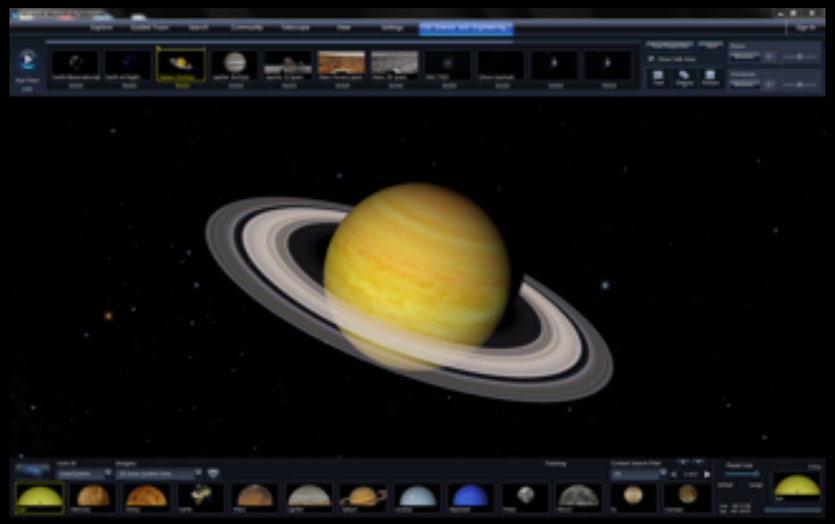

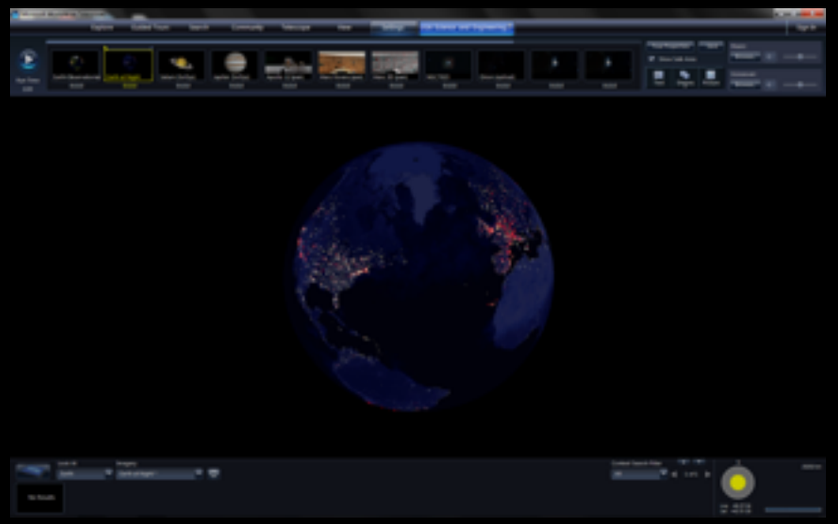

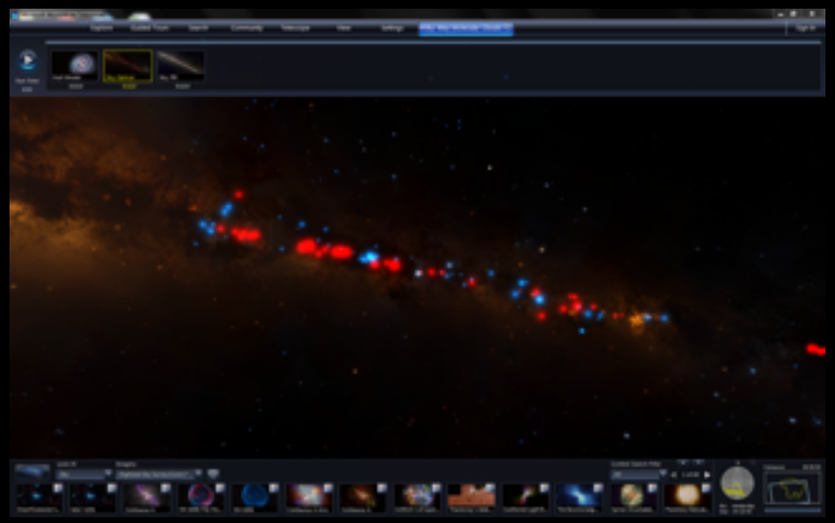

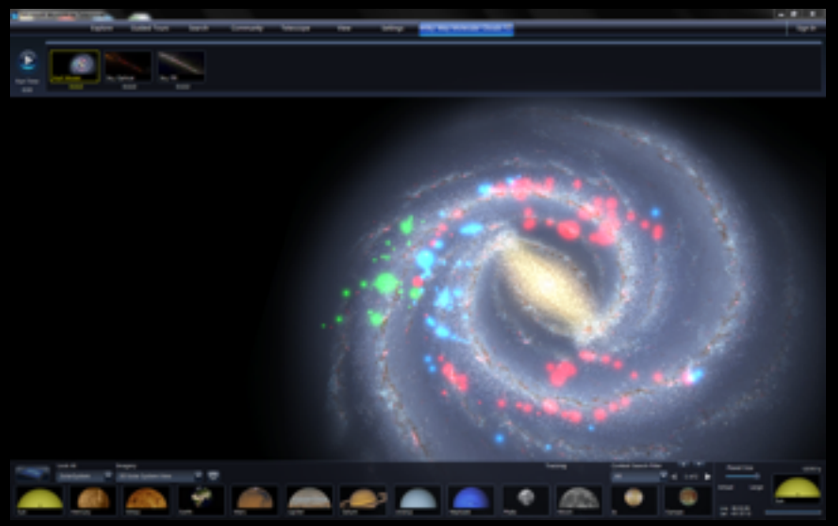

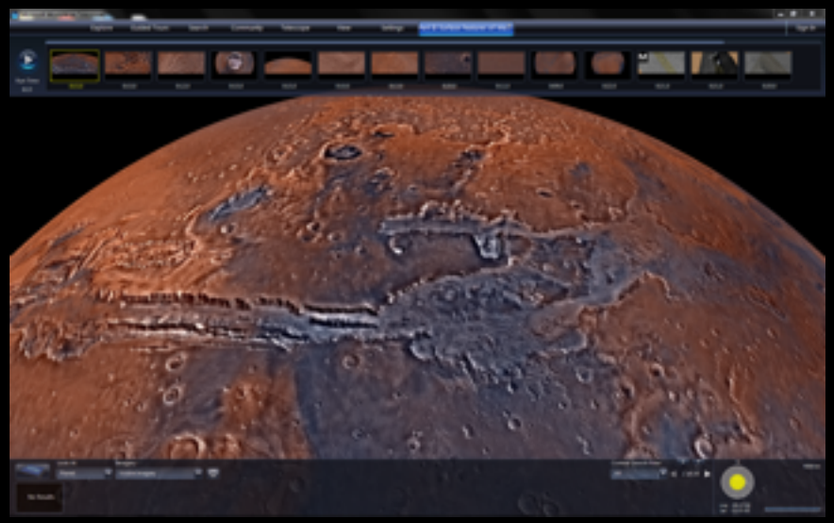

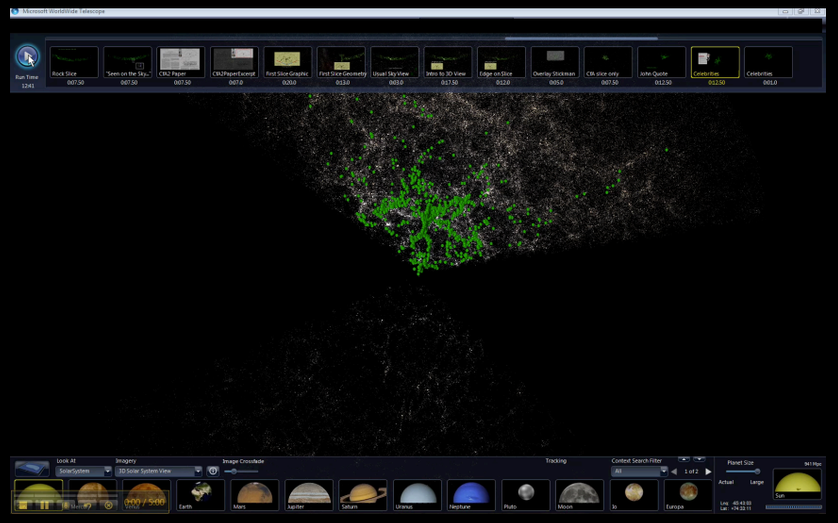

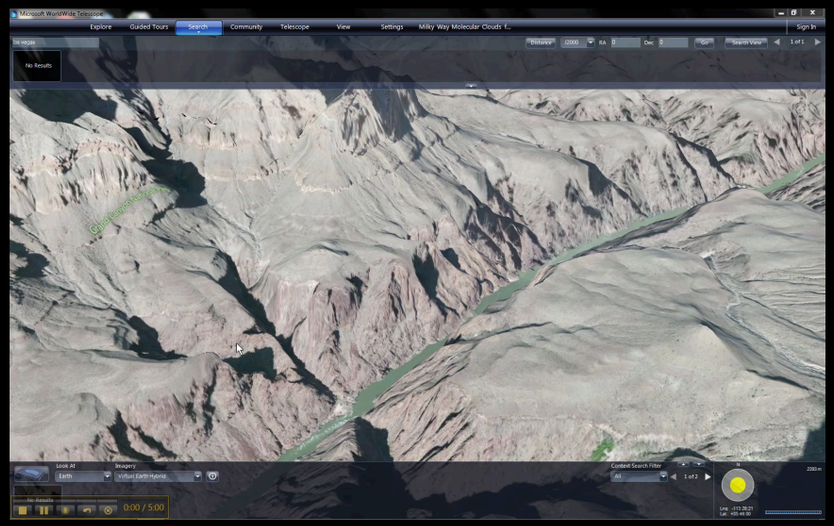

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The Skeleton of the Milky Way

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

with collaborators at (alphabetically by current insitution):

American Astronomical Society: Thomas Robitaille

Boston University: James Jackson

Haystack Observatory: Jens Kauffmann

Harvard - Smithsonian: Thomas Dame, Doug Finkbeiner, Mark Reid, Catherine Zucker

Netflix: Christopher Beaumont

Northeastern Univeristy: Michelle A. Borkin

U. Connecticut: Cara Battersby

U. Munich, Germany: Andreas Burkert

U. Manchester, UK: Rowan Smith

U. Vienna, Austria: Joao F. Alves

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

The Spitzer Infrared Nearby Galaxies Survey (SINGS) Hubble Tuning-Fork

The Spitzer Space Telescope observed 75 galaxies as part of its SINGS (Spitzer Infrared Nearby Galaxies Survey) Legacy Program. The galaxies are presented here in a Hubble Tuning-Fork diagram, which groups galaxies according to the morphology of their nuclei and spiral arms. The designation of these galaxies and their placement in the diagram is based on their visible-light appearance. The main goal of the SINGS program is to characterize the infrared properties of a wide range of galaxy types. The images of the galaxies are composites created from data taken by IRAC (the Infrared Array Camera) at 3.6 and 8.0 μm, and MIPS (the Multiband Imaging Photometer for Spitzer) at 24 μm.

The infrared range probed by these and other observations taken for the SINGS project allows for the detailed study of star formation, dust emission, and the distribution of stars in each galaxy. Light from old stars appears as blue in the images, while the lumpy knots of green and red light are produced by dust clouds surrounding newly born stars. The elliptical galaxies on the left are almost entirely made of old stars, while spiral galaxies like our own Milky Way are rich in young stars and the raw materials for future star formation.

More information can be found at:
http://sings.stsci.edu/

Unbarred Spirals

Weak Bulge

Strong Bulge

Intermediate Spirals

Strong Bulge

Ellipticals

Irregulars

Weak Bulge

Barred Spirals

Poster and composite images created from SINGS observations by Karl D. Gordon (Oct 2007)
Blue=IRAC 3.6μm (stars)
Green=IRAC 8μm
(aromatic features from dust grains/molecules)
Red=MIPS 24μm (warm dust)

SINGS Team

Robert Kennicutt, Jr. (Principle Investigator), Daniela Calzetti (Deputy Principle Investigator), Charles Engelbracht (Technical Contact), Lee Armus, George Bendo, Caroline Bot, Brent Buckalew, John Cannon, Daniel Dale, Bruce Draine, Karl Gordon, Albert Grauer, David Hollenbach, Tom Jarrett, Lisa Kewley, Claus Leitherer, Aigen Li, Sangeeta Malhotra, Martin Meyer, John Moustakas, Eric Murphy, Michael Regan, George Rieke, Marcia Rieke, Helene Roussel, Kartik Sheth, J.D. Smith, Michele Thornley, Fabian Walter & George Helou

1936: “The Realm of the Nebulae” by Edwin Hubble

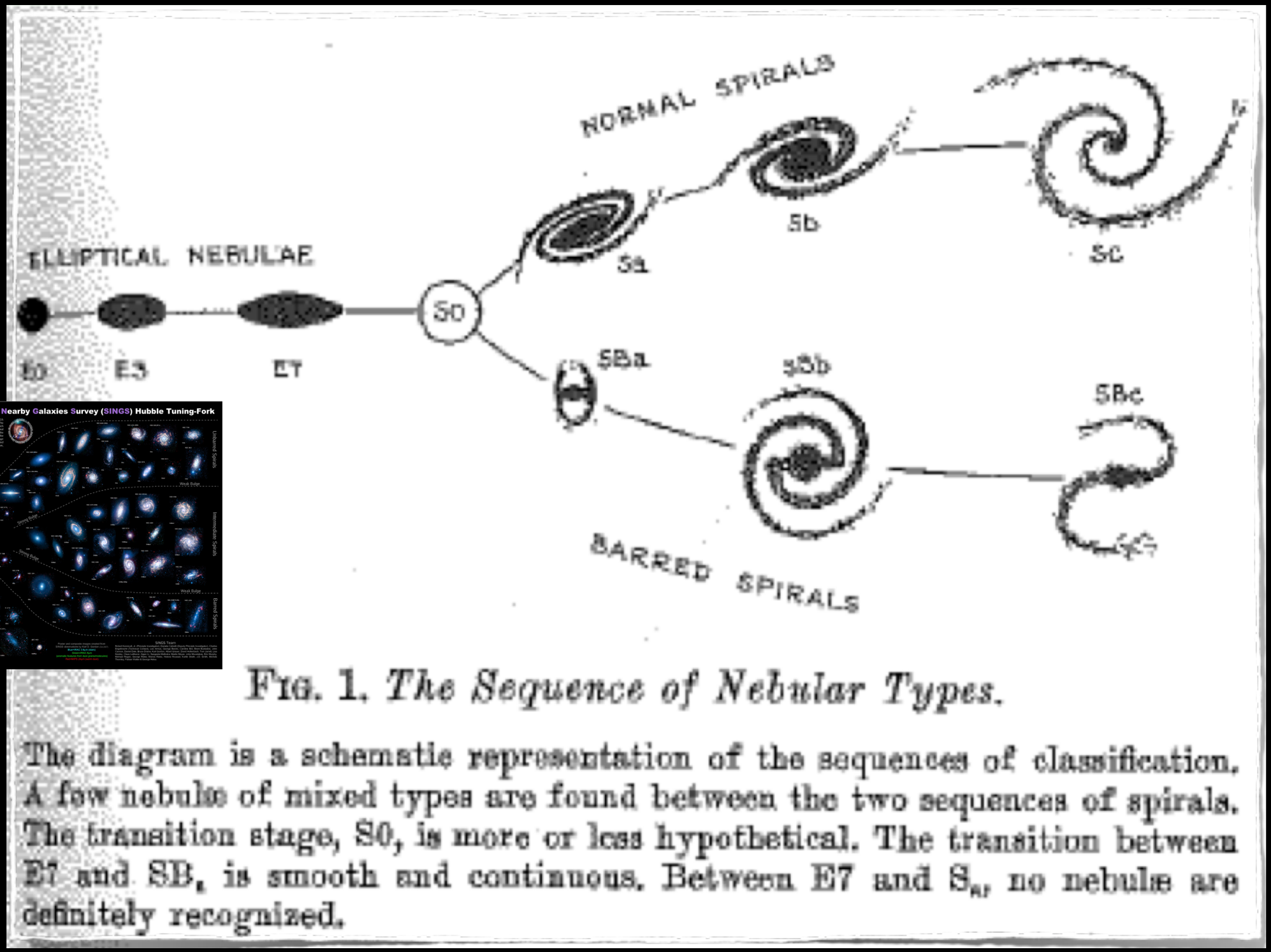


FIG. 1. *The Sequence of Nebular Types.*

The diagram is a schematic representation of the sequences of classification. A few nebulæ of mixed types are found between the two sequences of spirals. The transition stage, S0, is more or less hypothetical. The transition between E7 and SB$_a$ is smooth and continuous. Between E7 and S$_a$, no nebulæ are definitely recognized.

“Hubble’s Tuning Fork Diagram”

The Shapley-Curtis Debate at the
Smithsonian Natural History Museum, 1920

From National Academy of Sciences,
Smithsonian Institution, Washington, D. C.
(Carl H. Butman, Representative).

For Release to Afternoon Papers,
Monday, April 26

for Files

HOW MANY UNIVERSES ARE THERE?

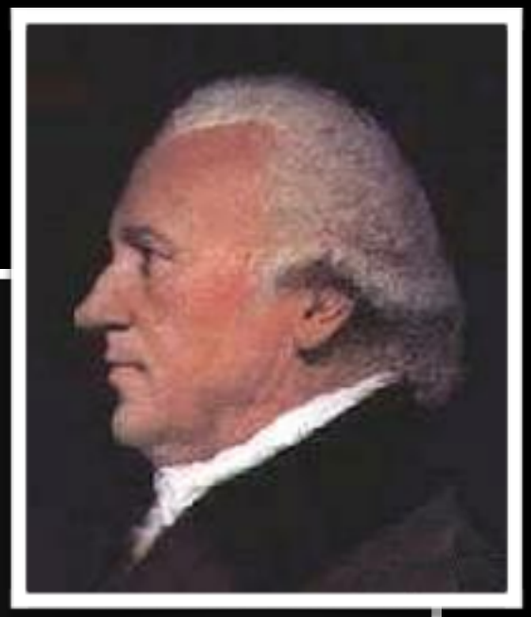
This evening two California astronomers will discuss the Size of the Universe, and present their views as to whether or not there is only one or several universes, before the National Academy of Sciences, which is now in session in Washington.

In this public meeting, Dr. Harlow Shapley of the Mt. Wilson Solar Observatory, will discuss recently secured evidence pointing to the dimensions of our galaxy of stars, known popularly as the Milky Way, which he believes to be ten times greater than is held in the older theories concerning the dimensions and compositions of the Milky Way. In other words, he claims that it takes light about three hundred thousands of years to cross from one side to the other of the space occupied by the 3,000,000,000 stars of which our sun is the nearest one. He holds the spiral nebulae, those clam-shell-like cloudy luminous objects seen by great telescopes, to be inside our system.

Doctor Shapley's views will be followed by the discussion of Doctor Heber D. Curtis of the Lick Observatory, who will defend the older view that our Milky Way is approximately of the dimensions suggested by Newcomb, about 30,000 light-years in diameter, with the spiral nebulae regarded as very probably individual galaxies of "island universes", like ours. Thus there may be [illegible] million other universes each having 3,000,000,000 stars. Inhabitants of [illegible] numerous universes would see our Milky Way as a spiral nebula. The lect[illegible] these two learned astronomers will be followed by a general discussion [illegible] the auditors present who are interested in the development of this new [illegible] in scientific research.

The Shapley-Curtis Debate at the Smithsonian Natural History Museum, 1920

William Herschel's Milky Way Galaxy in 1781



"Herschel made two major discoveries that had an important bearing on our understanding of the cosmos. First, that we live in a huge collection of stars called the **Milky Way**, and second that there are a great many "**fuzzy patches**" called **nebulae**, some of which consisted of stars, and others of luminous clouds."

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)

Stars your Eyes would See

Optical

Dust + Dying Stars

"Glowing" Dust

Infrared

For fun…

Composite

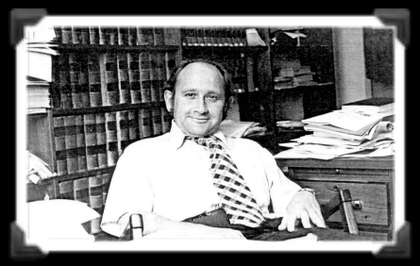
Infrared & X-rays

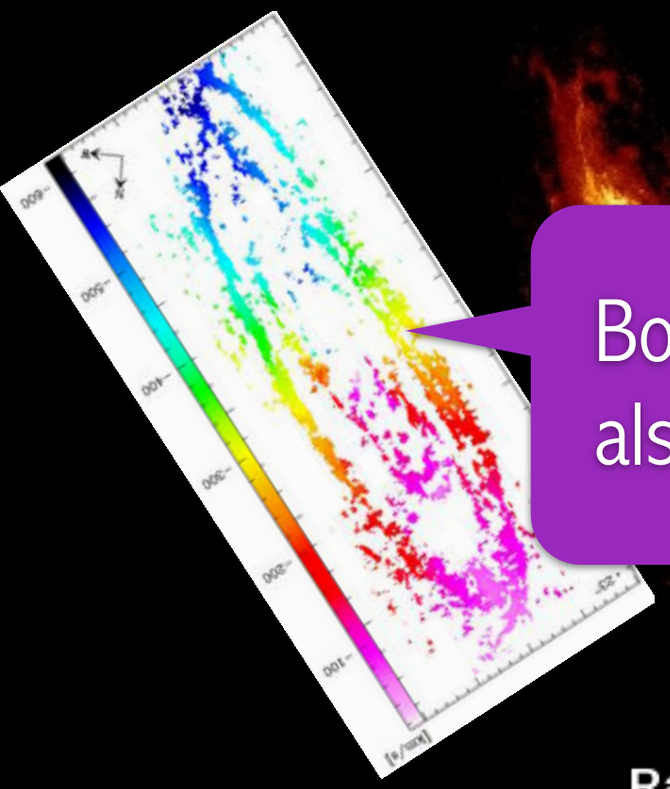
"Dying" Stars

X-rays

The Andromeda Galaxy (M31)

Gas, Dust, Stars at Many Wavelengths

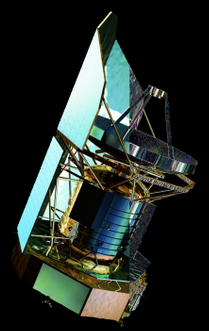




Bonus: “spectral line mapping,” especially in the radio, also gives velocity, thanks to the Doppler effect

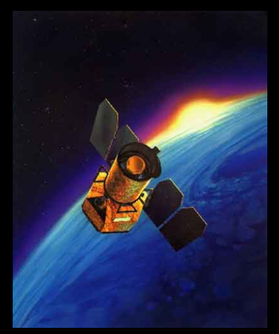
Radio

Infrared



Visible

Ultra-violet

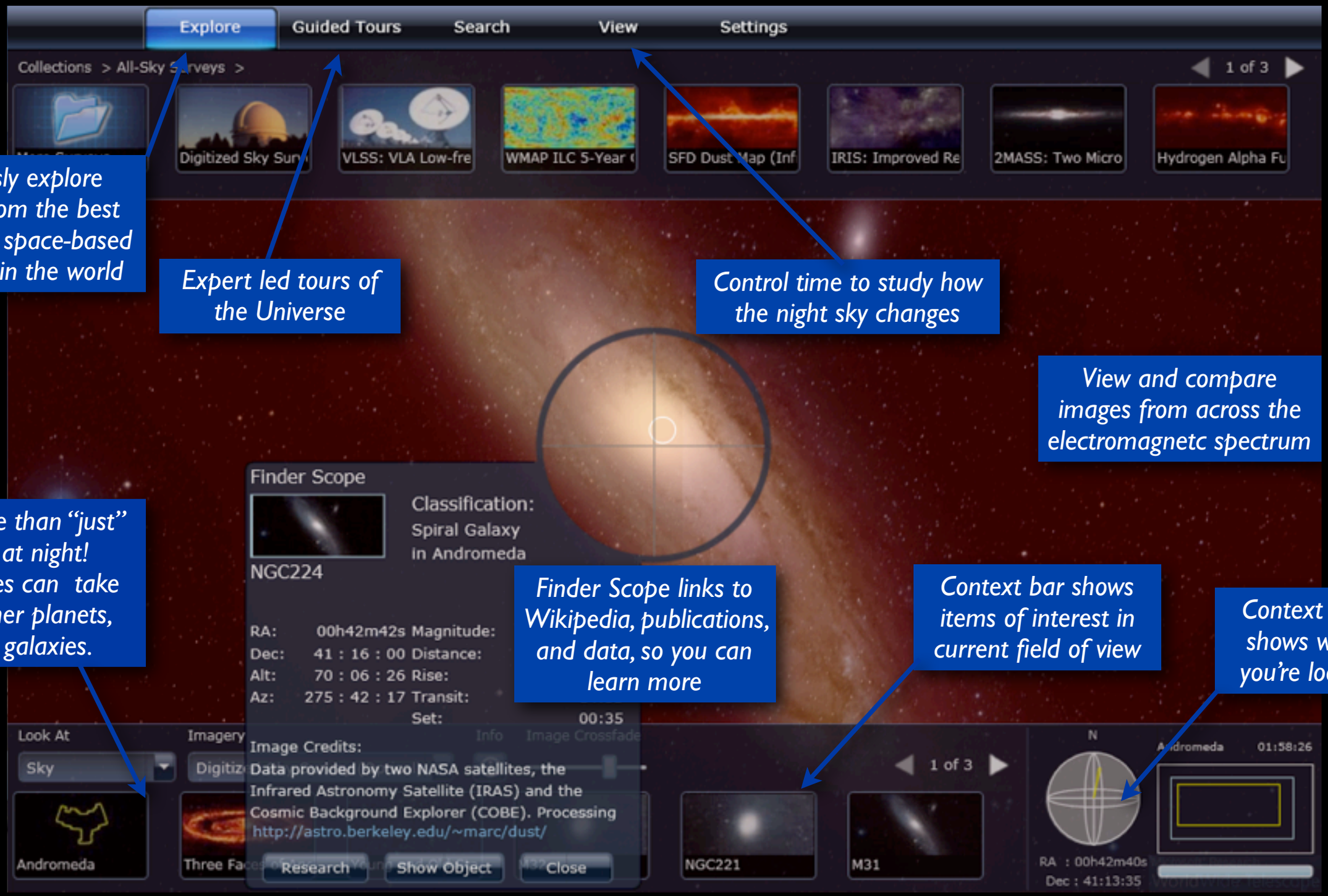


X-ray

American Astronomical Society WorldWide Telescope

[demo]

worldwidetelescope.org



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Finder Scope links to Wikipedia, publications, and data, so you can learn more

Context bar shows items of interest in current field of view

Context globe shows where you're looking.

The Skeleton of the Milky Way

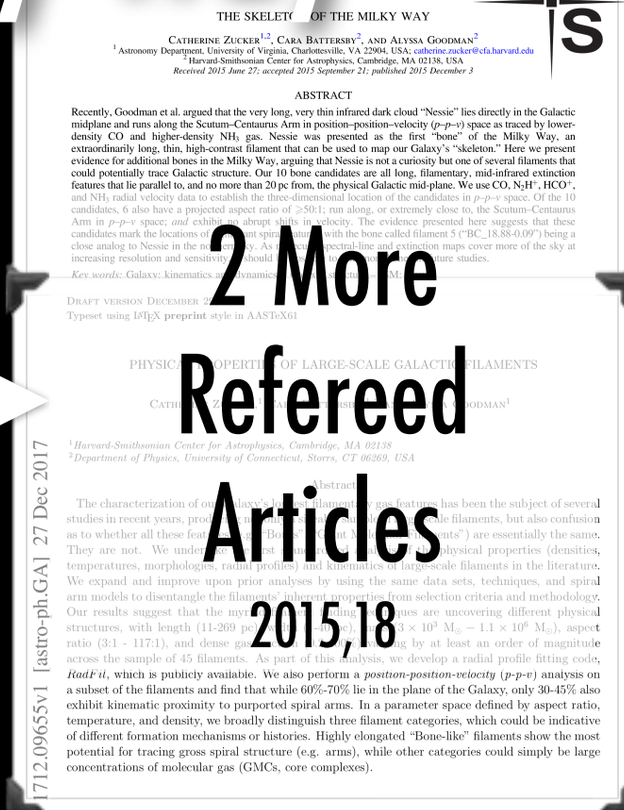
Au Authorea

WorldWide Telescope

Open Preprint 2013

Refereed Article 2014

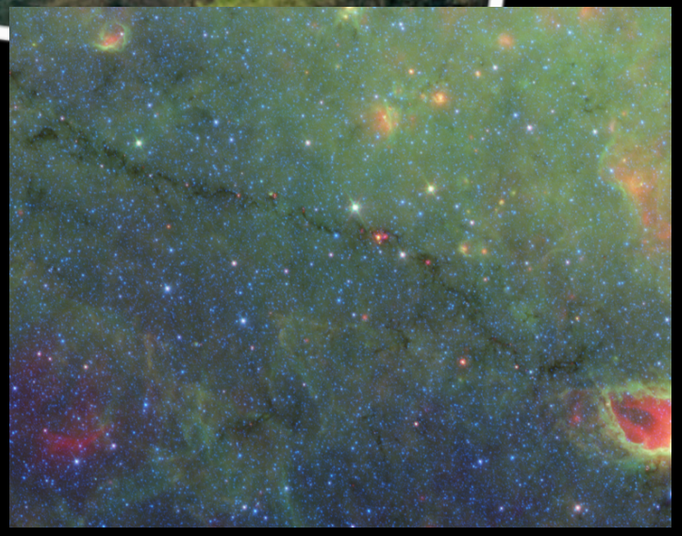
Open Preprint 2014

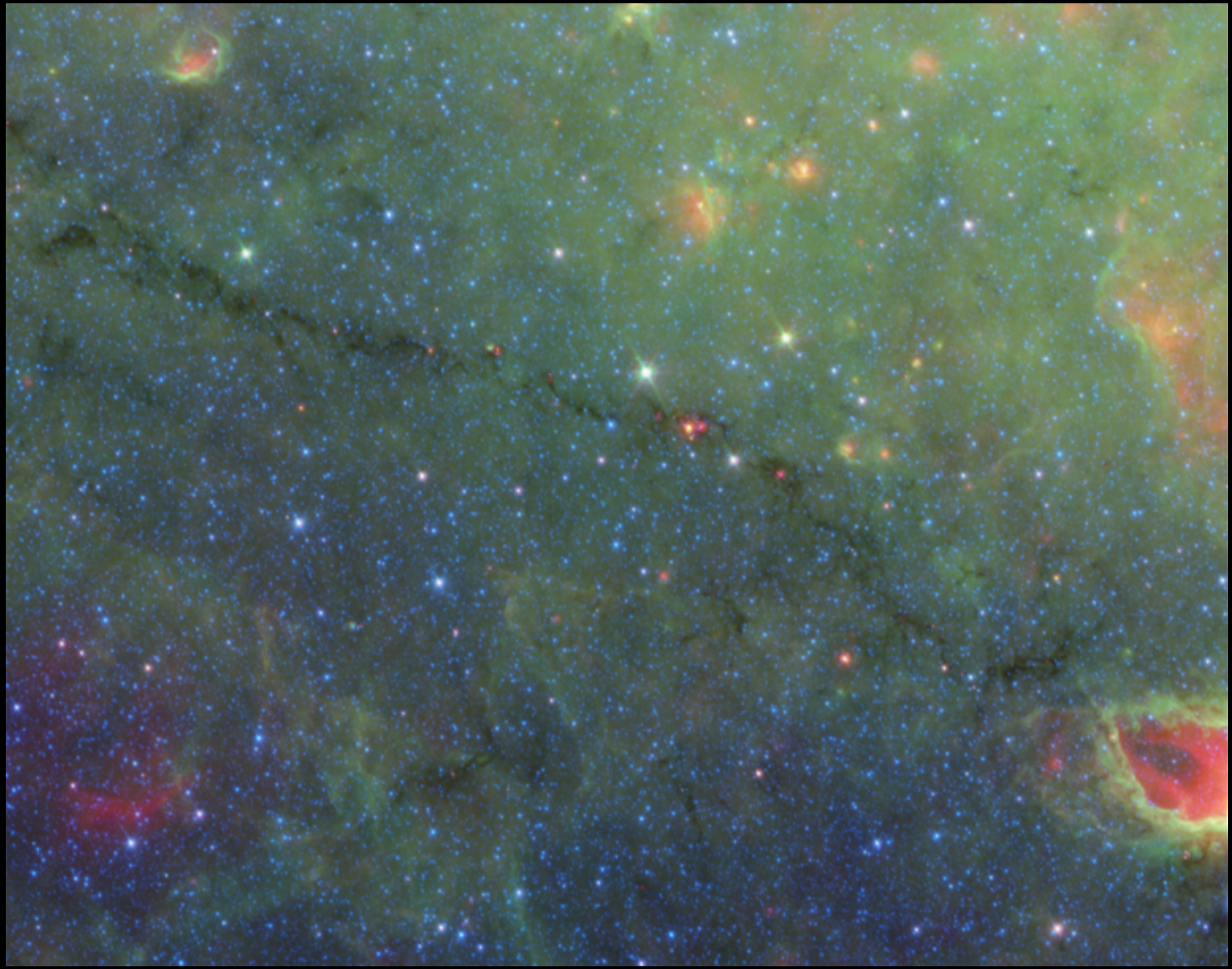


2 More Refereed Articles 2015,18

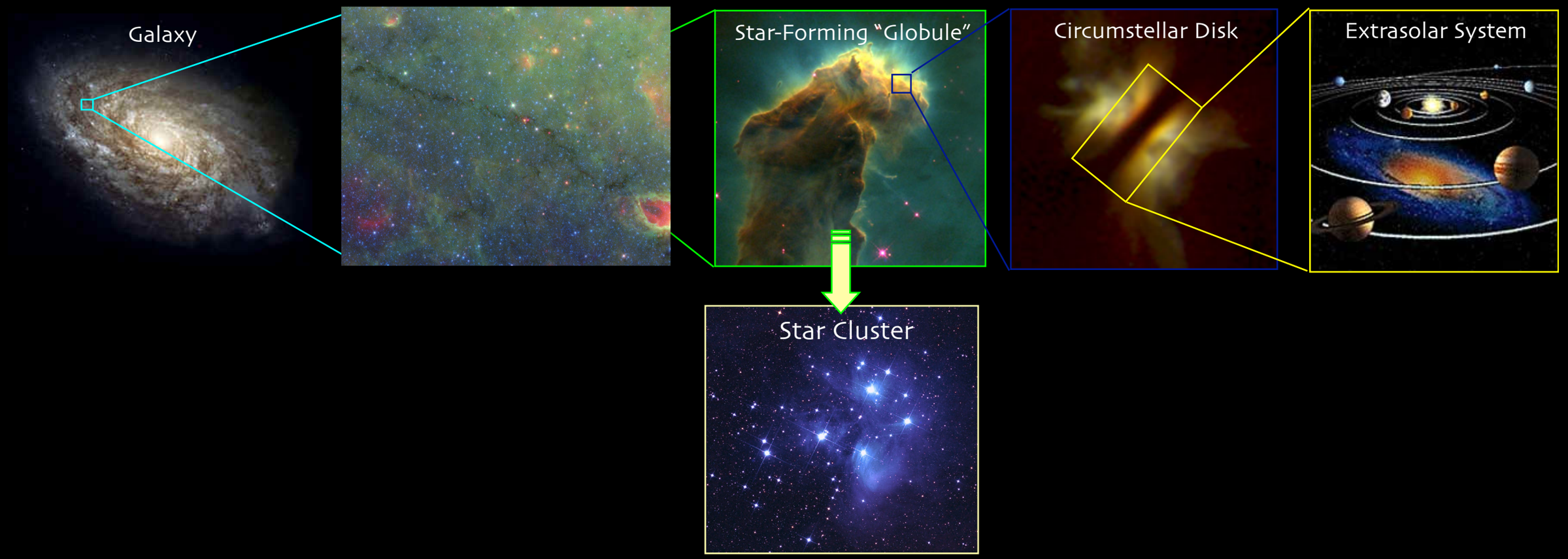
Once upon a time (2012), in an enchanted castle (in Bavaria)

...at a conference about star formation





Star and Planet Formation



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!

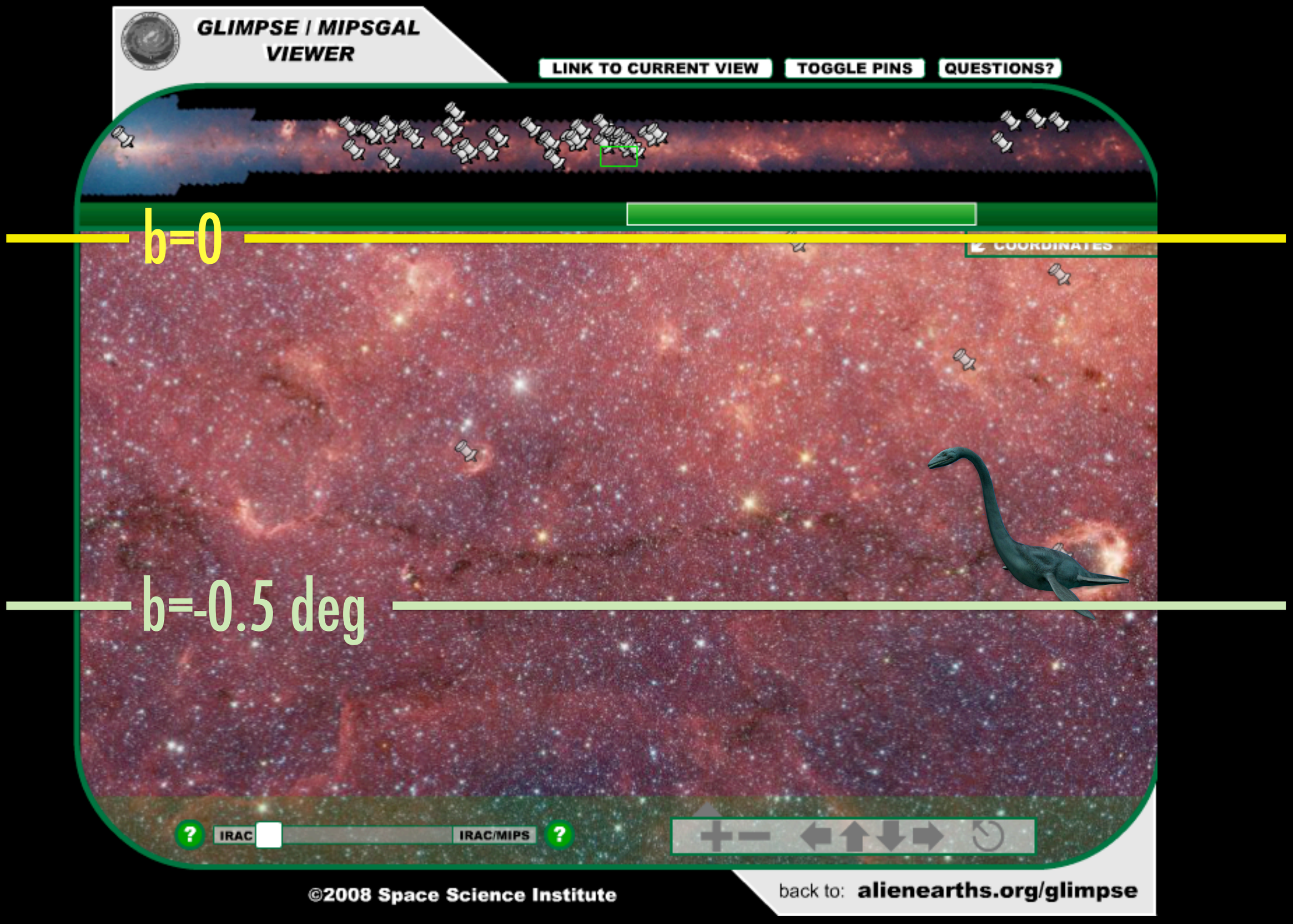
The Milky Way

“Galactic Plane”

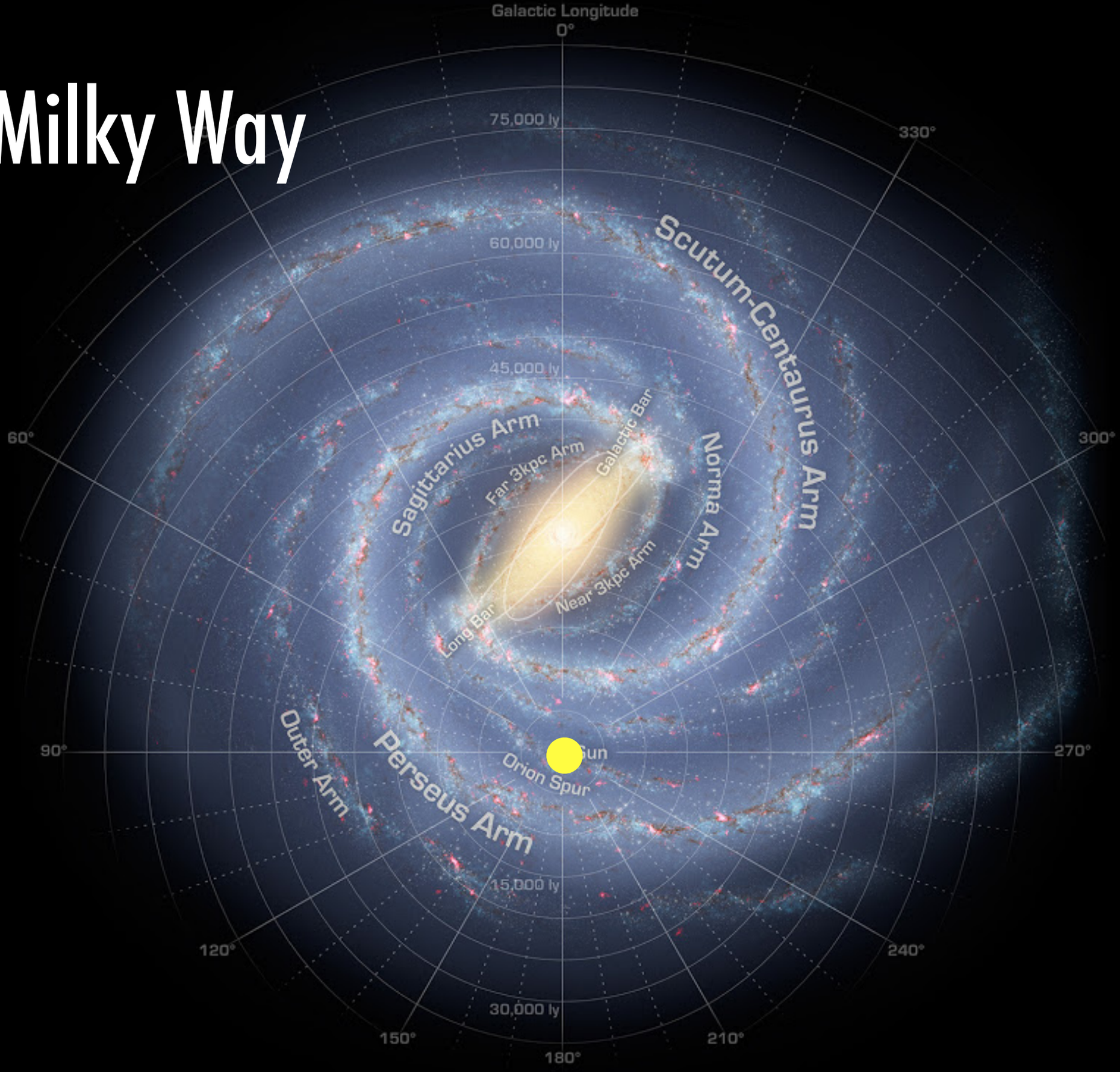
The Milky Way
(Artist's Conception)

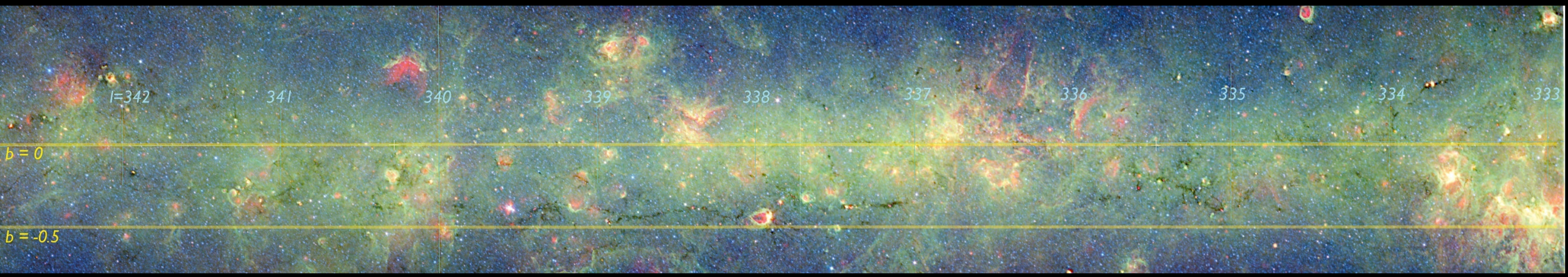
"Is Nessie Parallel to the Galactic Plane?"

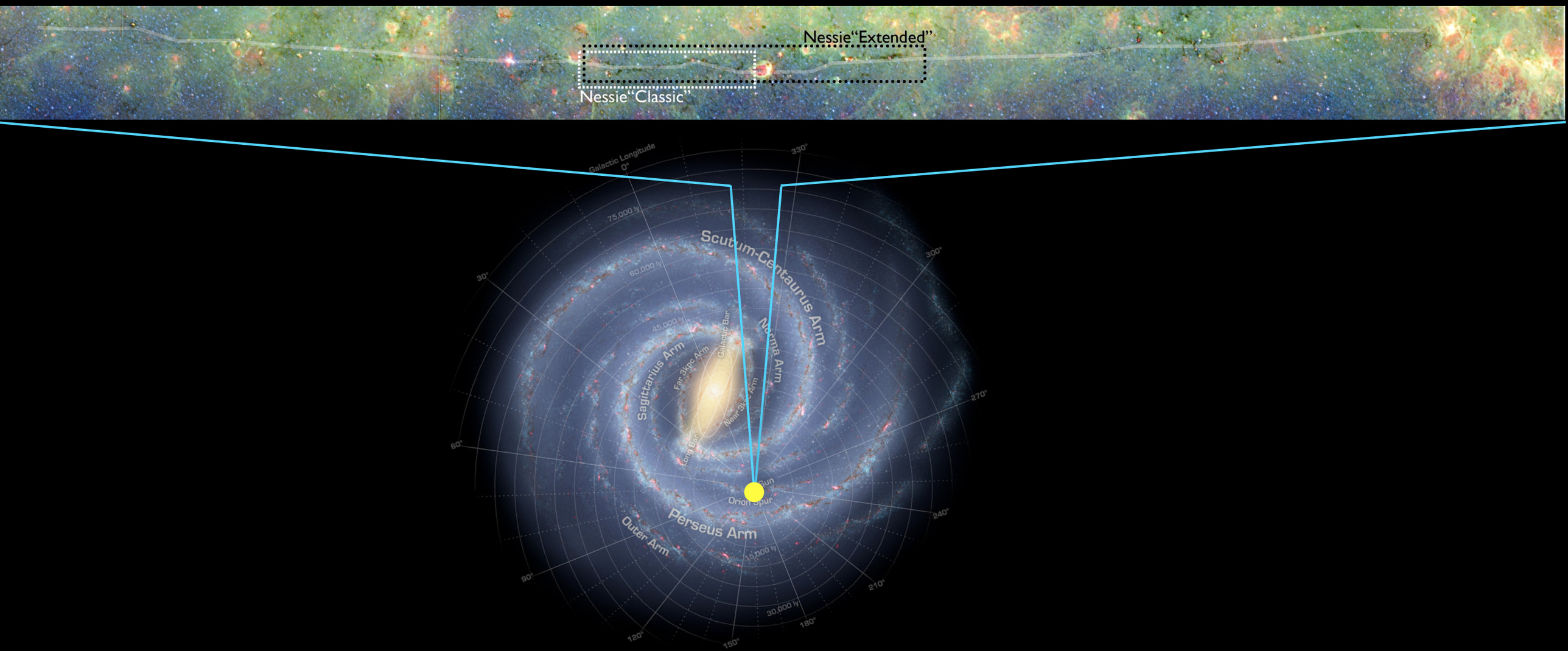
Yes, but why not at Zero of Latitude (b=0)?

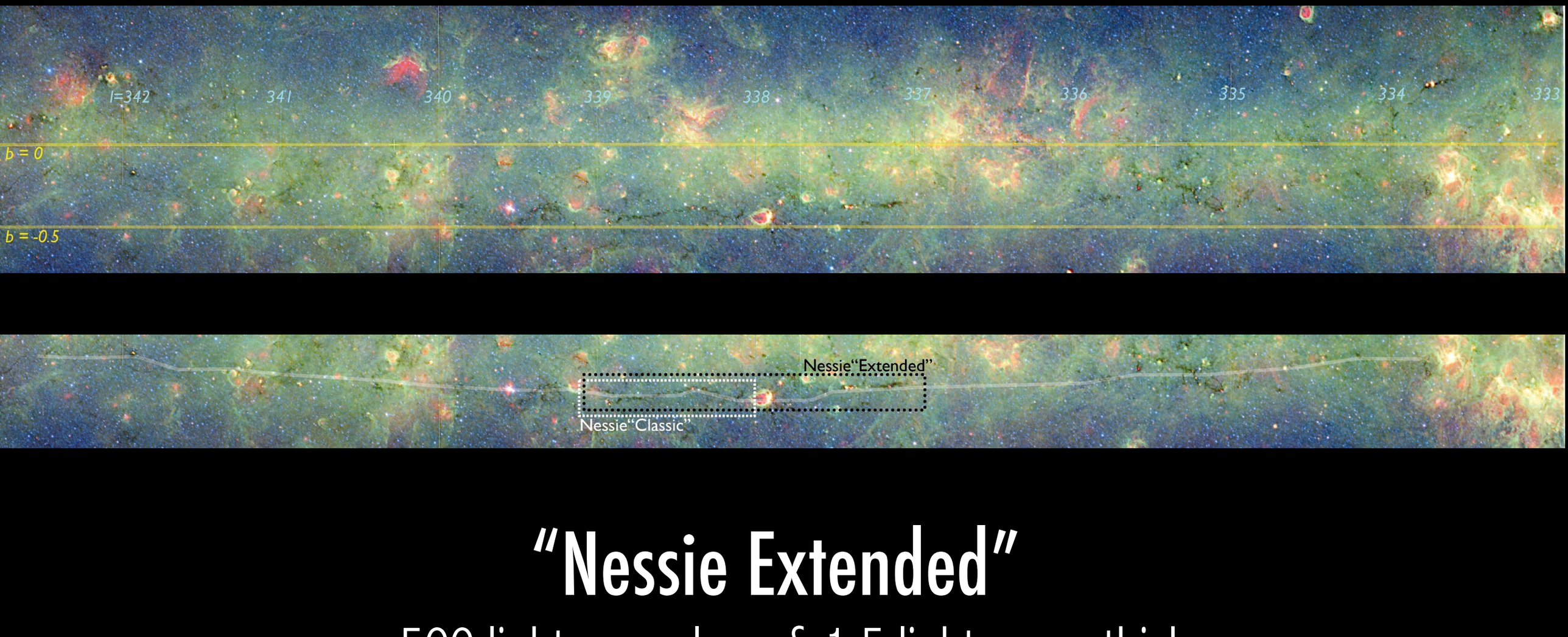


The Milky Way




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
Galactic Bar
Far 3kpc Arm
Near 3kpc Arm
Long Bar
Sun
Orion Spur



"Nessie Extended"

~500 light years long & 1.5 light years thick

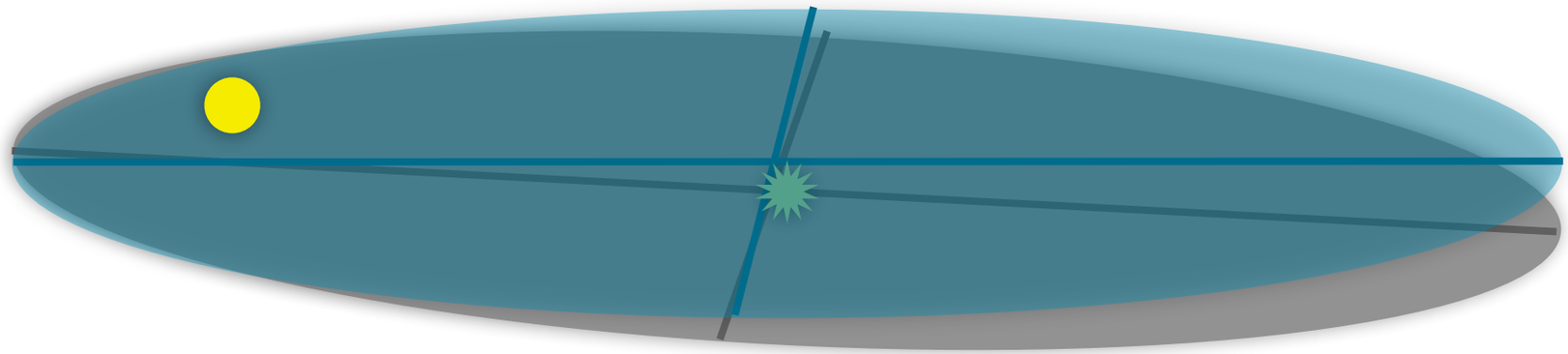
300:1 axial ratio

200,000 solar masses

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

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]

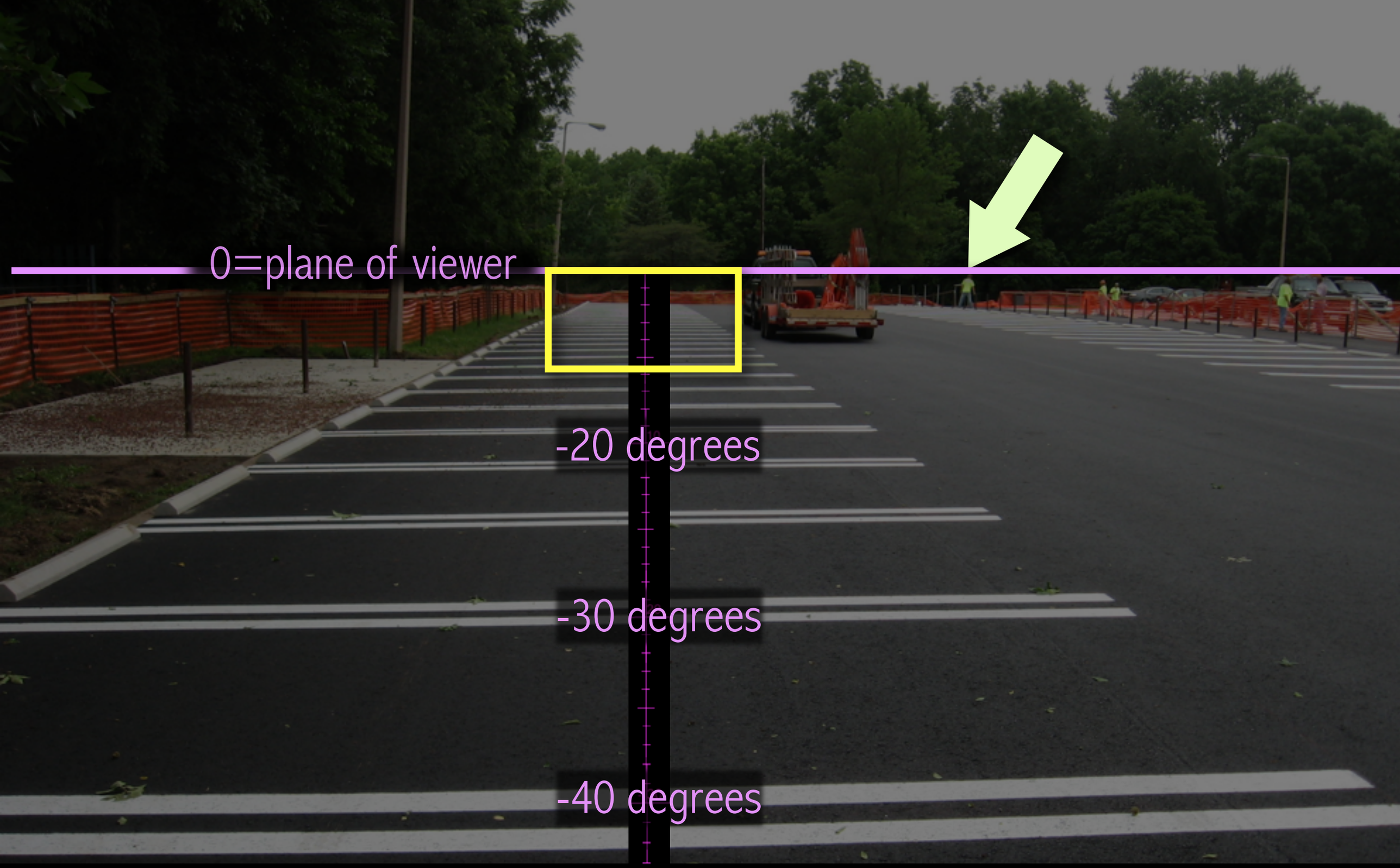
Sun is ~75 light years "above" the IAU Milky Way Plane

+

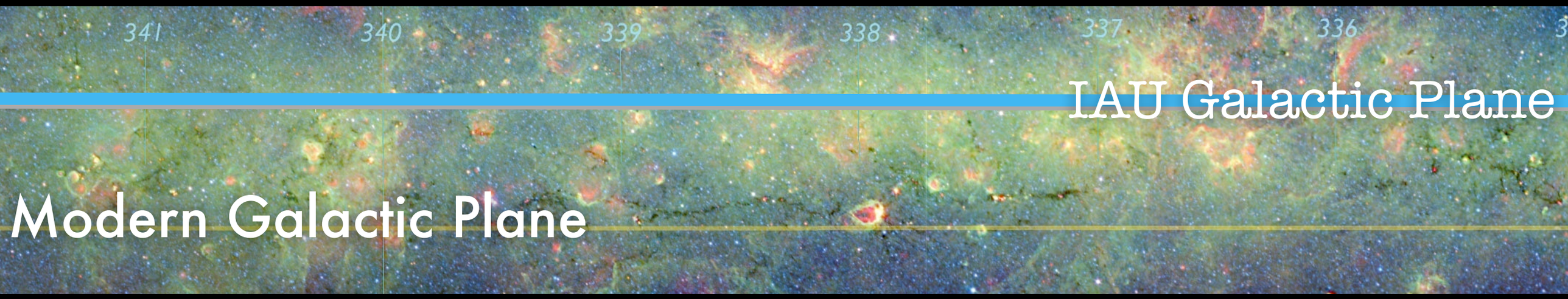
Galactic Center is ~20 light years offset from the IAU Milky Way Center

=

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



"Viewed from known elevation, features in a flat plane are found at angular positions given by their distance."



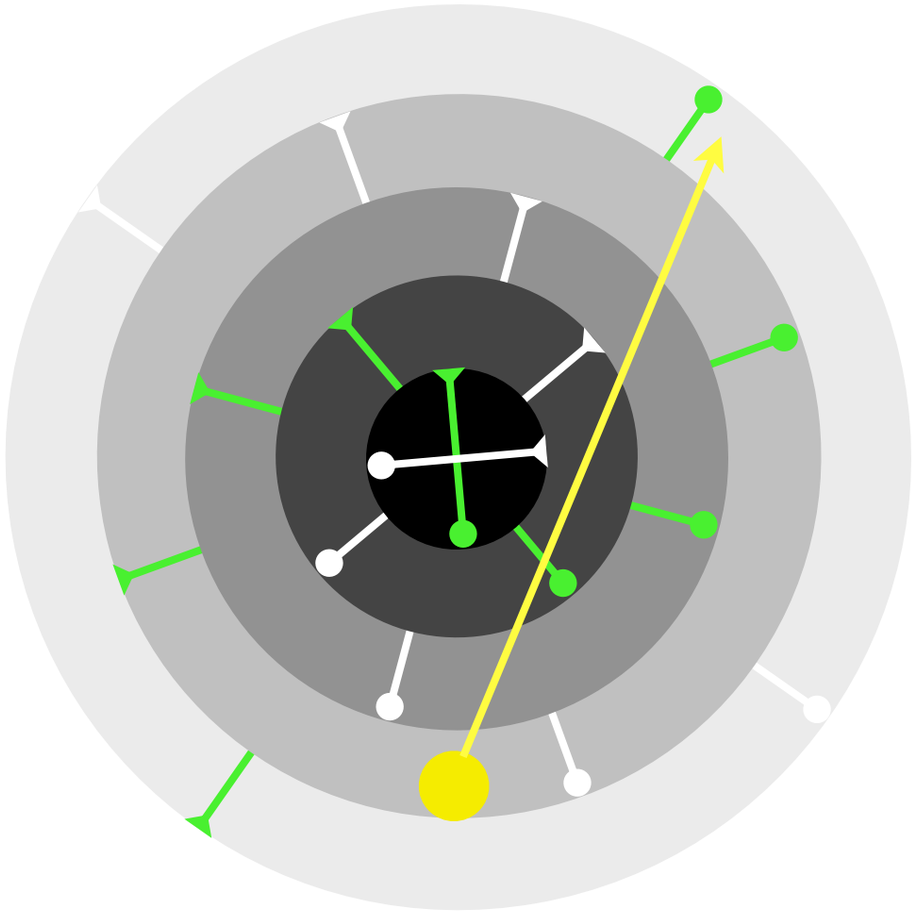
Yes, Nessie is EXACTLY in the Galactic Plane!

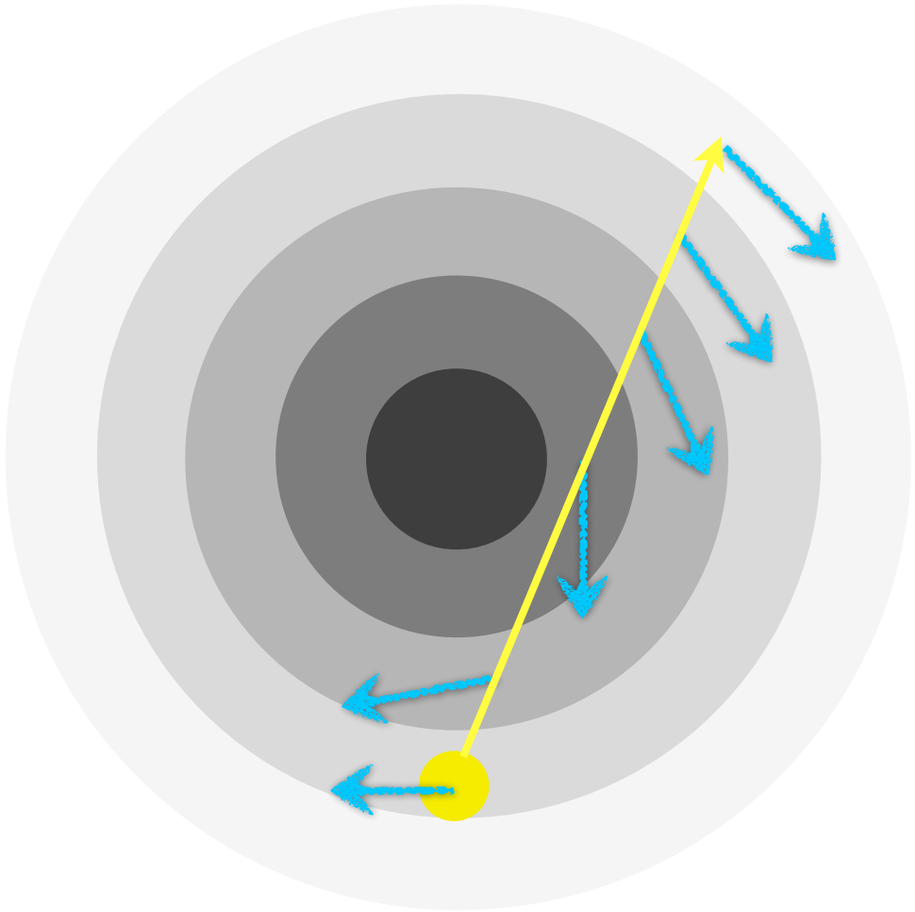
(0.4 degrees "below" the IAU plane)

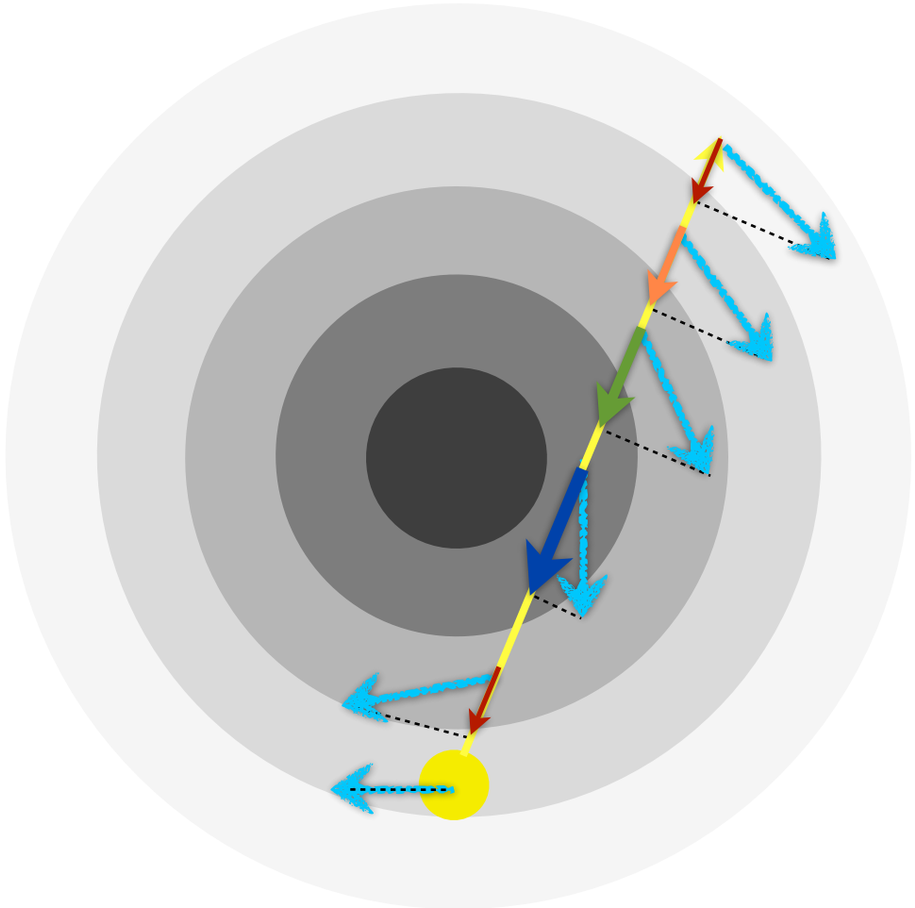
What about its distance?

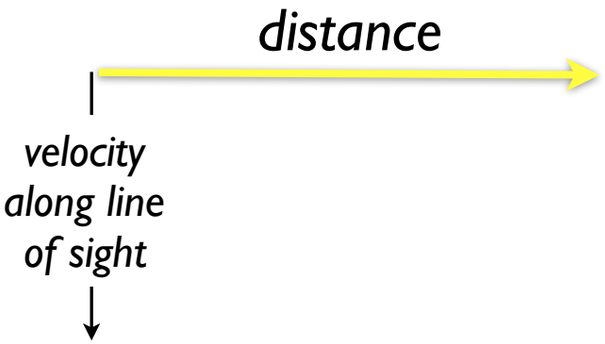
we can use "radial velocities" to estimate distance in a rotating galaxy...

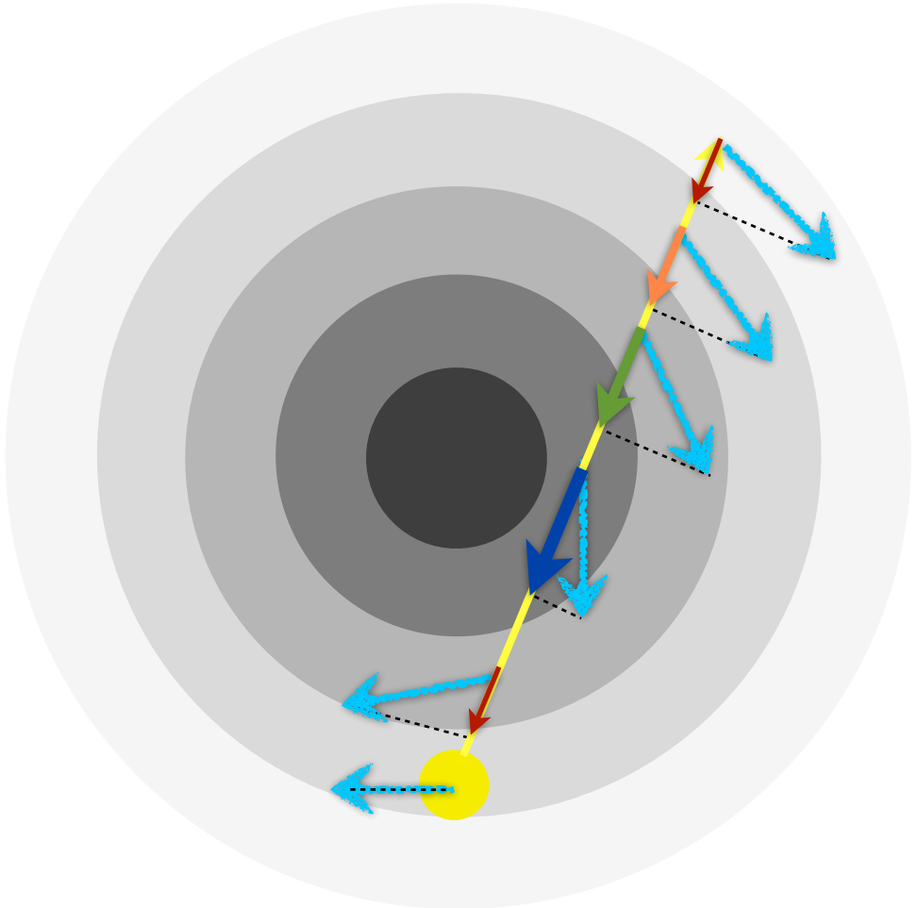
A Rotating (Spiral) Galaxy Observed from its Outskirts...

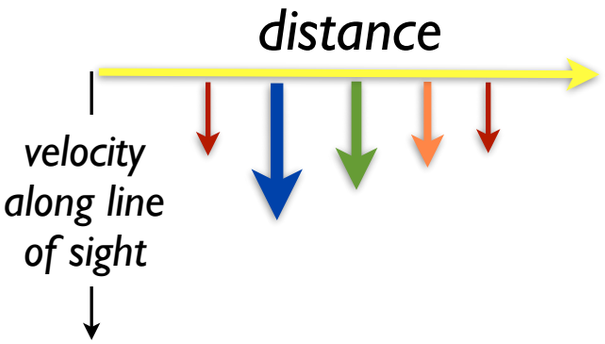




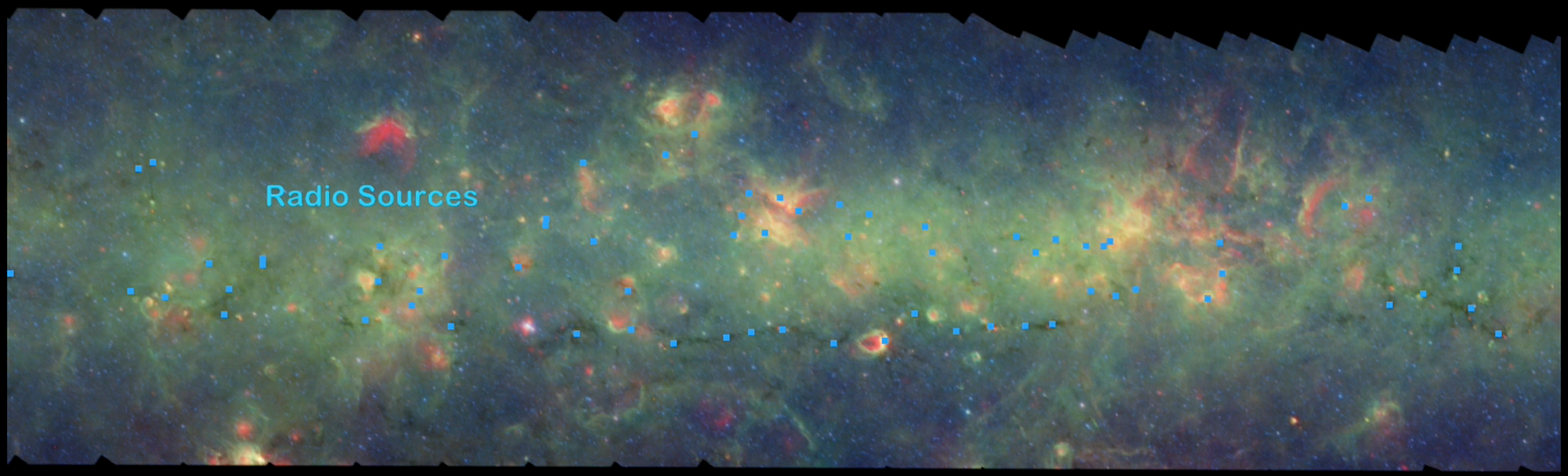



distance
velocity
along line
of sight

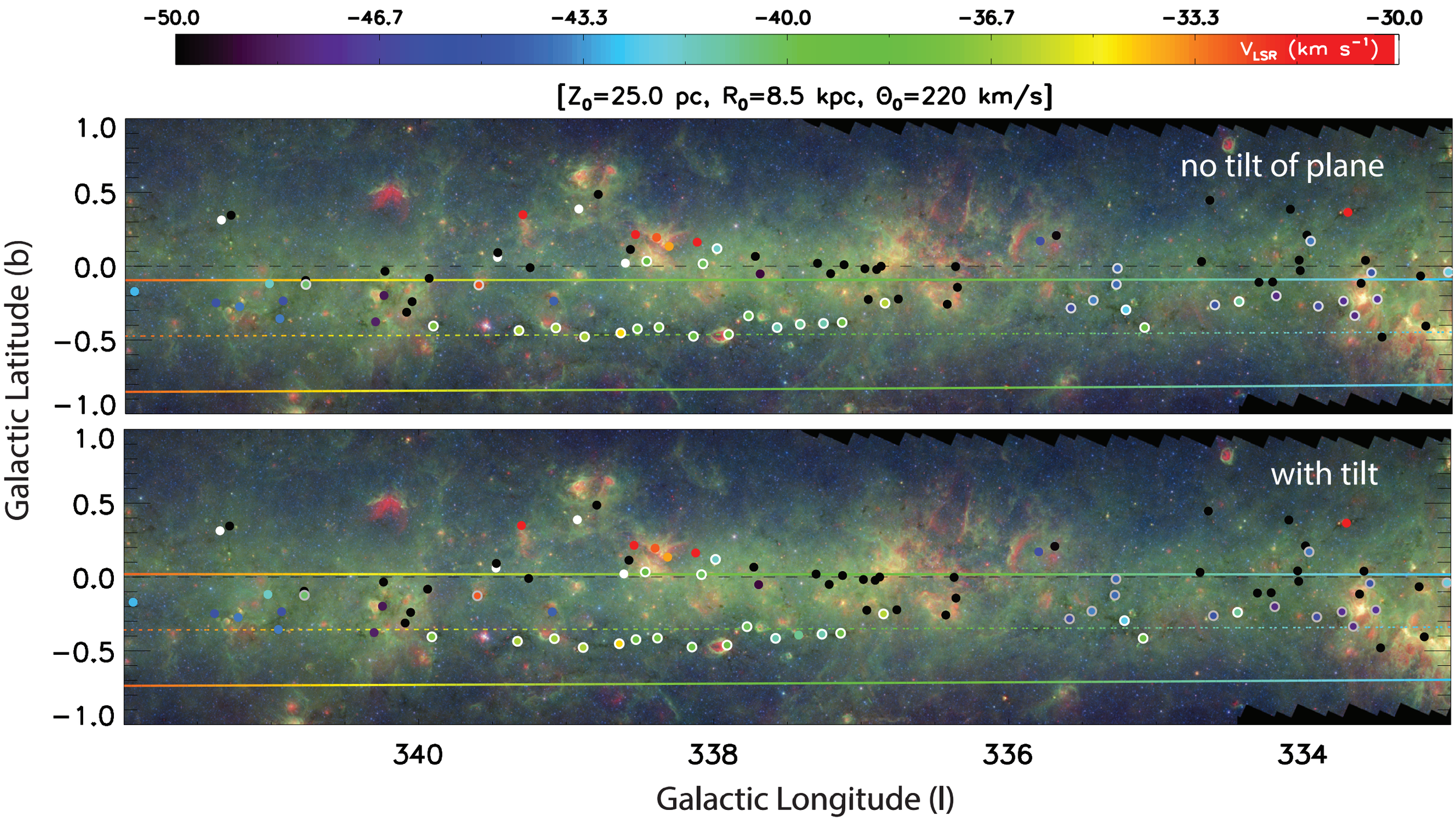


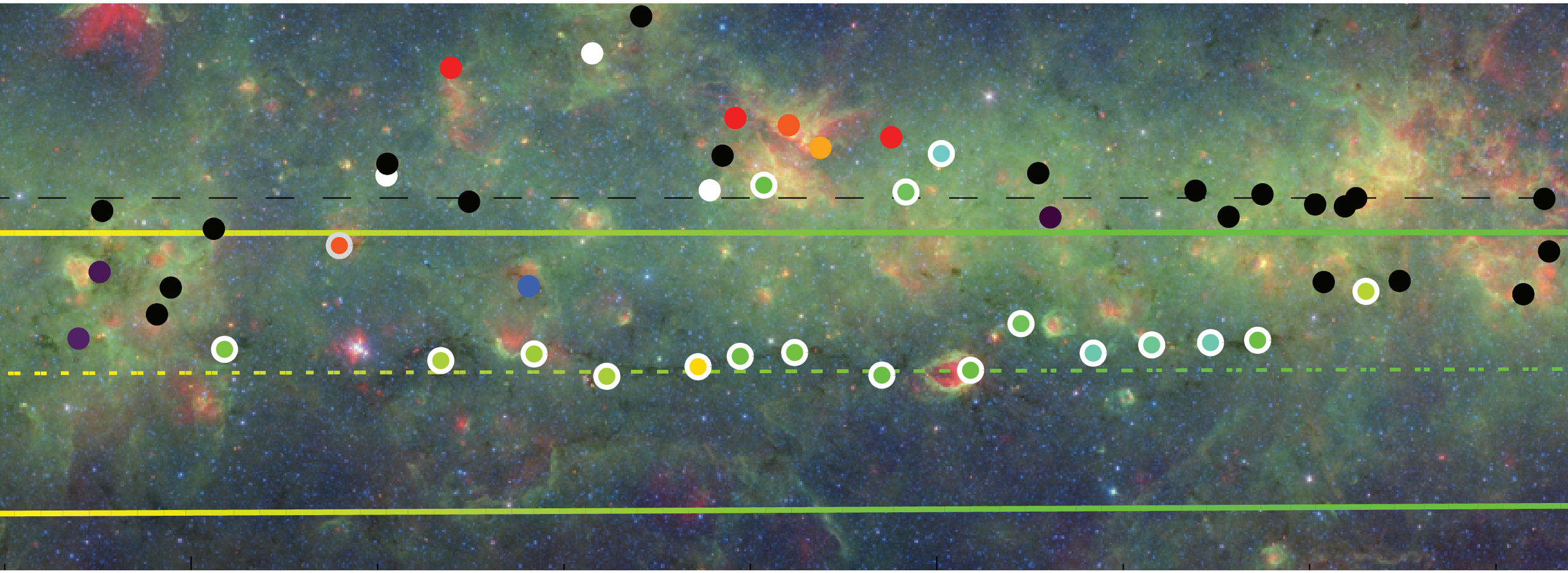

distance
velocity
along line
of sight

Velocity to Distance



In the plane and at the distance of spiral arm!



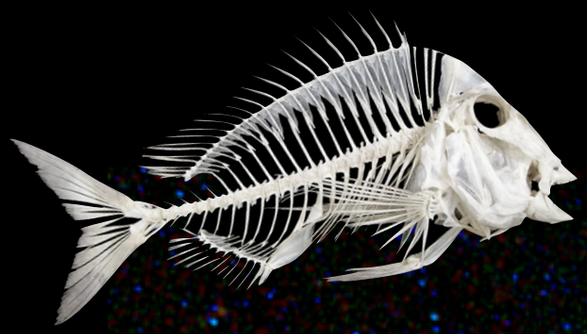


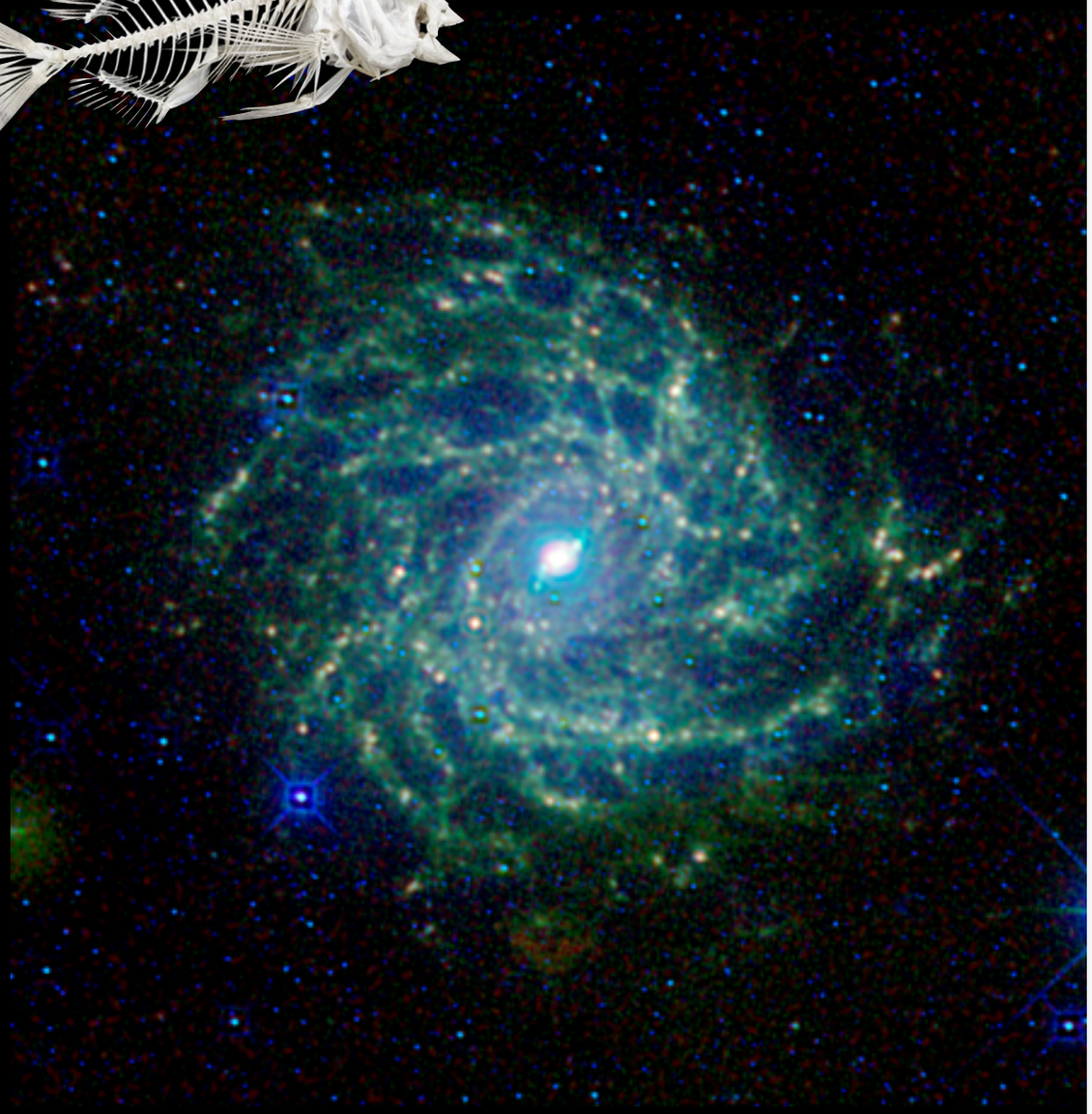
...eerily precisely...

Monster to Bone

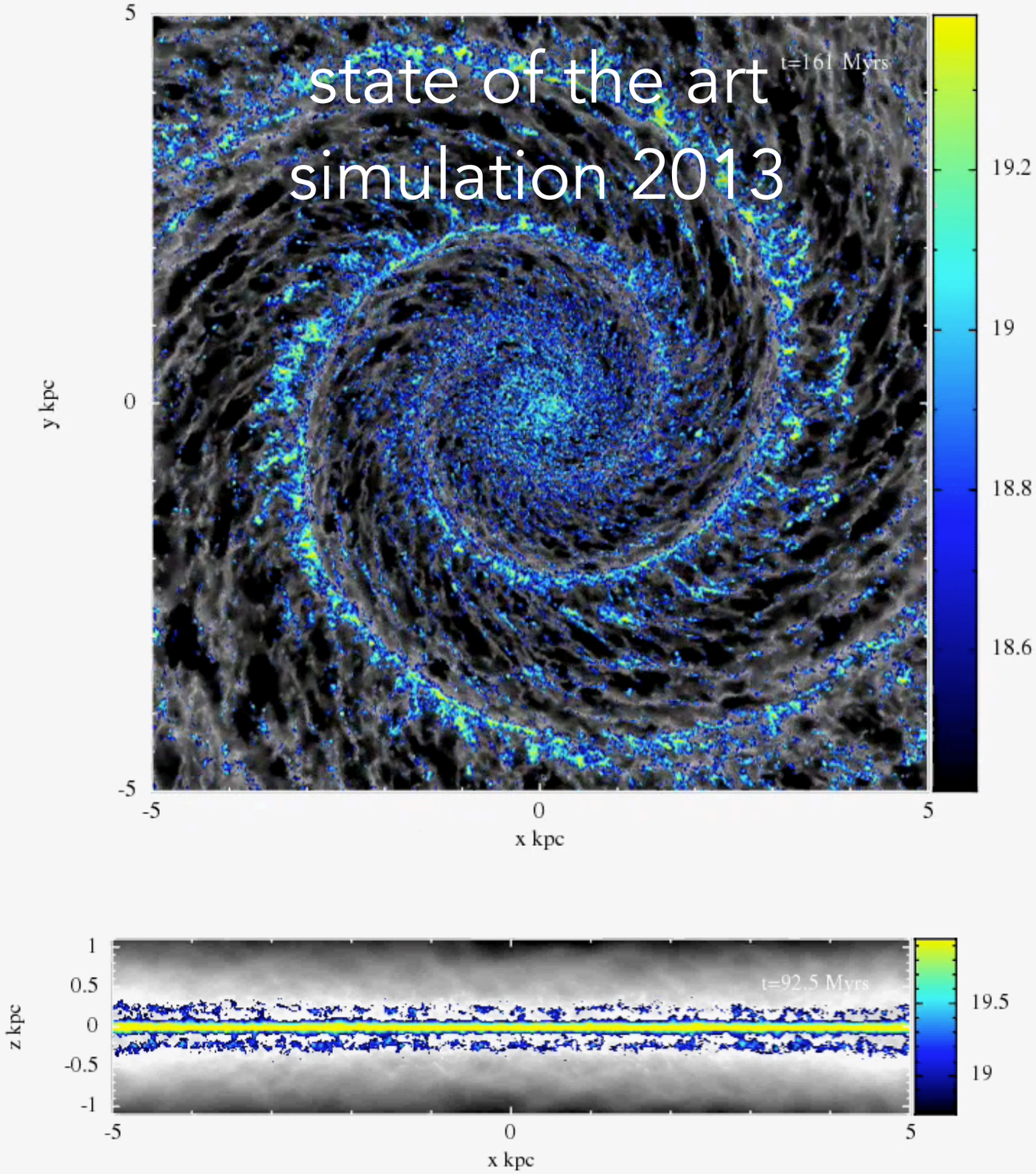
There could be 1000s more of these to find...a full skeleton perhaps?

A full 3D skeleton?





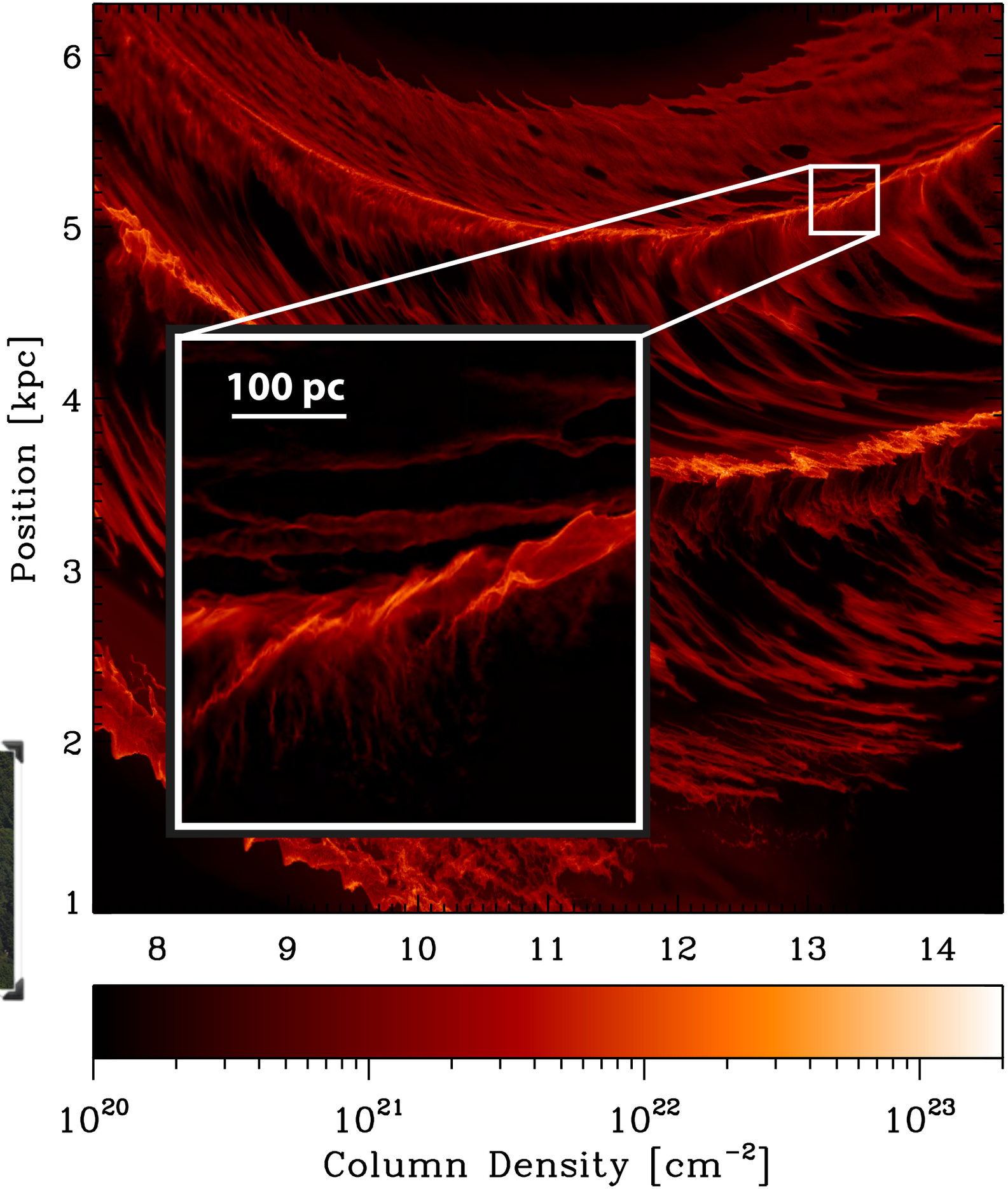
(flipped) image of IC342 from Jarrett et al. 2012; WISE Enhanced Resolution Galaxy Atlas



simulations courtesy Clare Dobbs

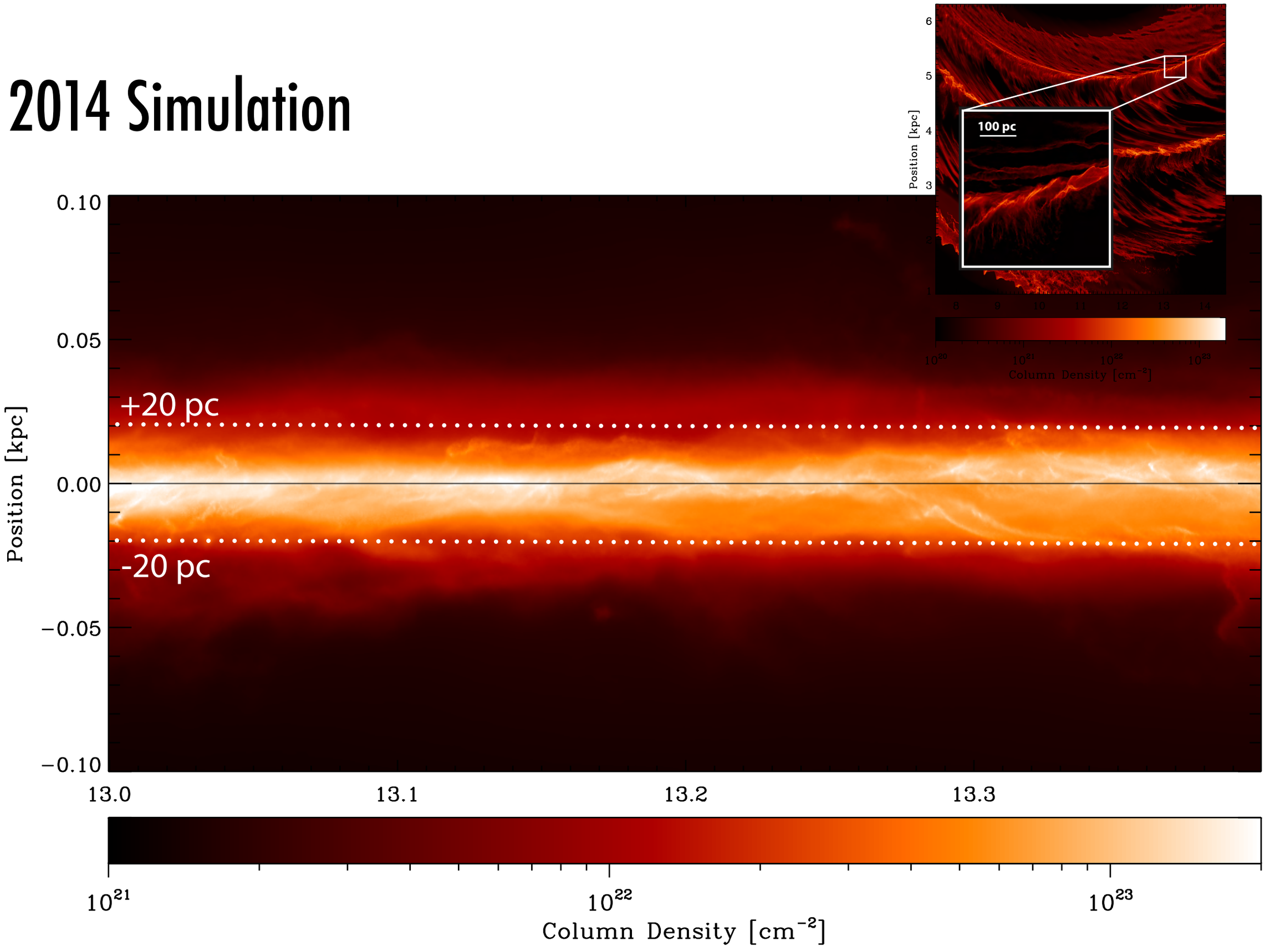
Then...

2014 Simulation

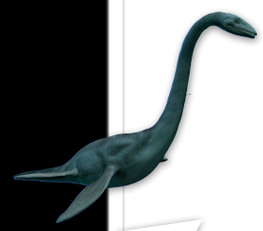


Smith et al. 2014, using AREPO

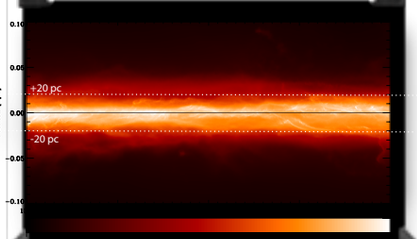
2014 Simulation



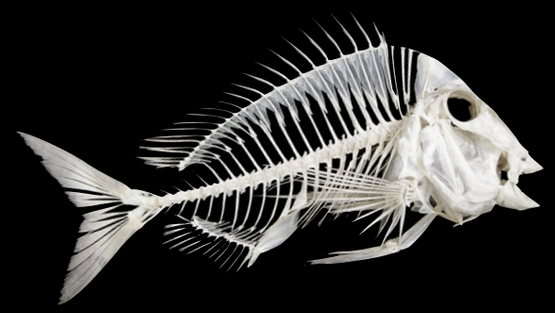
Smith et al. 2014, using AREPO

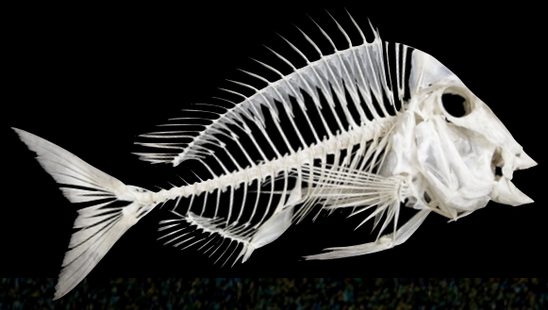


Open Preprint 2013

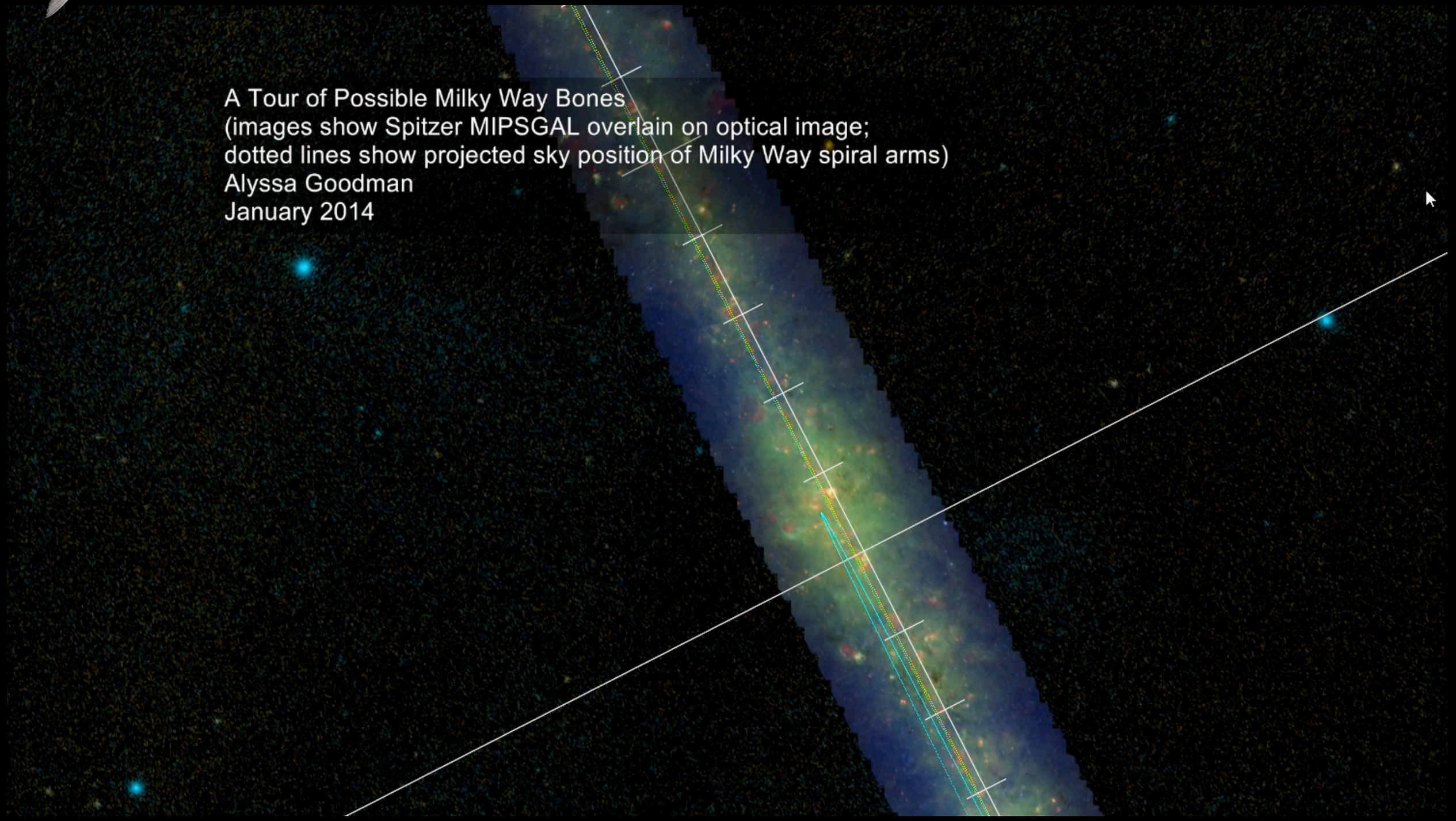


Refereed Article 2014





2014: Can we find more bones?

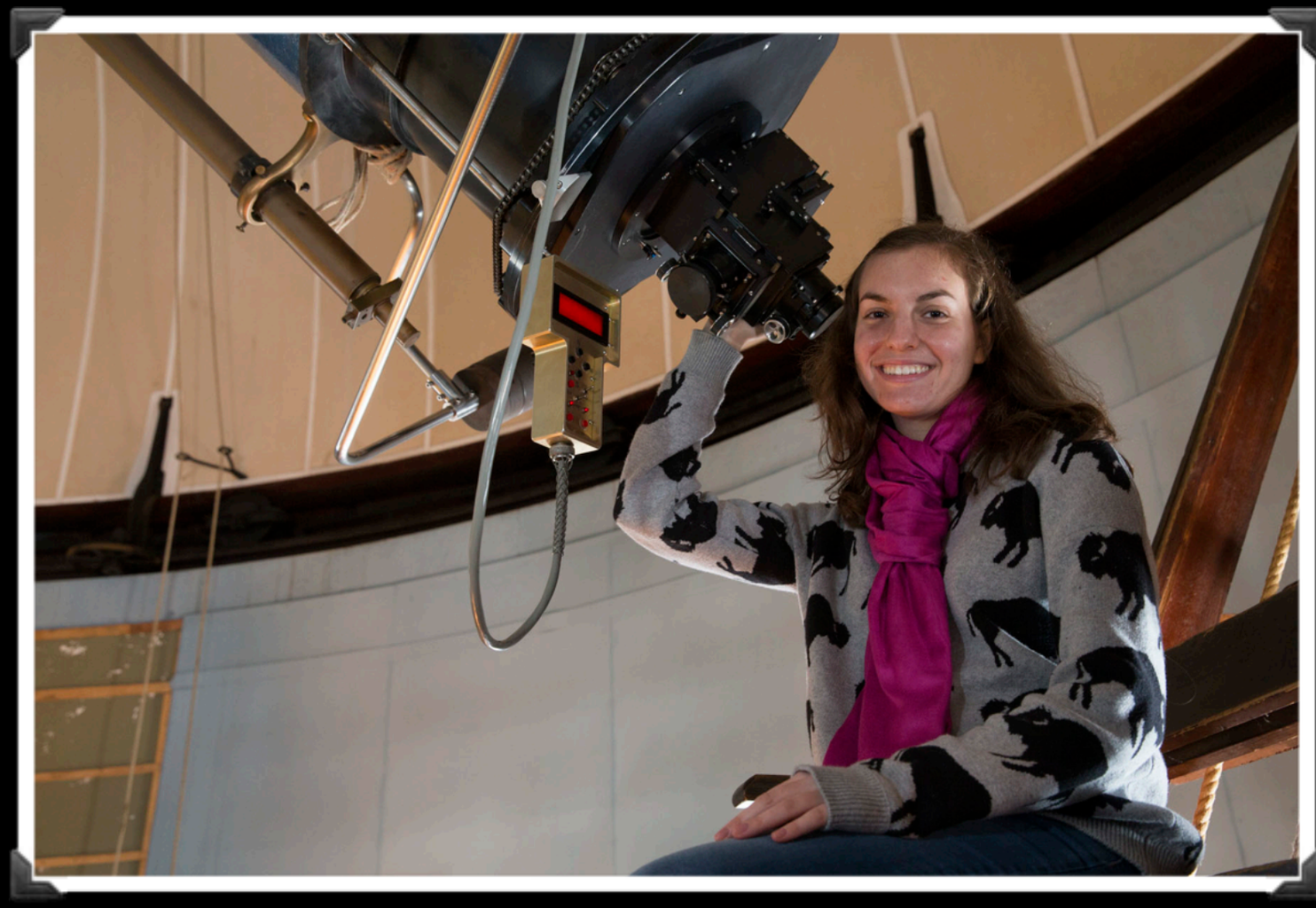


[demo]

40 months of work...

Cara Battersby

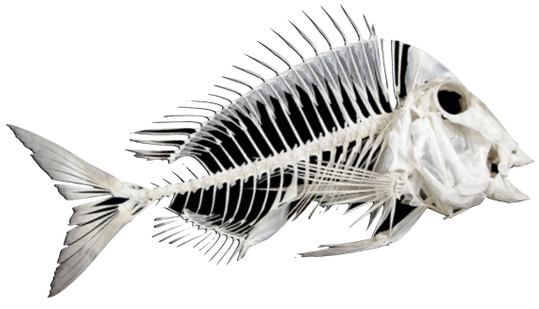
UConn Professor, former Harvard-Smithsonian postdoc

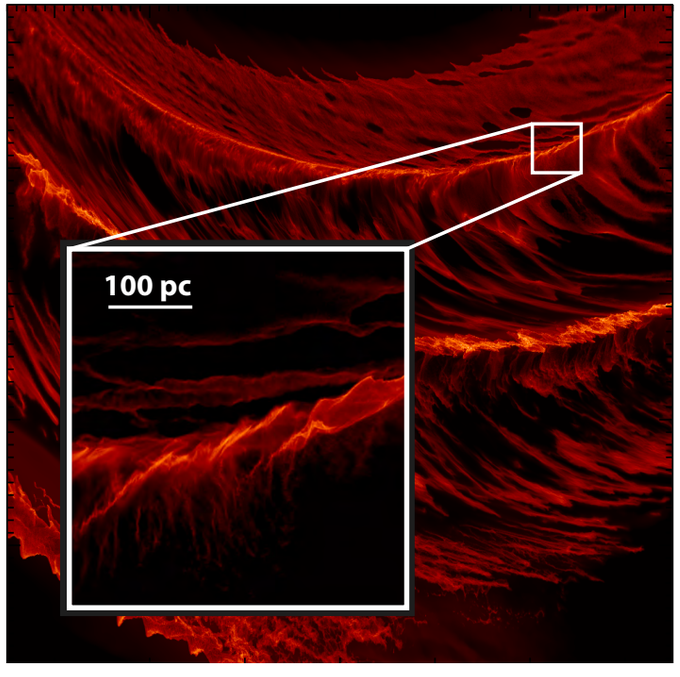


Catherine Zucker

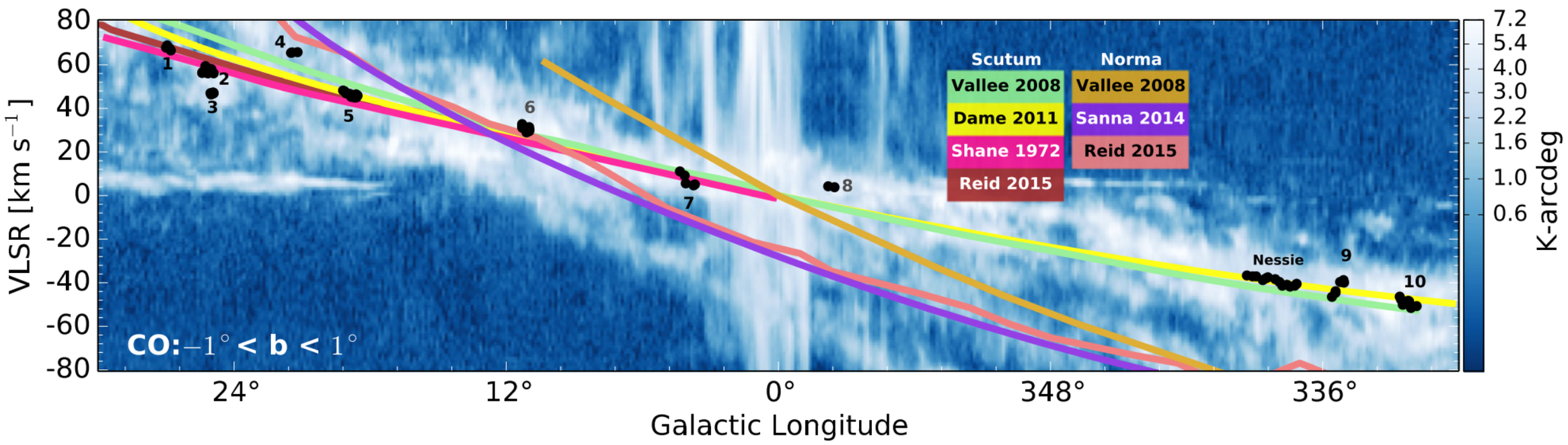
Harvard Graduate Student

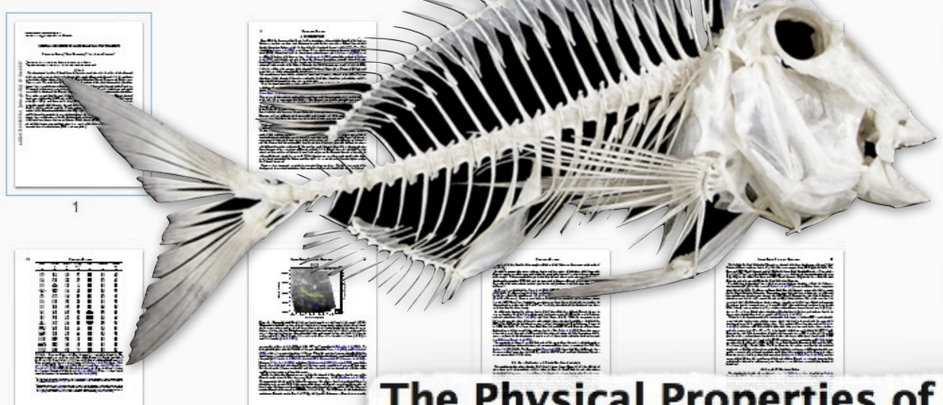
2018: Yes, we are piecing together a skeleton





Both on the sky, and along the line of sight (so in “3D”), we find “bones” in the right places to give a detailed skeleton.





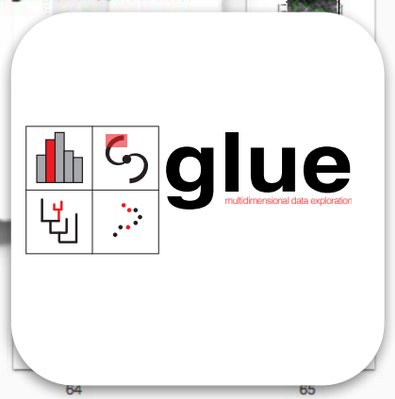
The Physical Properties of Large-Scale Galactic Filaments

Catherine Zucker, Cara Battersby, Alyssa Goodman

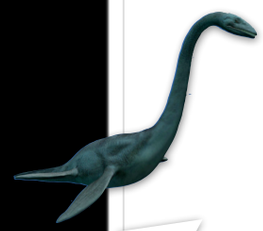
(Submitted on 27 Dec 2017)

The characterization of our Galaxy's longest filamentary gas features has been the subject of several studies in recent years, producing not only a sizeable sample of large-scale filaments, but also confusion as to whether all these features (e.g. "Bones", "Giant Molecular Filaments") are essentially the same. They are not. We undertake the first standardized analysis of the physical properties (densities, temperatures, morphologies, radial profiles) and kinematics of large-scale filaments in the literature. We expand and improve upon prior analyses by using the same data sets, techniques, and spiral arm models to disentangle the filaments' inherent properties from selection criteria and methodology. Our results suggest that the myriad filament finding techniques are uncovering different physical structures, with length (11–269 pc), width (1–40 pc), mass (3×10^3 $M_\odot$ $- 1.1 \times 10^6$ $M_\odot$), aspect ratio (3:1 – 117:1), and dense gas fraction (0.2–100%) varying by at least an order of magnitude across the sample of 45 filaments. As part of this analysis, we develop a radial profile fitting code, *RadFil*, which is publicly available. We also perform a $position - position - velocity$ $(p-p-v)$ analysis on a subset of the filaments and find that while 60%–70% lie in the plane of the Galaxy, only 30–45% also exhibit kinematic proximity to purported spiral arms. In a parameter space defined by aspect ratio, temperature, and density, we broadly distinguish three filament categories, which could be indicative of different formation mechanisms or histories. Highly elongated "Bone-like" filaments show the most potential for tracing gross spiral structure (e.g. arms), while other categories could simply be large concentrations of molecular gas (GMCs, core complexes).

Comments: Submitted to The Astrophysical Journal
Subjects: **Astrophysics of Galaxies (astro-ph.GA)**
Cite as: **arXiv:1712.09655 [astro-ph.GA]**
(or **arXiv:1712.09655v1 [astro-ph.GA]** for this version)



Au Authorea



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The Bones of the Milky Way

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

This is a preprint. The published article is available at the Astrophysical Journal (ApJ 797 53) (Goodman 2014). This online version, published in December 2012, is available as an online "Authorea" preprint, and you can use the article's URL to cite that.

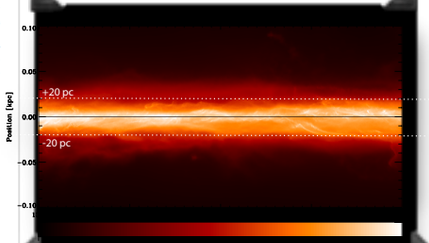
Open Preprint 2013

Abstract

ABSTRACT The very long, thin infrared 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 images from the Spitzer Space Telescope shows that this IRDC is at least 2, and possibly as many as 8 times longer than originally been claimed by Nessie's discoverers, Jackson et al. (2010); its aspect ratio is therefore at least 300:1 and possibly as large as 800:1. A careful accounting for both the Sun's offset from the Galactic plane and the $(l', b') = (0, 0)$ position defined by [illegible] in 1959 shows that the [illegible] distance to the Scutum-Centaurus Arm is not $b = 0$, but instead closer to $b = -0.4$, which is the latitude of Nessie to within a few pc. Apparently, Nessie lies *in* the Galactic mid-plane. The [illegible] low-density (CO) and high-density (NH_3) gas associated with the Nessie dark 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 filamentary features should be associated with a galaxy's spiral arms. Nessie is situated in the close [illegible] to the Sun toward the inner Galaxy, and appears almost perpendicular to our line of sight, making it a feature of its kind to detect from our location (a shadow of an Arm's bone, illuminated by the [illegible]). Although the Sun's (~ 25 pc) offset from the Galactic plane is not large in comparison with the half-thickness of the plane as traced by Population I objects such as GMCs and HII regions (~ 200 pc; Rix et al. (2013)), it may be significant compared with an extremely thin layer that might be traced out by Nessie-like "bones" of the Milky Way. Future high-resolution extinction and molecular line data may therefore allow us to exploit the Sun's position above the plane to gain a (very foreshortened) view "from above" of dense gas in Milky Way's disk and its structure.

1 Introduction

Determining the structure of the Milky Way, from our vantage point within it, is a perpetual challenge for astronomers. We know the Galaxy has spiral arms, but it remains unclear exactly how many, cf. (Vallée, 2008). Recent observations of maser proper motions give unprecedented accuracy in determining the three-dimensional position of the Galaxy's center and rotation speed (Reid et al., 2009, Brunthaler et al., 2011). But, to date, we still do not have a definitive picture of the Milky Way's three dimensional structure.



THE ASTROPHYSICAL JOURNAL, 797:53 (13pp), 2014 December 10 doi:10.1088/0004-637X/797/1/53
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THE BONES OF THE MILKY WAY

ALYSSA A. GOODMAN[1], JOÃO ALVES[2], CHRISTOPHER N. BEAUMONT[1], ROBERT A. BENJAMIN[3], MICHELLE A. BORKIN[4], ANDREAS BURKERT[5], THOMAS M. DAME[6], JAMES JACKSON[7], JENS KAUFFMANN[8], THOMAS ROBITAILLE[9], AND ROWAN J. SMITH[10]
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Received 2013 December 16; accepted 2014 July 30; published 2014 November 25

ABSTRACT

The very long and thin infrared 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 images 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; its aspect ratio is therefore at least 300:1 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 $(l', b') = (0, 0)$ position 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 $b = -0.4$, which is the latitude of Nessie to within a few parsecs. An analysis of the radial velocities of low-density (CO) and high-density (NH_3) gas associated with the Nessie dark 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. The Scutum–Centaurus Arm is the closest mid-plane segment of the inner Galaxy, and, at the longitude of Nessie, it is almost perpendicular to our line of sight, making it a feature of its kind to detect from our location (see as a shadow elongated along a bone from our vantage point within the Galaxy). Although the Sun's (~25 pc) offset from the Galactic mid-plane is not large in comparison with the half-thickness of molecular line observations of the Galactic "bones" of the Milky Way. Future high-resolution extinction and molecular line observations will therefore allow us to exploit the Sun's position above the plane to gain a (very foreshortened) view "from above" the dense gas in the Milky Way's disk and its structure.

Key words: dust, extinction – galaxies: star formation – Galaxy: kinematics and dynamics – Galaxy: structure – ISM: clouds – ISM: kinematics and dynamics – ISM: structure

Online-only material: color figures

1. INTRODUCTION

Determining the structure of the Milky Way from our vantage point within it is a perpetual challenge for astronomers. We know the Galaxy has spiral arms but it remains unclear exactly how many (see Vallée 2008). Recent observations of maser proper motions give unprecedented accuracy in determining the three-dimensional (3D) position of the Galaxy's center and rotation speed (Reid et al. 2009; Brunthaler et al. 2011). But, to date, we still do not have a definitive picture of the Milky Way's 3D structure.

The analysis offered in this paper suggests that some infrared dark clouds (IRDCs)[11]—in particular very long, very dark, clouds—appear to delineate major features of our Galaxy as would be seen from outside of it. In particular, we study a >3° long cloud associated with the IRDC called "Nessie" (Jackson et al. 2010), and we show that it appears to lie parallel to and no more than just a few parsecs from the true Galactic plane.

Our analysis uses diverse data sets, but it hinges on combining those data sets with a modern understanding of the meaning

[11] The term "infrared dark cloud", or "IRDC", typically refers to any cloud that is opaque in the mid-infrared.

Determining the structure of the Milky Way, from our vantage point within it, is a perpetual challenge for astronomers. We know the Galaxy has spiral arms, but it remains unclear exactly how many, cf. (Vallée, 2008). Recent observations of maser proper motions give unprecedented accuracy in determining the three-dimensional position of the Galaxy's center and rotation speed (Reid et al., 2009, Brunthaler et al., 2011). But, to date, we still do not have a definitive picture of the Milky Way's three dimensional structure.

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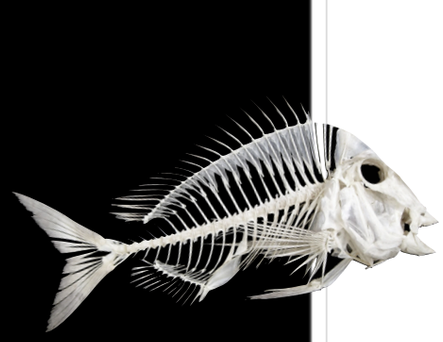

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The Milky Way Skeleton

Catherine Zucker, Cara Battersby, Alyssa Goodman

1 Abstract

Recently, Goodman et al. (2014) argued that a very long, very thin infrared dark cloud "Nessie" lies directly in the Galactic mid-plane and runs along the Scutum-Centaurus arm in position-position-velocity space as traced by low density CO and high density NH_3 gas. Nessie was presented as the first "bone" of the Milky Way, an extraordinarily long, thin, high contrast filament that can be used to map our galaxy's "skeleton." We present evidence for additional "bones" in the Milky Way galaxy, arguing that Nessie is not a curiosity but one of many filaments that could potentially trace Galactic structure. Our list of ten bone candidates are all long, filamentary, mid-infrared extinction features which lie parallel to, and no more than twenty parsecs from, the physical Galactic mid-plane. We use CO, N_2H+, and NH_3 radial velocity data to establish the location of the candidates in position–velocity space. Of the ten filaments, three candidates have a projected aspect ratio [illegible] to, the Scutum-Centaurus arm in position–velocity space. These three candidates are Nessie-like [illegible] spiral arms in both physical space and position-velocity space. Other candidates could be spurs, feathers, or interarm clouds associated with the Milky Way's galactic structure. As molecular spectral-line and extinction [illegible] more of the sky at increasing resolution and sensitivity, we hope to [illegible] in future studies, to ultimately create a global-fit to the galaxy's spiral arms by piecing together individual skeletal features. This work is supported in part by the NSF REU and DOD ASSURE programs under NSF grant no. 1262851 and by the Smithsonian Institution.

Open Preprint 2014

2 Introduction

Over the past several decades, astronomers have begun to define the structure and kinematic properties of the Milky Way. Yet, despite a large conglomeration of literature on the subject, many key questions remain. For instance, how many spirals arms does the Milky Way have, cf. (Vallée 2008)? What is the location of these arms? And how would these arms appear to an observer viewing the Milky Way from the outside? An understanding of the Milky Way's three dimensional structure has eluded us, largely due to the fact that we are embedded in the galaxy we are attempting to delineate.

THE ASTROPHYSICAL JOURNAL, 815:23 (25pp), 2015 December 10 doi:10.1088/0004-637X/815/1/23
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THE SKELETON OF THE MILKY WAY

CATHERINE ZUCKER[1,2], CARA BATTERSBY[2], AND ALYSSA GOODMAN[2]
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Received 2015 June 27; accepted 2015 September 21; published 2015 December 3

ABSTRACT

Recently, Goodman et al. argued that the very long, very thin infrared dark cloud "Nessie" lies directly in the Galactic midplane and runs along the Scutum–Centaurus Arm in position–position–velocity (p–p–v) space as traced by lower-density CO and higher-density NH_3 gas. Nessie was presented as the first "bone" of the Milky Way, an extraordinarily long, thin, high-contrast filament that can be used to map our Galaxy's "skeleton." Here we present evidence for additional bones in the Milky Way, arguing that Nessie is not a curiosity but one of several filaments that could potentially trace Galactic structure. Our 10 bone candidates are all long, filamentary, mid-infrared extinction features that lie parallel to, and no more than 20 pc from, the physical Galactic mid-plane. We use CO, N_2H^+, HCO^+, and NH_3 radial velocity data to establish the three-dimensional location of the candidates in p–p–v space. Of the 10 candidates, 6 also have a projected aspect ratio of ≥50:1; run along, or extremely close to, the Scutum–Centaurus Arm in p–p–v space; *and* exhibit no abrupt shifts in velocity. The evidence presented here suggests that these candidates mark the locations of the Galaxy's spiral arms, with the bone called filament 5 ("BC_18.88-0.09") being a close analog to Nessie in the first quadrant. As [illegible] spectral-line and extinction maps cover more of the sky at increasing resolution and sensitivity, we should [illegible] future studies.

Key words: Galaxy: kinematics [illegible] dynamics [illegible]

Draft version December [illegible]
Typeset using LaTeX **preprint** style in AASTeX61

PHYSICAL PROPERTIES OF LARGE-SCALE GALACTIC FILAMENTS

CATH[illegible] ALYSSA GOODMAN[1]

[1] *Harvard-Smithsonian Center for Astrophysics, Cambridge, MA 02138*
[2] *Department of Physics, University of Connecticut, Storrs, CT 06269, USA*

Abstract

The characterization of our Galaxy's [illegible] filamentary gas features has been the subject of several studies in recent years, prompting [illegible] filaments, but also confusion as to whether all these features [illegible] ments") are essentially the same. They are not. We under[illegible] physical properties (densities, temperatures, morphologies, radial profiles) and kinematics of large-scale filaments in the literature. We expand and improve upon prior analyses by using the same data sets, techniques, and spiral arm models to disentangle the filaments' inherent properties from selection criteria and methodology. Our results suggest that the many [illegible] ing techniques are uncovering different physical structures, with length (11-269 pc [illegible] pc), mass (3×10^3 $M_\odot$ – 1.1×10^6 $M_\odot$), aspect ratio (3:1 - 117:1), and dense gas [illegible] ng by at least an order of magnitude across the sample of 45 filaments. As part of this analysis, we develop a radial profile fitting code, *RadFil*, which is publicly available. We also perform a *position-position-velocity* (p-p-v) analysis on a subset of the filaments and find that while 60%-70% lie in the plane of the Galaxy, only 30-45% also exhibit kinematic proximity to purported spiral arms. In a parameter space defined by aspect ratio, temperature, and density, we broadly distinguish three filament categories, which could be indicative of different formation mechanisms or histories. Highly elongated "Bone-like" filaments show the most potential for tracing gross spiral structure (e.g. arms), while other categories could simply be large concentrations of molecular gas (GMCs, core complexes).

2 More Refereed Articles 2015,18

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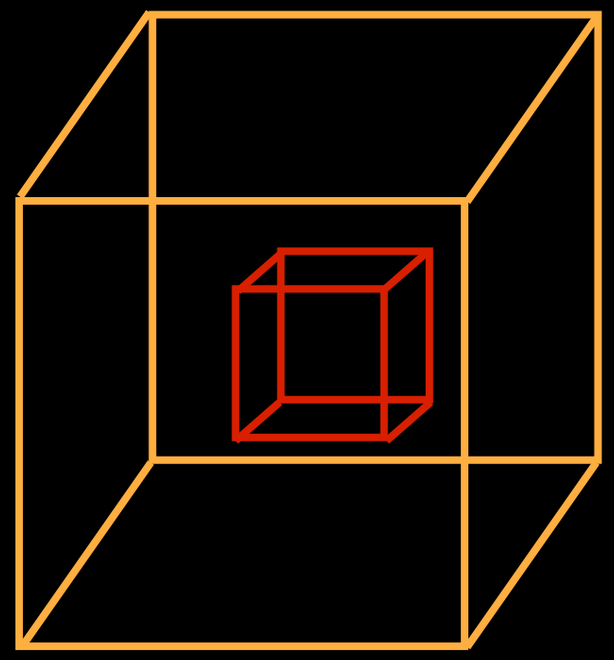

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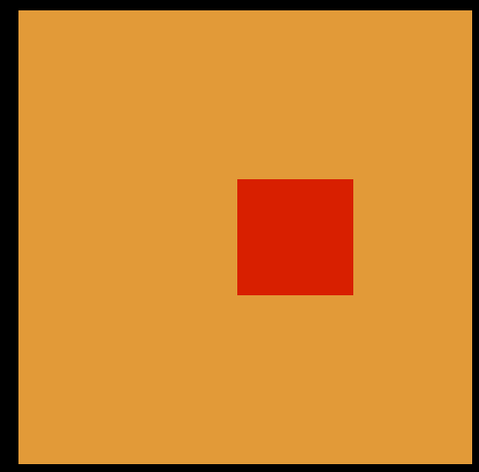

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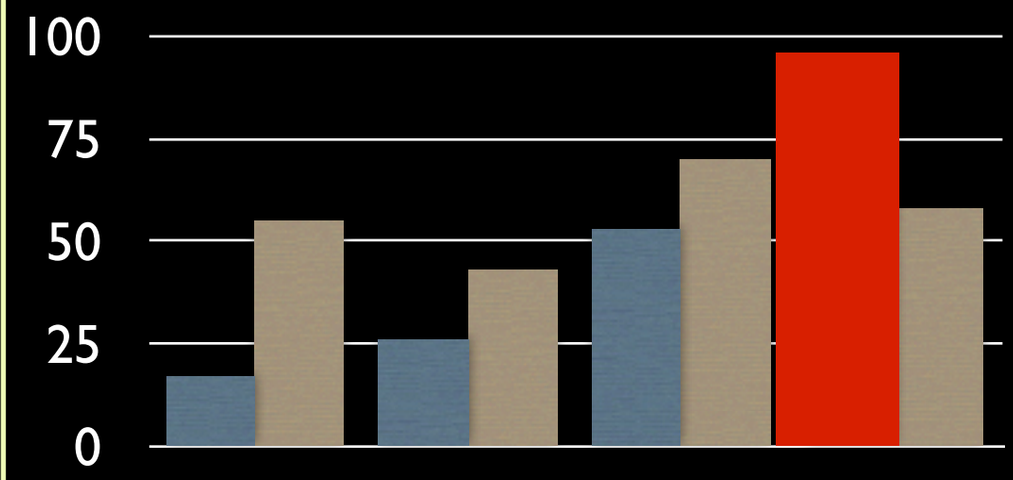
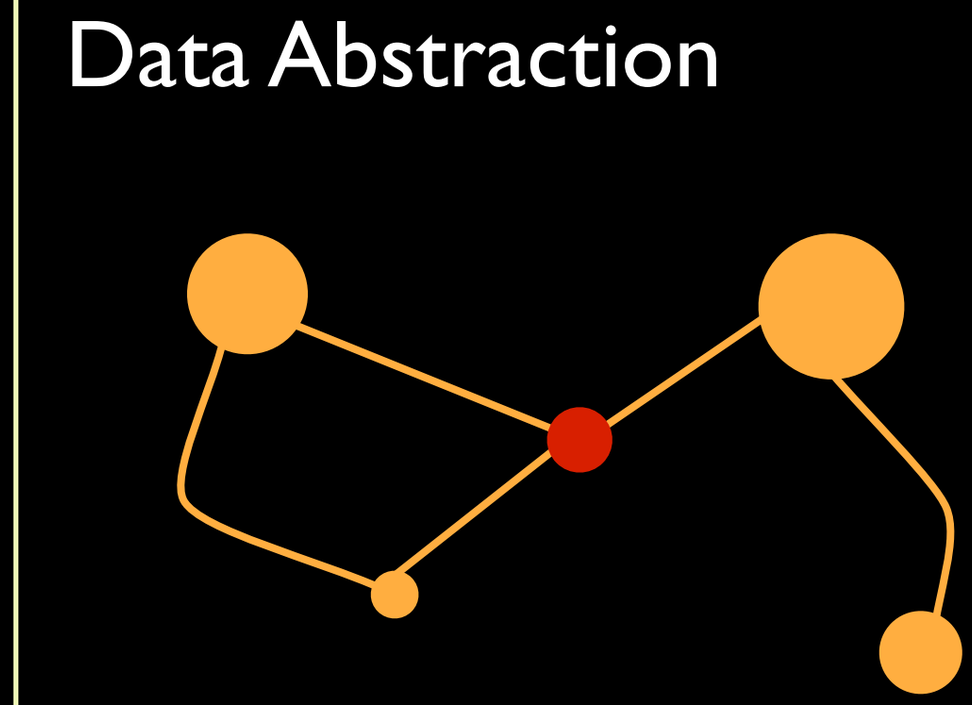




figure, by M. Borkin, reproduced from Goodman 2012, "Principles of High-Dimensional Data Visualization in Astronomy"

NESSIE IN GLUE+WWT

Glue

Data Collection

Data
- HOPS_ammonia_catalog_ICRS
- Nessie_13CO_ThrUMMS_slab
- Nessie_GLIMPSE_8micron_cropped
- Nessie_HIGAL_Column_Density[PRIMA...

Subsets
- Nessie
  - Nessie (HOPS_ammonia_catalog_I...
  - Nessie (Nessie_13CO_ThrUMMS_sl...
  - Nessie (Nessie_GLIMPSE_8micron_...
  - Nessie (Nessie_HIGAL_Column_De...

Link data

Plot Layers - WorldWideTelescope (WWT)
- Nessie (HOPS_ammonia_catalog_ICRS)
- HOPS_ammonia_catalog_ICRS

Color:
Size: 3
Opacity:
RA: ra
Dec: dec
Center view on layer

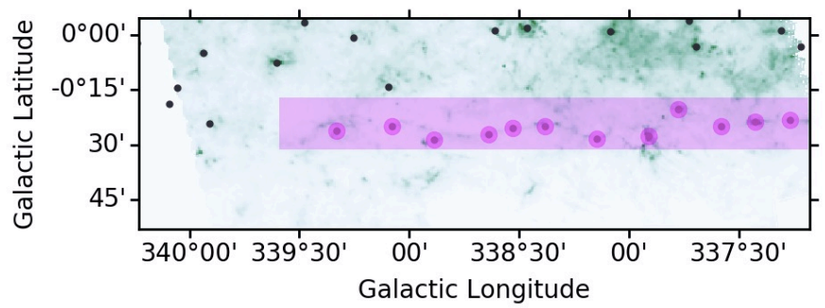
Plot Options - WorldWideTelescope (WWT)
Foreground: IRIS: Improved Reprocessing
Opacity:
Background: Digitized Sky Survey (Color)
Galactic Plane mode

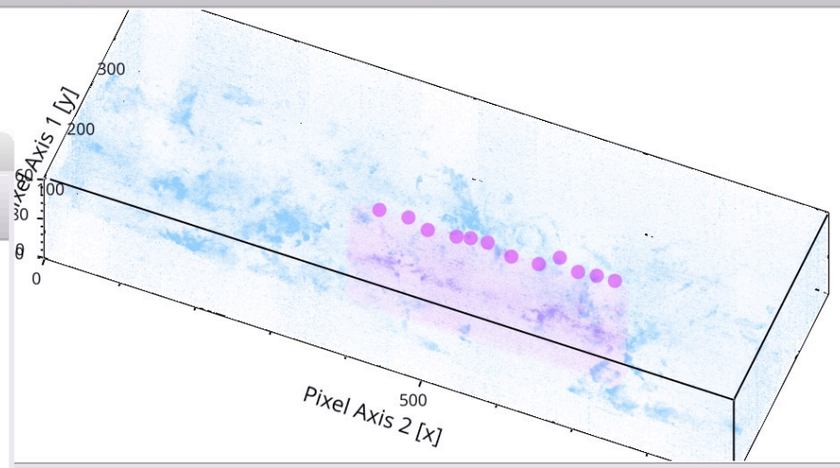
Selection Mode:

View Console

Tab 1

2D Image





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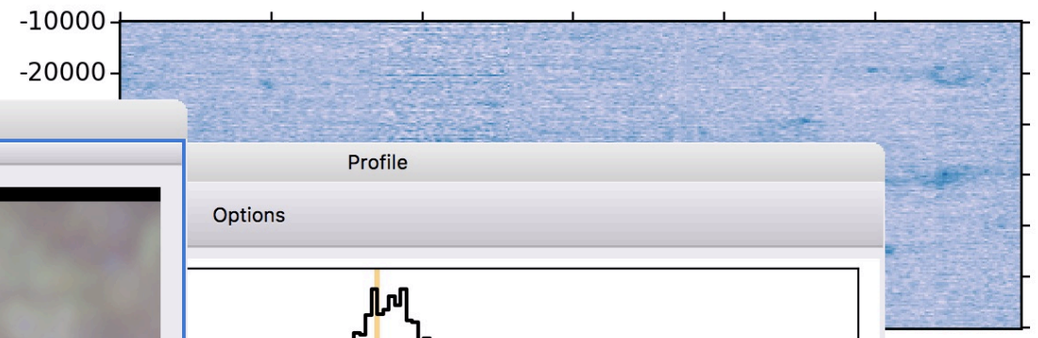
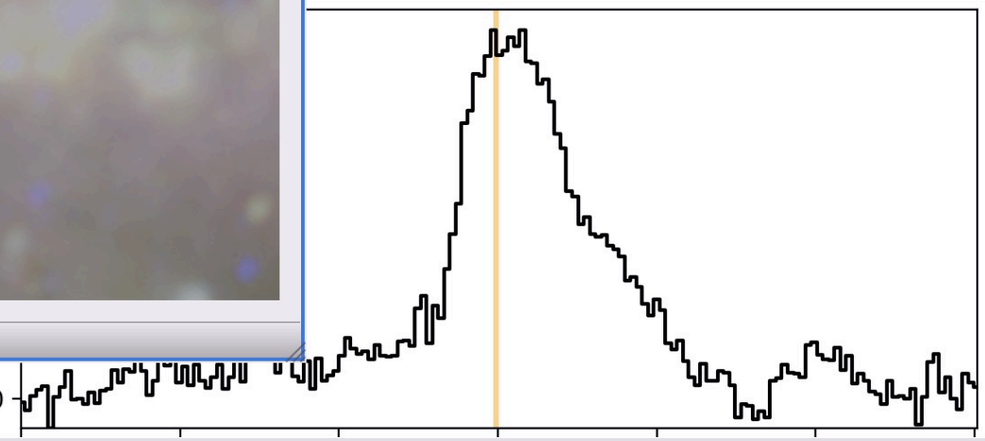


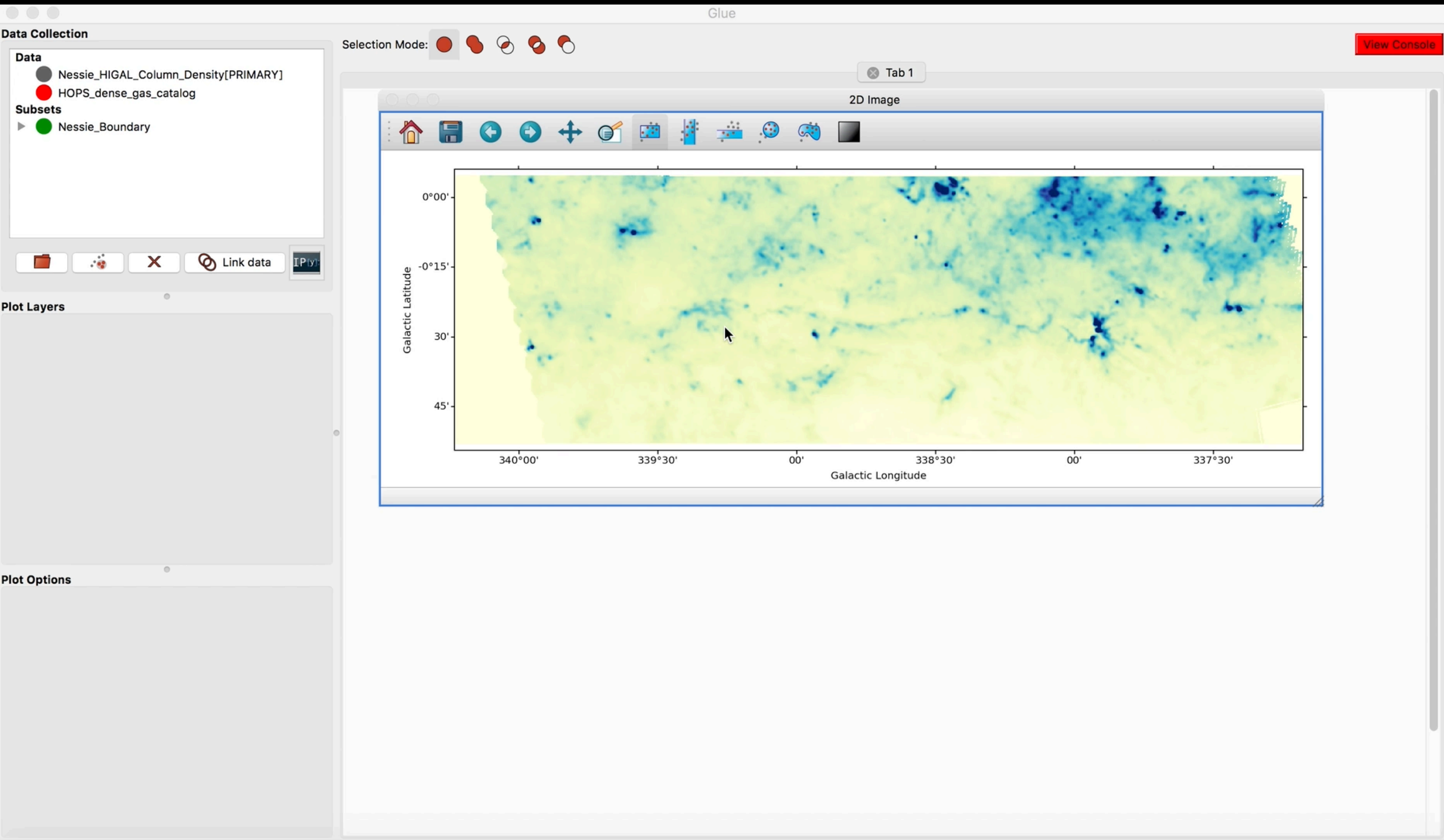
WorldWideTelescope (WWT)

Profile

Options



NESSIE IN GLUE+WWT



The Skeleton of the Milky Way: Credits

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Supported by Microsoft Research NSF NASA Smithsonian

The "Paper" of the Future

Alyssa Goodman, Josh Peek, Alberto Accomazzi, Chris Beaumont, Christine L. Borgman, How-Huan Hope Chen, Merce Crosas, Christopher Erdmann, August Muench, Alberto Pepe, Curtis Wong + Add author Re-arrange authors

A 5-minute video demonsration of this paper is available at this YouTube link.

1 Preamble

A variety of research on human cognition demonstrates that humans learn and communicate best when more than one processing system (e.g. visual, auditory, touch) is used. And, related research also shows that, no matter how technical the material, most humans also retain and process information best when they can put a narrative "story" to it. So, when considering the future of scholarly communication, we should be careful not to do blithely away with the linear narrative format that articles and books have followed for centuries: instead, we should enrich it.

Much more than text is used to commuicate in Science. Figures, which include images, diagrams, graphs, charts, and more, have enriched scholarly articles since the time of Galileo, and ever-growing volumes of data underpin most scientific papers. When scientists communicate face-to-face, as in talks or small discussions, these figures are often the focus of the conversation. In the best discussions, scientists have the ability to manipulate the figures, and to access underlying data, in real-time, so as to test out various what-if scenarios, and to explain findings more clearly. **This short article explains—and shows with demonstrations—how scholarly "papers" can morph into long-lasting rich records of scientific discourse**, enriched with deep data and code linkages, interactive figures, audio, video, and commenting.

The Skeleton of the Milky Way

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

with collaborators at (alphabetically by current insitution):

American Astronomical Society: Thomas Robitaille

Boston University: James Jackson

Haystack Observatory: Jens Kauffmann

Harvard - Smithsonian: Thomas Dame, Doug Finkbeiner, Mark Reid, Catherine Zucker

Netflix: Christopher Beaumont

Northeastern Univeristy: Michelle A. Borkin

U. Connecticut: Cara Battersby

U. Munich, Germany: Andreas Burkert

U. Manchester, UK: Rowan Smith

U. Vienna, Austria: Joao F. Alves

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