The Nature and Orbit of the Ophiuchus stream

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with

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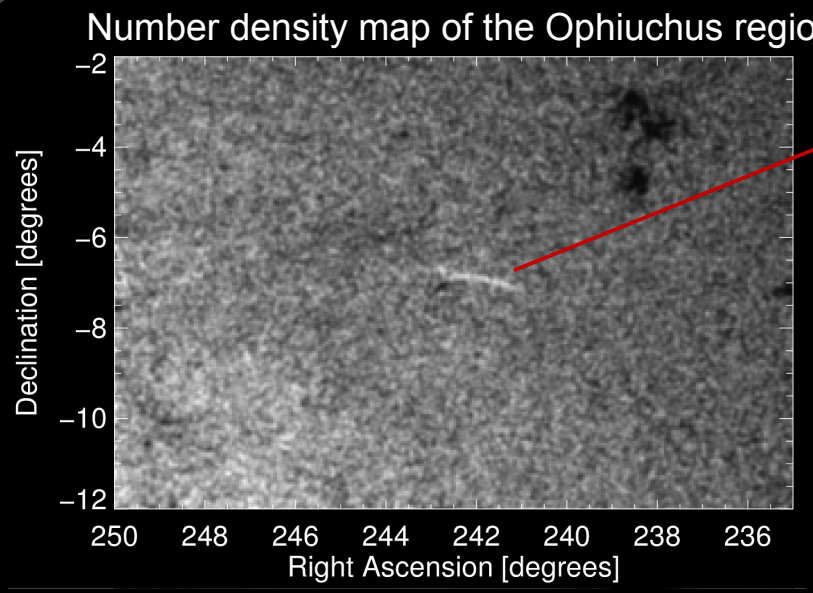
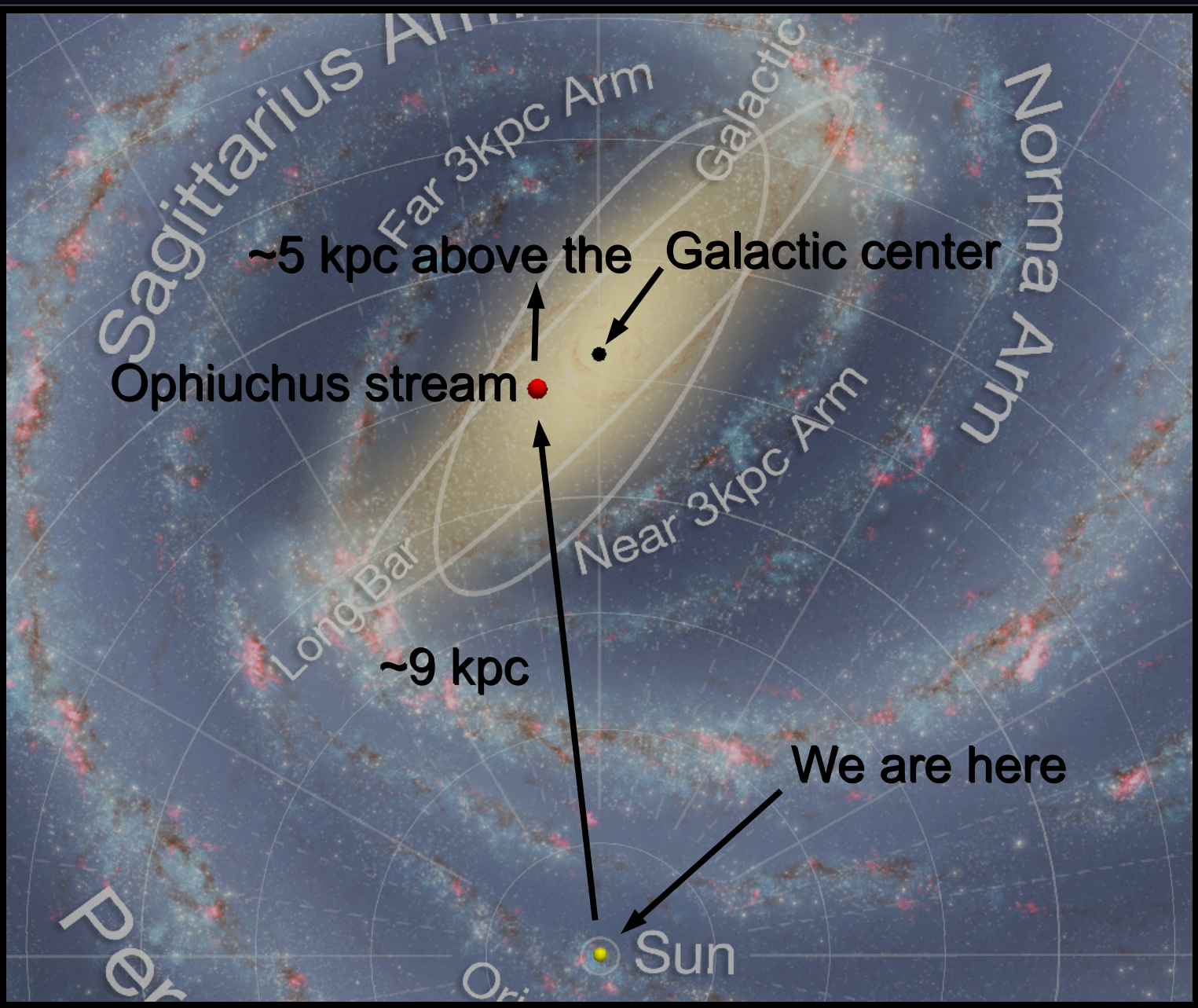
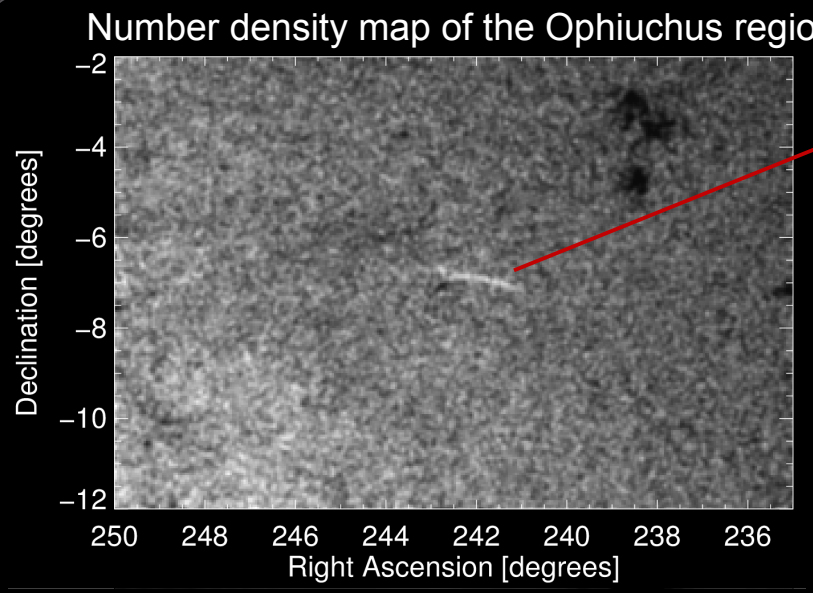
Introduction



- Discovered in the PanSTARRS1 (PS1) photometric catalog (Bernard et al. 2014)
- Old stellar population (>10 Gyr)
- Metal-poor ([Fe/H] ~ -1.3 dex)
- Apparently thin (17 pc) and short (~370 pc)


Sagittarius Arm
Far 3kpc Arm
Galactic
Norma Arm
~5 kpc above the
Galactic center
Ophiuchus stream
Near 3kpc Arm
Long Bar
~9 kpc
We are here
Sun

Unsolved Puzzles



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- Old stellar population (>10 Gyr)
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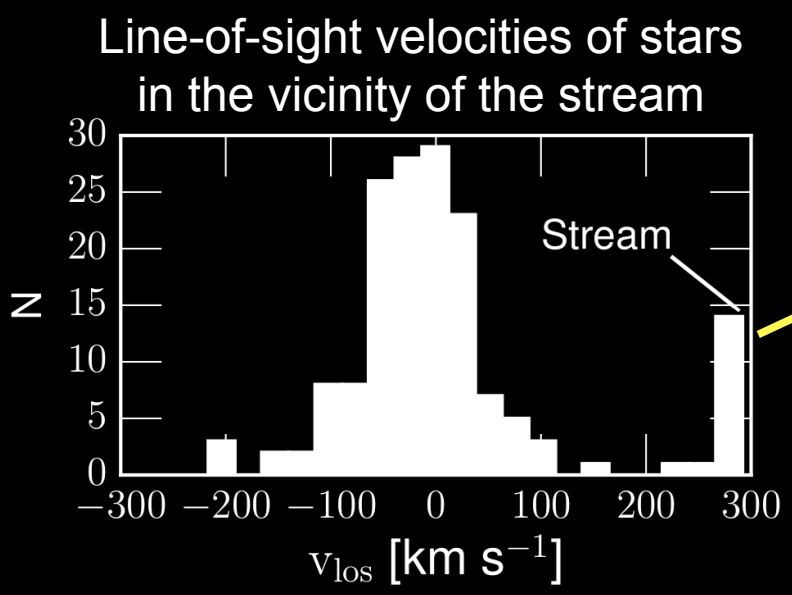
- Unsolved puzzles:
  - Old population, but short stream → recently disrupted?
  - No visible progenitor
  - Need to know the orbit → need velocities, distances, and proper motions

Line-of-Sight Velocity

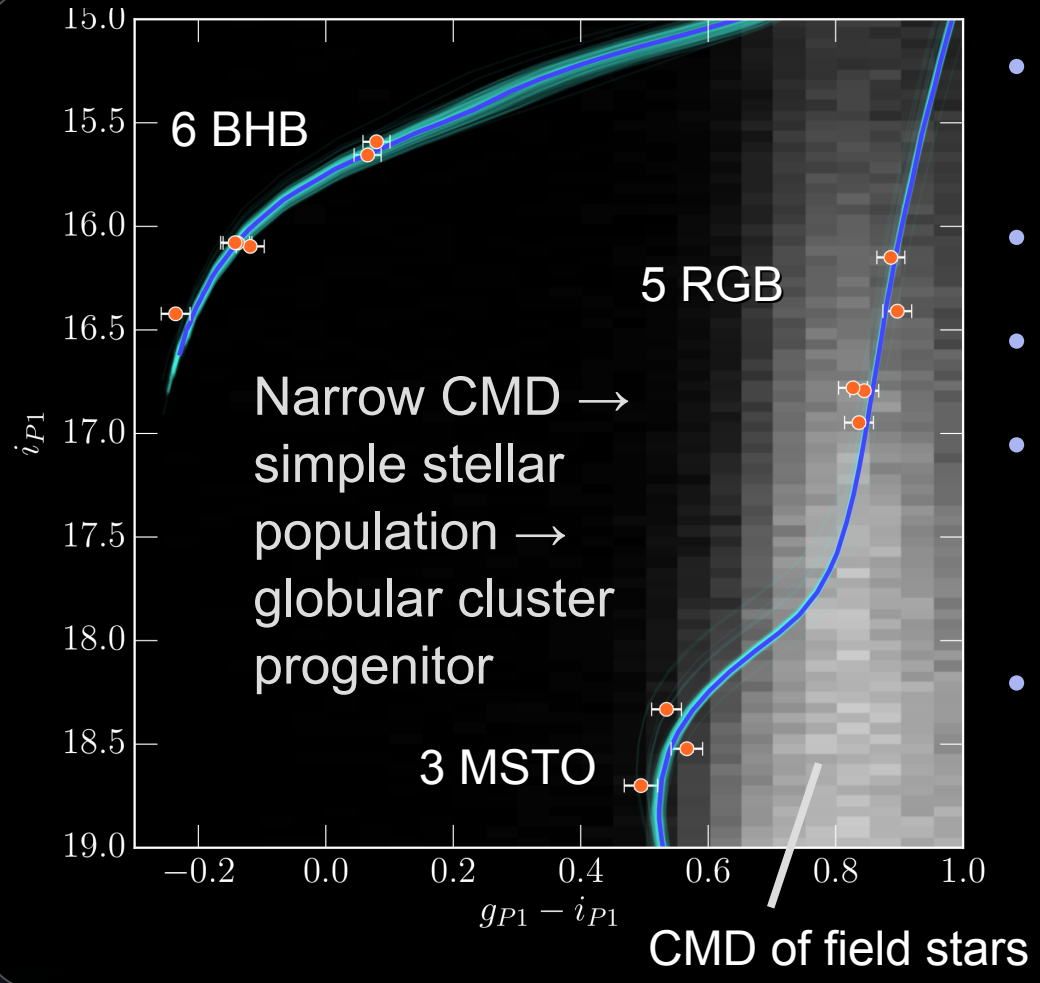


- Precise velocities (< 2 km/s)
- Identified 14 members (6 BHB, 5 RGB, 3 MSTO stars)
- Receding at v_{los} ~ 290 km/s and has a velocity gradient of 4±1 km/s/deg
- velocity dispersion < 0.5 km/s → kinematically cold stream
- α-enhanced, [Fe/H] = -2 dex, < 0.05 dex scatter in [Fe/H] → simple stellar population (globular cluster progenitor)

Distance

- Fit CMD using 14 confirmed members
- Model with 8 parameters

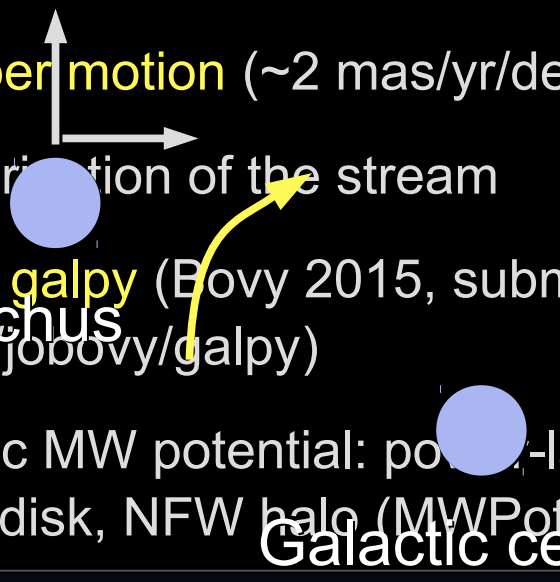
Distance



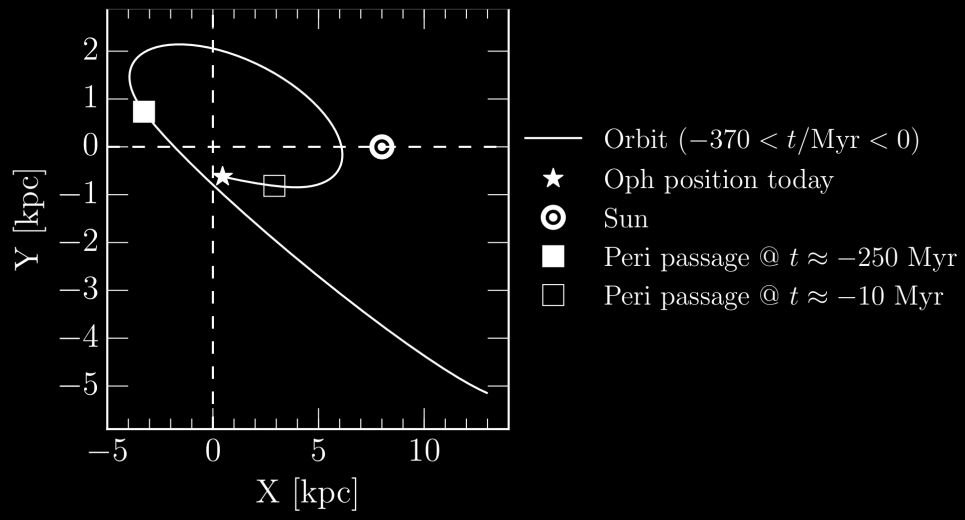
- Fit CMD using 14 confirmed members
- Model with 8 parameters
- Age: 12.7±0.3 Gyr
- Gradient in distance modulus (-0.23±0.03 mag/deg)
- Stream extends from 8 to 9.5 kpc → 1.6 kpc long, not 370 pc!

Proper Motion and the Orbit of the Stream

- Proper motions: PS1 + recalibrated (using PS1) USNO-B catalog positions → precision of 2 mas/yr
- Use all stars in the vicinity that match the position and CMD of the stream (a probabilistic model with 20 parameters)
- Moving away from the plane and towards the Galactic center
- Gradients in proper motion (~2 mas/yr/deg, signif. at >2.5σ level)
- Full 6-D characterization of the stream
- Orbit fitting using galpy (Bovy 2015, submitted to ApJ; http://github.com/jobovy/galpy)
- Assume a realistic MW potential: power-law bulge with a cutoff, Miyamoto-Nagai disk, NFW halo (MWPotential2014 in galpy)



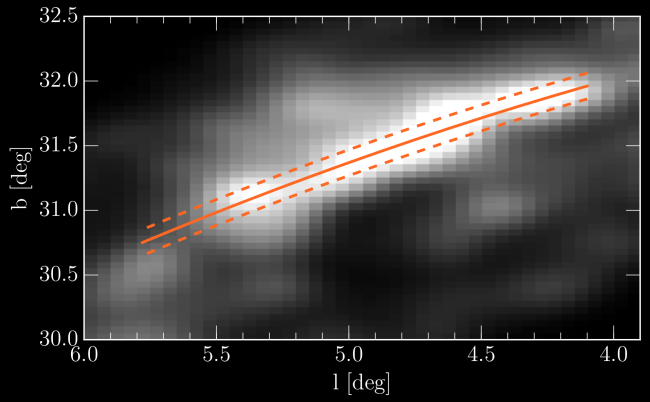
Orbit of the Ophiuchus Stream



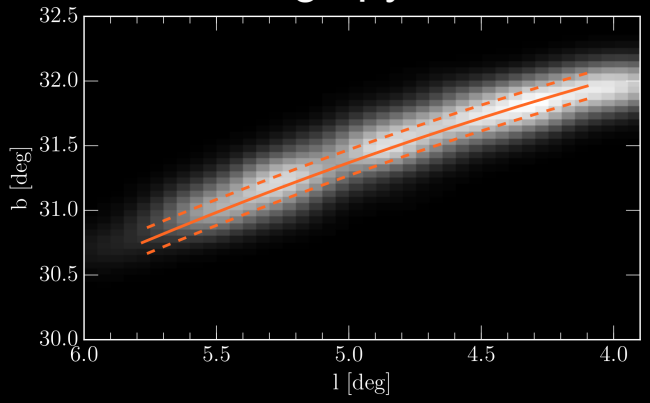
- Pericenter: 3.5 kpc
- Apocenter: 17.5 kpc
- Eccentricity: 0.67
- Periods: 360 Myr (orbital), 245 Myr (radial), 356 Myr (vertical) → > 50 disk+pericenter passages in the past 13 Gyr!
- Old population + short orbit → how did it survive for ~13 Gyr?

Time of Disruption and Dynamical Mass

Observed number density

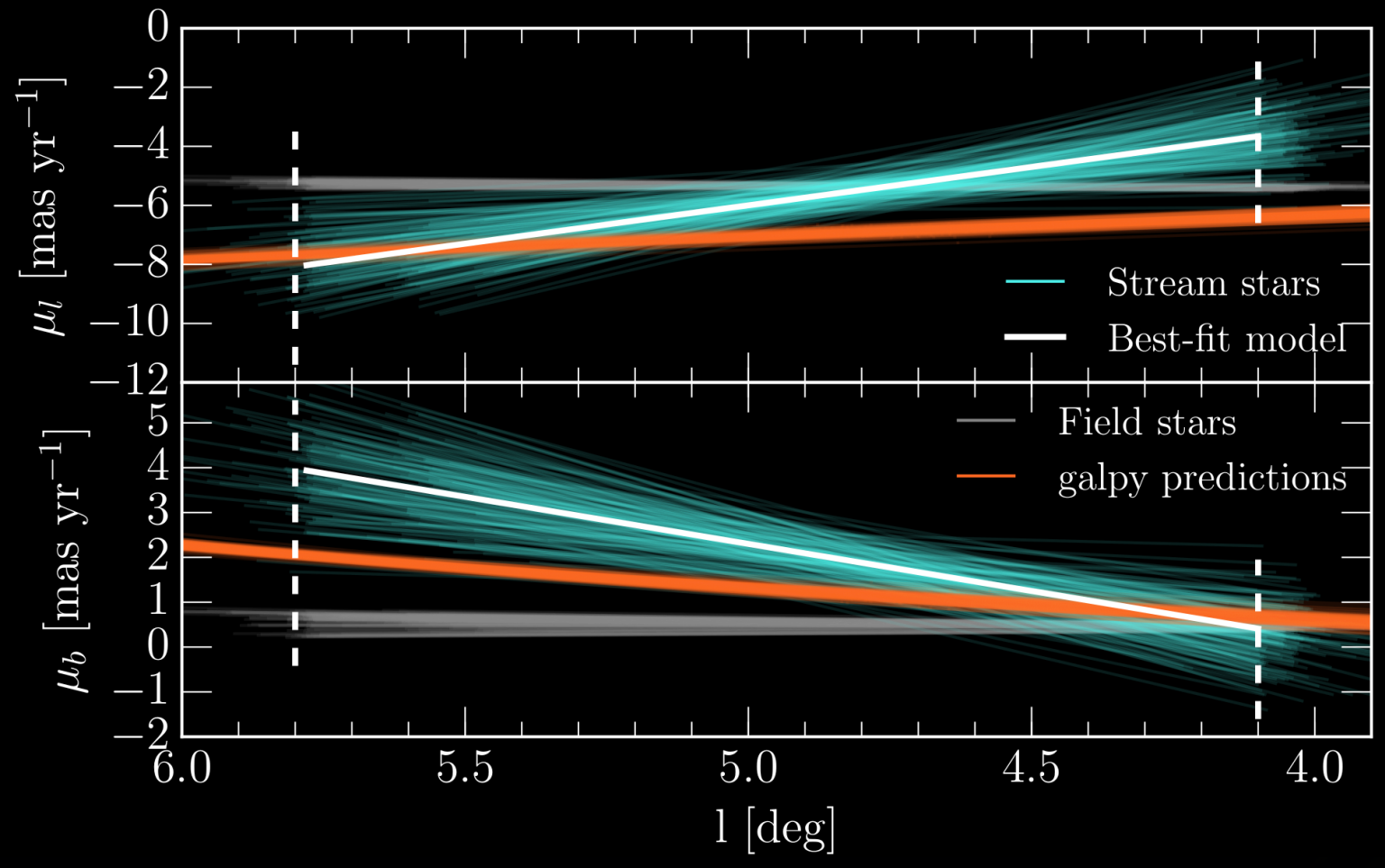


Mock galpy stream



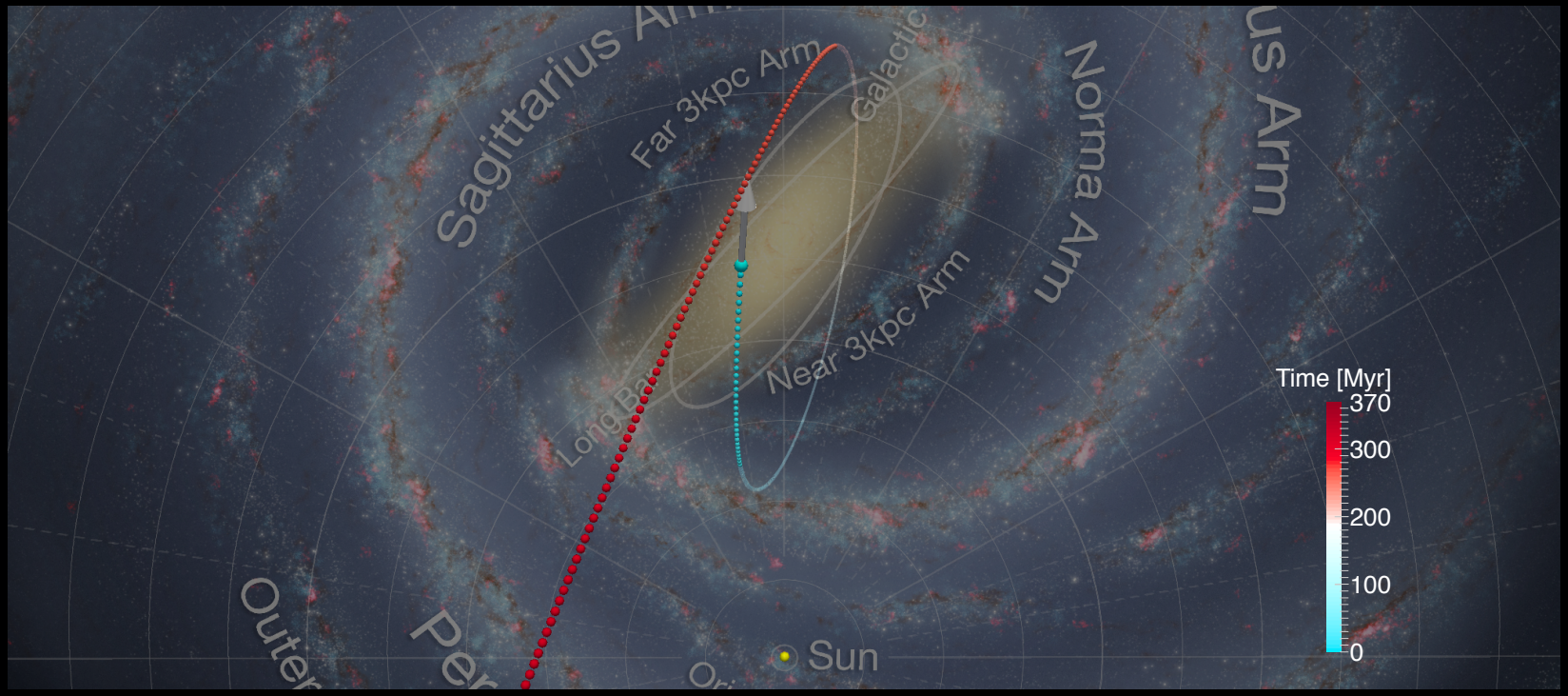
- Mock stream: need to assume a velocity dispersion of the stream and time of disruption
- σ_v proportional to width, t_{dis} proportional to length
- Good match for $\sigma_v \sim 0.4$ km/s, $t_{dis} \sim 170$ Myr
- Disrupted during the last disk+pericenter passage (~250 Myr ago)
- $\sigma_v \sim 0.4$ km/s $\rightarrow$ $M_{dyn} \sim 2 \cdot 10^4\ M_{sun}$ (like GD-1)

Observed vs. Predicted Proper Motions



Take-Away Messages

- We have fully characterized the Ophiuchus stream in position, kinematics, and color-magnitude space
- Progenitor: globular cluster ($M \sim 2 \cdot 10^4 M_{sun}$), some similarities with GD-1
- Puzzle solved: short due to viewing angle and recent disruption (~250 Myr ago)
- Still unresolved puzzle: where is the progenitor? N-body simulations needed.
- New puzzle 1: mismatch between observed and predicted proper motions → bad proper motions? stream is not orbit?
- New puzzle 2: How did the progenitor survive >50 disk+pericenter passages in the past 13 Gyr? Incorrect potential? Did its orbit change?


Sagittarius Arm
Far 3kpc Arm
Galactic
Norma Arm
Near 3kpc Arm
Sun
Time [Myr]
370
300
200
100
0