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

Date: Sep 25, 2018 11:00 AM

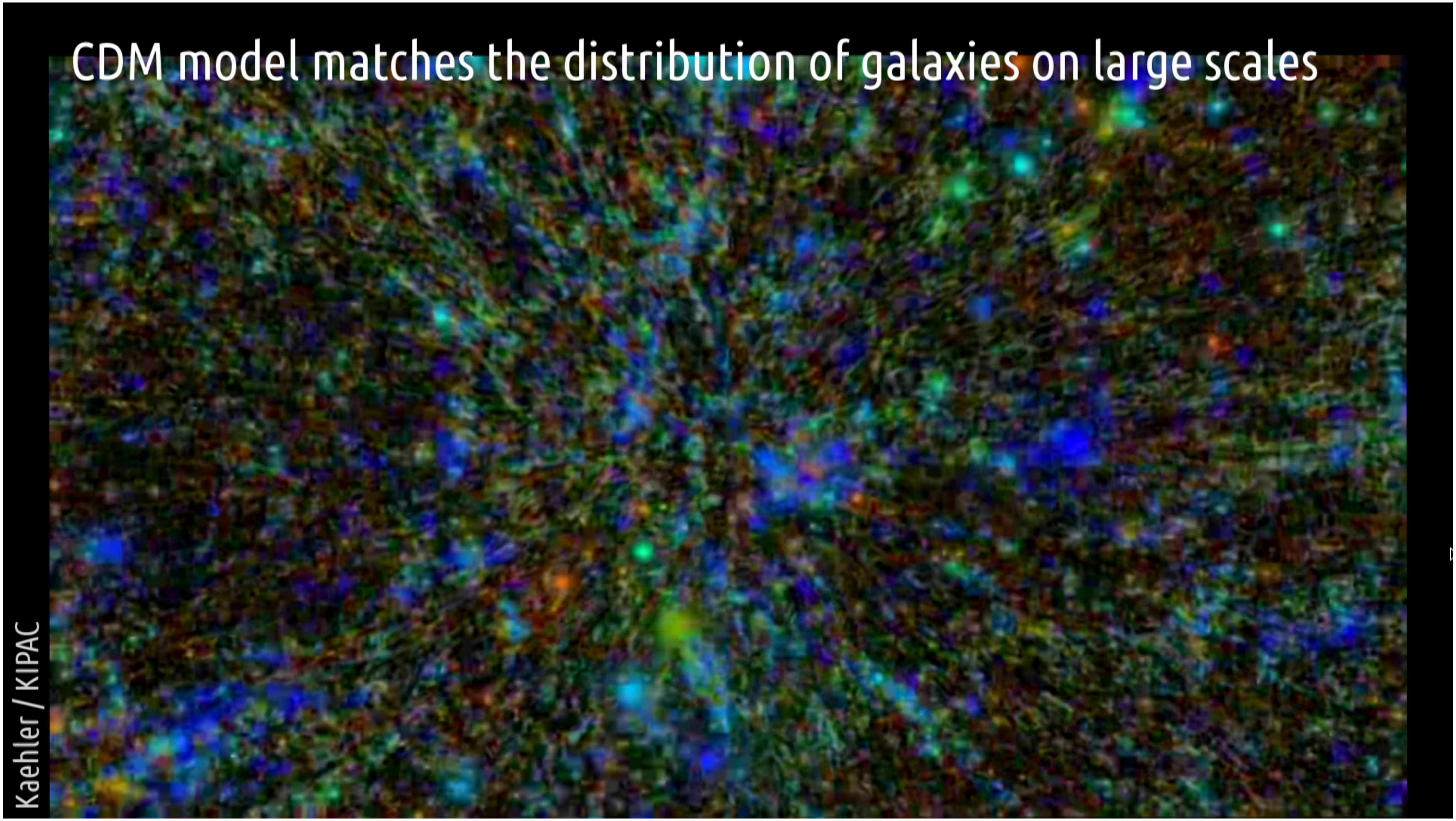
URL: http://pirsa.org/18090034

Abstract: <p>Stars orbiting in the halo of our galaxy, the Milky Way, are a window into the distribution of dark matter. In particular, tidally disrupted star clusters, which produce thin stellar streams, are optimal tracers of matter. Based on a Fisher-information calculation, we expect that the current data on the known Milky Way streams should constrain the radial profile and the shape of the inner halo to a precision of a few percent. In addition, stellar streams retain a detailed record of the matter field on small scales. Typically, streams are very thin -- approximately 100 times longer than they are wide, so even small gravitational perturbations introduce observable variations in the density of stars along the stream. Recently, significant gaps were detected in the GD-1 stellar stream, as well as stream stars displaced from the main stream. The observed structure is naturally reproduced in simulations where a stream like GD-1 encounters a massive perturber. None of the known Milky Way satellites has recently crossed paths with GD-1. If confirmed, the encounter scenario indicates the presence of an unknown, massive (~10^7 Msun) and compact (~<10 pc) object in the Milky Way -- the first evidence of dark substructure in a galactic halo.</p>

Ana Bonaca
ITC Fellow
Harvard - Smithsonian
Center for Astrophysics

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

CDM model matches the distribution of galaxies on large scales



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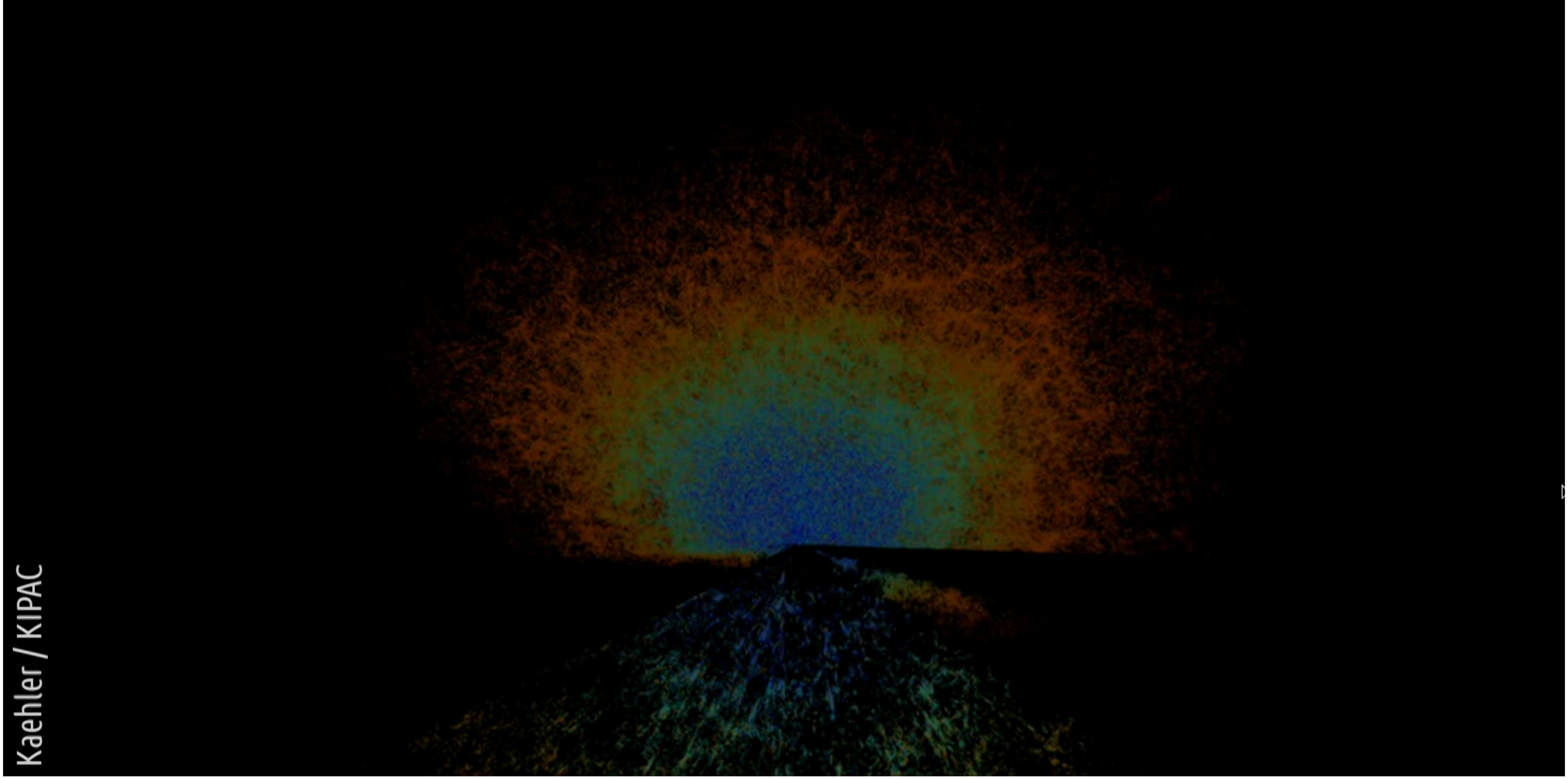
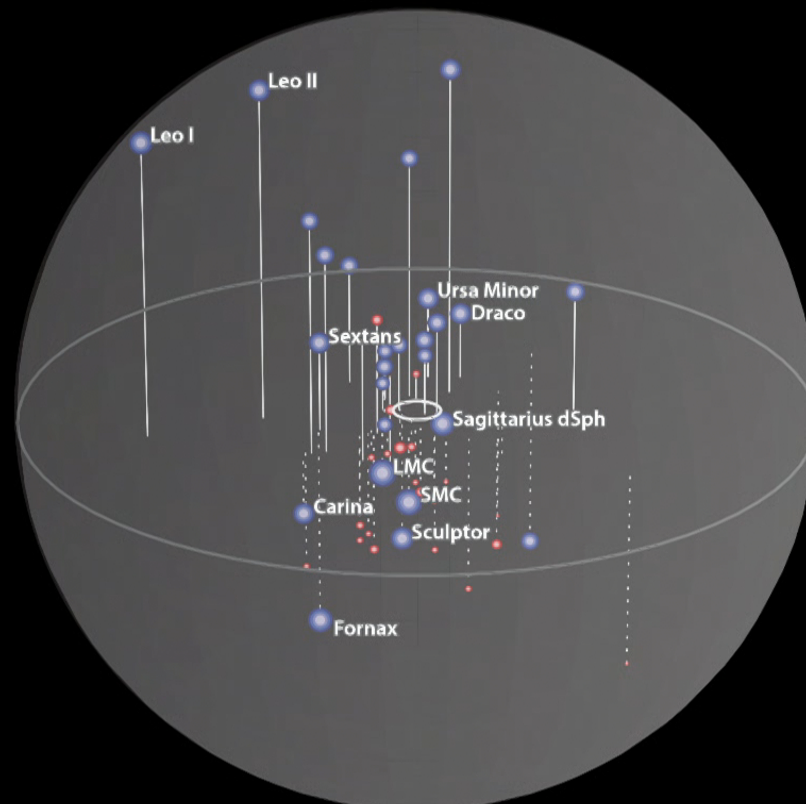


We don't see all the structure predicted by CDM on small scales

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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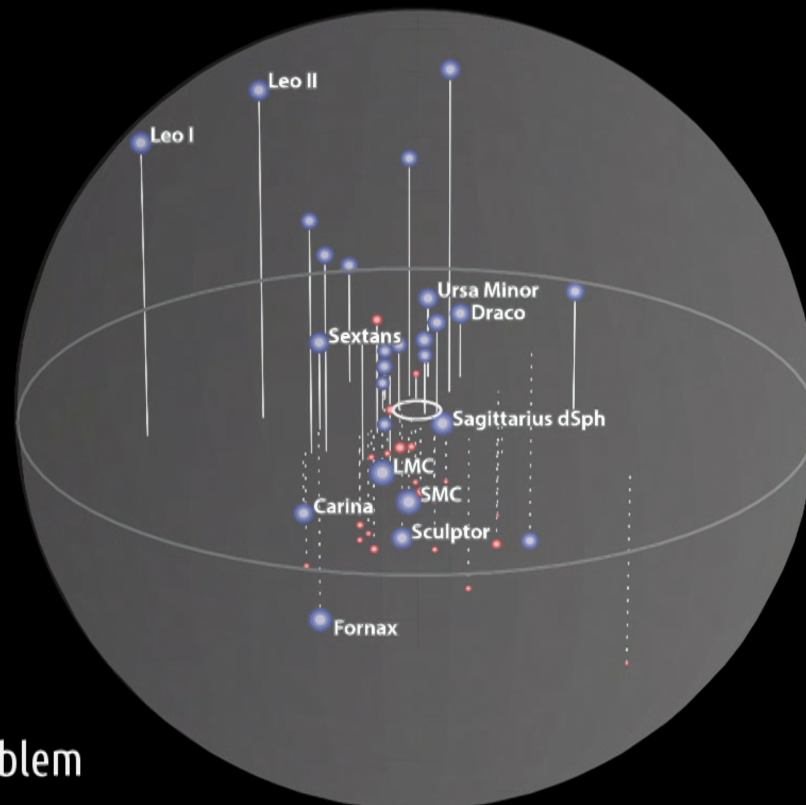
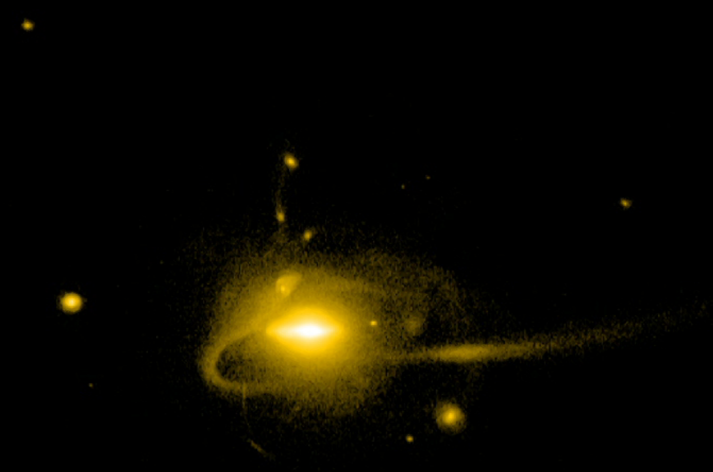


Pawlowski, Bullock, Boylan-Kolchin

The
Missing
Satellites Problem

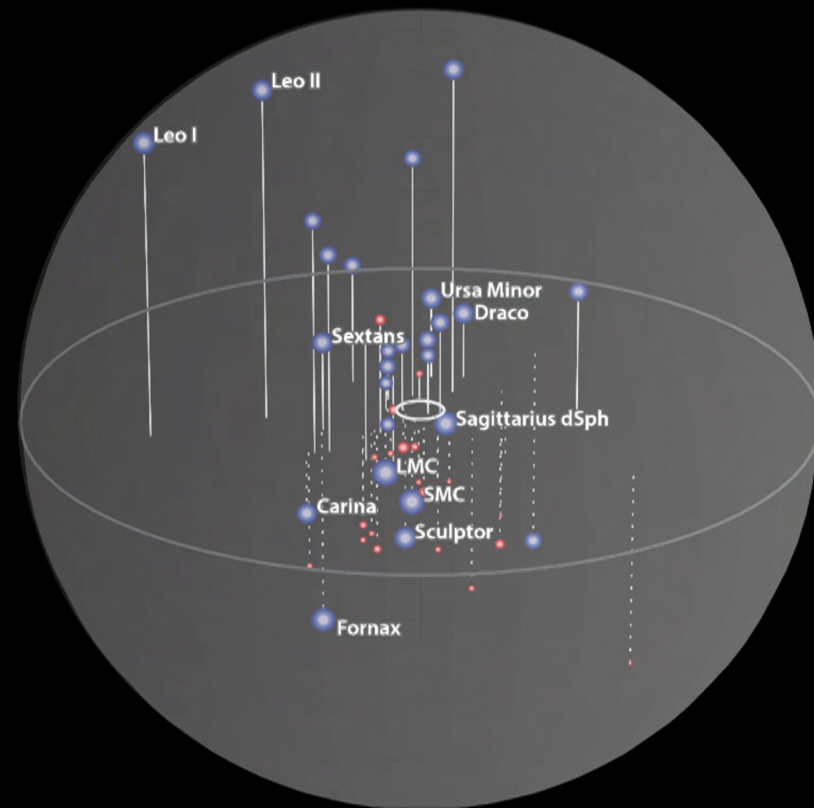
We don't see all the structure predicted by CDM on small scales

Stars in a simulated galaxy with baryons



Wetzel et al. (2016)

Satellite galaxies of the Milky Way



Pawlowski, Bullock, Boylan-Kolchin

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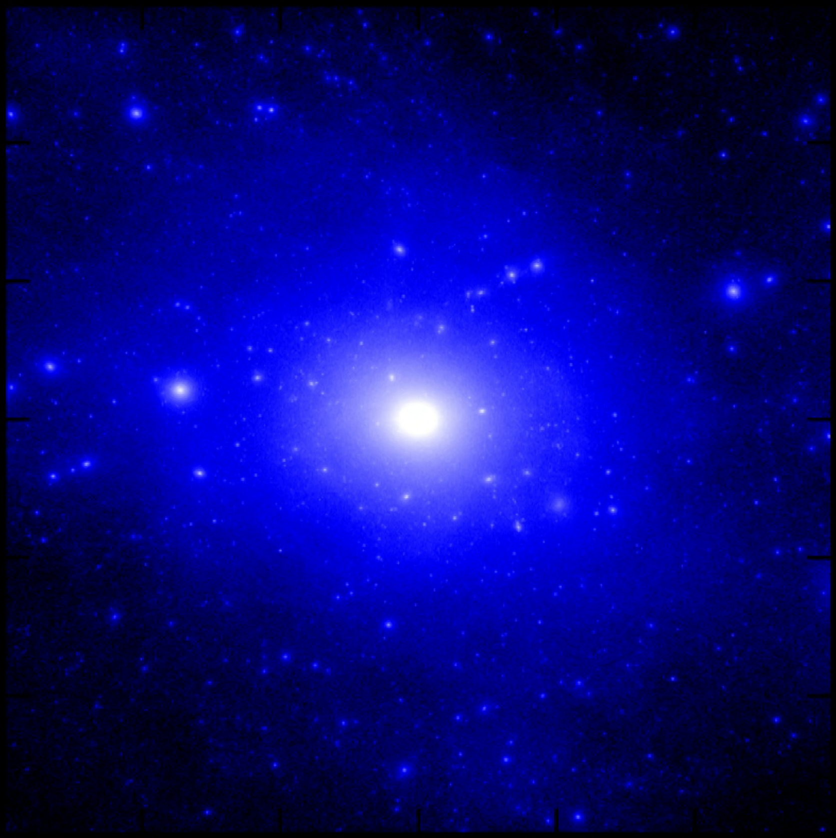
Dark matter in a simulated galaxy with baryons



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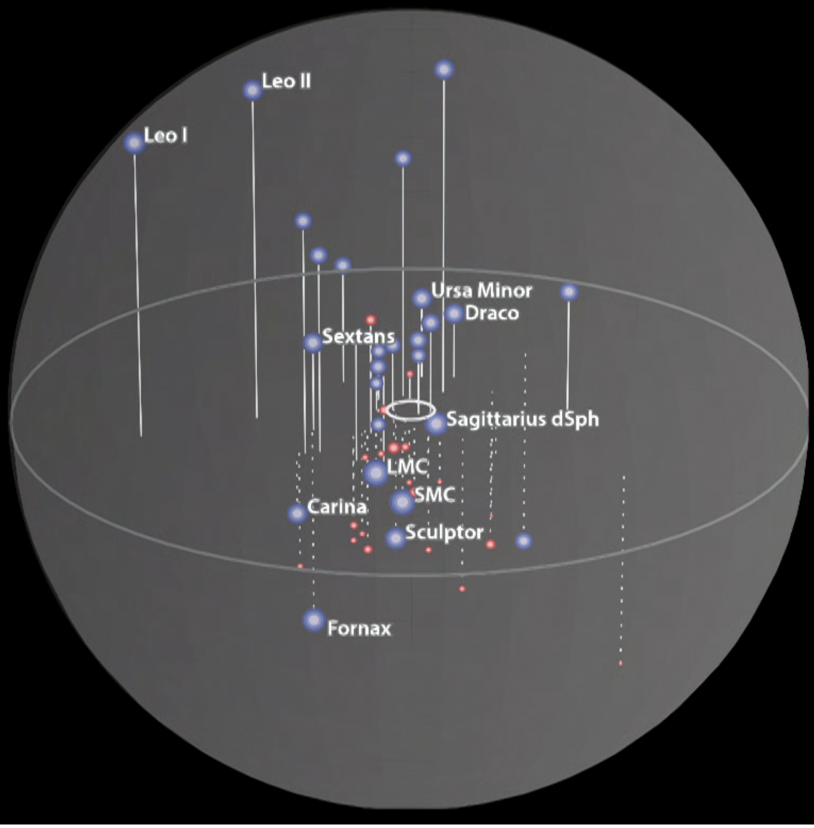


Pawlowski, Bullock, Boylan-Kolchin

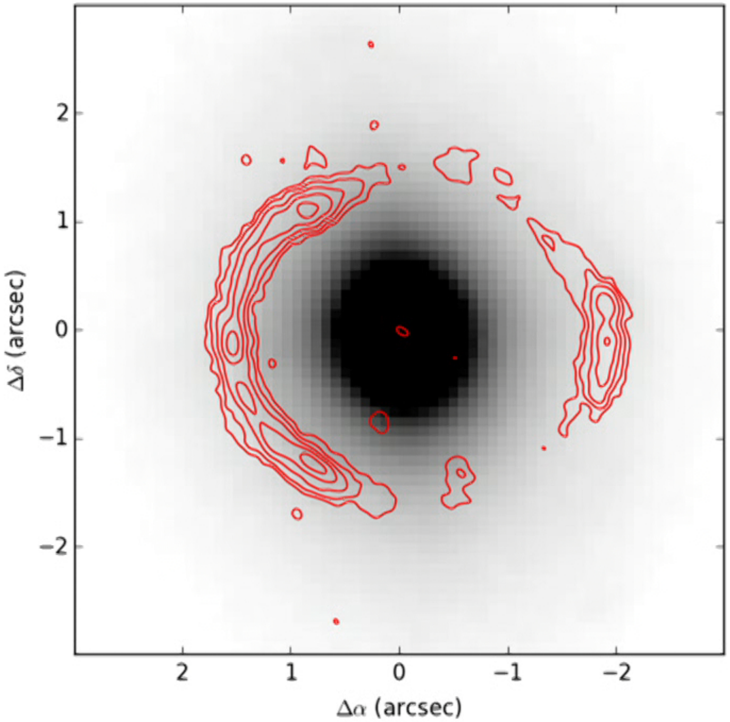
... the search for abundant dark matter (DM) halos with inferred virial masses substantially lower than the expected threshold of galaxy formation ($M \sim 10^8\,\mathrm{M}_\odot$) is the most urgent calling ...

The existence of these structures is an unambiguous prediction of all WIMP-based DM models (though it is not unique to WIMP models), and confirmation of the existence of dark (sub)halos with $M \sim 10^6\,\mathrm{M}_\odot$ or less would strongly constrain particle physics of DM and effectively rule out any role of DM free-streaming in galaxy formation.

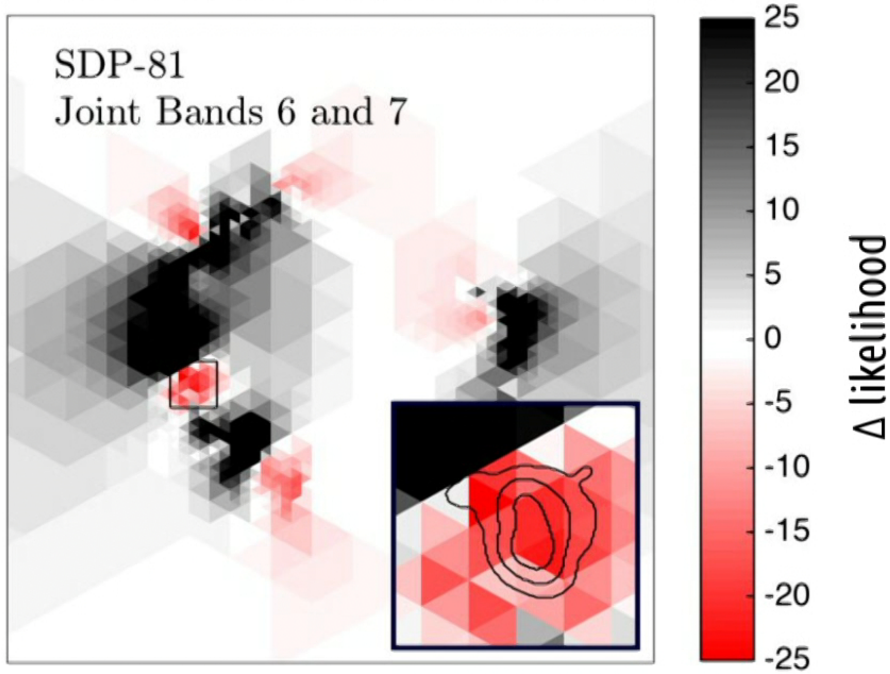
Bullock & Boylan-Kolchin (2017)

Subhalos can be detected as lensing anomalies

Gravitational lens SDP.81



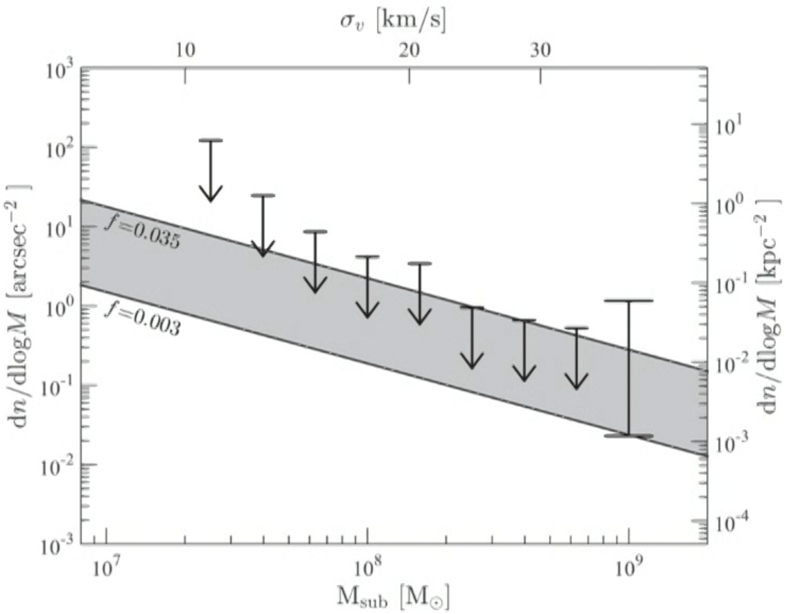
Source reconstruction requires a subhalo



Hezaveh et al. (2016)

Extragalactic searches

can discover a large sample of subhalos



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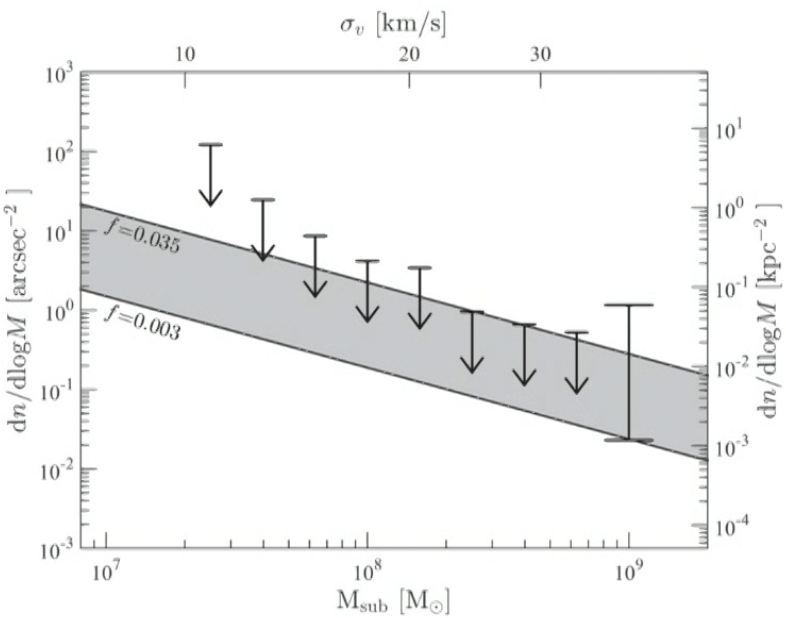

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Search in the Milky Way galaxy

would allow study of individual subhalos in a lot of detail

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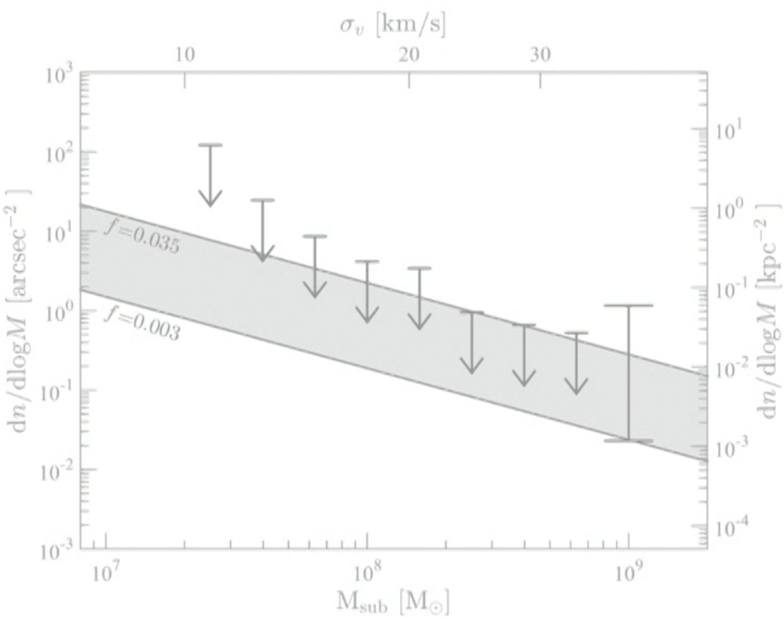

Hezaveh et al. (2016)

Search in the Milky Way galaxy

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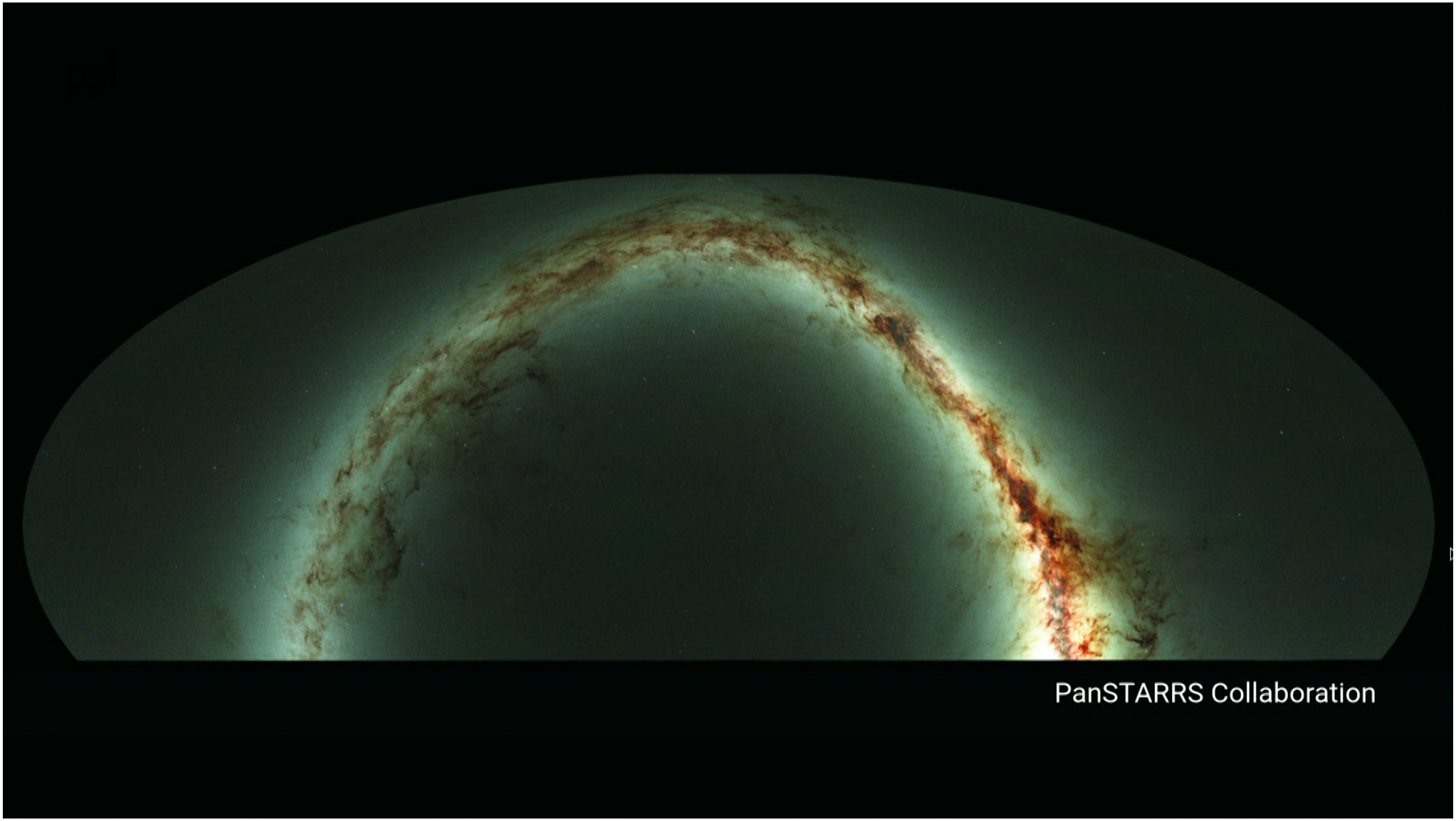
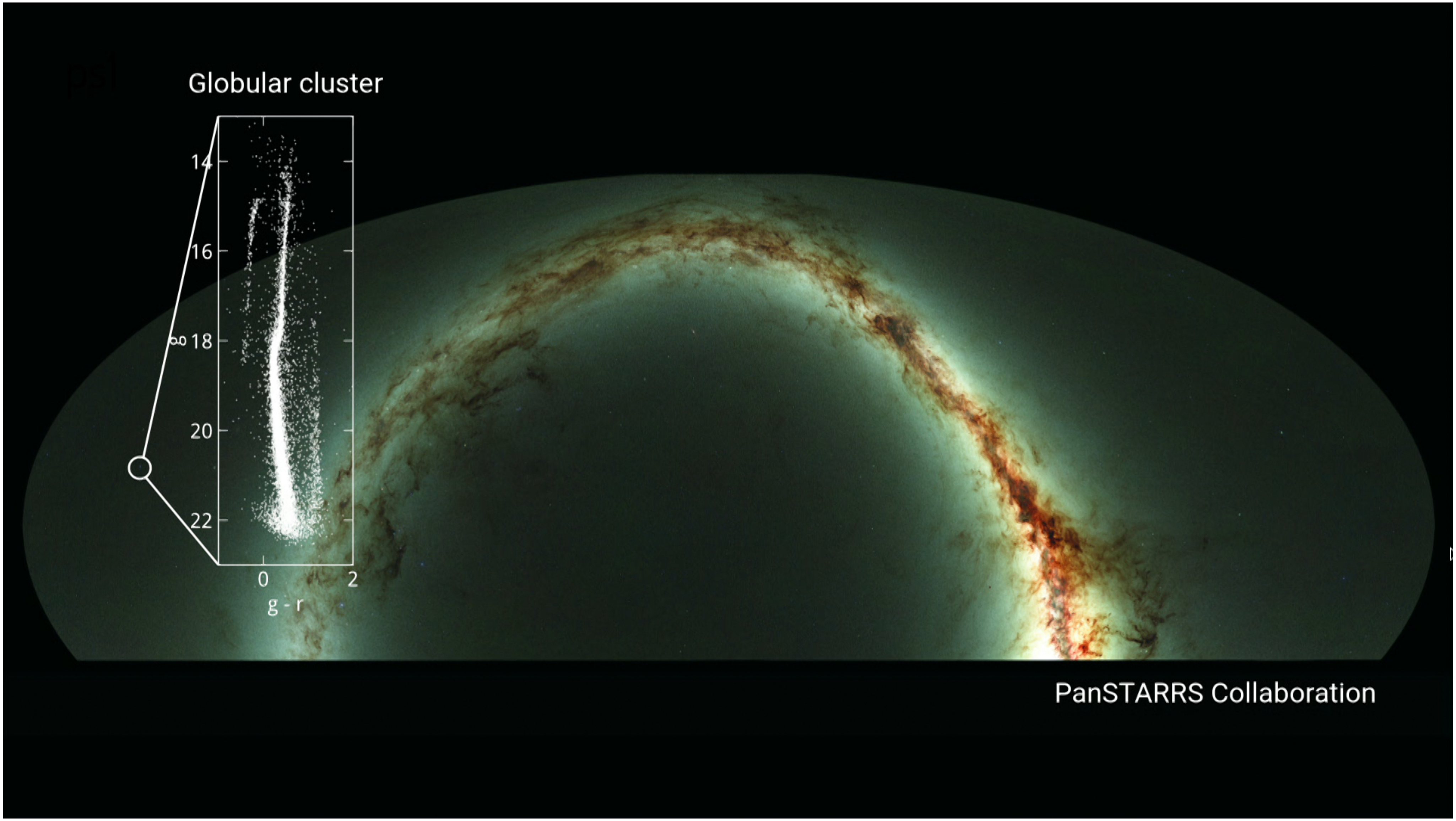
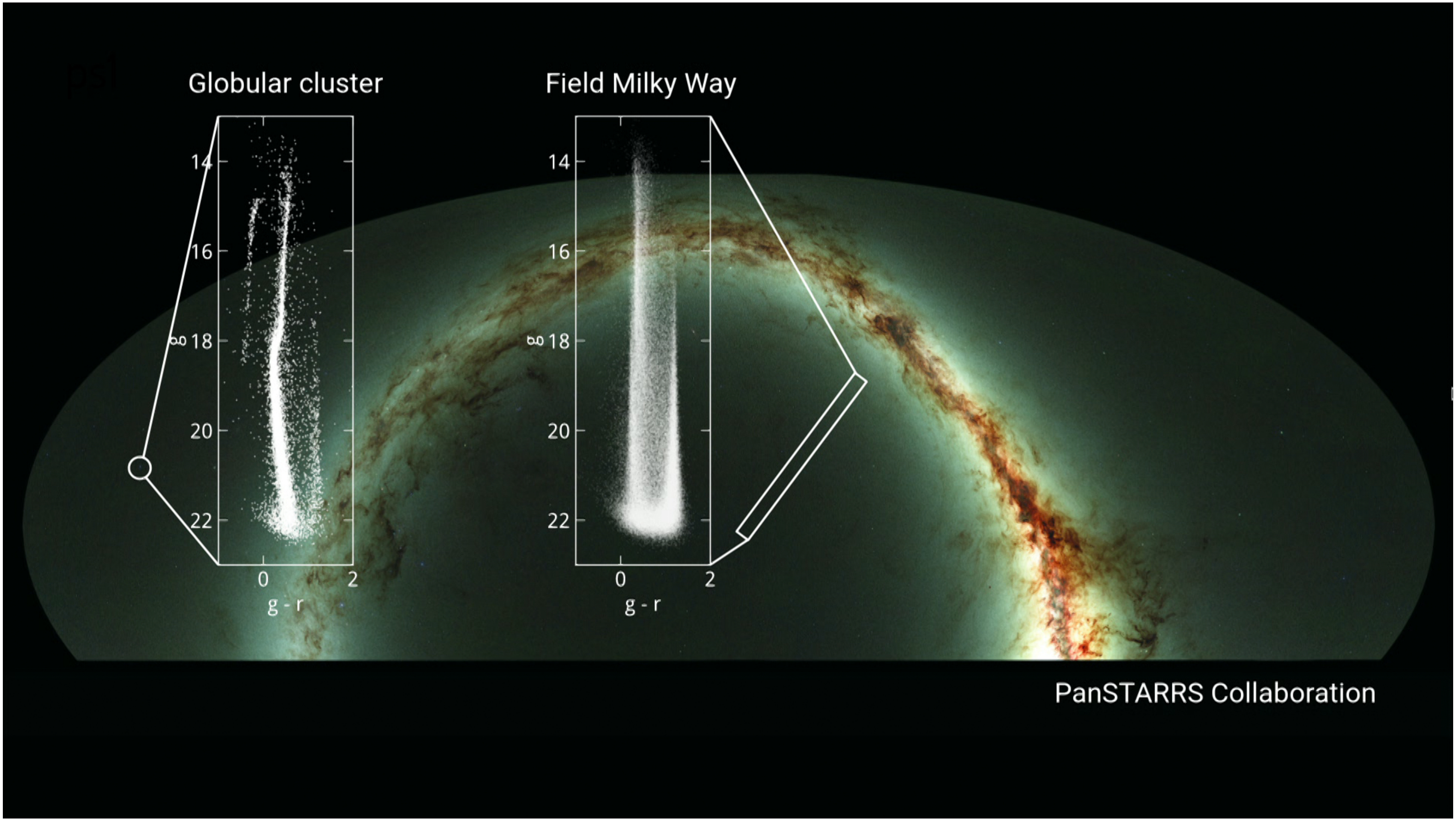
Outline:

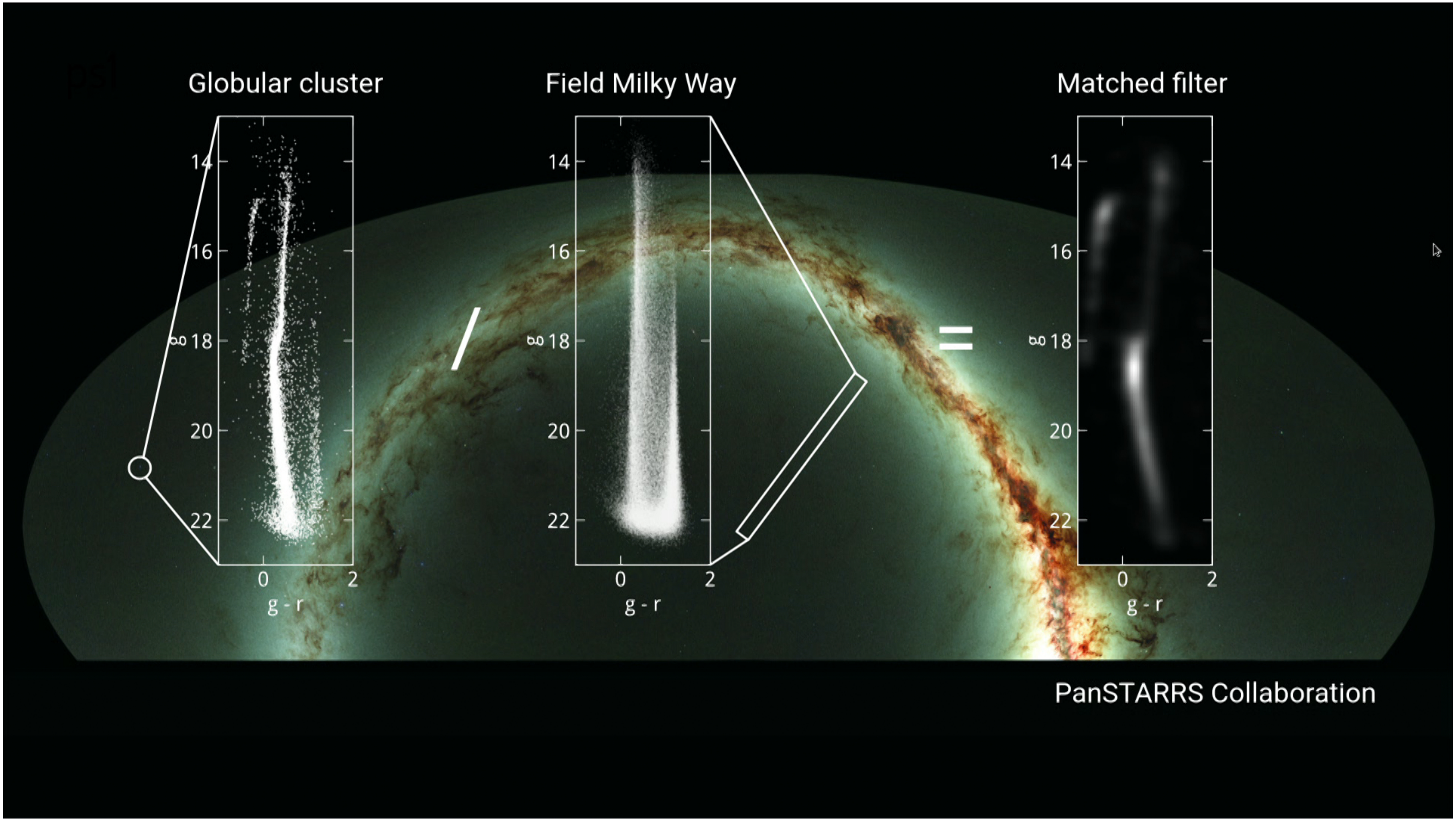
1) Find objects in the Milky Way halo that trace the gravitational potential

2) Search for signatures of deviations from the smooth distribution of matter


PanSTARRS Collaboration

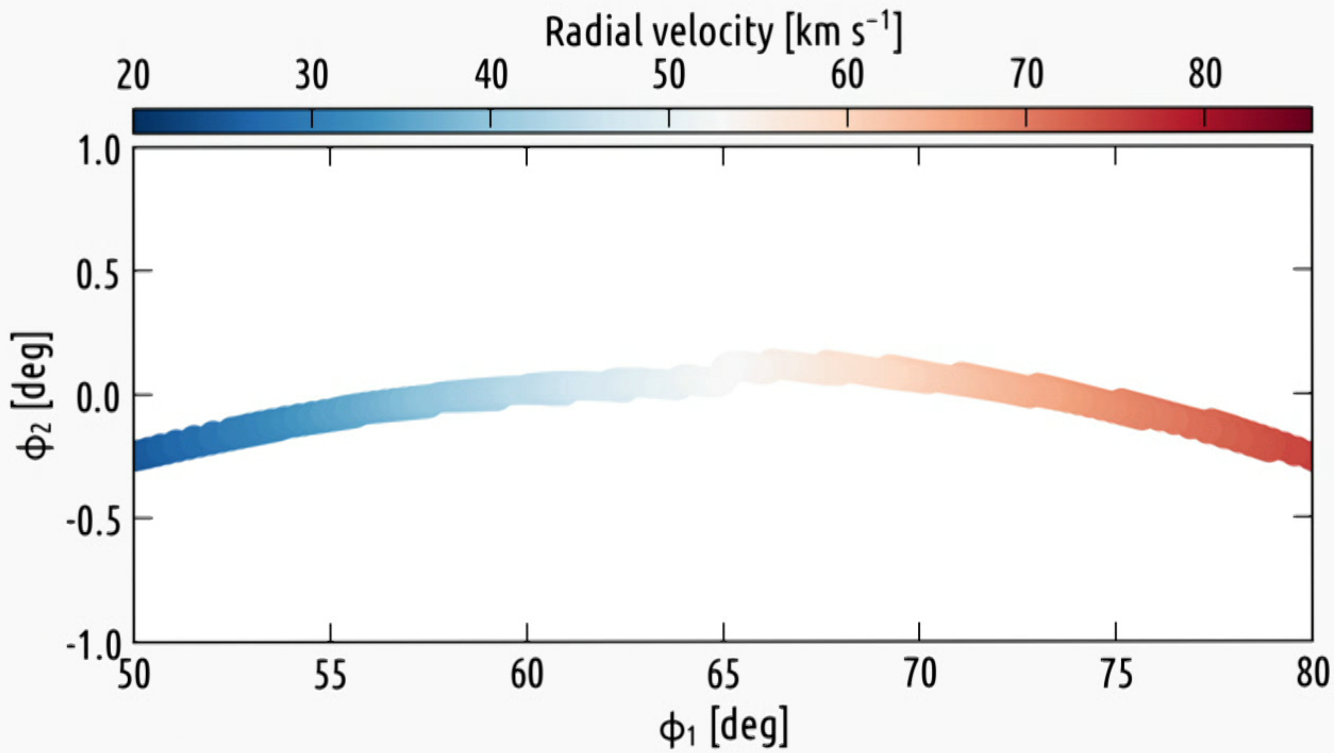

Globular cluster
14
16
18
20
22
g
0
2
g - r
PanSTARRS Collaboration


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

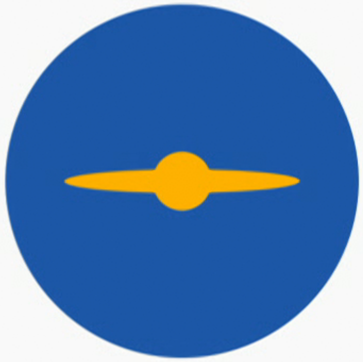

Globular cluster
Field Milky Way
Matched filter
/
=
14
16
18
20
22
g
0
2
g - r
PanSTARRS Collaboration


Stellar halo of the Milky Way
is rich with structure
Bonaca et al. (2012)

Stellar streams are shaped by the underlying matter distribution



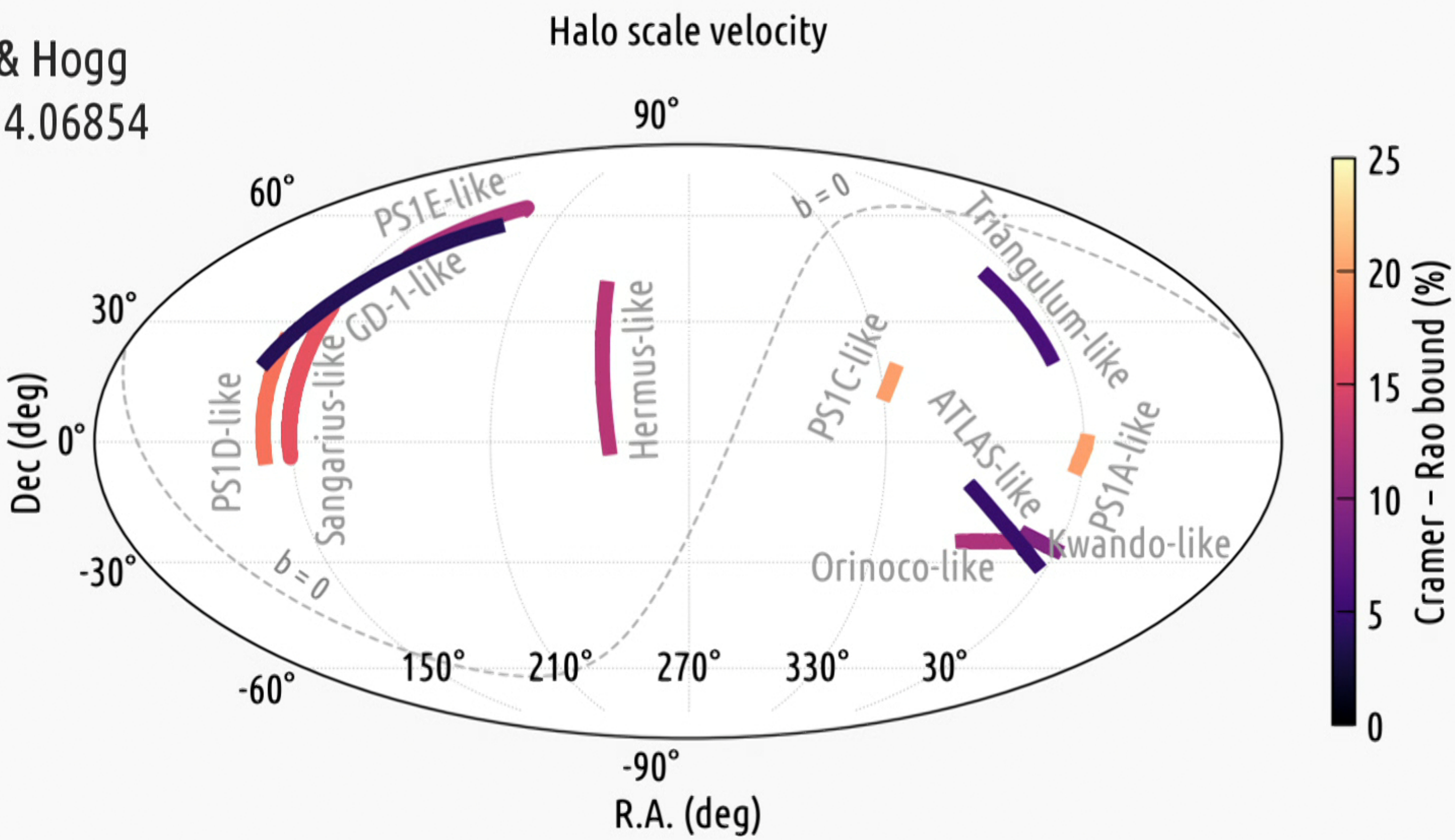
Bonaca et al. (2014)



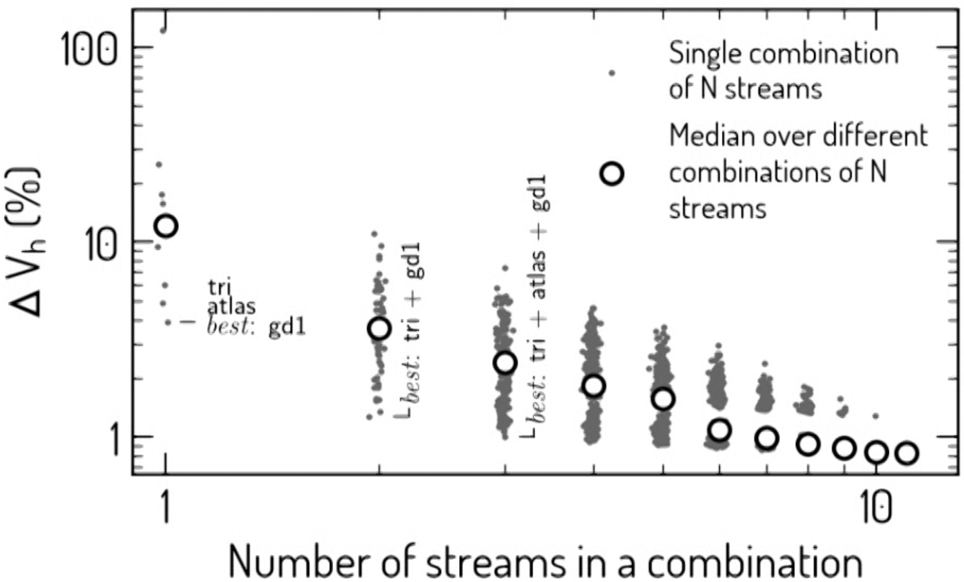
$\log M_d / M_\odot = 10.833$
$V_h = 430$ km / s
$q_z = 1.000$

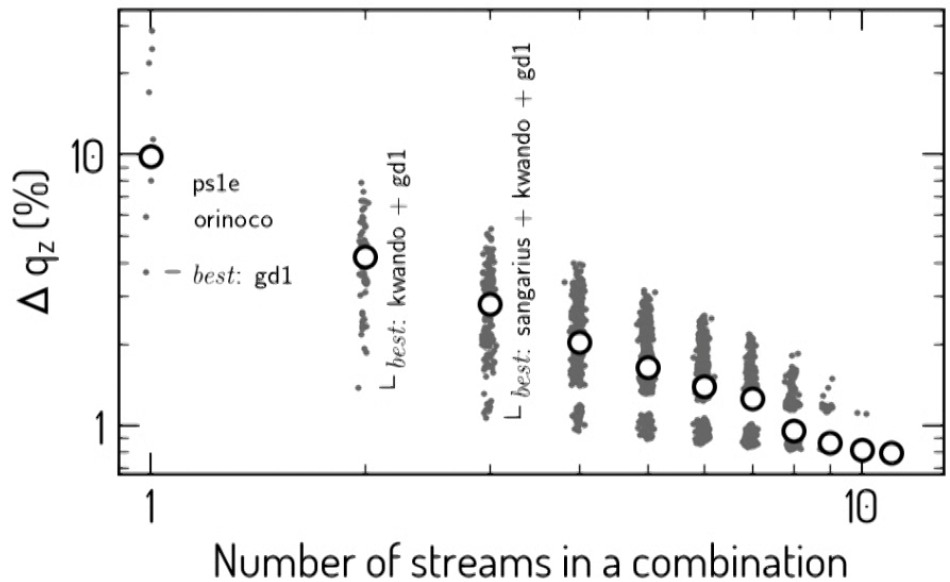
Different streams constrain different aspects of the Galactic halo

Bonaca & Hogg
arXiv:1804.06854



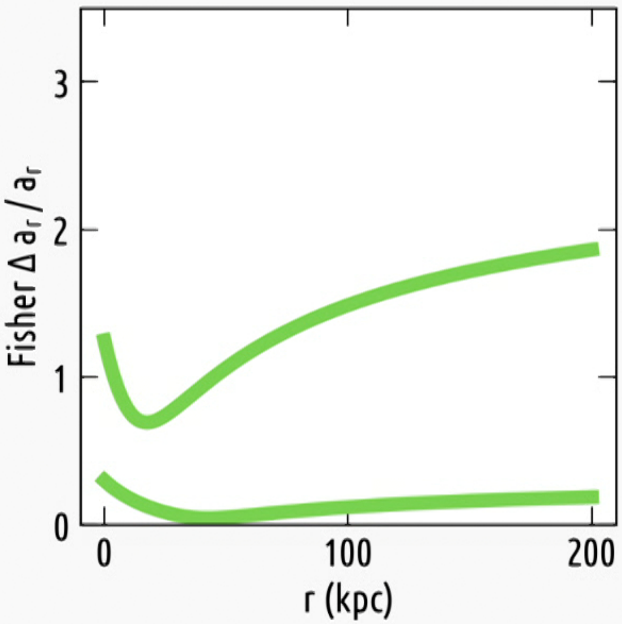
Multiple streams constrain the dark matter halo to better than 1%





Streams measure the mass enclosed within their current position

$$a_r(r) = \frac{GM(<r)}{r^2}$$



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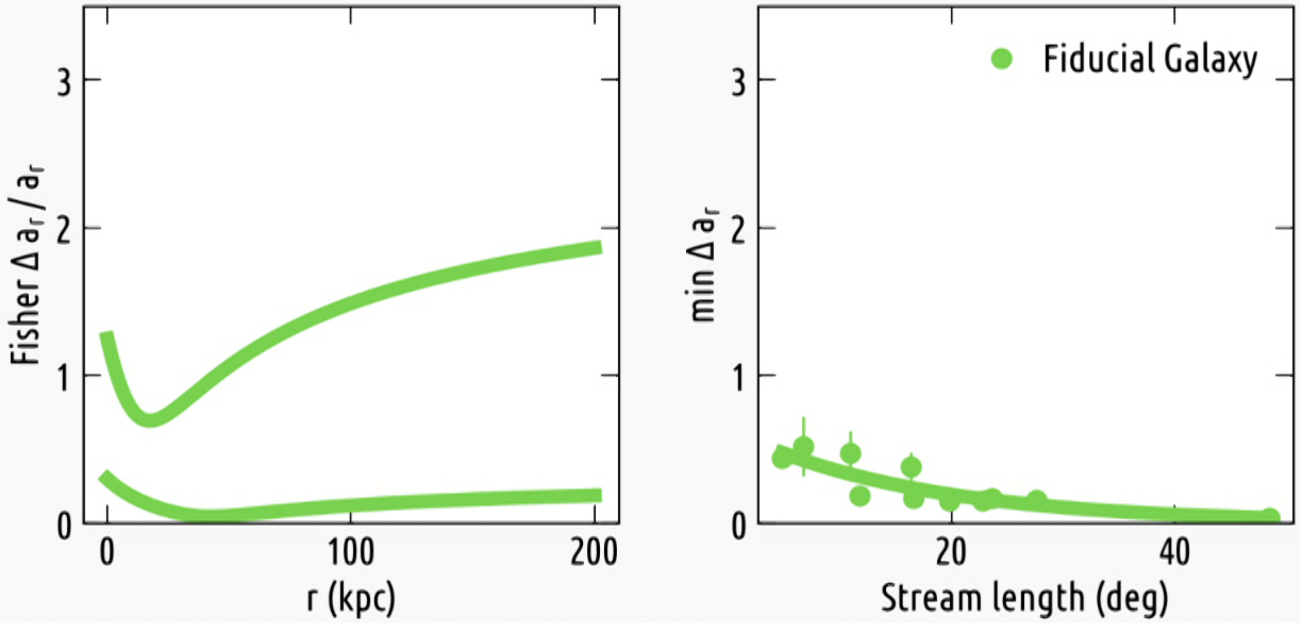

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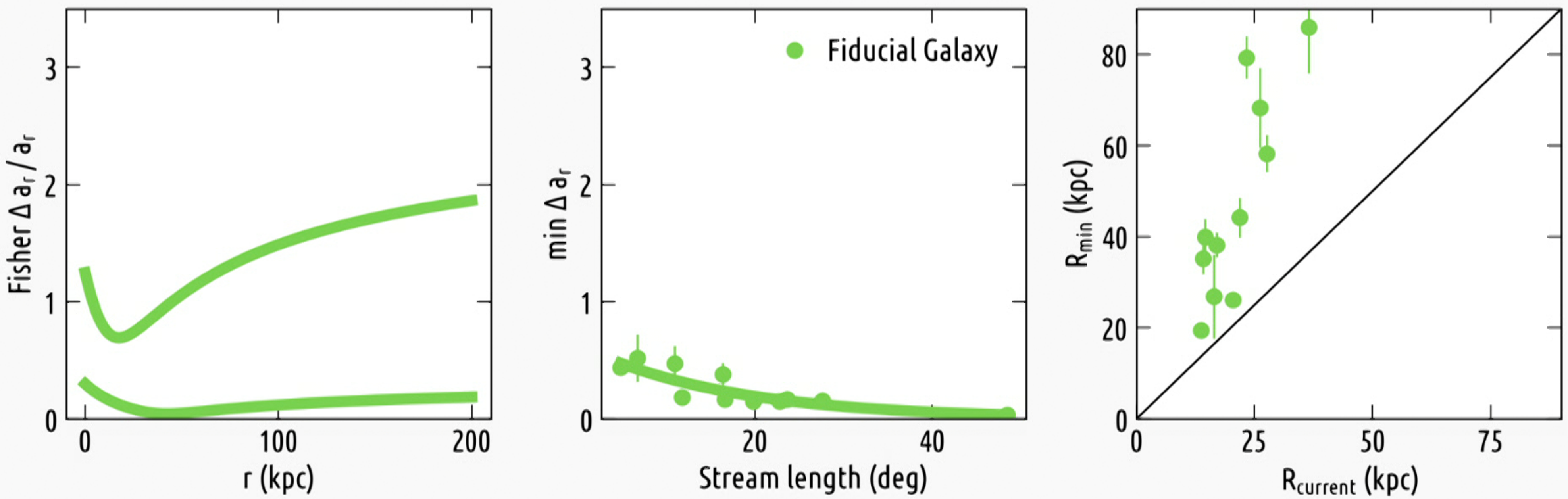

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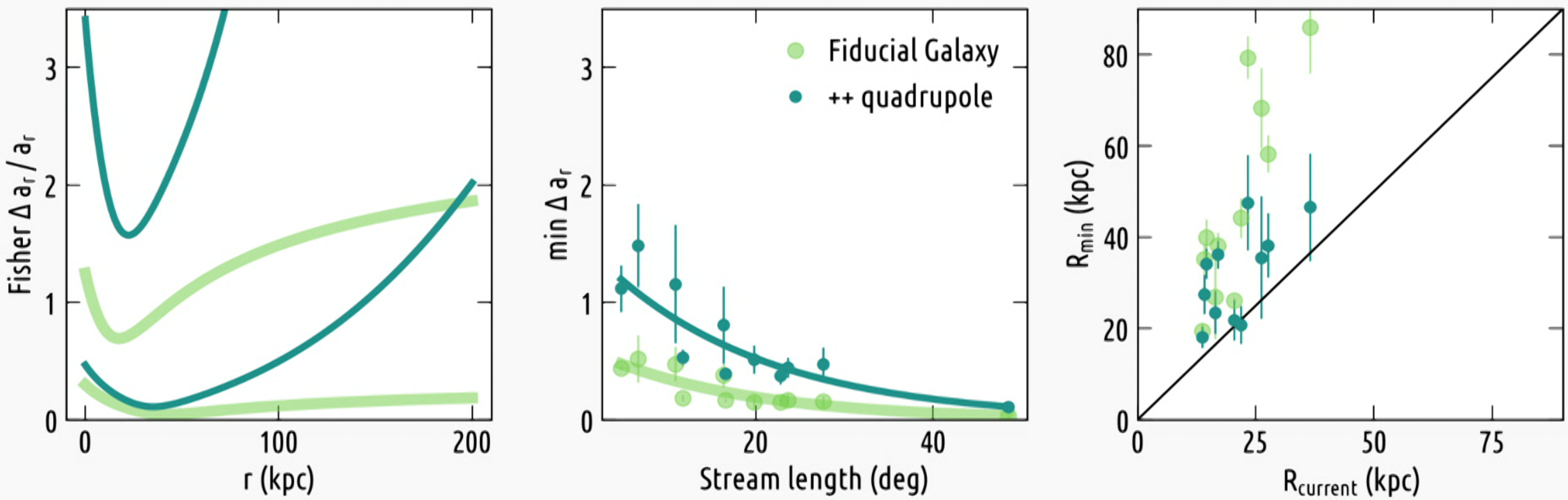
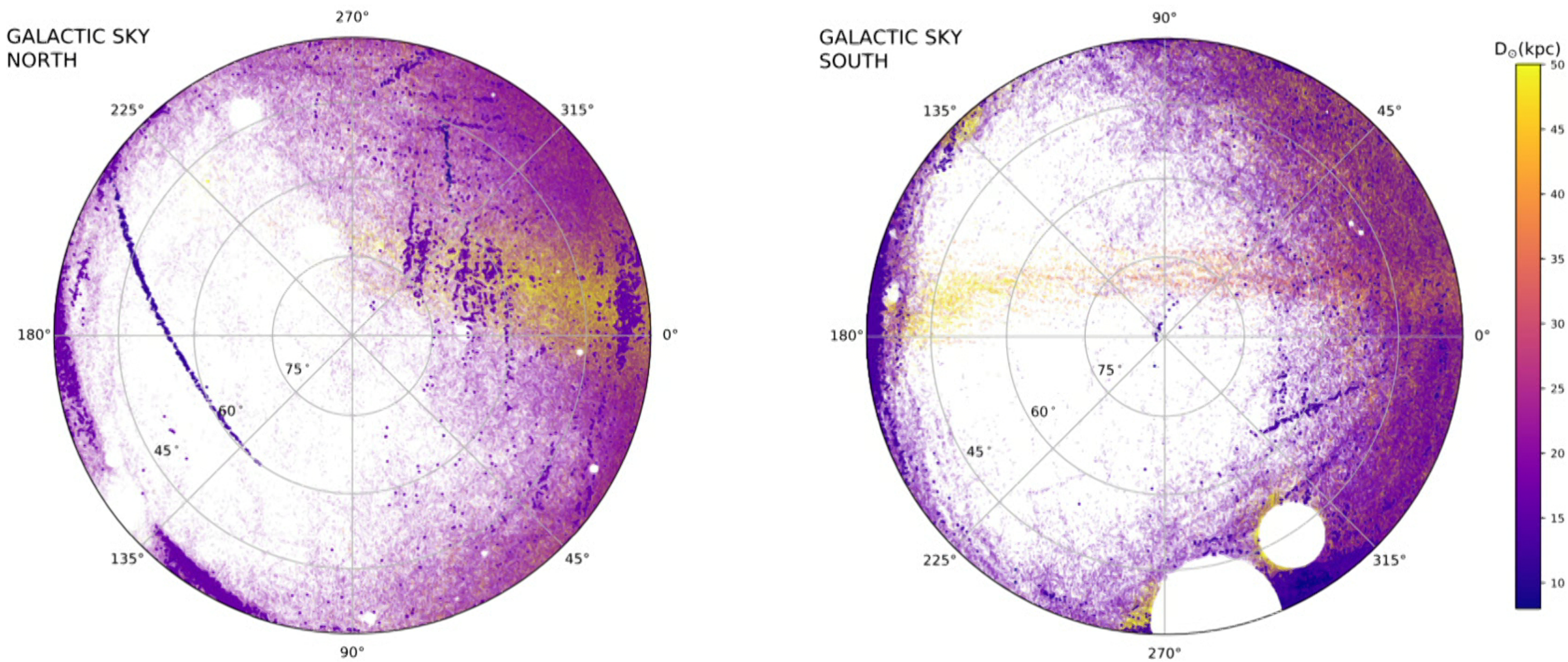


Streams span a range of Galactocentric distances



Malhan et al. (2018)

Nature of dark matter with tidal streams in the Milky Way

#1 Stellar streams can constrain global properties of a dark matter halo: radial profile and shape.

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Bonaca & Hogg
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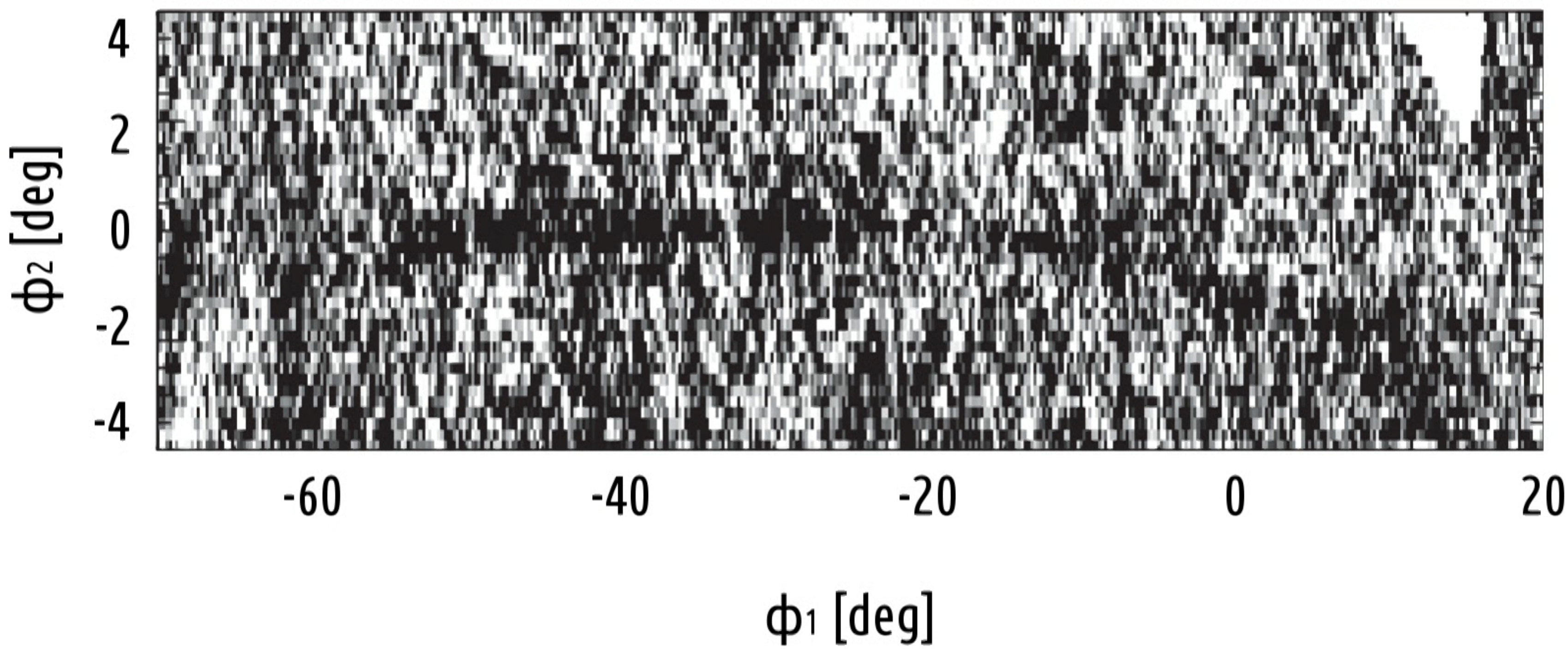
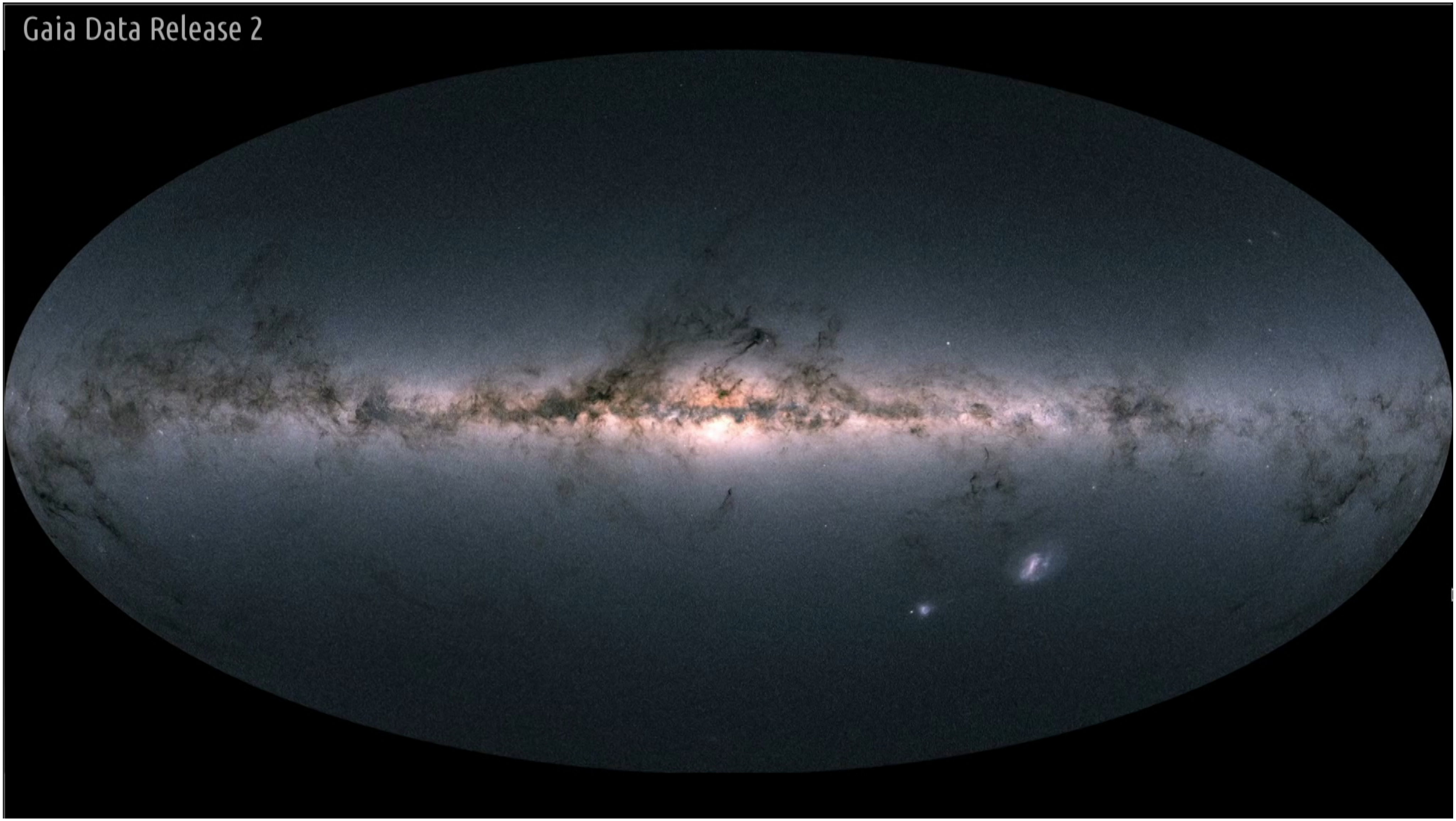
Identifying members of stellar streams is challenging

Koposov et al. (2010)

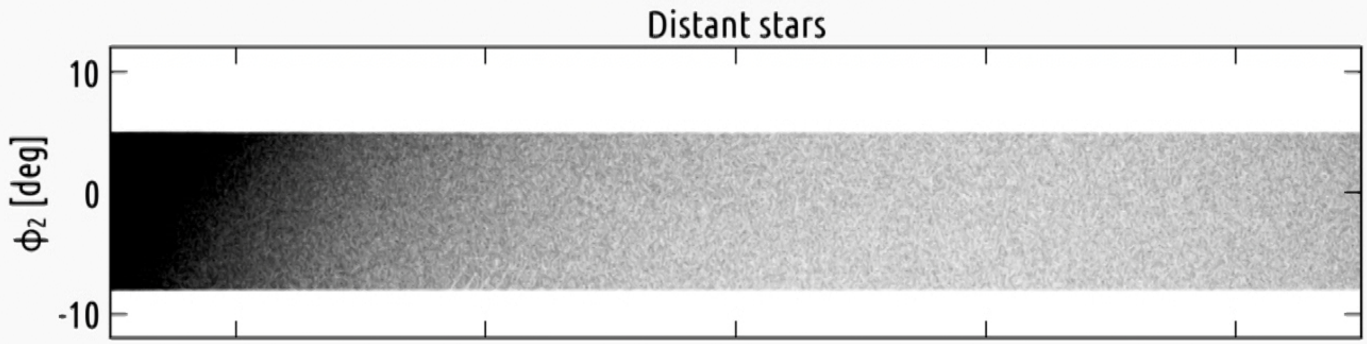



Gaia Data Release 2

Gaia Data Release 2

Gaia's view of the GD-1 stellar stream

Price-Whelan & Bonaca
arXiv:1805.00425



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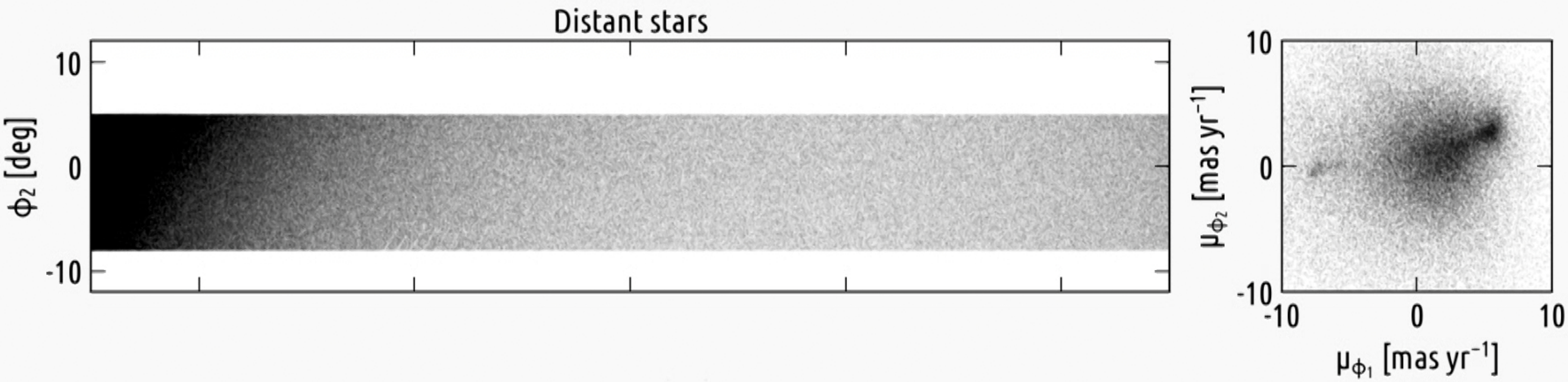

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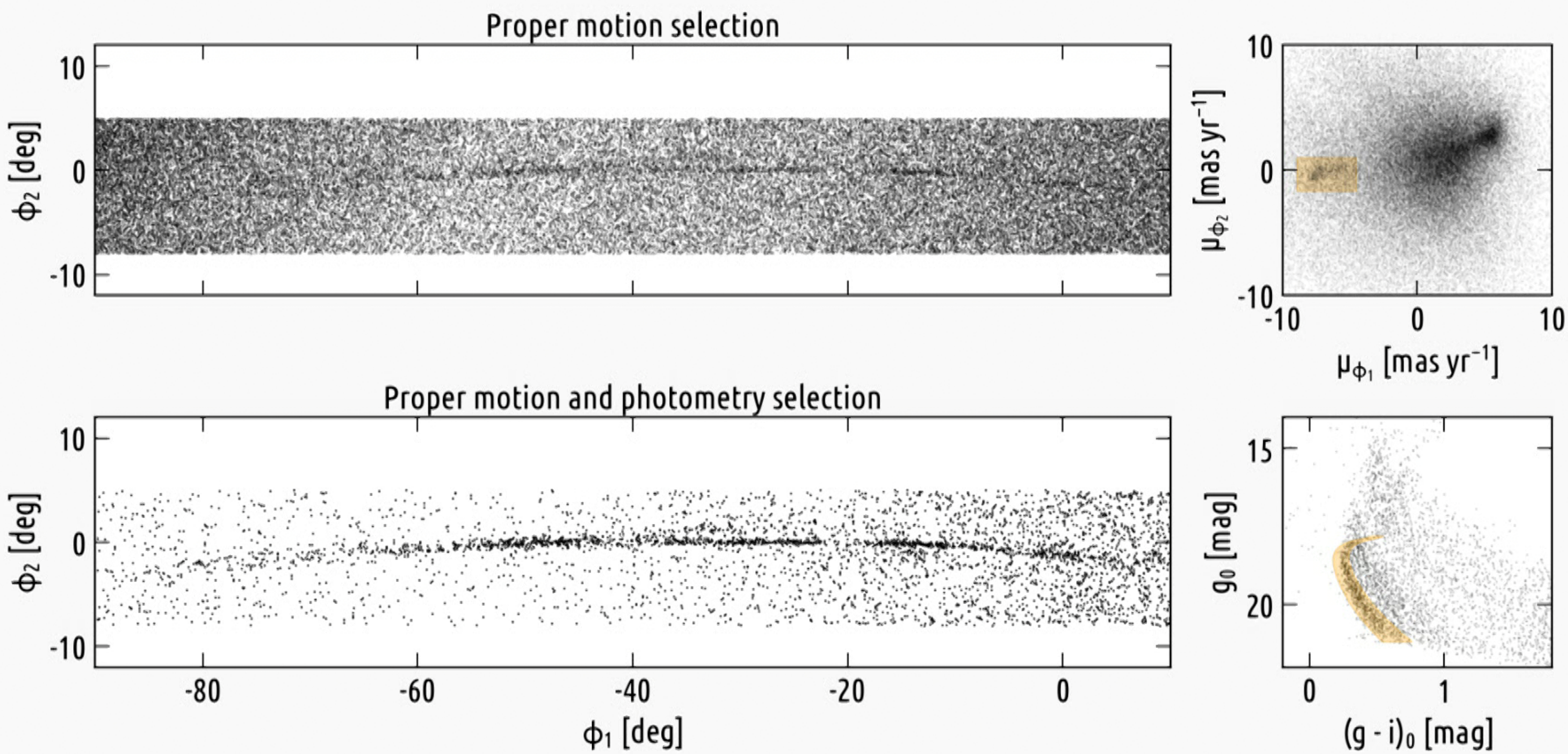

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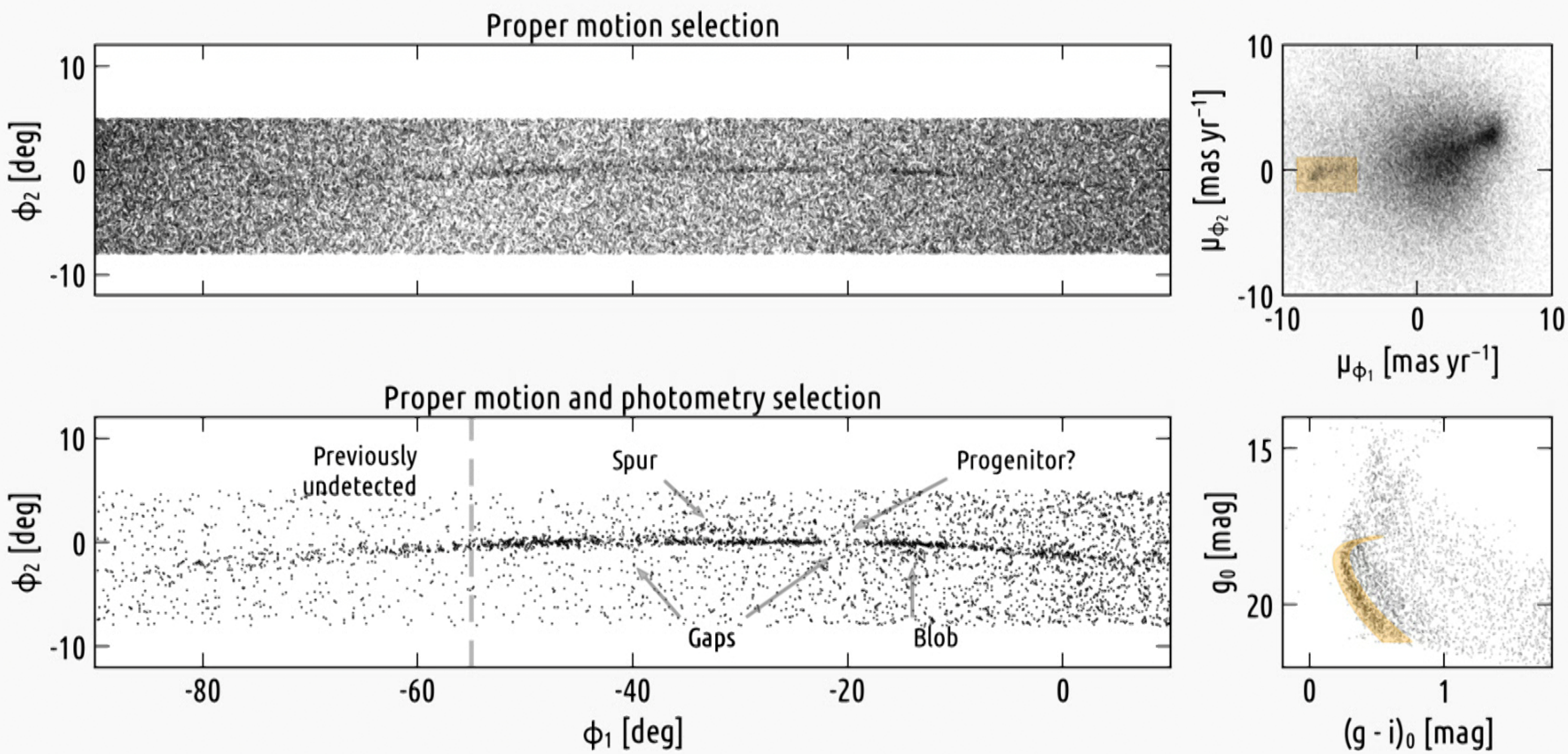
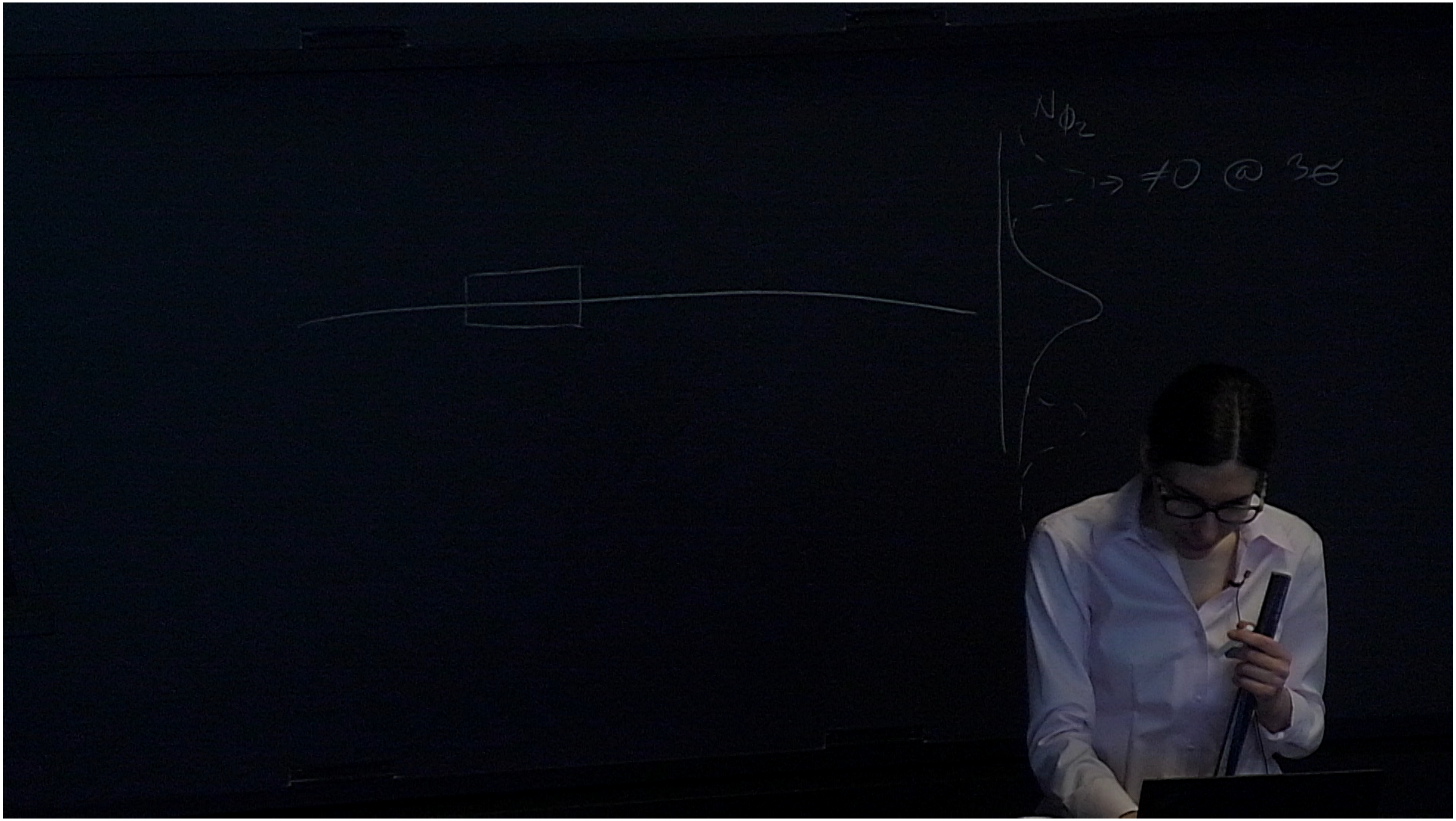
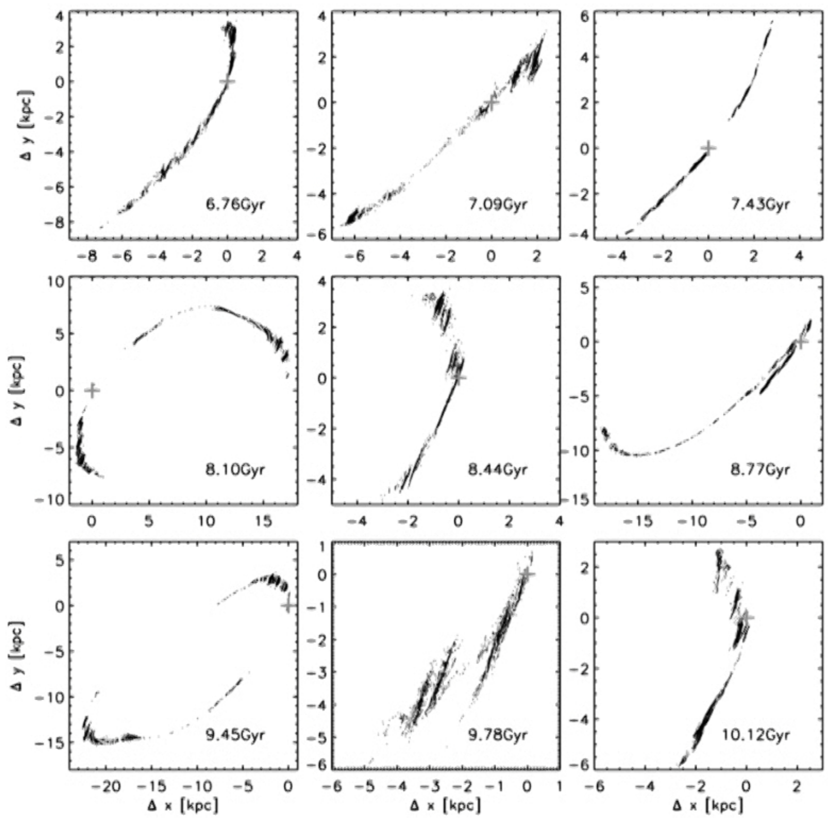
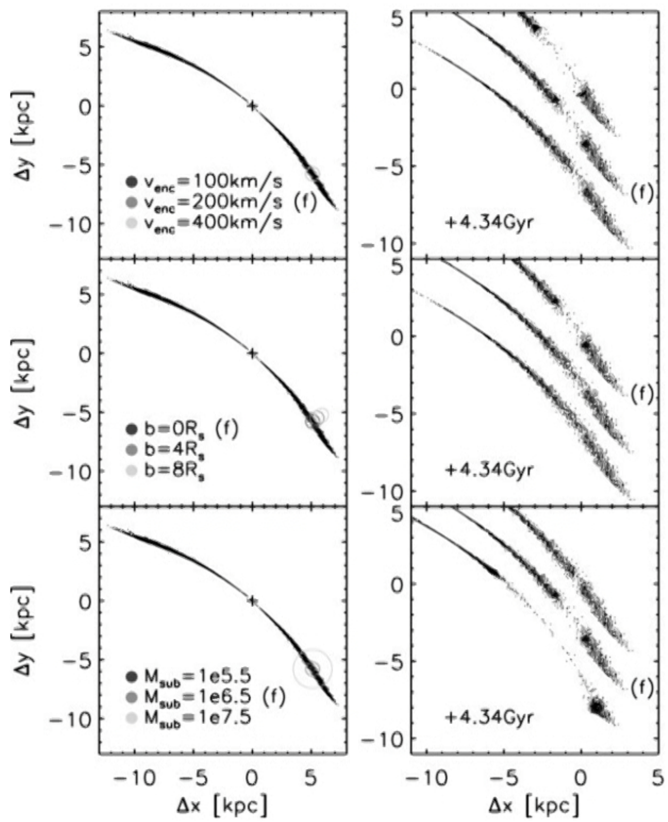



Nφ2
≠0 @ 3σ

Subhalo encounters produce gaps in streams

Yoon et al. (2011)





Carlberg (2009) | Carlberg (2012)
Ngan & Carlberg (2014) | Ngan et al. (2015)
Erkal & Belokurov (2015) | Ngan et al. (2016)
Erkal et al. (2016)

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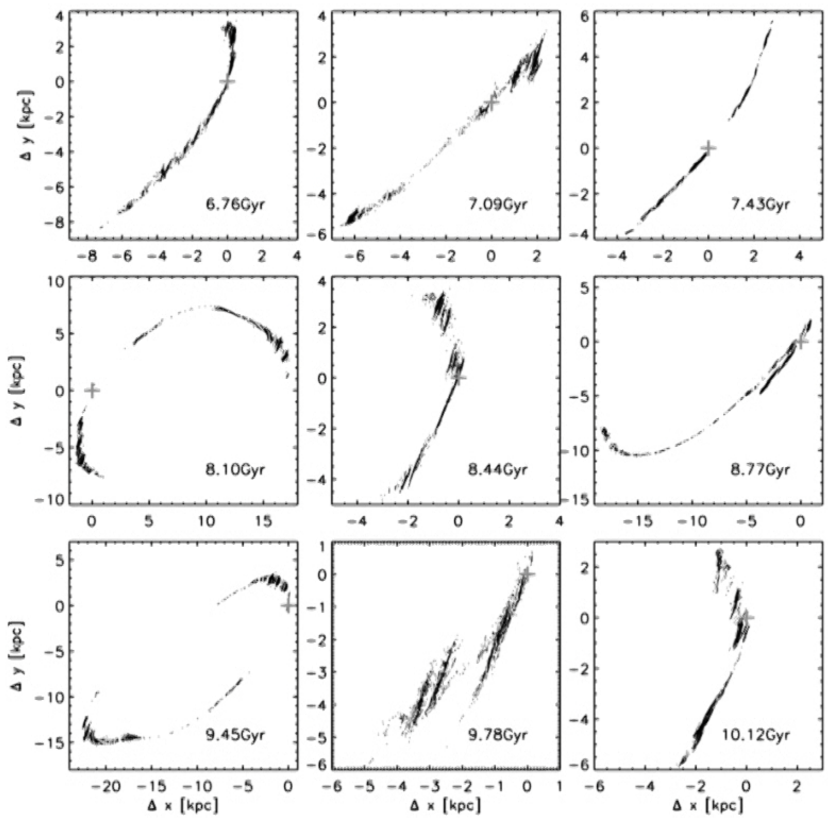

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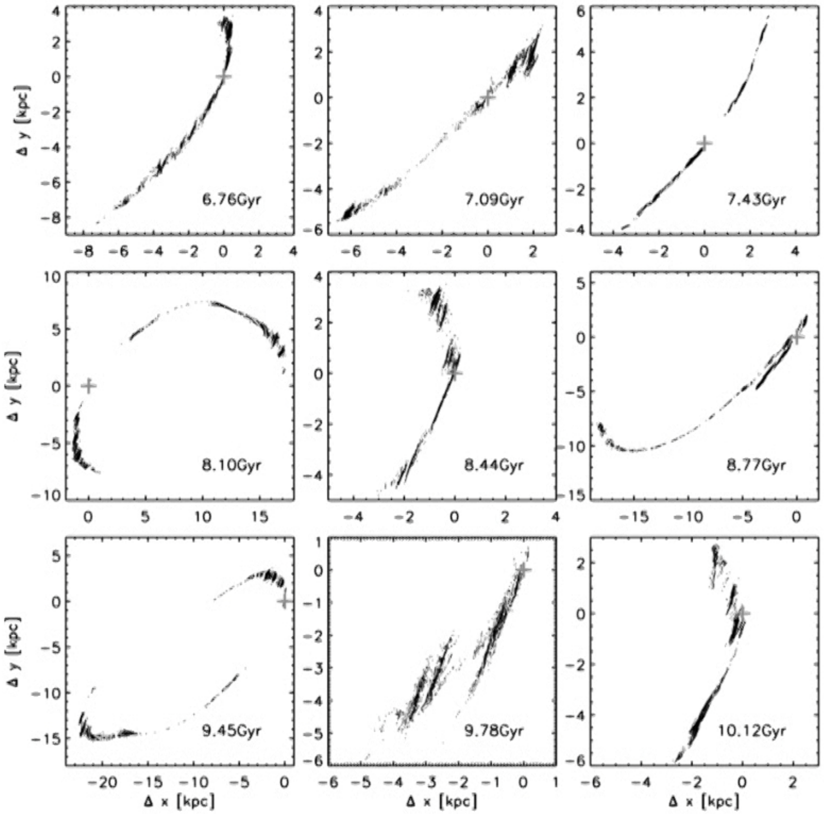

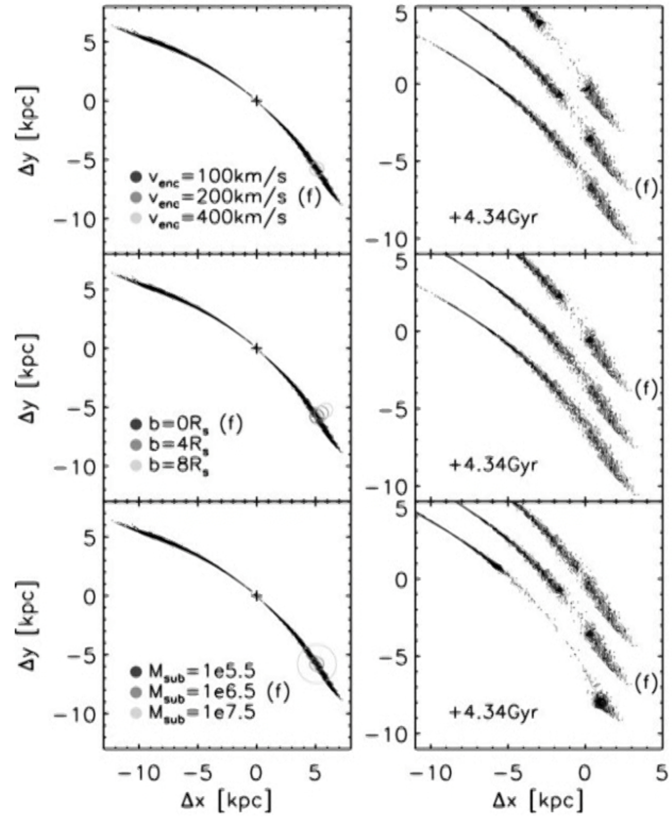

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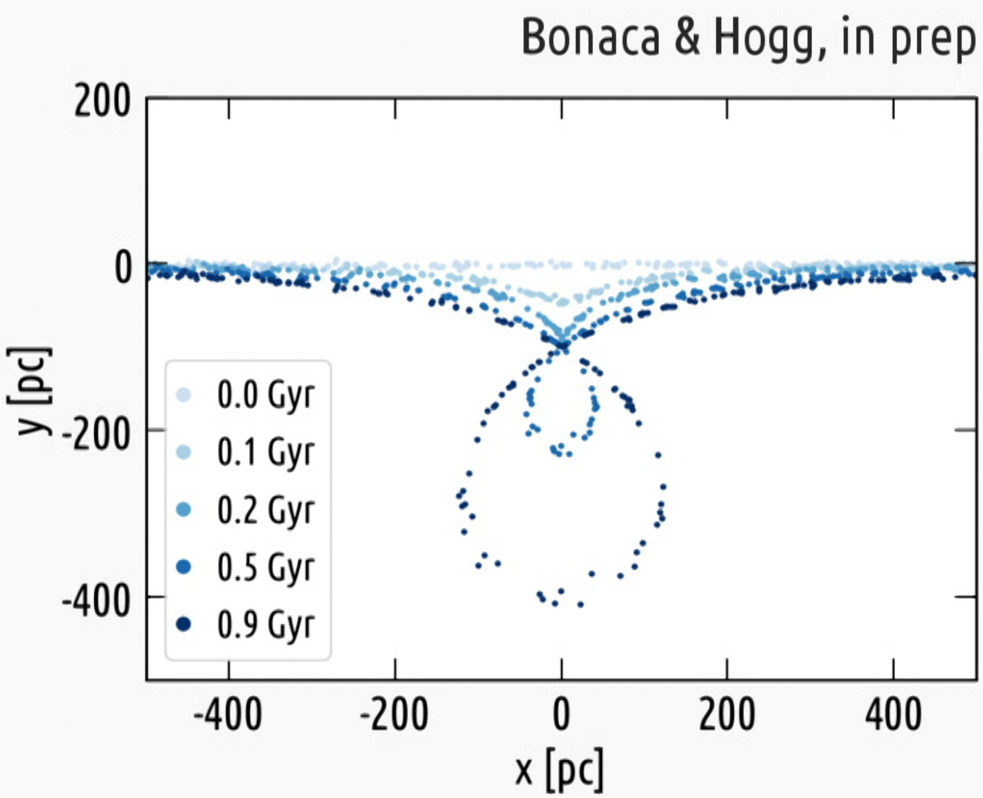
A massive perturber can pull stars from the stream



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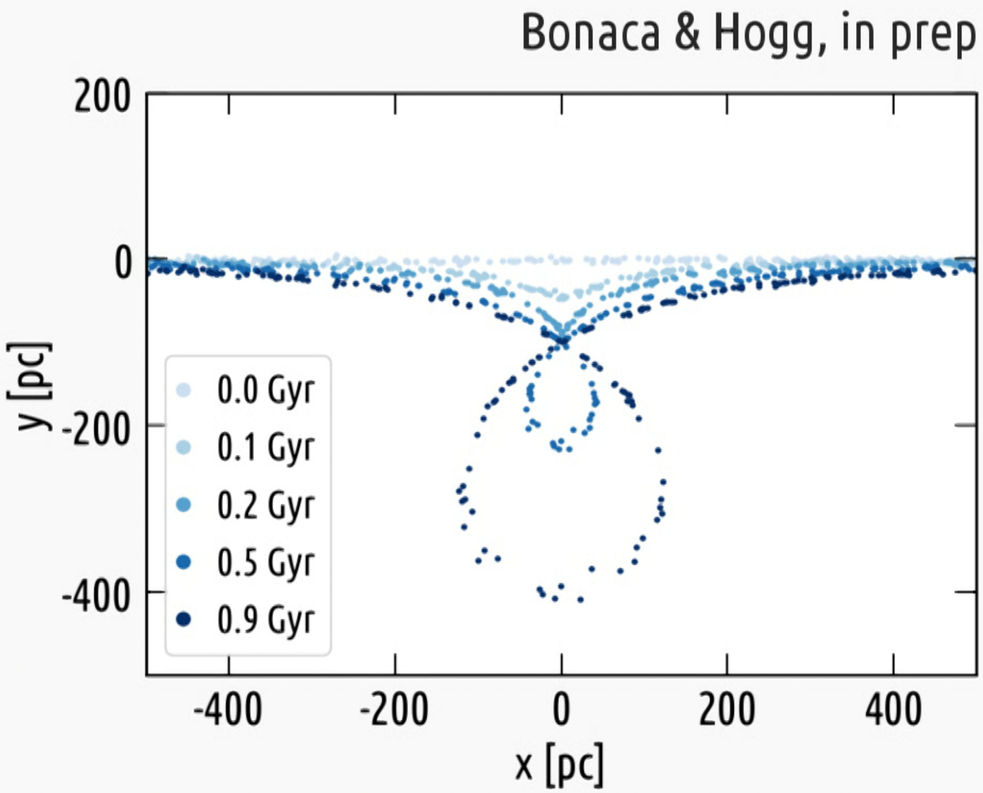
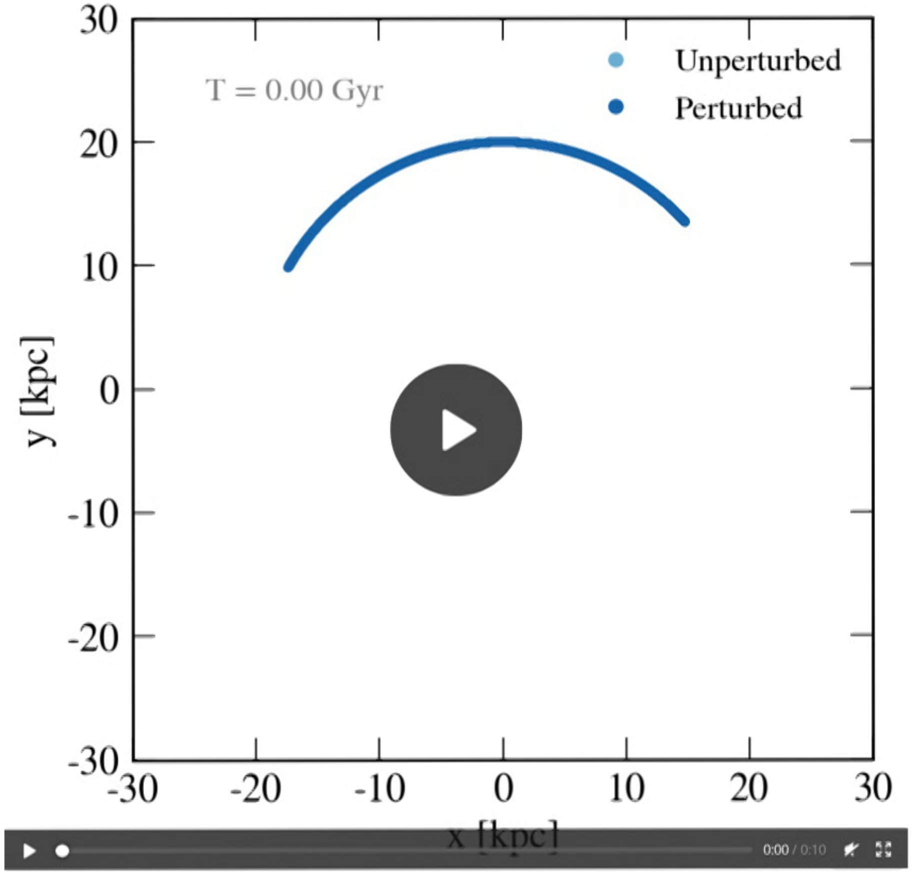


A massive perturber creates a gap in a stream orbiting the Galaxy



Subhalo perturbation
in a logarithmic potential

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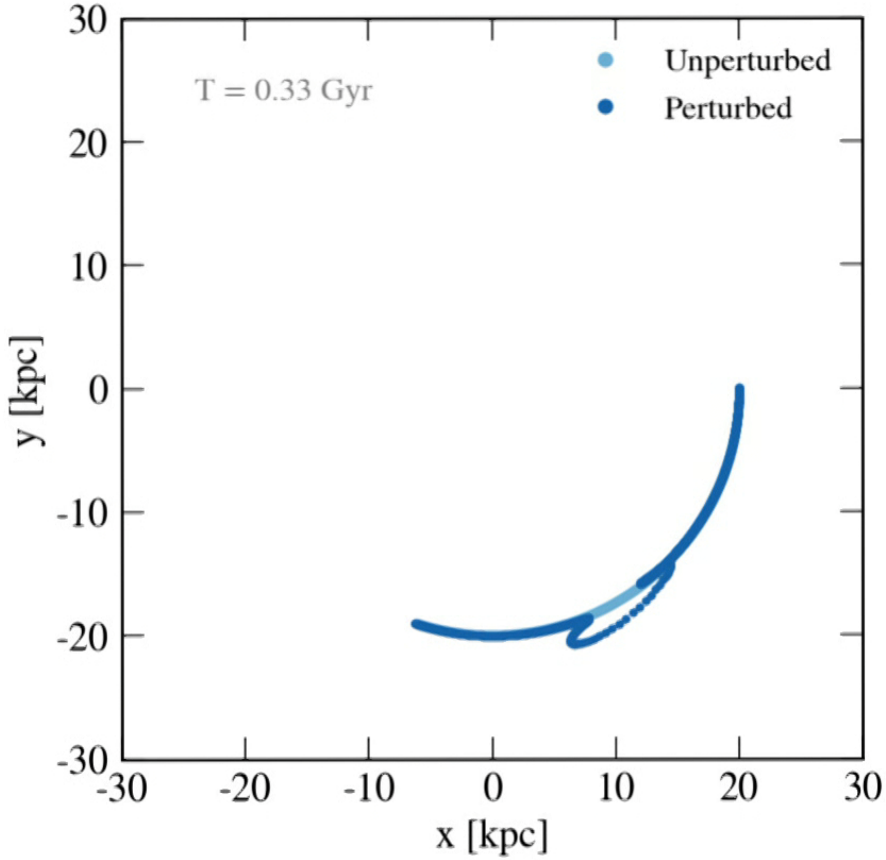

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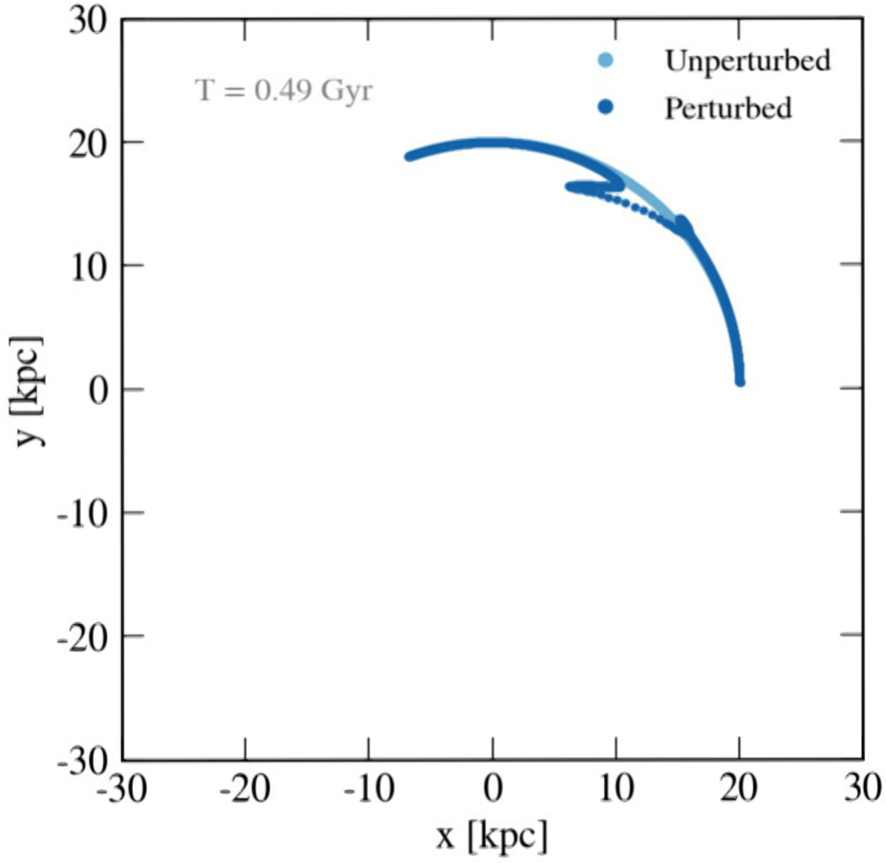

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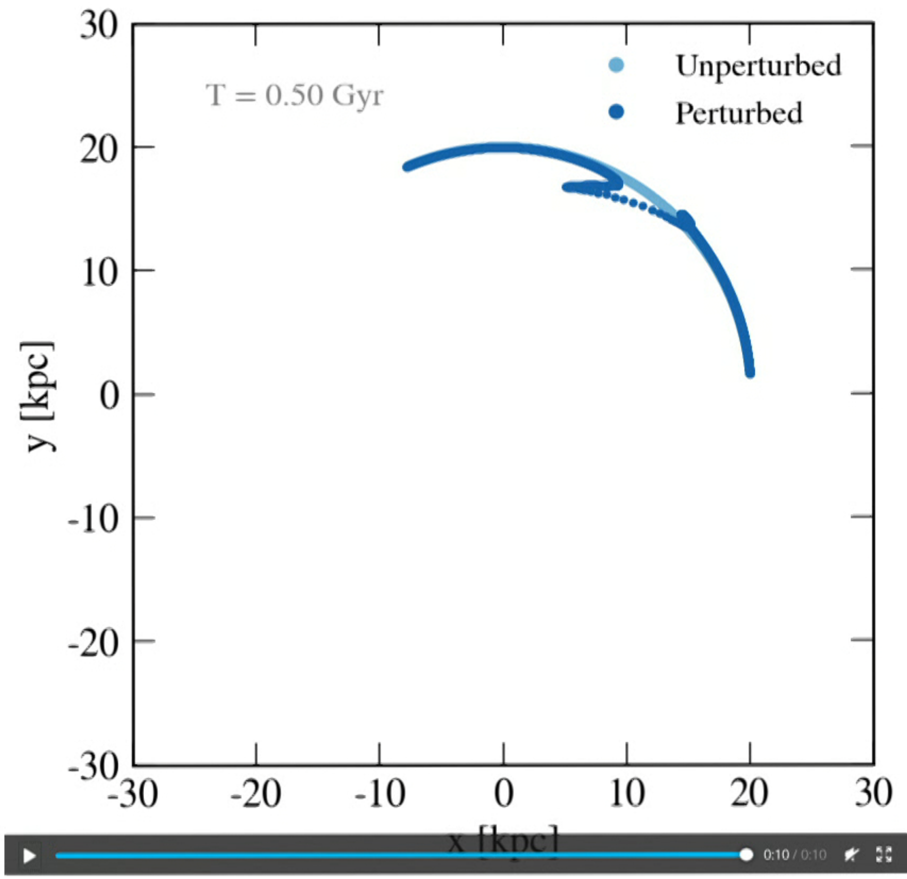

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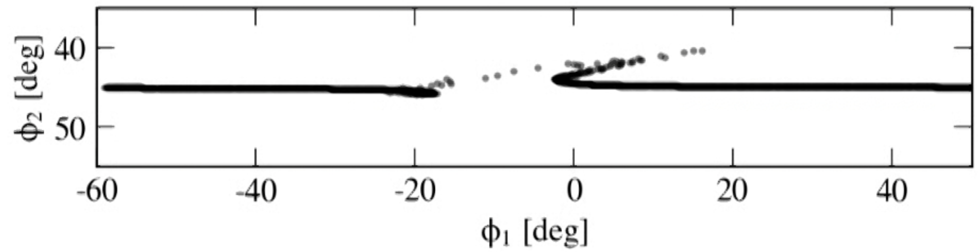
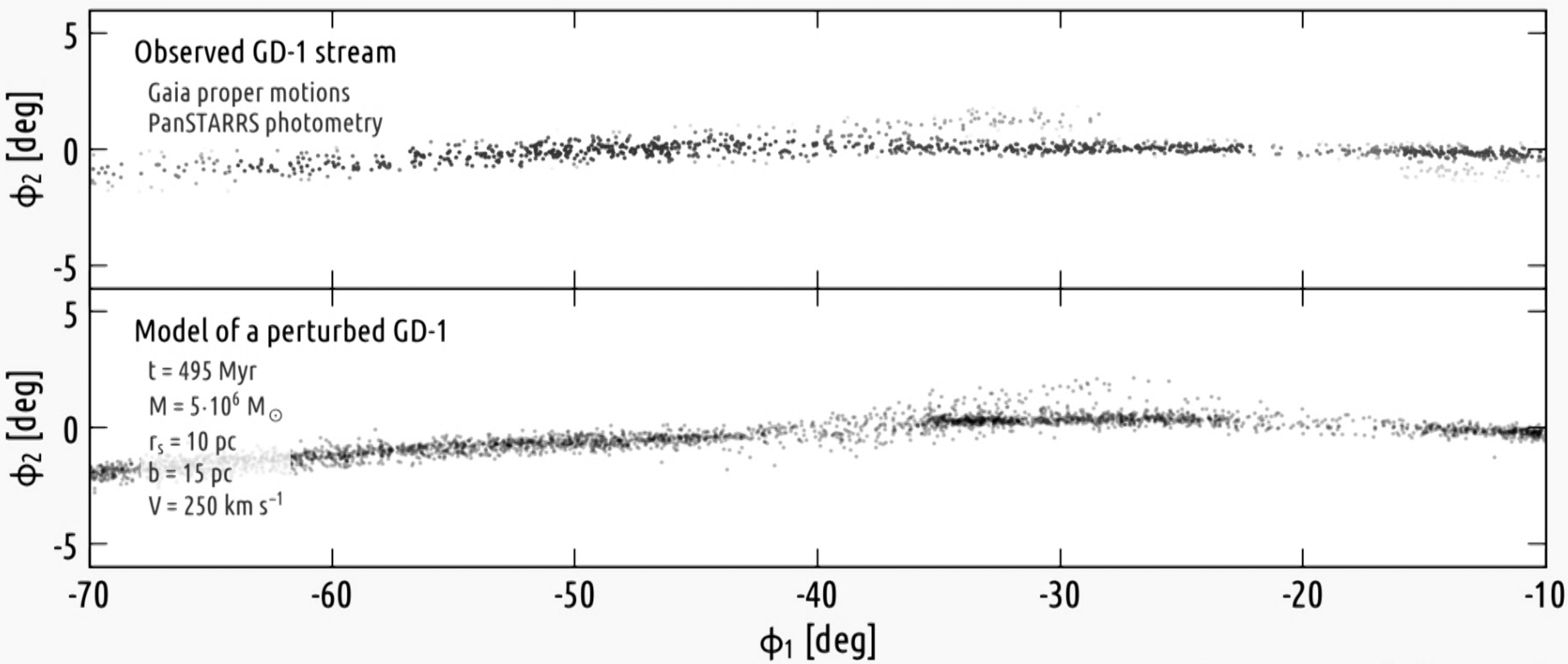


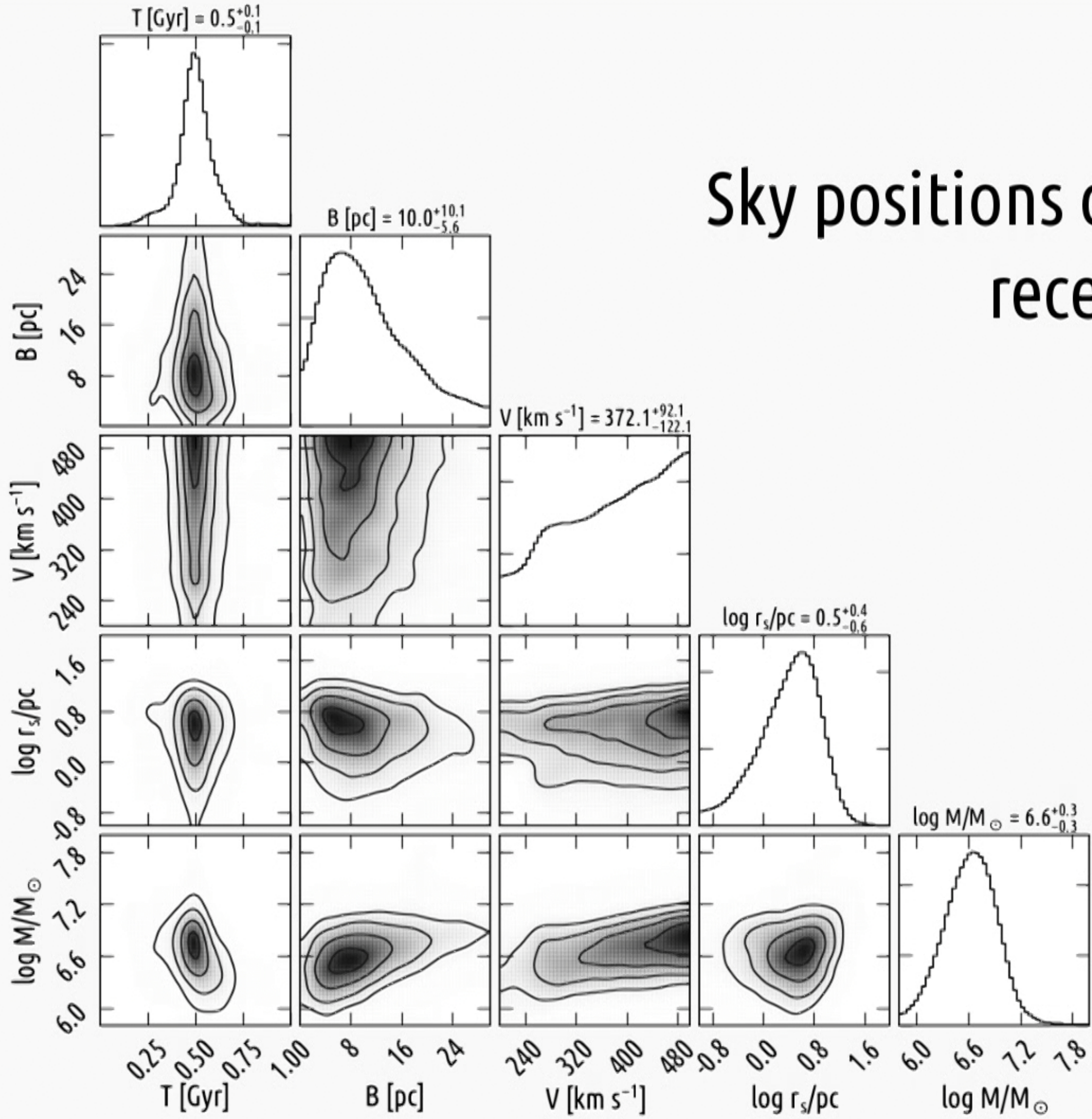
Most probable GD-1 members

Encounter qualitatively accounts for all features observed in GD-1

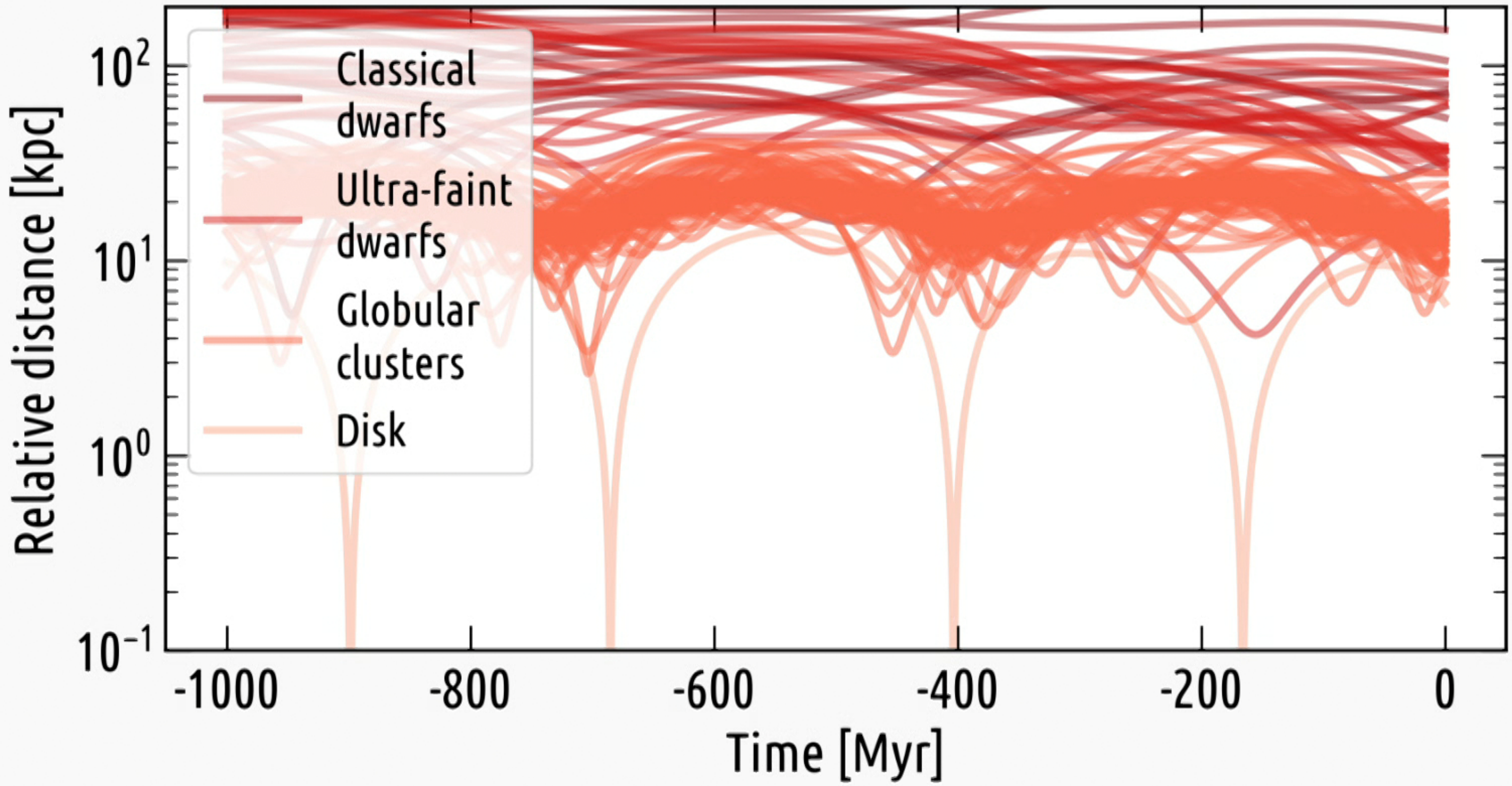


Bonaca et al. (in prep)

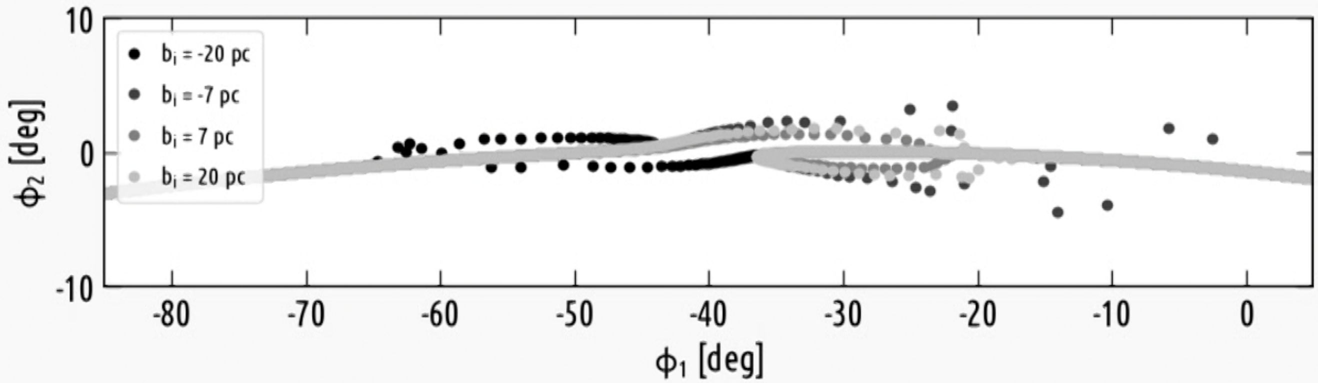
Sky positions of GD-1 stars prefer a recent, head-on collision with a dense object



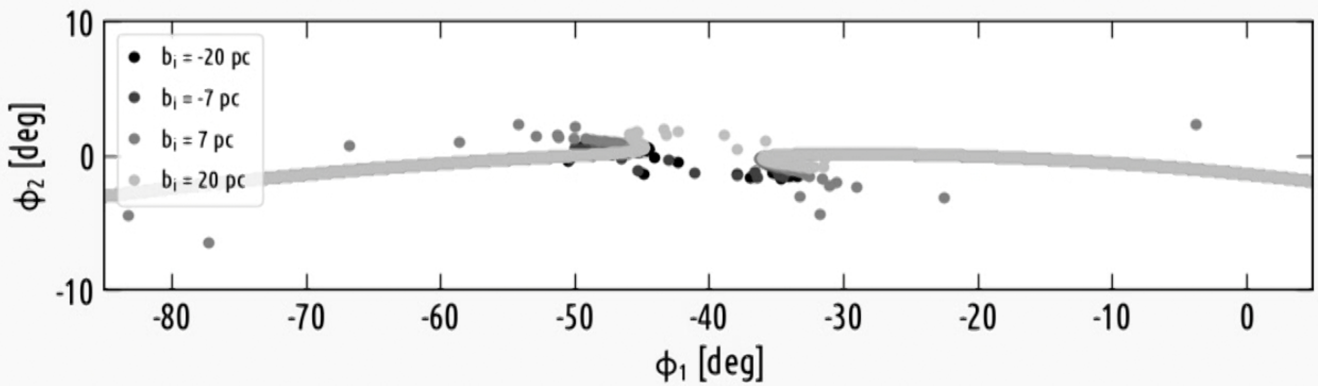
The GD-1 perturber is not a known satellite of the Milky Way



Molecular clouds are unlikely to have perturbed GD-1

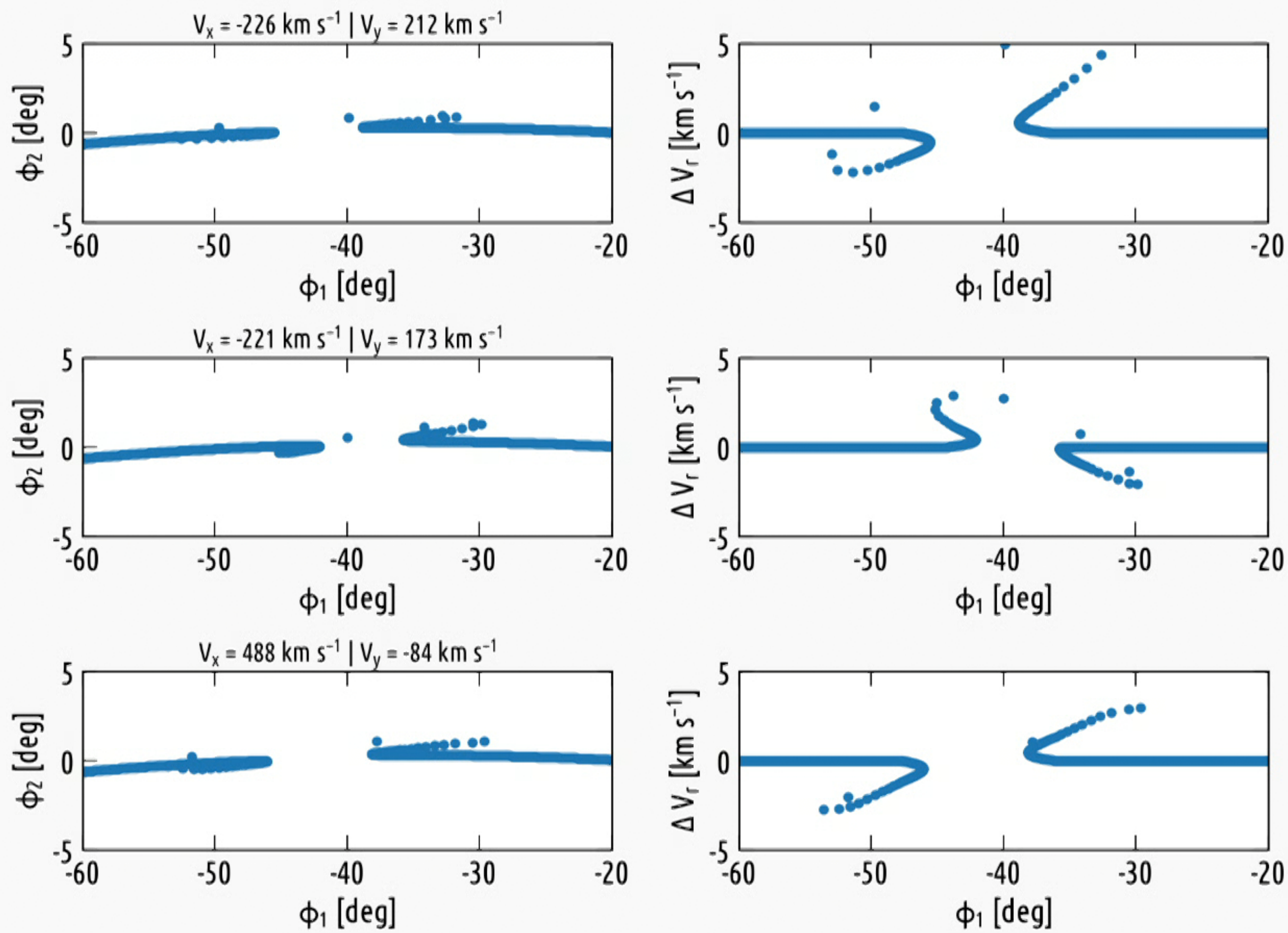


First disk crossing



Second disk crossing

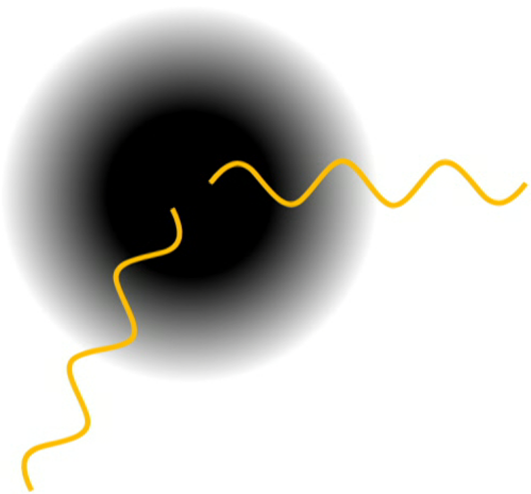
The orbit of the perturber is currently unconstrained



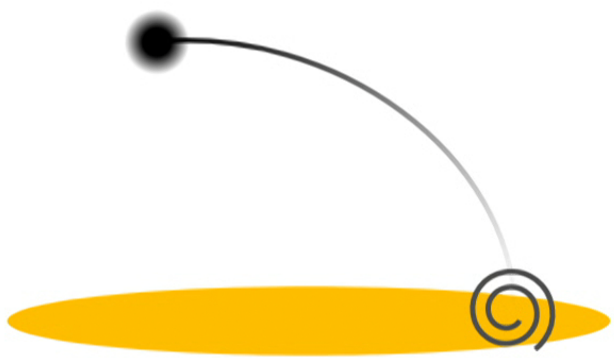
But measuring the velocity offsets between the GD-1 stream and spur will help.

Additional signatures of the hypothetical perturber:

Annihilation

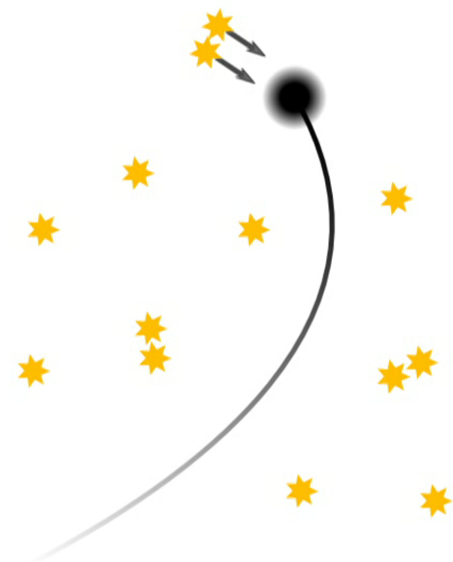


Disk disturbances



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

Perturbations of halo stars



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

Nature of dark matter with tidal streams in the Milky Way

#1 Stellar streams can constrain global properties of a dark matter halo: radial profile and shape.

Bonaca & Hogg
arXiv:1804.06854

#2 Stream gap and members observed beyond the main GD-1 stream can be explained by a recent encounter with a massive, dense perturber.

Price-Whelan & Bonaca
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