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The dark mass content of the Milky Way globular clusters NGC288 and NGC6218

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Abstract. We present an observational estimate of the fraction and distribution of dark mass in the innermost region of the two Galactic globular clusters NGC6218 and NGC288. We find that non-luminous matter constitutes more than 60% of the total mass in the region probed by our data ($R < 1.'6 \sim r_h$) in both clusters. The dark component appears to be more concentrated than the most massive stars, suggesting that it is likely composed of dark remnants segregated in the cluster core.

Key words. stars: kinematics and dynamics – stars: luminosity function, mass function – stars: Population II – globular clusters: individual (NGC 6218, NGC 288)

1. Introduction

The relative amount of luminous and dark matter (DM) to the overall mass budget of stellar systems contains crucial information on their nature, origin and evolution.

At odds with other DM dominated stellar systems populating contiguous regions of the luminosity-effective radius plane (Tolstoy, Hill, & Tosi 2009), globular clusters (GCs) appears to be deprived of DM (Heggie & Hut 1996). On the other hand, low-mass DM halos surrounding GCs progenitors are hypothesized by some model of GC formation (Peebles 1984) and observational claims of the possible existence of DM dominated GCs in the giant elliptical NGC5128 have been recently put forward by Taylor et al. (2015). Non-baryonic DM is not the only invisible matter contained in stellar systems. Indeed, the final outcome of the stellar evolution process of stars with different masses is represented by remnants (white dwarfs, neutron stars and black holes) whose luminosities are several orders of magnitude smaller than those of the least luminous Main Sequence stars.

In this contribution we present the result of the analysis of the most extensive photometric and spectroscopic datasets available for the two Galactic globular clusters (GCs) NGC288 and NGC6218, aimed at deriving their dark mass content and radial distribution. The full discussion of the results can be found in Sollima et al. (2016).

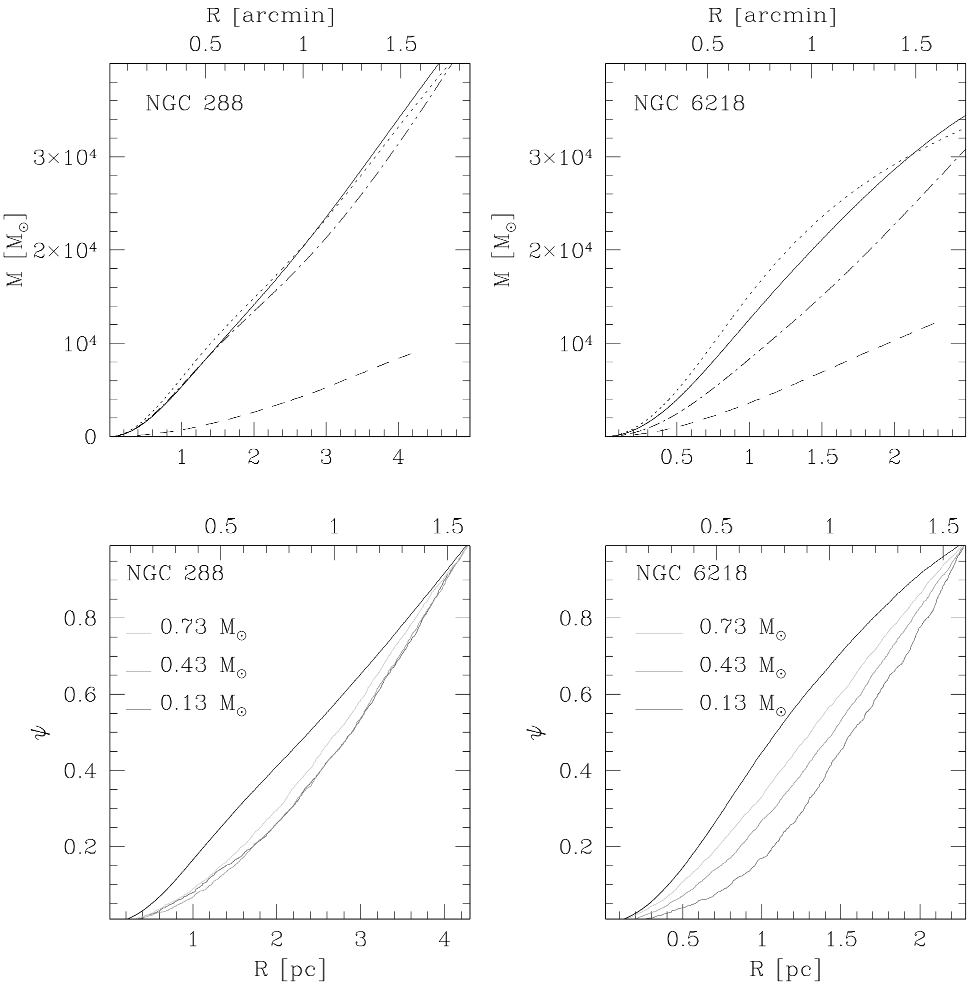

Fig. 1. *Top panels:* cumulative luminous mass profile (dashed lines) and dynamical mass profiles (obtained by assuming isotropy, radial and tangential anisotropy: solid, dot-dashed and dotted lines, respectively) derived for NGC 288 (left panels) and NGC 6218 (right panels). *Bottom panels:* comparison between the cumulative profile of dark mass (black thick lines) and those of stars in different mass bins (lighter lines) in NGC 288 (left panel) and NGC 6218 (right panel). All profiles are normalized at a distance corresponding to the ACS field of view.

2. Observational data

The main photometric database used in this work is constituted of deep catalogs obtained within the "Globular Cluster Treasury Project" (Sarajedini et al. 2007) from observations performed with the Advanced Camera for Surveys (ACS) onboard the Hubble Space Telescope. Auxiliary wide-field photometric data collected with the Wide Field Imager at the ESO2.2m telescope have been used to determine the radial density profile of the two analysed GCs across their entire extent.

The radial velocity database has been assembled using: *i)* spectra secured within the ESO Large Program 193.D-0232 (PI:

Ferraro) with the Fibre Large Array Multi-Element Spectrograph (FLAMES) using the high-resolution ($R \sim 18000$) grating HR21, *ii)* all the FLAMES spectra available in the ESO archive, and *iii)* the radial velocity database by Lane et al. (2010, 2011) constructed using observations with the multi-fiber spectrograph AAOmega mounted at the Anglo-Australian Telescope.

3. Method

The fraction and distribution of dark mass in the two analysed GCs have been determined by comparing the luminous and the dynamical mass profiles.

The luminous mass profile has been derived by summing the masses of individual stars detected in the deep ACS color-magnitude diagrams (CMDs). For this purpose, synthetic CMDs have been constructed using the theoretical isochrones of Dotter et al. (2010) with ages and metallicity appropriate for the two target clusters. A population of unresolved binaries has been simulated and the effect of photometric errors has been also taken into account. We associated to each observed star the mass of the closest synthetic particle (m_i) and a completeness factor (c_i) defined as the fraction of recovered artificial stars at the same magnitude, color and distance of the corresponding observed star. The cumulative radial distribution of the luminous mass has been then derived as:

$$M_{lum}(R) = \sum_{d_i<R} \frac{m_i}{c_i}.i \quad (1)$$

The dynamical mass profile $M_{dyn}(R)$ has been derived by solving the Jeans equation in spherical coordinates:

$$\frac{1}{\rho_*}\frac{d\rho_*\sigma_{r,*}^2}{dr} + 2\beta\frac{\sigma_{r,*}^2}{r} = -\frac{GM_{dyn}(r)}{r^2}. \quad (2)$$

where ρ_* and $\sigma_{r,*}$ are the 3D mass density and the radial component of the velocity dispersion of the tracer population, and $\beta \equiv 1 - \sigma_{t,*}/2\sigma_{r,*}$ is the anisotropy profile. The profiles of ρ_* and $\sigma_{r,*}$ have been derived by de-projecting the surface density and the line-of-sight velocity dispersion profiles derived from our dataset. We considered three cases: an isotropic profile, a radially anisotropic Osipkov-Merrit profile (Osipkov 1979; Merritt 1985) and a tangentially anisotropic profile.

4. Results

The luminous and dynamical mass profiles of the two analysed GCs within the ACS field of view are shown in the top panels of Fig. 1. It is apparent that in both GCs dynamical masses are significantly larger than the luminous ones across the entire surveyed area: at a projected distance of 1.′6, the fractions of dark mass are of 75±12% and 62.5±9.6% in NGC288 and NGC6218, respectively.

From the mass profiles derived above we determined the distribution of dark mass within the area surveyed by our analysis by simply subtracting at each radius the enclosed luminous mass to the dynamical one. The resulting cumulative distribution of dark mass normalized at 1.′6 is compared to those of stars in different mass bins in the bottom panels of Fig. 1. Note that that for both GCs the dark mass is more concentrated than any other mass group.

To interpret the observed overabundance of non-luminous mass, we analysed the snapshots at t=13 Gyr of three N-body simulations selected from the set of Contenta, Varri, & Heggie (2015) and compared their fraction of remnants with that measured in NGC288 and NGC6218 (see Fig. 2). Note that in two of such simulations dark remnants represent ~52% of the total mass within the same radius, only slightly smaller (within 2σ) than those estimated in the two analysed GCs. It is important to emphasize that all the simulated clusters lost more than 70% of their initial mass after 13 Gyr and the large majority (~ 87%) of their mass in remnants is constituted of white dwarfs.

5. Summary

The main result obtained in this paper is that the largest fraction (> 60%) of the mass con-

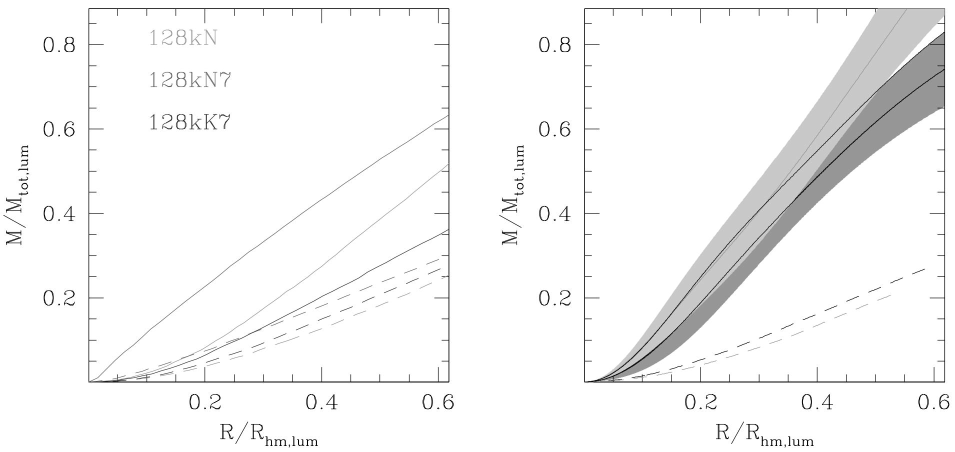

Fig. 2. *Left panel:* Comparison between the total cumulative mass profile (solid lines) and that of luminous stars (dashed lines) in three different N-body simulations (see details in Contenta, Varri, & Heggie 2015). *Right panel:* luminous (dashed) and dynamical (solid) mass profiles estimated for NGC 288 (light grey) and NGC 6218 (black). The shaded area indicate the 1σ uncertainty on the dynamical mass estimate at each radius.

tent of both the analysed GCs is dominated by centrally concentrated non-luminous mass.

The comparison with a suitable set of N-body simulations indicates that such a large mass excess is compatible with that of dark remnants (mainly white dwarfs) sunk in the core during the cluster lifetime as a result of mass segregation. This effect is particularly important in stellar systems subject to a strong tidal stress, where dark remnants are preferentially retained with respect to low mass stars.

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