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, Cara Battersby, Thomas M. Dame

ITA, Heidelberg: Rowan Smith

Max Planck Insitute for Astronomy: Thomas Robitaille

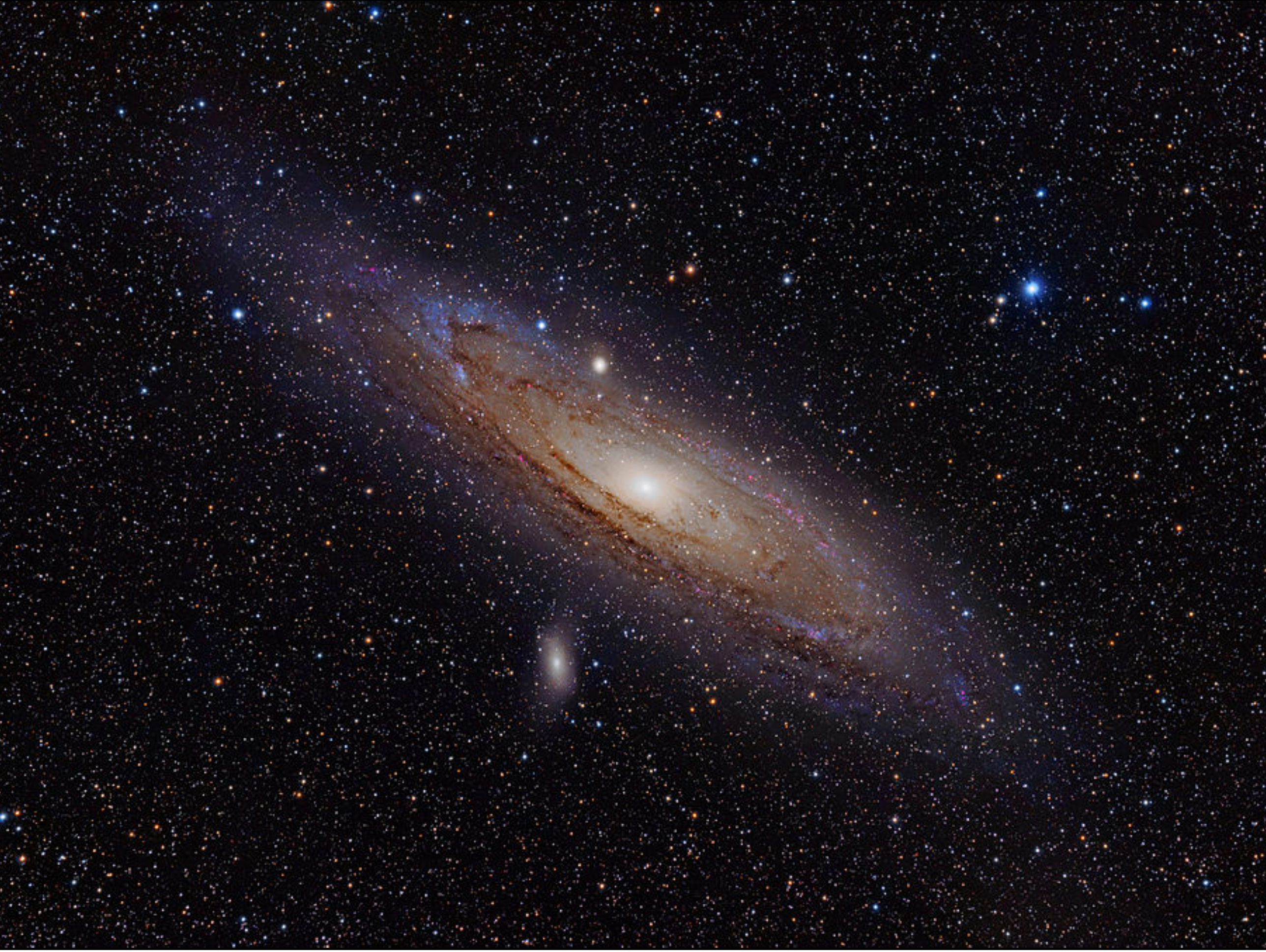
U. Munich: Andreas Burkert

U. Virginia: Catherine Zucker

U. Vienna: Joao F. Alves

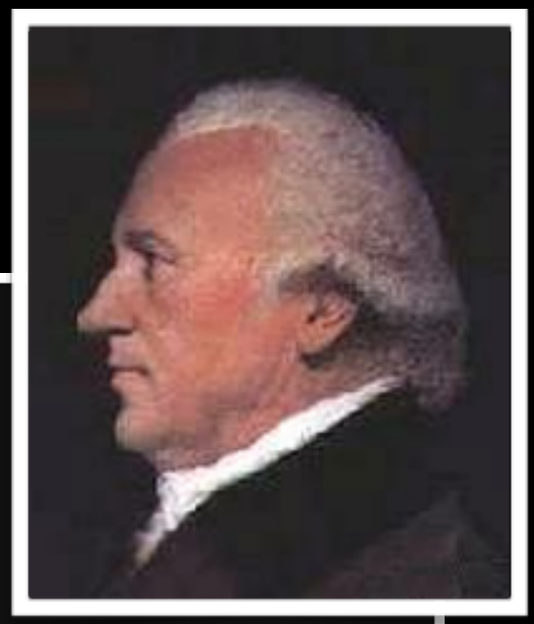
U. Wisconsin: Robert A. Benjamin

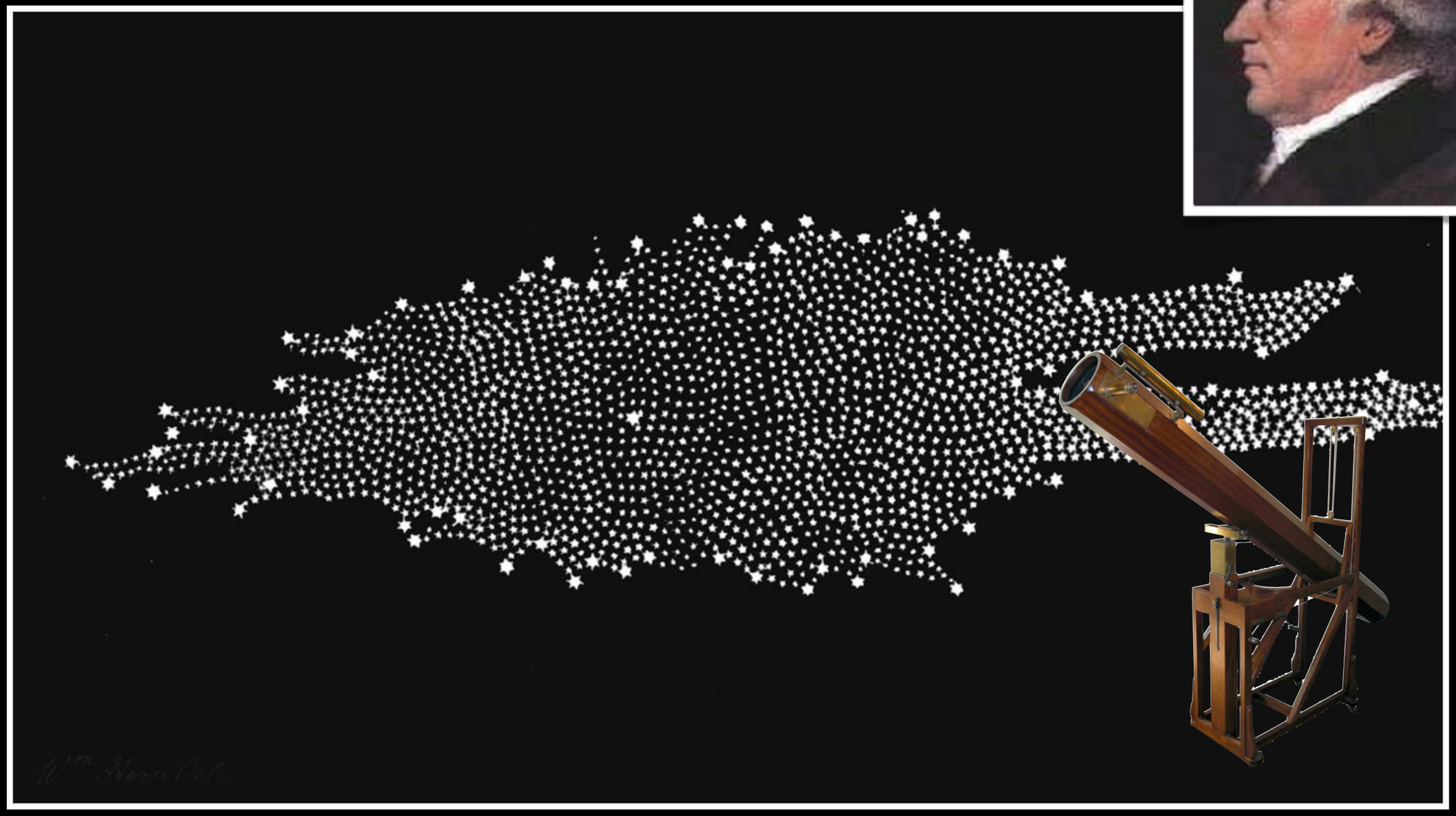
Music: Davis Jerome, Richard Woodhams & The Mozart Orchestra - Oboe Concerto in C Major: II. Adagio , by Sir William Hershcel



Monday, June 30, 2014

William Herschel's Milky Way Galaxy in 1781





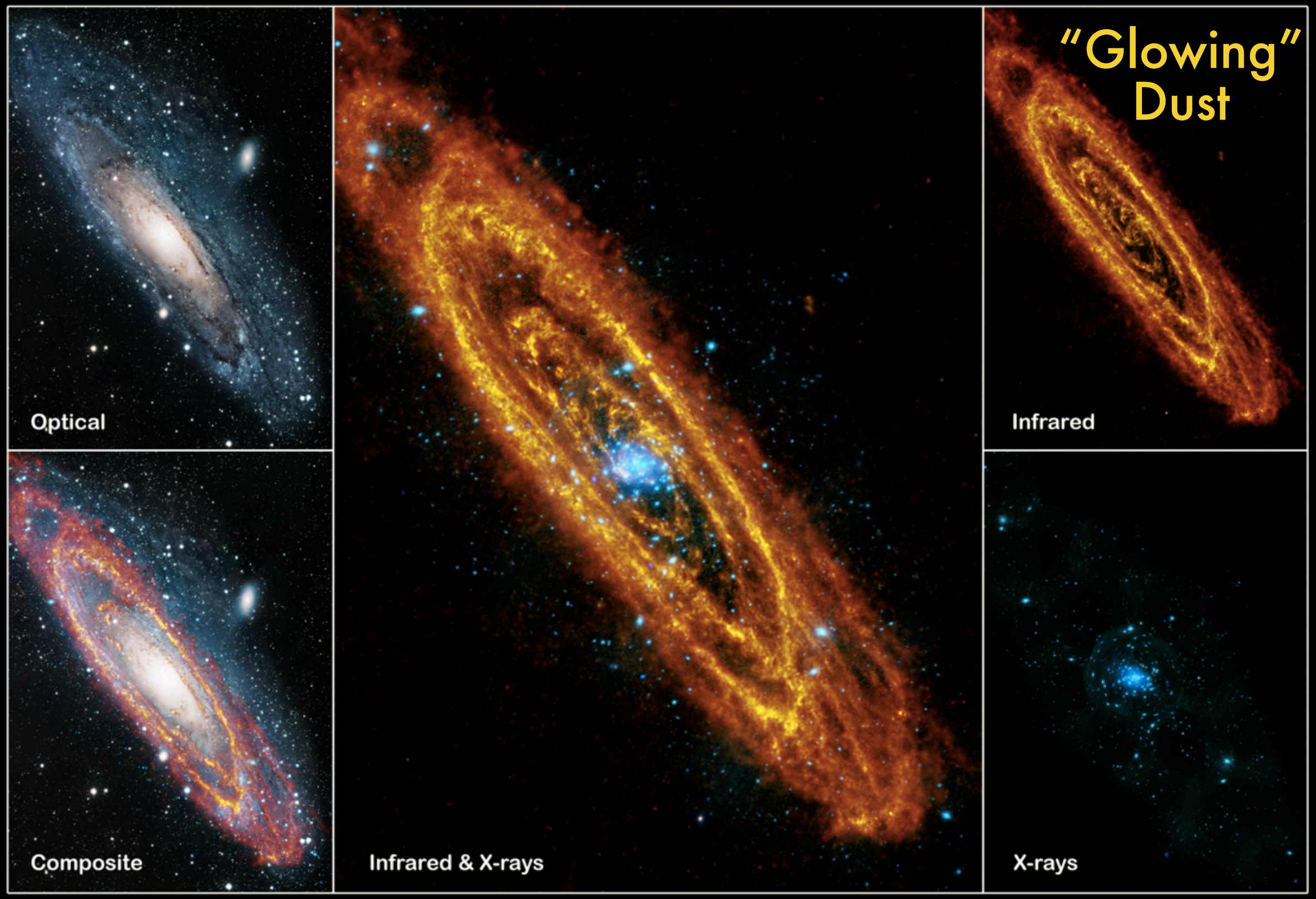
More info at http://cosmology.carnegiescience.edu/timeline/1781 (Herschel); http://cosmology.carnegiescience.edu/timeline/1920 (Shapley-Curtis)

The Andromeda Galaxy (M31)

The Andromeda Galaxy (M31)

The Andromeda Galaxy (M31)

Monday, June 30, 2014



The Andromeda Galaxy (M31)

Distance to M101 ~ 7 Mpc

ALMA-like resolution

10 kpc

1 kpc

60 kpc

Orion in CO

20 pc

1-m telescope

M101 hires STScI-PRC2006-10a.jpg

"An" Infrared Dark Cloud in the Milky Way...

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, Cara Battersby, Thomas M. Dame

ITA, Heidelberg: Rowan Smith

Max Planck Insitute for Astronomy: Thomas Robitaille

U. Munich: Andreas Burkert

U. Virginia: Catherine Zucker

U. Vienna: Joao F. Alves

U. Wisconsin: Robert A. Benjamin

Music: Davis Jerome, Richard Woodhams & The Mozart Orchestra - Oboe Concerto in C Major: II. Adagio , by Sir William Hershcel

The Bones of the Milky Way

Open Access, Open Data (Authorea.com)

Authorea BROWSE ABOUT CONTACT PLANS FEEDBACK BLOG HELP ALYSSA GOODMAN

PUBLIC WORKING DRAFT Index Settings Fork Quickedit 12 Comments Export

The Bones of the Milky Way

Alyssa Goodman, João Alves, Chris Beaumont, Tom Dame, James Jackson, Jens Kauffmann, Thomas Robitaille, Alberto Pepe, Michelle Borkin, Andreas Burkert, Robert A Benjamin + Add author

NOTES TO ONLINE READERS

This article was submtted to the Astrophysical Journal in December 2013.

The current online version is citable as an online "Authorea" preprint, and you can use the article's URL to do

Once upon a time (2012), in an enchanted castle (in Bavaria)

...at a conference about star formation

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

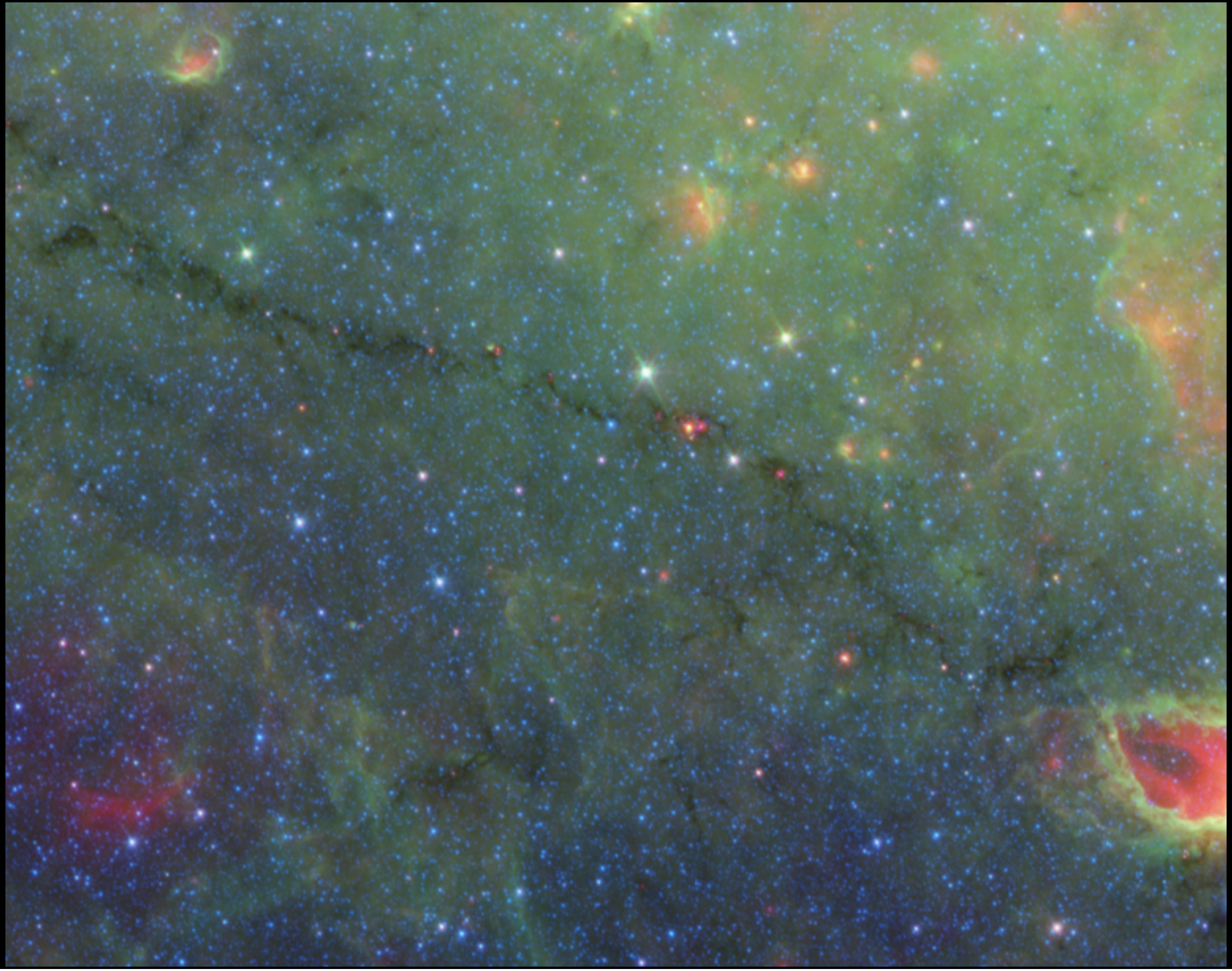
James M. Jackson[1], Susanna C. Finn[1], Edward T. Chambers[2], Jill M. Rathborne[3], and Robert Simon[4]
[1] Institute for Astrophysical Research, Boston University, Boston, MA 02215, USA; jackson@bu.edu, sfinn@bu.edu
[2] Department of Physics and Astronomy, Northwestern University, Evanston, IL 60208, USA; e-chambers@northwestern.edu
[3] Australia Telescope National Facility and Universidad de Chile, Santiago, Chile; rathborn@das.uchile.cl
[4] I. Physikalisches Institut, Universität zu Köln, 50937 Köln, Germany; simonr@ph1.uni-koeln.de
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



Once upon a time (2012), in an enchanted castle (in Bavaria)

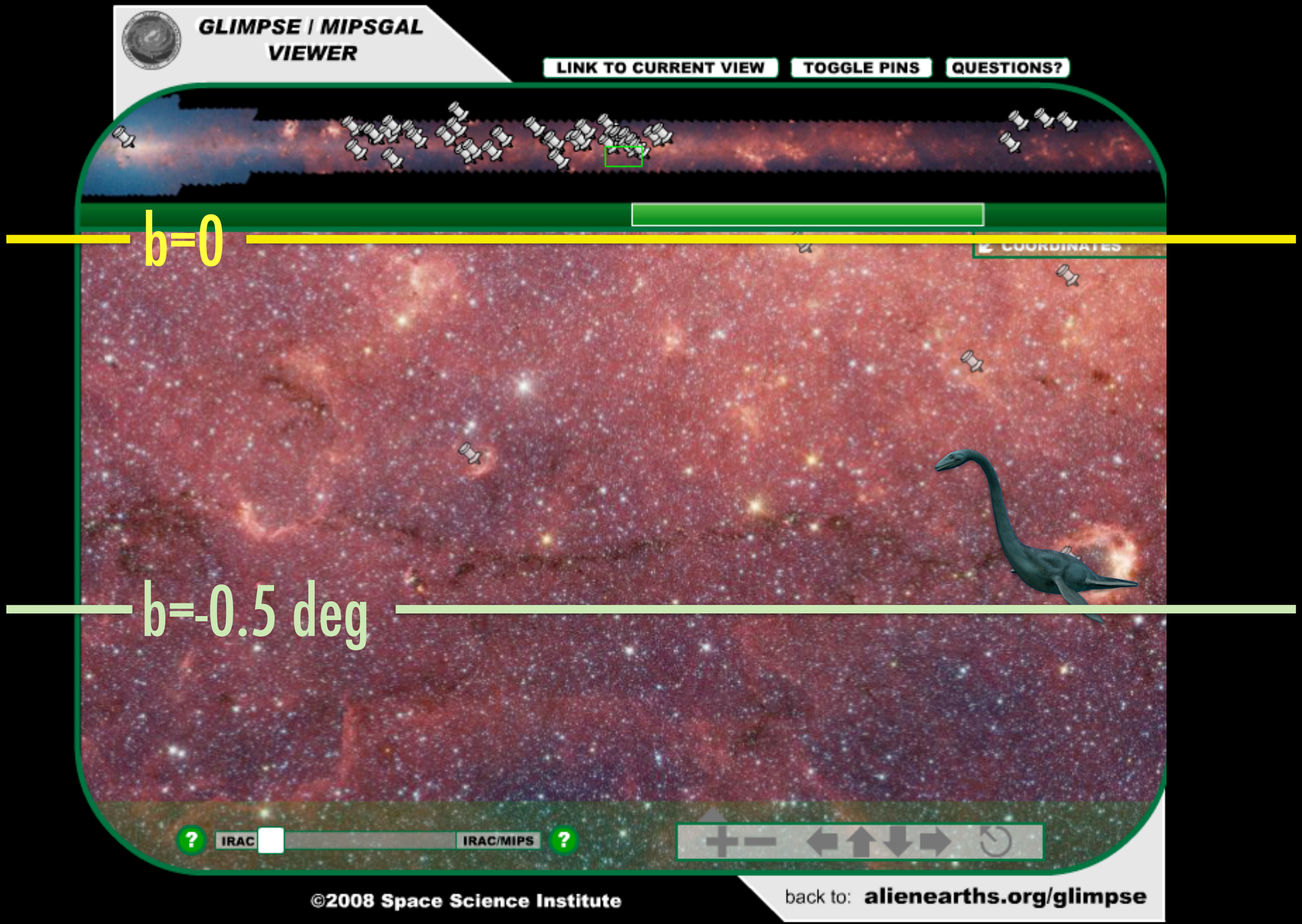
...at a conference about star formation

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

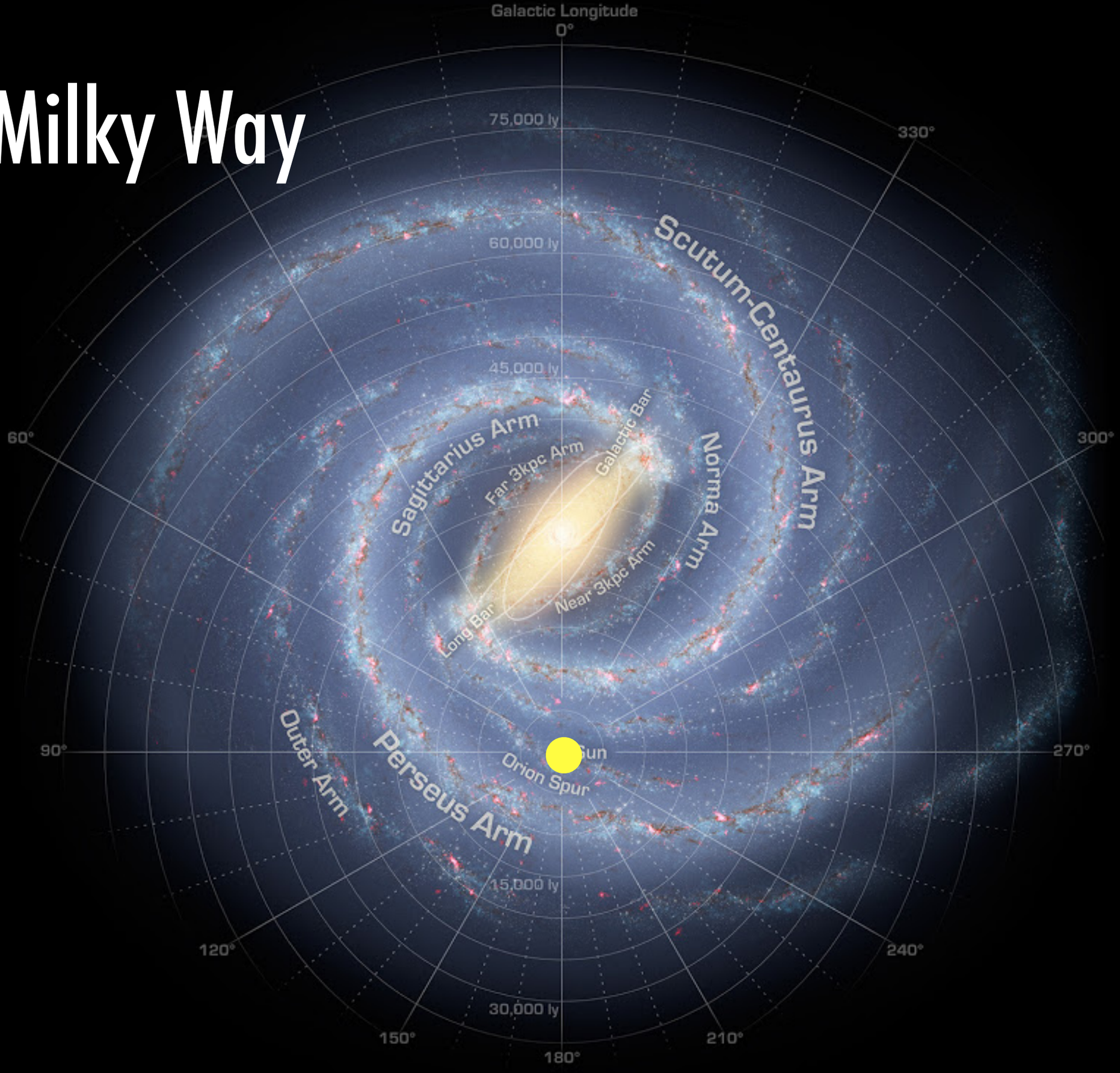
Answer *no one* immediately knew the answer!

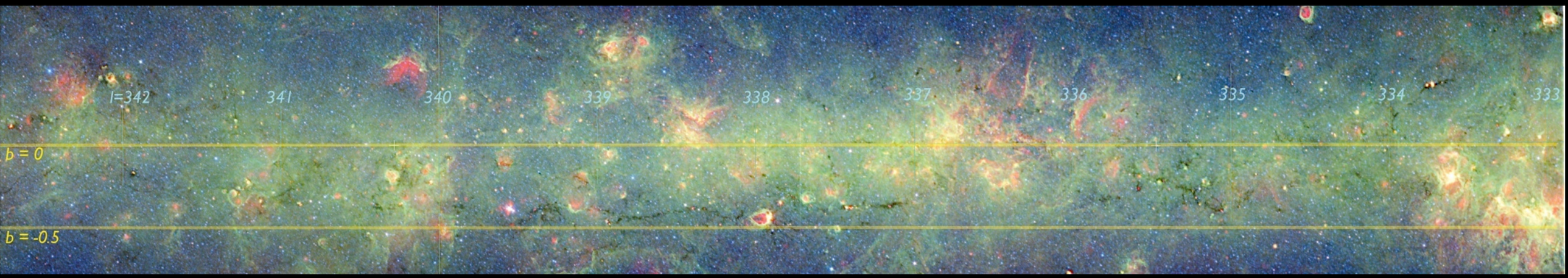
"Is Nessie Parallel to the Galactic Plane?"

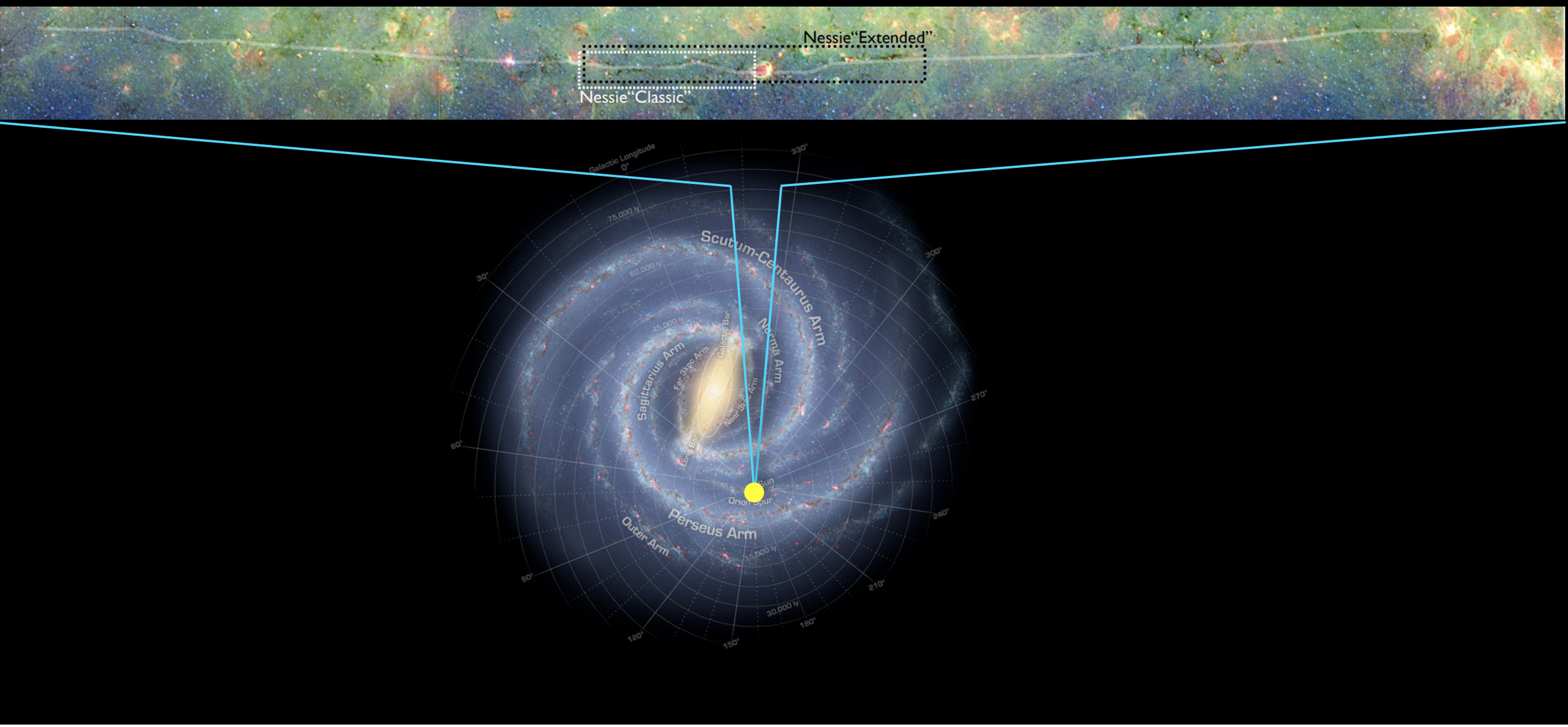
Yes, but why not at Zero of Latitude (b=0)?

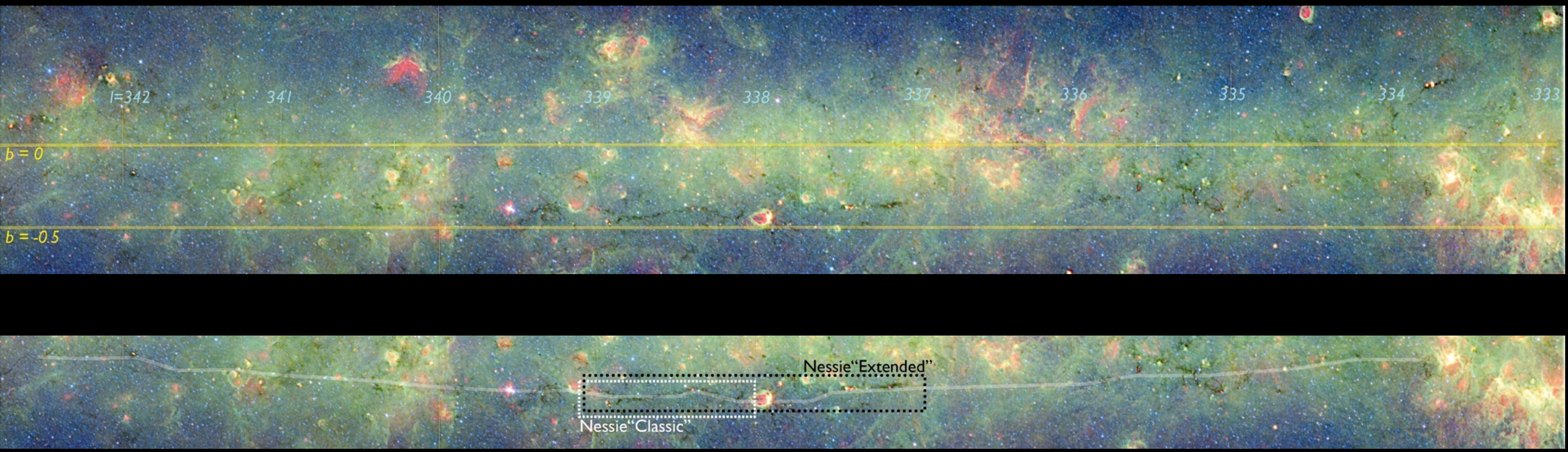


The Milky Way




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


Nessie "Extended"
Nessie "Classic"
Galactic Longitude
0°
30°
60°
90°
120°
150°
180°
210°
240°
270°
300°
330°
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
Far 3kpc Arm
Near 3kpc Arm
Galactic Bar
Long Bar
Sun
Orion Spur



"Nessie Extended"

~500 light years long & 1.5 light years thick

300:1 axial ratio

200,000 solar masses

BUT, why is it near b=-0.5, and not b=0?

Aspect Ratio for longest version of Nessie is 800:1

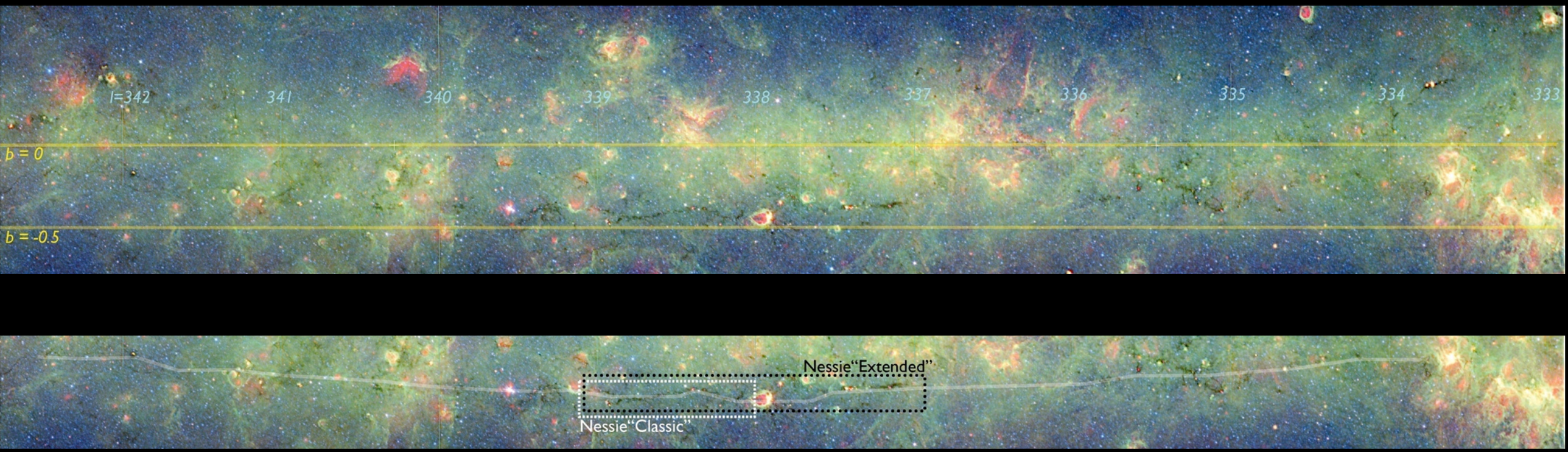
Table 1: Estimates of Nessie's Density and Mass

Assumptions:	*Baryonic mass of Milky Way (Msuns)*	*1.25E+11*
	Distance to Nessie (pc)	*3,100*

Nickname	Length *deg*	Radius *deg*	Length *pc*	Radius *pc*	Average density *cm^-3*	H2 column density *cm^-2*	Equiv. Av *mag*	Mass *Msuns*	Mass per unit length *Msuns/pc*	# to equal mass of Milky Way	aspect ratio
for innermost Spitzer IRDC...											
"Nessie Classic"	1.5	0.005	81	0.3	1E+5	8E+22	81	1E+5	1,208	1E+6	150
"Nessie Extended"	3	0.005	162	0.3	1E+5	8E+22	81	2E+5	1,208	6E+5	300
"Nessie Optimistic"	8	0.005	431	0.3	1E+5	8E+22	81	5E+5	1,208	2E+5	800
for envelope (width as observed in HNC, Jackson et al. 2010)...											
"Nessie Classic"	1.5	0.05	81	2.7	5E+2	4E+21	4	5E+4	604	3E+6	15
"Nessie Extended"	3	0.05	162	2.7	5E+2	4E+21	4	1E+5	604	1E+6	30
"Nessie Optimistic"	8	0.05	431	2.7	5E+2	4E+21	4	3E+5	604	5E+5	80

and is very, very, thin: tenths of pc in diameter!! (while 100s of pc long)

Goodman et al. 2013, see MilkyWayBones.org



"Nessie Extended"

~500 light years long & 1.5 light years thick

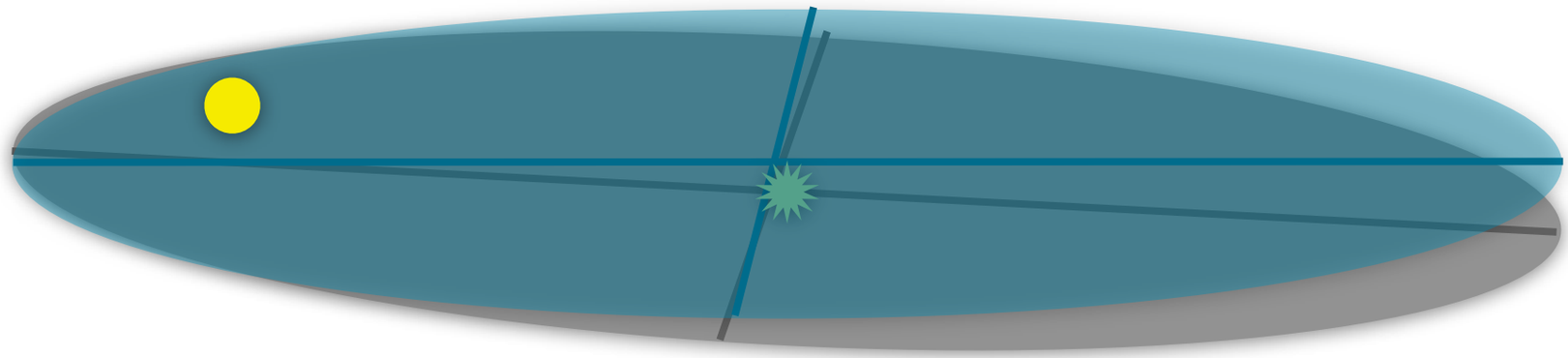
300:1 axial ratio

200,000 solar masses

BUT, why is it near b=-0.5, and not b=0?

Where are we, really?

"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

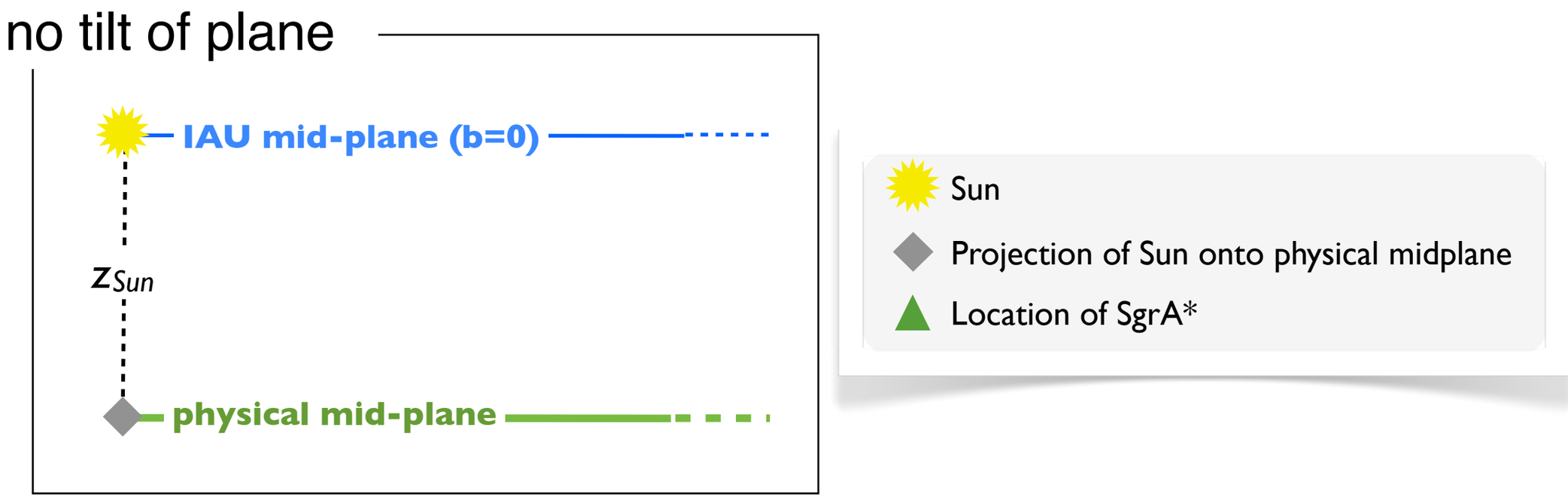
+

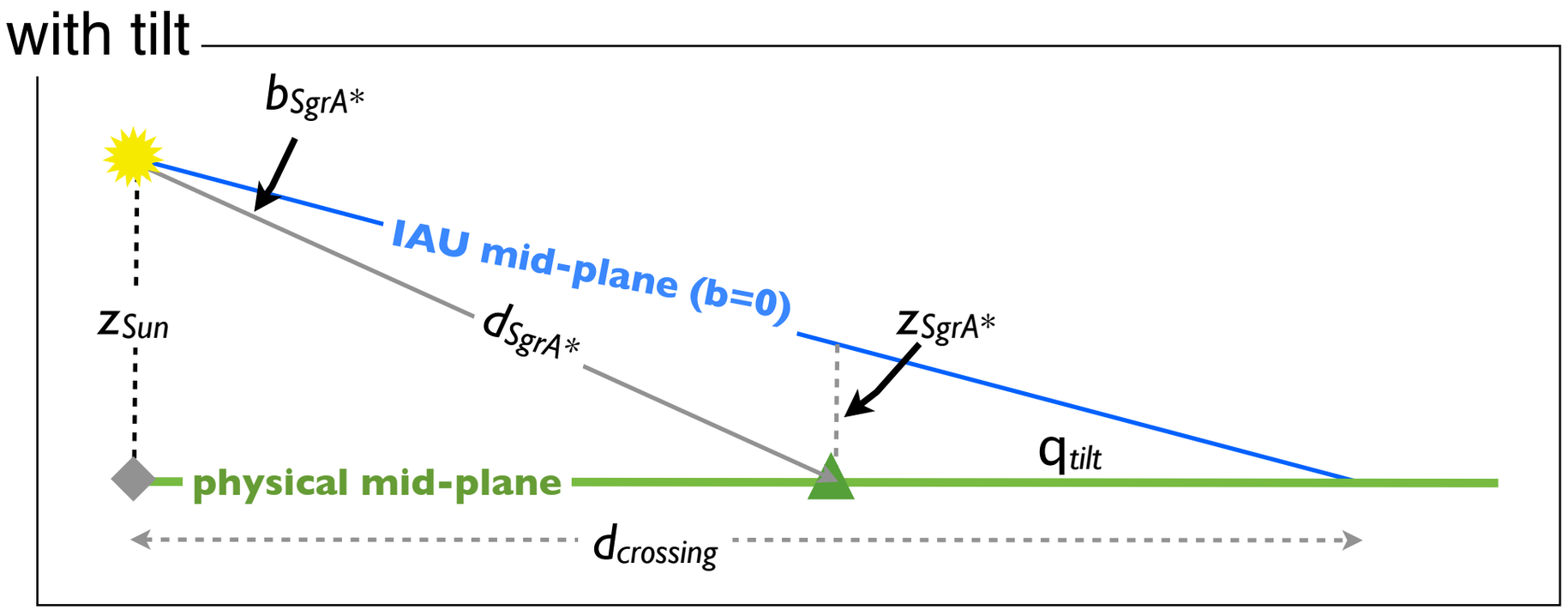
Galactic Center is ~20 light years offset from the IAU Milky Way Center

=

The **Galactic Plane is not quite where you'd think it is** when you look at the sky

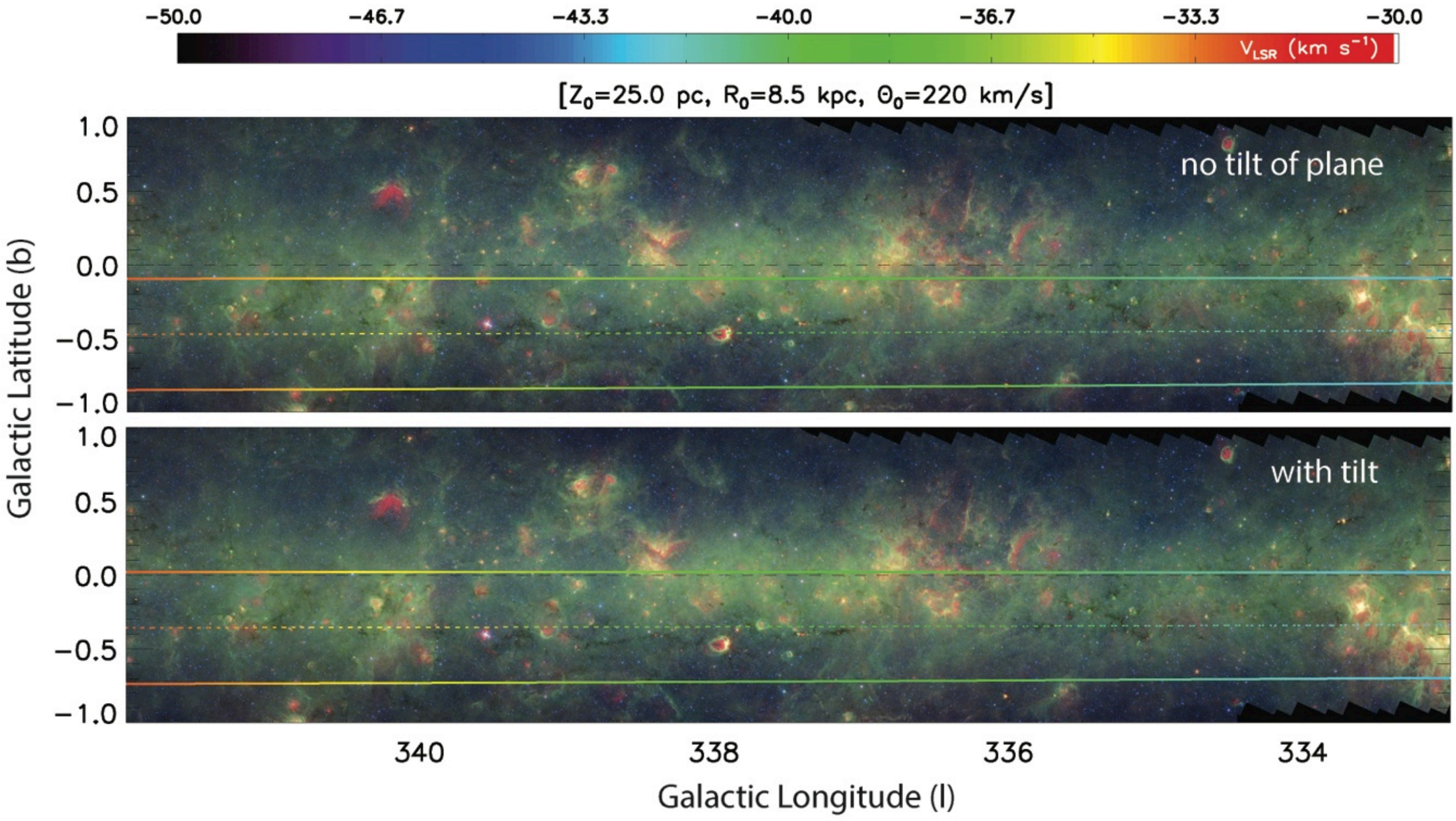
"In the Plane?"



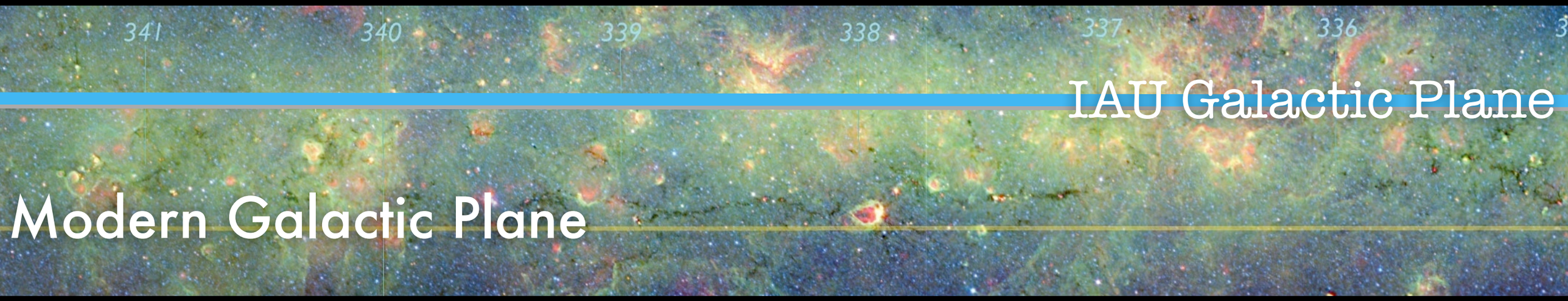


Goodman et al. 2013, see MilkyWayBones.org

"In the Plane?"



Goodman et al. 2013, see MilkyWayBones.org



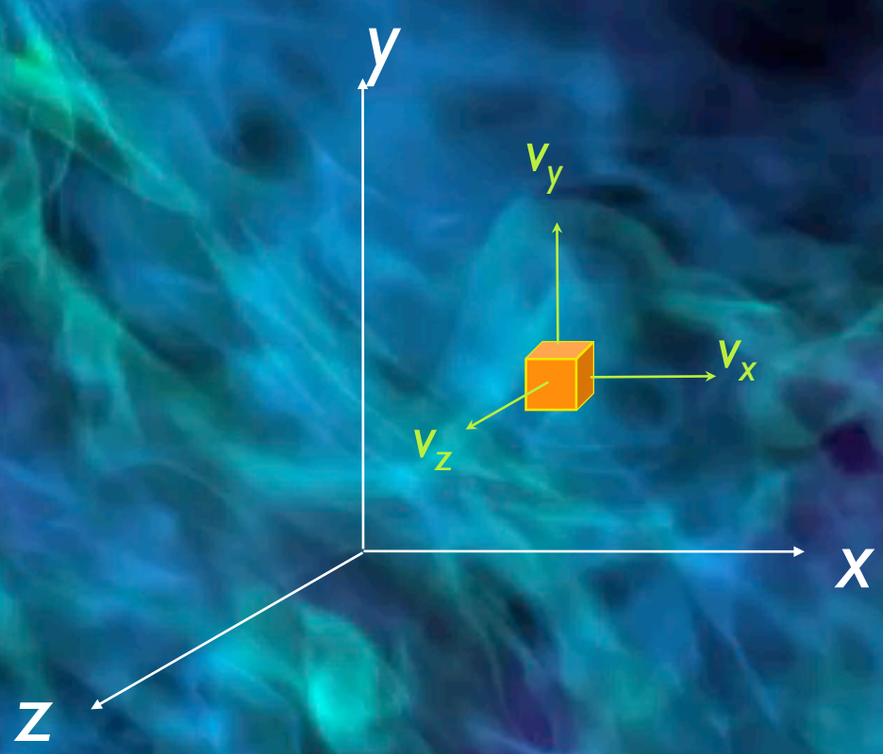
Yes, Nessie is EXACTLY in the Galactic Plane!

What about its distance?

we can use “radial velocities” to estimate distance in a rotating galaxy...

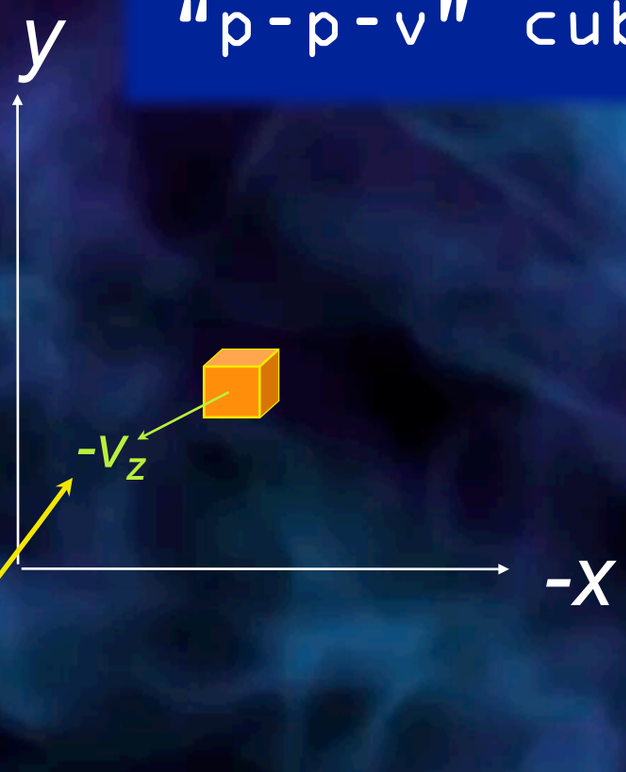
Quick Refresher: Spectral-Line Mapping

We wish we could measure…



But we can measure…

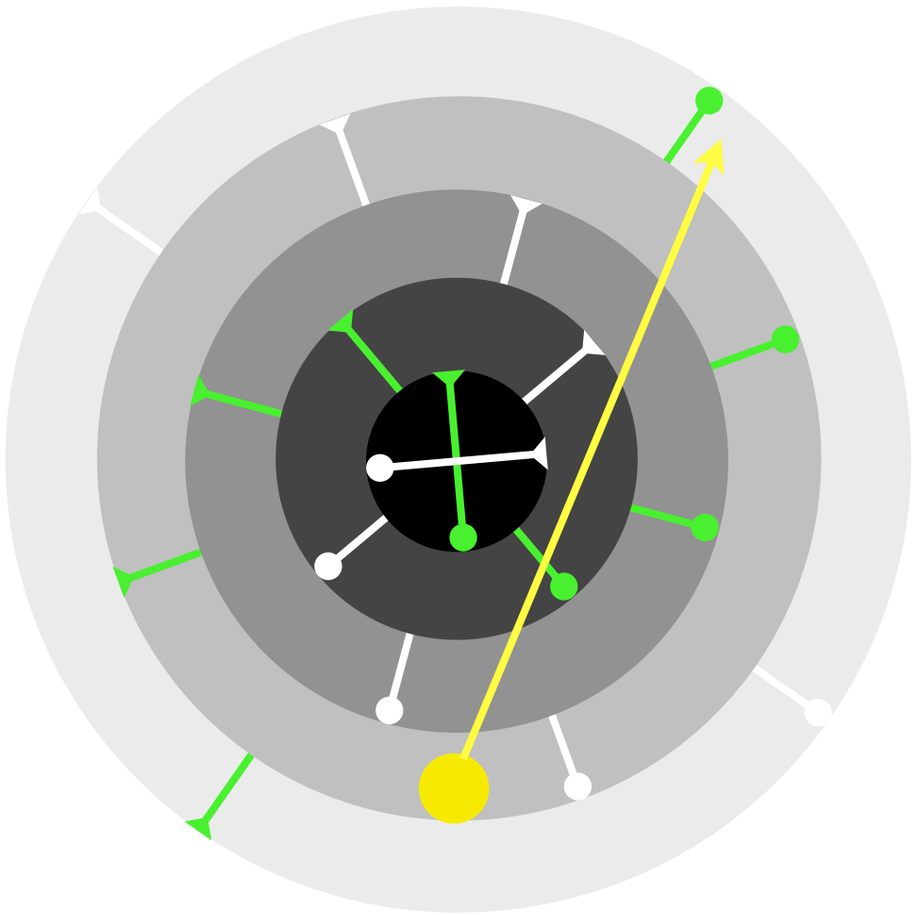
"p-p-v" cubes

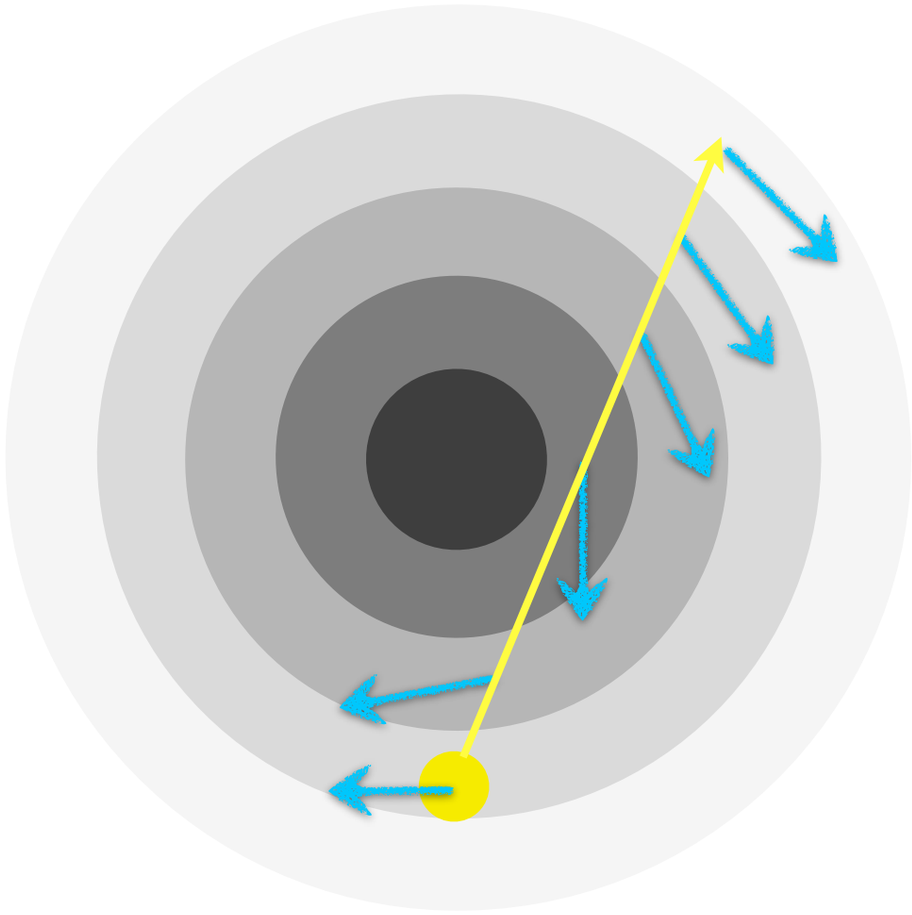


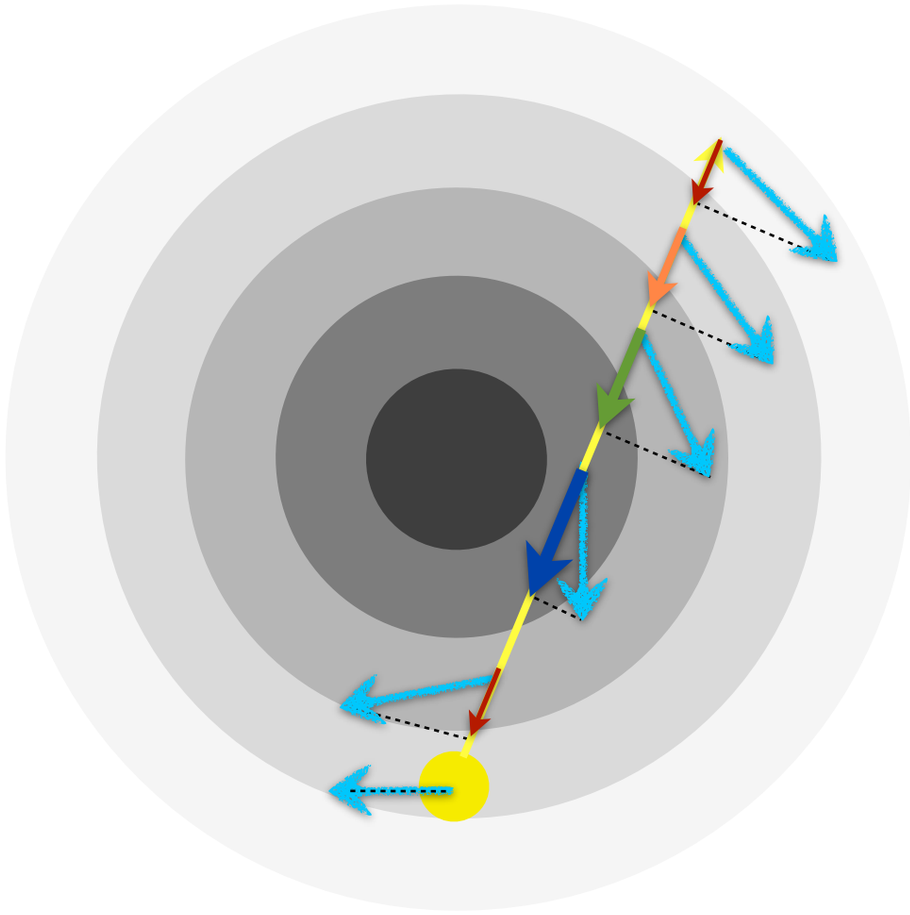
v_z *only* from "spectral-line maps"

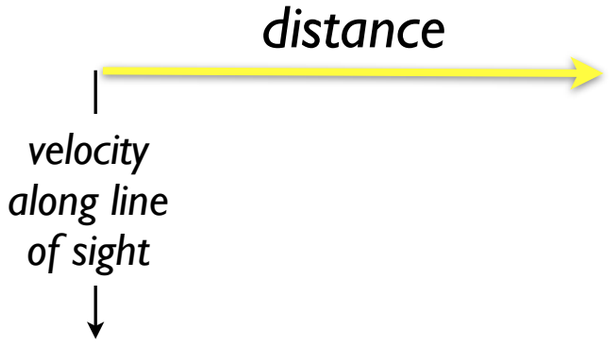
Hydrodynamic AMR Simulation, courtesy Stella Offner

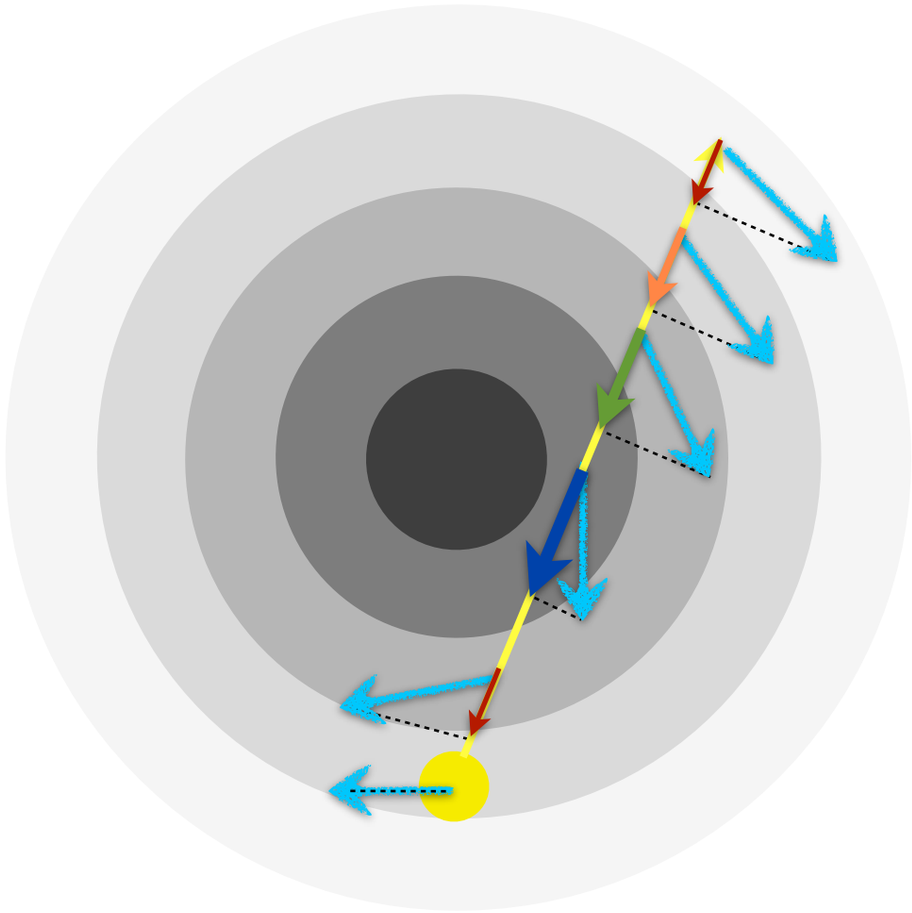
A Rotating (Spiral) Galaxy Observed from its Outskirts...

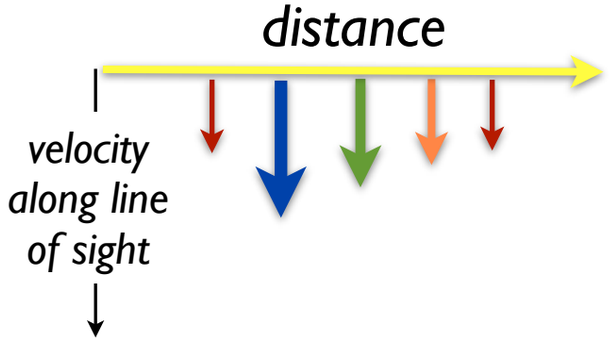


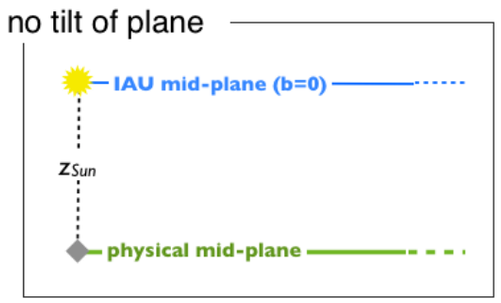




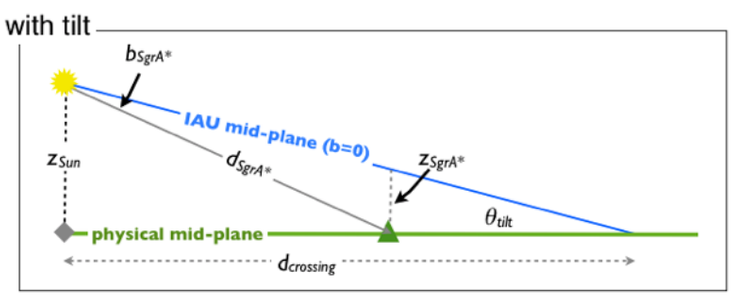

distance
velocity
along line
of sight

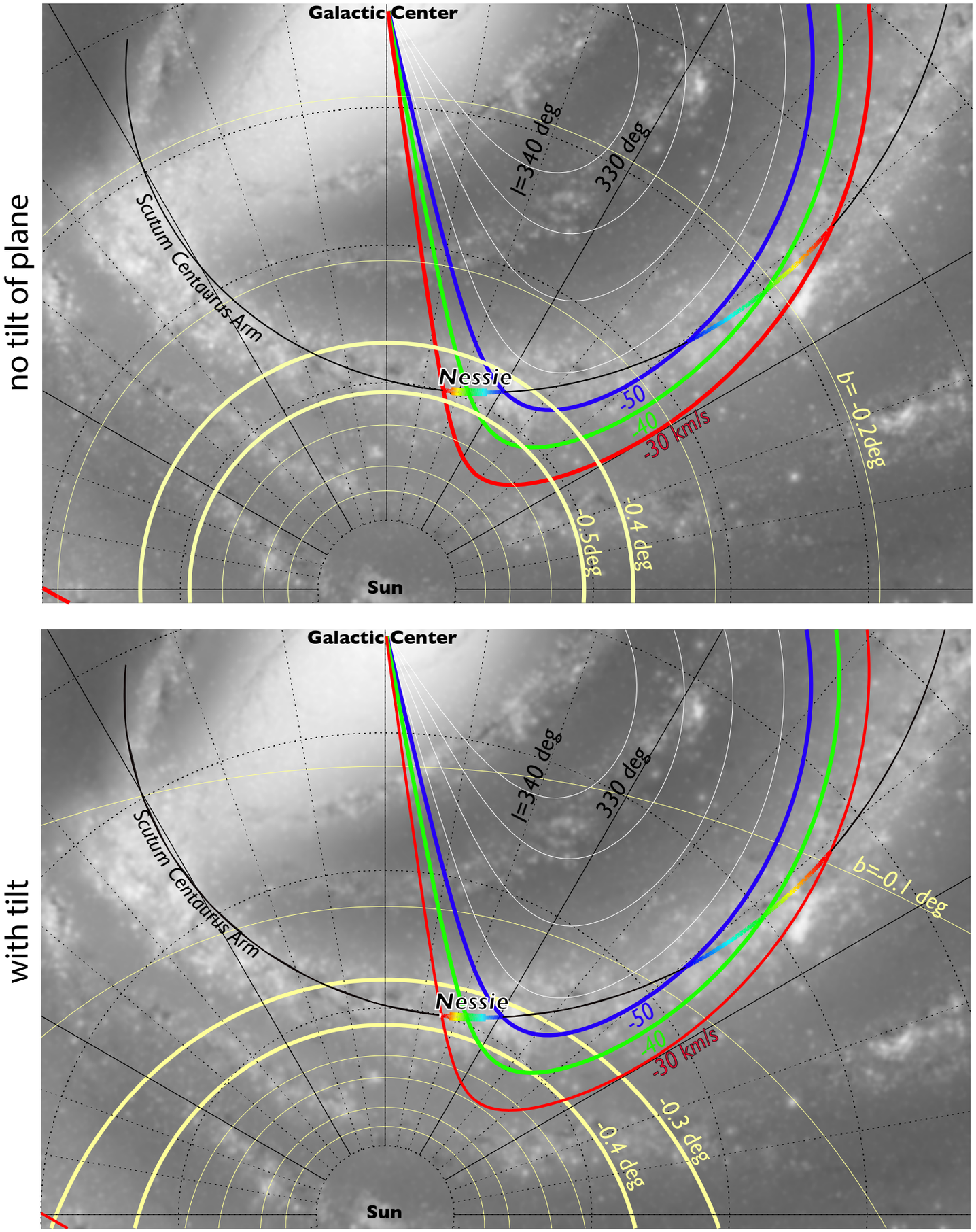



distance
velocity
along line
of sight



Predictions in "3D" (p-p-v space)

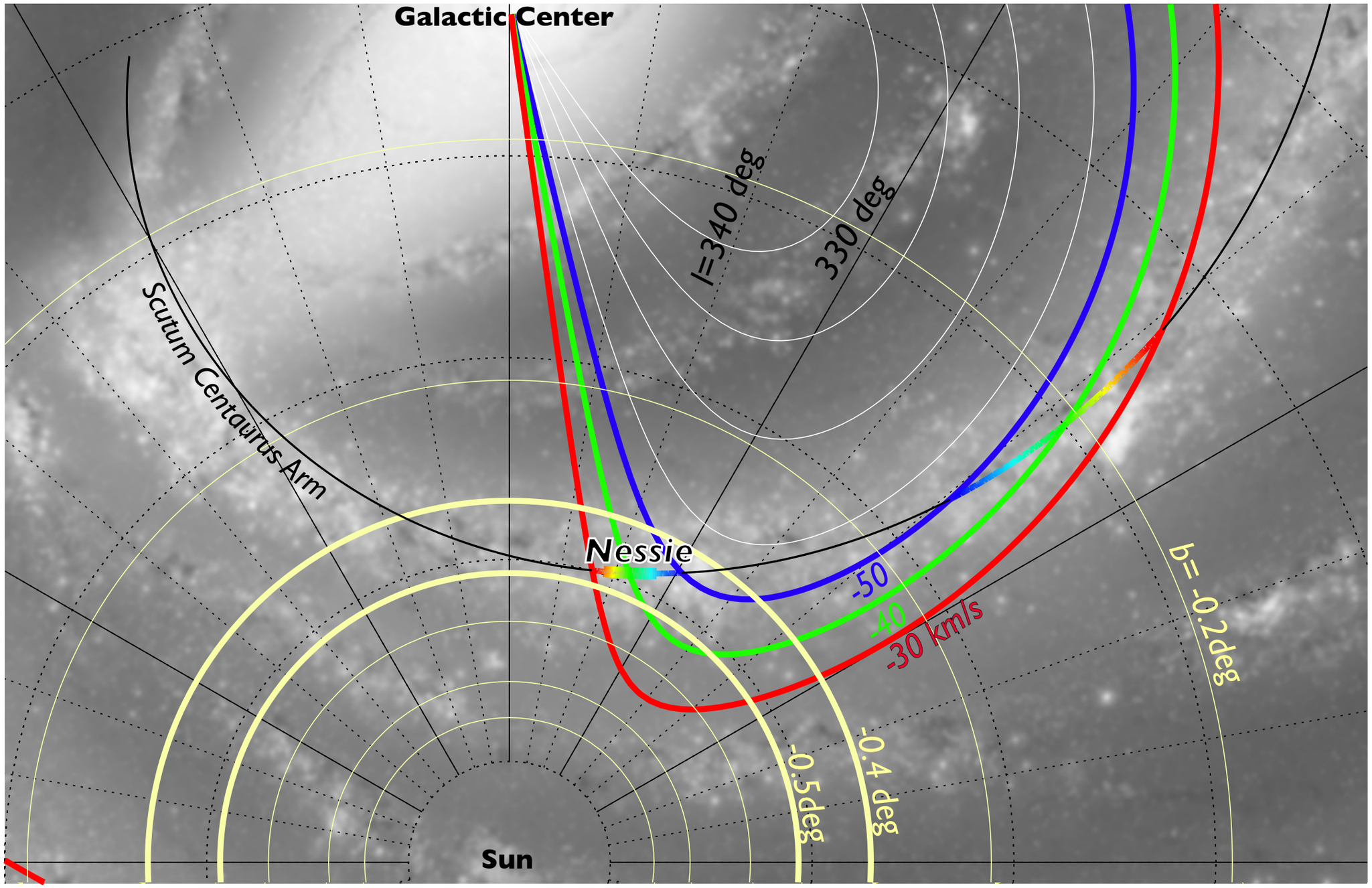




Goodman et al. 2013, see MilkyWayBones.org

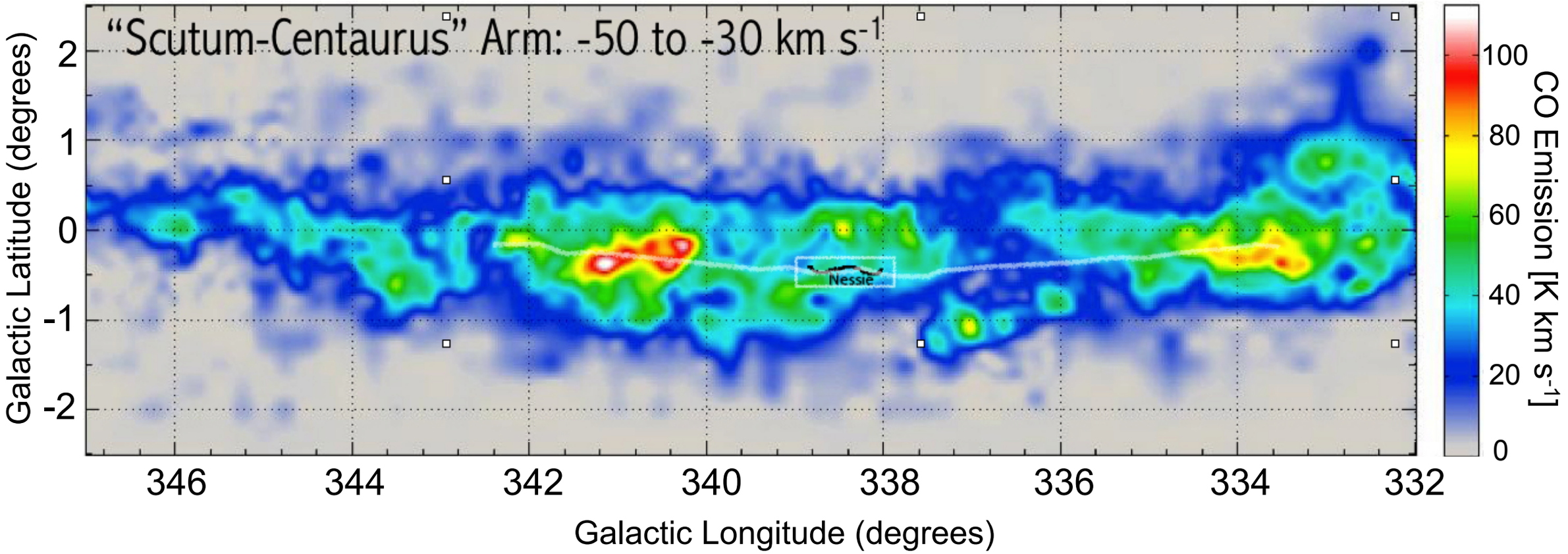
Predictions in "3D"

Including Galactic Center offset)



Goodman et al. 2013, see MilkyWayBones.org

Test in "3D": Is Nesssie at the Right Velocity? (CO)

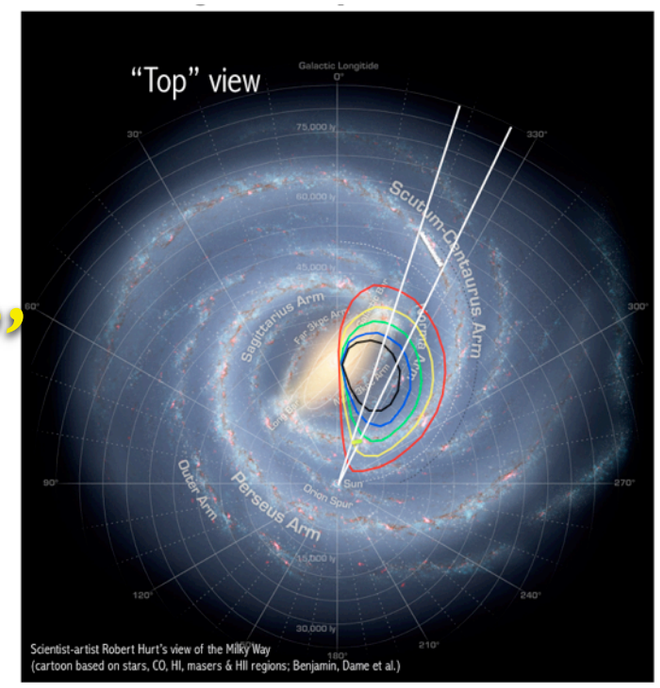


Goodman et al. 2013, see MilkyWayBones.org

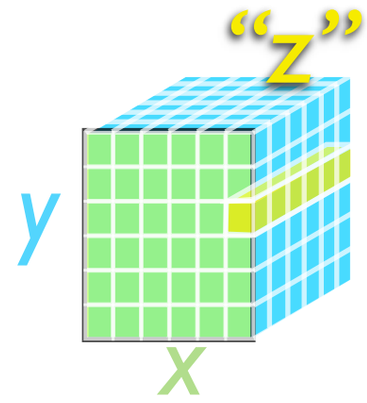
Velocity Constraints

"x"

"z"



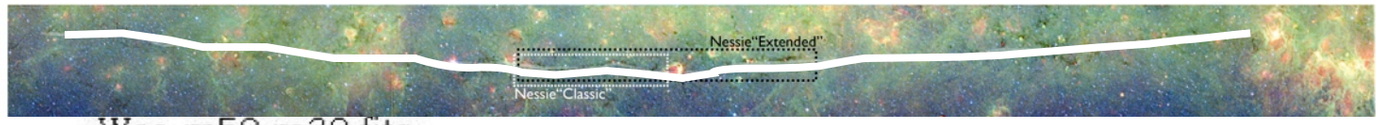
-20
-40
-60
-80
-100



x

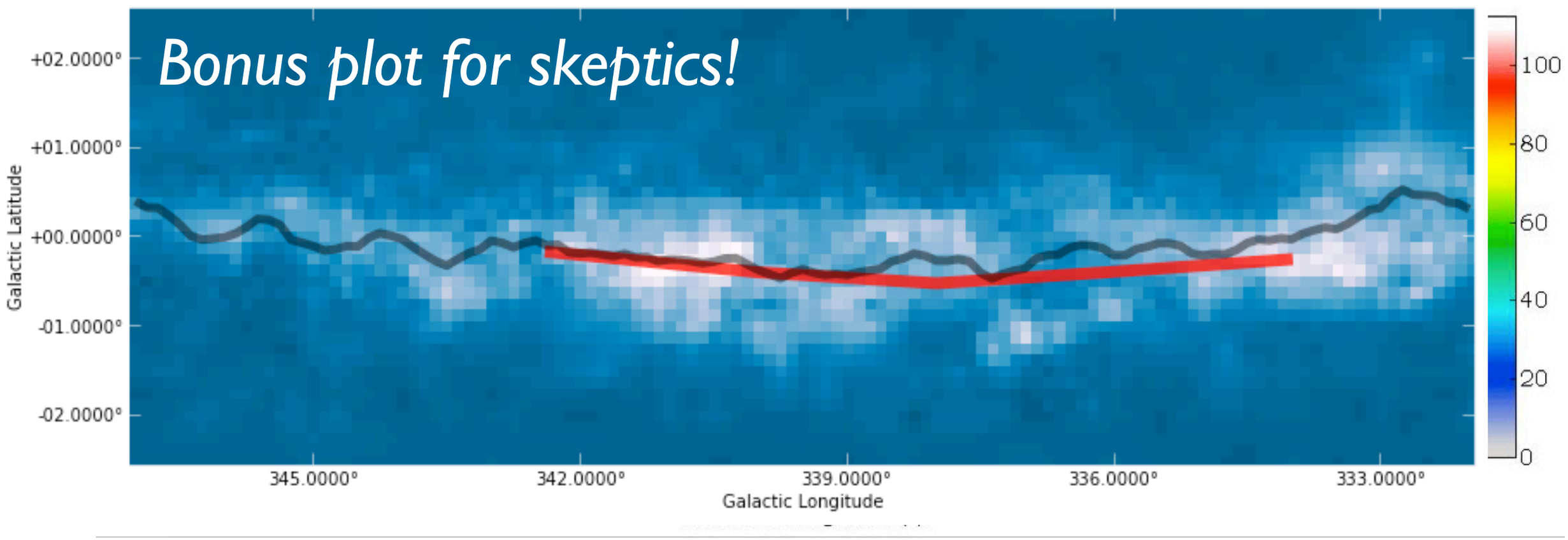
y

1 degree ~ 60 pc at 3.5 kpc

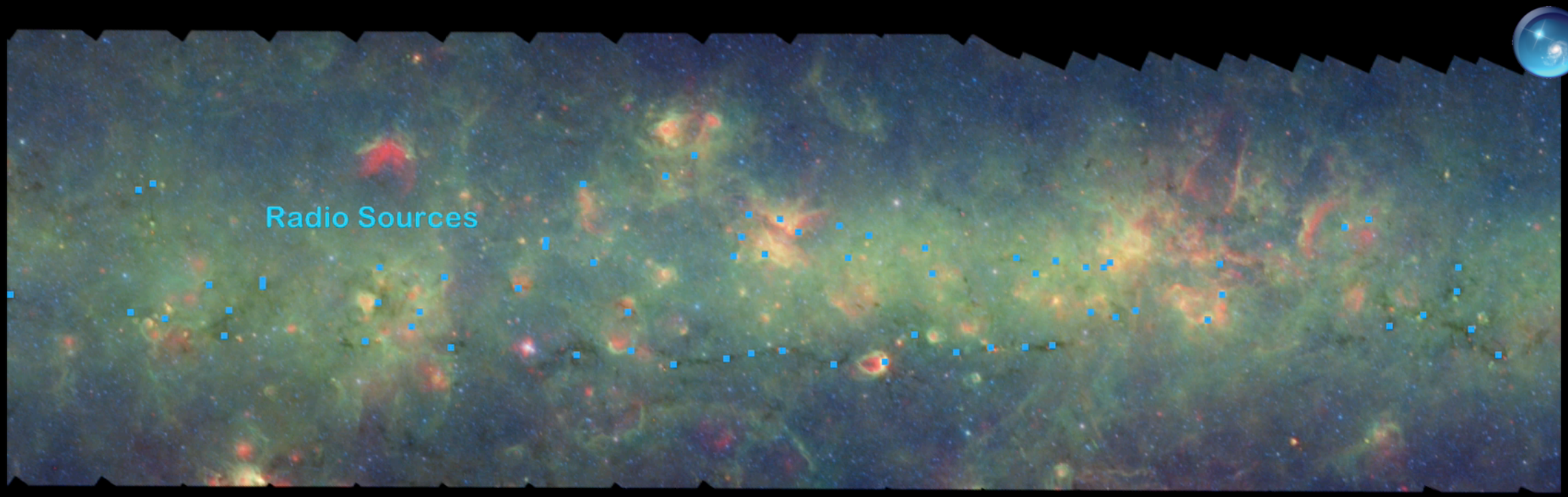


Wco m50 m30.fits

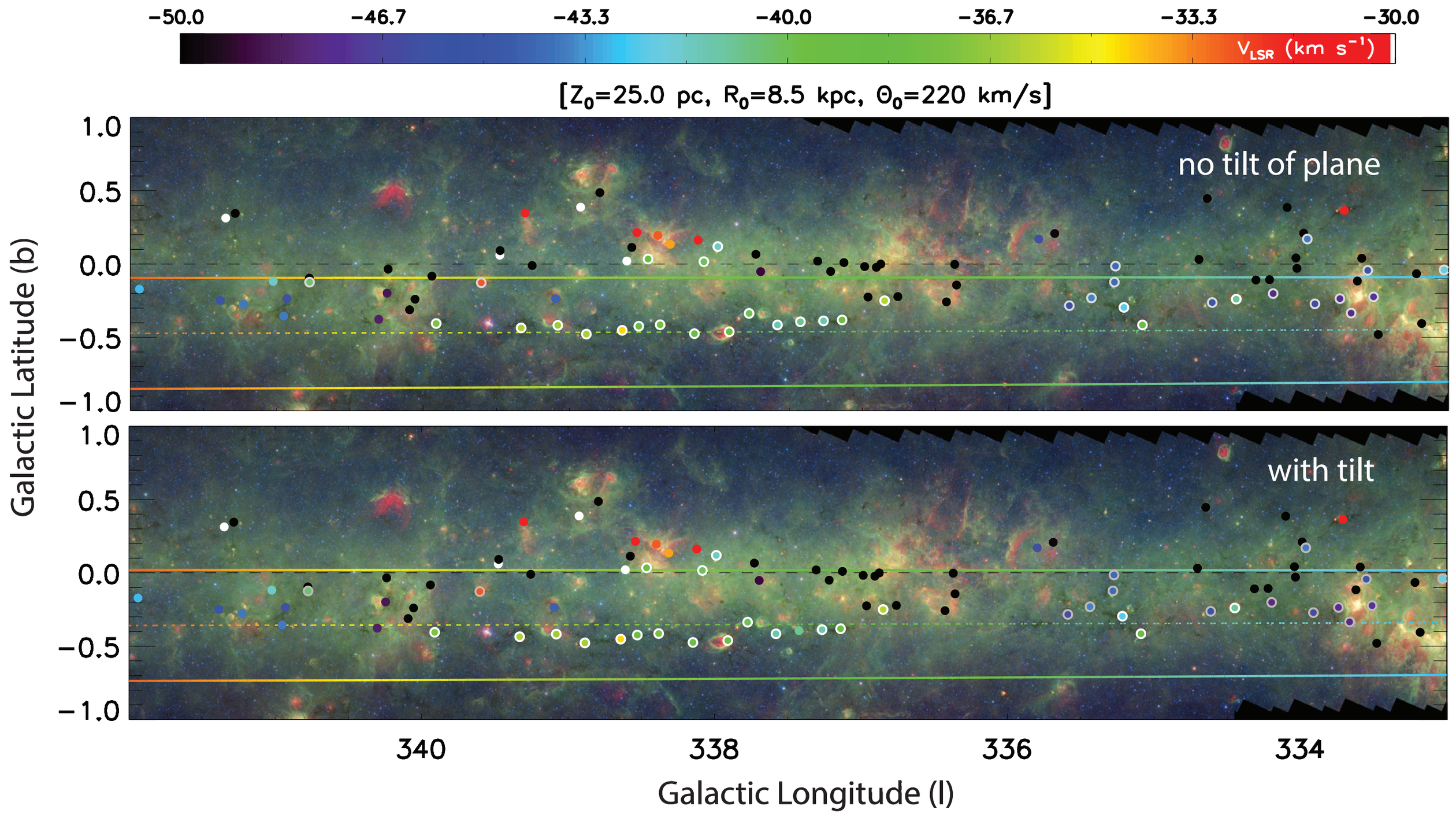
Bonus plot for skeptics!



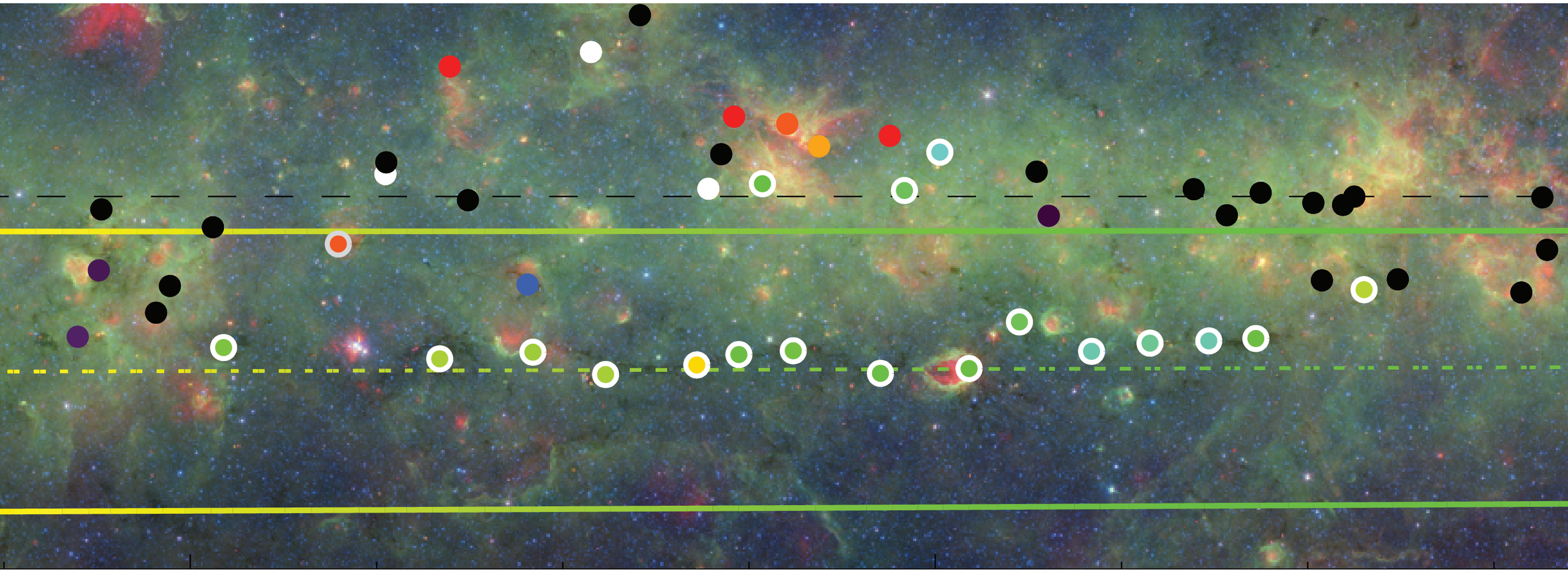
Dense Gas with known velocity (HOPS NH_3)



In the plane and at the distance of spiral arm!



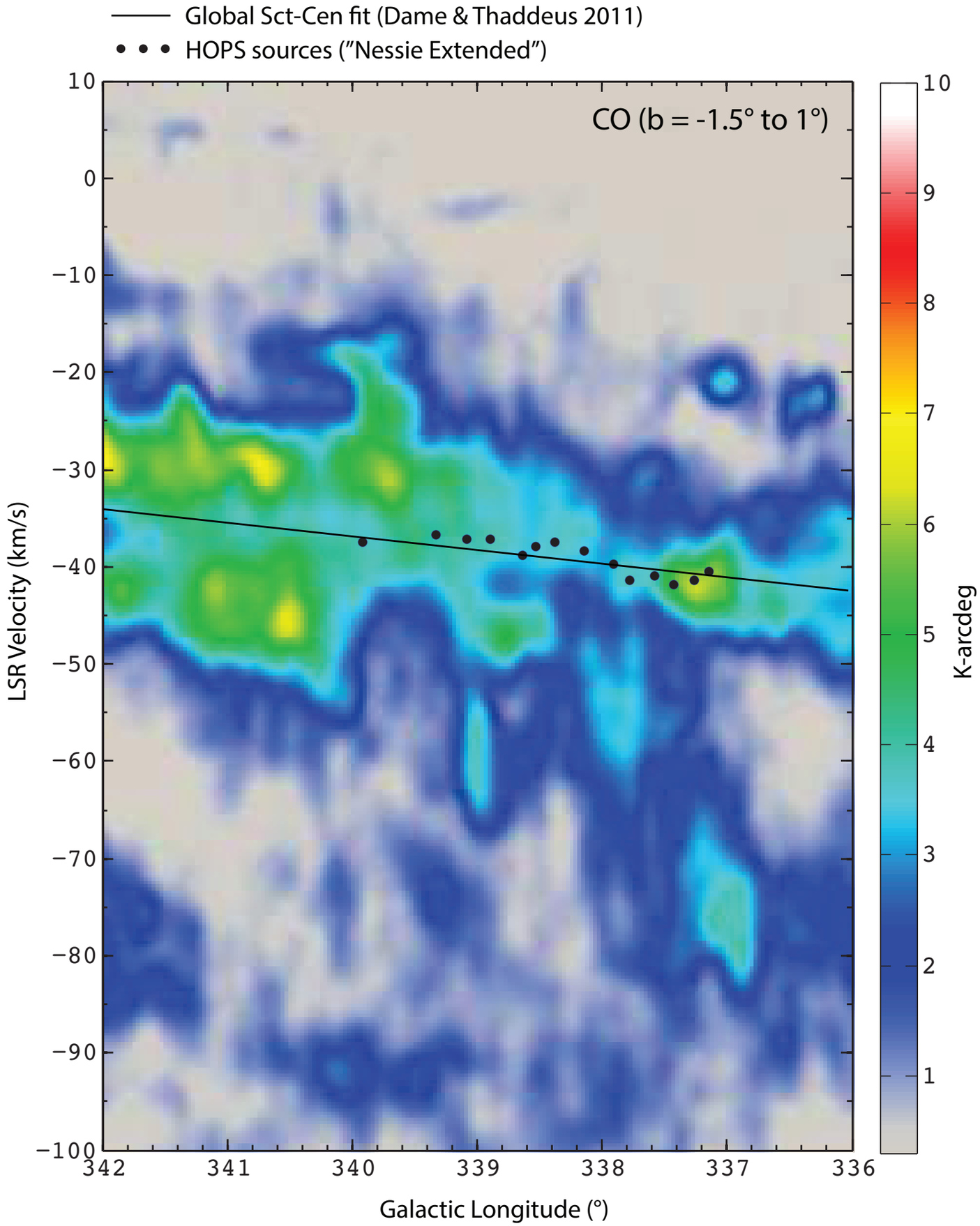
Goodman et al. 2013, see MilkyWayBones.org



...eerily precisely...

Goodman et al. 2013, see MilkyWayBones.org

...eerily precisely...



Goodman et al. 2013, see MilkyWayBones.org

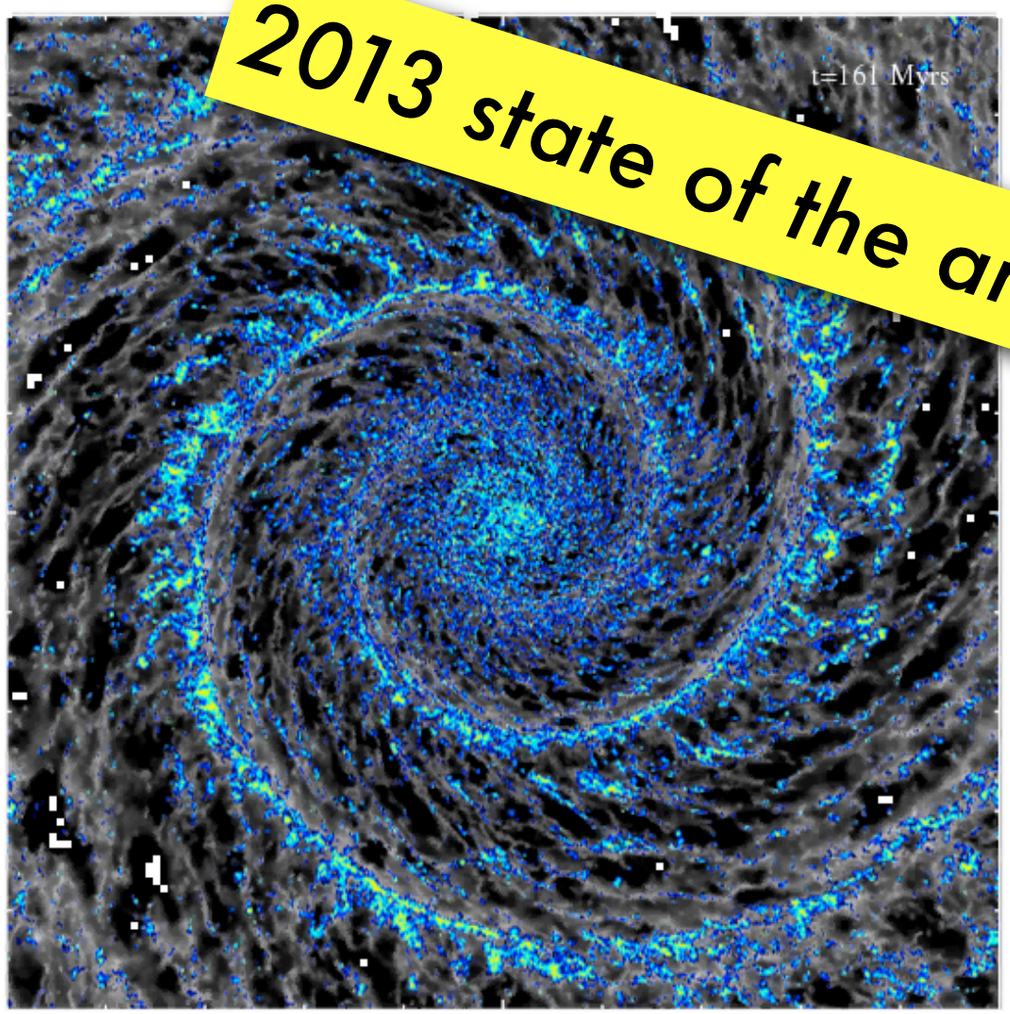
Monster to Bone

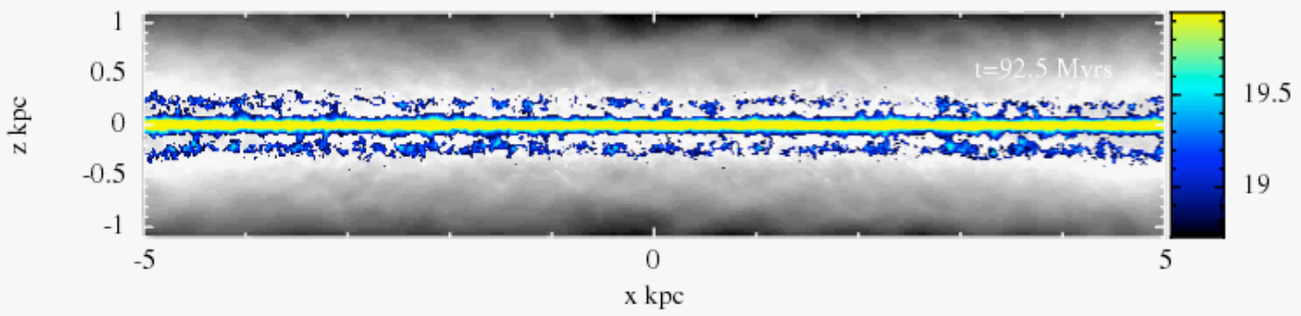
There could be 1000s more of these to find...a full skeleton perhaps?

A full 3D skeleton?

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

2013 state of the art





simulations courtesy Clare Dobbs

Google bones of the milky way

Sign In

Web Images Videos News Shopping More Search tools SafeSearch

2013 state of the art

Astronomy magazine

SUN & MOON MERCURY & VE
MARS, JUPITER & SATURN

	Sun	Moon
RISE	5:16 AM	5:48 AM
SET	8:36 PM	8:38 PM

HOME | THE MAGAZINE | NEWS | OBSERVING | PHOTOS | VIDEOS | B

The power of Astronomy to light the spark of exploration can begin with a single amazing moment at the telescopes eyepiece. Begin your journey with EXPL SCIEN

Home / News / First "bone" of the Milky Way identified

Like 0 Tweet 0 +1 0 Share

First "bone" of the Milky Way identified

Astronomers have identified a new structure in our galaxy — a long tendril of dust and gas.

By Harvard-Smithsonian Center for Astrophysics, Cambridge, Massachusetts | Published: Wednesday, January 09, 2013

RELATED TOPICS: MILKY WAY | SPITZER

Our Milky Way is a spiral galaxy — a pinwheel-shaped collection of stars, gas, and dust. It has a central bar and two major spiral arms that wrap around its disk. Since we view the Milky Way from the inside, its exact structure is difficult to determine.

Astronomers have identified a new structure in the Milky Way — a long tendril of dust and gas that they are calling a "bone."

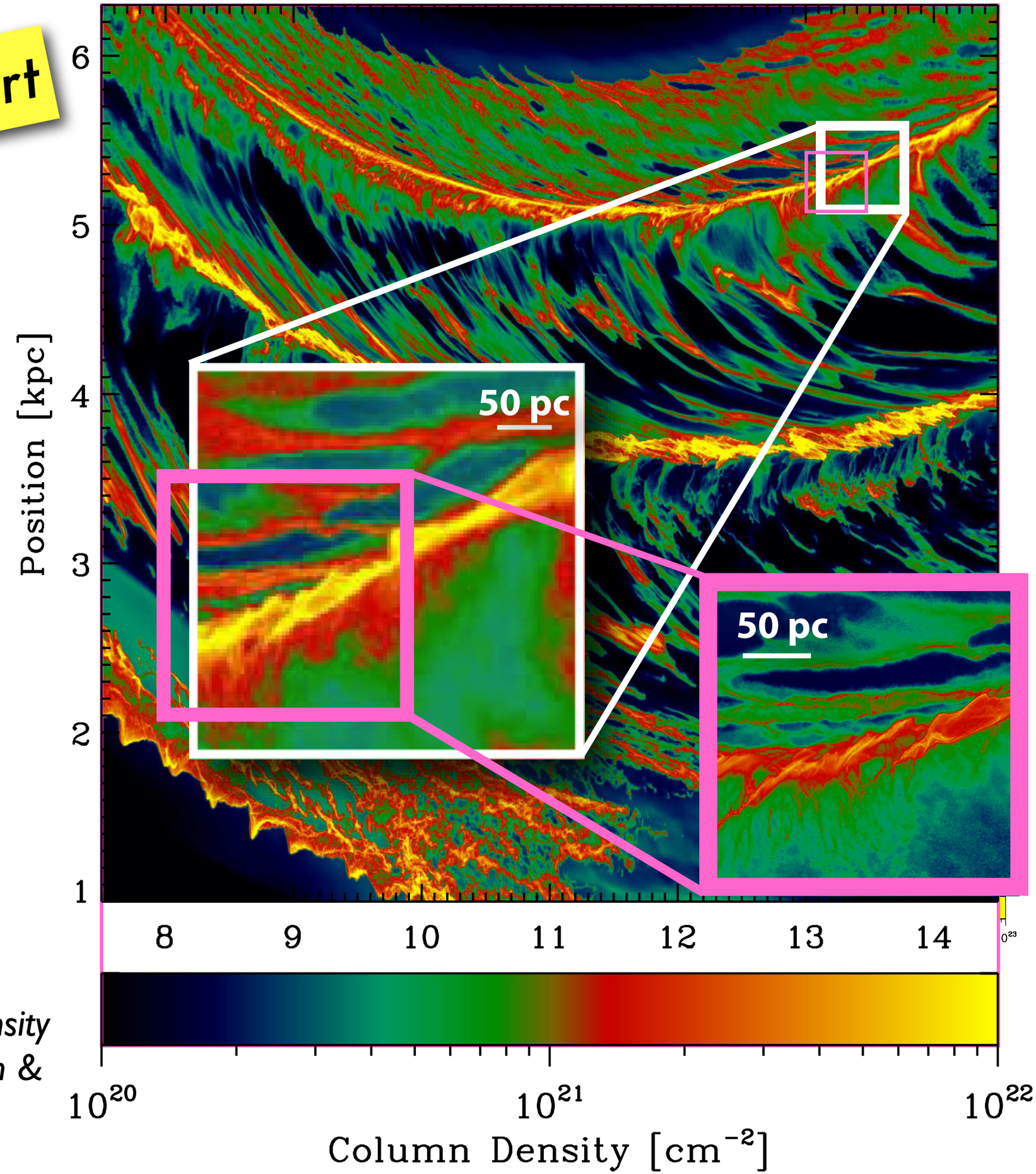
Researchers have identified the first "bone" of the Milky Way — a long tendril of dust and gas that appears dark in this infrared image from the Spitzer Space Telescope. Running horizontally along this image, the "bone" is more than 300 light-years long but only 1 or 2 light-years wide. It contains about 100,000 Suns' worth of material. // *Credit: NASA/JPL/SSC*

"This is the first time we've seen such a delicate piece of the galactic skeleton," said Alyssa Goodman of the Harvard-Smithsonian Center for Astrophysics (CfA) in

2014 state of the art

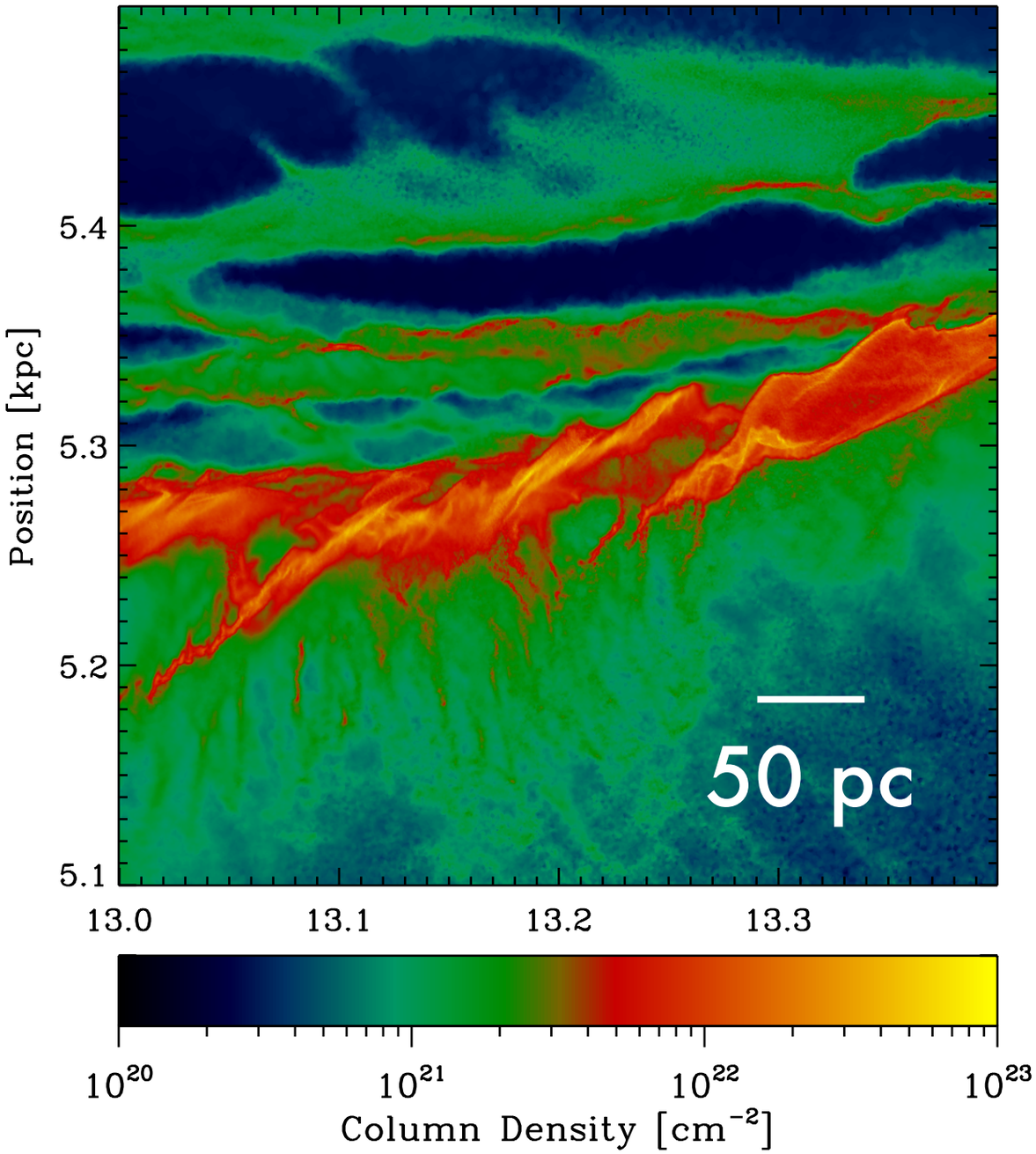
Highest-resolution simulation to date now shows...

Nessies should be there!

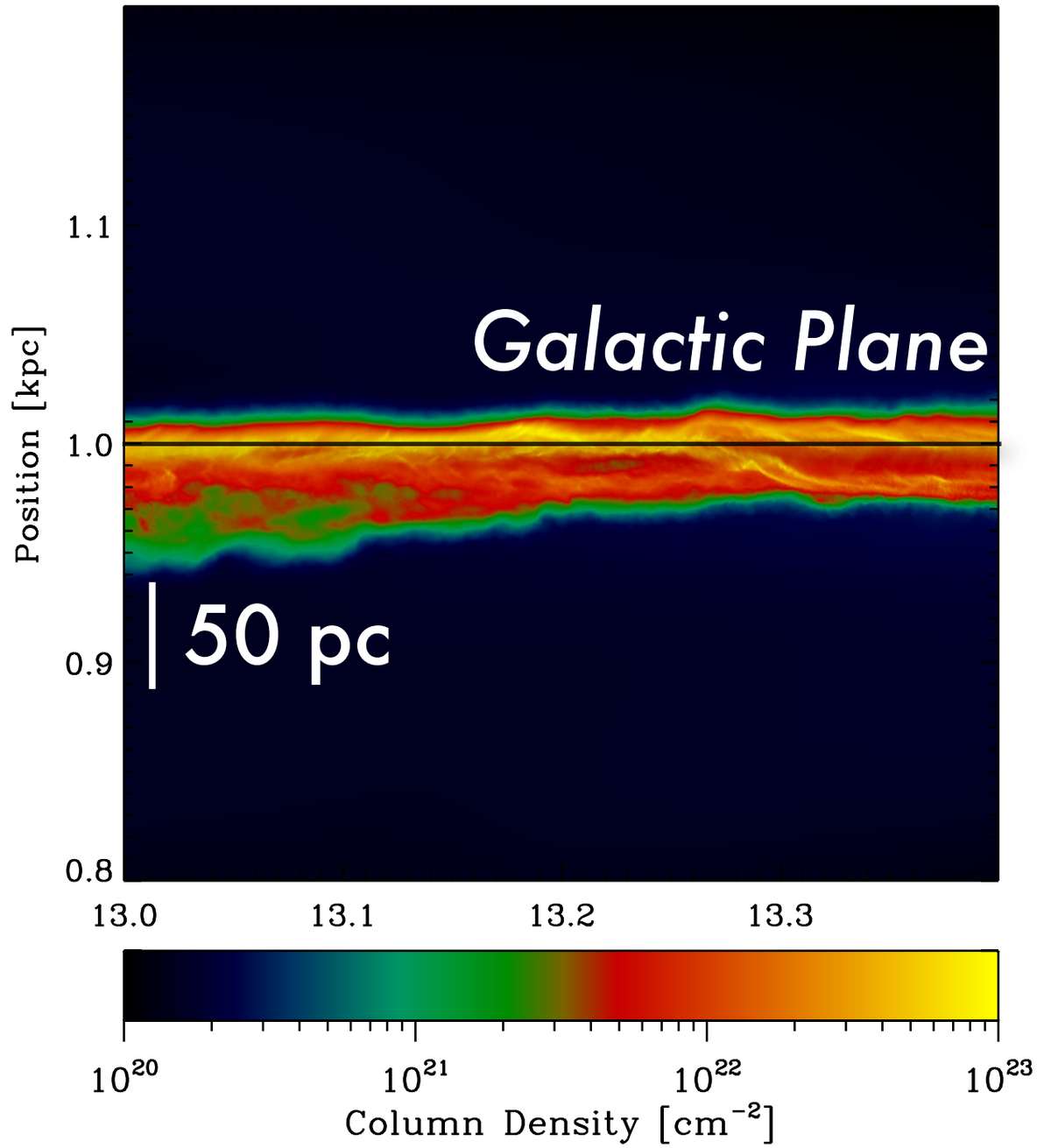


simulation of total H column density from Smith, Glover, Clark, Klessen & Springel 2014

"Top Down"

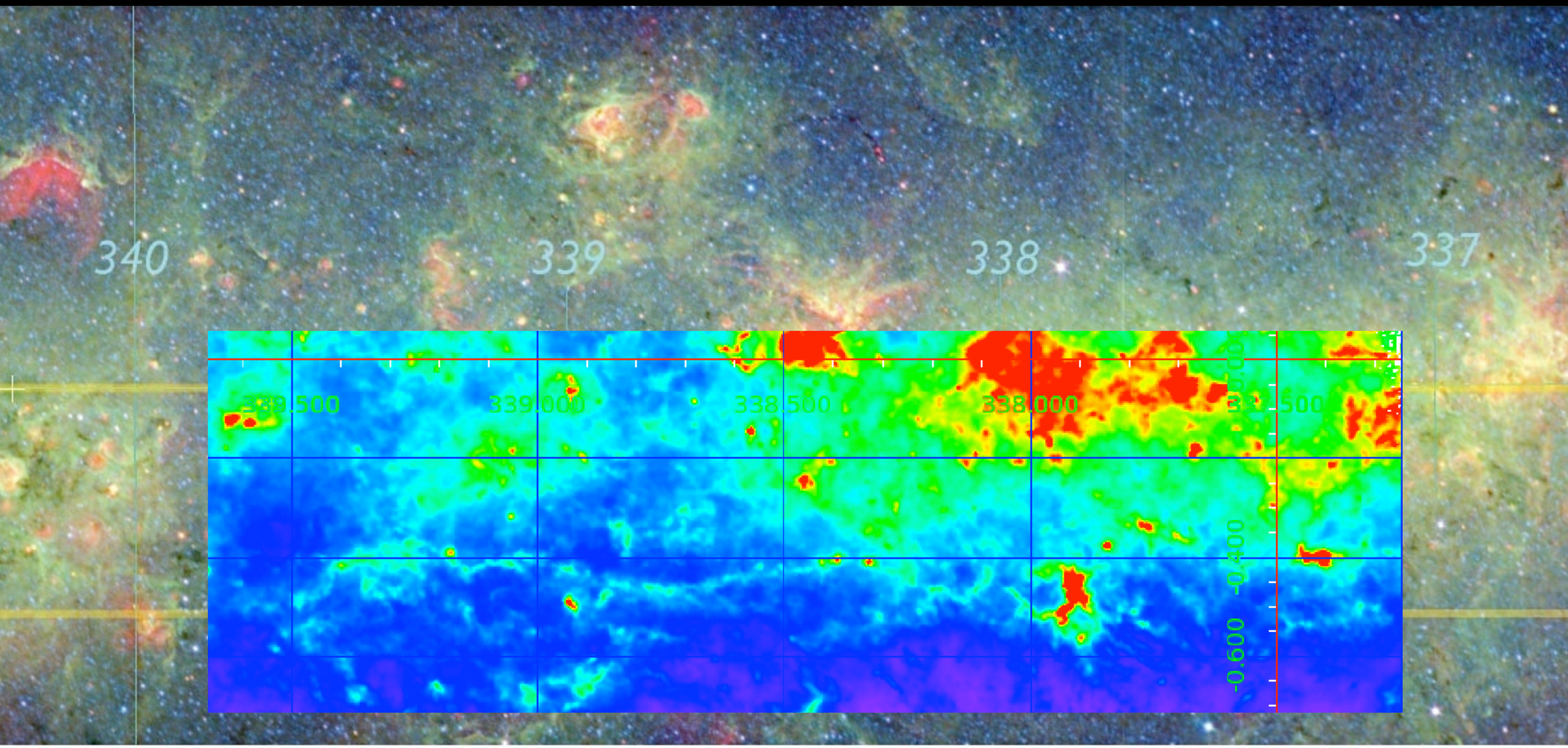


"Edge-On"

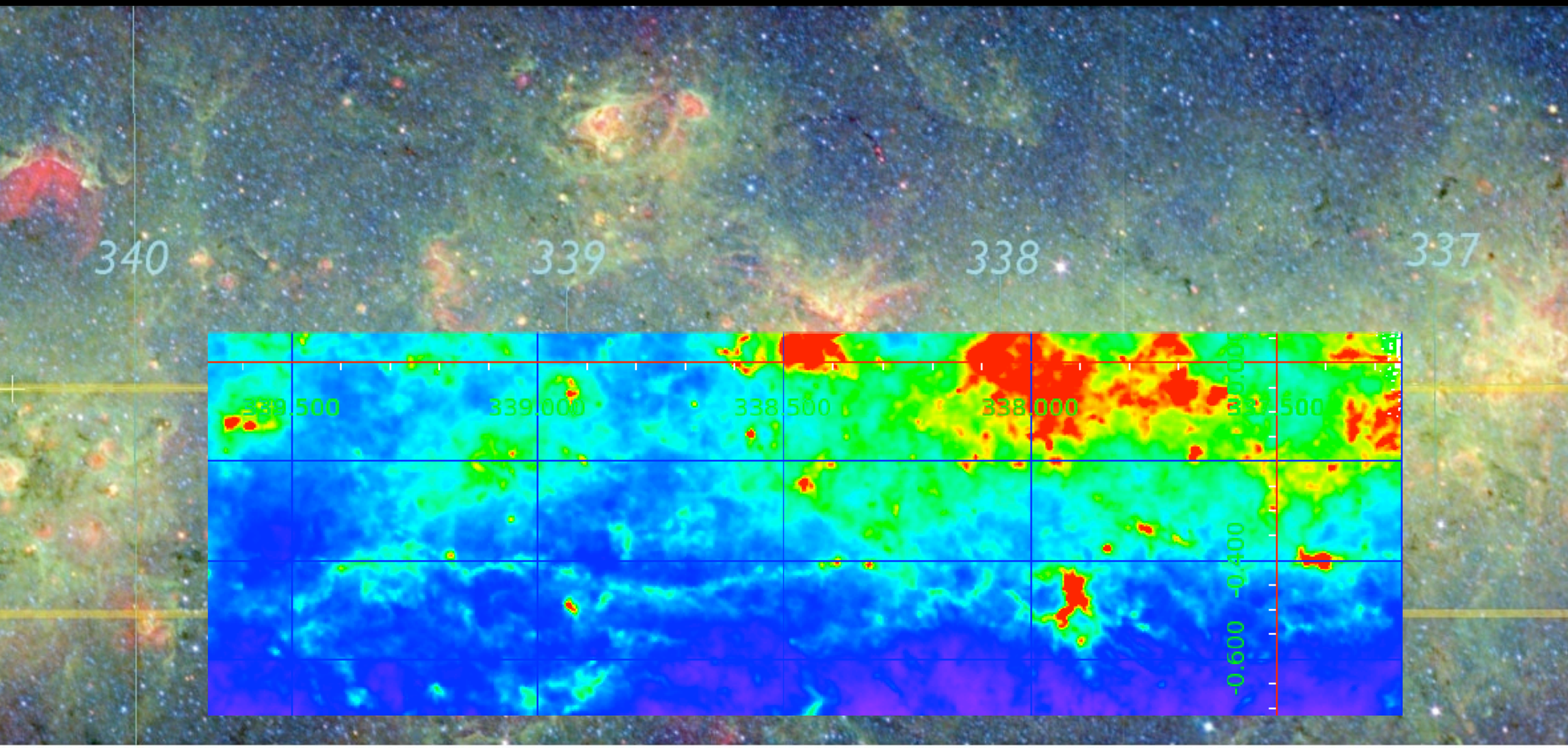


simulation of total hydrogen column density from Smith, Glover, Clark, Klessen & Springel 2014

Nessie as seen by Herschel
(thanks to Quang Nguyen-Luong, CITA)



Nessie as seen by Herschel
(thanks to Quang Nguyen-Luong, CITA)



Sea Monster to Skeletal Shadow

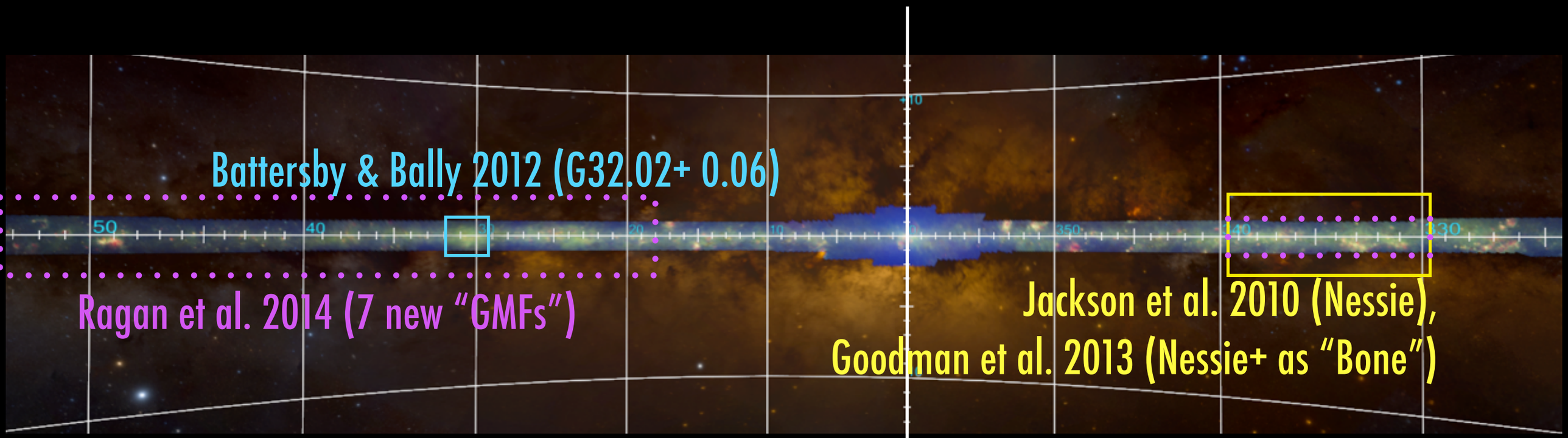
Spitzer GLIMPSE Image

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.

Identification of Long, Skinny Filaments near the Galactic Plane



+Summer 2014: Battersby, Zucker & Goodman are investigating 5 new candidates, identifed as close to projected arms

Strategies for going beyond Nessie differ...

Ragan et al. 2014 (7 new "GMFs")

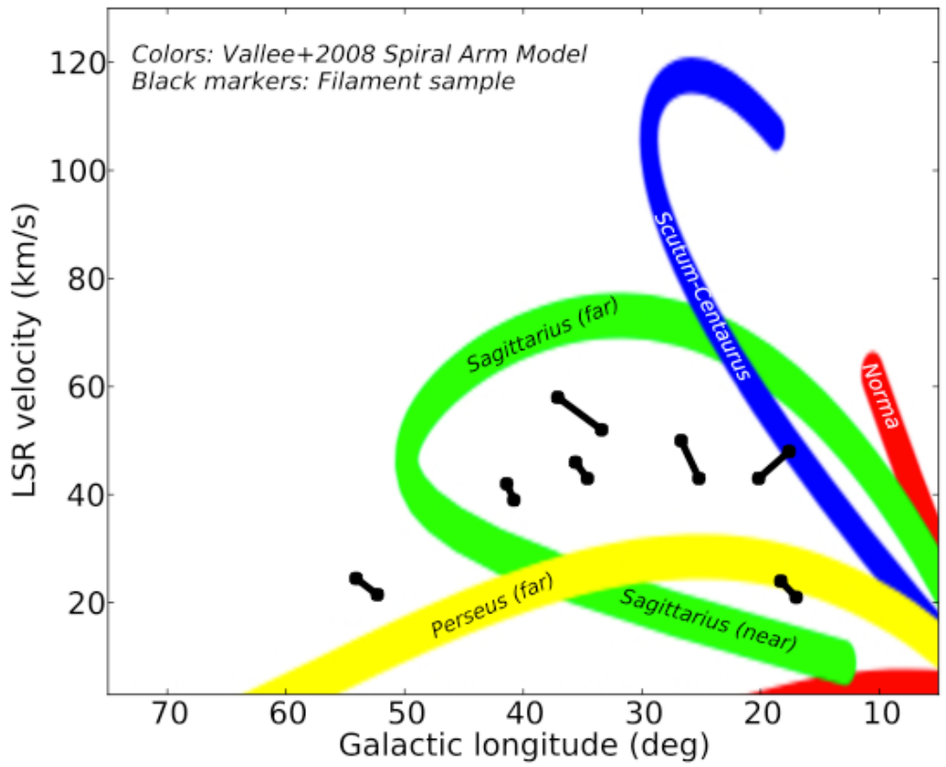
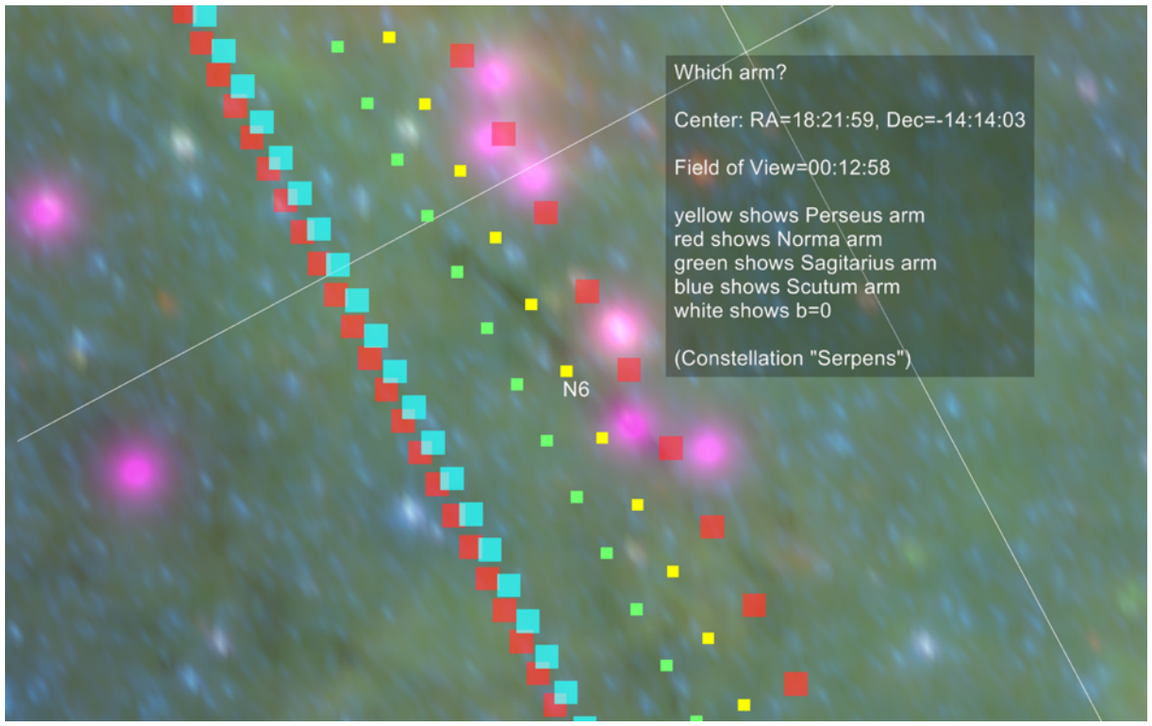
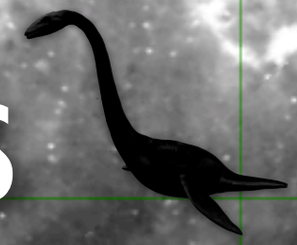


Fig. 4. Illustration of the predicted LSR velocities of the Norma (red), Scutum-Centaurus (blue), Sagittarius-Carina (green), and (far) Perseus (yellow) spiral arms as a function of Galactic longitude in the first quadrant taken from Vallée (2008). Each set of two black circles represent the filament sample, taking approximate values of v_{lsr} from the ends of the filaments.

Battersby/Zucker/Goodman et al. 2014



The Bones of the Milky Way: Credits



Seamless Astronomy-style tools used in this project

SEAMLESS ASTRONOMY
Linking scientific data, publications, and communities

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

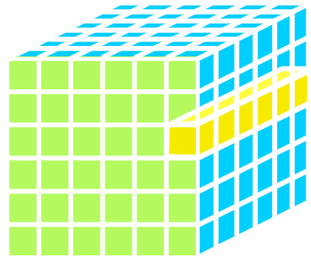
NASA

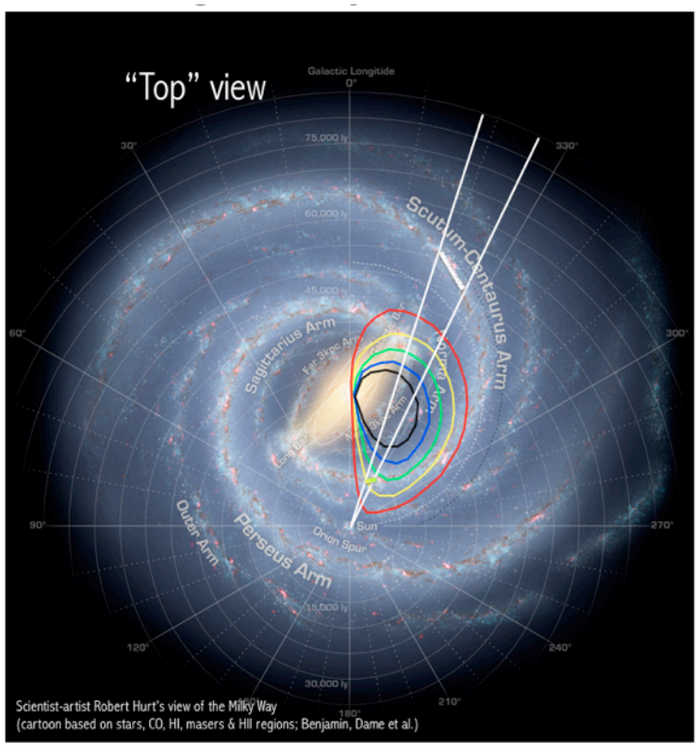
VERITAS

Smithsonian

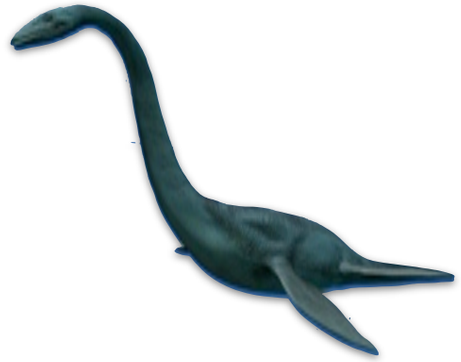
"The Making of" the Bones of the Milky Way

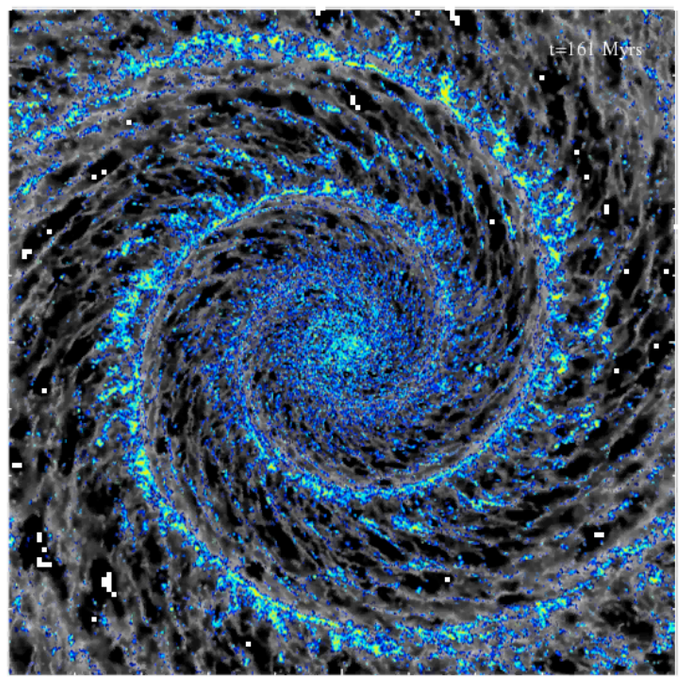
SEAMLESS ASTRONOMY
Linking scientific data, publications, and communities





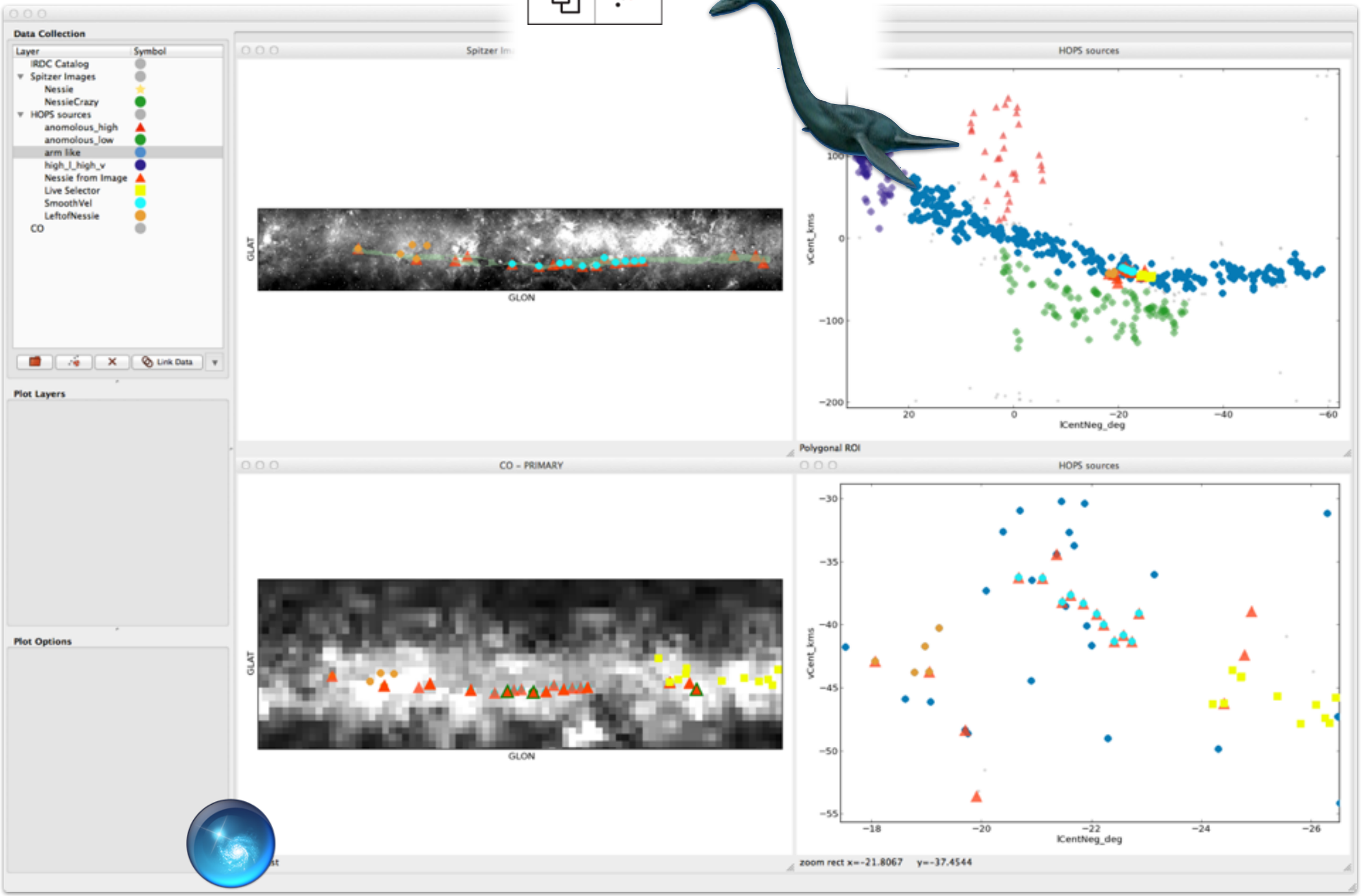
-20
-40
-60
-80
-100





glue

multidimensional data exploration

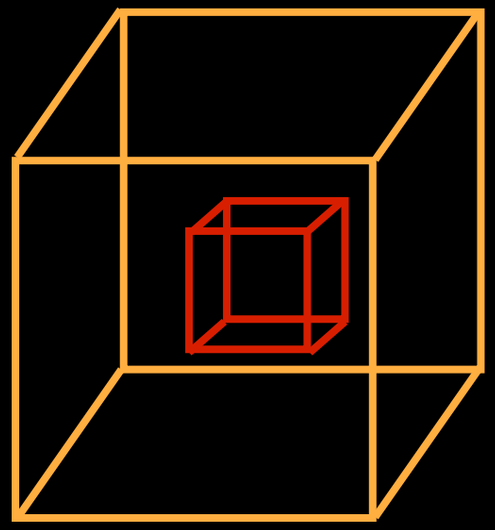


http://www.glueviz.org/en/latest/

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

"Linked Views" = glue

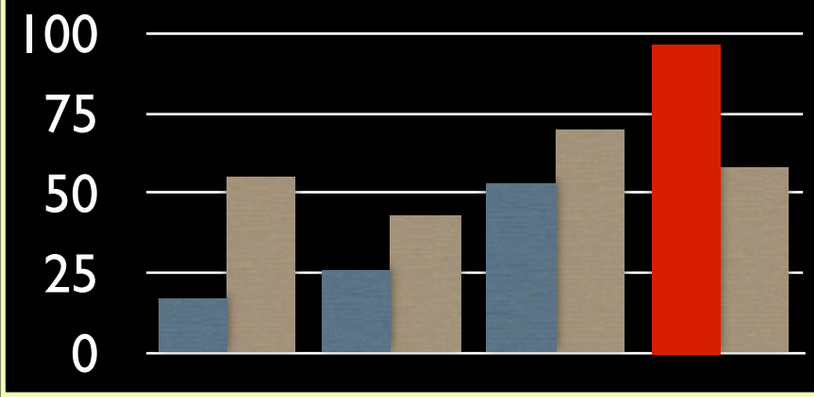
multidimensional data exploration



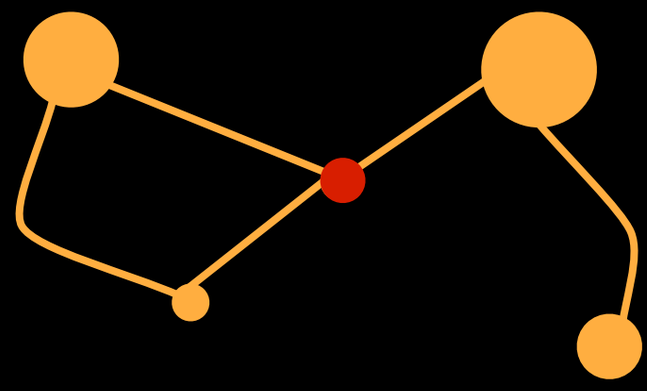
3D

2D

Statistics



Data Abstraction



What is glue?

Glue 0.1 documentation » next index

Table Of Contents

Glue Documentation
Indices and tables

Next topic

Installing Glue

This Page

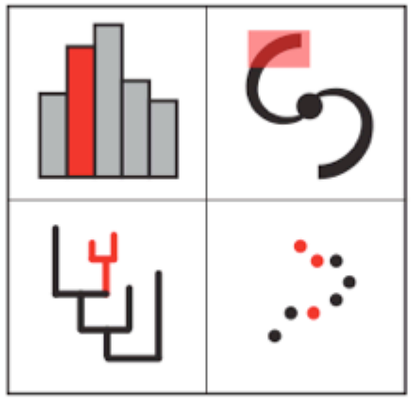
Show Source
Show on GitHub
Edit on GitHub

Quick search

Go

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

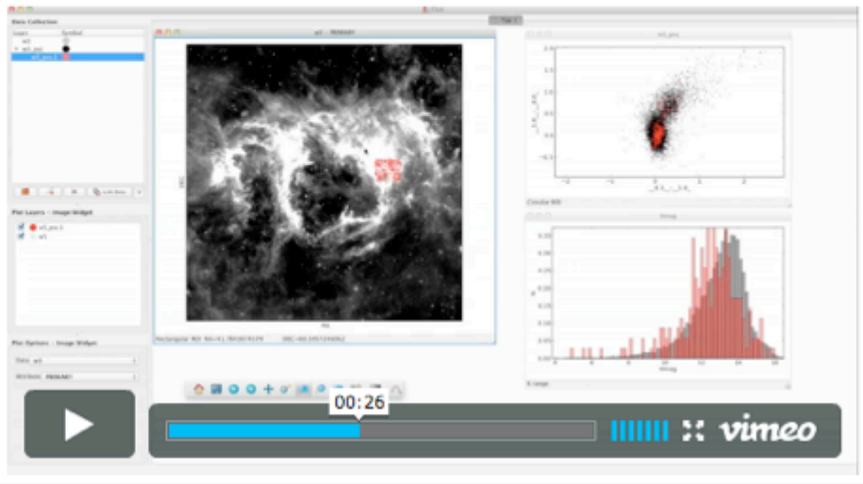
Glue Documentation



glue
multidimensional data exploration

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

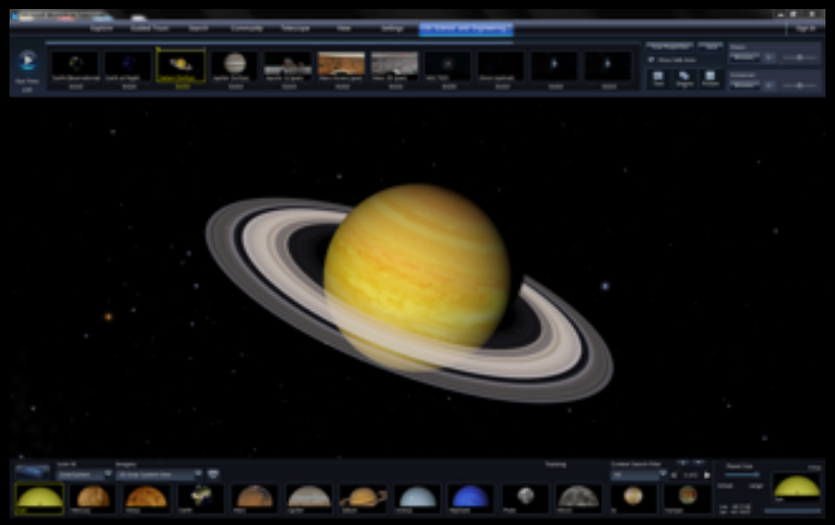
- **Linked Statistical Graphics.** With Glue, users can create scatter plots, histograms and images (2D and 3D) of their data. Glue is focused on the brushing and linking paradigm, where selections in any graph propagate to all others.
- **Flexible linking across data.** Glue uses the logical links that 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.

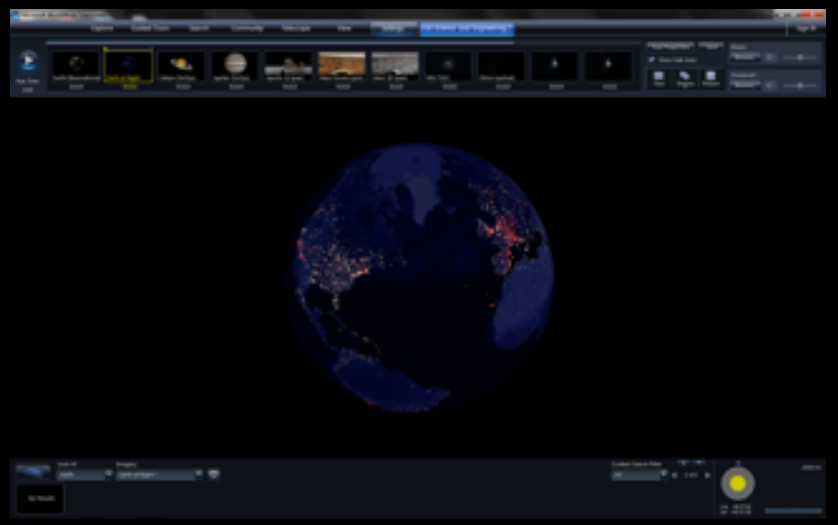


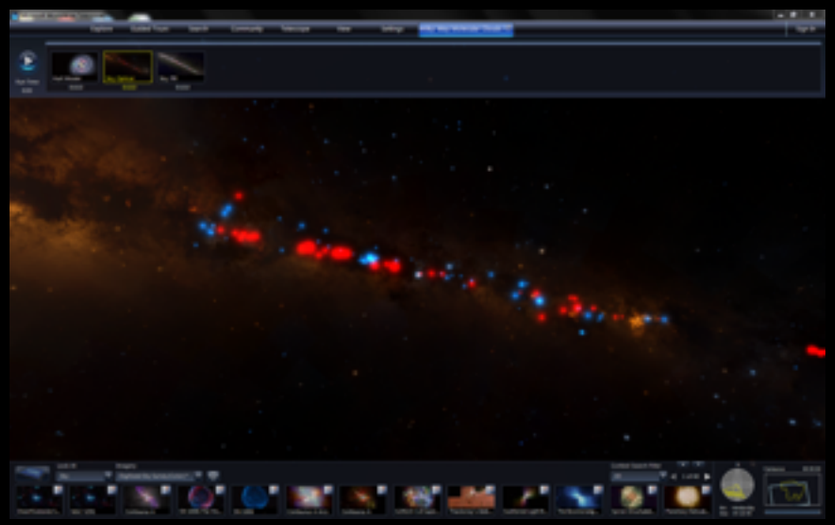
[the film!]

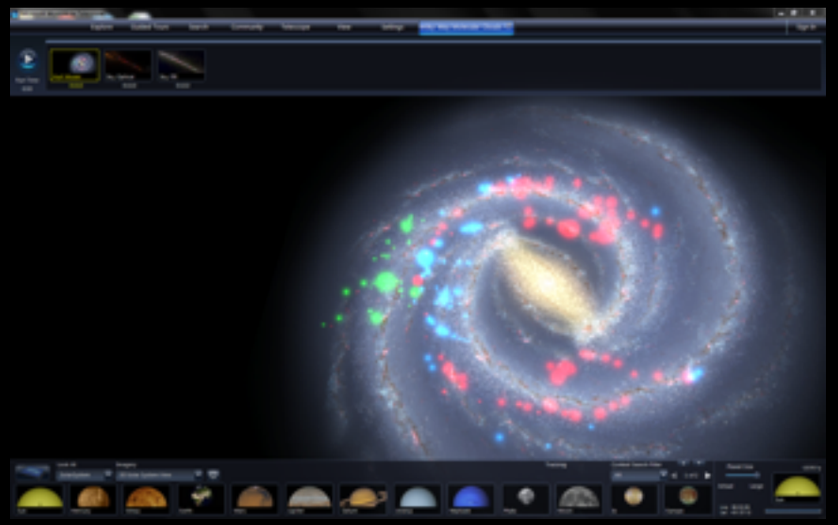
python™

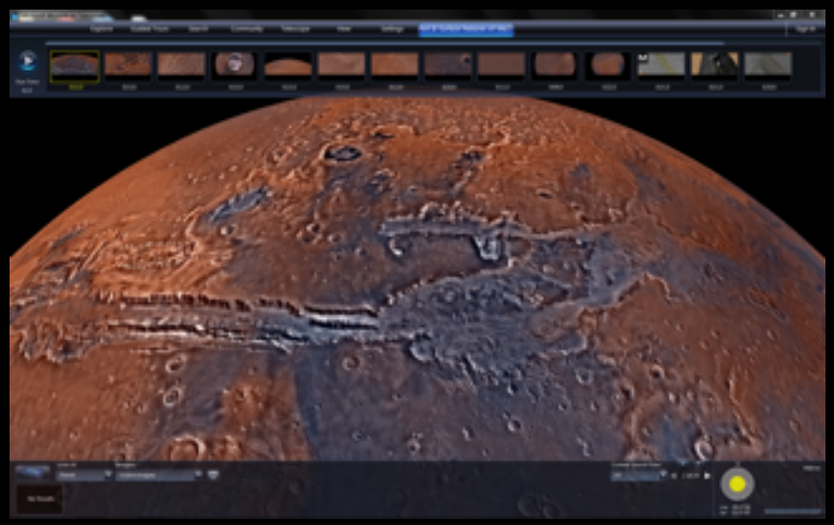
Glue collaboration: ***Beaumont****, Borkin, Goodman, Pfister, Robitaille*

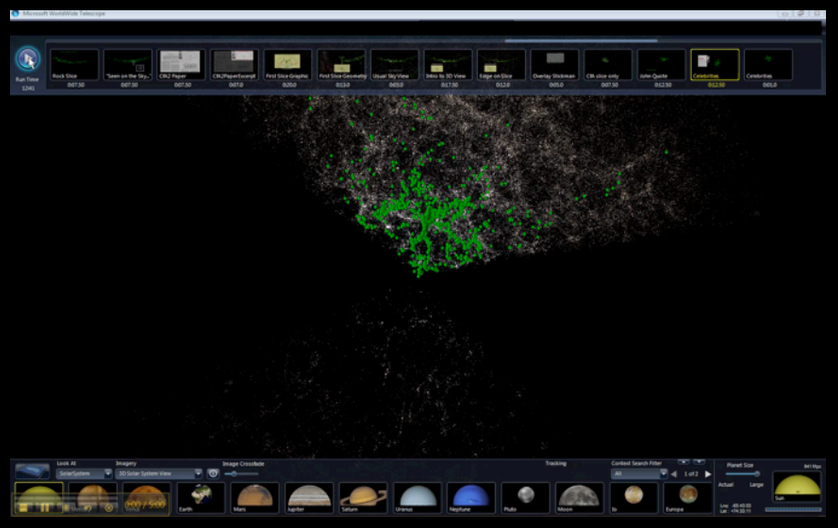


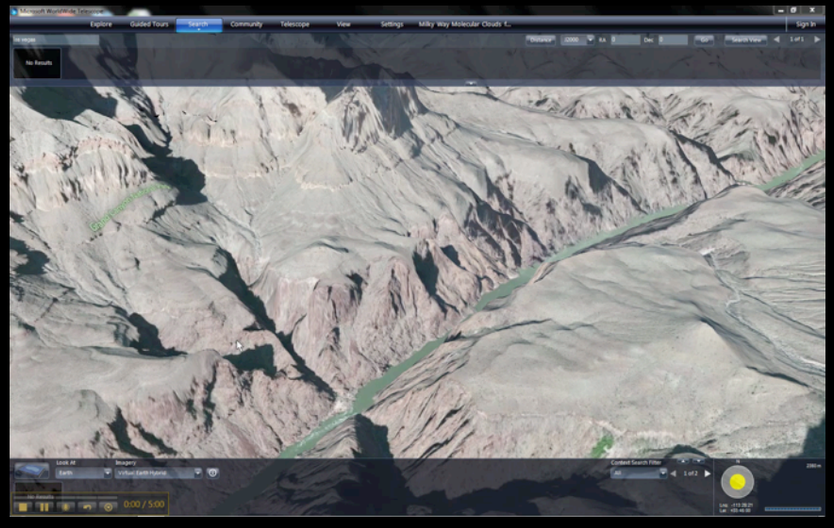












Experience WWT at **worldwidetelescope.org**

milkywaybones.org
worldwidetelescope.org