

Galactic Archaeology : The Story of our Cosmic Home

Keith Hawkins (UT Austin)
Hot Science, Cool Talks (HSCT)



Where is our Cosmic Home?

Milky Way

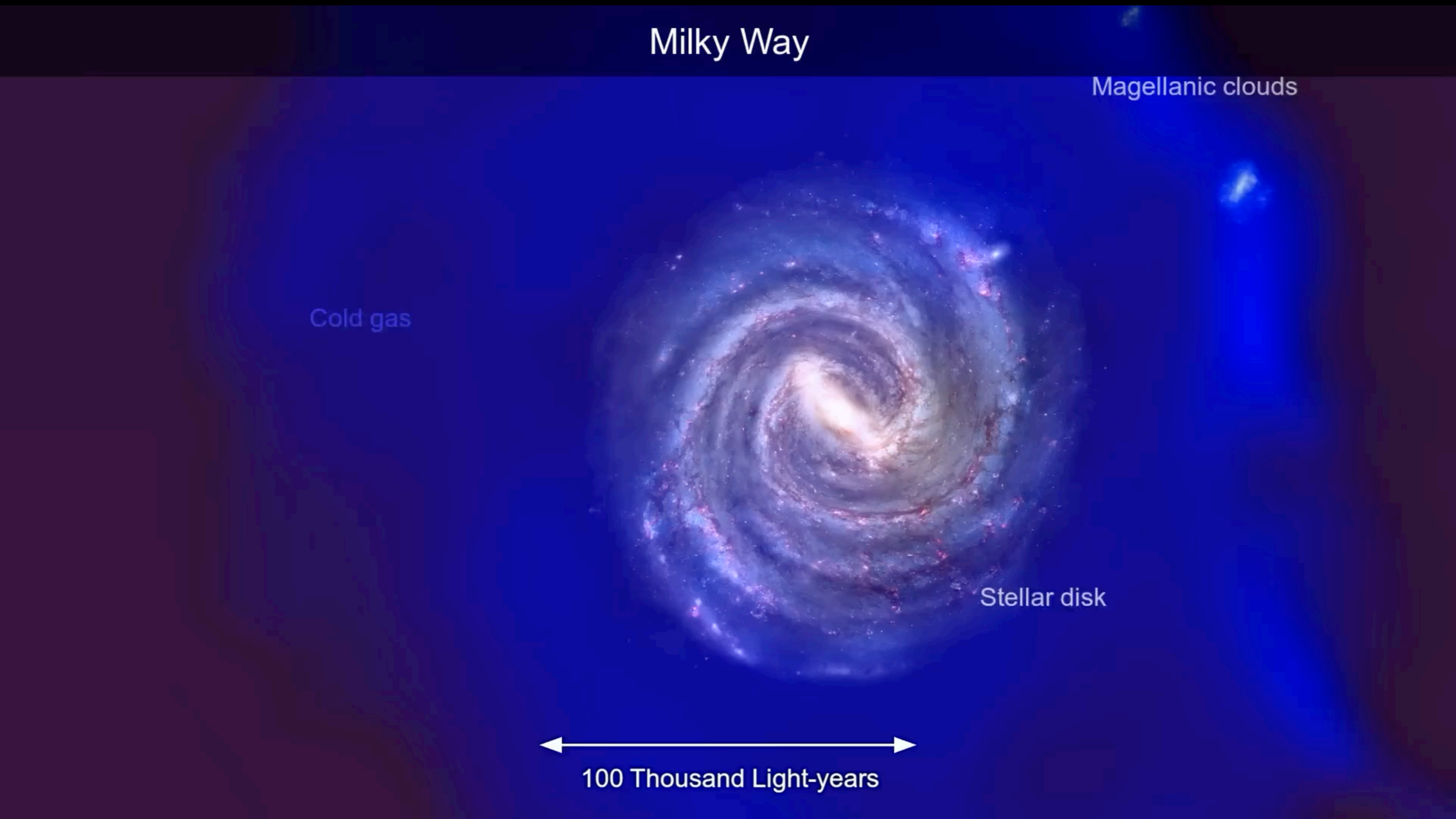
Magellanic clouds

Cold gas

Stellar disk



100 Thousand Light-years



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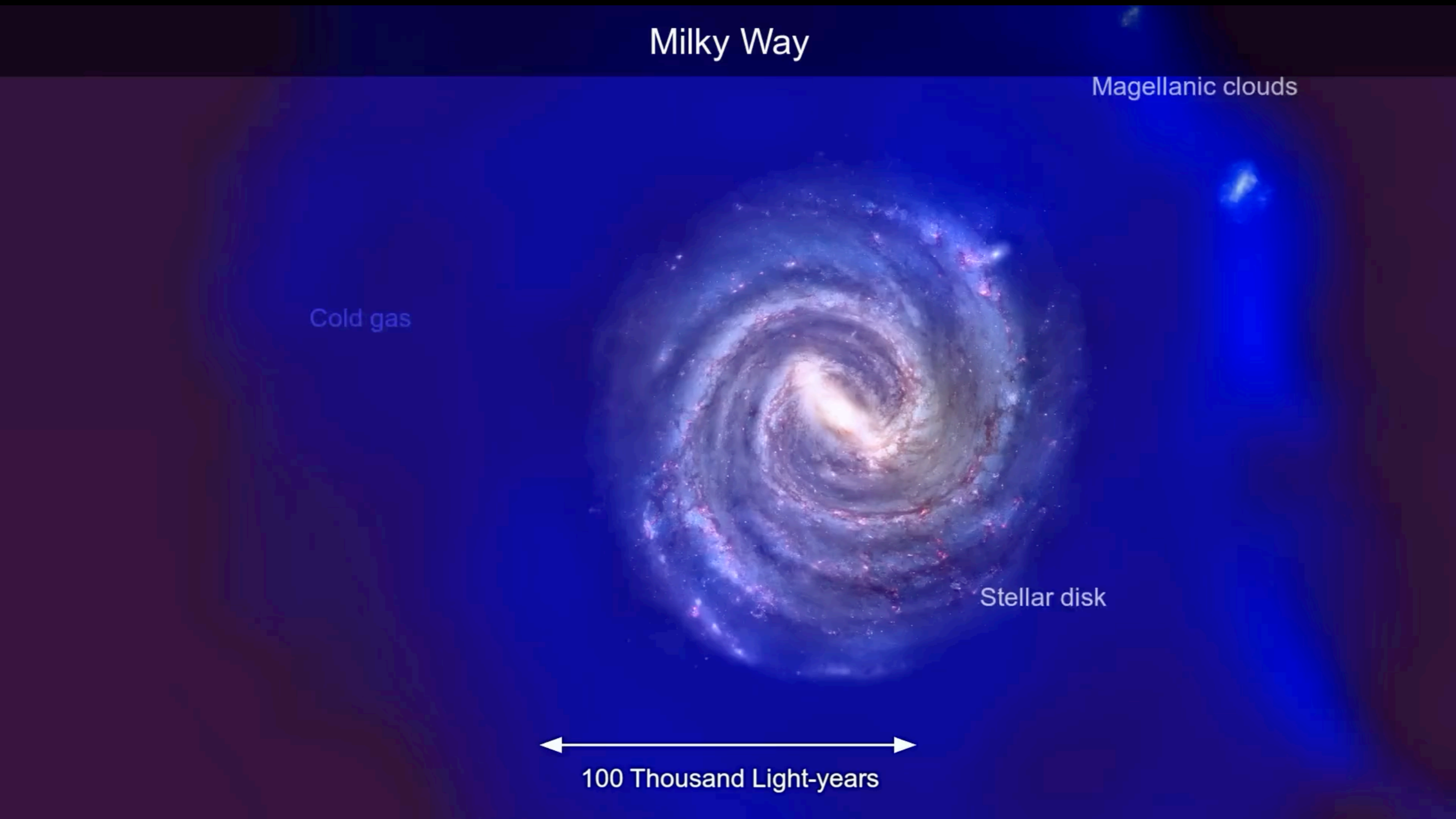
Magellanic clouds

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What is the story of our Cosmic Home?



Note: Artists impression of our cosmic home... be thinking is this artist impression real?





Stars



Stars



Dust



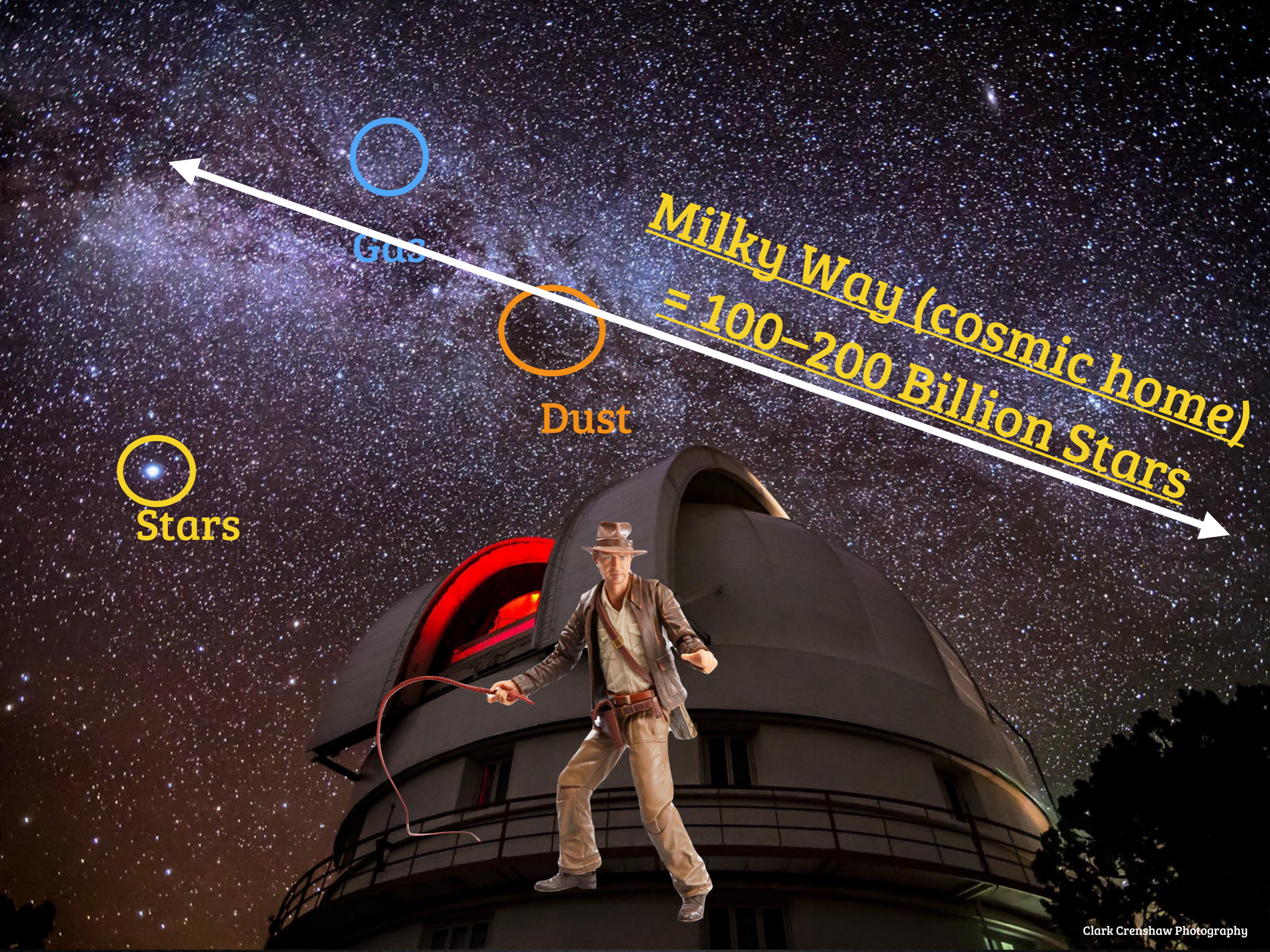
Gas



Dust



Stars



**Im curious... about so many aspects of our
cosmic home**



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How do galaxies in the universe form?

Im curious... about so many aspects of our cosmic home

How do galaxies in the universe form?

How did our Galaxy and its stars form ?

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How do galaxies in the universe form?

How did our Galaxy and its stars form ?

How did our Galaxy assemble and evolve?

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How is our Galaxy structured?

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How does our Galaxy make planets (outside our solar system) and what are they made of ?

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How does our Galaxy make planets (outside our solar system) and what are they made of ?

These are the questions that drive me!

Like any (good?) scientist ...



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**These questions can be answered through the scientific
method**

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- **Question —>**

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- **Hypothesis —>**

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This sounds so “middle school”... but training our students at the graduate+ level to do this is KEY!

So lets start with one of these questions



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How is our Galaxy structured?

So lets start with one of these questions

How is our Galaxy structured?

Not trivial b/c we live inside the Galaxy

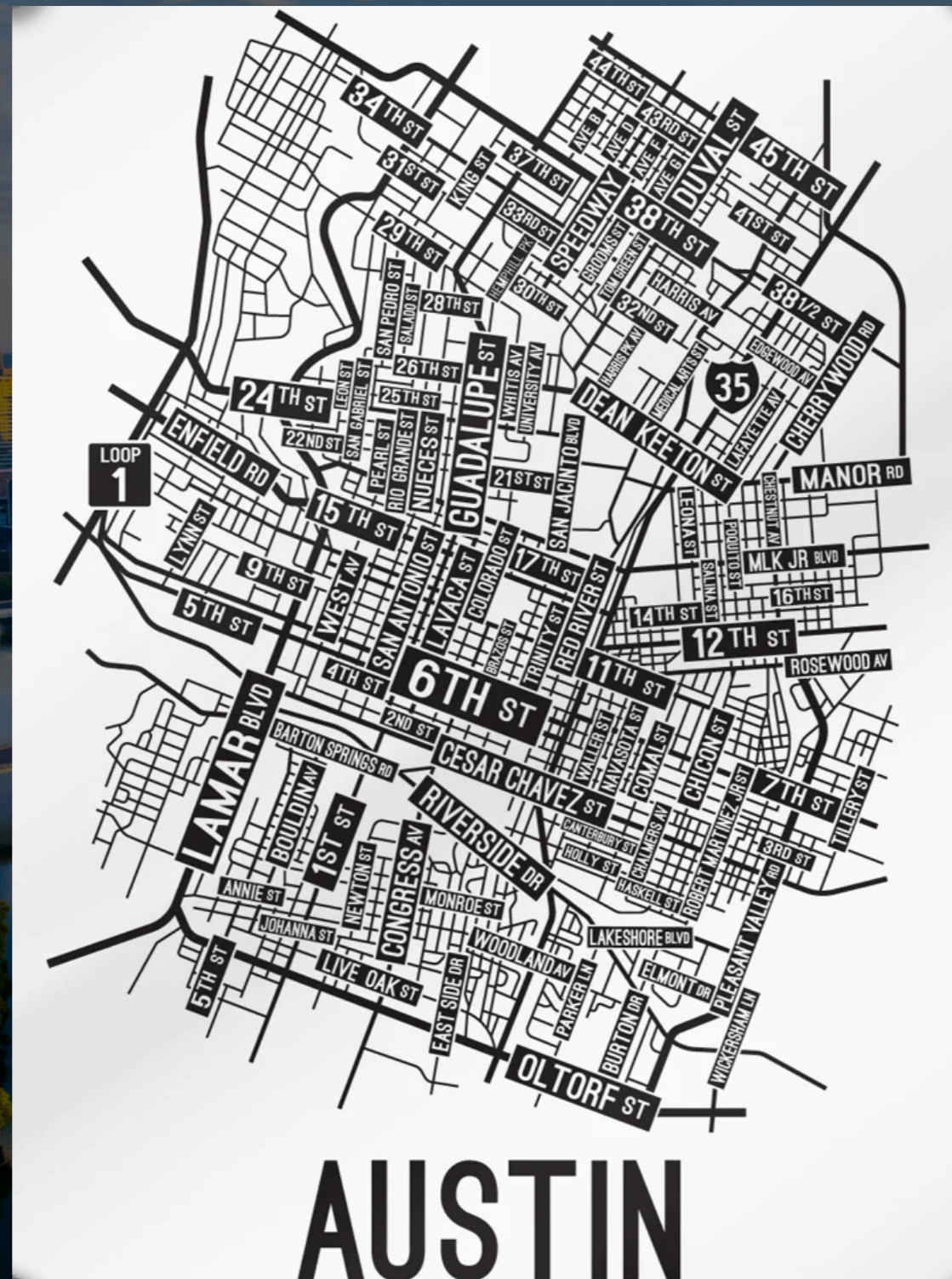
A Terrestrial Example of this Question

Can you draw a map of (downtown) Austin?



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How is our Galaxy structured?

The next thing to do in the Scientific method is too ...

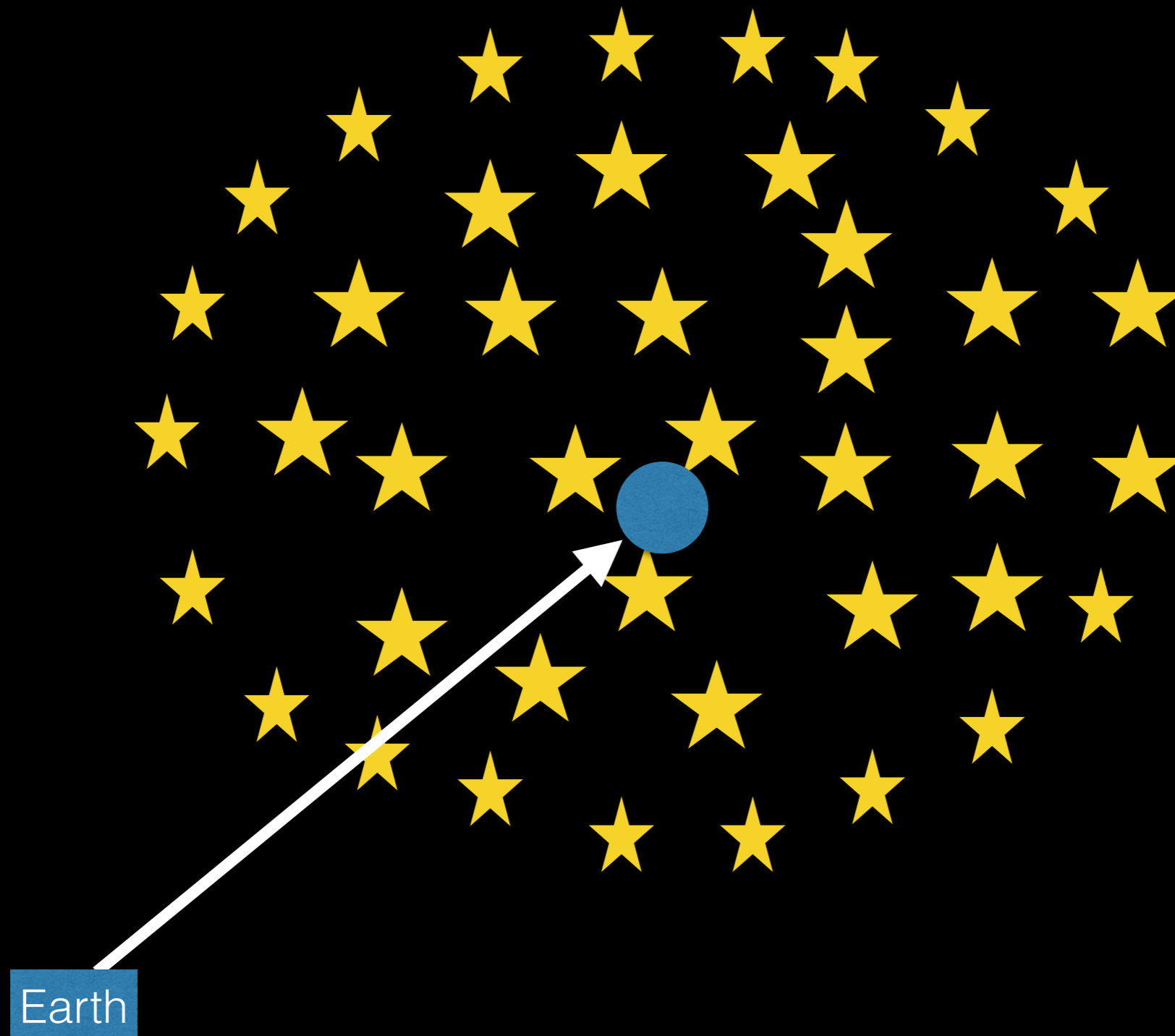
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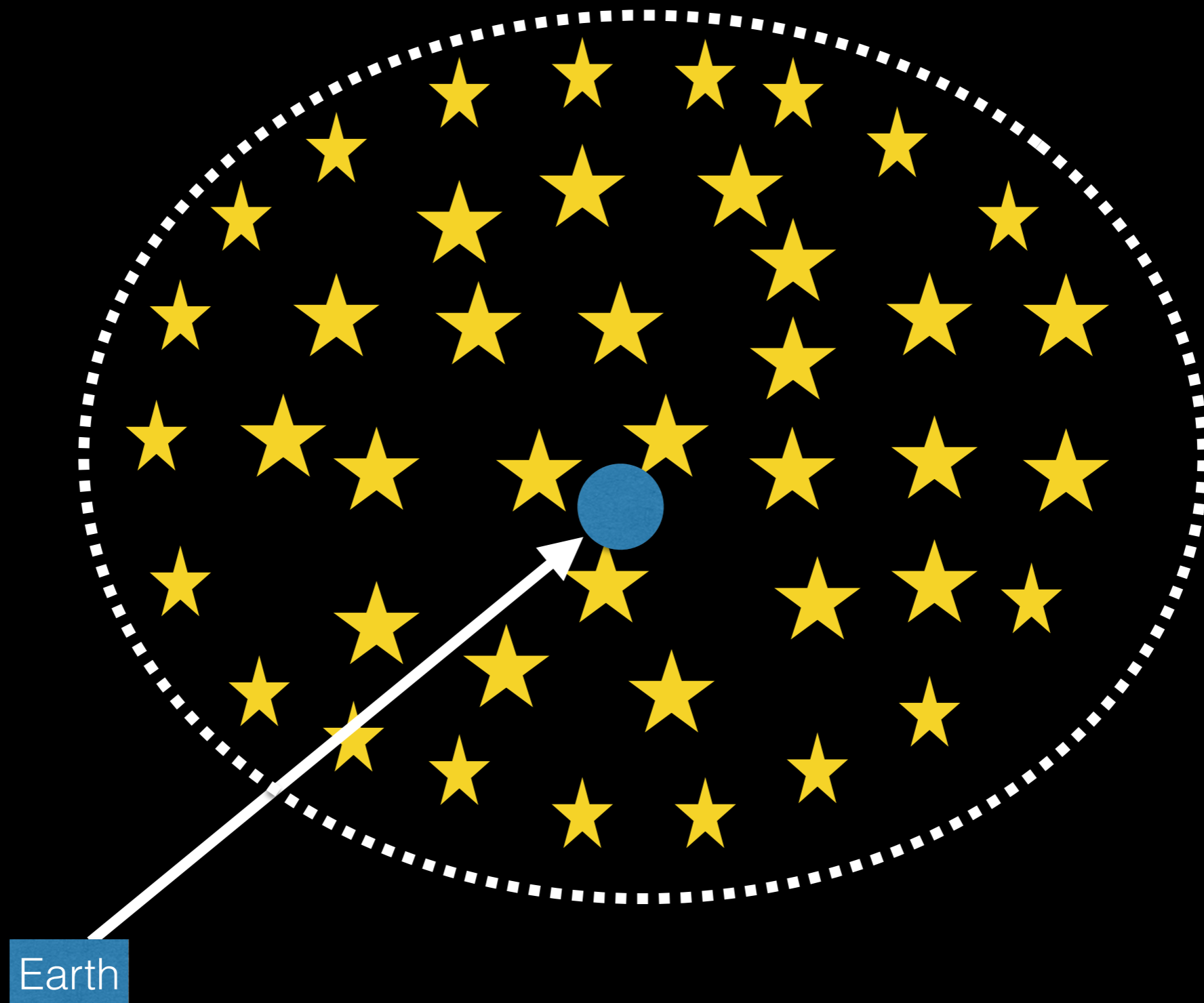
The next thing to do in the Scientific method is too ...

Make a hypothesis

Hypothesis 1: The Milky Way is a “ball” of stars (elliptical galaxy)



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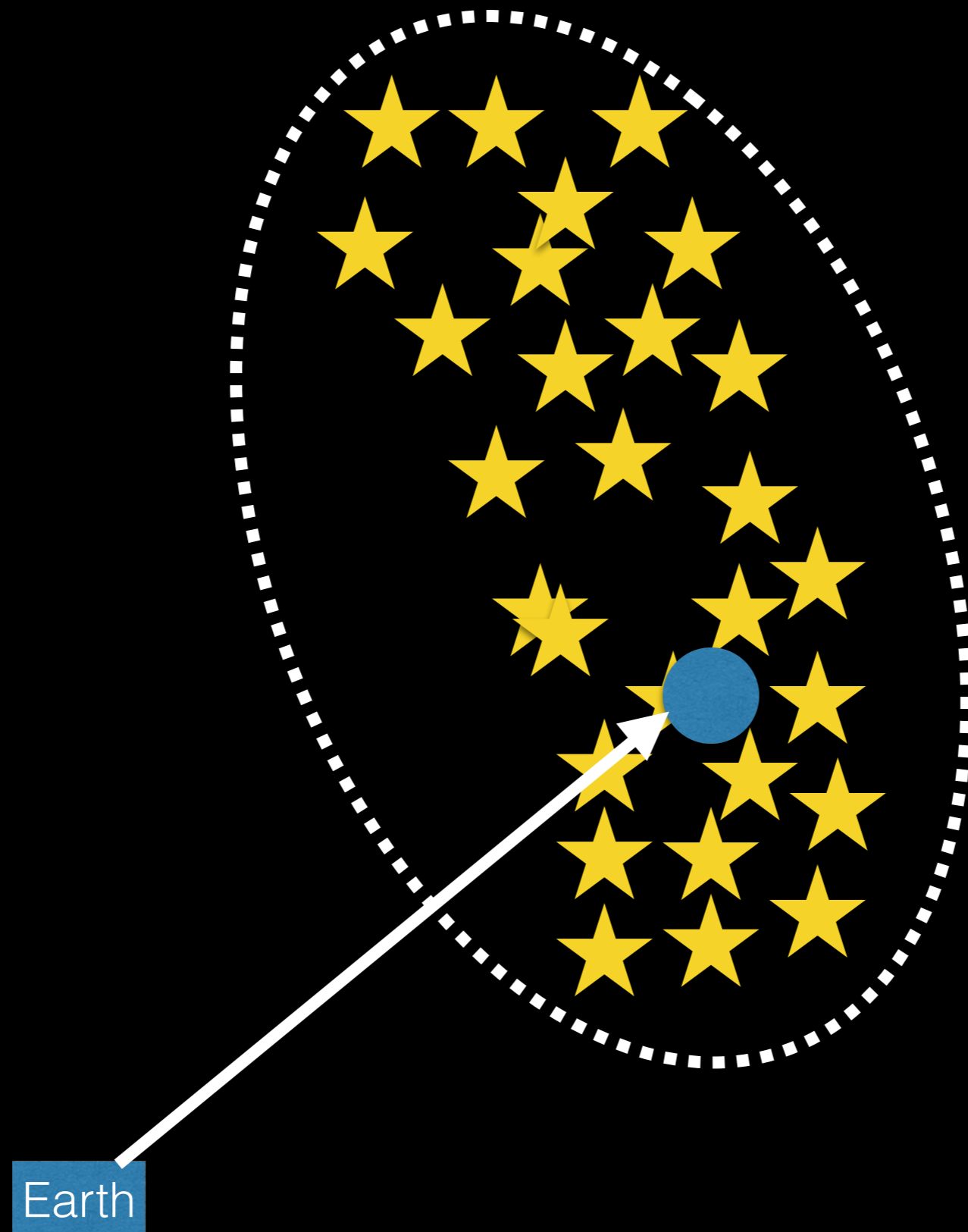
Hypothesis 1: The Milky Way is a ball of stars



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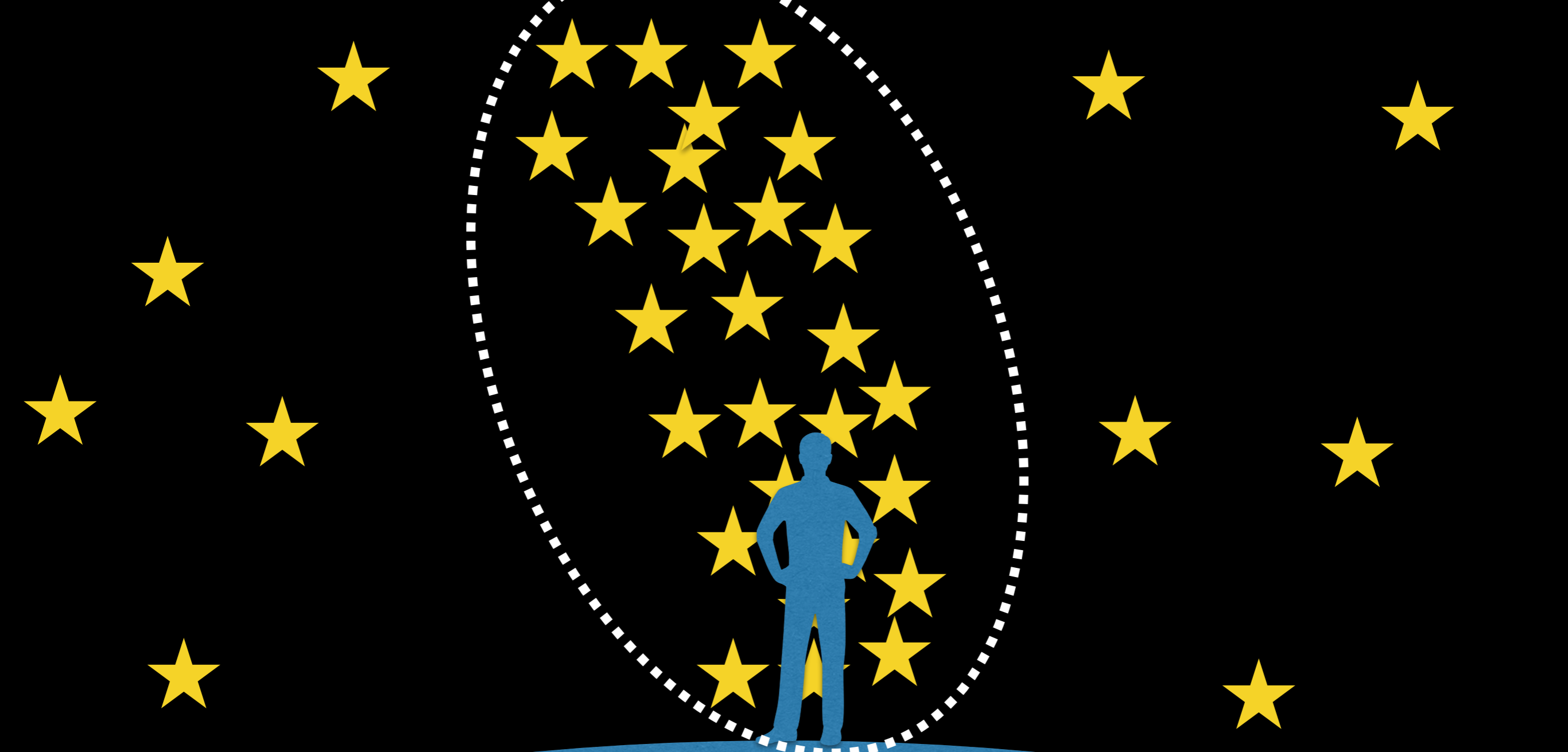
Prediction 1: If we sit inside the “ball of stars” and look up from the Earth we will see roughly equal numbers of stars in all directions

Hypothesis 2: The Milky Way is a disk of stars (spiral galaxy)

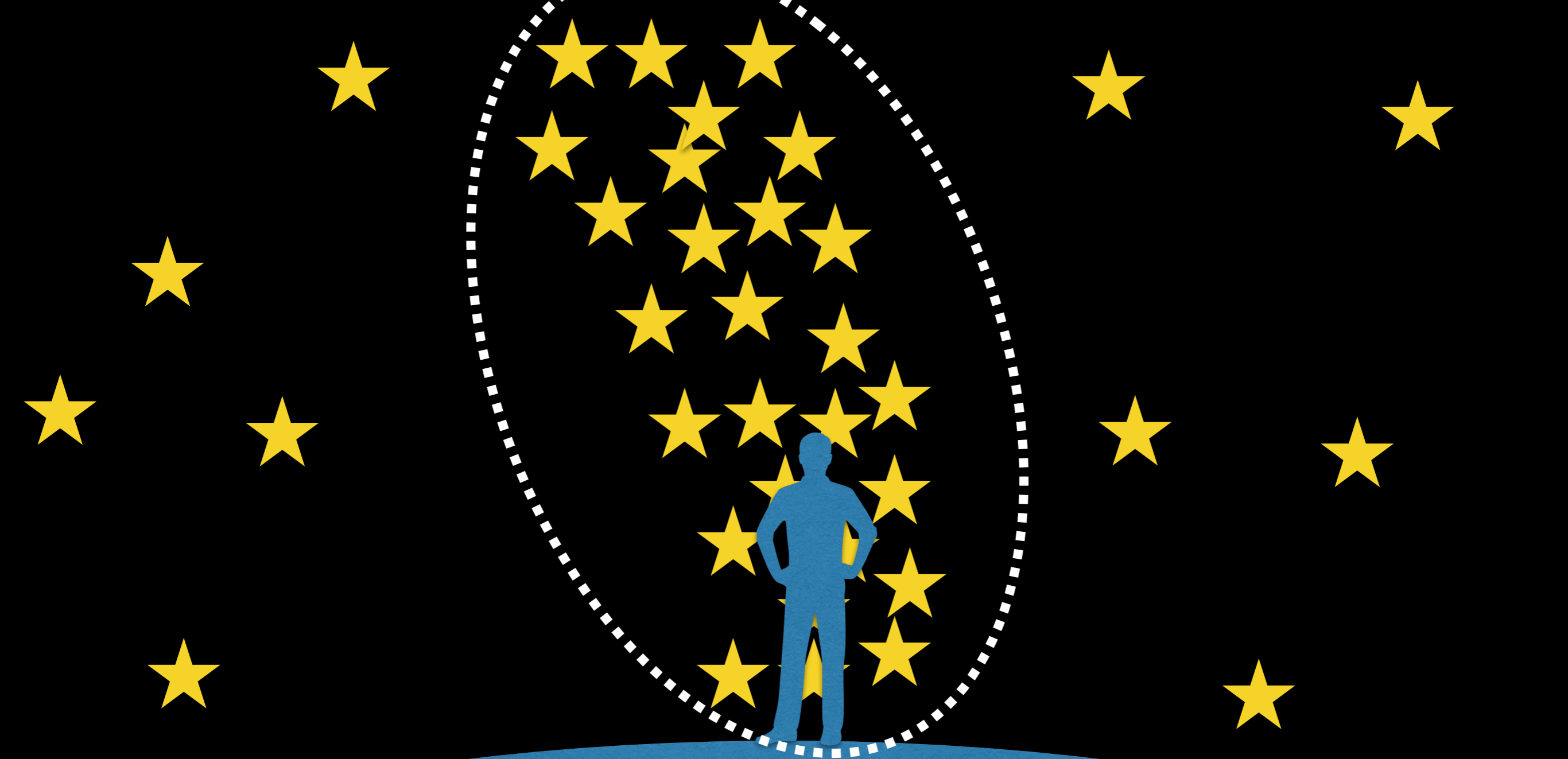




Hypothesis 2: The Milky Way is a disk of stars



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Hypothesis 2: The Milky Way is a disk of stars

Prediction 2: If we sit inside the “disk of stars” and look up from the Earth, we will see stars concentrated along the “disk” of the galaxy

**Let's make an observation from West
Texas... what do we learn?**




Hypothesis 2 ✓ (the milky way has a disk of stars)



**Let's make an observation from the
Southern Hemisphere... what do we
learn?**





Hypothesis 2 
(the milky way has
a disk of stars)



Hypothesis 1 ✓
(the old 'bulge' of
the MW is a ball of
stars)

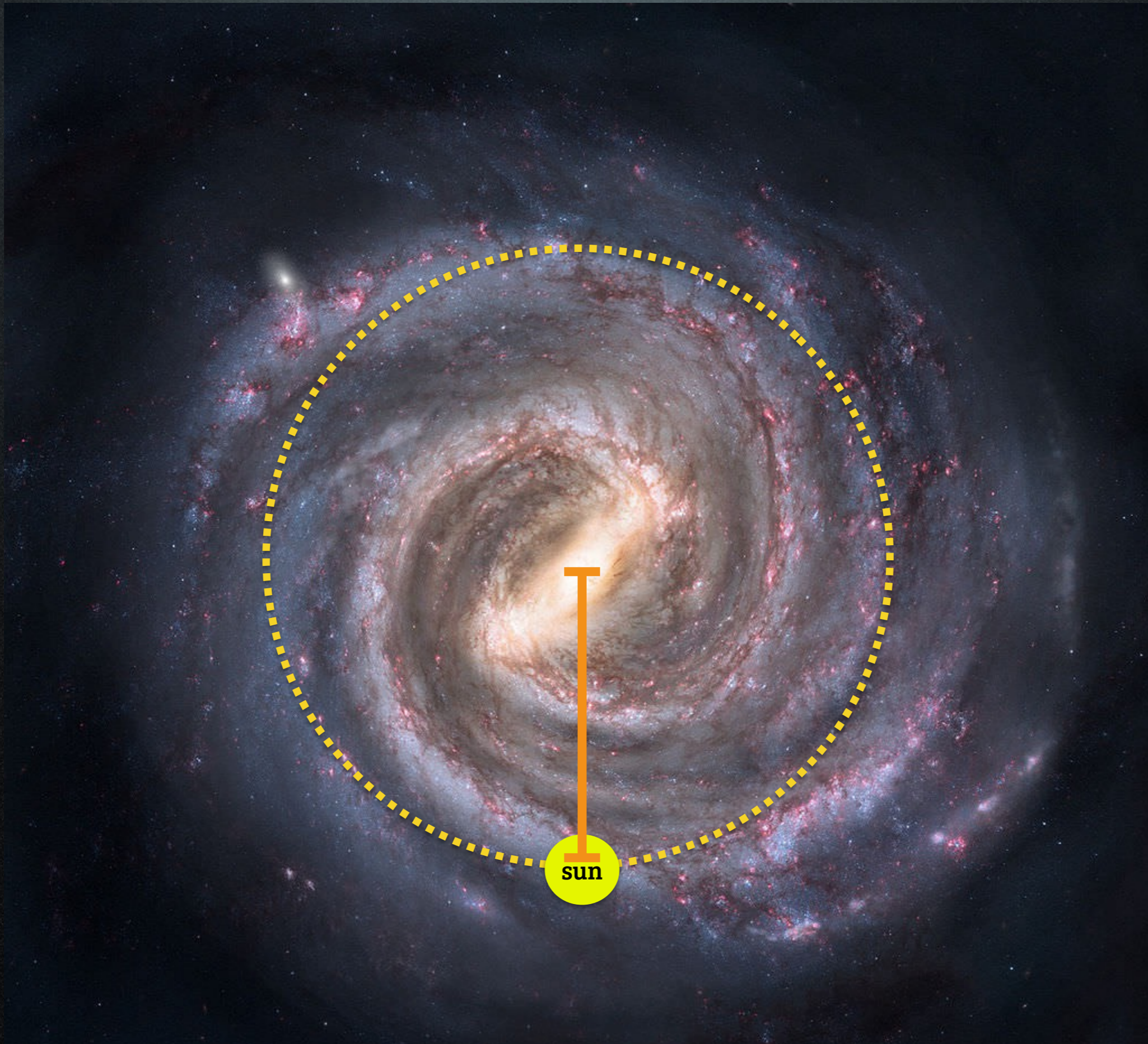
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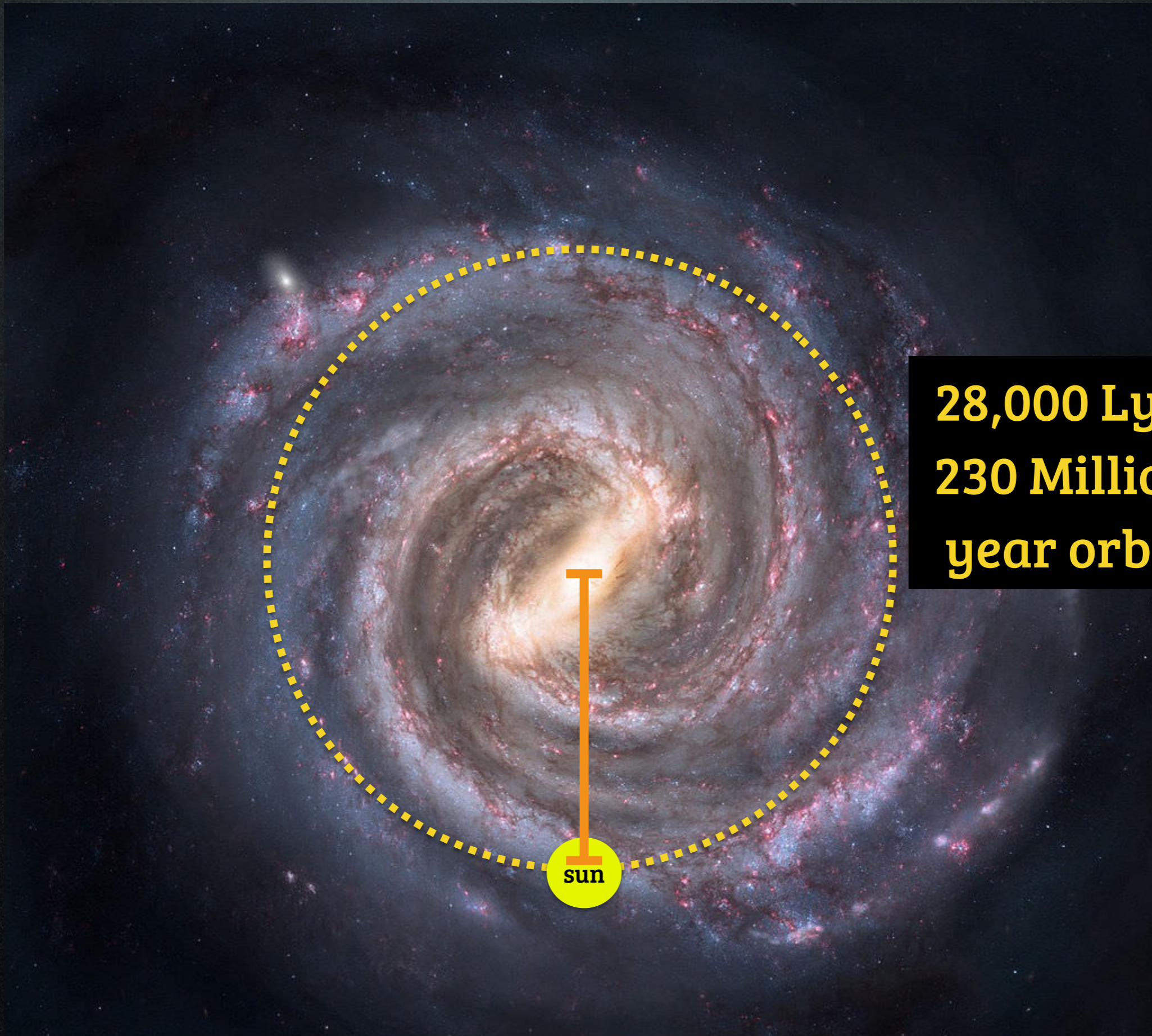
Anatomy of our Cosmic Home: Barred Spiral Galaxy



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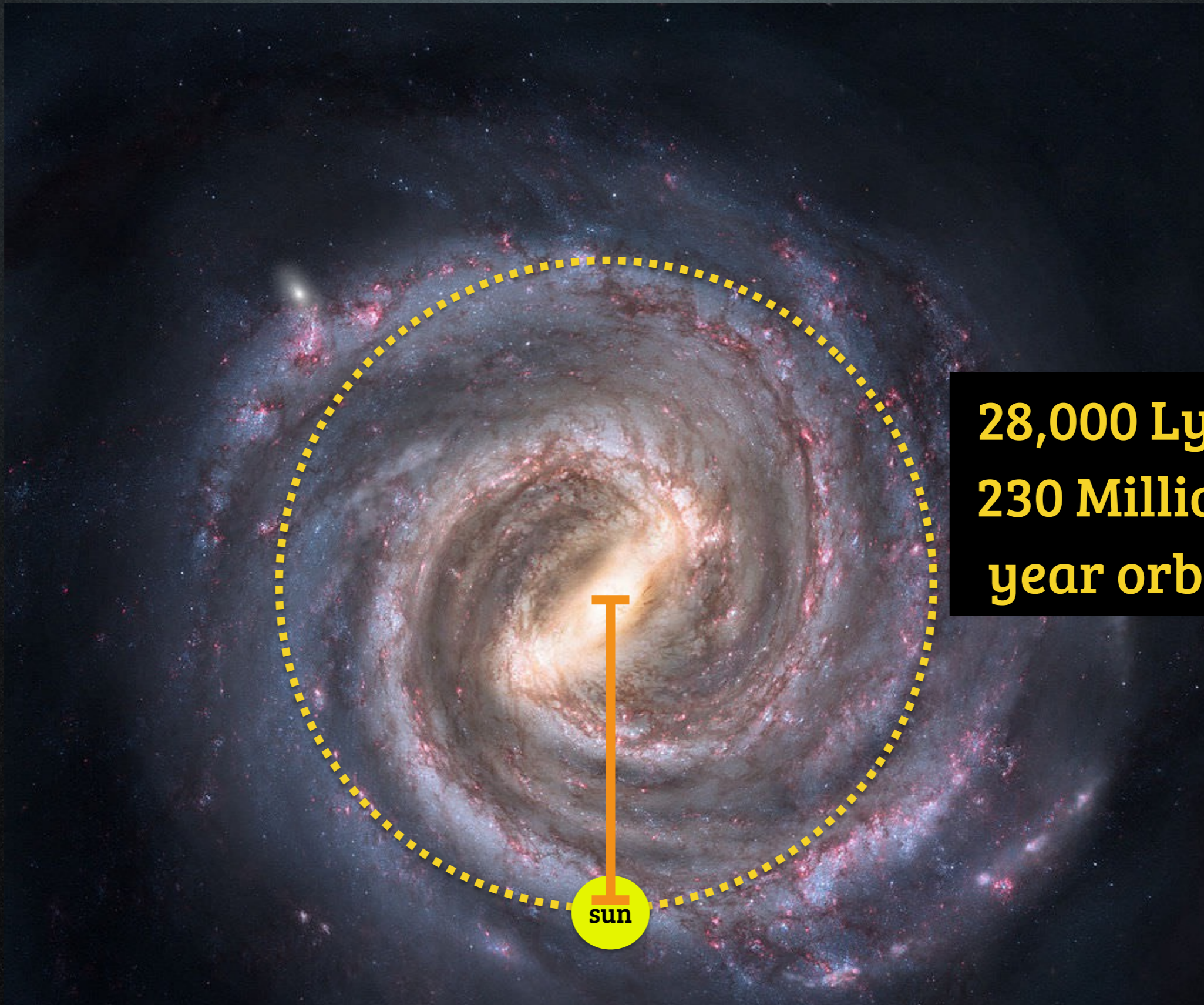
Anatomy of our Cosmic Home: Barred Spiral Galaxy



**28,000 Lyr;
230 Million
year orbit**

sun

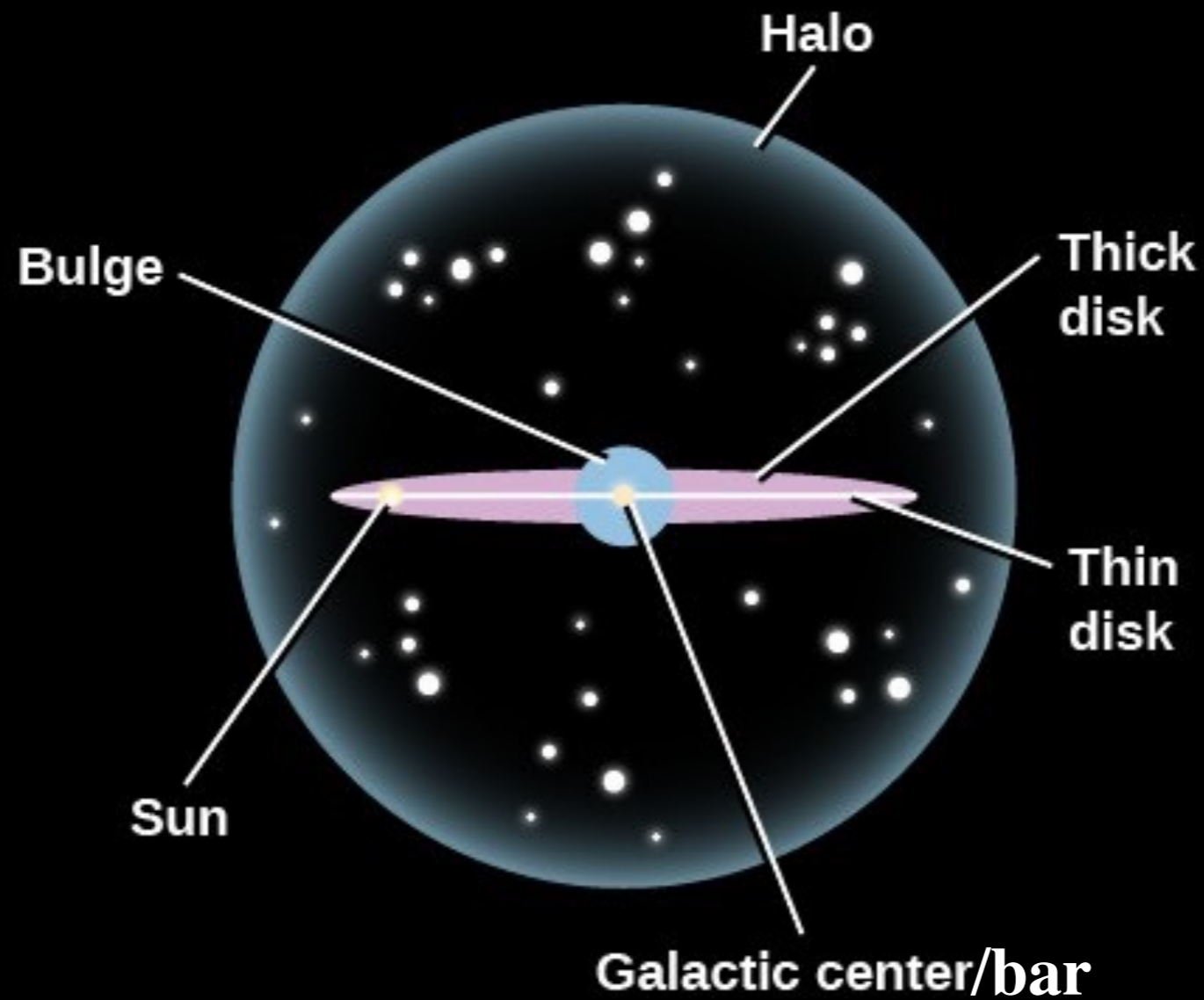
Anatomy of our Cosmic Home: Barred Spiral Galaxy



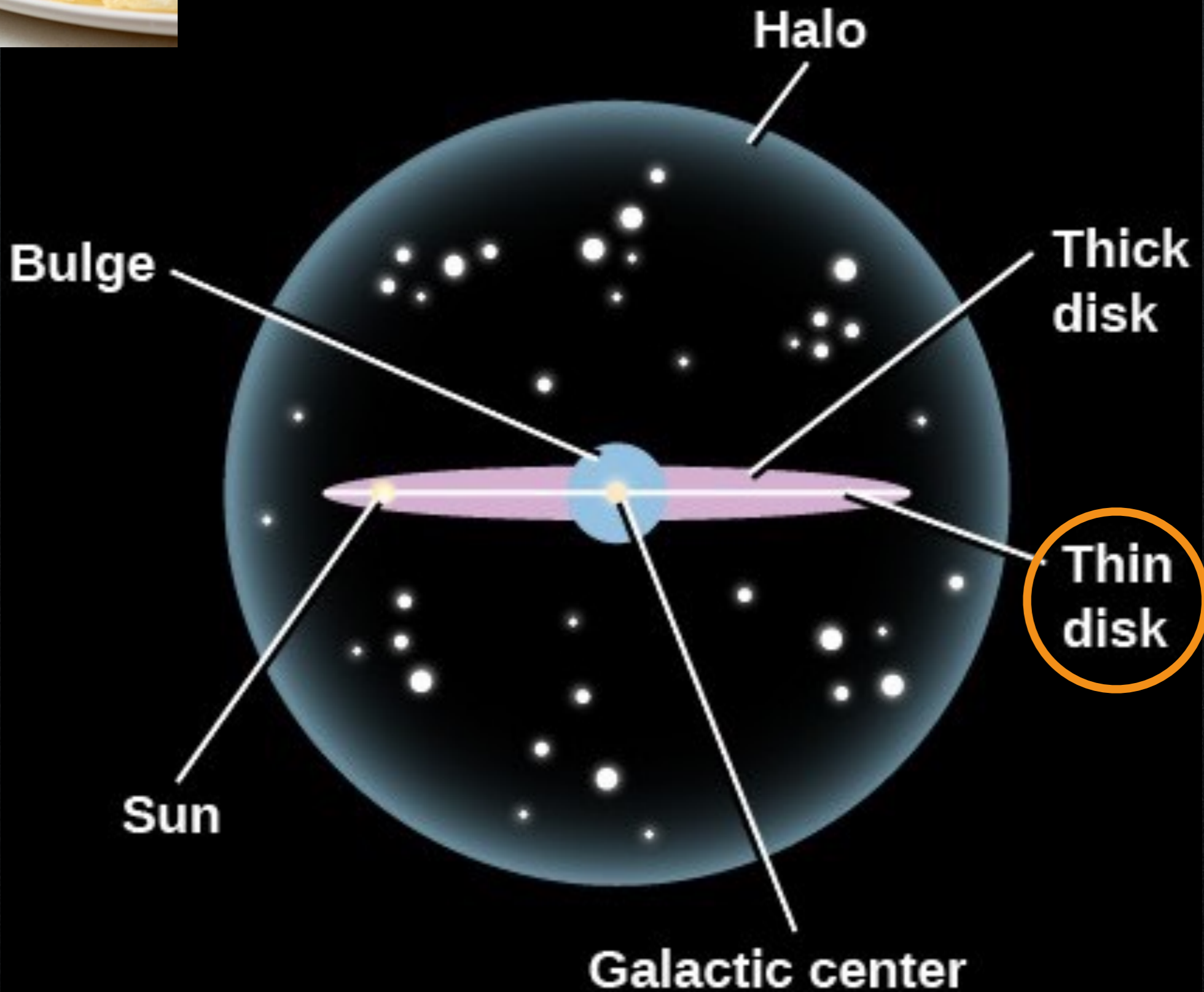
**28,000 Lyr;
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Artist impression but how do we know this is real?

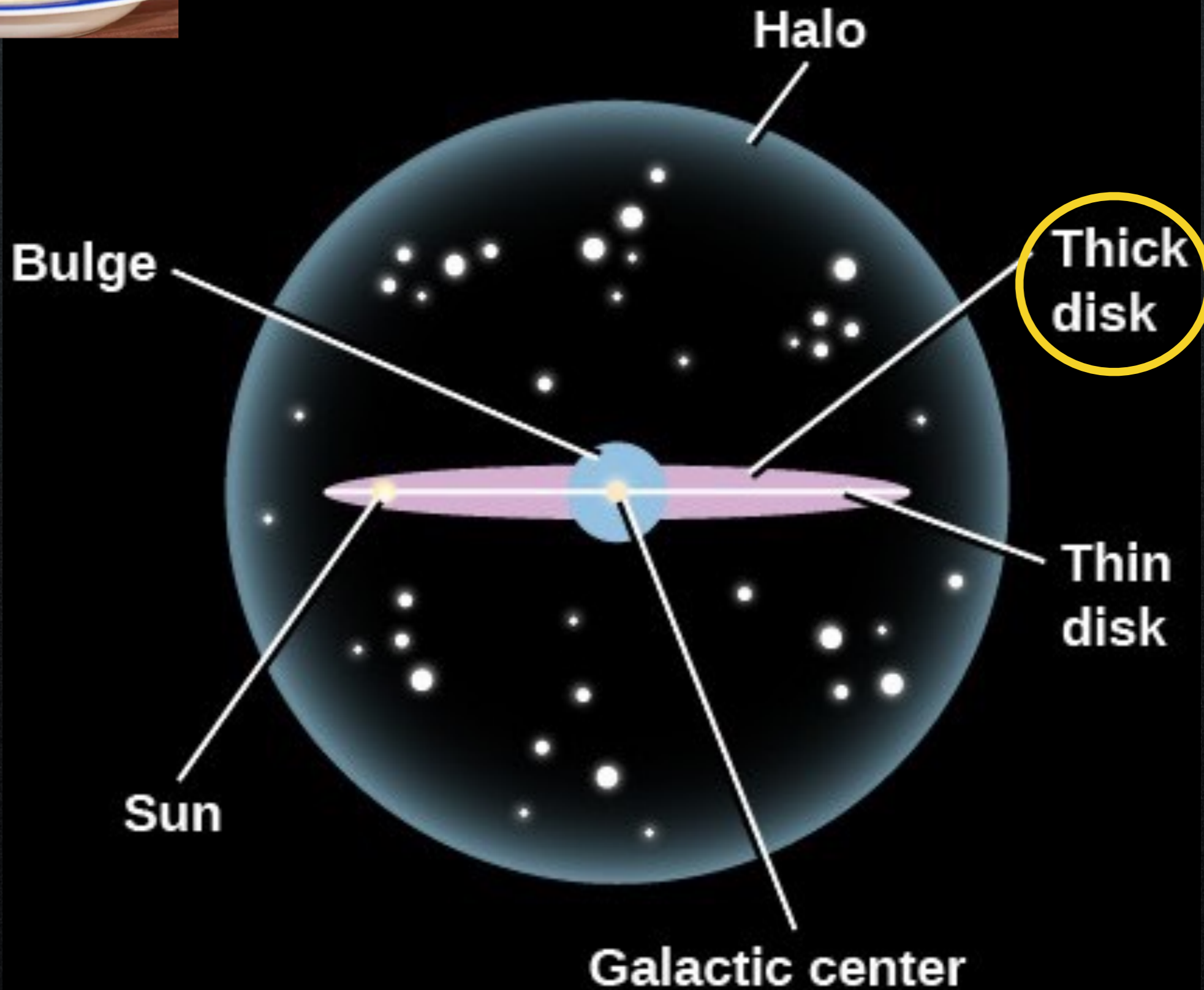
Barred Spiral Galaxy with 5 components



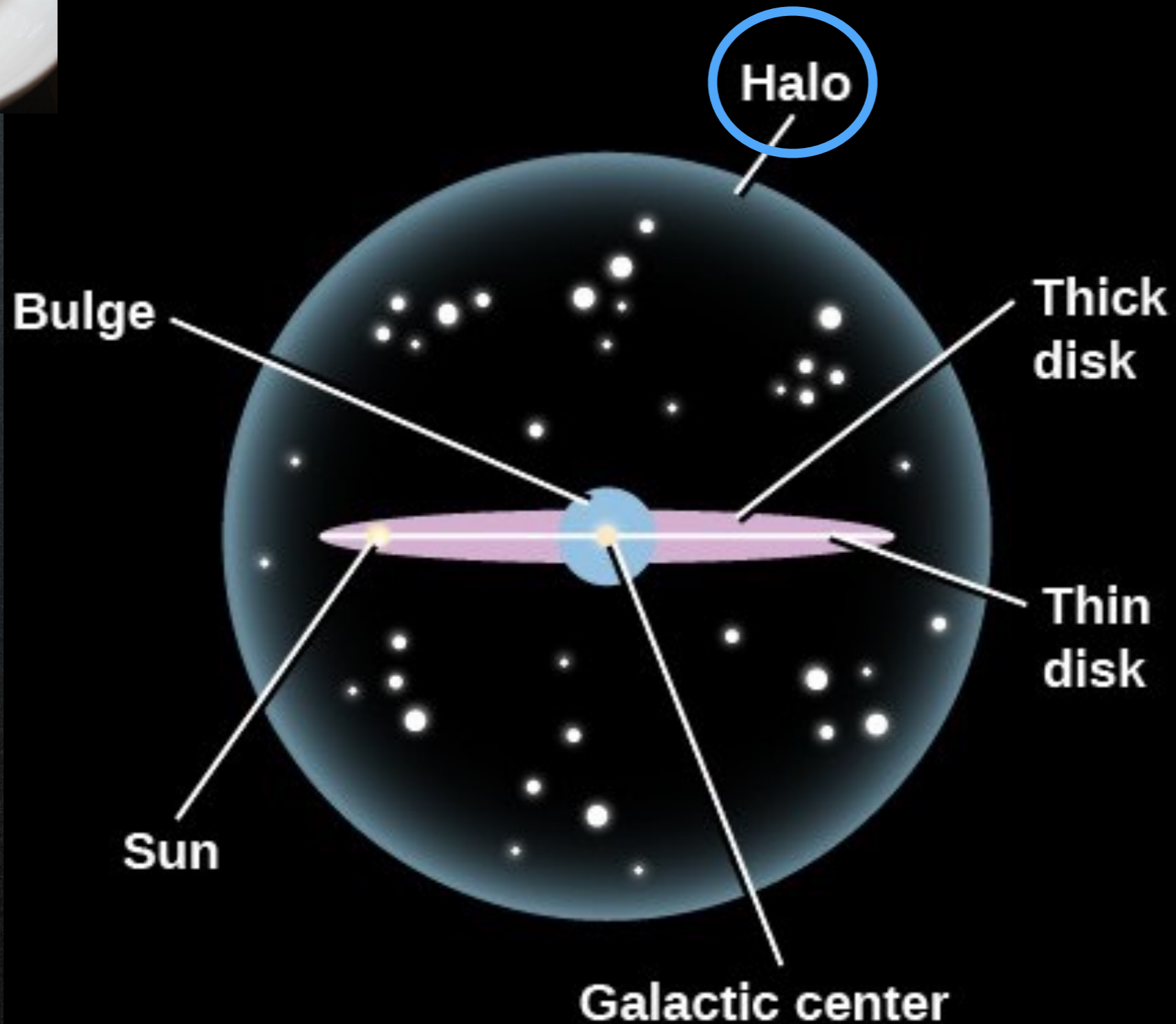
The Thin Disk



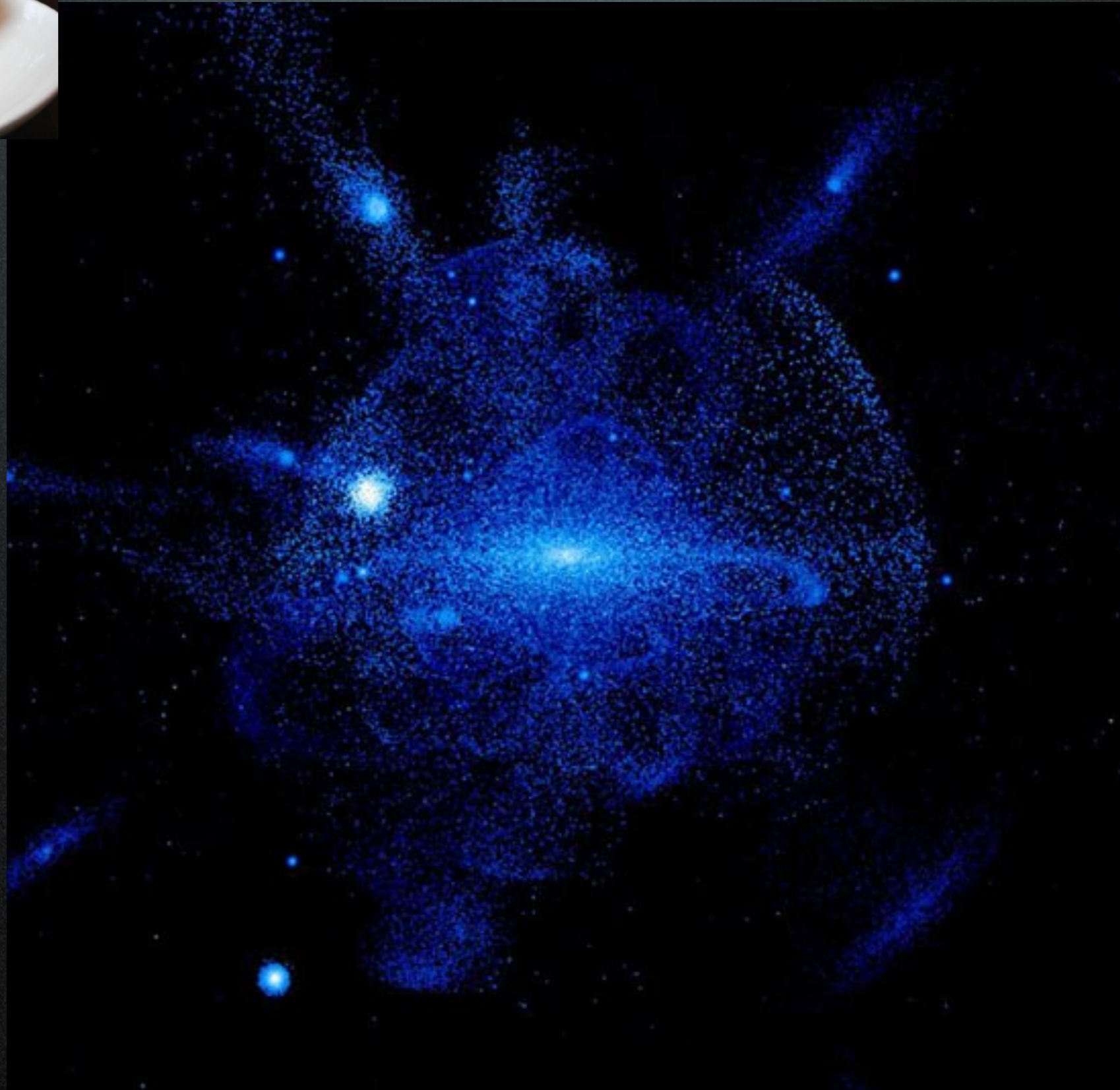
The Thick Disk



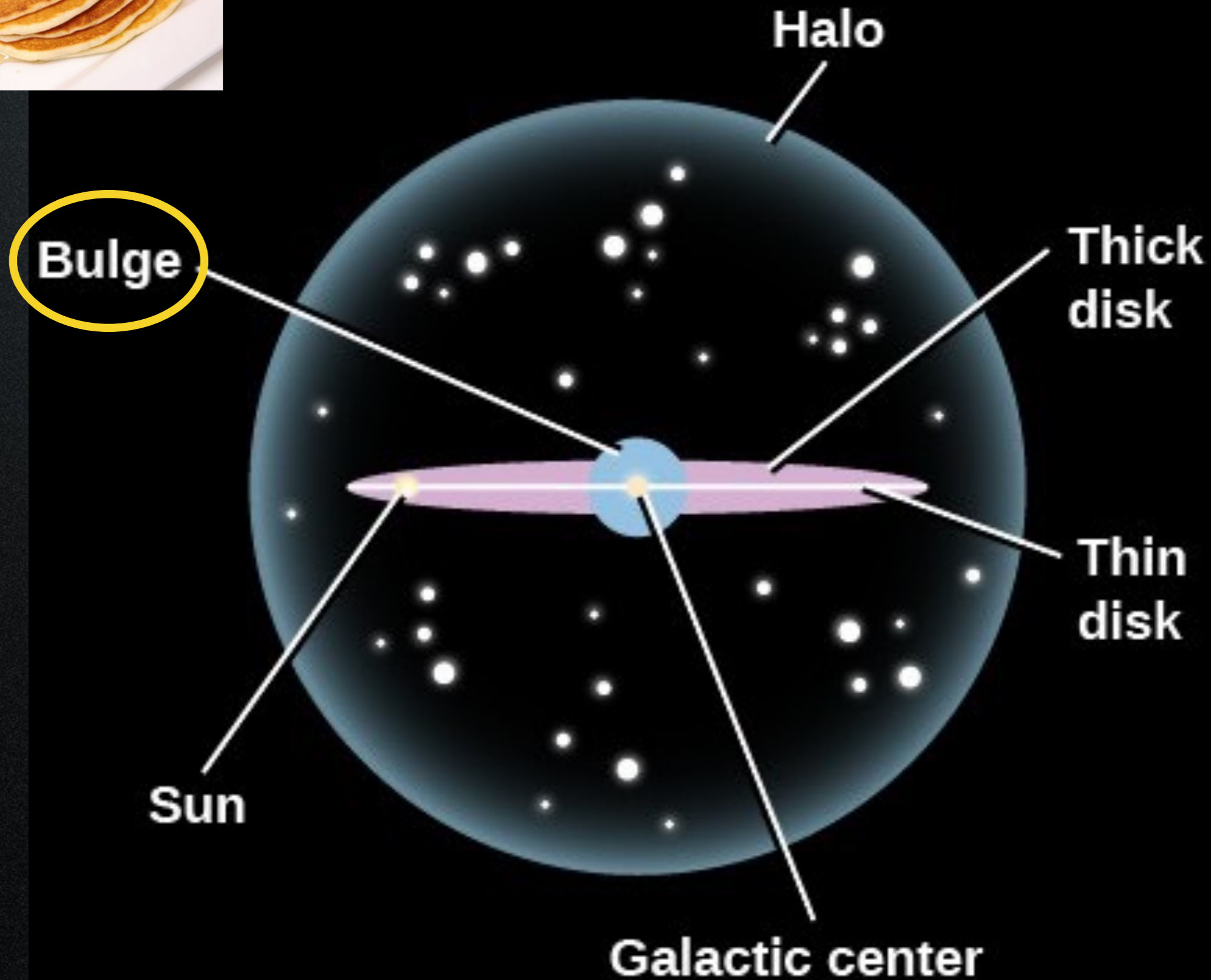
The (stellar) halo



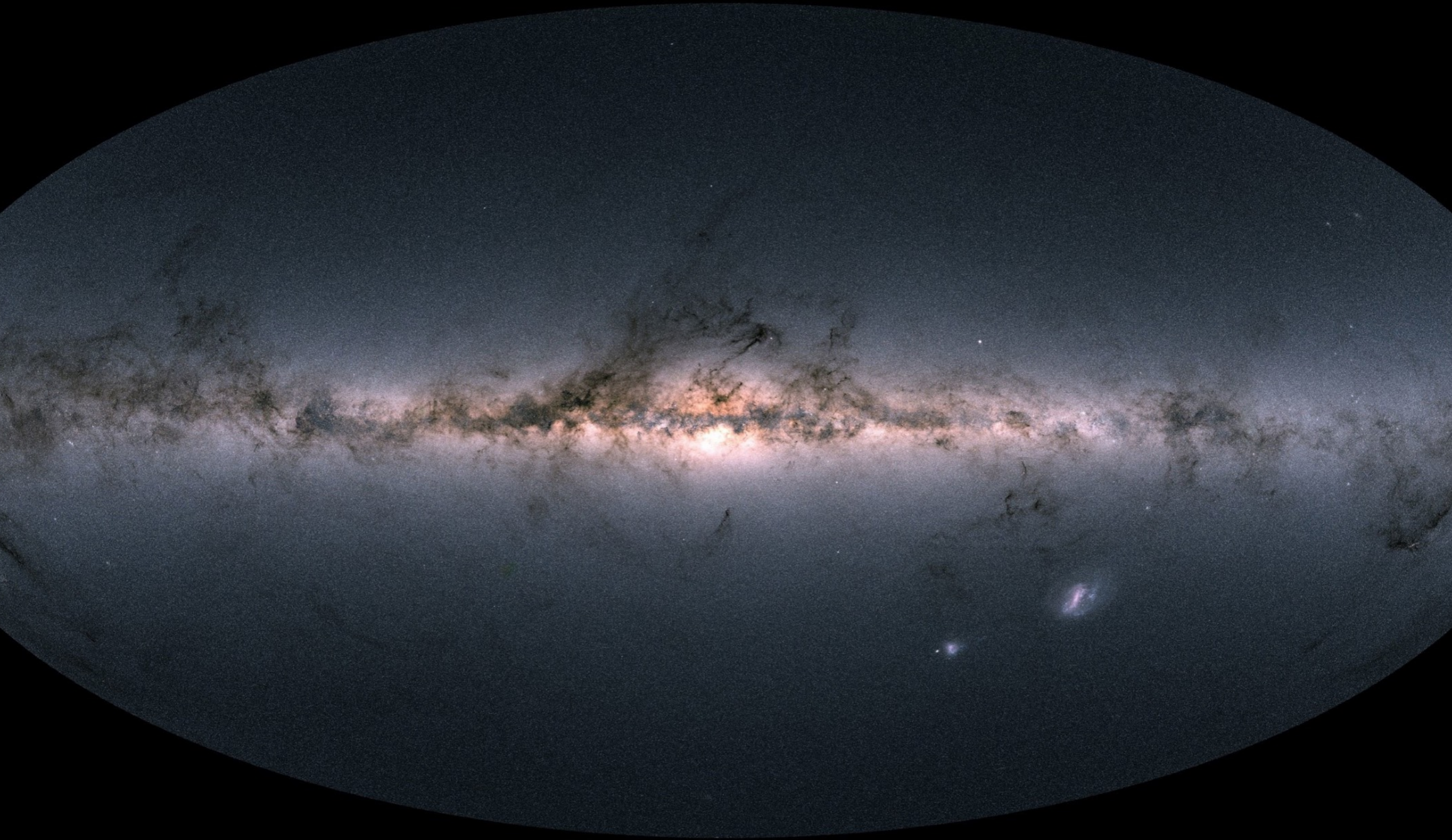
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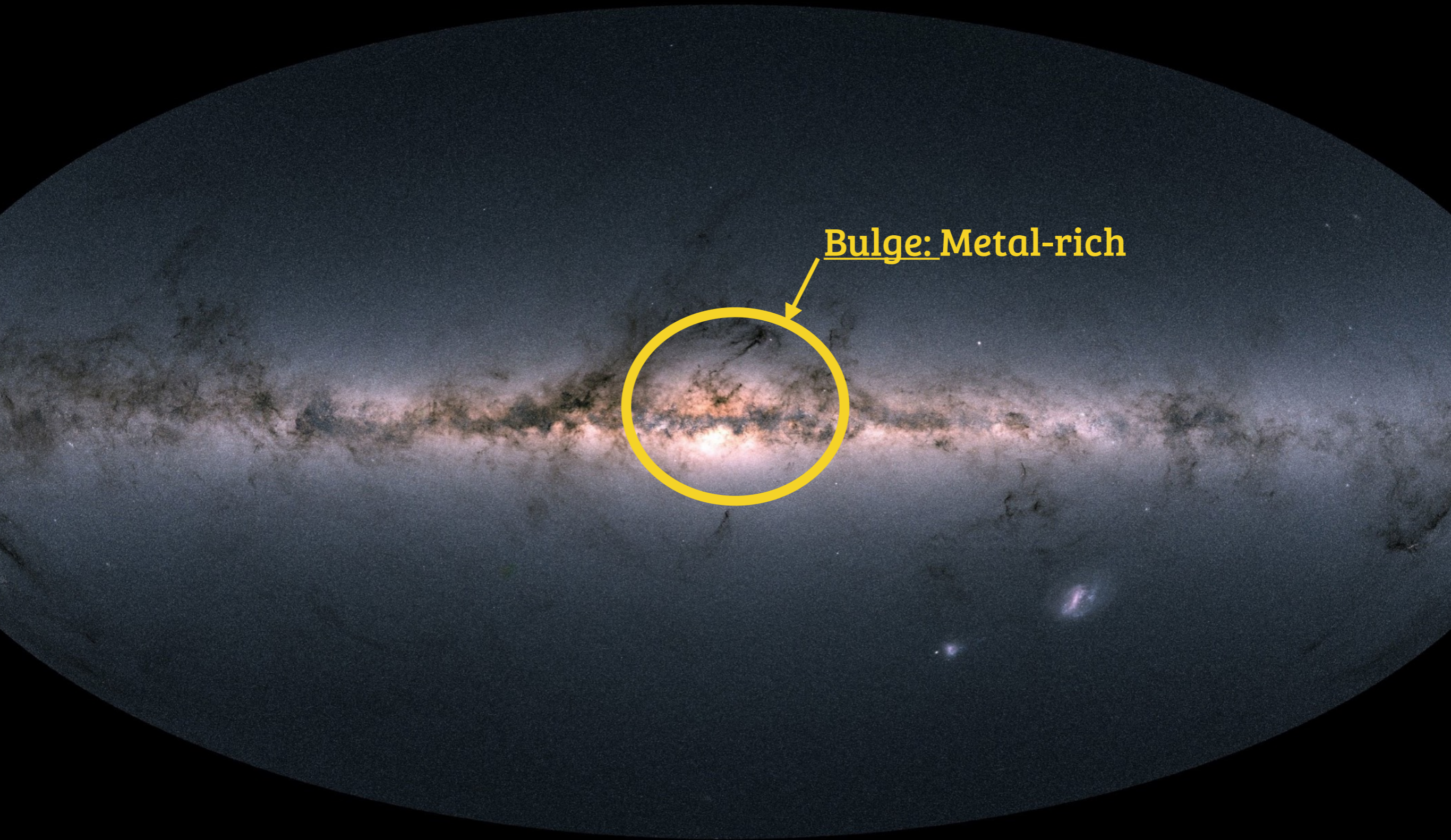
The Bulge



Modern View of the Milky Way

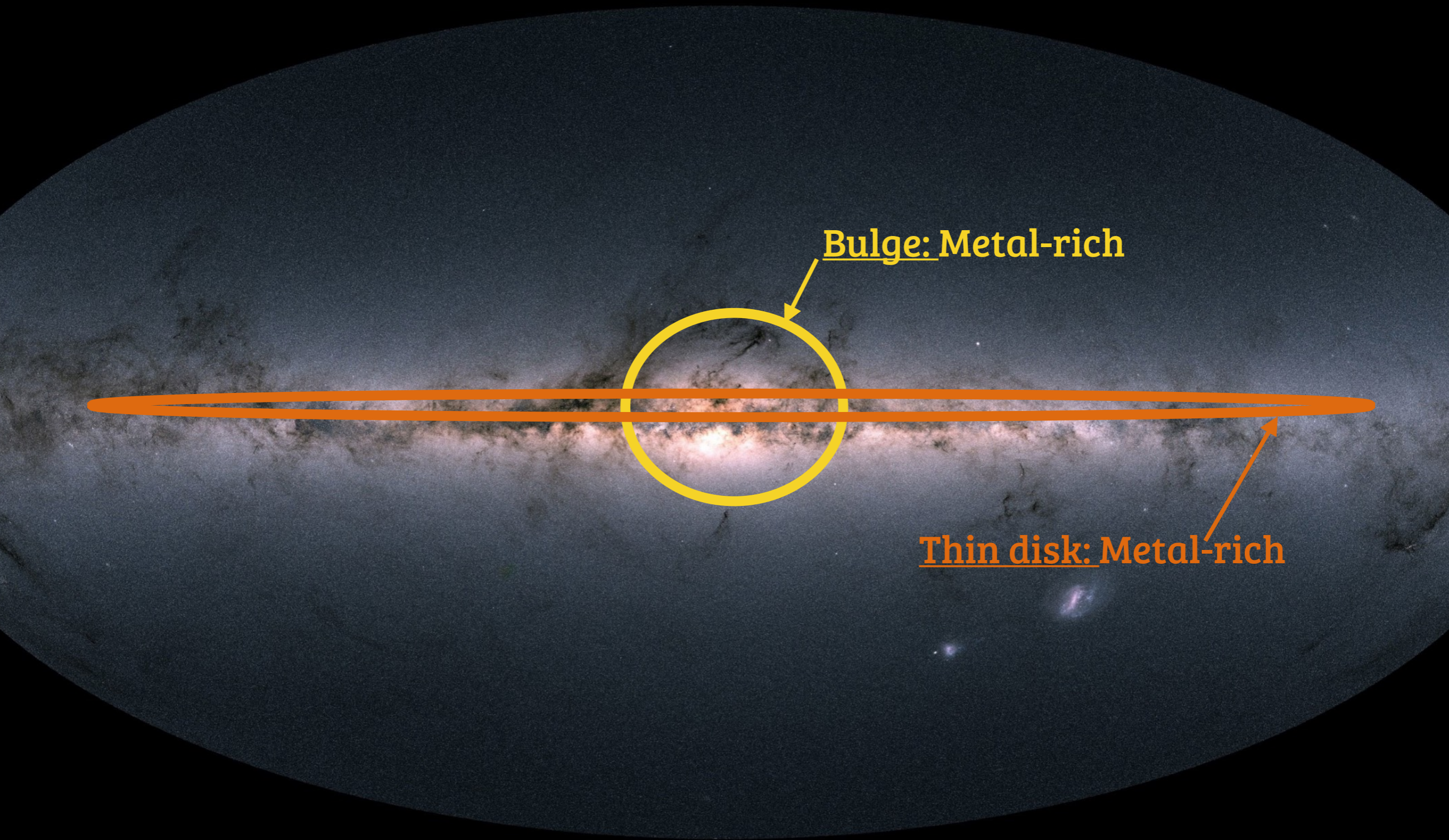


Modern View of the Milky Way



Bulge: Metal-rich

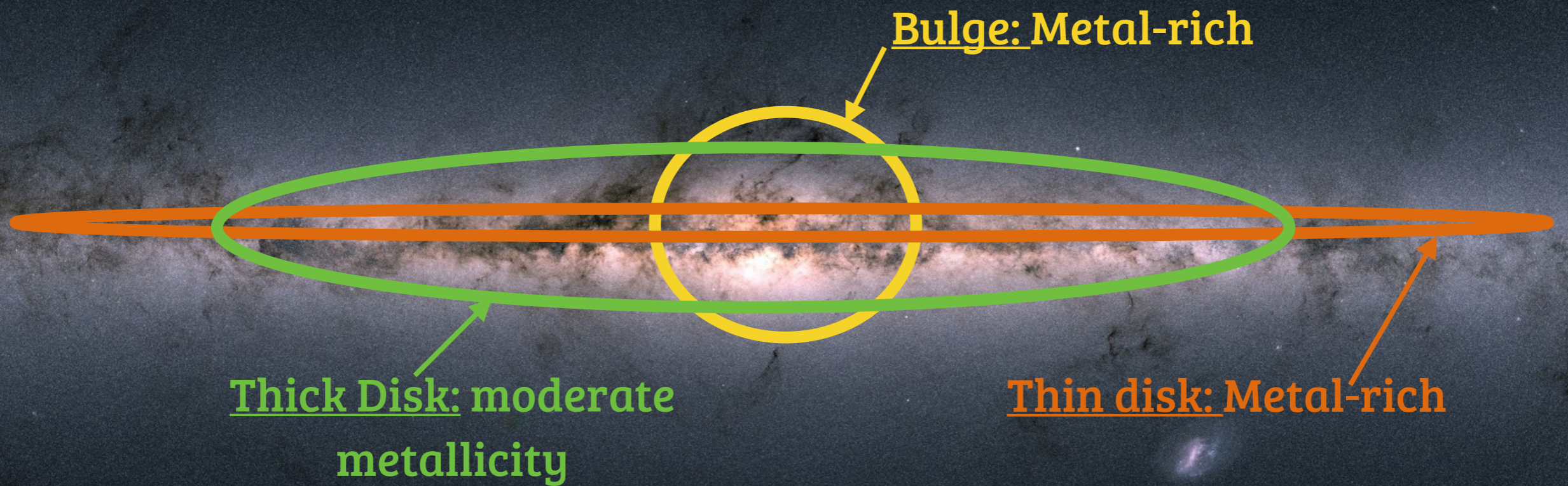
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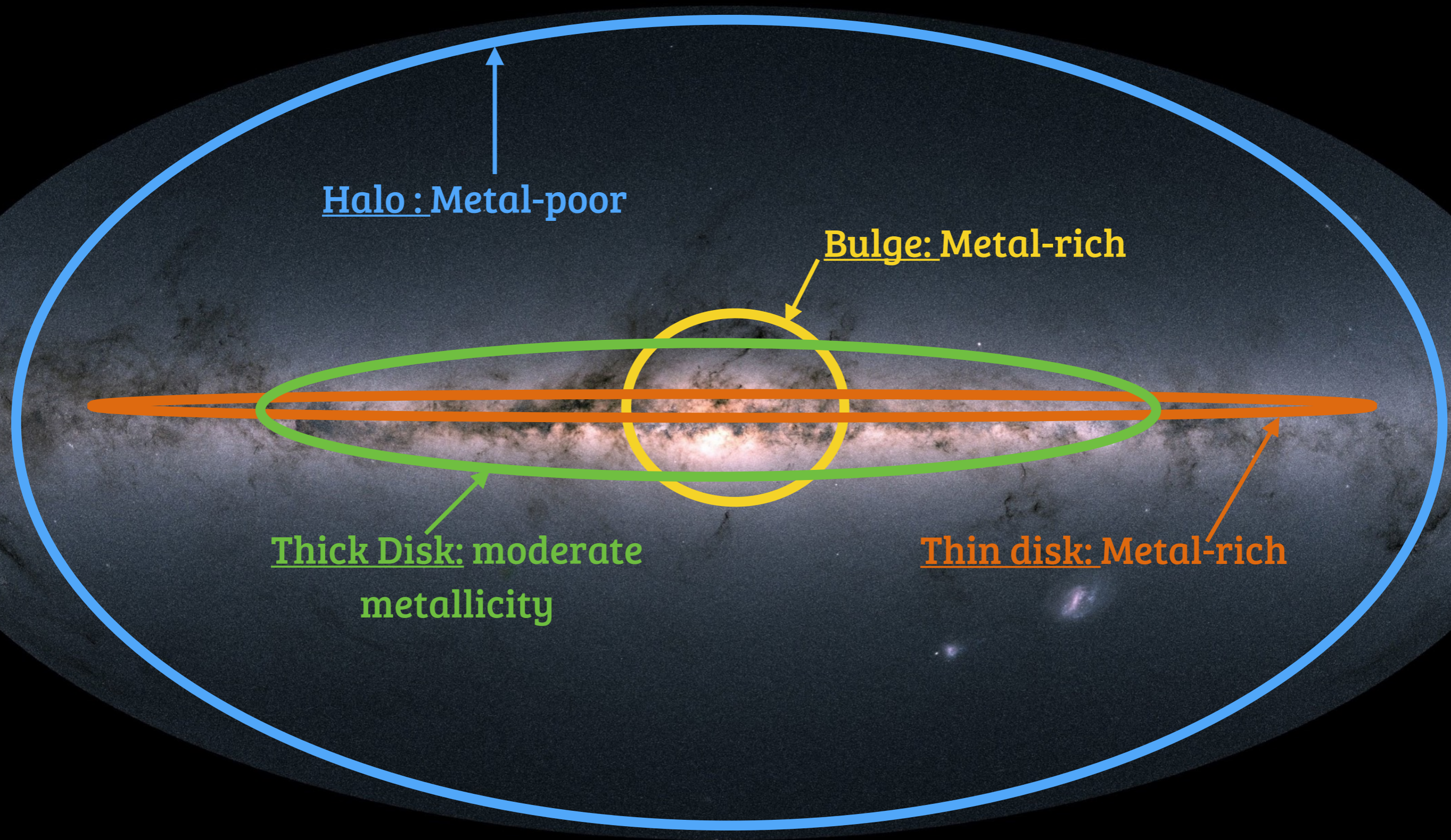
Bulge: Metal-rich

Thin disk: Metal-rich

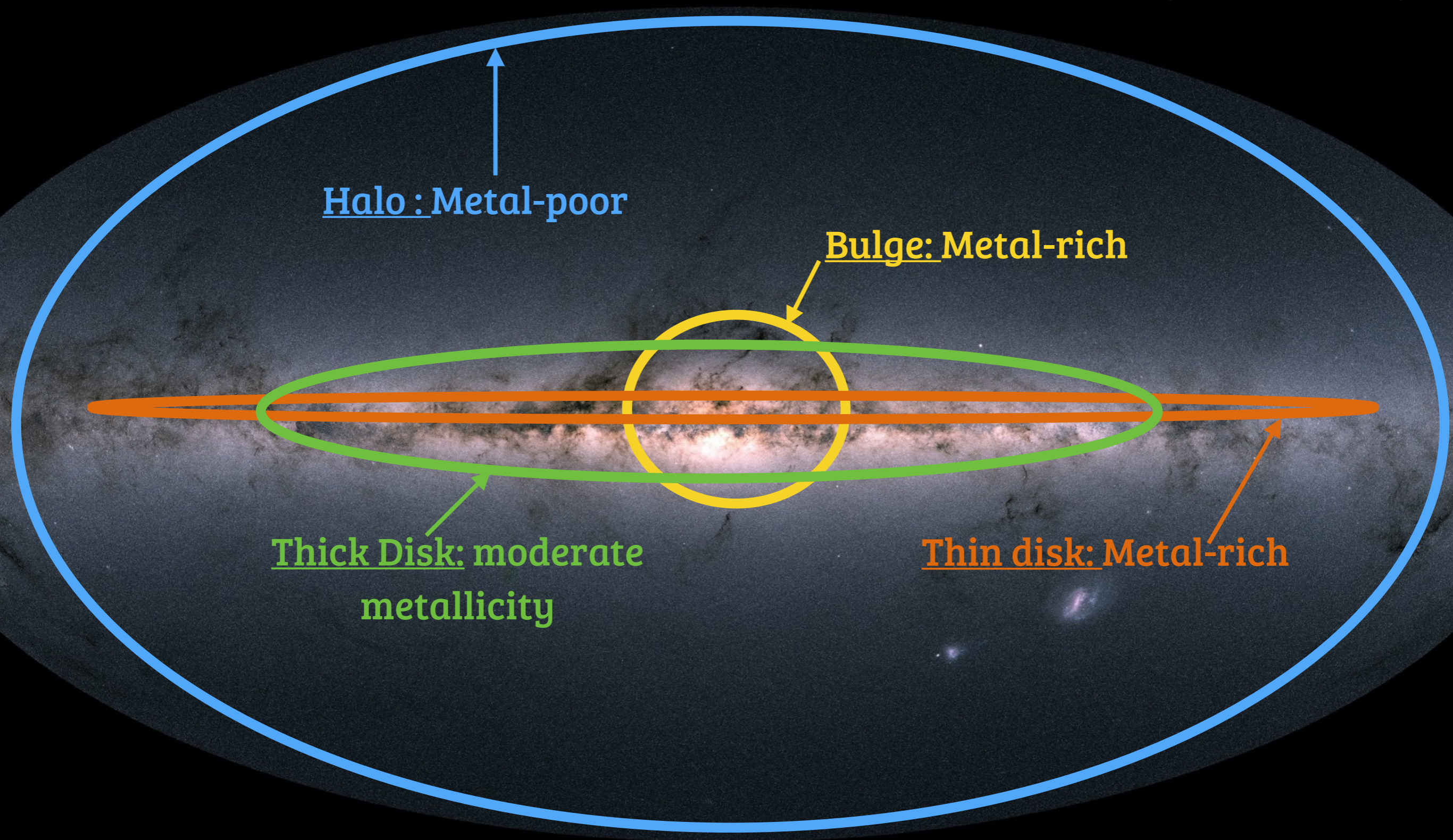
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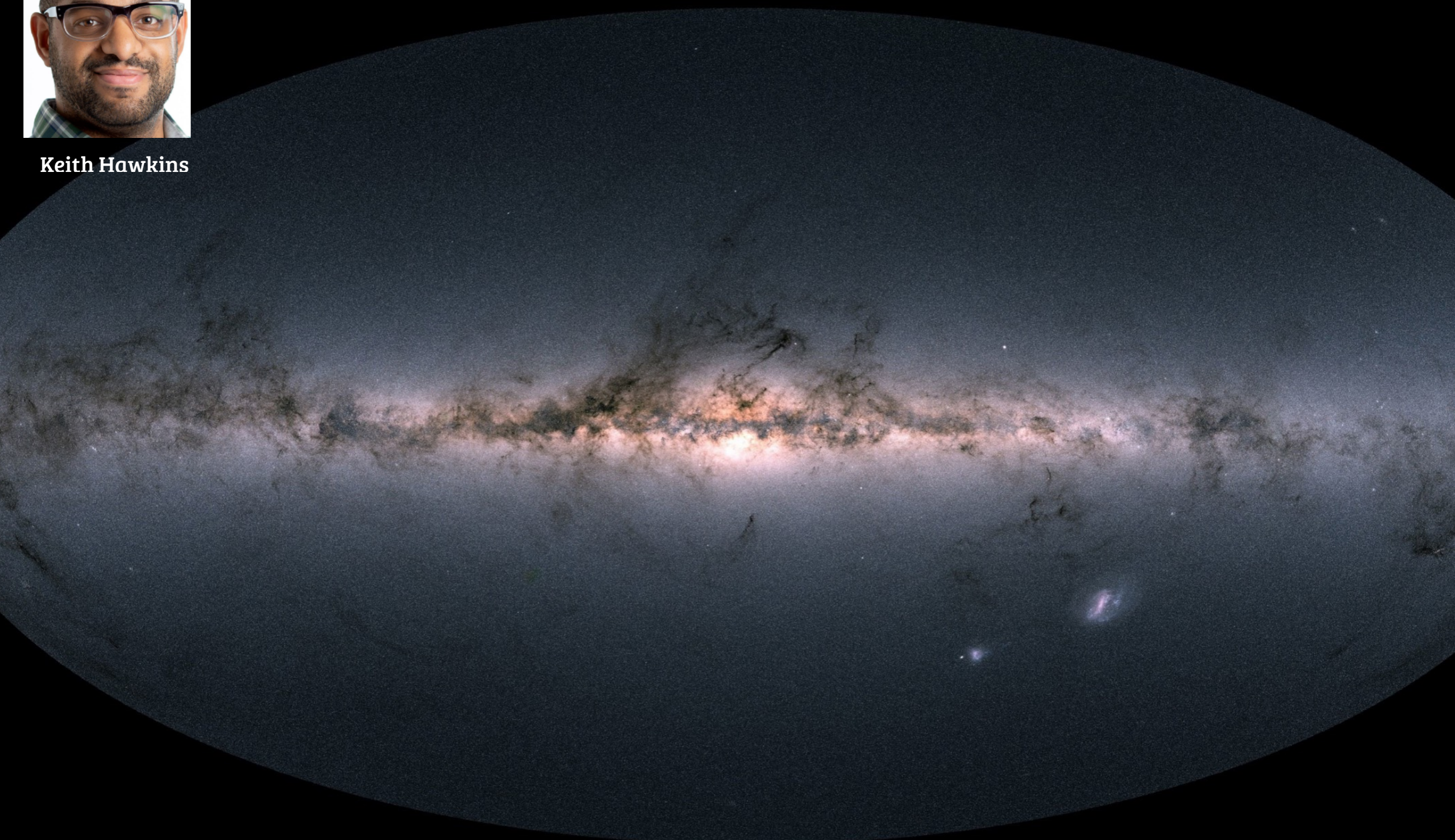


Note: Debates about these components still exist!



Keith Hawkins

Divide and Conquer



+ Undergrads : 2 (current) +15 (former)

Divide and Conquer



Keith Hawkins



Maddie Lucey
(Bulge) → NSF
AAPF



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Divide and Conquer



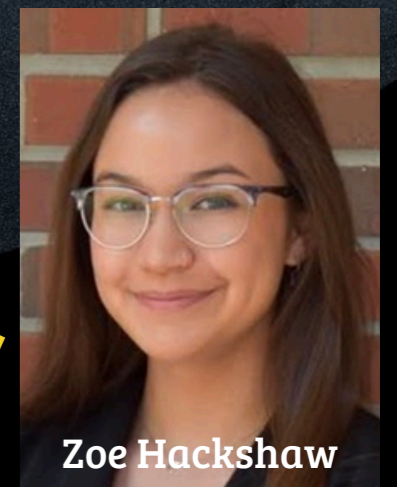
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Dionysis Gakis



Zoe Hackshaw

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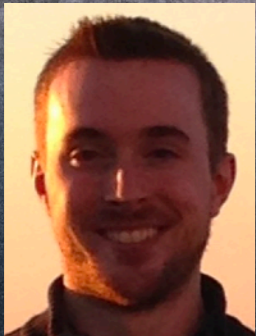
Divide and Conquer



Keith Hawkins



Maddie Lucey
(Bulge) —> NSF
AAPF



Zack Maas —>
visiting Asst. Prof



Catherine Manea -
—> NSF AAPF



Tyler Nelson —>
uni lecturer.



Malia Kao



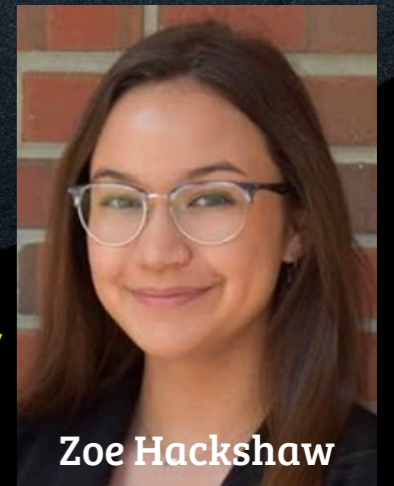
Carlos Juardo



Kaleo Toguchi-
Tani



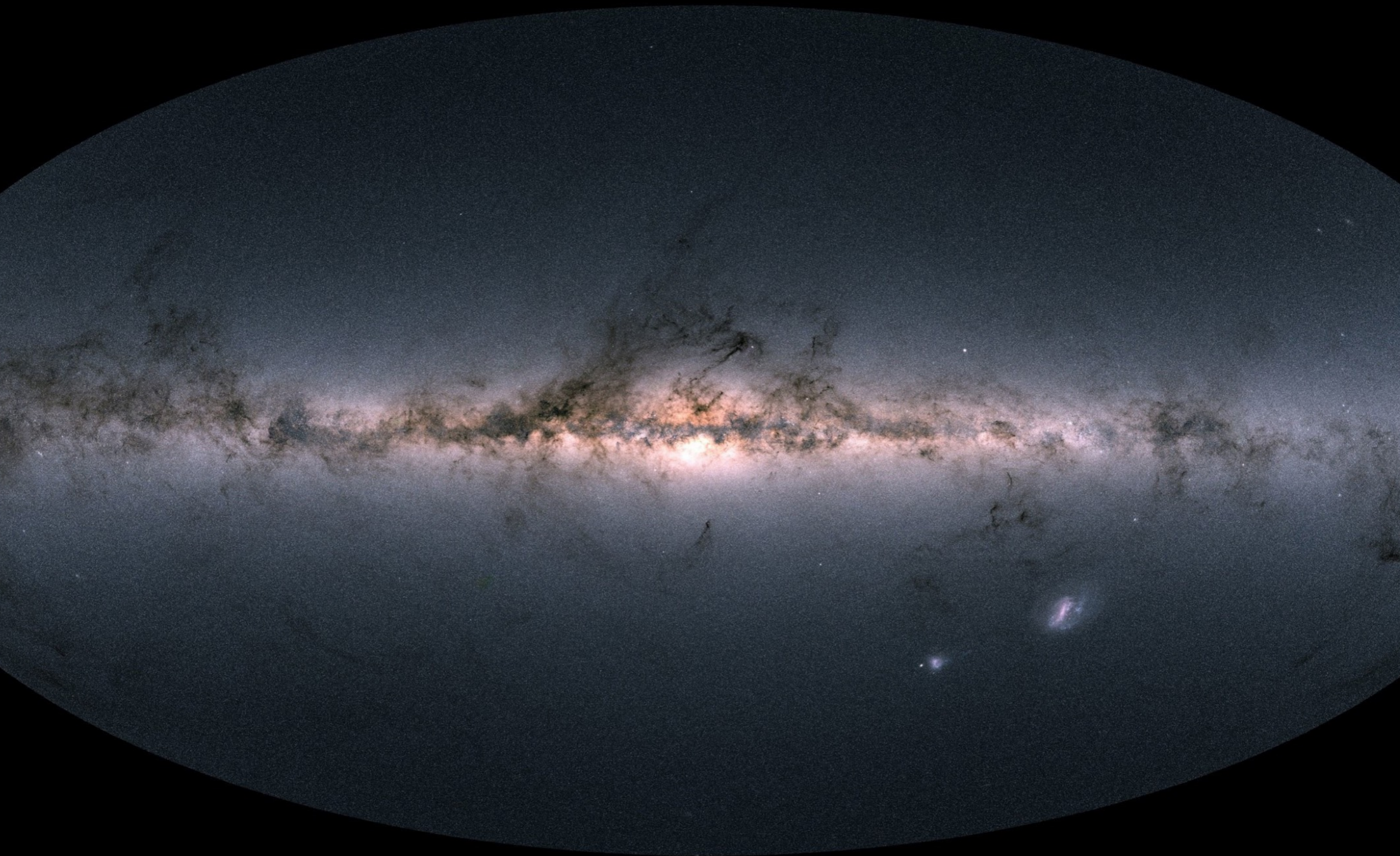
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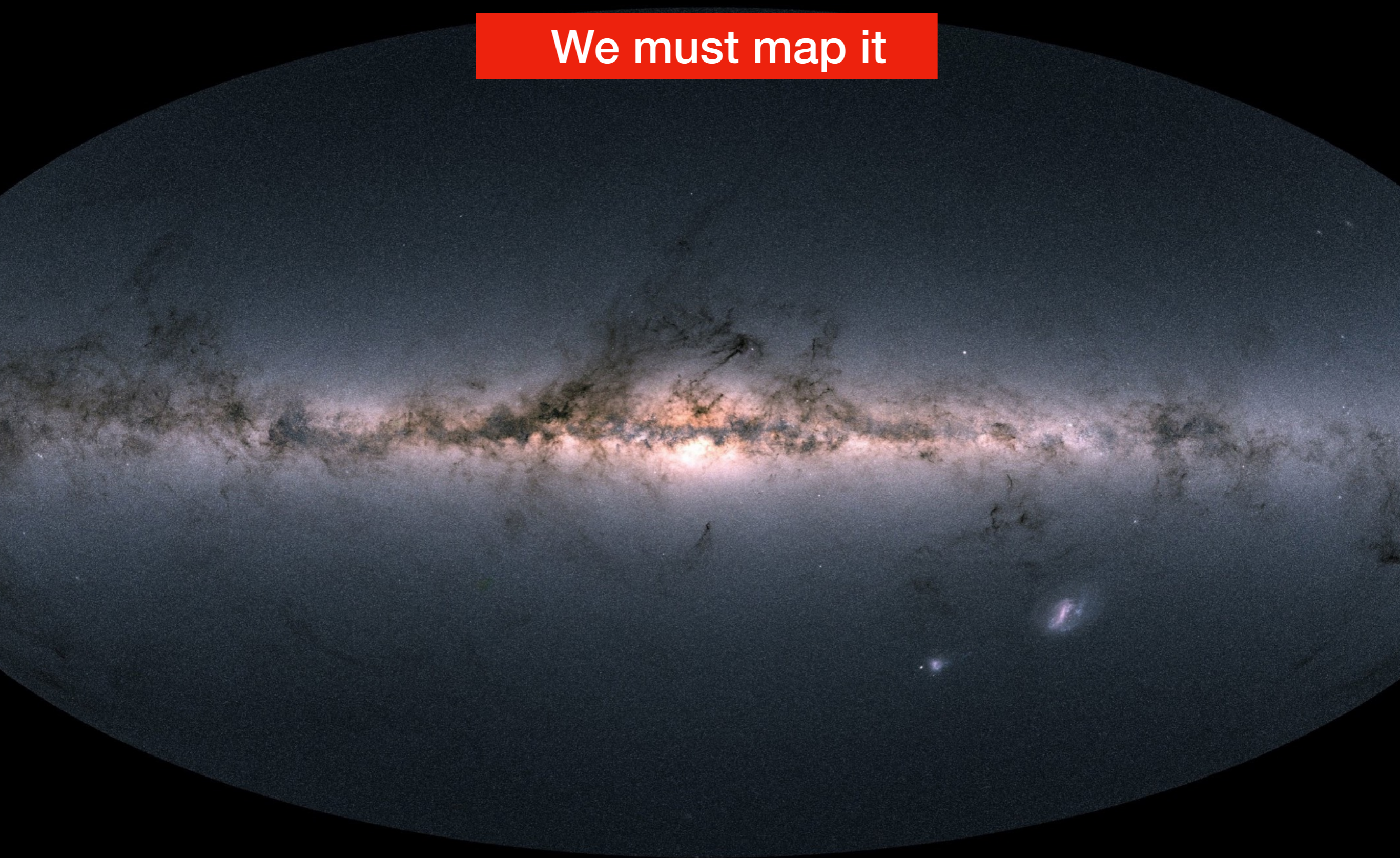
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To fully understand our galaxy



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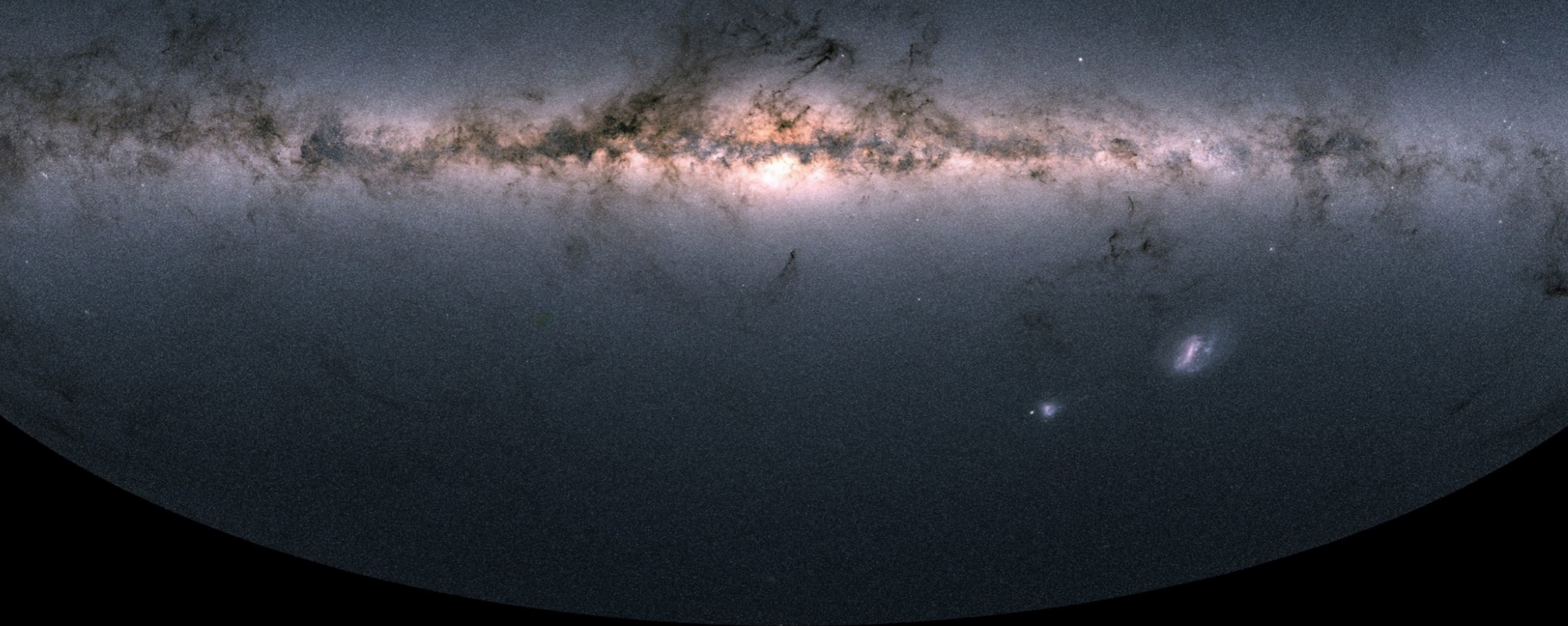
We must map it



To fully understand our galaxy

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In particular, chemical maps of our galaxy inform how it formed! Let's work together to build a "toy model" of the map of 'metals' across our Galaxy




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of the
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Advance Access publication 2023 April 27
<https://doi.org/10.1093/mnras/stad1244>








Chemical cartography with LAMOST and *Gaia* reveal azimuthal and spiral structure in the Galactic disc

Keith Hawkins   

Department of Astronomy, The University of Texas at Austin, 2515 Speedway Boulevard, Austin, TX 78712, USA

DRAFT VERSION MAY 29, 2024
Typeset using L^AT_EX twocolumn style in AASTeX631

[X/Fe] Marks the Spot: Mapping Chemical Azimuthal Variations in the Galactic Disk with APOGEE








ZOE HACKSHAW ¹, KEITH HAWKINS ¹, CARRIE FILION ², DANNY HORTA ³, CHERVIN F. P. LAPORTE ⁴,
CHRISTOPHER CARR ⁵ AND ADRIAN M. PRICE-WHELAN ³

¹*Department of Astronomy, The University of Texas at Austin, 2515 Speedway Boulevard Austin, TX 78712, USA*

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<https://doi.org/10.3847/1538-4357/ac346c>

OPEN ACCESS

Dynamical Origins of Azimuthal Metallicity Variations in the Galactic Disk: Insights from Kinematic Ridges with *Gaia*

Carlos Jurado ¹, Keith Hawkins ¹, Jason A. S. Hunt ², Zoe Hackshaw ¹, Carrie Filion ³, Neige Frankel ⁴, and Christopher Carr ⁵

¹*Department of Astronomy, The University of Texas at Austin, 2515 Speedway Boulevard, Austin, TX 78712, USA; carlosjurado@utexas.edu*
²*School of Mathematics & Physics, University of Surrey, Guildford, GU2 7XH, UK*
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Received 2025 October 21; revised 2025 December 30; accepted 2026 January 4; published 2026 February 6



Carlos Juado



Zoe Hackshaw

Toy “Model” —>
Start with our artist
impression from earlier



Toy “Model” →
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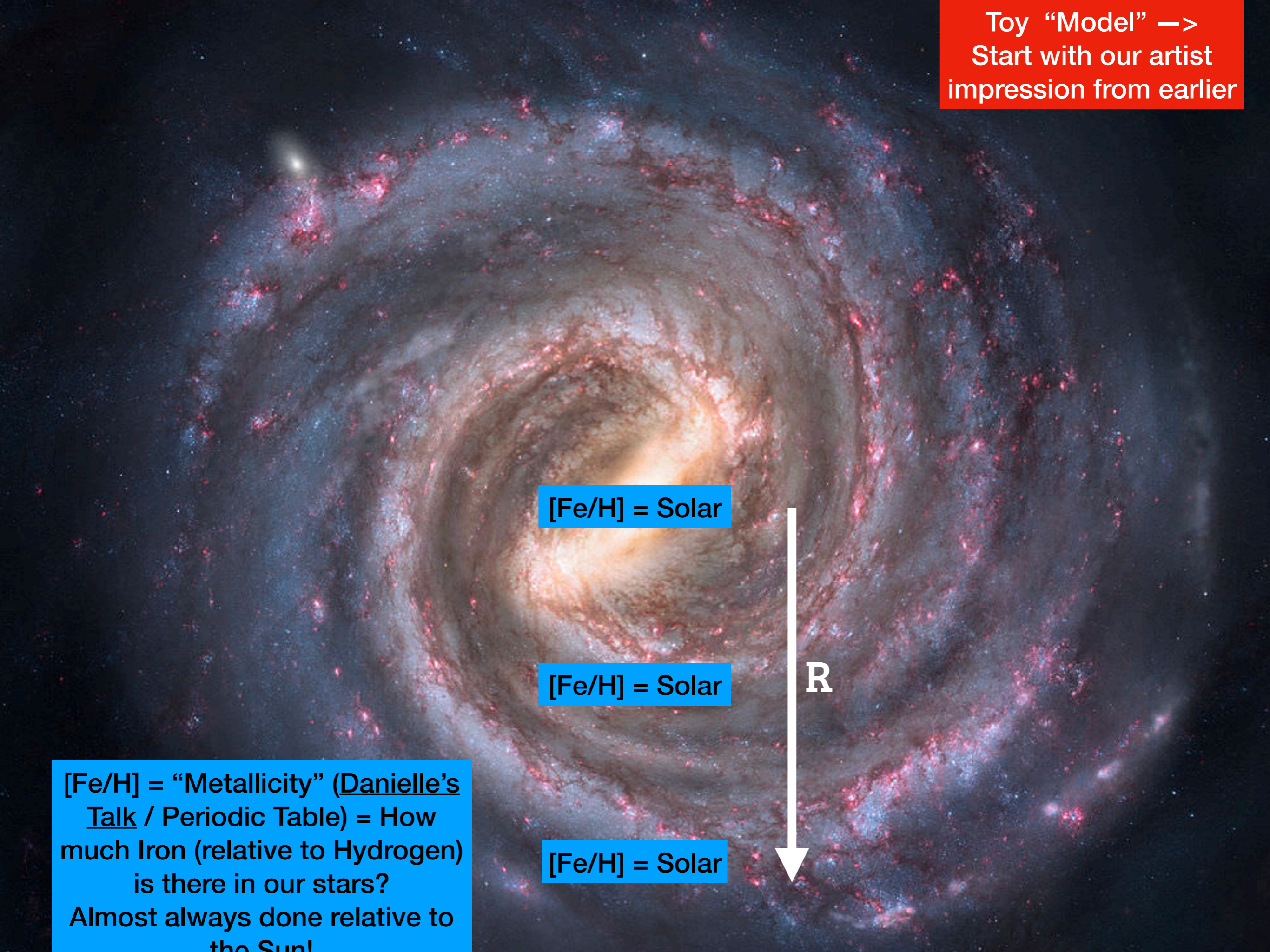
$[\text{Fe}/\text{H}]$ = “Metallicity” (Danielle’s
Talk / Periodic Table) = How
much Iron (relative to Hydrogen)
is there in our stars?
Almost always done relative to
the Sun!

Toy “Model” →
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[Fe/H] = Solar

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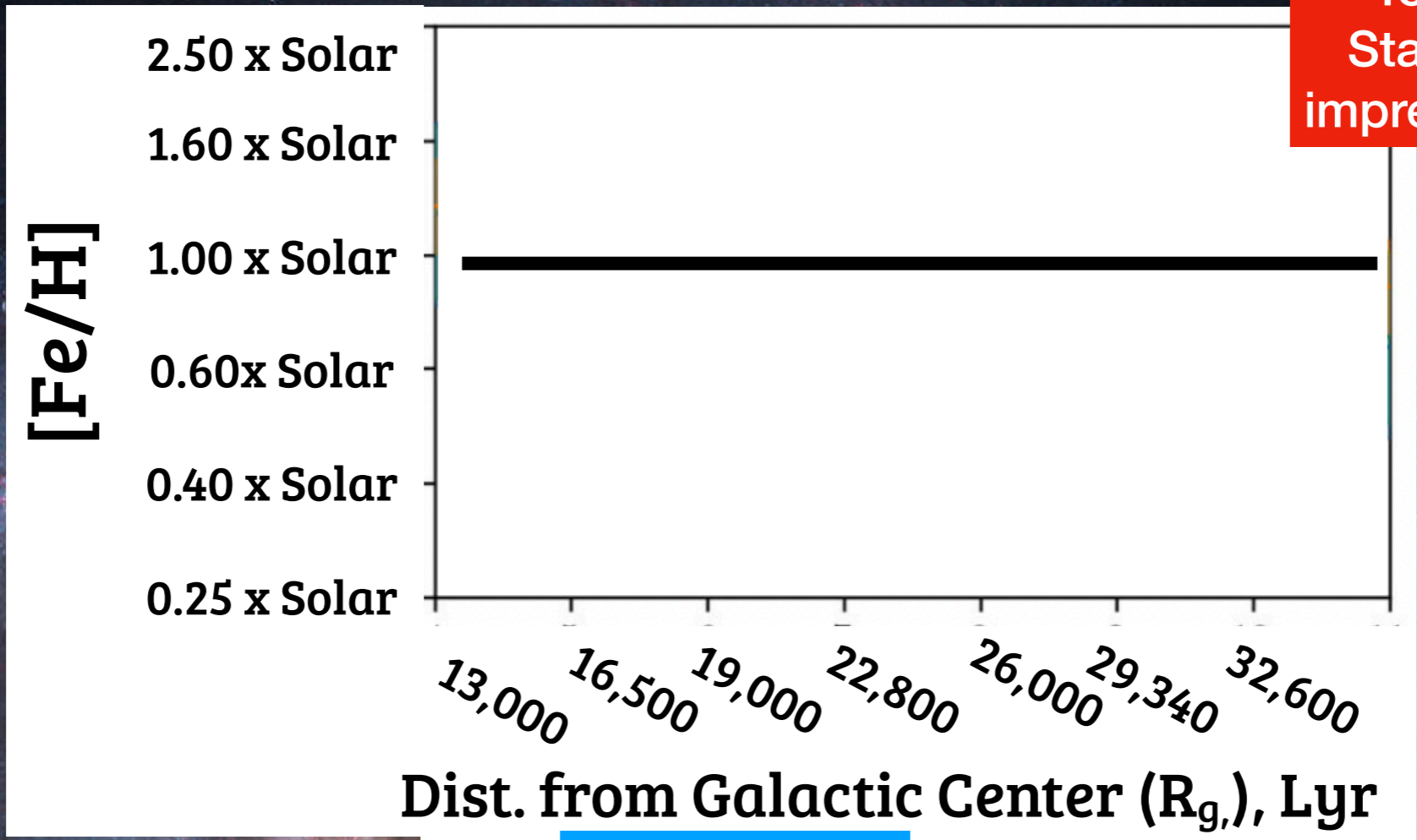
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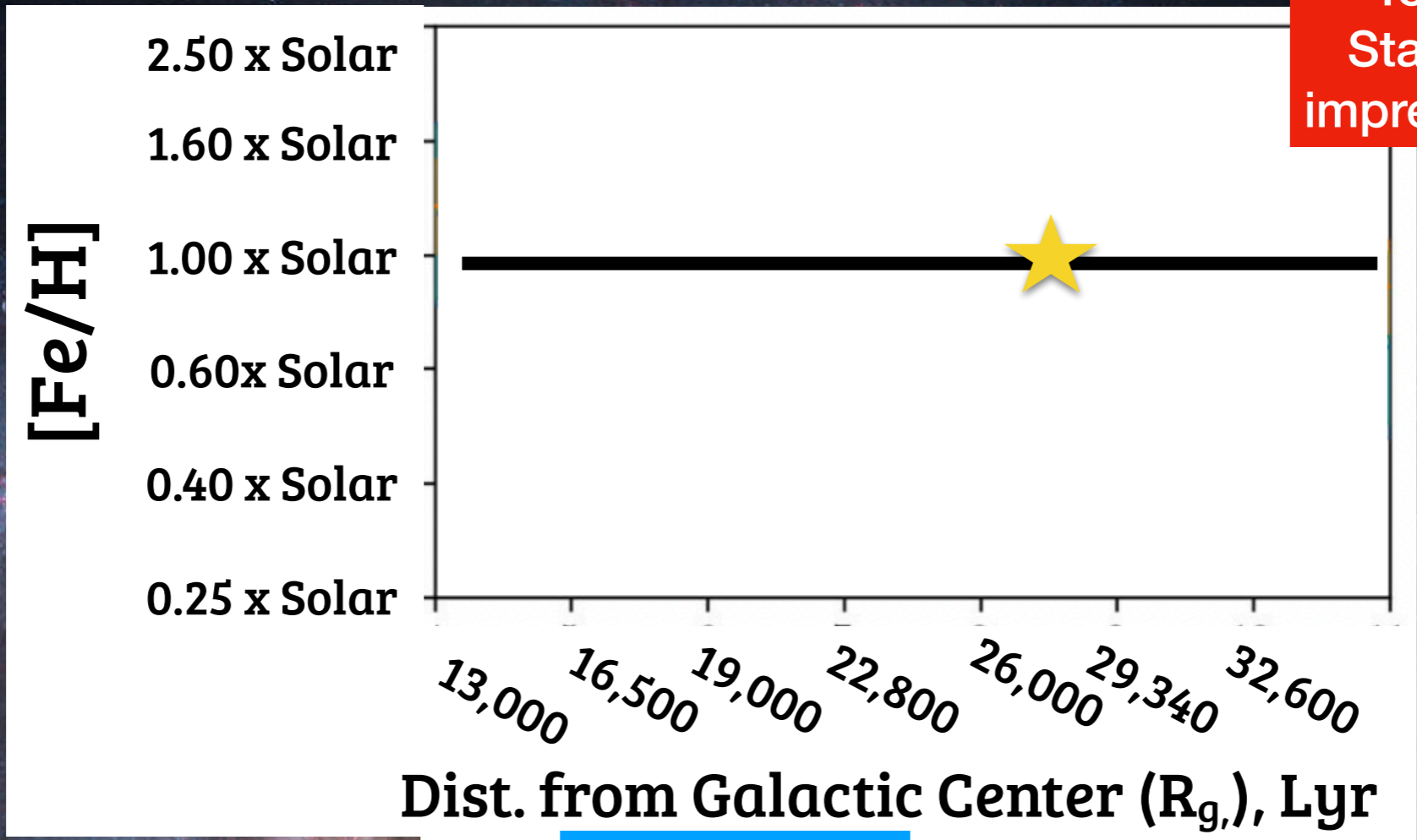
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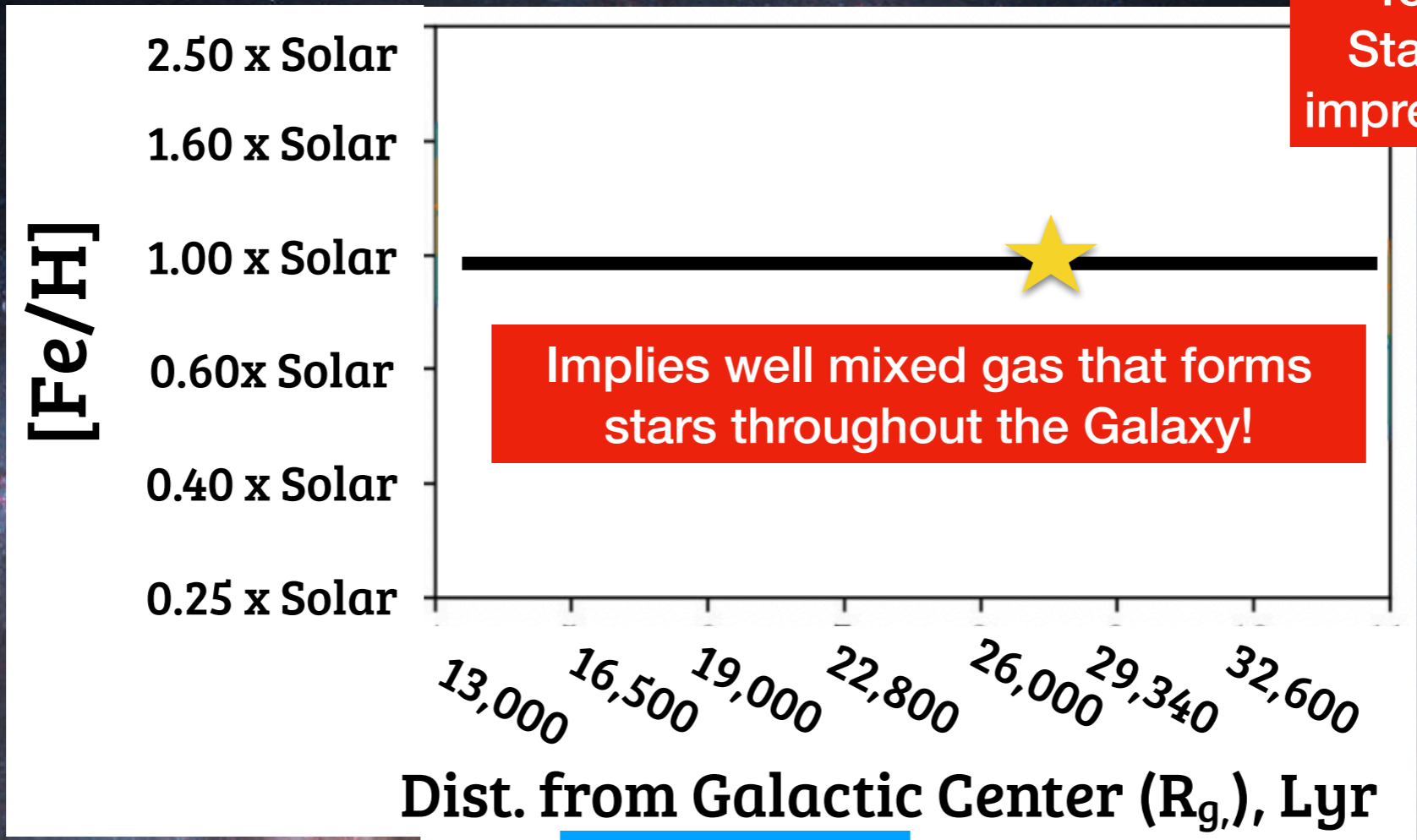
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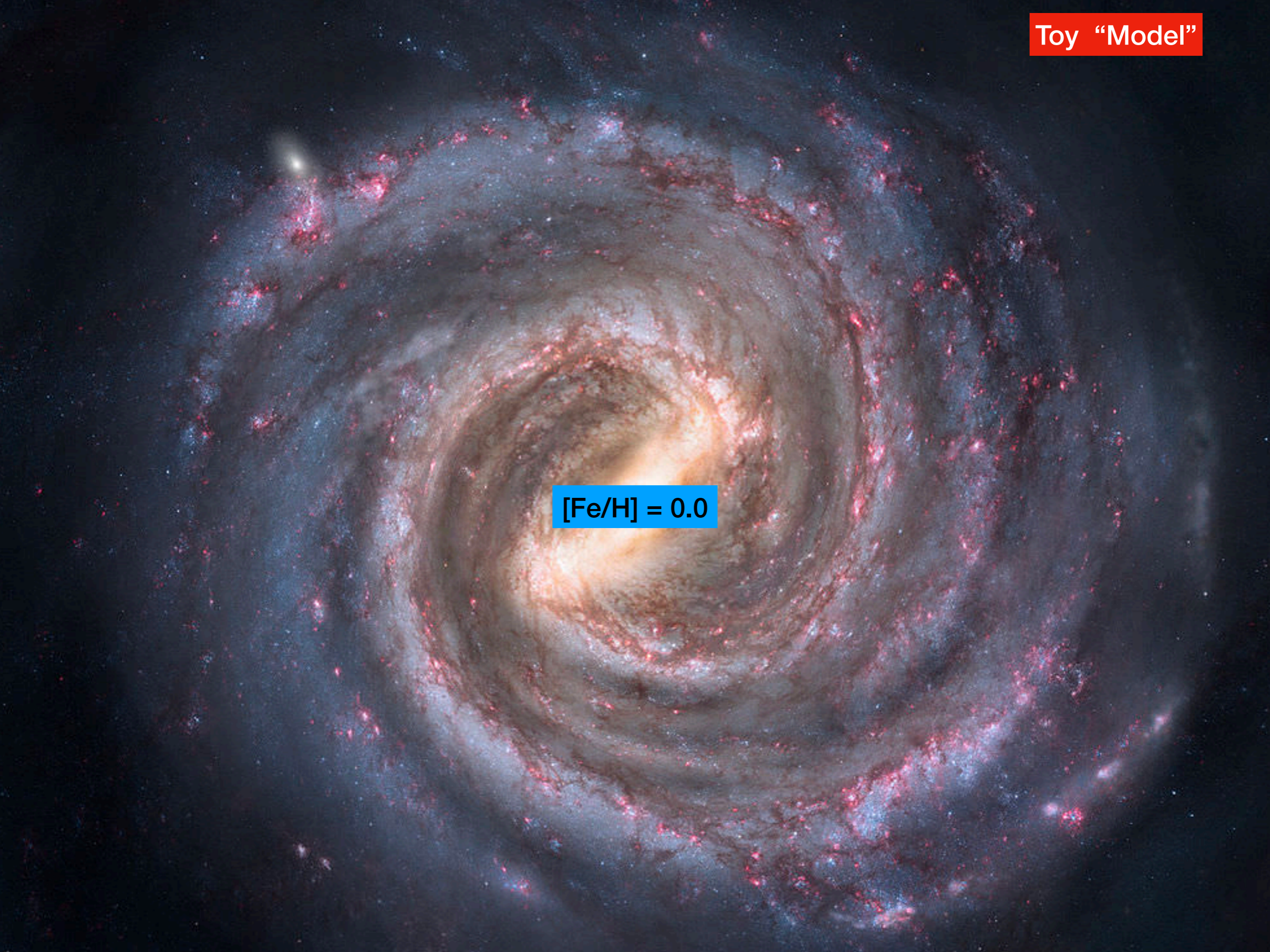
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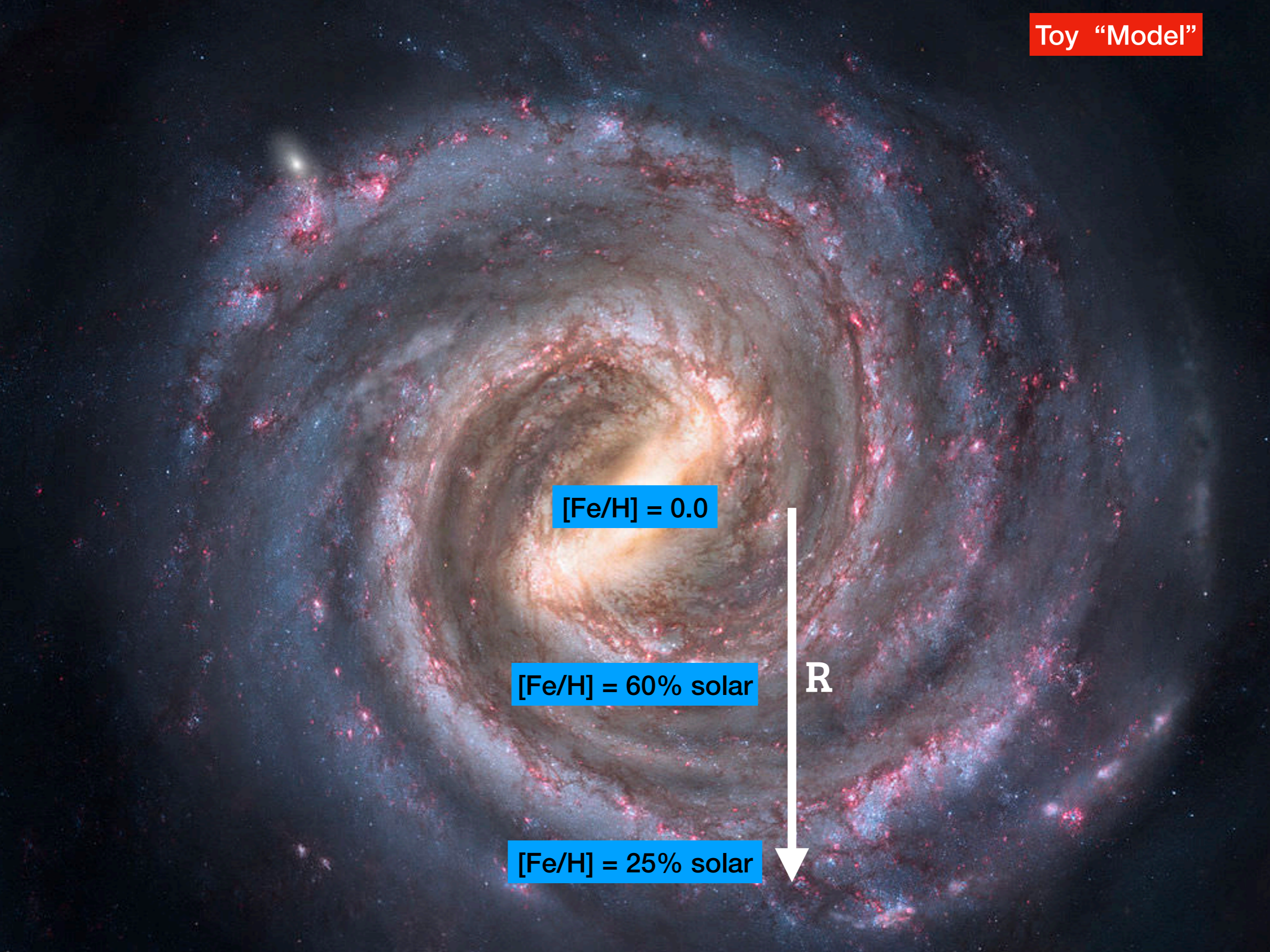
R

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[Fe/H] = 0.0



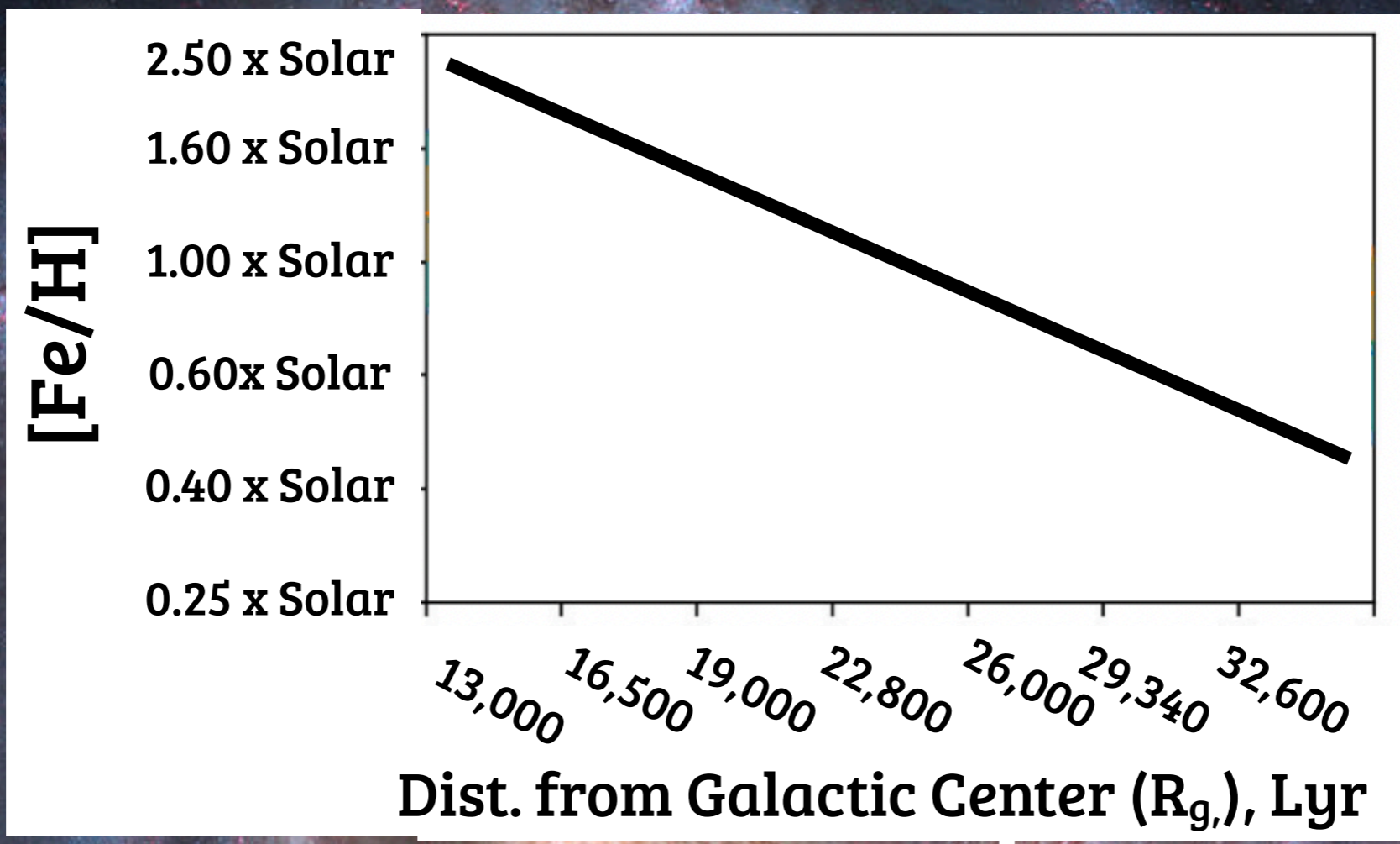


[Fe/H] = 0.0

[Fe/H] = 60% solar

[Fe/H] = 25% solar

R

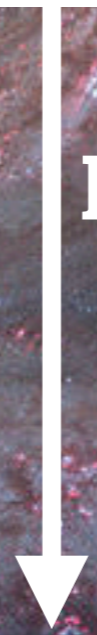


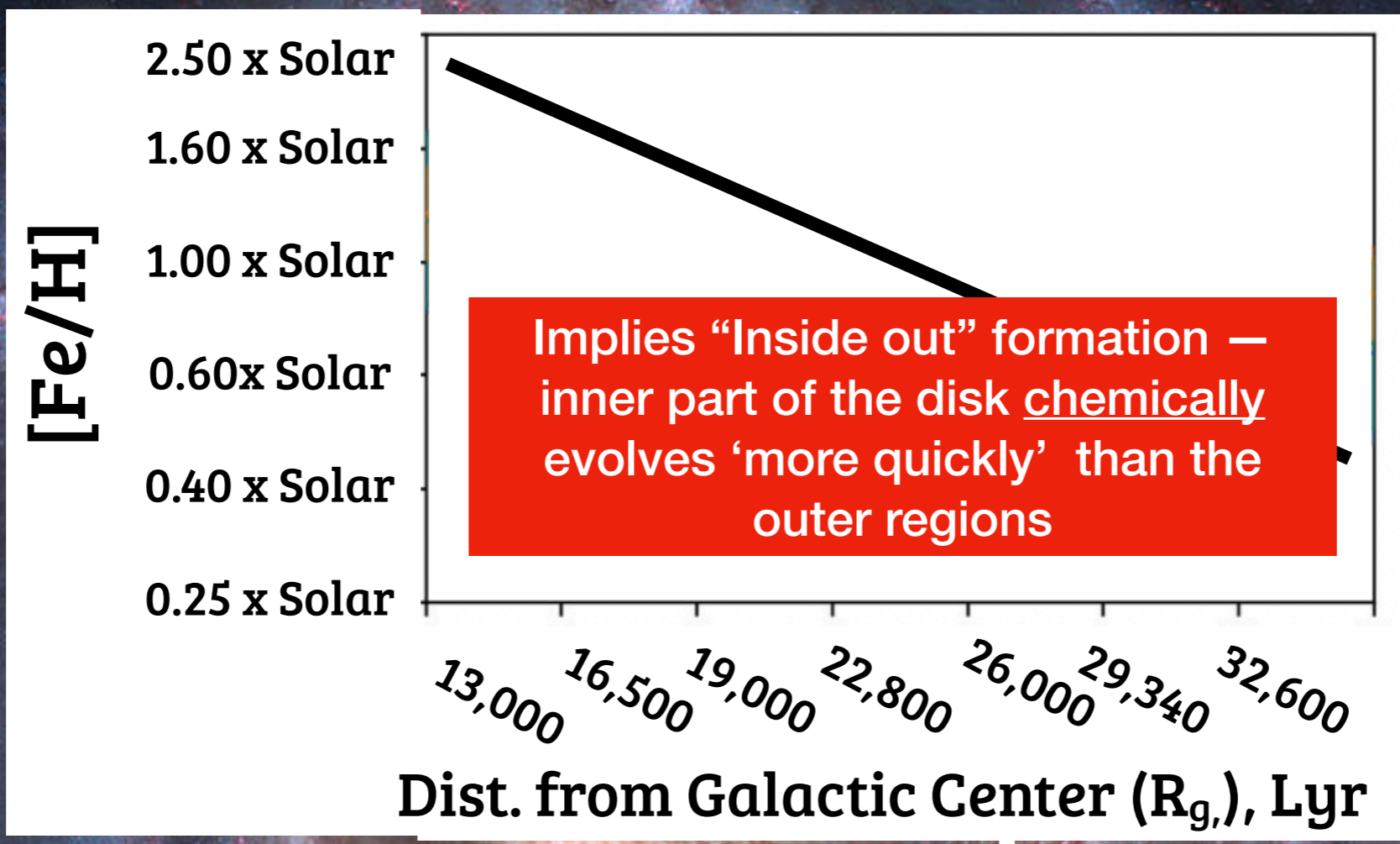
Dist. from Galactic Center (R_g), Lyr

[Fe/H] = 60% solar

R

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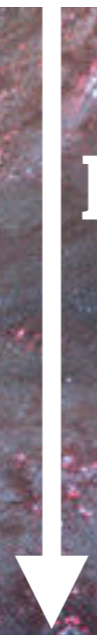


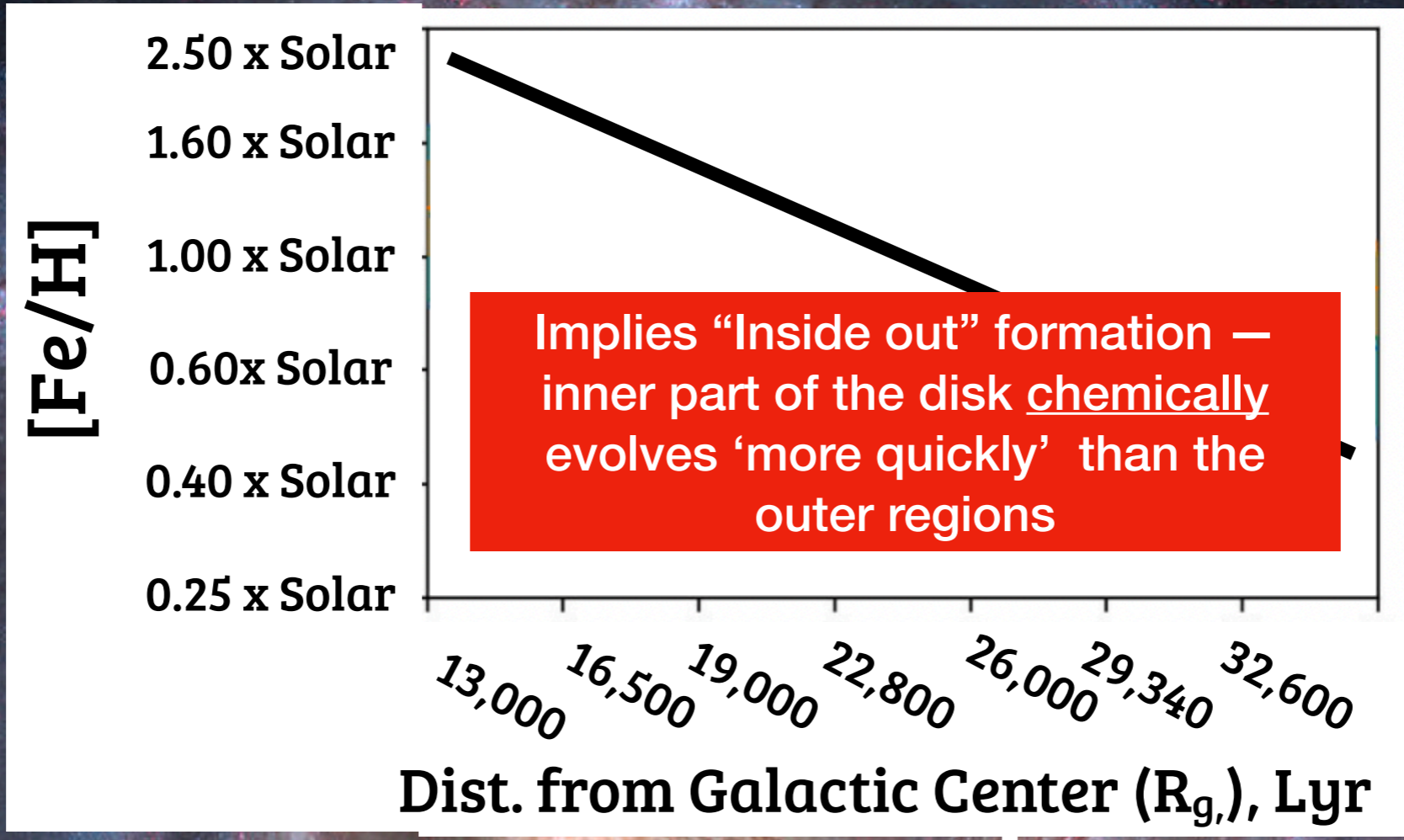


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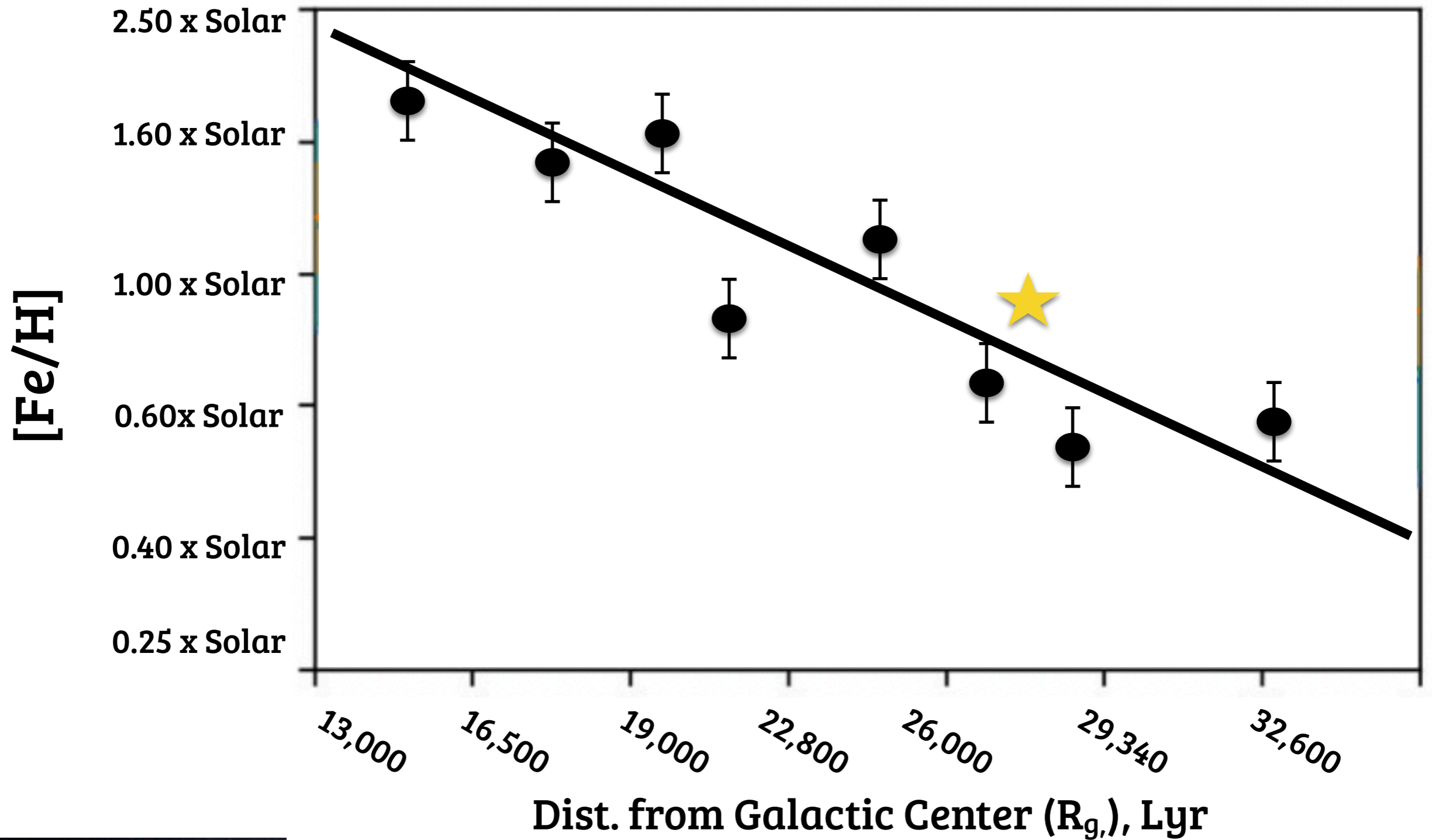
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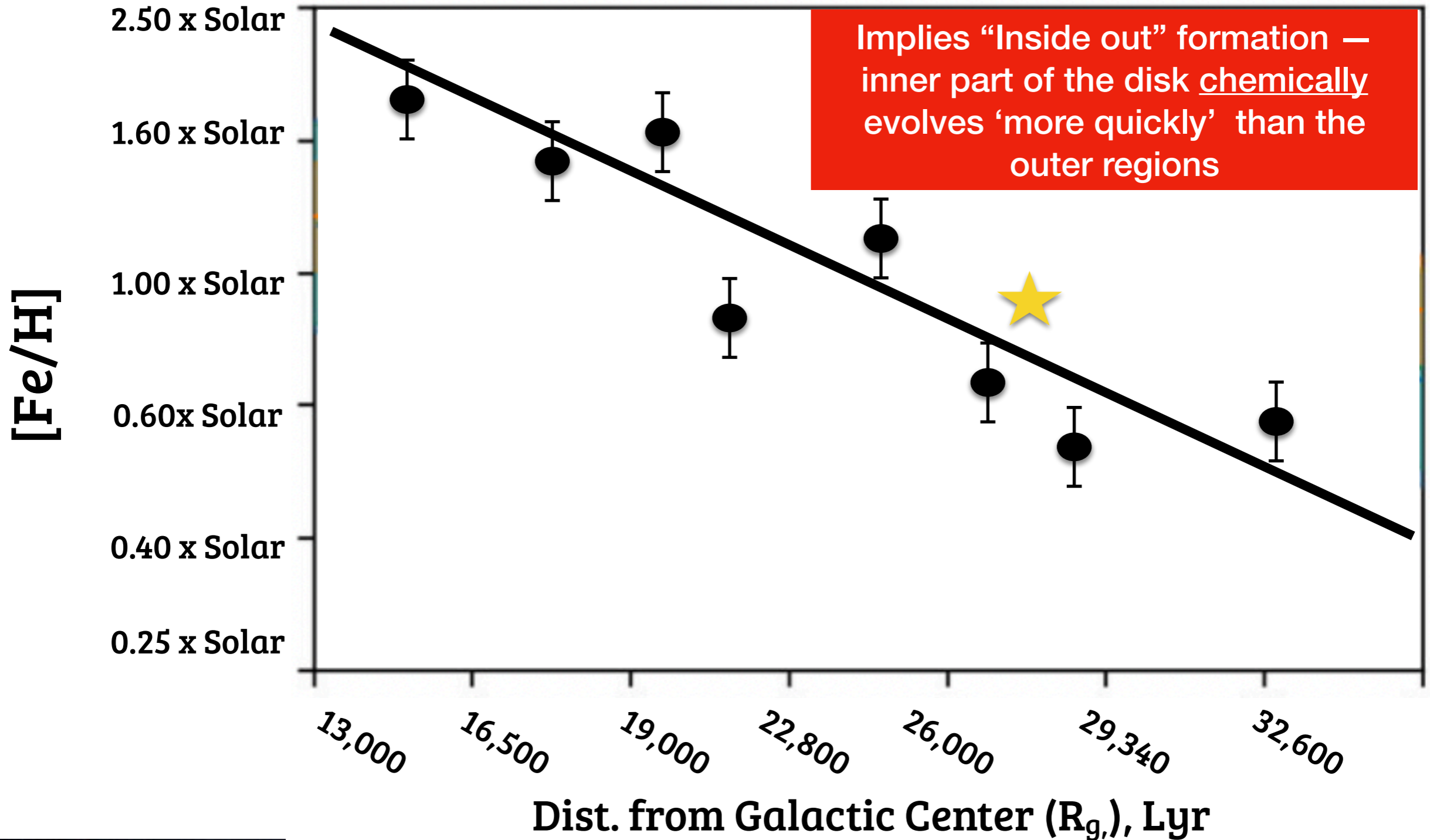
[Fe/H] = 25% solar

Assumption : All stars at a given R has same metallicity across all azimuthal angles (other galaxies imply this is not a good assumption!)

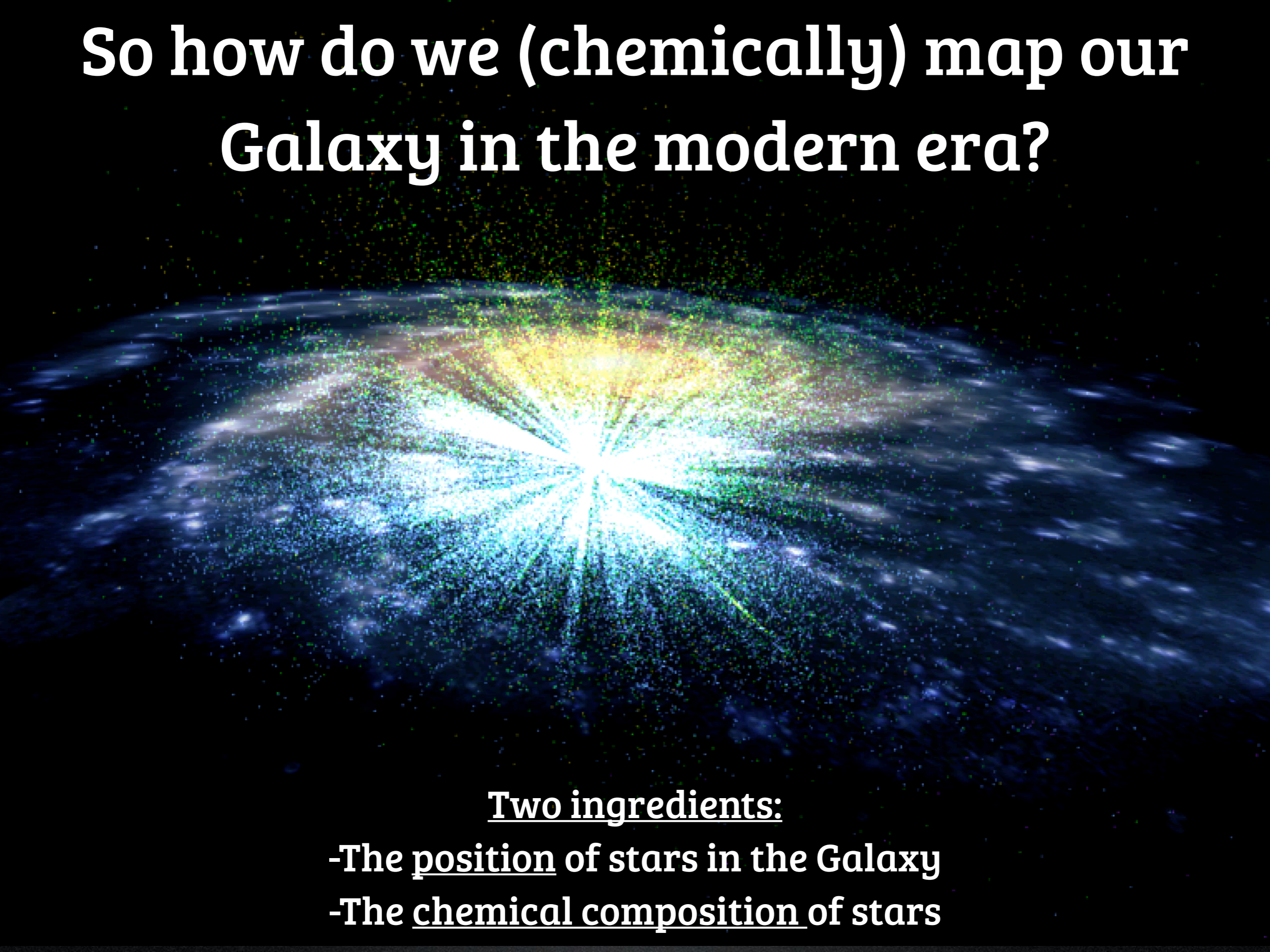
Real Data for <10 star clusters (based on Mayor 1976)



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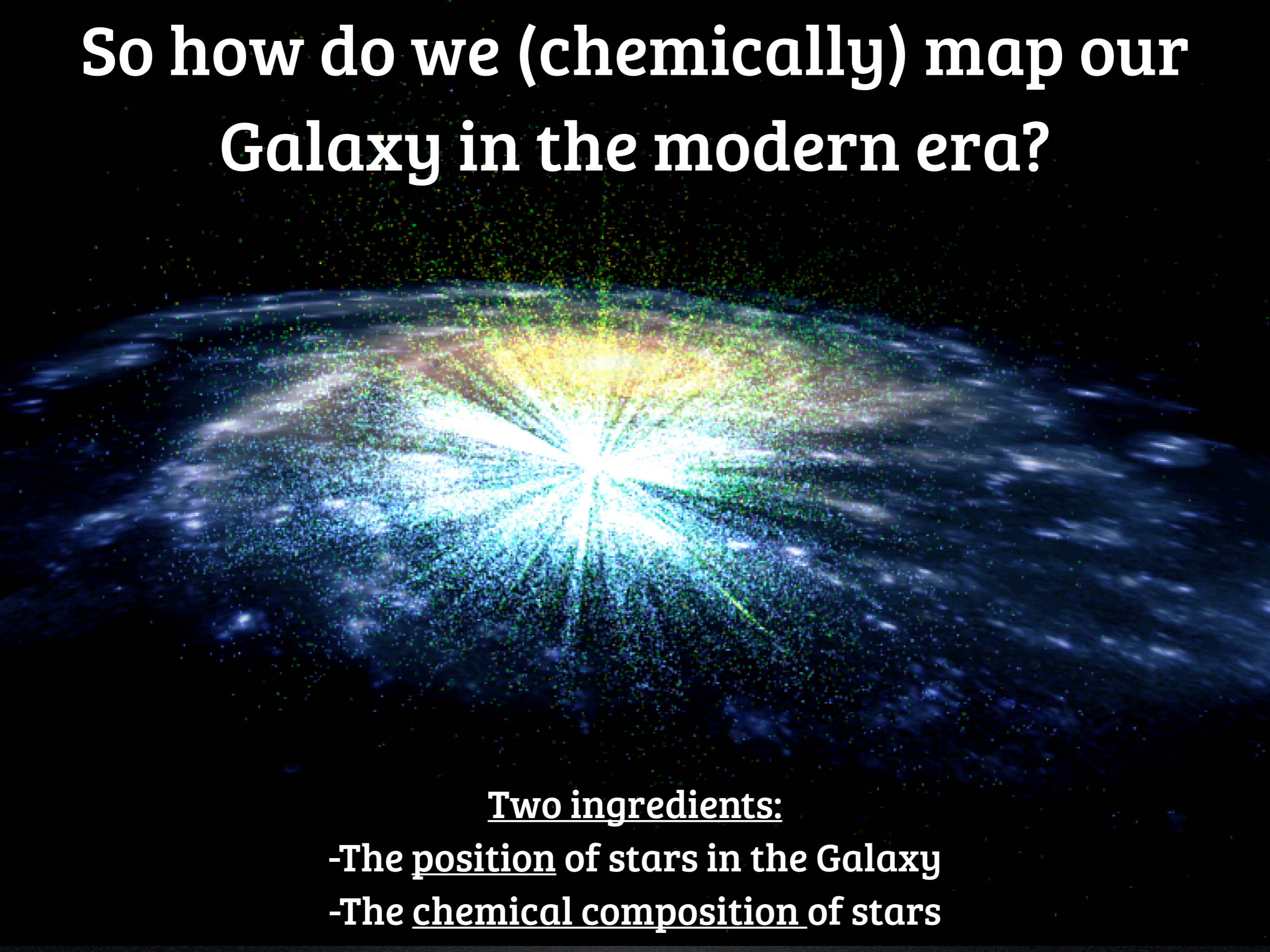
So how do we (chemically) map our Galaxy in the modern era?



Two ingredients:

- The position of stars in the Galaxy
- The chemical composition of stars

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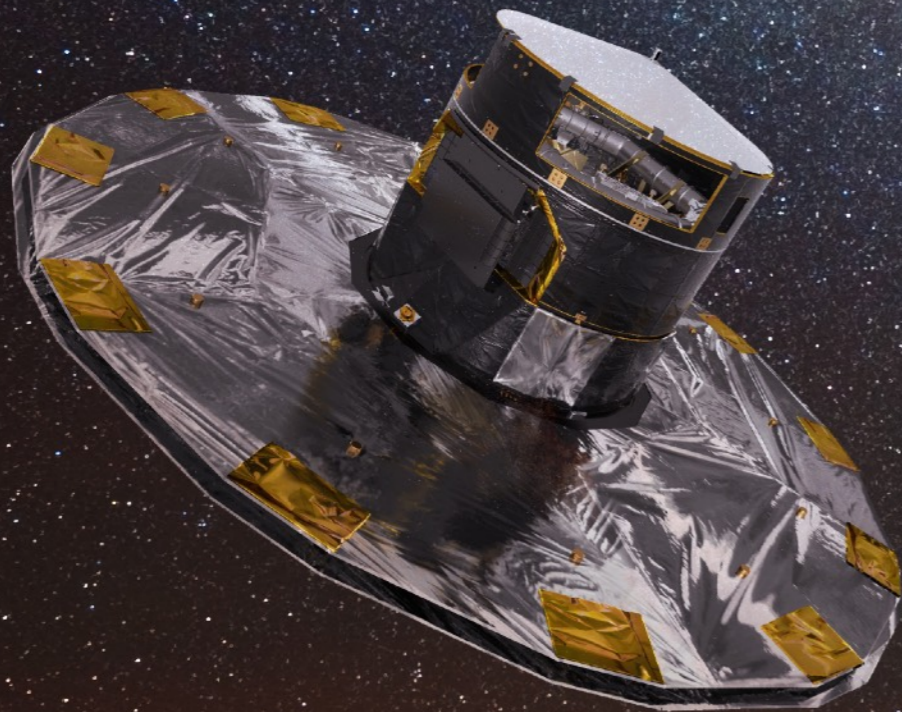


Two ingredients:

- The position of stars in the Galaxy
- The chemical composition of stars

Ingredient 1: Positing Stars with Gaia

Tag: The Billion Star Surveyor



Ingredient 1: Positing Stars with Gaia

Tag: The Billion Star Surveyor

★ Produce the most precise 3-D
map of the Galaxy ever

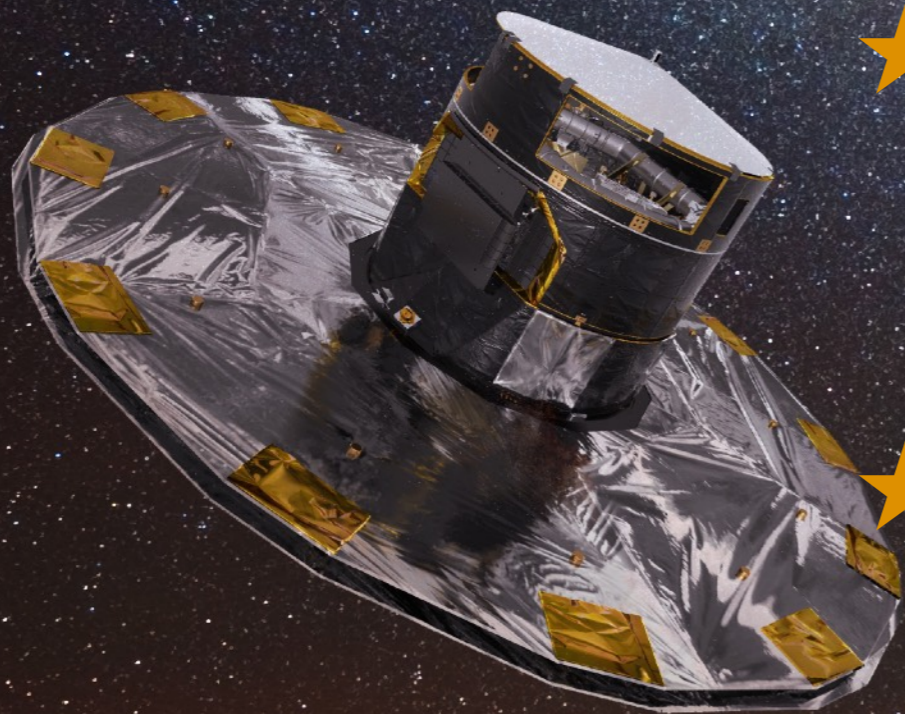
attempted 🌌

★ Its why I went to Cambridge

for PhD 🎓

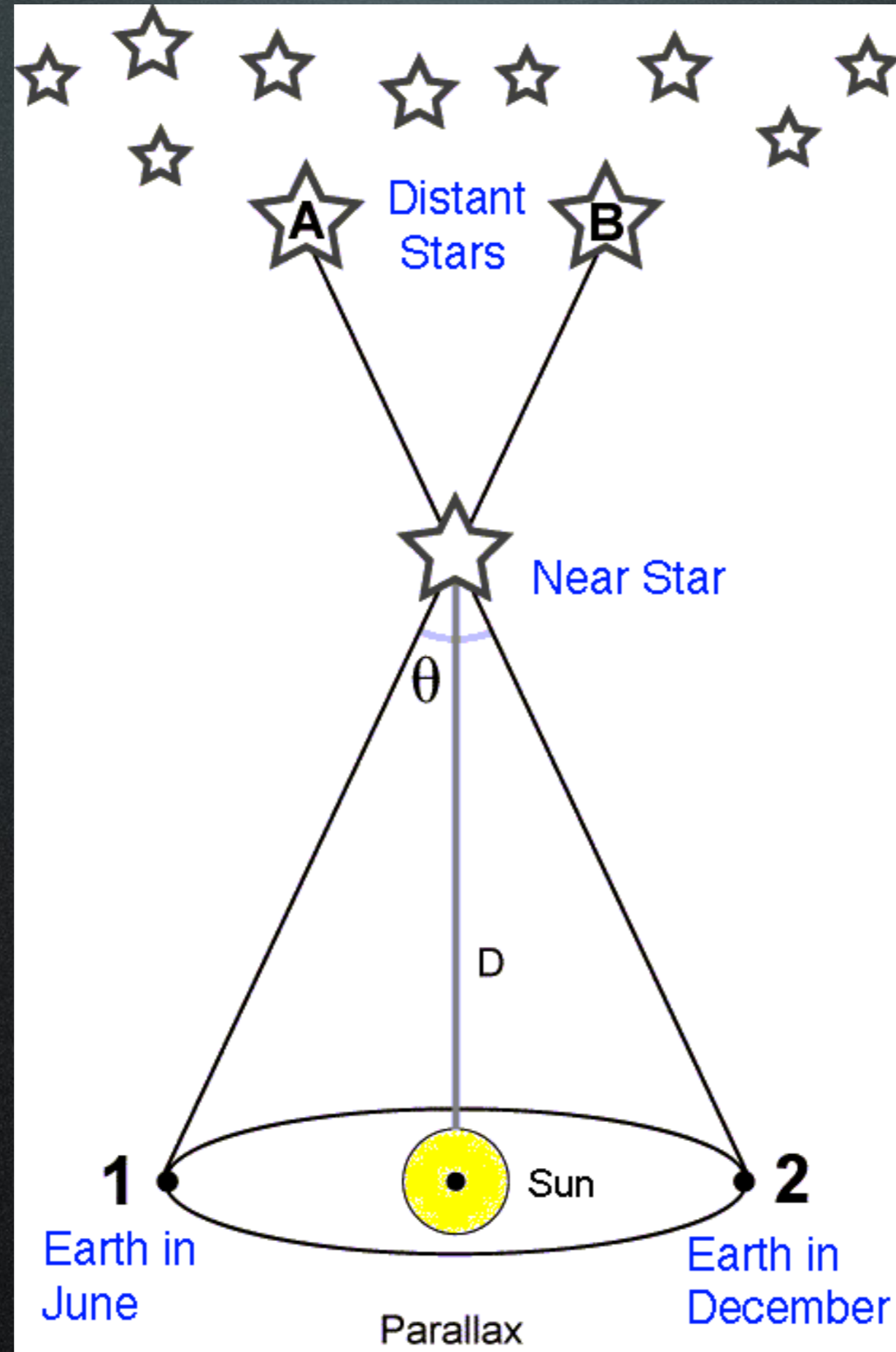
★ Gaia has mapped 2 BILLION

stars (~1-2% of the MW 😱)...



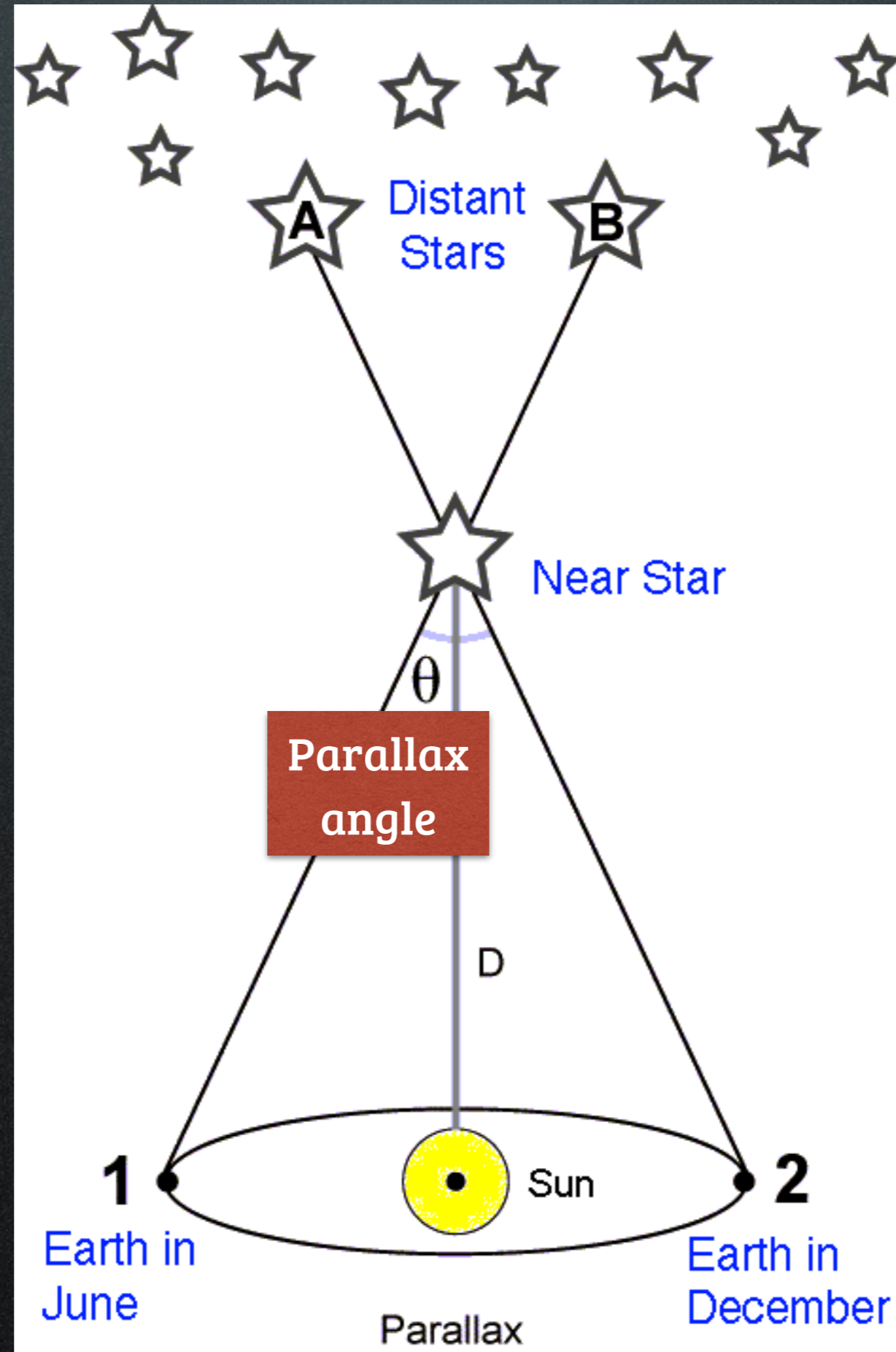
How will Gaia Measure distances?

Parallax



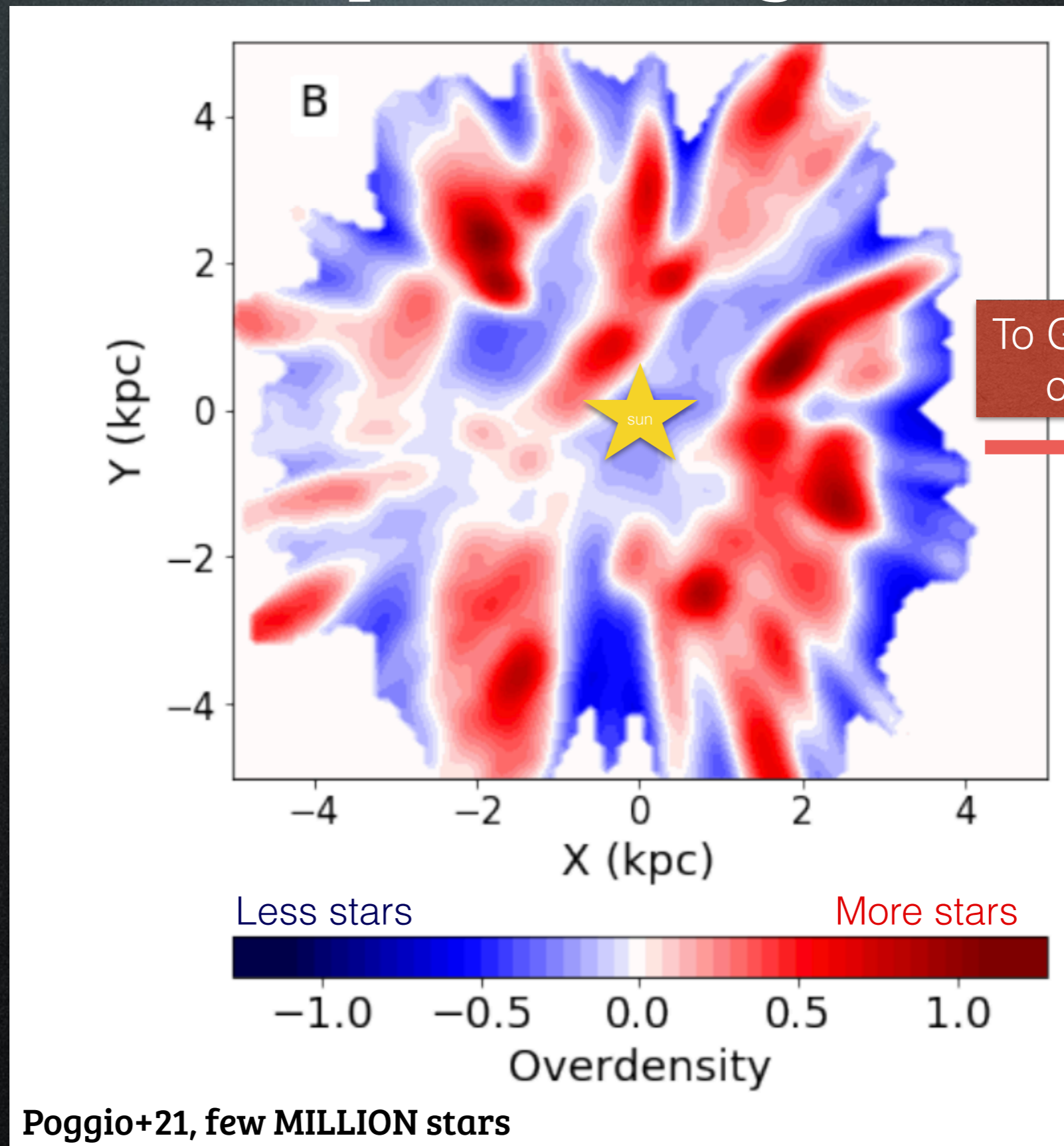
How will Gaia Measure distances?

Parallax





Position of millions of stars reveal the Milky Way is a Spiral Galaxy



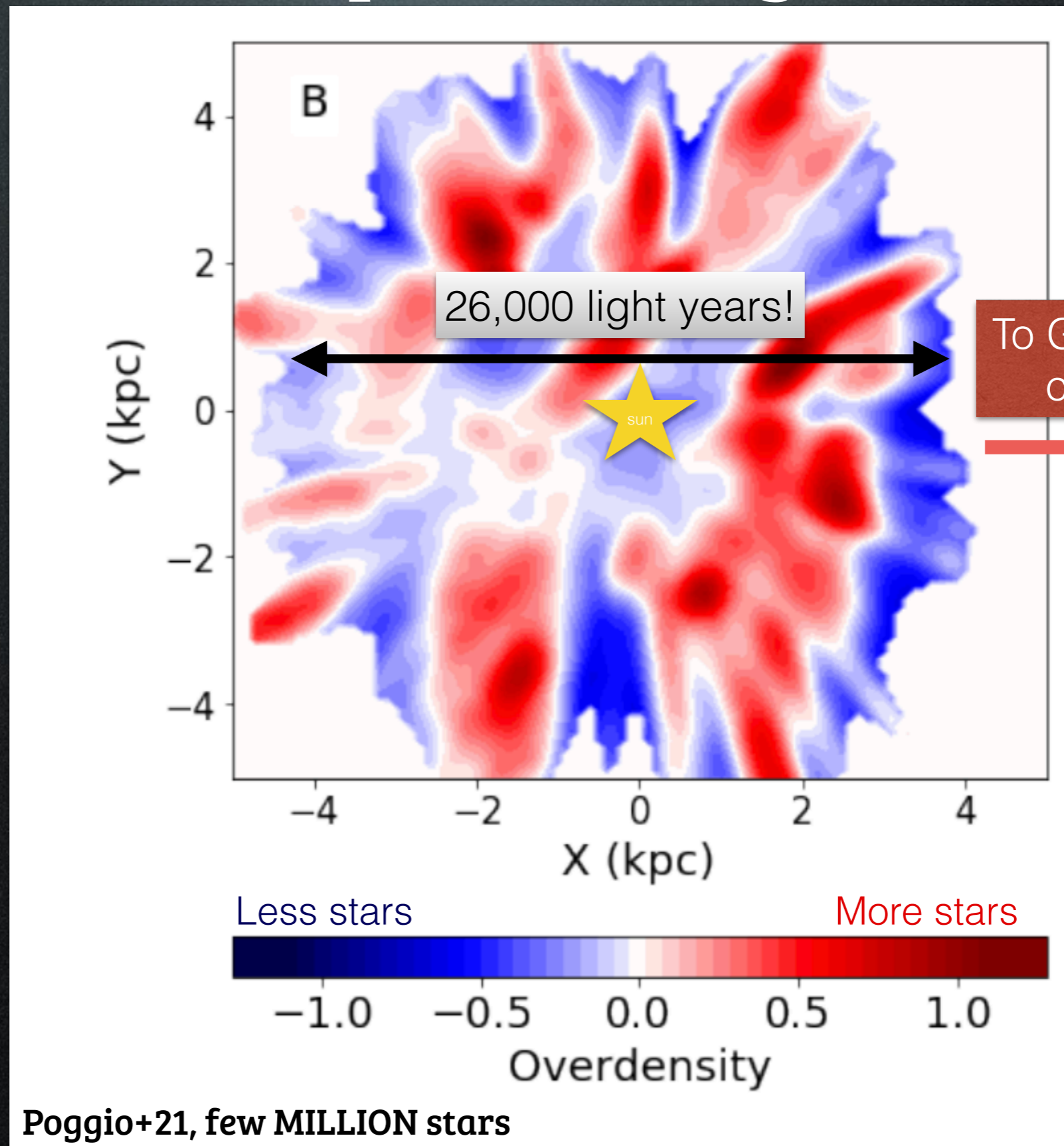
Hawkins 2023

Here:

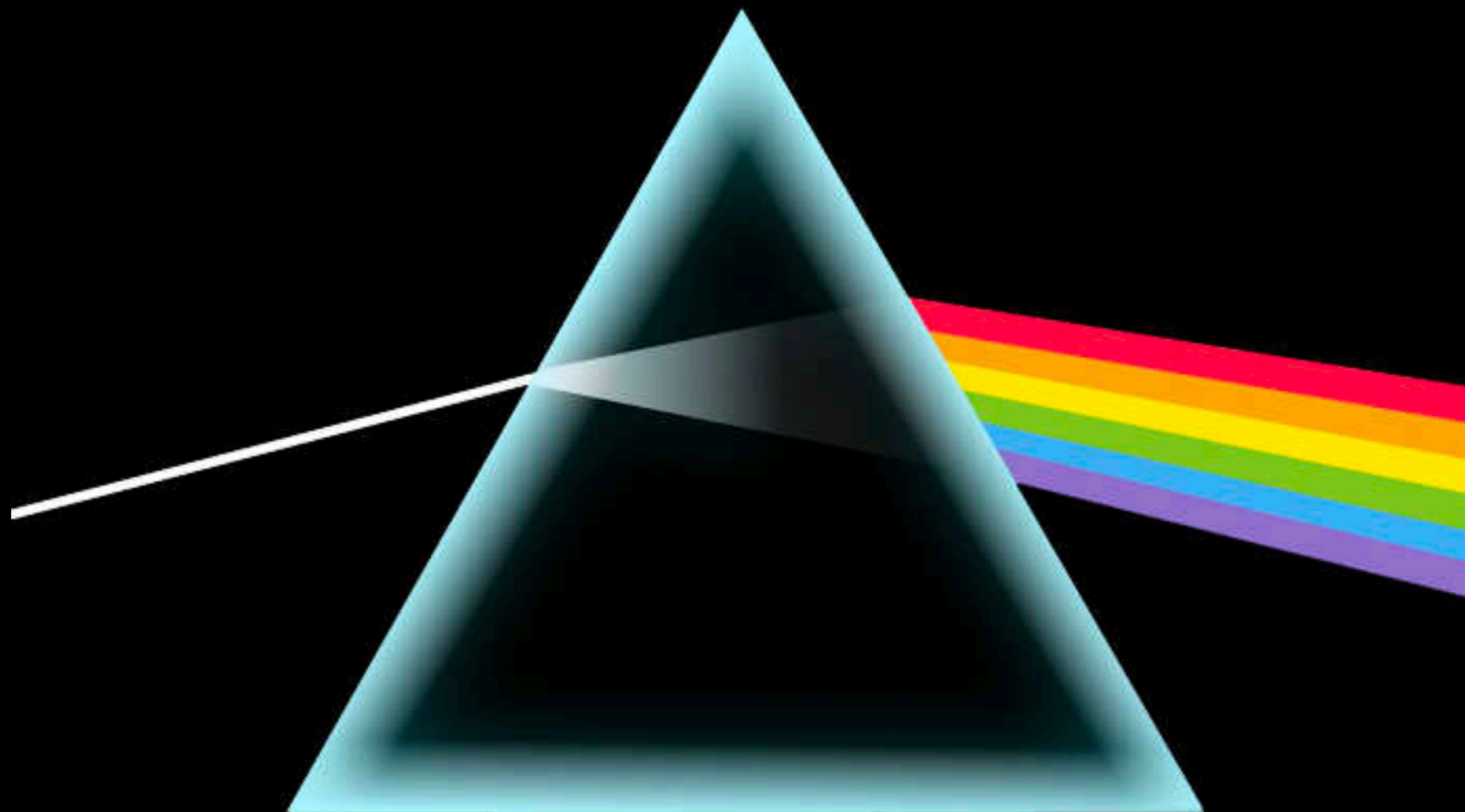
“kpc” = kiloparsec =
1,000 parsecs =
3,260 light years

Poggio+21, few MILLION stars

Position of millions of stars reveal the Milky Way is a Spiral Galaxy

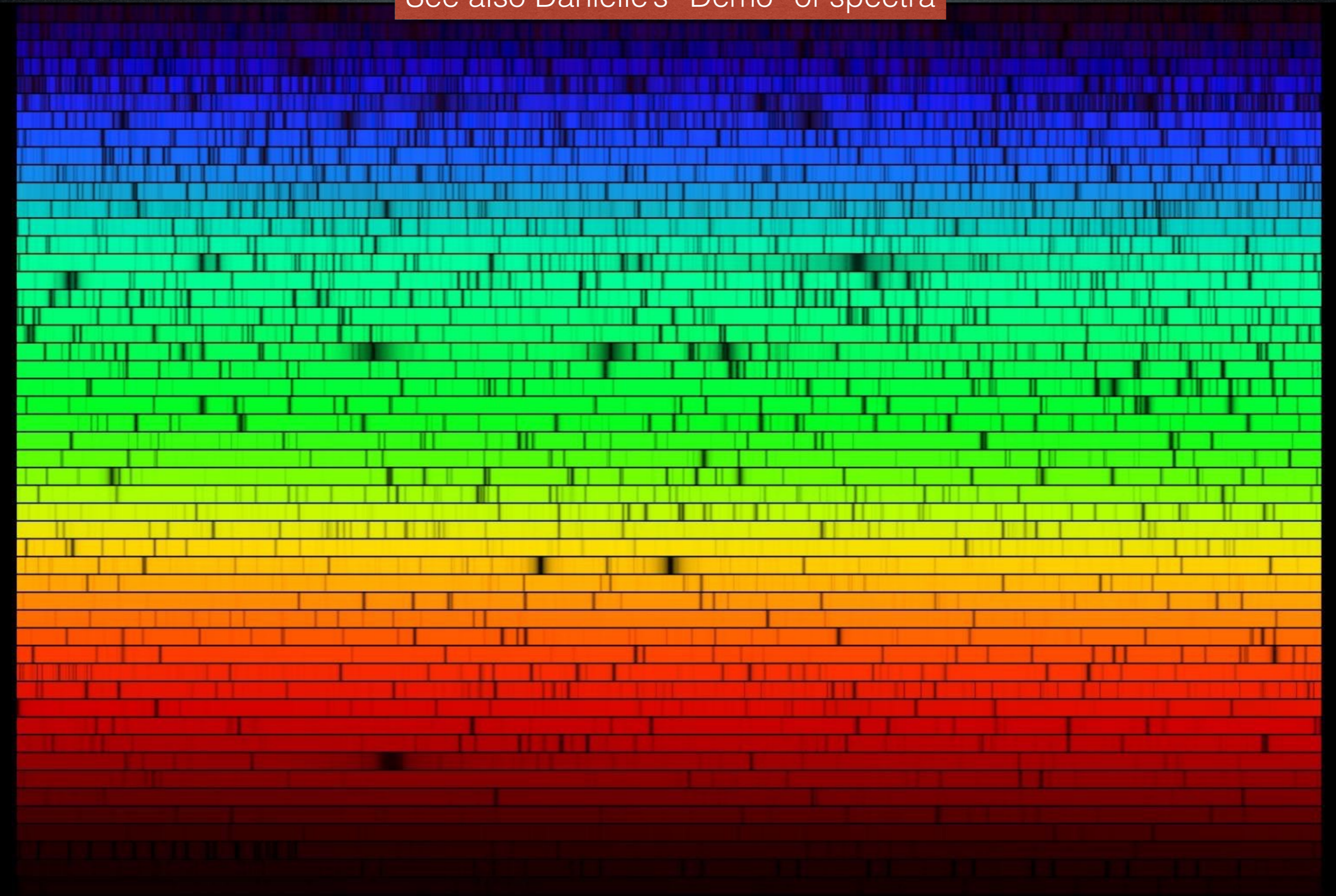


Ingredient 2: Spectroscopy as an chemical tool



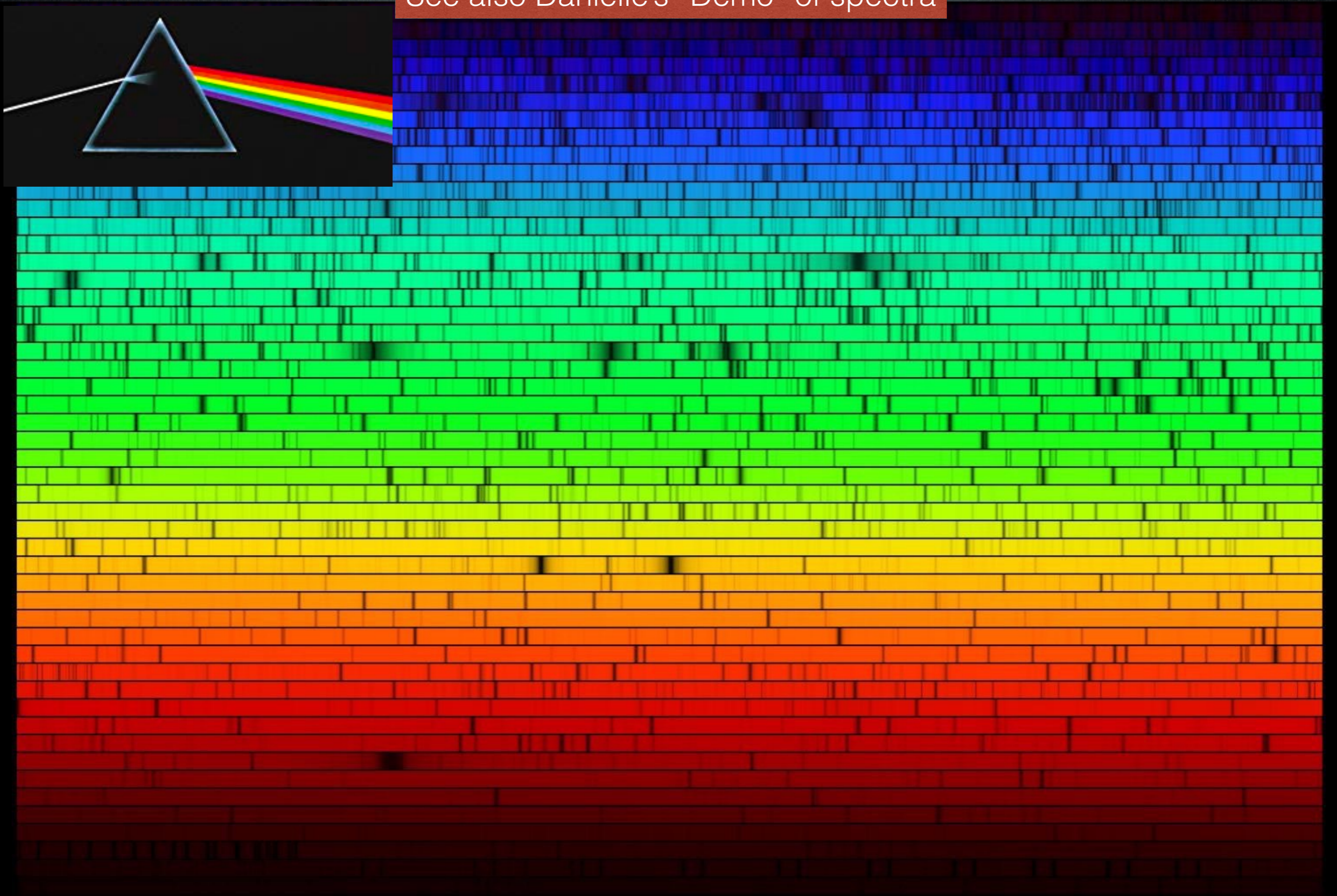
Spectroscopy: Learning Stellar DNA

See also Danielle's "Demo" of spectra



Spectroscopy: Learning Stellar DNA

See also Danielle's "Demo" of spectra



Spectroscopy: Learning Stellar DNA

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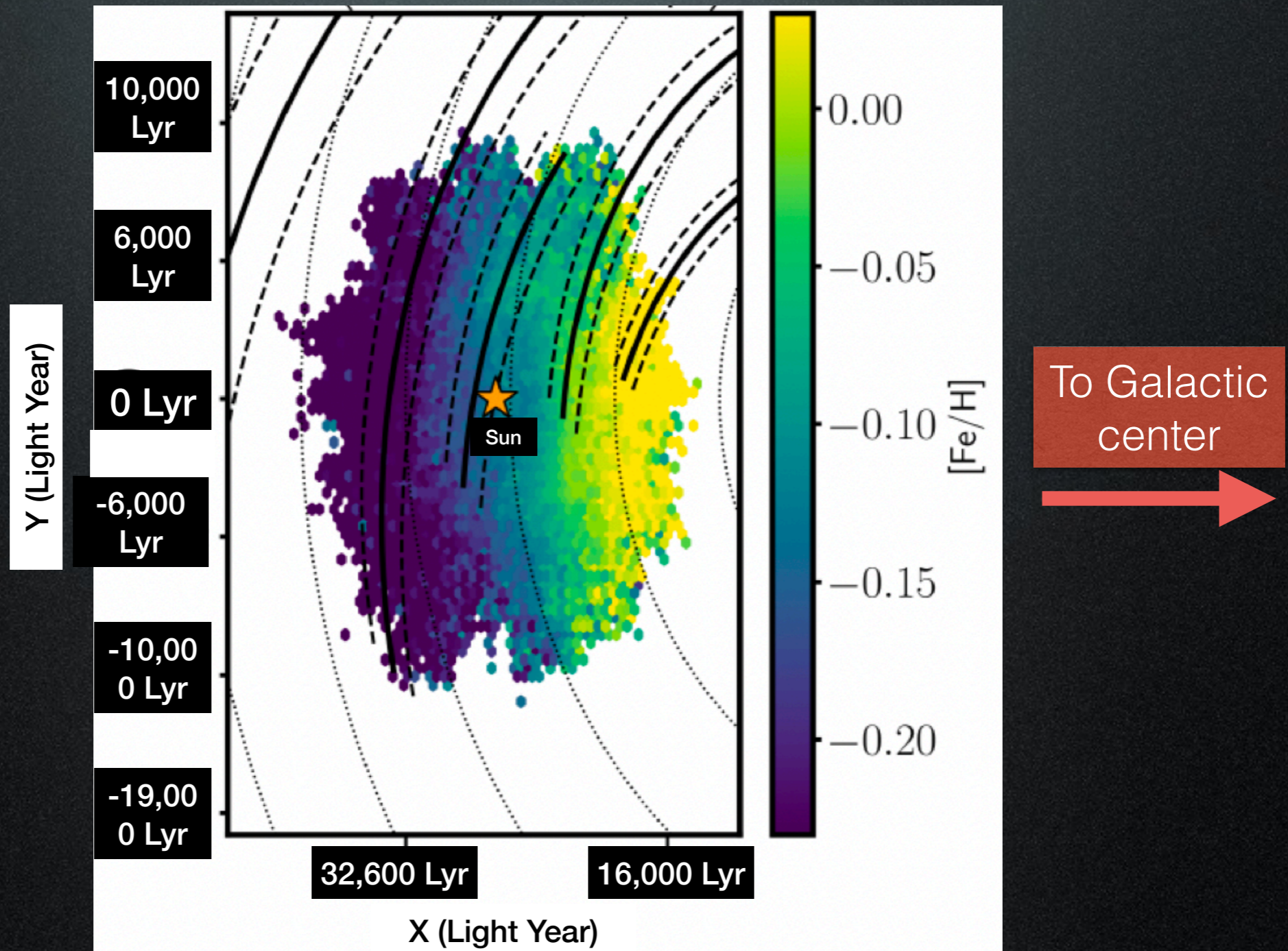
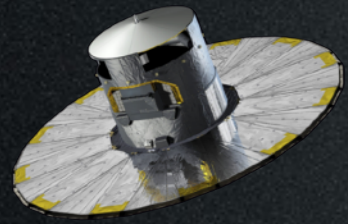
Spectroscopy: Learning Stellar DNA

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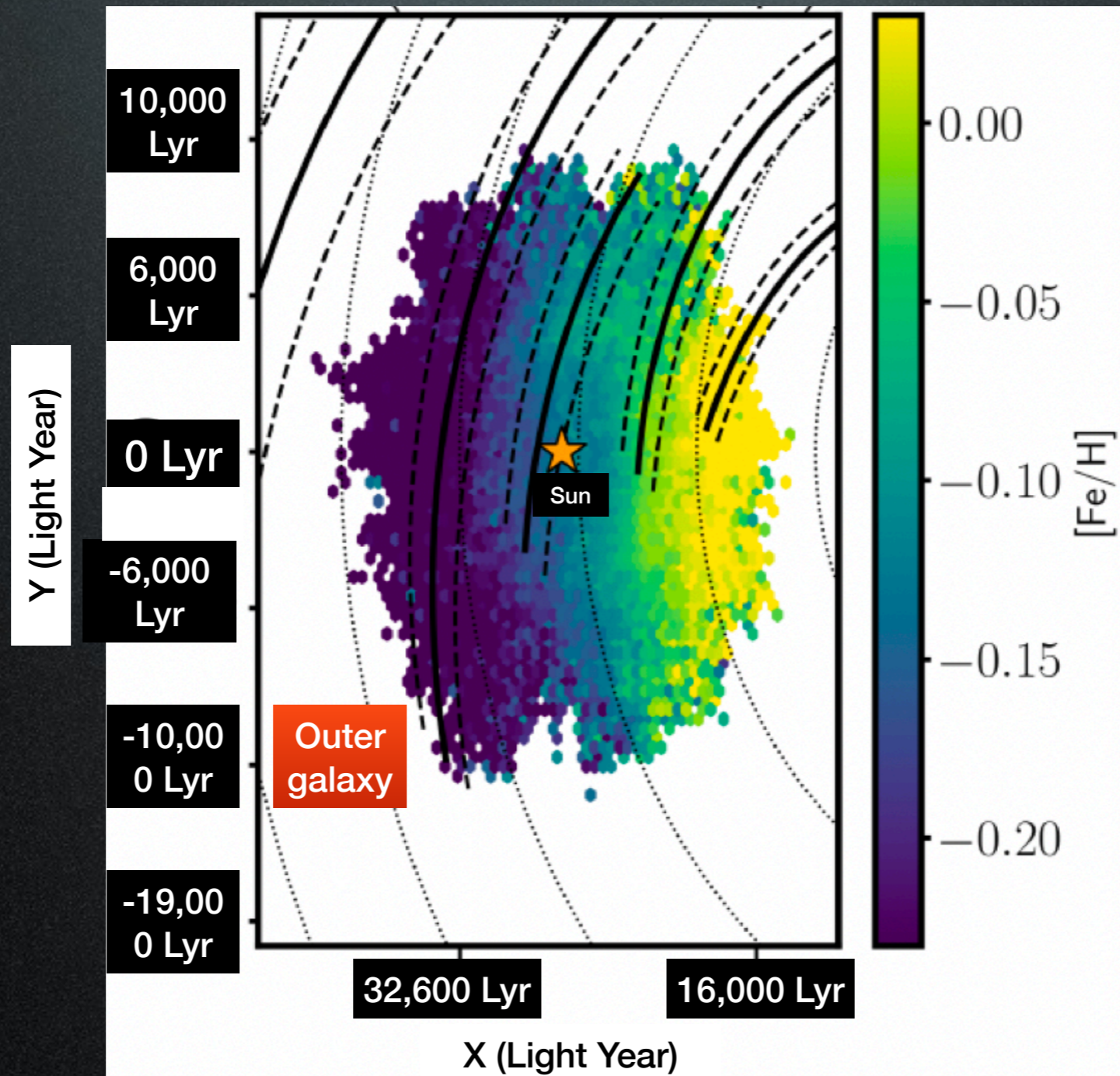
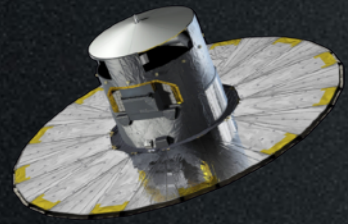


**UT Austin is world leader in traditional stellar chemistry
And these Archaeological tools have taught us about Galactic
structure**

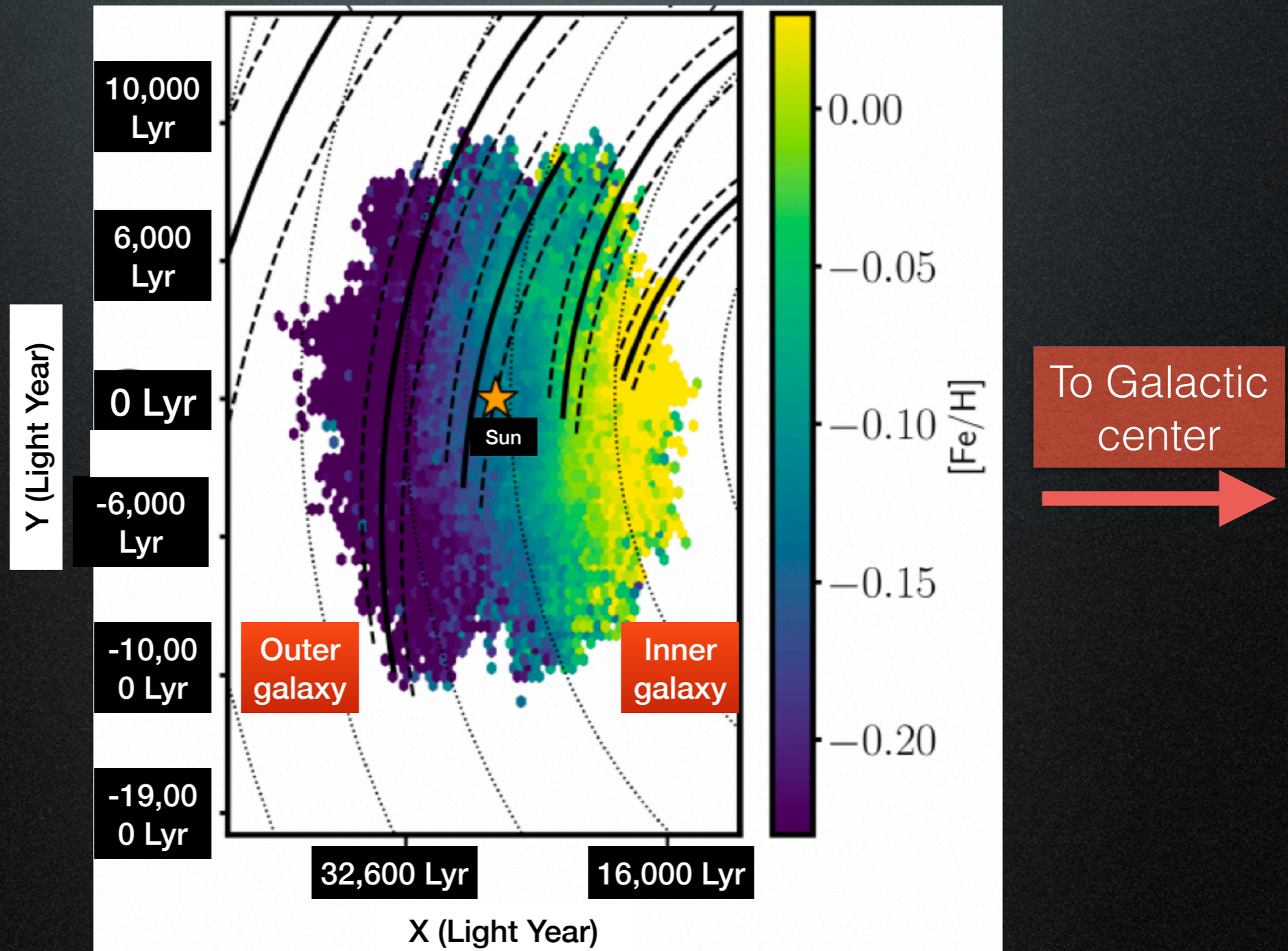
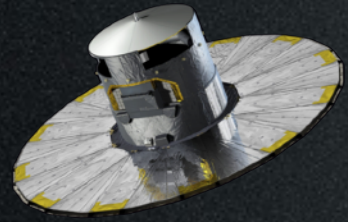
The chemical map of millions of stars in the Galaxy



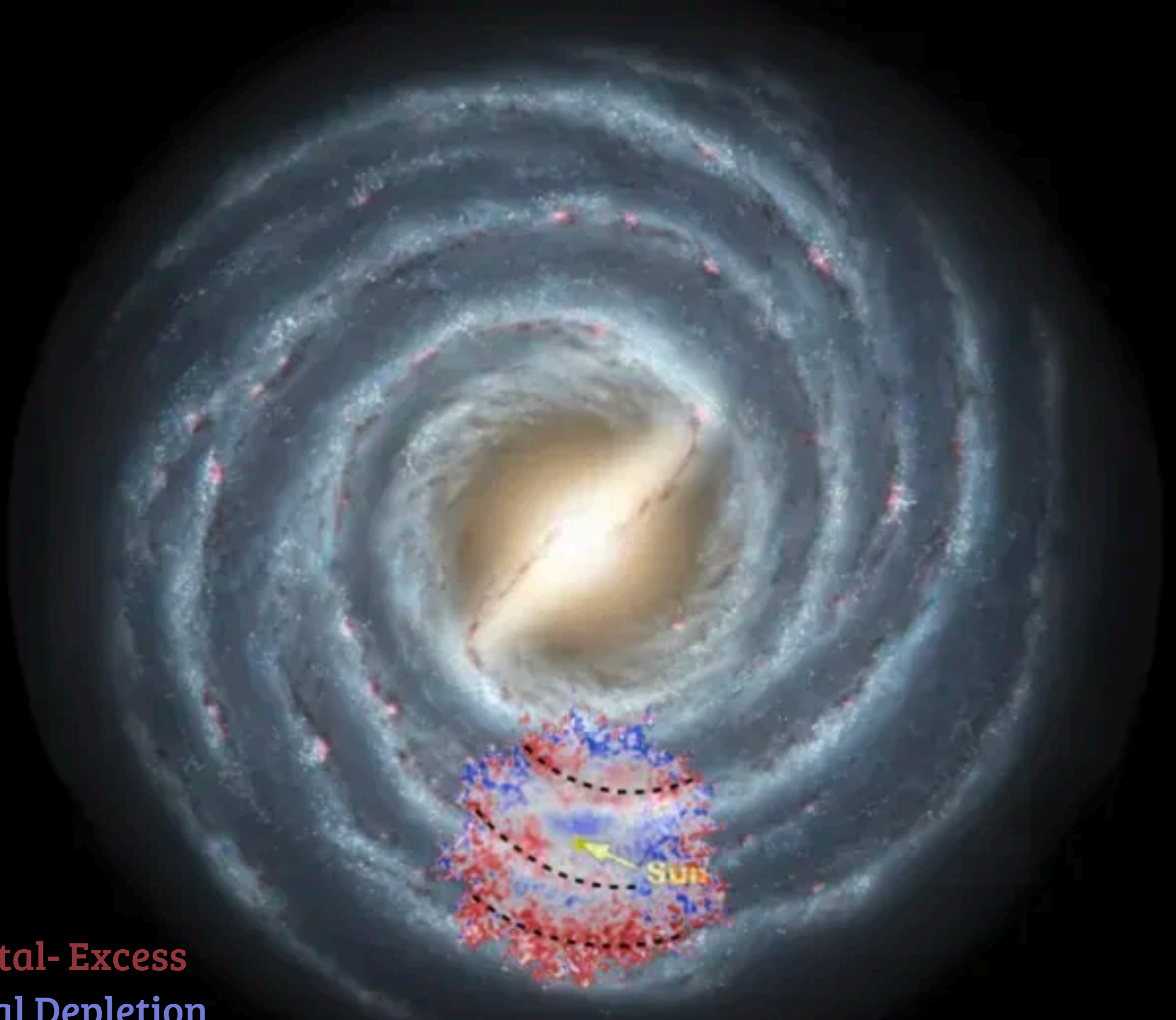
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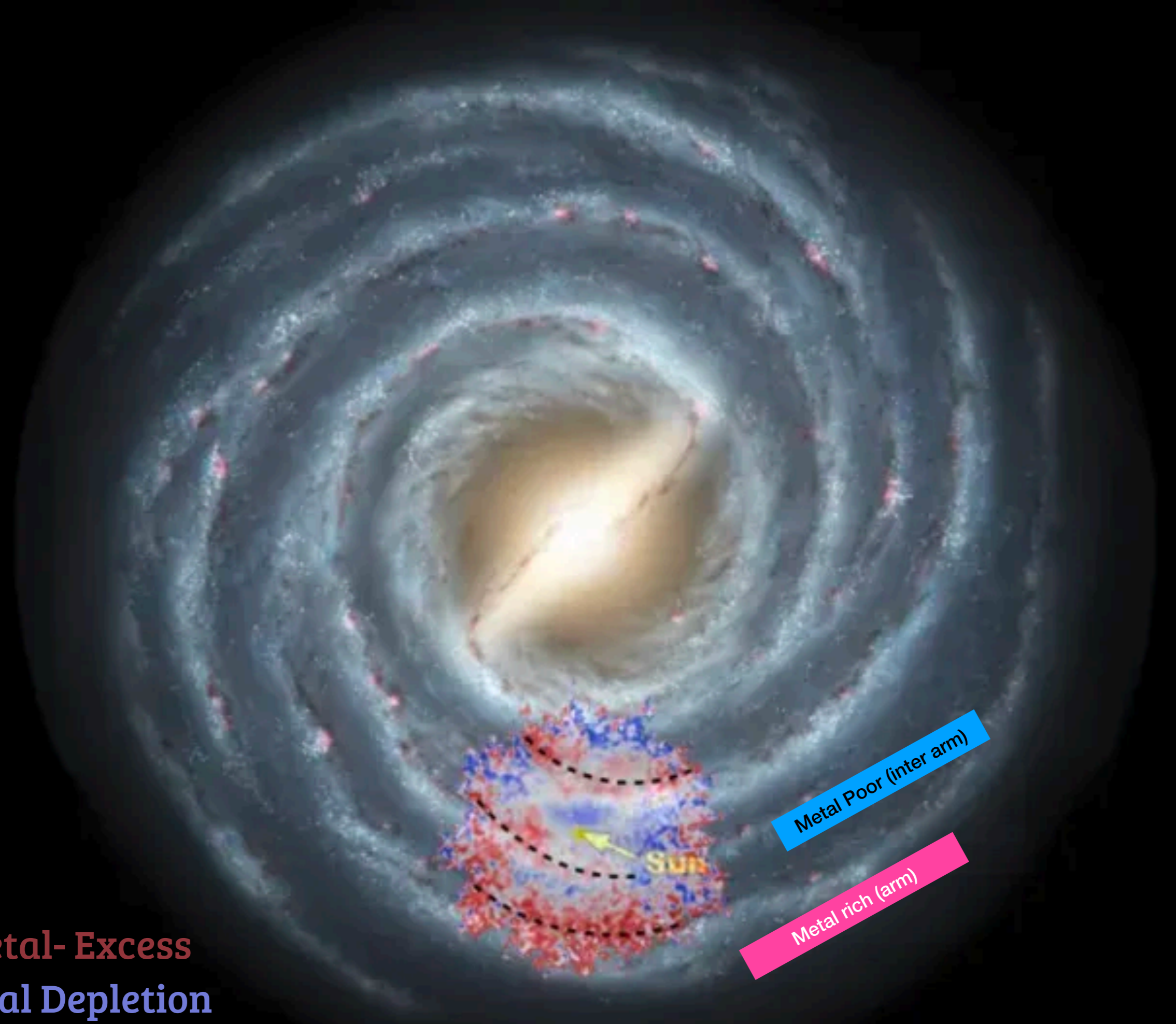
The chemical map of millions of stars in the Galaxy



Metal- Excess
Metal Depletion



Metal- Excess
Metal Depletion



Metal Poor (inter arm)

Metal rich (arm)

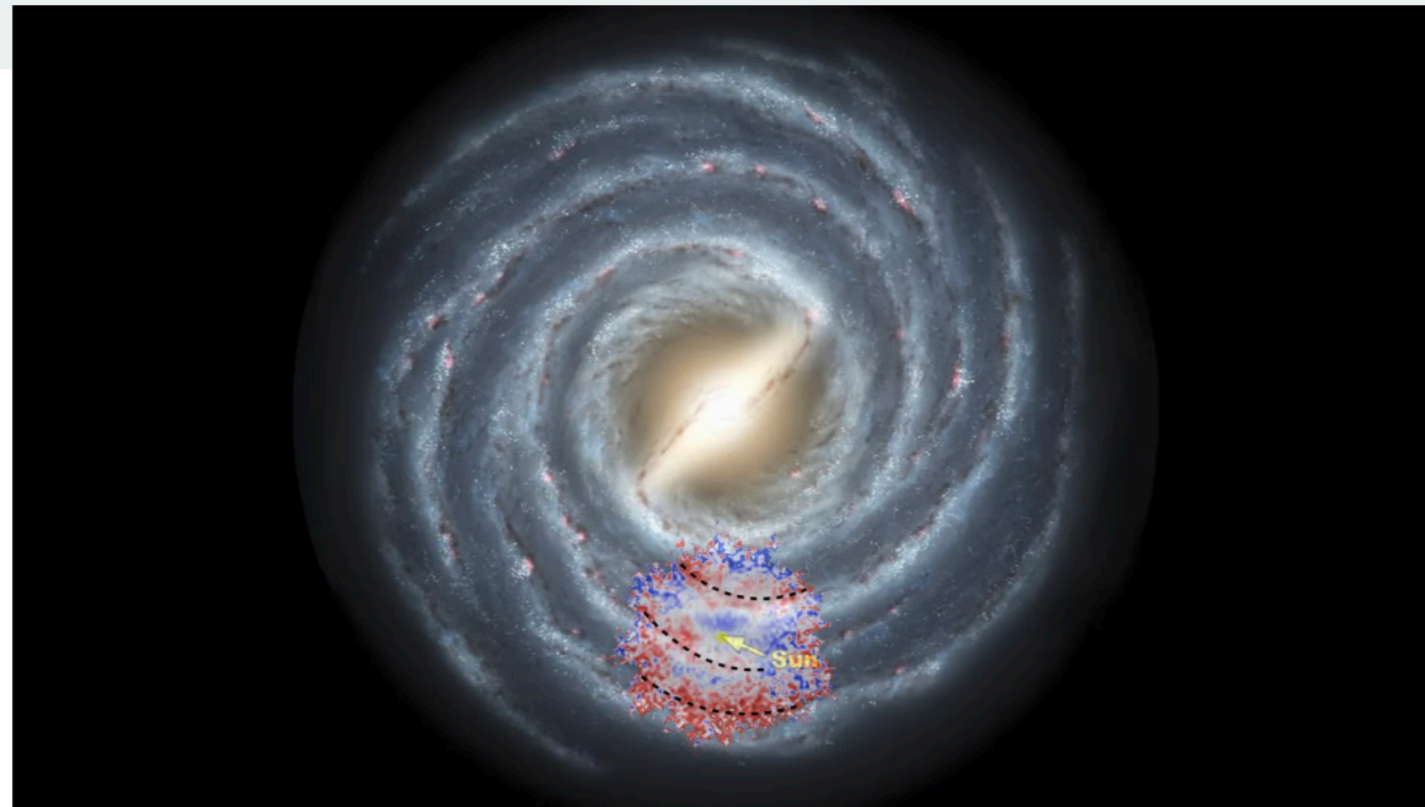


RESEARCH

Chemical Cartography Reveals the Milky Way's Spiral Arms

JULY 14, 2023 • BY EMILY HOWARD

The method overcomes the challenges of dust that block the view of some of the Milky Way's stars.



Hawkins' model superimposed over a NASA Jet Propulsion Laboratory illustration of the Milky Way. Red and blue spots indicate objects with a high or low metallicity, respectively. High metallicity (red) corresponds to the presence of young stars, which are more abundant in spiral arms. Credit: K. Hawkins (UT Austin), NASA/JPL-Caltech/R. Hurt (SSC/Caltech).

Keith Hawkins, assistant professor of astronomy at The University of Texas at Austin, has used chemical cartography – also known as chemical mapping –

Share



Metal- Exce
Metal Depletion

**Chemically mapping the Galaxy has
revealed ...**

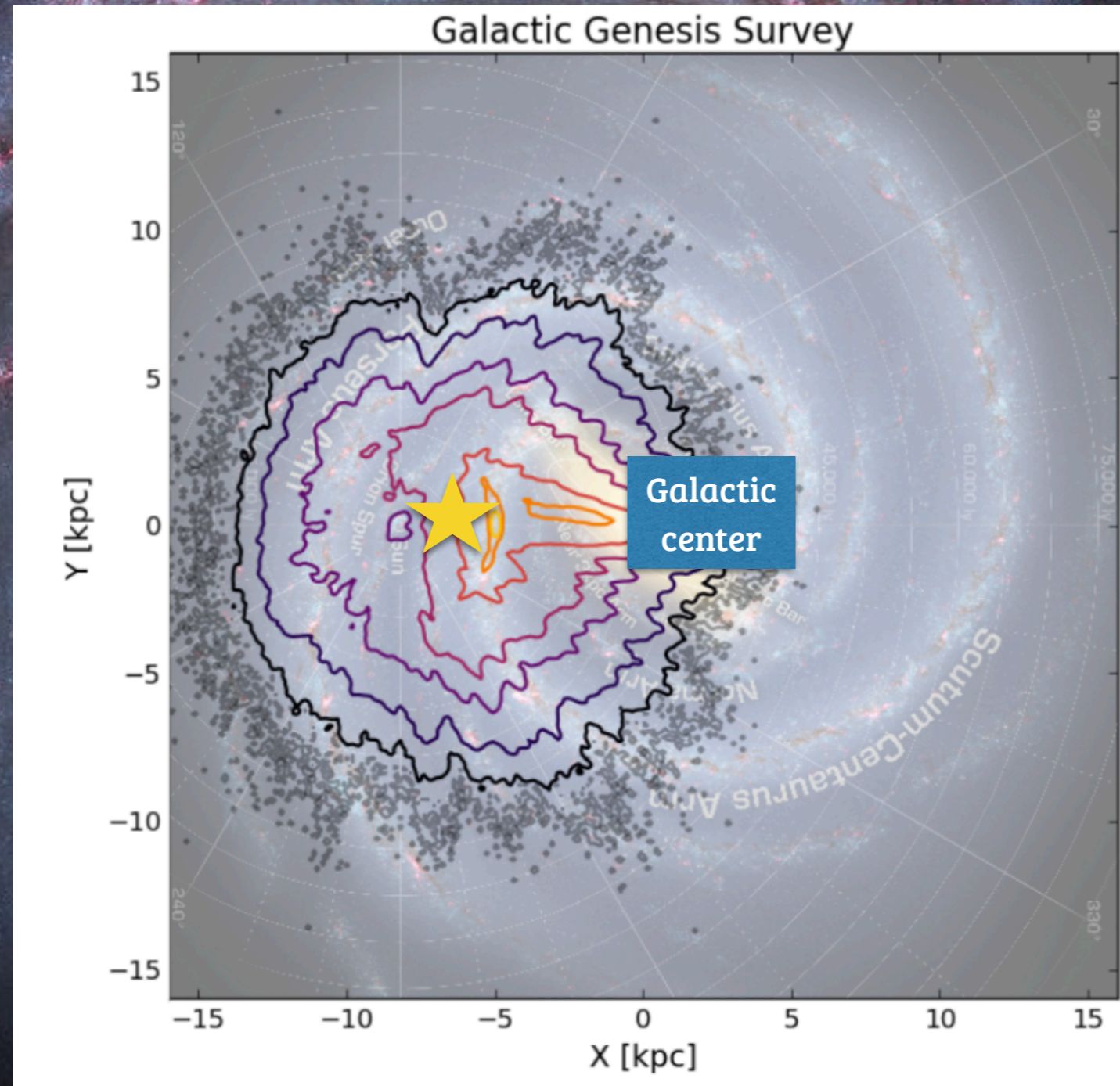


Chemically mapping the Galaxy has revealed ...



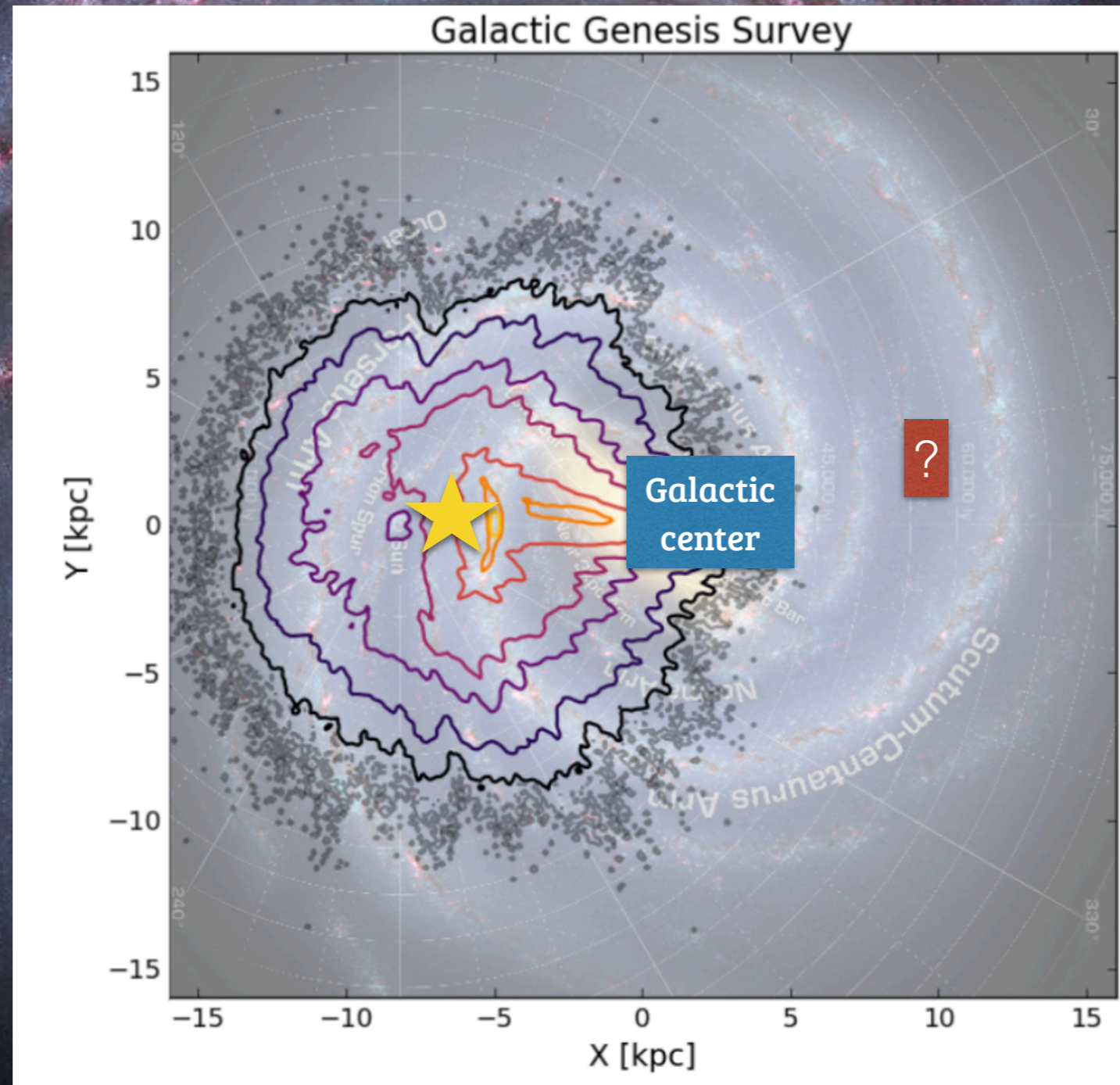
Our Cosmic home (the Milky Way's Galactic disk) formed "inside out" and it has spiral arms. Our Sun/Solar System lives at the edge of one spiral arm.

A New Mission for me: A first explorer of far side of the Milky Way



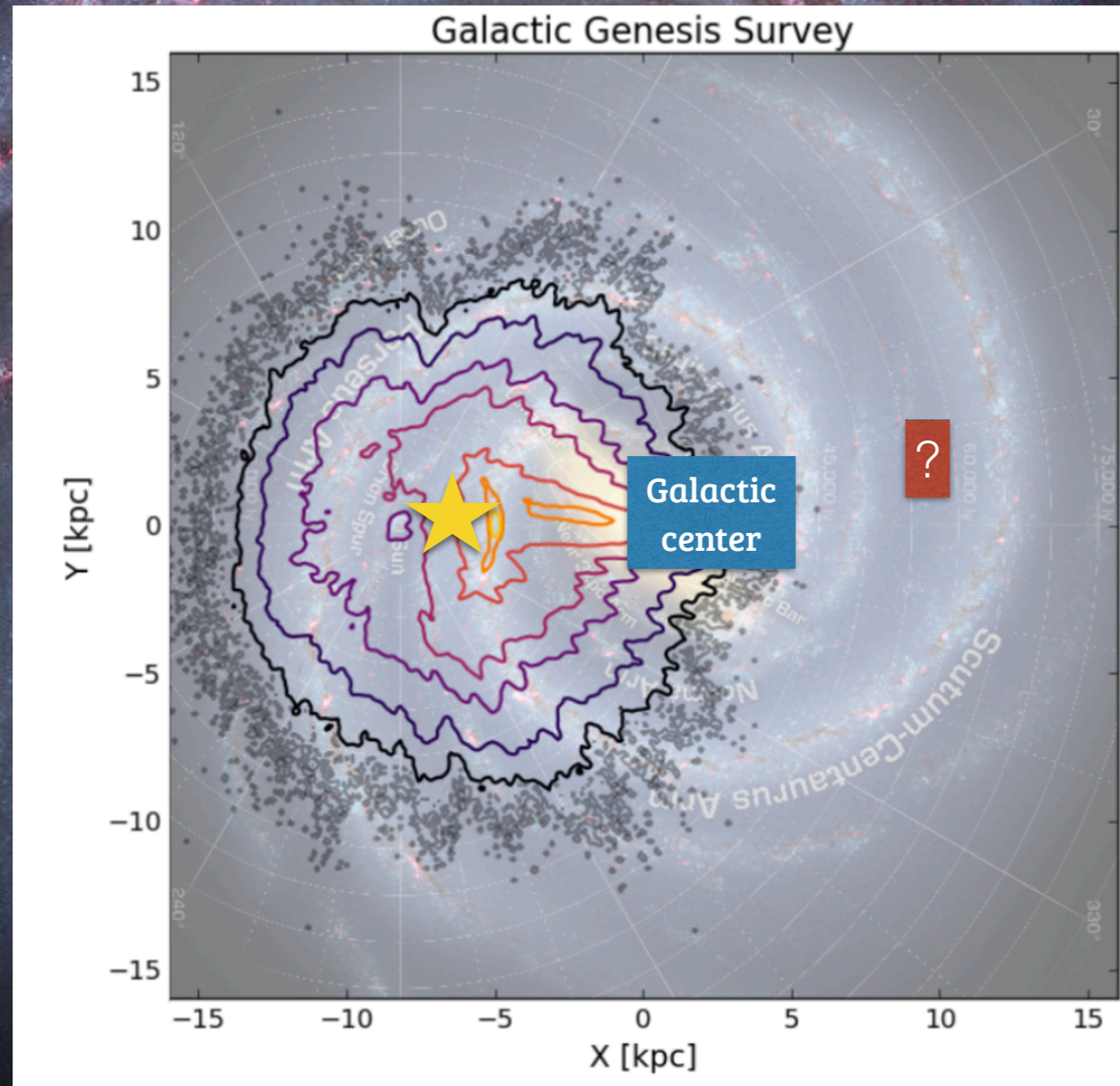
Hawkins+2026 (in prep)

A New Mission for me: A first explorer of far side of the Milky Way



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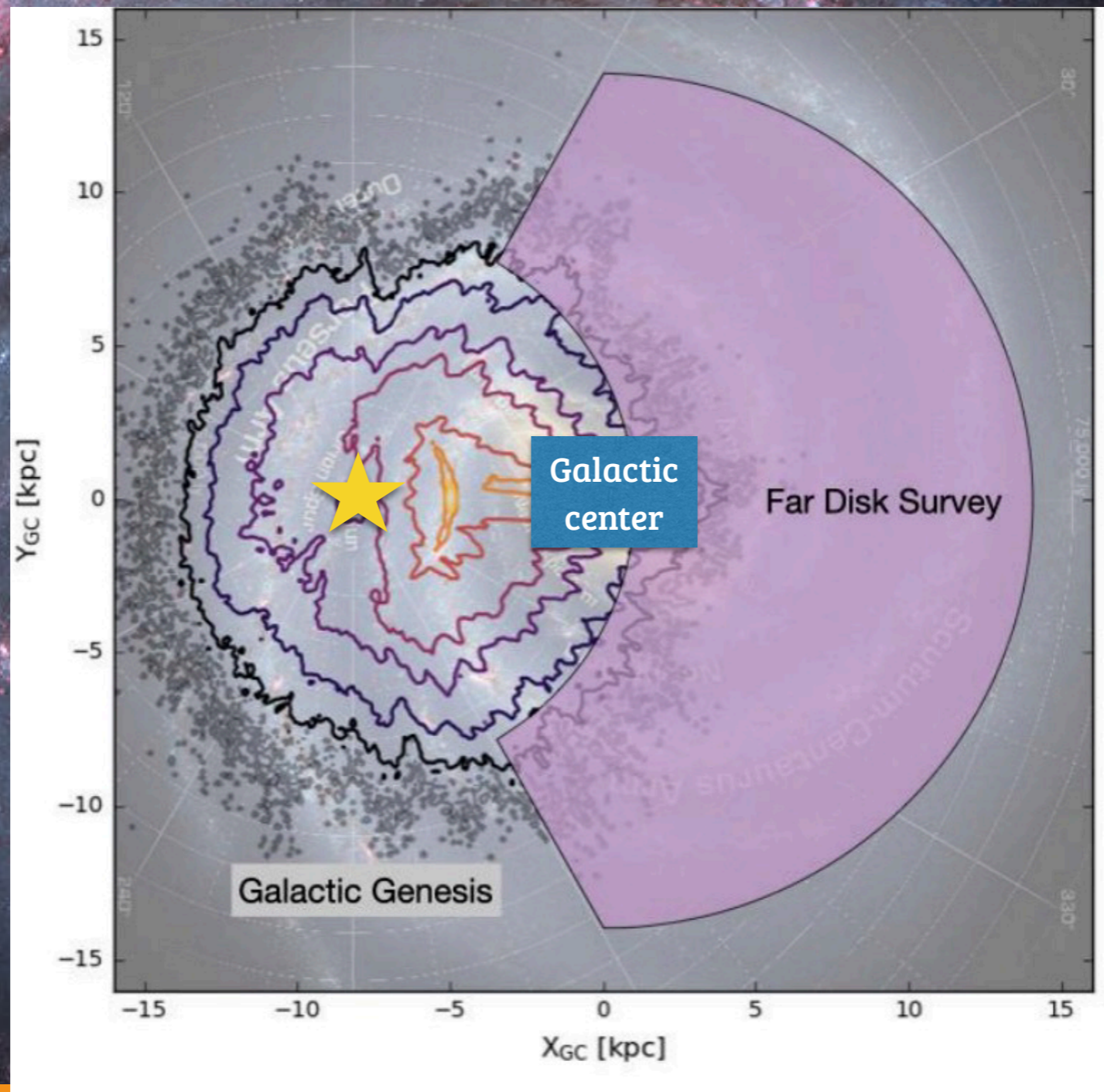
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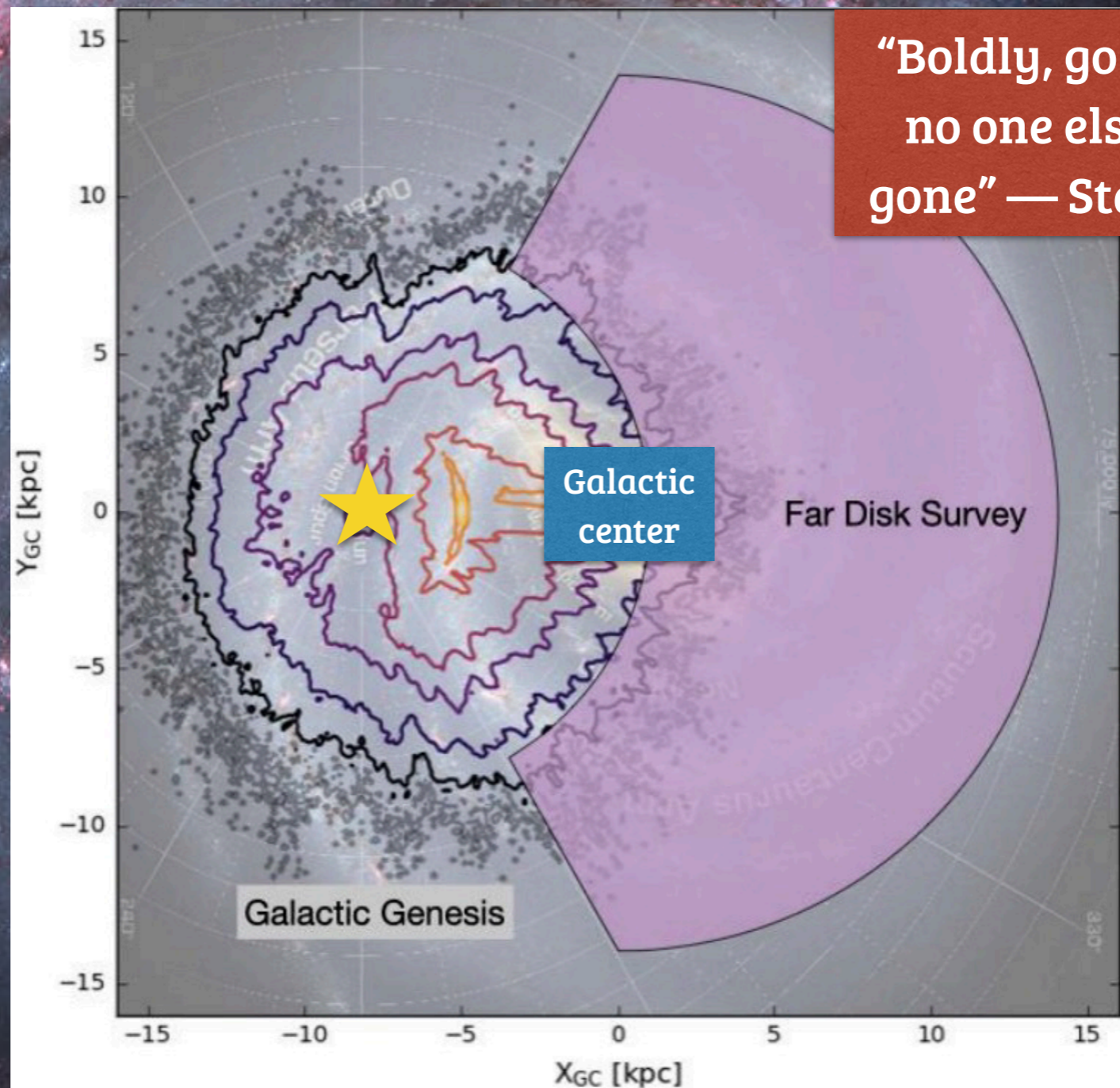
The "After Sloan-V" project — Director

A New Mission for me: A first explorer of far side of the Milky Way



The “After Sloan-V” project — Director

A New Mission for me: A first explorer of far side of the Milky Way



“Boldly, go where no one else has gone” — Star Trek

The “After Sloan-V” project — Director

**Chemical mapping can inform us
our history!**





**Chemical mapping can inform us
our history!**

**But it can also inform the history of 'life' elsewhere
in the Galaxy !**



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Maybe we share our cosmic home with others....



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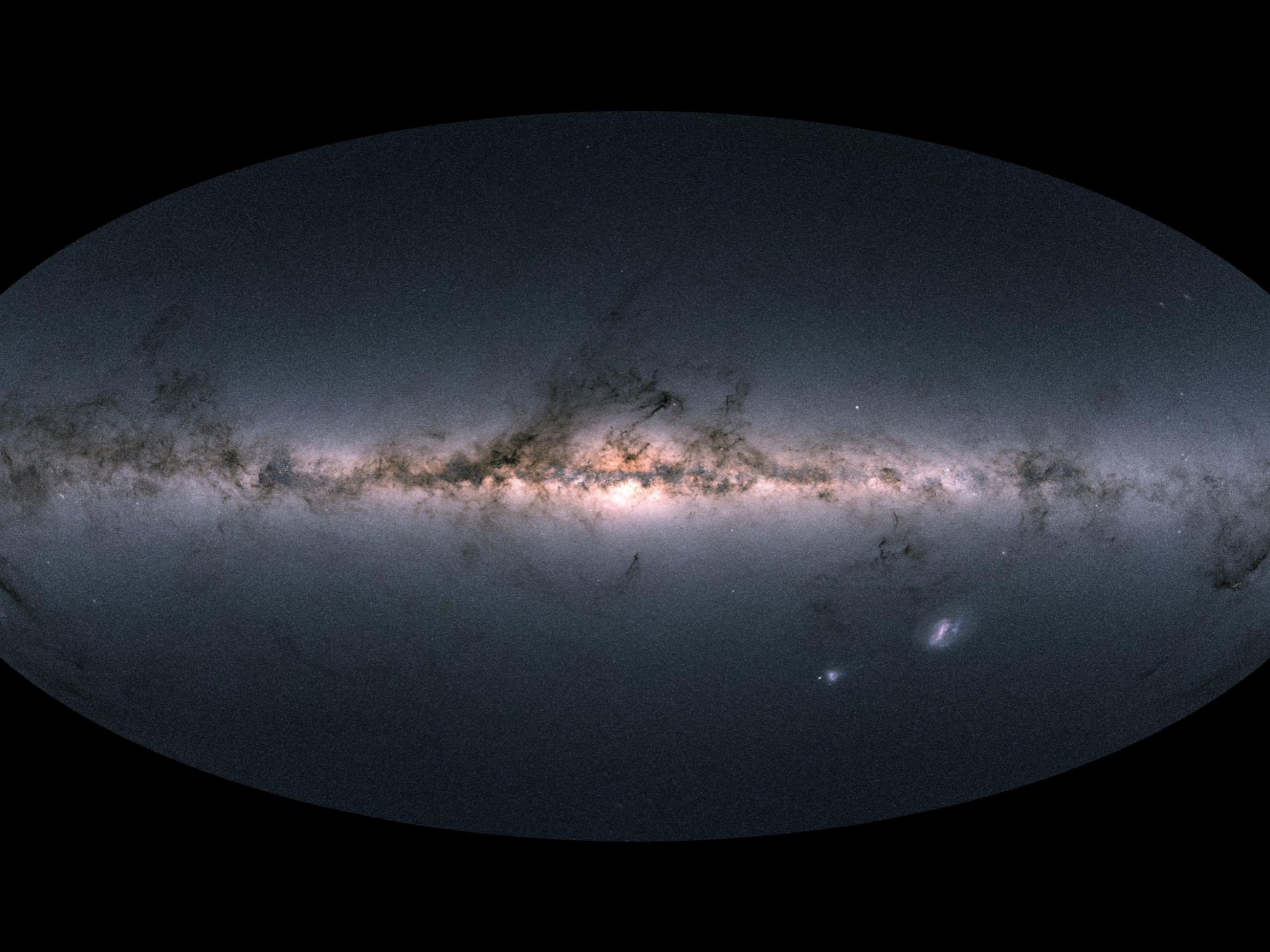
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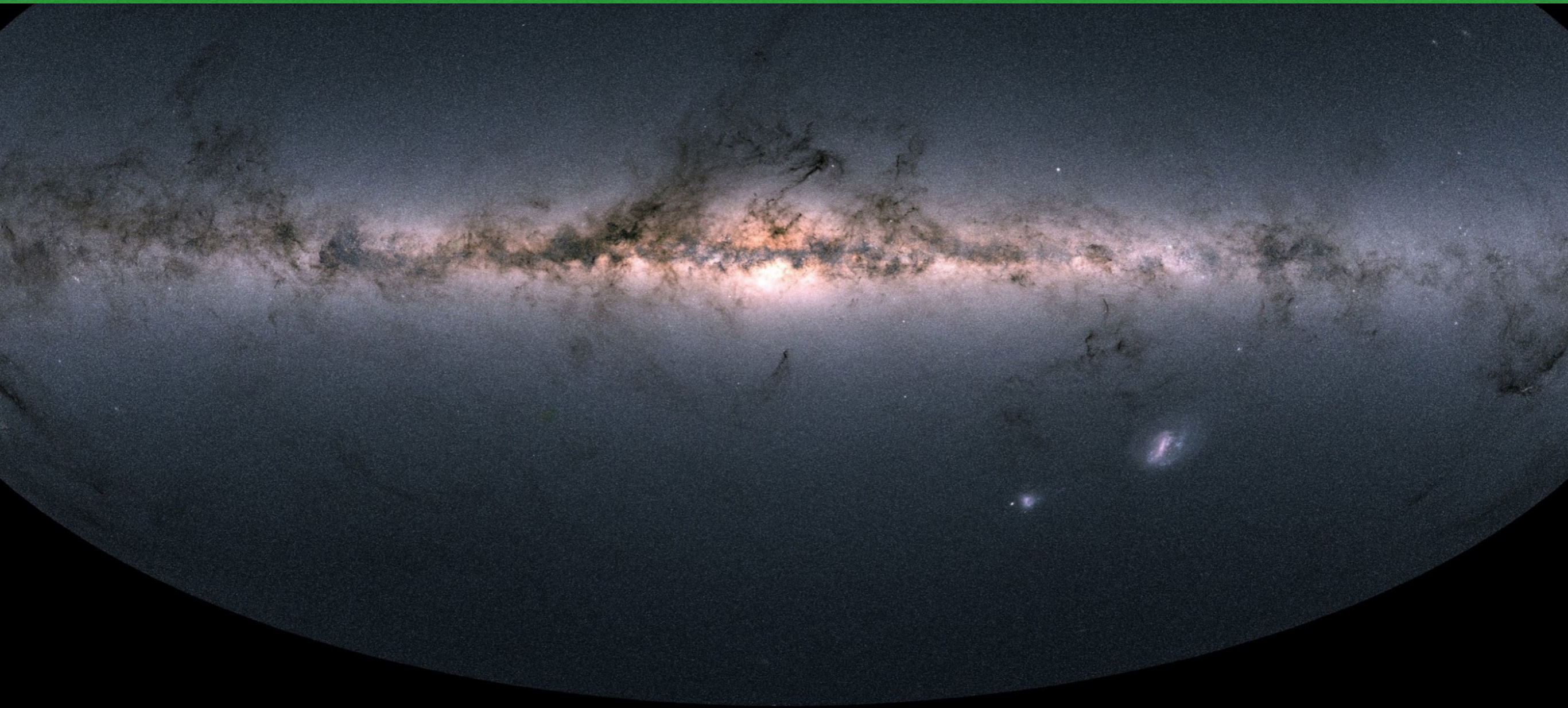
But where would they be?

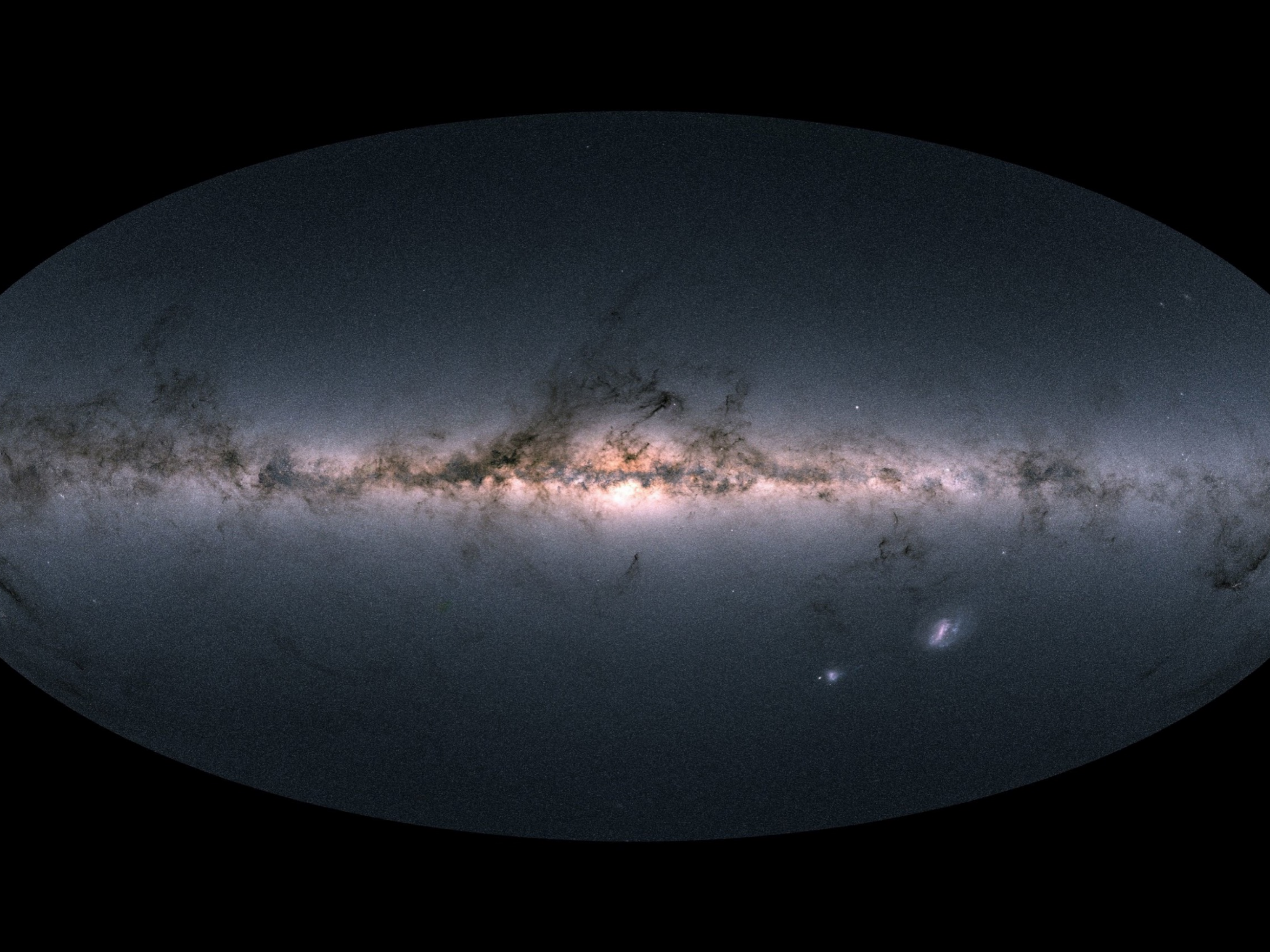
A Post-Tenure Pivot : Connecting Galactic Archaeology and Galactic structure to “Search for Life” on Exoplanets

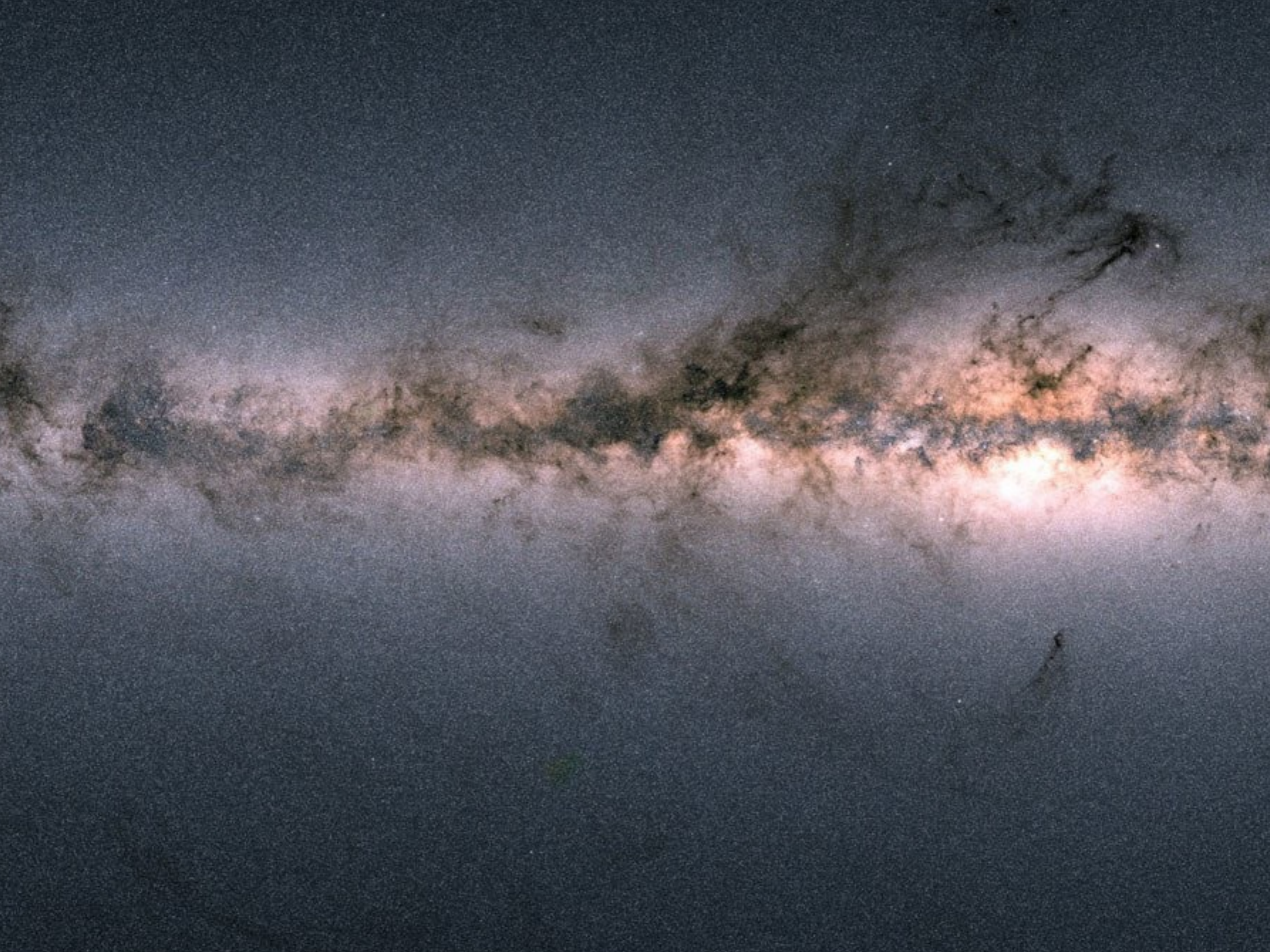


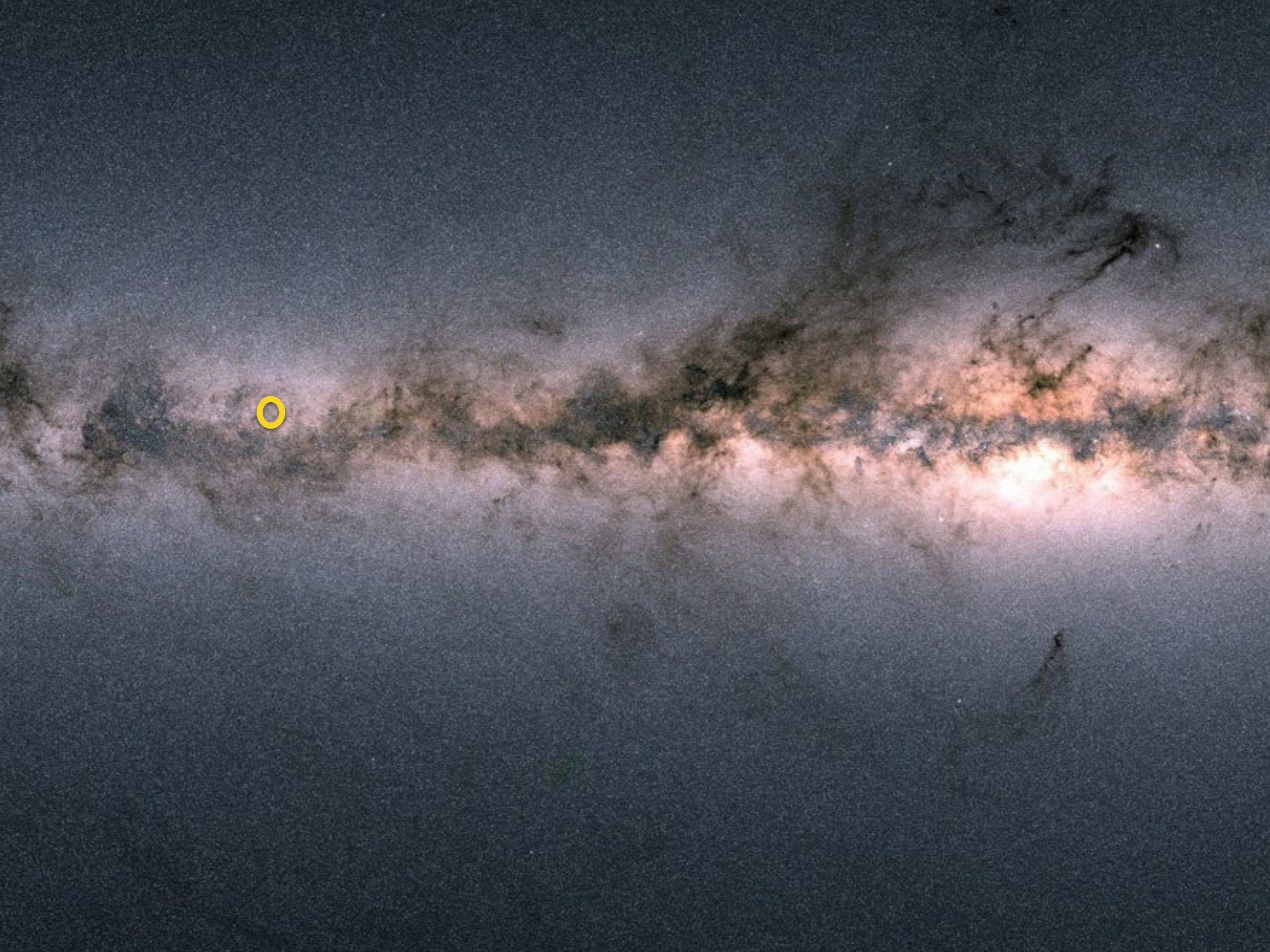


What are other planets outside of our solar system made out of and do they harbor the key elements for life (as we know it?)







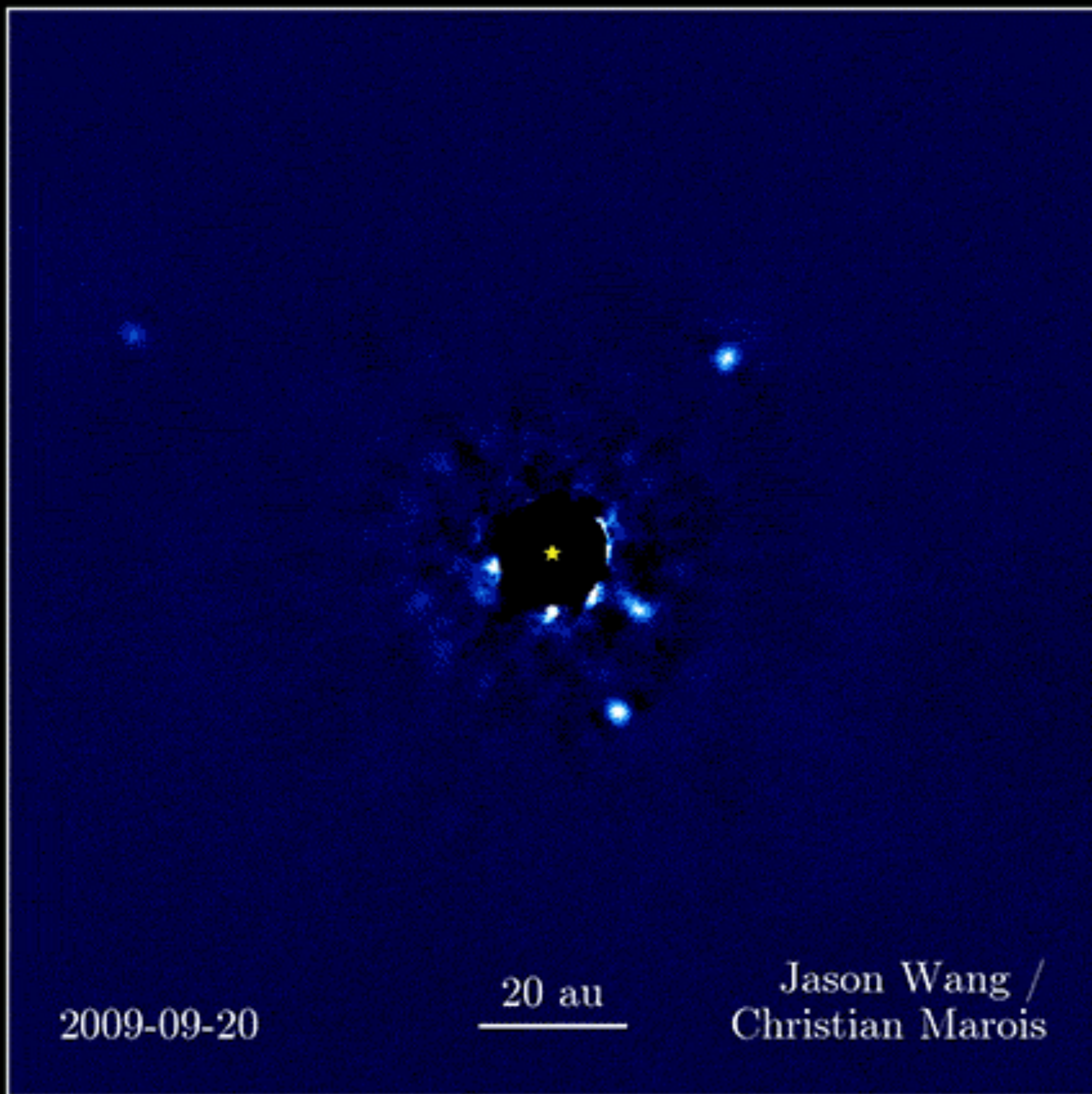


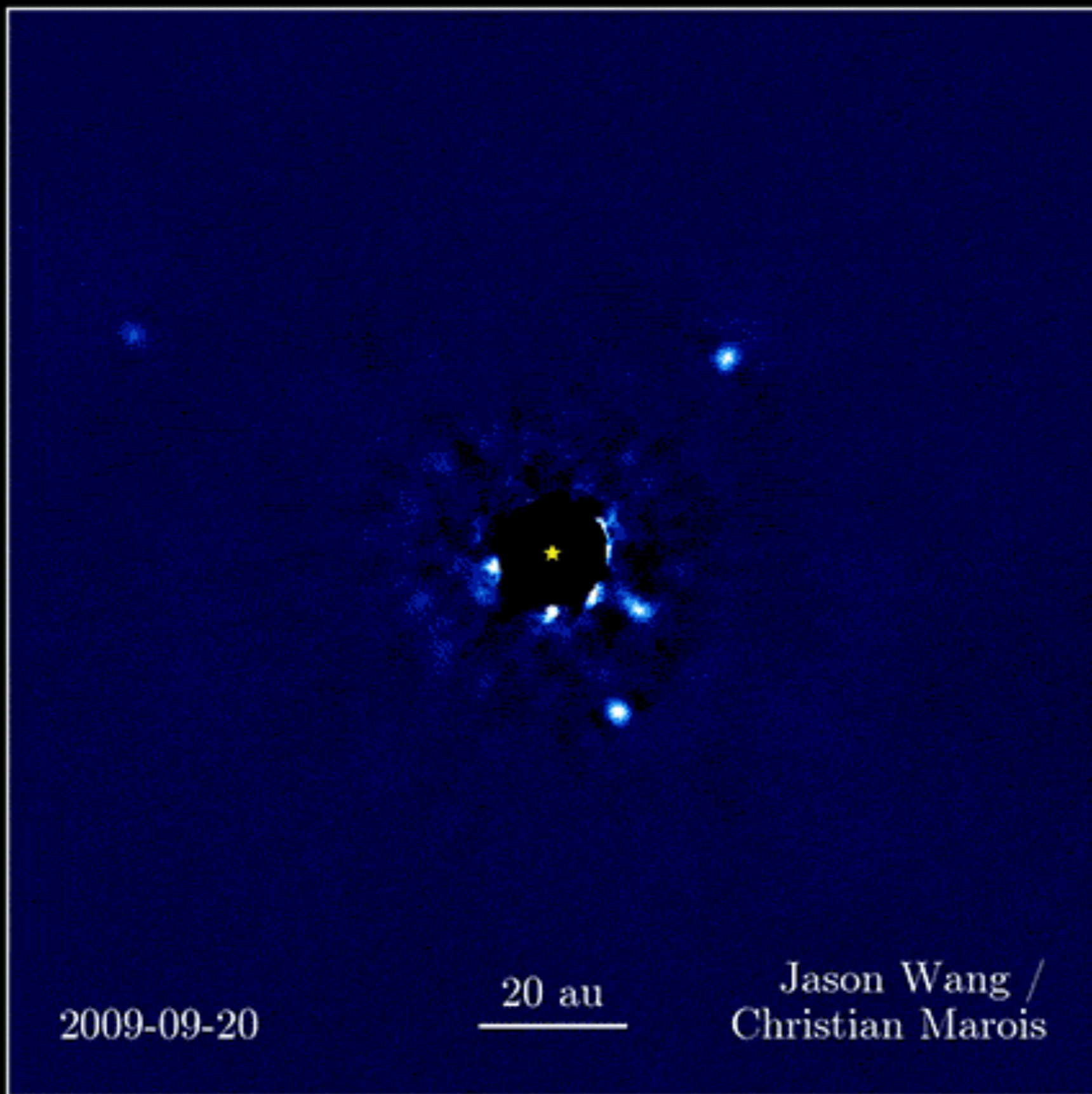


HR 8799

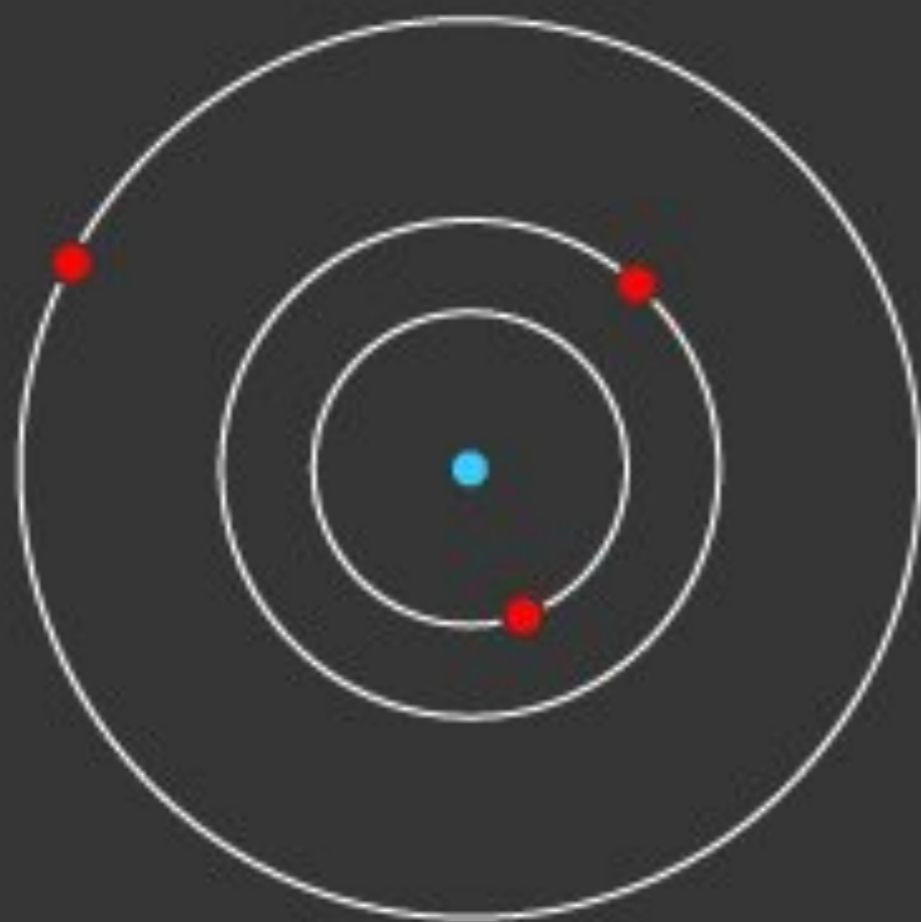


HR 8799

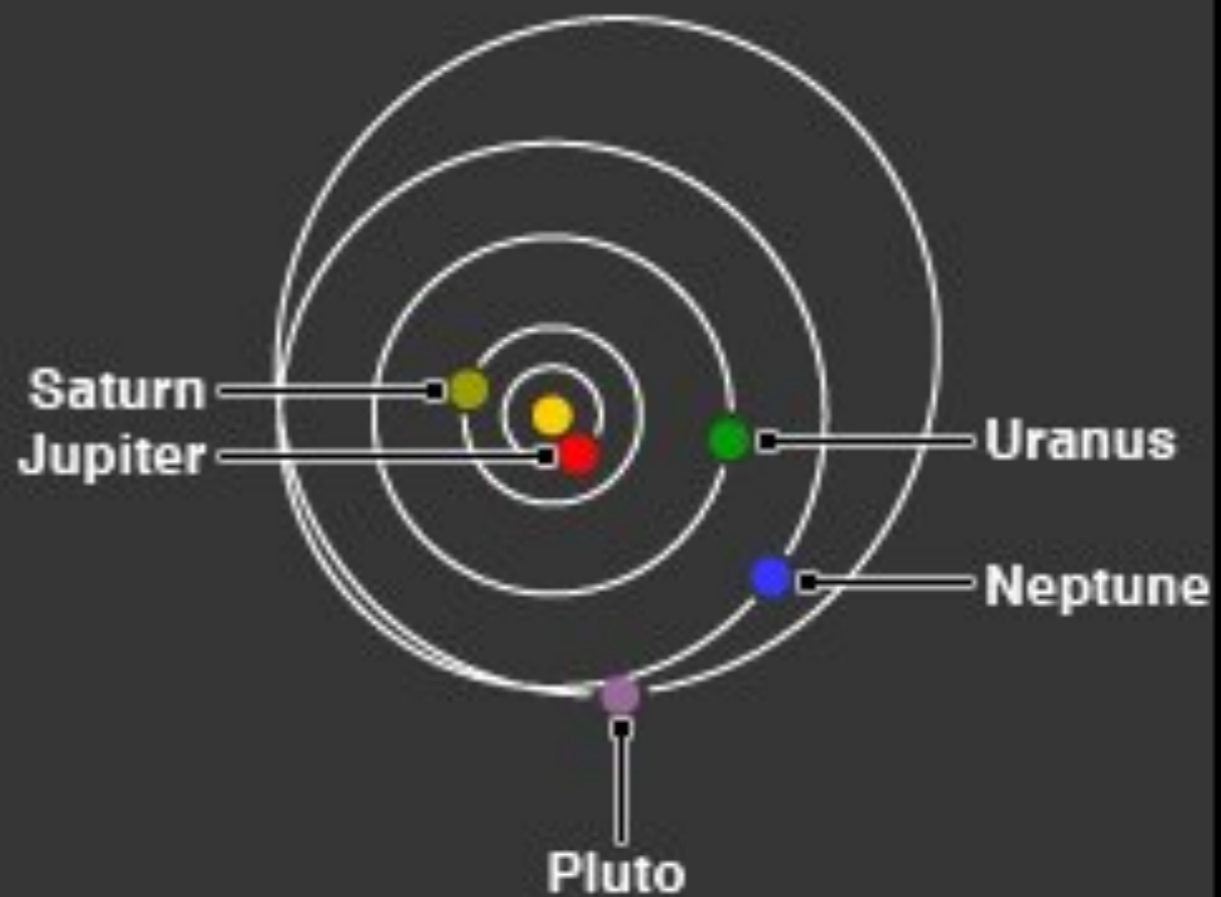




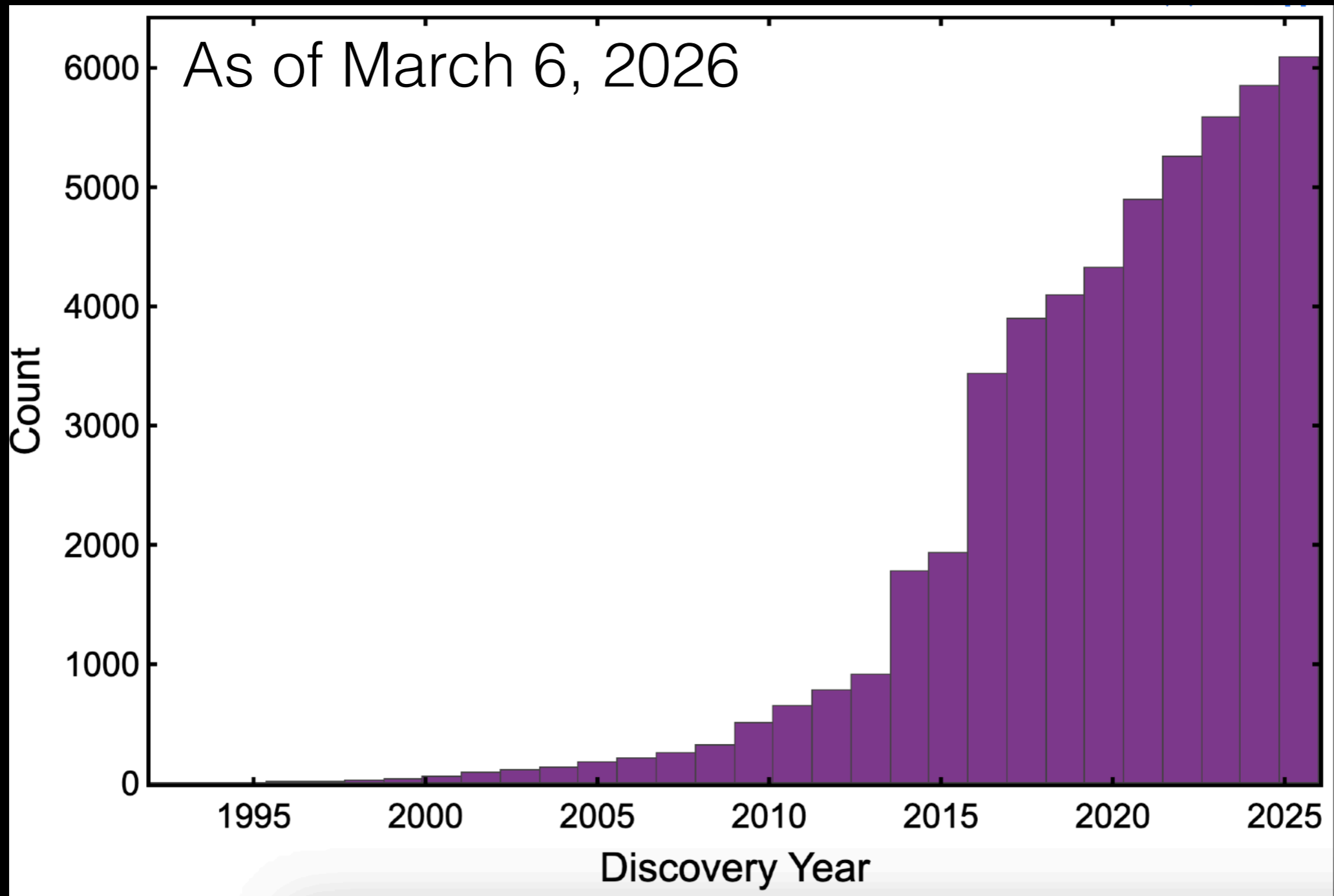
HR 8799 SOLAR SYSTEM



OUR SOLAR SYSTEM

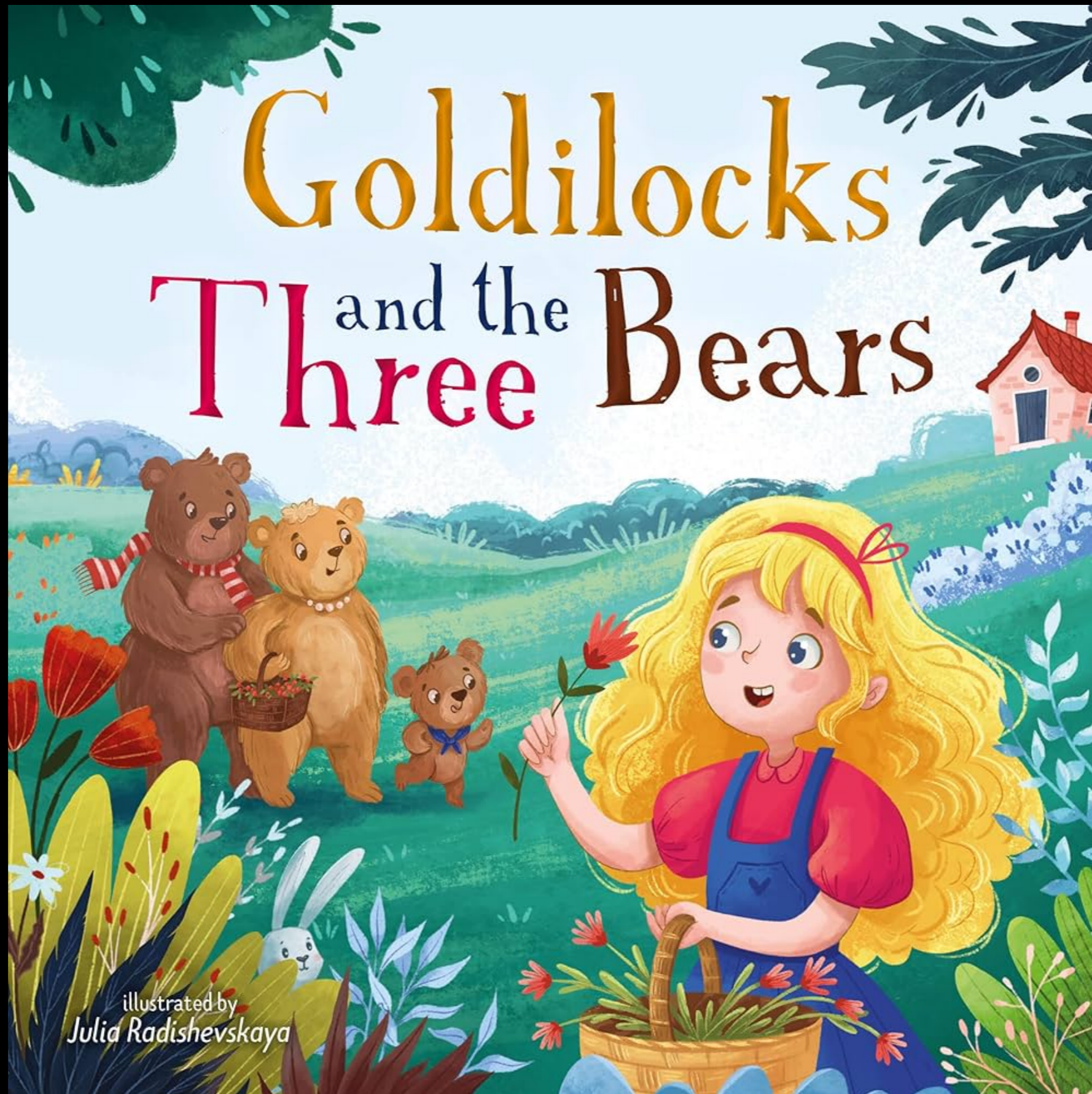


But this is 1 of more than 6000+ planets found



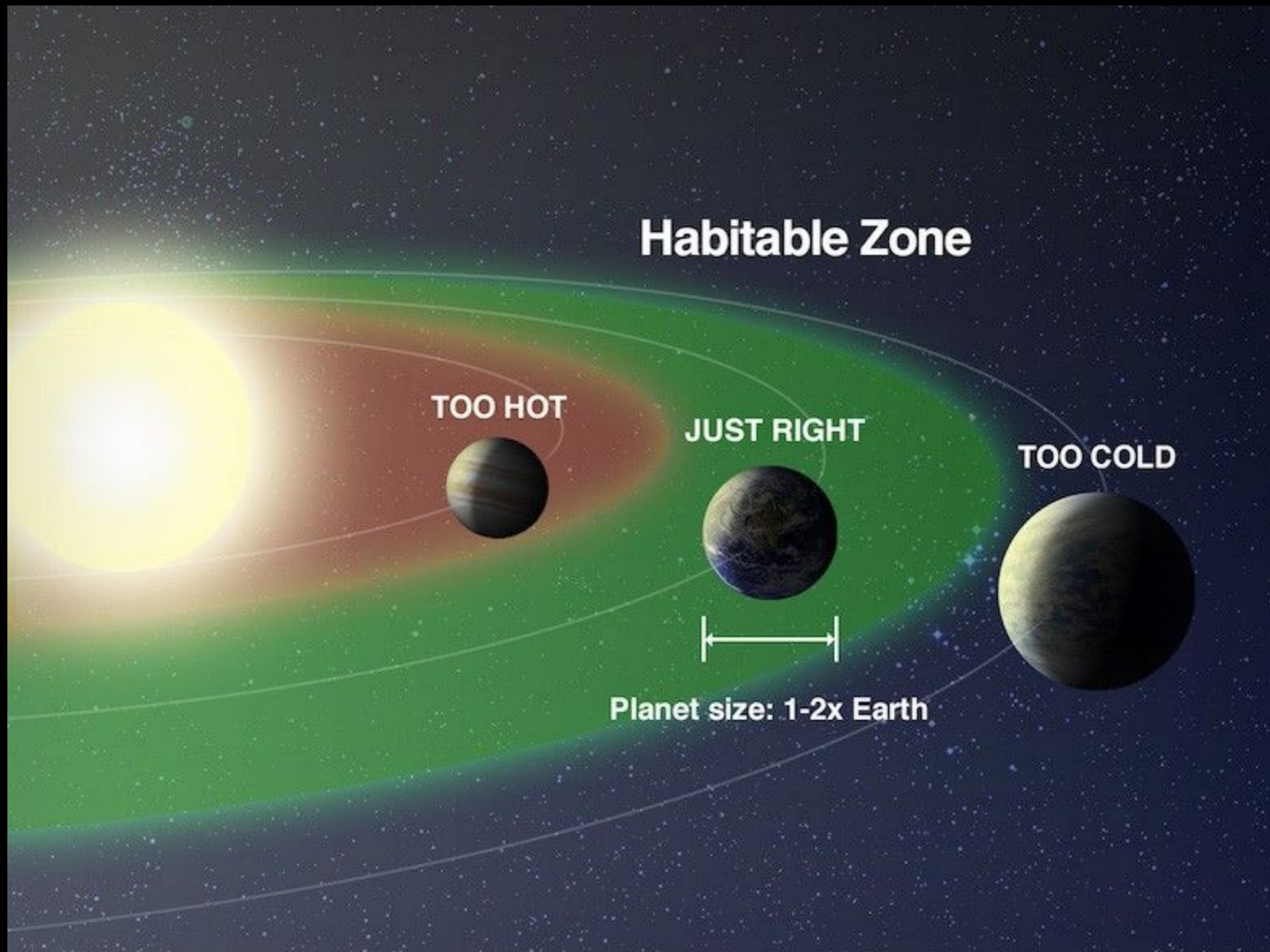
We now know there are Planets but are they habitable?

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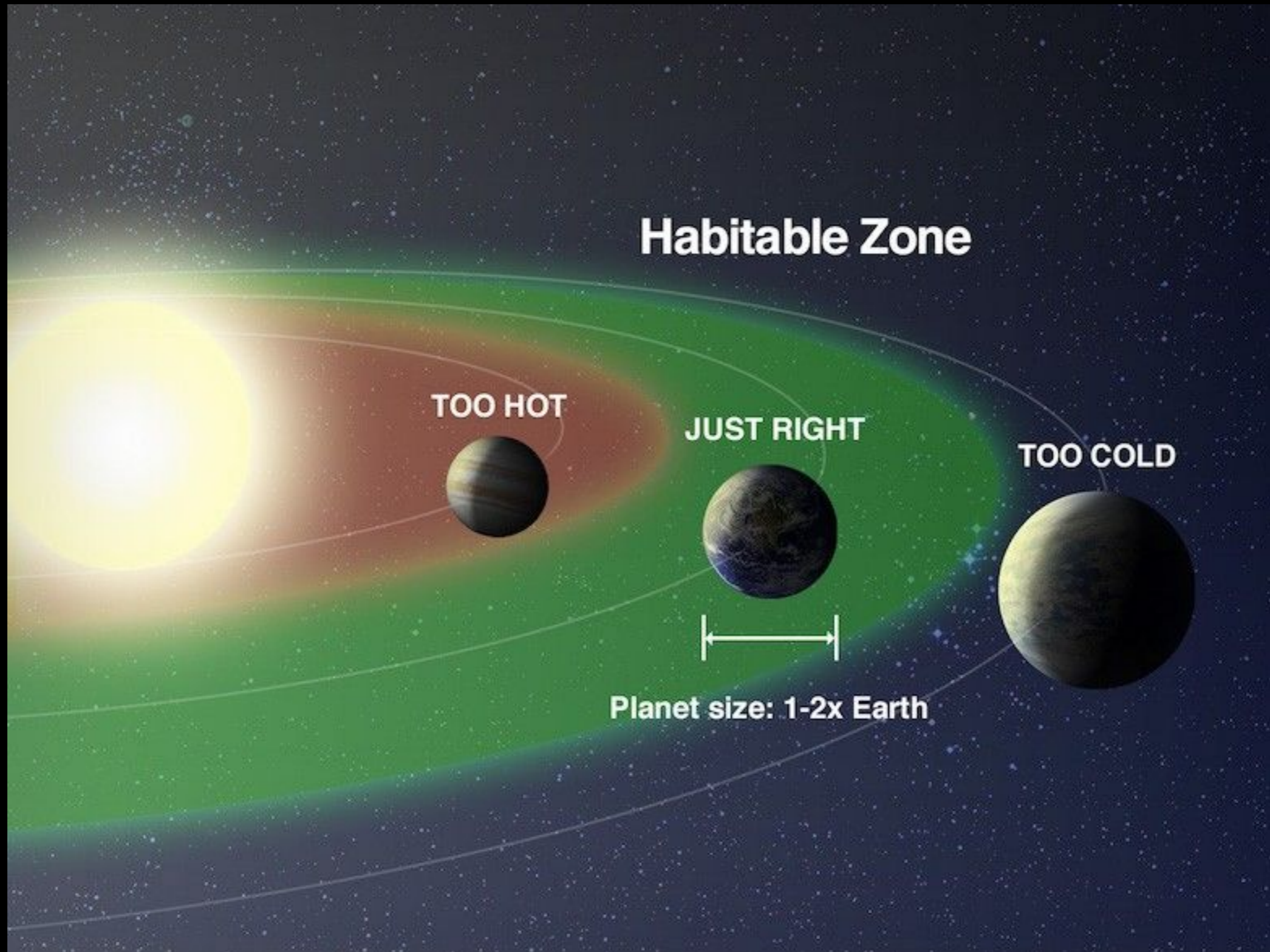


illustrated by
Julia Radishevskaya

We now know there are Planets but are they habitable?



The Habitable Zone alone isn't enough.. how do you know the planet has the material for life?



First, we check its host star for the key elements for life (CHNOPS)

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First, we check its host star for the key elements for life (CHNOPS)

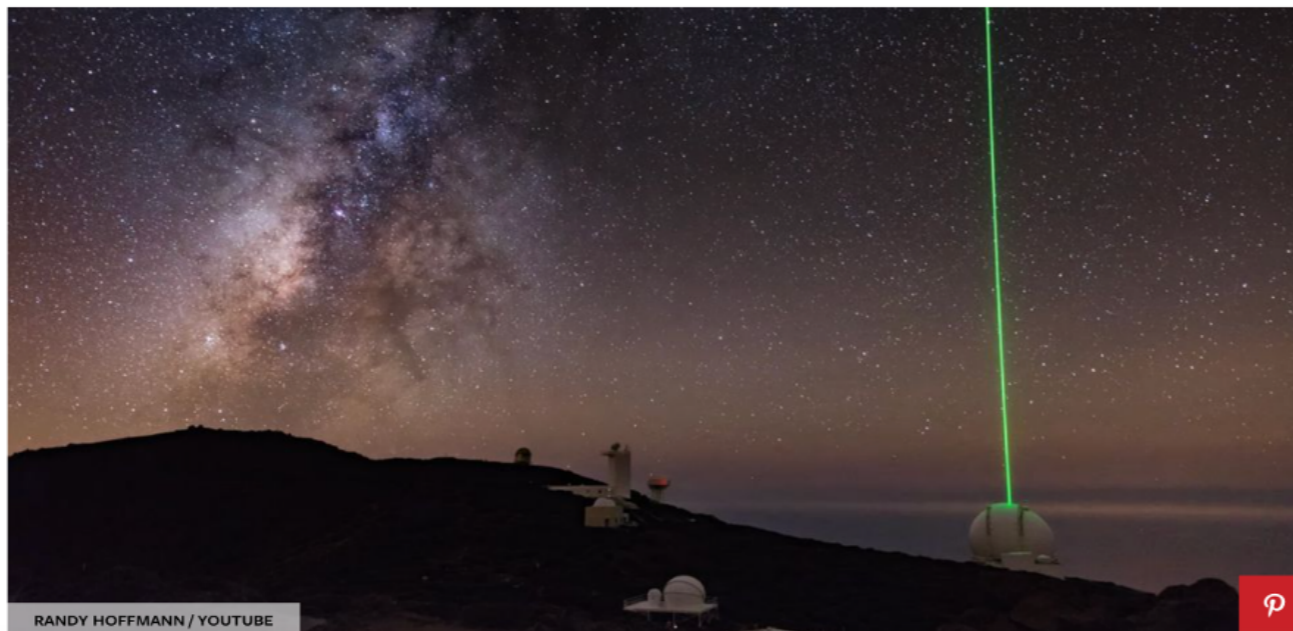


To Find Life in Our Galaxy, Follow the Phosphorus

New research into the composition of supernova remnants suggests phosphorus might be isolated in parts of the galaxy—and phosphorus is a requirement for life as we know it.



// BY [JAY BENNETT](#) APR 4, 2018



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First, we check its host star for the key elements for life (CHNOPS)



THE ASTRONOMICAL JOURNAL, 164:61 (15pp), 2022 August

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<https://doi.org/10.3847/1538-3881/ac77f8>



The Galactic Distribution of Phosphorus: A Survey of 163 Disk and Halo Stars*

Zachary G. Maas^{1,2} , Keith Hawkins² , Natalie R. Hinkel³ , Phillip Cargile⁴ , Steven Janowiecki⁵ , and Tyler Nelson² 

¹ McDonald Observatory, The University of Texas at Austin, 2515 Speedway Boulevard, Austin, TX 78712, USA; zgmaas@utexas.edu

² Department of Astronomy, The University of Texas at Austin, 2515 Speedway Boulevard, Austin, TX 78712, USA

³ Southwest Research Institute, 6220 Culebra Road, San Antonio, TX 78238, USA

⁴ Center for Astrophysics | Harvard & Smithsonian, 60 Garden Street, Cambridge, MA 02138, USA

⁵ University of Texas, Hobby–Eberly Telescope, McDonald Observatory, TX 79734, USA

Received 2022 April 1; revised 2022 June 3; accepted 2022 June 6; published 2022 July 20



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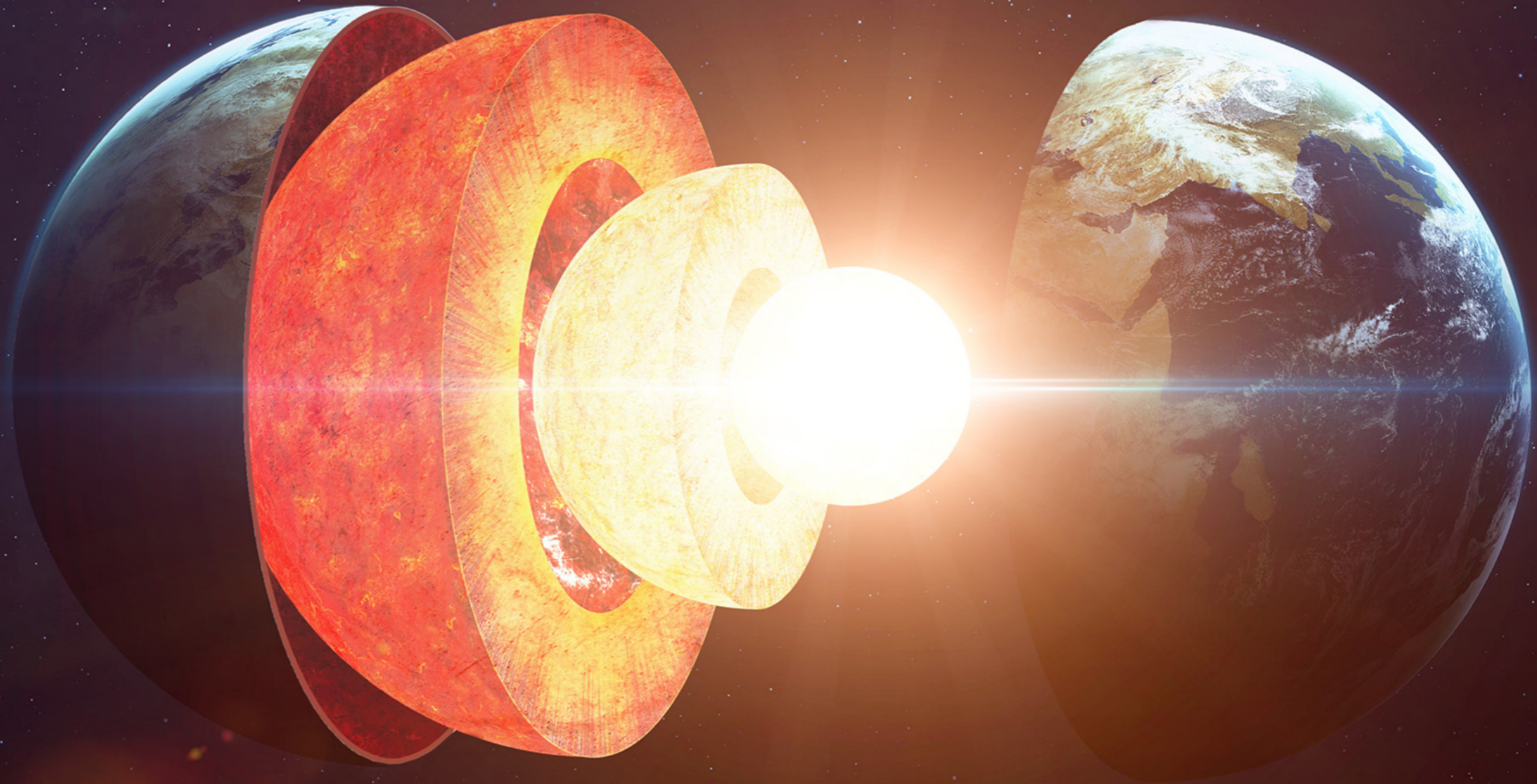
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Recently (2025) awarded a large NSF GLOW grant to work with a petrologist (Chen Sun/ UT Austin) to understand how the elements for life are distributed cosmically and within a planetary interior



Second... we want to know what the planet is actually made of



How do we know the interior composition of an exoplanet?



How do we know the interior composition of an exoplanet?

Ripping them apart and dumping them into the stars we see



But first we have to actually find the planets being ripped apart



We start with stars that look featureless in their spectra (white dwarfs) and try to find some that have “extra lines” using Gaia data for 100,000 white dwarfs indicating the metals falling onto the star



**Polluted White Dwarfs offer rare glimpse into
a planetary interior outside the solar system
—> High Impact to finding them**





The Universe > Stars

My group has developed AI methods to find these systems (Kao+2024) in Gaia and follow up w/ HET McDonald!



Over 300 hidden planet-devouring stars within the Milky Way found by AI

News By Sharmila Kuthunur published August 7, 2024

"The inside of the planet is literally being of the star for us to look at."

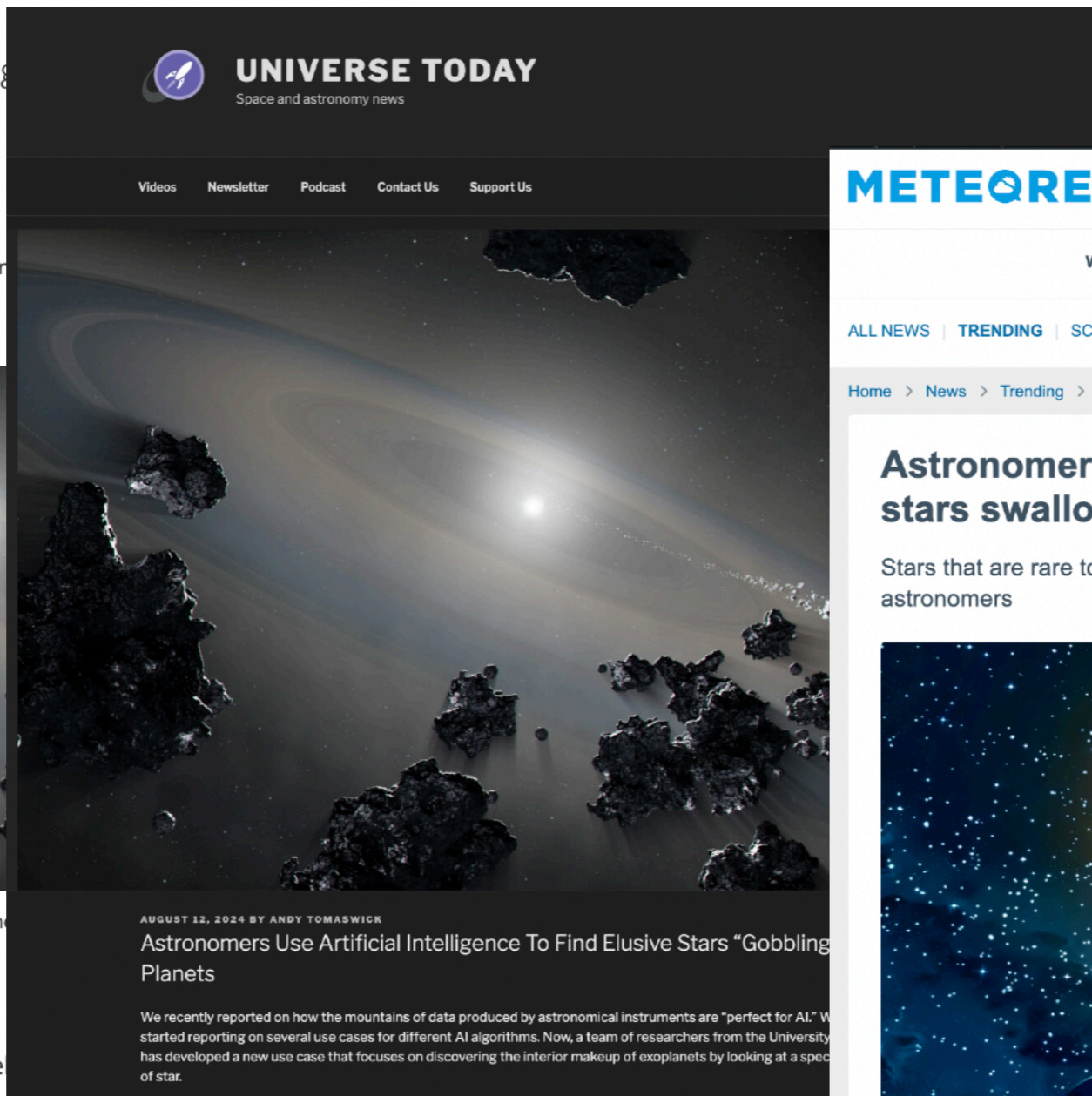
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An illustration shows a dead white dwarf star surrounded by the credit: NASA, ESSA, Joseph Olmsted (STScI.)

Billions of years from now, any alien civilization the solar system would find Earth not as our be but as bits and pieces of metal polluting our sun.

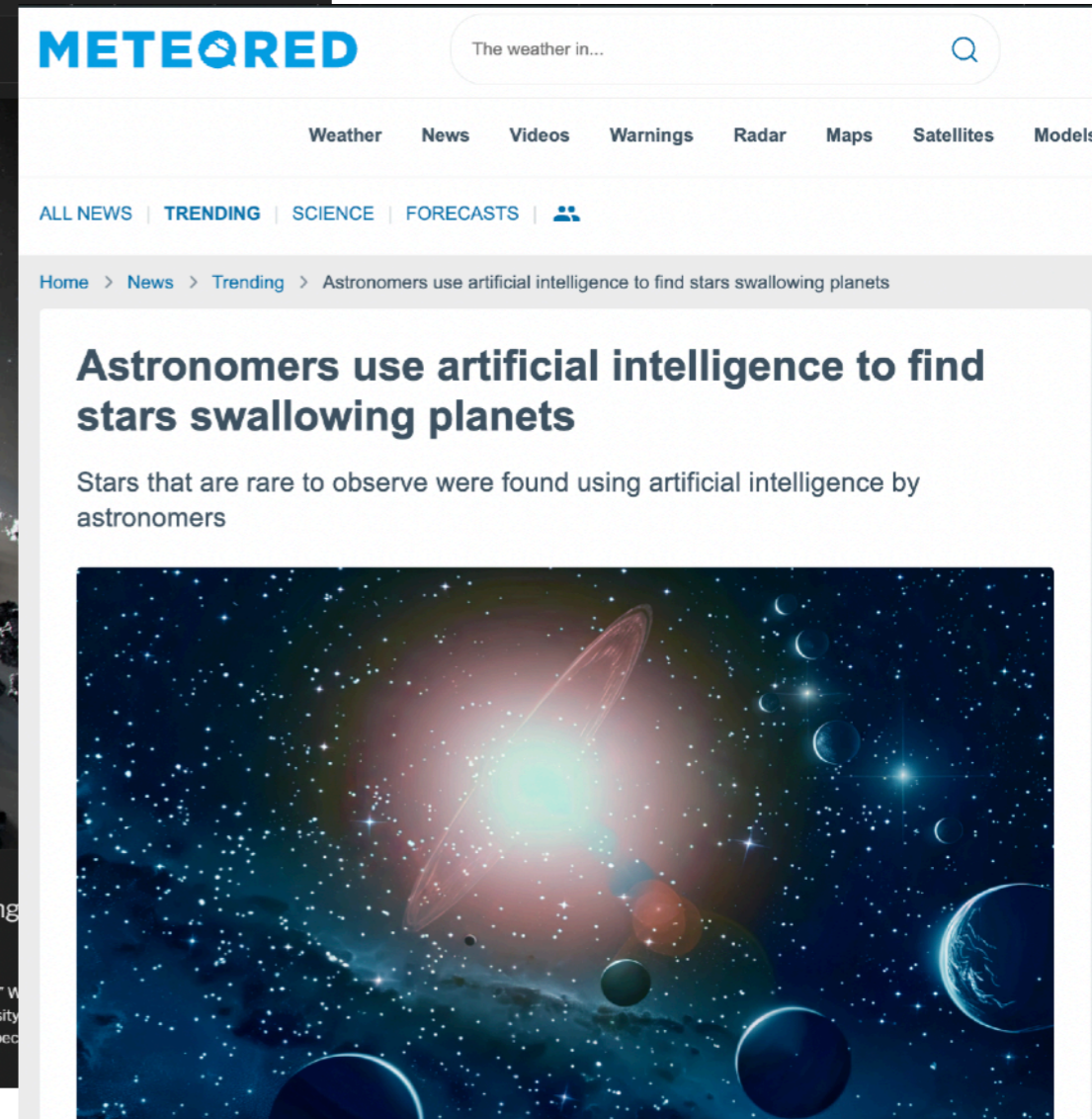



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AUGUST 12, 2024 BY ANDY TOMASWICK
Astronomers Use Artificial Intelligence To Find Elusive Stars "Gobbling Planets"

We recently reported on how the mountains of data produced by astronomical instruments are "perfect for AI." We started reporting on several use cases for different AI algorithms. Now, a team of researchers from the University has developed a new use case that focuses on discovering the interior makeup of exoplanets by looking at a spec of star.



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Home > News > Trending > Astronomers use artificial intelligence to find stars swallowing planets

Astronomers use artificial intelligence to find stars swallowing planets

Stars that are rare to observe were found using artificial intelligence by astronomers





The Universe > Stars

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An illustration shows a dead white dwarf star surrounded by the credit: NASA, ESSA, Joseph Olmsted (STScI.)

Billions of years from now, any alien civilization the solar system would find Earth not as our be but as bits and pieces of metal polluting our sun.

UNIVERSE TODAY
Space and astronomy news

It is not clear though that these are real or if AI deceived us! Thus we must check

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The weather in...

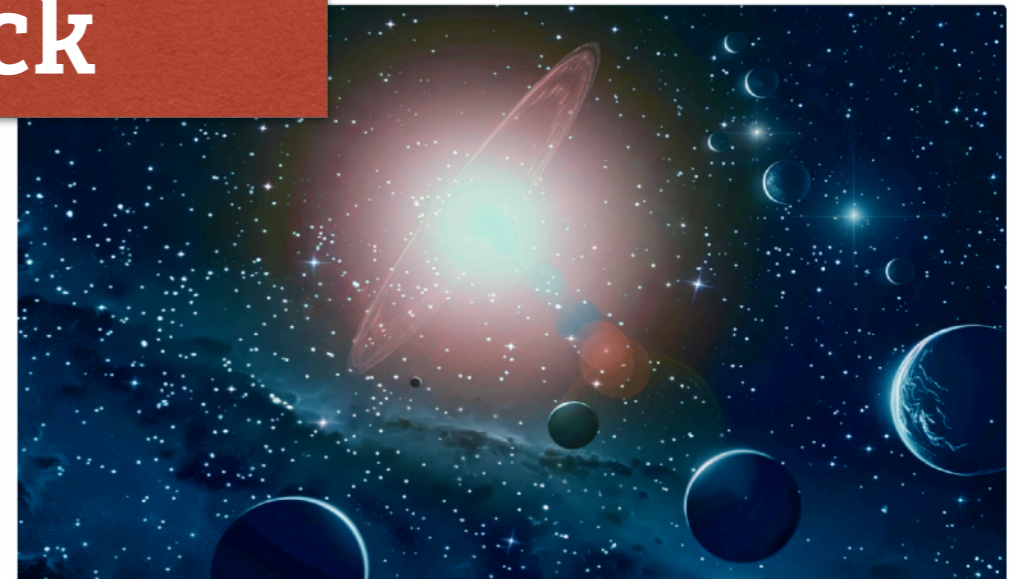
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...ers use artificial intelligence to find stars swallowing planets

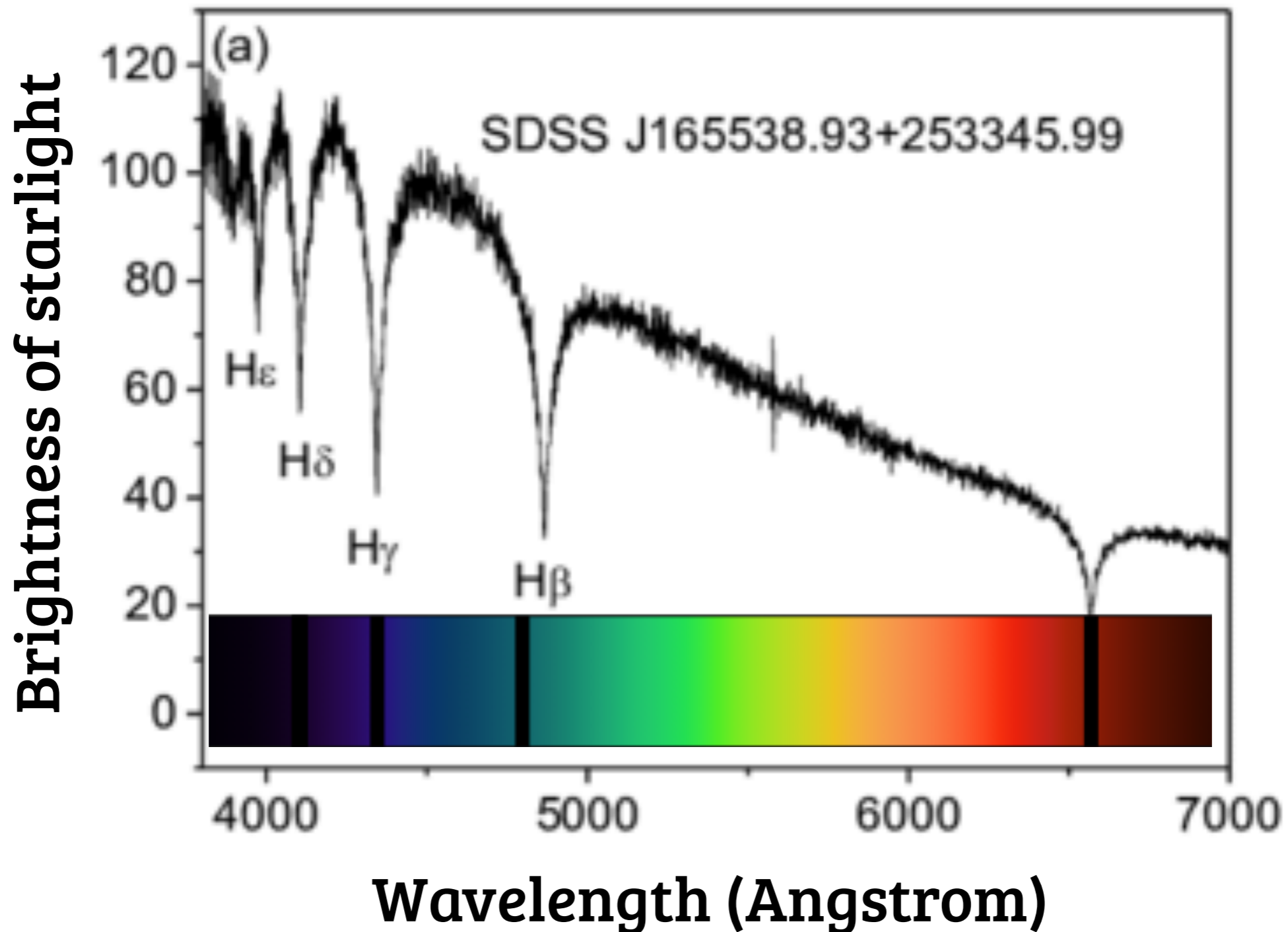
...se artificial intelligence to find g planets

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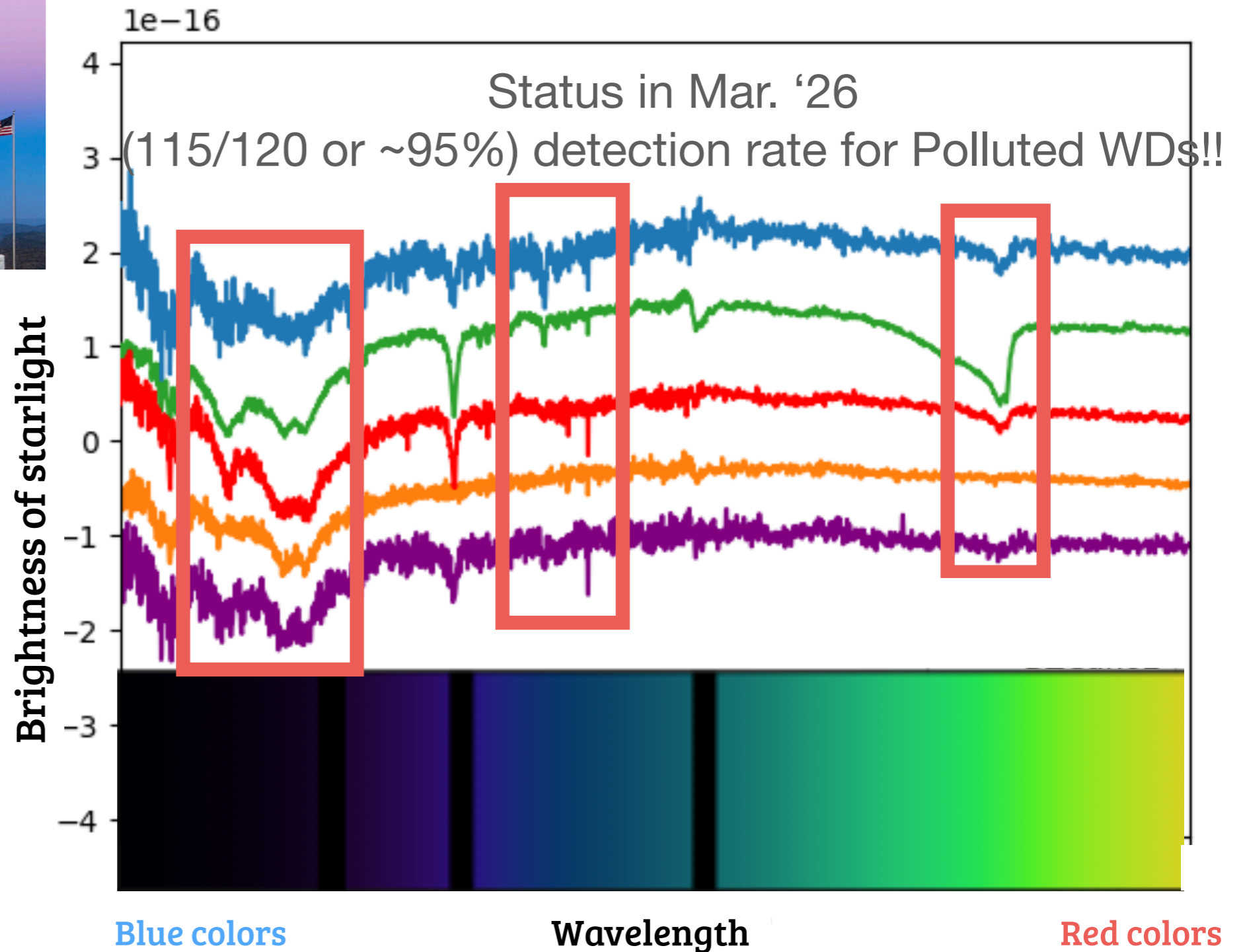


Typical White Dwarf Spectrum

Just Hydrogen!



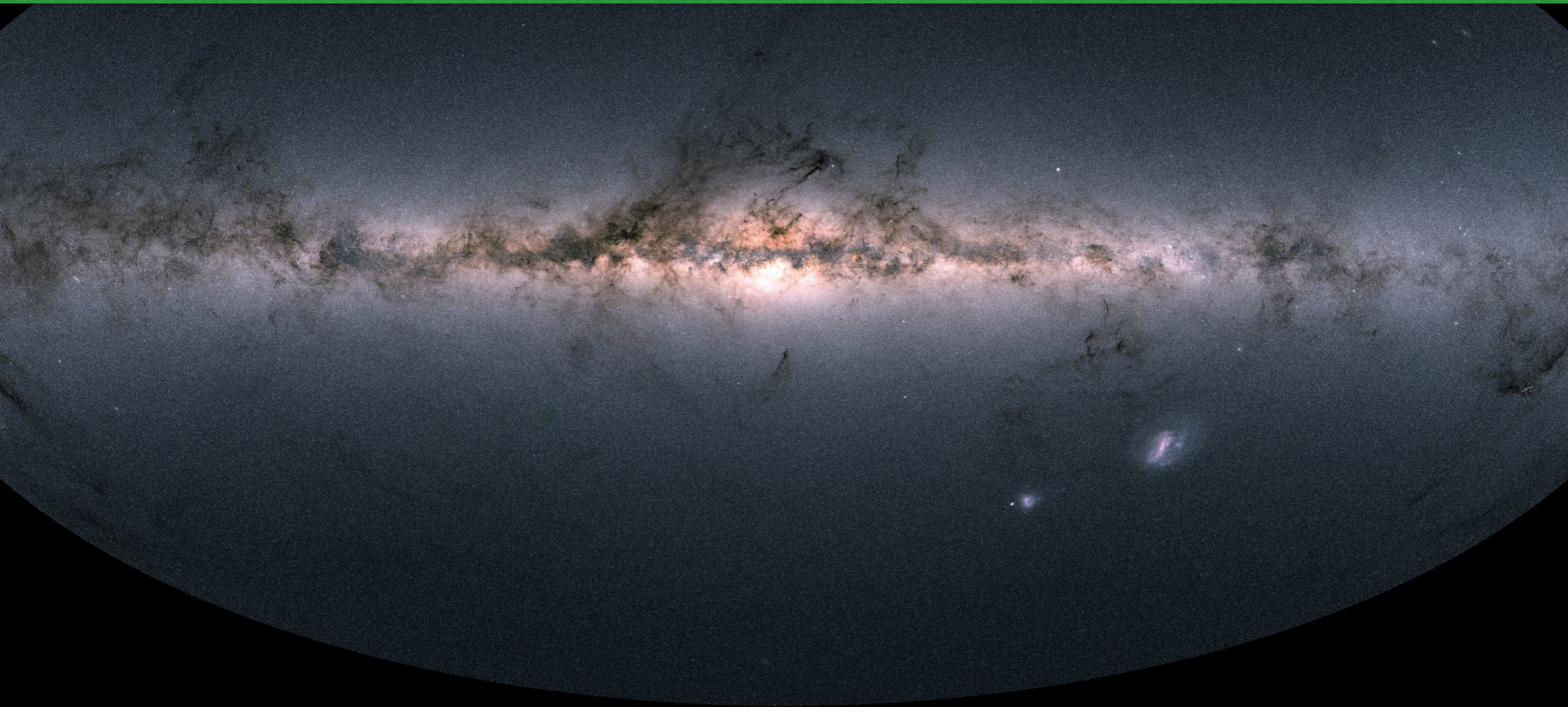
Polluted White Dwarfs now confirmed with HET/McDonald (wouldn't be possible w/o MDO)



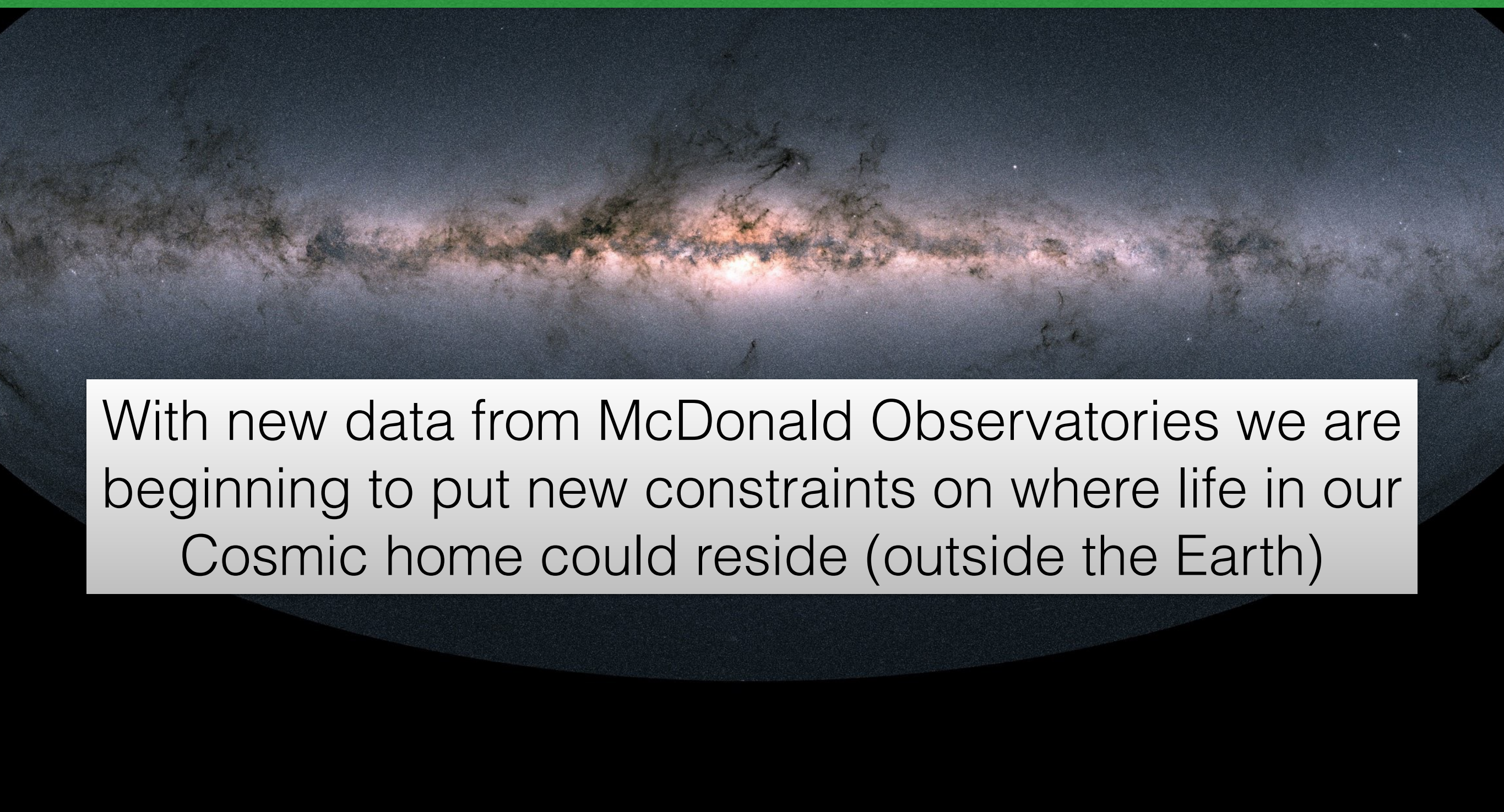
Currently have ~95% detection rate for newly polluted WDs (Kao+2025, Hawkins+in prep)

McDonald/HET enables us to measure detail abundance ratios w/ these spectra to learn about the content of planets outside the solar system. Y'all are of the first to see new data from HET!

What are other planets outside of our solar system made out of and do they harbor the key elements for life (as we know it?)



What are other planets outside of our solar system made out of and do they harbor the key elements for life (as we know it?)



With new data from McDonald Observatories we are beginning to put new constraints on where life in our Cosmic home could reside (outside the Earth)























**Thank you for listening, for supporting
our work and for being our champions
in science to help us uncover the
cosmic story that makes us human**



