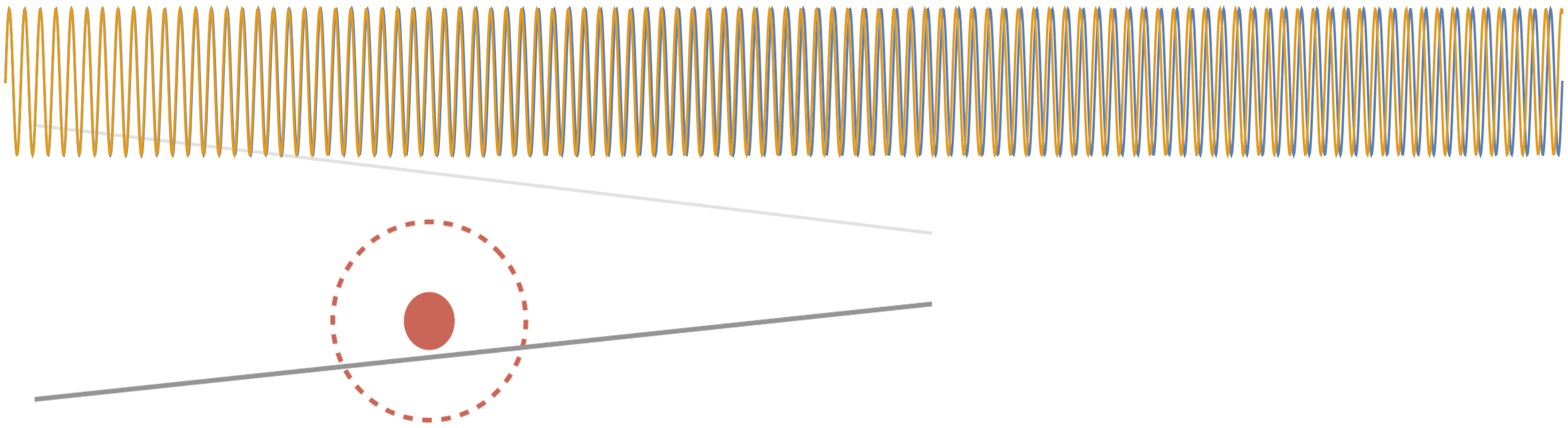
Probing Dark Matter Waves and PBH with Compact Stars



Sunghoon Jung

Seoul National University

Neples 2019 @ KIAS, 2019/09/24

Gravity probes of two extremes

- DM waves : Light scalar DM's effect can be collectively enhanced to astronomical size.

→ "perturbed chirping of GW" from NS inspirals.

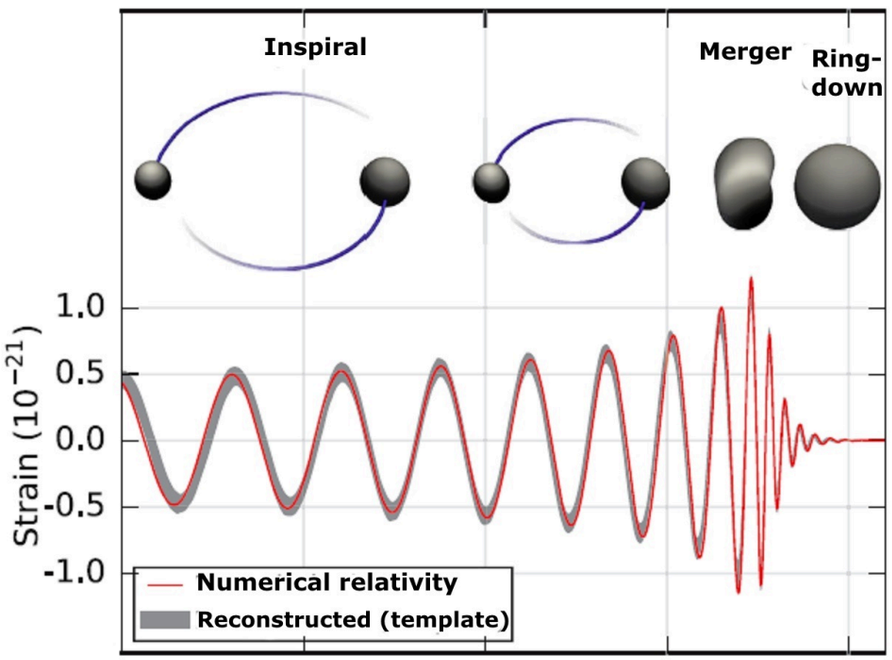
- PBH : No ways to probe light PBHs.

→ "Lensing Parallax of GRB"

- GW era!
  - What can we see?

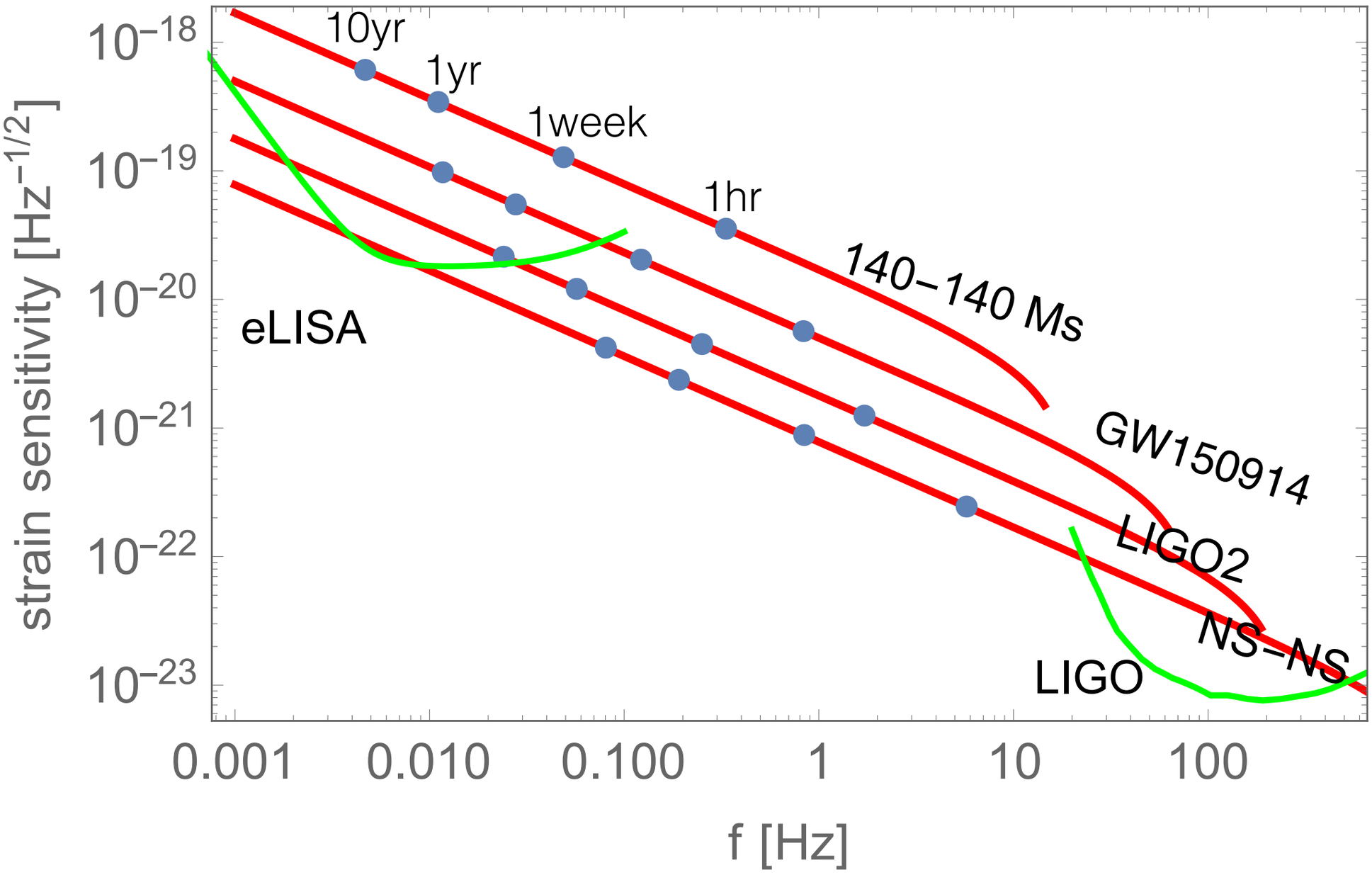
- “seeing” = extracting encoded information.
  GW waveform evolution — *chirping* — is a key property.

- What “Dark Matter” info can be encoded & extracted?



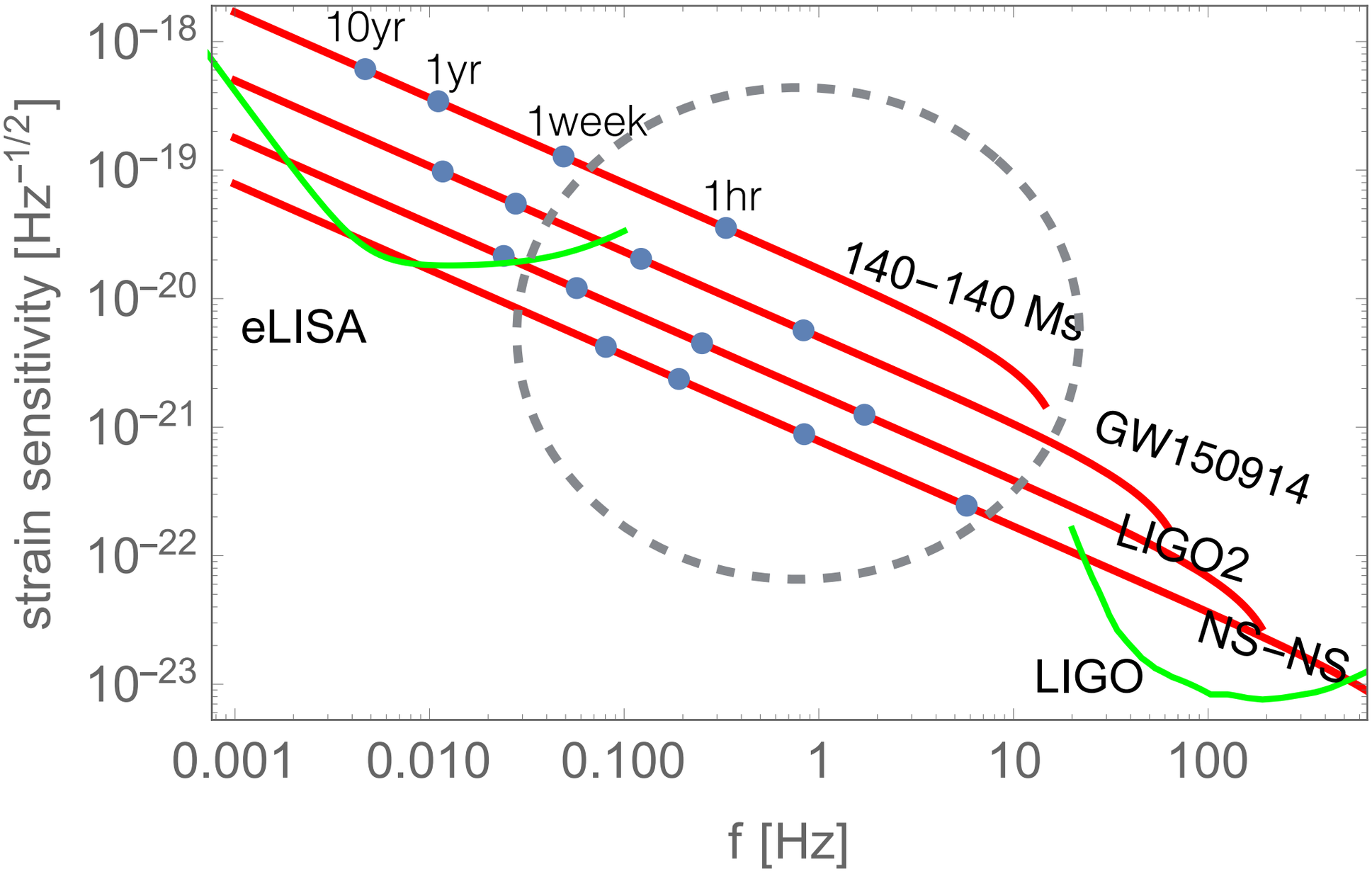
GW lifetime curve

Spending long time at low frequency, gradually chirping.



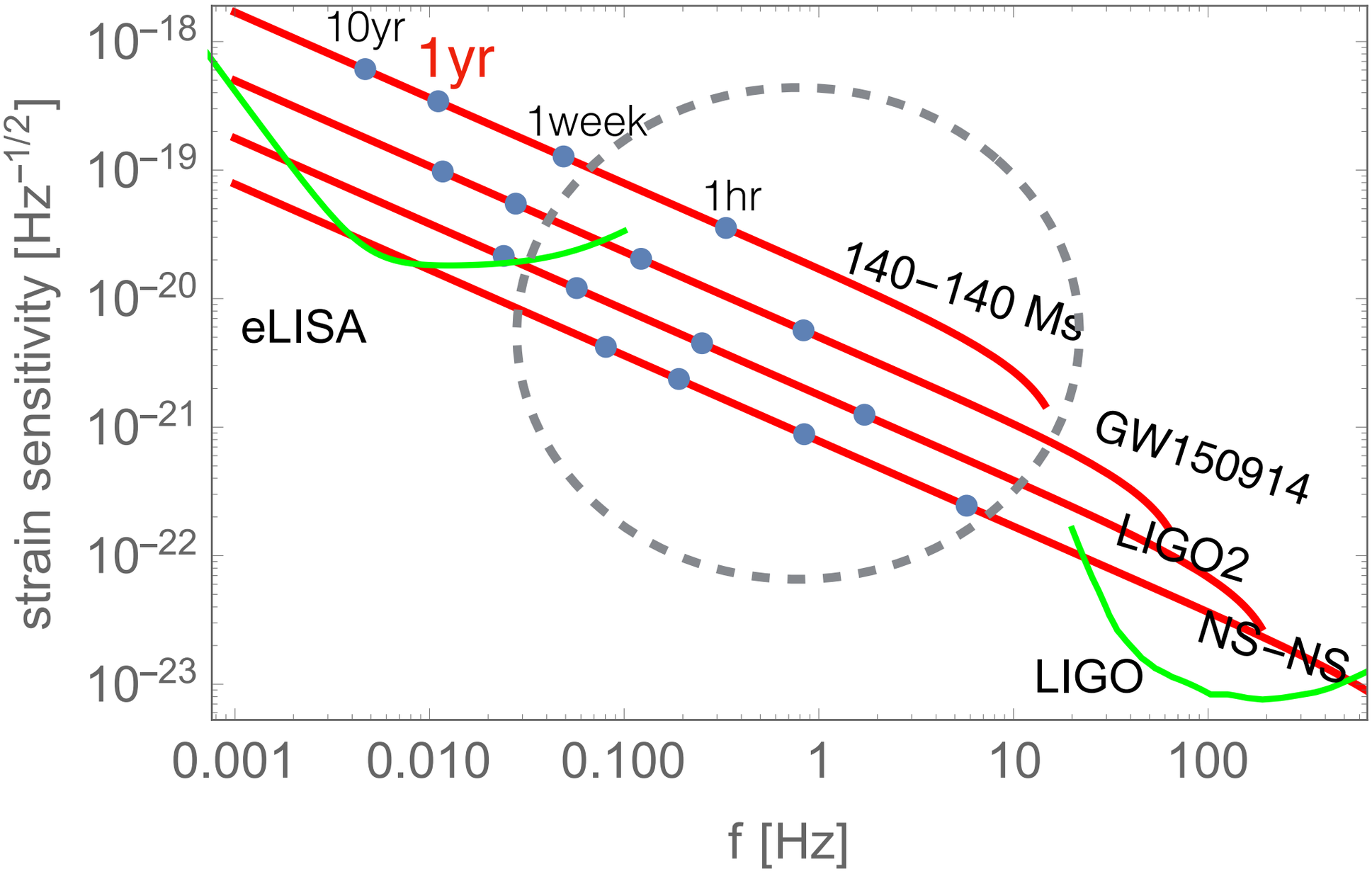
Mid-frequency band

Is mid-frequency just an interpolation btwn LIGO and LISA?

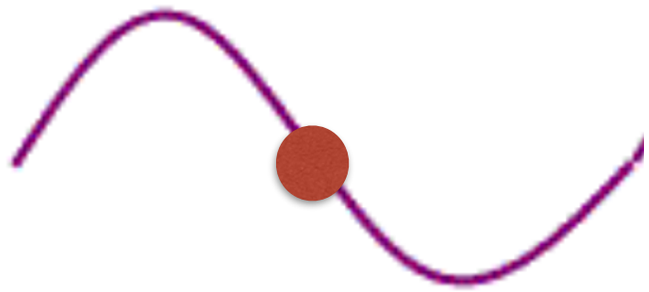


Mid-frequency band

No! Forming a highest-frequency band with year-long measurement,,,



DM wave



- Lightest possible spin-0 DM 10^-23 eV.
- Although light, their effects are astronomically enhanced and time-oscillating.
- GW is again an exciting lab to probe them.

DM wave

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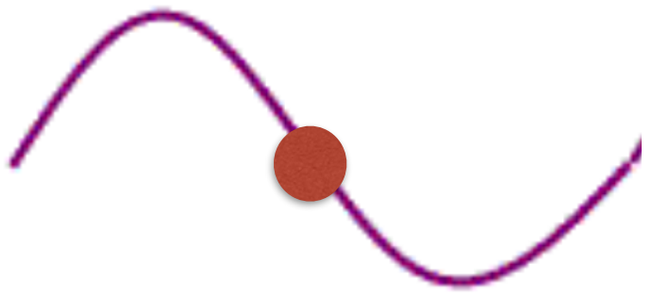


$$\phi(t) \propto \cos m_\phi t$$

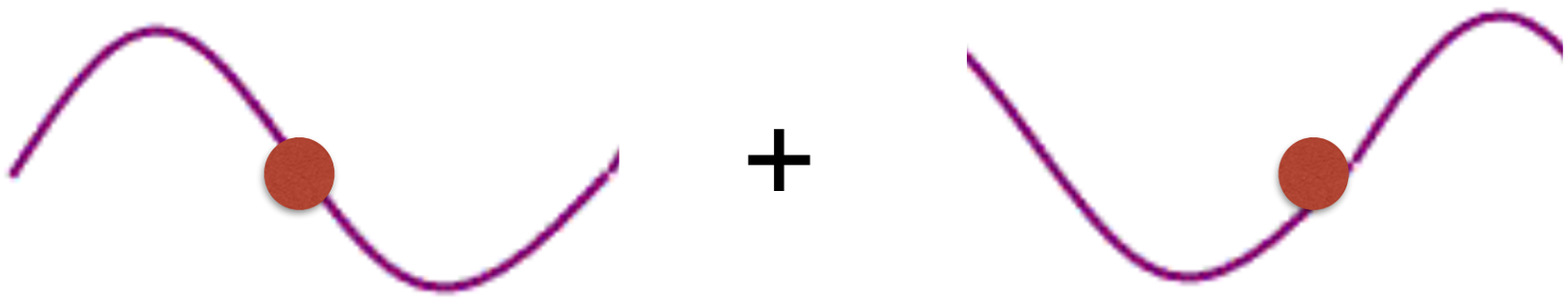
Compton frequency $\frac{1}{m_\phi} = \frac{\hbar}{m_\phi c}$ ~ **1 yr** for 10^-22 eV, **1 min** for 10^-16 eV

DM wave

- Lightest possible spin-0 DM 10^-23 eV.

- Although light, their effects are astronomically enhanced and time-oscillating.

$\phi(t) \propto \cos m_\phi t$ $\phi(t) \propto \cos(m_\phi t + \alpha)$



Second DM quanta with “same Compton frequency” but with “different phase” is added.

DM wave

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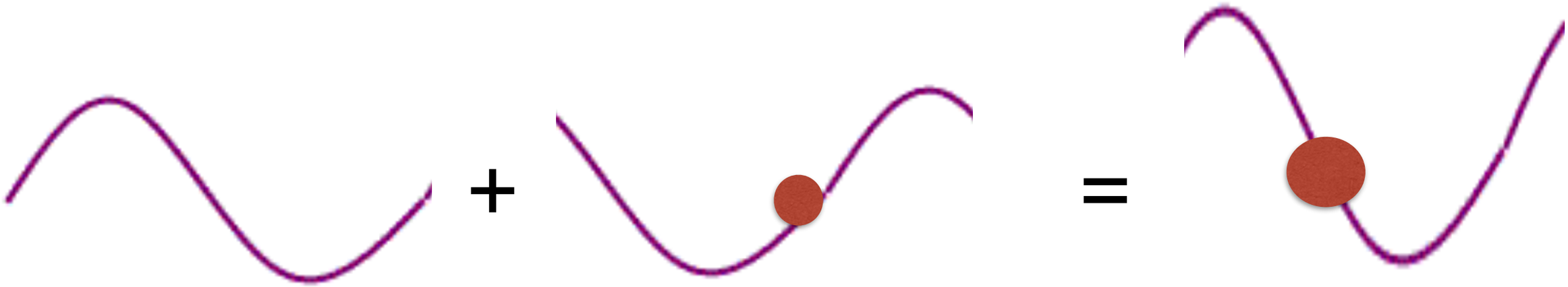
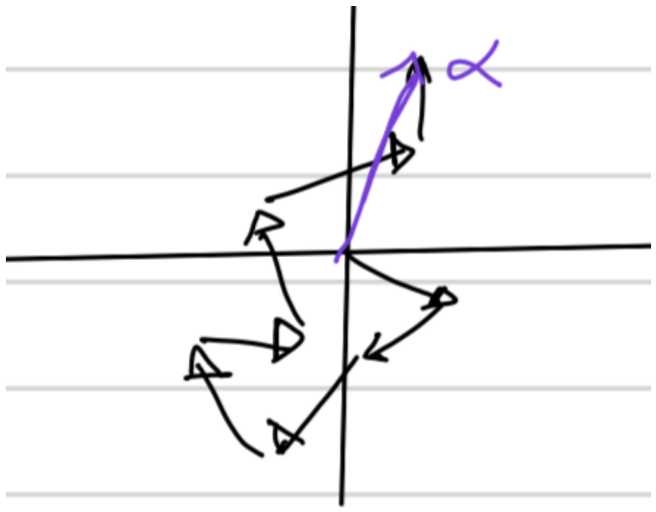


Resulting DM wave added but not exactly twice.

DM wave

- Lightest possible spin-0 DM 10^-23 eV.
- Although light, their effects are astronomically enhanced and time-oscillating.

$$\phi(t) \propto \sqrt{N_{\rm DM}} \cos m_\phi t$$



Adding N DM quanta is a “N-random walk”.

DM wave

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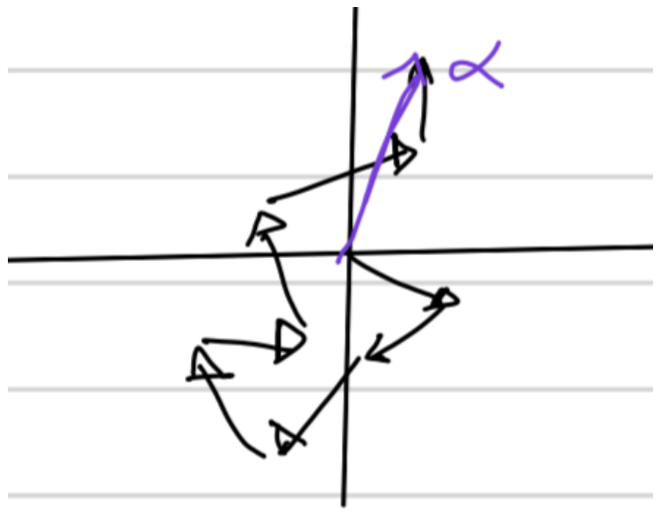
$$\phi(t) \propto \sqrt{\frac{\rho_{\rm DM}}{m_\phi}} \cos m_\phi t$$



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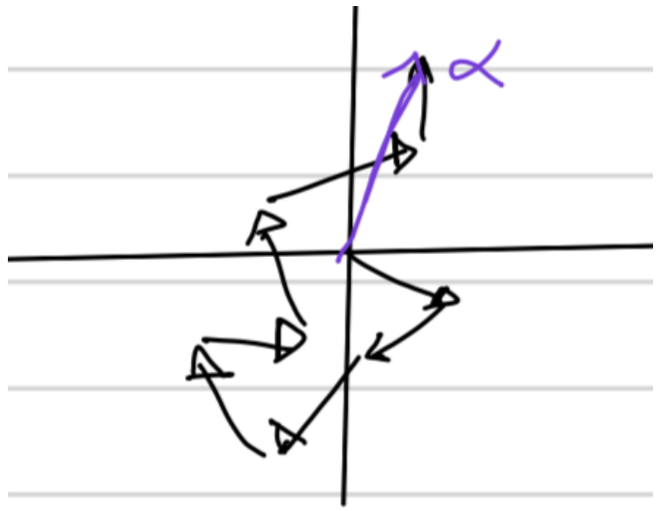
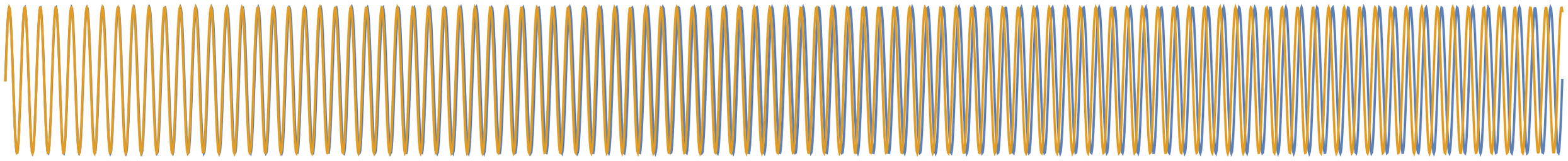


Adding N DM quanta is a “N-random walk”.

DM wave (density) is **collectively enhanced** to astronomical size and **oscillating in time**!

DM wave



Precisely speaking, DM particle has energy dispersion.

But DM wave coherence is kept for long time (million periods).

$$E_1 - E_2 \simeq m_\phi v^2 \sim 10^{-6} m_\phi \quad \Rightarrow \quad \Delta\tau_{\rm coherence} \simeq \frac{1}{m_\phi v^2} \simeq \frac{10^6}{m_\phi}$$

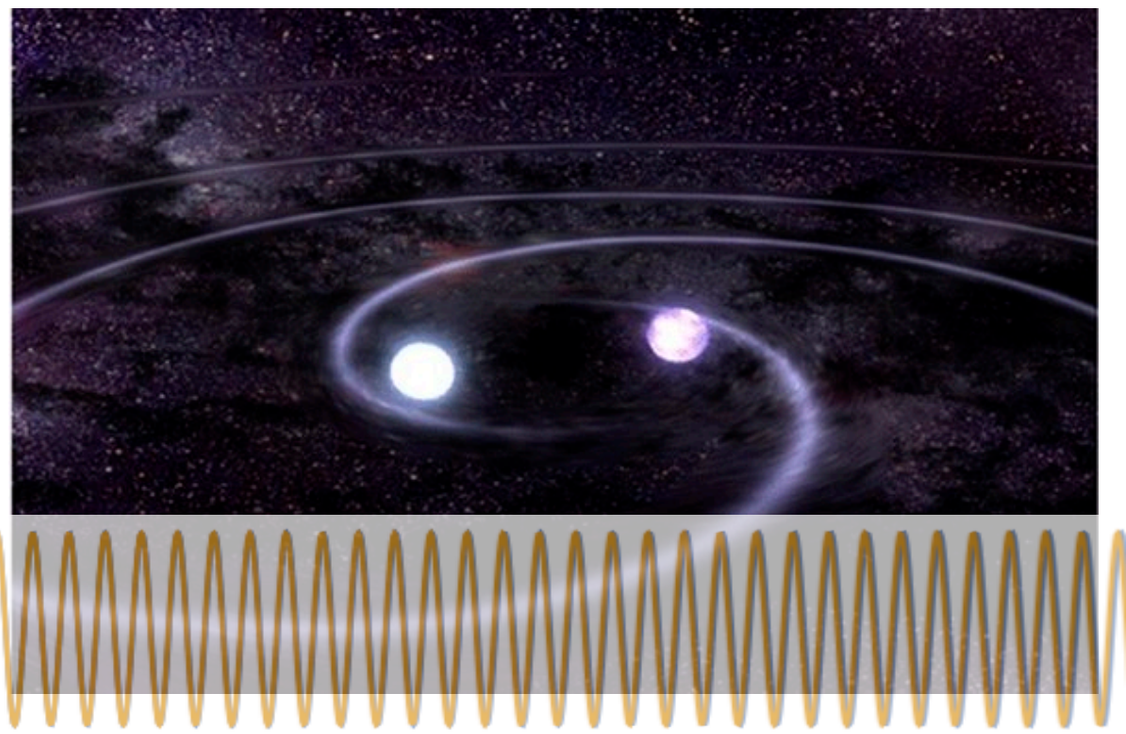
Neutron mass-shift

- If such scalar DM interacts with the neutron,
  the neutron-star mass shifts and oscillates in time.

$$\frac{\delta \mathcal{M}}{\mathcal{M}}(t) \propto \phi(t) \propto \sqrt{\rho_{\rm DM}} \cos m_\phi t$$

$$\frac{1}{m_\phi} = \frac{\hbar}{m_\phi c}$$

~ 1 yr for 10^-22 eV, 1 min for 10^-16 eV



GW inherently sensitive to mass-shift

GW exquisitely sensitive to mass-shift

- GW evolution is governed by the binary masses.

  → A tiny phase-shift due to mass-shift in each GW cycle accumulates over millions of GW cycles!

$$\frac{\Delta\mathcal{M}}{\mathcal{M}} \sim (\mathrm{SNR})(N_{\mathrm{cyc}}) \sim 10^{-8}$$

c.f.) $\Delta D_L/D_L \sim \mathrm{SNR} \sim 10^{-2}$

Ncyc ~ 10^7 huge enhancement

(for last 1-year measurement of NS-NS merger)

PRD(2019) H.G.Choi and S.Jung

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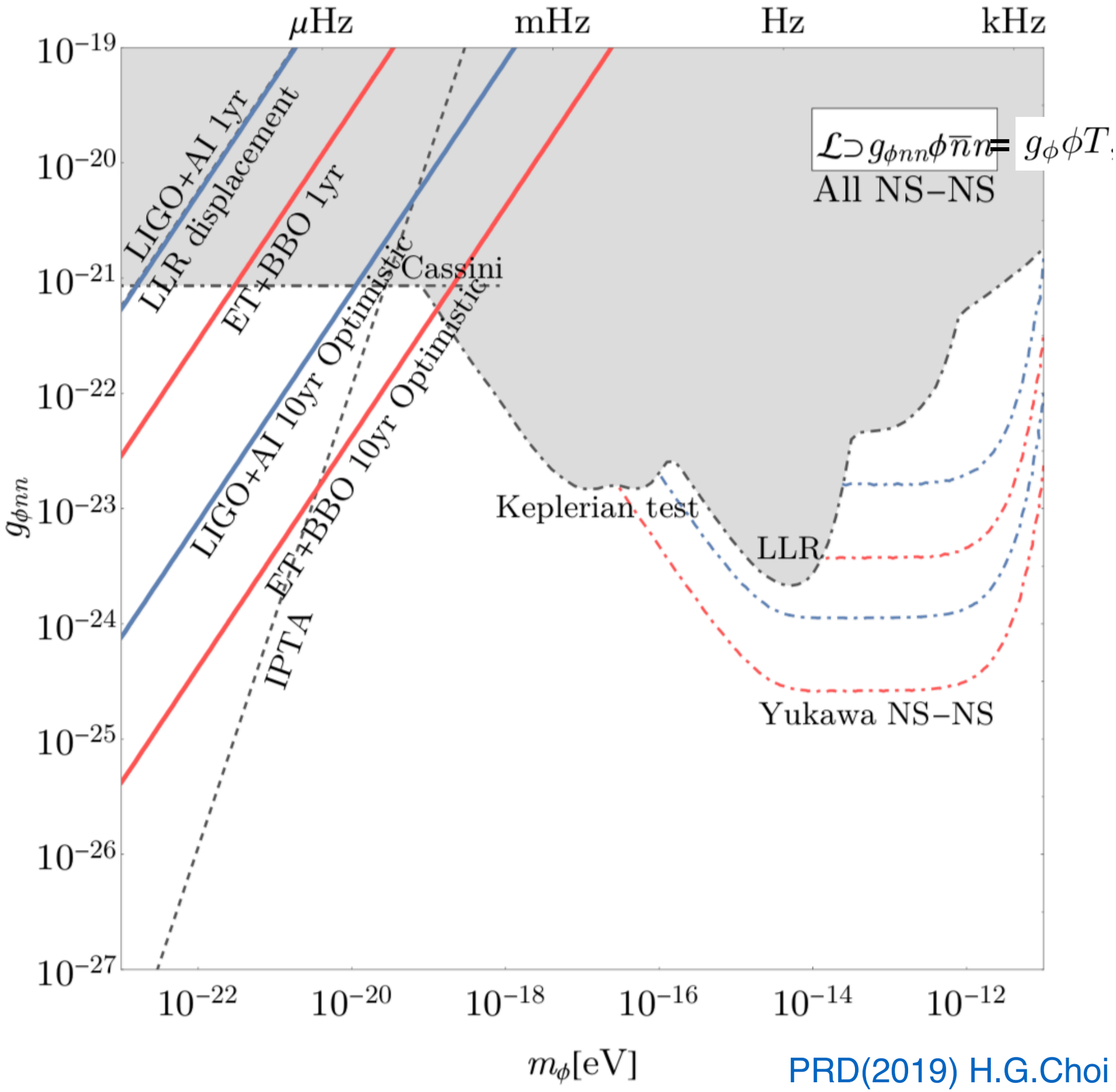
- Ncyc is max for highest-freq long-time measurement.

PRD(2019) H.G.Choi and S.Jung

Detection prospects



PRD(2019) H.G.Choi and S.Jung

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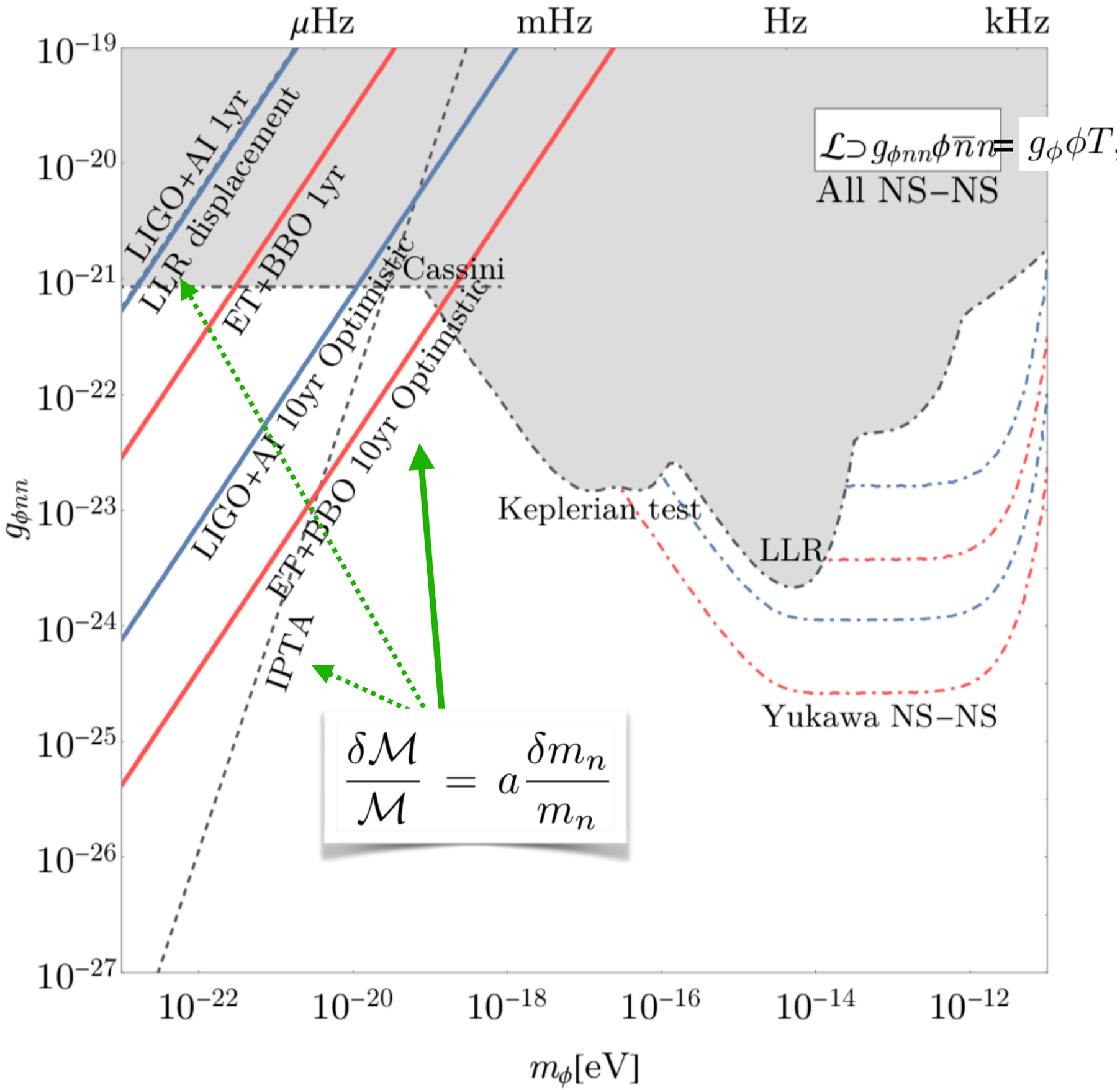

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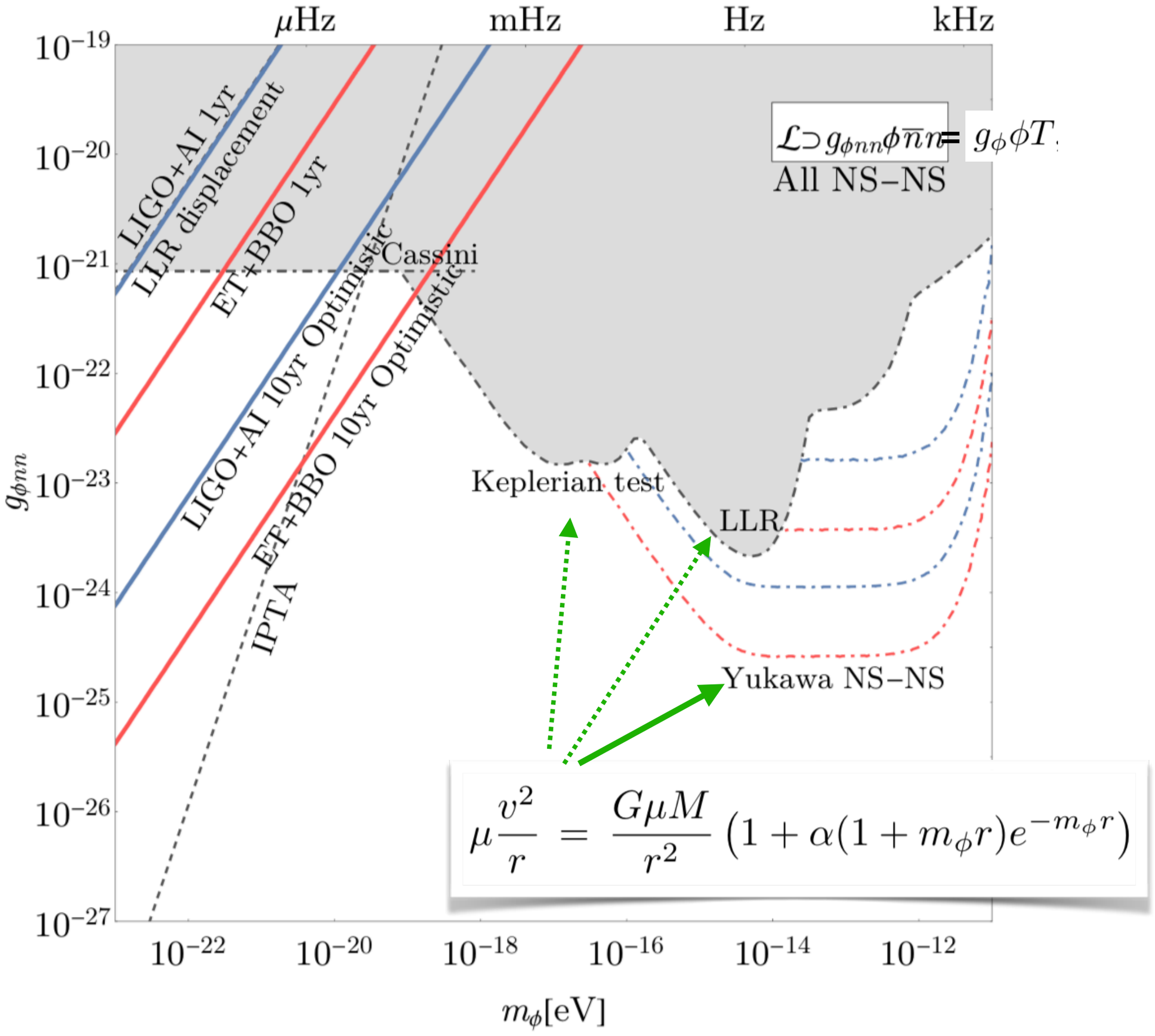

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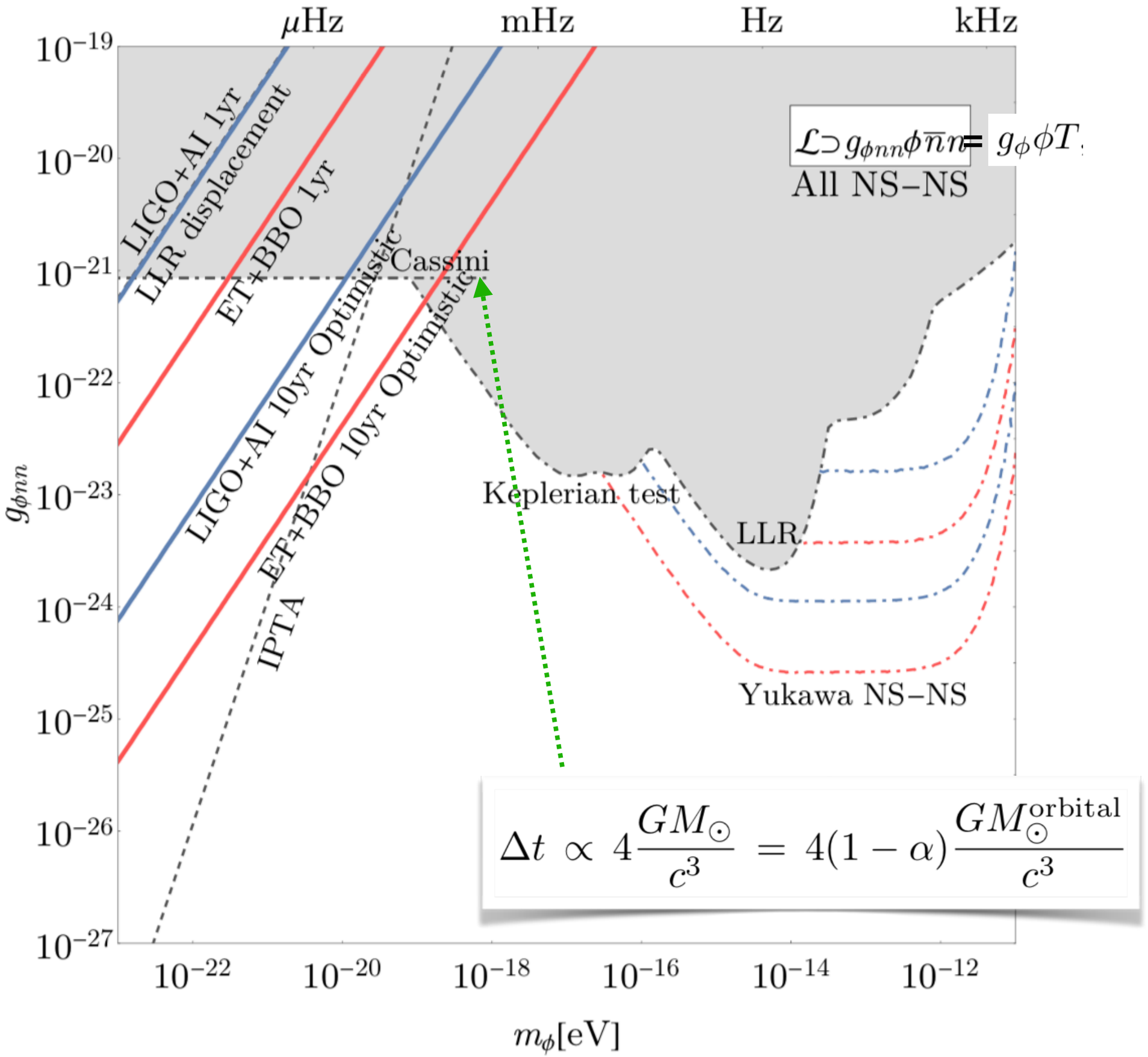
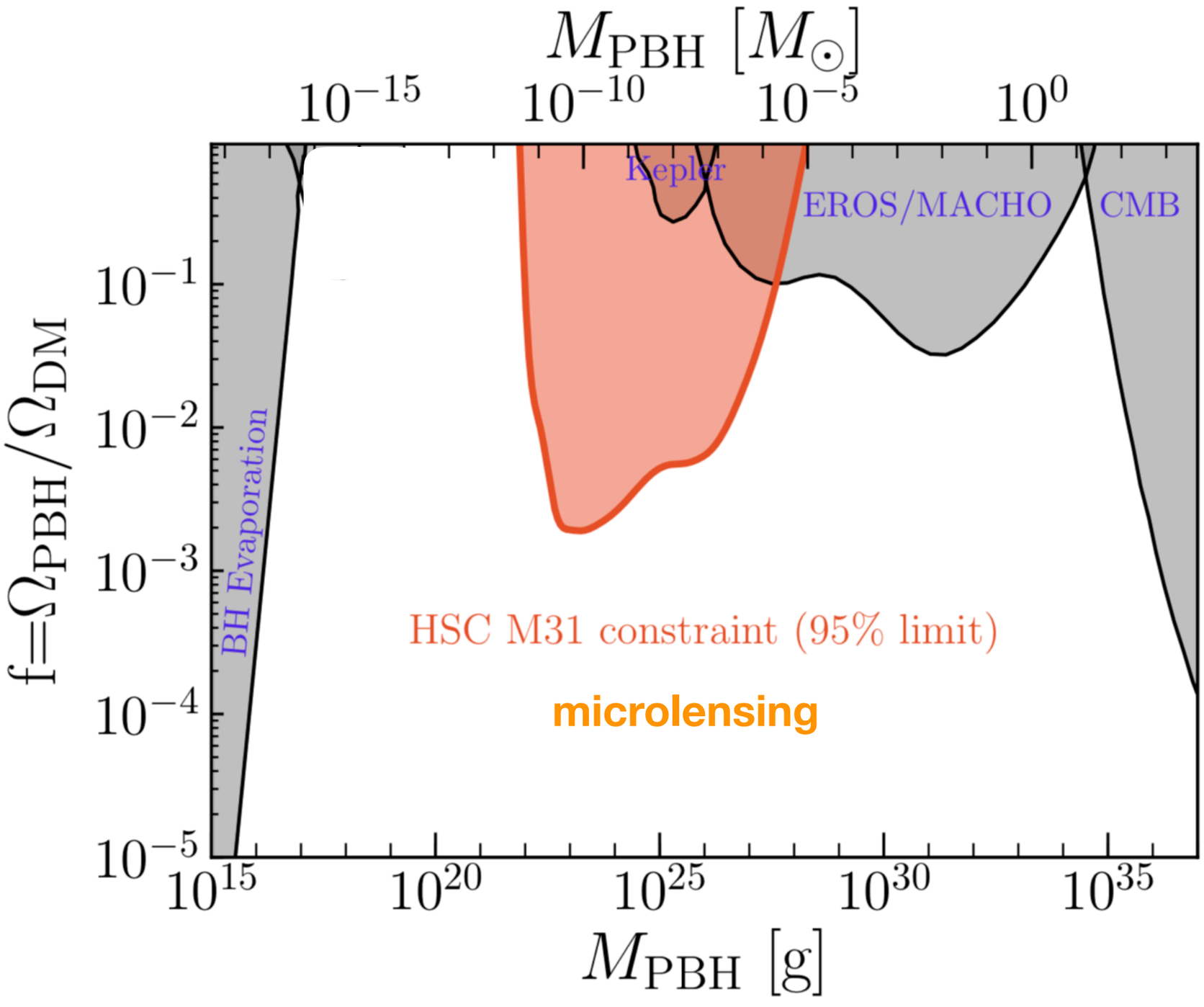


$$\Delta t \propto 4\frac{GM_\odot}{c^3} = 4(1-\alpha)\frac{GM_\odot^{\text{orbital}}}{c^3}$$

New idea on PBH DM search



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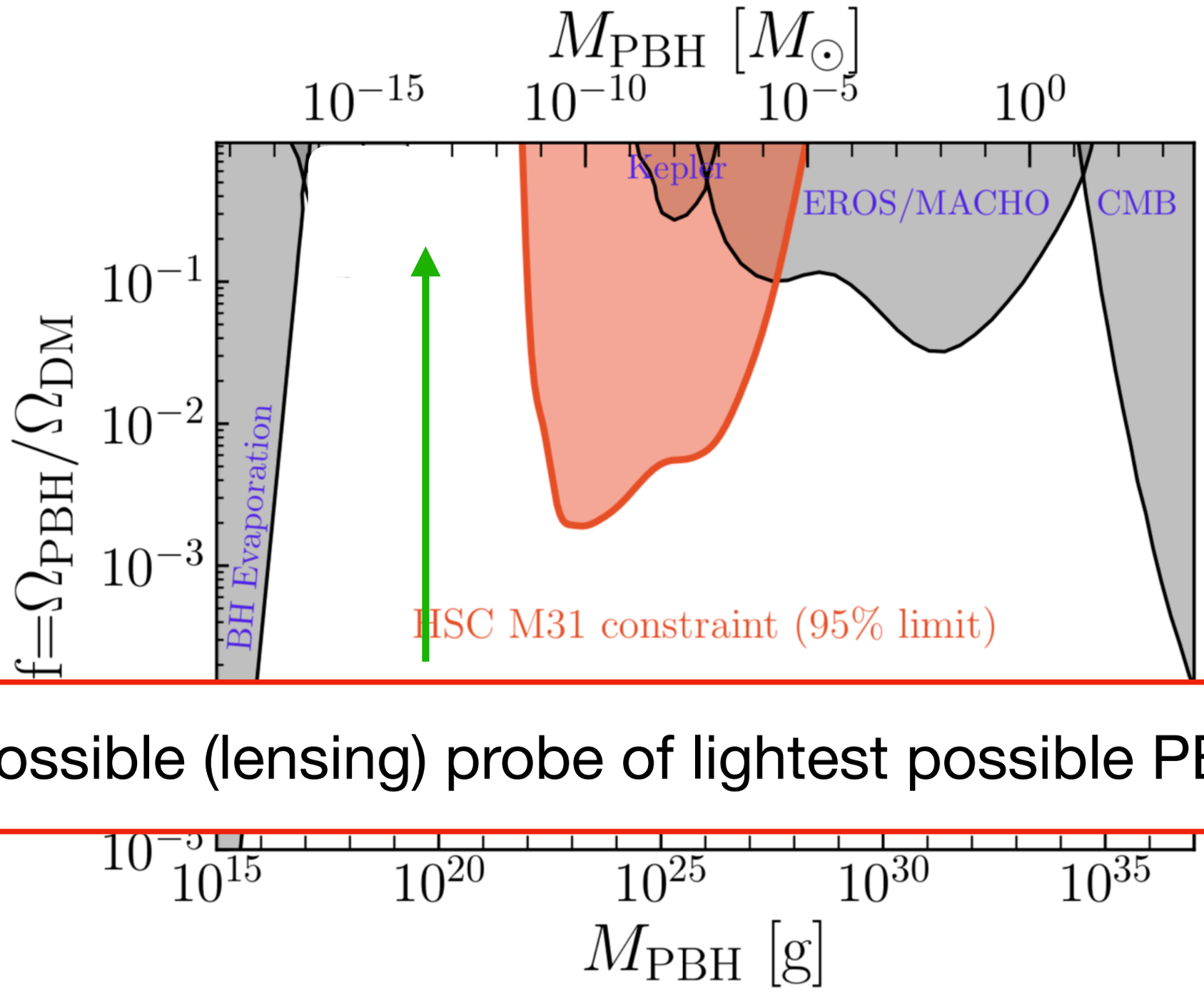
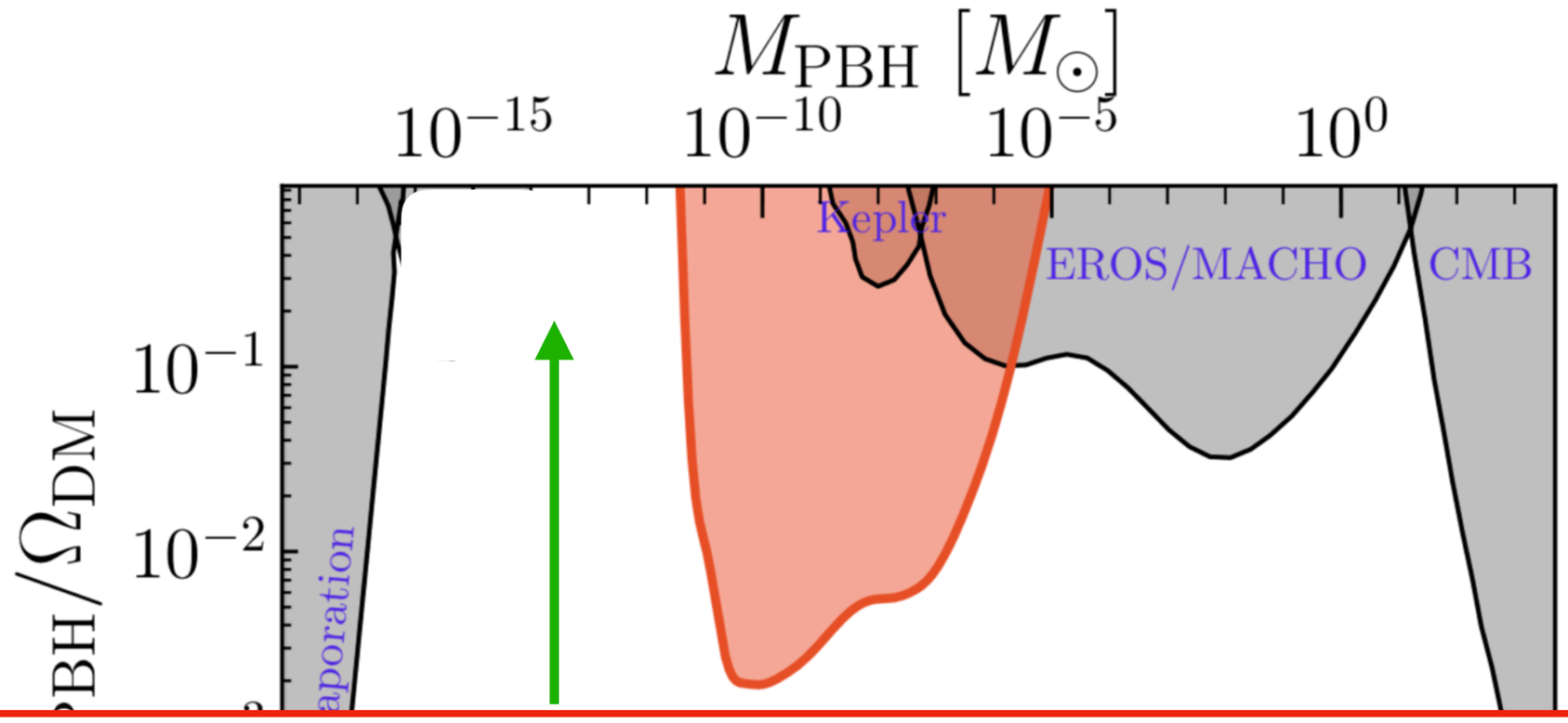


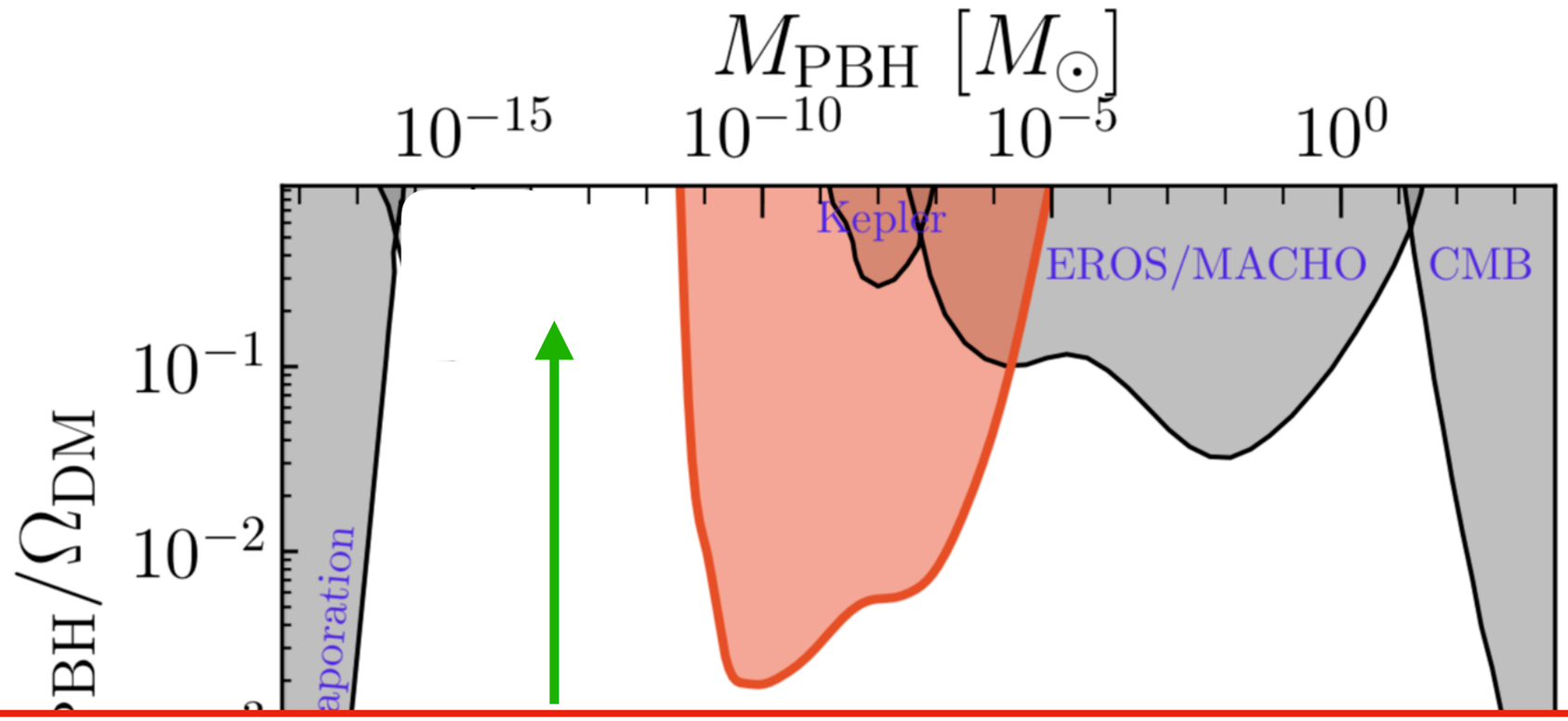
- No possible (lensing) probe of lightest possible PBH DM.

New idea on PBH DM search



- Two inherent difficulties with “microlensing of nearby stars”:
- 1. Nearby stars appear large > nearby PBH r_E is small.
  2. IR/optical wavelength is long > PBH R_sch is small.

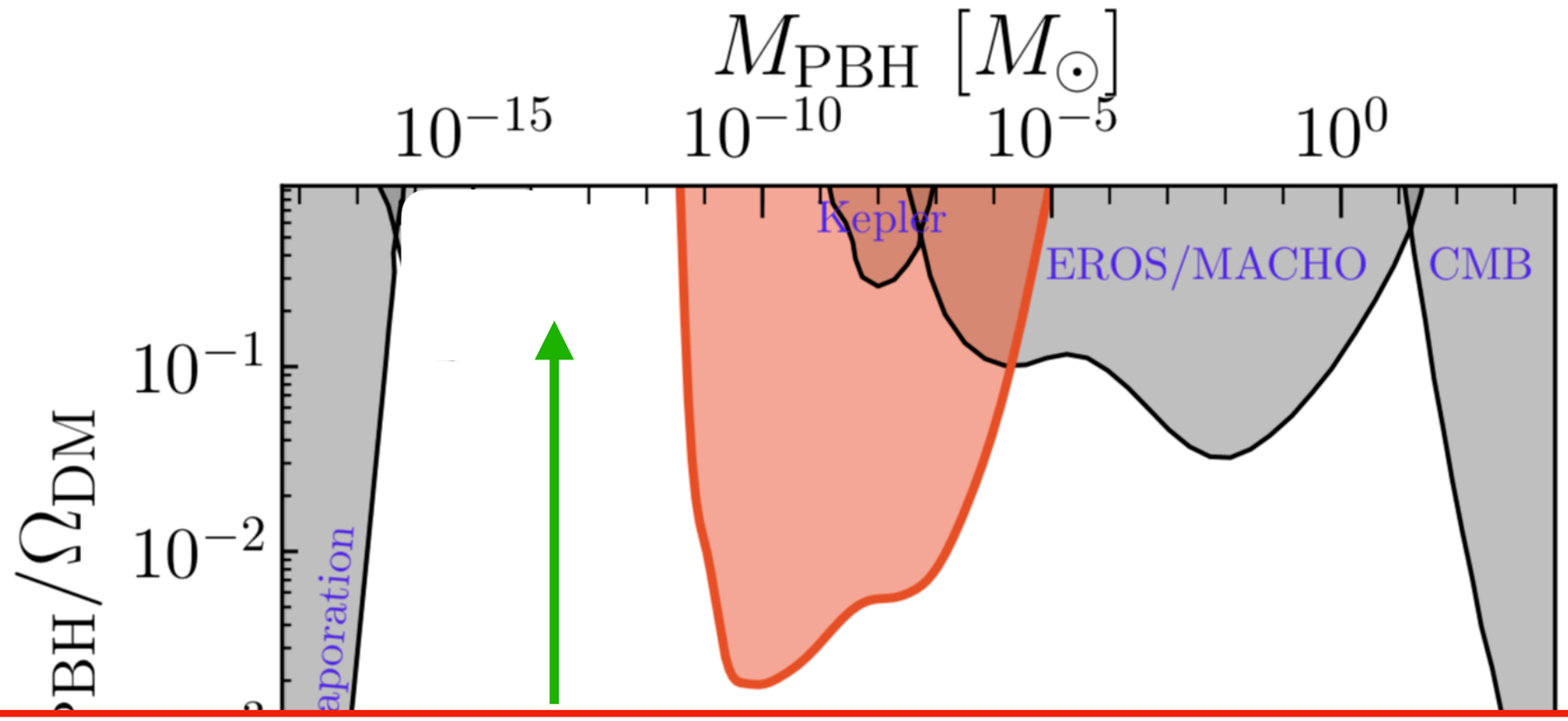
New idea on PBH DM search



- GRB can overcome both:

  1. At cosmo distance, GRB appears small < PBH r_E large.
  2. Gamma-ray wavelength is small < PBH r_Sch.

New idea on PBH DM search



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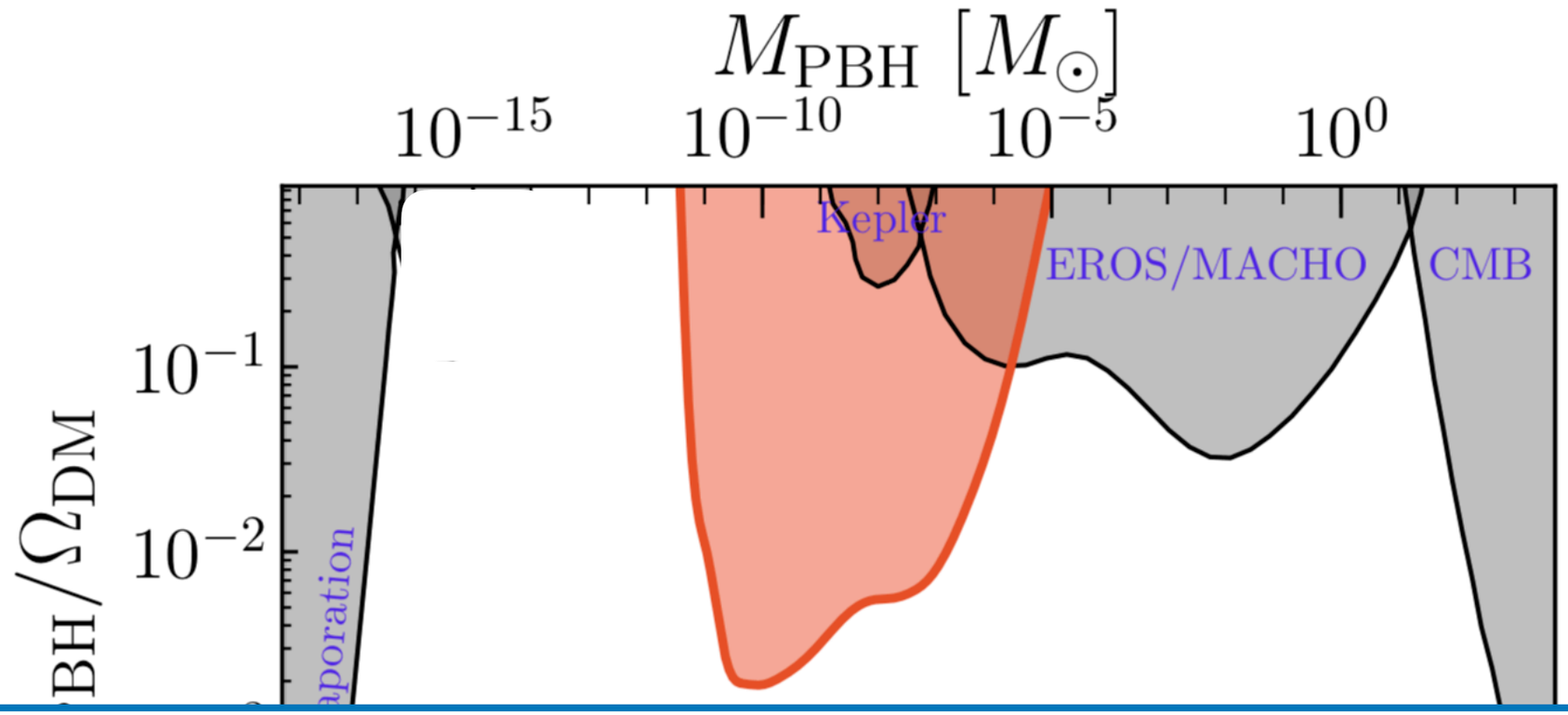
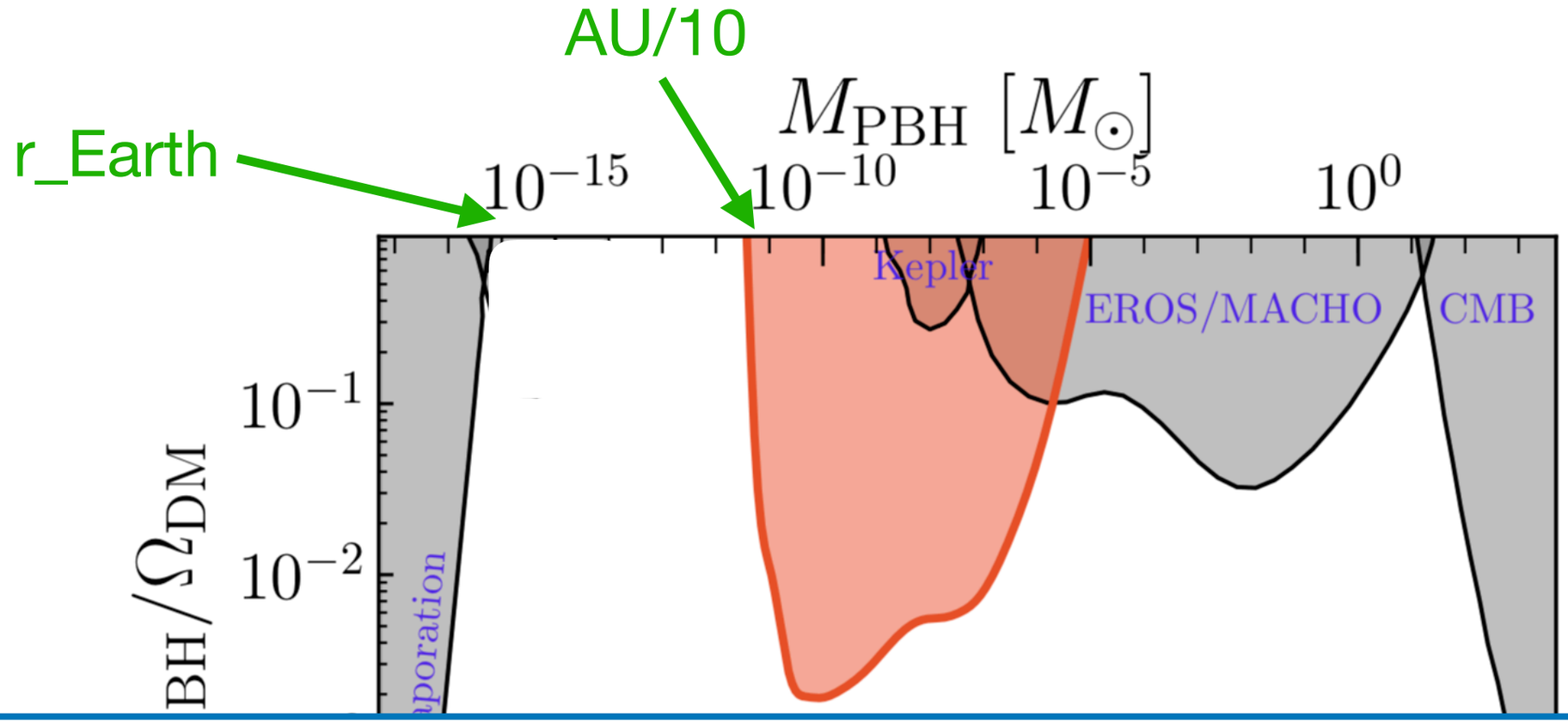


- But GRB is a short pulse. How can we tell it's lensed?!

1908.00078, S.Jung and T.H.Kim

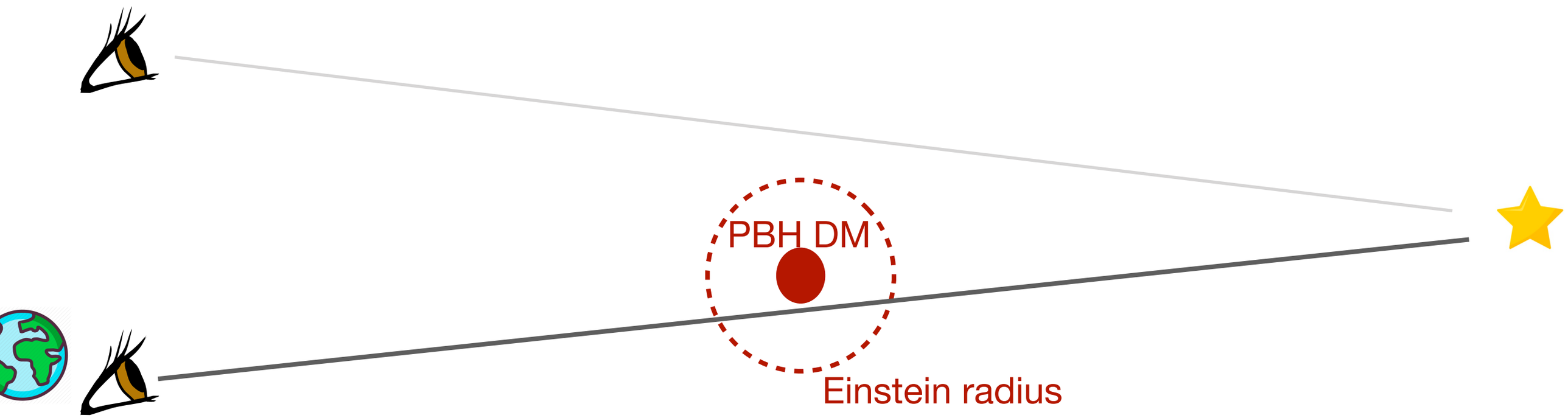
New idea on PBH DM search



- But GRB is a short pulse. How can we tell it's lensed?!
- The Einstein radius of this mass range *happens* to be the astrophysical scale accessible to us : r_Earth ~ AU !

1908.00078, S.Jung and T.H.Kim

Lensing parallax of GRB



- GRB pulses observed by spatially separated detectors can measure different lensing magnifications.

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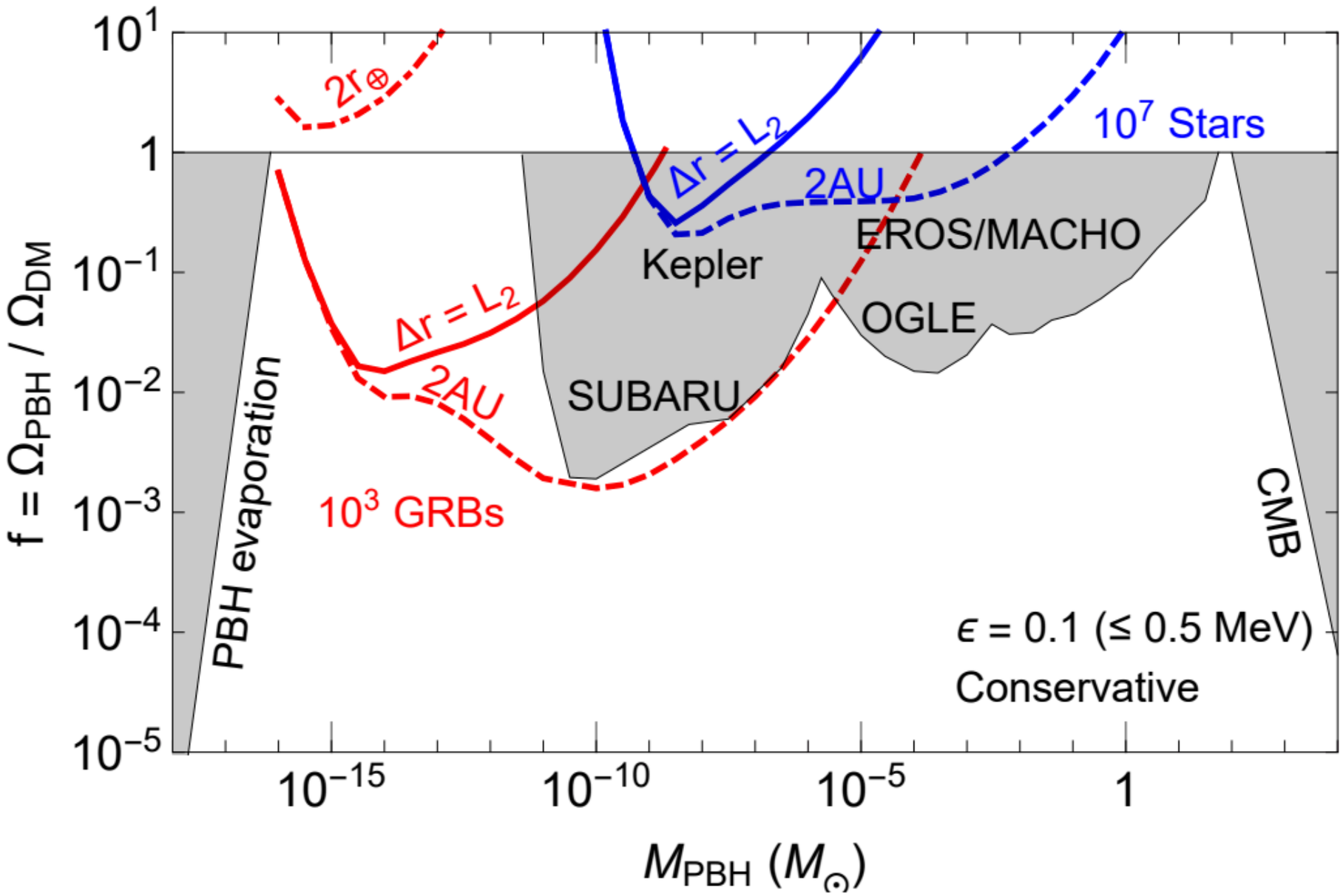
GRB lensing parallax



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Dark Odyssey 2020

Gravitational-Wave Probes of Dark Universe

- Workshop on GW, DM, particle astro como.
  (bridge btwn those fields)

- 2020, January 4-6 (Sat-Mon) @ Seoul National University

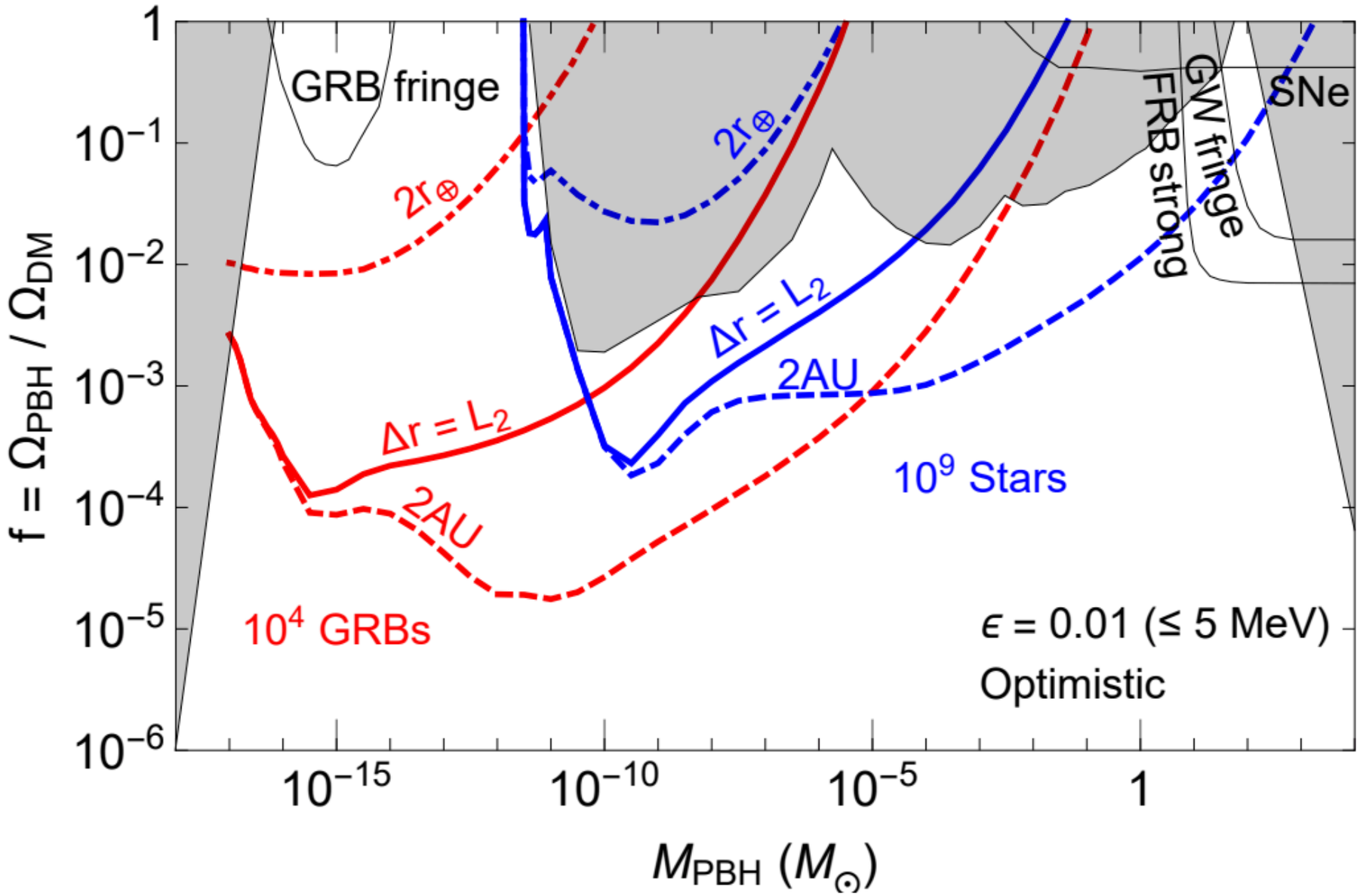
- Open soon.
  (Let me know if you are interested in: sunghoonj@snu.ac.kr)

Organizers: Sunghoon Jung, Seung J. Lee, Yue Zhao

LOC: Chunglee Kim, Chan Park

back up

GRB lensing parallax



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