apctp asia pacific center for theoretical physics

CAU-IBS BSM workshop
June 8, 2026

Micro Black Holes may be Dark Matter of the Universe

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APCTP + …

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APCTP

The Asia Pacific Center for Theoretical Physics (APCTP) was established in Pohang, Korea in June 1996, with C.N. Yang as its founding President.

As an international NGO, its current 19 member countries & regions include Australia, Beijing, Canada, India, Indonesia, Japan, Kazakhstan, Korea, Kyrgyzstan, Lao PDR, Malaysia, Mongolia, Philippines, Singapore, Taipei, Thailand, Uzbekistan, Vietnam, Cambodia. More countries & regions in the Asia-Pacific region are expected to join the Center in the near future.

Aim : As an international organization in the field of theoretical, the Center aims the lead basic science in the Asia Pacific region.
Roles : To create a basic research hub and to enhance global leadership capability. To provide an academic platform for theoretical physics community in the Asia Pacific region

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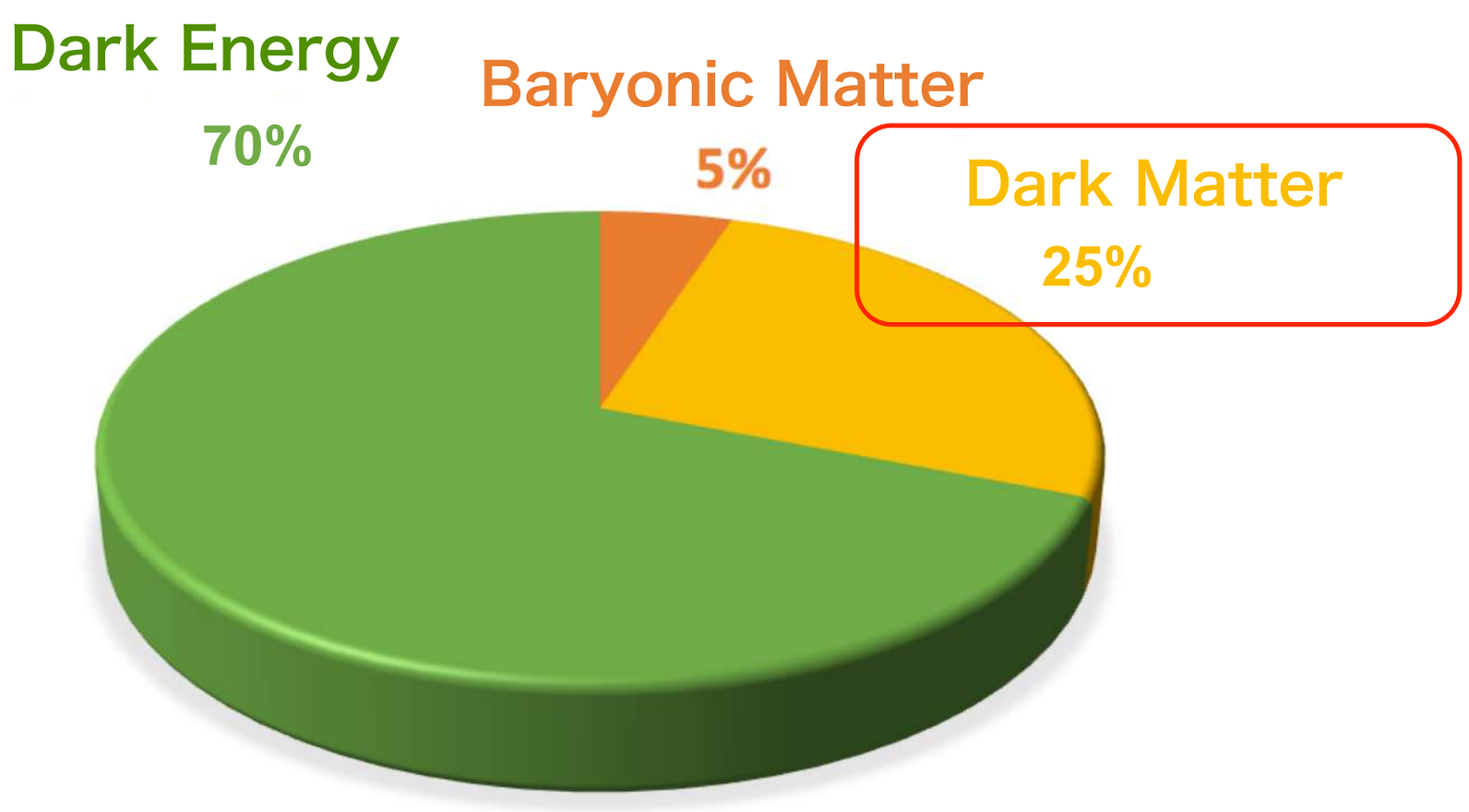
Constituents of the Universe

- normal (baryonic) matter occupies only ~ 5 percent
- dominant component is Dark Energy: completely unknown → future issue
- next dominant component is Dark Matter: undiscovered particles?

black holes?



What is Dark Matter made of?

necessary properties

- transparent to light: Transparent matter rather than Dark matter

  - CMB, galactic rotation curves, gravitational lensing,…

  almost non-interacting with normal (baryonic) matter

- halo formation due to gravity: no pressure to stop contraction

  - Large scale structure formation, …

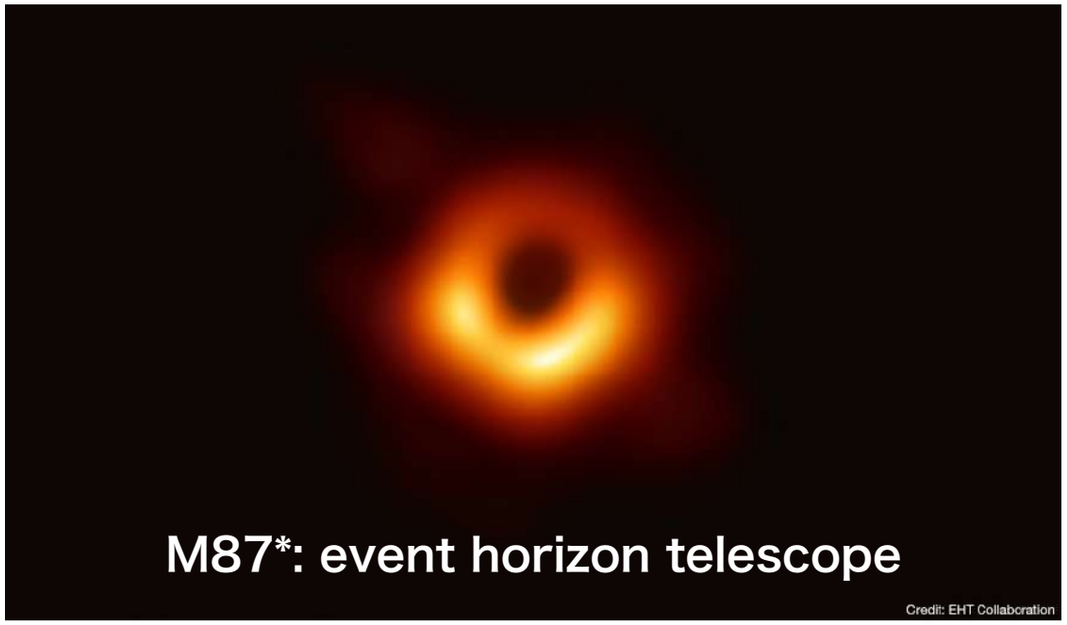
  very cold ⇨ Cold Dark Matter: $w \equiv \frac{p}{\rho} \ll 1$

candidates

- WIMPs
- ALPs, extremely light bosons
- dark photons, dark gravitons, …
- Black Holes (BHs)!

BHs are one of the best candidates, as they interact only through gravity

“observed” BHs



BH mass＝$6.5\times10^{9}M_{\odot}$

size=100 AU

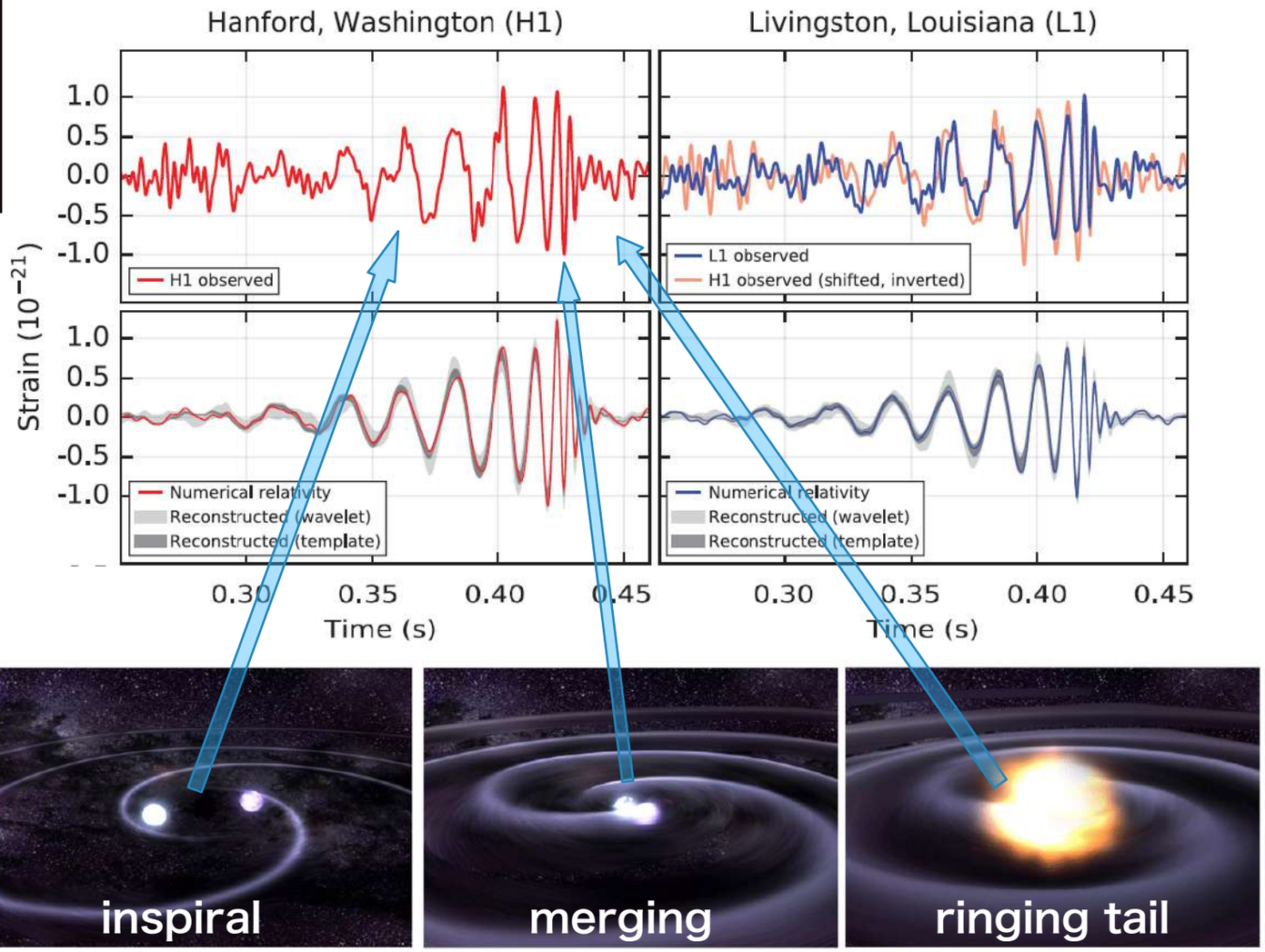
1AU=1.5x10⁸km
distance btw Sun and Earth

super massive BH

massive BH

BH mass＝$30M_{\odot}$ x 2

size＝200 km



GW140914: LIGO

Origin？

Primordial BH (PBH)

- BH formed in the very early Universe

  at least, $t < 10^5$ yr or $T<1$ eV

- most probably, due to large spacetime fluctuations produced from Inflation

cosmological spacetime diagram

log L

$1/H_0$

strong constraints
from CMB & LSS

almost no constraint
on small scales

Rad-dom.
$1/H \sim a^2$

a/H_0

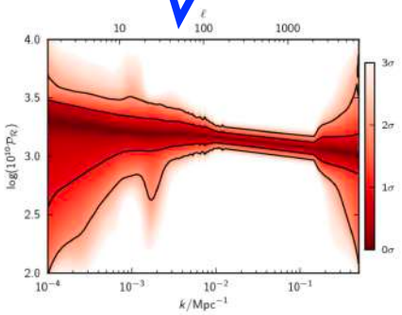
a/k_*

reheating

$\gtrsim$ 20 efolds

a_* a_{end} $a_{re\text{-}entry}$ a_{eq} 1

N= log a



Planck

$k_* = Ha_*$

There may be a high peak in the curvature perturbation spectrum

cosmological spacetime diagram

log L

$1/H_0$

probes late stage of inflation

Rad-dom.
$1/H \sim a^2$

a/H_0

a/k_*

reheating

$\gtrsim$ 20 efolds

a_*

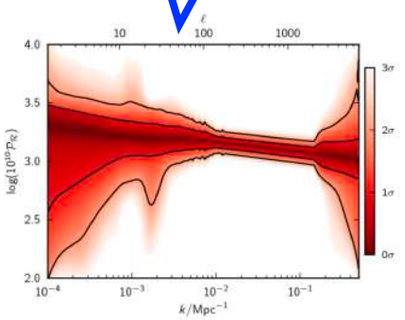
a_{end}

$a_{re-entry}$

a_{eq}

1

N= log a



$k_* = Ha_*$

The peak re-enters horizon during radiation era.
PBH will form if the amplitude is 0(1).

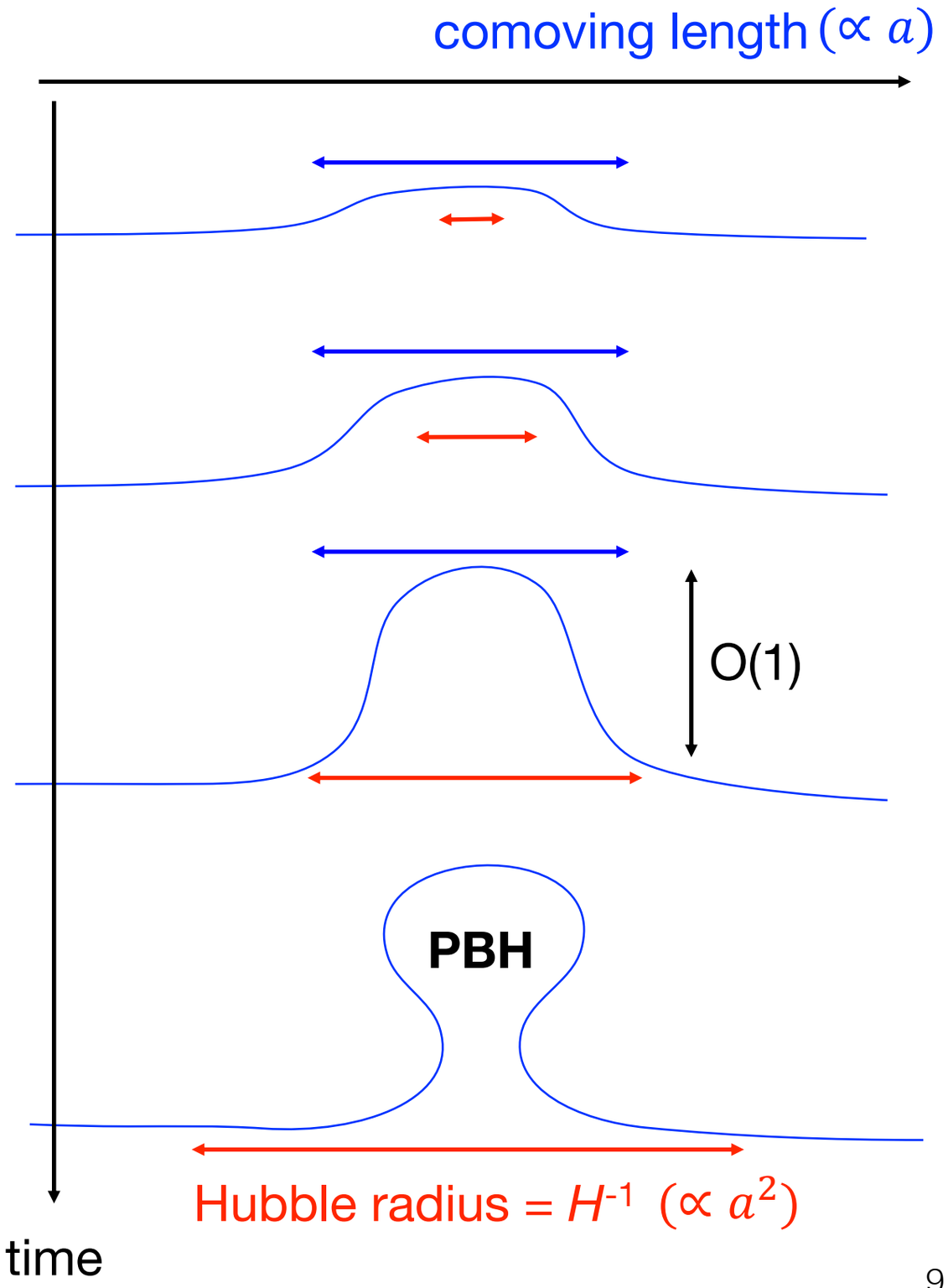
Carr and Hawking ('74)

Conventional PBH formation in a nutshell

Hawking (1971), Carr & Hawking (1974), …

- Primordial Black Holes (PBHs) are those formed in the very early universe, conventionally when the universe was radiation-dominated.
- Presumably they originate from a large positive curvature perturbation produced during inflation (which hence should be a rare event).
- For a BH to form during radiation dominance, the perturbation must be O(1) on the Hubble horizon scale.

$$M_{\mathrm{PBH}} \sim M_{\mathrm{horizon}} \sim \left(\frac{100\mathrm{MeV}}{T}\right)^2 M_\odot \sim \left(\frac{\ell}{1\mathrm{pc}}\right)^2 M_\odot$$



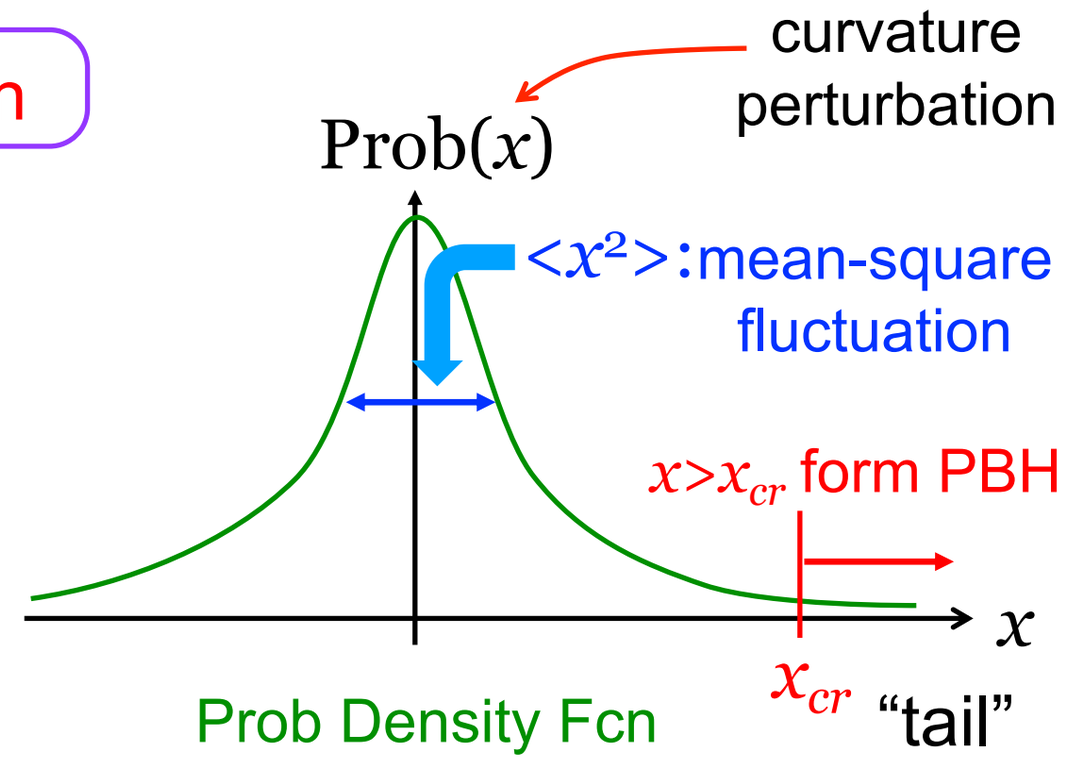
more about PBH

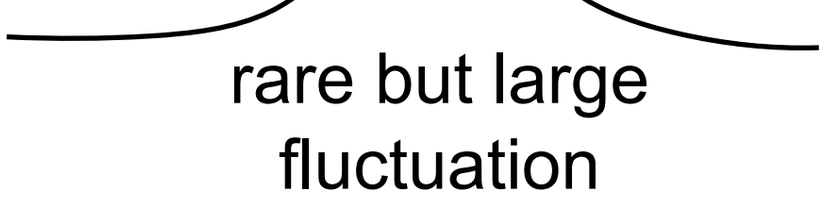
Rare large spacetime (curvature) fluctuations collapse to form PBHs

vacuum fluctuations from inflation

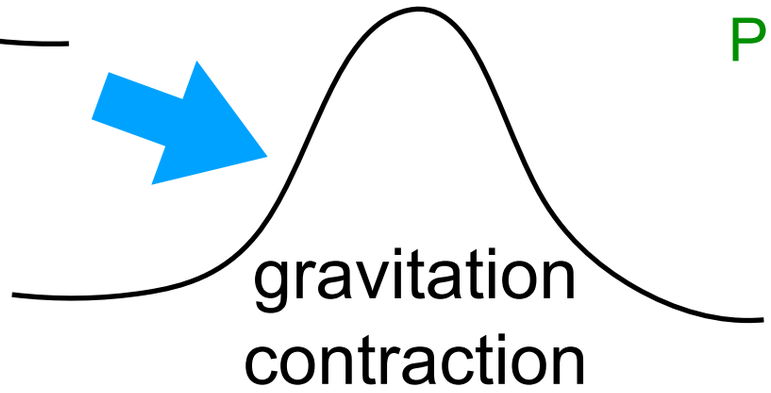
- formed perhaps in 10^{-20} ~1 sec
- ranging from asteroid size to $10^5\ M_\odot$

($\sim 10^{15}$ kg) ($\sim 10^{35}$ kg)

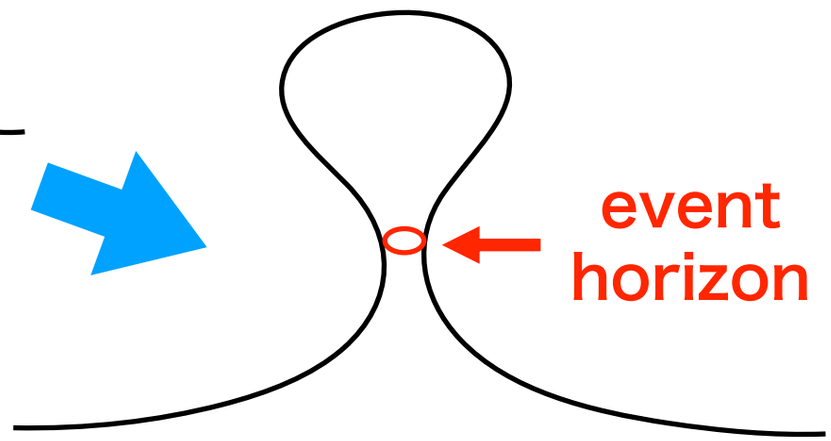




rare but large fluctuation



gravitation contraction

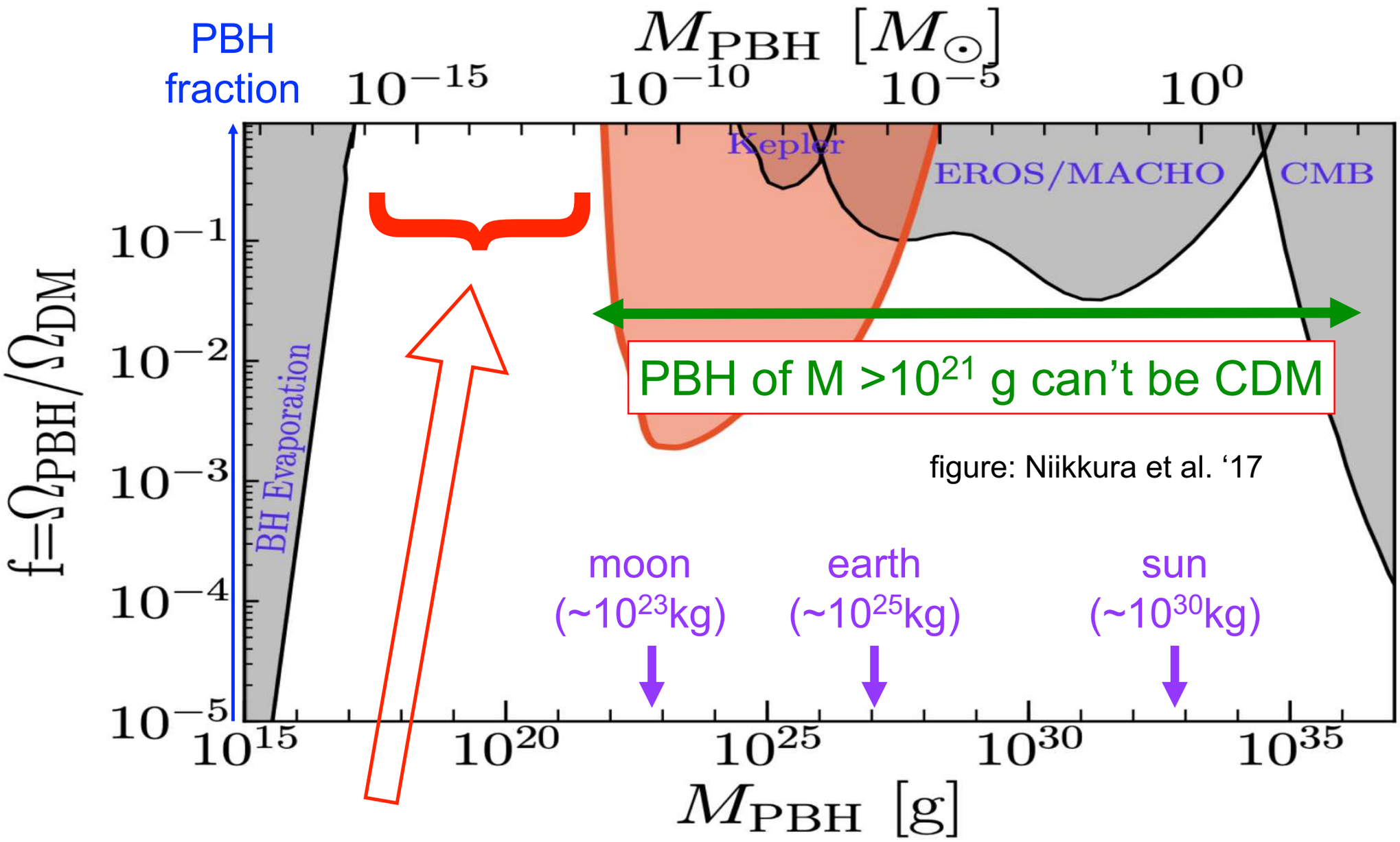


BH formation

BH of mass <10^{30}kg ($\approx M_\odot$)
must be PBH

no astrophysical process

PBH=CDM?



PBH of M >10^{21} g can't be CDM

figure: Niikkura et al. '17

M < 10^{21} g : BH is too small to be seen by Gravitational Lensing

∵ BH size << optical wavelength

diffraction!

BH radius:

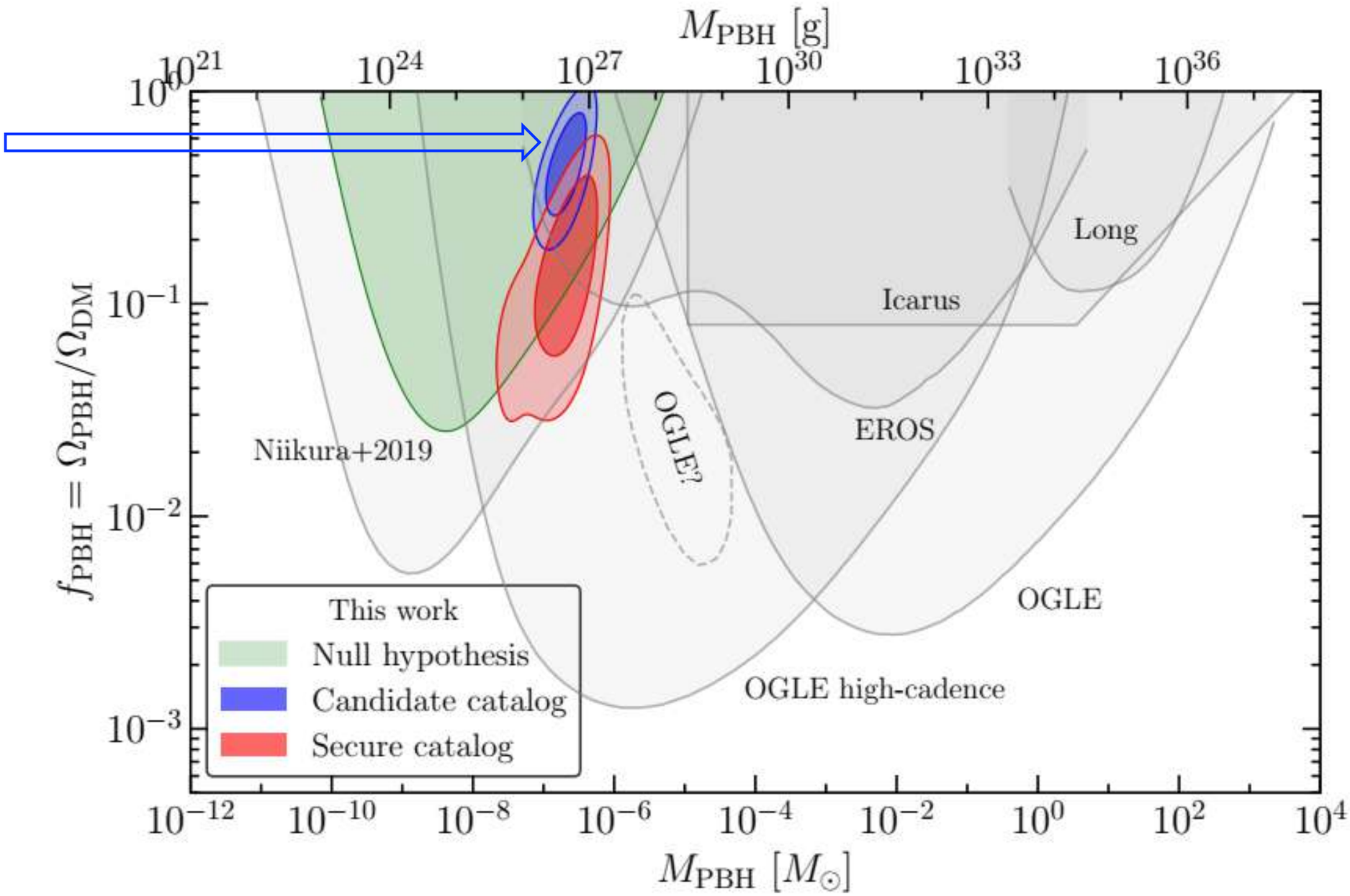
$$r_g = 2GM_{BH}/c^2 = 10^{-7}\mathrm{cm}\left(\frac{M}{10^{21}\mathrm{g}}\right)$$

observational updates

Subaru HSC indicates the existence of PBHs!

Sugiyama, Takada, Yasuda, Tominaga: 2602.05840

planet-size PBH could be CDM!



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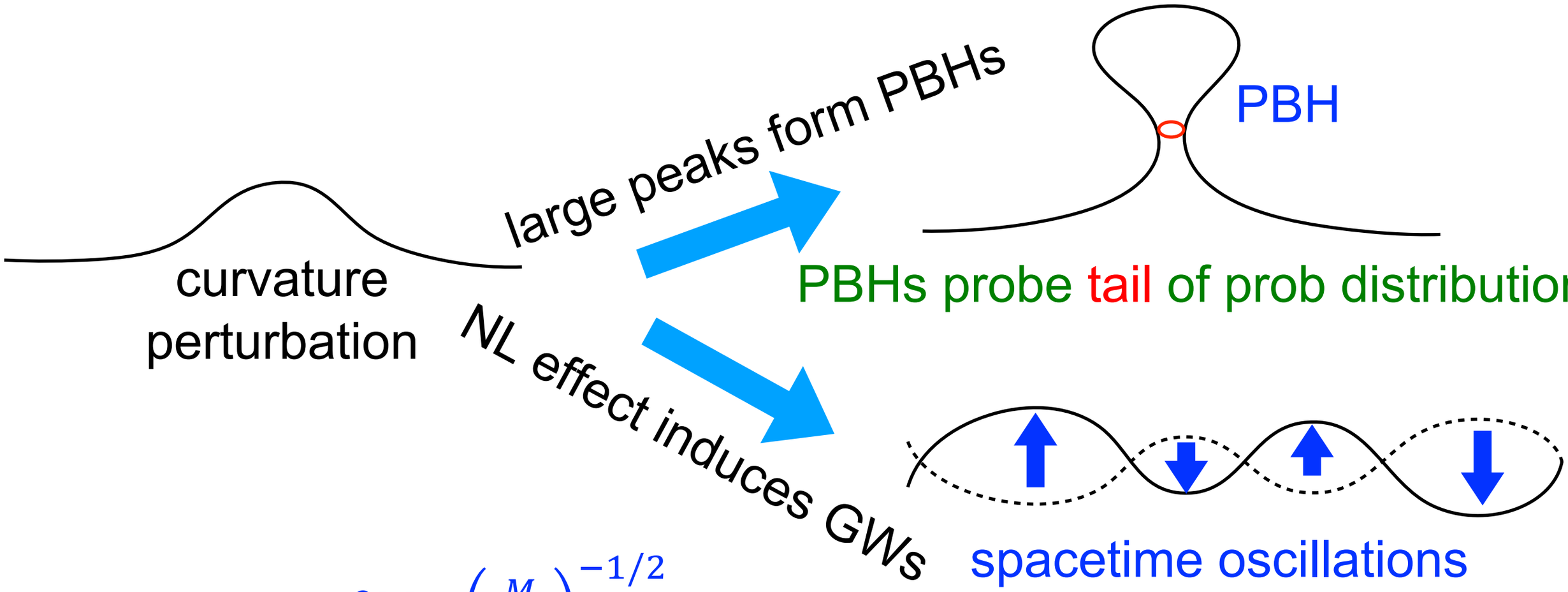
GWs capture PBHs!



$$f \approx 3\times10^{-9}\,\mathrm{Hz}\left(\frac{M}{M_\odot}\right)^{-1/2}$$

induced GWs probe power spectrum

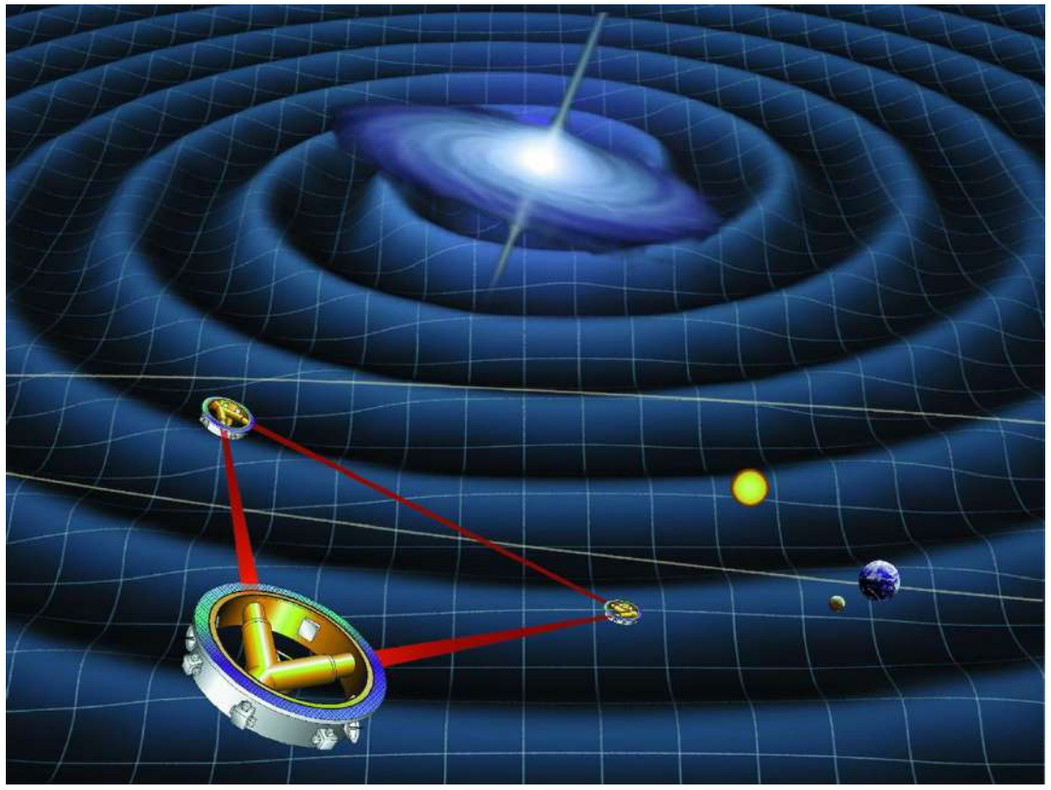
PBH = CDM with M_{PBH} ~10^{21}g
generates GWs with f~10^{-3} Hz

⇨ Background GWs in LISA/Taiji/TianQin band

*for planet-size PBH, f~10^{-6} Hz

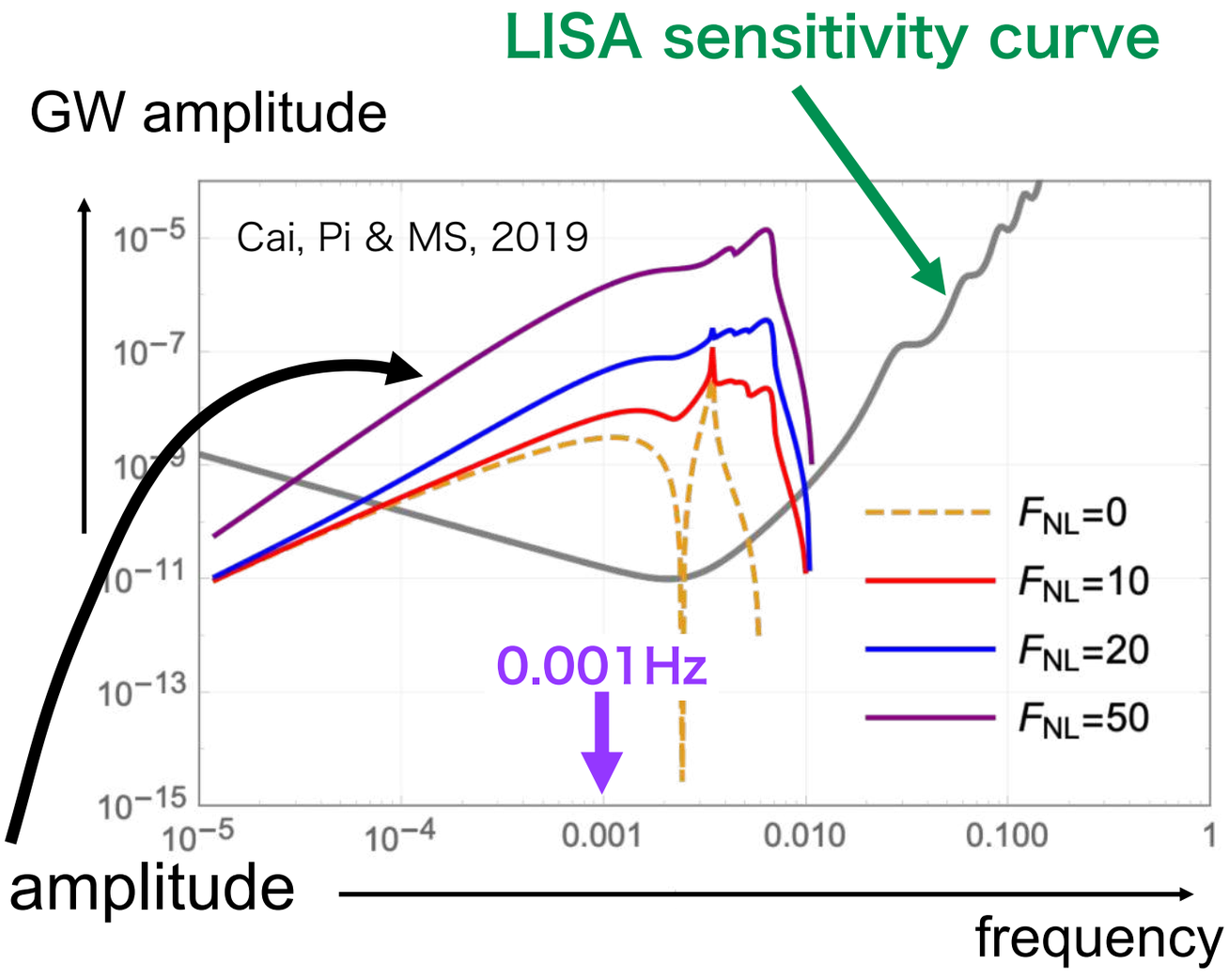
↕ space-based GW detectors

GW Observatory in Space



LISA 2035? (ESA+NASA)
arm length: 5,000,000 km

Taiji/TianQin 203X ? (China)
arm length:
3,000,000 km/1,732,000 km



PBH=CDM scenario will be proved/disproved!

Summary

Micro PBHs may be Dark Matter of the Universe

- normal (baryonic) matter constitutes only 5%

  visible components like stars and galaxies

- 70% is Dark Energy

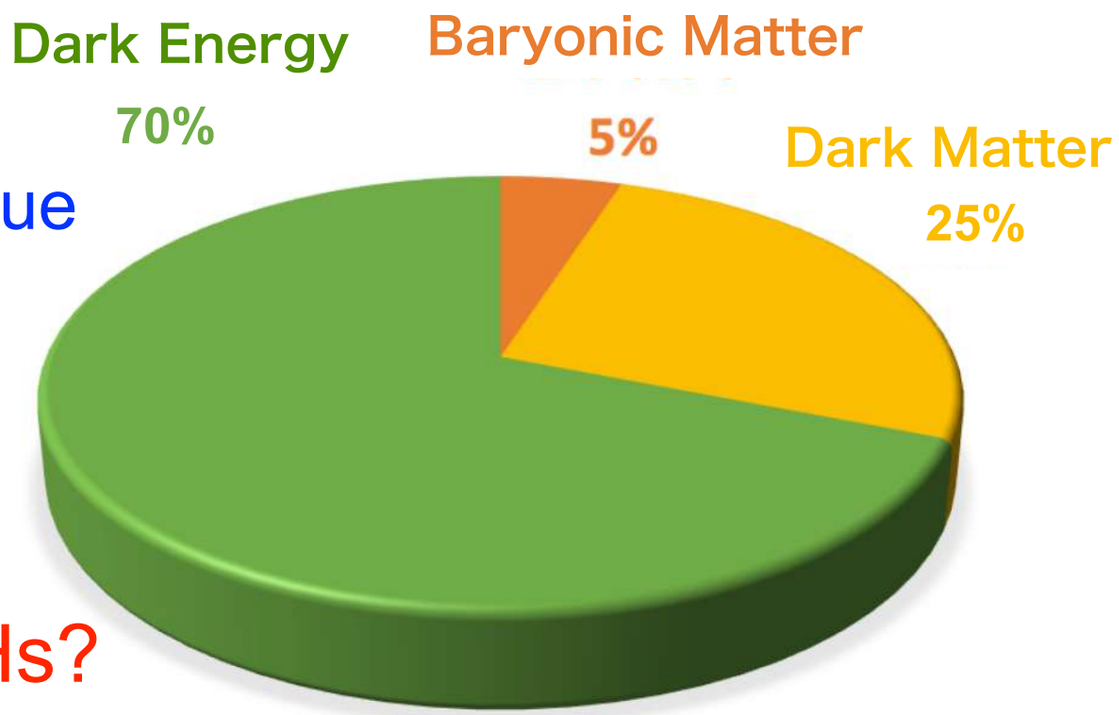
  completely unidentified: future issue

- 25% is Dark Matter

  unidentified: WIMPs? ALPs?

  or

  microscopic PBHs?



Obs of GW background will tell us the answer!