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Gravitational wave signals from star clusters

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Single-Binary encounters in star clusters

Hubble Space Telescope image of NGC 1898, a globular cluster in the Large Magellanic Cloud.

We need:

- dense environment
- hard binaries : $E_b = \frac{G\, m_1\, m_2}{2\, a} \geq \frac{1}{2} m_* \sigma^2$

We choose nuclear star clusters (NSC):

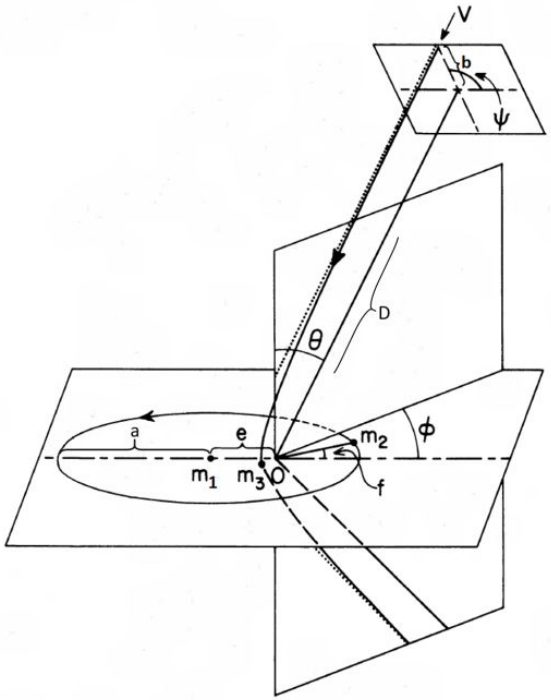
- high escape velocity (hundreds km s^{-1})
- easy to estimate, long lived, same age

Goal:

★ Mapping the characteristic frequency and the strain amplitude of these sources. Are these signals detectable from our interferometers?

G S
S I

Initial conditions



Credit: Hut & Bahcall 1983

- binary masses m1 & m2 and intruder mass m3
  computed from the astrophysical evolution of stars in a dense environment
- binary semi major axis a and eccentricity e
  in order to have an hard binary with *e* drawn following the thermal eccentricity distribution
- velocities v
  from a Maxwellian distribution
- geometrical parameters: angles ϕ,ψ,θ , orbital phase, impact parameter b, initial distance of the intruder D
- spins of the three BHs
- NSC properties

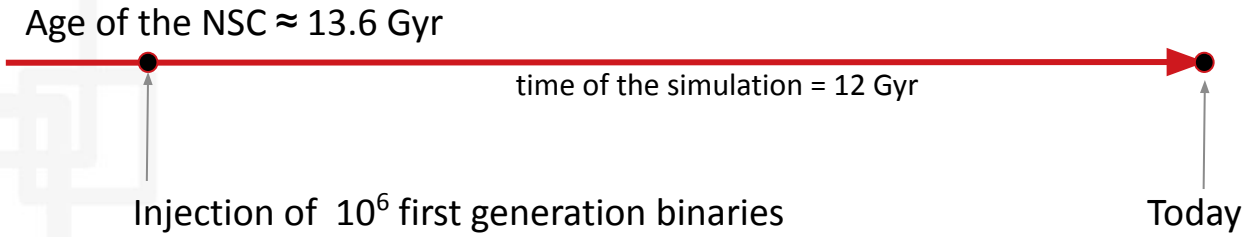
Number of encounters

★ We set up a simulation in which binaries evolve over time due to three-body encounters and gravitational wave emission in the cluster.

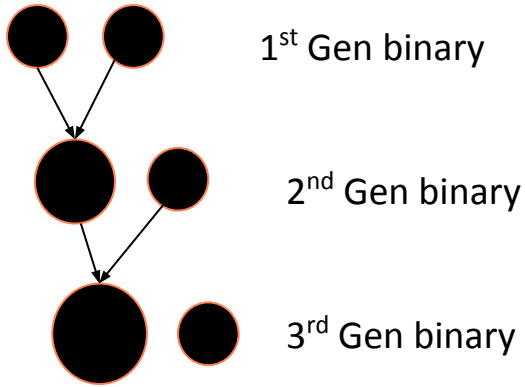
✗ we don't know the number of BBHs in NSC as a function of redshift

✓ we can estimate it at the formation of the cluster $\rightarrow N_{BBH} \approx 7.5$

➔ At D=160Mpc there is the evolution of 10^6 first generation binaries



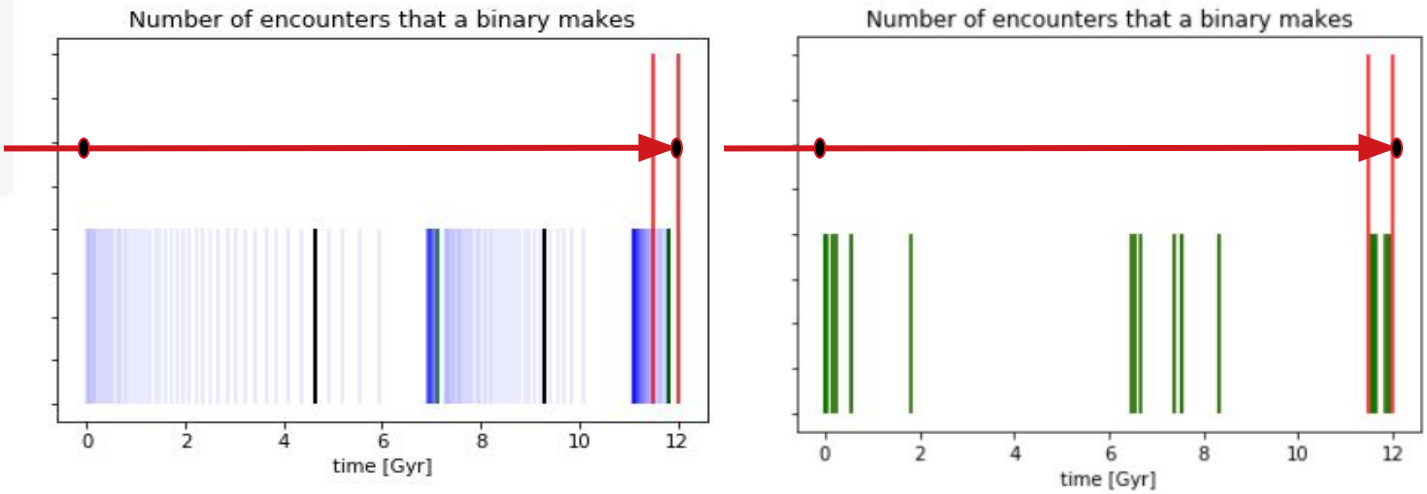
Scheme of hierarchical mergers



Number of encounters

Two different sizes of the NSC core:

- ★ 1 pc (lower limit)
- ★ 0.1 pc (upper limit)



Conditions:

- ❑ Time of the simulation & velocities
- ❑ *Sma* with respect to the critical *sma*
- ❑ Merger: kick velocity, new masses, new spins

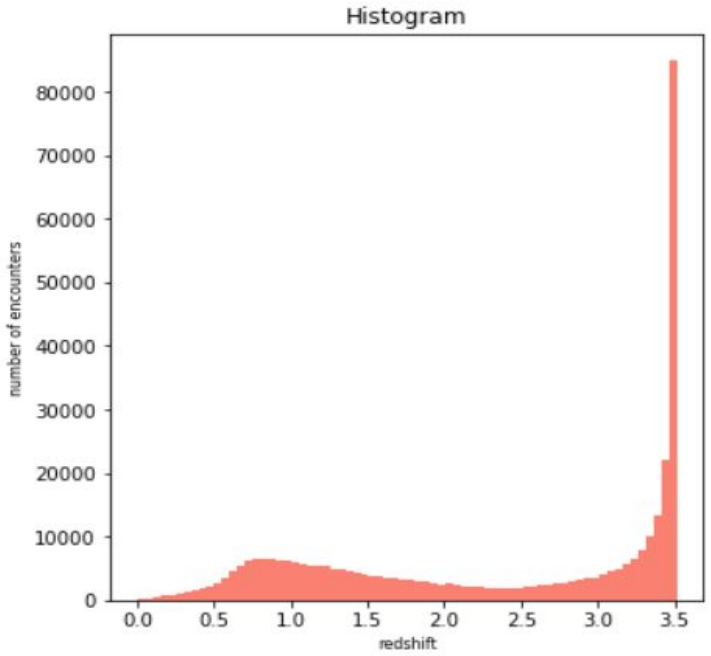
Legend:

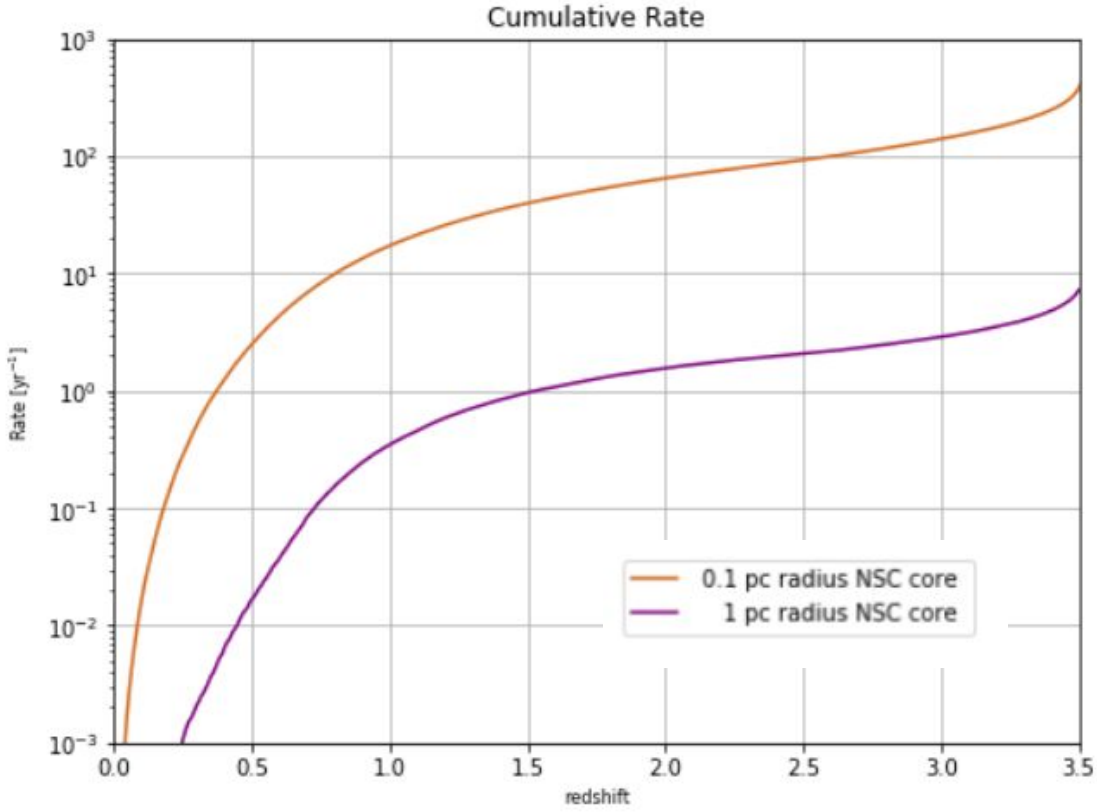
- ❖ Blue: the intruder is a star
- ❖ Green: the intruder is a BH
- ❖ Black: $a = a_{critical}$
- ❖ Red: sphere of 160Mpc radius

Rate

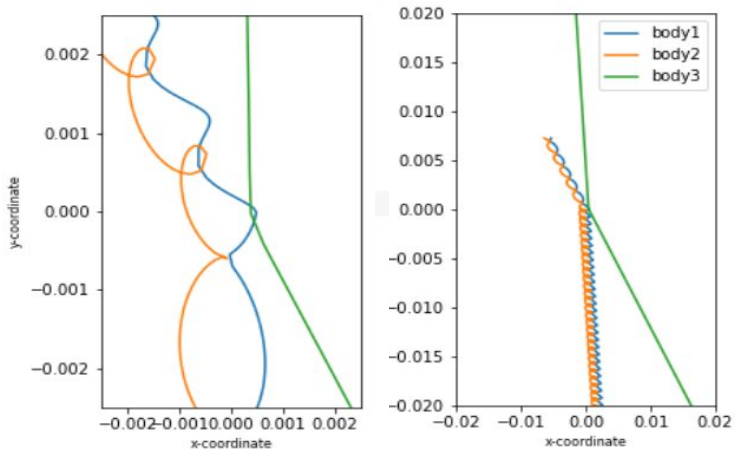
From 10^6 original binaries:

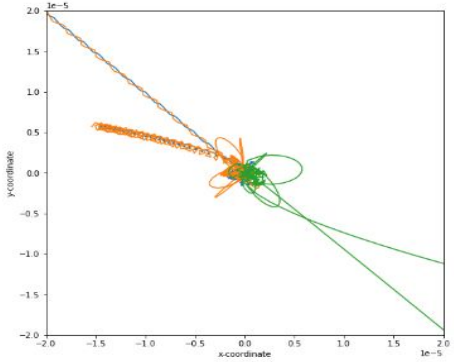
- ★ 1 pc radius : 3.6×10^5 encounters
- ★ 0.1 pc : 2×10^7 encounters

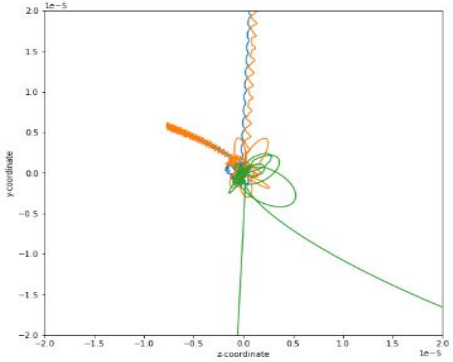




ARWV Nbody code







From the *Number of encounters* calculation:

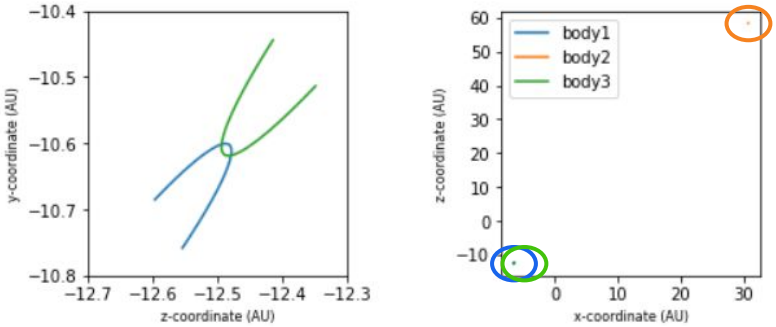
- We have a snapshot of:
  m1, m2, sma of the binary, m3, redshift
- we assign to the encounter:
  ecc of the binary, v, b and angles

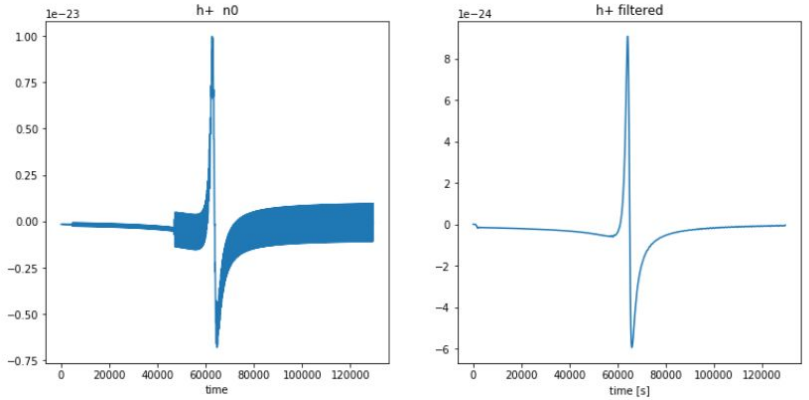
Simulated with ARWV:

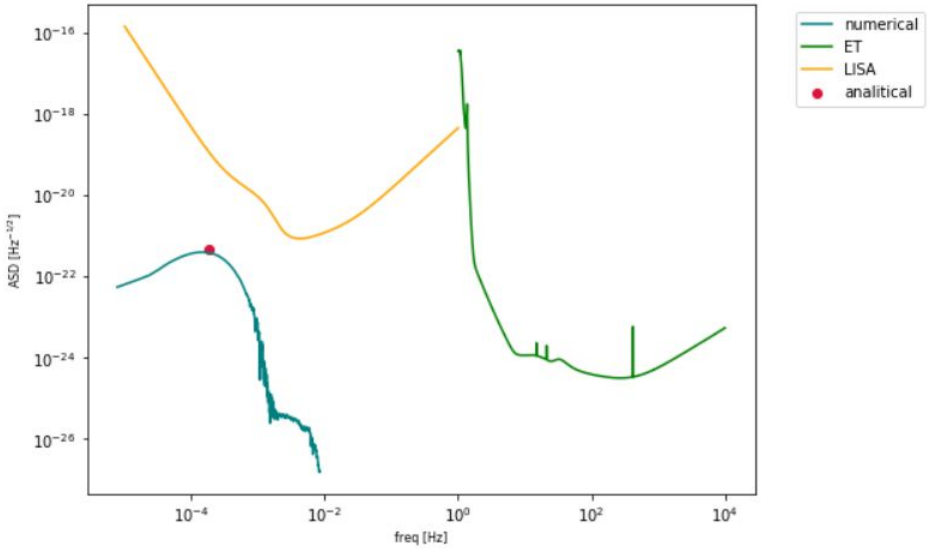
we selected a sample in order to find some useful events for ET and LISA:

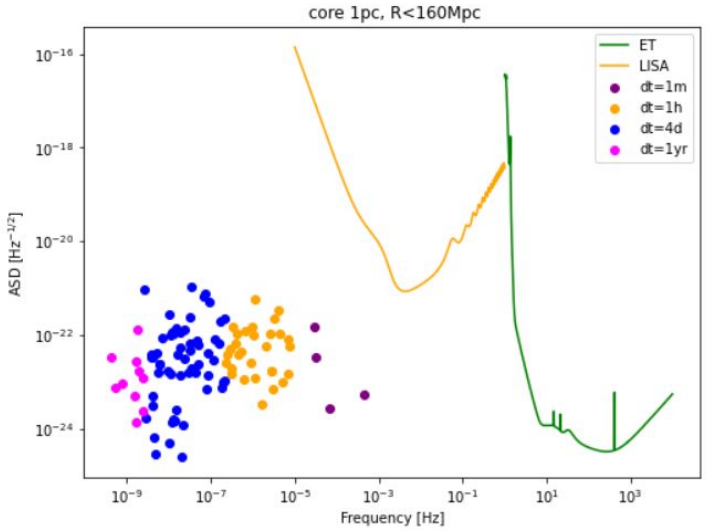
- R < 160Mpc
- v > 190 km/s
- M1> 450 Msun
- Sma < 0.2 AU

GW signal


y-coordinate (AU)
z-coordinate (AU)
body1
body2
body3
z-coordinate (AU)
x-coordinate (AU)


h+ n0
1e−23
time
h+ filtered
1e−24
time [s]


numerical
ET
LISA
analitical
ASD [Hz^-1/2]
freq [Hz]


core 1pc, R<160Mpc
ET
LISA
dt=1m
dt=1h
dt=4d
dt=1yr
ASD [Hz^-1/2]
Frequency [Hz]

Conclusions

- We are working on identifying the range of frequencies-amplitudes that single-binary encounters occupy.
- Until now two-body hyperbolic encounters have been studied and are now of interest to the LIGO/Virgo community for the next data taking runs.
- All cluster dynamical models predict single binary encounters. Detecting their GW signal will corroborate such models.
- Single binary encounters can act as a new source of information on the BHs mass population.