Probing Exotic(Dark) Compact Objects in the Center of Galaxies with Gravitational Waves from the Extreme Mass Ratio Inspirals

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Huaike Guo, Jing Shu, Yue Zhao, Phys. Rev. D 99, 023001
Huaike Guo, Kuver Sinha, Chen Sun, arXiv:1904.07871

Ordinary and Exotic Compact Objects

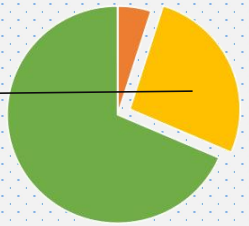
Ordinary

- Neutron Stars
- White Dwarfs
- Black Holes

Exotic

- Neutron Stars
- White Dwarfs
- Black Holes
- Primordial Black Holes
- Boson Stars
- Quark Stars
- ...

?

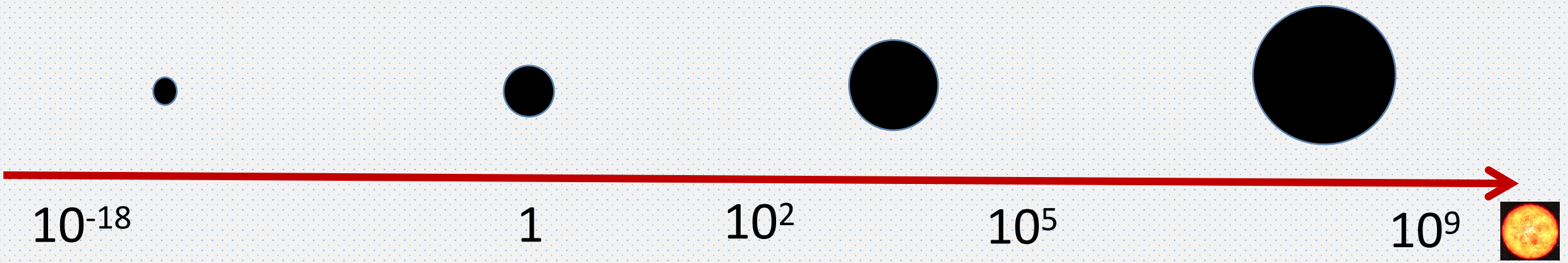


see also

B. Lehmann
N. Fernandez
C. Sun
N. Orlofsky
J.H. Chang
J. Setford
S.D. Lu

$$C = \frac{G}{c^2}\frac{M}{R}$$

ECO Mass



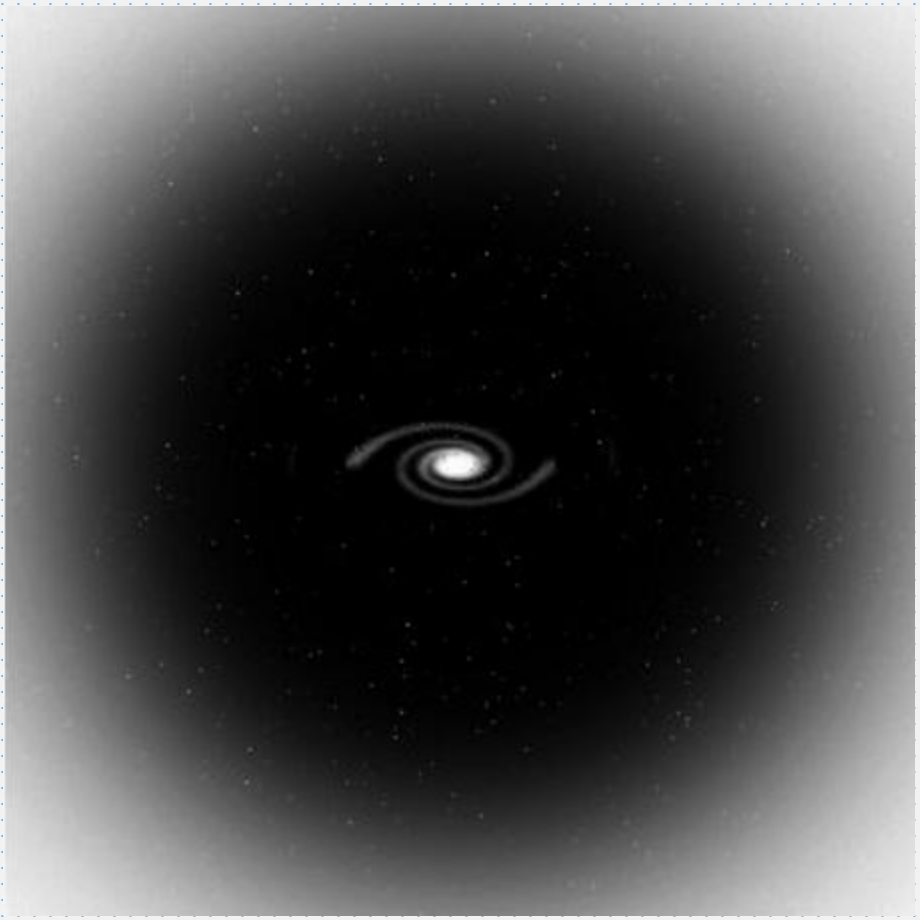
10^{-18} 1 10^{2} 10^{5} 10^{9}

SBH IMBH SMBH

PBH

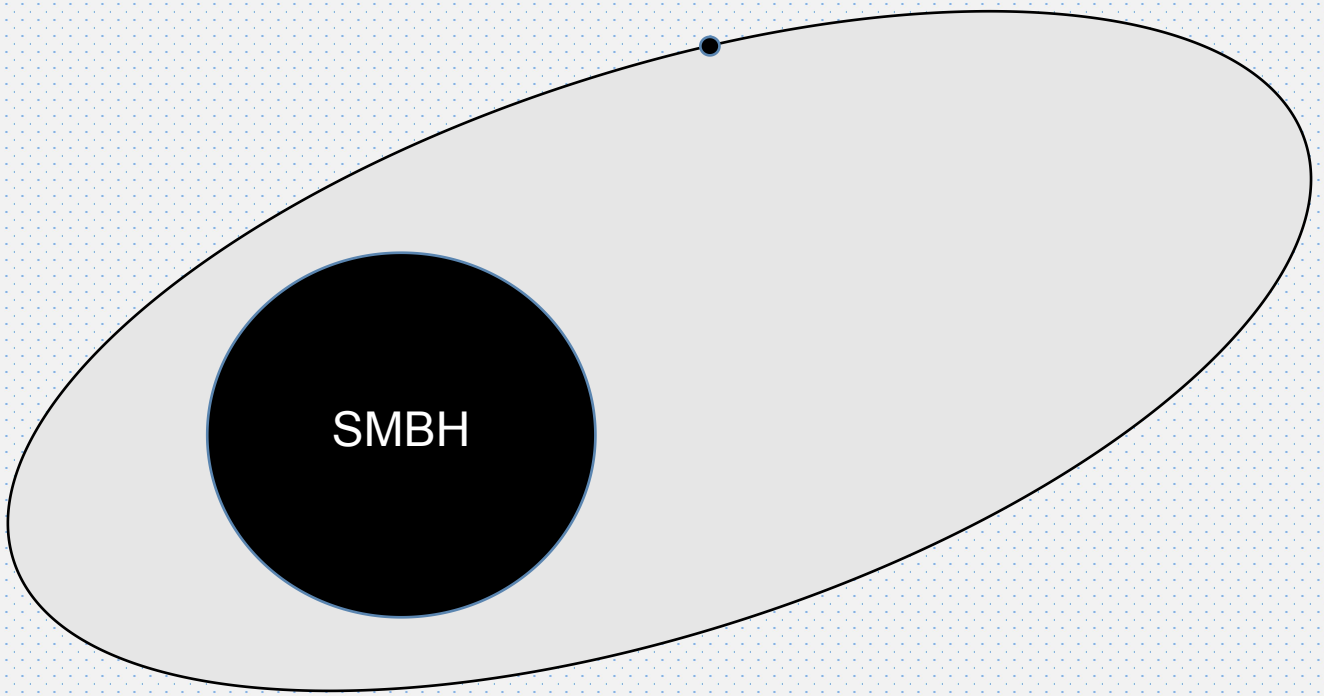
ECOs

Extreme Mass Ratio Inspiral

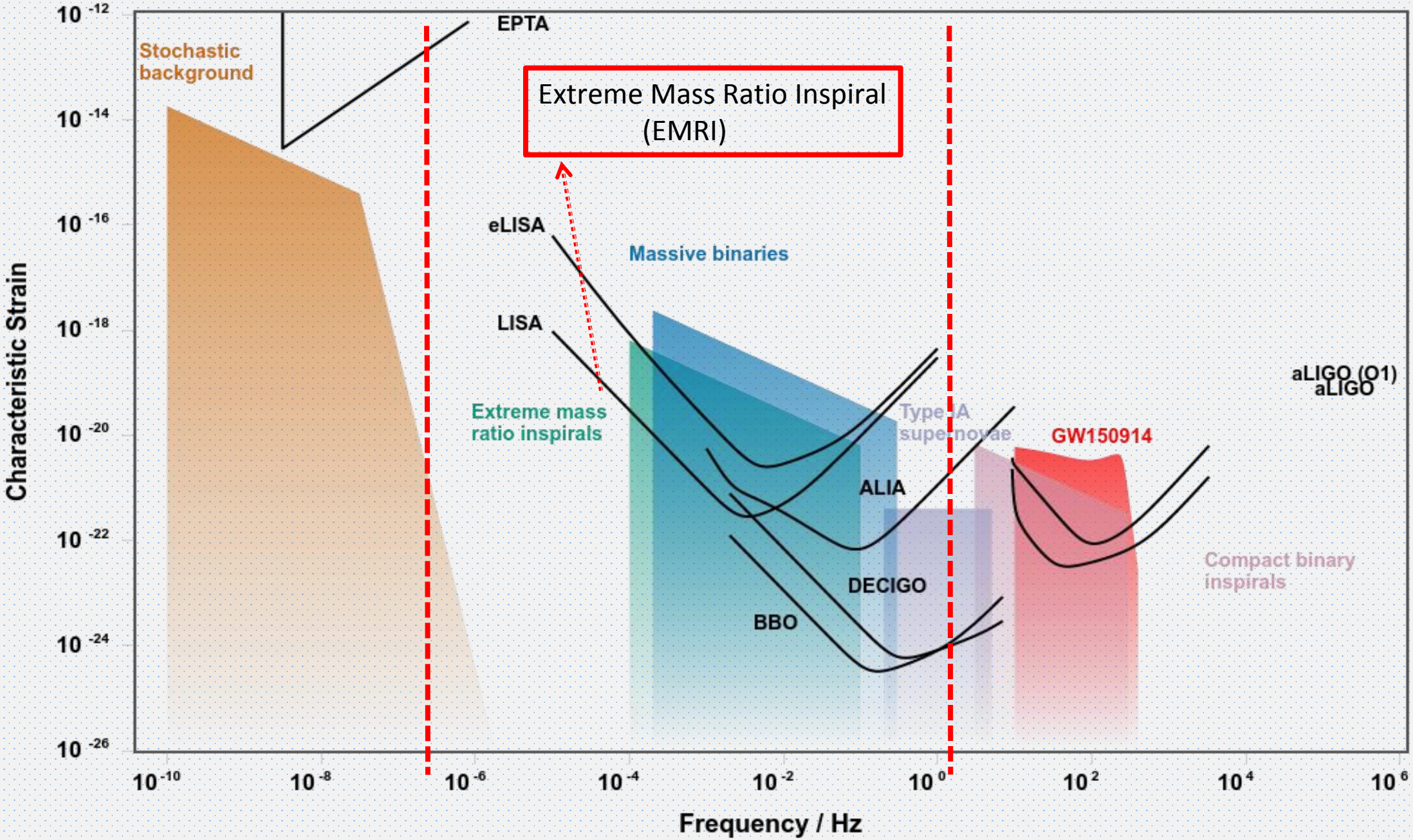


http://archive.ncsa.illinois.edu/Cyberia/Cosmos/RotationsReckon.html

Extreme Mass Ratio Inspiral



- m/M << 1 (e.g.,$10/10^6$)

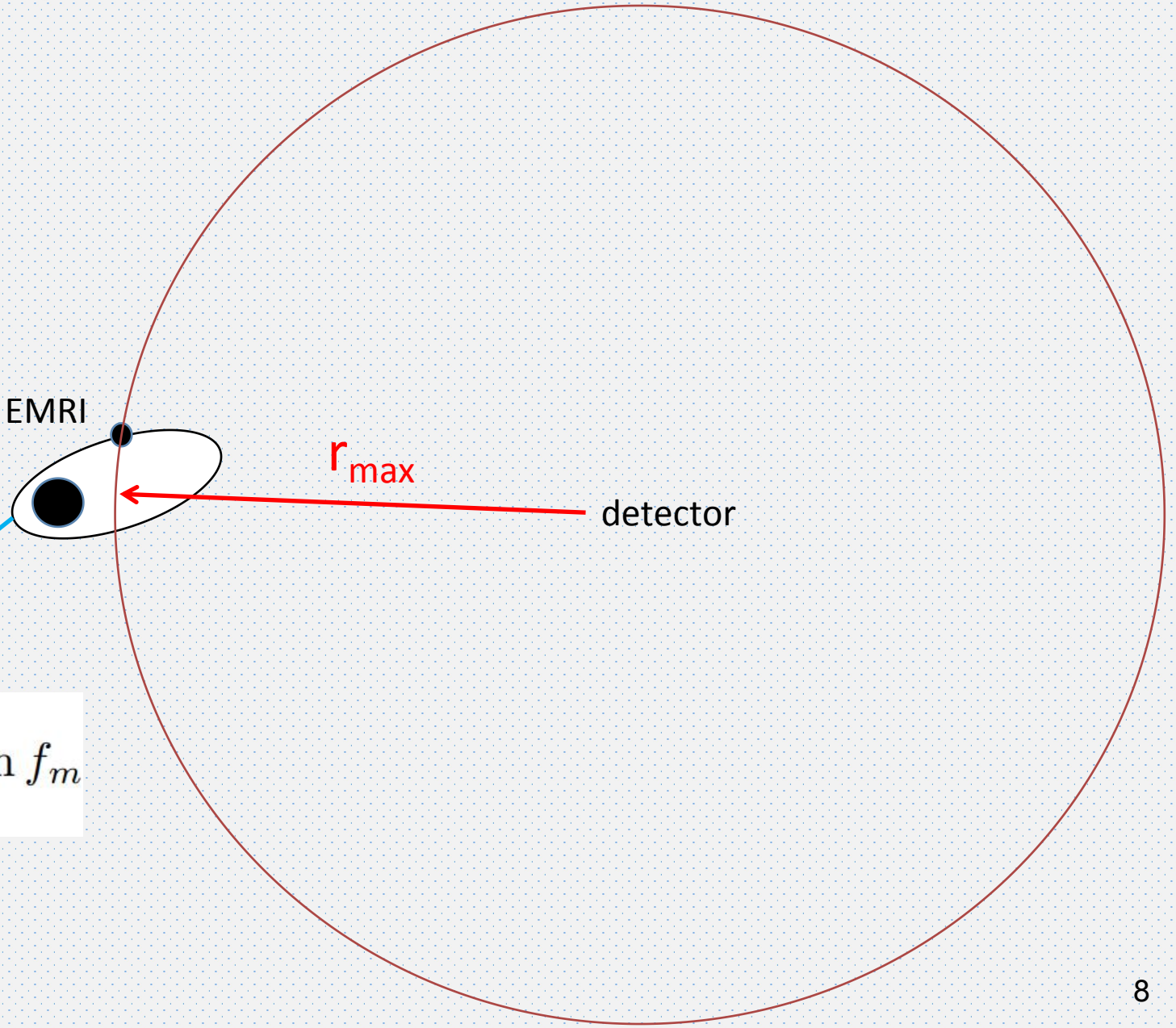


Moore, Cole and Berry, Class. Quantum Grav. 32 (2015) 015014

Gravitational Waves from Extreme Mass Ratio Inspiral

- Signal is long-lasting, large SNR even for sub-solar mass ECO
- Parameters can be determined very precisely. (e.g.,10^{-5})
- For much sub-solar mass PBH, once detected, we know it is not Stellar BH.

Signal-to-Noise Ratio

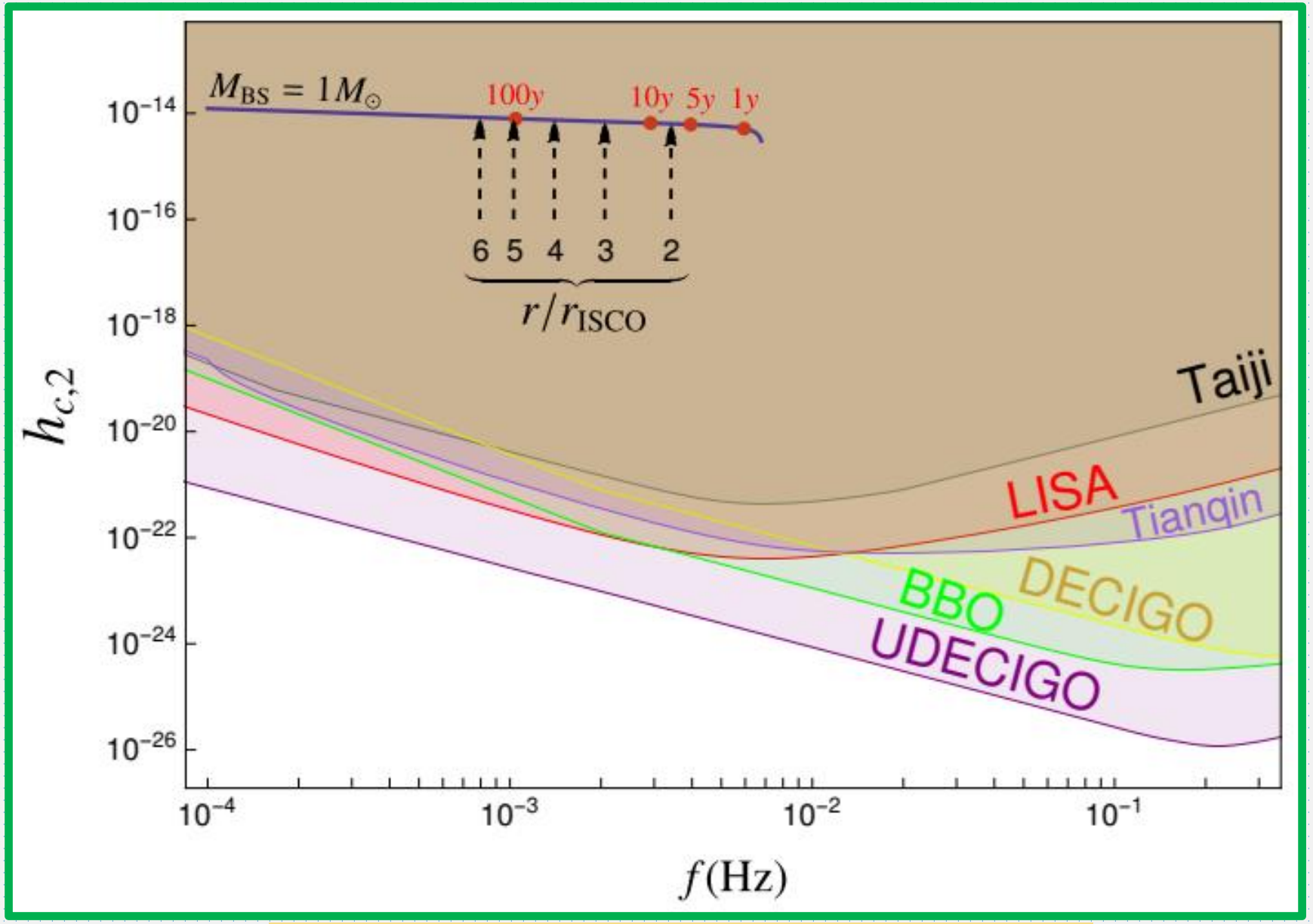


SNR = 20

$$\mathrm{SNR}^2 = \frac{\mathcal{S}^2}{\mathcal{N}^2} = \sum_m \int \left[\frac{h_{c,m}(f_m)}{h_n(f_m)}\right]^2 d\ln f_m$$

Matched-filtering

Noise



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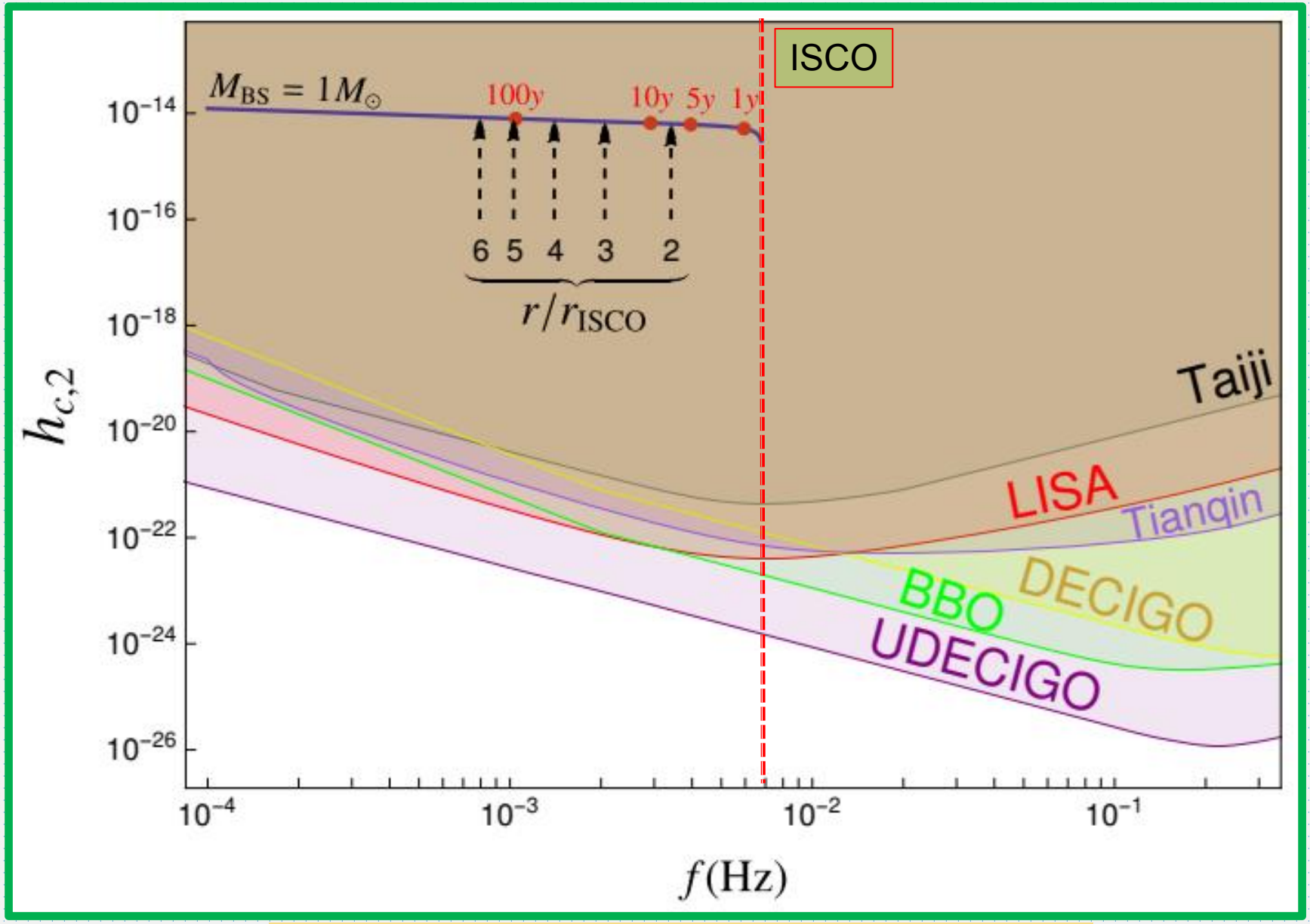

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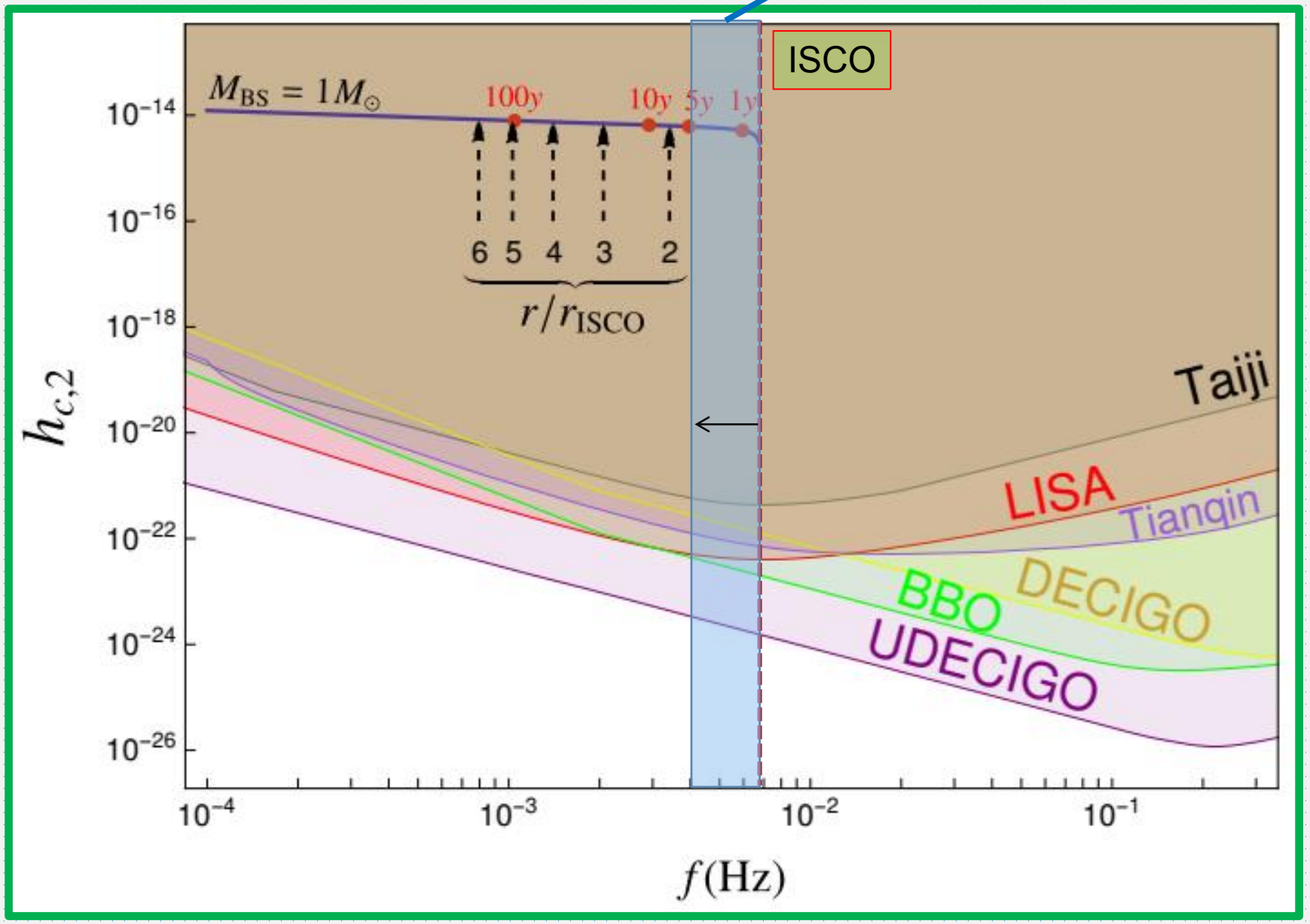

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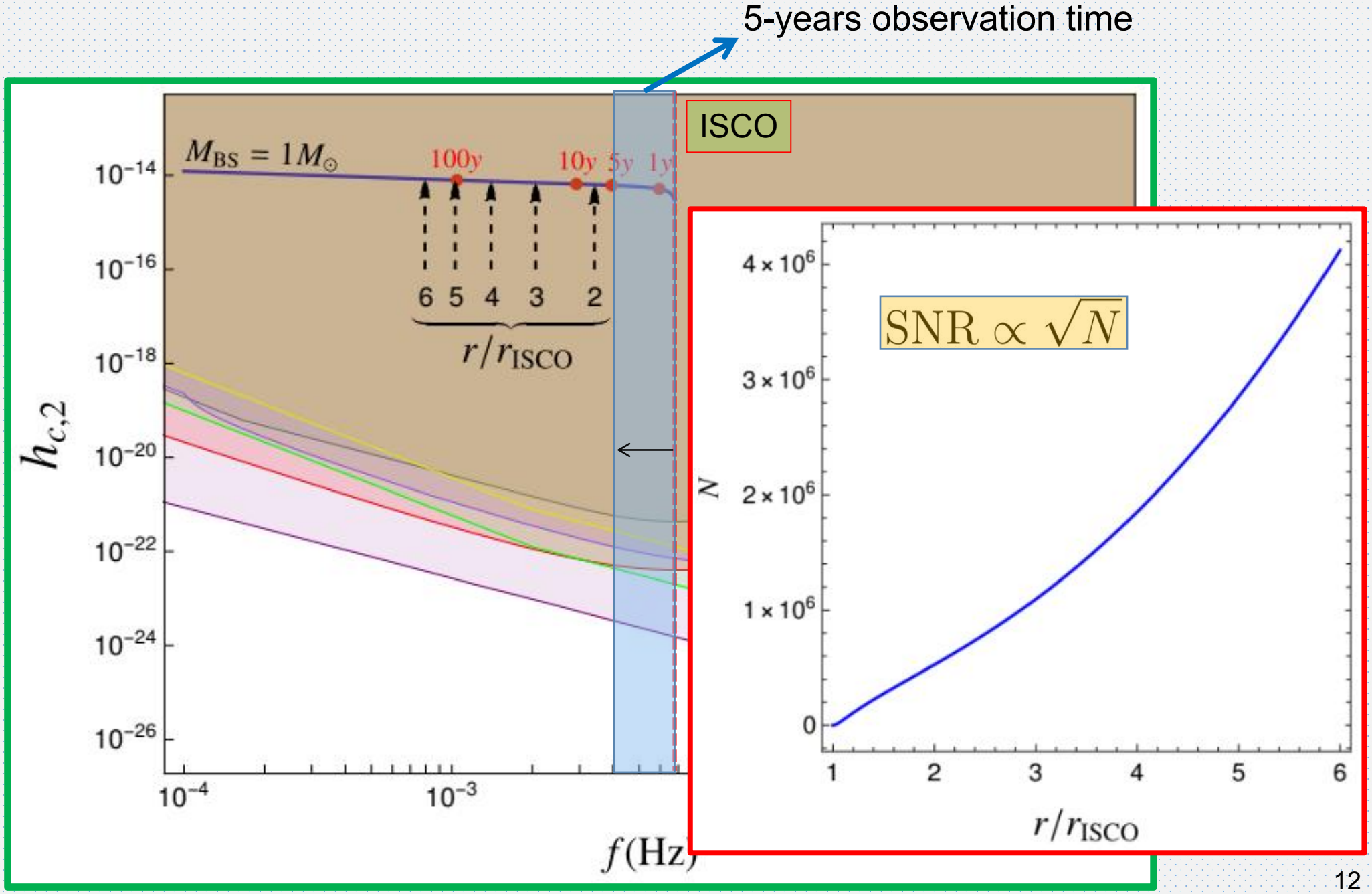

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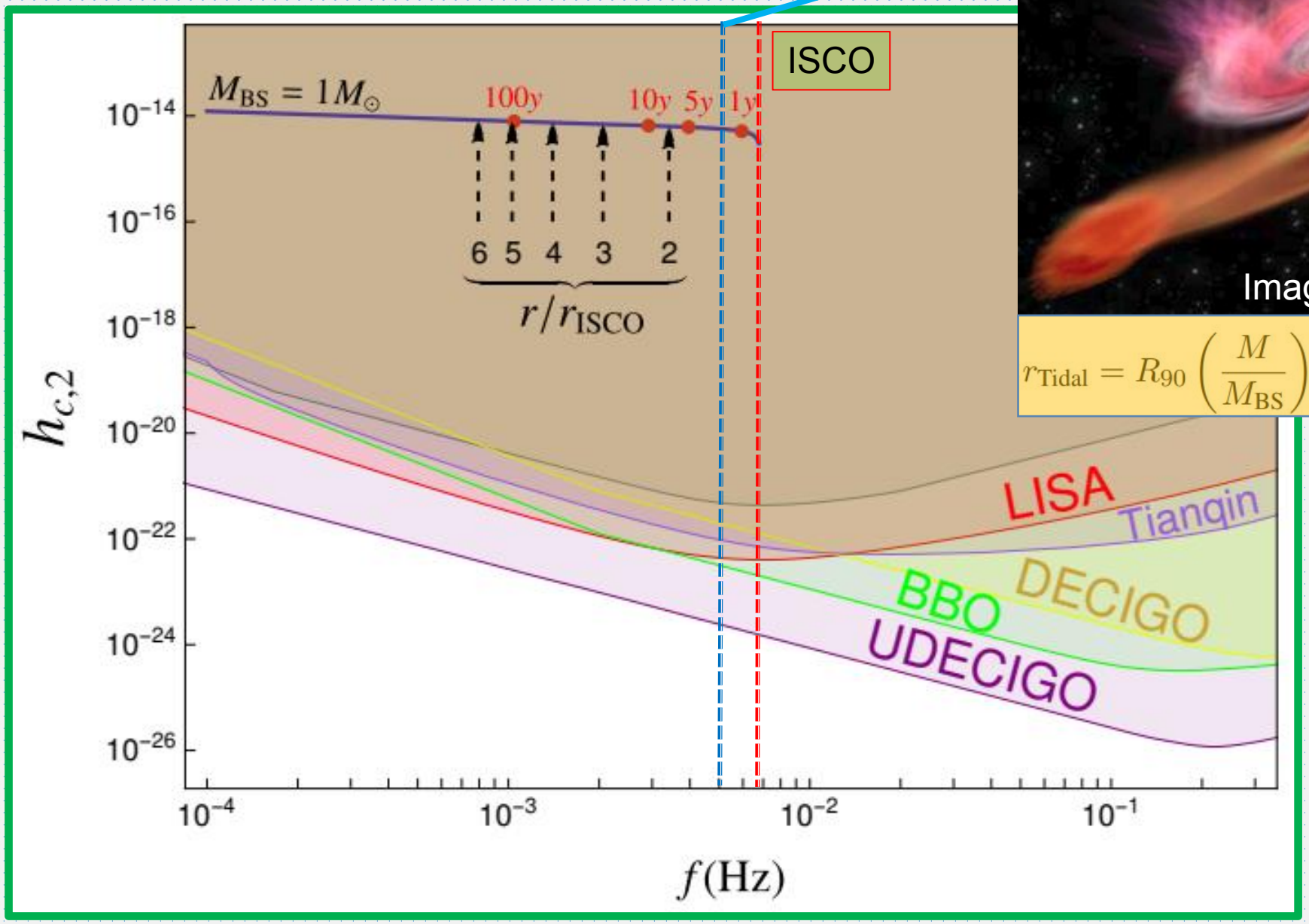

$$r_{\rm Tidal} = R_{90}\left(\frac{M}{M_{\rm BS}}\right)^{1/3} = \frac{(M_{\rm BS}{}^2 M)^{1/3}}{C_{\rm BS}}$$

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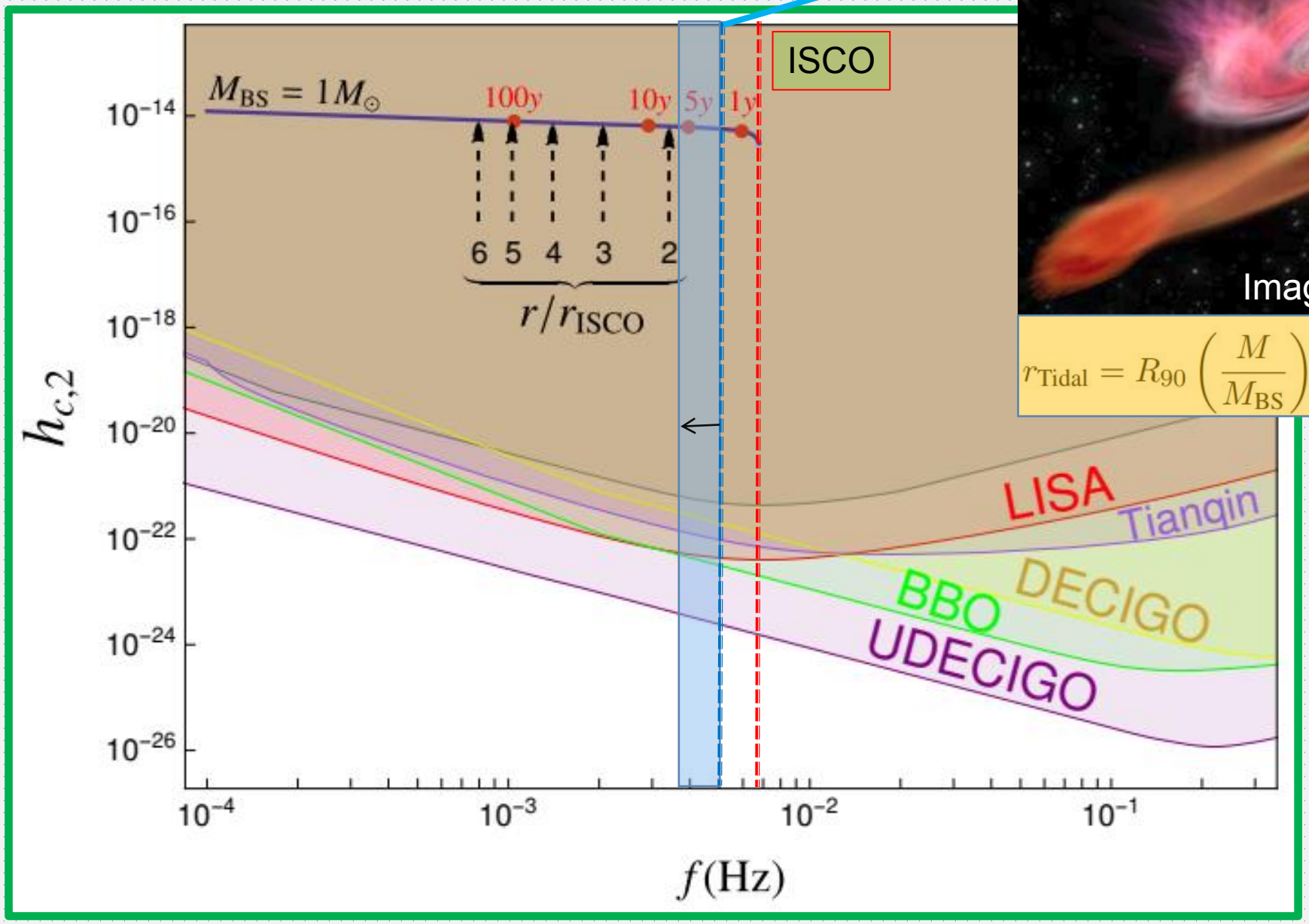

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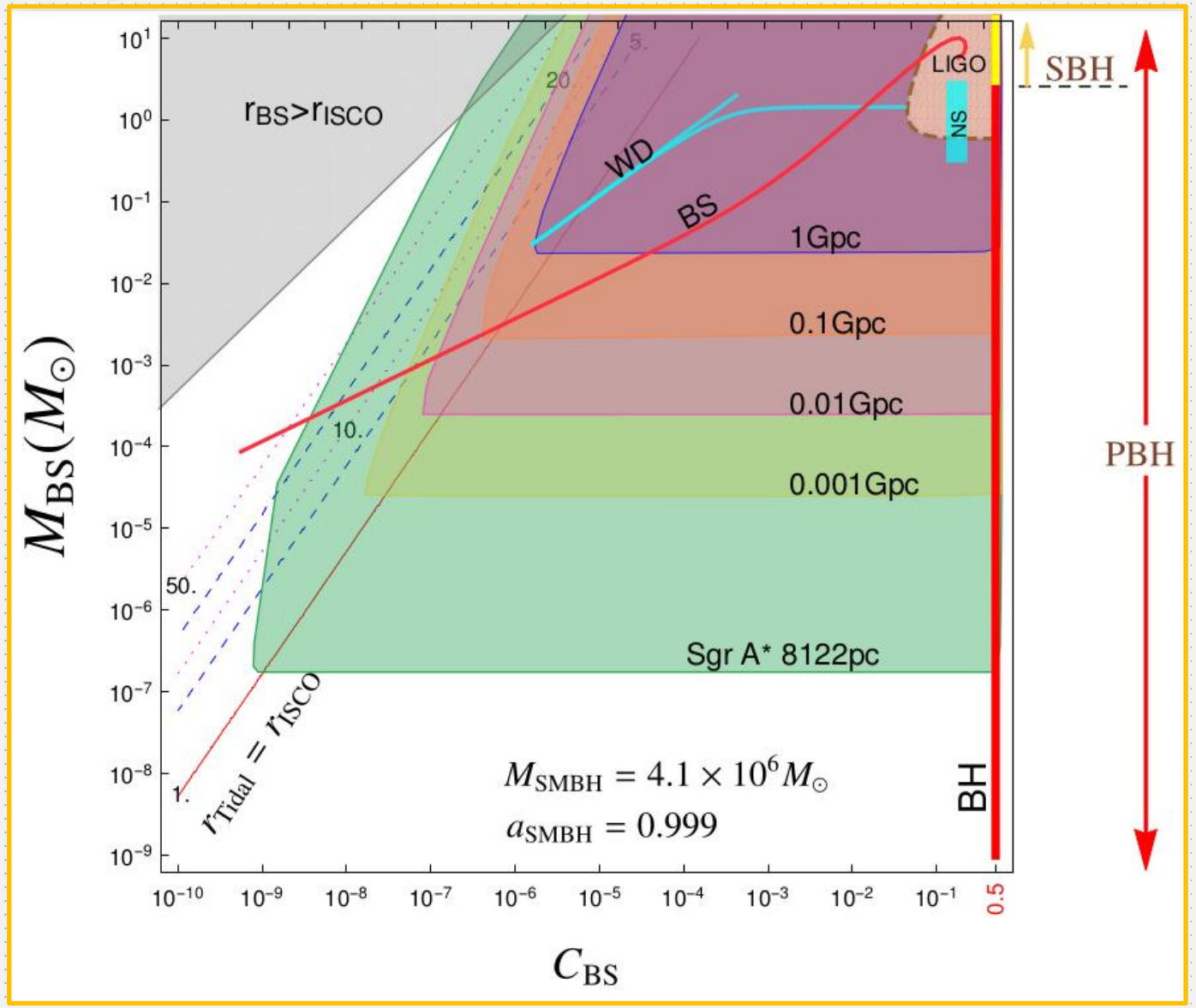
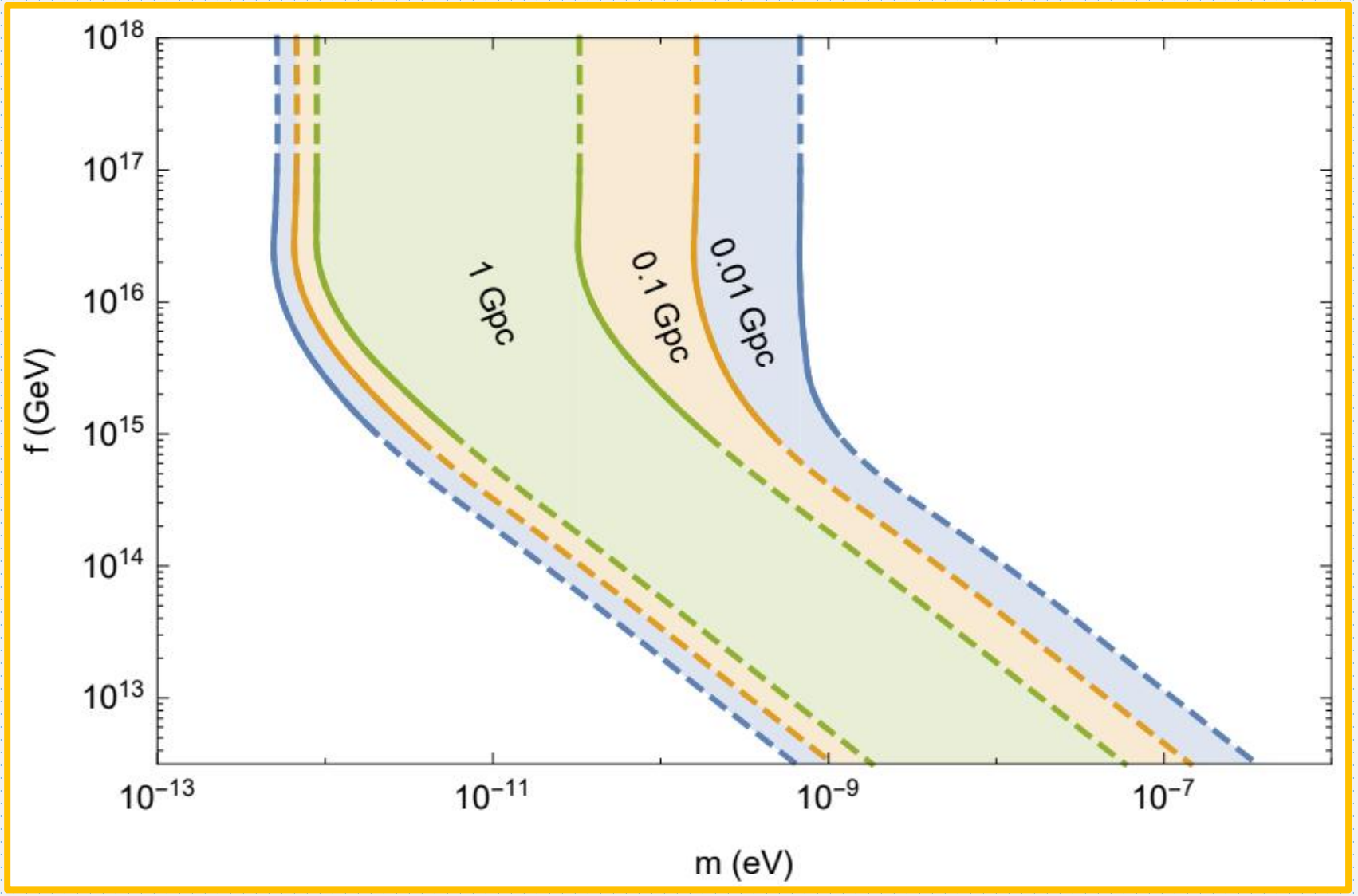
Sensitivity of ECO Detection with GW from EMRI



Huaike Guo, Kuver Sinha, Chen Sun, arXiv:1904.07871

Sensitivity of BS Detection with GW from EMRI



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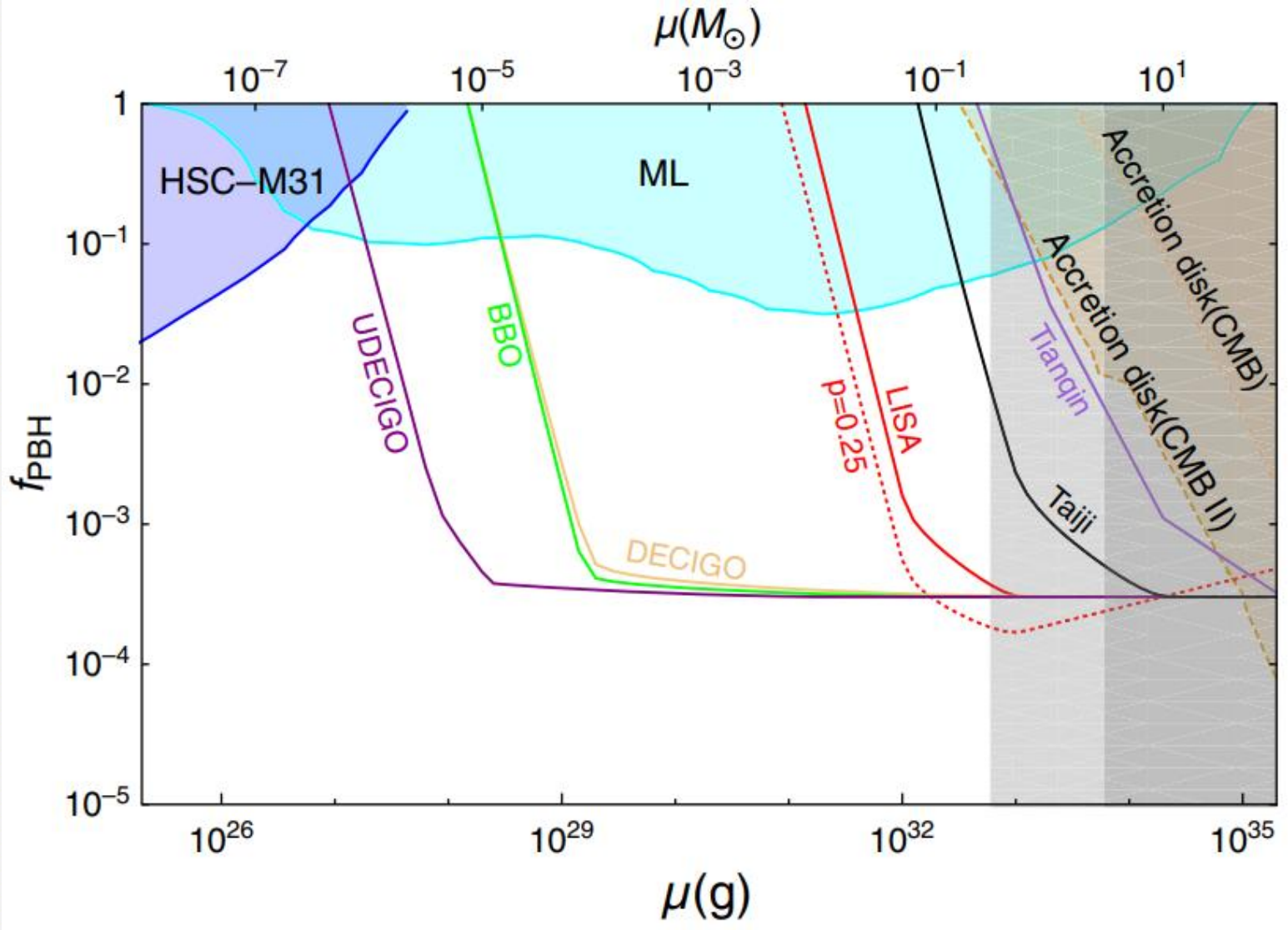
Event Rate Estimation

$$\Gamma = \int \mathcal{R}(M,\mu) \left(\frac{dn(M,z)}{dM} dM\right) (p(s,z)ds) \left(\frac{dV_c}{dz} dz\right)$$

- ~pc region around the SMBH (radius of influence)
- DM Halo profile (cuspy, cored or spiky)
- Stellar dynamics near the SMBH(2-body relaxation, resonant relaxation, mass segregation...)

Constraining ECO Dark Matter



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EM Counterparts

- Luminous ECO?
- Collision with other stars
- Tidal Disruption Events(more promising)

Summary

- EMRI is a powerful way of probing ECOs
- Future space-based GW detectors might discover sub-solar mass ECOs.

Thanks!