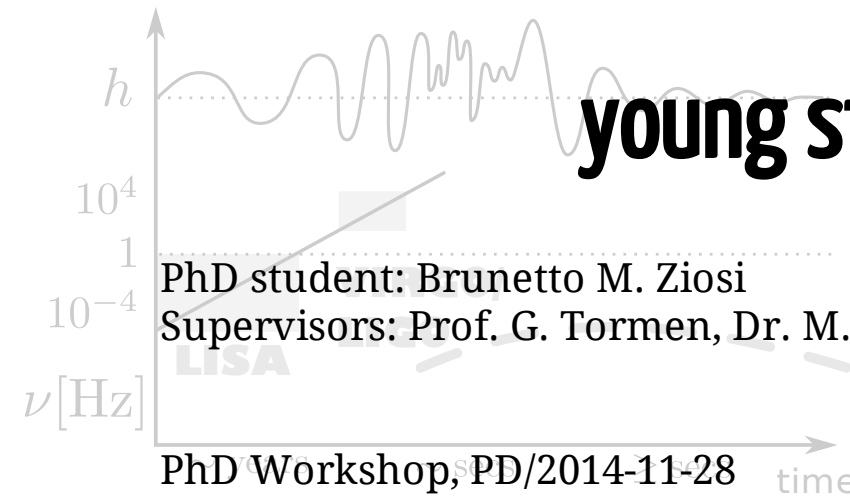
Gravitational waves from the nursery of stars: simulating black hole mergers in young star clusters



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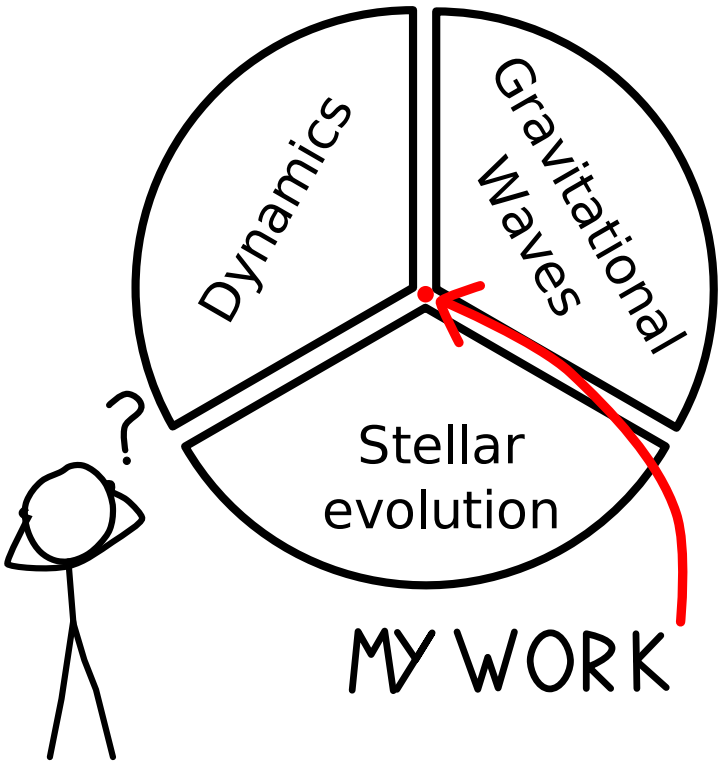
Supervisors: Prof. G. Tormen, Dr. M. Mapelli

PhD Workshop, PD/2014-11-28

Outline

Introduction



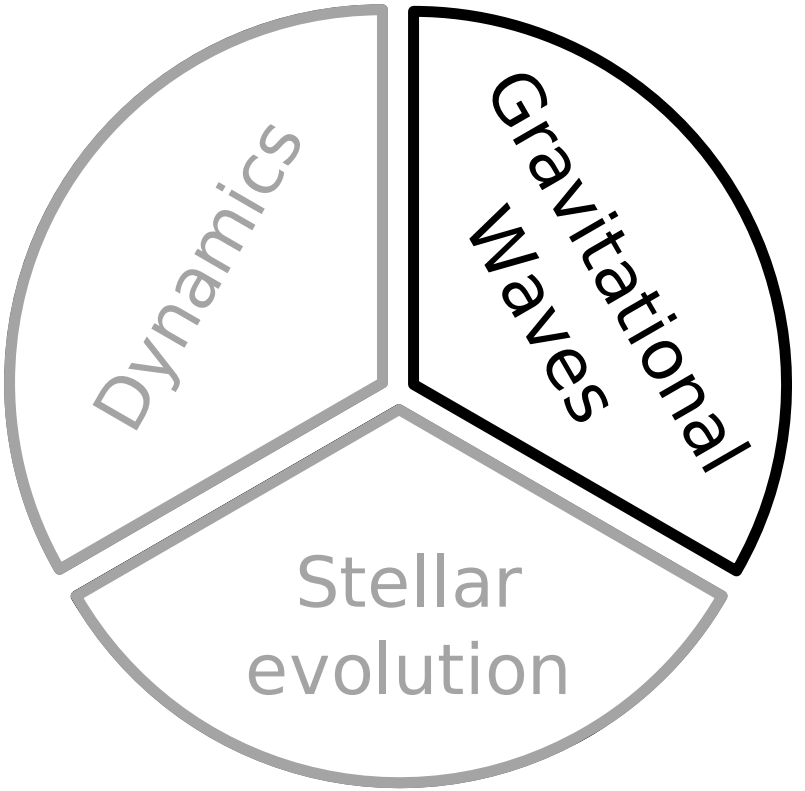
My work

The impact of ...

1. ... **dynamics** and **metallicity**...
2. ... a galactic **tidal field**...
3. ... different initial **structural properties** of SCs...

on the formation and evolution of double compact-object binaries

Gravitational waves



GWs

- Direct confirmation of General Relativity

- GWs from **BH-BH binaries** during inspiral and merger events

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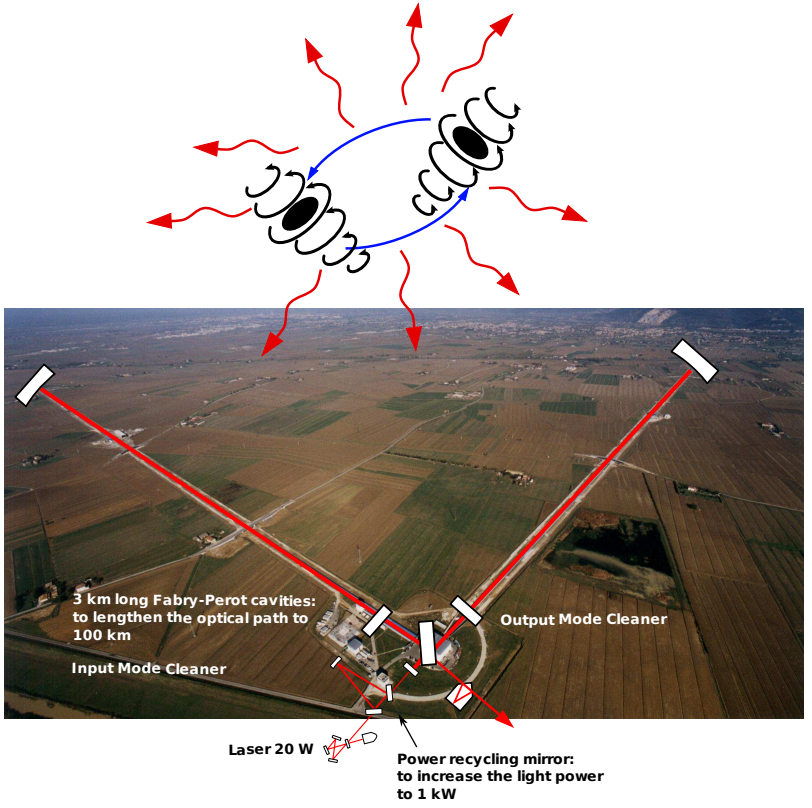
- Now it is the perfect time: **Adv. Virgo/LIGO**!!

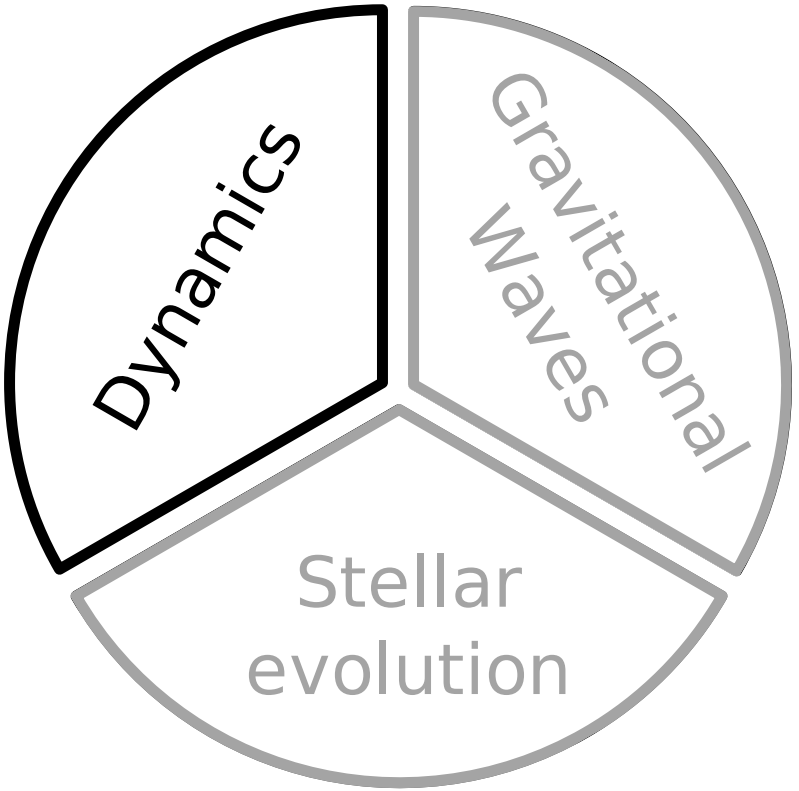
- Investigate processes with no EM emission

- **Multi-messenger astronomy** for those objects emitting both EM and (strong) GW signals

"... ripples in the space-time propagating at the speed of light... "

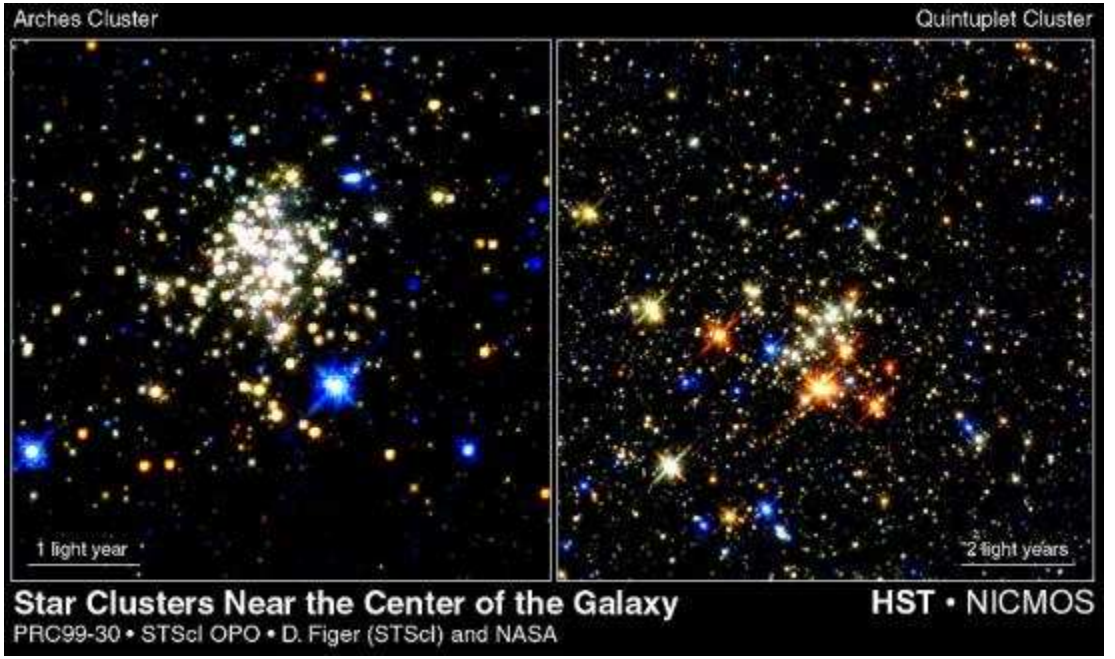


Dynamics



YSC Facts

- YSCs are birthplace for ~ 80% of stars in the local universe
  (Lada&Lada, 2003)



- They dissolve into the galactic disk because of the galactic tidal field, releasing their content

YSC Facts

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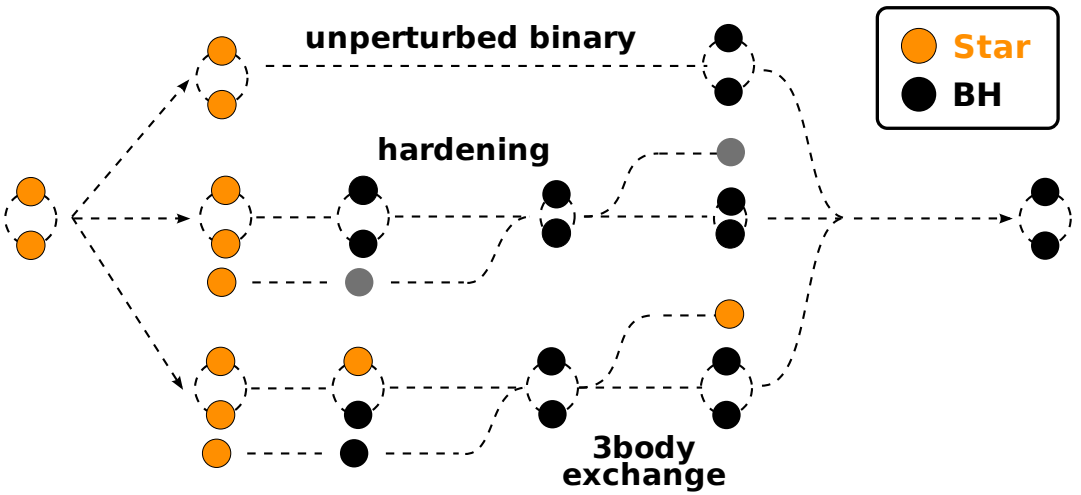
- (Collisional) YSCs are
  - young (< 100 Myr)
  - relatively massive ($10^3 - 10^7 \mathrm{M}_\odot$),
  - dense ($10^3 - 10^6$ pc^{-3})

  groups of stars

- Y**D**SCs are sites of intense dynamical activity: central $t_{\mathrm{relax}} \sim 10 - 100$ Myr

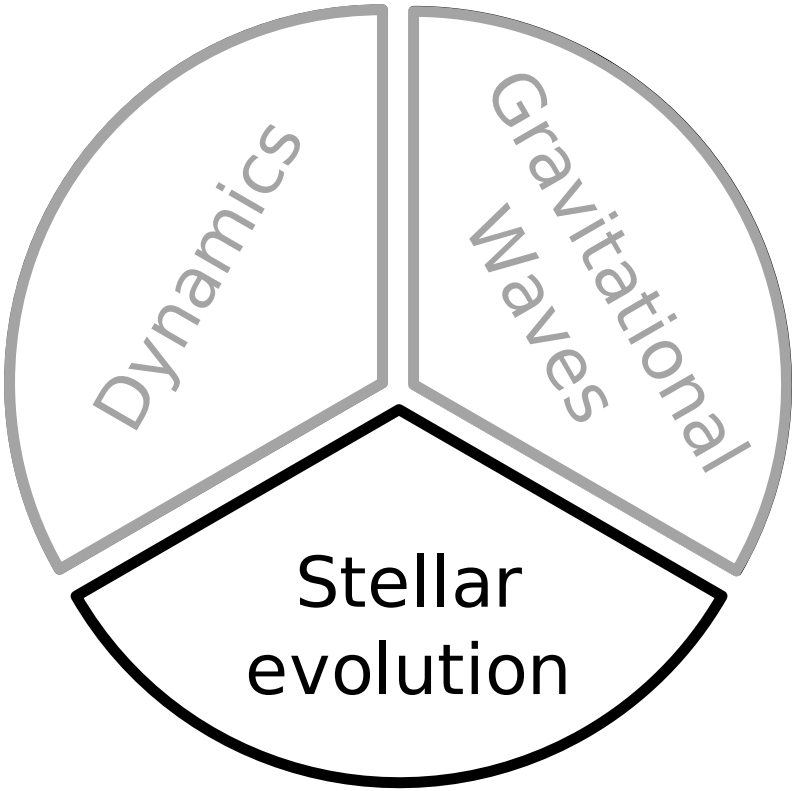
Stellar encounters

3-body encounters $\rightarrow$ hardening & exchanges

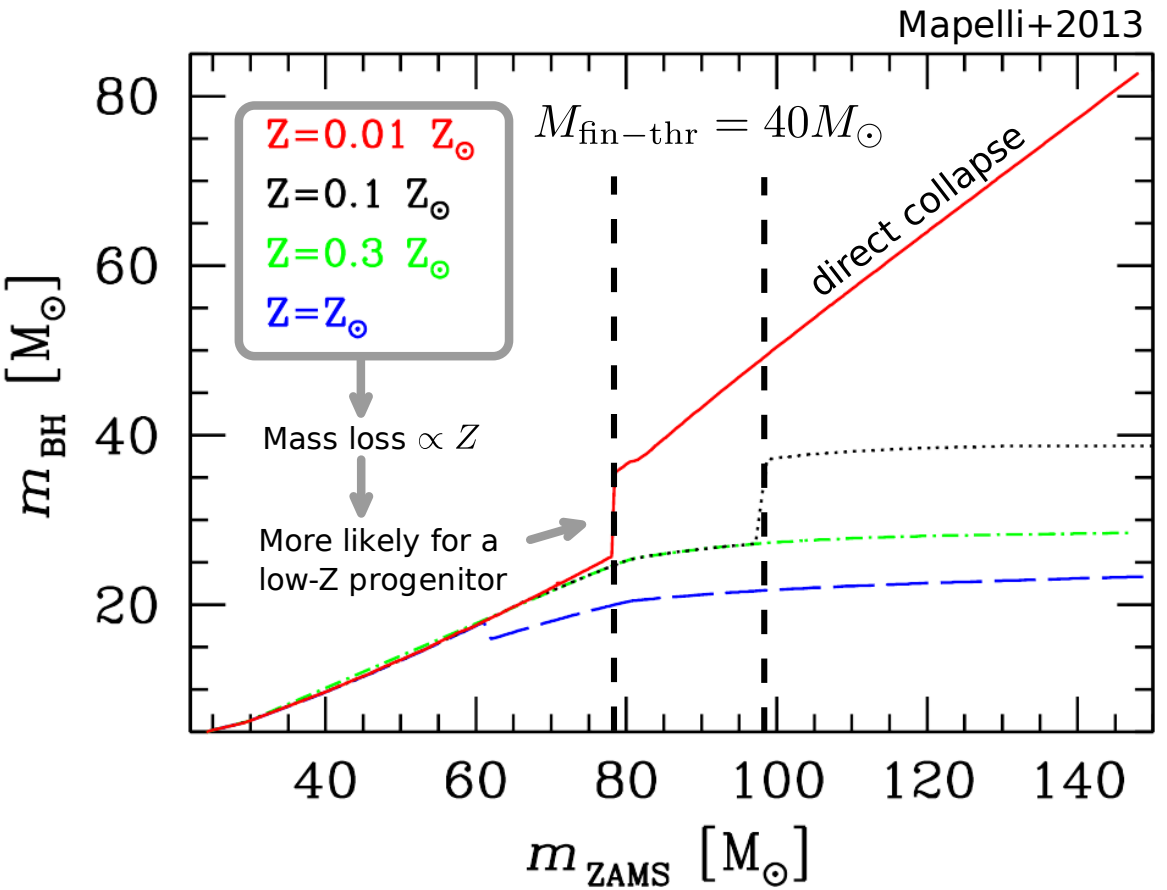


BHs have high masses $\Rightarrow$ high probability to acquire a companion through 3-body exchange

Stellar evolution

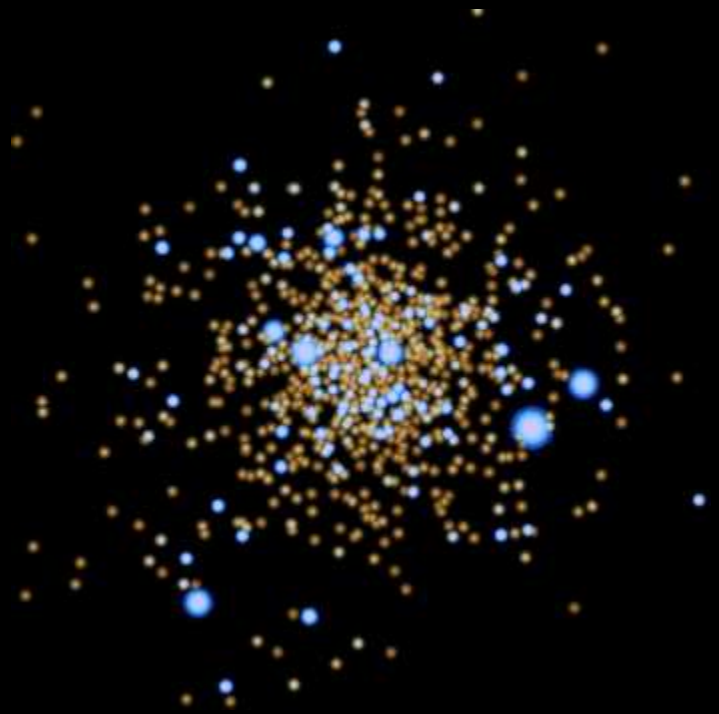


Stellar evolution



(Fryer 1999, Fryer&Kalogera 2001, Mapelli+2013)

Starlab



- N-body + stellar evolution
- Each particle is a star (with its physics)
- Updated to take into account different metallicities

My work

The impact of ...

1

... **dynamics** and **metallicity**...

2

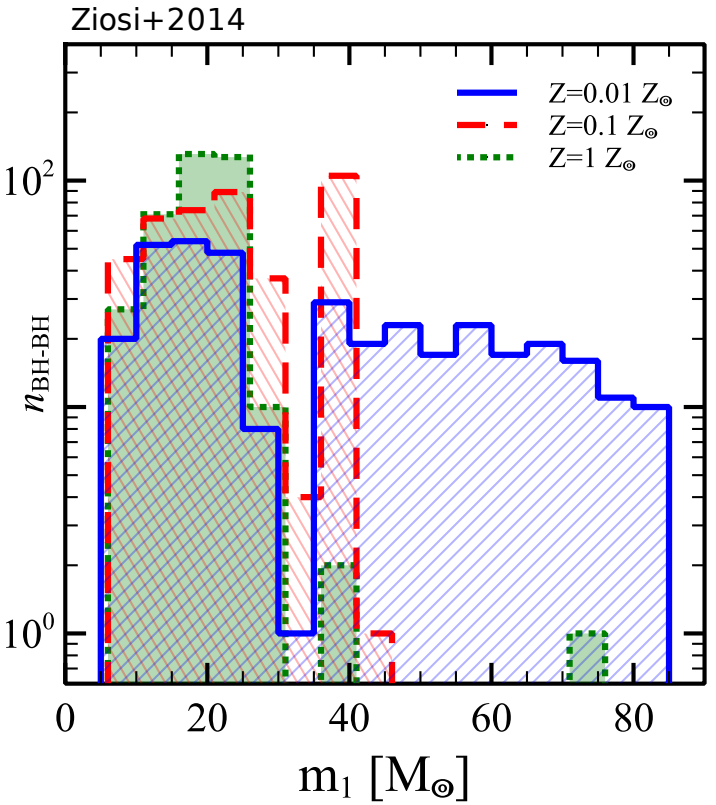
... a galactic **tidal field**...

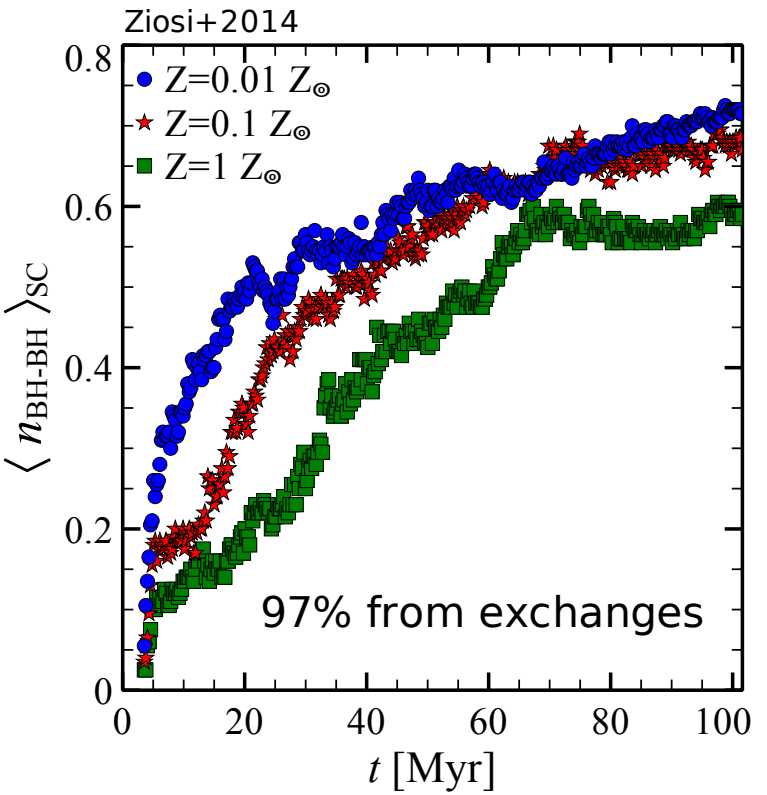
3

... different initial **structural properties** of SCs...

on the formation and evolution of double compact-object binaries.

Dynamics and metallicity





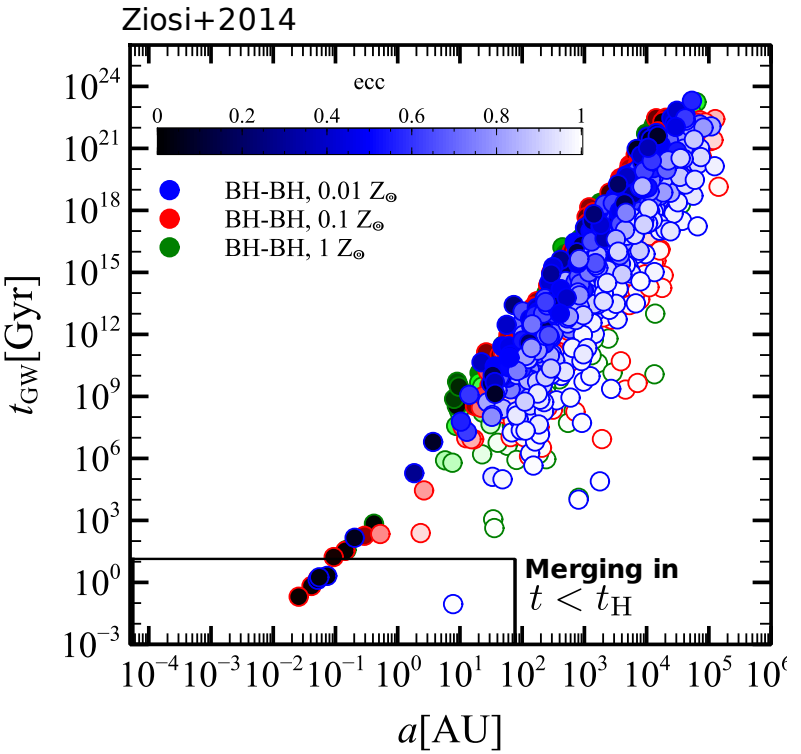
Dynamics and metallicity

Coalescence timescale

- Analysis of the binary properties: SMA, eccentricity, mass, ...
- Derived the time needed to coalesce because of GWs emission (Peters 1964):

$$t_{\rm GW} \propto \frac{a^4(1-e^2)^{7/2}}{m_1 m_2 m_T}$$

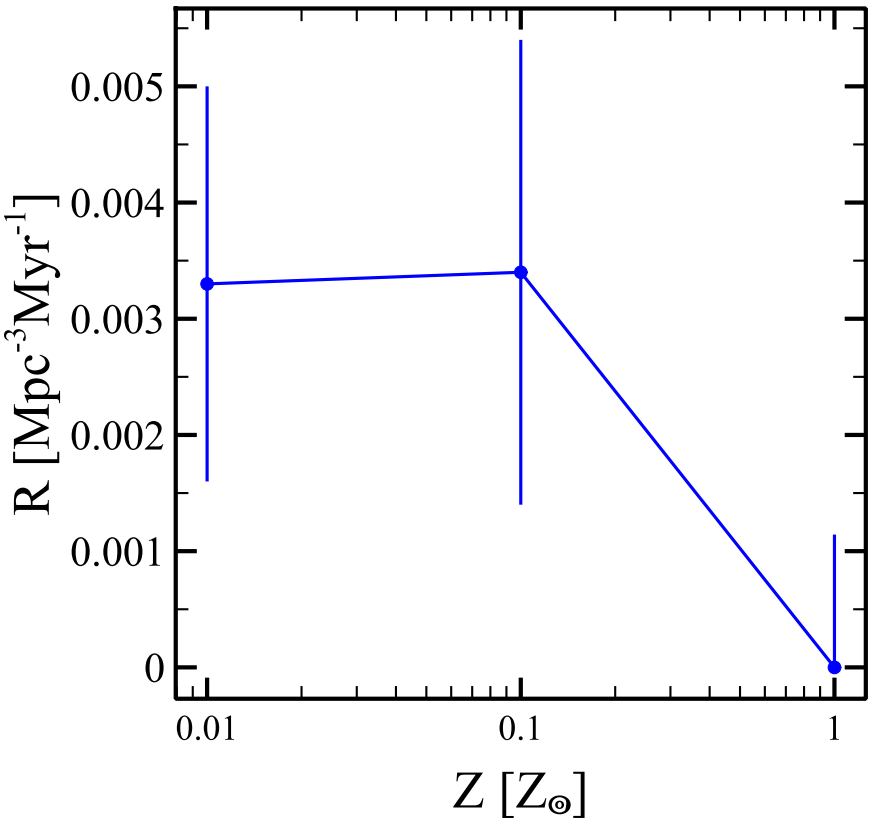
- 7 BH-BH in less than t_H over 600 simulations



Dynamics and metallicity

More info
arxiv.org/abs/1404.7147
MNRAS 441, 3703–3717

Merger rates



Dynamics and metallicity

What else?

The results I obtained, however, stand on two critical assumptions:

- SCs live **unperturbed** in **isolation** for 100 Myr
- Random realizations of a **single SC model**

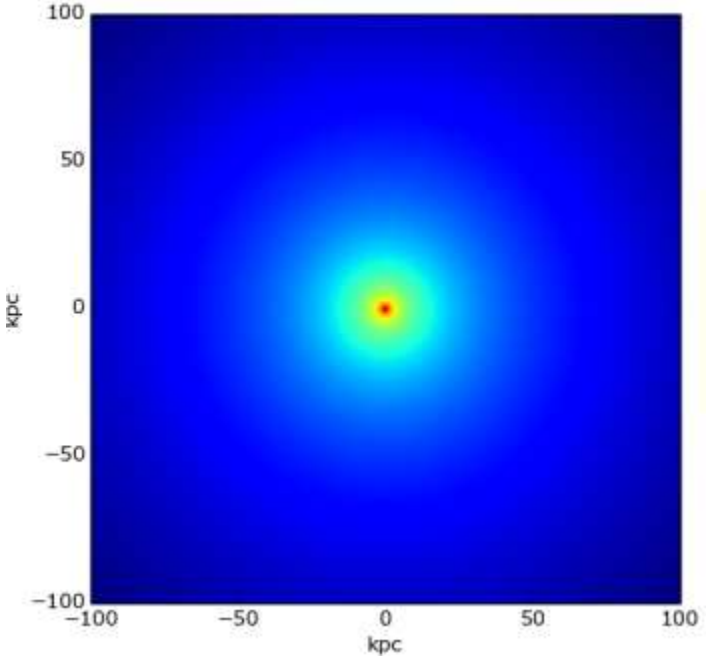
Both these assumptions can heavily affect our estimate of BH demographics.

Tidal fields

Why?

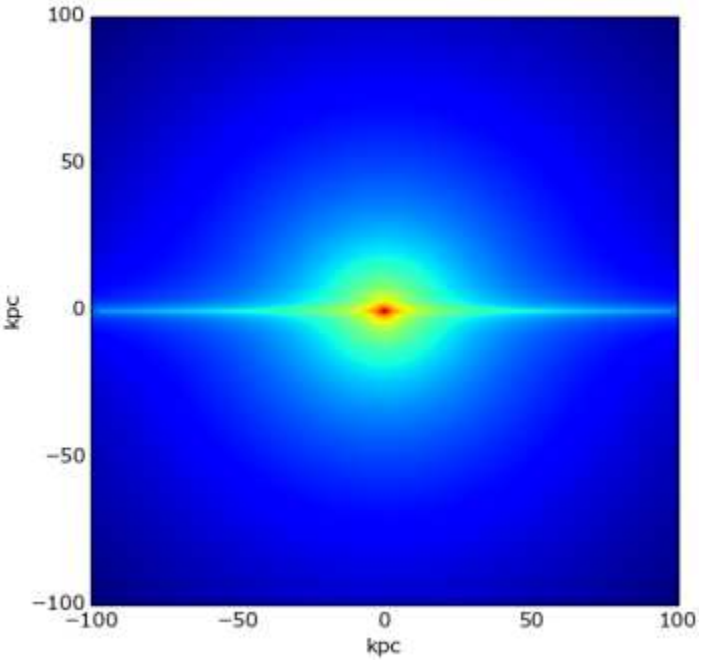
- YSCs are **not isolated** in the universe
- Overestimate the cluster **lifetime**
- Dynamical interactions
- Interesting:
    - Cluster close to the galactic center
    - Cluster in the solar region
    - Eccentric orbit

Tidal fields: which one?



Starlab public version

Spherical bulge (Plummer) only



My upgraded version

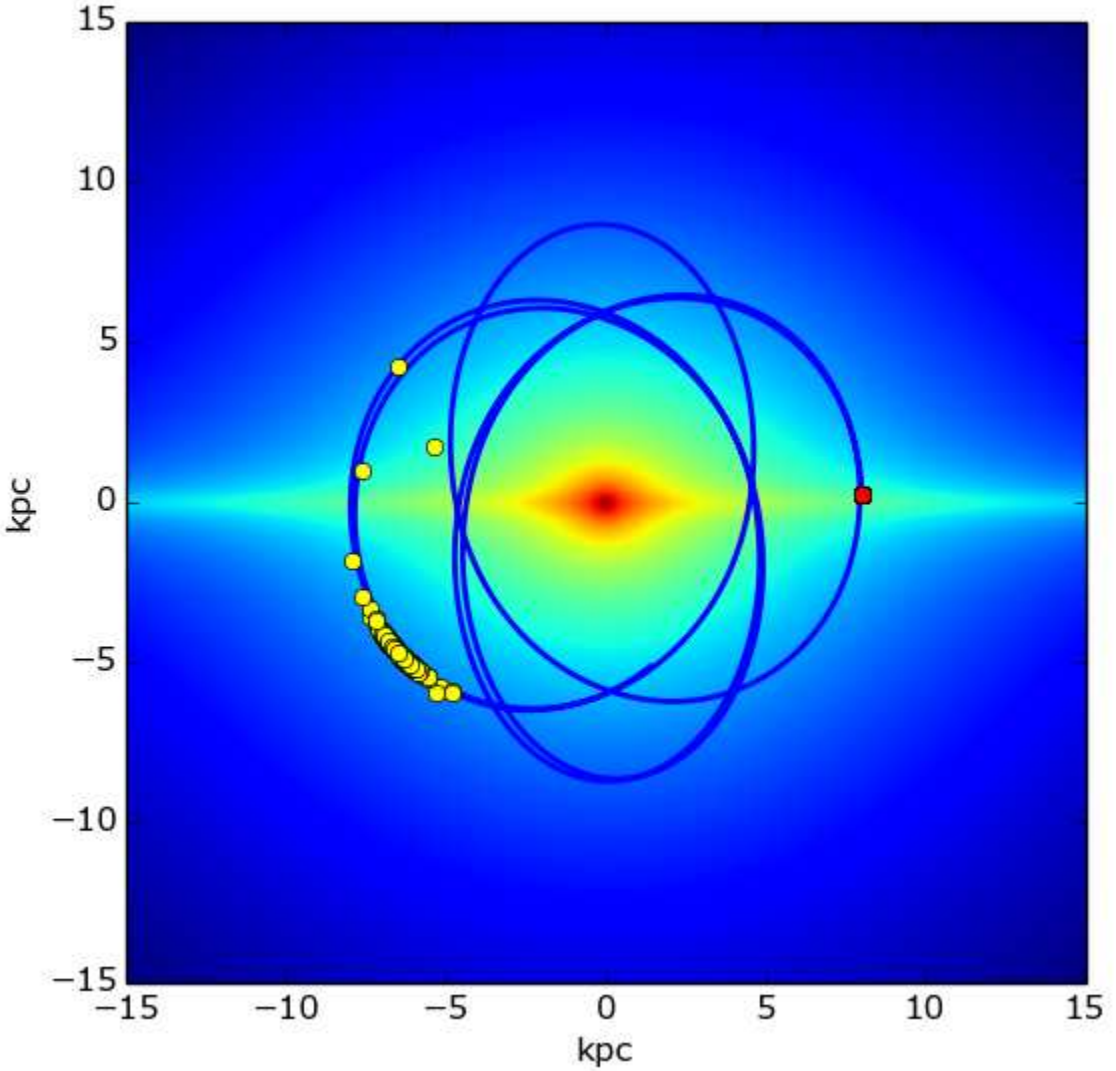
Bulge + disk + halo
(Milky Way-like potential)
(Ziosi+2015a in prep., Allen&Santillan 1991)

Tidal fields

Why?

Which?

Test



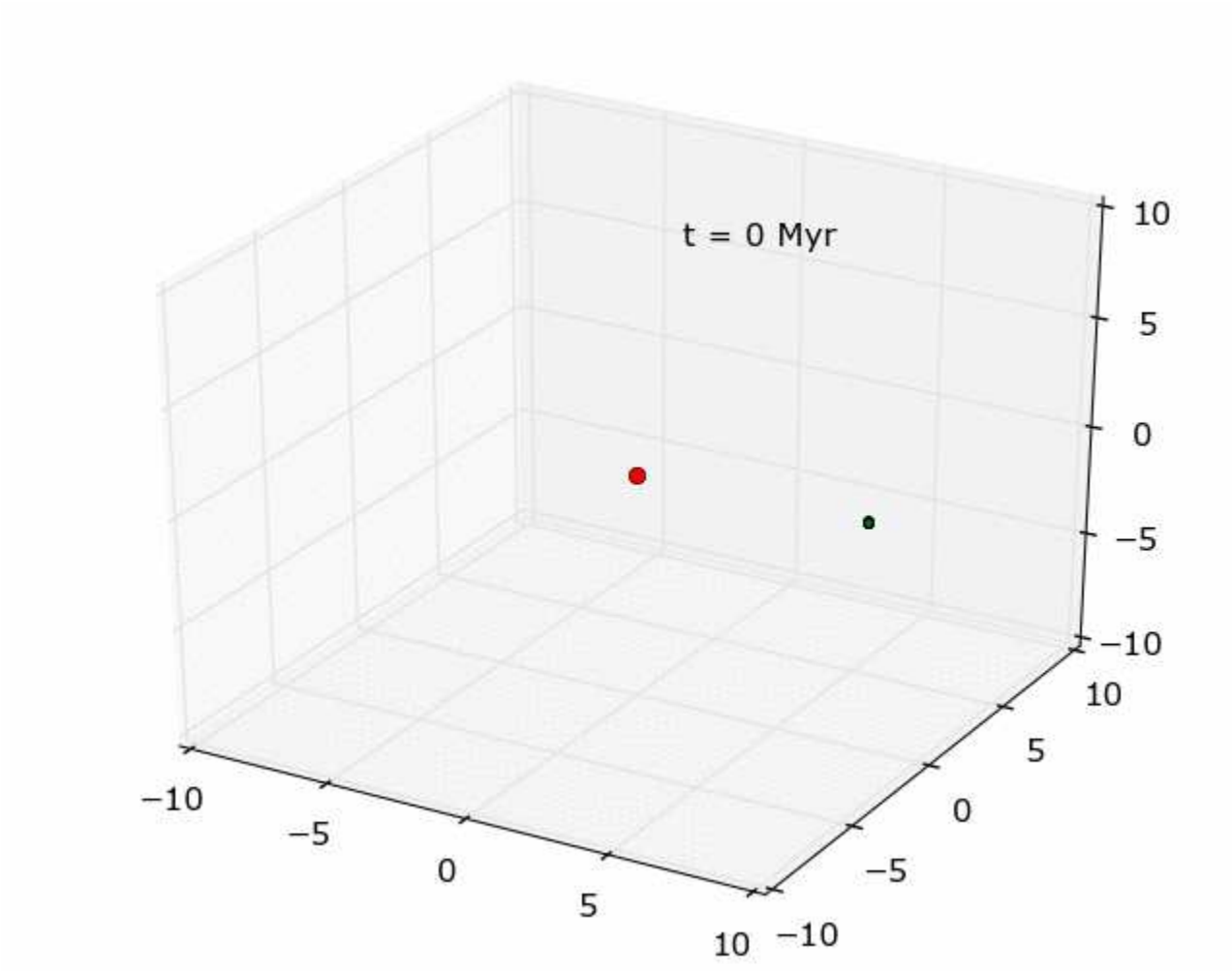
Polar orbit to test the code superimposed to the galactic density map.

Tidal fields

Why?

Which?

Test



Structural properties

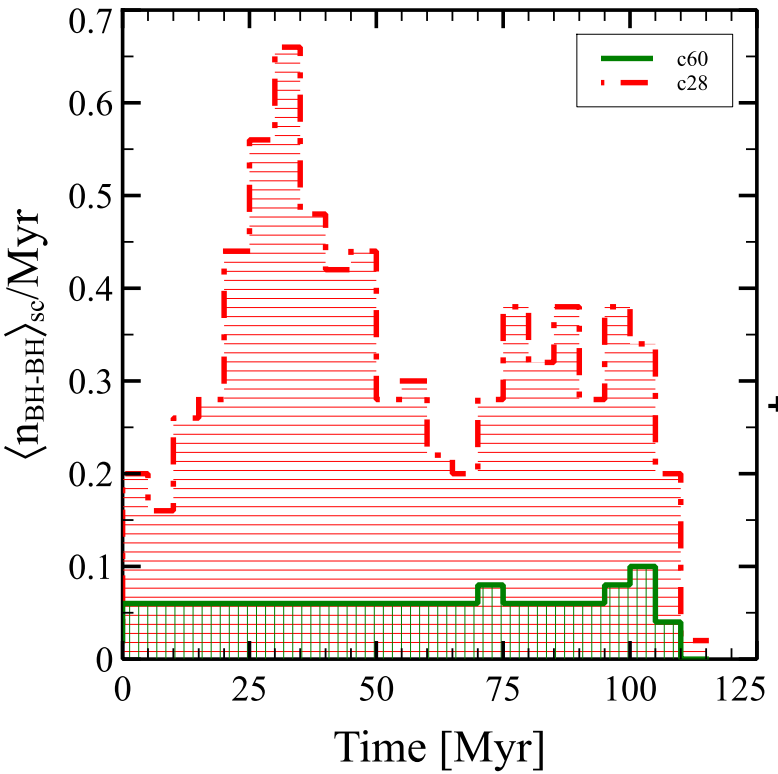
- Structural properties $\Leftrightarrow$ dynamical interaction rate
- Which **characteristics** of the SCs are **more important**?
- **Calibrate** our results on the real population
- ~10^3 simulations (Ziosi+2015b, in prep.)

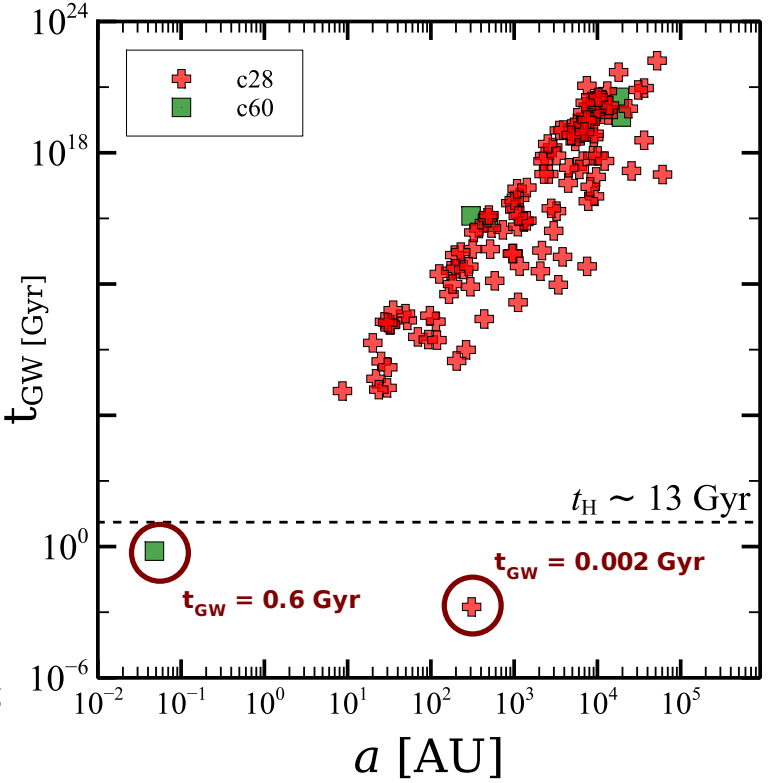
Gravitational well depth W_0	3, 5, 9
Number of stars N_* :	$1 \times 10^4, 5 \times 10^4, 1 \times 10^5, 5 \times 10^5$
Virial radius $r_{\rm v}$ (pc)	1, 3, 5
Metallicity Z ($Z_\odot$)	0.1, 1
Primordial binaries fraction $f_{\rm PB}$	0.05, 0.1, 0.2

Structural properties - Highlights

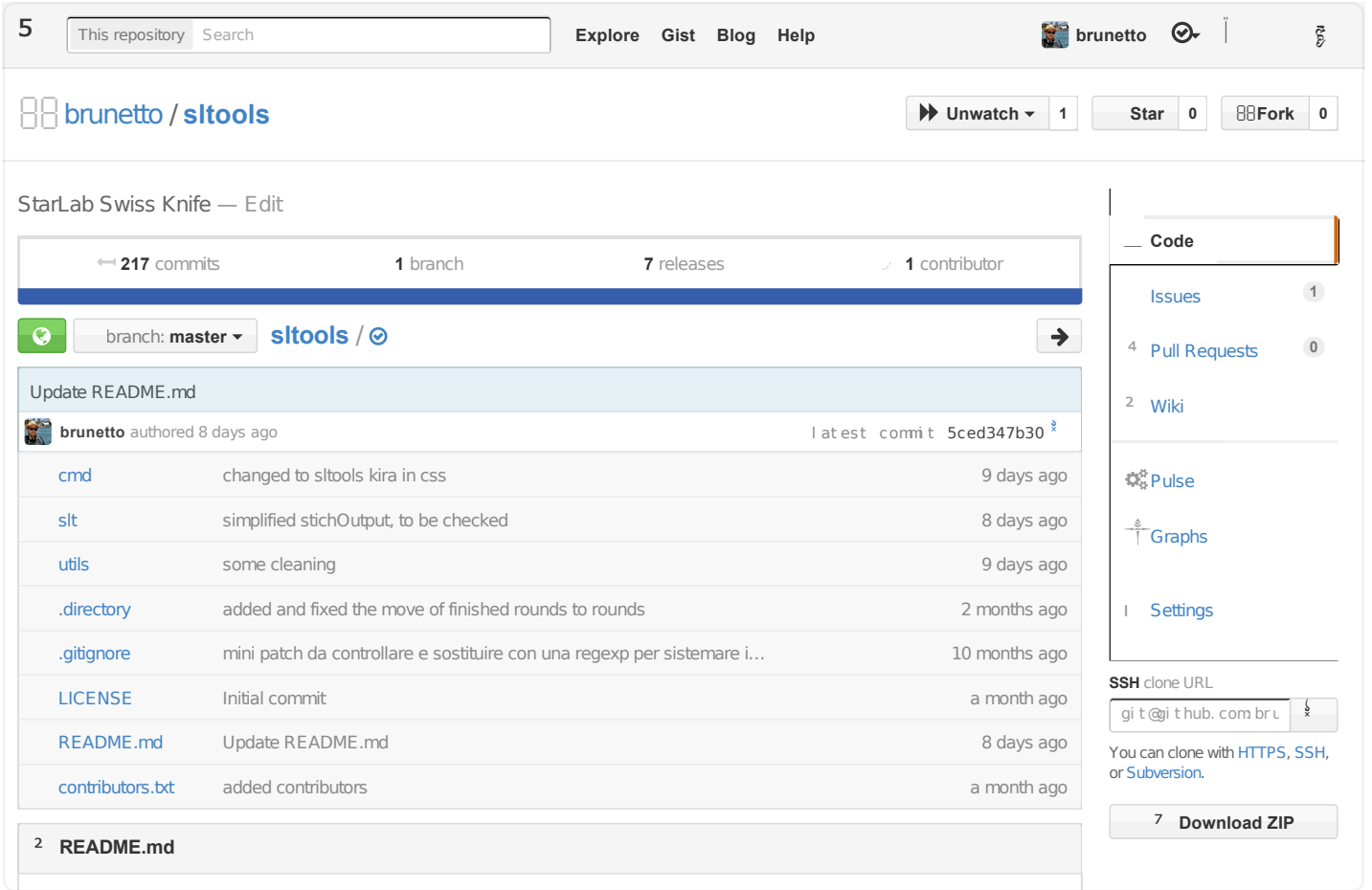
c28: more concentraded,
5% primordial binaries

c60: less concentrated,
10% primordial binaries





https://github.com/brunetto/sltools



Conclusions

- I analyzed 600 simulations to study the impact of dynamics and metallicity on the formation and evolution of DCOBs (Ziosi+2014):
  - Low metallicity favours the **early** formation of **heavy** and **stable** BH-BH binaries
  - It's likely that a massive BH **acquires a companion** through **dynamical exchanges**
  - Metallicity has a role in determining the final **merger rates**

- I implemented and tested **Allen&Santillan tidal field** in `StarLab`: runs and analysis in progress (Ziosi+2015a, in prep.)

- I prepared a grid of simulations to study clusters with **different initial conditions**: runs and analysis in progress (Ziosi+2015b, in prep.)

Thank you!;D