Shedding light on gravitational waves through GPU computing

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arxiv.org/abs/1404.7147


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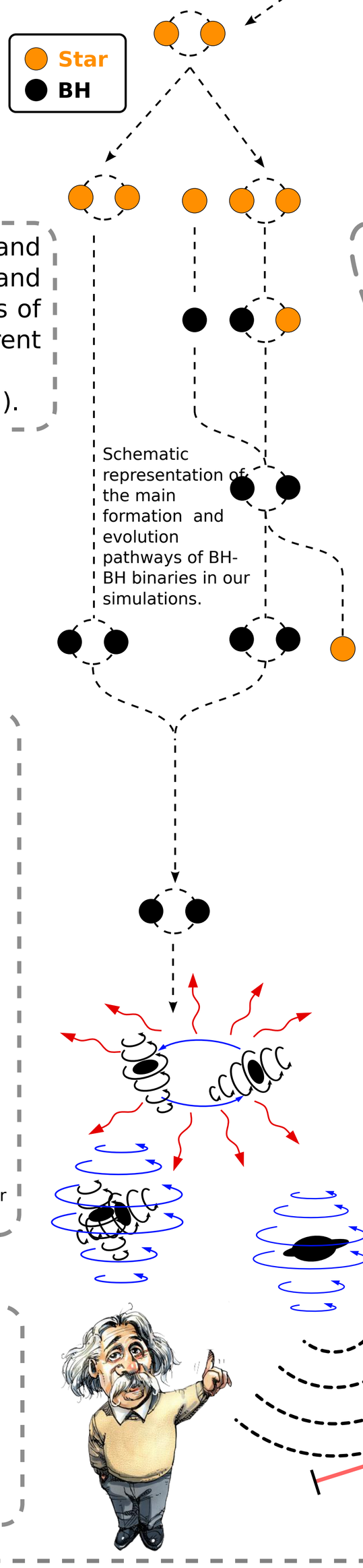
Overview

Mergers of black hole (BH) and neutron star (NS) binaries in dense star clusters are expected to be powerful sources of gravitational waves (GWs).

It is extremely important to understand the **dynamical evolution** of BH and NS binaries, and to make predictions of their **merger rate** in different **astrophysical environments** (Ziosi et al. 2014, Ziosi et al. in prep.).

Metallicity is important:
- Heavier BHs form from metal-poor stars
- They tend to form BH-BH binaries at early times
- These binaries are more stable

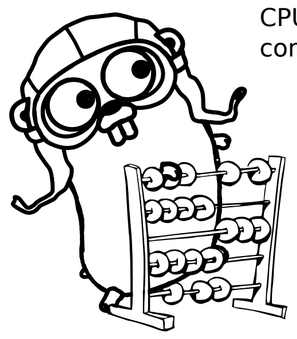
Environment:
young dense star cluster were stars evolve and dinamically interact

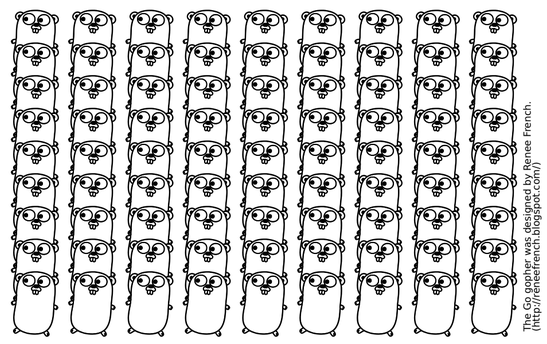


Schematic representation of the main formation and evolution pathways of BH-BH binaries in our simulations.

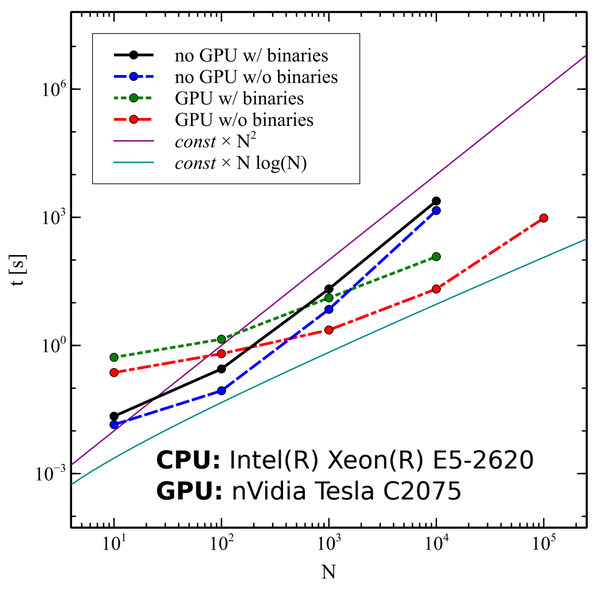
GPUs

Simulating BH and NS binaries in star clusters is a **challenging task**, because it requires to couple an **accurate integration of dynamics** with advanced **recipes for stellar and binary evolution**. To reach this goal, we make use of **advanced direct-summation N-body codes** (Portegies Zwart et al. 2001, Mapelli et al. 2013), which are well suited to run on graphics processing units (**GPUs**).


CPUs are single complex generic computational tools.



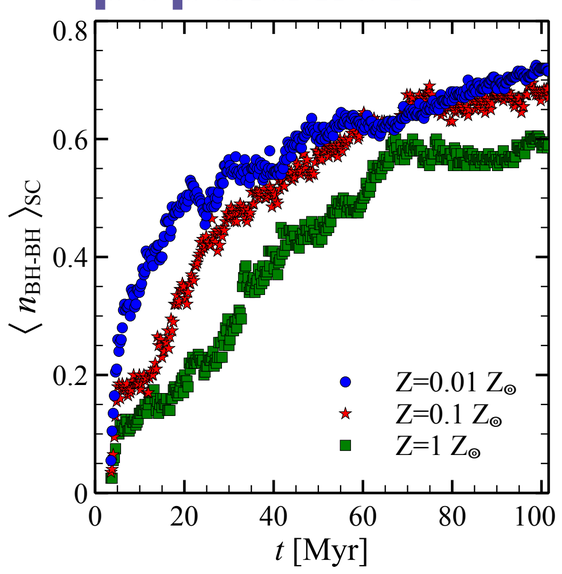
GPUs are a huge set of simple but massive parallel computational units.



GPU are **essential** to run our simulations in reasonable times. Because of the **massive parallel** execution, **gravity computations** can benefit of very large **speed-ups**.

Outcomes

BH binaries population

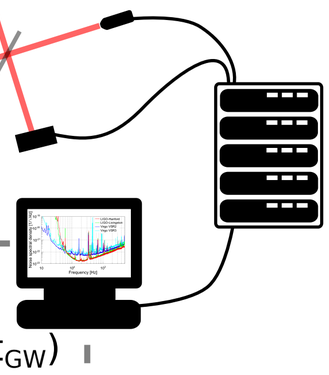


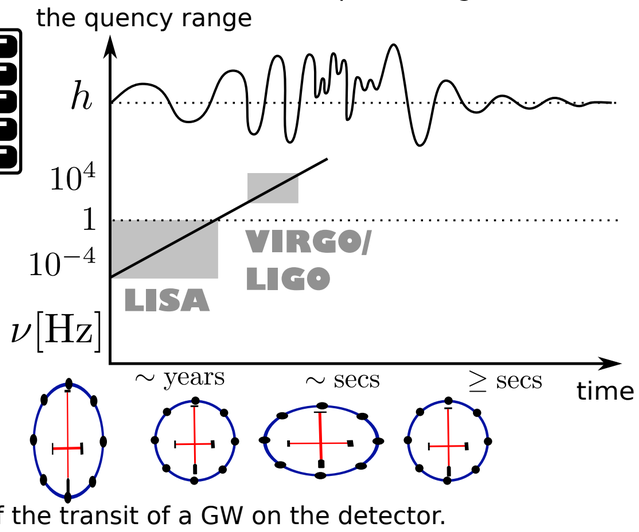
Average number of BH-BH binaries per star cluster as a function of time for different metallicities.

Dynamics is important:
- It enhances the formation of DCOBs: 97% of BH-BH binaries come from exchanges
- It hardens binaries and can modify the eccentricity

GWs

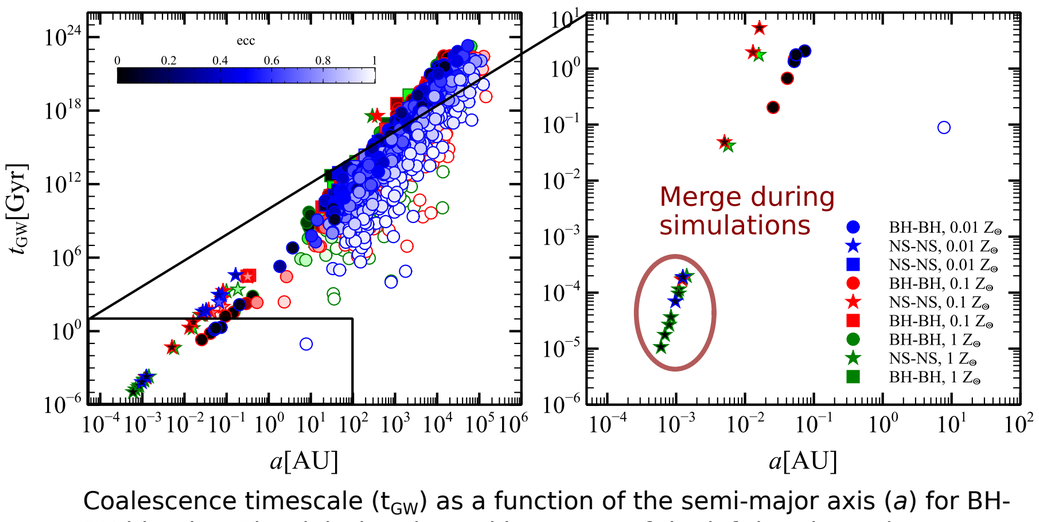
GWs are one of the most fascinating predictions of Einstein's theory.
They have **not been directly detected so far**, but the new second-generation GW interferometers, Advanced LIGO and Virgo, will start operating in the next two years, prompting the expectations of a large scientific community (Abadie et al. 2010).





Effect of the transit of a GW on the detector.

Coalescence timescale



Coalescence timescale (t_{GW}) as a function of the semi-major axis (a) for BH-BH binaries. The right-hand panel is a zoom of the left-hand panel.

- Coalescence timescale (t_{GW}) is the time a system needs to reach semi-major axis a=0 due to orbital decay by GW emission (Peters 1964)
- 7 DBHs with t_{GW} < 13 Gyr (0 for $Z=Z_{\odot}$)
- 17 DNSs with t_{GW} < 13 Gyr
- 11 DNS mergers during the simulations

$\longrightarrow$ over the 600 simulated star clusters

Bibliography

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- Mapelli et al. 2013, MNRAS, 429, 2298
- Portegies Zwart et al. 2001, MNRAS, 321, 199
- Peters P.C., 1964, Phys. Rev., 136, 1224
- Abadie et al., 2010, CQG, 27, 173001