ASTR 511

Galactic Astronomy

Lecture 02

The Solar Neighborhood

Prof. James Davenport (UW)

Winter 2023

AAS Prep

- Reminder: AAS is next week, no ASTR 511 class
  - Homework 1 is DUE on Friday!
- Tips:
  - Try to attend all 4 days if possible
  - Go to plenary talks, wide range of sessions
  - Town Halls are 1) interesting, and 2) have free food!
- **Are you presenting? Let us know!**

Let’s travel outward…

- Today: Starting close, heading outward in the Solar Neighborhood
- This is NOT a comprehensive list of all nearby things.
- Going to discuss the structures and systems that are nearby, out to a few hundred pc

Q: What do you consider the “Solar Neighborhood?”

https://en.m.wikipedia.org/wiki/File:Milky_Way_Galaxy.jpg

- How far do you think that the **“Solar Neighborhood”** region extends, and why?
- Where does it begin?

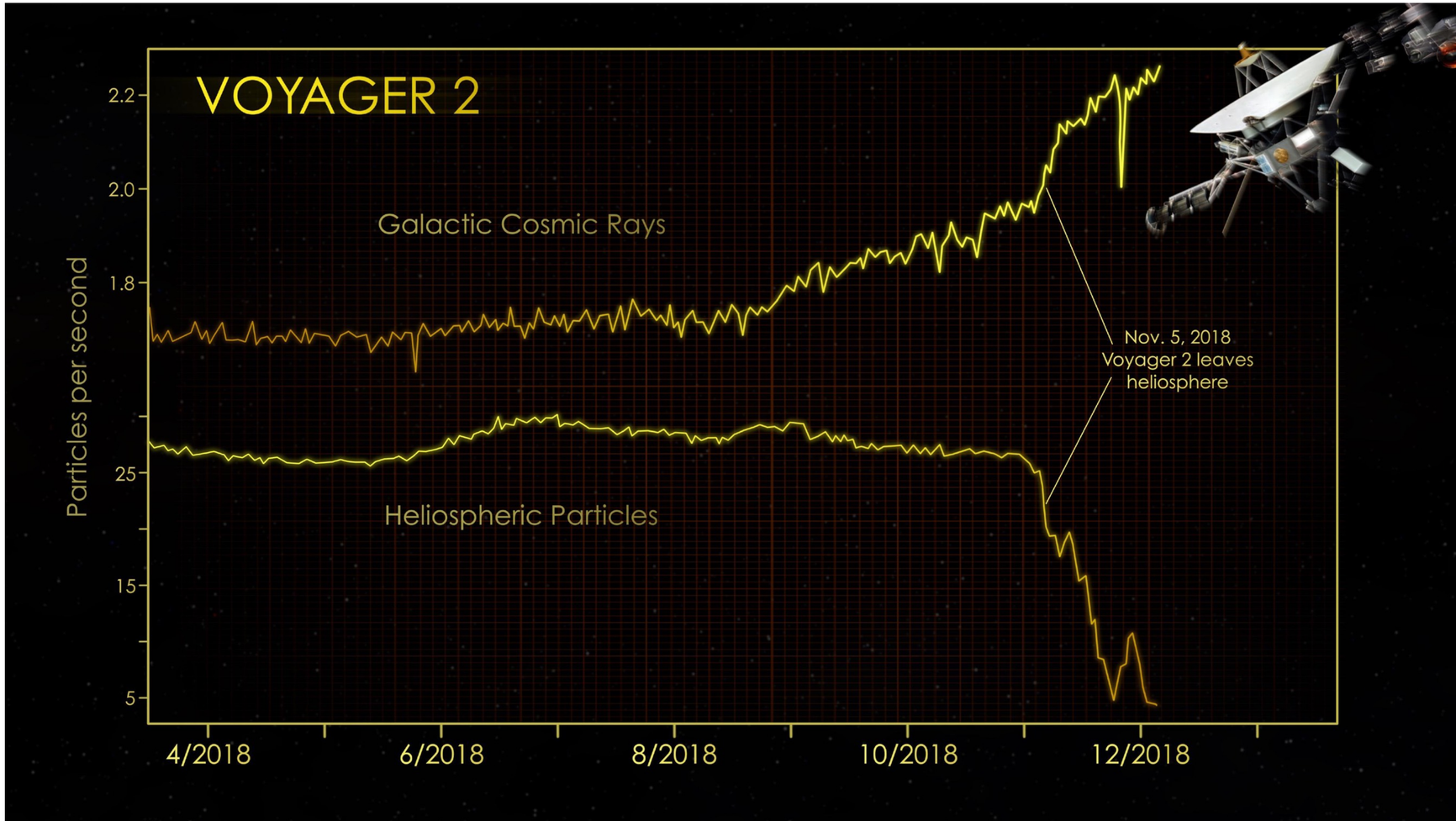
The Edge of the Solar System

- Where the “Galaxy” (or at least interstellar space) begins

- Voyager 1: 2012
  Voyager 2: 2018

- Pioneer 11: 2027
  Pioneer 10: 2057

  [New Horizons: 2043]



The Edge of the Solar System

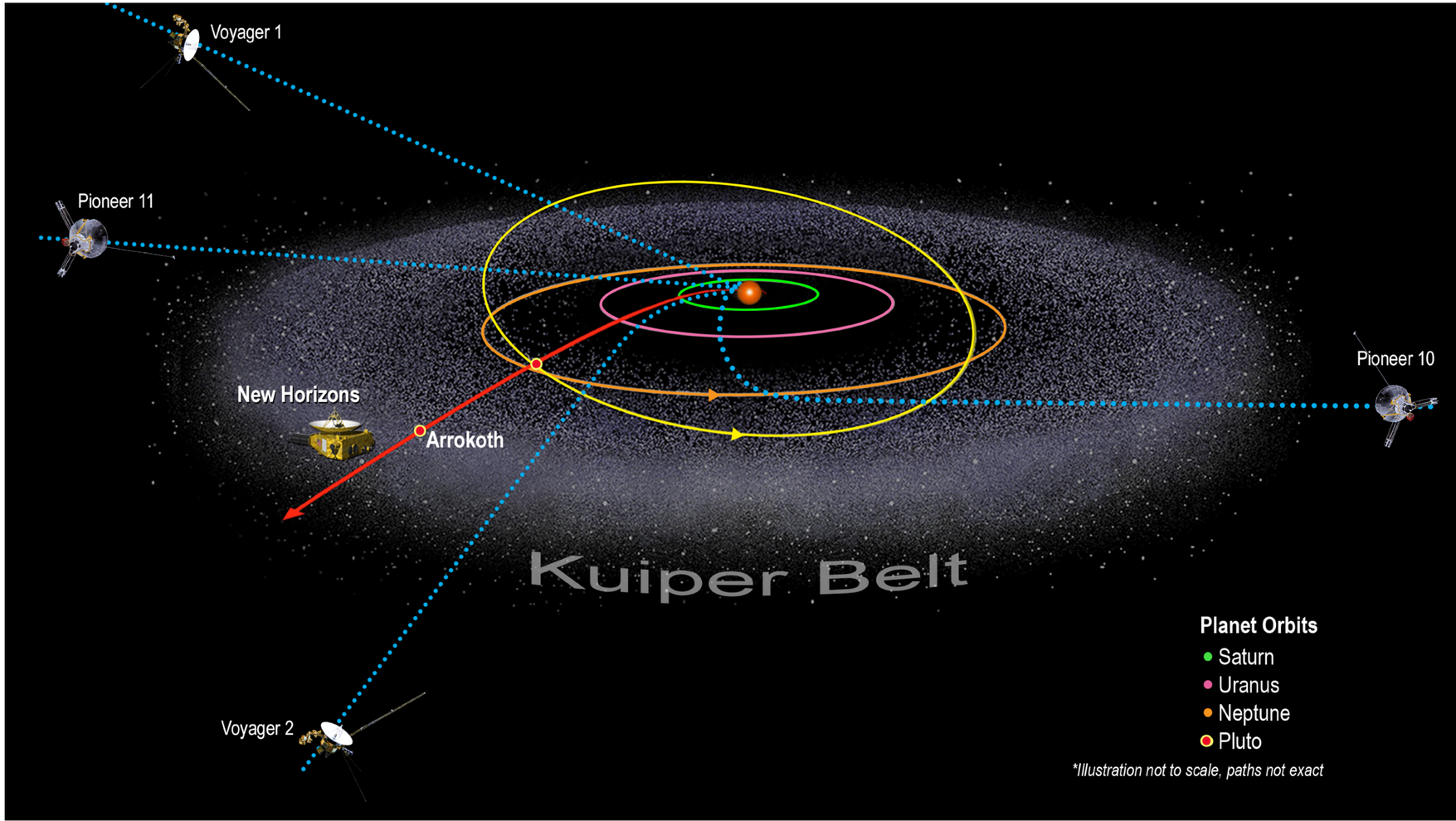
- Where the “Galaxy” (or at least interstellar space) begins

https://www.nasa.gov/feature/nasa-s-new-horizons-reaches-a-rare-space-milestone

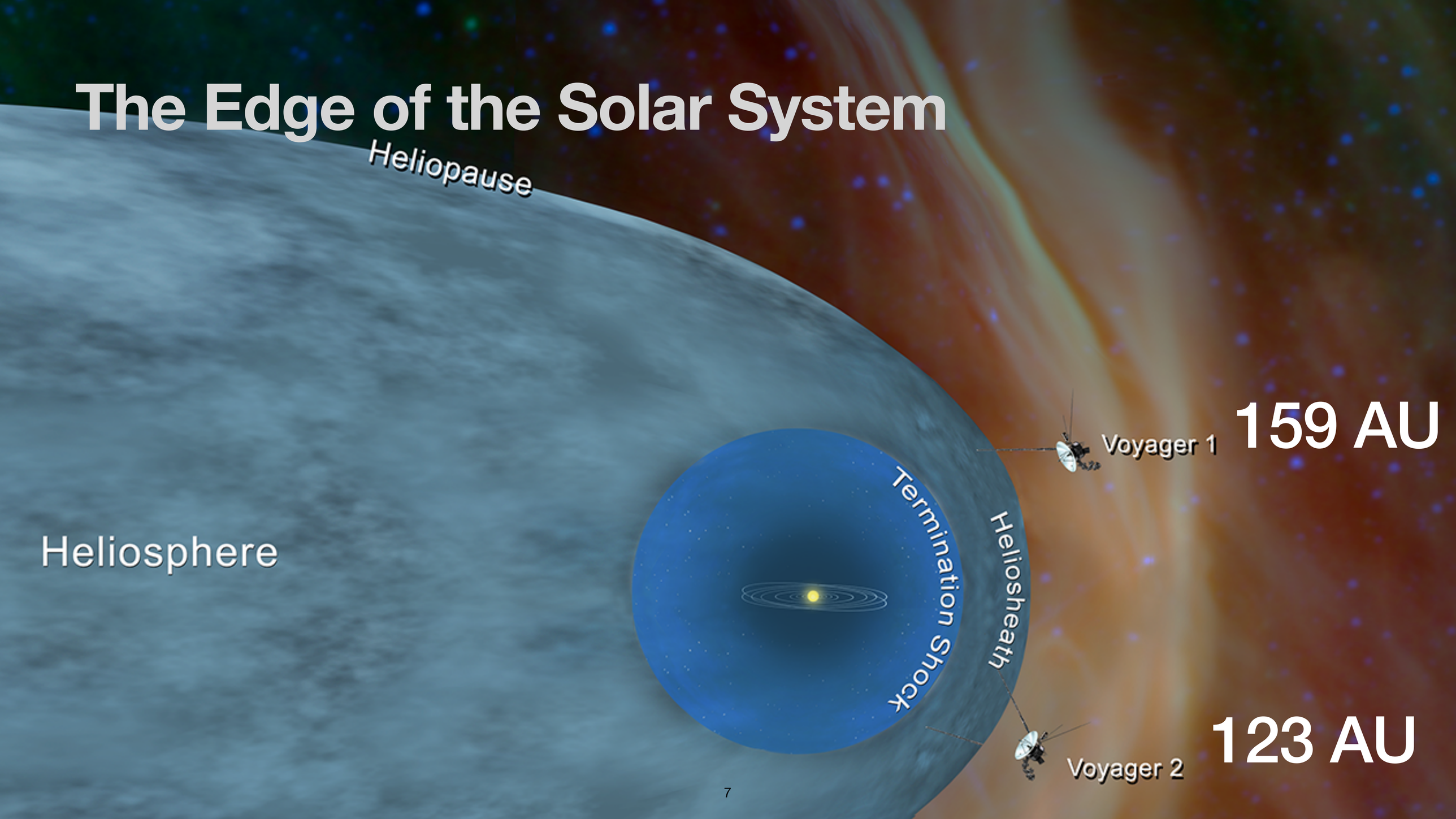
- Voyager 1: 2012
  Voyager 2: 2018

- Pioneer 11: 2027
  Pioneer 10: 2057

  New Horizons: 2043

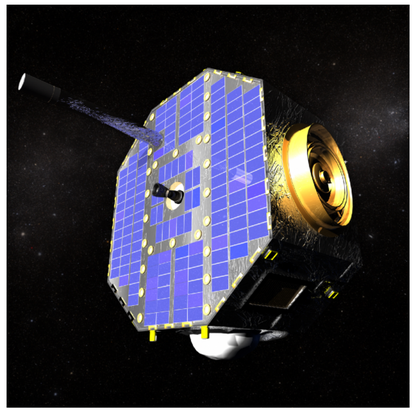


The Edge of the Solar System



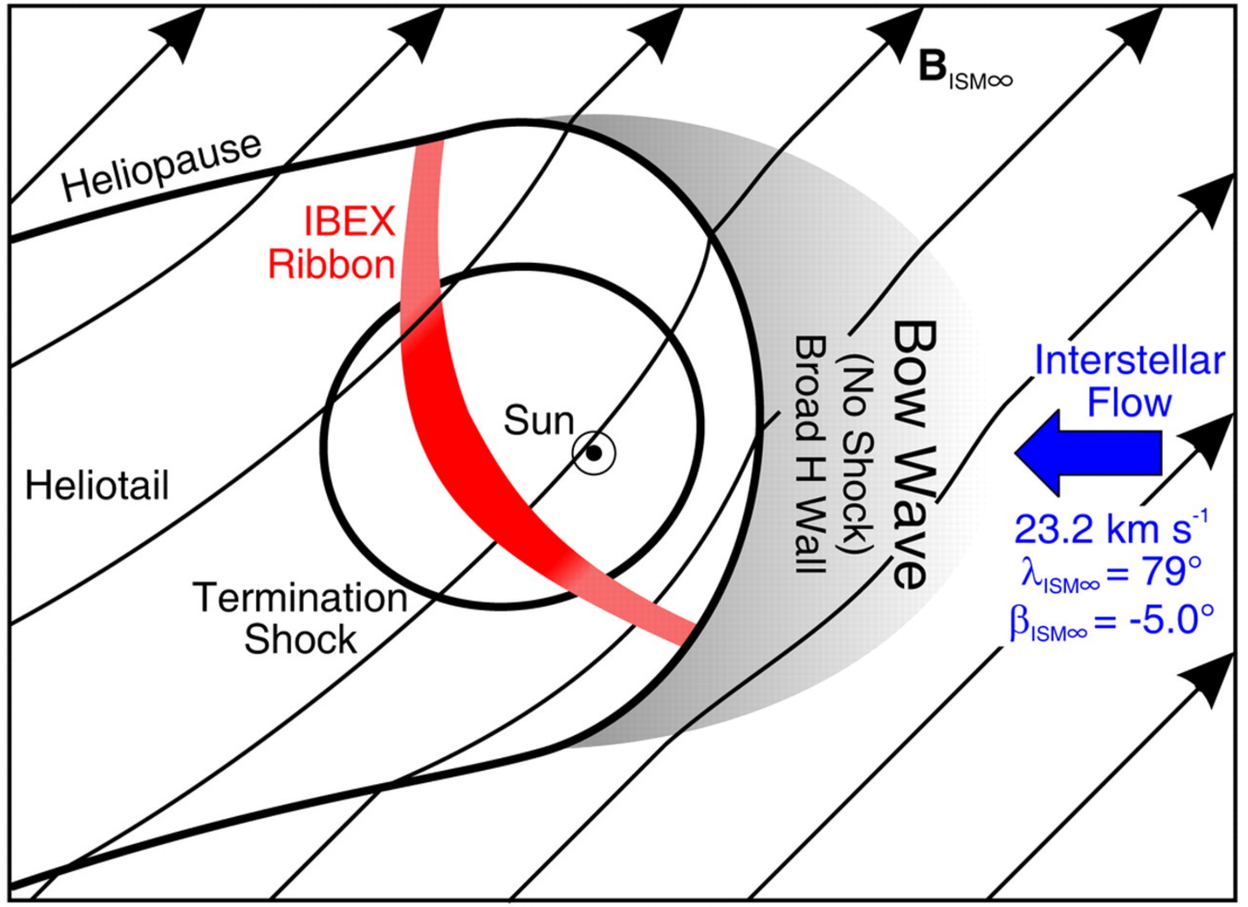
The Edge of the Solar System

- But wait… is there no sharp edge (bow shock) !?



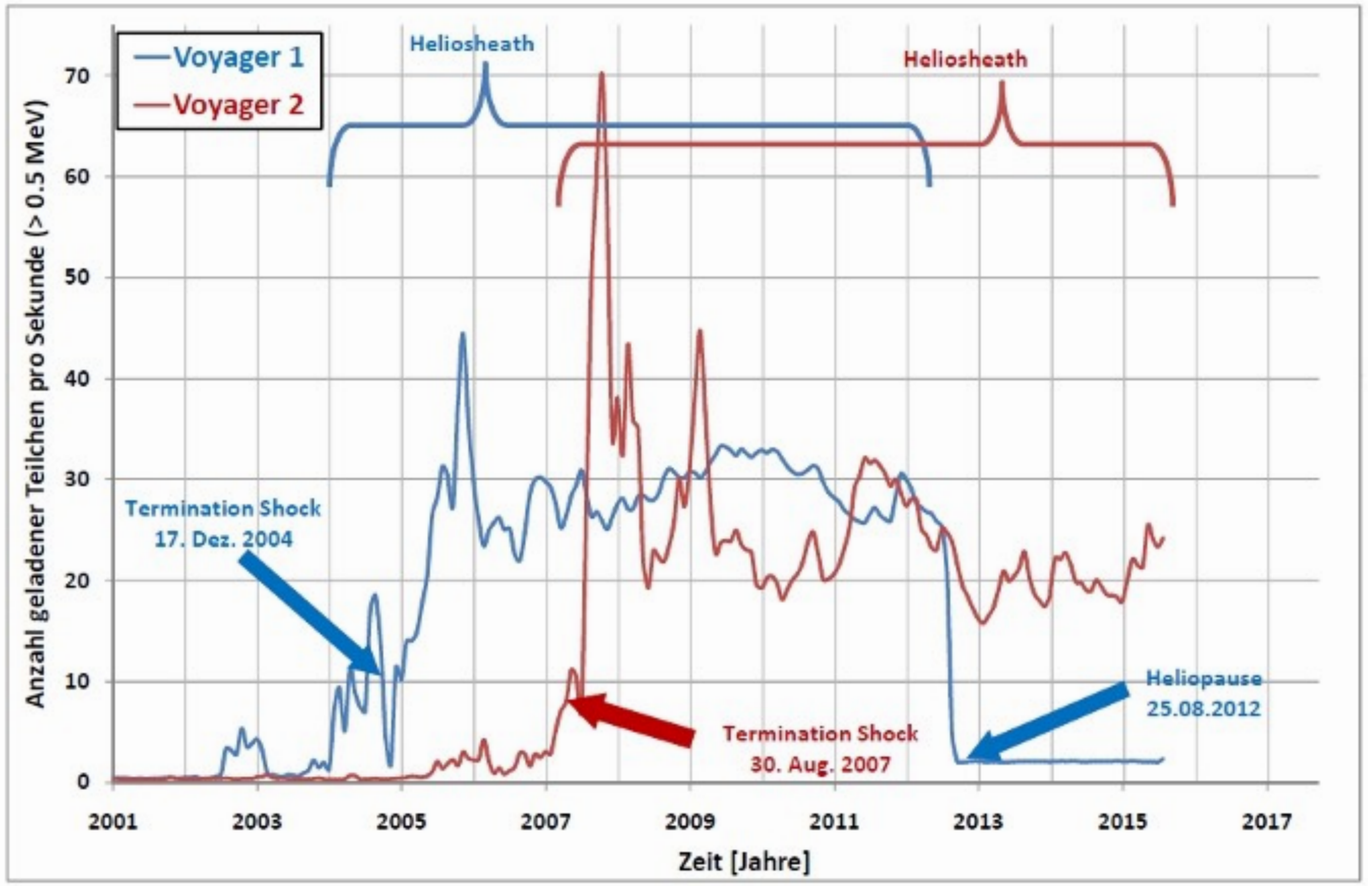
IBEX, launched 2008, still going!

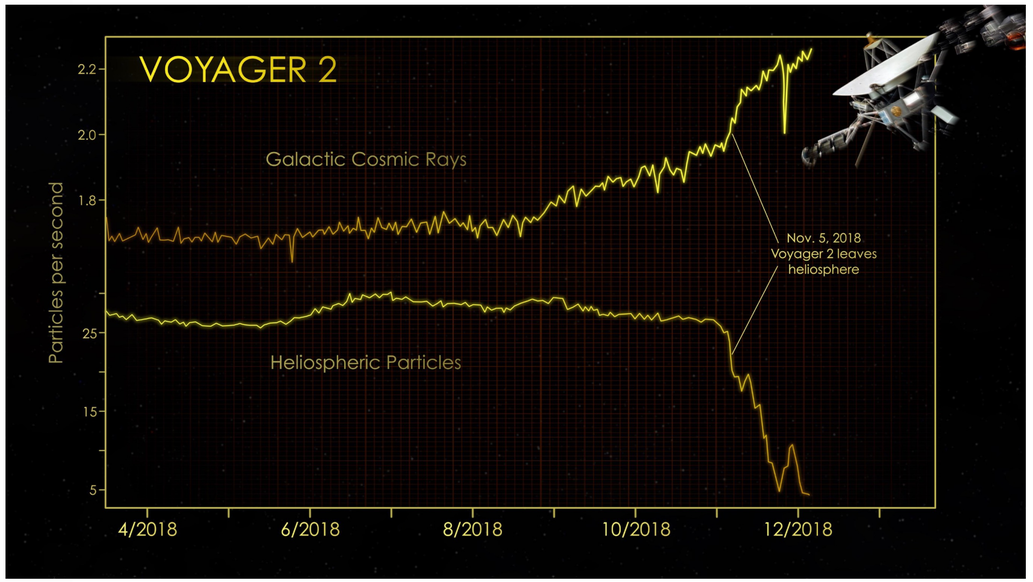
https://www.nasa.gov/mission_pages/ibex/allsky_map.html



http://www.sciencemag.org/content/early/2012/05/09/science.1221054.abstract

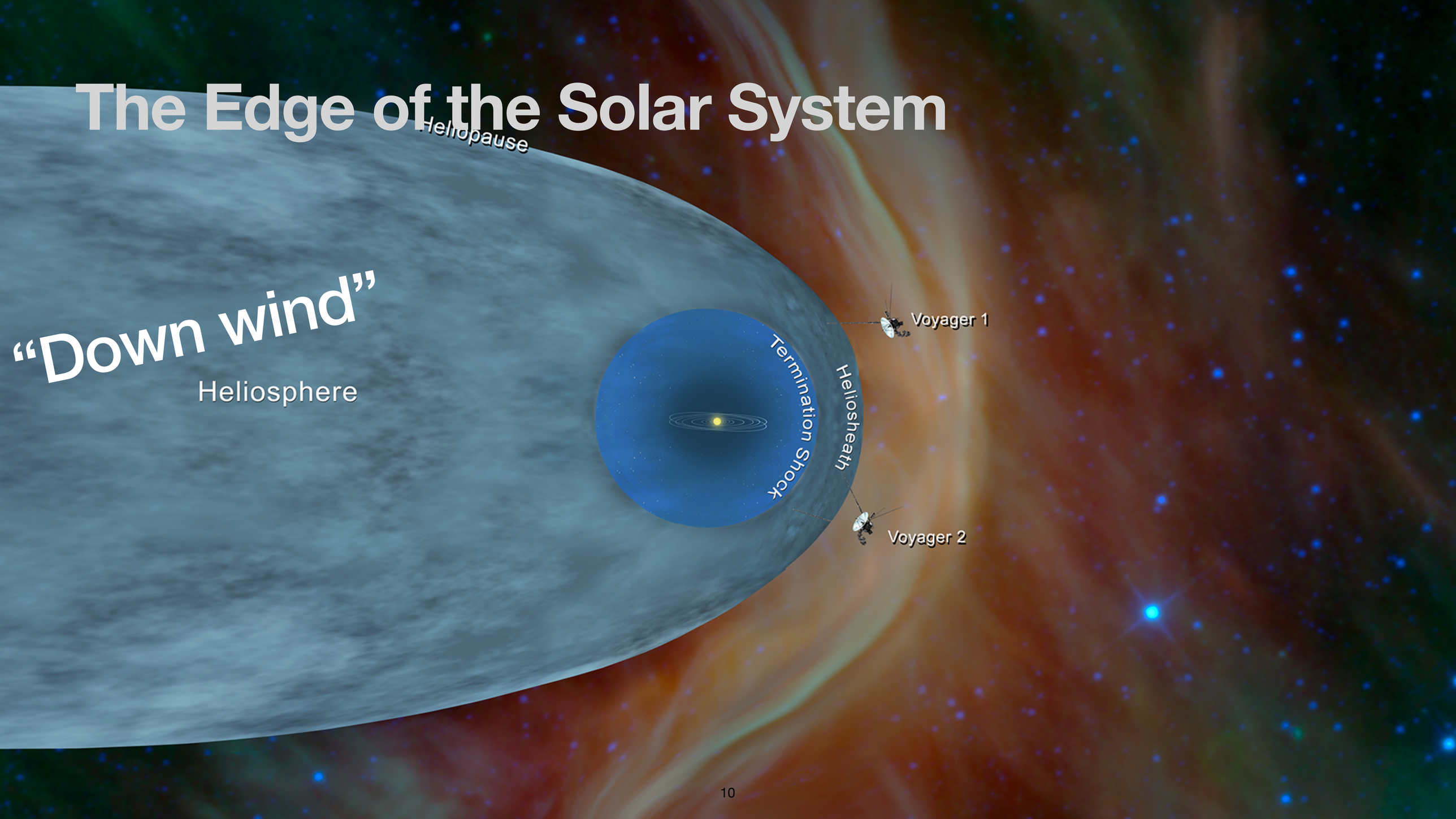
The Edge of the Solar System



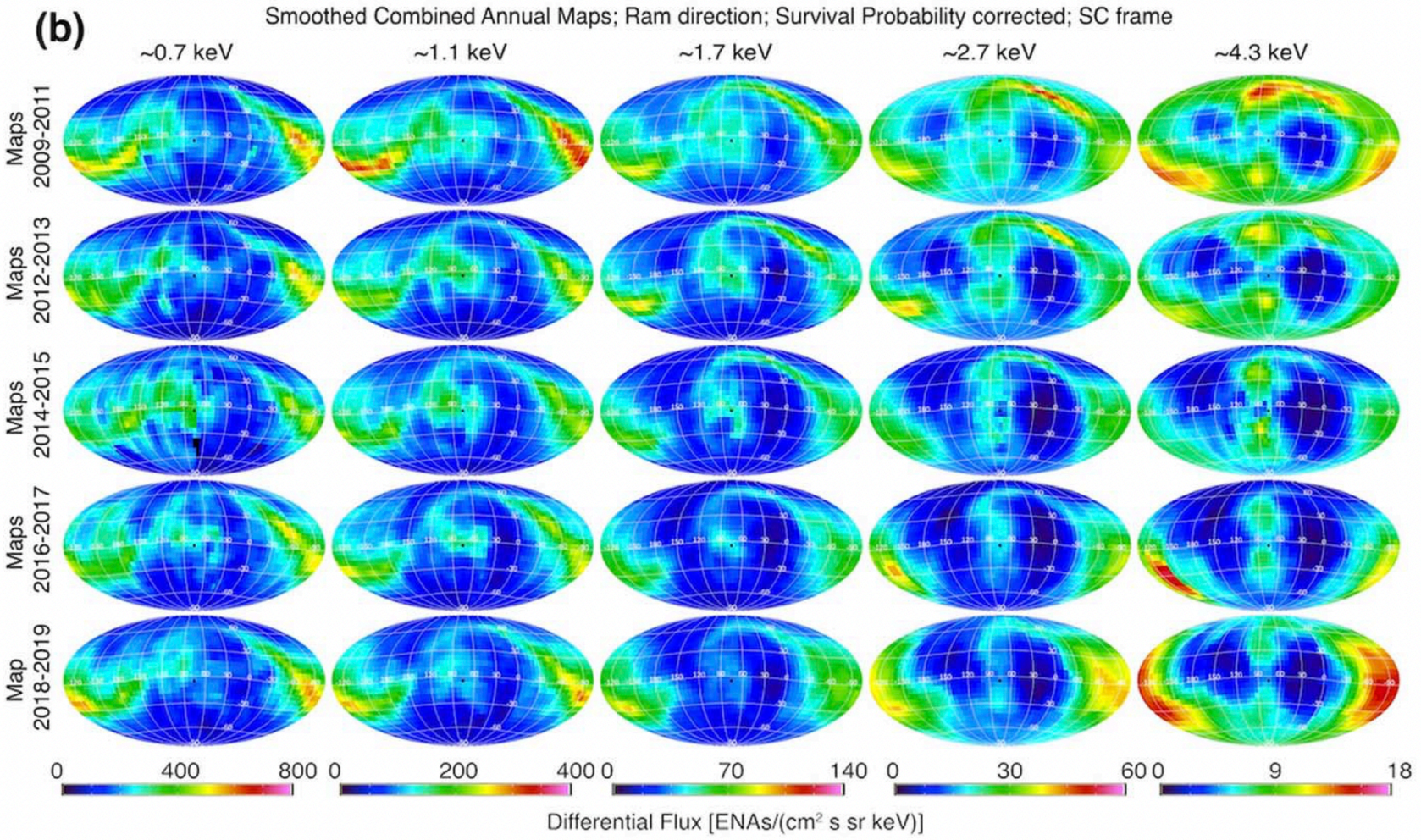


Looks like some kind of edge, but still may have very extended wave also

The Edge of the Solar System



The Edge of the Solar System



Complex “heliotail” structure

Variations over time, change w/ Solar activity cycle!

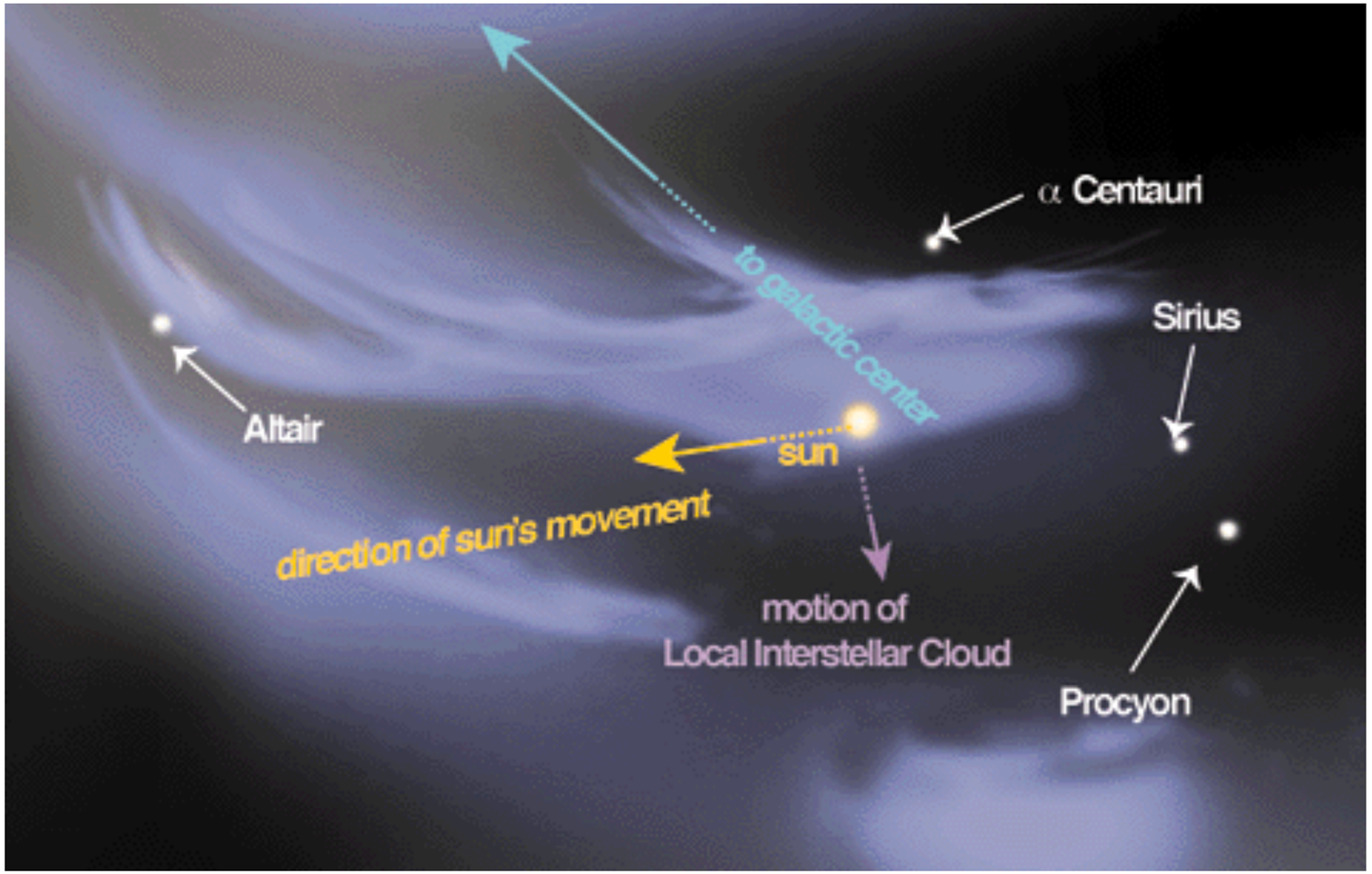
https://ui.adsabs.harvard.edu/abs/2022ApJS..261...27D/abstract

$d < 1\,\mathrm{lyr}$

- Not much out there… that we can see
  - *should* be lots of “interstellar asteroids” !
- Mean stellar density of our neighborhood is: 0.14 stars / pc^3
- Definitely some ISM out there… but without stars, very hard to infer structure or kinematics of nearby foreground ISM
- Beginnings of the **“Local Fluff”…**

$d < 1\text{pc}$

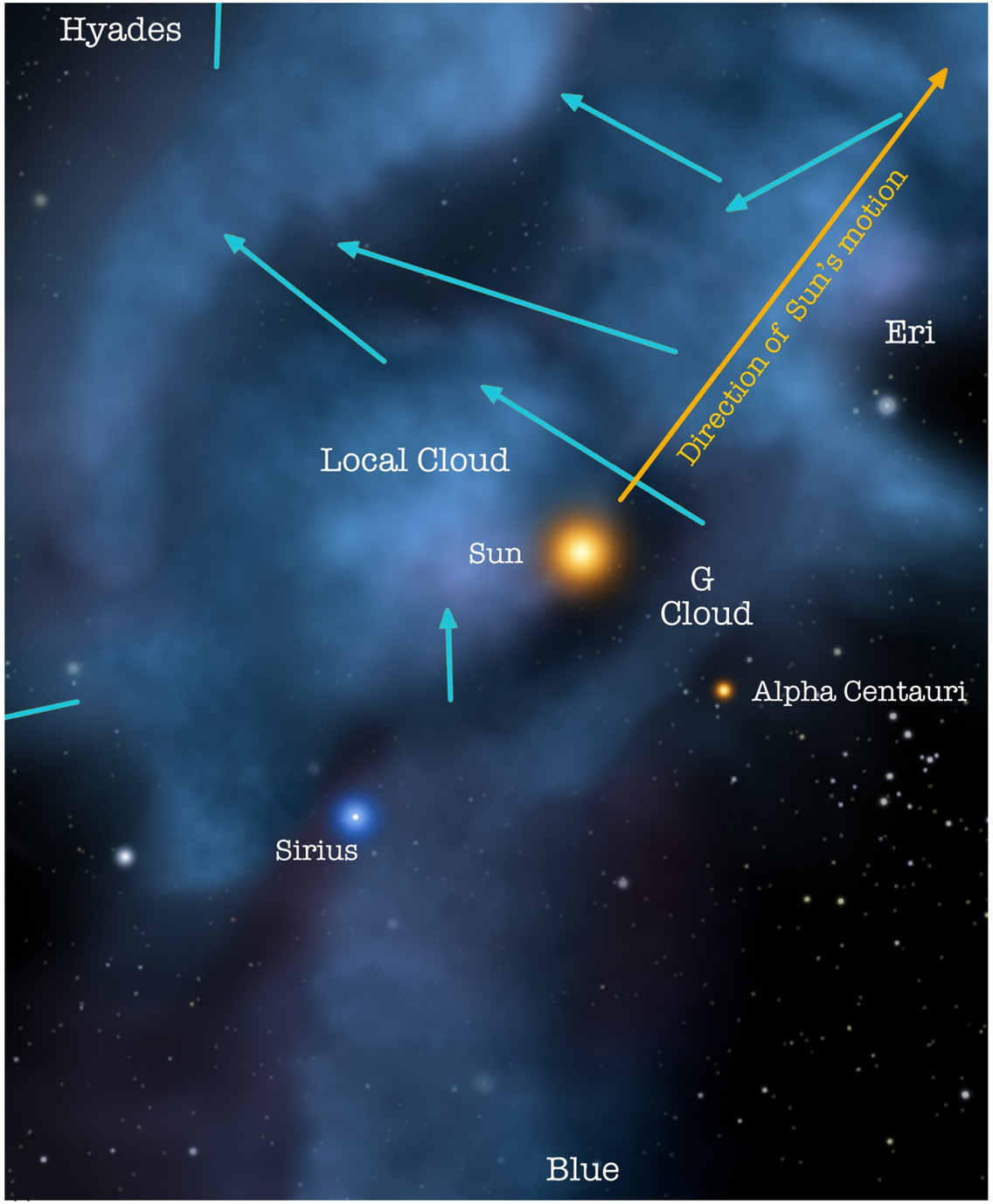
- **“Local Fluff"**



https://apod.nasa.gov/apod/ap020210.html

$d < 1\text{pc}$

- **“Local Fluff"**



https://www.nasa.gov/mission_pages/sunearth/news/gallery/solar-journey.html

$d < 1\text{pc}$

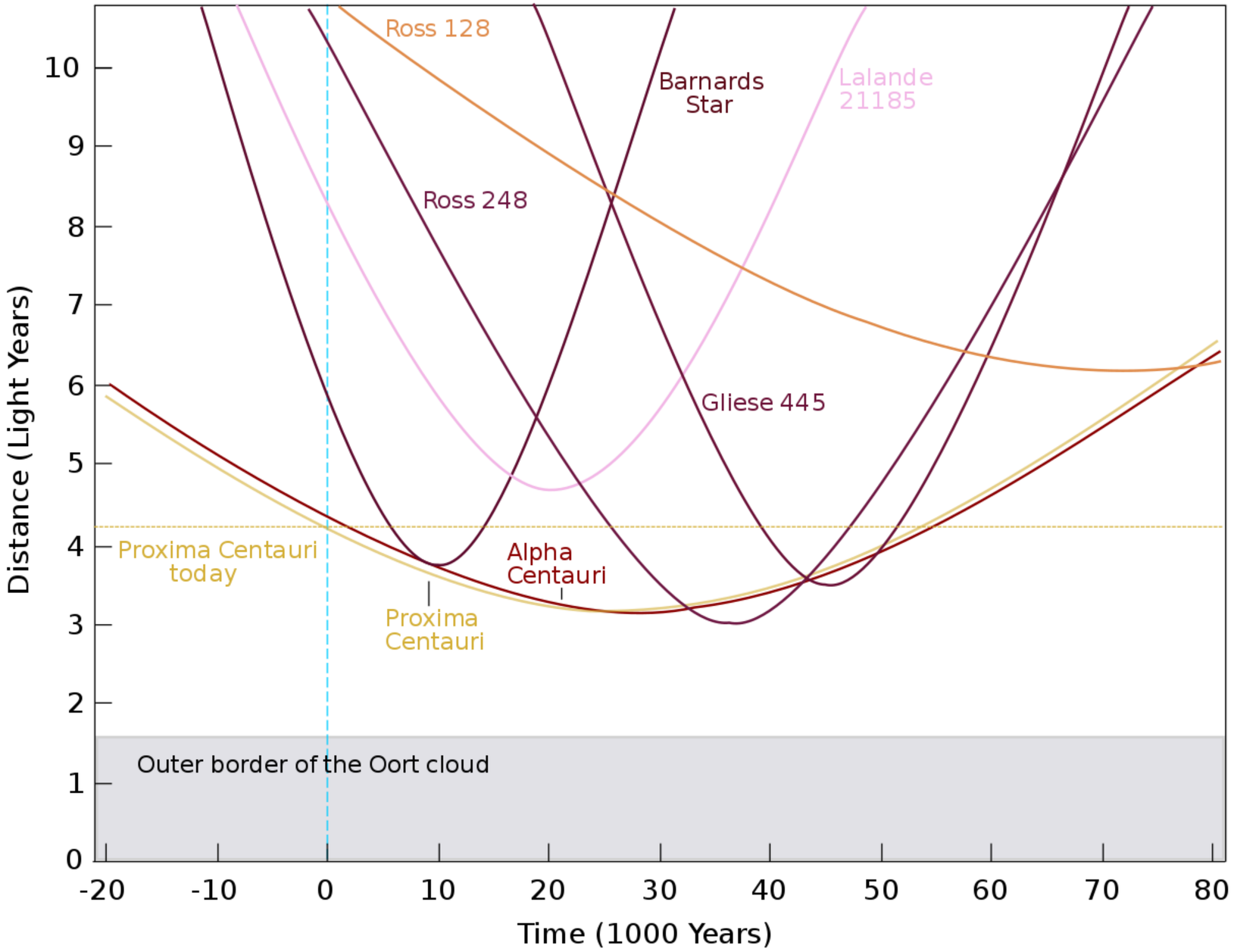
Abstract. The Local Interstellar Cloud (LIC) is the region of the interstellar medium (ISM) that surrounds and helps to shape the heliosphere. The LIC is part of a collection of nearby low density warm clouds known as the Complex of Local Interstellar Clouds (CLIC), all of which exist inside the hot Local Bubble. Observations of interstellar neutral He atoms flowing into the heliosphere by the IBEX mission and Voyager have constrained the temperature of the LIC to be roughly 7500 K. This temperature is consistent with that derived from absorption line measurements toward nearby stars. Such observations also indicate that the LIC is partially ionized with elemental abundances consistent with a moderate level of depletion onto dust grains as might occur for low density ISM that has been subject to a shock that partially destroyed the dust. The temperature of the cloud is not unusual for the warm ionized medium in the ISM, but it is less ionized than typical. We discuss the various processes that may be important for heating the LIC. We show that the only viable heat source for the ongoing heating of the CLIC is photoionization. Equilibrium models of the ionization and heating of the LIC allow for solutions that match the observations, but the likely origins of the local interstellar medium suggest that the situation is more complex. We propose an evolution scenario in which the clouds were formerly cold and were heated by shocks to reach their current warm state. We present new magneto-hydrodynamical calculations of the evolution of the local ISM. Multiple supernova models can match the parameters of the Local Bubble and heat the cold clouds as desired, though the many constraints on the clouds and bubble have yet to be fully satisfied by the models.

Slavin (2018)
https://iopscience.iop.org/article/10.1088/1742-6596/1100/1/012022

$d < 1\text{pc}$

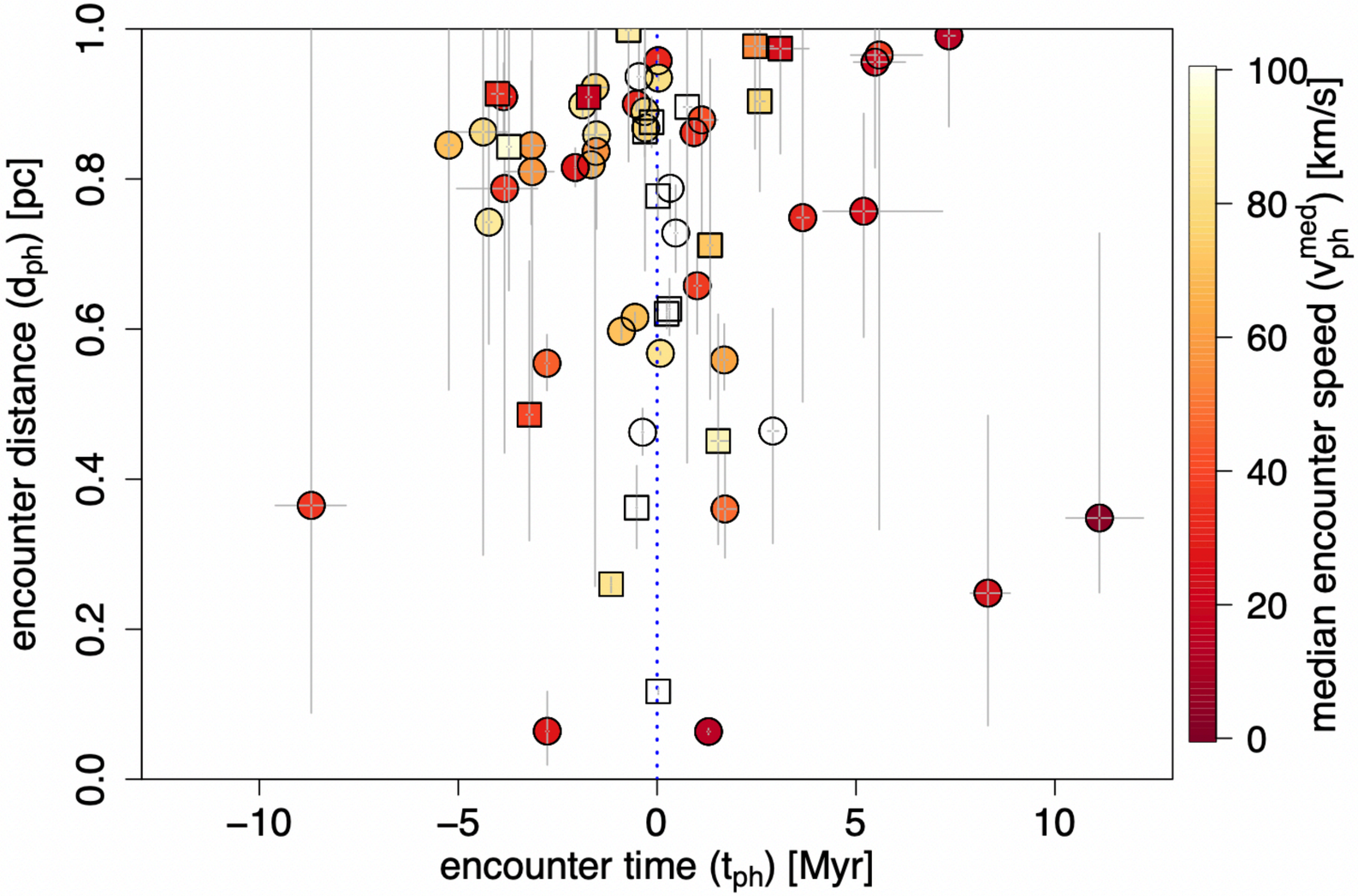
No stars within 1pc (currently)

Prox Cen: 1.3pc



https://commons.wikimedia.org/wiki/File:Near-stars-past-future-en.svg

$d < 1\text{pc}$



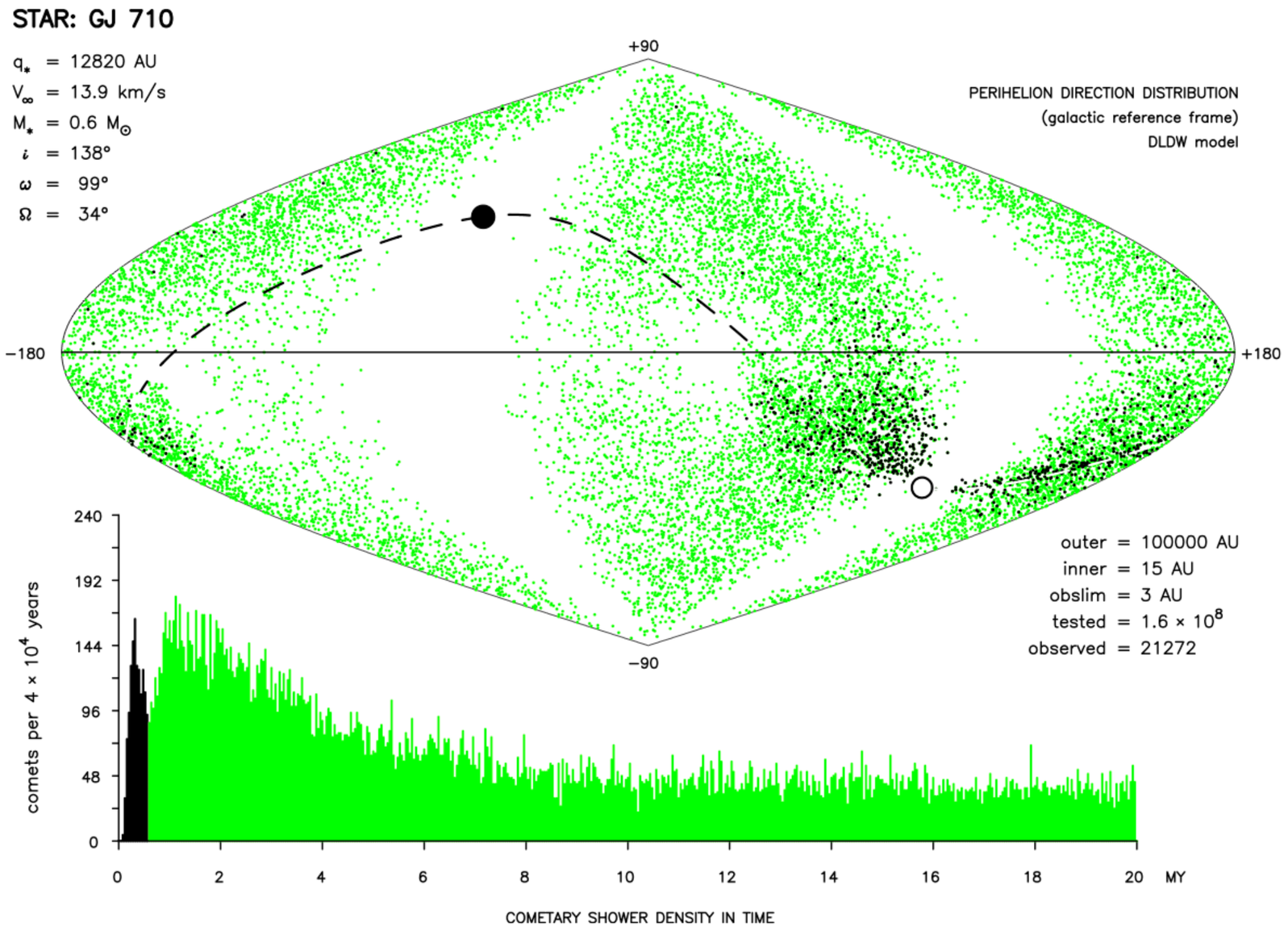
Bailer-Jones (2022)

https://arxiv.org/abs/2207.06258

$d < 1\text{pc}$

Gliese 710

1.3Myr from now,
comes 0.06pc away(!)



https://ui.adsabs.harvard.edu/abs/2016A%26A...595L..10B/abstract

$d < 5\text{pc}$

- **A few stars! Can you name any?**
- Free floating planets
- Local Interstellar Cloud (LIC) Complex
  - Sometimes called the CLIC…

$d < 5\mathrm{pc}$

- **Q: What nearby stars can you name?**

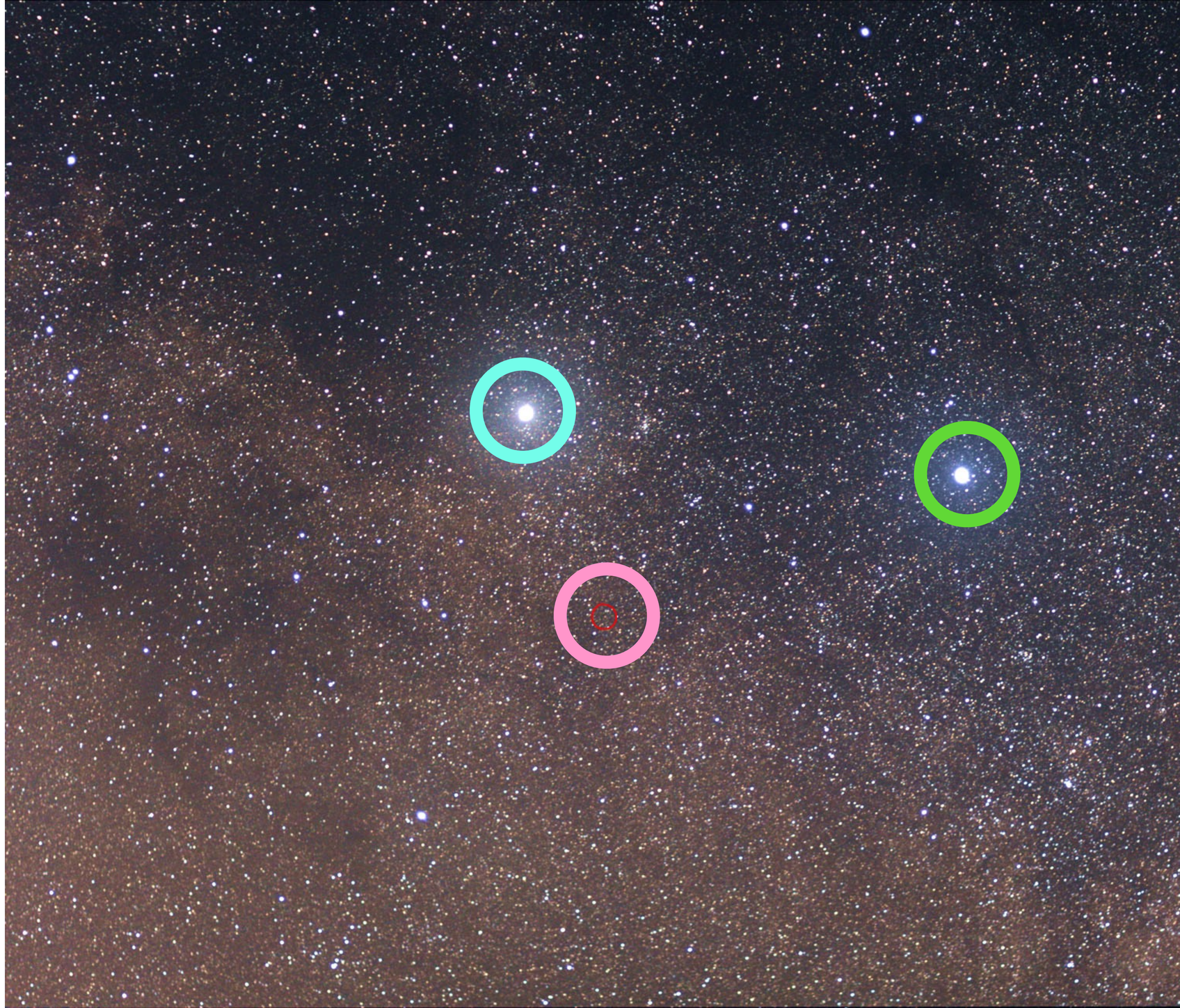
$d < 5\text{pc}$

Alpha, **Beta**, **Proxima Cen**

G2, K1, M6 dwarfs

~5 Gyr old

Planets… so far only found around Proxima

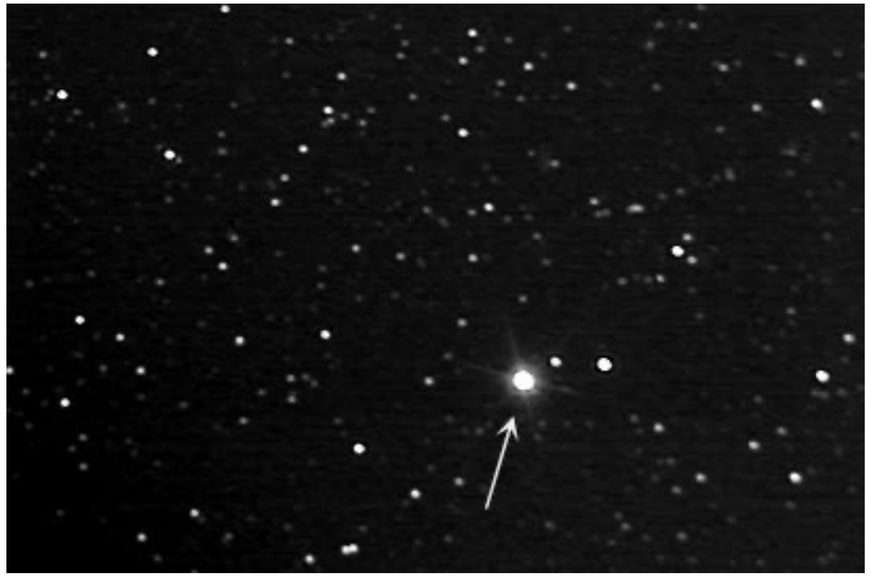


$d < 5\text{pc}$

Barnard's Star

Highest proper motion (10"/yr)

Very old M4, still occasional flares!

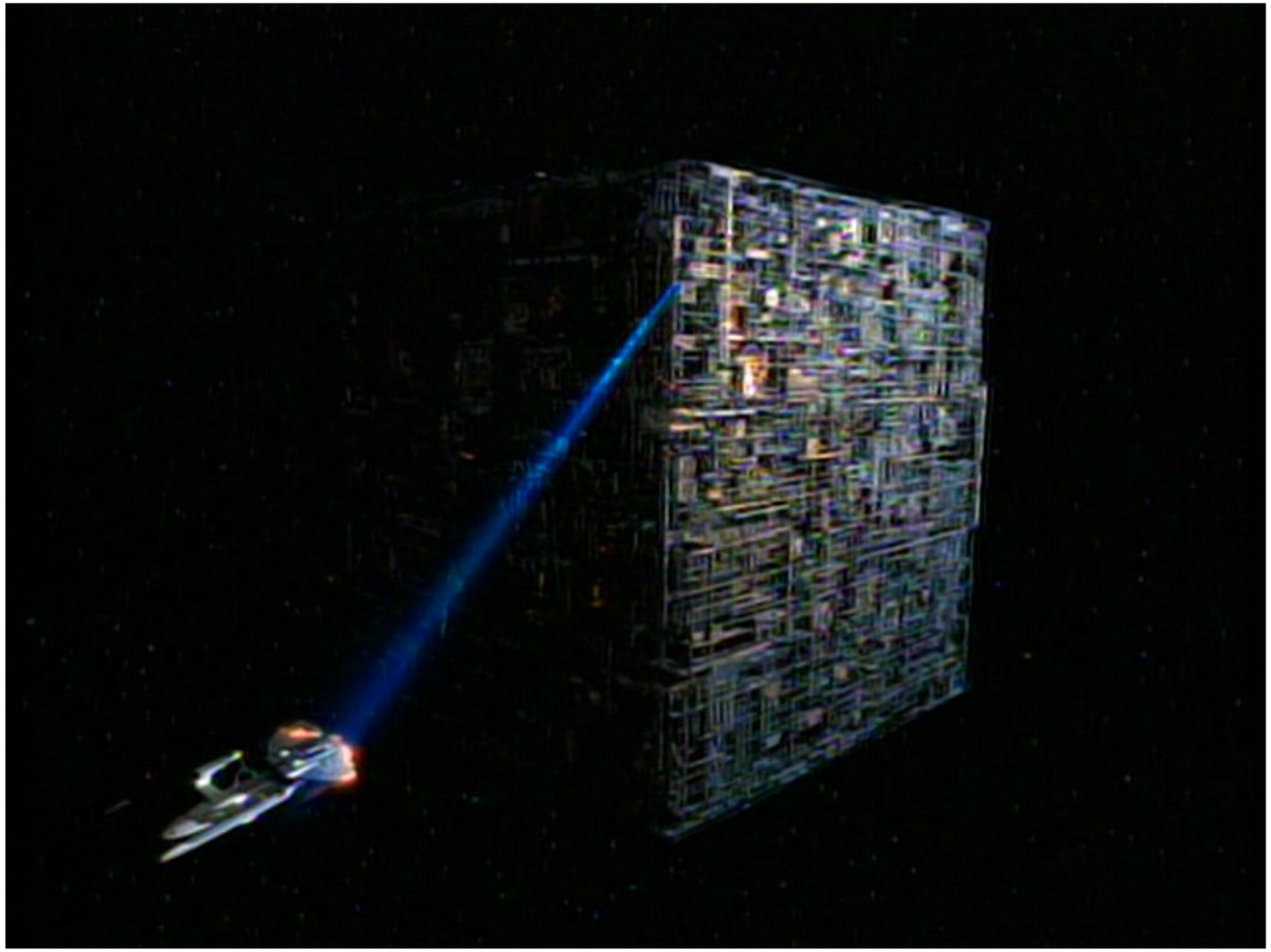


https://en.wikipedia.org/wiki/File:Barnard2005.gif

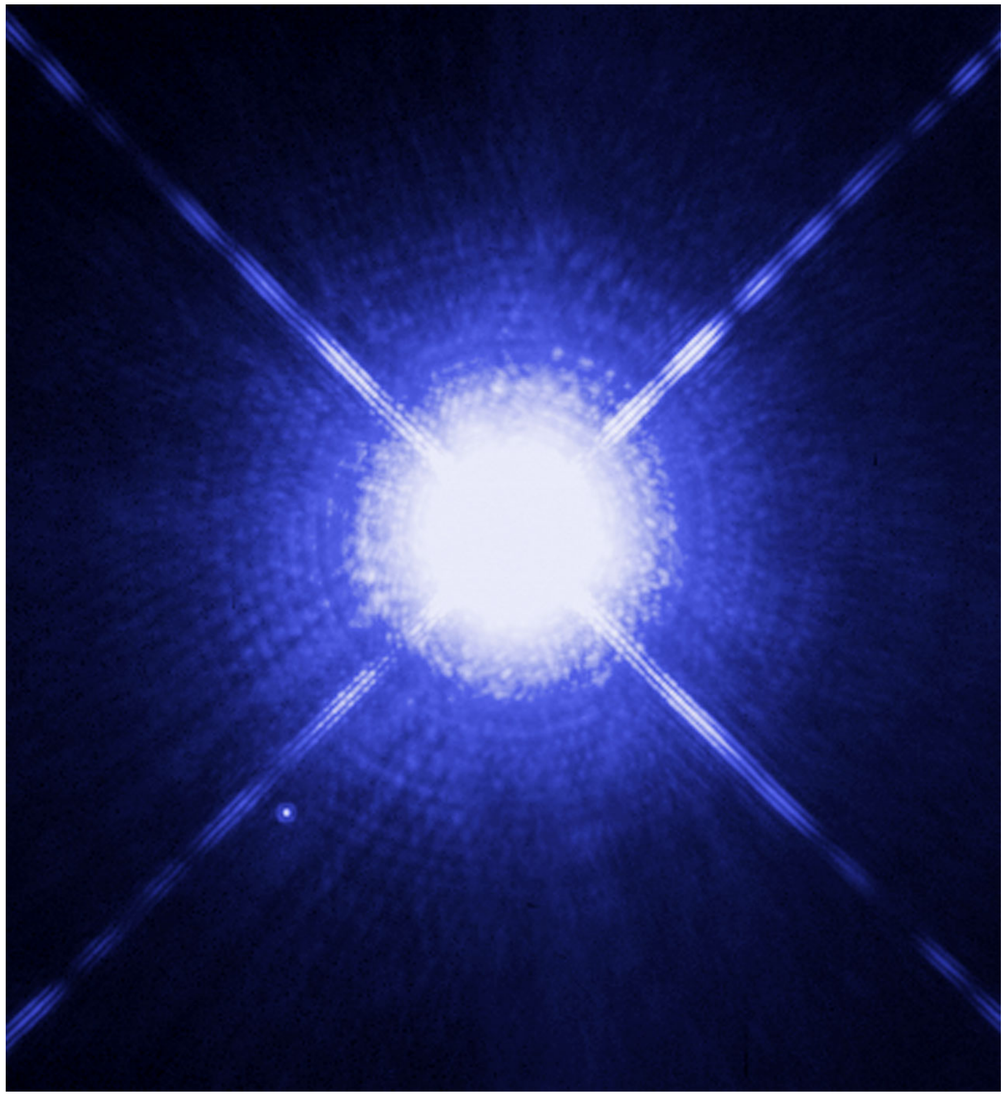
$d < 5\text{pc}$

Wolf 359: M6,
planet-hosting flare star

https://en.wikipedia.org/wiki/Wolf_359



$d < 5\text{pc}$



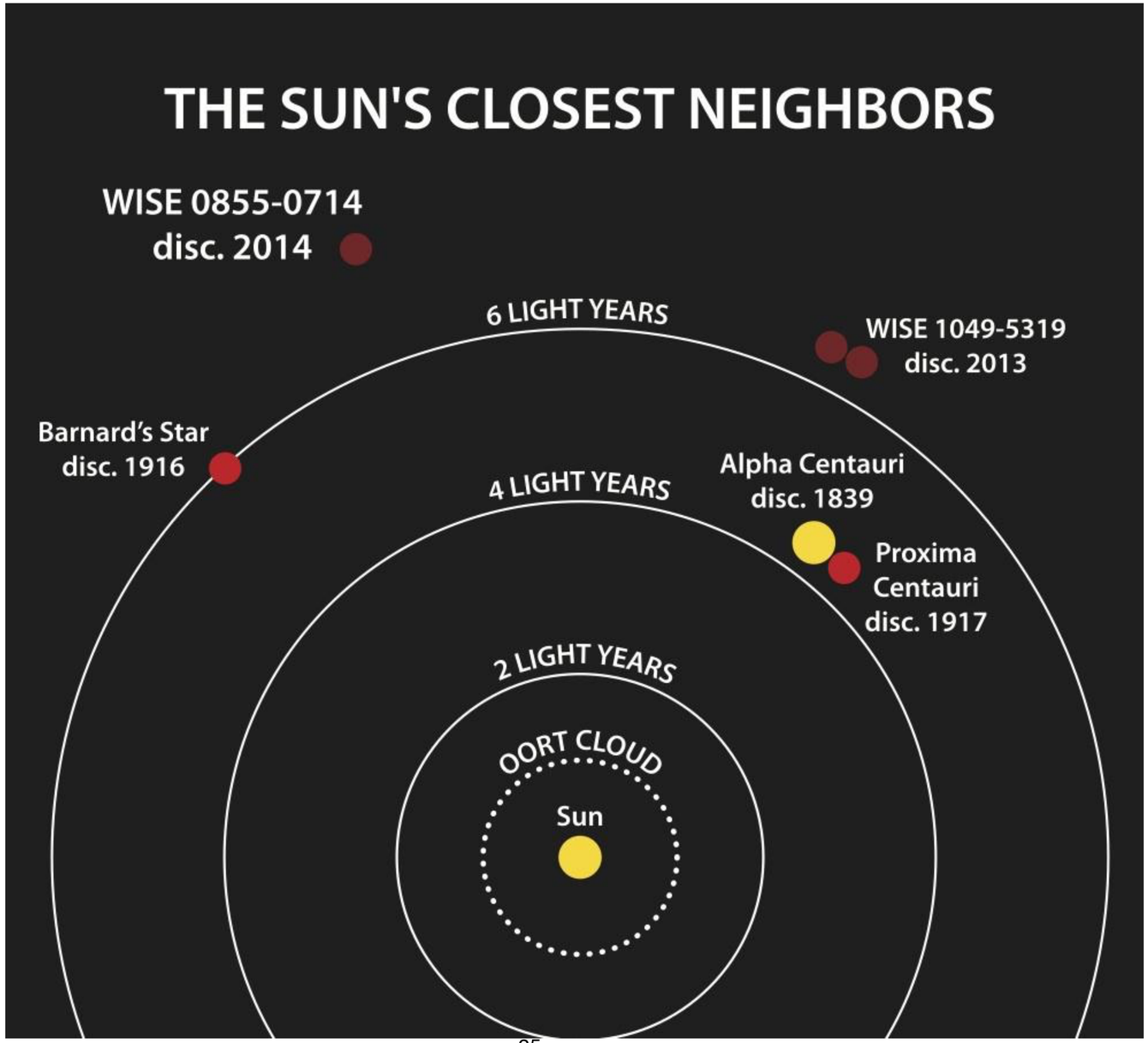
https://esahubble.org/images/heic0516a/

- **Sirius**, the “dog star”
- Brightest star in the sky
- A star + WD
- 2.64pc
- First star w/ RV’s measured!
- One of first proper motions!

$d < 5\text{pc}$

<u>WISE 0855–0714</u>

~5 Mjup (Y dwarf)



<u>Luhman 16AB</u>

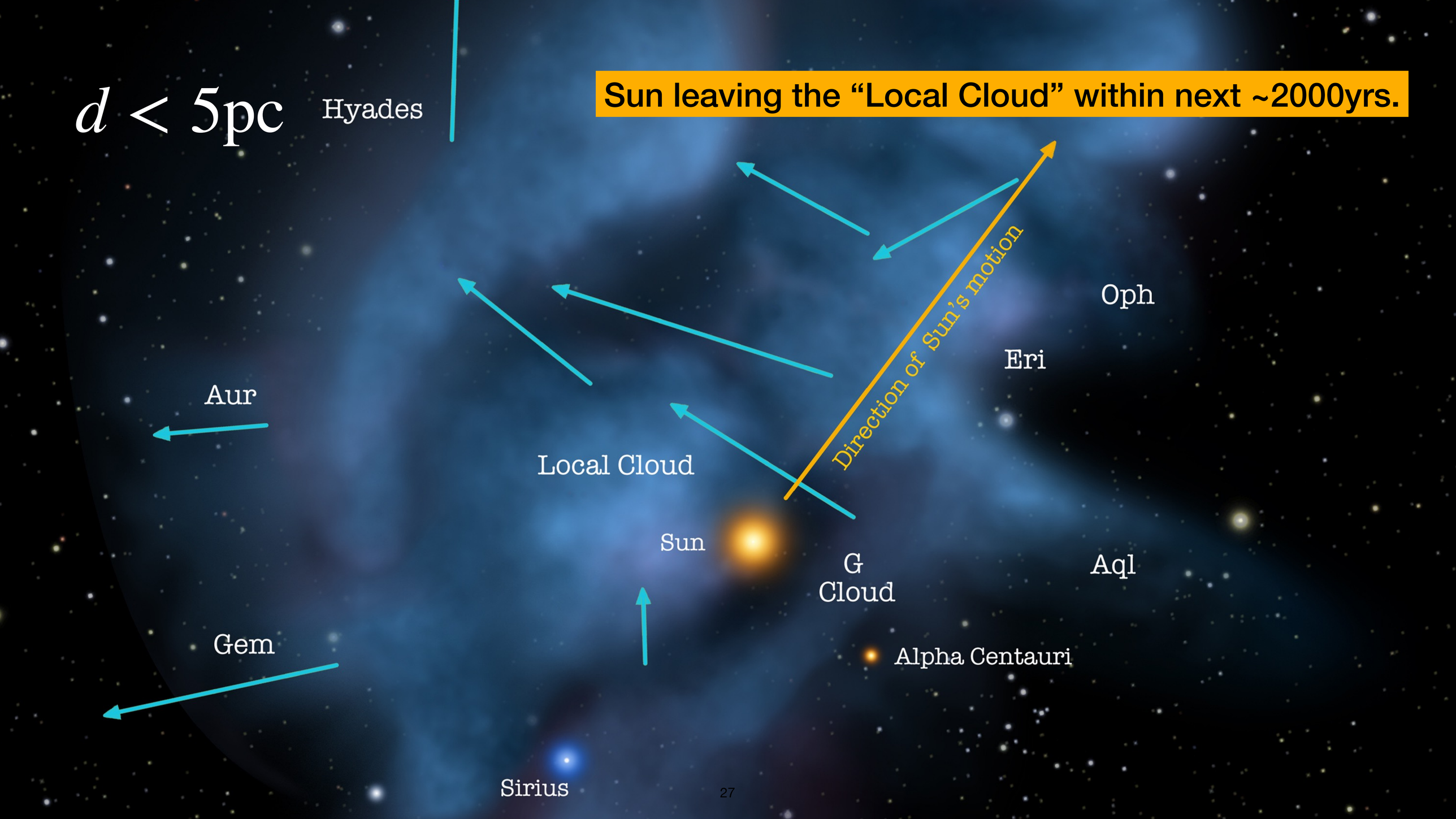
Both ~30 Mjup

https://photojournal.jpl.nasa.gov/catalog/PIA18003

$d < 5\text{pc}$

- **So super nearby we have…**
  - 1 higher mass star,
  - a couple solar mass stars,
  - a handful of M dwarfs
  - a few brown-dwarf or “rouge planet” type objects

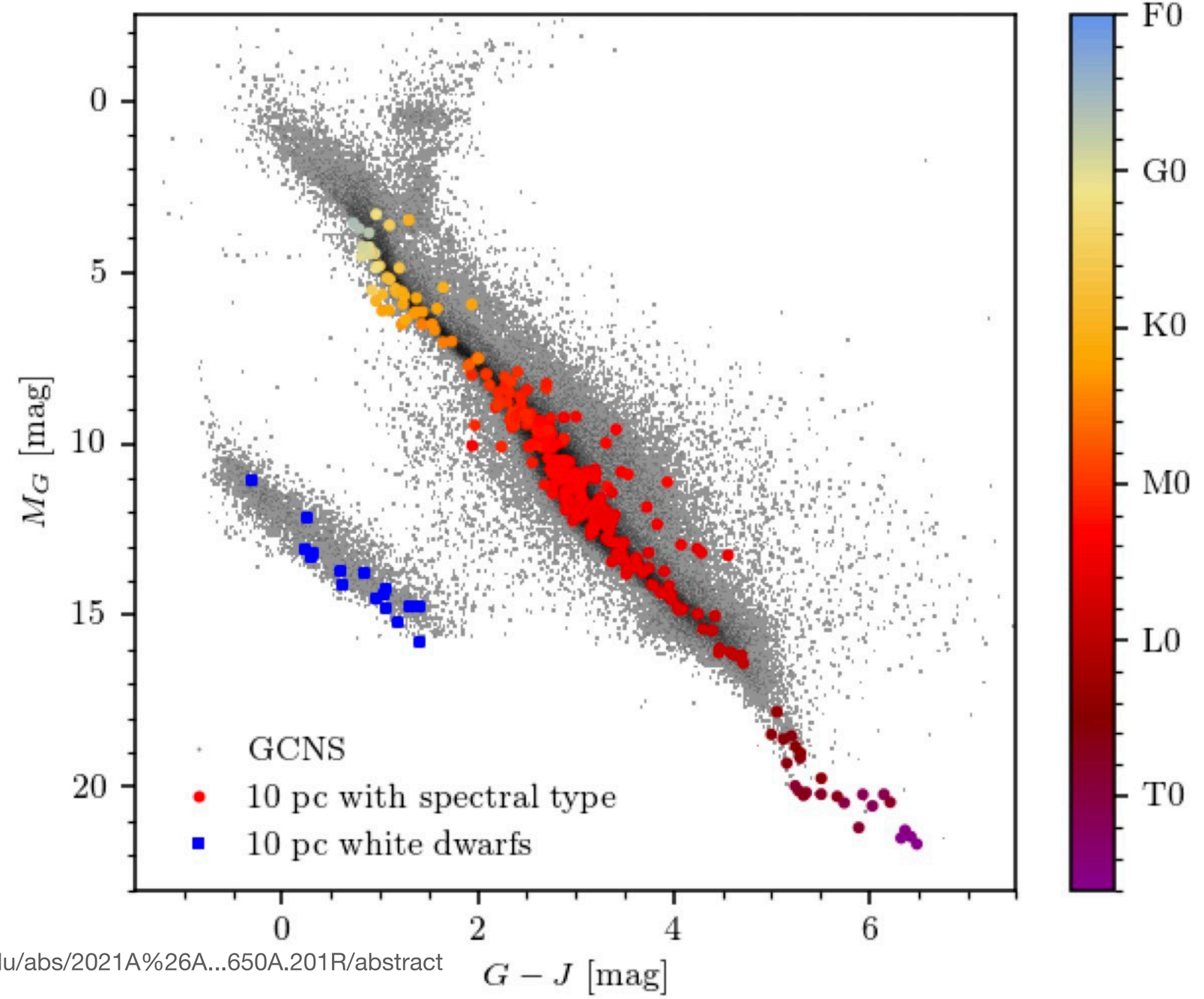
- **Already we’re learning something about stars!**
  (More in a couple weeks!)


$d < 5$pc
Hyades
Sun leaving the “Local Cloud” within next ~2000yrs.
Direction of Sun’s motion
Oph
Eri
Aur
Local Cloud
Sun
G
Cloud
Aql
Gem
Alpha Centauri
Sirius

$d < 10\text{pc}$

- 540 stars in 339 systems
- More Y dwarfs!

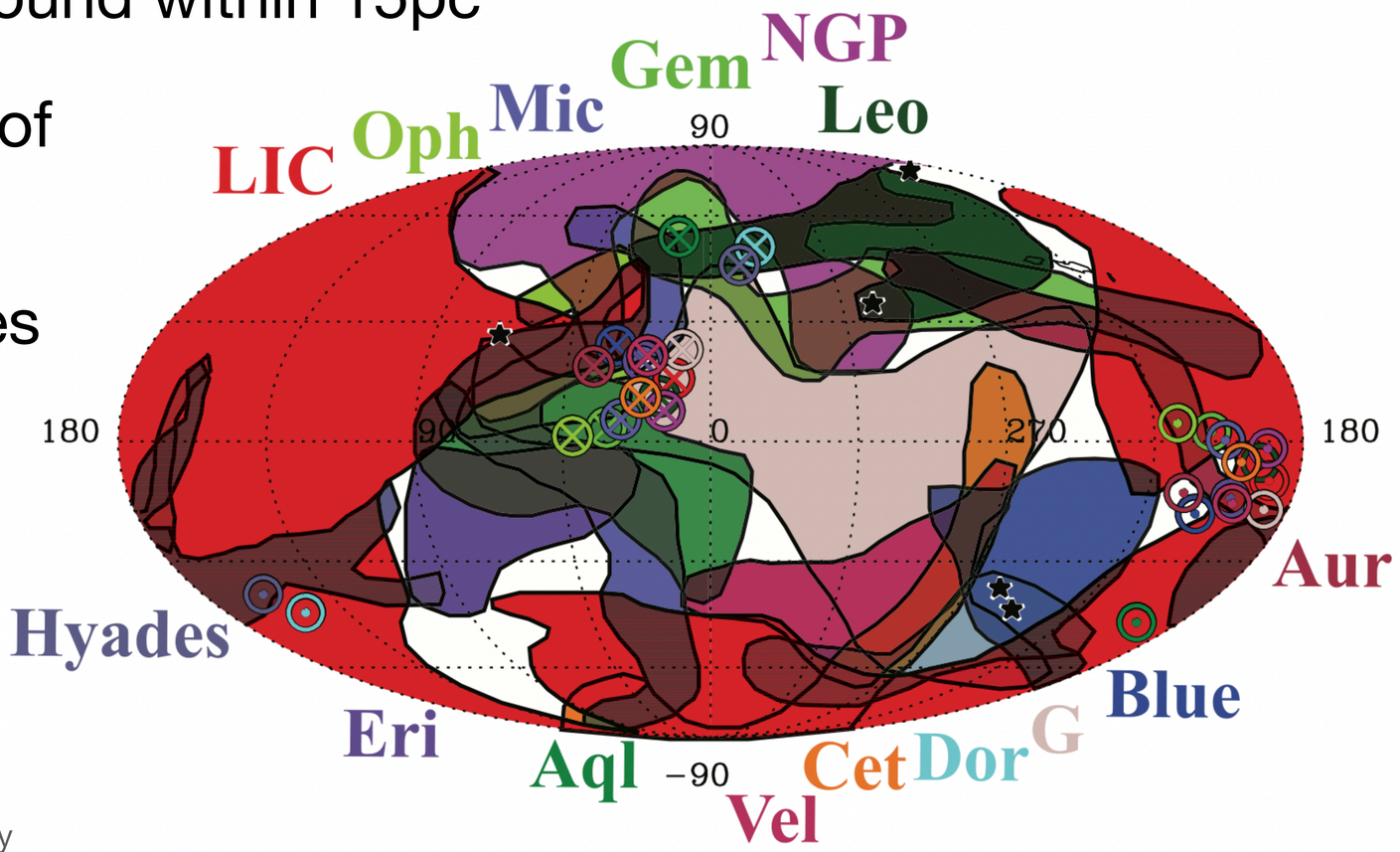
- Moving groups?
- Actual structure of LIC!



https://ui.adsabs.harvard.edu/abs/2021A%26A...650A.201R/abstract

$d < 10\text{pc}$

- At least 15 distinct “Clouds” found within 15pc
- Sun appears to be near edge of LIC and G-Cloud
- This is mapped using velocities of ISM lines along line-of-sight to nearby stars (“pencil beams”)



Redfield & Linsky
https://ui.adsabs.harvard.edu/abs/2008ApJ...673..283R/abstract

See also: https://ui.adsabs.harvard.edu/abs/2018JPhCS1100a2016L/abstract

$d < 10\text{pc}$

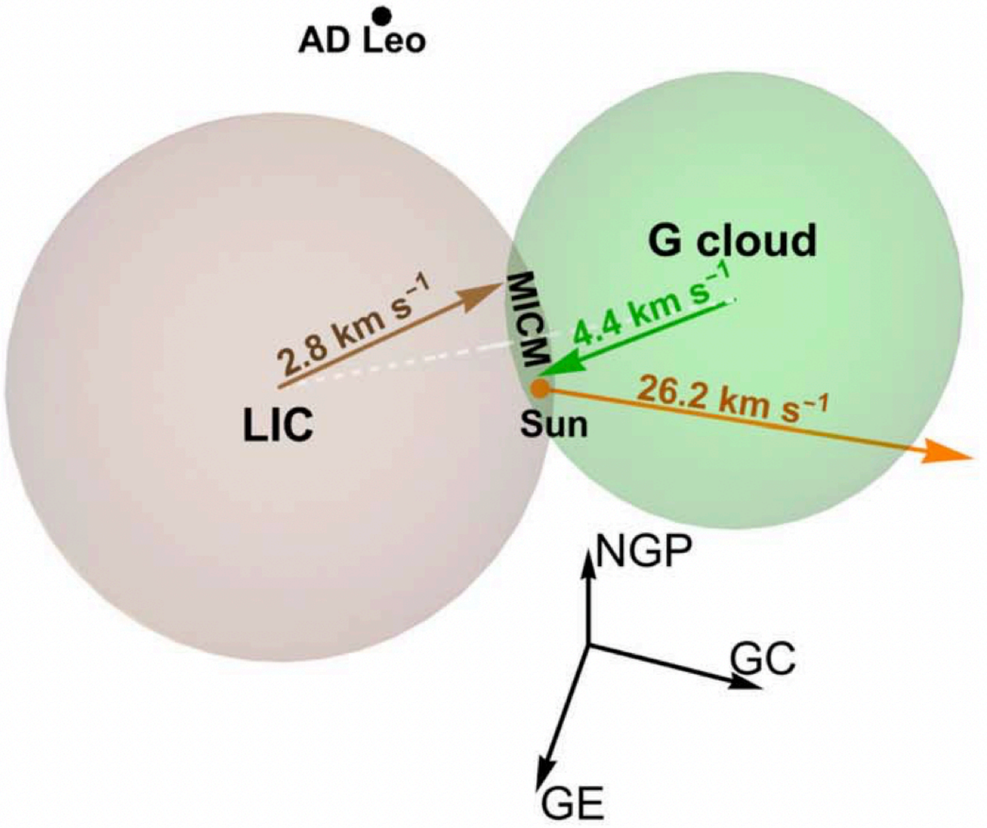
- At least 15 distinct “Clouds” found within 15pc (the CLIC)
- Sun appears to be near edge of LIC and G-Cloud

continuum. For every sightline, we detect at least one velocity component and often two to six components even for stars located within 5 pc. Our detection of multiple velocity components along the same short sightline indicates that the LISM gas has velocity structure with scales of order one pc or smaller. With this large data set, Redfield & Linsky (2008) (hereafter RL08) developed a model of the partially ionized LISM gas consisting of many discrete components, which we call clouds, for which we assume that the gas moves coherently with the same velocity vector and physical properties (temperature and turbulence). While this model is simple, it fits the data quite well (Redfield & Linsky 2015), but we intend to test this model when there is sufficient data to see whether the clouds have inhomogeneous properties, as proposed by Gry & Jenkins (2014), or may have nonthermal velocity distributions.

See also: https://ui.adsabs.harvard.edu/abs/2018JPhCS1100a2016L/abstract

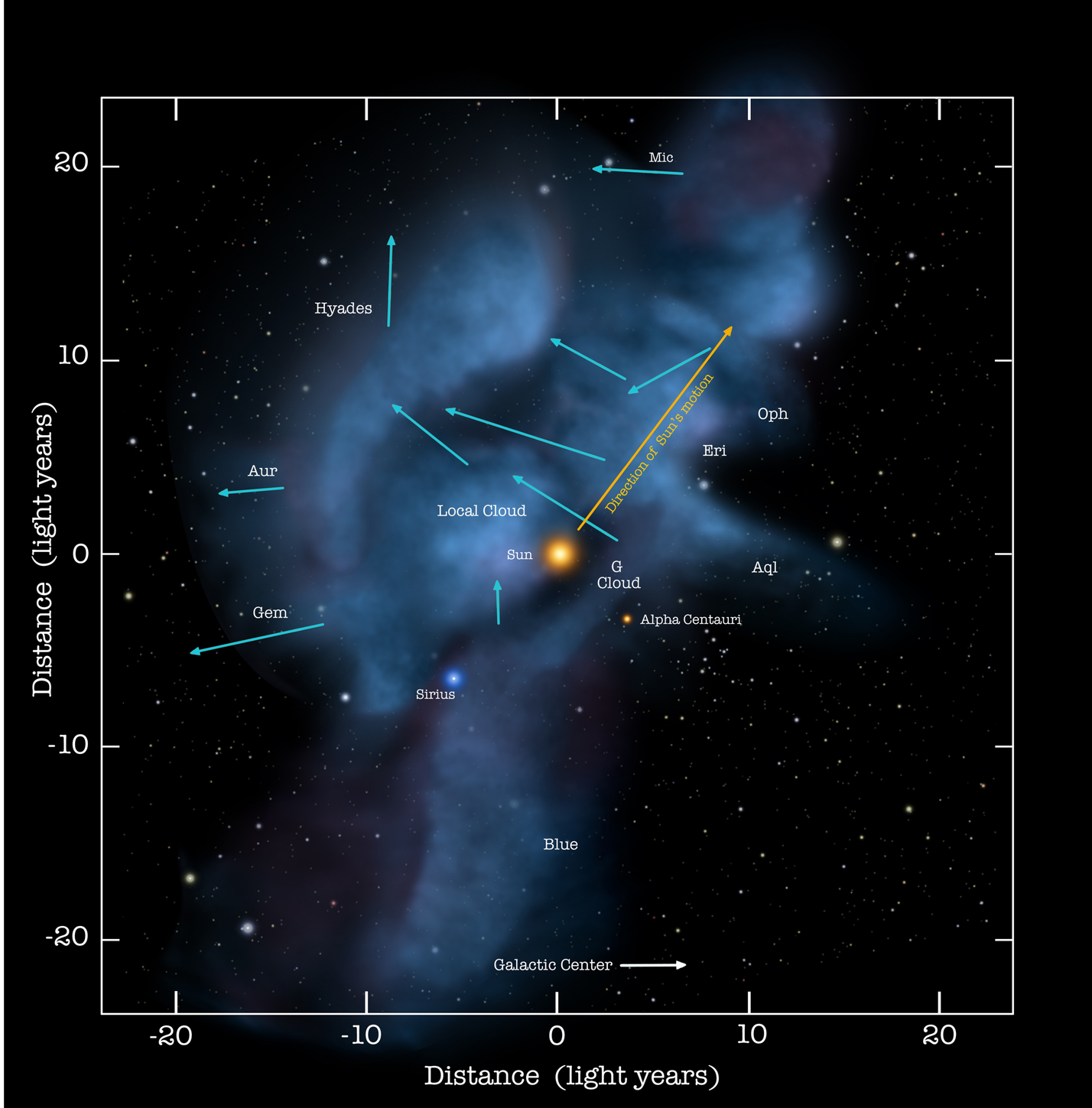
$d < 10\text{pc}$

- LIC and G-Cloud may be interacting, abnormally high amount of neutral H near the Sun



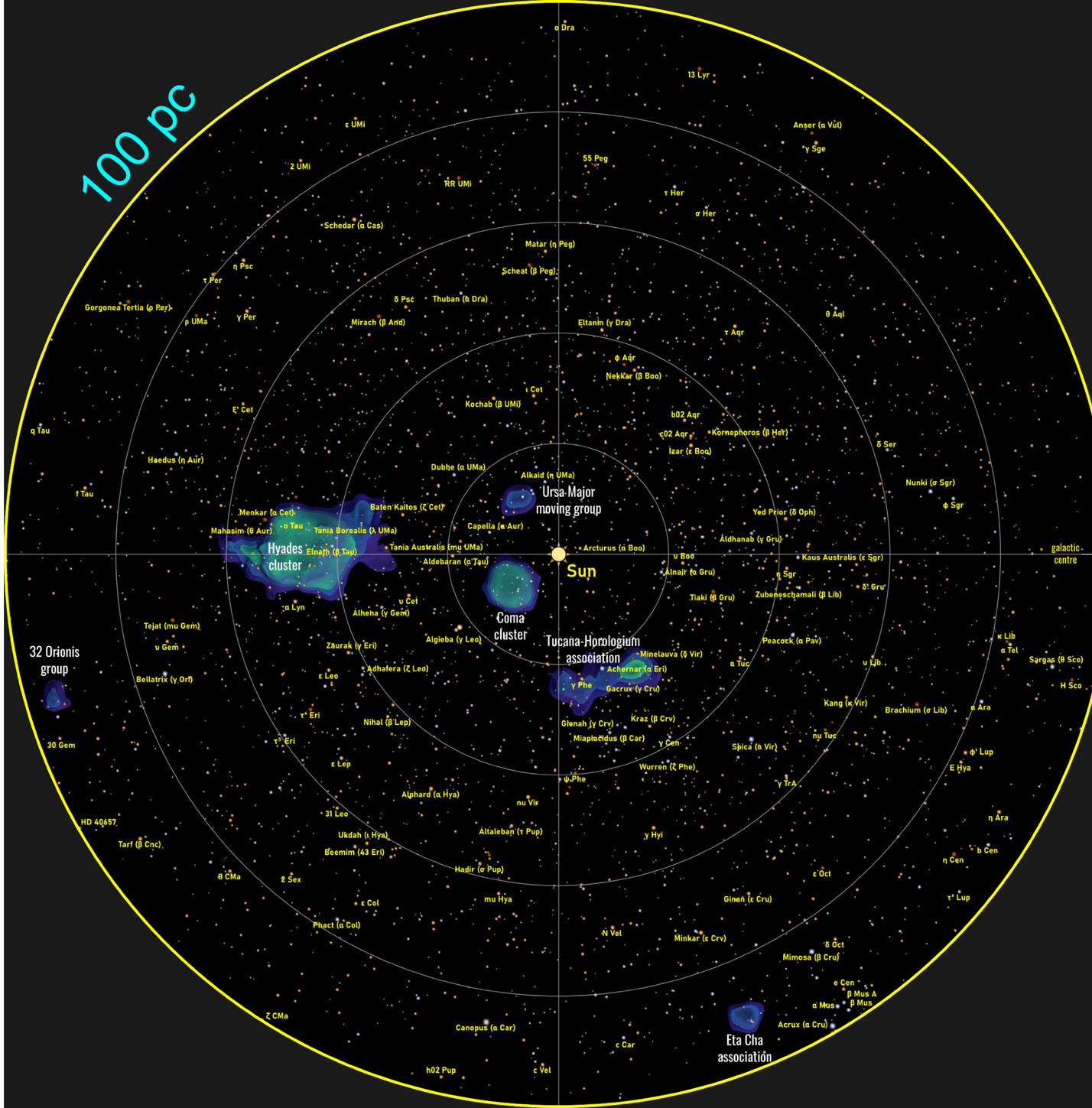
Swaczyna+2022
https://ui.adsabs.harvard.edu/abs/2022ApJ...937L..32S/abstract

$d < 10\text{pc}$

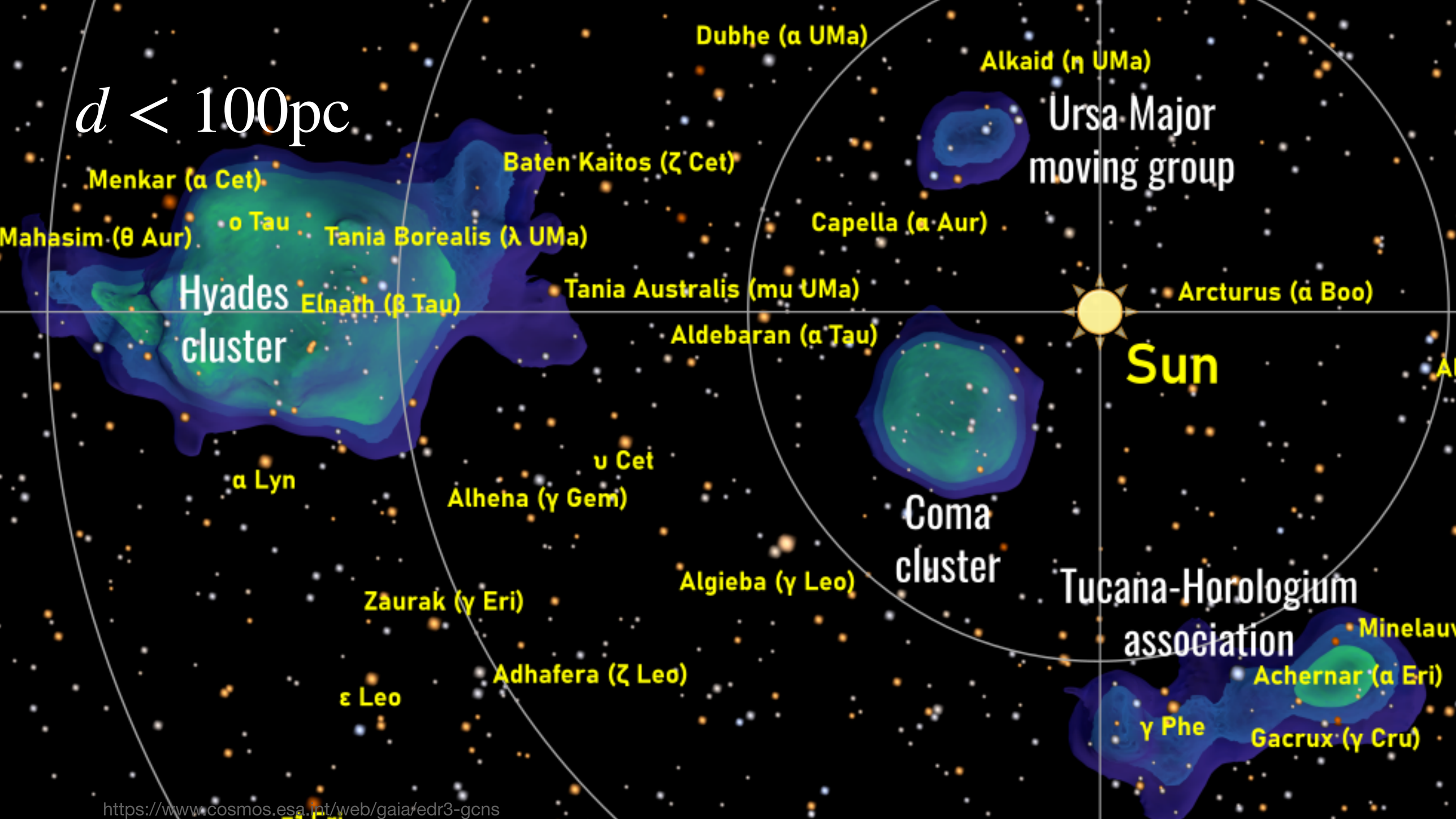

Mic
Hyades
Direction of Sun's motion
Oph
Eri
Aur
Local Cloud
Sun
G
Cloud
Aql
Gem
Alpha Centauri
Sirius
Blue
Galactic Center
20
10
0
-10
-20
Distance (light years)
-20
-10
0
10
20
Distance (light years)

$d < 100\text{pc}$

- **Gaia Catalog of Nearby Stars**
  N~330k stars, highly complete!
- Clusters & moving groups
  (Hyades, Ursa Major, Beta Pic…)
- Some very young stars &
  associations (e.g. TW Hydrae)



https://www.cosmos.esa.int/web/gaia/edr3-gcns


$d < 100$pc
Dubhe (α UMa)
Alkaid (η UMa)
Ursa Major
moving group
Baten Kaitos (ζ Cet)
Menkar (α Cet)
o Tau
Mahasim (θ Aur)
Tania Borealis (λ UMa)
Capella (α Aur)
Hyades
cluster
Elnath (β Tau)
Tania Australis (mu UMa)
Arcturus (α Boo)
Aldebaran (α Tau)
Sun
υ Cet
α Lyn
Alheha (γ Gem)
Coma
cluster
Algieba (γ Leo)
Zaurak (γ Eri)
Tucana-Horologium
association
Minelauv
Adhafera (ζ Leo)
Achernar (α Eri)
ε Leo
γ Phe
Gacrux (γ Cru)
https://www.cosmos.esa.int/web/gaia/edr3-gcns

$d < 500\text{pc}$

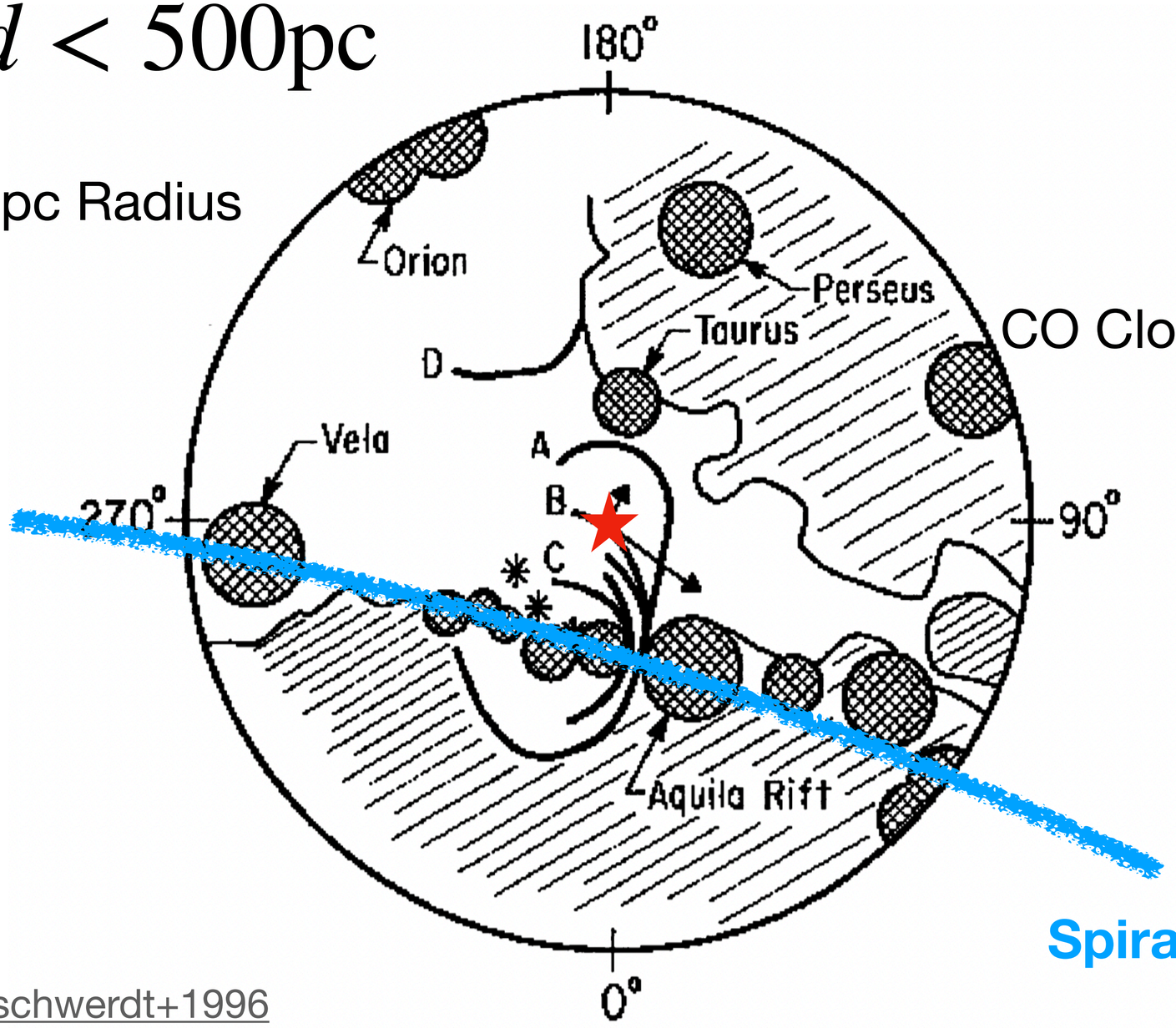
- Hint of spiral arm(s)
- Other galaxies show big variations in SFH on few hundred pc scales
- Finally get our first Planetary Nebulae!
  - Helix Nebula (200pc)
- Radcliffe Wave & Local Bubble

https://en.wikipedia.org/wiki/Helix_Nebula#/media/File:NGC7293_(2004).jpg

The Local Bubble

$d < 500\text{pc}$

~500pc Radius



Hints that **we live in a bubble** started to be seen in early 1970's

Both from location of star forming regions & molecular clouds, but also from radio maps

Spiral-ish structure?

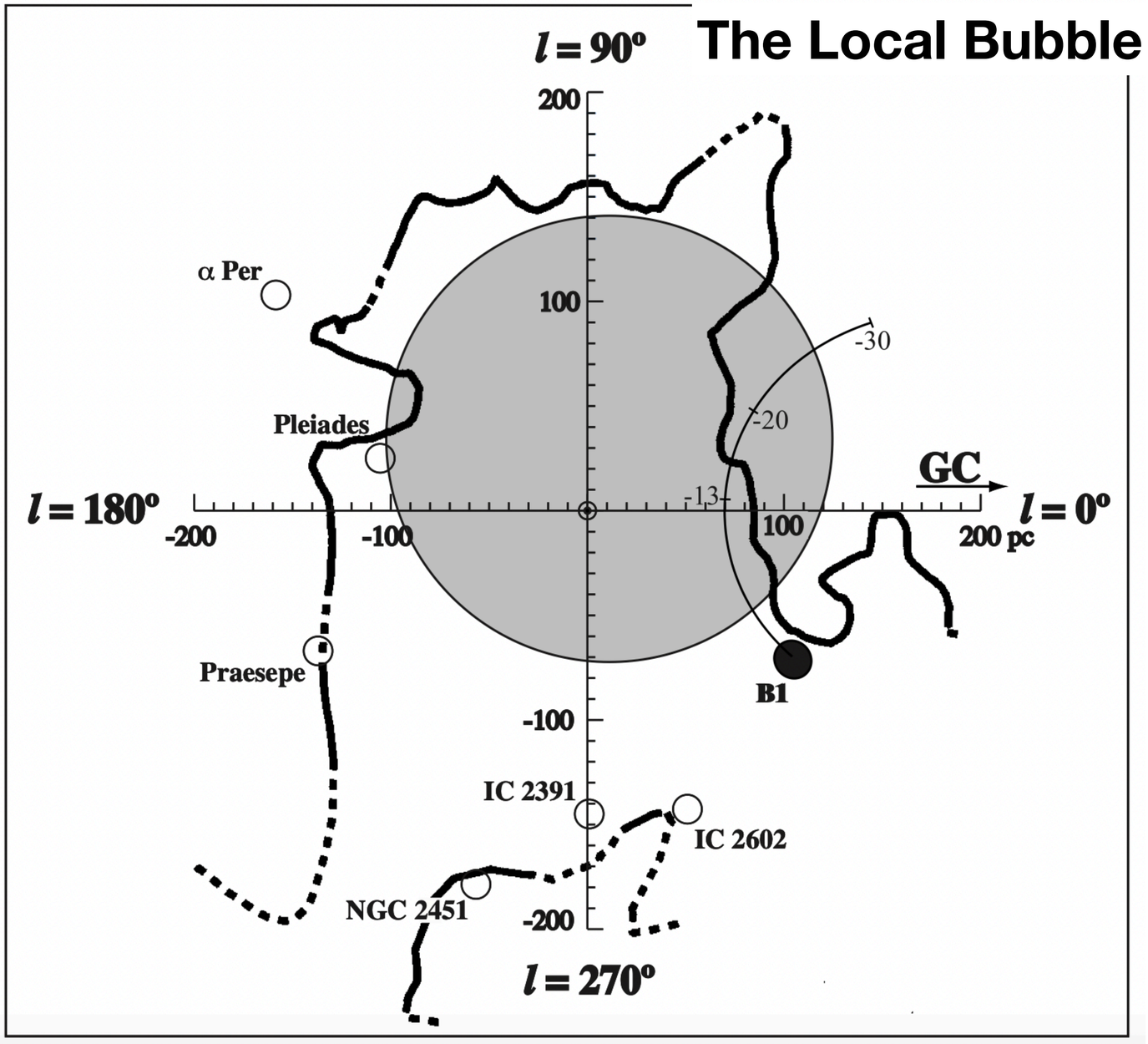
Breitschwerdt+1996

$d < 500\text{pc}$

A large region of low ISM density

Likely driven by SNe

~20 SNe in last few Myr



https://ui.adsabs.harvard.edu/abs/2002A%26A...390..299B/abstract

$d < 500\text{pc}$

The Local Bubble

Structure of Local Bubble impacted by neighboring Bubbles (e.g. Loop I, II, III…)

Fig. 3. Map of N_H values multiplied by $sin|b_{II}|$ (colour coded) . The Sco-Cen supershell encloses the radio Loop I (solid circle). The dashed lines mark the annular H I feature in the interaction area of Loop I and the Local Hot Bubble.

LIC formed here!

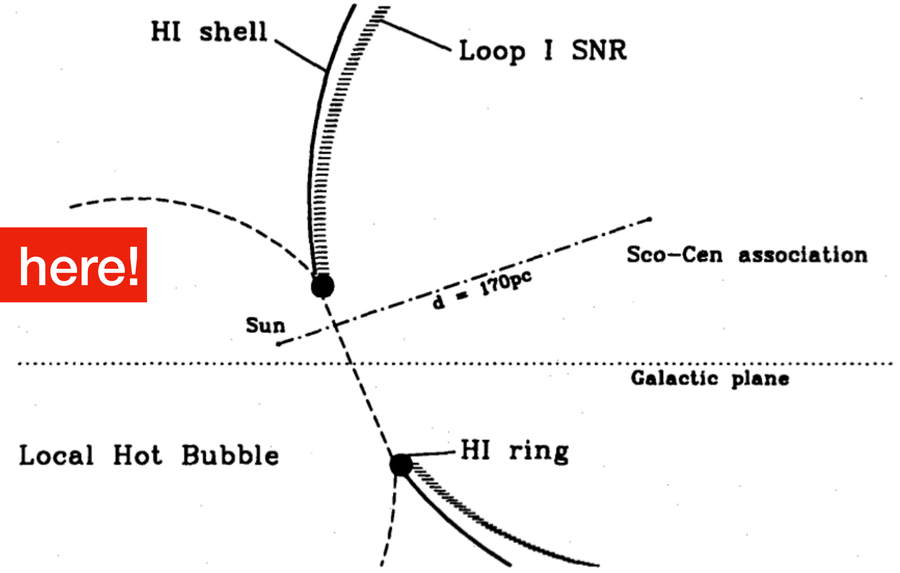


Fig. 5. Schematic vertical cut (normal to the Galactic plane) through the interaction area of Loop I and the LHB.

https://ui.adsabs.harvard.edu/abs/1995A%26A...294L..25E/abstract

$d < 500\text{pc}$

The Local Bubble

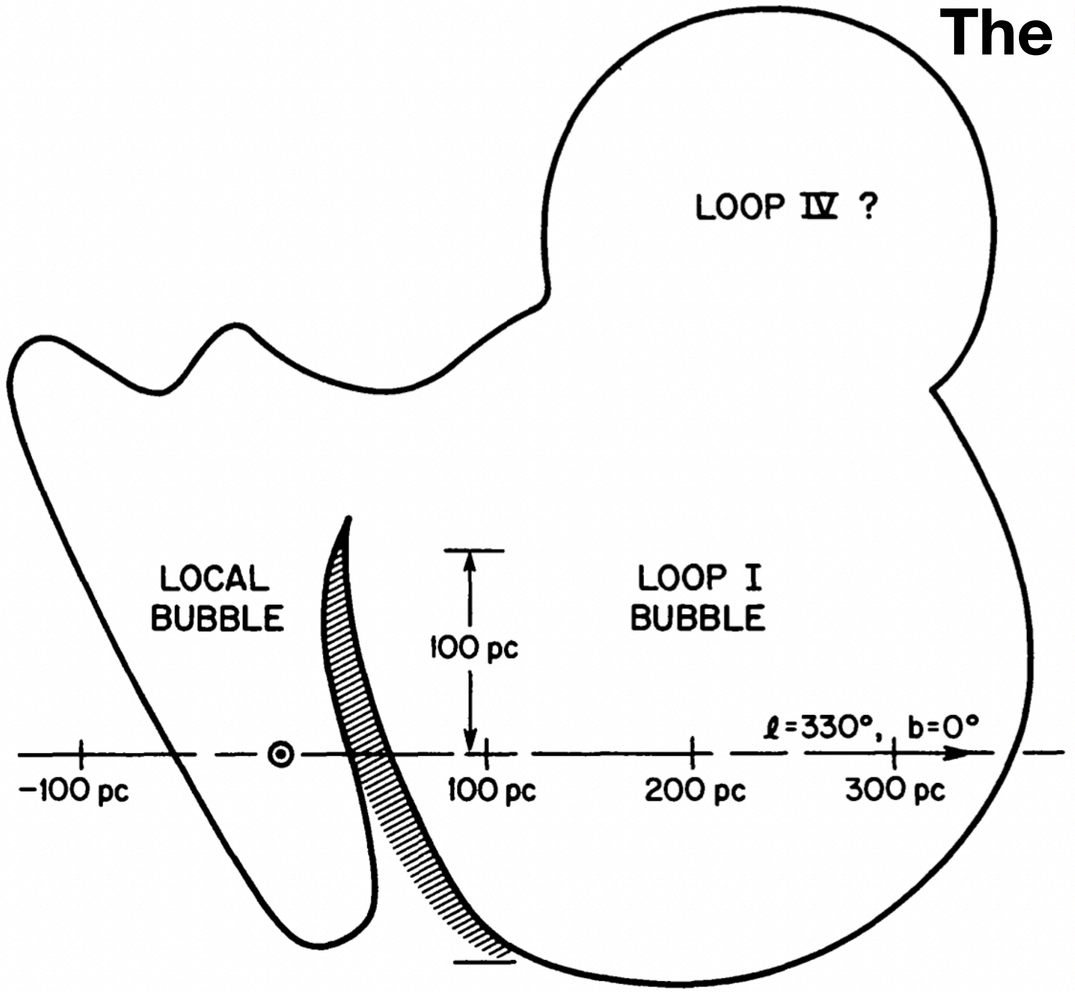
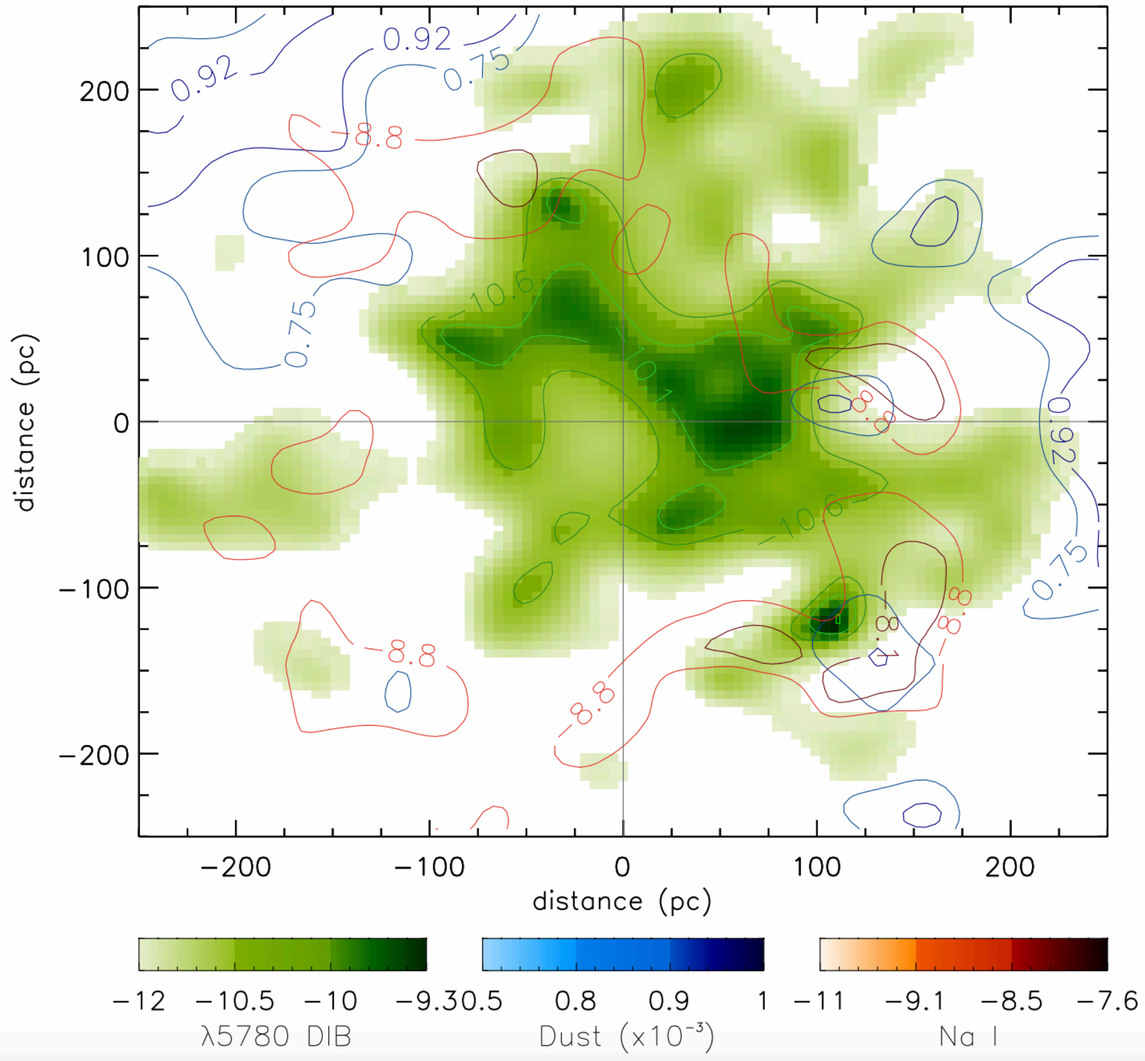


Figure 2 Schematic representation of the relationship between the Local and Loop I Bubbles and the Sun, including the intervening wall of H I. The column density of this wall decreases with latitude. The distance scale of the Loop I center is uncertain and was chosen a bit on the large side to make this figure sensible [combined views of (97) and (52)].

https://ui.adsabs.harvard.edu/abs/1987ARA%26A..25..303C/abstract

$d < 500\text{pc}$

The Local Bubble

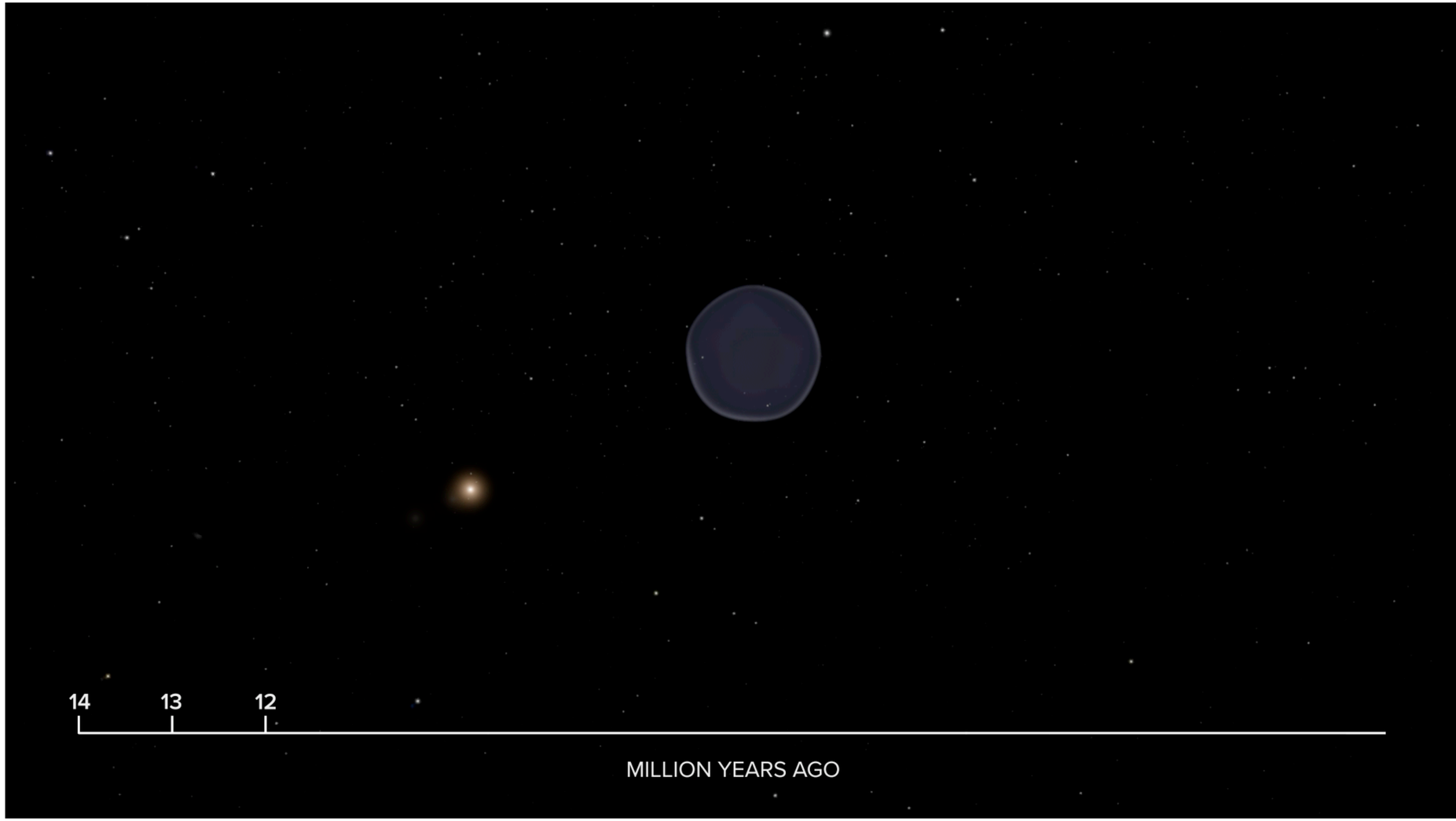


Local Bubble can be mapped via Diffuse Interstellar Bands (DIBS)

https://ui.adsabs.harvard.edu/abs/2019NatAs...3..922F/abstract

$d < 500\text{pc}$

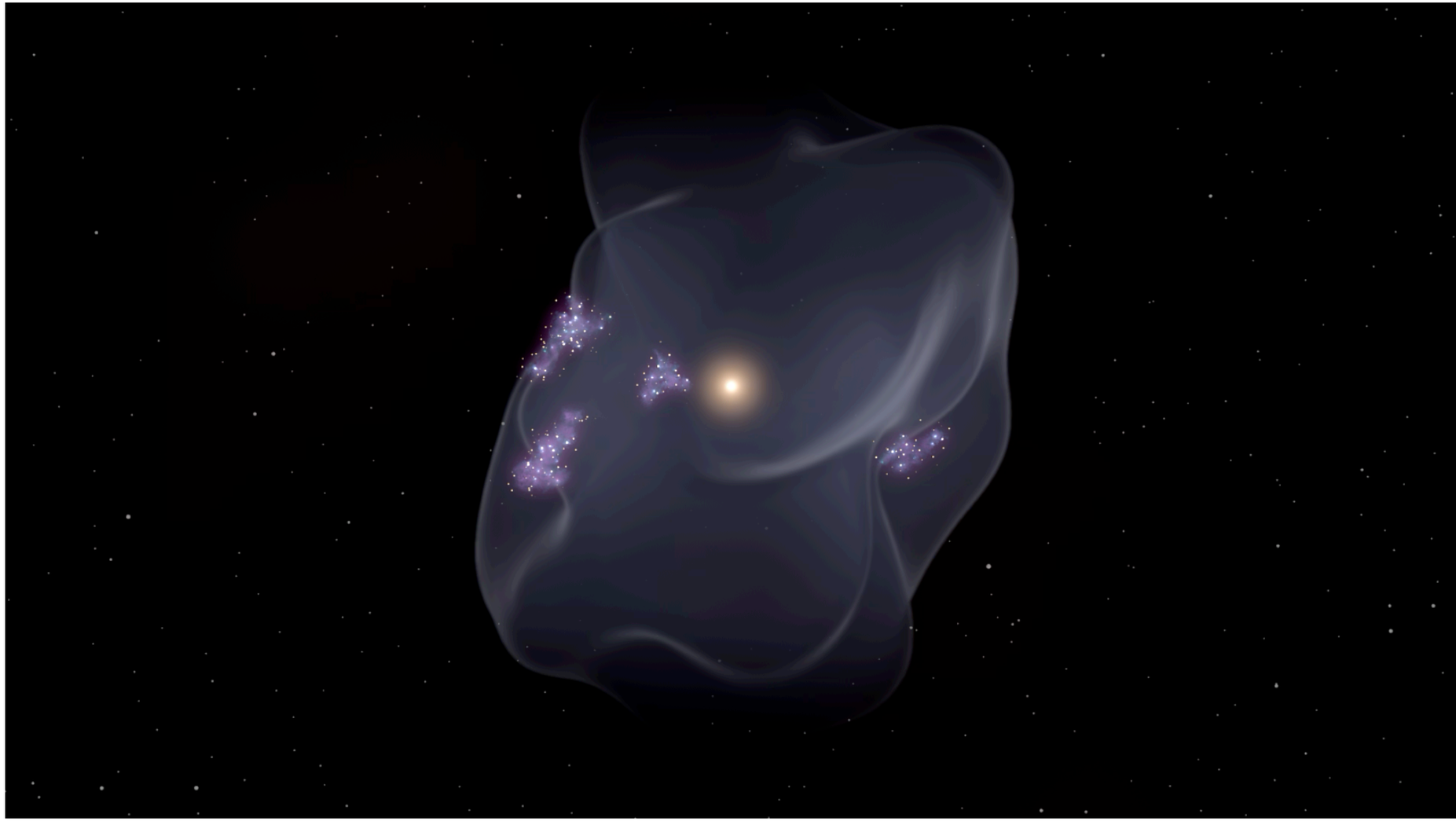
The Local Bubble



https://www.cfa.harvard.edu/news/9506/imagelist

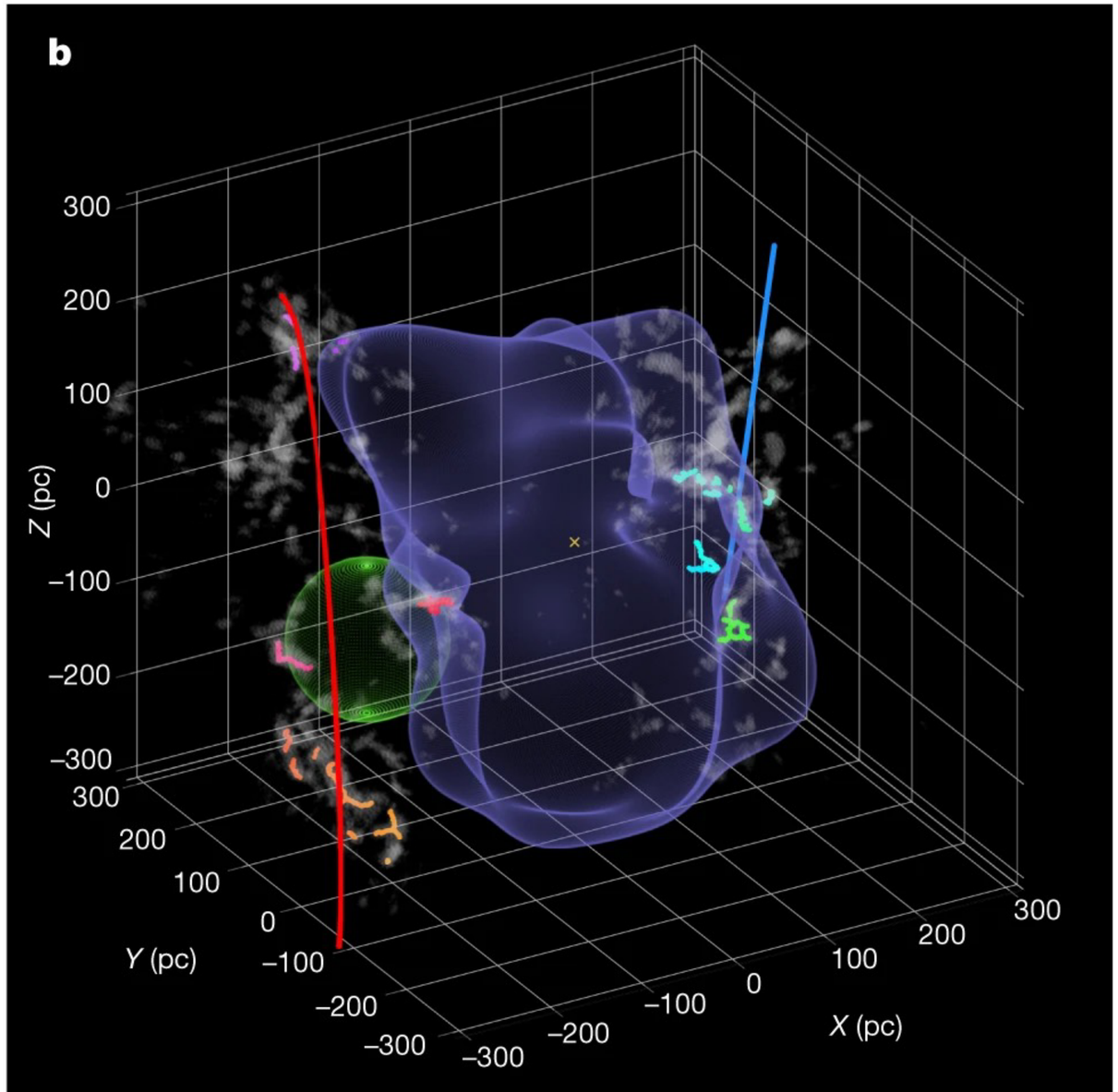
$d < 500\mathrm{pc}$

The Local Bubble



https://www.cfa.harvard.edu/news/9506/imagelist

$d < 500\text{pc}$



The Local Bubble

Nearly all star forming regions near the Sun appear to be on the surface of the Local Bubble

& they tend to move outward

SNe feedback ->
GMC formation & collapse ->
star formation!

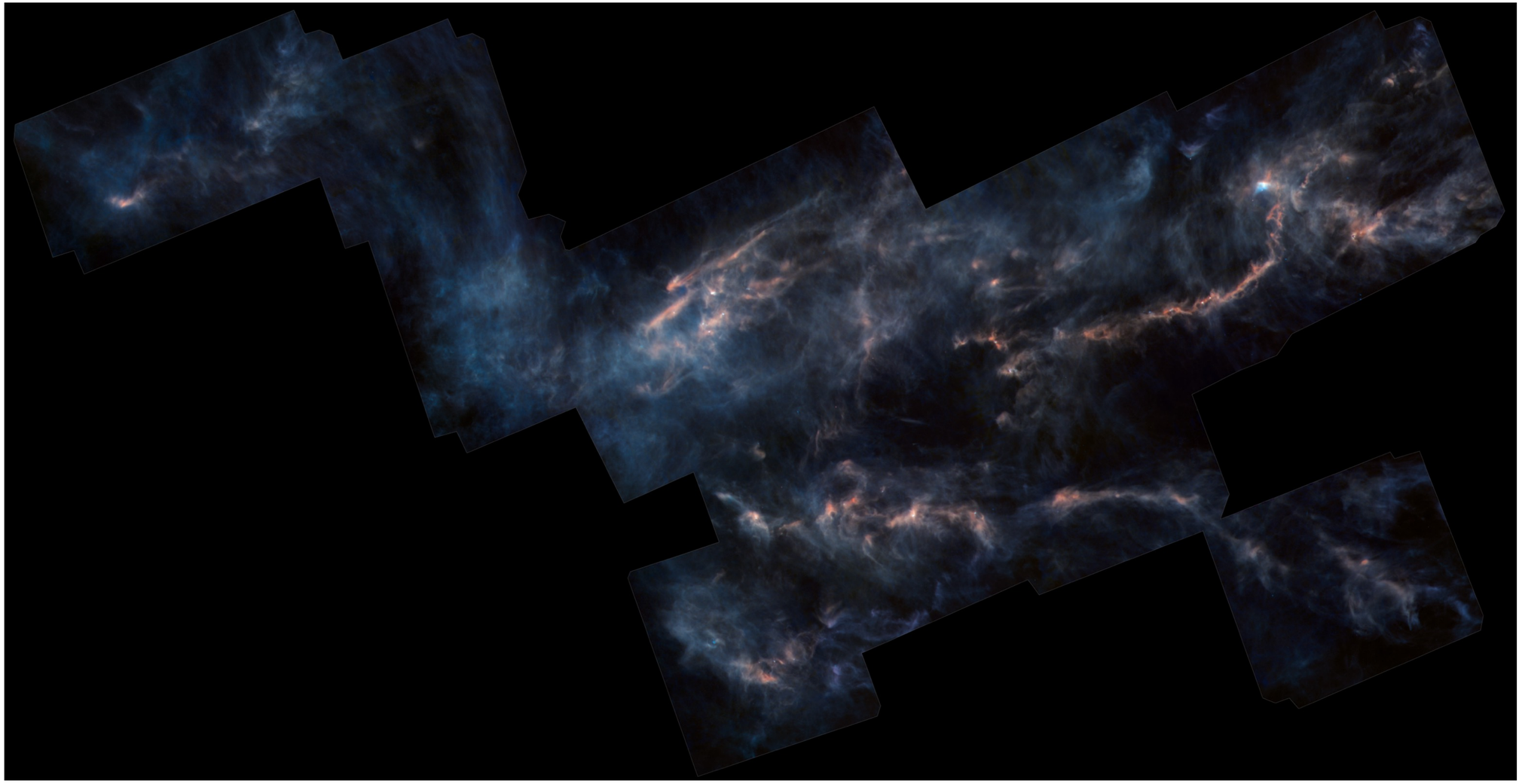
Much of this structure revealed in last 2-5years!

https://www.nature.com/articles/s41586-021-04286-5

$d < 500\text{pc}$

Nearby molecular clouds

Tend to be found in groups and along lines…

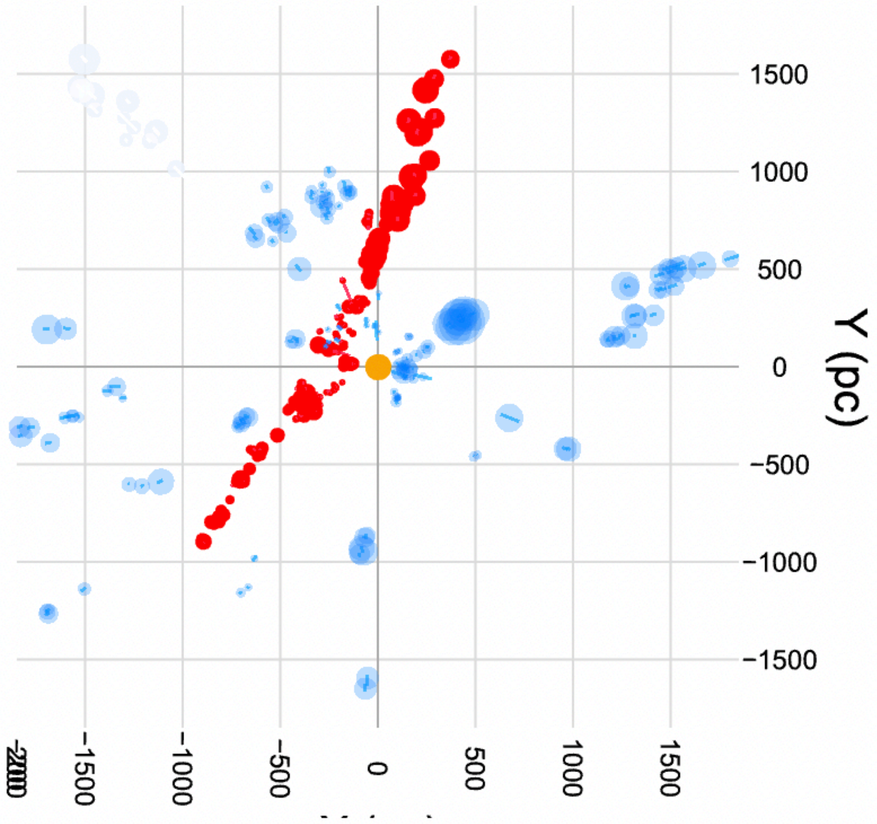


https://en.wikipedia.org/wiki/File:Herschel's_view_of_the_Taurus_molecular_cloud_ESA384012.jpg

$d < 500\text{pc}$

“Radcliffe Wave”
C. Zucker+2020

Long line of star forming regions

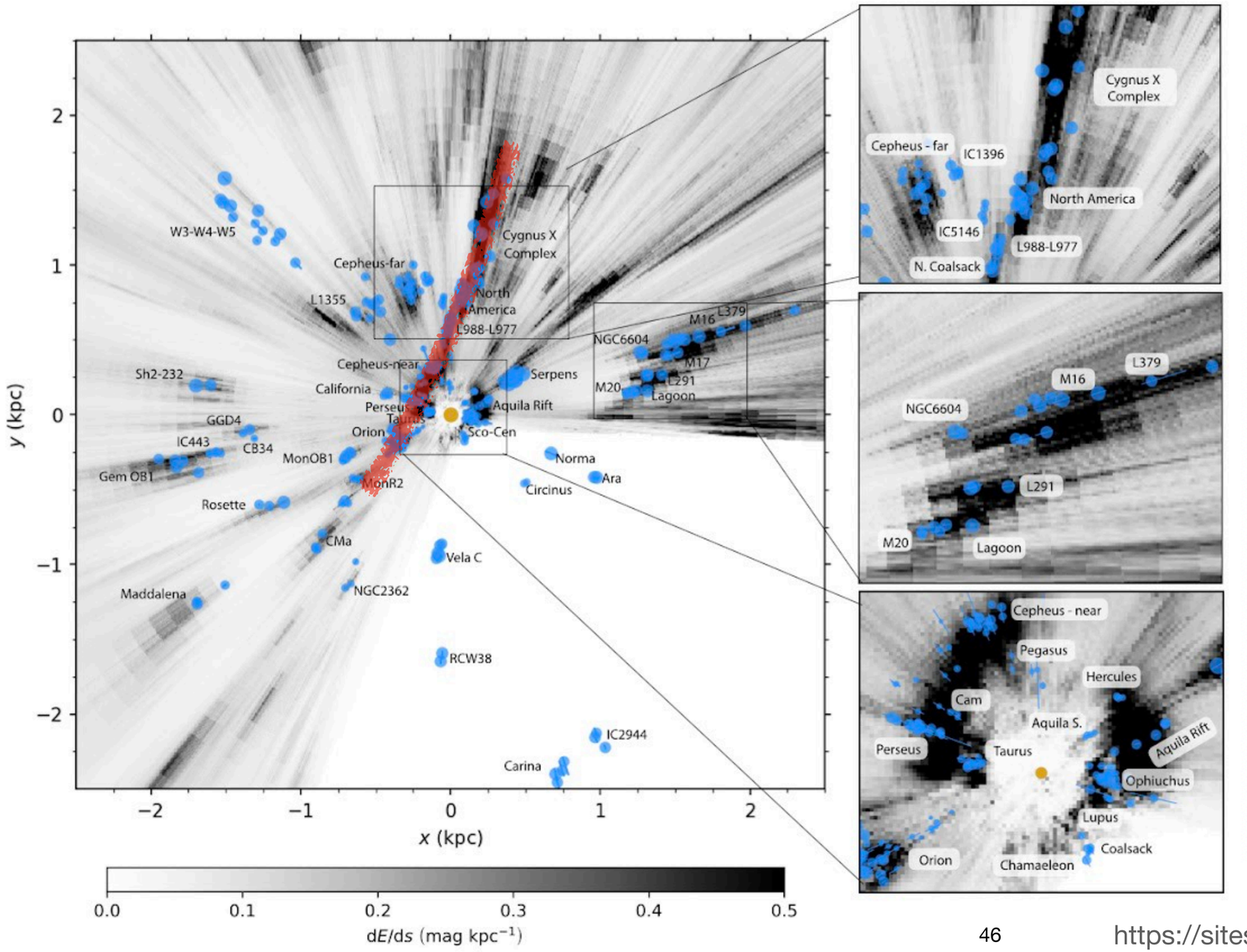


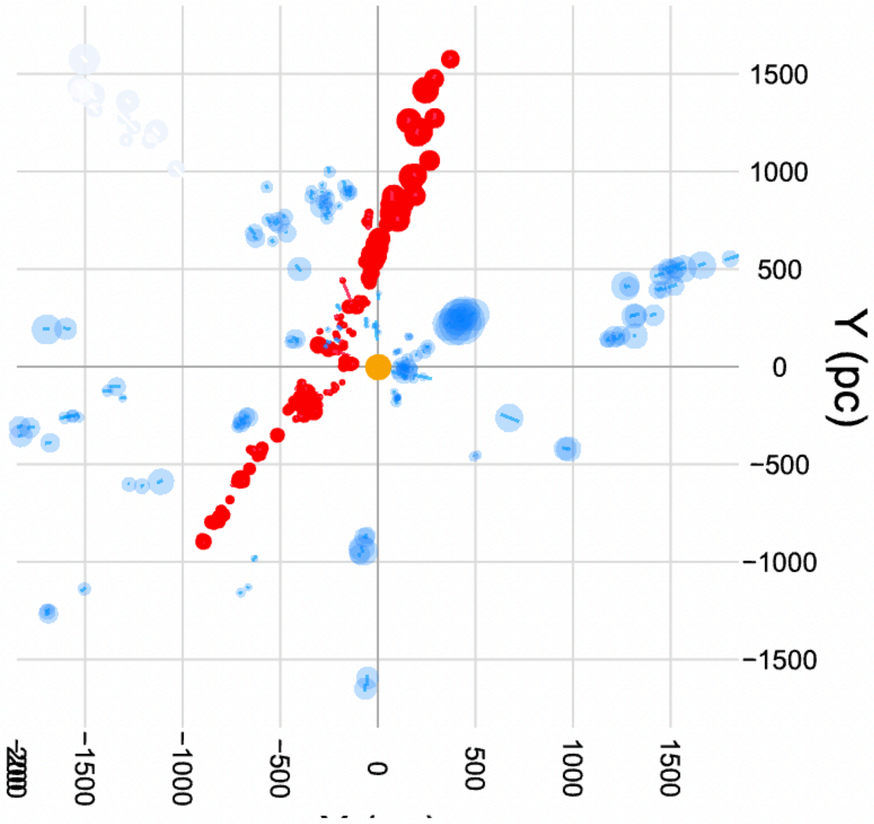
https://sites.google.com/cfa.harvard.edu/radcliffewave/home?authuser=0

$d < 500\text{pc}$

“Radcliffe Wave”
C. Zucker+2020

Long line of star forming regions

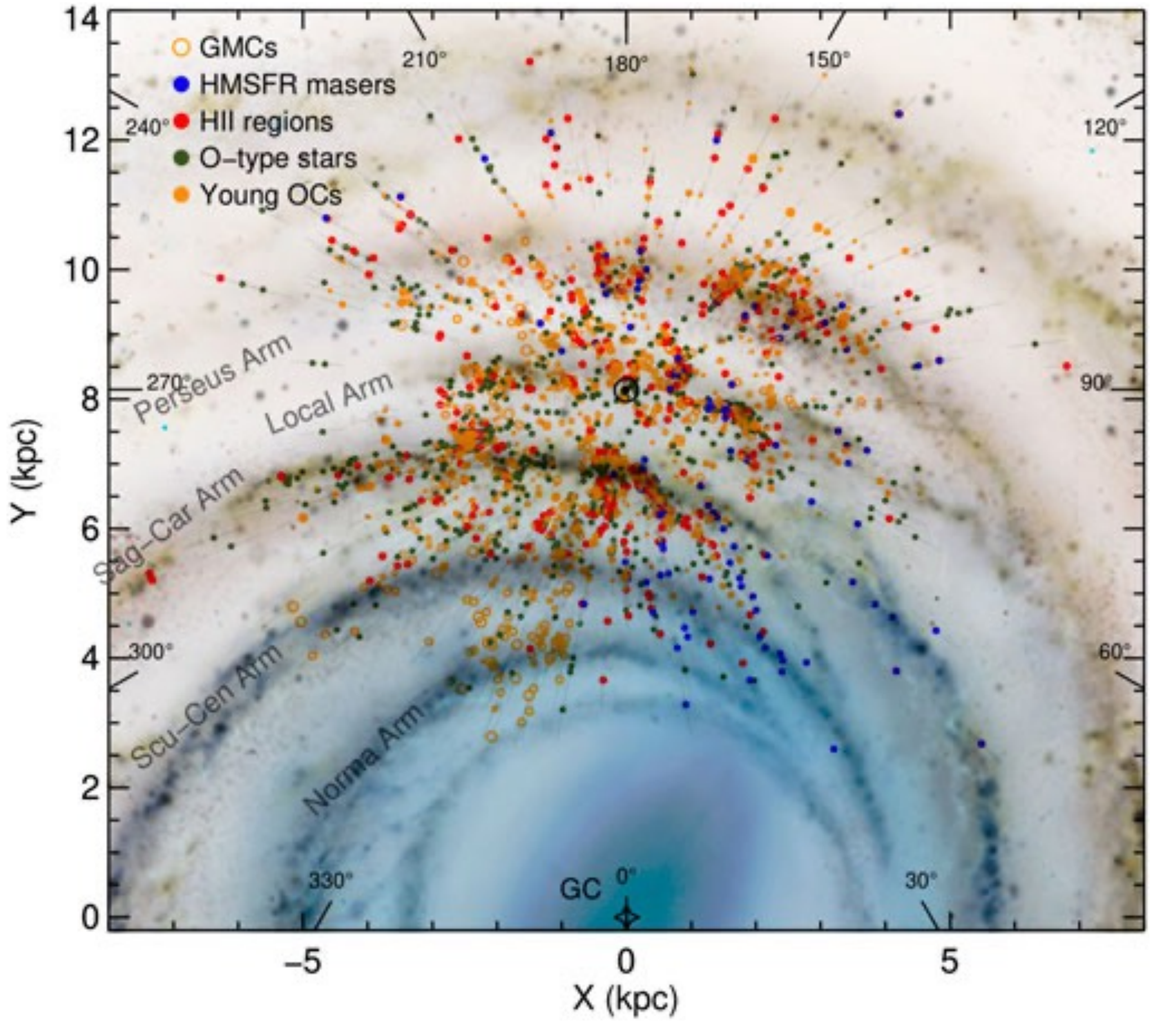




https://sites.google.com/cfa.harvard.edu/radcliffewave/home?authuser=0

$d > 500\text{pc}$

More in a few weeks…



https://www.frontiersin.org/articles/10.3389/fspas.2021.671670/full

Next time:

- NO class next week (AAS)
  - Do Homework 1!
- AAS 241 debrief (Tues)
- History of Galactic Astronomy (Thurs)