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EXTENDED STRUCTURE IN GLOBULAR CLUSTERS WITH GAIA

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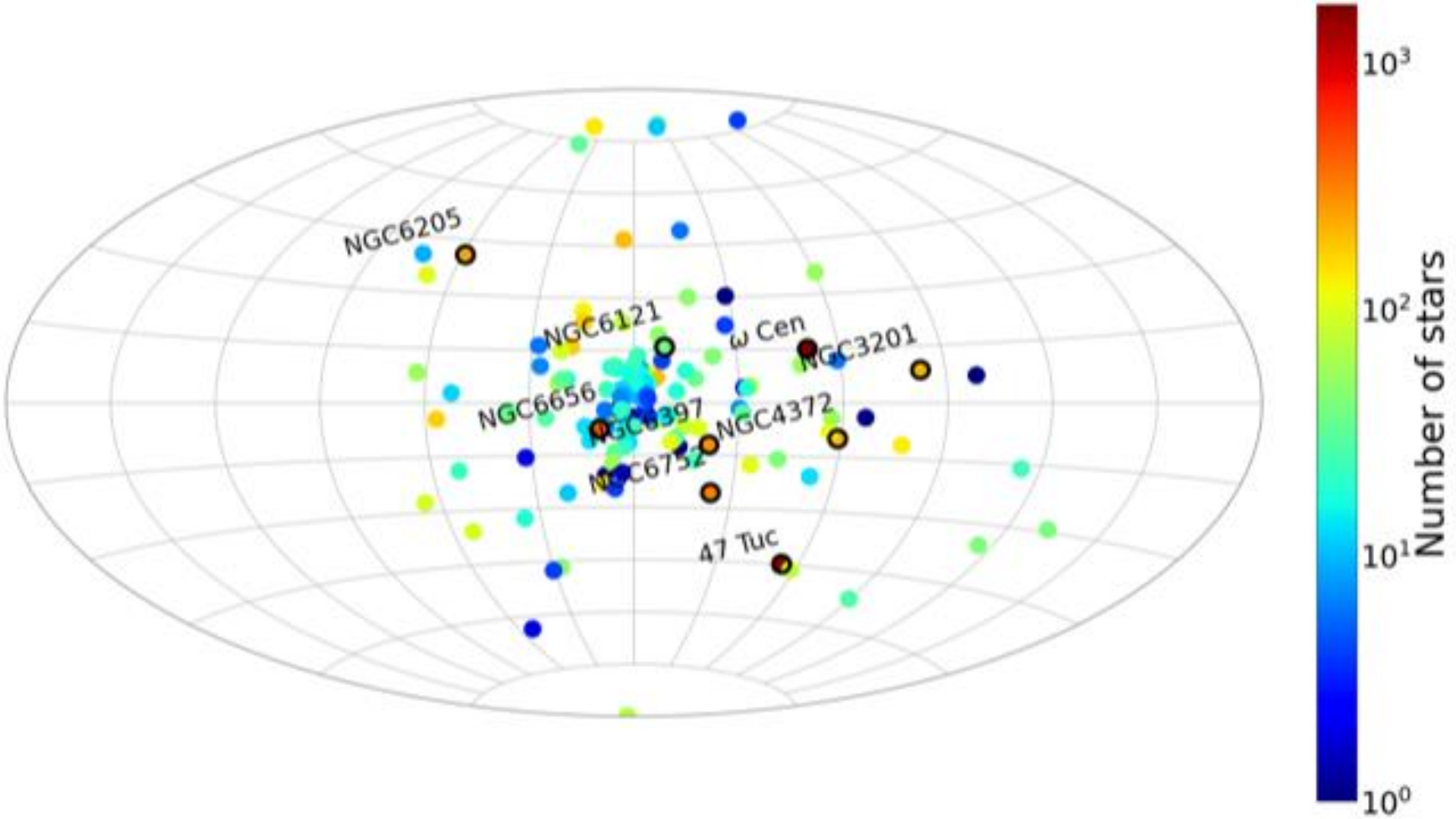
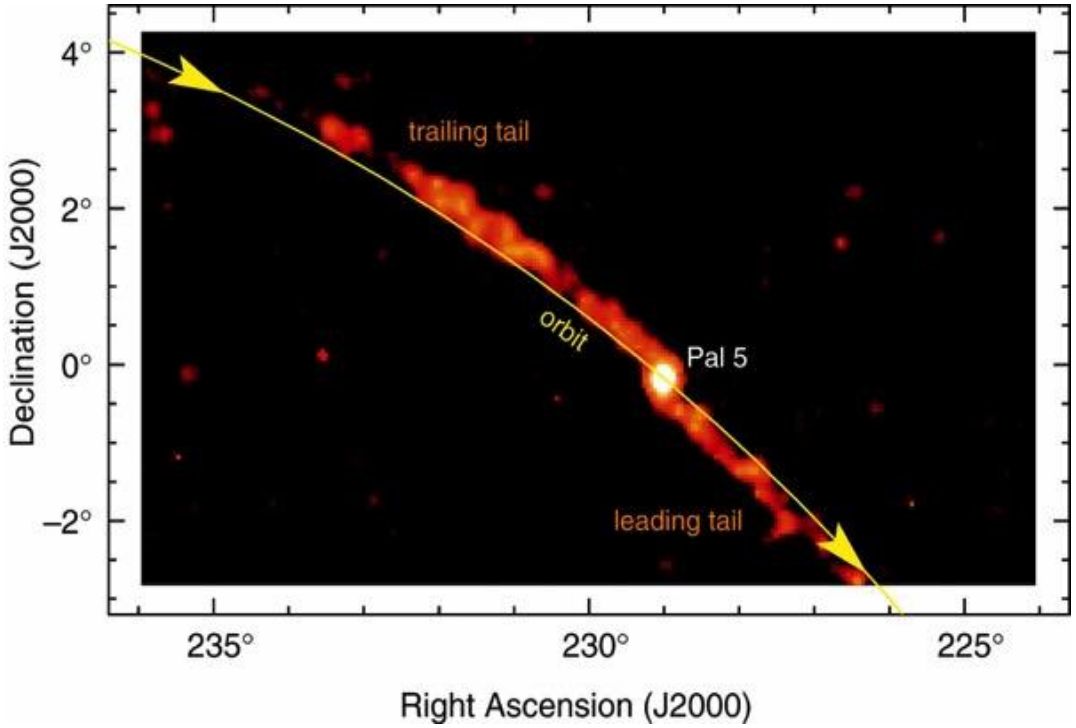
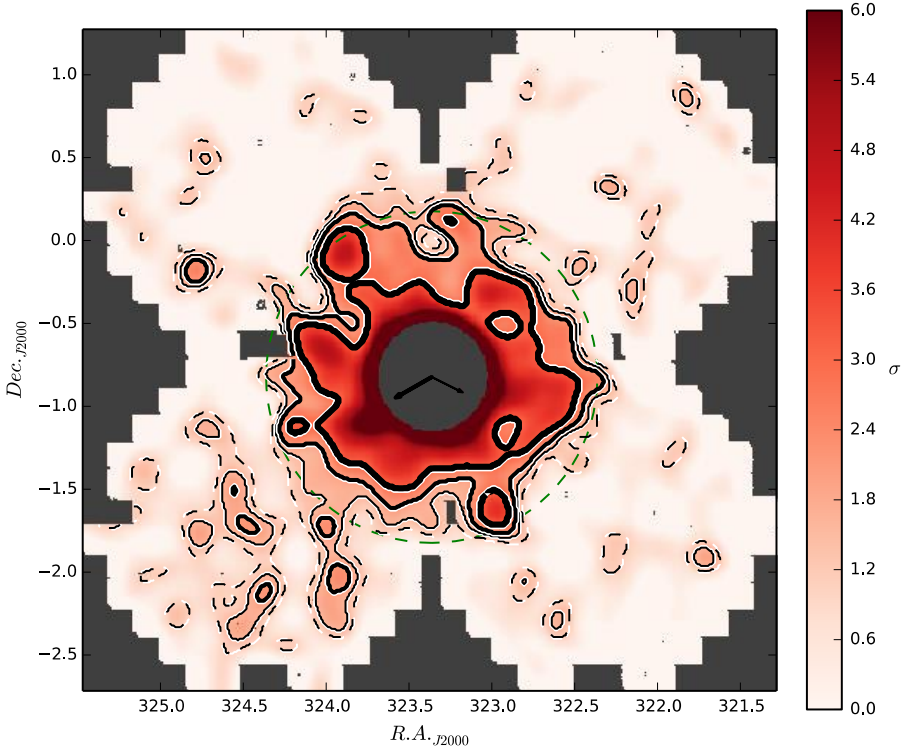
with Anna Lisa Varri, Annette Ferguson & Jorge Peñarrubia



Katz et al. 2022



Odenkirchen et al. 2001



Kuzma et al. 2016

The Ground Work

We retrieve a 5 deg radius around approx. 60 GCs from Gaia DR3.

Some data filtering:

- Have colour index >1.6 mag (removing field dwarfs).
- Stars within 3 kpc with resolved parallaxes.
- Poor or no astrometric solution (re-normalised unit weight error).
- Isochrone fitting and sigma clipping on photometry.

The Technique: Likelihood

The likelihood function takes the form of a mixture model, and it contains three components:

$$\mathcal{L}_{tot} = f_{cl+ex}\left(f_{cl}\mathcal{L}_{cl} + (1 - f_{cl})\mathcal{L}_{ex}\right) + (1 - f_{cl+ex})\,\mathcal{L}_{MW}$$

We calculate membership probability as:

$$P_{mem} = \frac{f_{cl+ex}\left(f_{cl}\mathcal{L}_{cl} + (1 - f_{cl})\mathcal{L}_{ex}\right)}{\mathcal{L}_{tot}}$$

See Kuzma et al 2021 MNRAS

The Technique: Proper Motions

Each component has two factors to consider – proper motion and spatial distributions.

Proper motions are modelled as bivariate Gaussian distributions. Cluster + extended components have the same proper motion.

See Kuzma et al 2021 MNRAS

The Technique: Spatial Distributions

Spatial distributions are different for each component:

- **King (1962) model for the cluster;**
- **Linear gradient model for the foreground;**
- **Quadrupole model for the extended component:**

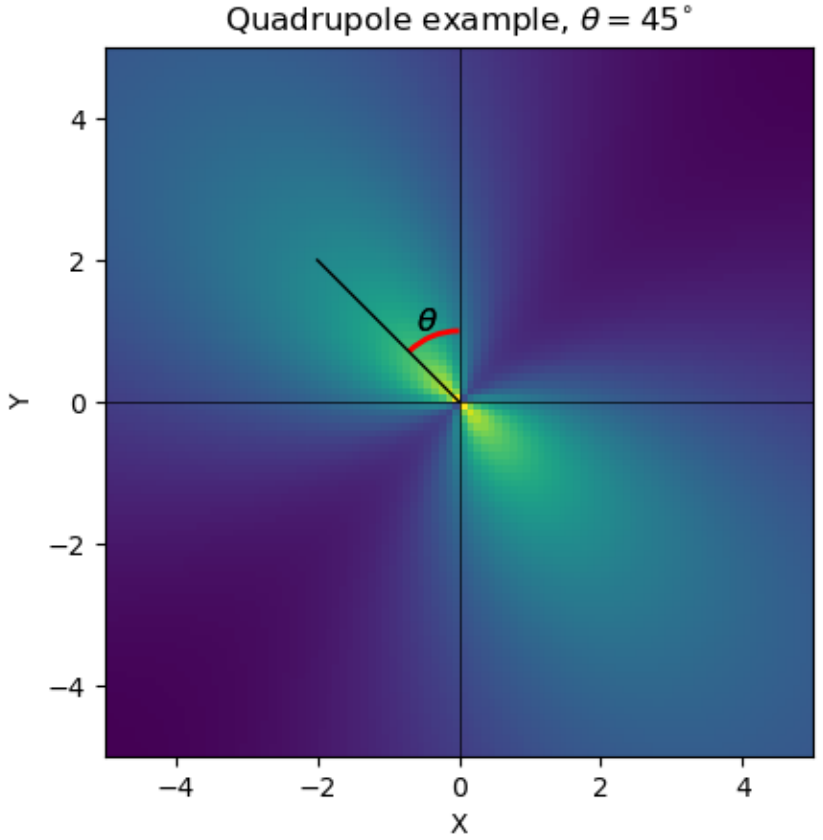
$$\Sigma(r,\theta) = (1+r)^{-\gamma}(1+\kappa_{ex}\ \cos^2(\theta-\theta_{ex}))$$

Kuzma et al 2023A, in prep

ue: Spatial Distributions

Spatial distribut ach component:

- King (1962) r
- Linear gradi round;



- **Quadrupole model for the extended component:**

$$\Sigma(r,\theta) = (1+r)^{-\gamma}(1+\kappa_{ex}\ \cos^2(\theta-\theta_{ex}))$$

Kuzma et al 2023A, in prep

Validation: Sample Design

We simulated a series of GCs with different parameters and debris to explore how the technique behaves:

- - 10^5 particles with 0.1% – 1% mass in the debris;
- - Proper motions both inside and outside the field motions;
- - GCs at 5 and 15 kpc;
- - Varying galactic latitudes.

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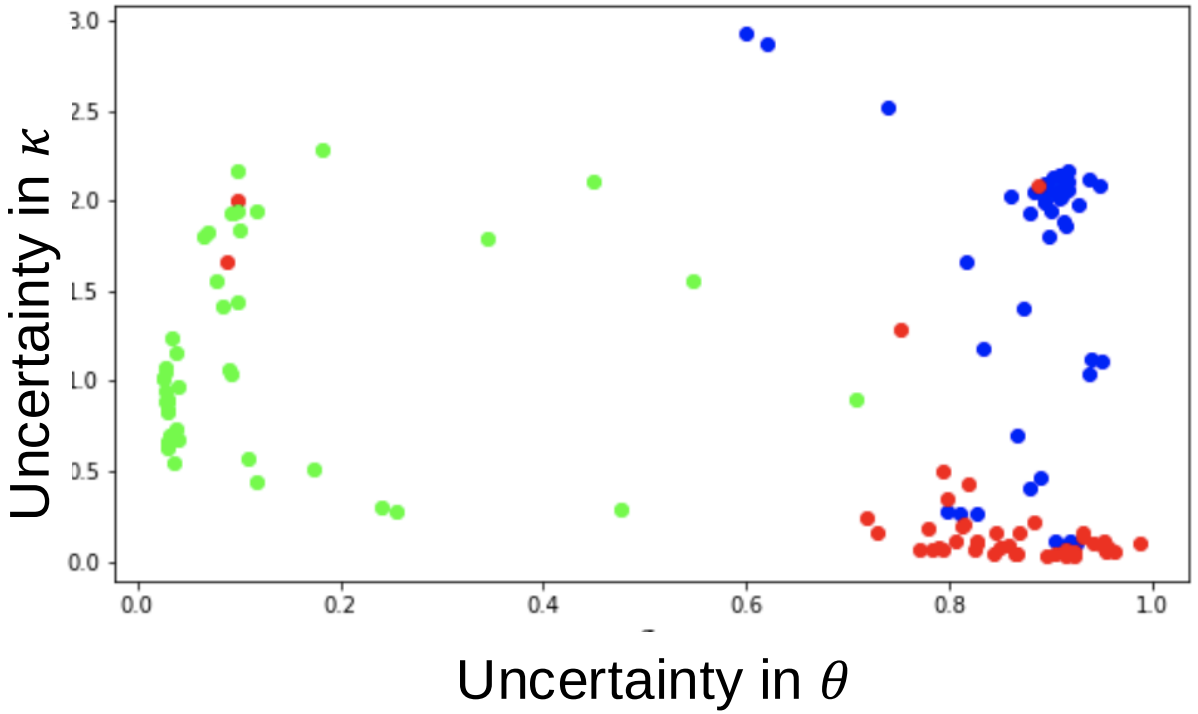
Validation: Optimal Classification



Exploring the uncertainty in θ, κ and γ, we can group the known debris using k-mean clustering.

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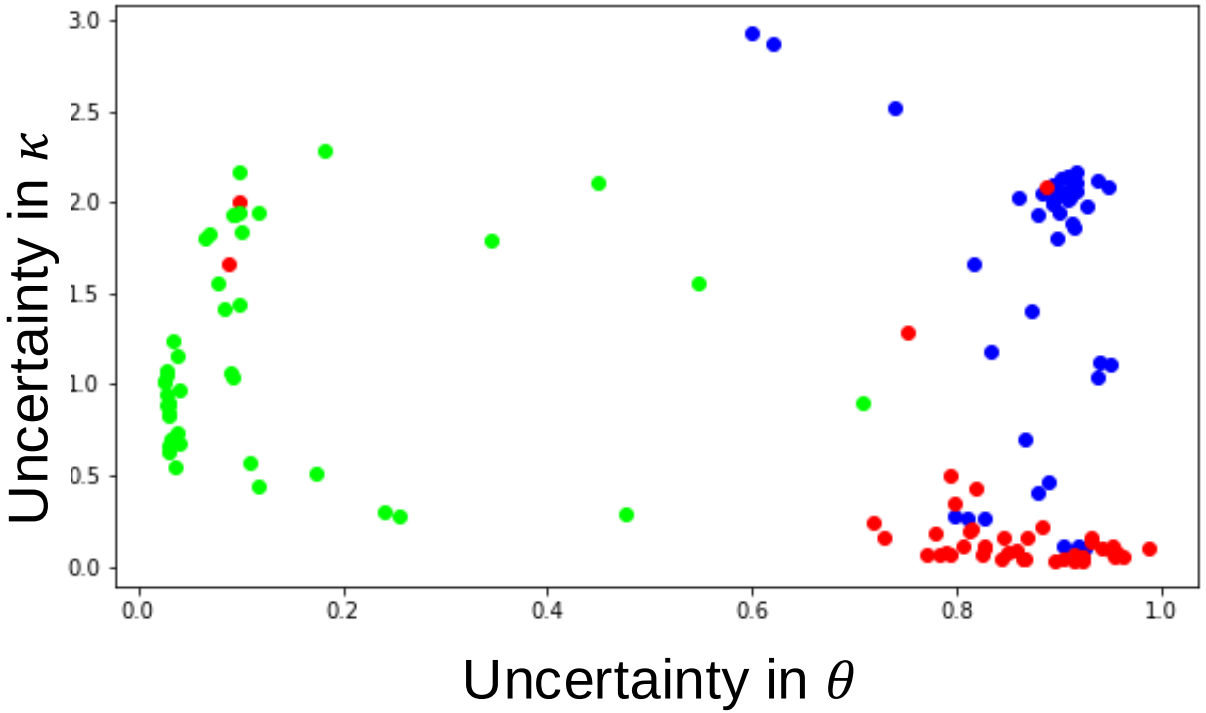
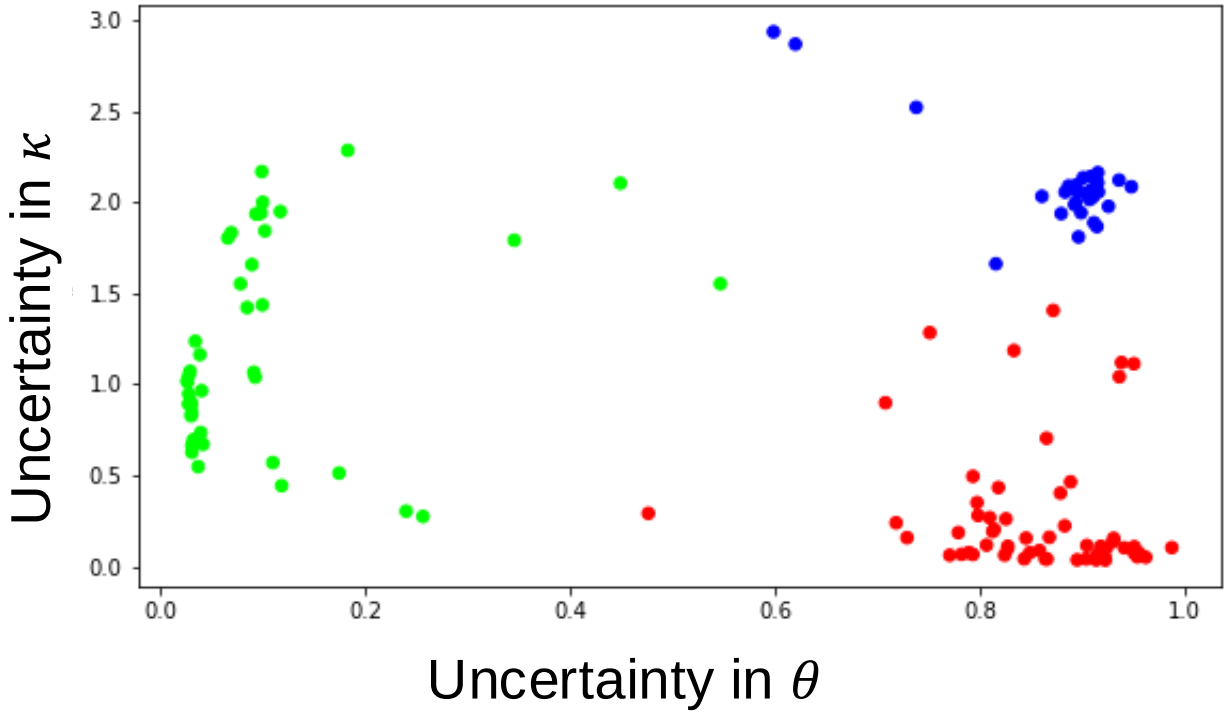
Validation: Clustering Comparison



"True" classification



"Agnostic" *k*-means clustering

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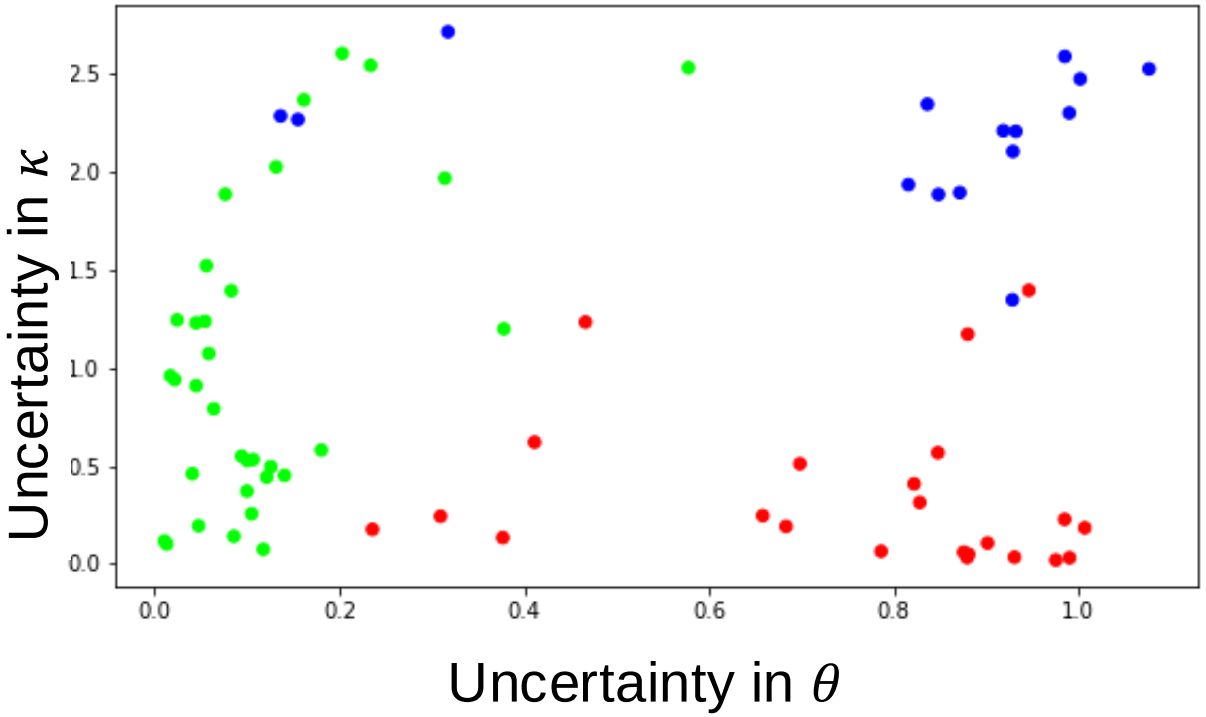
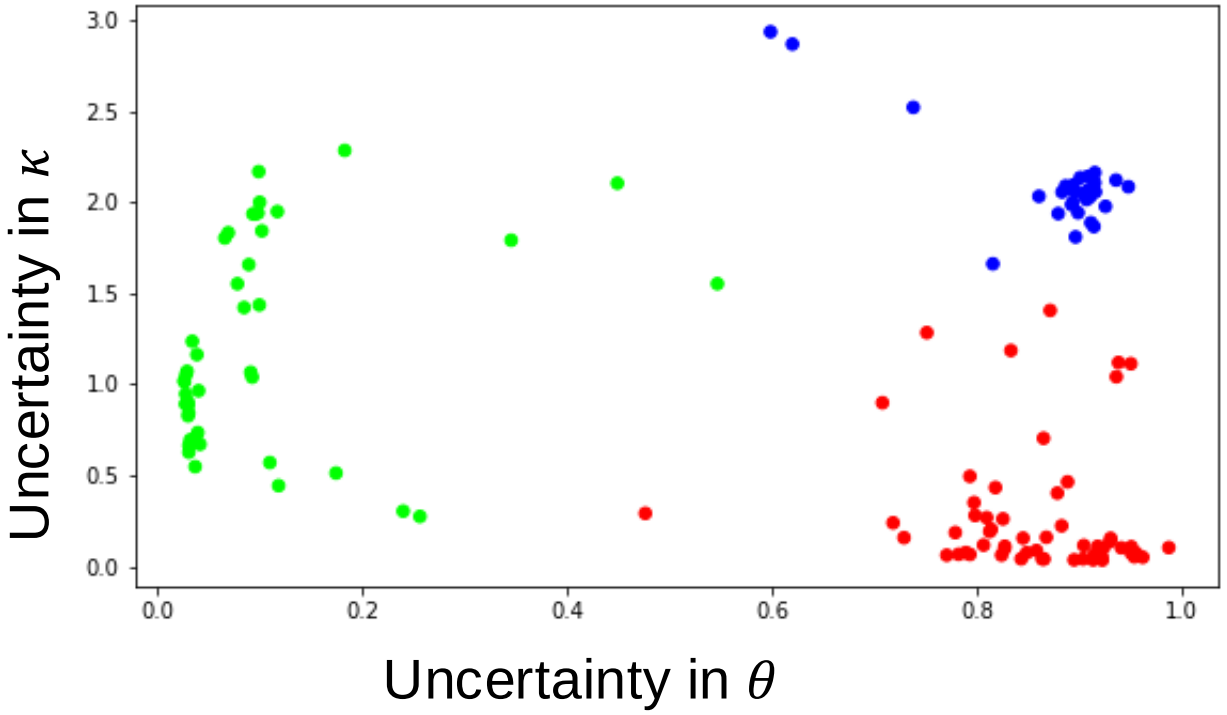
Getting real …



MW GC data



***k*-means clustering**

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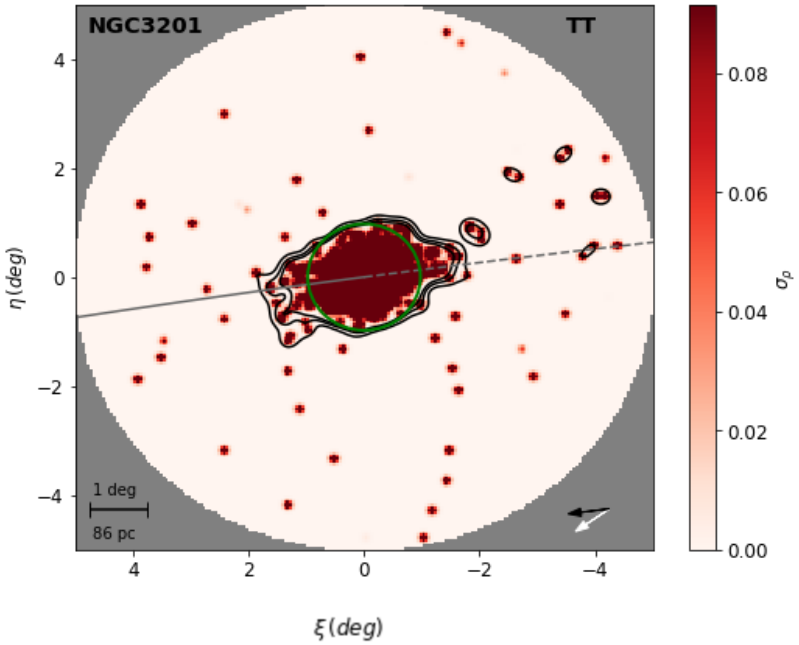
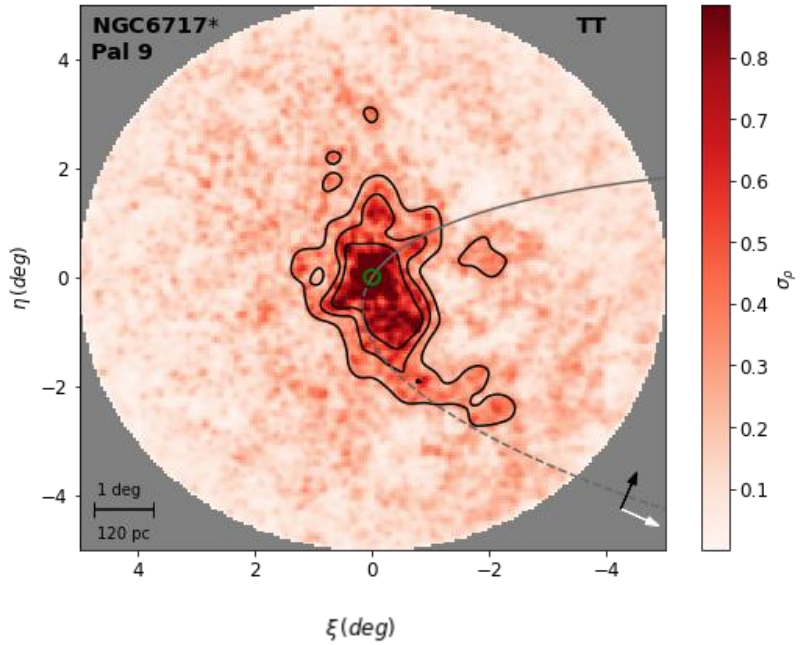
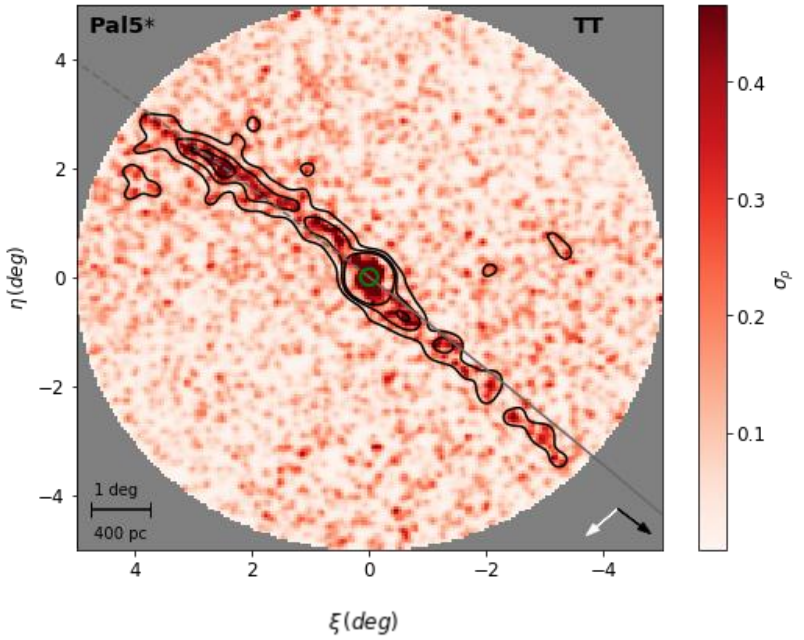
Results!

Tidal Tails…



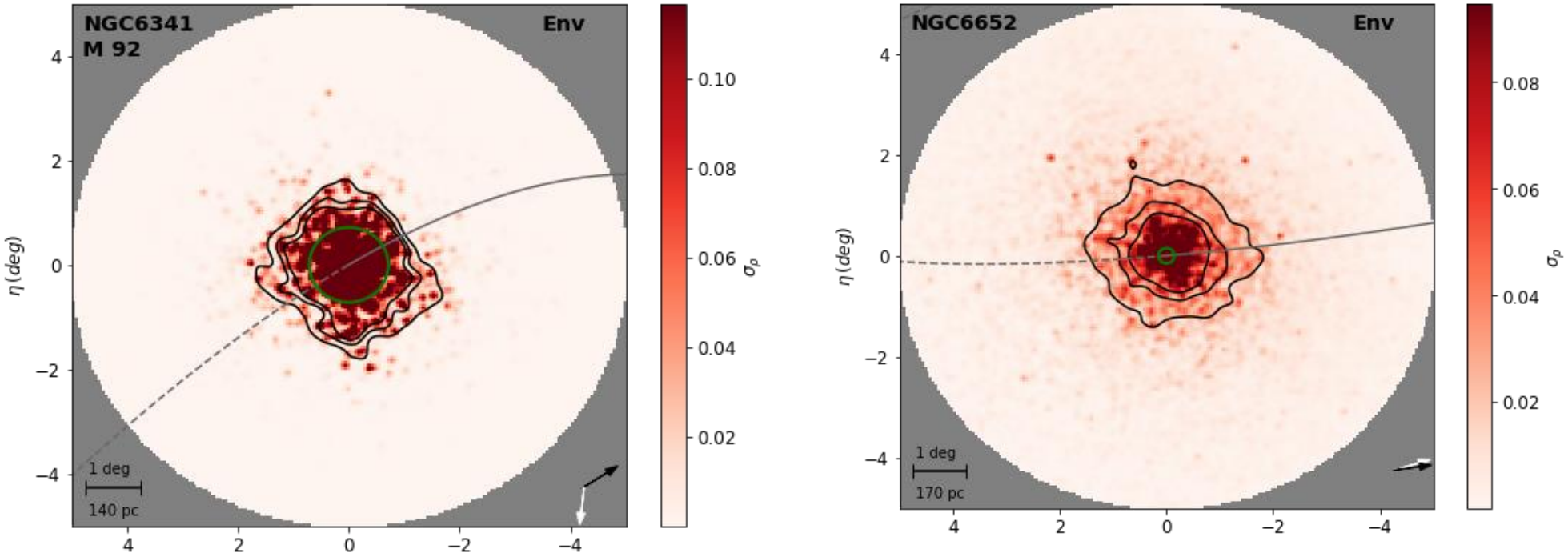




Familiar and new detections!

Results!

…and Envelopes!



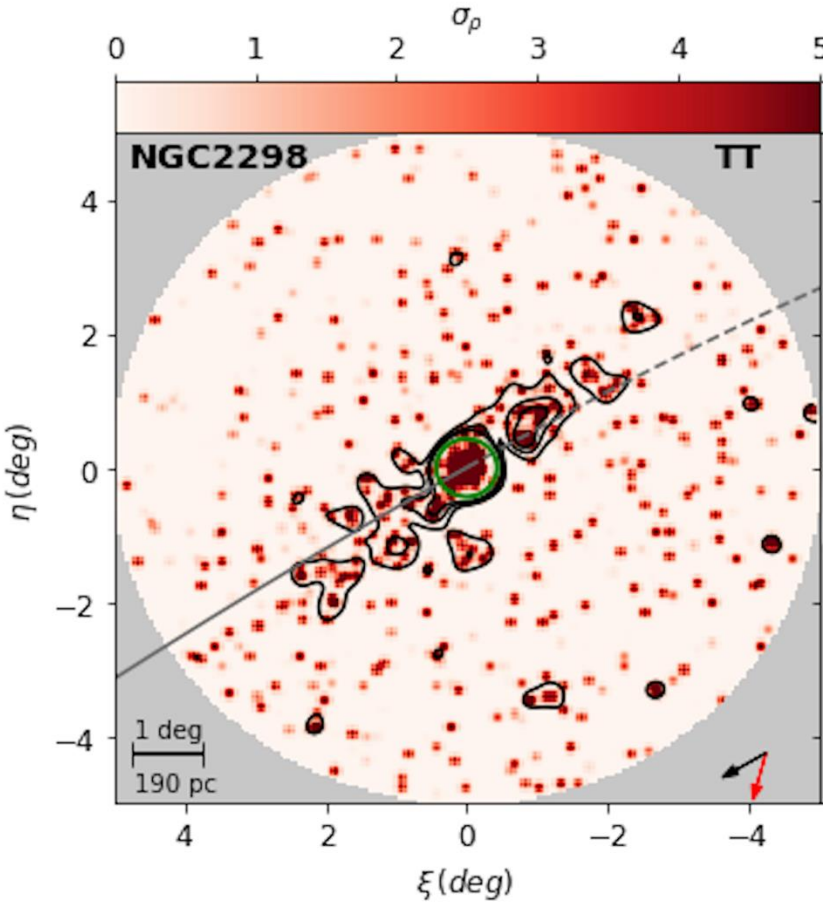
First application to Omega Cen: Kuzma et al 2021.
Stay tuned for the full sample soon!

The Numbers

What are the numbers?

Out of the ~60 GCs:

- **40% GCs have tidal tails (7 new detections)**
- **36% GCs possess envelopes (6 new detections)**
- **24% GCs show no debris**



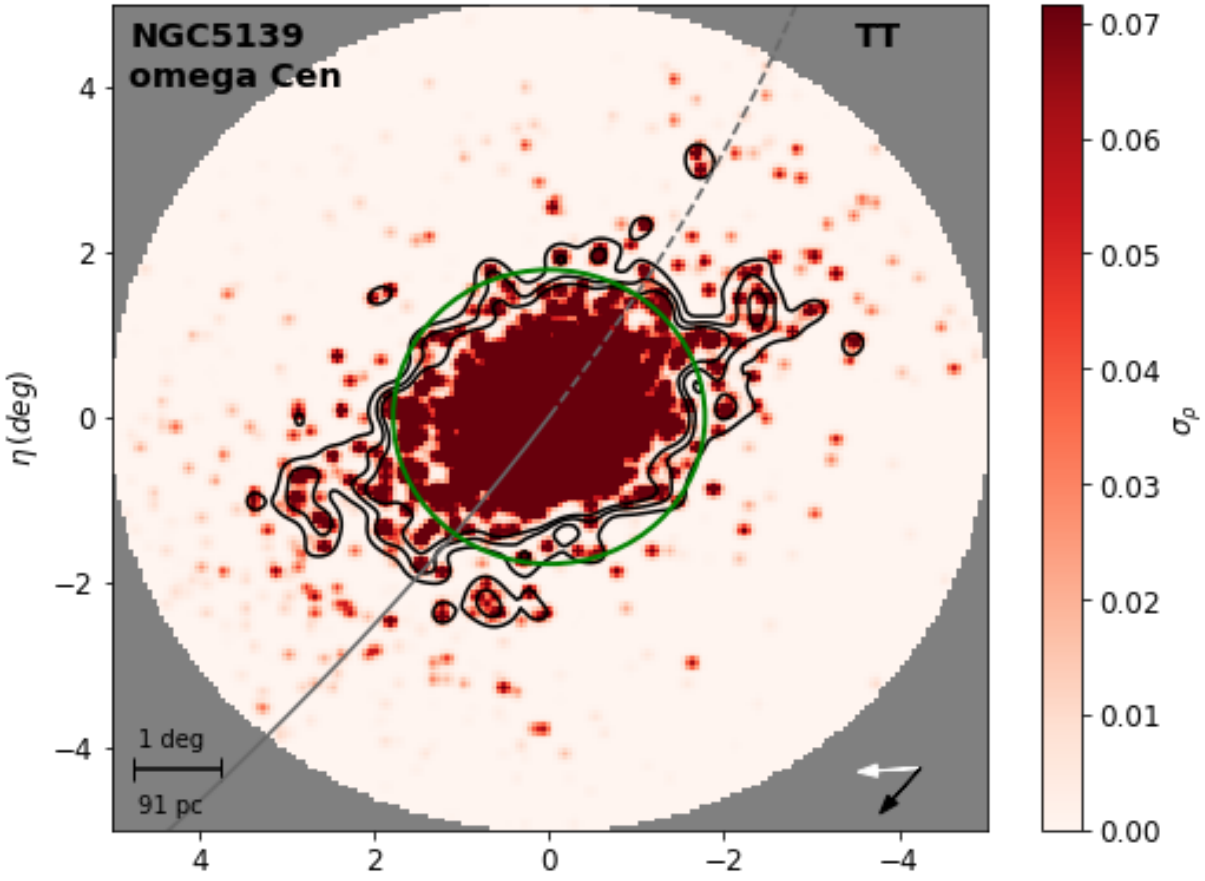
Kuzma et al 2023A in prep

Moving Forward

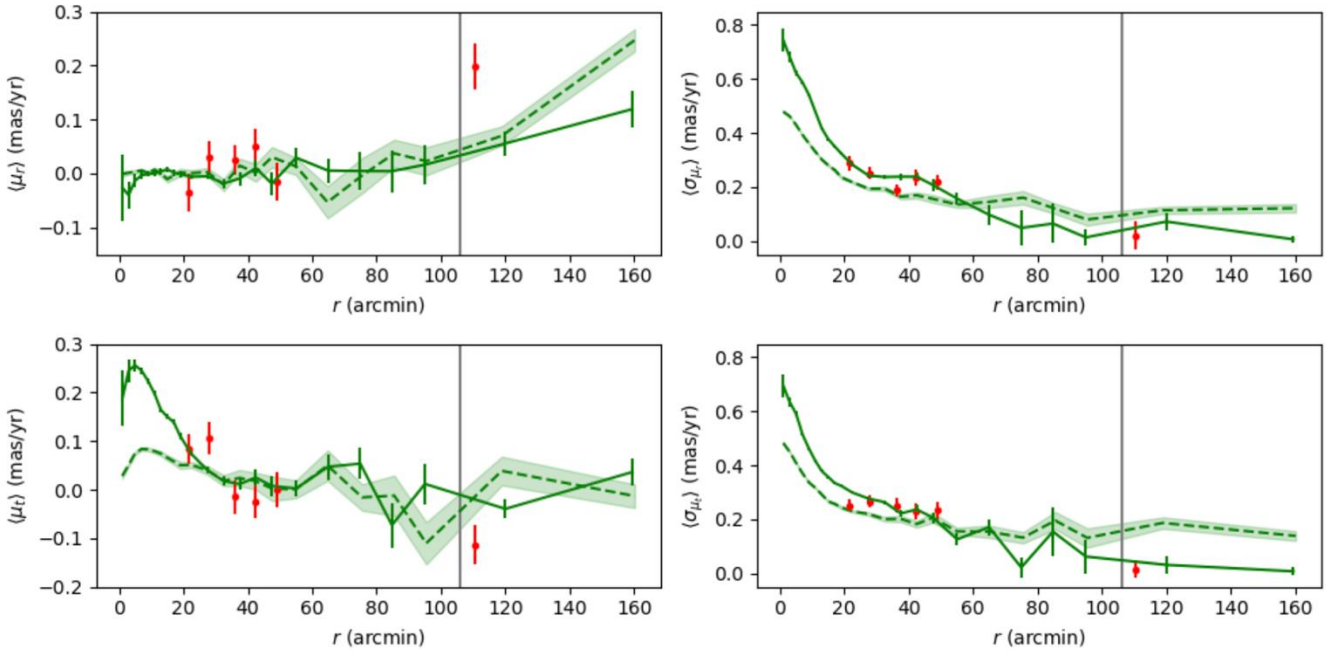
Analysis of the types of debris when compared to structural and dynamical properties is underway.

Kinematics of the extended structure in proper motion space is possible but tricky.

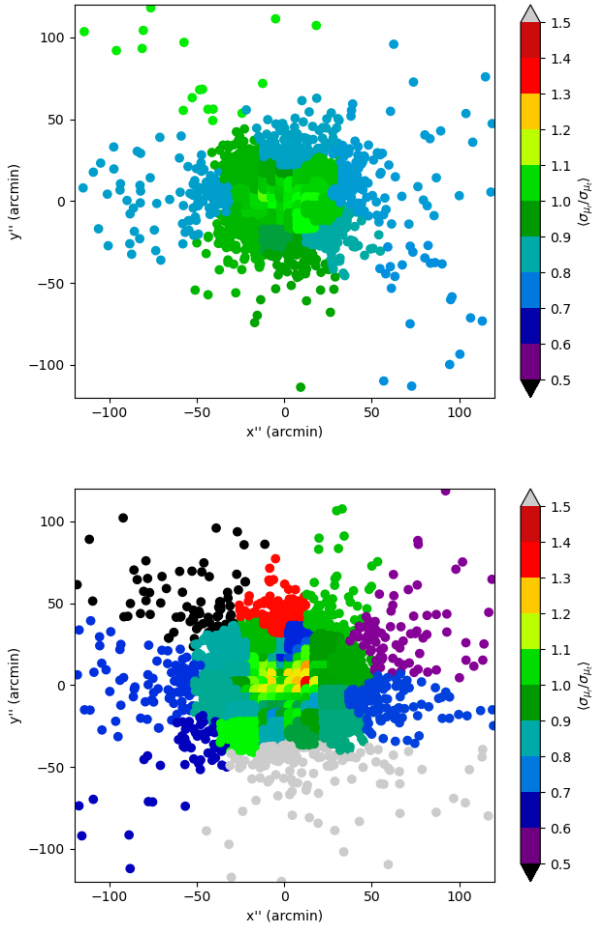
We are looking at the kinematics of NGC 5139 out to a three degree clustercentric radius (Kuzma in prep, 2023B).



Kinematics to Large Radii



↑ Radial velocities to fill in the gap between the King tidal radius and the Jacobi radius. Be careful with projection effects!



2D Anistropy maps for Omega Centauri. →

Kuzma et al. in prep 2023B

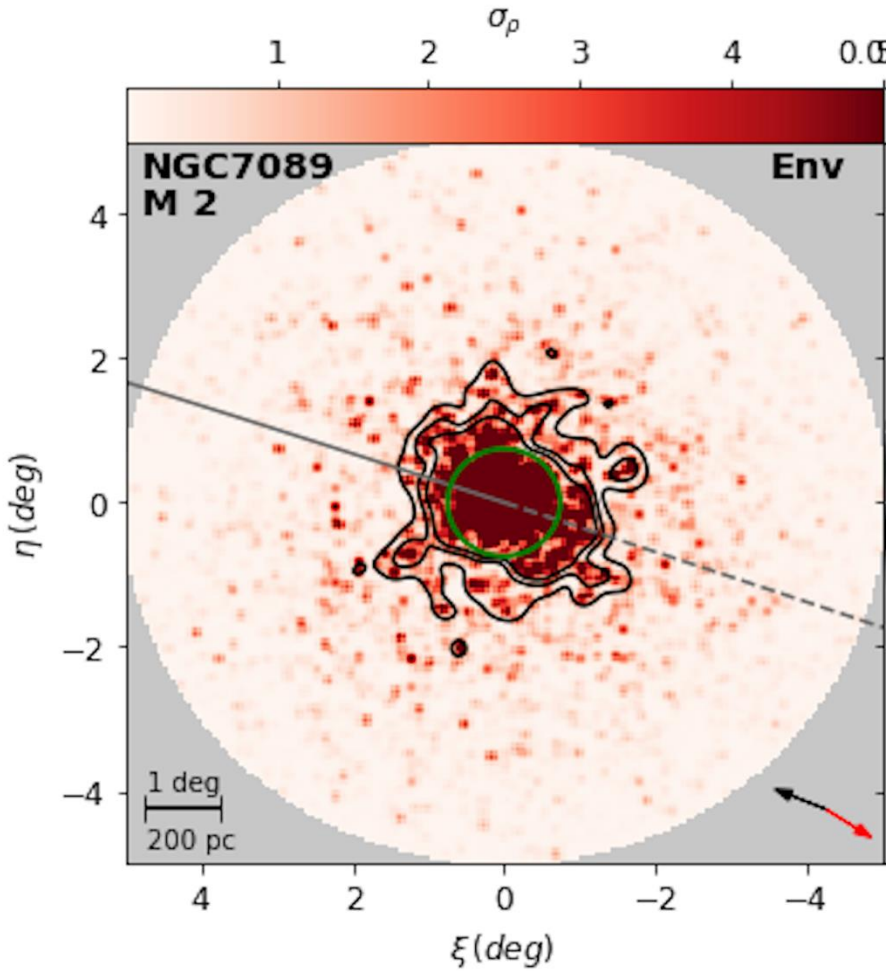
The Future

This technique will allow us to identify stars in the peripheries of GCs with radial velocities, perform chemical tagging, and establish 3-D kinematics with:

- WEAVE (M2 targeted with SV)
- 4MOST

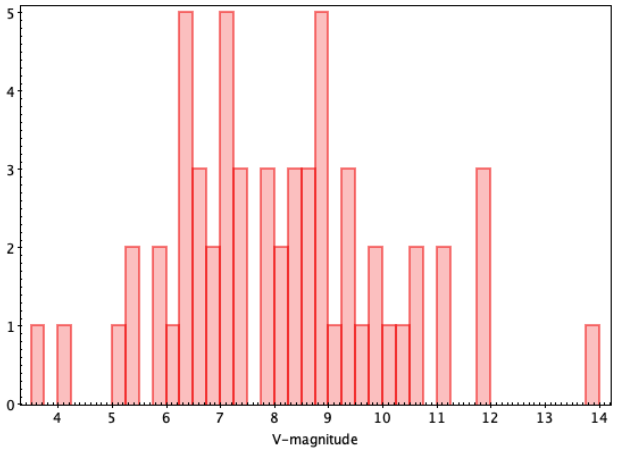
Also…

- Gaia FDR!



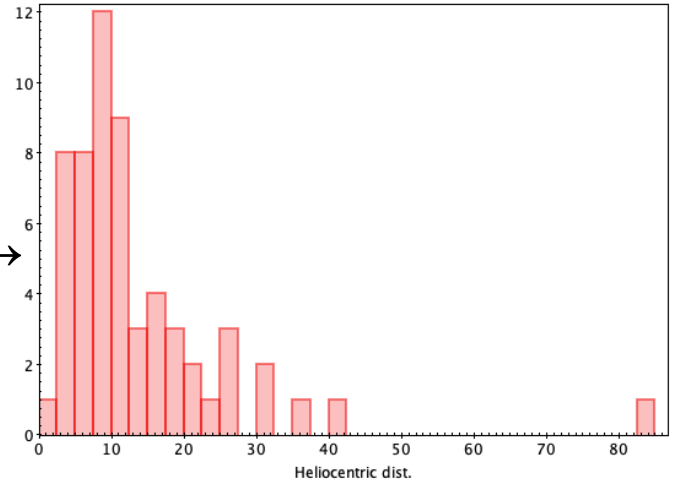
HISTOGRAMS

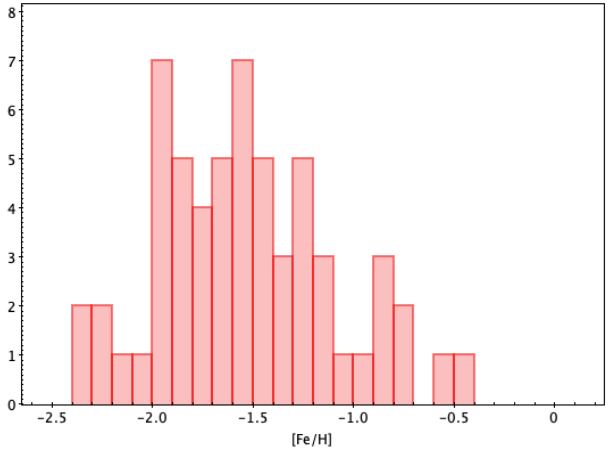
GC Sample



← V-band Magnitude

Heliocentric distance →





← Metallicity

Galactic Latitude →