Preliminary study of Extra-Galactic globular clusters and embedded gas globular clusters with MOCCA

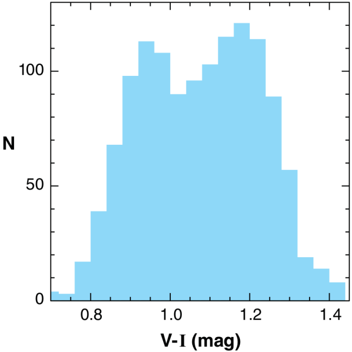
Agostino Leveque

PhD at Nicolaus Copernicus Astronomical Center (CAMK)

4^{th} Sverre Aarseth N-body meeting
December 4th 2019, Prague

ExtraGalactic Globular Clusters: color bimodality

The most interesting properties of Extra Galactic Globular Clusters (EGGCs) has been the discovery of color bimodality, as it has been shown in recent spectroscopic studies.
They can be used as a tracer of star formation histories of early-type galaxies and the galaxy-galaxy interactions.

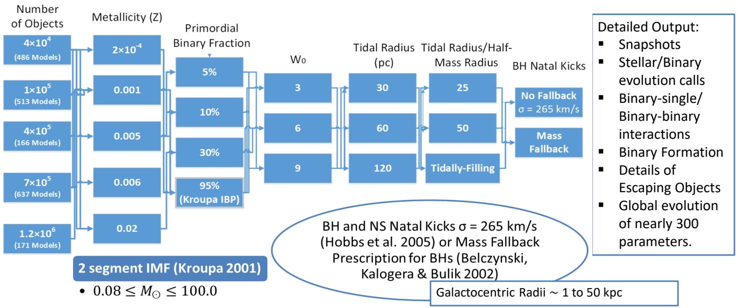


Credit to Larsen et al, 2001

The peaks correspond to $[Fe/H] \sim -1.5$ and -0.5

MOCCA-Survey Database I Project

- Database of nearly 2000 GC models sampling the following initial parameter space



Credit to: Askar et al., 2017

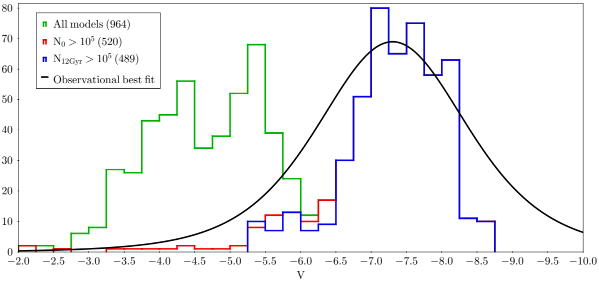
Dynamical state: model selection

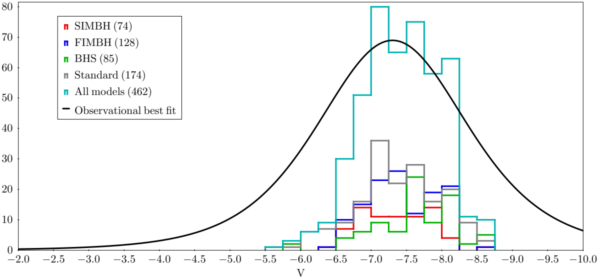
We selected models according to their dynamical state at 12 *Gyr*, dividing in four groups:

- **Fast scenario** (FIMBH), presence of an IMBH (BH with masse > 150 $M_{\odot}$) formed before 1 *Gyr* (Giersz et al., 2015);
- **Slow scenario** (SIMBH), presence of an IMBH formed after 1 *Gyr* (Giersz et al., 2015);
- **Black Hole Subsystem** (BHS), presence of a BH subsystem ($N_{BH} > 40$);
- **Standard**, absence of an IMBH and of a BHS.

We obtained the integrated absolute magnitude of the entire GC for five different optical bands (U, B, V, R, I) using the FSPS code. We did not consider any absorbtion or reddening.

Results: V distribution

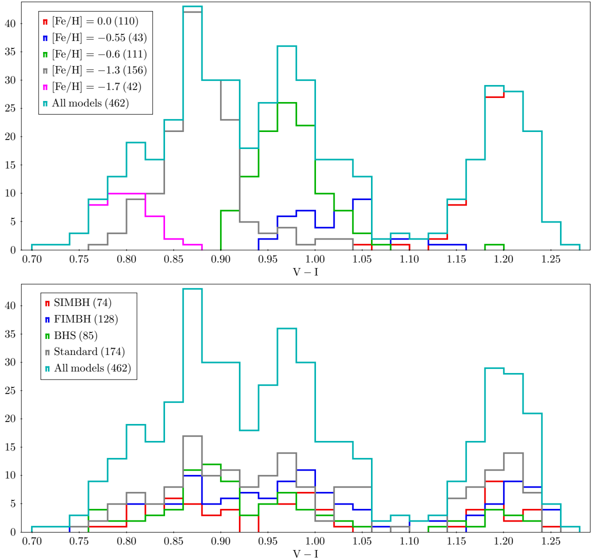




Lack of simulations in our sample as expalained in Askar et al. (2017.)

All the dynamical state models have a similar distributions.

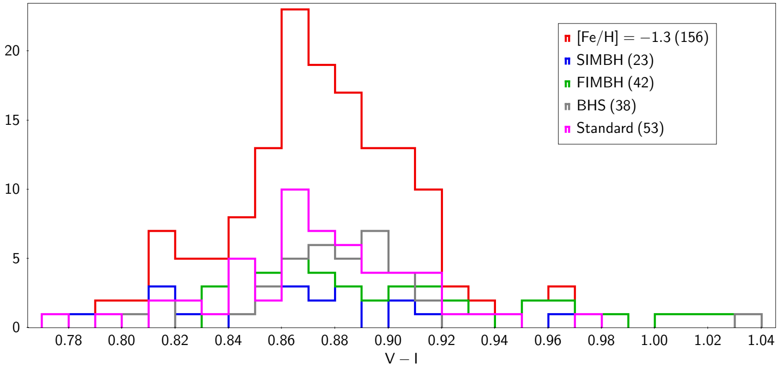
Results: $V - I$ color distribution



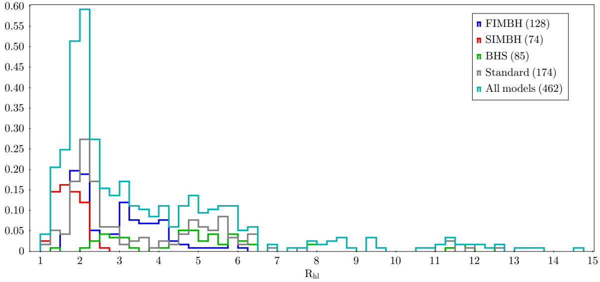
Metallicity is the main feature to describe the $V - I$ color distribution, but it is not the only one.

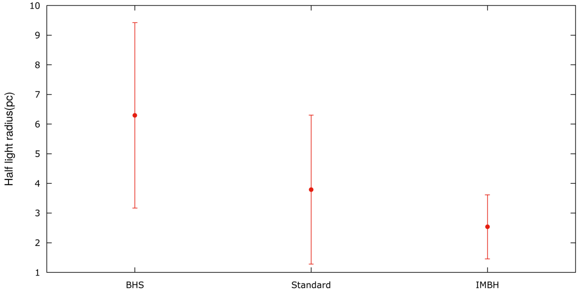
There is no dependence on the type of the model for $V - I$ color.

V-I distribution for $[Fe/H] = -1.31$



Results: half-light radius distribution

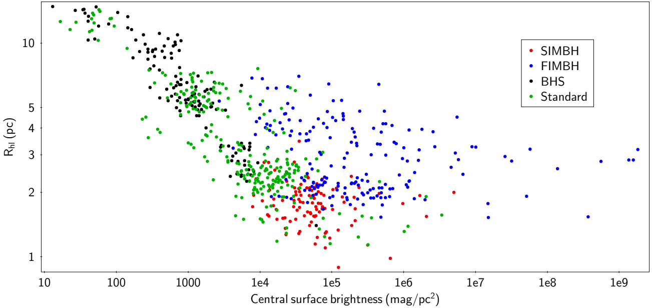


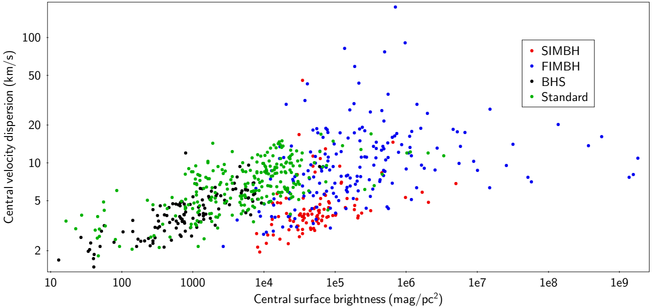


Half-light radius (R_{hl}) distribution for different dynamical state models.

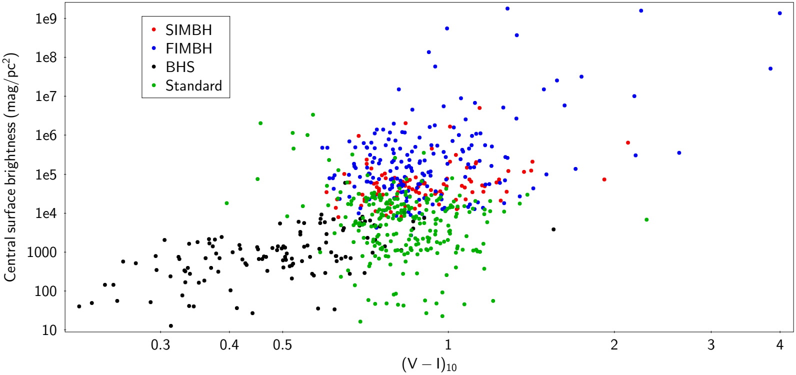
GC with large observed R_{hl} should not contain IMBHs, whereas GC with very large R_{hl} could contain BHSs.

Results: central surface brightness





Results: central surface brightness vs color



EGGC: conclusions

- Obtained integrated absolute magnitude for EGGCs, focusing on V band and $V - I$ color;
- incompleteness of the sample comparing V distribution;
- confirmed that metallicity plays an important role in the $V - I$ color distribution, but it is not the only one main feature;
- no a $V - I$ color dependence on the dynamical state of the cluster;
- systems with a BHS subsystem have, on average, a bigger half light radius ($> 8\,pc$), and models with an IMBH have, on average, a small value ($< 4\,pc$);
- strong correlation between central surface brightness and V-I color inside 10% light radius.

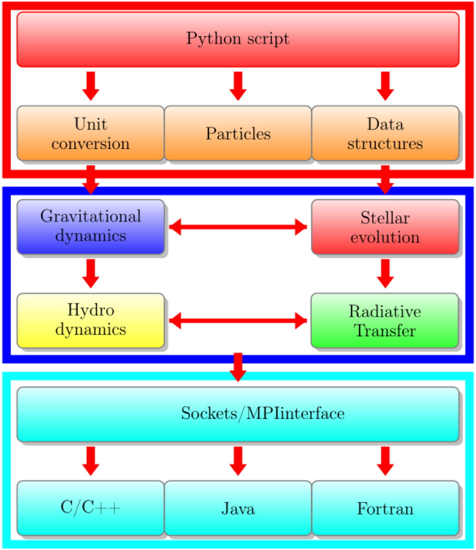
Next step: create mock observation of such database, determining all properties as in an observation data (for example colors, the half light radius, velocity dispersion, surface brightness).

The AMUSE framework

The **A**strophysical **Mu**ltipurpose **S**oftware **E**nvironment (AMUSE, Portegies Zwart et al., 2009) is a software framework for astrophysical simulations, in which existing codes from different domains, such as stellar dynamics, stellar evolution, hydrodynamics and radiative transfer can be easily coupled.

AMUSE uses the standard Message Passing Interface protocol (MPI) and SmartSockets to communicate among different codes. For this reason, it is necessay that the module as to be written in a language with MPI or Smart Sockets bindings.

The AMUSE framework - structure



Credit to Portegies Zwart & McMillan (2018)

Initial conditions for embedded gas clusters

Initial conditions for stars:

- Plummer distribution;
- $N = 10^5,\ 2 \cdot 10^5$;
- no binary (initial nor dynamical);
- $rh = 0.5,\ 1.0\ pc$;
- Kroupa IMF with masses between 0.08 and $100 M_\odot$.

The gas has been treated as an analytical external (Plummer) potential:

$$M_g(t) = M_g(0) \qquad t < \tau_d;$$

$$M_g(t) = M_g(0)\ exp\left(-\frac{t-\tau_d}{\tau_g}\right) \qquad t > \tau_d,$$

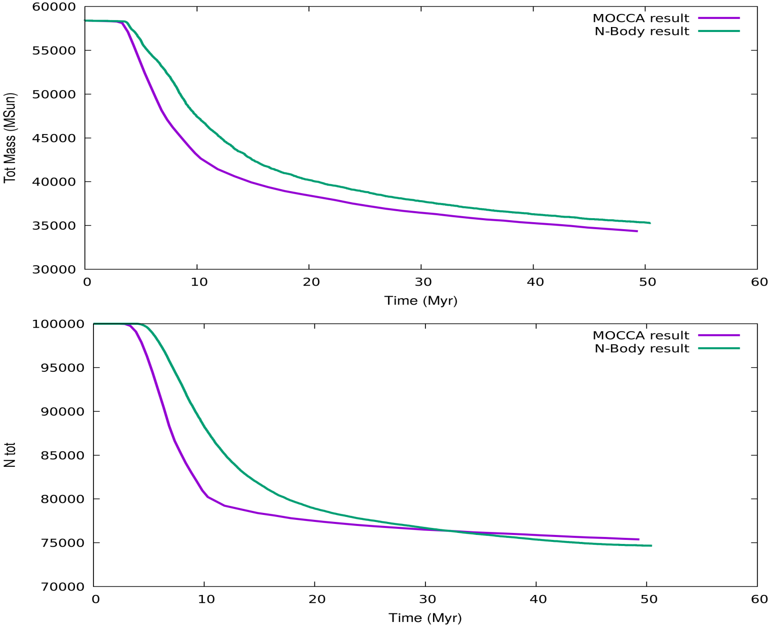
with:

$$M_g(0) = M_{cl}(0)\left(\frac{1}{\epsilon} - 1\right),$$

$$\tau_g \approx r_h(0)/v_g.$$

In our simulation, we used: $\tau_d = 0.1\ Myr$, $\epsilon = 1/3$, $v_g = 10\ km/s$ (see Banerjee & Kroupa, 2018).

Embededd gas comparison: $N = 100k$, $rh = 0.5\,pc$



Embededd gas comparison: $N = 100k$, $rh = 0.5\,pc$