Southern Stellar Stream Spectroscopic Survey (S^5)

- **TSL et al (2019), arXiv: 1907.09481**: *The Southern Stellar Stream Spectroscopic Survey (S5): Overview, Target Selection, Data Reduction, Validation, and Early Science*
- **Shipp, TSL et al (2019), arXiv: 1907.09488**: *Proper Motions of Stellar Streams Discovered in the Dark Energy Survey*
- **Koposov, Boubert, TSL et al (2019), arXiv:1907.11725**: *~~The Great Escape:~~ Discovery of a nearby 1700 km/s star ejected from the Milky Way by Sgr A**
- **Wan, Lewis, TSL et al (2020), arXiv:2007.14577**: *The tidal remnant of an unusually metal-poor globular cluster.*
- **Ji, TSL et al (2020), arXiv:2008.07568**: *The Southern Stellar Stream Spectroscopic Survey (S5): Chemical Abundances of Seven Stellar Streams*
- **TSL et al (2021), arXiv:2006.10763**: *Broken into Pieces: ATLAS and Aliqa Uma as One Single Stream*
- **Hansen, Ji, Da Costa, TSL et al (2021), arXiv: 2104.13883**: *S^5: The destruction of a bright dwarf galaxy as revealed by the chemistry of the Indus stellar stream*

More info (e.g. papers, data, collaboration, etc) at:

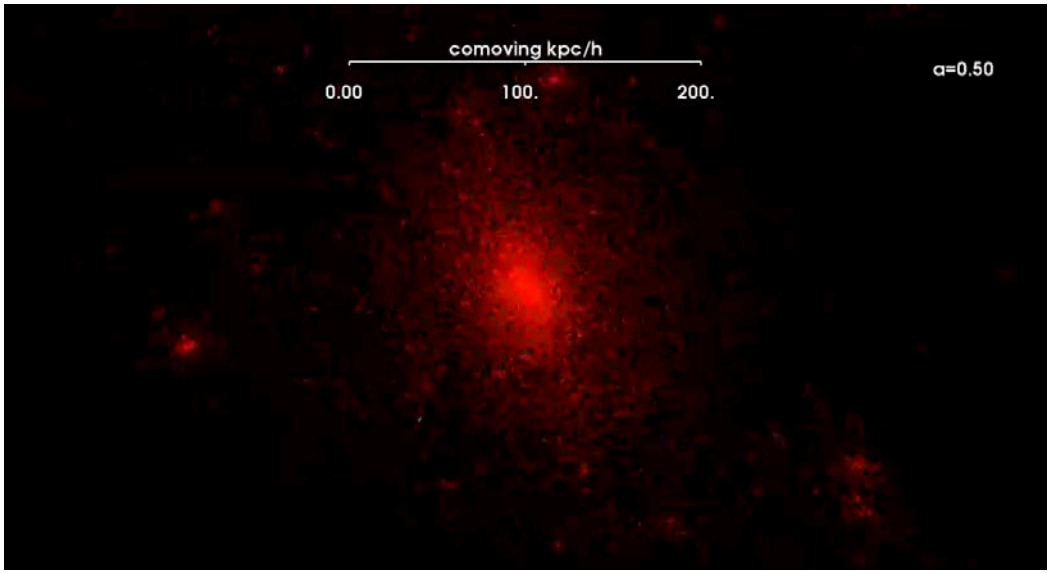
https://s5collab.github.io/

Southern Stellar Stream Spectroscopic Survey (S^5)

Ting Li

NASA Einstein Fellow, Carnegie-Princeton Fellow

Carnegie Observatories



Credit: Denis Erkal

The Carnegie Observatories

PRINCETON UNIVERSITY

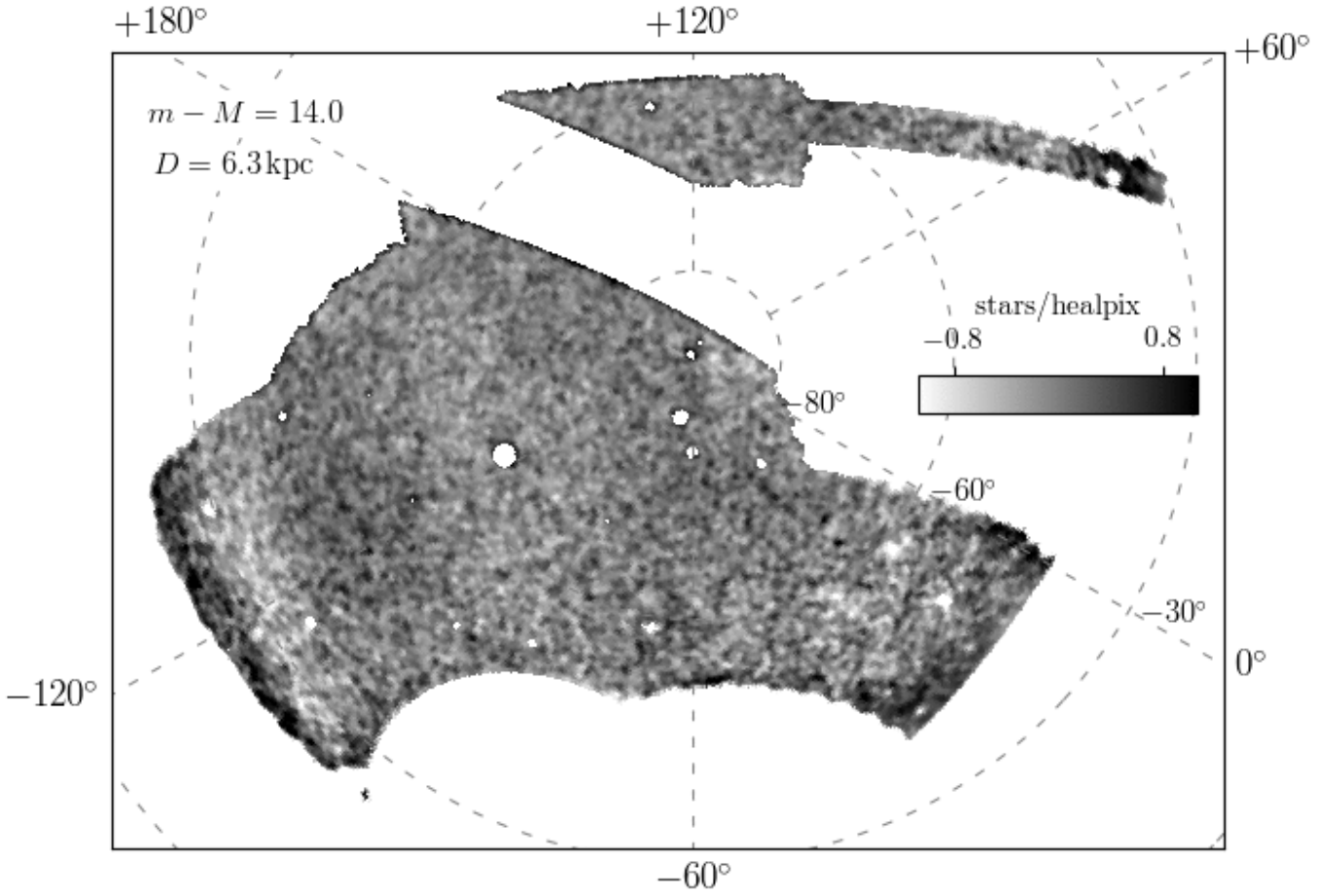
NHFP

NASA

N3AS Seminar

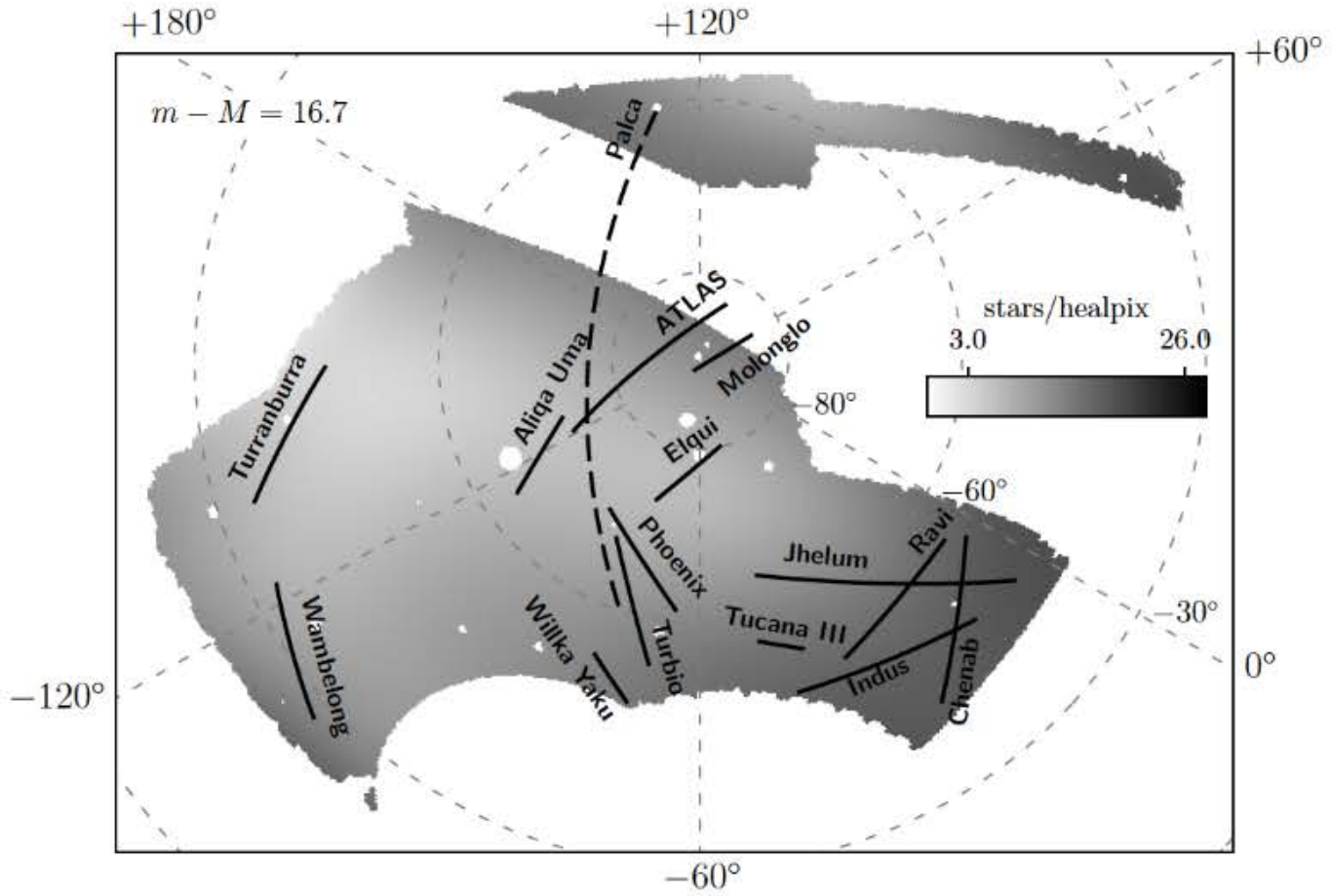
May 11, 2021

Streams in the Dark Energy Survey



Shipp et al. 2018
(DES Collaboration)

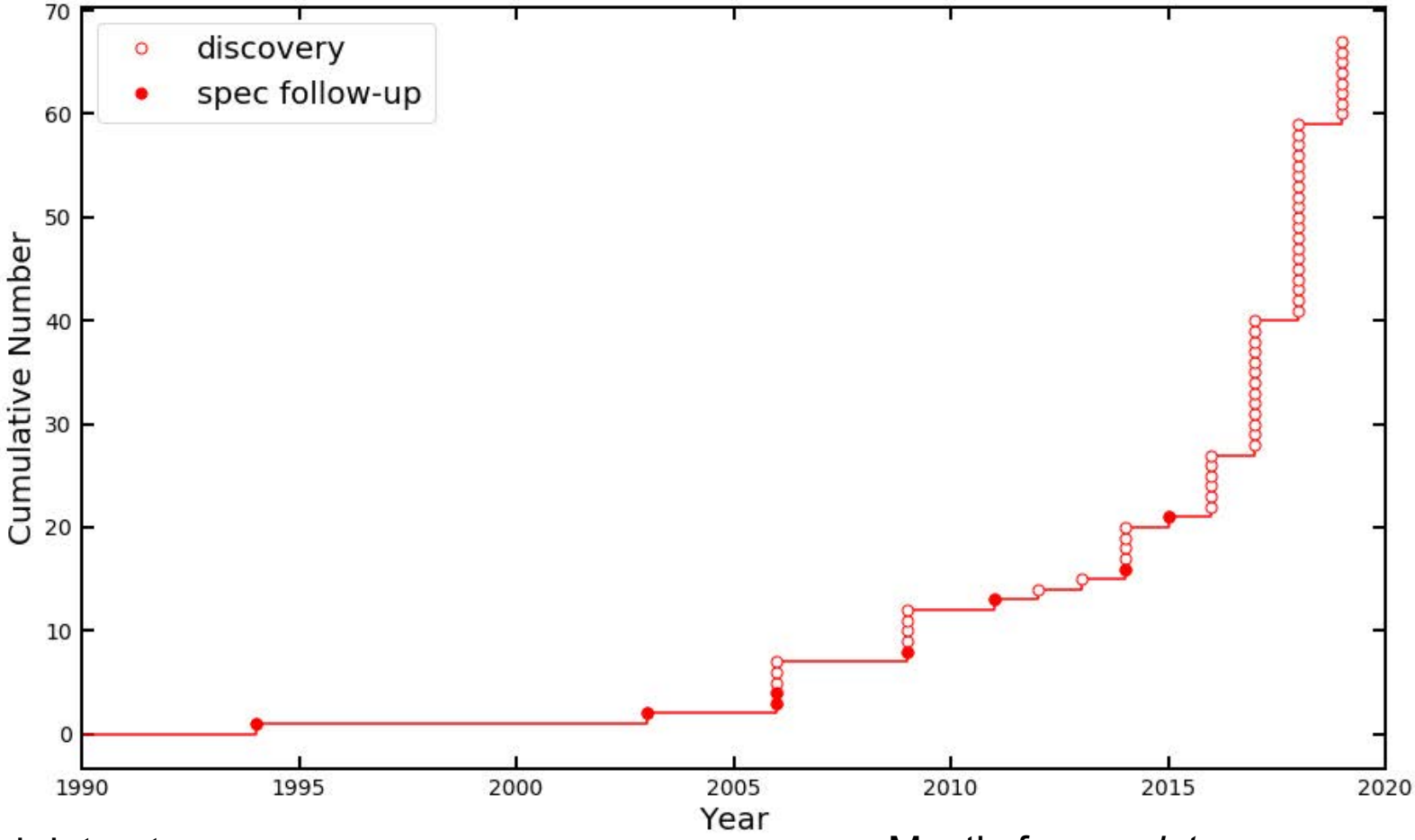
Streams in the Dark Energy Survey



13 new streams from DES + 2 previous known

Shipp et al. 2018
(DES Collaboration)

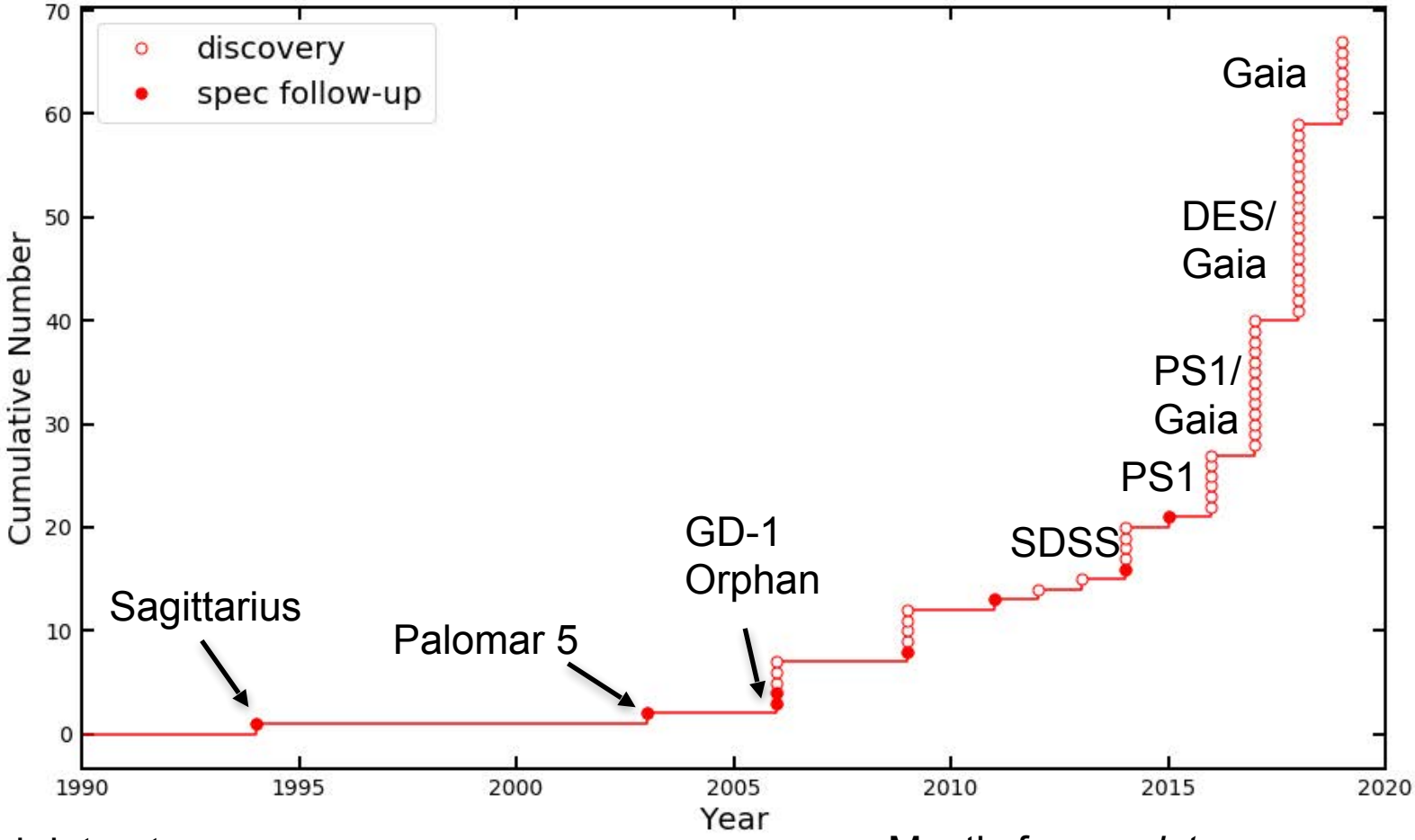
Milky Way Stellar Stream Discovery Timeline



Compiled data at
https://tinyurl.com/y6gggvee

Mostly from *galstream*
https://github.com/cmateu/galstreams

Milky Way Stellar Stream Discovery Timeline



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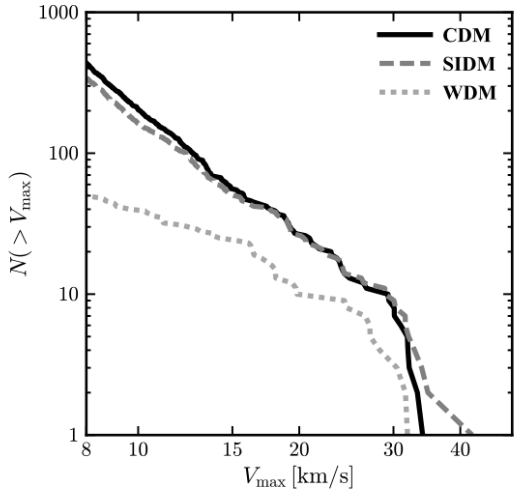
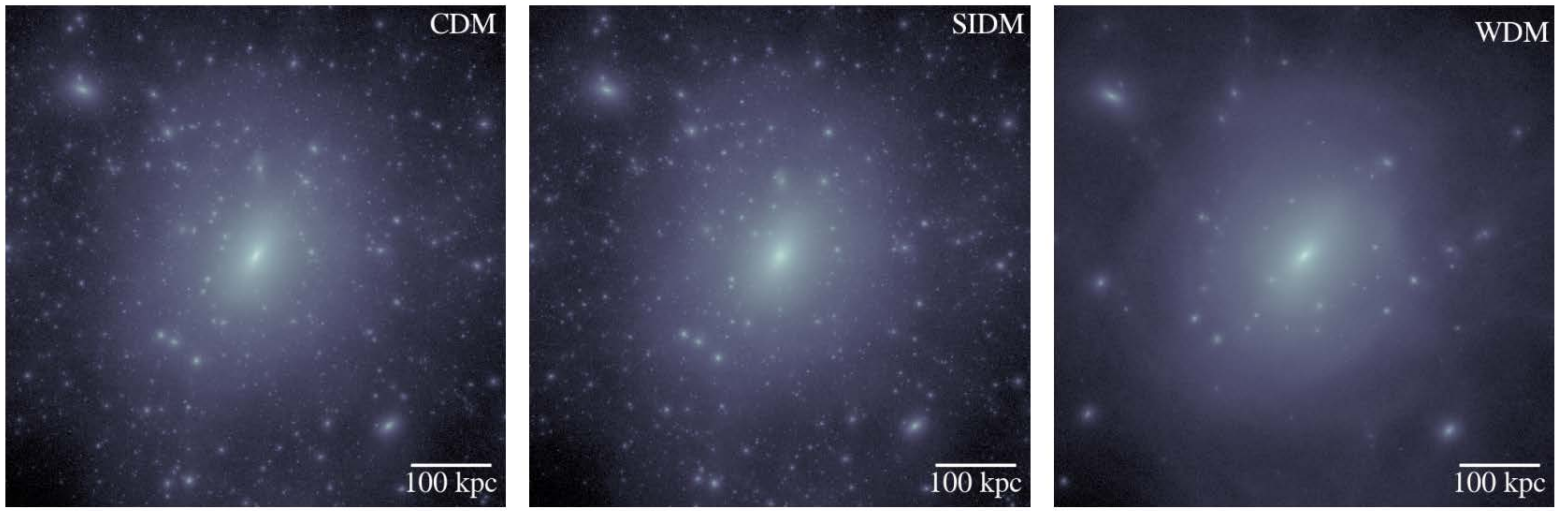
Dark Matter Subhalos Mass Function



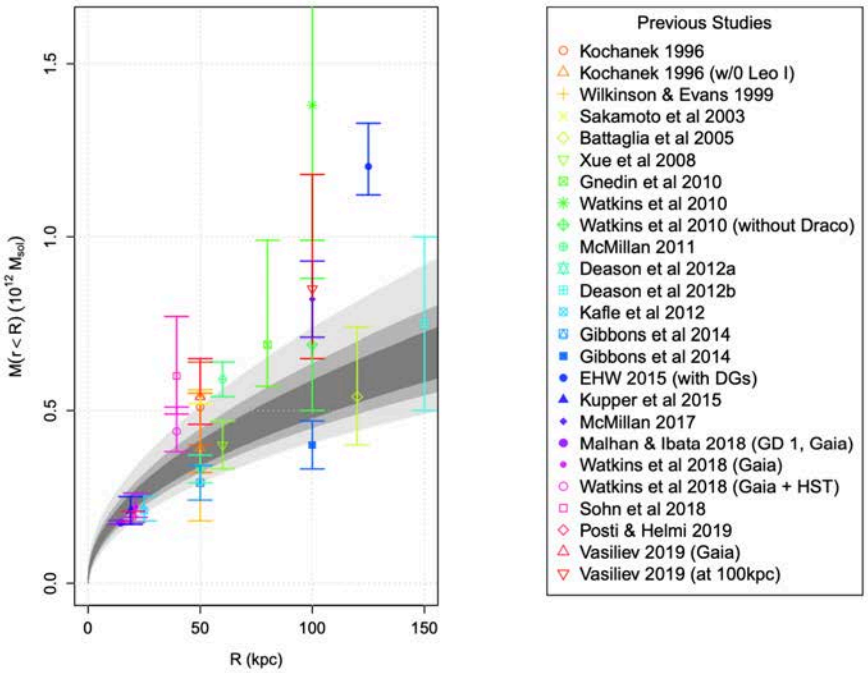
Number of dark matter subhalo is determined by:

- Mass of the host halo
- Dark matter models:
  - Warm dark matter (WDM)
  - Cold dark matter (CDM)
  - Self-interacting dark matter (SIDM)

Bullock & Boylan-Kolchin 2017



Milky Way Mass and Potential

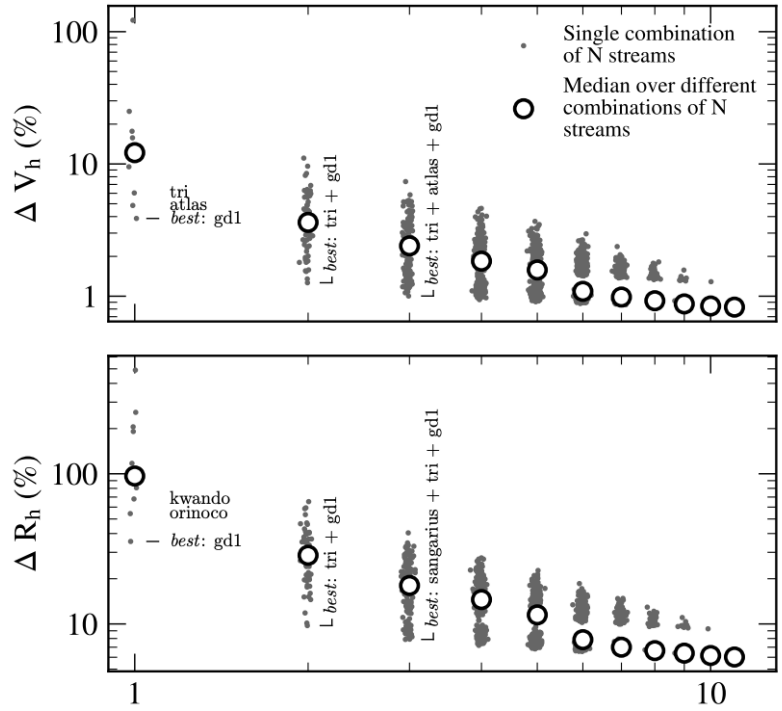


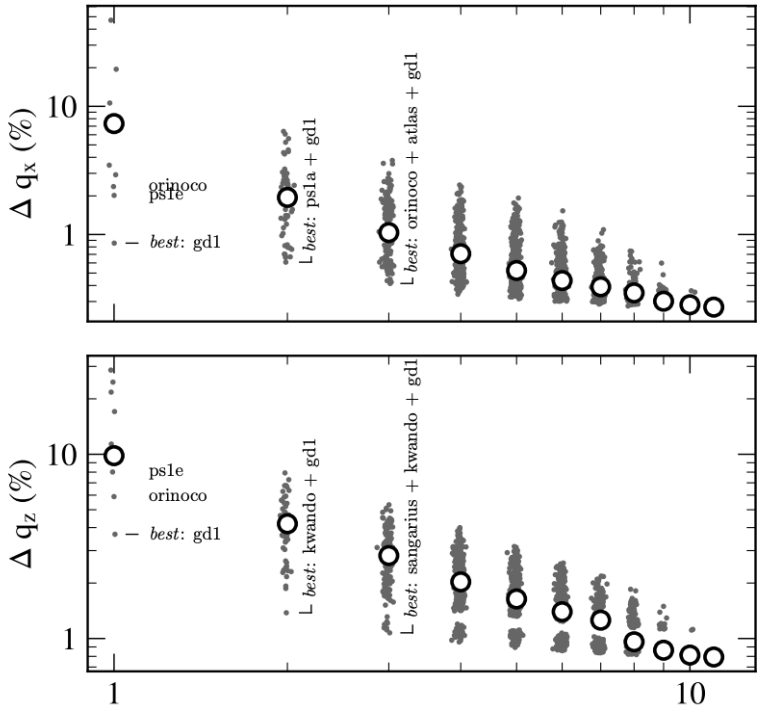
Eadie & Juric+2019

Mostly using point tracers (e.g. globular clusters, dwarf galaxies) or single stellar stream

Milky Way Mass and Potential

Halo scale velocity



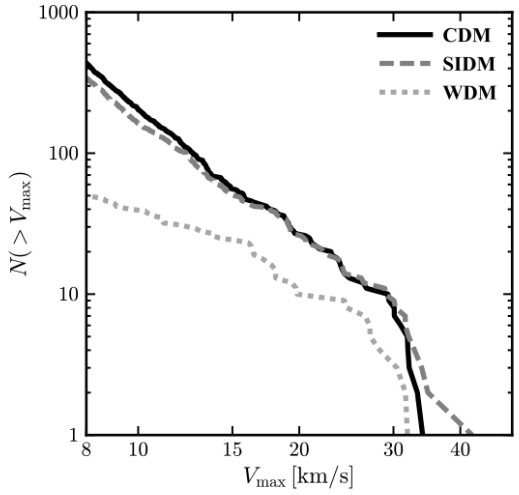


flattening

Halo scale radius

Bonaca+2018

Dark Matter Subhalos Mass Function



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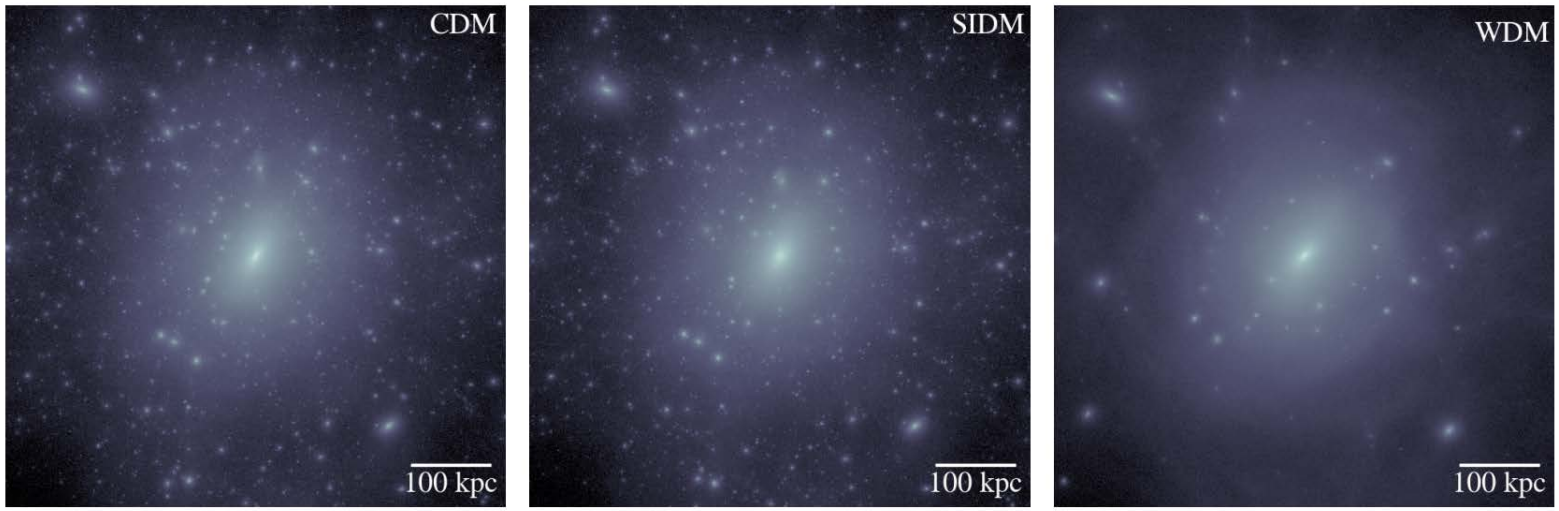
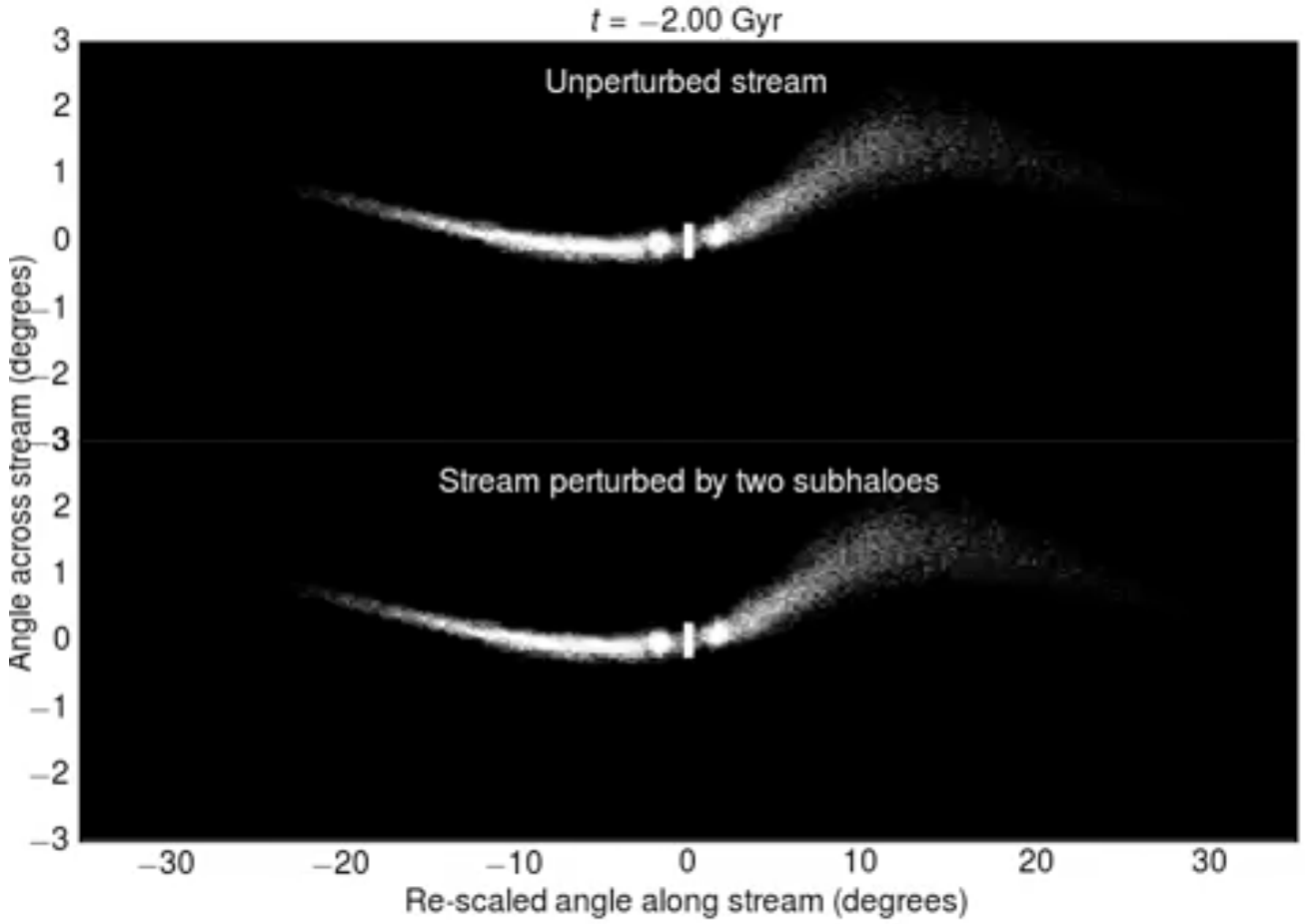
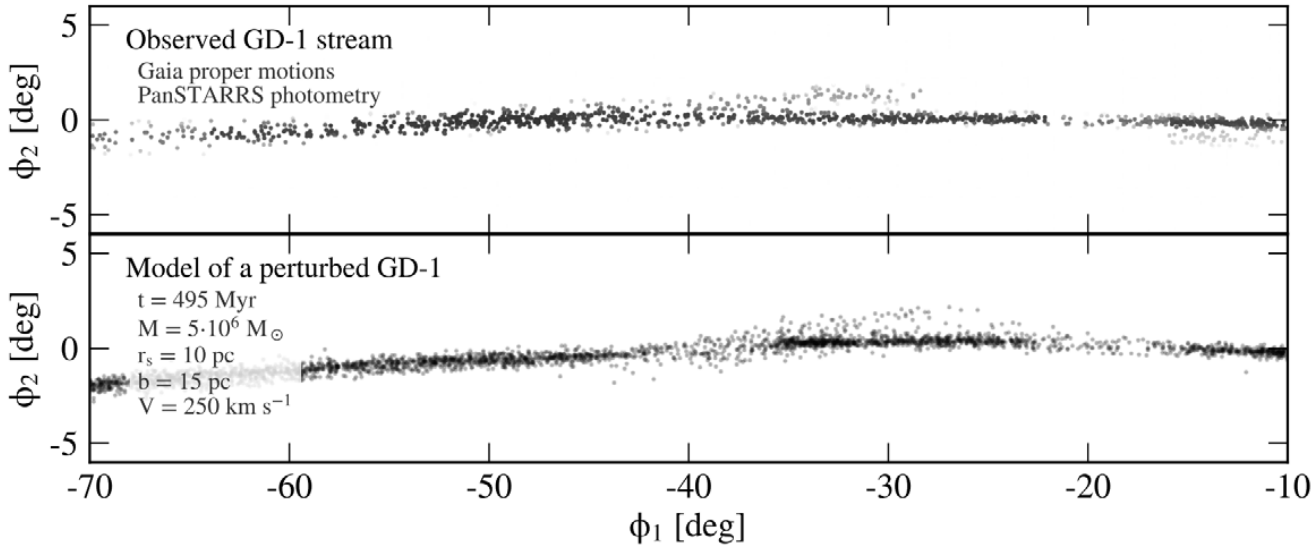


Gaps in Cold Streams



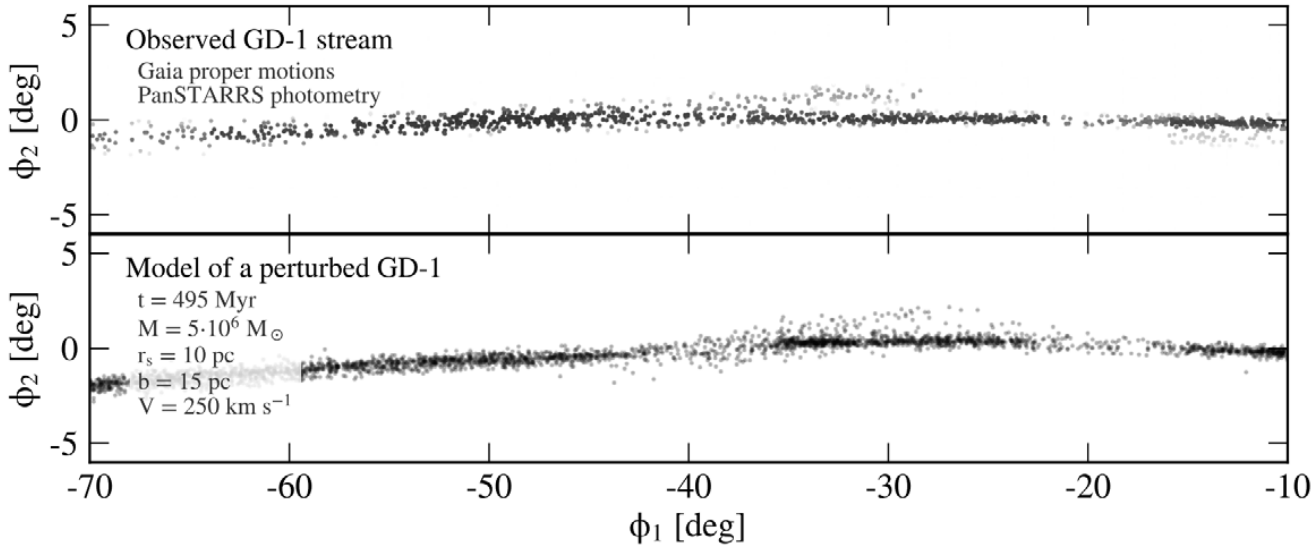
Credit: Denis Erkal

Gaps and spur in GD-1 stream

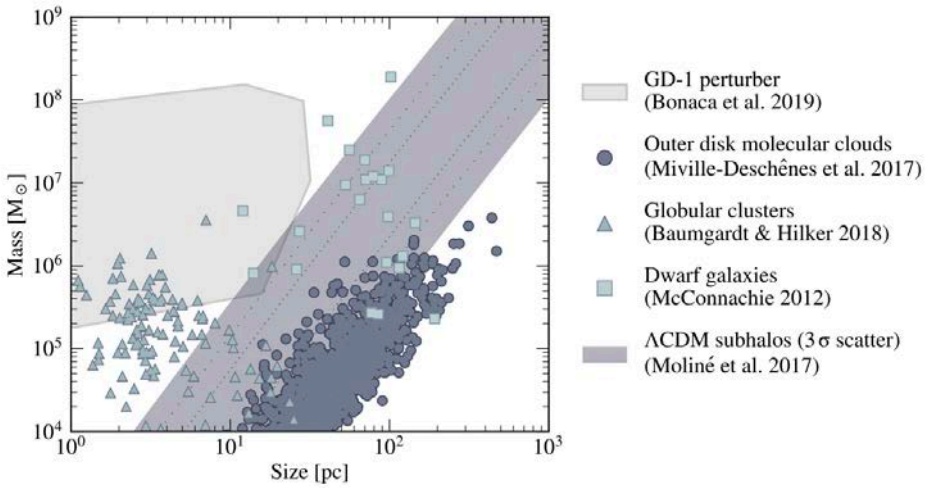


Bonaca+2019

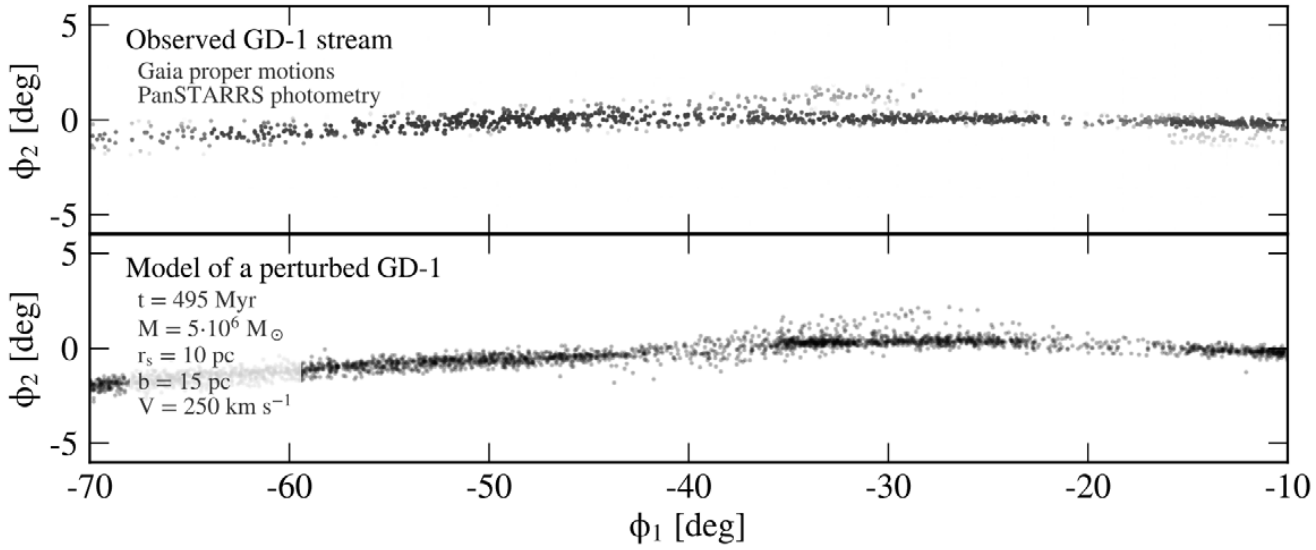
Gaps and spur in GD-1 stream



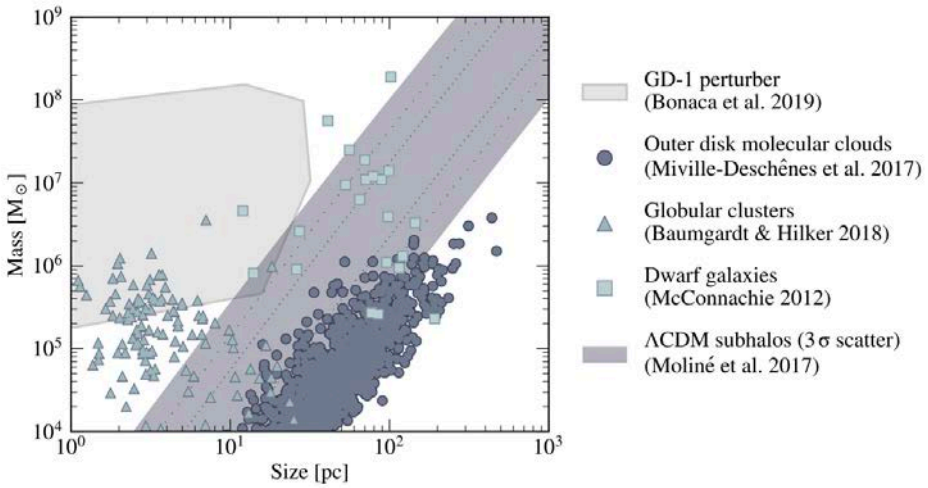
Bonaca+2019



Gaps and spur in GD-1 stream



Bonaca+2019



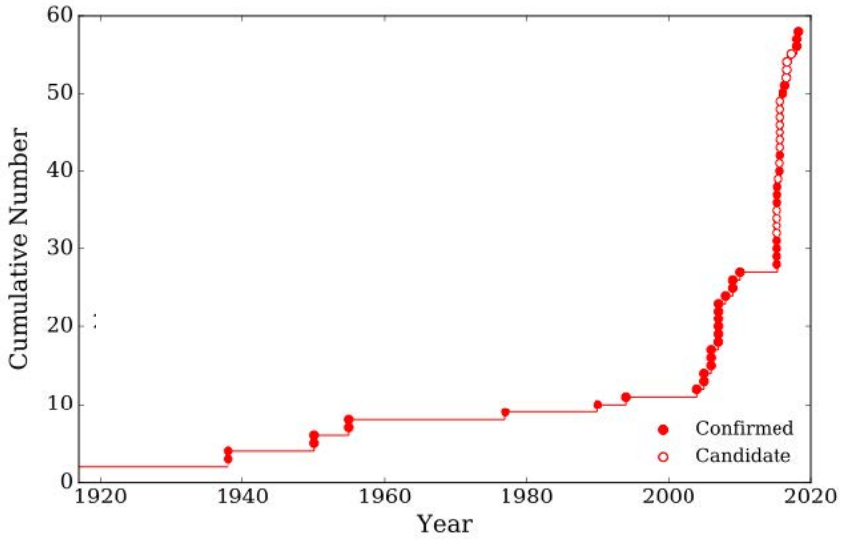
However, de Boer et al (2019) shows that the spur might caused by an interaction with Sagittarius dwarf galaxy.

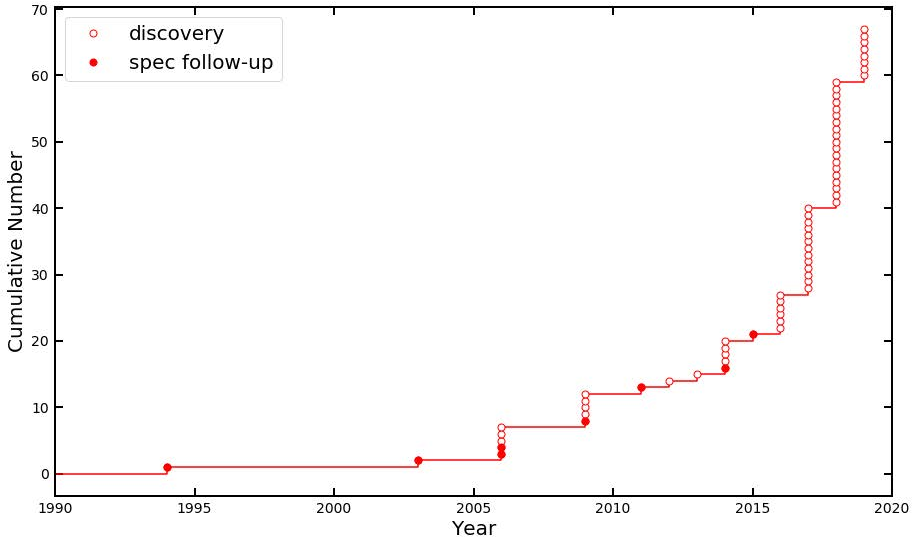
Why Spectroscopy?

- Spectroscopic Follow-up Observations can:
  - Confirm the streams
  - Provide info on kinematics and chemistry
  - Characterize stream progenitors
  - Identify perturbation signatures

Status on Spectroscopic Follow-up in 2018

Milky Way Stellar Streams: ~ 10%

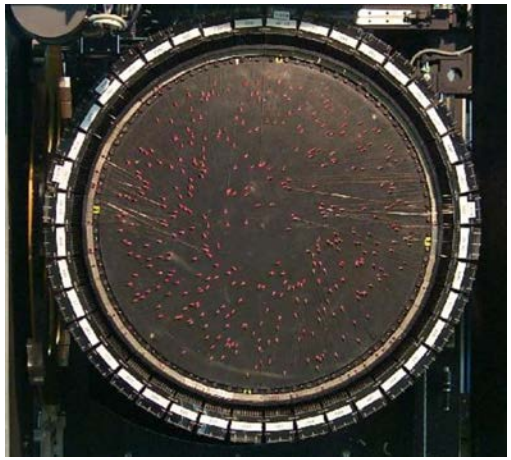




Milky Way Satellite Galaxies: > 70%

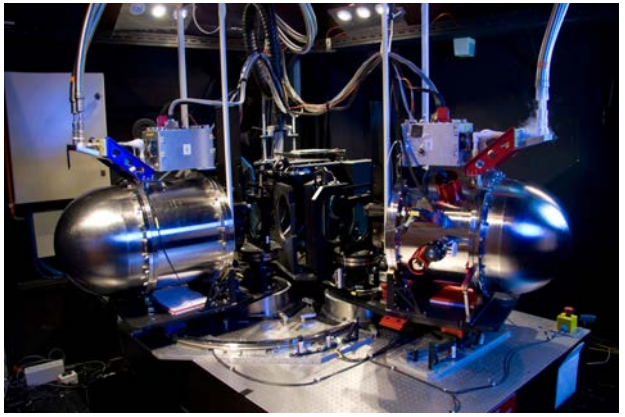
High Multiplexity, Wide Field-of-View, 4m Telescope

AAT: Anglo-Australian Telescope (4 meter) at Siding Spring Observatory



2df: 2-deg (in diameter) field fiber positioner w/ 400 fibers

AAOmega: a dual-arm optical spectrograph



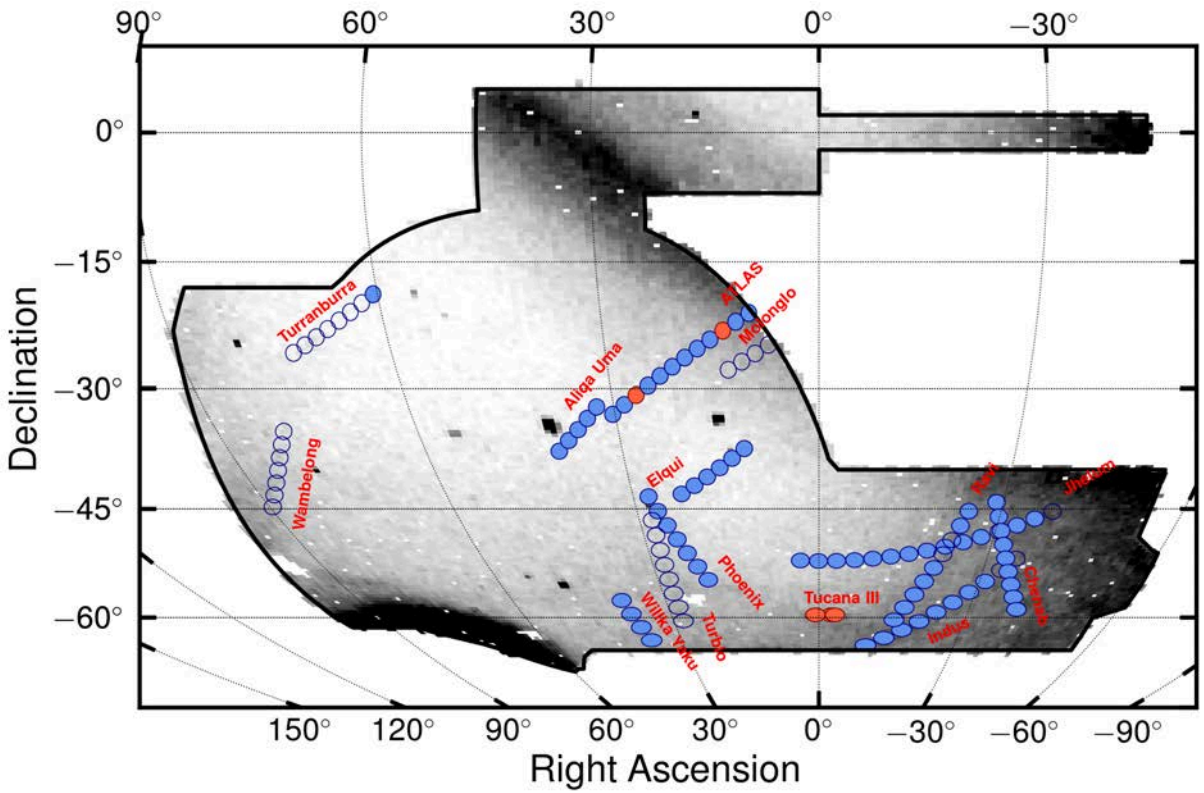
Southern Stellar Stream Spectroscopic Survey (S^5)

https://s5collab.github.io/

- Started in 2018
- AAT + 2df/AAOmega
- ~30 Members from USA/ Australia/UK

Leadership: Ting Li, Daniel Zucker, Geraint Lewis, Kyler Kuehn
Builders: Denis Erkal, Alex Ji, Sergey Koposov, Dougal Mackey, Nora Shipp, Jeffrey Simpson, Zhen Wan
Members: Joss Bland-Hawthorn, Jeremy Mould, Sahar Allam, Eduardo Balbinot, Keith Bechtol, Vasily Belokurov, Andrew Casey, Lara Cullinane, Gary Da Costa, Gayandhi De Silva, Alex Drlica-Wagner, Marla Geha, Yao-Yuan Mao, Sarah Martell, Andrew Pace, Sanjib Sharma, Josh Simon, Douglas Tucker, Kathy Vivas, Risa Wechsler, Brian Yanny

S^5 in 2018



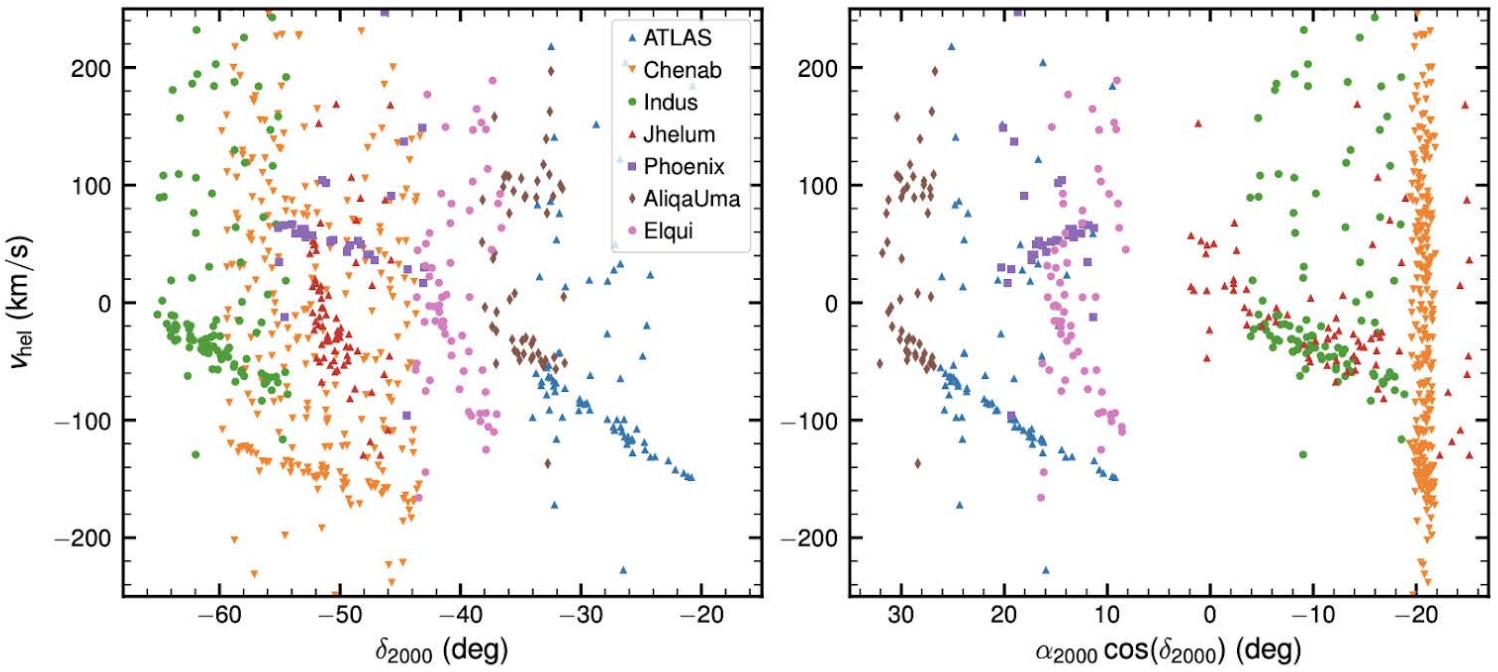
9+1 DES streams fully mapped in 2018

TSL et al. 2019
(S^5 Collaboration)

Observed
Pilot program

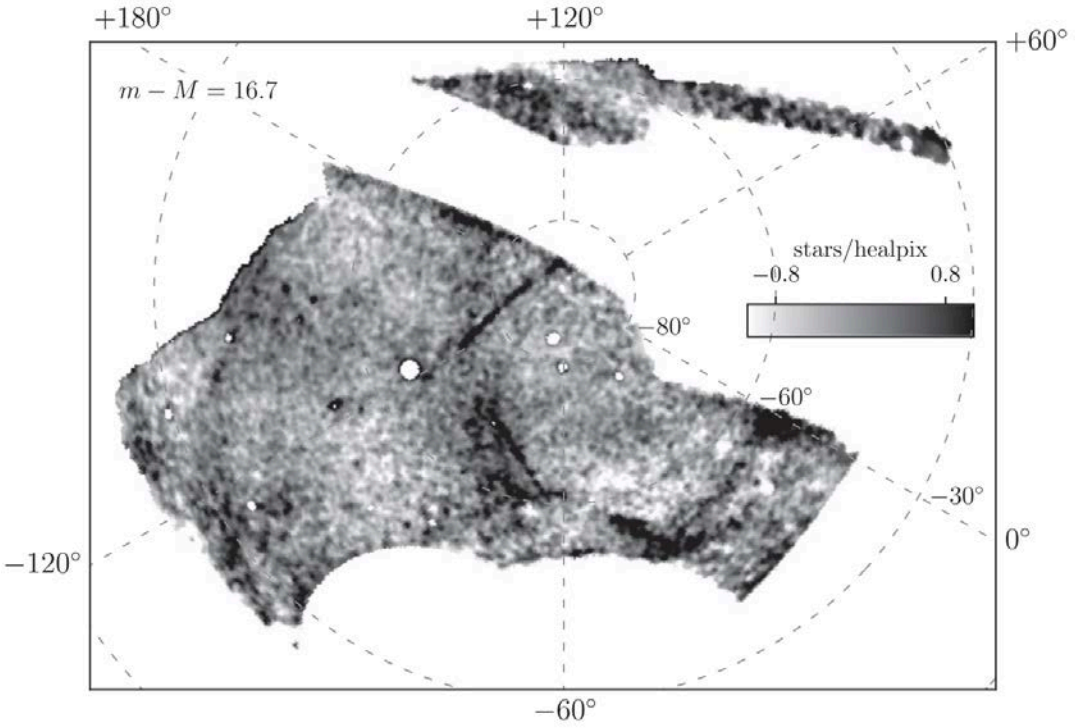
S^5 Stream Survey

7 confirmed streams (ATLAS, Aliqa Uma, Jhelum, Indus, Chenab, Elqui, Phoenix)



TSL et al. 2019
(S^5 Collaboration)

ATLAS+AliqaUma



Shipp et al. 2018
(DES Collaboration)

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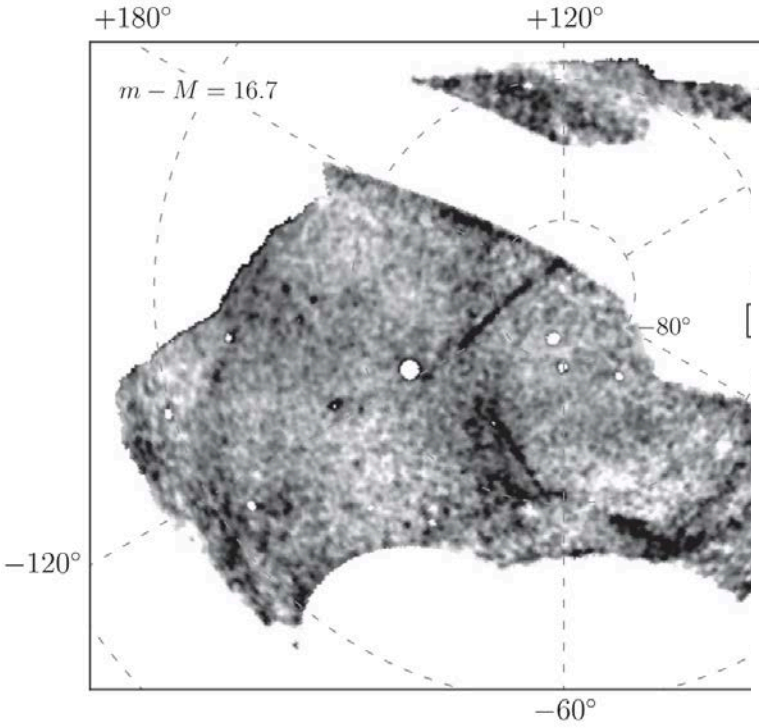

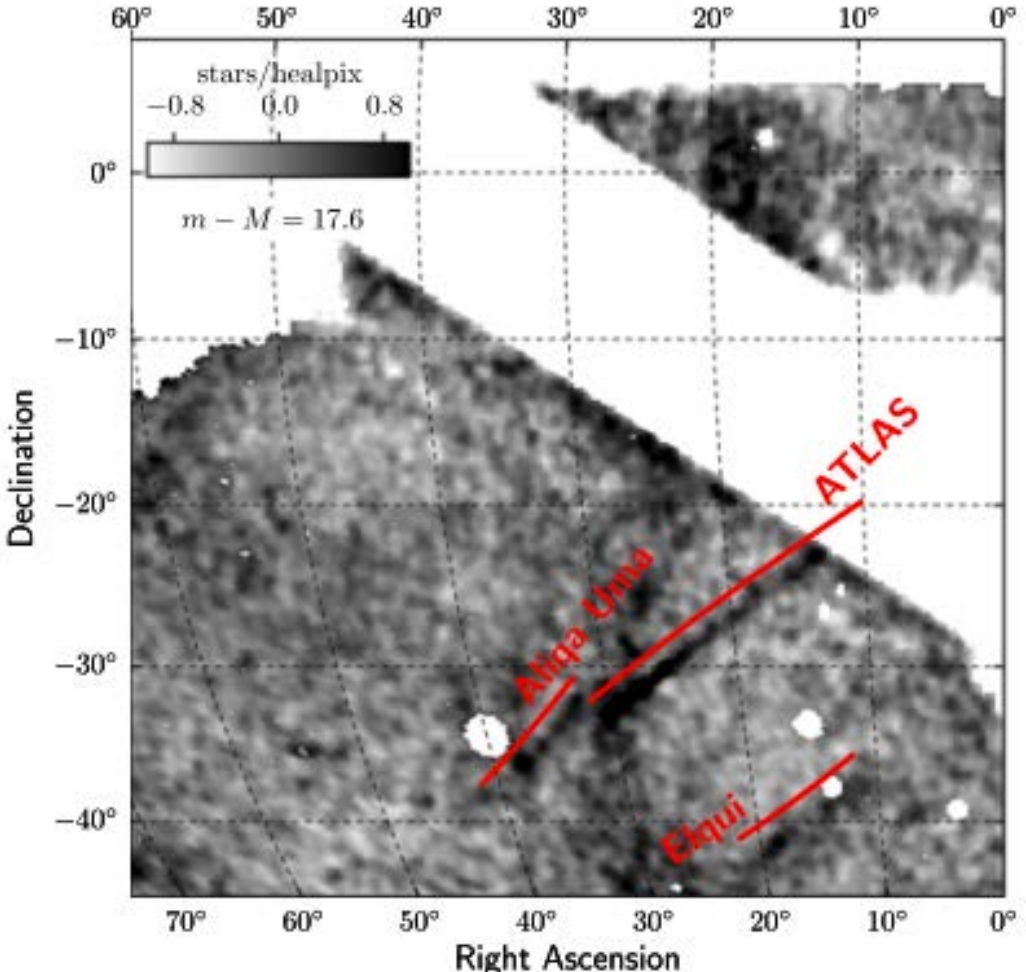

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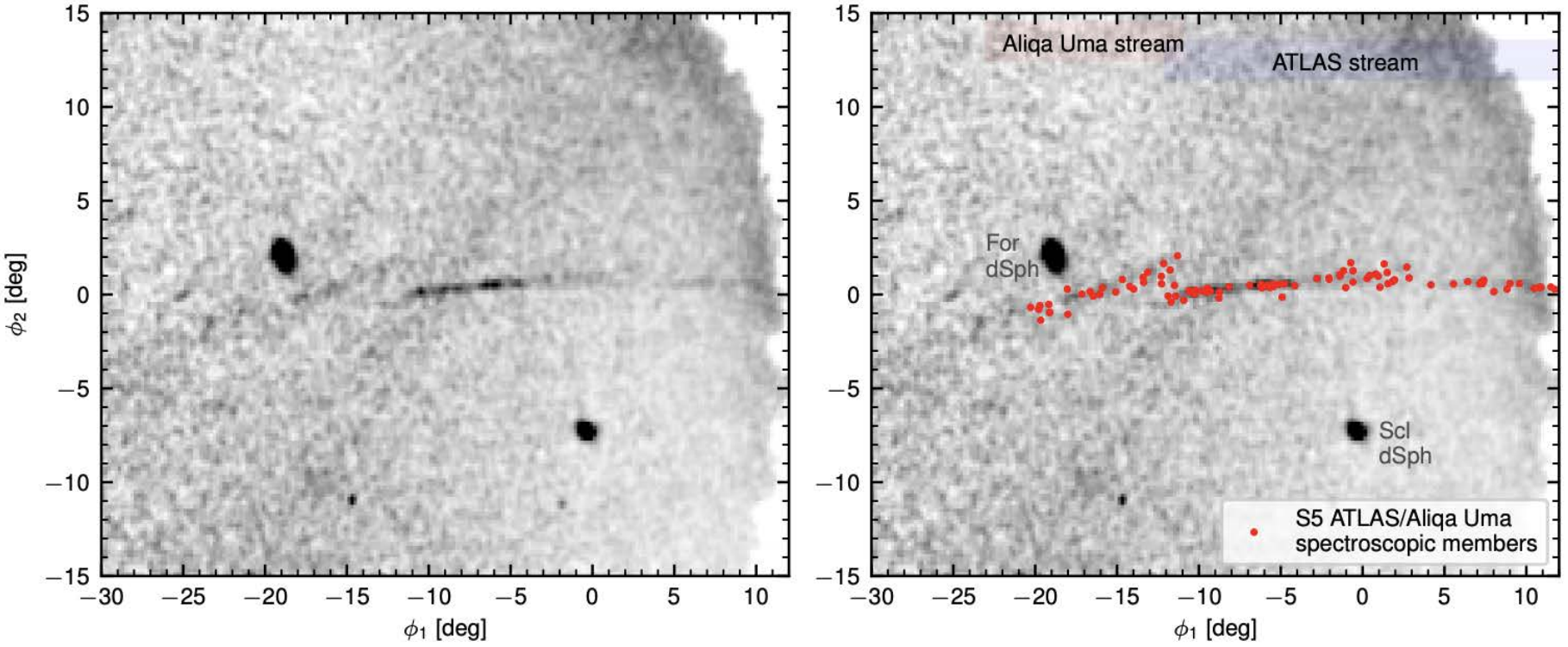
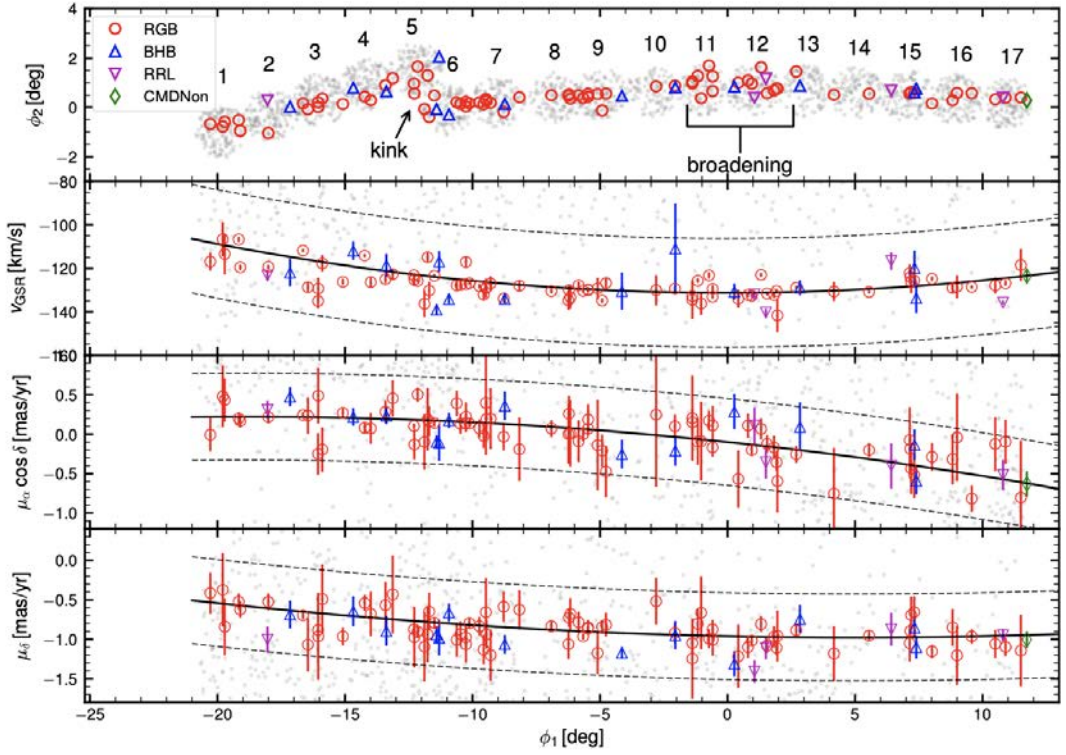
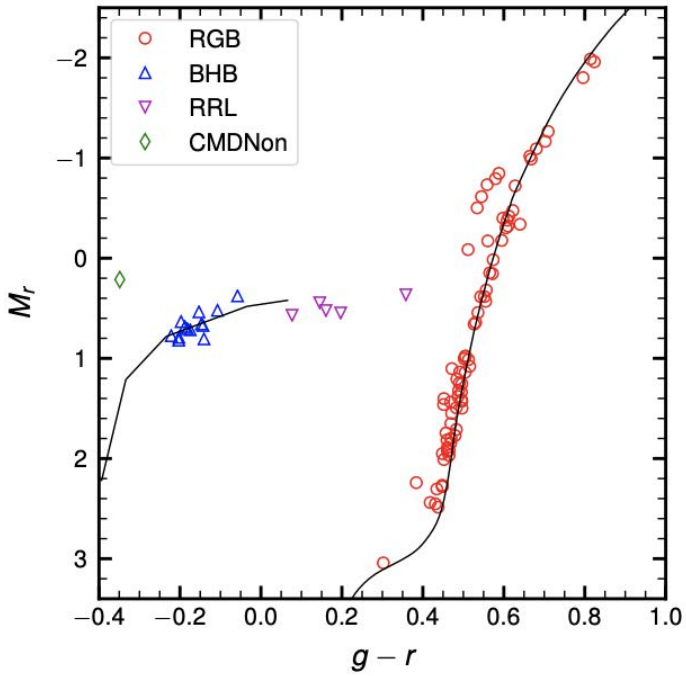
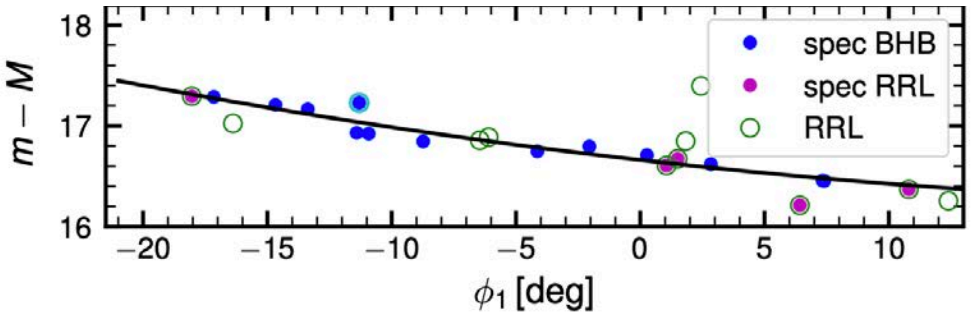


TSL et al. 2020
(S^5 Collaboration)

ATLAS+AliqaUma: A broken stream?







TSL et al. 2020
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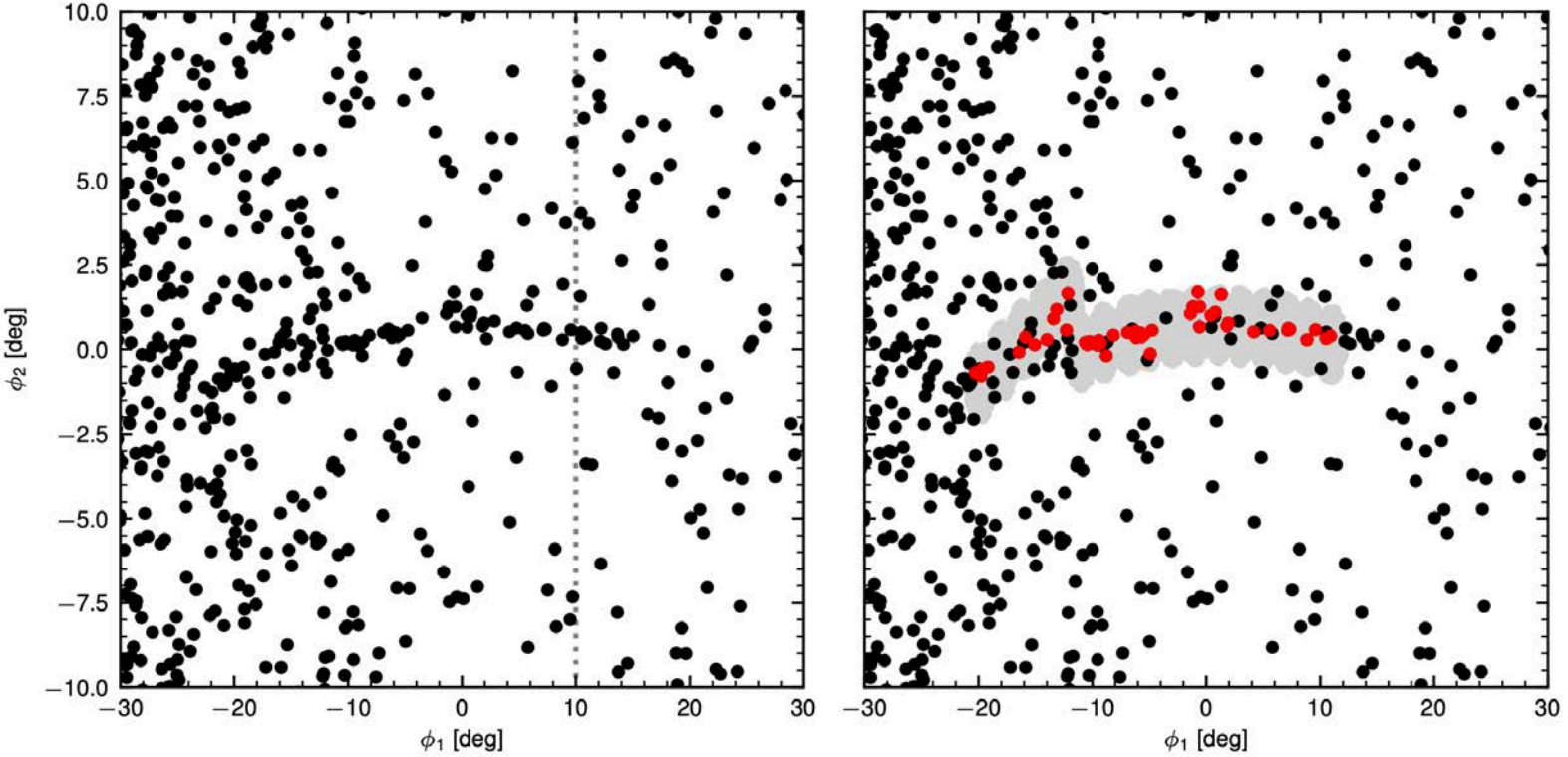
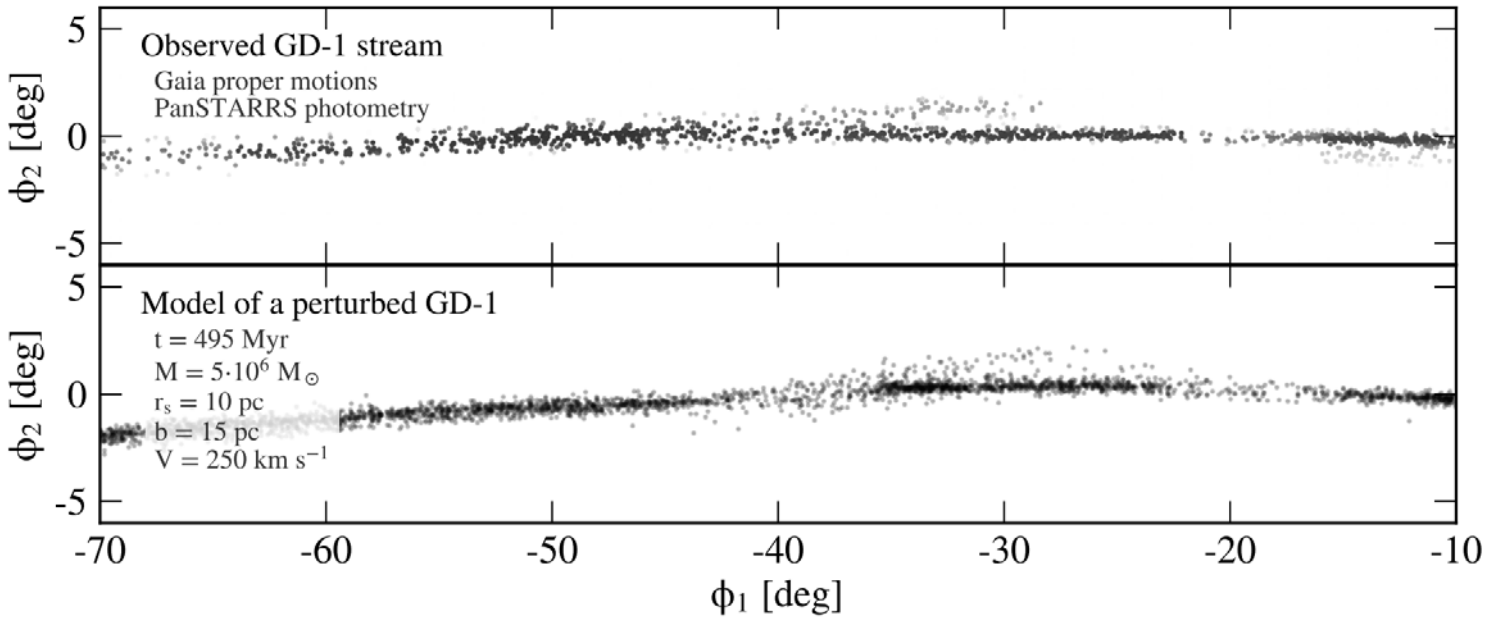


TSL et al. 2020
(S^5 Collaboration)

Gaps and spur in GD-1 stream

- Mass function of dark matter subhalos



Bonaca+2019

ATLAS+AliqaUma: A broken stream?

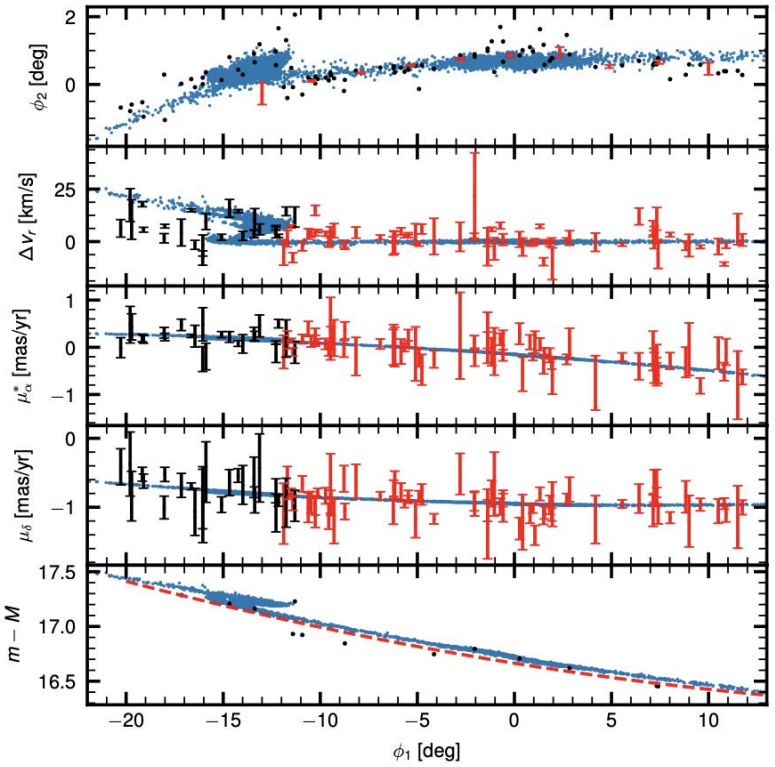
- ? Milky Way Bar
- ? Giant Molecular Clouds
- ? Spiral Arms
- ? Classical Satellite Galaxies
- ? Globular Clusters
- ? Progenitor

TSL et al. 2020
(S^5 Collaboration)

ATLAS+AliqaUma: A broken stream?

Perturbation Might Be Caused by Sagittarius Dwarf Galaxy

- ✗ Milky Way Bar
- ✗ Giant Molecular Clouds
- ✗ Spiral Arms
- ? Classical Satellite Galaxies
- ✗ Globular Clusters
- ✗ Progenitor



TSL et al. 2020
(S^5 Collaboration)

ATLAS+AliqaUma: A broken stream?

Perturbation Might Be Caused by Sagittarius Dwarf Galaxy

- ✗ Milky Way Bar
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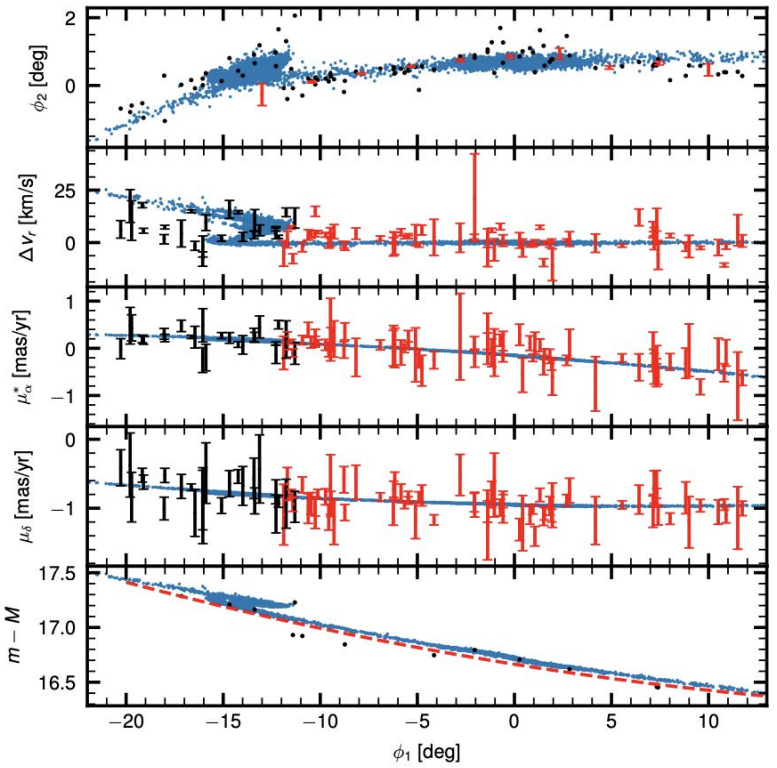
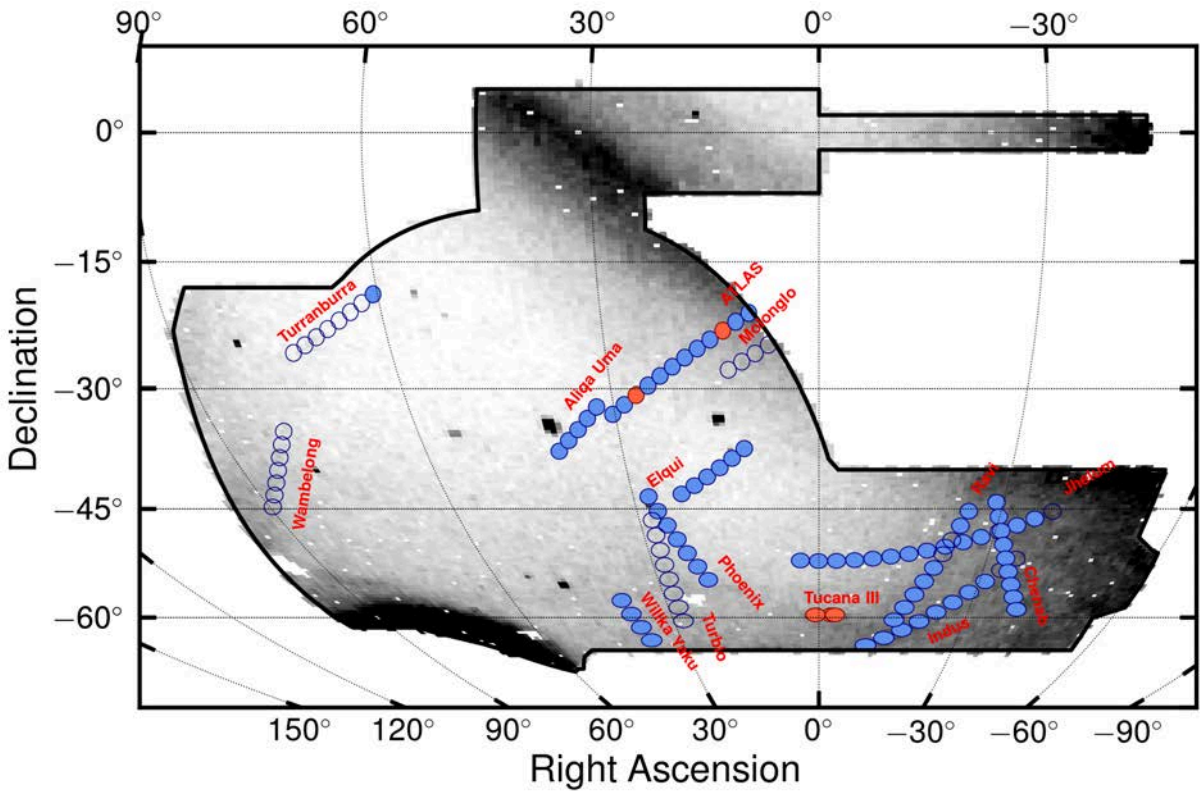
- ✗ Globular Clusters
- ✗ Progenitor
- ? Dark Matter Subhalo



TSL et al. 2020
(S^5 Collaboration)

S5 in 2018

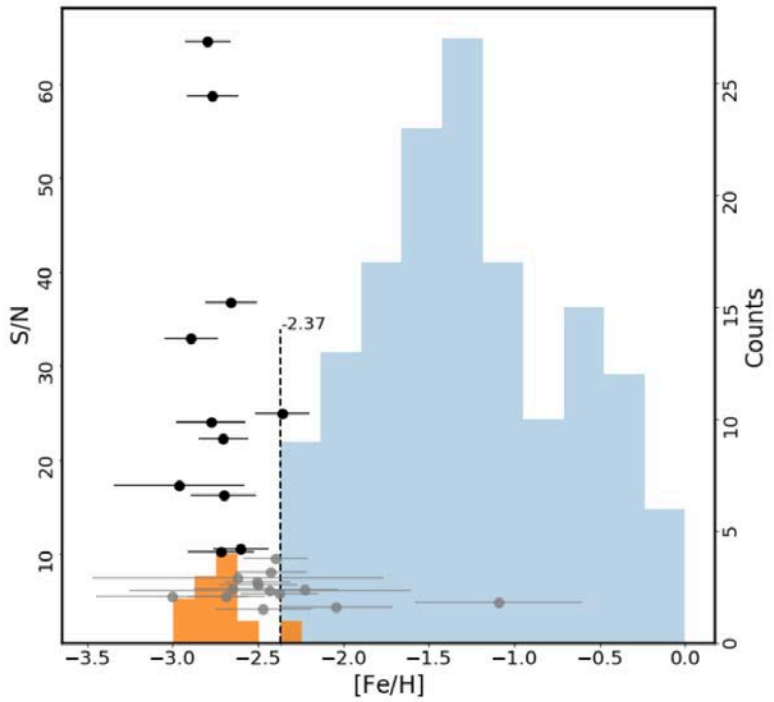


Observed

Pilot program

TSL et al. 2019
(S5 Collaboration)

Phoenix Stream

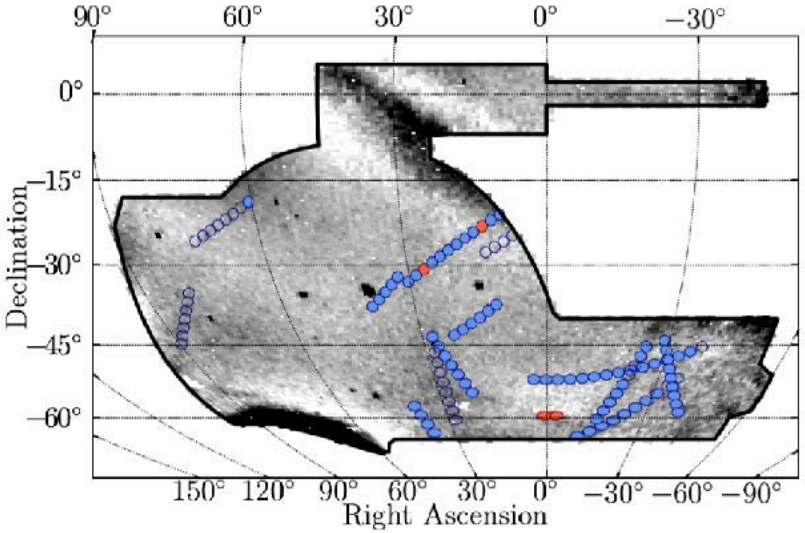


Cyan: globular cluster in Milky Way
Orange: stars in Phoenix Stream

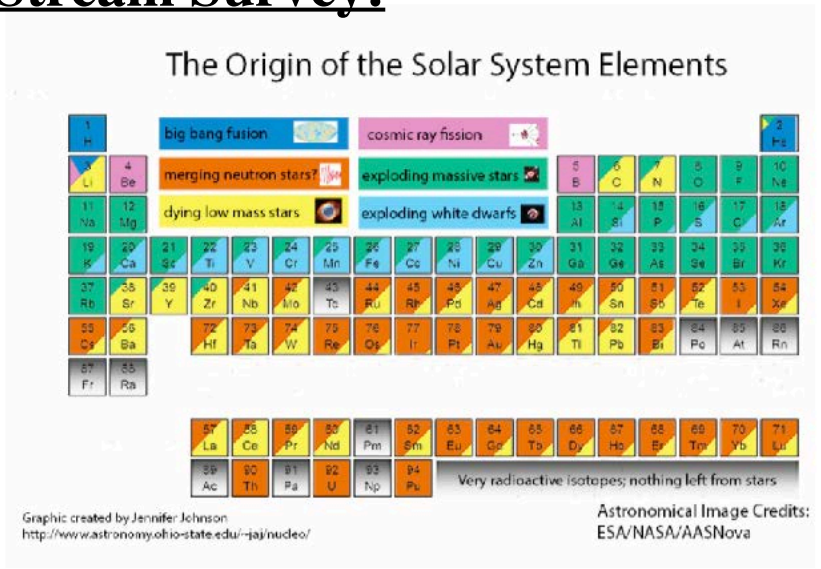
More metal-poor than any known globular cluster (GC) in the Milky Way!

Wan, Lewis, TSL et al. 2020 Nature
(S^5 Collaboration)

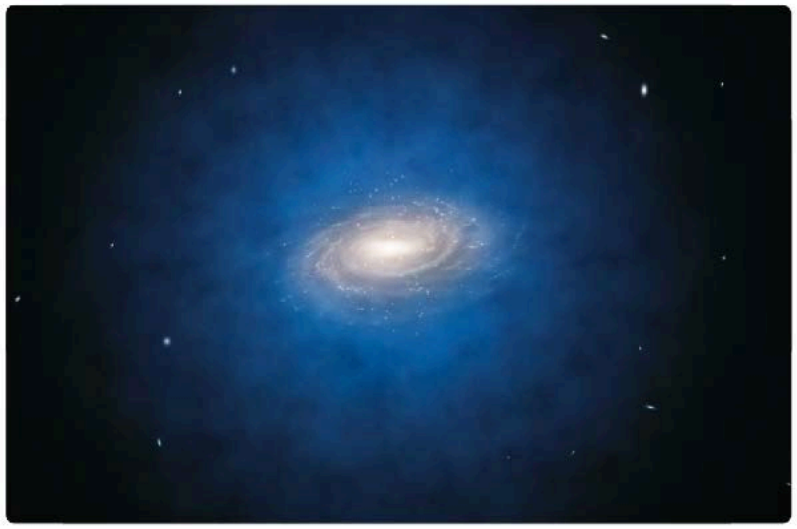
S5 - More than a Stream Survey!



S5 - STREAMS



S5 - HIRES

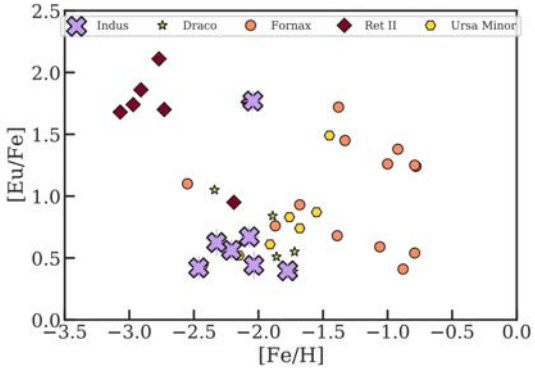


S5 - HALO

S5 - LOWZ

S⁵ - More than a Stream Survey!

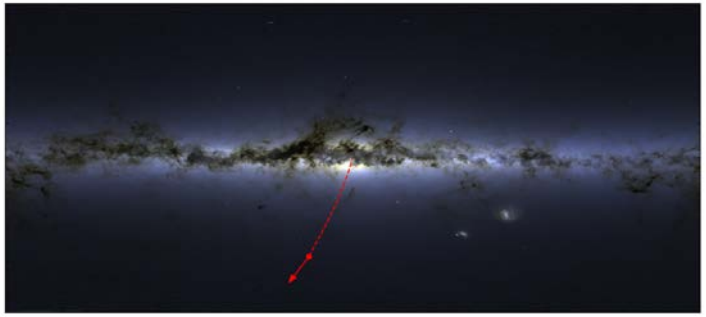
S⁵ - HIRES



First highly rapid neutron-capture r-process enhanced star to be discovered in a disrupted dwarf galaxy stream

Ji, TSL et al (2020)
Hansen, Ji, Da Costa, TSL et al (2021)

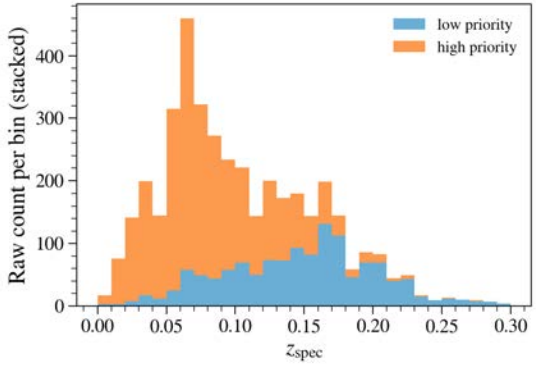
S⁵ - HALO



Fastest main sequence star (v3d ~1700 km/s) ejected from the Galactic Center

Koposov, Boubert, TSL et al. (2019)

S⁵ - LOWZ



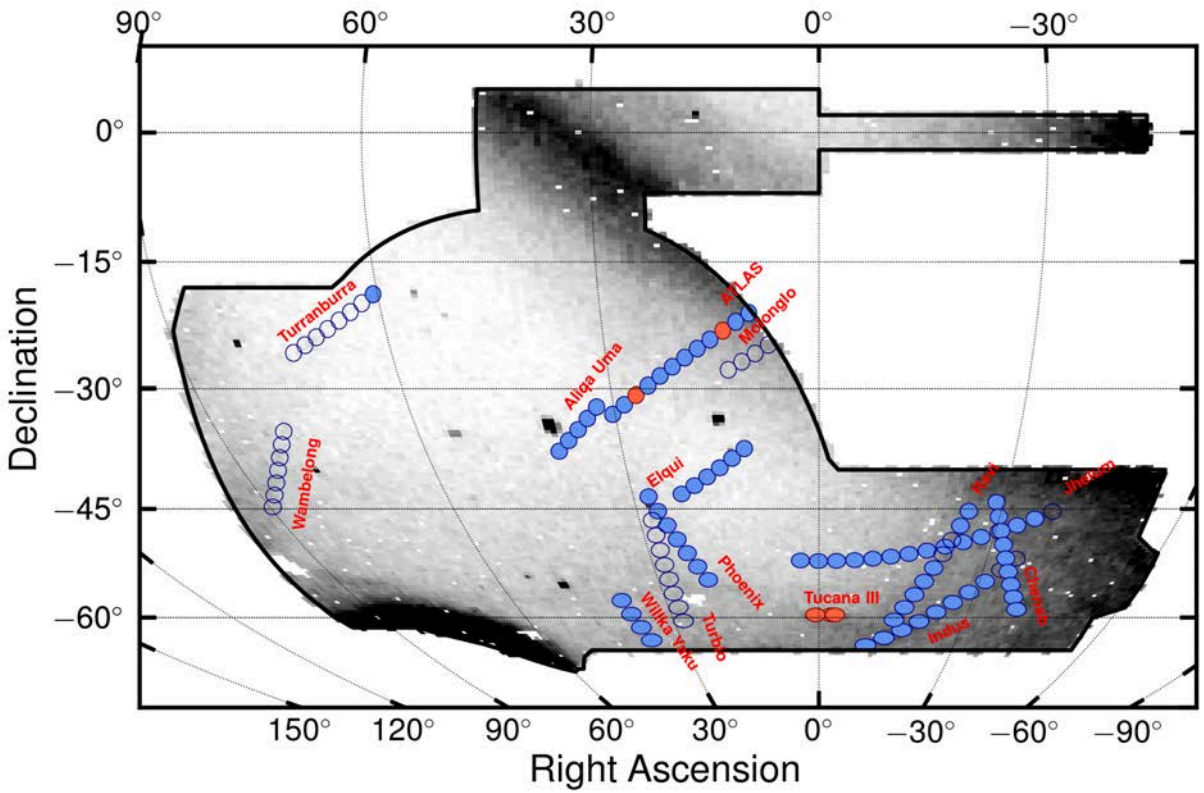
~5500 galaxies observed

~4000 redshifts secured

~600 galaxies z < 0.05

~100 galaxies z < 0.02

S5 in 2018

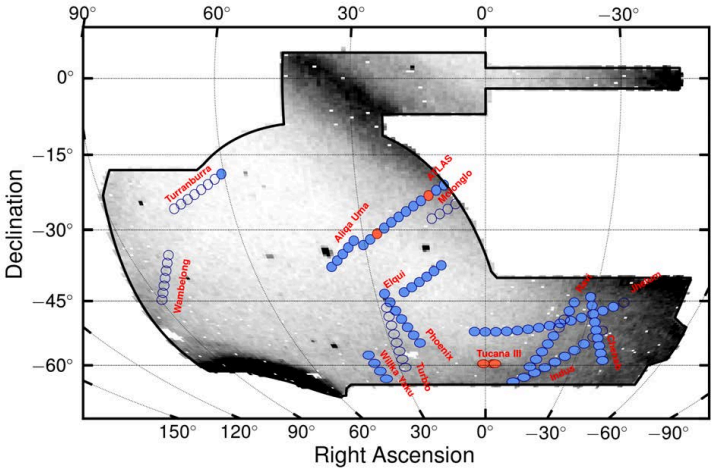


Observed

Pilot program

TSL et al. 2019
(S5 Collaboration)

S^5 in 2018

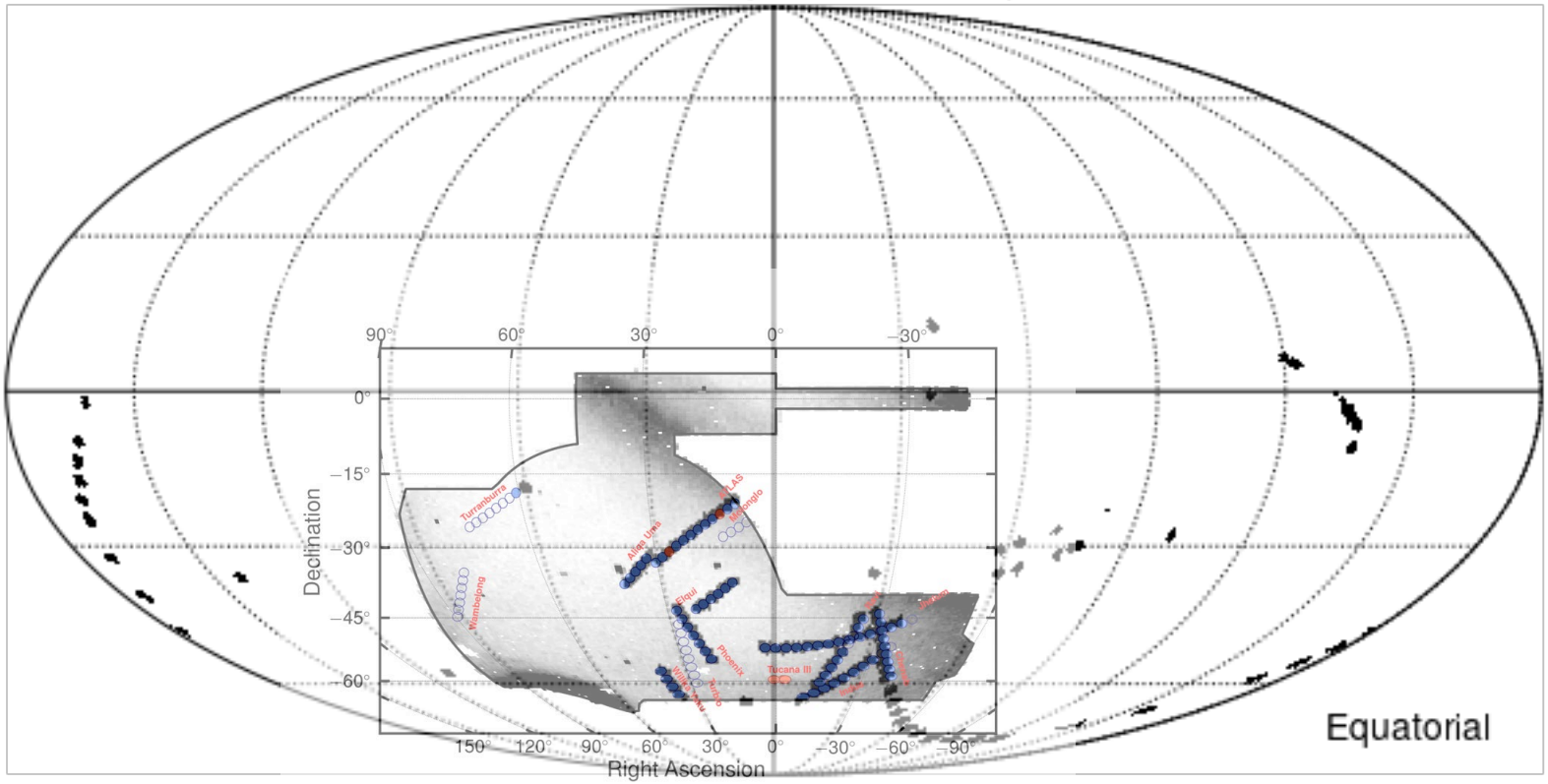


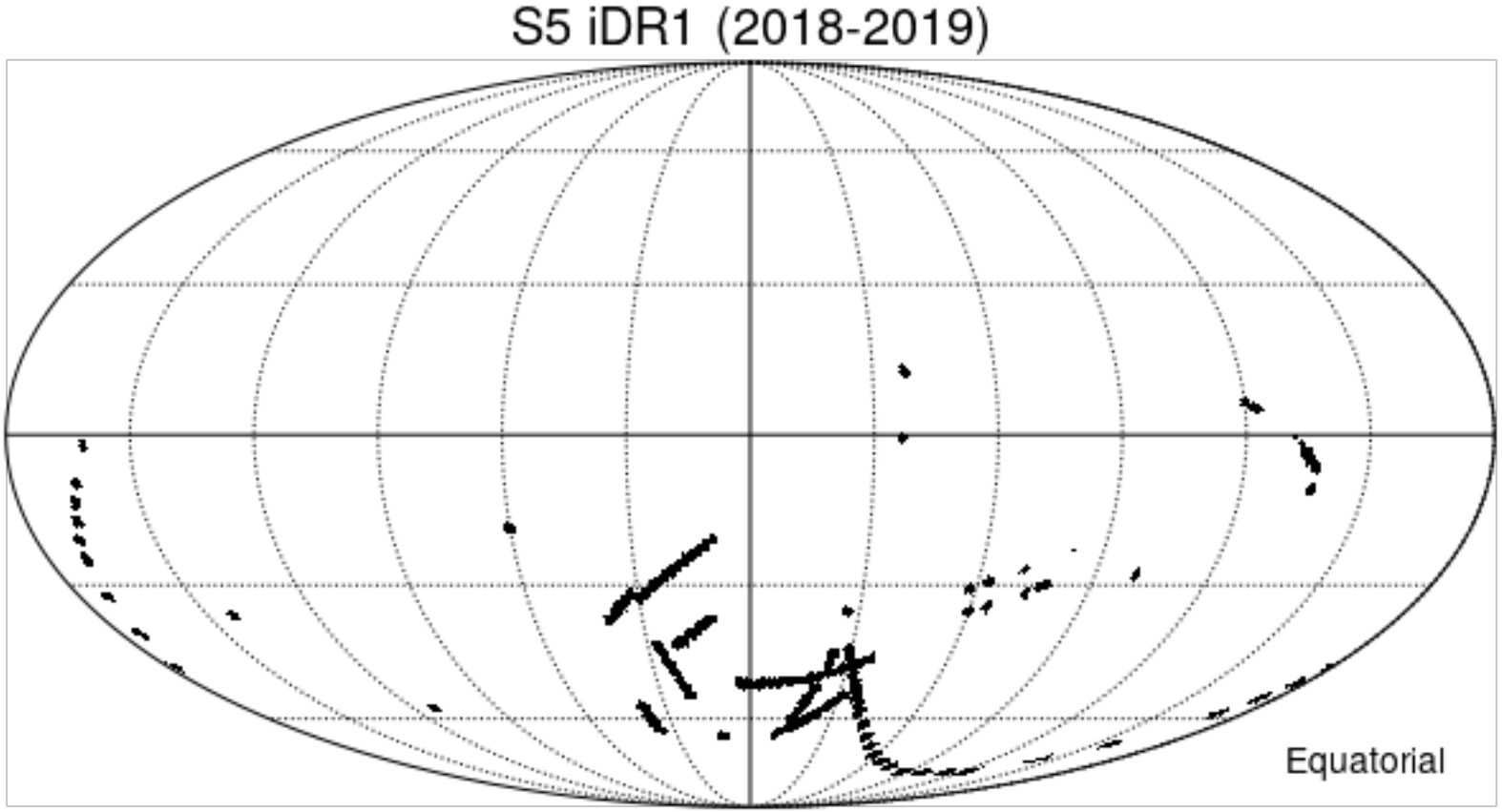
Observed

Pilot program

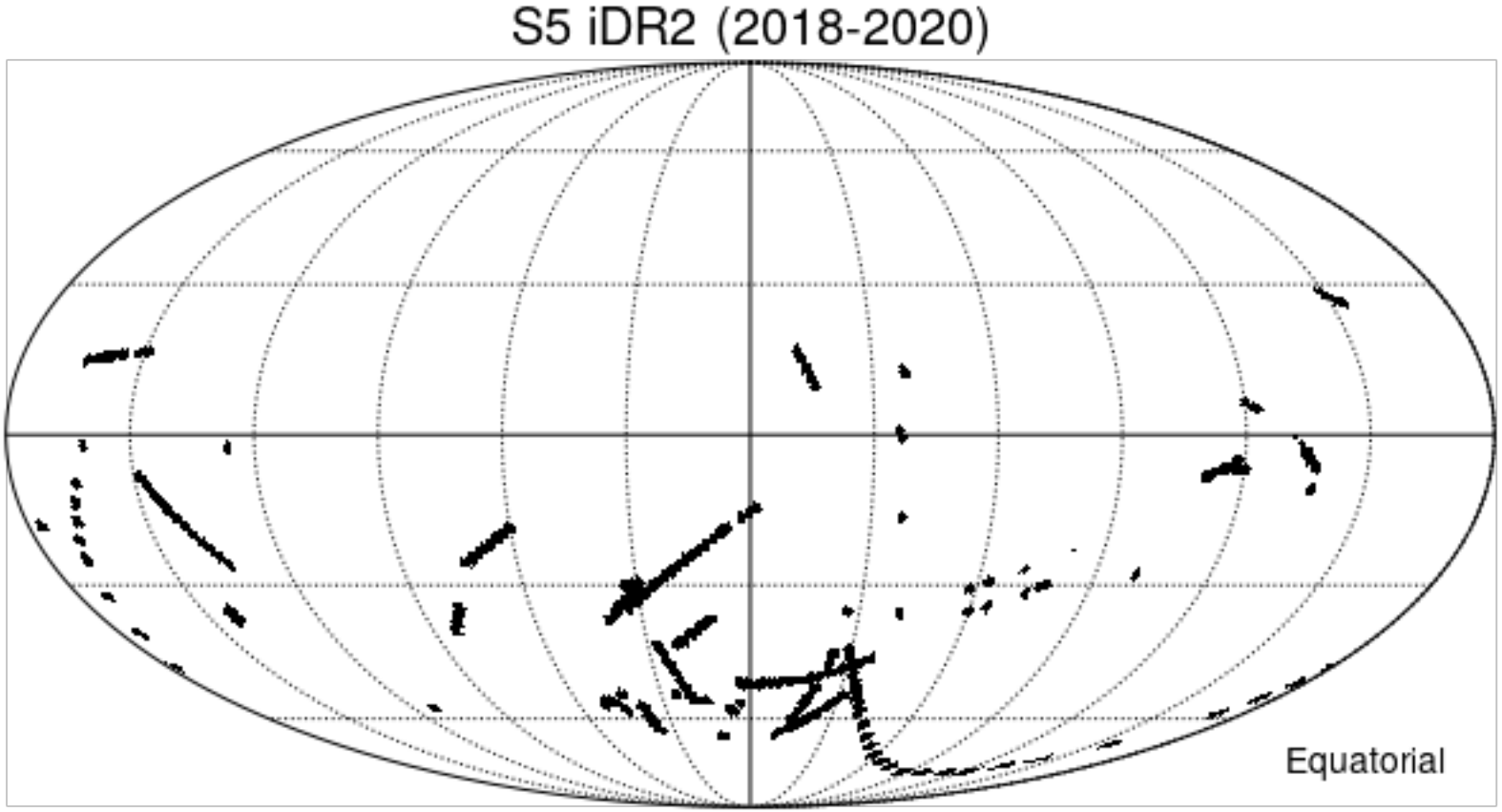
TSL et al. 2019
(S^5 Collaboration)

S5 iDR1 (2018-2019)





12 streams, ~300 sq. deg
~30 AAT nights
First Public Data Release in April 2021 via Zenodo



20+ streams (partially) mapped
~500 sq. deg
Over a total of 50+ AAT nights

S^5 Summary

- S^5 is an ongoing survey that maps the stellar streams in the Southern Hemisphere.
- S^5 has observed 20+ stellar streams.
- ATLAS and Aliqa Uma streams, which are previously thought unrelated, are actually one stream. The perturbation is likely caused by a dark matter sub halo flyby.
- Phoenix stream is more metal poor than any known globular cluster.
- S^5 also has a high-resolution program to study the chemical abundances of member stars in these streams
- In additional to stellar streams, S^5 also has a Milky Way halo survey and a low redshift galaxy survey.
- We have found the fastest main-sequence star using S^5 data. It was kicked away from Galactic Center ~5 Myr ago.
- Experience/Lessons for future spectroscopic surveys (e.g. DESI, WEAVE, 4MOST…)
- The first public data release (DR1) happened in April 2021.