


Macroscopic Dark Matter Detection with Extreme Mass Ratio Inspirals and mini-EMRIs

Huaike Guo

UCAS (ICTP-AP)

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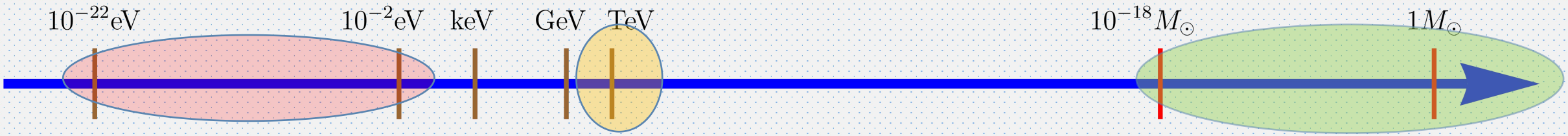
HG, Andrew Miller [2205.10359]

HG, Kuver Sinha, Chen Sun, Joshua Swaim, Daniel Vagie, JCAP [2010.15977]

HG, Kuver Sinha, Chen Sun, JCAP [1904.07871]

HG, Jing Shu, Yue Zhao, PRD [1709.03500]

Dark Matter Candidates



ultralight particles
(axion, dark photon)

WIMP

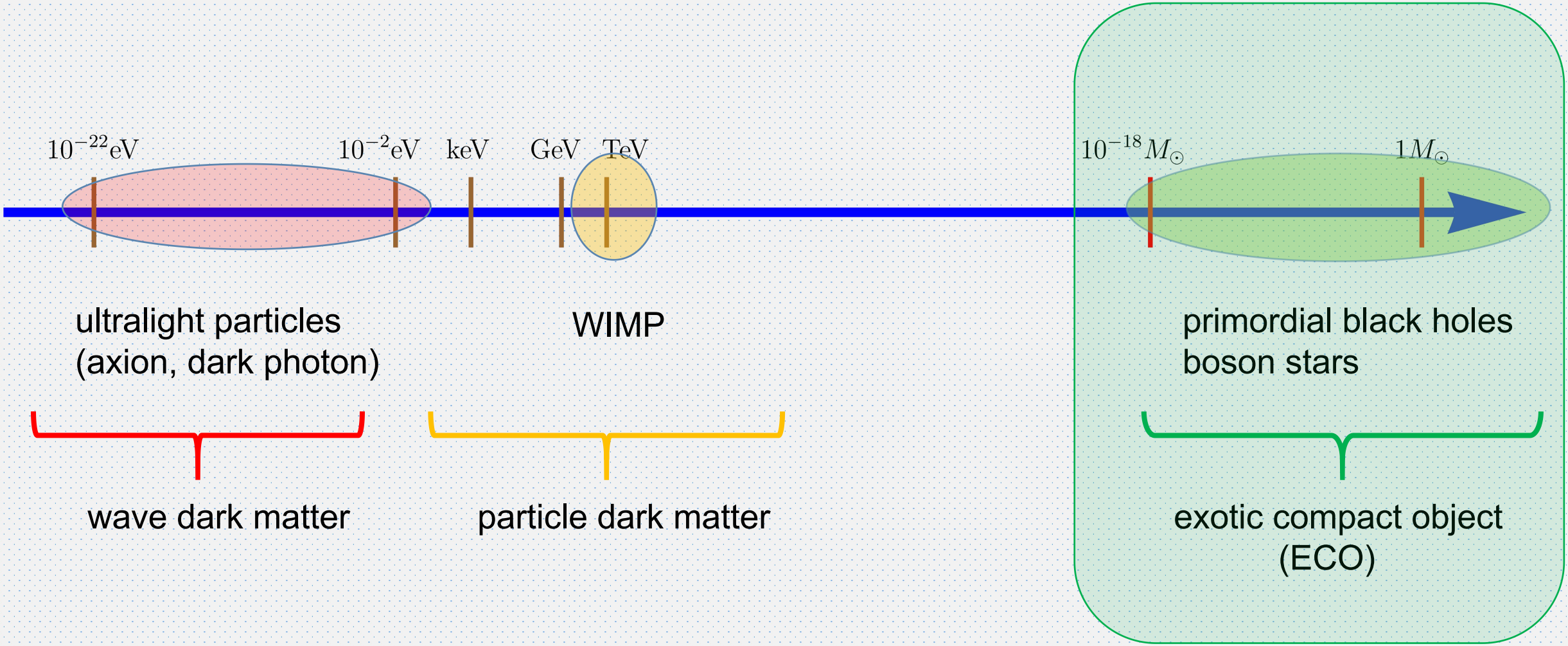
primordial black holes
boson stars

wave dark matter

particle dark matter

exotic compact object
(ECO)

Dark Matter Candidates



Ordinary and Exotic Compact Objects

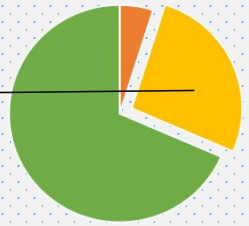
Ordinary

- Neutron Stars
- White Dwarfs
- Black Holes

Exotic

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

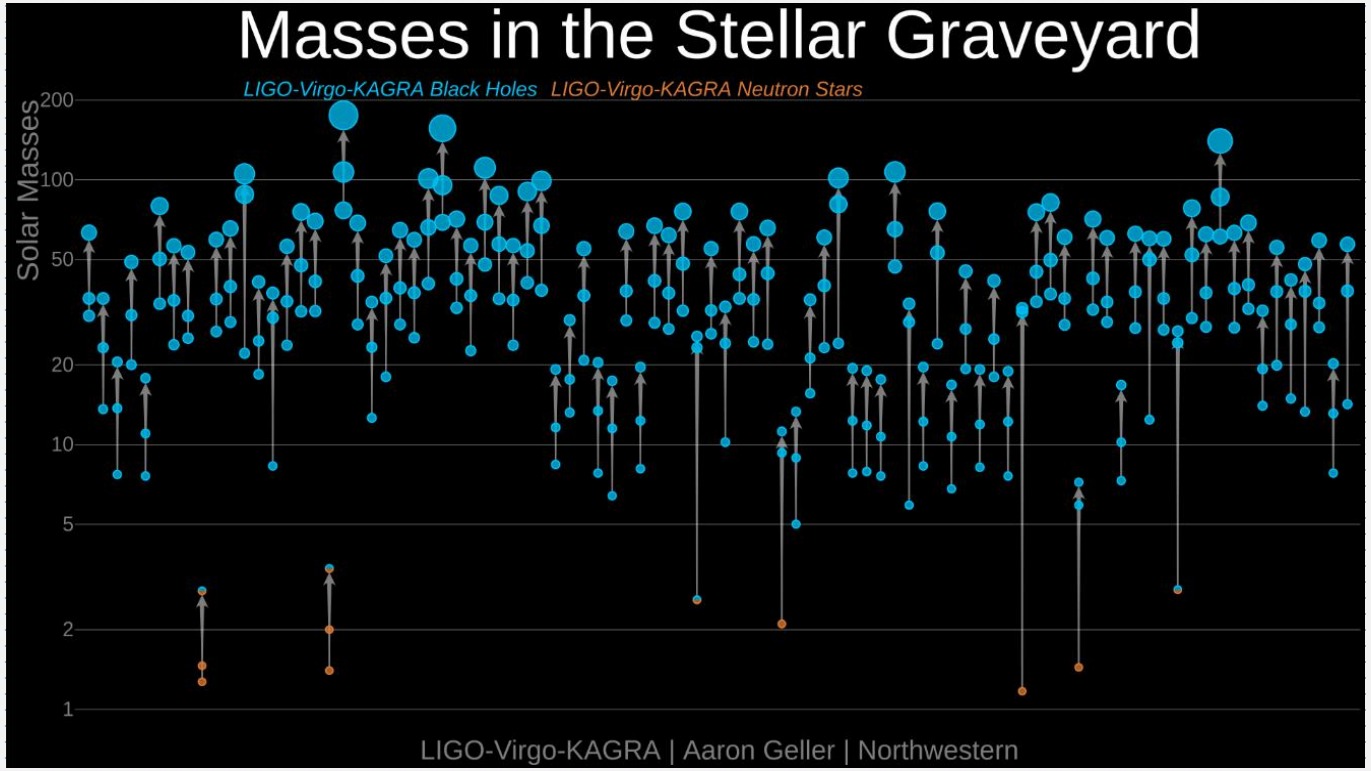
?



Did LIGO detect ECOs?

- Difficult to distinguish
- Mass as discriminator

  (SBH cannot be subsolar)



PRL 116, 201301 (2016) PHYSICAL REVIEW LETTERS week ending 20 MAY 2016

Did LIGO Detect Dark Matter?

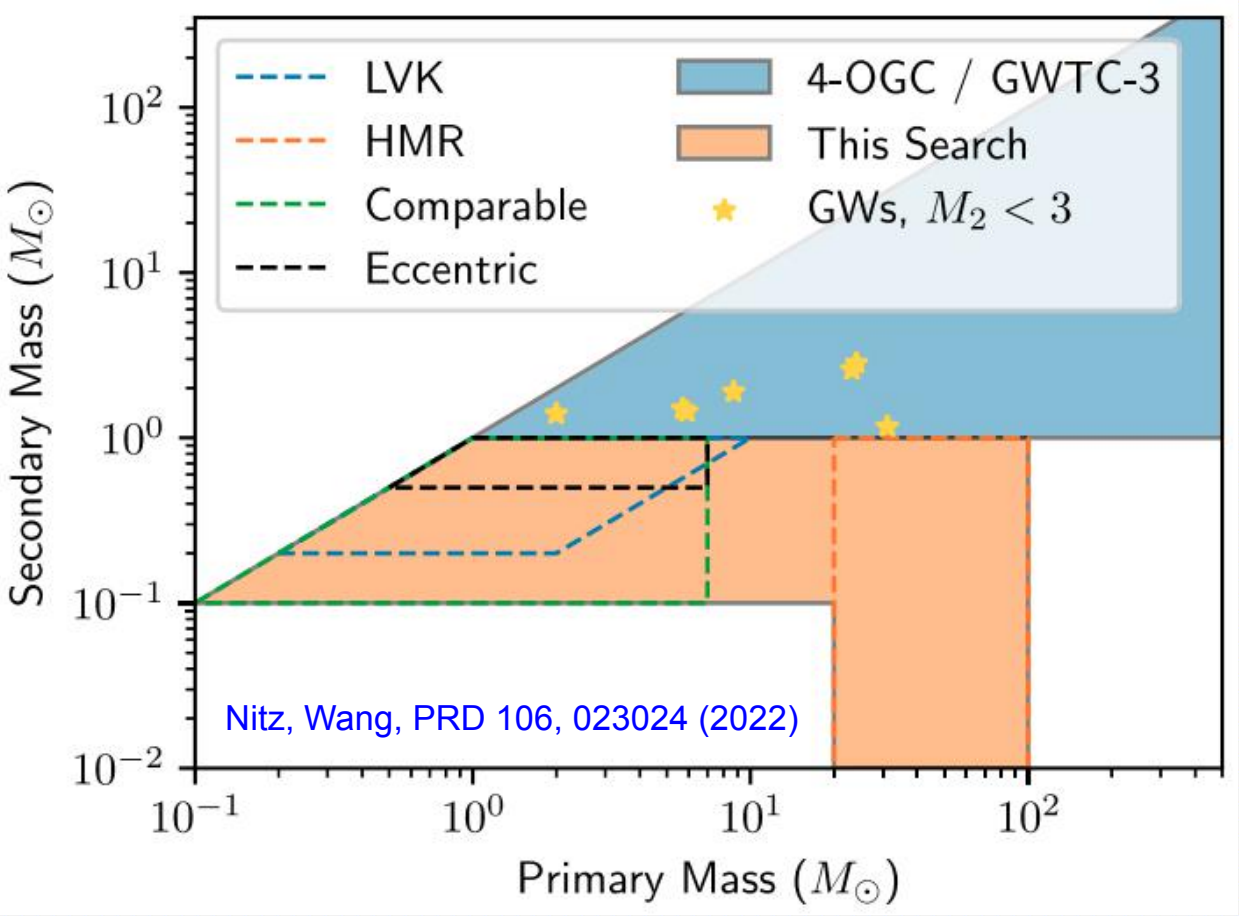
Simeon Bird,* Ilias Cholis, Julian B. Muñoz, Yacine Ali-Haïmoud, Marc Kamionkowski, Ely D. Kovetz, Alvise Raccanelli, and Adam G. Riess
Department of Physics and Astronomy, Johns Hopkins University, 3400 North Charles Street, Baltimore, Maryland 21218, USA
(Received 4 March 2016; published 19 May 2016)

GW190521 as a Merger of Proca Stars: A Potential New Vector Boson of 8.7×10^{-13} eV

Juan Calderón Bustillo, Nicolas Sanchis-Gual, Alejandro Torres-Forné, José A. Font, Avi Vajpeyi, Rory Smith, Carlos Herdeiro, Eugen Radu, and Samson H. W. Leong
Phys. Rev. Lett. **126**, 081101 – Published 24 February 2021

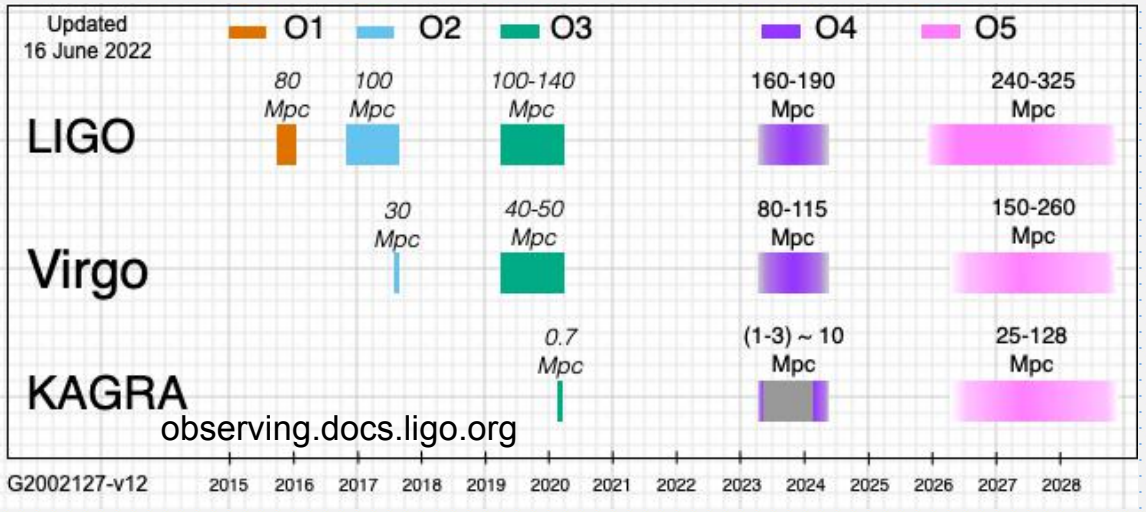
Subsolar PBH Searches

Rising interest in subsolar PBH searches (LVK, ...)



- Method: matched-filtering
- All assuming ultracompact objects

Need to take generic compactness into account for generic ECOs



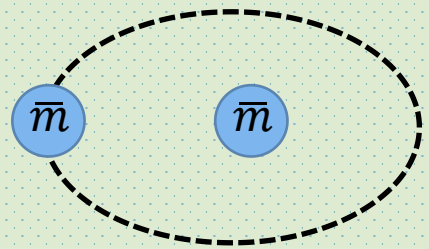
How to Search for Light ECOs

- Amplitude and SNR increase as the chirp mass increases

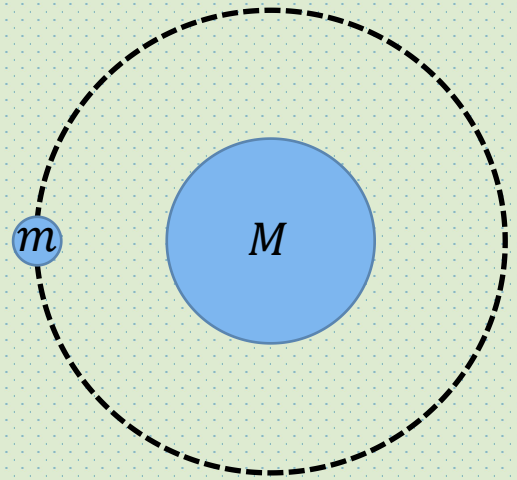
the chirp mass

$$M_c = \frac{(m_1 m_2)^{3/5}}{(m_1 + m_2)^{1/5}}$$

Same Chirp Mass Binaries



equal subsolar masses



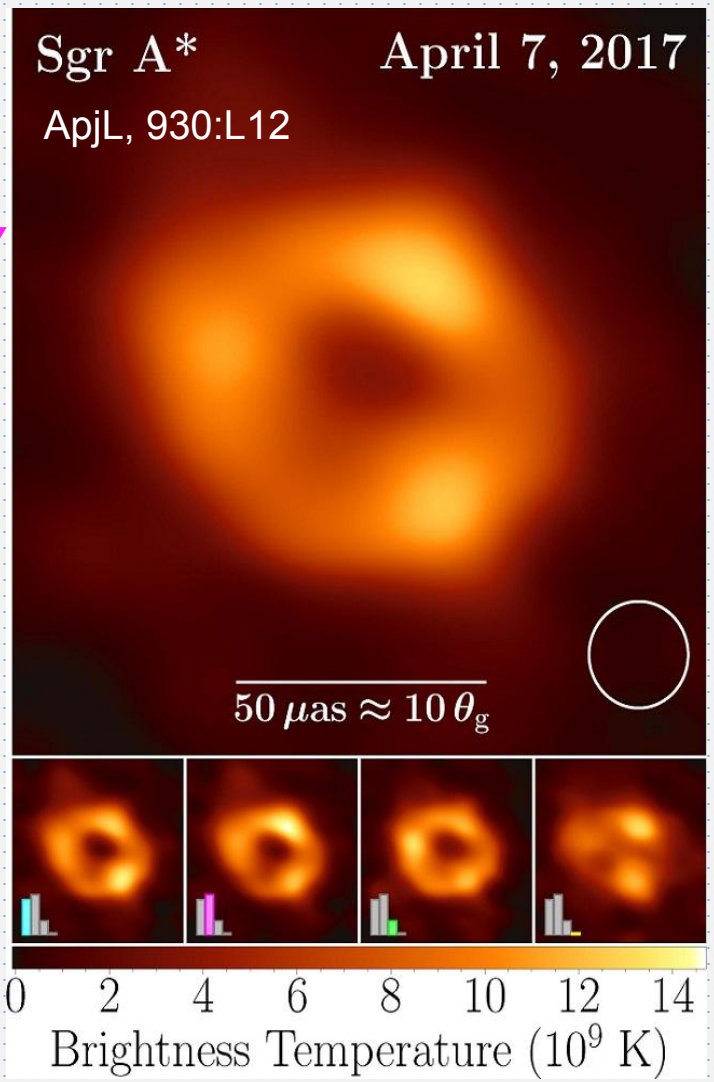
large mass ratio

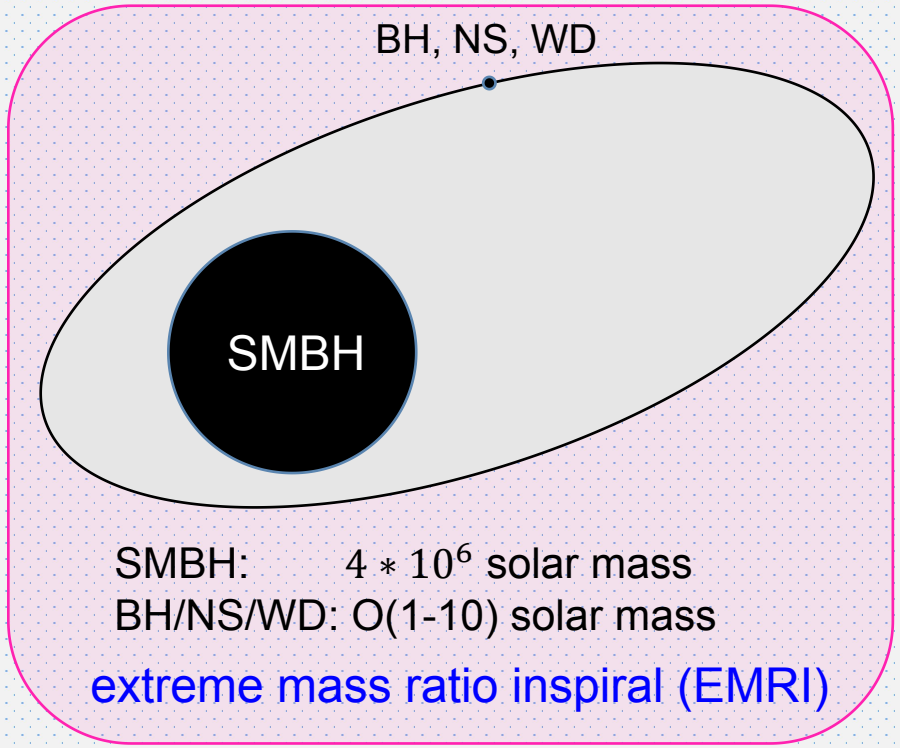
$$\frac{m}{\bar{m}} \approx 2^{-1/3} \left(\frac{\bar{m}}{M}\right)^{2/3} \quad \Rightarrow \quad m \ll \bar{m} \ll M$$

To probe a lighter one, make the other one heavier: larger mass ratio

The Extreme Mass Ratio Inspiral (EMRI)

Wikipedia



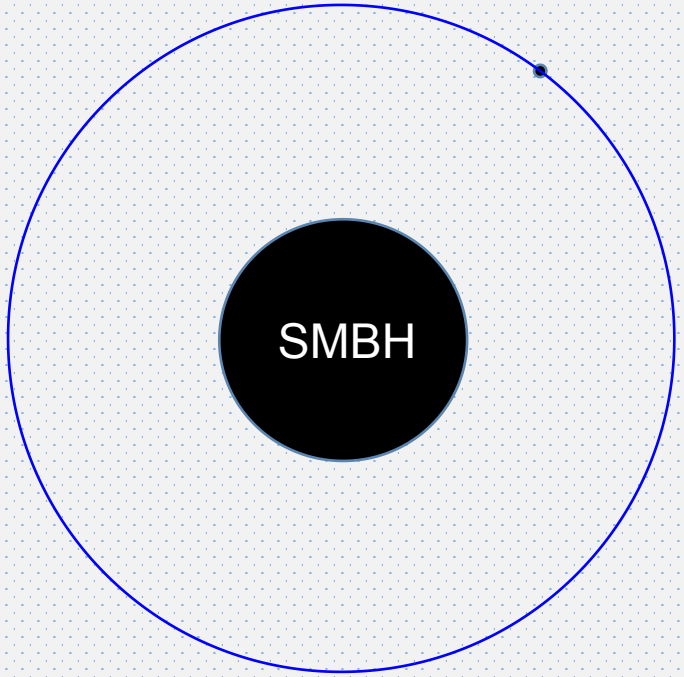


SMBH: $4 * 10^6$ solar mass

BH/NS/WD: O(1-10) solar mass

extreme mass ratio inspiral (EMRI)

Typical Frequencies

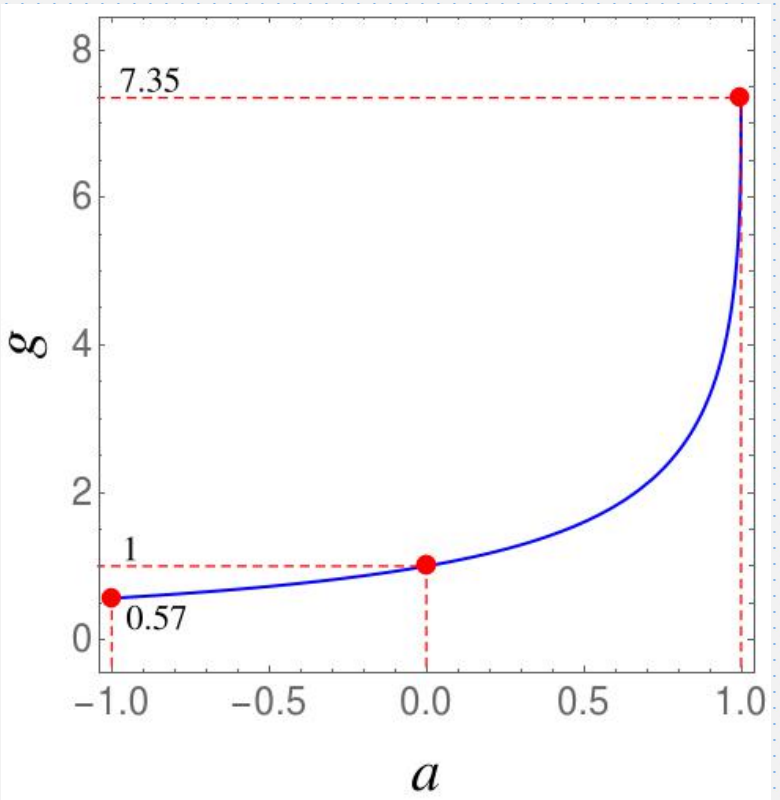


Innermost stable circular orbit

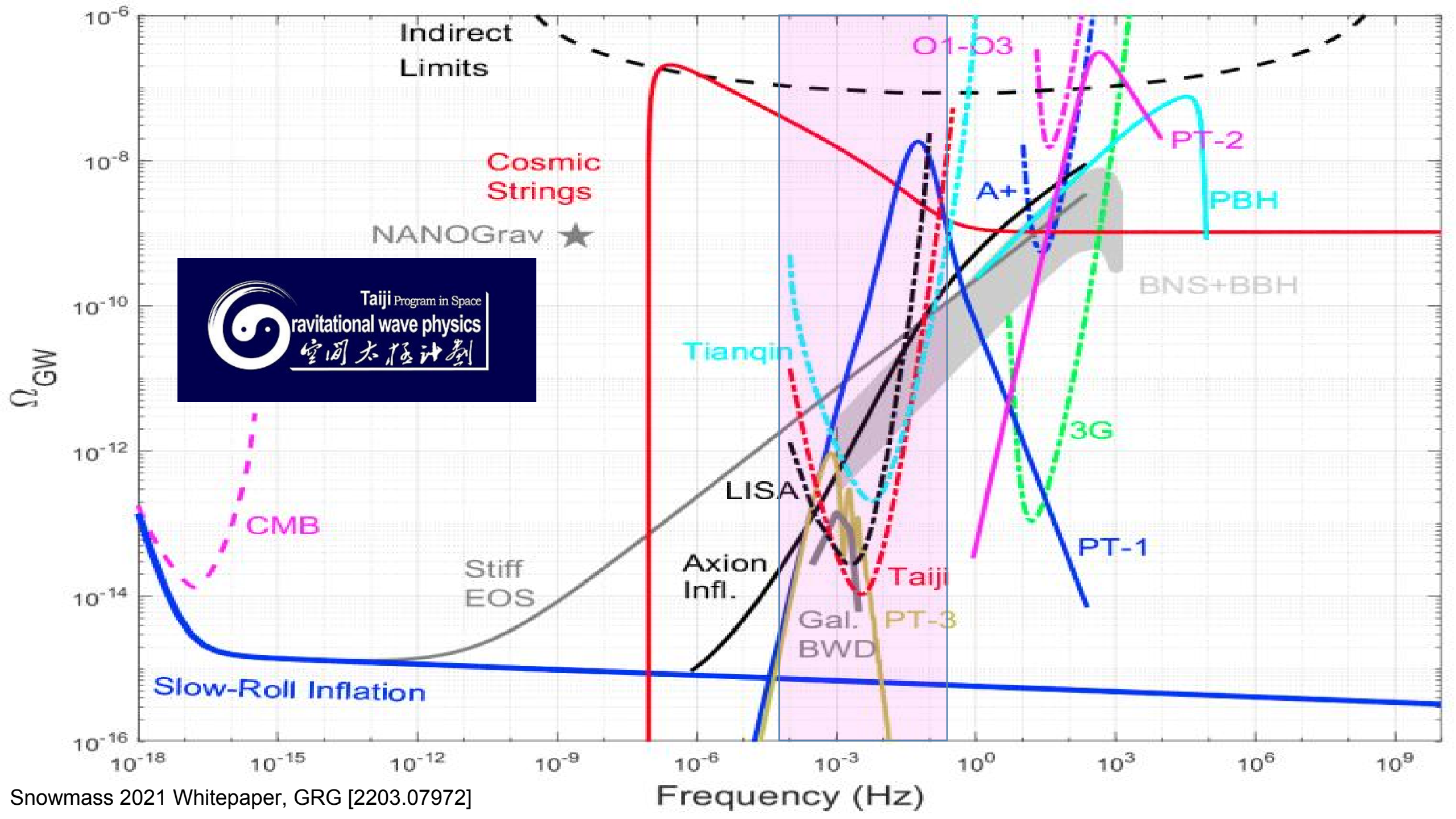
$$f_{\rm ISCO} = 4.4{\rm kHz}\left(\frac{1M_\odot}{M}\right)\left(\frac{n}{2}\right)g(a)$$

Bardeen, Press, Teukolsky, ApJ,178,347, 1972

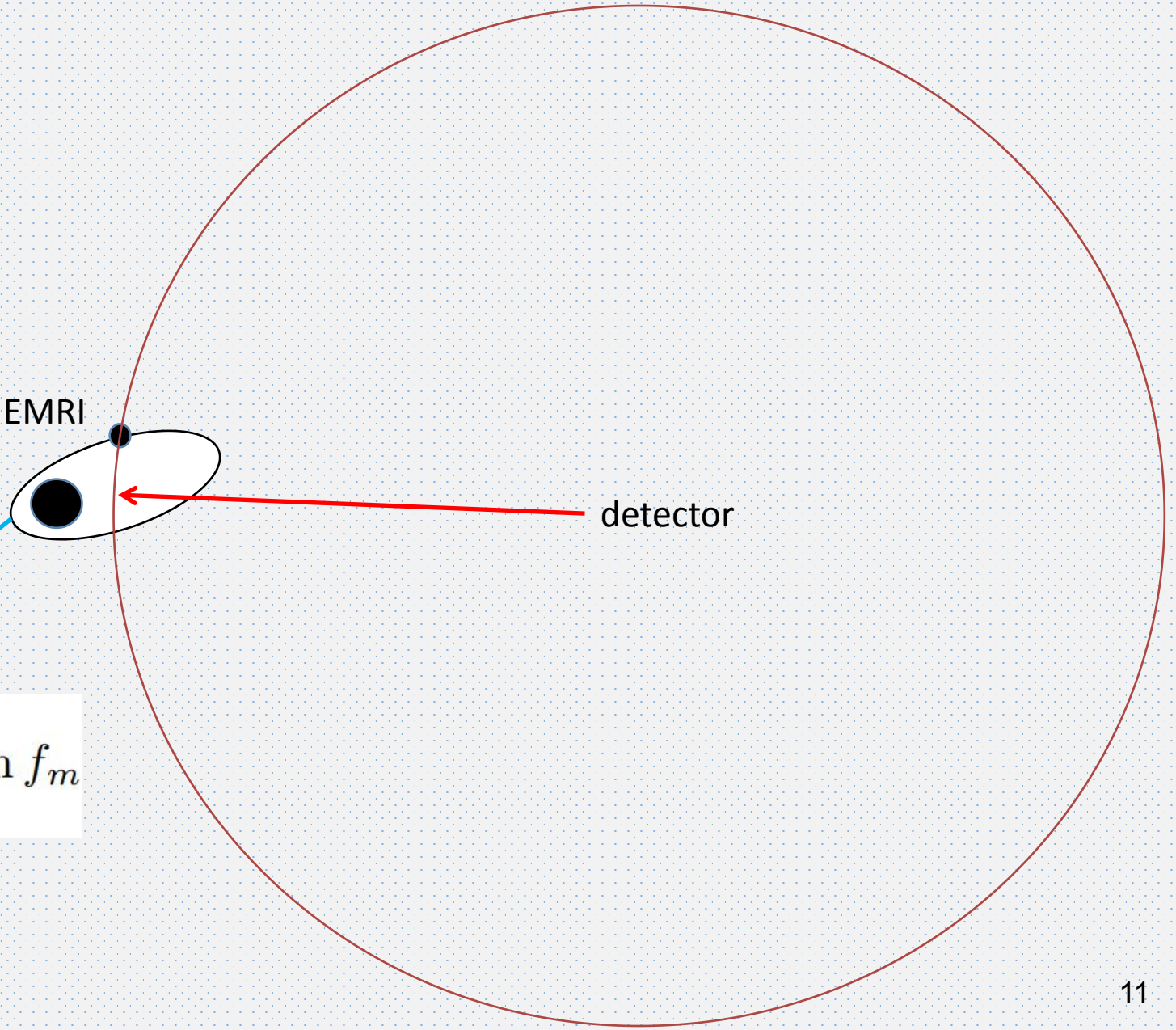
Typical frequency: mili-Hz.



Important target for space-based gravitational wave detectors



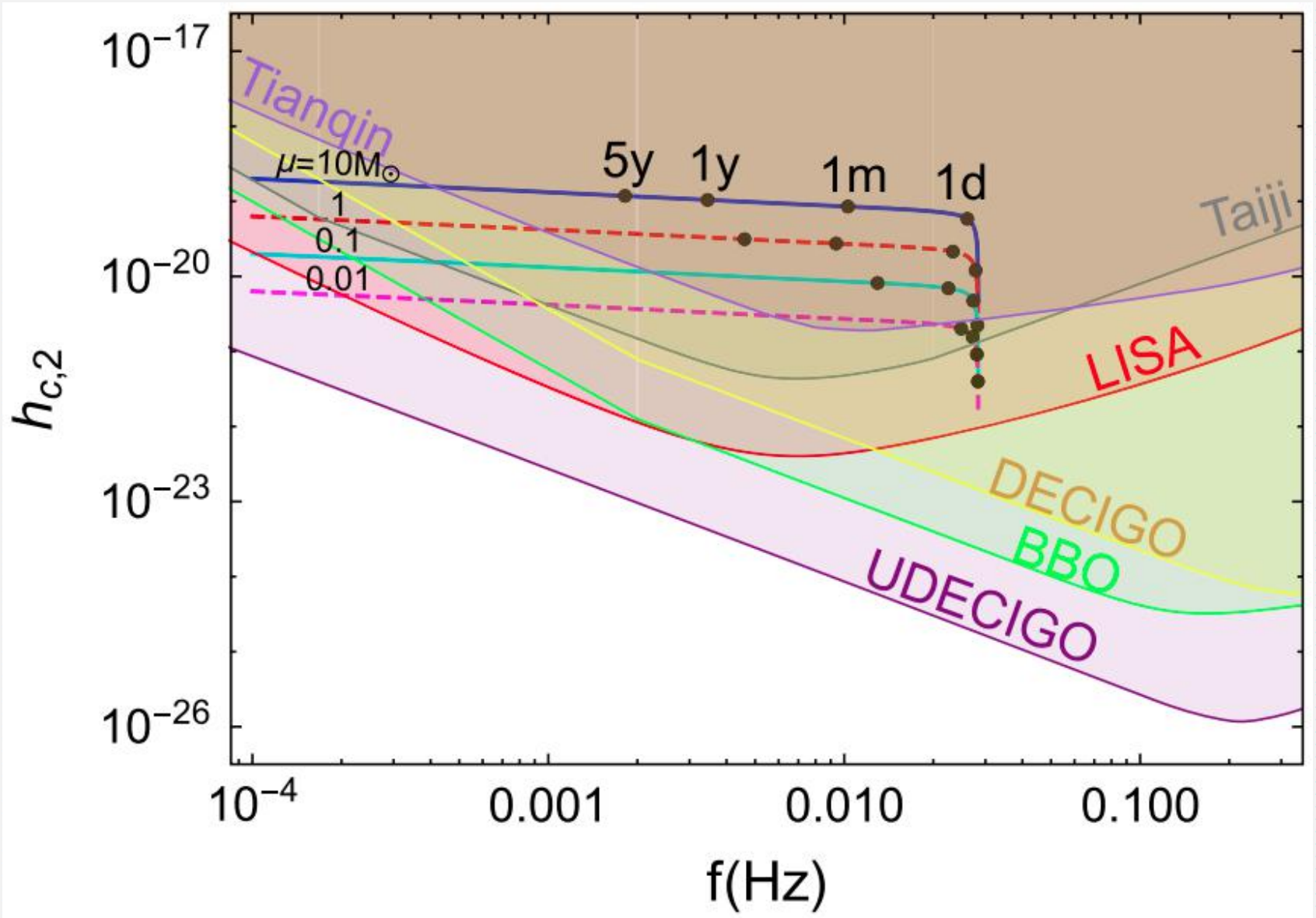
Snowmass 2021 Whitepaper, GRG [2203.07972]



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

Matched-filtering

Noise

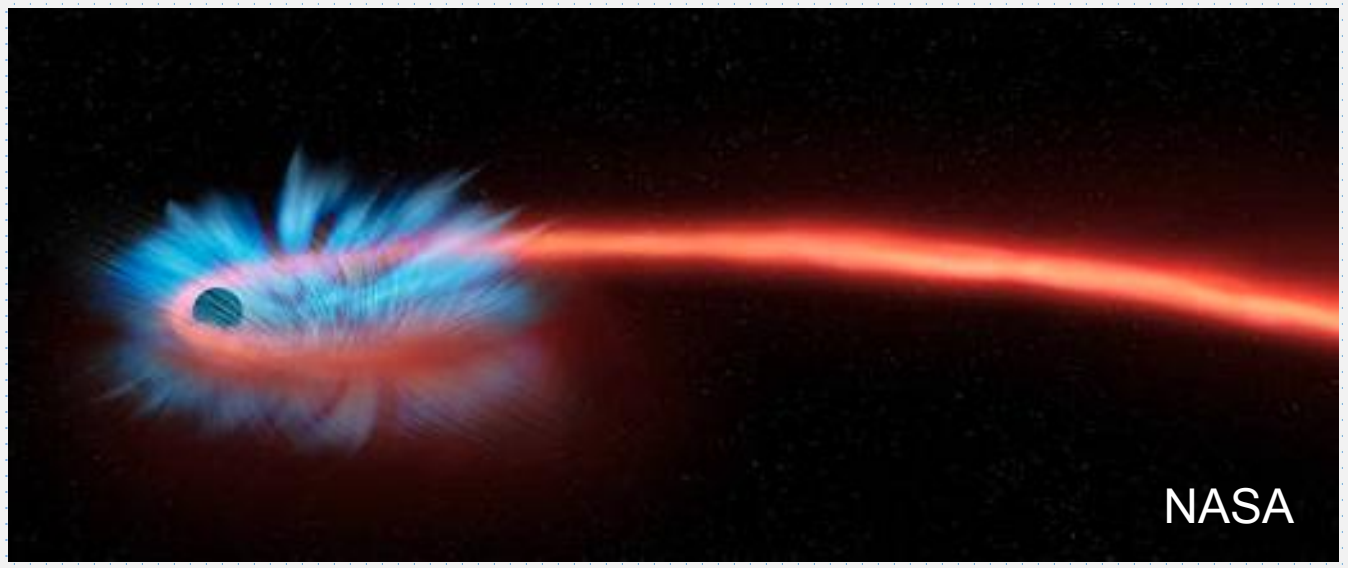


HG, Jing Shu, Yue Zhao, PRD [1709.03500]

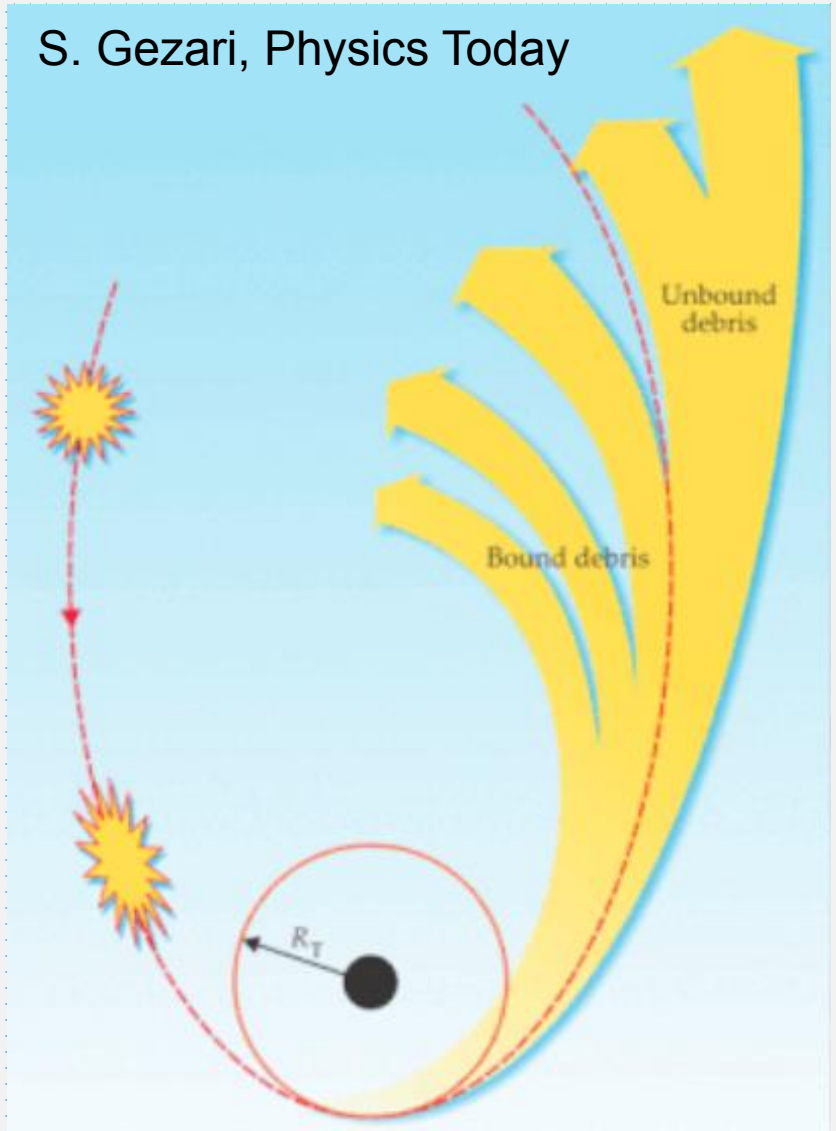
Tidal Disruption

Signal will be cut-off when tidal disruption occurs
(fISCO might not be reached)

Tidal radius: $$r_{\mathrm{tidal}} = \frac{(m^2 M)^{1/3}}{C}$$



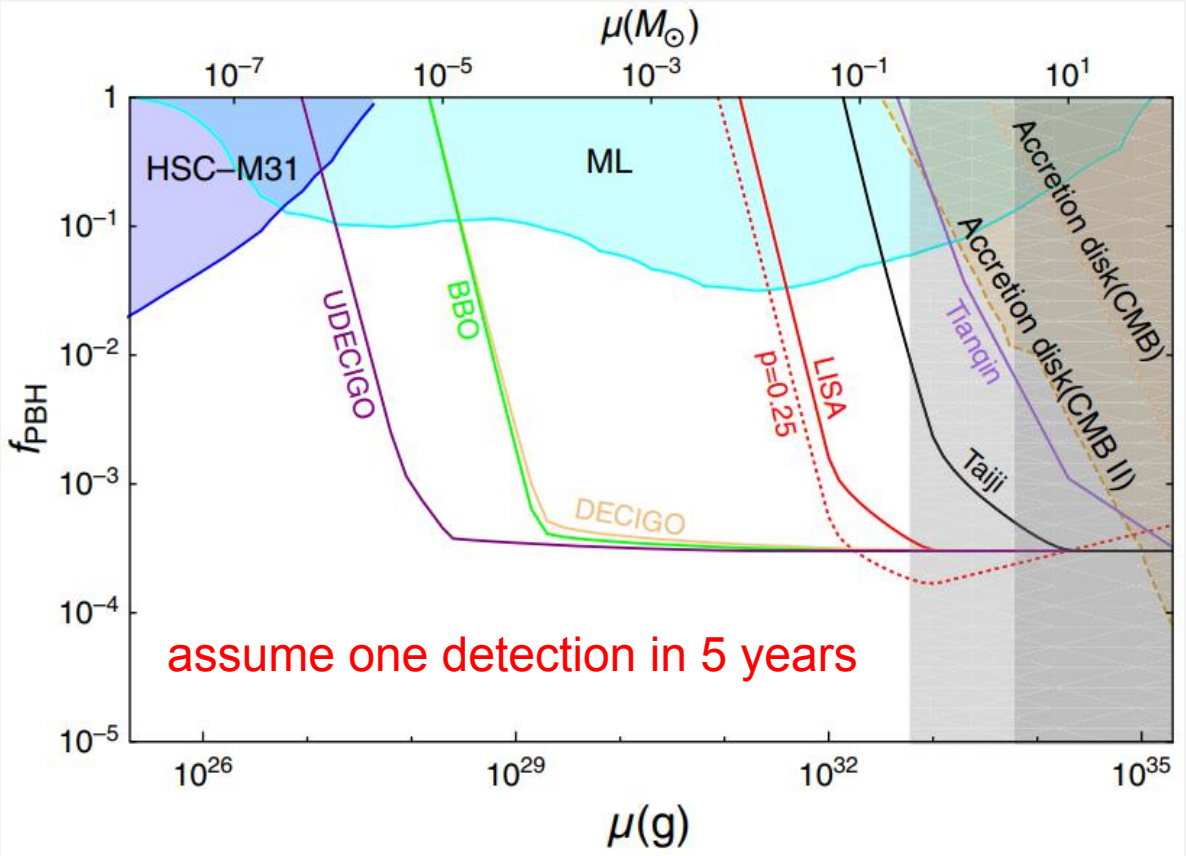
S. Gezari, Physics Today



Sensitivity with EMRI

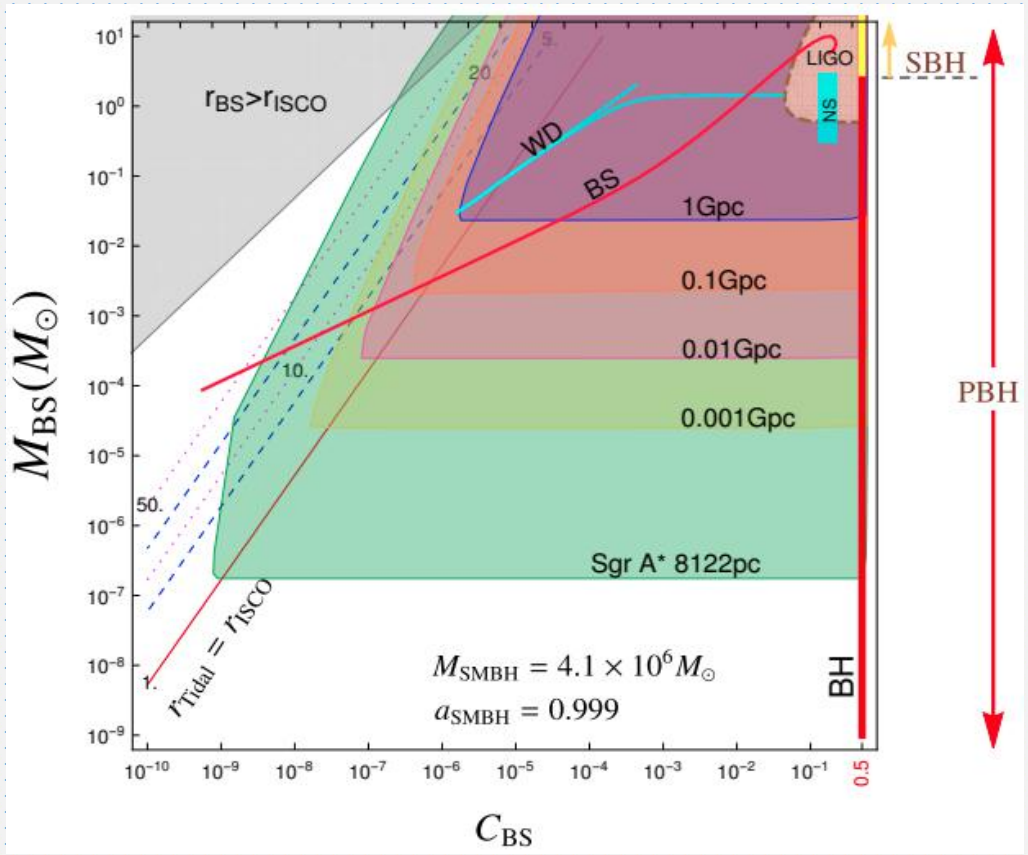
- Sensitive to a large region of parameter space

Constraining PBH



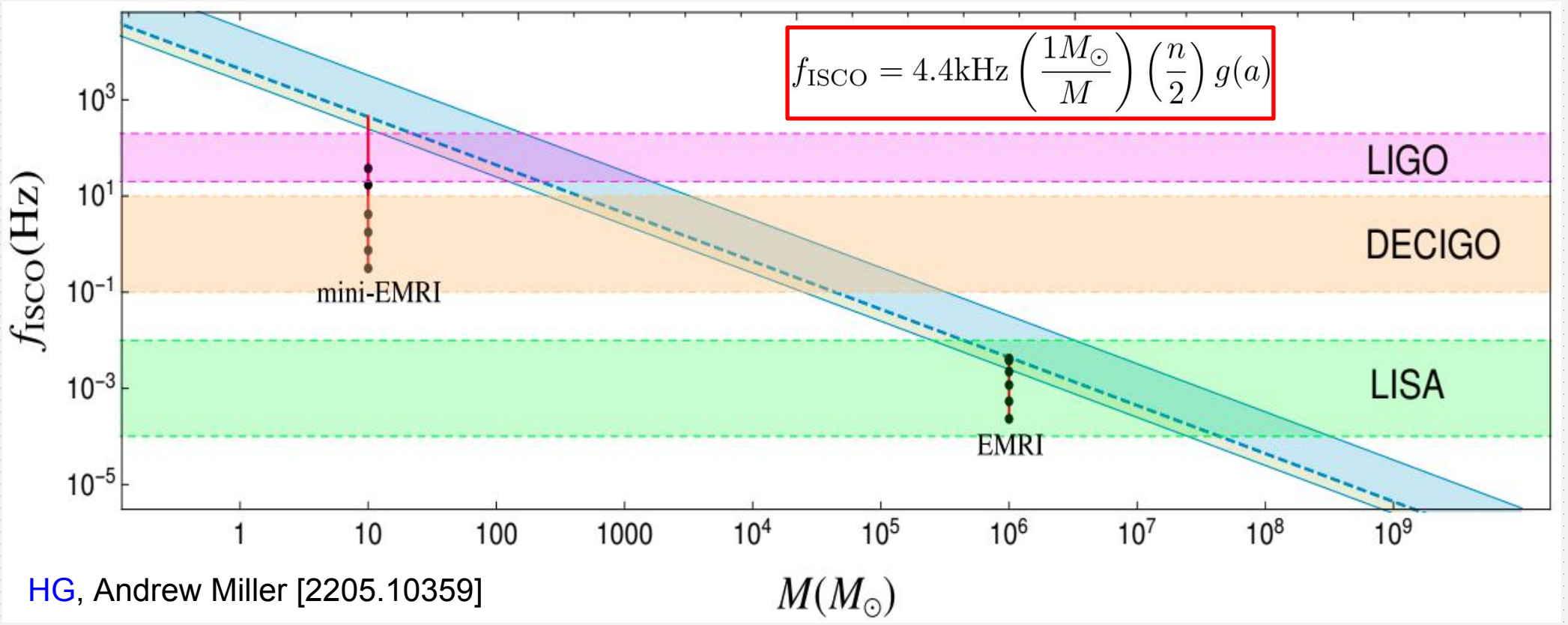
HG, Jing Shu, Yue Zhao, PRD [1709.03500]

Sensitivity to Generic Exotic Compact Objects



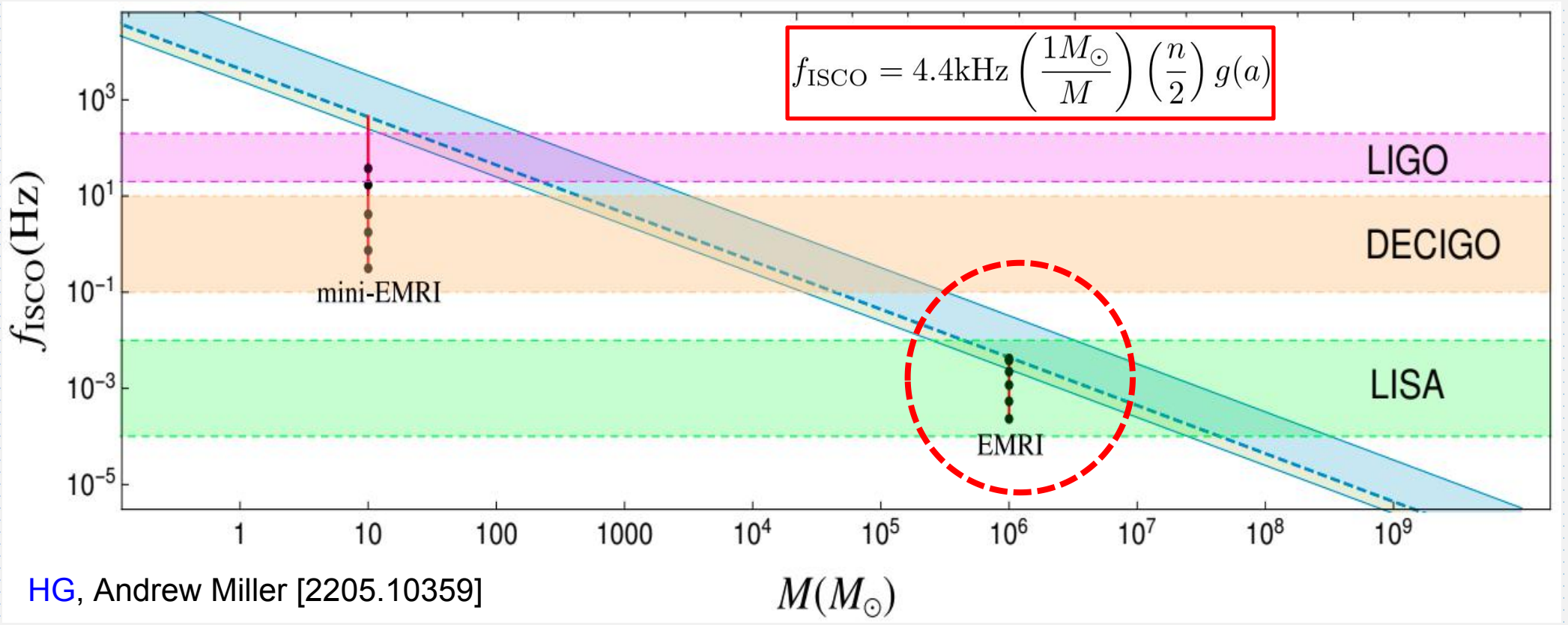
HG, Kuver Sinha, Chen Sun, JCAP [1904.07871]

mini-EMRIs



HG, Andrew Miller [2205.10359]

mini-EMRIs



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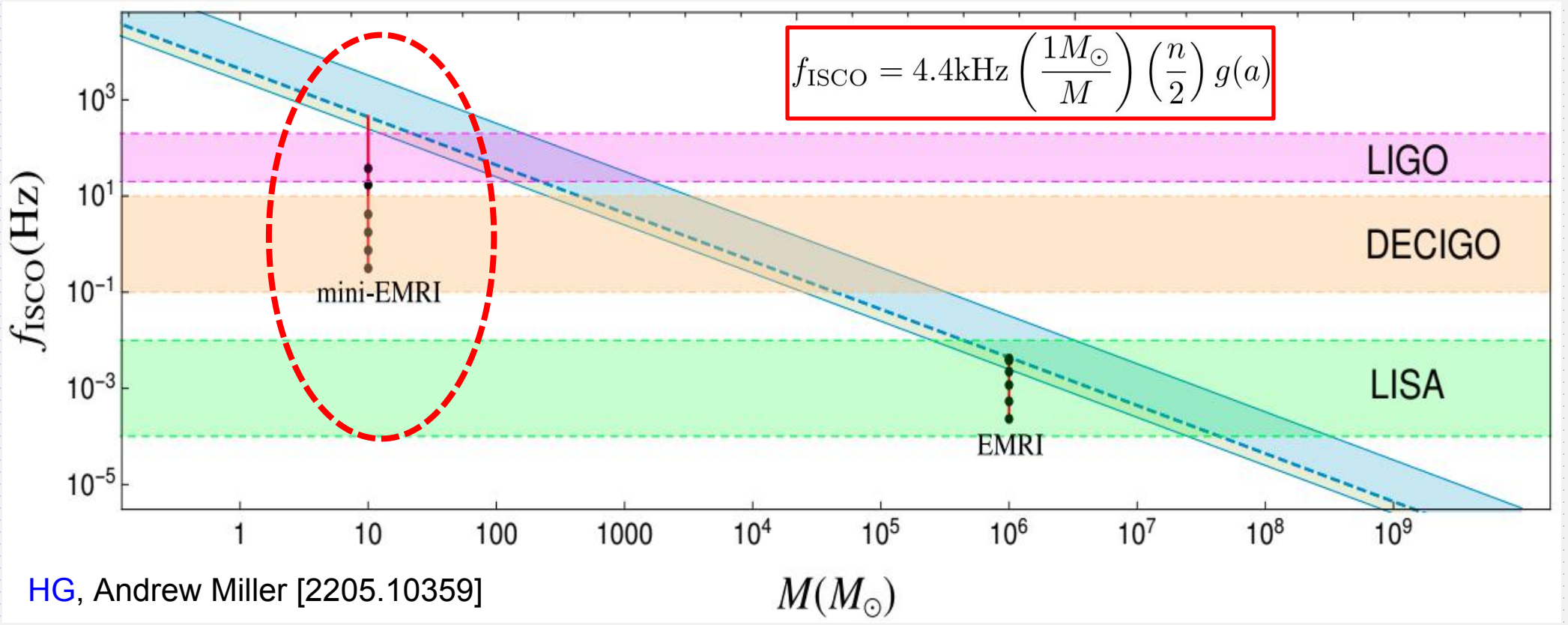
mini-EMRIs



HG, Andrew Miller [2205.10359]

Similar systems:

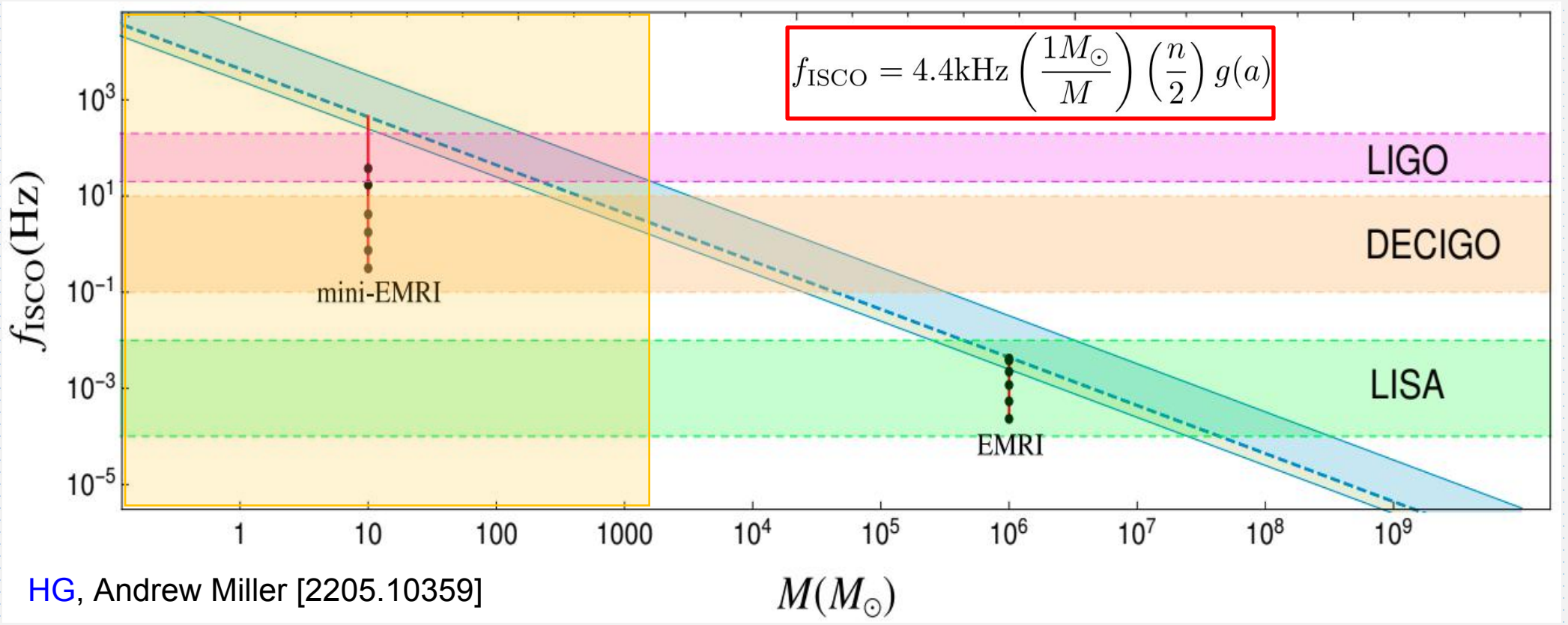
Davoudiasl, Giardino, Phys.Lett.B 768, 198 (2017)

Pan, Lyu, Yang, PRD 105, 083005 (2022)

Barsanti et al PRL 128, 111104 (2022)

LIGO can detect (non-standard) EMRIs!

mini-EMRIs



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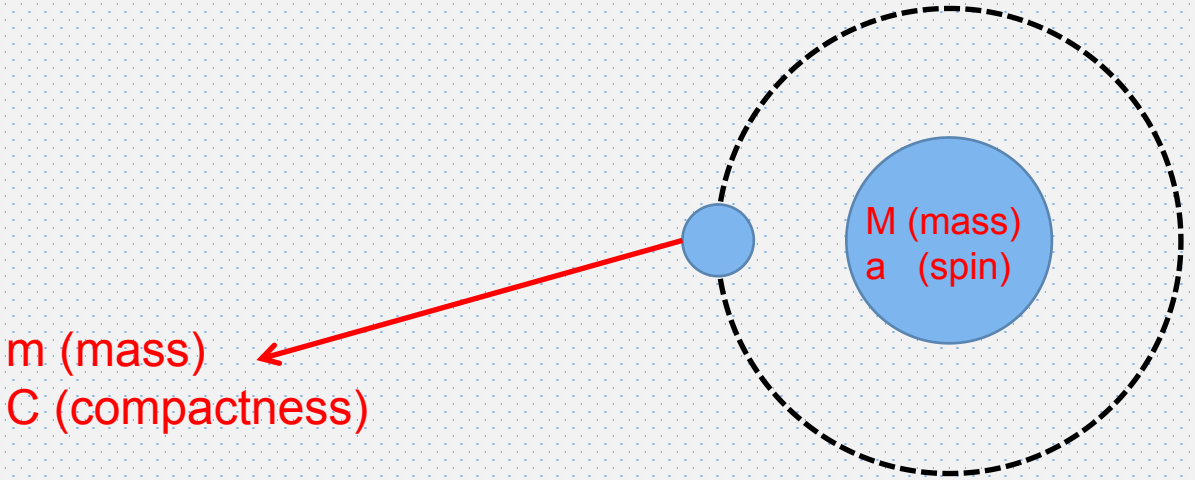
LIGO can detect (non-standard) EMRIs!

mini-EMRIs

- Consider the heavier one to be ultra compact (such as BH, PBH)
- Allow a less compact light one, described by compactness (C=mass/radius)



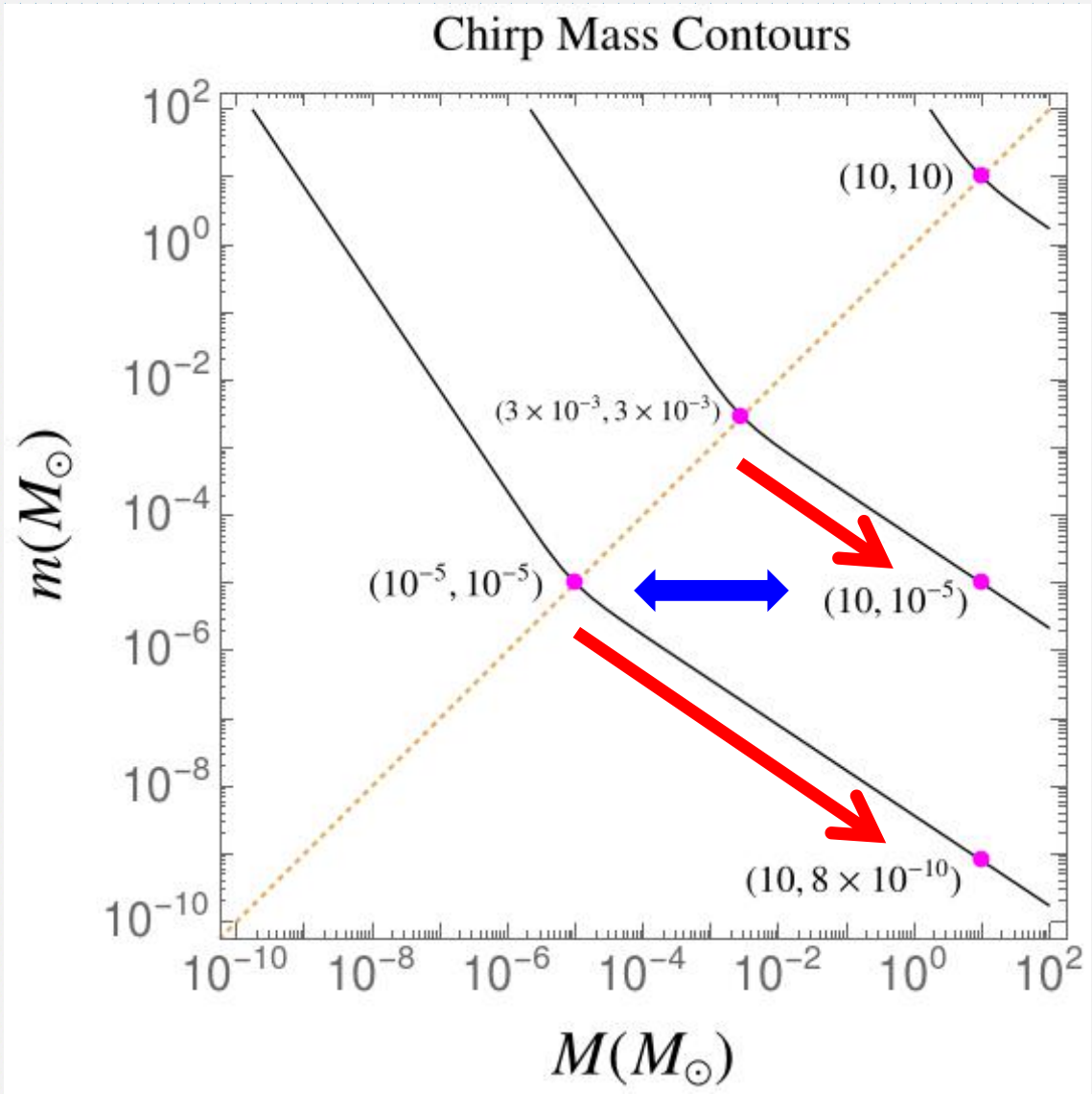
$$m \lesssim \mathcal{O}(10^{-2}) M_\odot$$

$$M \lesssim \mathcal{O}(1000) M_\odot$$

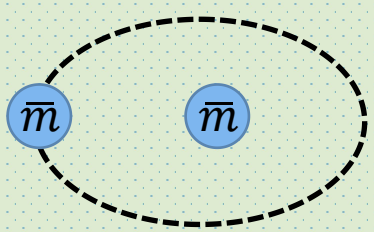
(detectable by LIGO)

There can be many variants

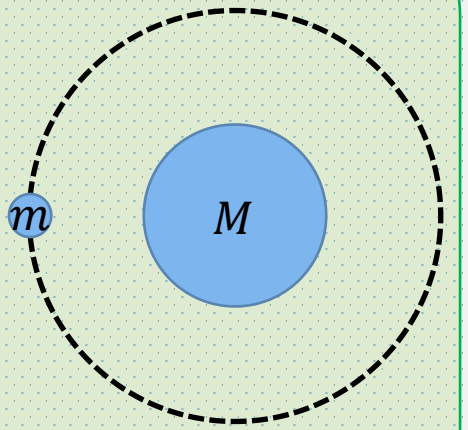
mini-EMRIs: Probe lighter ECO



Same Chirp Mass Binaries

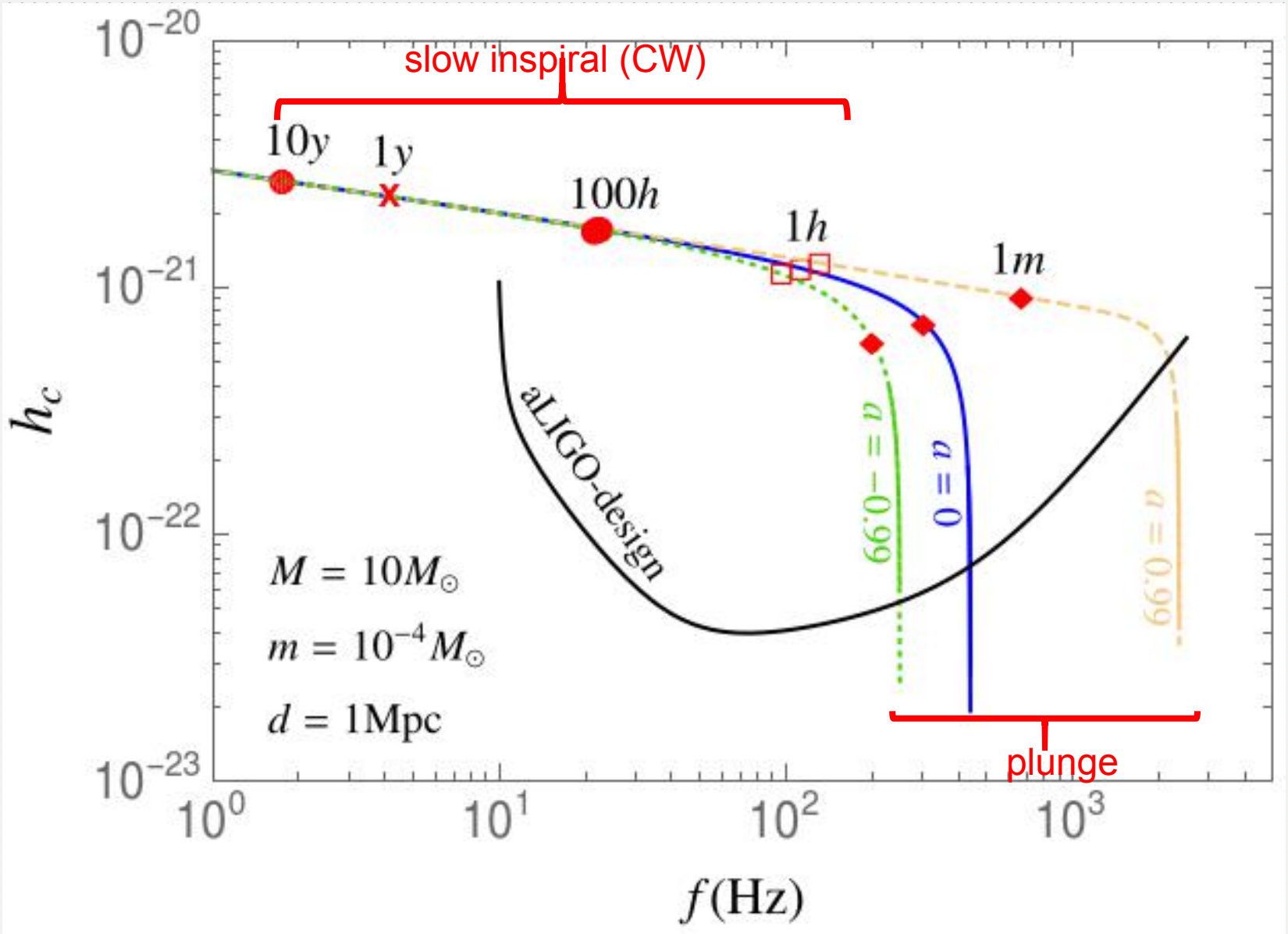


equal subsolar masses



Mini-EMRI

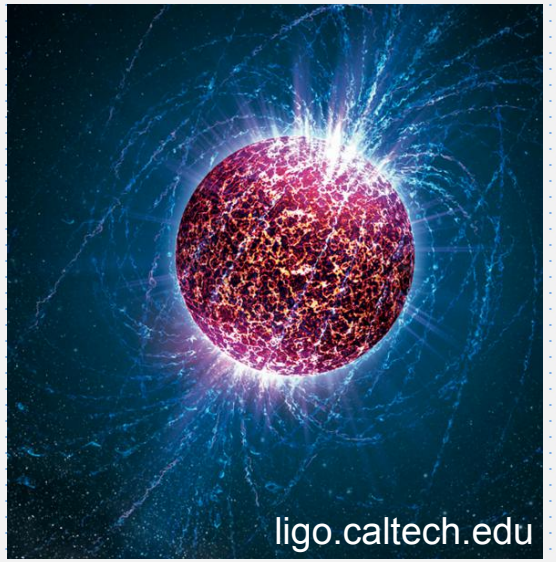
$$\frac{m}{\bar{m}} \approx 2^{-1/3}\left(\frac{\bar{m}}{M}\right)^{2/3} \Rightarrow m \ll \bar{m} \ll M$$



HG, A.Miller [2205.10359]

Search Strategies

- Signal is similar to continuous waves from neutron stars
- Search strategies can be employed for mini-EMRIs



- ✓ targeted searches (known black holes, neutron stars as the heavier object)
- ✓ all-sky searches (blind searches)

Search Techniques

Coherent Searches (matched-filtering)

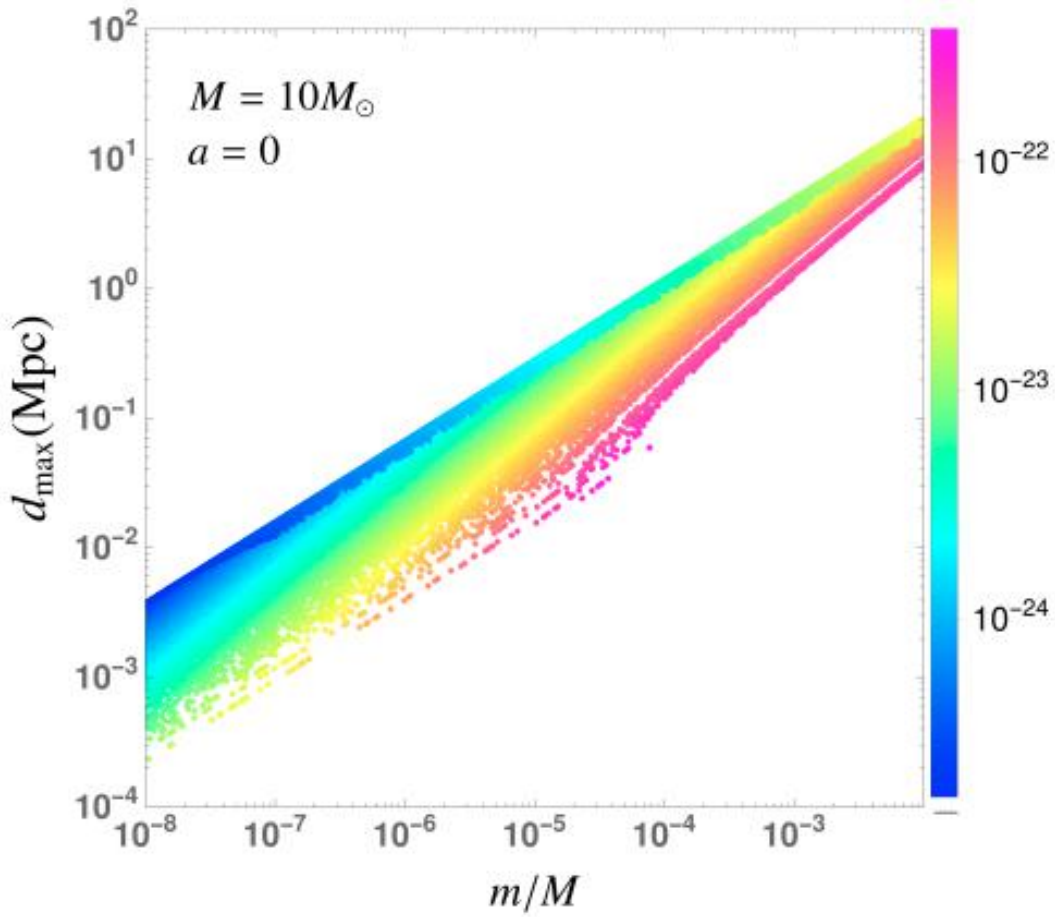
- The optimal method (better sensitivity)
- However, long duration, gaps, non-Gaussian noise
- Computationally challenging (especially all-sky)

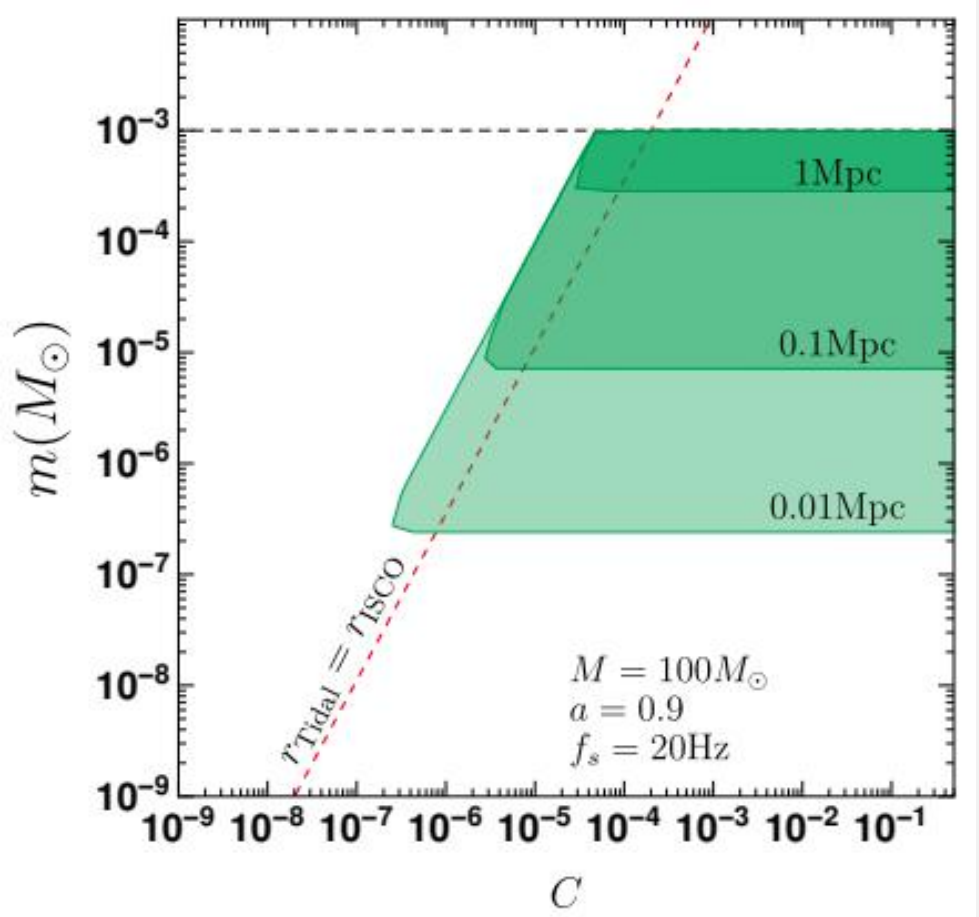
Incoherent Searches

- Reduced sensitivity
- Mature and robust methods
- Computationally feasible

We employ the mature incoherent search methods

mini-EMRI Sensitivity to ECOs





HG, A.Miller [2205.10359]

Summary

- EMRIs are ideal systems for searches of subsolar ECOs
- LIGO can detect mini-EMRIs
- mini-EMRIs allow searching for much lighter (subsolar) ECOs
- mini-EMRIs discoverable up to O(kpc - 10Mpc)

Thanks!