ω Cen - an Ultra Compact Dwarf Galaxy?

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Abstract. We study the merging of star clusters out of cluster aggregates similar to Knot S in the Antennae on orbits close to the one of ω Cen by carrying out high resolution numerical N-body simulations. We want to constrain the parameter space which is able to produce merger objects with similar properties as ω Cen.

Keywords: globular clusters: individual: ω Cen – methods: N-body simulations – galaxies: formation – galaxies: star clusters – galaxies: dwarfs

1. Introduction

Interactions of gas-rich disk galaxies show intense bursts of star formation. For example, HST-images of the Antennae (Whitmore et al. 1999) reveal that the knots of intense star formation produce clusters of massive young star clusters. These aggregates which we call super-clusters (= cluster of star clusters; not to confuse with super stellar cluster (SSC), which are individual massive star clusters) appear to contain dozens to hundreds of massive star clusters within a region spanning only a few hundred pc to a kpc in radius.

On the other hand, new observations of the central galaxy of the Fornax cluster revealed a new class of unresolved, compact objects (Hilker et al. 1999, Phillipps et al. 2001) with radii of a few hundred pc, which are called ultra compact dwarf galaxies (UCD). Also in a few lenticular field galaxies (e.g. NGC 1023) Larson and Brodie (2000, 2002) found star clusters with extremely large effective radii ($r_{\text{eff}} > 7$ pc) which they call faint fuzzies.

Here we show N-body results concerning the dynamical evolution of such super-cluster aggregates. All simulations of super-clusters show a strong merging behaviour building up compact merger objects in few super-cluster crossing times (Fellhauer et al. 2002). Depending on the initial conditions of our simulations (strong or weak tidal field; massive or extended low-mass super-cluster) our resulting merger objects have similar properties like the new classes of objects above (Fellhauer \\& Kroupa 2002a/b).

But placing compact and massive super-clusters in strong tidal fields on an orbit similar to ω-Cen reveals an object which has similar prop-

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erties like the most massive globular cluster (GC) in the Milky Way. ω-Cen is not only the most massive GC, it has also some strange properties like different populations of stars (different ages and metallicities). It shows signs of rotation with a maximum rotation speed of 8 km/s (Freeman 2001).

2. Setup

We use the particle-mesh code SUPERBOX (Fellhauer et al. 2000) which incorporates a hierarchical grid architecture allowing high resolution at the places of interest.

We model the single star clusters as Plummer spheres (Plummer 1911, numerical realisation: Aarseth et al. 1974) with a Plummer radius of 4 pc, which corresponds to the mean half-light radius found for the individual young star clusters in the Antennae (Whitmore et al. 1999). \( N_0 = 262 \) star clusters with a mass range of \( 10^4 - 10^6 \, M_\odot \) following a power-law mass spectrum, \( n(M_{cl}) \propto M_{cl}^{-1.5} \), are placed in a Plummer distribution with Plummer radius \( r_{pl}^{sc} \) of 20 pc, a cut-off radius of 100 pc and a total mass of \( M_{sc} = 10^7 \, M_\odot \) representing the super-cluster. The crossing time of the super-cluster is \( t_{cr}^{sc} = 2.6 \) Myr and the velocity dispersion of the clusters in the super-cluster is \( \sigma_{sc} = 25.2 \, \text{kms}^{-1} \). Additionally we choose the sense of rotation of all clusters in the super-cluster to be the same to investigate the resulting rotation-law of the merger object. A super-cluster is expected to rotate if it forms from a contracting and locally differentially rotating inner tidal arm.

The super-cluster is placed on an eccentric orbit with perigalacticon at 2.1 kpc and apogalacticon at 7.5 kpc. The orbit is inclined such that the maximum \( Z \)-distance from the disc plane is about 2 kpc. The parameters are chosen to be representative of the knots seen to contain many star clusters in the Antennae galaxies, while the orbital inclination is motivated by the orbit of ω-Cen (Dinescu et al. 1999). The host galaxy is represented by an analytical potential, which consists of a disc modelled as a Plummer-Kuzmin potential and a spherical halo component modelled as a logarithmic potential:

\[
\Phi_{gal} = \Phi_{disc} + \Phi_{halo}
\]

\[
= -\frac{G M_{disc}}{\sqrt{R^2 + (a + \sqrt{Z^2 + b^2})^2}} - \frac{1}{2} v_0^2 \ln(R_{gal}^2 + R^2),
\]

with \( M_{disc} = 10^{11} \, M_\odot \), \( a = 3 \) kpc, \( b = 0.3 \) kpc, \( v_0 = 200 \, \text{km/s} \) and \( R_{gal} = 50 \) kpc which sums up to an almost flat rotation curve with a rotation speed of 220 kms\(^{-1} \).
It is possible to follow the evolution with a particle-mesh code that neglects dynamical effects of two-body relaxation, because the half-mass (bulk) two-body relaxation time of the single star clusters, which can be estimated from (Binney & Tremaine 1987)

\[
t_{\text{relax}} = \frac{664}{\ln(0.5N)} \left( \frac{M_{\text{cl}}}{10^5 M_\odot} \right)^{1/2} \left( \frac{1M_\odot}{m} \right) \left( \frac{r_{0.5}}{1 \text{pc}} \right)^{3/2} \text{Myr},
\]

is \(\approx 800\) Myr for a \(10^4\) \(M_\odot\) star cluster ranging up to 4.4 Gyr for a \(10^6\) \(M_\odot\) star cluster, while the merging timescale is much shorter (Fellhauer et al. 2002). Furthermore, as shown below, the resulting merger objects have relaxation times of a Hubble-time or longer.

3. Results

After the merging process is over (\(\approx 150\) Myr) the object loses mass due to tidal shaping on its eccentric orbit. Because of the collision-free code no mass-loss due to internal evolution (evaporation because of two-body encounters = two-body relaxation) is taken into account. But taking Eq. 2 the merger object has a relaxation time of about 60 Gyr, therefore mass-loss due to evaporation should be a minor effect. The bound mass of the merger object is about \(8.5 \times 10^6\) \(M_\odot\) after formation and after 10 Gyr of tidal shaping it still has \(4.5 \times 10^6\) \(M_\odot\). The mass after formation is smaller than the sum of the merged star clusters because of massloss during the violent merging process. Most of this unbound material gets spread along the orbit of the merger object but some of these stars can still be found in the neighbourhood or even within the merger object. One can see this clearly in the line-of-sight velocity dispersion. This causes a rise in velocity dispersion shortly within and beyond the tidal radius, which is due to these unbound stars which have a totally different velocity signature than the bound stars.

After 10 Gyr the half-mass radius of the object is 19 pc and the total size (tidal radius) is about 100 pc (93 at perigalacticon and 120 at apogalacticon). Fitting a King-profile to the surface density distribution gives a core radius (= effective or half-light radius) of 8.5 pc and a central surface density of 9500 \(M_\odot/\text{pc}^2\) which corresponds to a central surface brightness (taking \(M/L = 3.0\)) of about 18 mag./arcsec\(^2\). A better fit to the data would be an exponential profile in the inner part with a power law profile with power index \(-5.6\) for the outer part. The 3D velocity dispersion of the merger object is about 24 km/s, while the line-of-sight velocity dispersion is about 14 km/s. The maximum rotation velocity of our object is 4 km/s.
Table I. Properties of $\omega$-Cen.

| Property                           | Value                  |
|------------------------------------|------------------------|
| galactocentric distance            | 6.7 kpc                |
| total luminosity $M_V$             | $-10.3$ Mag.           |
| total mass ($M/L = 4.1$)          | $5.1 \cdot 10^6$ $M_\odot$ |
| core radius                        | 3.7 pc                 |
| half-mass radius                   | 6.1 pc                 |
| tidal radius                       | 64.6 pc                |
| velocity dispersion                | 21.9 km/s              |
| maximum rotation velocity          | 8 km/s                 |
| metallicity                        | -1.62 (mean); -1.8 to -0.8 |
| age                                | 15 Gyr; age spread 4 Gyr |

4. Outlook

Although our best model does not yet have exactly the same properties as $\omega$-Cen, we think that we are on the right way to solve the puzzle of the origin of $\omega$-Cen. Our merger object is still not heavy enough and too large compared to $\omega$-Cen.

A possible explanation of the age and metallicity spread and the high rotation speed could be an underlying population of old stars stemming from a dissolved dwarf galaxy plunging into the Milky Way and causing the star burst and the formation of the super-cluster, which leads to the building of $\omega$-Cen in the above described scenario. This scenario is being studied with numerical experiments that have started recently.

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