~~Boundary between~~ Dwarf Galaxies and Star Clusters

Ting S. Li
University of Toronto
on behalf of the S^5 (and DESI) collaborations

Dwarf Galaxies, Star Clusters, and Streams in the LSST Era
July 10, 2024

Southern Stellar Stream Spectroscopic Survey (S^5)

Key Members of S5 Team

https://s5collab.github.io/

Since 2018

Ting Li

Daniel Zucker

Geraint Lewis

Kyler Kuehn

Alex Ji

Sergey Koposov

Denis Erkal

Nora Shipp

Yao-Yuan Mao

Andrew Pace

Peter Ferguson

Kaitlin Webber
(Poster on S5)

Benjamin Cohen
(Poster on S5)

Sam Usman
(Poster on S5)

Aldo Mura

Guilherme
Limberg

and Joss Bland-Hawthorn, Gary Da Costa, Lara Cullinane, Eduardo Balbinot, Andrew Casey, Gayandhi De Silva, Alex Drlica-Wagner, Marla Geha, Terese Hansen, Sophia Lilleengen, Jennifer Marshall, Sarah Martell, Clara Martinez-Vazquez, Jeremy Mould, Josh Simon, Kathy Vivas and many more …

Disrupted/Disrupting Dwarf Galaxies and Star Clusters

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Dwarf Galaxies, Star Clusters, and Streams in the LSST Era
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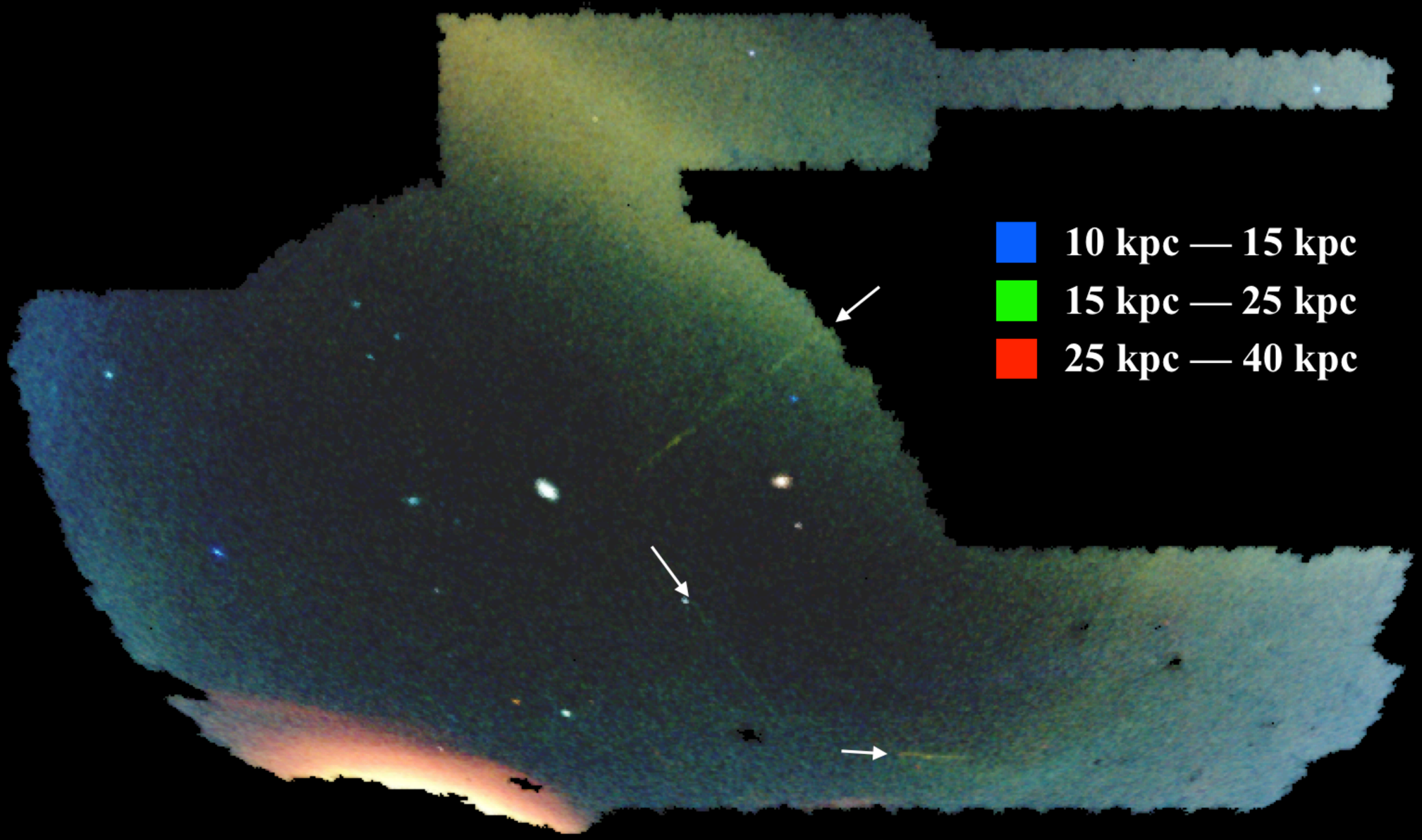
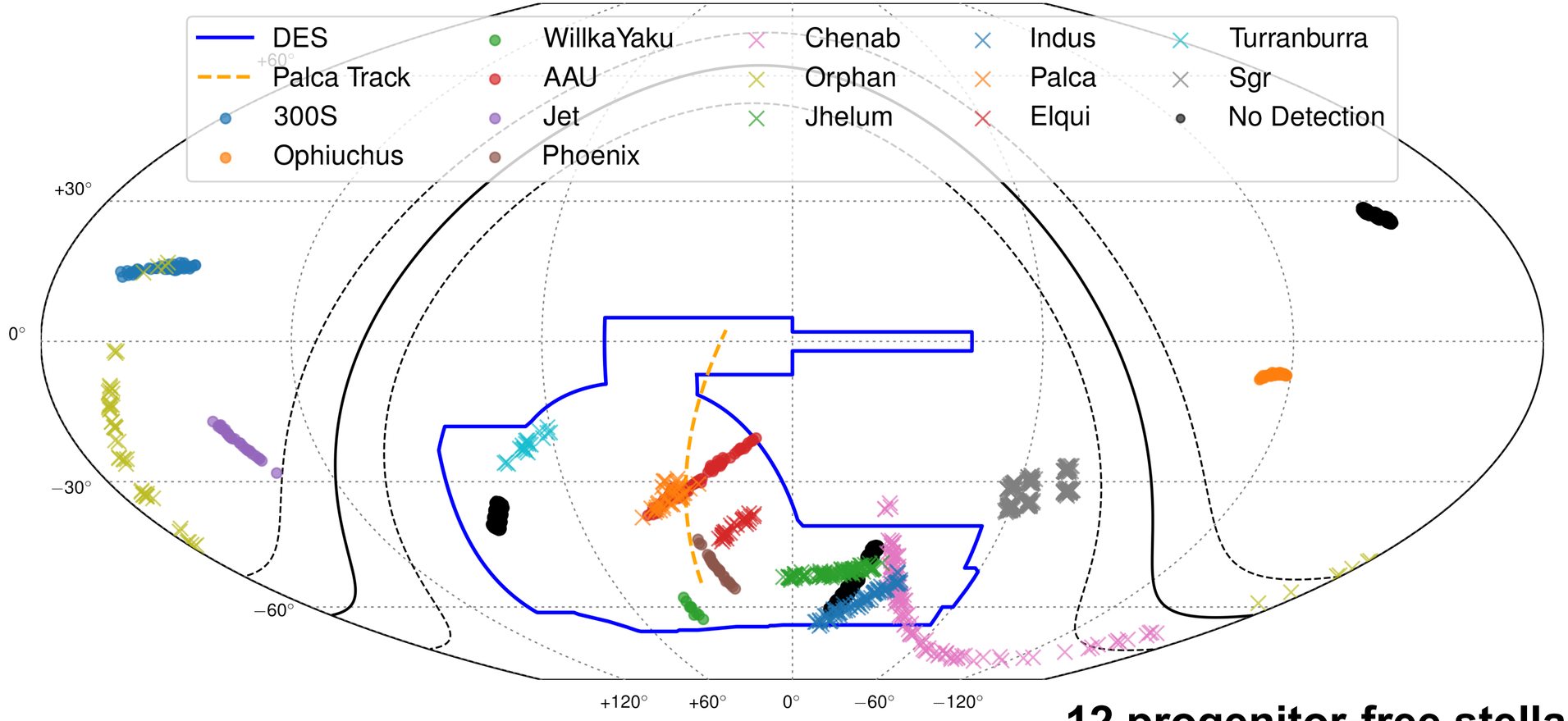
SOUTHERN SKY



Dark Energy Survey DES / Shipp, Drlica-Wagner et al. 2018

Orbital and Chemical Properties of Stellar Streams

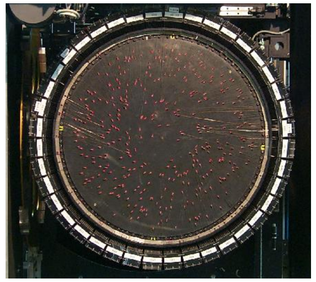


S5: The Orbital and Chemical Properties of One Dozen Stellar Streams
TSL et al (2022), arXiv: 2110.06950

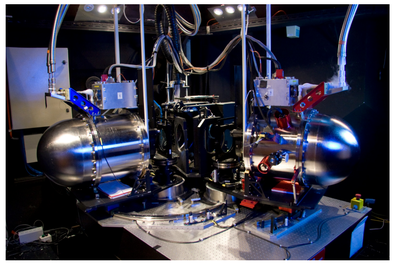
12 progenitor-free stellar streams at ~10-50 kpc observed in 2018-2020

S^5: DES+Gaia+AAT+Magellan/VLT

3.9-m Anglo-Australian Telescope (AAT)



2-degree-Field (2df) fibre positioned



AAOmega spectrograph

Efficient Target Selection w/

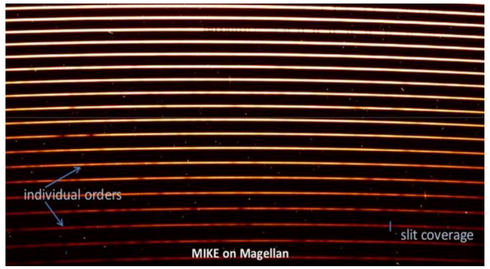
DES DR1 photometry Gaia DR2 proper motions

DARK ENERGY SURVEY

gaia

6.5-m Magellan Telescope

MIKE spectrograph



The Southern Stellar Stream Spectroscopic Survey (S5): Overview, Target Selection, Data Reduction, Validation, and Early Science
TSL et al. 2019, arXiv:1907.09481
(S5 Collaboration)

The Southern Stellar Stream Spectroscopic Survey (S5): Chemical Abundances of Seven Stellar Streams.
Ji, TSL et al (2020), arXiv: 2008.07568
(S5 Collaboration)

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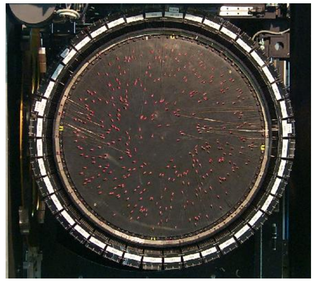

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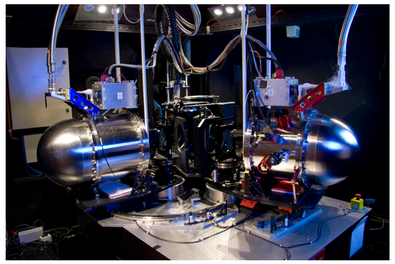

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DARK ENERGY SURVEY

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Check out posters by Sam Usman & Kaitlin Webber

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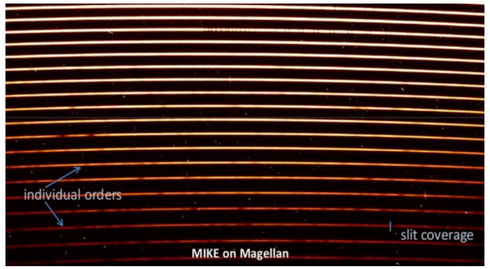

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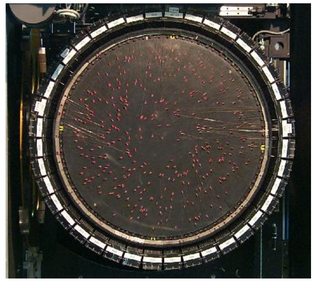
3.9-m Anglo-Australian Telescope (AAT)

Check out posters by Sam Usman & Kaitlin Webber

- 100+ AAT nights in 2018-2023
- 1 public data release (2018-2019)
- 16 papers published/submitted
- 7(?) papers in prep

https://s5collab.github.io/



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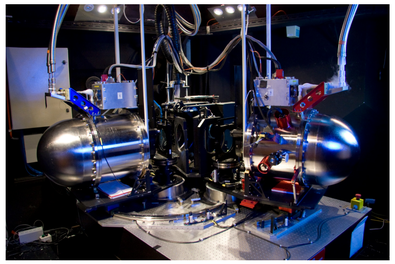

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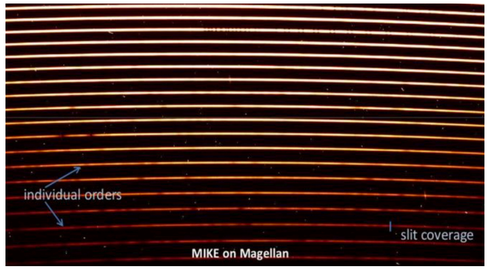

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Science with Stellar Streams

Formation of Milky Way's Stellar Halo

- *What are the building blocks of Milky Way's stellar halo?*
- *Where are the Pop III stars?*

Milky Way Mass & Potential

- *Is Milky Way's virial mass 0.8 or 1.6 x 10^{12} Msun?*
- *Is Milky Way's potential spherical or triaxial?*

Dark Matter Subhalos Mass Function

- *Is dark matter cold or warm or self interacting?*
- *Can we find dark matter sub halos at <10^{8} $M_{\odot}$?*

Globular cluster streams below [Fe/H] < -2.5

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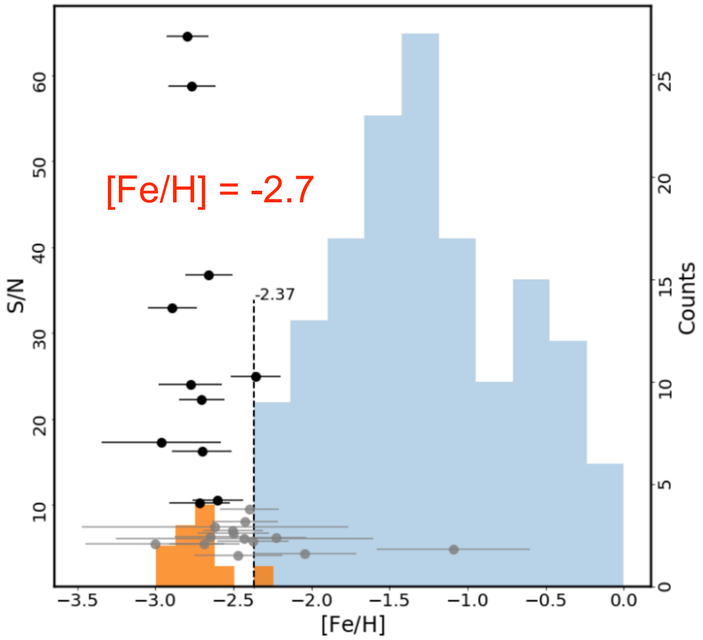
Phoenix Stream: more metal-poor than any known globular cluster



Cyan: globular cluster in Milky Way
Orange: stars in Phoenix Stream

Wan, Lewis, TSL et al. (2020) Nature
(S5 Collaboration)

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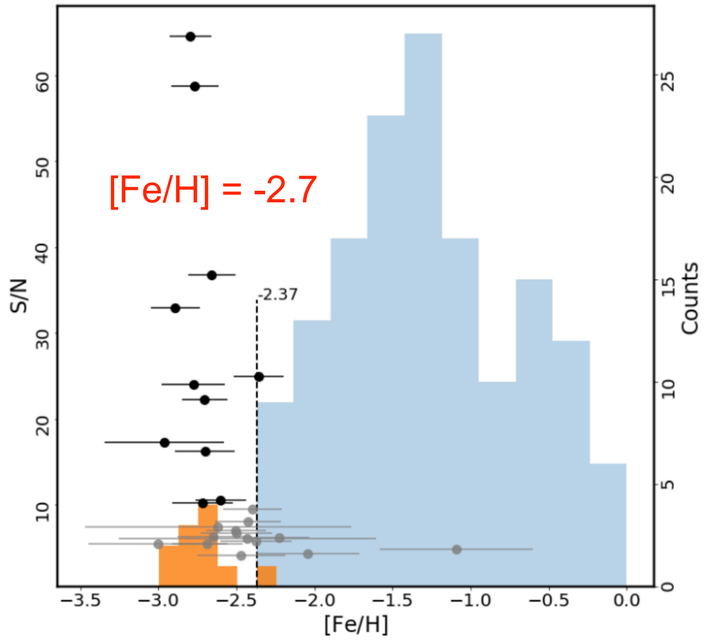

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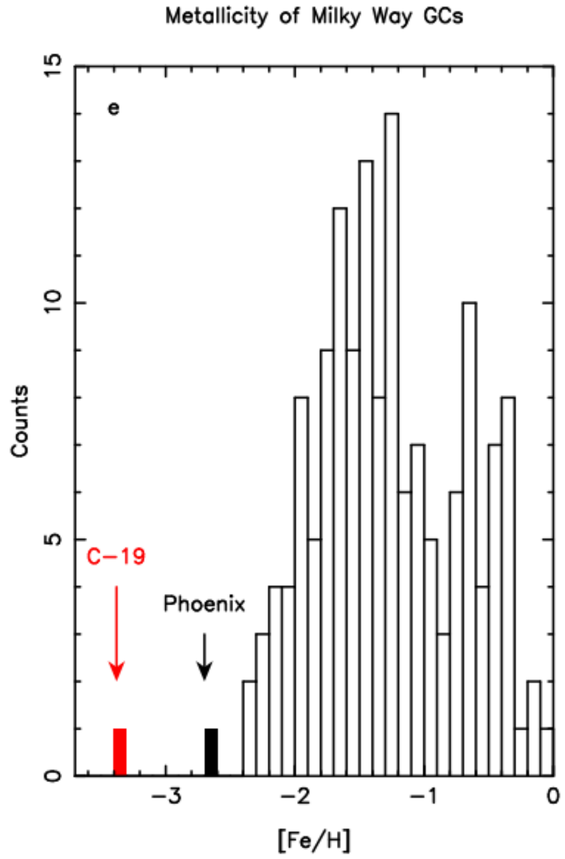
Orange: stars in Phoenix Stream

Wan, Lewis, TSL et al. (2020) Nature (S5 Collaboration)

C-19 Stream — [Fe/H] = -3.4!



Martin et al. (2022) Nature

Mass & Potential Constraints with Orphan-Chenab Stream

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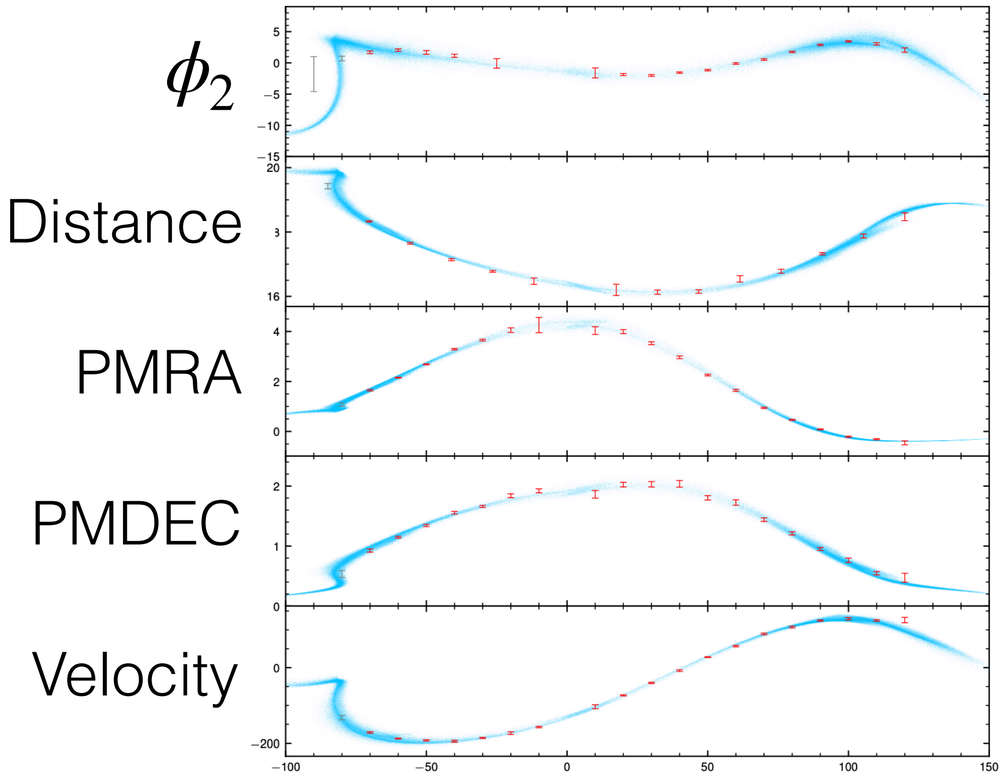
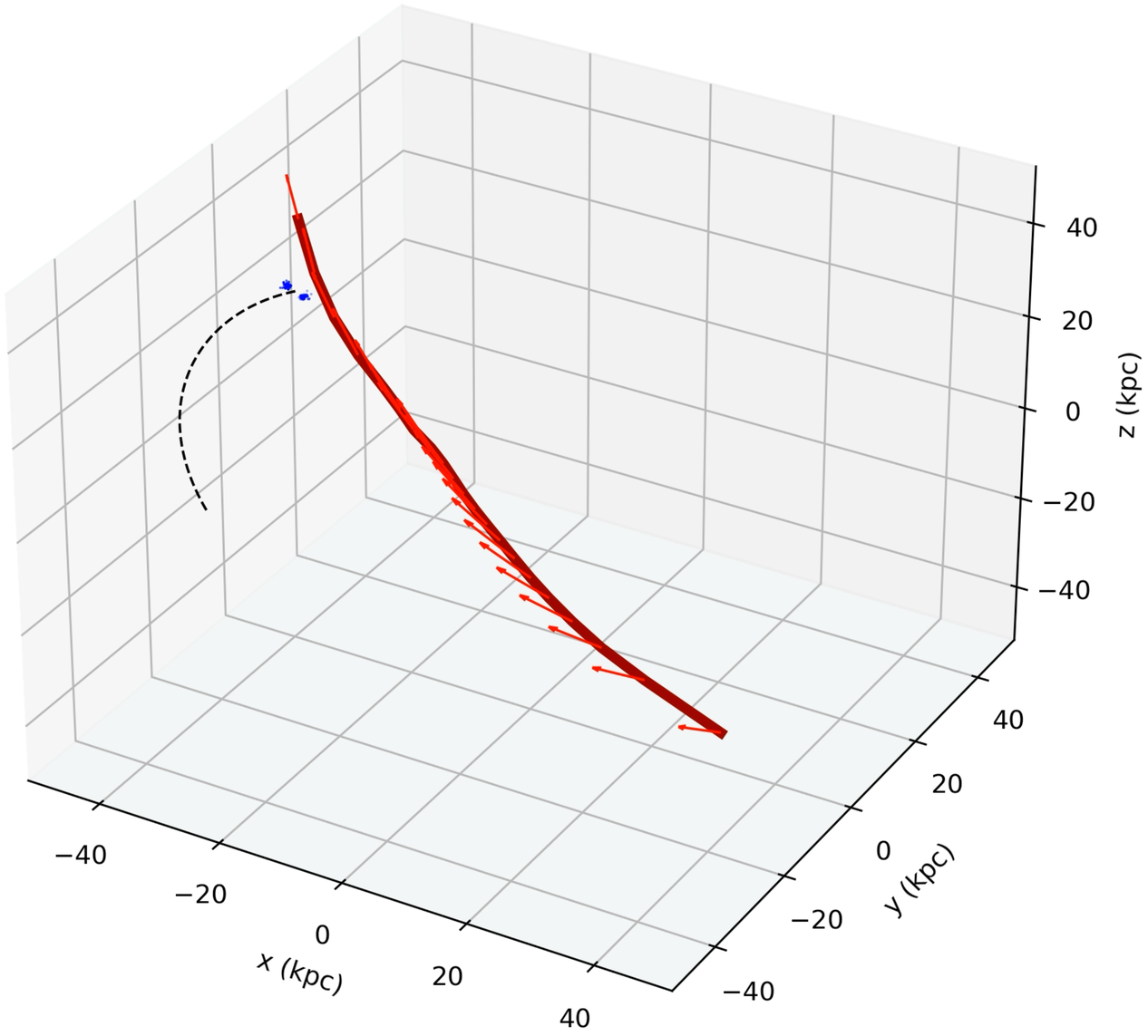
Constraint mass of Milky Way and LMC simultaneously



Koposov, Erkal, TSL et al. (2023) (S5 Collaboration)

See also Erkal+2019, Shipp+2021



Credit: Denis Erkal

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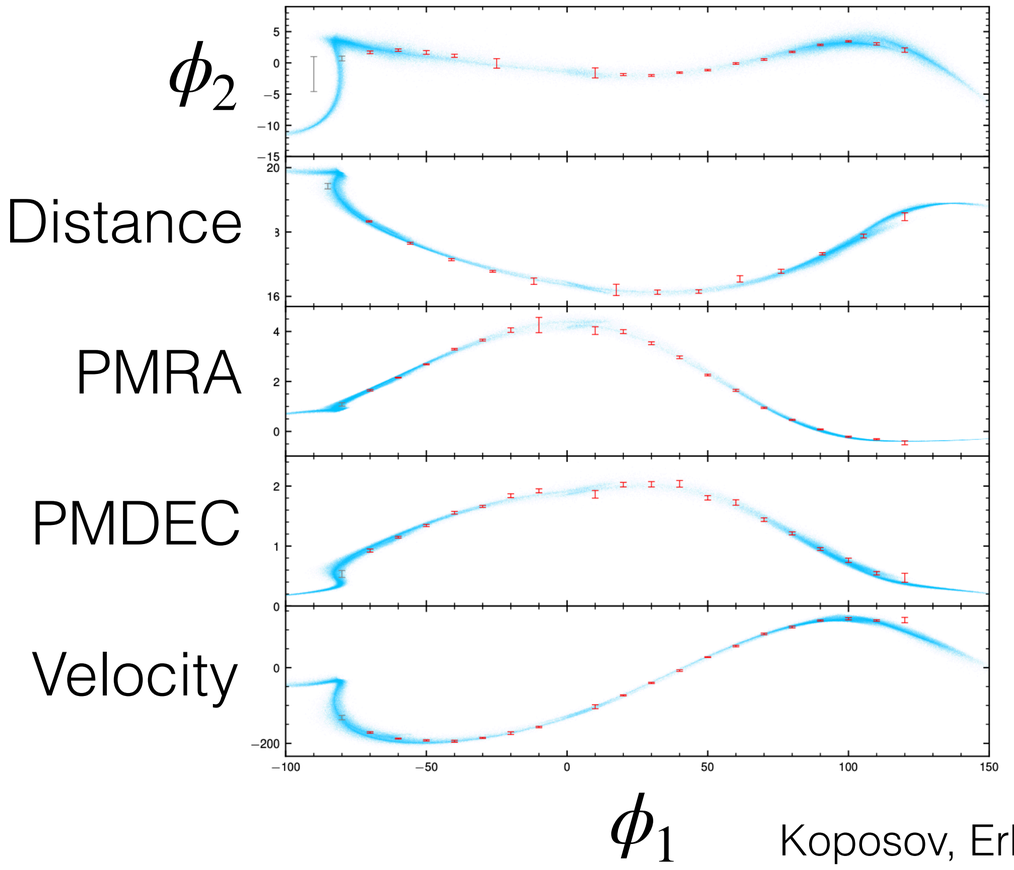

Koposov, Erkal, TSL et al. (2023) (S5 Collaboration)

Is the predicted kink real? Yes?!

Milky Way Mass & Potential

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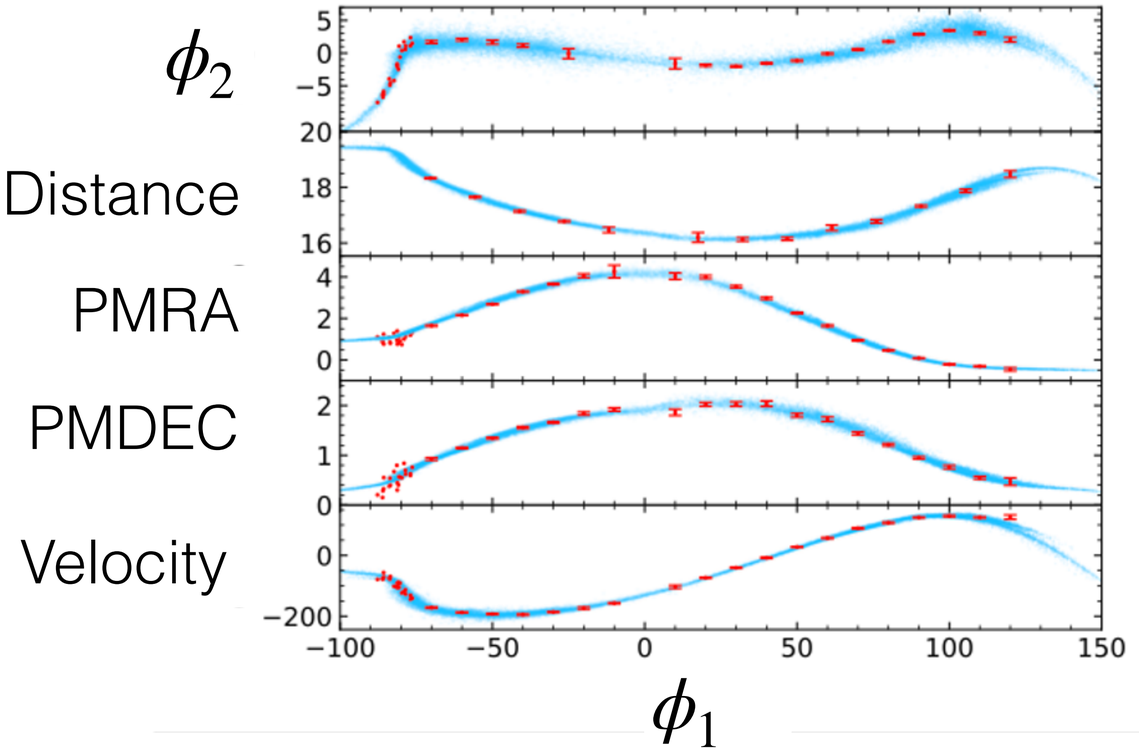
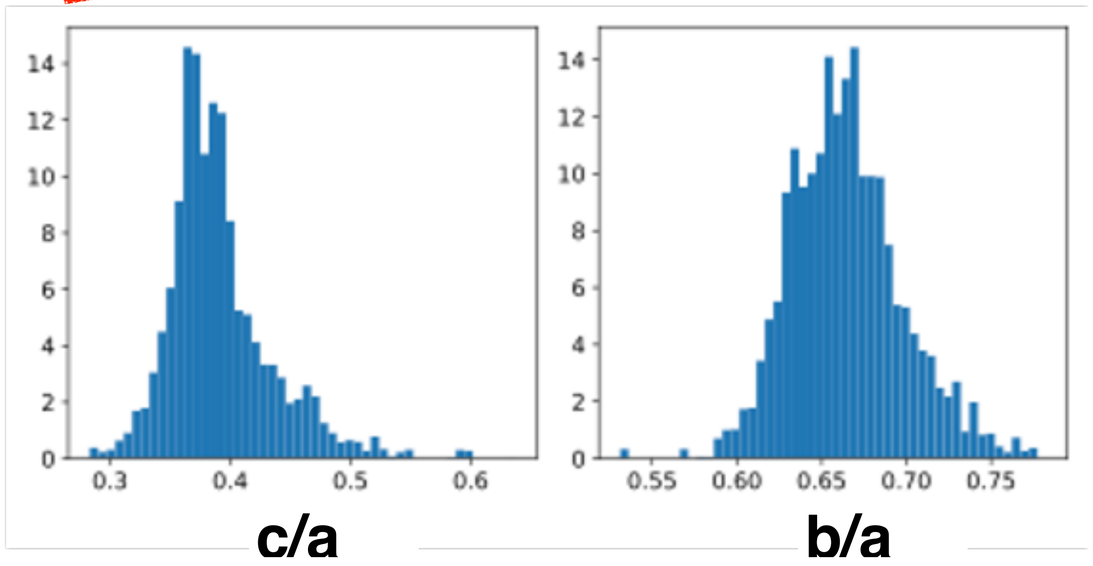


Erkal et al. In prep
(S5 Collaboration)

A triaxial halo is needed to fit the data

Preliminary



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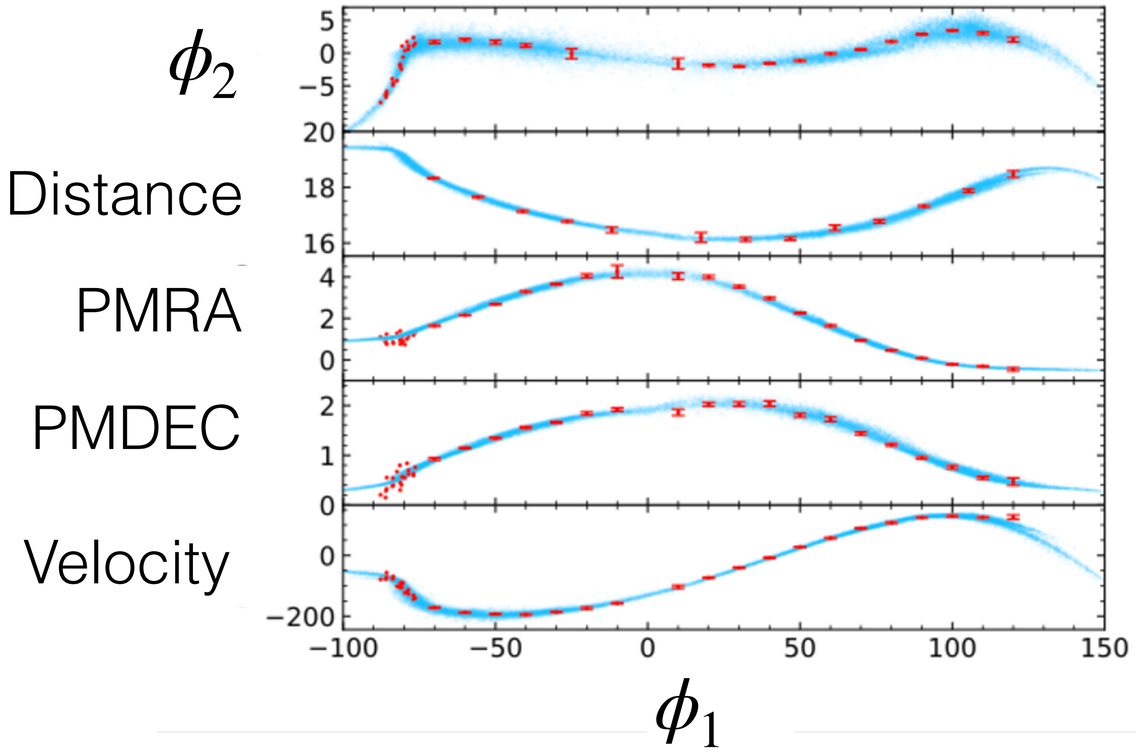

Erkal et al. In prep
(S5 Collaboration)

Streams perturbed by dark matter subhalos?

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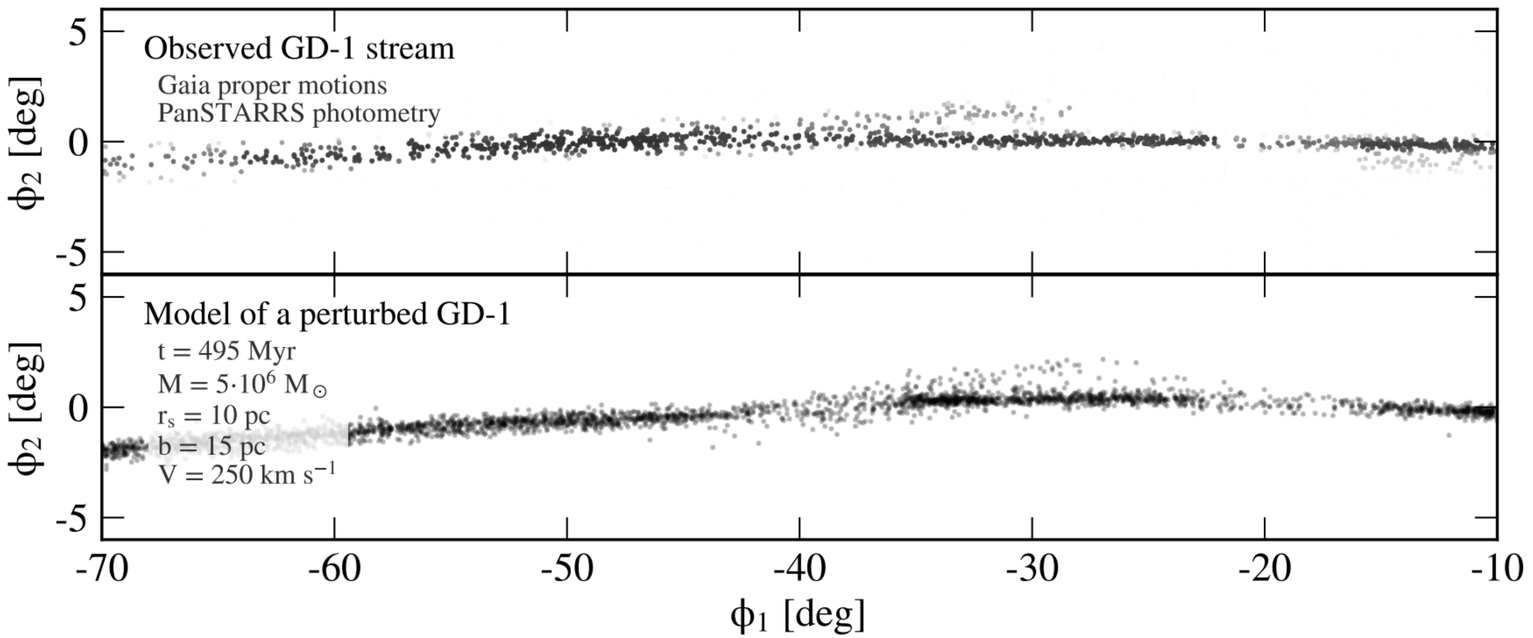

Bonaca et al. (2019)

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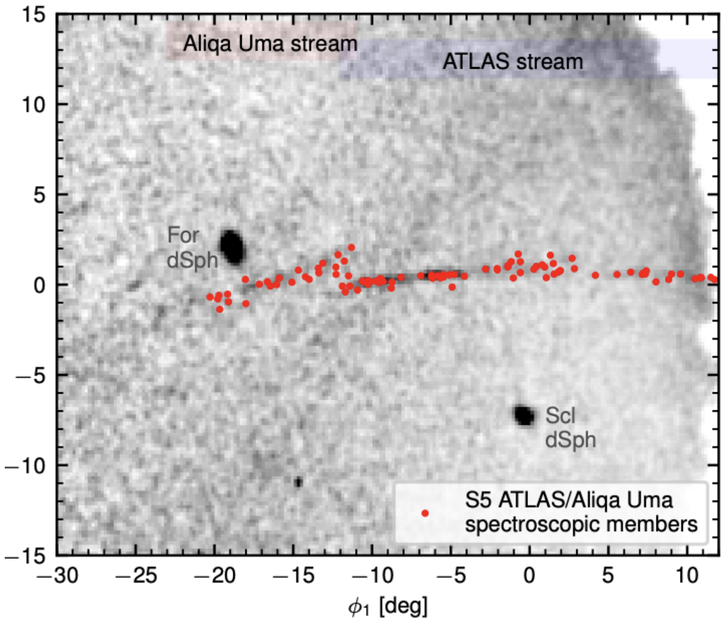
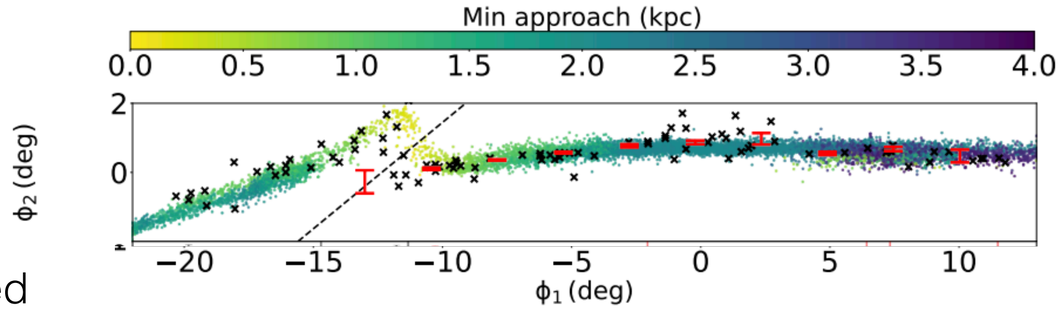
ATLAS-Aliqa Uma Stream @ 20-30 kpc



TSL et al. (2021)
(S5 Collaboration)

Perturber: $M_{sat} = 10^7 M_\odot$, $rs_{sat} = 0.3\,kpc$



Hilmi, Erkal et al, submitted
(S5 Collaboration)

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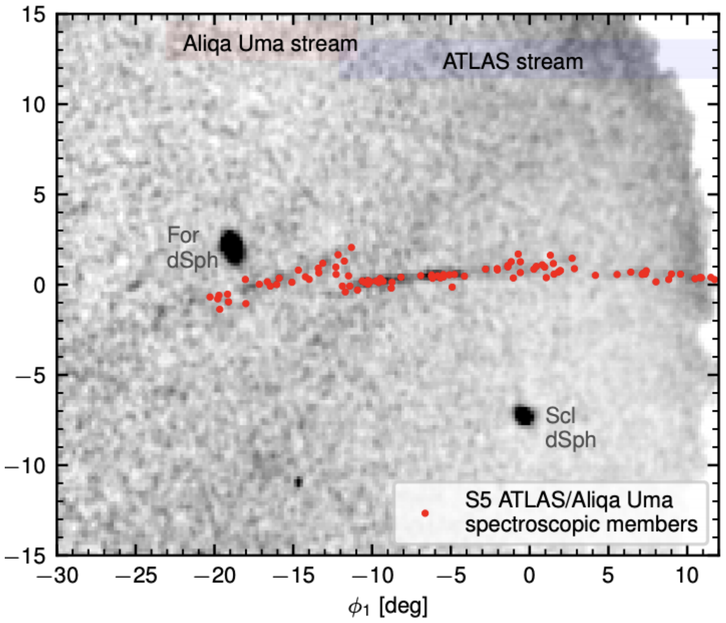
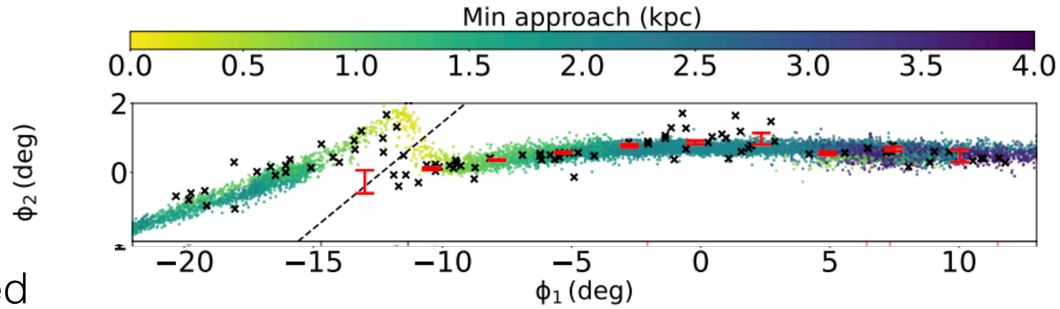


TSL et al. (2021)
(S5 Collaboration)

Check out Benjamin Cohen's poster a morphology study of the 300 km/s Stellar Stream, or 300S (also known as Gaia-10)

Perturber: $M_{sat} = 10^7\,M_\odot$, $rs_{sat} = 0.3\,kpc$



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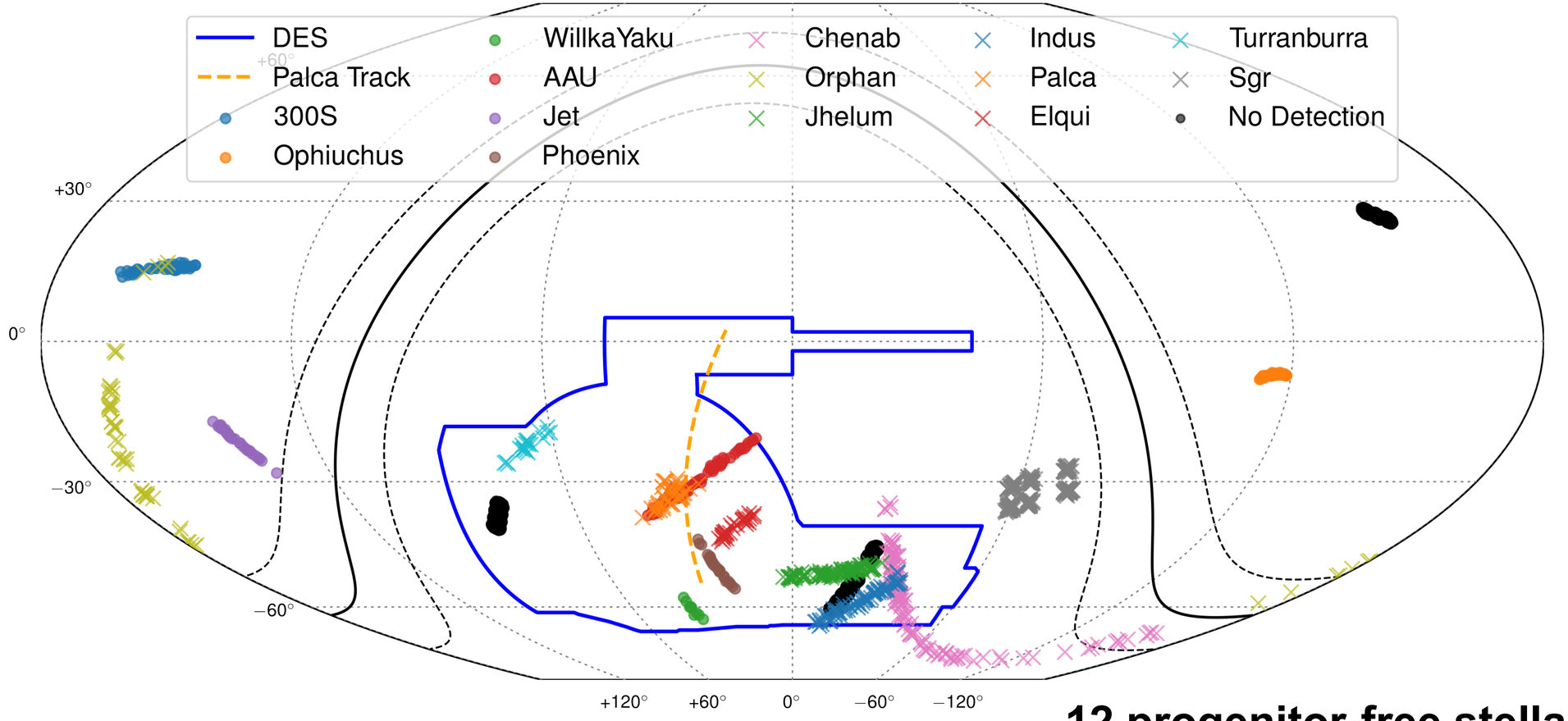
Orbital and Chemical Properties of Stellar Streams



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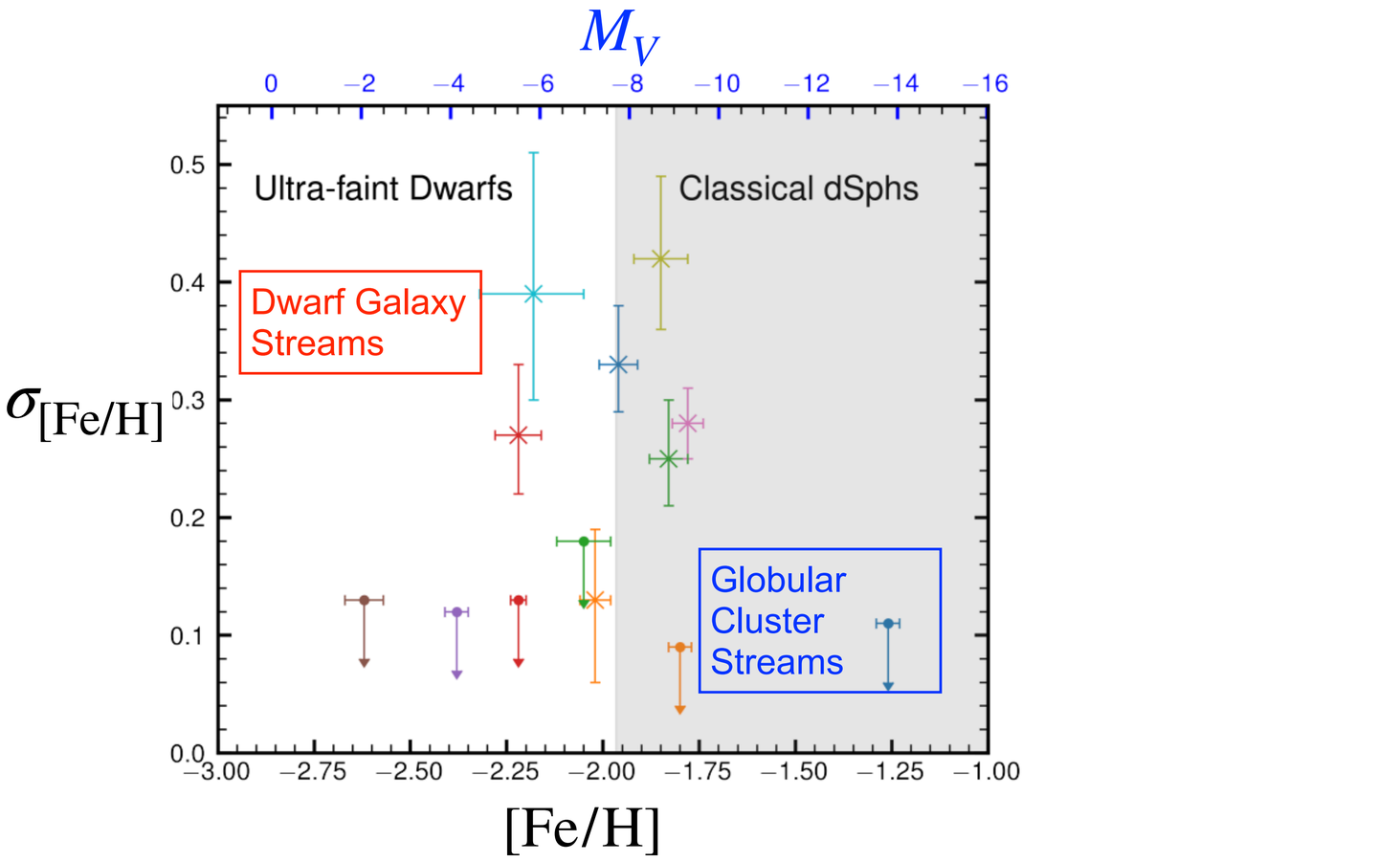
(S5 Collaborations)

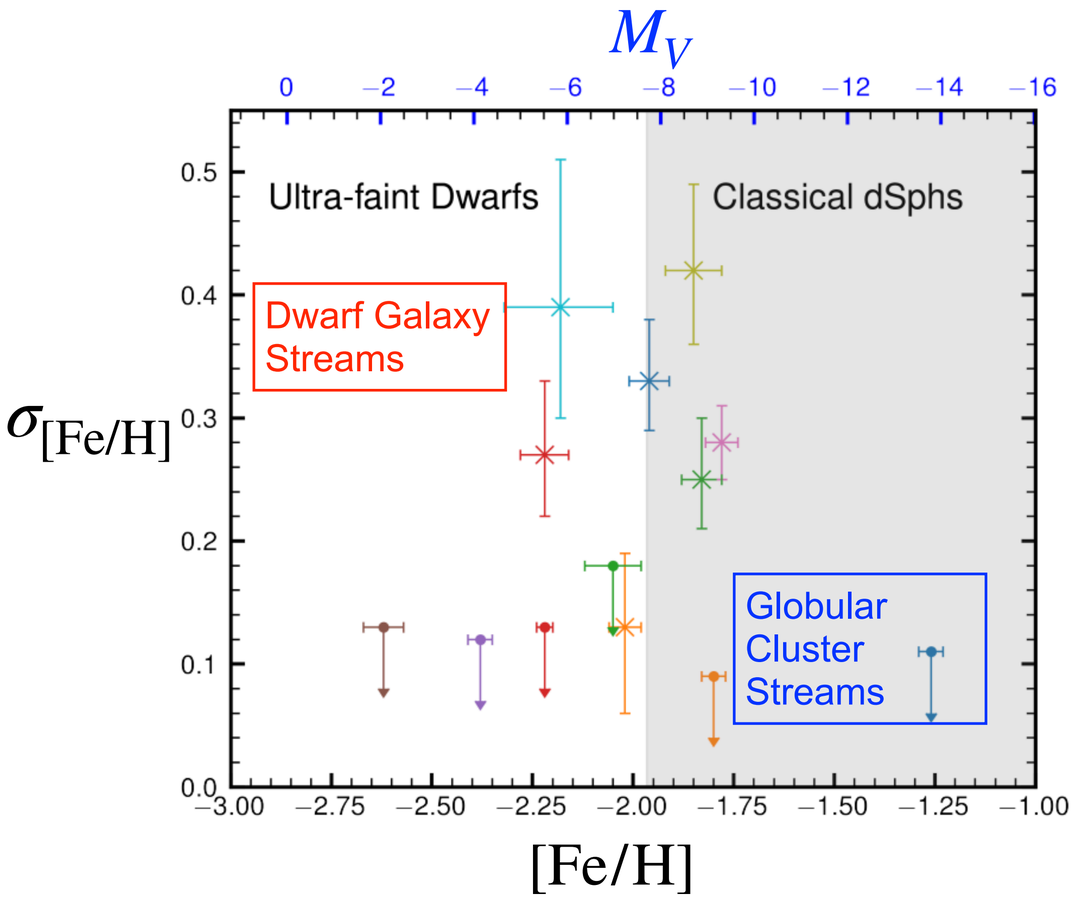
12 progenitor-free stellar streams at ~10-50 kpc observed in 2018-2020

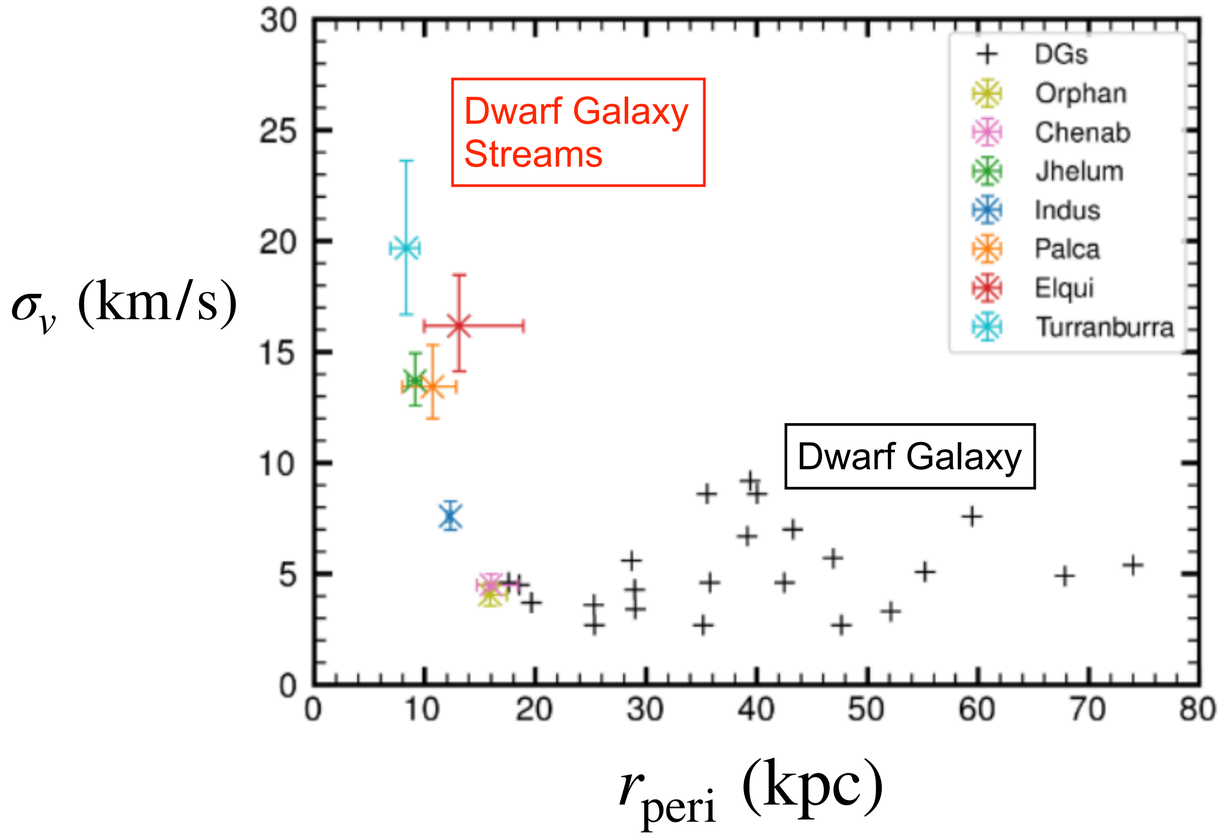
Luminosity / Stellar Mass of the Stream Progenitors: No more metal-rich / massive dwarf galaxy streams



TSL et al (2022)
(S5 Collaboration)

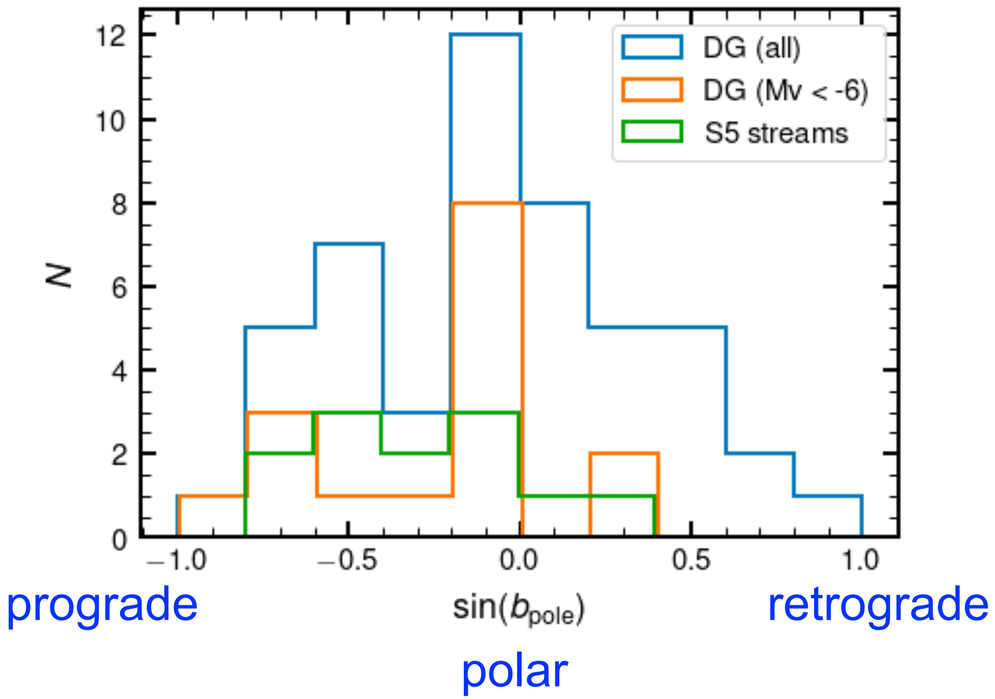
Velocity dispersion of disrupted dwarfs: orbital dependent? Smaller pericenter, higher dispersion





TSL et al (2022)
(S5 Collaboration)

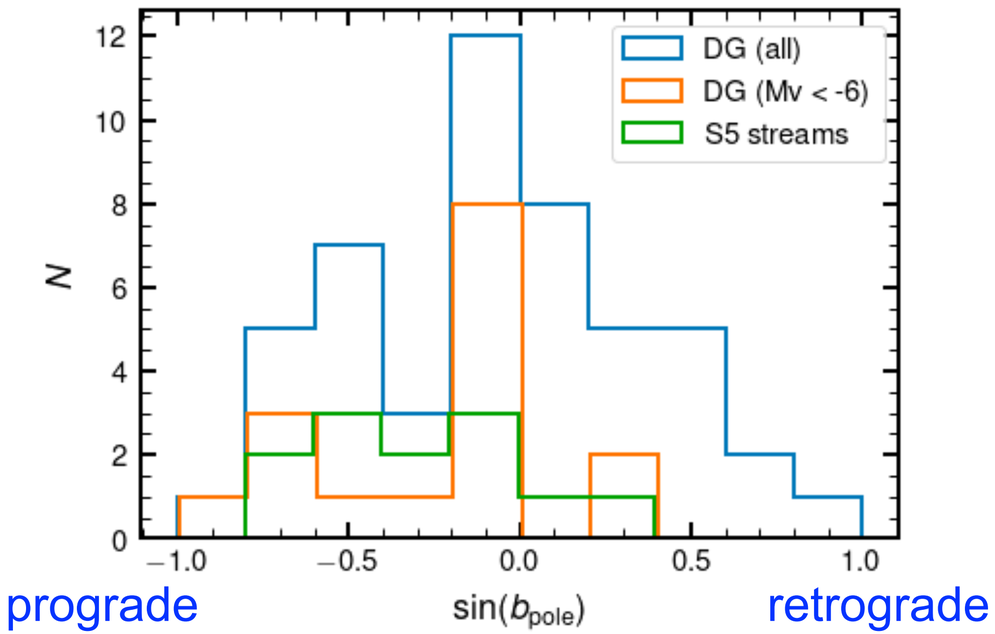
Orbits of the streams:
more prograde than retrograde, similar to massive dwarf galaxies

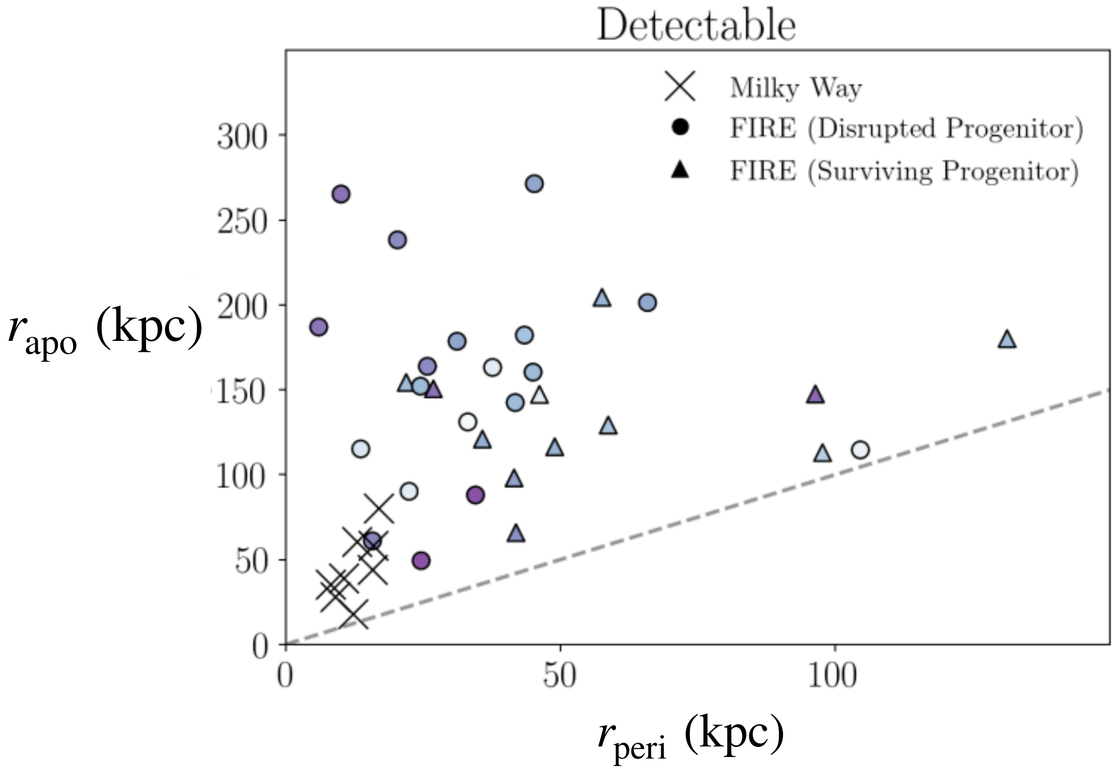


Both massive dwarf galaxies (DGs) and streams prefer a prograde orbit.

TSL et al (2022)
(S5 Collaboration)

Orbits of the streams:
observations have closer orbits than FIRE simulations (over disruption?)





Both massive dwarf galaxies (DGs) and streams prefer a prograde orbit.

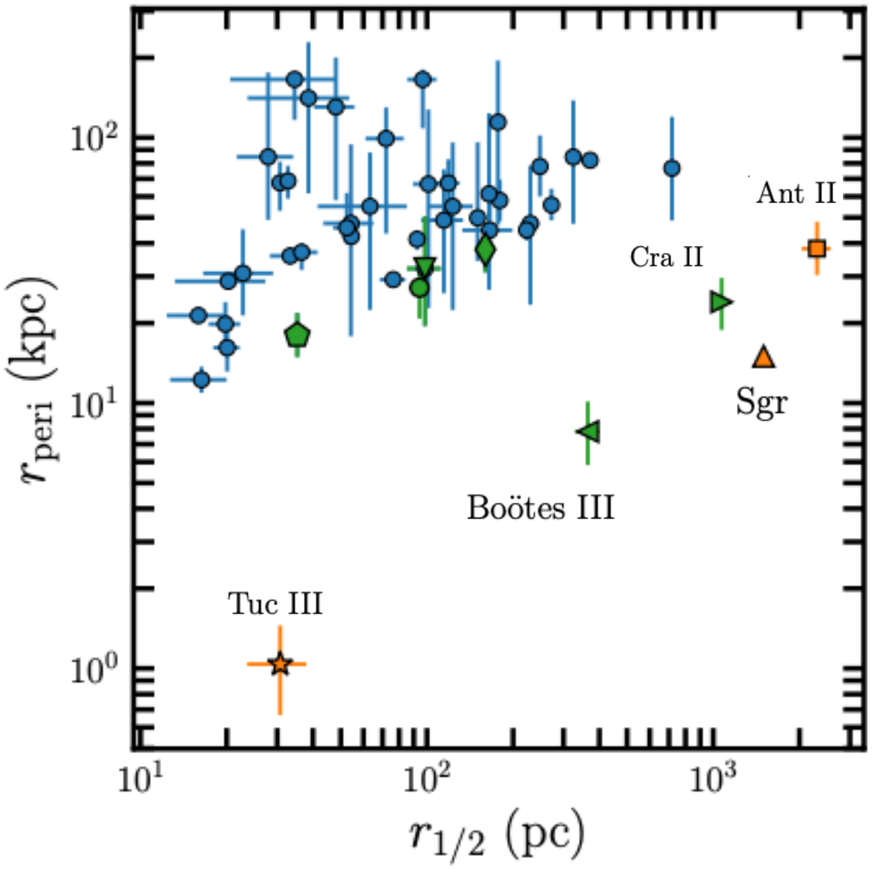
TSL et al (2022)
(S5 Collaboration)

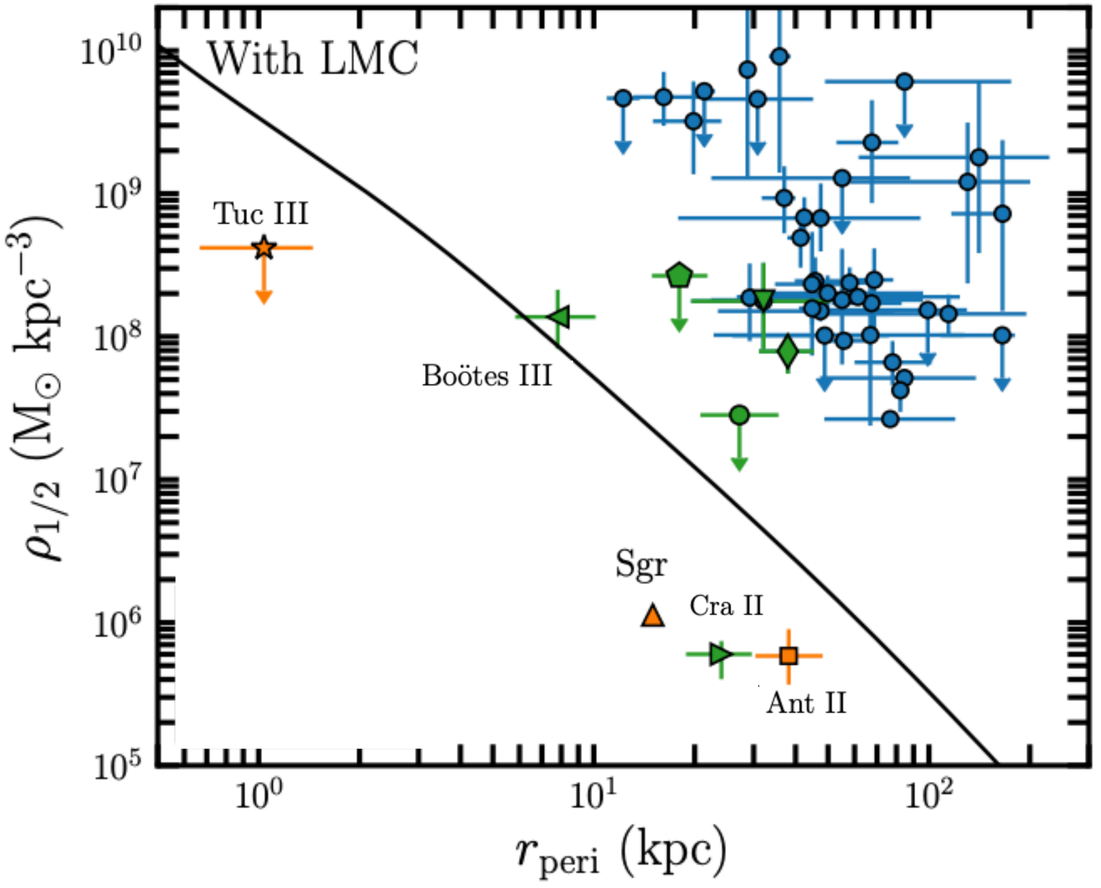
Shipp et al. w/ TSL (2022)
(S5 & FIRE Collaboration)

Now moving from
Progenitor-less Streams / Disrupted Dwarfs
To
Streams w/ Progenitor / Disrupting Dwarfs

Disrupting star clusters in backup slides

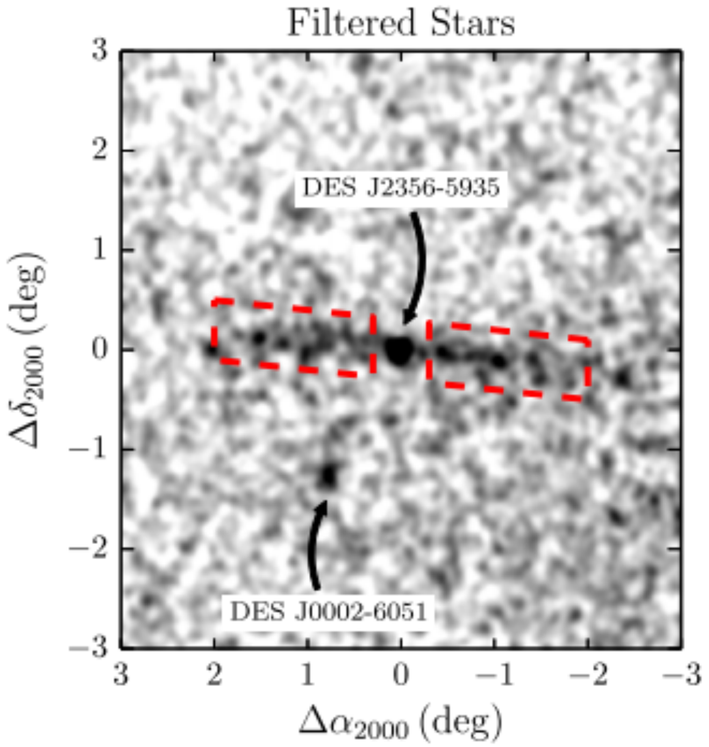
Disrupting dwarf galaxies



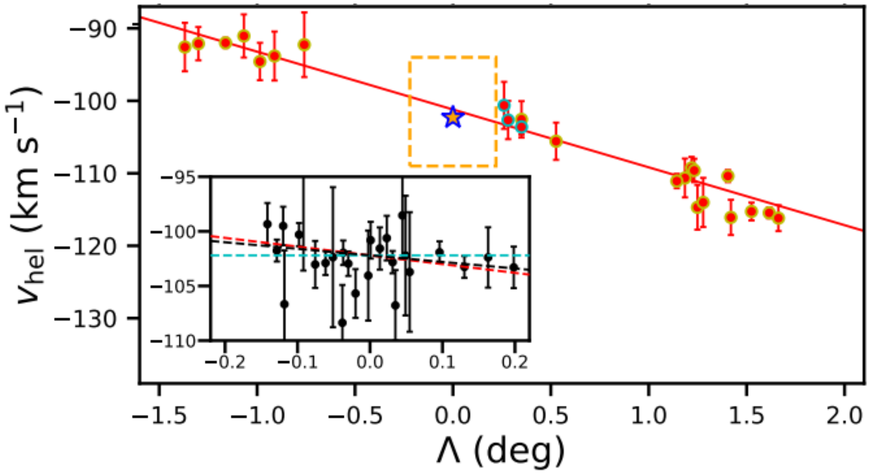


A. Pace, D. Erkal, TSL, 2022

Tucana III: a dwarf galaxy(?) with 1 kpc pericenter



Drlica-Wagner+2015
(DES collaboration)



TSL+2018
(DES Collaboration)

Antlia 2: An ultra diffuse galaxy in Milky Way?

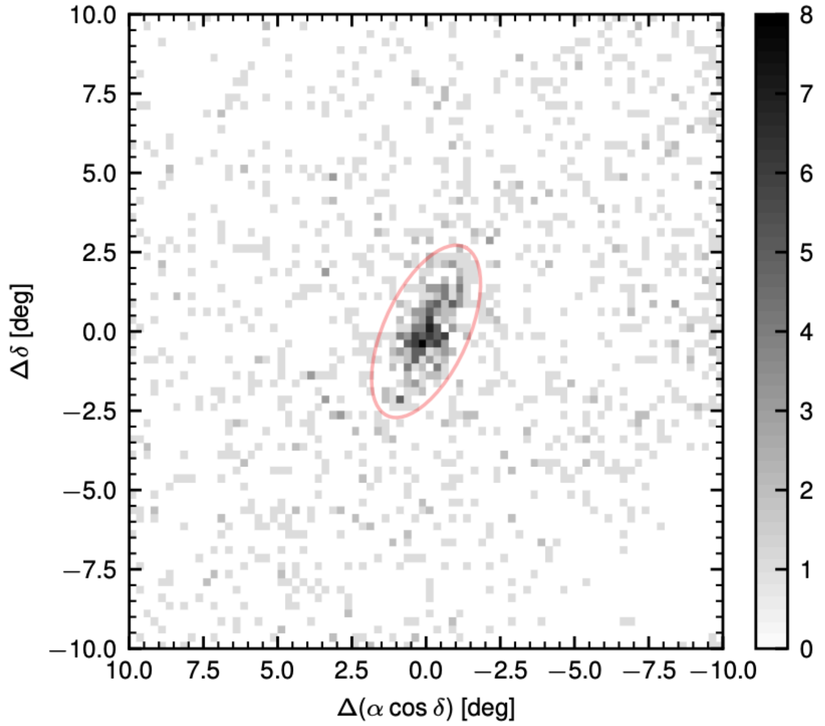
Distance: 130 kpc

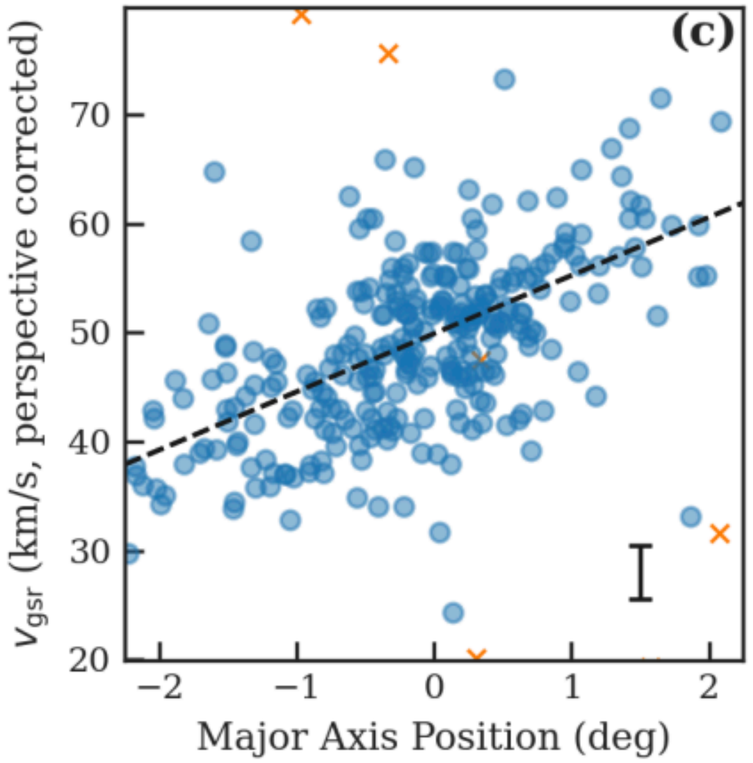
Size: half-light radius ~ 4 kpc

SB ~ 32 mag/arcsec^2

Pericenter: 40 kpc

Apocenter: 140 kpc

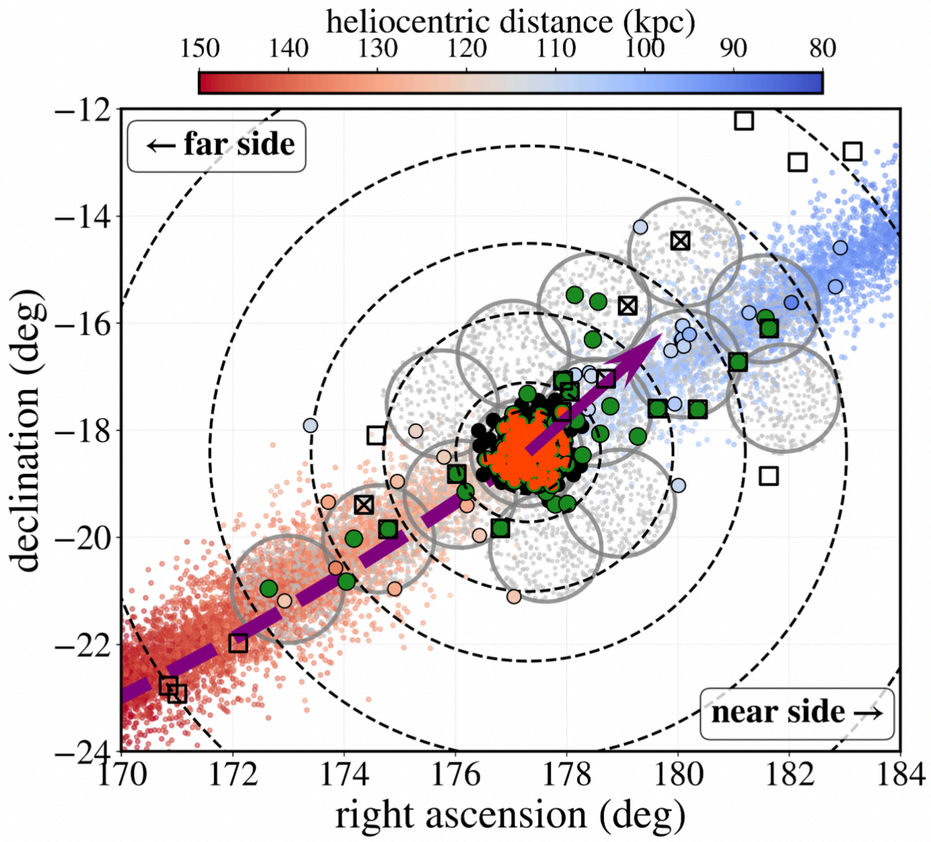




A. Ji, S. Koposov, TSL et al. 2021
(S^5 Collaboration)

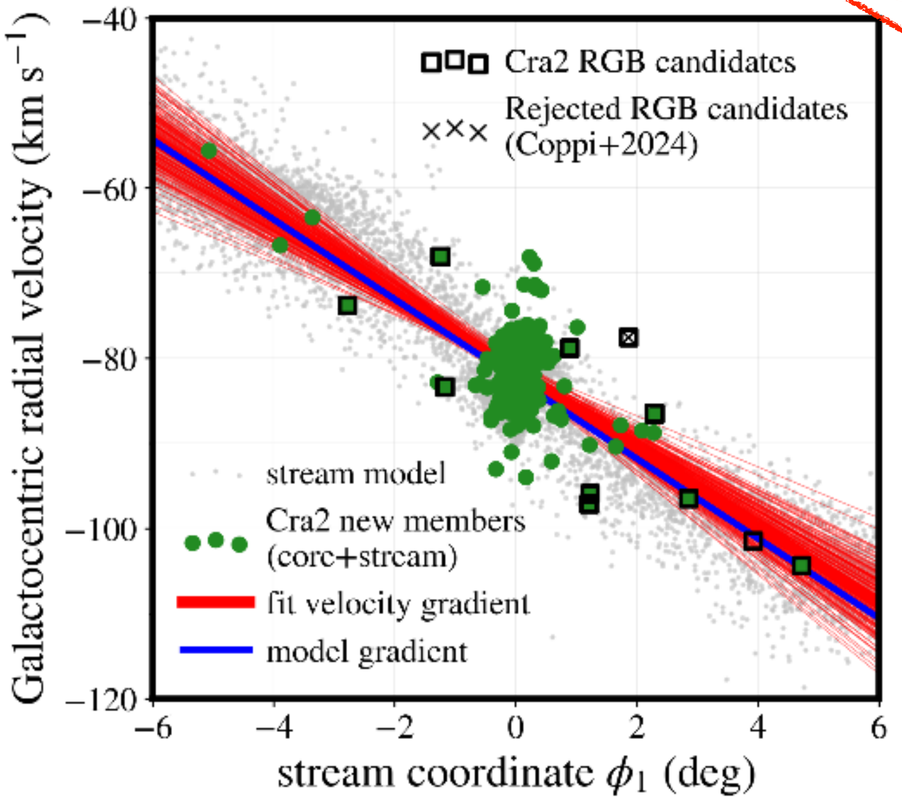
Crater II: tidal tails detected

Guilherme Limberg



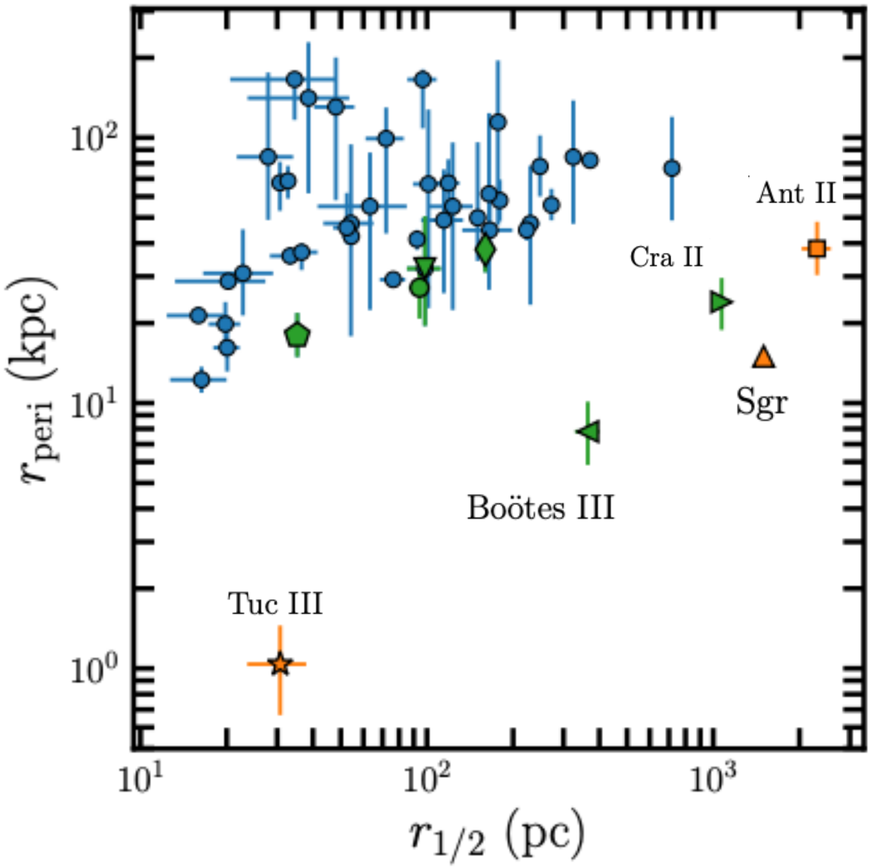
Velocity Gradient

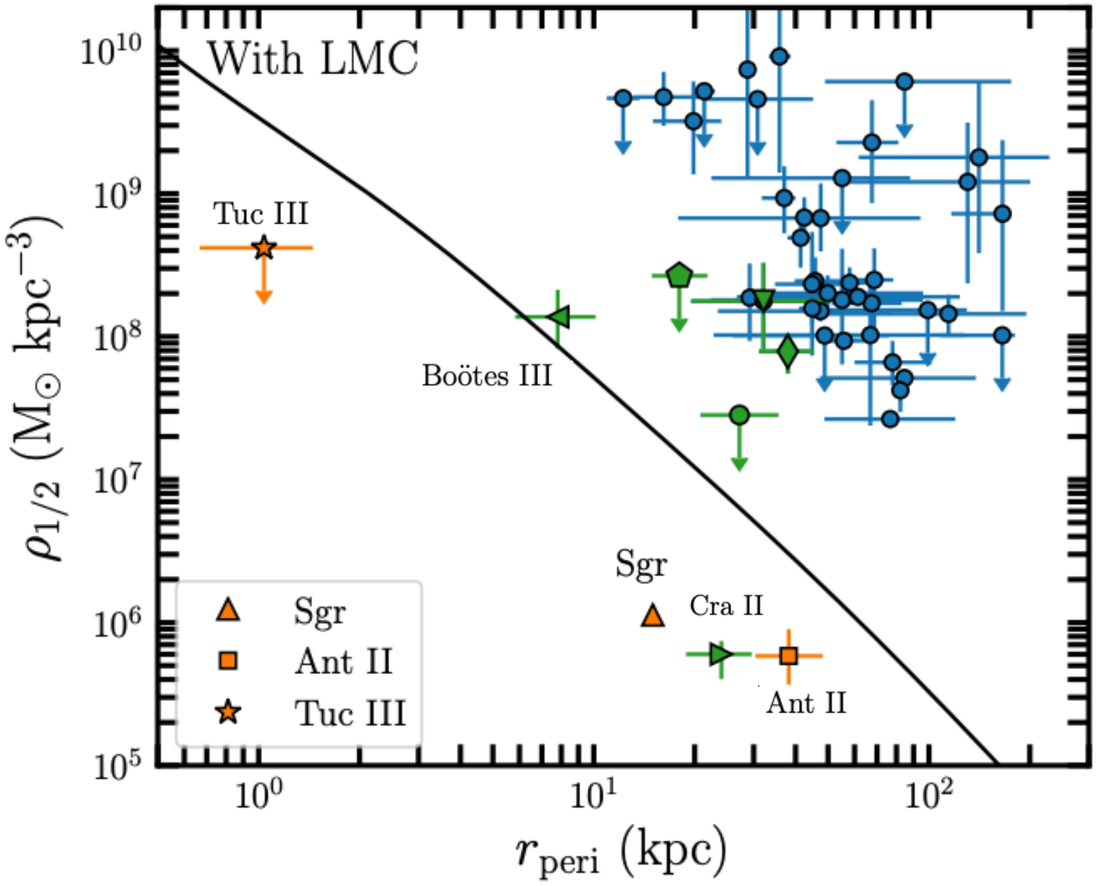
Preliminary



G. Limberg et al. (in prep)
(S5 collaboration)

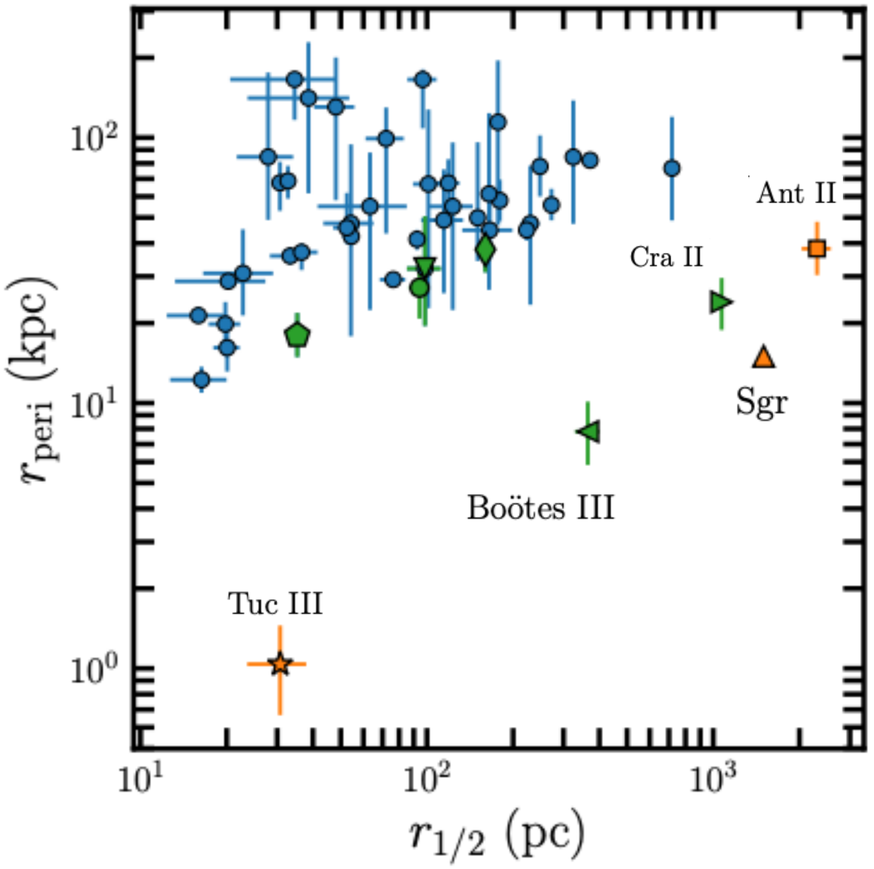
Bootes III: under tidal stripping?

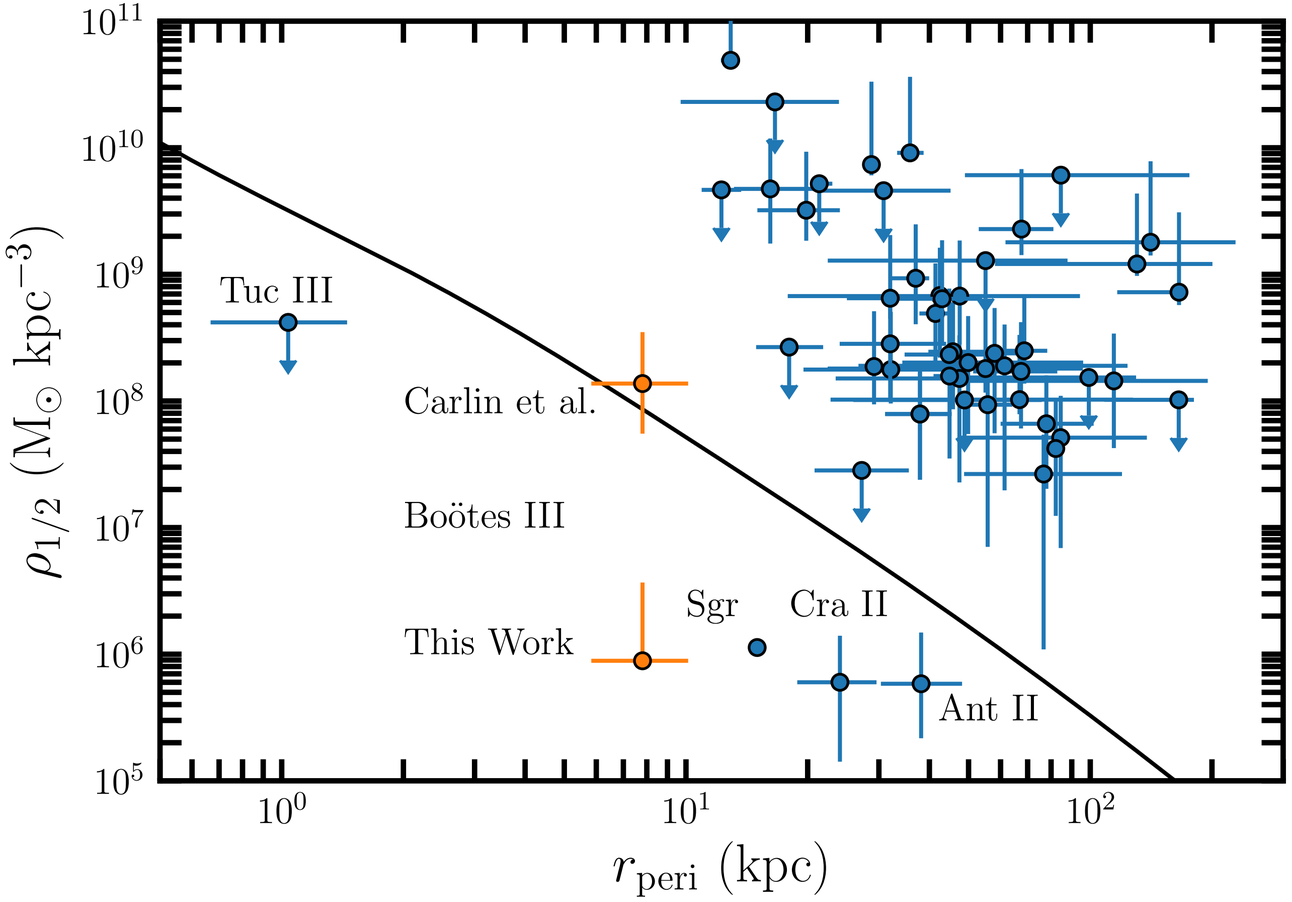




A. Pace, D. Erkal, TSL, 2022

Bootes III: under tidal stripping? Yes!

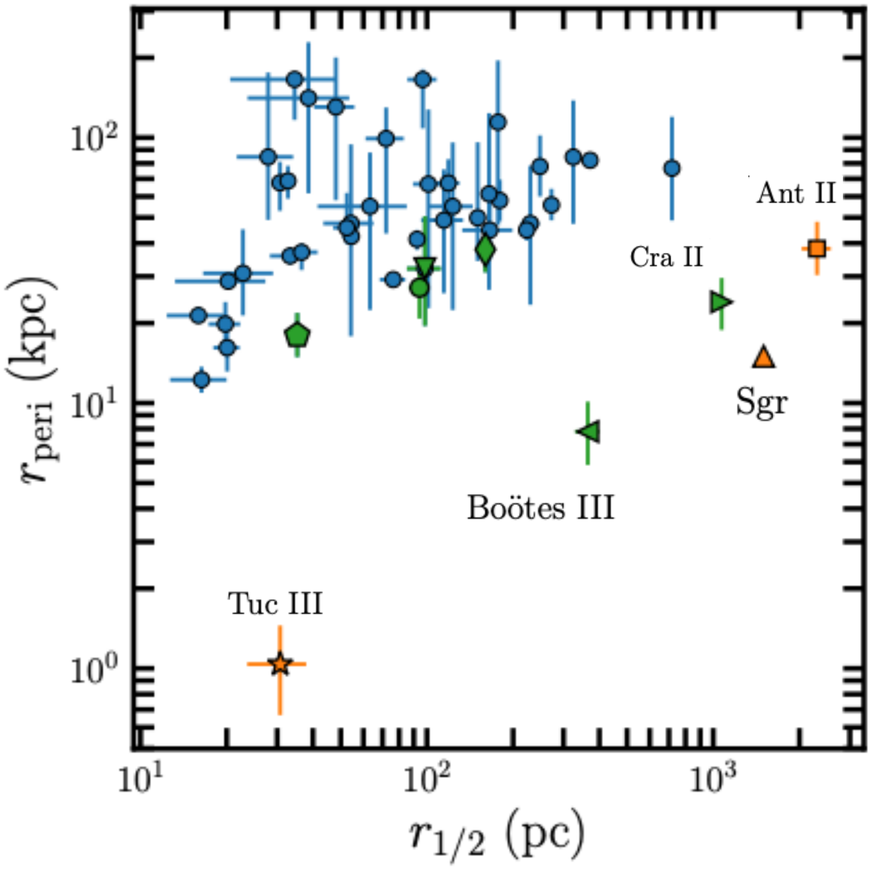


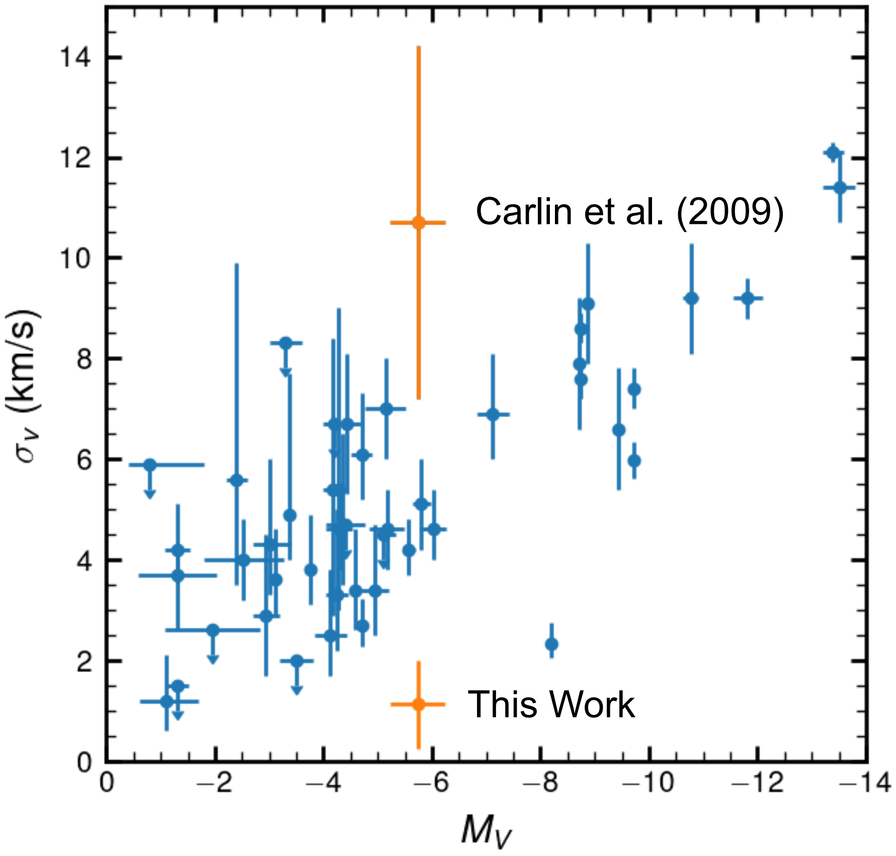


A. Pace, D. Erkal, TSL, 2022

TSL, S5 collaboration (in prep)

Bootes III: Velocity dispersion 10 —> 1 km/s

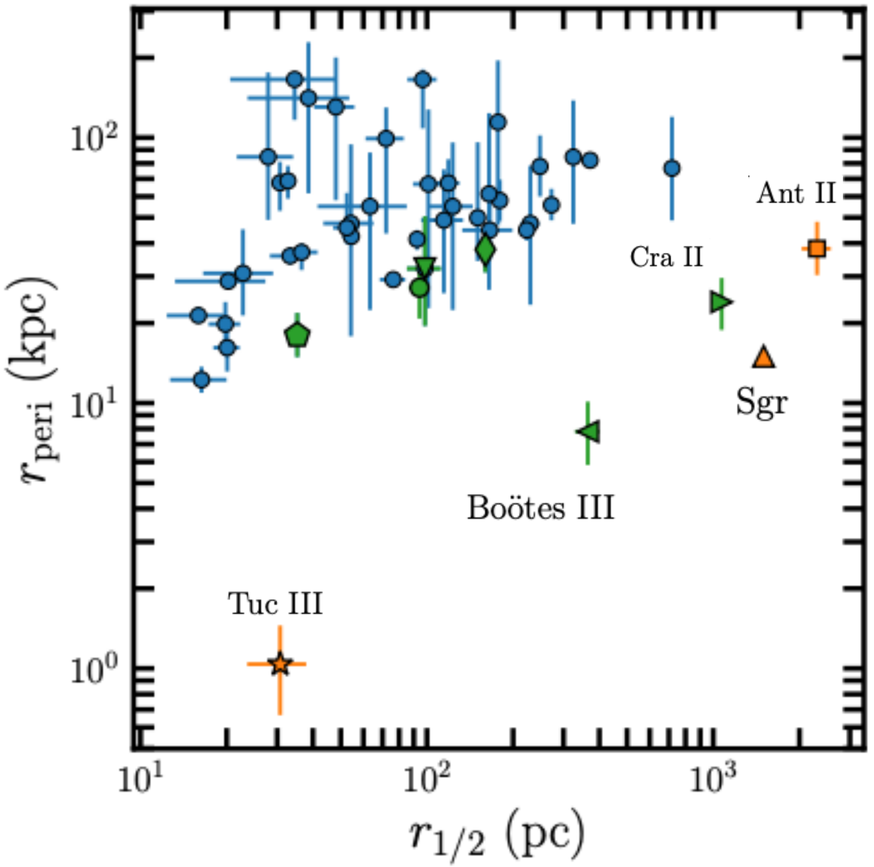


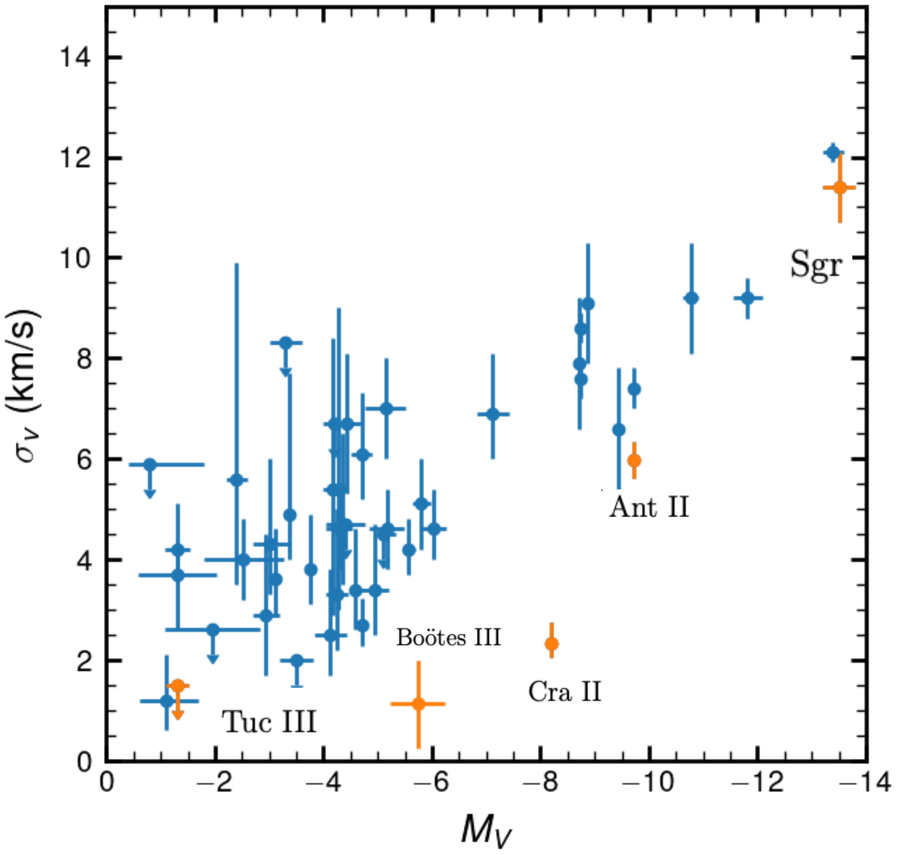


A. Pace, D. Erkal, TSL, 2022

TSL, S5 collaboration (in prep)

All disrupting dwarf galaxies have a smaller dispersion than intact ones



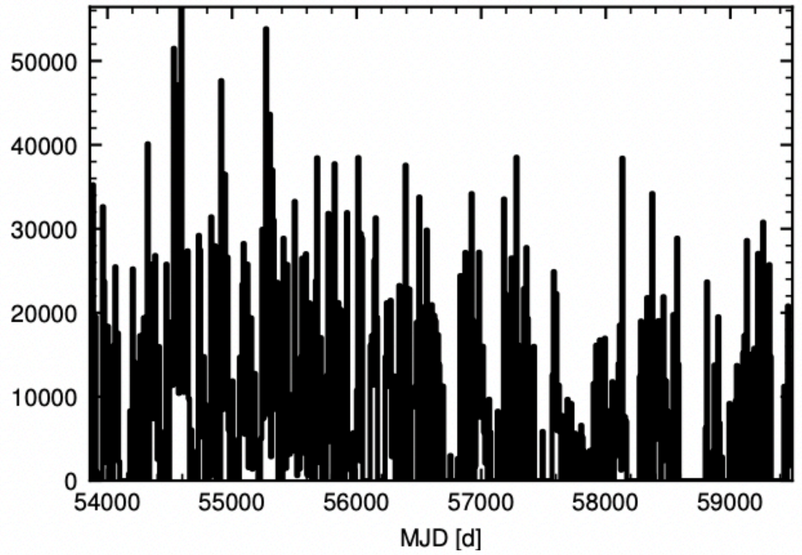


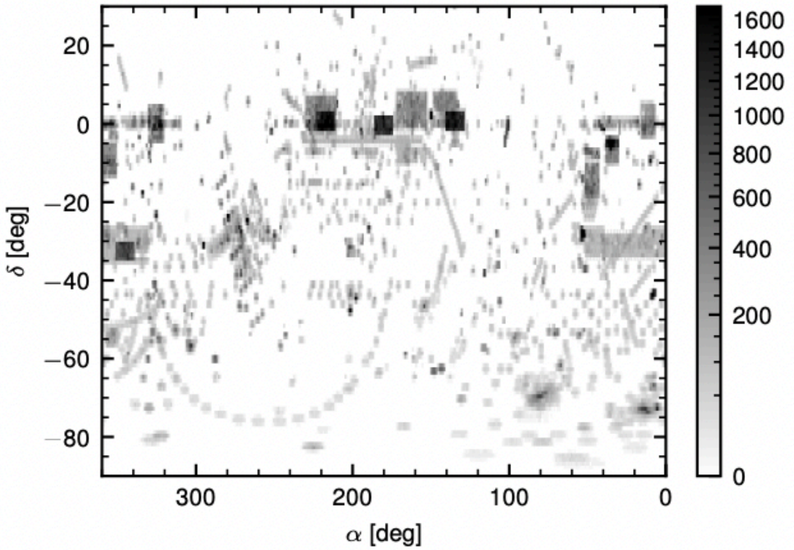
A. Pace, D. Erkal, TSL, 2022

TSL, S5 collaboration (in prep)

Data release plan for S5

- *S5 DR1: April 2021 (https://zenodo.org/records/4695135)*
  - *2018-2019*
- *S5 DR2: Early 2025?*
  - *2018-2023*
- *AAT Archival data release: Fall 2024?*
  - *2006- early 2022*
  - *Stellar catalog w/ S5 pipeline (+ all spectra)?*
  - *2.3M spectra, 0.9M good stellar fit*





DESI — Dark Energy Spectroscopic Instrument

DARK ENERGY SPECTROSCOPIC INSTRUMENT

U.S. Department of Energy Office of Science

MWS — Milky Way Survey

Co-chairs: Leandro Beraldo e Silva (U Arizona)
Ting Li (U of Toronto)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DARK ENERGY SPECTROSCOPIC INSTRUMENT

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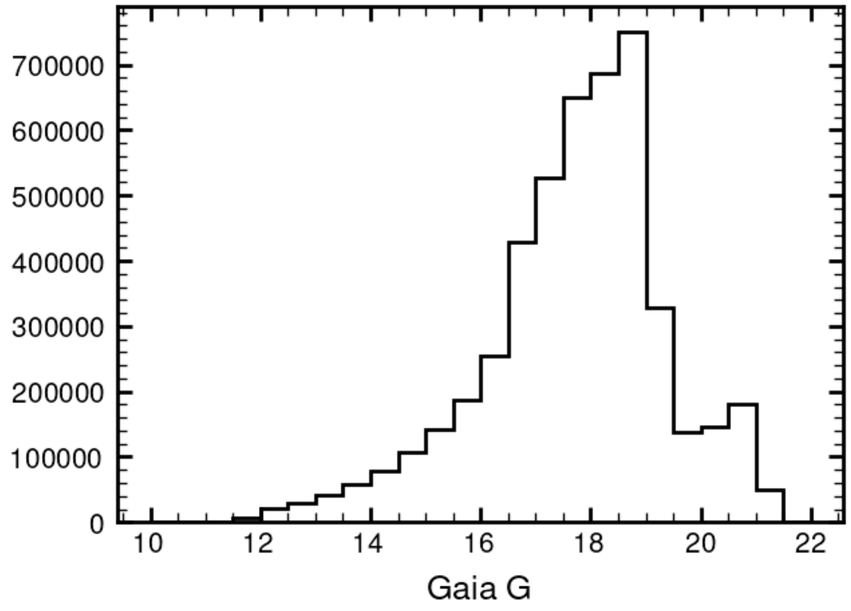
DESI Milky Way Survey



S5 also observes 16-19th mag
S5/AAT needs 2 hr, while DESI needs 3 min (dark) or 10 min (bright)

Systematic floor in RV: ~0.6-0.9 km/s

Draco dwarf galaxy: 200 members in 2 hrs
(60 hrs MMT time for 500 members)

- Early Data Release in June 2023
  - Commission + SV: Dec 2020 - May 2021
  - 600k targets observed (400k w/ RVerr < 10 km/s)

DESI Early Data Release Milky Way Survey Value-Added Catalogue
Koposov et al. 2024, arXiv: 2407.06280
(DESI Collaboration)

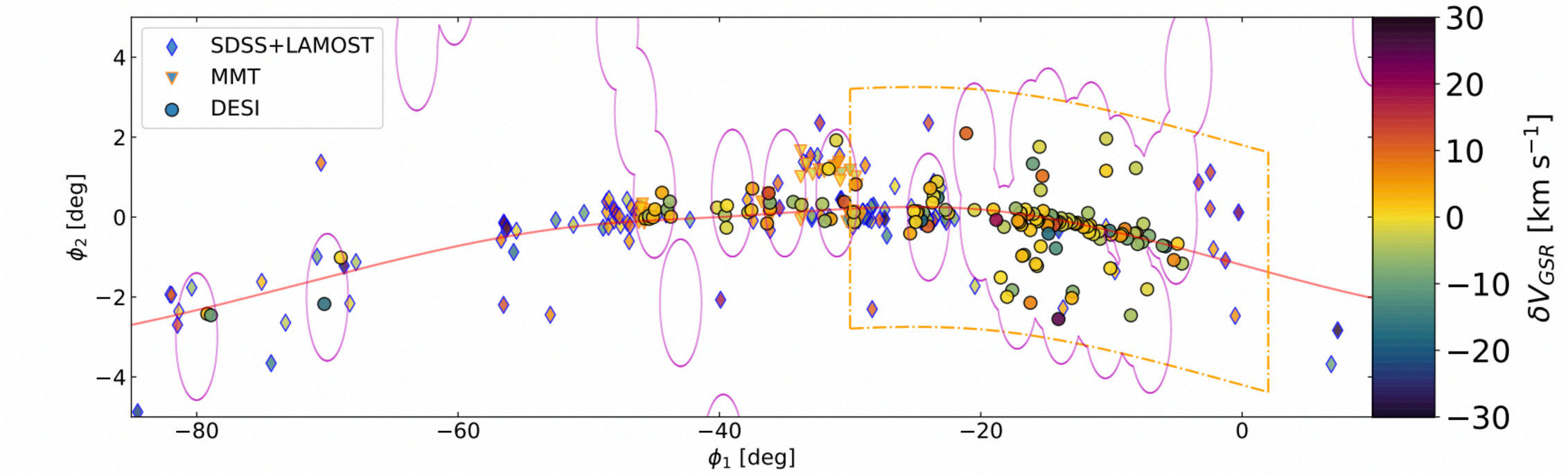
- DR1 (expected March 2025)
  - EDR + Year 1: May 2021 - June 2022
  - 6M targets observed (4M w/ RVerr < 10km/s)

- DR2 (2027? TBD)
  - EDR + Year 1-3: May 2021 - May 2024
  - 16M targets observed (11M w/ RVerr < 10 km/s)

DARK ENERGY SPECTROSCOPIC INSTRUMENT

U.S. Department of Energy Office of Science

GD-1 stream in DESI



126 new GD-1 members, including members in cocoon feature

GD-1 Stellar Stream and Cocoon in the DESI Early Data Release
Valluri et al. 2024, arXiv: 2407.06336
(DESI Collaboration)

Southern Stellar Stream Spectroscopic Survey (S^5)

Key Members of S5 Team

https://s5collab.github.io/

Since 2018

Ting Li

Daniel Zucker

Geraint Lewis

Kyler Kuehn

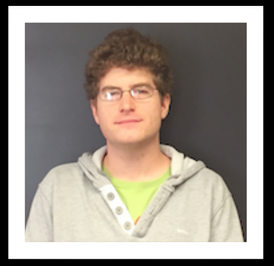
Alex Ji

Sergey Koposov

Denis Erkal

Nora Shipp

Yao-Yuan Mao



Andrew Pace

Peter Ferguson

Kaitlin Webber (Poster on S5)

Benjamin Cohen (Poster on S5)

Sam Usman (Poster on S5)

Aldo Mura

Guilherme Limberg

and Joss Bland-Hawthorn, Gary Da Costa, Lara Cullinane, Eduardo Balbinot, Andrew Casey, Gayandhi De Silva, Alex Drlica-Wagner, Marla Geha, Terese Hansen, Sophia Lilleengen, Jennifer Marshall, Sarah Martell, Clara Martinez-Vazquez, Jeremy Mould, Josh Simon, Kathy Vivas and many more …