Contribution of stripped nuclear clusters to globular cluster and ultra-compact dwarf galaxy populations

Joel Pfeffer[1,2], Brendan Griffen[3], Holger Baumgardt[1], Michael Hilker[2]

[1]University of Queensland, [2]European Southern Observatory (ESO), [3]MIT Kavli Institute for Astrophysics and Space Research

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Introduction

The formation mechanism of ultra-compact dwarf galaxies (UCDs) and their relation to globular clusters (GCs) and dwarf galaxies is unknown and under much debate, however a number of scenarios have been proposed. They may be:

- the high-mass end of the GC mass function (Mieske, Hilker & Misgeld 2012);
- the end result of star cluster mergers in dense star cluster complexes (Brüns & Kroupa 2012); or
- the nuclei of tidally stripped dwarf galaxies (Bekki et al. 2003, Pfeffer & Baumgardt 2013).

Most UCDs are found in nearby galaxy clusters, such as Virgo and Fornax, especially around giant elliptical galaxies therein, which suggests a relationship between UCDs and the assembly of galaxy clusters. In this study we use the high-resolution Millennium II cosmological simulation (Boylan-Kolchin et al. 2009) combined with the semi-analytic galaxy formation model (SAM) of Guo et al. (2011) to predict the contribution of galactic nuclei formed by the tidal stripping of nucleated dwarf galaxies to GC and UCD populations of galaxies.

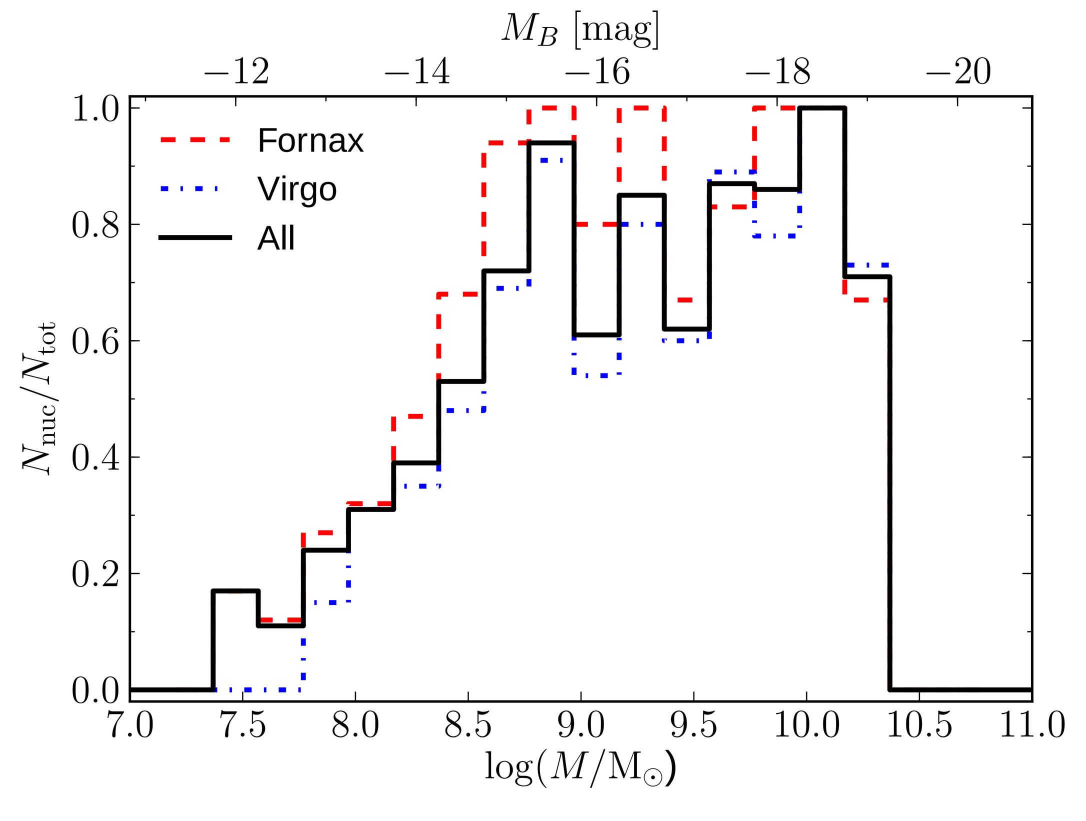
Methods

In order to identify galaxies in the simulations which may form stripped nuclei (UCDs formed by tidal stripping) we search the merger trees of all galaxy clusters at $z = 0$ in the SAM with virial masses larger than $10^{13}\,M_\odot/h$. To decide if a galaxy forms a stripped nucleus we find all galaxies in the merger trees which undergo a galaxy merger according to the SAM. A stripped nucleus is formed in such a merger if:

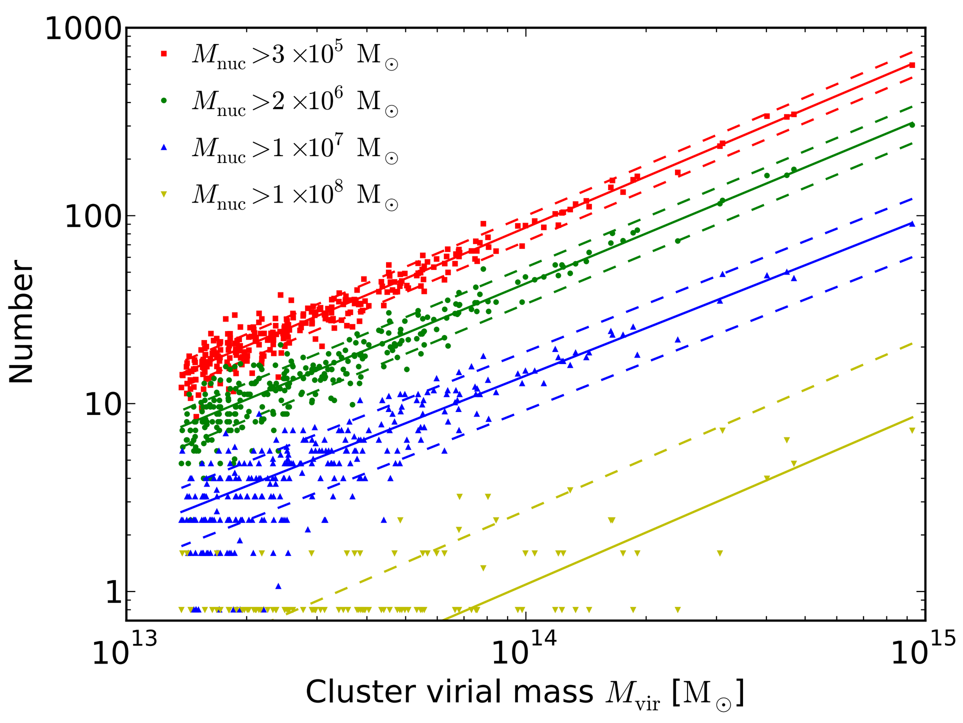
- The progenitor galaxy has a stellar mass between 10^8 and $10^{11}\,M_\odot$.
- The merger was a minor merger (based on dynamical mass: stars+gas+dark matter within r_s).
- The merger happens > 2 Gyr ago to allow time for a UCD to form (e.g. Pfeffer & Baumgardt 2013).
- The formed UCD does not spiral into its host galaxy centre by dynamical friction.

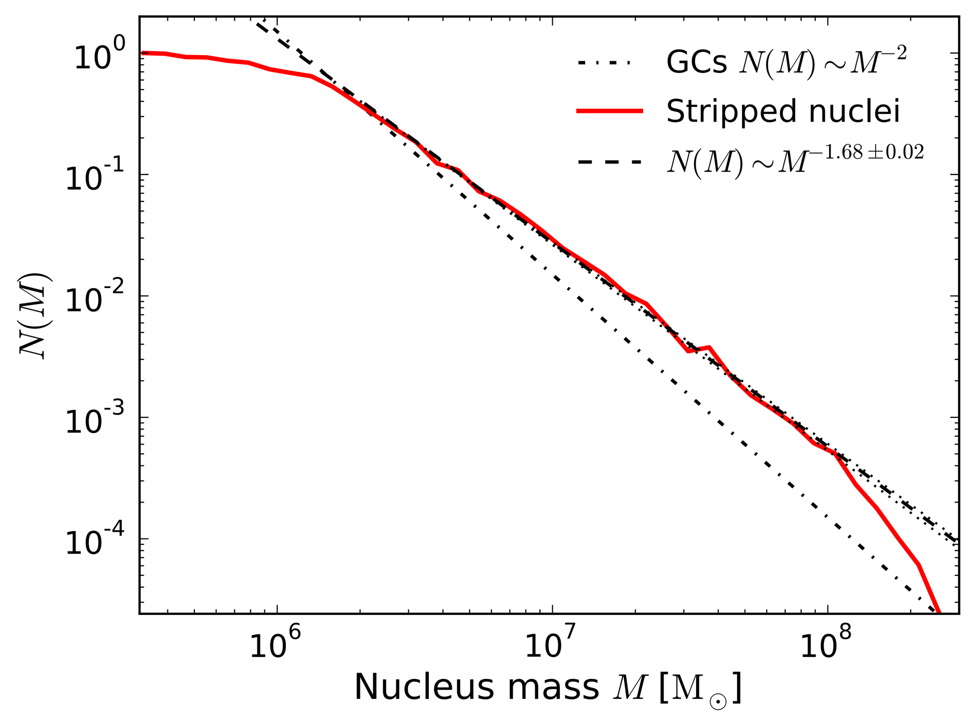
We assign the stripped nucleus a mass of 0.3 per cent the stellar mass of the progenitor galaxy in the snapshot before merging occurs, based on the mean nucleus-to-galaxy luminosity ratio for early-type galaxies.

The fraction of galaxies that are nucleated is taken from observations of galaxies in the Virgo (ACS Virgo Cluster Survey) and Fornax (ACS Fornax Cluster Servery) clusters **(below)**. We take an average nucleated fraction of 80 per cent for galaxies more massive than $M = 4.7 \times 10^8\,M_\odot$ ($M_B = -15$ mag). For galaxies less massive than this, we choose a fraction that varies linearly (in log-space) between 80 per cent at $M = 4.7 \times 10^8\,M_\odot$ and 0 per cent at $M = 2.9 \times 10^7\,M_\odot$ ($M_B = -12$ mag). For galaxies with masses larger than $10^{11}\,M_\odot$ we assume nuclei no longer exist due to destruction by supermassive black holes (Graham & Spitler 2009).

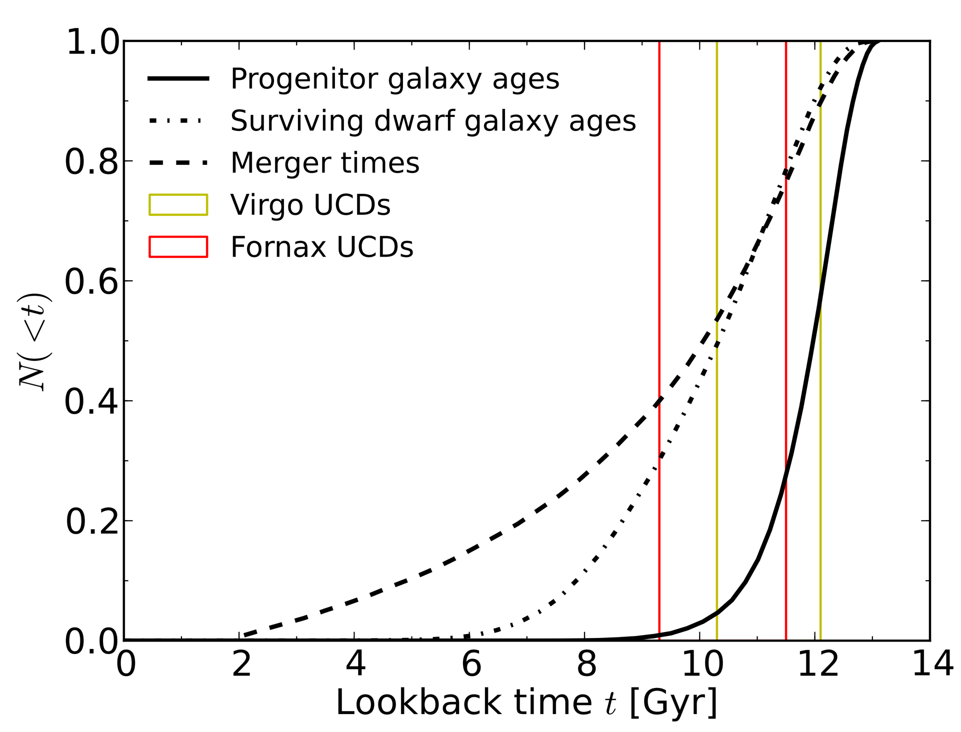


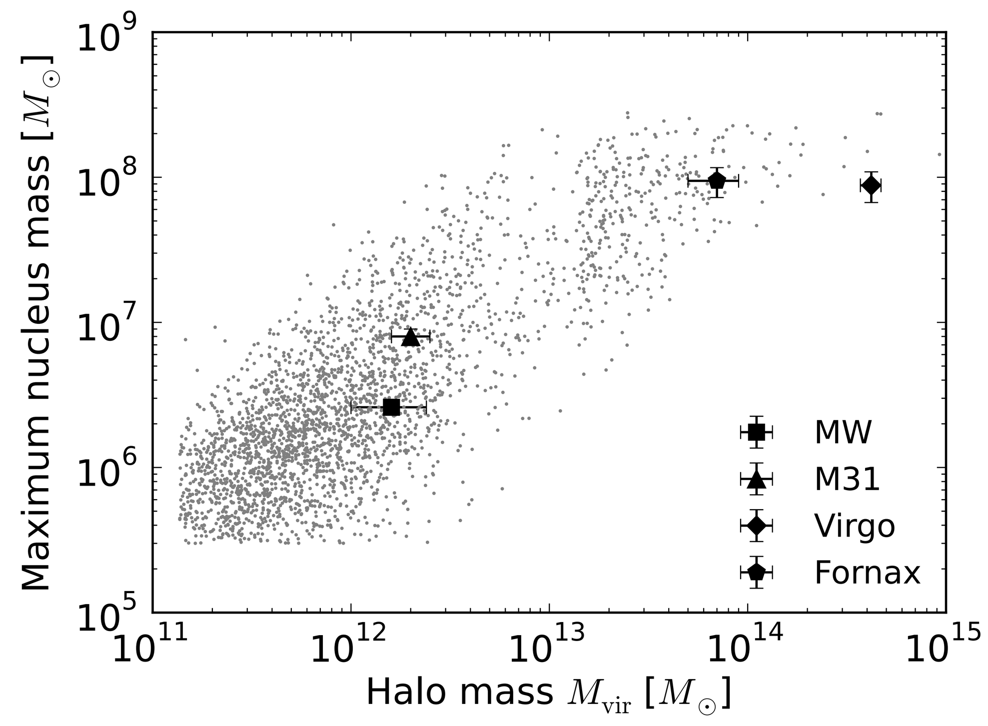
Results





(Above left) The number of stripped nuclei formed above a given mass located within the projected cluster virial radius at $z = 0$ for individual galaxy clusters. The best fit for each population is shown by a solid line. The number of stripped nuclei scales with cluster virial mass slightly less than linearly ($N \sim M_{vir}^{0.9}$). **(Above right)** Normalized mass function of the stripped nuclei for all clusters (solid line) compared with the mass function of GCs (black dash-dotted line; arbitrarily scaled such that GCs have the same absolute number at $2 \times 10^6\,M_\odot$). The best-fitting slope for the stripped nuclei with masses between 2×10^6 and $10^8\,M_\odot$ is shown by the black dashed line. The mass function of stripped nuclei is significantly flatter than that of GCs. Therefore stripped nuclei should dominate UCD numbers at the high-mass end.





(Above left) Normalized cumulative distribution of the predicted ages and merger times for disrupted galaxies which form stripped nuclei. The galaxy ages are the mass-weighted ages of the galaxies in the semi-analytic model. The merger times shows the times when the simulated UCDs are formed. We also show the standard deviation of ages of UCDs in the Virgo and Fornax clusters for comparison (Francis et al. 2012). If galaxy nuclei form between formation and merging of the progenitor galaxies, the predicted ages for stripped nuclei agree well with the ages of UCDs. **(Above right)** Mass of the most massive stripped nucleus formed for individual galaxies compared to the halo virial mass of the host galaxy. For the Milky Way, M31 and the Virgo and Fornax clusters the most massive GC or UCD are shown (ω Cen, G1, VUCD7 and UCD3, respectively). The most massive UCD predicted for galaxies agrees well with the masses of those observed.

Conclusions

In this paper we present the first work to study GC and UCD formation within the framework of cosmology. Our main conclusions are summarized as follows:

- The contribution of stripped nuclei will be most important among high-mass GCs and UCDs.
- The most massive UCDs predicted to form via tidal stripping in clusters and Milky Way-sized haloes agree well with the most massive GCs/UCDs observed.
- For a Fornax-sized galaxy cluster, we predict ~25 UCDs more massive than $2 \times 10^6\,M_\odot$ come from tidally stripping, while the observed number of UCDs is ~200.

We conclude that most UCDs in galaxy clusters are probably simply the high mass end of the GC mass function.

More details of our simulations can be found in Pfeffer et al. 2014 (submitted to MNRAS).

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