The role of galaxy mergers on the evolution of star clusters

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Abstract

- Interacting galaxies favor the formation of star clusters but are also suspected to affect their evolution through an intense and rapidly varying tidal field.
- They monitor the structure and mass evolution of a population of clusters in a galaxy major merger using N-body simulations.
- On the long timescale the merger only modifies the clusters orbits.
- The tidal perturbations of the galactic collisions are too short lived and not strong enough to significantly influence the structure and dissolution of realistically dense/massive star clusters.

Previous Work

- An evaporating/dissolving cluster in a galaxy beyond the local group leaves no clear observational signature for us to find.
- Idealized galaxies with an analytical description of the tides has been intensively used to improve our understanding of the dynamical evolution of non-isolated clusters (e.g. Webb et al. 2013).
- A semi-analytical description of star clusters in a cosmological context allowed to probe the effect of complex tides on stellar populations (e.g. Kruijssen et al. 2011).

Relevance

- Renaud, Gieles & Boily (2011, hereafter RGB11) merged the two approaches by integrating any tidal effect into N-body simulations of star clusters, allowing for the exploration of the evolution of star clusters within complex, time-dependent galactic potentials, like those of mergers.
- This work applies that method to a large number of clusters in rapidly-varying tidal fields.

Methodology

- This work uses the NBODY6 code (Nitadori & Aarseth 2012).
- First, a simulation of a galaxy is performed: each particle represents a possible star cluster. One particle is followed along its orbit and the associated tidal tensors are extracted.
- In a second simulation, NBODY6tt creates a star-by-star N-body model of a star cluster, reads the tensors, interpolates them in time, computes the tidal forces at the positions of the N stars of the cluster and adds them to the internal gravitational force due to the $N - 1$ other stars.

Some characteristics

- Tidal tensors were computed using a tree-code along several orbits in a purely gravitational model of NGC 4038.
- The clusters half-mass densities vary from 10^3 to 10^4 $M_\odot$ pc^{-3}, which makes the models comparable in mass and density to Westerlund 1, NGC 3603 or even the Arches for the densest ones.

Drawbacks

- In each cluster, all stars have been given the same mass (1 $M_\odot$), to avoid mass segregation and stellar evolution effects and to focus on the tides.
- Initial positions and velocities of the stars were based on a virialised Plummer (1911) model.
- Stellar formation and evolution are not considered.

Results I: Individual Cases

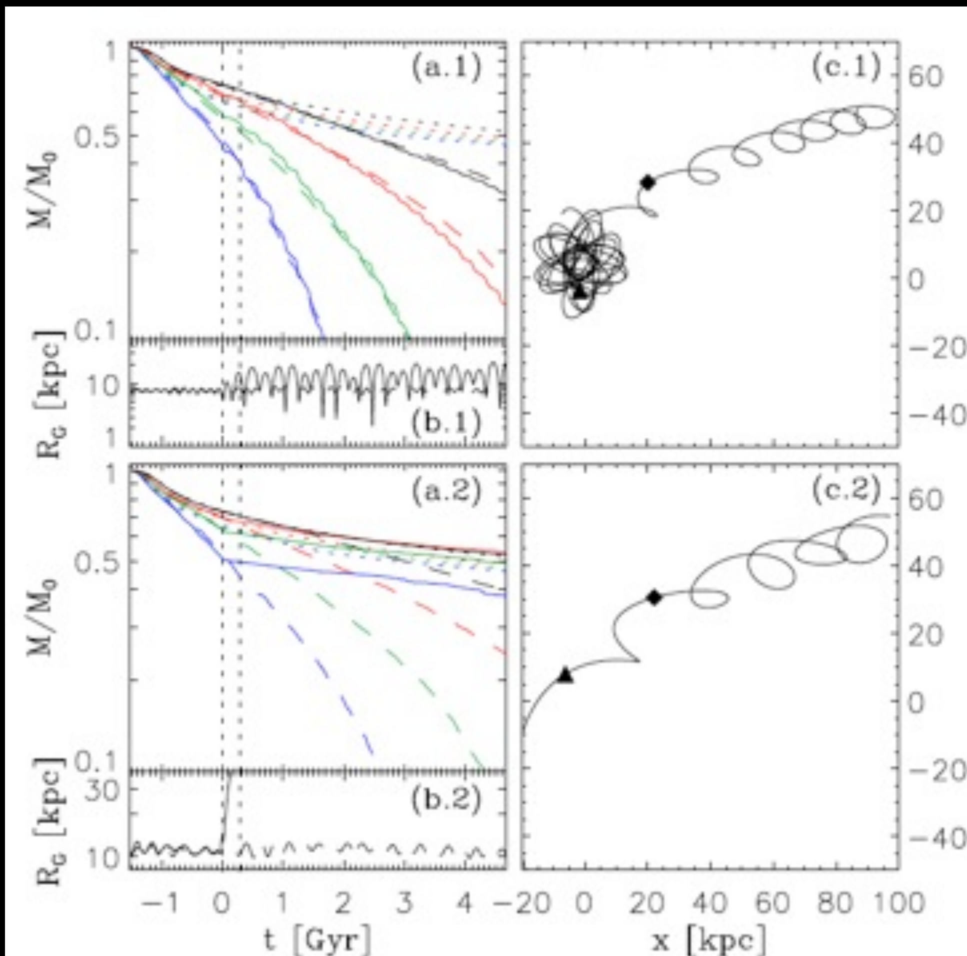

Figure 1. Evolution of clusters along two orbits arbitrarily selected. Panels (a): normalized mass of the clusters, without tides (dotted curves), in the isolated galaxy (dashed) and in the merger (solid). The colour indicates the initial mass of the cluster (4000, 8000, 16000 and 32000 stars for blue, green, red and black respectively, all with an initial virial radius of 1 pc). Vertical dotted lines mark the galactic pericentre passages; the second one corresponds to the final coalescence. Panels (b): Galactocentric distance. Panels (c): Orbit of the clusters in the orbital plane of the merger. (The clusters start from the top-right corner. A diamond and a triangle indicate the position of the clusters at the times of the two galactic collisions. See Renaud et al. 2009 for details on the galactic simulation.)

Results II: Mass-loss

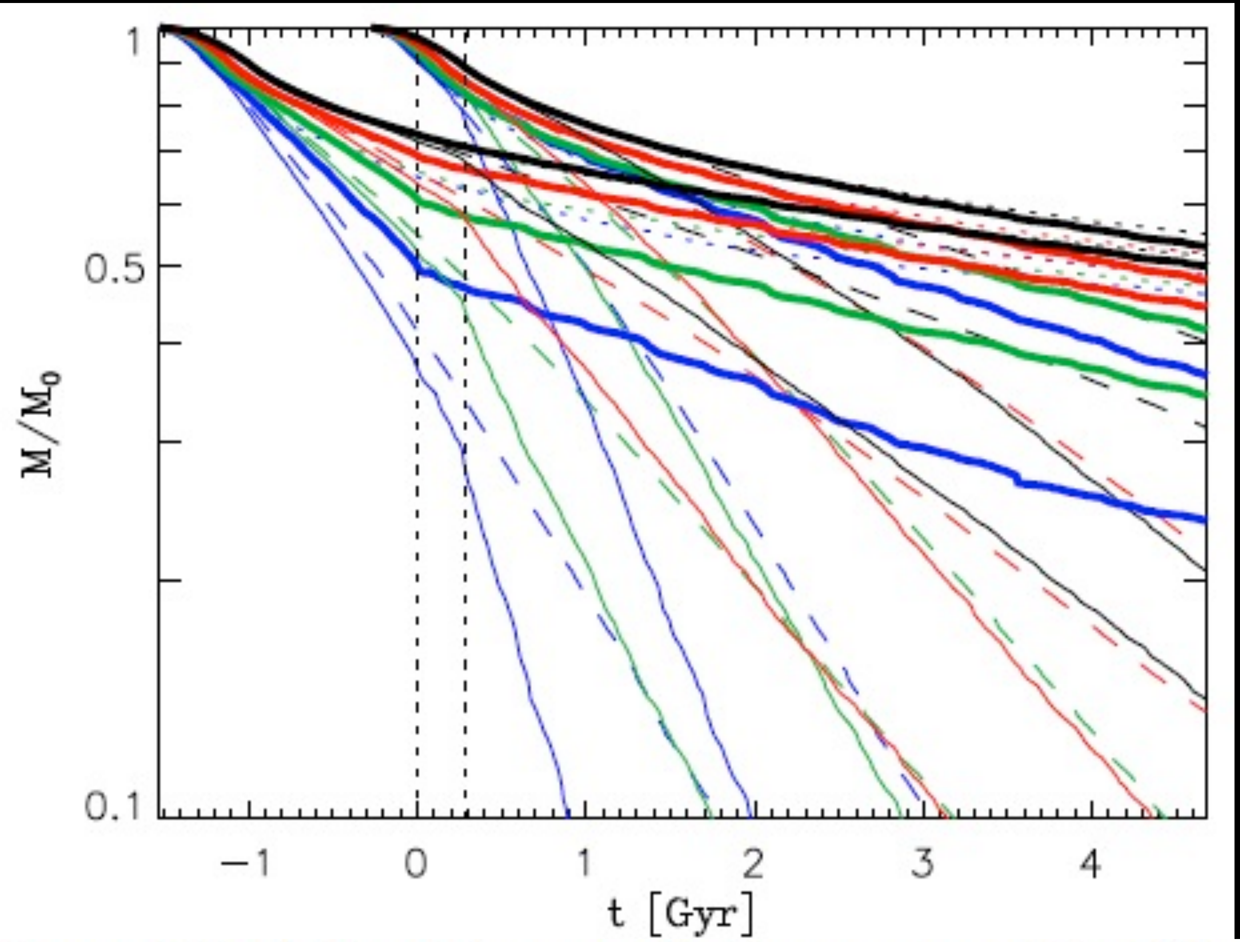

Figure 2. Evolution of the normalized mass averaged by telling apart the clusters ejected to large galactocentric radii by the galaxy-galaxy collision (solid thick line) from those remaining close to the center (solid thin line). The dashed lines represent all the clusters in the isolated disc and the dotted lines denotes the mass-loss without tides. As in Fig. 1, the colour indicates the initial mass of the cluster.

Results II: Mass-loss

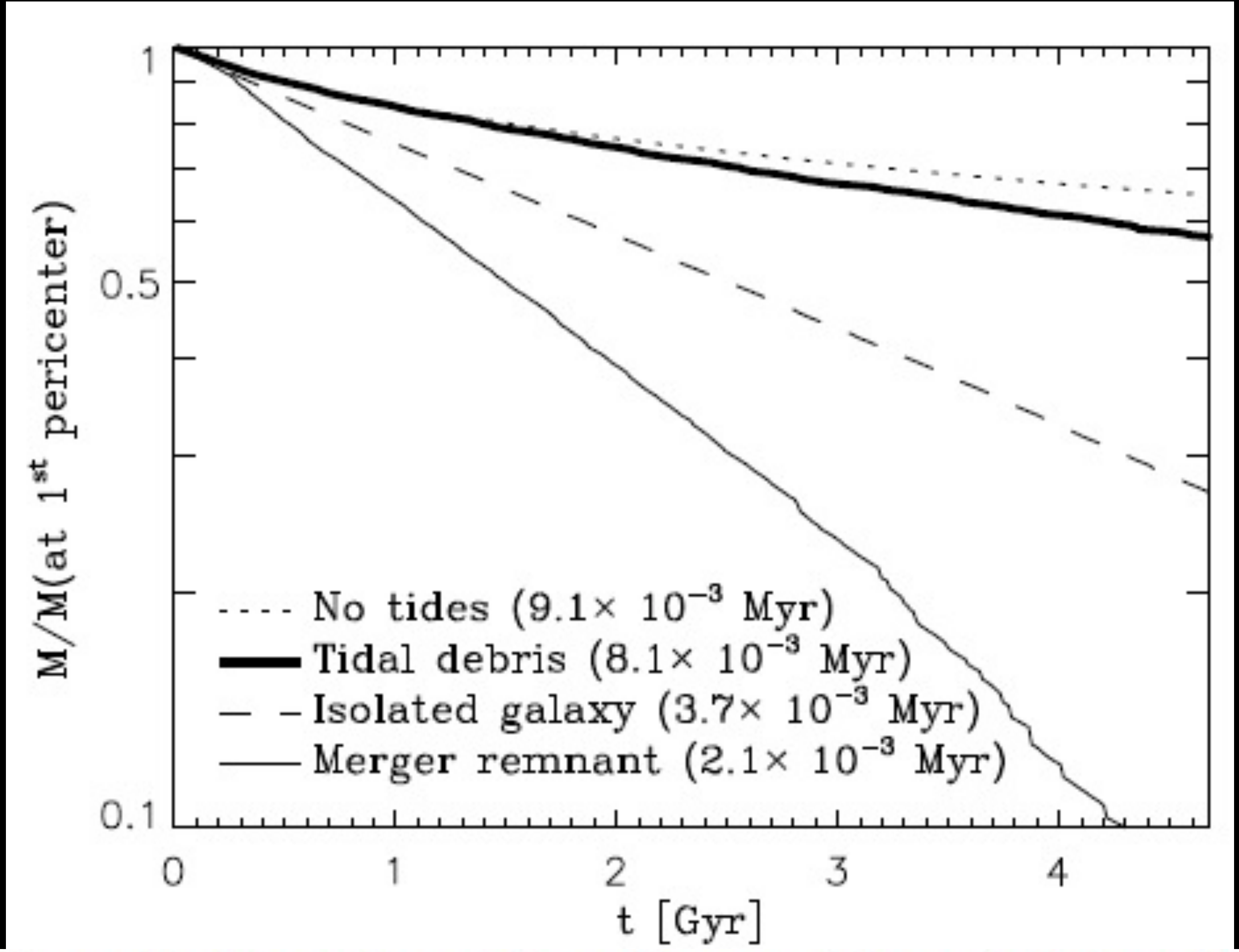

Figure 3. Dissolution of the entire population of clusters (all densities, all birth epochs and all orbits) for our four families of tidal histories since the first galactic collision. The mass is normalized to its value at the first pericenter passage. The number in parenthesis is the characteristic timescale τ of the exponential decay of the mass ($M \propto e^{-t/\tau}$).

Results III: Structural Evln

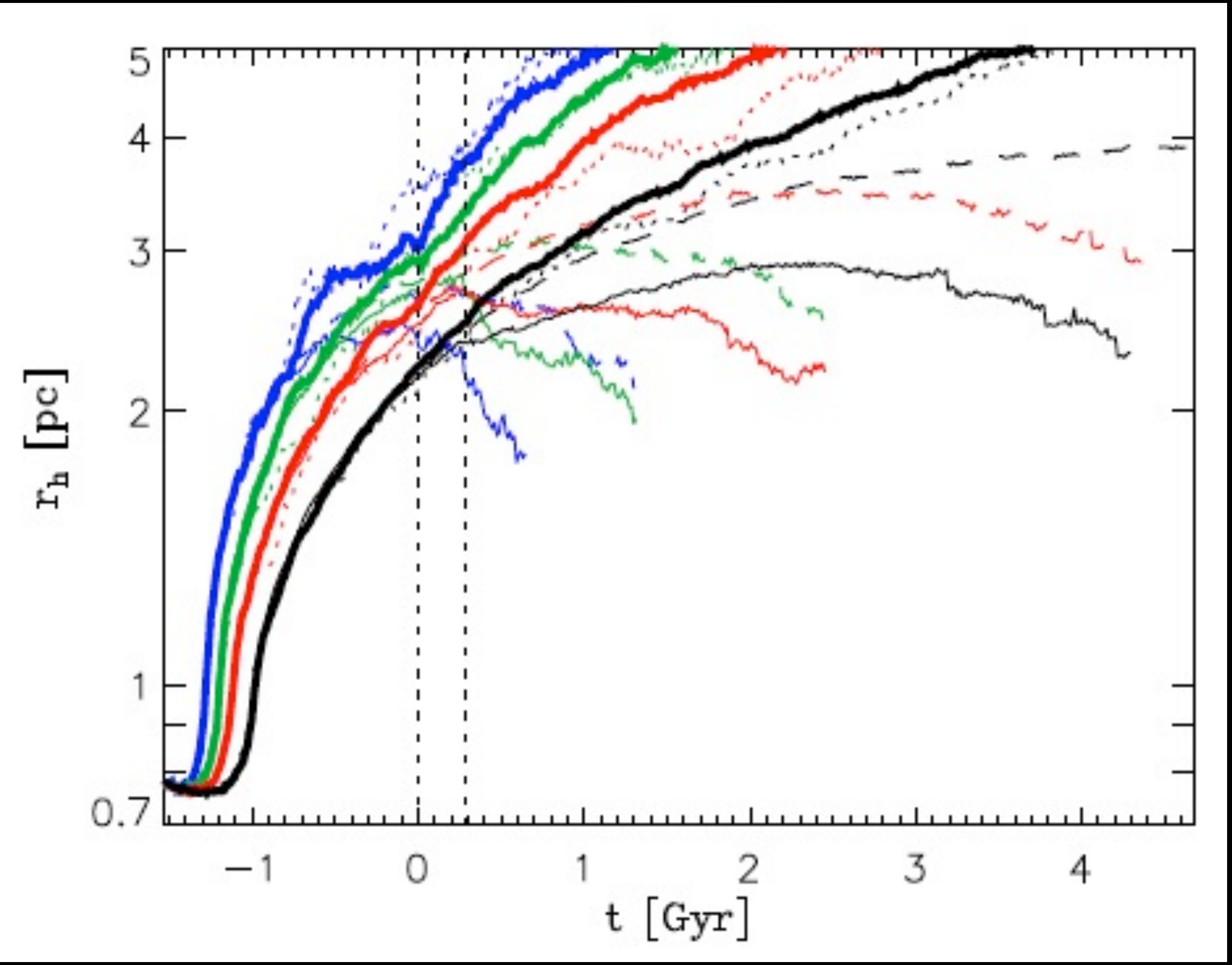

Figure 4. Evolution of the half-mass radius of our clusters. The curves are stopped when the corresponding average normalized mass is less than 0.15, making the half-mass radius very Poisson-noisy. Colors and linestyles are as in Fig. 2.

Results III: Structural Evln

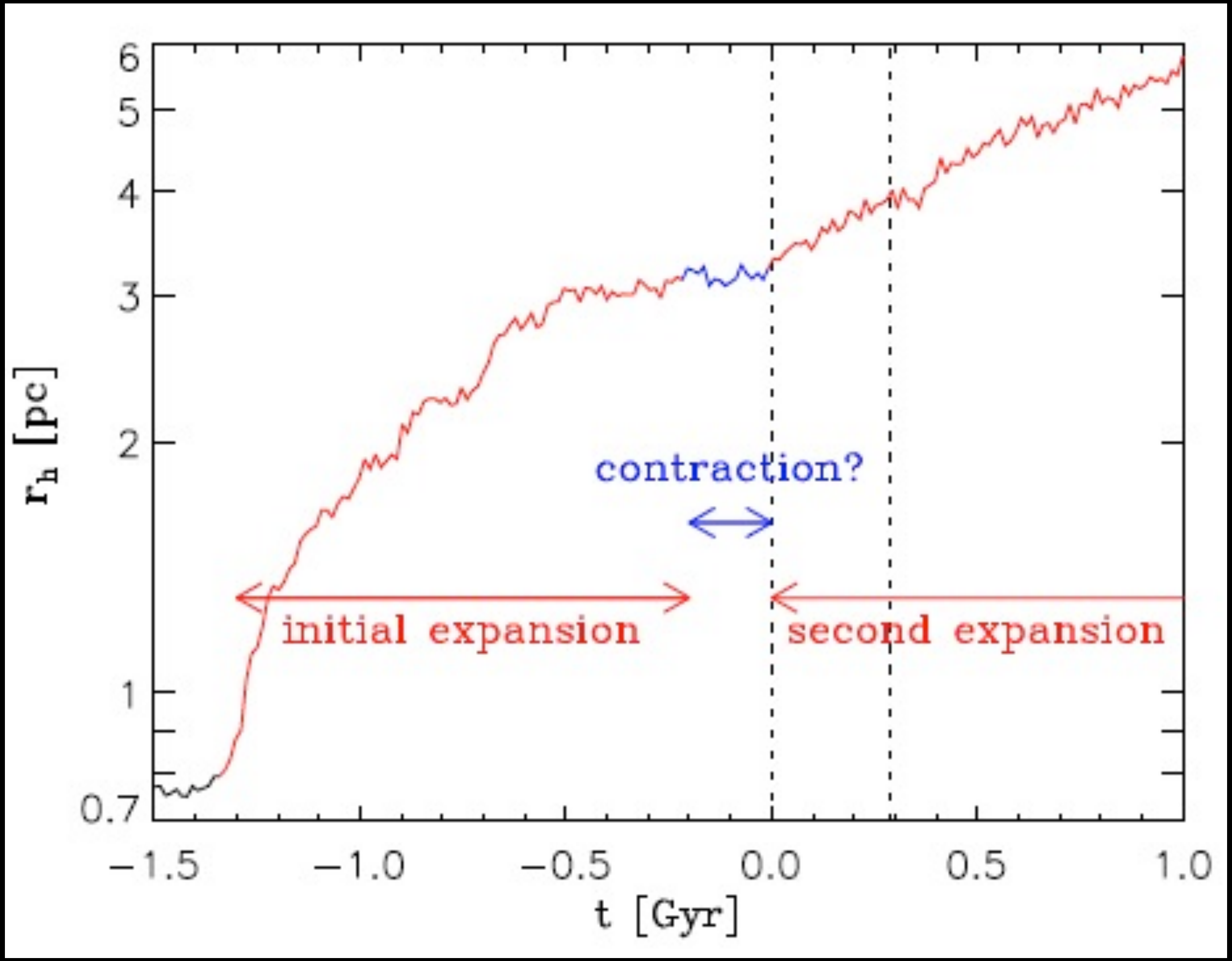

Figure 5. Evolution of the half-mass radius of a cluster sent in the tidal debris (one cluster of the group shown by the blue solid thick line in Fig. 4). The new tidal regime starting at $t = 0$ allows for a resumption of the expansion phase and leads to an extended cluster.

Conclusions

- The mass-loss rate of the clusters that remain bound to the merger remnant is higher than before the final coalescence phase. The clusters populating the tidal debris survive much longer, similarly to tide-free cases.
- The two-phases evolution of expansion and contraction of a cluster also exists in complex, time-varying tidal fields. The structural evolution does not strongly deviate from that of a constant tides case.
- At the time of the galactic collisions, the tides are too weak (although they reach their maximum intensity) and too short-lived ($< 10^{7-8}$ yr) to have a significant influence on the clusters. However, by modifying the orbit of the clusters, they indirectly affect their mass-loss over long timescales.