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

Ana Bonaca
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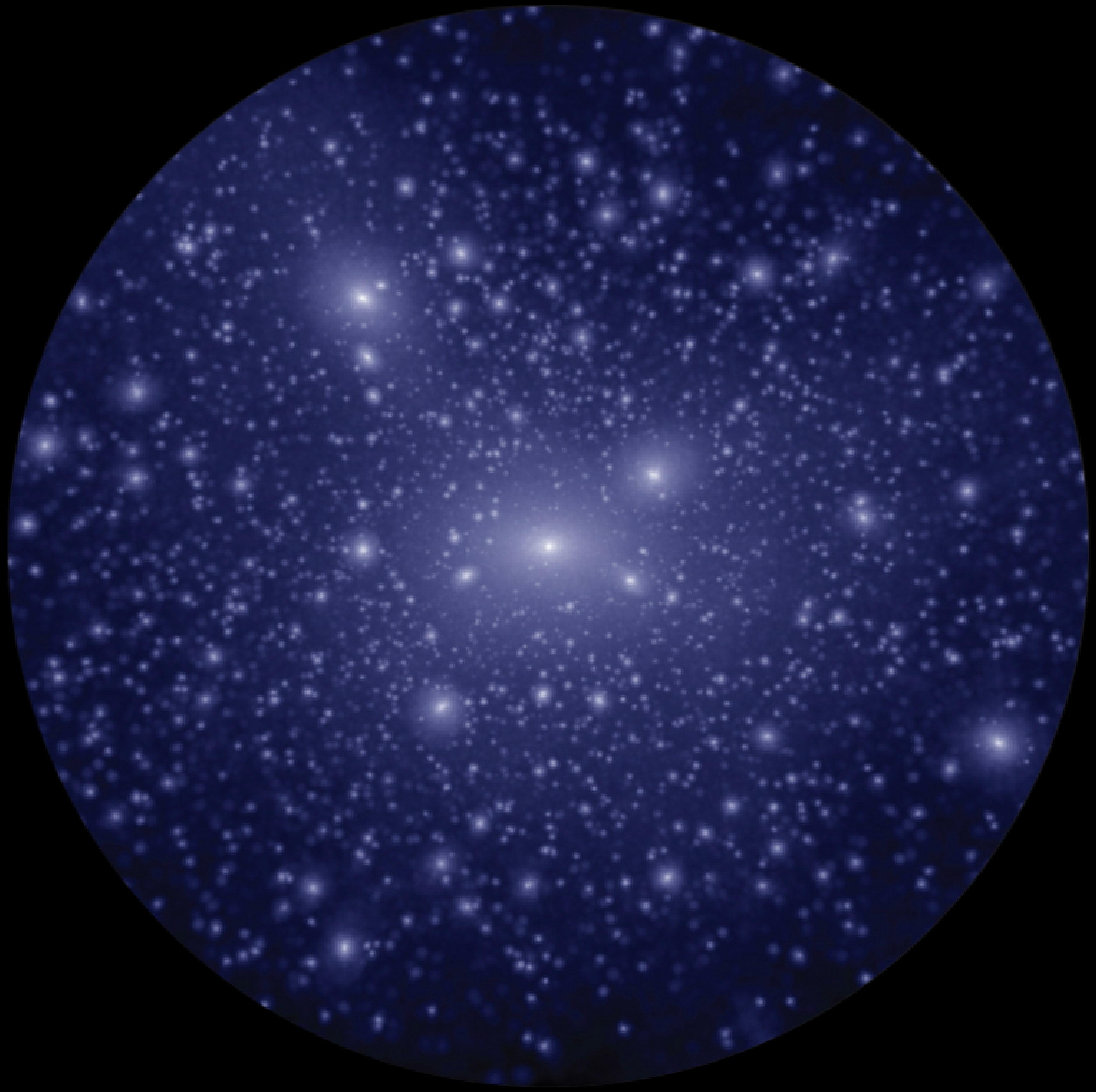
Center for Astrophysics
Harvard & Smithsonian

CDM model matches the distribution of galaxies on large scales

Kaehler / KIPAC

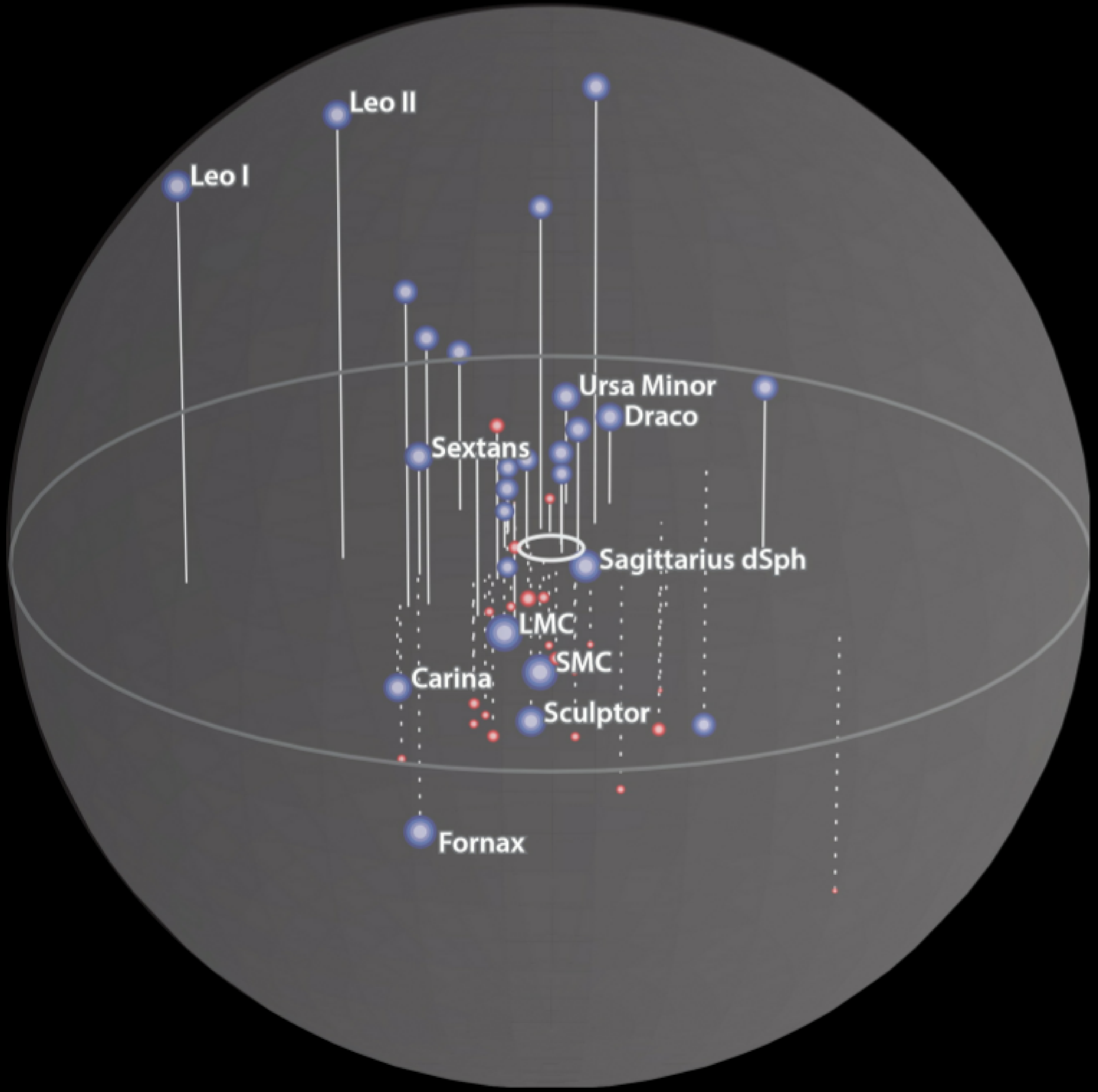
We don't see all the structure predicted by CDM on small scales

Dark matter in a simulated galaxy



Robles, Kelley, Bullock, Boylan-Kolchin

Satellite galaxies of the Milky Way



Pawlowski, Bullock, Boylan-Kolchin

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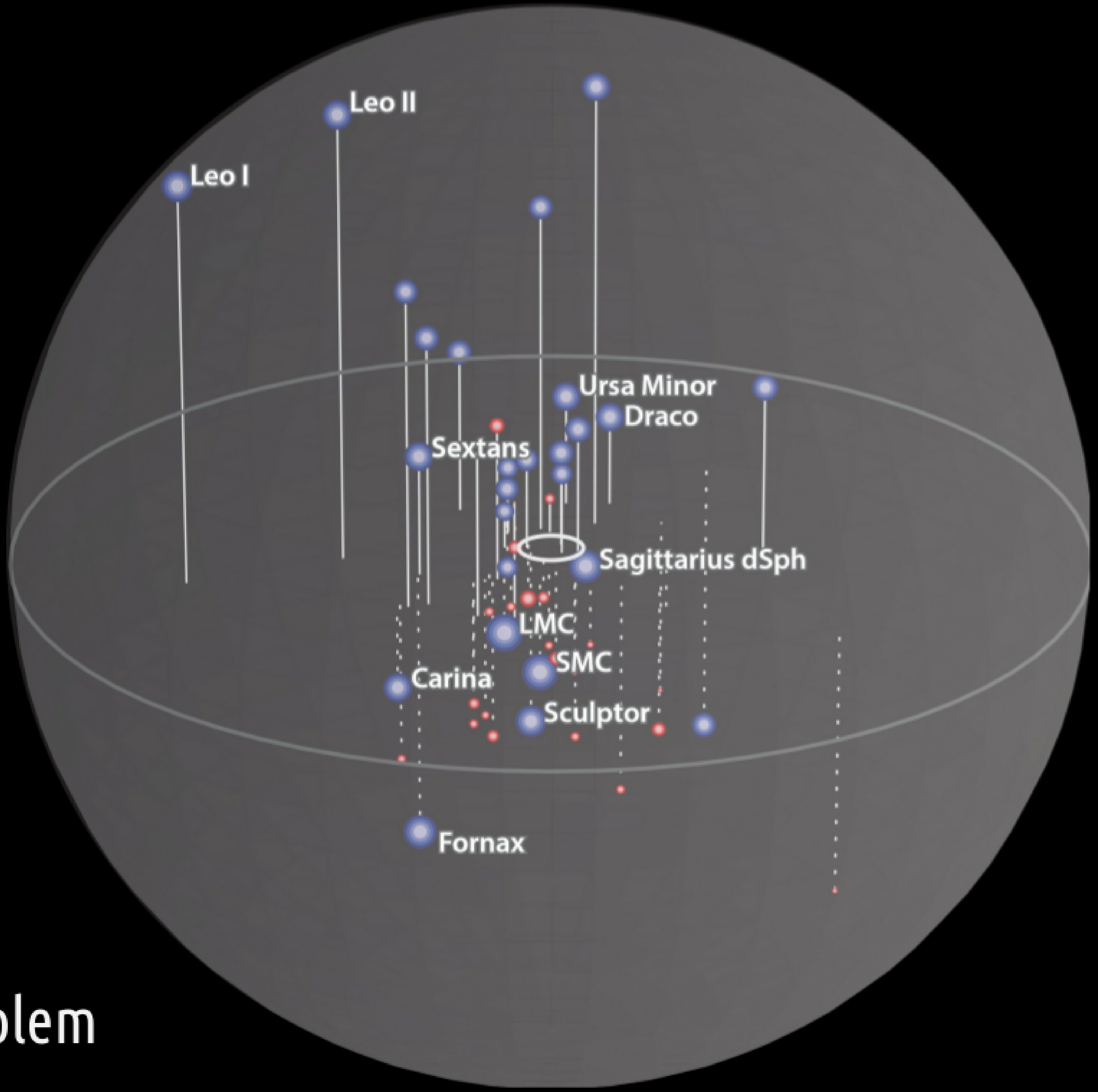
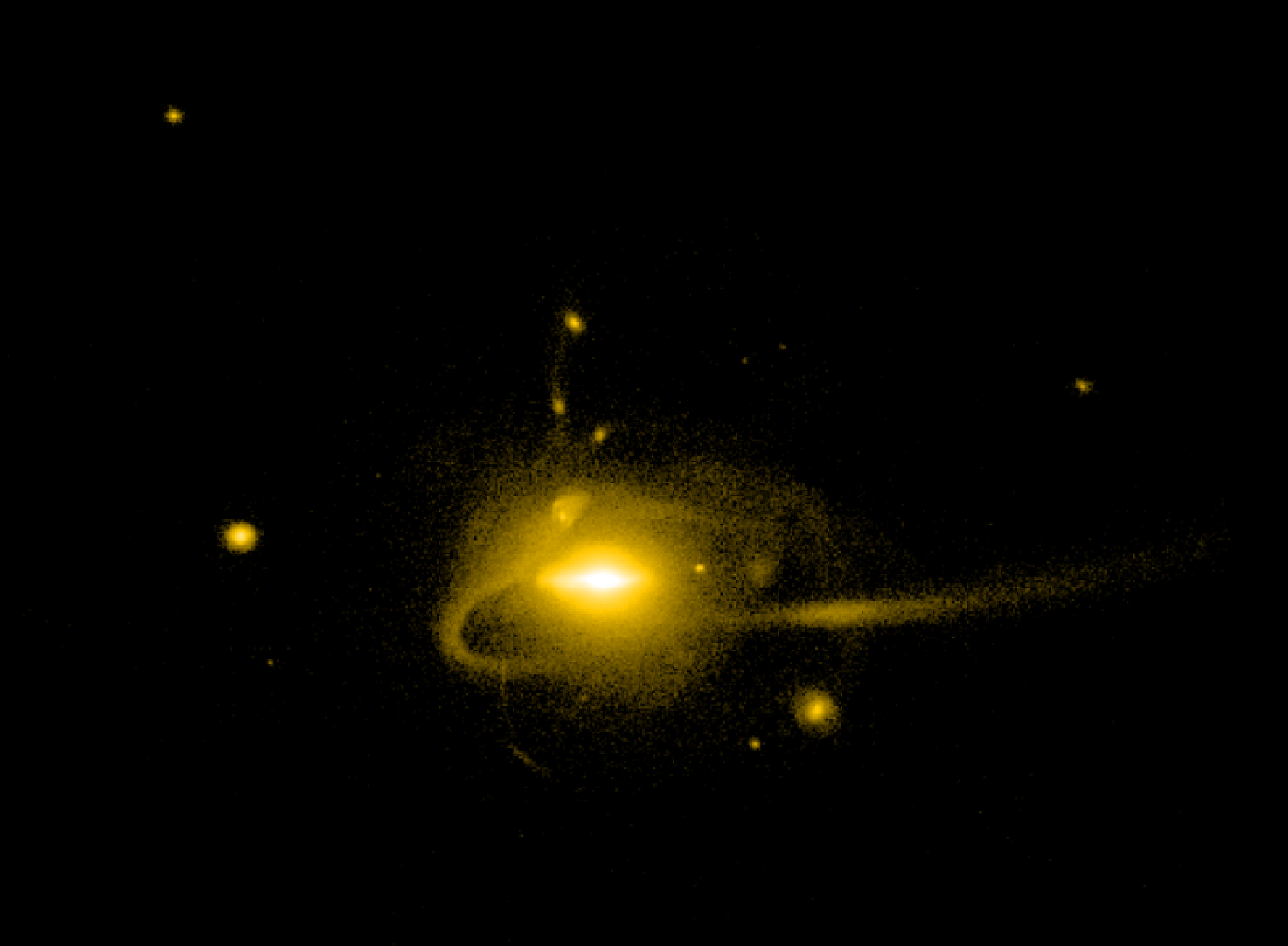


Pawlowski, Bullock, Boylan-Kolchin

The Missing Satellites Problem

We don't see all the structure predicted by CDM on small scales

Stars in a simulated galaxy with baryons



Wetzel et al. (2016)

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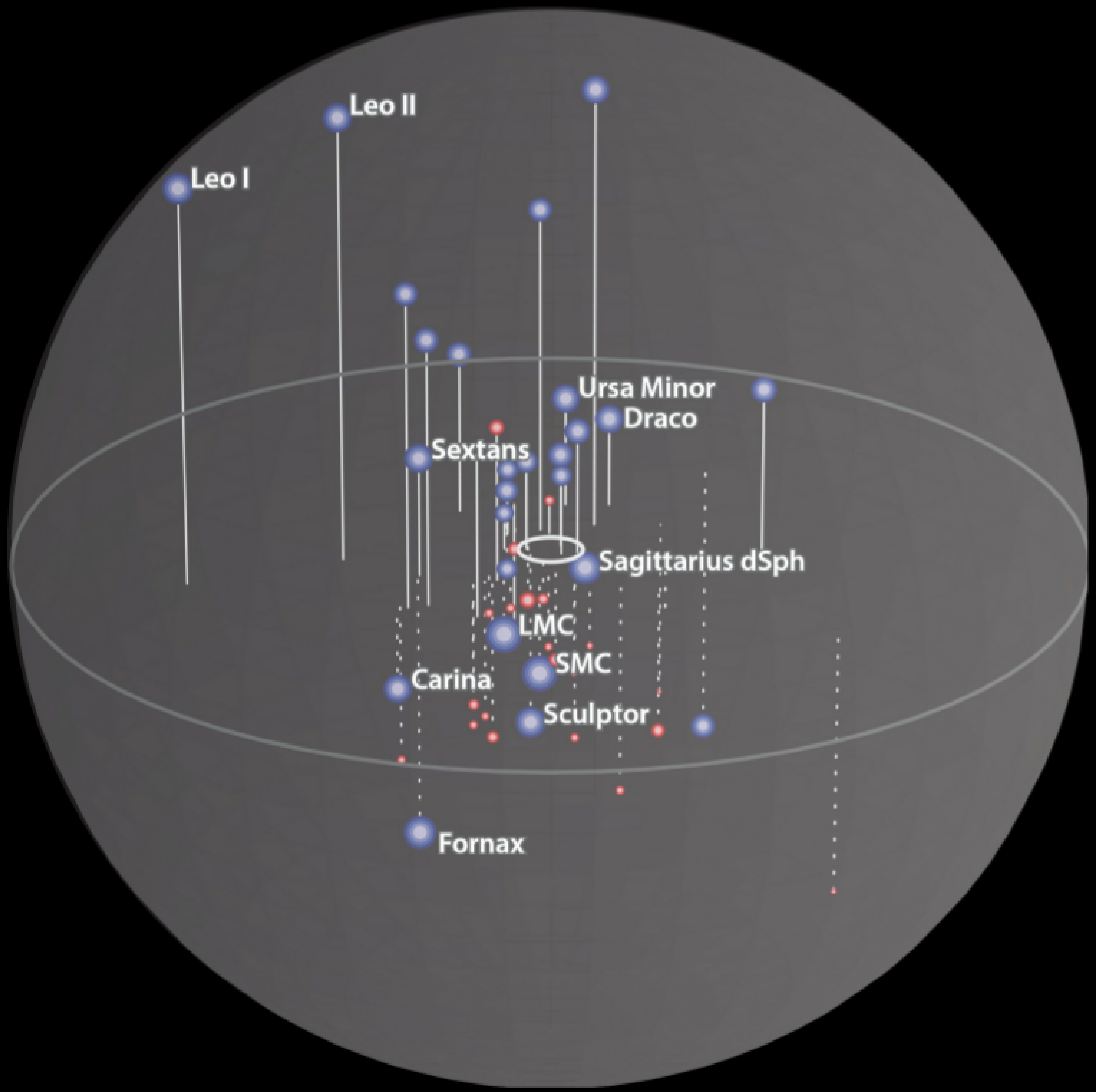

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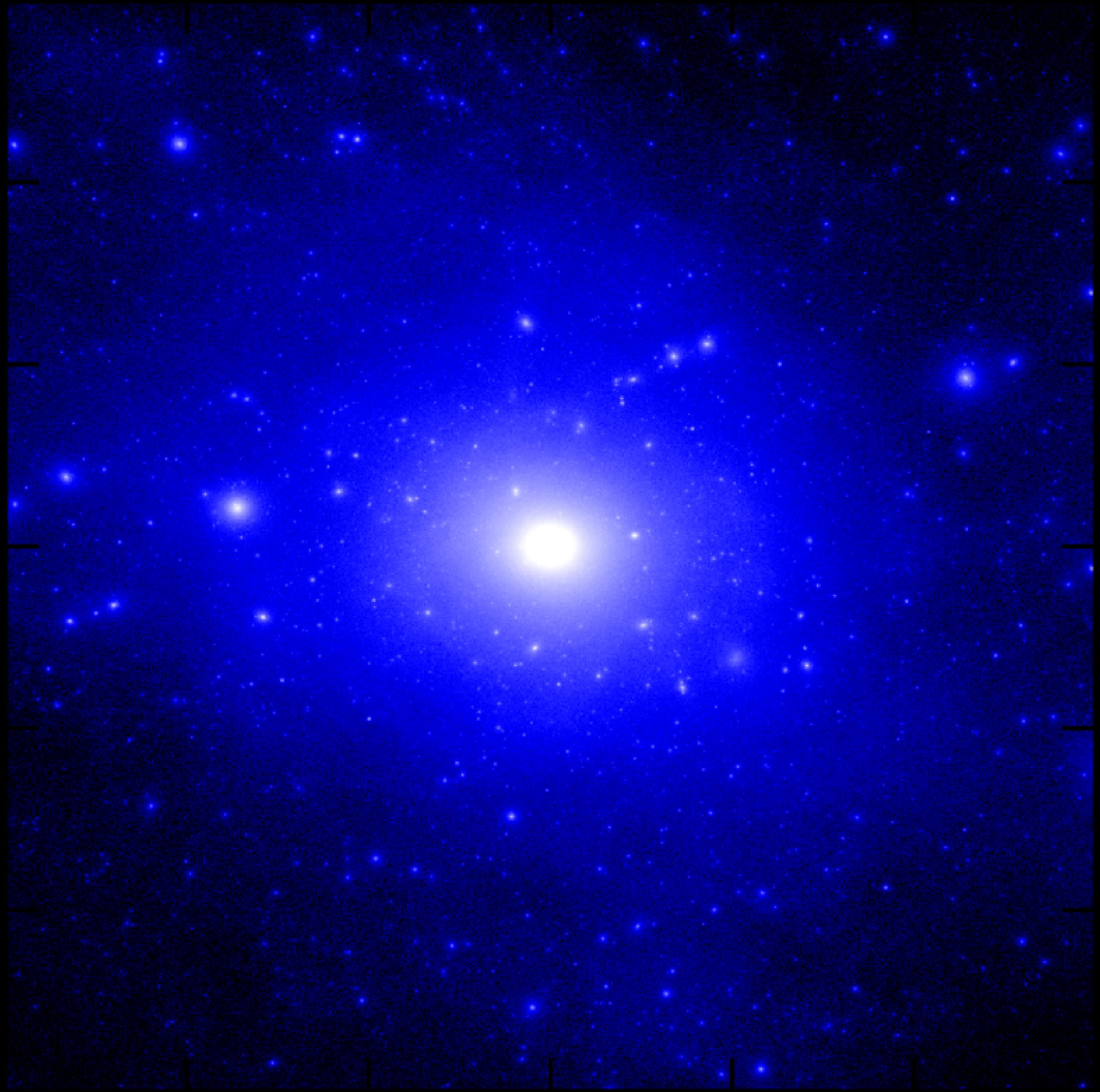

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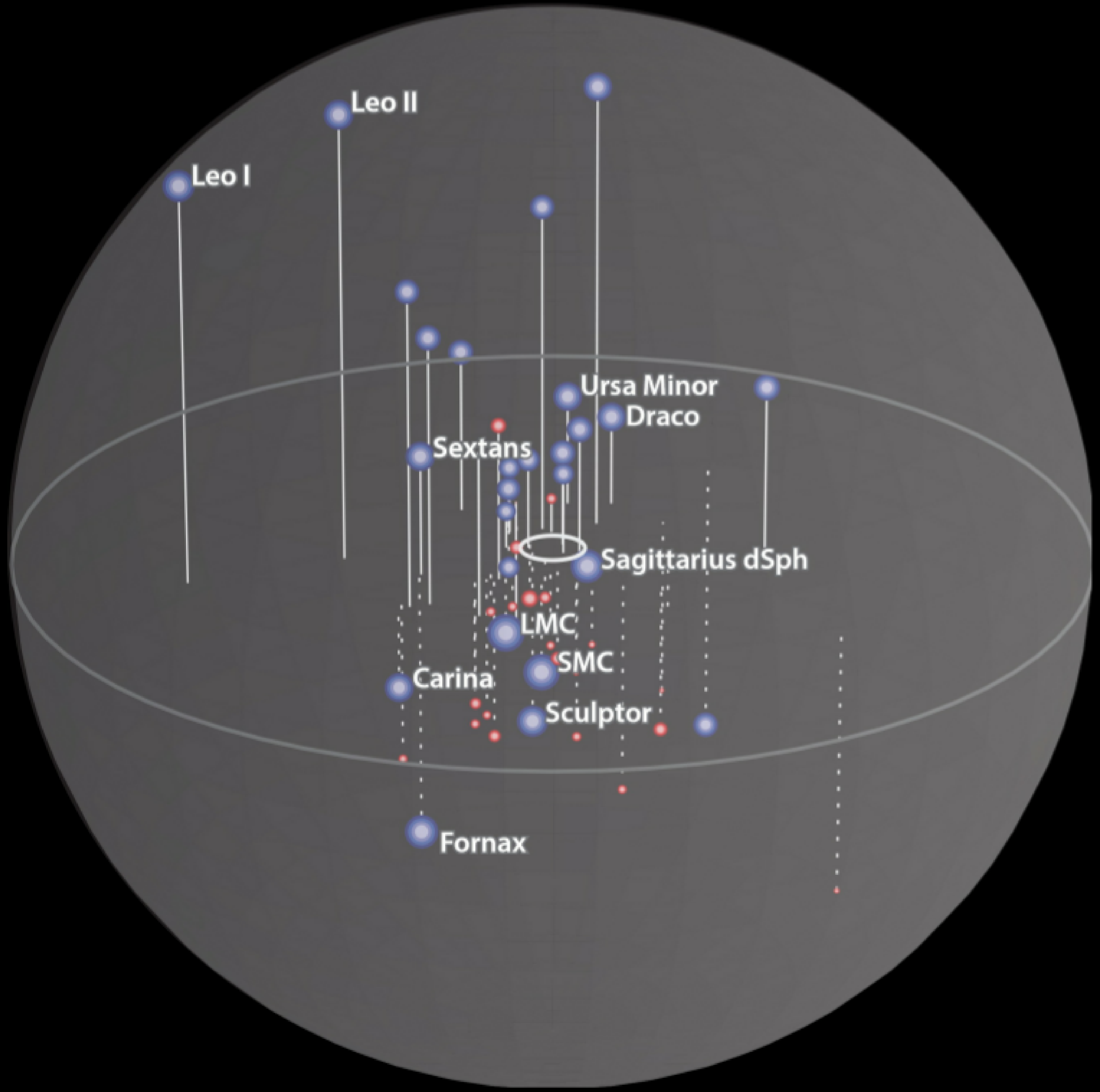
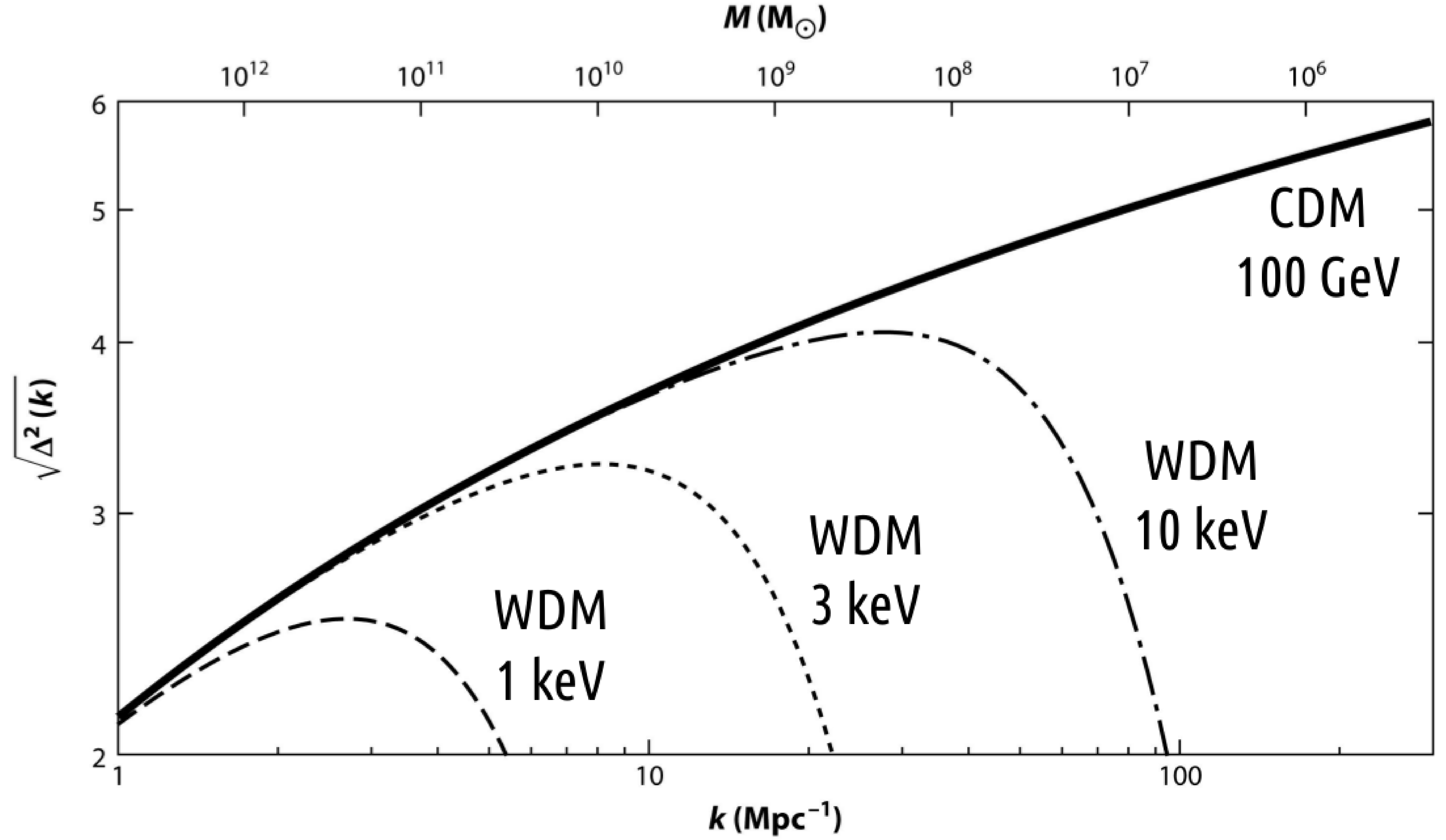


Pawlowski, Bullock, Boylan-Kolchin

Nature of dark matter is encoded in low-mass halos

... the search for abundant dark matter halos with inferred virial masses substantially lower than the expected threshold of galaxy formation ($M \sim 10^8\,\mathrm{M}_\odot$*) is the most urgent calling ...*

Bullock & Boylan-Kolchin (2017)



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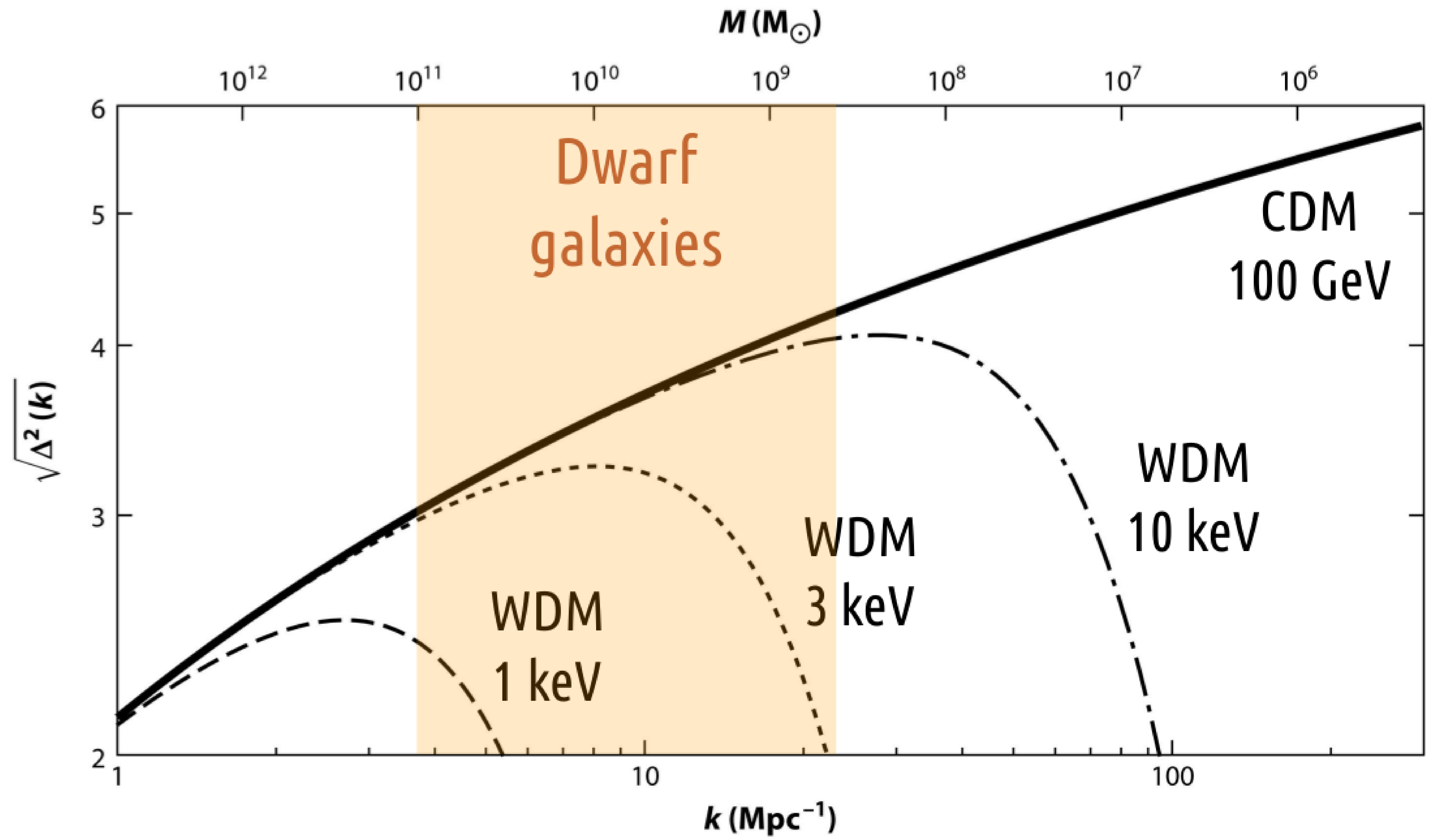
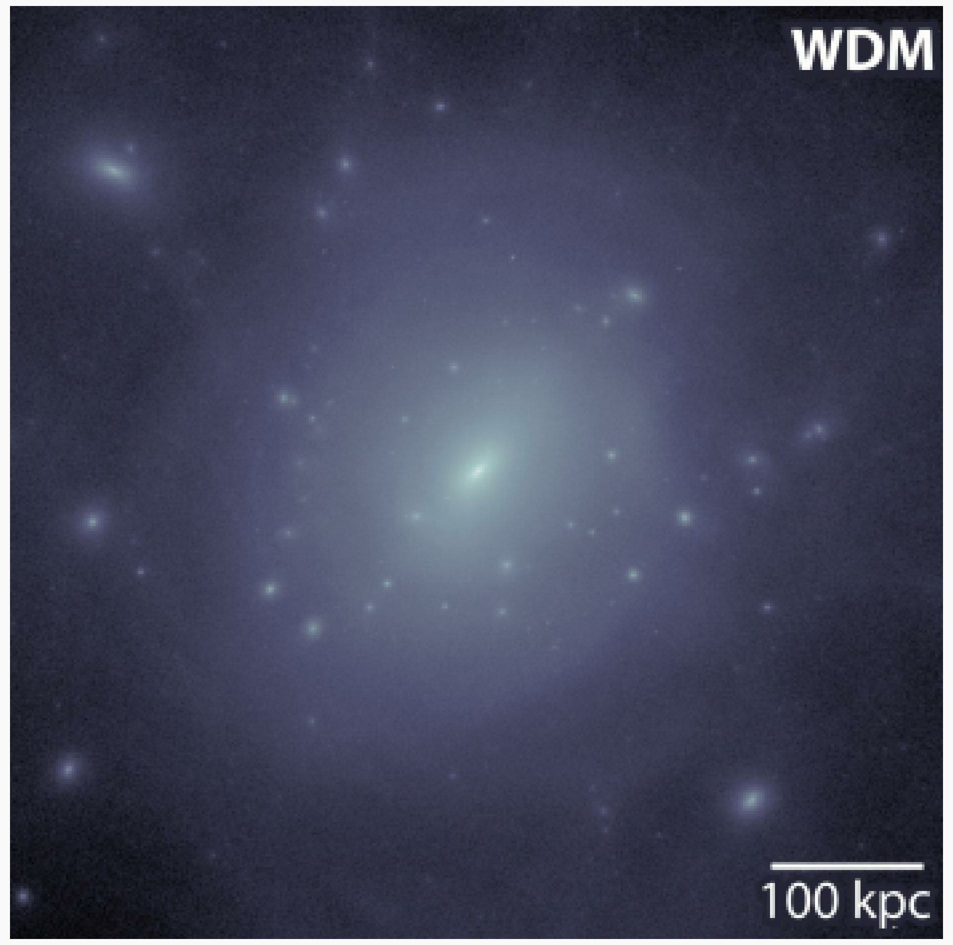
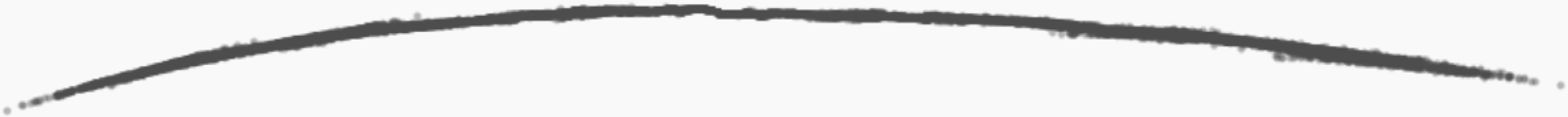


Globular clusters lose stars to form tidal streams

Stellar streams preserve a record of all gravitational interactions



Stellar stream in a smooth galaxy



Bonaca et al. (2014)

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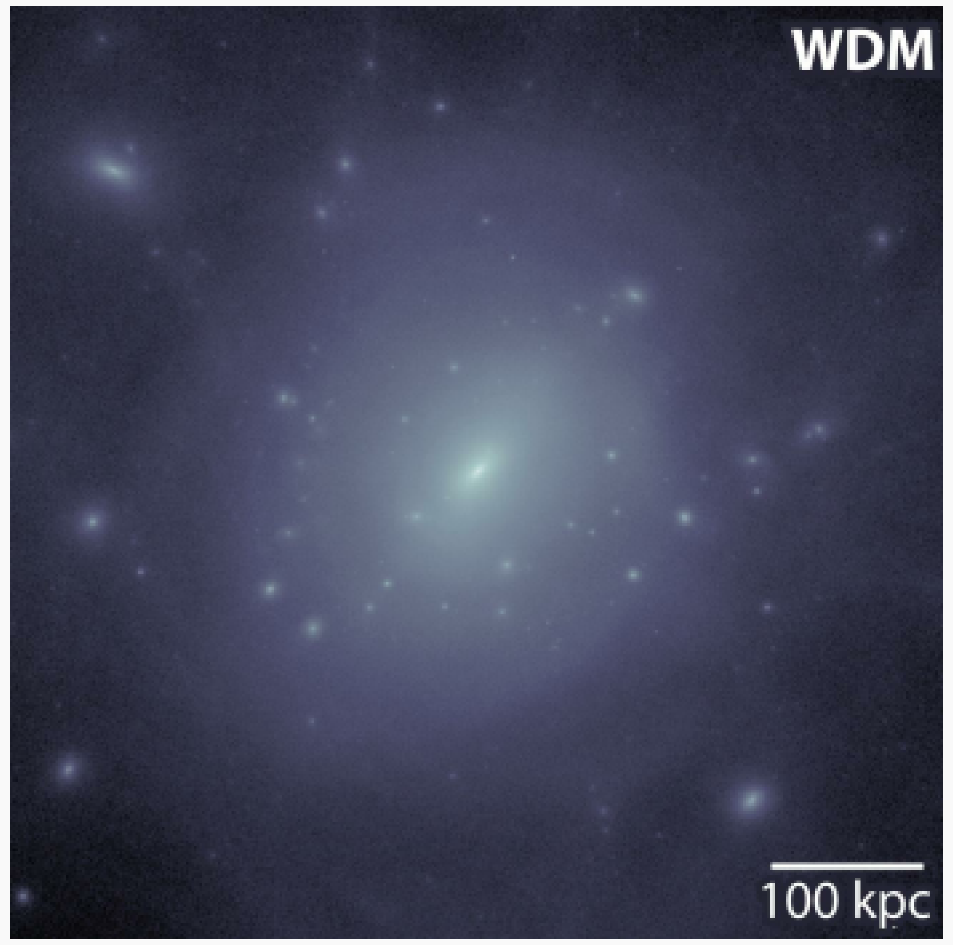

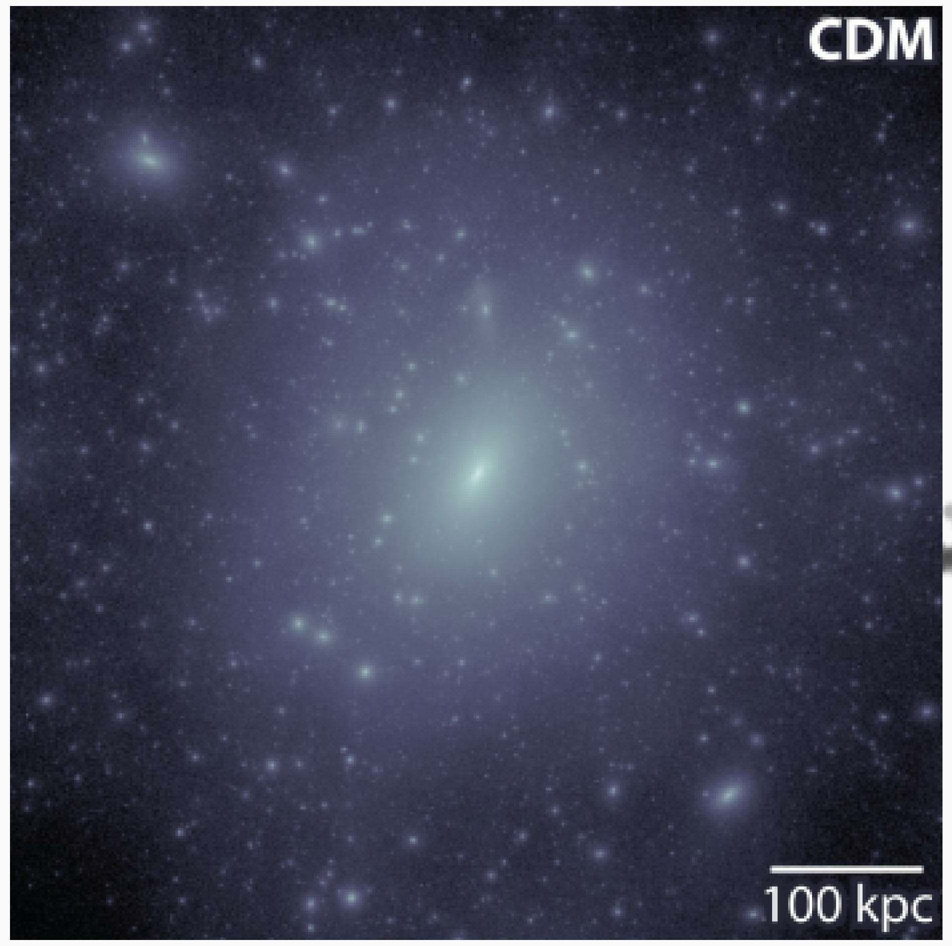

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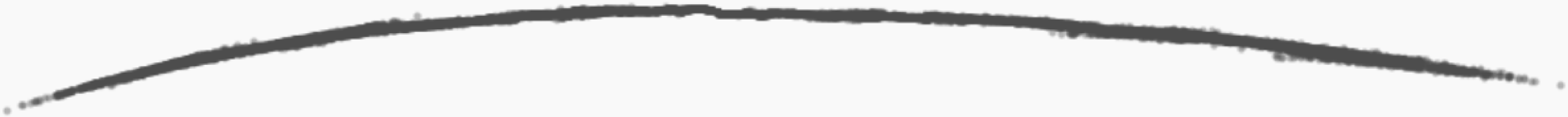

Stellar stream in a clumpy galaxy

Bonaca et al. (2014)

PanSTARRS Collaboration

PanSTARRS Collaboration


psl
Globular cluster
Field Milky Way
14
16
18
20
22
g
0
2
g - r
PanSTARRS Collaboration

psl
Globular cluster
Field Milky Way
Matched filter
14
16
18
20
22
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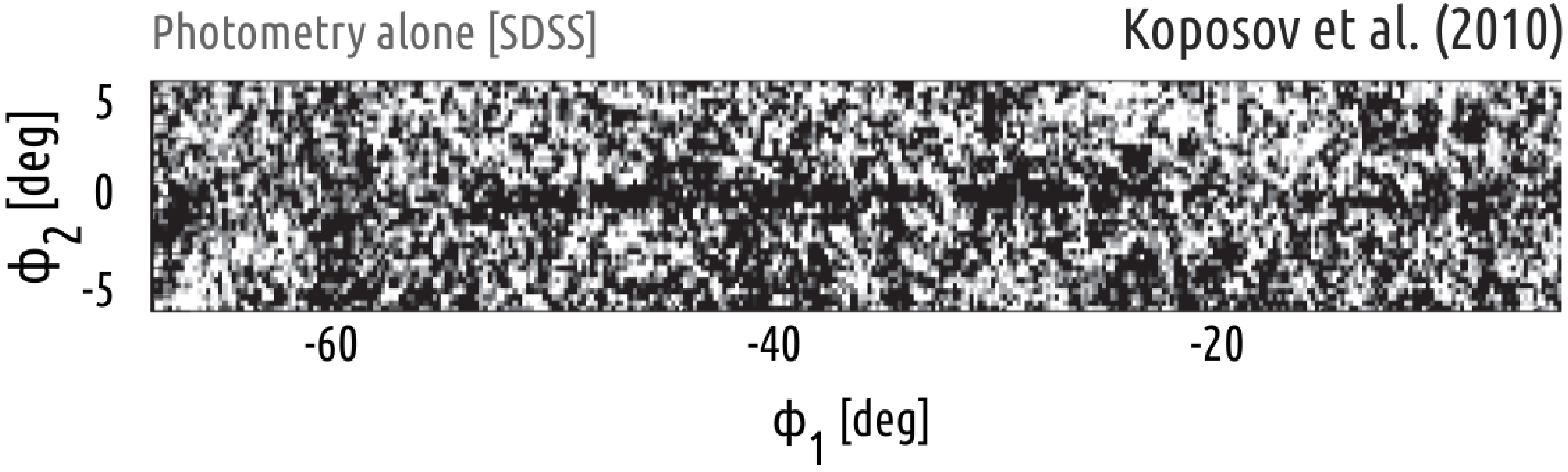
PanSTARRS Collaboration

Stellar halo of the Milky Way has plenty of tidal streams

Bonaca et al. (2012)

GD-1 has prominent gaps and stars outside of the main stream



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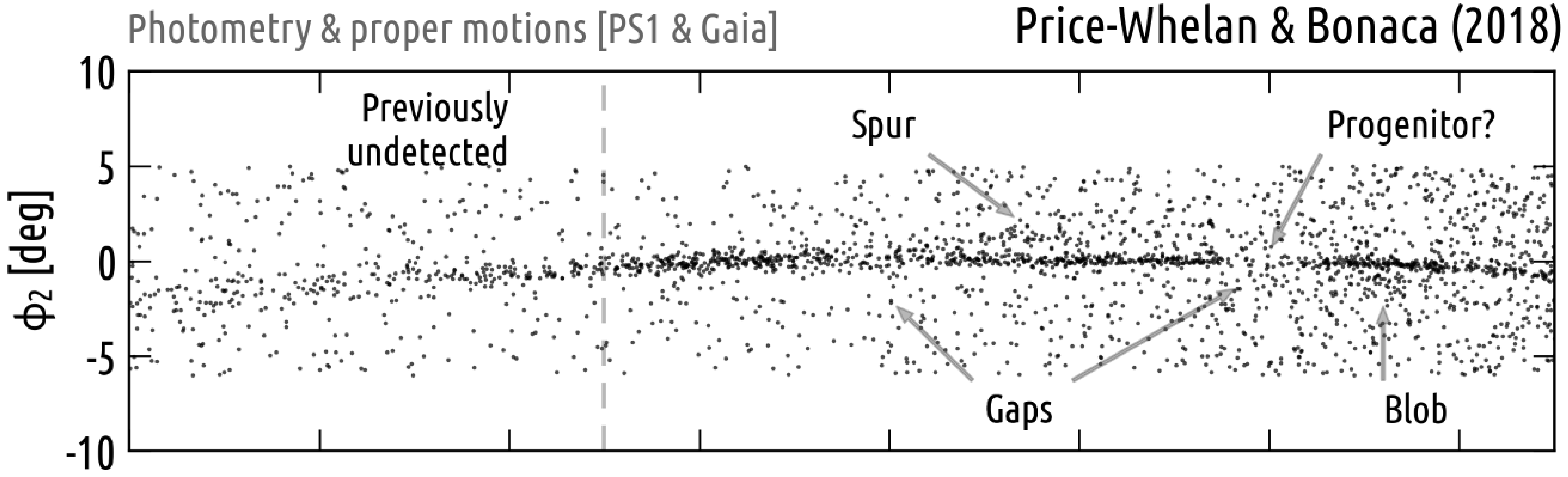

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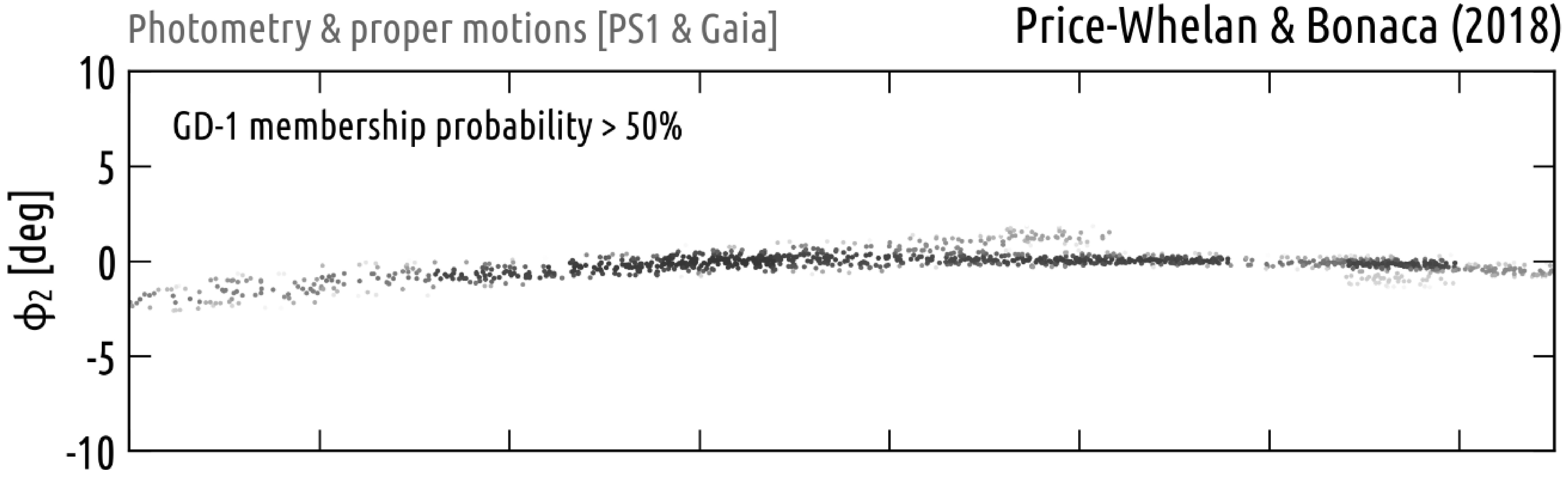

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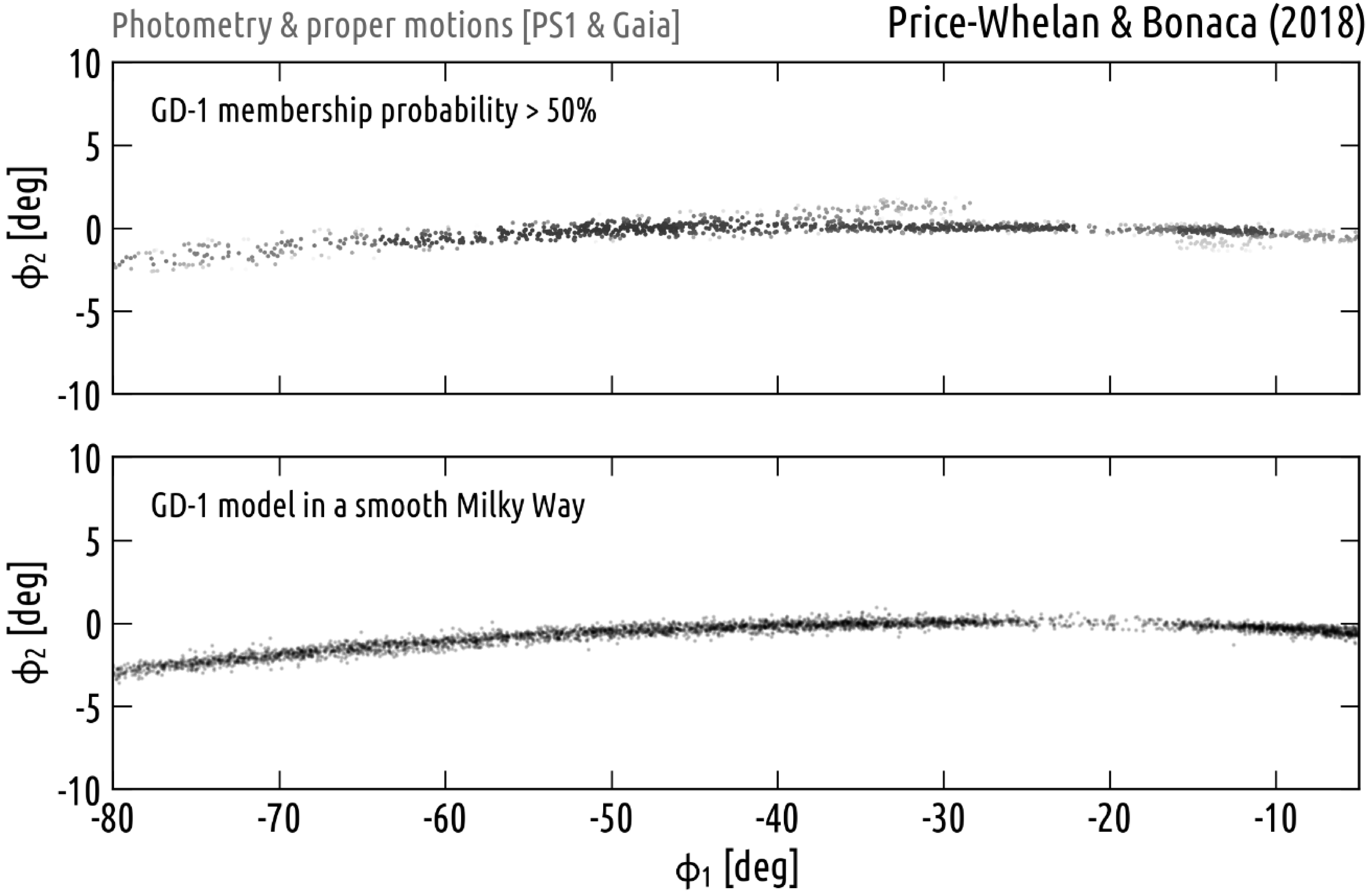
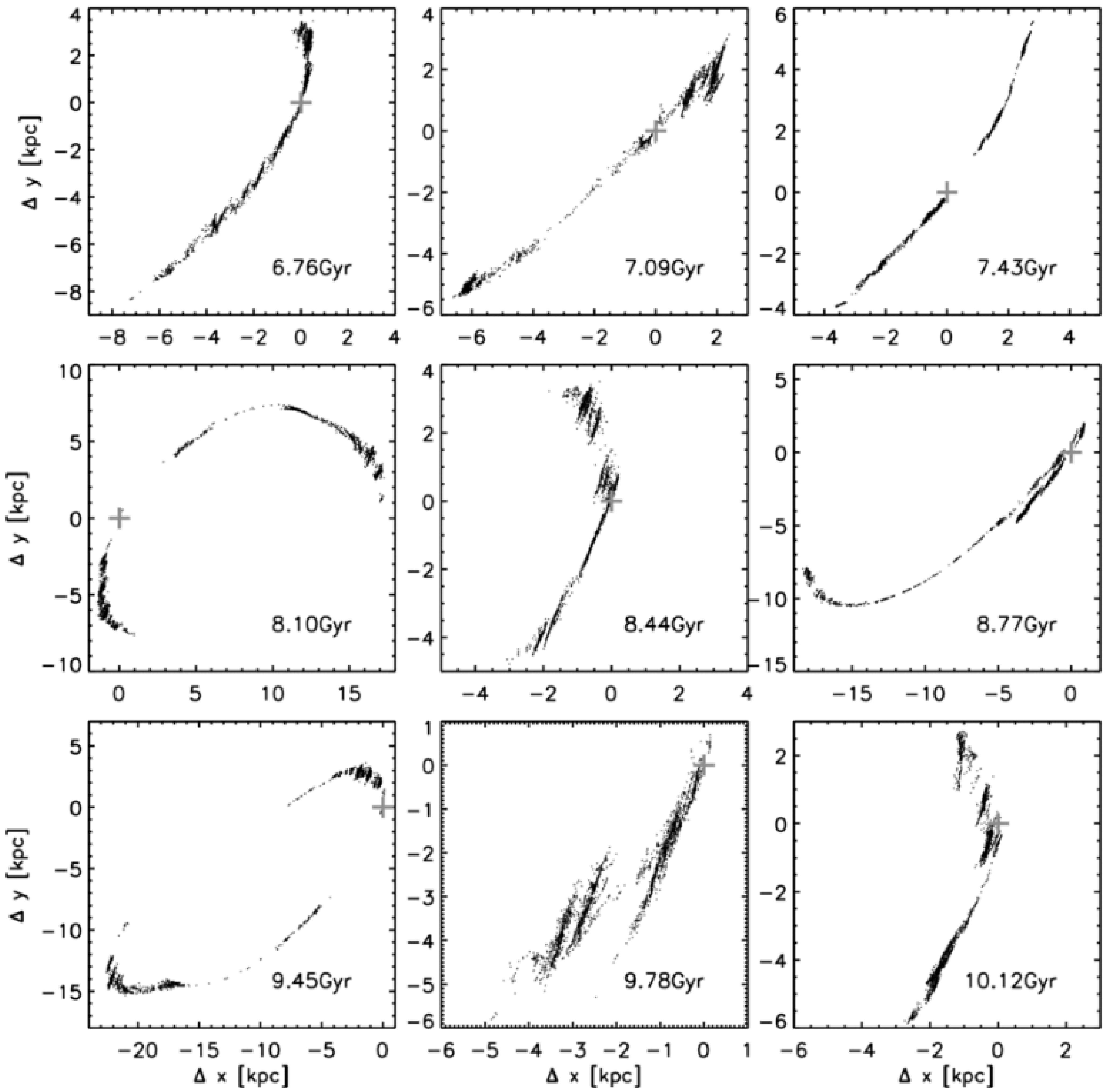


Subhalo encounters produce gaps in streams

Yoon et al. (2011)



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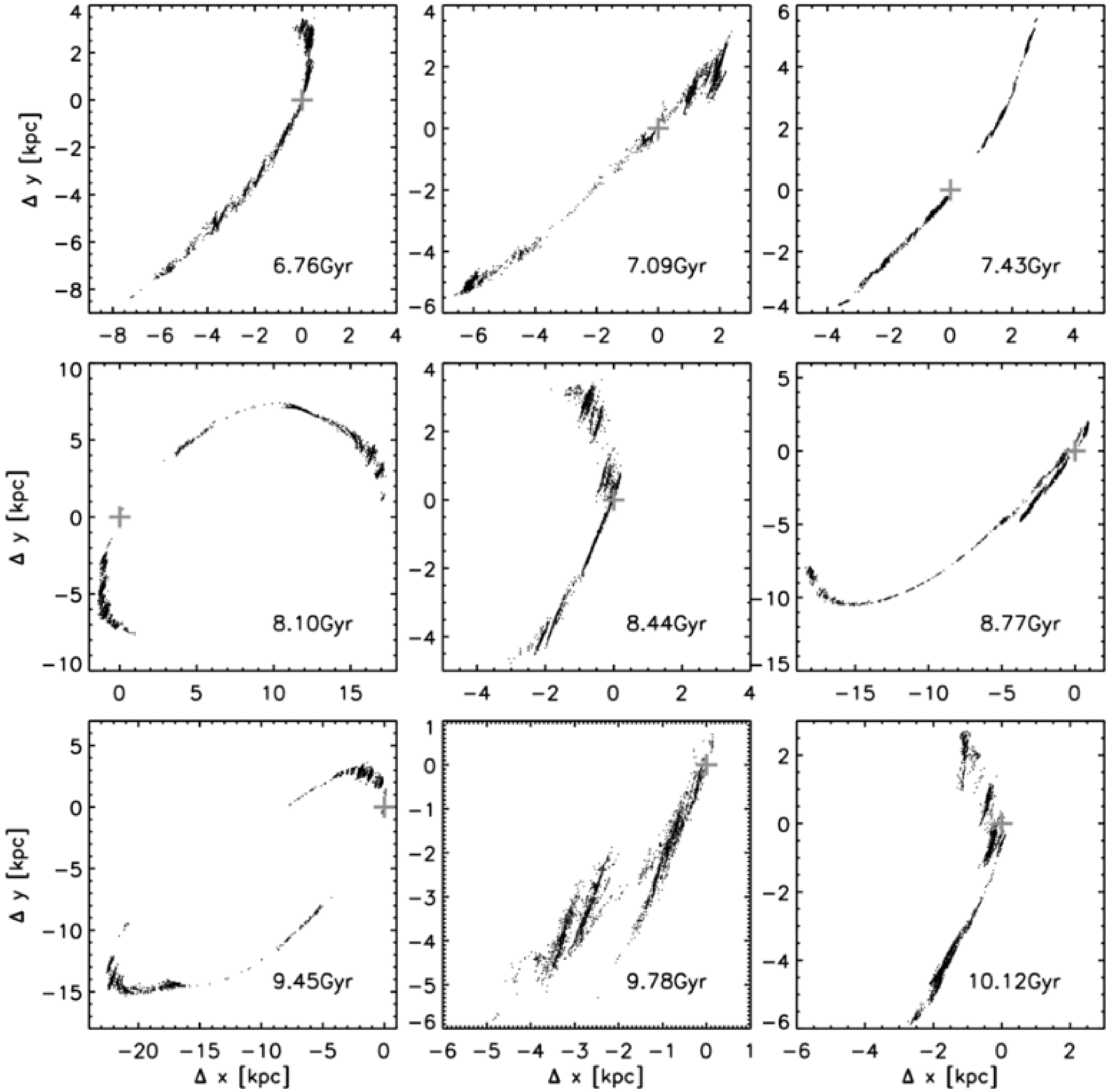

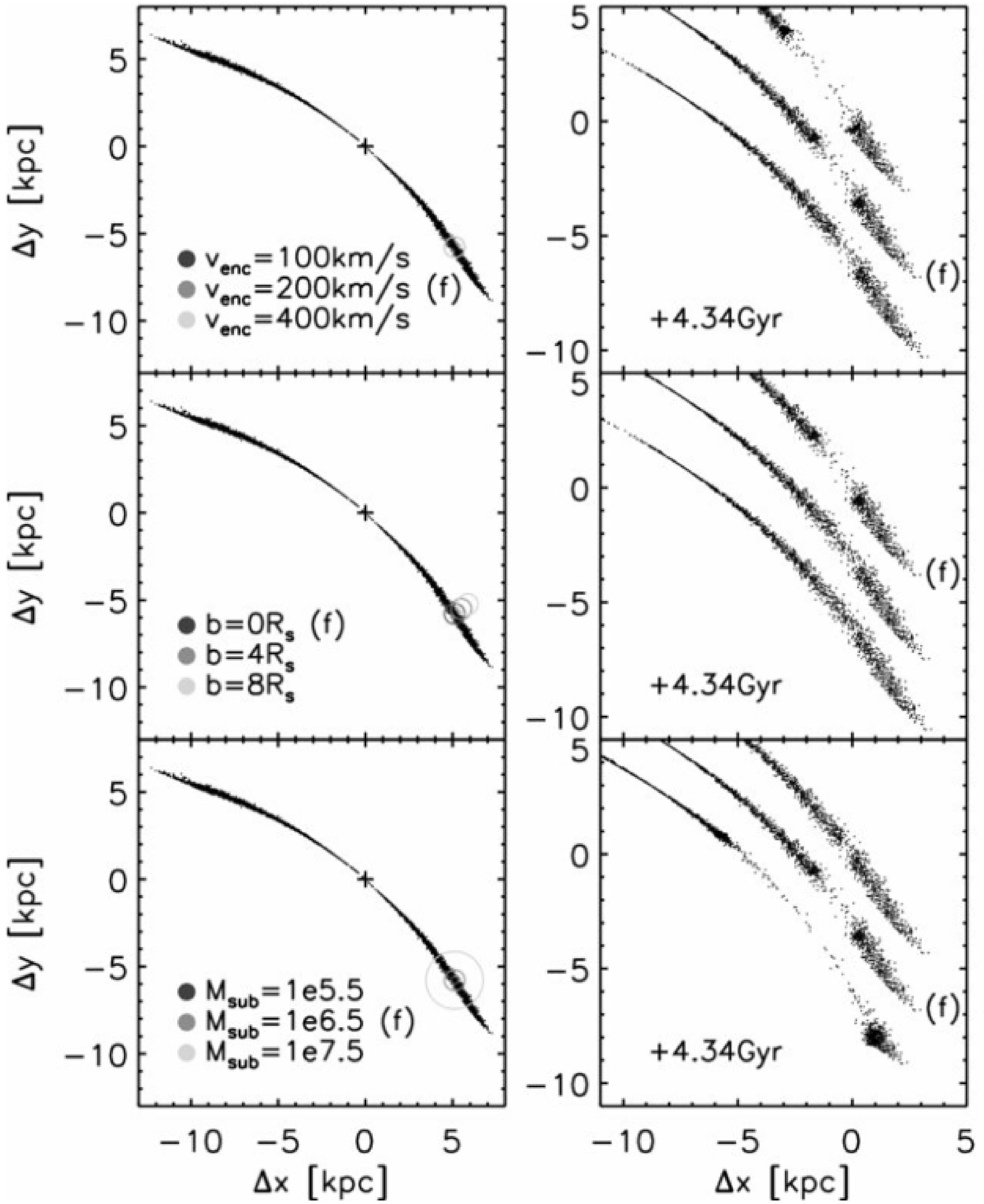

Carlberg (2009) | Carlberg (2012)
Ngan & Carlberg (2014) | Ngan et al. (2015)
Erkal & Belokurov (2015) | Ngan et al. (2016)
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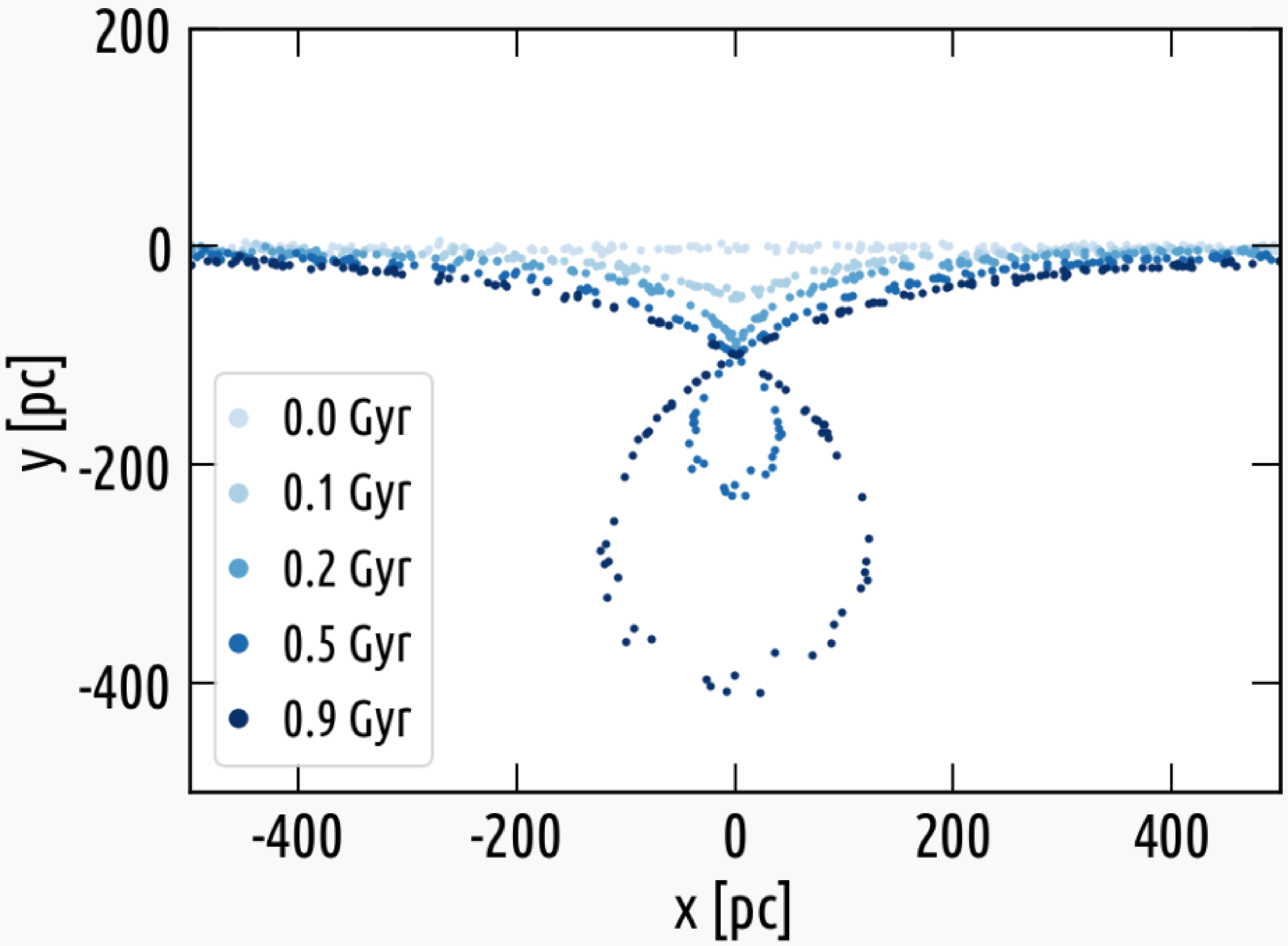
A massive perturber can pull stars from the stream

Bonaca & Hogg, in prep



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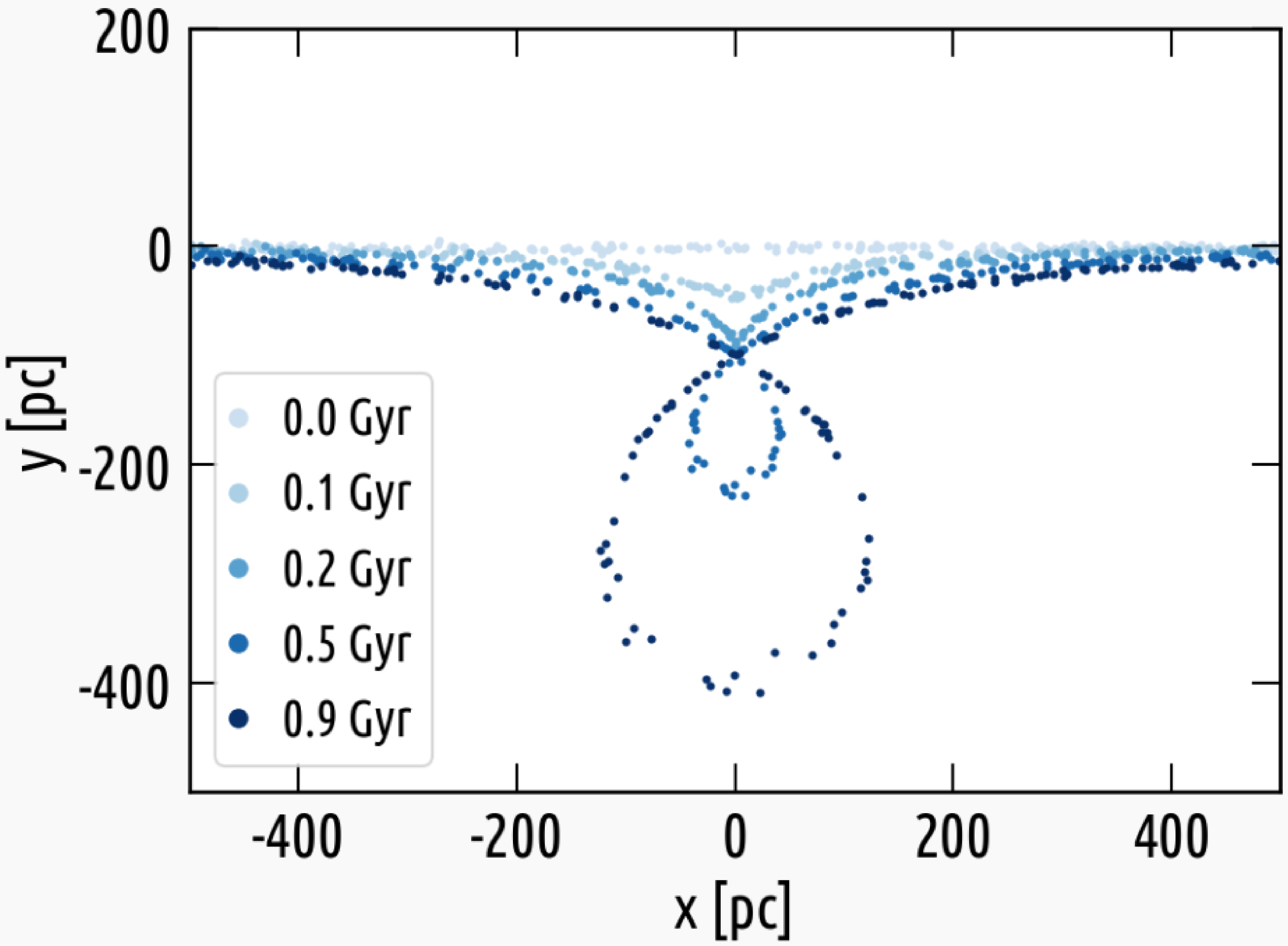

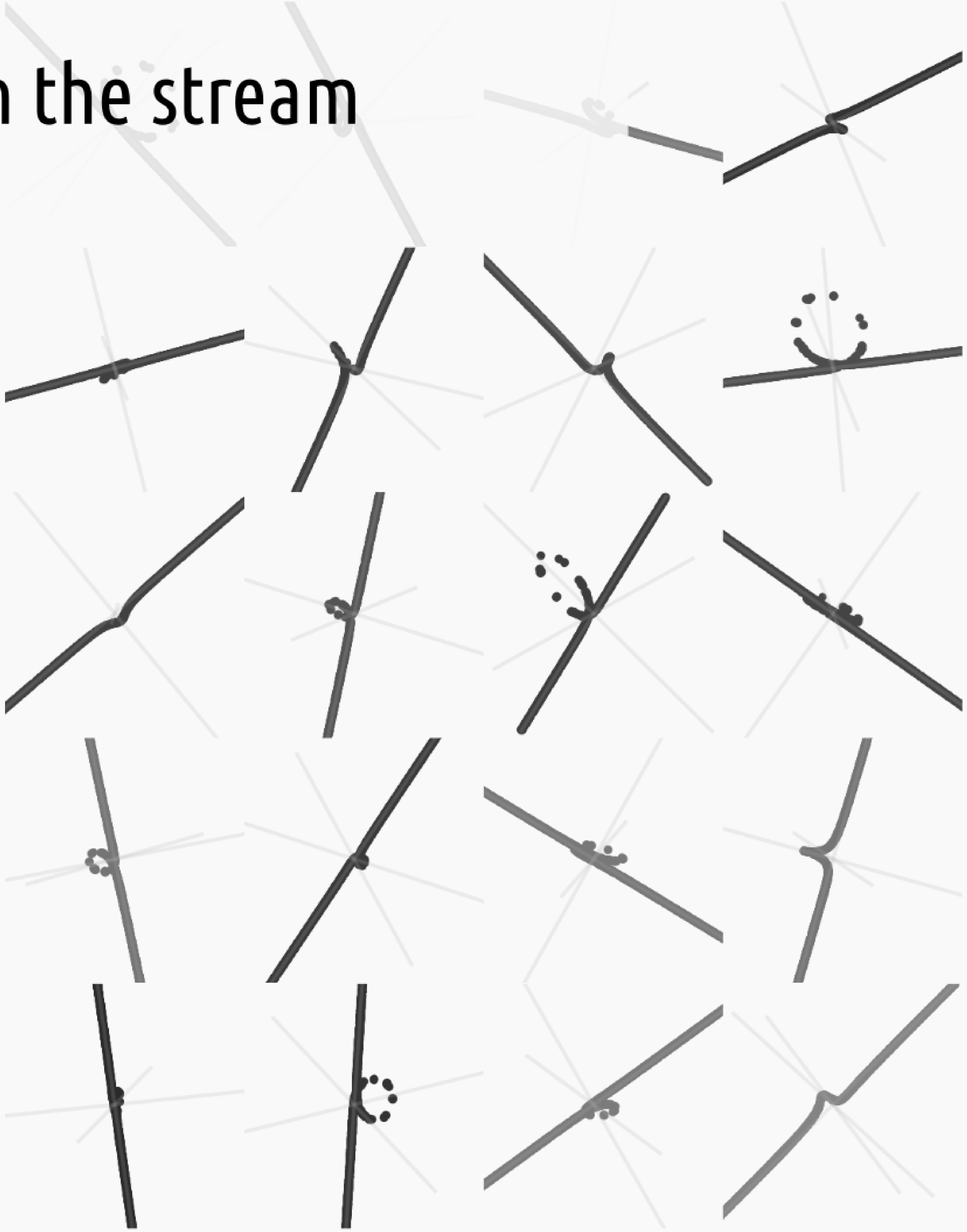

A massive perturber creates a gap in a stream orbiting the Galaxy

Subhalo perturbation
in a logarithmic potential

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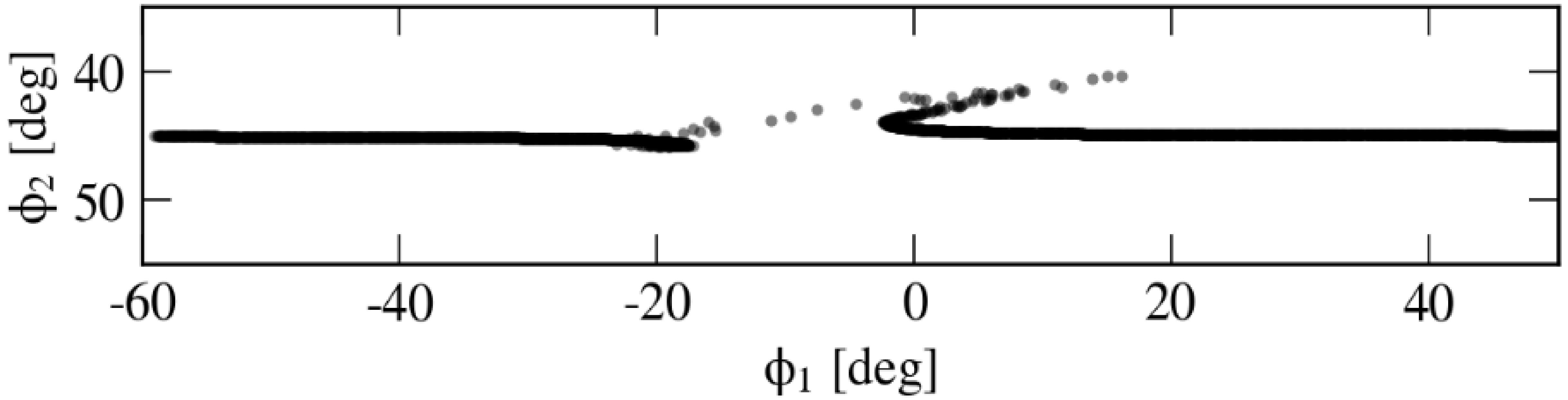
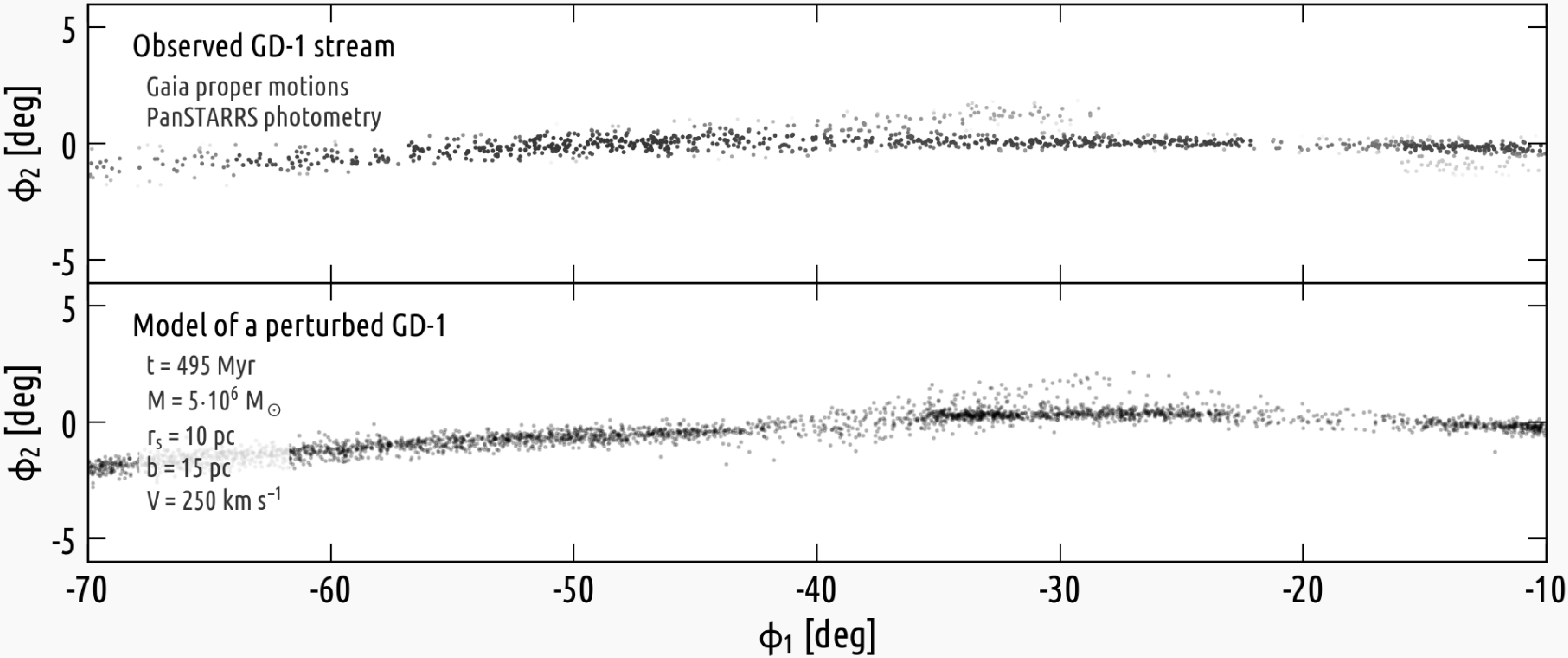


Most probable GD-1 members

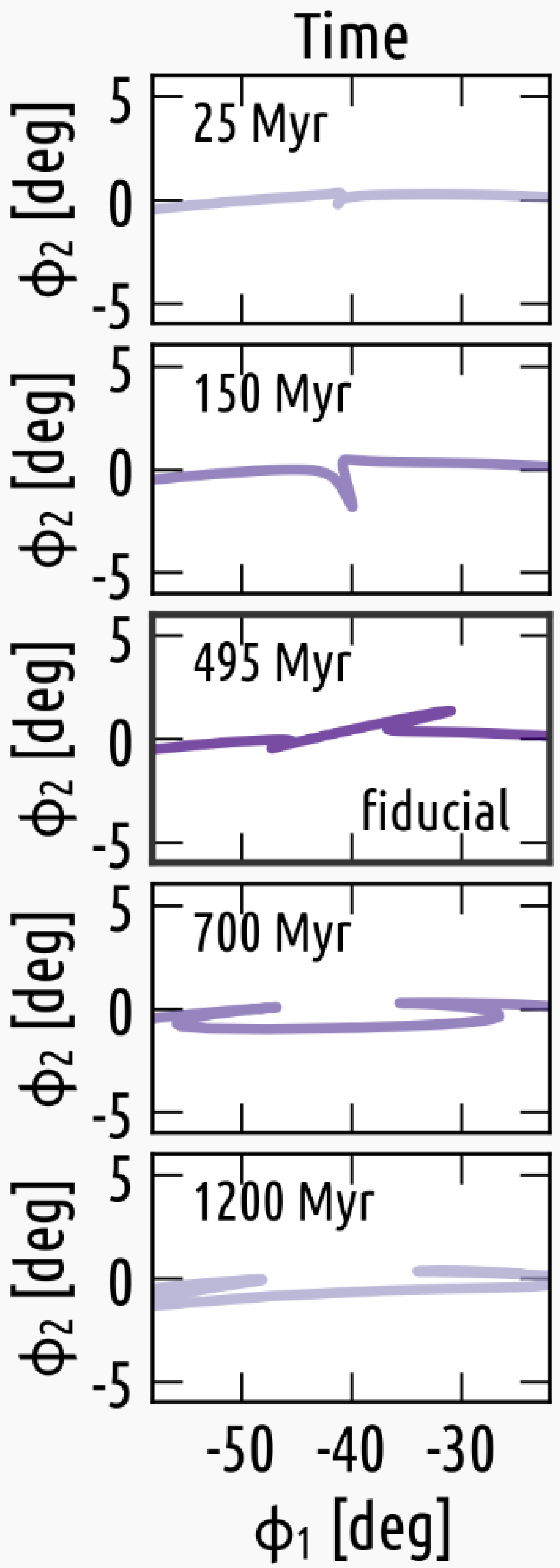
Realistic GD-1 encounter scenario

Encounter qualitatively accounts for all features observed in GD-1



Bonaca et al. (2019)

Stream morphology constrains the encounter parameters



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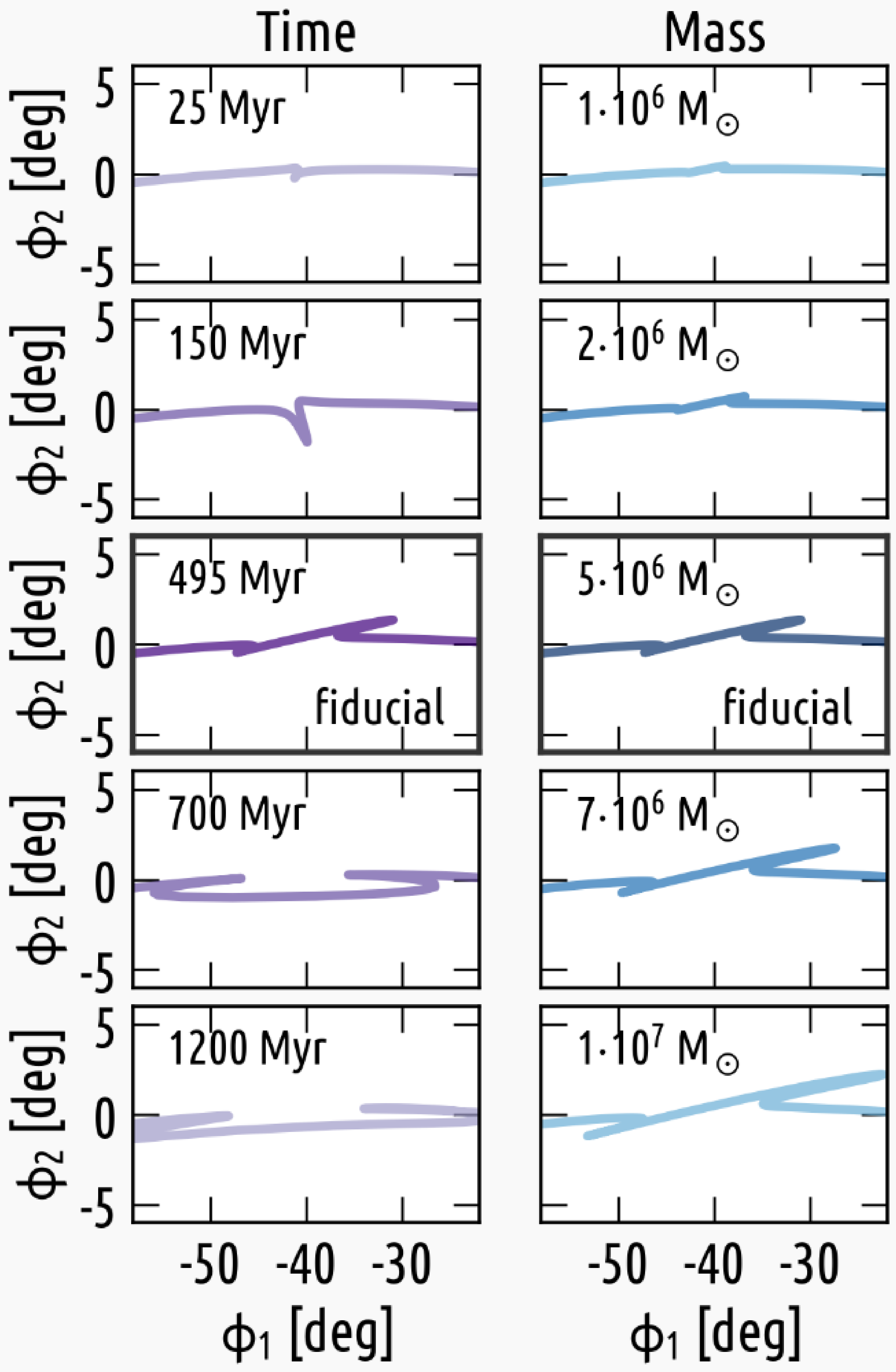

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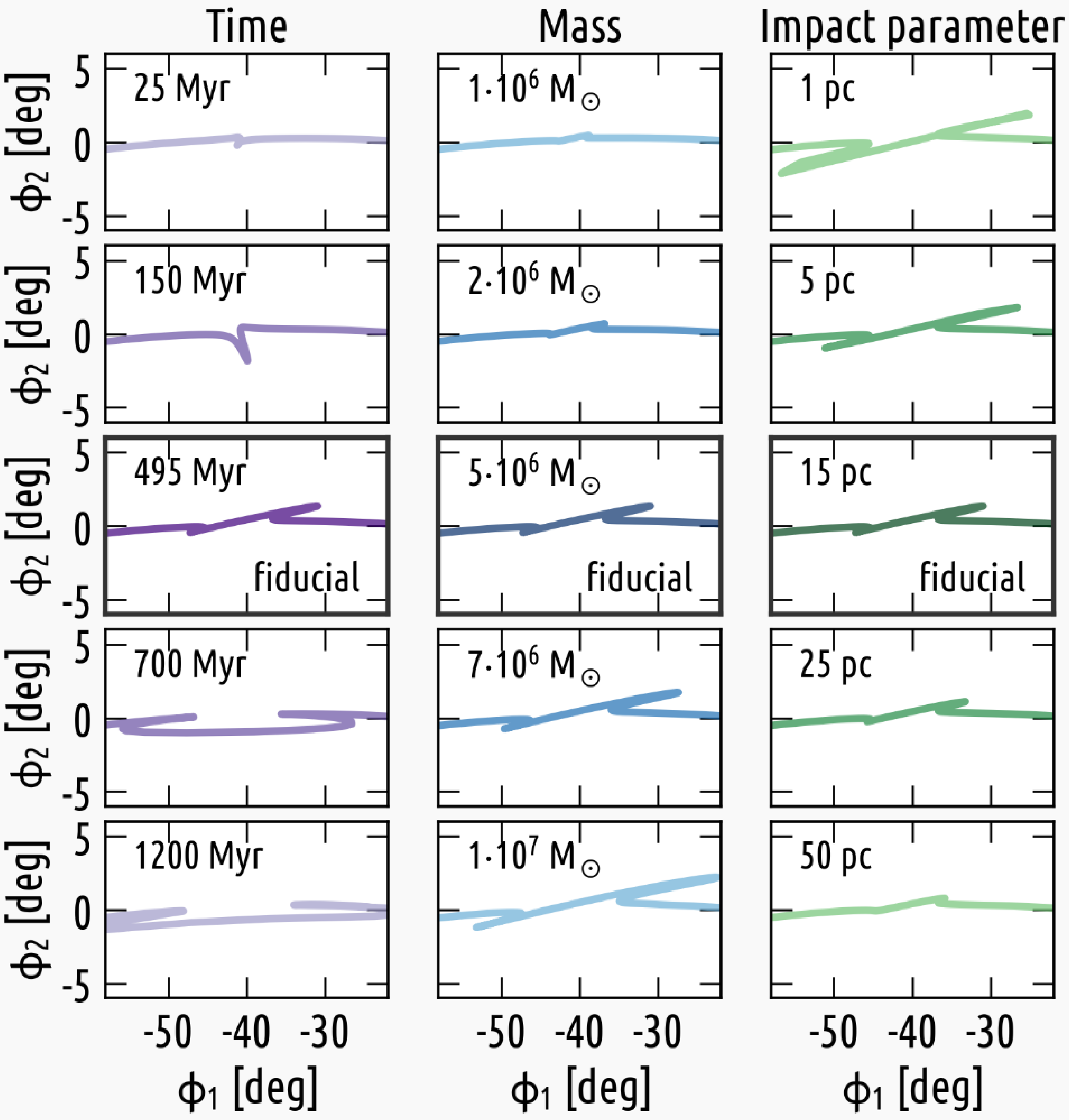

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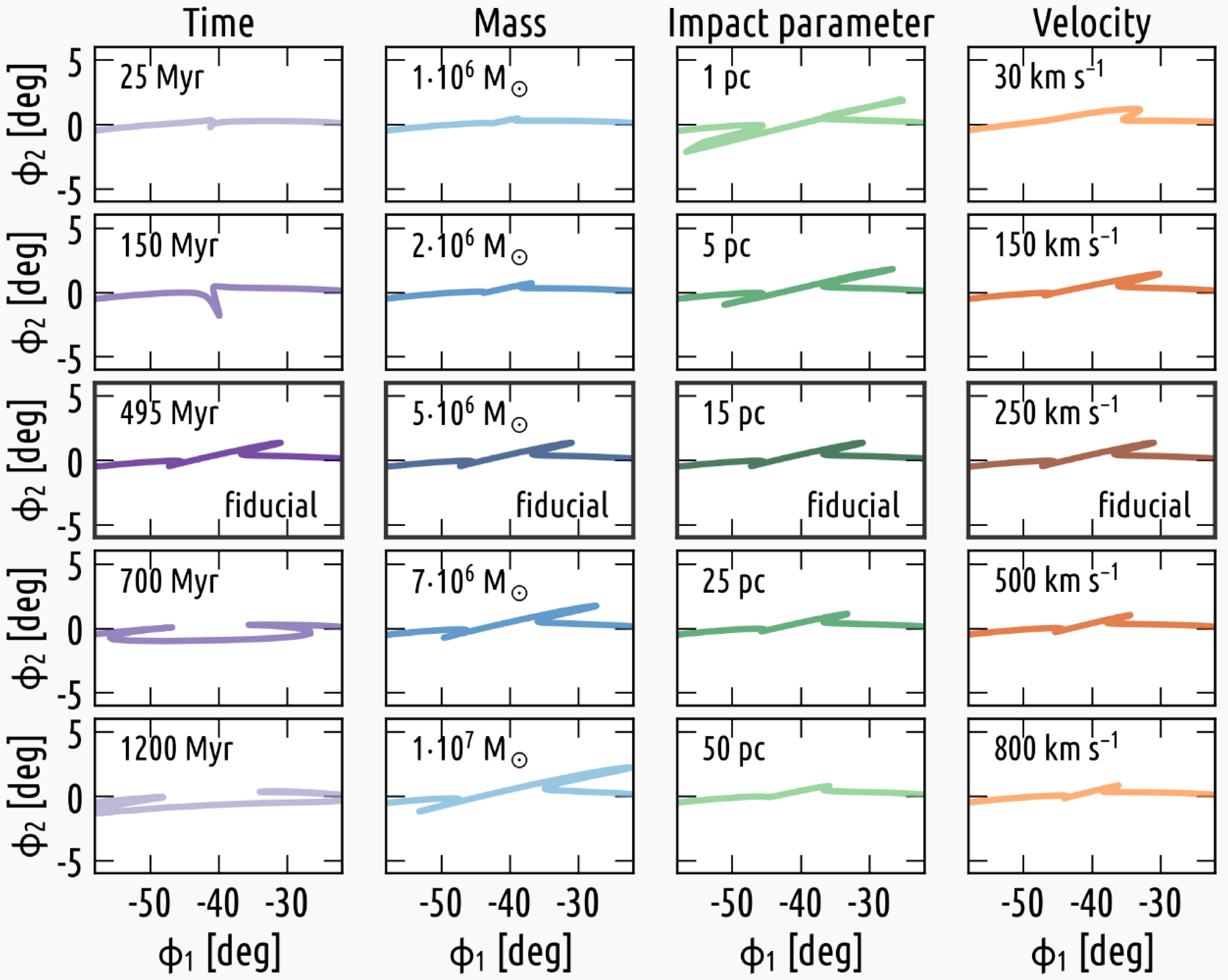

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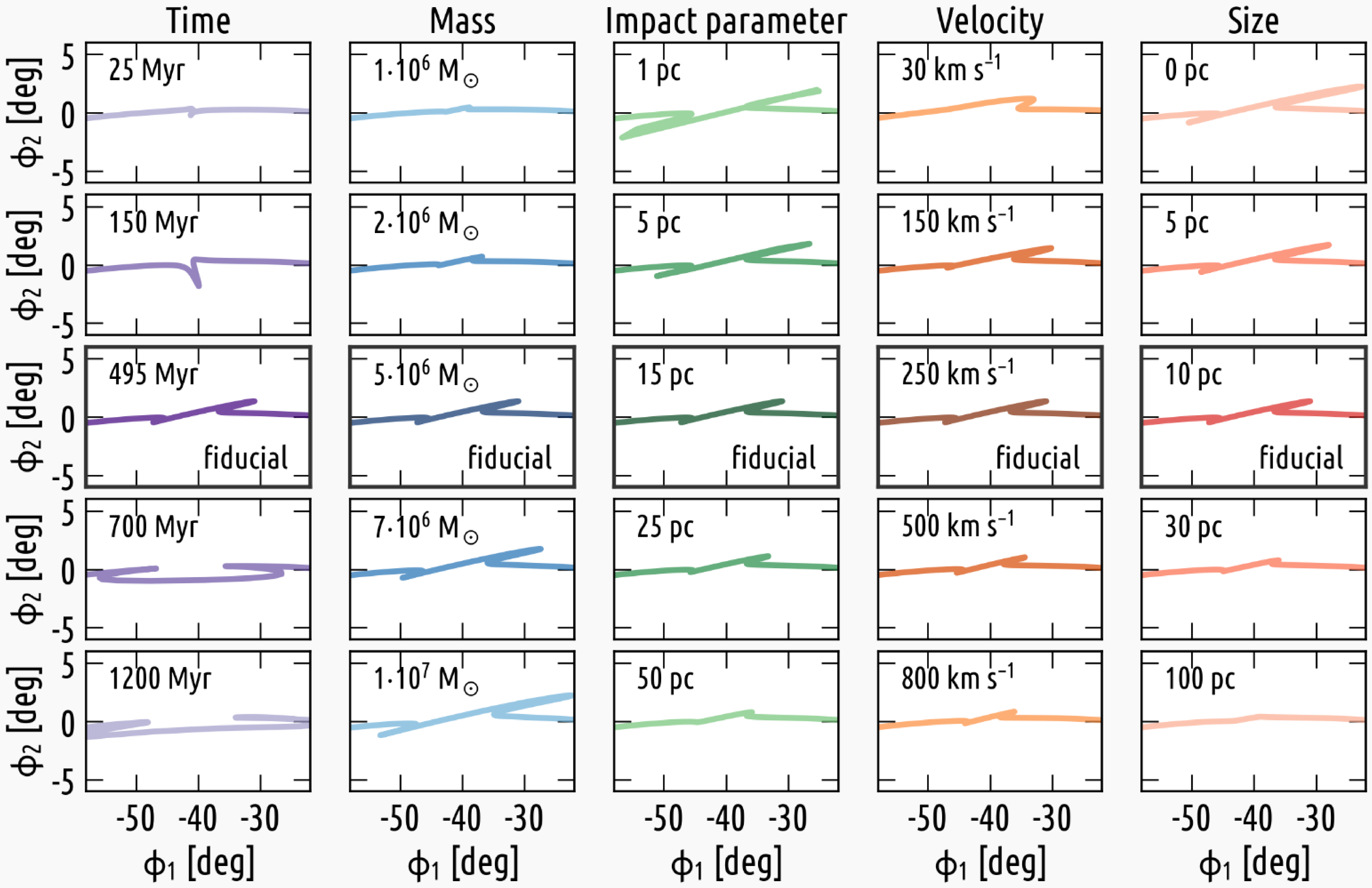
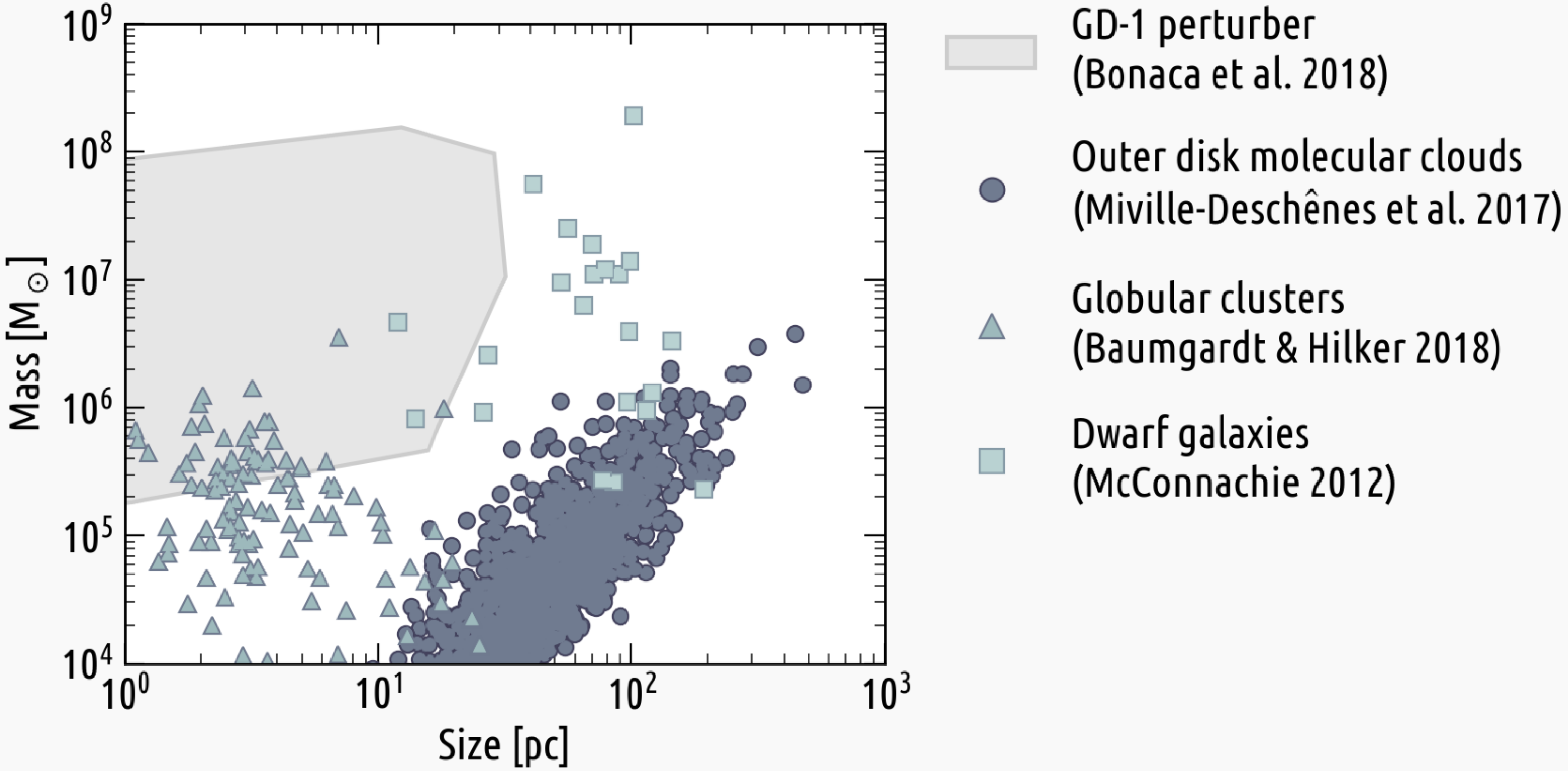


Dark matter subhalo is a plausible perturber of GD-1



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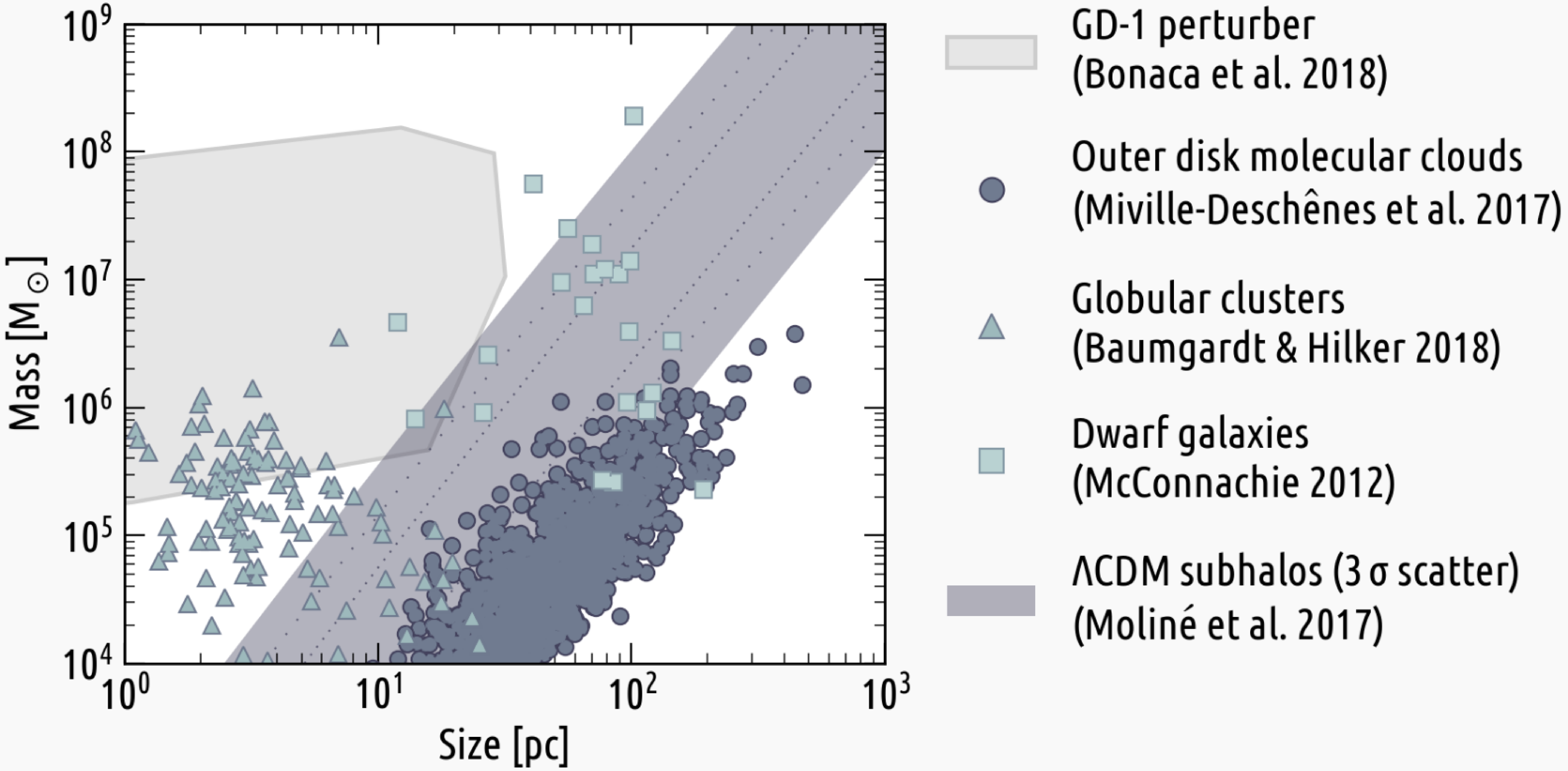

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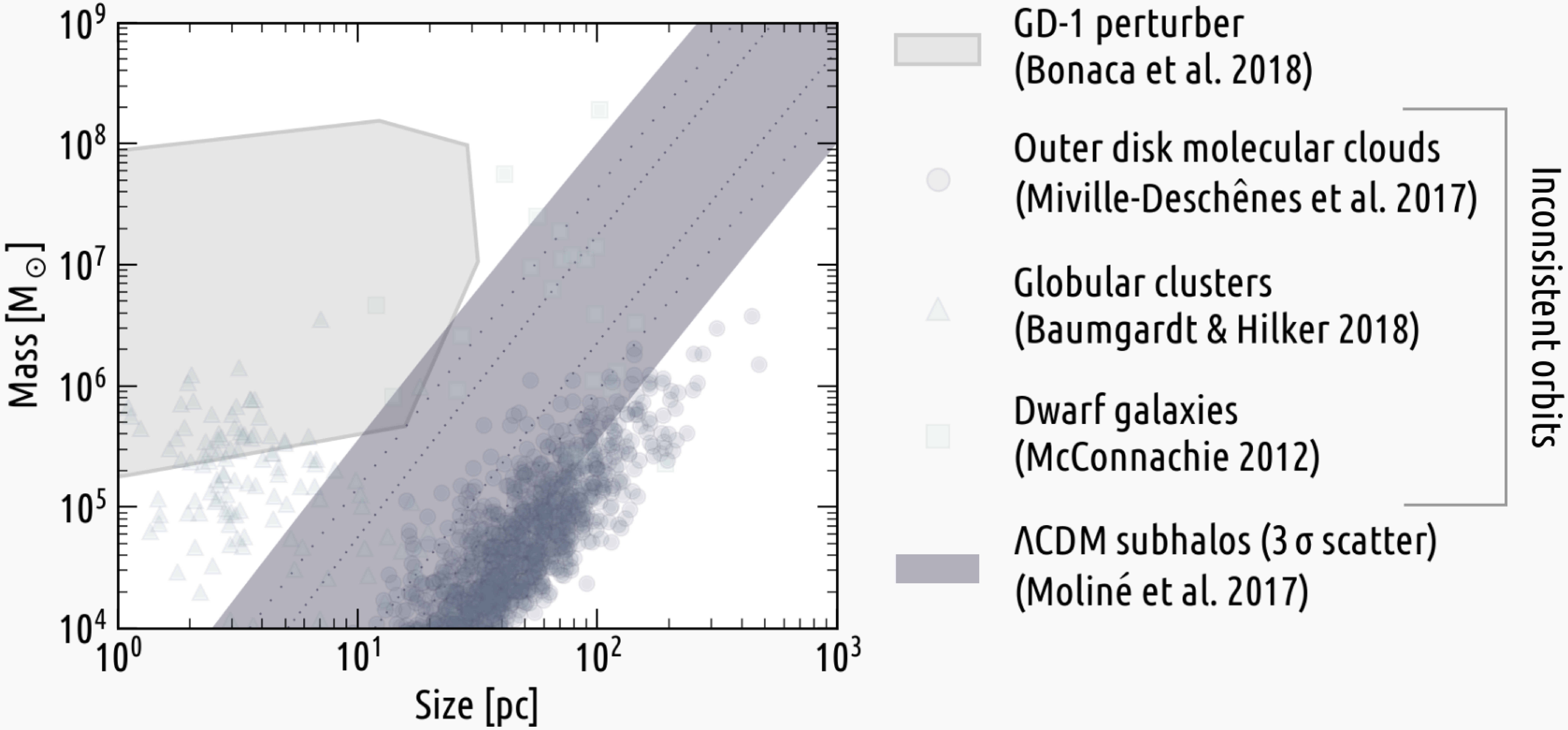

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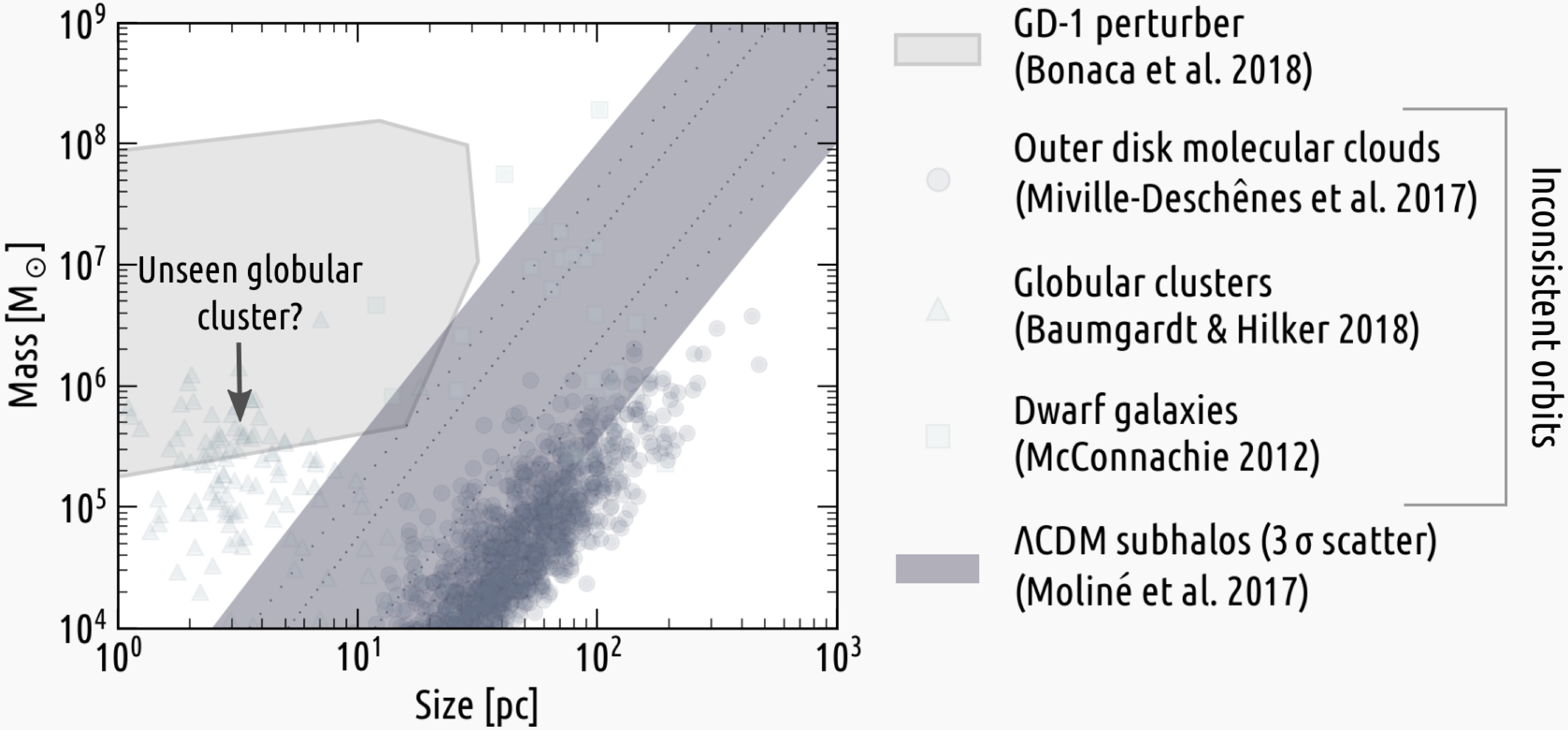

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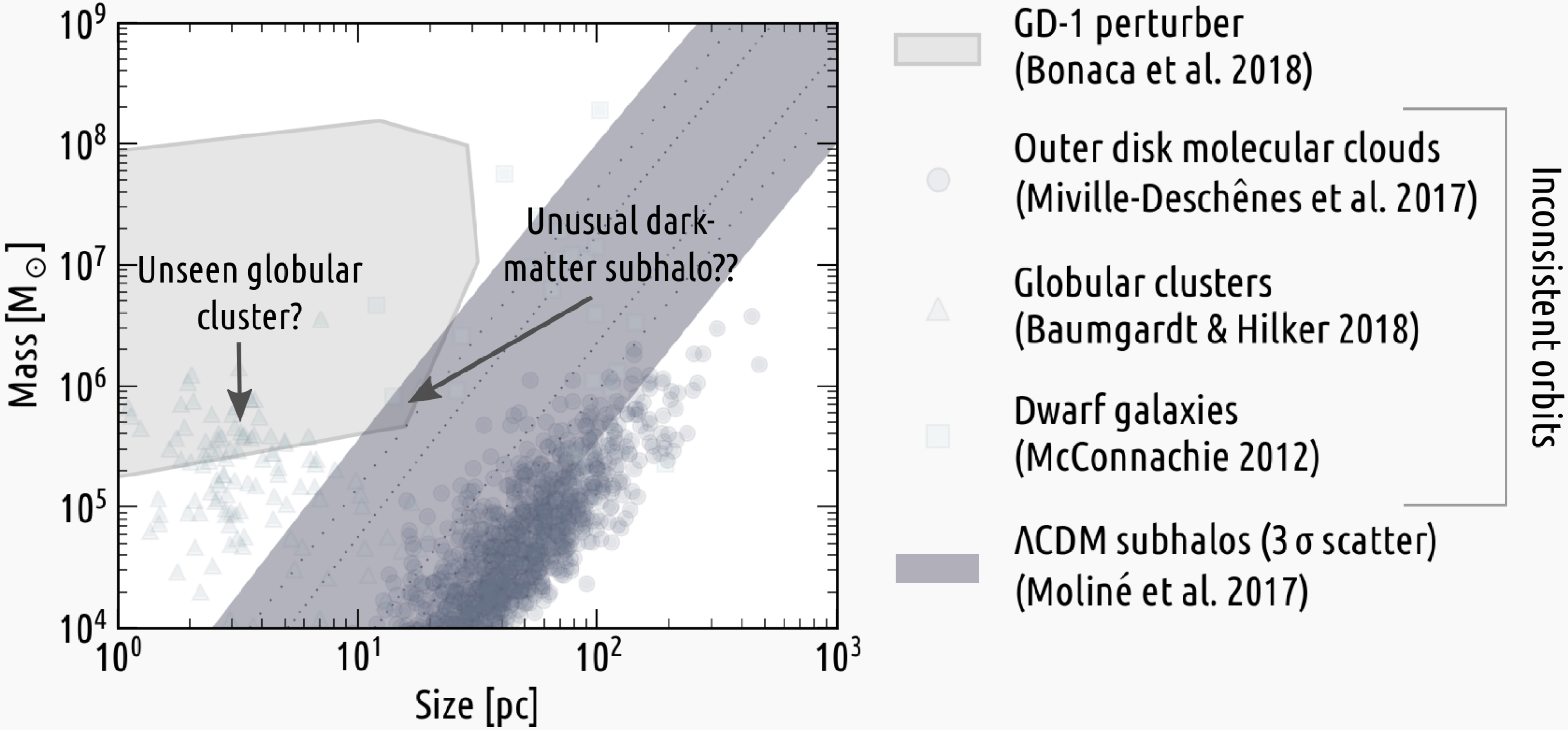

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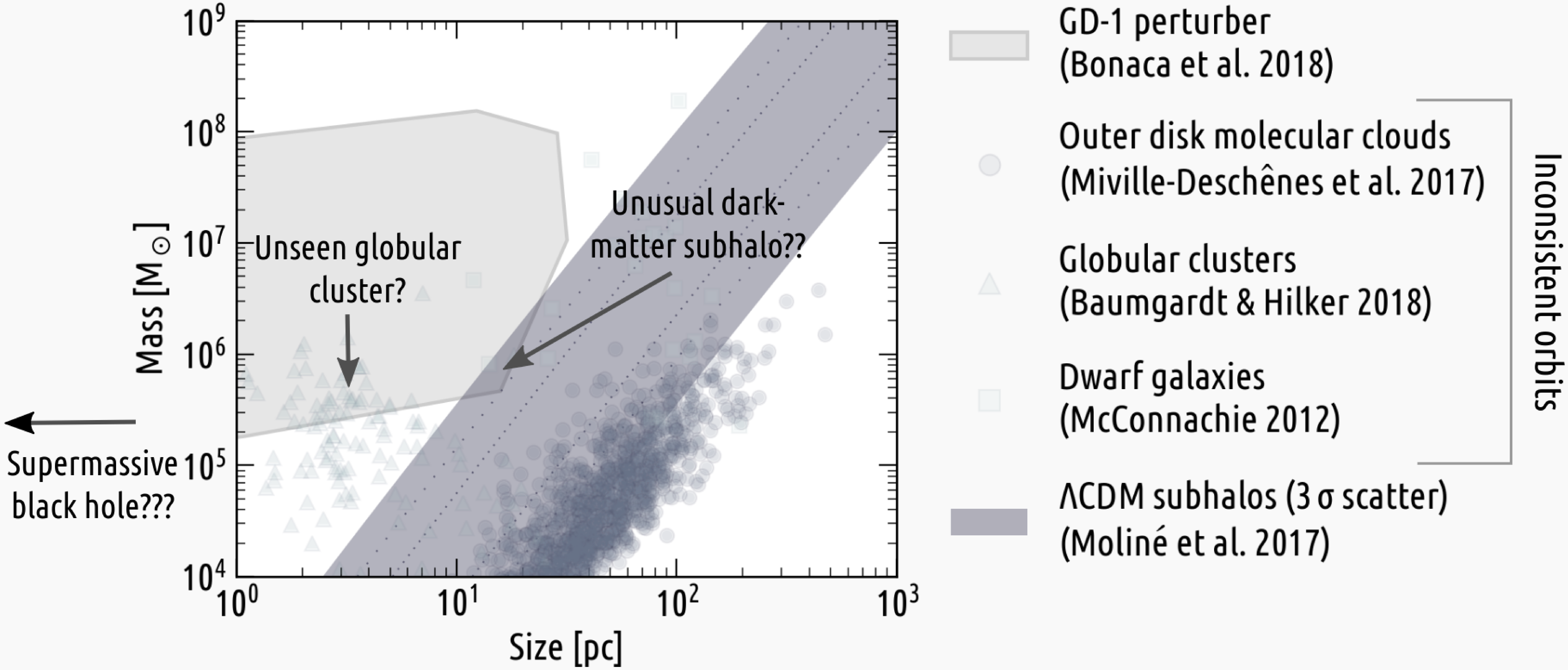
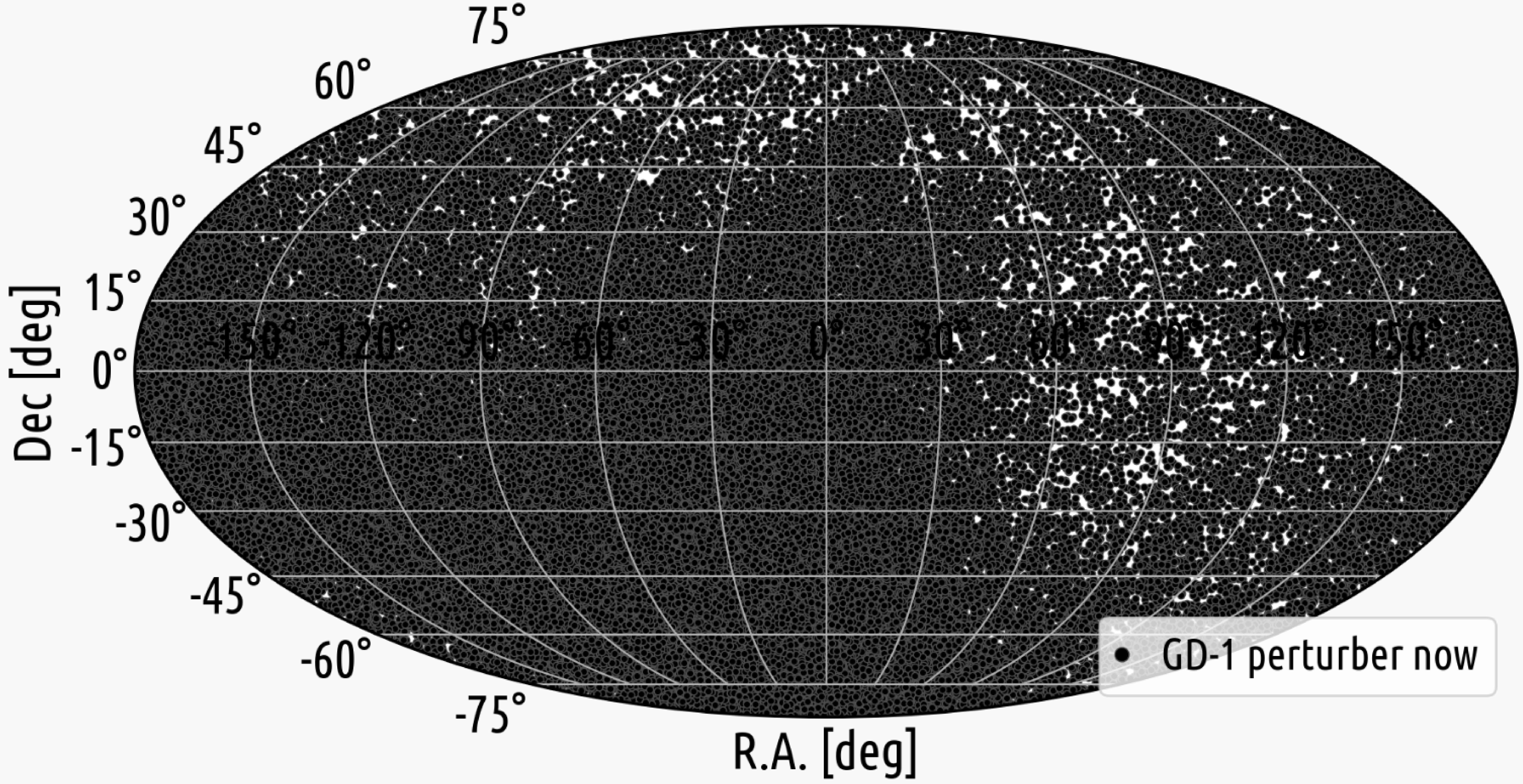


Stream morphology allows for a wide range of perturber orbits



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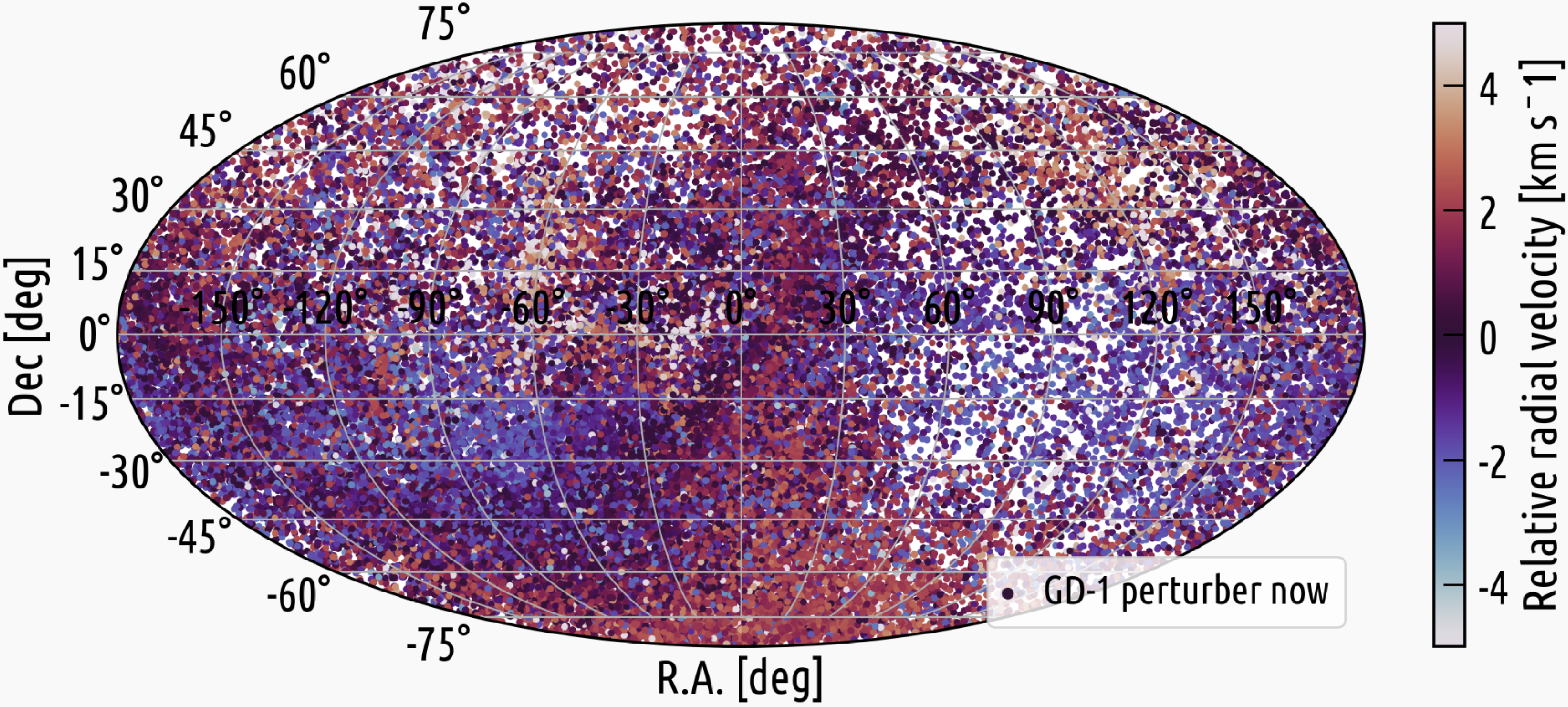
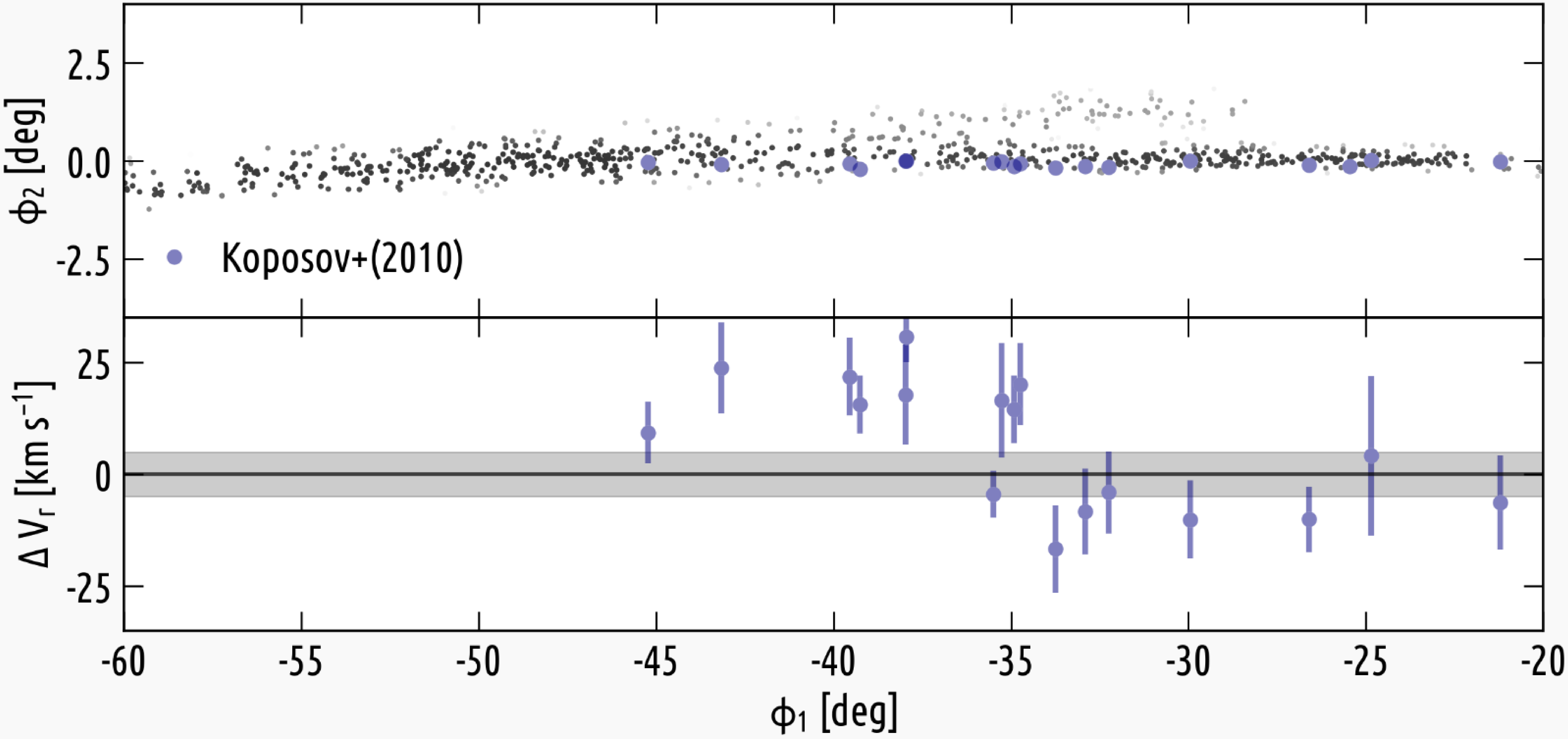


There is no radial velocity offset between the GD-1 stream and spur

Bonaca et al. (2020), arXiv:2001.07215



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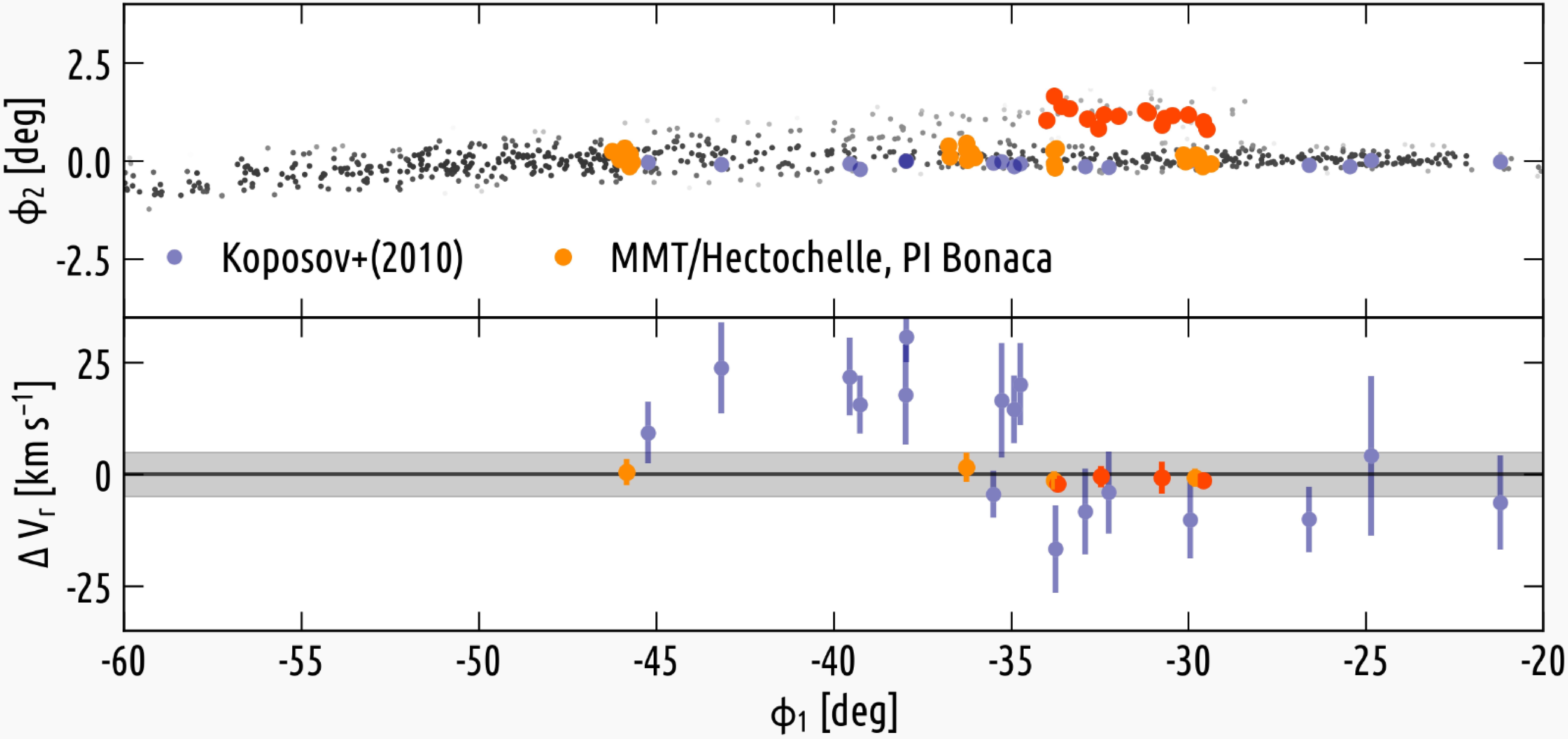

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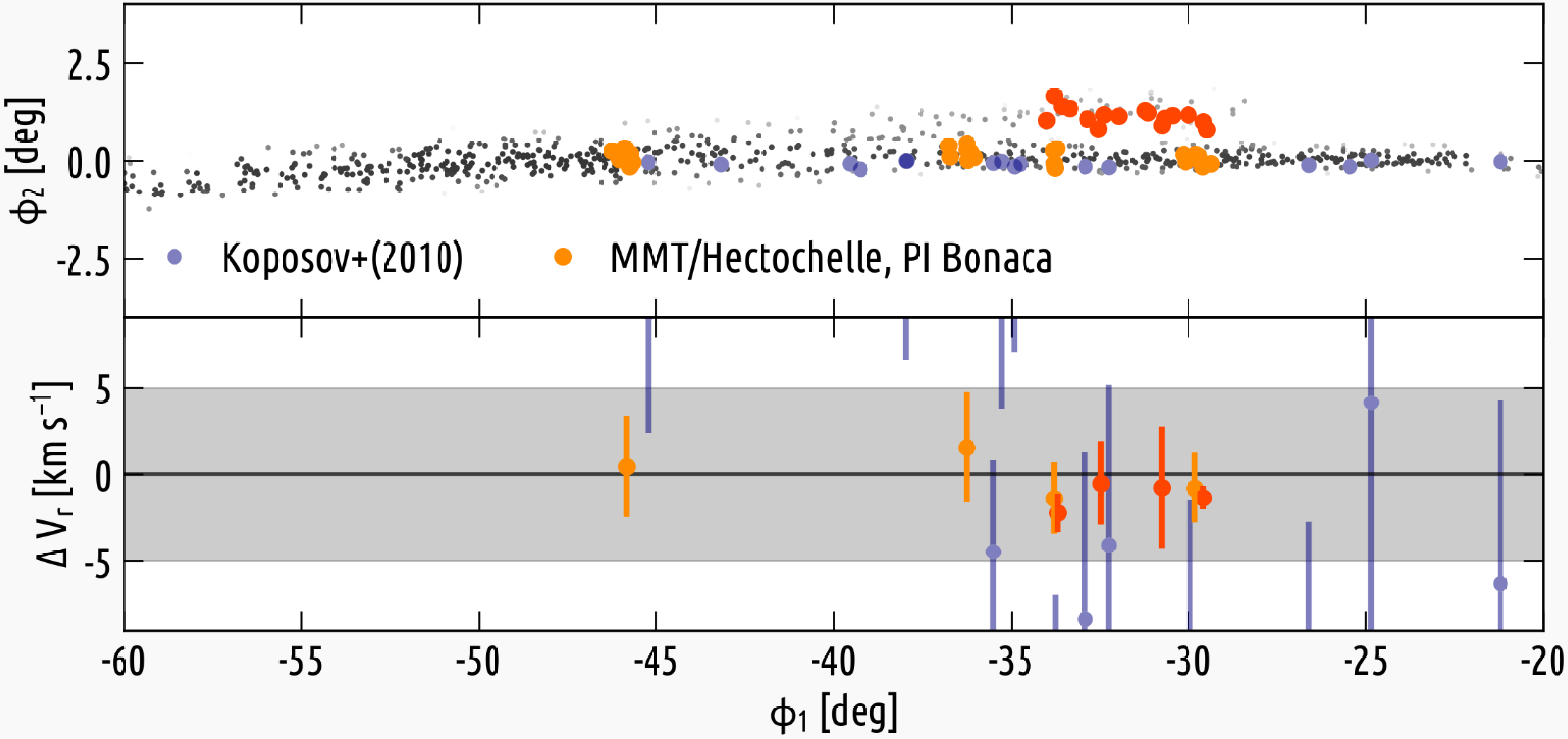
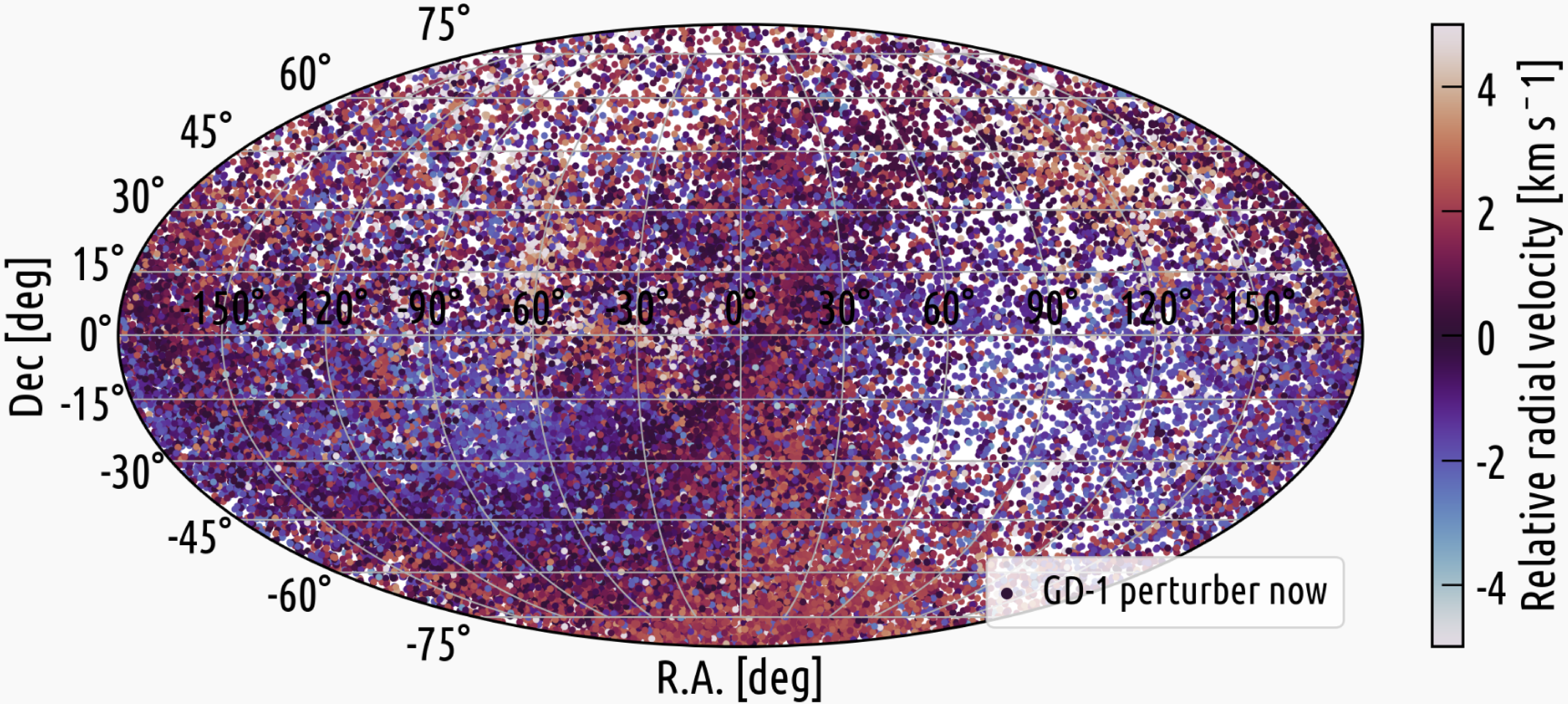


With kinematics, the GD-1 perturber is localized on the sky



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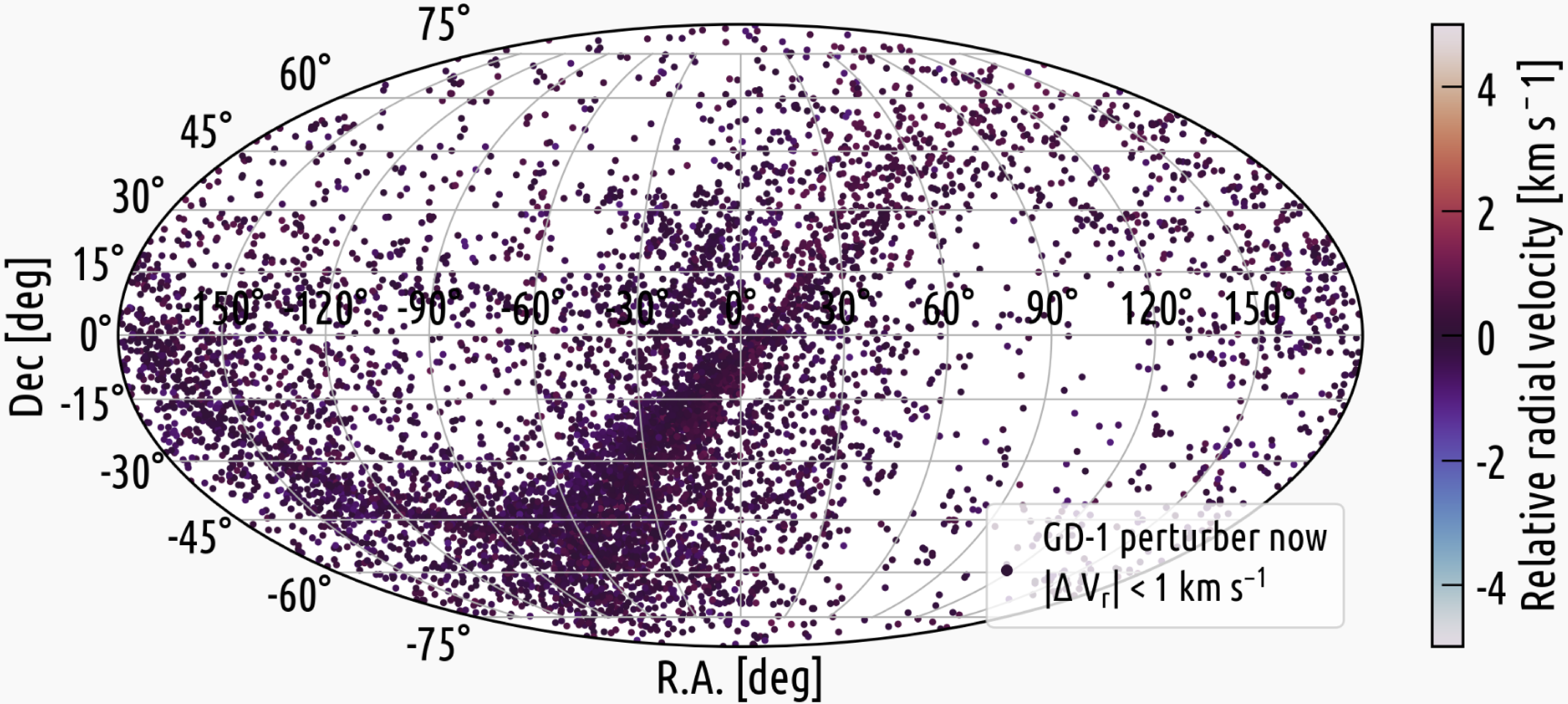

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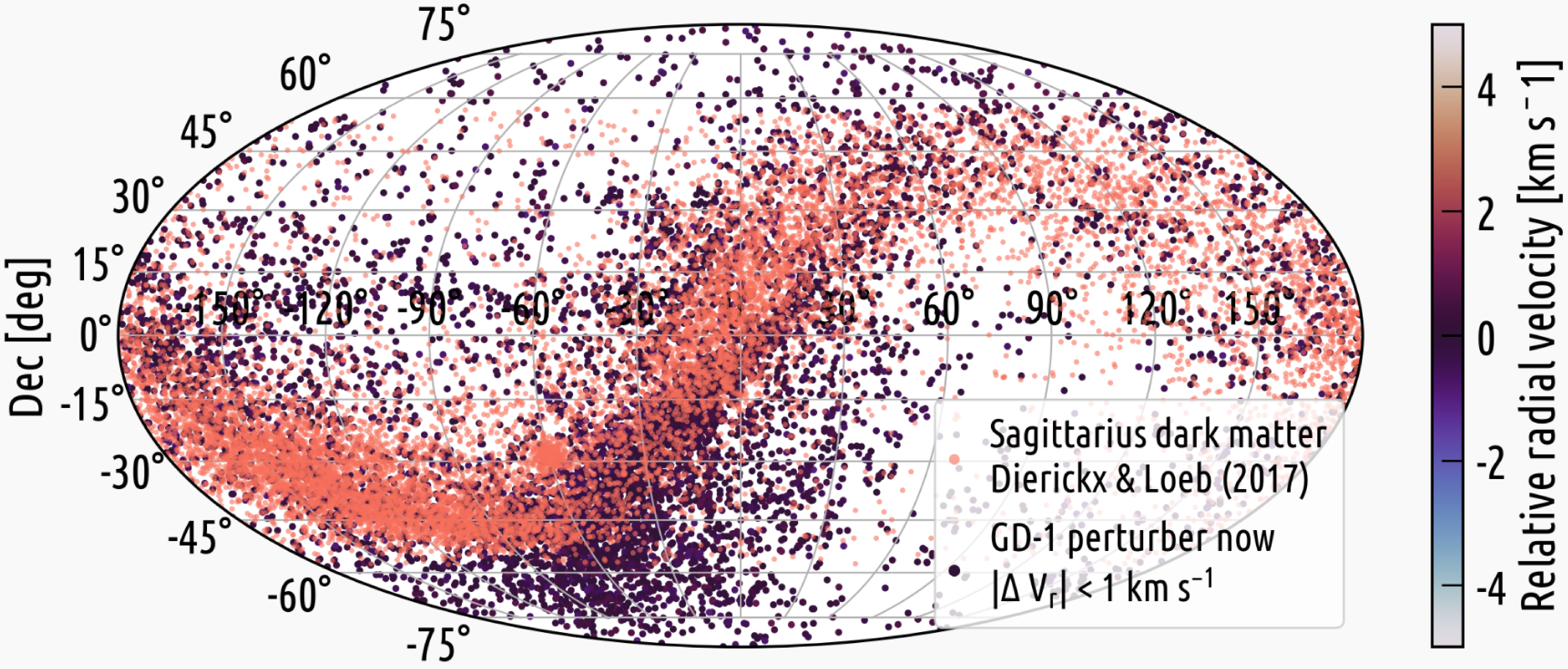

... and possibly related to the Sagittarius dwarf galaxy

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

#1
A stellar stream in the Milky Way is perturbed — possibly by a dark-matter subhalo

Price-Whelan & Bonaca (2018)
Bonaca et al. (2019)

#2
Precision kinematics of the perturbed stream localize the current position of the perturber
→ multi-messenger studies of dark matter?

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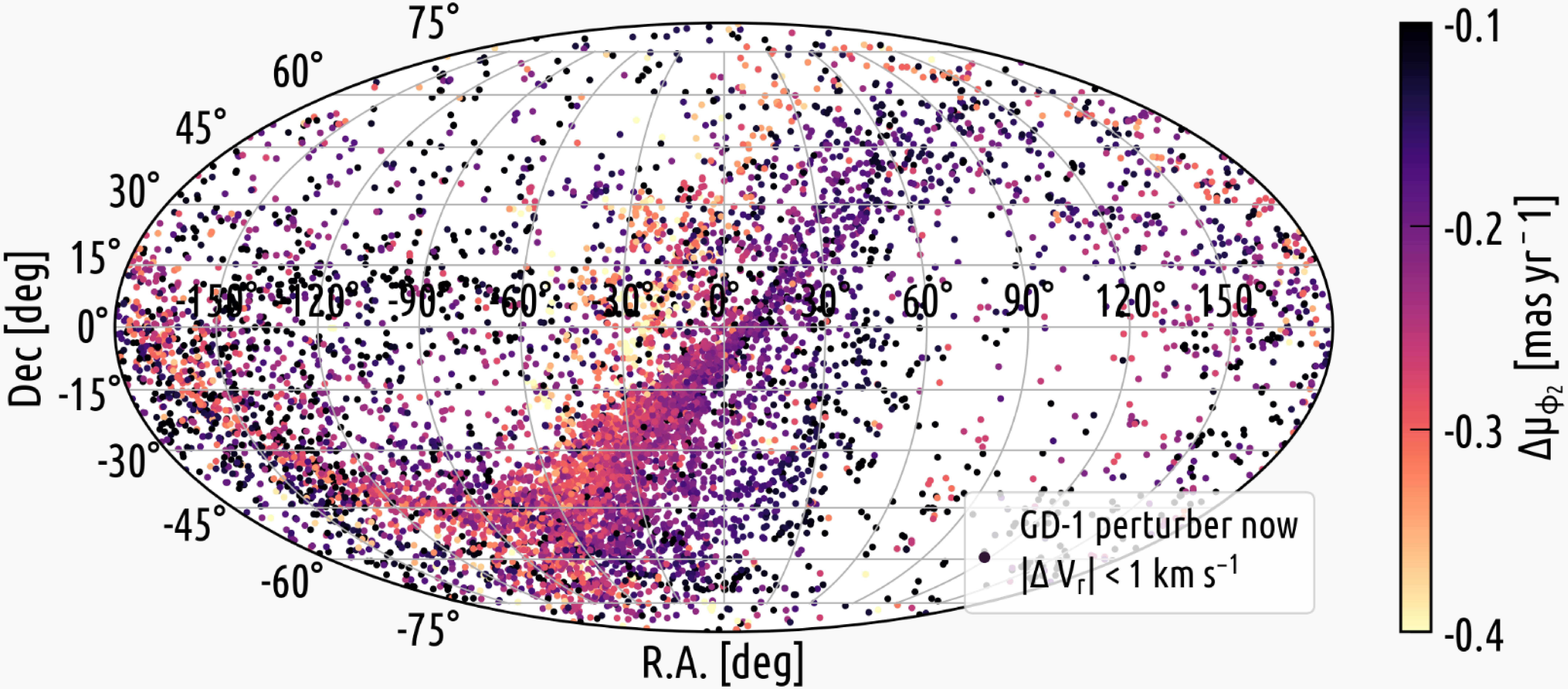
Can we rule out other sources of perturbation and conclusively identify dark dark-matter subhalos?

Has GD-1 stellar stream been perturbed by a dark-matter subhalo?



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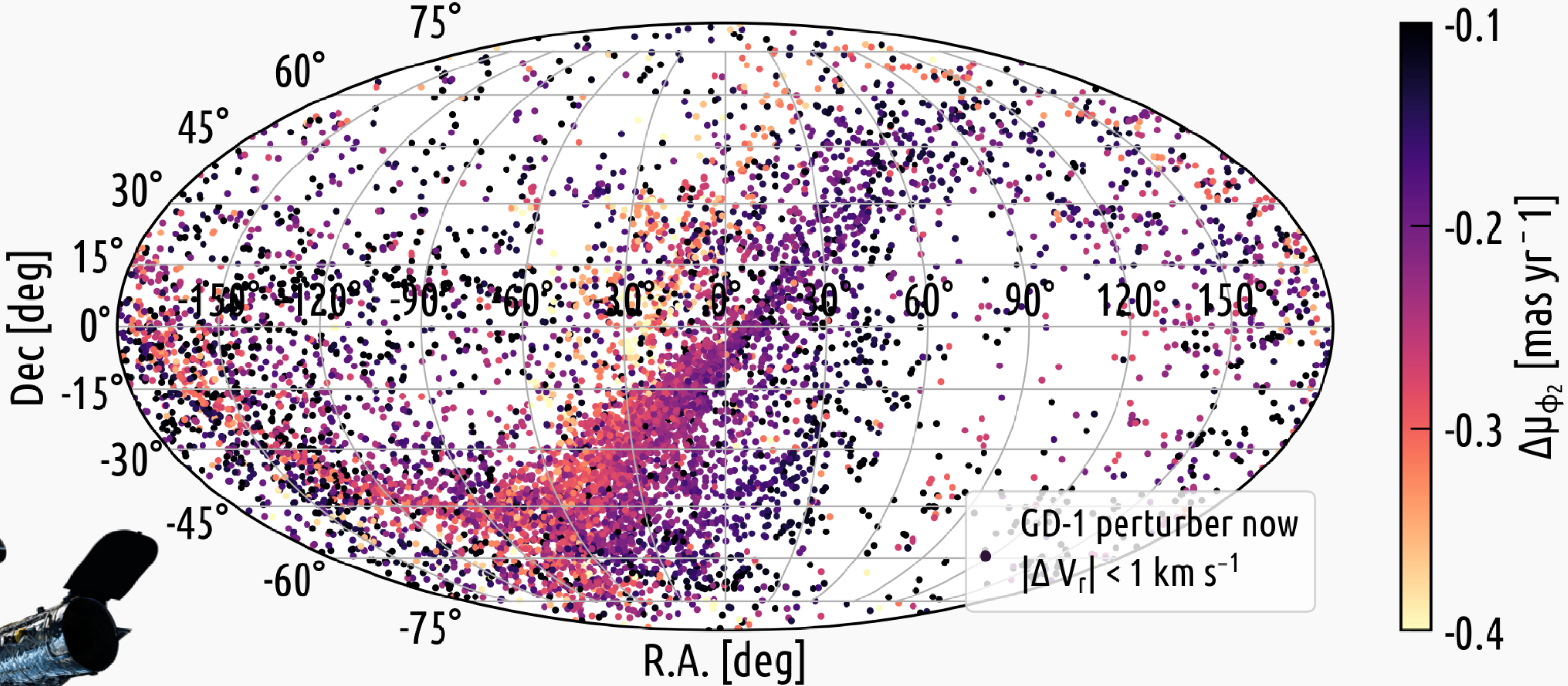

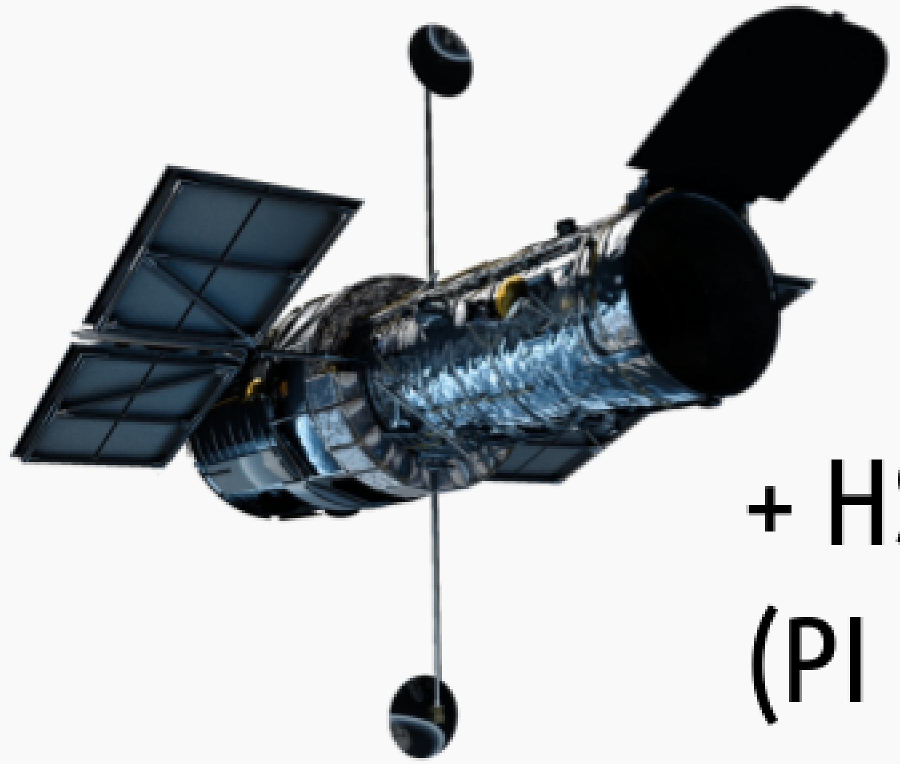

+ HST proper motions
(PI Bonaca, Cycles 27 & 29)

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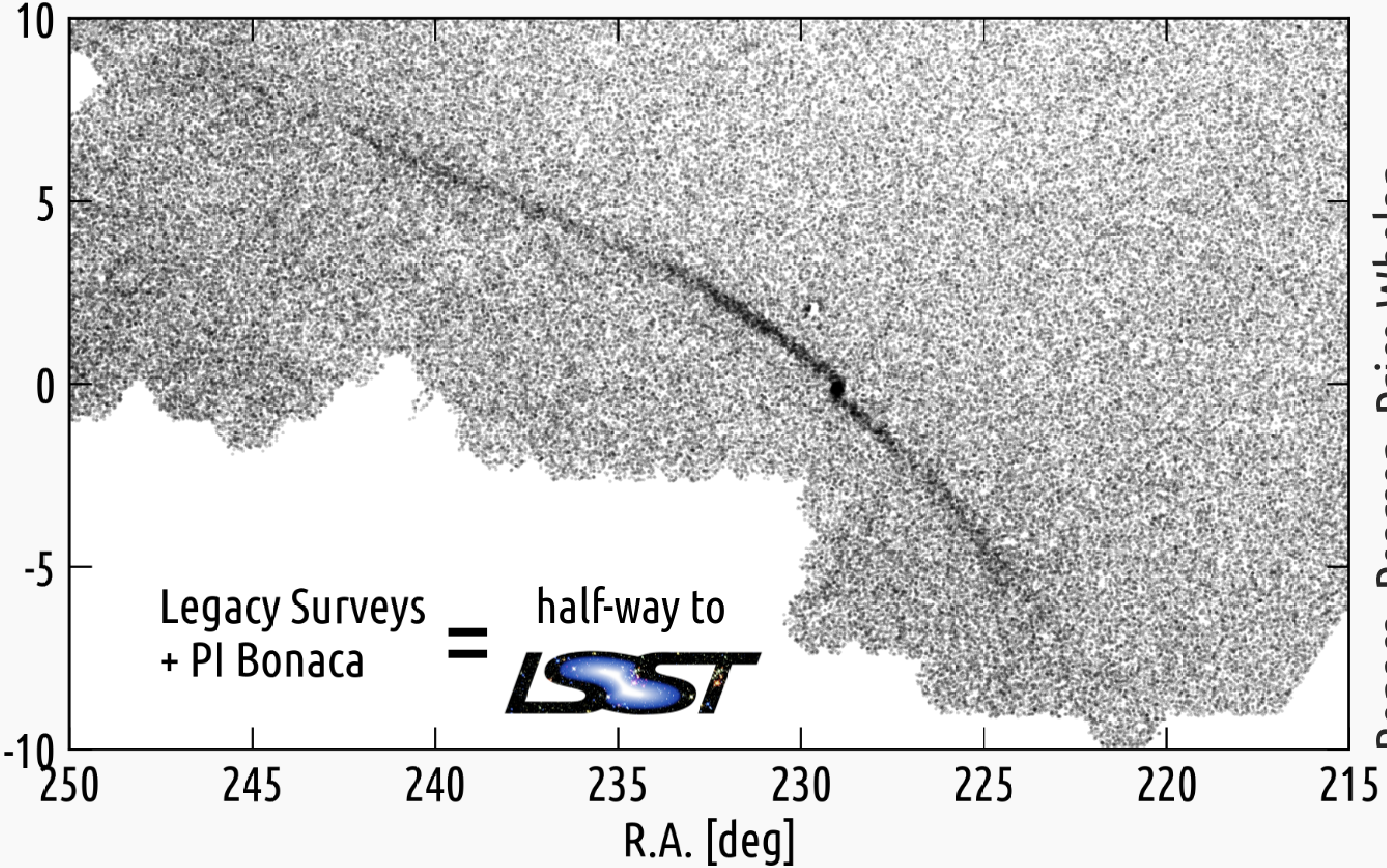

Bonaca, Pearson, Price-Whelan, et al. (2020), arXiv:1910.00592

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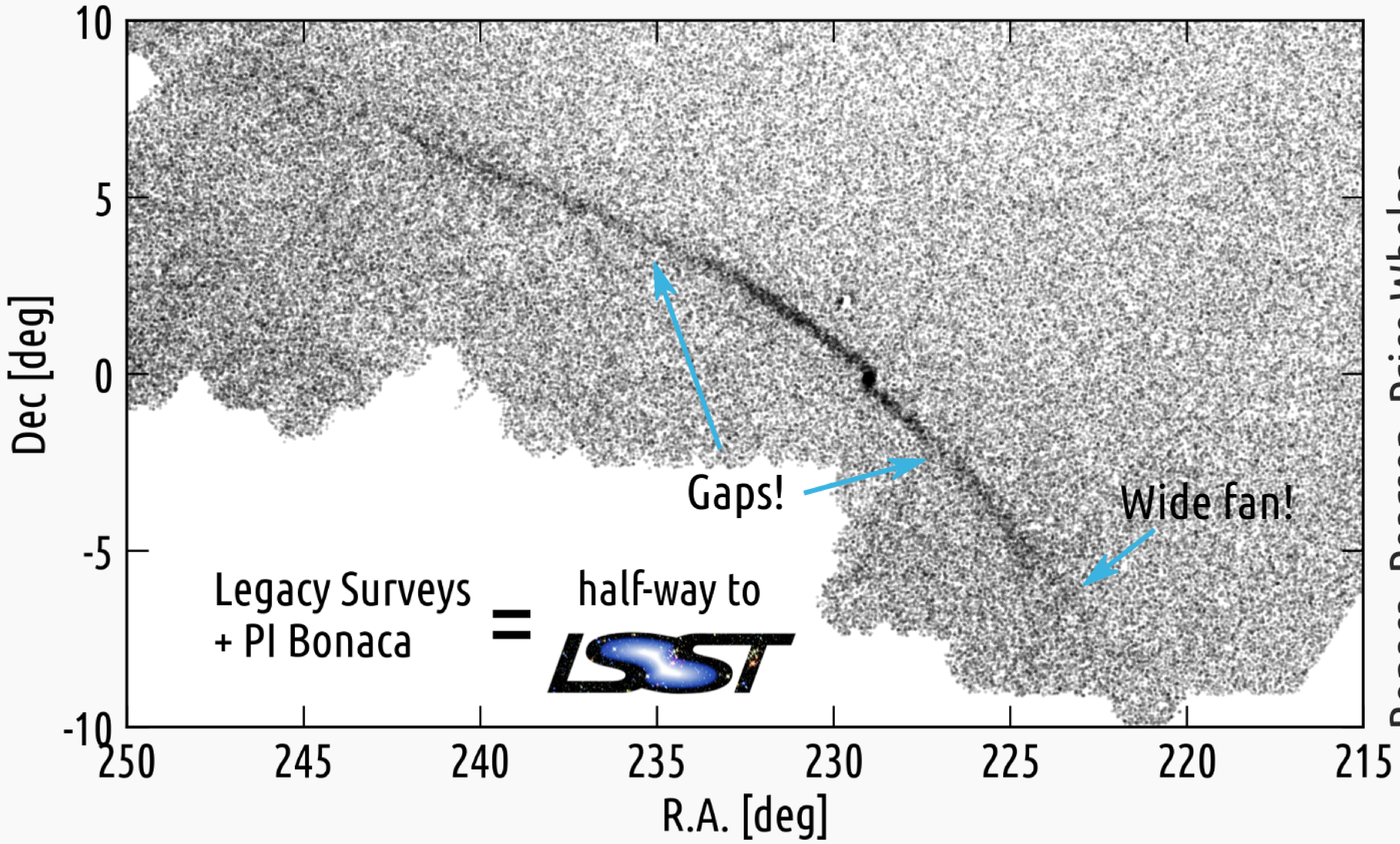

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In the LSST era, LCDM cosmology is falsifiable

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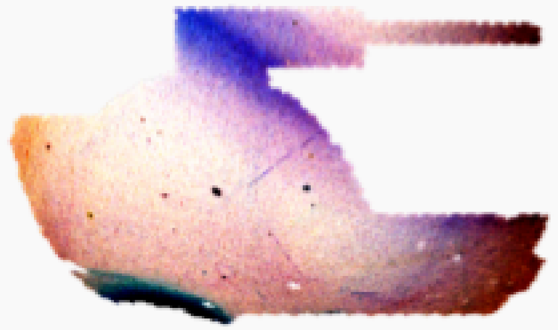

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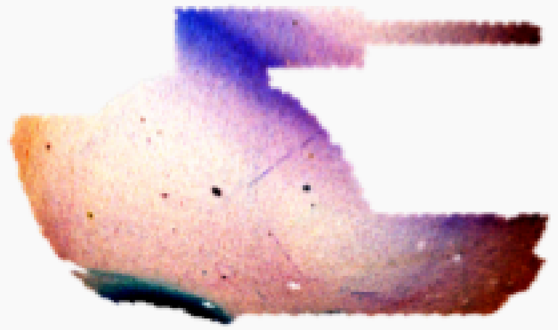

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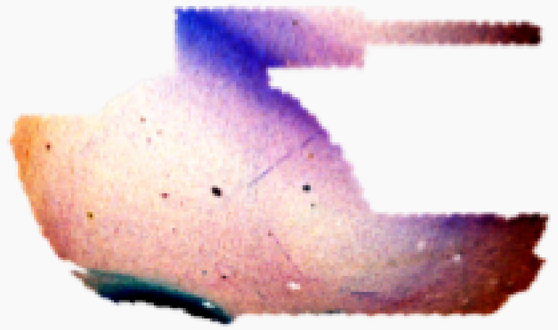

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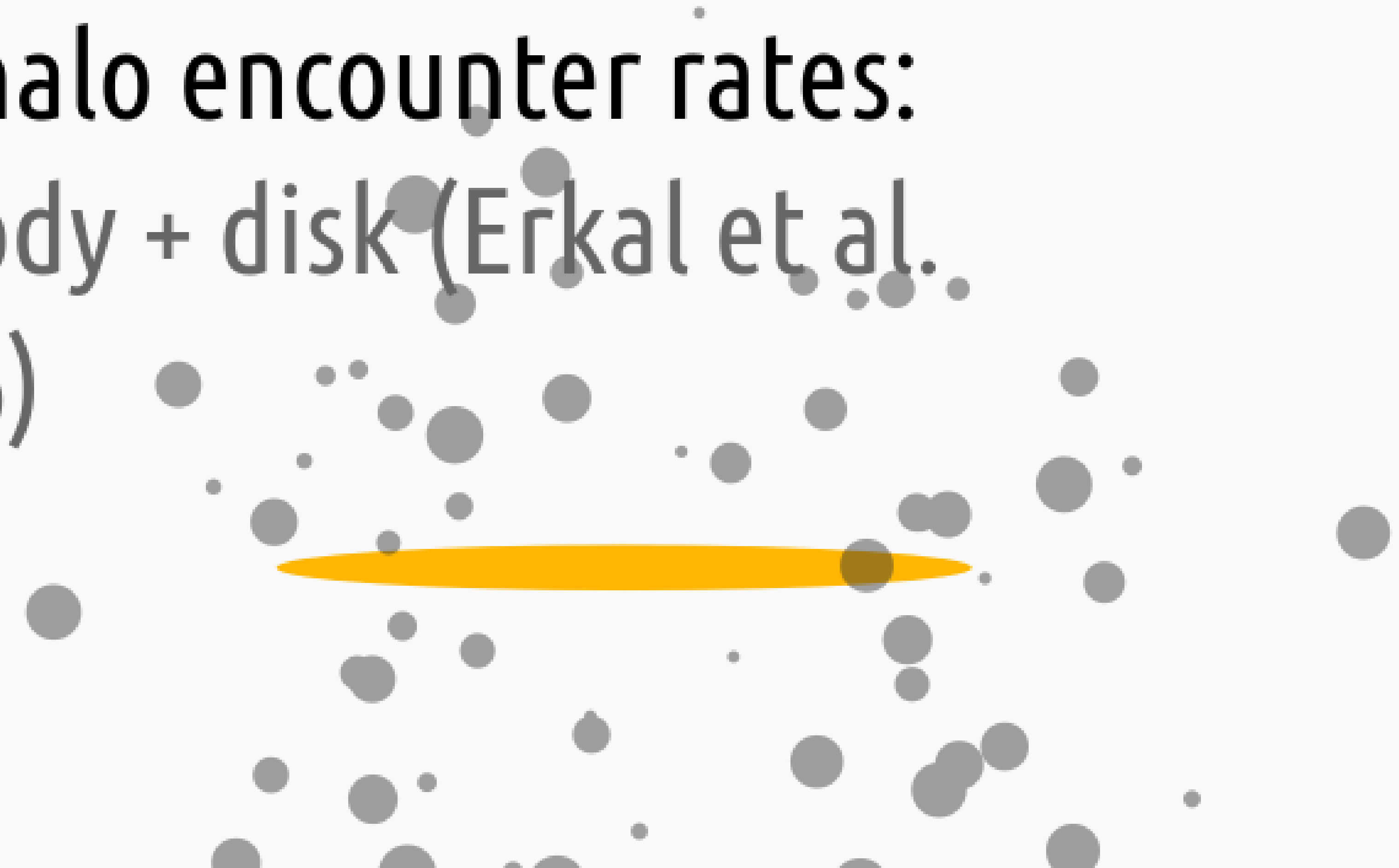

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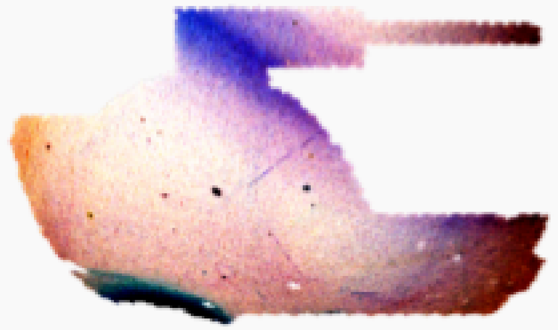

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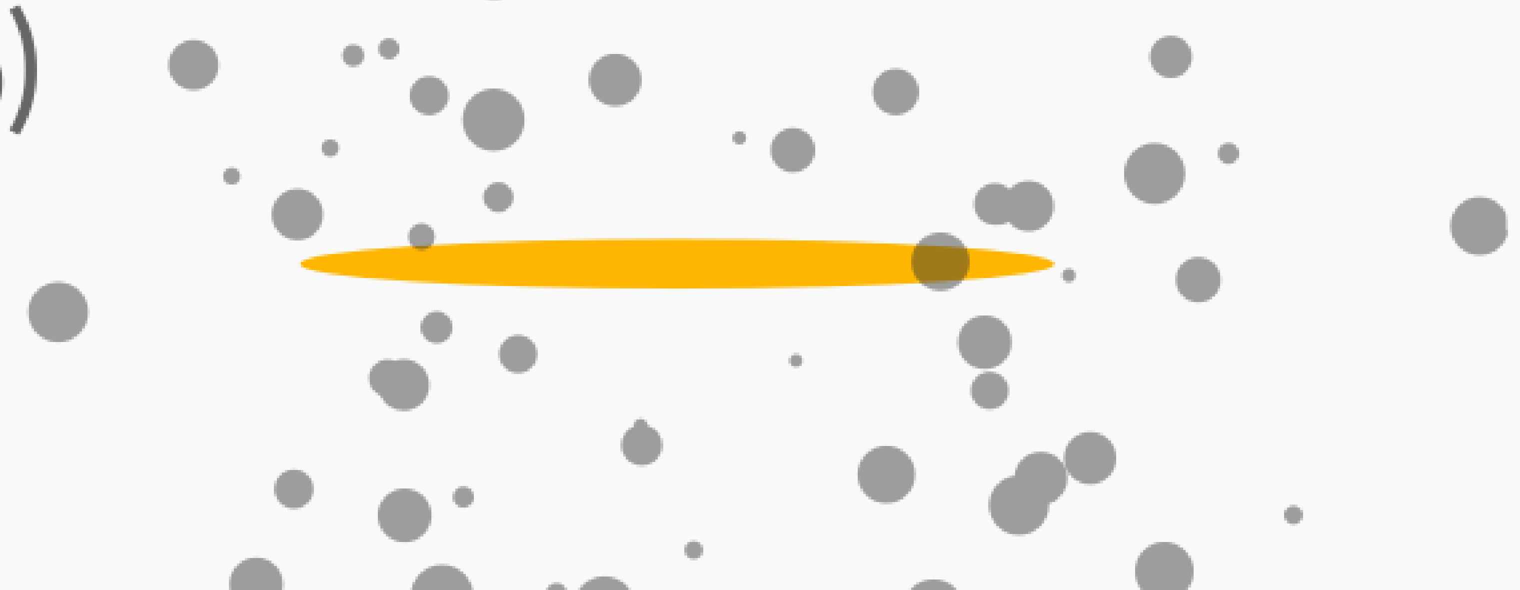

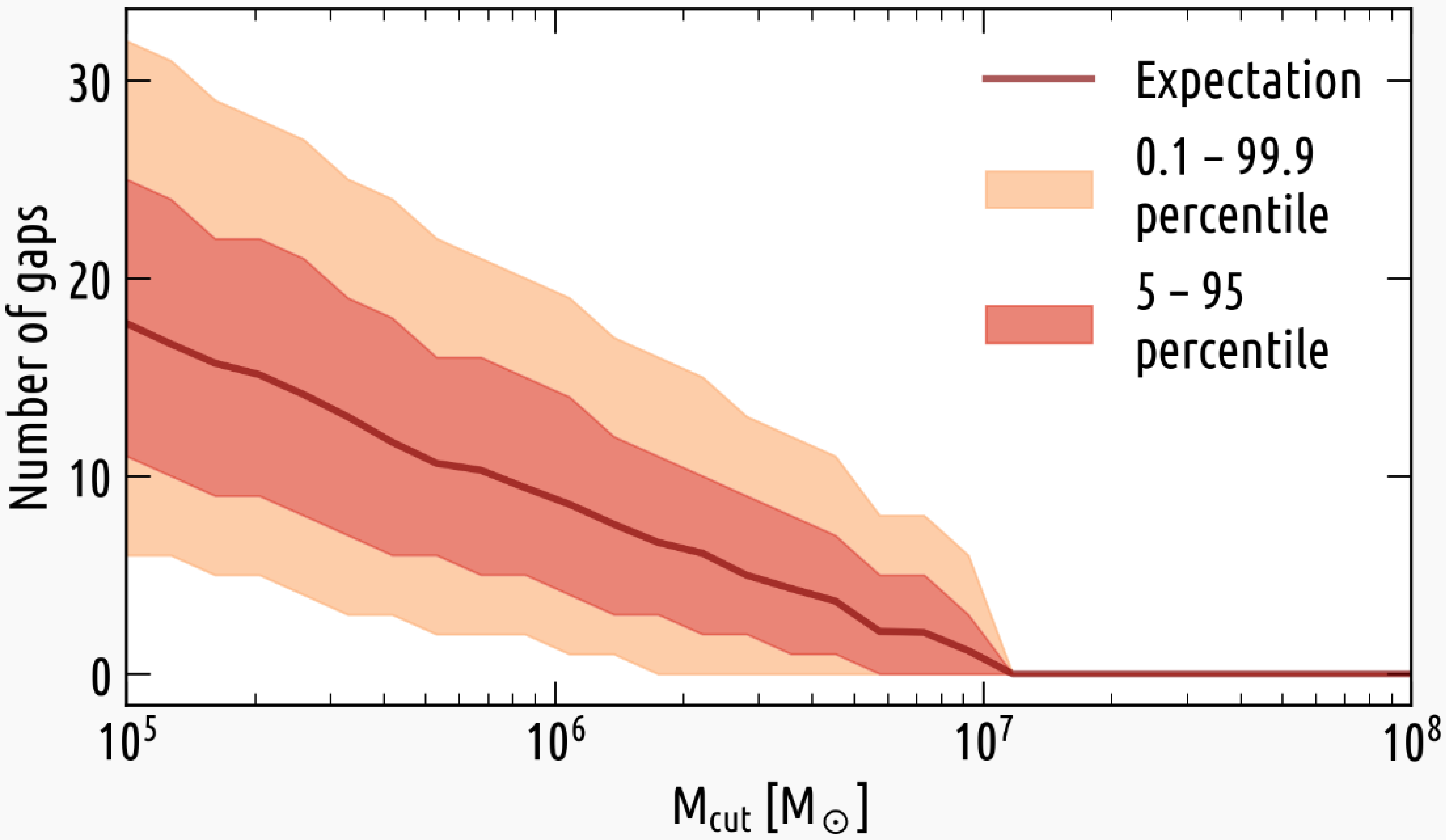

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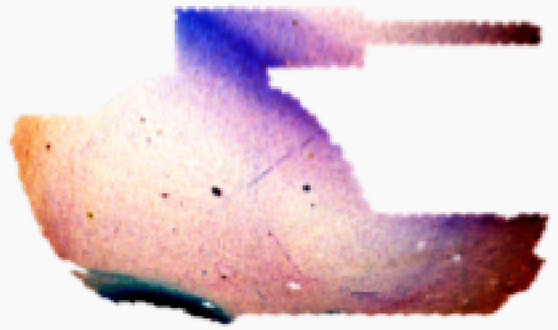
[1] streams in the LSST footprint:

13 known (Shipp et al. 2018)



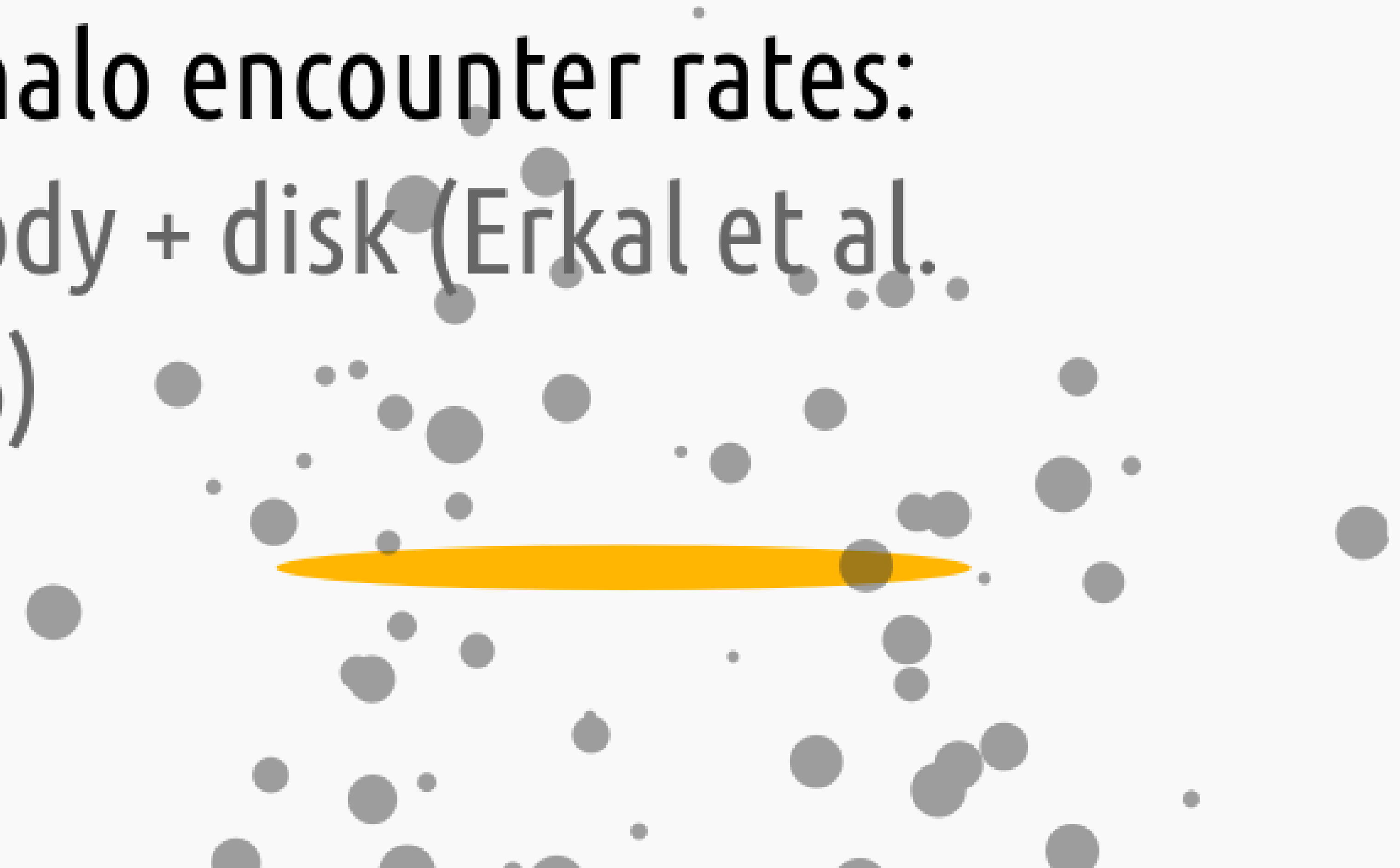
[2] minimum detectable subhalo:

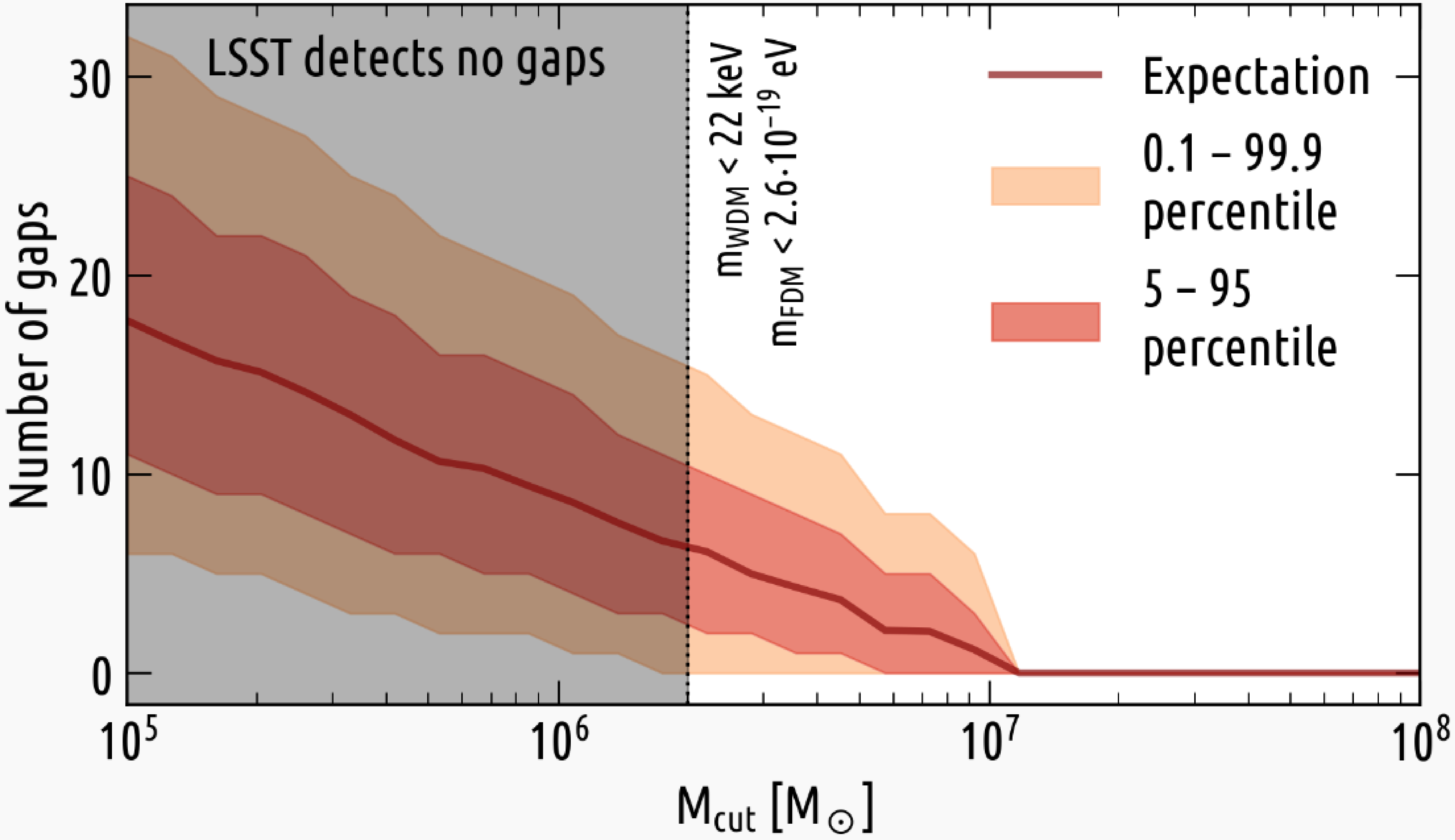
$\gtrsim 10^5\ M_\odot$

(Nora Shipp)

[3] subhalo encounter rates:

N-body + disk (Erkal et al. 2016)





Drlica-Wagner, Mao, ..., Bonaca, ... arXiv:1902.01055

An entire web of stellar streams awaits to be confidently revealed with the next generation of photometric surveys