Globular clusters from the Sagittarius dwarf Spheroidal galaxy

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Why Globular clusters?

- Globular clusters are very old (almost as old as the Universe!) and carry chemical and dynamical information about the initial conditions of their host galaxy.
- Given their typical stellar mass (of the order of 10^4 -10^5 solar masses), these systems have shorter dynamical time scales, and various dynamical processes (relaxation, mass segregation, core-collapse etc) can be studied looking at the distribution of stars in their outskirt regions.

Why Sagittarius Dwarf Spheroidal (Sgr dSph) galaxy?

The Sgr dSph satellite galaxy and its long stellar streams, emerging from its disruption, are quite prominent evidence of on-going accretion of a satellite galaxy onto the Milky Way. Besides the different arms of its stellar stream, the Sgr galaxy brought several globular clusters into the Milky Way. Hence, the extra-tidal region around these clusters can give us some idea about the various forces acting on the clusters

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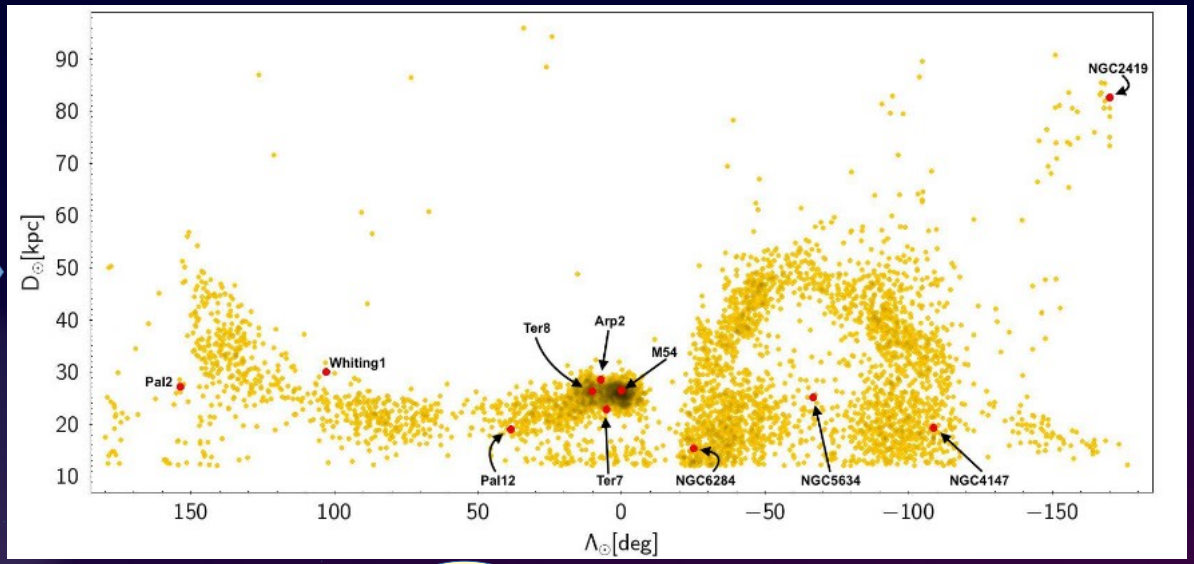
Position of the member globular clusters on a map of the Sgr dSph streams created using RR Lyrae stars from Gaia DR2, from Bellazzini et al 2020, 636, A107.



Confirmed members
M 54, Terzan 8, Terzan 7, Arp 2, Pal 12, Whiting 1.

Likely members
NGC 2419, NGC 5634, NGC 4147.

Unlikely members
NGC 6284, Pal 2.

Extra-tidal stars?
Stars which lie ouside the tidal radius of the cluster.

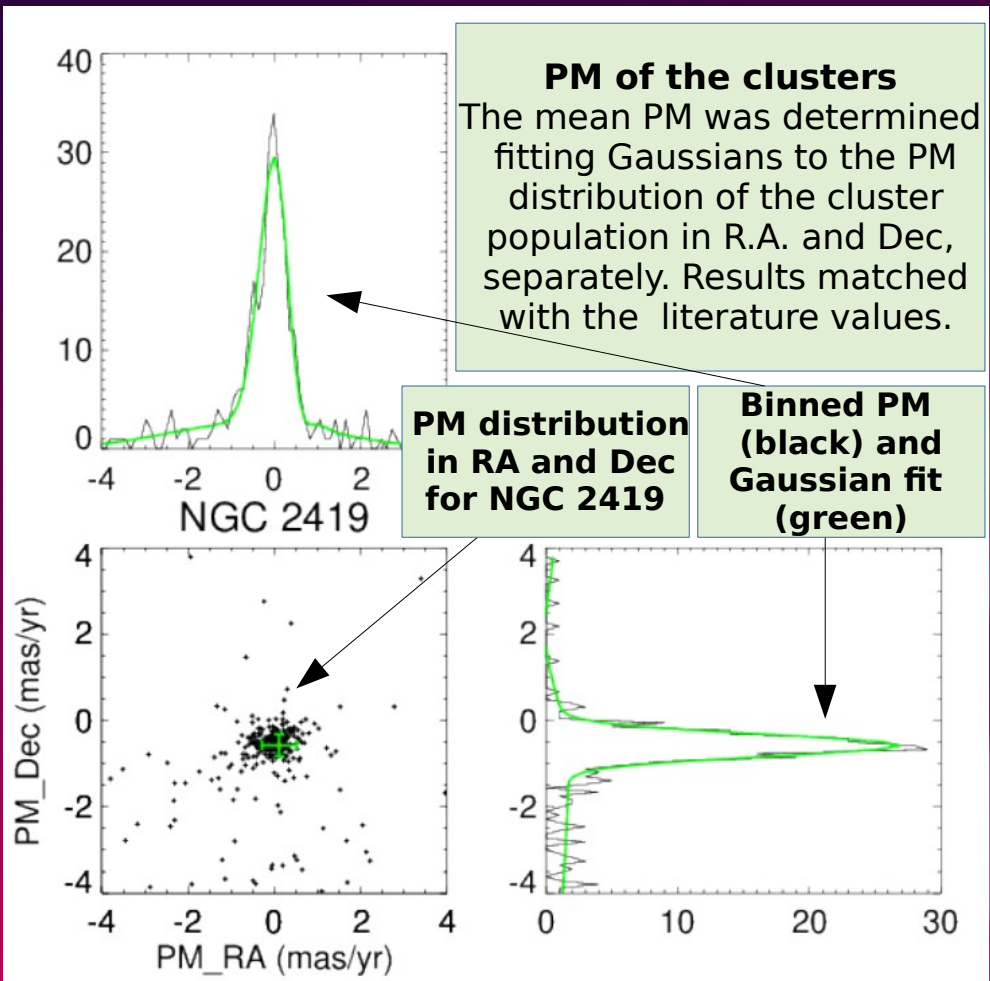
Why do we have extra-tidal stars?
These clusters lose stars due to various forces from the Galaxy, Sgr dSph galaxy and internal relaxation.

Which stars are considered as extra-tidal in this work?

1. Stars which have a projected distance to the cluster center inside rt<r<5rt, where rt is the tidal radius of the cluster.
2. Proper motion (PM) of the star must match with the PM of the cluster considering dispersion in the PM of the cluster and individual error in the PM of the star.
3. Stars that lie on the color-magnitude diagram of the cluster (i.e., are part of the same stellar population).

For details about astrometric cleaning of the data and selection process, please refer to Kundu et al 2019, MNRAS, 483, 1737 and\or Kundu et al 2019, 2019, MNRAS, 489, 4565.

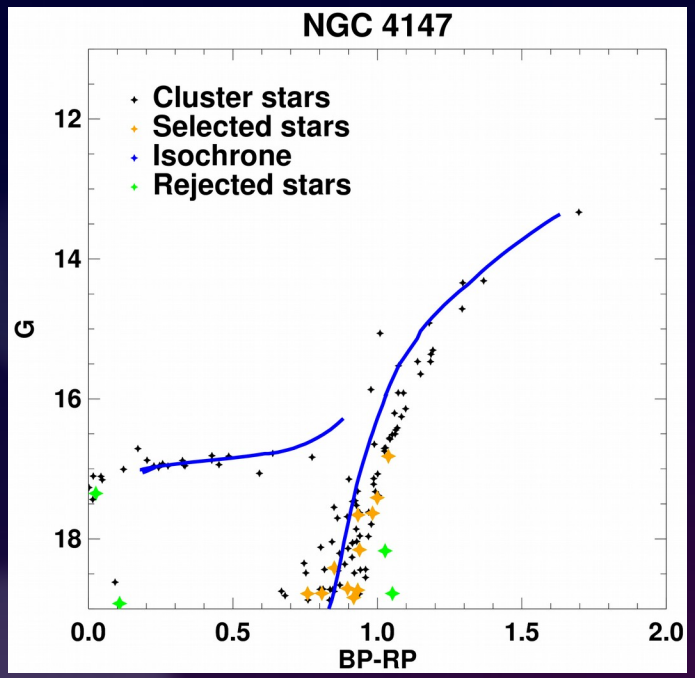
PM of the clusters
The mean PM was determined fitting Gaussians to the PM distribution of the cluster population in R.A. and Dec, separately. Results matched with the literature values.

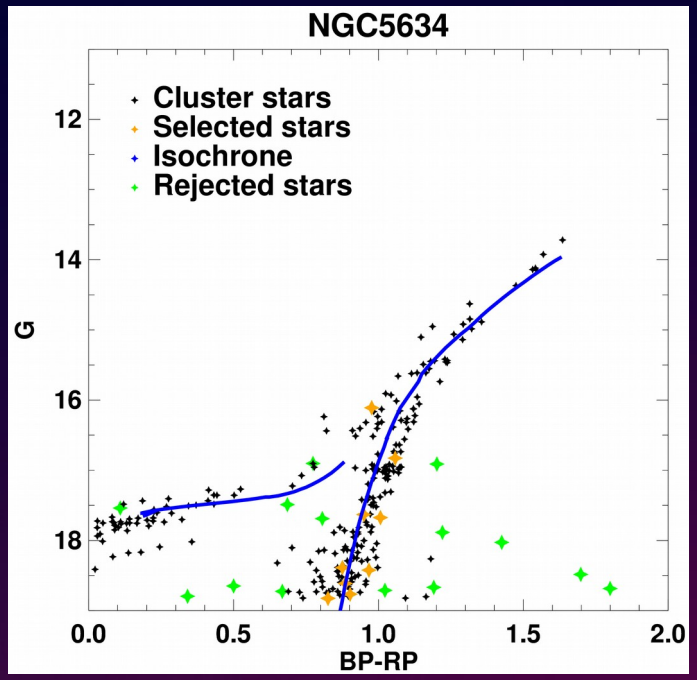


PM distribution in RA and Dec for NGC 2419

Binned PM (black) and Gaussian fit (green)

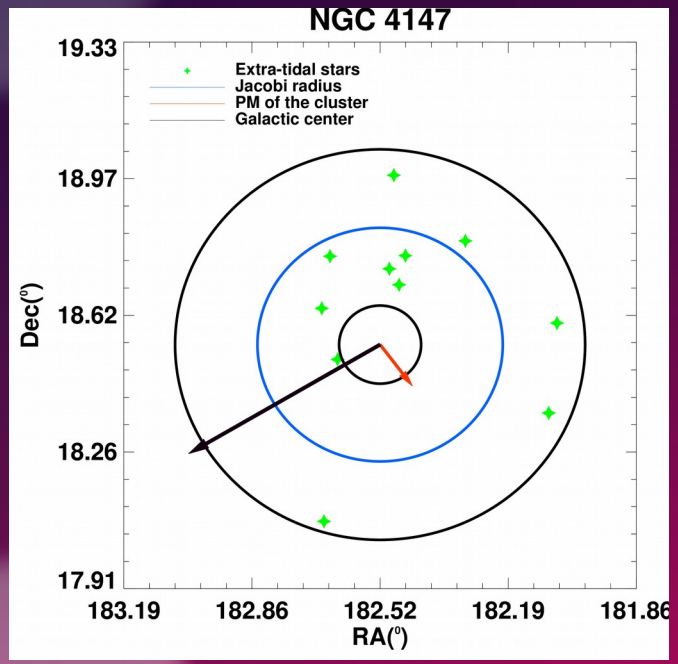
De-reddened CMDs (extra-tidal stars follow the stellar population of the cluster!)

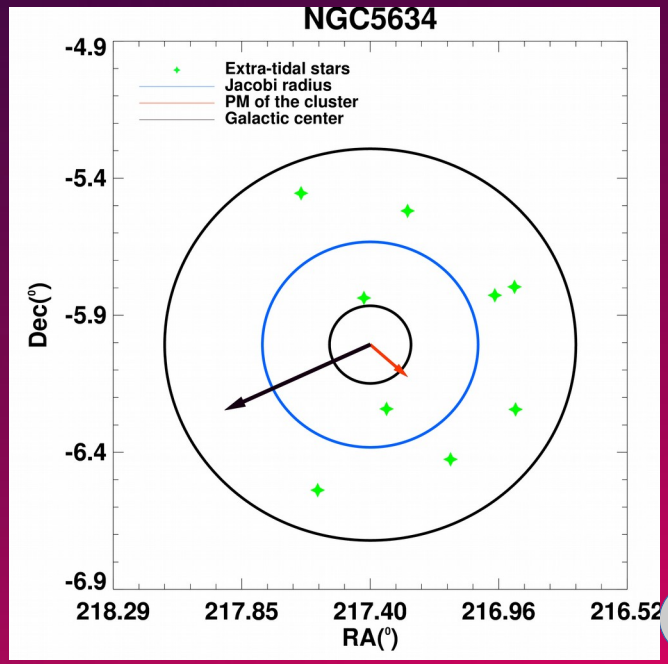




Jacobi Radius?
Tidal Radius?

Spatial distribution of extra-tidal stars (inner black circle is rt and outer black circles is 5rt)





Stars which are outside the Jacobi radius are completely out of the cluster's gravitational potential and hence are not attached to the cluster anymore. Stars which are outside the rt but inside the Jacobi radius of the clusters have higher chance of escaping the cluster potential.

Results and conclusions

!! Eureka !!

Cluster	# extra-tidal stars
Terzan 7	305
Arp 2	2019
M 54	2910

Cluster	# extra-tidal stars
NGC 4147	11
Terzan 8	50
NGC 5634	9
NGC 2419	15

- We used Gaussian fit to determine the PM of the 10 globular clusters most likely associated to the Sgr dSph. Our PM matches with the literature values within 1 sigma.
- Out of the 10 globular clusters analysed in our work 7 clusters show the signatures of extra-tidal stars.
- We found considerable extra-tidal stars outside the Jacobi radius of these 7 clusters which means that these stars are completely detached from the clusters.
- The analysis seems accurate for NGC 4147, Terzan 8, NGC 5634 and NGC 2419. Most of the extra-tidal stars for all these clusters (except NGC 4147) lie outside the Jacobi radius. For NGC 4147, NGC 5634 and NGC 2419 most of the extra-tidal stars lie in a direction which is opposite to the PM of the cluster and away from the Galactic center.
- Presence of extra-tidal stars in the clusters indicates that they could be experiencing high gravitational forces from the Sgr dSph galaxy, Milky Way and/or both.

Future plans

- We plan to study the orbit of the clusters for which we have positive results.
- We also plan to get an estimate of the mass which is lost by the extra-tidal stars determined in this work.
- Near future spectroscopy surveys such as WEAVE, MOONs, SDSS-V and 4-MOST will help to disentangle the chemodynamics properties of the outermost regions of these GCs and other, for the moment we are examining available high-resolution near-infrared data such as APOGEE-2.

Literature parameters from:

- Isochrones: http://stev.oapd.inaf.it/cgi-bin/cmd
- Literature PM: Vasiliev E., 2019, MNRAS, 484, 2832
- Tidal Radii: Mackey, A. D. & Van Den Bergh, S. 2005, MNRAS, 360, 631–645