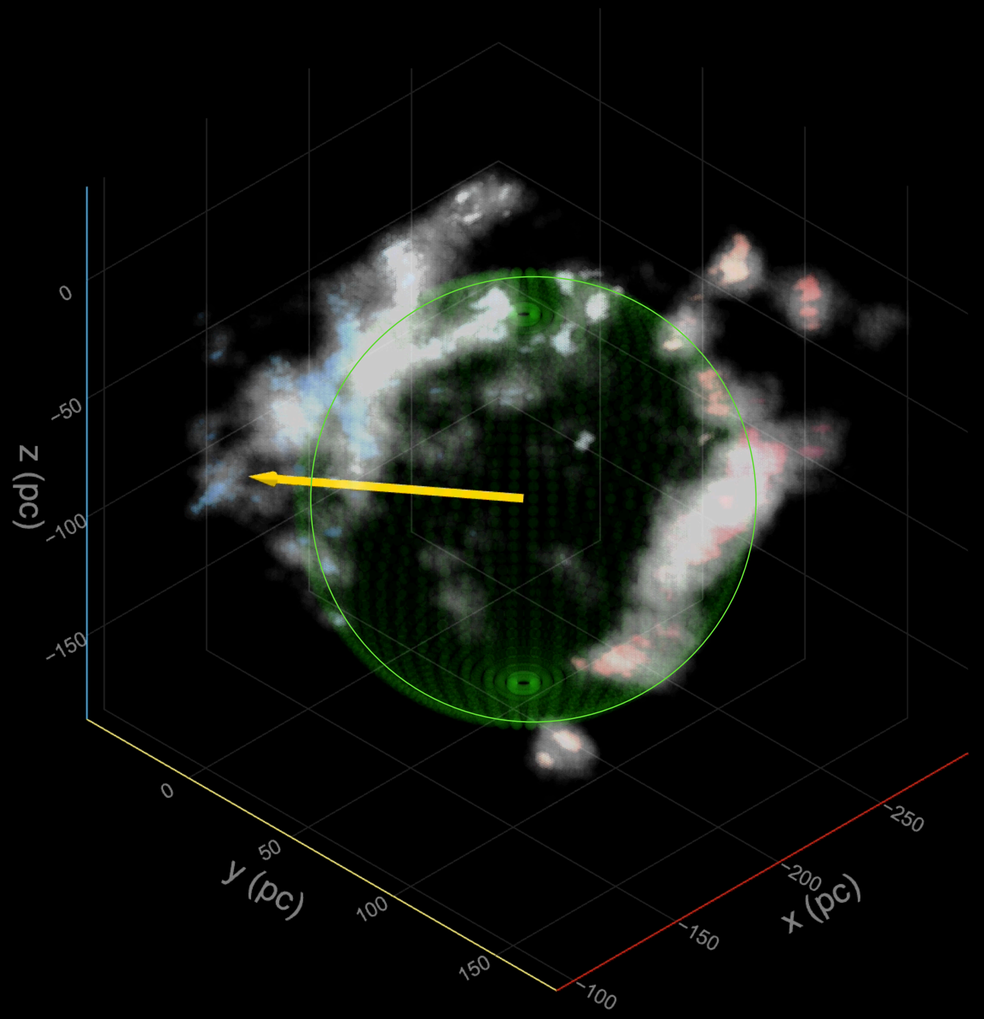
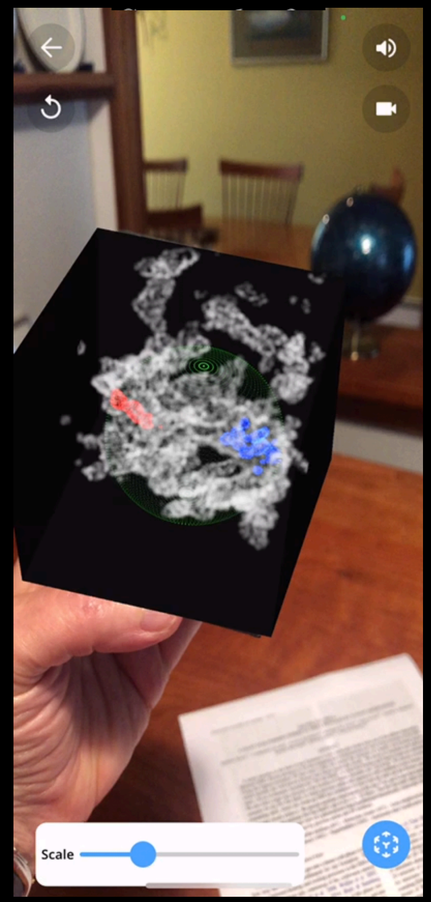
2021 “PERSEUS-TAURUS SUPERSHELL”



TINYURL.COM/UNIVERSE-IN-MY-HAND



AUGMENTED REALITY

TODAY

MILKYWAY3D.org

SCAN ME

Welcome to a new view of the Milky Way... in 3D!

MilkyWay3D.org is an open-data open-source discovery hub, providing data, visualization, and research tools for studying the MilkyWay in 3D.

INFRASTRUCTURE ⟷ SCIENCE ⟷ EDUCATION & OUTREACH

assembling data as a community,
using modern, open-source practices

glue

AMERICAN ASTRONOMICAL SOCIETY WORLDWIDE TELESCOPE

OpenSpace

linking position and motion across dimensions,
using the plug-in architecture enabled by glue
(plug-ins include WorldWide Telescope, OpenSpace & more)

MAST

The Dataverse Project

DIGITAL universe

making data accessible online for decades

Lead: Alyssa Goodman, CfA

enabling studies of how galaxies turn
gas into stars, using...

stellar positions, clusters, motions

topology, positions & motions of (long) features

tracers of feedback & magnetic fields

details on star-forming regions...and more!

Lead: Catherine Zucker, CfA

connecting real research data,
software, and science to learners

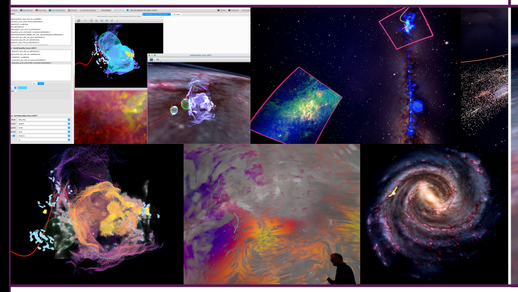
OpenSpace

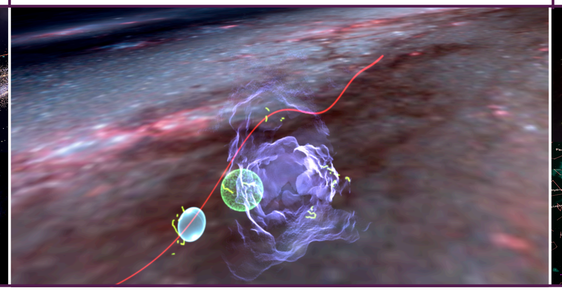
real-time data exploration
anywhere, including in planetaria

CosmicDS

"Cosmic Data Stories"
teach data science using
astronomical data & tools

Lead: Jackie Faherty, AMNH





TEAM: Harvard/Smithsonian CfA (Jonathan Carifio, Alyssa Goodman, Ralf Konietzka, Theo O'Neill, Patricia Udomprasert, Catherine Zucker), **AMNH** (Brian Abbott, Micah Acinapura, Carter Emmart, Jackie Faherty); **Linkoping University** (Alex Bock) ; **University of Vienna** (Joao Alves, Sebastian Ratzenbock); **glue solutions, inc./Aperio** (Thomas Robitaille); **University of Wisconsin, Whitewater** (Bob Benjamin), **STScI/Johns Hopkins** (Josh Peek), **Max Planck IfA** (Gordian Edenhofer); **Northeastern University** (Michelle Borkin); and YOU?!

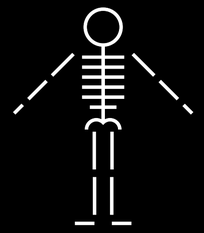
Join us, contribute, and yes, you get a T-Shirt.

2 MilkyWay3D.org founders wearing the colors (grad student Theo O’Neill & AMNH’s Dr. Jackie Faherty, at the Flatiron Insitute, NYC, Fall 2023

2010 2014 2015 2018 2020 2024 2021 2024 2022 2022

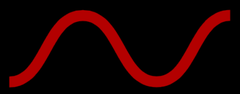
Nessie

Bones



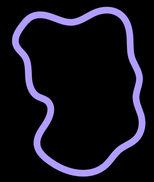
Skeleton

Perseus

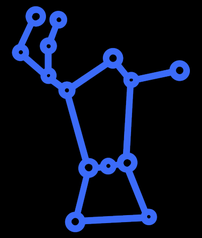


RadWave

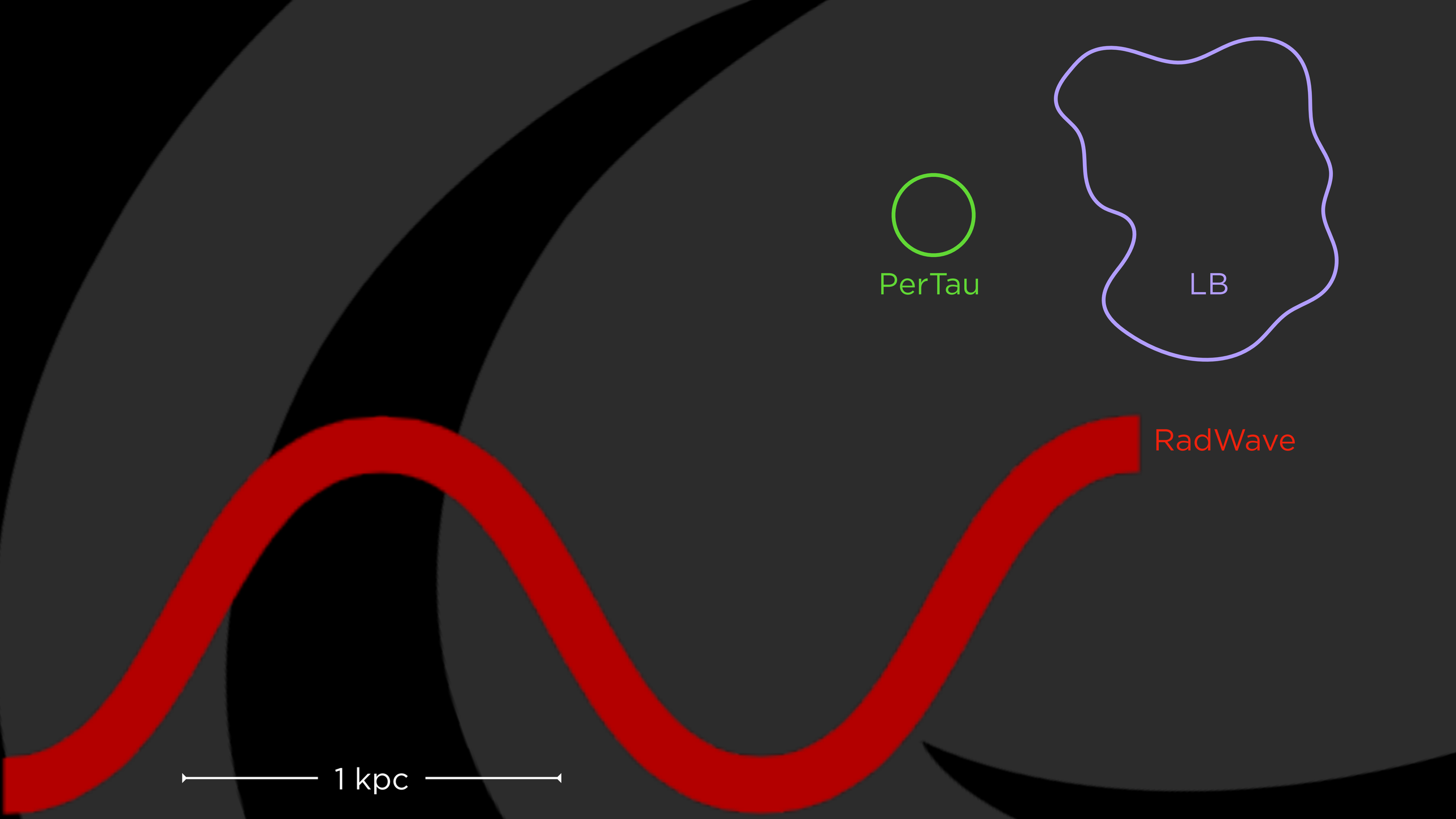
PerTau



LB



Barnard++


PerTau
LB
RadWave
1 kpc

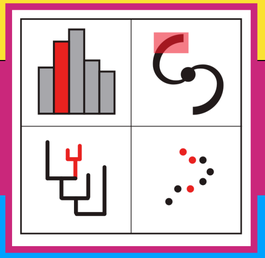
Credits: S. Payne-Wardenaar / K. Malhan, MPIA

NEW Milky Way

what it looks like

how we know

why it matters



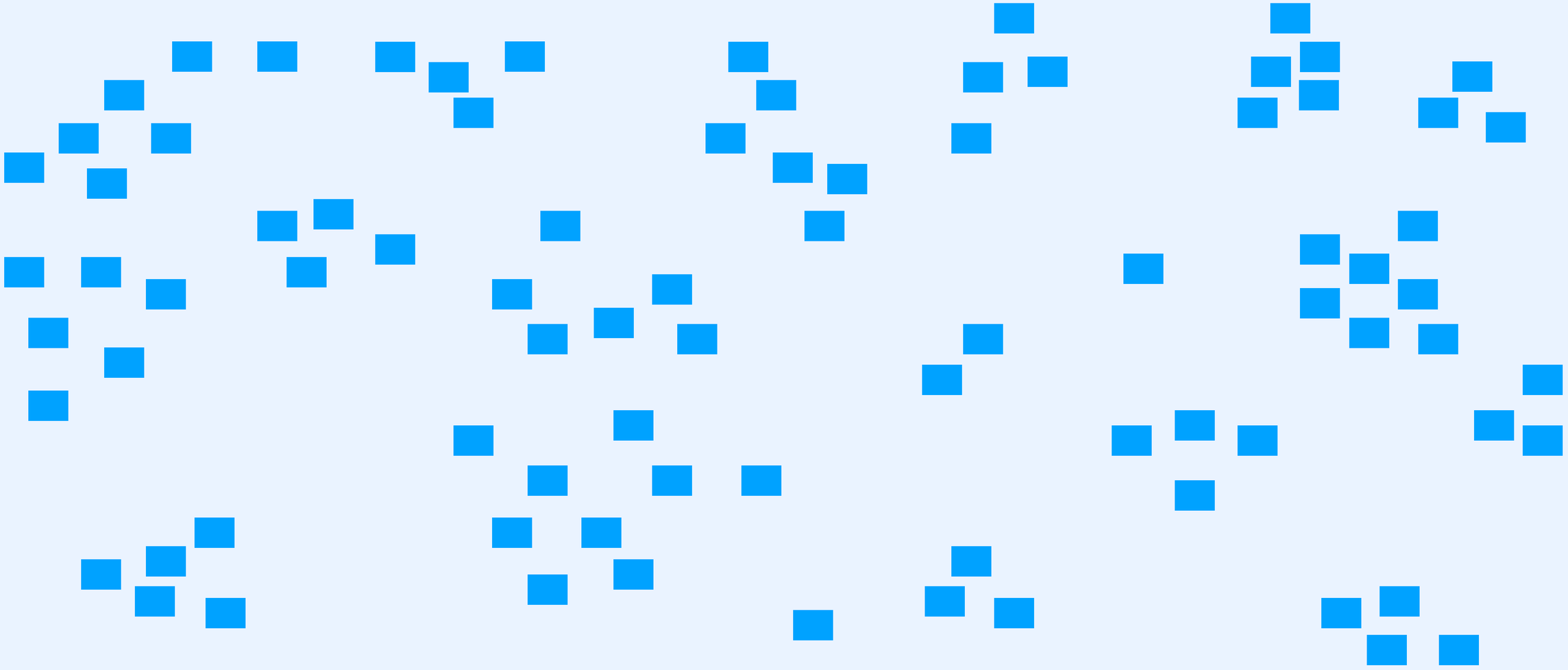
Alyssa Goodman, Center for Astrophysics | Harvard & Smithsonian

featuring especially the work of João **Alves**++., Shmuel **Bialy**, Andi **Bukert** ++., Gordian **Edenhofer**, Torsten **Enßlin** ++, Doug **Finkbeiner** ++., Michael **Foley**, Ralf **Konietzka**, Reimar Leike, Theo **O'Neill**, Juan **Soler**, Catherine **Zucker** & the **glue** team

WHERE ARE WE?

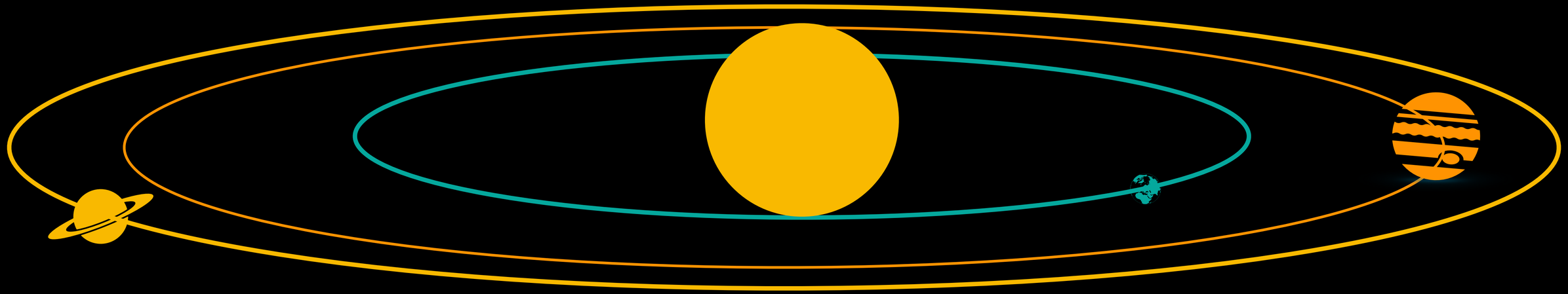
WHERE ARE WE?

WHERE ARE WE?



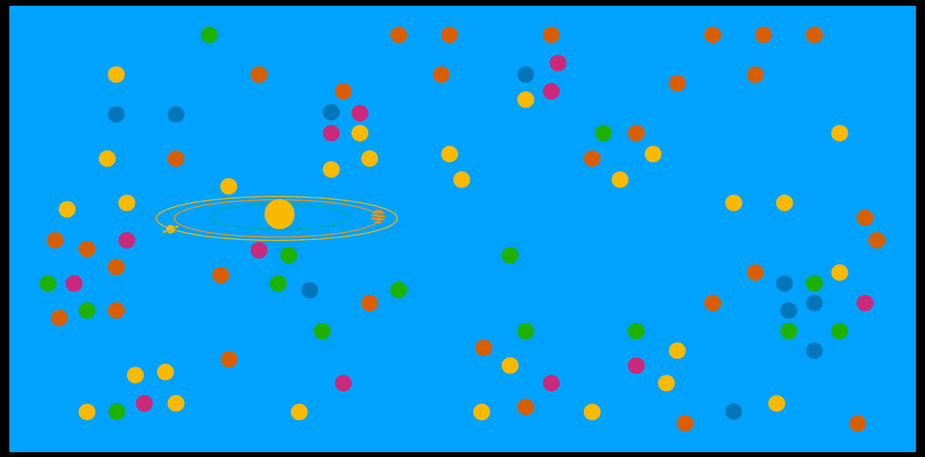
our **Universe** contains MANY billions of **galaxies**

ours is called “The Milky Way” and it contains about 1 hundred billion stars

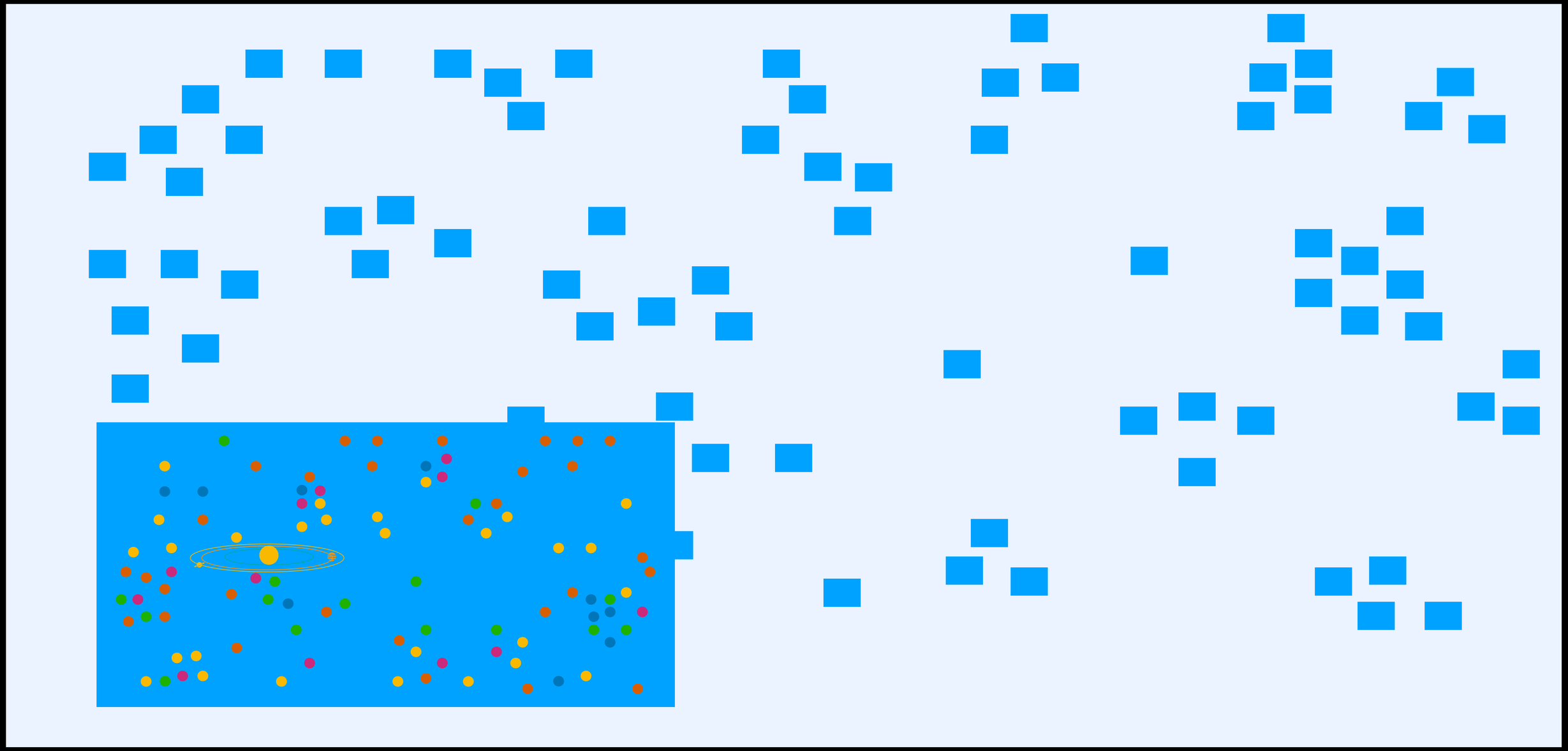


around most of the stars are systems of planets (ours is called “**The Solar System**”)

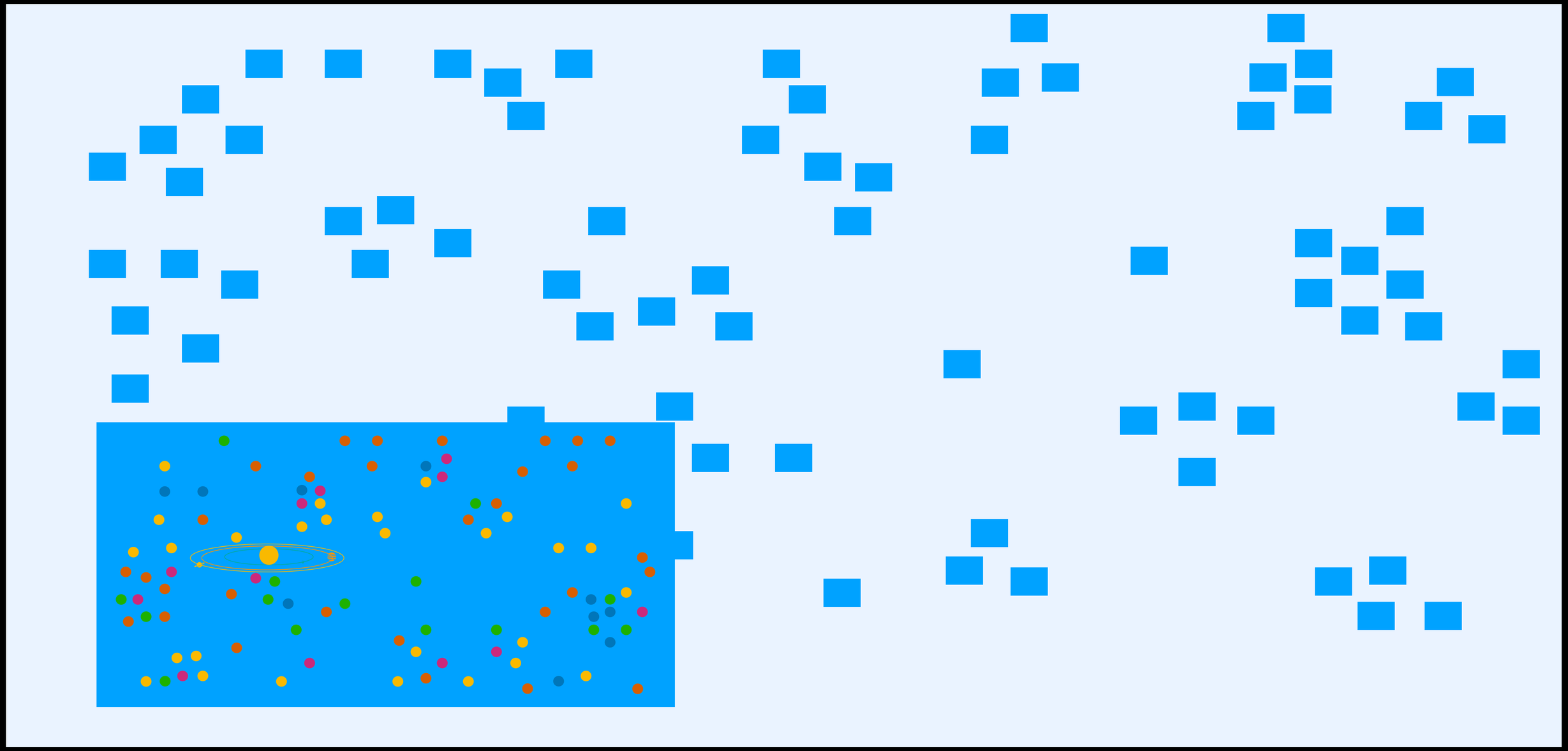
our home planet is **Earth**



Earth resides in the **Solar System**, around the **Sun**, which is one of MANY **stars**, in the **Milky Way**,

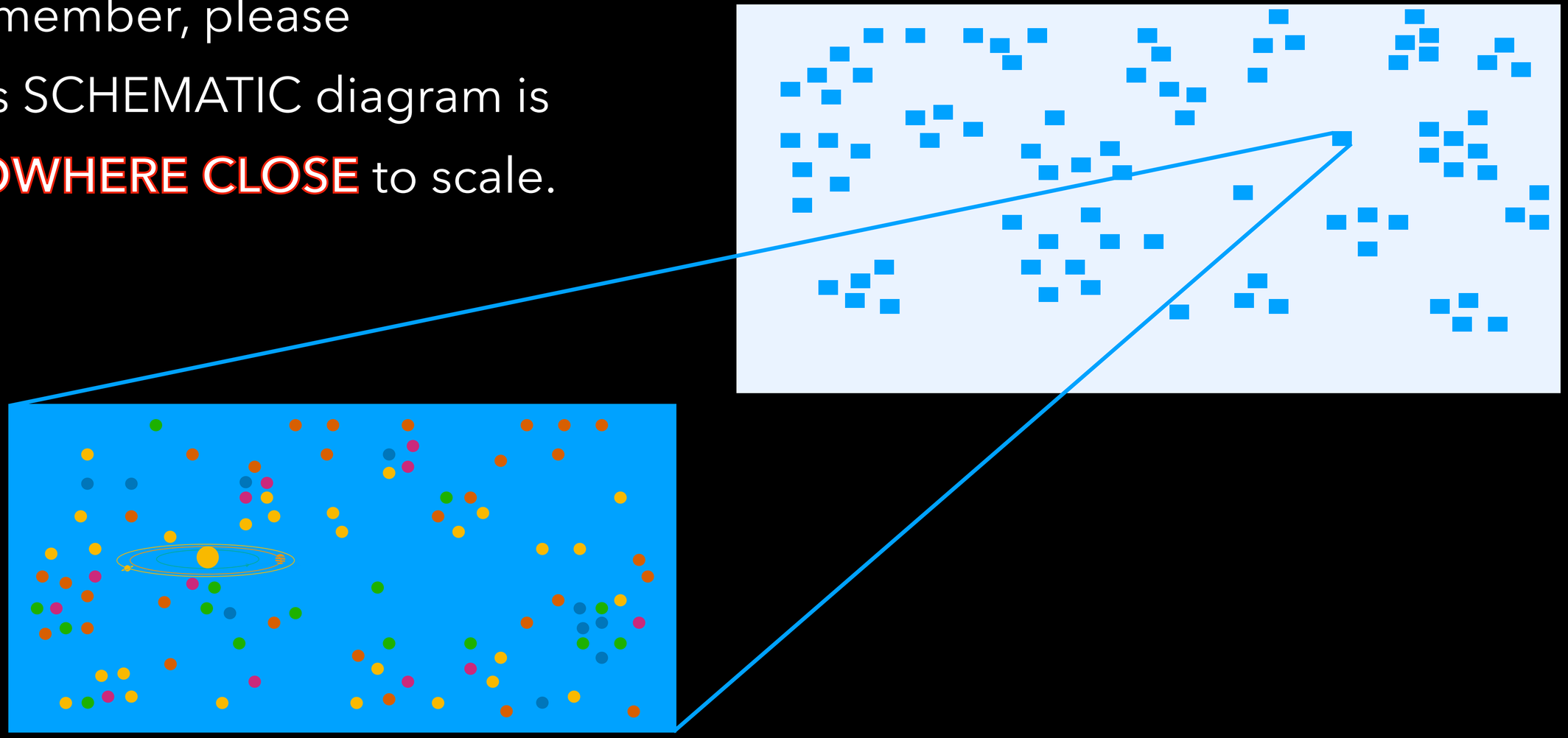


Earth resides in the **Solar System**, around the **Sun**, which is one of MANY **stars**, in the **Milky Way**, which is one of MANY **galaxies**, in our **Universe**



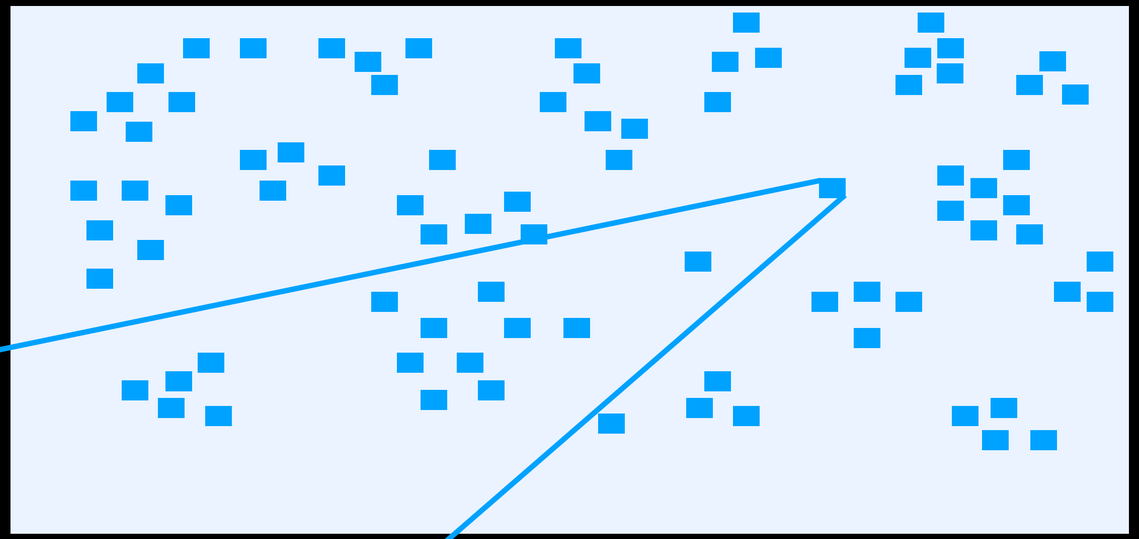
Earth resides in the **Solar System**, around the **Sun**, which is one of MANY **stars**, in the **Milky Way**, which is one of MANY **galaxies**, in our **Universe**

Remember, please
this SCHEMATIC diagram is
NOWHERE CLOSE to scale.



Earth resides in the **Solar System**, around the **Sun**, which is one of MANY **stars**,
in the **Milky Way**, which is one of MANY **galaxies**, in our **Universe**

And, actually, that boring blue box likely looks something more like this…



…cartoon!

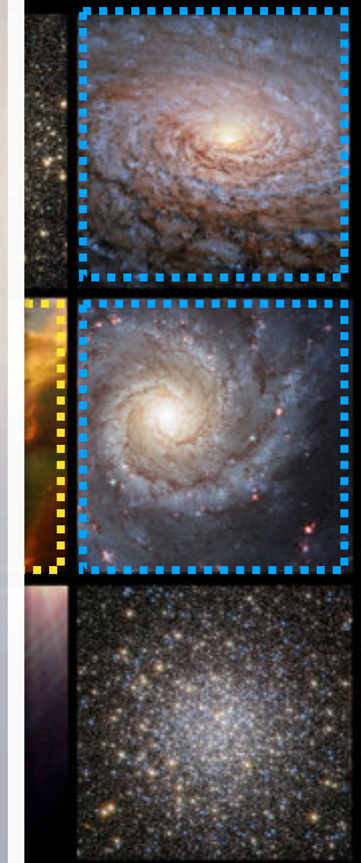
“Messier” Objects
(images, *not* cartoons)

star-forming nebulae

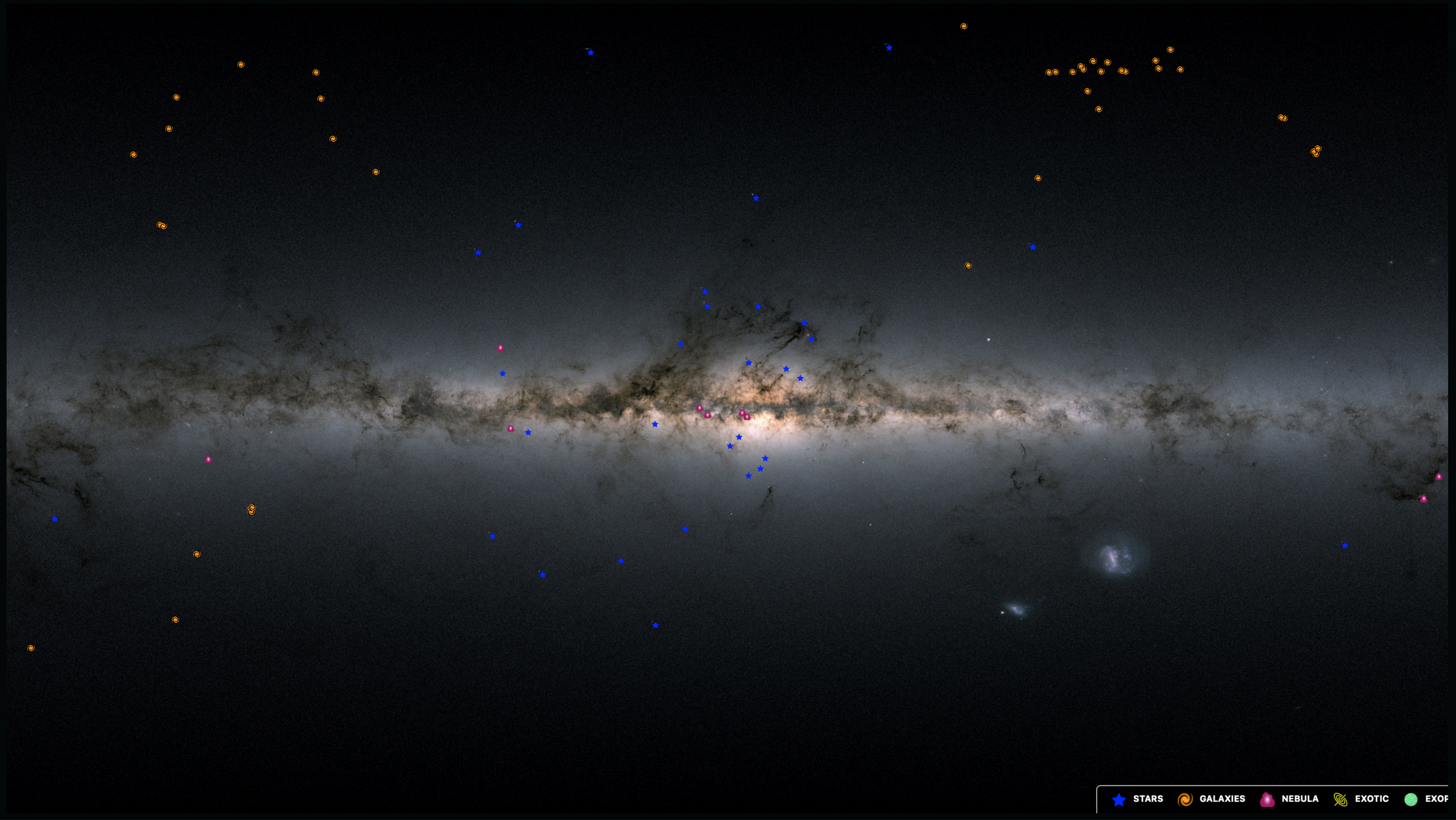
galaxies

Mes·sier, Charles
| ˈmesiə, mesye, ˌmesēˈā, mesˌyā |
(1730–1817), French astronomer. He discovered a number of nebulae, galaxies, and star clusters, which he designated by M numbers.

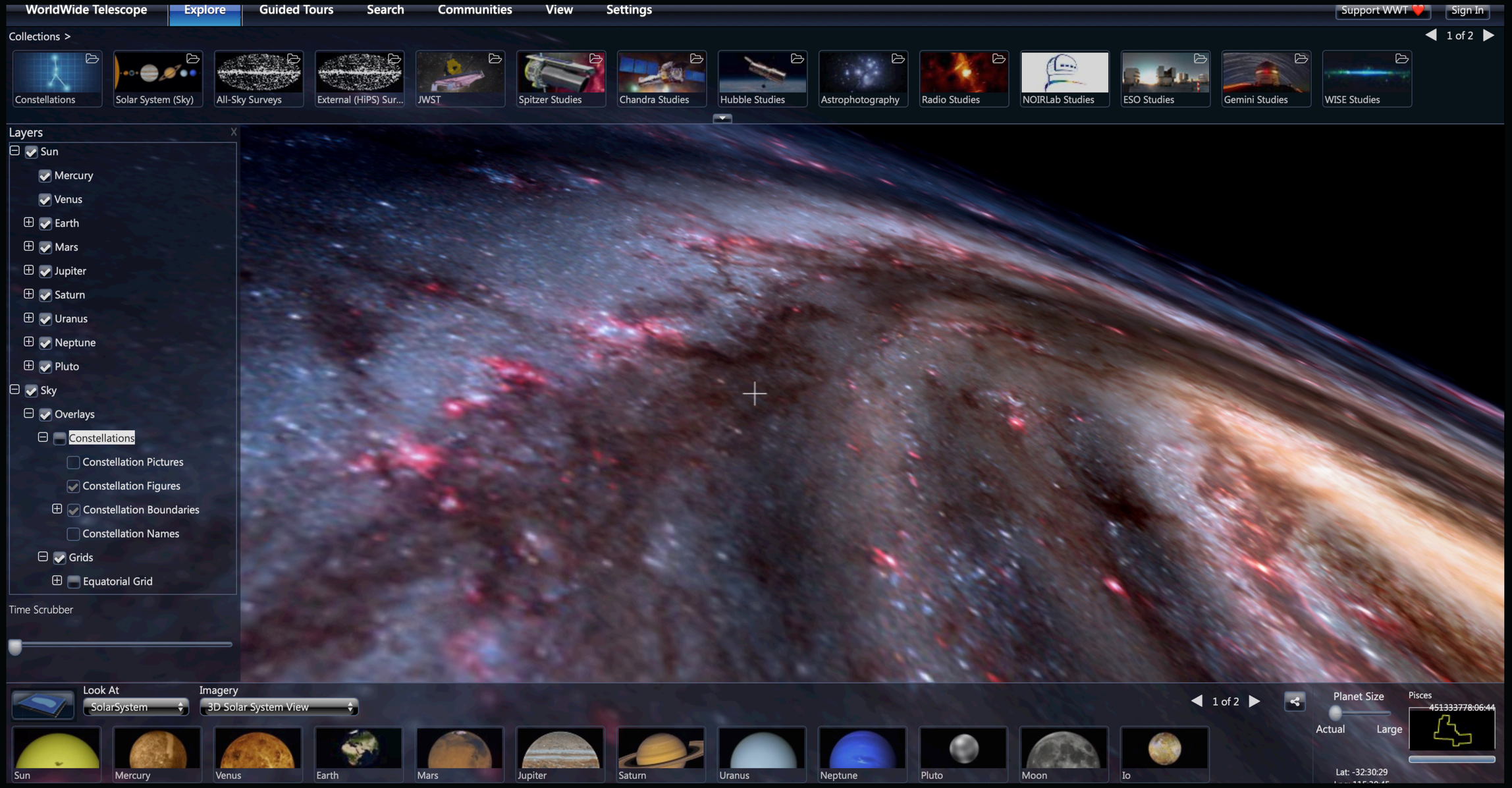
mess·y | ˈmesē | adjective (**messier** | ˈmesēər |, **messiest** | ˈmesēist |)
1 untidy or dirty: *his messy hair*.
• generating or involving mess or untidiness: *stripping wallpaper can be a* **more**



images all from Hubble Space Telescope



Start the presentation to see live content. Still no live content? Install the app or get help at PollEv.com/app



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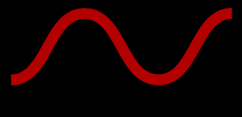
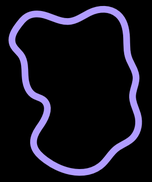


2020
2024

2021



2022
2024

2023 and beyond!

2020 The Radcliffe Wave

presented by Alyssa Goodman,
Center for Astrophysics | Harvard & Smithsonian,
Radcliffe Institute for Advanced Study

Nature paper by: João Alves[1,3], Catherine Zucker[2], Alyssa Goodman[2,3],
Joshua Speagle[2], Stefan Meingast[1], Thomas Robitaille[4],
Douglas Finkbeiner[3], Edward Schlafly[5] & Gregory Green[6]

representing
(1) University of Vienna; (2) Harvard University;
(3) Radcliffe Insitute; (4) Aperio Software;
(5) Lawrence Berkeley National Laboratory;
(6) Kavli Insitute for Particle Physics and Cosmology

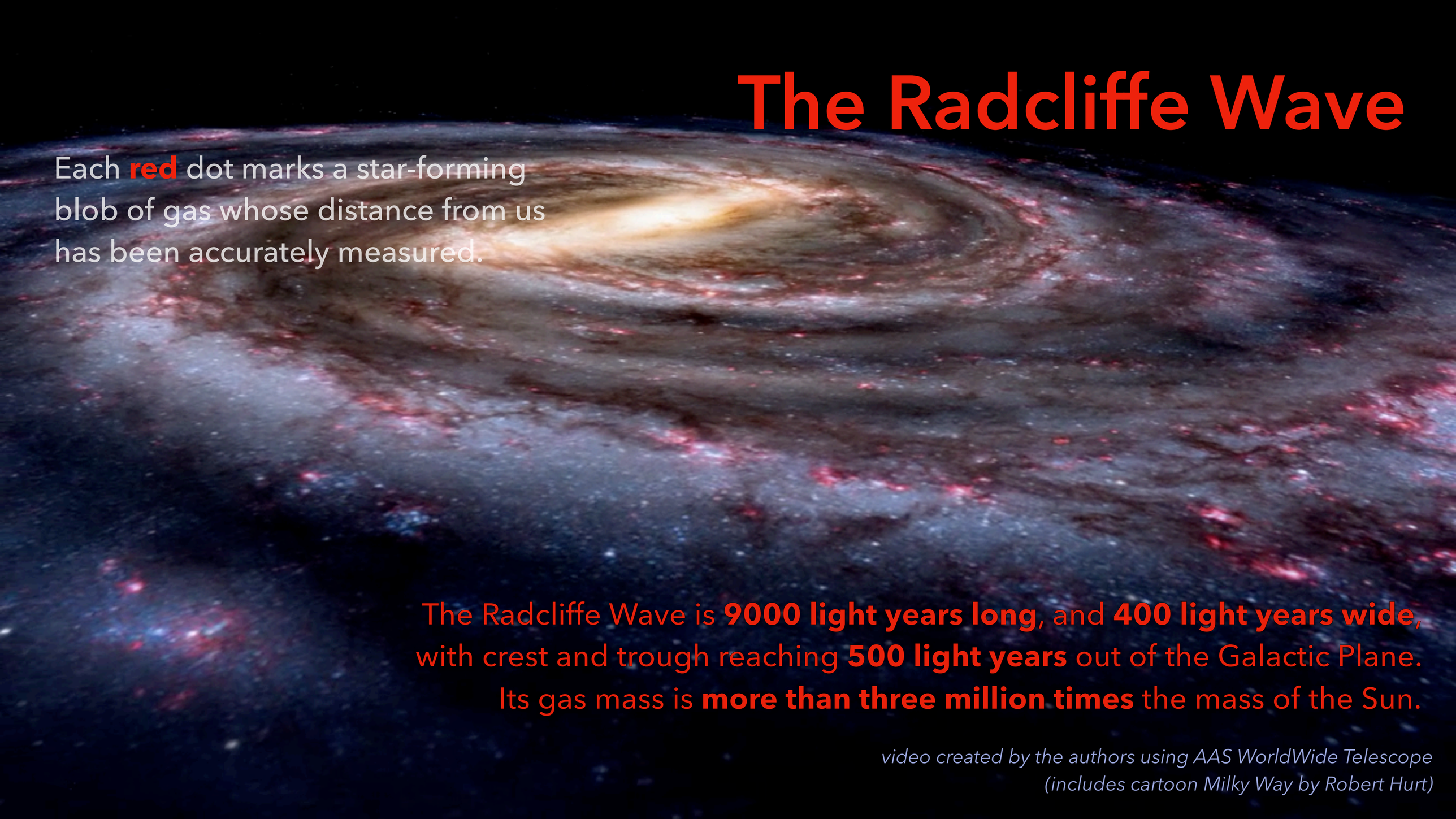
The Radcliffe Wave

CARTOON*

DATA

*drawn by Dr. Robert Hurt, in collaboration with Milky Way experts based on data; as shown in screenshot from AAS WorldWide Telescope

The Radcliffe Wave



Each **red** dot marks a star-forming blob of gas whose distance from us has been accurately measured.

The Radcliffe Wave is **9000 light years long**, and **400 light years wide**, with crest and trough reaching **500 light years** out of the Galactic Plane. Its gas mass is **more than three million times** the mass of the Sun.

video created by the authors using AAS WorldWide Telescope (includes cartoon Milky Way by Robert Hurt)

The Radcliffe Wave

ACTUALLY 2 IMPORTANT DEVELOPMENTS

DISTANCES!!

We can now measure distances to gas clouds in our own Milky Way galaxy to ~5% accuracy.

Zucker et al. 2019; 2020

RADWAVE

Surprising wave-like arrangement of star-forming gas *is* the "Local Arm" of the Milky Way.

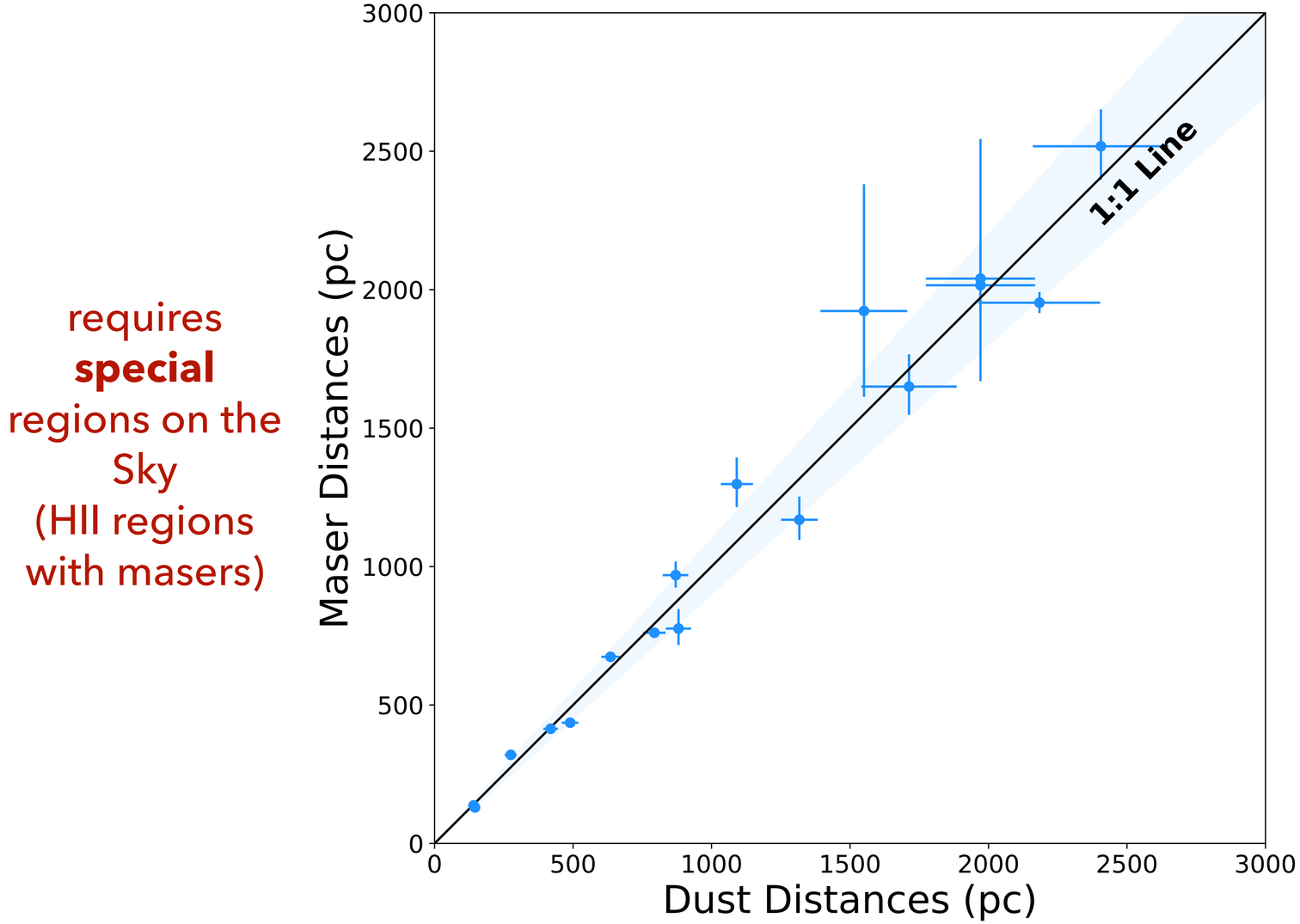
Alves et al. 2020

"Why should I believe all this?"

DISTANCES!!

We can now measure distances to gas clouds in our own Milky Way galaxy to ~5% accuracy.

requires **special** regions on the Sky (HII regions with masers)



can be used **anywhere** there's dust & measurable stellar properties

Zucker et al. 2019

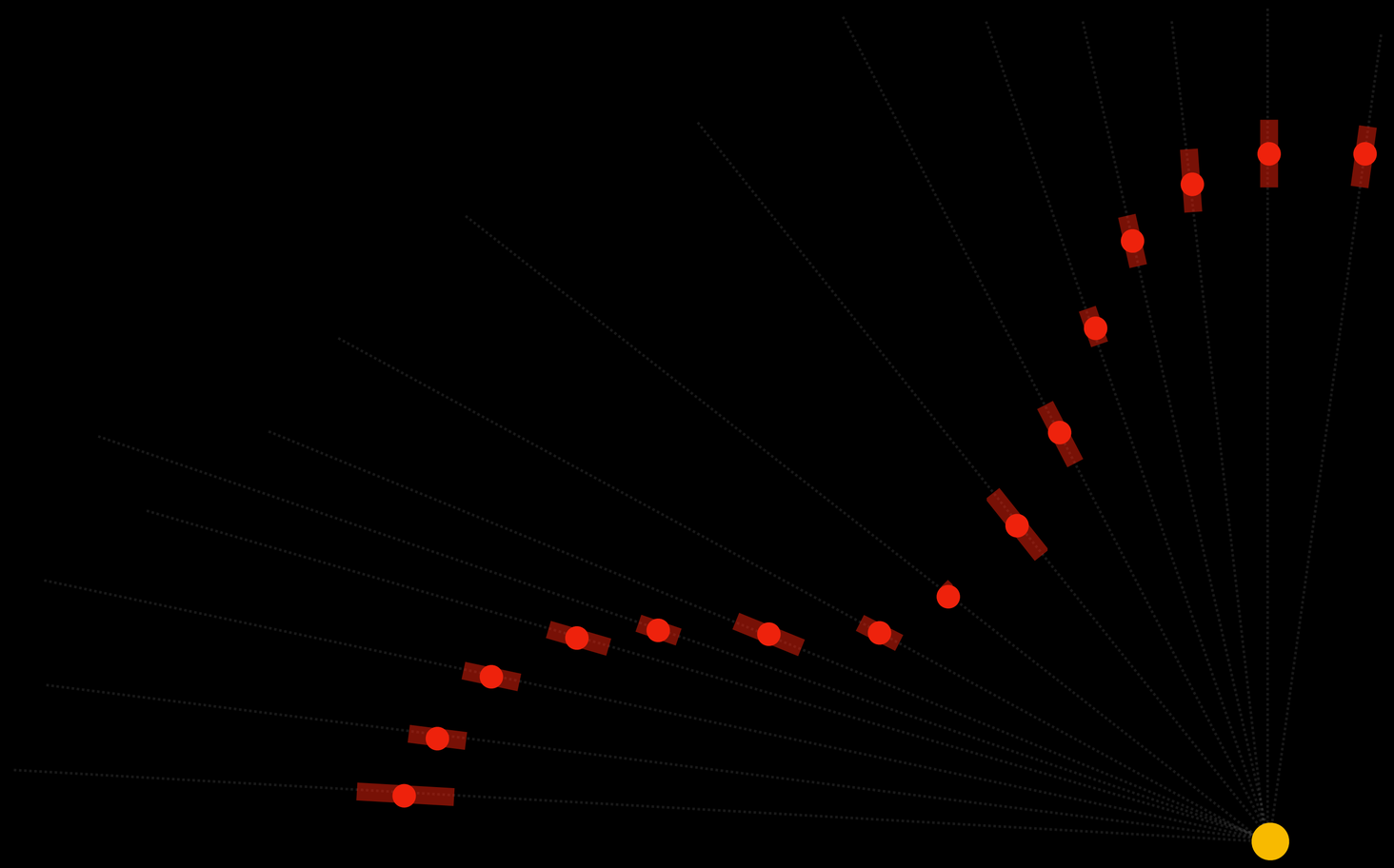
DISTANCES!!

We can now measure distances to gas clouds in our own Milky Way galaxy to ~5% accuracy.

Uncertain Distances

SCHEMATIC CARTOON(!)

Distances estimates **BEFORE** 3D dust mapping & Gaia (~30%)



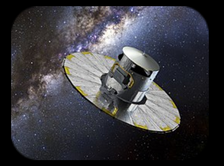
"The Radcliffe Wave"

SCHEMATIC CARTOON(!)

Distances estimates **AFTER** 3D dust mapping & Gaia (~5%)

HOW= 3D dust mapping*

+ Gaia*

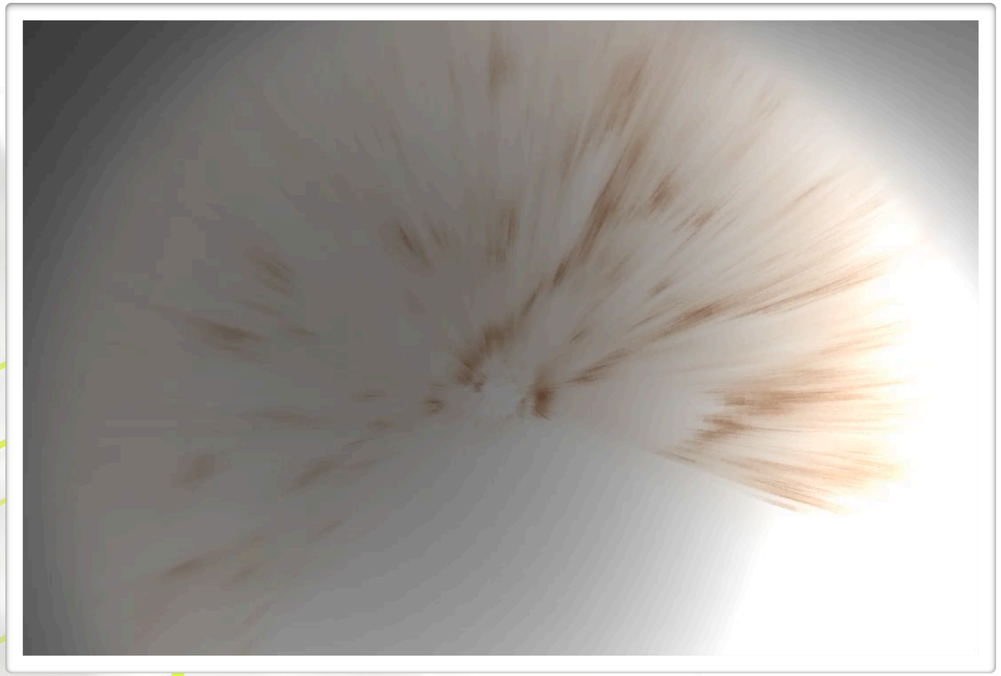


+ glue*

+ WorldWide Telescope

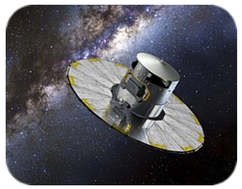
*2 million CPU hours, Harvard *800 million stars, ESA *NASA/JWST, NSF *Microsoft Research, NSF, AAS

Extinction & Reddening, from Color Imaging



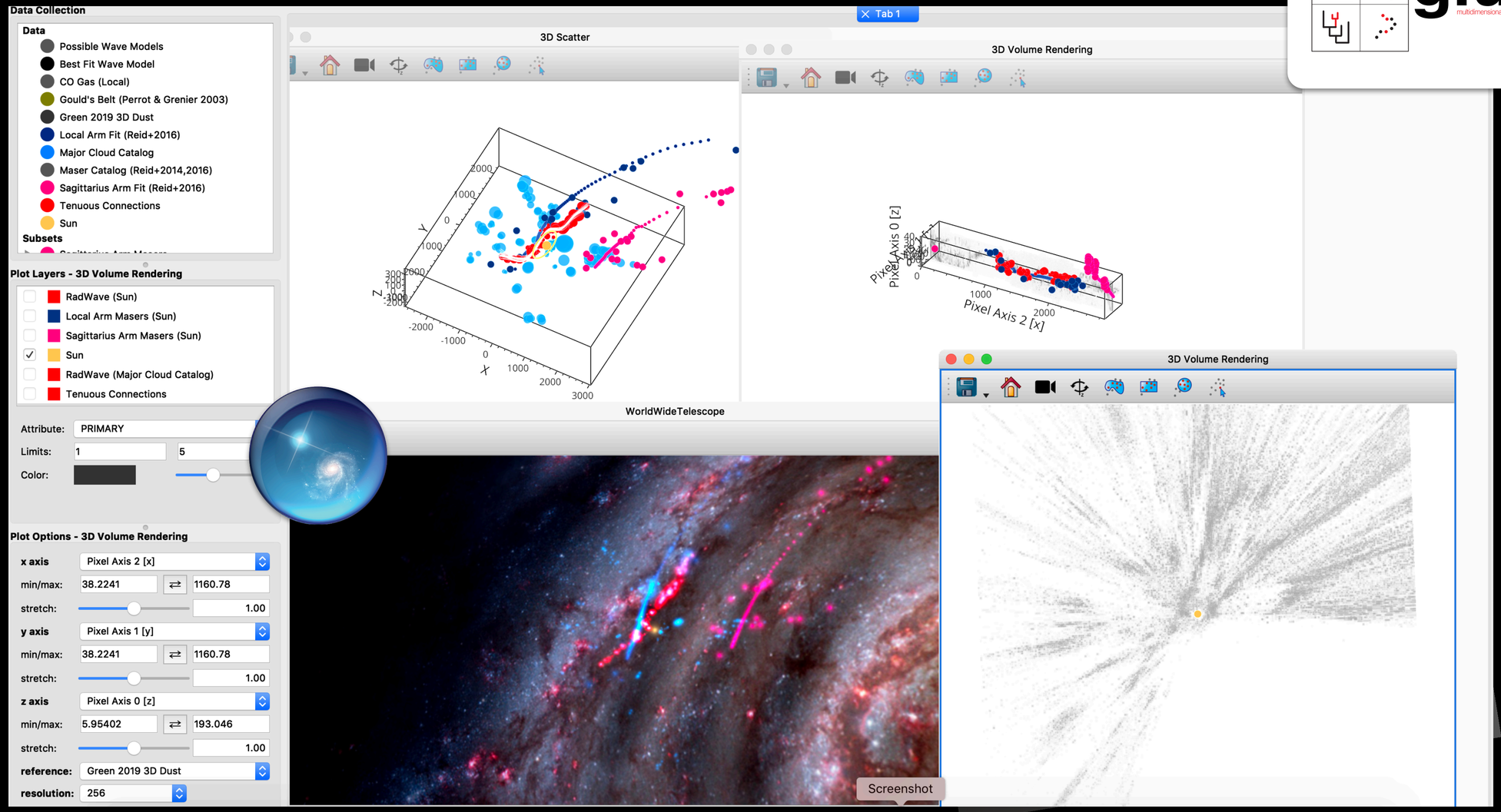
Green et al. 2019

Can infer matter's distance from *dust's* effects on stars.



WARNING: schematic diagram, NOT to scale (credit A. Goodman, 2019)

“Seeing” The Radcliffe Wave, in 3D



AAS WorldWide Telescope: worldwidetelescope.org

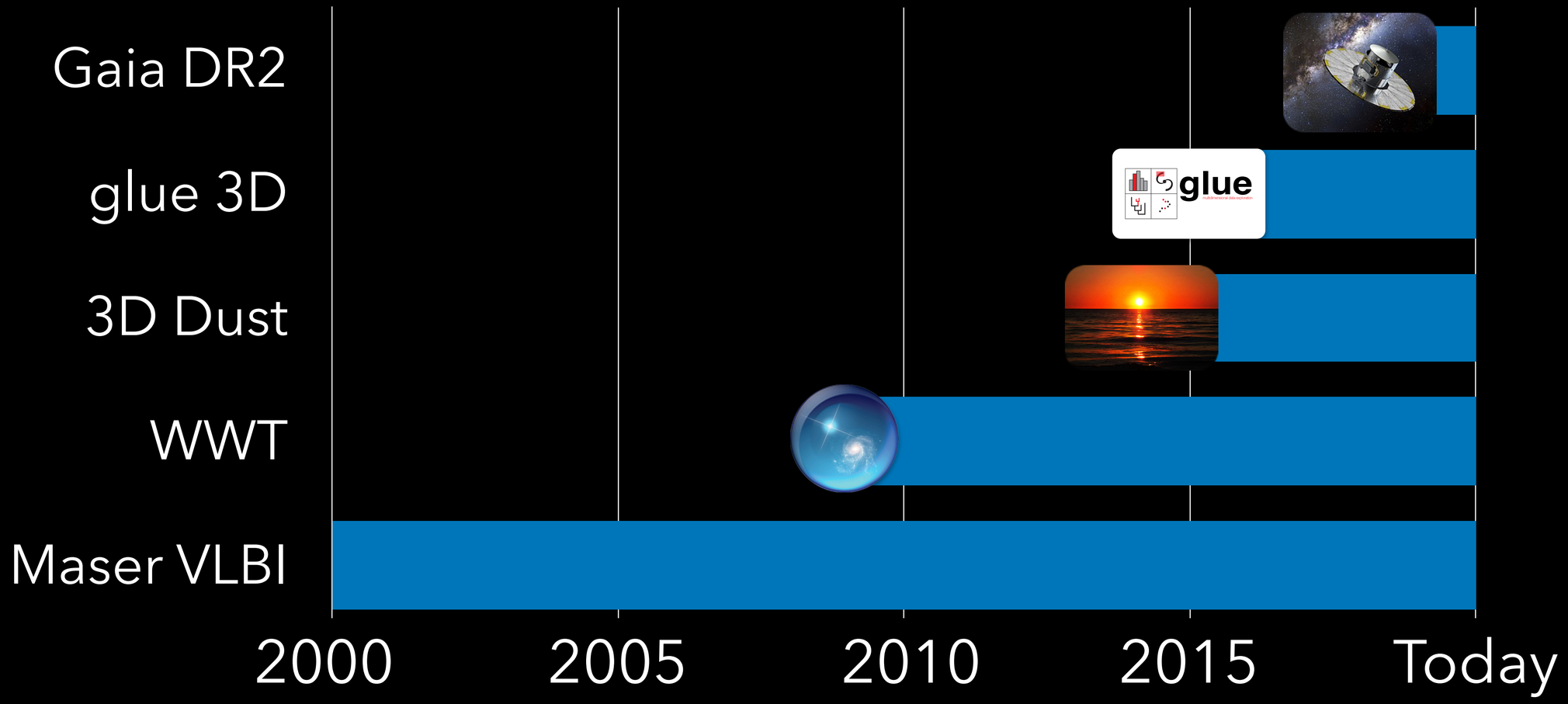
glue: glueviz.org

WHY DIDN'T WE FIND THE RADCLIFFE WAVE SOONER?

It's not apparent in 2D on the Sky.

AAS WorldWide Telescope: worldwidetelescope.org glue: glueviz.org

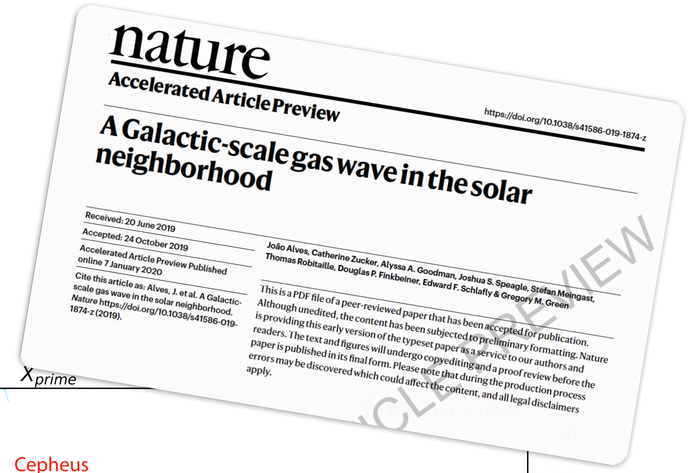
WHY DIDN'T WE FIND THE RADCLIFFE WAVE SOONER?



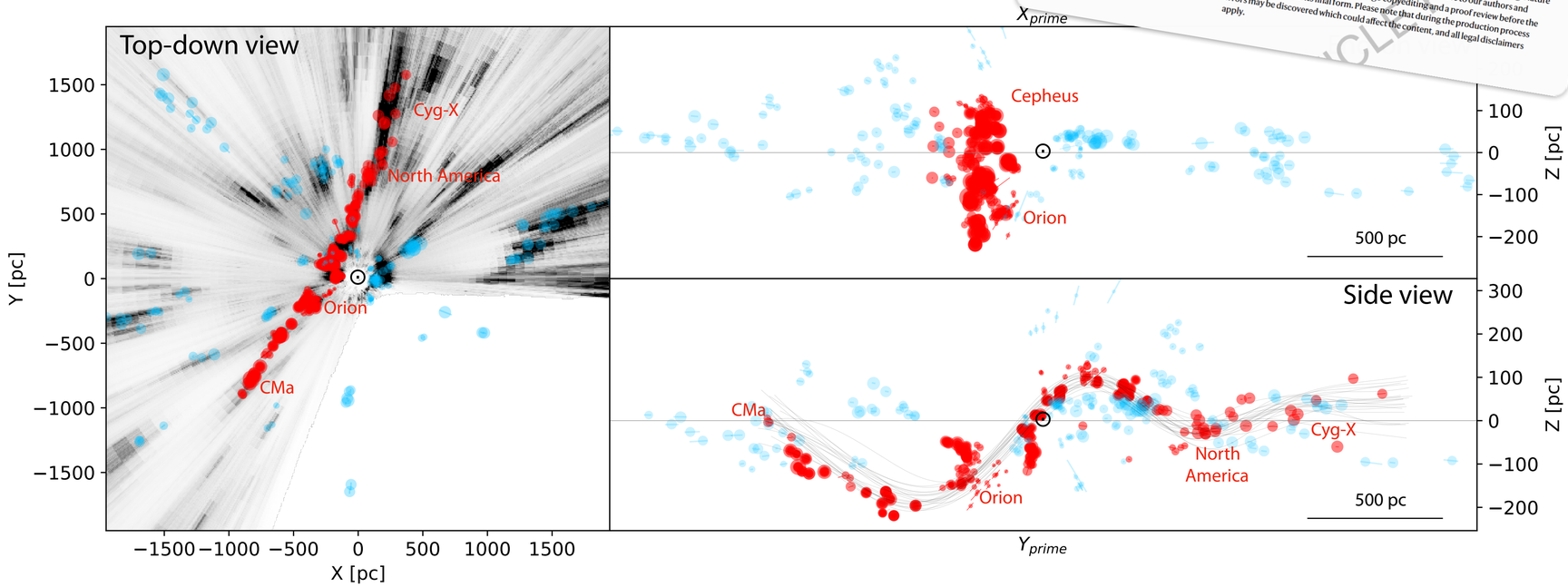
The Radcliffe Wave

RADWAVE

Surprising wave-like arrangement of star-forming gas *is* the "Local Arm" of the Milky Way.



click the figure to launch interactive…



João Alves, Catherine Zucker, Alyssa Goodman, Joshua Speagle, Stefan Meingast, Thomas Robitaille, Douglas Finkbeiner, Edward F. Schlafly, and Gregory Green 2020, *Nature* (today)

Alves et al. *Nature* paper & two distance catalog papers by Zucker et al. (2019, 2020) include several interactive figures (via plot.ly & bokeh), and deep links to data (on Dataverse) and code (on GitHub) inspired by AAS "Paper of the Future" (Goodman et al. 2015)

RADWAVE
Surprising wave-like arrangement of star-forming gas *is* the “Local Arm” of the Milky Way.

“So What,” for Astronomers?

demise of “Gould's Belt”

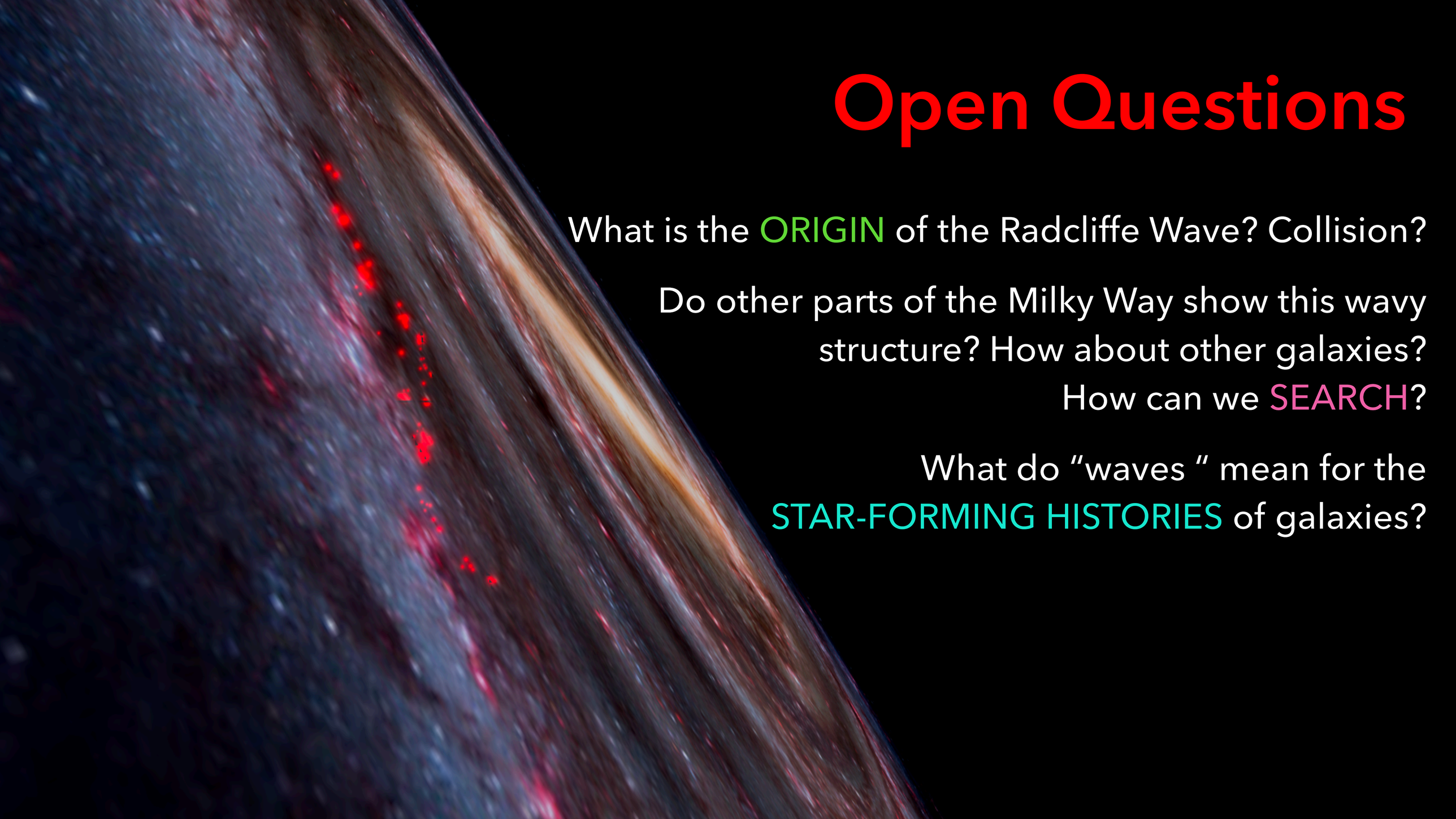
end to 100-year-old paradigm

“Local Arm" not shaped as we thought it was, locally

arm is “straight" from top-down

big wave in “arm” never previously observed

wave’s origin unknown (collision? dark matter? accretion?)



Open Questions

What is the ORIGIN of the Radcliffe Wave? Collision?

Do other parts of the Milky Way show this wavy structure? How about other galaxies? How can we SEARCH?

What do “waves “ mean for the STAR-FORMING HISTORIES of galaxies?

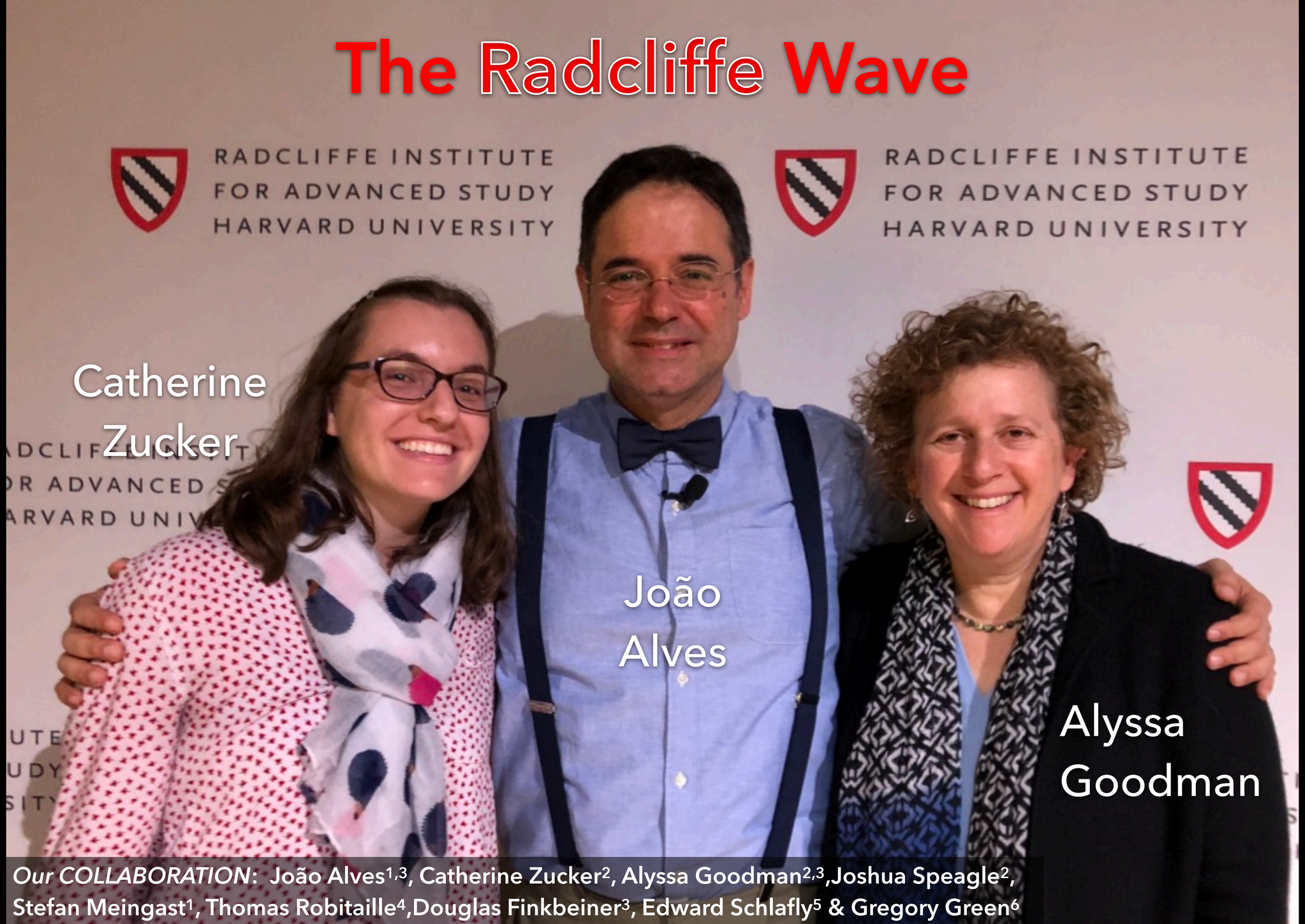
SURF the Radcliffe Wave

It appears that the Sun, on its galactic orbit, crossed the Radcliffe Wave 13 million years ago, and may cross it again in the future.

video created by the authors using AAS WorldWide Telescope (includes cartoon Milky Way by Robert Hurt)

Find these slides, the papers, videos, WWT Tours, and much more at: tinyurl.com/RadWave

The Radcliffe Wave



Our COLLABORATION: João Alves[1,3], Catherine Zucker[2], Alyssa Goodman[2,3],Joshua Speagle[2], Stefan Meingast[1], Thomas Robitaille[4],Douglas Finkbeiner[3], Edward Schlafly[5] & Gregory Green[6]

NASA
SciX
[SciXplorer.org]
DASK
yt
CosmicDS
Astronomy
APOD
Picture of the Day
Jdaviz
jupyter
OpenSpace
NASA SCIENCE
ACTIVATION
WorldWide Telescope Ambassadors
www.tambassadors.org
astropy
NumPy
Zarr
xarray
JWST
glue
genes
glue
multidimensional data exploration

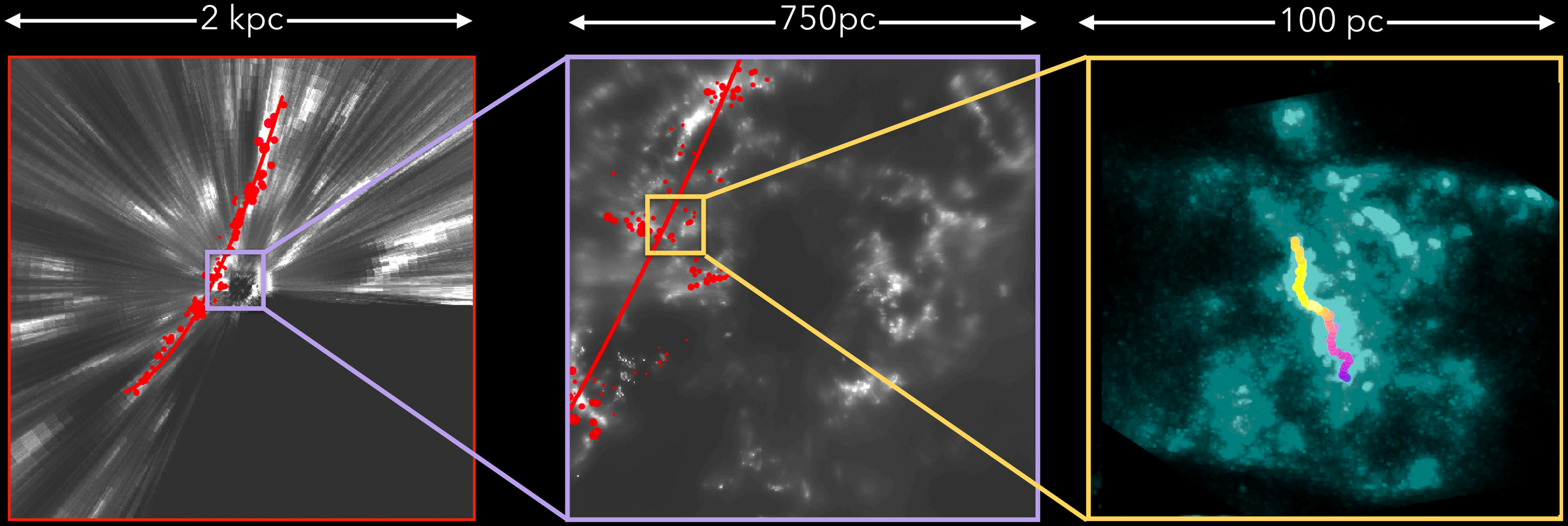
TECH interlude

Using the **LIVE-env.org** website, let's ask:

- What is **glue**?
- What is it* used for in **Astronomy, Biology, GIS**?
- Why will LIVE be even better?
  - **browser**-based, more_**tools**, more_**customizable**, **AI**, more **AR**
- How does LIVE-Astro **relate** to **MilkyWay3D.org**?
- Who is **paying** for this?

*"it" is glue–> LIVE, and importantly, LIVE is a new ***collaboration*** *with Jupyter leaders and many, many, others*

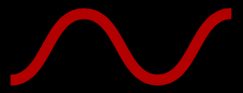
2019 to 2021: from distances to shapes

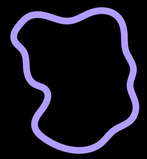


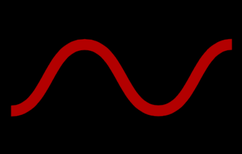
Zucker et al. 2020; Zucker & Speagle et al. 2019; Alves et al. 2020; Green et al. ***2019***

Leike, Glatzle, & Enßlin ***2020***

Zucker et al. ***2021****; Leike, Glatzle, & Enßlin 2020*







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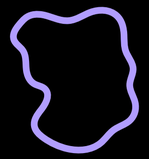

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2023 and beyond!

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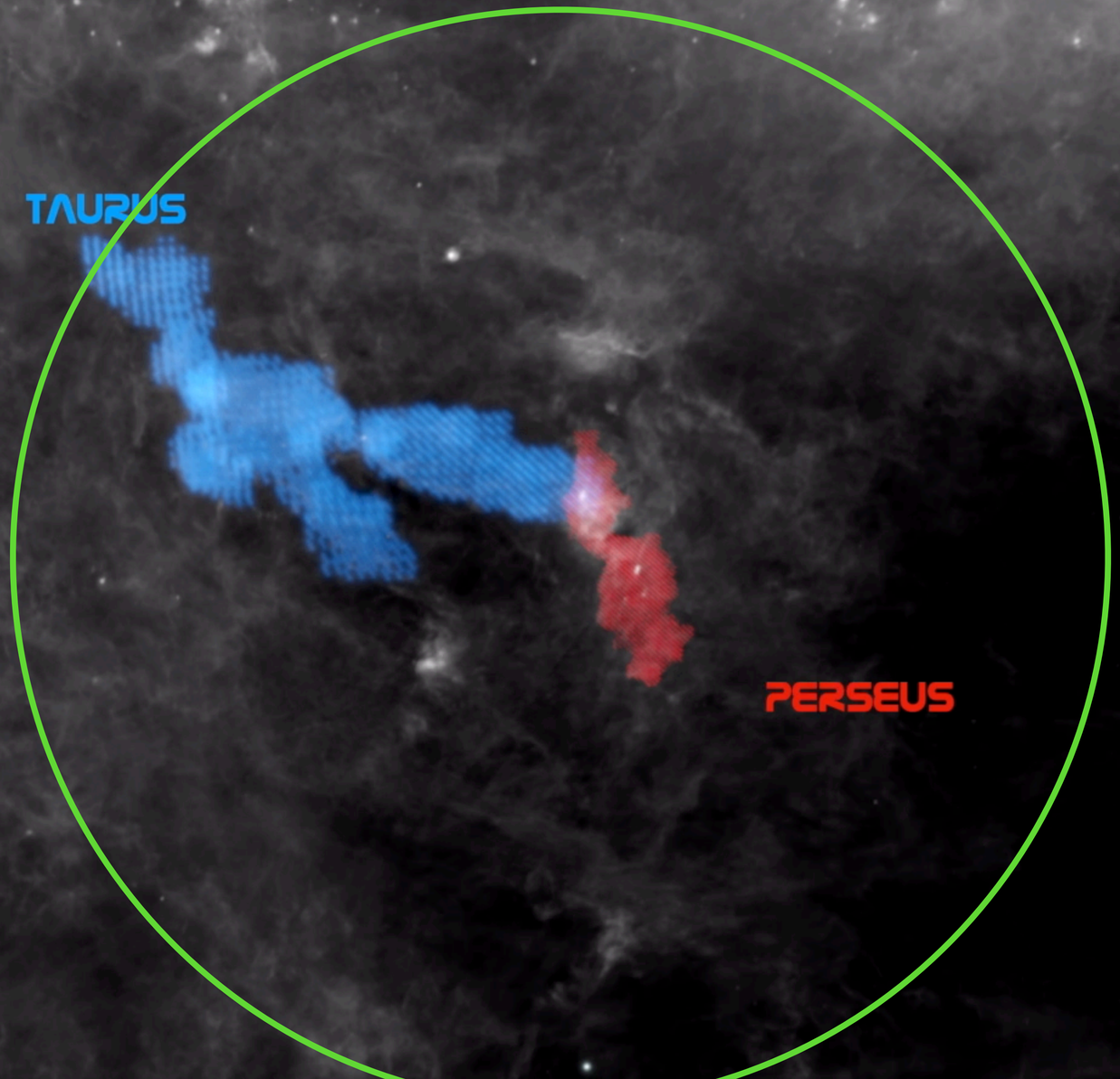
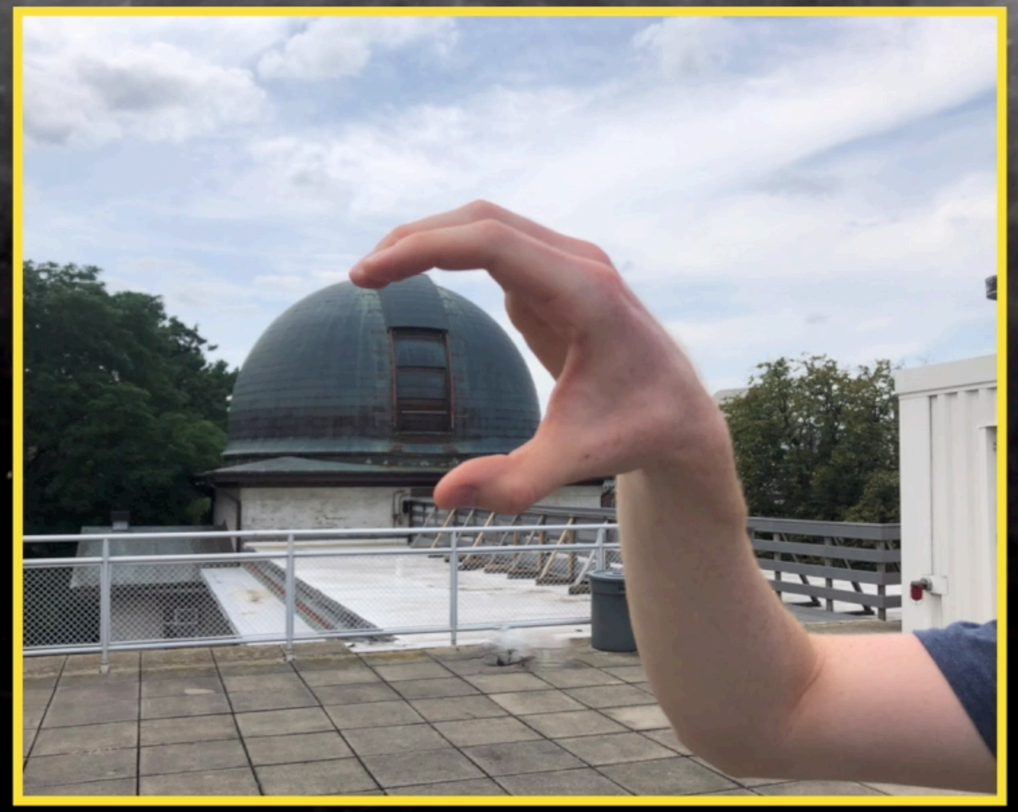




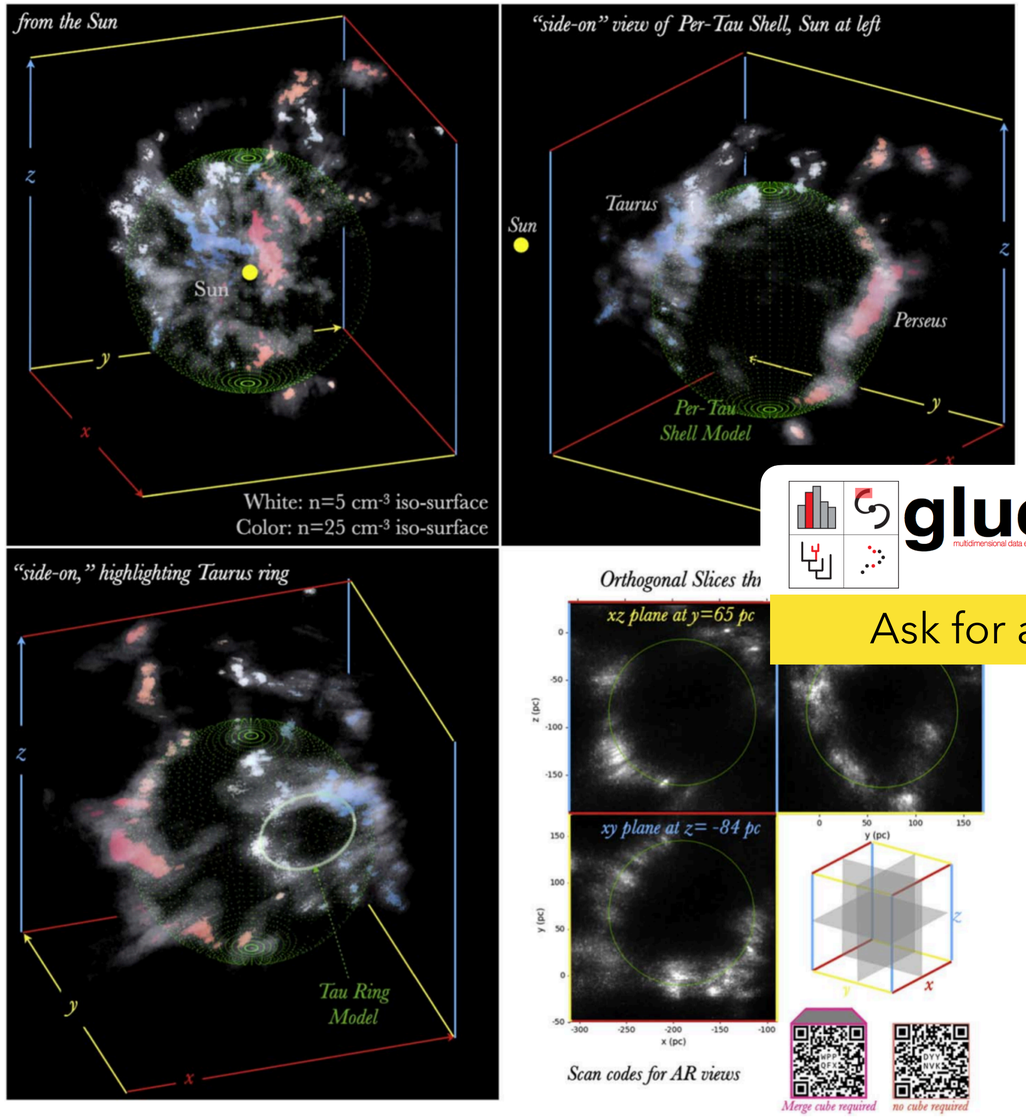


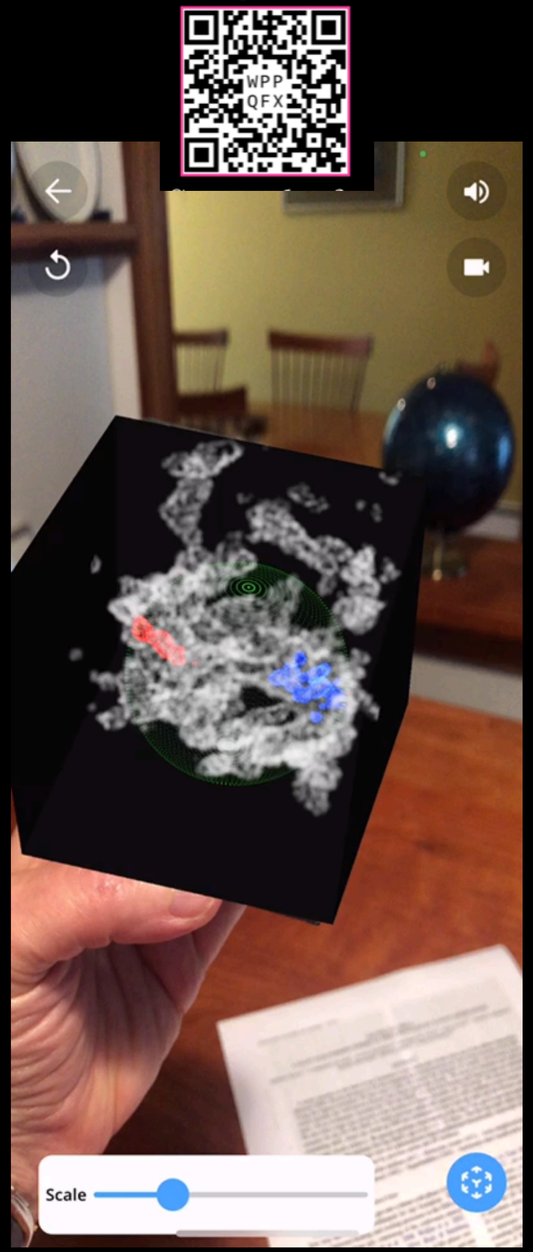
Figure 2. 3D views of the Per-Tau shell (for an interactive version[8] of this figure click here [9]; see Figure 5 for more static visualizations). Plotted are density iso-surfaces at levels $n = 5$ cm^{-3} (gray) and $n = 25$ cm^{-3} (color), overlaid with our spherical-shell model, radius $R_s = 78$ pc, distance from the Sun $d = 218$ pc. The $n = 25$ cm^{-3} surfaces are colored by distance from the Sun (blue-to-red). Top-left panel: view from the Sun (compare with Figure 1). Top-right panel: a side view of the region. Perseus and Taurus and their diffuse envelopes are arranged on two opposing sides of the Per-Tau shell. Bottom-left panel: another side view emphasizing the Tau Ring. The ellipse is the Tau Ring model (Appendix B). Bottom-right panel: 2D density slices along the *xy*, *xz*, *yz* planes. All planes intersect at shell's center. In all panels *xyz* are the Heliocentric Cartesian Galactic Coordinates.

2. *Tau Ring:* in a sky projection the Tau Ring is seen almost edge-on. The near side of the Tau Ring connects with the main body of Taurus at $d \approx 150$ pc, whereas the farthest part extends to $d \approx 220$ pc.

3. *The Fictitious Connection*: A filament seems to connect Taurus to Perseus. This connection is only a coincidental projection effect, where in actuality the filament is located at the distance of Taurus, and does not physically connect

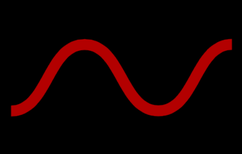
glue multidimensional data exploration → COSPACES

Ask for a demo later, please.



Bialy et al. 2021

The Dataverse® Project



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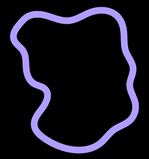

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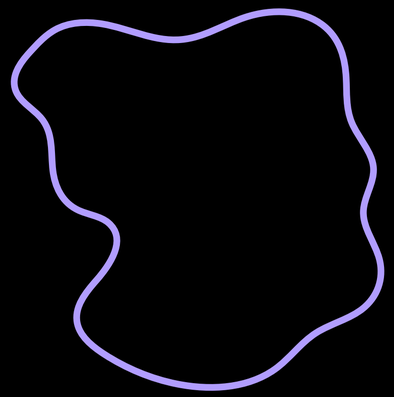
2023 and beyond!

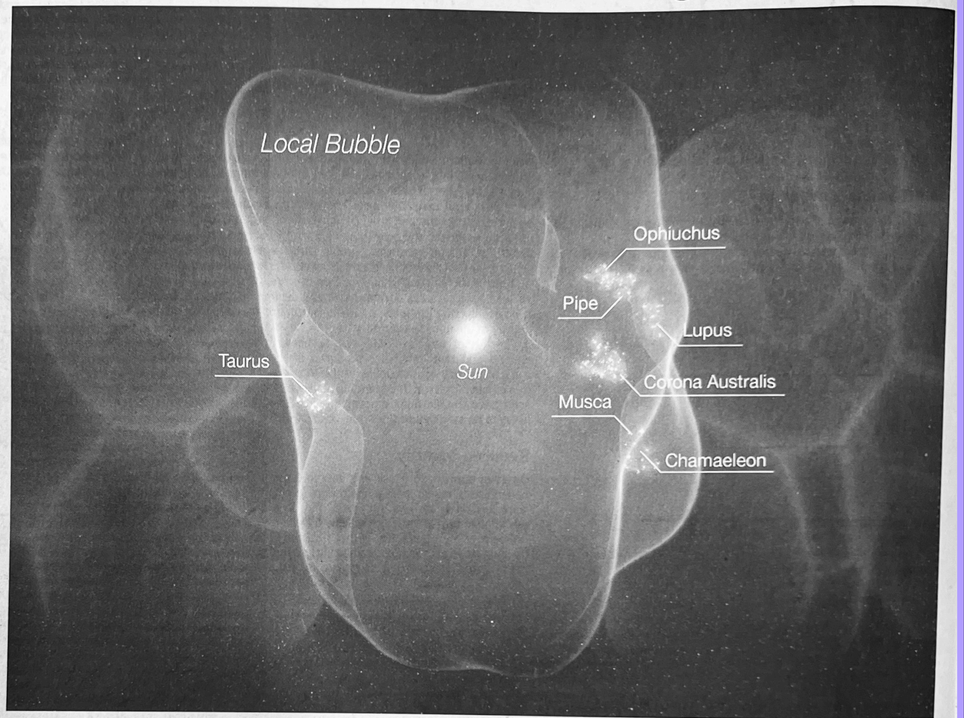


2022

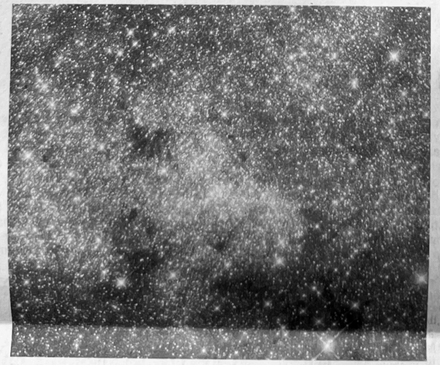
OUT THERE | DENNIS OVERBYE

Where Our Bubble Ends, Our Understanding Begins

By mapping a region devoid of gas and dust, scientists learn more about star formation.



LEAH HUSTAK (STSCI)/CFA



NASA

Above, an illustration of the Local Bubble, which formed in the Milky Way, left, when supernova explosions drove off all the gas and dust from a 1,000-light-year-wide region.

JUST A BIT TOO LATE for New Year celebrations, astronomers have discovered that the Milky Way galaxy, our home, is, like champagne, full of bubbles.

As it happens, our solar system is passing through the center of one of these bubbles. Fourteen million years ago, according to the astronomers, a firecracker chain of supernova explosions drove off all the gas and dust from a region roughly 1,000 light-years wide, leaving it bereft of the material needed to produce new generations of stars.

As a result, all the baby stars in our neighborhood can be found stuck on the edges of this bubble. There, the staccato force of a previous generation of exploding stars has pushed gas clouds together into forms dense enough to collapse under their own ponderous if diffuse gravity and condense enough to ignite, as baby stars. Our sun, 4.5 billion years old, drifts through the middle of this space in a coterie of aged stars.

"This is really an origin story," Catherine Zucker said in a news release from the Harvard-Smithsonian Center for Astrophysics. "For the first time, we can explain how all nearby star formation began."

Dr. Zucker, now at the Space Telescope Science Institute in Baltimore, led a team that mapped what they call the Local Bubble in remarkable detail. They used data from a number of sources, particularly Gaia, a European spacecraft, that has mapped and measured more than a billion stars, to pinpoint the locations of gas and dust clouds.

Last year, a group of scientists led by João Alves, an astrophysicist at the University of Vienna announced the discovery of the Radcliffe Wave, an undulating string of dust and gas clouds 9,000 light-years long that might be the spine of our local arm of the galaxy. One section of the wave now appears to be part of our Local Bubble.

The same group of scientists published their latest findings in Nature, along with an elaborate animated map of the Local Bubble and its highlights.

The results, the astronomers write, provide "robust observational support" for a long-held theory that supernova explosions are important in triggering star formation, perhaps by jostling gas and dust clouds into collapsing and starting on the long road to thermonuclear luminosity.

Astronomers have long recognized the Local Bubble. What is new, said Alyssa Goodman, a member of the team also from the Harvard-Smithsonian Center for Astrophysics, is the observation that all local star-forming regions lie on the Local Bubble's surface. Researchers previously lacked the tools to map gas and dust clouds in three dimensions. "Thanks to 3-D dust-mapping, now we do," Dr. Goodman said.

According to the team's calculations, the Local Bubble began 14 million years ago with a massive supernova, the first of about 15; massive stars died and blew up. Their blast waves cleared out the region. There are now no stars younger than 14 million years in the bubble, Dr. Goodman said.

The bubble continues to grow at about 4 miles a second. "Still, more supernovae are expected to take place in the near future, like Antares, a red supergiant star near the edge of the bubble that could go any century now," Dr. Alves said. "So the Local Bubble is not 'done.'"

With a score of well-known star-forming regions sitting on the surface of the bubble, the next generation of stars is securely on tap.

The team plans to go on and map more bubbles in the our Milky Way flute of champagne. There must be more, Dr. Goodman said, because it would be too much of a coincidence for the sun to be smack in the middle of the only one.

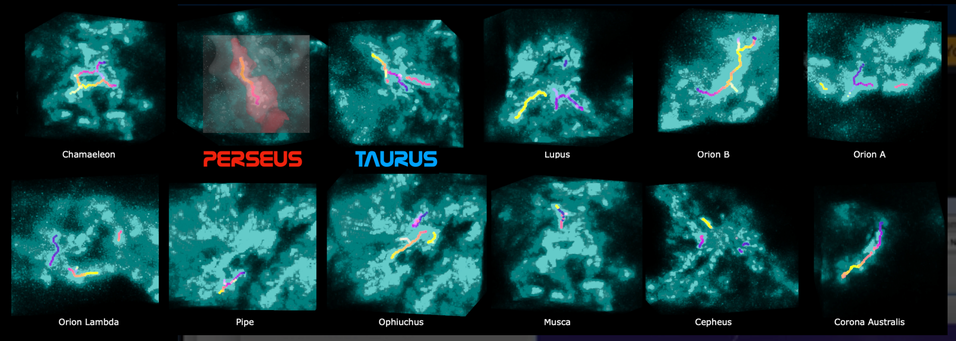
The sun's presence in this one is nonetheless coincidental, Dr. Alves said. Our star wandered into the region only five million years ago — long after most of the action — and will exit about five million years from now.

The motions of the stars are more irregular than commonly portrayed, as they are bumped gravitationally by other stars, clouds and the like, Dr. Alves said.

"The sun is moving at a significantly different velocity than the average of the stars and gas in the solar neighborhood," he noted. This would enable it to catch up and pass — or be passed by — the bubble.

"It was a revelation," Dr. Goodman said, "how kooky the sun's path really is compared with a simple circle."

The truth...



THE NEW YORK TIMES, TUESDAY, JANUARY 25, 2022

OUT THERE | DENNIS OVERBYE

Where Our Bubble Ends, Our Understanding Begins

By mapping a region devoid of gas and dust, scientists learn more about star formation.

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NYT, January 25, 2022

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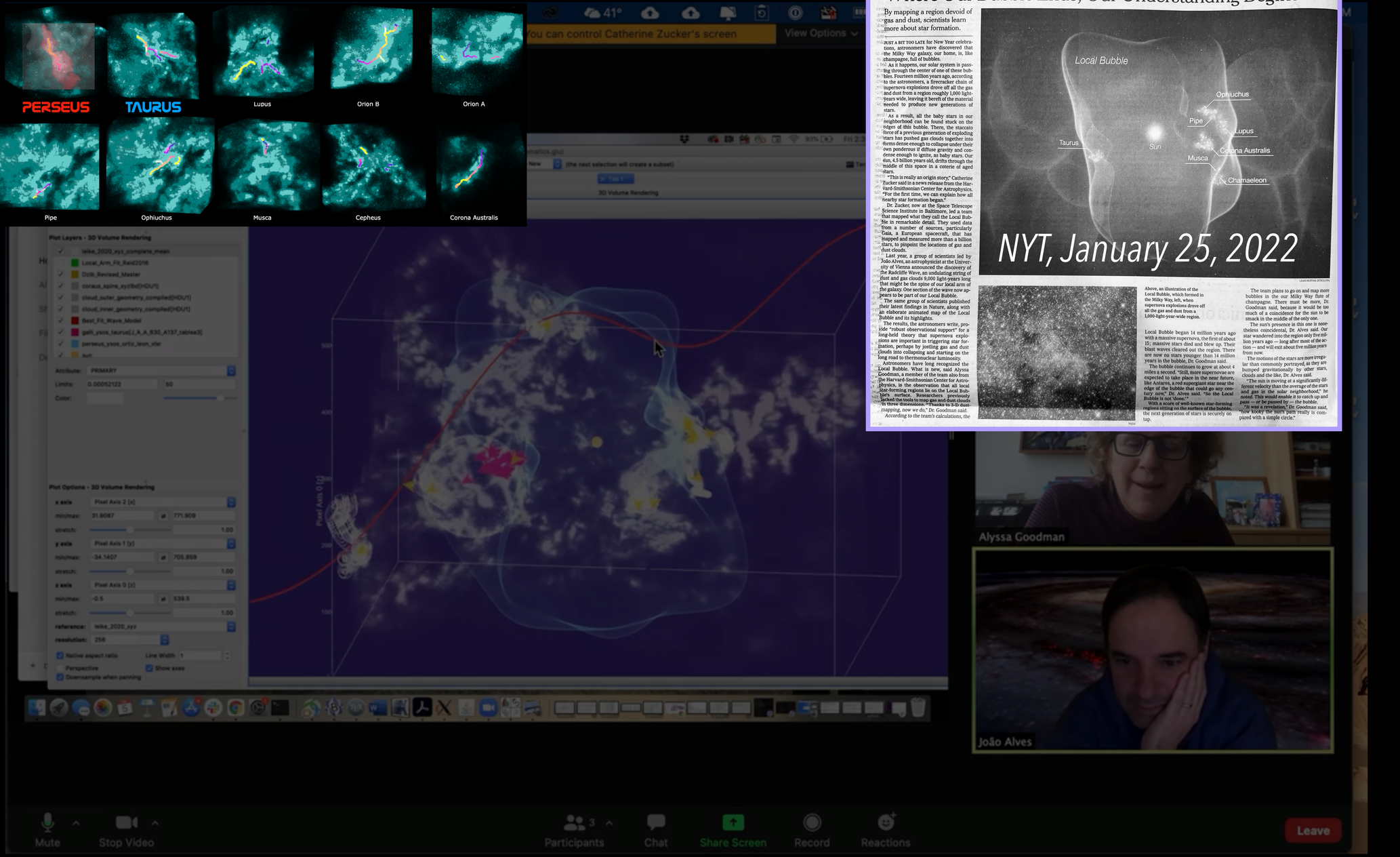

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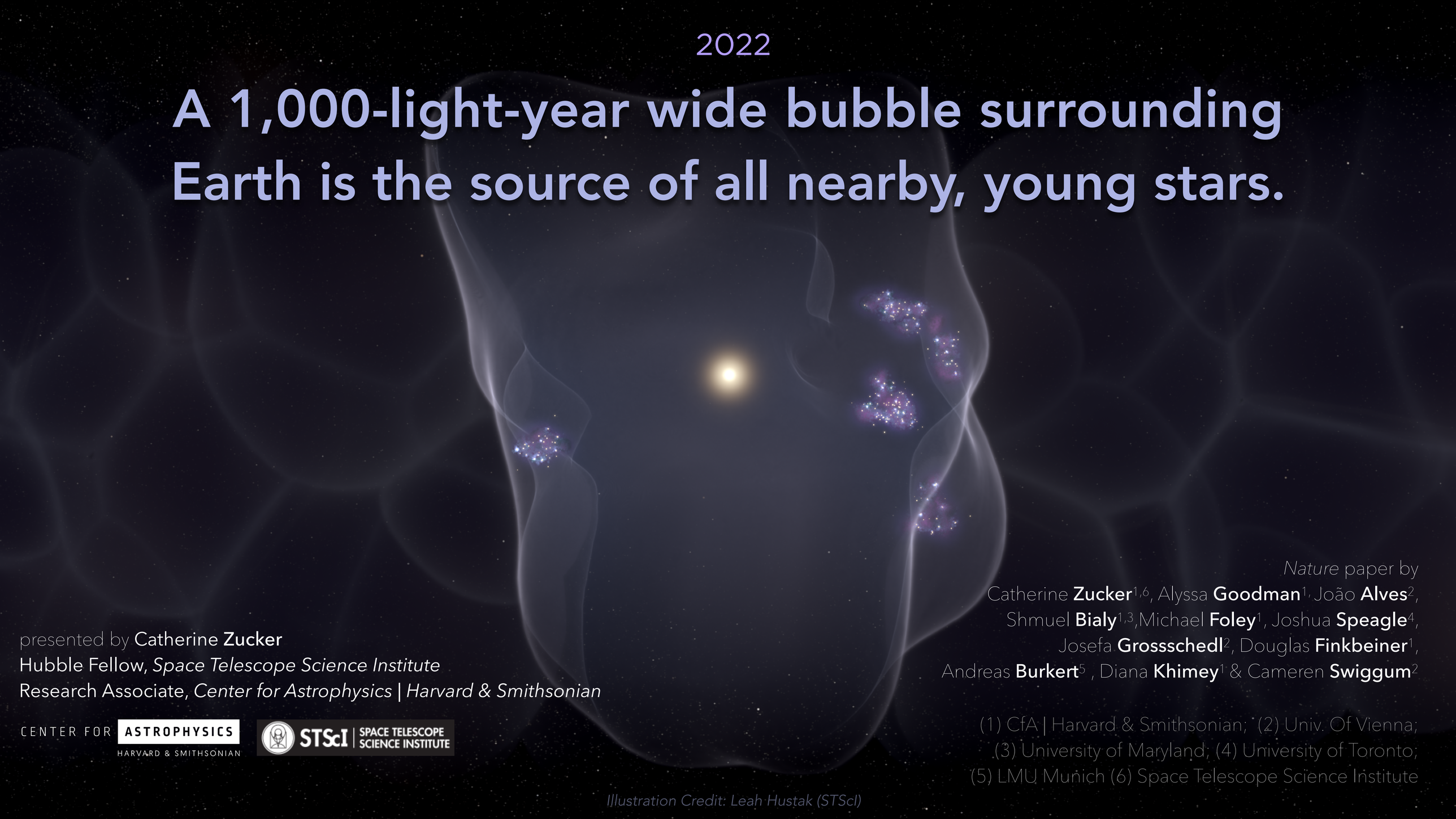
A 1,000-light-year wide bubble surrounding Earth is the source of all nearby, young stars.



presented by Catherine **Zucker**
Hubble Fellow, *Space Telescope Science Institute*
Research Associate, *Center for Astrophysics | Harvard & Smithsonian*

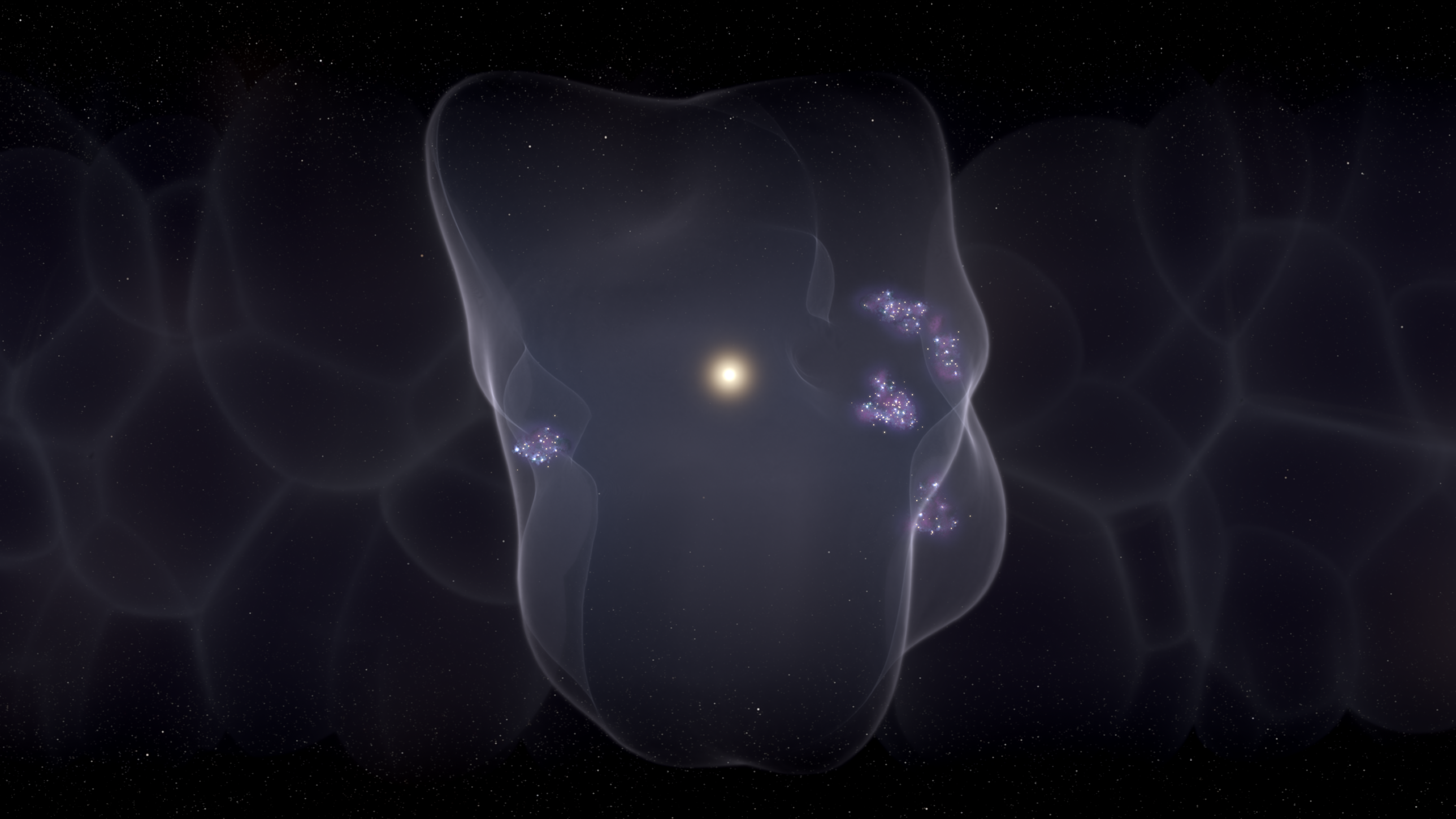
CENTER FOR ASTROPHYSICS HARVARD & SMITHSONIAN

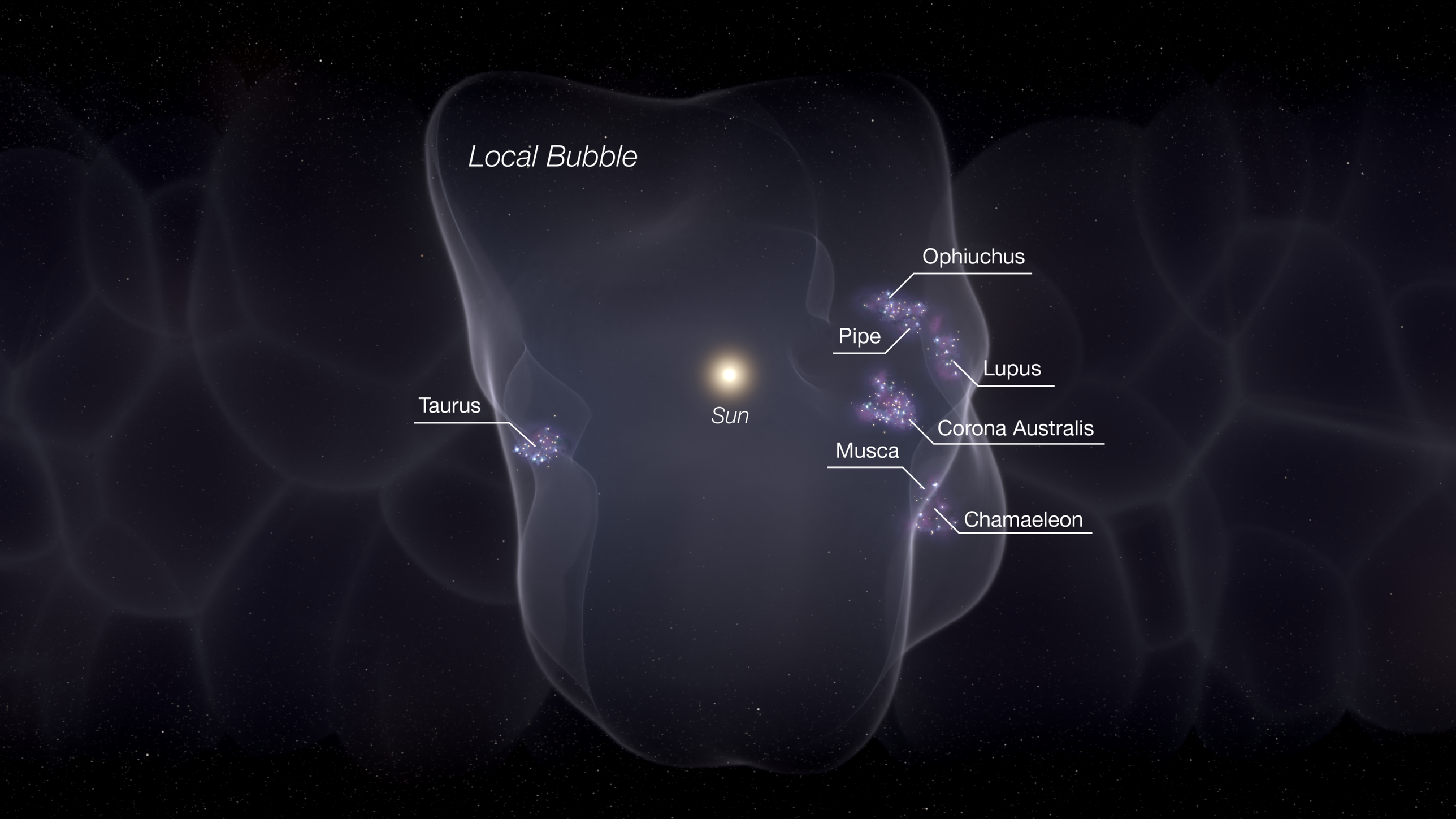
STScI | SPACE TELESCOPE SCIENCE INSTITUTE

Nature paper by
Catherine **Zucker**[1,6], Alyssa **Goodman**[1], João **Alves**[2],
Shmuel **Bialy**[1,3],Michael **Foley**[1], Joshua **Speagle**[4],
Josefa **Grossschedl**[2], Douglas **Finkbeiner**[1],
Andreas **Burkert**[5] , Diana **Khimey**[1] & Cameren **Swiggum**[2]

(1) CfA | Harvard & Smithsonian; (2) Univ. Of Vienna;
(3) University of Maryland; (4) University of Toronto;
(5) LMU Munich (6) Space Telescope Science Institute

Illustration Credit: Leah Hustak (STScI)




Local Bubble
Ophiuchus
Pipe
Lupus
Taurus
Sun
Corona Australis
Musca
Chamaeleon

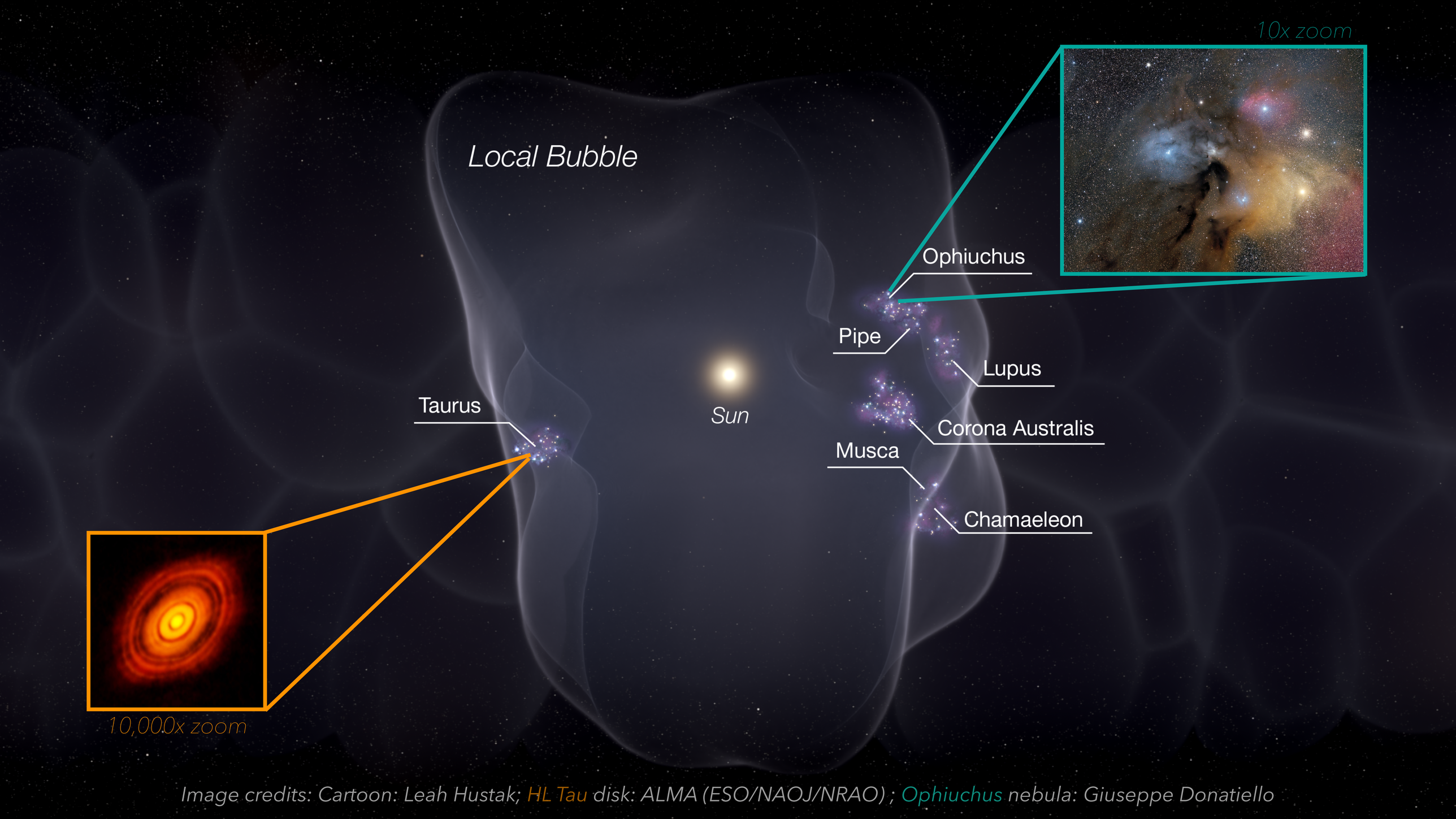
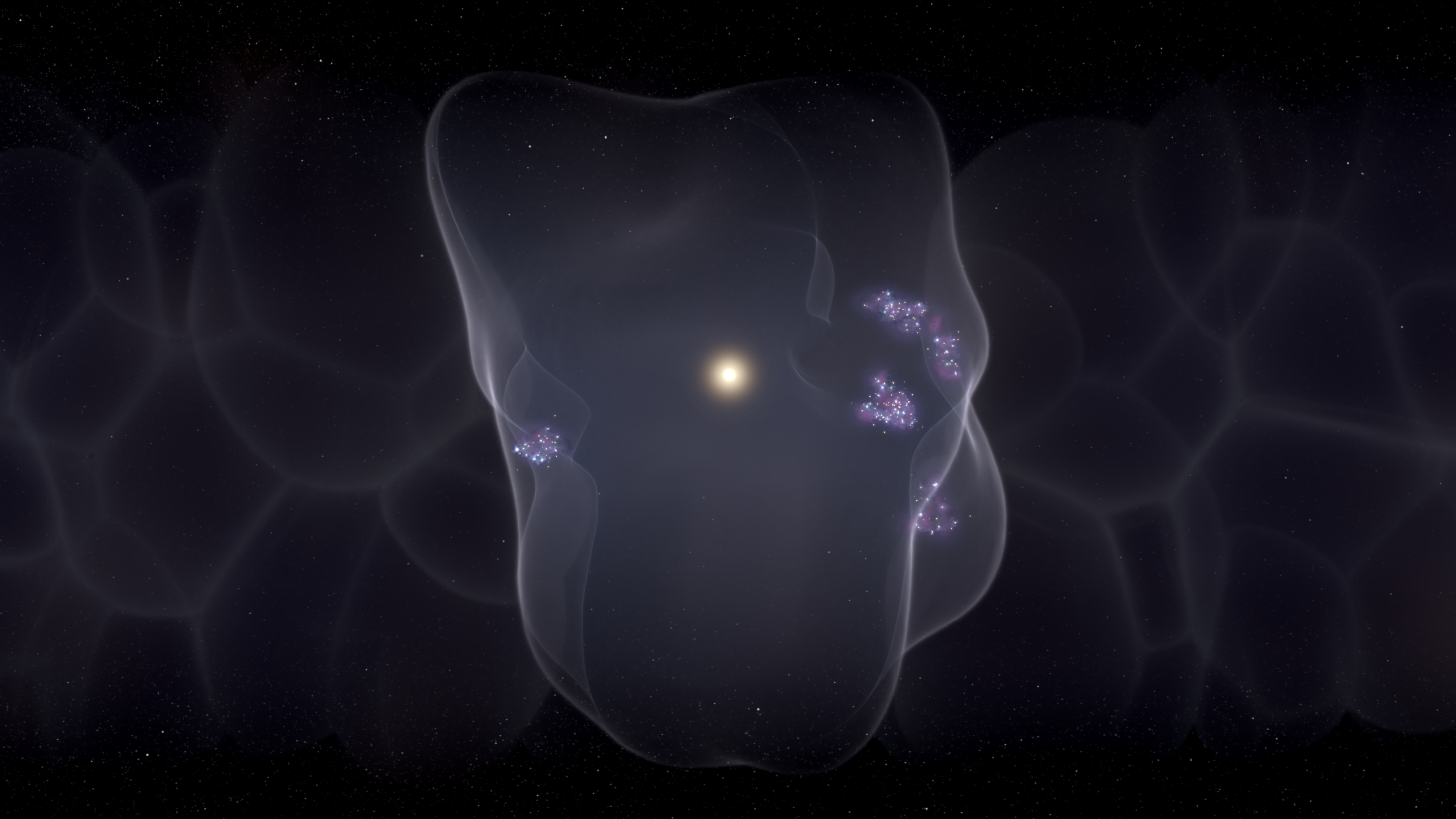


Image credits: Cartoon: Leah Hustak; HL Tau disk: ALMA (ESO/NAOJ/NRAO) ; Ophiuchus nebula: Giuseppe Donatiello

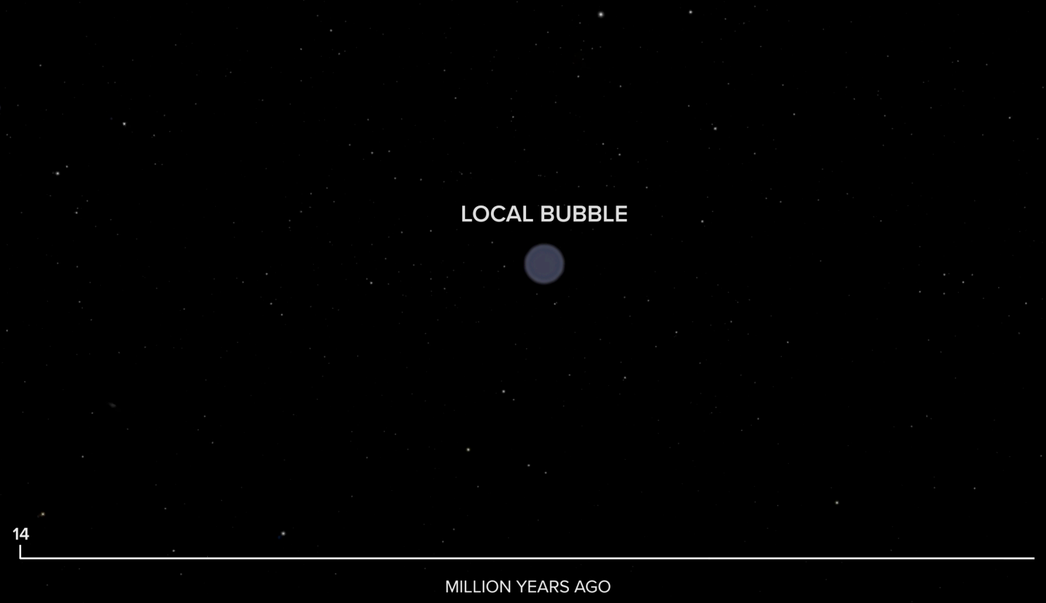


We can reconstruct the evolutionary history of our Galactic neighborhood.

We can reconstruct the evolutionary history of our Galactic neighborhood.

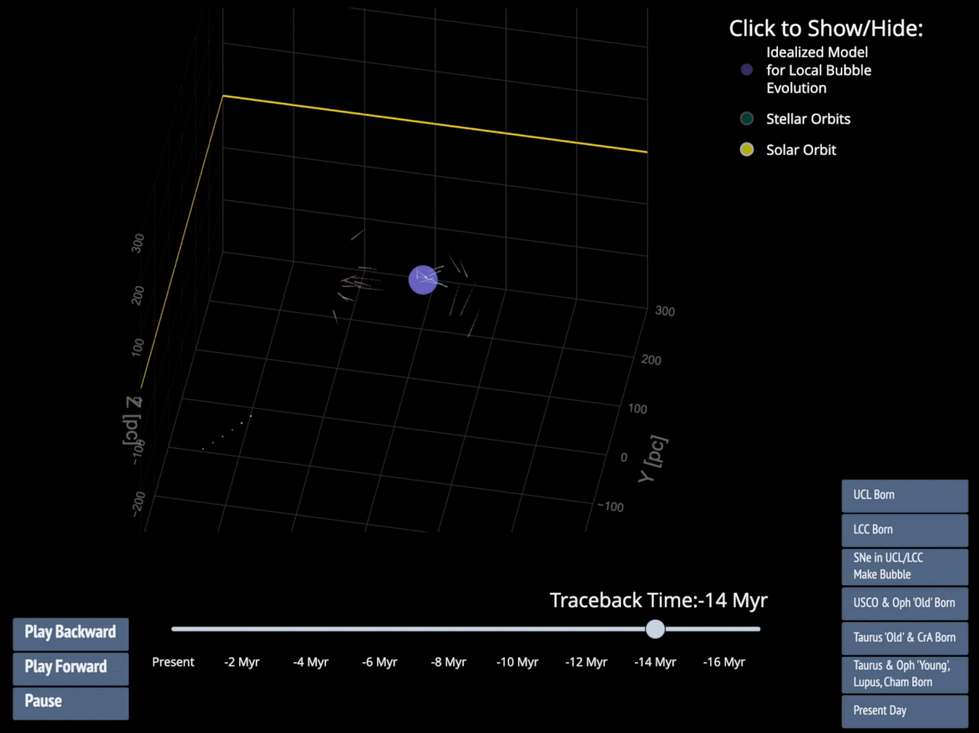
A chain of events beginning 14 million years ago with powerful supernova explosions created a gigantic bubble with a surface ripe for star formation

“Cartoon”



“Real Data”

(Zucker et al. 2022, *Nature*)



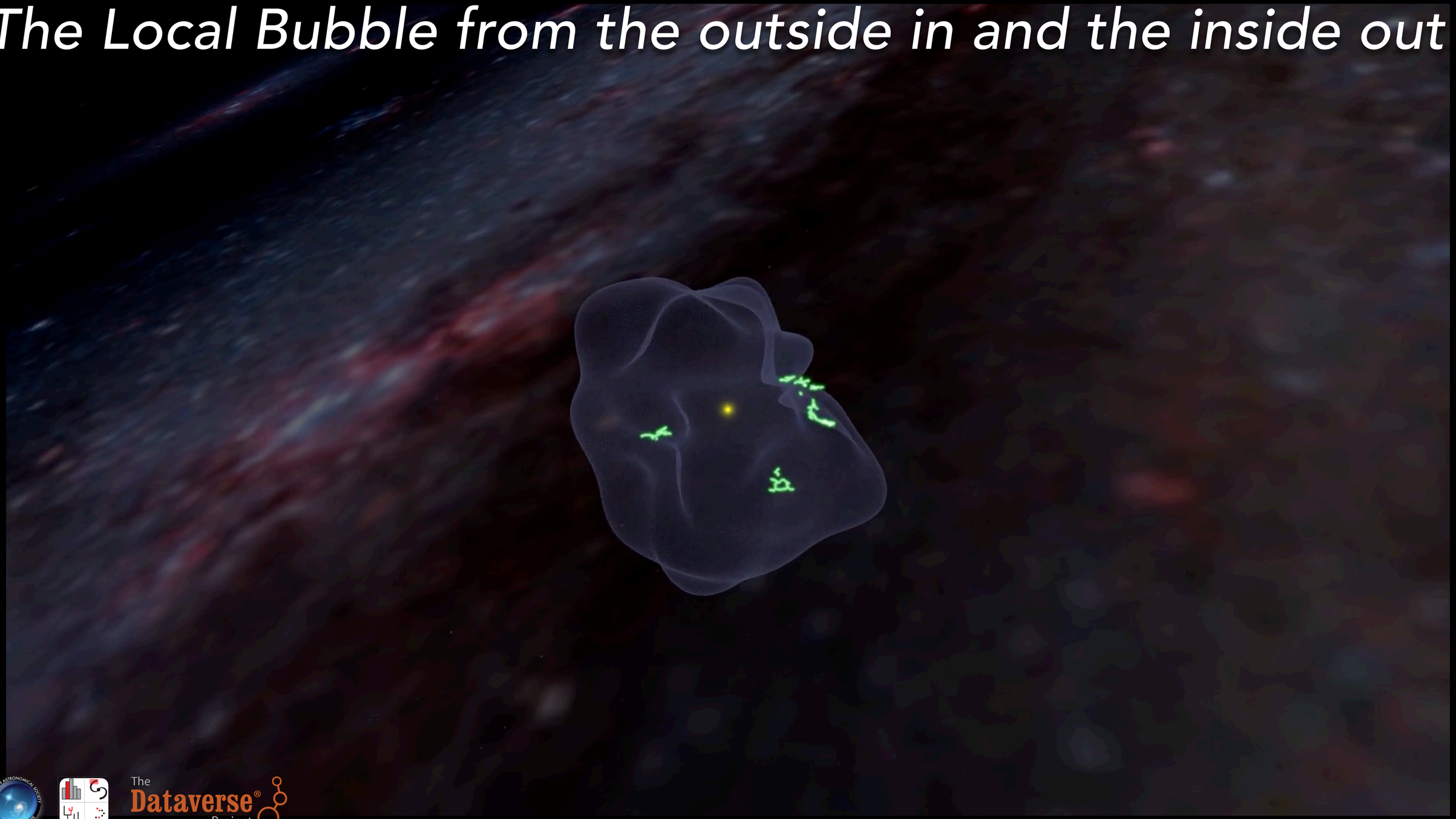
[try the interactive figure]

glue → plotly

The Local Bubble from the outside in and the inside out

The Dataverse® Project

The Local Bubble from the outside in and the inside out



The Dataverse® Project

How did the Sun wind up in the bubble? (by accident)

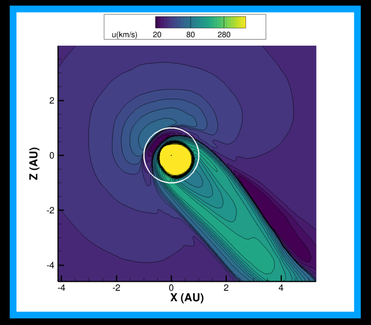
The Sun was over 1,000 light years away when the bubble first started forming.

How did the Sun wind up in the bubble? (by accident)

The Sun entered the bubble 5 million years ago and now sits near the bubble's center.

How did the Sun wind up in the bubble? (by accident)

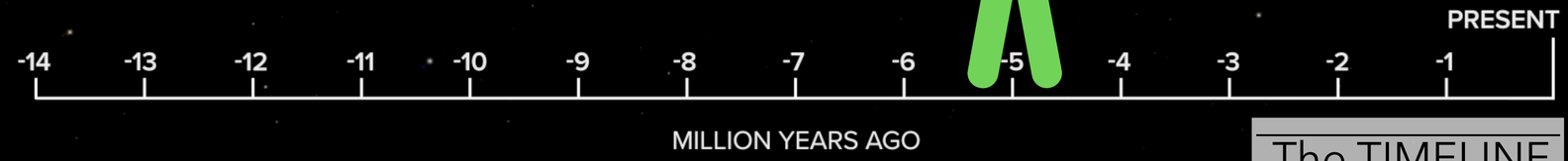
What does the Sun's time in the bubble mean for Earth?



See Opher et al. 2024 (Heliosphere shrinks as Sun passes through Local Bubble, exposes Earth!)

The timeline is **consistent** with supernova iron deposits[1,2] in the Earth's crust!

[1] Wallner et al. 2016
[2] Breitschwerdt et al. 2016



The TIMELINE CONSORTIUM

So What?

In the present day, almost every single nearby, young star lies on the surface of the Local Bubble

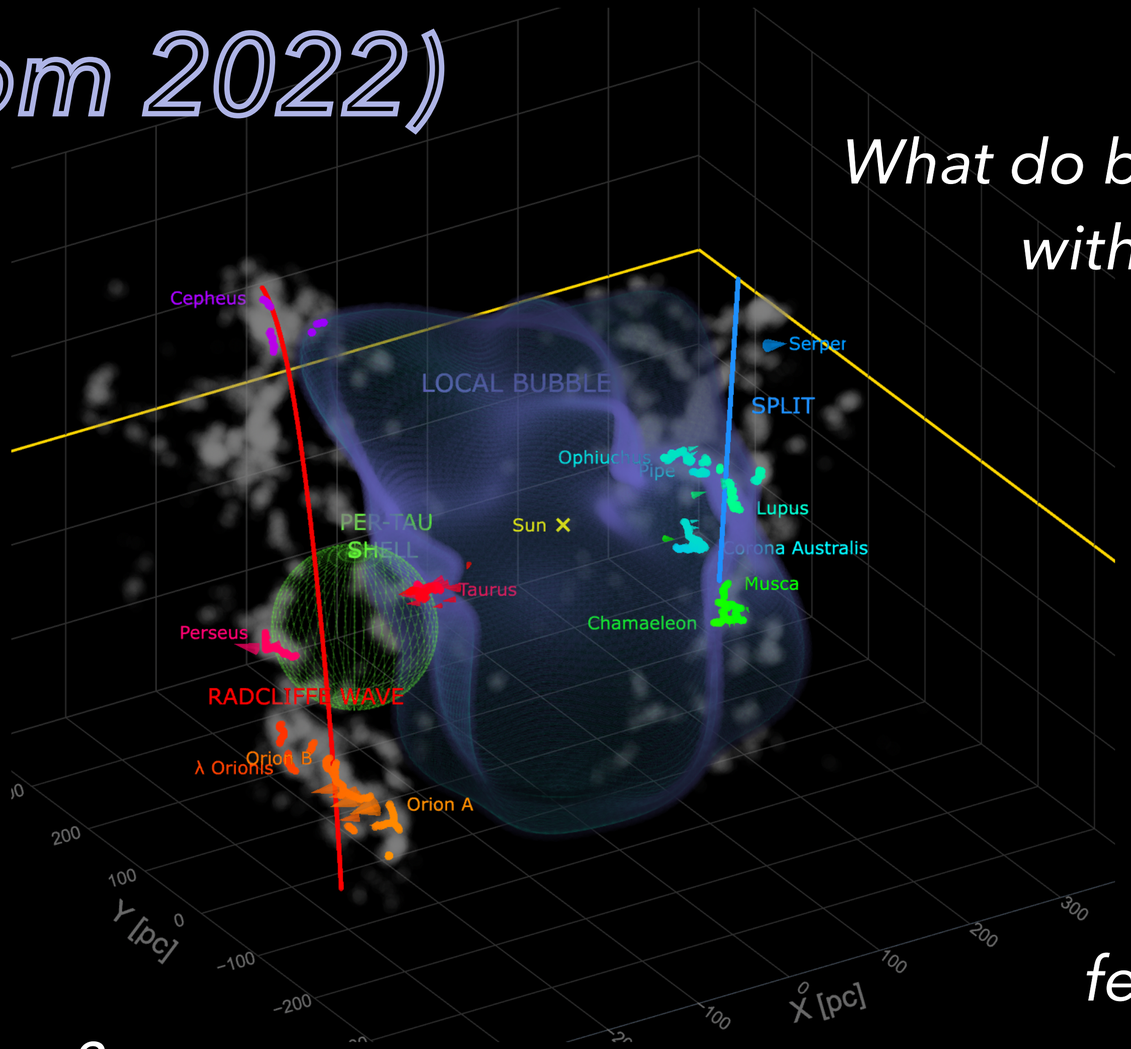
We can now explain how all nearby star formation began

Supernovae can "sweep up" gas into dense clouds that ultimately form new stars (evidence for 50-year-old theory)

Sun's "luck" (centered in bubble) suggests that bubbles must be pervasive across the Galaxy, implying "bubbly" Milky Way

"Next" *(from 2022)*

What do bubbles have to do with SPIRAL structure? Anything?



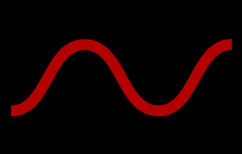
How do we SEARCH for other bubbles?

How do these bubbles INTERACT with each other?

Can observations now measure supernova feedback's effect on galaxy EVOLUTION?

[try the interactive figure]

Local Bubble model [Pelgrims et al. 2020] , Superbubble expansion model [El-Badry et al. 2019], 3D Dust Maps [Leike et al. 2020, Lallement et al. 2019]



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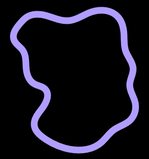

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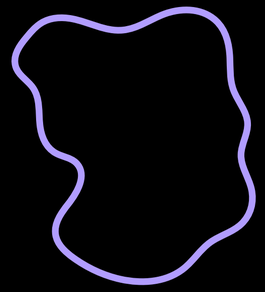
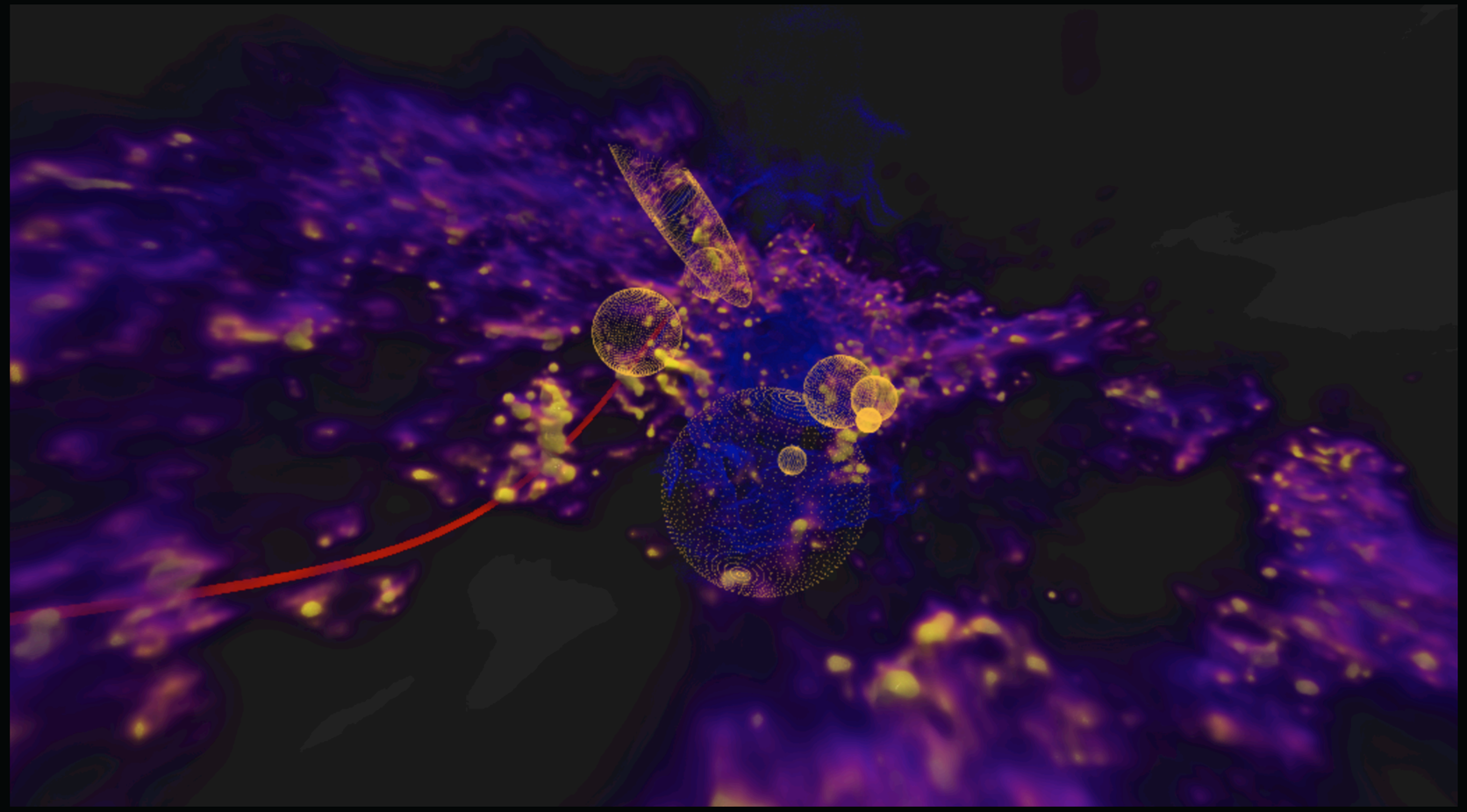


We now think the LOCAL BUBLE is actually a LOCAL CHIMNEY

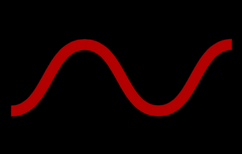
Thanks to O’Neill et al.

2024



O’Neill et al. Local Chimney 2024 +++

Start the presentation to see live content. Still no live content? Install the app or get help at **PollEv.com/app**



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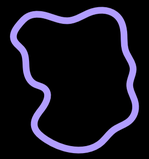
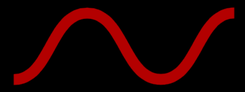
2024

2021

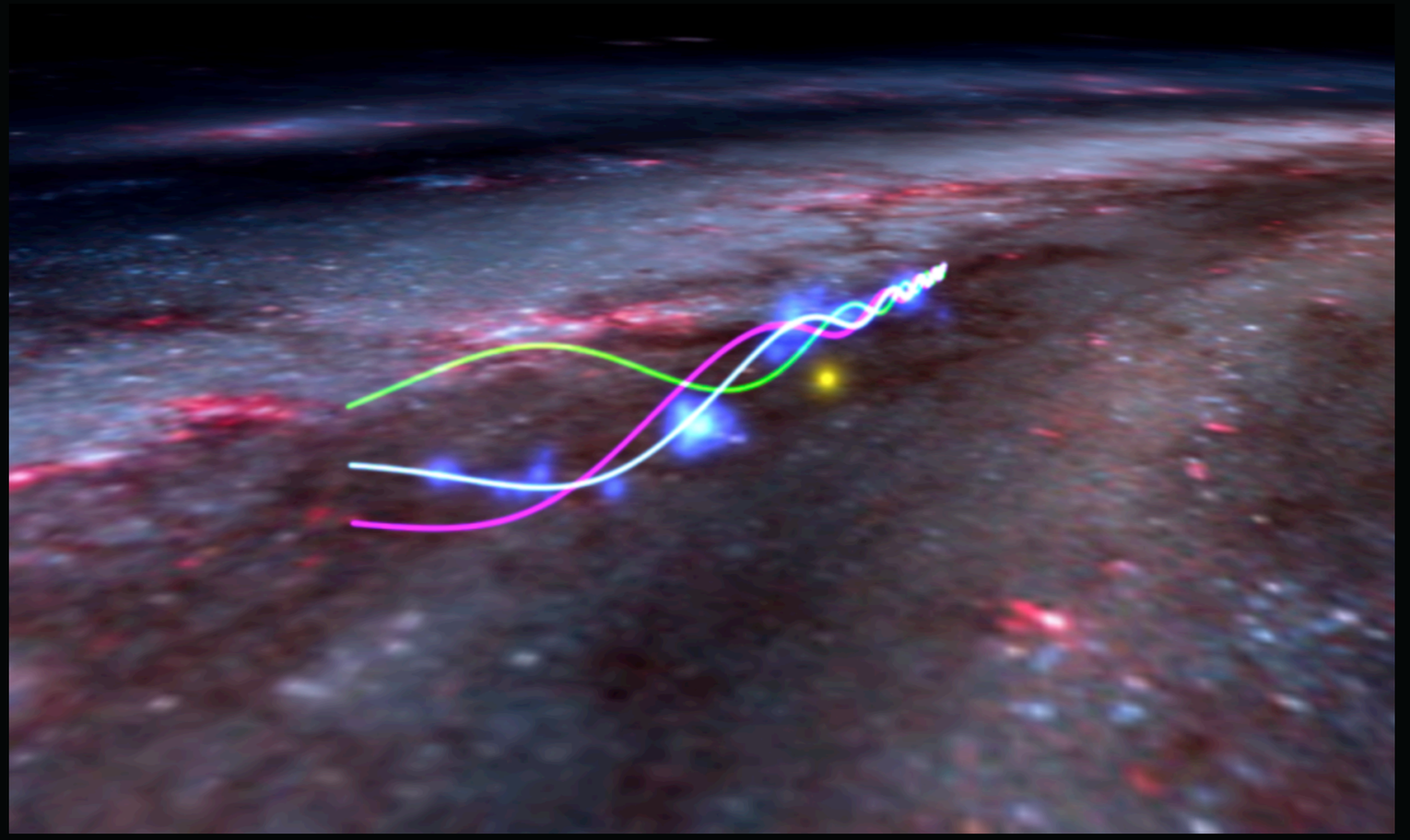


2022
2024

2023 and beyond!

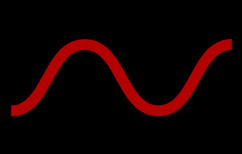


We now know the RADCLIFFE WAVE is actually WAVING.
Thanks to Konietzka et al.
2024



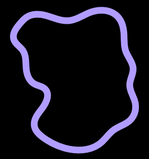
Konietzka et al. — Oscillating RadWave *Nature*, 2024

Start the presentation to see live content. Still no live content? Install the app or get help at **PollEv.com/app**



2020
2024

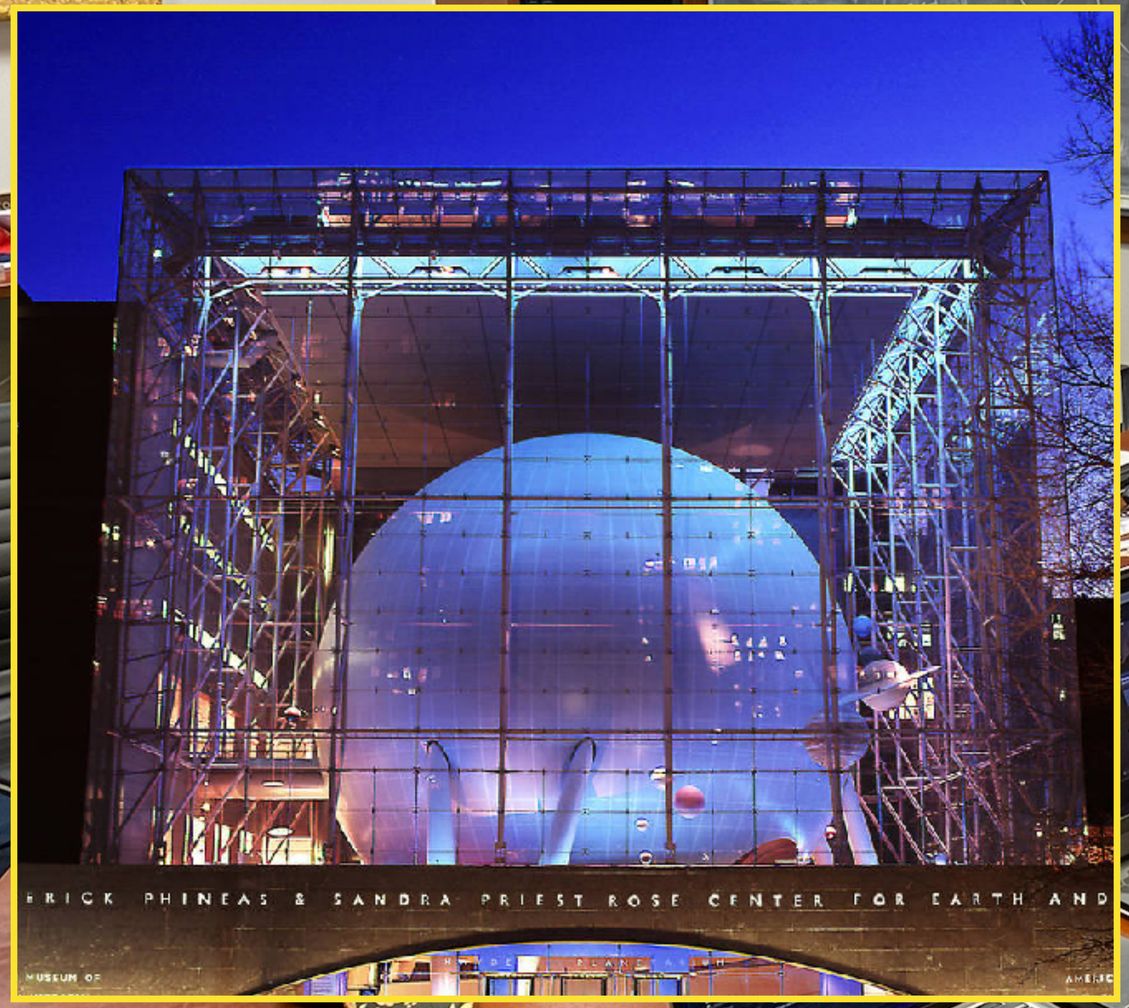
2021



2022
2024

2023 and beyond!

Stay-tuned for more at MilkyWay3D.org



MILKYWAY3D.org

SCAN ME

Welcome to a new view of the Milky Way... in 3D!

MilkyWay3D.org is an open-data open-source discovery hub, providing data, visualization, and research tools for studying the MilkyWay in 3D.

INFRASTRUCTURE ⟷ SCIENCE ⟷ EDUCATION & OUTREACH

assembling data as a community, using modern, open-source practices

glue

WORLDWIDE TELESCOPE

OpenSpace

linking position and motion across dimensions, using the plug-in architecture enabled by glue

(plug-ins include WorldWide Telescope, OpenSpace & more)

The Dataverse Project

DIGITAL universe

making data accessible online for decades

Lead: Alyssa Goodman, CfA

enabling studies of how galaxies turn gas into stars, using...

stellar positions, clusters, motions

topology, positions & motions of (long) features

tracers of feedback & magnetic fields

details on star-forming regions...and more!

Lead: Catherine Zucker, CfA

connecting real research data, software, and science to learners

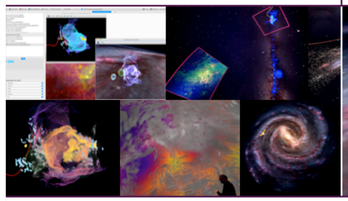
OpenSpace

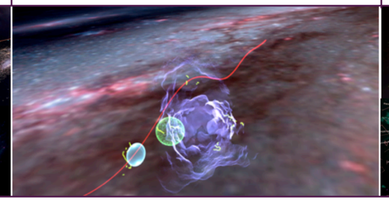
real-time data exploration anywhere, including in planetaria

CosmicDS

"Cosmic Data Stories" teach data science using astronomical data & tools

Lead: Jackie Faherty, AMNH





TEAM: Harvard/Smithsonian CfA (Jonathan Carifio, Alyssa Goodman, Ralf Konietzka, Theo O'Neill, Patricia Udomprasert, Catherine Zucker), **AMNH** (Brian Abbott, Micah Acinapura, Carter Emmart, Jackie Faherty), **Linkoping University** (Alex Bock) ; **University of Vienna** (Joao Alves, Sebastian Ratzenbock); **glue solutions, inc./Aperio** (Thomas Robitaille); **University of Wisconsin, Whitewater** (Bob Benjamin), **STScI/Johns Hopkins** (Josh Peek), **Max Planck IfA** (Gordian Edenhofer); **Northeastern University** (Michelle Borkin); and YOU?!

Join us, contribute, and yes, you get a T-Shirt.

Glue (/Users/aagoodman/Library/CloudStorage/GoogleDrive-goodman.alyssa@gmail.com/.shortcut-targets-by-id/1e4RysNClnsaerZT11AaNJ9GKPS9q7vZg/MilkyWay3D.ORG/Sessions/munich_d

Open Session | Export Session | Import Data | Export Data/Subsets | Link Data | Arithmetic attributes | Active Subset: None/Create New (the next selection will create a subset)

Data Collection

- Foley2022_arXiv_2212.01405_OrionShell_MW3D[HDU1]
- Reid2019_ApJ_885_131_LocalArmFit_MW3D[HDU1]
- Reid2019_ApJ_885_131_SGNArmFit_MW3D[HDU1]
- Reid2019_ApJ_885_131_MW3D[HDU1]
- Hunt2023_arXiv_2303.13424_MW3D[HDU1]
- Lallement2019_A+A_625_A135_Split_MW3D[HDU1]
- Edenhofer_2023_3D_Dust_XYZ_Revised-2

Subsets

Plot Layers - 3D Volume Rendering

- [x] Edenhofer_2023_3D_Dust_XYZ_Revised-2
- [x] Zucker2021_ApJ_919_35_spines_MW3D[HDU1]
- [x] Bialy2021_ApJL_919_L5_MW3D[HDU1]
- [x] Pelgrims2020_A+A_636_A17_lmax10_MW3D[HDU1]
- [x] Alves2020_Nat_578_237_MW3D[HDU1]
- [x] Leike2020_A+A_639_A138_xyz_cube_MW3D

Attribute: PRIMARY

Limits: 5.89626e-08 | 0.00643762

Color:

Plot Options - 3D Volume Rendering

x axis Pixel Axis 2 [x]

min/max: -73.9532 ⇄ 812.953

stretch: 1.00

y axis Pixel Axis 1 [y]

min/max: -73.9532 ⇄ 812.953

stretch: 1.00

z axis Pixel Axis 0 [z]

min/max: -54.101 ⇄ 593.101

stretch: 1.00

reference: Leike2020_A+A_639_A138_xyz_cube_MW3D

resolution: 256

- [x] Native aspect ratio
- [ ] Perspective
- [ ] Downsample when panning

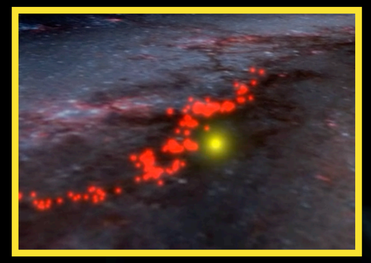
Line Width 1

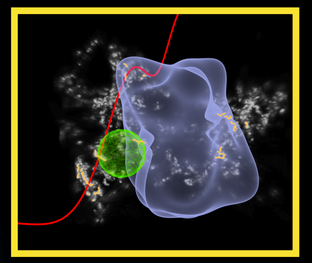
- [ ] Show axes

Tab 1 | Tab 2 | Tab 3

3D Volume Rendering

[demos upon request]





cf milkyway3D.org

glue
multidimensional data exploration

extra slides

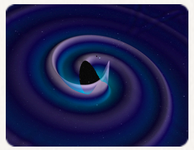
Opinion

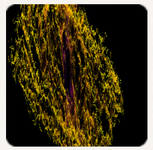
The New Universe

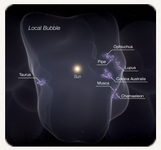
MEMPHIS, SUNDAY OCTOBER 23, 2022

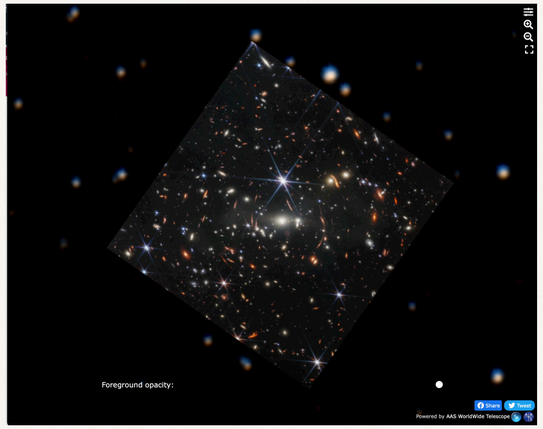
WHAT DO EXPENSIVE NEW TELESCOPES DO FOR HUMANITY TODAY?

Are mega-projects like ALMA, LIGO, JWST, and Gaia worth the billions?



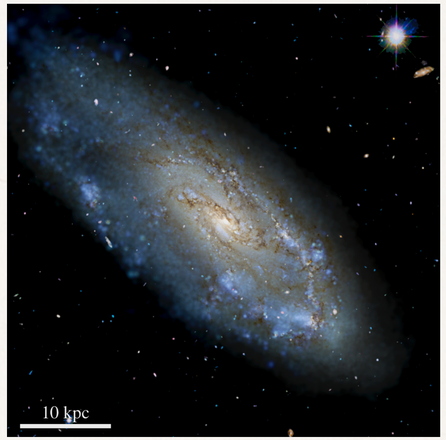


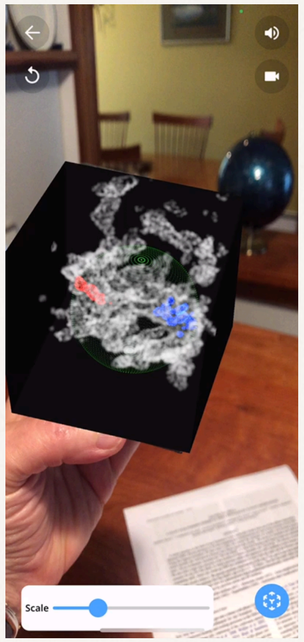




ARE COMPUTERS THE NEW TELESCOPES?

New galaxies in-silico, the early Universe without physics, and new stars forming in your hand.



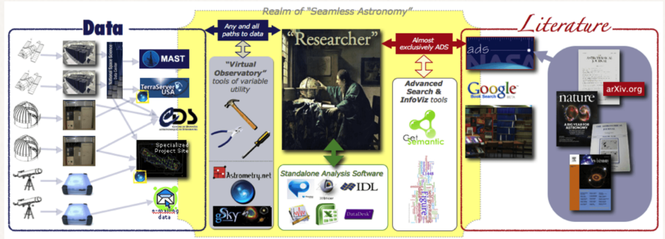


IS ASTROPHYSICS BEING (RE)ORGANIZED?

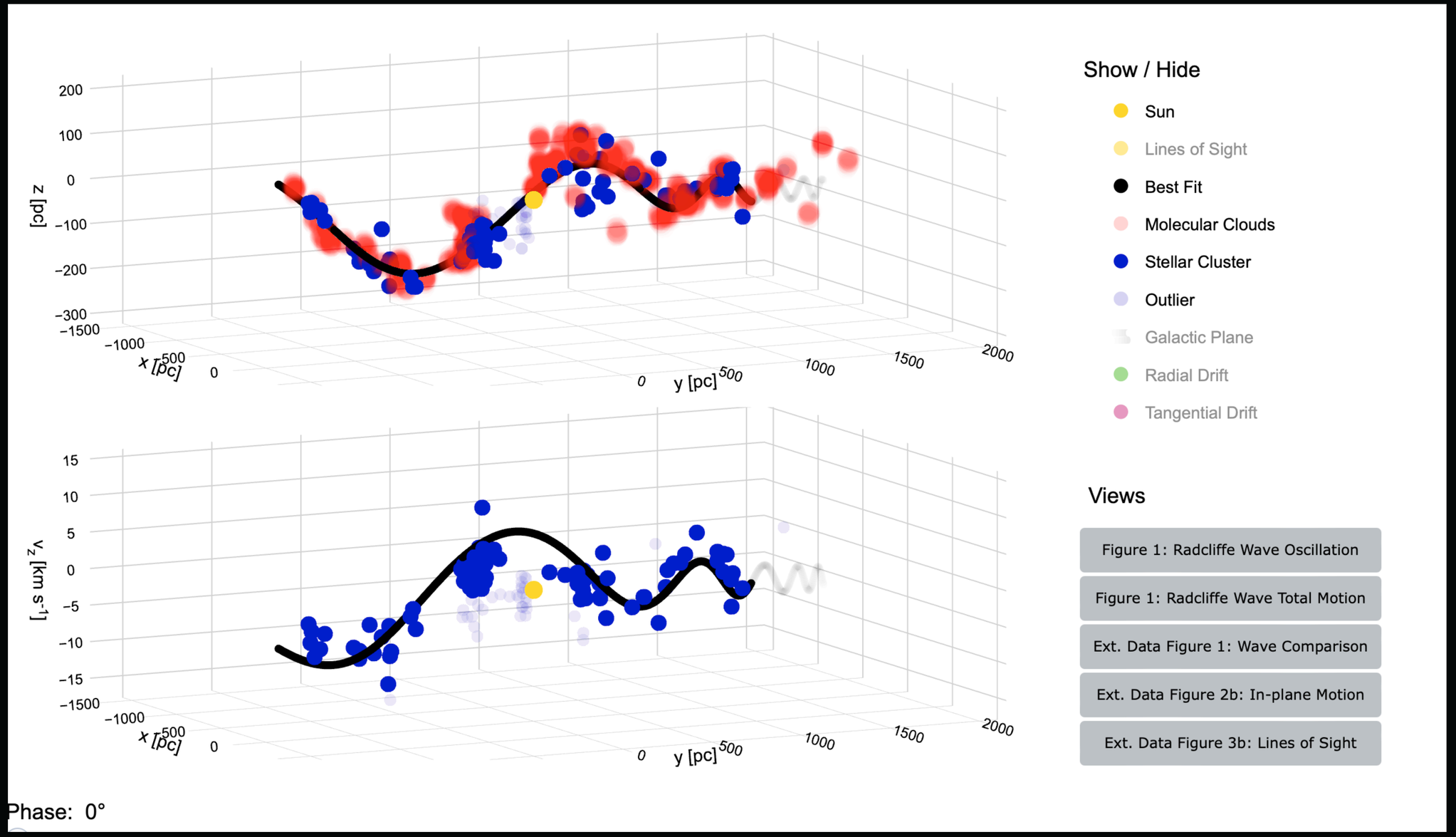
Lone stargazers are a rarer and rarer breed in professional astronomy. Teams and data scientists seem the way of the future, and tools that talk to each other are essential.

SEAMLESS ASTRONOMY

Linking scientific data, publications, and communities



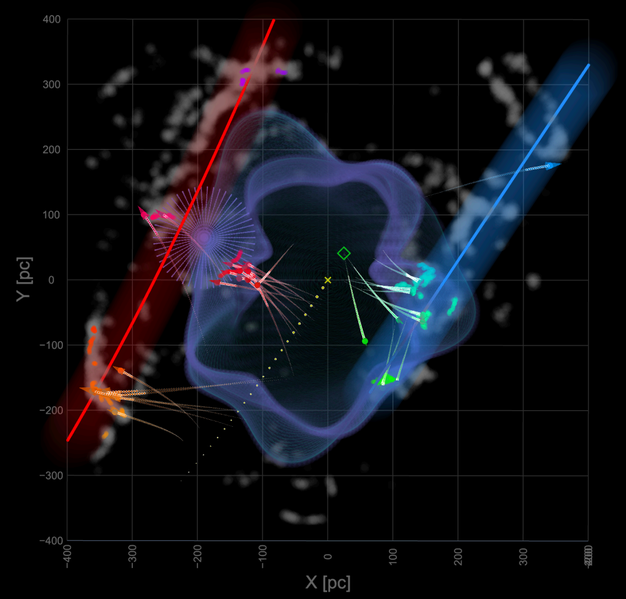
Editor: Alyssa Goodman, Center for Astrophysics | Harvard & Smithsonian, @AlyssaAGoodman



Konietzka et al. — Oscillating RadWave *Nature*, 2024

Start the presentation to see live content. Still no live content? Install the app or get help at **PollEv.com/app**

And back in 2022,
we wondered:
What (MAYBE!) caused the prior star formation that caused the SNe that caused the Local Bubble?



Traceback Time:Present

Play Reverse Pause

Present -1 Myr -2 Myr -3 Myr -4 Myr -5 Myr -6 Myr -7 Myr -8 Myr -9 Myr -10 Myr -11 Myr -12 Myr -13 Myr -14 Myr -15 Myr -16 Myr -17 Myr -18 Myr -19 Myr -20 Myr

Click to see what MIGHT have happened...

Then, in 2023…

1. Andi Burkert sent Ralf Konietzka to Cambridge.
2. We realized the RadWave is so big that p-p-p-v from CO is useful enough to suggest oscillation.
3. Joao Alves et al. made really, really, good 6D clusters of young stars using Gaia.
4. Ralf found the RadWave IS oscillating — and drifting outward from the Galactic Center.
5. BONUS: also, dark matter probably didn't kill the dinosaurs.

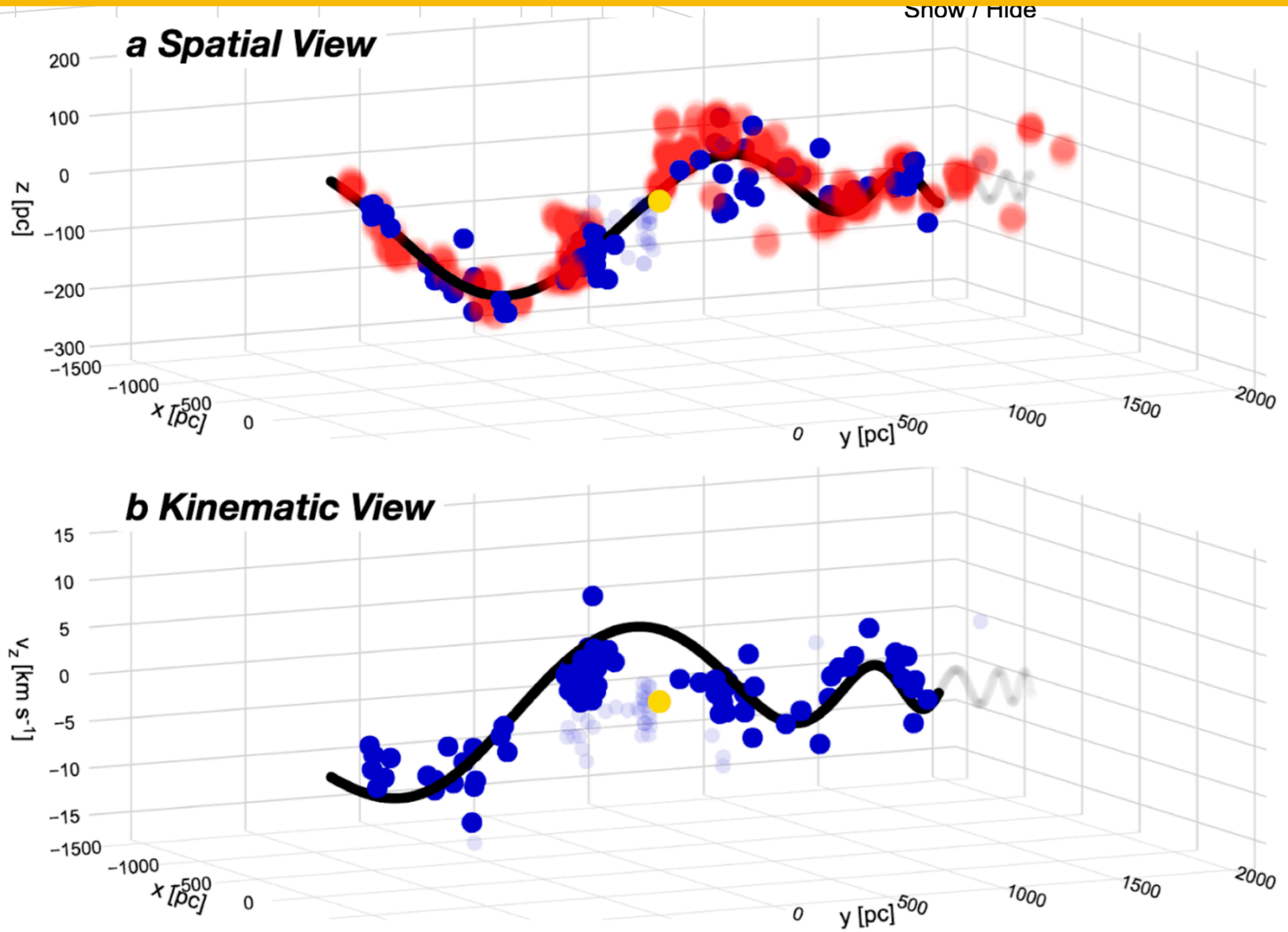
Konietzka, R., Goodman, A., Zucker, C., Burkert, A., Alves, J., Foley, M., Swiggum, C. 2023. To be submitted to Nature, June 2023. **The Radcliffe Wave is Oscillating**

Embargoed—please do not share—this slide will be removed from slides online.

Phase Space Analysis of the Local Interstellar Medium

The Oscillation of the Radcliffe Wave

Ralf Konietzka



Master's Thesis
at the Faculty of Physics
Ludwig-Maximilians-University of Munich

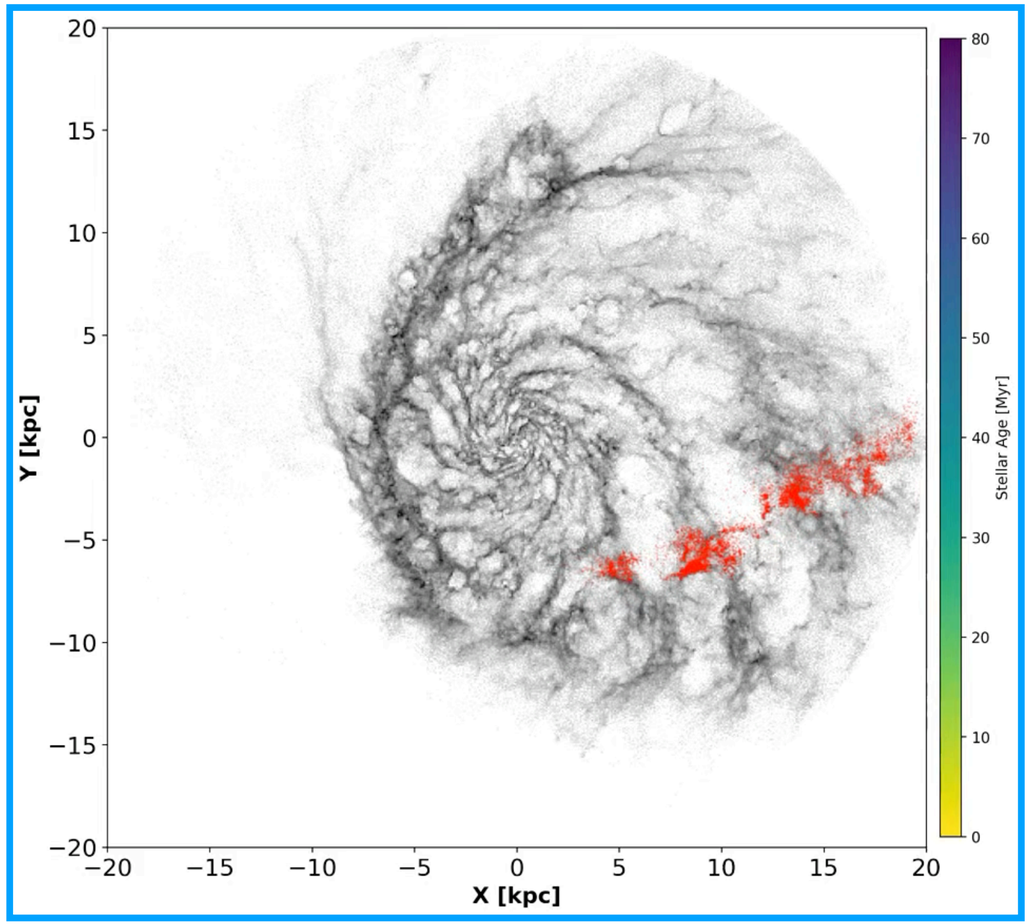
Submitted by
Ralf Konietzka
born in Nuremberg

Supervised by
Prof. Dr. Alyssa Goodman
Prof. Dr. Andreas Burkert

Munich, June 12, 2023

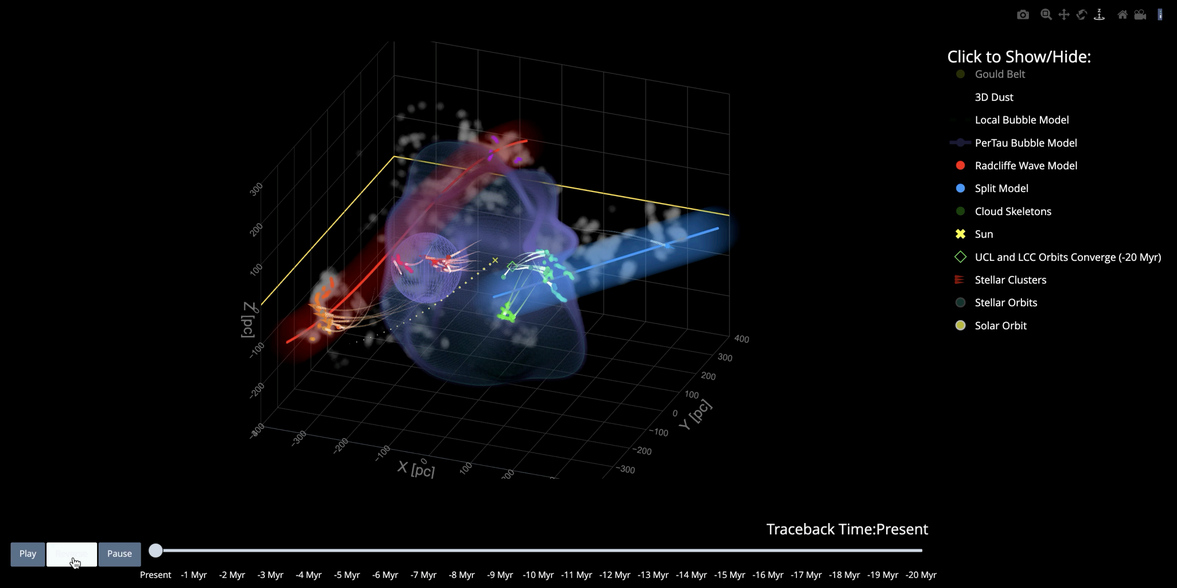
Konietzka, R., Goodman, A., Zucker, C., Burkert, A., Alves, J., Foley, M., Swiggum, C. 2023. To be submitted to Nature, June 2023. The Radcliffe Wave is Oscillating

“Snapshots” can be deceiving– pattern speed is NOT real motion!



Loebman and Zucker, AG et al 2023

“Crazy” stuff *IS* happening?!



https://faun.rc.fas.harvard.edu/czucker/Interactive_Figure3_Alyssa.html, based on Zucker et al. 2022 (& now Konietzka et al. 2023)

Where are we? Why does star formation, in **nebulae**, in **galaxies**, matter?

Why is OUR Galaxy a **cartoon** in **WWT**? (Mapping from inside requires 3D measurements—no distances.)

2020: RadWave
- 3D dust mapping
- Gaia
- **glue** & **WWT** (viz)

2021: PerTau
- adds **AR**

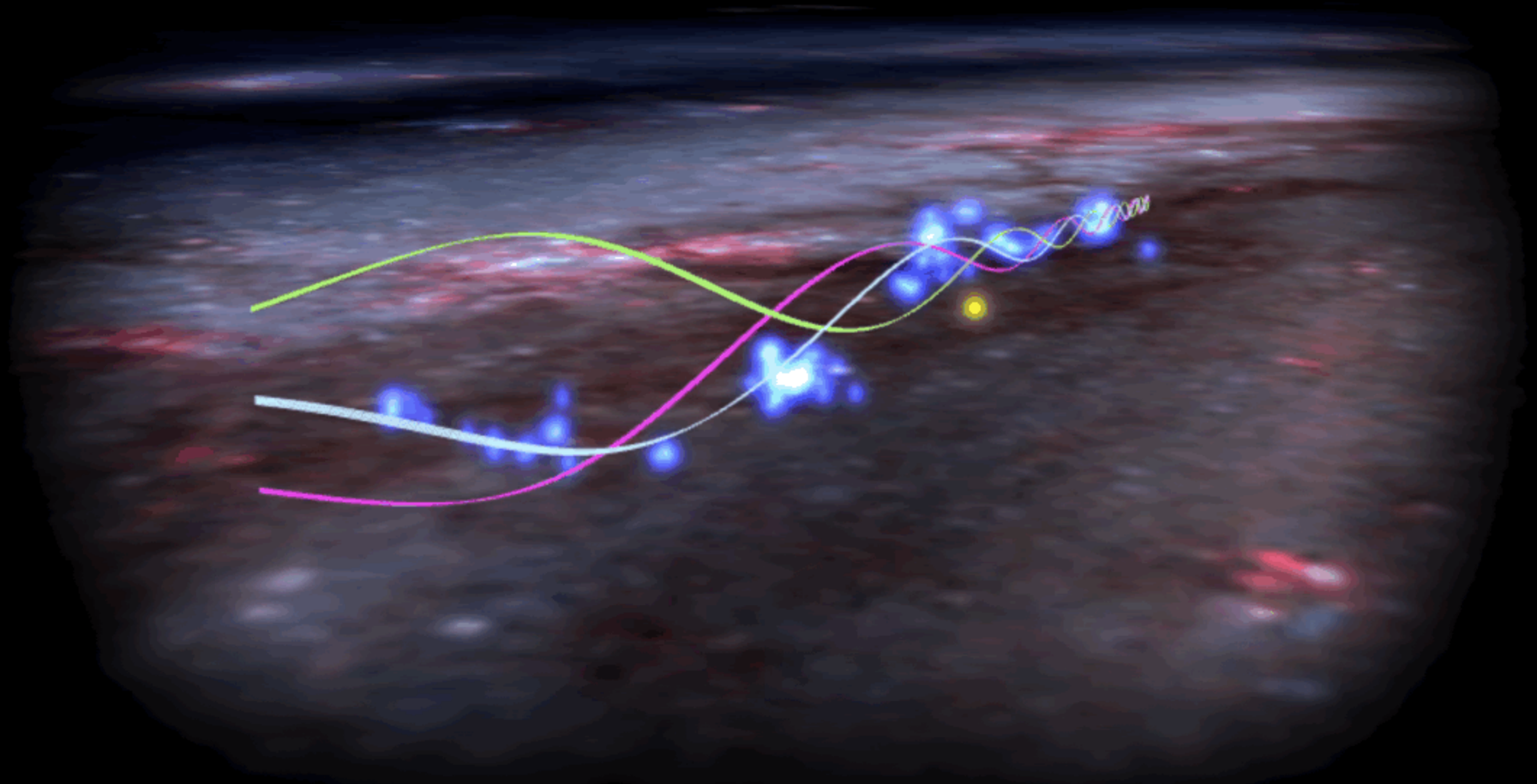
2022: Local Bubble
- astonishing—motivates a full map
- includes MOTIONS

2023: GP map from GE
- makes a full map even more realistic

2024 —RadWave Waving (MOTION)

2024 ++ MilkyWay3D.org Science
Education (AMNH, CosmicDS RadWave)
Infrastructure LIVE-astro.org LIVE-env..org

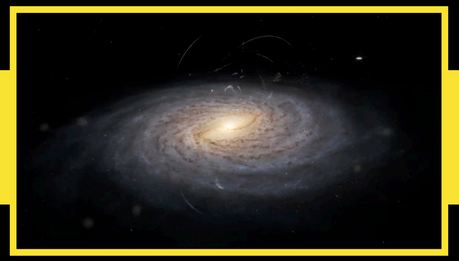
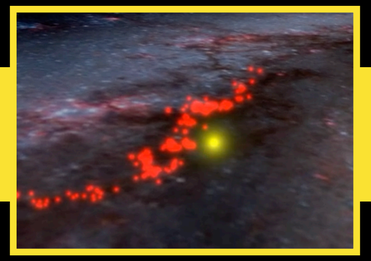
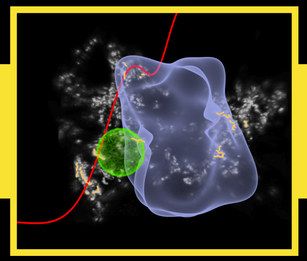
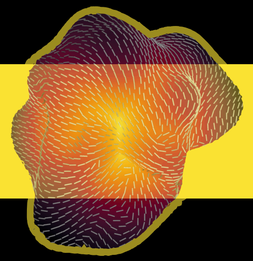
THE RADCLIFFE WAVE IS WAVING



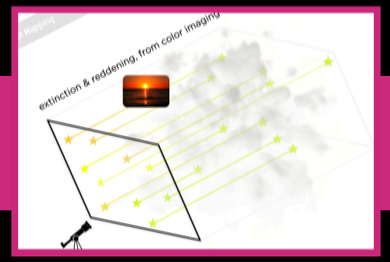
Konietzka et al. 2024, *Nature*, this coming Tuesday (“embargoed”)

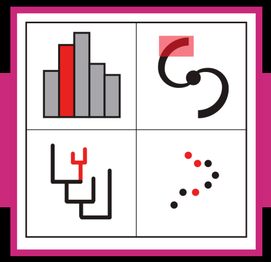
The NEW Milky Way

what it looks like

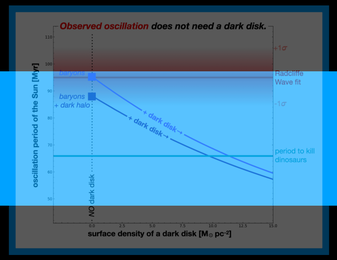





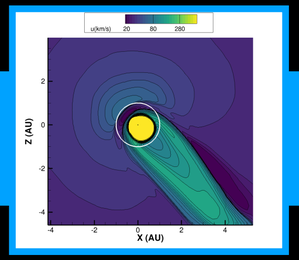
how we know

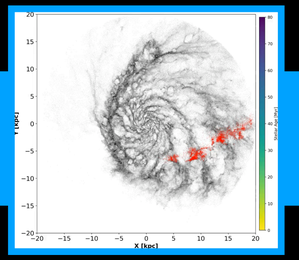


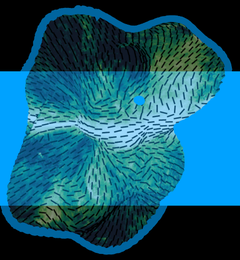


why it matters

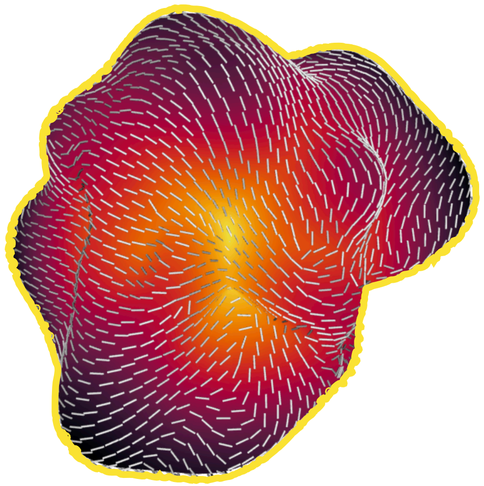








A 3D Map of the Local Bubble's Magnetic Field



Explore Interactive Figures from the paper

Figure 1: Local-to-total Extinction Ratio

Figure 3: 3D Vector Field

Figure 4: Environment

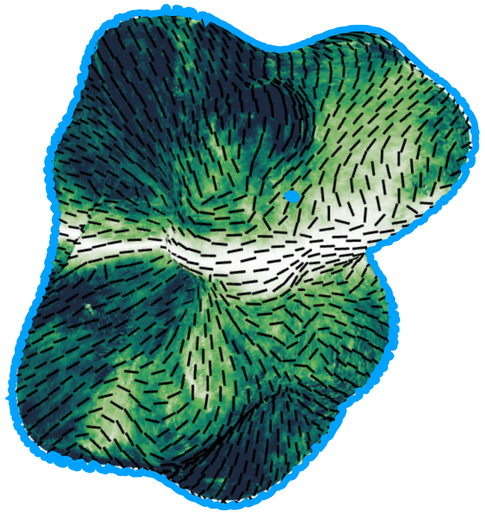
Figure 5: Distance

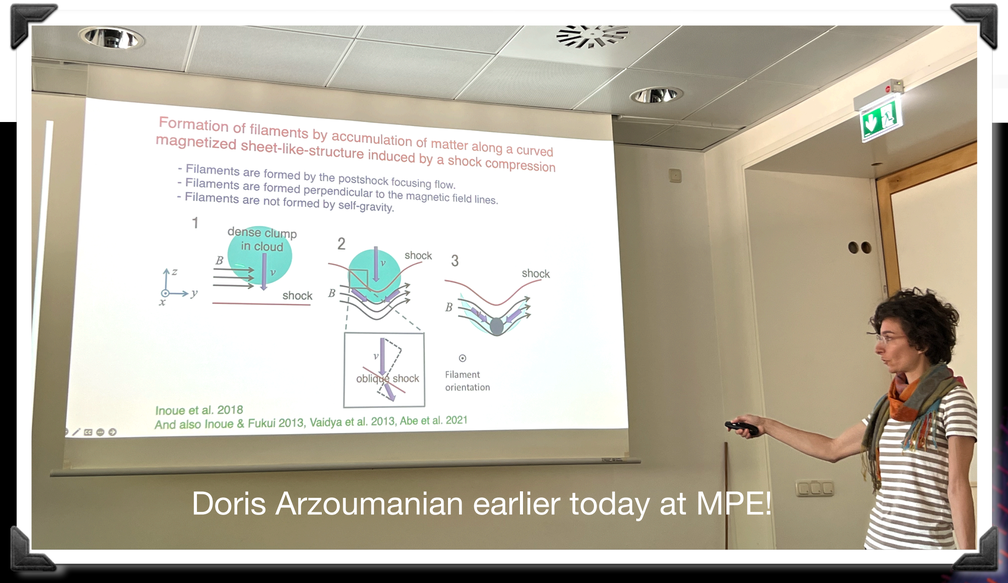
Figure 6: Inclination from plane-of-the-sky, Gamma

Figure 7: Polarization fraction p

Figure 8: Dispersion S

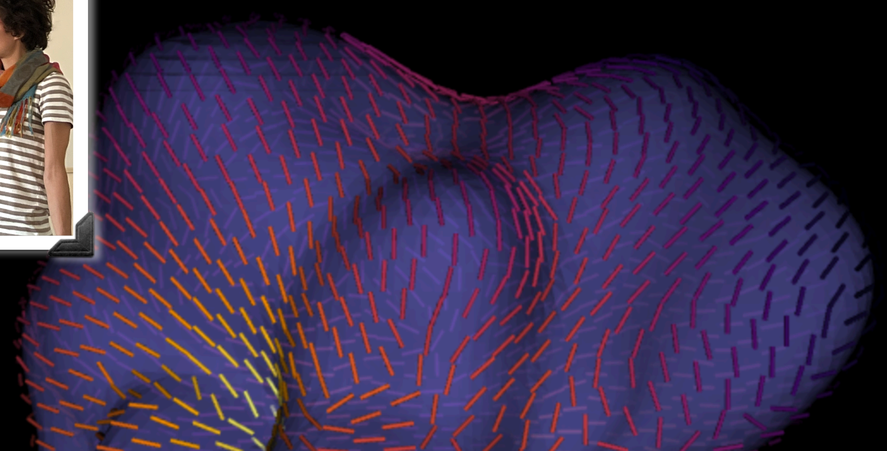
Figure 12: Background Starlight





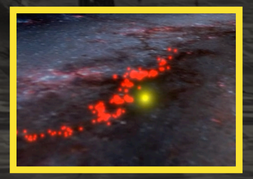
Doris Arzoumanian earlier today at MPE!

https://theo-oneill.github.io/magneticlocalbubble/

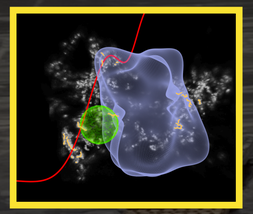


O'Neill et al. 2023

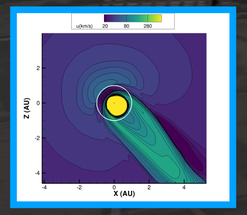
WHAT'S NEW?



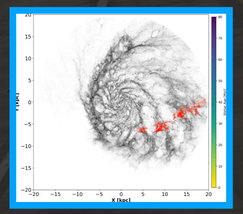
Arms of galaxies (1) look like they "wave," and (2a) they move like that too. (2b) There appears to be almost no dark matter in the Milky Way's disk.)



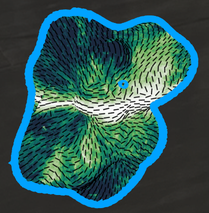
(3a) Feedback from supernovae & winds are as important as theorists said it was 50 years ago, even though observers didn't believe them. (3b) Star forming clouds may largely form at the intersection of feedback bubbles.



(4a) The Sun is "just passing through" our Local Bubble & Earth's (4b, planets') radiation history is determined by this kind of "interstellar weather."

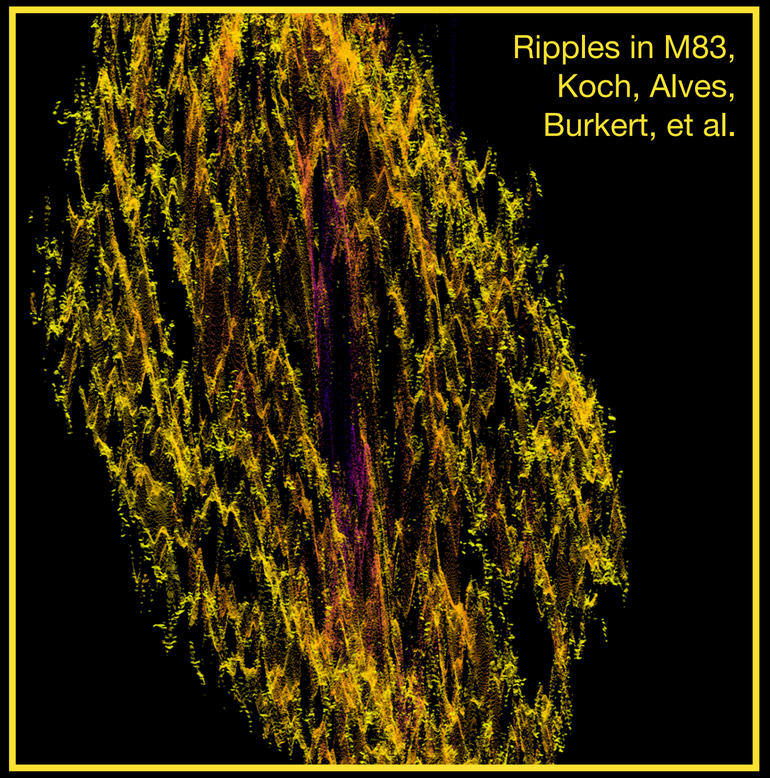


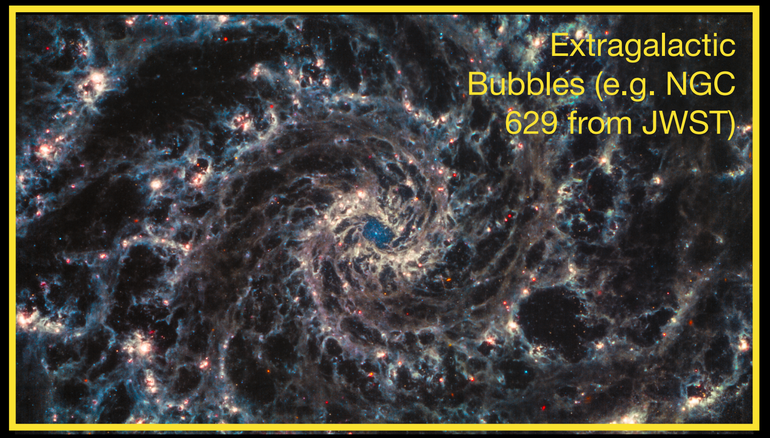
(5) Parts (arms?) of galaxies that appear "near each other" today, did NOT start out that way. Pattern speeds are deceiving.



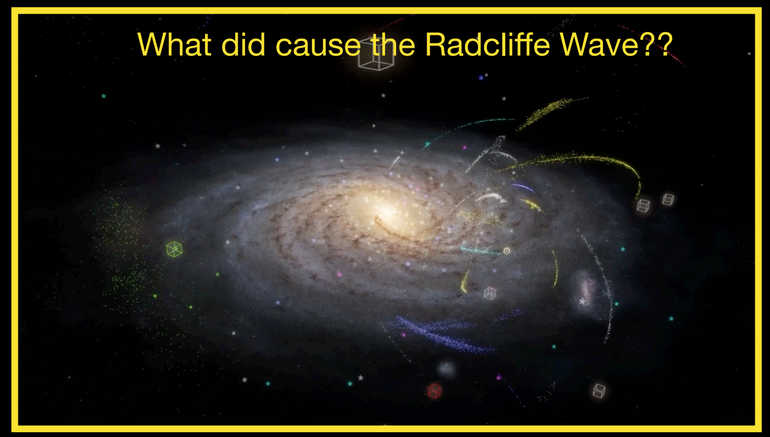
(6) Magnetic fields appear swept-up into feedback bubble's surfaces.

WHAT'S NEXT? (2023 edition)

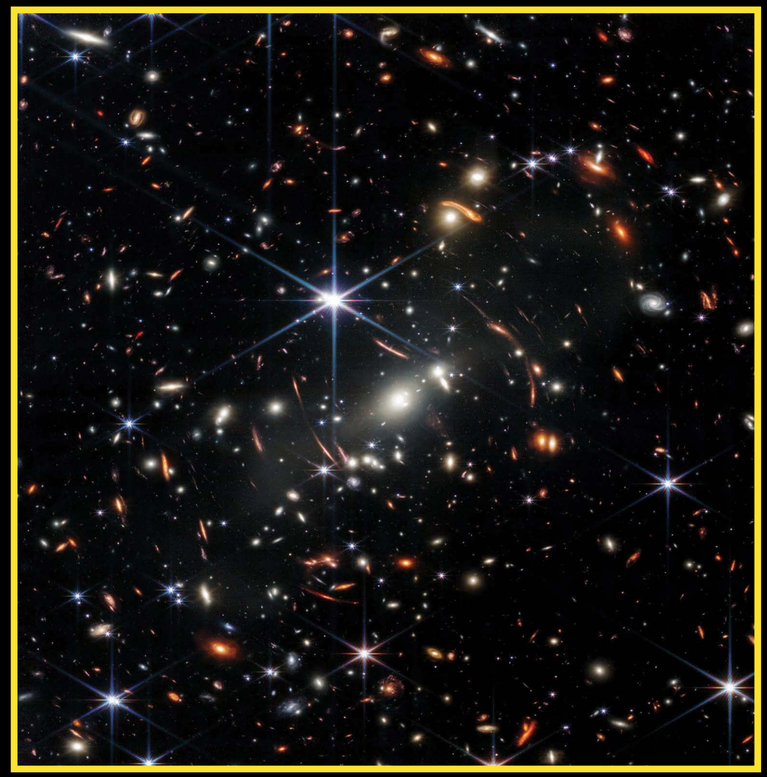




milkyway3d.org (ask me to say more!)

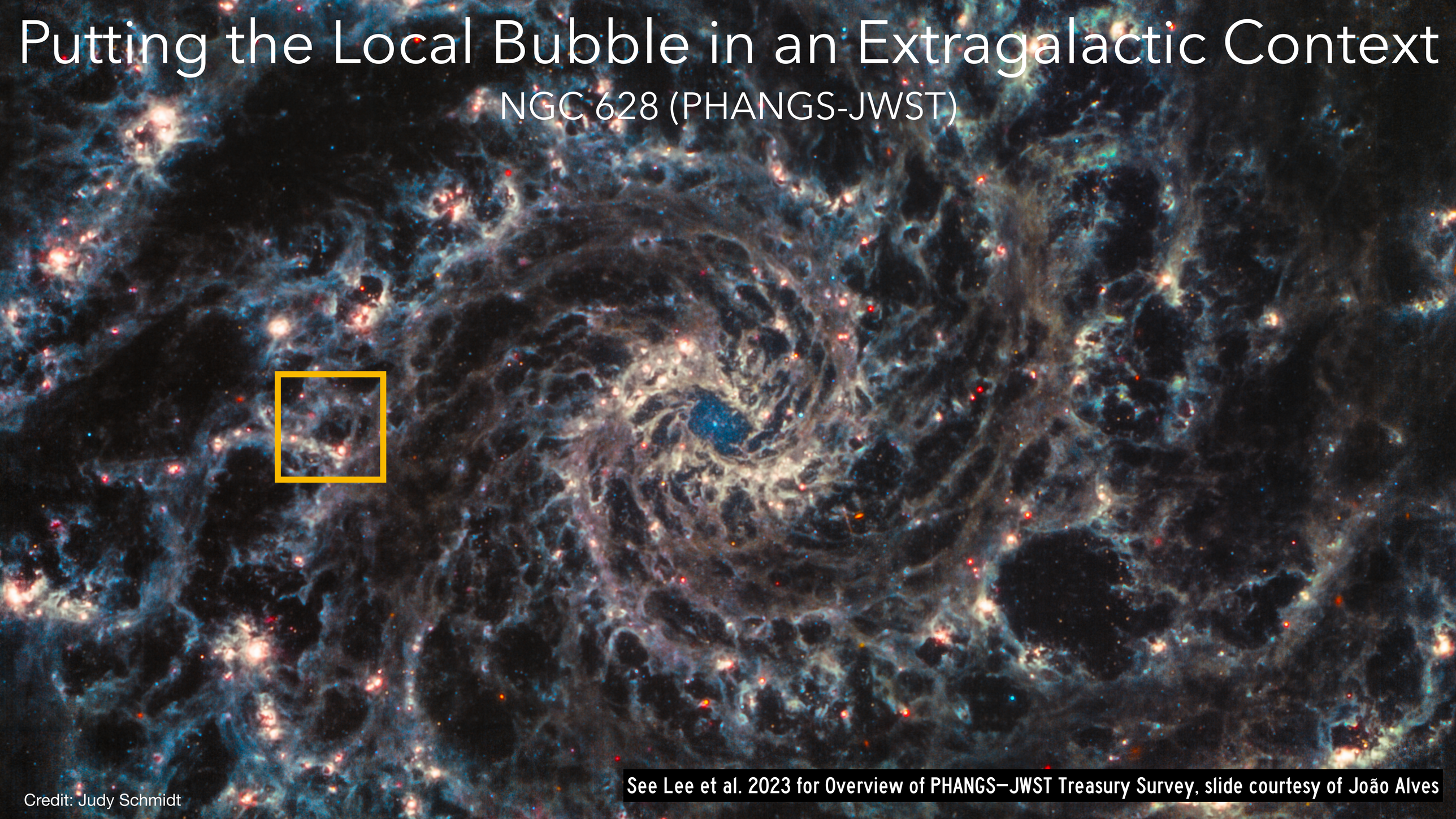


How does a detailed understanding of time-resolved topography of MW stars & gas help extragalactic modeling?



Putting the Local Bubble in an Extragalactic Context

NGC 628 (PHANGS-JWST)



Credit: Judy Schmidt

See Lee et al. 2023 for Overview of PHANGS–JWST Treasury Survey, slide courtesy of João Alves

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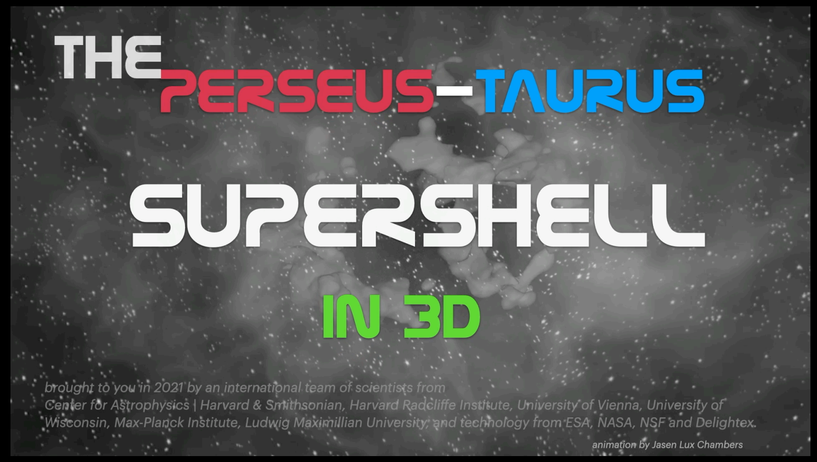
Flying through the "New" Milky Way

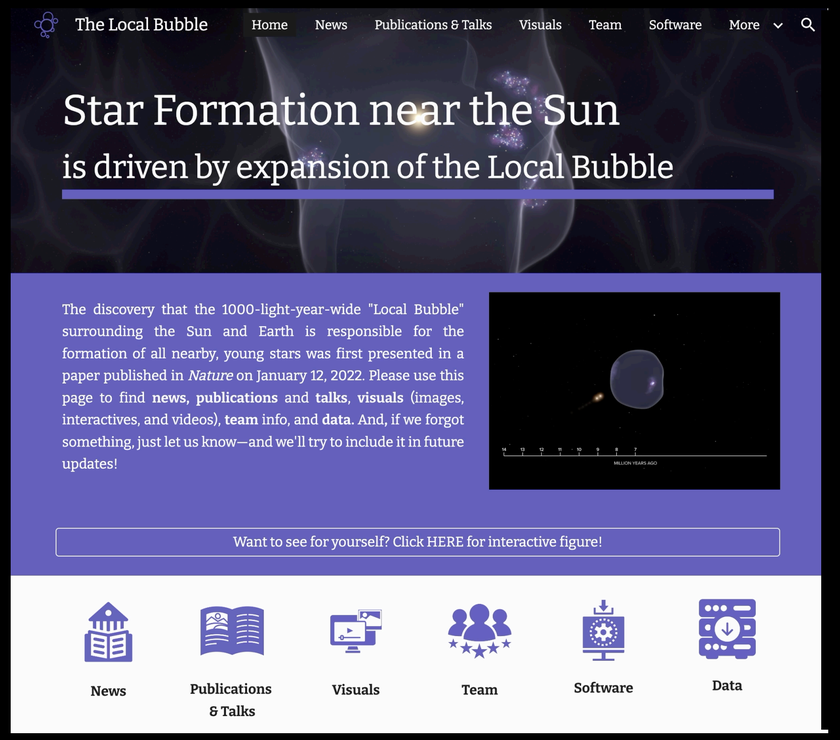
more information about our collaboration at milkyway3D.org

The New Milky Way online
(as of 1/23)

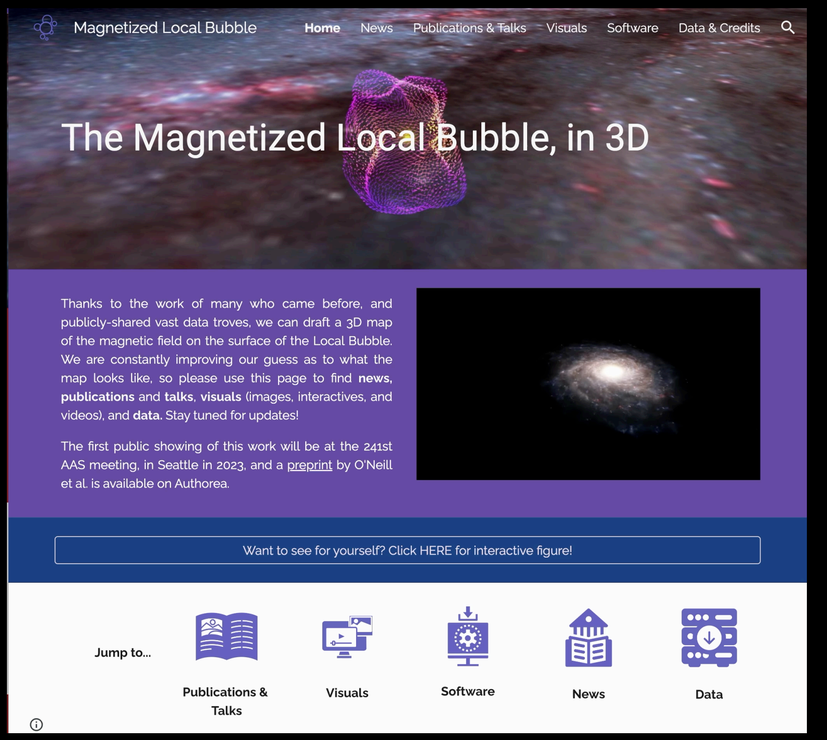
2021



2020

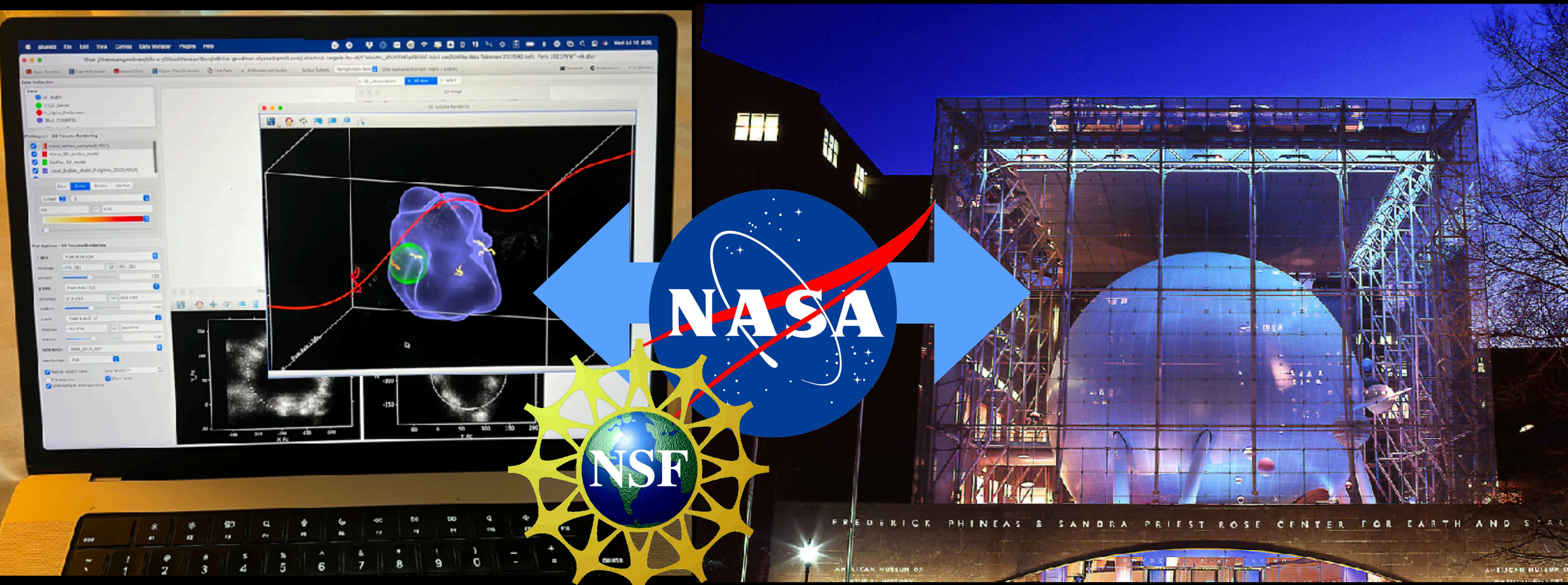


2022



2023 (today!)

H + He
Main Sequence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multidimensional data exploration
OpenSpace
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WORLDWIDE TELESCOPE
NASA
NSF
FREDERICK PHINEAS & SANDRA PRIEST ROSE CENTER FOR EARTH AND

Welcome to a new view of the Milky Way... in 3D!

Soon, milkyway3d.org will serve as a hub for the interconnected set of outreach, education, and research resources that will result from the interconnections we're in the process of making.

Our project includes new software development; approaches to data sharing; and scientific research questions propelling our collaboration forward.

milkyway3D.org

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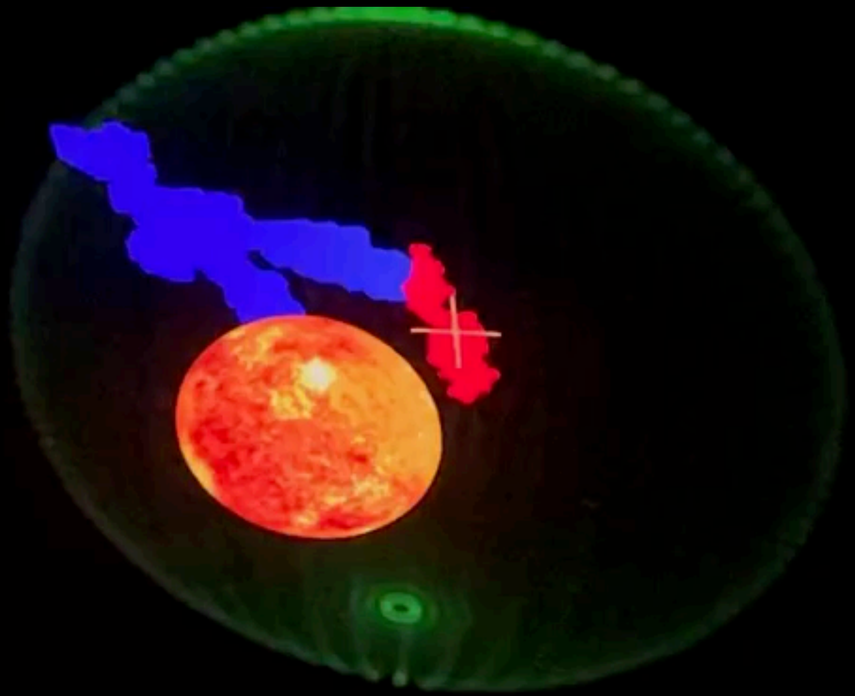
Multidimensional data exploration
OpenSpace



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multidimensional data exploration

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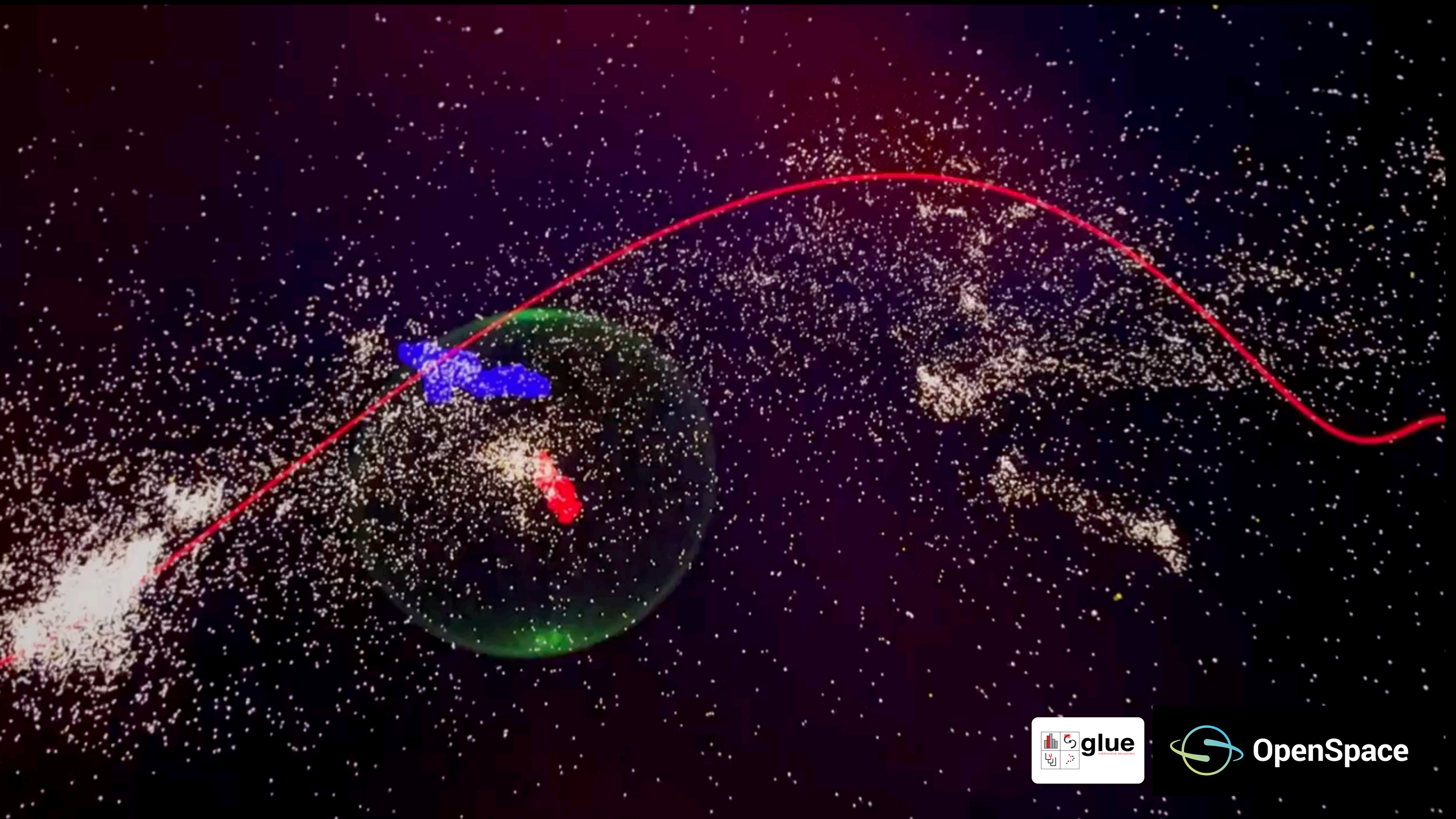
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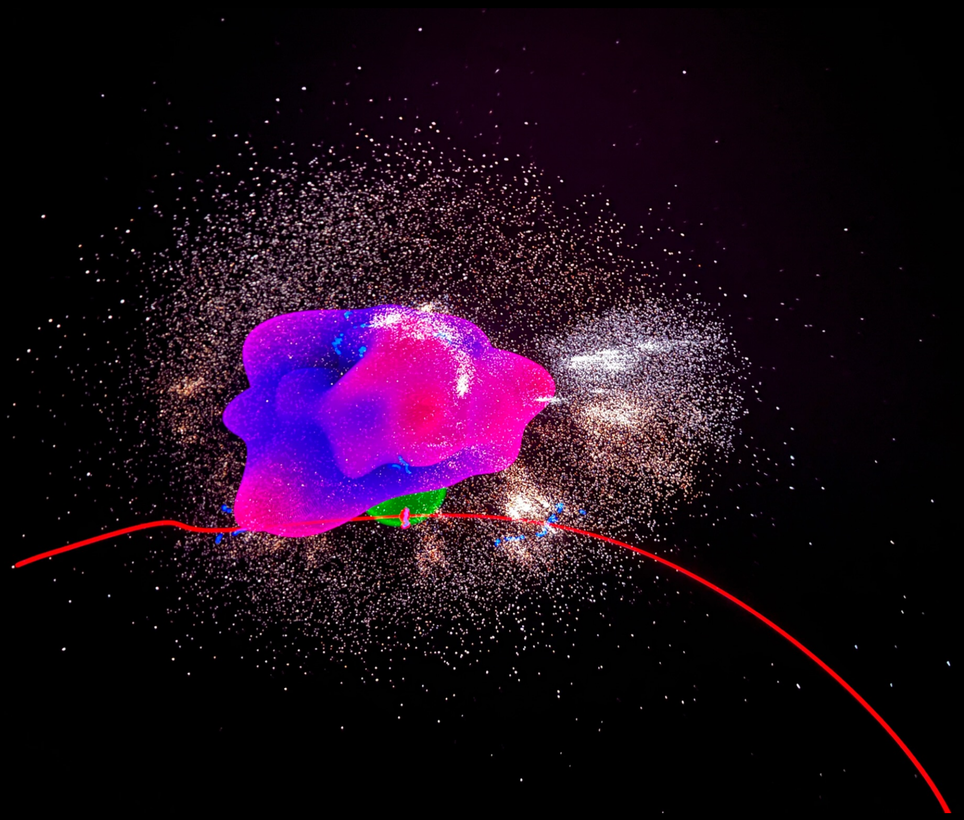

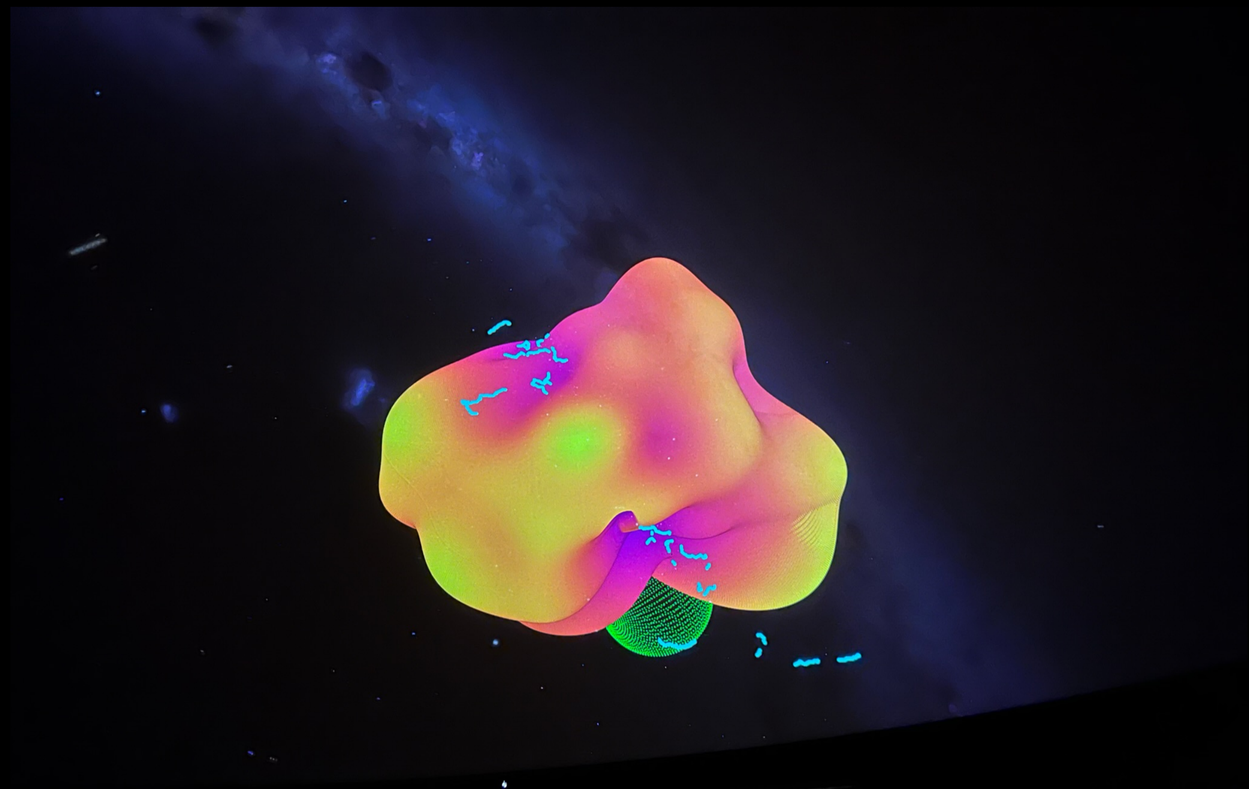

glue
multidimensional data exploration

OpenSpace

***great* 1D, 2D** and **3D** data manipulation, flexible architecture facilitating plug-ins, data transfer, and interactive data exploration; "glupyter" flavor runs in web pages

glue
multidimensional data exploration

CosmicDS

plug-in in-use on Hayden Planetarium dome

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plug-in shows WWT images in context in 3.

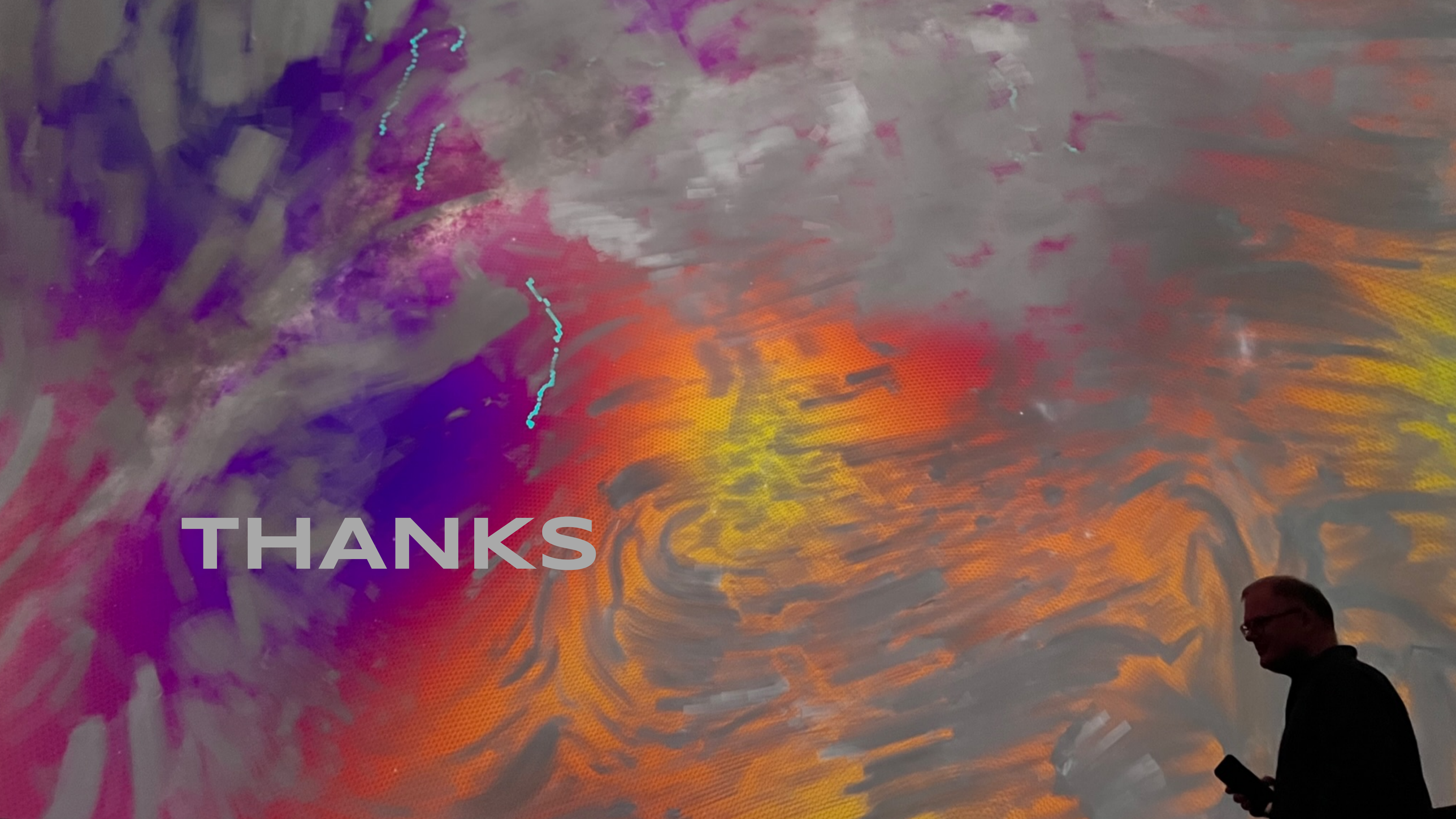
OpenSpace

***great* 2D** object and all-sky images
limited 3D functionality

limited 2D all-sky images
***great* 3D** functionality

The "Perseus-Taurus Superbubble"
a demo of the need for 2D-3D contextualization functionality

This video was composited using the WWT and OpenSpace, making some use of prototype plug-ins, but 2D and 3D imagery was aligned manually by experts. As a generalizable STEM concept, it explains the deceptive "forced perspective" made possible in when objects at very different distances, in 3D, appear to touch in 2D.


THANKS