The formation of massive "dark" systems in star clusters and their relation with intermediate mass black holes

Star Clusters as Cosmic Laboratories for Astrophysics, Dynamics and Fundamental Physics

Cosmic Lab – Modest 16

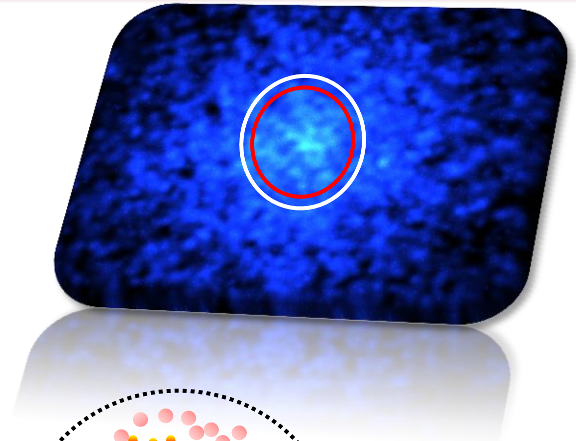
Bologna

Manuel Arca Sedda

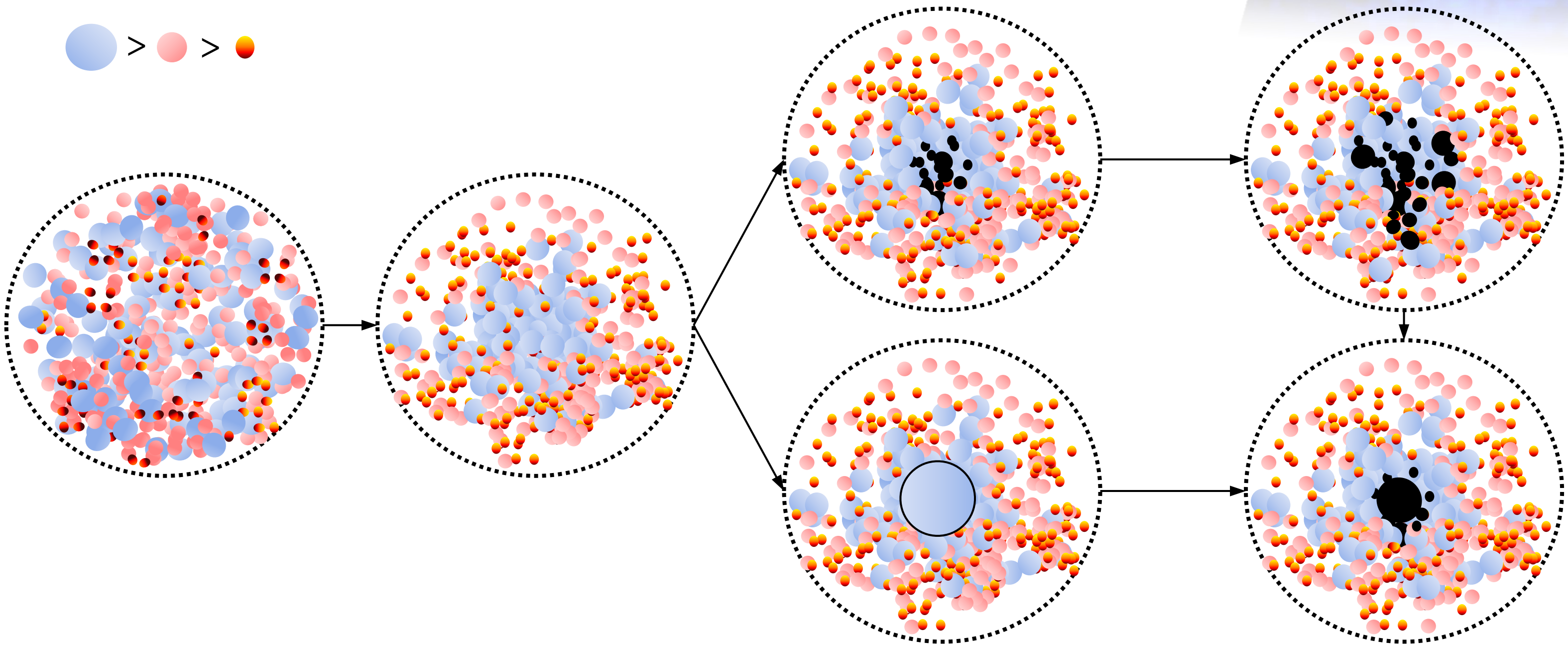
Università di Roma – Sapienza

April 18-22, 2016

Introduction



Several globular clusters contains at their centre more mass than expected, why?



Can a heavy sub-system mime the gravitational effects induced by an IMBH?[1]

[1] Arca Sedda M., 2016, MNRAS, 455, 35-50

Numerical approach

- Semi-analytic models: mass segregation and stellar evolution (tools CODESSE, CODEBSE)
  - Physical processes included: dynamical friction[2] (CODE) and stellar evolution[3] (SSE), recently also for primordial binaries (BSE);
  - Sampling star positions and velocities: flat (models U) and Dehnen (D) mass distribution;
  - Sampling star masses: Kroupa (models K), Salpeter (S), flat (R) initial mass function;
  - Host cluster mass: $M_{GC} = 10^3 - 2\times 10^6$ $M_\odot$;
  - Host cluster metallicity: $Z = 0.02$ ($= Z_\odot$) (models A) and 0.0004 (typical value for GCs, models B);
  - Database provided by Lutzgendorf et al. (2013), and data by Lanzoni et al. (2013) and Haggard et al. (2013).
- N-body simulations:
  - HIGPUS[4]: runs on GPUs, Hermite 6° order with block-time steps, no treatment for binaries and close encounters;
  - HIGPUSSE[1]: HIGPUS + SSE;
  - ARWC-M: modified version of a serial N-body code that implements the algorithmic regularization for close encounters[5] and external potential;

Table 1. Parameters of the cluster models.

Model	IMF	$\rho(r)$	Z	M_{GC} ($M_\odot$)
A1	K	U	0.02	10^3–3×10^6
A2	K	D	0.02	10^3–3×10^6
A3	S	U	0.02	10^3–3×10^6
A4	S	D	0.02	10^3–3×10^6
A5	F	U	0.02	10^3–3×10^6
A6	F	D	0.02	10^3–3×10^6
B1	K	U	0.0004	10^3–3×10^6
B2	K	D	0.0004	10^3–3×10^6
B3	S	U	0.0004	10^3–3×10^6
B4	S	D	0.0004	10^3–3×10^6
B5	F	U	0.0004	10^3–3×10^6
B6	F	D	0.0004	10^3–3×10^6

Notes. Column 1: name of the model. Column 2: IMF used to sample masses of the stars: Kroupa (K); Salpeter (S) and flat (F). Column 3: spatial density profile of the stars: uniform (U) and Dehnen (D). Column 4: metallicity of the cluster. Column 5: masses of the cluster models.

2 Arca Sedda M., Capuzzo-Dolcetta R., 2014, ApJ, 785, 51
3 Hurley J. R. et al., 2000, MNRAS, 315, 543
4 Capuzzo-Dolcetta R. et al., 2013, JCP,236, 580
5 Mikkola S., Tanikawa K., 1999, MNRAS, 310, 745

RESULTS 1/2: formation of a massive sub-system (MSS)

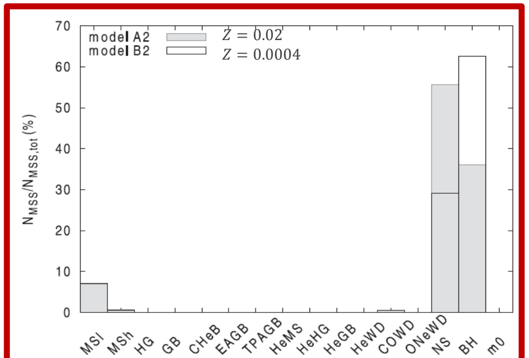
MSS composition

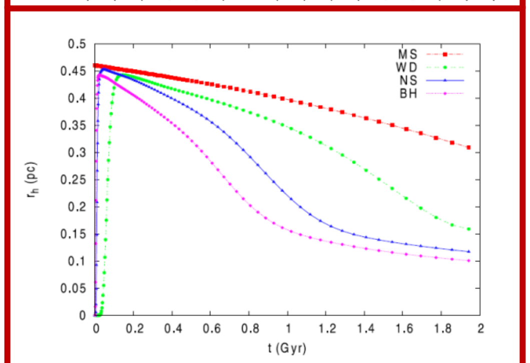
$$\tau_{DF} = K(e,\gamma,t_{cr})\left(\frac{m_*}{M_{GC}}\right)^{-0.67}\left(\frac{r_*}{r_{GC}}\right)^{1.76}$$

$$r_{MSS} = r_{GC}\frac{\mu}{1-\mu}; \qquad \mu = \left(\frac{m_*}{M_{GC}}\right)^{1/(3-\gamma)}$$

$$r_*(t) = r_*\left[1-\frac{t}{\tau_{DF}(r_*)}\right]^{0.57}$$

$$\epsilon_{DF} = 1-\tau_{DF}/\tau_{DFNb} < 20\%$$



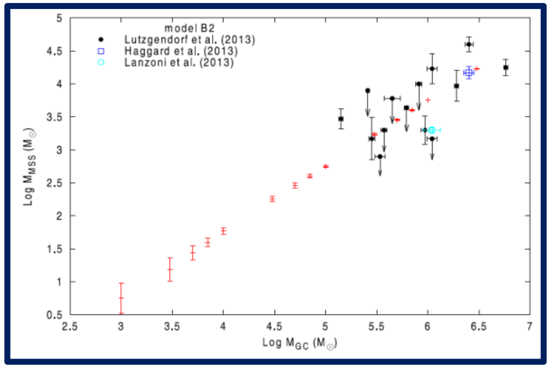


Scaling relations

$$\mathrm{Log}\left(\frac{M_{MSS}}{M_\odot}\right) = a\,\mathrm{Log}\left(\frac{M_{GC}}{M_\odot}\right) + b,$$

ωCen:
$M_{MSS} = (1.45 \pm 0.03) \times 10^3 M_\odot$

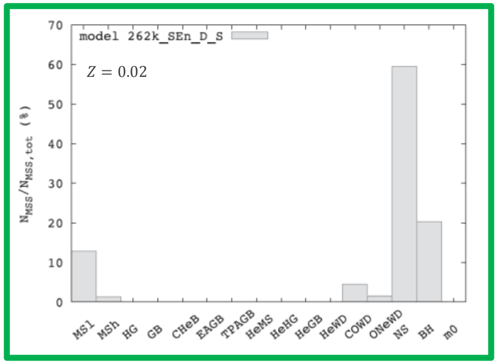
NGC6388:
$M_{MSS} = (6{,}4 \pm 1.2) \times 10^3 M_\odot$

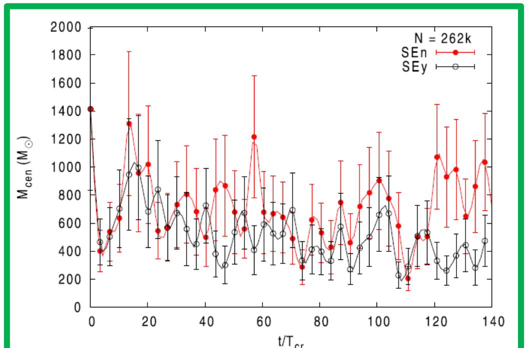


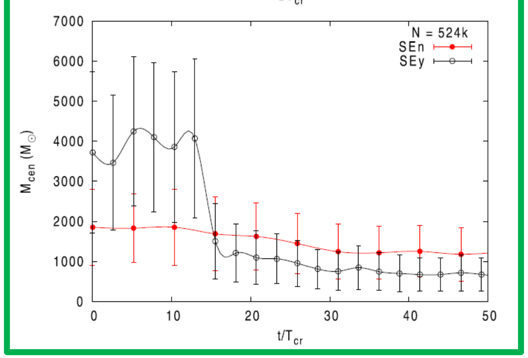
N-body simulations (8k-524k stars)

- SE: yes vs not;
- MSS composition and size;
- GC density profile and dispersion:

$$\Sigma(R) \propto R^{+1.30\pm0.05}$$
$$\sigma(R) \propto R^{-0.12\pm0.01}$$
$$R < 0.1\mathrm{pc}$$



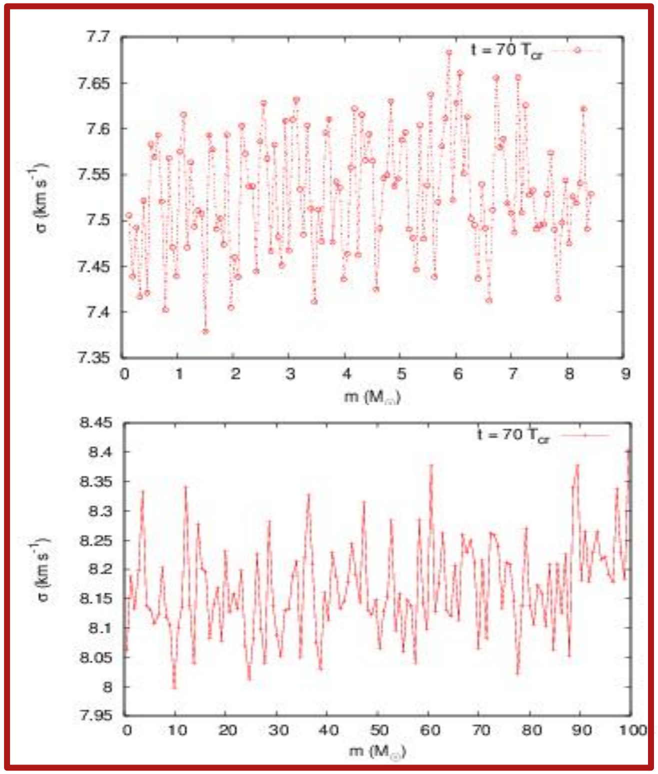




Manuel Arca Sedda
MODEST16, 17-22 April ,Bologna

RESULTS 2/2:

- Energy equipartition: is $\sigma(m) \propto m^{-2}$? No !
  the dispersion increases
  - Pros: precise integration of gravitational encounters and stellar evolution;
  - Cons: does not account for close interactions and binary stars.



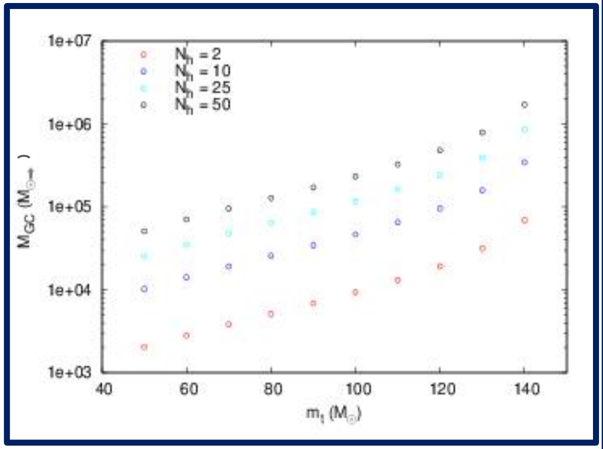
- Primordial binaries

$$N(m_*) = \int_{m_*}^{m_M} f(m)dm$$

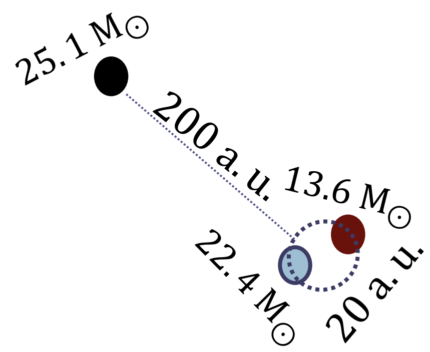
For a Kroupa IMF

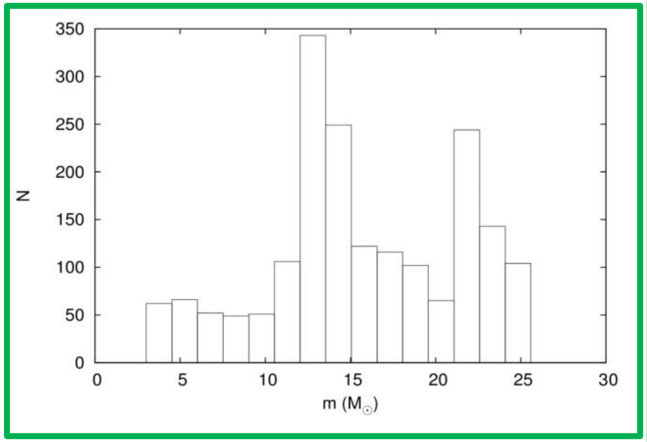
$$N(m_* > 120\ \mathrm{M}_\odot) = 2$$

implies $M_{GC} \geq 10^4 \mathrm{M}_\odot$



- Gravitational waves sources
  - CODE: ARWC-M
  - Host mass: $10^4 \mathrm{M}_\odot$
  - $N_{BH} = 30$





$$M_{BH1} + M_{BH2} = 36\ \mathrm{M}_\odot$$
$$M_{BH3} = 25.1\ \mathrm{M}_\odot$$