MOCCA Survey Database I. - Projects. What Next?

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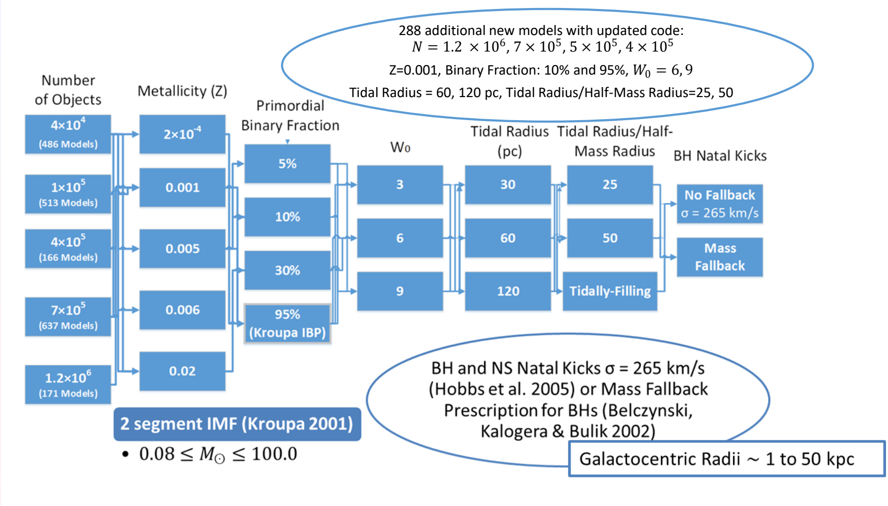
Outline of the presentation

OUTLINE

- **MOCCA Survey Database I** - Short description;
- **Ongoing Projects** - Projects concerning properties of different populations of compact objects;
- **New Version of the MOCCA Code** - BSE and IBP upgrades, better determination of the system parameters when an IMBH is present, better info about different populations of objects, multiple stellar populations, residual gas, new FewBody code with GR and tidal dissipative effects, two-body dissipative effects, hierarchical systems.

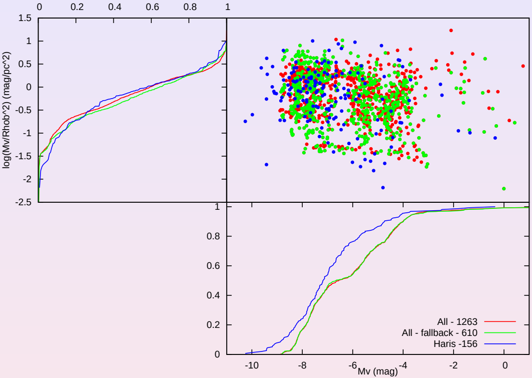
MOCCA-Survey Database I



MOCCA Survey Database cont.

OUTPUT

- Global parameters - cluster and population of objects
- Snapshot every 100 Myr
- Interactions - all types separately
- Escapers
- Restarts - all types of interactions

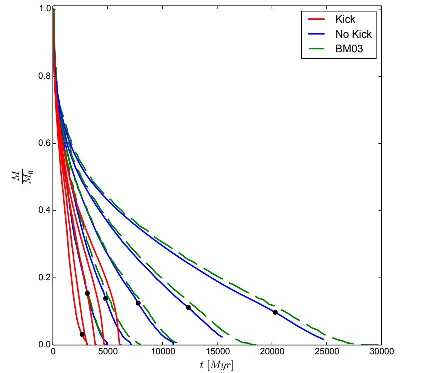


Models for the Survey were not selected to match the observed Milky Way GCs.

Any combination of global observational properties of GCs cannot be used to clearly distinguish between different cluster models because there is a strong degeneracy with respect to the initial conditions.

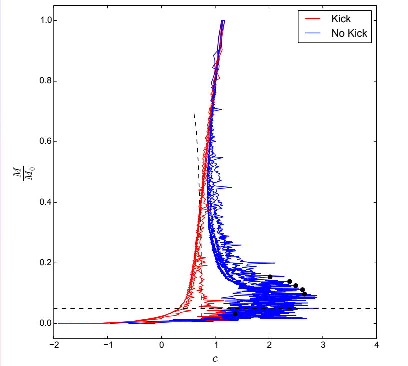
It can be assumed that the Survey cluster models are representative of the MW GC population.

NSs and BHs Retention



Credit: Contenta et al. (2015)

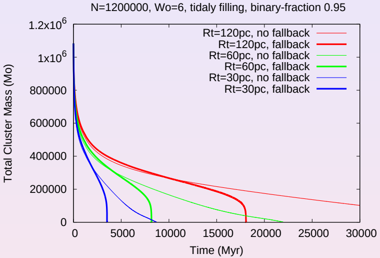
The retention (or not) of NSs can have a very strong influence on GC global evolution.

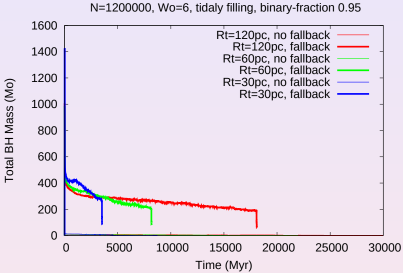


Credit: Contenta et al. (2015)

Clear distinction between models dominated by the stellar evolution mass loss or by the relaxation

NSs and BHs Retention

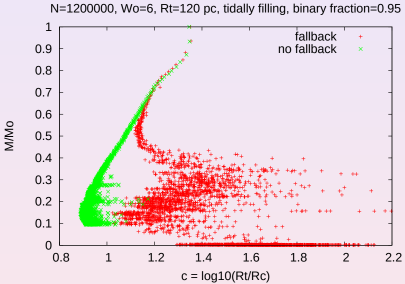


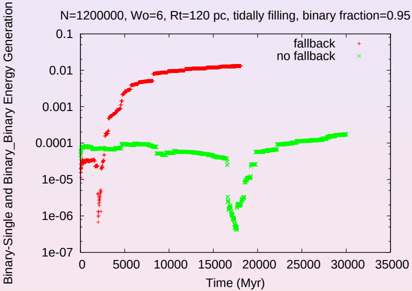


Models which retain larger number of BHs (mass fallback ON) dissolve faster than models which kick out most BHs (mass fallback OFF). This is opposite behavior than for NSs. Models with mass fallback enter the post-core collapse phase and yet show the fast dissolution feature.

BH-subsystem formation in the cluster centers. Very efficient energy generation in dynamical interactions between massive BHs, which for tidally filling systems leads to the unstable mass loss.

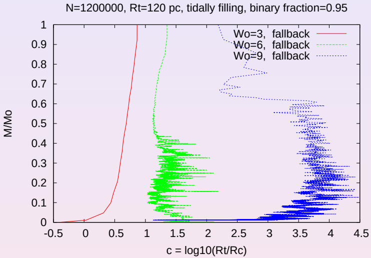
NSs and BHs Retention

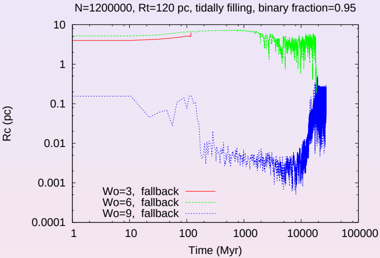




Energy generation two orders of magnitude larger in the model with BH Subsystem!

NSs and BHs Retention





Strong dependence on the Wo:

Wo=3 - dissolution dominated by mass loss,

Wo=6 - dissolution dominated by the energy generation in BH dynamical interactions,

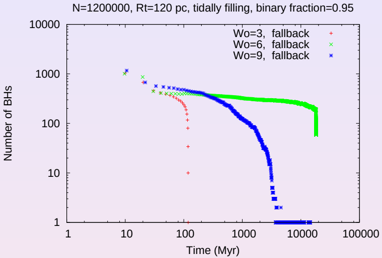
Wo=9 - IMBH formation.

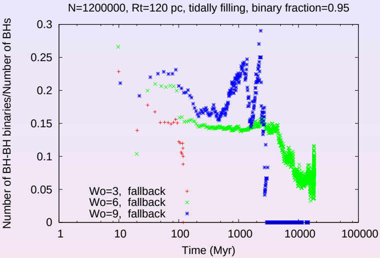
The smaller the tidal radius the faster the cluster evolution - shorter relaxation time.

The smaller the binary fraction the faster the cluster evolution - shorter relaxation time.

ONLY TIDALLY FILLING MODELS SHOW FAST CLUSTER DISRUPTION.

NSs and BHs Retention





Relatively large number of BHs coexists with IMBH and it is, on a timescale of about a few Gyr, depleted by interactions with IMBH.

For Wo=6 model the BH Subsystem is slowly depleted.

BH binary fraction at the beginning stays relatively large and quickly drops at the time of the core collapse.

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 small BH-BH merger rate AND A LOT OF FREE FLOATING BHs IN THE GALACTIC BULGE

Microlensing on BHs could provide a useful observational constraint.

BH-BH Mergers: Spins and Recoil Kicks

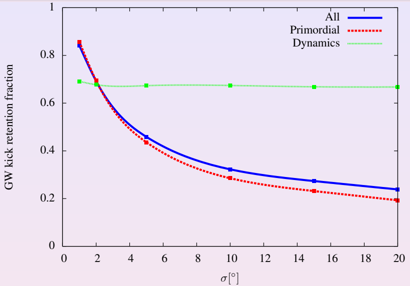
Mergers only inside GCs and only due to gravitational wave emission: primordial - 3400, dynamical 1050

The magnitude of GW kick velocity calculated according to Baker et al. (2008) - function of BH mass ratio, spin amplitudes and their alignment

BH merger products which were kicked out from the system were also taken out from the further retention fraction computation - only 350 dynamical mergers left. BH mergers which stay in the system get spin calculated according to Rezzolla et al. (2008)

Primordial - nearly aligned, Dynamical - randomly distributed

Credit: Jakub Morawski



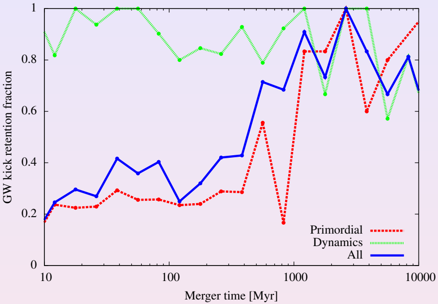
Three different assumptions about BH spins:

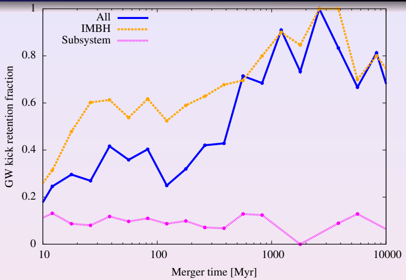
random, according to Belczynski et al. (2017), BH mass and Z dependence, and constant - 0.5

The overall BH retention fraction does not strongly depend on the assumed BH spin distribution,.

Good agreement with earlier semi-analytic and analytic predictions

BH-BH Mergers: Spins and Recoil Kicks





The retention fraction for Dynamical binaries is about 0.8 and is a consequence of very small mass ratio

The retention fraction for Primordial binaries substantially increases after 1 Gyr due to decrease of the mass ratio

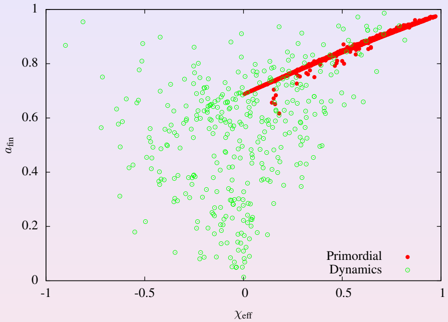
The larger the cluster concentration the larger the retention fraction

Retention fraction for models with BH Subsystems is very small - 0.1

The time evolution of the retention fraction for models with IMBHs is a consequence of the evolution of retention fractions for Primordial and Dynamical binaries

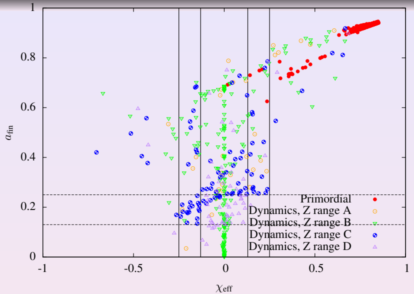
Small retention fraction for models with BH Subsystems does not spoil the IMBH formation scenario

BH-BH Mergers: Spins and Recoil Kicks



Tight relation between χ_{eff} and a_{fin} for Primordial mergers - spins nearly aligned and mass ratio close to 1

For Dynamical interactions the observed shape is a consequence that the mass ratio is very small and $\chi_{eff} \approx a_{fin} cos(\theta)$



The "cross" shape is a consequence of the Z dependence of the BH spins and small mass ratios for merging BHs.

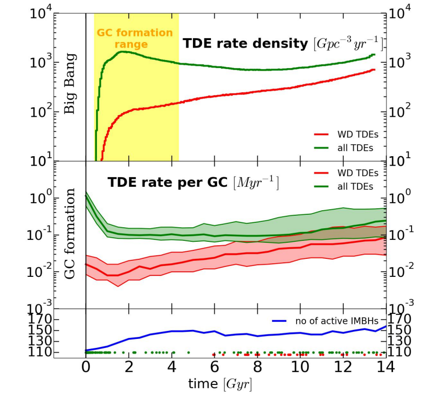
Limited range for Primordial mergers is a consequence of high spin for low BH masses

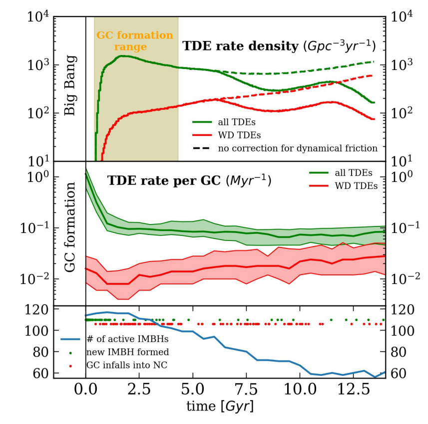
For larger mass ratios the "cross" shape will still be there but smeared. Effective spin will be rather small.

Ongoing Projects - MOCCA Survey Database

- Evolution of GCs with BH Subsystem and IMBHs - Can IMBHs and BH Subsystems be identified on the bases of global GCs observational properties? (Manuel Arca-Sedda, Abbas Askar, Jangsuk Hong, Jakub Morawski)
- MSP, CVs, TDEs and delayed SNe - Properties in NSC and in GCs (Manuel Arca-Sedda, Giacomo Fragione, Diogo Belloni, Jakub Klencki, Abbas Askar, Arkadiusz Hypki, Mónica Zorotovic, Matthias Schreiber, Teresa Jerabkova)
- Blue Stragglers and other types of binaries - Possible constrains on the Initial Binary Population (Nathan Leigh, Mirco Simunovic, Abbas Askar, Diogo Belloni, Arkadiusz Hypki)
- Mass Function Evolution (Holger Boumgardt, Sollima Antonio)
- Reanalysis of all 3- and 4-body interactions with Fewbody code with tidal and GW dissipative effects (Johan Samsing, Alessandro Trani, Mario Spera, Arkadiusz Hypki, Abbas Askar)

Tidal Disruption Events with IMBH

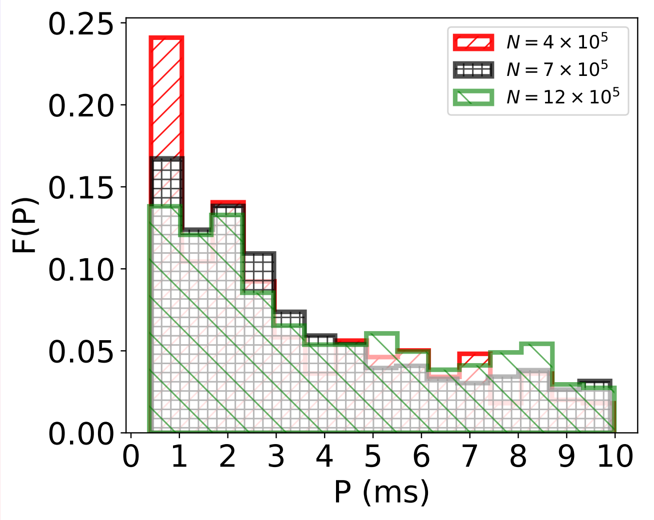




Collaborators: Jakub Klencki, Nathan Leigh, Manuel Arca-Sedda, Giacomo Fragione, Abbas Askar, Arkadiusz Hypki

- WD-IMBH type - 344755, MS-IMBH type 750753, Other-IMBH 42934.
- Most TDEs are formed in massive GCs with relatively small Galactocentric distances. Some of GCs can, in a few Gyrs, migrate to the Galactic center and then TDEs will have different distribution.
- Present day TDE rate density is smaller by factor of 3-4 when the evolution of GCs in the galactic environment is taken into account.
- Number of "active" GCs in which TDEs are happening is by factor of about 2 smaller that at the beginning.

Millisecond Pulsars



Credit: Giacomo Fragione

MOCCA - Work in Progress

- New Fewbody code with GR and tidal dissipation effects and background gas - Mario Spera, Johan Samsing, Alessando Trani, Taeho Ryu, Nathan Leigh, Aaron Geller, Abbas Askar, Diogo Belloni, Arkadiusz Hypki
- Upgraded population synthesis codes: BSE, MOBSE, StarTrack, SEVN, Binary-c and Simulation Codes - Mario Spera, Michela Mapelli, Nicola Giacobbo, Krzysztof Belczynski, Grzegorz Wardzinski, Arkadiusz Hypki, Robert Izzard, Diogo Belloni, Abbas Askar, Jarrod Hurley, Melvin Davies, Manuel Arca-Sedda, Long Wang, Rainer Spurzem, Ross Church
- Multiple Stellar Populations - Arkadiusz Hypki, Abbas Askar, Diogo Belloni, Agostino Laveque
- Improvements in the code logical flow, initial binary properties and better description of systems with IMBHs - Arkadiusz Hypki, Diogo Belloni, Pavel Kroupa, Abbas Askar, Agostino Laveque
- Hierarchical Systems - Arkadiusz Hypki