Ana Bonaca

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Center for Astrophysics

Uncovering the nature of dark matter with stellar streams in the Milky Way

SPACE.com

Our Milky Way Galaxy Weighs As Much As 1.5 Trillion Suns

By Mike Wall 10 days ago Science & Astronomy

SKY & TELESCOPE
THE ESSENTIAL GUIDE TO ASTRONOMY

The Milky Way Contains the Mass of 1.5 Trillion Suns

By: **Monica Young** | March 18, 2019

The Guardian

Scientists discover what the Milky Way weighs

We are here

~90% of the Milky Way galaxy is invisible

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Significant resources are dedicated to the search for dark matter

Interacts with ordinary matter ?

[LUX experiment: $10M]

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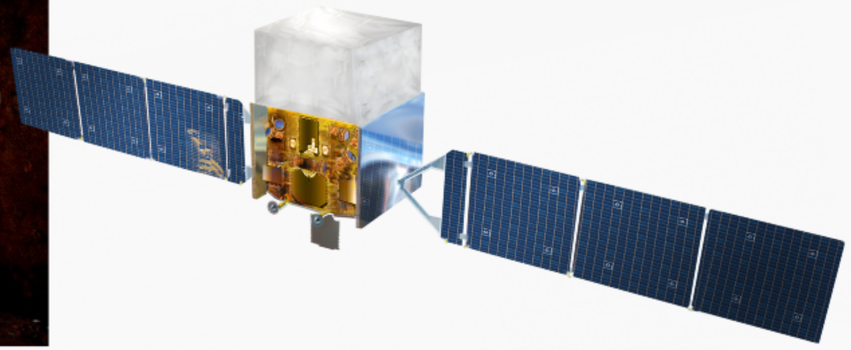

[Fermi satellite: $600M]

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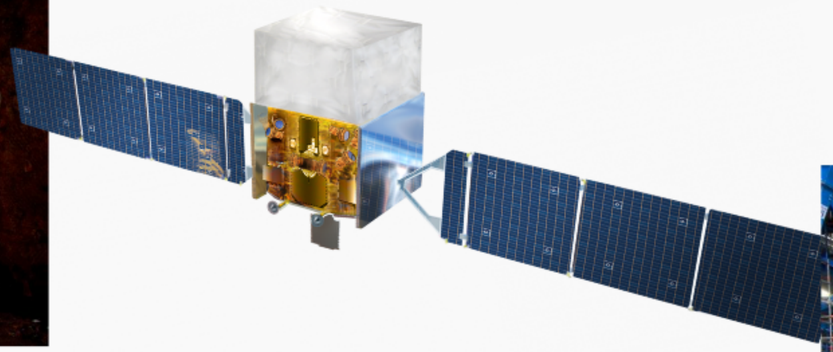
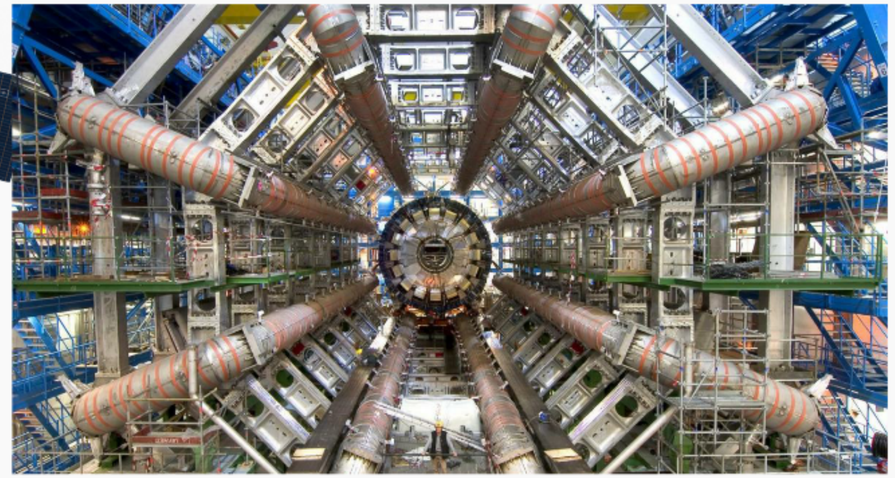


[Fermi satellite: $600M]

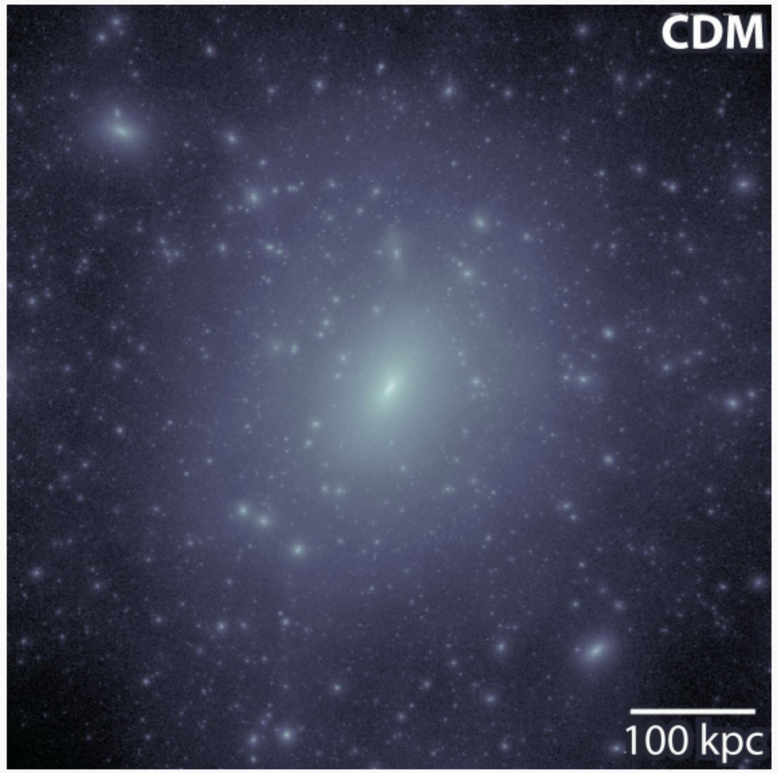
Can be produced in a lab ?



[LHC in CERN: $8B]

The nature of dark matter is encoded in its spatial distribution

Particle mass ~ GeV



The nature of dark matter is encoded in its spatial distribution

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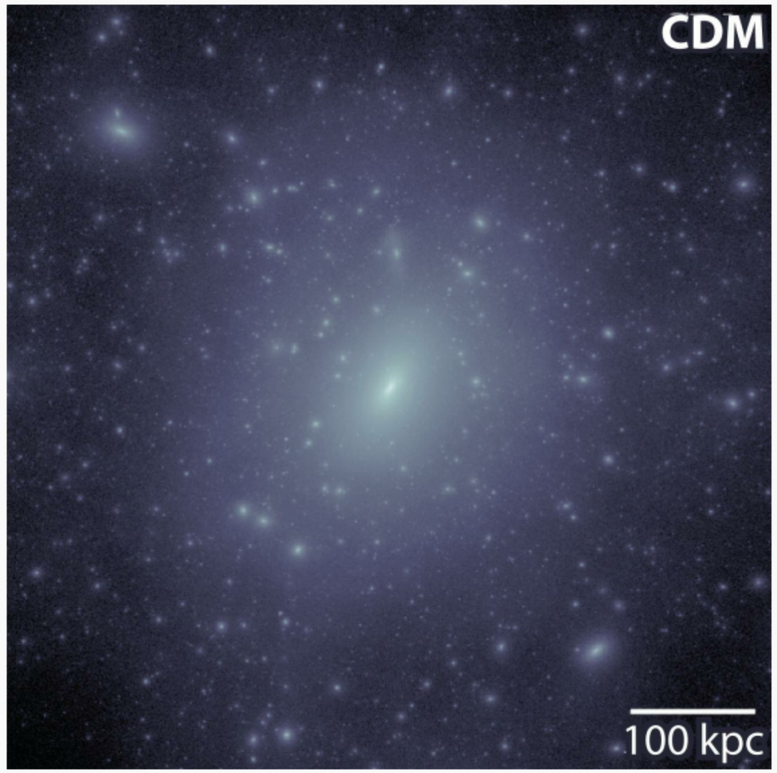
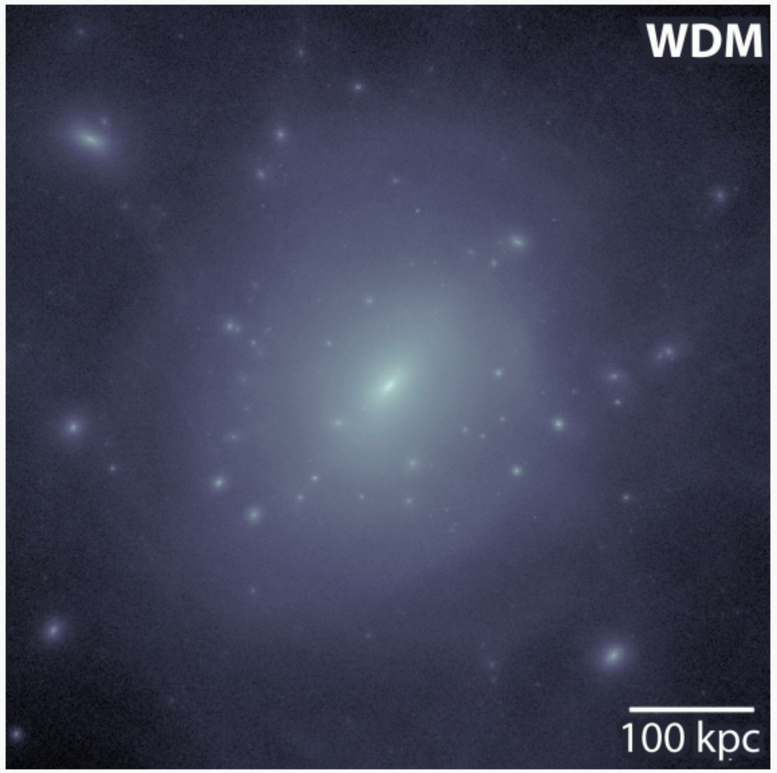


Particle mass ~ keV



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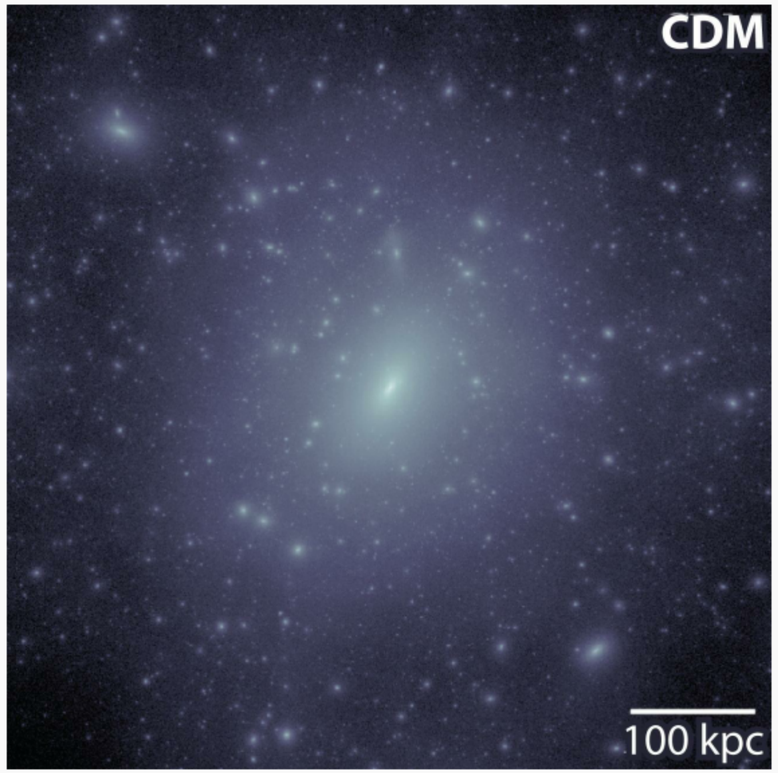
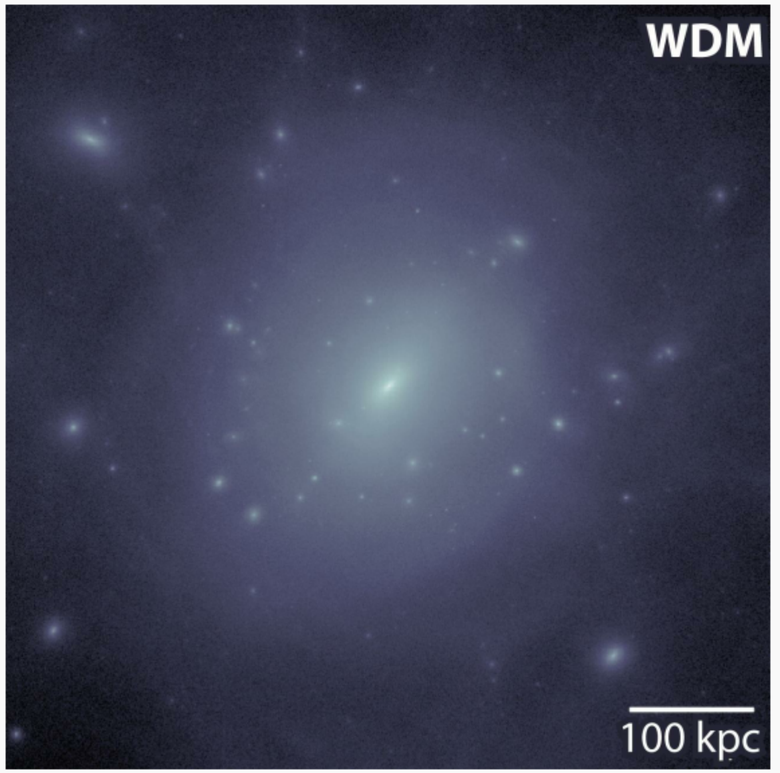
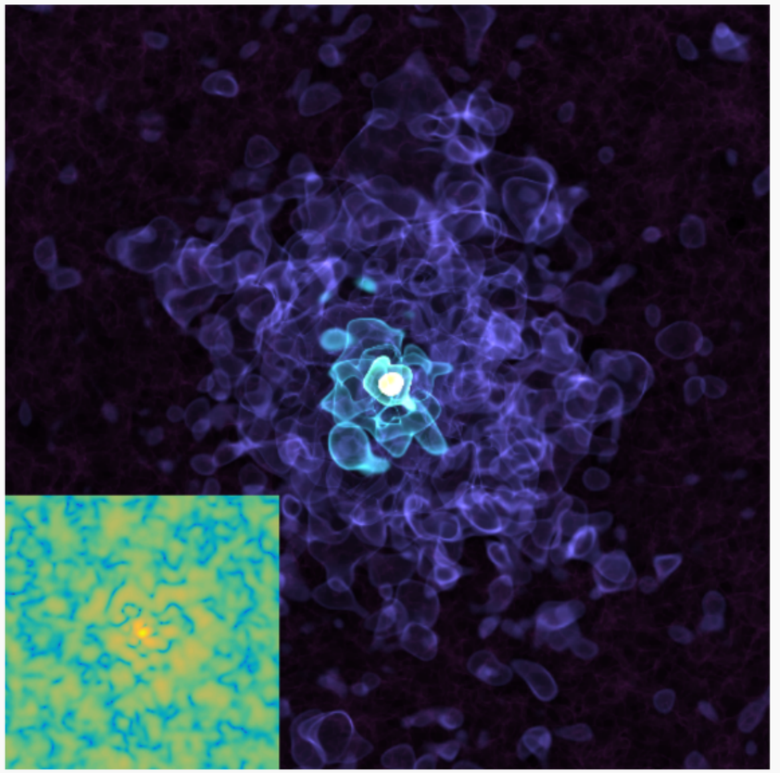


Particle mass ~ keV



Particle mass ~ 10^{-22} eV



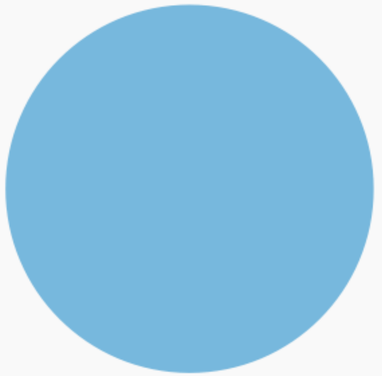
Goal: Create a high-resolution map of dark matter in the Milky Way

Coal Oil Point Reserve

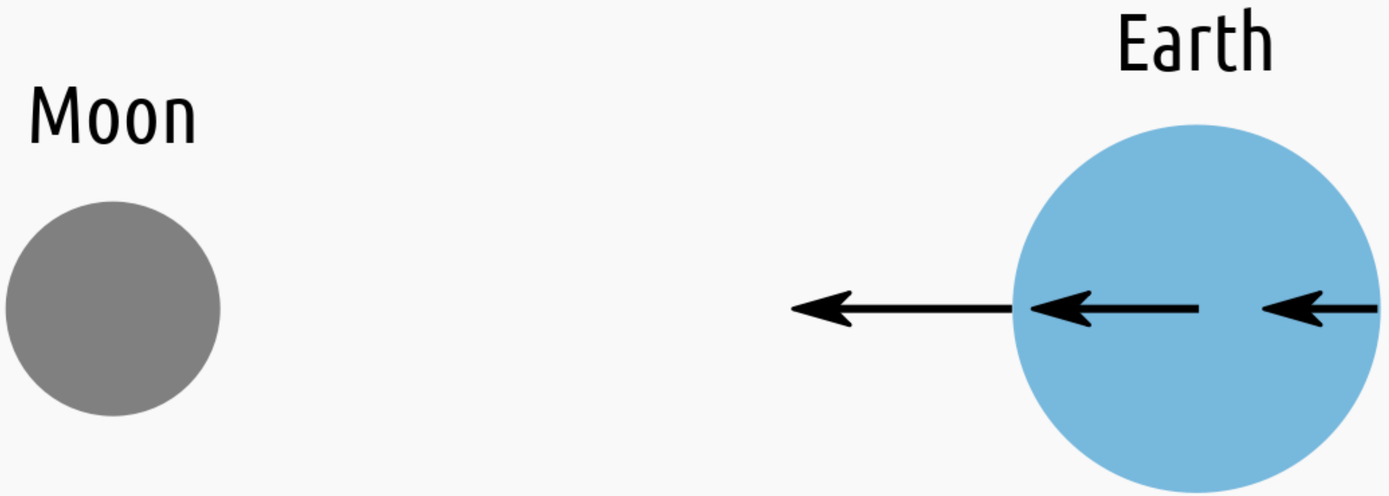
Gravitational pull of the Moon creates tides

Moon

Earth



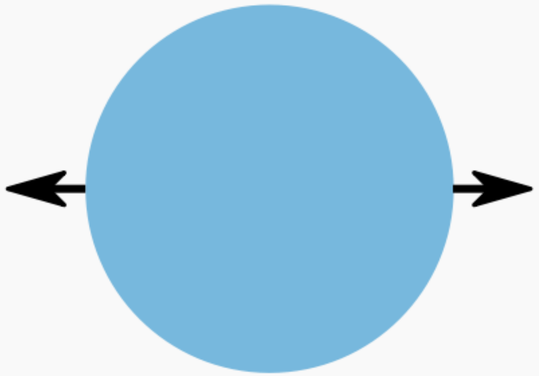
Gravitational pull of the Moon creates tides



Gravitational pull of the Moon creates tides

Moon

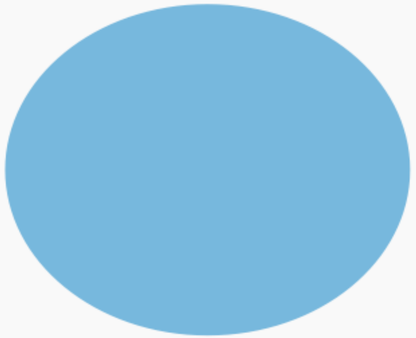
Earth (from Earth's perspective)



Gravitational pull of the Moon creates tides

Earth (from Earth's perspective)

Moon



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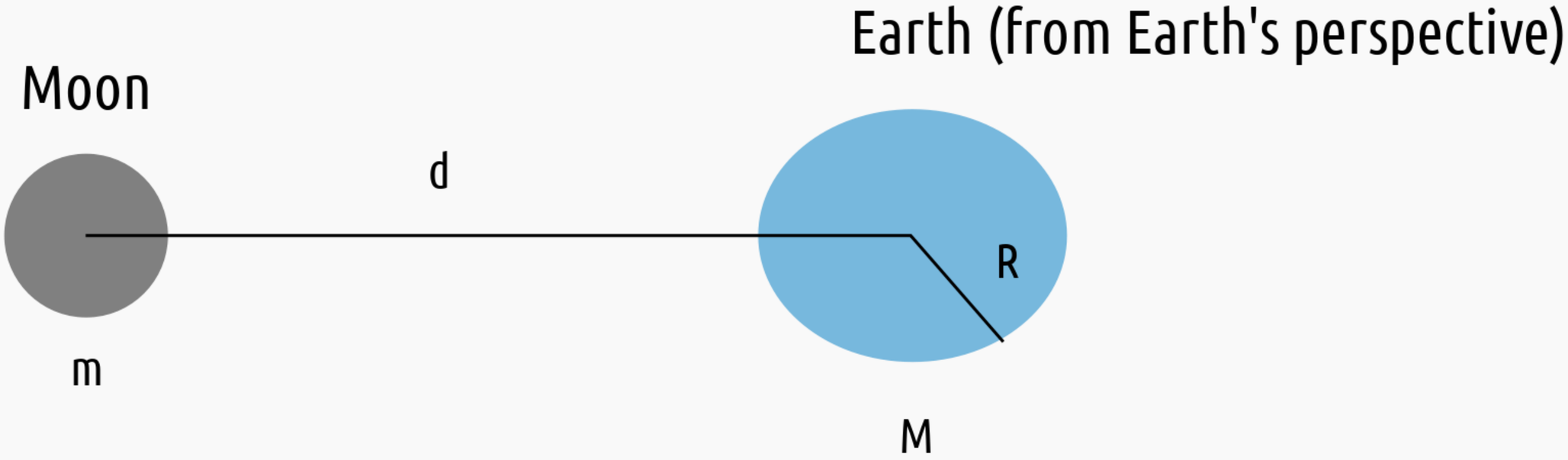
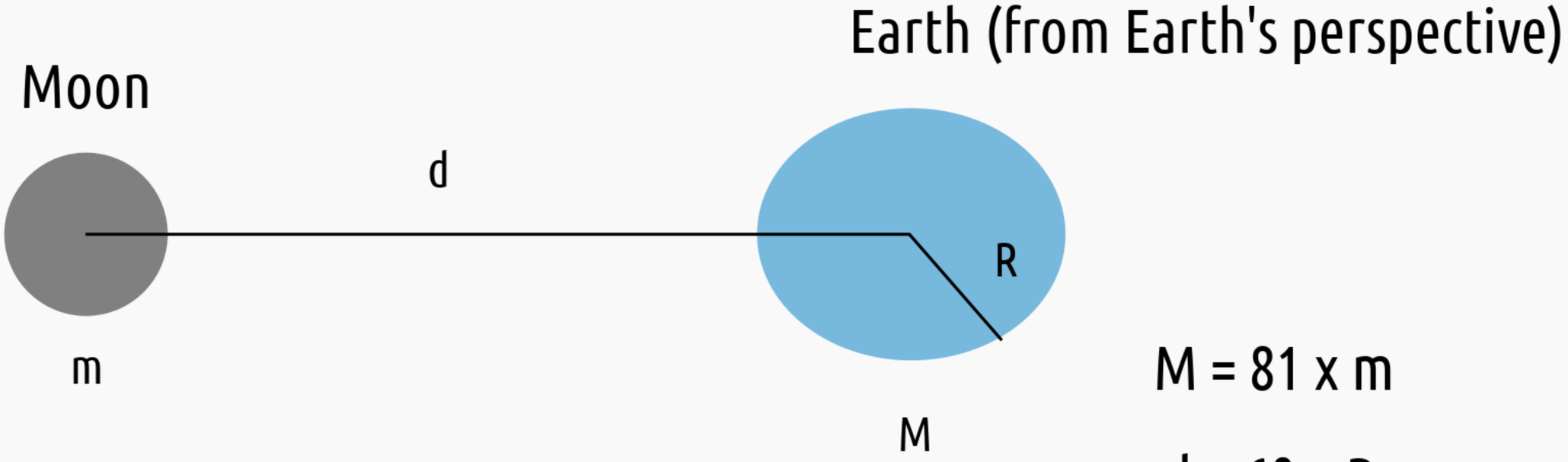


$$\frac{\text{Tidal acceleration}}{\text{Earth's acceleration (gravity)}} \quad \frac{\Delta a}{a} = \left(\frac{R}{d}\right)^2 \frac{m}{M} \frac{1-2d/R}{(1-d/R)^2}$$

Gravitational pull of the Moon creates tides



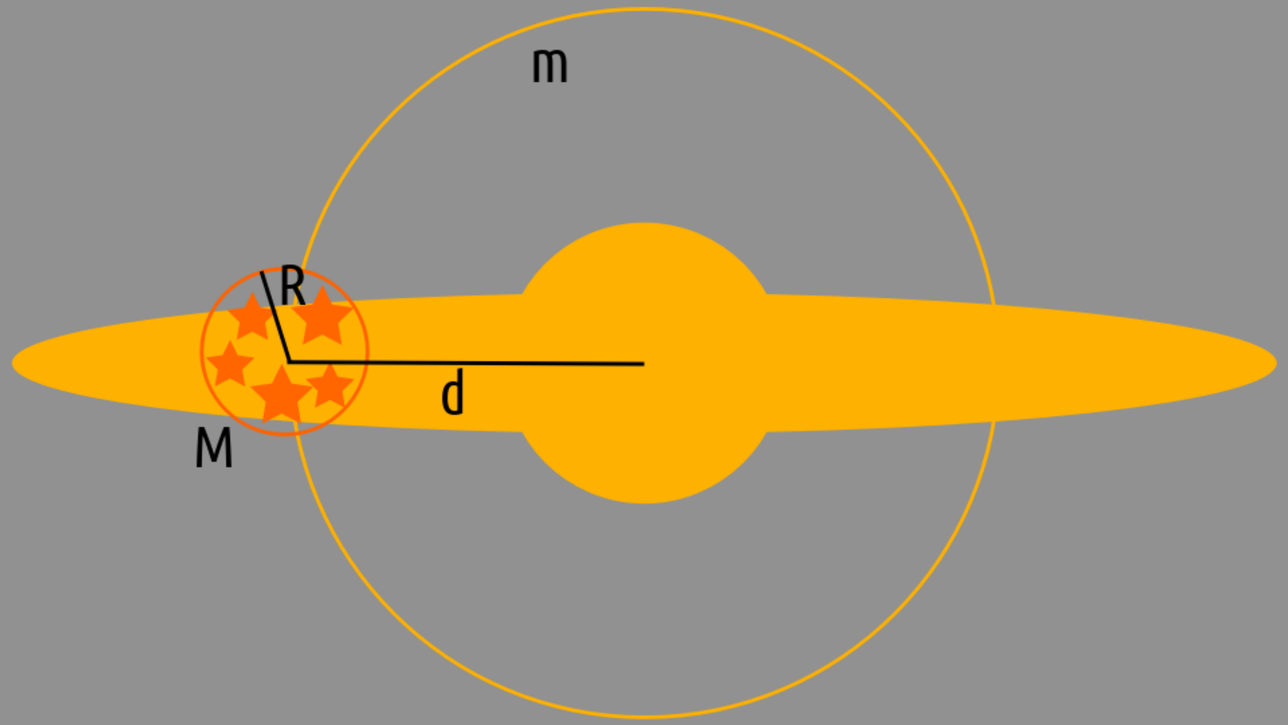
M = 81 x m

d = 60 x R

$$\frac{\text{Tidal acceleration}}{\text{Earth's acceleration (gravity)}} \quad \frac{\Delta a}{a} = \left(\frac{R}{d}\right)^2 \frac{m}{M} \frac{1-2d/R}{(1-d/R)^2} \longrightarrow 10^{-5}\% = 0.00001\%$$

Gravitational pull of the Milky Way creates tides, too!

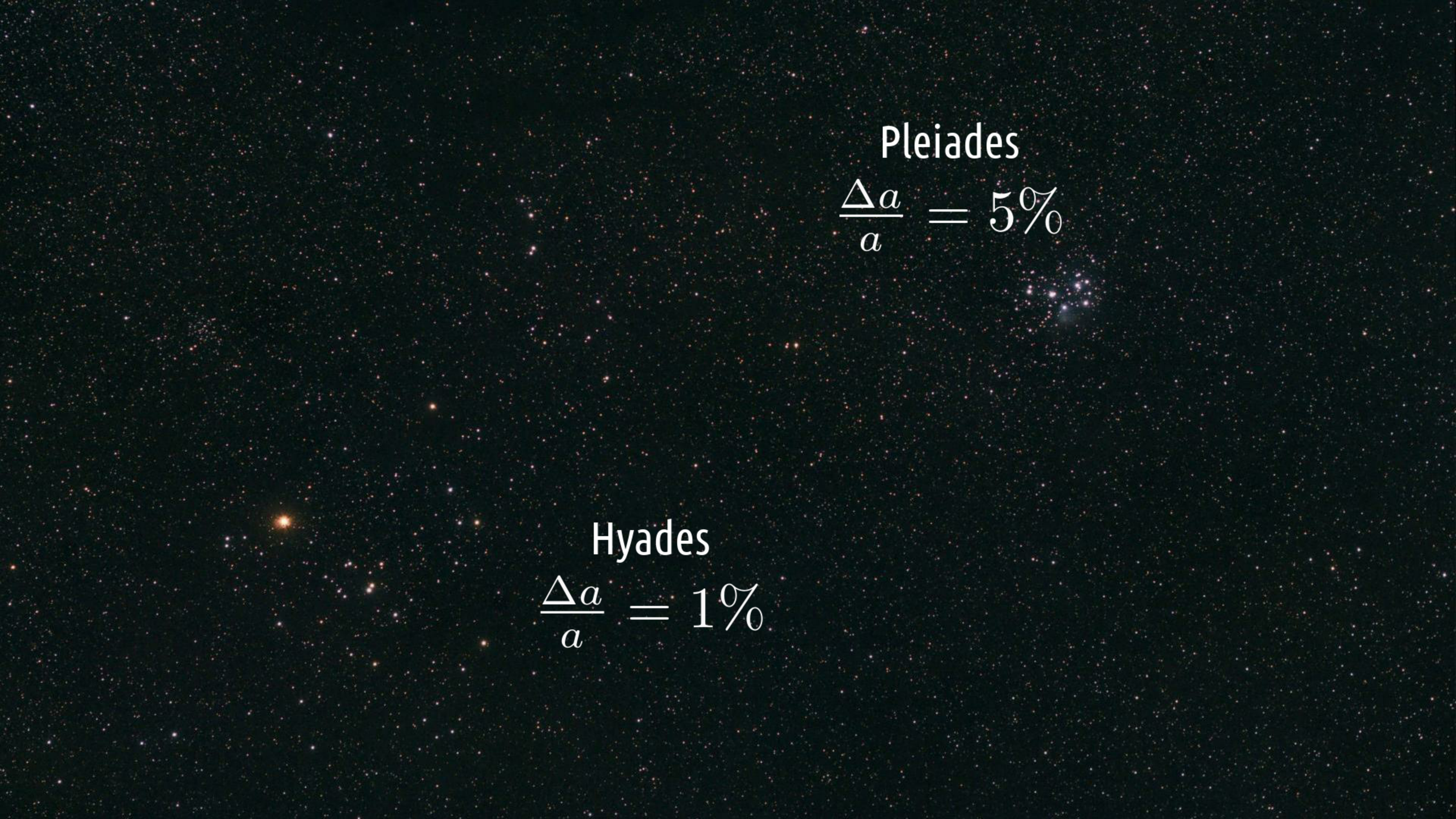
Gravitational pull of the Milky Way creates tides, too!



For a star cluster close to the Sun

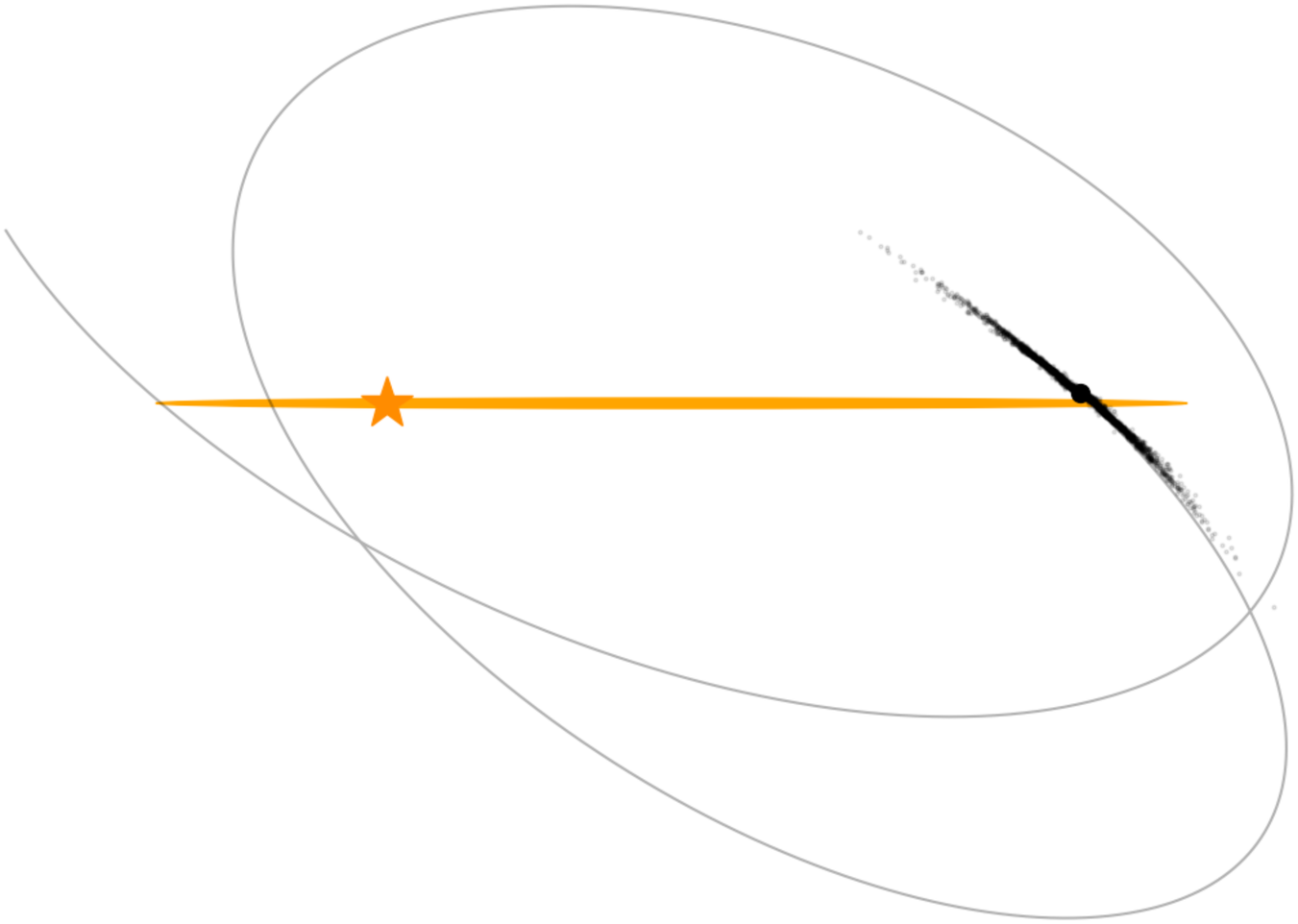
$$\frac{R}{d} = 5 \times 10^{-4}$$

$$\frac{m}{M} = 2 \times 10^{8}$$

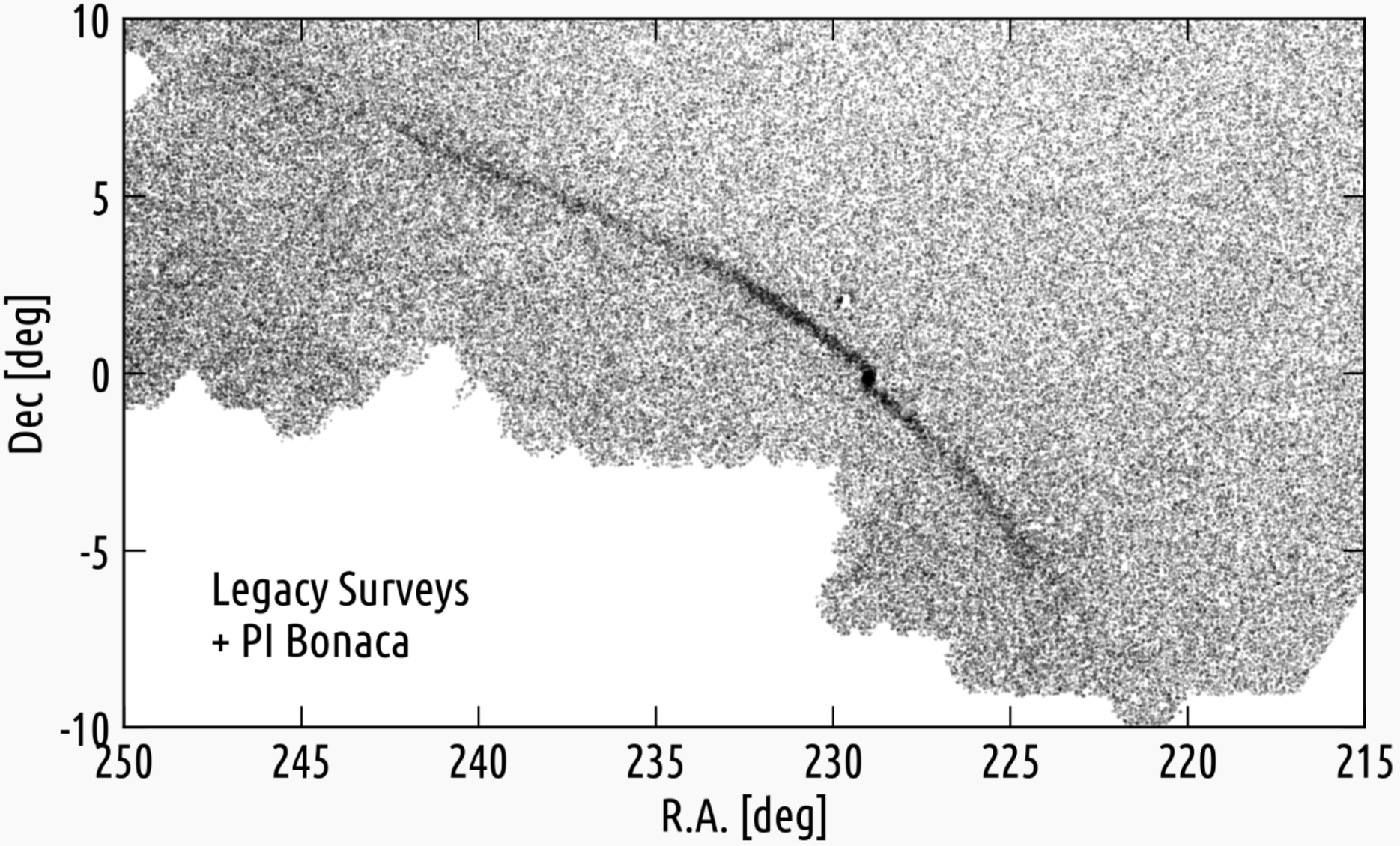

Pleiades
$\frac{\Delta a}{a} = 5\%$
Hyades
$\frac{\Delta a}{a} = 1\%$

Globular clusters lose stars to form tidal streams

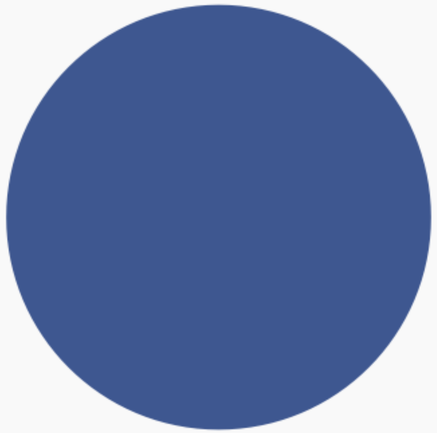
800 million years



Globular cluster Palomar 5 has a tidal stream of stars

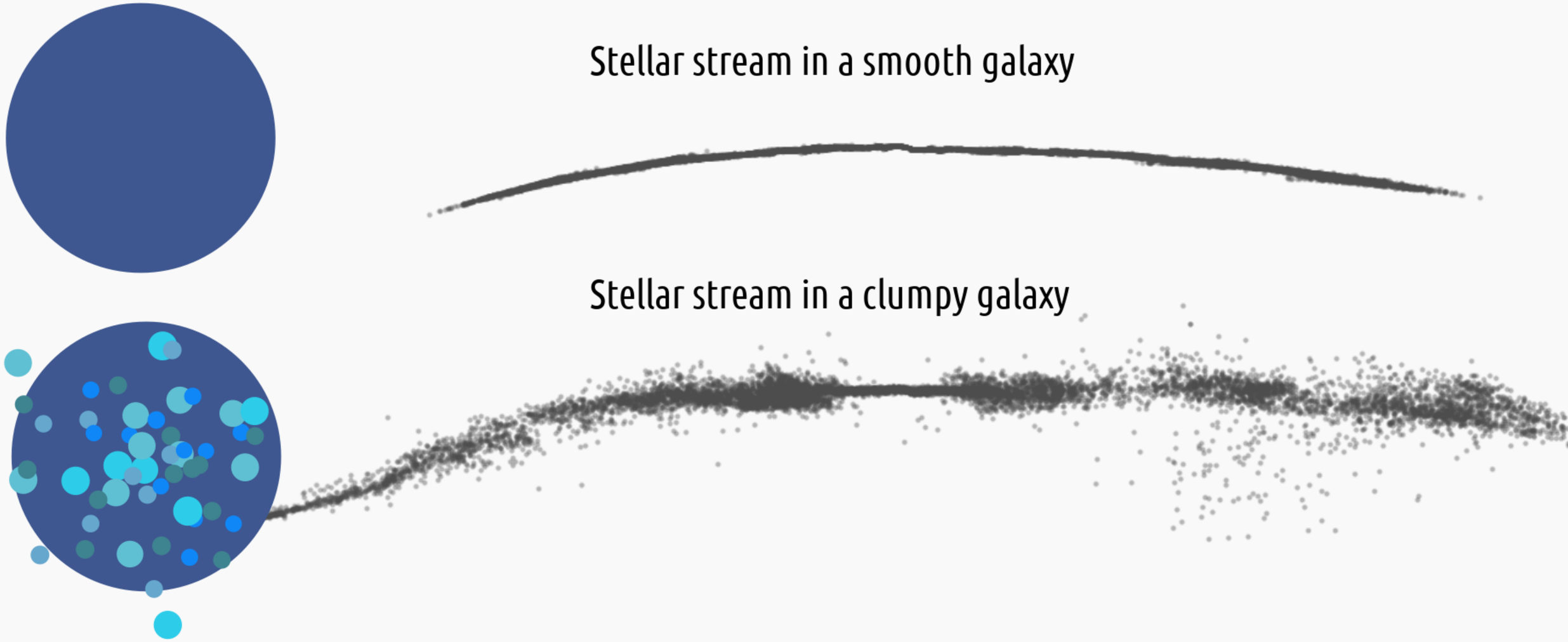


Stellar streams preserve a record of all gravitational interactions

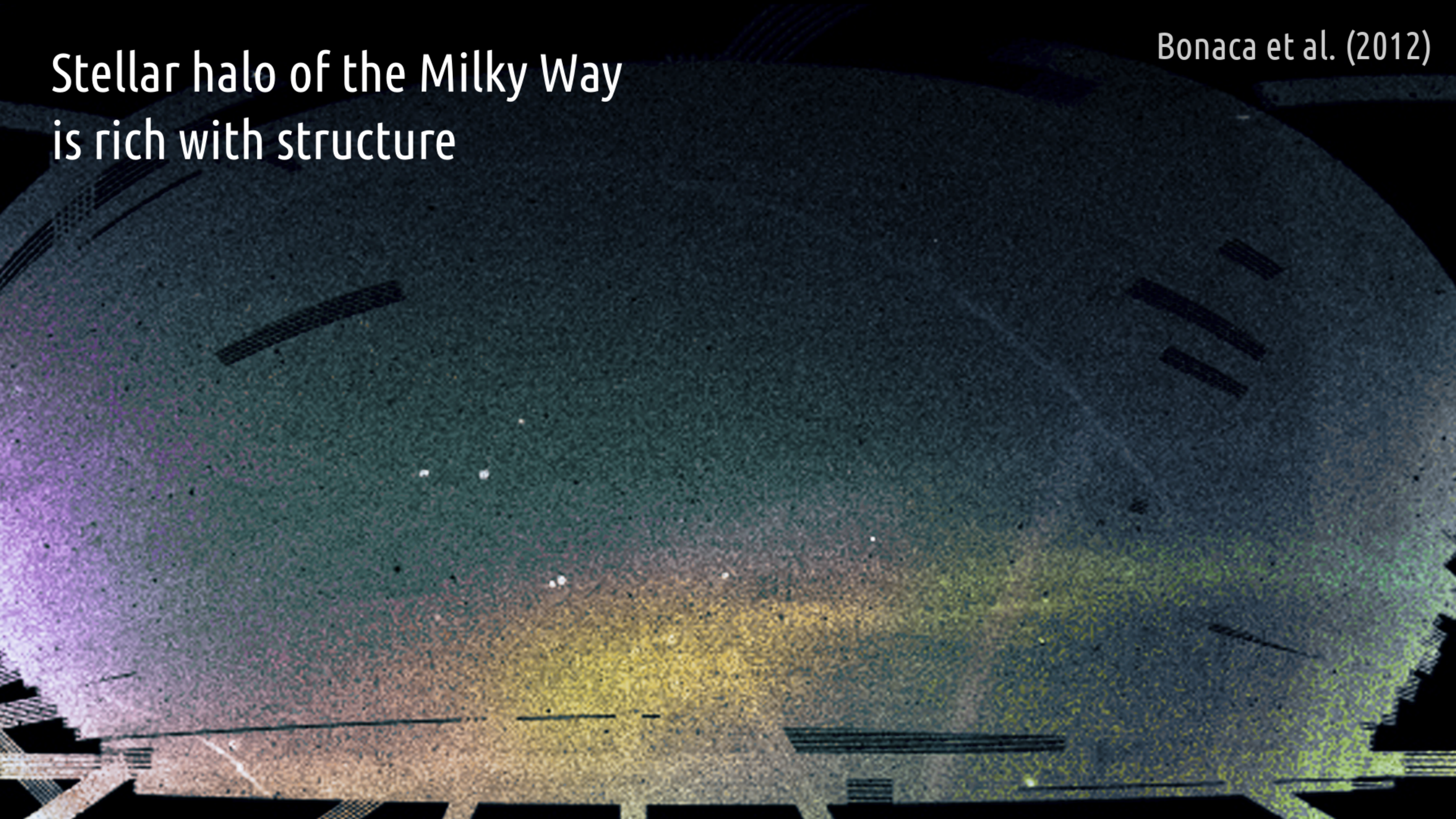


Stellar stream in a smooth galaxy

Stellar streams preserve a record of all gravitational interactions

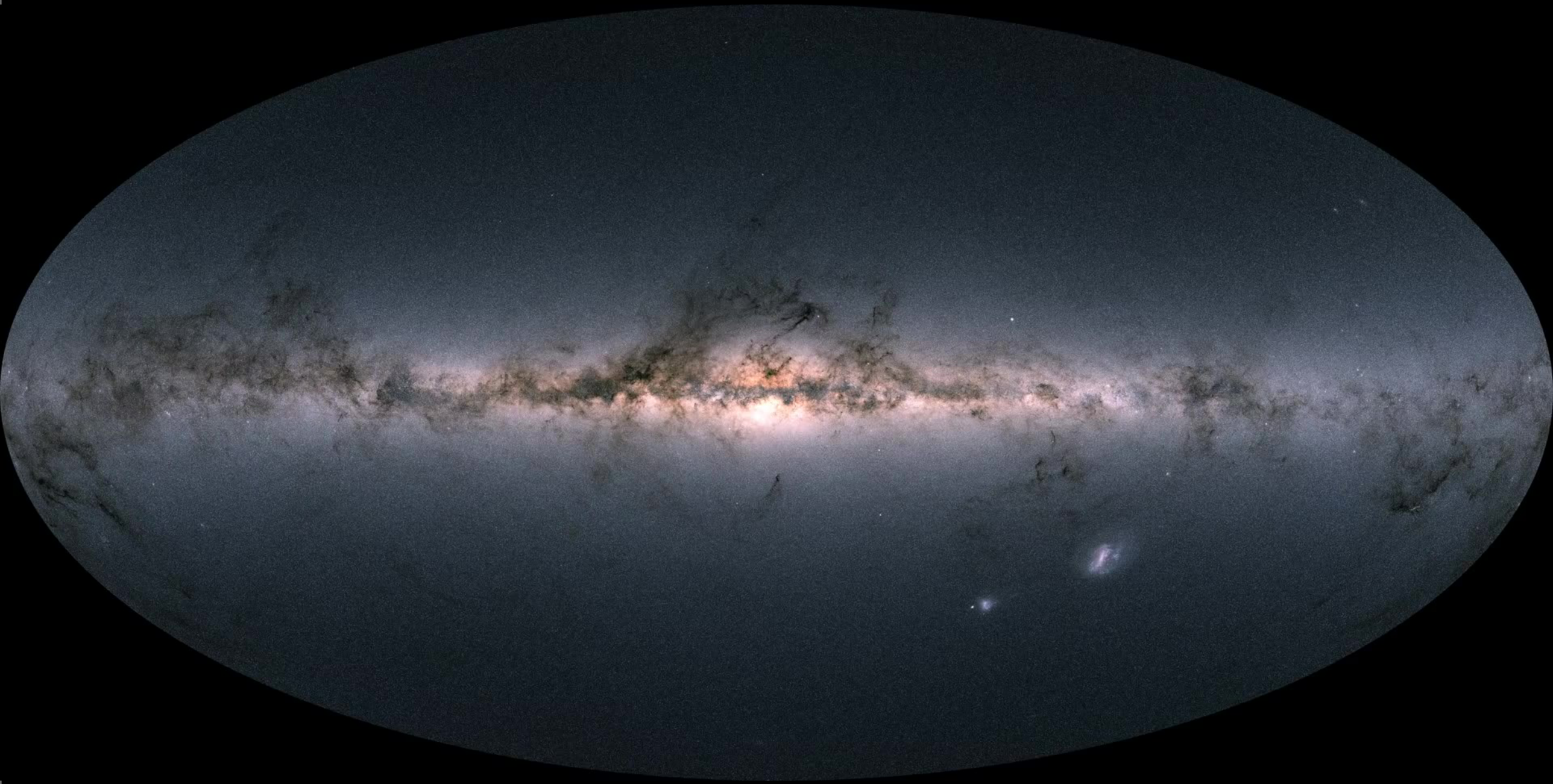


Stellar halo of the Milky Way is rich with structure

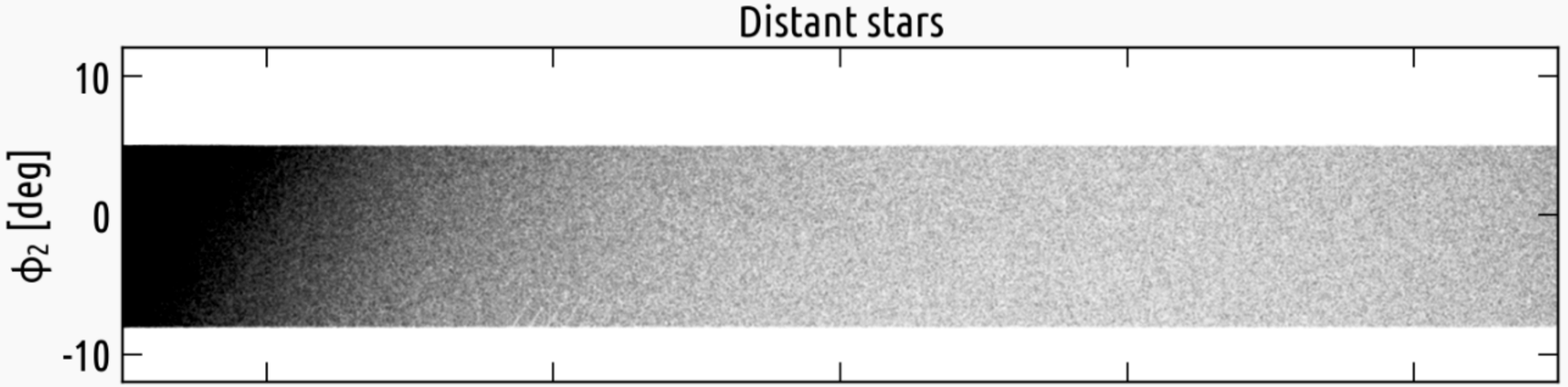


Bonaca et al. (2012)

Gaia Data Release 2



Gaia's view of the GD-1 stellar stream



Price-Whelan & Bonaca (2018)

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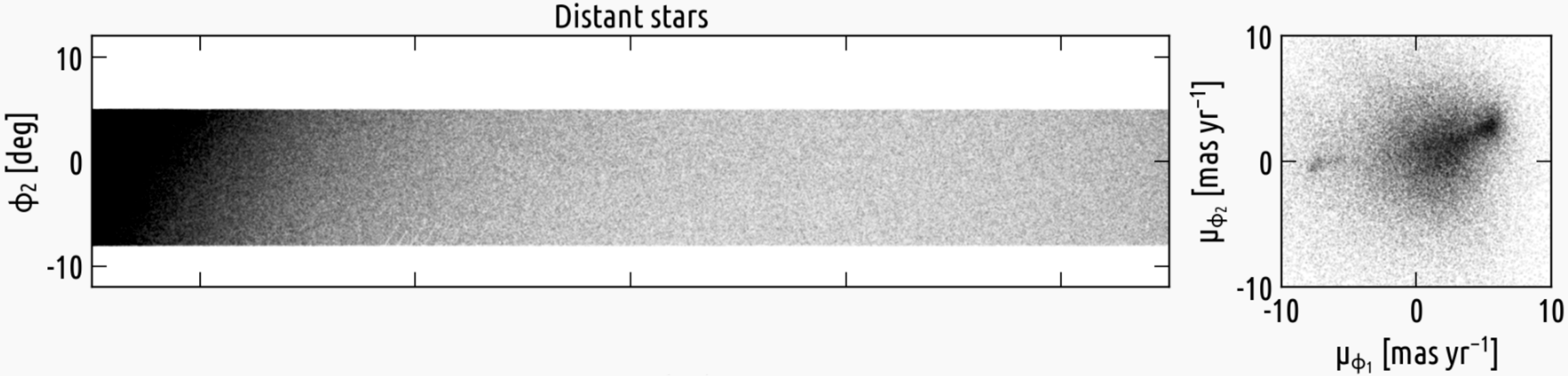

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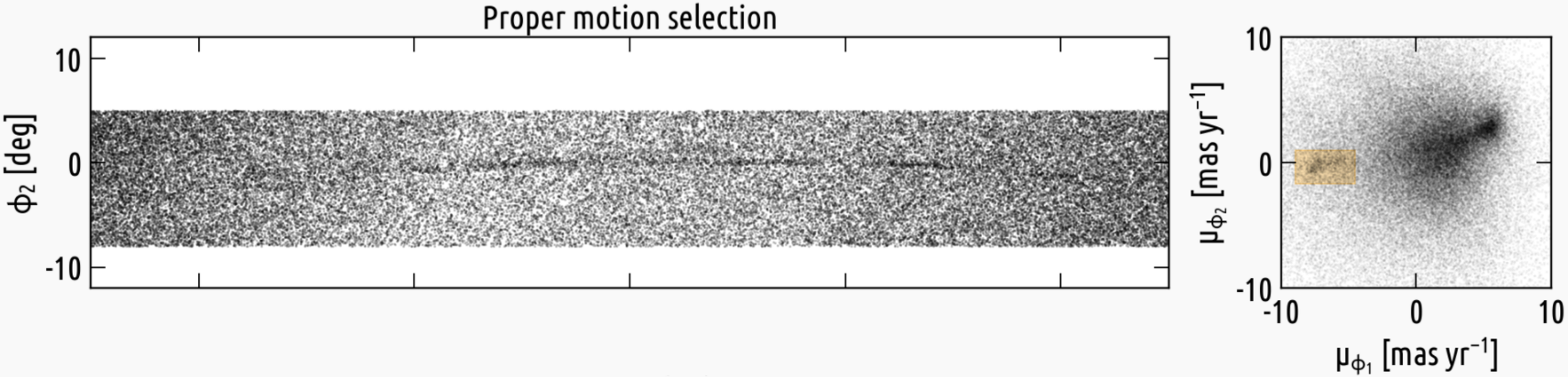

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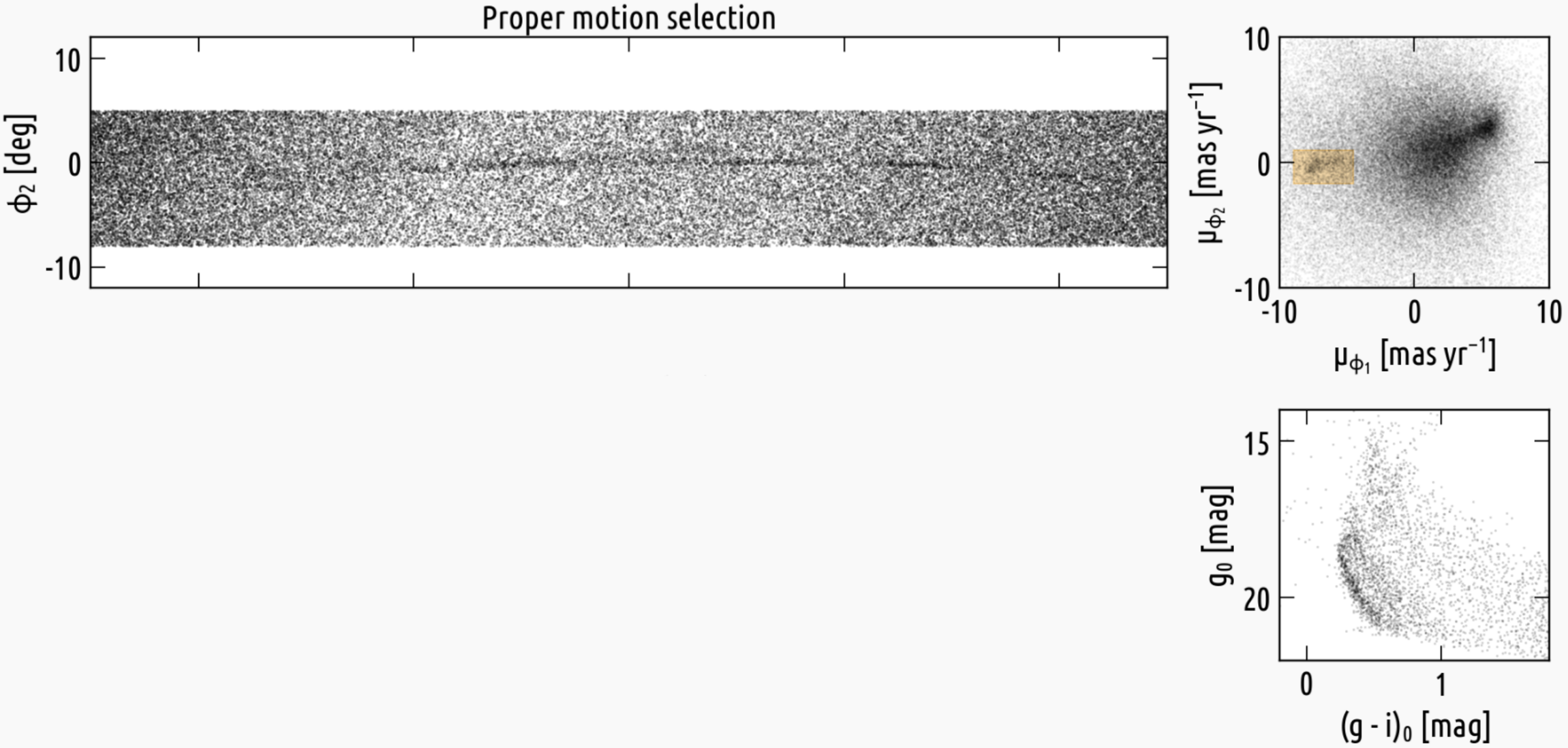

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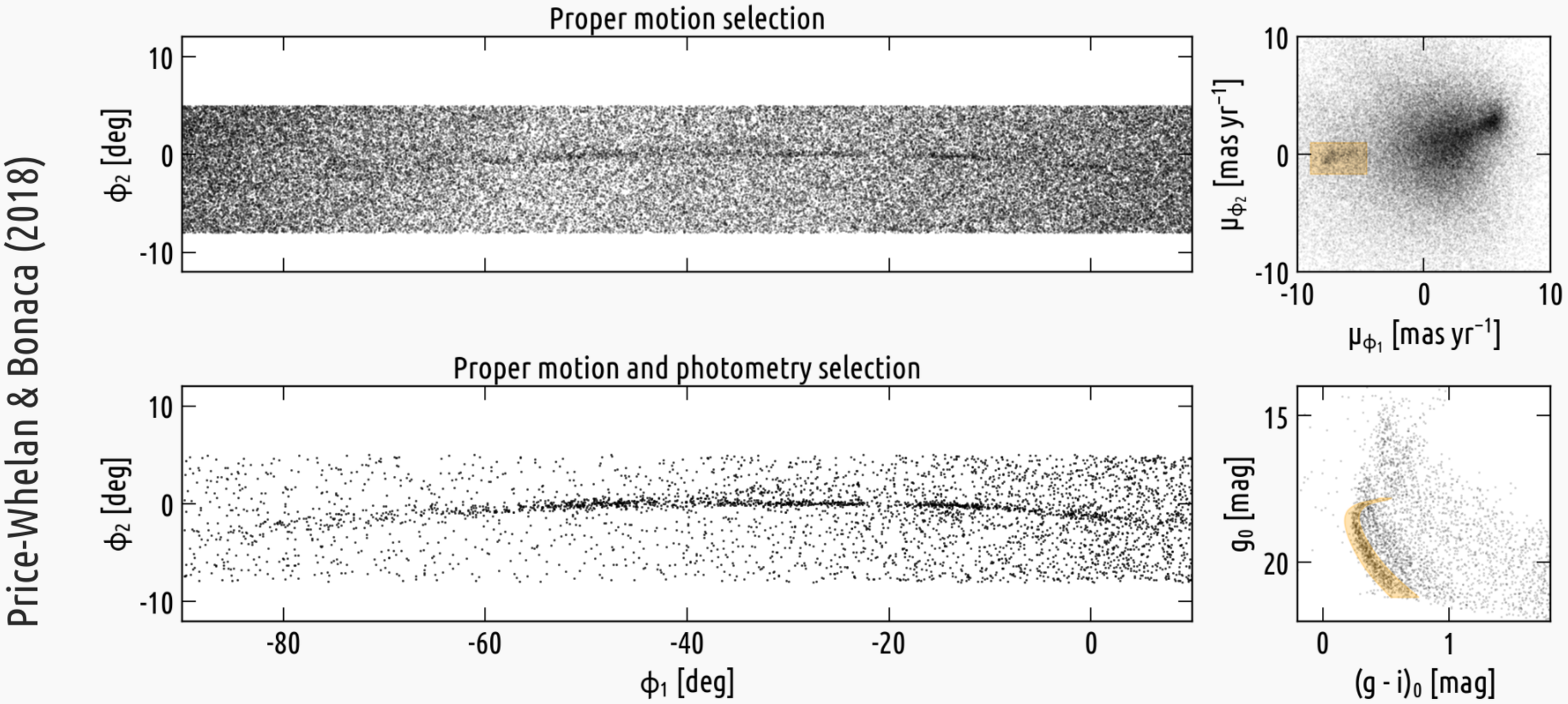

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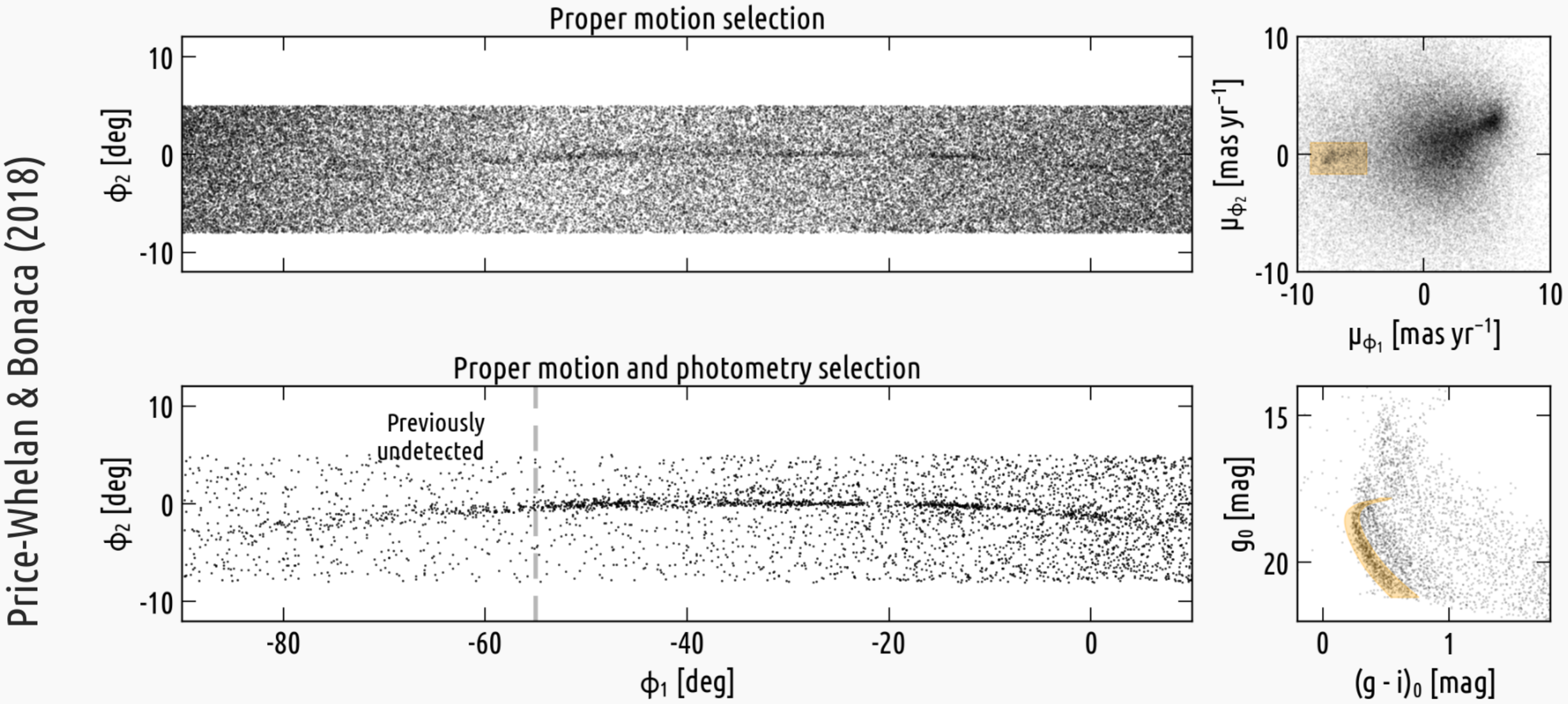

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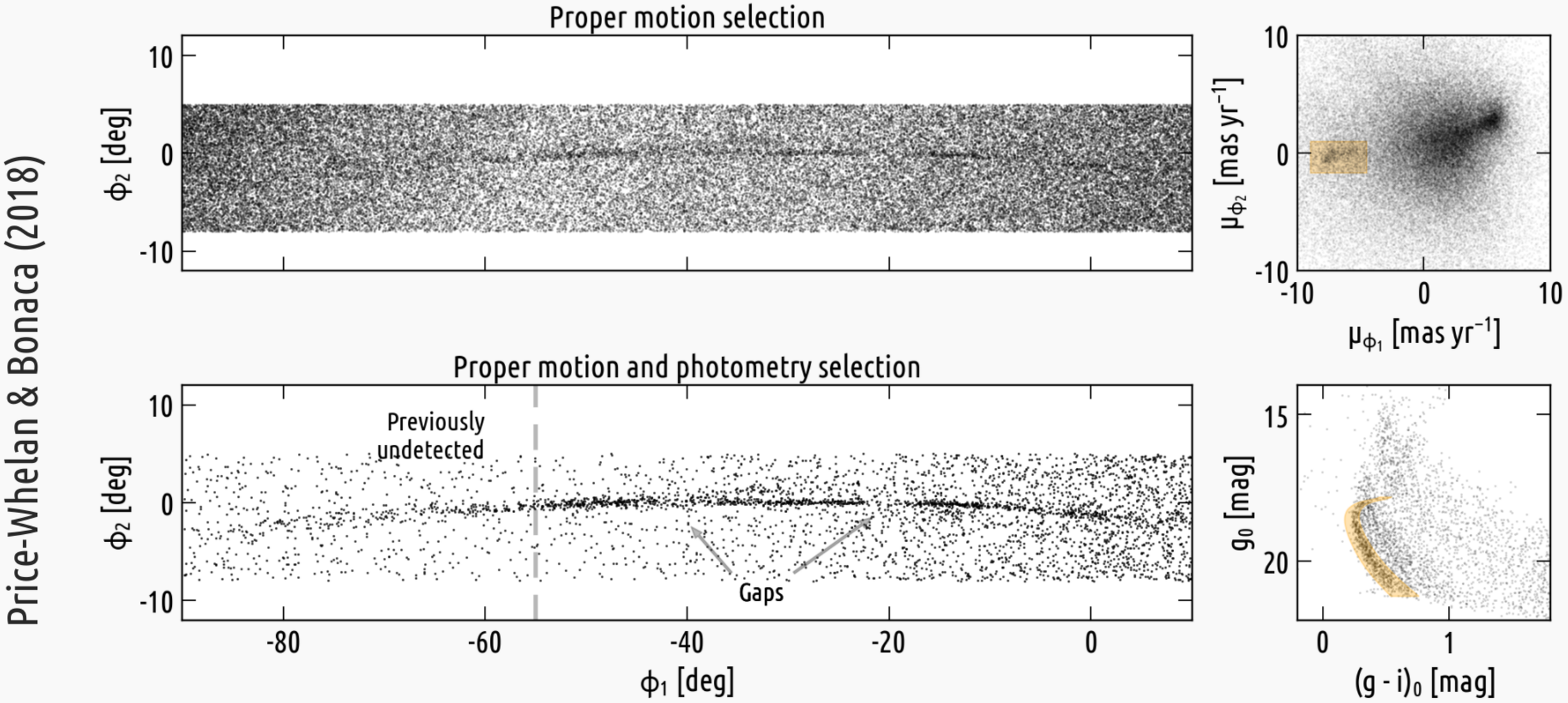

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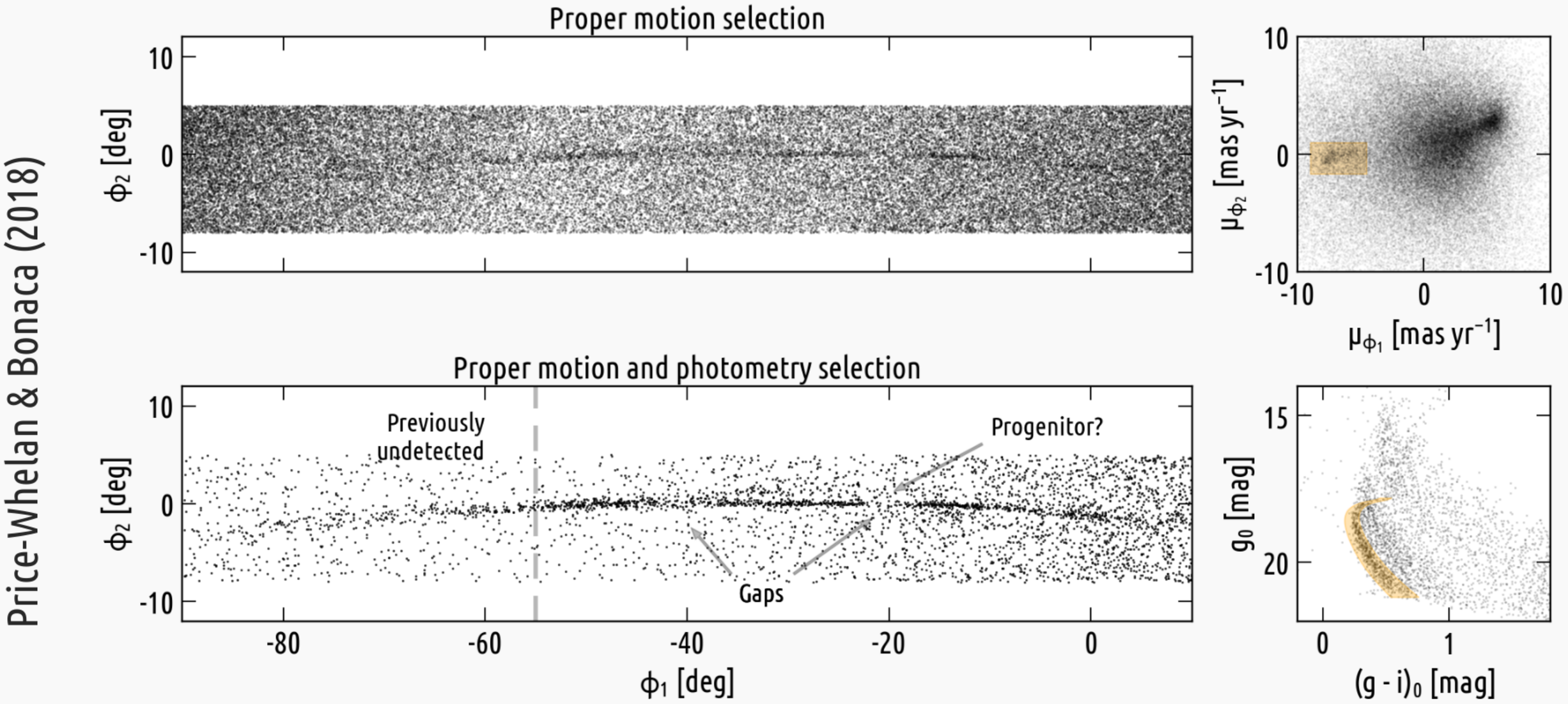

Price-Whelan & Bonaca (2018)

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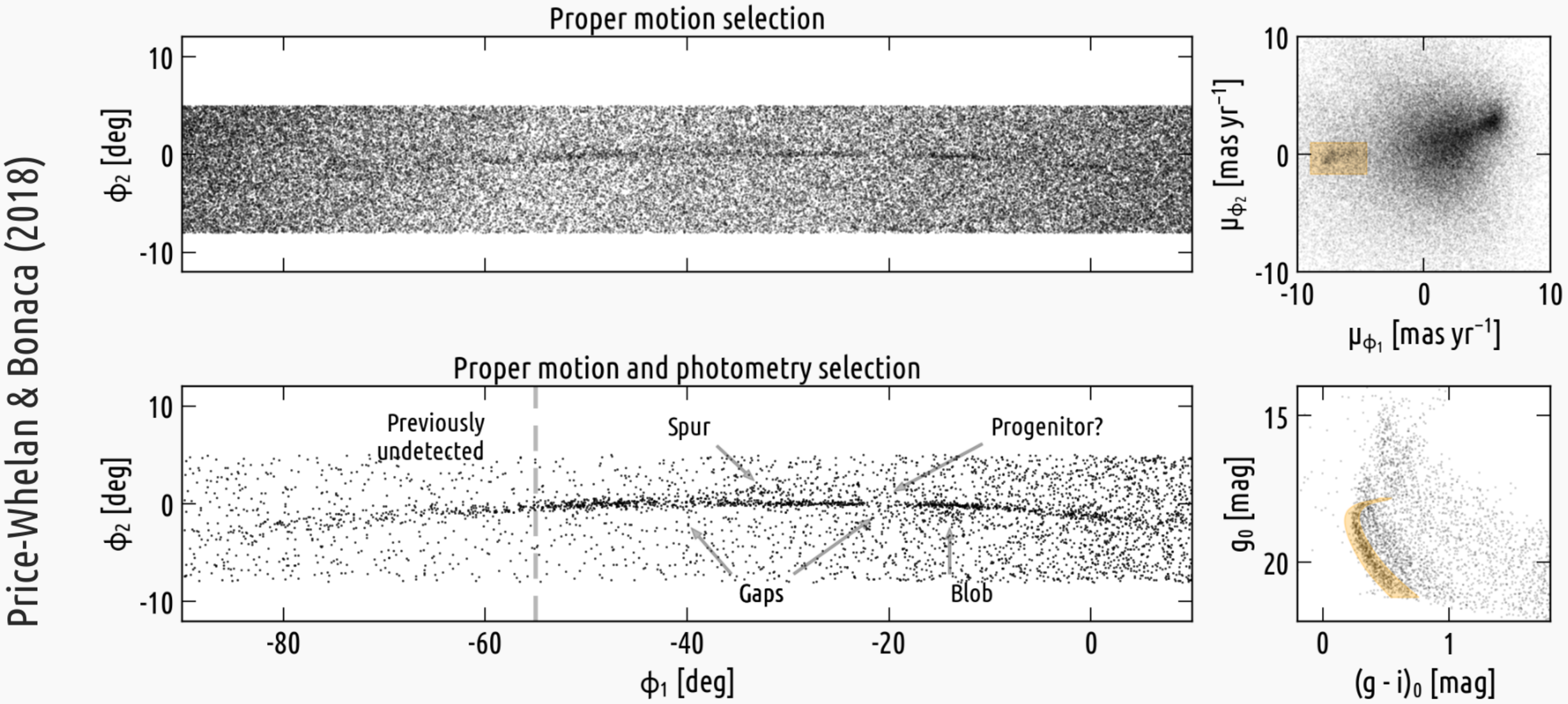
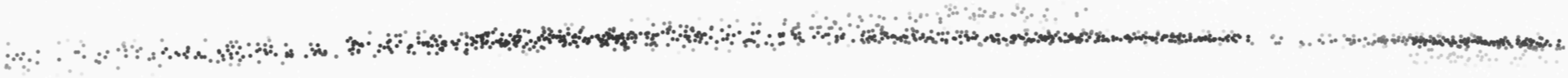


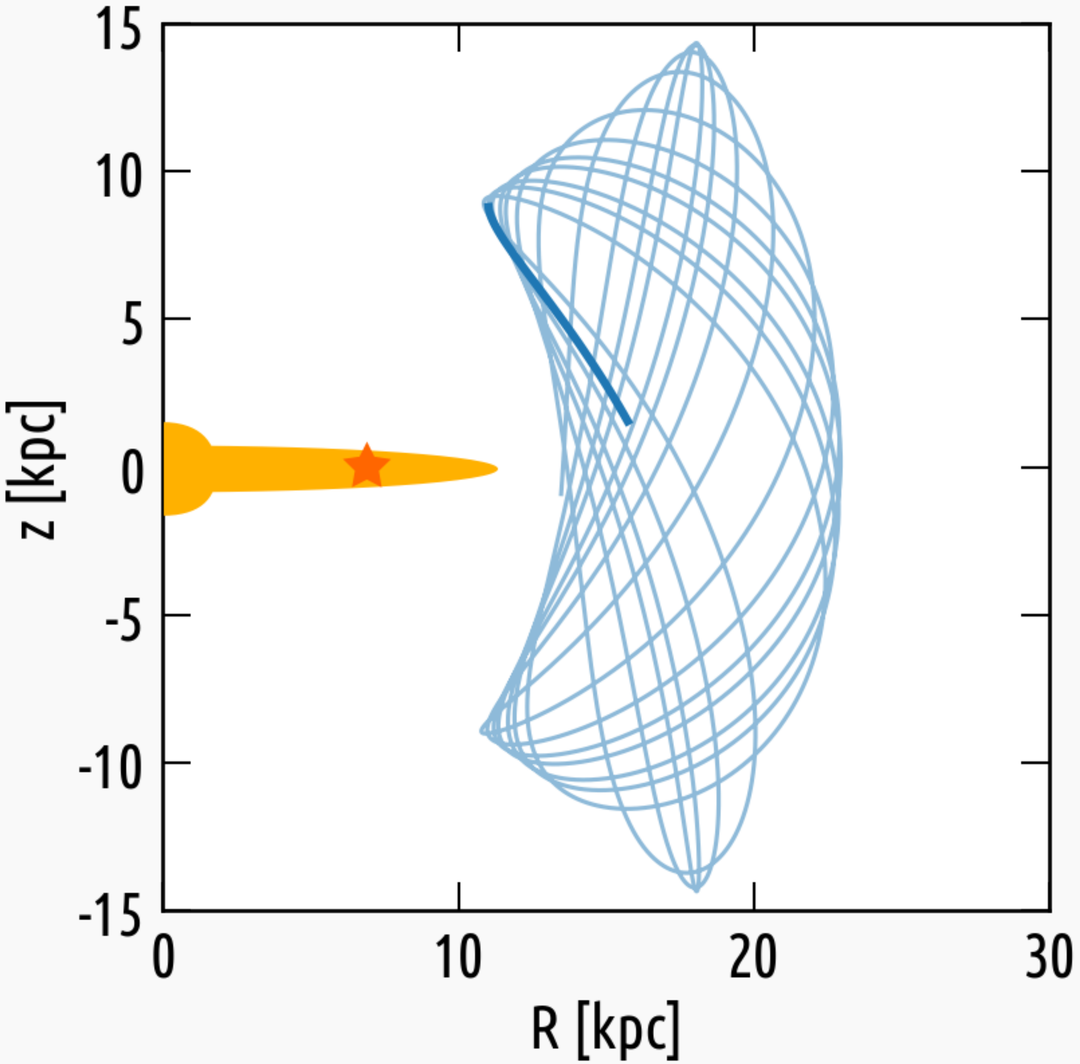
Price-Whelan & Bonaca (2018)

Observed GD-1 stellar stream



Model stellar stream

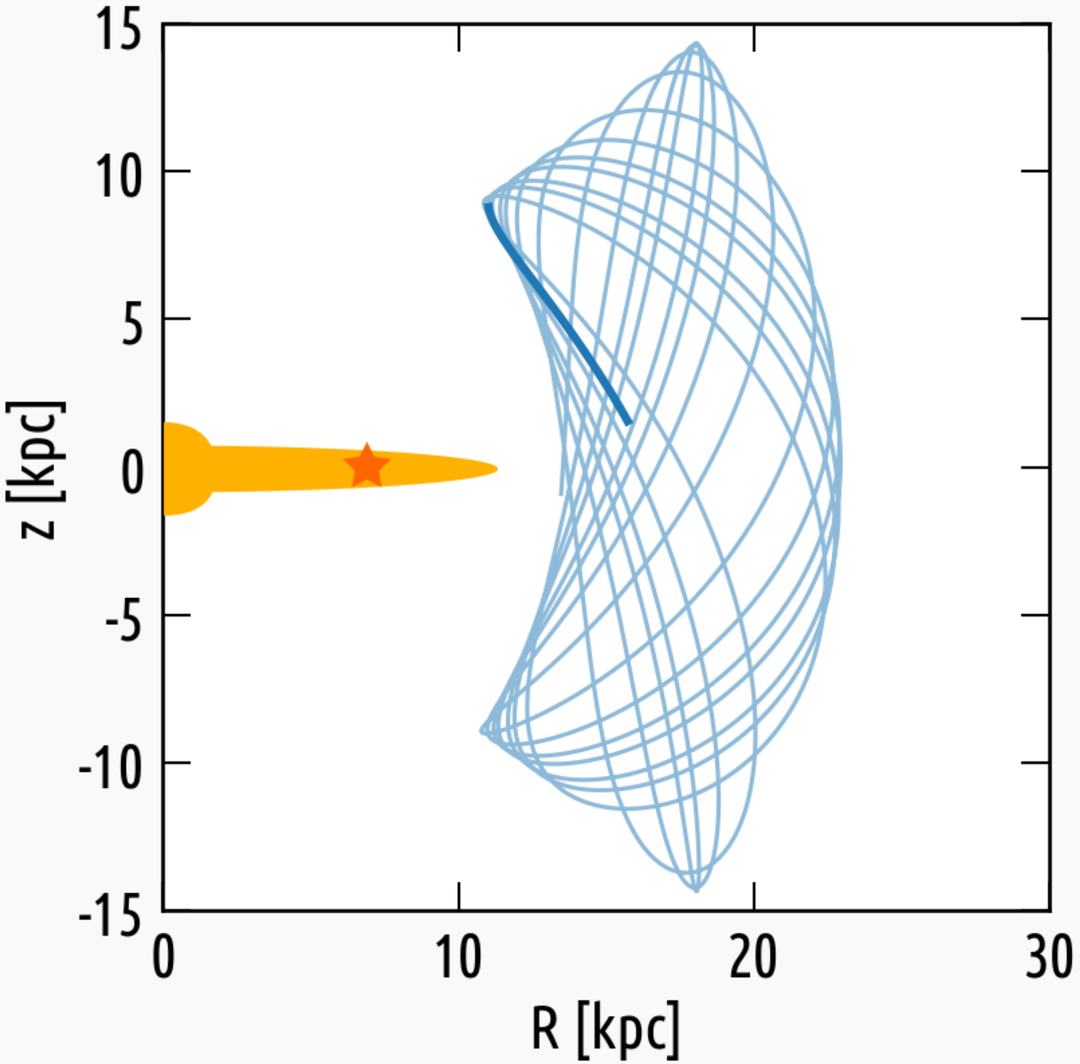
Who perturbed the GD-1 stream?



Whodunit:

(or candidates for the perturber)

Who perturbed the GD-1 stream?



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Globular cluster?

Dark matter clump?

Black hole?

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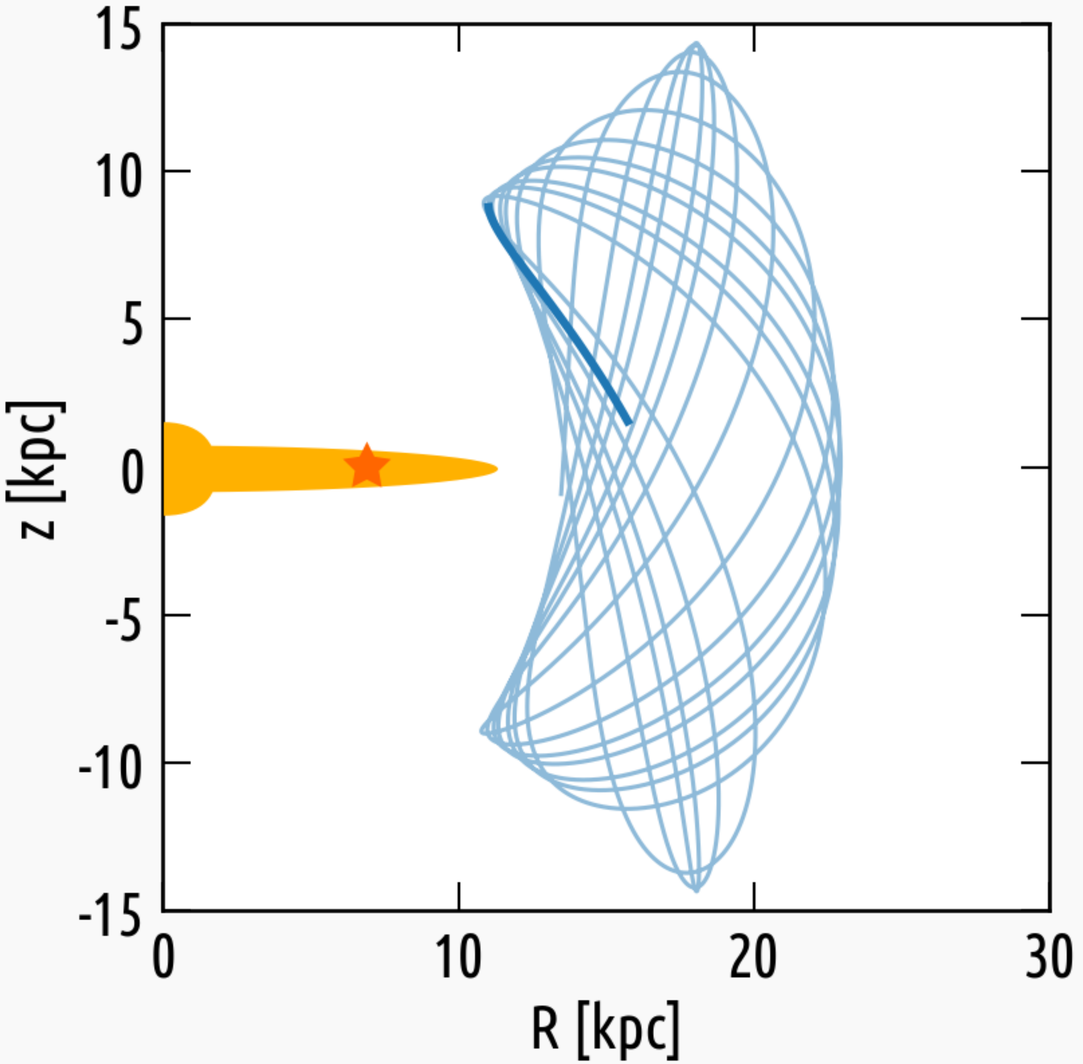

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(or candidates for the perturber)

Globular cluster?

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Howdunit:
(or properties of the perturber)

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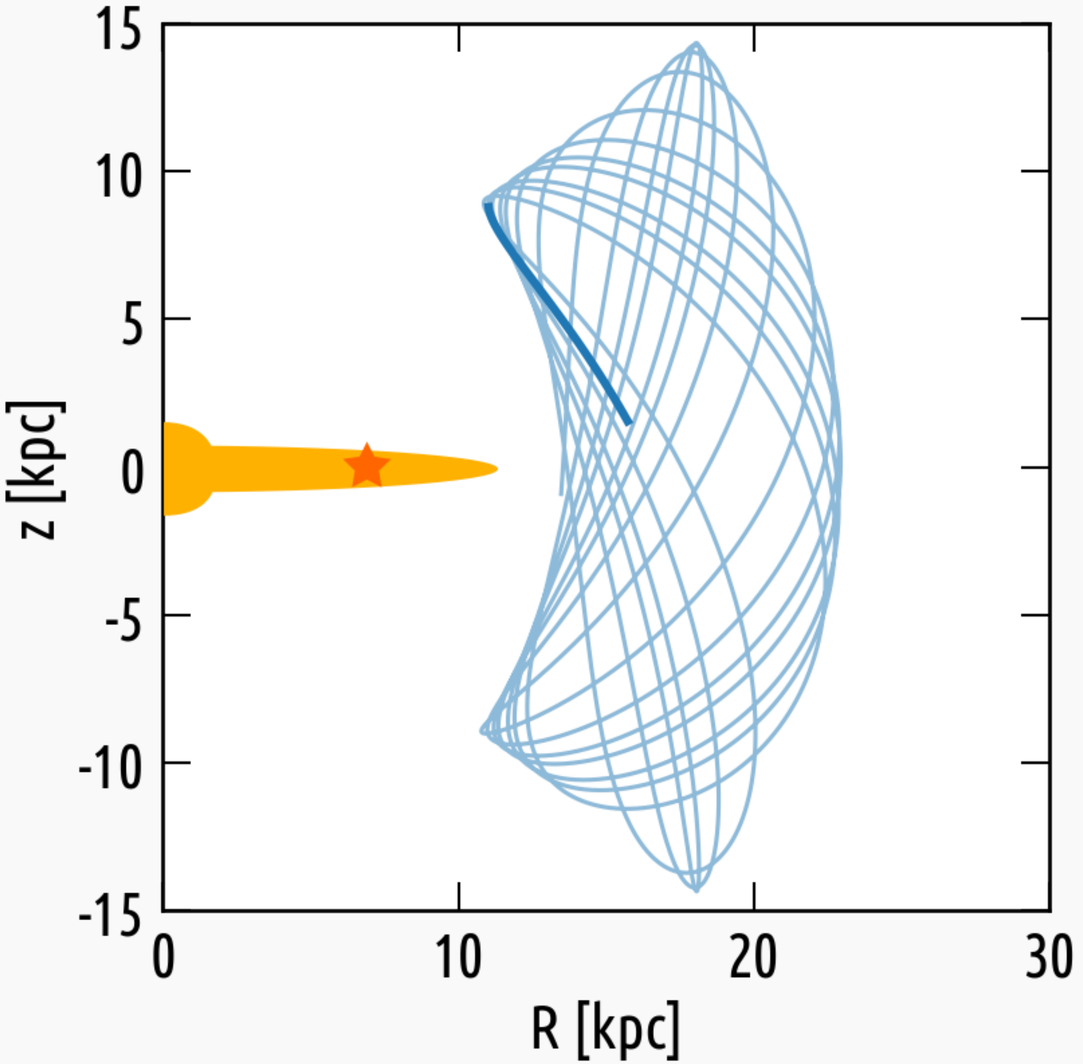


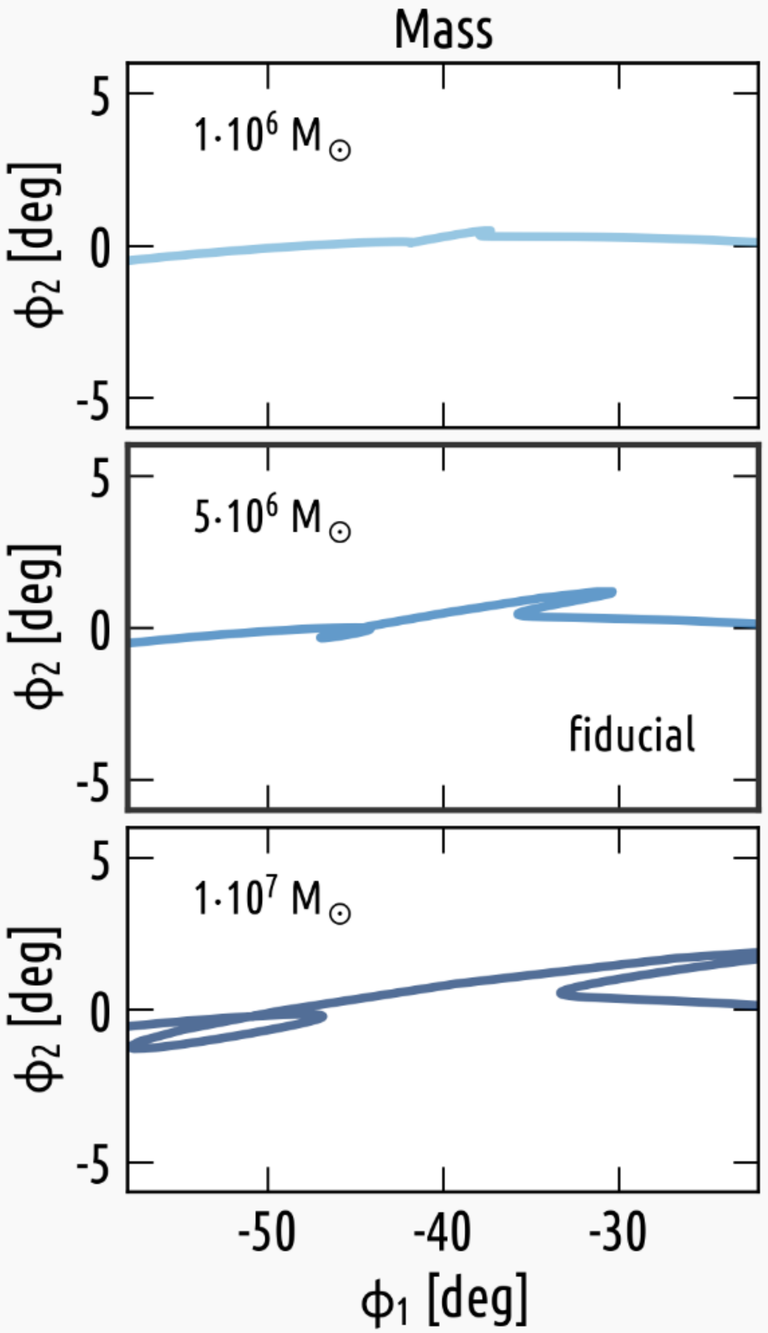
Whodunit:
(or candidates for the perturber)

- Globular cluster?
- Dark matter clump?
- Black hole?

Howdunit:
(or properties of the perturber)

- Mass
- Size
- Closest distance

Stream structure constrains the encounter parameters



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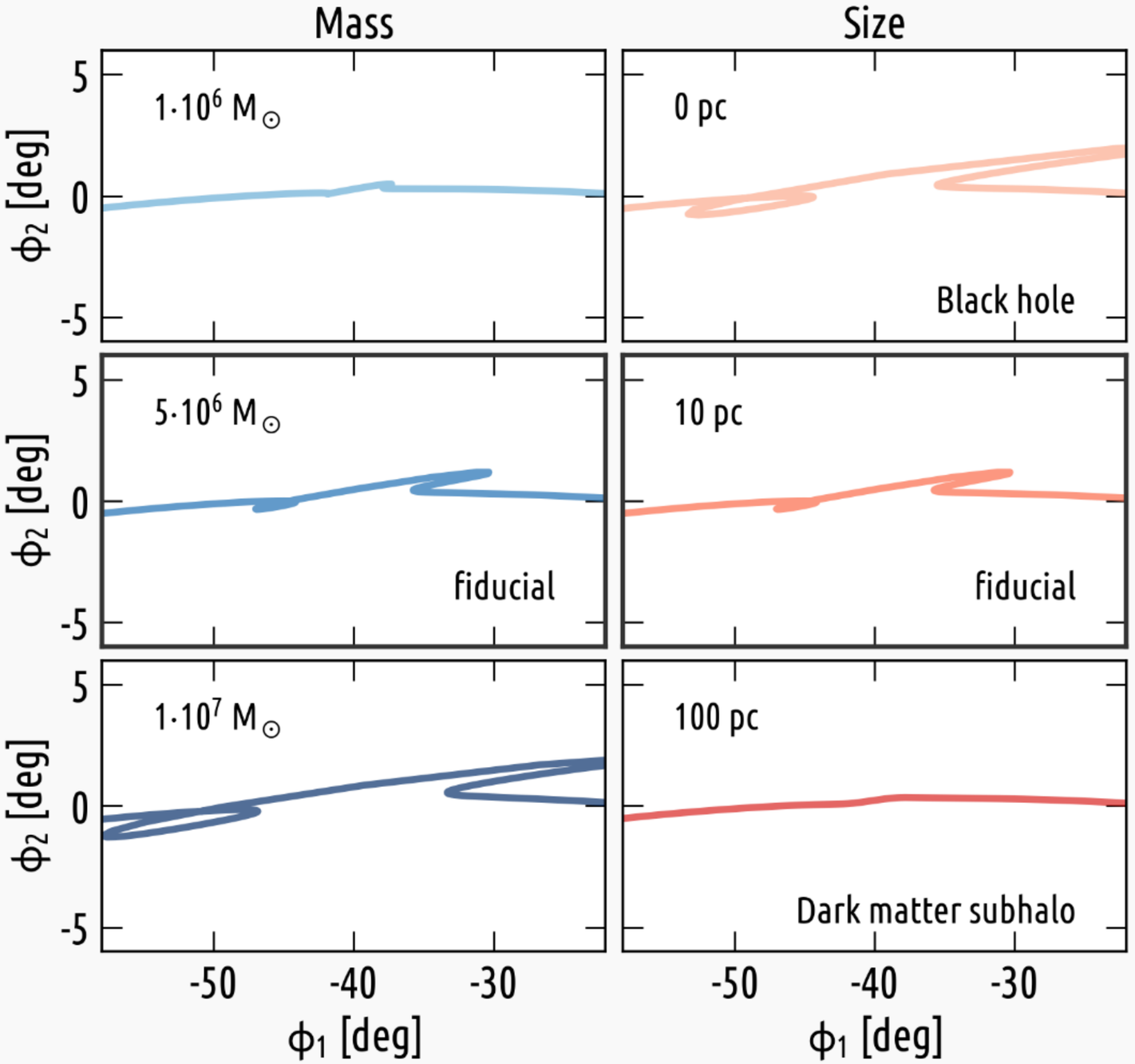

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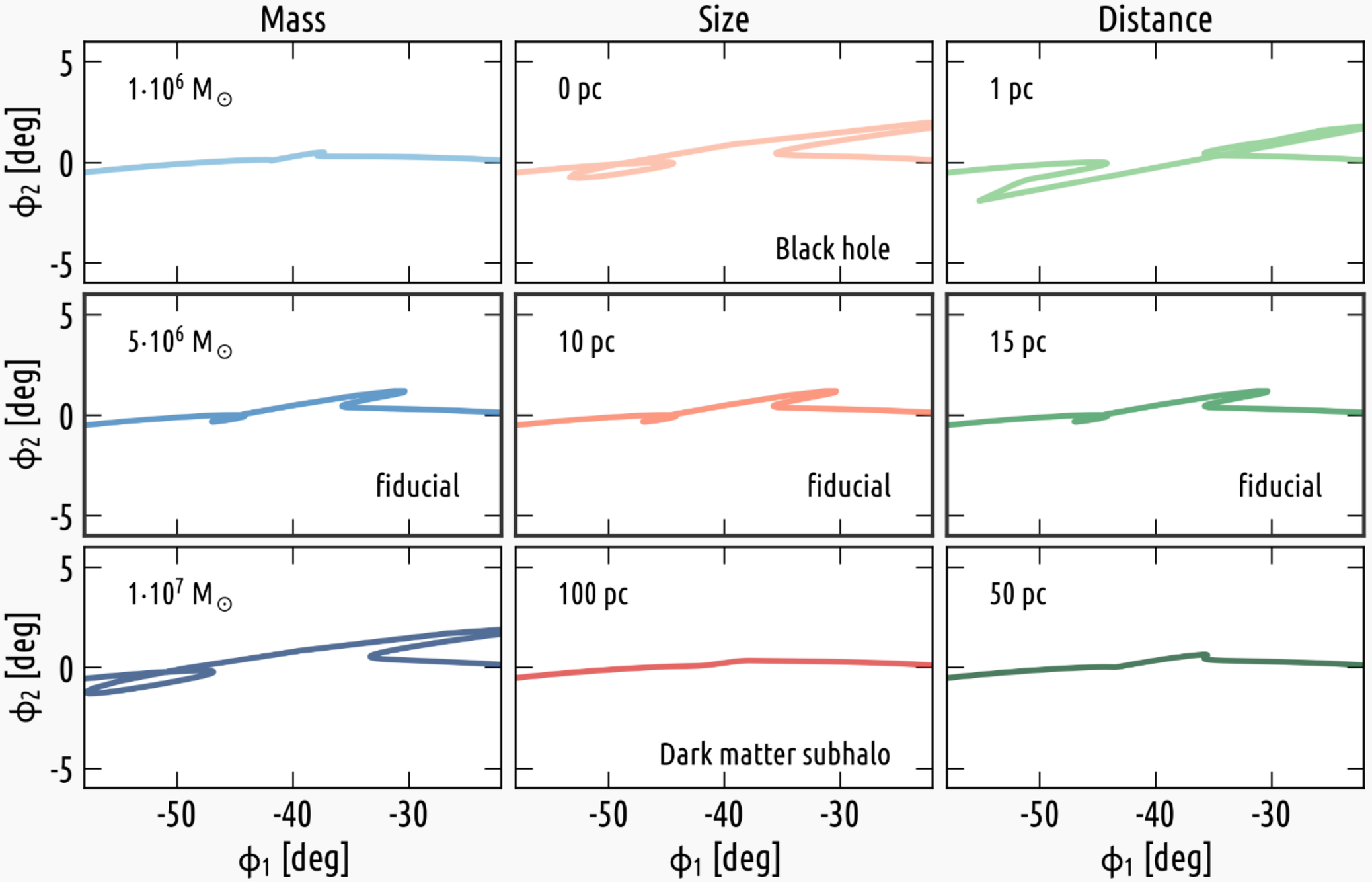
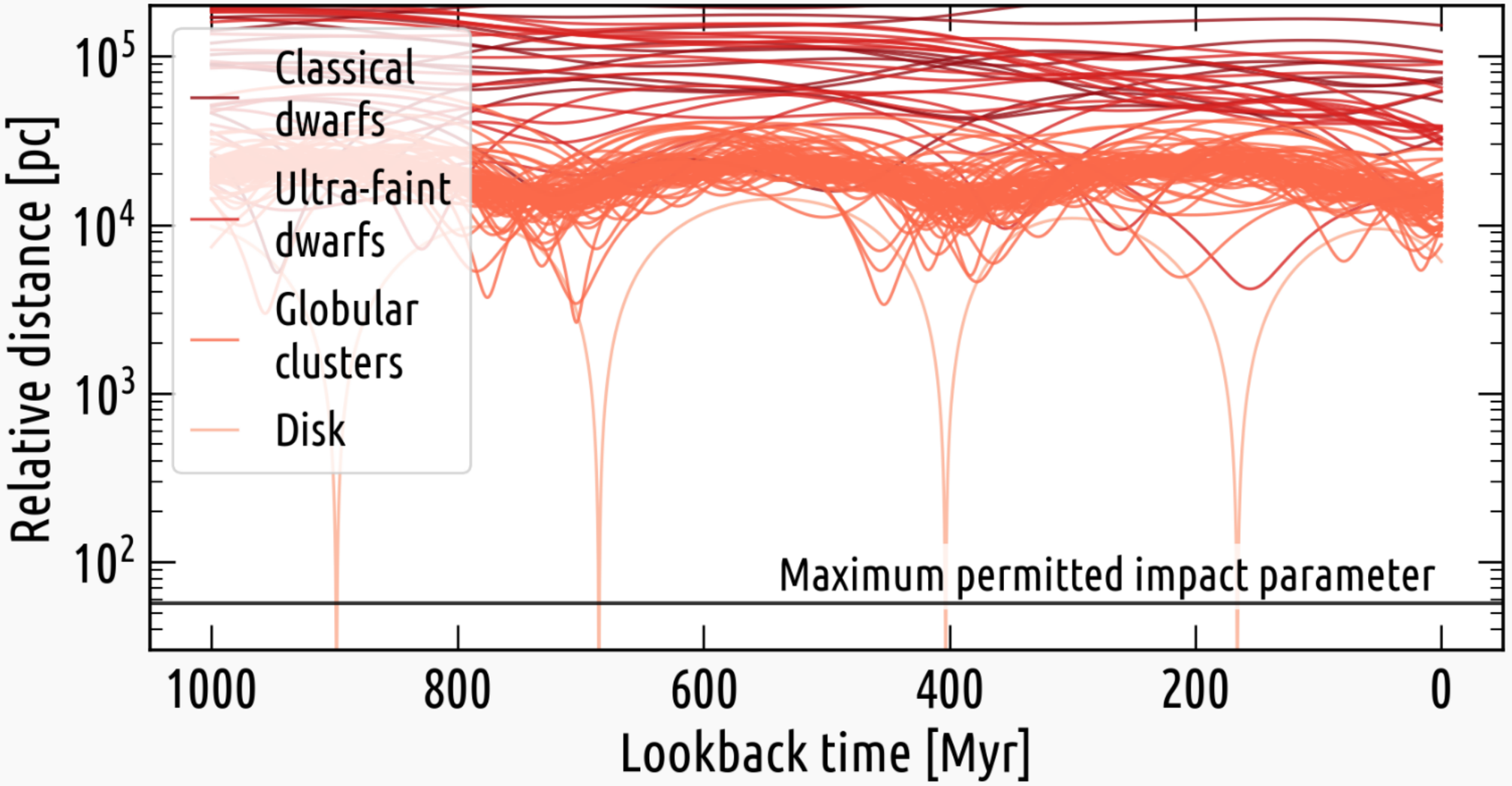
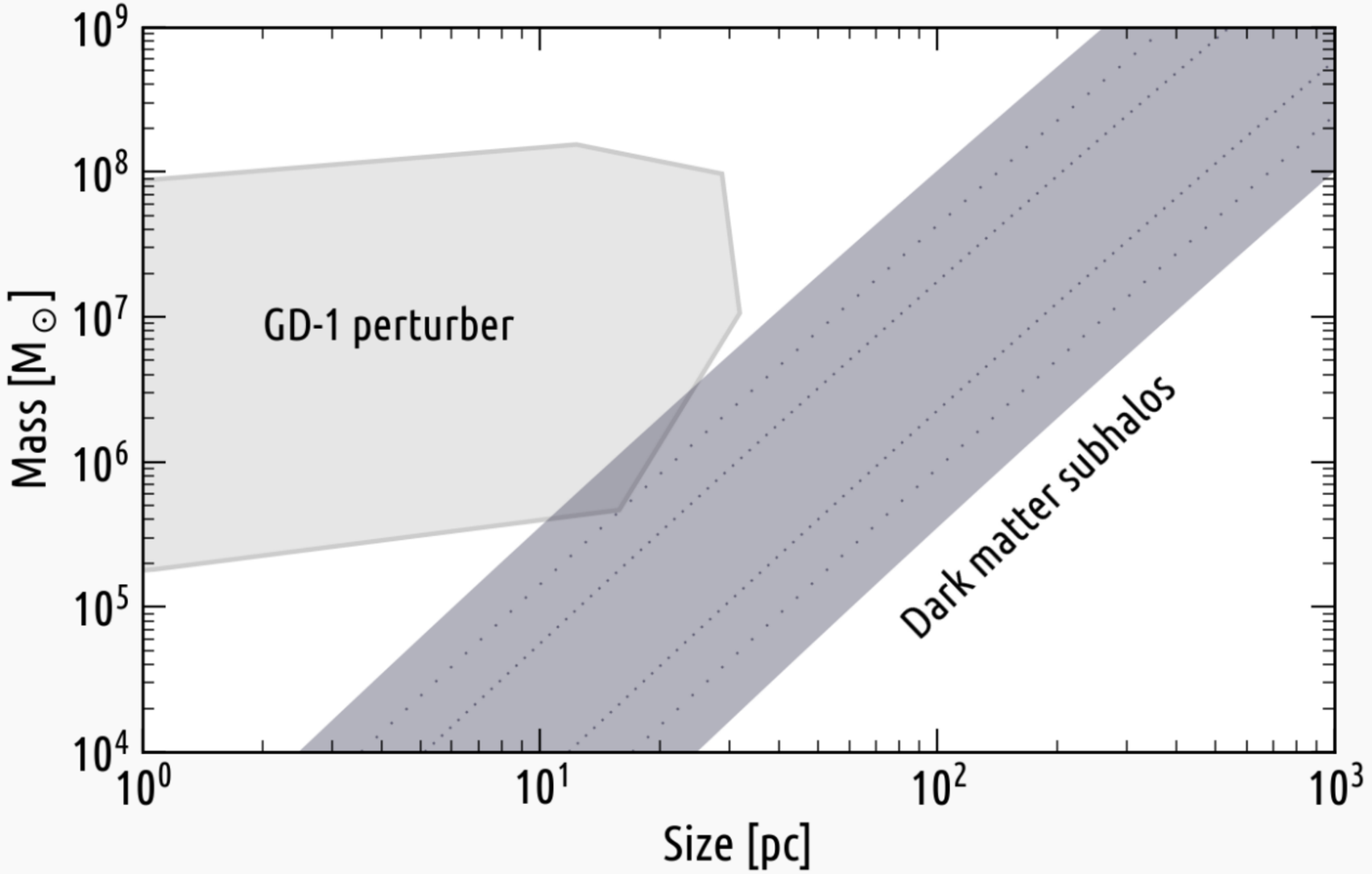


The GD-1 perturber is not a known satellite of the Milky Way

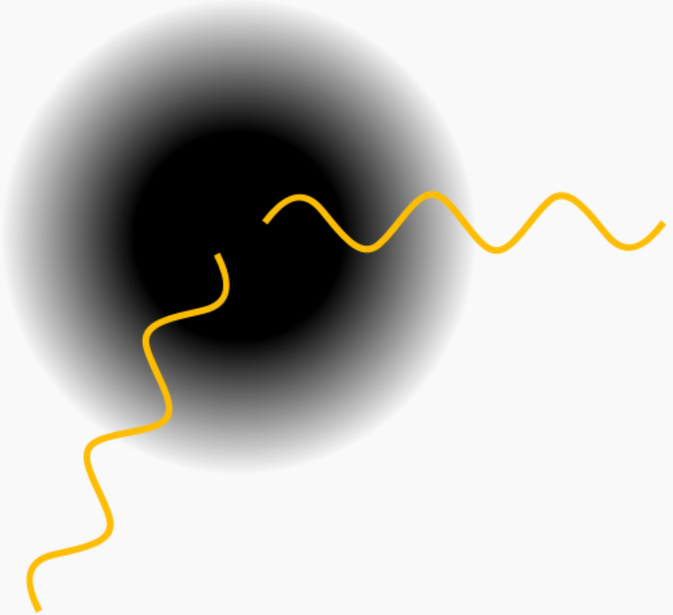


Dark matter subhalo is a plausible perturber of GD-1



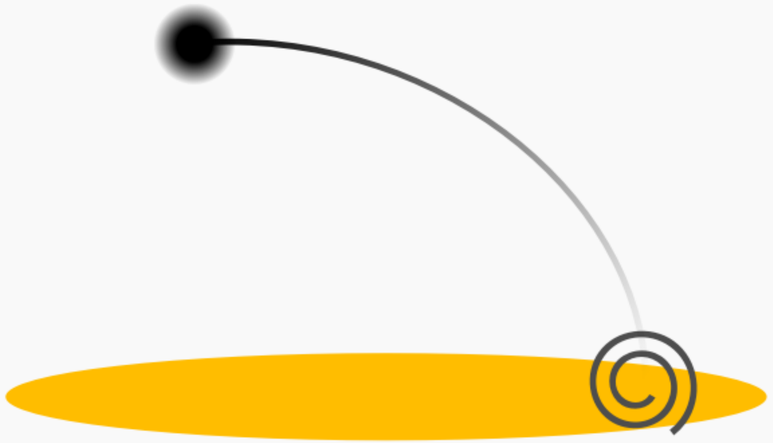
Additional signatures of the hypothetical perturber:

Annihilation



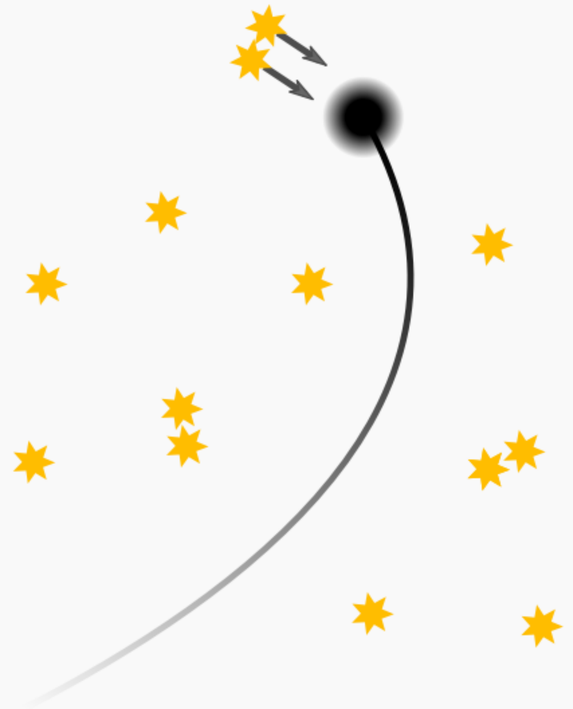
(e.g., Albert et al. 2017)

Disk disturbances



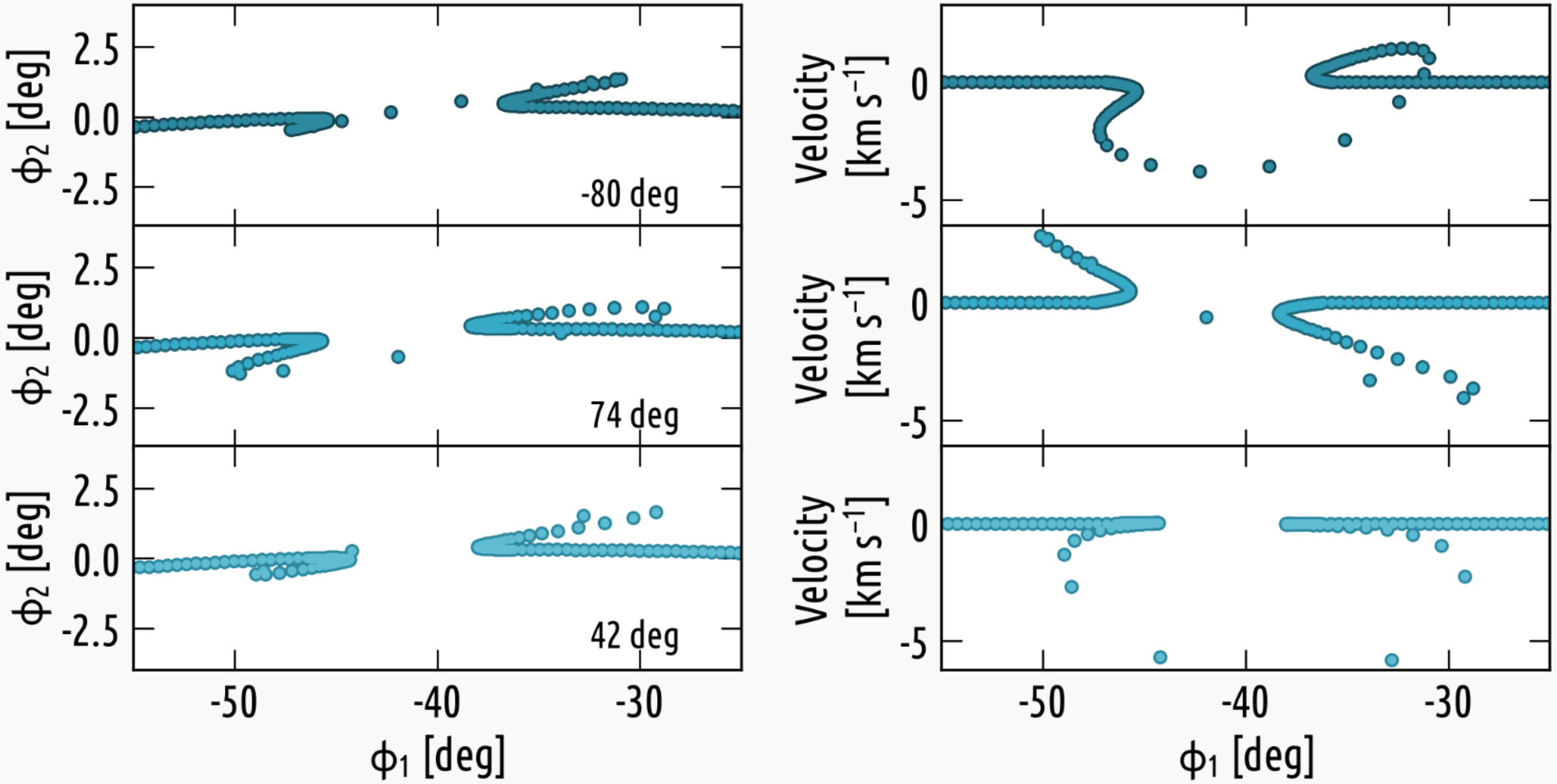
(e.g., Antoja et al. 2018)

Perturbations of halo stars

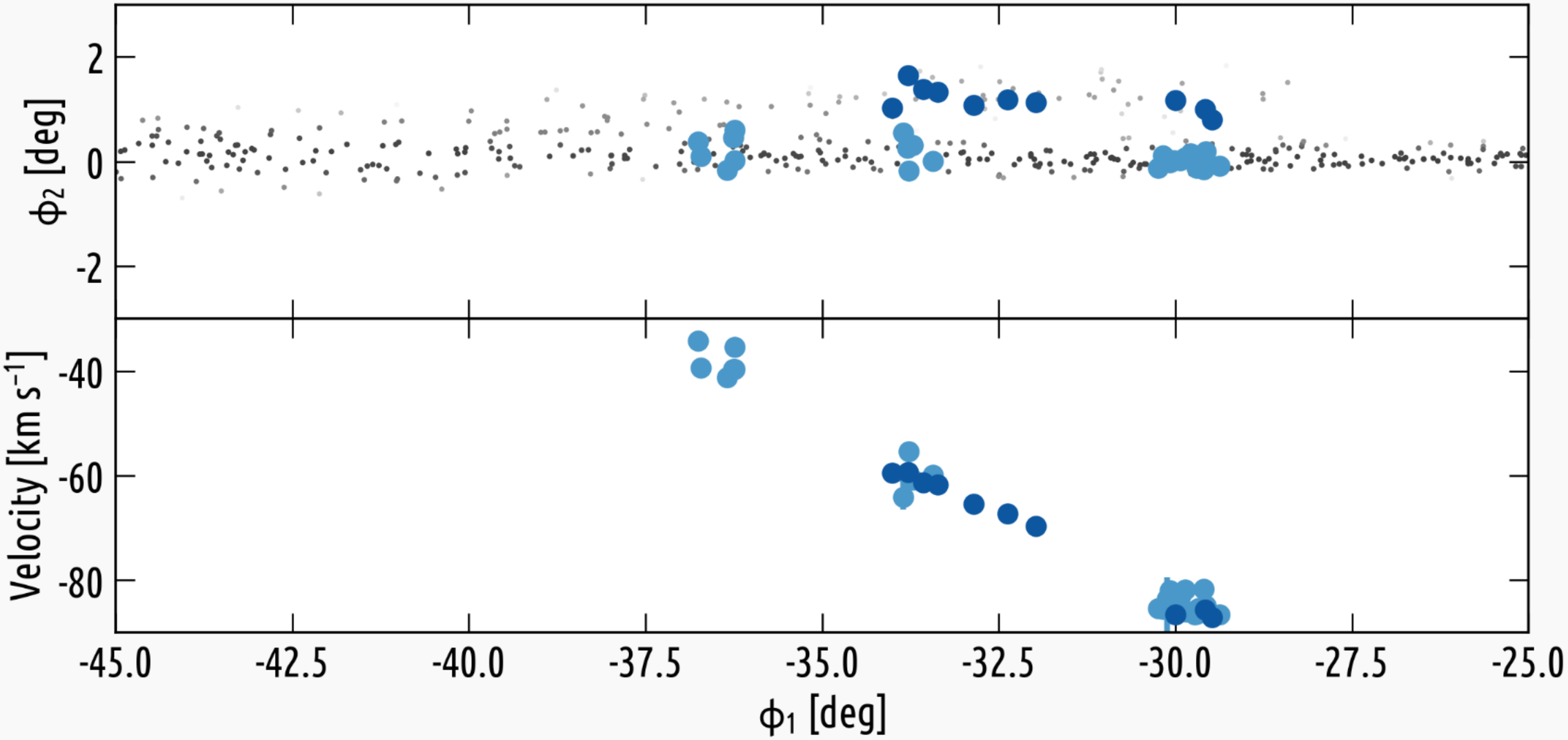


(e.g., van Tilburg et al. 2018)

Relative velocity will determine the perturber's orbit



Perturbed stars are moving at the speed of unperturbed stars



In the next decade, we will find streams throughout the Milky Way