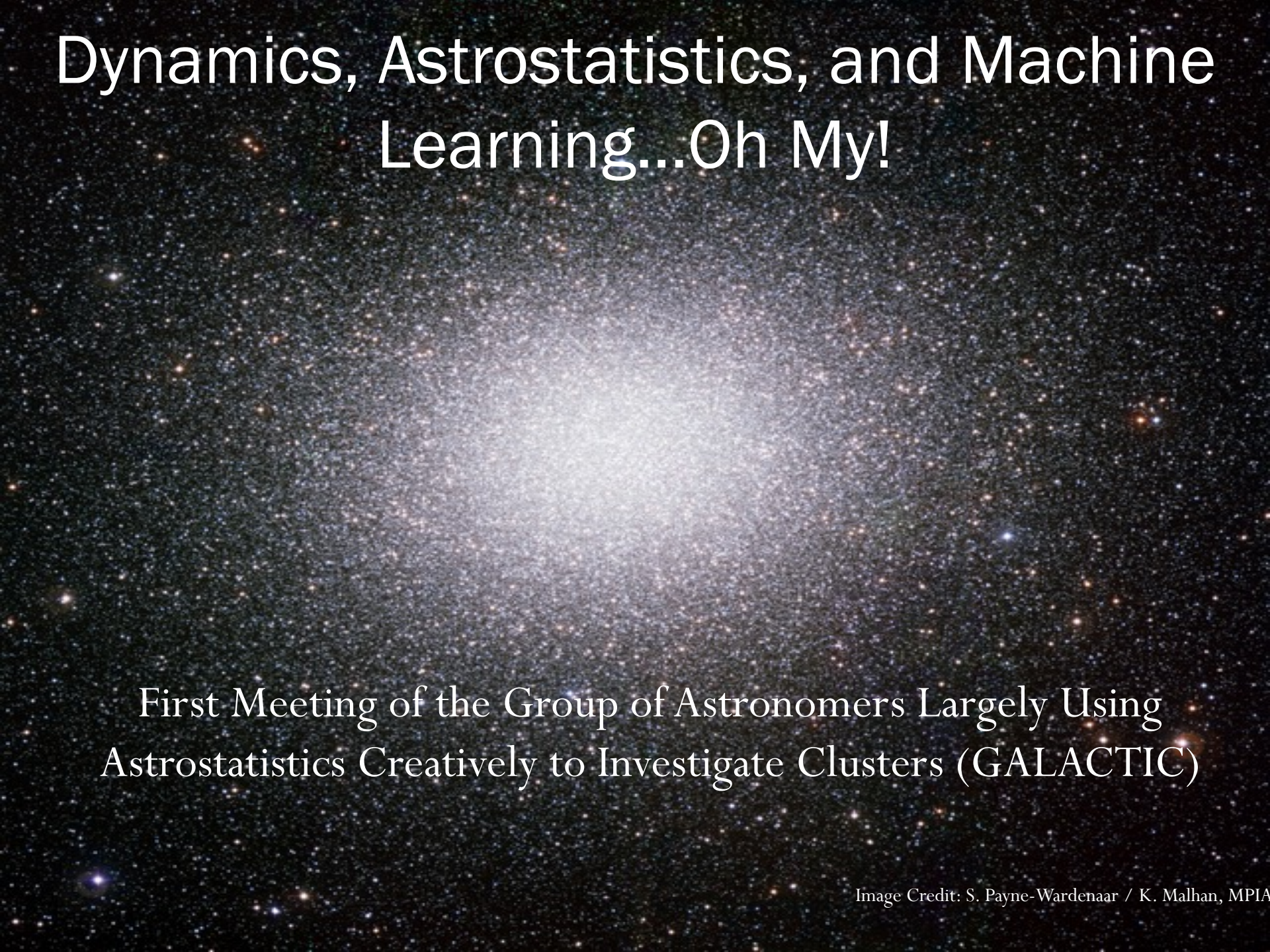
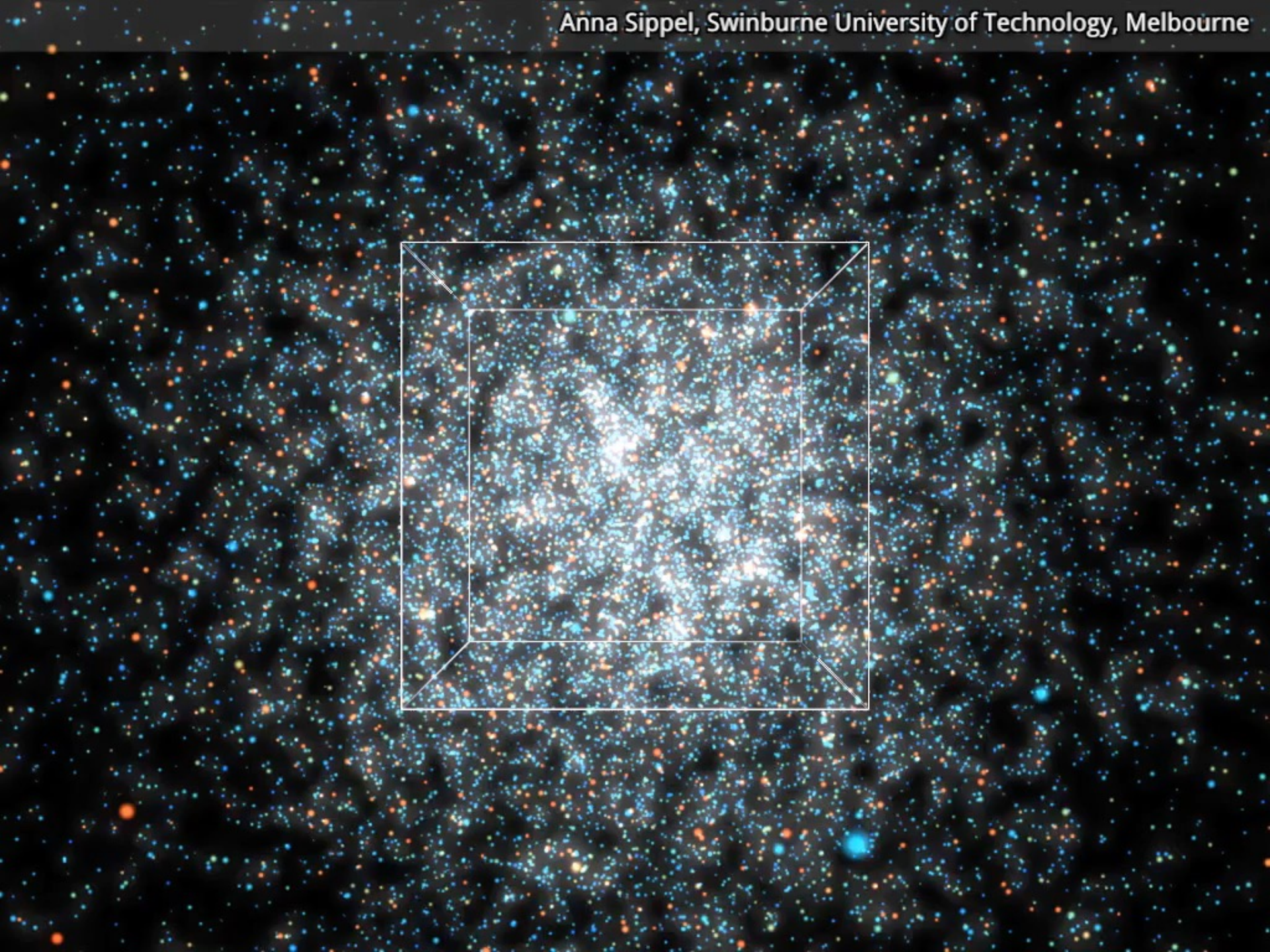
Dynamics, Astrostatistics, and Machine Learning...Oh My!



First Meeting of the Group of Astronomers Largely Using Astrostatistics Creatively to Investigate Clusters (GALACTIC)

Image Credit: S. Payne-Wardenaar / K. Malhan, MPIA

Anna Sippel, Swinburne University of Technology, Melbourne

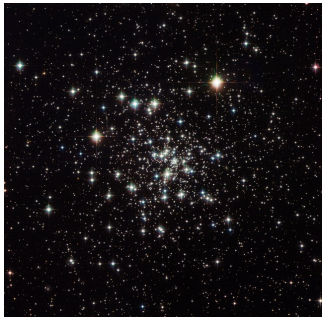


Star Formation Occurs in Clustered Environments

- Stars do not form alone
  - True of both early and current star formation
- Gas clouds fragment, allowing multiple stars to form
- Form clusters less than 100 pc in size
  - 50% of mass within a few pc

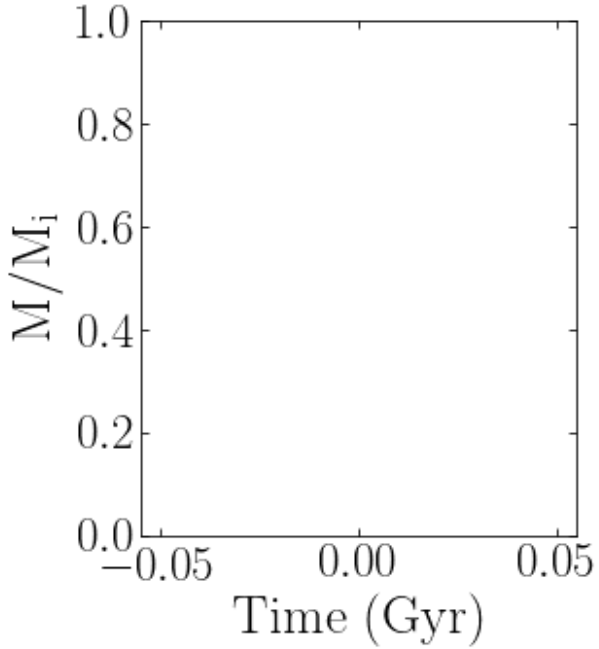
End Products of Star Formation

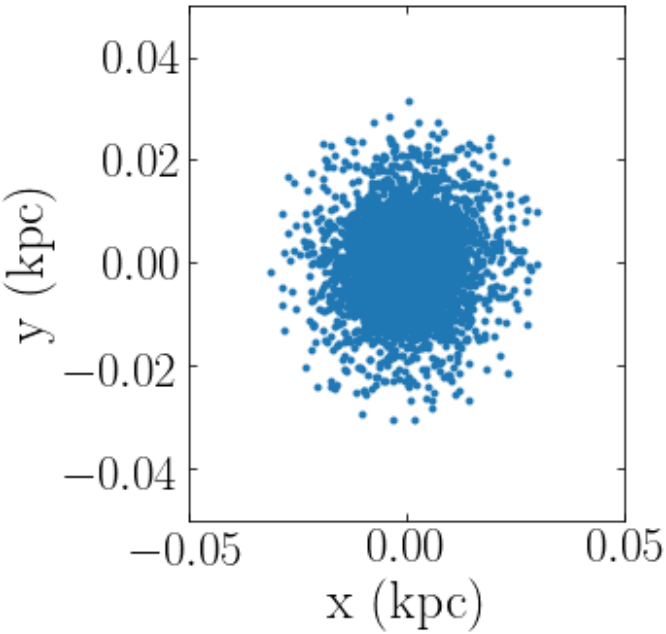
High-Mass / Dense Clusters
(Globular Clusters)



Low-Mass / Extended Clusters
(Open Clusters)

Very Low-Mass / Loosely Bound Associations
(OB Associations)


1.0
0.8
0.6
0.4
0.2
0.0
M/M$_i$
−0.05
0.00
0.05
Time (Gyr)


0.04
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−0.04
y (kpc)
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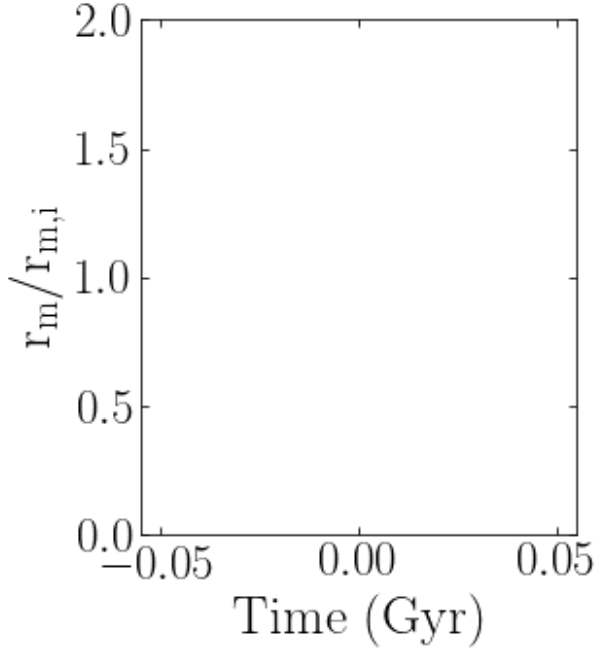
x (kpc)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r$_m$/r$_{m,i}$
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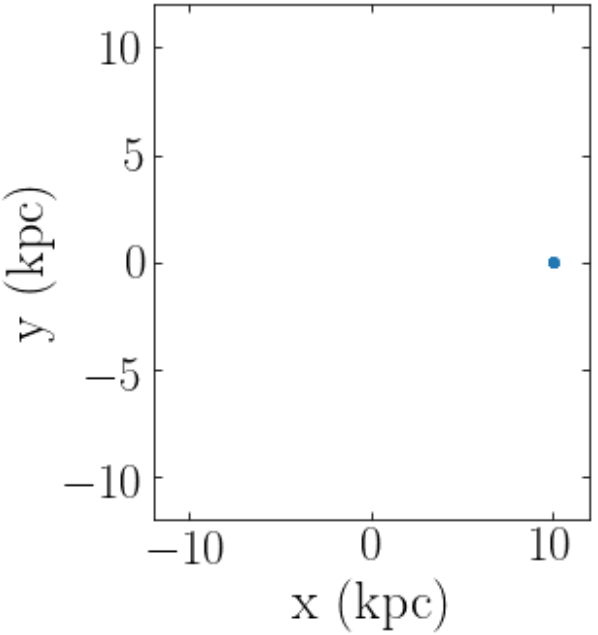
Time (Gyr)


10
5
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y (kpc)
−10
0
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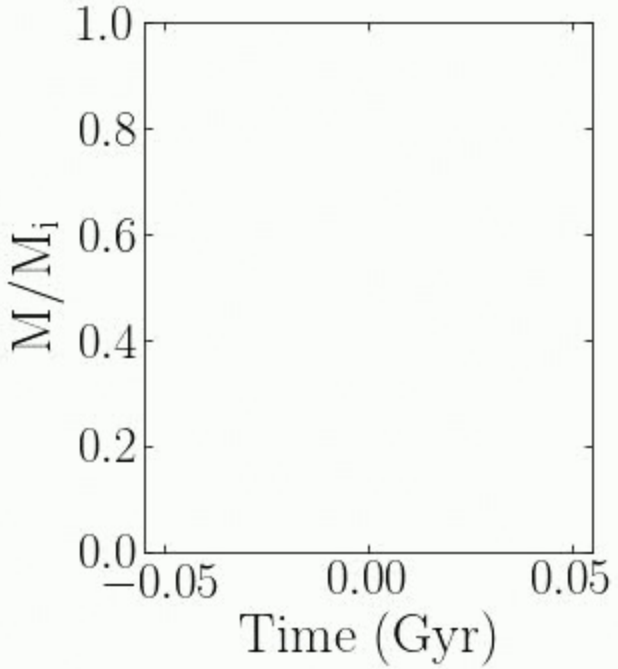
x (kpc)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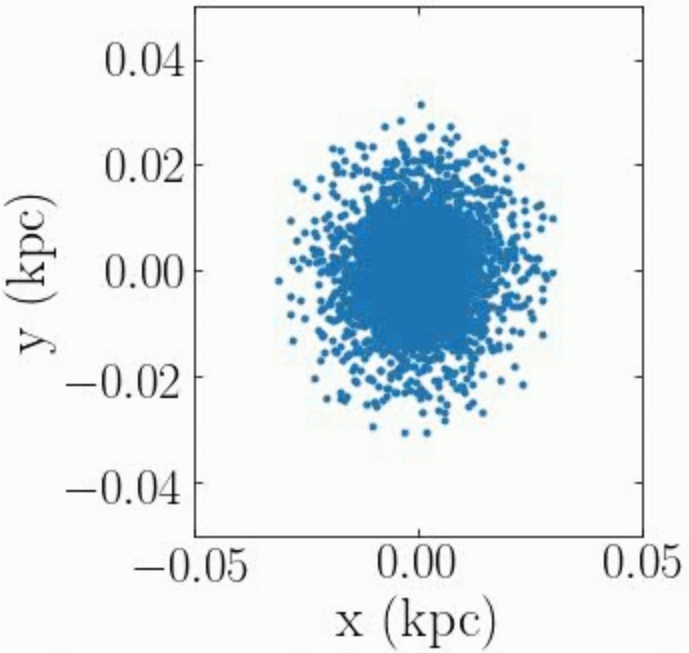
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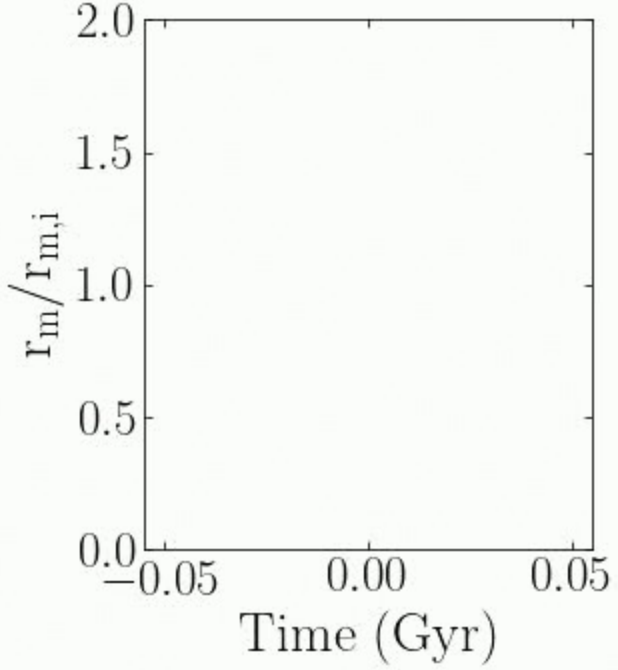
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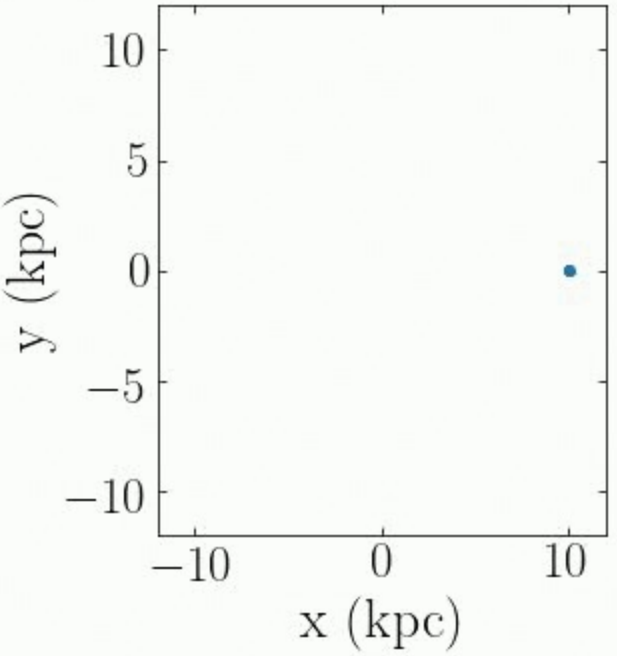
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y (kpc)
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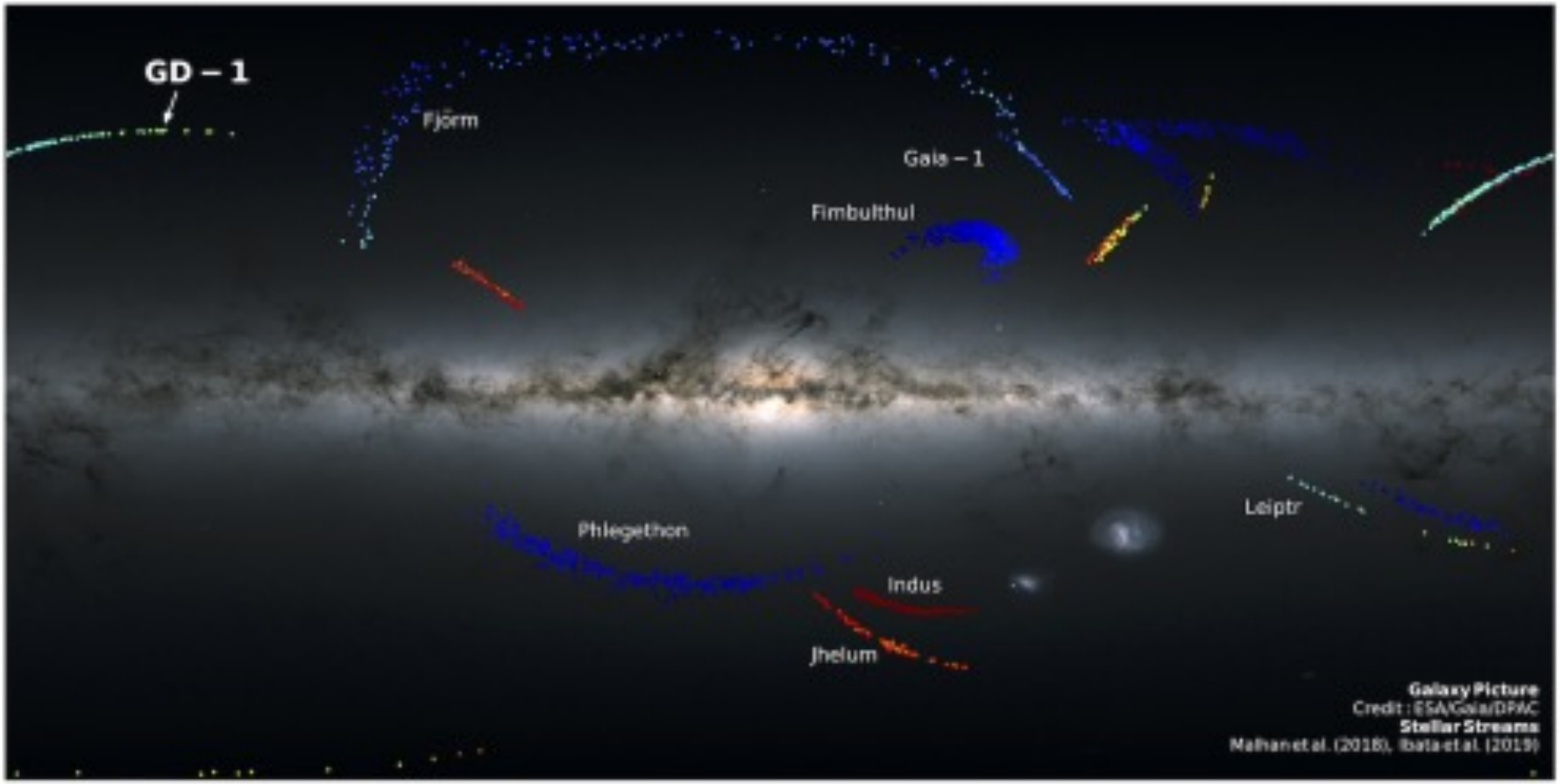
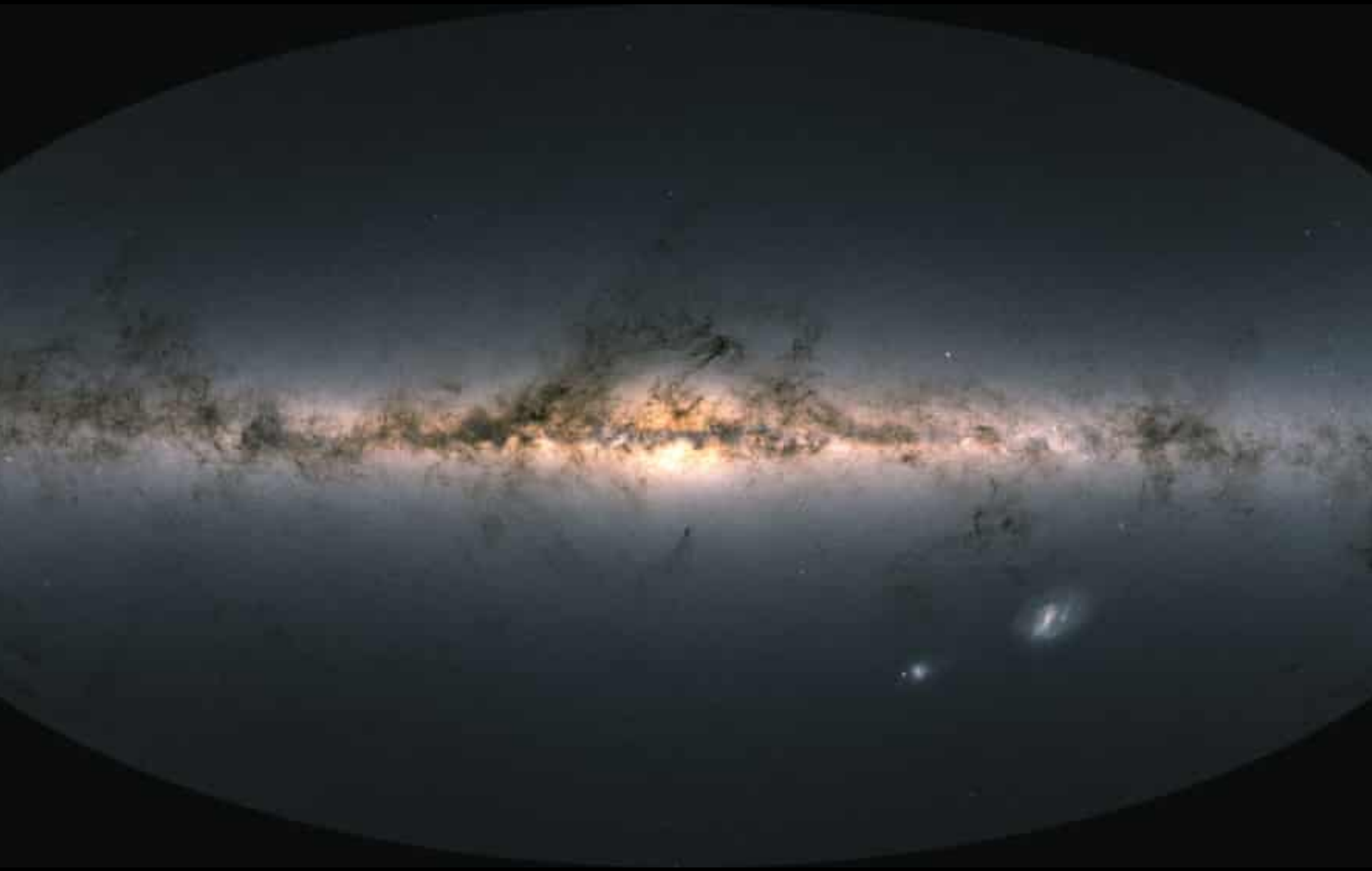
10
x (kpc)

Tidal Tails / Stellar Streams



Malhat et al. 2018



Star Clusters Are Everywhere

- Spiral Galaxies
  - Halo Clusters
  - Disk Clusters
- Dwarf Galaxies
- Elliptical Galaxies

Why study star clusters?

- Initial mass and size functions reveal formation process and environment
  - Understand star formation in local and high-redshift Universe
- Star cluster evolution strongly linked to galaxy formation, evolution and structure
  - Map distribution of matter in a galaxy
  - Possible to reconstruct a galaxy's merger history

Revealing the Milky Way's Dissolved Star Cluster Population with Dynamics, Chemistry, and High Dimensional Analysis

Grondin, S., Webb, J.J., Leigh, N., Speagle, J., Kahlifeh, R. 2022, MNRAS, Submitted

Webb, J.J., Price-Jones, N., Bovy. J., Hunt, J.A.S., Portegies-Zwart, S., Mackereth, J.T., Leung, H.W., 2020, MNRAS, 494, 2268

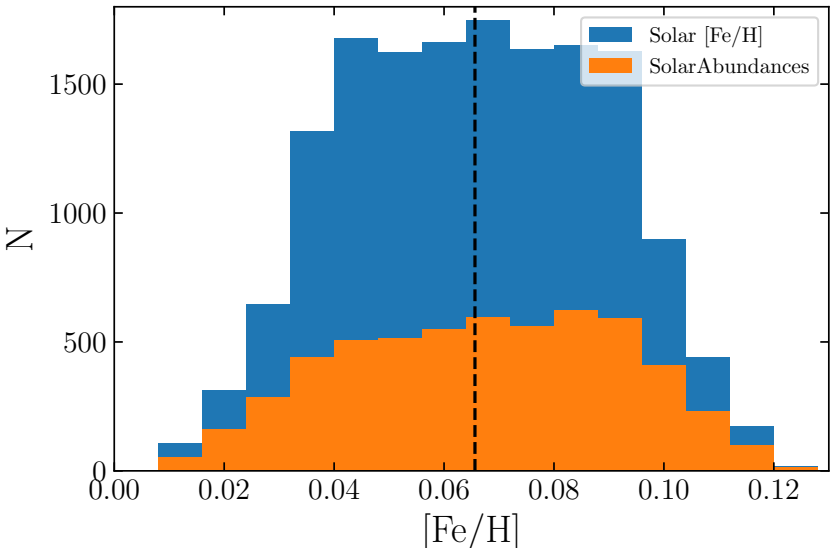
Price-Jones, Bovy, Webb, et al. 2022, MNRAS, 4996, 5101

Chemo-dynamical Tagging

- Stars that form in the same clustered environment will have similar chemical abundances across a wide range of elements
- As a star cluster dissolves, there is a limited kinematic parameter space that an escaped star can occupy
- How do we match stars across a large N-dimensional parameter space?

Large Surveys

- When combined we have **COMPOSITION** and **ORBITS** of over 200,000 stars!!
- Are any consistent with being born in and escaping from the same cluster/association?



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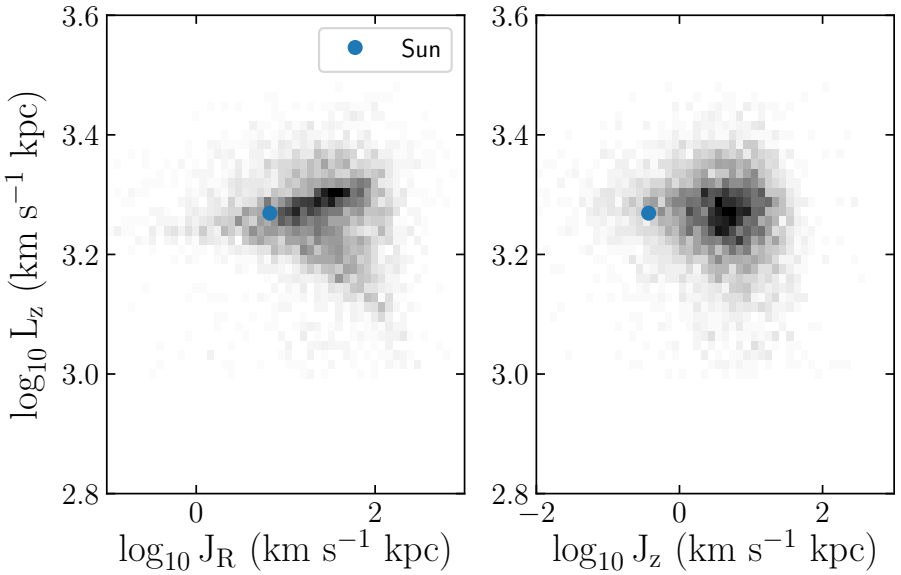
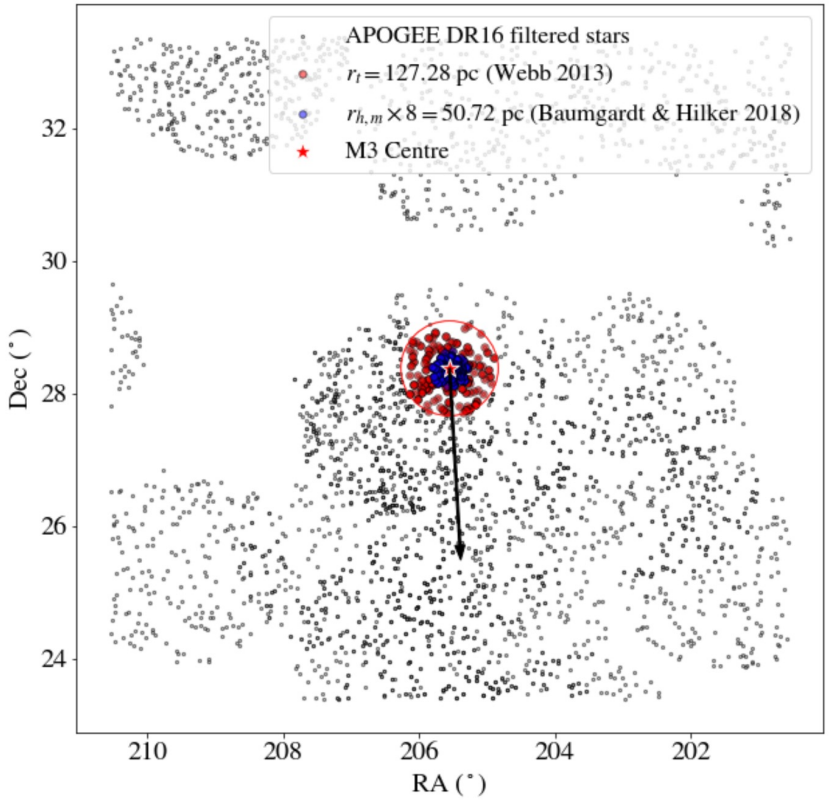
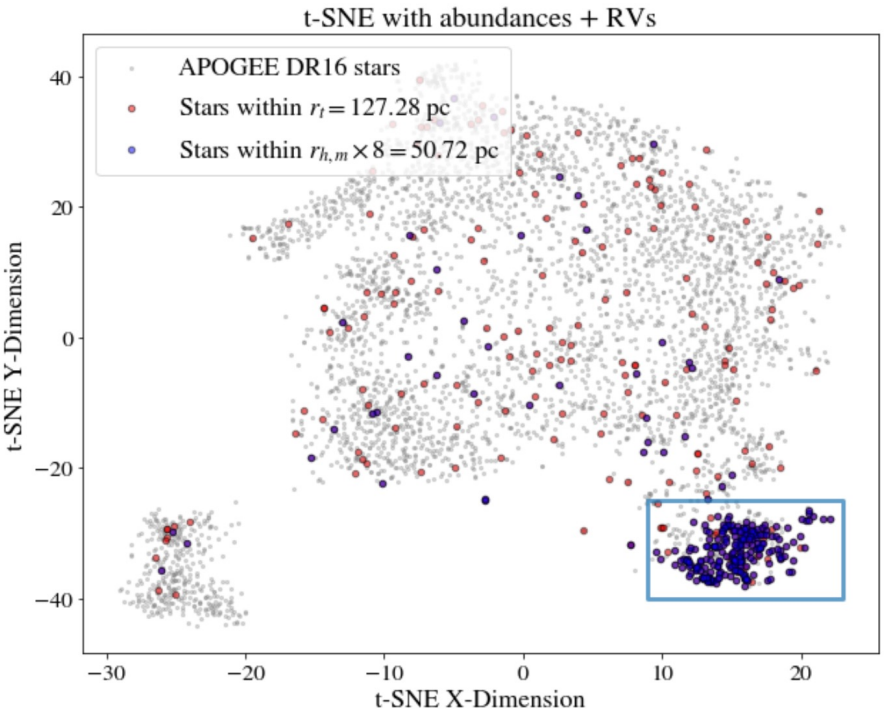


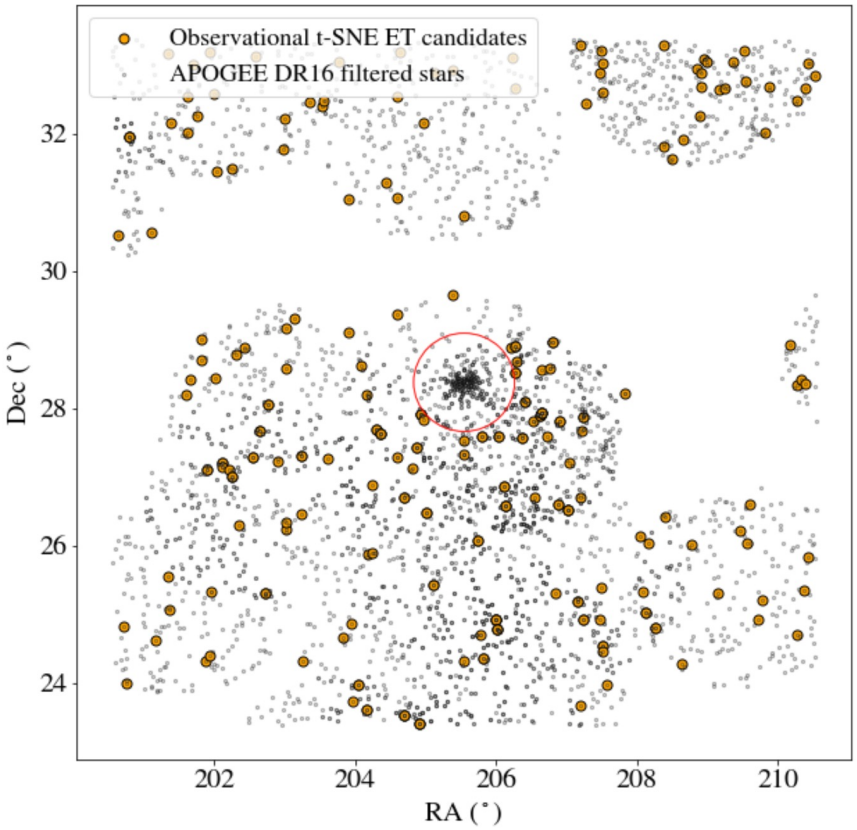
M3 Cluster Stars in APOGEE

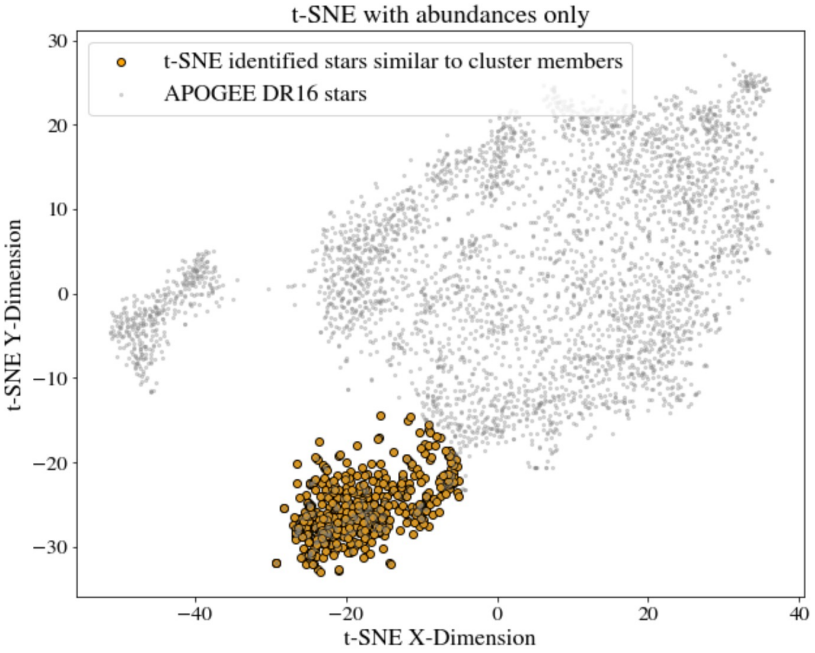




Credit: Grondin et al. 2022

“Extra-tidal” Stars in APOGEE

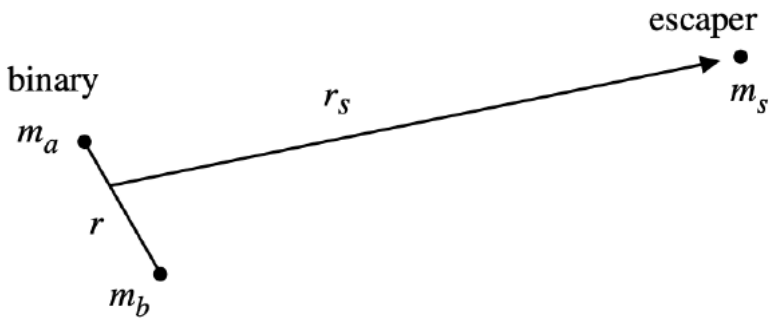




Credit: Grondin et al. 2022

Core Ejections

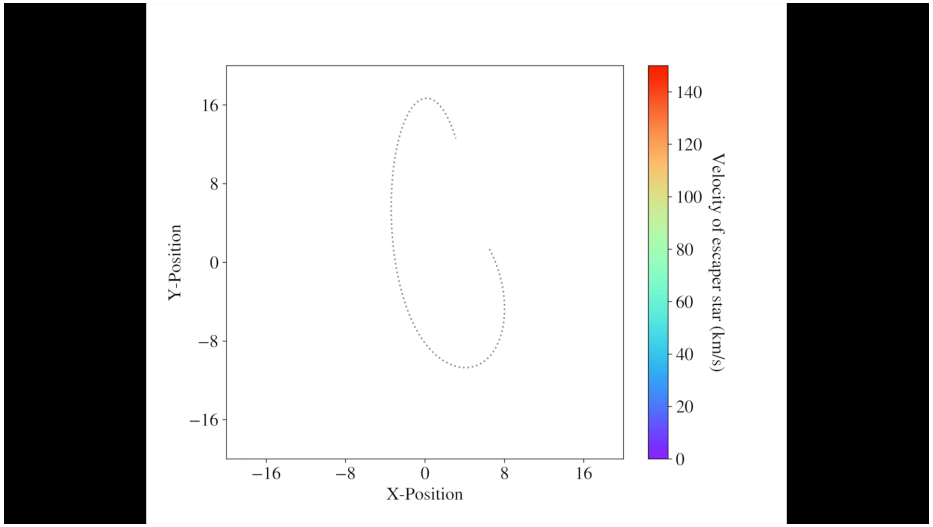
- Three-body interactions in star cluster cores result in stars receiving large velocity kicks
- Stars are ejected from a cluster's core in random directions
- Recovering these stars informs us about a star clusters mass loss history and central dynamics



Valtonen & Karttunen 2006

Corespray – Currently available on GitHub

- Sample three-body interactions within the core of a star cluster
- Generate kick velocities in random directions
- Integrate orbit of kicked stars within combined potential of Milky Way and host cluster
- Statistical representation of an ejected star's properties



Credit: Grondin et al. 2022

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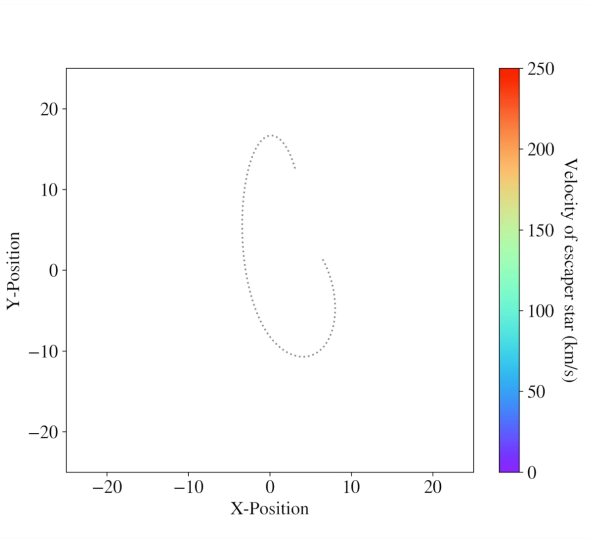
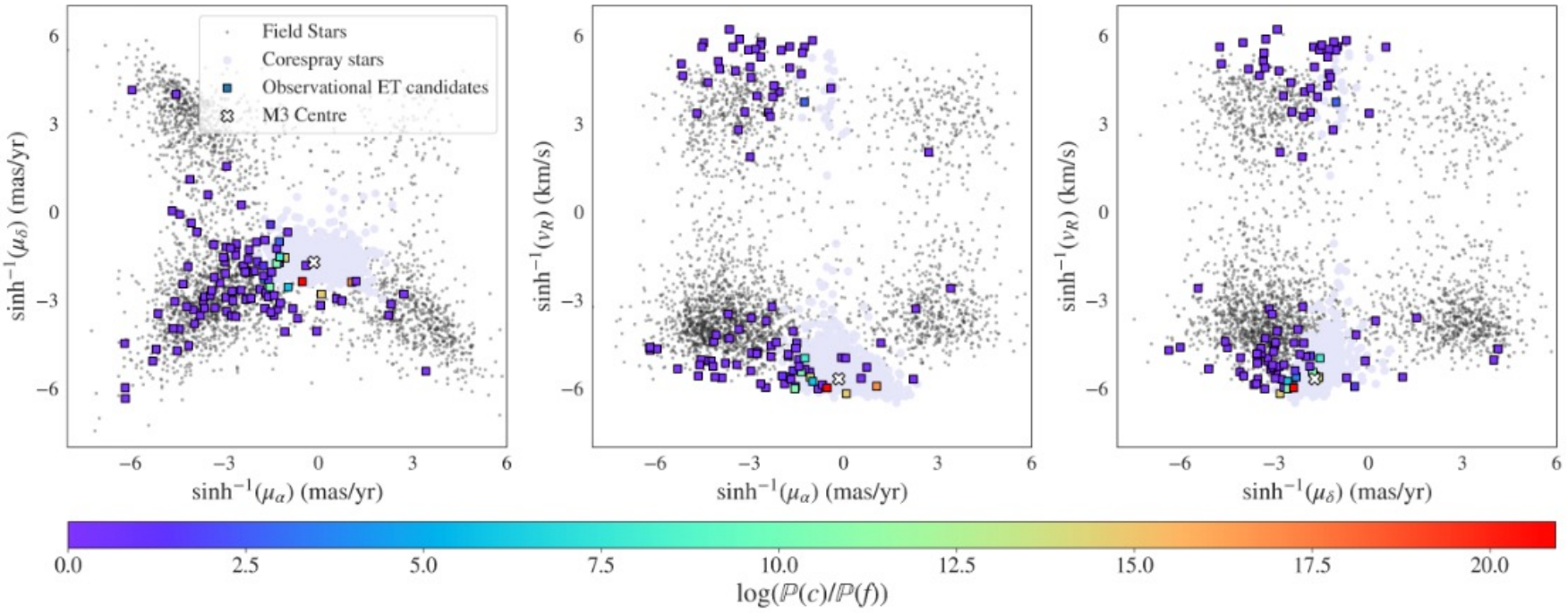


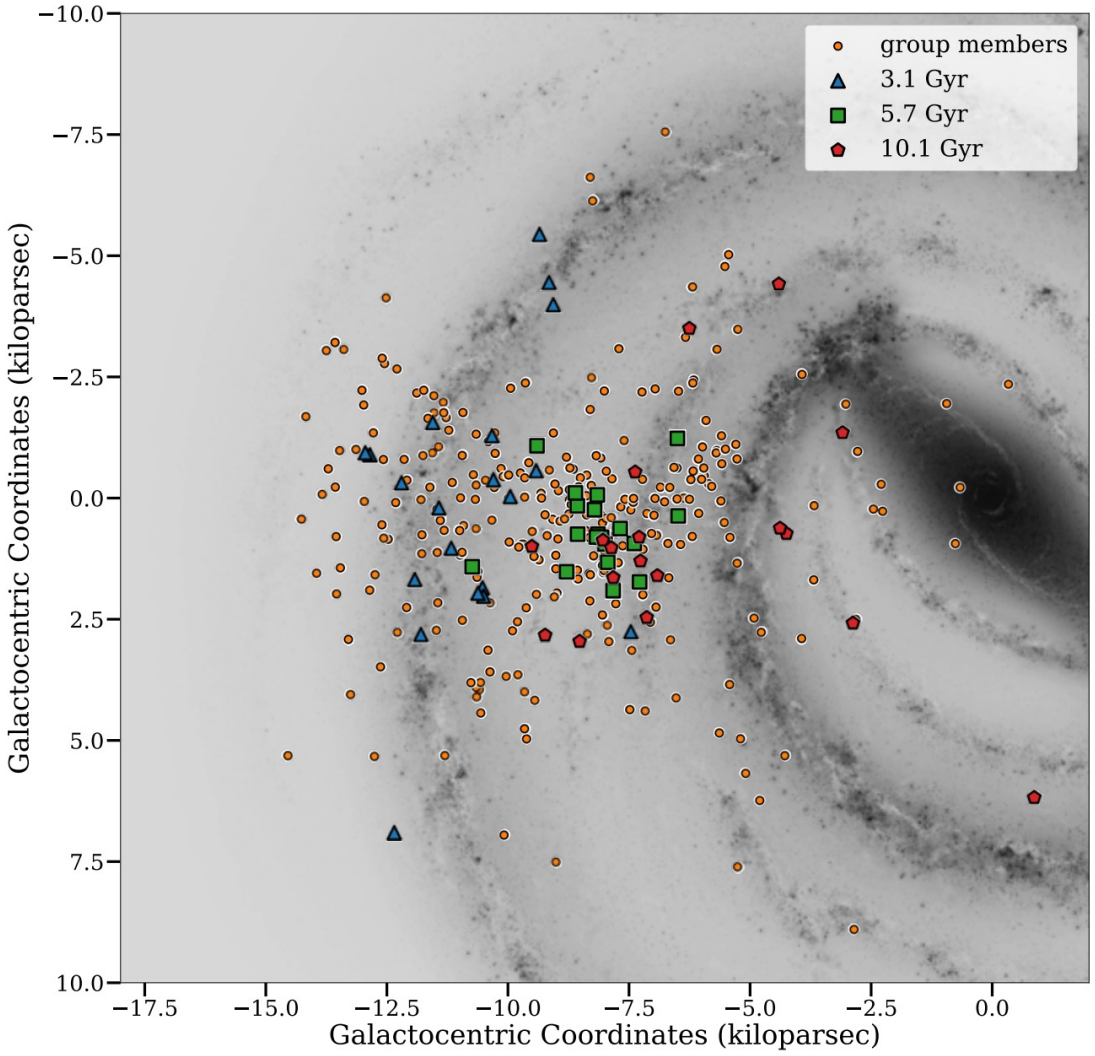
Credit: Grondin et al. 2022

Kinematics of Ejected Stars



Credit: Grondin et al. 2022

Even possible with no known host



Price-Jones et al. 2020

Dissolved Star Clusters and Streams

- Dissolution sensitive to the details of their host galaxy
  - Bar, spiral arms, disk, GMCs, dark matter sub-halos
  - Possible to constrain host galaxy with cluster/stream/escaped star properties
- High dimensional analysis of abundances and kinematic properties of field stars a step towards recovering "lost" clusters

Extra Tidal Stars

- Finding extra tidal stars requires chemo-dynamical tagging of field stars
- Reveals a cluster's mass loss history and birth conditions
- Can be sensitive to properties of the cluster's core and binary fraction

So much more to do!

- The GALCTIC Group will be continuing the process of chemo-dynamically tagging stars in the Milky Way through four broadly defined avenues:
  - A robust treatment of observational uncertainty and error propagation in the chemo-dynamical tagging process
  - An exploration of the effectiveness of different machine learning algorithms in chemo-dynamical tagging
  - The application of the ”Grondin Method” to new datasets
  - Improving and expanding the dynamics package “corespray” to better understand the range of spatial and kinematic properties that escaped cluster stars can have

End Goals

- A fully automated ”Grondin Method” that includes a range of dynamical processes and machine learning algorithm options
- A complete chemo-dynamical tagging of the APOGEE/Gaia catalogue
  - Database of confirmed cluster members and extra-tidal star candidates
  - Identification of newly discovered streams/clusters/groups

Admin

- Prof. Josh Speagle and Prof. Jeremy Webb can be listed as your AST 424/425/430 co-supervisors
- Plan is to meet as a group weekly, with smaller meetings scheduled as needed
- Most communication will probably be done over Slack from here on out
  - Let us know if you didn't get added to our Slack Channel
- A group github repo is almost done being put together that will have some T-SNE, UMAP, and corespray tutorials for everyone to check out

Today's/Short-term goals

- Answer any questions you all have about potential projects
- Clearly outline some projects for every member of the GALACTIC Group
- Get started on the project proposals!