How a "WorldWide Telescope" helped Astronomers discover the "Bones" of the Milky Way

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

3500 YEARS OF OBSERVING

Stonehenge, 1500 BC

Ptolemy in Alexandria, 100 AD

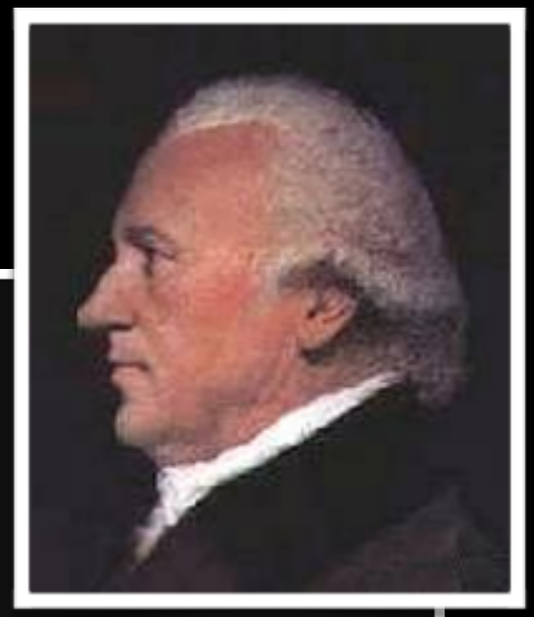
Observatory Tower, Lincolnshire, UK, c. 1300

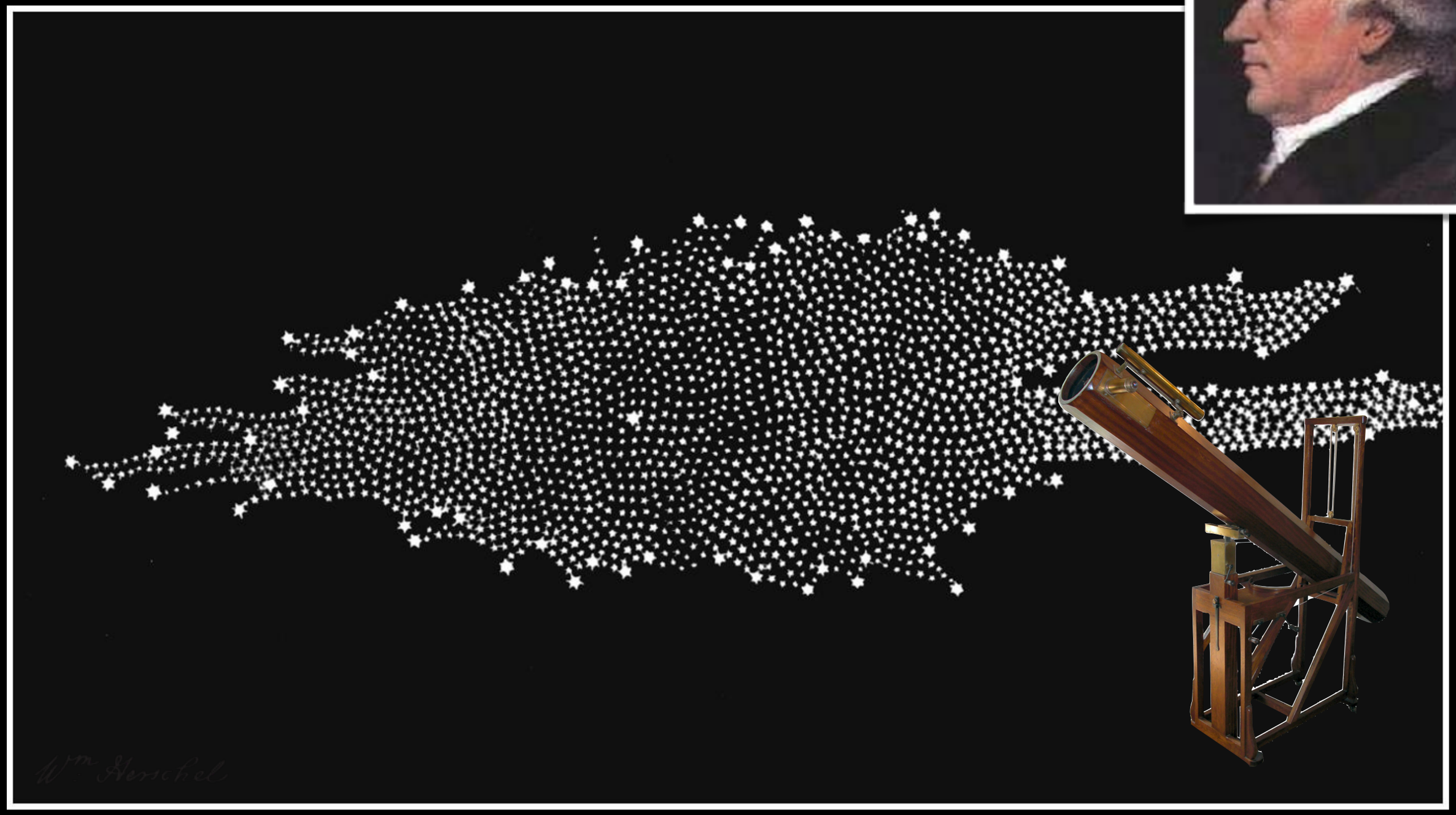
naked-eye/telescope

Galileo, 1600

The "Scientific Revolution"

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)

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Galileo, 1600

The "Scientific Revolution"

multi-wavelength

Reber's Radio Telescope, 1937

ground/space-based

NASA/Explorer 7 (Space-based Observing) 1959

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)

3500 YEARS OF OBSERVING

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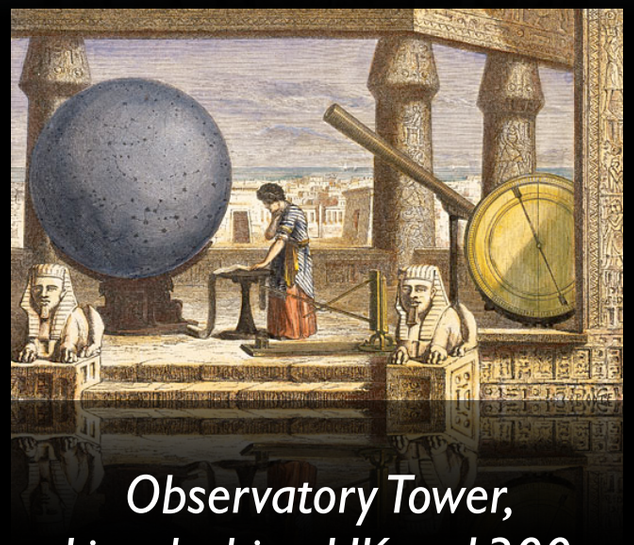
Ptolemy in Alexandria, 100 AD



Observatory Tower, Lincolnshire, UK, c. 1300

naked-eye/telescope

Galileo, 1600

The "Scientific Revolution"

multi-wavelength

Reber's Radio Telescope, 1937

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"The Internet"

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

21st Century Virtual Observatories & Online Astronomy

"WorldWide Telescope"

created by Curtis Wong & Jonathan Fay at Microsoft Research
released 2008…open-sourced & hosted by AAS 2015

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

...at a conference about "The Early Phases of Star Foration"

Andi Burkert asked a question:

Is Nessie "parallel to the Galactic Plane"?

No one knew.

The Milky Way

“Galactic Plane”

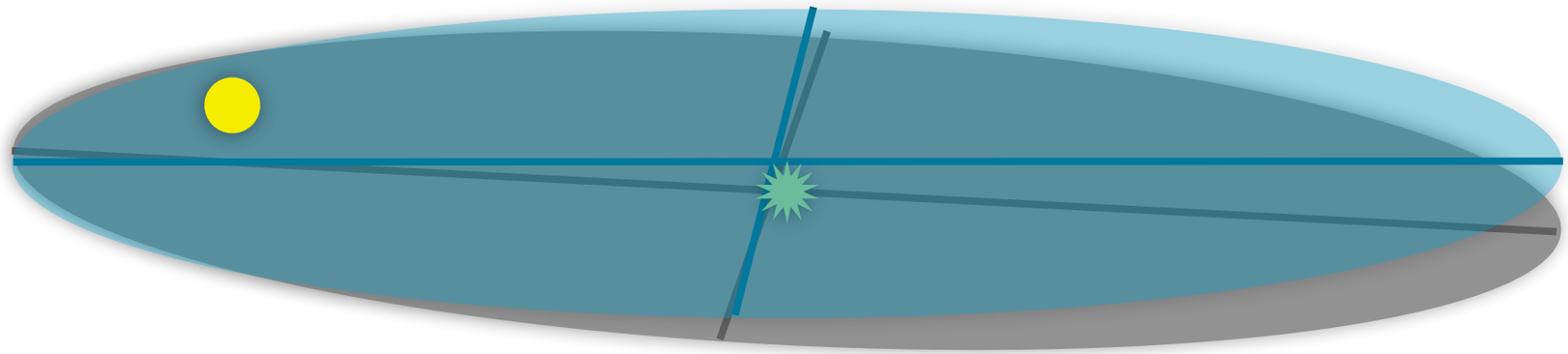
The Milky Way
(Artist's Conception)

“Is Nessie Parallel to the Galactic Plane?”

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

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

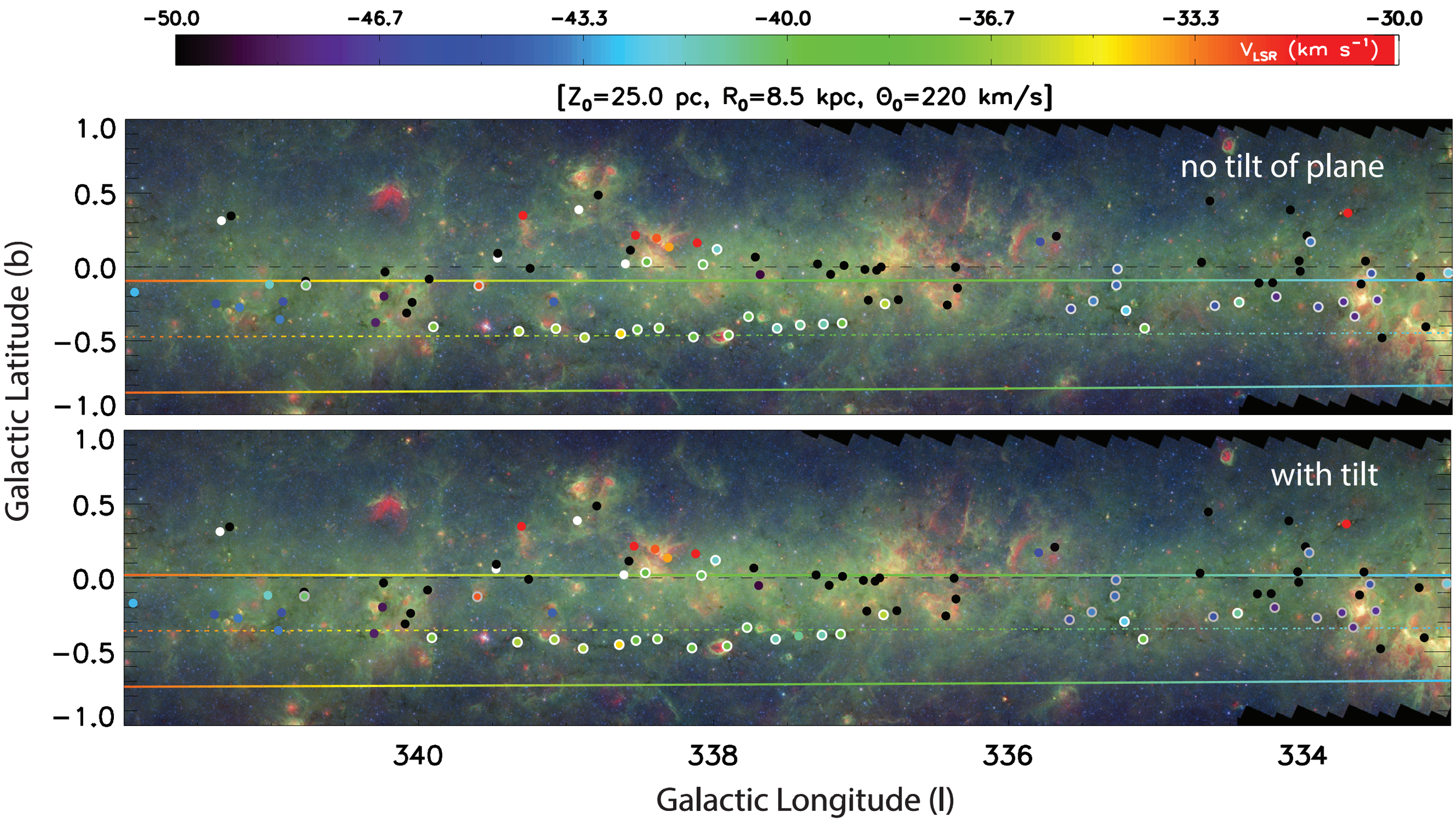
+

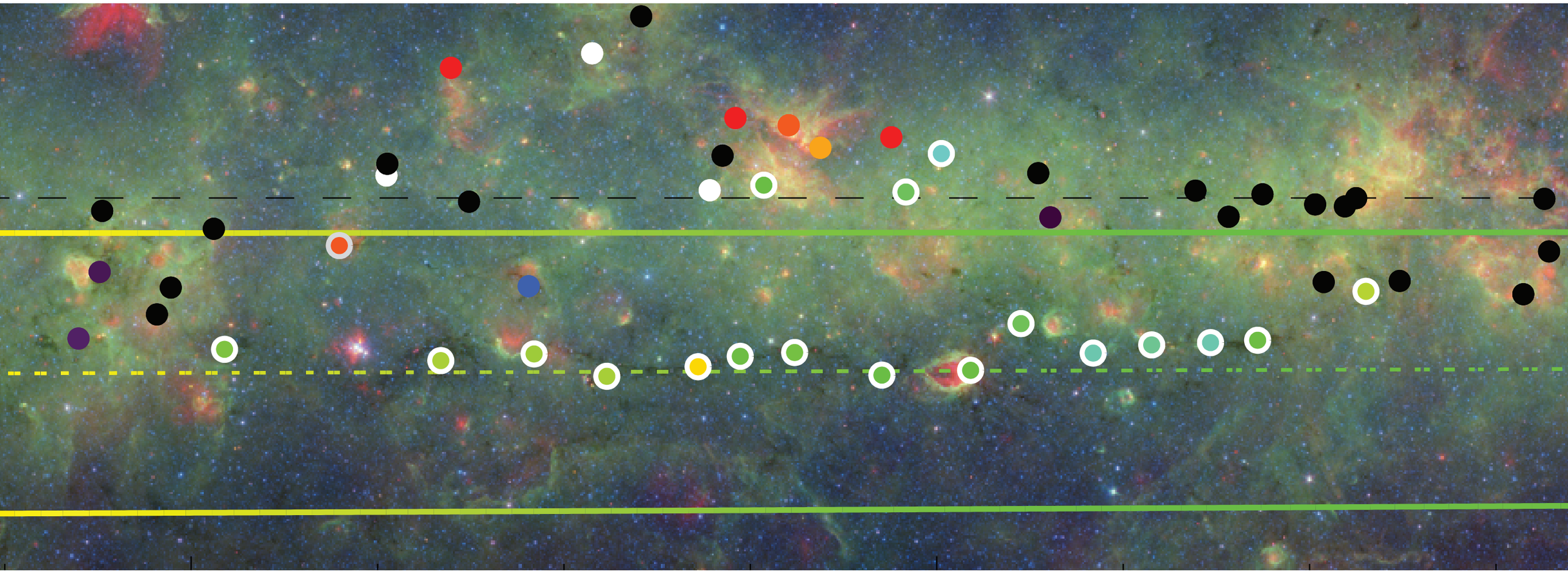
Galactic Center is ~20 light years offset from the IAU Milky Way Center

=

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

In the plane, at distance of spiral arm!

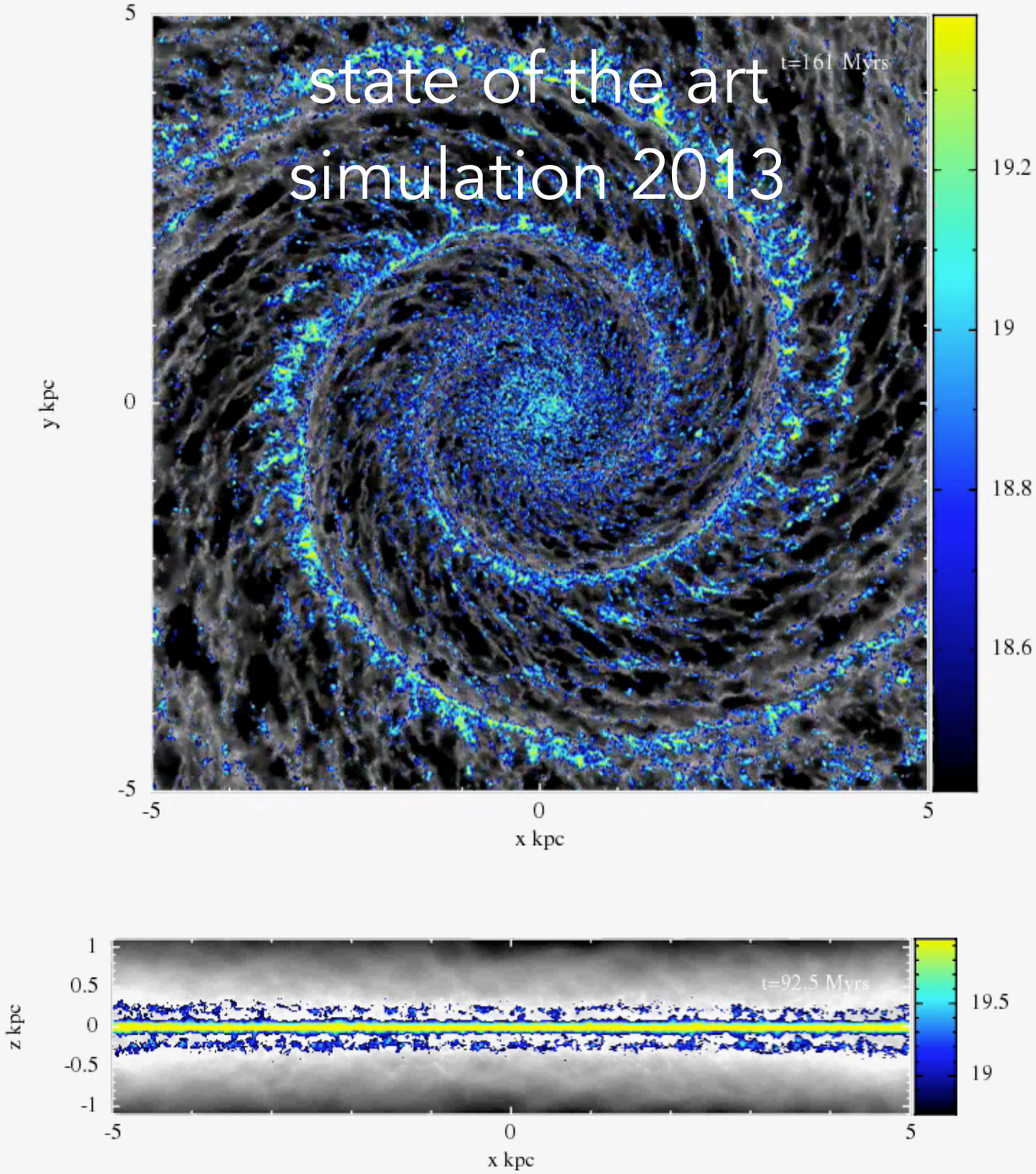




...eerily precisely...

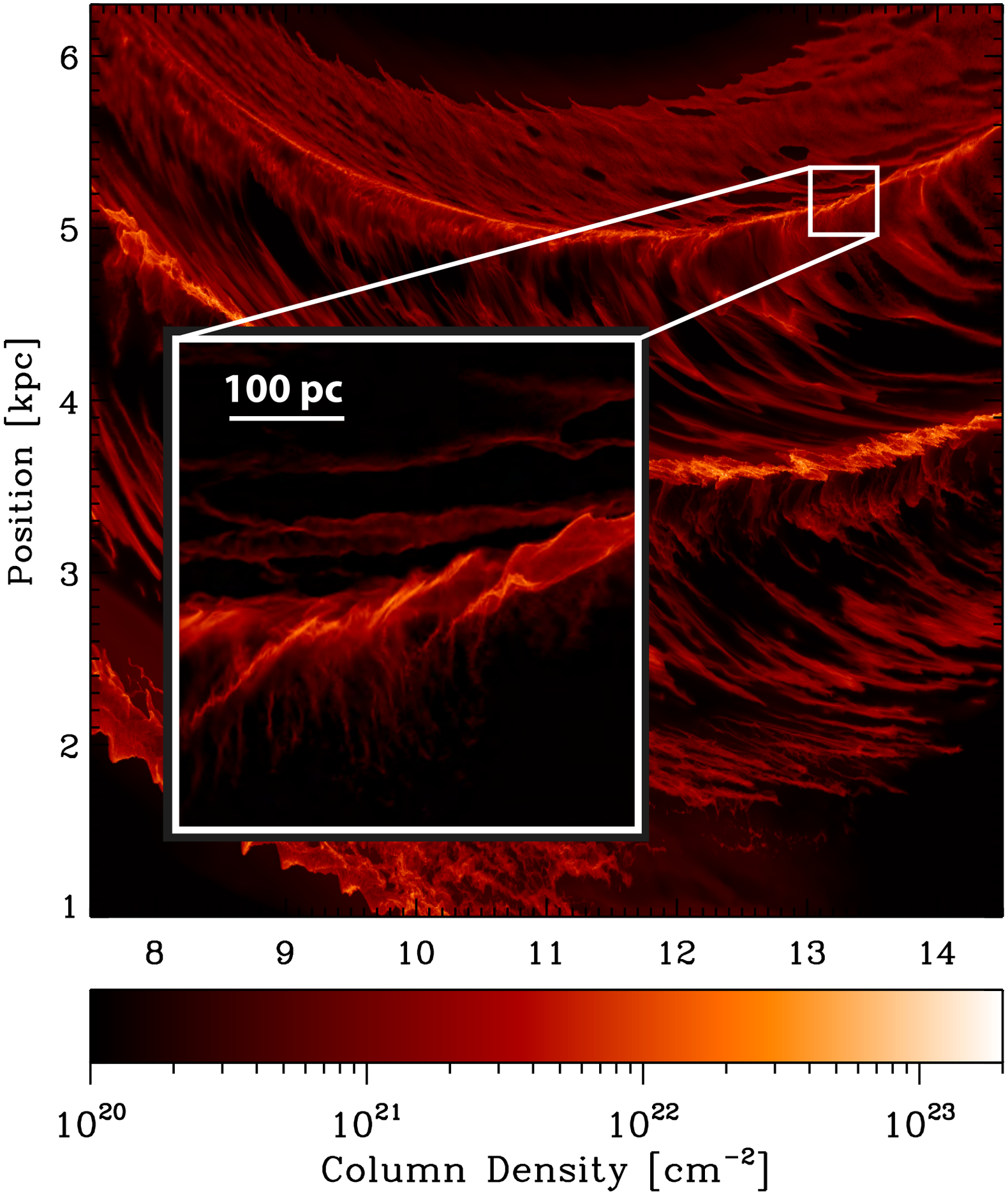
A full 3D skeleton?

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



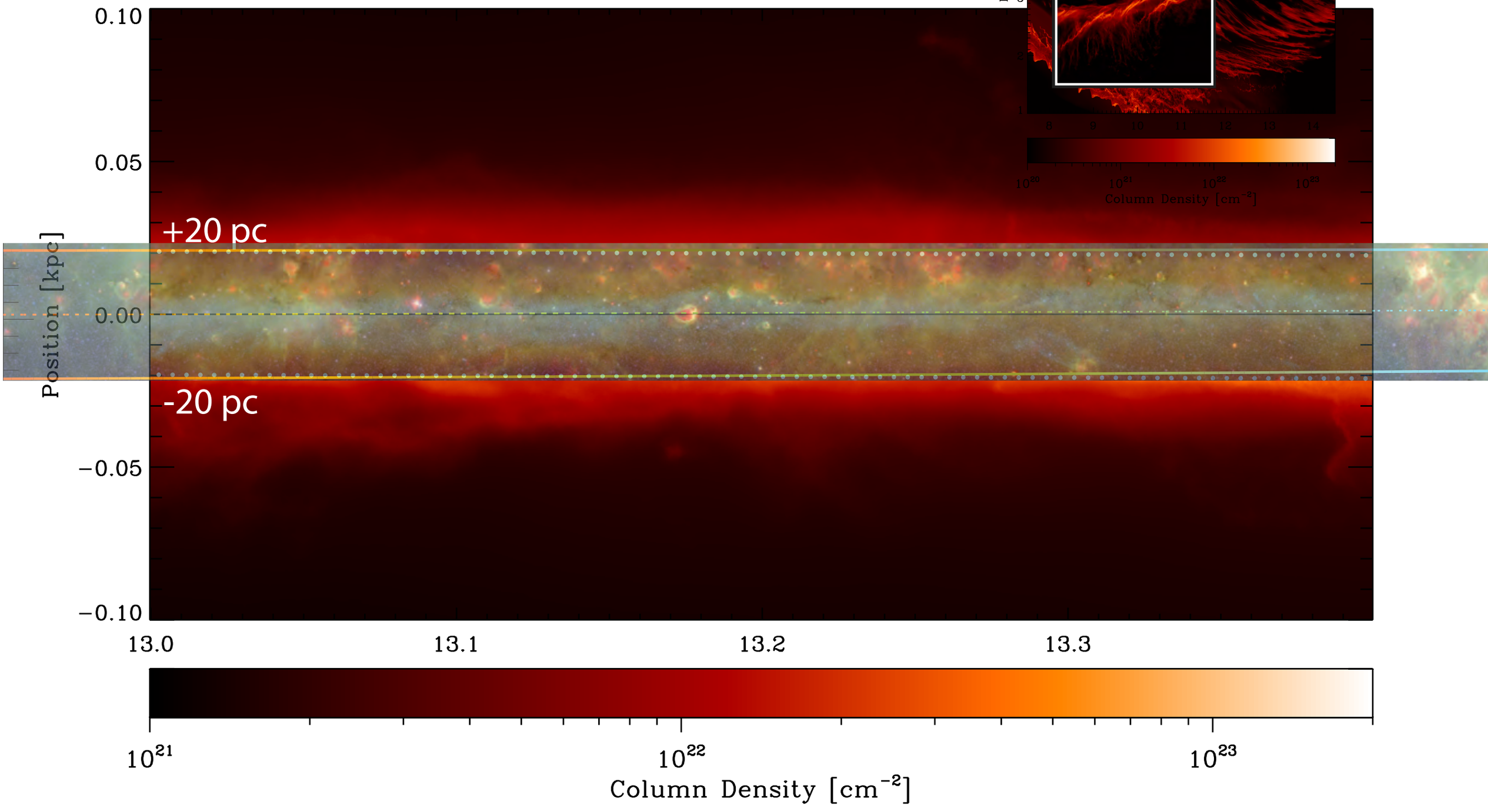
simulations courtesy Clare Dobbs

2014 Simulation



Smith et al. 2014, using AREPO

2014 Simulation



Smith et al. 2014, using AREPO

The Astrophysical Journal, 797:53 (13pp), 2014 December 10 doi:10.1088/0004-637X/797/1/53

THE BONES OF THE MILKY WAY

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[8] California Institute of Technology, Pasadena, CA 91125, USA
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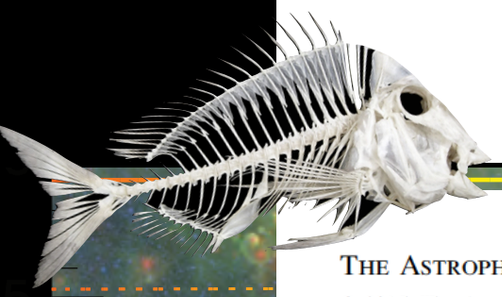
Received 2013 December 16; accepted 2014 July 30; published 2014 November 25



The Astrophysical Journal, 815:23 (25pp), 2015 December 10 doi:10.1088/0004-637X/815/1/23

THE SKELETON OF THE MILKY WAY

Catherine Zucker[1,2], Cara Battersby[2], and Alyssa Goodman[2]
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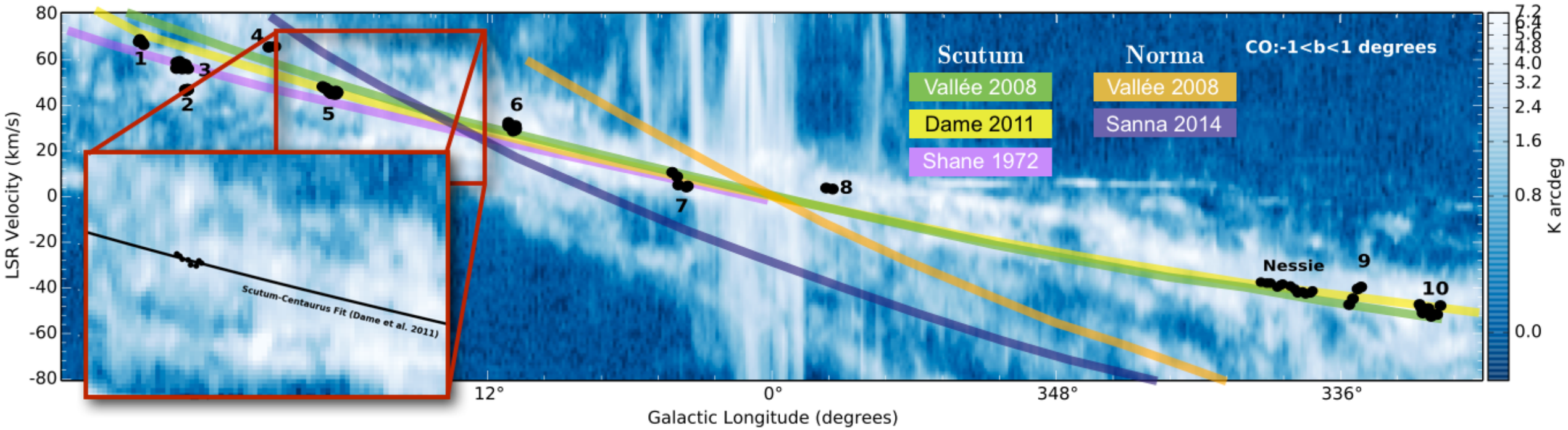
ABSTRACT

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 $\geqslant$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 significant spiral features, with the bone called filament 5 ("BC_18.88-0.09") being a close analog to Nessie in the northern sky. As molecular spectral-line and extinction maps cover more of the sky at increasing resolution and sensitivity, it should be possible to find more bones in future studies.

Key words: Galaxy: kinematics and dynamics – Galaxy: structure – ISM: clouds

6 OUT OF 10 WWT-IDENTIFIED BONE CANDIDATES TURN OUT TO BE EXCELLENT IN "3D"

(POSITON-POSITION-VELOCITY SPACE)



Blue image in the background shows CO position-velocity diagram based on Dame et al. 2001

Draft version July 27, 2017
Typeset using LaTeX **preprint** style in AASTeX61

PHYSICAL PROPERTIES OF LARGE-SCALE GALACTIC FILAMENTS

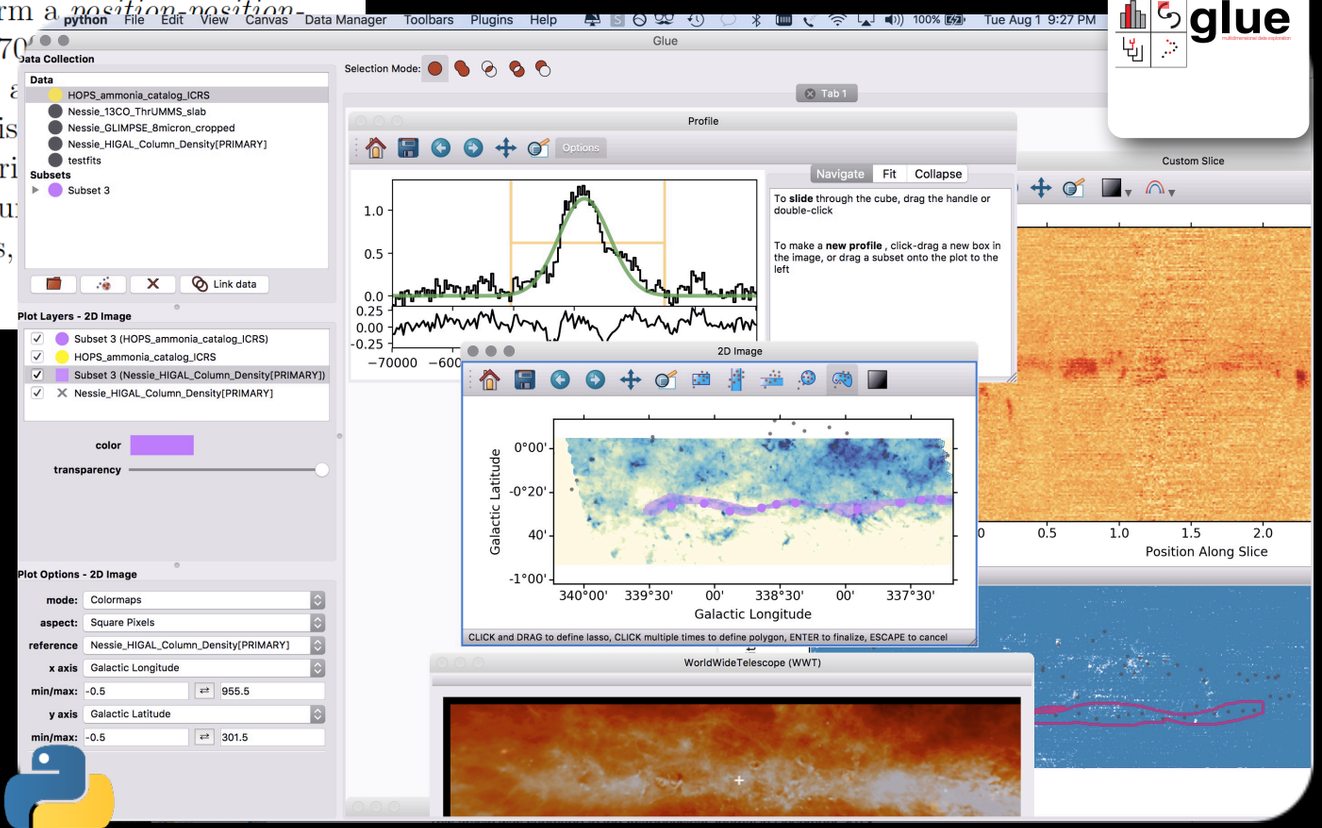
Catherine Zucker, Cara Battersby, Alyssa Goodman[1]

[1] *Harvard-Smithsonian Center for Astrophysics*

Abstract

The characterization of our Galaxy's longest filamentary gas features has been the subject of a number of 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 quantities length (10-268 pc), width (1-40 pc), mass (3×10^3 $M_\odot$ $- 1.1 \times 10^6$ $M_\odot$), aspect ratio (3:1 - 104:1), and dense gas fraction (0.2-100%) varying by at least an order of magnitude across the sample of 45 filaments. We perform a *position-position-velocity* (*p-p-v*) analysis on a subset of the filaments and find that while 60%-70
the Galaxy, only 30-45% also exhibit kinematic proximity to purported spiral a
space defined by aspect ratio, temperature, and density, we broadly distinguis
egories, which could be indicative of different formation mechanisms or histori
"Bone-like" filaments show the most potential for tracing gross spiral structu
other categories could simply be large concentrations of molecular gas (GMCs,

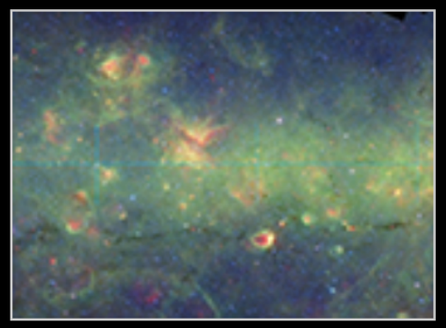
2017 "The Bone Wars" (& glue)



WorldWide Telescope *Stories*

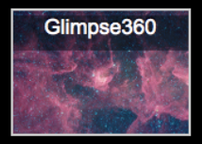
STORIES OF WORLDWIDE TELESCOPE IN ACTION

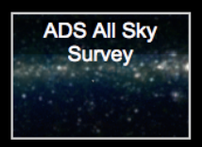
Research



MILKY WAY BONES

More Stories...





Outreach

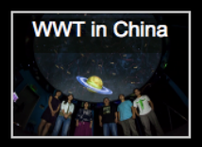
COSMIC WONDER

More Stories...

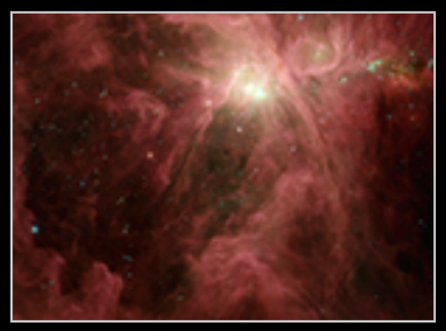
K12

WWTA MOON PHASES

More Stories...

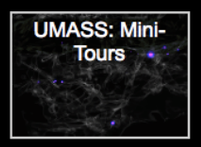


University



GRAD STUDENT LEARNING MODULES

More Stories...

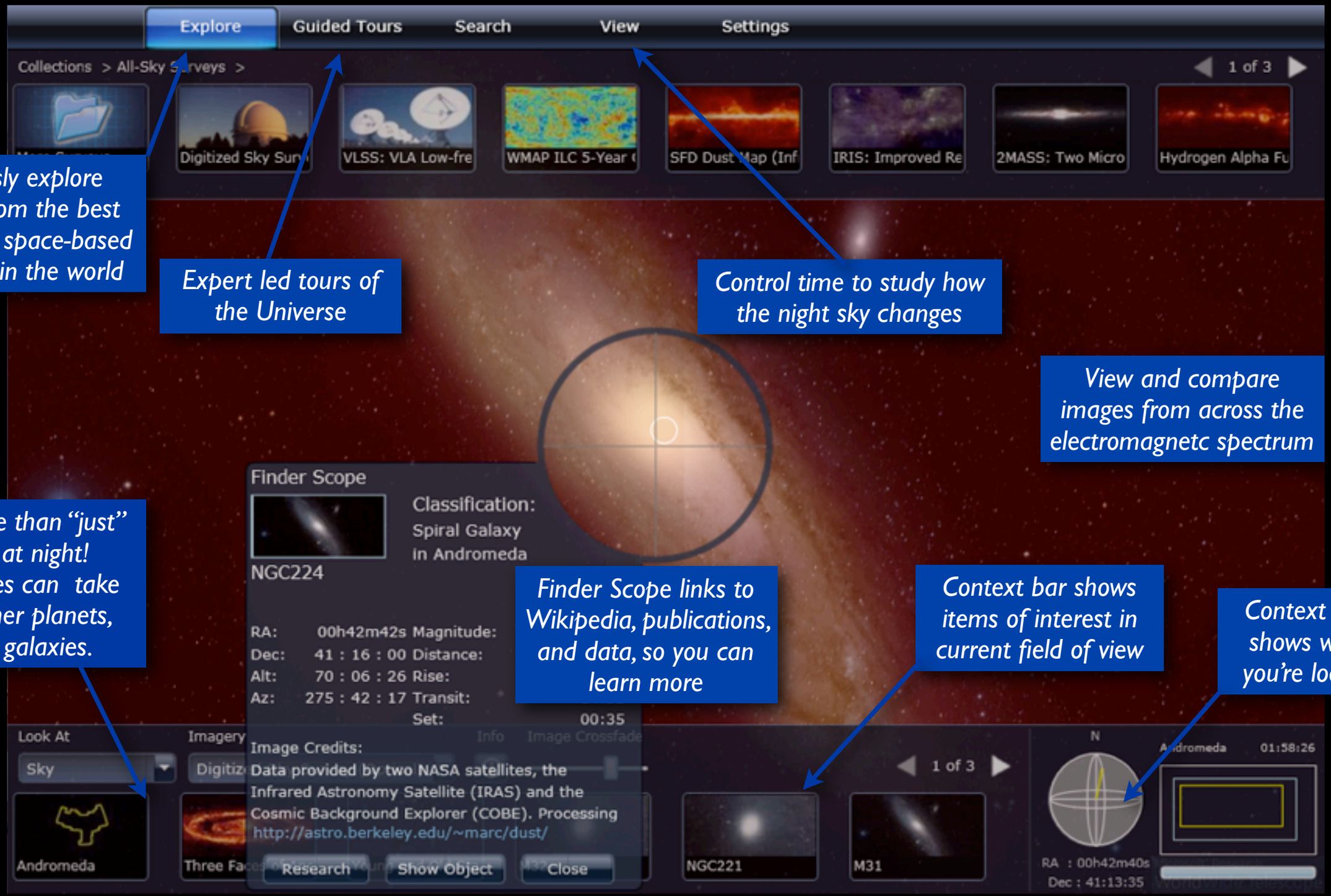


wwtstories.org

Microsoft® Research WorldWide Telescope

[demo]

worldwidetelescope.org



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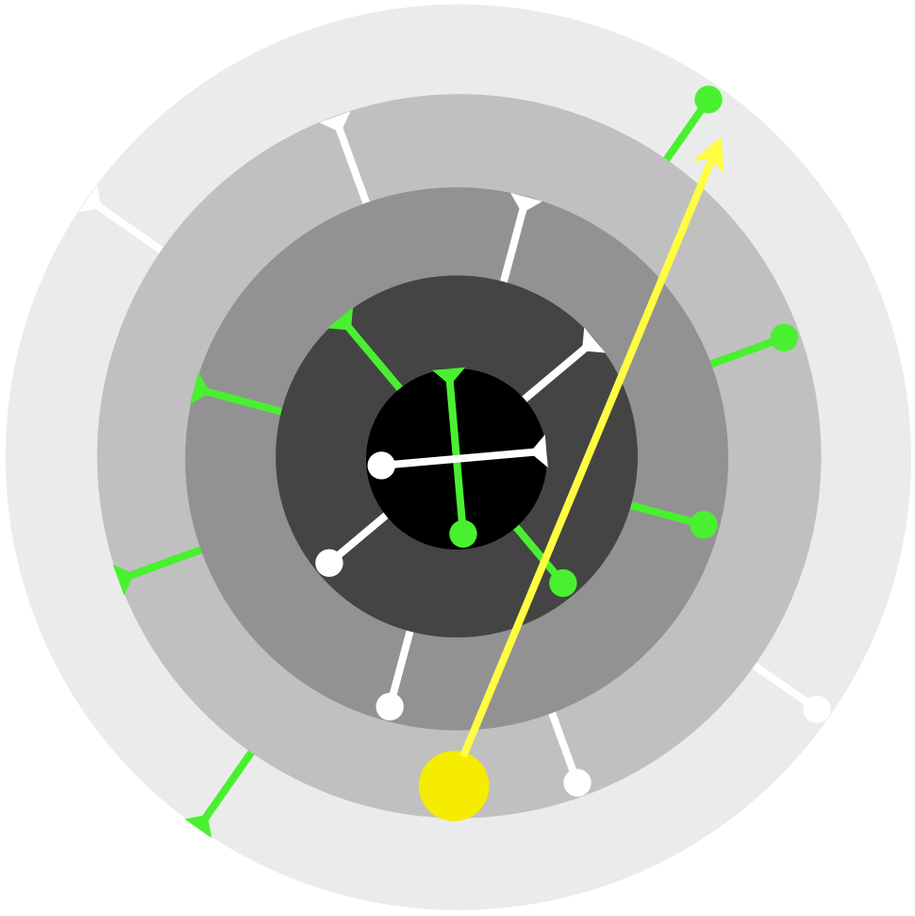
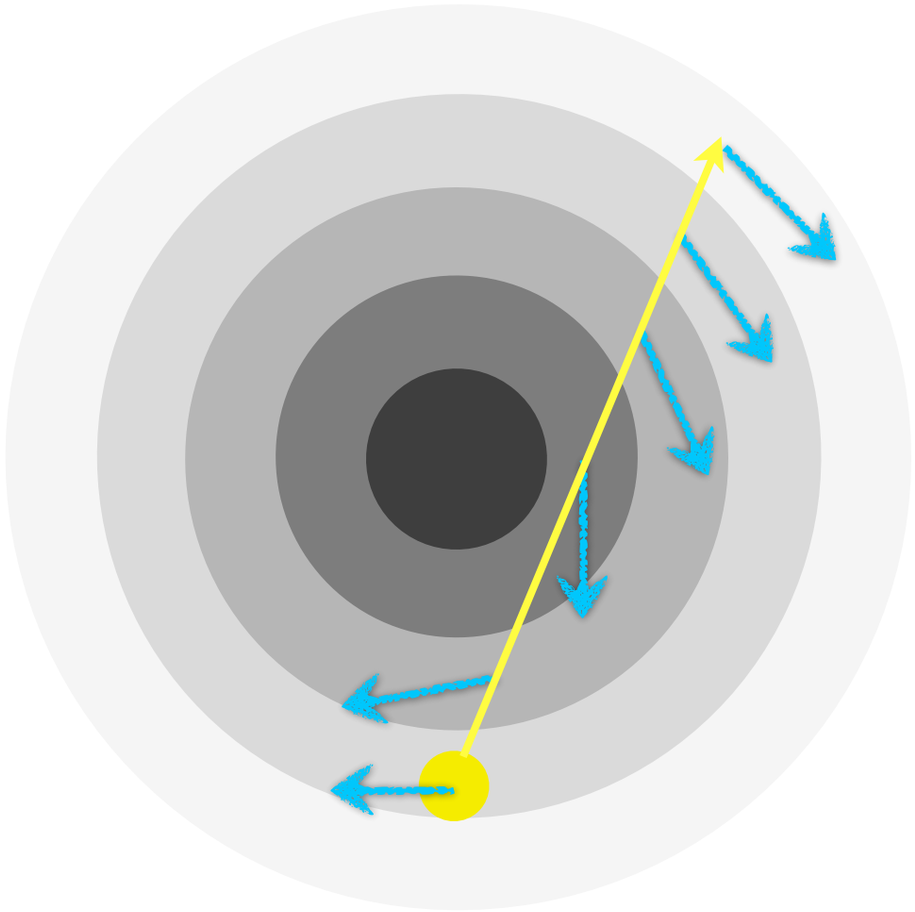
Finder Scope links to Wikipedia, publications, and data, so you can learn more

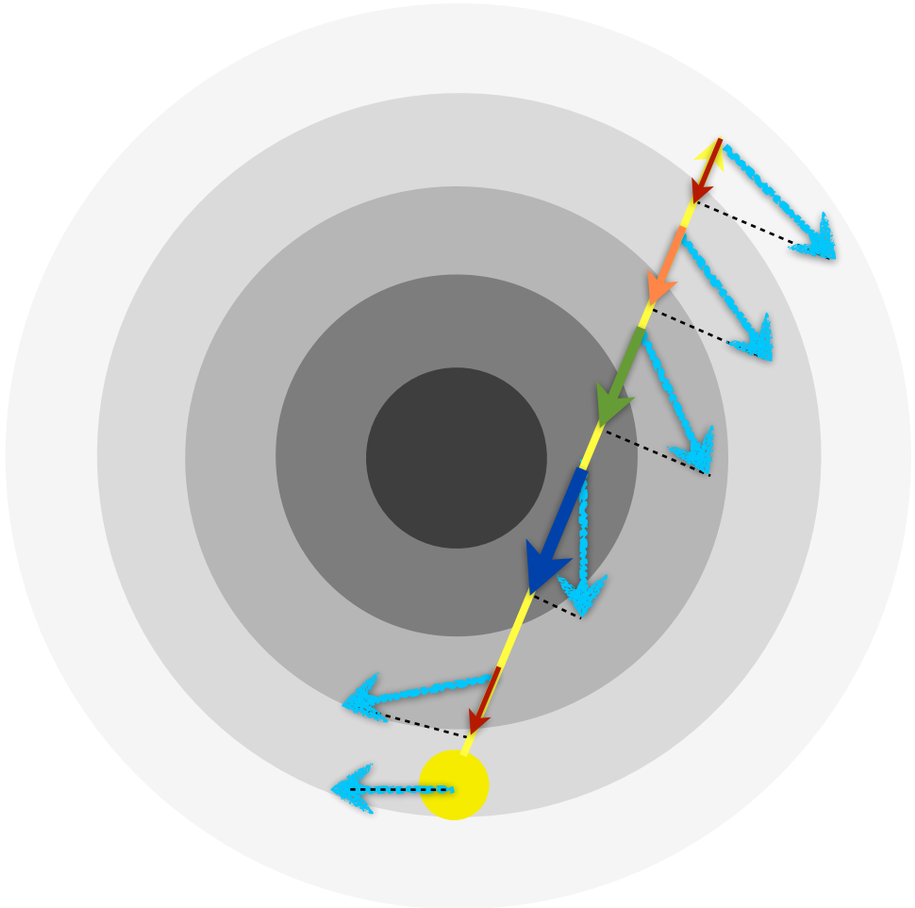
Context bar shows items of interest in current field of view

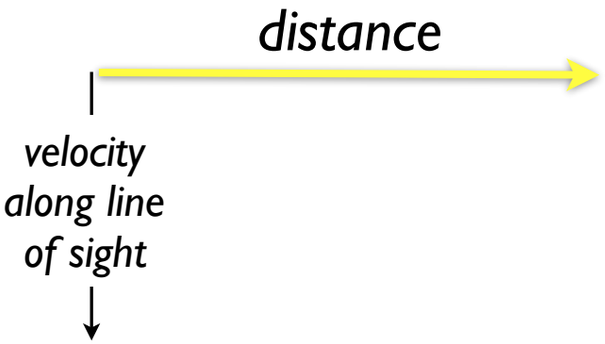
Context globe shows where you're looking.

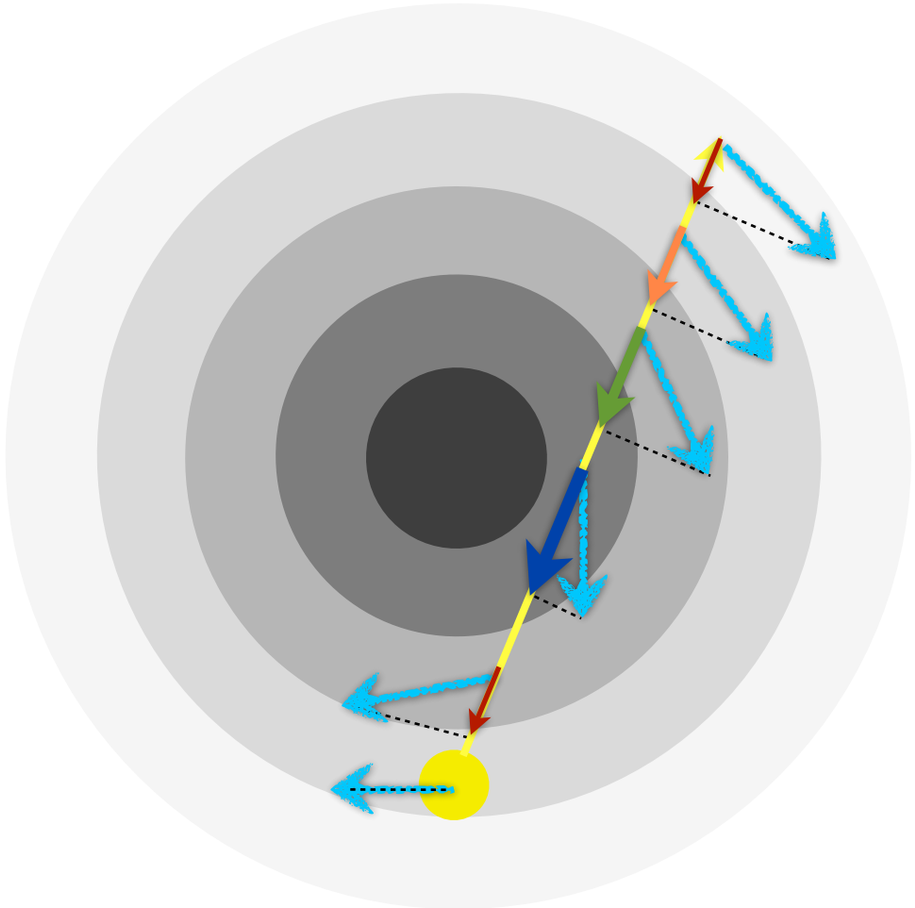
A Rotating (Spiral) Galaxy Observed from its Outskirts...

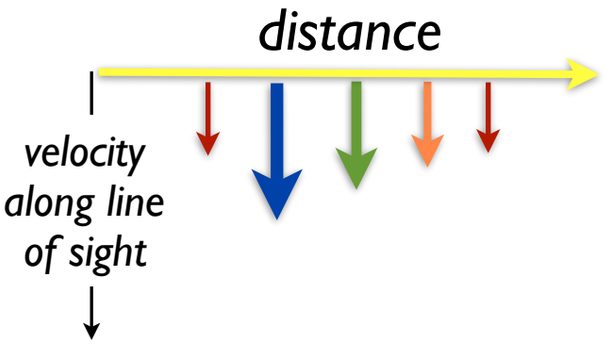






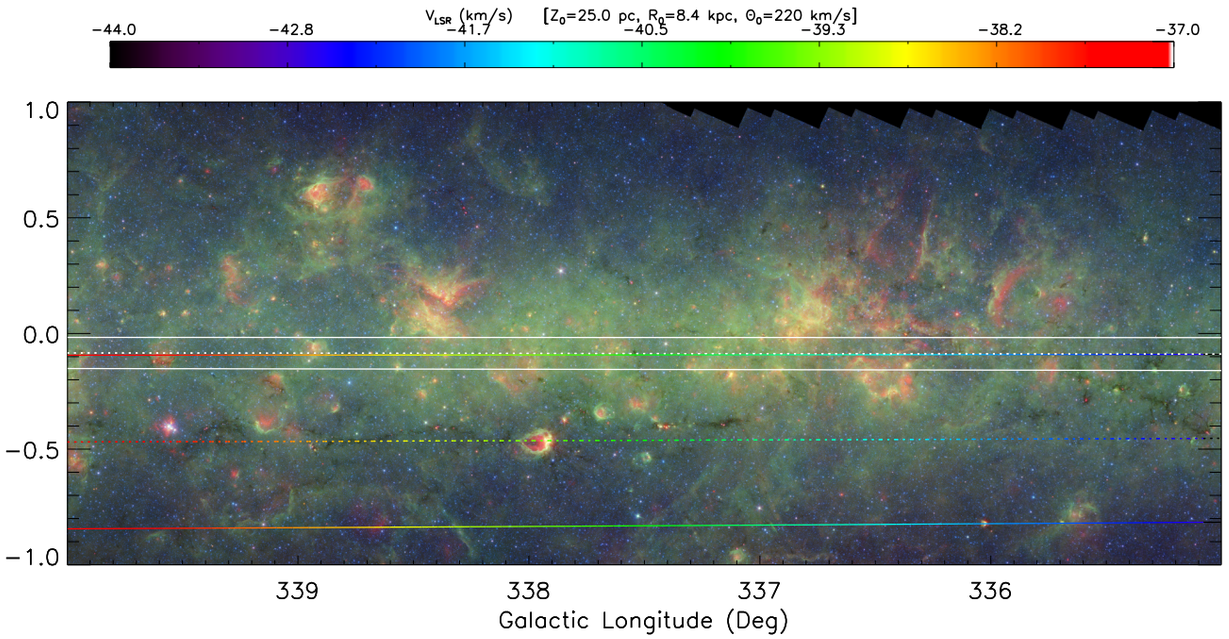

distance
velocity
along line
of sight



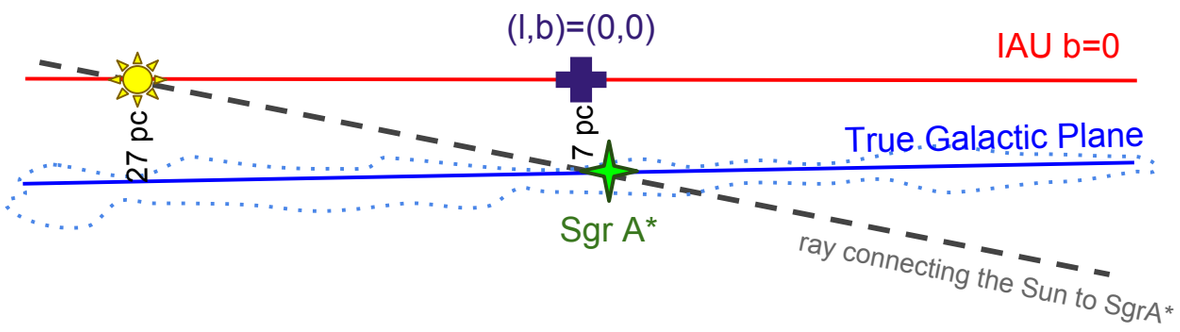

distance
velocity
along line
of sight

Where is "Nessie," in 3D?

How close to "in" the plane?



Drawing is schematic--NOT to scale



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

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