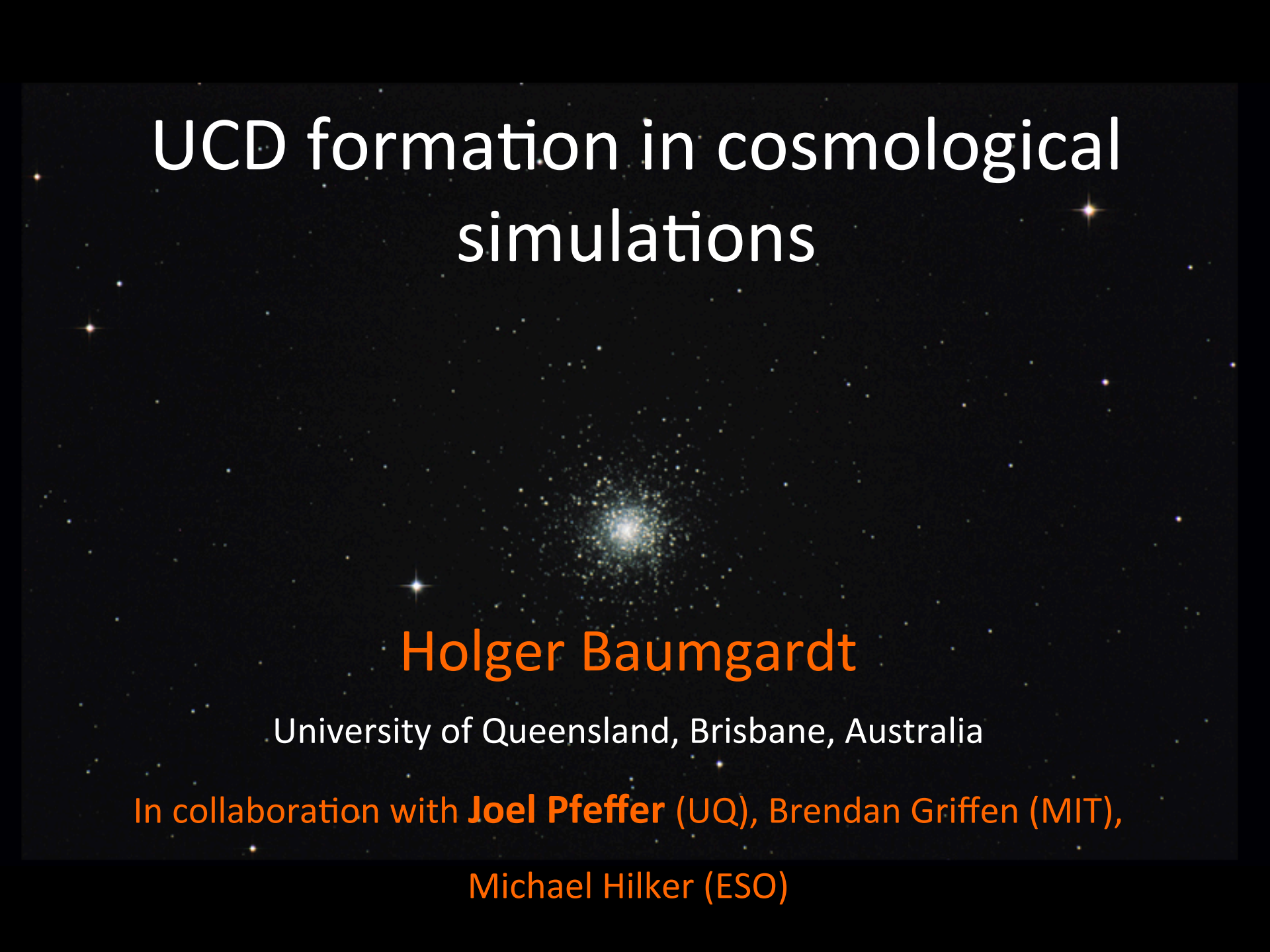
UCD formation in cosmological simulations



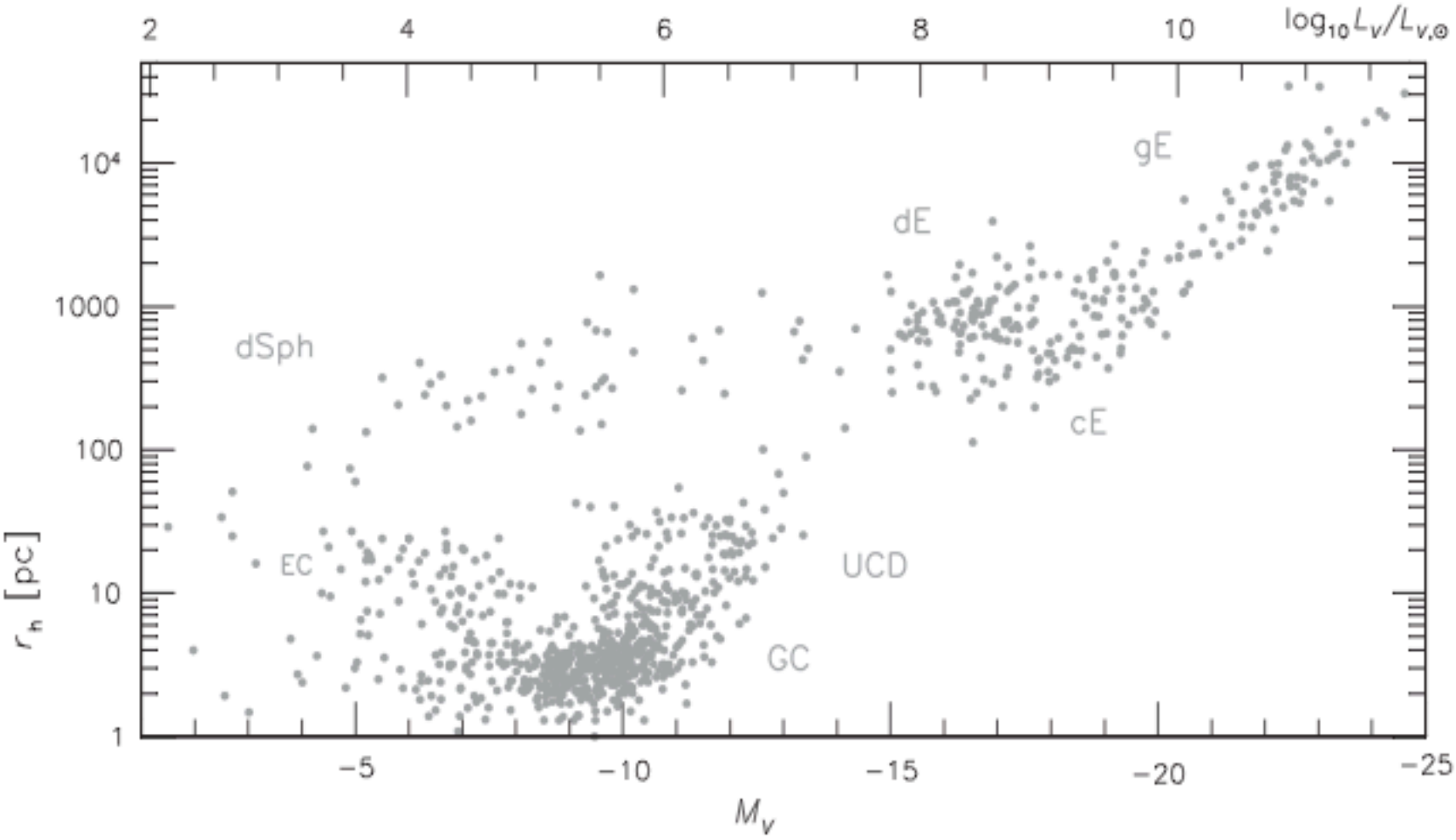
Holger Baumgardt

University of Queensland, Brisbane, Australia

In collaboration with **Joel Pfeffer** (UQ), Brendan Griffen (MIT),

Michael Hilker (ESO)

Ultra-compact dwarf galaxies (UCDs)



(from Brodie et al. 2011)

Formation scenarios for UCDs

So far it is not clear where UCDs come from. The main scenarios that are being discussed in the literature are:

- UCDs are massive globular clusters and form in the same way (e.g. Mieske et al. 2002, Forbes et al. 2008).
- UCDs form from the merging of several globular clusters (e.g. Fellhauer & Kroupa 2002, Brüns et al. 2011).
- UCDs are the remnants of stripped dwarf galaxy nuclei (Bekki et al. 2001, Pfeffer & Baumgardt 2013).
- UCDs are a recoiling clusters formed by the ejection of SMBHs (Merritt et al. 2009)

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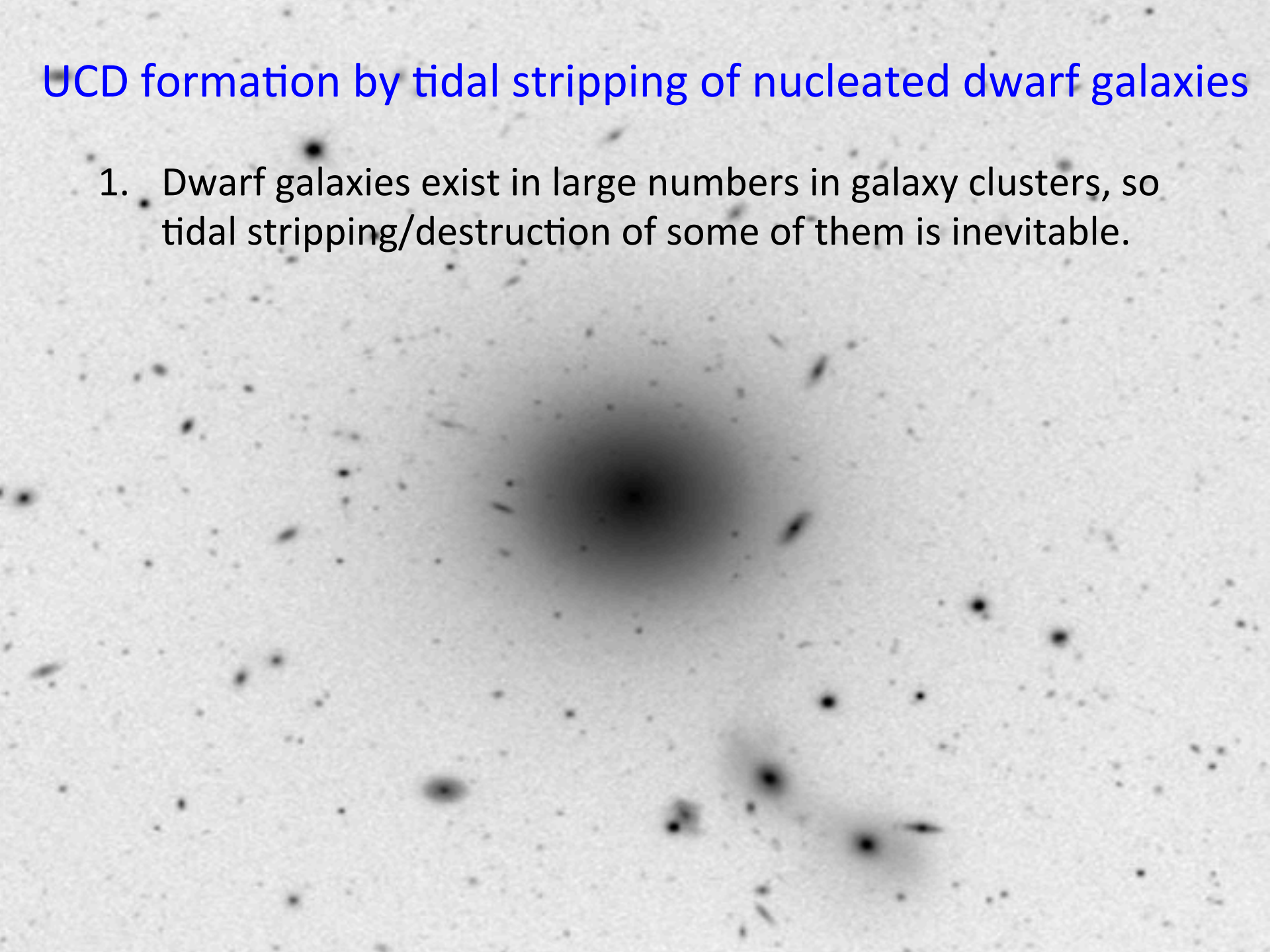
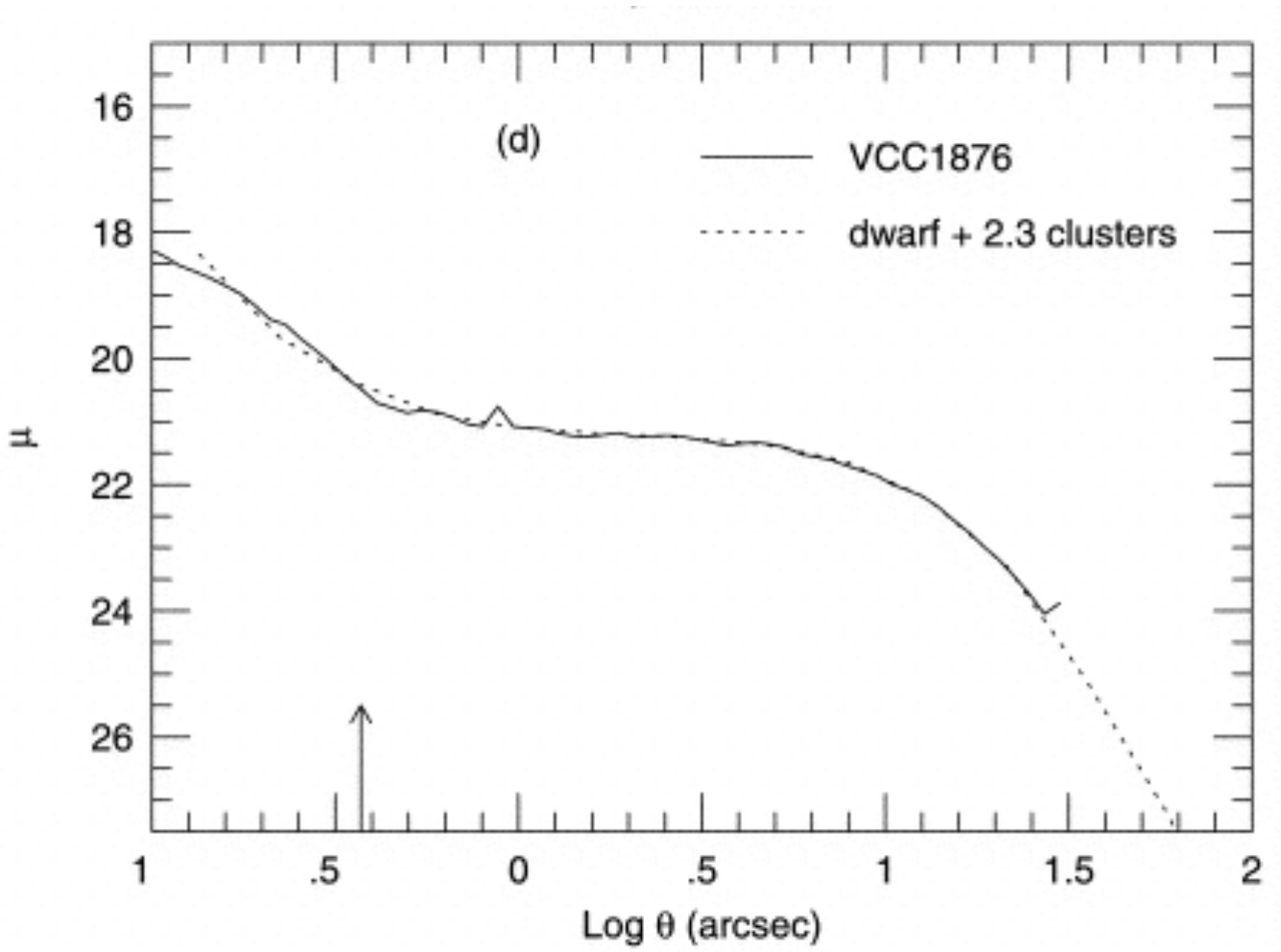
UCD formation by tidal stripping of nucleated dwarf galaxies

1. Dwarf galaxies exist in large numbers in galaxy clusters, so tidal stripping/destruction of some of them is inevitable.



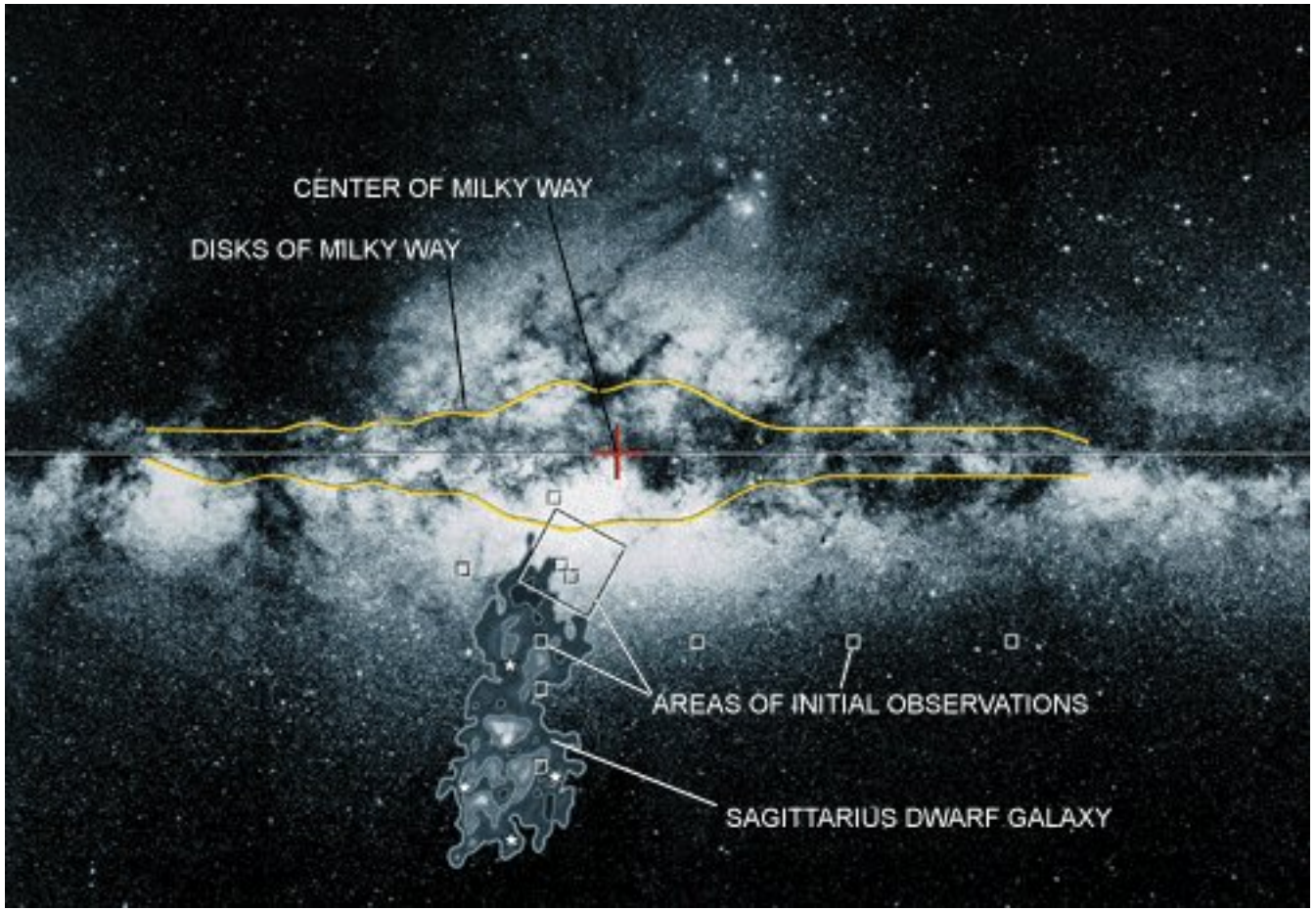
UCD formation by tidal stripping of nucleated dwarf galaxies

2. About 80% of all dE galaxies contain nuclei in their centers with masses similar to UCDs

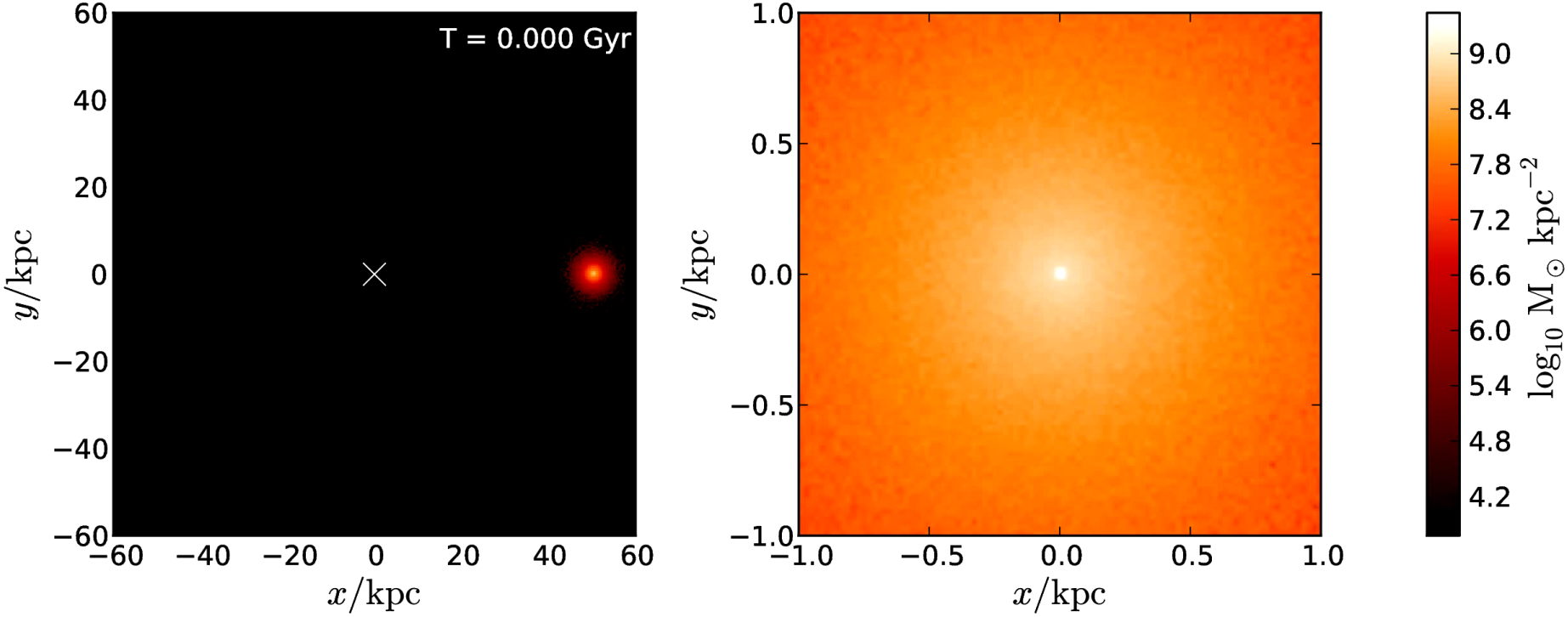


UCD formation by tidal stripping of nucleated dwarf galaxies

3. We actually see ongoing nucleation of a dwarf galaxy in the Milky Way in the case of the M54/Sagittarius system.

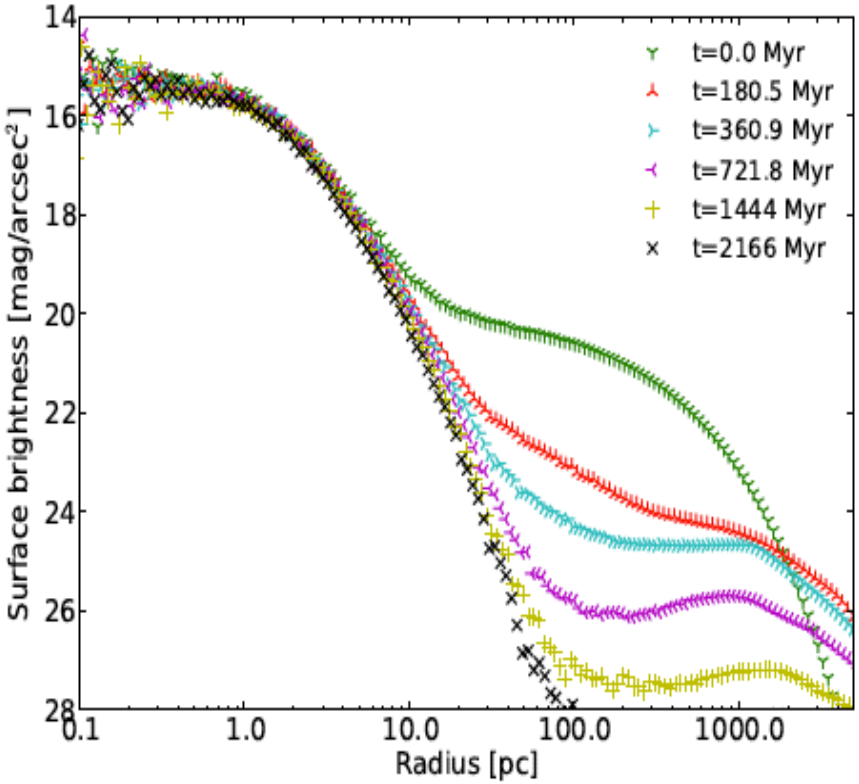


N-body simulations of tidal stripping

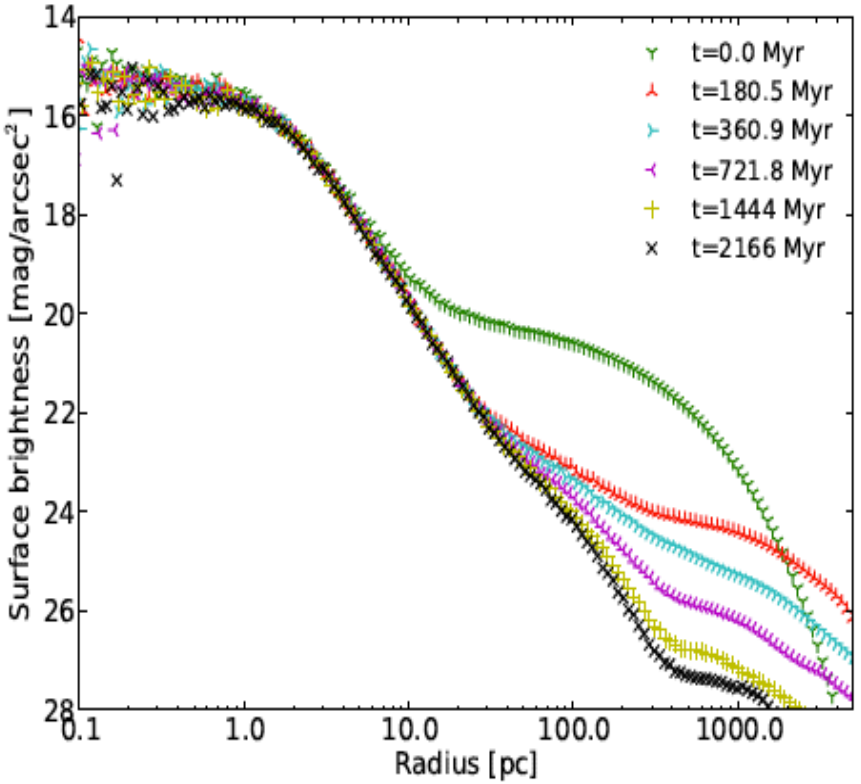


Tidal stripping of dwarf galaxies

Strong tidal interaction

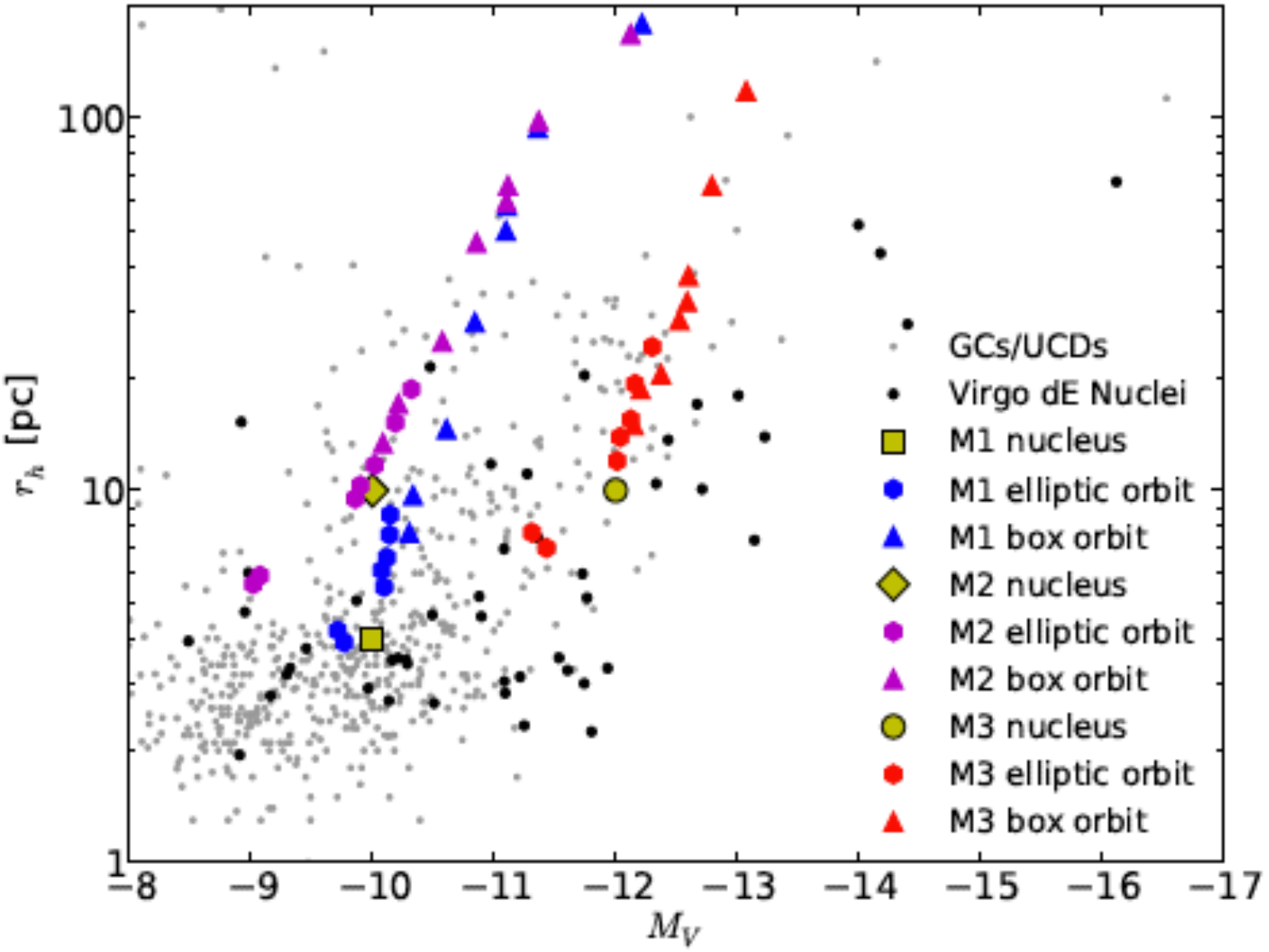


Weaker tidal interaction



(from Pfeffer & Baumgardt 2013)

Final size of stripped nuclei vs. UCD sizes



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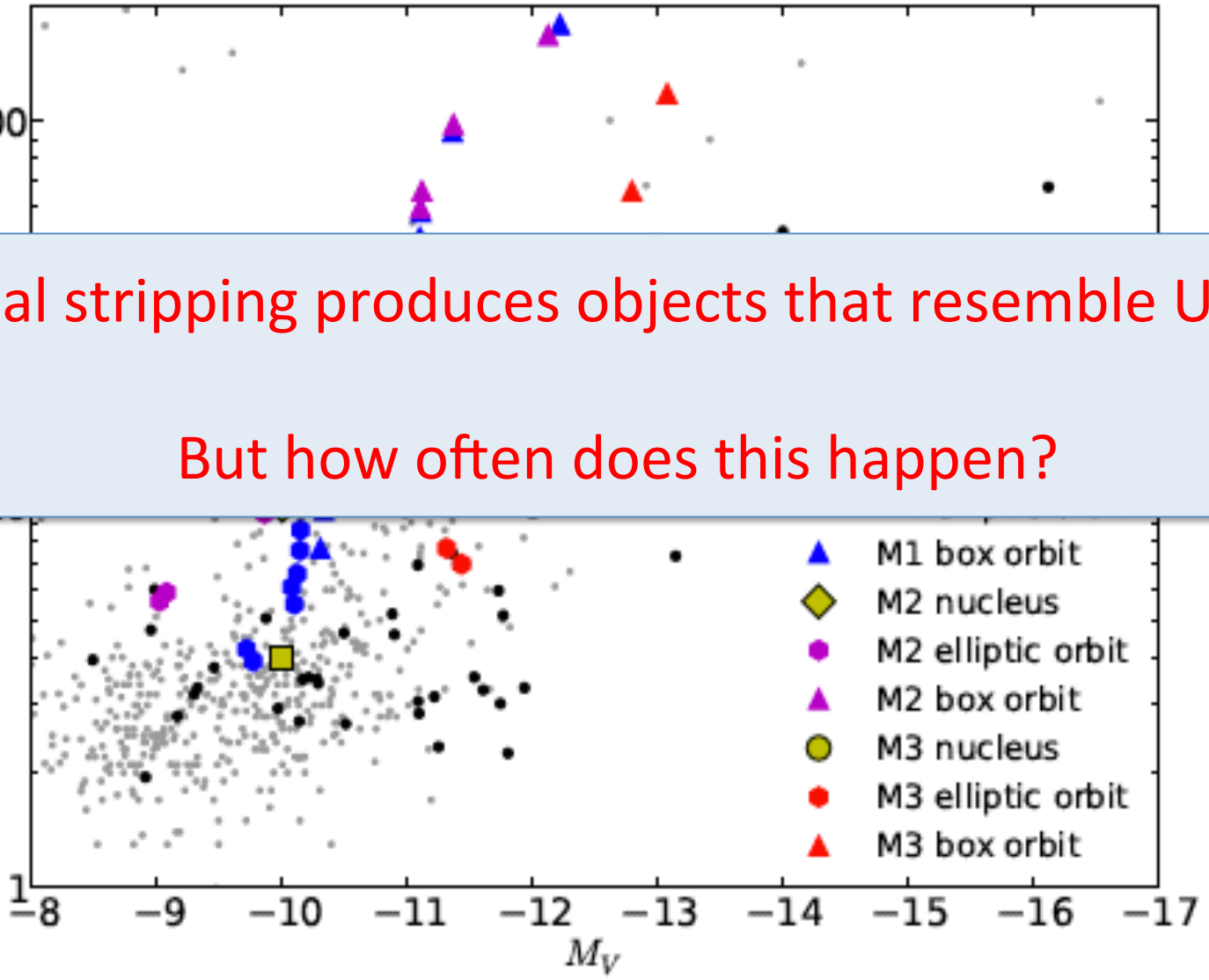
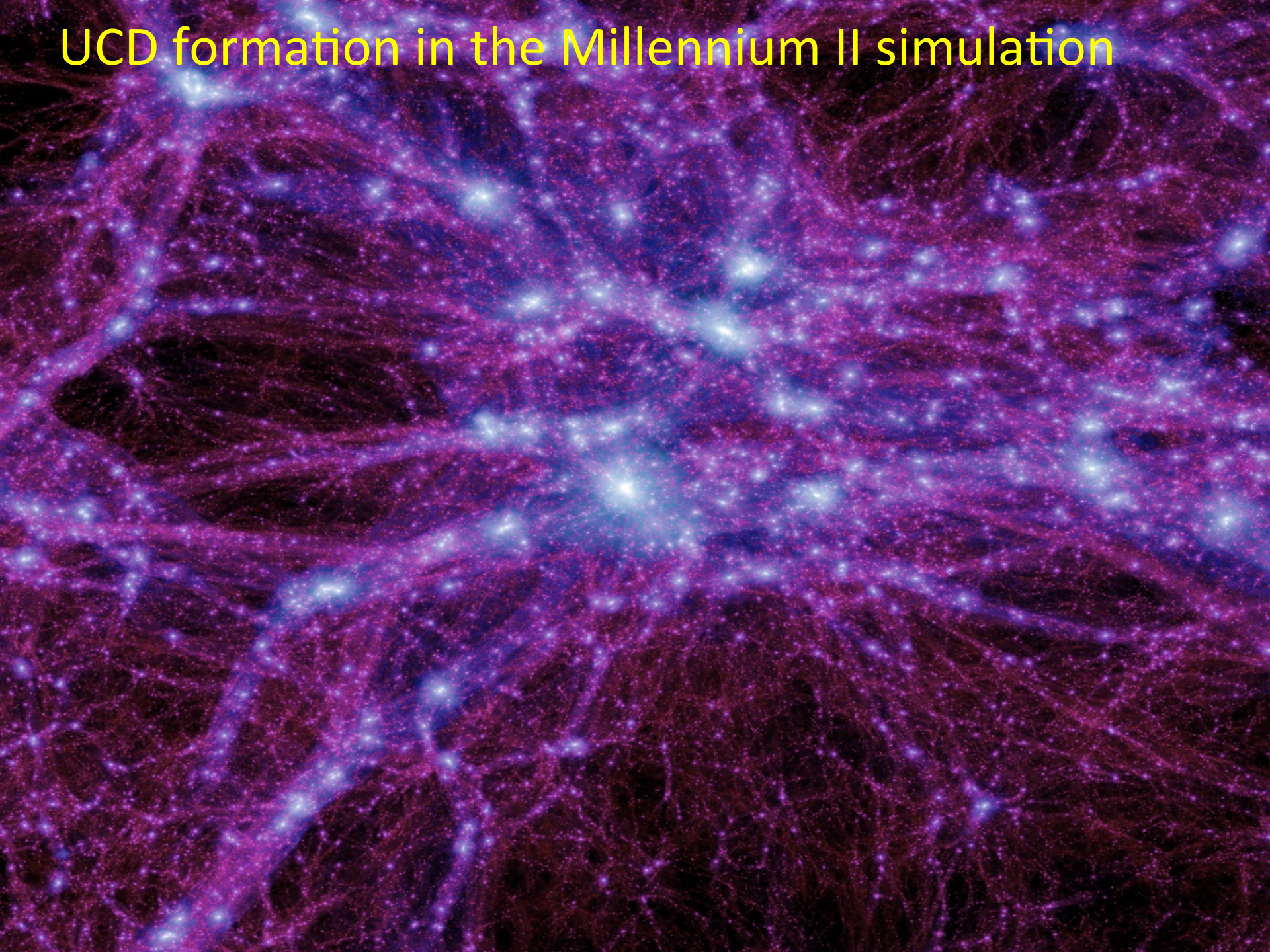


Tidal stripping produces objects that resemble UCDs

But how often does this happen?

(from Pfeffer & Baumgardt 2013)


UCD formation in the Millennium II simulation

UCD formation in the Millennium-II simulation

In order to test if the tidal stripping scenario also produces the right number and spatial distribution of UCDs, we searched for tidally disrupted halos in the Millennium-II simulation.

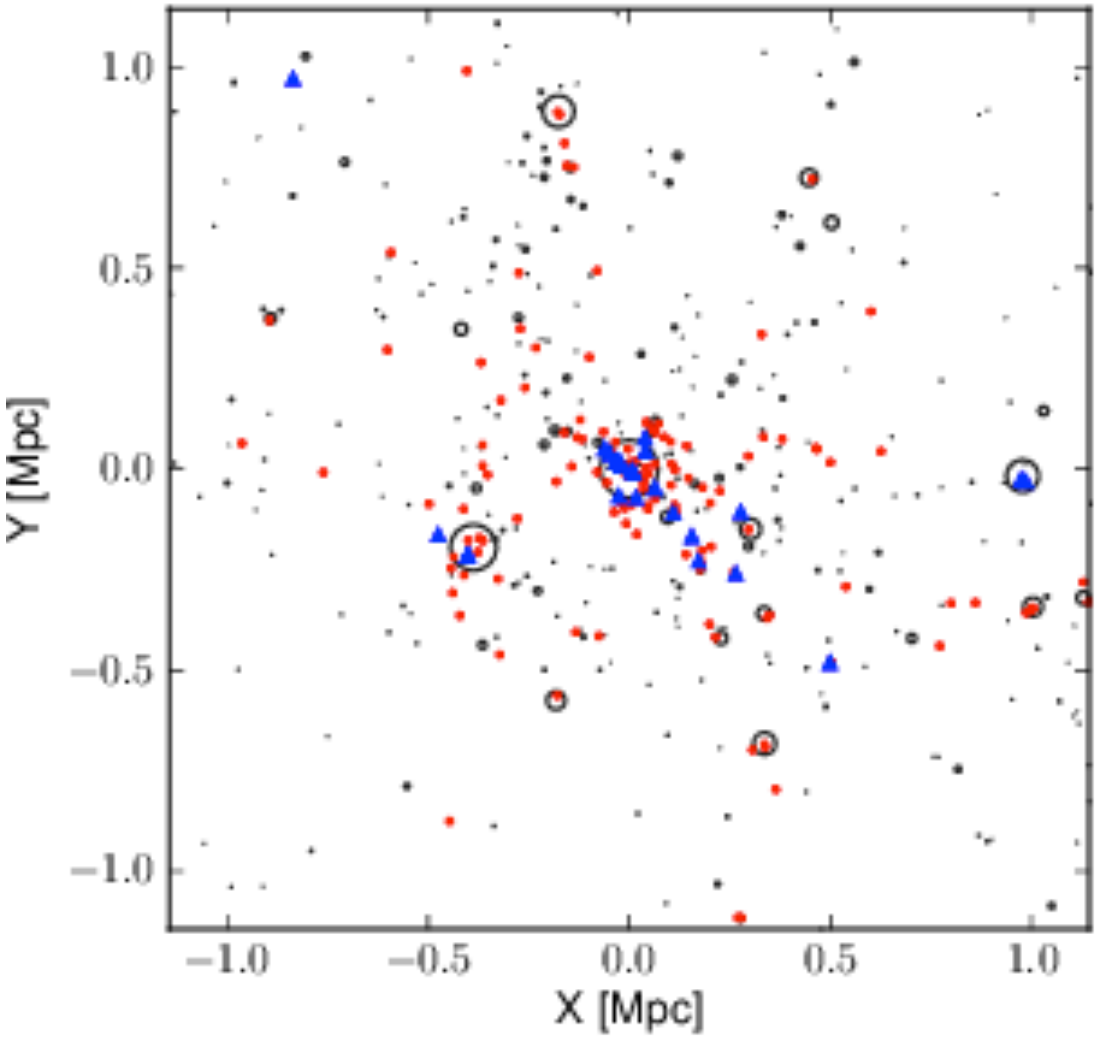
We followed the merger trees of individual haloes at z=0 back in time to identify merger events that could lead to UCD formation.

We used the semi-analytic simulations by Guo et al. (2010) to determine the stellar masses of the halos before disruption and assumed that the nuclei of disrupted galaxies contained 0.3% of the stellar mass of the halos.

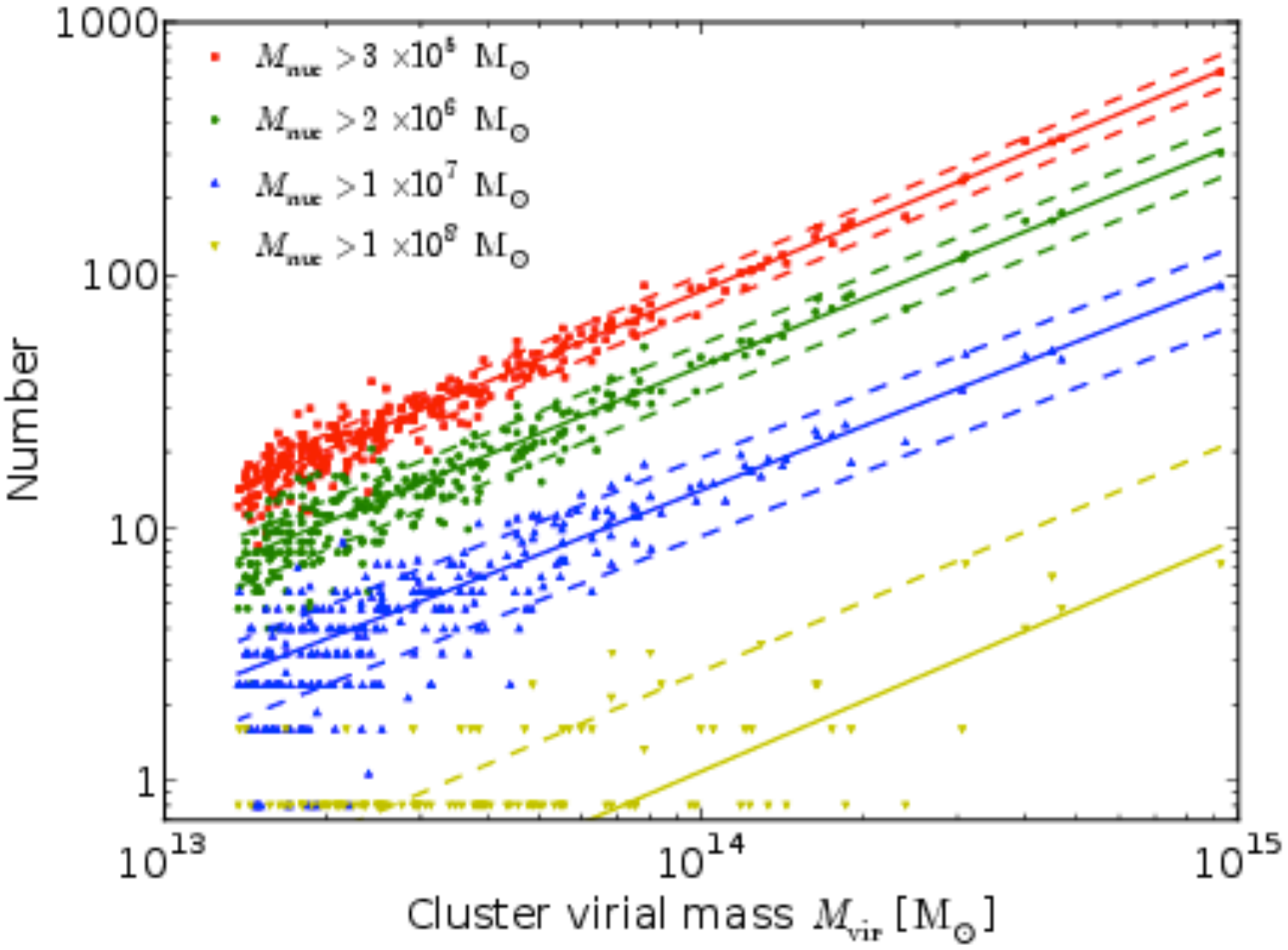
Spatial distribution of nucleated dwarf galaxies in a Virgo size galaxy cluster

Nuclei are strongly concentrated towards the cluster center and significantly more concentrated than surviving dwarf galaxies.

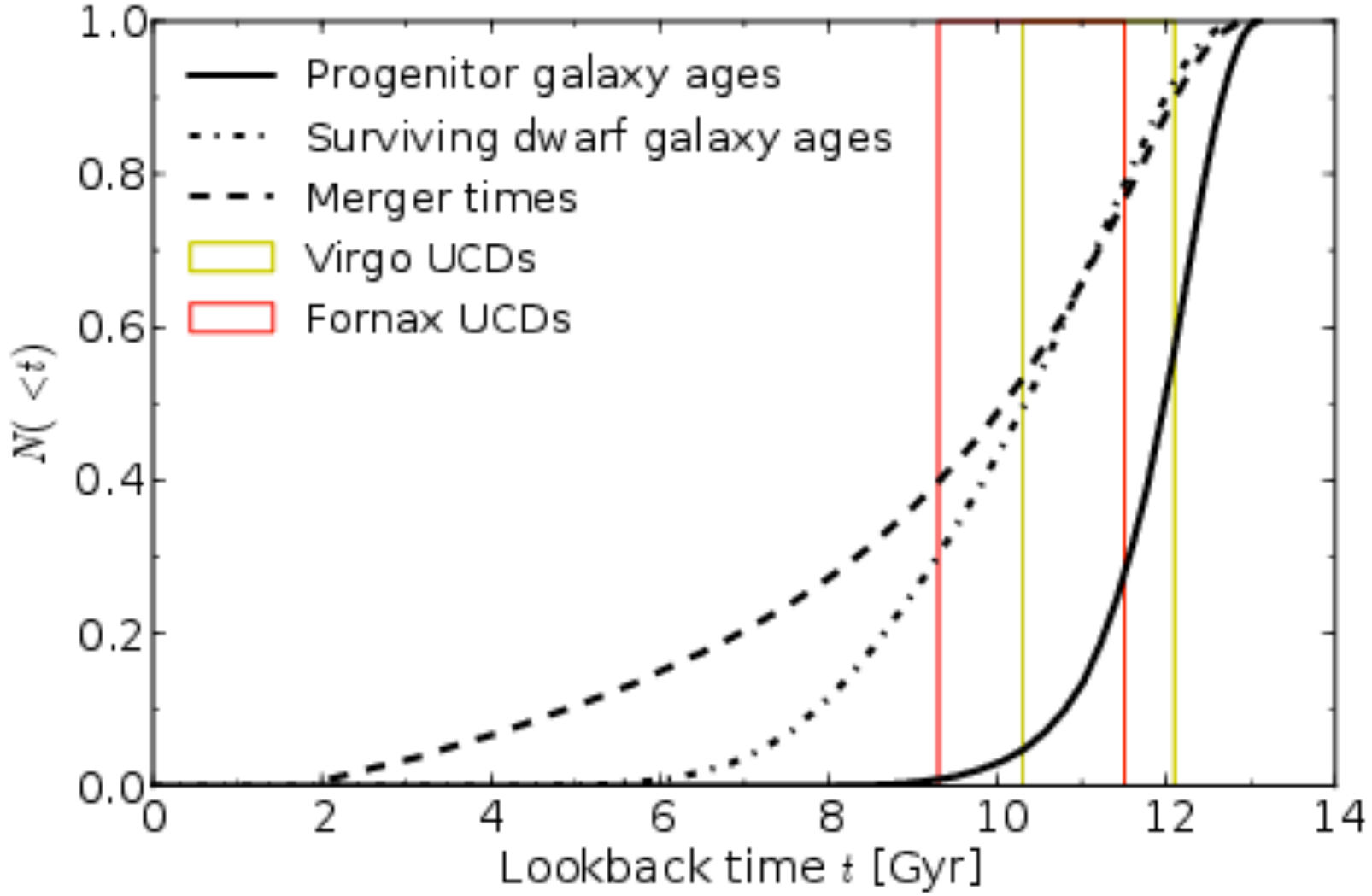
About 30% of nuclei are bound to the satellite galaxies, the rest is bound to the central galaxy.



Absolute numbers of stripped nuclei

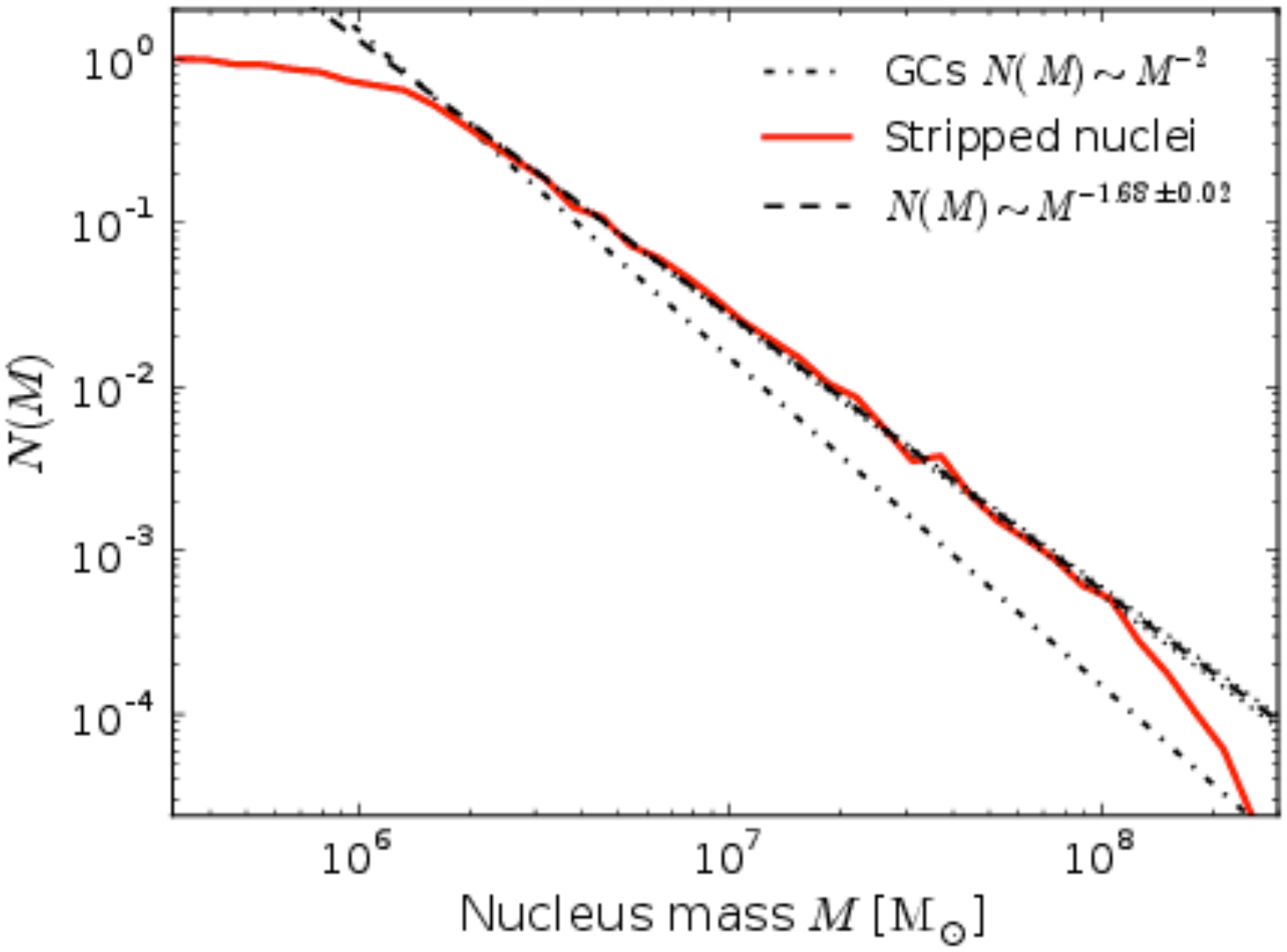


Ages of the stripped nuclei vs. UCD ages



(from Pfeffer et al. 2014)

Mass function of stripped nuclei



(from Pfeffer et al. 2014)

Results for Individual Halos

Number of stripped nuclei in a Milky Way sized galaxy halo

We predict that 2.0±1.3 GCs in the Milky Way with a mass larger than $3 \cdot 10^5$ $M_\odot$ and 1.2±0.7 GCs with a mass larger than $2 \cdot 10^6$ $M_\odot$ are stripped nuclei.

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Currently 6 galactic GCs are thought of being the remnants of dwarf galaxies due to either a spread in heavy-element abundances (Omega Cen, M22, NGC 1851, NGC 2419, NGC 3201) and/or ages (Omega Cen, Terzan 5).

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Our results are compatible with a scenario where Omega Cen and one or more of the other GCs are stripped nuclei.

Number of stripped nuclei in galaxy clusters

Observed number of UCDs in Fornax:

Mass ($M_\odot$)	$R < 83$ kpc	$R < 300$ kpc
$> 2 \times 10^6$	>146	>193
$> 10^7$	16	23

Predicted number of UCDs:

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$> 2 \times 10^6$	$13.5^{+9.1}_{-8.2}$	$23.5^{+10.3}_{-8.8}$
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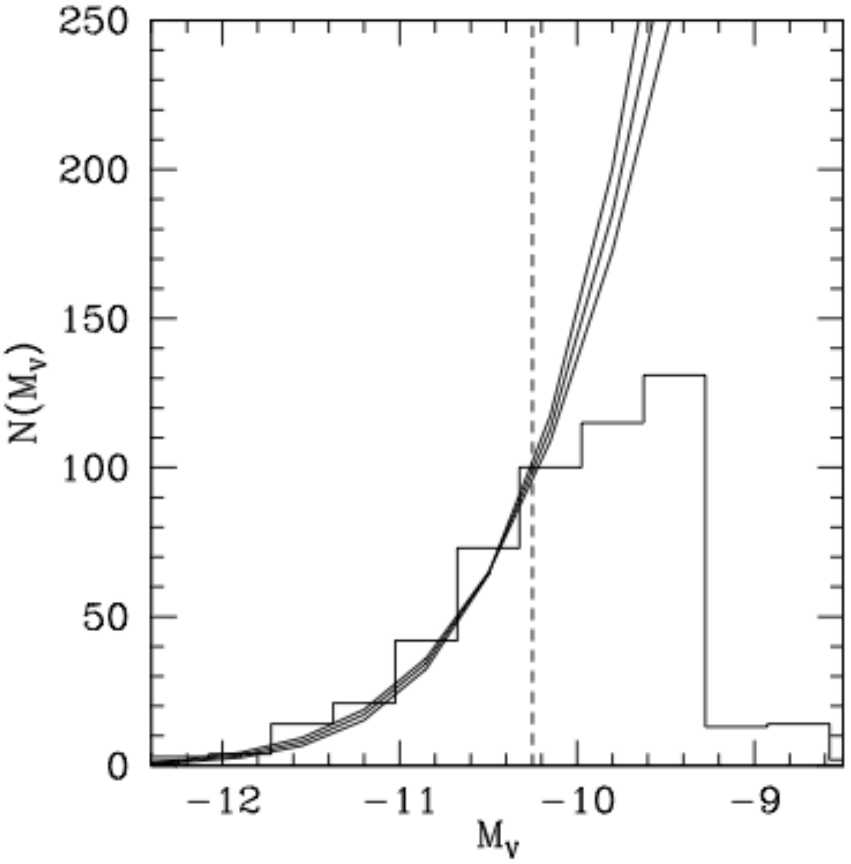
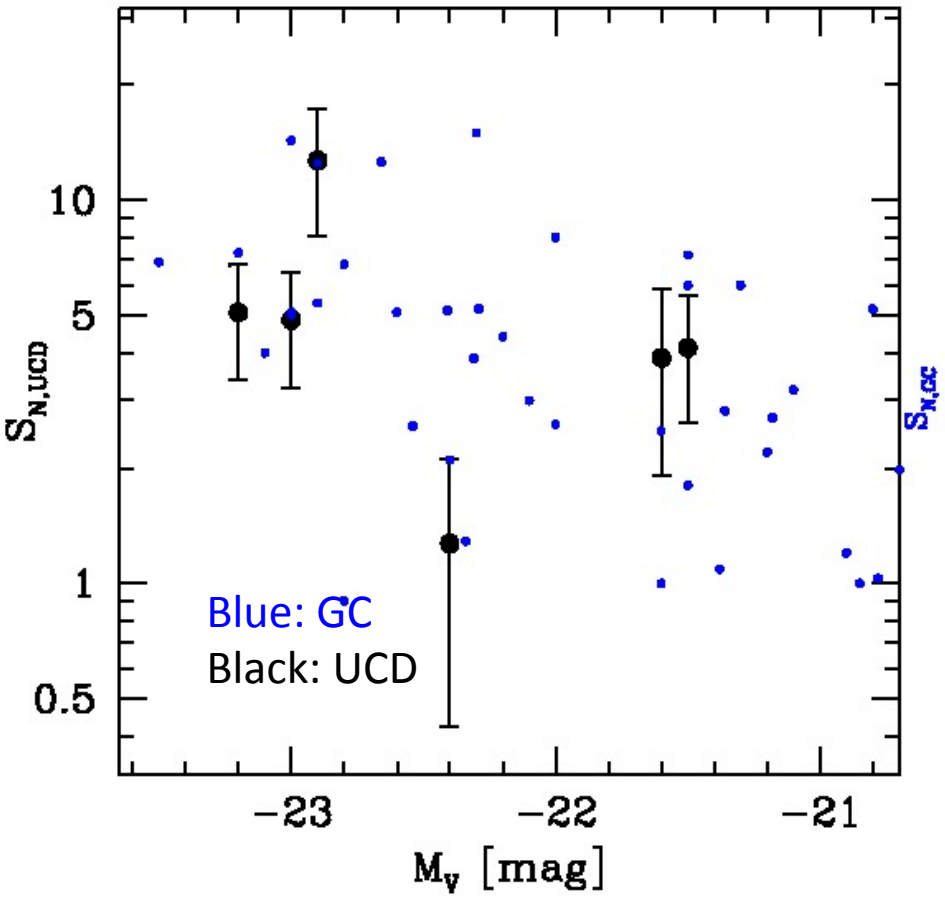
10% of all UCDs in Fornax with masses larger than $2 \cdot 10^6$ $M_\odot$ and 30% of those with masses larger than 10^7 $M_\odot$ are stripped nuclei.

Where do the remaining UCDs come from?

LF of GCs/UCDs in Fornax



Specific frequencies of GCs/UCDs



from Mieske et al. (2012)

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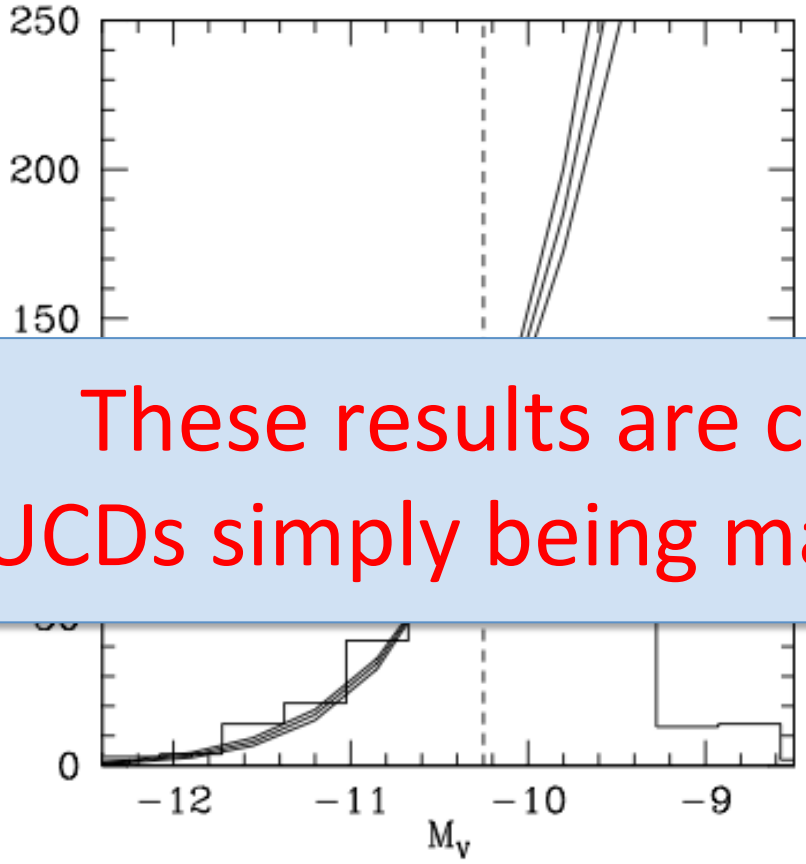

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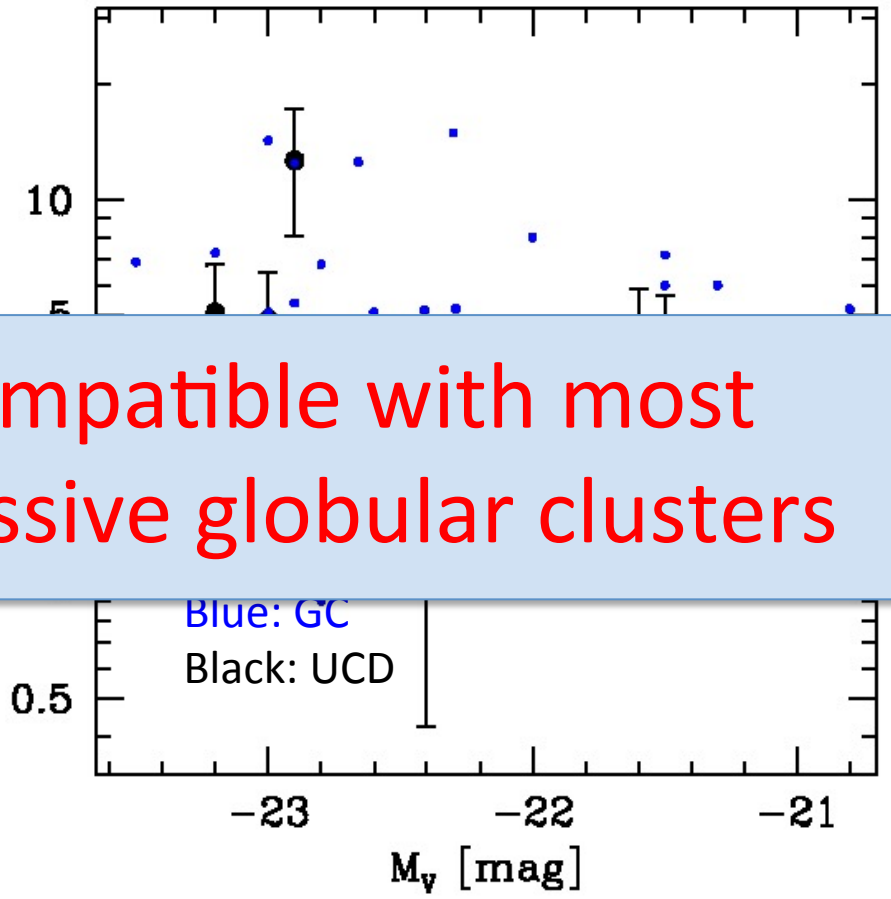


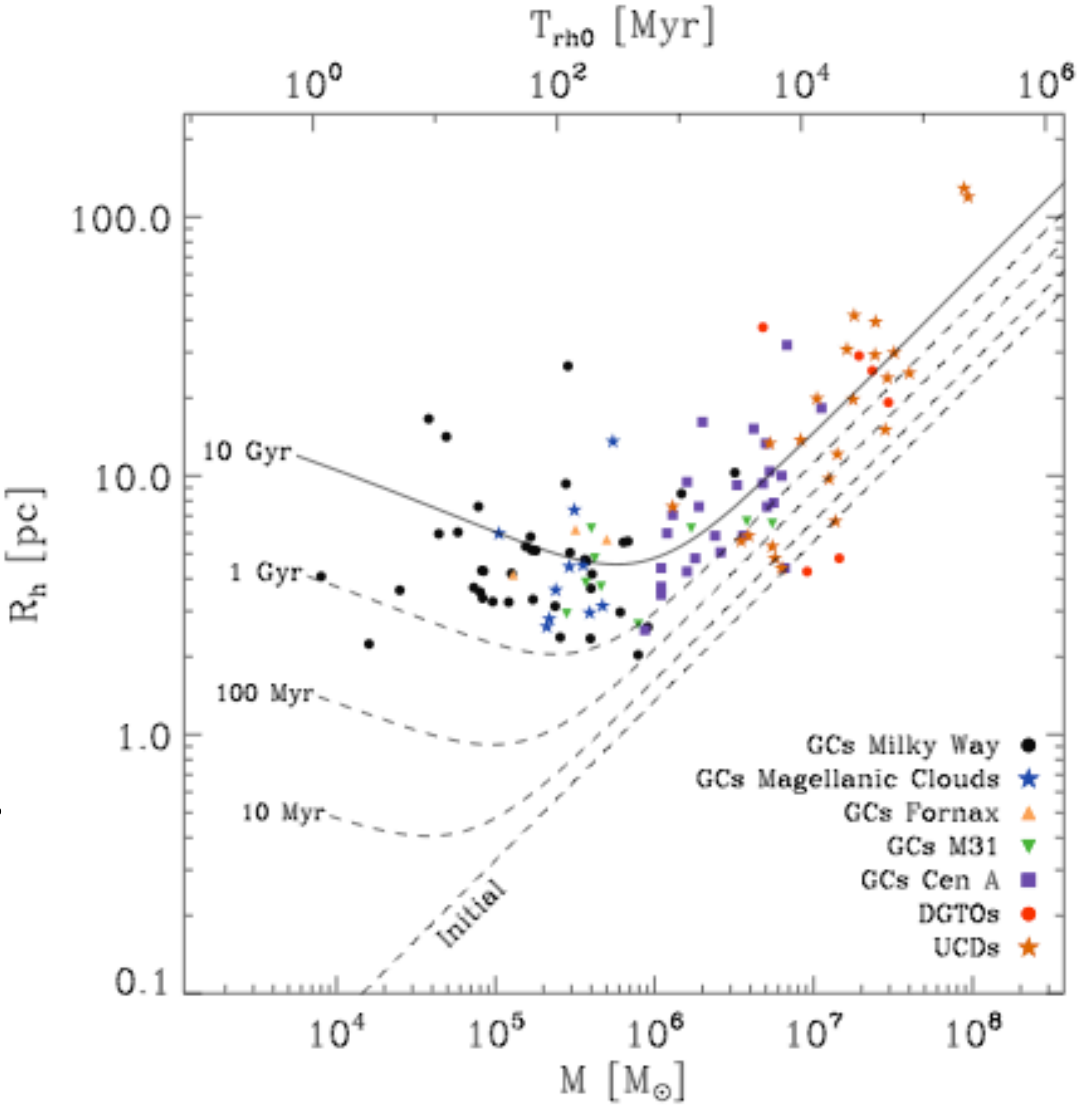
These results are compatible with most UCDs simply being massive globular clusters

from Mieske et al. (2012)

Mass-radius relation for globular clusters and UCDs

Data is fully compatible with both GCs and UCDs having started with the same mass-radius relation.

The absence of a mass radius relation for globular clusters might simply be due to dynamical evolution.



from Gieles et al. (2010)

Conclusions

- Our simulations predict that a few massive globular clusters in the Milky Way and Andromeda are stripped nuclei of dwarf galaxies.

- In large galaxy clusters, about 10% of all UCDs with masses larger then $2 \cdot 10^6$ $M_\odot$ and 30% of those with masses larger than 10^7 $M_\odot$ are stripped nuclei.

- Most of the remaining UCDs are probably simply large globular clusters.

- If you want to know what this means in terms of the internal UCD kinematics and the possible presence of super-massive black holes in UCDs, see Steffen Mieske's talk !