Stellar Streams from Globular Clusters Beyond the Milky Way

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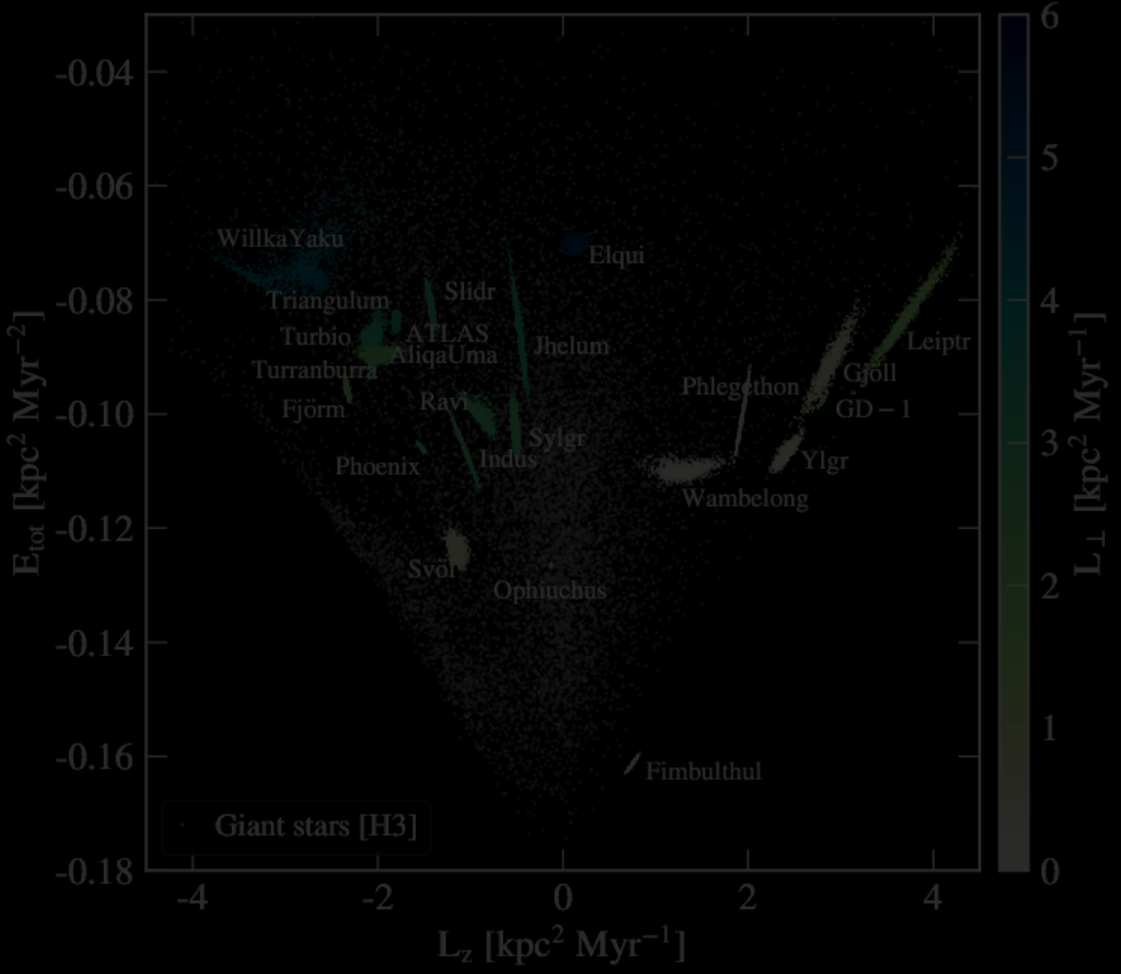
CCPP, New York University

In collaboration with T. Starkenburg, S. Clark, K. V. Johnston + others

Image credit:
S5 Collaboration

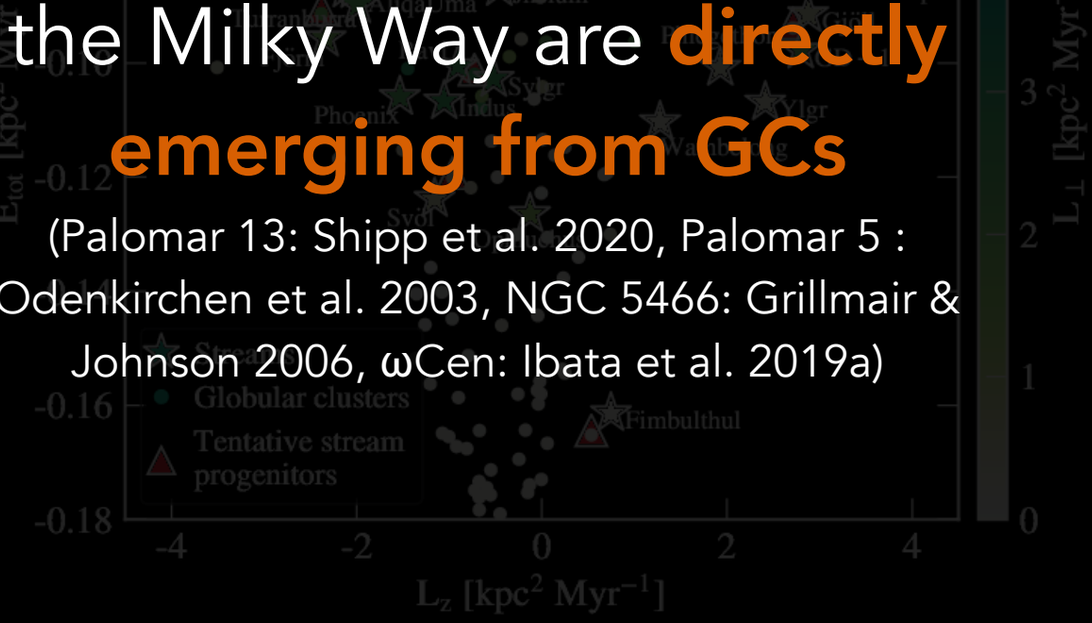
We know about 150 GCs in the MW

and we know about 76(?) GC streams



Very **few stellar streams** in the Milky Way are **directly emerging from GCs**

(Palomar 13: Shipp et al. 2020, Palomar 5 : Odenkirchen et al. 2003, NGC 5466: Grillmair & Johnson 2006, ωCen: Ibata et al. 2019a)



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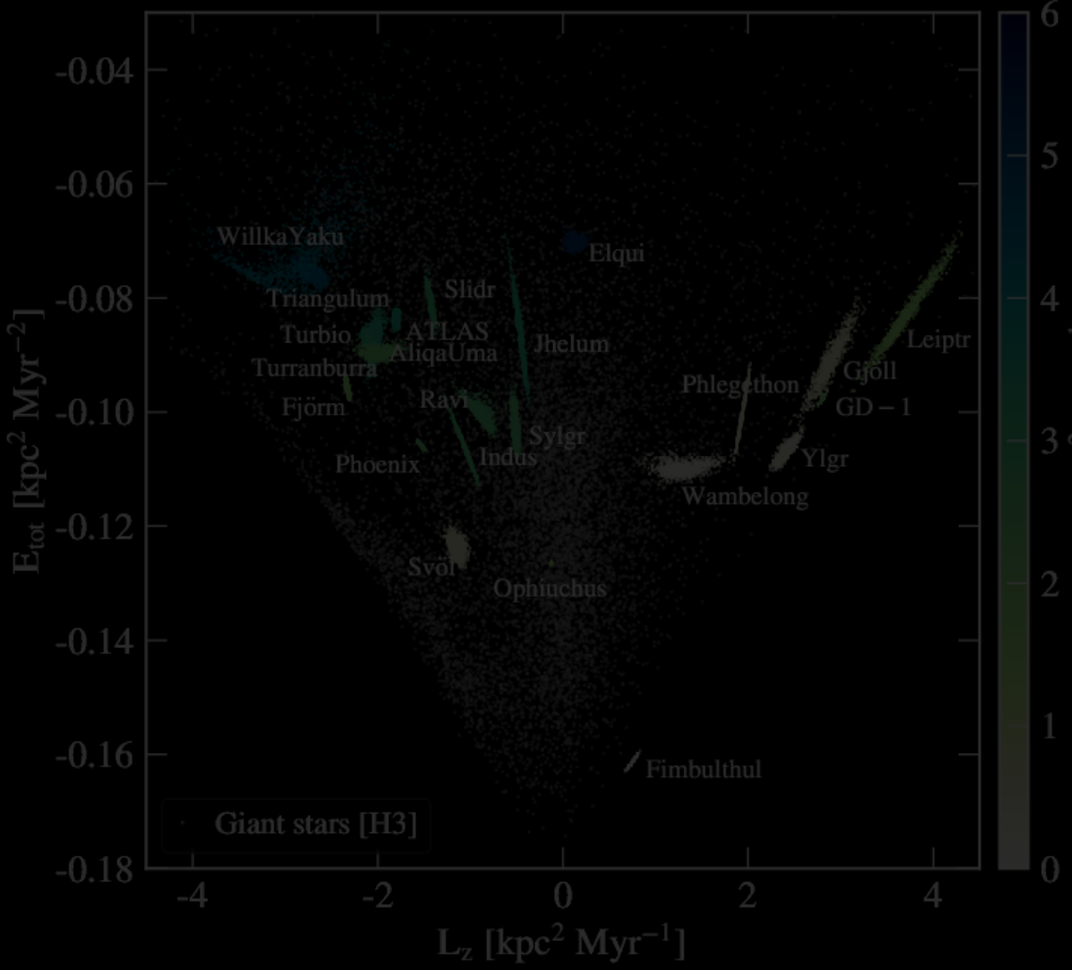

Balbinot & Gieles 2017

"Tidal tails around GCs only become detectable close to full dissolution, leading to a high fraction of GC streams without progenitors"

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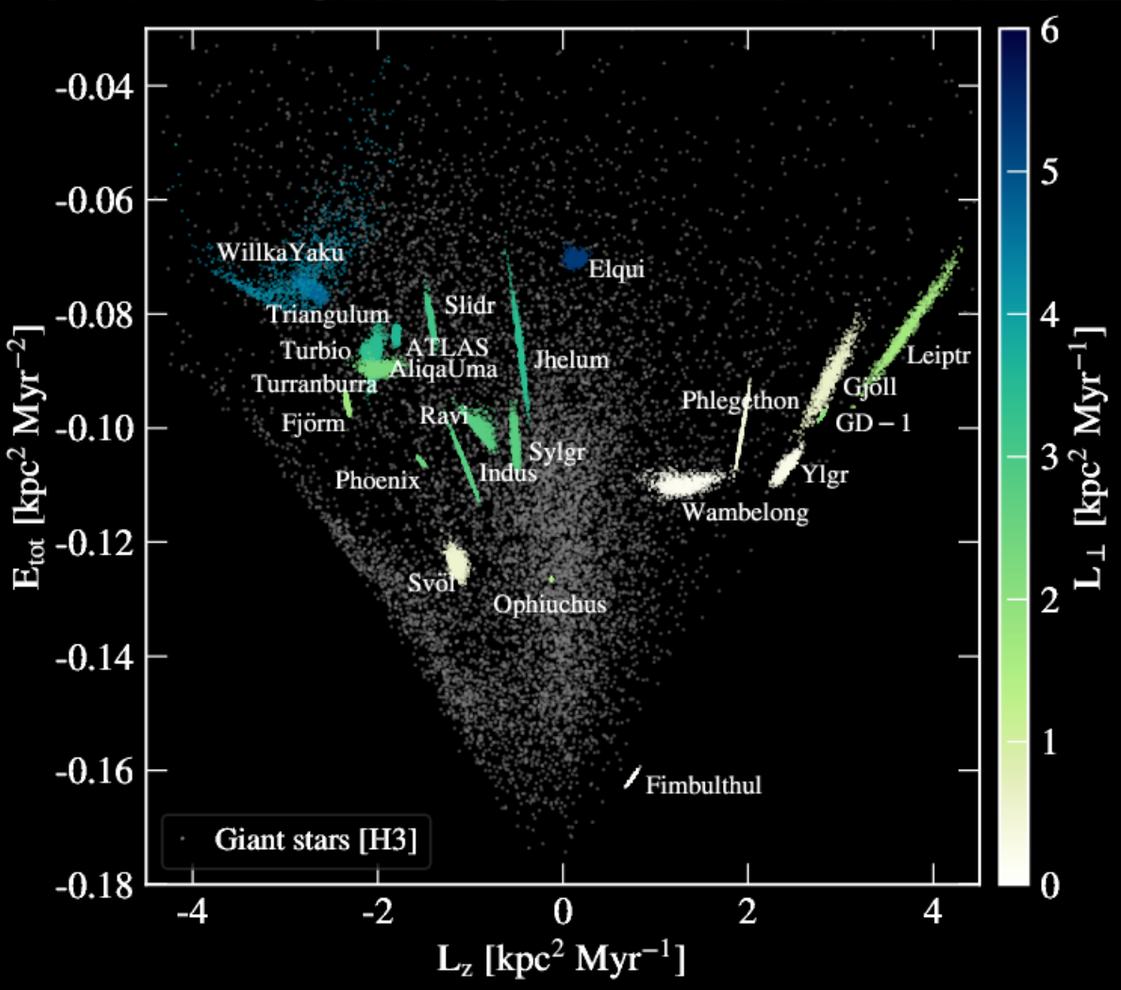

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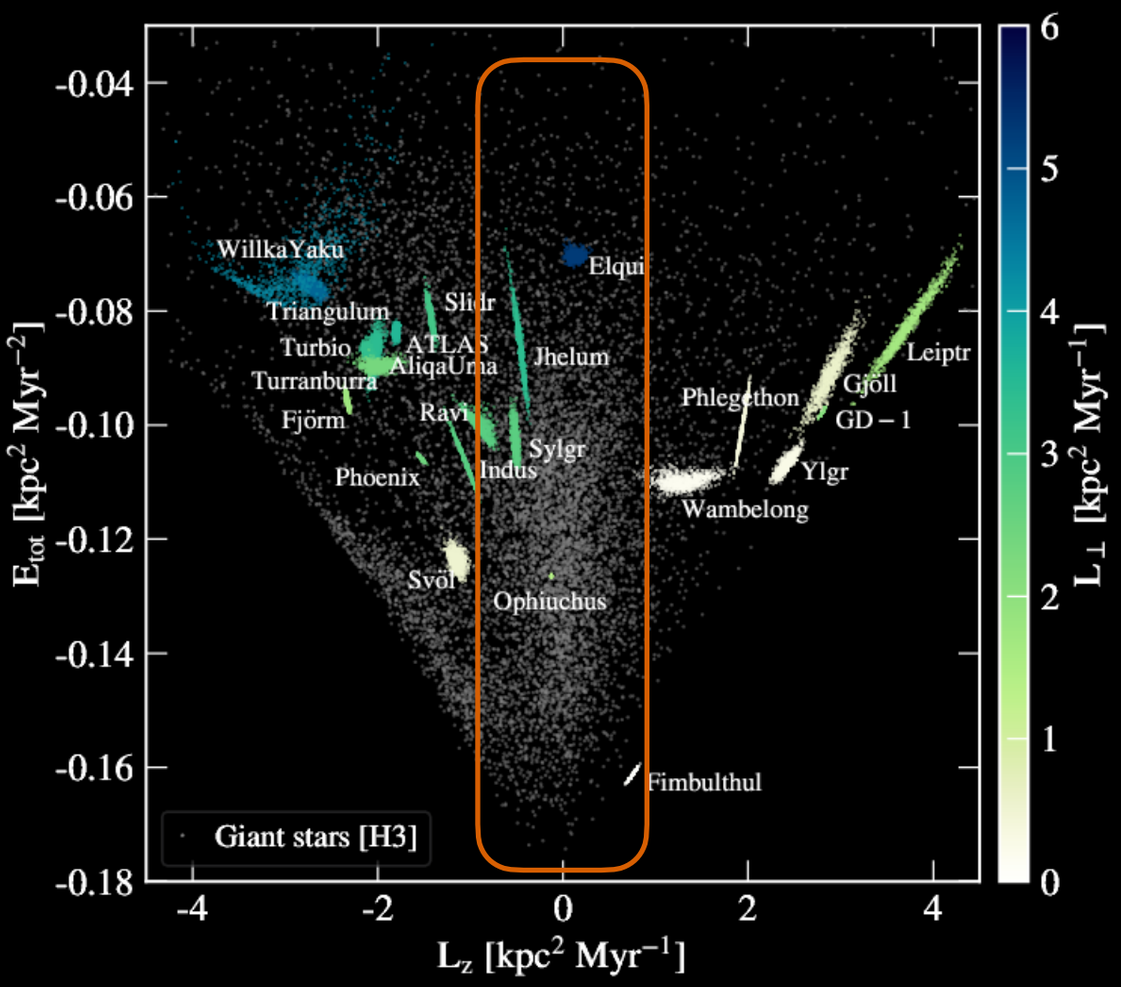

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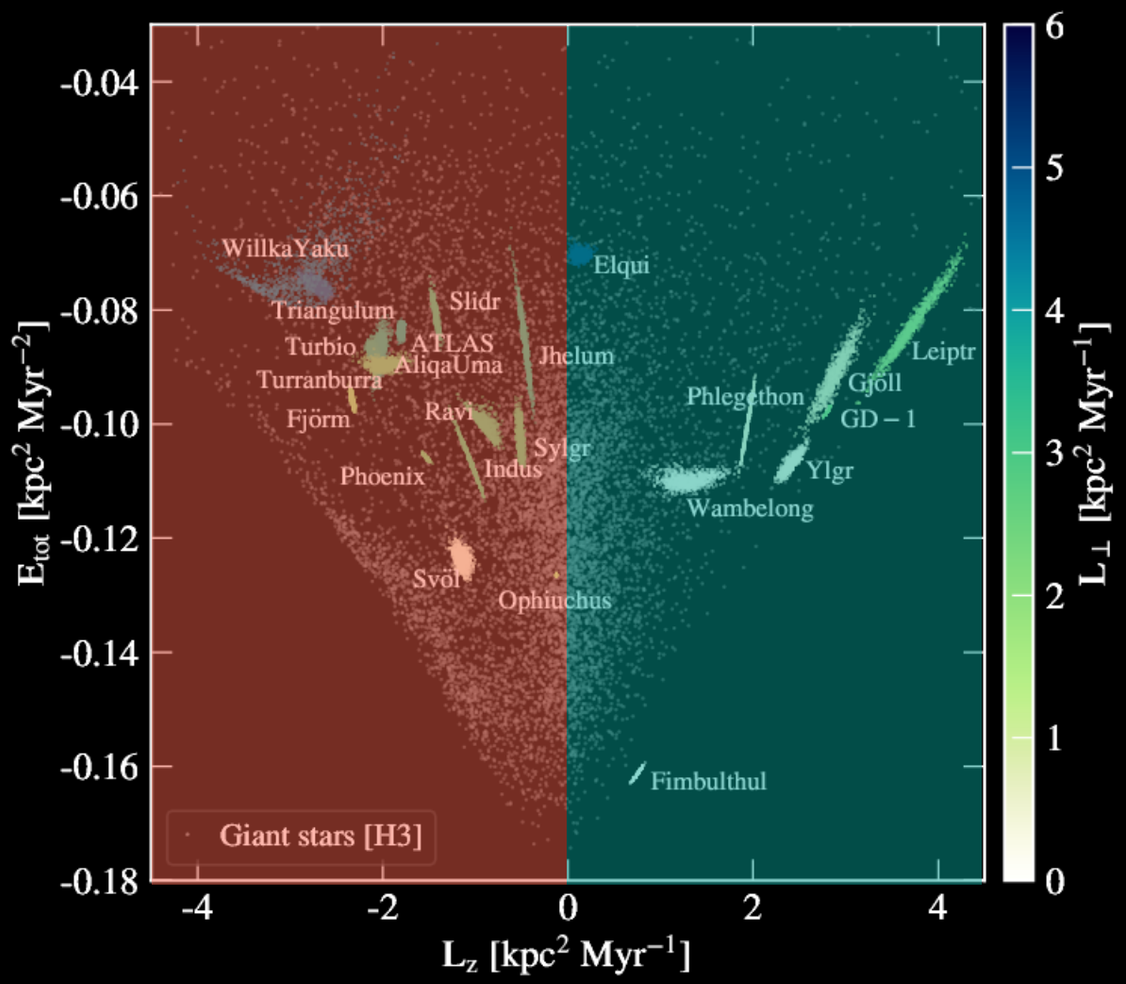


We know which streams are prograde and retrograde with respect to the disks, and we know their orbit types (e.g., radial, circular).

Image credit:
S5 Collaboration

Bonaca et al. 2021

What have we learnt from the globular cluster streams in the Milky Way?

Image credit:
S5 Collaboration

Dark matter distribution

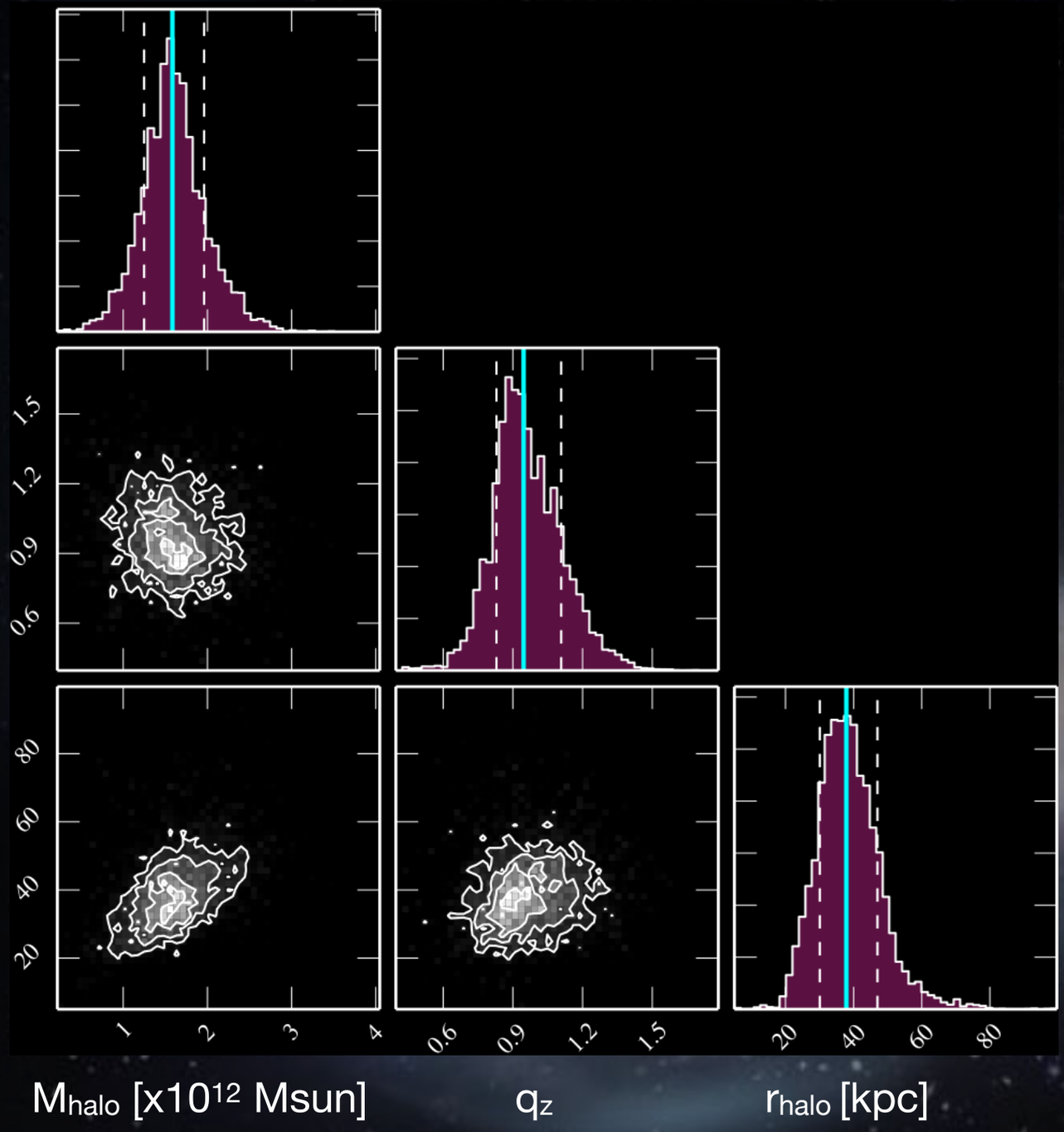
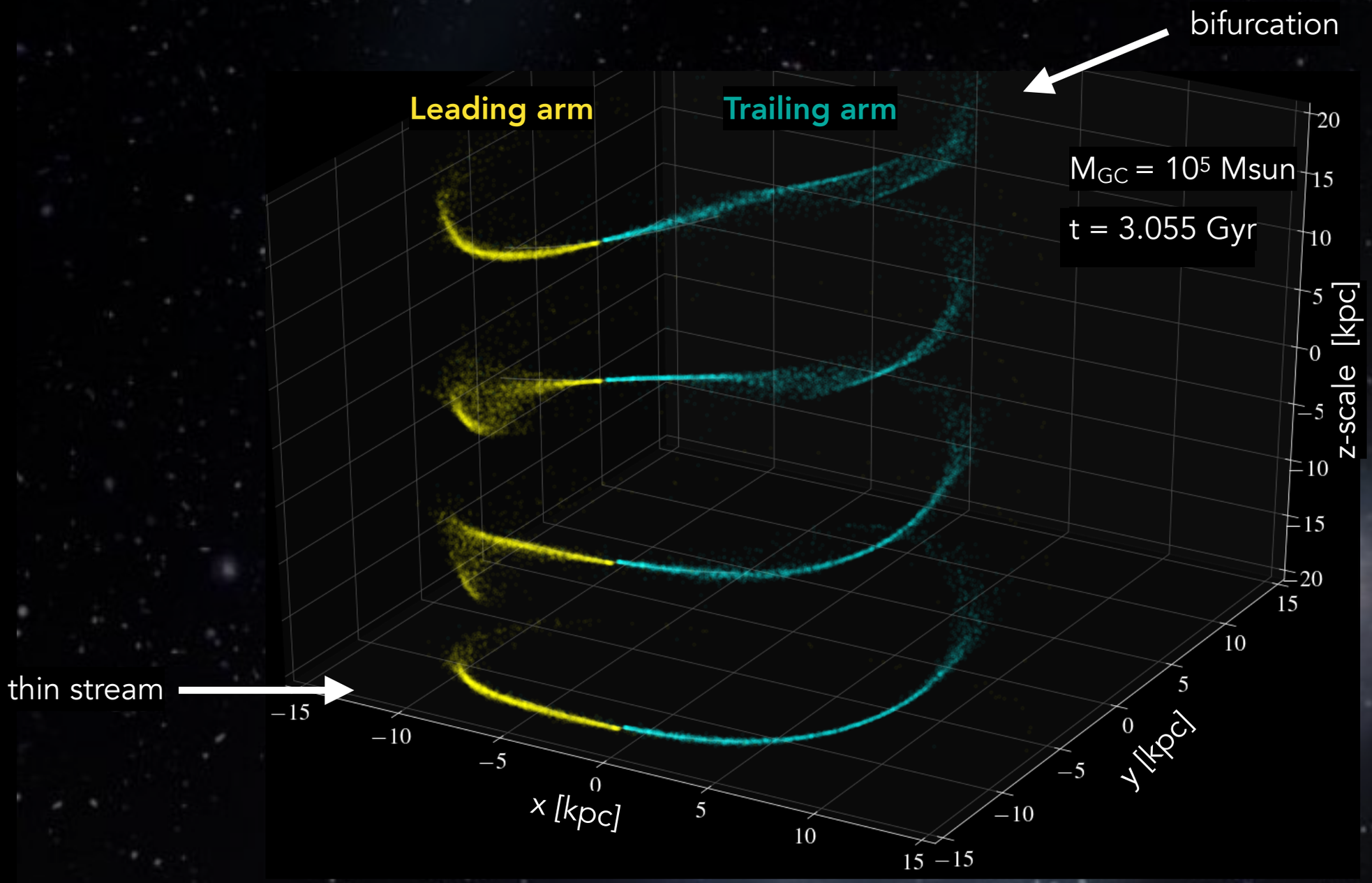


Image credit:
S5 Collaboration

e.g., Kuepper et al. 2015, Koposov et al. 2010, Bovy et al. 2017

Orbit structure and potential shape

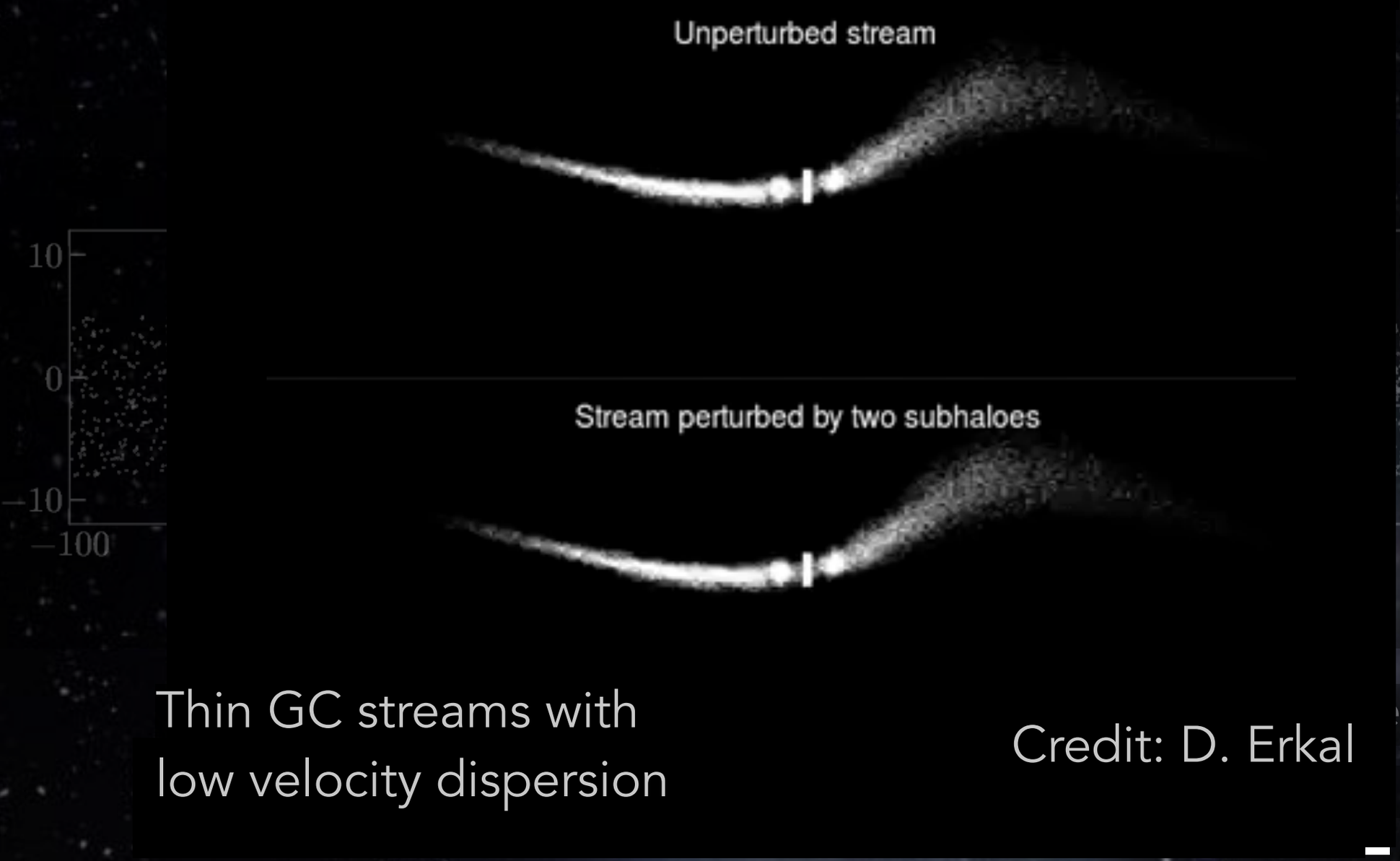


T. Yavetz, Pearson+ 2021, T. Yavetz, Pearson+, in prep.

See also “stream-fanning”: Pearson et al. 2015
Price-Whelan, Pearson+ 2016

Image credit:
S5 Collaboration

Hints of dark matter substructure



Thin GC streams with
low velocity dispersion

Credit: D. Erkal

Image credit:
S5 Collaboration

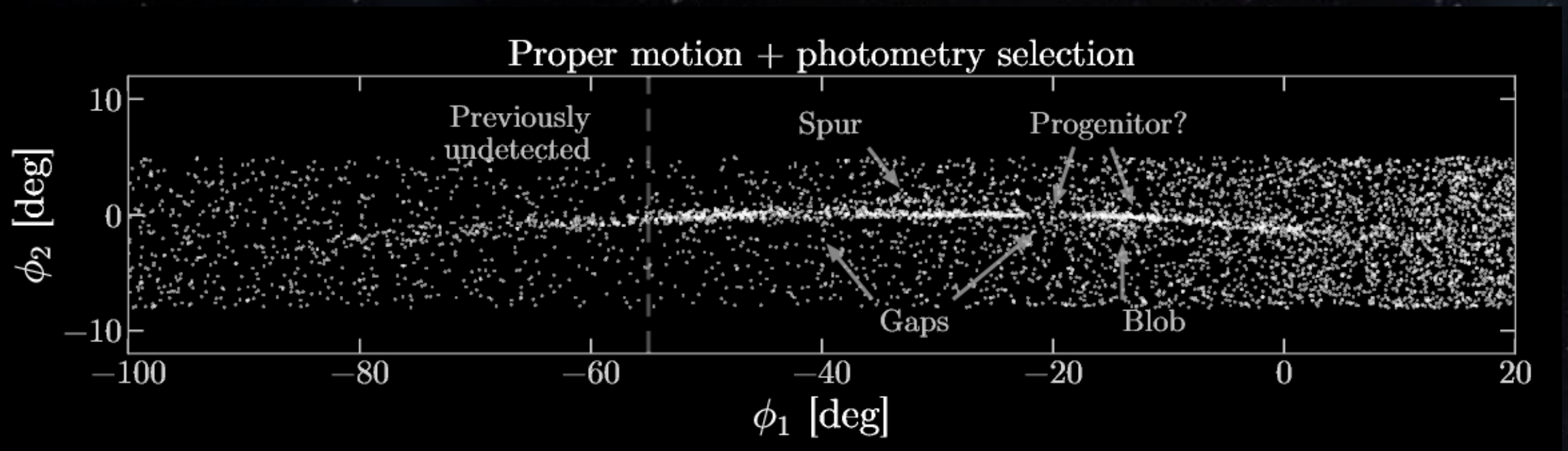
Test of LCDM

e.g., Yoon et al. 2011, Carlberg et al. 2012,
Erkal et al. 2016 Bonaca et al. 2019

t al. 2019
et al. 2018

Hints of dark matter substructure

GD-1



Gaia: Price-Whelan & Bonaca 2018, Bonaca et al. 2019

See also T. de Boer et al. 2018

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S5 Collaboration

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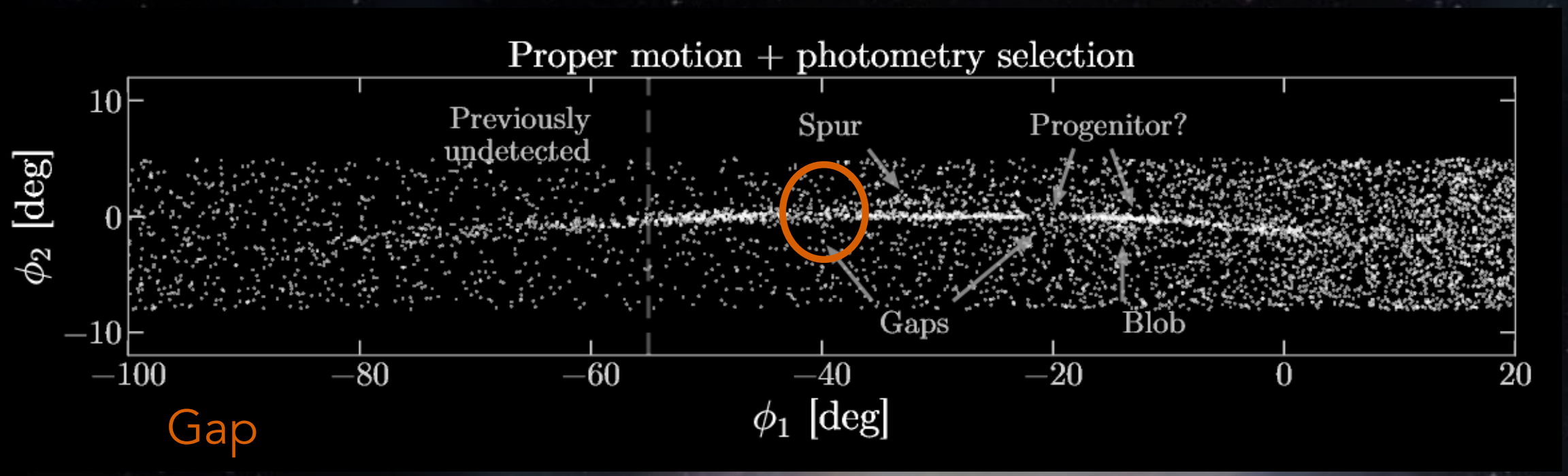

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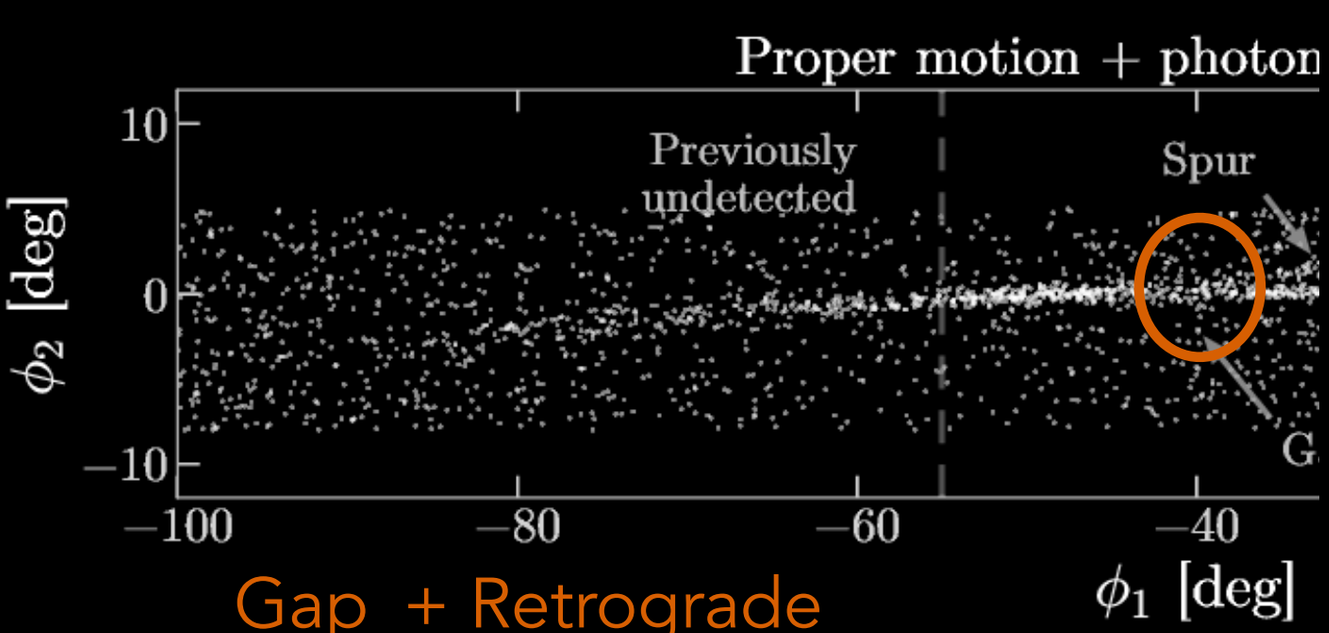
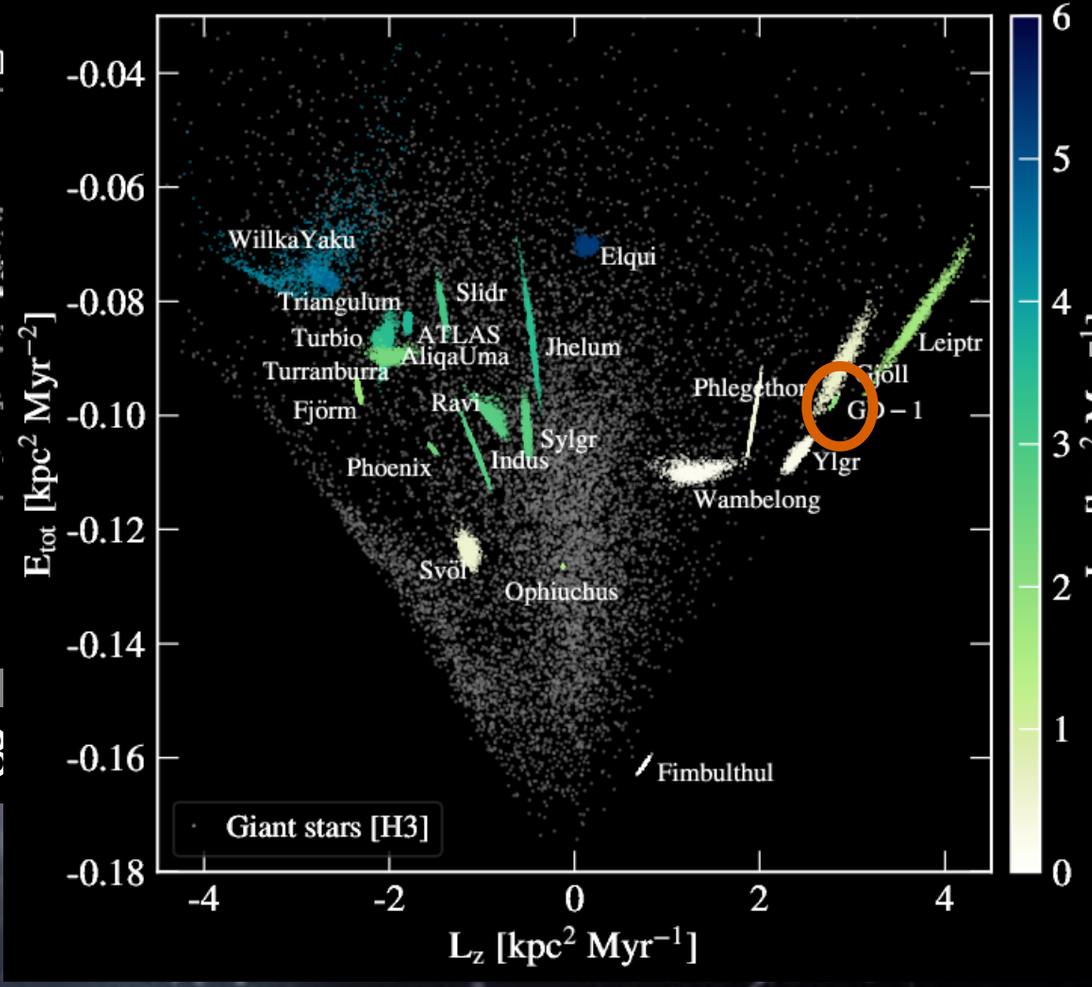




Gaia: Price-Whelan & B

Image credit:
S5 Collaboration

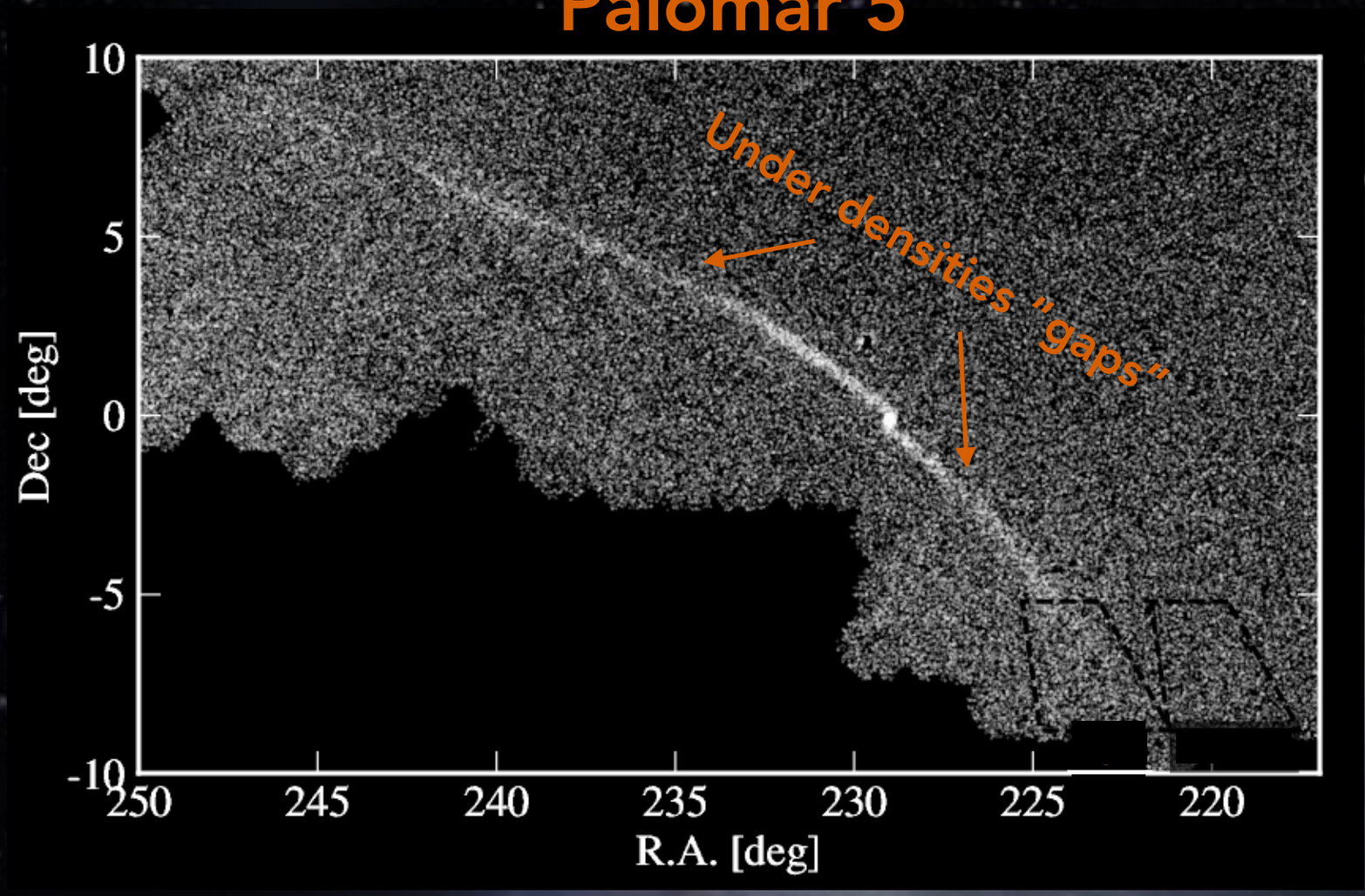
But the Milky Way is **just one** galaxy with **a lot** going on

…and we only know of a handful of streams with gaps

Image credit:
S5 Collaboration

Some of the streams look weird

Palomar 5



Bonaca, Pearson et al. 2020

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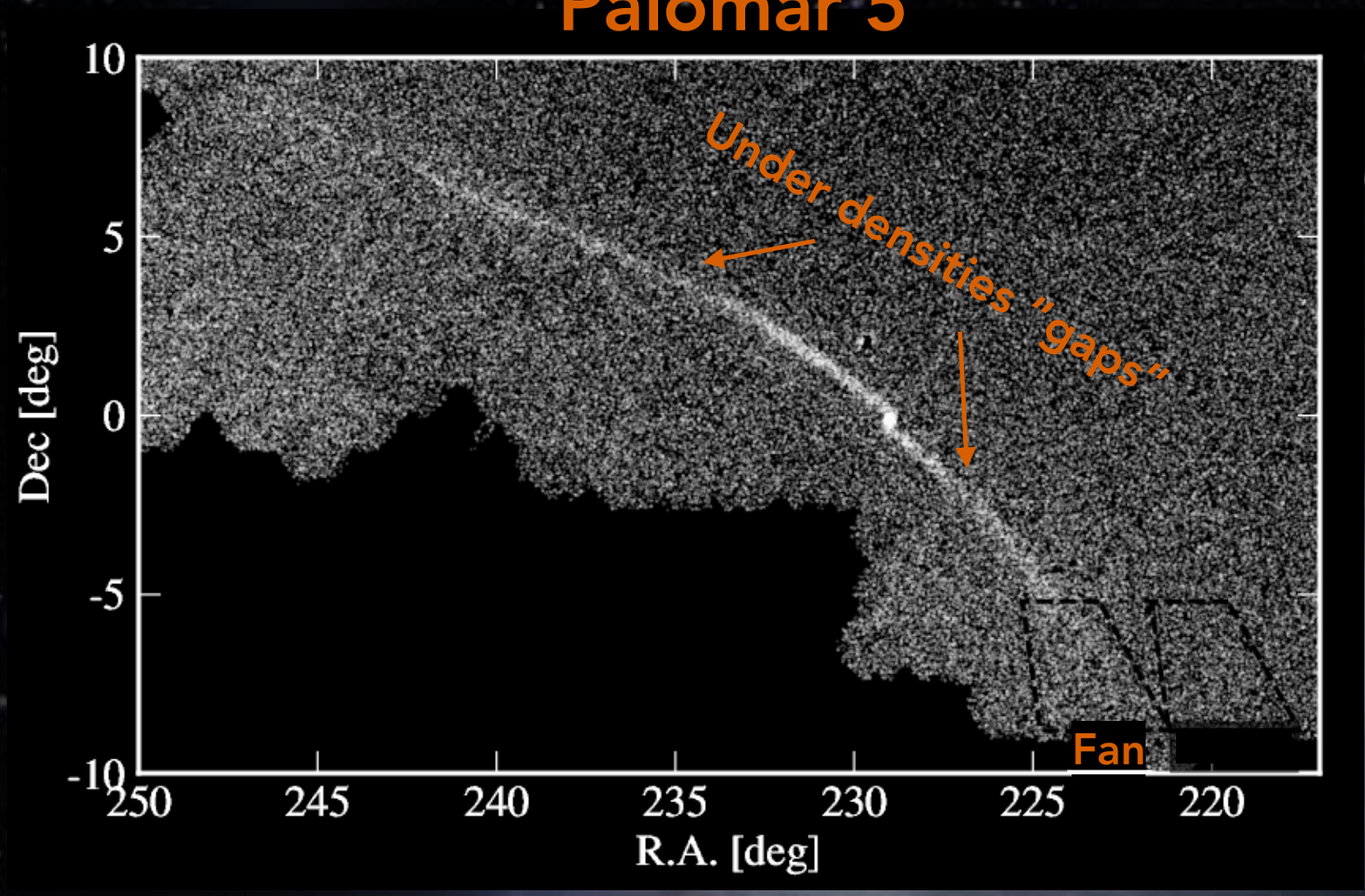

Bonaca, Pearson et al. 2020

See also kinematics in Kuzma et al. 2022

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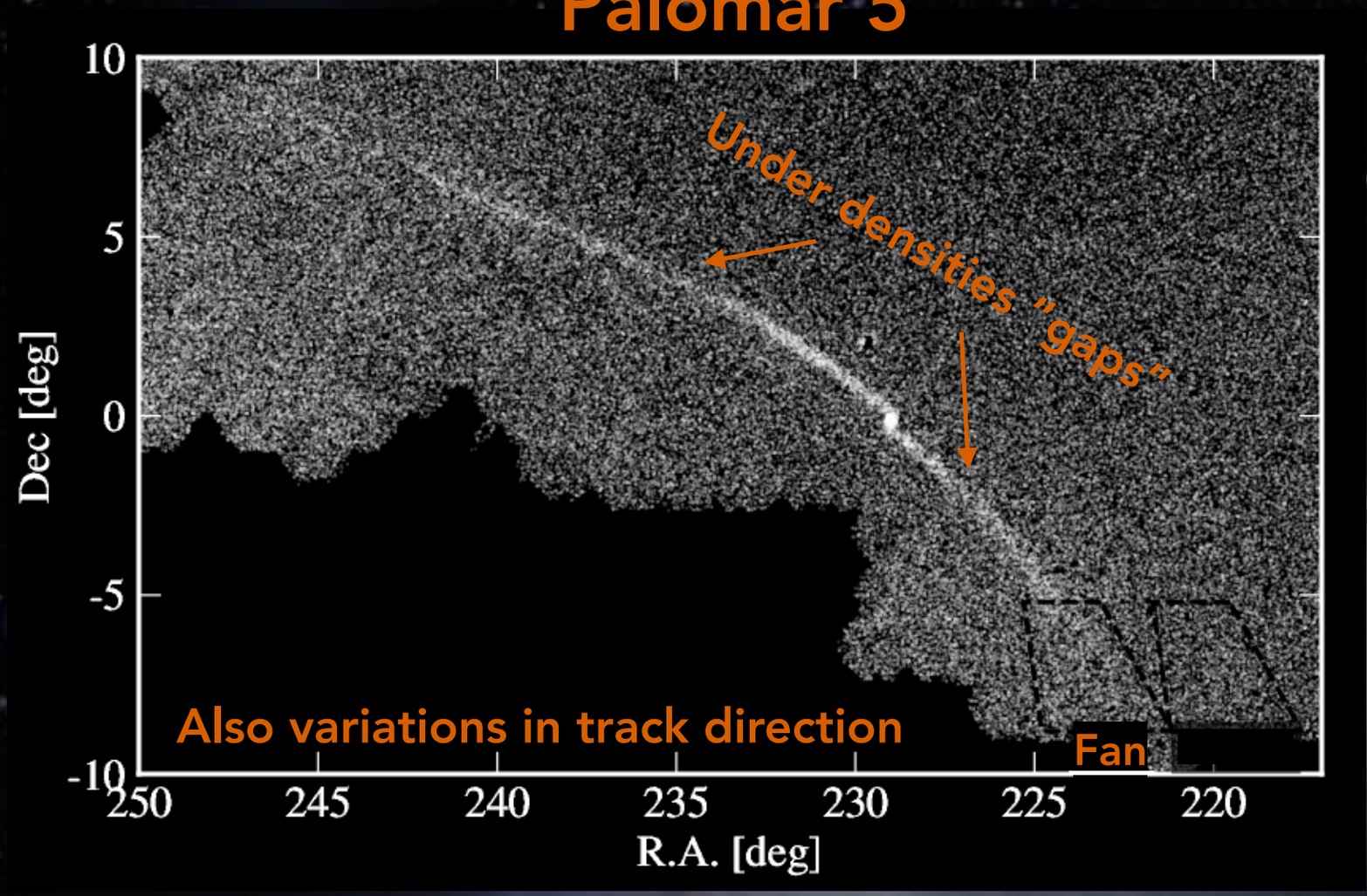

Bonaca, Pearson et al. 2020

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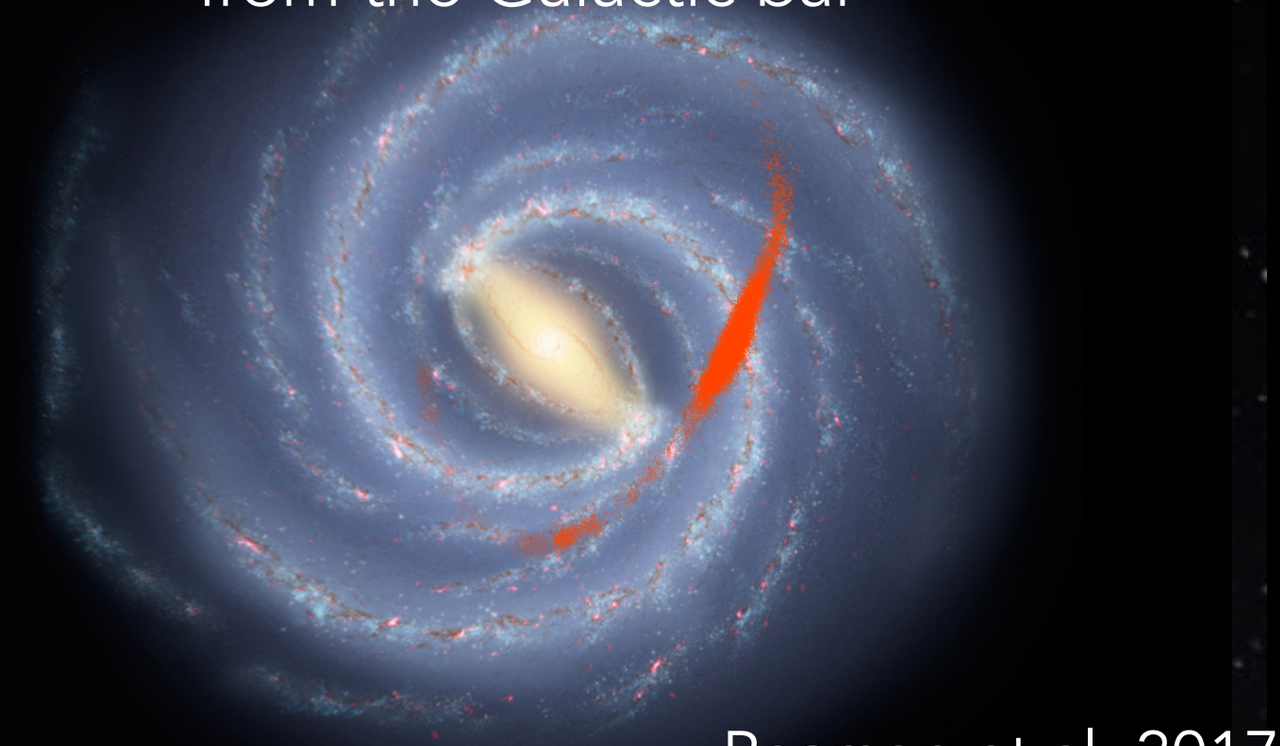
S5 Collaboration

The Galactic bar can mess things up

Gaps, fan and **track variations** in Pal 5
can form due to **torques**
from the Galactic bar



Pearson et al. 2017
Bonaca, Pearson et al. 2020

See other bar + stream papers:
Price-Whelan et al. 2016
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How do we distinguish from subhalo gaps?

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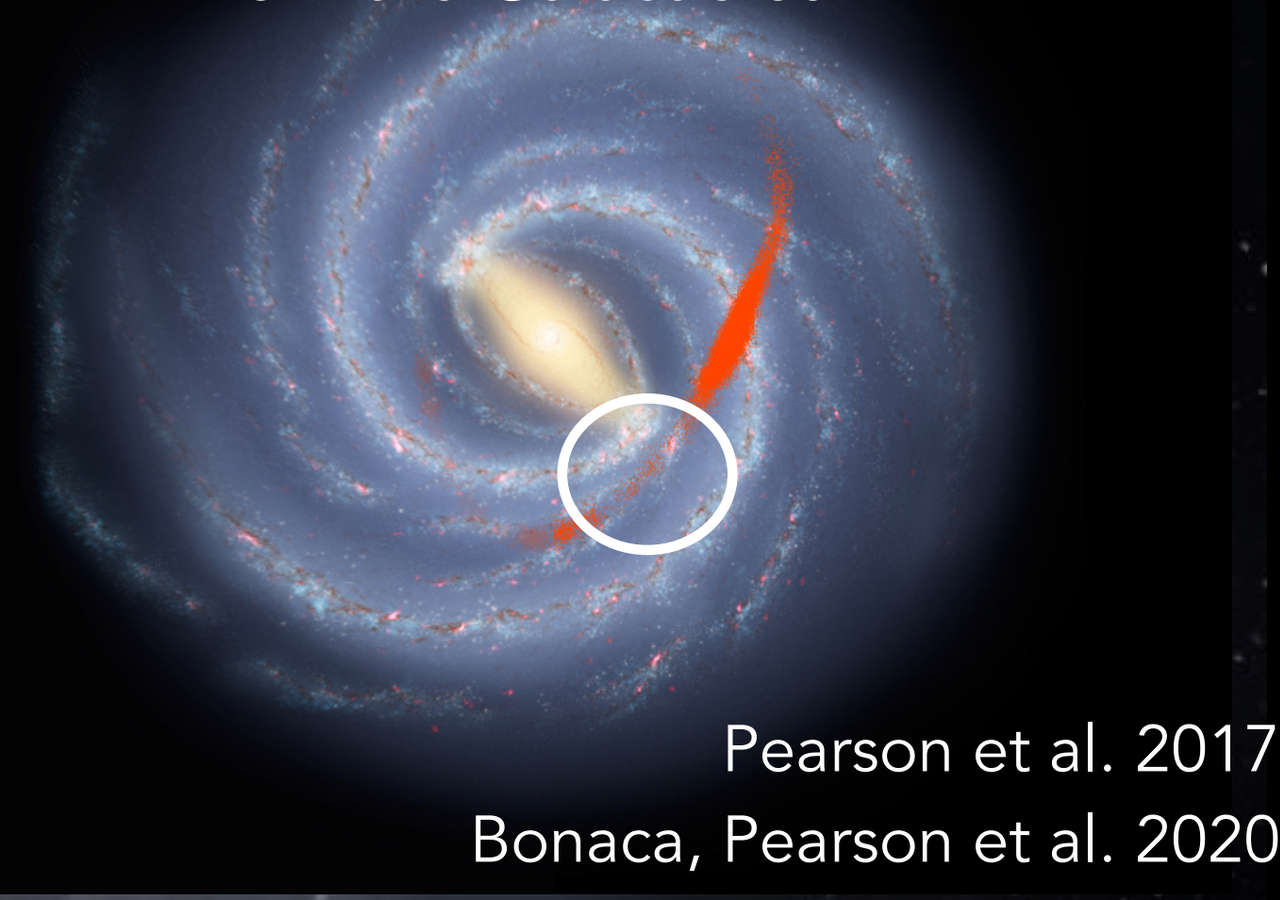

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The Galactic bar can mess things up

How do we distinguish from subhalo gaps?

1) Use streams on retrograde orbits

2) Use streams with large pericenters far from the bar

3) Gaps from baryonic perturbers should be timed with disk passages

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Pearson et al. 2017

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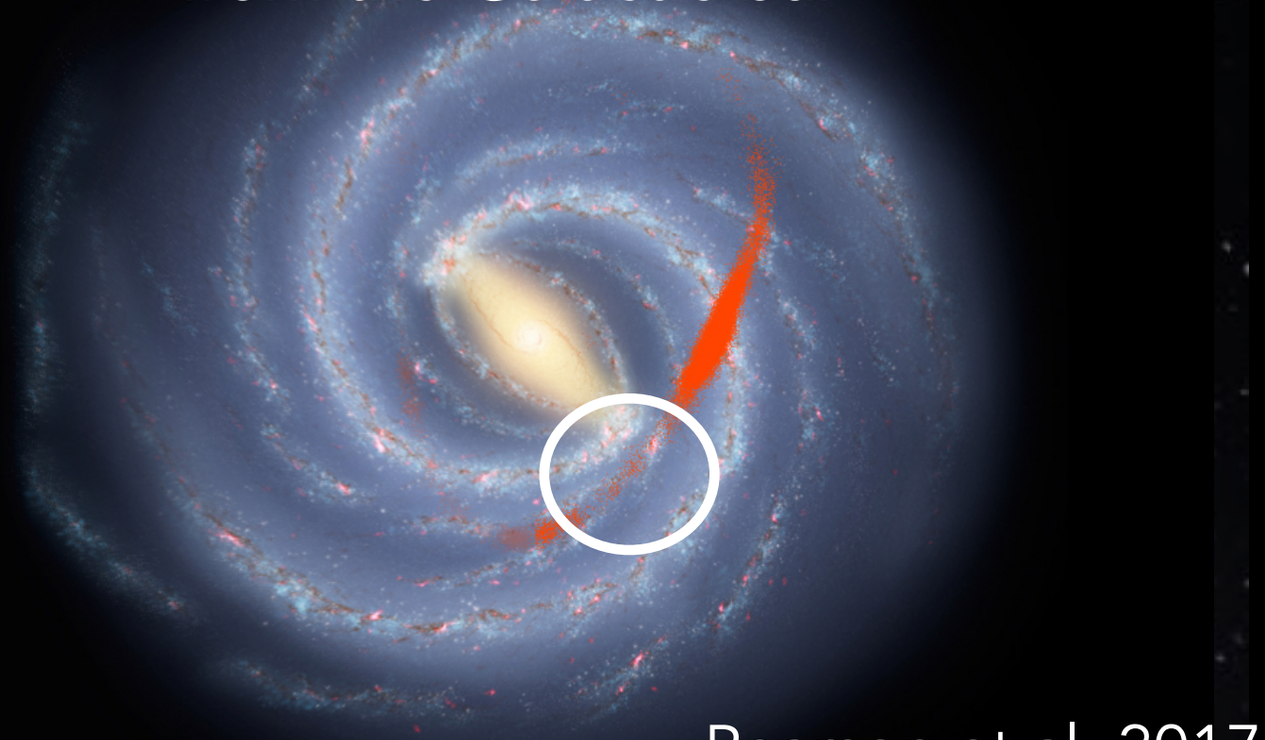

Pearson et al. 2017

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See other bar + stream papers:
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Molecular clouds (Amorisco et al. 2016) and **spiral arms** (Banik & Bovy 2019) can cause **gaps** too. Conclusion: it's a bit tricky in the MW

Image credit:
S5 Collaboration

Wouldn’t it be great if we could get **statistical samples** of thin stellar streams in **other galaxies**?

Image credit:
S5 Collaboration

Many known external dwarf streams

NGC 577: The Stellar Stream Legacy Survey

Martinez-Delgado, Pearson+ 2021

NGC 4449 (dwarf stream around dwarf)

Martinez-Delgado et al. 2012

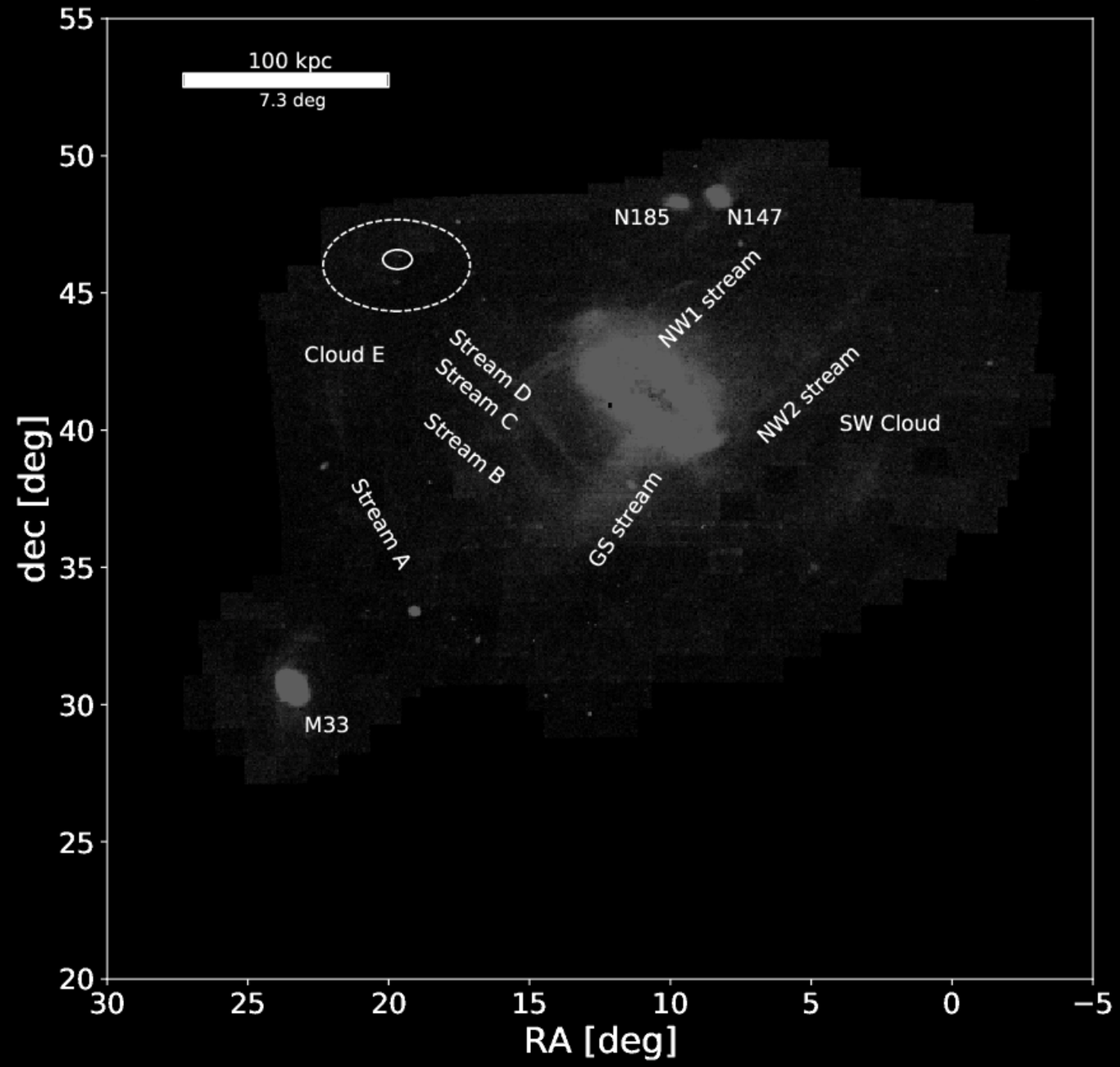
See also Carlin et al. 2019

Image credit:
S5 Collaboration

Let’s turn to the Andromeda Galaxy

Although it does have molecular clouds, spiral arms, bar

PAndAS data: McConnachie et al. 2009, 2019



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Pearson, Clark, Starkenburg + 2022

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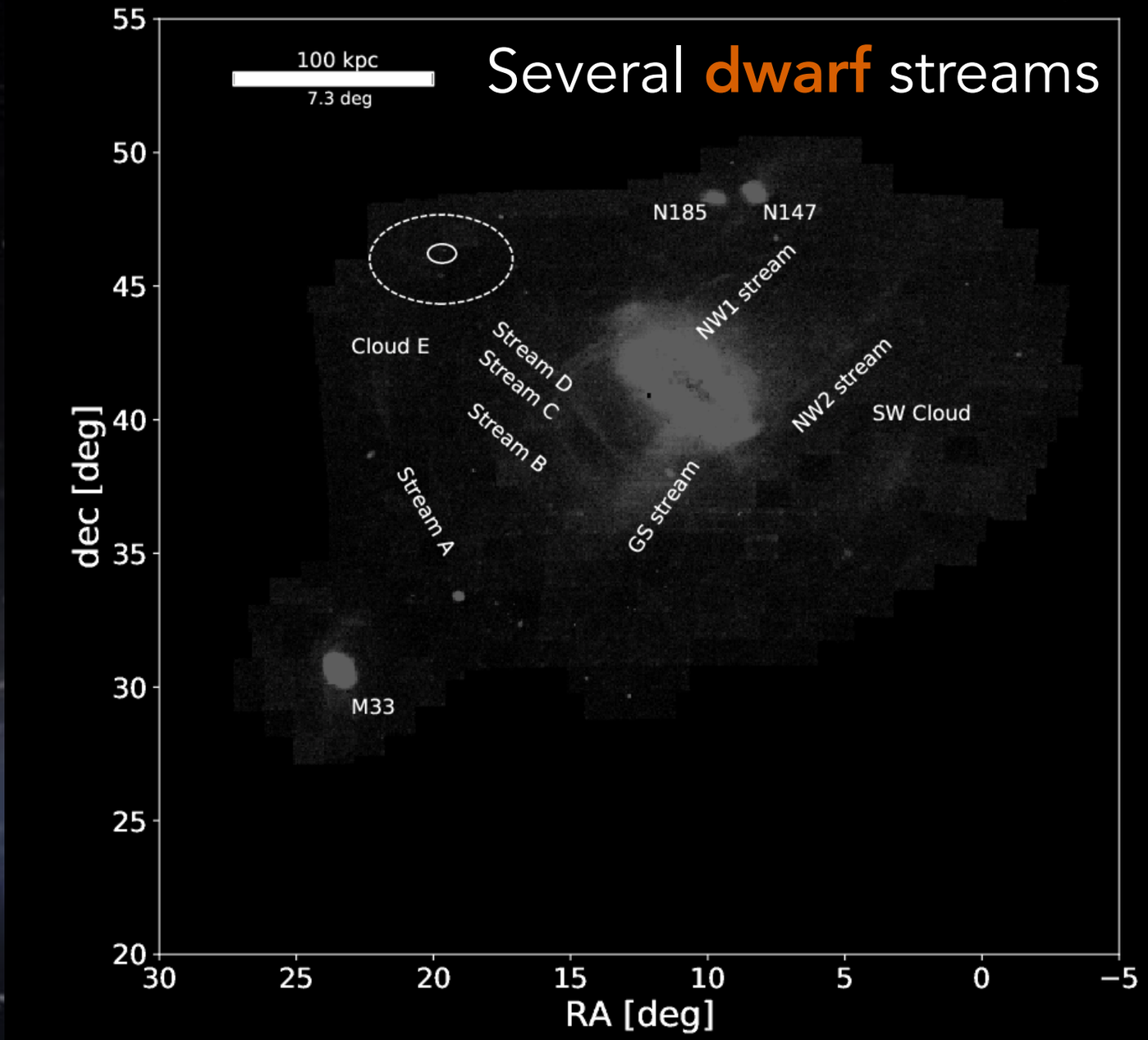

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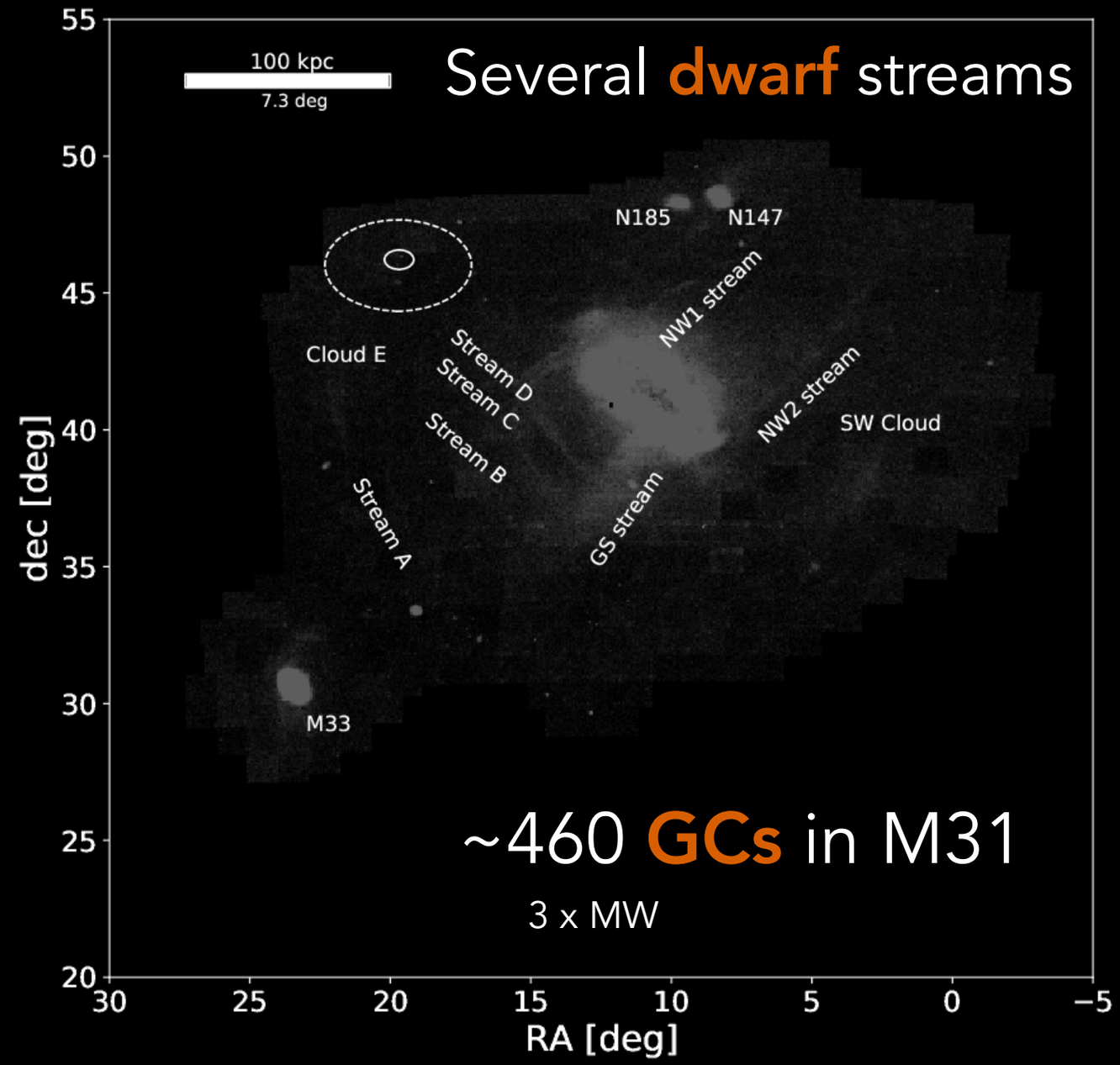

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S5 Collaboration

Pearson, Clark, Starkenburg + 2022

Let's turn to the Andromeda Galaxy

But **no thin GC streams** near GCs in HST follow-ups

Huxor et al. 2014

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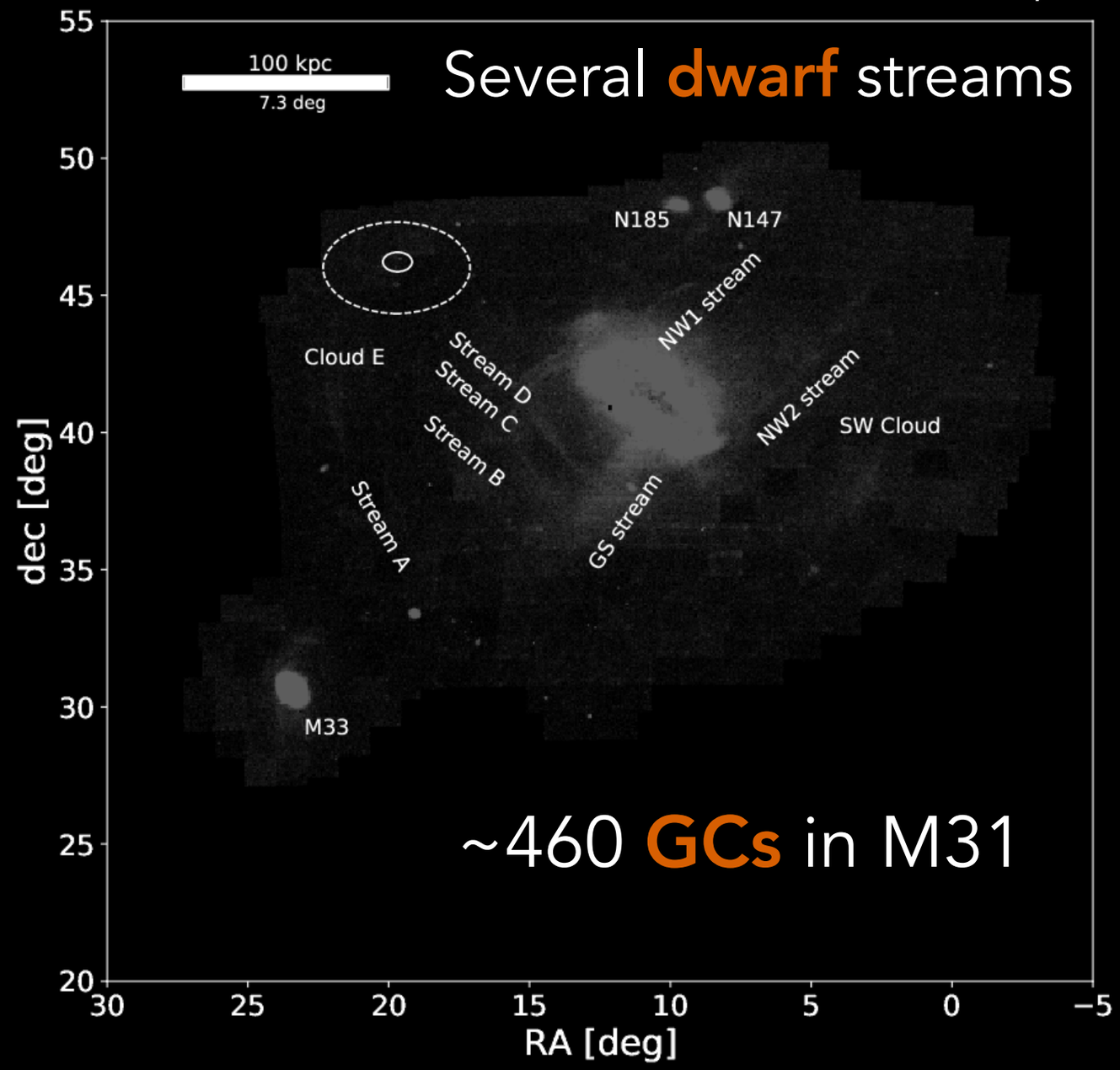

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S5 Collaboration

Pearson, Clark, Starkenburg + 2022

Let's turn to the Andromeda Galaxy

But maybe we shouldn't expect there to be… (Balbinot & Gieles 2017)

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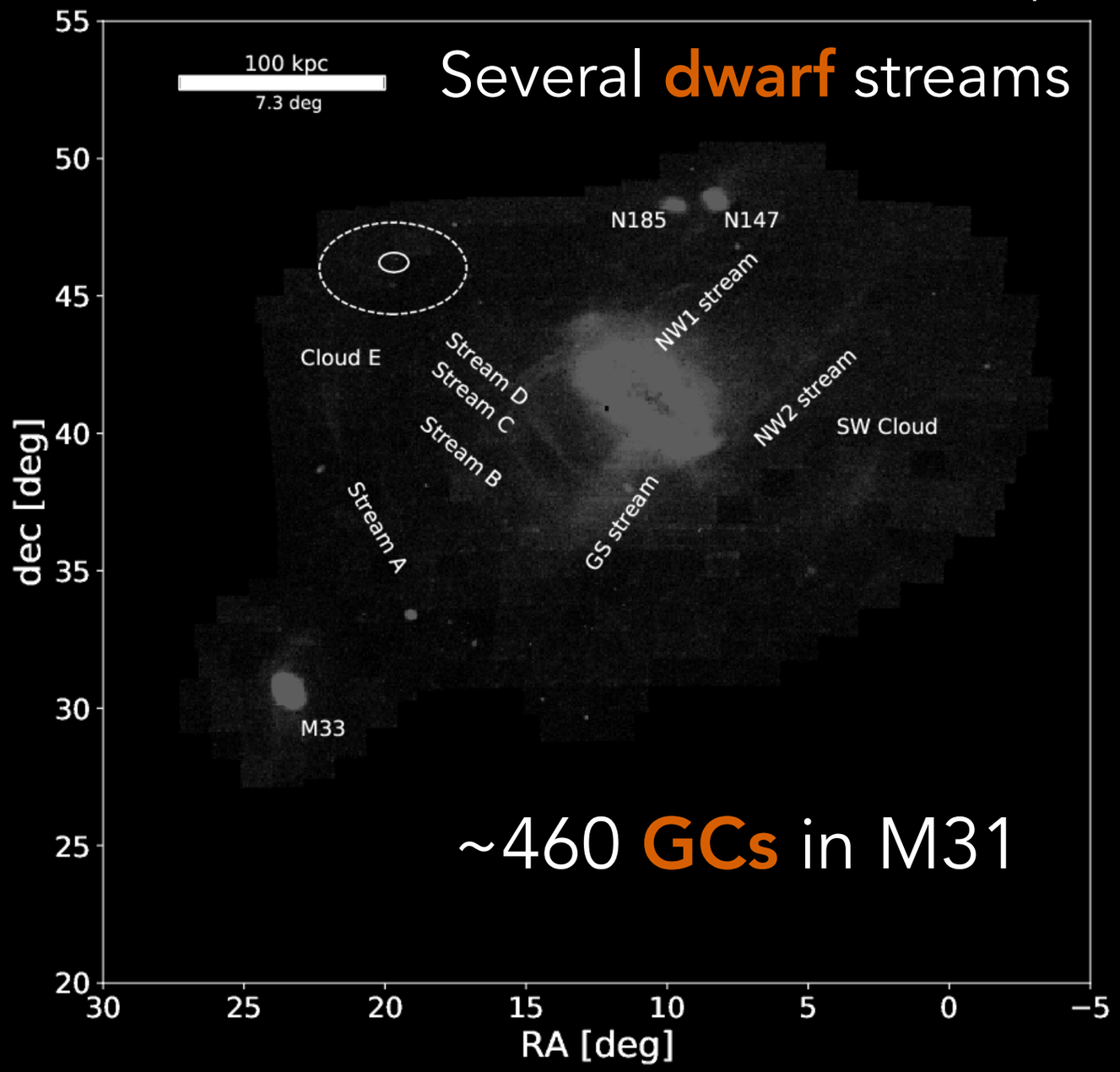

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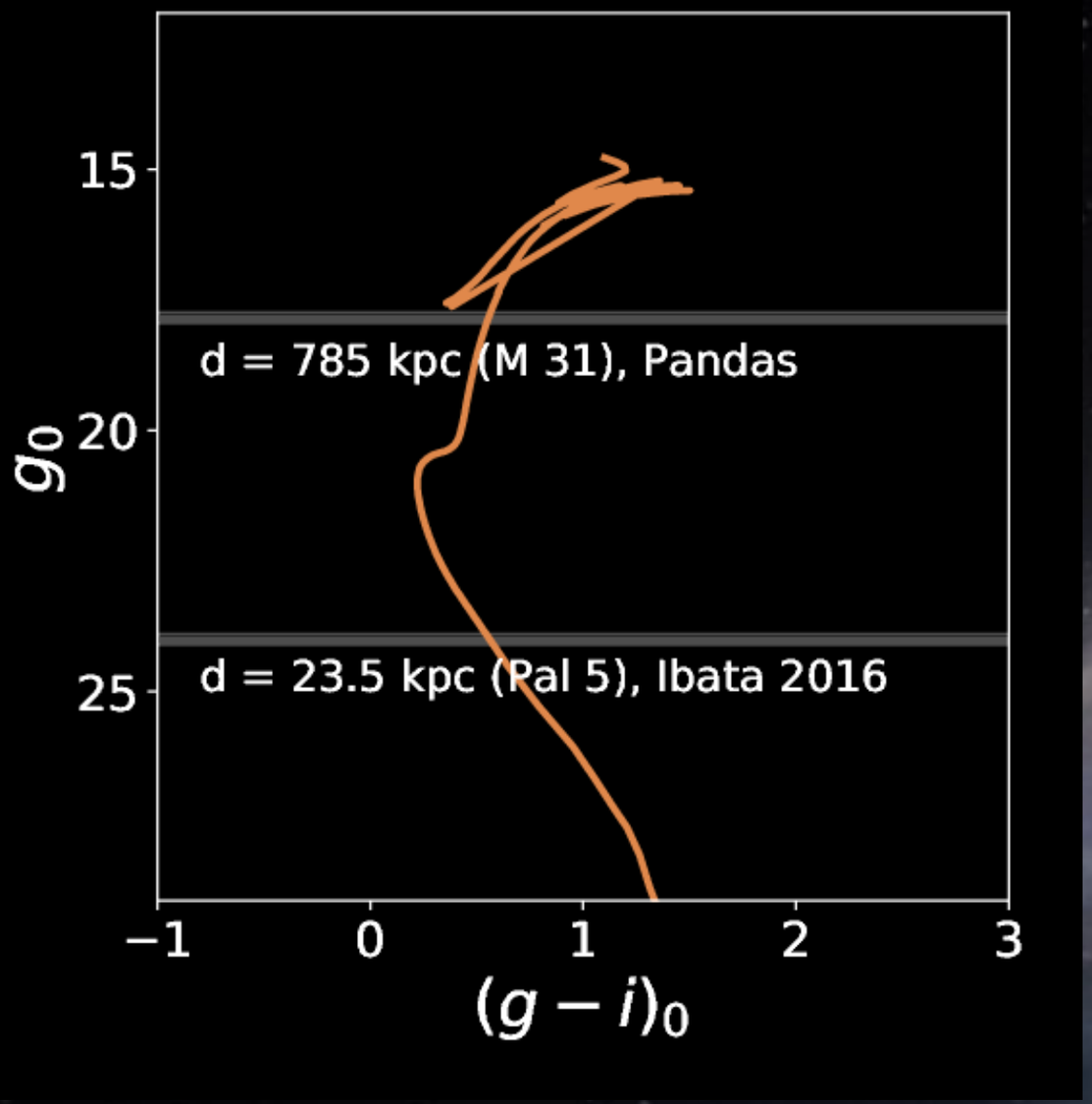
Let’s do a blind search instead

Inject Pal 5-like streams to M31



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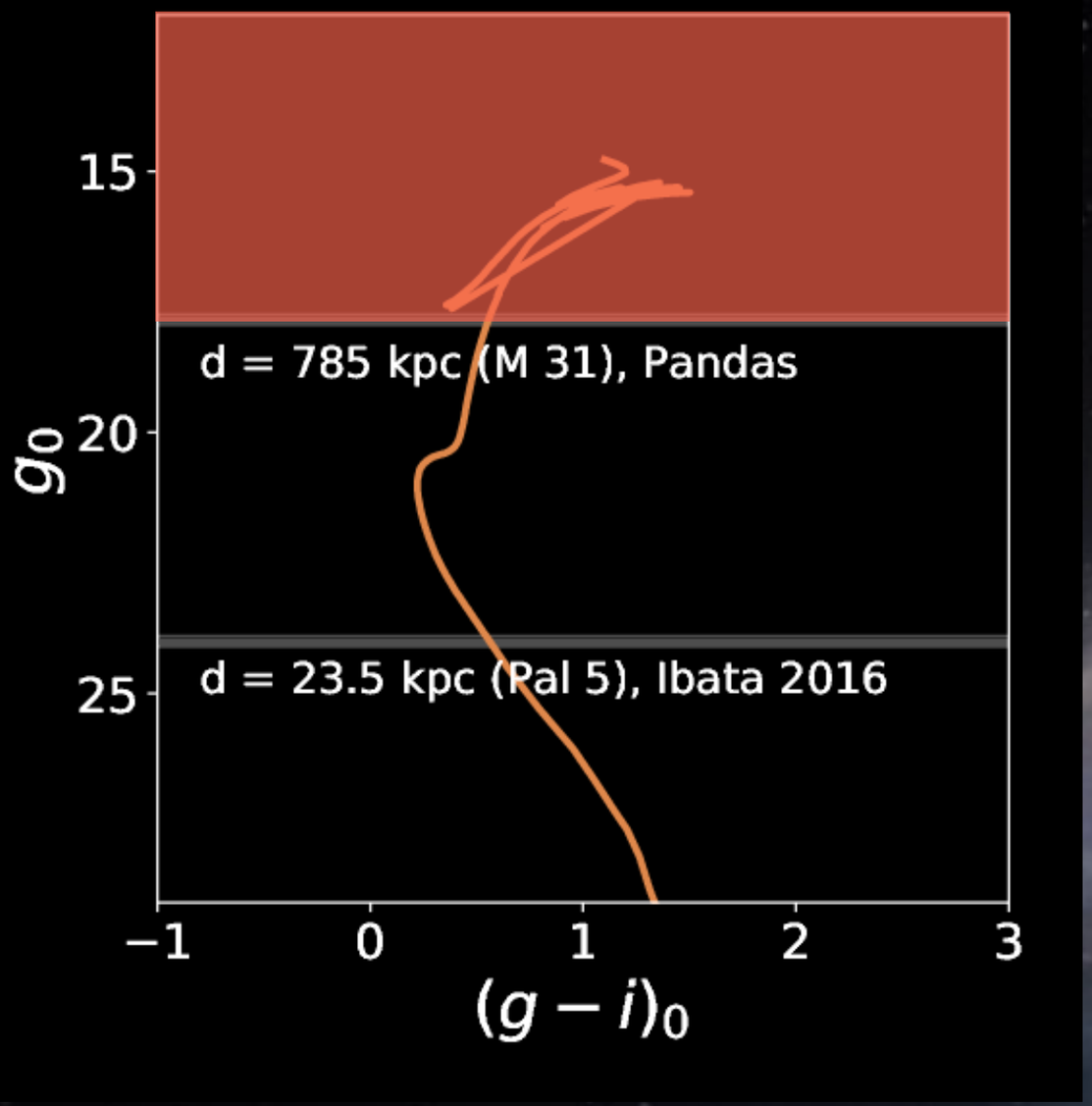

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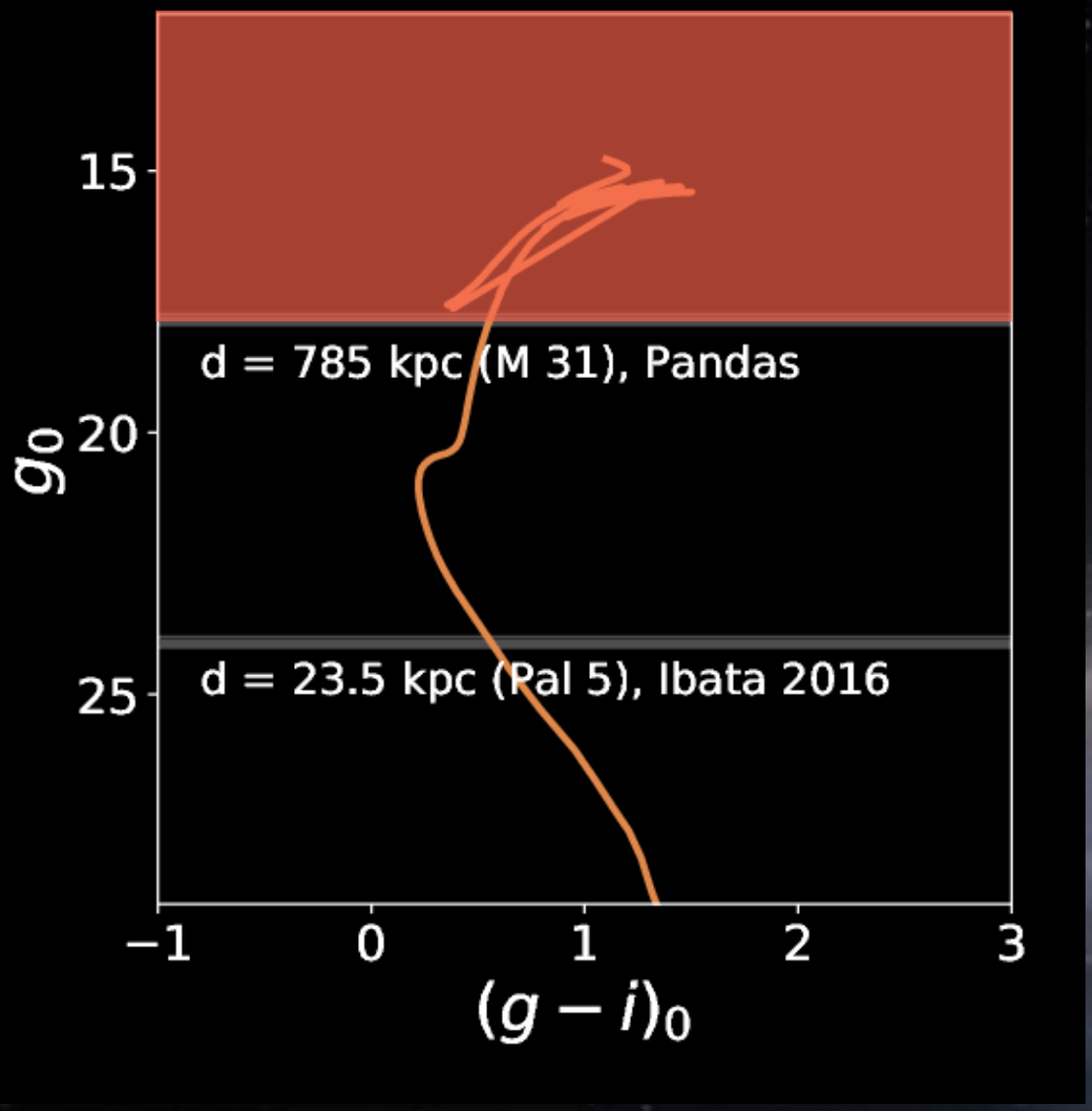

Pearson, Starkenburg et al. 2019

Length, width, and number of stars scaled for a Pal 5-like stream in M31

Image credit:
S5 Collaboration

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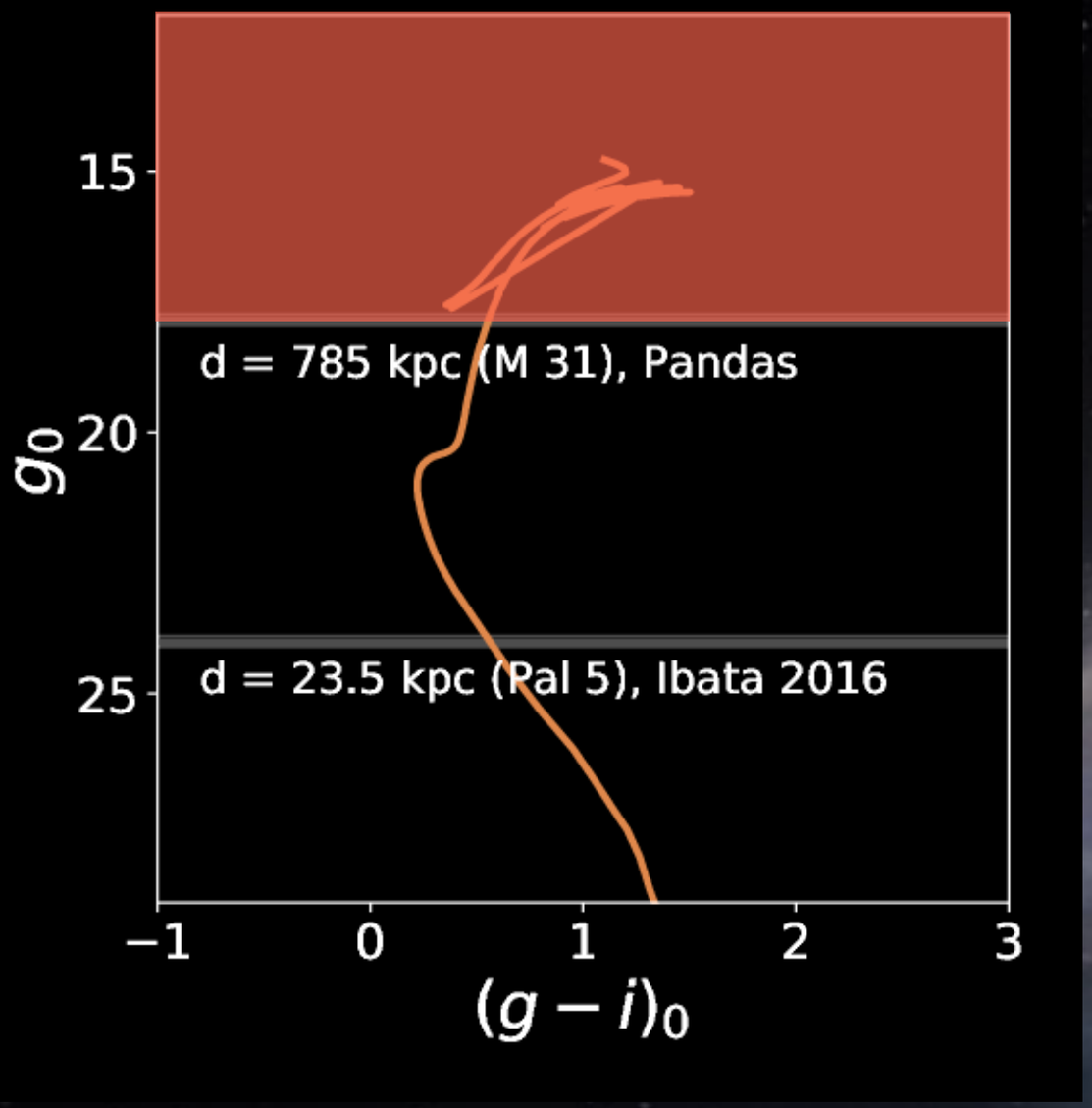

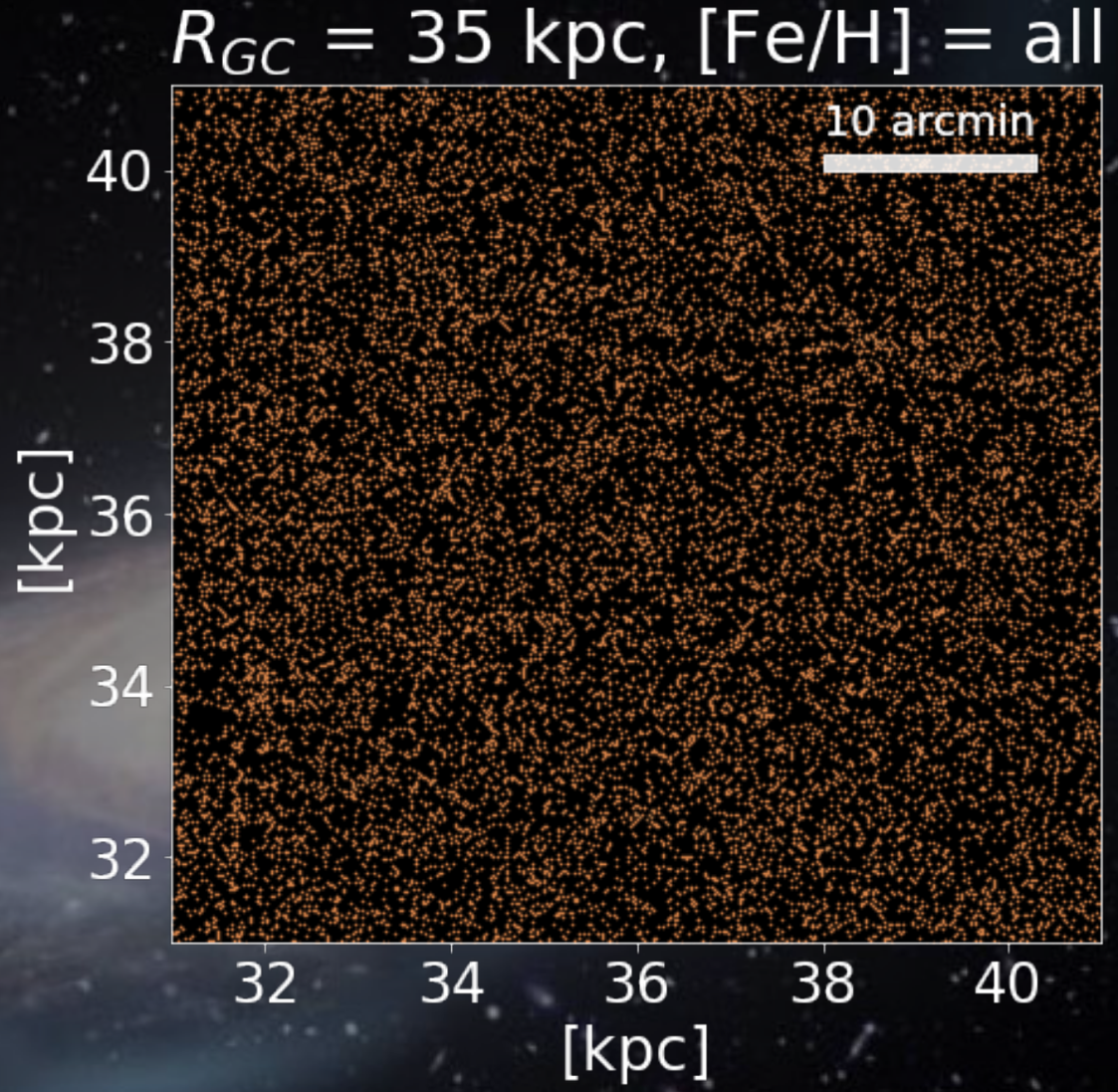

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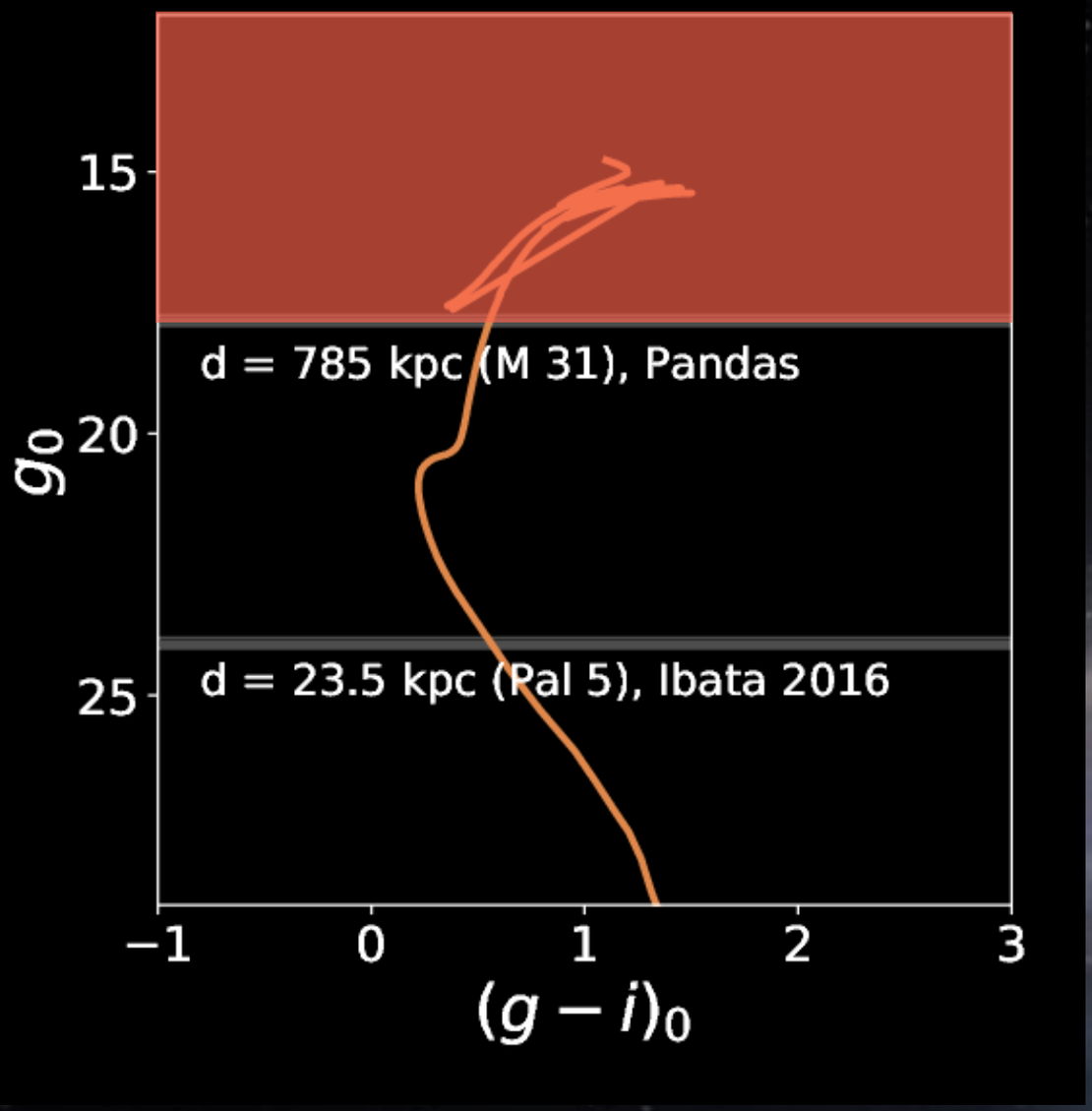

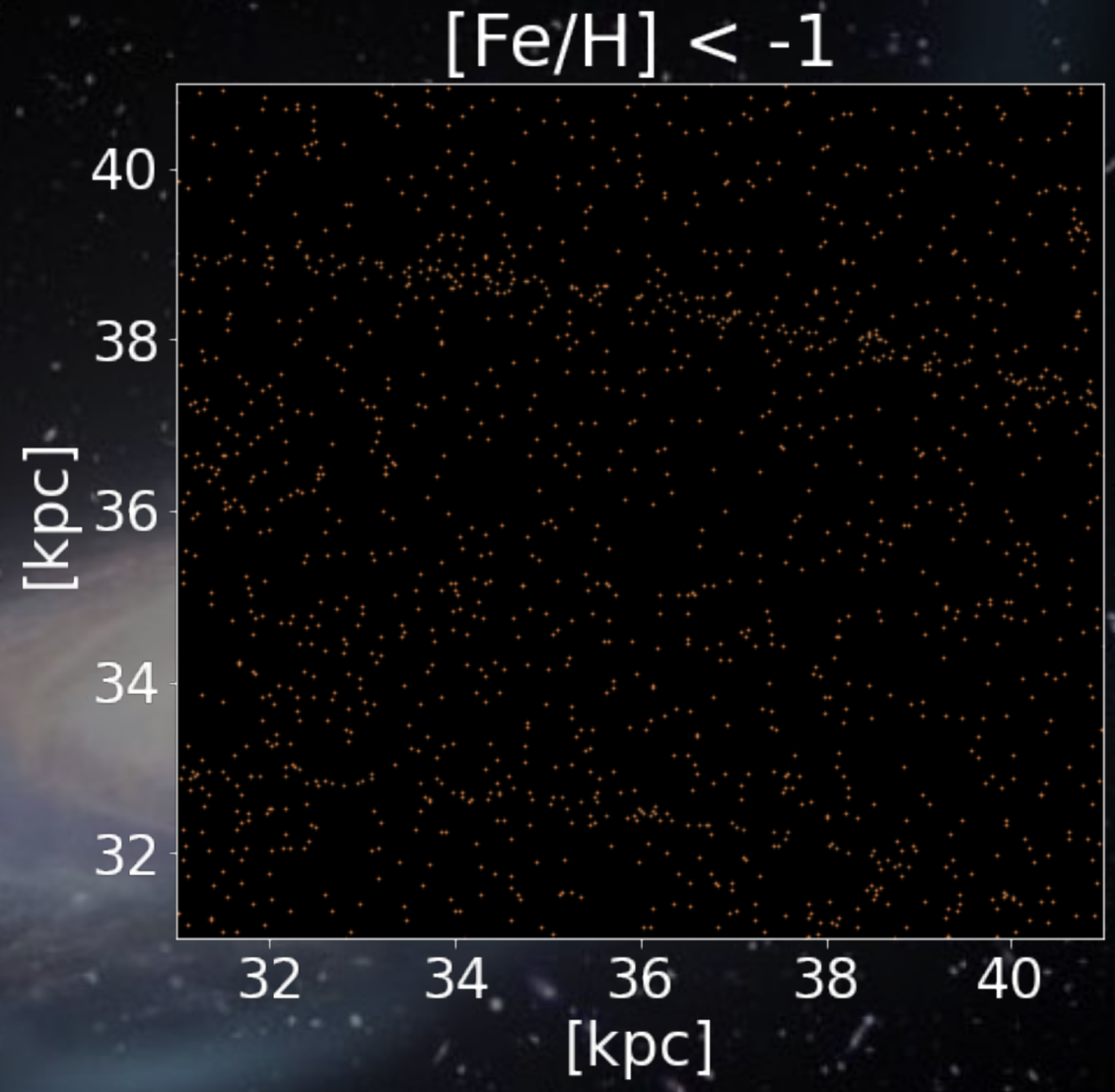

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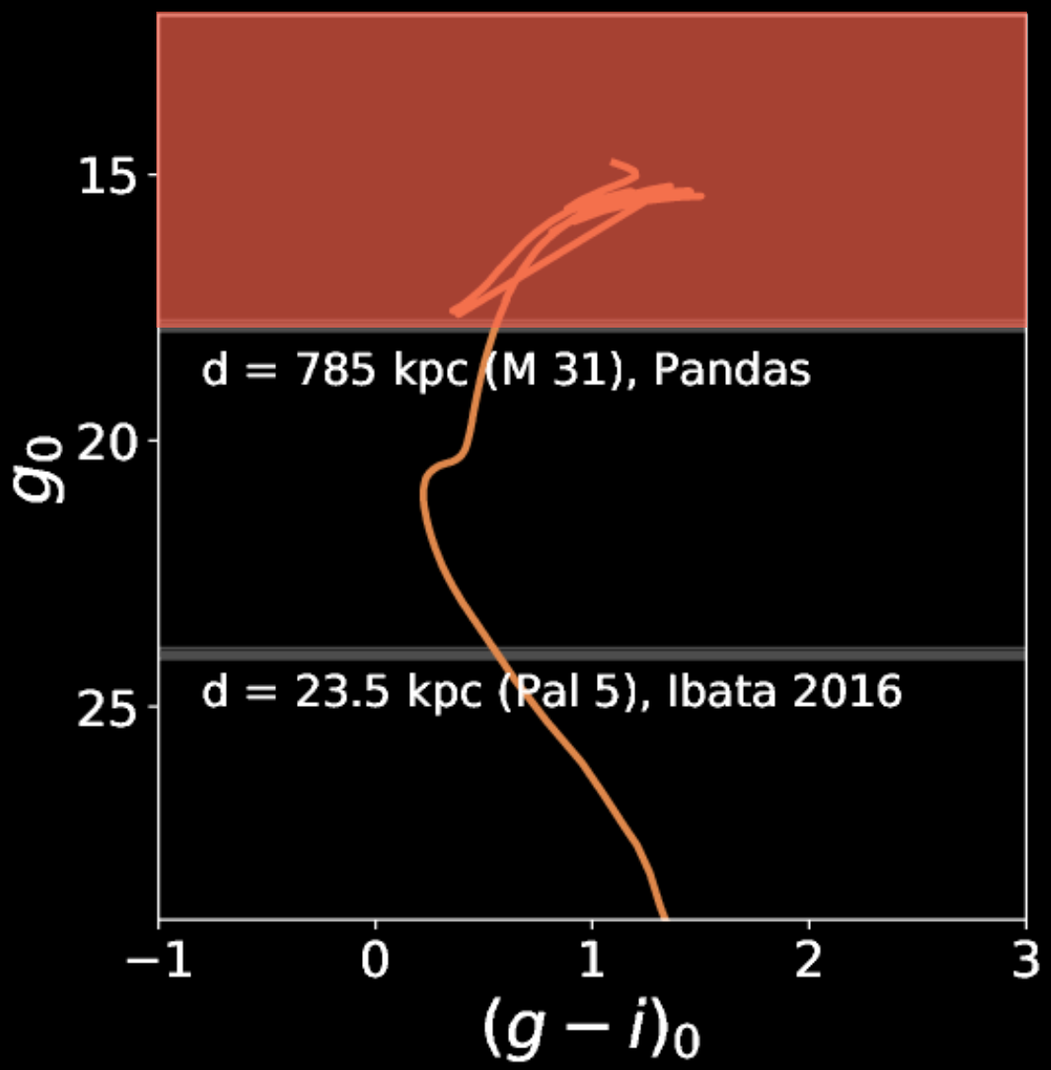
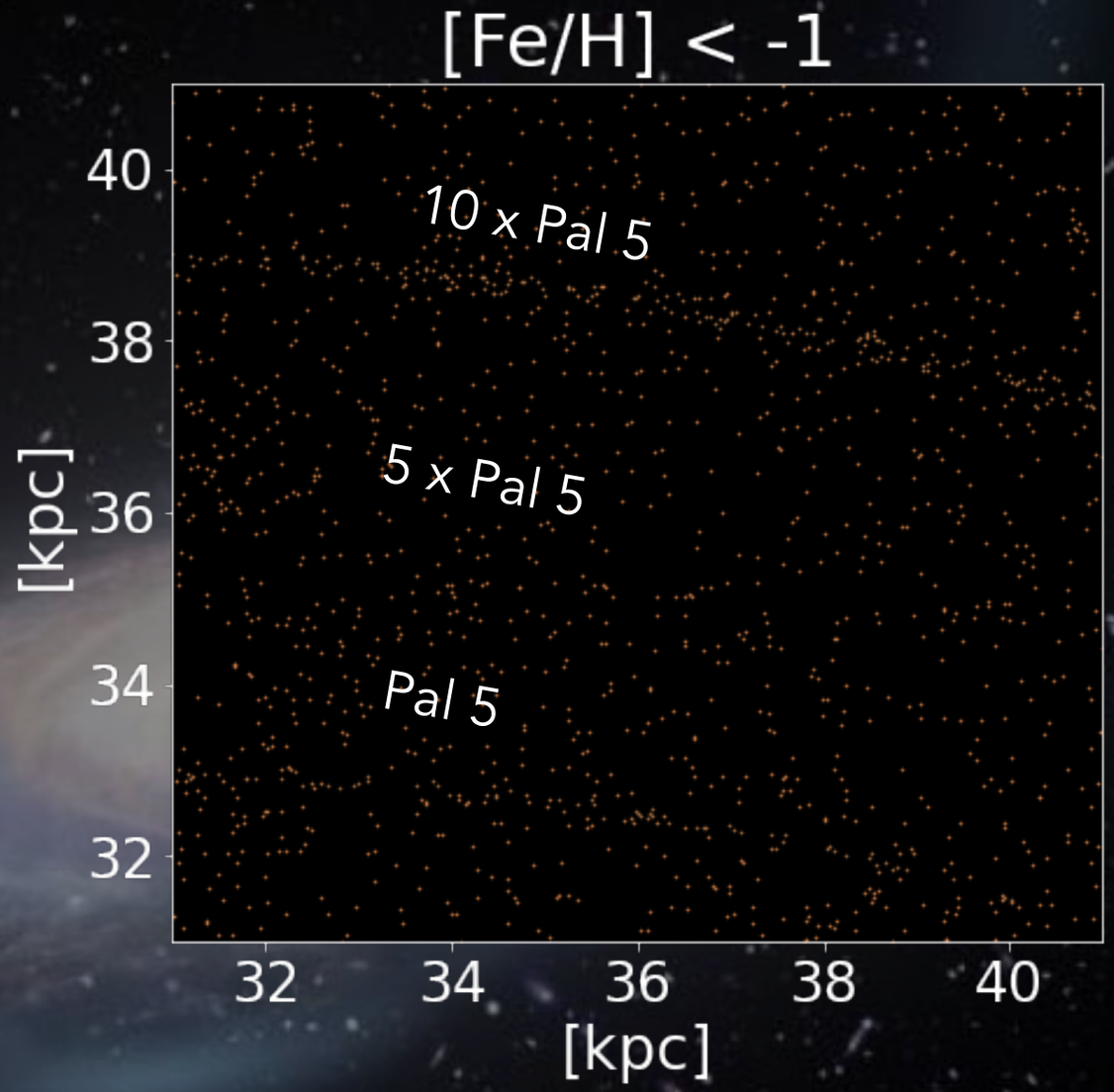




Pearson, Starkenburg et al. 2019

Image credit:
S5 Collaboration

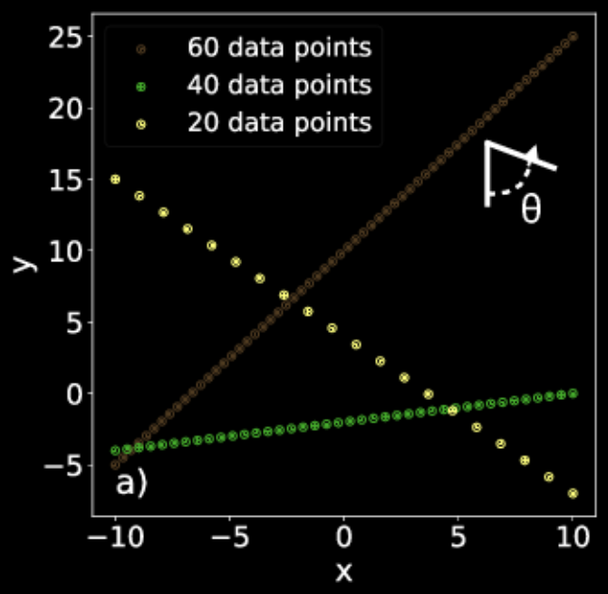
We can maybe detect GC streams with 5-10 x the mass of Pal 5 in **current PAndAS data** after a **metallicity cut**

Image credit:
S5 Collaboration

Systematic search for stellar streams

The Hough Stream Spotter (HSS)

Pearson, Clark, Starkenburg+ 2022



Three different lines
with a different
number of points

Image credit:
S5 Collaboration

github.com/sapearson/HSS

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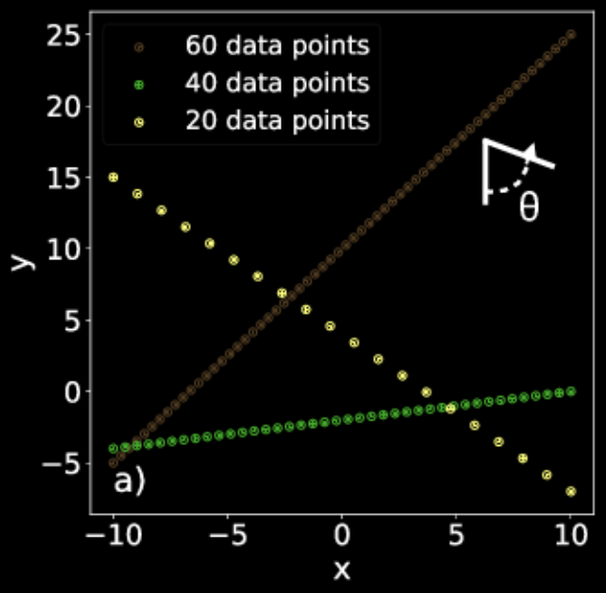

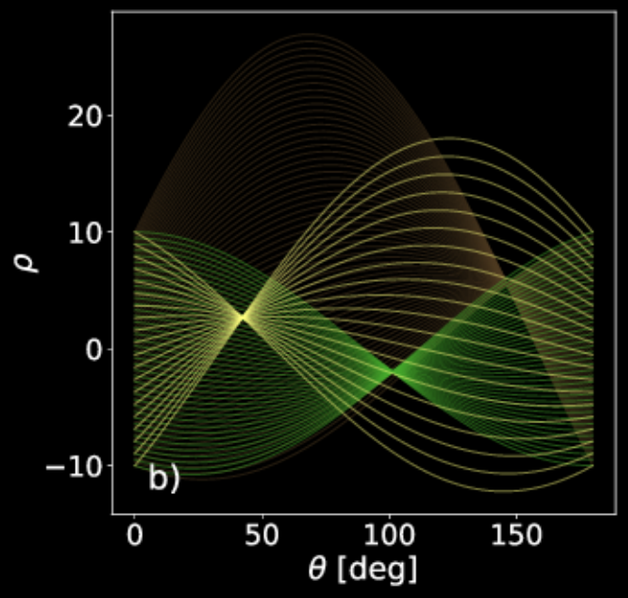

Hough Transform

Hough 1962

$$\rho = xcos(\theta) + ysin(\theta)$$

Image credit:
S5 Collaboration

github.com/sapearson/HSS

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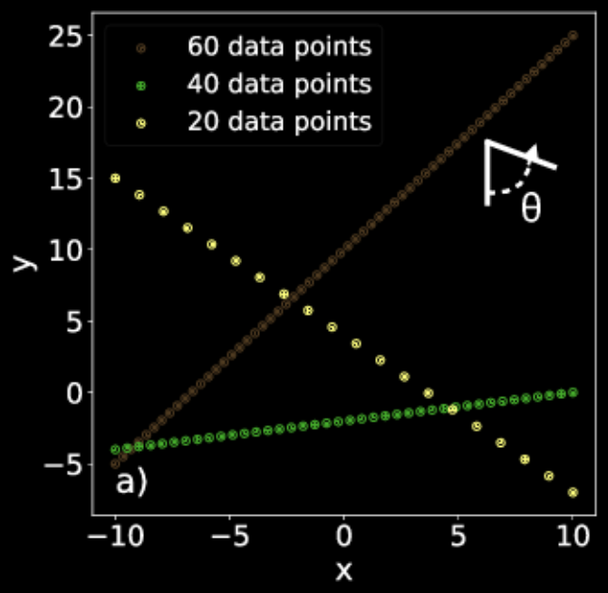

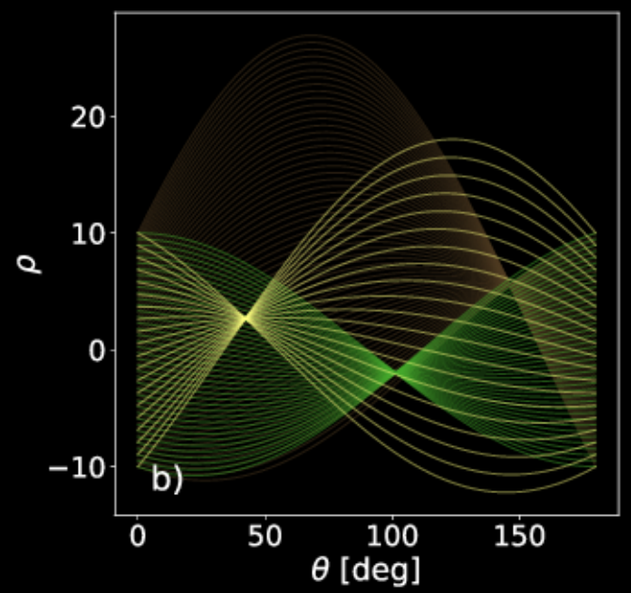

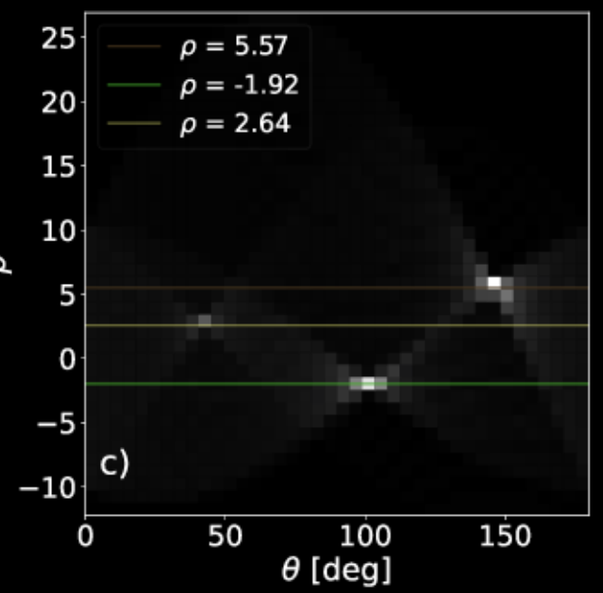

Look at intensity (where do most sinusoids overlap)

Image credit:
S5 Collaboration

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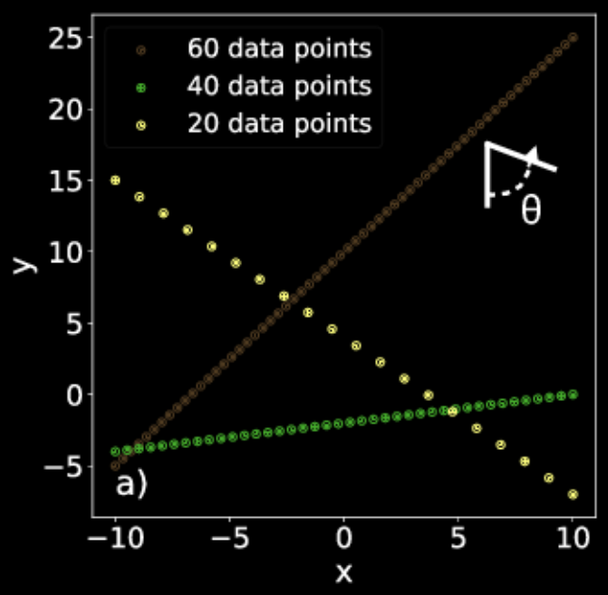
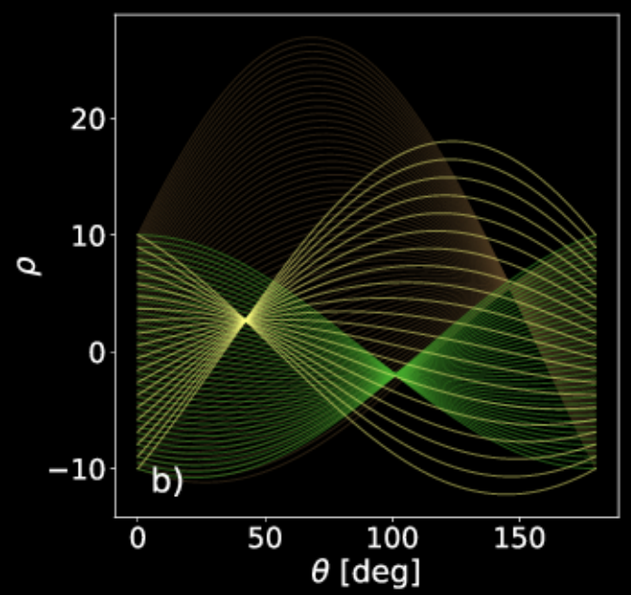
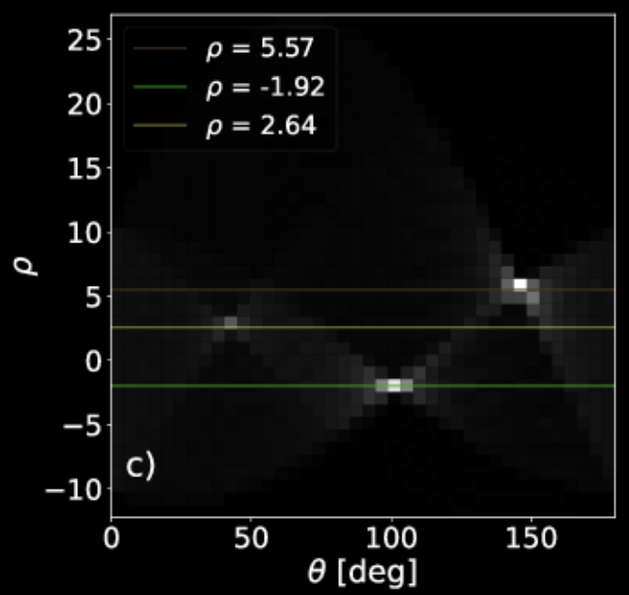
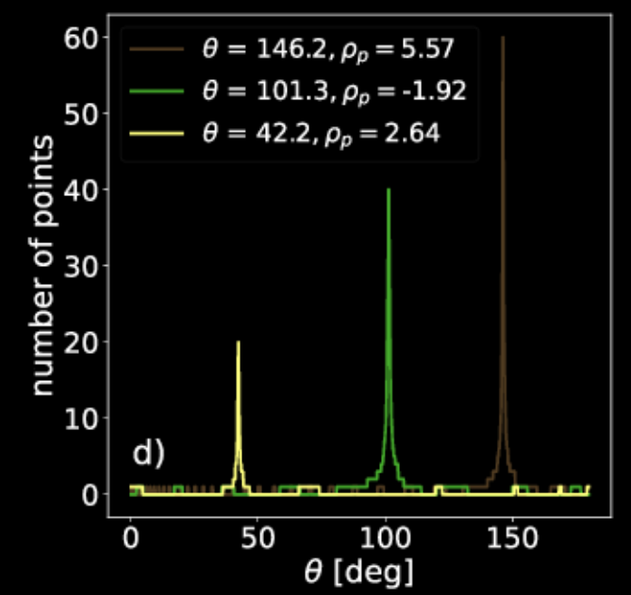








Recover straight lines' angles and their number of points

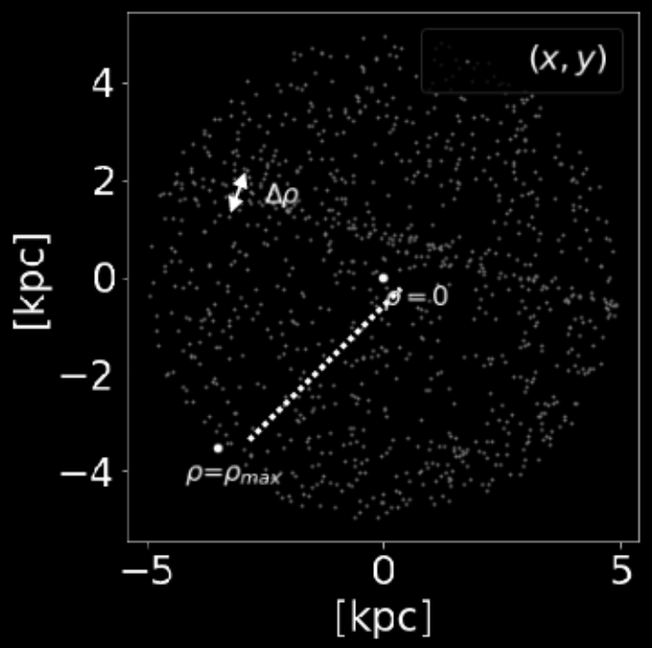
Image credit:
S5 Collaboration

github.com/sapearson/HSS

Systematic search for stellar streams

The Hough Stream Spotter (HSS)

Pearson, Clark, Starkenburg+ 2022



Inject 10 x Pal 5-like stream to PAndAS data

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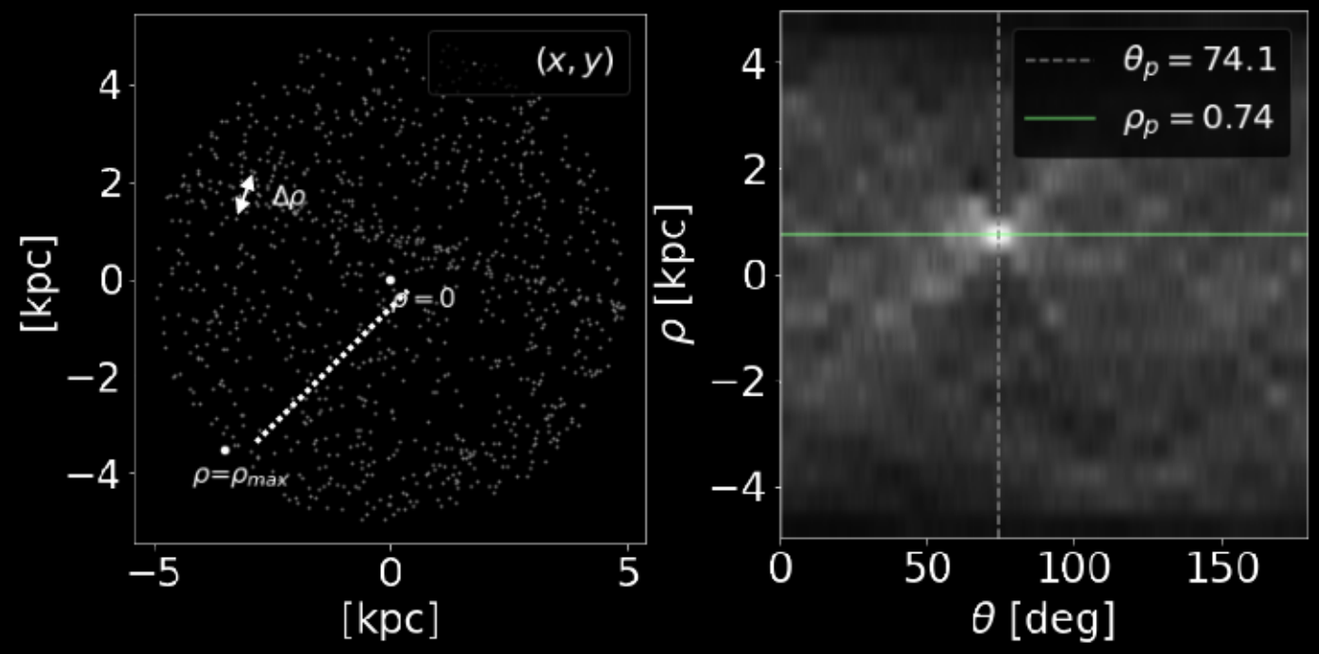

Hough Transform and bin by the width of the stream to find peak in intensity

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S5 Collaboration

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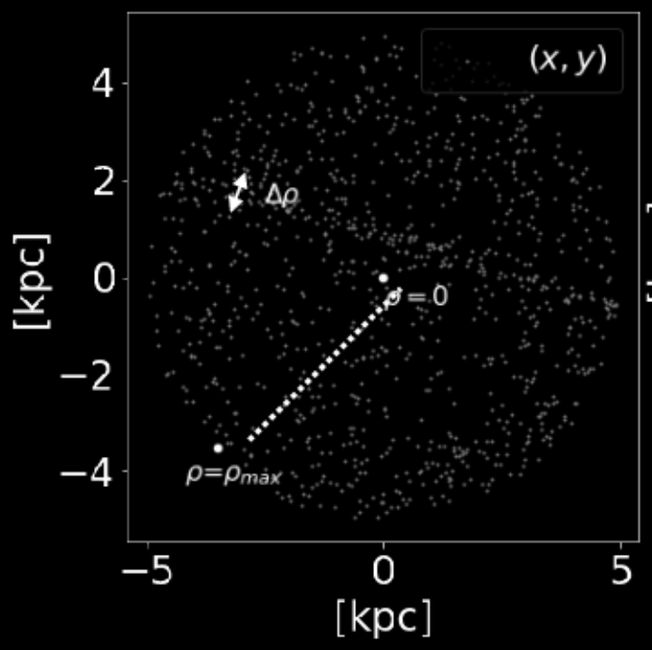

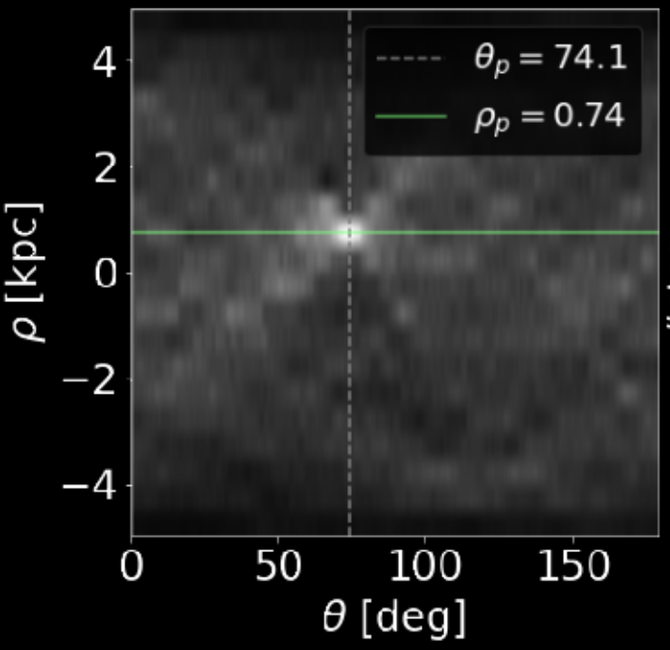

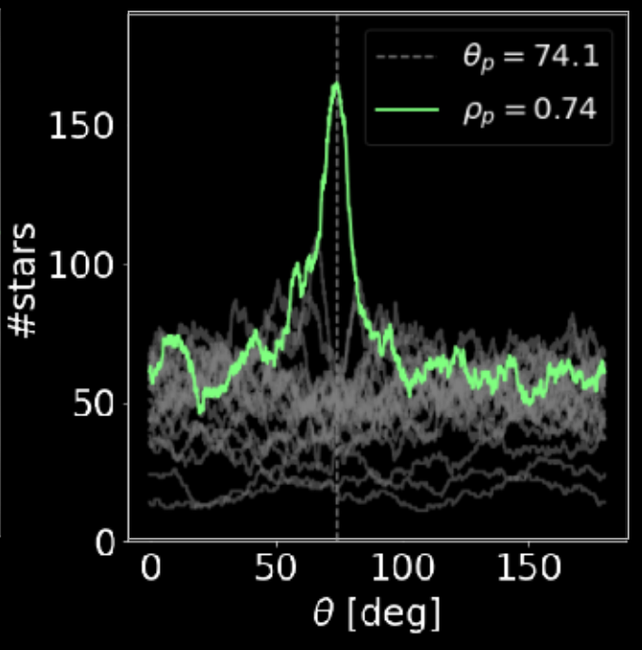

Recover the stream angle and its number of stars

Image credit:
S5 Collaboration

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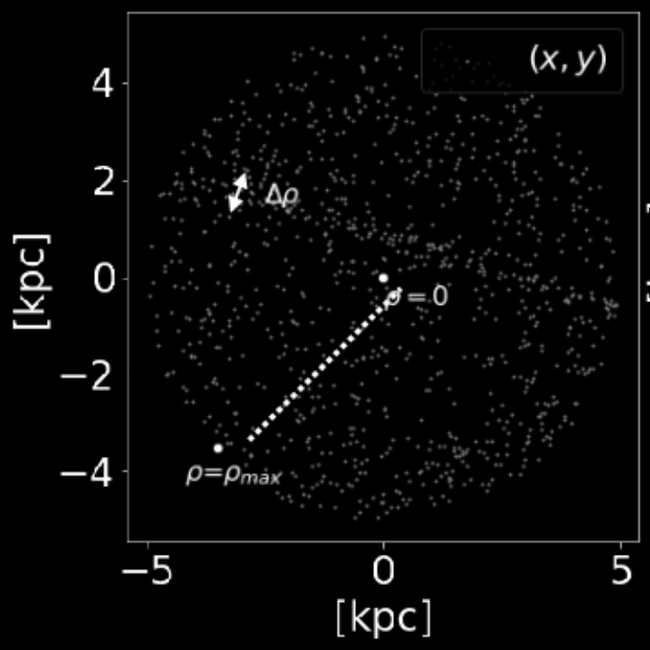
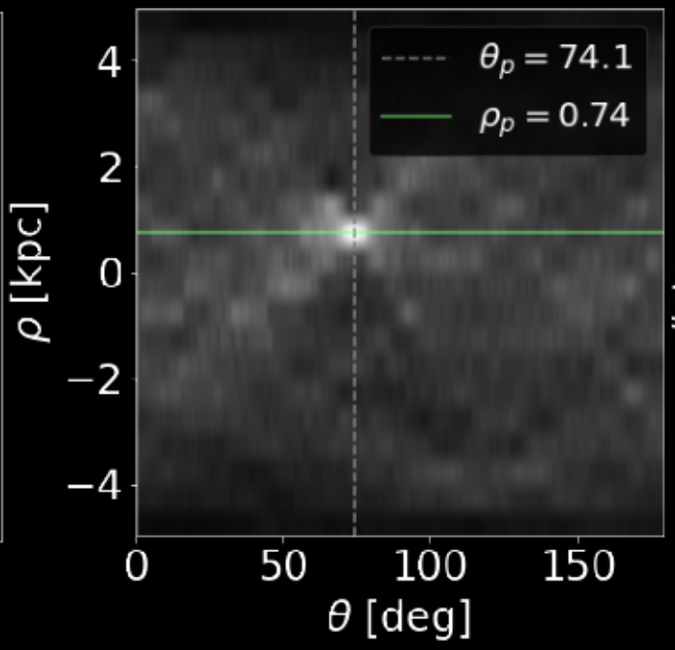
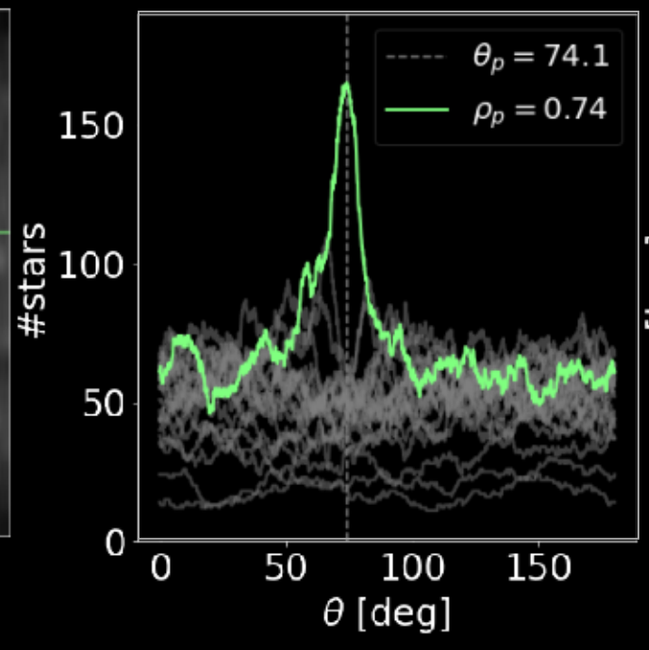
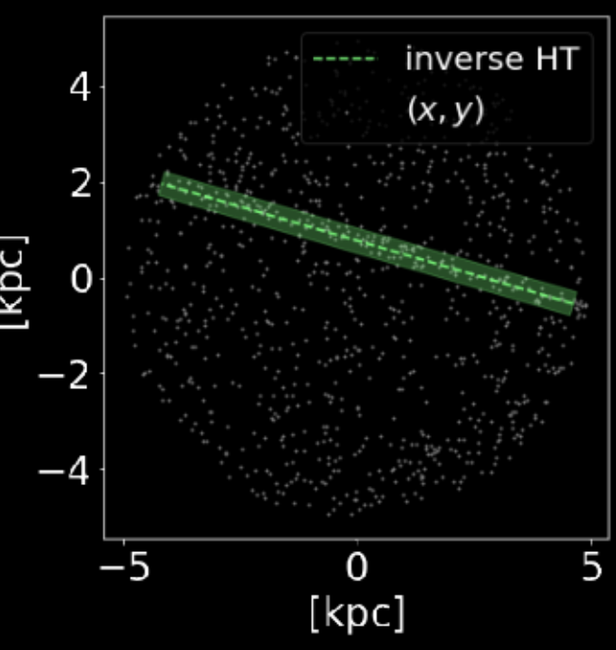








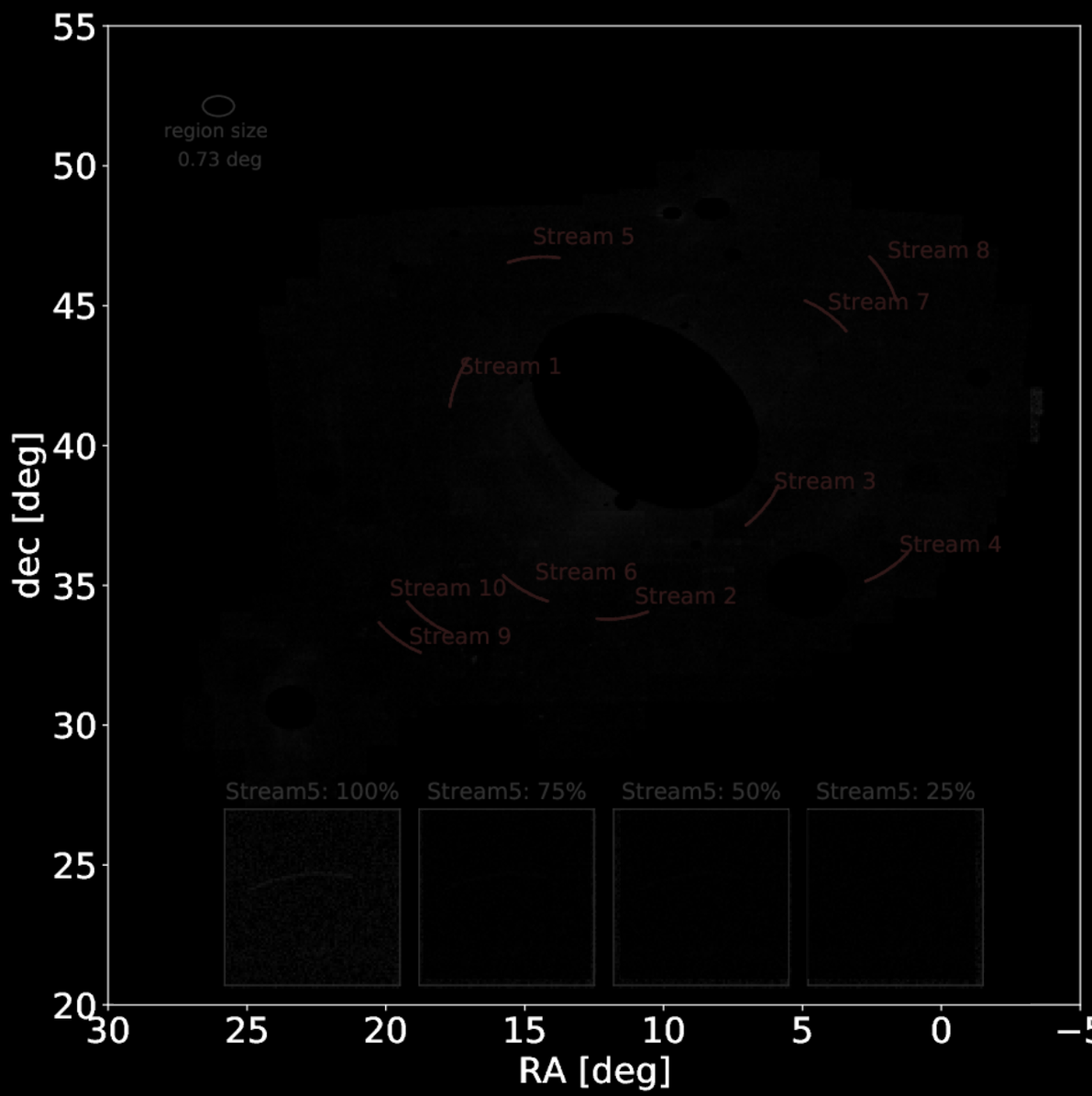
Inverse Hough Transform to recover the stream

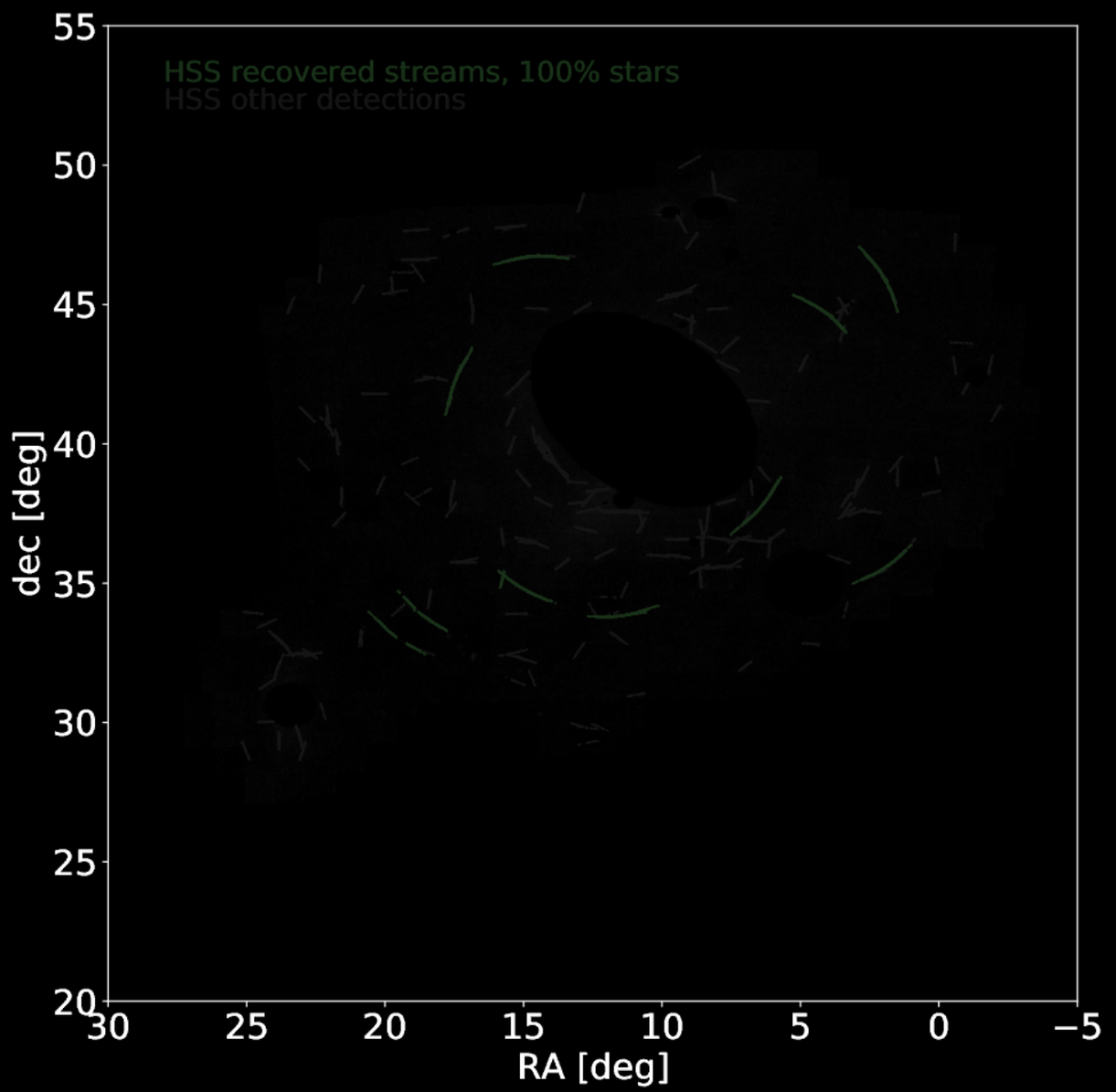
Image credit:
S5 Collaboration

github.com/sapearson/HSS

Systematic search for stellar streams

Completeness checks with the HSS





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S5 Collaboration

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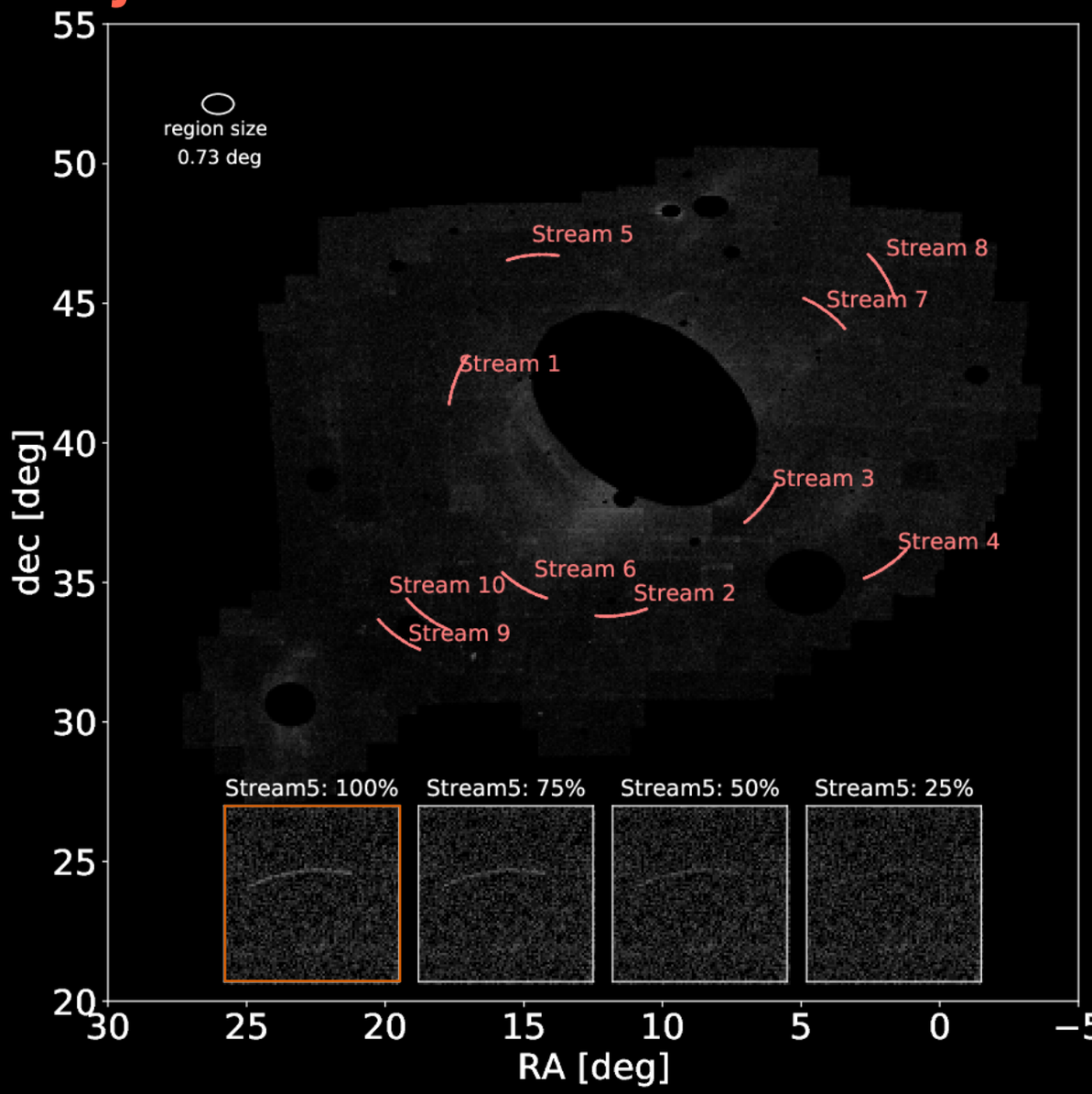
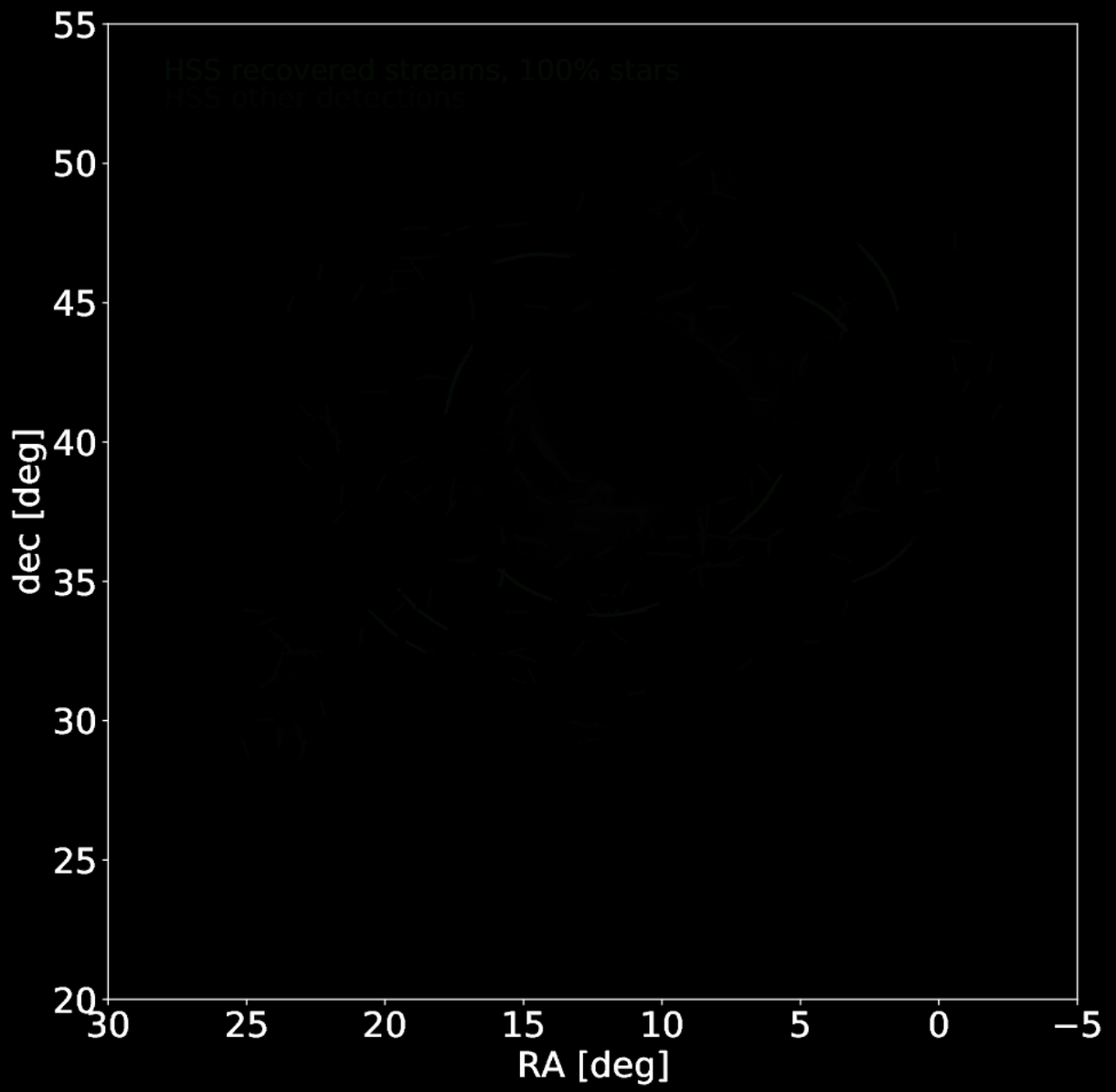
Systematic search for stellar streams

Completeness checks with the HSS

Inject ten 10 x Pal 5-like streams





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Systematic search for stellar streams

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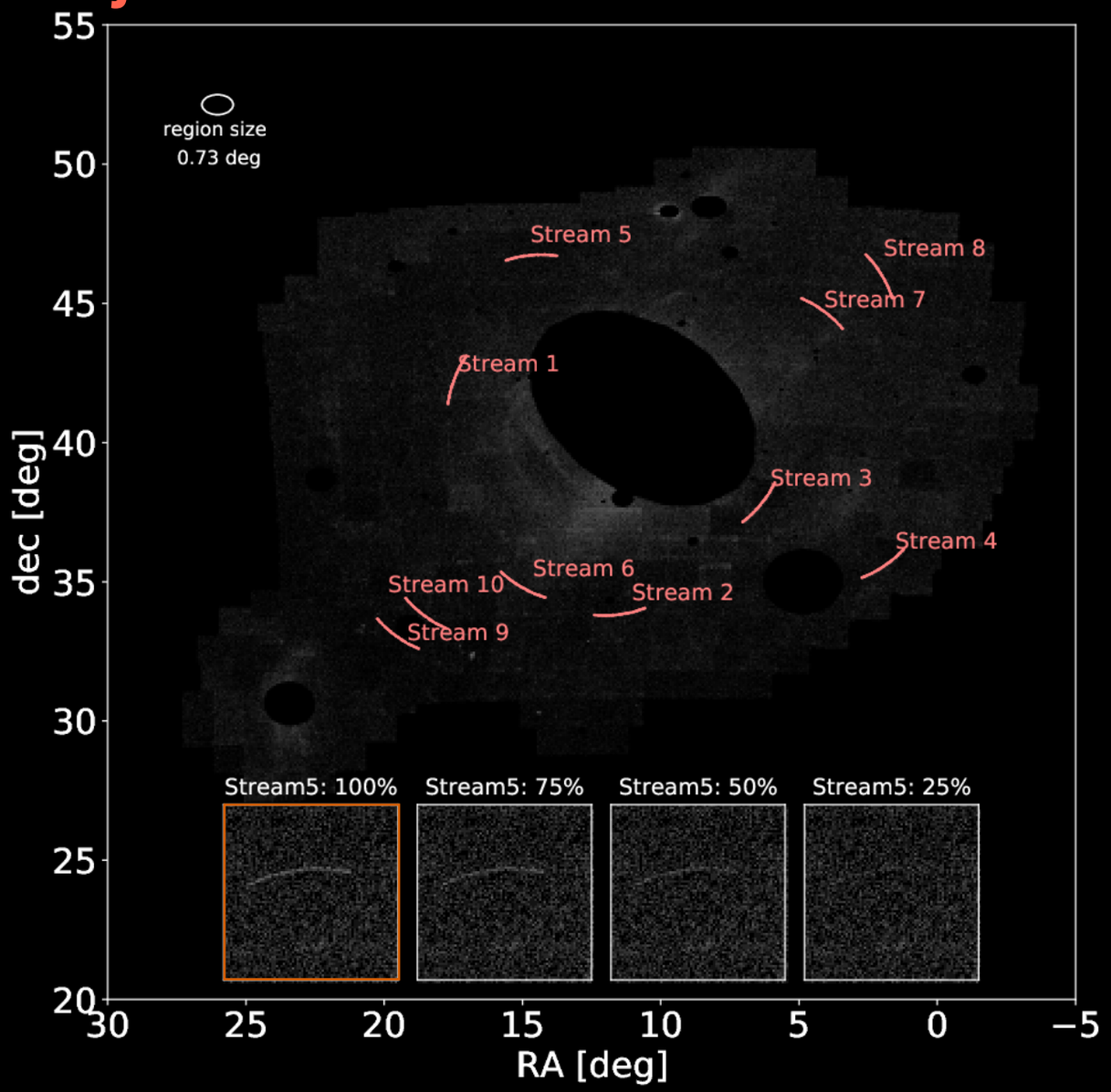
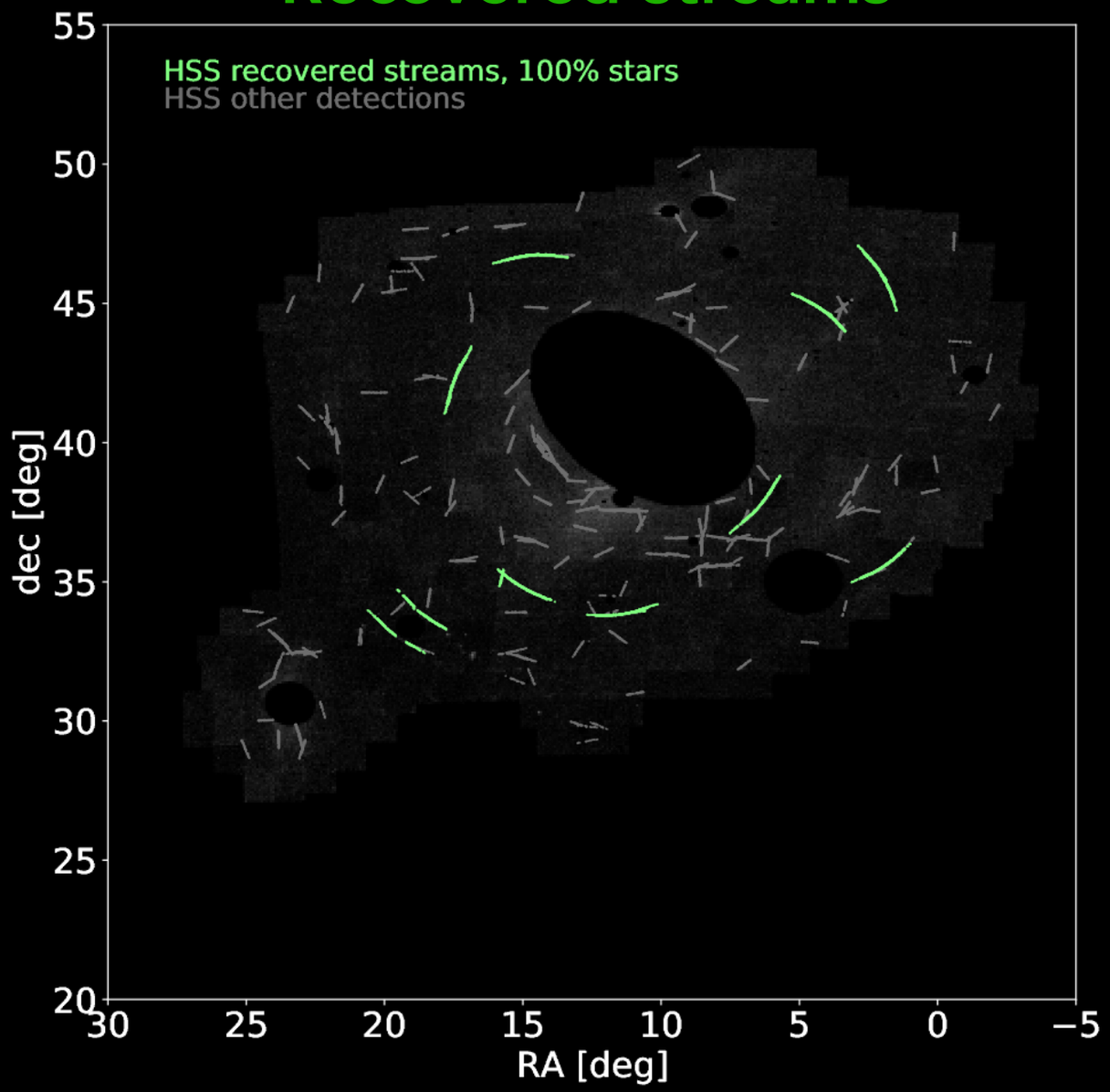


Recovered streams



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Systematic search for stellar streams

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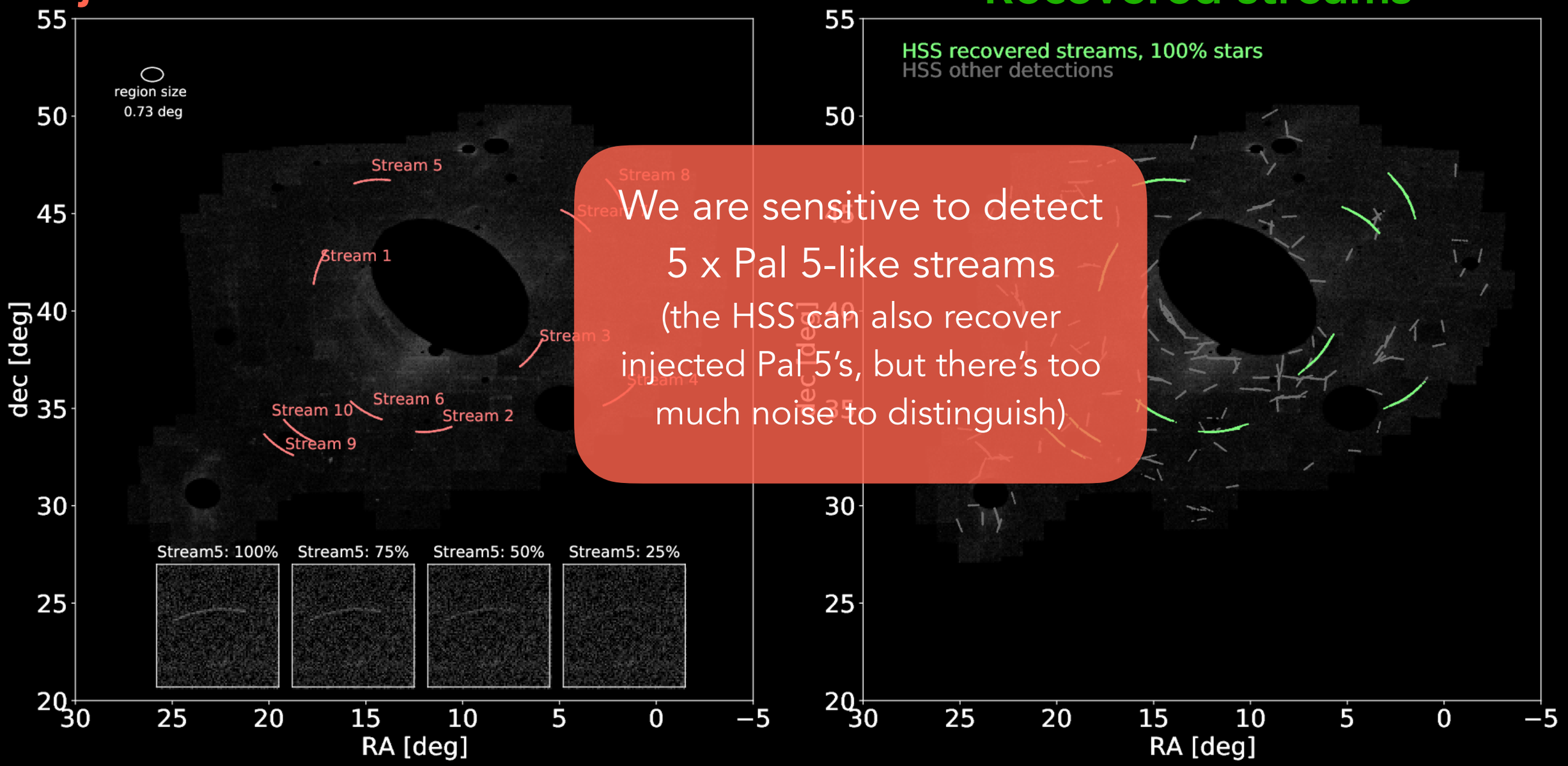


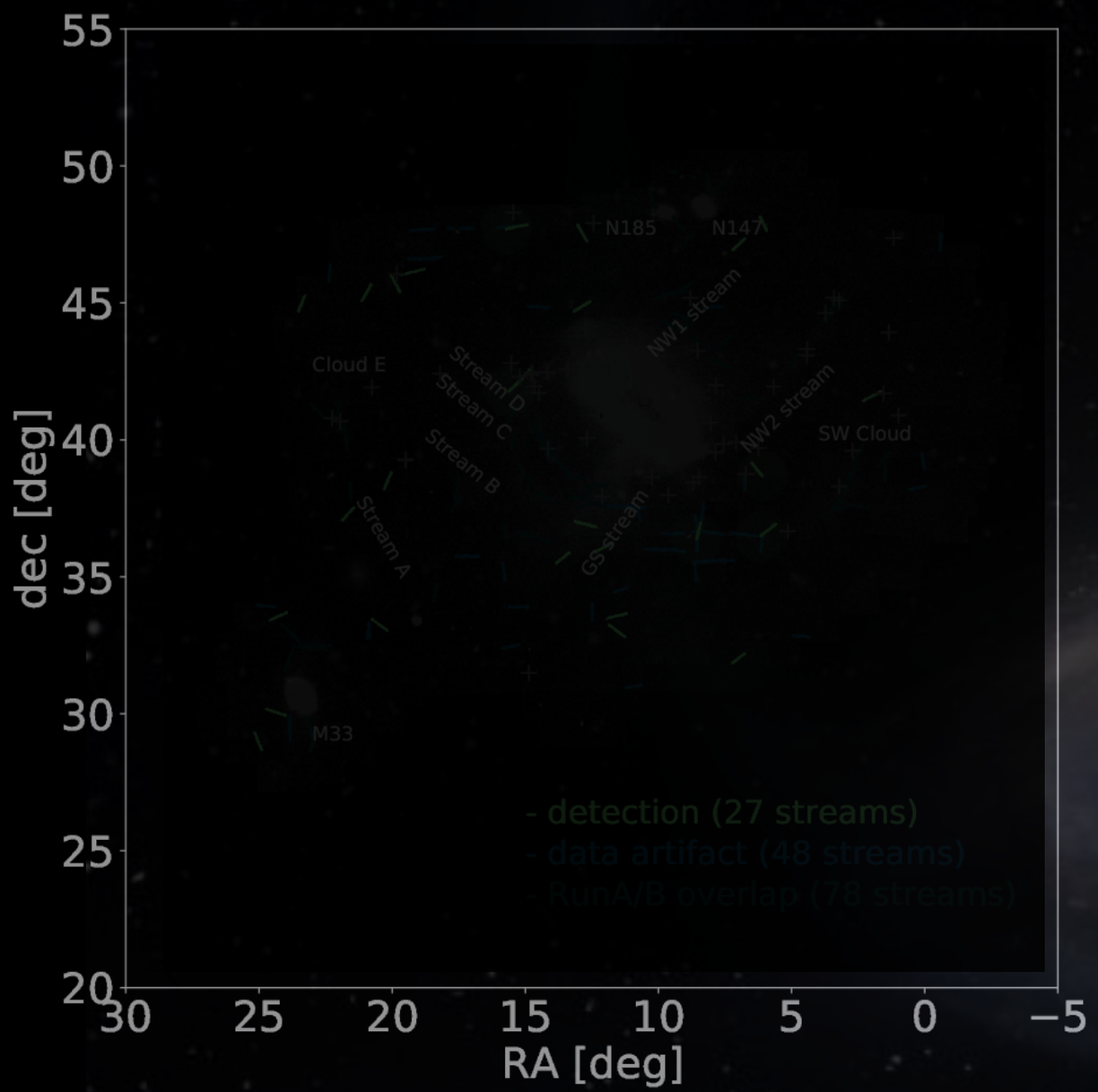
We are sensitive to detect
5 x Pal 5-like streams
(the HSS can also recover injected Pal 5's, but there's too much noise to distinguish)

Image credit:
S5 Collaboration

Pearson, Clark, Starkenburg+ 2022

Systematic search for stellar streams

Blind run: Hints of GC stream detections



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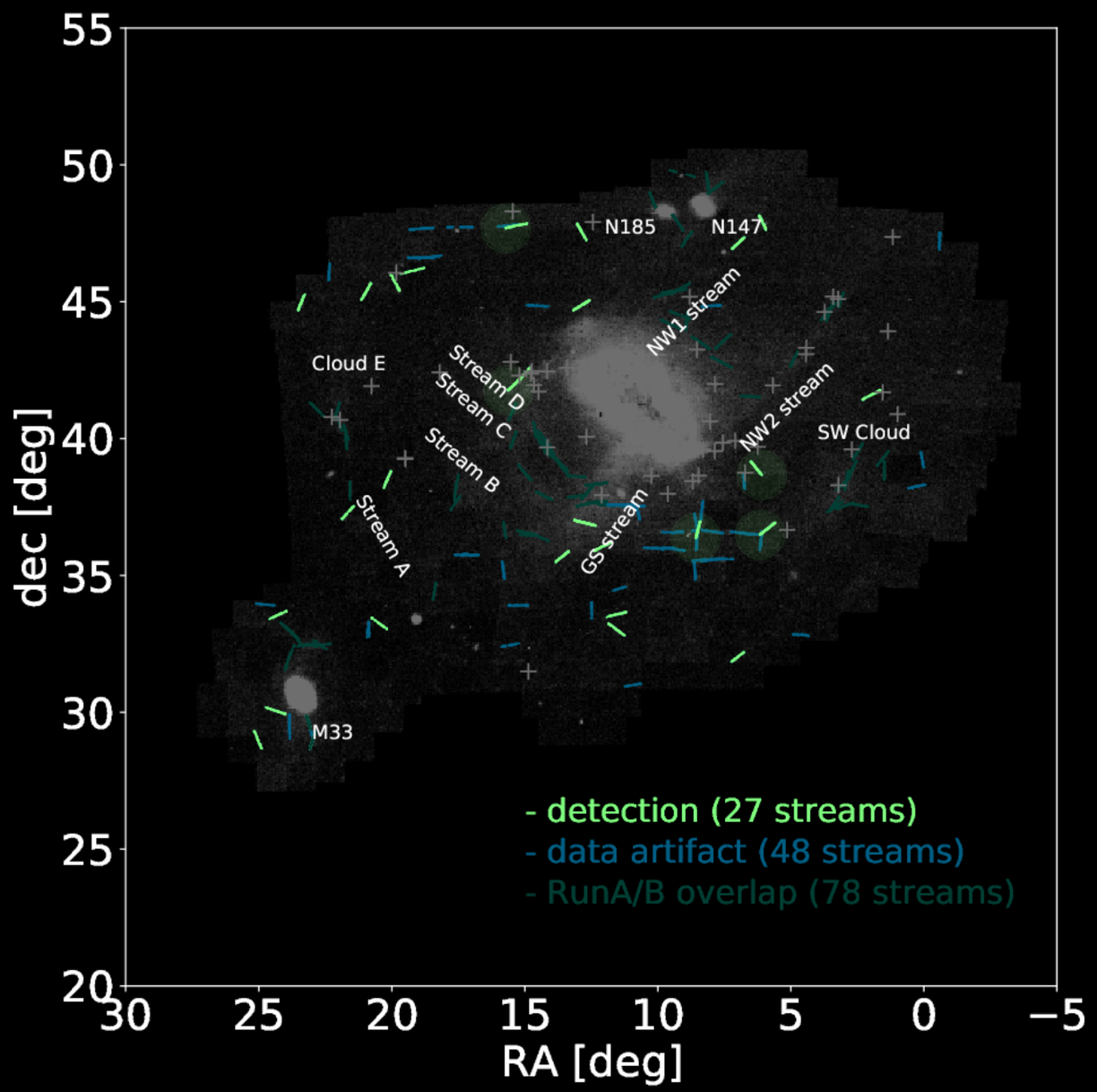

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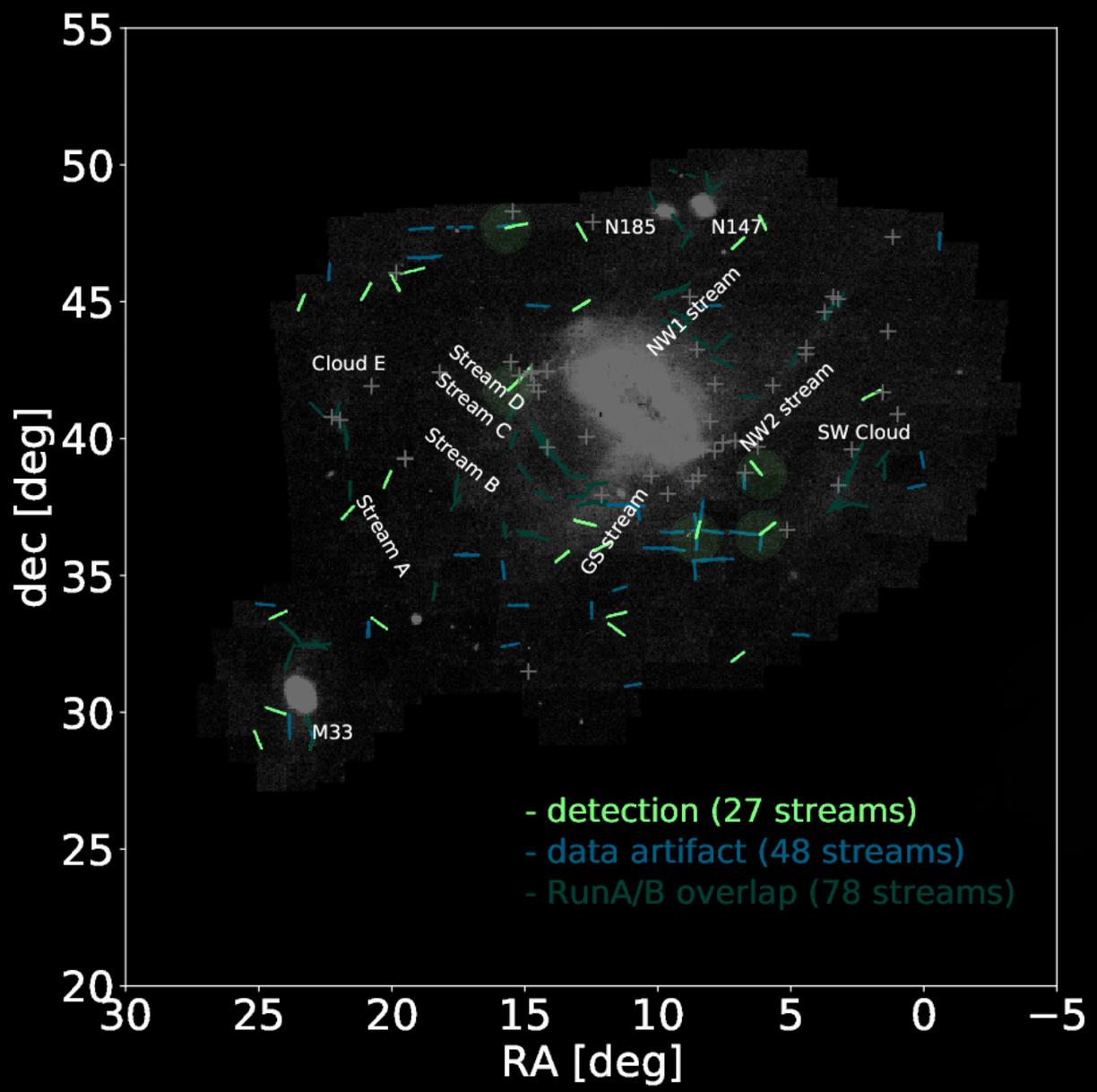

We don’t see the long, 5 x Pal 5-like streams in the data, but we might be partially recovering them.

Image credit:
S5 Collaboration

Pearson, Clark, Starkenburg+ 2022

Systematic search for stellar streams

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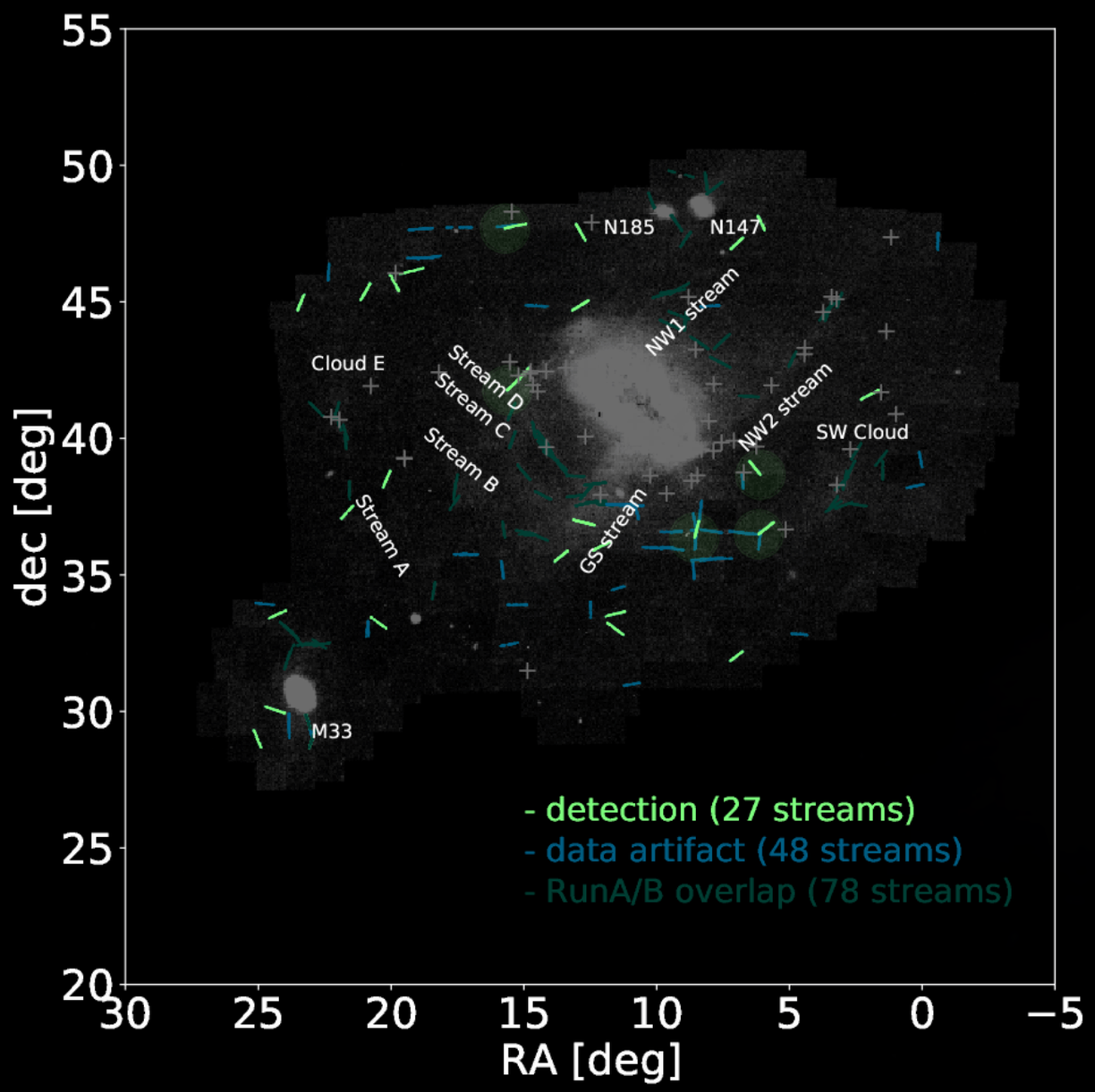

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S5 Collaboration

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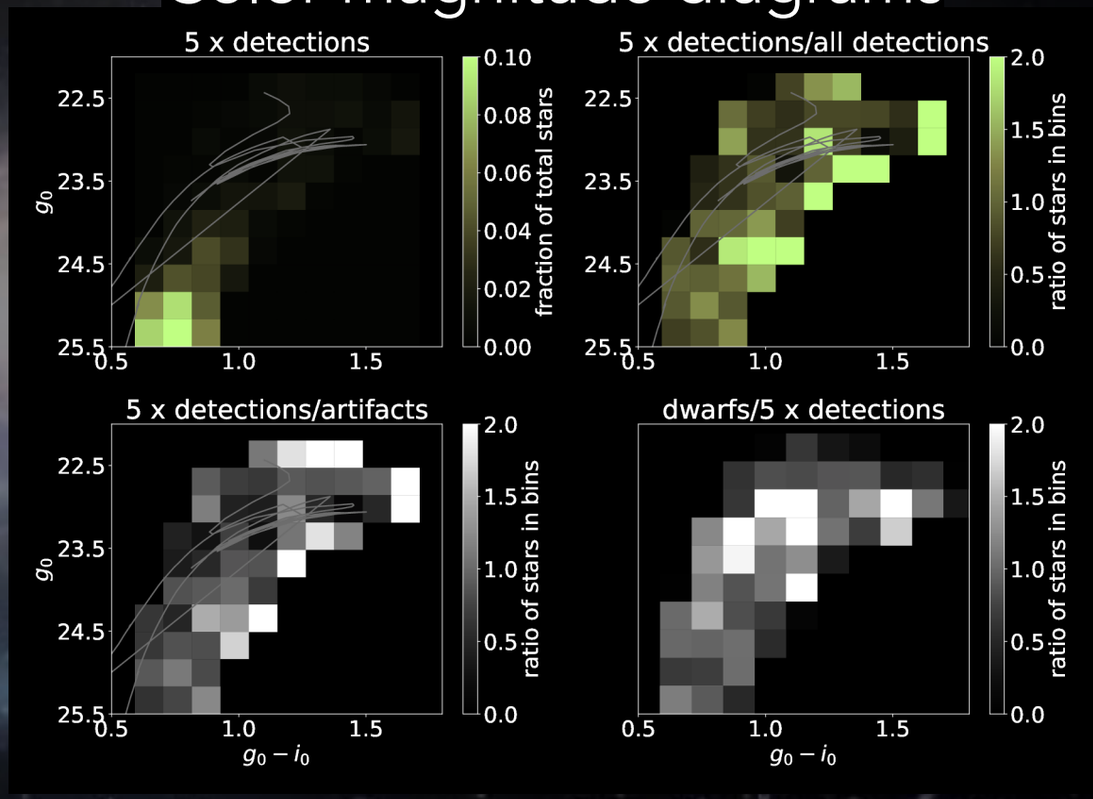
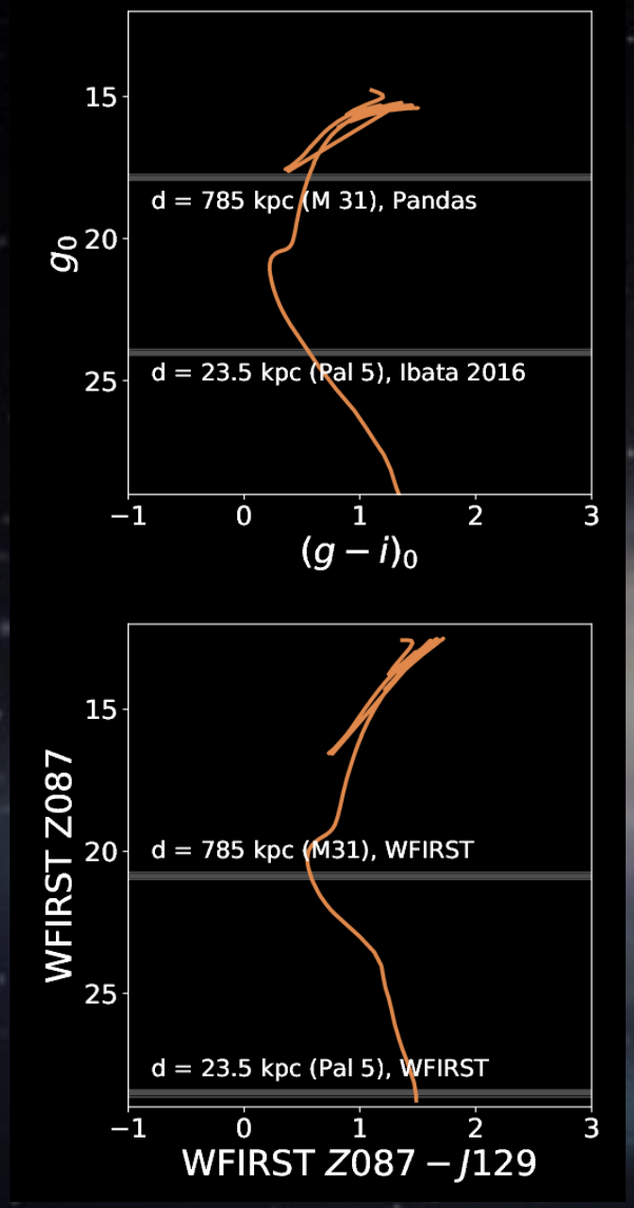
Color-magnitude diagrams



Pearson, Clark, Starkenburg+ 2022

Systematic search for stellar streams

GC streams with the Roman Space Telescope



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S5 Collaboration

Pearson, Starkenburg et al. 2019

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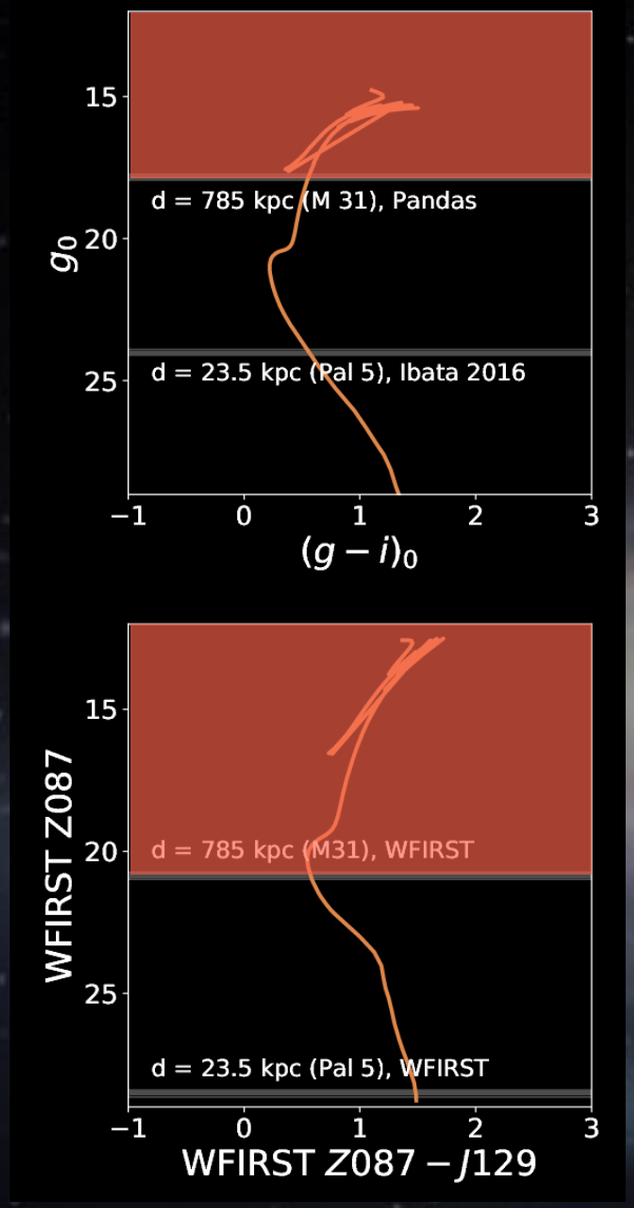

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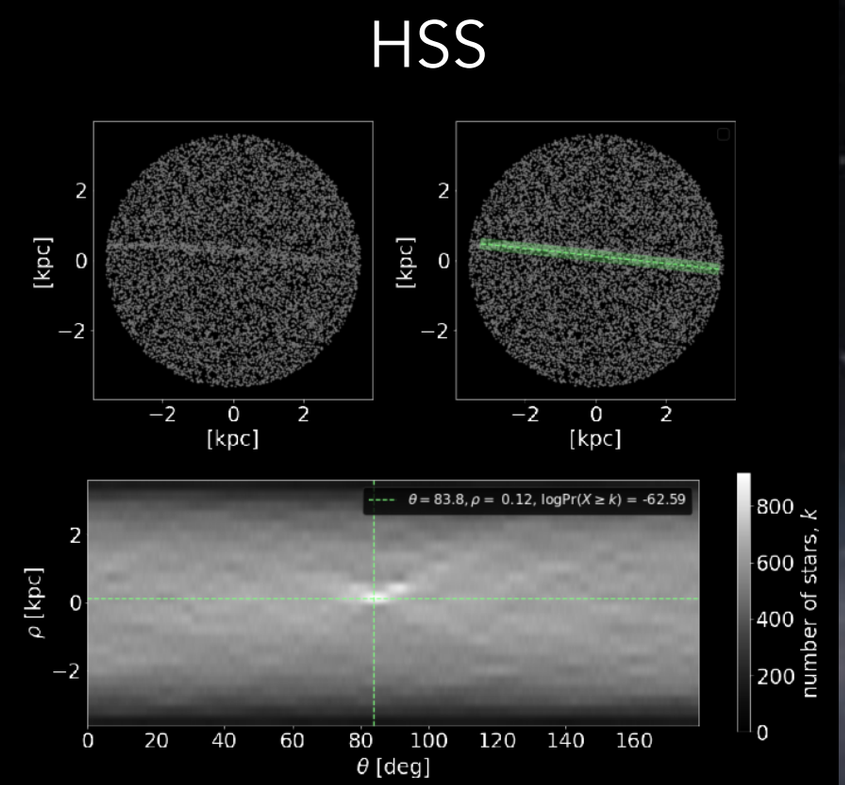


50% Pal 5 in 1h Roman data of M31

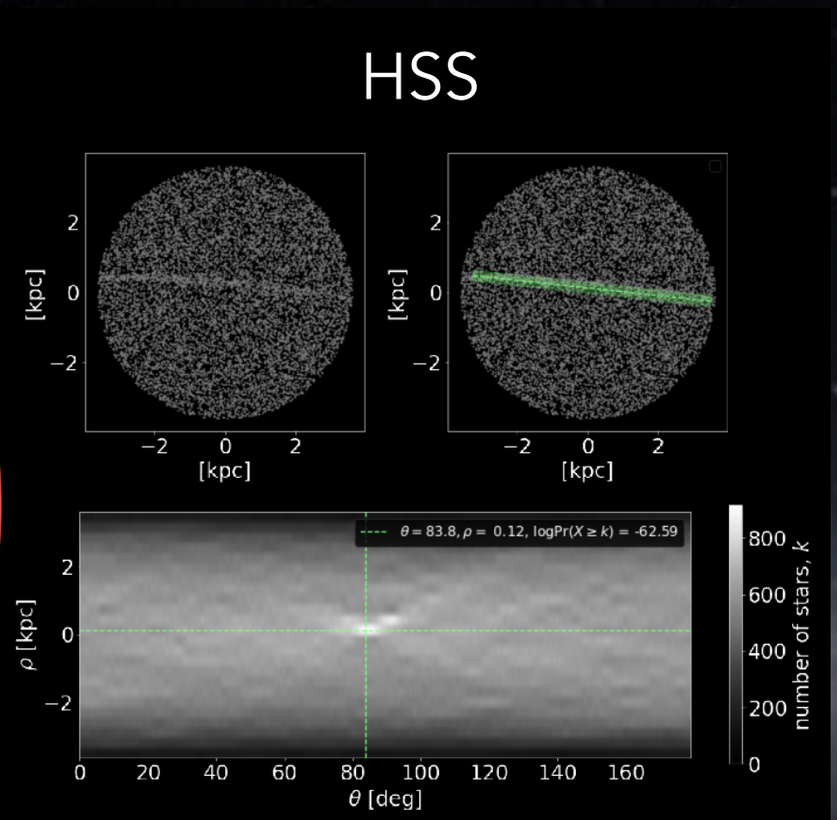
Image credit:
S5 Collaboration

Pearson, Clark, Starkenburg+ 2022

Systematic search for stellar streams

GC streams with the Roman Space Telescope

100s of nearby galaxies



50% Pal 5 in 1h Roman data of M31

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S5 Collaboration

Pearson, Clark, Starkenburg+ 2022

Exciting questions to ask

about thin streams in other galaxies

How many thin streams are there? How does this compare to GC populations/accretion histories? Does this affect M_{GC} vs halo mass relations (can we do better if we count streams also)?

Where are the long, thin streams located? What type of halos are consistent with their shapes? (T. Yavetz et al. 2021)

Do the streams have detectable gaps? (C. Aganze et al., in prep)

Can we use external streams for potential recovery?
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S5 Collaboration

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Image credit:
S5 Collaboration

Summary

There are no streams more massive than 5 x Pal 5 in the M31 PAndAS data

We find 27 GC stream candidates in M31 with the Hough Stream Spotter (HSS), need deeper data to confirm

Roman combined with HSS will find Pal 5-like and lower mass GC streams in 100s of nearby galaxies

Future work: gaps searches, potential recovery, orbit structure

Thanks!

Image credit:
S5 Collaboration