High M/L ratios of UCDs: a variation of the IMF?

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Various studies have established that the dynamical M/L ratios of ultra-compact dwarf galaxies (UCDs) tend to be at the limit or beyond the range explicable by standard stellar populations with canonical IMF. We discuss how IMF variations may account for these high M/L ratios and how observational approaches may in the future allow to discriminate between those possibilities. We also briefly discuss the possibility of dark matter in UCDs.

1 Introduction: elevated M/L ratios in UCDs

In recent years, significant effort has been put into studying the internal dynamics of extragalactic compact stellar systems in the mass regime of massive globular clusters and ultra-compact dwarf galaxies ($10^6 < M/M_\odot < 10^8$) (Drinkwater et al. 2003, Martini & Ho 2004, Hasanoglu et al. 2005, Maraston et al. 2004, Rejkuba et al. 2007, Evstigneeva et al. 2007, Hilker et al. 2007, Mieske et al. 2008; see also Dabringhausen et al. 2008 and Forbes et al. 2008). A striking outcome of these studies is that the dynamical M/L ratios of massive compact stellar systems are on average about two times larger than for normal globular clusters of comparable metallicity. This is illustrated in Fig. 1. The rise of M/L ratios starts at about $2\times10^6 M_\odot$, separating ordinary globular clusters at lower masses, from the so-called ultra-compact dwarf galaxies, at higher masses (see also Mieske et al. 2008). Possible reasons for these high M/L ratios include extreme stellar mass functions (Mieske & Kroupa 2008; Dabringhausen, Hilker & Kroupa 2008) or densely packed dark matter (Goerdt et al. 2008).

2 Possible explanations

2.1 Bottom-heavy IMF

A bottom heavy stellar initial mass function (IMF) may be a possible explanation for the high M/L\textsubscript{\odot} ratios of UCDs. Such steep low-mass stellar IMFs may result if the radiation field, stellar winds and supernova explosions in UCDs were so intense during their formation, that pre-stellar cloud cores were ablated before they could fully condense to stars (Kroupa & Bouvier 2003). By confirming such an overabundance of low-mass stars with respect to a canonical

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\begin{figure}[h]
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\includegraphics[width=0.5\textwidth]{fig1}
\caption{Mass vs. M/L for compact stellar systems. Literature sources are Mieske et al. (2008, green dots), Rejkuba et al. (2007, cyan), Hasanoglu et al. (2005, red) Evstigneeva et al. (2007, magenta), Hilker et al. (2007, green asterisk), and Milky Way globular clusters (McLaughlin & van der Marel 2005, black dots). The vertical dashed line at $2\times10^6 M_\odot$ indicates the approximate mass where the relaxation time is equal to one Hubble time (Mieske et al. 2008; Dabringhausen et al. 2008). All M/L ratio estimates have been normalised to solar metallicity (Mieske et al. 2008). The horizontal dotted lines indicate the M/L ratios expected for single stellar populations of age 13, 9, and 5 Gyr (from top to bottom, based on Bruzual & Charlot 2003 and Maraston et al. 2005).}
\end{figure}
IMF (Kroupa 2001), we would for the very first time have unambiguous evidence for a radically different star-formation process under extreme physical conditions when UCDs formed.

For diagnosing a bottom heavy IMF, one needs to study a portion of the spectrum where the hypothetical overabundant population of low-mass (main sequence) stars contributes significantly to the integrated spectrum. This is the case for the near-infrared wavelength region of the CO band ($2.3 \mu m < \lambda < 2.42 \mu m$, see Fig. 2). For intermediate to high metallicities, late type giant stars have a very strong CO absorption feature, while late type dwarf stars have a much weaker feature (see also Mieske & Kroupa 2008), independent of metallicity (e.g. Frogel et al. 1978). At a given metallicity, one thus expects a weaker CO index for high M/L ratios, provided that UCDs formed by tidal stripping. Indeed, it has been suggested that also GCs may have originated as centers of individual primordial dark matter halos (e.g. Lee et al. 2007, Bekki et al. 2007). If dark matter funneling is an efficient mechanism (Goerdt et al. 2008), one may therefore expect both UCDs and GCs to be formed with a significant fraction of dark matter. It is important to note that such an increase of dark matter density by some kind of funneling mechanism is necessary to explain a significant amount of dark matter in UCDs or GCs, since their present-day stellar and hence implied dark matter densities are up to 2-3 orders of magnitude higher than expected for cuspy dark matter halos of dwarf galaxy mass (Gilmore et al. 2007). This is shown in Fig. 4 In Baumgardt & Mieske (2008) the dynamical co-evolution of stars and dark matter in GCs/UCDs is studied.

2.3 Dark matter

Goerdt et al. (2008) have shown that funneling of dark matter to the central region of a disk galaxy, due to gas-infall, can significantly increase the M/L ratios in the nuclear region, and hence may explain the elevated M/L ratios of UCDs. In Dabringhausen, Kroupa & Baumgardt (2008, submitted to MNRAS), it is examined in detail how the top-heavy IMF slope $\alpha_3$ changes as M/L ratio increases. For this, they assume the IMF to be a multi-power law equal to the canonical IMF (e.g. Kroupa 2001) below $1 M_\odot$ but with a different slope, $\alpha_3$, above $1 M_\odot$. Their results are indicated in Fig. 3. The mean mass density within the half-mass radius of the joint sample of GCs and UCDs from Fig. 1 is plotted vs. their relaxation time (Mieske et al. 2008). The dotted line indicates the approximate central ($r \leq 10$ pc) density expected for cuspy dark matter halos of dwarf galaxy CDM halos (Gilmore et al. 2007).

**Fig. 4** The mean mass density within the half-mass radius of the joint sample of GCs and UCDs from Fig. 1 is plotted vs. their relaxation time (Mieske et al. 2008). The dotted line indicates the approximate central ($r \leq 10$ pc) dark matter densities expected for cuspy dark matter halos of dwarf galaxy CDM halos (Gilmore et al. 2007).

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These plots illustrate how an overabundance of low-mass stars in an old stellar population can be estimated from spectroscopy around the CO band (Kroupa & Gilmore 1994). The feature and continuum band definition of the photometric index is indicated by dotted lines at the bottom (Frogel et al. 1978). See also Mieske & Kroupa 2008 for more details. **Left:** Shown is a NIR spectrum of a M2II giant star (lower long dashed curve) and a M2V dwarf star (upper short dashed curve) from the catalog of Lancon & Rocca-Volmerange (1992), smoothed to 0.04 µ resolution. The CO index 0.16 mag of the M giant corresponds to the typical CO index of old stellar populations of intermediate metallicity ([Fe/H]∼ −0.7 dex, e.g. Frogel et al. 1978 and 2001, Goldader et al. 1997, Ivanov et al. 2000). The M dwarf has a much weaker CO feature, representative of a population of pure low-mass stars with upper mass cutoff $m_{\text{cut}} \approx 0.5 M_\odot$ (Kroupa & Gilmore 1994). Under the hypothesis that the high M/L ratios of UCDs are caused by an overabundance of unevolved low-mass stars like the M dwarf (Kroupa & Gilmore 1994), one would require those stars to contribute a significant fraction to the total UCD mass (3/4 for the highest M/L UCD known), and also a certain fraction to the K-band luminosity (see next panel). **Middle:** The spectrum of the canonical stellar population is shown as in the left panel. The solid line now indicates the case of 40% K-band luminosity contribution from an additional population of low-mass stars. This luminosity fraction is representative for the case when the additional low-mass stars make up 3/4 of the total mass, at a metallicity of about [Fe/H]=−0.7 dex (Mieske & Kroupa 2008). The dotted lines indicate the 1 σ error range of the spectrum, assuming a S/N of 150 per 0.04 µ resolution element. **Right:** The expected offset from the Frogel et al. [Fe/H]−CO relation (Frogel et al. 2001) is plotted vs. the mass of the compact stellar systems from Fig. 1. The offset arises from the assumption that M/L ratios above the mean value for galactic GCs are caused by a bottom-heavy IMF.

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Fig. 3  **Left:** Data points from Fig. II but with linear Y-axis. The (blue) solid line for masses below $2 \times 10^6 M_\odot$ indicates the mean M/L ratio of the sources. For larger masses, the (blue) solid line indicates a linear fit to the data points. **Right:** Assuming the behaviour of M/L as $f(M)$ as indicated by the solid lines in the left panel, this figure indicates how the high-mass IMF slope above 1 solar mass changes as $f(M)$. The various line shapes correspond to different cases of retained remnants, as indicated in the plot legend. The horizontal dashed line indicates the canonical IMF slope (Kroupa 2001).