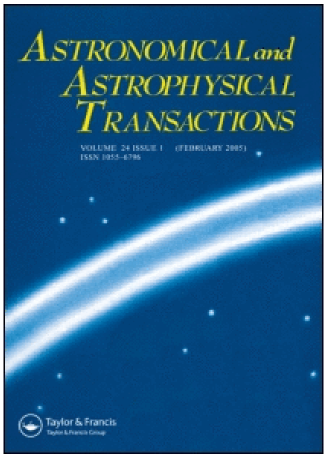

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DWARF-GALAXY-OBJECTS FORMED OUT OF MERGING STAR-CLUSTERS

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With this project we want to investigate the future fate of the clusters of young massive star-clusters (in this work called *super-clusters*) found in the tidal features of interacting galaxies. It is very likely that such configurations merge and build a dwarf galaxy object. Therefore we simulate compact super-clusters in the tidal field of a host-galaxy to investigate the influence of orbital or internal parameters. In this report the properties of the resulting merger-object and its dynamical evolution are studied. The surviving star-clusters count for the high specific cluster-frequency of these dwarf satellites and you also find surviving star-clusters along the orbit of the merger-object. The calculations carried out in this project show evidence for the scenario developed by Kroupa (1998), i.e. that dSph-galaxies are the remnants of disrupted dwarf satellites where the stars still resemble the same phase space and can be found as density enhancements in the sky. But because they are not a bound object anymore, mass estimates using virial equilibrium will lead to an unnecessarily high mass-to-light ratio and therefore to a high dark matter content of these objects.

KEY WORDS Methods: numerical – galaxies: interaction – galaxies: dwarf galaxies – galaxies: star clusters – star clusters: merging

1 SETUP

As a model for our massive star-clusters we use, for each, Plummer-spheres with 100000 particles, a Plummer-radius $R_{\rm pl} = 6$ pc and a cutoff radius $R_{\rm cut} = 30$ pc, giving a total mass of 10^6 $M_\odot$ and a crossing time of 1.4 Myr. Twenty of these clusters are placed in a compact group orbiting in an analytical logarithmic potential according to $\Phi(r) = 1/2\ v_{\rm circ}^2 \ln(R_{\rm gal}^2 + r^2)$ of the parent galaxy, with $R_{\rm gal} = 4$ kpc and $v_{\rm circ} = 220$ km s^{-1}. The case $v_{\rm circ} = 0$ is dealt with in Kroupa (1998). The distribution of the super-cluster is also Plummer-like with different Plummer-radii $R_{\rm pl}^{\rm sc}$ and the cutoff $R_{\rm cut}^{\rm sc}$ of 6 $R_{\rm pl}^{\rm sc}$. The position of the super-cluster is at $(D, 0, 0)$ with velocity $(0, v_y, 0)$. The number of clusters is kept constant at $N_0 = 20$. The simulations are performed with the particle-mesh code *Superbox* (Fellhauer *et al.*, 2000) which includes two levels of high-resolution sub-grids at the places of interest

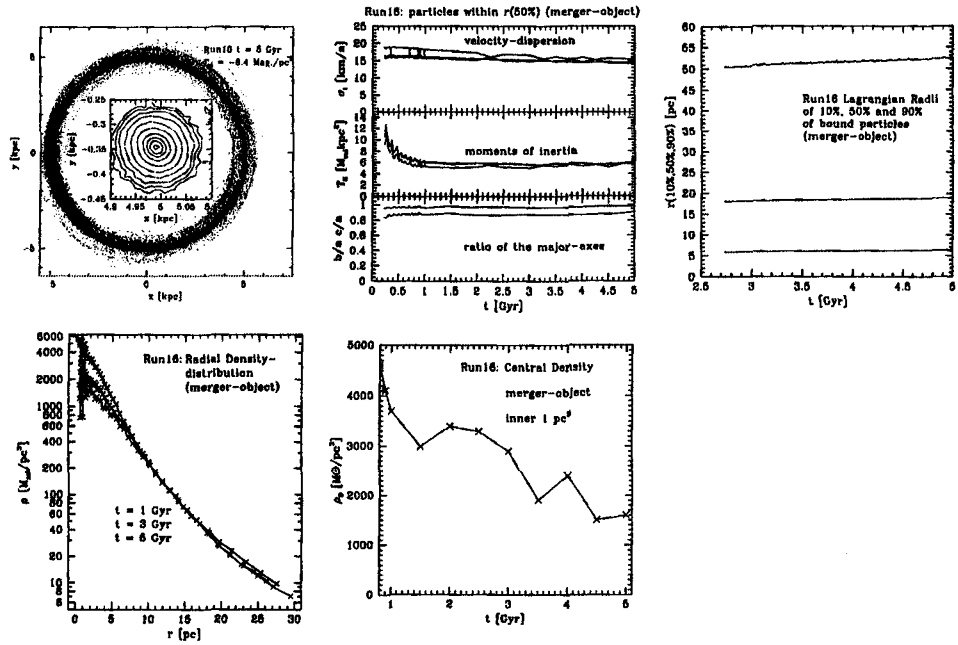

Figure 1 Internal properties of the merger-object in Run16. First: Contour-plot of the simulation after 5 Gyr. Blow-up shows the merger-object. Second: Velocity-dispersion, moments of inertia and axis-ratios. Third: Lagrangian Radii of the merger-object. Middle line shows the half-mass radius. Fourth: Radial Density of the merger-object. The density is calculated from a 10% subset of all particles in radial shells. Fifth: Time-development of the central density calculated at 1 pc radius from the subset.

(the super-cluster and the single clusters within). Our simulations cover a two-dimensional parameter-space. In physical quantities this is the size of the super-cluster $R_{\rm pl}^{\rm sc}$ and the distance of the super-cluster to the galactic center D. But one may also describe it in dimensionless parameters like $\alpha = R_{\rm pl}/R_{\rm pl}^{\rm sc}$ and $\beta = R_{\rm cut}^{\rm sc}/R_t$ where R_t is the tidal radius of the super-cluster.

2 COMPACT MERGER-OBJECTS

In all cases the merger-object is spherical and almost axisymmetric in its shape. The axis-ratios are almost equal to one (> 0.9, > 0.8). These objects are very small and compact with half-mass-radii about 20–50 pc and central densities (in the resolution limit of the numerical code of 1 pc) of about $1000 M_\odot$ pc^{-3}. The density profile itself looks exponential (see Figure 1). The total mass of such a merger-object is approximately $10^7 M_\odot$ depending on the number of clusters which have merged to build it up. The one-dimensional velocity-dispersion level is about 15 km s^{-1}. This means a measured line-of-sight velocity-dispersion would be about

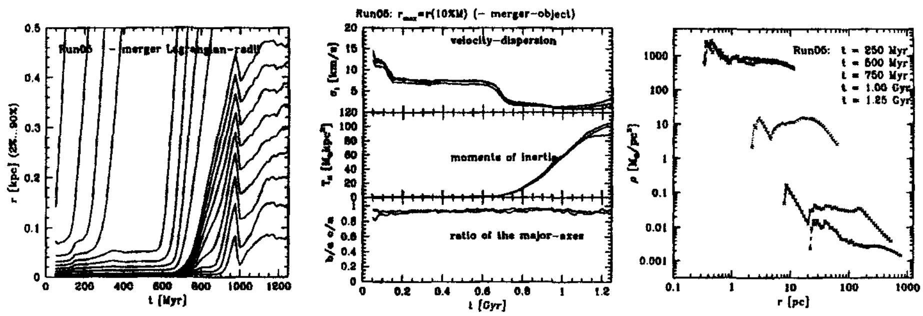

Figure 2 Left: Lagrangian-radii of the ⊖-object. Middle: Velocity-dispersion, moments of inertia and axis-ratios. Right: Radial density distribution at different times.

20 km s^{-1}. It is also shown clearly that these objects are able to survive over very long time-scales unless no other destruction process is invoked. What one also sees in the top left panel of Figure 1 is how the mass-loss (lost during the merging process) gets spread over the whole orbit of the system. This extreme mass-loss can include about 50% and more of the initial mass of the merging star-clusters. Within this mass-loss you find the surviving star-clusters (3 in this case). After the building phase of the merger-object is finished this object does not lose mass efficiently ($\approx$ 0.3% Gyr^{-1}). All these data suggests that the merger-object has similarities with a small dwarf elliptical (dE) galaxy. The small size may be due to the fact that only 20 star-clusters instead of hundreds are simulated.

3 DISSOLVED MERGER-OBJECTS

In two of our simulations this scenario is not true. In one simulation we found two merger-objects. One of these objects was destroyed due to tidal disruption when it passed through the line between Galactic Center and the other object. In another case the merger-object was very small with low central density (about 500 $M_\odot$/pc^3) on an eccentric orbit. The object was dissolved by tidal heating after the first perigalacticon passage. The resulting diffuse 'fluffy' objects, extending over several kpc in size, have very low densities ($\approx 0.1 M_\odot$ pc^{-3}). The velocity dispersion is about 1–3 km s^{-1}. So, these objects look like dSph-galaxies.

In Run05 we find two distinct merger-objects (called ⊕ and ⊖ in the following text). Both were built up in approximately the first 50 Myr. In the ⊕-object the star clusters 4, 7, 16, 17 and 20 merged together and the ⊖-object contains the clusters 8, 9, 15, 18 and 19. This means 50% of the star-clusters ended up in the merger-objects.

At the ⊖-object an expansion process starts right after the closest passage of the two objects, where the ⊖-object was found on a line between the ⊕-object and the center of the host-galaxy, and ends with the total disruption of the ⊖-object. The remnant is very fluffy in shape, has no core anymore and can hardly be seen on the contour plots. The maximum surface brightness is -0.74 Mag. pc^{-2} at $t = 1$ Gyr. The velocity dispersion drops to 1–2 km s^{-1} but then rises again, when more and more stars become unbound and travel on epicycles around their orbit around the galactic center (Figure 2). The central density dropped to 0.01–0.05$M_\odot$ pc^{-3} (Figure 2). While the $\oplus$-object shows tidal arms stretching out several kpc, the $\ominus$-object looks more like a fluffy blob of around 1 kpc diameter.

4 CONCLUSIONS

The resulting objects (MOs) look the same for all simulations. Because these objects are simulated without gas and no destruction process was taken into account they form as compact spherical objects which reproduce the properties of very small dwarf elliptical galaxies. They are very robust against tidal stripping of mass because they formed in a tidal field from the beginning. But there are a lot of processes which may lead to the dissolution of these MOs. First there is the process of dynamical friction and, in the case of elliptical orbits, tidal heating. Secondly there is of course the process of disk and/or bulge shocking. All these processes are not simulated within this project but should be in a future continuation. In one simulation the MO was tidally disrupted by a purely chance effect. This destroyed MO indeed showed the properties of a small dwarf spheroidal galaxy. We even could reproduce the high central velocity dispersion without the need for a high dark matter content in the object (mass-to-light ratio of 1.0).

We do not claim that our process of forming recycled second-generation dwarf galaxies is the only possible way these objects may form, but it is at least one possible way to explain the existence of dwarf galaxies in the vicinity of big 'normal' galaxies like our Milky Way. Also some 'side-effects' can be accounted for by our models. Calculations with low values of α take very long until all clusters finally ending in the MO are merged. In the meantime they account for the high specific globular cluster frequency found in dwarf galaxies. Also our models develop tidal tails which get spread all over the orbit around the host-galaxy. Surviving escaped star-clusters are also found on this orbit. We have similar findings for the Sagittarius dwarf spheroidal galaxy in our Milky Way.

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