MOCCA-SURVEY Database I: Dissolution of tidally filling star clusters harboring BH subsystem

Mirek Giersz

Nicolaus Copernicus Astronomical Center, Polish Academy of Sciences
Warsaw, Poland

mig@camk.edu.pl

with
Abbas Askar, Long Wang, Arkadiusz Hypki, Agostino Leveque and Rainer Spurzem

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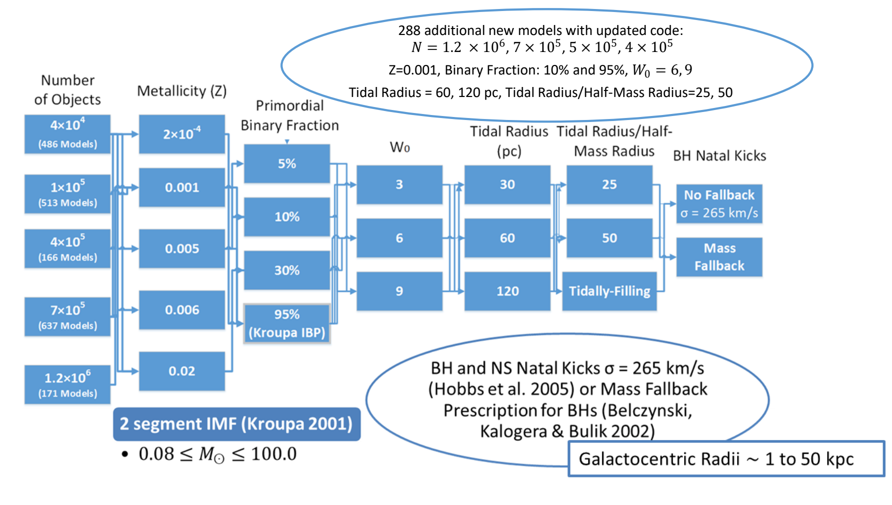
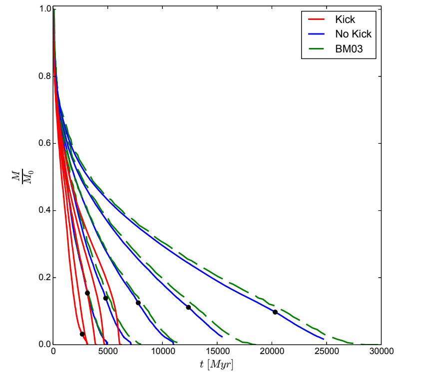
MOCCA-Survey Database I



Cluster Dissolution



Credit: Contenta et al. (2015)

Chernoff & Wweinberg 1990, Weinberg 1993, Fukushige & Heggie 1995, Gnedin & Ostriker 1997, Baumgardt & Makino 2003, Banerjee & Kroupa 2011, Whitehead et al. 2013, Contenta et al. 2015, Wang et al. 2019

TWO TYPES OF CLUSTER DISSOLUTION:

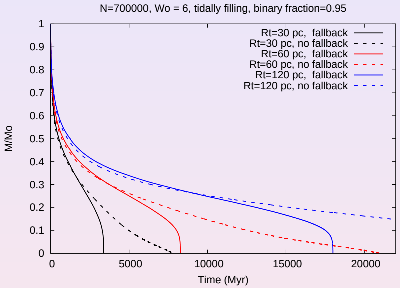
Slow or 'skiing' - relaxation-driven mass loss.

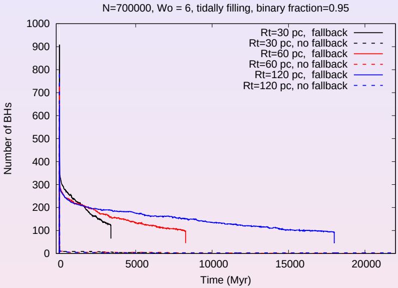
Abrupt or 'jumping' - mass loss connected with stellar evolution. Attributed to the loss of dynamical equilibrium within the cluster. No core collapse phase of evolution.

PHYSICAL PROCESSES INFLUENCING THE DISSOLUTION:

tidal field and type of the Galactic orbit, form of the Galactic potential and tidal shocking, primordial binary population, properties of the dark remnants in star cluster, crossing time-scale and type of IMF.

Cluster Dissolution



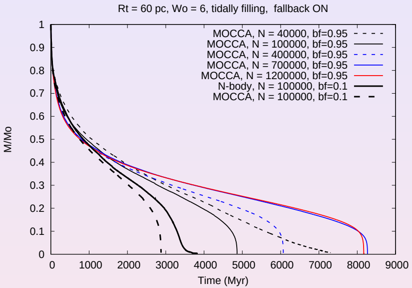


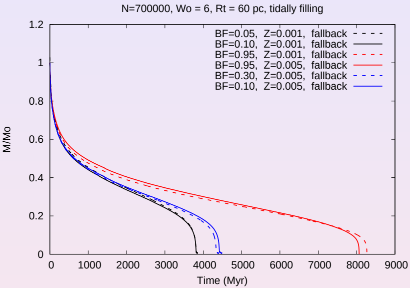
Models which retain a larger number of BHs (mass fallback ON) dissolve faster than models which kick out most BHs (mass fallback OFF). This is opposite behaviour than for NSs. Models with mass fallback enter the post-core collapse phase and yet show the fast dissolution feature.

Black hole subsystem (BHS) survives until the cluster dissolution.
BHS evolution has a strong influence on the final stages of the cluster dissolution

ONLY TIDALLY FILLING MODELS SHOW FAST CLUSTER DISRUPTION.

Cluster Dissolution





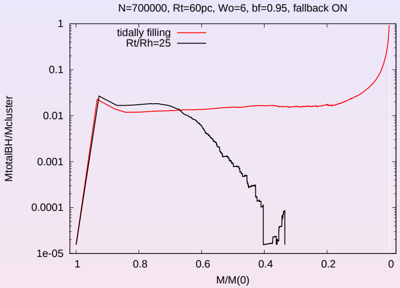
The larger the number of objects, or the larger the binary fraction, or the smaller the cluster concentration the longer the abrupt dissolution time. The dependence on metallicity is very small, as expected. For the model with N=40000 the cluster does not show the feature of abrupt dissolution - the BHS has too few BHs.

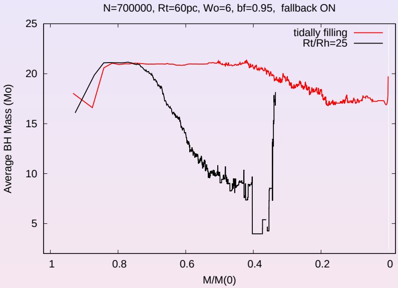
NBODY6++GPU simulation done by Long Wang confirms the MOCCA simulations.

The same initial conditions as in MOCCA

Small differences are connected with slightly different BSE code versions.

Cluster Dissolution

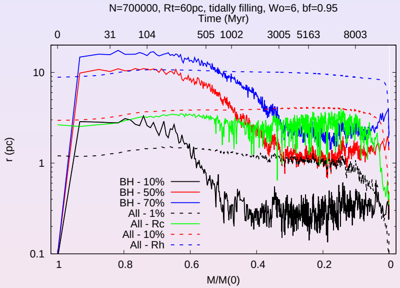


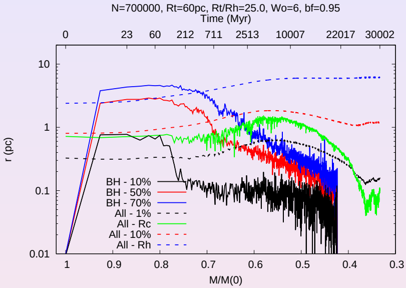


For a tidally filling cluster the BHS very slowly evolves - the number of BHs is kept nearly constant and the average BH mass is only slightly decreasing. For tidally under-filling models the evolution is much faster and BHS properties are quickly changing.

Cluster dissolution starts when the cluster mass is about 20% of its initial mass and the mass of the BH subsystem is about a few % of the cluster mass.

Cluster Dissolution





The BHS collapses at about 1 Gyr, but the mass segregation is going on up to about 3 Gyrs

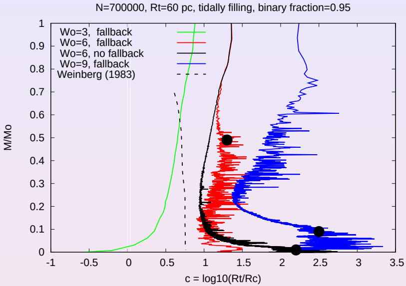
Balanced evolution up to about 7 Gyrs

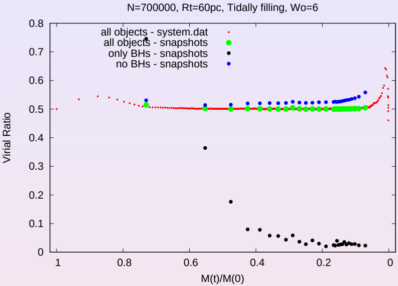
Then lost of equilibrium. the BHS seems to decouple from the rest of the clusters and dissolves.

The BHS evolves according to Breen & Heggie (2013) theory - balanced evolution with the whole cluster

The BHs in BHS are slowly "kicked out" on the half-mass relaxation time scale.

Cluster Dissolution





Strong dependence on the Wo:

Wo=3 - dissolution dominated by mass loss,

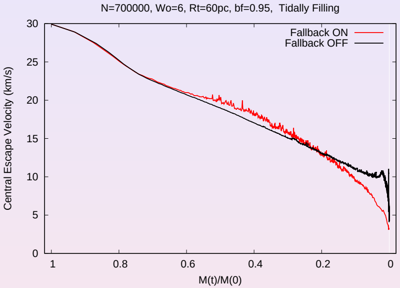
Wo=6 - dissolution dominated by the BH Subsystem. Early core collapse connected with BH mass segregation.

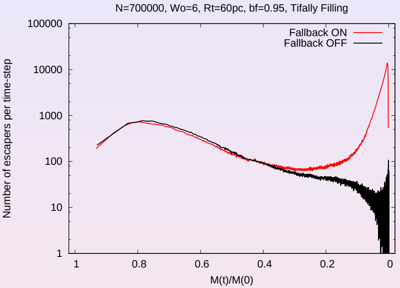
Wo=9 - IMBH formation.

Dissolution - lost of equilibrium

Cluster dissolution for a tidally filling model is connected with the decoupling of the BHS from the rest of the cluster and the loss of dynamical equilibrium by other objects. Luminous objects become hot. BHS stops to collapse further at around the mass fraction equal to about 0.2 - slow increase of the BHS Lagrangian radii. The BHS starts to disrupt itself.

Cluster Dissolution





Cluster is constantly tidally stripping and the internal cluster structure is not strongly changing, so the escape velocity becomes smaller and smaller.

More and more objects can be kicked out from the BHS and also from the cluster

Smaller central escape velocity means also smaller central velocity dispersion and accordingly, larger rate of dynamical interactions and also larger escape rate.

CLUSTER LOSES ITS DYNAMIC EQUILIBRIUM

Conclusions

Tidally filling clusters with BHS in the center can show abrupt dissolution, provided that initially the King concentration parameter is moderate and BHS can survive until the cluster death. The cluster dissolution is controlled by a strong energy generation in dynamical interactions inside the BHS and strong tidal stripping - sudden loss of dynamical equilibrium and decoupling of BHS from the rest of the cluster.

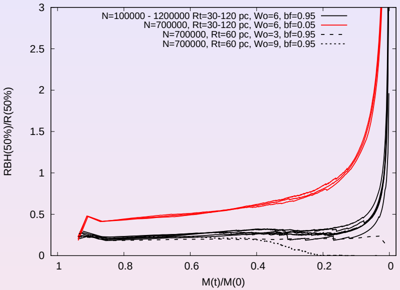
Such mechanism should also operate for tidally under-filling clusters with top-heavy IMFs.

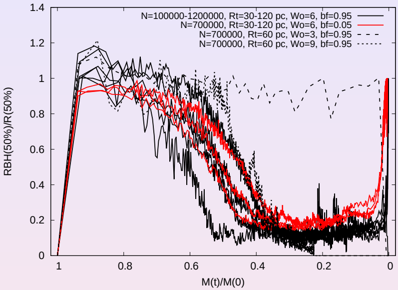
Just before the abrupt dissolution, a cluster will look like a 'dark cluster' as described by Banerjee & Kroupa 2011, which is a different kind of 'Dark Cluster', harbouring an IMBH with mass comparable to the cluster mass Askar et al. 2017.

The fast dissolution of massive tidally filling clusters can have strong influence on the estimated rate of BH-BH mergers from GCs.

If clusters are born tidally filling and close to the Galactic center, then we can expect a lot of free floating BHs in the Galactic Bulge.

Cluster Dissolution





$$\frac{R_{h-BHS}}{R_h} = \frac{M_{BHS}^{3/5} m_{BH}^{2/5} ln^{2/5} \Lambda_{BH}}{M^{3/5} m^{2/5} ln^{2/5} \Lambda}$$

(Breen & Heggie 2013)

Perfect confirmation of the Breen & Heggie theory

Small differences in the curves level off are connected with more complicated nature of real systems compared to only two-component system and Henon's principle