PROBING BLACK HOLE MERGER HISTORY WITH GRAVITATIONAL WAVES

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1. Introduction

MOTIVATION:

- Massive black holes (MBH), residing at the centers of many (if not all) galaxies, have masses ranging from $10^4 - 10^{10}$ solar masses and are undeniably intertwined with their galactic hosts [1]. Moreover, they have already existed when the Universe was less than 800 Myrs old. Unfortunately, we are still unable to explain these relations in a detailed and consistent way and thus the origin, properties and evolution of both, MBH and galaxies themselves remain as open questions.

SOLUTION?

- LISA (Laser Interferometer Space Antenna) mission will detect gravitational waves from merging MBH up to redshift $z \sim 20$ (age of the Universe $\sim$ 180 mln years). This will allow us to study the early stages of MBH formation and subsequent evolution.
- Hereby, we present our calculations of LISA sensitivity and detection rates for MBH population generated in a novel semi-analytic galaxy evolution model SHARK [2].
- SHARK is based on SURFs N-body simulations using ΛCDM cosmology [3]. Central MBHs grow via 3 channels a) mergers, b) star bursts and c) radio mode accretion. The mergers of central MBHs are assumed to occur instantaneously after their host galaxies merge.

2. Methods

SNR CALCULATIONS:

The signal to noise ratio (SNR) averaged over sky location, inclination and polarization is given by [4]:

$$\overline{SNR^2} = \frac{16}{5}\int \frac{2fTS_h(f)}{S_n(f)} d(ln\ f), \tag{1}$$

where T is the observation time, $S_n(f)$ is the LISA sensitivity curve and $S_h(f)$ is the one-sided, angle averaged, power spectral density of the signal.

DETECTION RATES:

The expected number of mergers per year is given by [5]:

$$\frac{d^2N}{dzdt} = 4\pi c N_{com}(z)\left(\frac{d_L(z)}{1+z}\right)^2 \ [year^{-1}] \tag{2}$$

where $N_{com}(z)$ is the merger rate density per unit comoving volume, $d_L(z)$ is the luminosity distance and c is the speed of light.

SHARK SIMULATION PARAMETERS:

- Hubble constant	$H = 100 \cdot h\ [\mathrm{km\,s^{-1}Mpc^{-1}}], h = 0.6751$
- BH seed mass	$m_{seed} = 10^4\ [M_\odot\, h^{-1}]$
- Halo seed mass	$m^{halo}_{seed} = 10^{10}\ [M_\odot\, h^{-1}]$
- Simulation box side size	$L_{box} = 210\ [\mathrm{Mpc}\, h^{-1}]$

3. Results

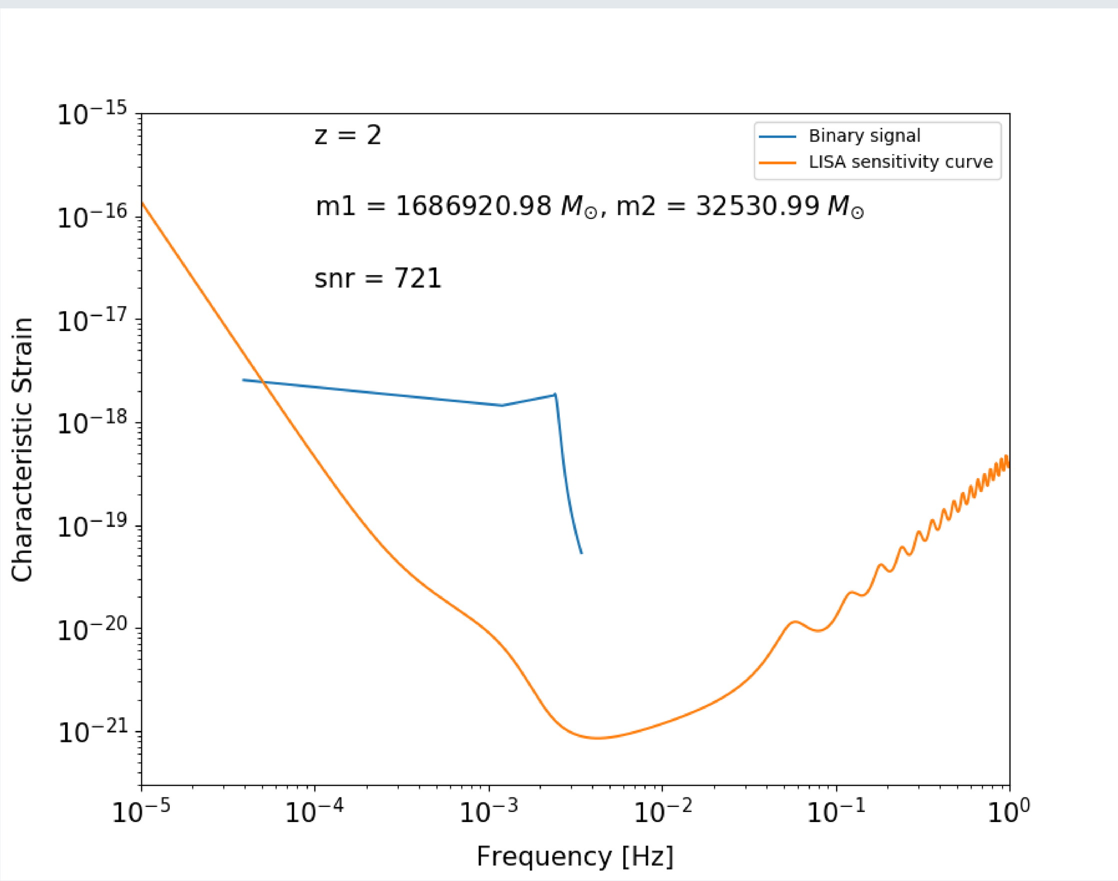

Fig.1 LISA characteristic strain and example MBH merger signal for 4 years observation time.

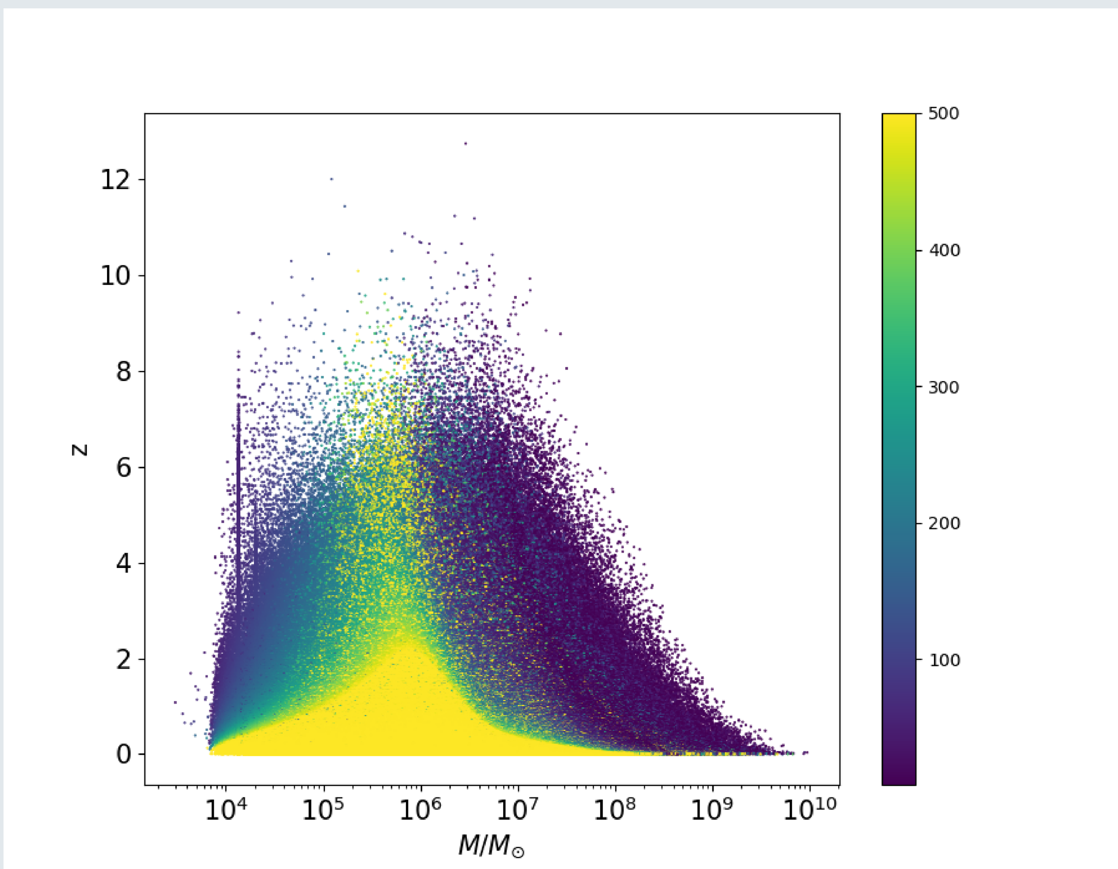

Fig.2 All MBH mergers with SNR>7.

In **Fig.1** we present the characteristic strain of LISA with an example merger signal taken from our MBH binaries population with the total mass around 10^6 solar masses and located at redshift 2. This corresponds to parameter space for which LISA is expected to be most sensitive. It can be seen in **Fig.2** where we plotted all MBH binaries simulated by SHARK at a given redshift as a function of total mass. The color bar shows the predicted SNR (the range is limited to value 500 for readability). In **Fig.3** we present the expected number of LISA detections with SNR>7 calculated for MBH population simulated in SHARK.

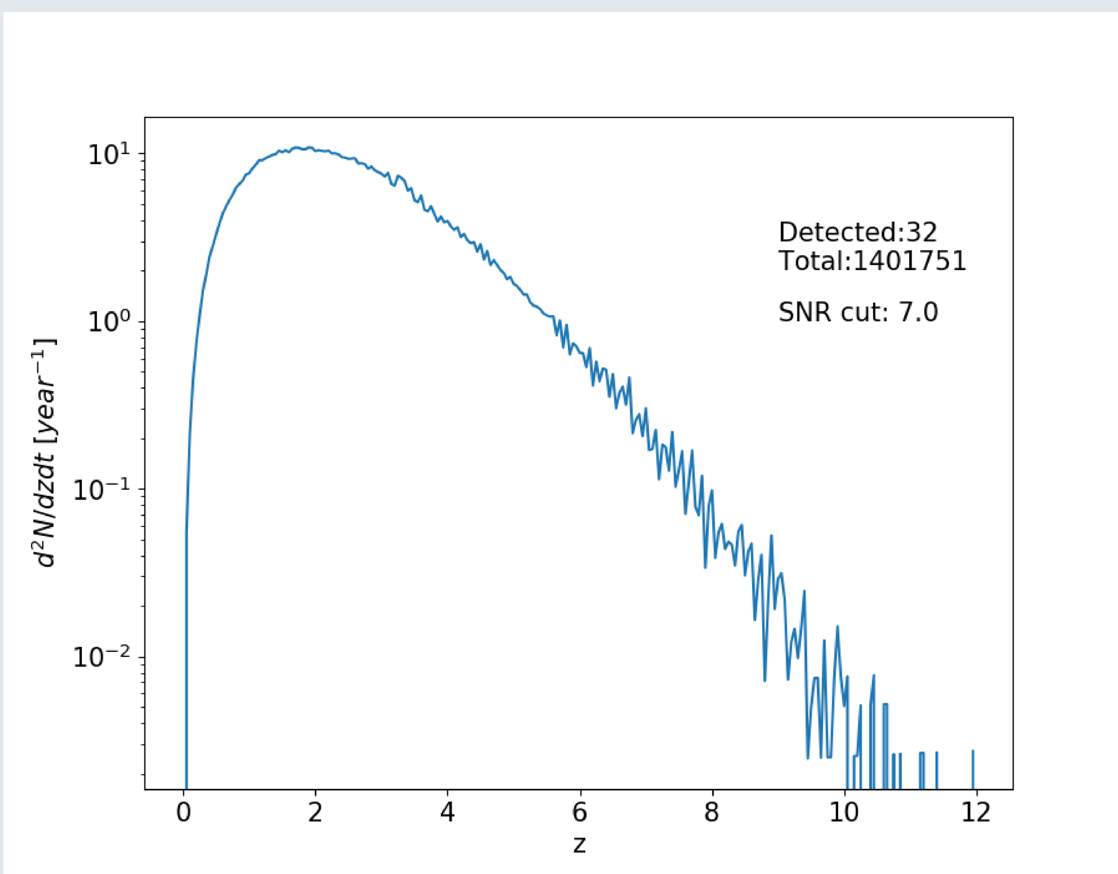

Fig.3 MBH merger detection rate per year.

4. Conclusions

- LISA detection rate predictions for SHARK MBH population ($\sim$ 32 per year) are consistent with recent studies of other simulations (e.g. [6],[7]).
- Various prescriptions of physical processes implemented in SHARK will allow to put more stringent constraints on current MBH formation and evolution models when compared with actual LISA detections in the future.

5. Future work

- Simulate a number of MBH populations using different physics models implemented within SHARK and compare their gravitational wave signature. In particular, we will extend our studies with analysis of MBH merger time delays.
- Calculate LISA SNR using more sophisticated waveforms which take into account realistic binary parameters, e.g. sky location, substantial mass ratio, orbital eccentricity.
- Analyse gravitational signal from SHARK MBH populations in Pulsar Timing Array band (sensitive for masses above 10^6 solar masses)

6. References

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