How do young stars leave home?

And why might that matter?

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And why might that matter?

an "agent-based" view for a star

effects on planetary habitability

details of feedback

bigger questions of "mixing" over space-time

effects on planetary habitability

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CrossMark

The Passage of the Solar System through the Edge of the Local Bubble

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Abstract

The Sun moves through the interstellar medium (ISM) at a velocity of $\sim$19 pc Myr^{-1}, making the conditions outside the solar system vary with time over millions of years. Today's solar system is protected from interstellar particles by the heliosphere, the bubble formed by the solar wind as the Sun moves through the ISM, which engulfs the planets. There is geological evidence from ^{60}Fe that Earth was in direct contact with the ISM 2–3 and 5–7 million years ago (MYA). Recent work argues that the Sun encountered a massive cold cloud 2 MYA as part of the Local Ribbon of Cold Clouds that shrunk the heliosphere and exposed Earth to the ISM. Here, we consider the effects of the passage of the Sun through the edge of the Local Bubble occurring at $6.8^{+0.5}_{-0.4}$ MYA assuming that the Sun encountered a cloud with a density of 900 cm^{-3}. If we consider additional turbulent motion within the cloud due to shocks, the density encountered can be as low as 283 cm^{-3}. Clouds of this density cover a small but nonzero ($\lesssim$4.6%) fraction of the surface of the Local Bubble, making an encounter plausible. Using a state-of-the art magnetohydrodynamic model, we show that the heliosphere shrank to a scale smaller than Earth's orbit, thereby exposing Earth to cold dense ISM, consistent with ^{60}Fe evidence. The timing of the event matches perturbations observed in the paleoclimate record recovered from deep-sea sediments. The passage through the Local Bubble's surface and contraction of the heliosphere therefore may have impacted the climate and biosphere significantly, suggesting a new driver of major events in Earth's history.

Unified Astronomy Thesaurus concepts: Solar wind (1534); Heliopause (707); Astrospheres (107); Interstellar medium (847); Magnetohydrodynamics (1964); Interstellar medium wind (848); Stellar winds (1636)

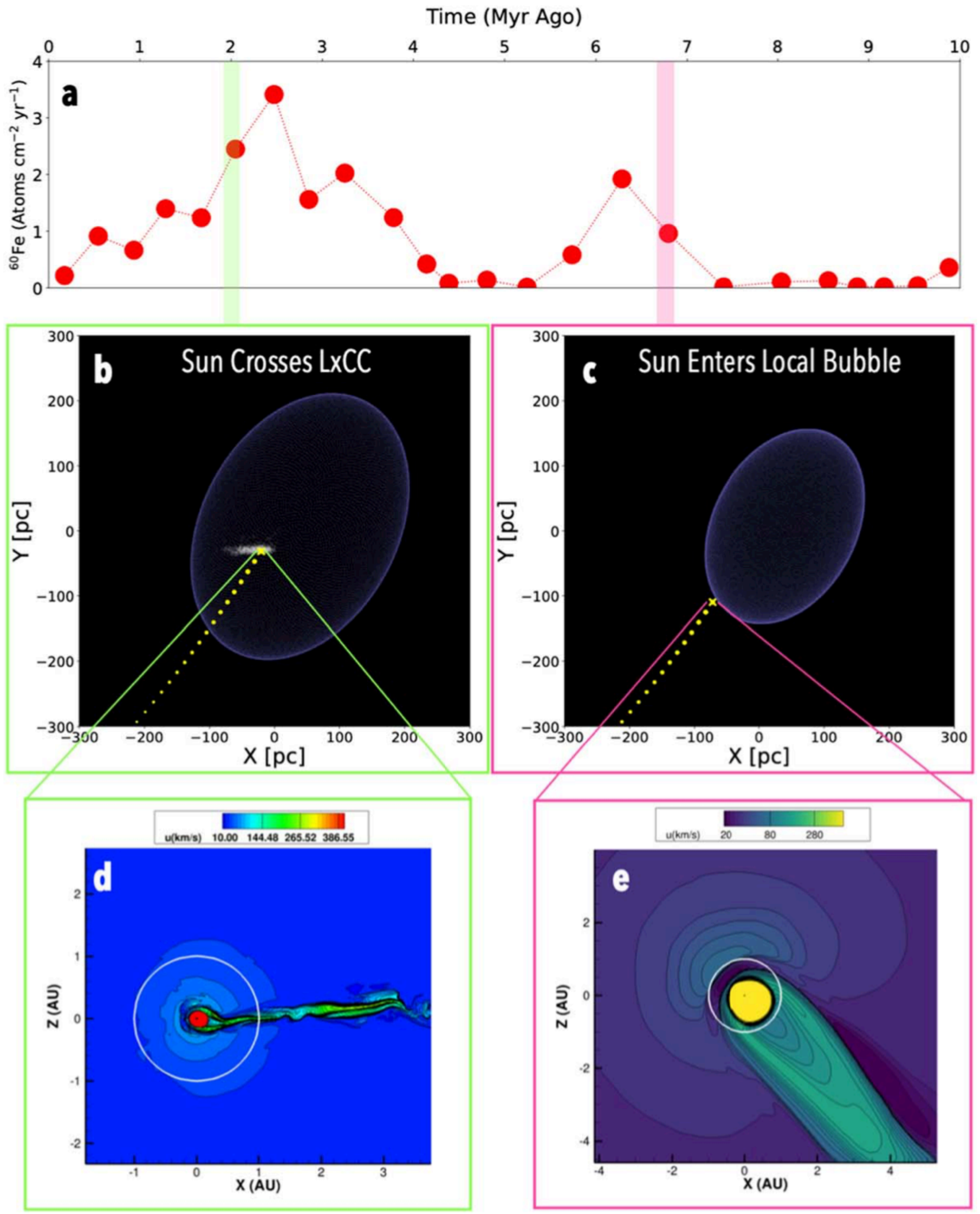
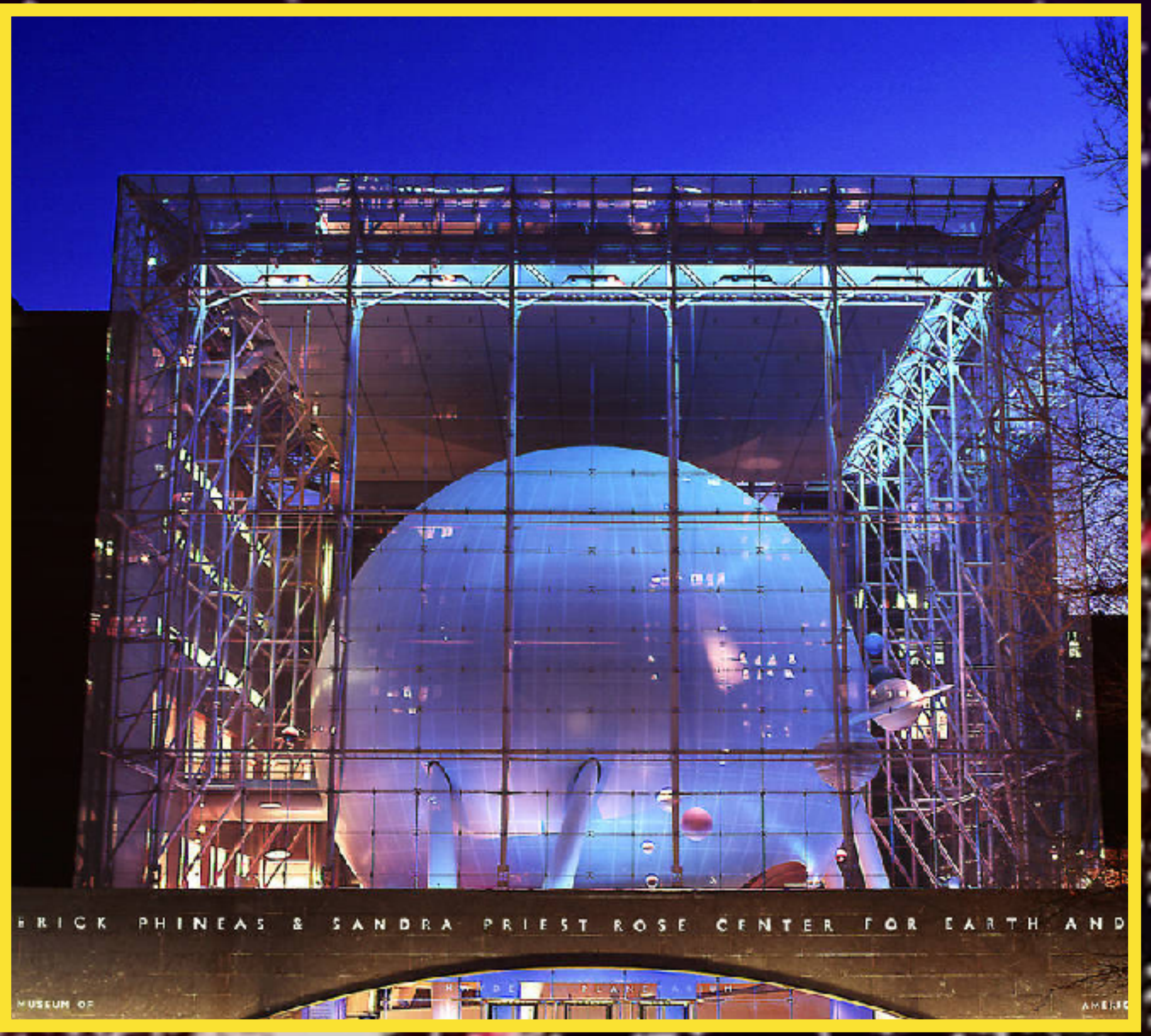


Figure 4. Evolution of the Sun and the dense ISM at two time snapshots occurring 2 MYA (panel (b)) and 7 MYA (panel (c)). We run two independent MHD simulations based on the backward trajectories of two different interstellar structures (the LxCC and the Local Bubble's shell). The motion of the LxCC is exclusively discussed in Opher et al. (2024). The motion of the Local Bubble is constrained in this work, based on a modification to the original expansion described in Zucker et al. (2022). In both cases, the Sun's trajectory is determined to cross the 3D trajectory of the clouds at locations/times that may coincide with peaks in ^{60}Fe. Under this premise, we run two independent MHD simulations given assumptions about the density of the LxCC and the Local Bubble's shell and constraints on the relative velocities between the Sun and these interstellar structures. The purple surface in both panels shows an idealized model for the elliptical expansion of the Local Bubble. 7 MYA (panel (c)), the Sun entered the surface of the Local Bubble, shrinking the heliosphere to 0.7 au and exposing the Earth (white orbit) to the dense, cold ISM. Then, 2 MYA the Sun passes through the LxCC (panel (b)), shrinking the heliosphere to 0.22 au (panel (d)) and again exposing the Earth to the dense, cold ISM. The interactions between the Sun and the bubble's surface/LxCC are consistent with the ^{60}Fe records (panel (a), adapted from Figure 1 of Wallner et al. 2021), which shows two peaks at $\sim$2–3 MYA and $\sim$6–7 MYA. An interaction version of panels (b) and (c) showing the full time progression of the Sun and the idealized bubble's surface is available at https://faun.rc.fas.harvard.edu/czucker/Paper_Figures/Local_Bubble_Sun_Crossing_Opher23.html. The time sequence can be played forward or backward and has buttons to go to specific times. Links on the right can be clicked to turn various portions of the interactive figure on or off.

Seeing the Milky Way in 3D



MilkyWay3D.org

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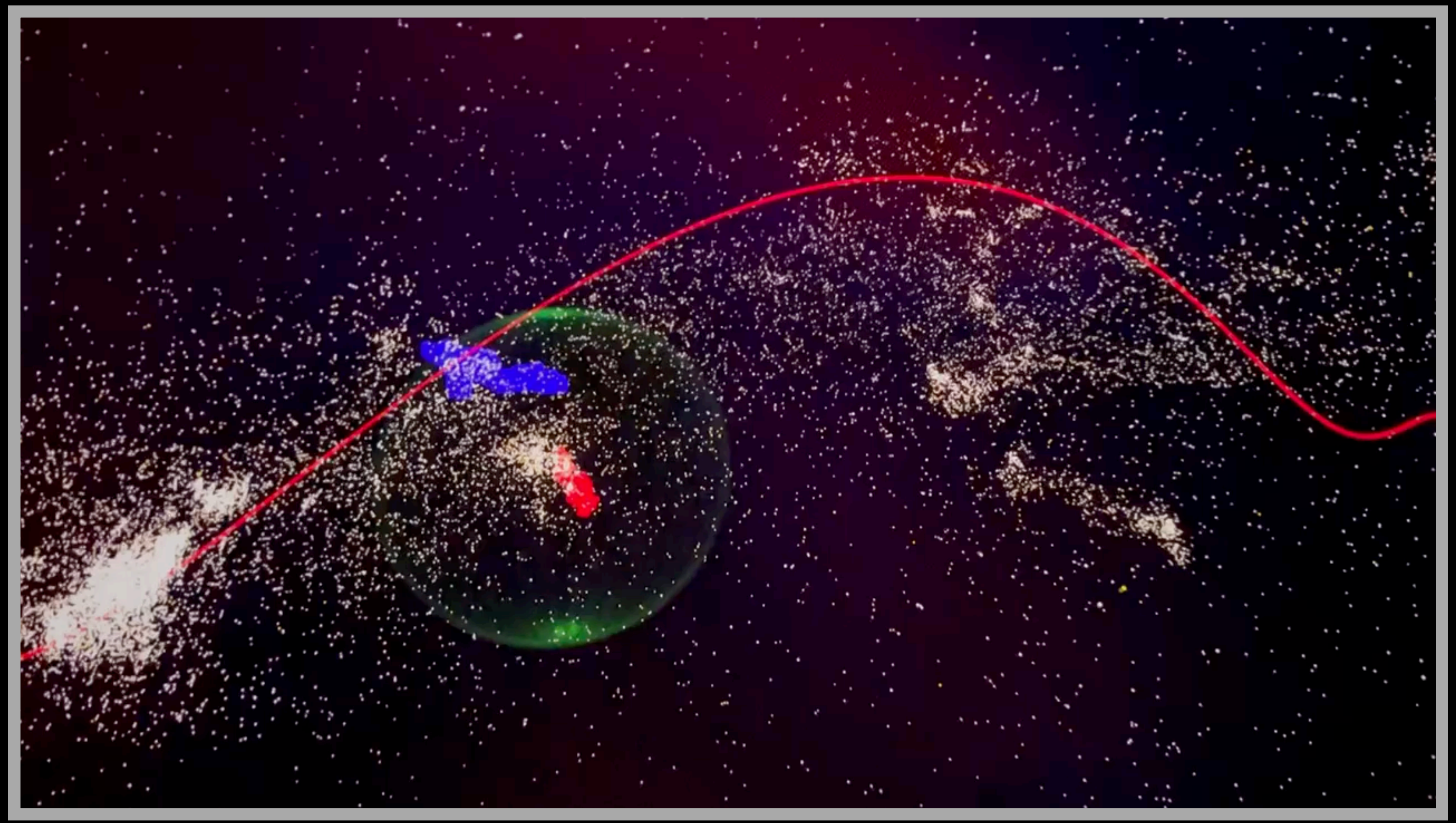
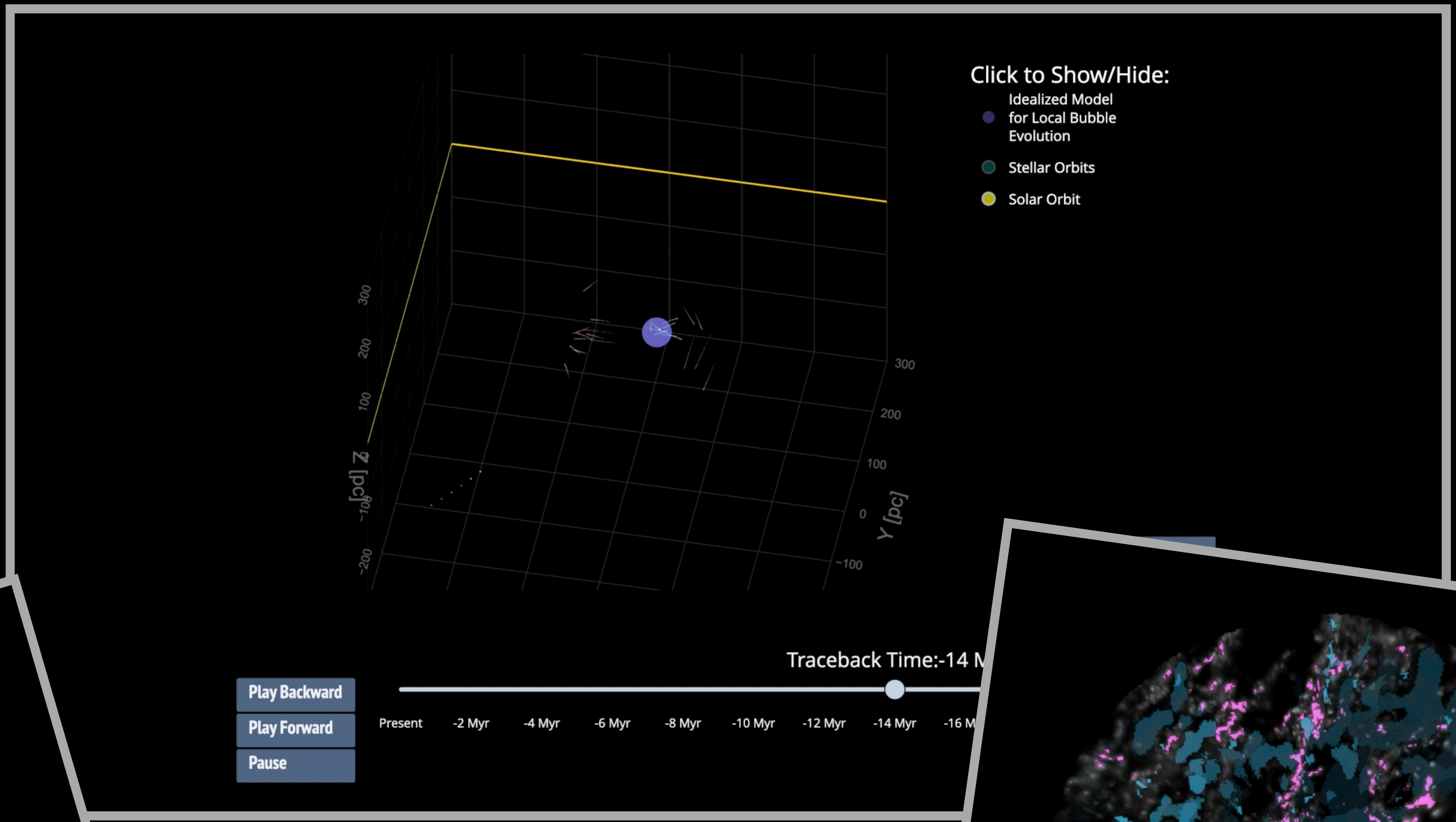
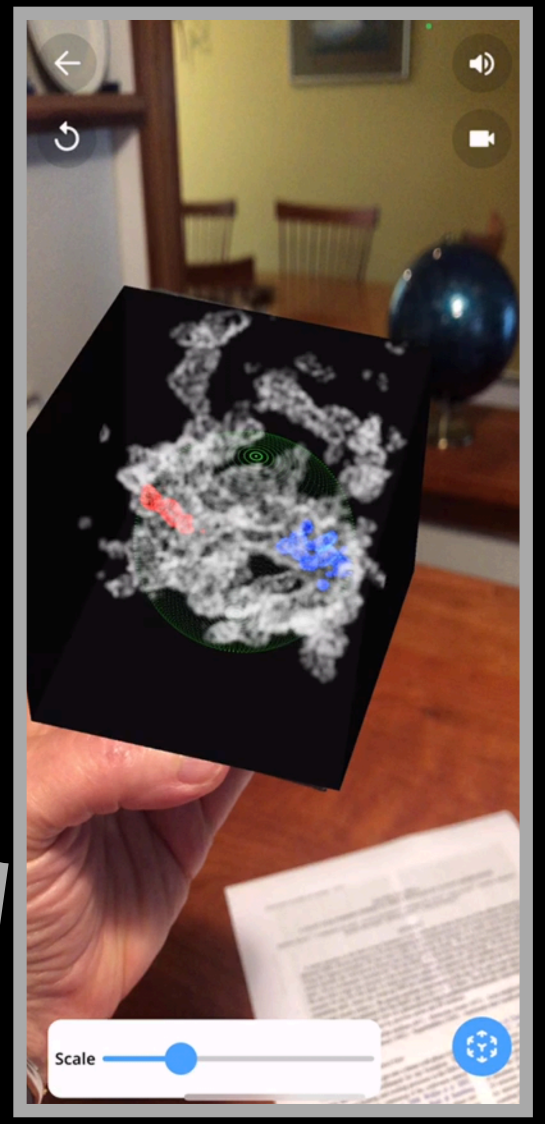
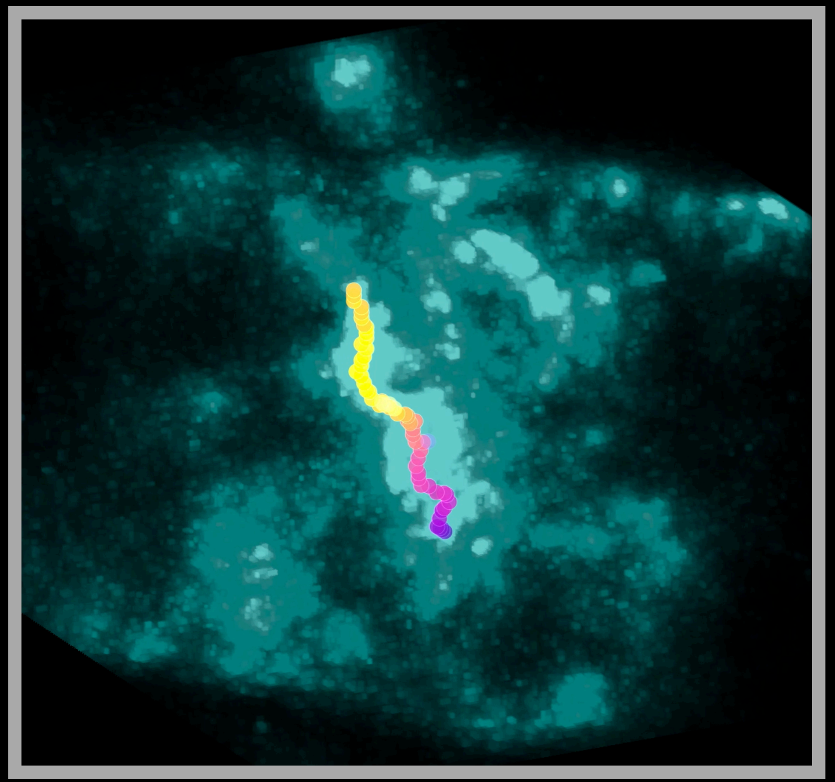
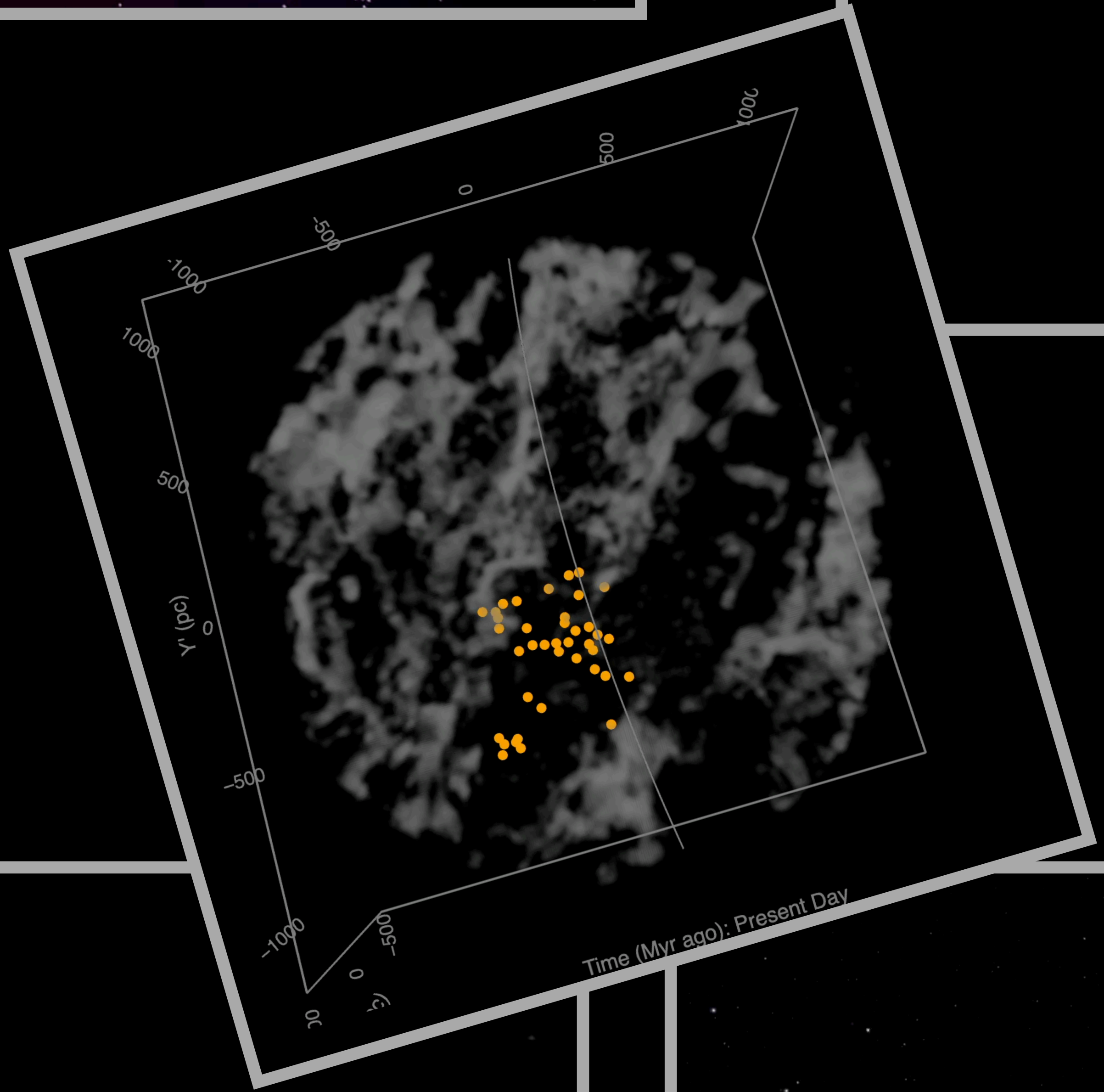
with many Collaborators!, please see MilkyWay3D.org











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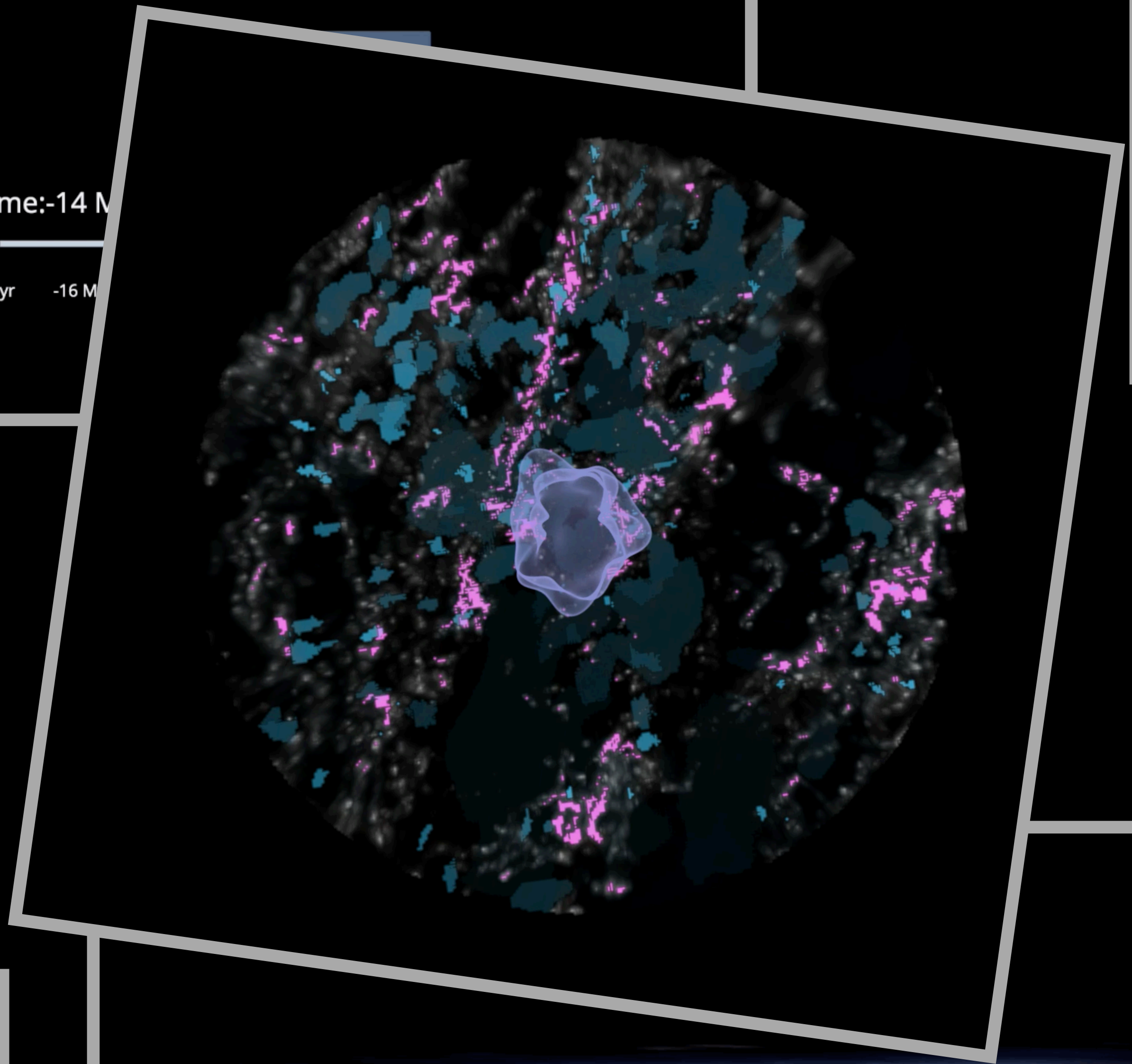
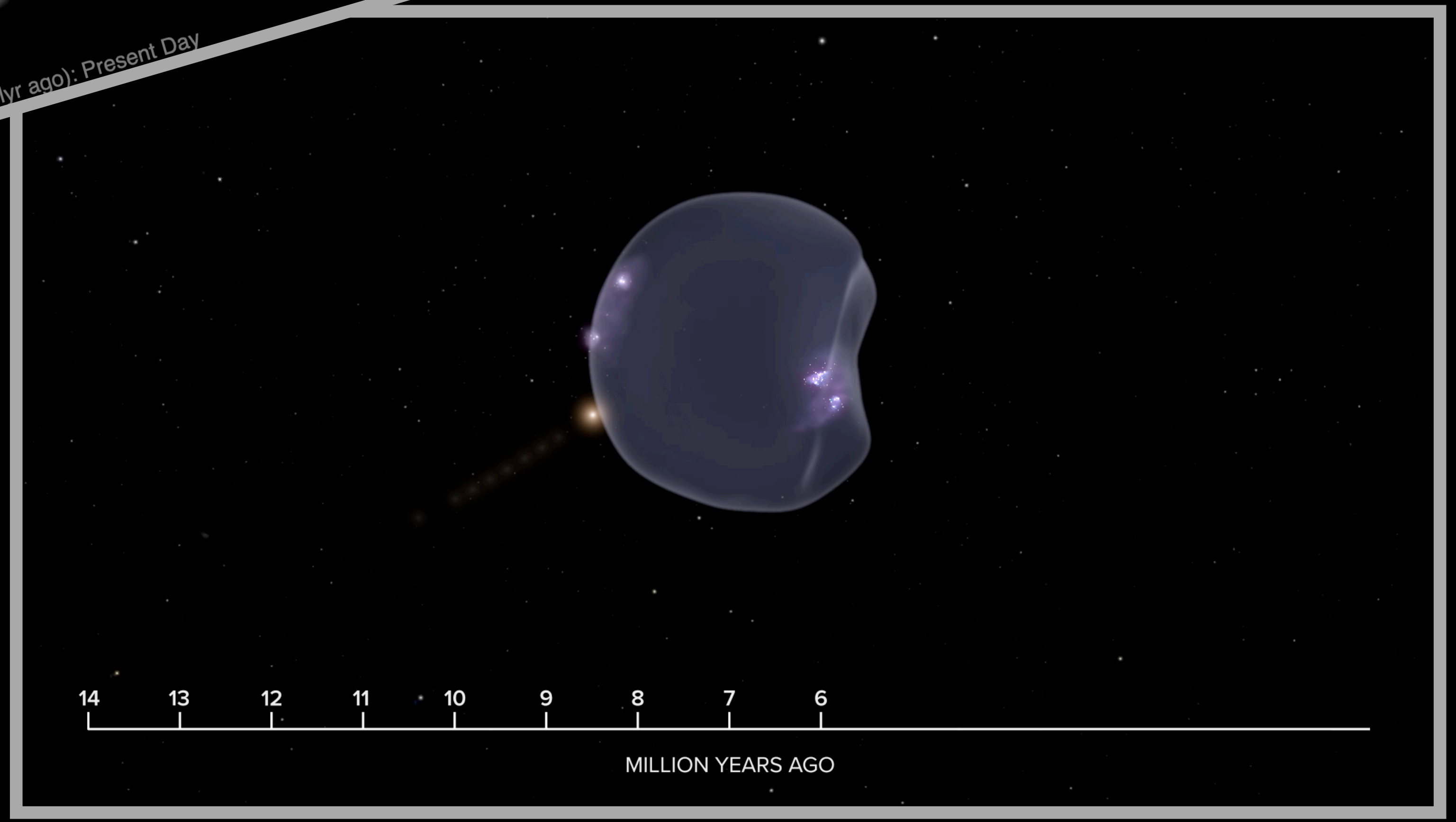
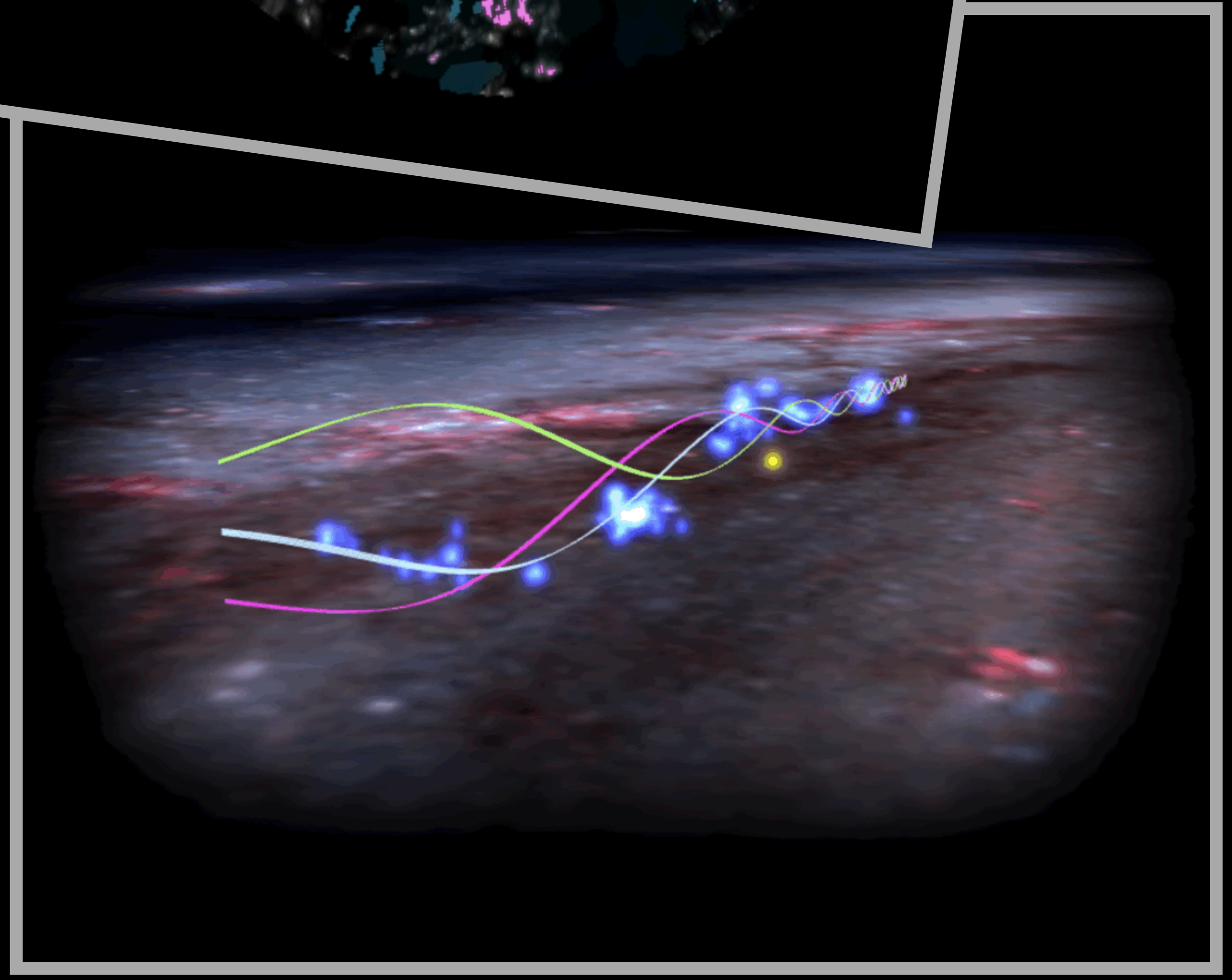
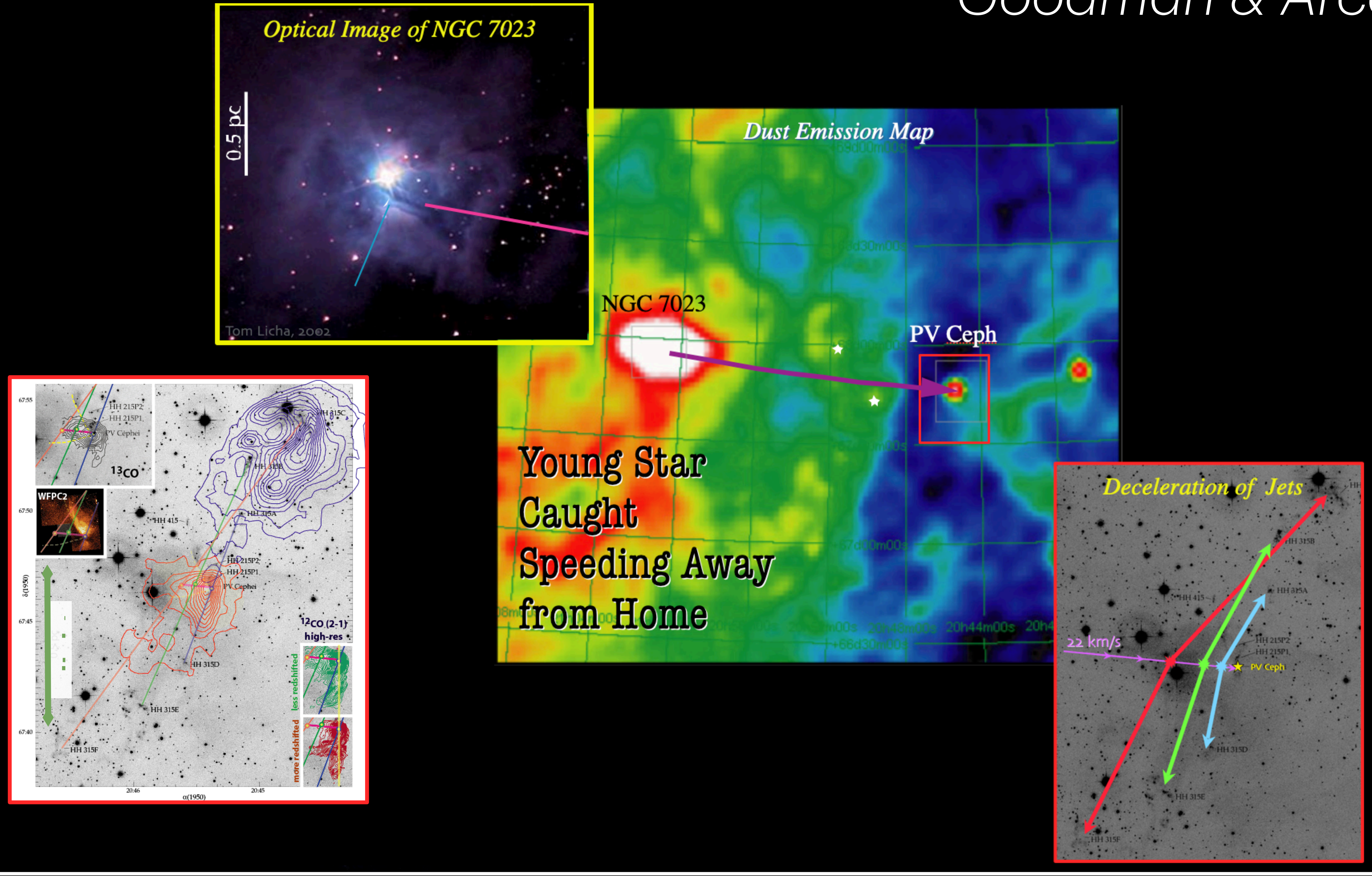






Zucker et al. 2021, Bialy et al. 2021; Zucker et al. 2022, Konietizka et al. 2024, O'Neill et al. 2024, Swiggum et al. 2024

Goodman & Arce 2004



Sun et al. 2025

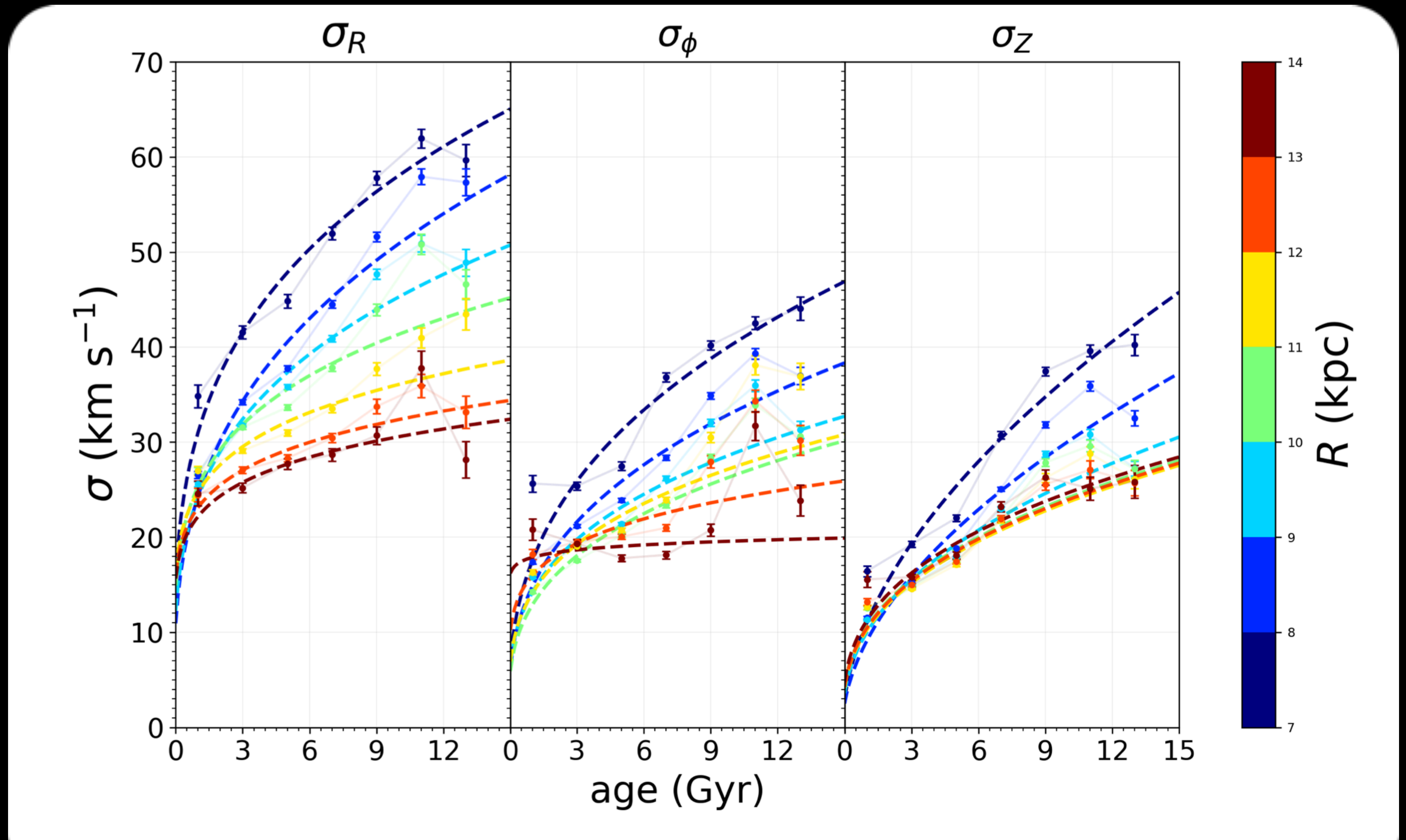
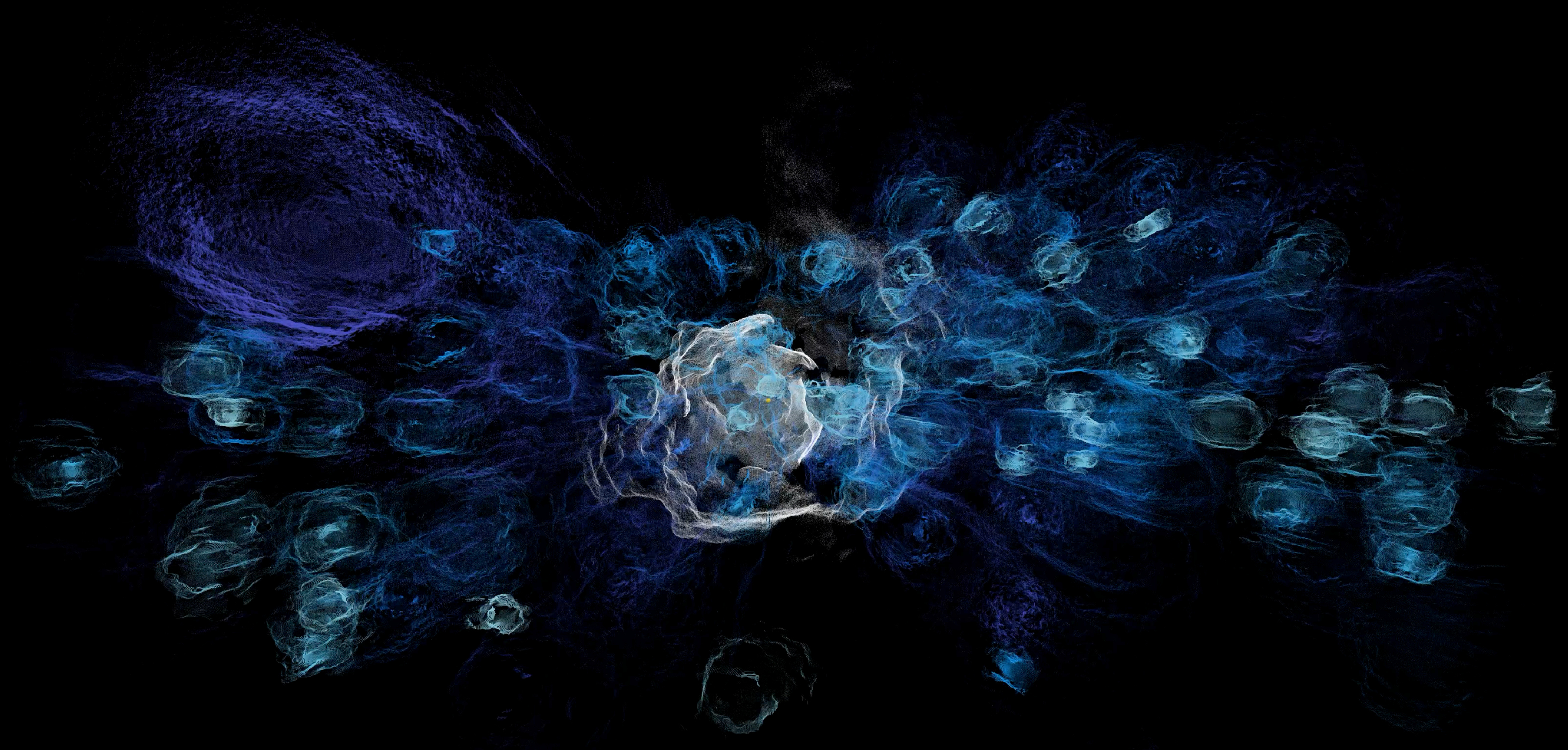
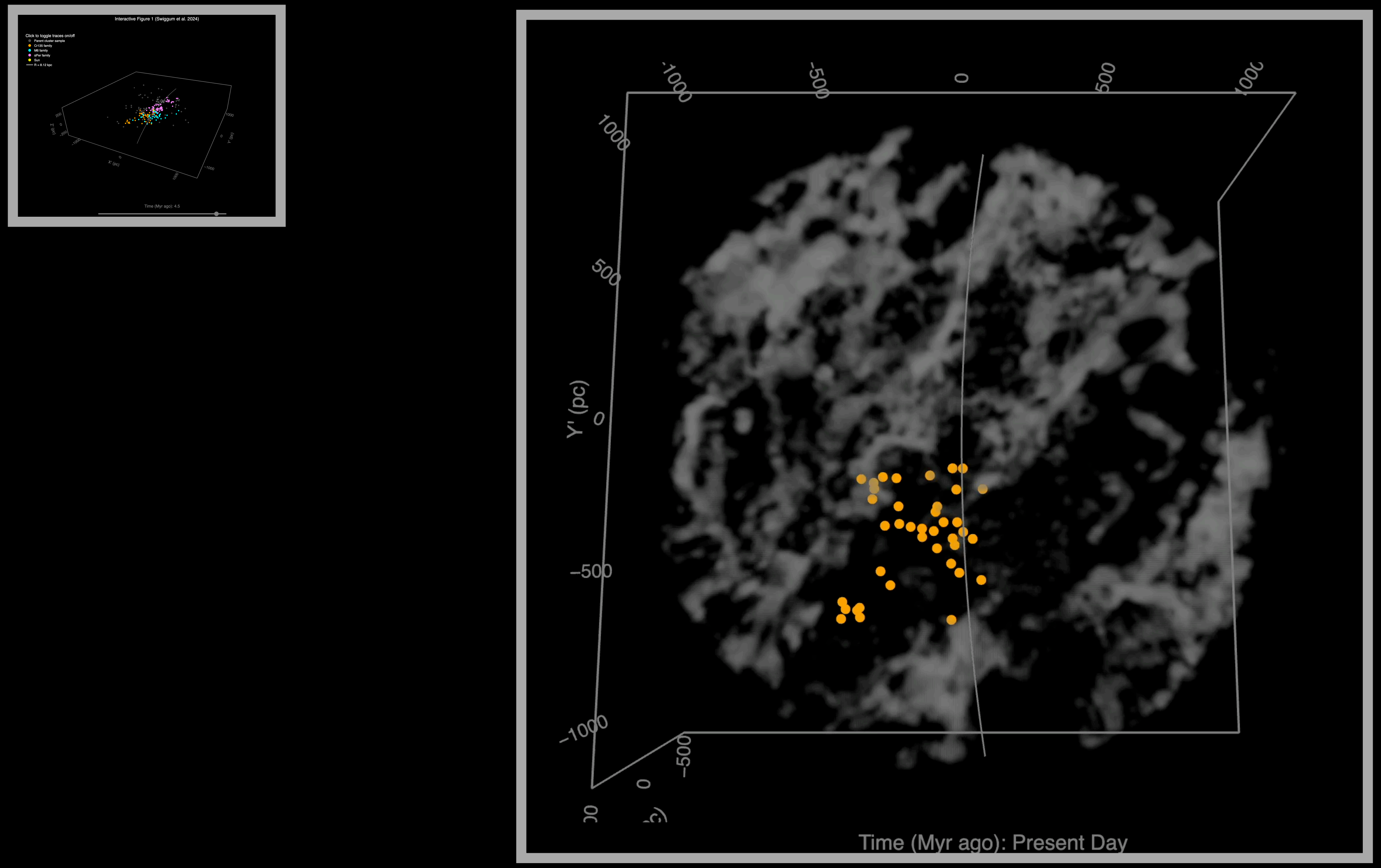


Figure 2. The AVRs of the whole RC sample stars at different R bins, color-coded by mean R. From left to right represent respectively the AVR of σ_R, σ_ϕ an σ_Z. The dashed lines represent the best fit with equation (1) for various R bins.

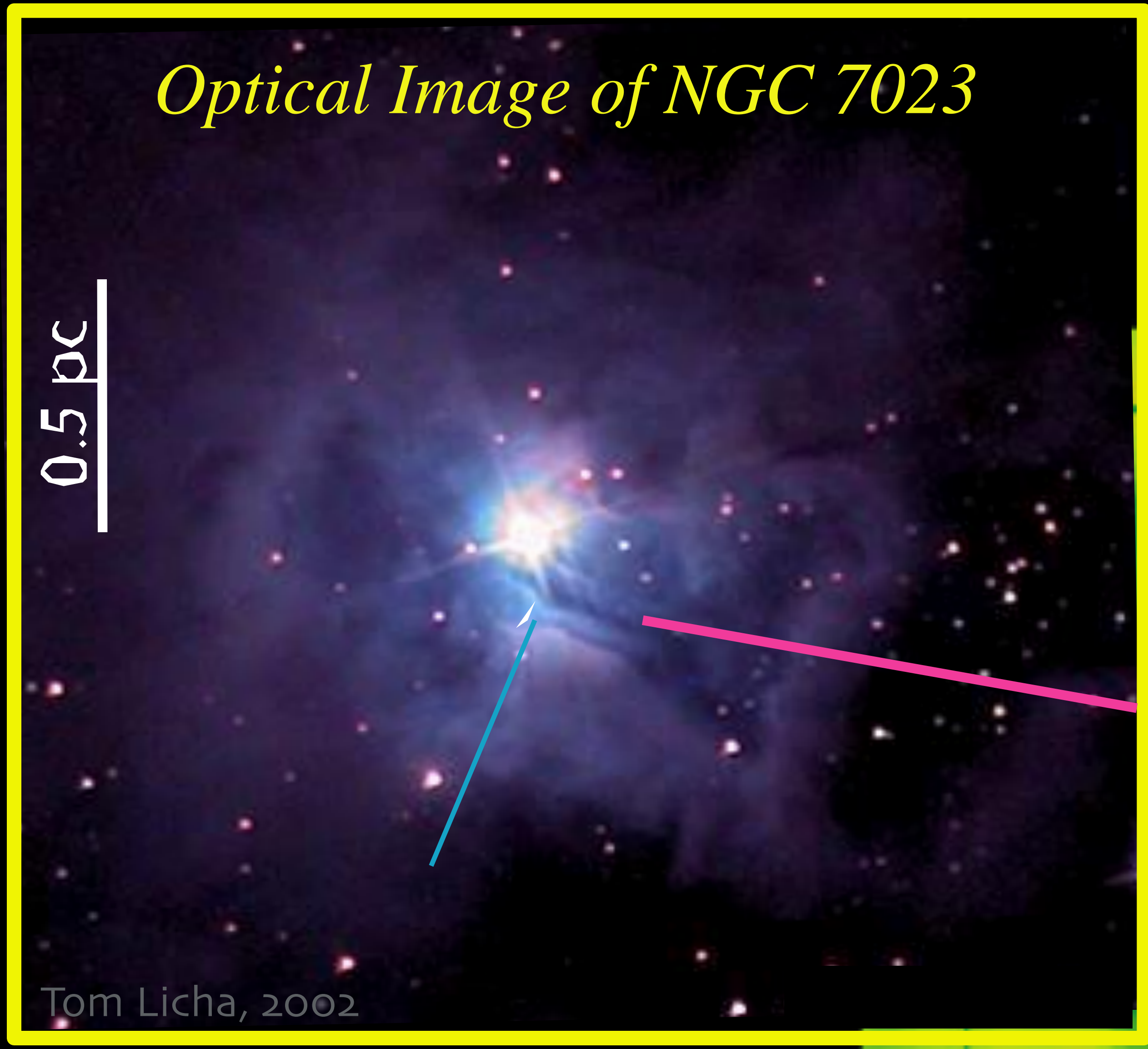


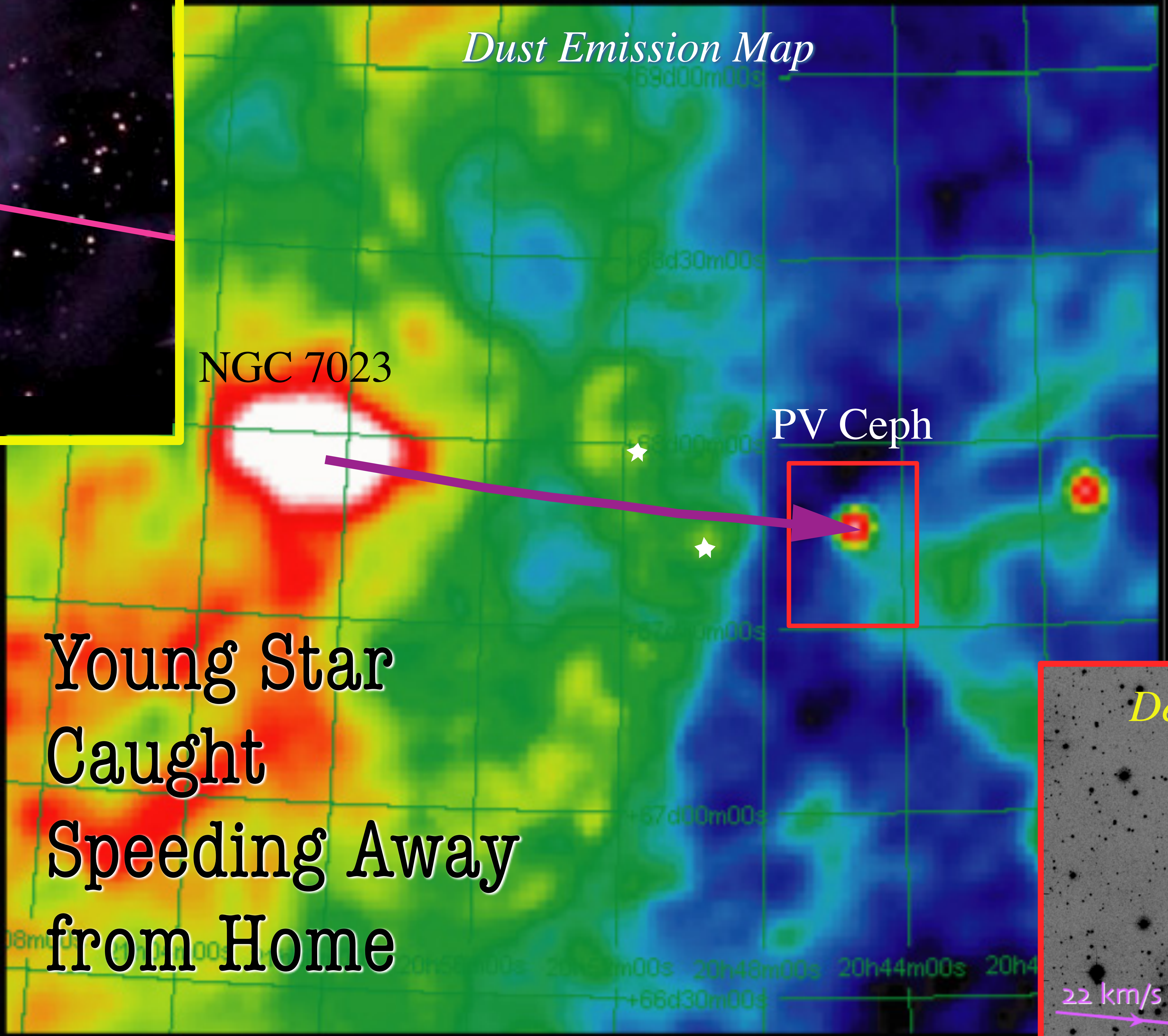
O'Neill et al. 2025



Swiggum et al. 2024

Young Star moving High Speed





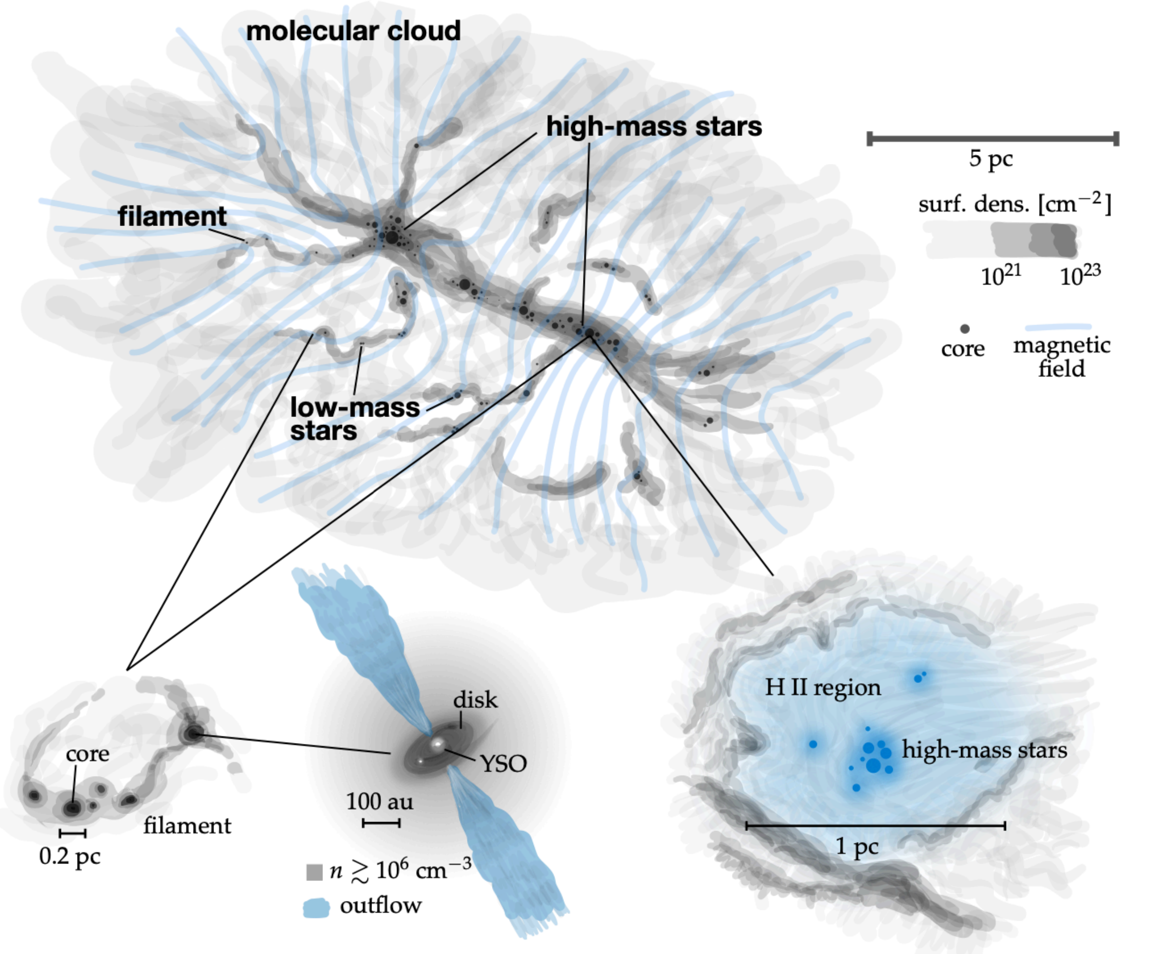
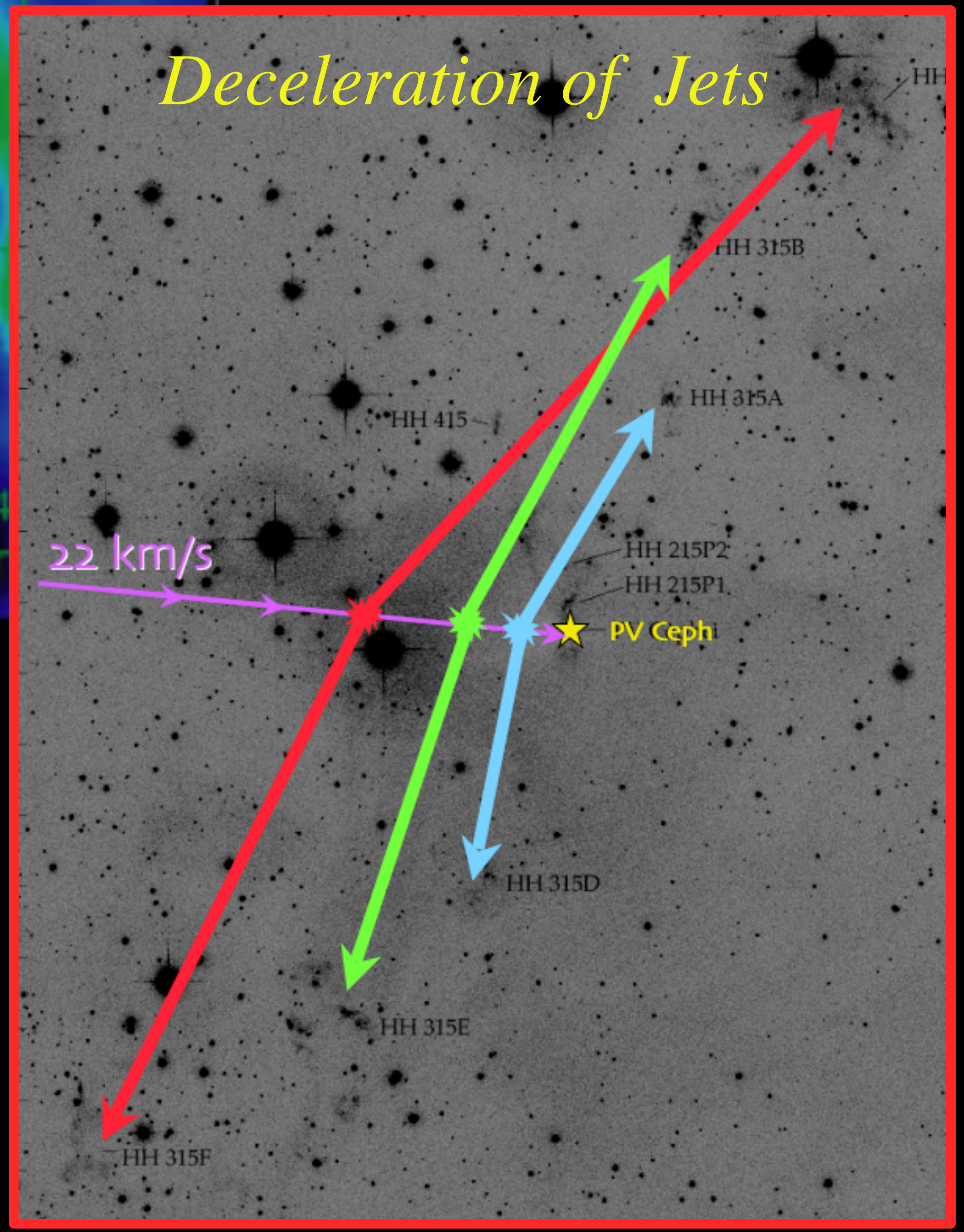


Figure 6

Sketch of a star formation complex encompassing low- and high-mass star formation. While the top-part presents a large, magnetized filamentary cloud with low- and high-mass star formation occurring in different density regimes, the insets in the bottom part outline sub-aspects. While cores, disks and jets can be found in low- and high-mass regions, the feedback processes exclusively stem from high-mass stars. The figure is inspired by observational and numerical data from Grudić et al. (2022b), Soler et al. (2019), Traficante et al. (2023), Oliva & Kuiper (2023b), and a Hubble image of Orion (credit: NASA, C.R. O'Dell and S.K. Wong). The entire figure is created by André Oliva.

Beuther, Kuiper & Tafalla 2025

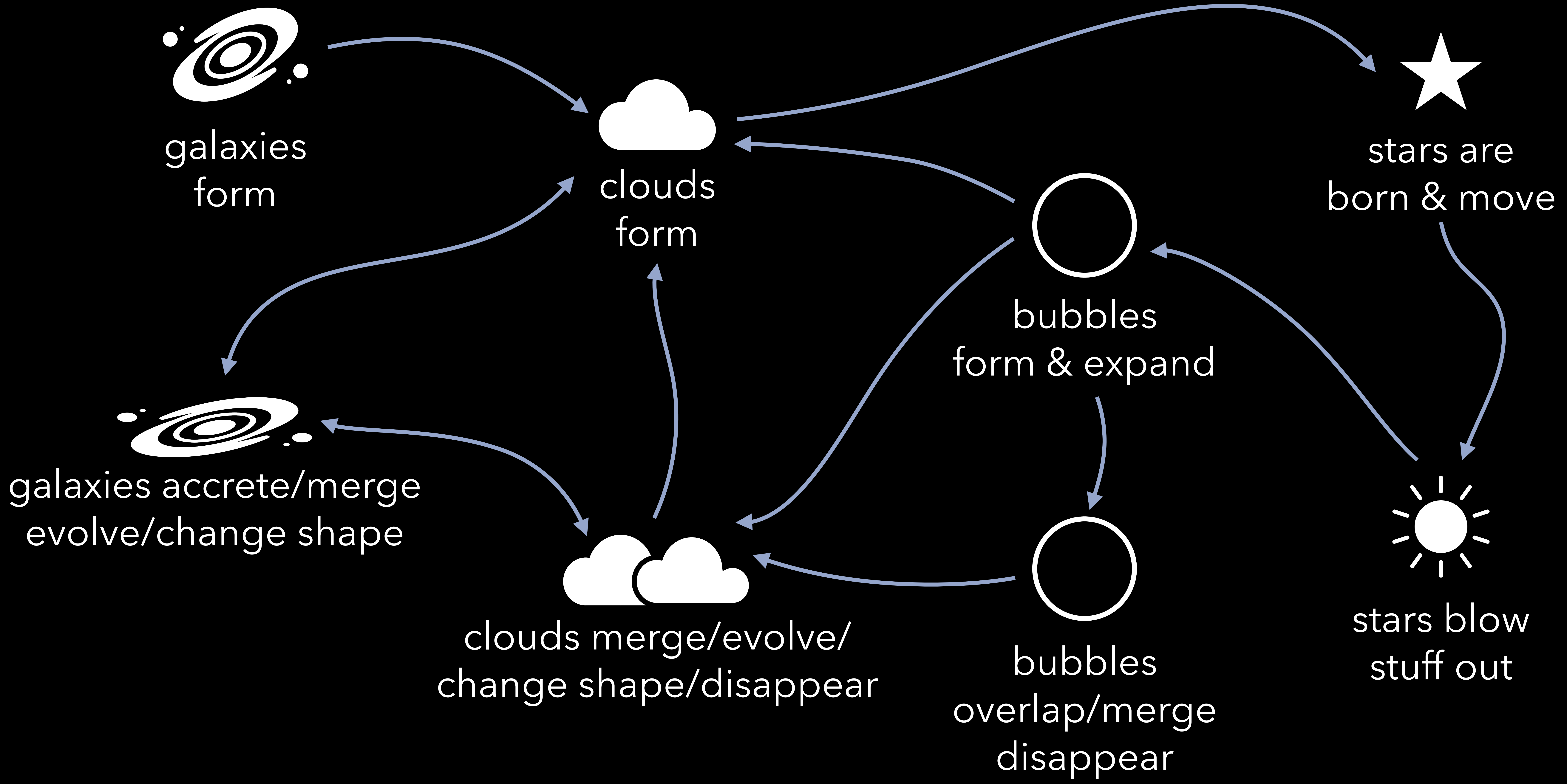


Speed=22 km/s

Age=0.5 million years

Goodman & Arce 2004

"Everything, Everywhere, All at Once"



"Everything, Everywhere, All at Once"

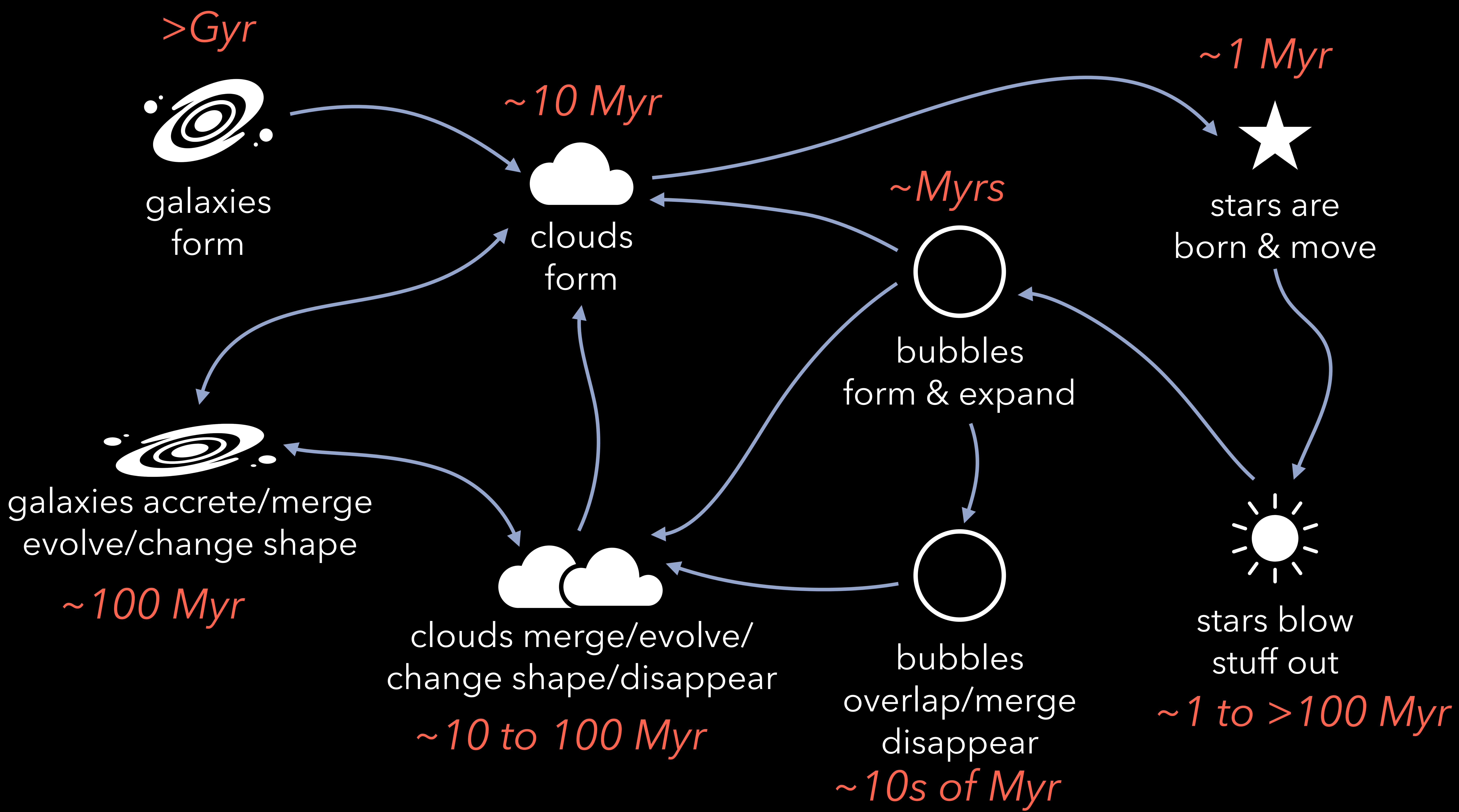
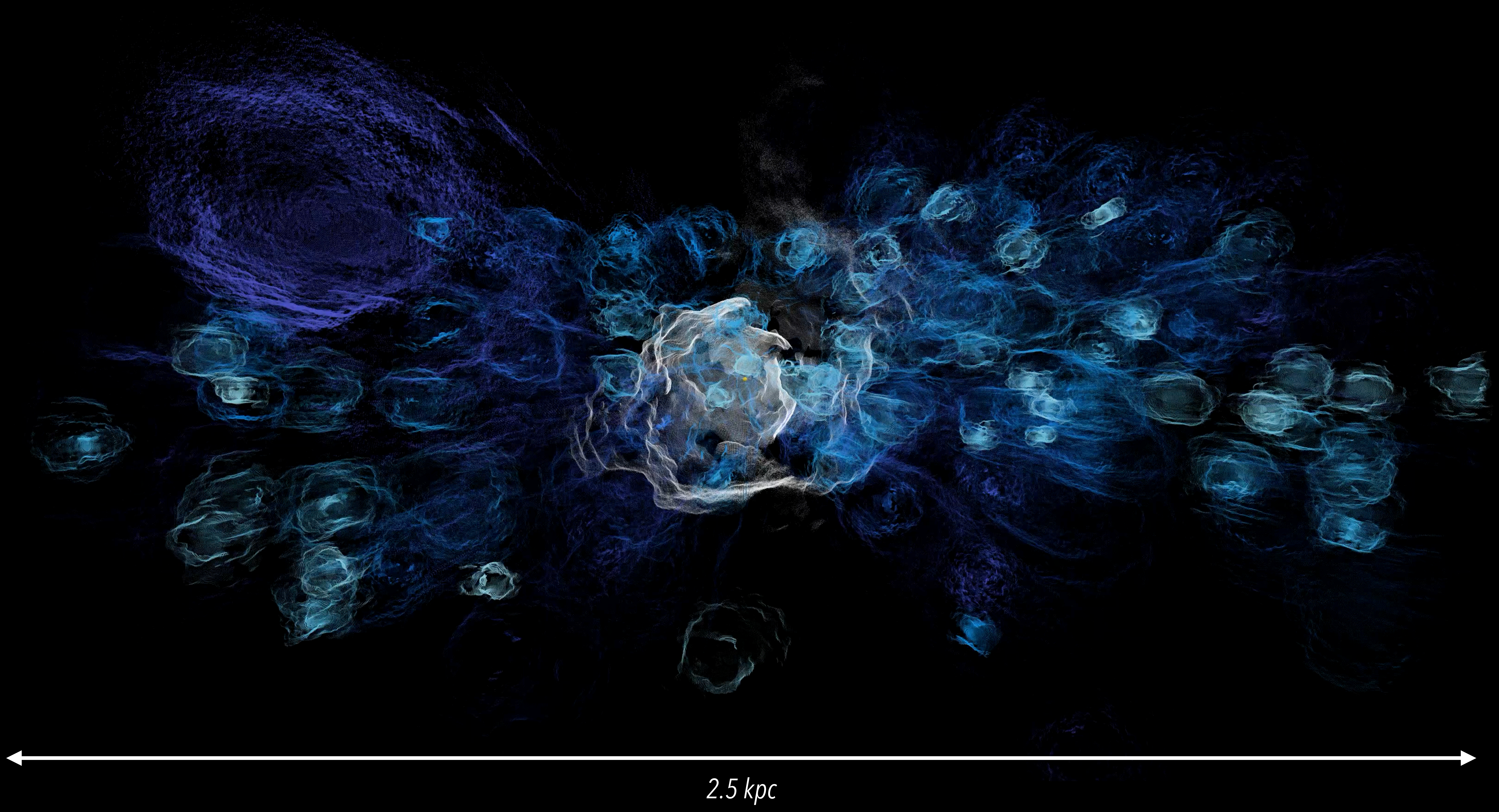
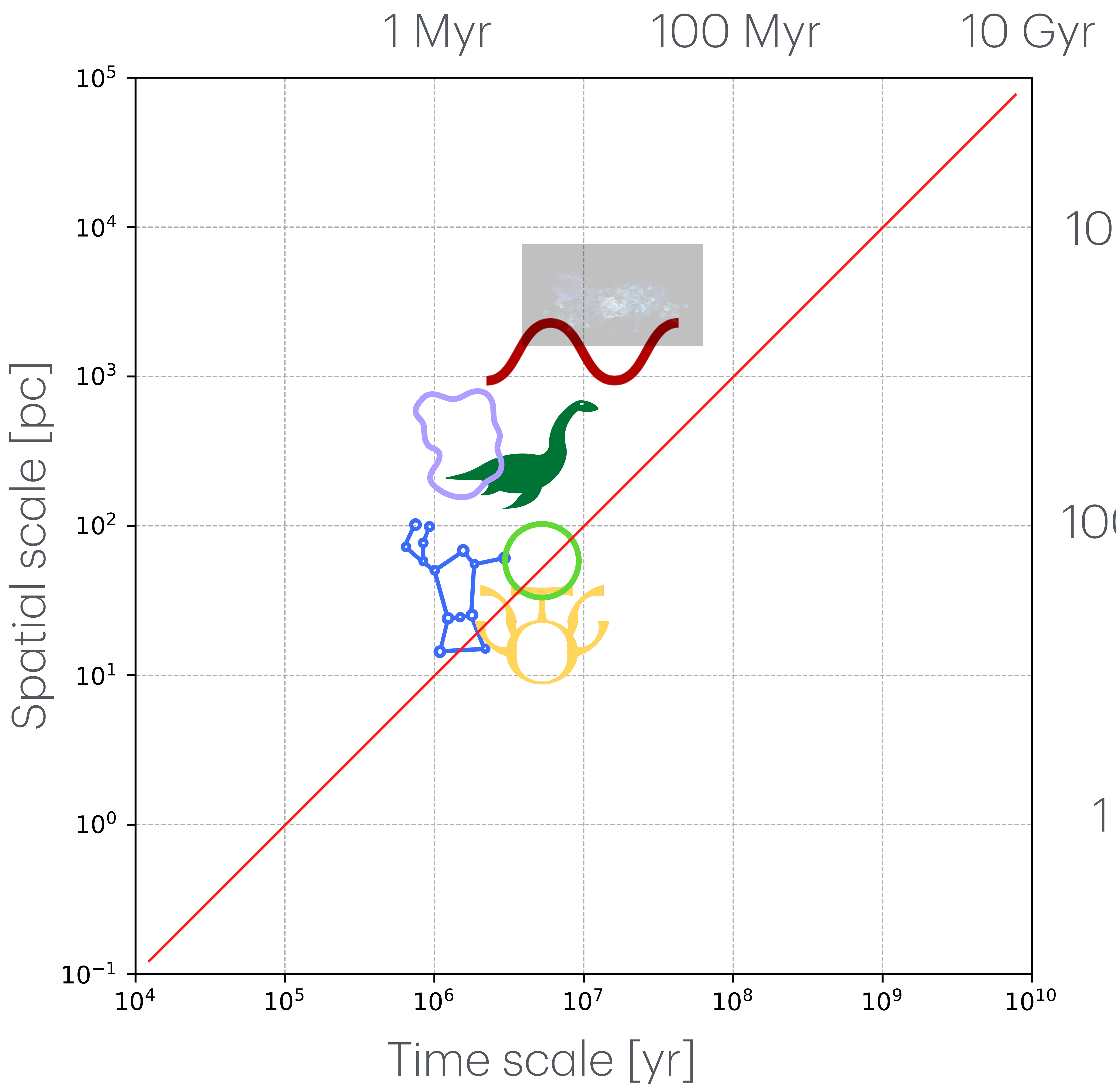
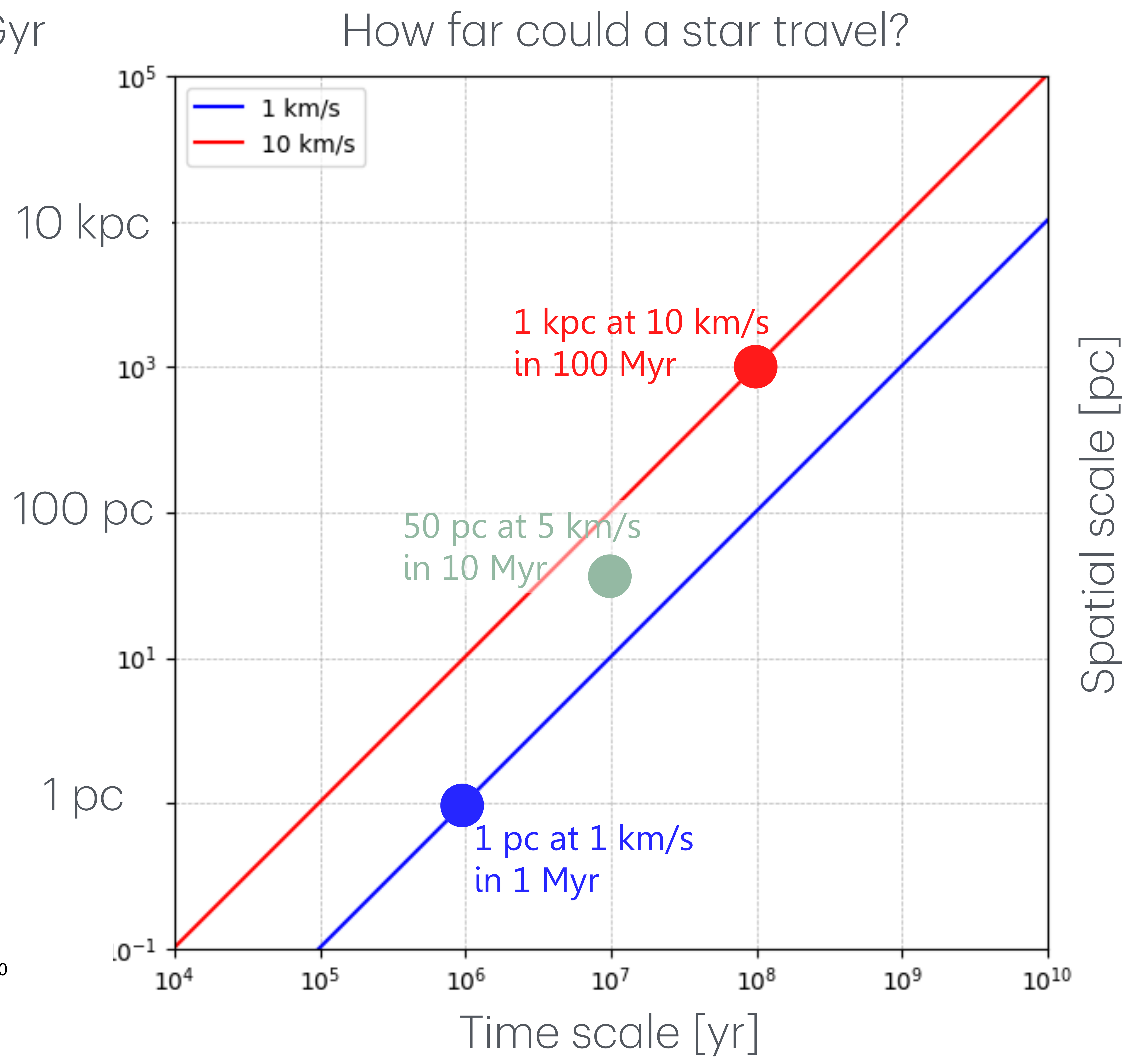


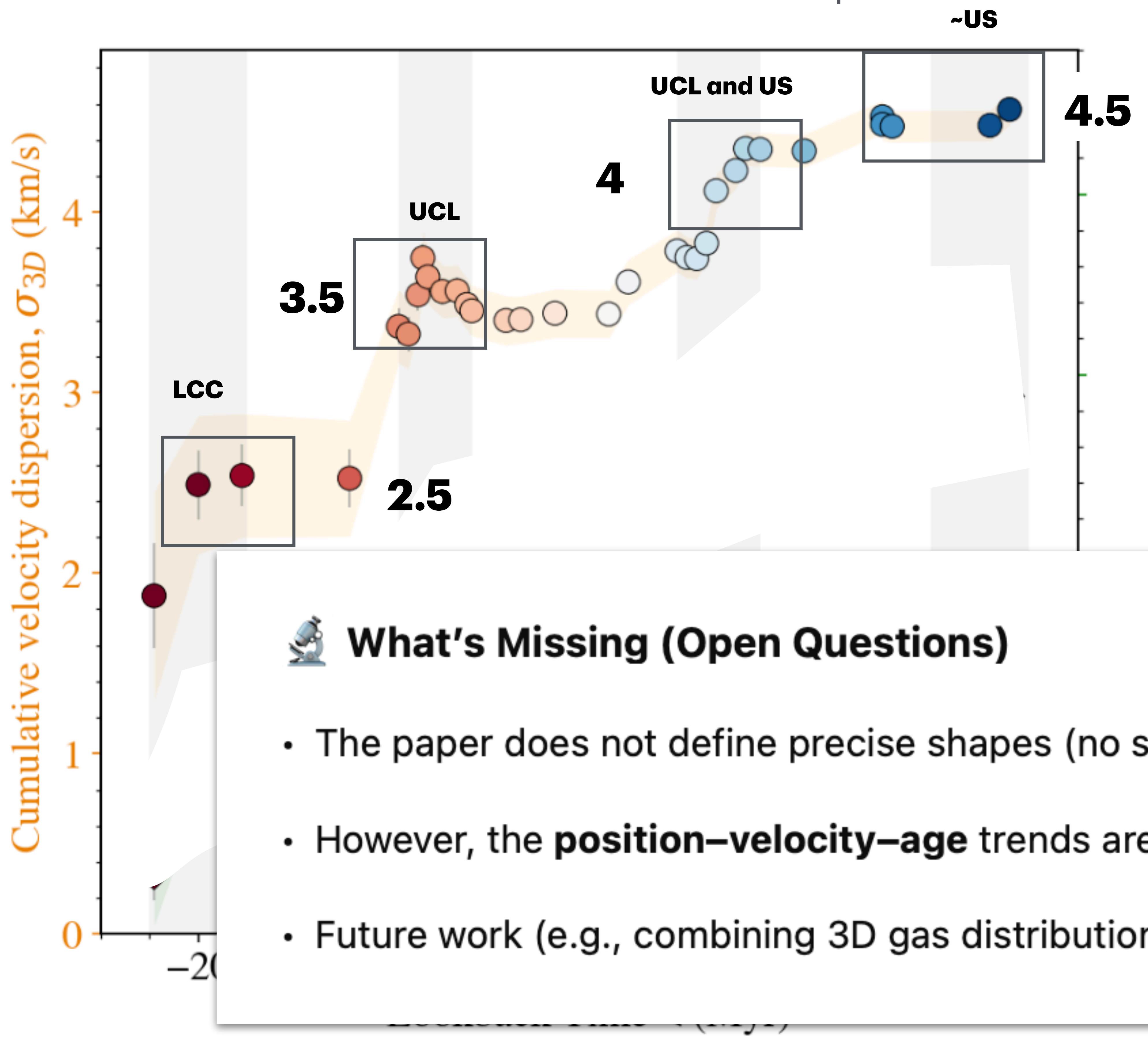
figure courtesy of Theo ***O'Neill***

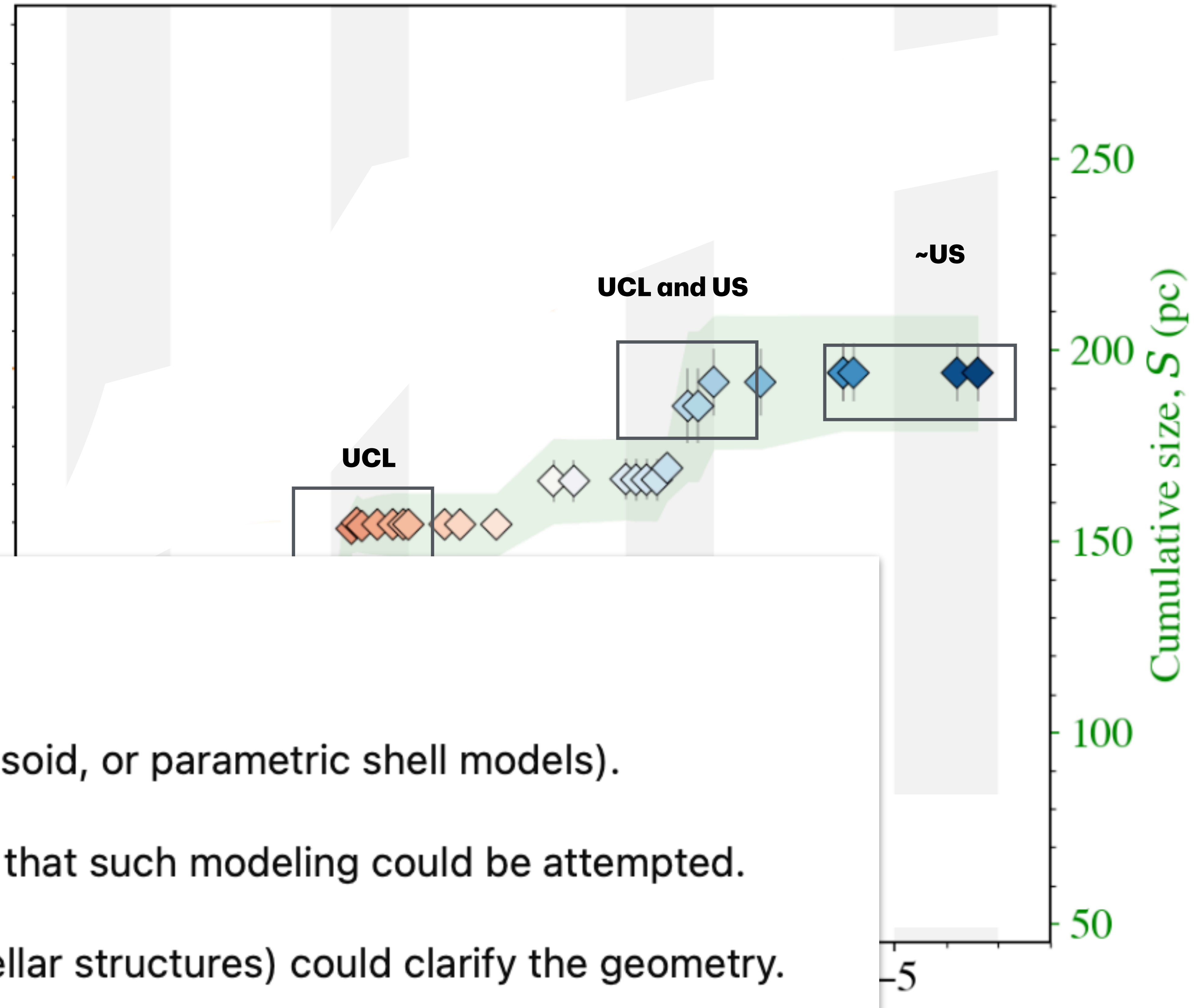



1 Myr
100 Myr
10 Gyr
Spatial scale [pc]
Time scale [yr]


How far could a star travel?
1 km/s
10 km/s
10 kpc
100 pc
1 pc
1 kpc at 10 km/s
in 100 Myr
50 pc at 5 km/s
in 10 Myr
1 pc at 1 km/s
in 1 Myr
Spatial scale [pc]
Time scale [yr]

discrete episodes of feedback-driven cluster formation





🔬 What's Missing (Open Questions)

- The paper does not define precise shapes (no spherical fit, ellipsoid, or parametric shell models).
- However, the **position–velocity–age** trends are strong enough that such modeling could be attempted.
- Future work (e.g., combining 3D gas distributions with these stellar structures) could clarify the geometry.

Fig. 1. Temporal evolution of the cumulative 3D velocity dispersion (σ_{3D}, orange, left axis) and cumulative spatial extent (S, green, right axis) for Sco-Cen over the last 20 Myr. The four vertical gray bars indicate the four main star formation events in Sco-Cen, as discussed in R23b. The orange and green shaded regions show the 2σ uncertainty ranges of the two trends.

Fig. 1. Temporal evolution of the cumulative 3D velocity dispersion (σ_{3D}, orange, left axis) and cumulative spatial extent (S, green, right axis) for Sco-Cen over the last 20 Myr. The four vertical gray bars indicate the four main star formation events in Sco-Cen, as discussed in R23b. The orange and green shaded regions show the 2σ uncertainty ranges of the two trends.

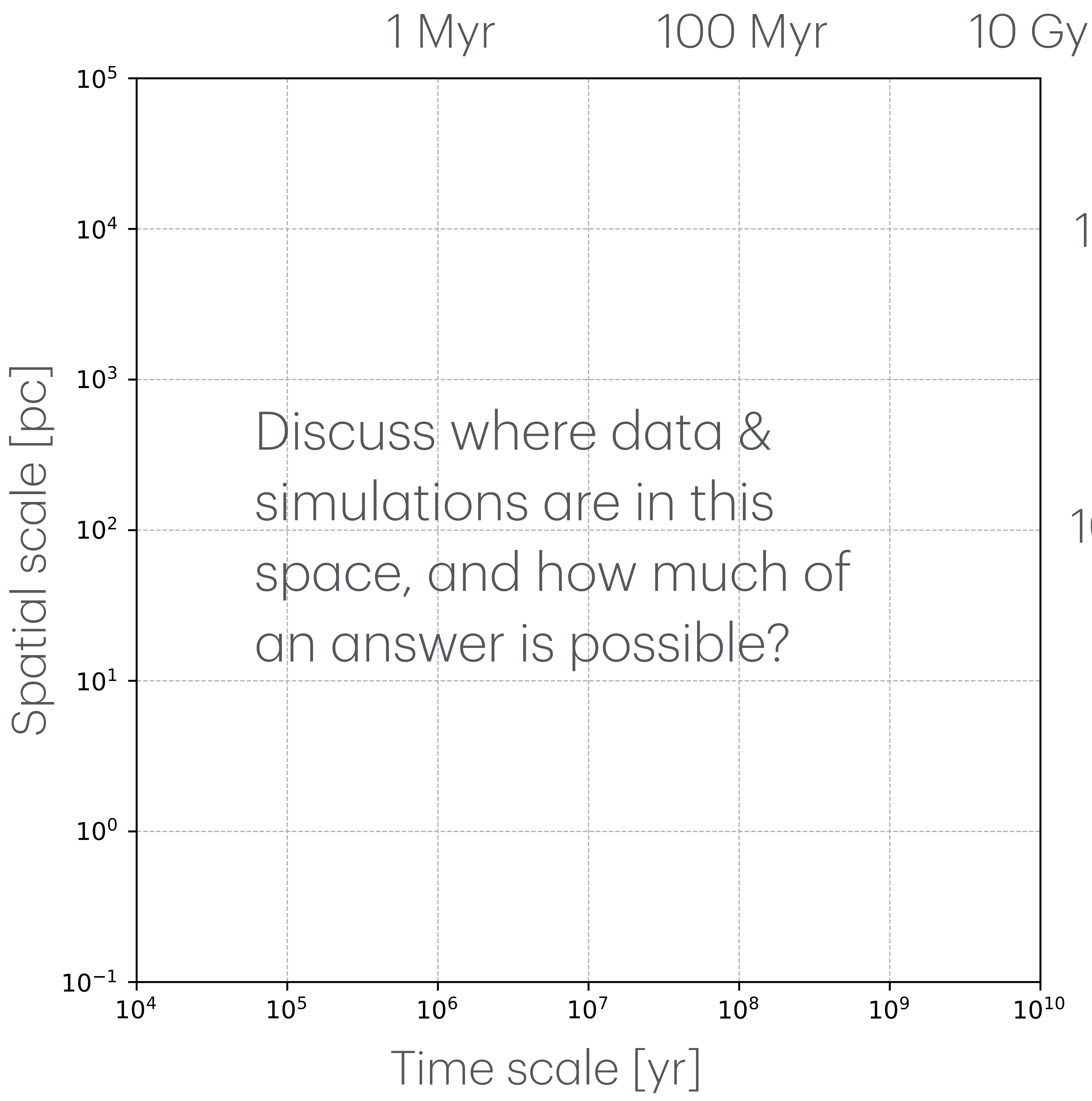
First Episode (~20 Myr ago): Formation of older clusters primarily in the LCC region.

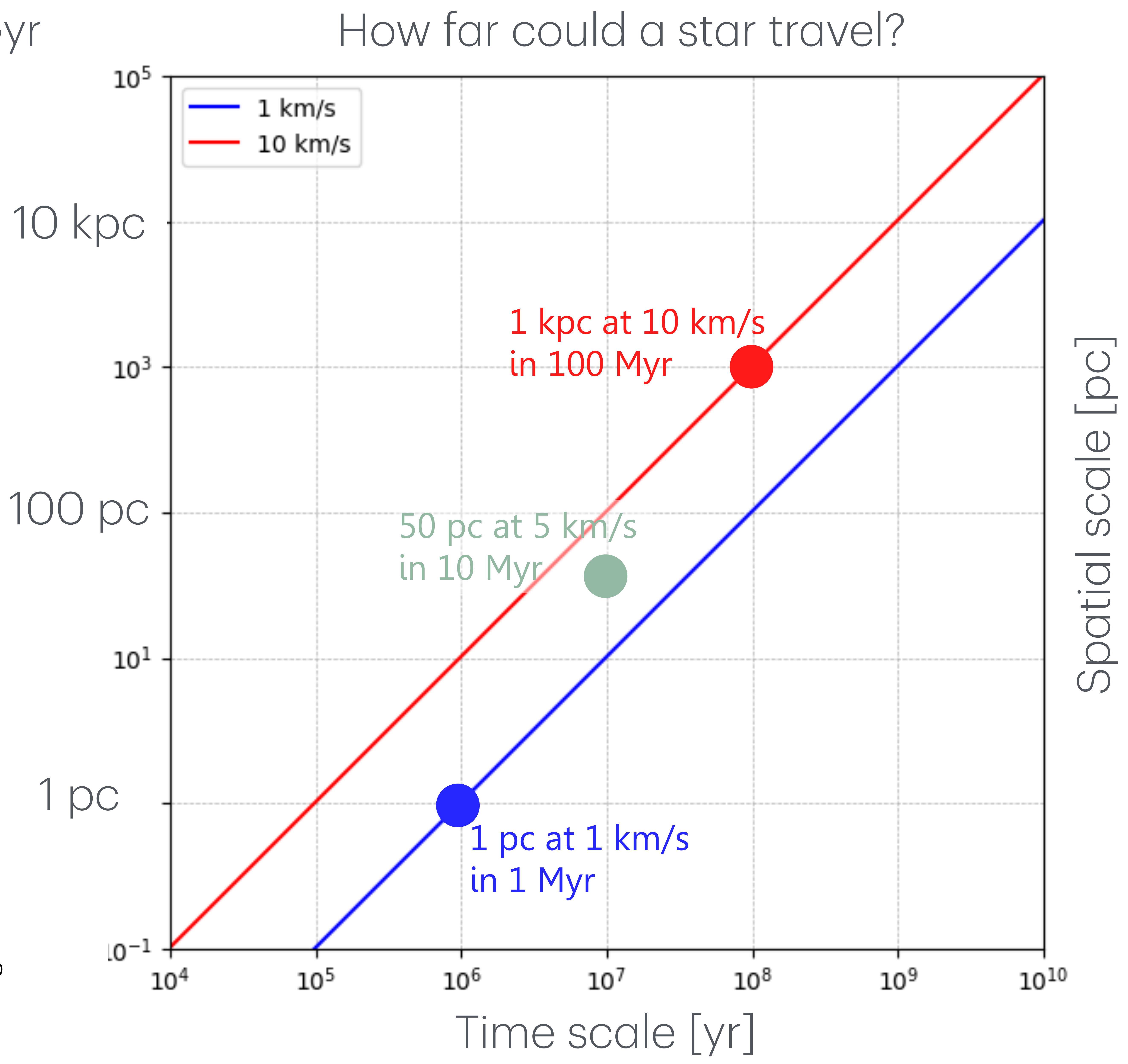
Second Episode (~15 Myr ago): Emergence of clusters in the UCL area.

Third Episode (~10 Myr ago): Development of clusters bridging UCL and US regions.

Fourth Episode (~5 Myr ago): Recent cluster formation predominantly in the US region

Großschedl et al. 2025, in prep. please do not distribute


1 Myr
100 Myr
10 Gyr
Discuss where data & simulations are in this space, and how much of an answer is possible?
Spatial scale [pc]
Time scale [yr]
10^{-1}
10^{0}
10^{1}
10^{2}
10^{3}
10^{4}
10^{5}
10^{4}
10^{5}
10^{6}
10^{7}
10^{8}
10^{9}
10^{10}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1 km/s
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1 pc at 1 km/s in 1 Myr
Spatial scale [pc]
Time scale [yr]
10^{1}
10^{3}
10^{5}
10^{4}
10^{5}
10^{6}
10^{7}
10^{8}
10^{9}
10^{10}

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