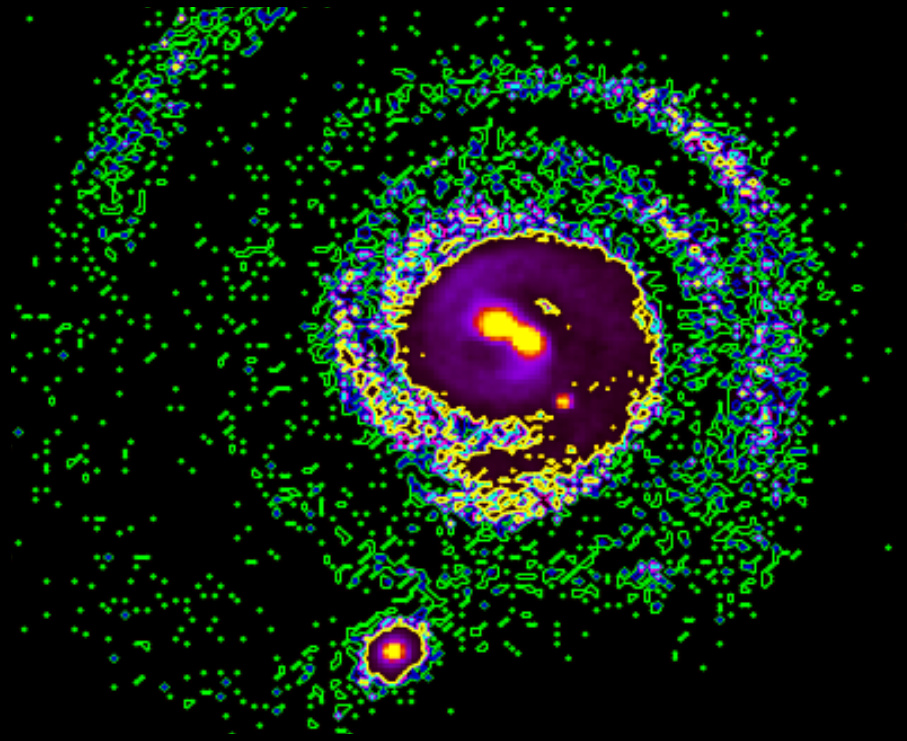
The MEGaN project: investigating the evolution of galactic nuclei and their environment

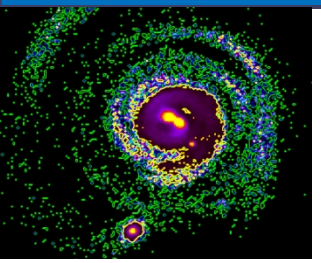


Trilateral meeting Germany - Russia - Ukraine

Astronomisches Rechen Institute

May 30th-31st , 2017

Manuel Arca Sedda
ARI-ZAH
Heidelberg University



The MEGaN project: modelling the evolution of galactic nuclei

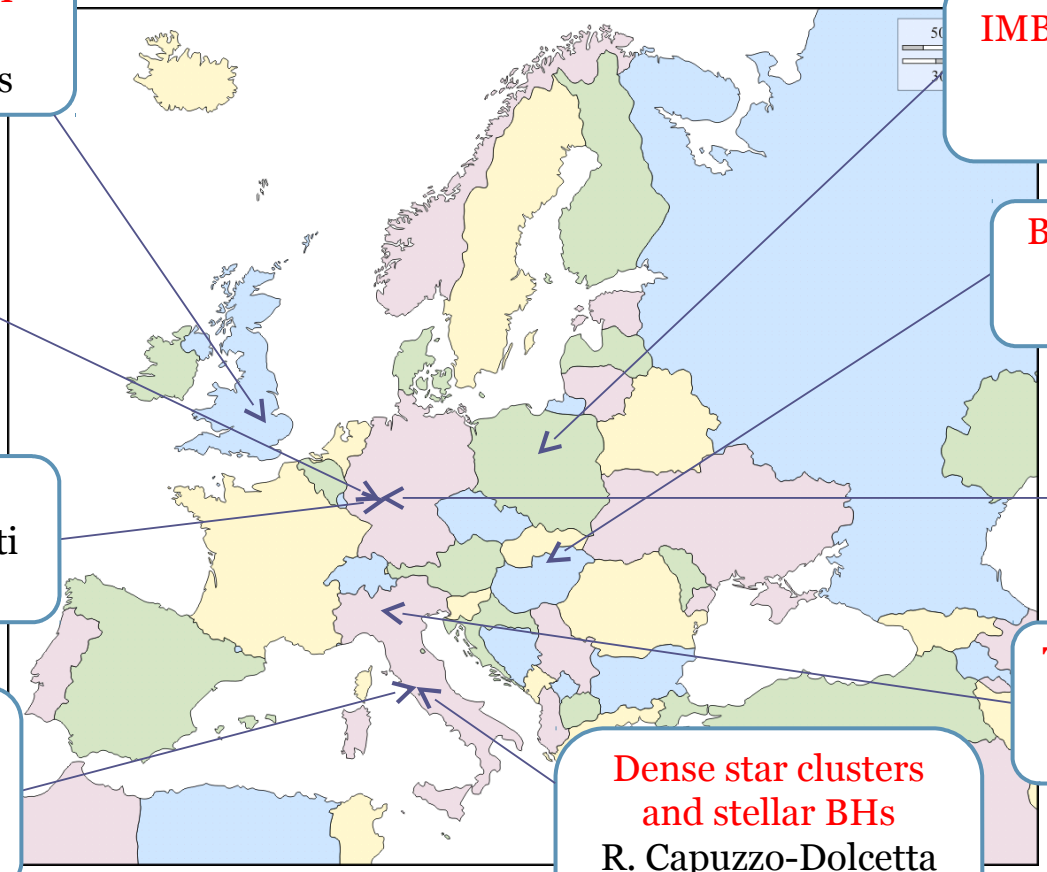
funded by the University of Rome Sapienza through the grant 52/2015

IMBH-SMBH interactions
A. Gualandris

IMBH/BH sub. formation
M. Giersz
A. Askar

SMBHB evolution
R. Spurzem
P. Berczik

BHs and BHBs evolution
B. Kocsis
G. li



Nuclear Clusters
A. Mastrobuono-Battisti
I. Georgiev

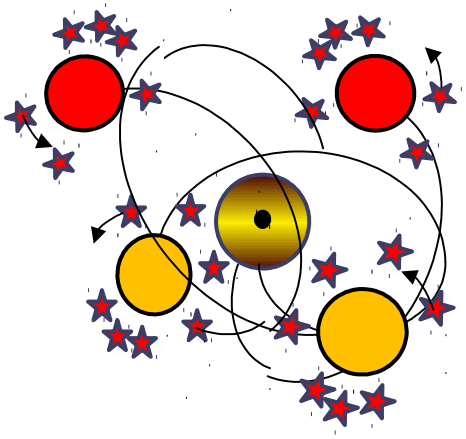
Galaxy clusters and SMBH interactions
M. Donnari
A. Graham

TDEs and dwarf galaxies
M. Colpi
M. Dotti

Nuclear and star clusters, galaxies and SMBHs
R. Capuzzo-Dolcetta

Dense star clusters and stellar BHs
R. Capuzzo-Dolcetta
G. Fragione
S. Rastello
I. Tosta e Melo

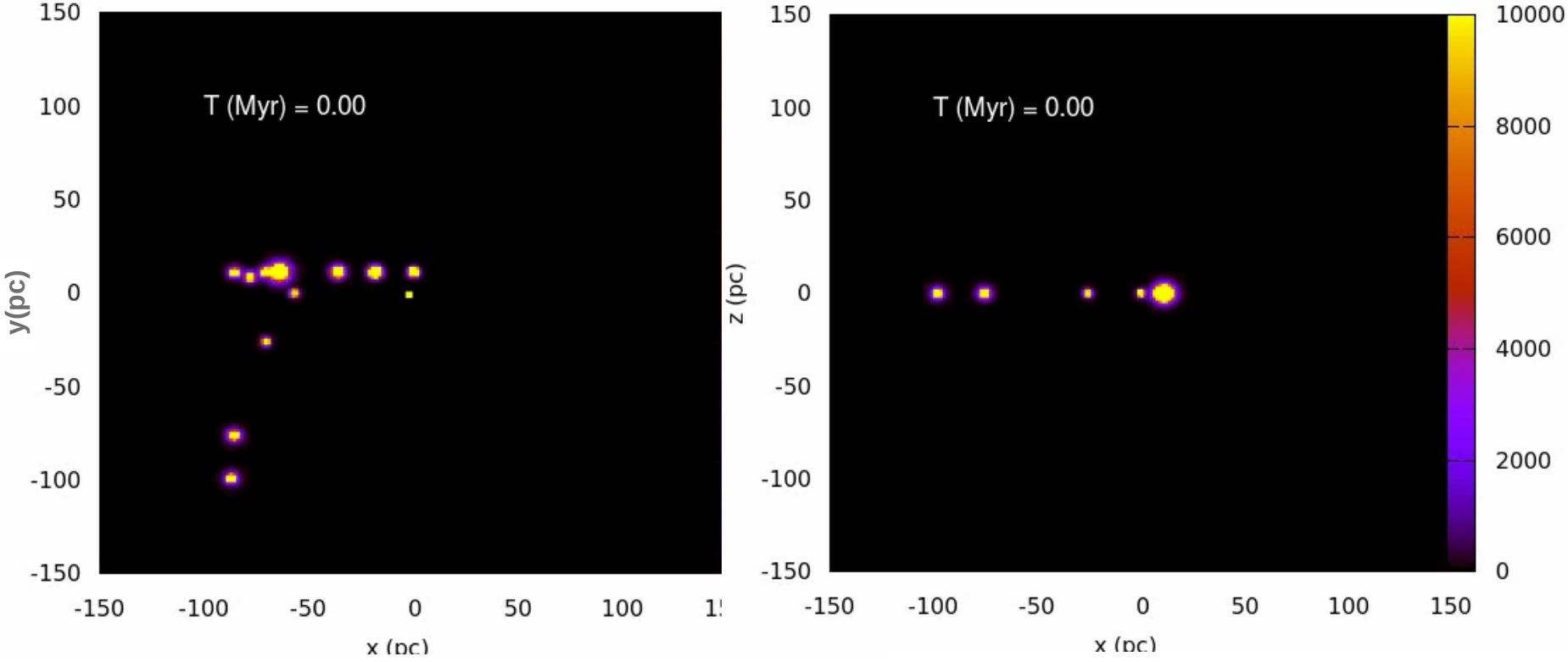
NCs and SMBHs



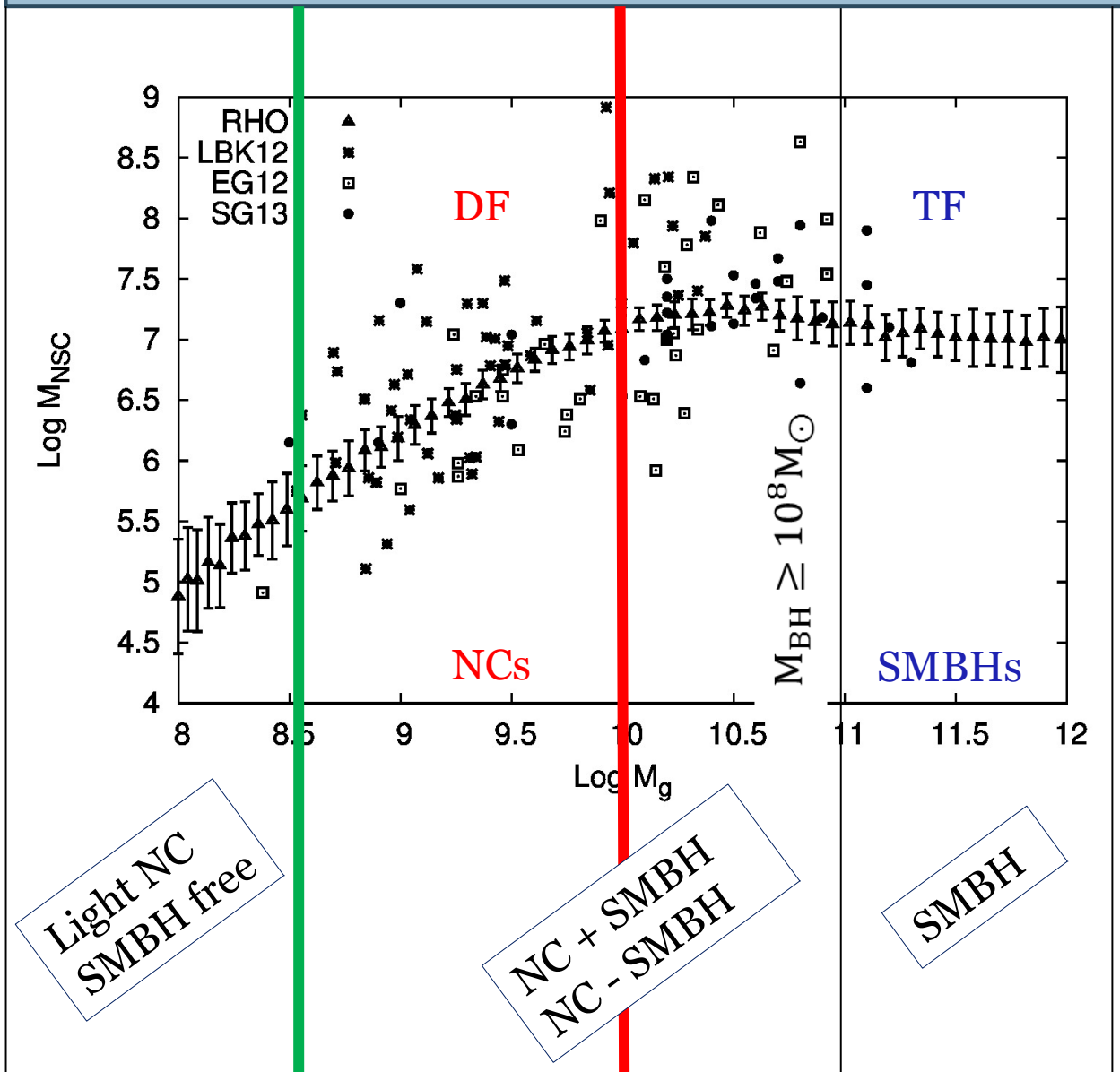
The dry-merger scenario

A NC can form:

- If a SMBH is pre-existent
- If a SMBH is not present
- On small time-scales (<1 Gyr)



NCs and SMBHs: star clusters infall scenario



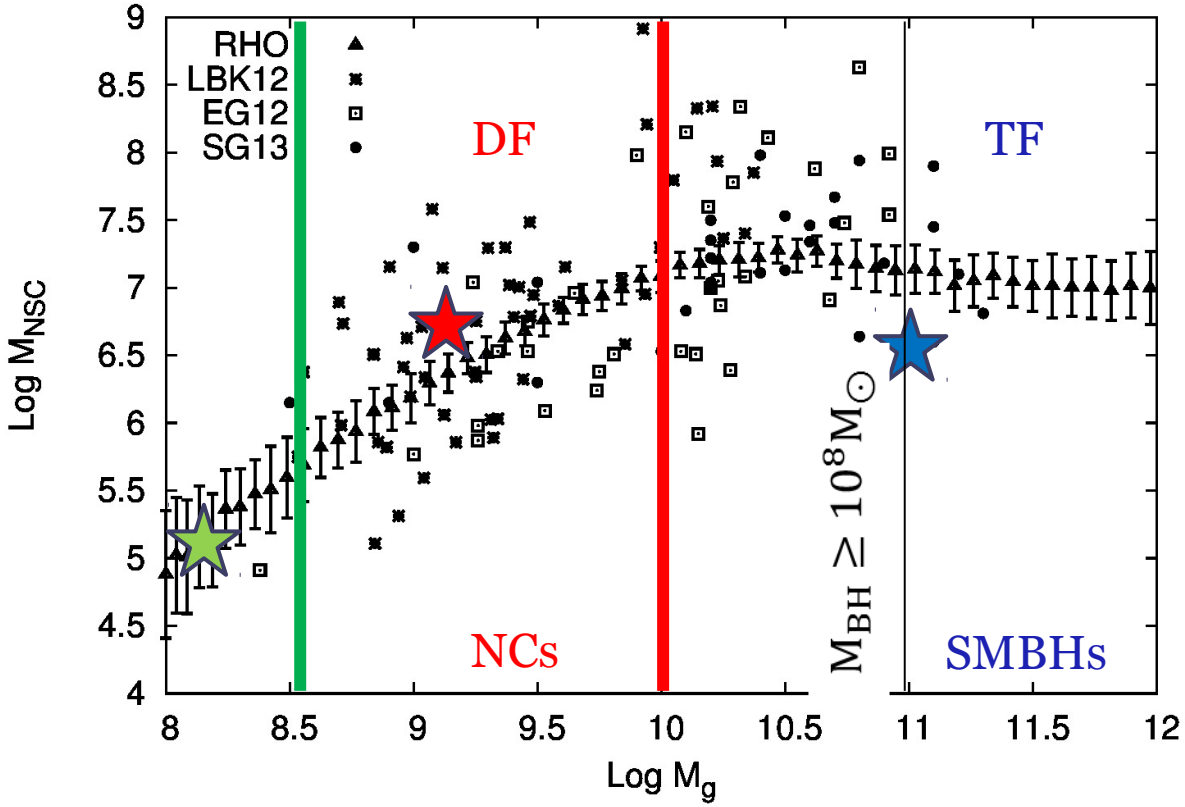
✓ Dynamical Friction + Tidal Forces

Arca Sedda M., Capuzzo-Dolcetta R., 2014, MNRAS, 444, 3738-3755c

Antonini F., 2013, ApJ, 763, 62

Gnedin O., Ostriker J., Tremaine S., 2014, ApJ, 785, 71

NCs and SMBHs: star clusters infall scenario



Fornax (dwarf)

Henize (starburst)

MEGaN (elliptical)

Arca Sedda & Capuzzo-Dolcetta, 2016, MNRAS, 461, p.4335-4342

Arca-Sedda et al., 2015, Apj, 806, 220

Arca-Sedda et al., 2016, MNRAS, 456, 2457

Arca Sedda & Capuzzo-Dolcetta, 2017, MNRAS,464, 3060

Arca-Sedda & Capuzzo-Dolcetta, in prep.

Arca-Sedda & Capuzzo-Dolcetta, in prep.

NCs and SMBHs: star clusters infall scenario

DF

- ✓ Dearth of NCs and/or SMBHs in dwarf spheroidals;
- ✓ Acquire informations about dSph formation history;
- ✓ Formation of NCs in starburst galaxies;
- ✓ Formation of rotating NSD in middle-weight galaxies;

$M_{BH} \geq 10^8 M_\odot$

TF

- ✓ Dearth of NCs in massive galaxies hosting very massive SMBHs;
- ✓ Computational challenge;
- ✓ Strong dynamical feedback from the central SMBH can:
  - ✓ enhance TDEs,
  - ✓ produce HVSs,
  - ✓ force stellar BHBs to merge,
  - ✓ enhance IMBH-SMBH collisions

Arca Sedda & Capuzzo-Dolcetta, 2016, MNRAS, 461, p.4335-4342

Arca Sedda & Capuzzo-Dolcetta, 2017, MNRAS,464, 3060

Arca-Sedda et al., 2015, Apj, 806, 220

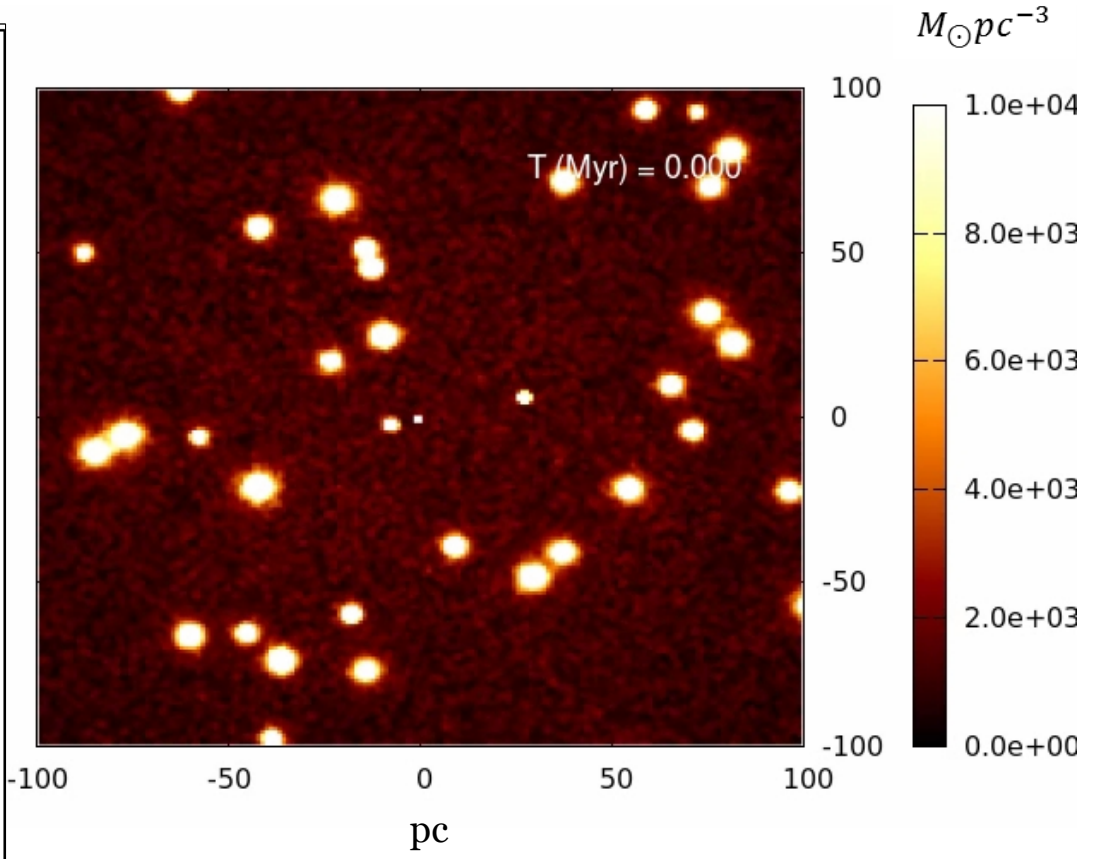
Arca-Sedda et al., 2016, MNRAS, 456, 2457

Arca-Sedda & Capuzzo-Dolcetta, 2017, 464, 3060

The MEGaN simulation: N-body modelling of a massive galactic nucleus

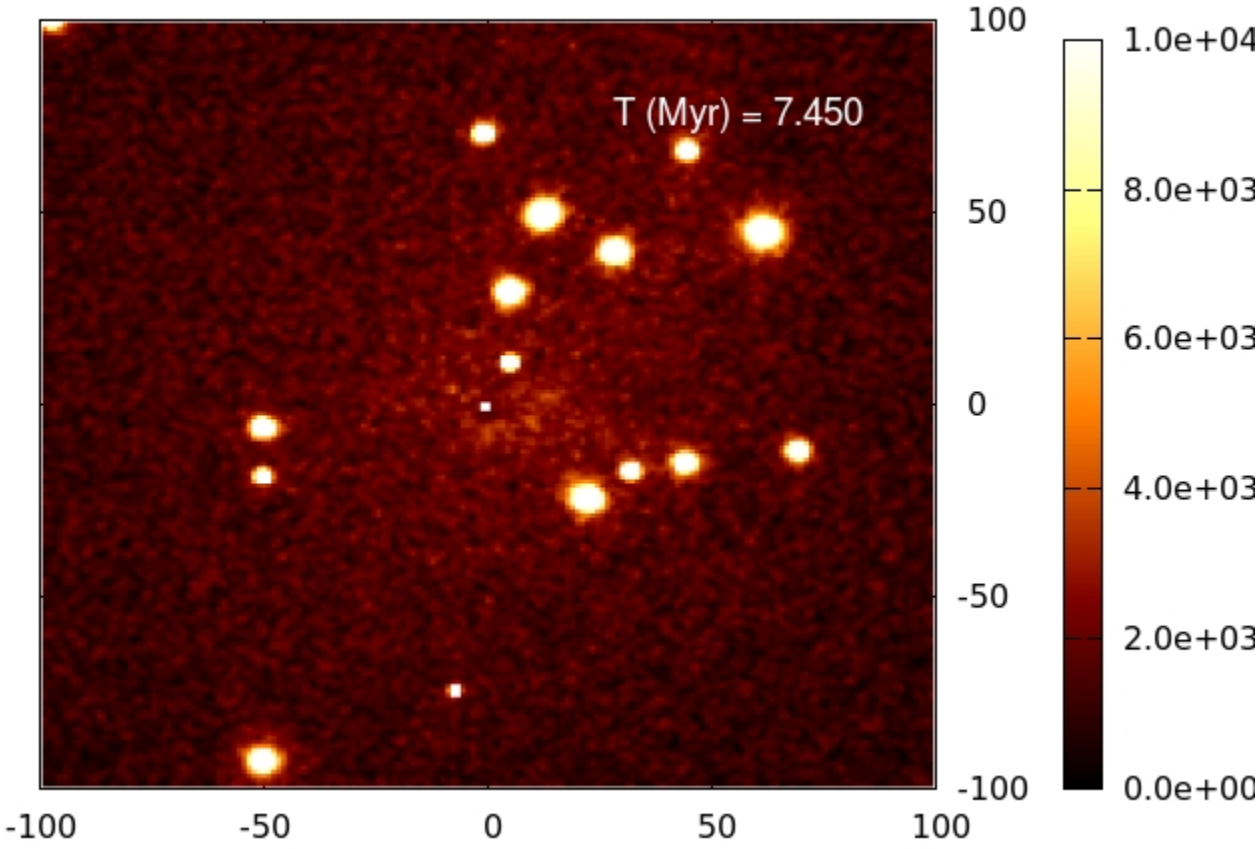
THE MEGaN simulation

- central SMBH mass
  $M_{SMBH} = 10^8\ M_\odot$;
- host galaxy mass:
  $M_g = 10^{11} M_\odot$,
  density profile inner slope:
  $\gamma = 0.1$;
- GCs: No = 42
  masses in the range
  $(0.3 - 2) \times 10^6 M_\odot$;
- Total No. of particles > 1M;
- Individual particle mass $10^2 M_\odot$.



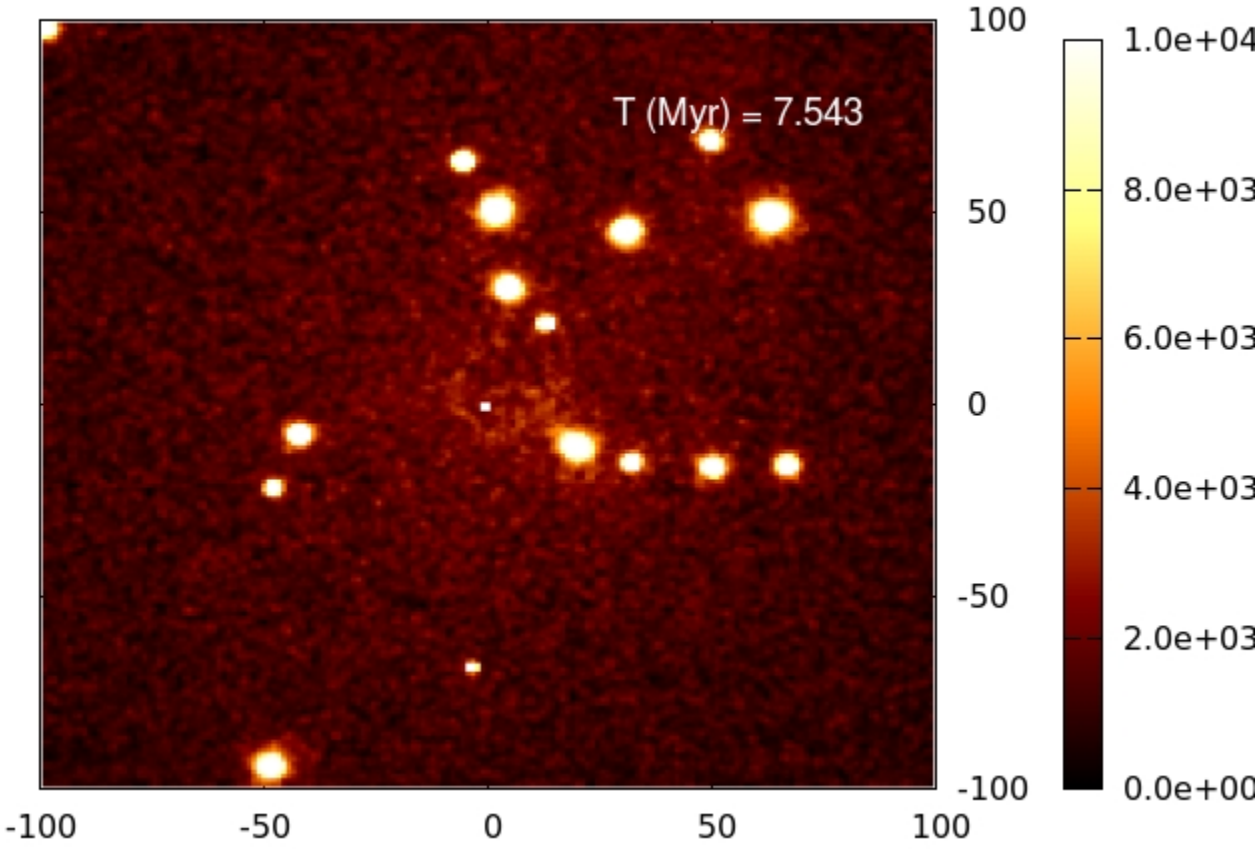
THE MEGaN simulation: results (2/4)

Formation of high-velocity stars



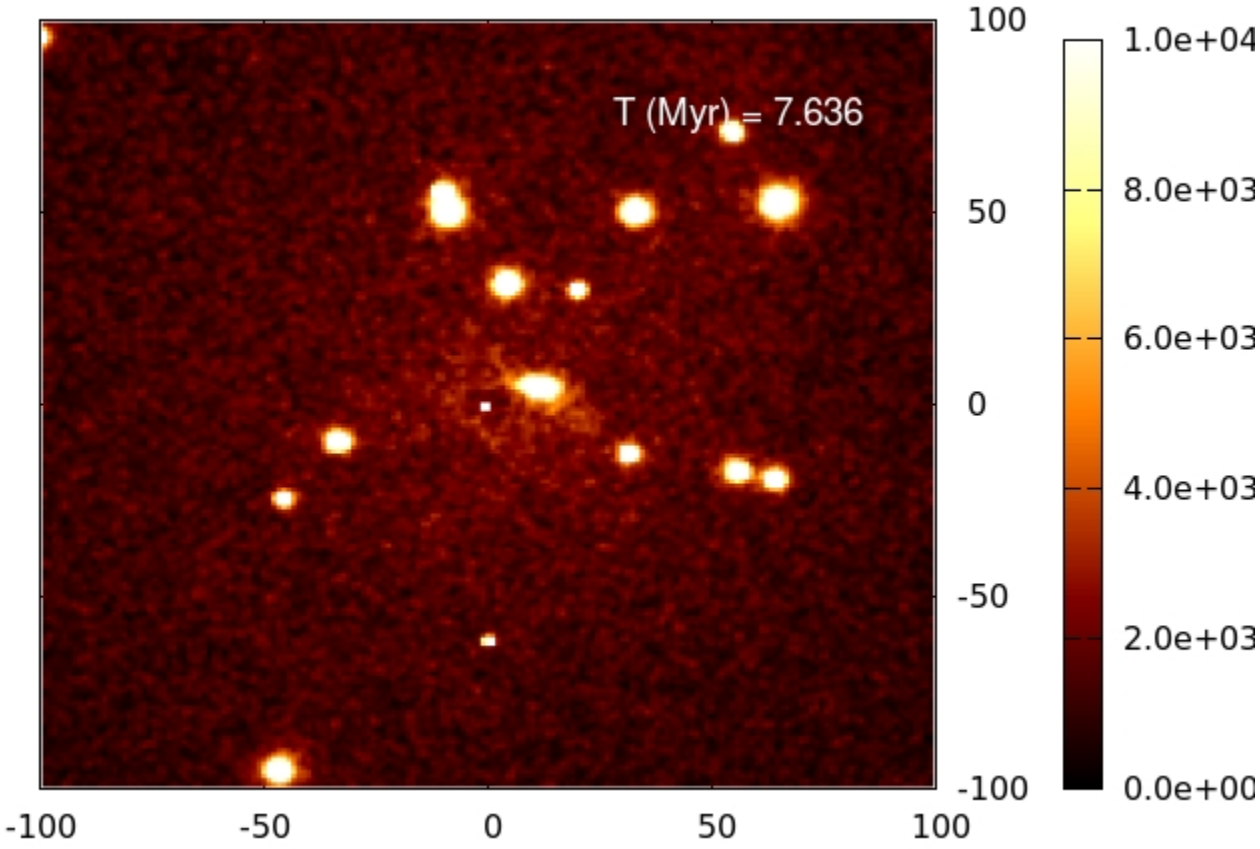
THE MEGaN simulation: results (2/4)

Formation of high-velocity stars



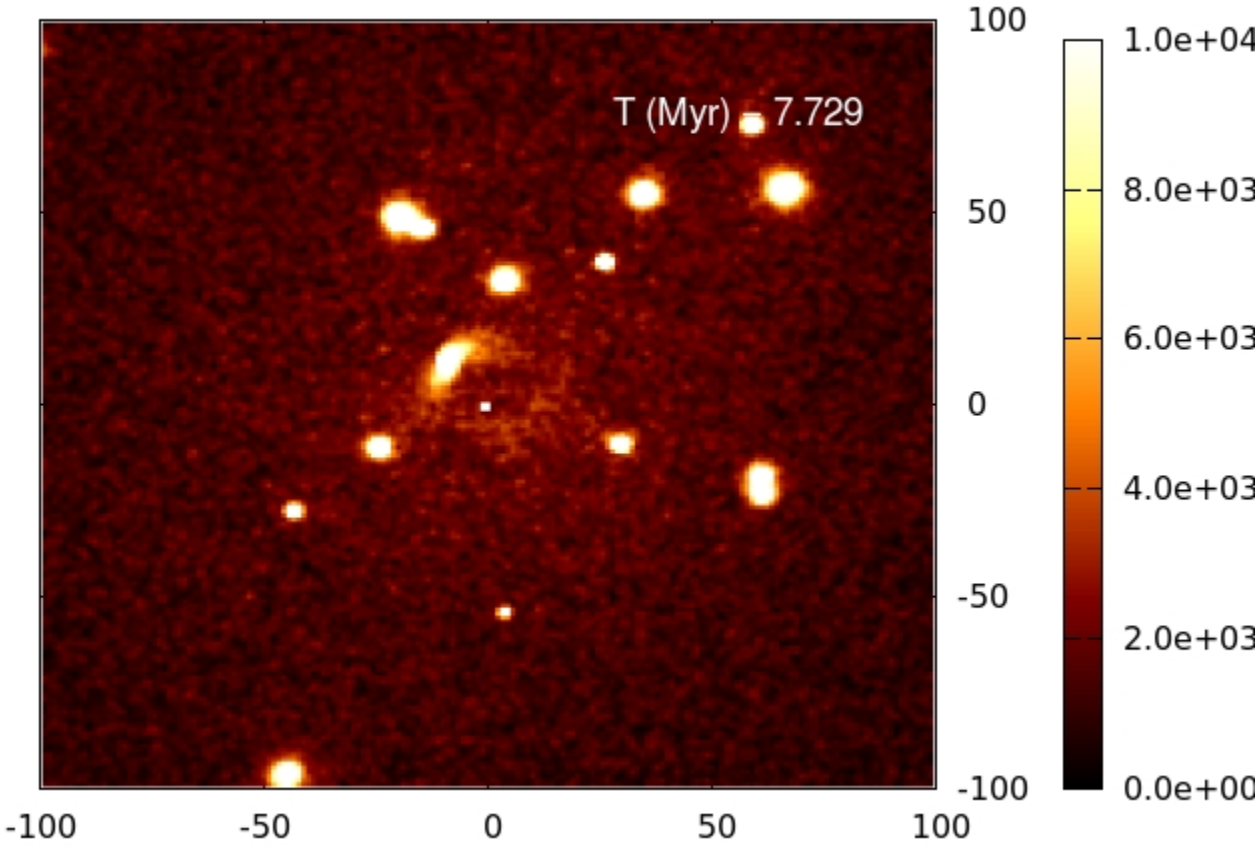
THE MEGaN simulation: results (2/4)

Formation of high-velocity stars



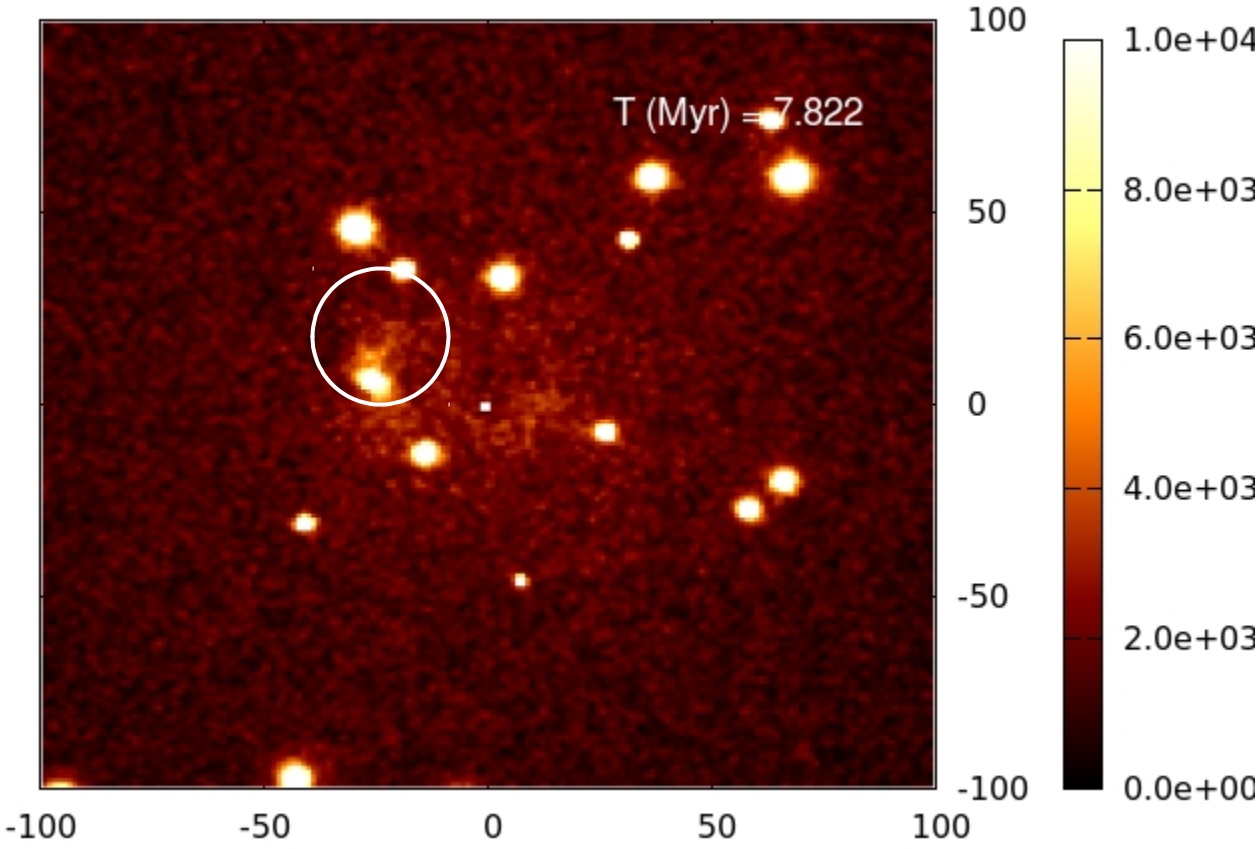
THE MEGaN simulation: results (2/4)

Formation of high-velocity stars



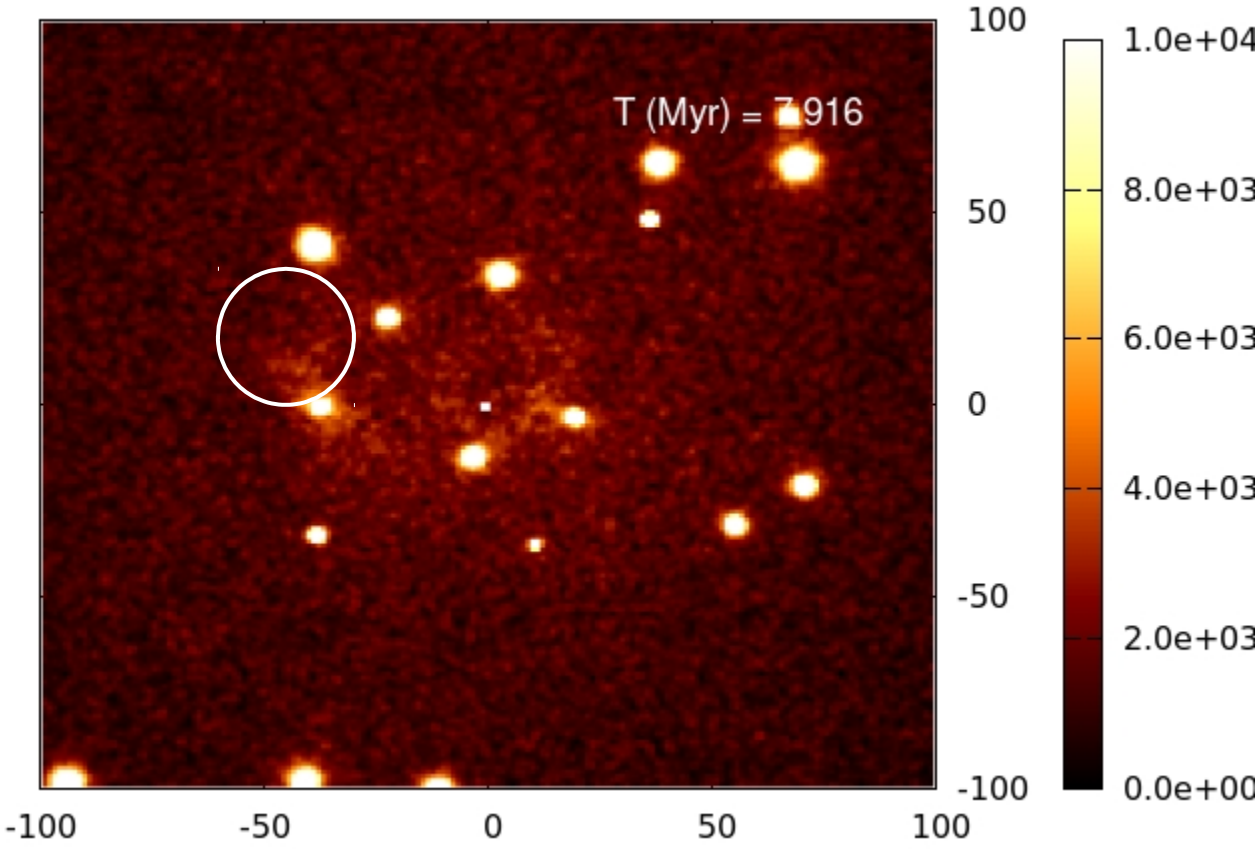
THE MEGaN simulation: results (2/4)

Formation of high-velocity stars



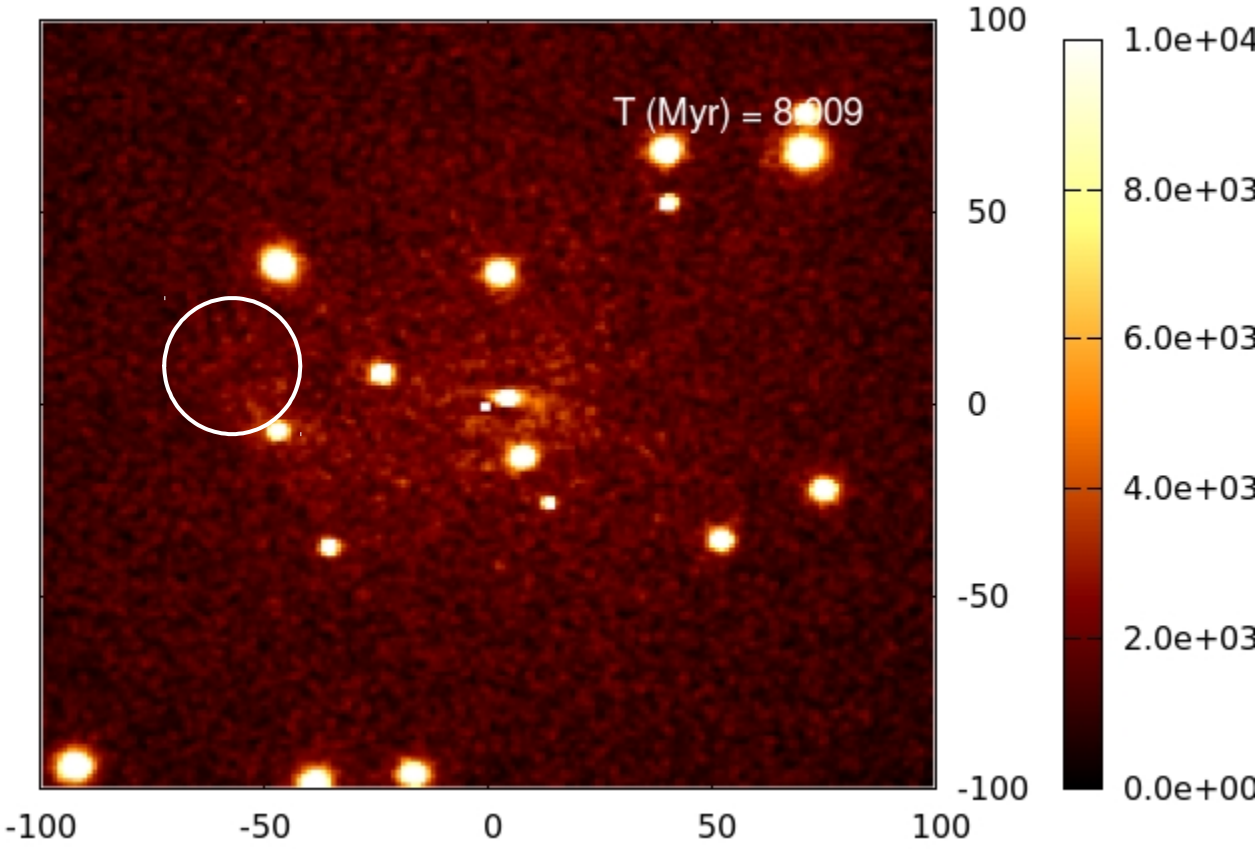
THE MEGaN simulation: results (2/4)

Formation of high-velocity stars



THE MEGaN simulation: results (2/4)

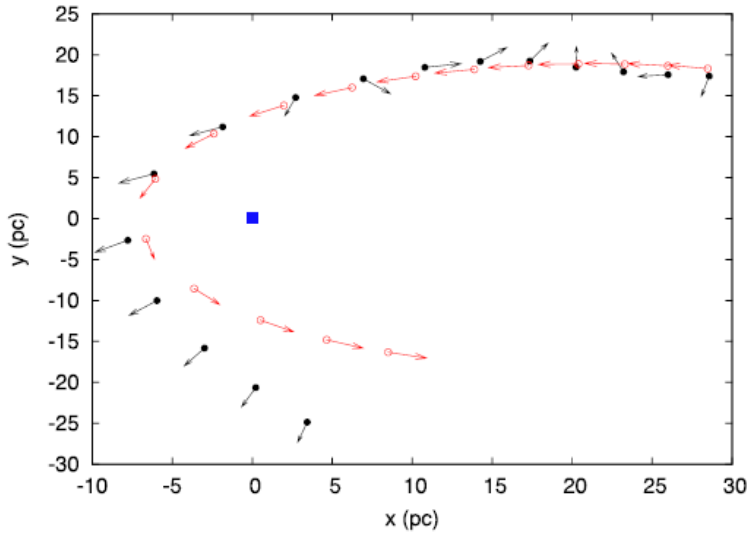
Formation of high-velocity stars

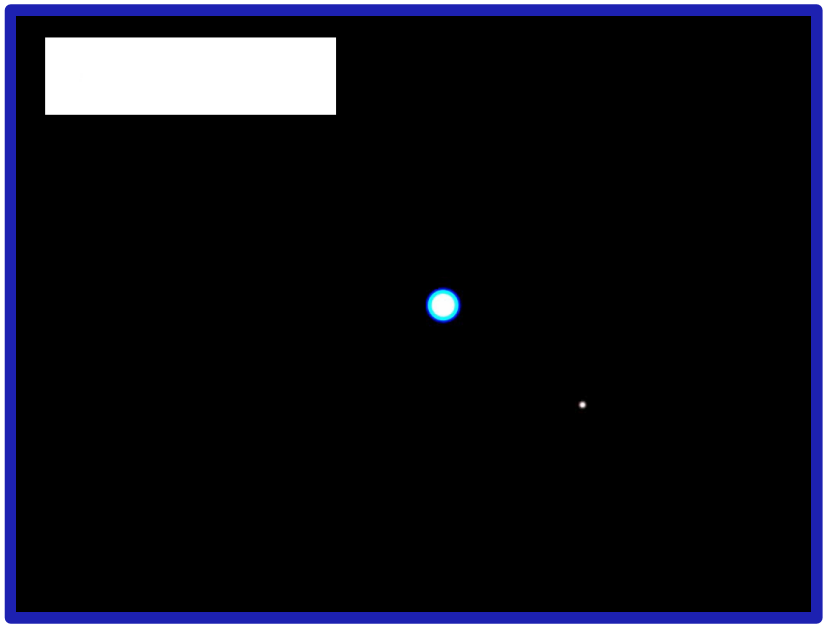


THE MEGaN simulation: results (2/4)

Formation of high-velocity stars

100pc



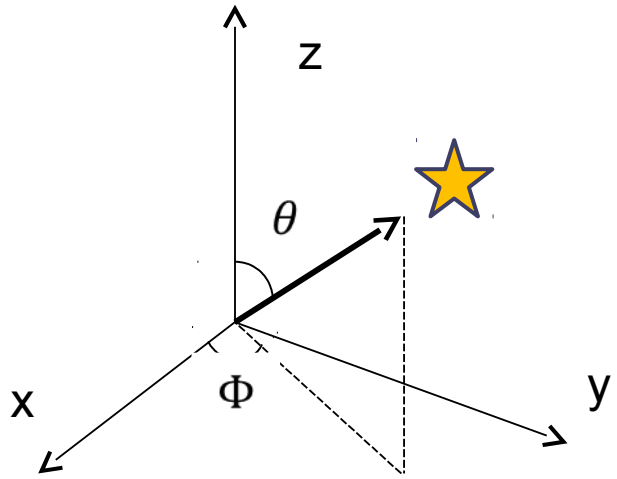


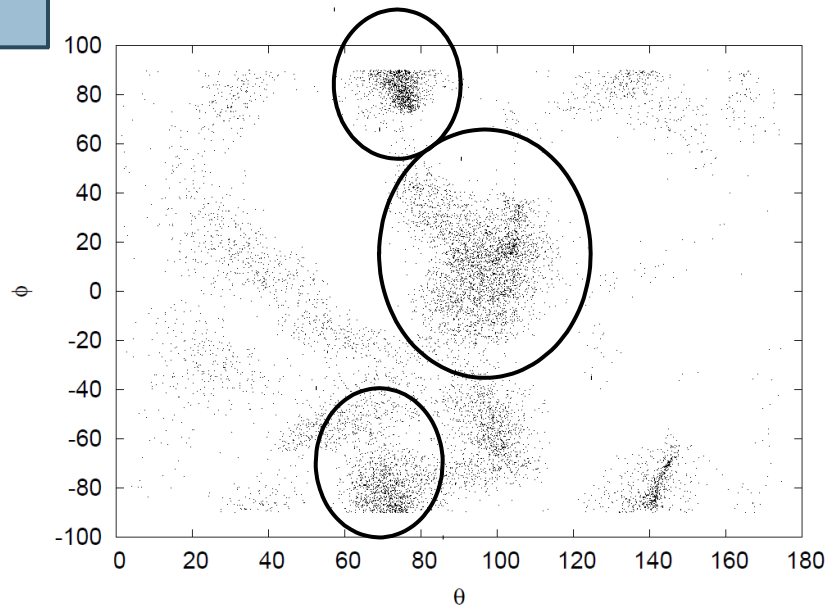
Arca-Sedda et al., 2016, MNRAS, 456, 2457

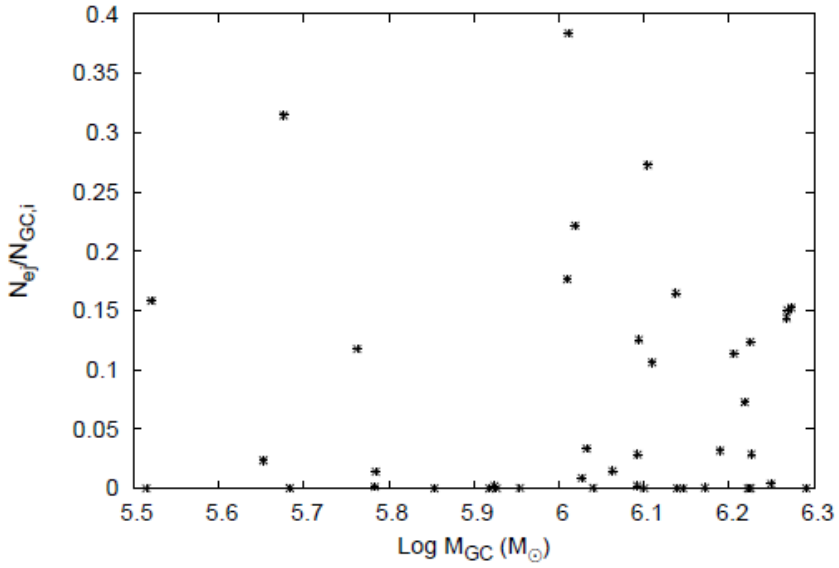
Capuzzo-Dolcetta and Fragione, 2015, MNRAS, 454, 2677

THE MEGaN simulation: results (2/4)

Formation of high-velocity stars





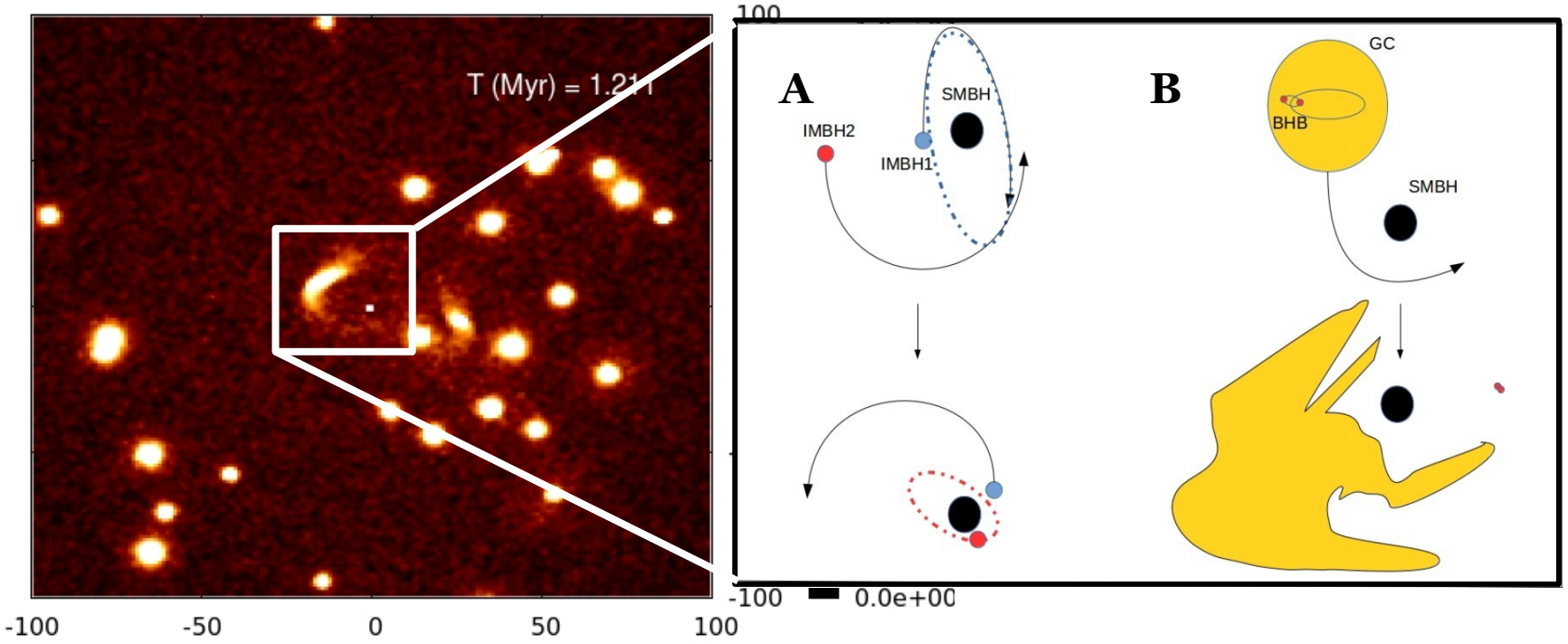


- **2%** of the total GCS stars are ejected with $v_{ej} \simeq 140 - 500 km/s$;
- 0.02% with $v_{ej} > 1500 km/s$.

- Assuming a Kroupa IMF ($\langle m \rangle = 0.62\ M_{\odot}$) we estimate
  $\simeq 10^2$ **HVSs** with $v_{ej} > 1500\ km\ s^{-1}$
  $\simeq 10^4$ with $v_{ej} \geq 200\ km\ s^{-1}$

THE MEGaN simulation: results (3/4)

Production of coalescing stellar black hole binaries (BHBs)



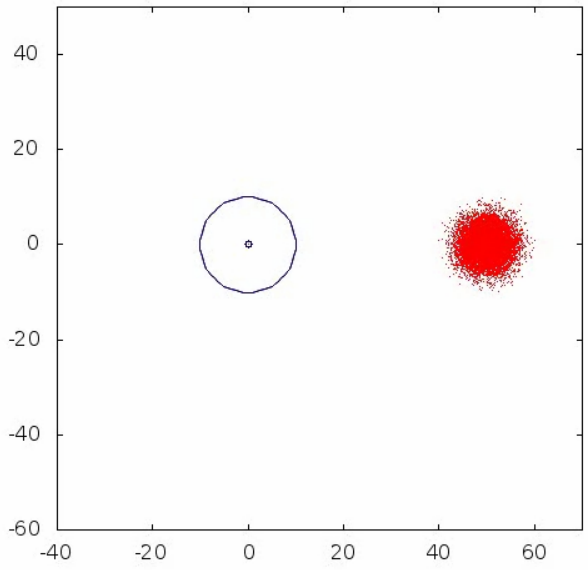
A) The triple interaction leads to a significant enhancement of SMBH-IMBH coalescence

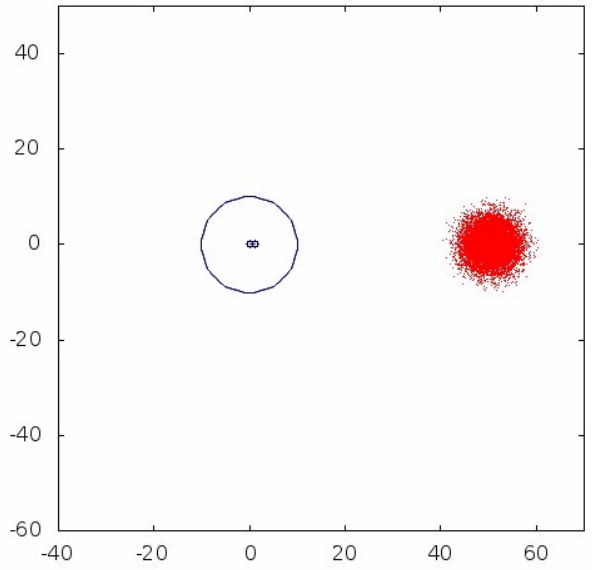
B) The gravitational 4-body scattering leads to a significant increase of the BHB eccentricity, reducing the coalescence time-scale of several order of magnitudes

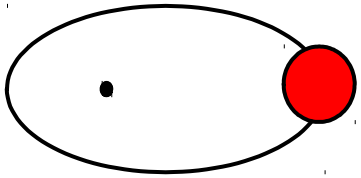
A more complex system: SMBHB and NCs

Collab.: R. Spurzem, P. Berczik, R. Capuzzo-Dolcetta, M. Sobolenko, G. Fragione

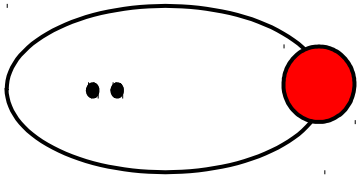
A simpler case: BHB in a galactic nucleus undergoes a close encounter with a globular cluster







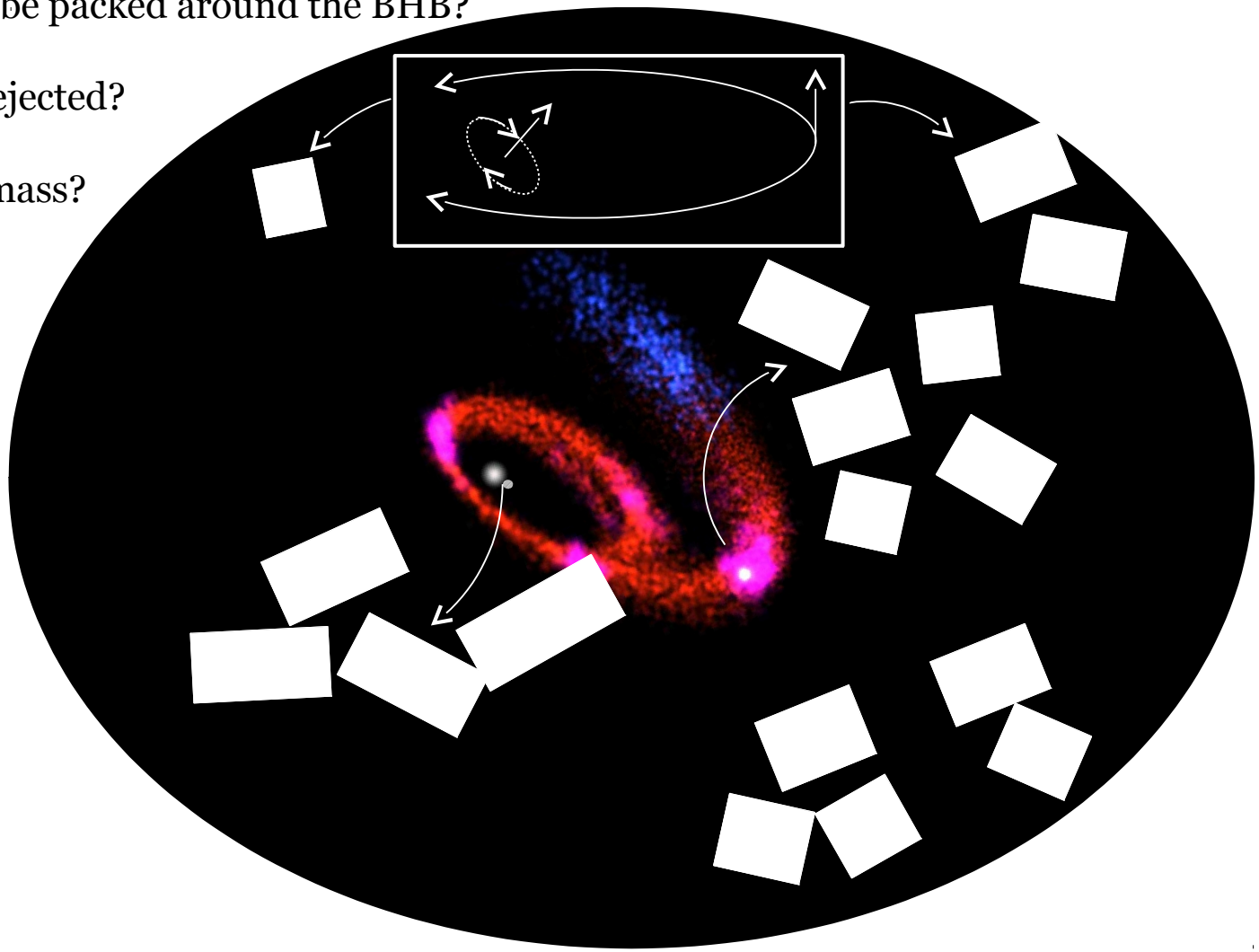
SMBH + GC



BHB + GC

A more complex system: SMBHB and NCs

- Can a three body encounter facilitate BHB coalescence?
- How much mass can be packed around the BHB?
- How much stars are ejected?
- Which is their kind/mass?



A more complex system: SMBHB and NCs

Let's try to reduce the problem ...

- GC eccentricity (2 choices)
- SBHB total mass (2 choices)
- SBHB mass ratio (2 choices)
- SBHB eccentricity (3 choices)
- Mutual orbits: co/counter rotating; co-planar or perpendicular (4 choices)

Tot: 2 x 2 x 2 x 3 x 4 = 72 !!

Initial sample:

equal mass SBHB
only counter-rotating and co-planar

12 simulations

A more complex system: SMBHB and NCs

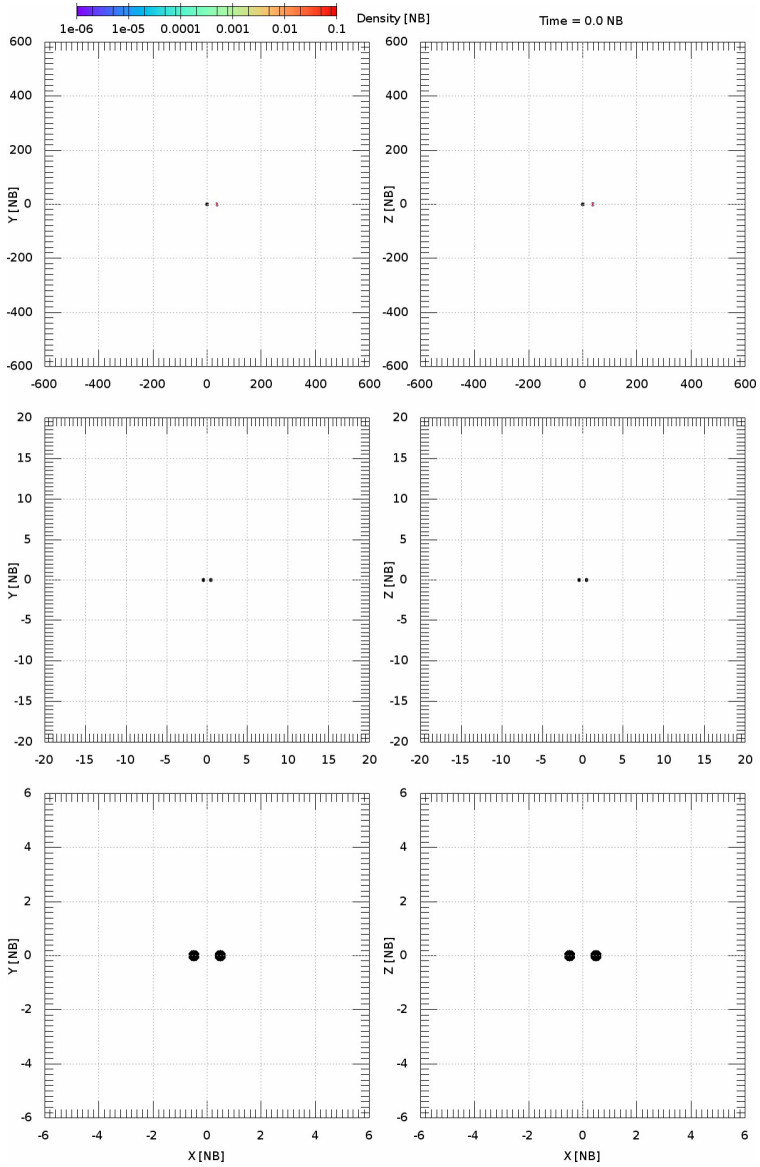
Numerical model:

- GC: King (1962) N = 2^{16}
- Galaxy: Dehen (1993)
  - External potential
  - $M_g = 10^{11} M_\odot; r_g = 2kpc; \gamma = 0.5$
- Logarithmic Halo
  - External potential
  - $v_c(8kpc) = 250km/s$

- Hardware (Heidelberg):
  - Kepler cluster (4 GPUs Nvidia K20)
- Hardware (Rome):
  - HPC workstations AC16a and AC16b (4 GPUs Nvidia Titan X each)
  - HPC workstation AC9 (1 GPU Radeon HD 7990, 2 GPUs Radeon HD7970)

- 1 simulation (15 Myr): 80 hours / 1GPU (using both PhiGPU and HiGPUs)

A more complex system: SMBHB and NCs

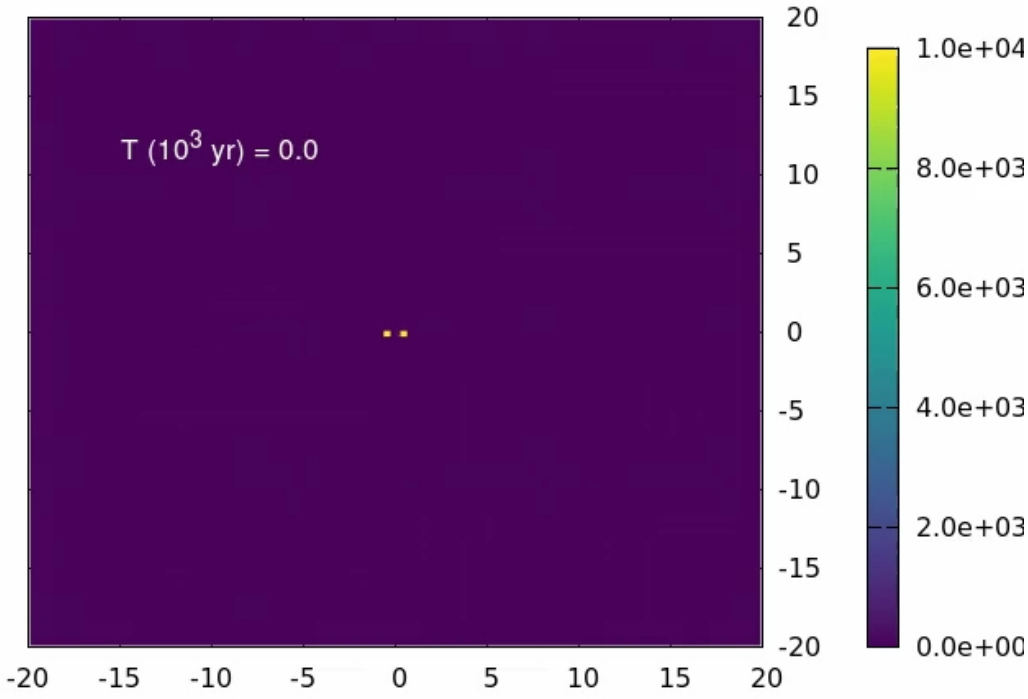


Left:

$$M_{cl} = 0.1\, M_{bhb} \; - \; e_{cl} = 0.5$$

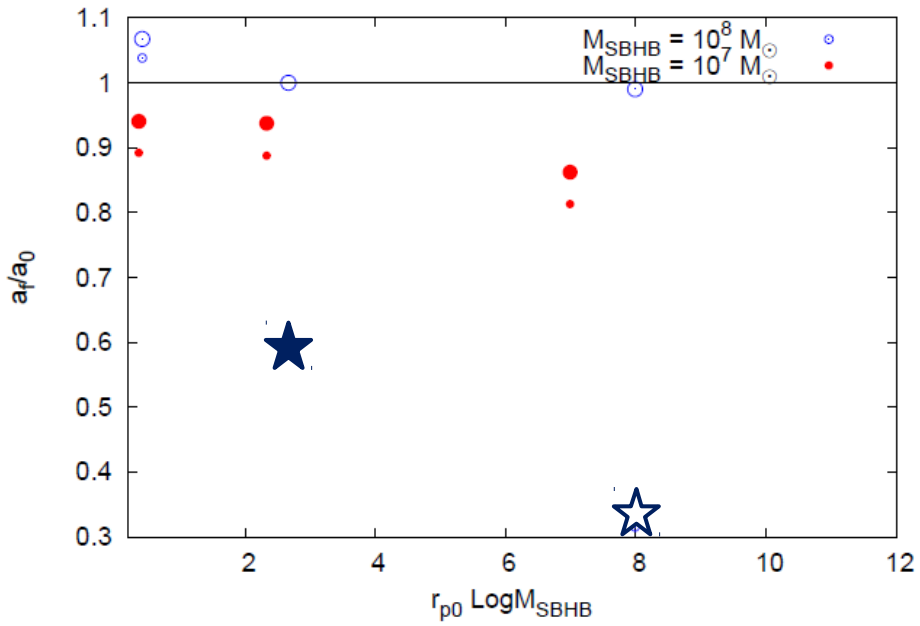
Bottom:

$$M_{cl} = 0.01\, M_{bhb} - e_{cl} = 0.9$$



thanks for the movie to M. Sobolenko

A more complex system: SMBHB and NCs

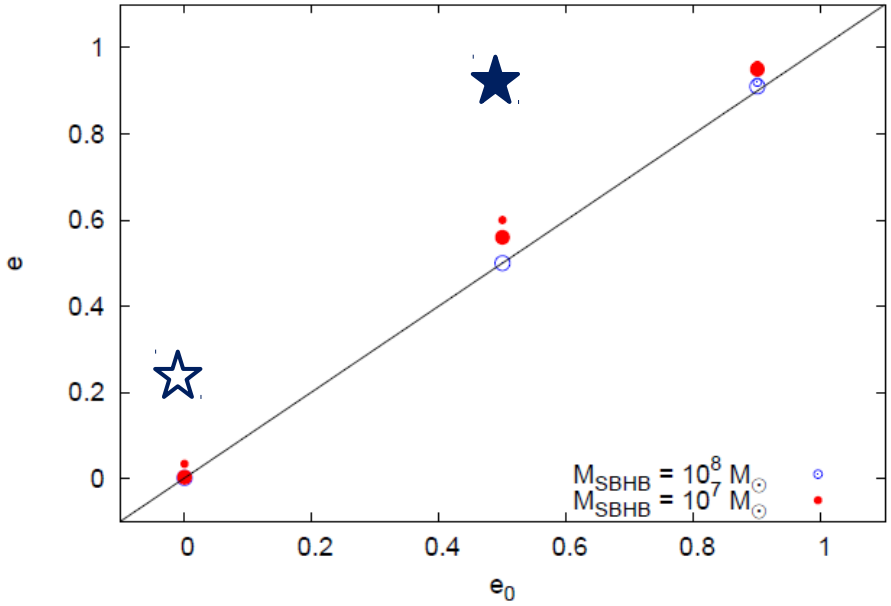


- $e_{bhb} = 0$
- $e_{cl} = 0.5$
- $M_{cl}/M_{bhb} = 0.01$
- $t_{GW}/t_{GW0} = 3 \times 10^{-3}$

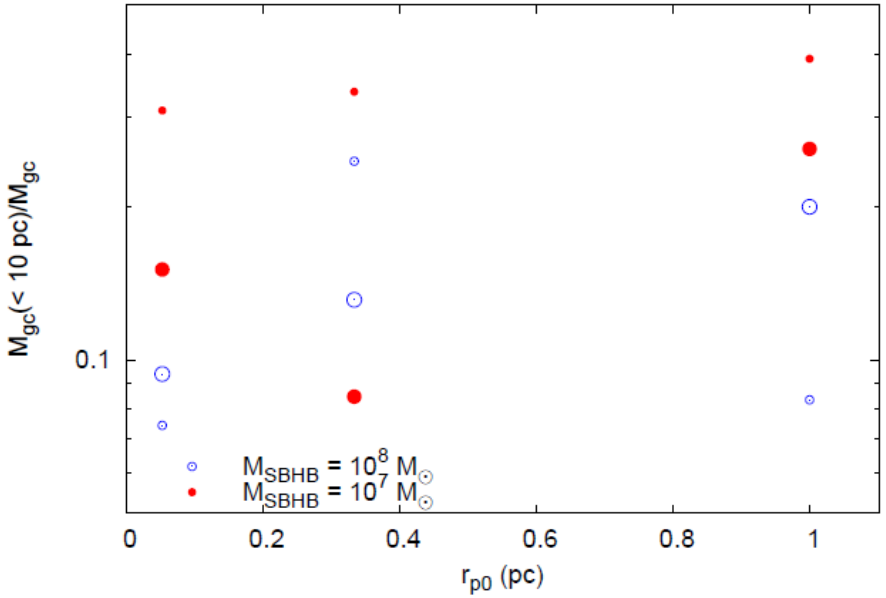
$e_{cl} = 0.5$

$e_{cl} = 0.9$

- $e_{bhb} = 0.5$
- $e_{cl} = 0.5$
- $M_{cl}/M_{bhb} = 0.01$
- $t_{GW}/t_{GW0} = 2 \times 10^{-4}$

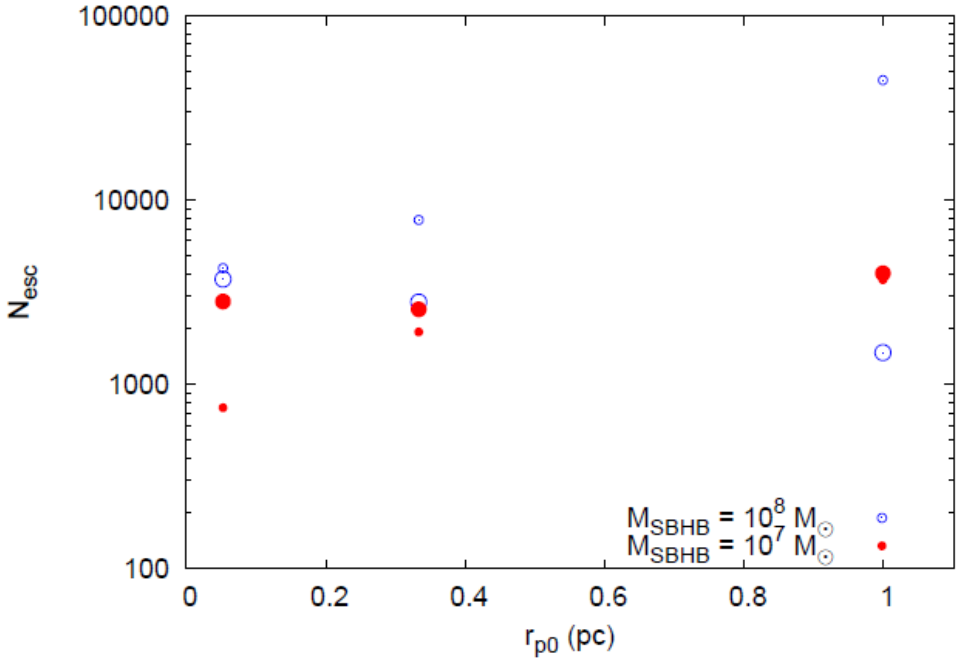


A more complex system: SMBHB and NCs



NC formation significantly obstaculated by tidal forces

Tidal disruption efficient:on average 15% of the GC mass is ejected away in form of high-velocity stars (v = 100-1000 km/s)



A more complex system: SMBHB and NCs

What are we missing?

- GCs sub-sampled … 65k → 2M particles (run time on 1GPU > 140yr)

- galaxy static potential: dynamical friction?

- stellar evolution ?

- stellar strong encounters, pairing, collisions?

Need of huge HPC facilities … maybe PRACE Tier-0 systems?

Piz Daint at CSCS would allow us to carry out a one-to-one model of star cluster infalling toward a SMBHB