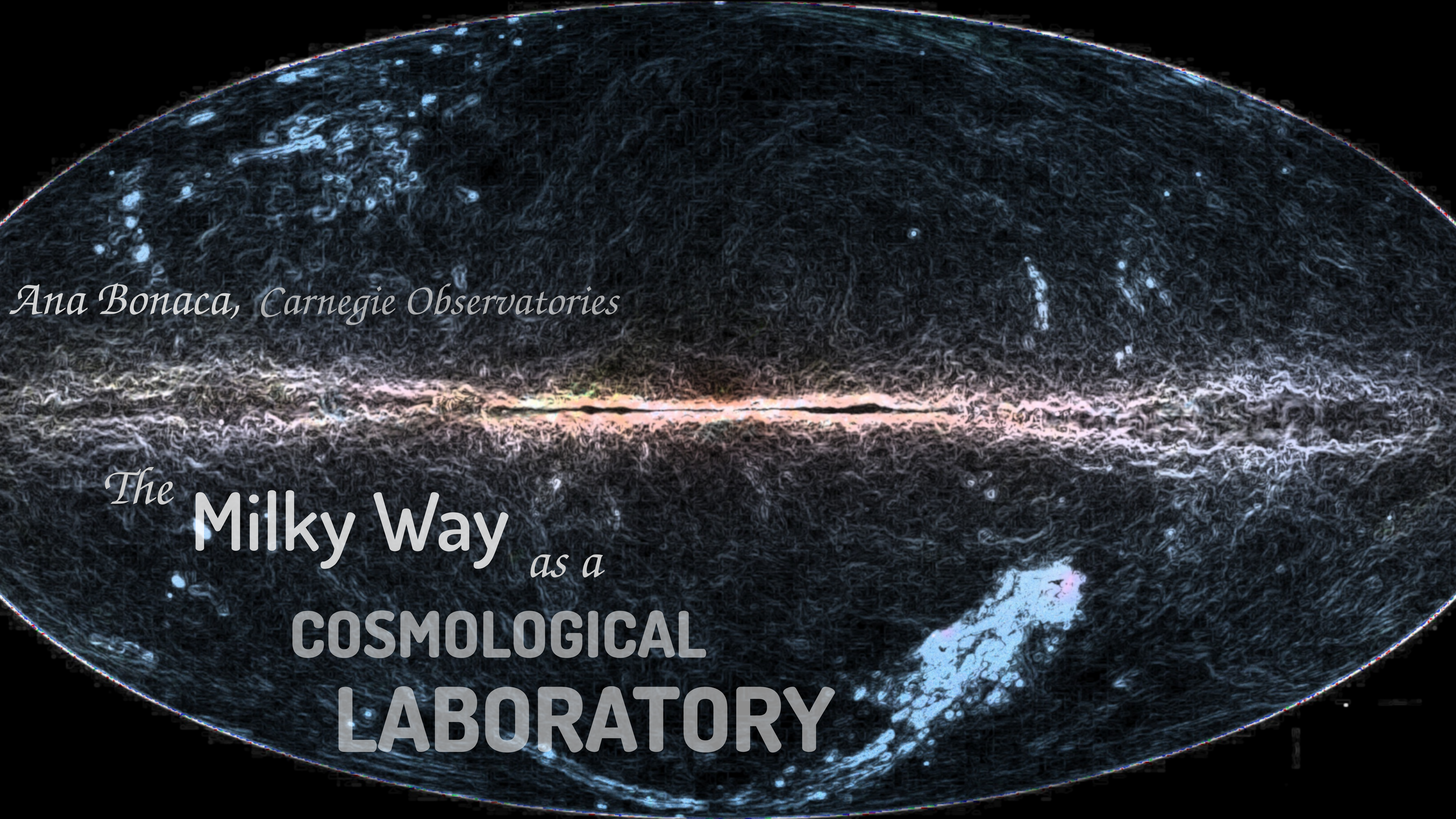
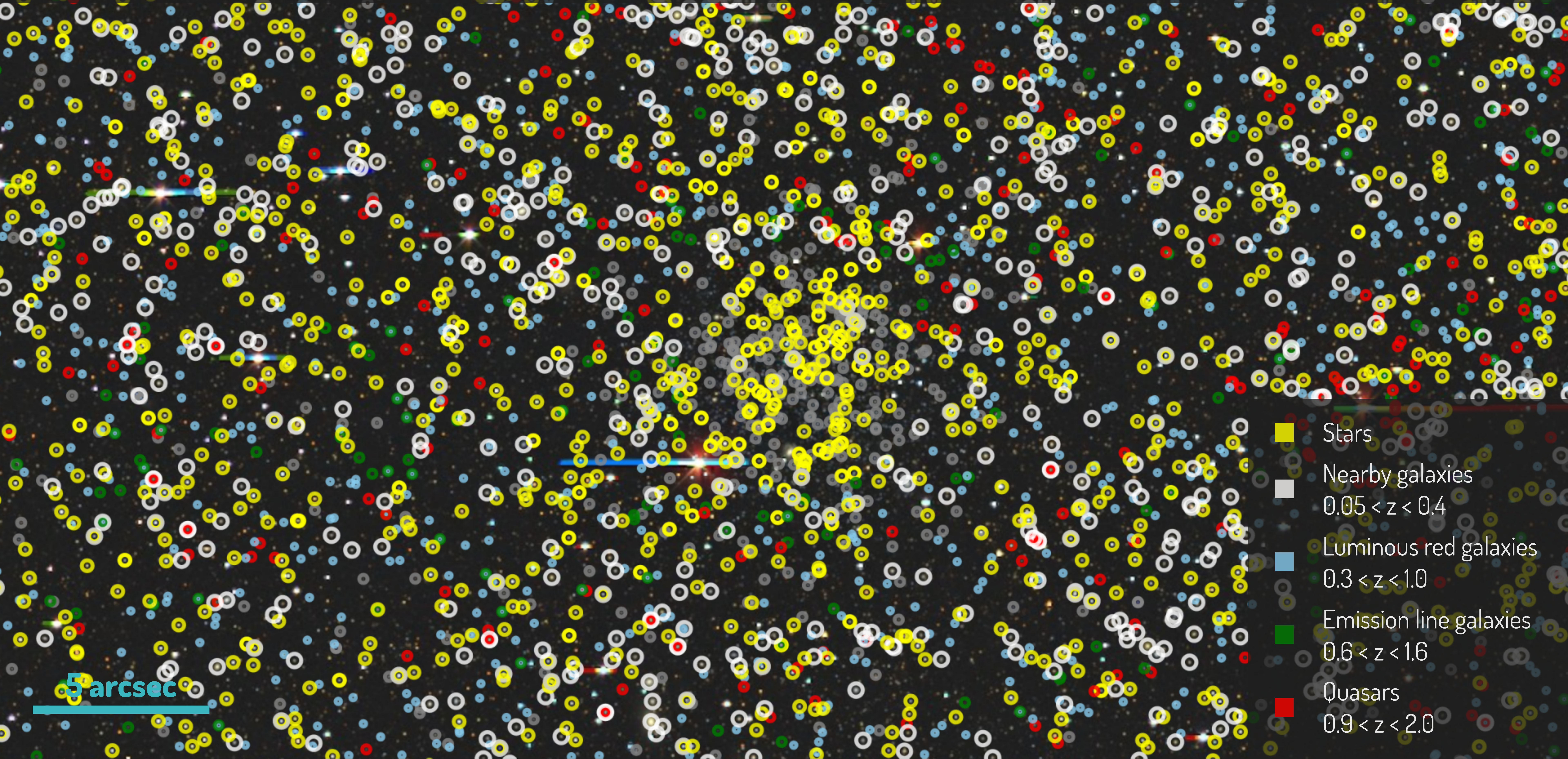


Ana Bonaca, Carnegie Observatories

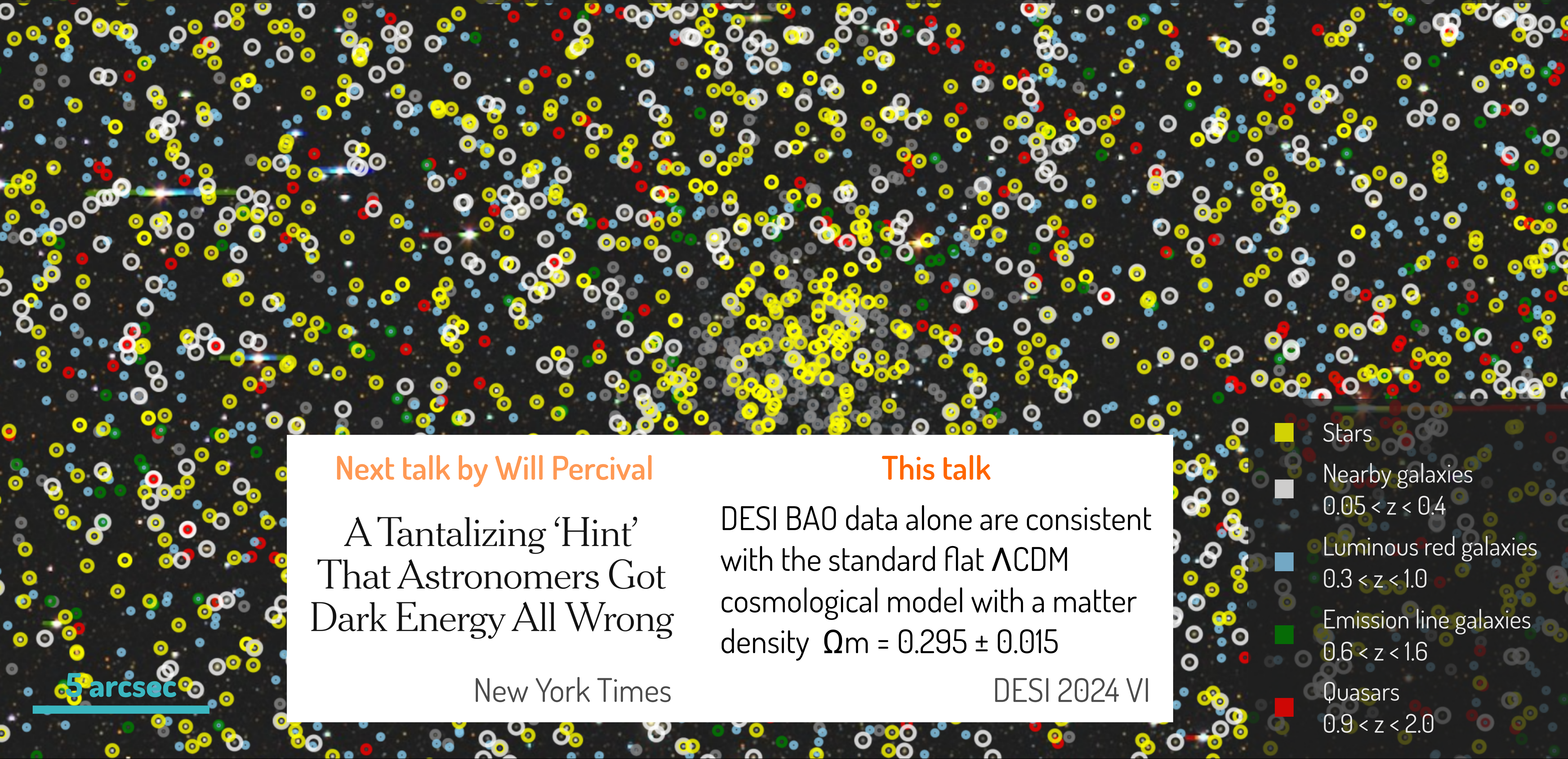
The Milky Way *as a* COSMOLOGICAL LABORATORY

First results from the Dark Energy Spectroscopic Instrument

First results from the Dark Energy Spectroscopic Instrument



First results from the Dark Energy Spectroscopic Instrument



Next talk by Will Percival

A Tantalizing 'Hint' That Astronomers Got Dark Energy All Wrong

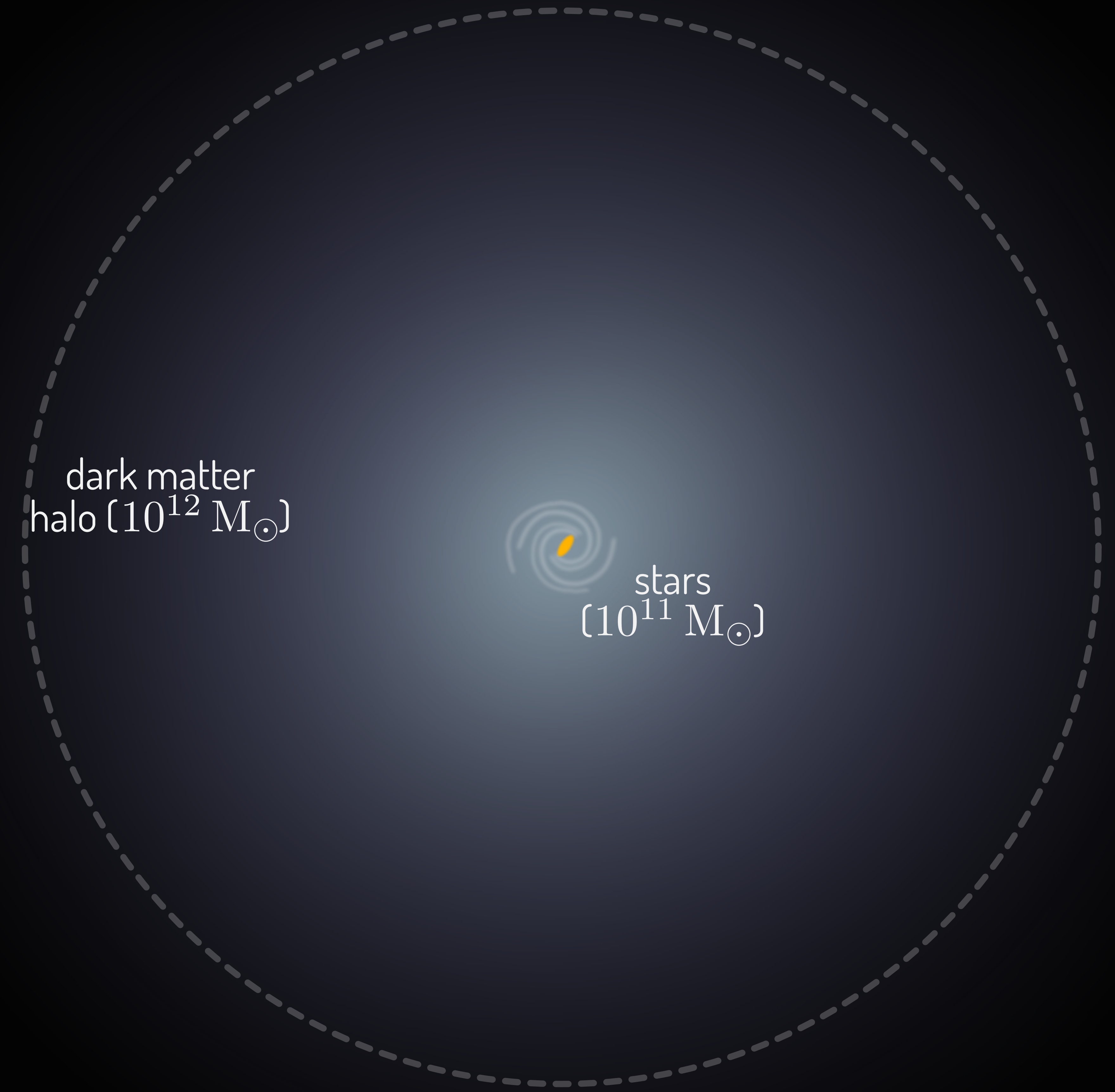
New York Times

This talk

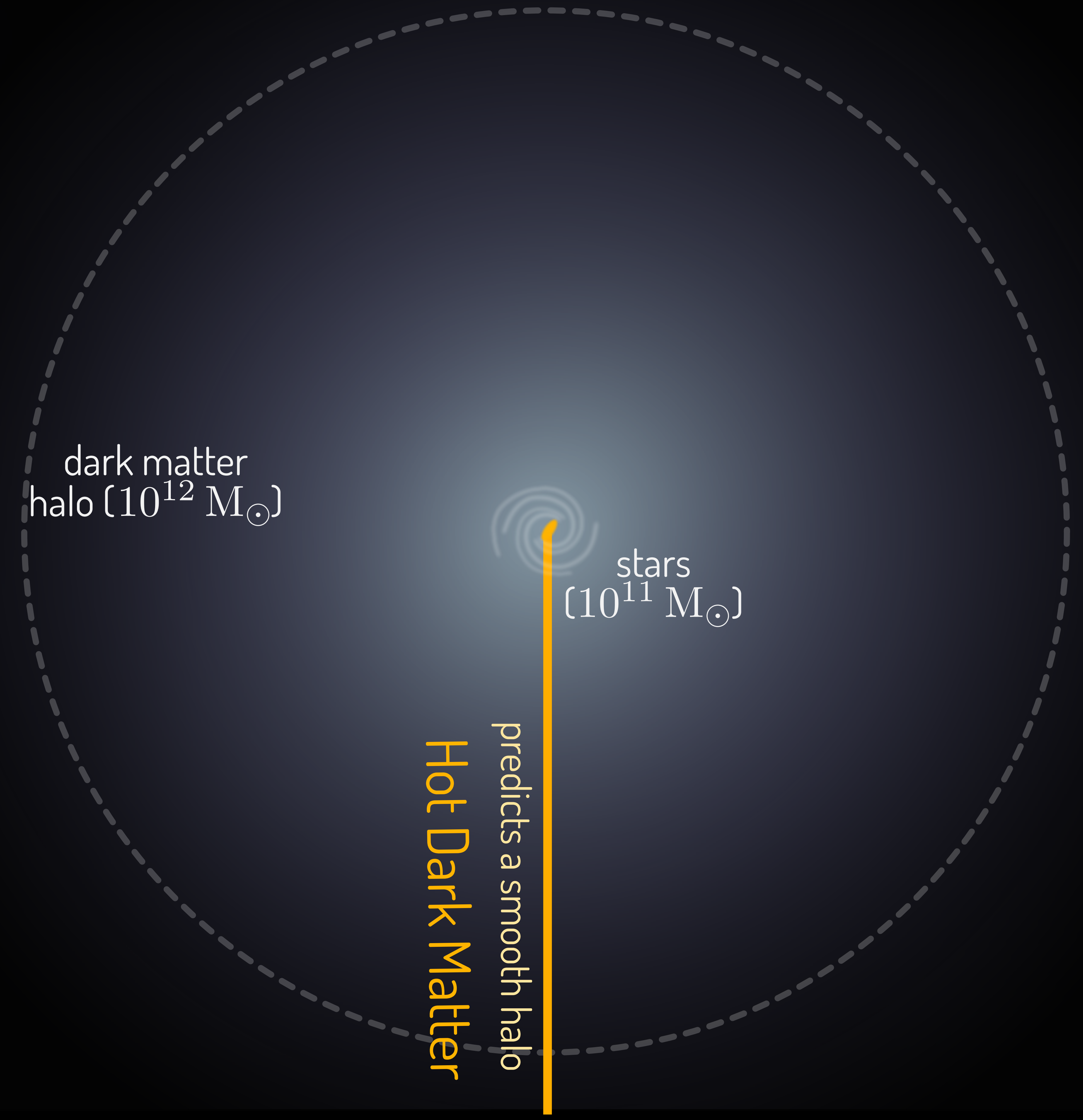
DESI BAO data alone are consistent with the standard flat ΛCDM cosmological model with a matter density $\Omega_m = 0.295 \pm 0.015$

DESI 2024 VI

The nature of dark matter is encoded in its spatial distribution



The nature of dark matter is encoded in its spatial distribution



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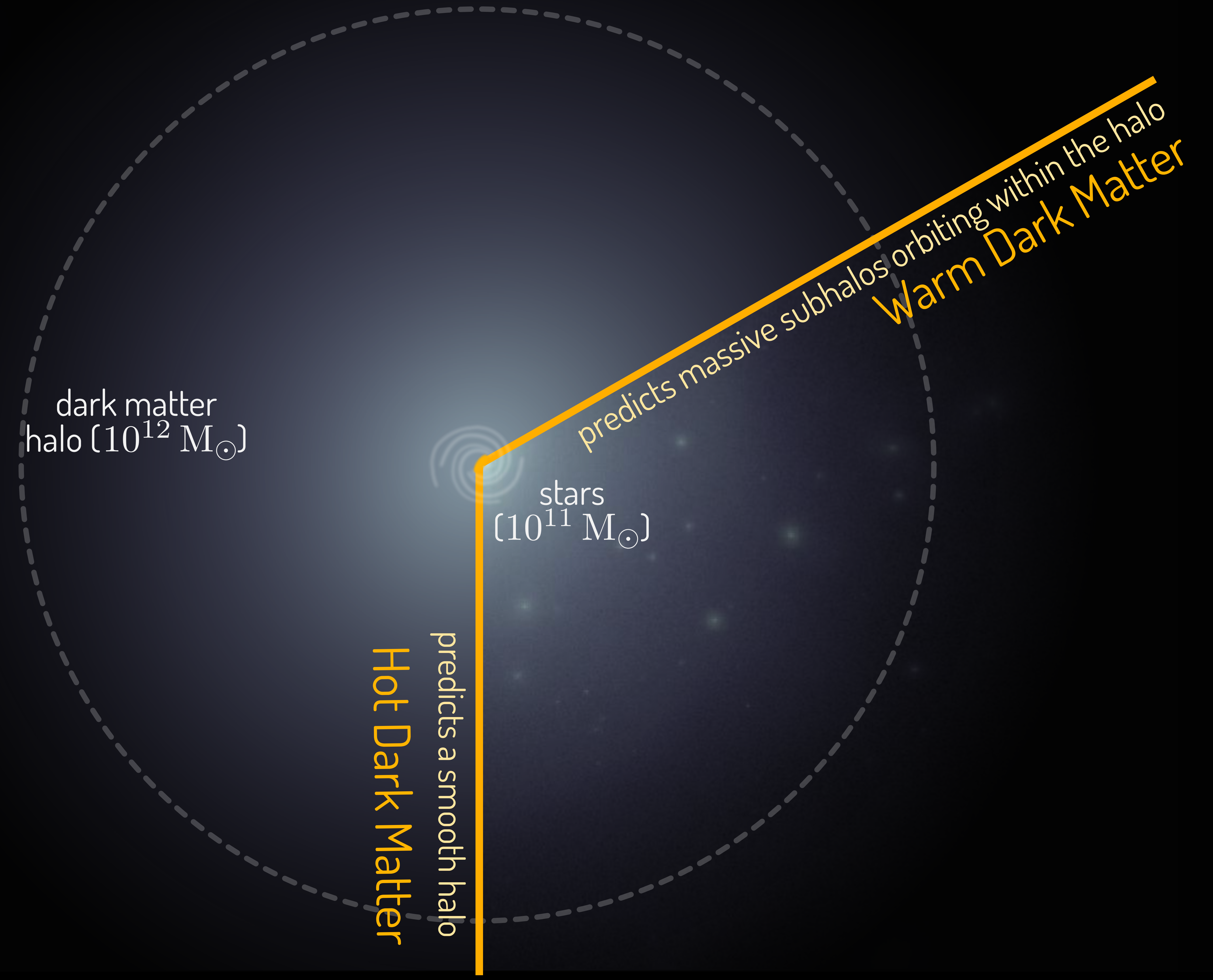

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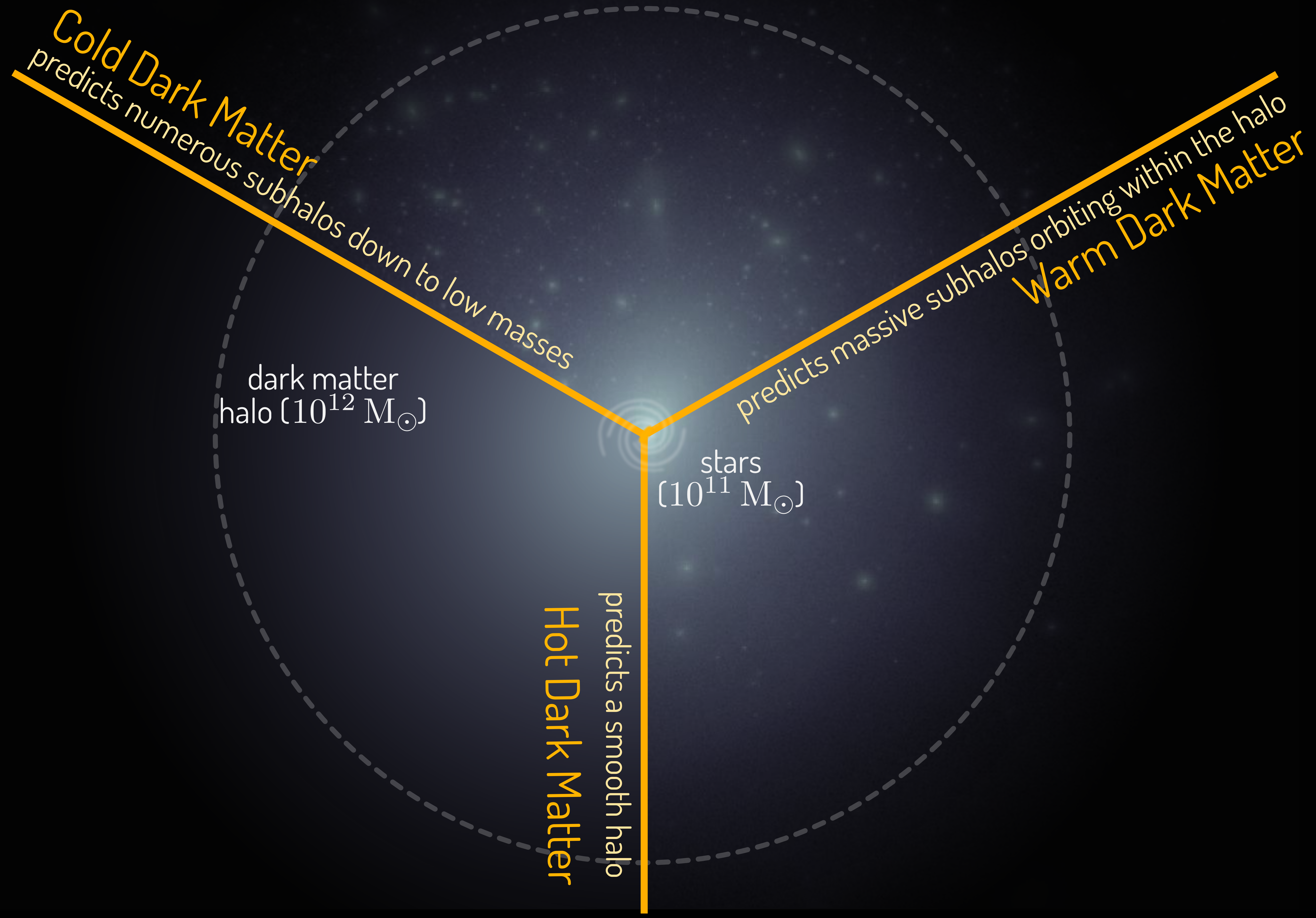

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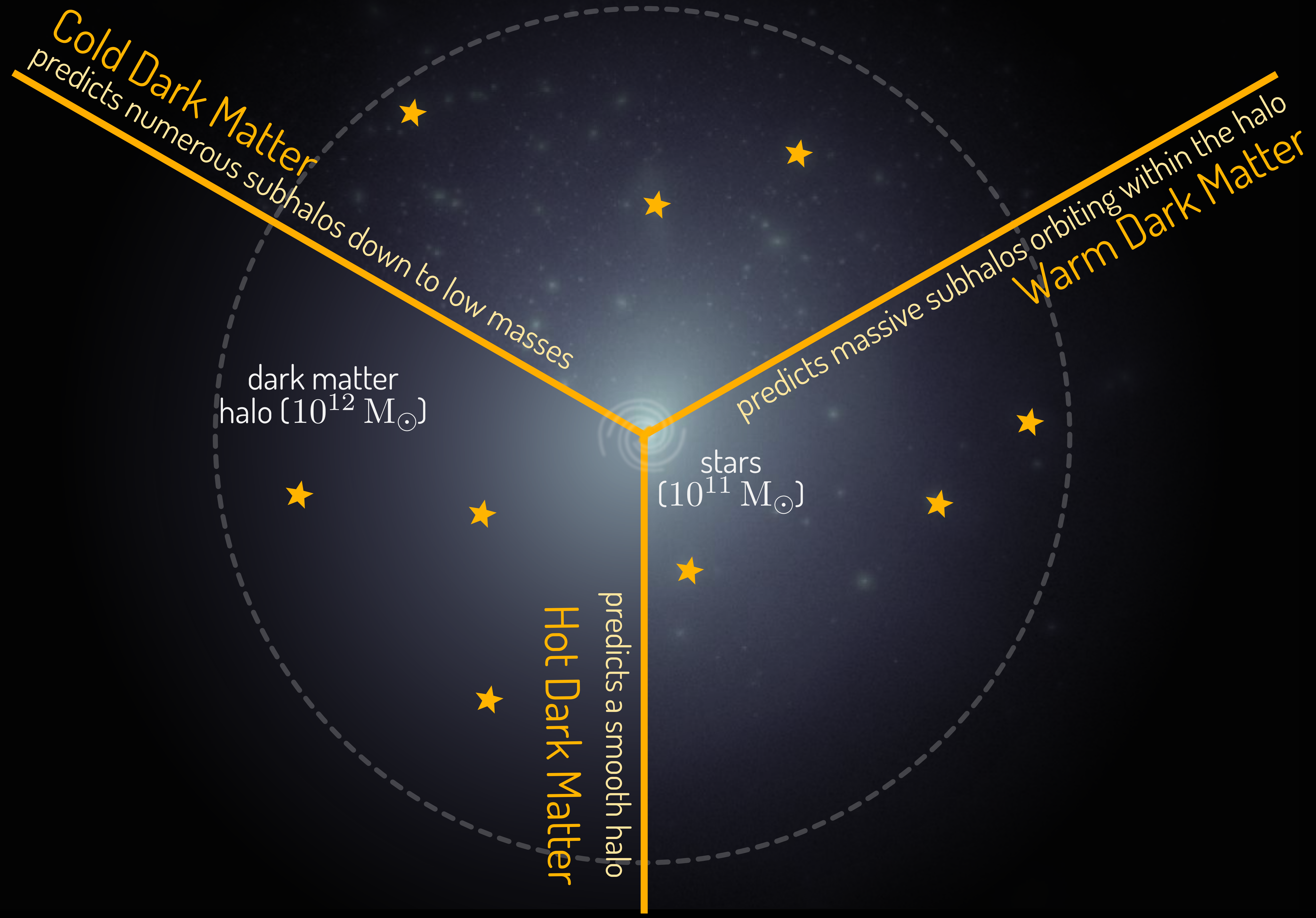
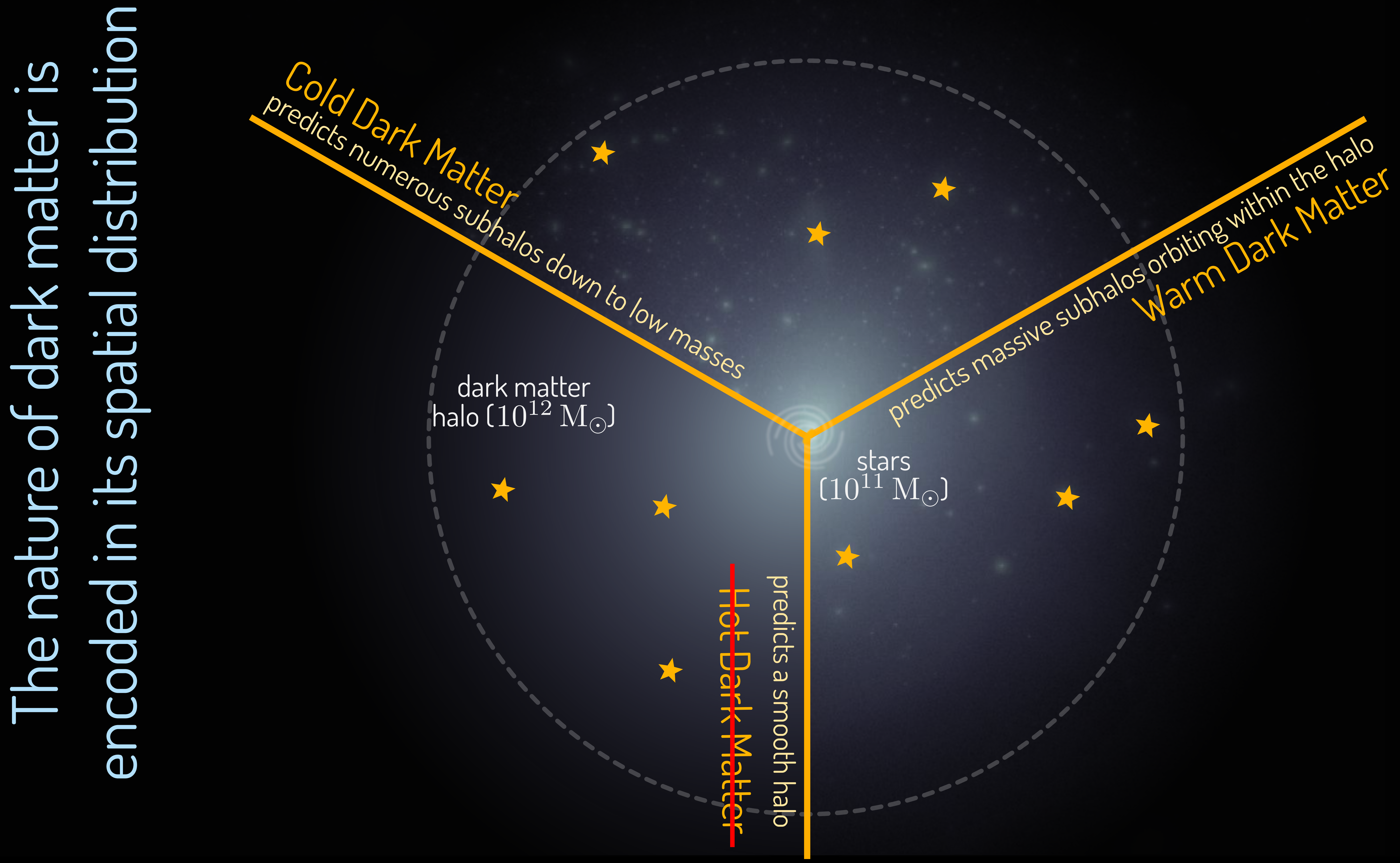
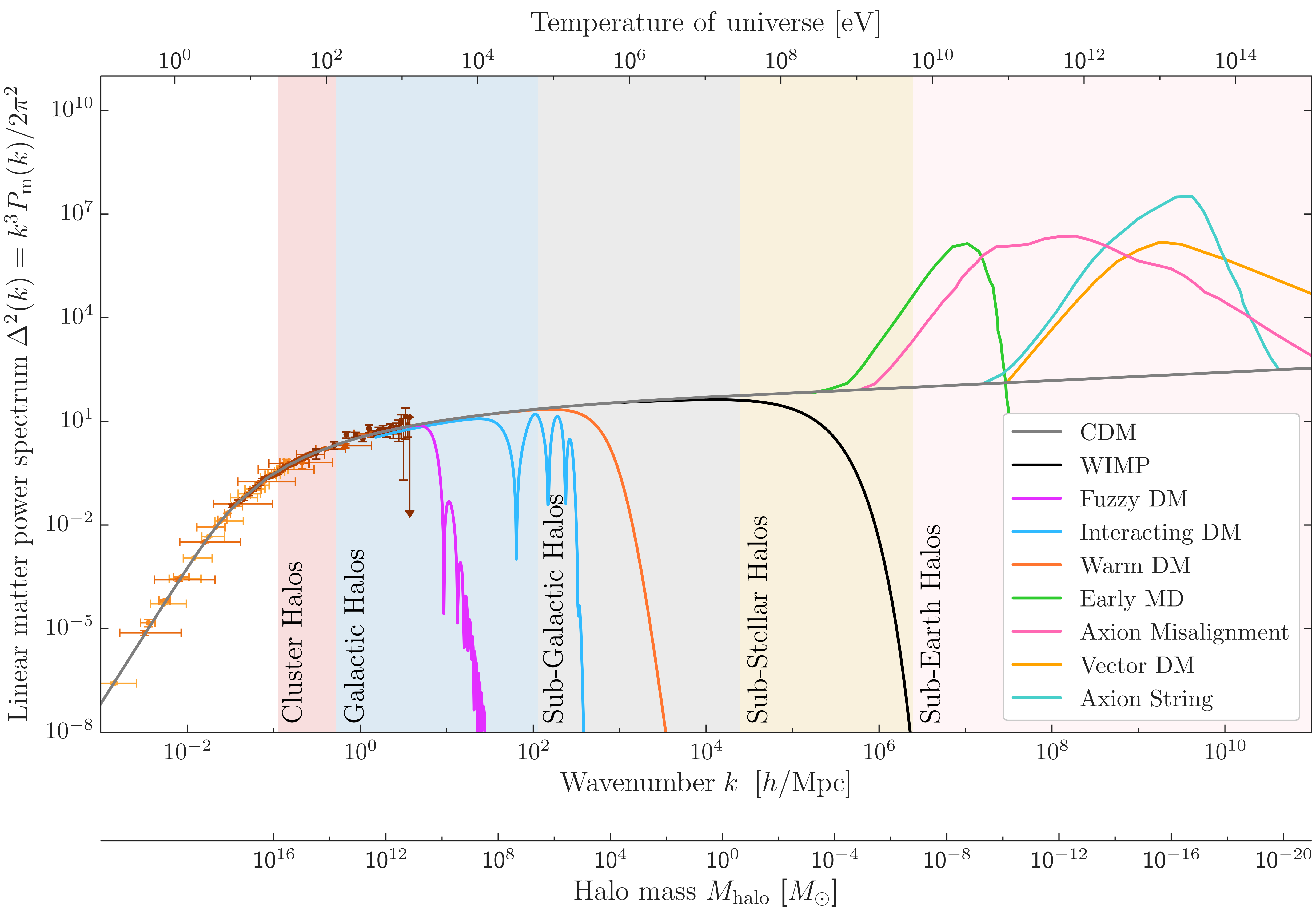



The nature of dark matter is
encoded in its spatial distribution
Cold Dark Matter
predicts numerous subhalos down to low masses
Warm Dark Matter
predicts massive subhalos orbiting within the halo
Hot Dark Matter
predicts a smooth halo
dark matter
halo (10^{12} $M_\odot$)
stars
(10^{11} $M_\odot$)

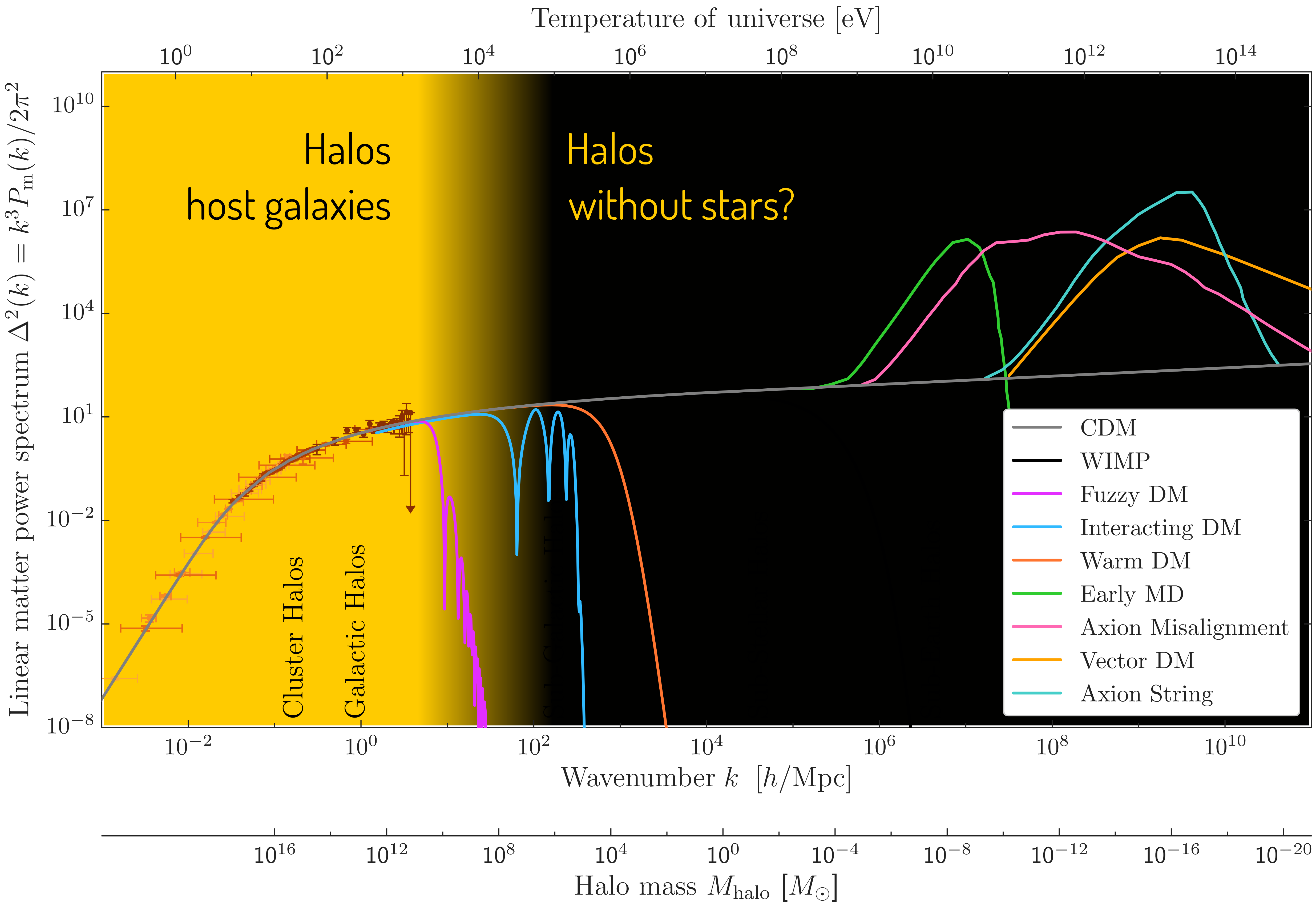
The minimum dark matter halo mass determines its nature



Bechtol et al., arXiv:2203.07354

The minimum dark matter halo mass determines its nature

Bechtol et al., arXiv:2203.07354



… the search for abundant dark matter halos with inferred virial masses substantially lower than the expected threshold of galaxy formation is the most urgent calling …

Bullock & Boylan-Kolchin (2017)

A driving question: Do completely dark subhalos exist?

Strong lensing anomalies

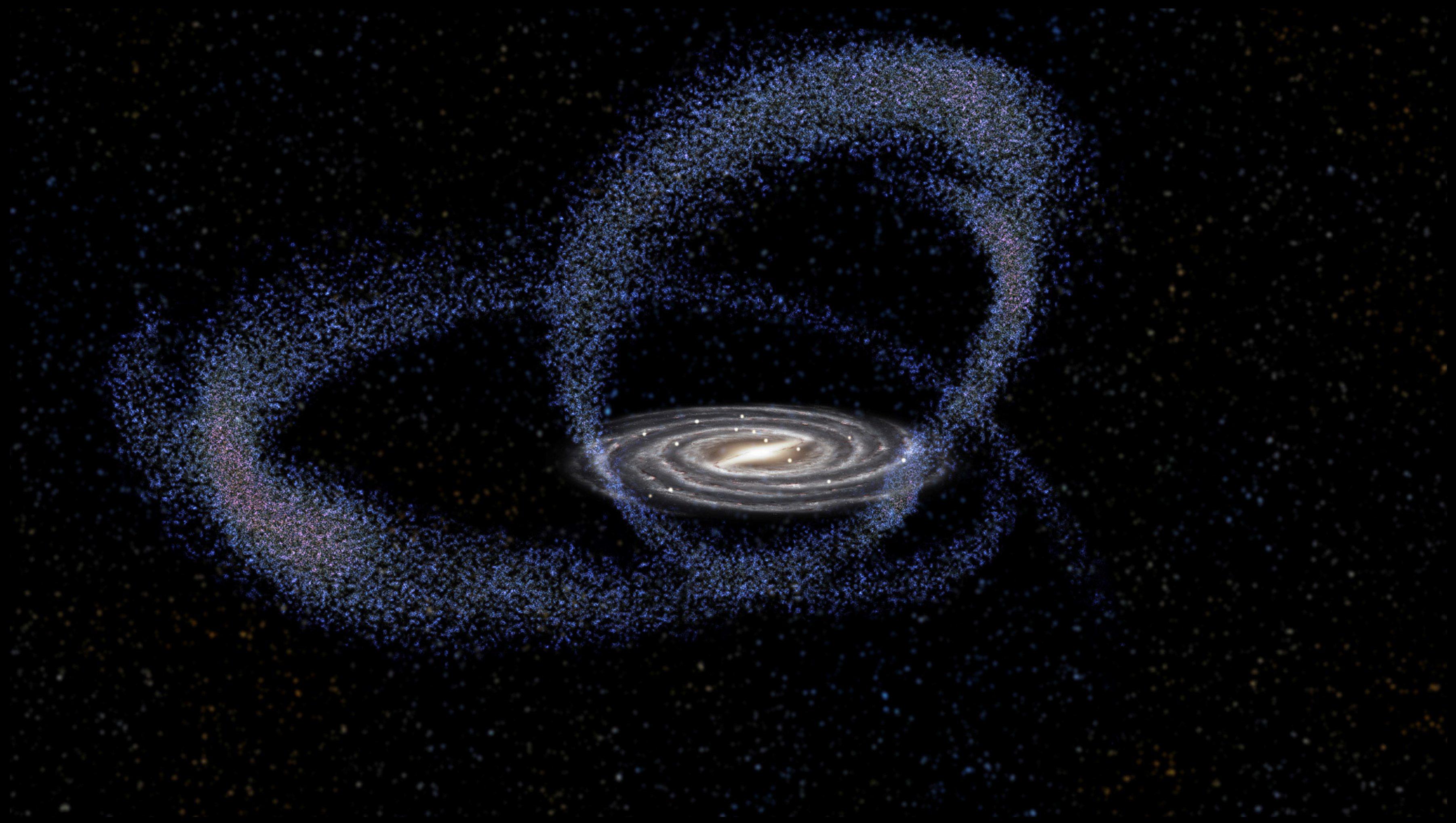
Dalal & Kochanek (2002)

A driving question: Do completely dark subhalos exist?

Strong lensing anomalies

Dalal & Kochanek (2002)

Stellar stream perturbations



Johnston et al. (2002), Ibata et al. (2002)

A driving question: Do completely dark subhalos exist?

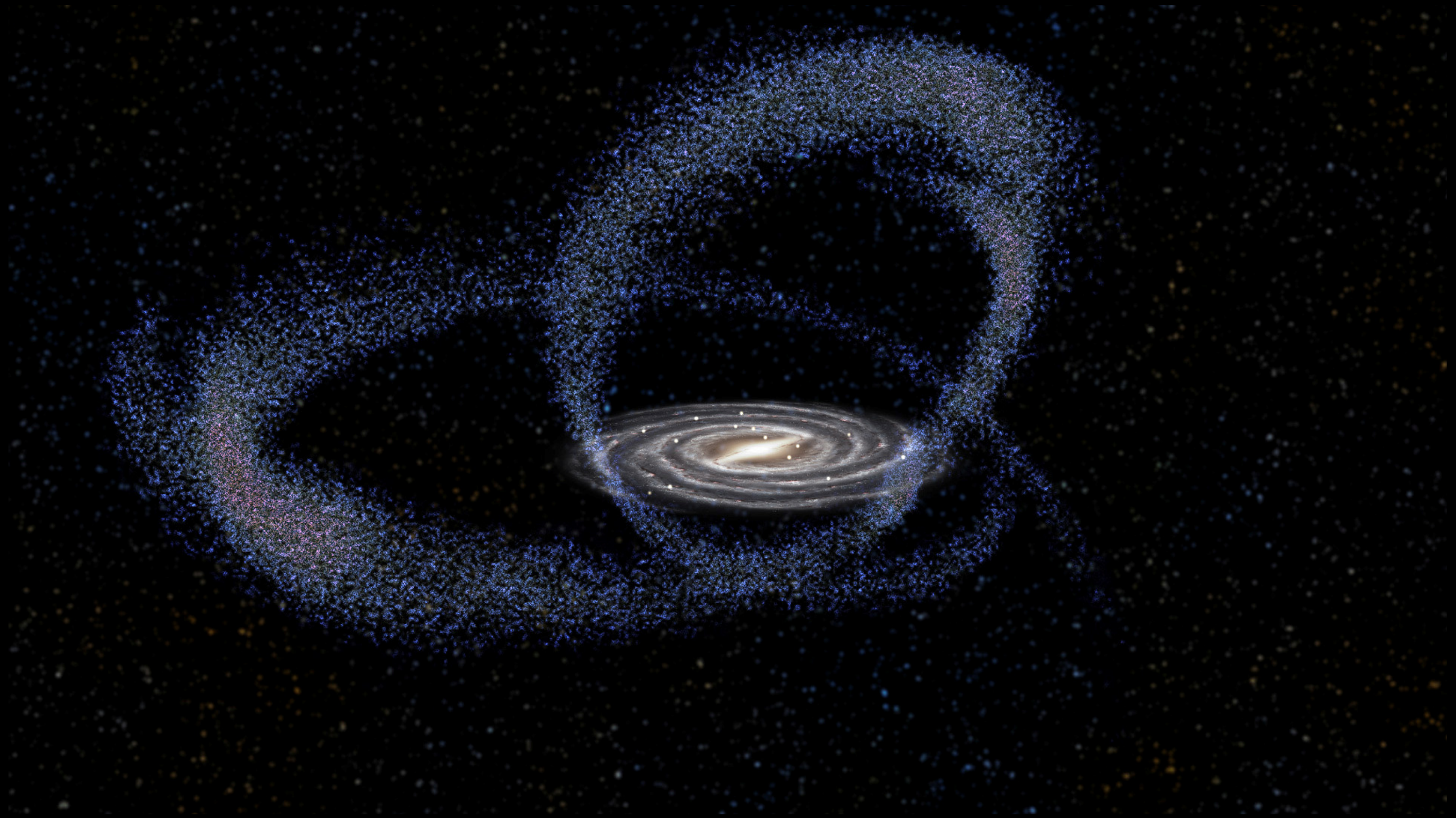
Strong lensing anomalies

Dalal & Kochanek (2002)

Number of hosts: 10 – 100

Subhalo mass: ~10^7 Msun

Stellar stream perturbations

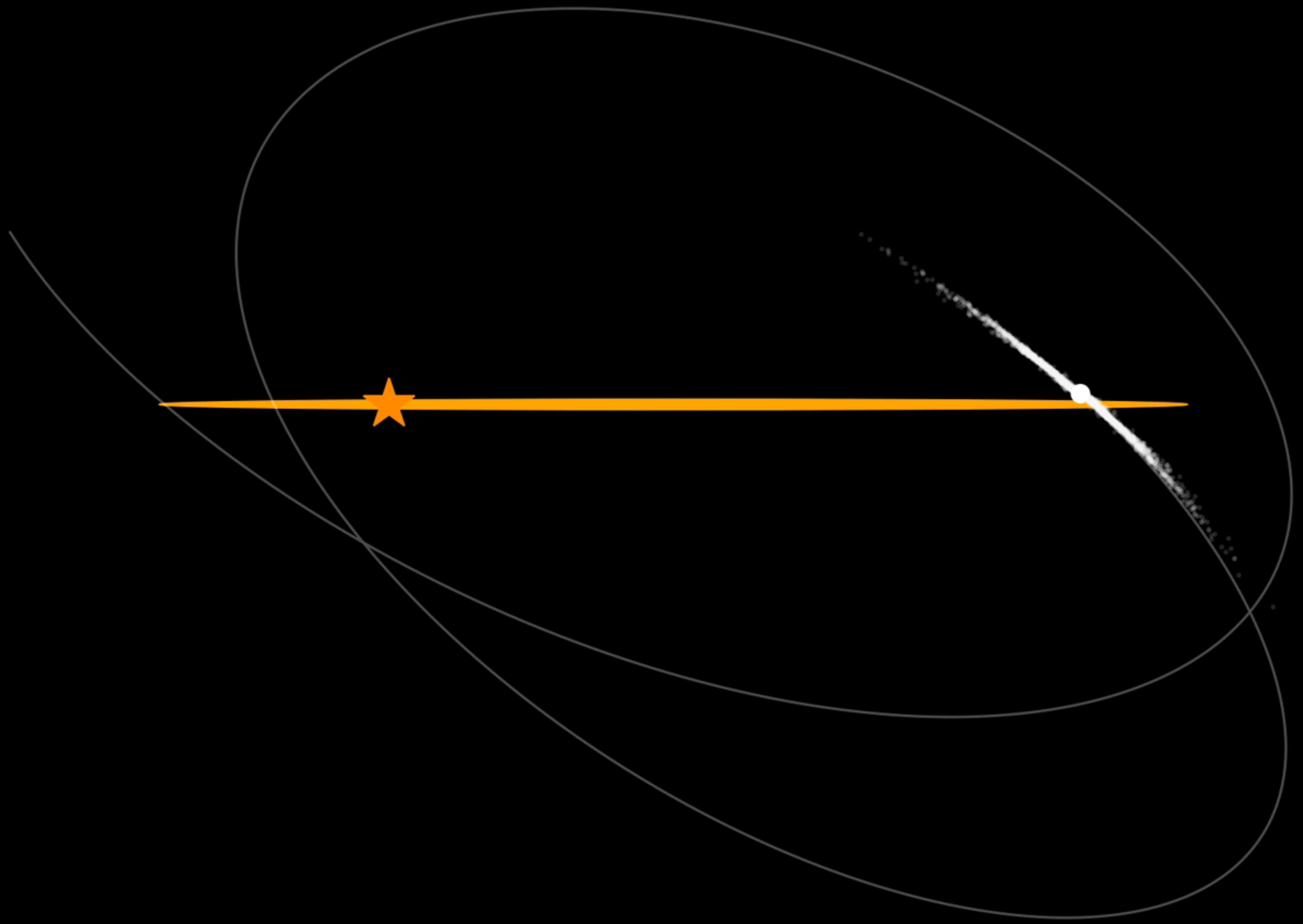


Johnston et al. (2002), Ibata et al. (2002)

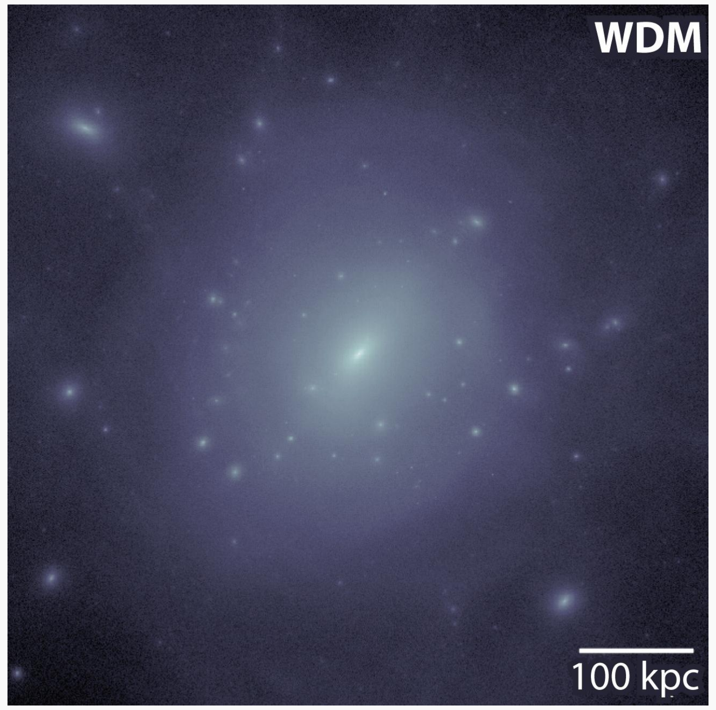
Number of hosts: 1

Subhalo mass: ~10^5 Msun

800 million years

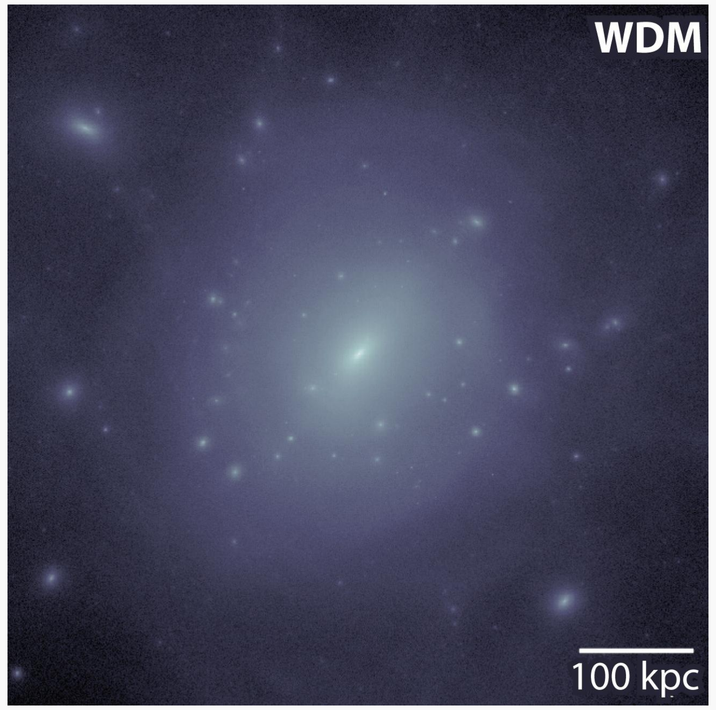


Stellar streams preserve a record of all gravitational interactions

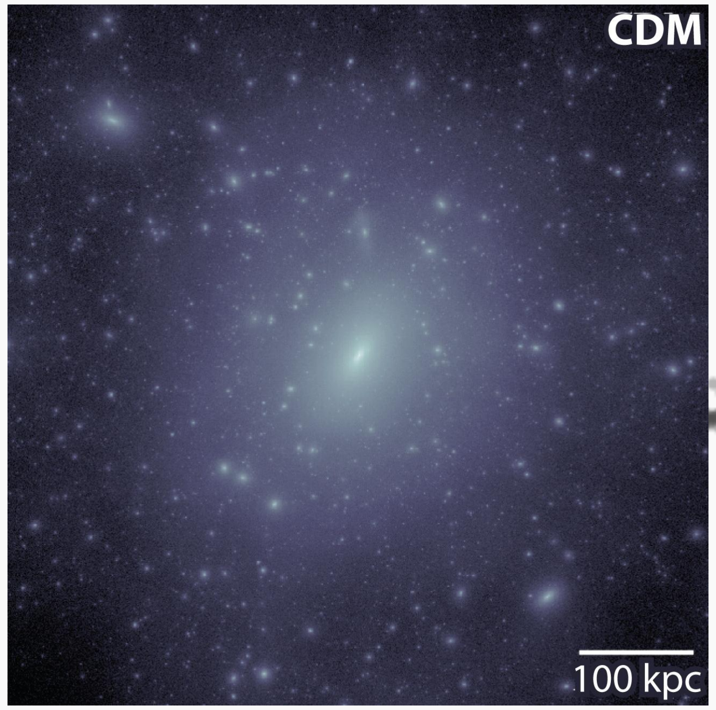


Stellar stream in a smooth galaxy

Stellar streams preserve a record of all gravitational interactions



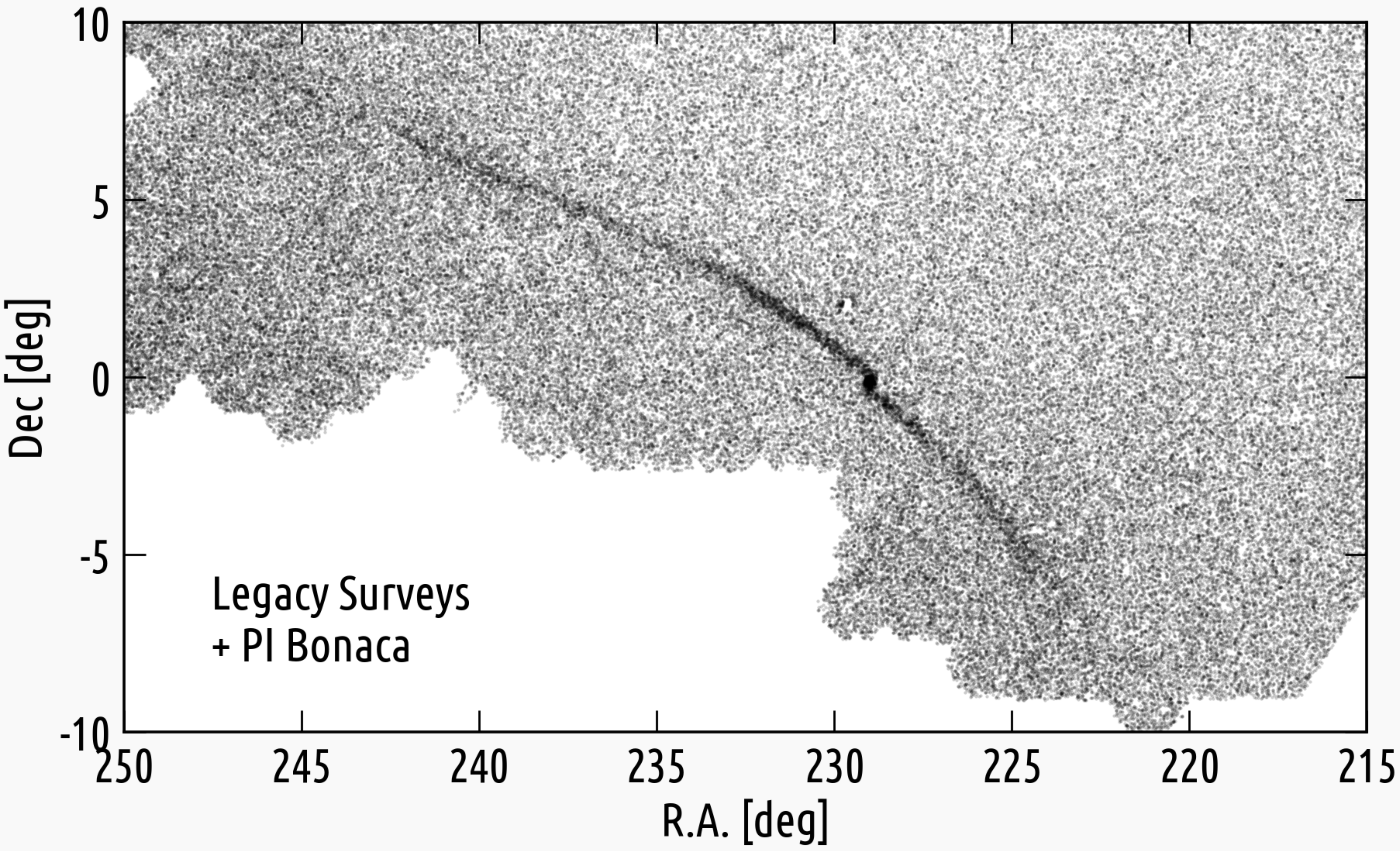
Stellar stream in a smooth galaxy



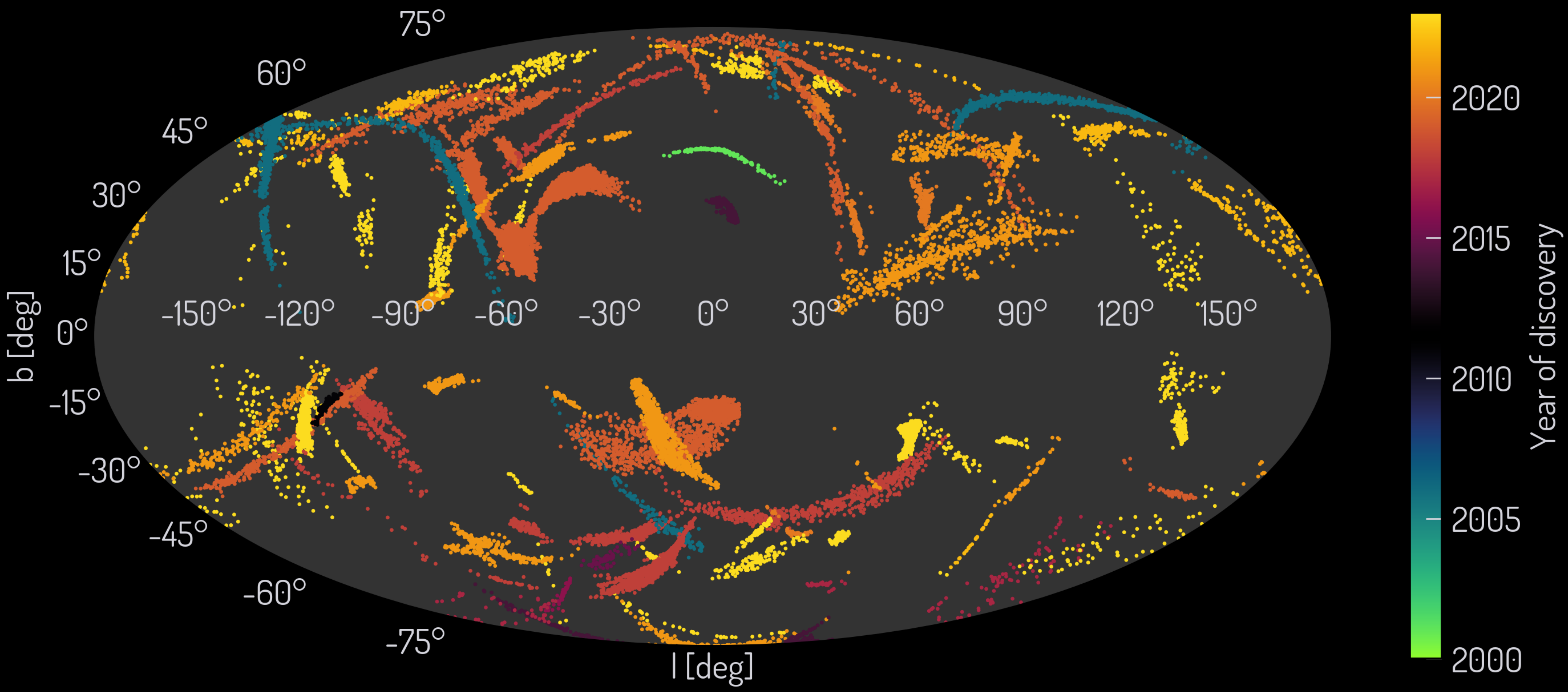
Stellar stream in a clumpy galaxy

Bonaca et al. (2014)

Palomar 5 globular cluster has extended tidal tails

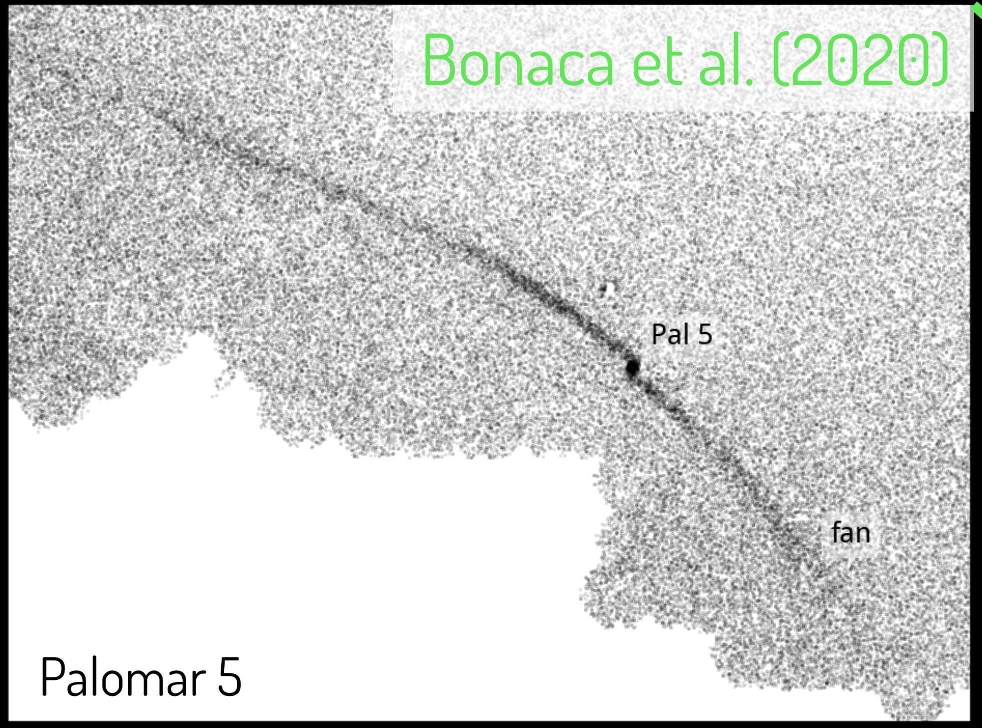


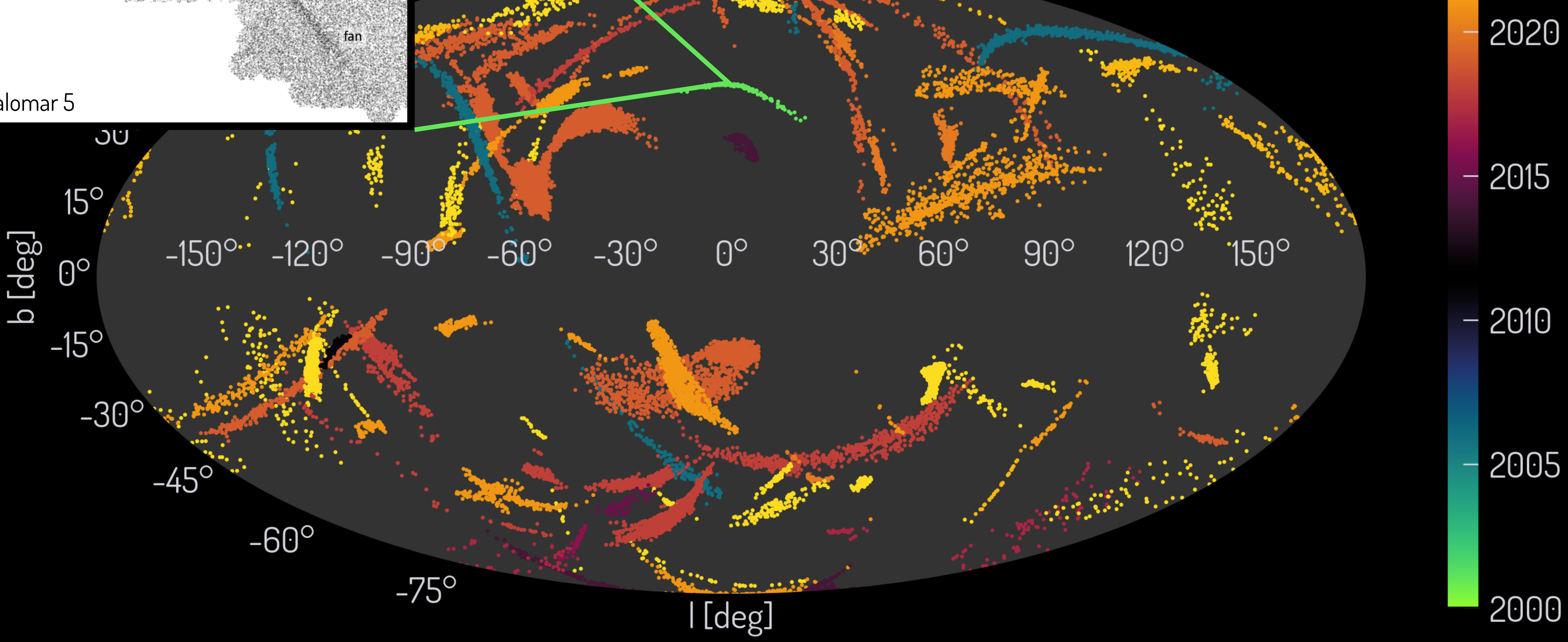
A ~hundred cold stellar streams are now known in the Milky Way



based on Ibata et al. (2023)

stellar streams are now known in the Milky Way





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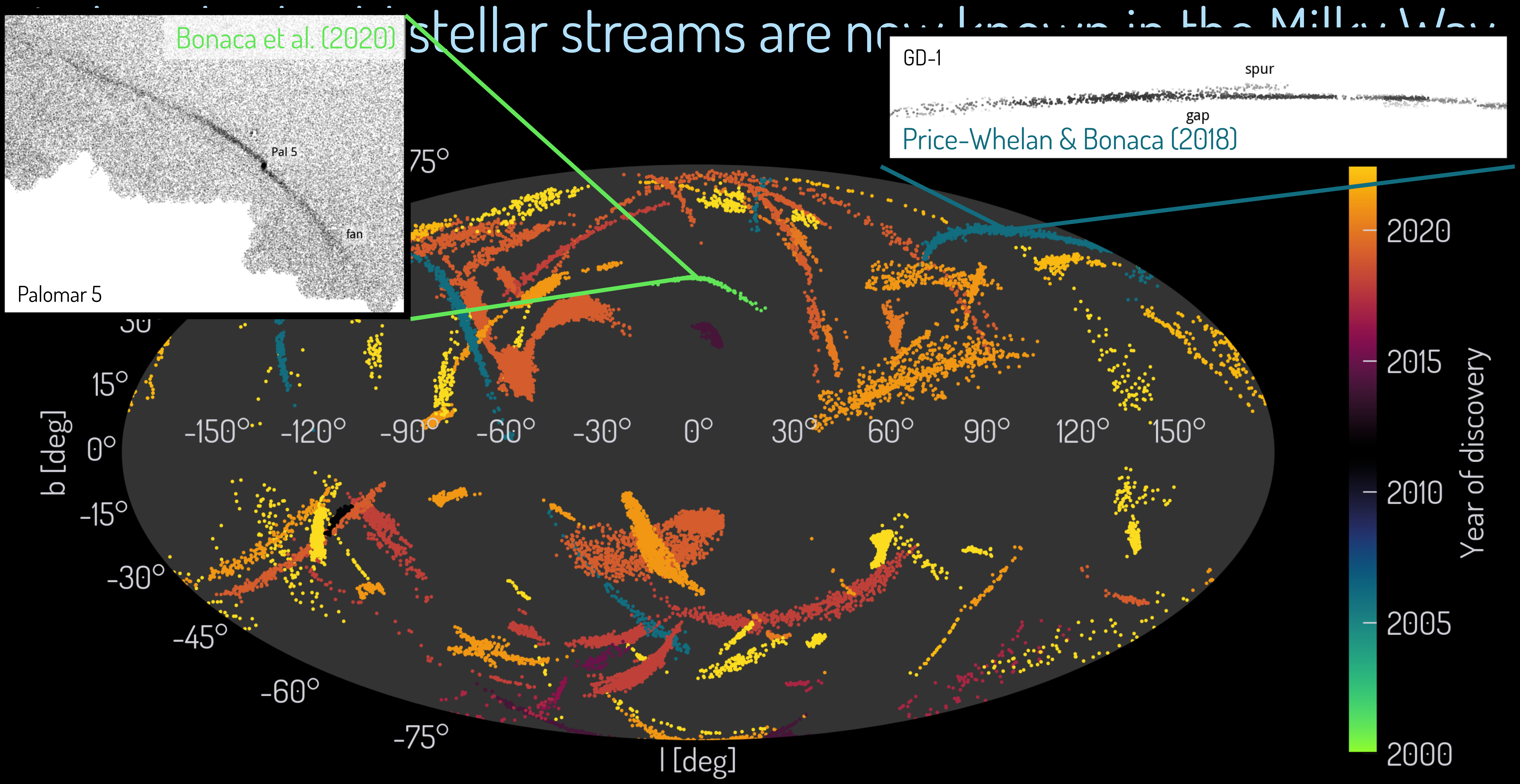

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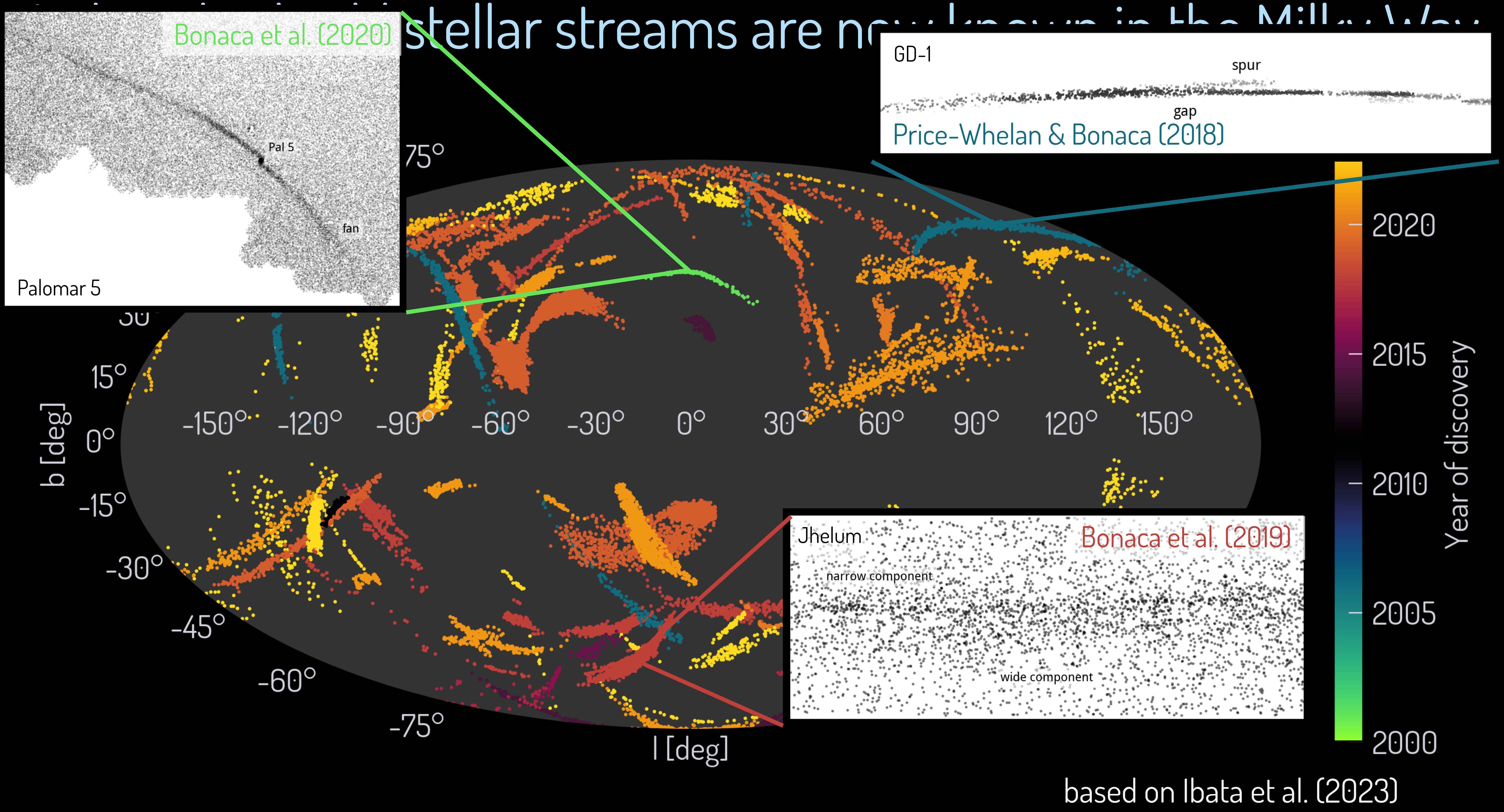
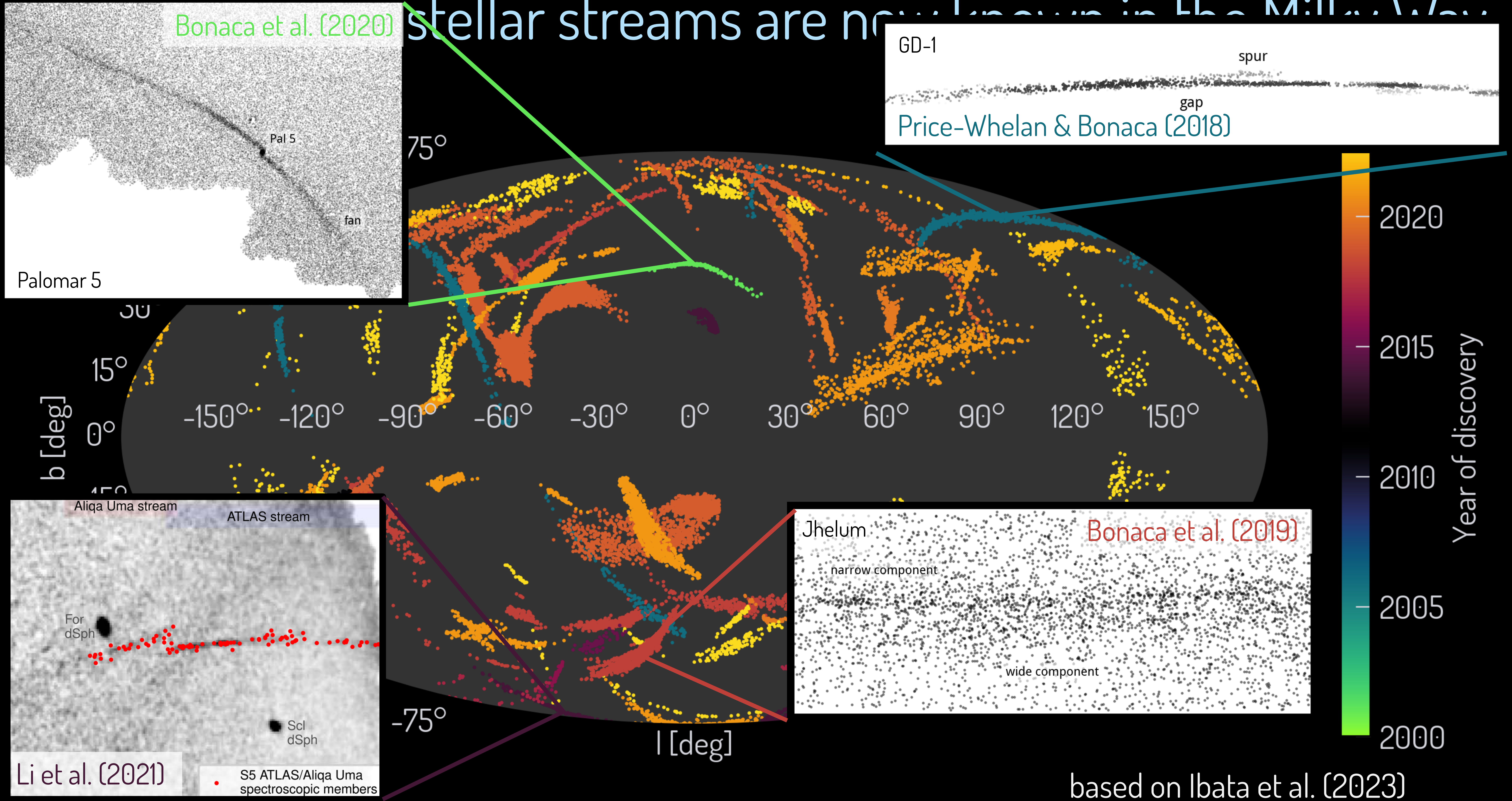


stellar streams are n
Bonaca et al. (2020)
Pal 5
fan
Palomar 5
GD-1
spur
gap
Price-Whelan & Bonaca (2018)
Jhelum
Bonaca et al. (2019)
narrow component
wide component
75°
30°
15°
0°
-15°
-30°
-45°
-60°
-75°
b [deg]
-150°
-120°
-90°
-60°
-30°
0°
30°
60°
90°
120°
150°
l [deg]
2020
2015
2010
2005
2000
Year of discovery
based on Ibata et al. (2023)

stellar streams are n...



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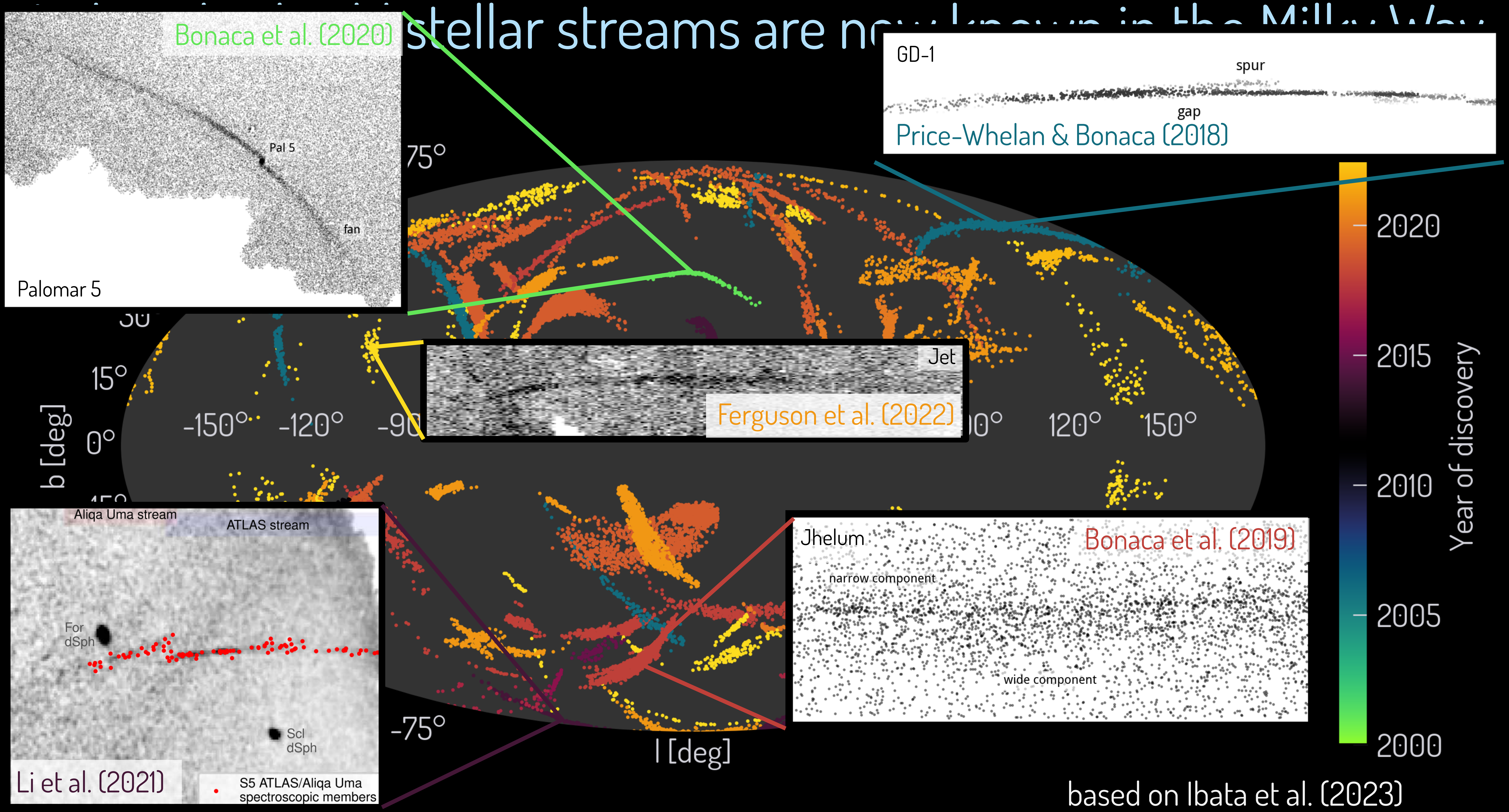
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75°
30
15°
0°
b [deg]
-150°
-120°
-90
Jet
Ferguson et al. (2022)
0°
120°
150°
-75°
l [deg]
Aliqa Uma stream
ATLAS stream
For dSph
Scl dSph
Li et al. (2021)
S5 ATLAS/Aliqa Uma spectroscopic members
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narrow component
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2020
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2010
2005
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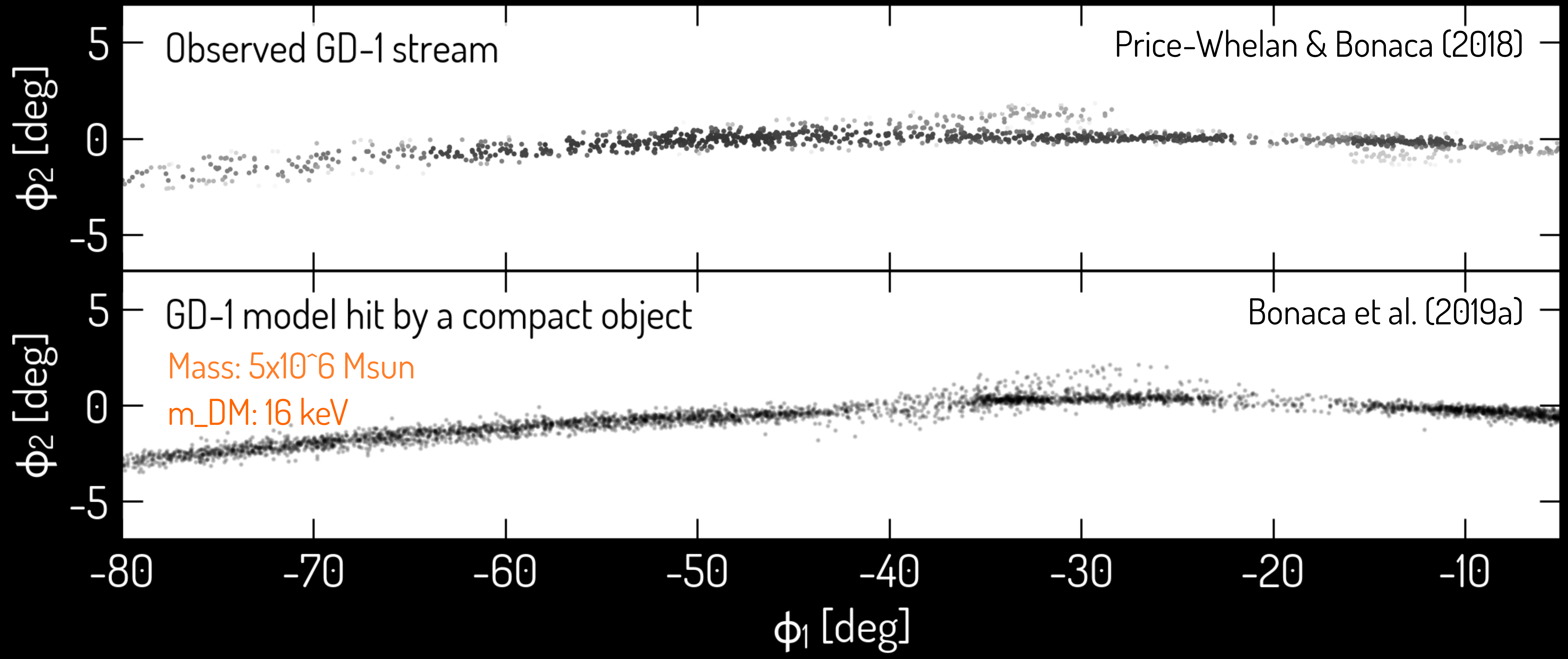
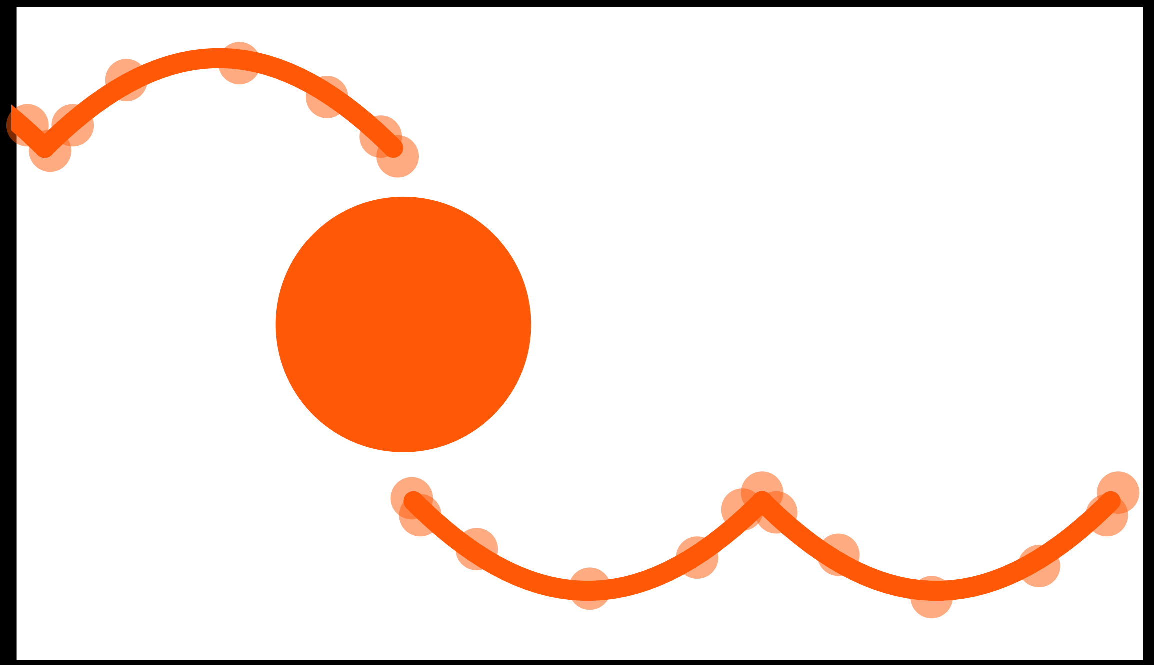
Possible first detection of a dark-matter subhalo



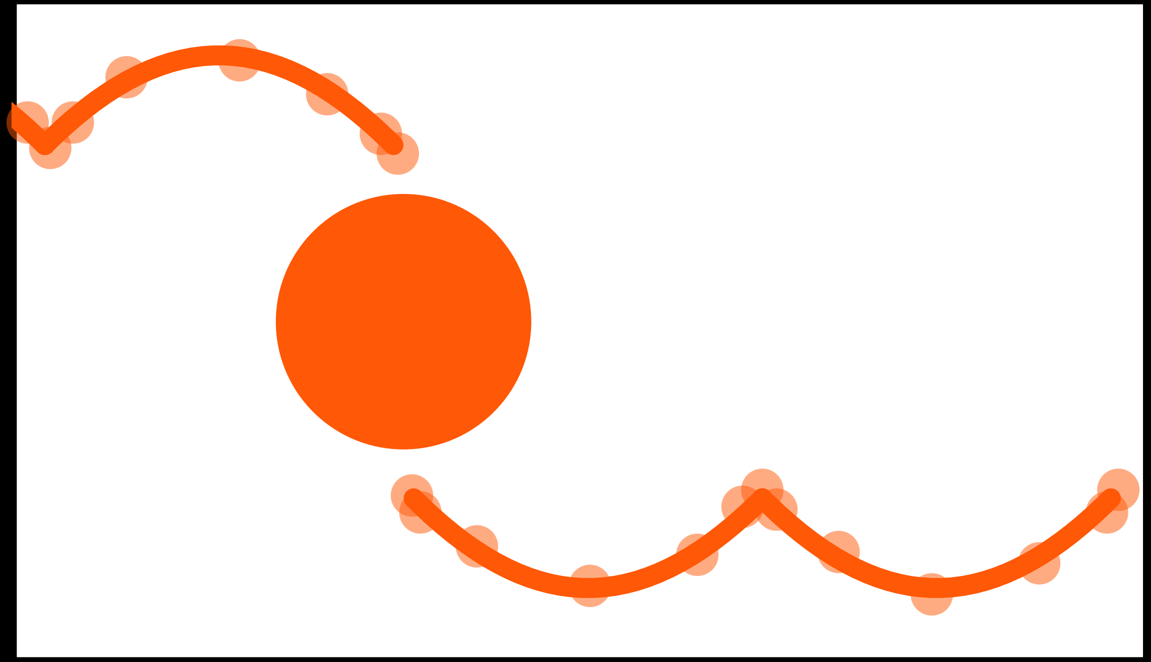
Complex stream morphologies can arise from:



Epicyclic overdensities

Küpper et al. (2008) • Just et al. (2009)

Complex stream morphologies can arise from:



Epicyclic overdensities

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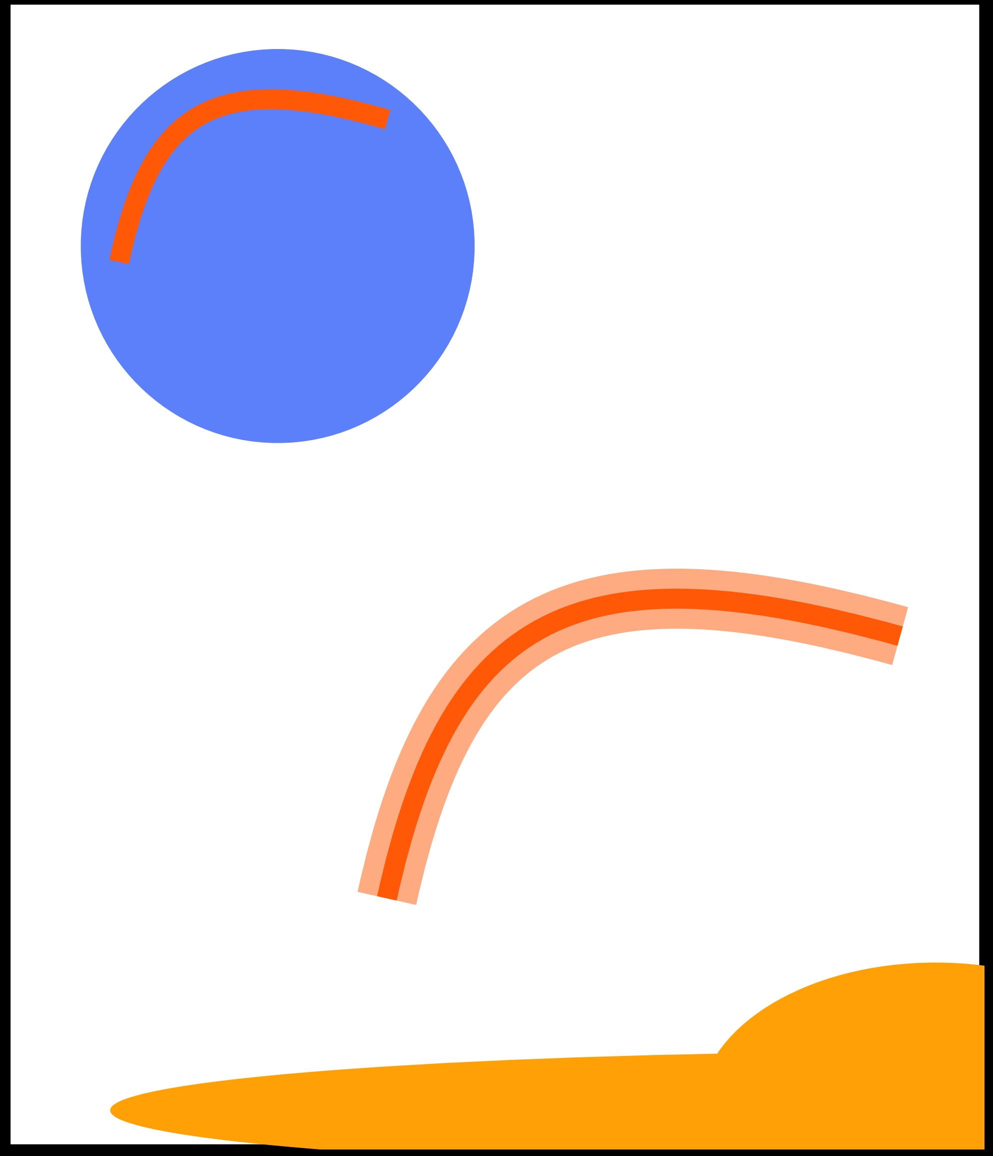
Host galaxy



Carlberg (2019) • Malhan et al. (2020)

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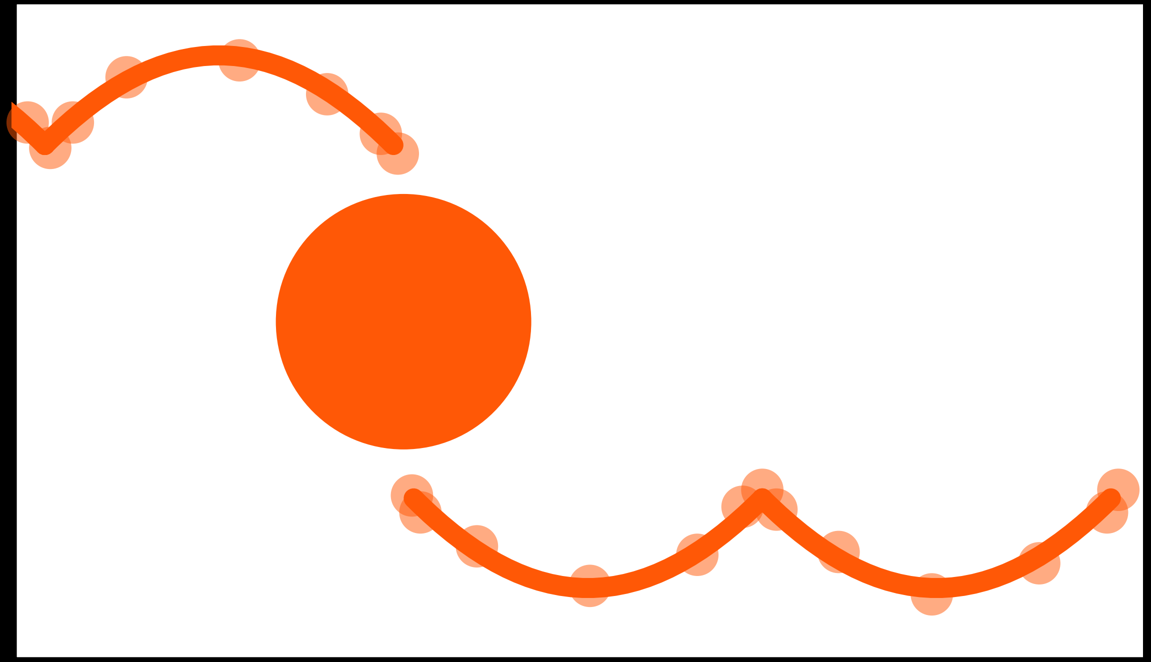

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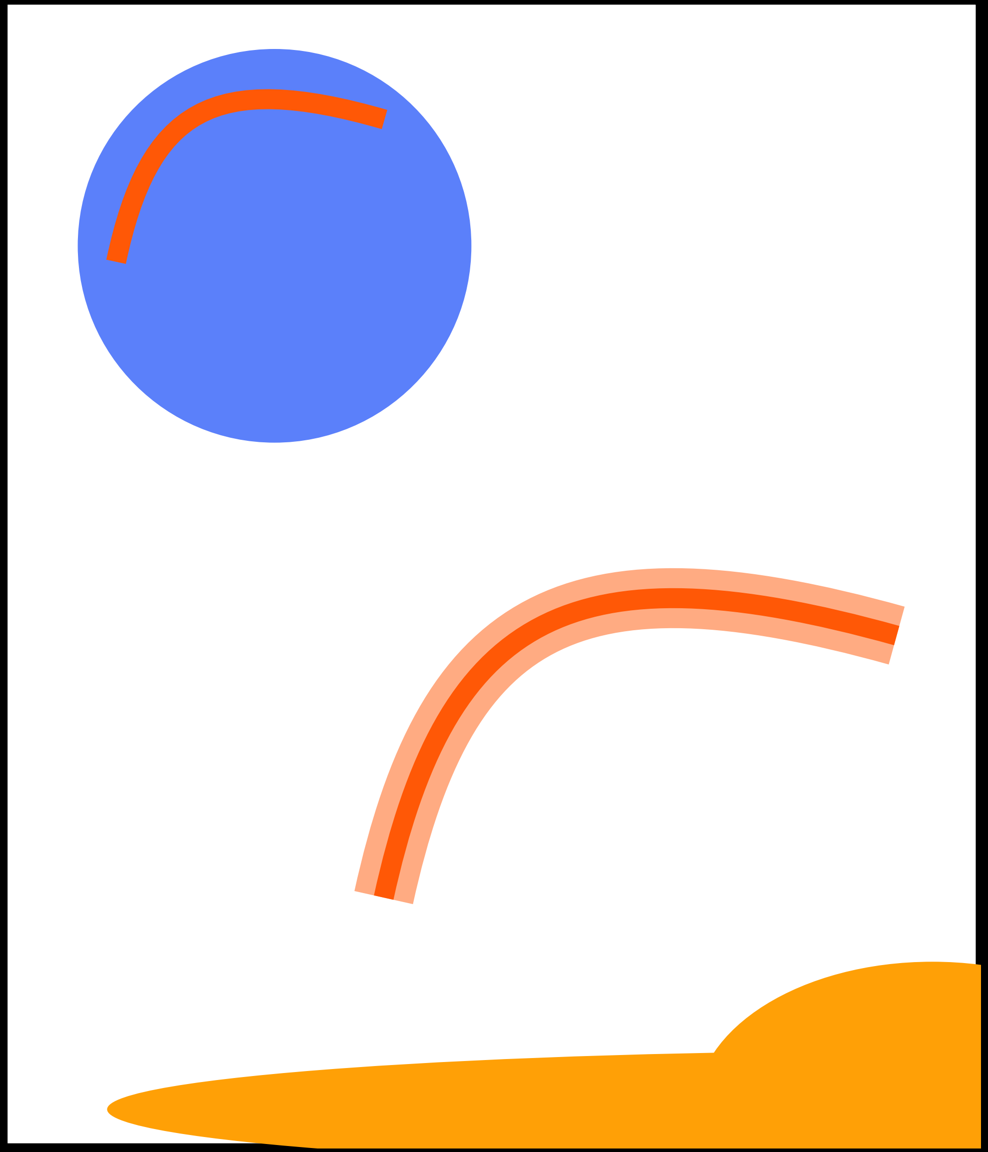

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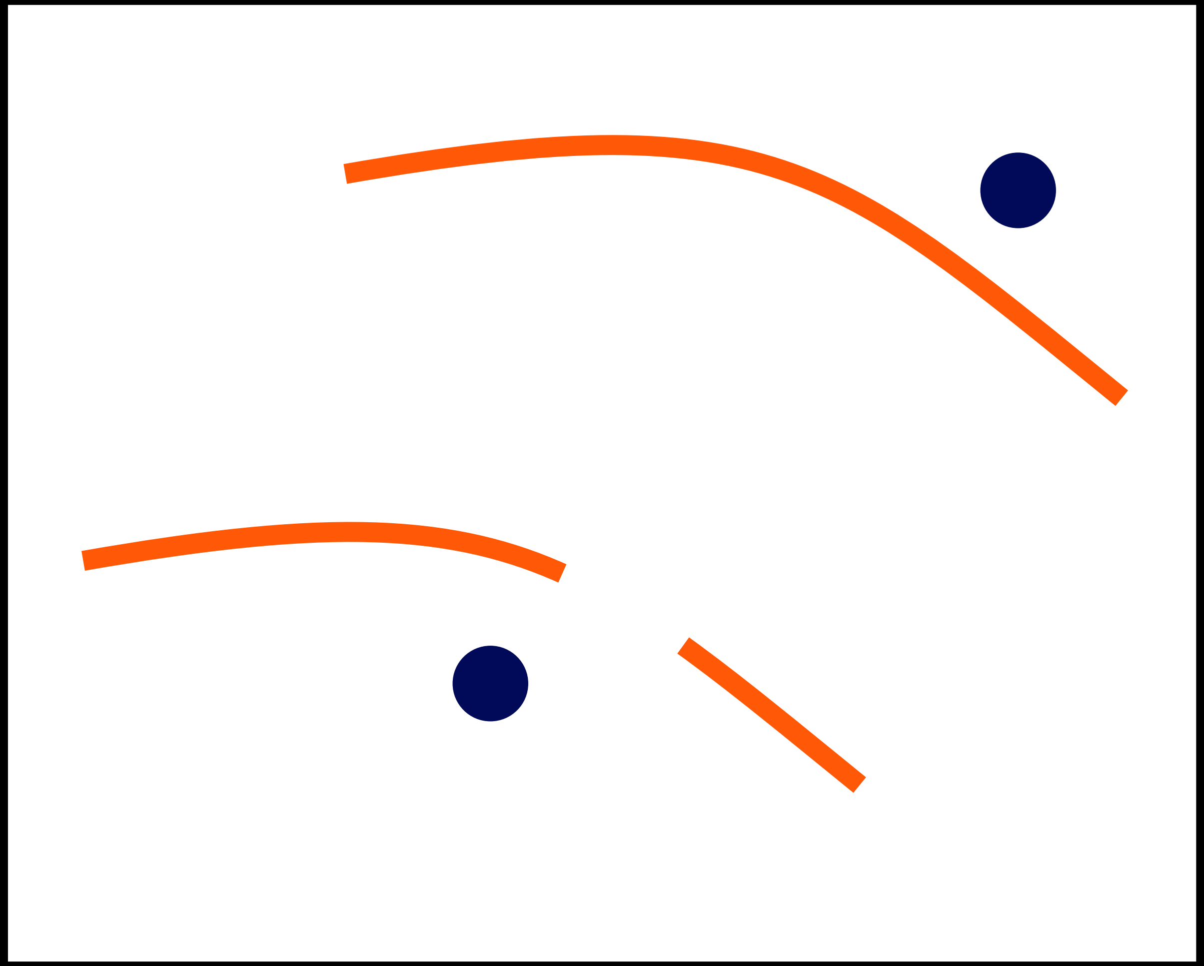
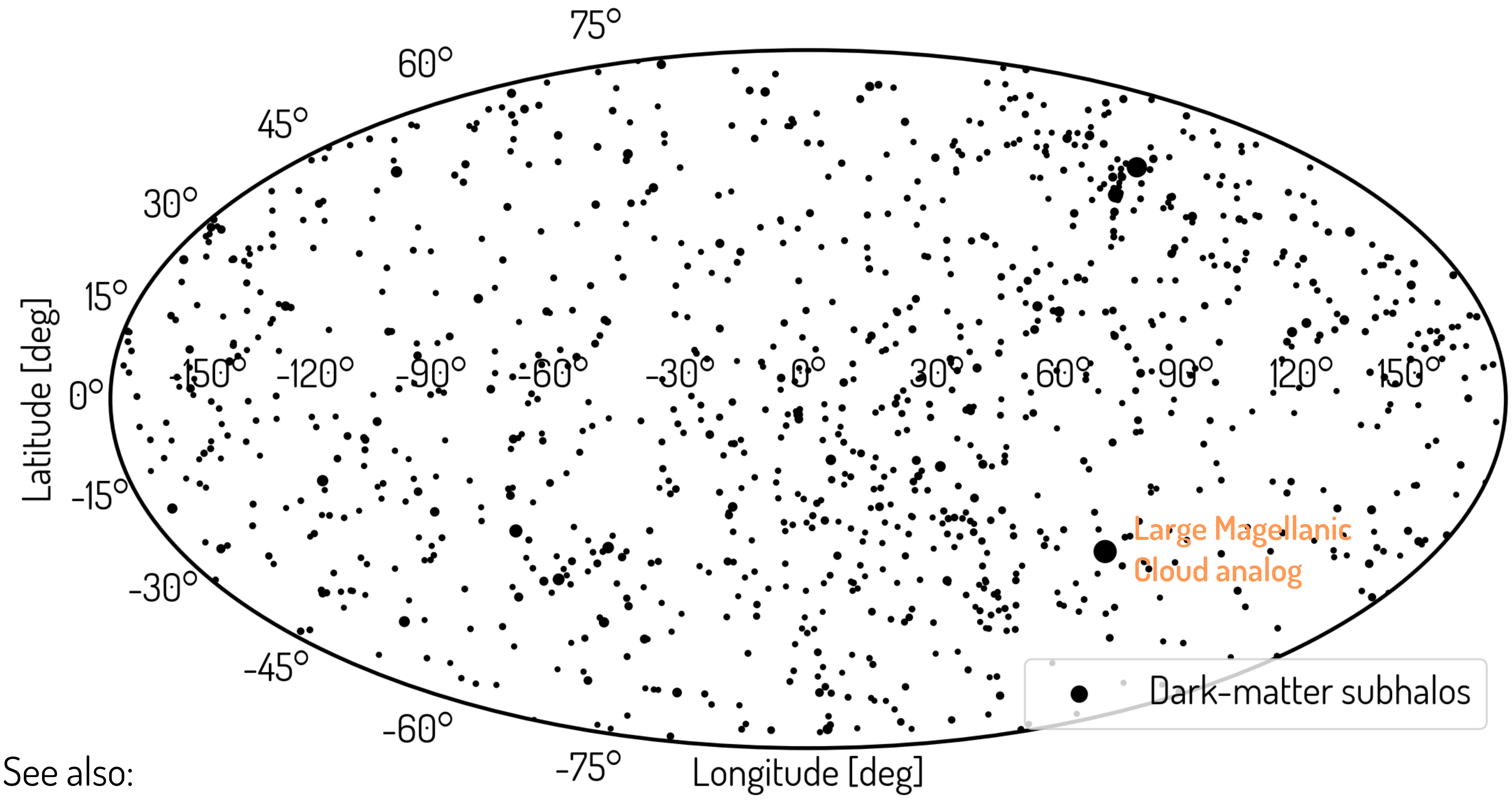


Impacts

Johnston et al. (2002) • Ibata et al, (2002)

Studying stellar streams as a population in the Milky Way

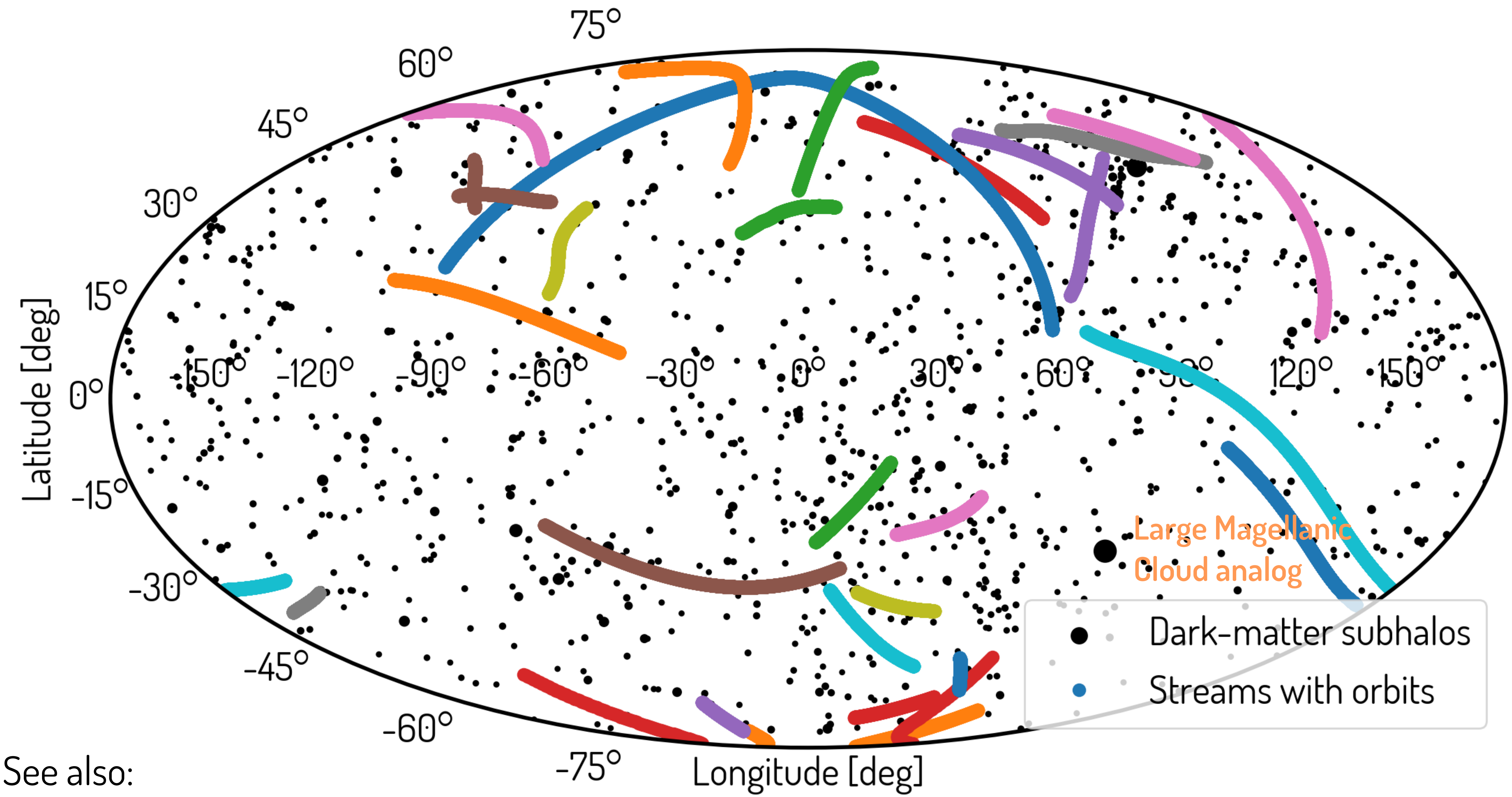


Brigette Vazquez Segovia
CASSI 2022

Ethan Nadler
Carnegie/USC

See also:
Petersen & Penarrubia (2020, 2021)

Studying stellar streams as a population in the Milky Way



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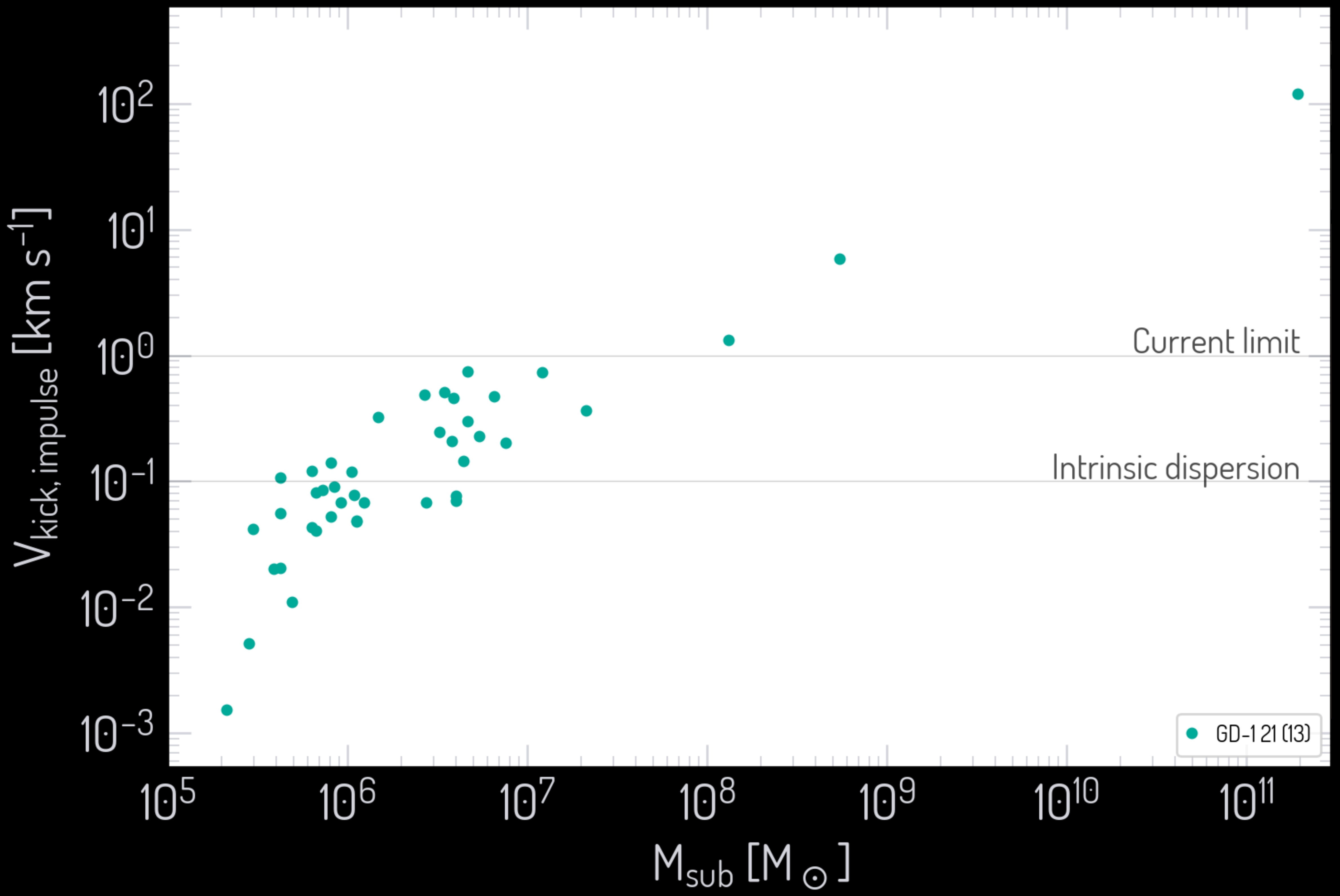
Dozens of stream - subhalo impacts are expected in CDM



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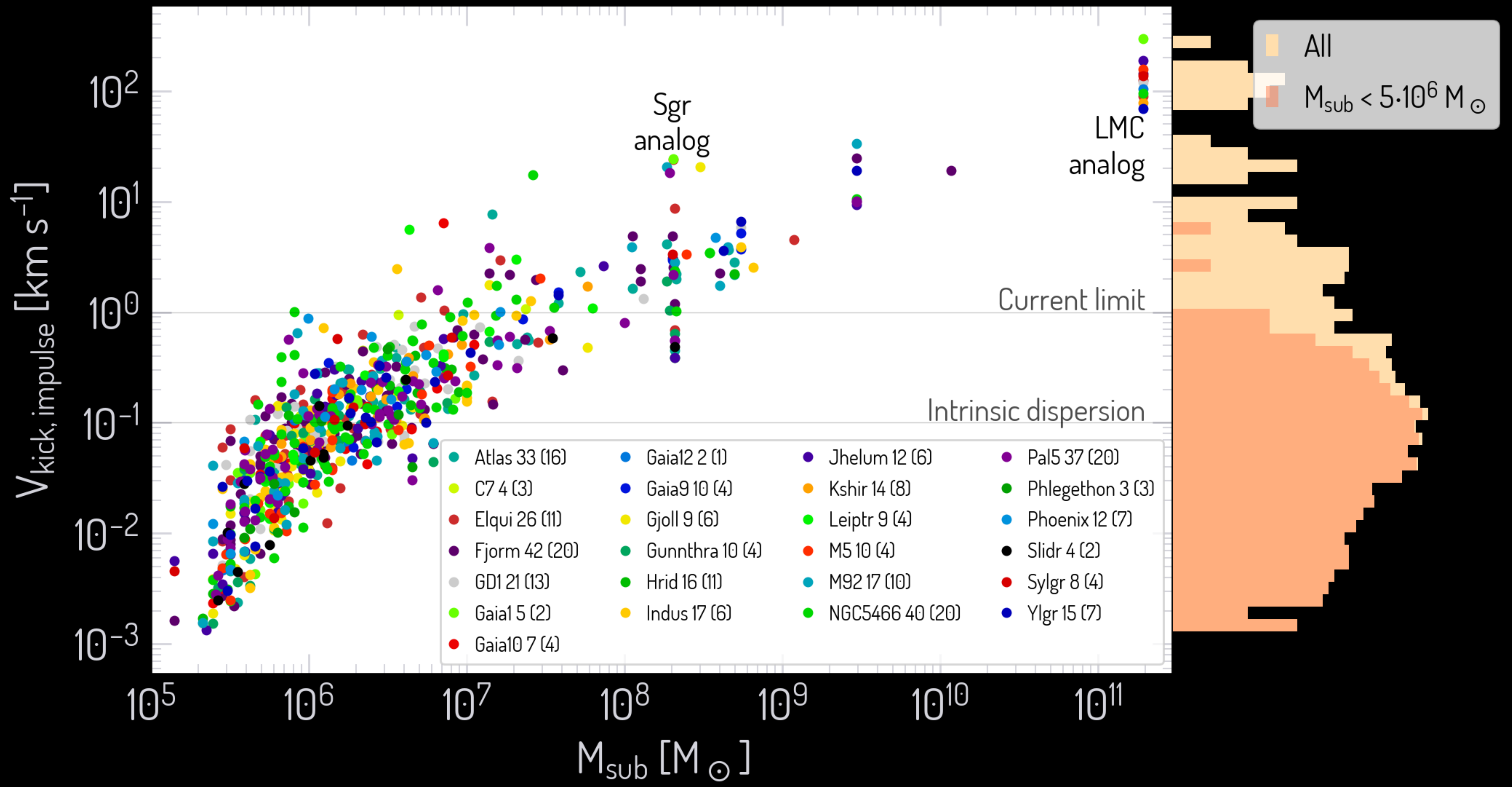
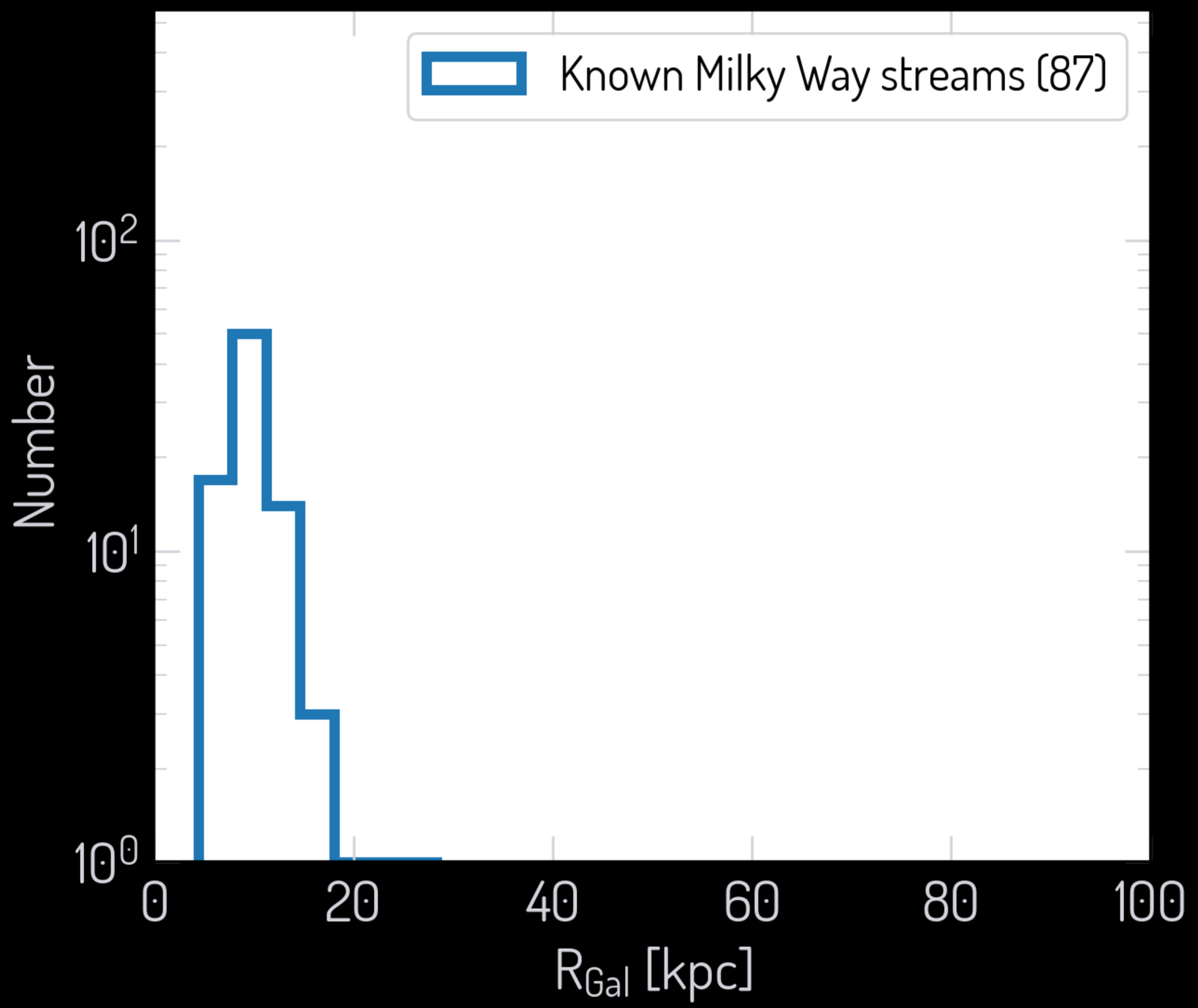


Are there more streams waiting to be discovered?

Streams currently detected in the inner Milky Way



Pearson, Bonaca, Chen & Gnedin (in prep)

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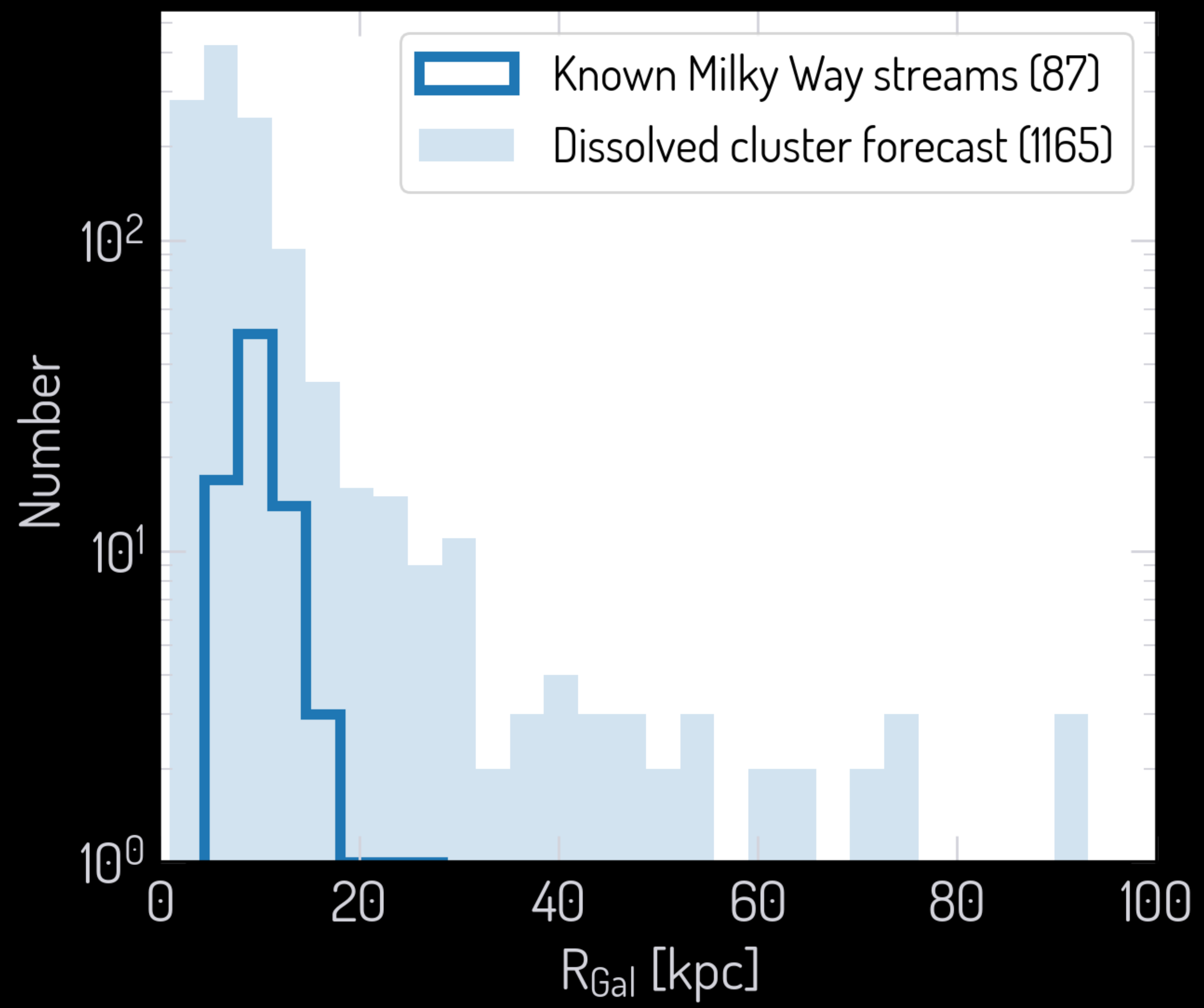

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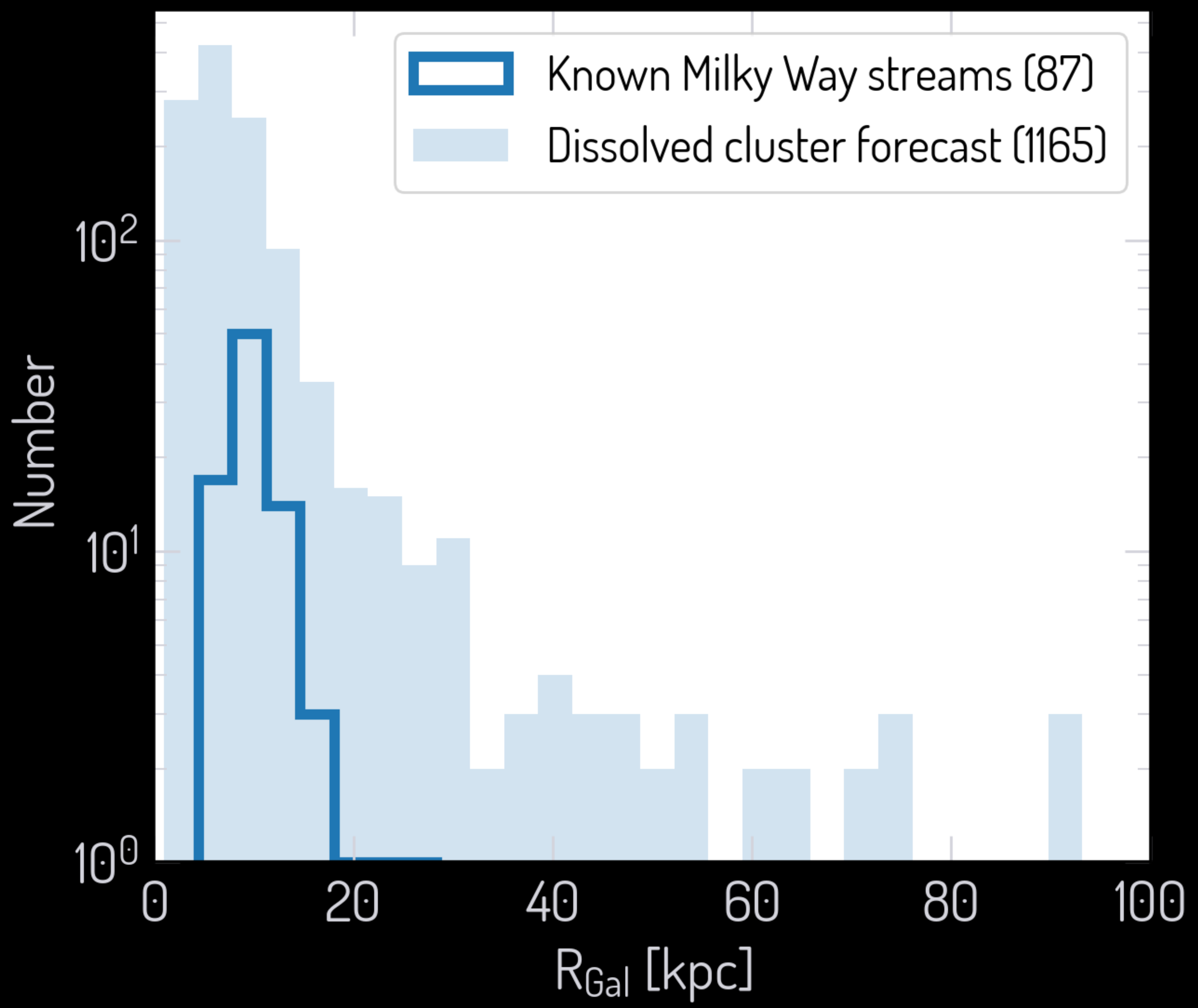


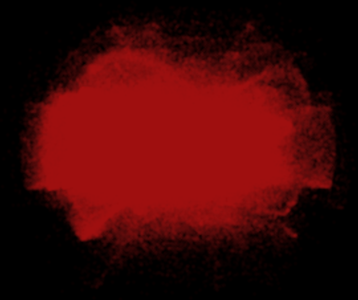
Pearson, Bonaca, Chen & Gnedin (in prep)

Vera Rubin Observatory, designed to map the outer Milky Way

LSST First Light	Survey Operations	Data Release 1
Q1 2025	Q3 2025	Q4 2026

The Milky Way halo in the LSST era

r < 10 kpc (893)



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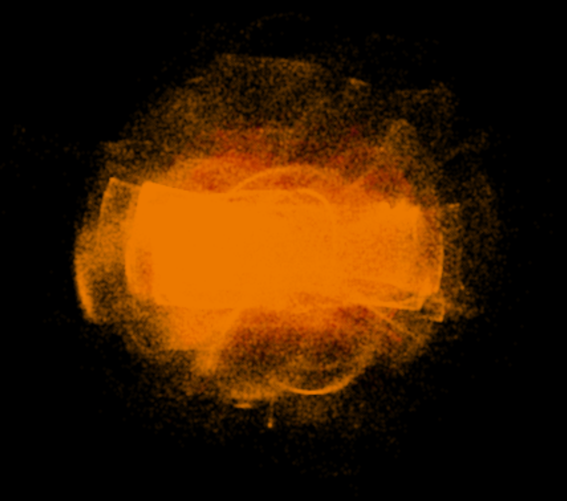
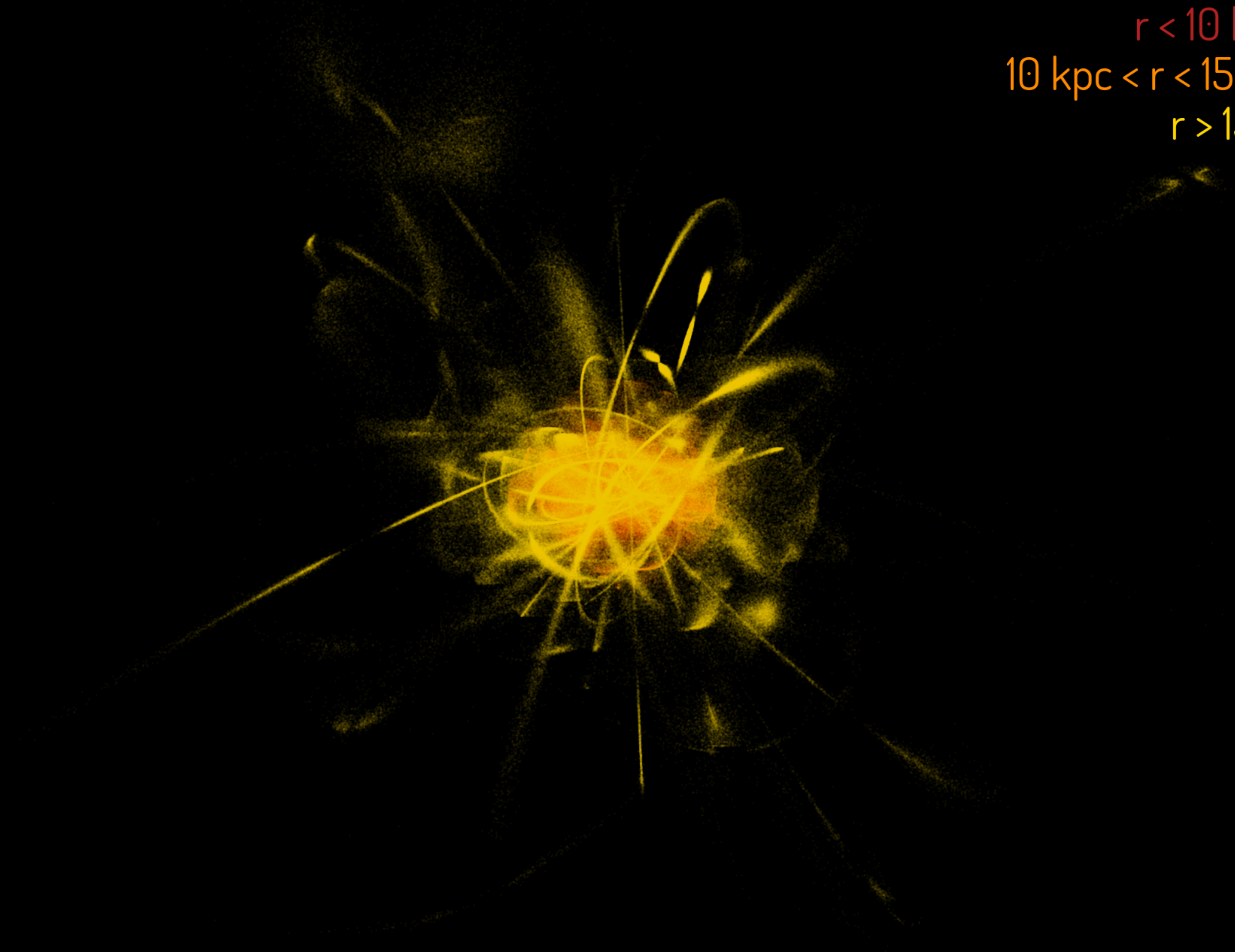


r < 10 kpc (893)

10 kpc < r < 15 kpc (159)

The Milky Way halo in the LSST era

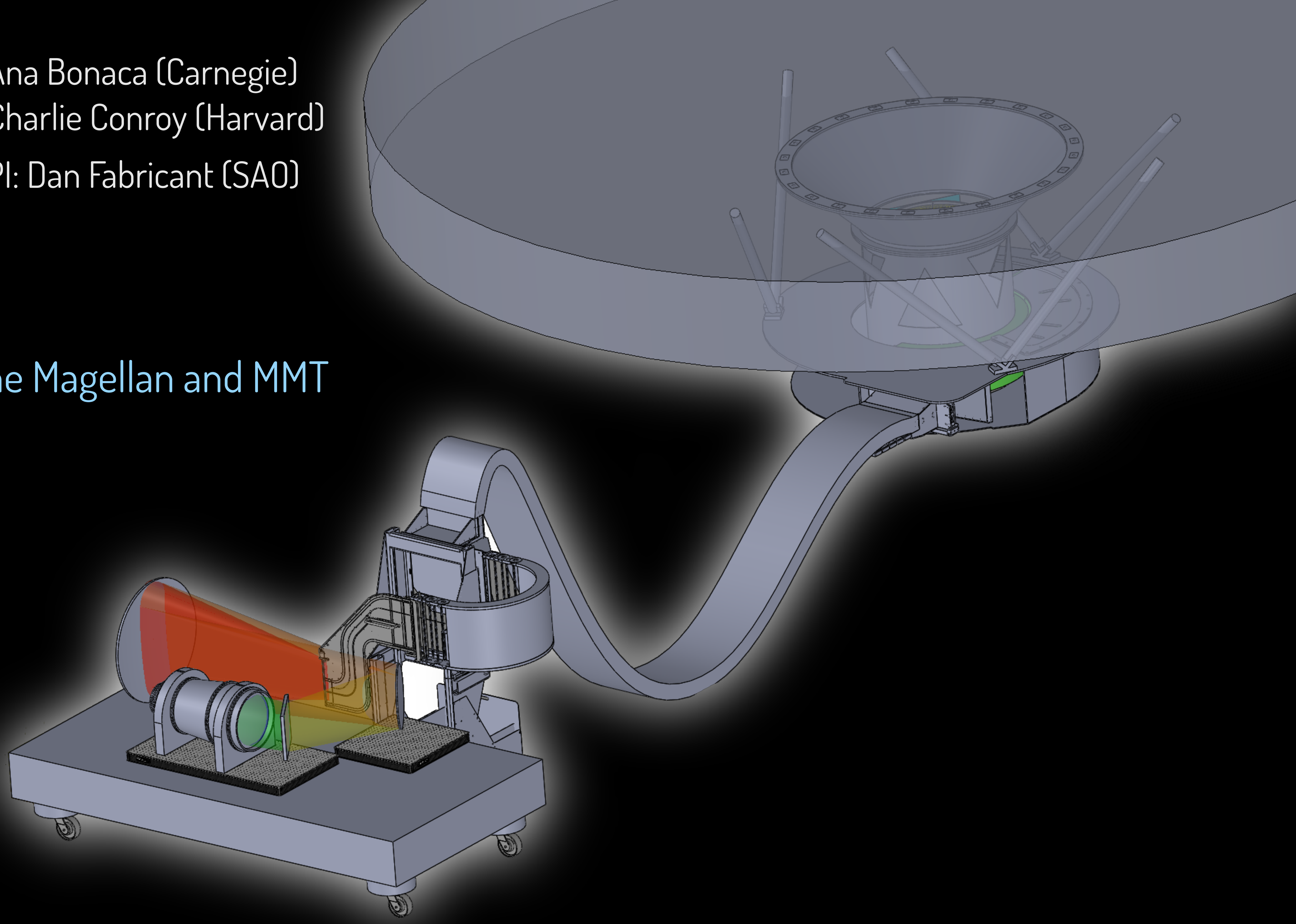


Project PIs: Ana Bonaca (Carnegie)
Charlie Conroy (Harvard)

Instrument PI: Dan Fabricant (SAO)

ViaSpec

Twin spectrographs for the Magellan and MMT



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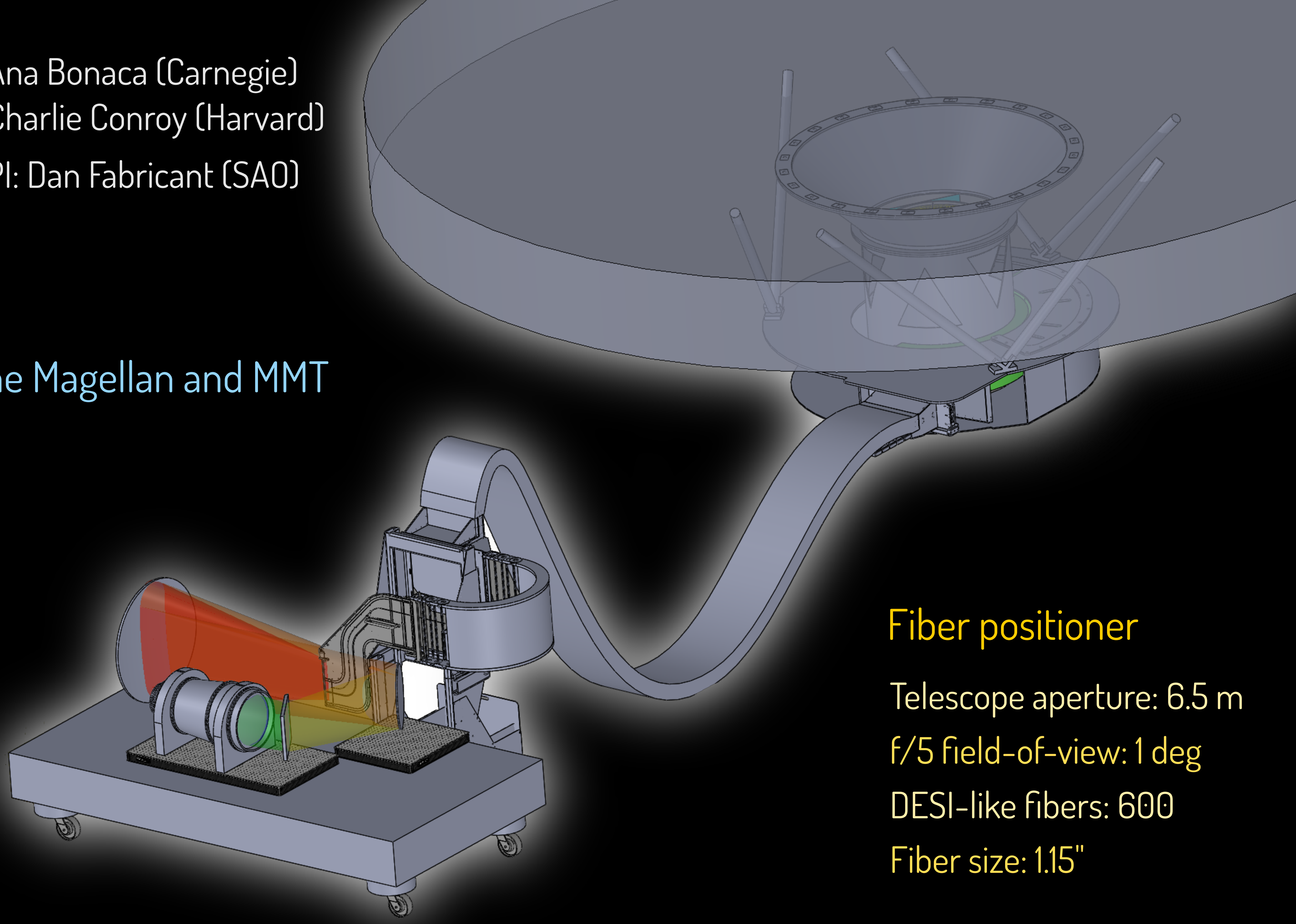

Fiber positioner

Telescope aperture: 6.5 m

f/5 field-of-view: 1 deg

DESI-like fibers: 600

Fiber size: 1.15"

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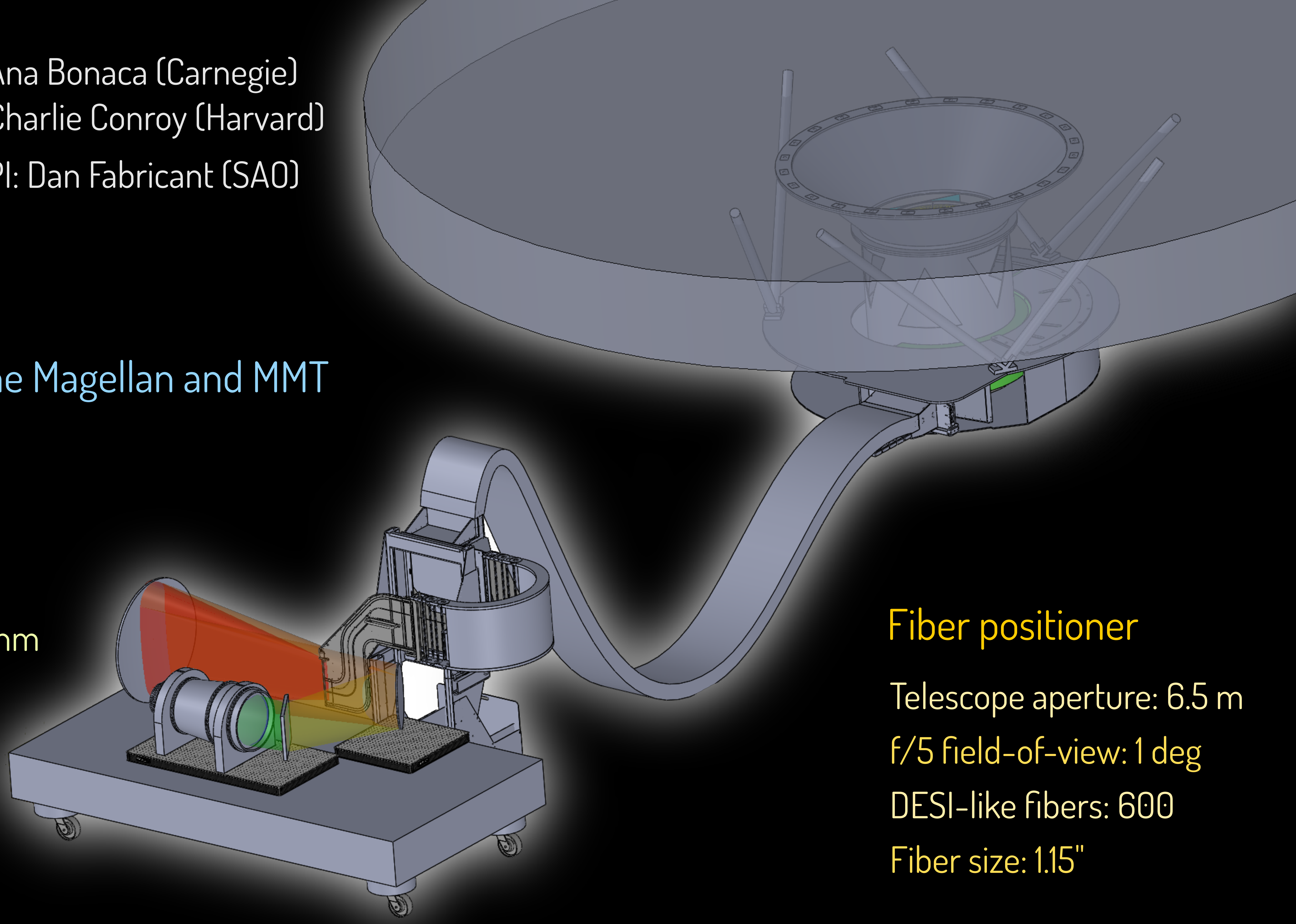
Twin spectrographs for the Magellan and MMT



Spectrograph

Spectral coverage: 510 - 595 nm

Binary grating: 2,000 lpm

Resolution: 15,000 - 20,000

Fiber positioner

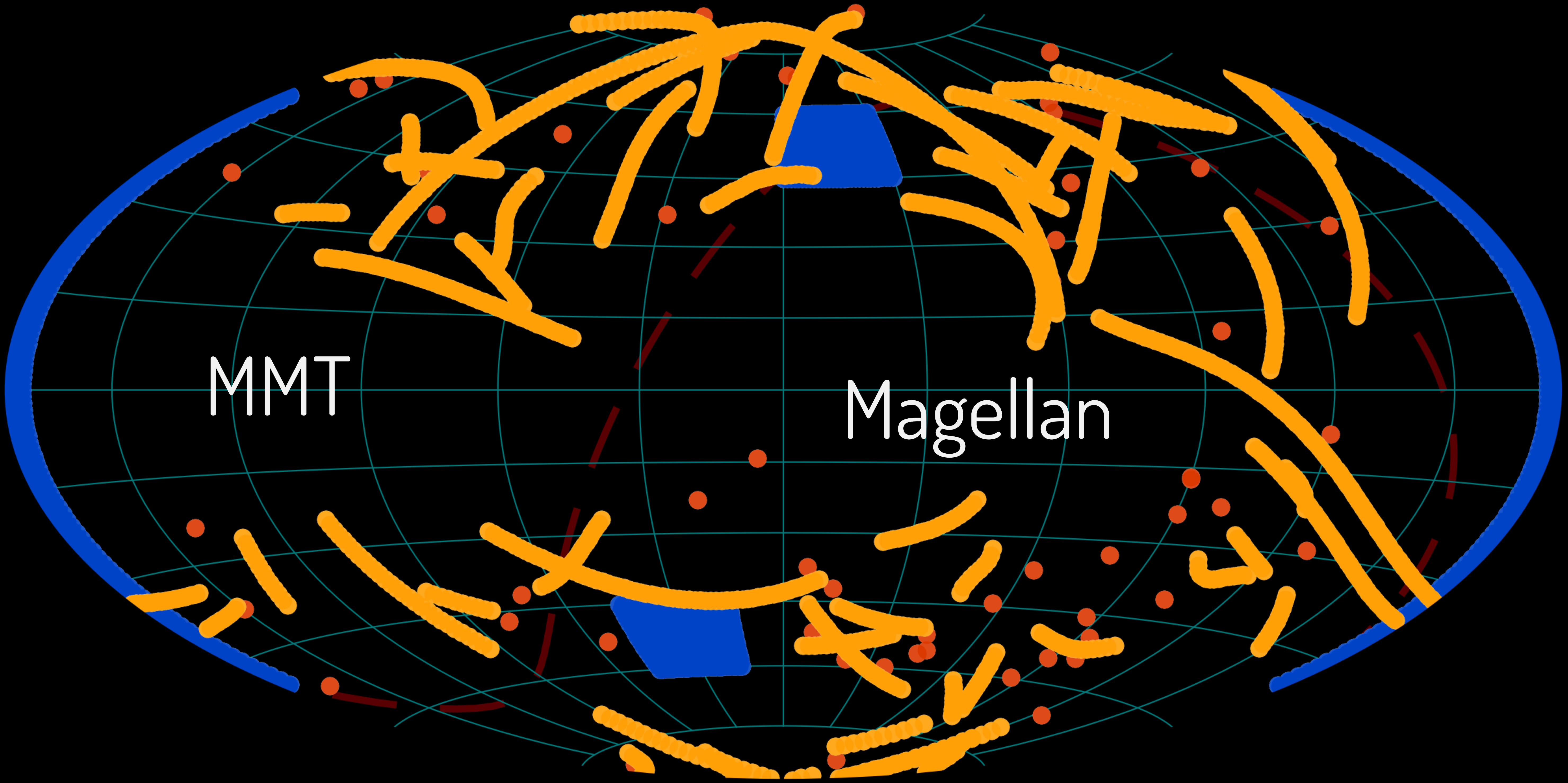
Telescope aperture: 6.5 m

f/5 field-of-view: 1 deg

DESI-like fibers: 600

Fiber size: 1.15"

The Via Survey of the Milky Way's halo



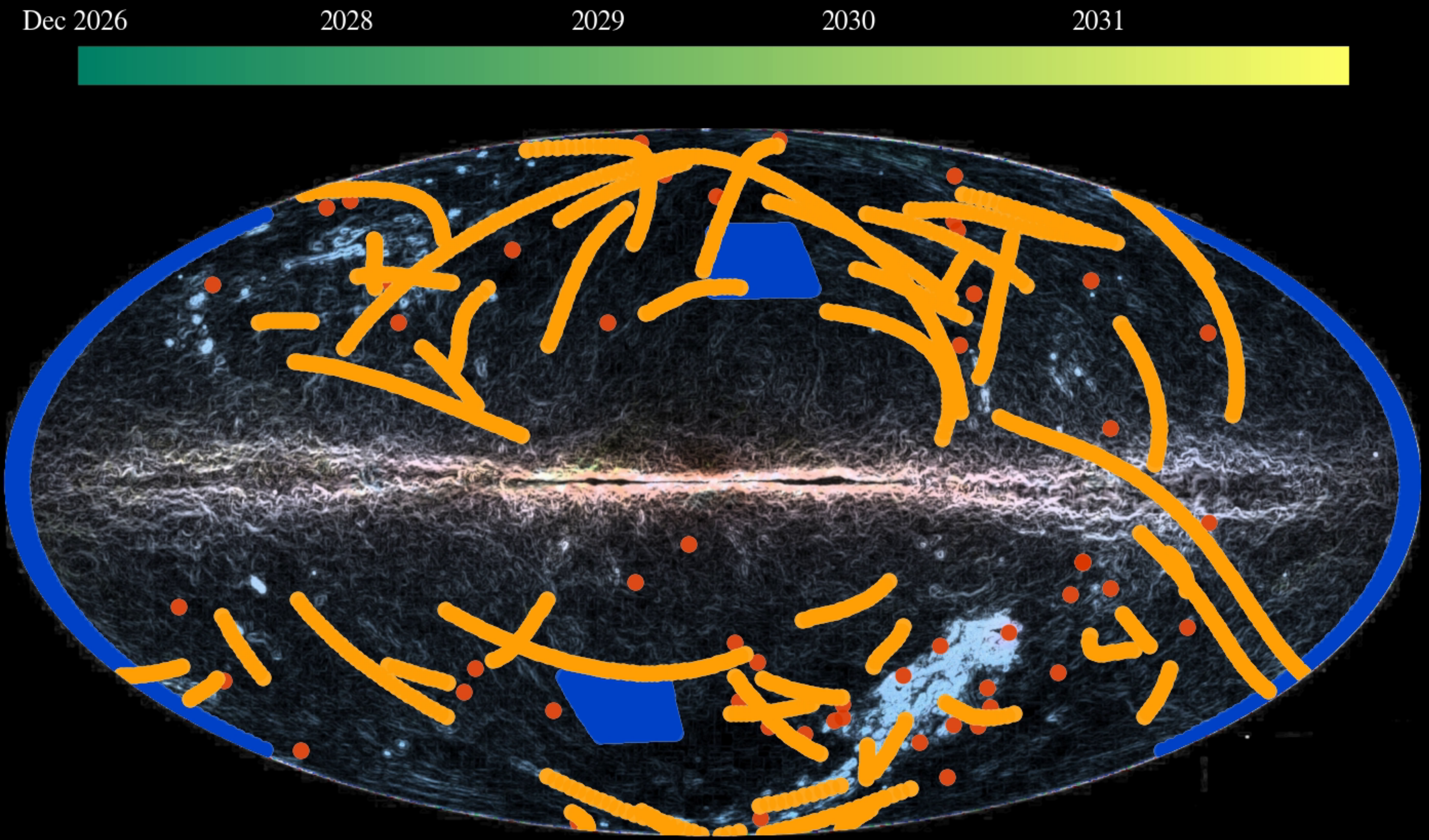
Stellar streams
nature of dark matter

Dwarf galaxies
edge of galaxy formation

Contiguous areas
cold gas tomography

Primary Survey design: 1 hr exposure | S/N = 10 at G=20 | σ_{V_r} = 100 m/s | $\sigma_{[Fe/H]}$ = 0.02 dex

The Via Survey of the Milky Way's halo



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An incoming challenge

We are gearing up to measure extremely precise kinematics on the Galactic scale (so far the only positive detection of dark matter).

Topics open for discussion:

- optimal methods for extracting dark matter signatures
- forecasting structure of dark matter halos in a highly non-linear regime
- mapping new models of dark matter to this space