Exotic(Dark) Compact Object Searches with 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, JCAP 1909,032 (2019)

Ordinary and Exotic Compact Objects

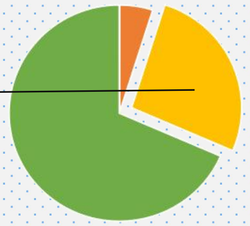
Ordinary

- Neutron Stars
- White Dwarfs
- Black Holes

Exotic

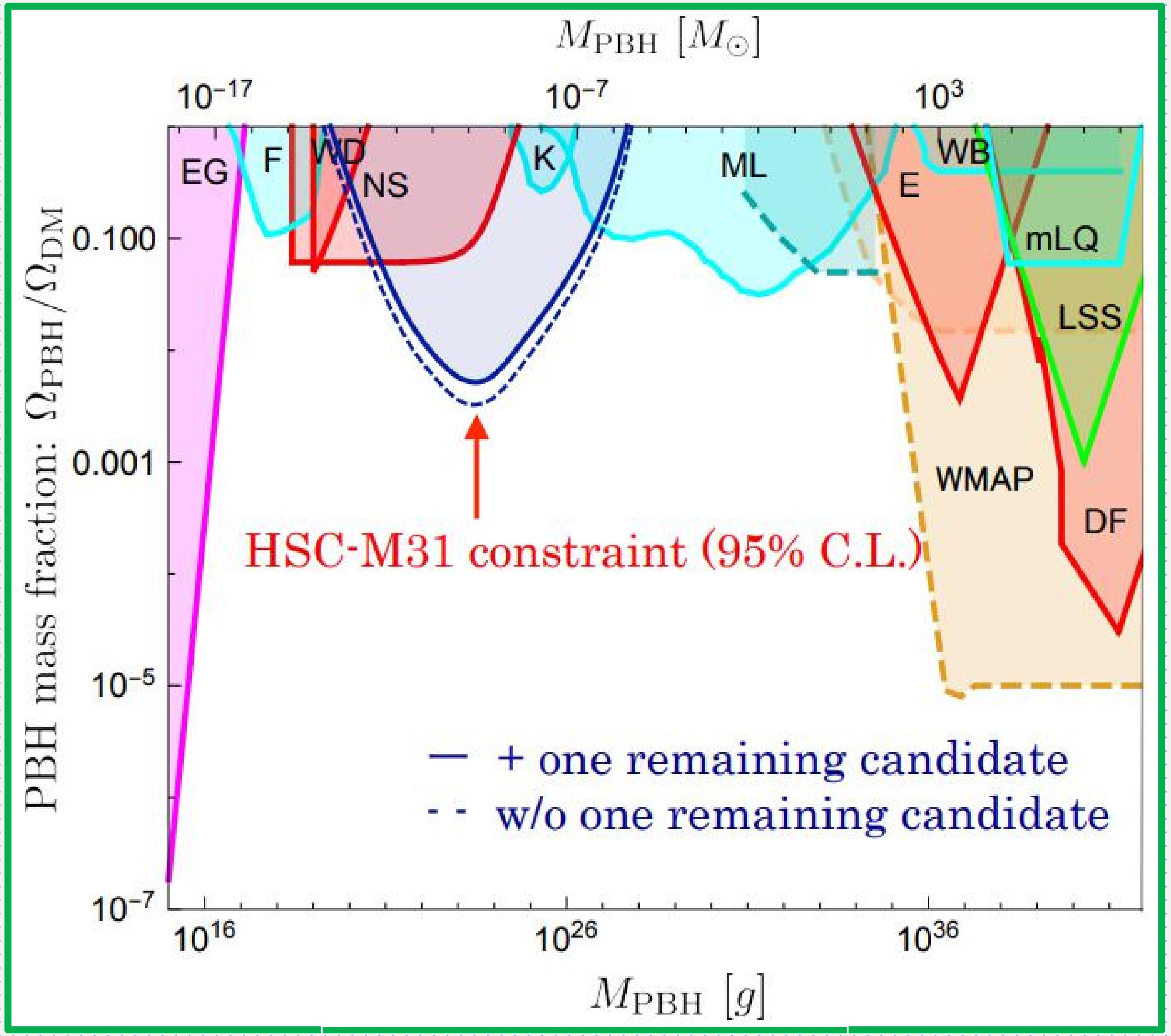
- Neutron Stars
- White Dwarfs
- Black Holes
- Primordial Black Holes
- Boson Stars
- Quark Stars
- ...

?



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

Primordial Black Holes

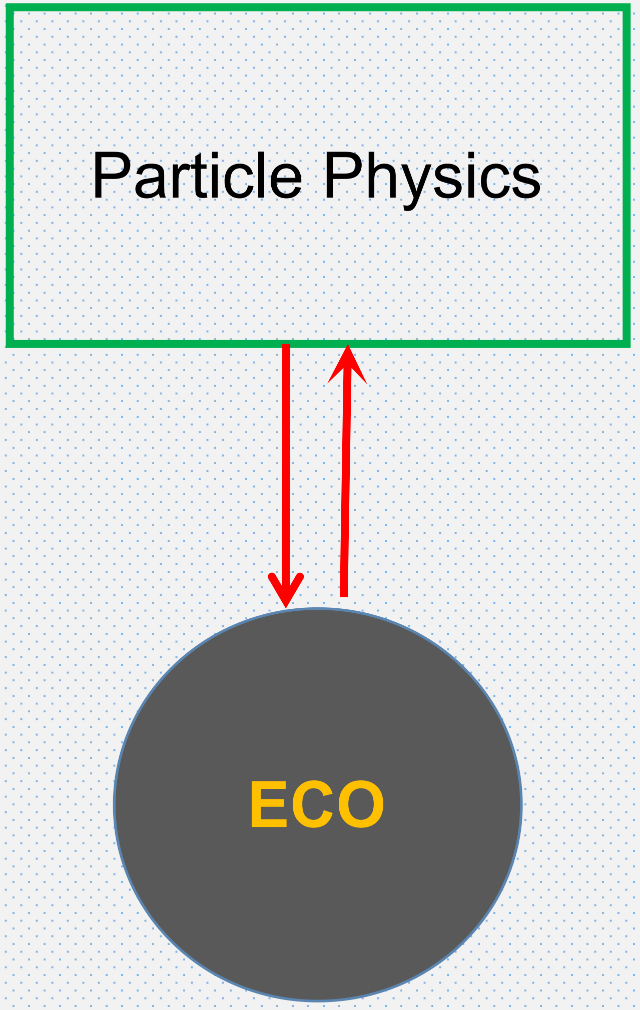


Carr, et al PRD,94,083504

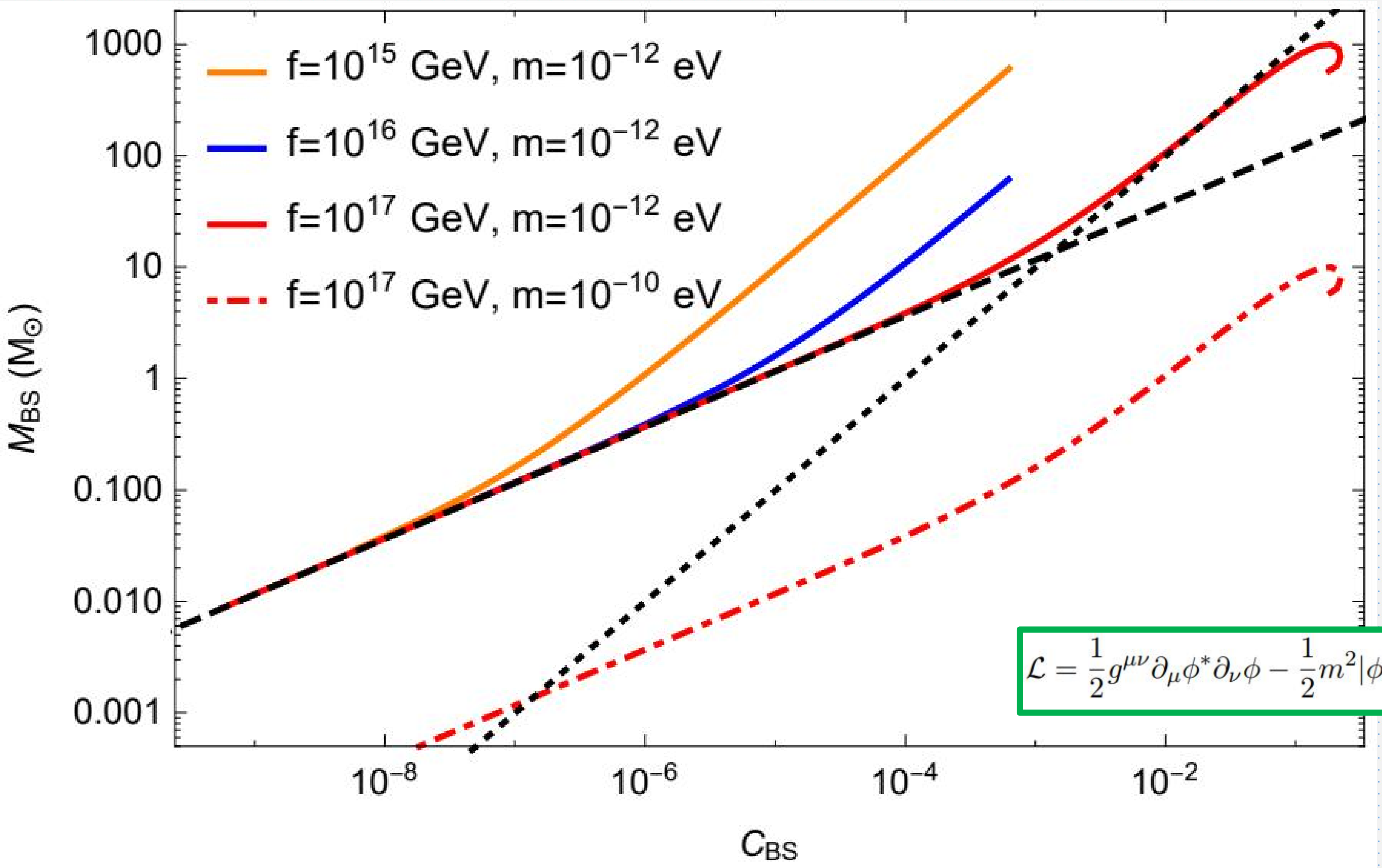
see talks of
Stefano Profumo
Sam McDermott

Boson Stars

- (Mini)Boson Star(self-interactions or not)
- Solitonic Boson Star(specific potential)
- Oscillaton(real scalar field)
- Proca Star(massive vector)
- Axion Stars(dense or dilute)



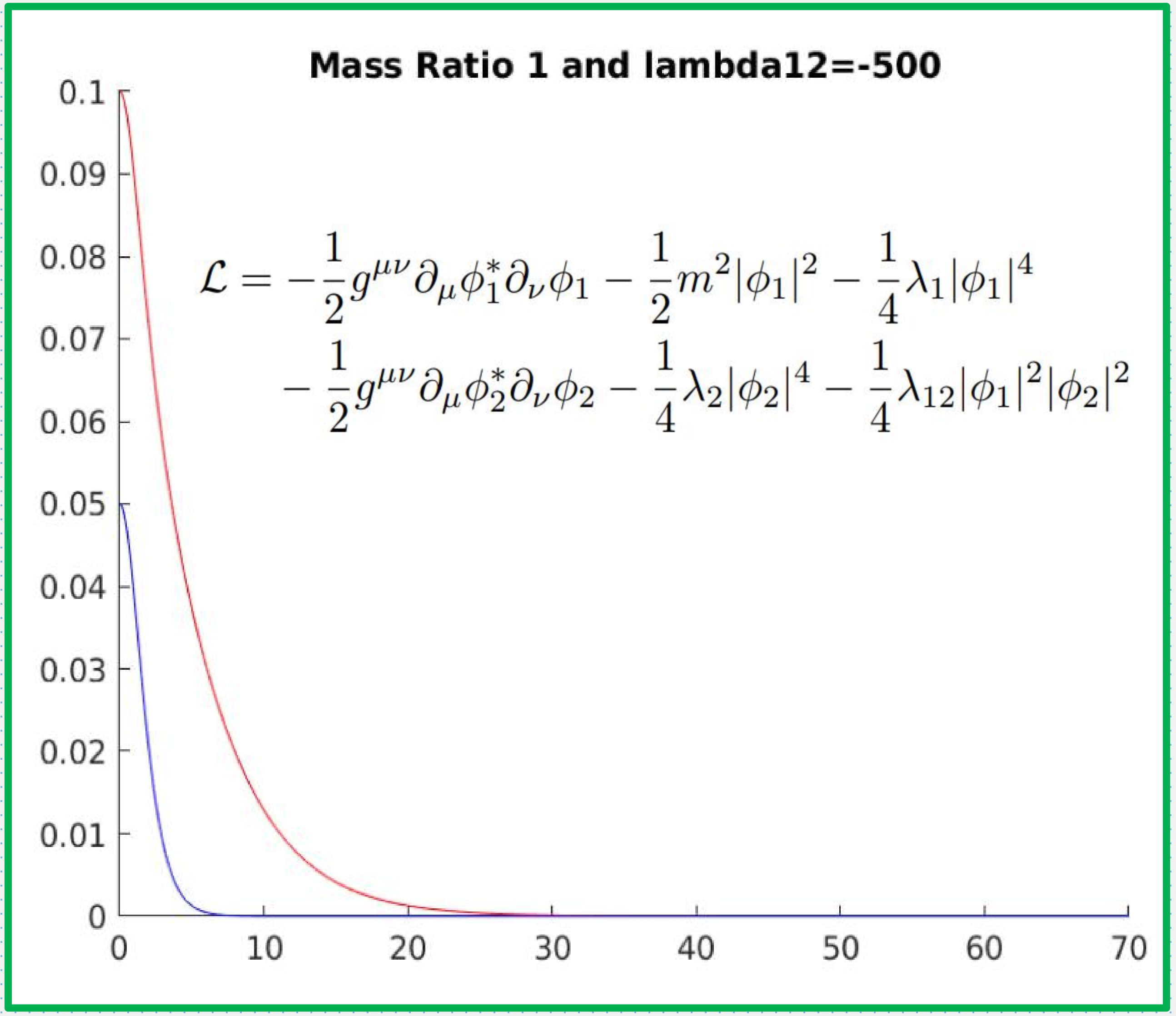
Boson Stars: One Scalar



$$\mathcal{L} = \frac{1}{2} g^{\mu\nu} \partial_\mu \phi^* \partial_\nu \phi - \frac{1}{2} m^2 |\phi|^2 - \frac{\lambda}{4} \left(\frac{m^2}{f^2} \right) |\phi|^4$$

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

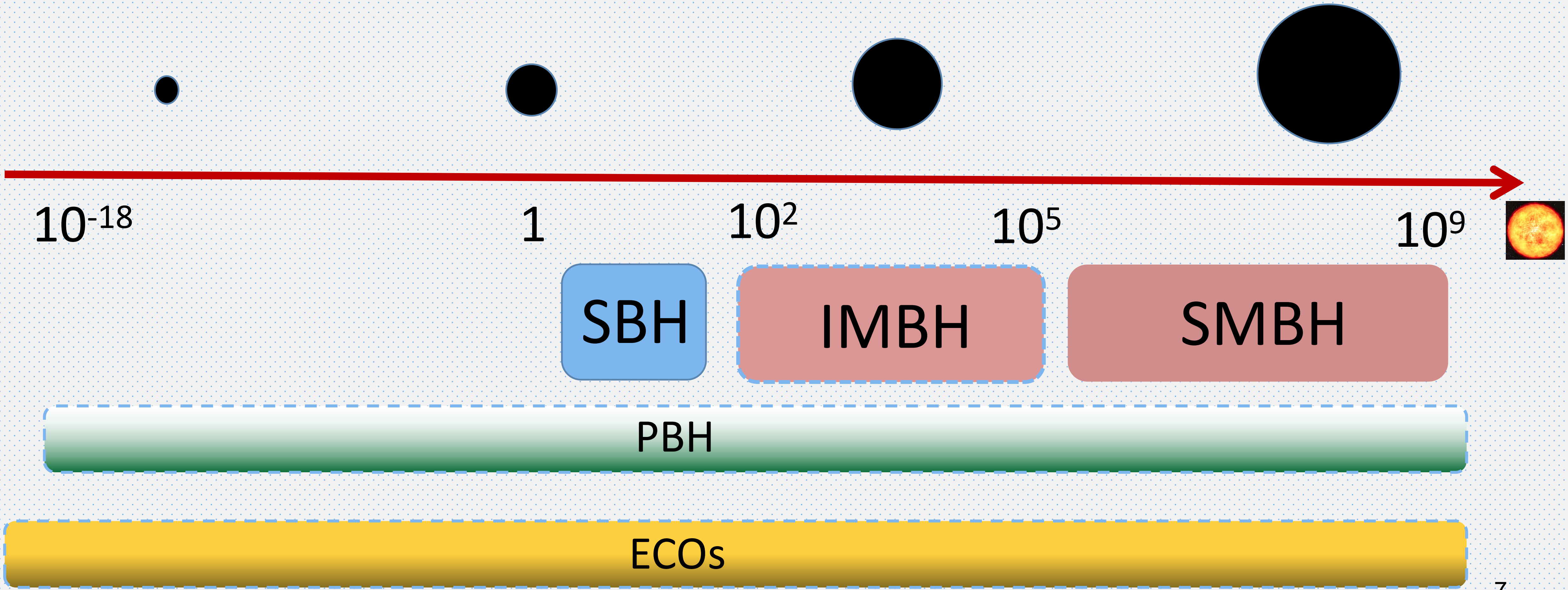
Boson Stars: Two Scalars



$$\mathcal{L} = -\frac{1}{2}g^{\mu\nu}\partial_\mu\phi_1^*\partial_\nu\phi_1 - \frac{1}{2}m^2|\phi_1|^2 - \frac{1}{4}\lambda_1|\phi_1|^4 - \frac{1}{2}g^{\mu\nu}\partial_\mu\phi_2^*\partial_\nu\phi_2 - \frac{1}{4}\lambda_2|\phi_2|^4 - \frac{1}{4}\lambda_{12}|\phi_1|^2|\phi_2|^2$$

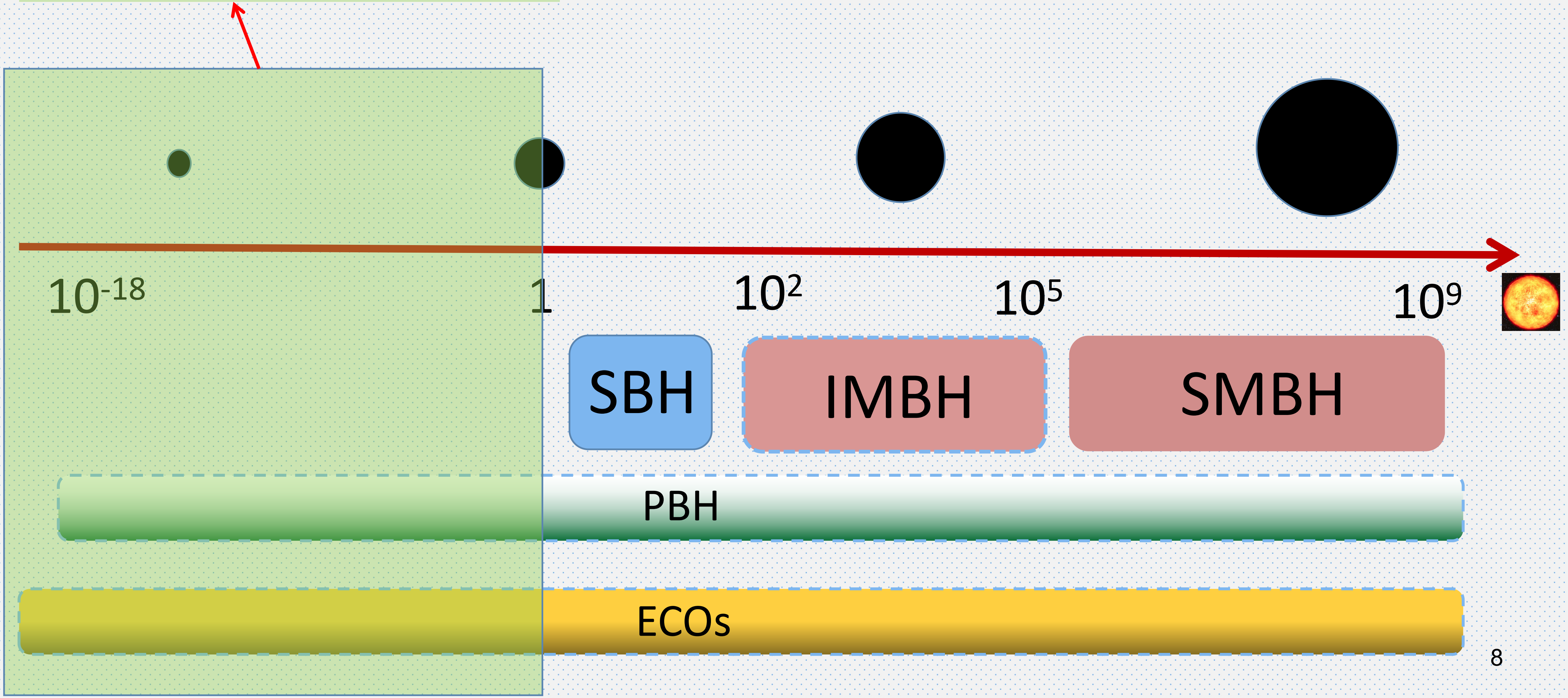
Huaike Guo, Kuver Sinha, Chen Sun, Joshua Swaim, Daniel Vagie, in preparation

ECO Mass

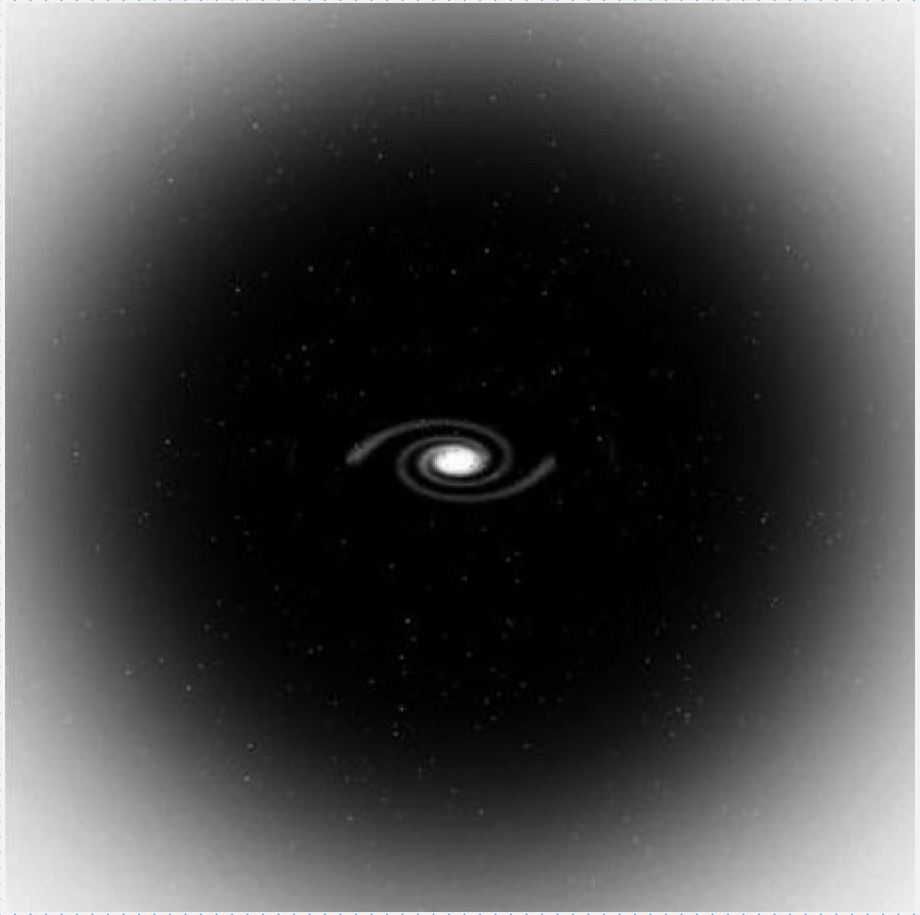


ECO Mass

- background free from ordinary COs
- large number density

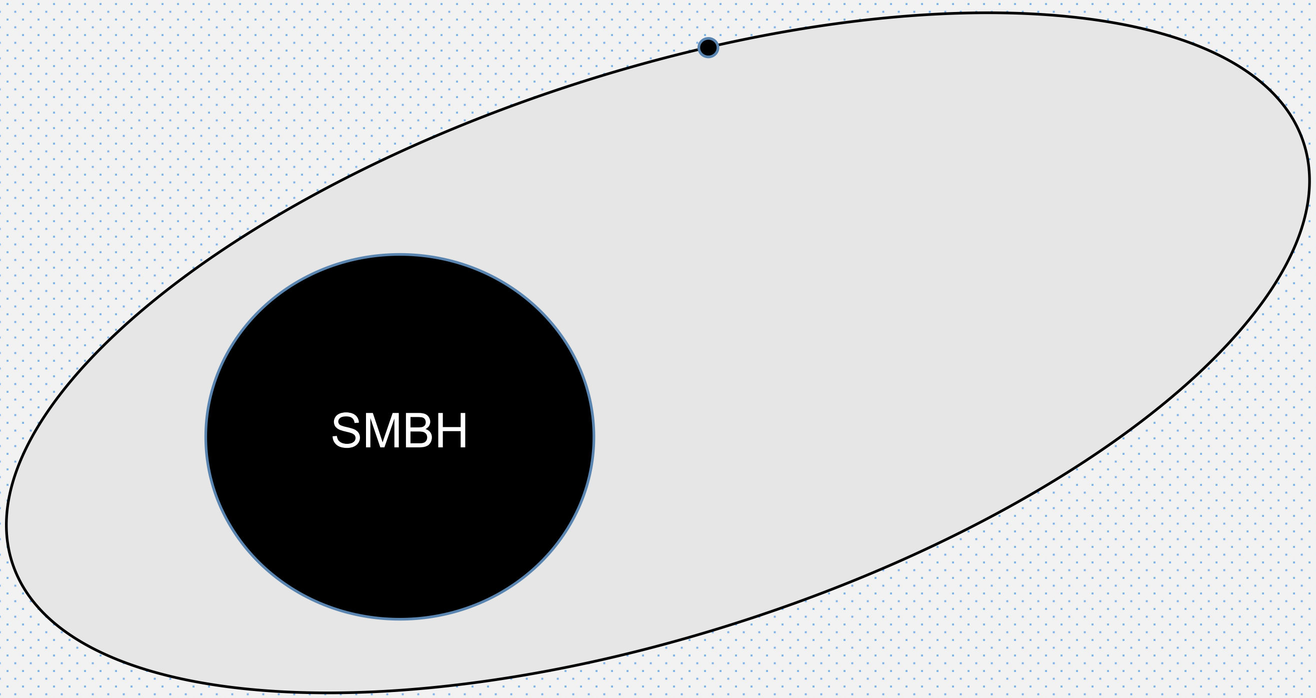


Extreme Mass Ratio Inspiral

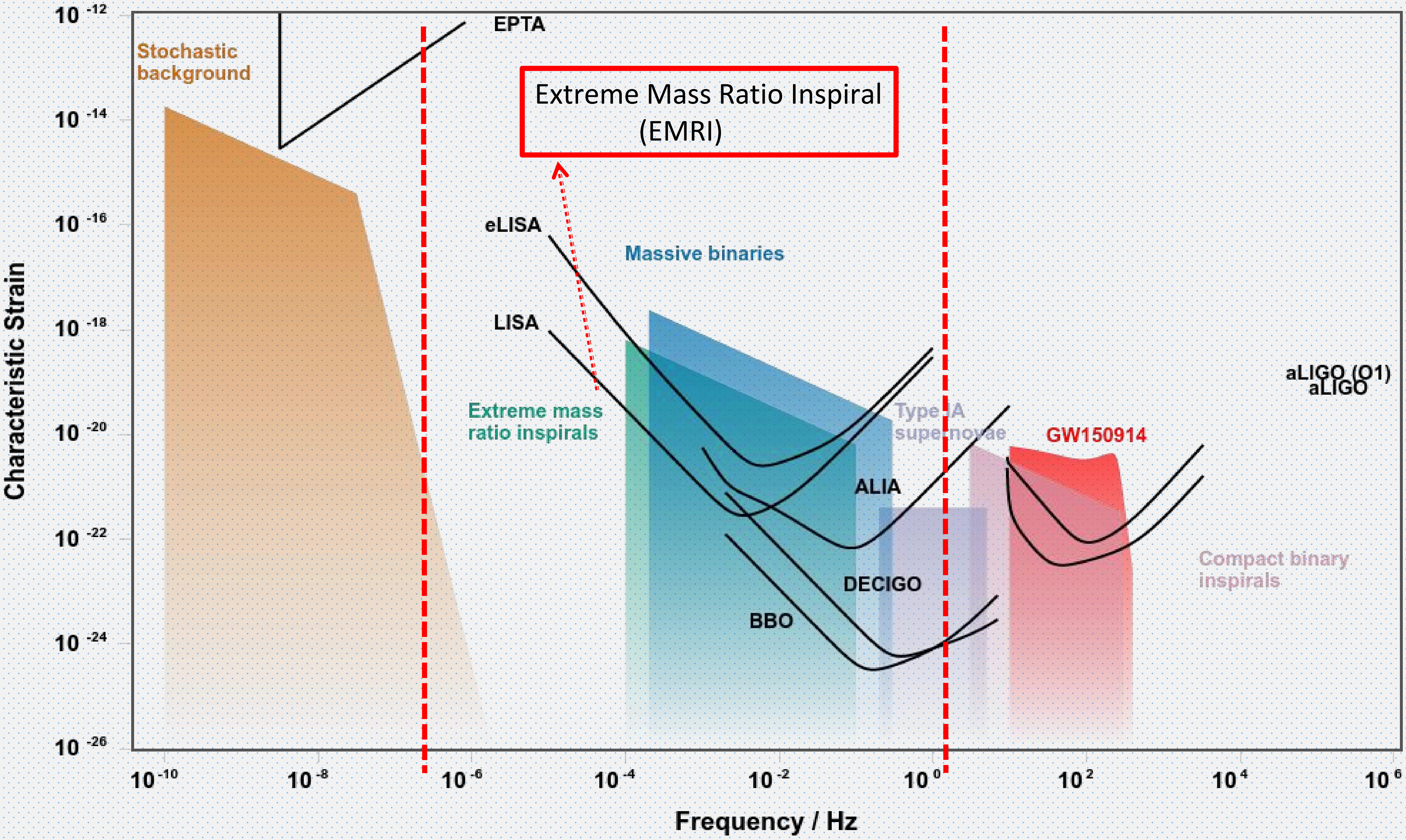


http://archive.ncsa.illinois.edu/Cyberia/Cosmos/RotationsReckon.html

Extreme Mass Ratio Inspiral



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

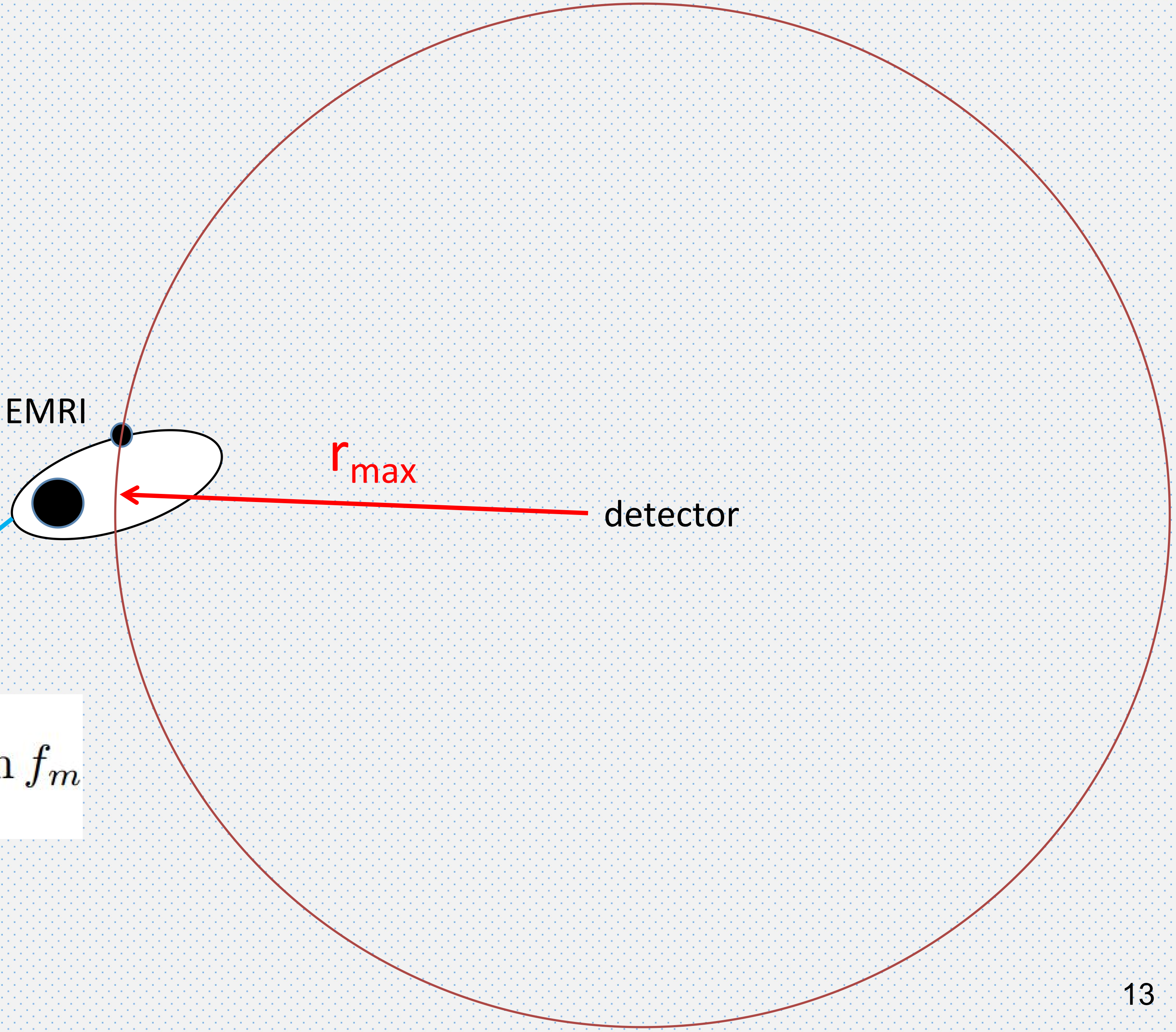


Moore, Cole and Berry, Class. Quantum Grav. 32 (2015) 015014

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

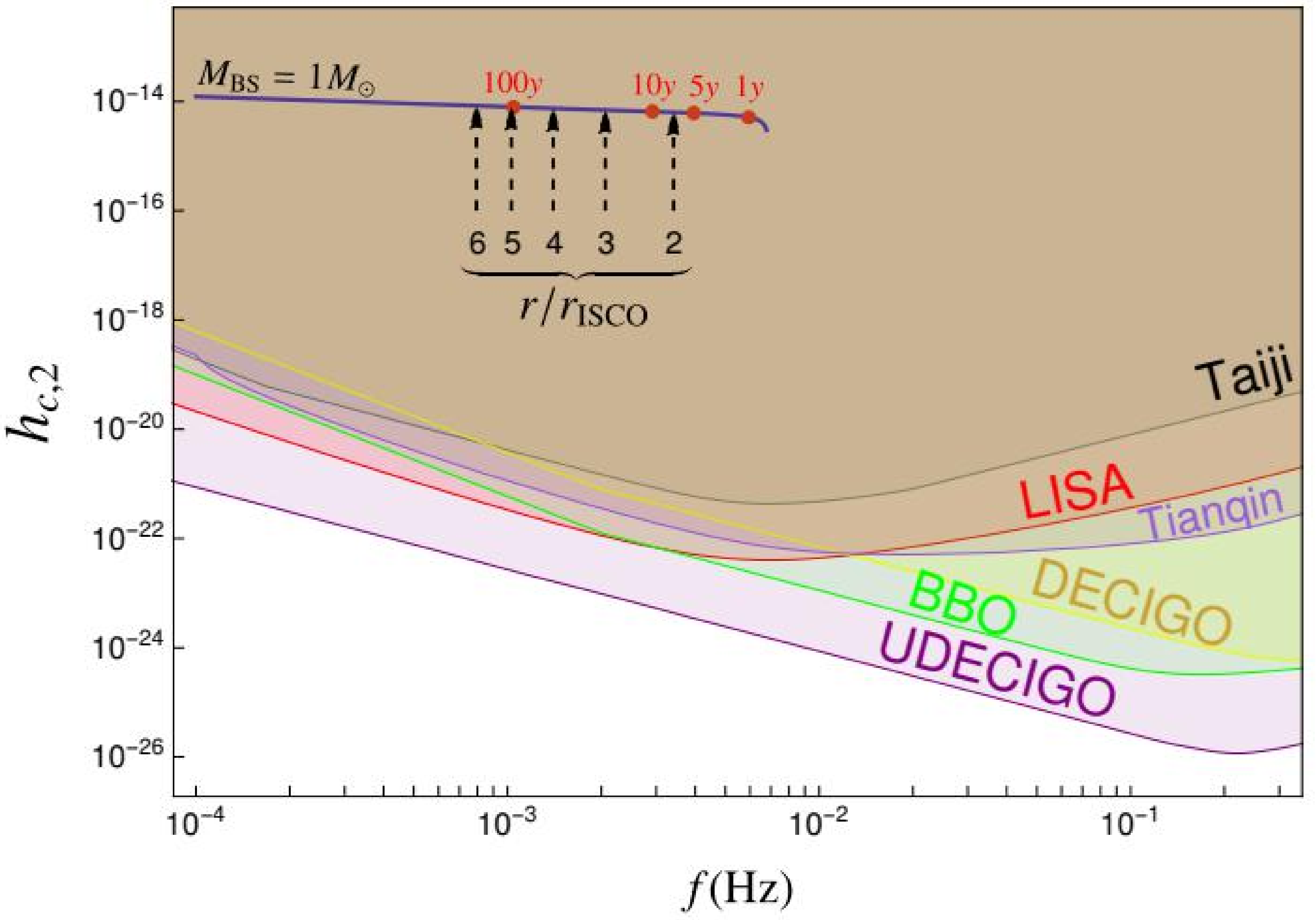


SNR = 20

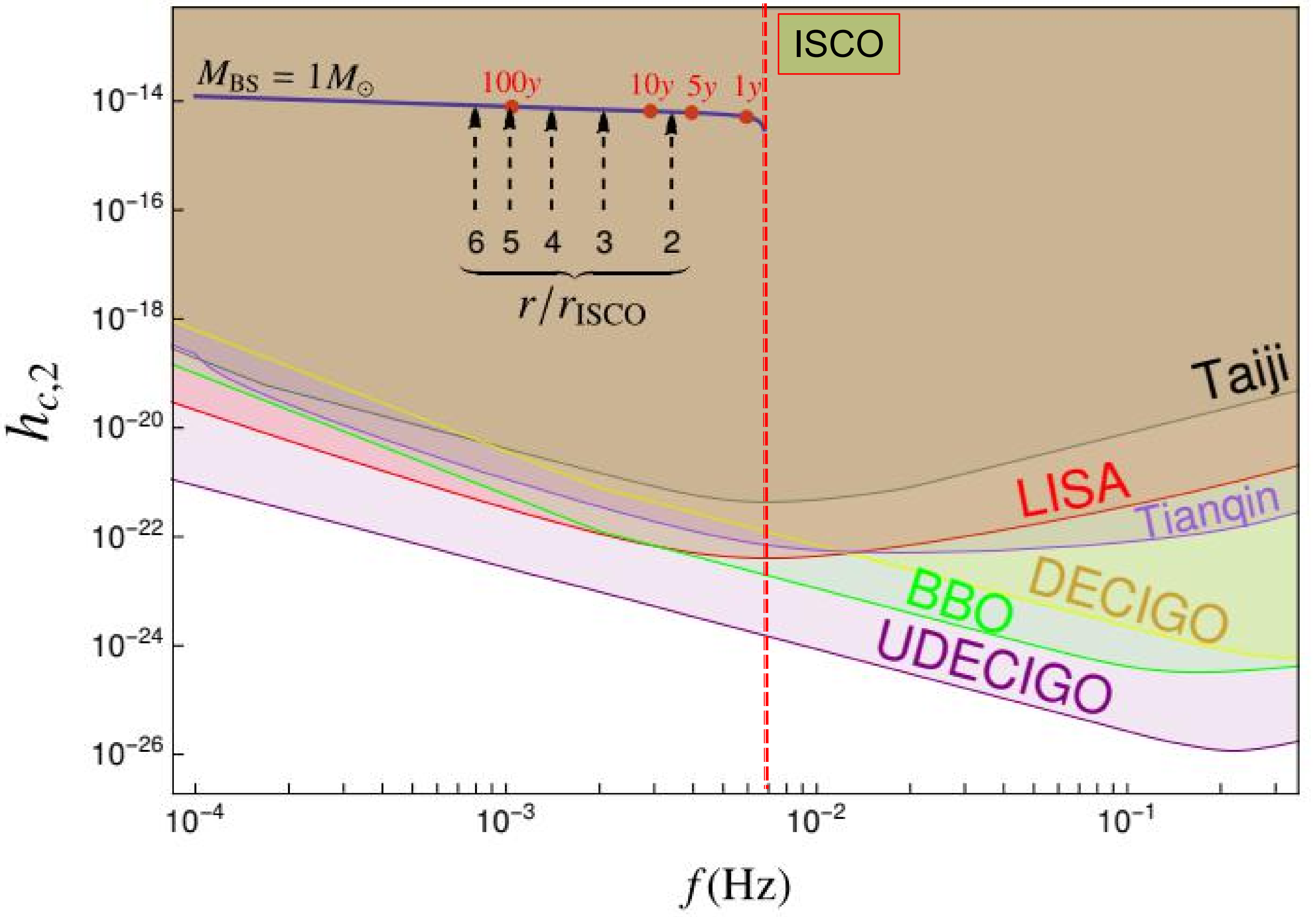
$$\mathrm{SNR}^2 = \frac{\mathcal{S}^2}{\mathcal{N}^2} = \sum_m \int \left[\frac{h_{c,m}(f_m)}{h_n(f_m)}\right]^2 d\ln f_m$$

Matched-filtering

Noise

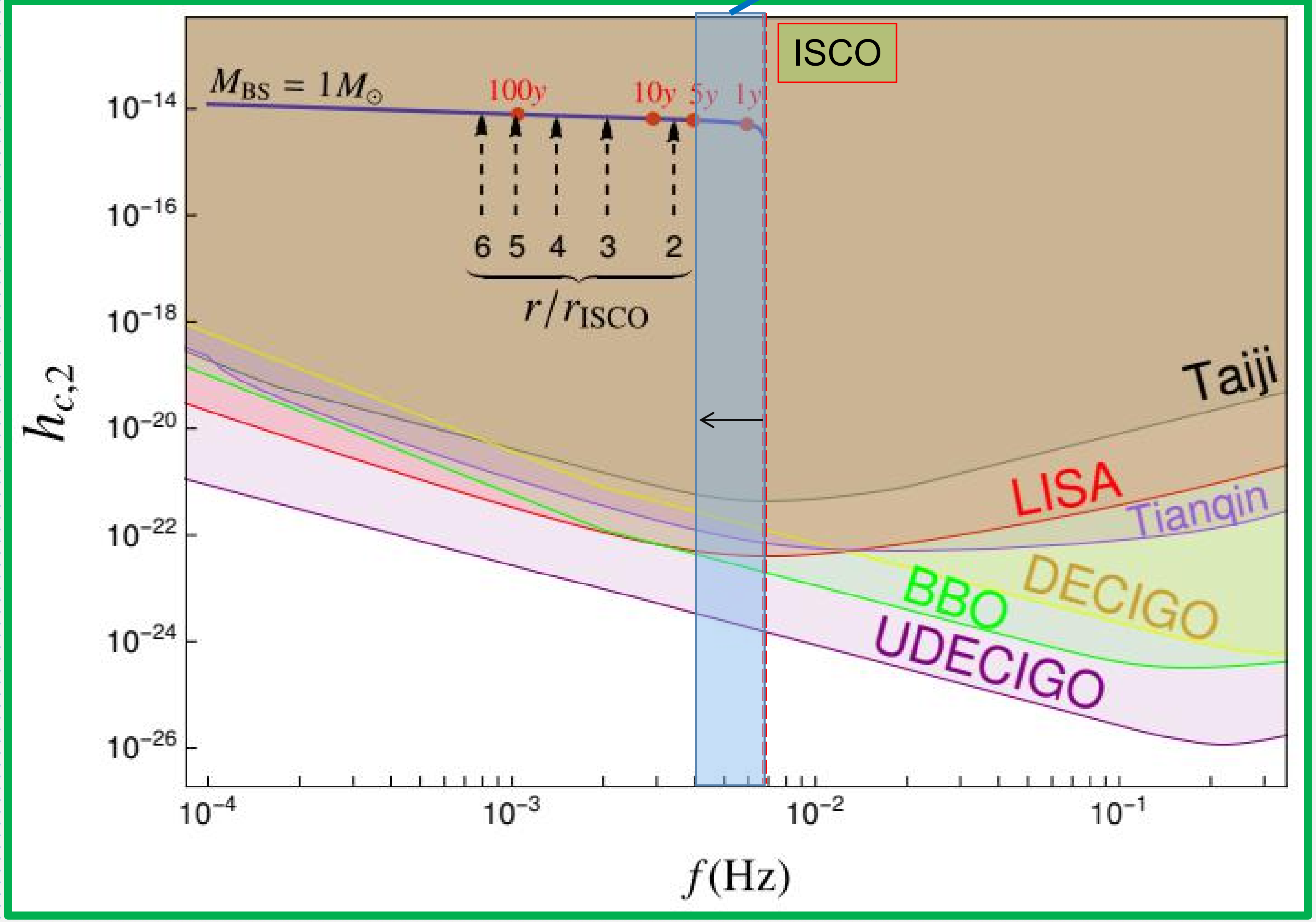


Huaike Guo, Kuver Sinha, Chen Sun, JCAP 1909,032 (2019)



Huaike Guo, Kuver Sinha, Chen Sun, JCAP 1909,032 (2019)

5-years observation time



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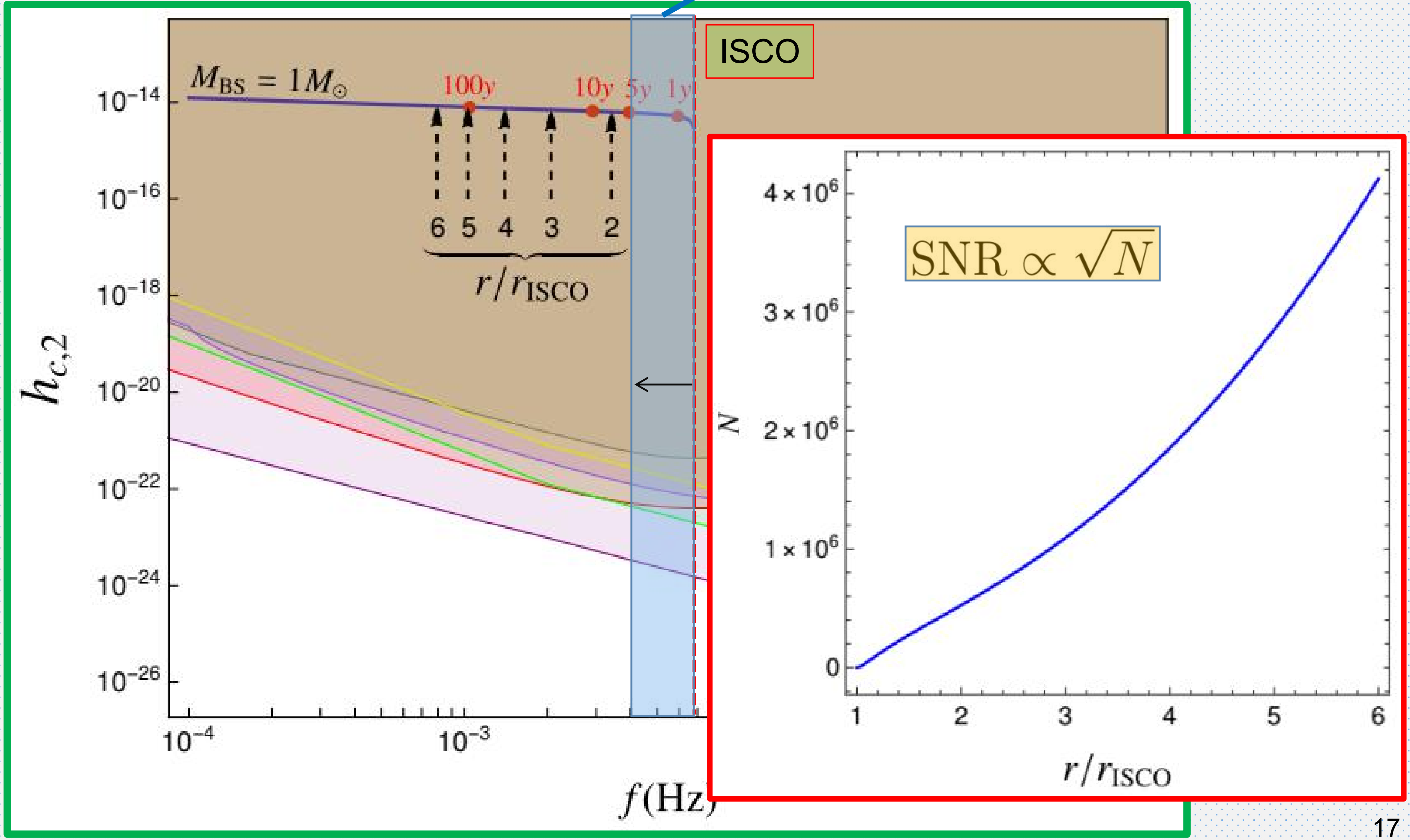

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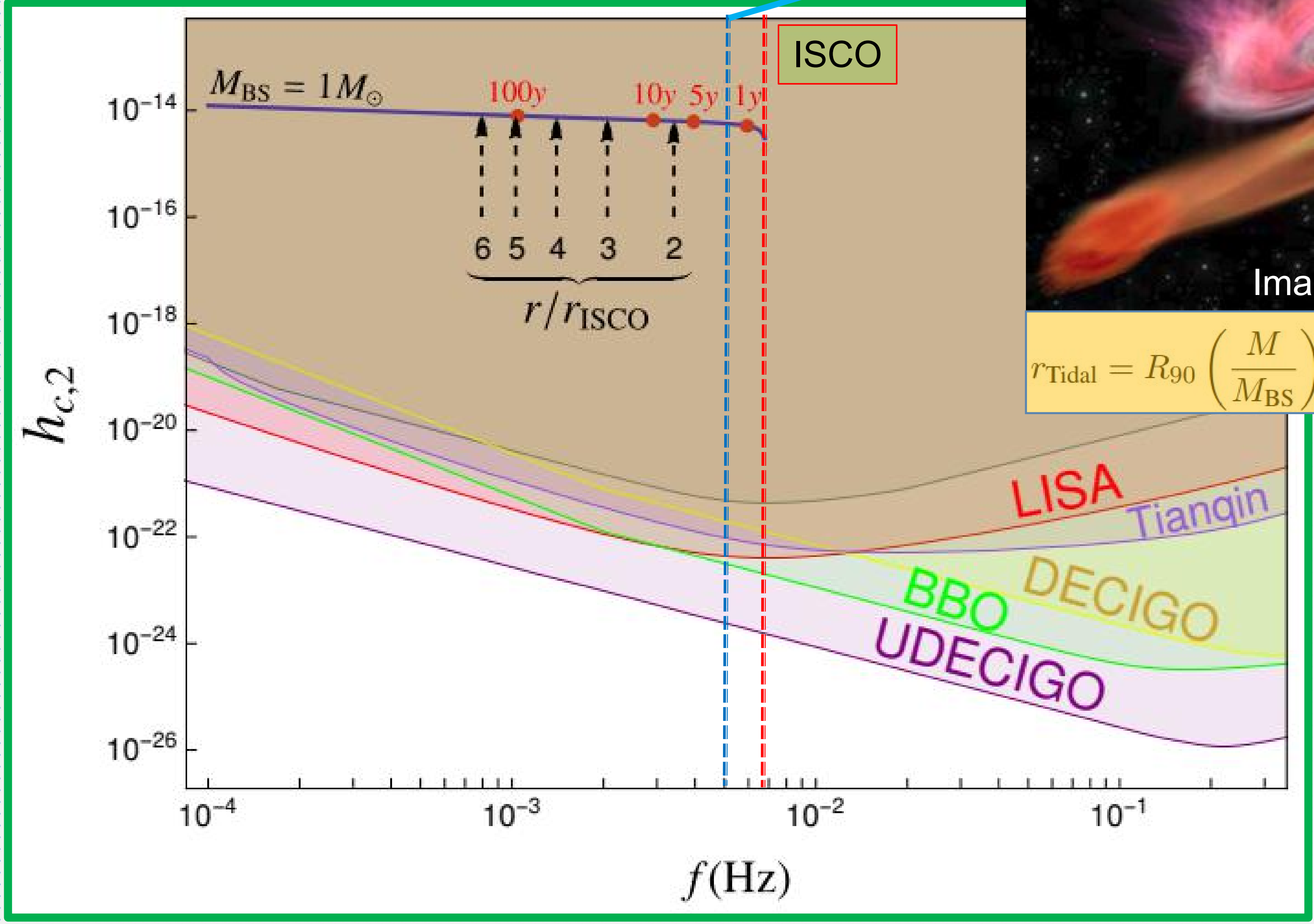
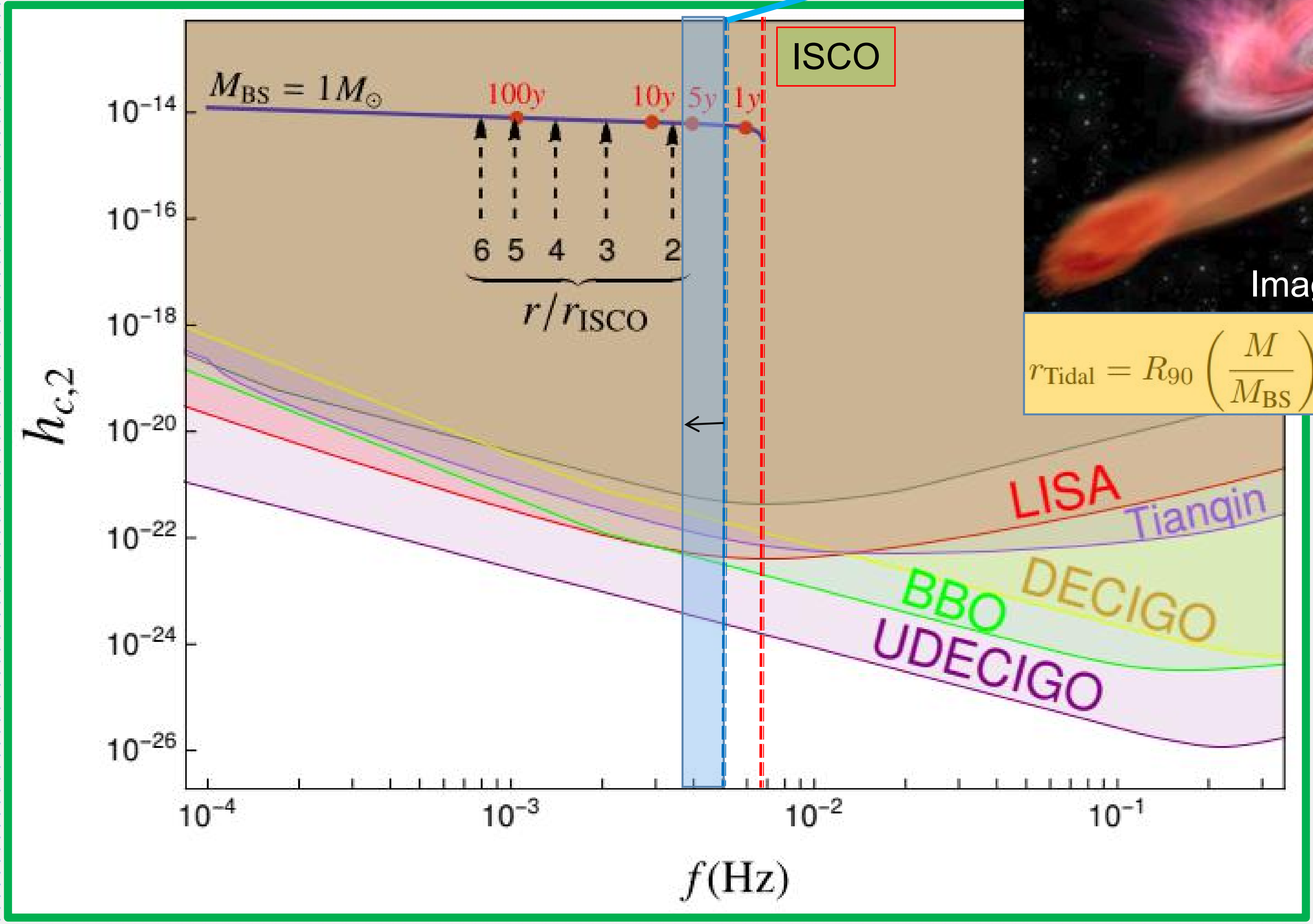


$$r_{\rm Tidal} = R_{90}\left(\frac{M}{M_{\rm BS}}\right)^{1/3} = \frac{(M_{\rm BS}{}^2 M)^{1/3}}{C_{\rm BS}}$$

Huaike Guo, Kuver Sinha, Chen Sun, JCAP 1909,032 (2019)



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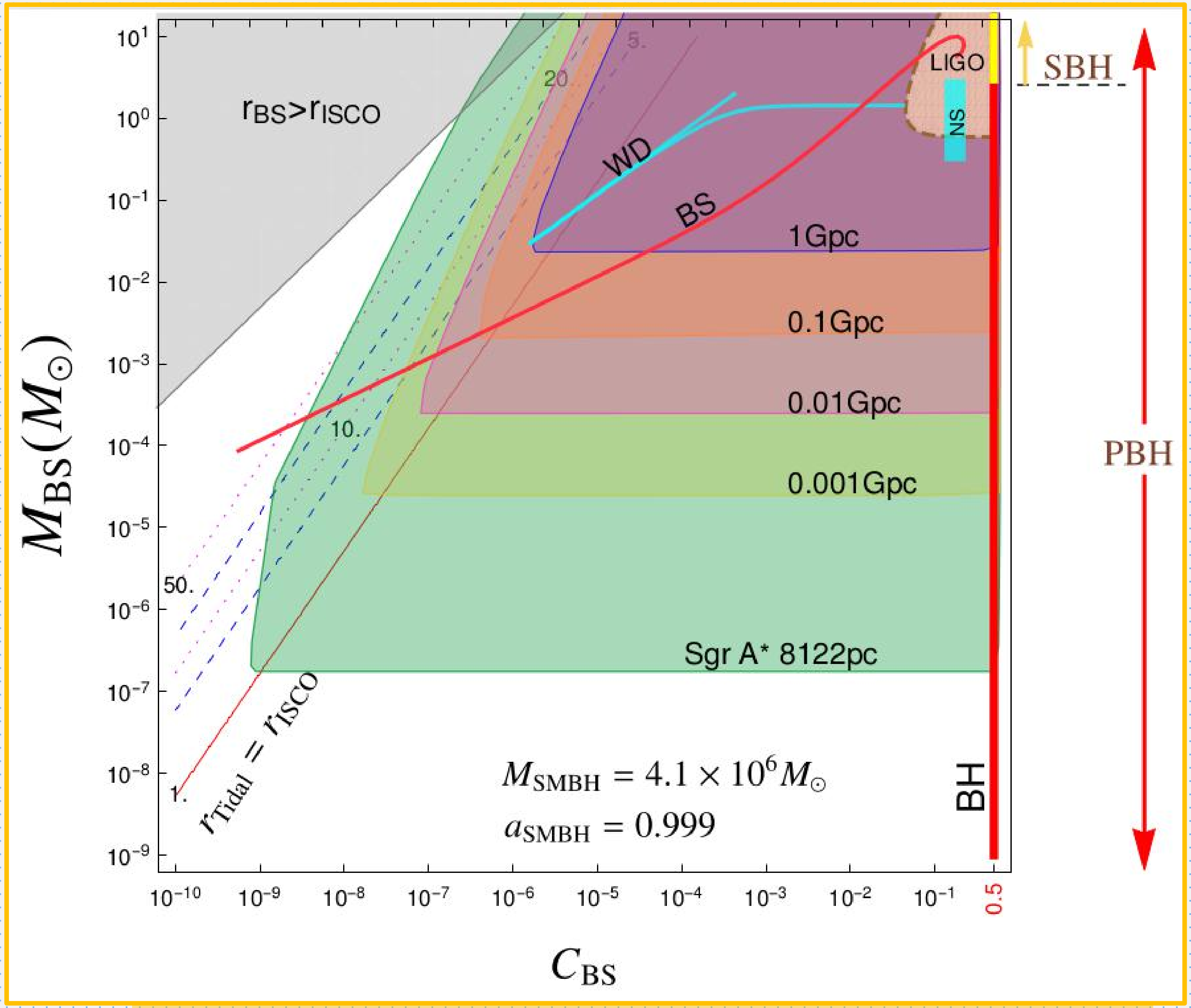
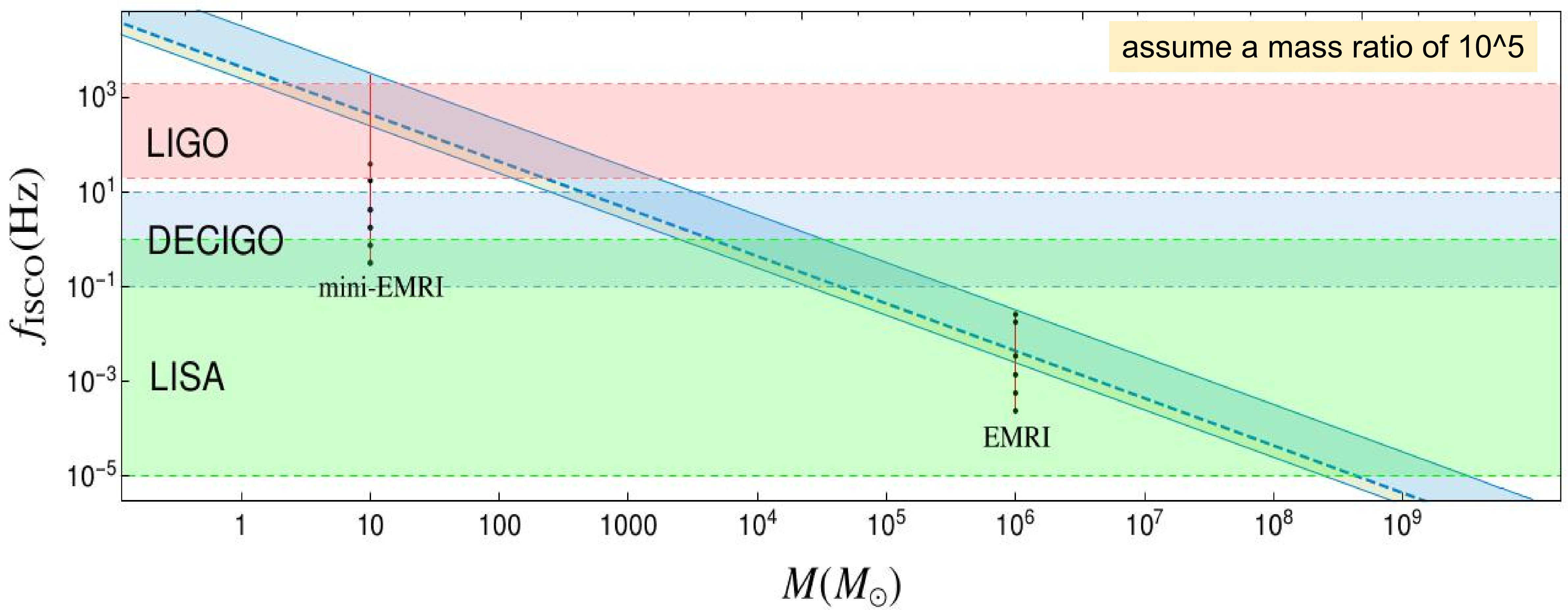
Prospect of ECO Detection with GW from EMRI



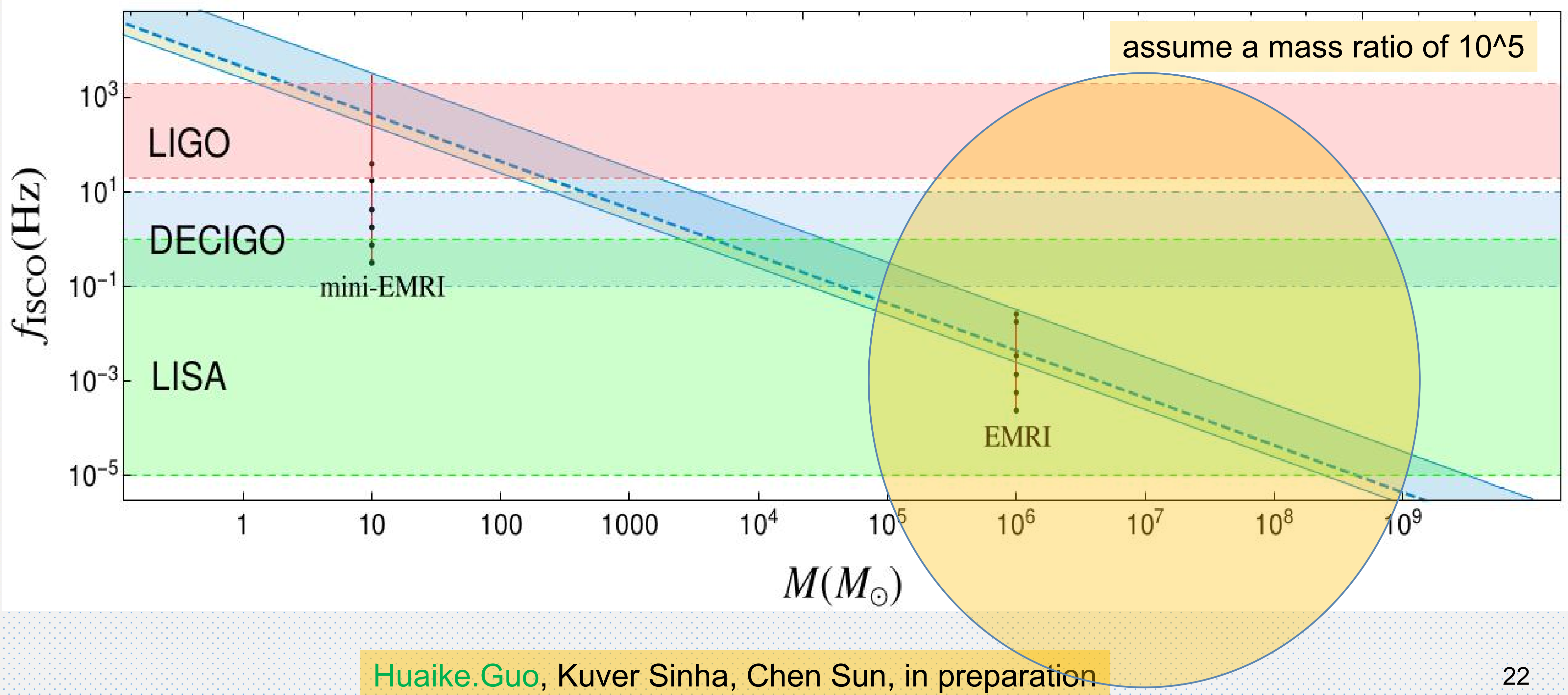
Huaike Guo, Kuver Sinha, Chen Sun, JCAP 1909,032 (2019)

EMRI in LIGO Data



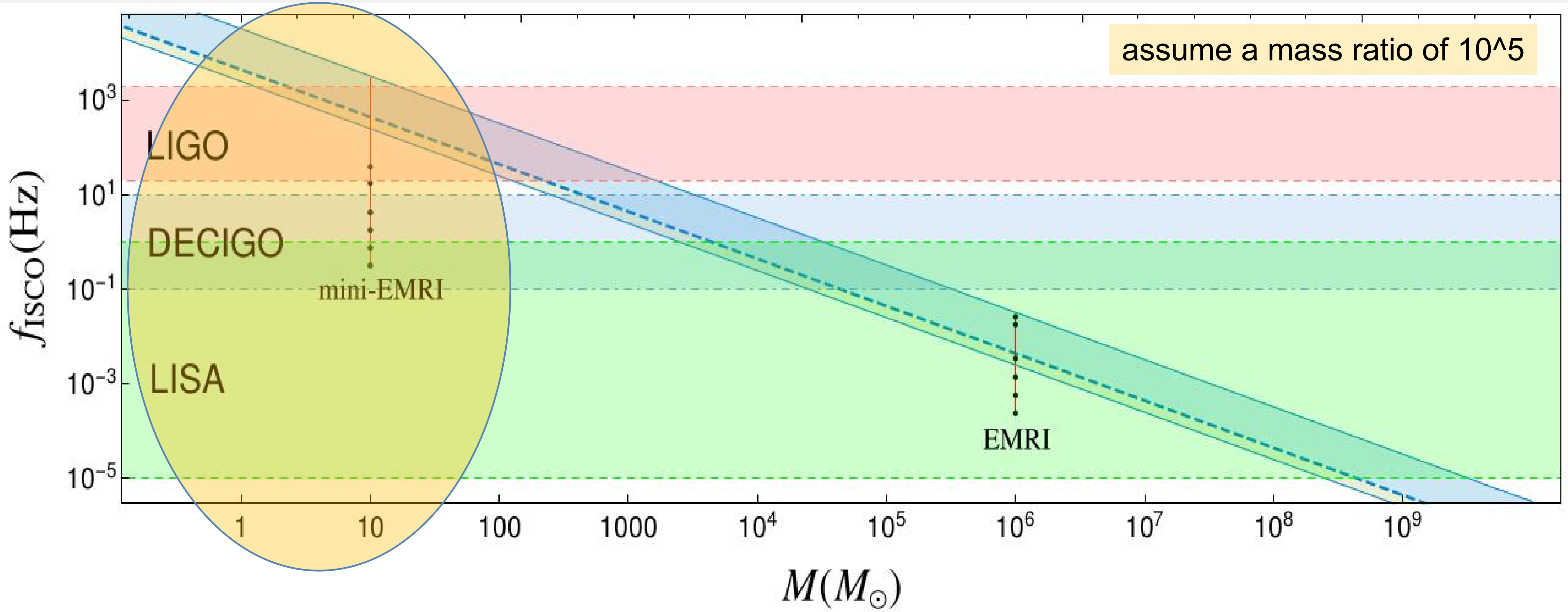
Huaike.Guo, Kuver Sinha, Chen Sun, in preparation

EMRI in LIGO Data



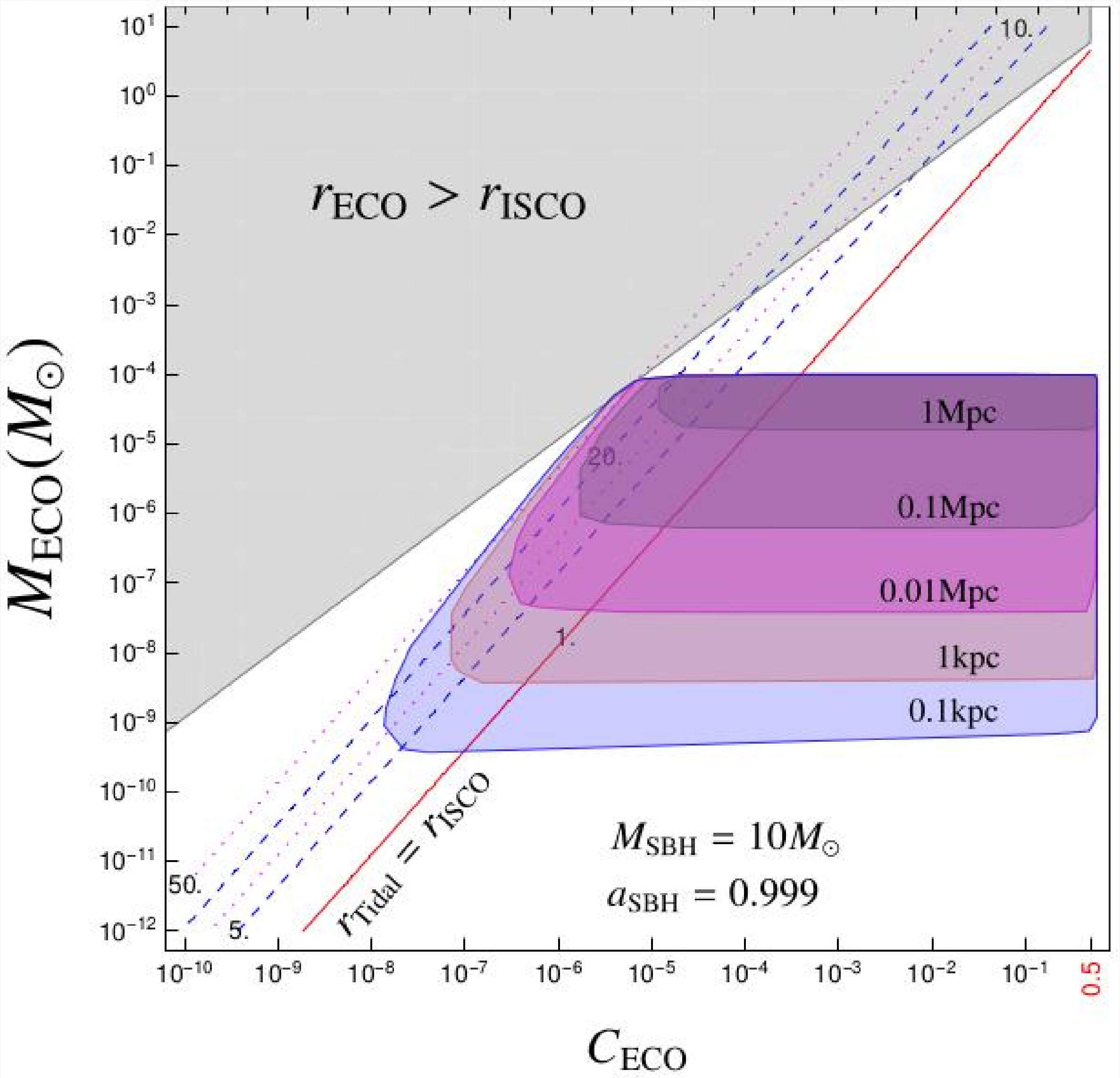
Huaike.Guo, Kuver Sinha, Chen Sun, in preparation

EMRI in LIGO Data



Huaike.Guo, Kuver Sinha, Chen Sun, in preparation

EMRI in LIGO Data



200 hours

- Nearest NS: ~76 - 306 pc
- Nearest WD: ~3pc
- Nearest SBH: ~1kpc

Huaike.Guo, Kuver Sinha, Chen Sun, in preparation

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!