Searching for Mini Extreme Mass Ratio Inspirals with Gravitational-Wave Detectors

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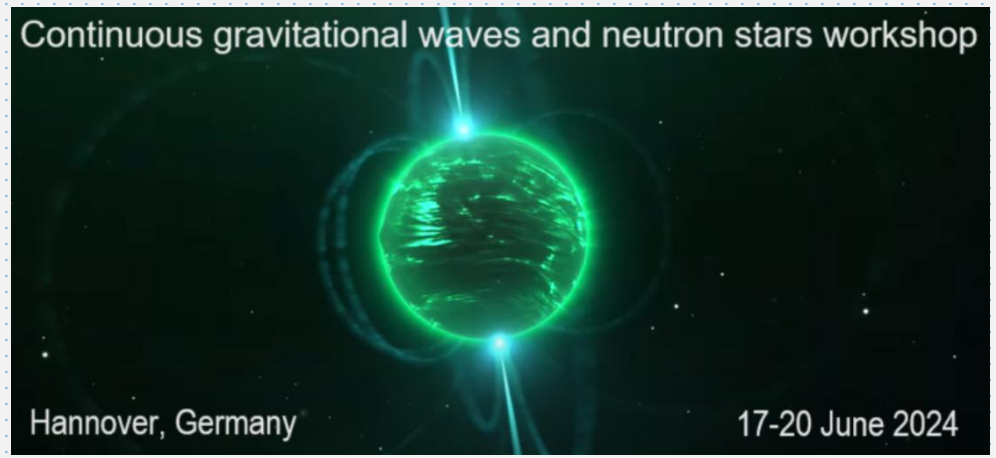
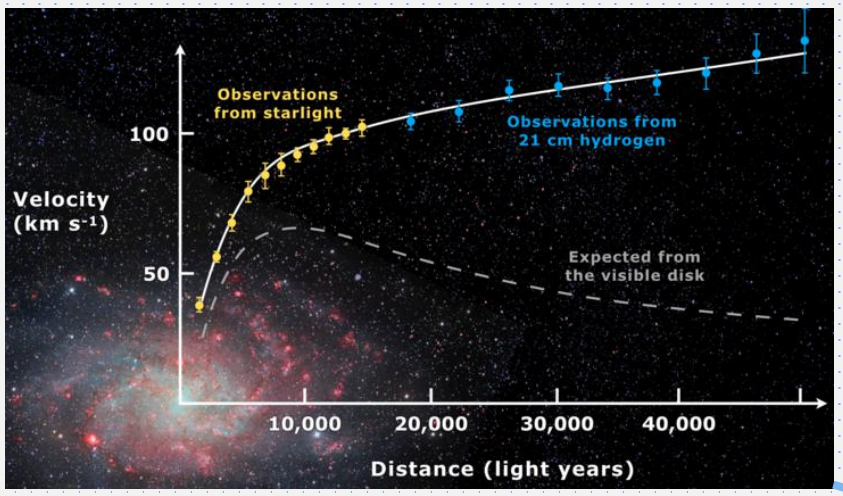
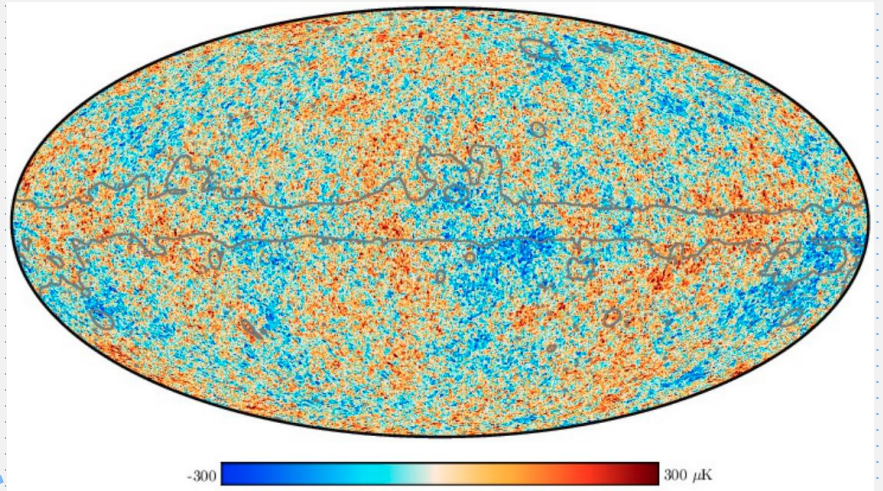
June 19, 2024



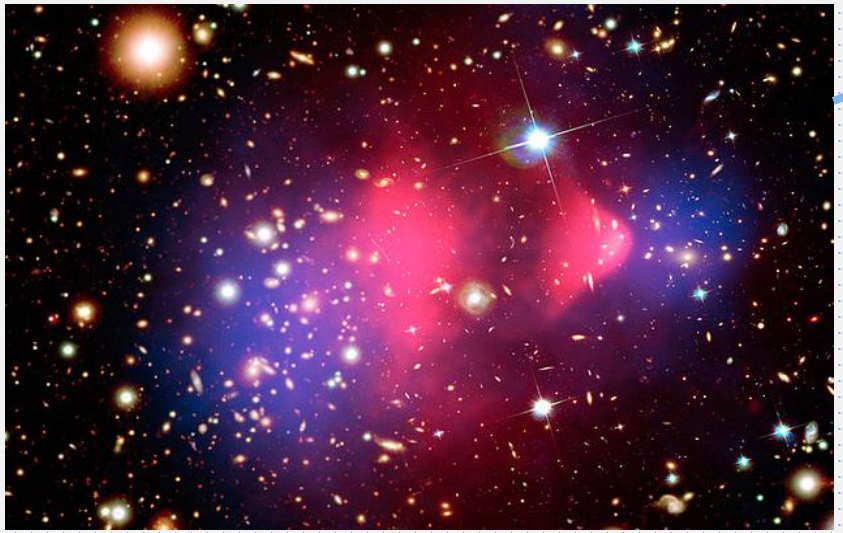
HG, Andrew Miller [2205.10359]

Dark Matter: Observational Evidence

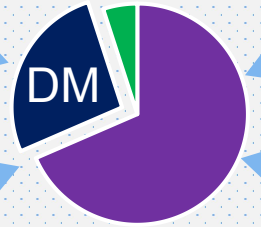




Planck 2018

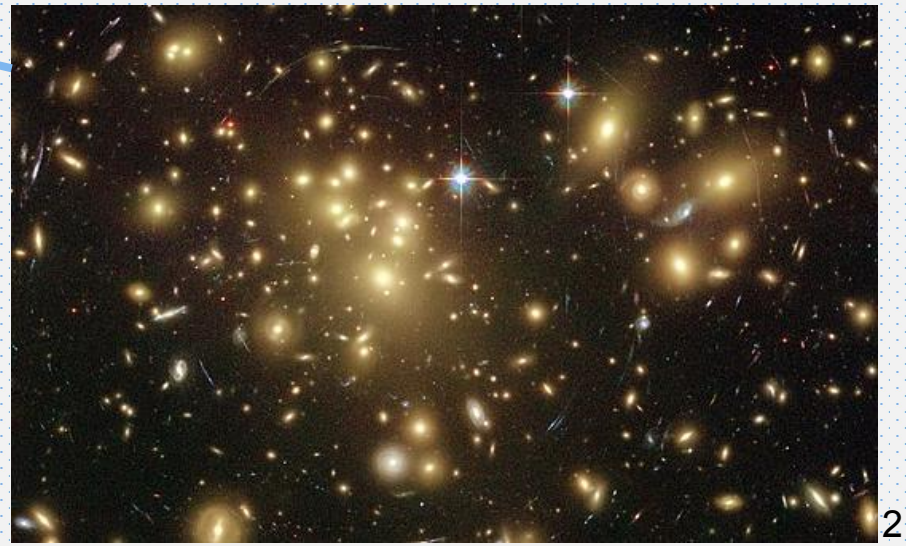


Wikipedia

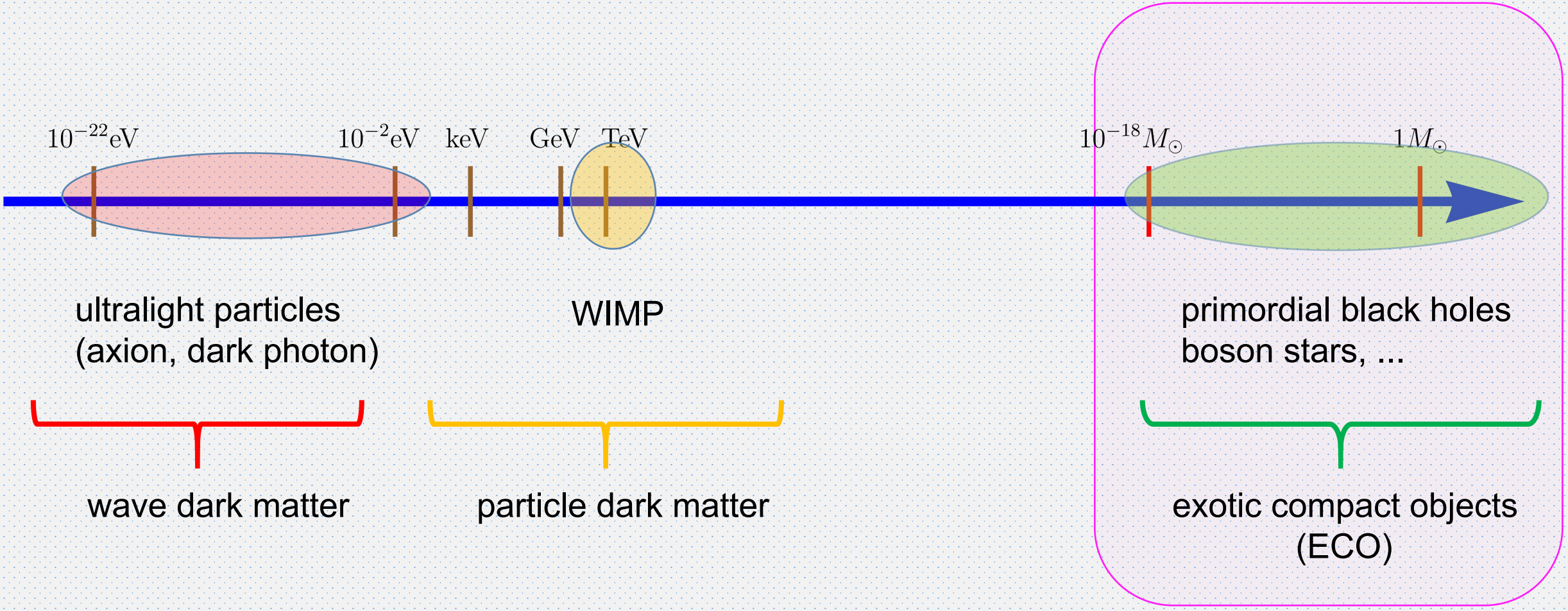


$$\Omega_c = 0.26$$

(PDG2022)



Dark Matter Candidates



$$C = \frac{GM}{c^2 R}$$

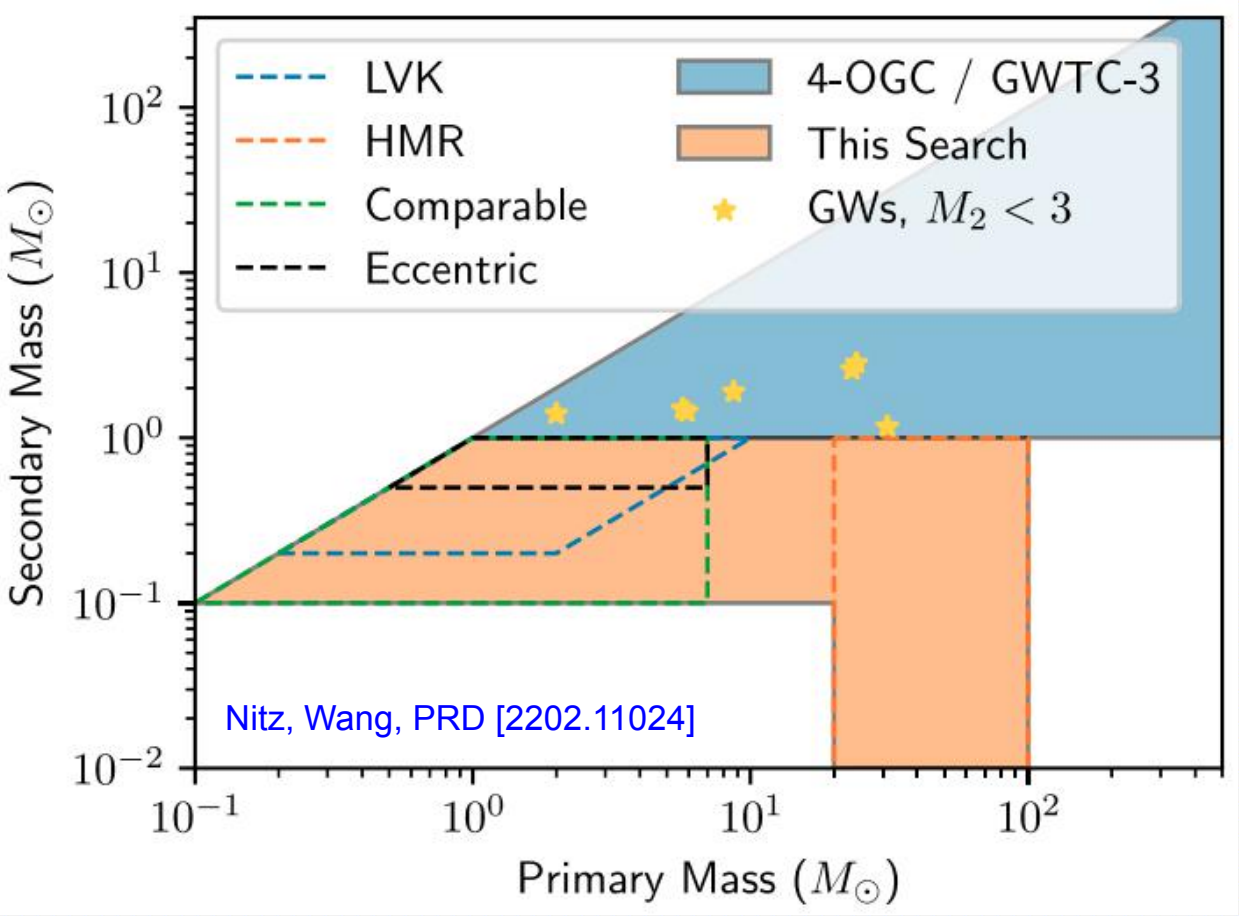
Earth: $\sim 10^{-10}$
Sun: $\sim 10^{-6}$

Did LIGO detect ECOs?
subsolar compact object detection means something new

Subsolar PBH Searches

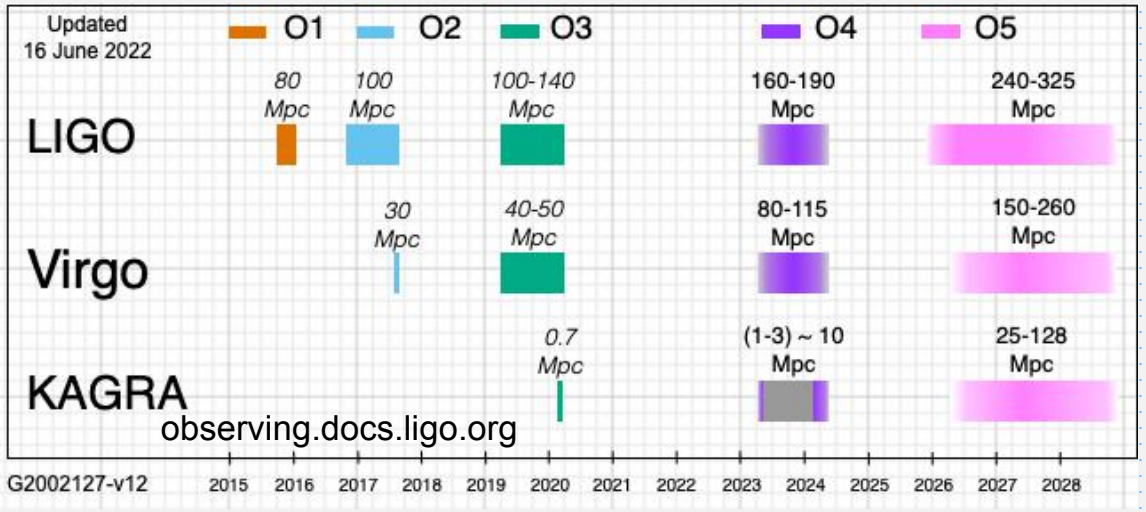
See also Andrew's talk

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



- Method: matched-filtering
- All assuming ultracompact objects

Need to take generic compactness into account for generic ECOs



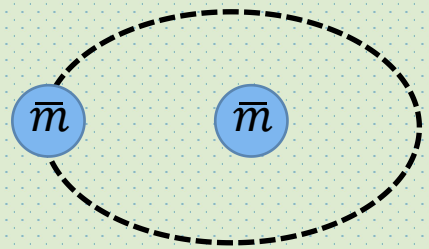
How to Search for Very Light ECO?

Signal becomes stronger as the chirp mass increases

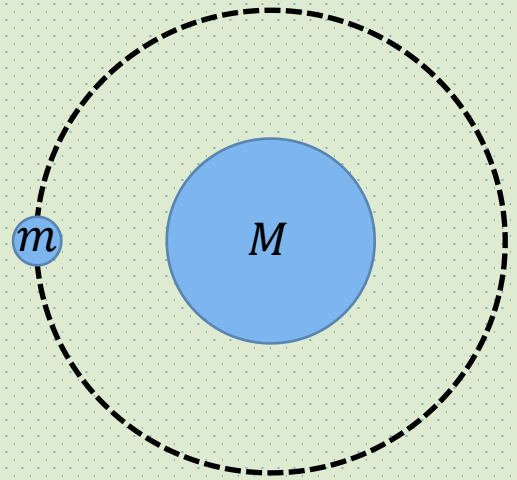
the chirp mass

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

Same Chirp Mass Binaries



equal subsolar masses



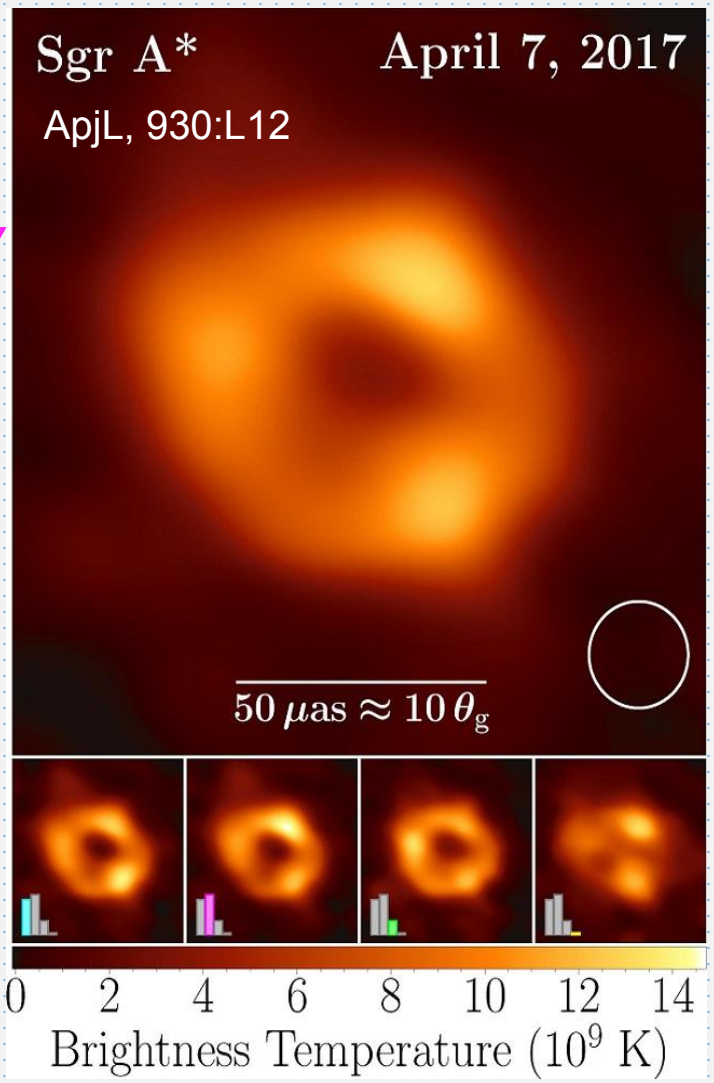
large mass ratio

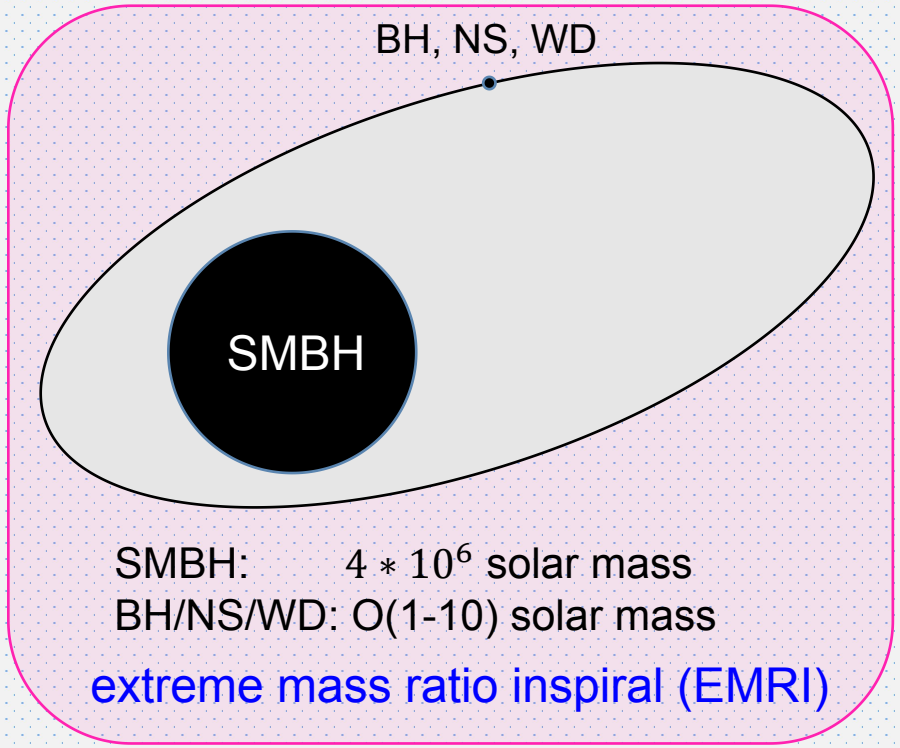
$$\frac{m}{\bar{m}} \approx 2^{-1/3} \left(\frac{\bar{m}}{M}\right)^{2/3} \quad \Rightarrow \quad m \ll \bar{m} \ll M$$

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

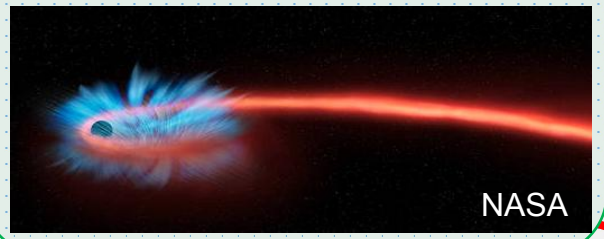
extreme mass ratio inspiral (EMRI)

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

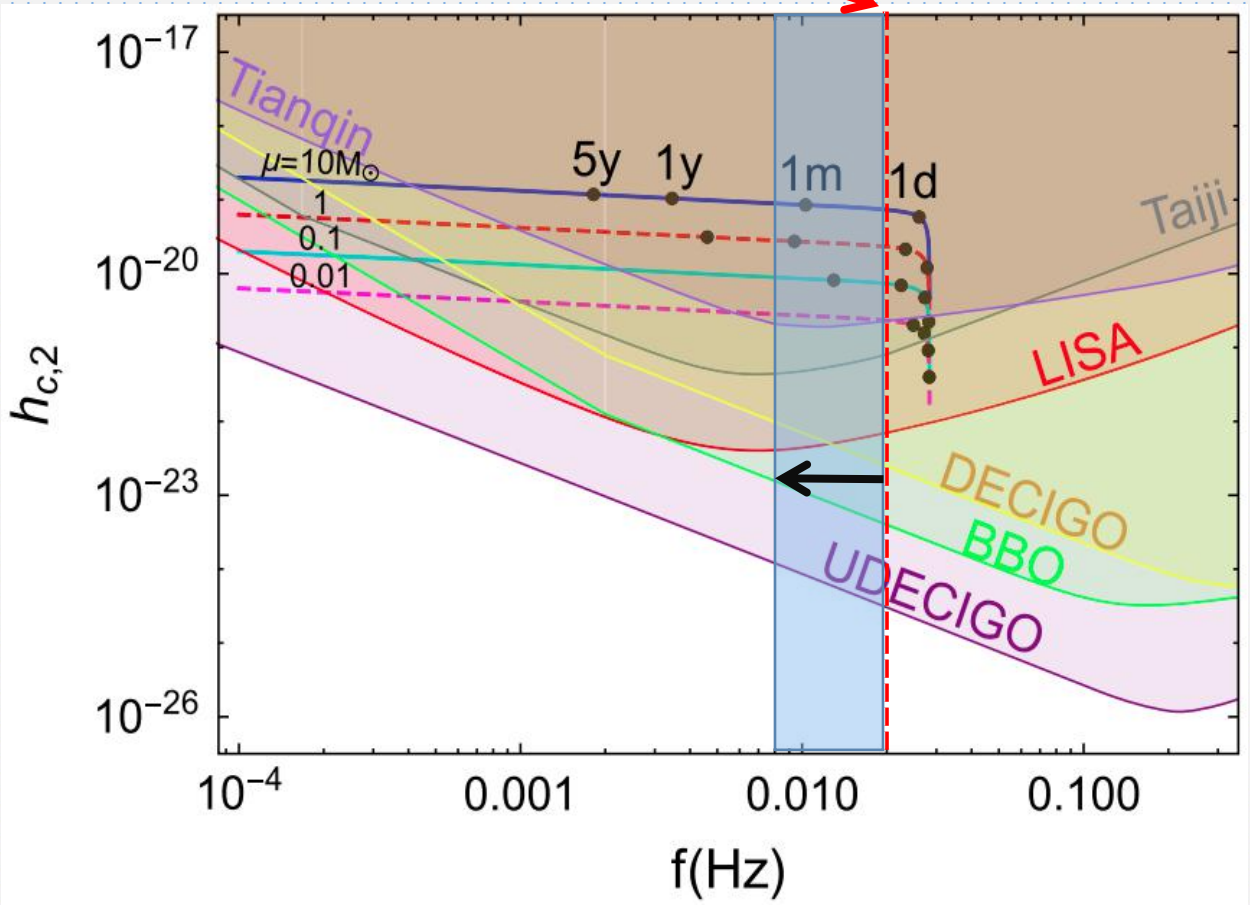
Babak et al, PRD [1703.09722]

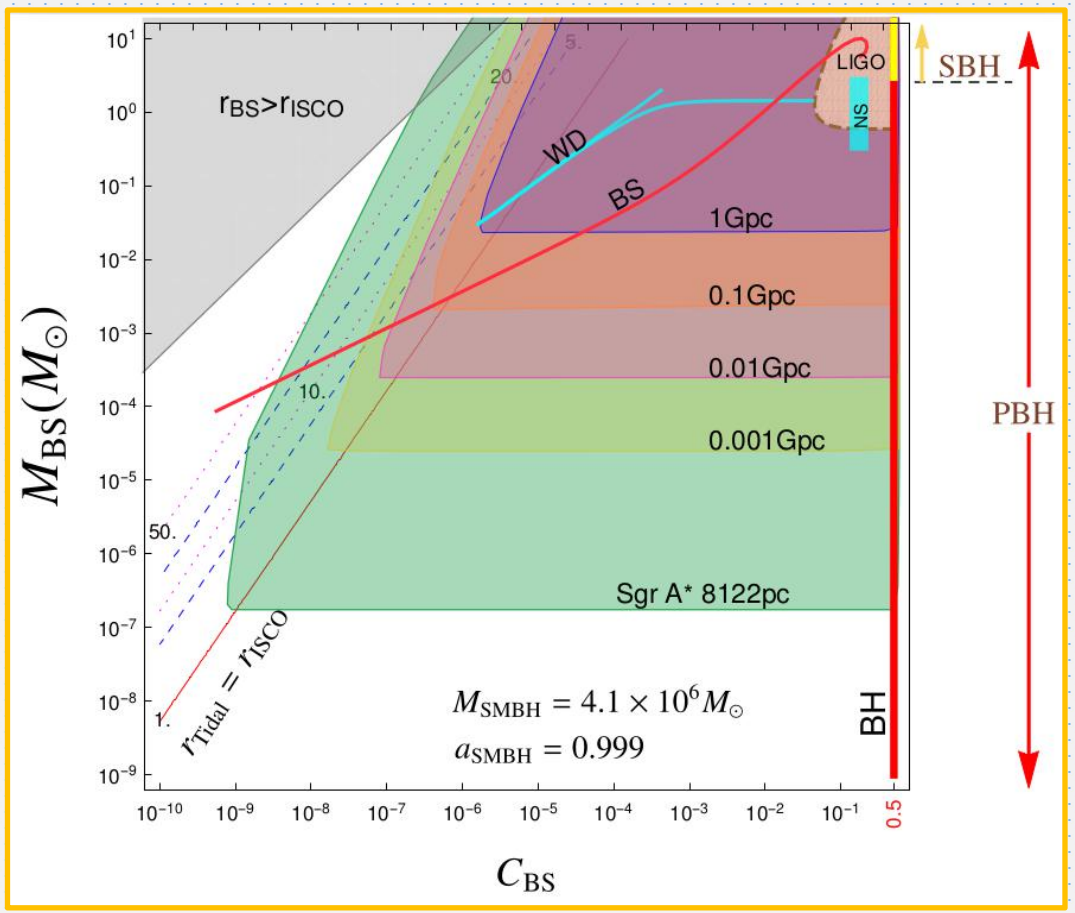
Sensitivity to ECOs

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



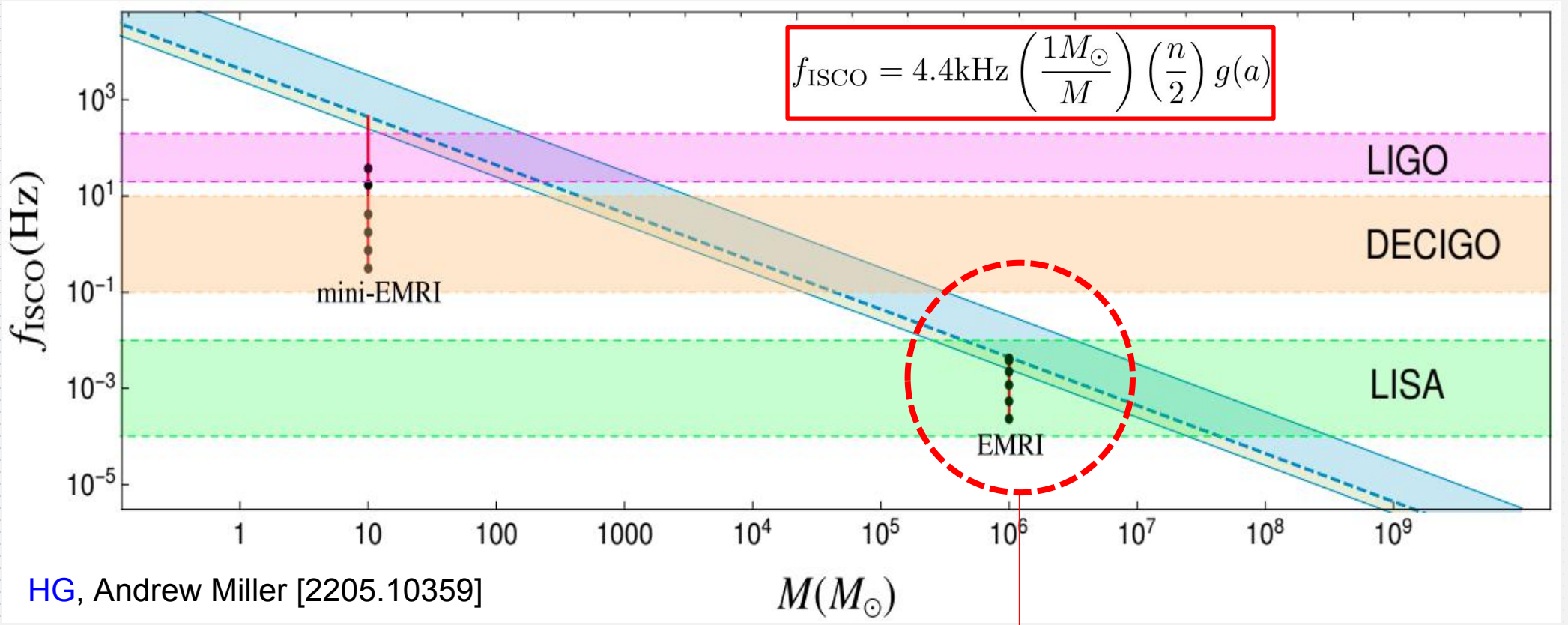
tidal disruption





HG, K.Sinha, C.Sun, 1904.07871 [JCAP], HG, J.Shu, Y.Zhao, PRD [1709.03500]

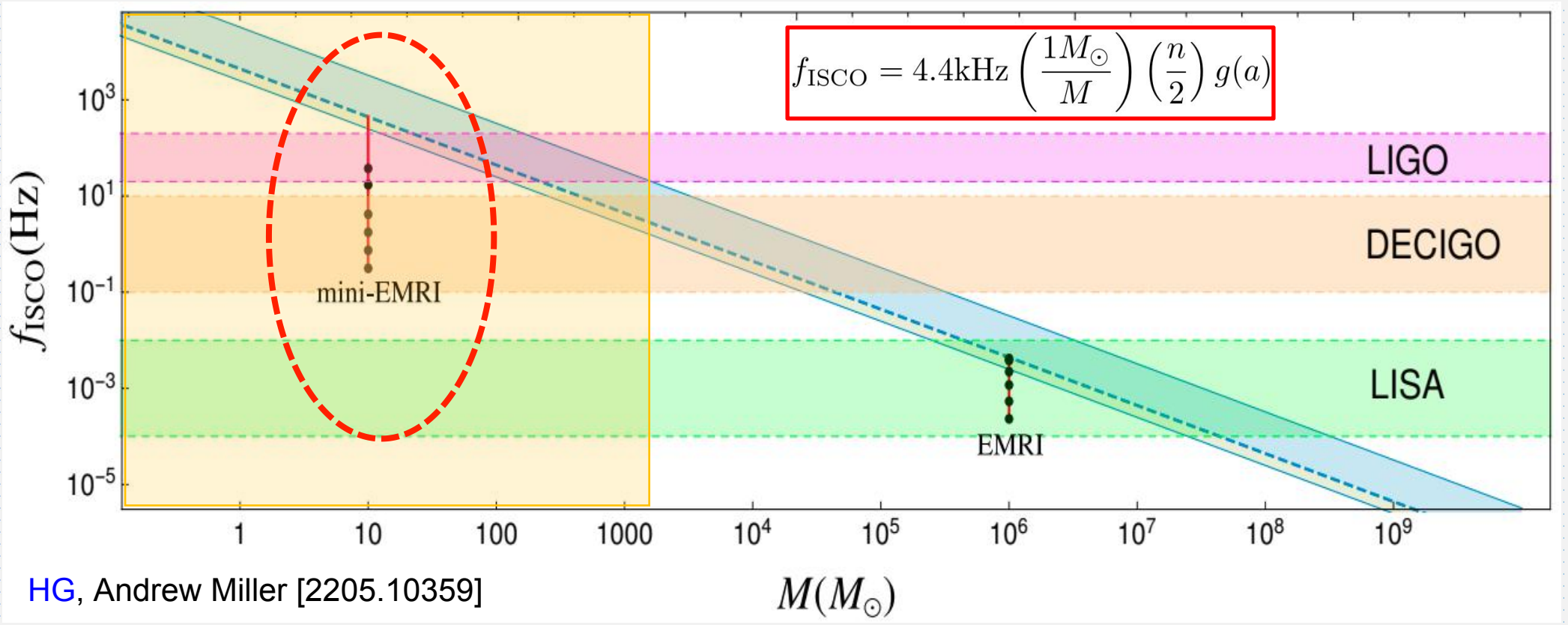
mini-EMRIs



HG, Andrew Miller [2205.10359]

a standard EMRI system

mini-EMRIs



HG, Andrew Miller [2205.10359]

Similar systems:

Davoudiasl, Giardino, PLB [1609.00907]

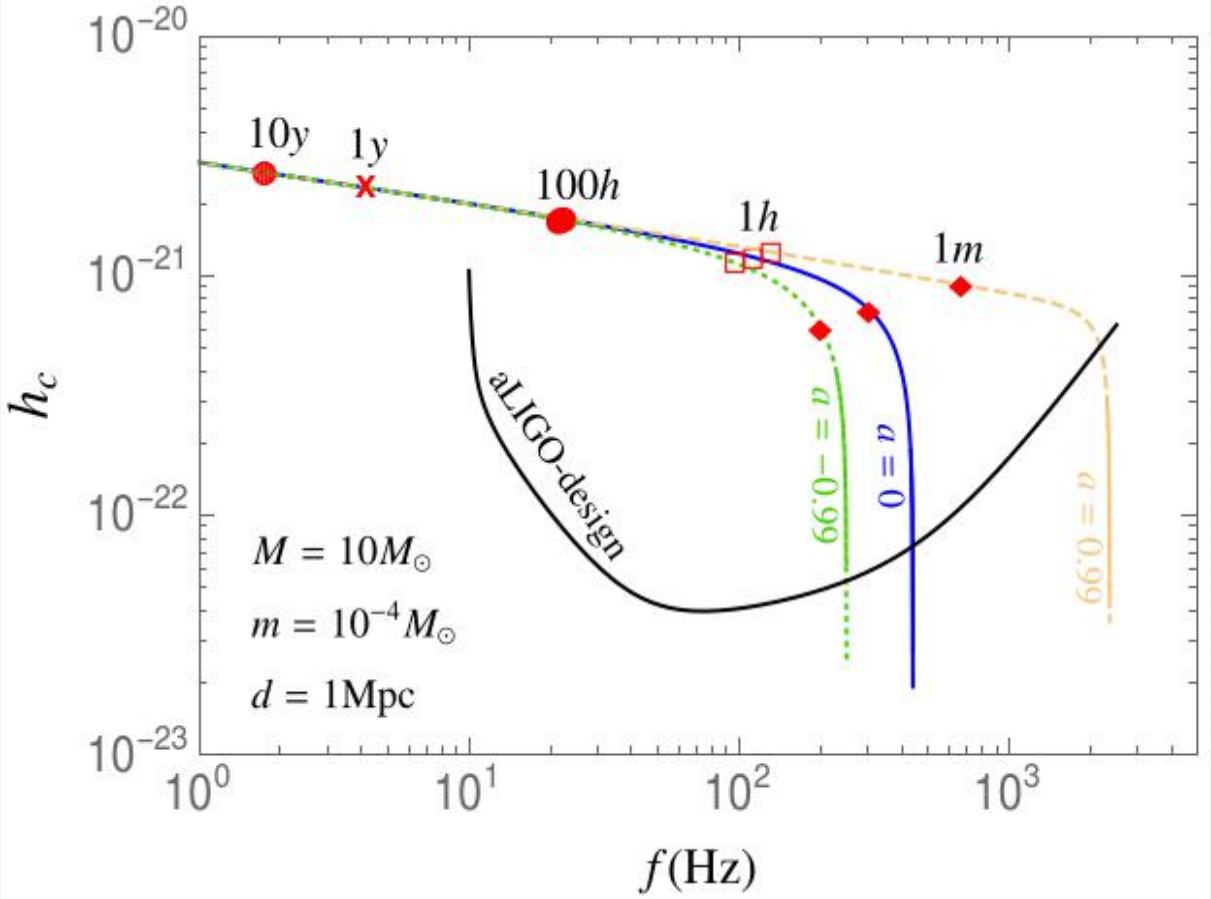
Pan, Lyu, Yang, PRD [2112.10237]

Barsanti et al PRL [2109.02170]

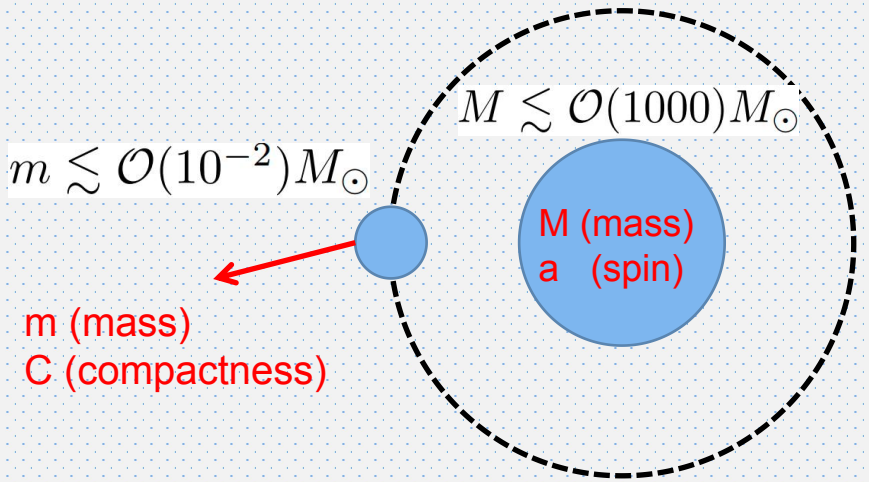
LIGO can detect (non-standard) EMRIs!

mini-EMRI at LIGO

- Both objects can be generic ECOs
- There can be many variants (ECO-BH/NS, ECO-ECO, ...)

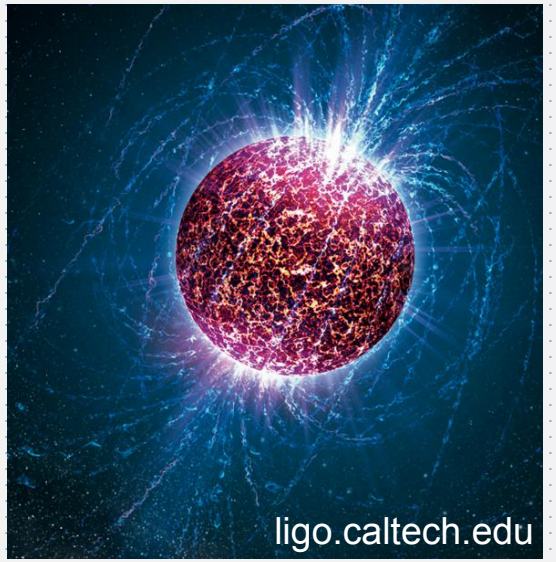


For simplicity: require the heavier one to be compact

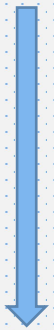


Search Strategies

See Karl, Badri, David's talks



- 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)
- ✓ directed searches (where their presence is more likely)
- ✓ all-sky searches (blind searches)

Search Techniques

See Karl, Badri, David's talks

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

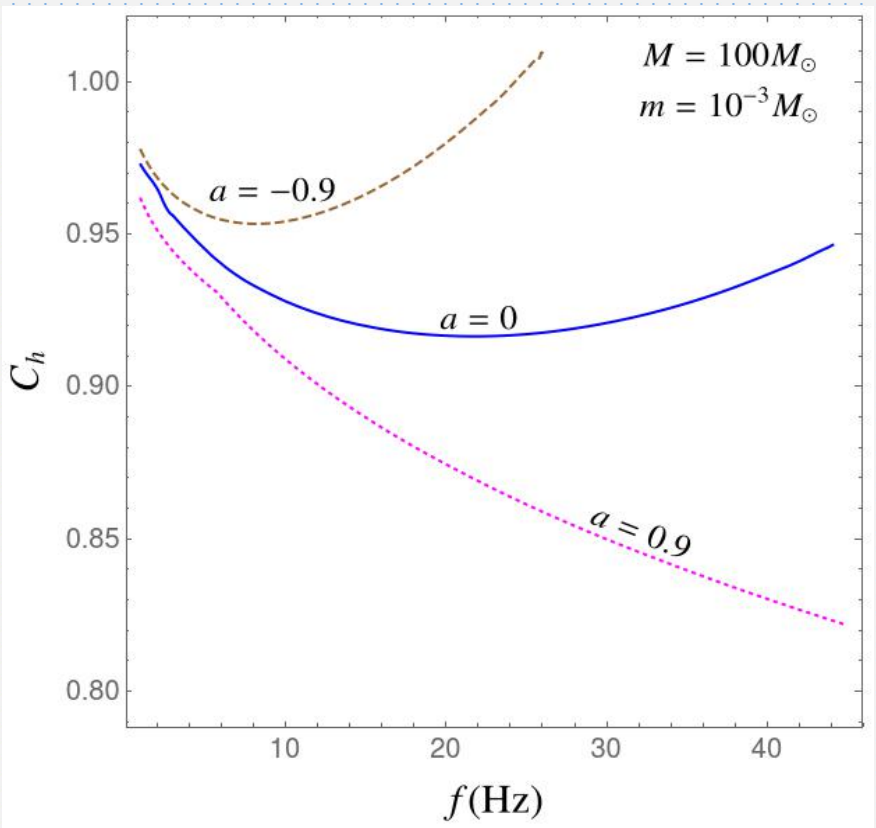
We employ here the incoherent search methods (generalized frequency Hough transform)
Astone et al, PRD [1407.8333], Miller et al, PRD [1810.09784]

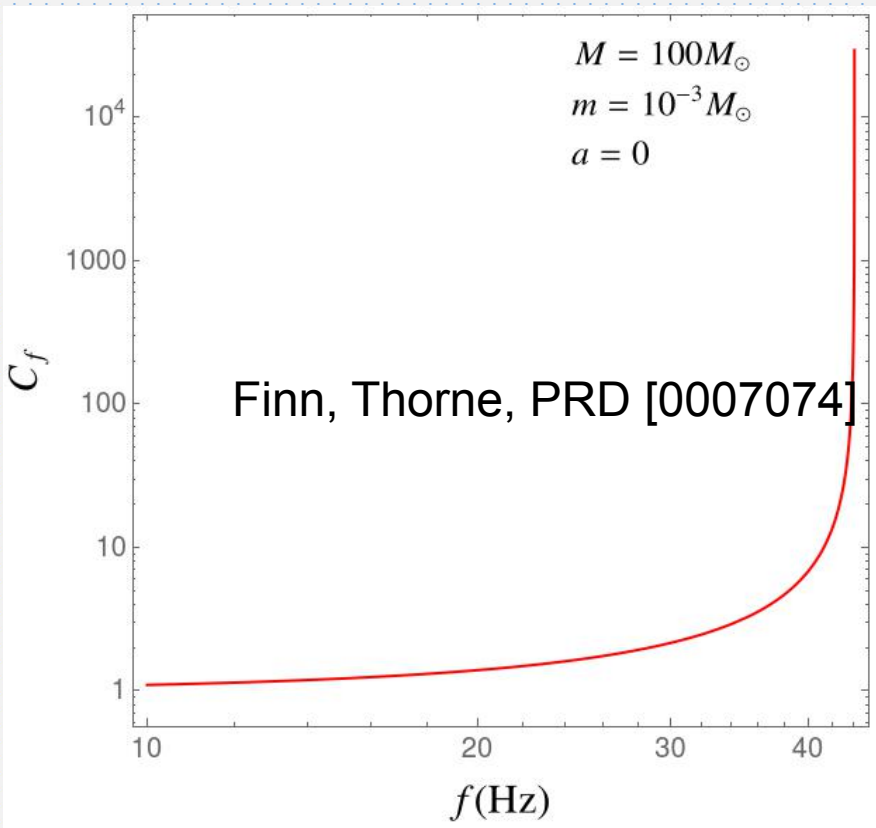
There is a parameter space where matched-filtering works.

Relativistic Effects

$$h_0 = \frac{4}{d}\left(\frac{GM_c}{c^2}\right)^{5/3}\left(\frac{\pi f}{c}\right)^{2/3} C_h(a,f)$$

$$\dot{f} = \frac{96}{5}\pi^{8/3}\left(\frac{GM_c}{c^3}\right)^{5/3} f^{11/3} C_f(a,f)$$



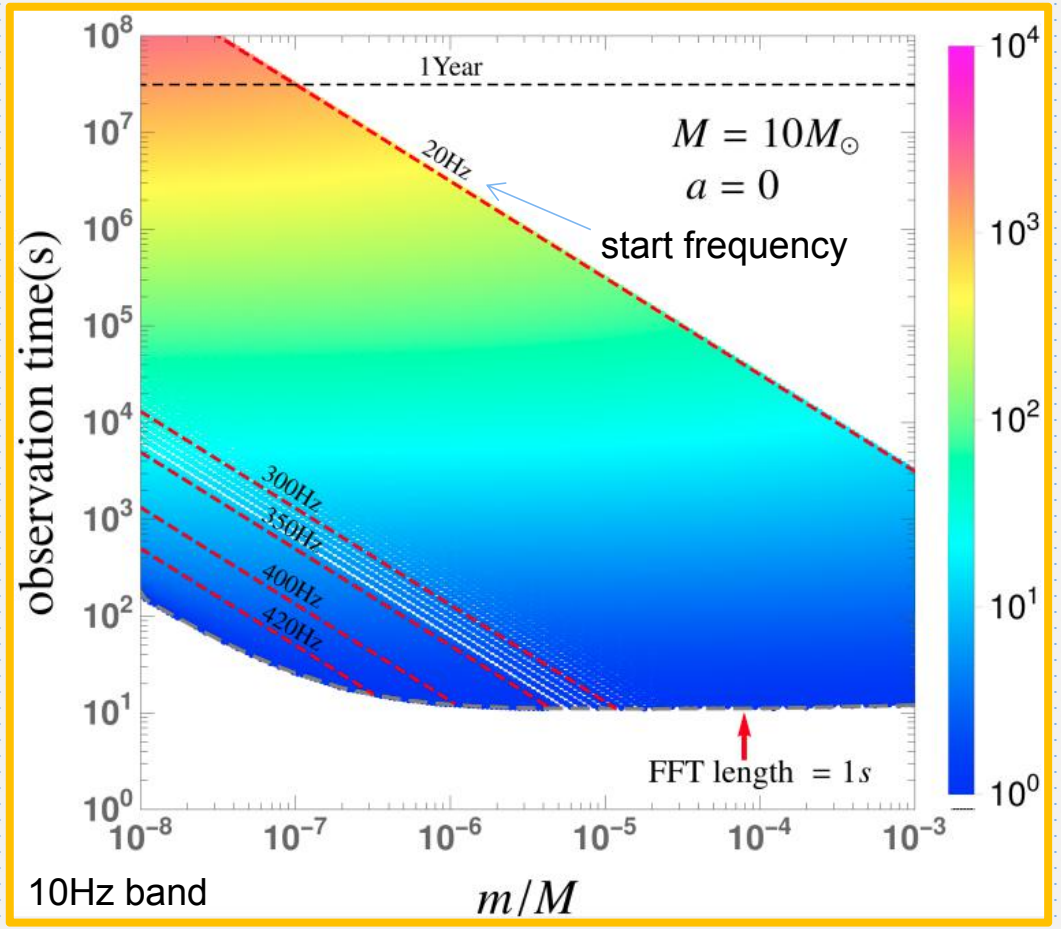


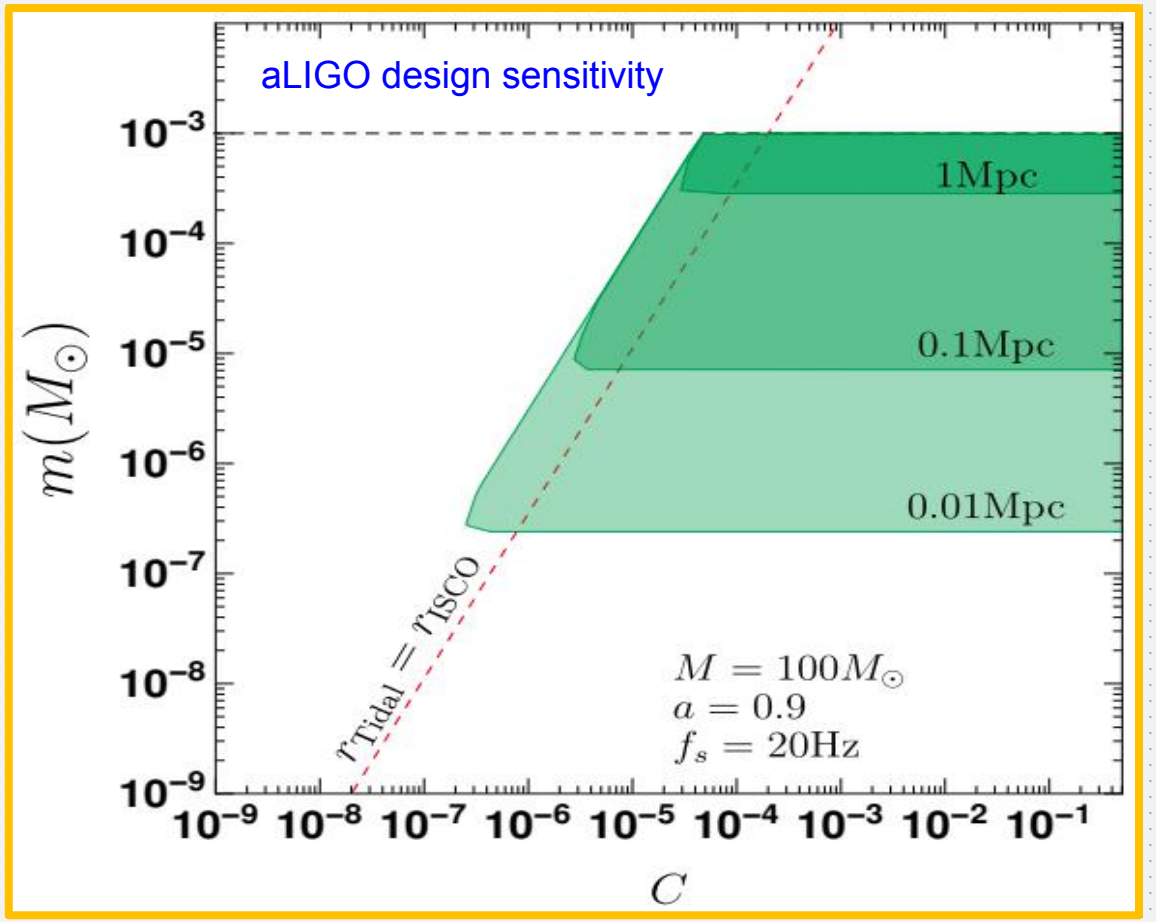
Finn, Thorne, PRD [0007074]

Modifications to the Hough algorithm

Sensitivity to mini-EMRIs

- mini-EMRIs can be detected at LIGO





HG, A.Miller, 2205.10359

Summary

- EMRIs are ideal systems for searches of very light (subsolar) ECOs
- LIGO can detect EMRIs (mini version)
- Strageties/Methods of CW searches can be directly applied
- mini-EMRIs discoverable up to O(kpc - 10Mpc)