# The Outer Halos of Globular Clusters: NGC 7089 (M2)

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ABSTRACT

The Pan-Andromeda Archaeological Survey team have shown that there are globular clusters associated with the large scale stellar streams present in the halo of M31, streams that are the remnants of the tidal disruption of dwarf galaxies (Mackey et al 2010). Within the halo of the Milky Way there are globular clusters associated with the on-going Sgr dwarf tidal disruption event, as well as a number of clusters that have been suggested as originating in disrupted accreted systems. We are targeting a sample of such clusters with the DECam and MegaCam wide field imagers to search for spatially extended populations that might represent the remnants of the original dwarf galaxy. We present preliminary results of our study of NGC 7089 (M2), a cluster that has been recently shown to possess similar chemical anomalies to those observed in NGC 1851. We find evidence for a large, asymmetric halo that we are able to trace to ~76 arcmin (~250 pc) from the cluster center, akin to the envelope seen surrounding NGC 1851. The shape of the halo is similar to the photographic results of Grillmair et al. (1995).

## Extended Structure

We observed 5 deep fields with DECam on the 4-m Blanco telescope and 4 deep fields with MegaCam on the 6.5-m Clay telescope, obtaining *g*-, *i*- imaging covering approximately 16 deg$^2$ with DECam and 0.8 deg$^2$ with MegaCam. Stars on the main sequence of M2 were identified via a selection box on the colour-magnitude diagram (Fig 1) and the background subtracted 2-D density distribution from the DECam imaging is displayed in Fig 2. Despite seeing no evidence for narrow tidal tails (as seen in Pal 5; Odenkirchen et al. 2001), we have revealed the presence of a large asymmetric halo surrounding the cluster which extends to a radial distance of ~76 arcmin (approximately 250 pc, M2 distance from the Sun: 11.5 kpc), 6 times the nominal tidal radius (12.5 arcmin, ~42 pc; Harris 1996). This is comparable to the halo seen around NGC 1851, which has a radius of 250 pc (Olszewzki et al. 2009).

The radial profile (azimuthally averaged), shown in Fig 3, complements the features seen in Fig 2. The inner measured densities agree with the fitted King (1962) profile, though the densities deviate from the profile at distances beyond the tidal radius. These points are well fit with a power law of index $g$ = -2.0 ± 0.1, steeper than that of NGC 1851 ($g$ = -1.24; Olszewski et al. 2009).

Recent studies of M2 have revealed peculiar stellar populations. Yong et al. 2014 showed a range in both s-process element abundances and [Fe/H] and Milone et al. 2015 discovered multiple subgiant branches. The extended outer structure we have uncovered adds to the anomalies that this cluster displays. These combined features suggest a connection between M2 and a disrupted dwarf, similiar to $w$ Centauri and M54. The former has long been suggested as the remaining core of a long-defunct dwarf galaxy and the latter resides at the center of the Sagittarius (Sgr) dwarf galaxy. Measuring the elemental abundance patterns of stars in the M2 halo would provide more concrete clues to its origin (as for NGC 1851 -- see Marino et al. 2014).

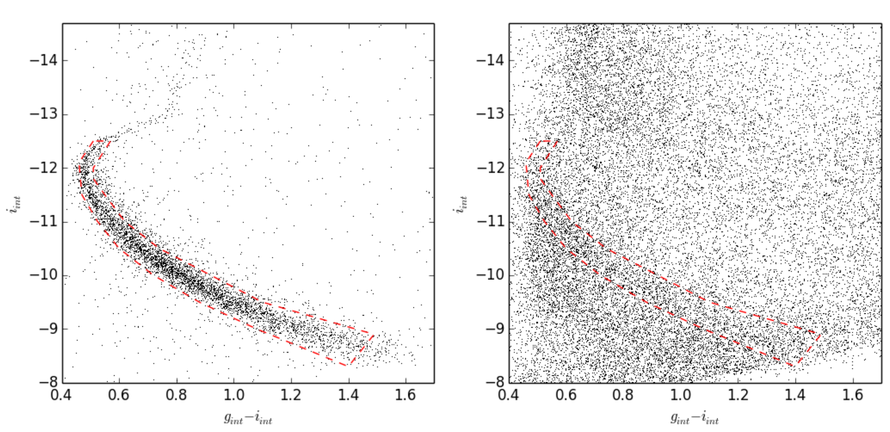


Fig 1: Colour-magnitude diagram of M2 from our DECam imaging. Left: stars within tidal radius (12.5') and right: stars between 2 and 5 times the tidal radius. The main sequence of M2 remains visible.

Pete Kuzma is a PhD student at the Research School of Astronomy and Astrophysics, Australian National University. In his thesis, he uses wide field imagers to look for stellar streams in the vicinity of distant globular clusters.

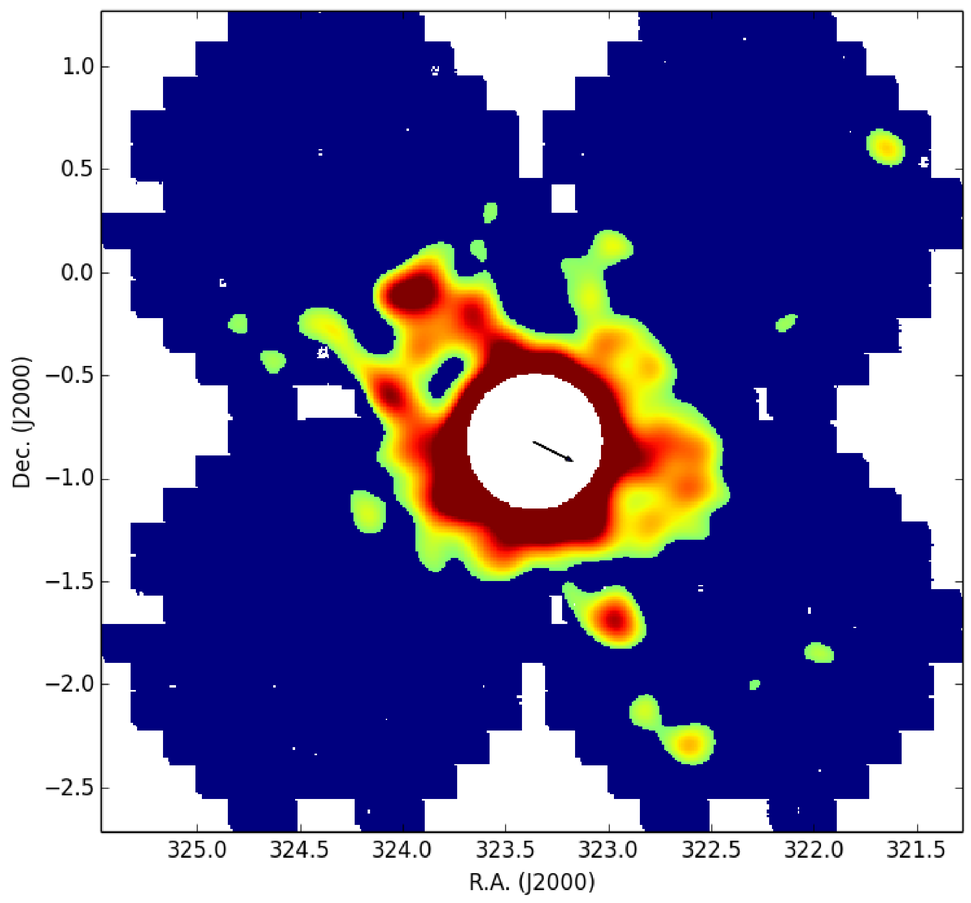


Fig 2: The background subtracted contour map of the surface density distribution of M2 as taken from 5 combined images observed with DECam. The highest values have been clipped and the inner 20' has been masked to help increase the contrast at low densities. The data was sorted into 0.6' x 0.6' bins and smoothed with a Gaussian filter of width 4.2'. The over-densities shown are 1.5 σ above the mean bin value. The central arrow indicates the direction of the galactic center.

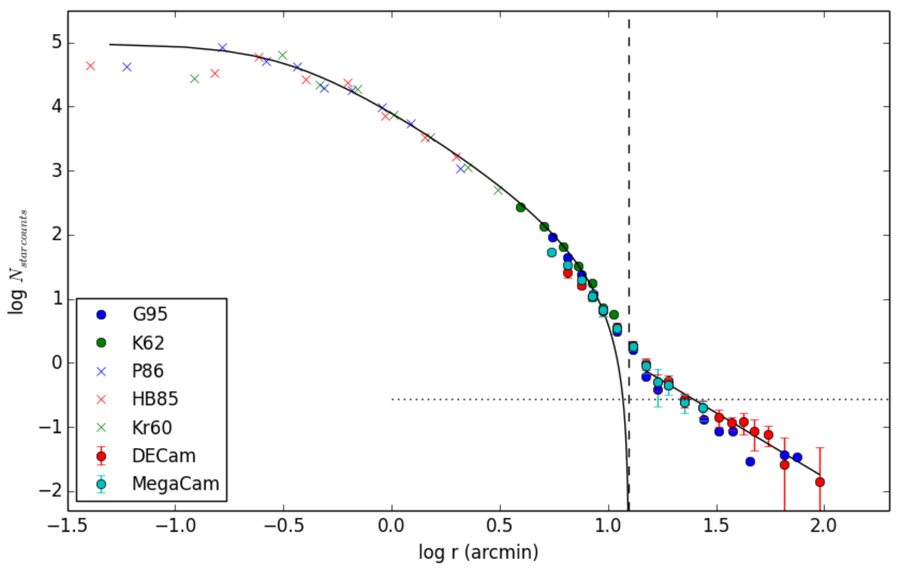


Fig 3: Radial surface density profile. Circles indicate star counts and crosses indicate aperture photometry (taken from the literature as indicated). All data sets have been normalized to our MegaCam profile data. The King (1962) profile is shown, where the core and tidal radius are taken from Harris (1996): this profile describes the inner data well. A power law of index $g$ = -2.0 ± 0.1 was fit to the bins at radii beyond the nominal tidal radii. The horizontal dotted line indicates the background level and the vertical dashed line shows the tidal radius.

References

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