Detectability of stochastic gravitational wave background from weakly hyperbolic encounters
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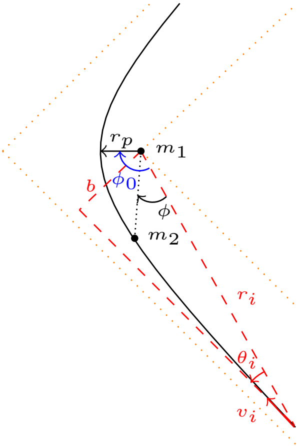
Motivation

- Globular clusters are ideal environment for hyperbolic encounters (Dymnikova, Popov, & Zentsova , 1982; Kocsis, Gáspár, & Márka , 2006).
- The number of encounters is sufficient for a stochastic gravitational wave (GW) background (SGWB) (Mukherjee, Mitra, & Chatterjee , 2021). We are interested in the accumulative effect of many events, not in individual bursts.
- Is the SGWB produced by these encounters sufficiently strong to be detected by GW detectors?
- The encounter rate depends on the number of black holes (BHs) in a cluster and on the number of clusters in a galaxy. Detecting a SGWB or not would put constraints on the numbers mentioned above.

Encounter setup



Hyperbolic trajectory of a secondary BH of mass m_2 in the field of a BH of mass m_1. The secondary BH is initially located at a distance r_i from the primary; the initial angle between the line connecting the bodies and the initial velocity v_i is θ_i. The azimuthal angle ϕ lies between the radial distance r and r_i. The $r_p \geq r_{sch}$ is the periapsis and ϕ_0 is the angle between r and r_p. The impact parameter b is defined as $b = r_i \sin\theta_i$.

Work assumptions

- We consider only weakly hyperbolic encounters, almost parabolic ($e \sim 1$).
- We use Newtonian mechanics for the trajectory.
- The planar trajectory of the secondary starts from a finite distance not infinity.
- We exclude head-on collisions.
- The globular clusters are assumed to be virialized.
- The initial velocity v_i is the virial velocity.
- We use the quadrupole formula to calculate the energy flux.
- We consider encounters up to redshift $z \leq 5$ (7.84 Gpc).
- The number of compact objects as function of redshift is taken from Kremer et al. (2020).
- We assume a standard ΛCDM for which $\Omega_\Lambda = 0.685$ and $\Omega_m = 0.315$.

Virial velocity and the eccentricity

$$v_i = \sqrt{\frac{GN^{\mathrm{tot}}\langle m\rangle}{3R_{\mathrm{gc}}}}$$

- $\langle m\rangle$ is the average mass of a star. We set $\langle m\rangle = M_\odot$.
- Vary the total number of stars N^{tot} and the cluster's radius R_{gc}.
- Or just vary v_i.

$$e_{\mathrm{min}} = 1 + \frac{2m_1}{(m_1+m_2)c^2 r_i}(r_i v_i^2 - 2G(m_1+m_2))$$

which comes from setting $r_p = r_{sch}$.

Parameters choice

$$\{r_{\mathrm{imin}}, r_{\mathrm{imax}}\} = \{0.03pc, 9.03pc\}$$

$$\{e_{\mathrm{imin}}, e_{\mathrm{imax}}\} = \{e_{\mathrm{imin}}, e_{\mathrm{imin}} + 4\ 10^{-9}\}$$

$$17M_\odot \lesssim m_1 \leq 55M_\odot$$

$$5M_\odot \leq m_2 \lesssim 25M_\odot$$

$$5km/s \leq v_i \leq 18km/s$$

Composite SGWB from weakly hyperbolic

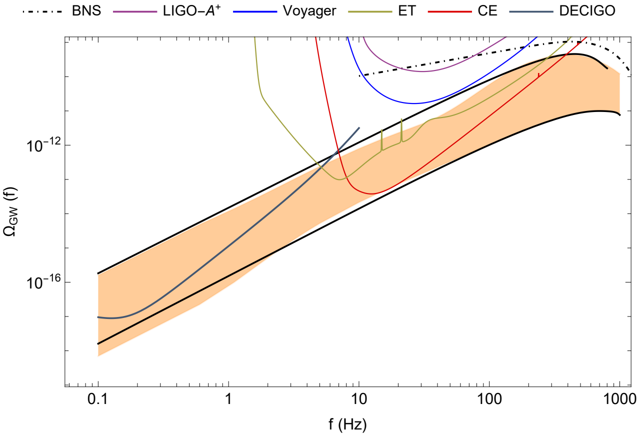


Figure: Dimensionless GW energy density spectrum Ω_{GW} of SGWB of weakly hyperbolic encounters. The orange area represents a composite result. The black lines around the orange area show fitted curves for this SGWB and their analytical forms can be found in (Kerachian et al. , 2024).

Conclusion

For the parameters choice and assumptions made, the SGWB of weakly hyperbolic encounters appears to be detectable by Einstein Telescope, Cosmic Explorer and DECIGO.

Thank you for your attention!

References

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