

# Observaciones de Sistemas Planetarios 2

**Clase anterior: Una teoría exitosa de formación planetaria debiese ser capaz de explicar las propiedades observadas tanto del Sistema Solar como de los sistemas extra-solares.**

# Formación de discos

## Problema del momentum angular

- Las observaciones del Sistema Solar y de los sistemas extra-solares sugieren que los planetas se forman alrededor de discos en torno a estrellas jóvenes.
- Para entender cómo se forman los planetas hay que entender primero cómo se forman las estrellas.

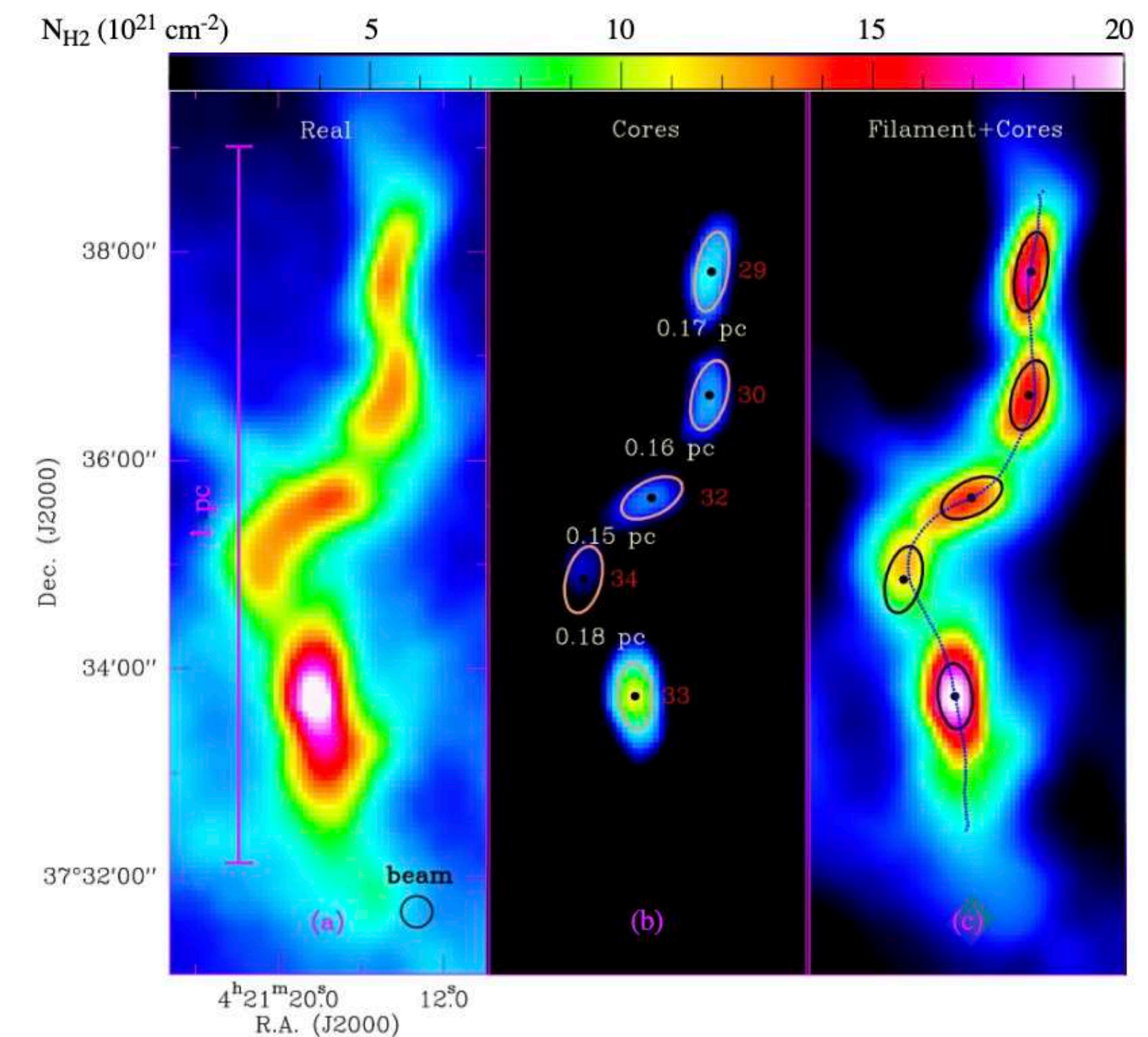
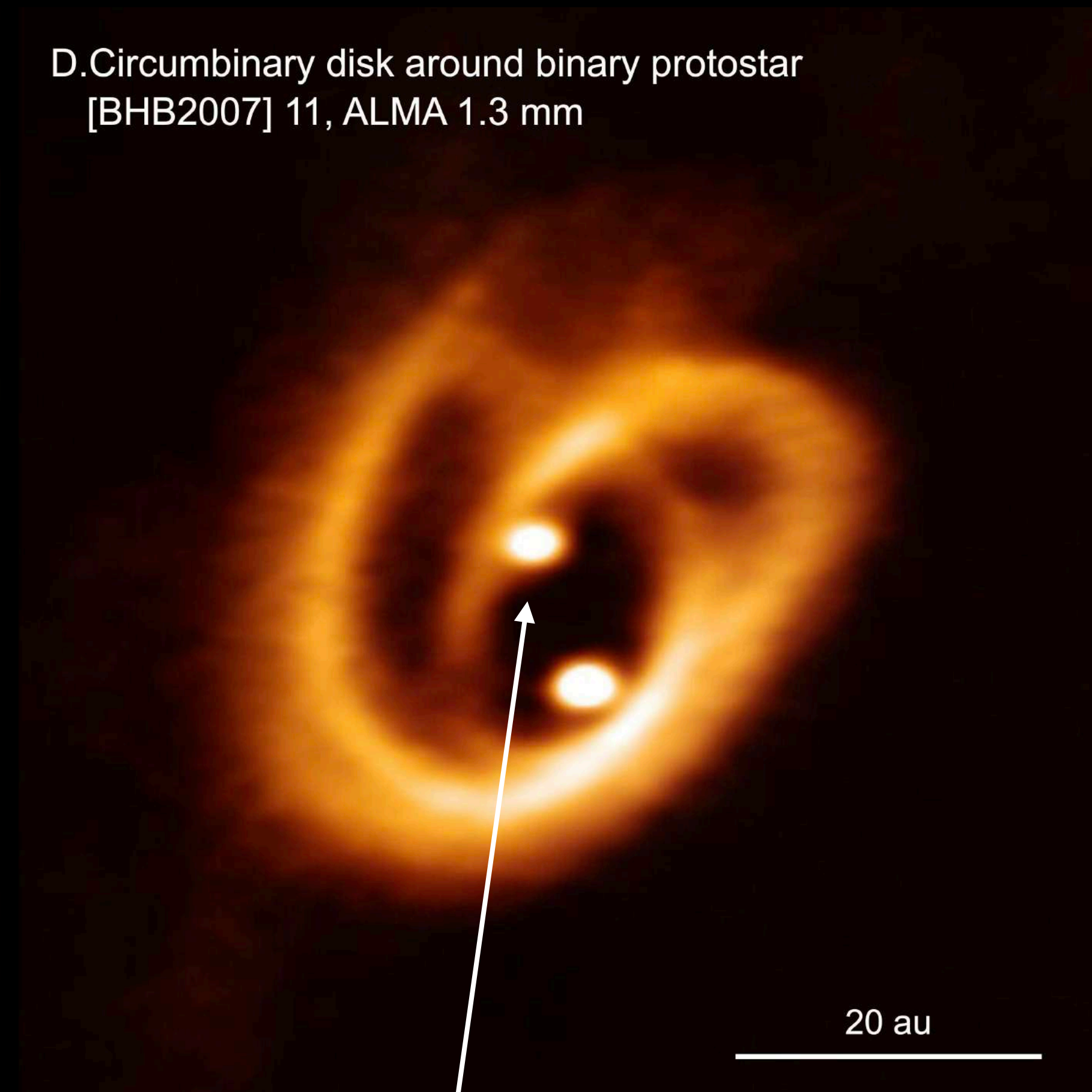
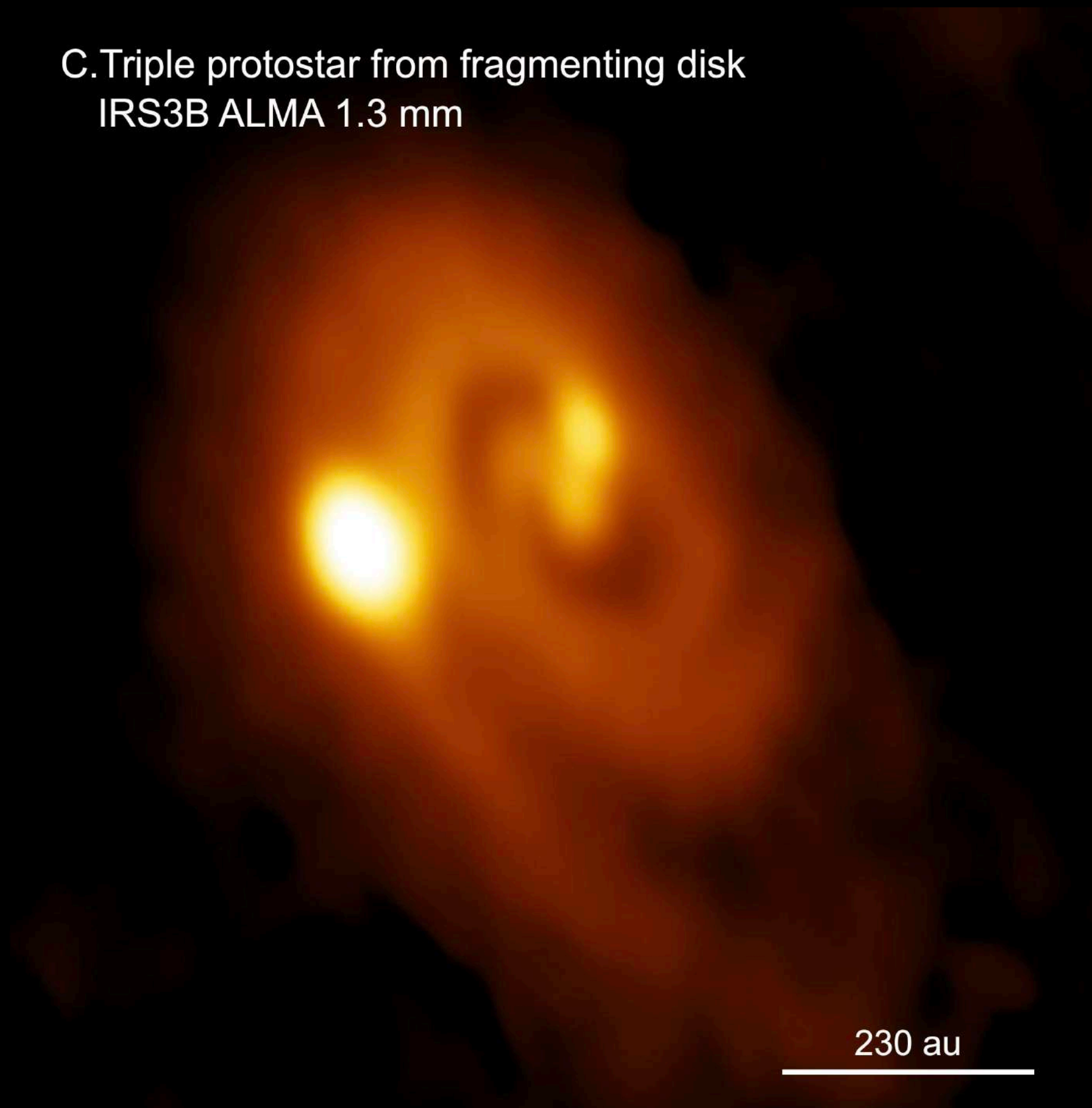
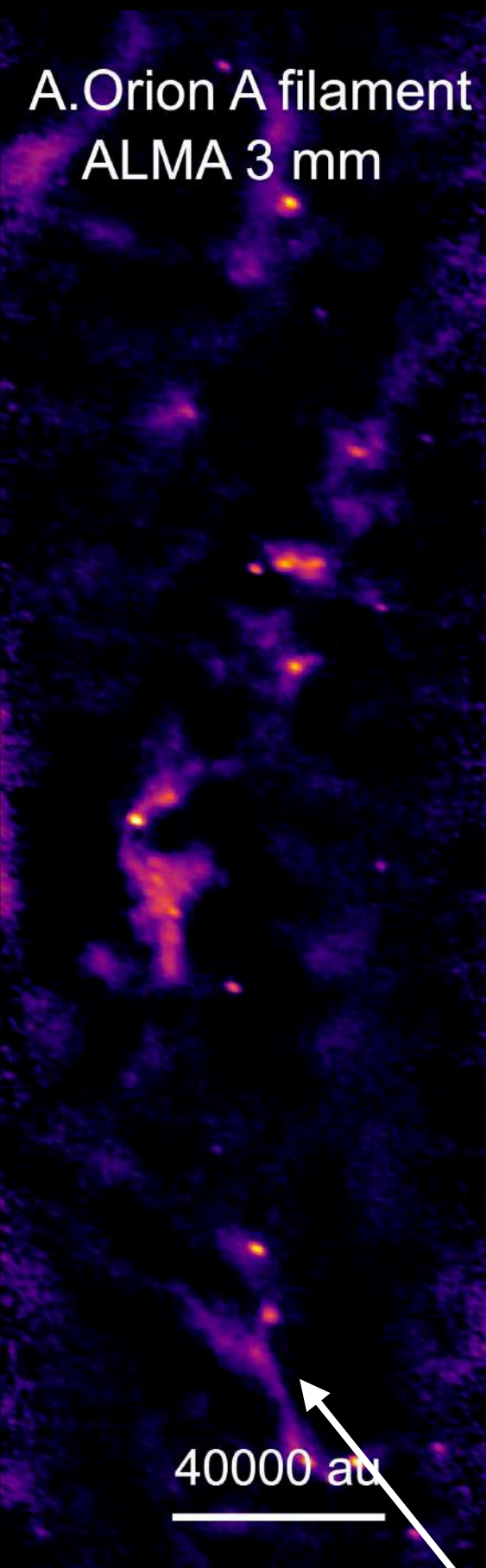


Fig. 10.—: Quasi-periodic separations of dense cores along a transcritical filament in the California molecular cloud (from [Zhang et al. 2020a](#)). From left to right, the panels display the original column density map of the filament as derived from *Herschel* data at  $18.2''$  resolution, and two filtered versions of this map emphasizing the dense cores identified along the filament with *getsources* ([Men'shchikov et al. 2012](#)), and the cores overlaid on the filament (after subtraction of the non-filamentary background), respectively.



Bonnor-Ebert sphere  
 $R_{\text{grumo}} \sim 0.2 \text{ pc}$

Protoestrella  
 $R_{\star} \sim 3 R_{\odot}$

# Conservación de $J$

Colapso gravitacional resulta en una compresión de 6-7 órdenes de magnitud!

- Momentum angular ( $J$ ) de una estrella (aprox).
- Momento de Inercia.
- $J$  se conserva.
- Límite inferior a la rotación de un grumo molecular.
- Eso da un límite superior al periodo de rotación de la estrella.

# Conservación de $J$

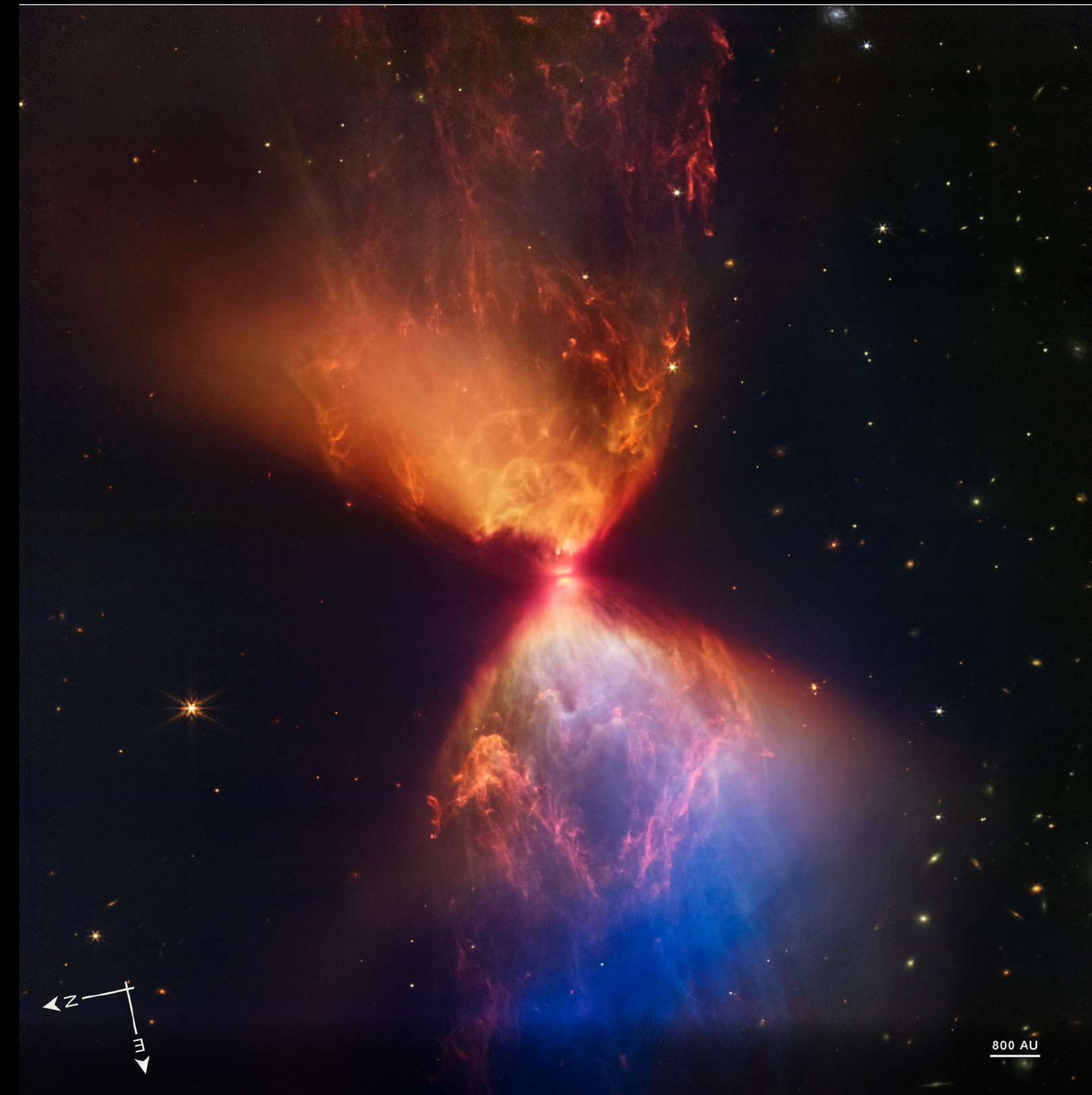
Colapso gravitacional resulta en una compresión de 6-7 órdenes de magnitud!

- Momentum angular ( $J$ ) de una estrella (aprox).  $J = I\Omega$
- Momento de Inercia.  $I = \frac{2}{5}MR^2$
- $J$  se conserva.  $I_{\text{inicial}} = I_{\text{final}}$   $\Omega_{\star} = \left(\frac{R_{\text{grumo}}}{R_{\star}}\right)^2 \Omega_{\text{grumo}}$
- Límite inferior a la rotación de un grumo molecular.  $\Omega_{\text{grumo}} > \Omega_{\text{MW}}$
- Eso da un límite superior al periodo de rotación de la estrella.  $t_{\text{rot}} = \frac{2\pi}{\Omega_{\star}} < 10 \text{ min}$

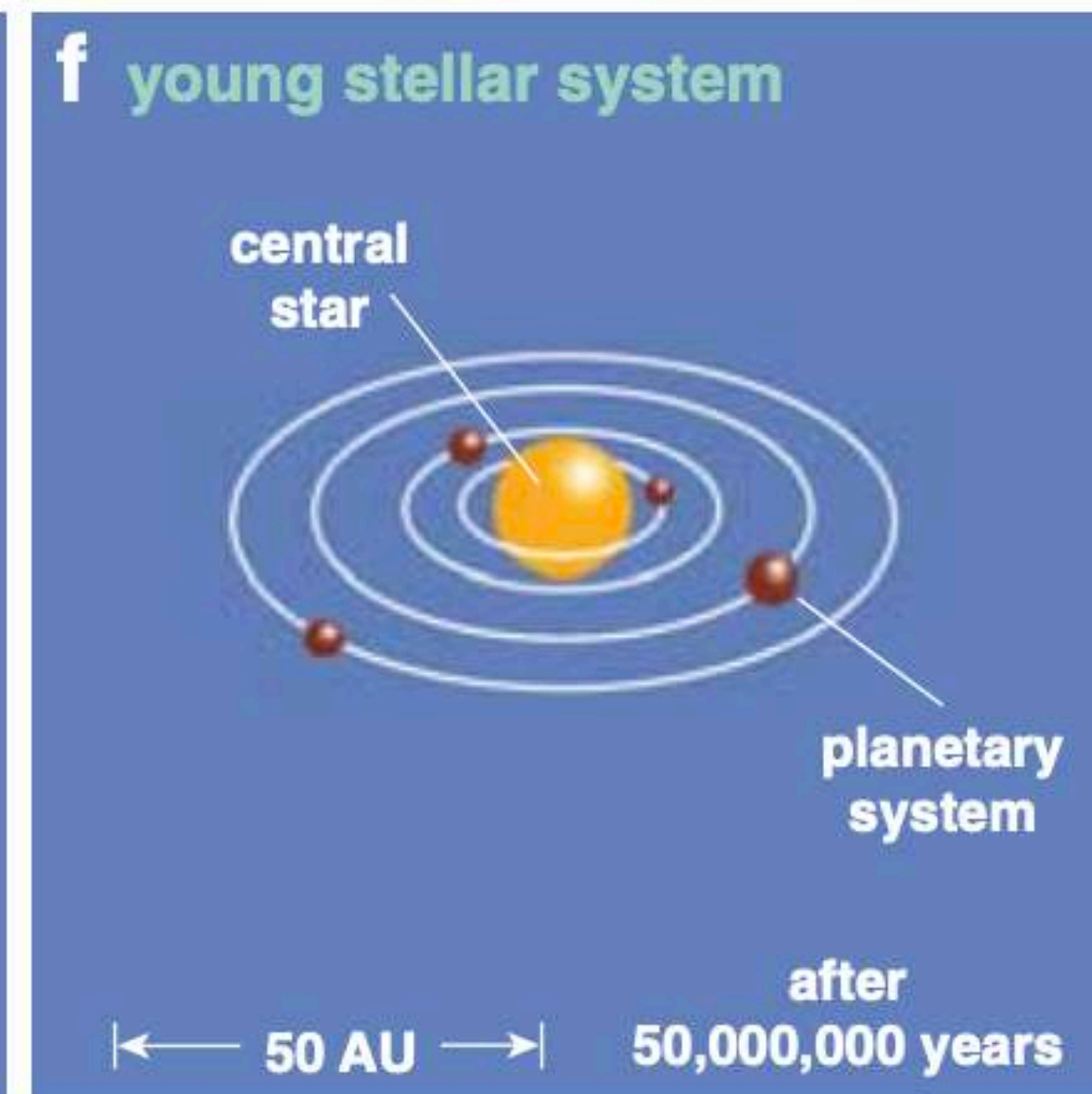
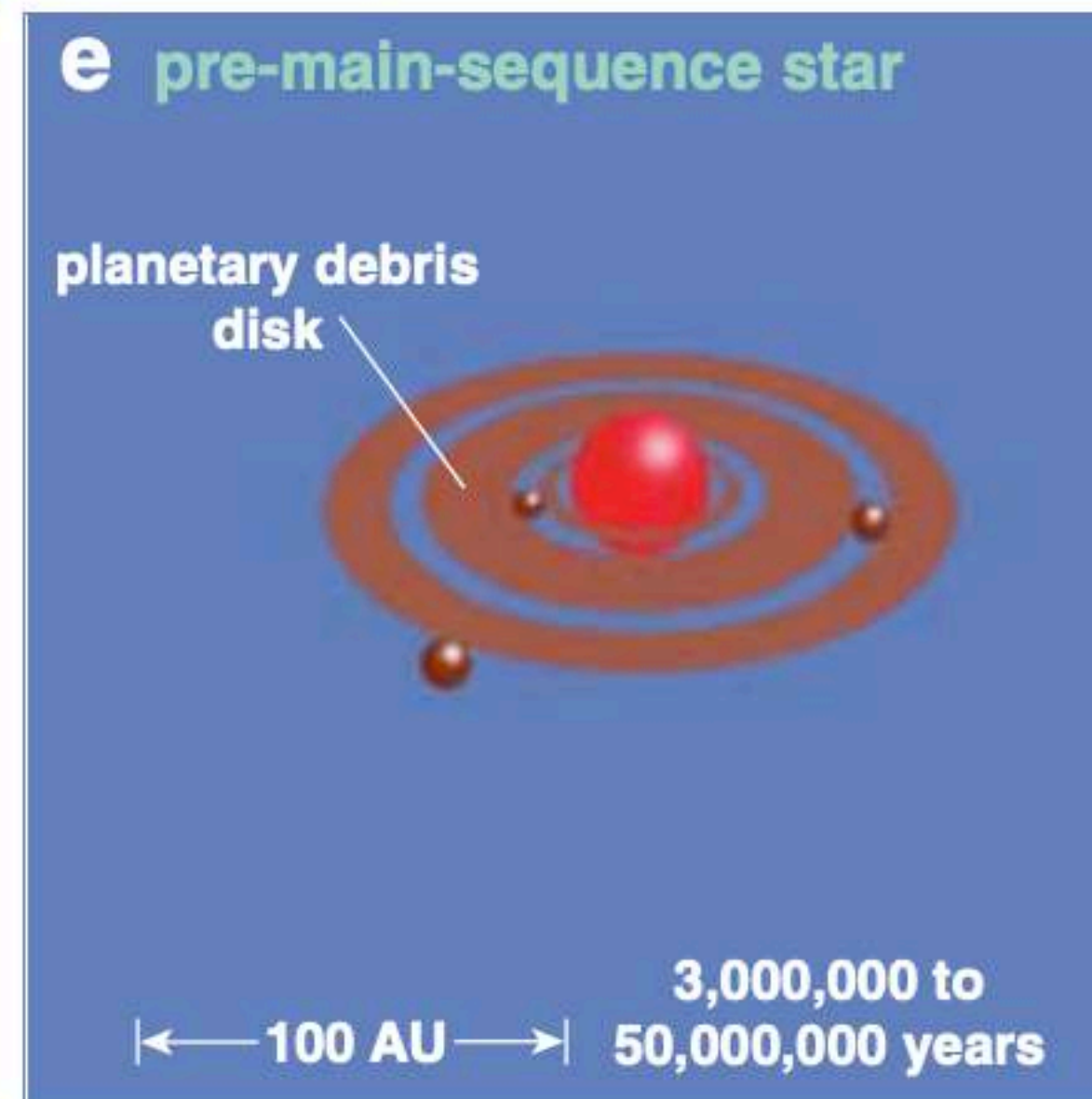
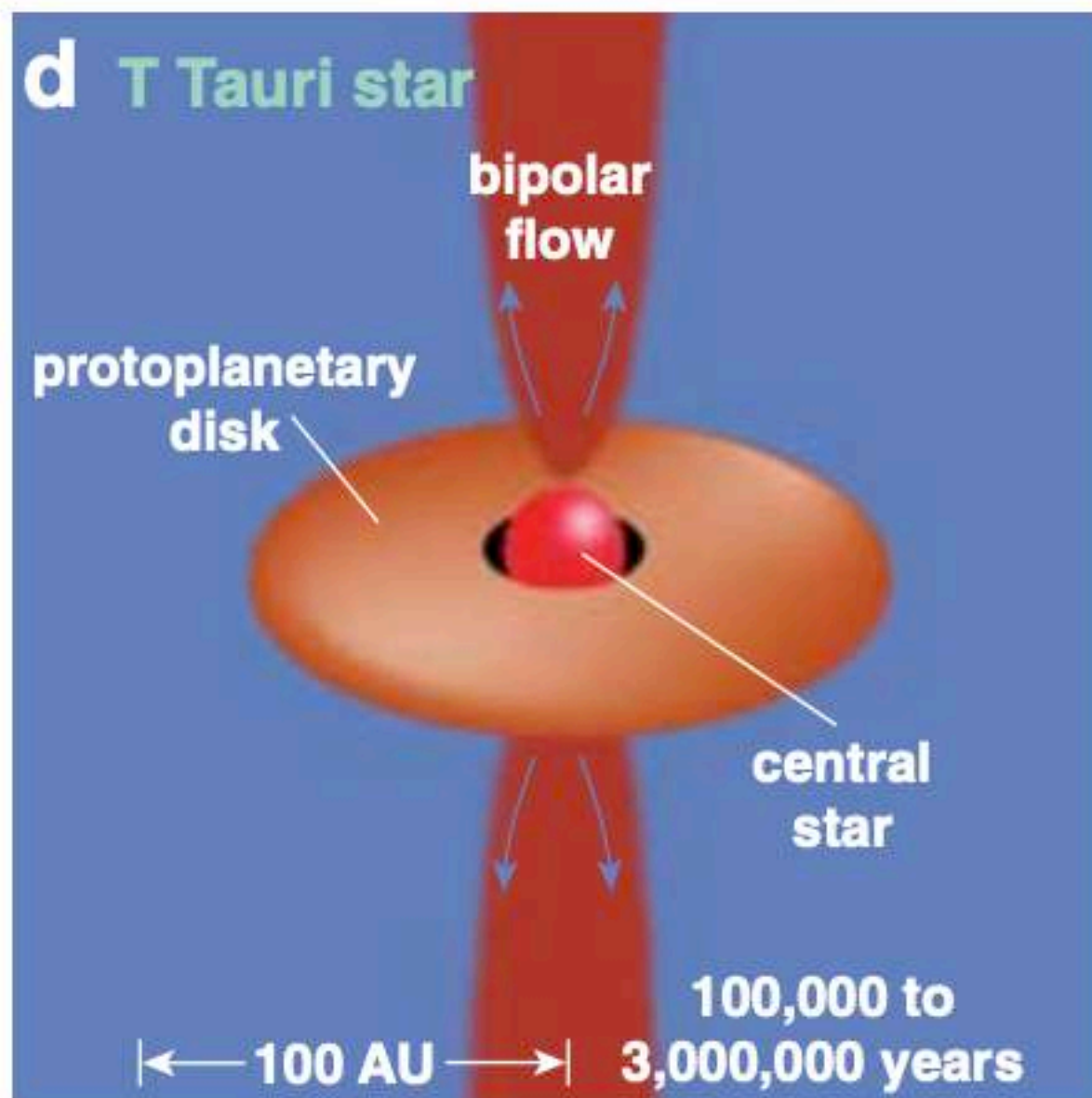
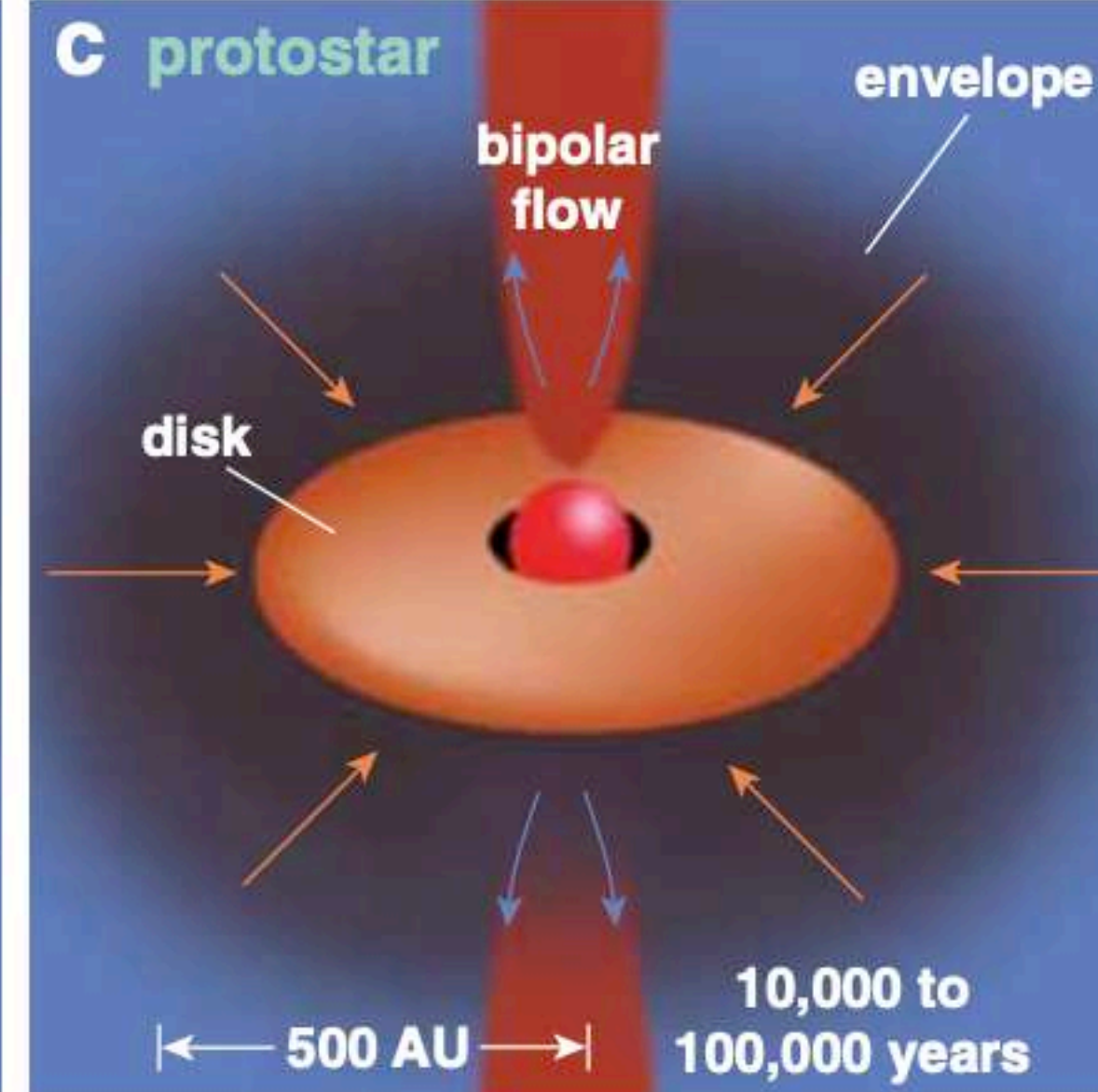
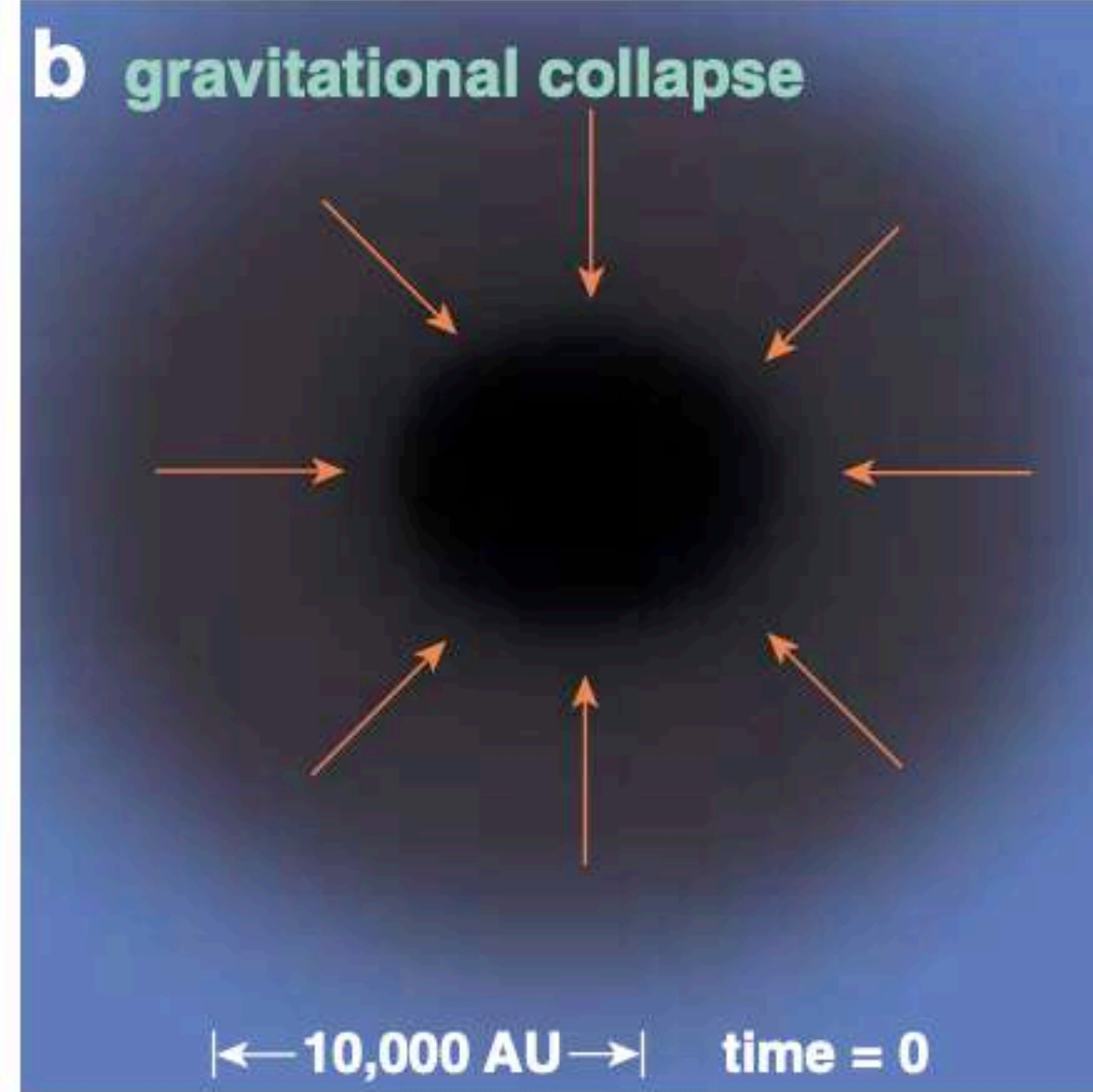
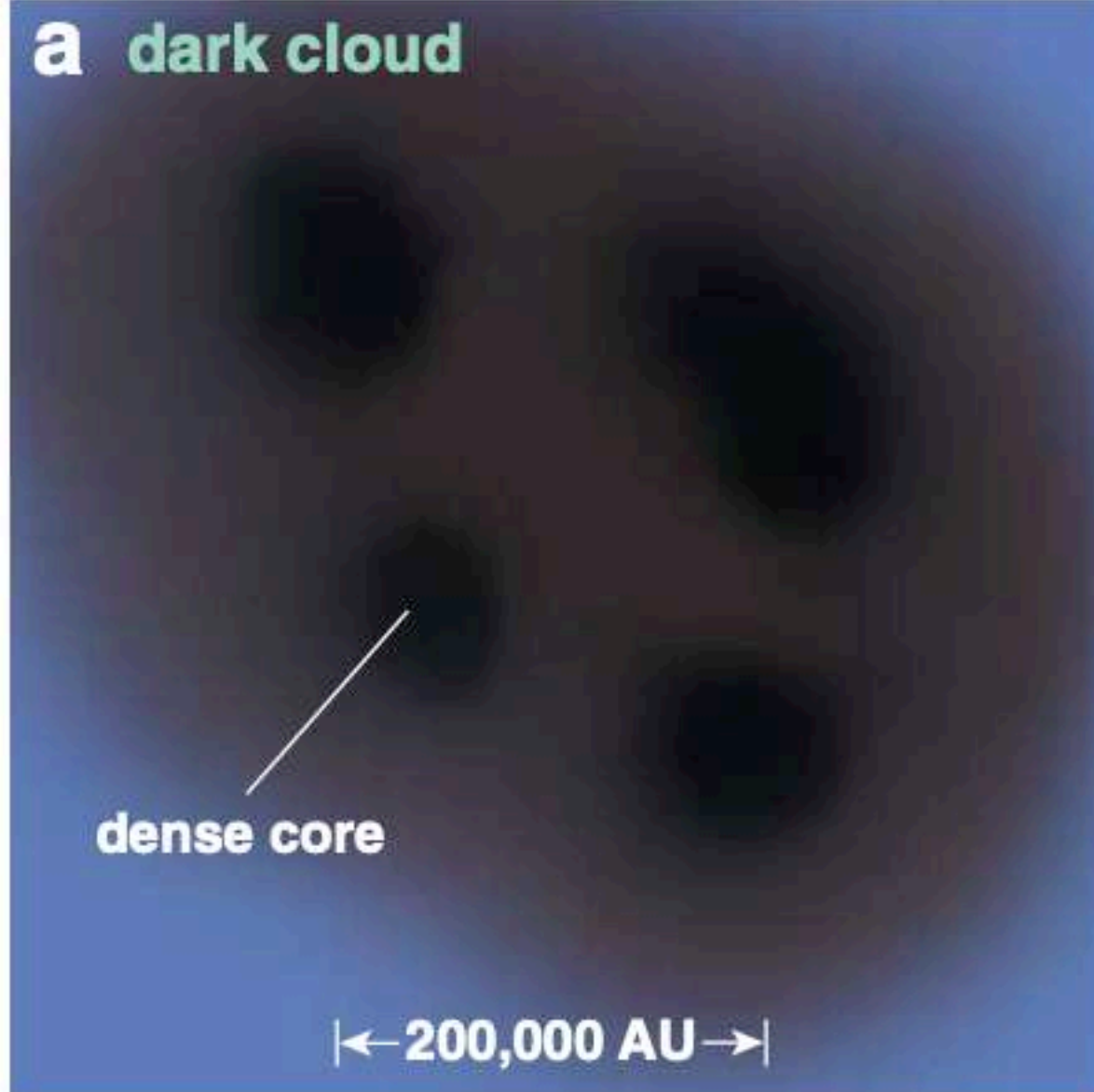
# ¿Cómo sobreviven las estrellas?

- Sistemas múltiples (~50% de las estrellas de campo están en sistemas múltiples).
- Pierden  $J$  a través de “outflows”.
- El colapso sucede a través de un disco, no directamente a la estrella.

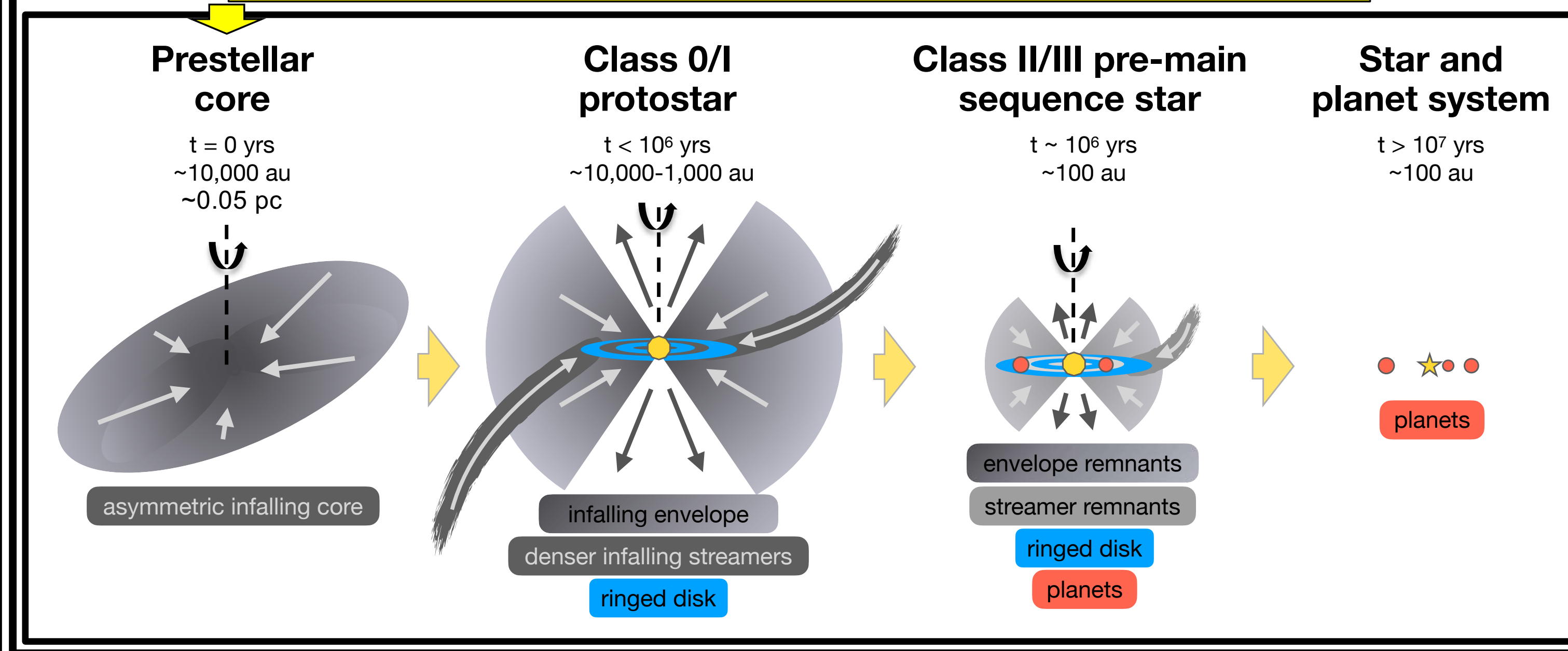
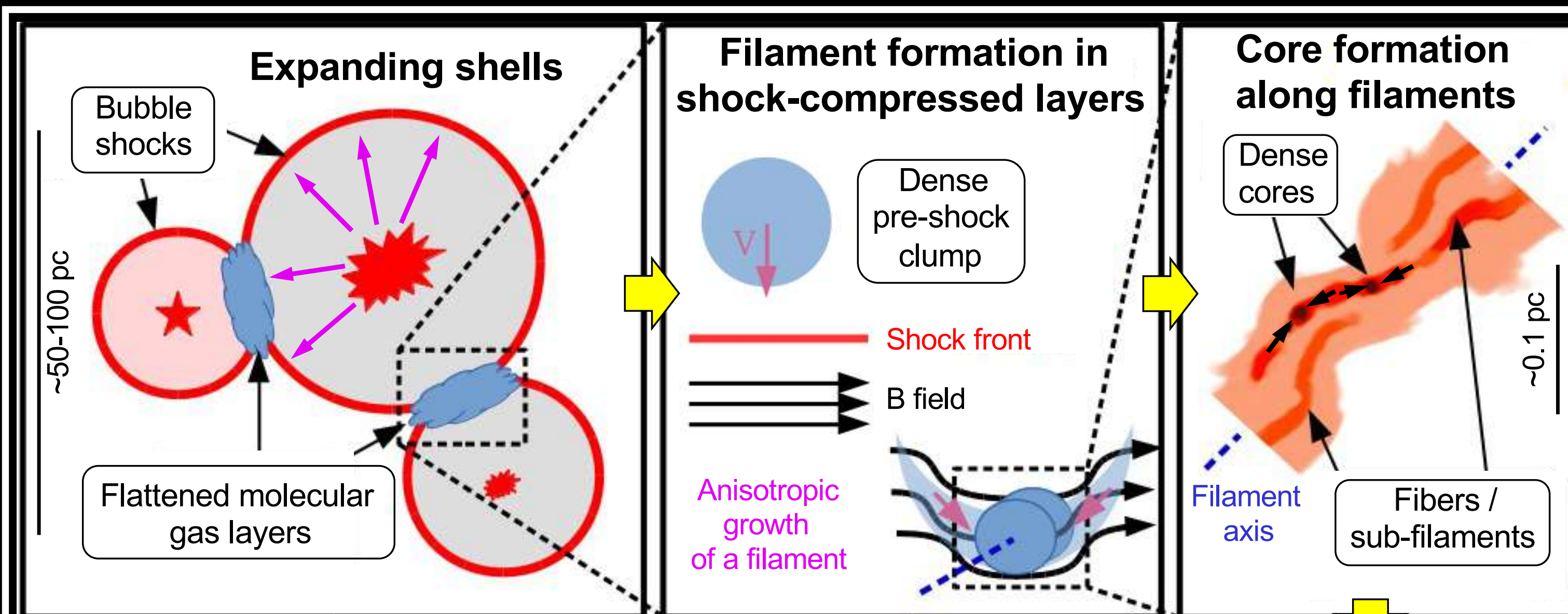
JAMES WEBB SPACE TELESCOPE  
L1527 IRS | IRAS 04368+2557



NIRCam Filters | F200W F335M F444W F470N

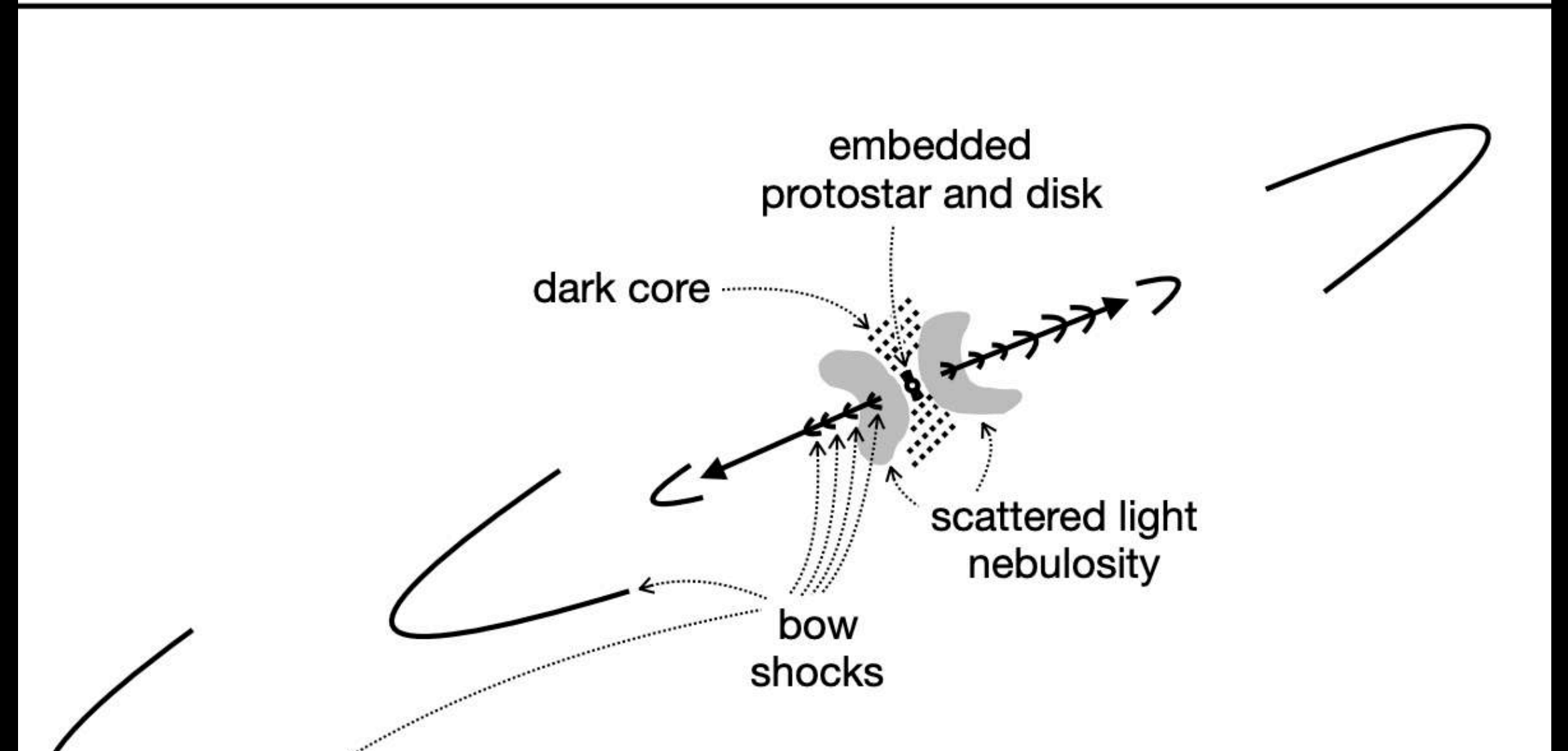






# HH212

- La pérdida de momentum angular a través de outflows da para un curso completo y lo dejaremos fuera de este curso.

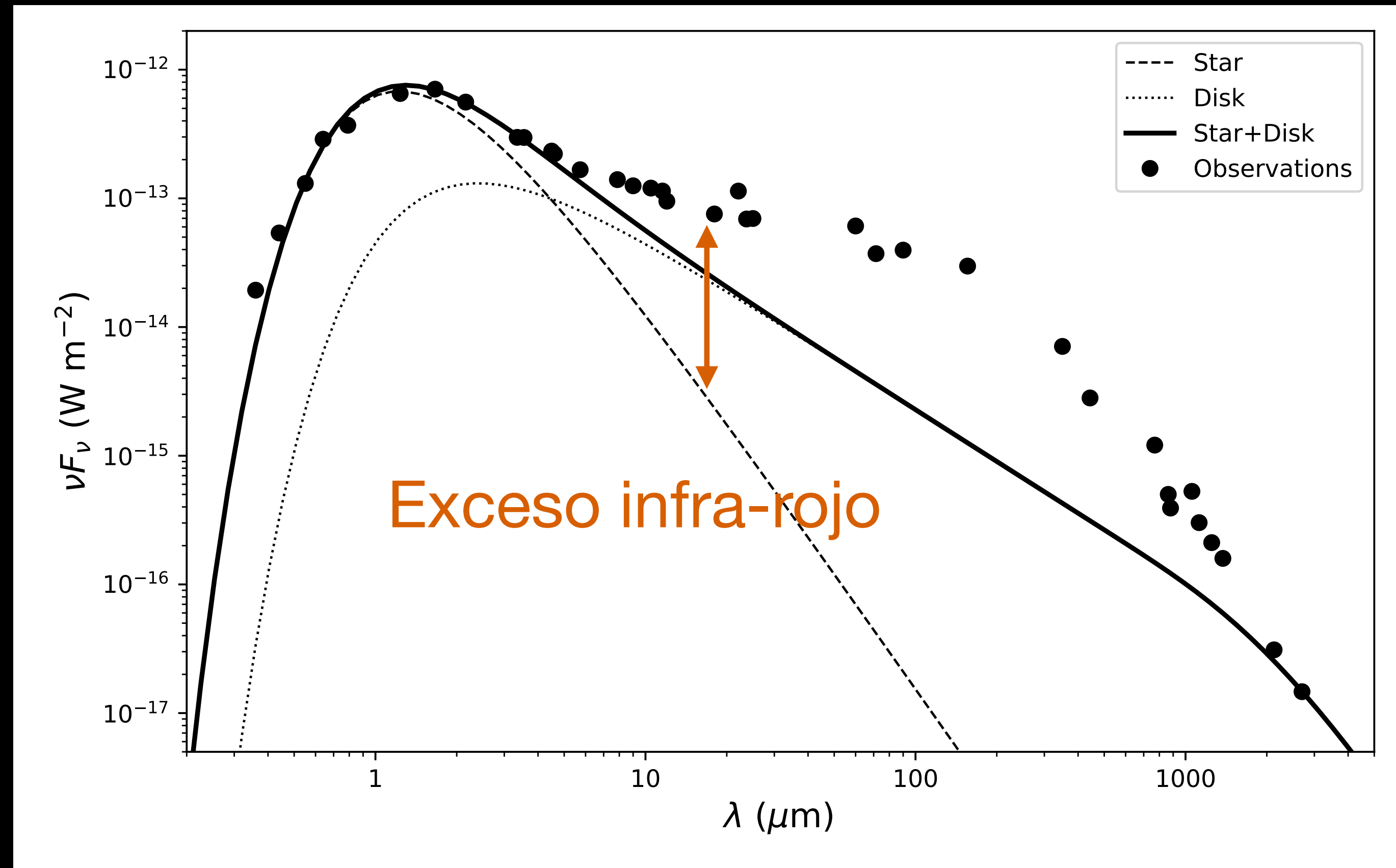


# Clasificación de YSOs

## Empírica, basada en la SED

- Exceso infra-rojo

$$\alpha_{\text{IR}} = \frac{d \log(\lambda F_{\lambda})}{d \log \lambda}$$

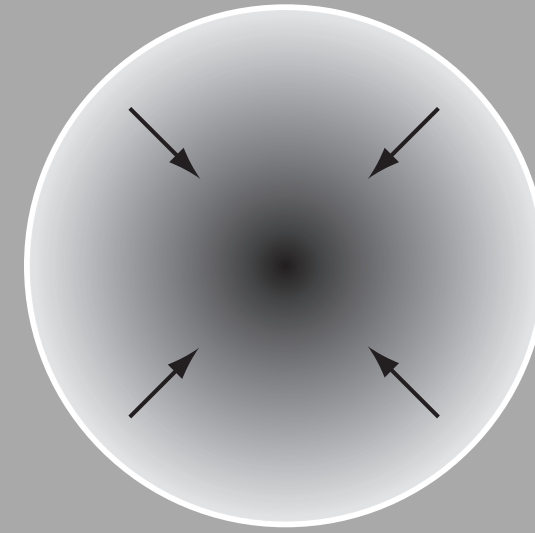


# Clasificación de YSOs

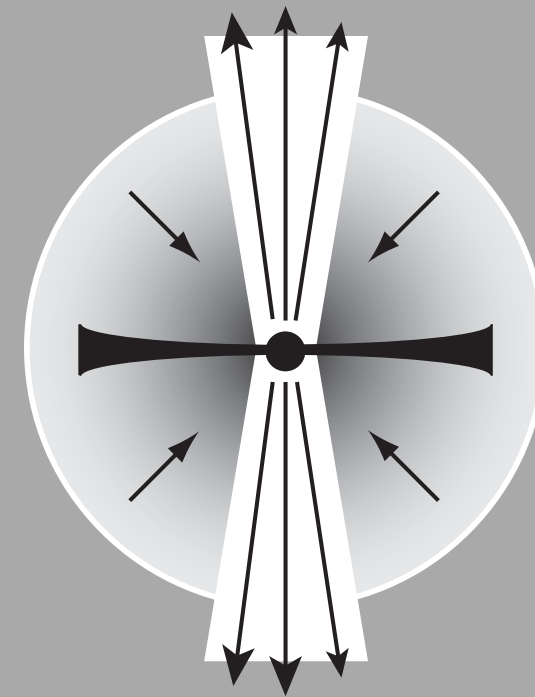
## Está conectada a evolución

- Clase 0: SED tiene máximo en el IR lejano, no hay flujo detectado en el IR cercano
- Clase I: SED plana en el IR cercano-medio.
- Clase II: SED cae entre IR cercano y medio.
- Clase III: la SED IR es esencialmente la de la fotosfera de una estrella.

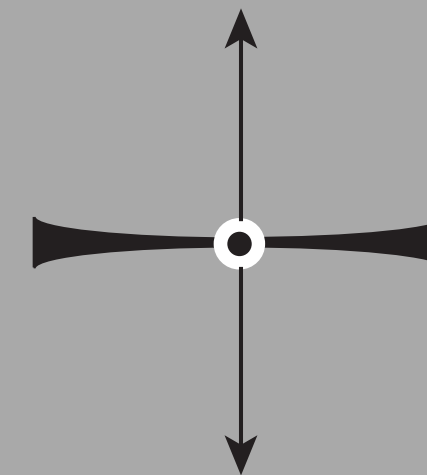
Class 0



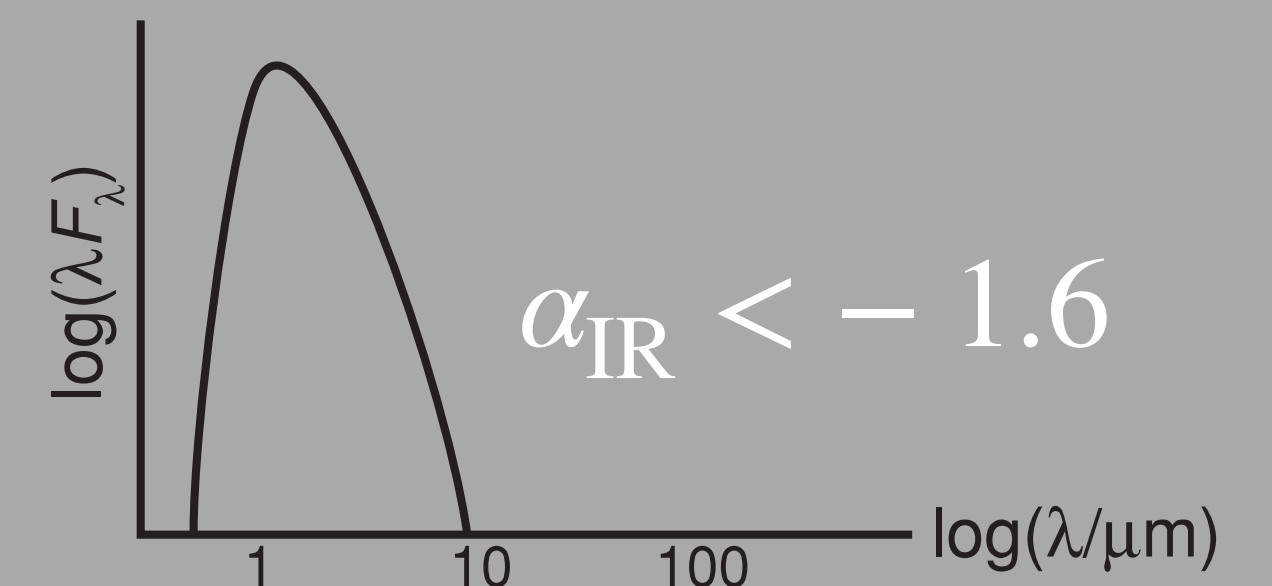
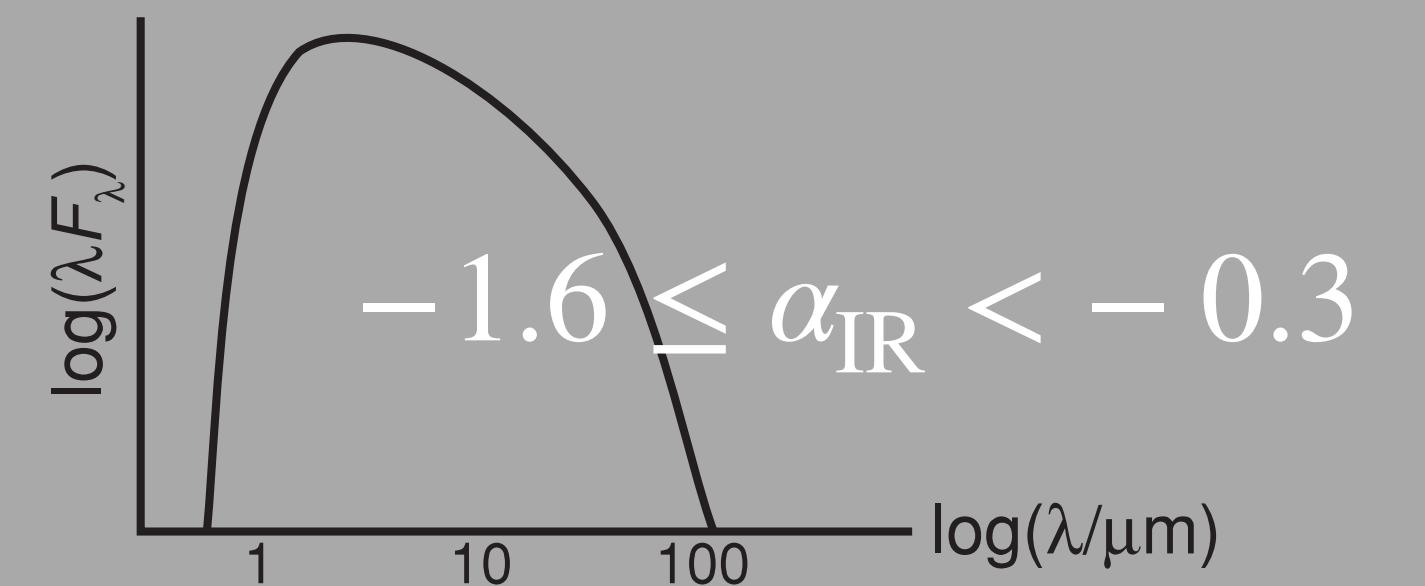
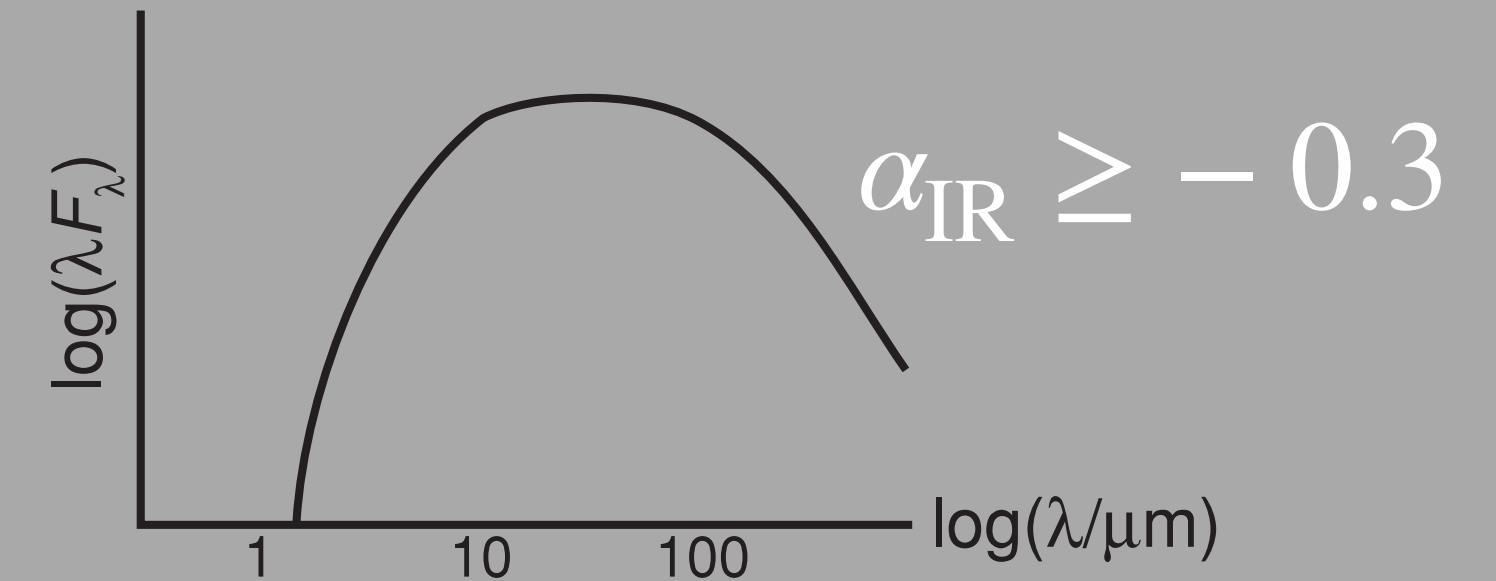
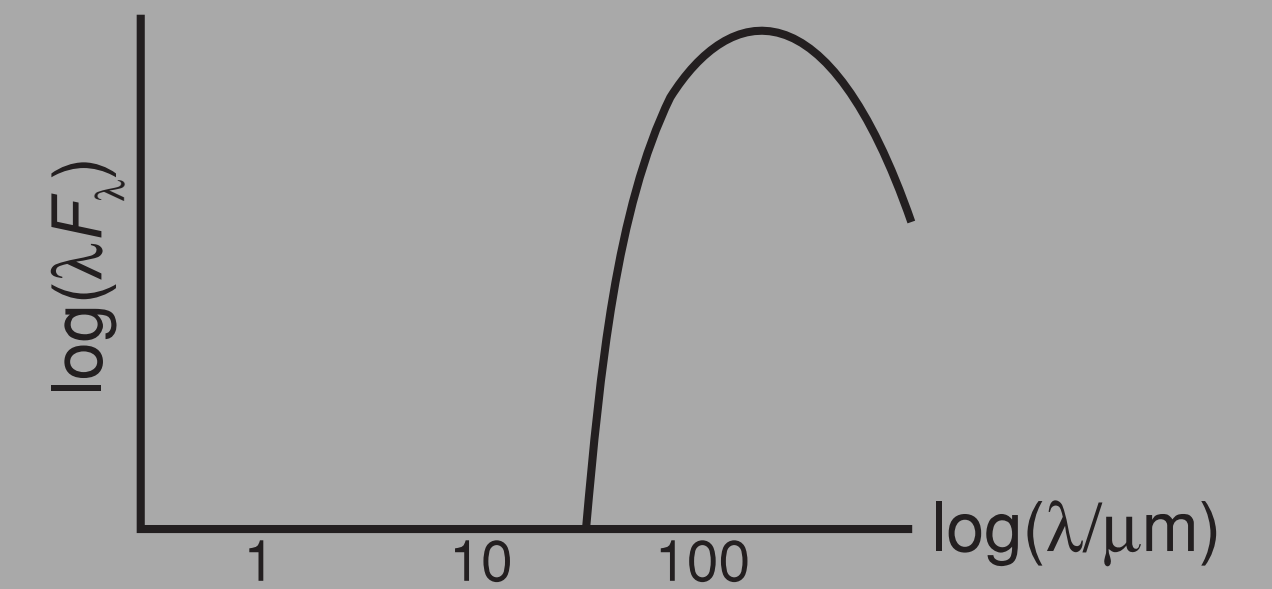
Class I



Class II  
(classical  
T Tauri star)



Class III  
(weak-lined  
T Tauri star)



**De qué estrellas estamos hablando?**

## **T Tauri**

Estudios iniciales definieron la clase “T Tauri” ya que mostraban:

- Variabilidad óptica
- Emisión cromosférica fuerte
- Asociación con nebulosidad

Luego se demostró que:

- Tienen emisión rayos-X
- Absorción de Li



Credit: Adam Block/Mount Lemmon SkyCenter/University of Arizona.

De qué estrellas estamos hablando?

## T Tauri

Estudios iniciales definieron la clase “T Tauri” ya que mostraban:

- Variabilidad óptica => **superficie activa**
- Emisión cromosférica fuerte => **acreción**
- Asociación con nebulosidad => **juventud**

Luego se demostró que:

- Tienen emisión rayos-X => **superficie activa**
- Absorción de Li => **baja temperatura del núcleo (juventud)**



Credit: Adam Block/Mount Lemmon SkyCenter/University of Arizona.

**De qué estrellas estamos hablando?**

## **Herbig AeBe**

- TTS son de tipo GKM y masas  $< 2 M_{\text{Sun}}$
- G. Herbig descubrió sus primos de masa intermedia masa  $\sim 2-8 M_{\text{Sun}}$
- Se llaman Herbig “AeBe” porque se caracterizan por líneas de emisión en su espectro
- TTS y Herbig AeBe son estrellas PMS



# George Herbig

*“When the historians of science look back on our times with the perspective of the years, all that we do today will certainly be seen to have been either wrong, or irrelevant, or obvious.”*



Figure 115: *Seventy years separate these two photos of Herbig at the telescope. To the left is a photo that appeared in Los Angeles Times on Nov 30, 1940, when Herbig was 20. To the right, Herbig at 90 is observing at the Keck-I telescope.*

From <http://ifa.hawaii.edu/SP1/HerbigBiography.pdf>



# Contexto galáctico

# The Solar Neighborhood in the Age of Gaia

Charla de Joao Alves en PPVII

Catherine **Zucker**, Space Telescope Science Institute

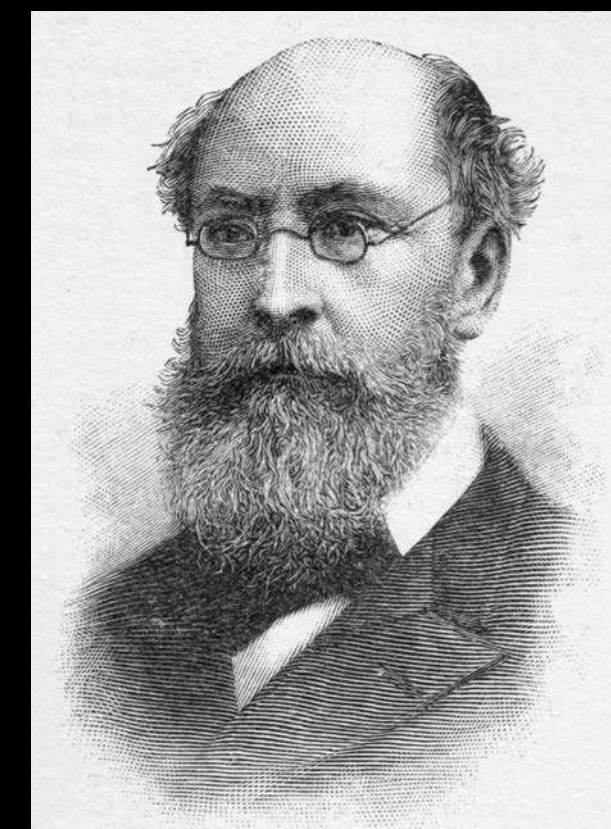
João **Alves**, University of Vienna

Alyssa **Goodman**, Center for Astrophysics | Harvard & Smithsonian

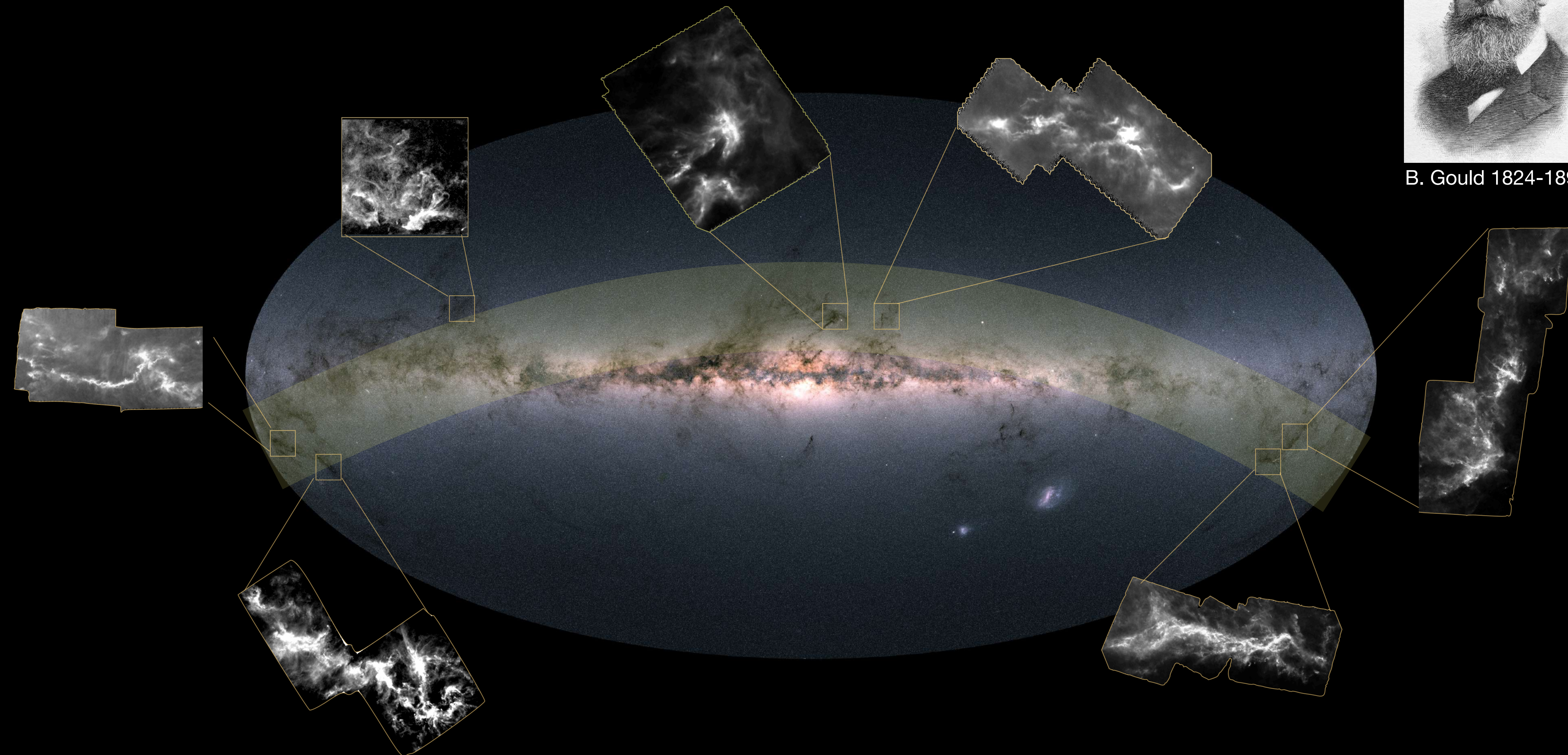
Stefan **Meingast**, University of Vienna

Phillip **Galli**, University of São Paulo

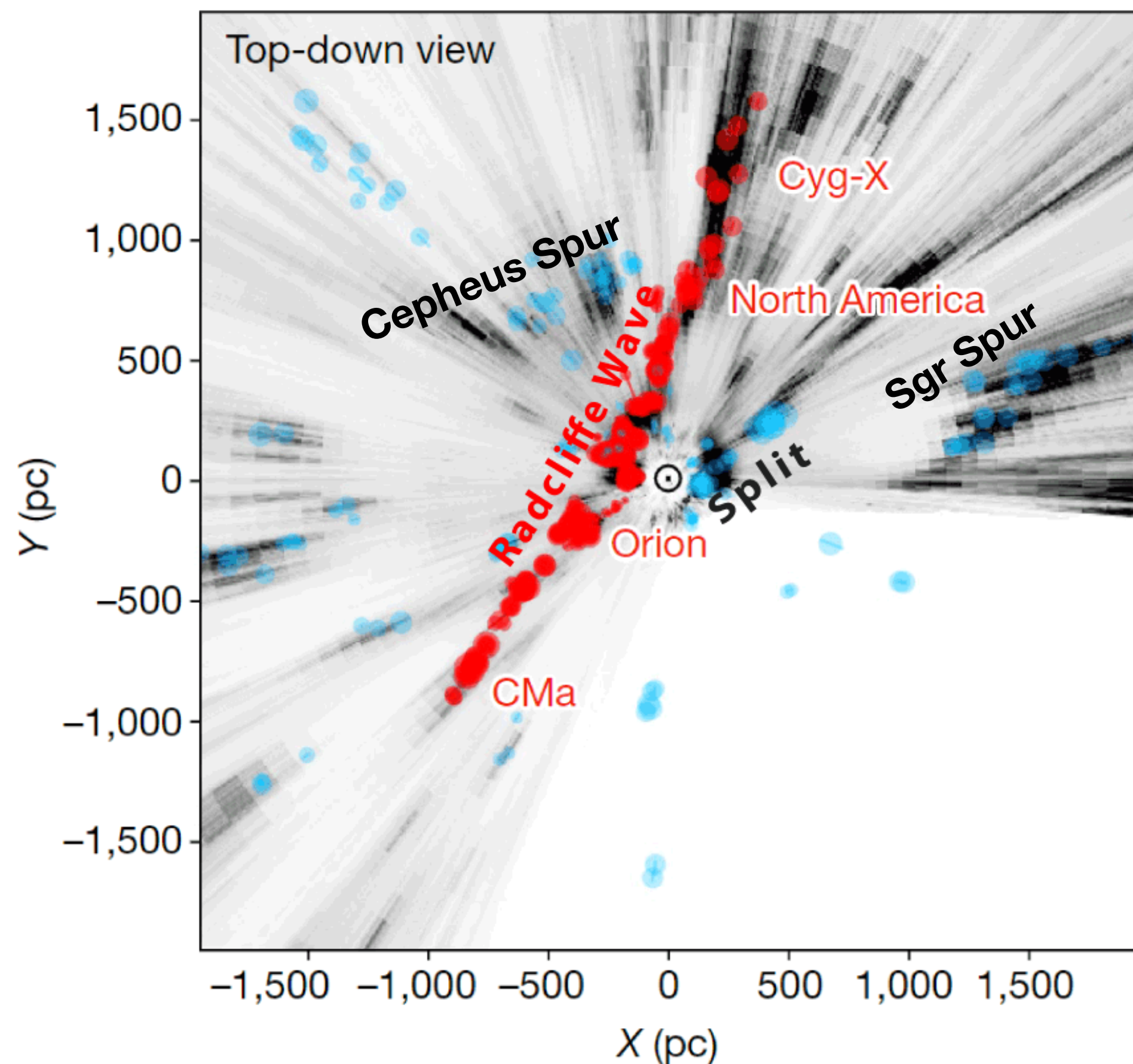
# The Gould's Belt



B. Gould 1824-1896



# The Radcliffe Wave



**At least 3 kpc long, and 120 pc wide, with crest and trough reaching 160 pc out of the Galactic Plane**

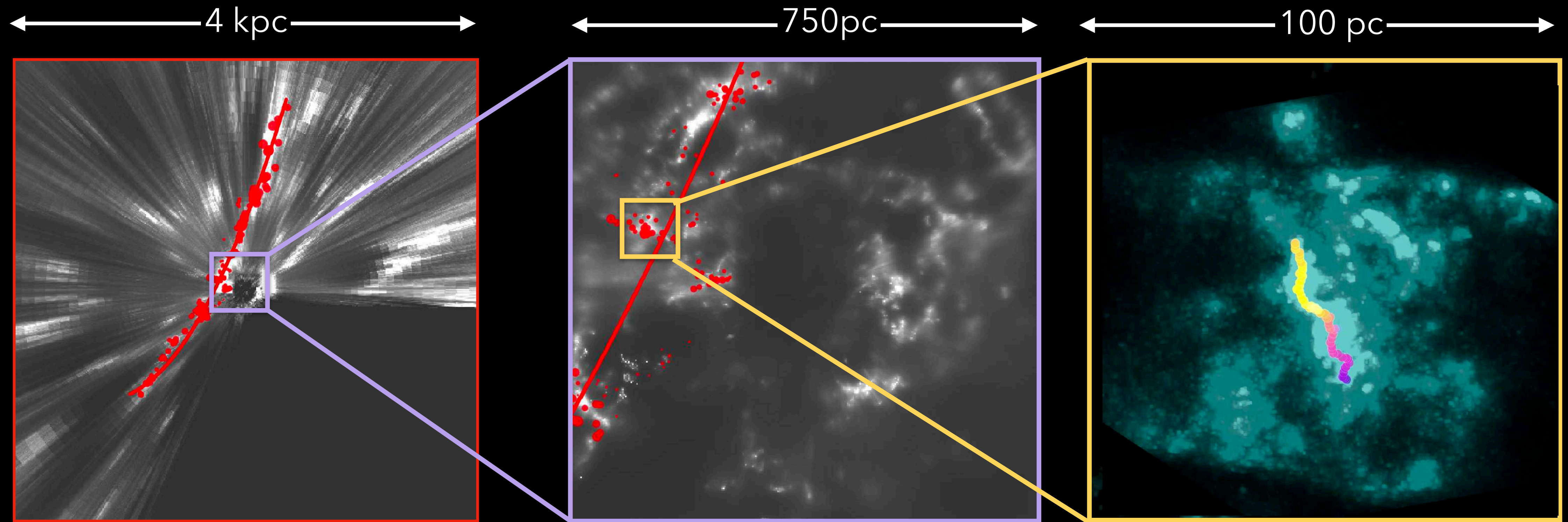
**Mass:  $>3 \times 10^6 M_{\text{Sun}}$**

# 3 kpc linear structure?



UGC 12158

# Post-Gaia view on molecular clouds



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

*Leike et al. 2020*

*Zucker et al. 2021*

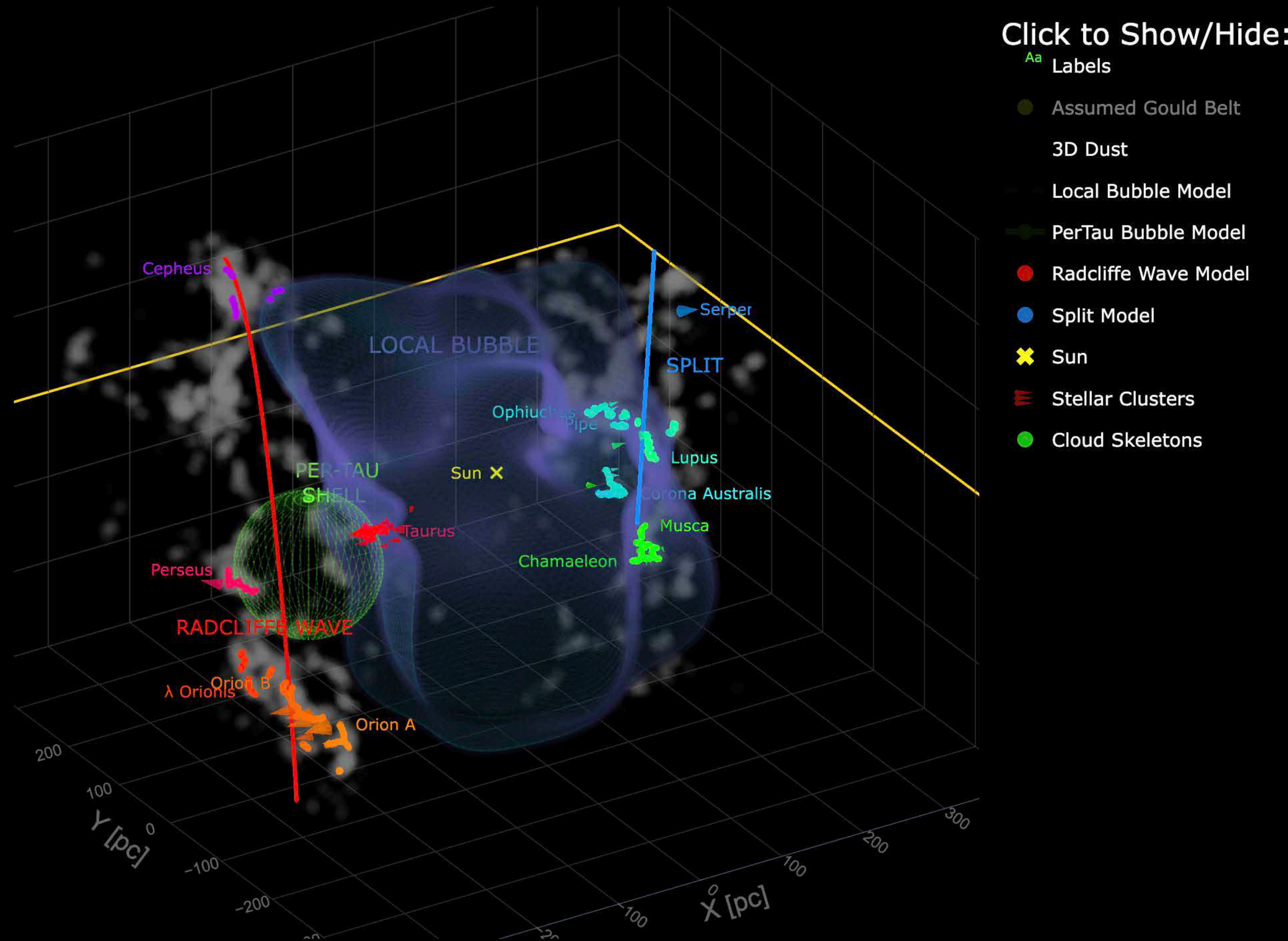
# The Local Bubble

Using the stellar “traceback” data, we fit for the bubble’s evolution using an analytic expansion model [see El-Badry et al. 2019]

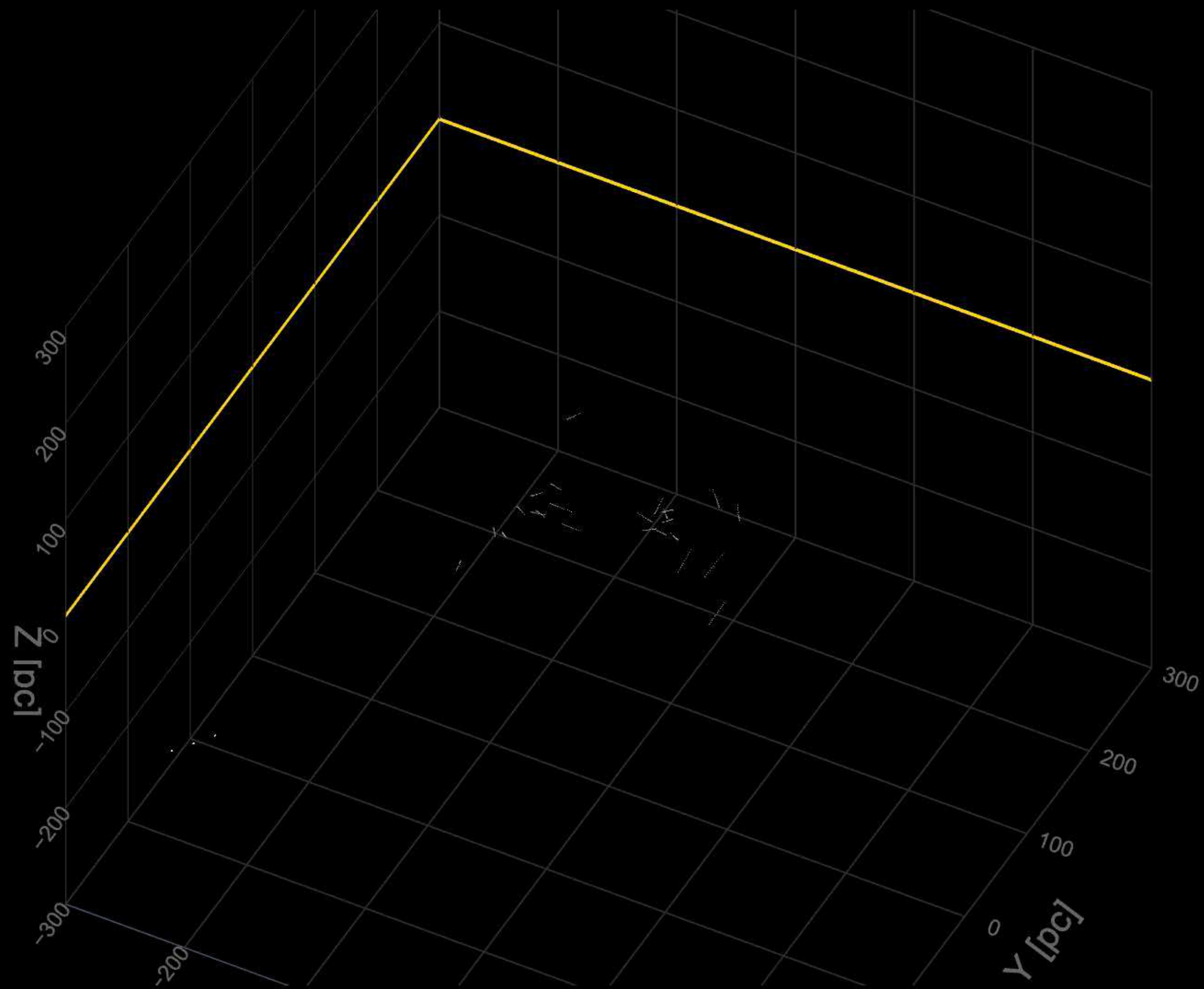
Assume the bubble is entirely supernova driven (neglect radiation pressure + stellar winds)

The model fits for:

- \* Time of first explosion
- \* Ambient ISM density
- \* Time interval between supernova explosions

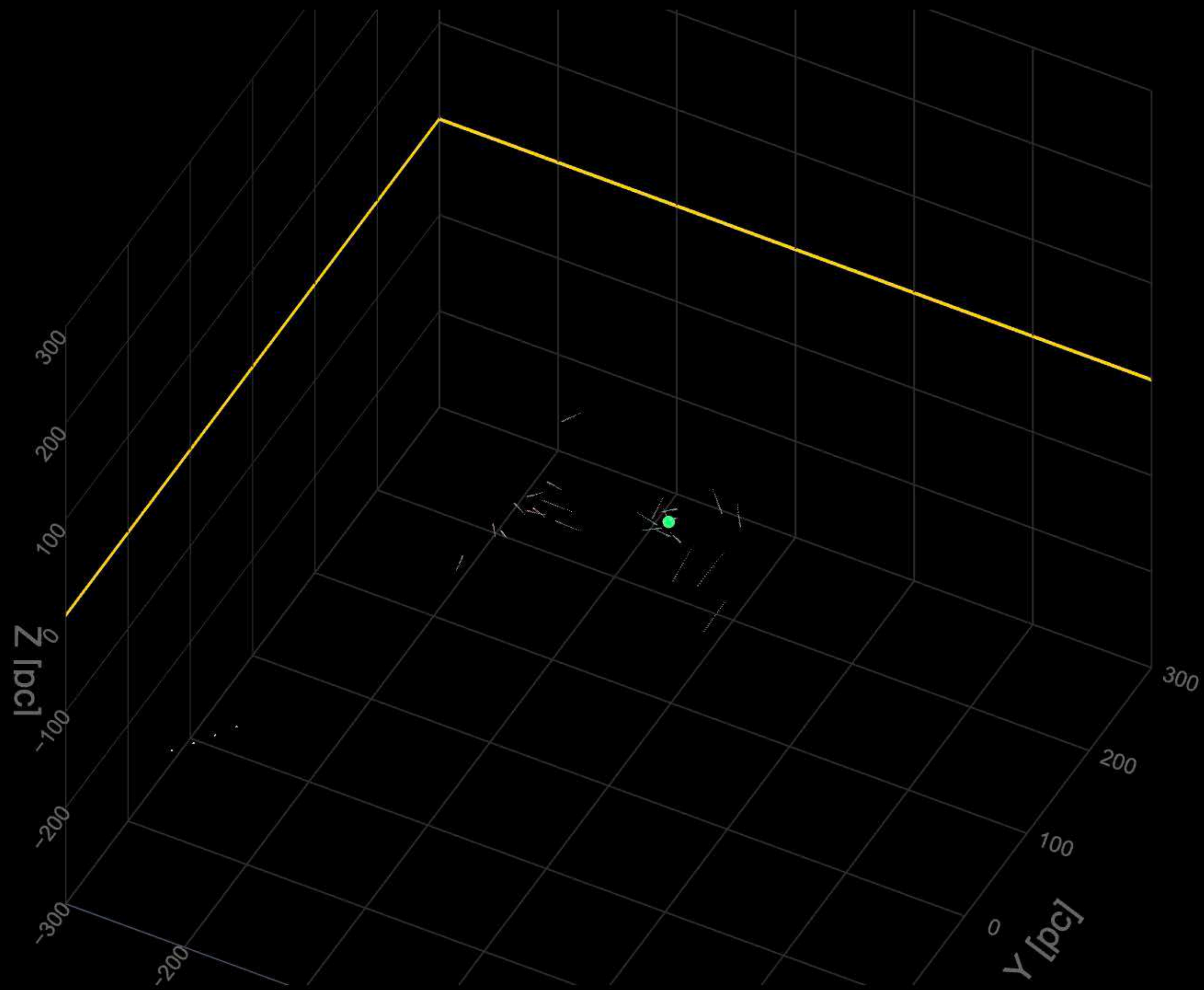


Zucker et al. 2022



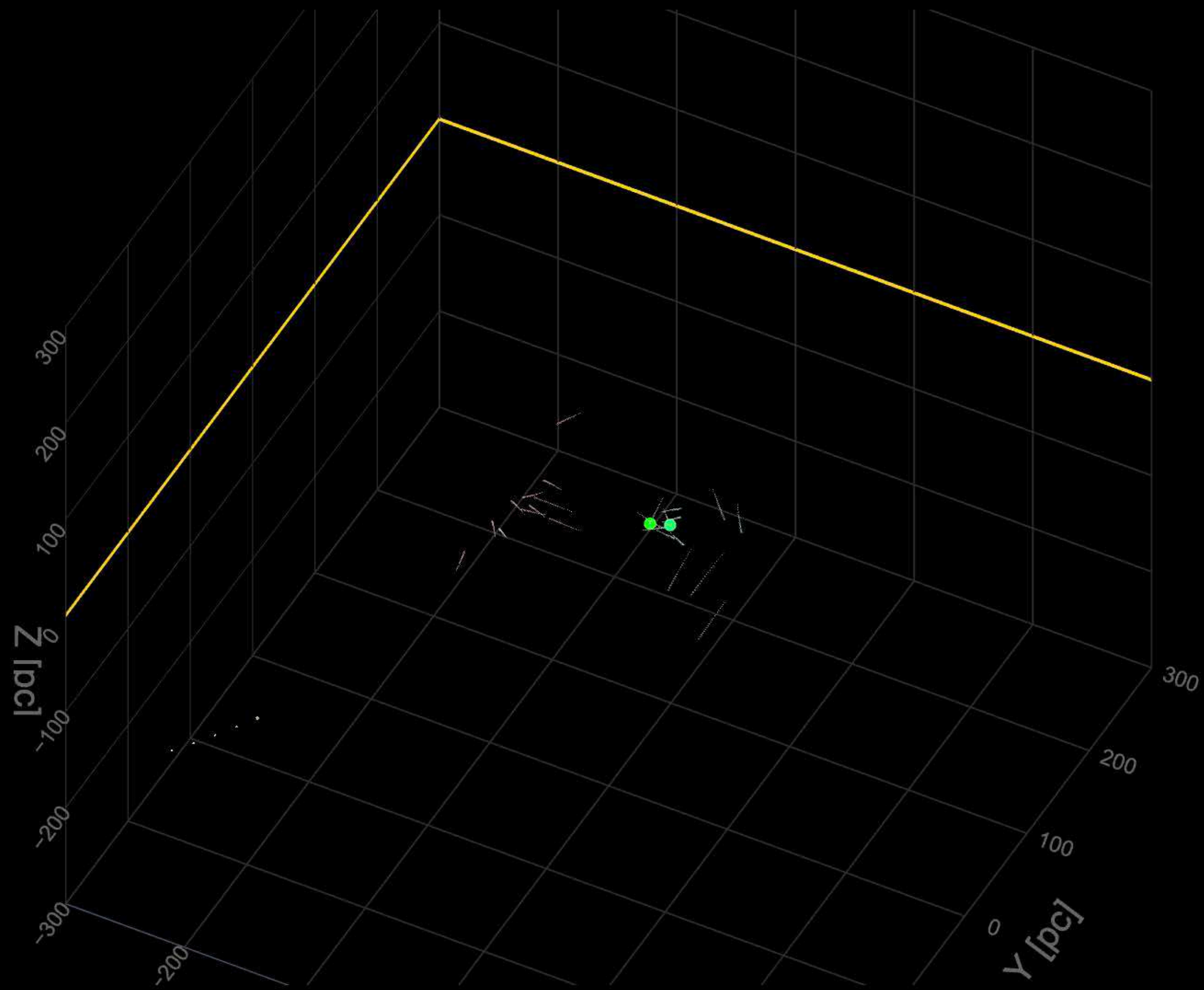
17 Myr Ago



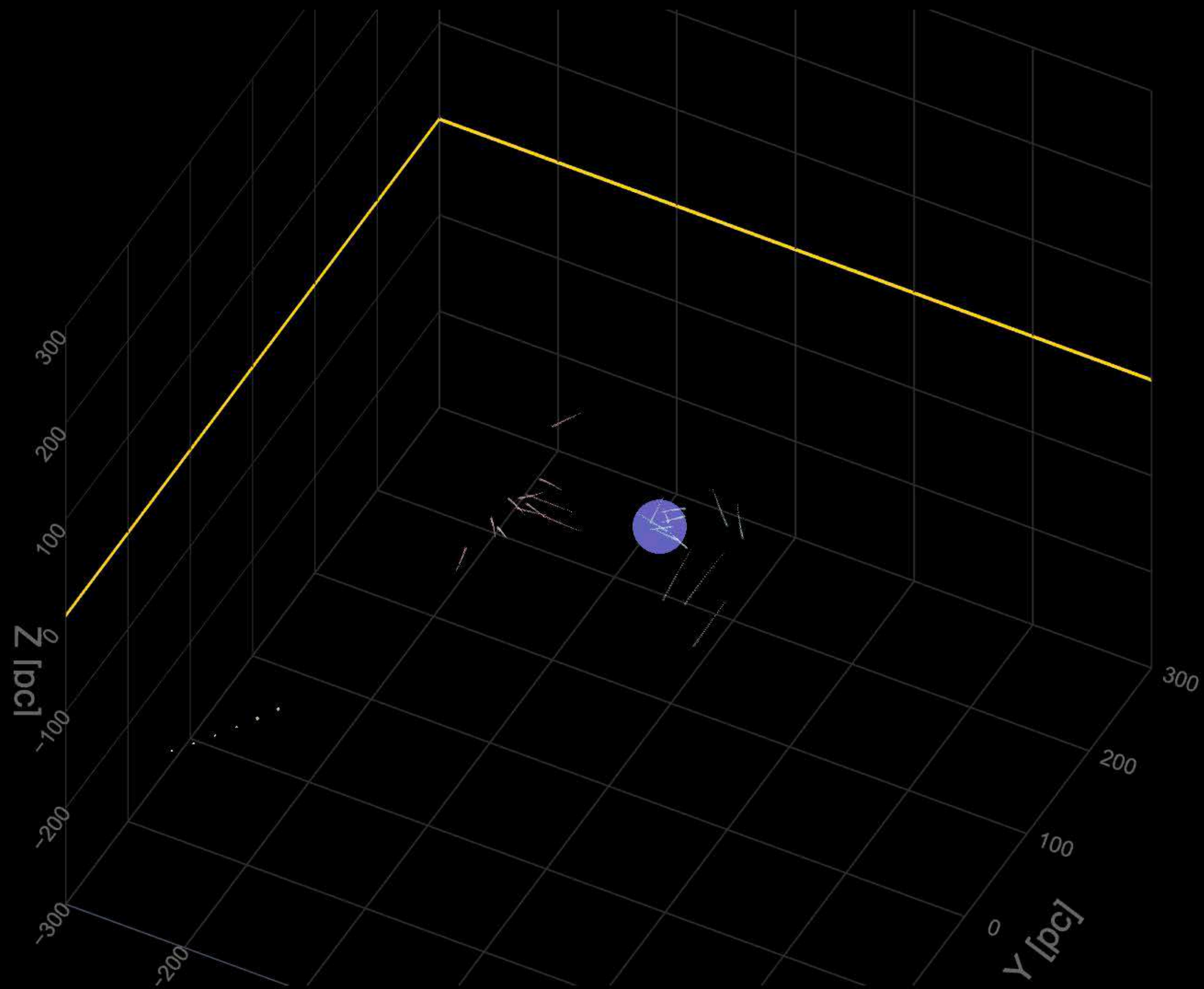


16 Myr Ago

Upper Centaurus Lupus  
("UCL") Born

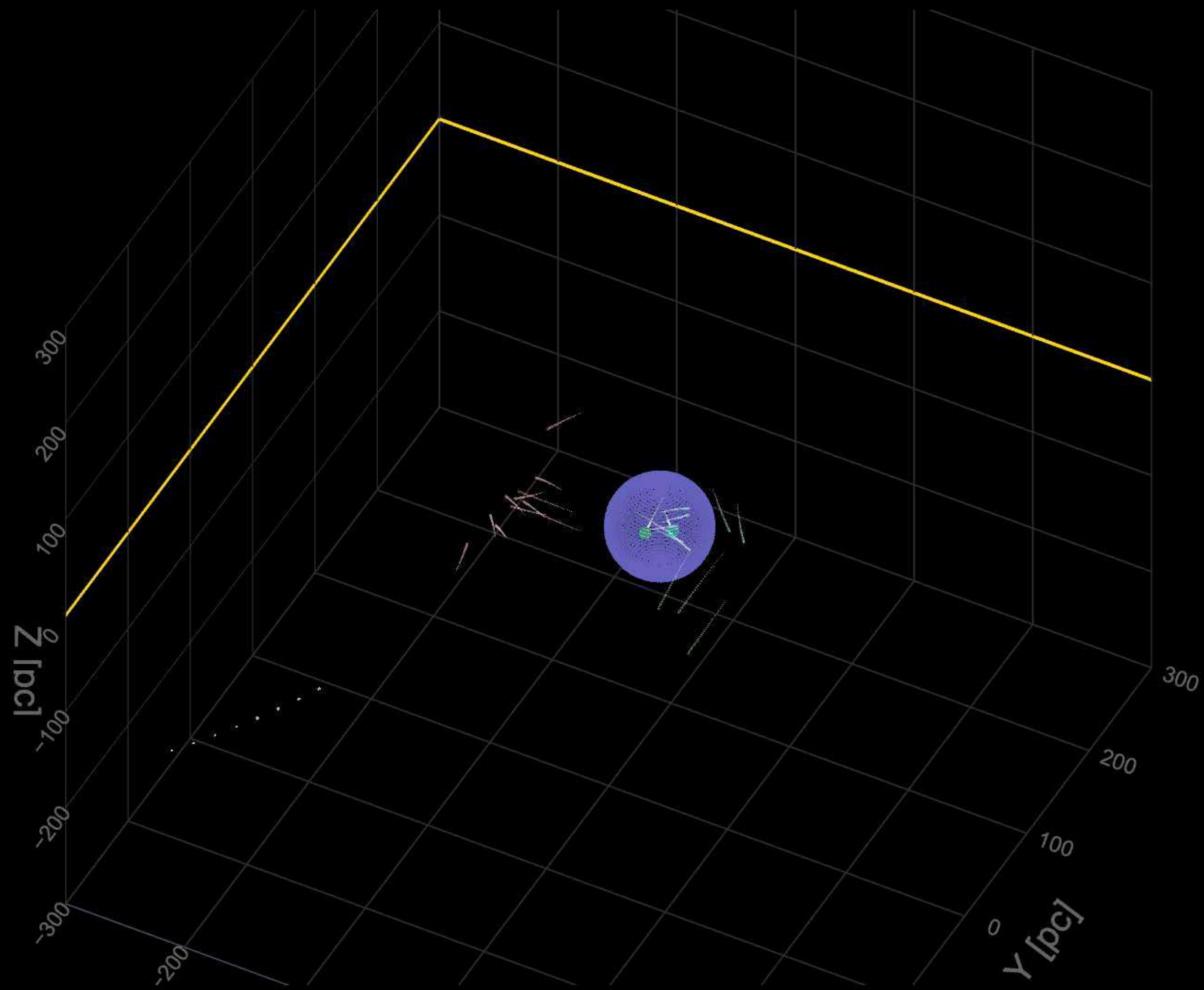


15 Myr Ago



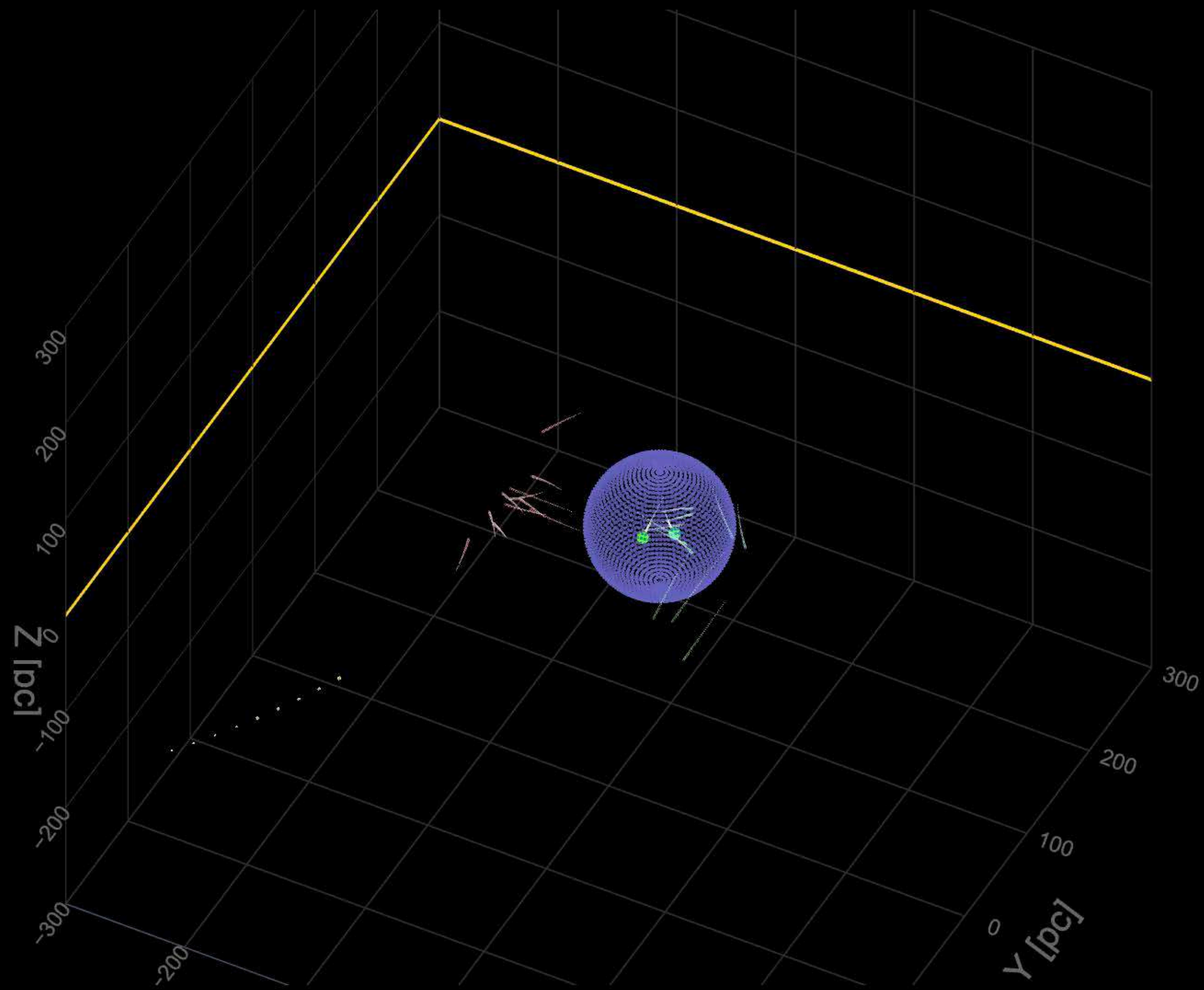
14 Myr Ago

Supernovae in UCL/  
LCC make bubble



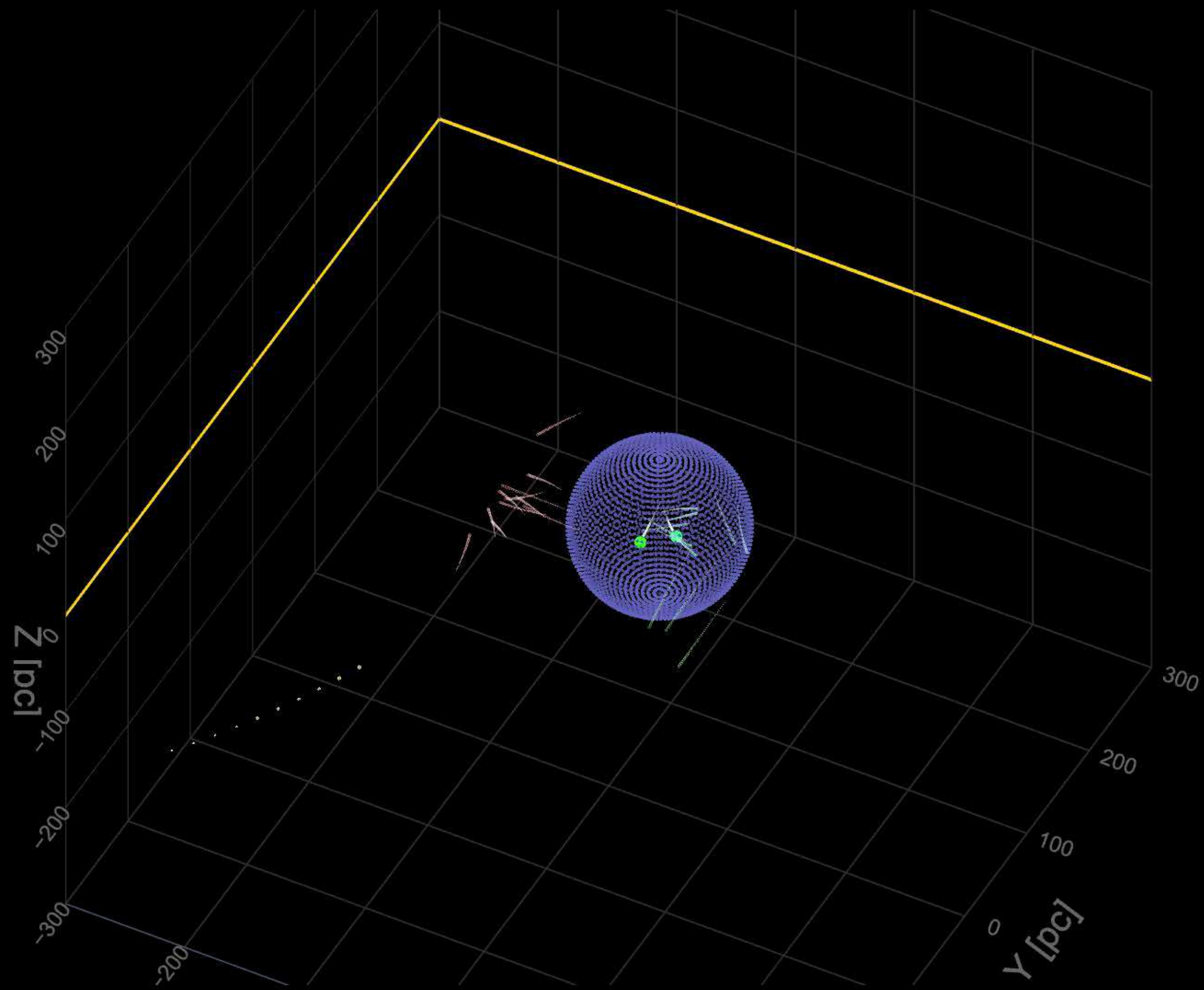
13 Myr Ago

Bubble expands



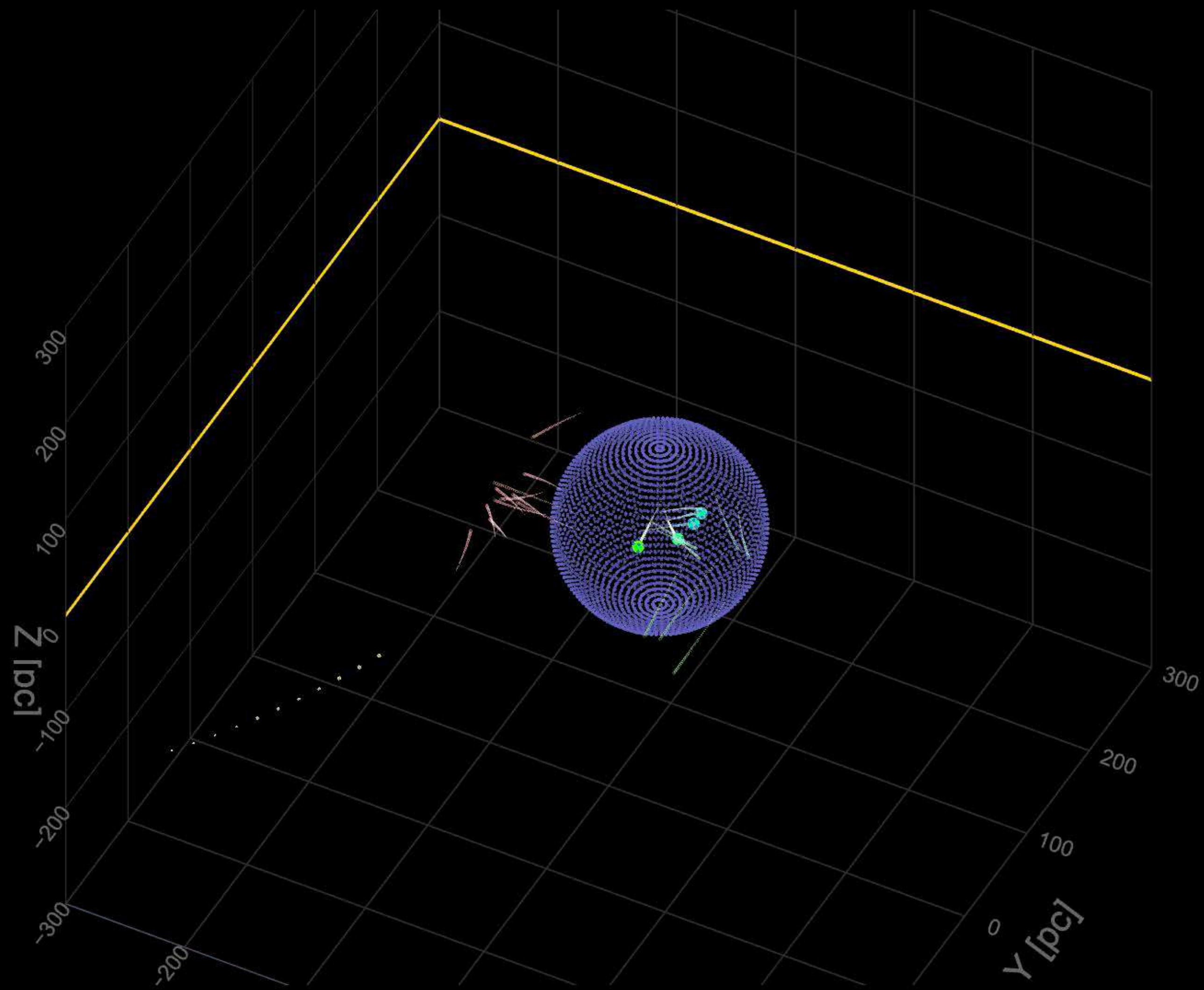
12 Myr Ago

Bubble expands



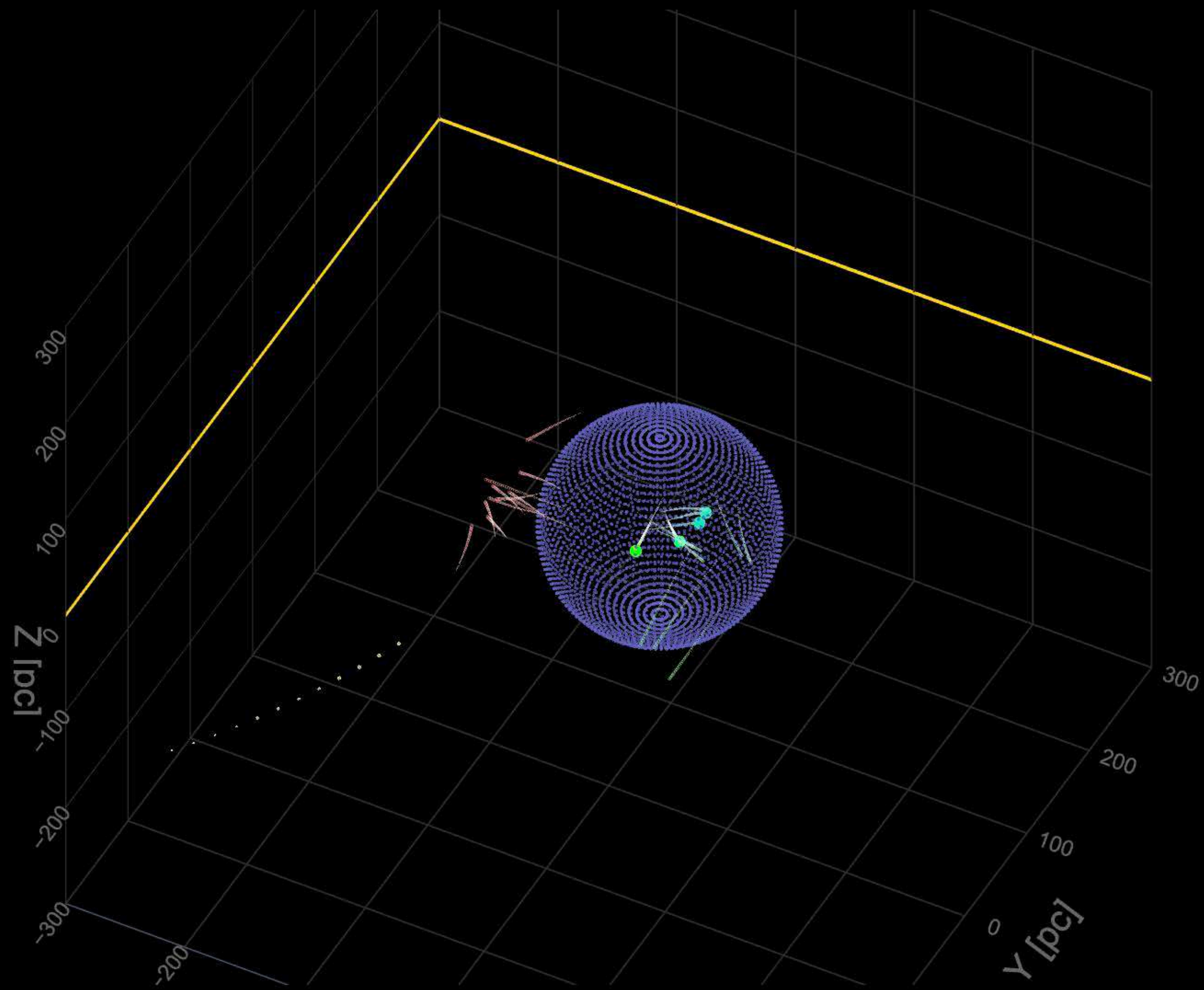
11 Myr Ago

Bubble expands



10 Myr Ago

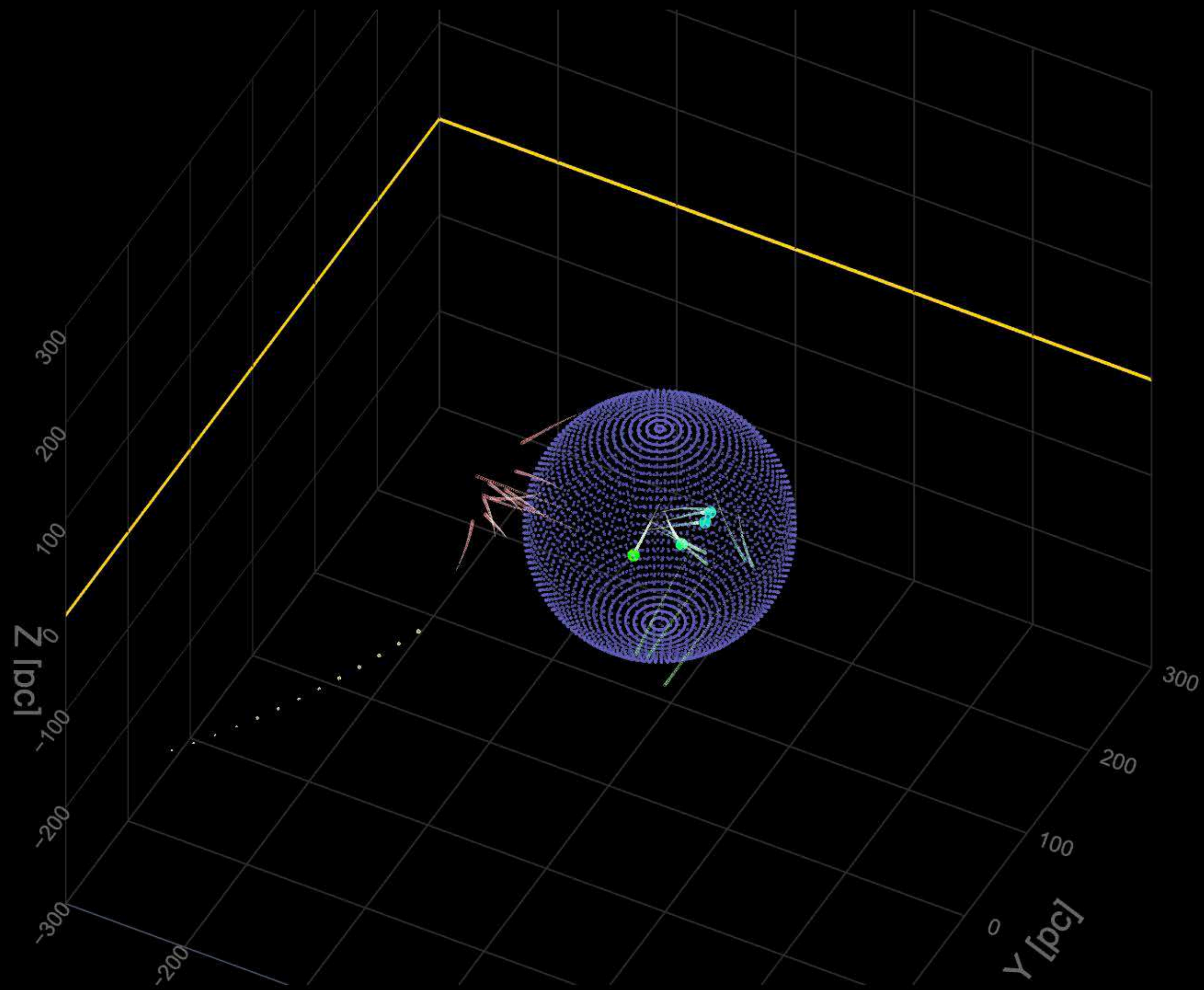
Stars in UpSco form



9 Myr Ago

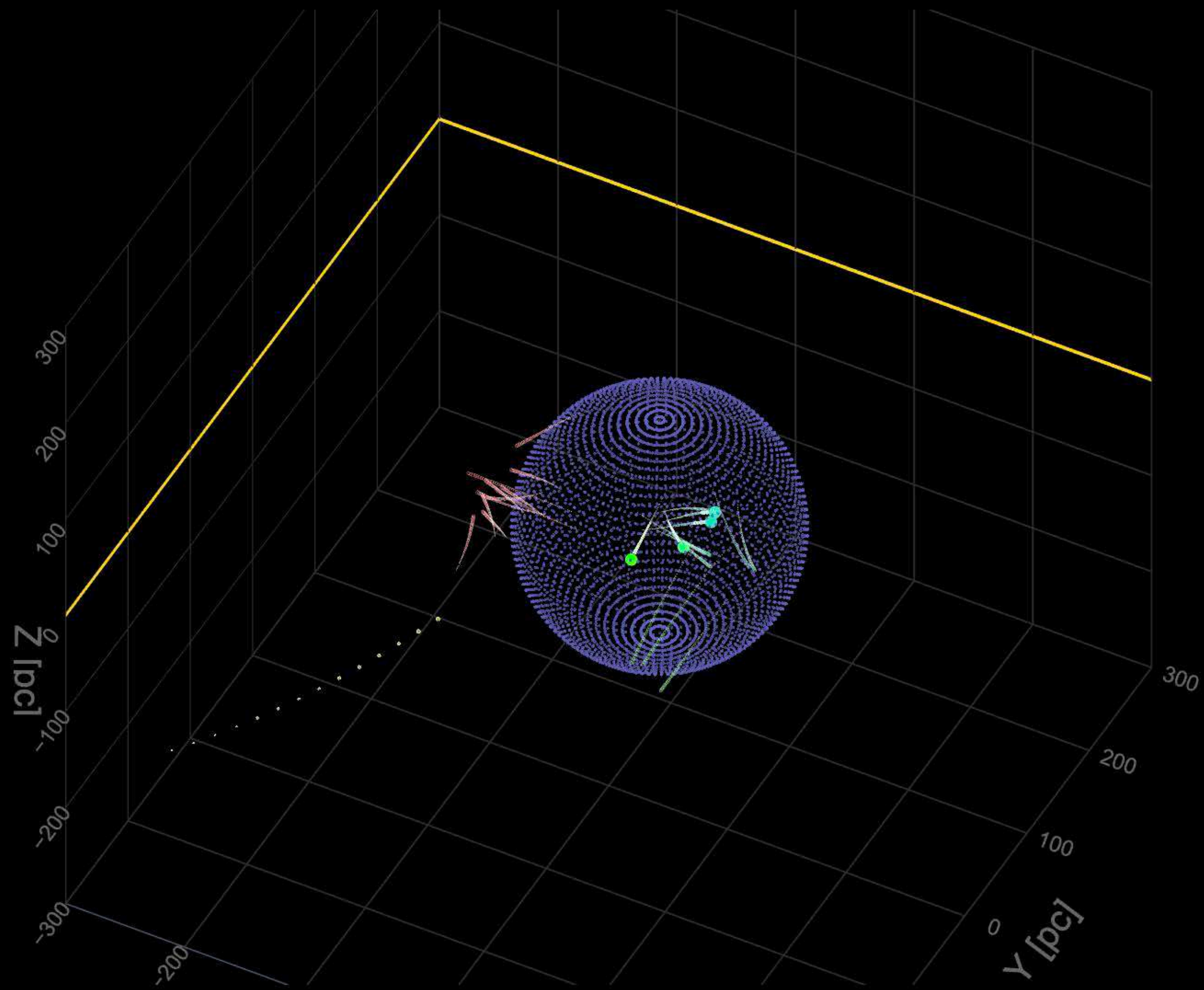
Bubble expands





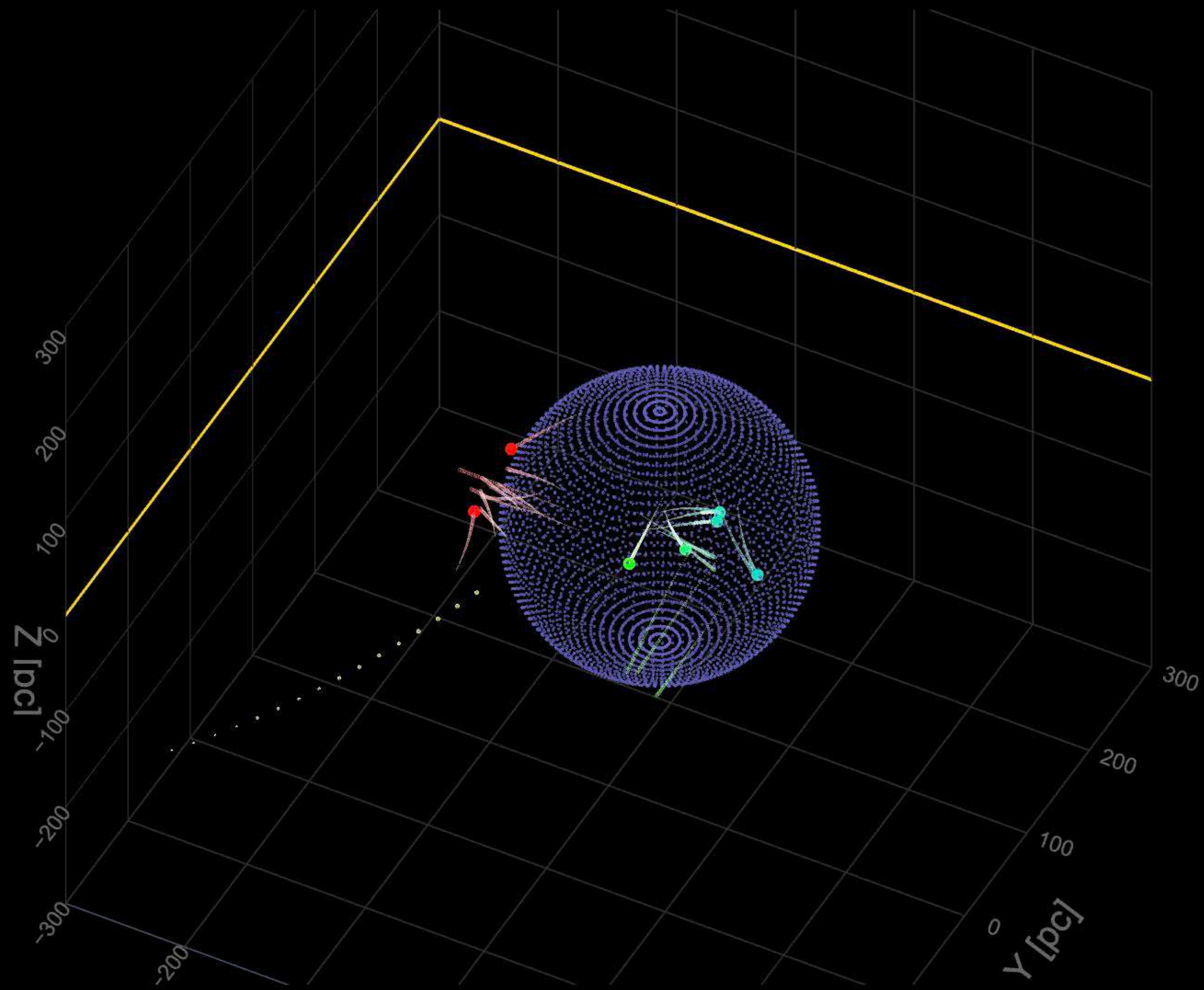
8 Myr Ago

Bubble expands



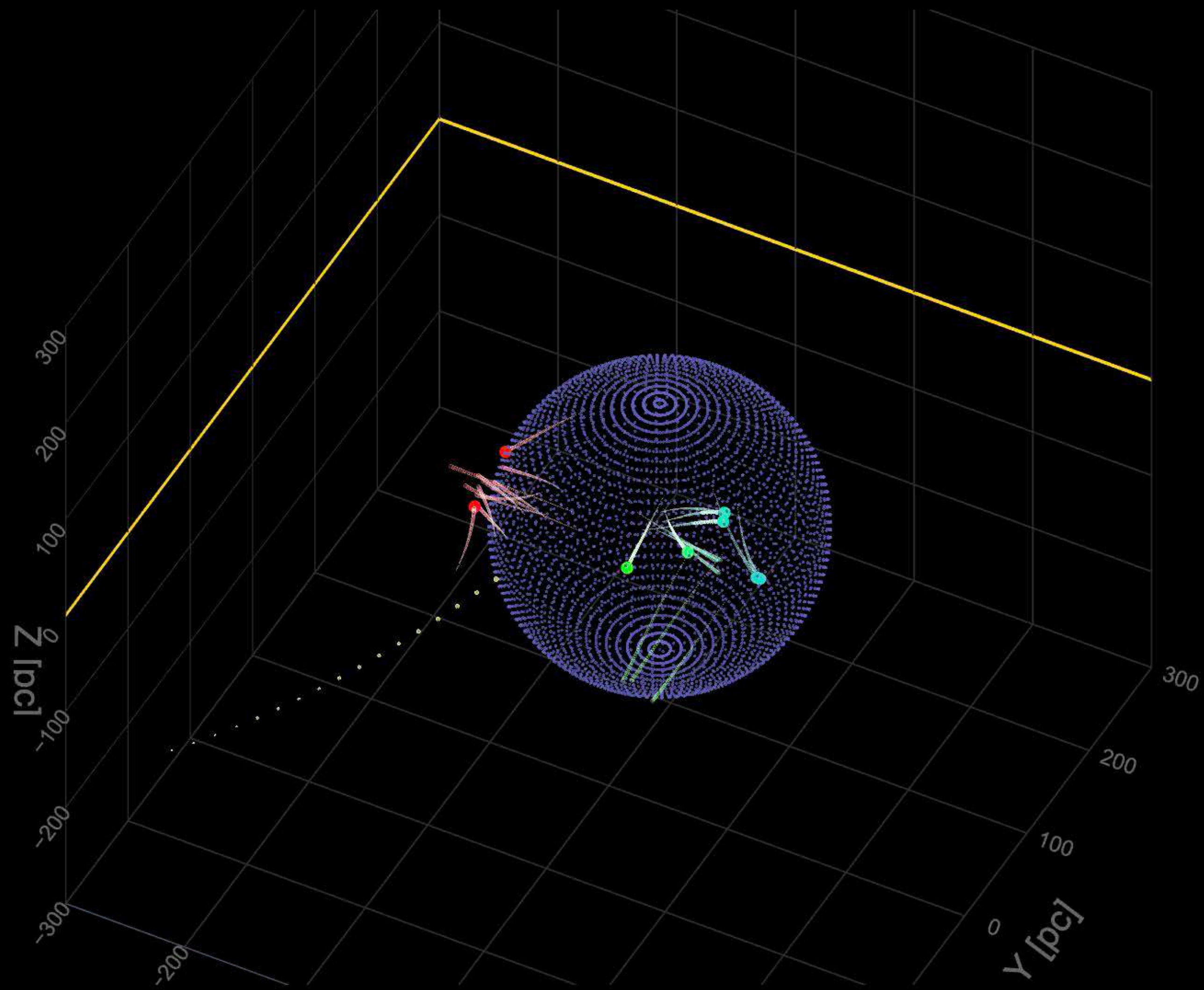
7 Myr Ago

Bubble expands

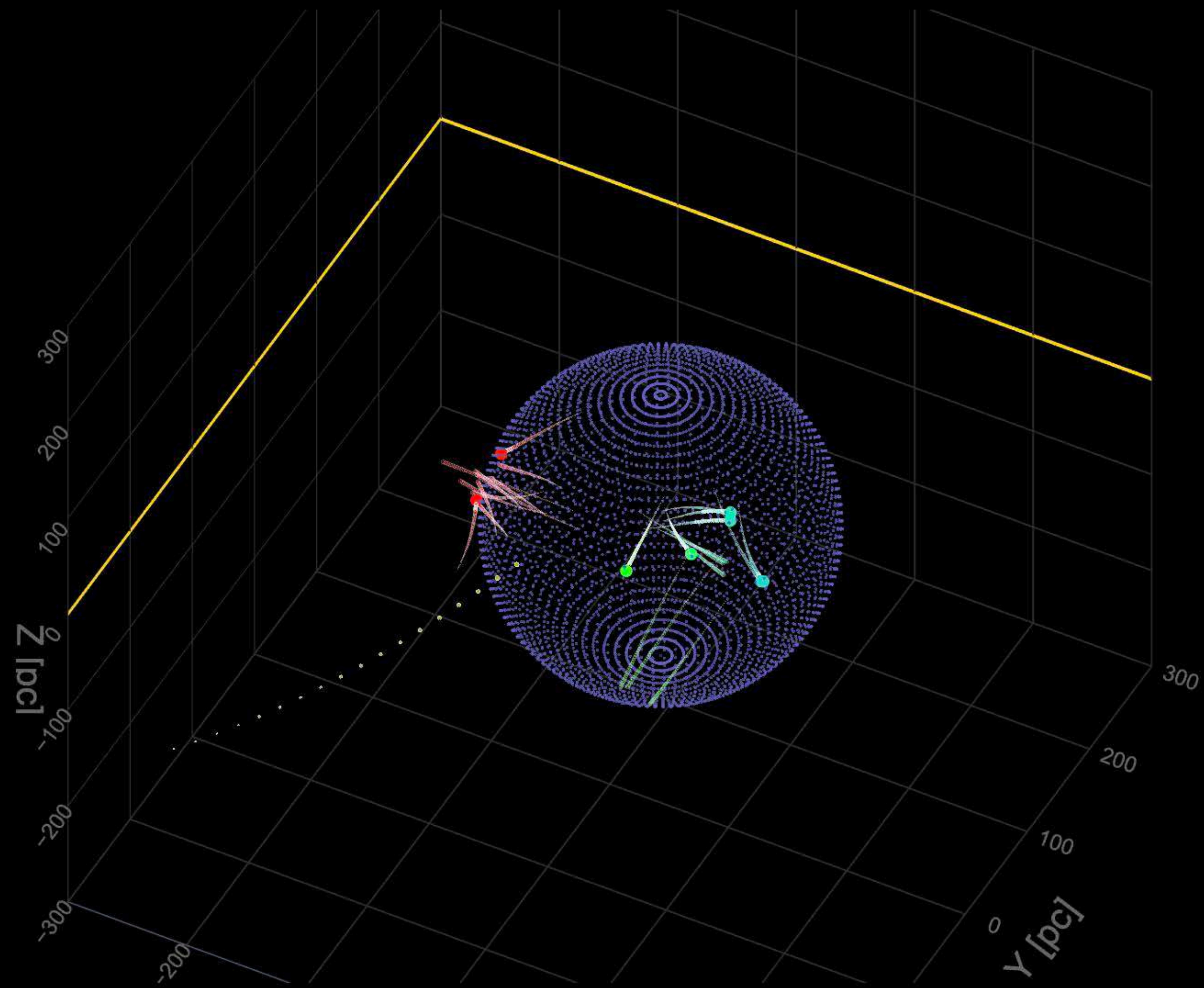


6 Myr Ago Stars in Corona Australis form

Stars in Taurus form

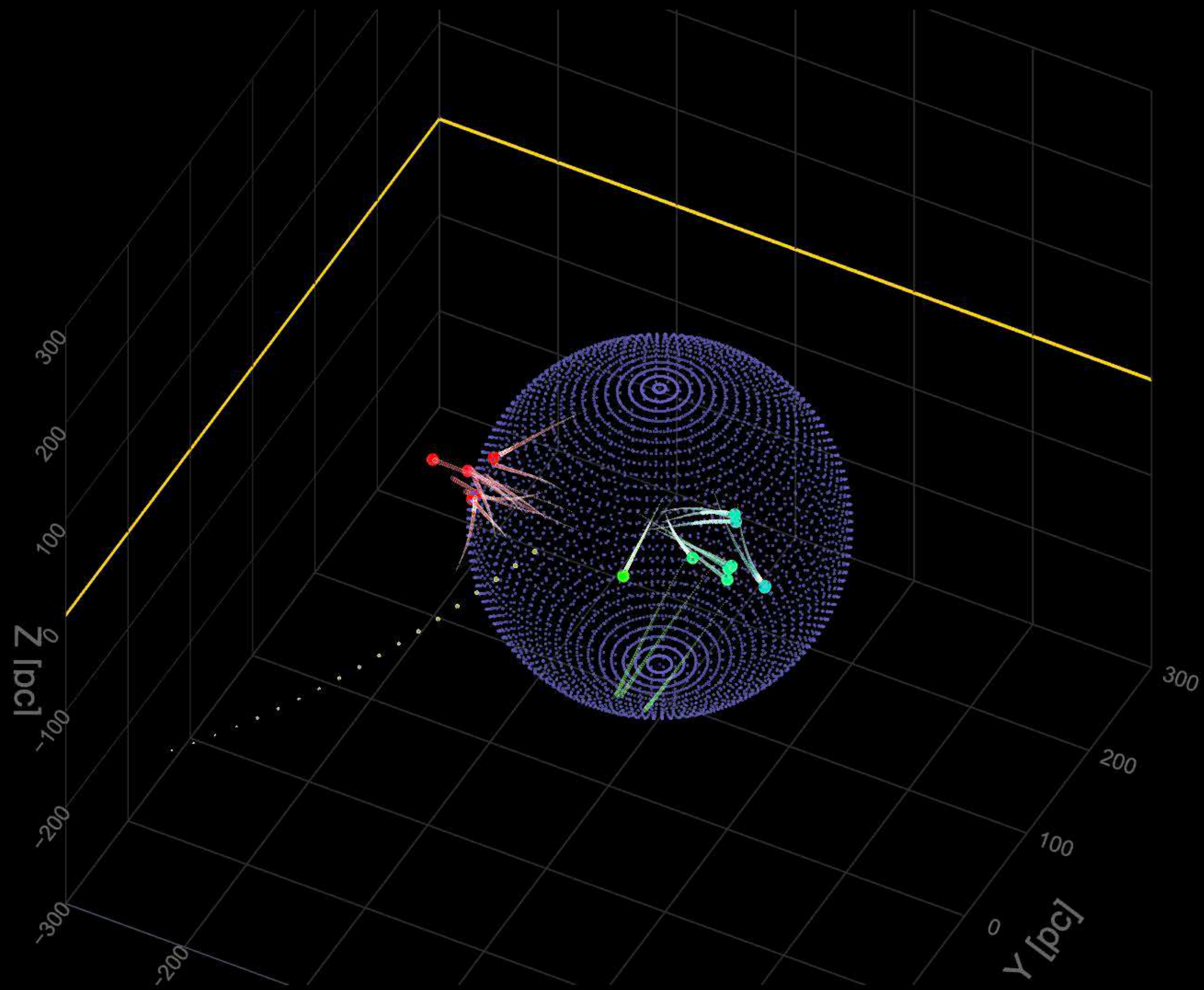


5 Myr Ago Stars in Corona Australis form



4 Myr Ago

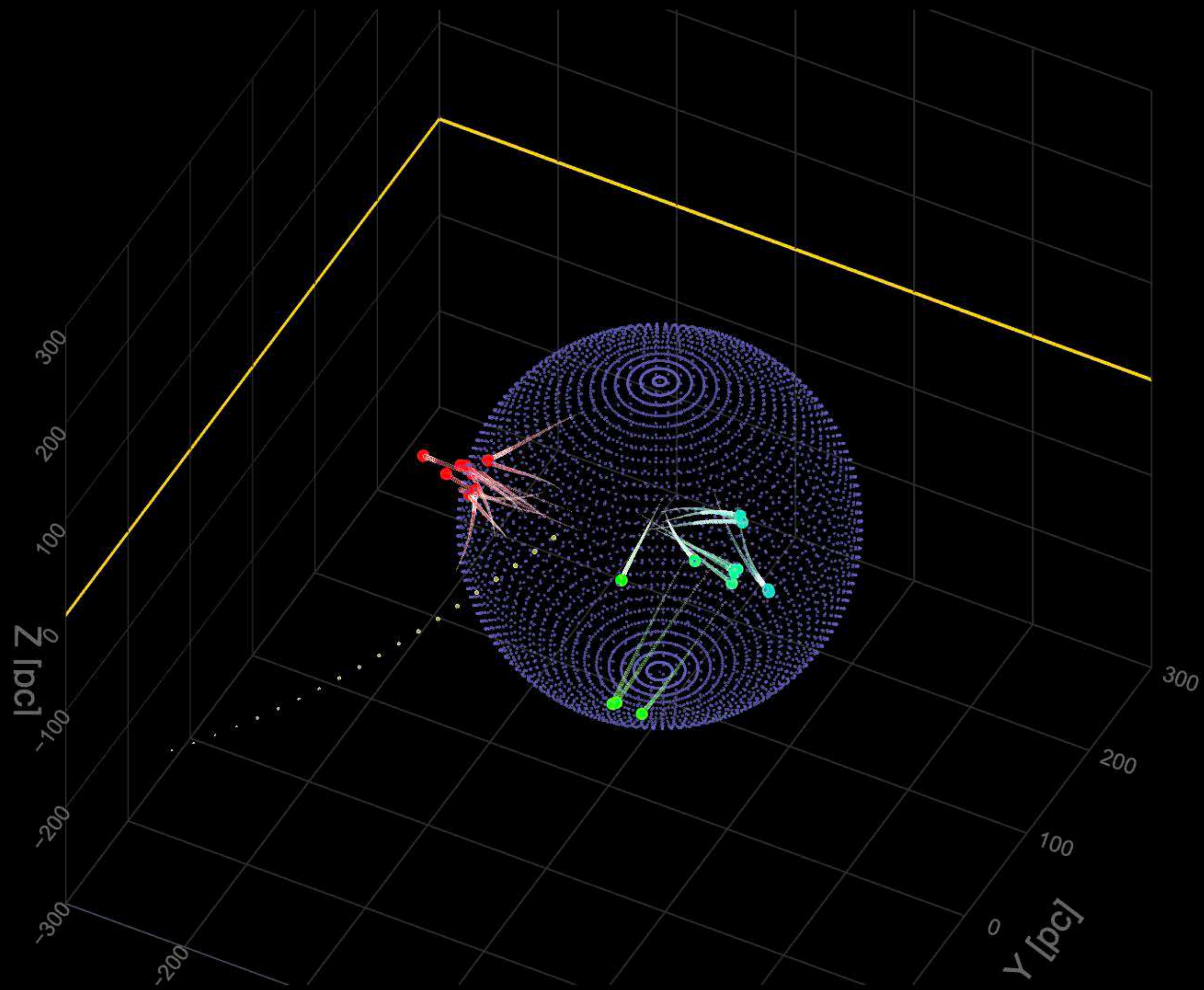
Bubble expands



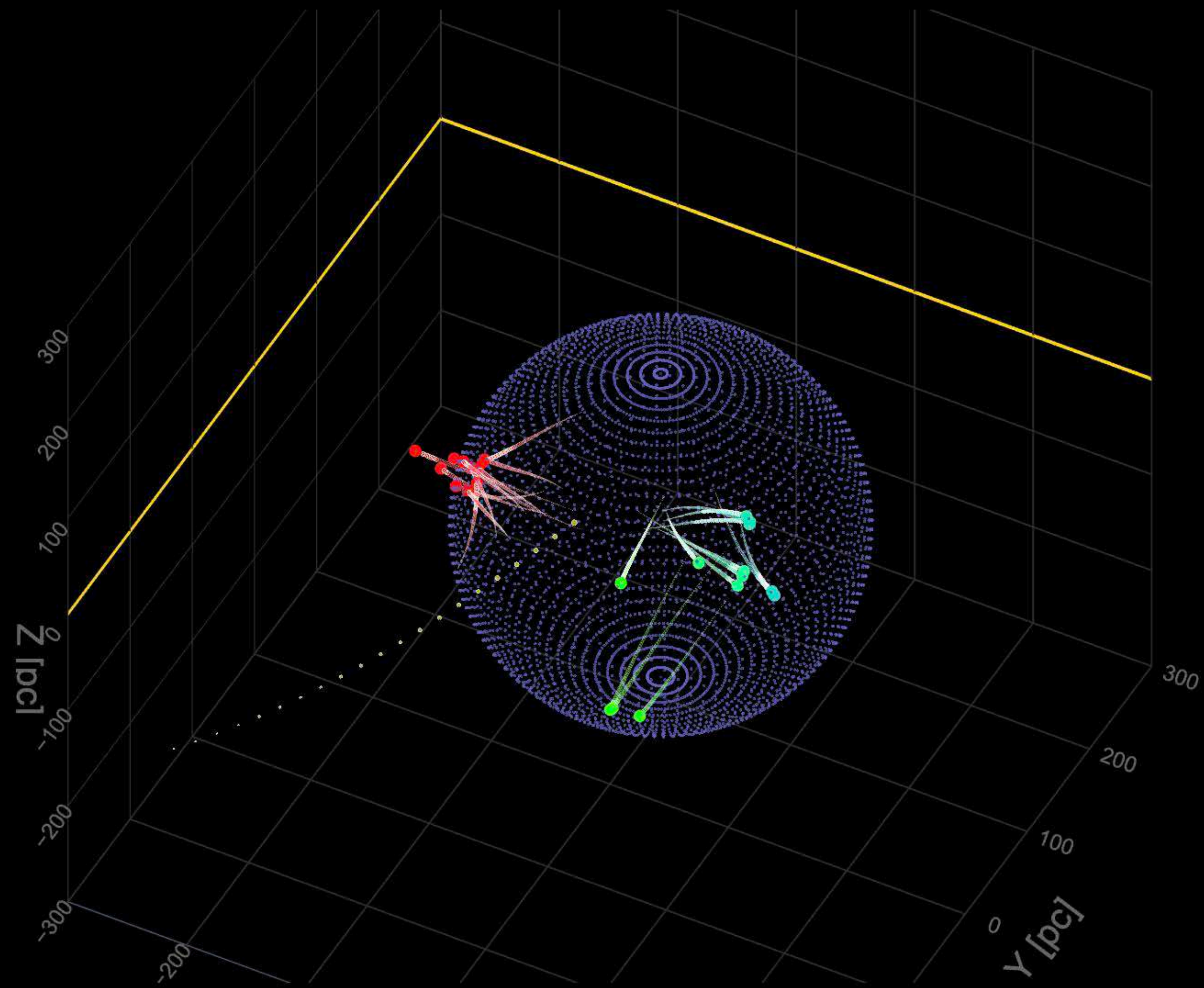
3 Myr Ago

Stars in Lupus form

Stars in Taurus form



2 Myr Ago Stars in Chamaeleon form  
Stars in Taurus form



1 Myr Ago

Stars in Ophiuchus form

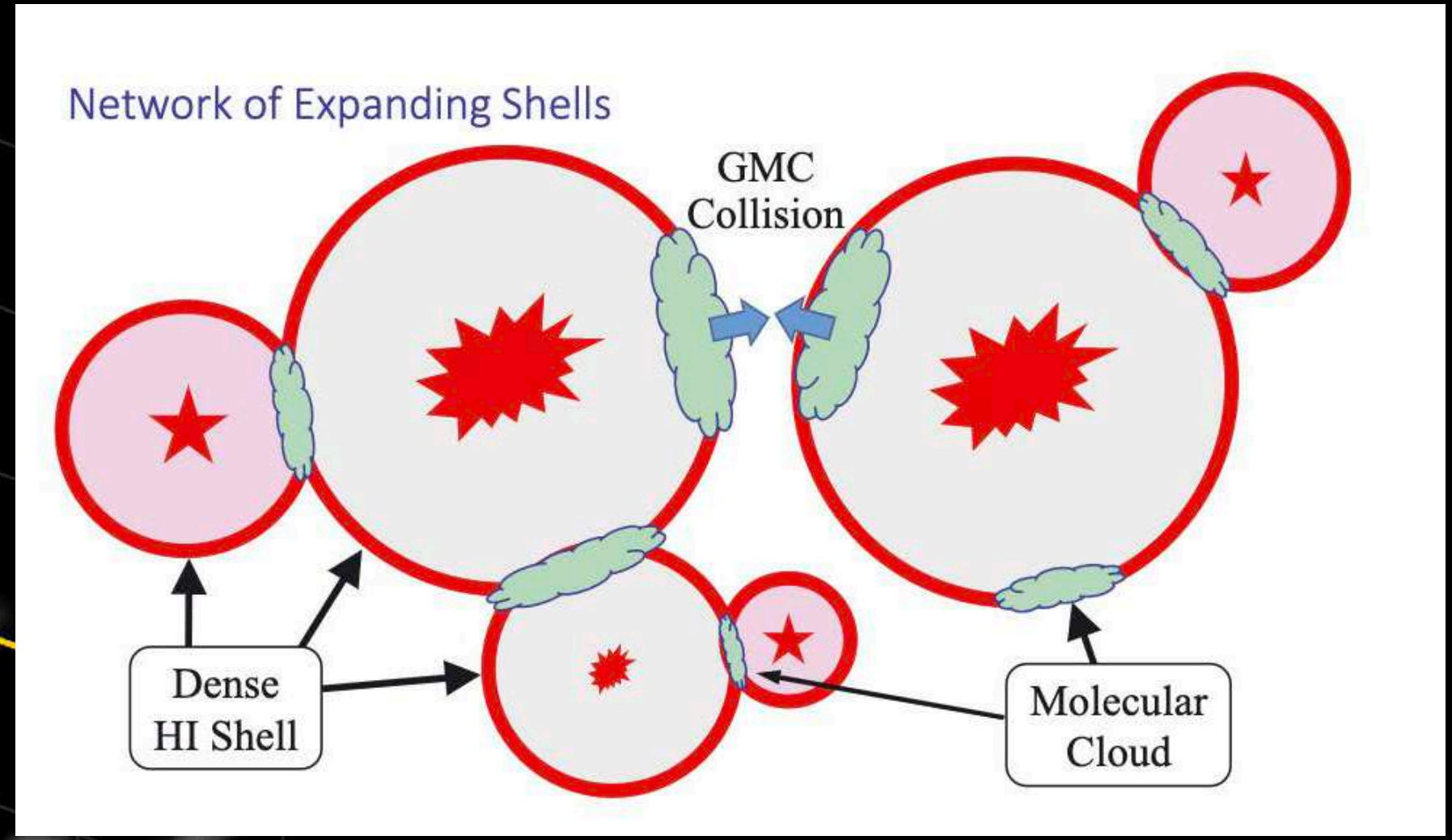
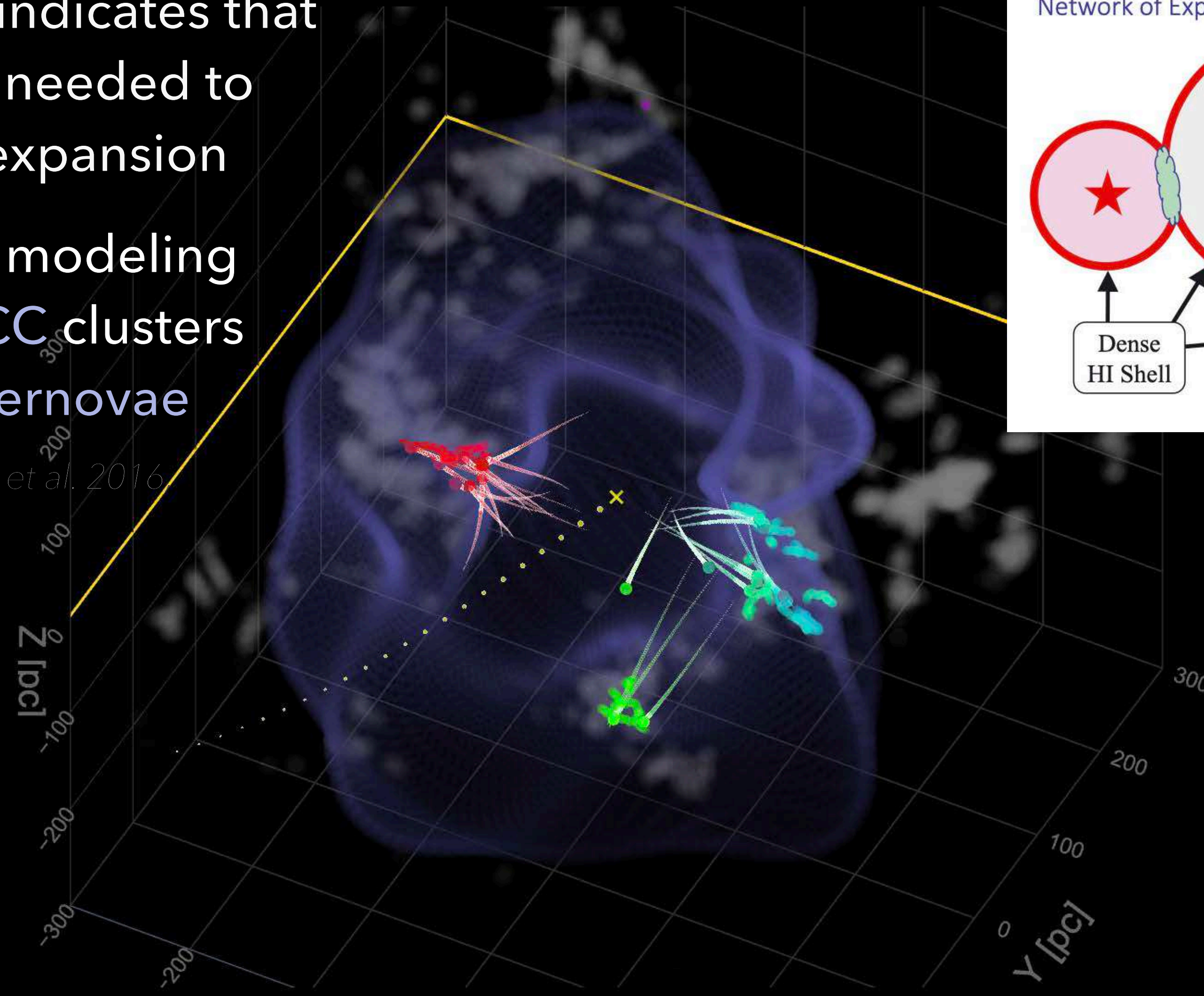
Stars in Taurus form



Momentum analysis indicates that 15 supernovae were needed to power the bubble's expansion

Population synthesis modeling indicates UCL and LCC clusters produced 14-20 supernovae

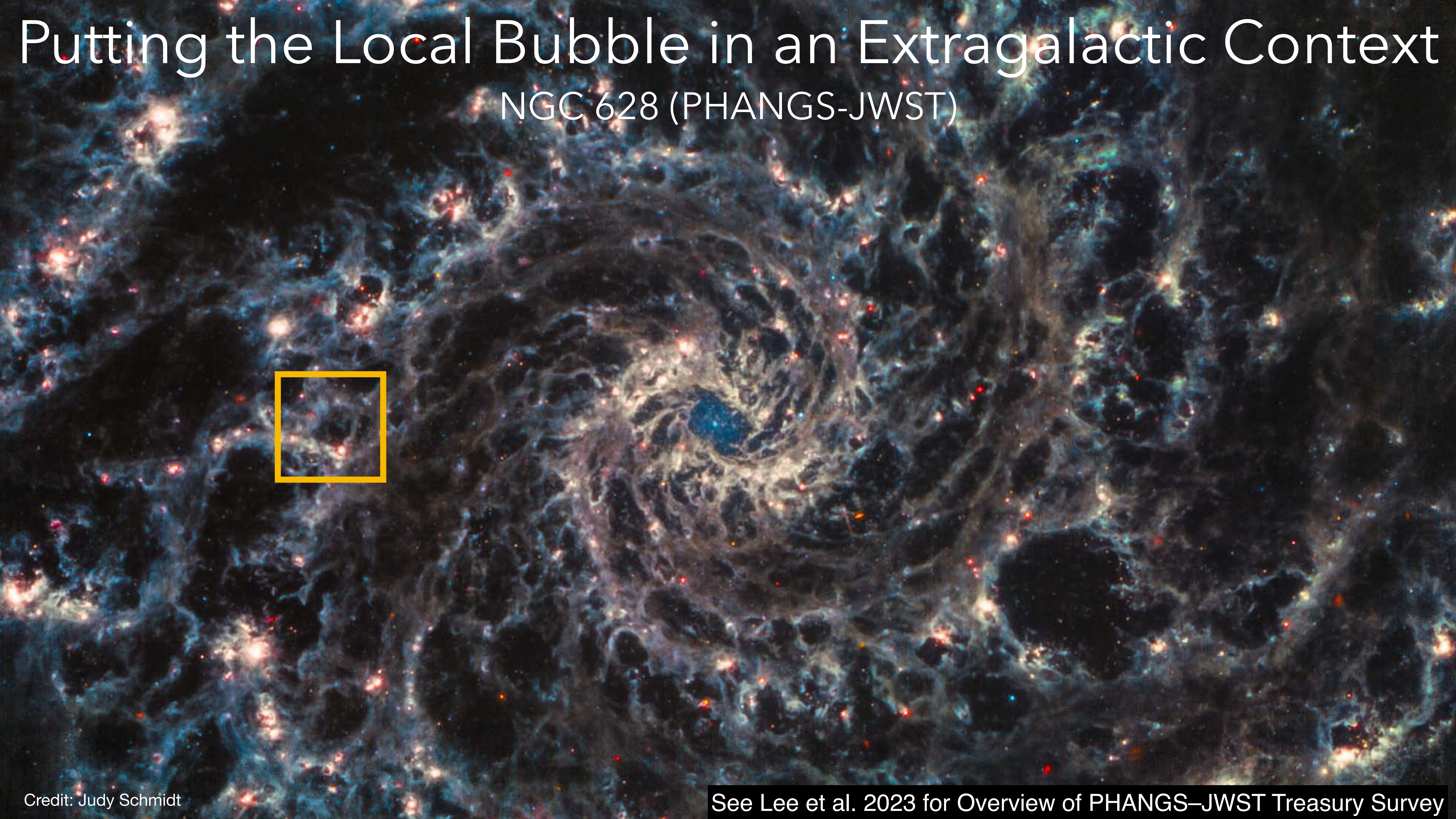
[Fuchs et al. 2006, Breitschwerdt et al. 2016, Maiz-Apellaniz 2001]



Inutsuka et al. 2015

Present

Dense gas & young stars envelope Local Bubble



# Putting the Local Bubble in an Extragalactic Context

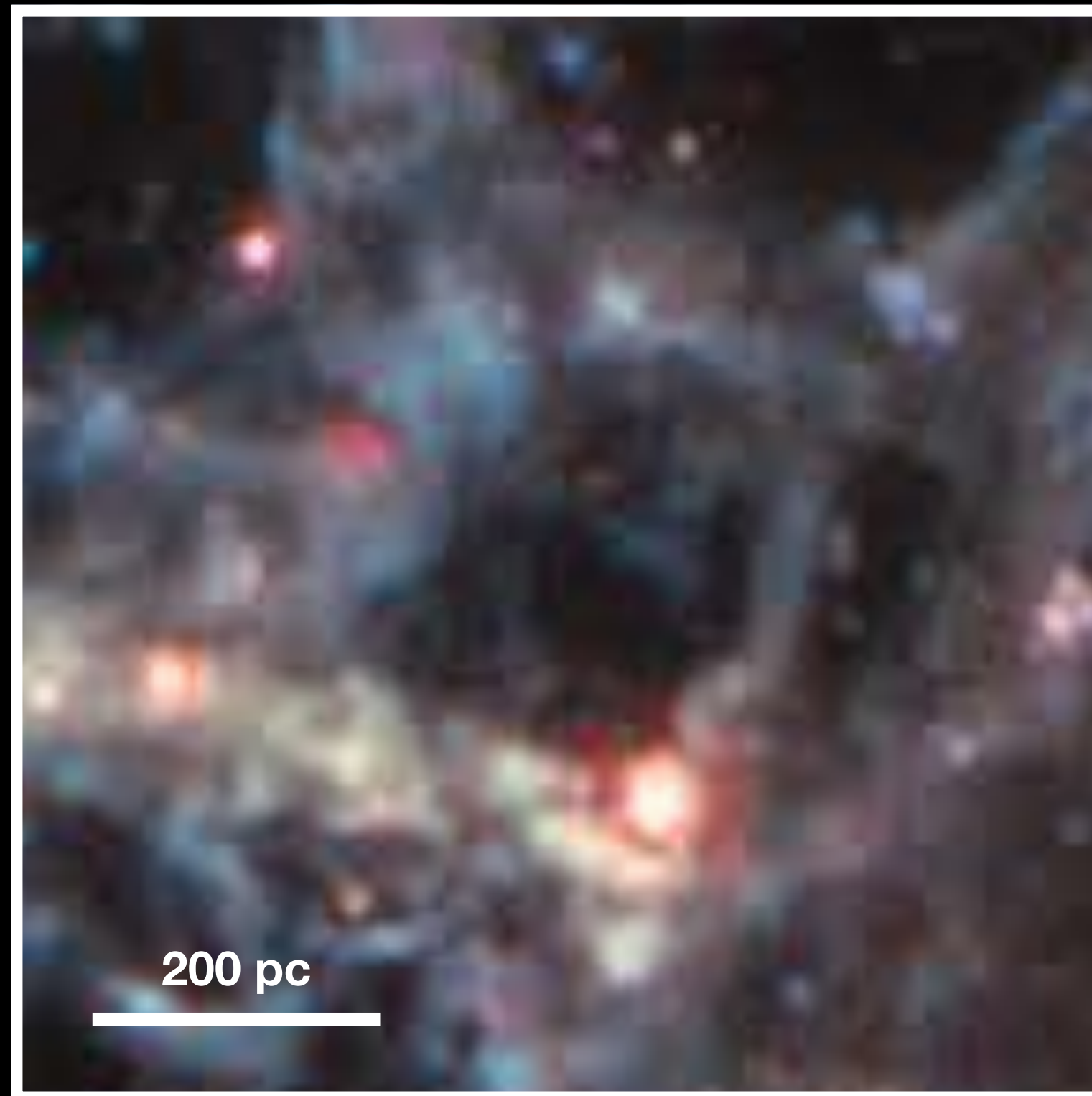
NGC 628 (PHANGS-JWST)



# Putting the Local MW in an Extragalactic Context

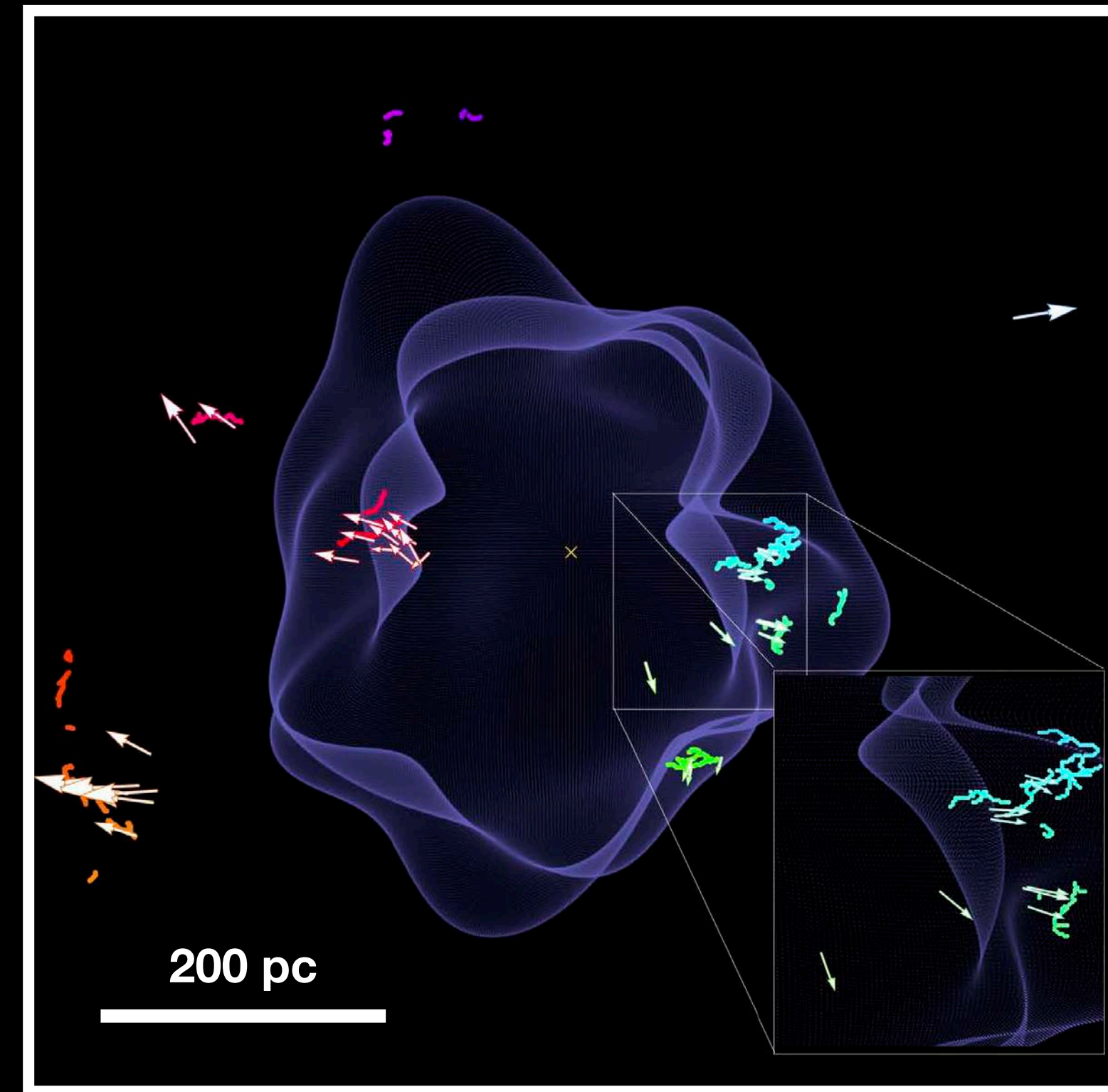
## NGC 628 (PHANGS-JWST)

Local Bubble Analog (M74)



Statistical view of star formation from external galaxies

Local Bubble



“6D” spatial-dynamical view of star formation from solar neighborhood



# Acrónimos!

## Qué esperar leyendo literatura de formación planetaria y estelar

- ALMA: Atacama Large (sub)millimeter Array
- VLT: Very Large Telescope
- SED: Spectral Energy Distribution
- ISM: Interstellar Medium
- GMC: Giant Molecular Cloud
- YSO: Young Stellar Object
- TTS: T Tauri Star
- WTTS: Weakly-lined T Tauri Star
- CTTS: Classical T Tour Star
- HAeBe: Herbig Ae Be star
- PMS: Pre-Main Sequence
- ZAMS: Zero Age Main Sequence
- HH: Herbig-Haro object