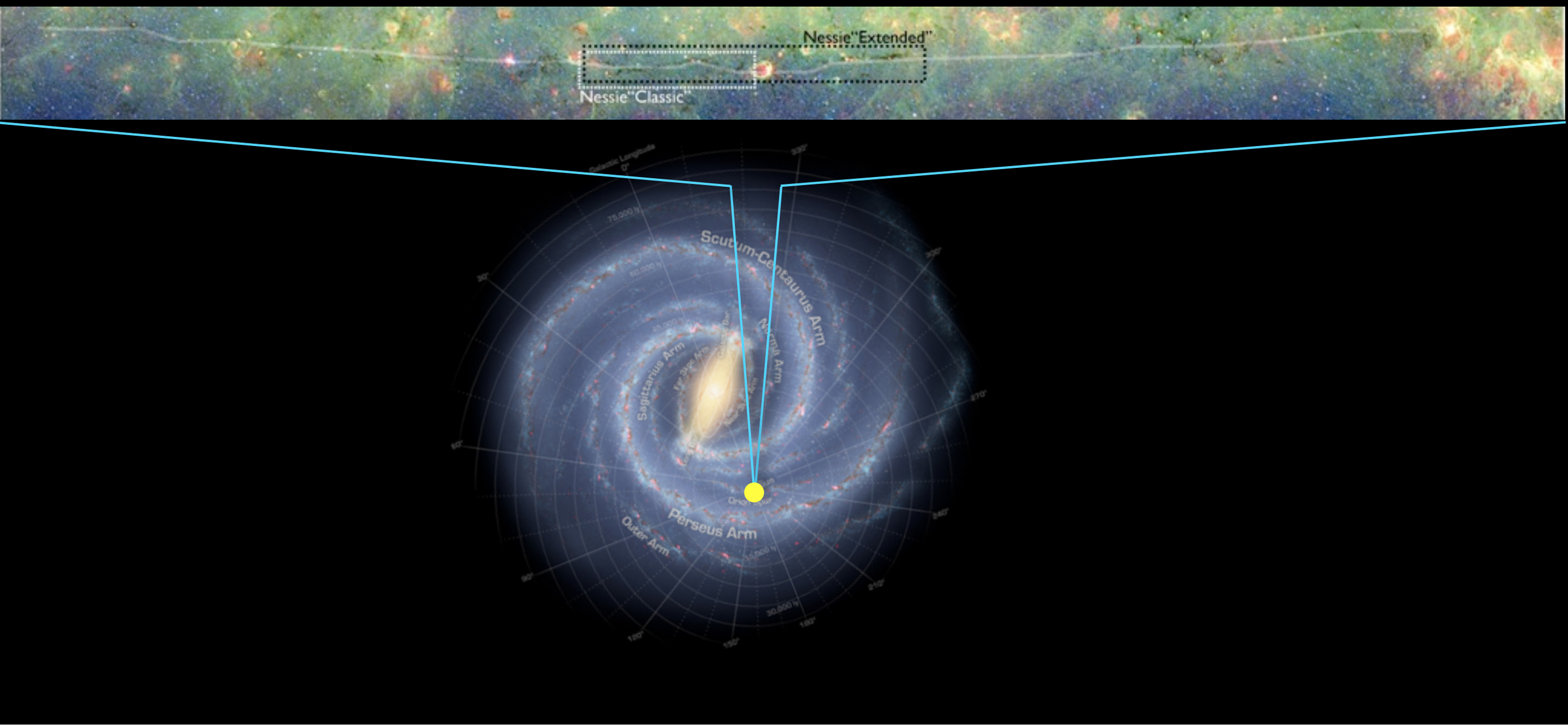
Question *Andi Burkert*: Is Nessie "parallel to the Galactic Plane"?

Answer *no one* immediately knew the answer!

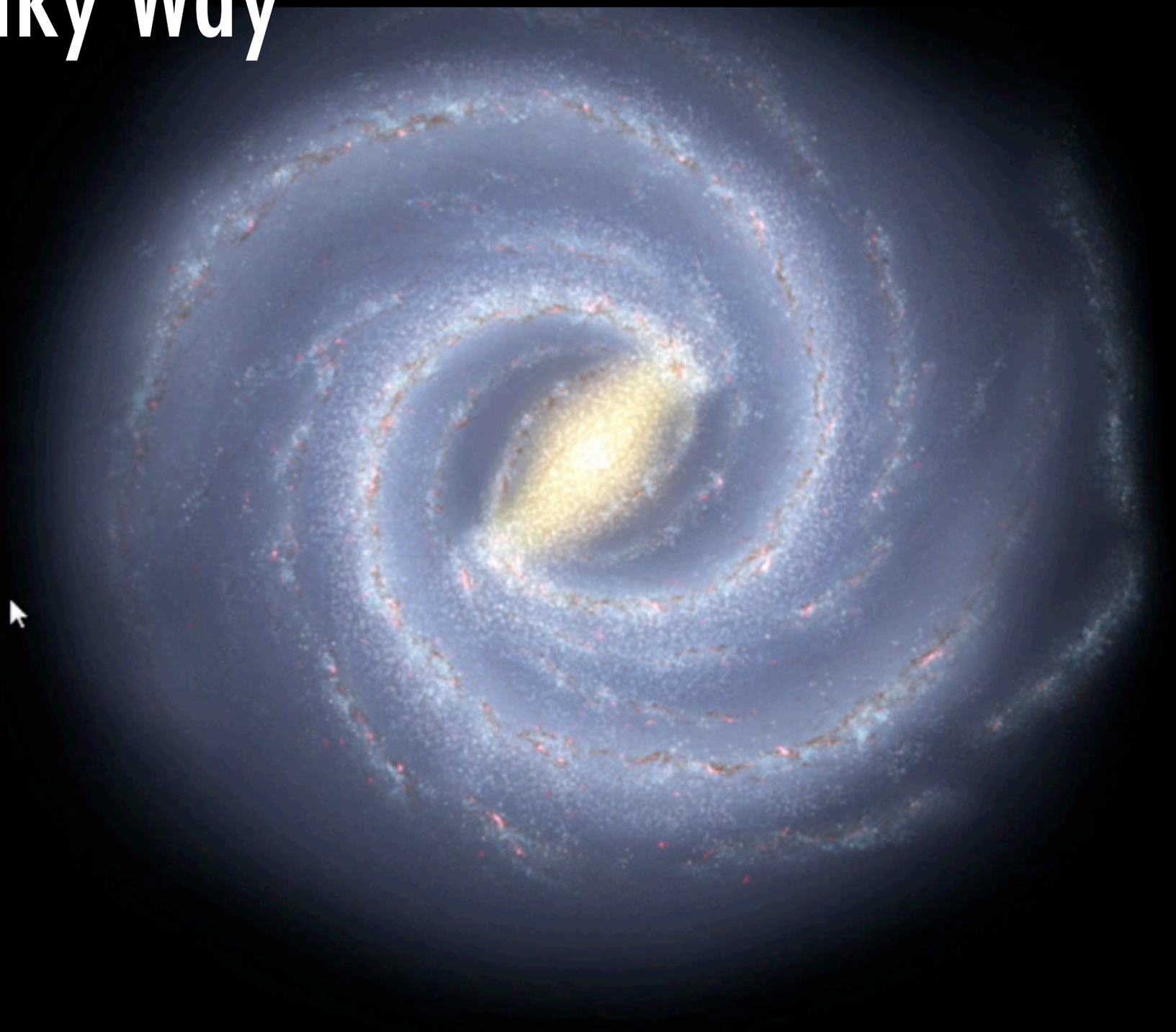
AG decides to look into this and...

"Is Nessie Parallel to the Galactic Plane?"


l=342
341
340
339
338
337
336
335
334
333
b = 0
b = -0.5

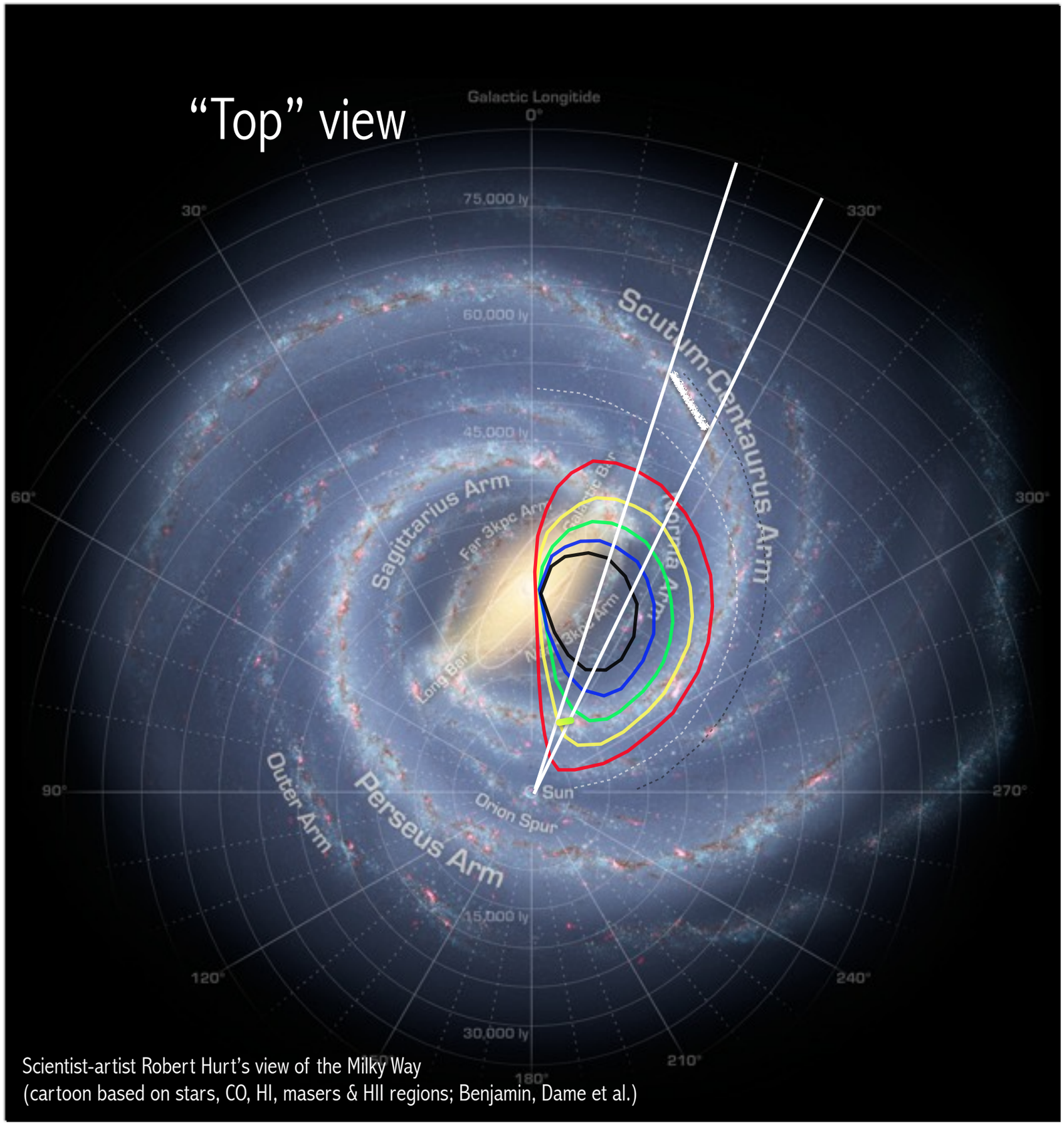

Nessie "Extended"
Nessie "Classic"
Scutum-Centaurus Arm
Norma Arm
Sagittarius Arm
Perseus Arm
Outer Arm

The Milky Way



The Milky Way
(Artist's Conception)

Using Velocity Constraints

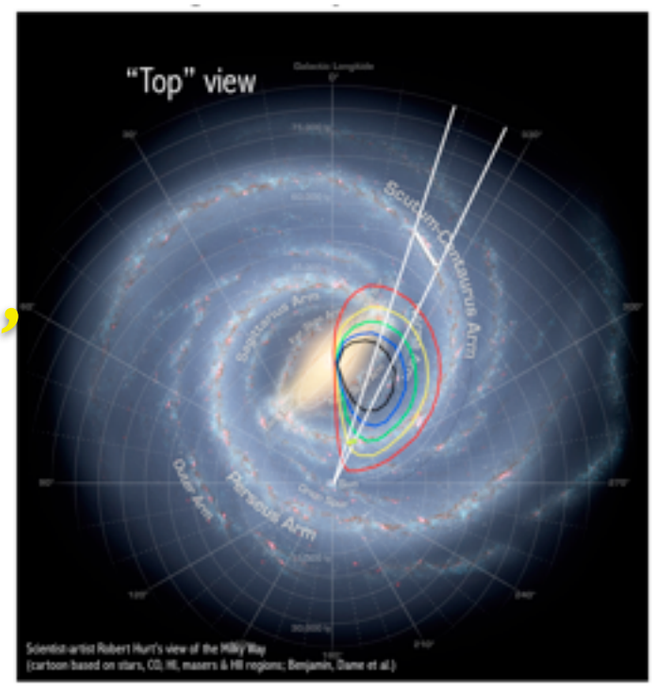


Scientist-artist Robert Hurt's view of the Milky Way
(cartoon based on stars, CO, HI, masers & HII regions; Benjamin, Dame et al.)

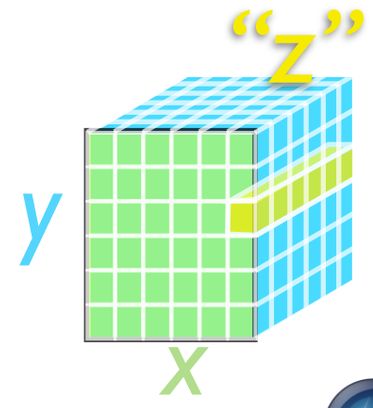
Using Velocity Constraints

"x"

"z"



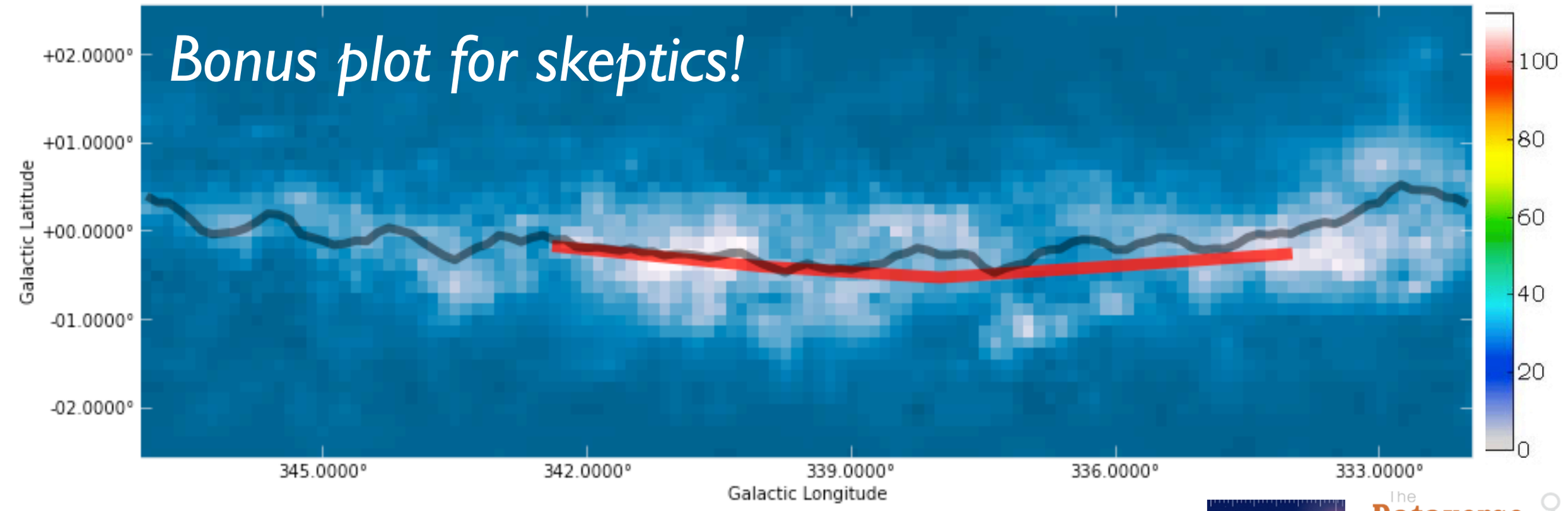
-20
-40
-60
-80
-100



x

y

Wco m50 m30.fits

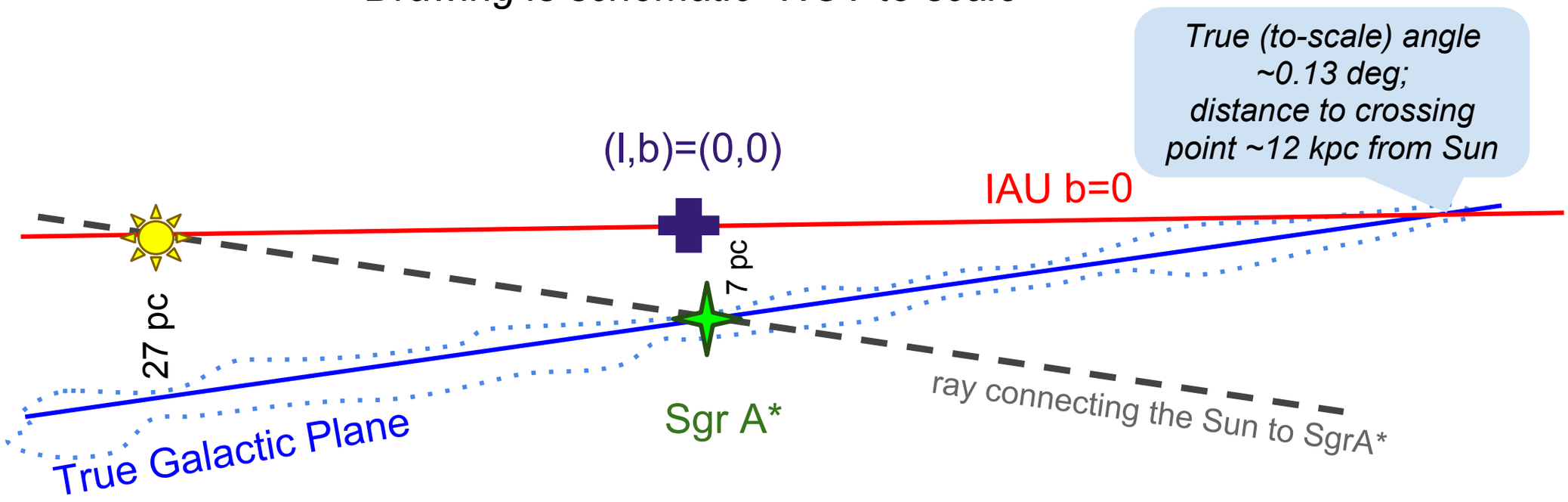


ads labs

The Dataverse Network™ Project

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

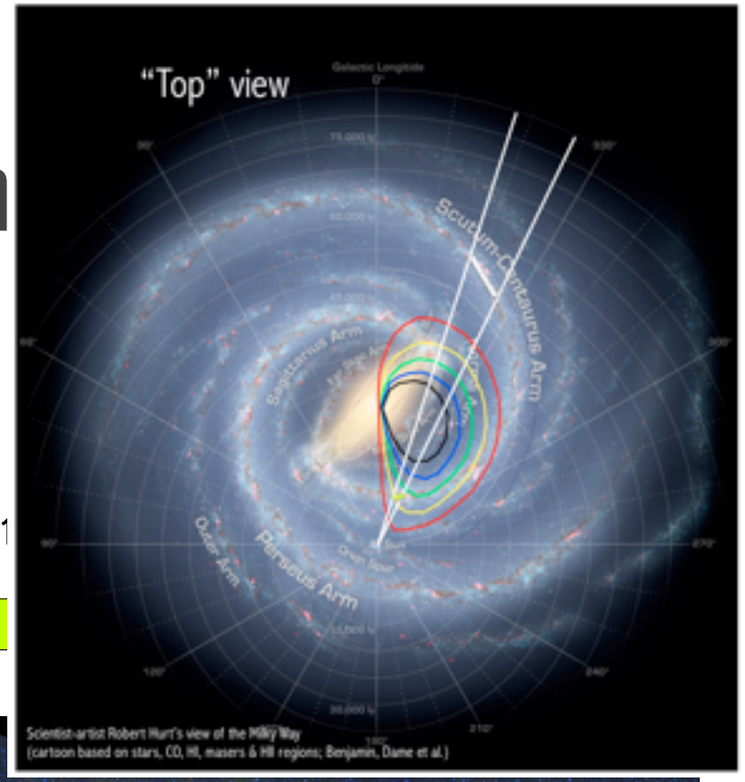
Drawing is schematic--NOT to scale



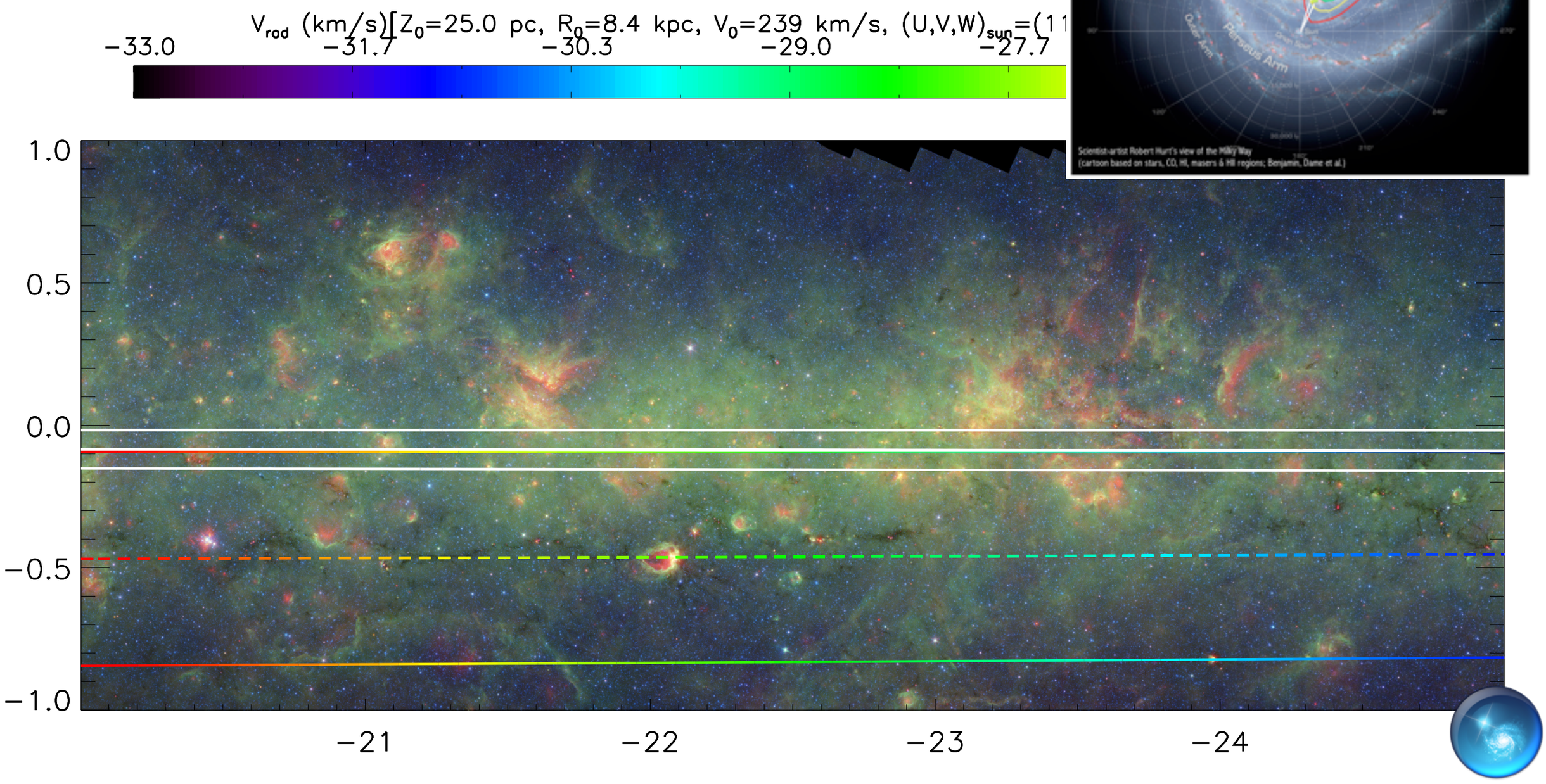
The equatorial plane of the new co-ordinate system must of necessity pass through the sun. It is a fortunate circumstance that, within the observational uncertainty, both the sun and Sagittarius A lie in the mean plane of the Galaxy as determined from the hydrogen observations. If the sun had not been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

[Blaauw et al. 1959]

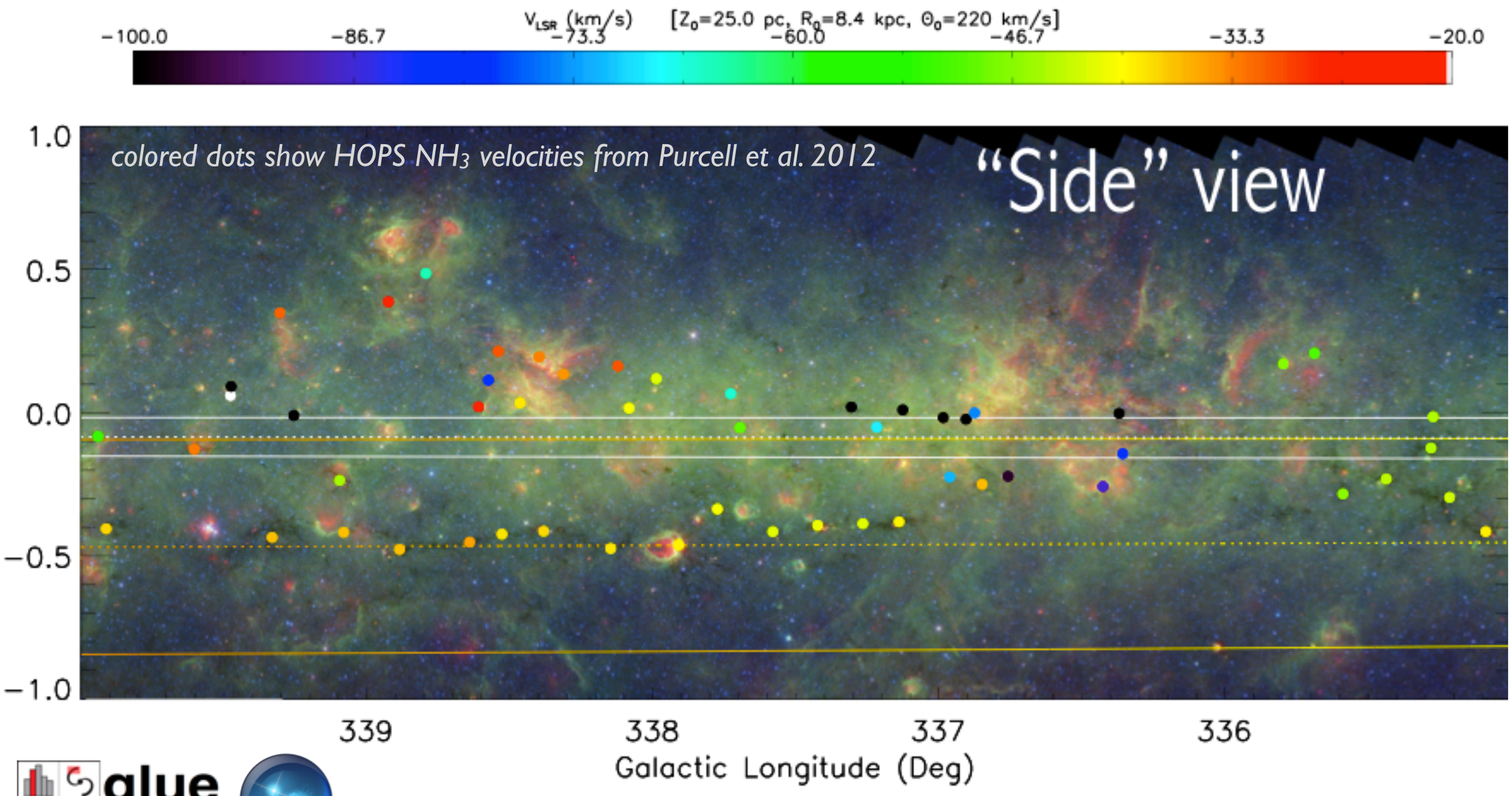
Predicted Near & Far Scutum-Centaurus Arm



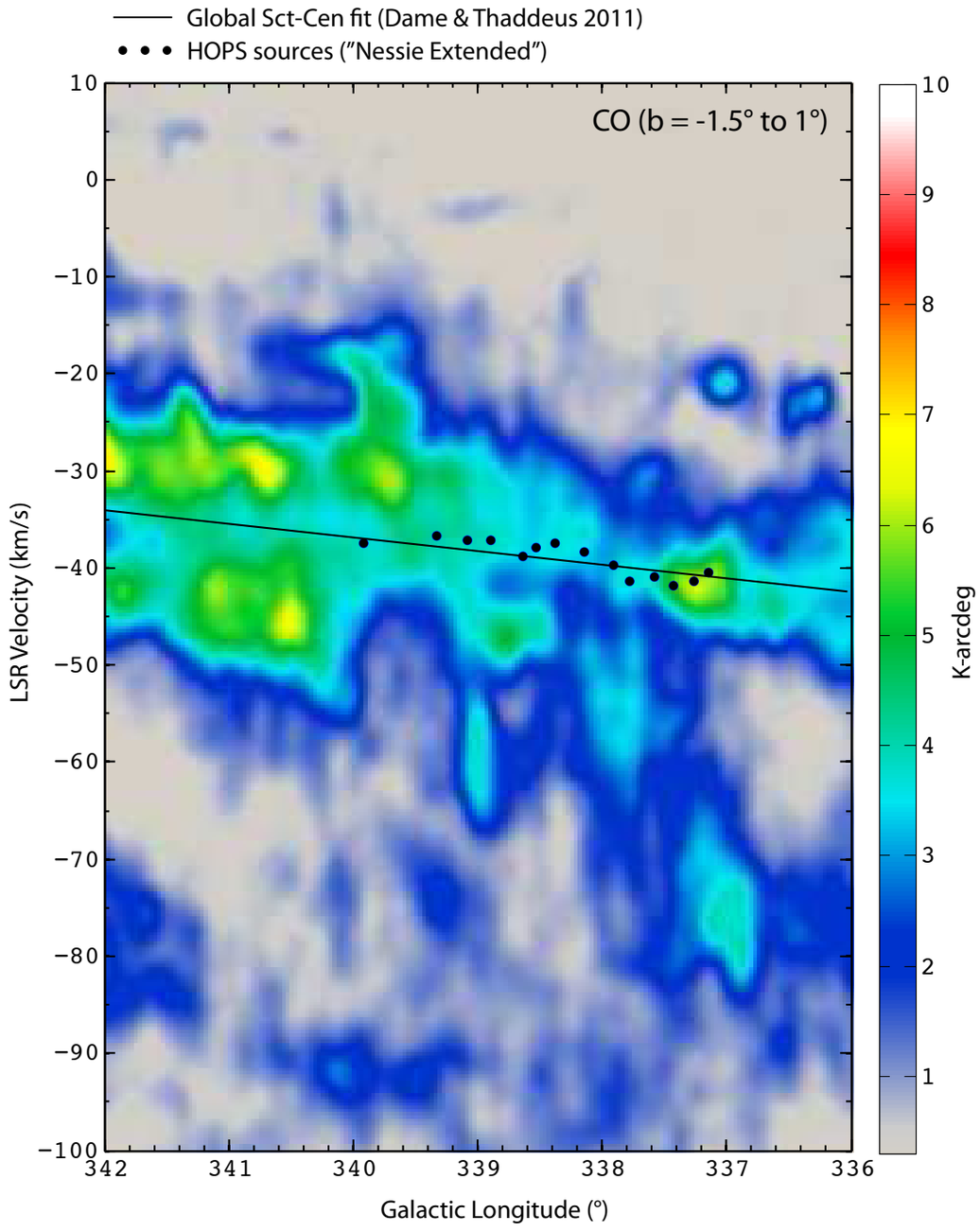
-20
-40
-60
-80
-100



Predicted Velocities match NH_3 Cores in Nessie Perfectly



Predicted Velocities match NH_3 Cores in Nessie Perfectly



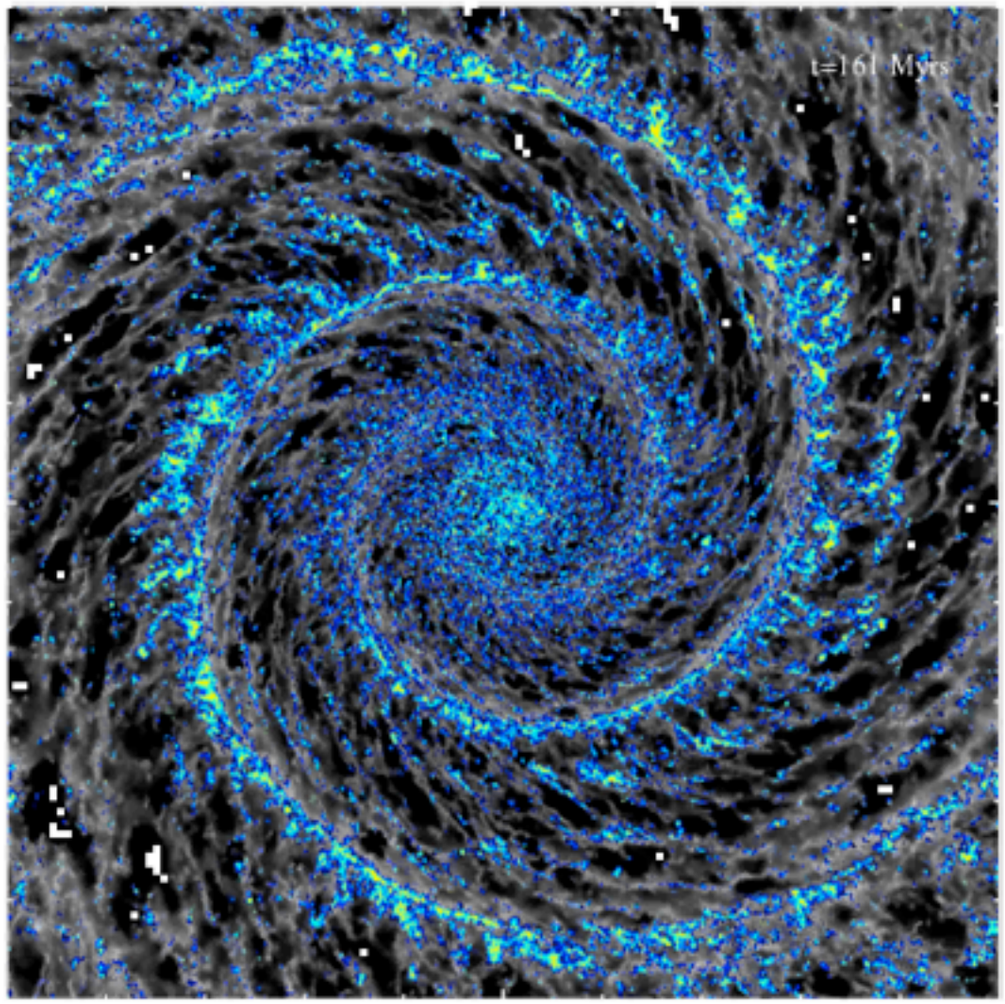
black dots show HOPS NH_3 velocities from Purcell et al. 2012; color is CO; line is log-spiral fit to full Scut-Cen Arm

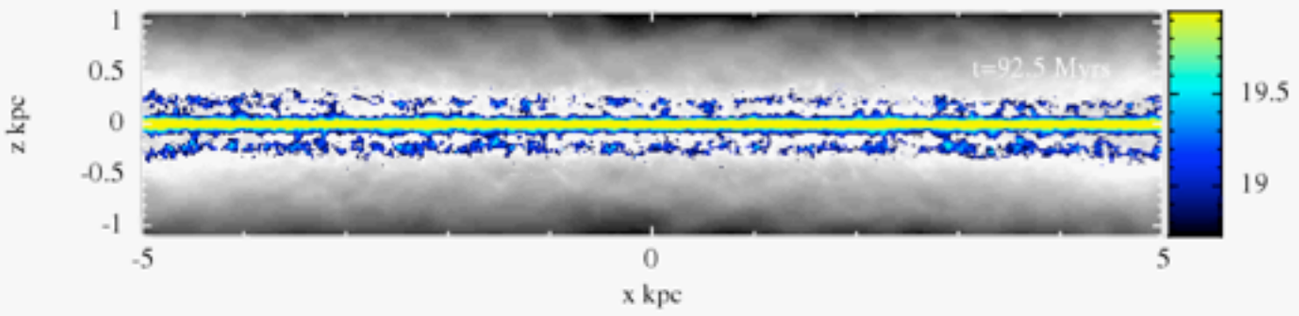
Nessie is a Bone of the Milky Way

(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: Authorea

literature

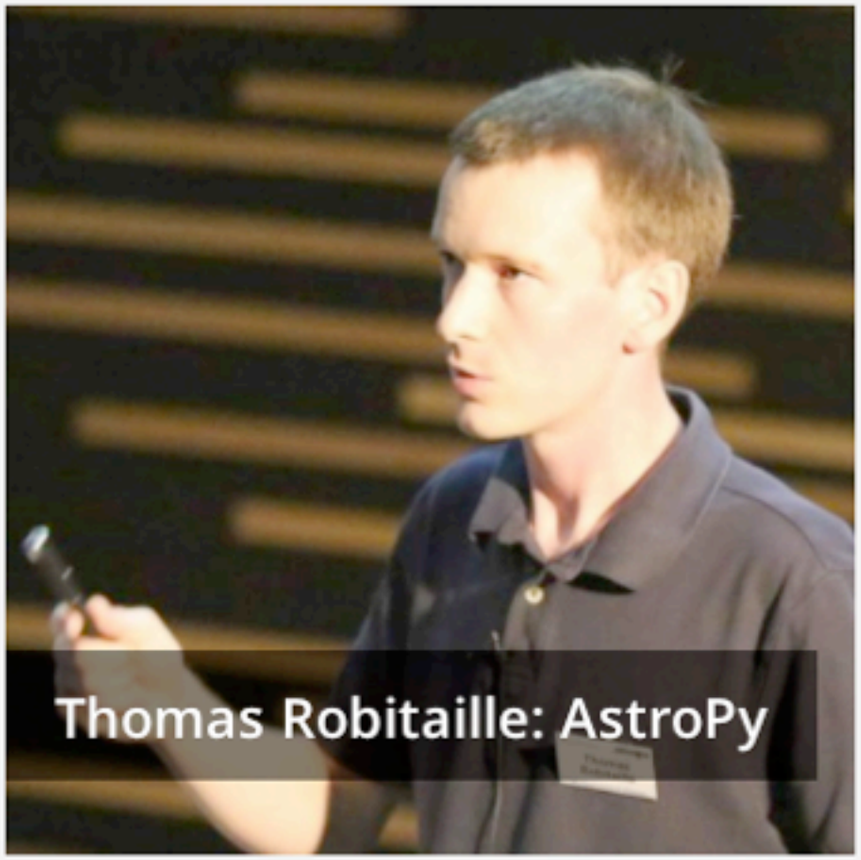
>code

data

each collaborative pr
(“paper”
be public or pr

versioning model=g

orea.com



Unproceedings of .Astronomy 4

We're very pleased to present the Unproceedings of the Fourth .Astronomy Conference (.Astronomy 4), which was held in Heidelberg, ...

Hack Day In New York

.Astronomy is all about sharing ideas and making astronomy happen. Sometimes this means producing code that can fit data really quickly ...

Come to Cambridge For .Astronomy 5

.Astronomy 5 will be hosted by Harvard's Seamless Astronomy group at Microsoft's NERD Center in Cambridge, MA, USA. Mark ...

Publishing with FigShare

Posted: September 6th, 2012 | **Author:** Aleks Scholz | **Comments:** 0

"Publishing 2.0" was an unconference session at this year's dotastronomy conference, and FigShare was one of the new tools discussed in this session. In a nutshell, FigShare is a free online repository for scientific results from all

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