High mass-to-light ratios of UCDs - Evidence for dark matter ?

Holger Baumgardt

Argelander-Institut für Astronomie, Universität Bonn

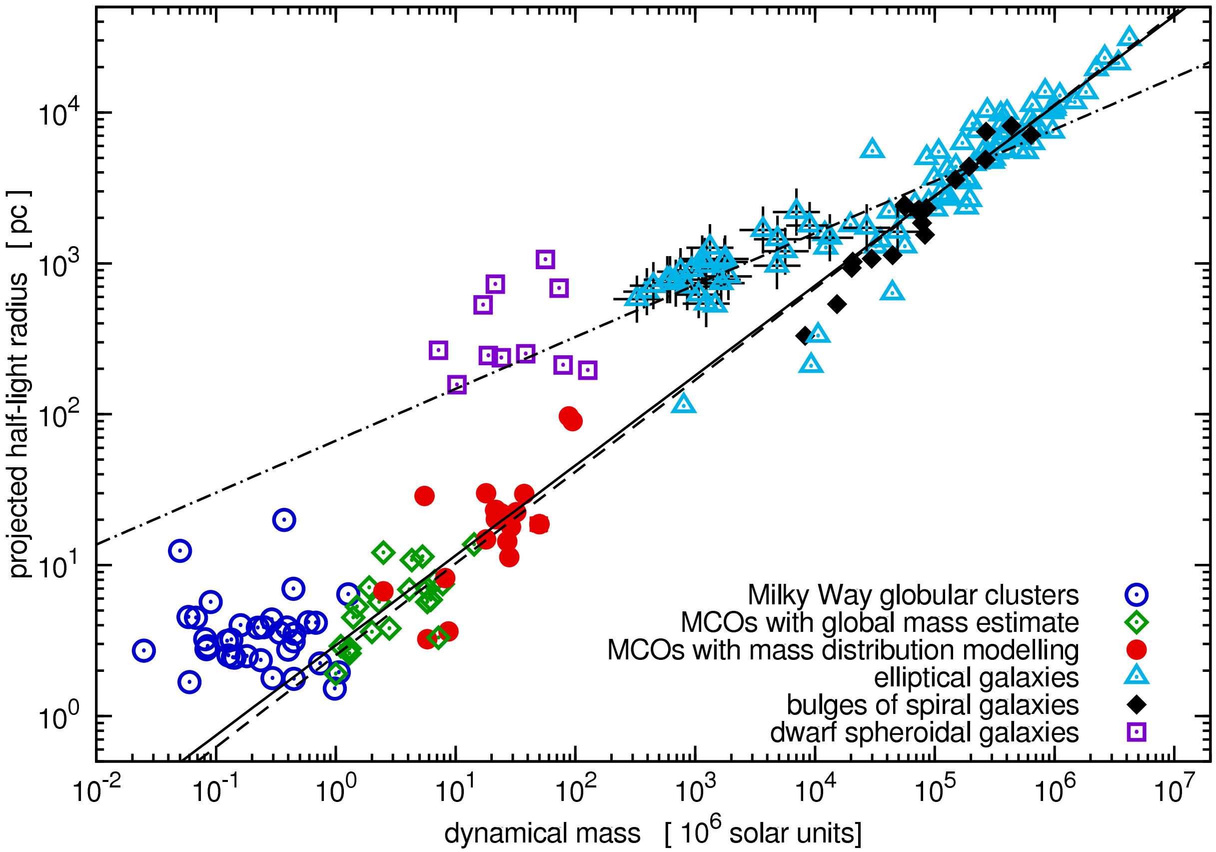
holger@astro.uni-bonn.de

in collaboration with

Steffen Mieske (ESO), Michael Hilker (ESO), Marina Rejkuba (ESO), Pat Côté (Herzberg Institute)

Ultra-compact dwarf galaxies

Ultra-compact dwarf galaxies (UCDs) are bright ($-11 < M_V < -13.5$) and compact ($7 < r_h < 100$ pc) stellar systems with ages of several Gyr and possibly up to 10 Gyr.



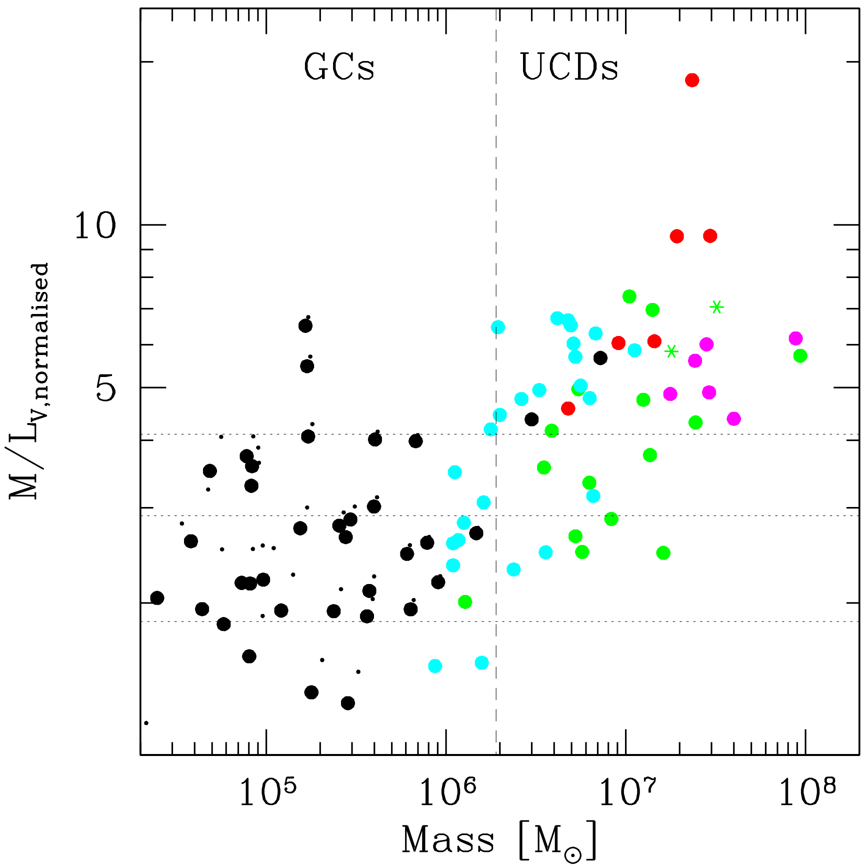
(from Dabringhausen et al. 2008)

Ultra-compact dwarf galaxies

One remarkable property of UCDs is their high mass-to-light ratio.

Compared to globular clusters, UCDs have about a factor two higher M/L ratios if one corrects for the different metallicities.

The M/L ratios of UCDs are also higher than those predicted by stellar evolution theories assuming e.g. a Kroupa (2001) IMF.



(from Mieske et al. 2008)

Ultra-compact dwarf galaxies

Several possible formation mechanism have been suggested for UCDs, they could for example:

- Simply be massive globular clusters (Forbes et al. 2008)
- Form as the result of mergers between globular clusters (Fellhauer & Kroupa 2002)
- Formed from small-scale peaks in the dark matter power spectrum (Drinkwater et al. 2004)
- Form as stripped nuclei of dwarf elliptical galaxies (Oh, Lin & Aarseth 1995, Bekki et al. 2003, Goerdt et al. 2008)

Ultra-compact dwarf galaxies

❒ Goerdt et al. (2008) have investigated a scenario in which UCDs form through adiabatic gas infall into the centers of dwarf spiral galaxies. During this infall, dark matter is funneled into the centers, leading to elevated mass-to-light ratios of the nuclear star clusters.

❒ Later tidal stripping leaves only the nuclear star cluster behind which becomes a UCD.

❒ Dark matter could therefore explain the high mass-to-light ratios of UCDs.

$\Longrightarrow$ Since a similar formation scenario is discussed for a few globular clusters as well (e.g. Omega Cen), one would expect that at least some globular clusters also formed with significant amounts of dark matter in their centers.

Dark matter depletion from dense stellar systems

- Dark matter would get depleted from the centers of stellar systems due to mass segregation of the heavier stars against the light dark matter particles.

- The timescale of this process is given by (Baumgardt & Mieske 2008):

$$T_{Fric} = 5.9 \left(\frac{M_{Tot}}{10^6 M_\odot}\right)^{1/2} \left(\frac{R_H}{5pc}\right)^{3/2} \left(\frac{<m>}{M_\odot}\right)^{-1} \text{Gyr}$$

- Since the friction timescale is short for globular clusters and long for UCDs, this could explain why globular clusters have normal mass-to-light ratios and UCDs high ones.

Simulating dark matter depletion

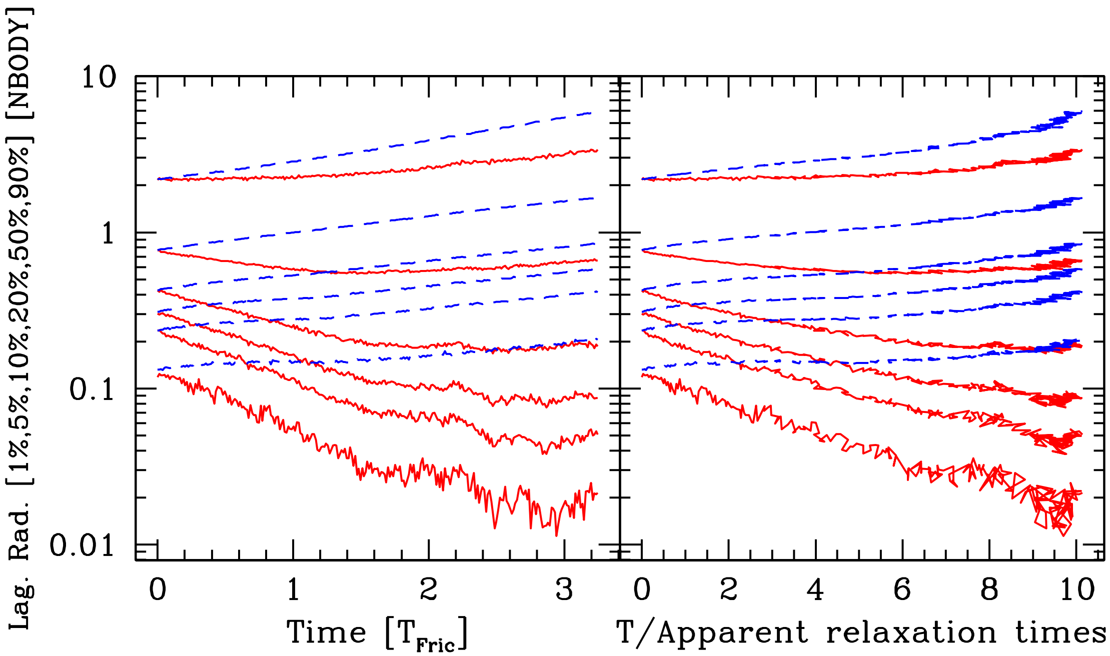
- In order to study the co-evolution of a system of dark matter particles and stars, we have run a number of N-body simulations, using the Aarseth N-body program NBODY4.

- All clusters had initially 10^5 particles. The stars followed a mass-function typical for a globular cluster at $T = 12$ Gyr. The masses of the dark matter particles were varied bewteen 0.01 and $0.1 M_\odot$ to study any possible dependence of the results on the assumed particle mass.

- The simulations were run for several friction times to study the depletion of dark matter from the centers of the systems.

Simulating dark matter depletion

The following picture shows Lagrangian radii for a system composed out of stars (red) and dark matter (blue):

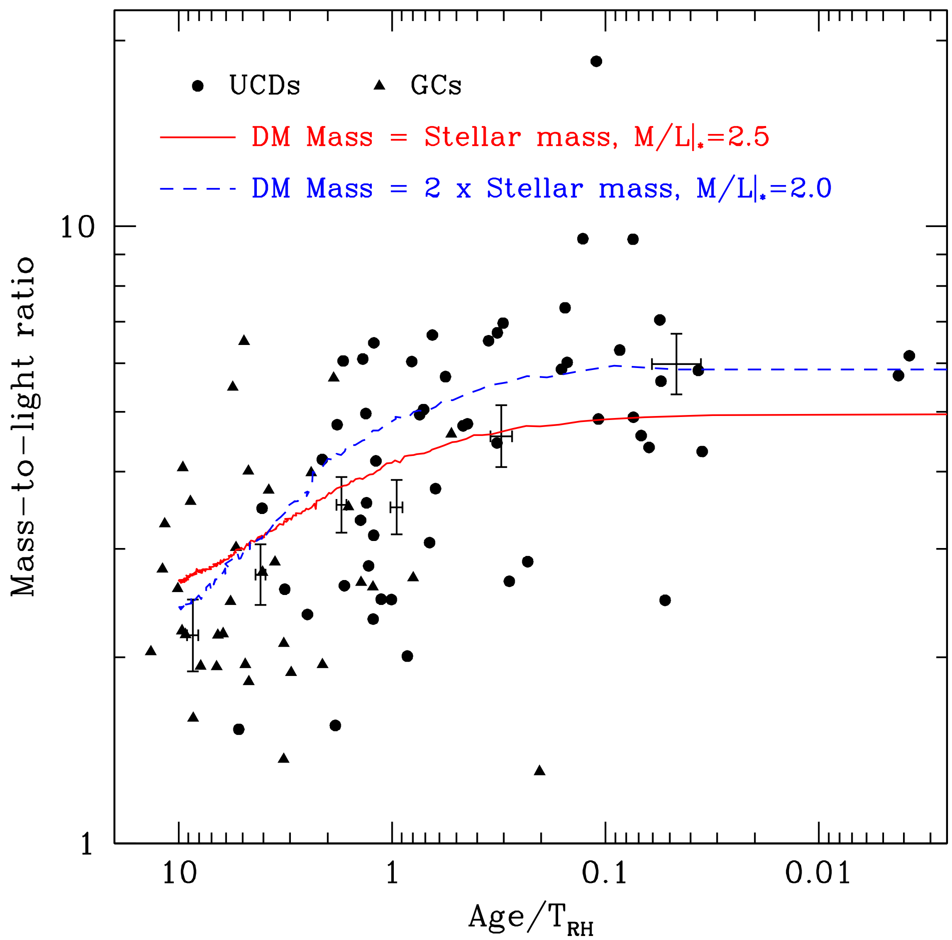


It can be seen that while the stars sink into the center, the dark matter particles are pushed towards the outer cluster parts. After several friction times, the center is nearly free of dark matter.

Simulating dark matter depletion

This picture shows observed M/L ratios of globular clusters and UCDs and M/L ratios determined from stars inside the half-mass radius of the simulated clusters.

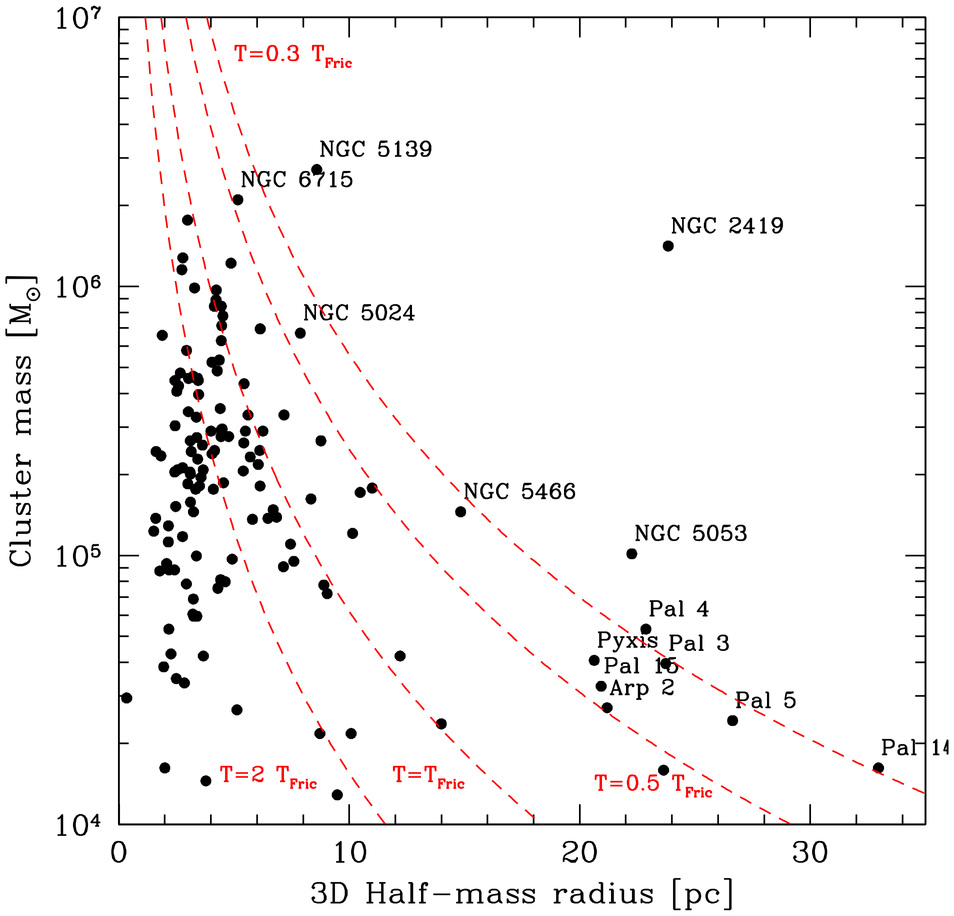
The observed M/L ratios show a clear trend in the sense that dynamically older systems have lower M/L ratios. The same trend is seen in the simulations.



Dark matter in globular clusters ?

If the previous scenario is correct, galactic globular clusters should contain dark matter, at least in their outer parts. Clusters with large T_{Fric} might still be dark matter dominated in their centers.

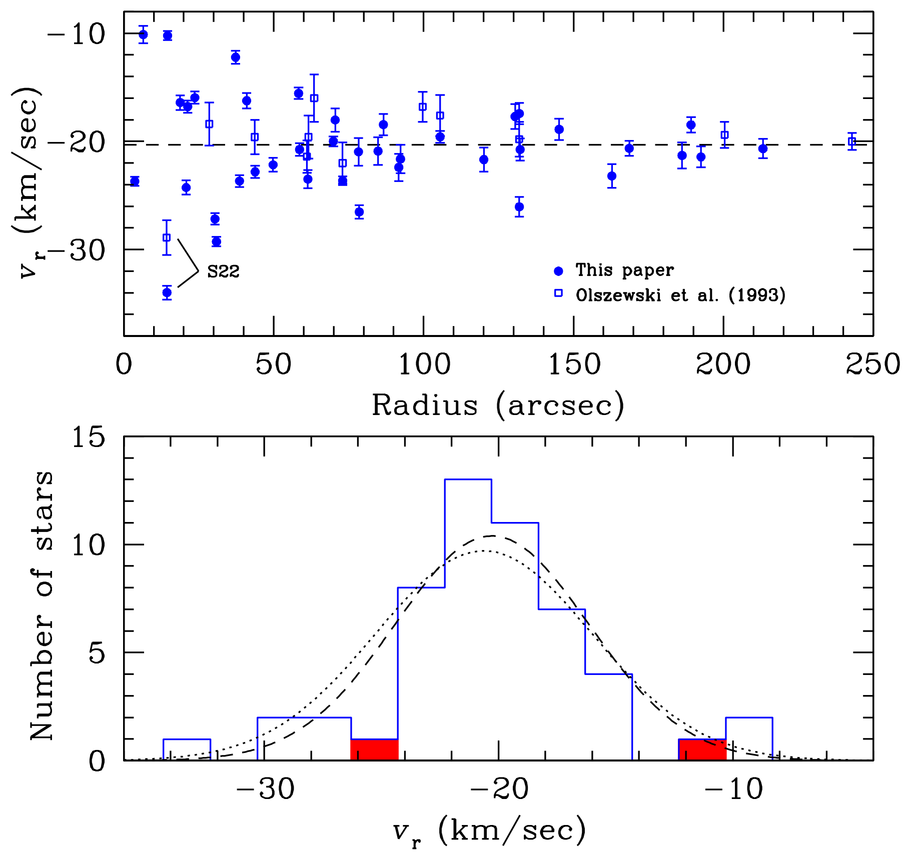
The plot to the right shows friction times for galactic globular clusters. NGC 2419 would be the most likely candidate to host dark matter.



The M/L ratio of NGC 2419

In order to test for DM, we measured the velocity dispersion of NGC 2419. From 40 stars, we find a velocity dispersion of $\sigma = 4.1 \pm 0.5$ km/sec.

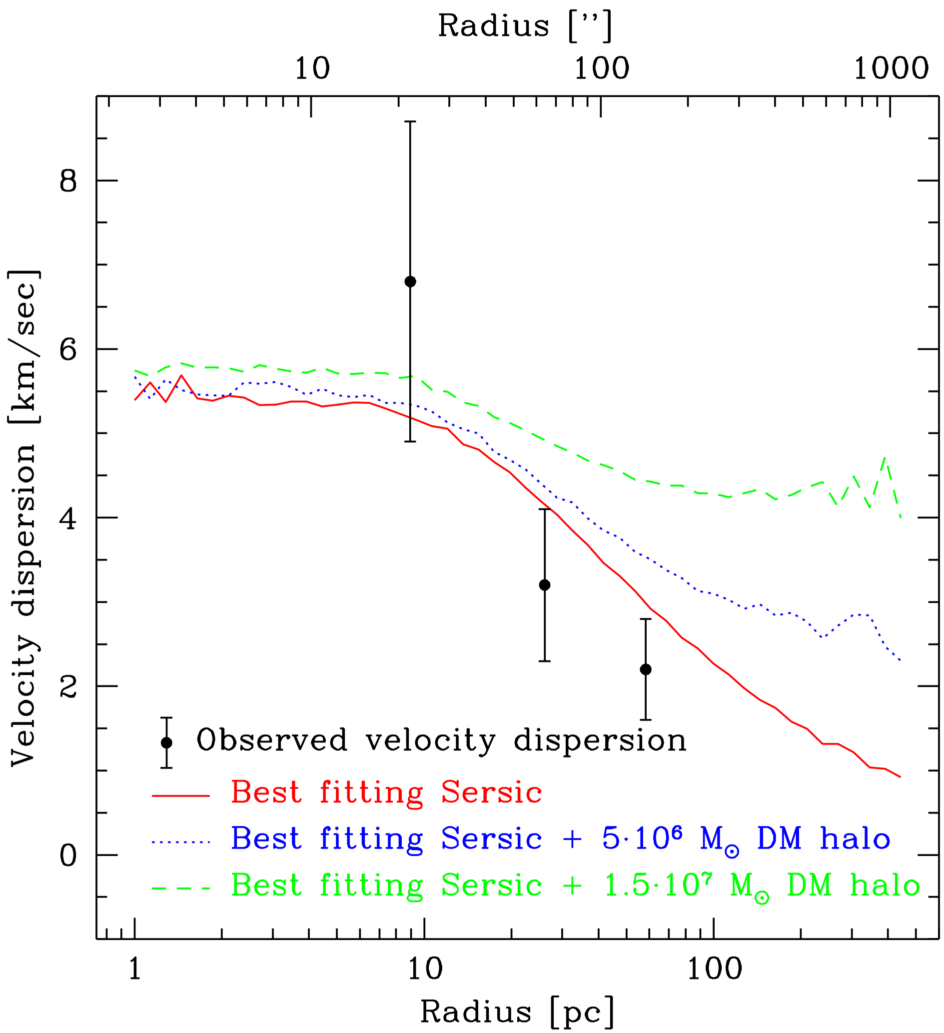
From the vel. dis., we derive a mass-to-light ratio of $M/L = 2.0 \pm 0.5\, M_\odot/L_\odot$, signifcantly higher than the M/L ratio of Olszewski et al. (1993): $M/L = 0.7 \pm 0.4$. Our value is consistent with the M/L ratio of a Kroupa (2001) IMF at the metallicity of NGC 2419 ($M/L = 1.9 M_\odot/L_\odot$).



The M/L ratio of NGC 2419

In addition, the velocity dispersion profile of NGC 2419 does not show a rise in M/L towards the outer cluster parts, as might be epxected if it is surrounded by a dark matter halo.

There is therefore no evidence of dark matter in NGC 2419 down to a level of about 0.02 $M_\odot/pc^3$, which is significantly lower than the DM densities found in dSph galaxies (Gilmore et al. 2007).



(from Baumgardt et al. 2009)

Conclusions

- ❐ NGC 2419 has a M/L ratio in agreement with a standard IMF and no depletion of low-mass stars, which is in agreement with expectations based on its long relaxation time and large tidal radius.

- ❐ We found no evidence for a sizeable amount of dark matter in this cluster (and also Pal 4 and Pal 14, see Jordi et al. 2009), which argues against formation of globular clusters in dark matter halos.

- ❐ The high mass-to-light ratios of UCDs still remain unexplained. What happens at a mass limit of $2 \cdot 10^6$ $M_\odot$?

- ❐ If globular clusters self-enrich themselves, NGC 2419 should be made up of mainly first generation stars since tidal stripping is inefficient. In this case, the M/L ratio we measured would imply that first generation stars form with canonical IMFs, not top-heavy ones.