A Possible Formation Scenario for the Heavy Weight Young Cluster W3 in NGC 7252

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1. Introduction

In the merger remnant system NGC 7252 Maraston et al. (2004) found the most luminous star cluster known to date, W3. They determined its mass via two independent ways. First they used the total luminosity of $M_V = -16.2$ and a stellar M/L derived from a single stellar population model to determine the mass to 7.2 $\times 10^6$ M$_\odot$. As an independent proof of this heavy weight mass they derived the dynamical virial mass by measuring the velocity dispersion, which turned out to be quite high at $\sigma = 45 \pm 5$ km/s and they determined the effective radius to be $R_{\text{eff}} = 17.5 \pm 1.8$ pc. This translates into $8 \pm 2 \times 10^6$ M$_\odot$. The age of this object is about 300–500 Myr, which points to the fact that it was formed during the merger event of the host system. Star and mass of this object leads to the conclusion that it is rather one of the recently discovered ultra-compact dwarf galaxies (UCD) found in the Fornax clusters (Hilker et al. 1999, Phillips et al. 2000) than an ‘ordinary’ global globular cluster.

These UCD galaxies are believed to be the cores of stripped dwarf galaxies (Bekki et al. 2003, Mieske et al. 2004). We propose a formation scenario which is closely related to the massive starburst caused by the interaction of two gas-rich disc galaxies. In interacting systems like the Antennae (NGC 4038/39) (Whitmore et al. 1999, Zhang & Fall 1999) one sees regions of intense star formation with very high star densities and up to hundreds of young massive star clusters have formed. These star clusters complete (cf. super-cluster) span regions of a few hundred parsecs in diameter. Kroupa (1998) argues that these super-clusters will be found outside our galaxy and cause their age ($\approx$ 10 Myr) indicates that they should be either already dispersed (if unbound) or should be at least dense less in the central region or would have collapsed because the free-fall time is short enough. Simulating super-clusters, by means of stellar dynamical N-body simulations, Fellhauer et al. (2002) found that the star clusters within these super-clusters merge on very short time-scales (a few dozens to a few hundred Myr) namely a few crossing-times of the super-cluster.

The resulting merger-objects can be characterised by their large effective radii. They show similar properties like the UCDs (Fellhauer et al. 2002) found that the star clusters within these super-clusters merge on very short time-scales (a few dozens to a few hundred Myr) namely a few crossing-times of the super-cluster.

2. Setup

The simulations are carried out with a particle-mesh code with high-resolution sub-grids which stay focused on the simulated objects (Superbox, for a detailed description see Fellhauer et al. 2000). The super-cluster in our simulation is represented by a Plummer sphere with a Plummer radius of 100 pc and a cut-off radius of 400 pc. The clusters inside this super-cluster have a total mass of $9.9 \times 10^6$ M$_\odot$, which leads to a crossing time of the super-cluster of 9.3 Myr. Inside the Plummer sphere of the super-cluster, the particles have positions and velocities according to the Plummer distribution function. The ‘particles’ themselves are Plummer spheres representing the star clusters with Plummer radii of 4 or 10 pc respectively, masses of $10^5$ and $5 \times 10^5$ M$_\odot$, crossing times of 0.35 Myr and 1.3 Myr for the Plummer radii presented in the Antennae (Zhang & Fall 1999). The effective radius of the light clusters is chosen according to the mean effective radius of the star clusters in the Antennae (Whitmore et al. 1999) while the effective radius of the heavy ones rather represent merger-objects of many light star clusters. To model hundreds of lighter and maybe thousands of ultra-light star clusters is beyond the capabilities of our code.

This super-cluster is now placed into an galactic potential, consisting of a logarithmic potential for the underlying halo, a Plummer-Kuzmin disc and a Hernquist bulge, which add up to a flat rotation curve of 220 km/s. The super-cluster is placed at a distance of 20 kpc initially (apogalacticon) on an eccentric orbit to mimic a varying potential field.

3. Results

In Fig. 1 the contour plot of the merger object is shown (left at $t = 390$ and middle at $t = 500$ Myr). This is the suggested age range of W3. The contours are spaced in magnitudes and ranges are converted to luminosities taking a mass-to-light ratio of 1. This underestimates the luminosity almost by a factor of 10 because the stellar population of this age has a $M/L = 0.1\pm0.2$ (according to a single stellar population model run with Starburst99, Leitherer et al. 1999). In our model these two time-slices mark the transition to the regime where many star clusters are visible as separate entities and the time when most of the star clusters have already merged or are dissolved within the merger object. The unmerged star clusters also cause little wiggles in the surface density profile. Unfortunately NGC 7252 and W3 are too far away to resolve the surface density profile in detail. But these wiggles are found in resolved young massive star clusters in the LMC (Schweizer 1983).

Another interesting fact is that the merger object shows a cuspy structure with a dynamically cold core. The profile can be fitted by either two King profiles or two exponentials (as shown in the middle row of Fig. 1) and the velocity dispersion is rising in the innermost part and reaches its maximum beyond the transition between the core and the envelope (Fig. 1 bottom right). The outer part of the velocity dispersion can be fitted with an exponential profile with an exponential scale length of the order of the tidal radius of the object. A detailed listing of the fitting parameters can be found in the tabular. An explanation for the cuspy core is that normally our merger objects are much lighter and consist only of these cores and the stripped particles during the merger process get lost. This time the merger object is heavy enough to keep the stripped particles bound as an envelope.

In Fig. 2 we show the dynamical evolution of the total mass, the effective radius and the velocity dispersion of our model, whose dynamical evolution was followed for 5 Gyr. The horizontal line in the left panel as well as the boxes in the two other panels shows the values measured for W3. We adopt a maximum tidal velocity dispersion of our model in our agreement with the data of W3. Only the effective radius of our model is too small compared with W3. It starts decreasing at the onset of the tidal process and increases slightly until the majority of the star clusters have merged. Then the core of the merger object has formed and the effective radius drops to about 5 pc. But note the extremely large value at $t = 700$ Myr. At exactly that time a late merger event of one of the remaining star clusters happened. If our formation scenario is correct, it points to the fact that we catch W3 at the time when a star cluster merges with the core of the object mimicking a large effective radius.

The further dynamical evolution is mainly governed by the tidal shaping of the object due to its eccentric orbit. It leads to a successive mass loss and an increase in the effective radius as well as a decrease in the velocity dispersion, because mainly stars with higher velocities and from the outer parts are lost at each pericentric passage.

Looking at the merger object after 5 Gyr of its dynamical evolution (see Fig. 1 right panel) shows that this object is very stable against tidal disruption. Also the dynamically cold core is not a transient feature but survives the whole dynamical evolution. The total mass of the object is still of the order of 6 $\times 10^6$ M$_\odot$ which is an order of magnitude more than the most massive globular cluster (M-Cen) of the Milky Way. The relaxation time-scale of this object adopting the formula from Spitzer & Hart (1971) $t_{\text{relax}} = 0.138 \sqrt{(M_{\text{tot}}/U) (U/\sigma^2)}$, where $M_{\text{tot}}$ is the mass of the object, $t_{\text{relax}}$ is the half-mass radius (151.7 pc at $t = 5$ Gyr), the average stellar mass ($\mu = 0.68 M_{\odot}$) and using the universal mass function of Kroupa (2001) and $U$ the number of stars. This leads to $t_{\text{relax}} \approx 4000$ Gyr.

This shows clearly that this object is not a globular cluster anymore but definitely a large galactic object.