CORRELATING GRAVITATIONAL WAVE AND GAMMA-RAY SIGNALS FROM PRIMORDIAL BLACK HOLES

Based on ArXiv:2202.04653 with

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PRIMORDIAL BLACK HOLES

ASTEROID-MASS PRIMORDIAL BLACK HOLES

Why Asteroid-Mass?

- Less constrained
- Upcoming gamma-ray observations
- Clear production mechanism
- Correlation with gravitational waves

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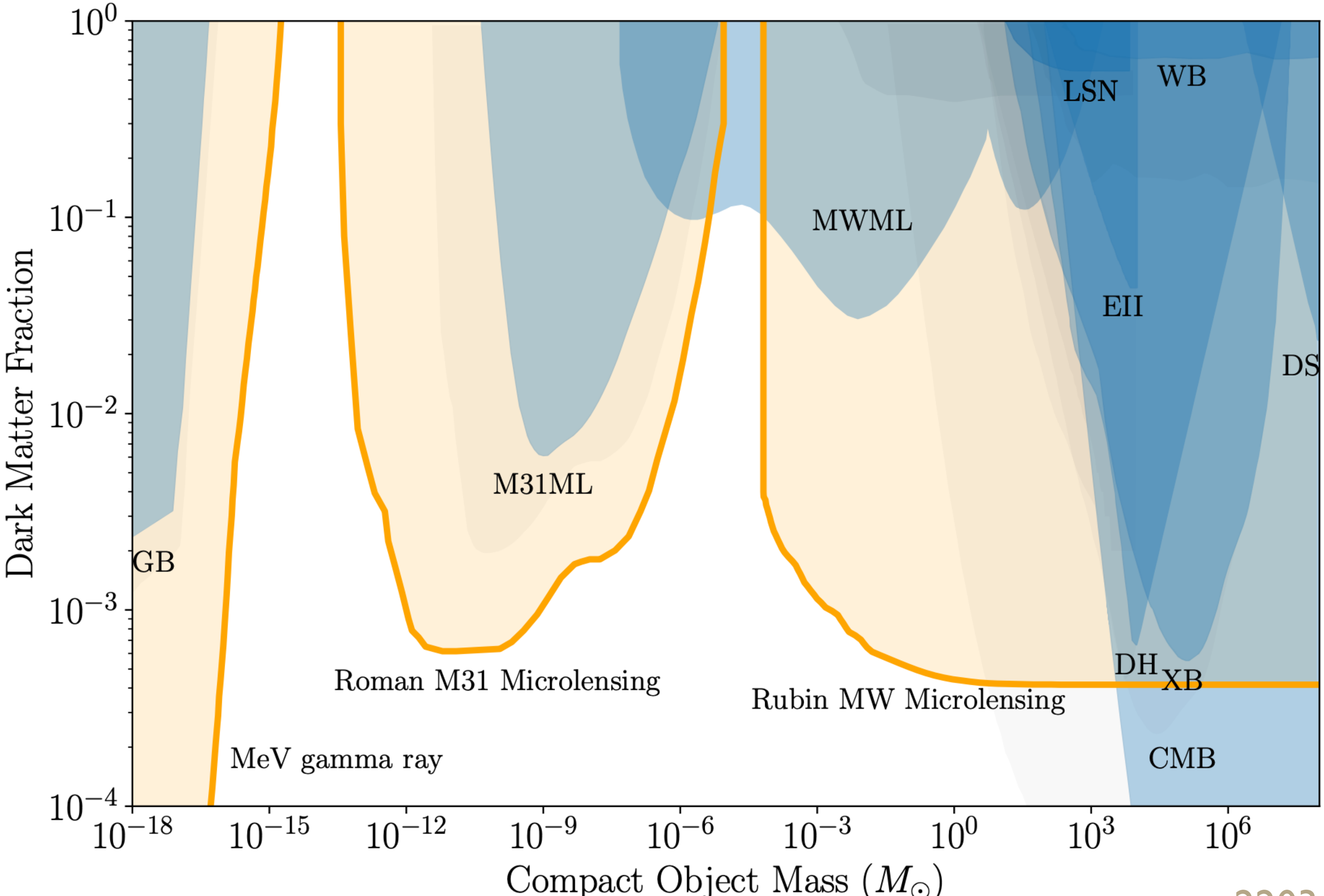
PBH Constraints



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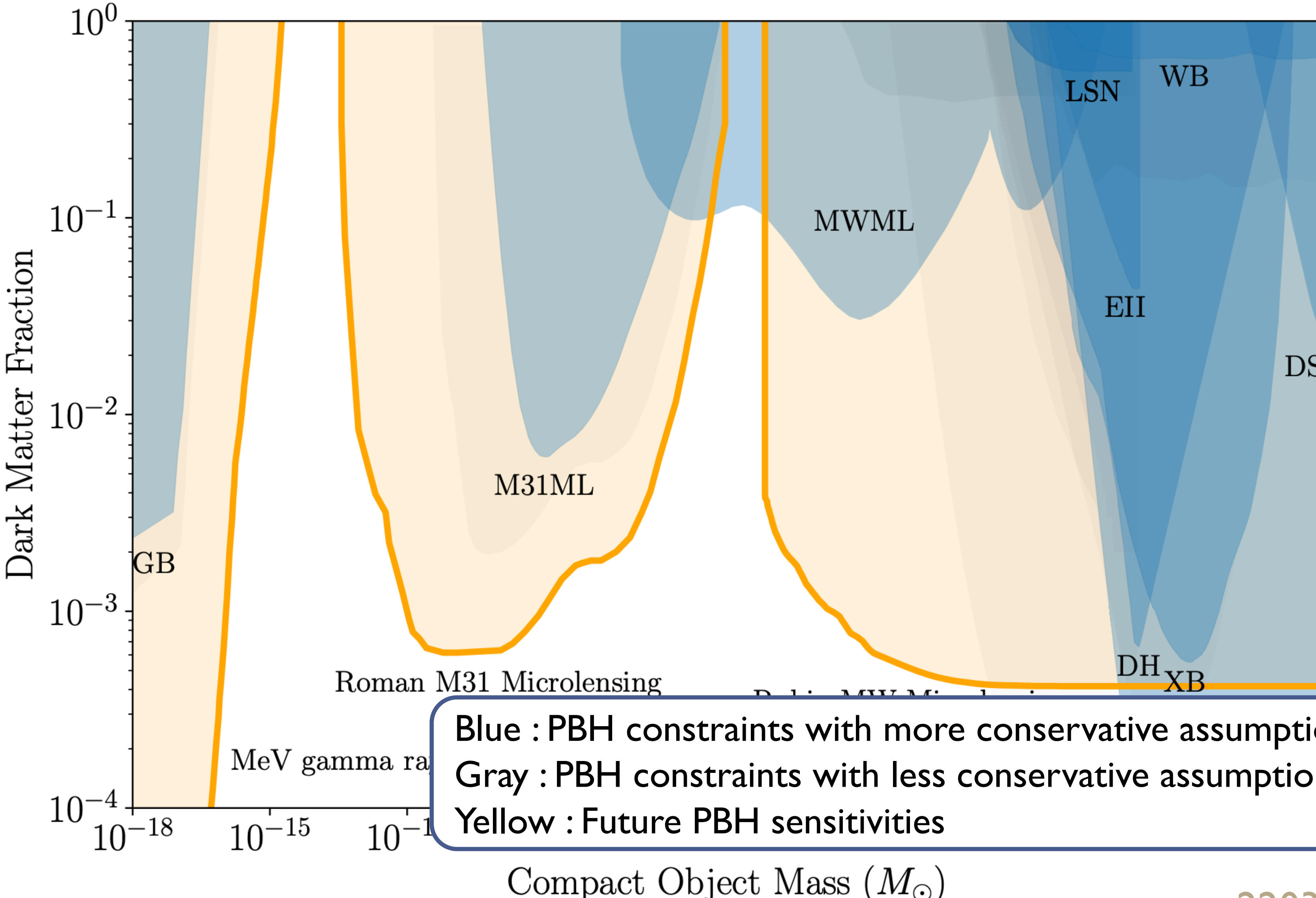
PBH Constraints



Blue : PBH constraints with more conservative assumptions
Gray : PBH constraints with less conservative assumptions
Yellow : Future PBH sensitivities

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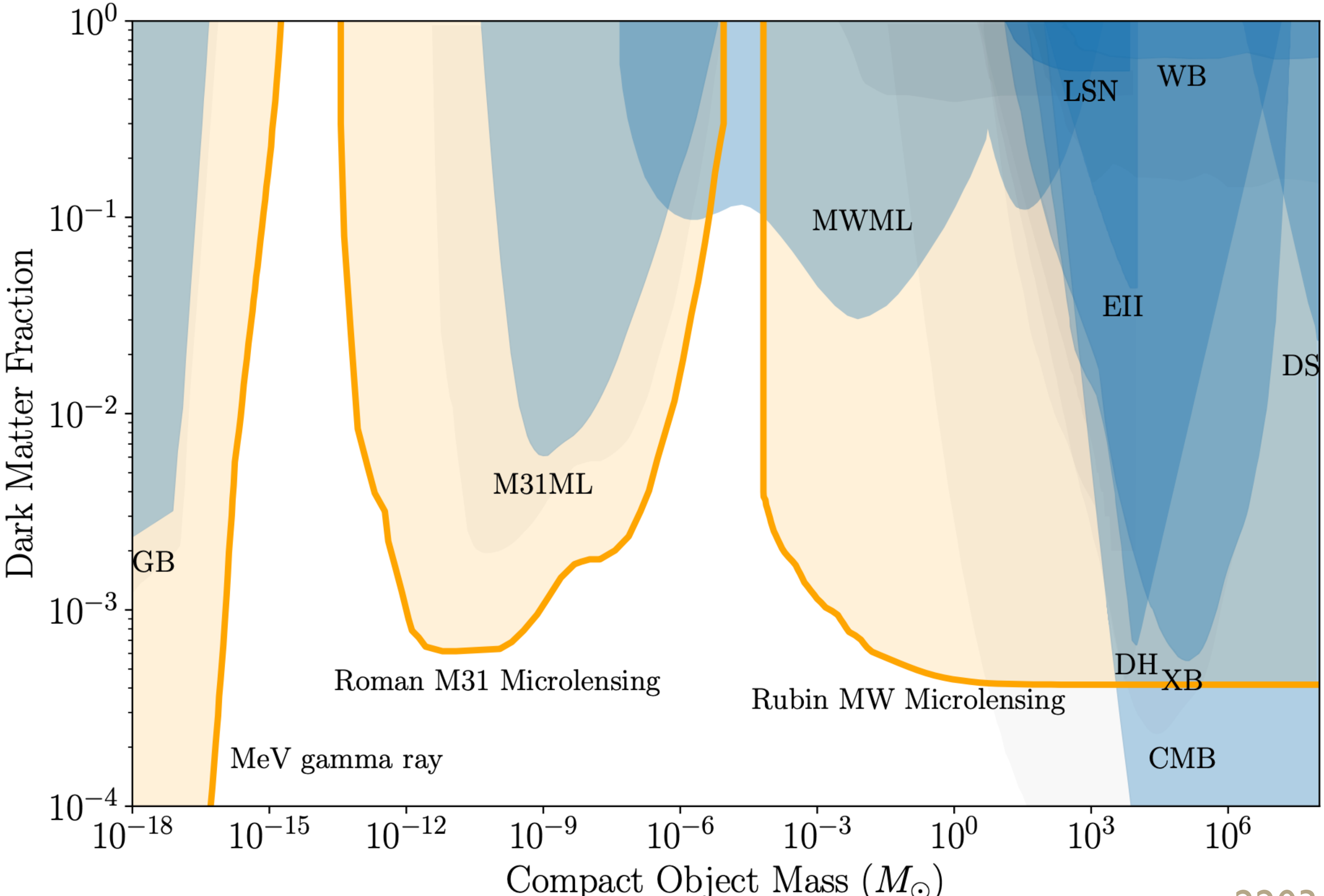
PBH Constraints



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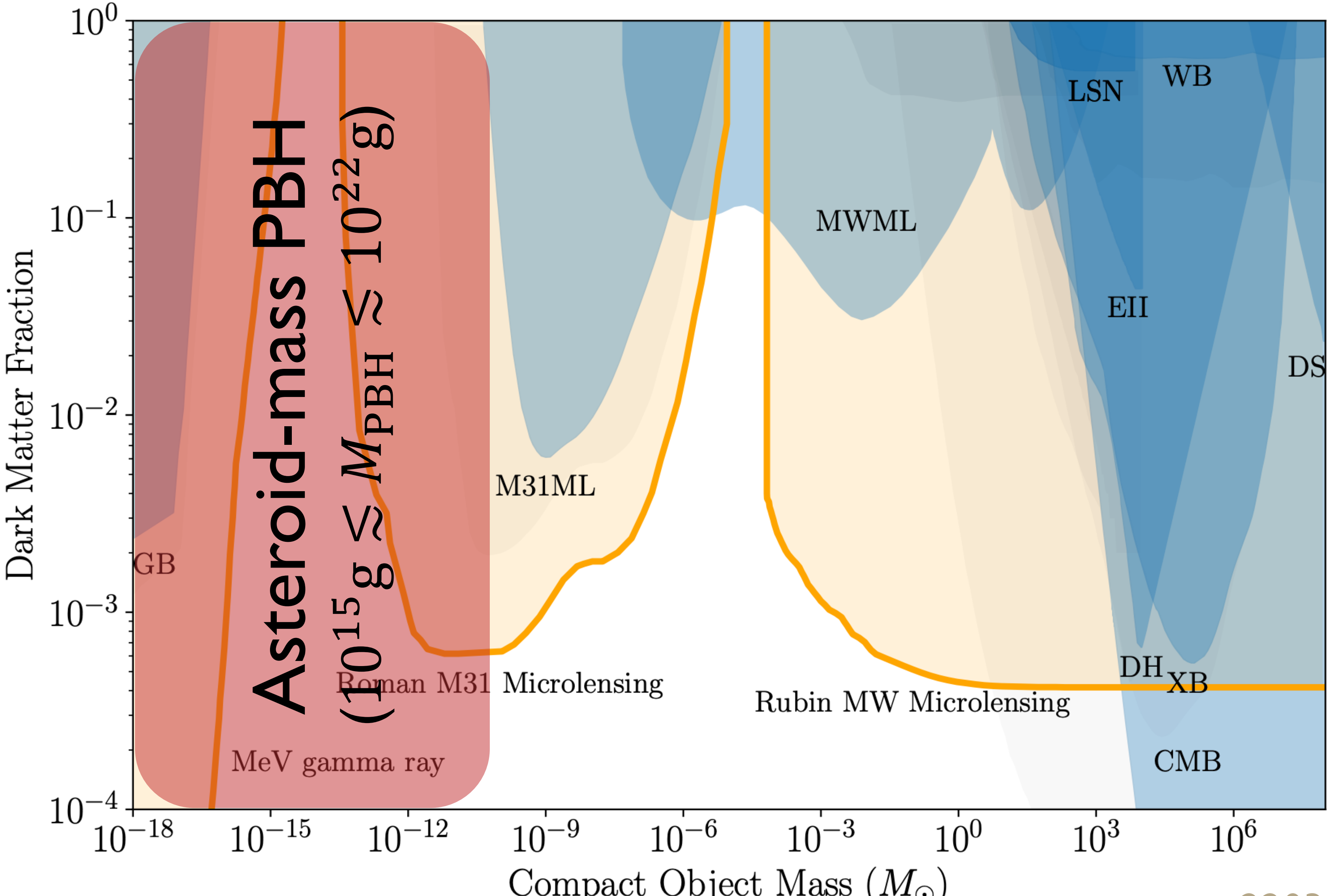
PBH Constraints



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Hawking Radiation

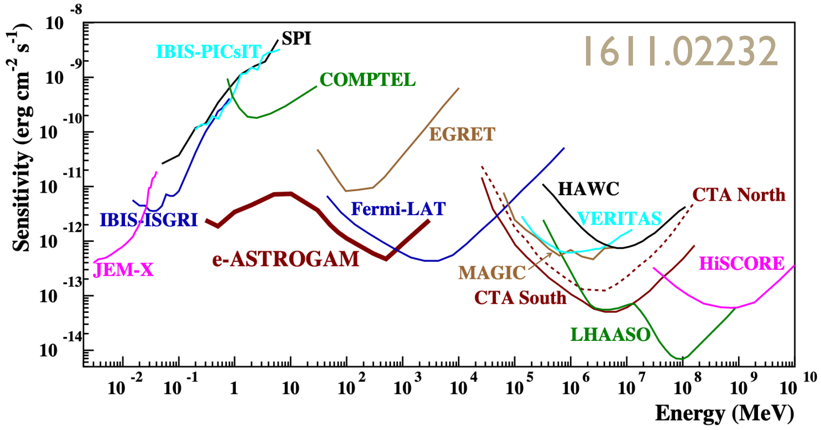
- Black holes emits Hawking radiation with the Hawking temperature

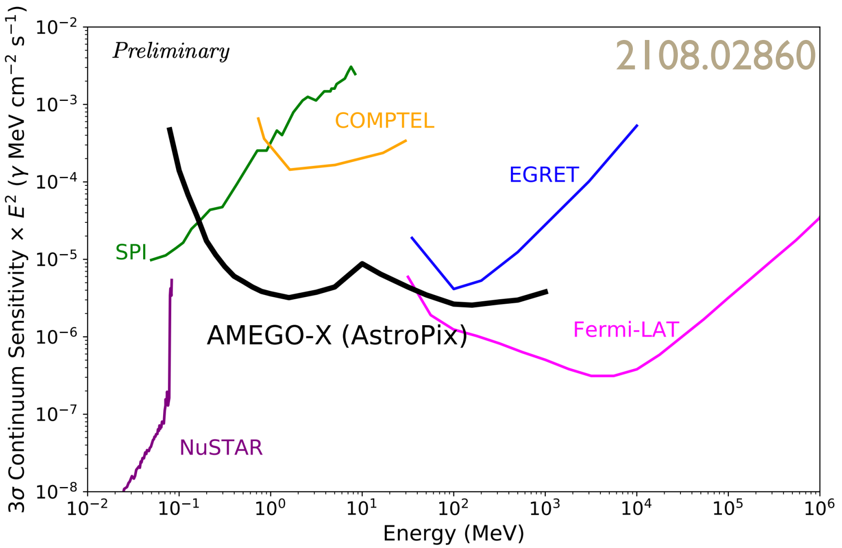
$$T_{\mathrm{BH}} = \frac{1}{8\pi G M_{\mathrm{BH}}} \sim 1\ \mathrm{MeV}\left(\frac{10^{16}\mathrm{g}}{M_{\mathrm{BH}}}\right)$$

- Asteroid-mass PBH emits MeV-scale photons

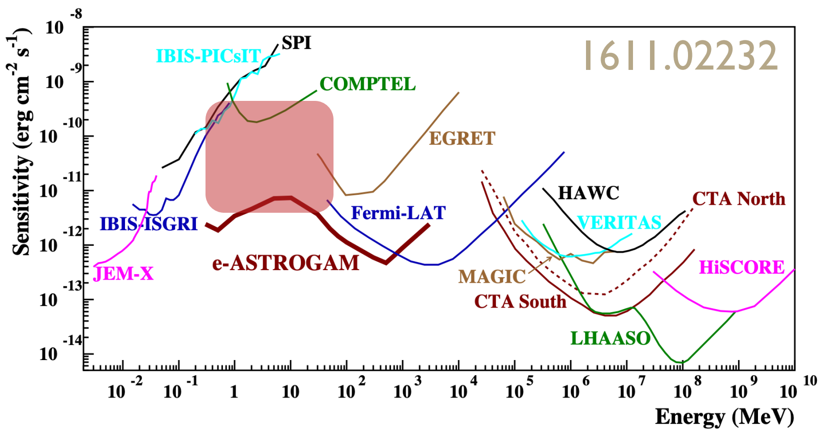
- Those photons can be detected in future gamma-ray observations

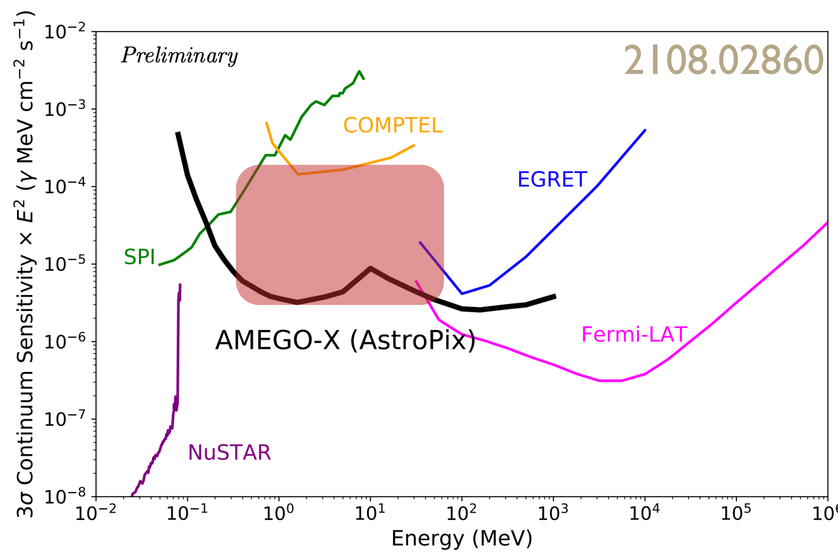
Gamma-ray signals from PBH





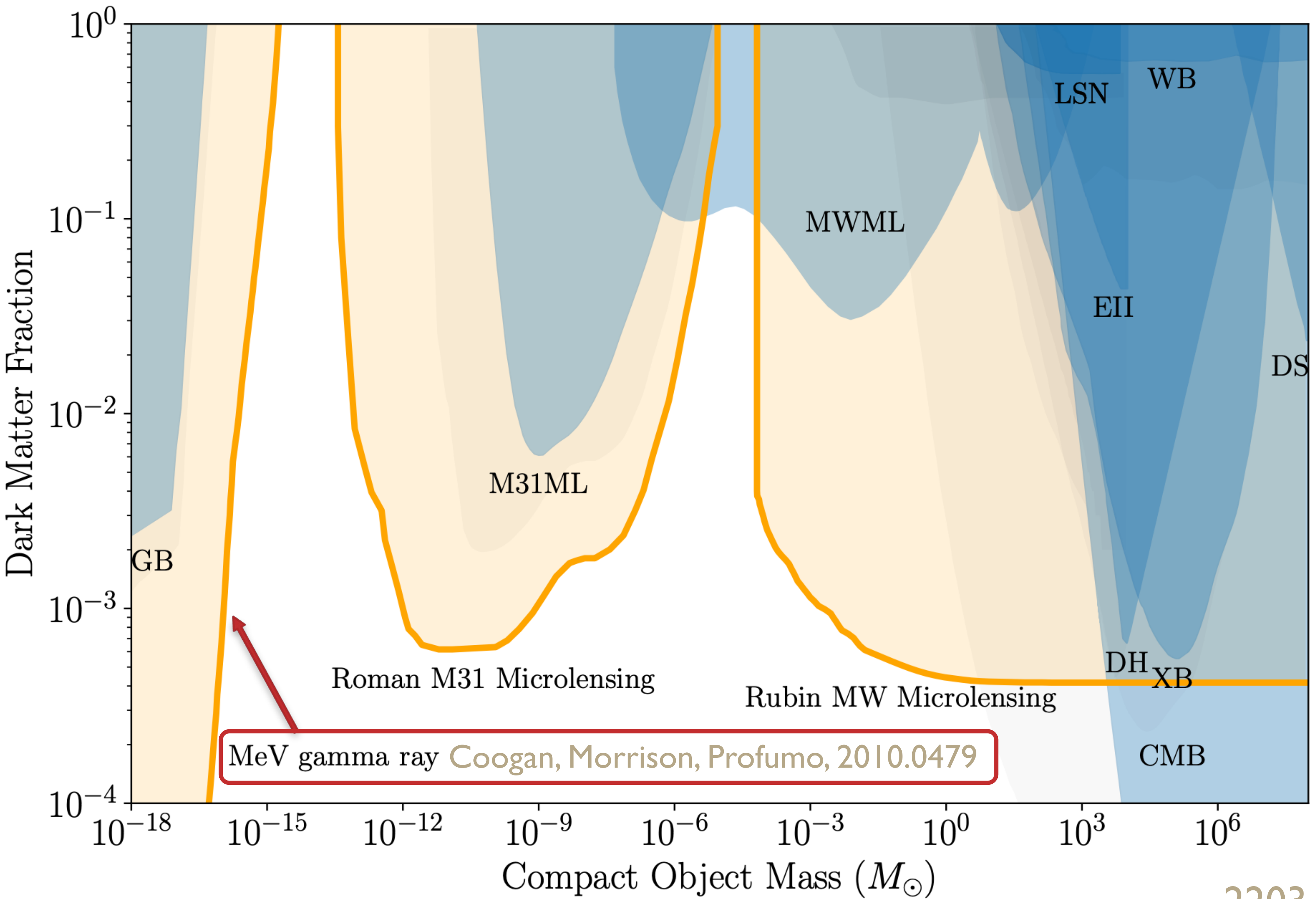
Gamma-ray signals from PBH





- Covers $0.1\ \mathrm{MeV} \lesssim E_\gamma \lesssim 100\ \mathrm{MeV}$
- Corresponds to $10^{14}\mathrm{g} \lesssim M_{\mathrm{PBH}} \lesssim 10^{17}\mathrm{g}$

PBH Constraints



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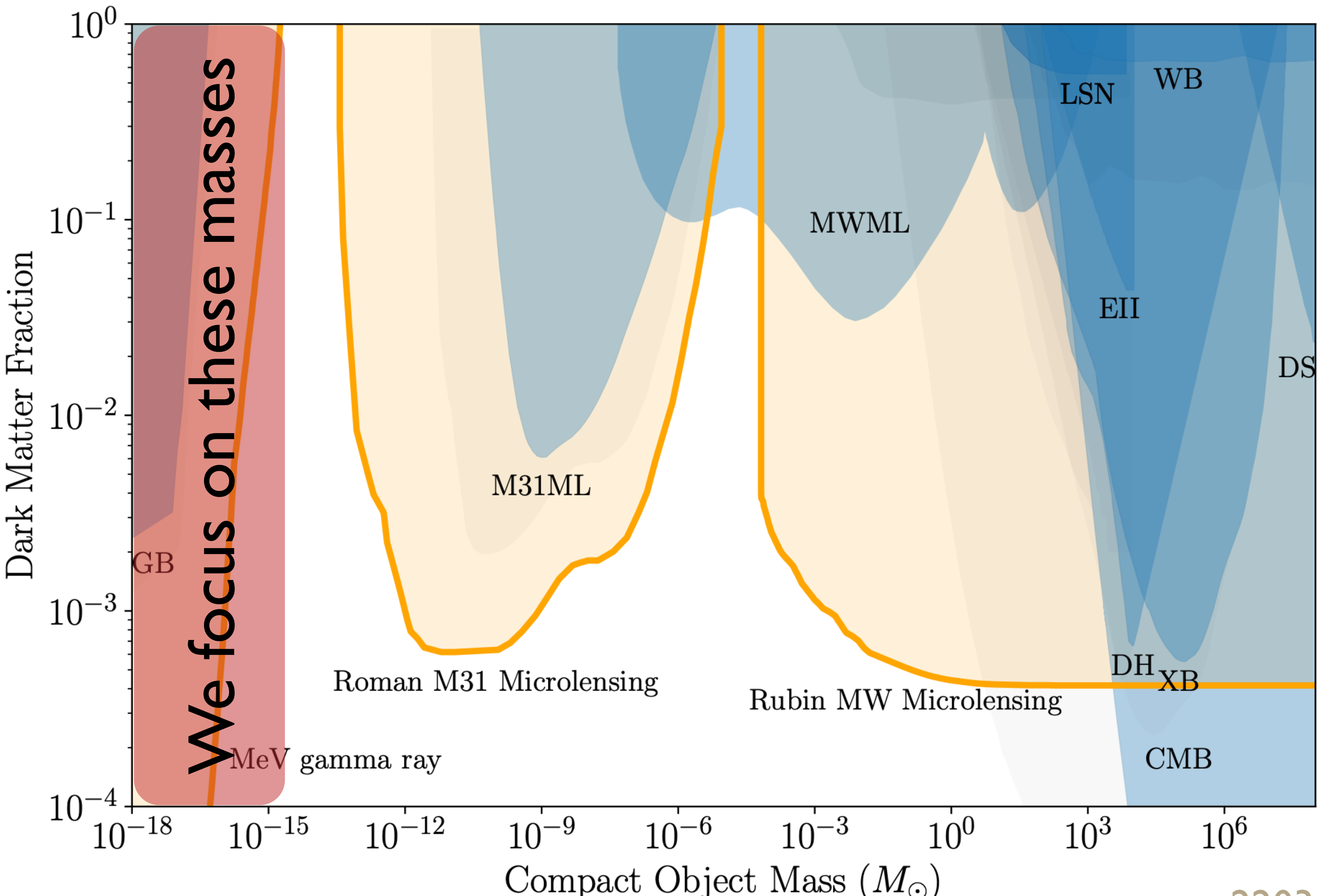
PBH Constraints



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Large Curvature Perturbations

- PBH can be produced from the collapse of Hubble patches with large perturbations
- Such large perturbations are less constrained on small scales ($k \gg 1\mathrm{Mpc}^{-1}$)
- We use Press-Schechter formalism and get

$$M_{PBH} \sim 10^{17}\mathrm{g}\left(\frac{10^{15}\mathrm{Mpc}^{-1}}{k_p}\right)^2$$

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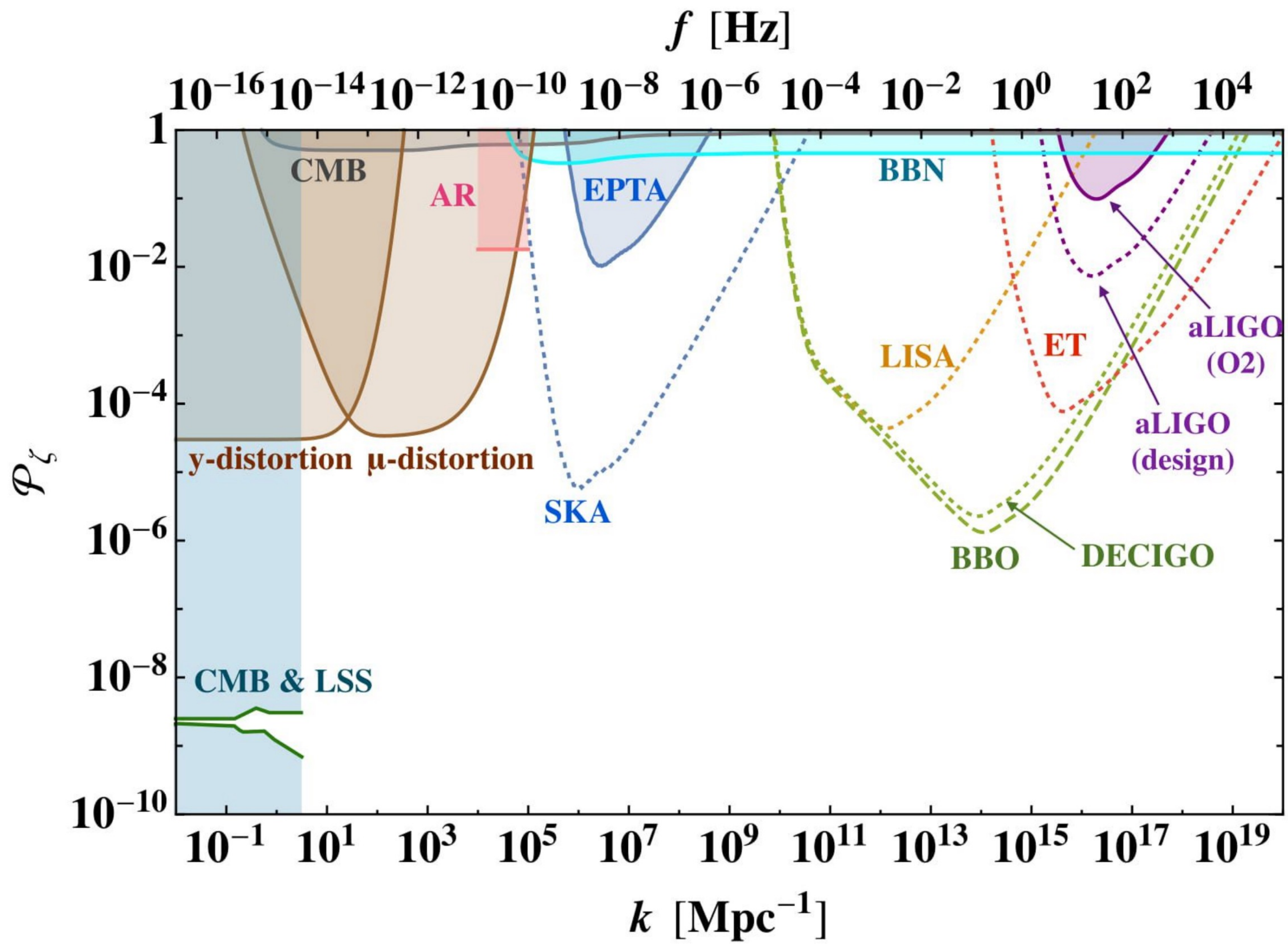
GW from curvature perturbations

- GWs are necessarily produced from the primordial curvature perturbations at second-order

- These induced GW can be large due to the large amplitude of perturbations at small-scale

- $f_{GW} \sim 1\,\mathrm{Hz}\left(\frac{10^{15}\mathrm{Mpc}^{-1}}{k_p}\right)^2$

Curvature perturbation constraints and sensitivity



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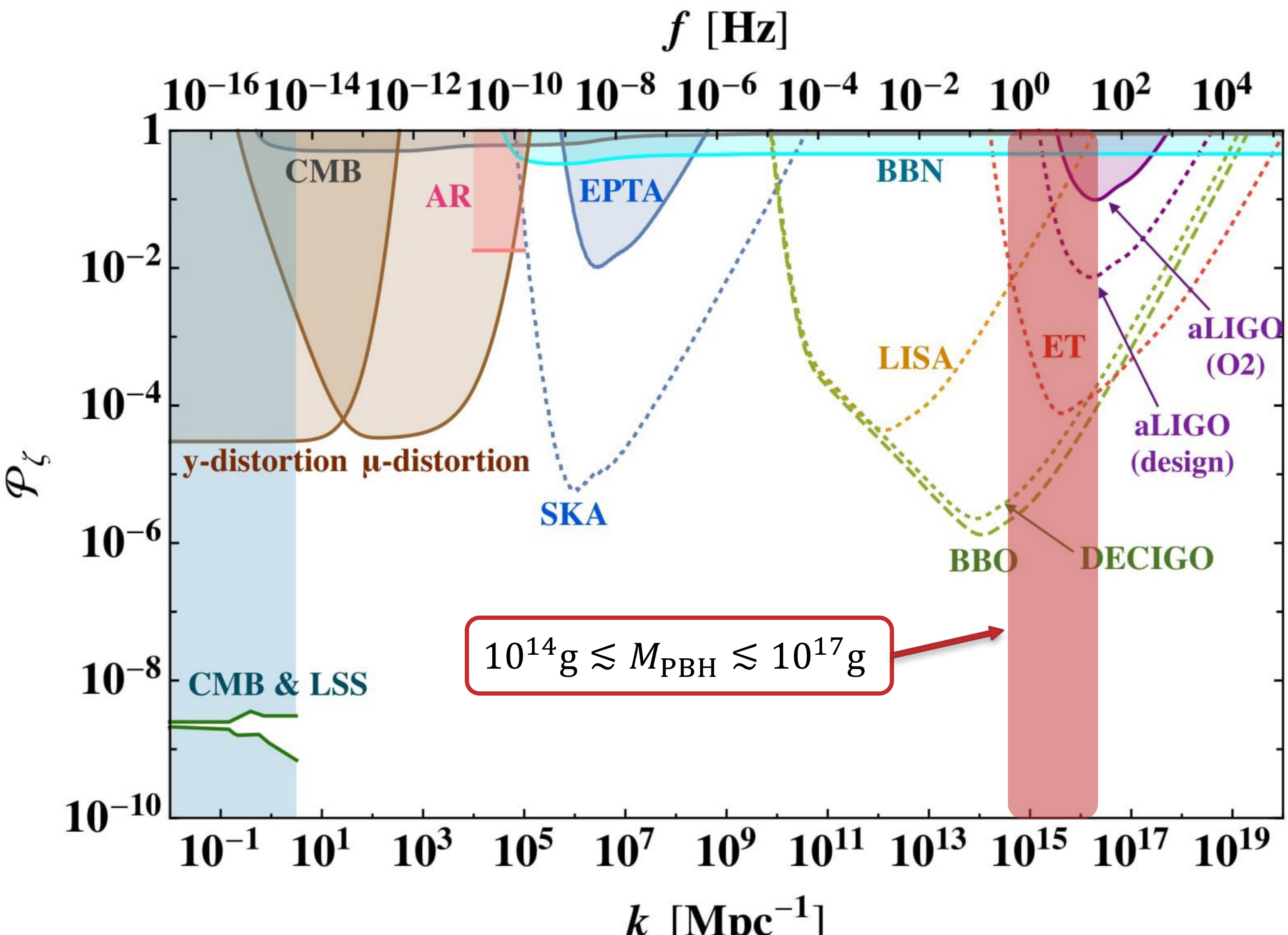
Curvature perturbation constraints and sensitivity



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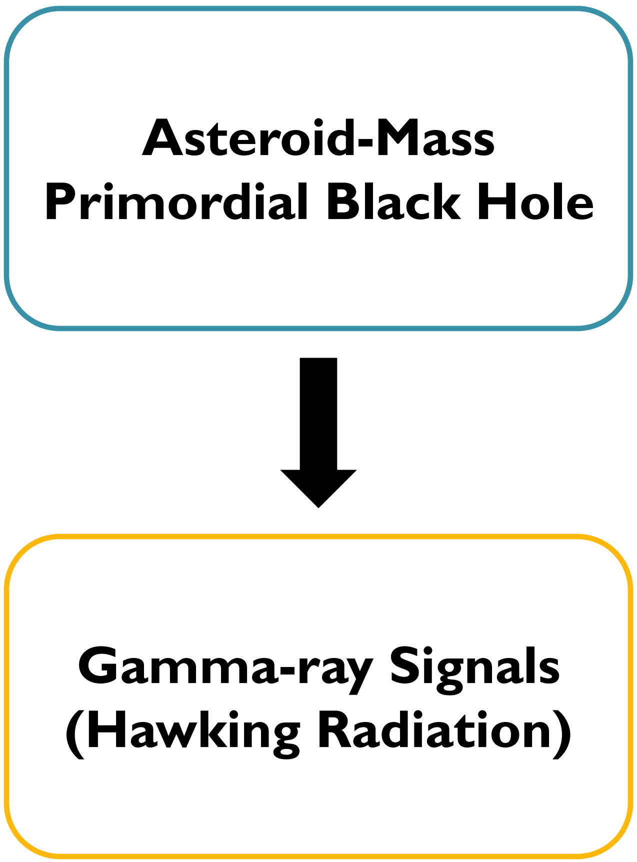
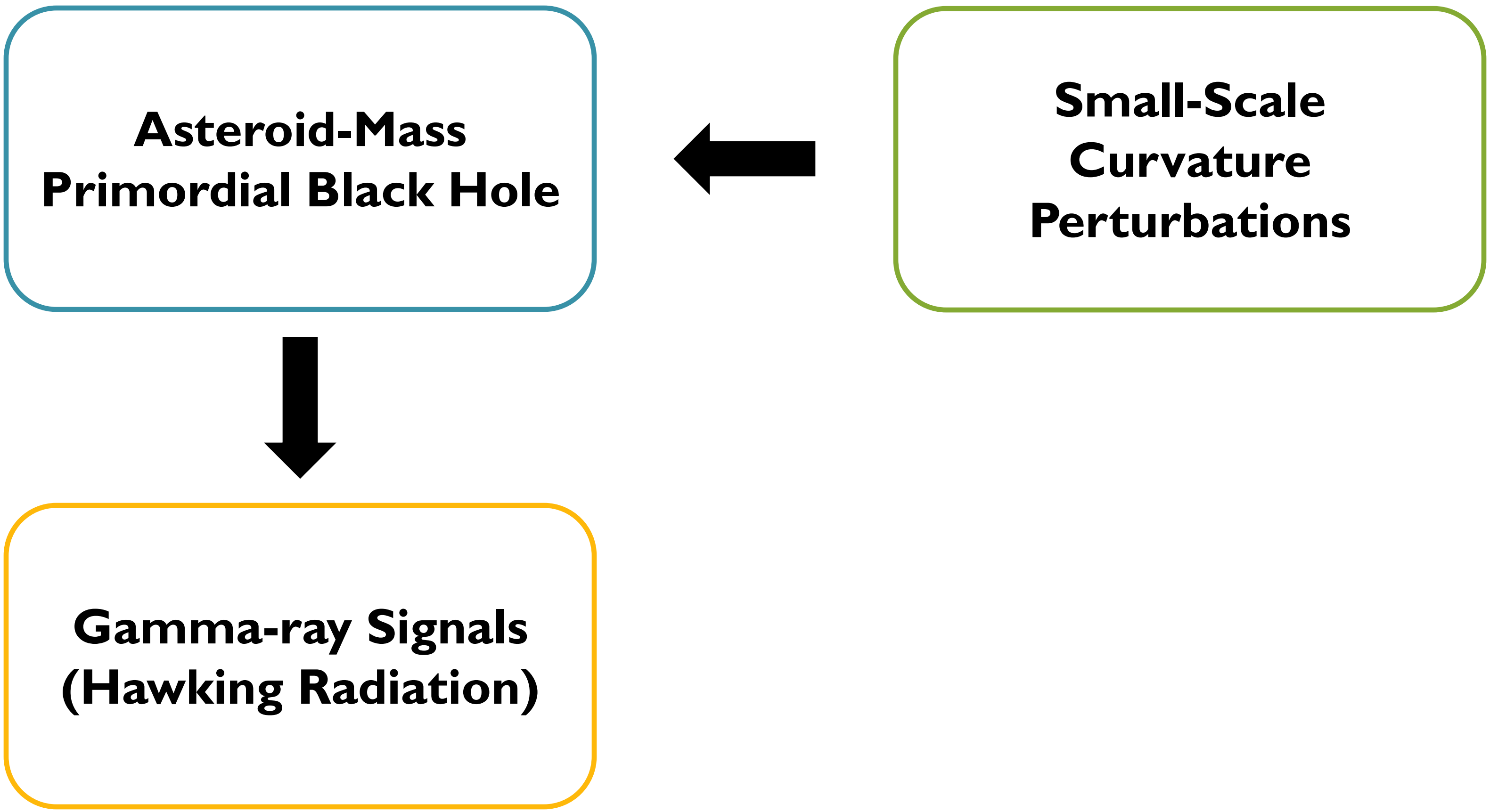
Big Picture

Asteroid-Mass Primordial Black Hole

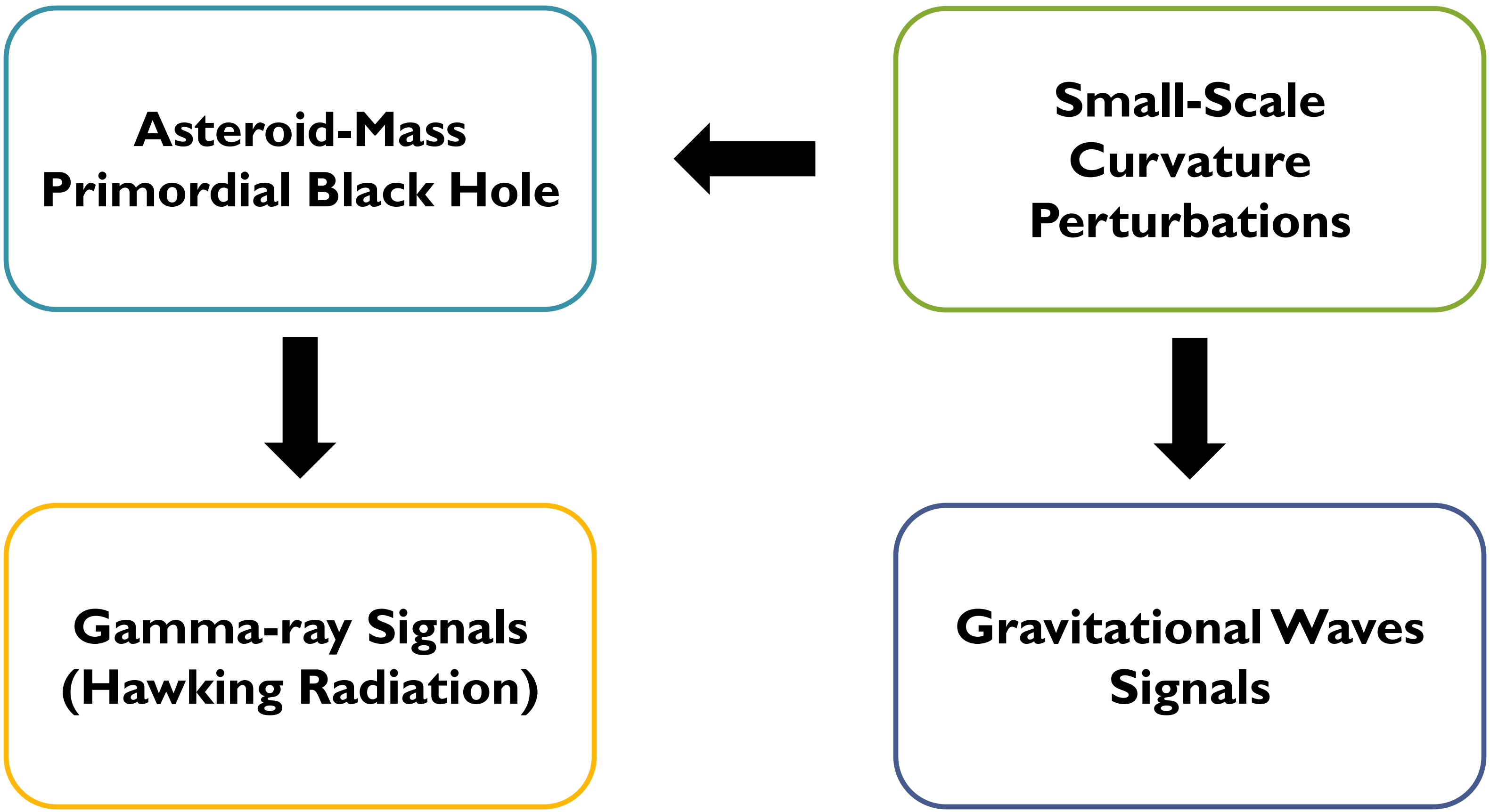
Big Picture


Asteroid-Mass
Primordial Black Hole
Gamma-ray Signals
(Hawking Radiation)

Big Picture

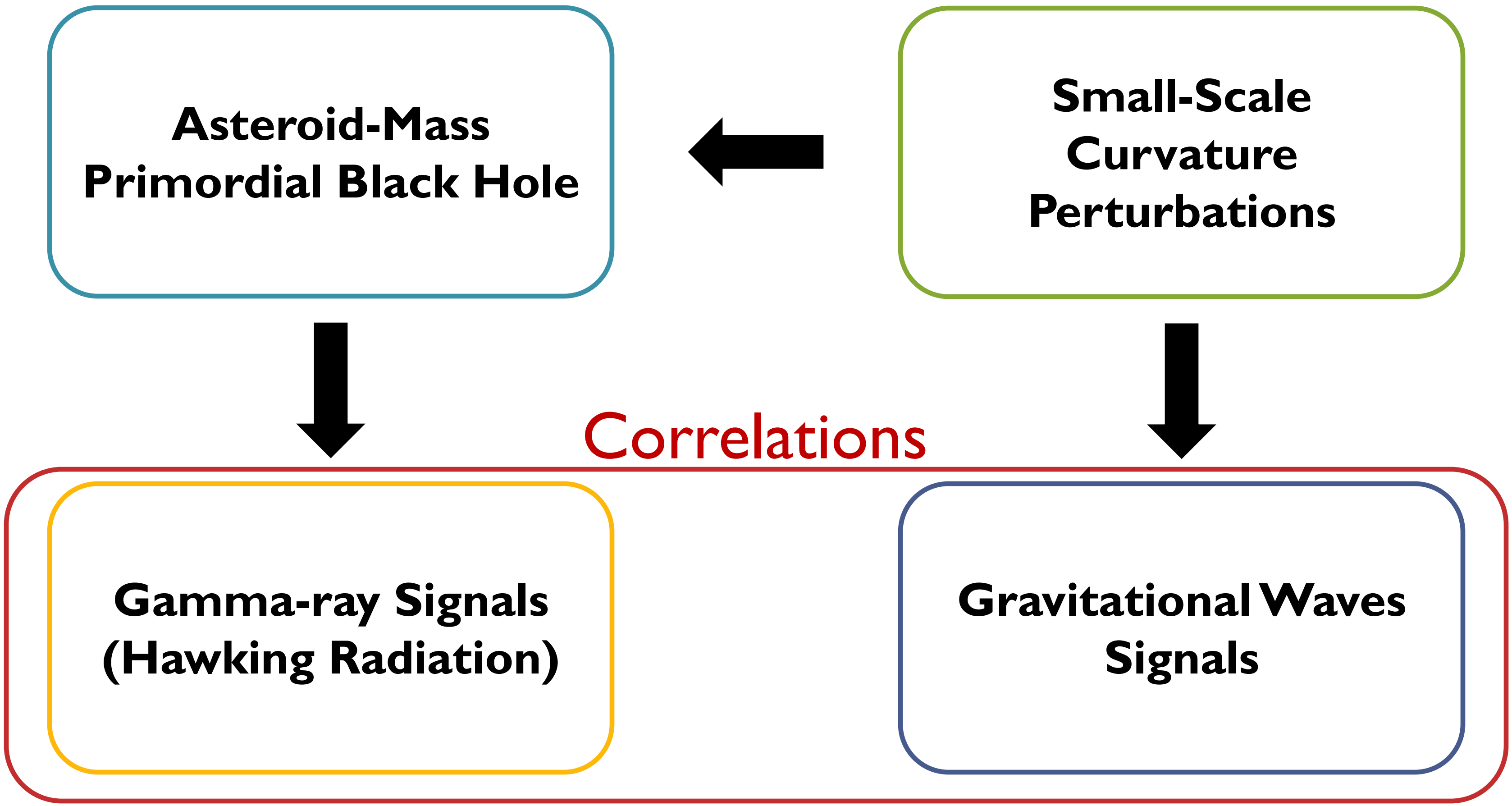

Asteroid-Mass
Primordial Black Hole
Small-Scale
Curvature
Perturbations
Gamma-ray Signals
(Hawking Radiation)

Big Picture

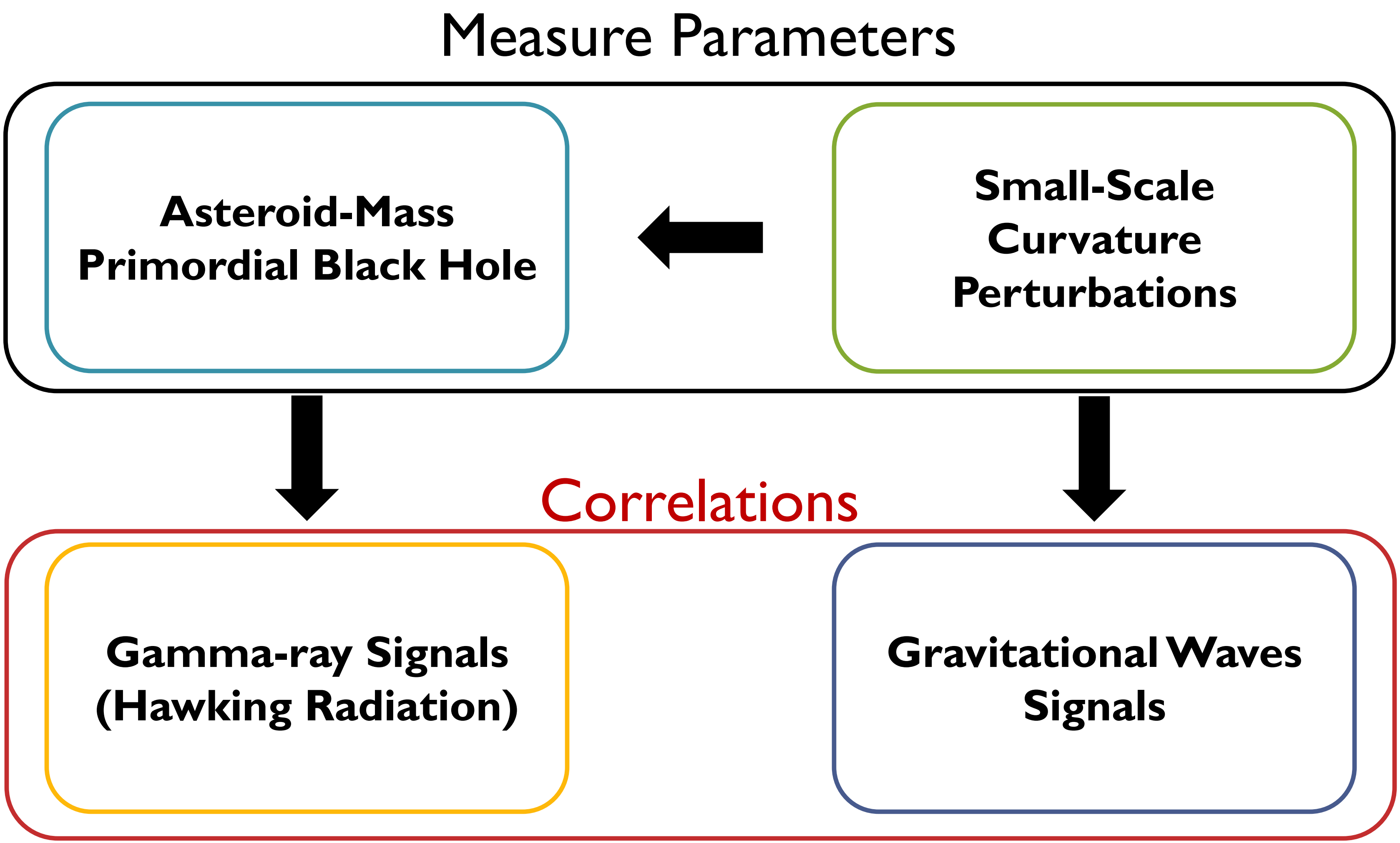


Asteroid-Mass Primordial Black Hole
Small-Scale Curvature Perturbations
Gamma-ray Signals (Hawking Radiation)
Gravitational Waves Signals

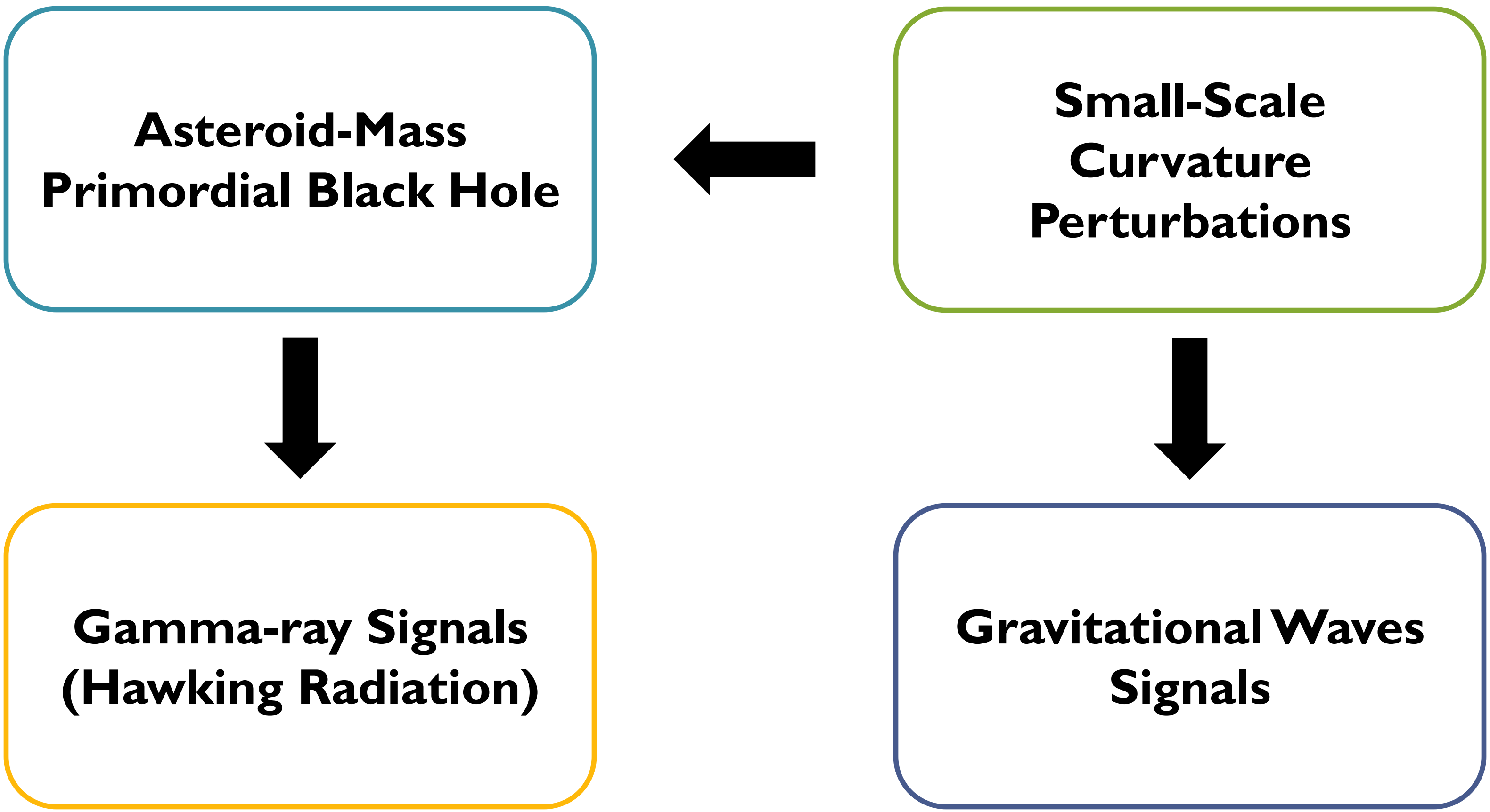
Big Picture


Asteroid-Mass Primordial Black Hole
Small-Scale Curvature Perturbations
Correlations
Gamma-ray Signals (Hawking Radiation)
Gravitational Waves Signals

Big Picture


Measure Parameters
Asteroid-Mass Primordial Black Hole
Small-Scale Curvature Perturbations
Correlations
Gamma-ray Signals (Hawking Radiation)
Gravitational Waves Signals

Big Picture


Asteroid-Mass Primordial Black Hole
Small-Scale Curvature Perturbations
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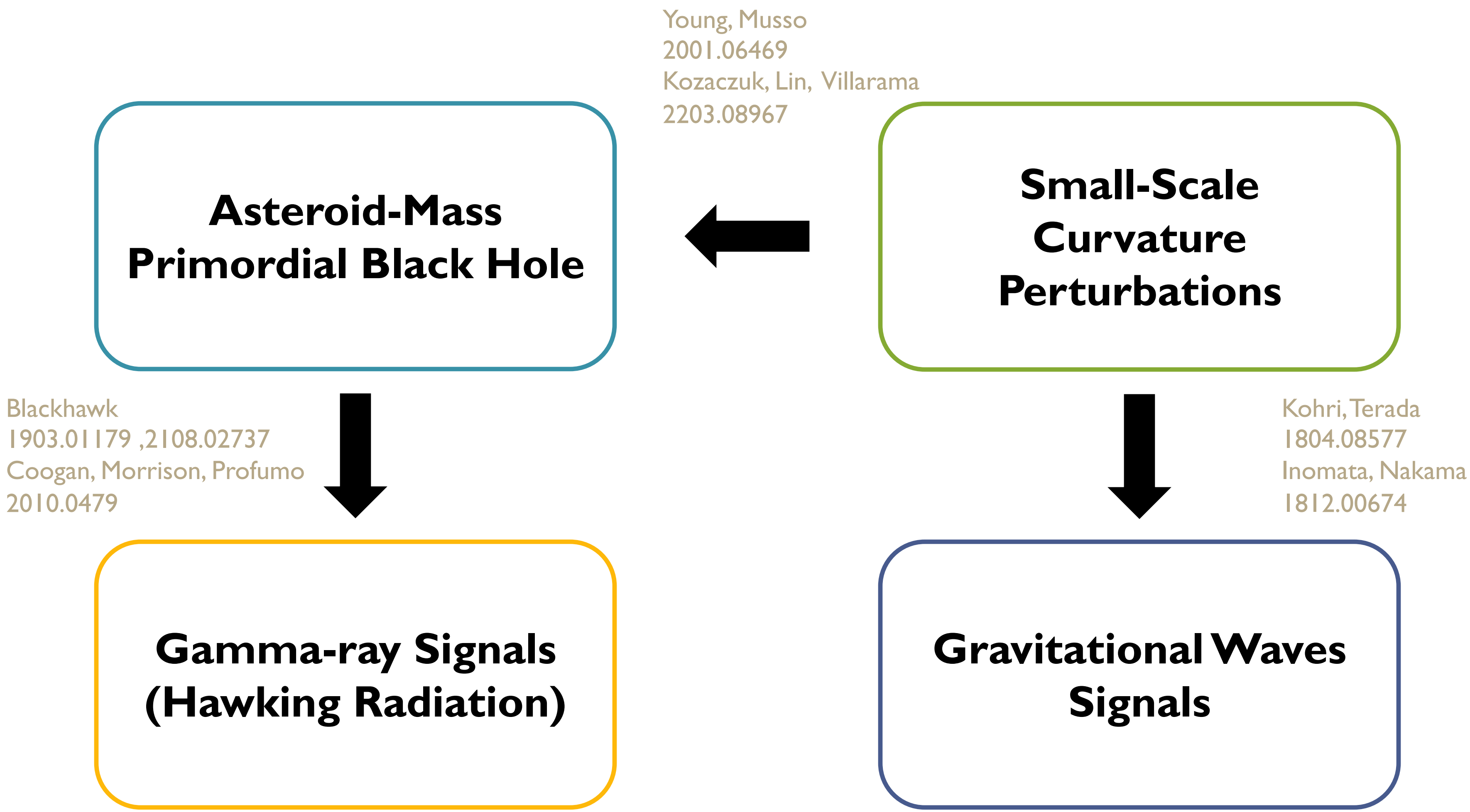
Big Picture



Young, Musso
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Asteroid-Mass Primordial Black Hole
Small-Scale Curvature Perturbations
Blackhawk
1903.01179 ,2108.02737
Coogan, Morrison, Profumo
2010.0479
Kohri, Terada
1804.08577
Inomata, Nakama
1812.00674
Gamma-ray Signals (Hawking Radiation)
Gravitational Waves Signals

ANALYSIS

Two types of curvature perturbations

- δ-function : $A_\delta \delta\left(\log\left(\frac{k}{k_p}\right)\right)$

- Log-normal : $\frac{A}{\sqrt{2\pi\sigma}} \exp\left(-\frac{\left(\log k - \log k_p\right)^2}{2\sigma^2}\right)$

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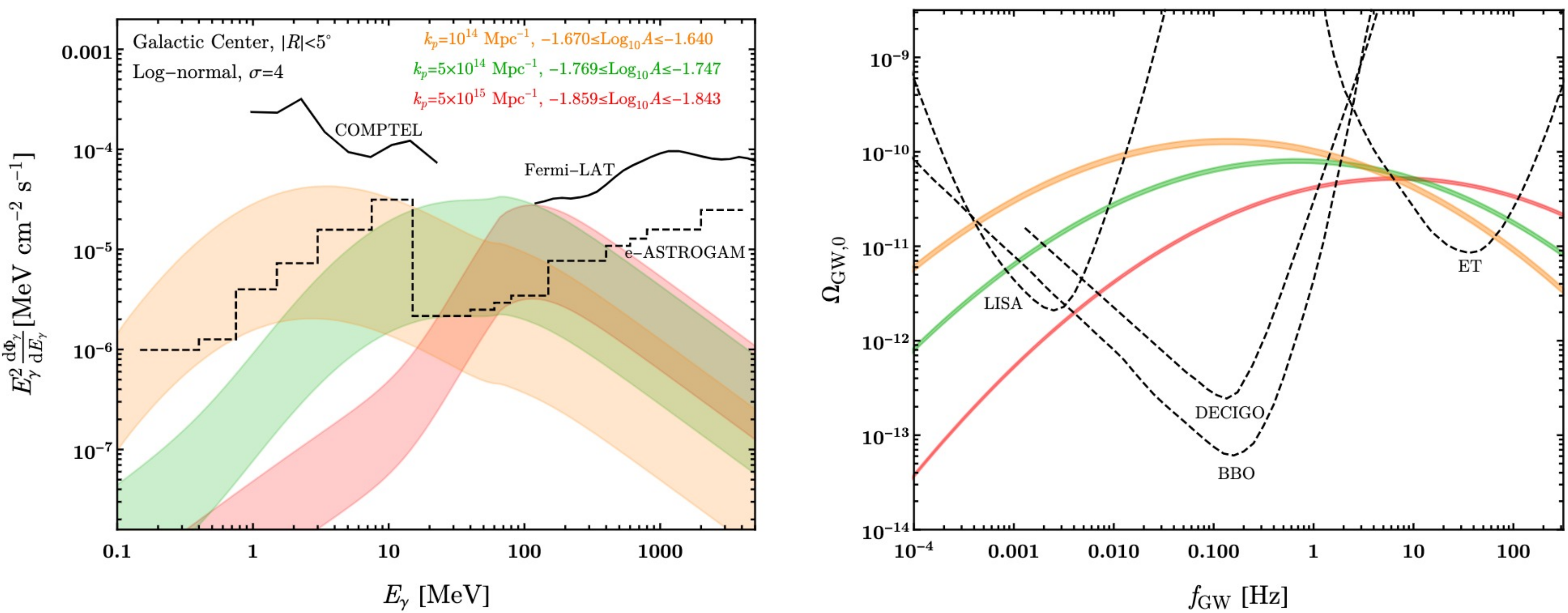
Free parameters : A, σ, k_p

Correlations between gamma-ray and GW signals



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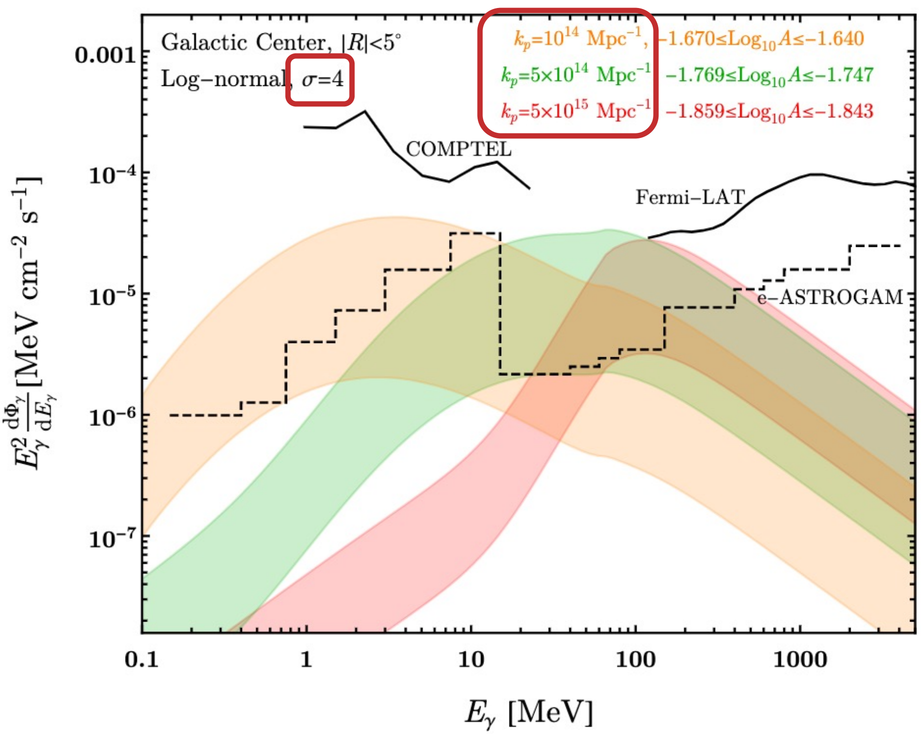

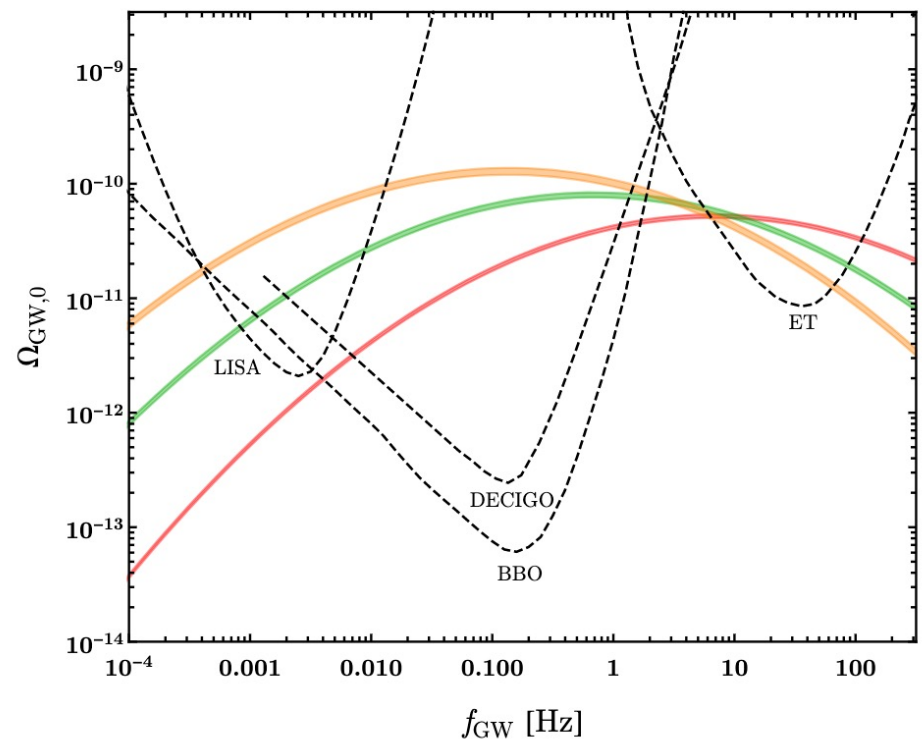

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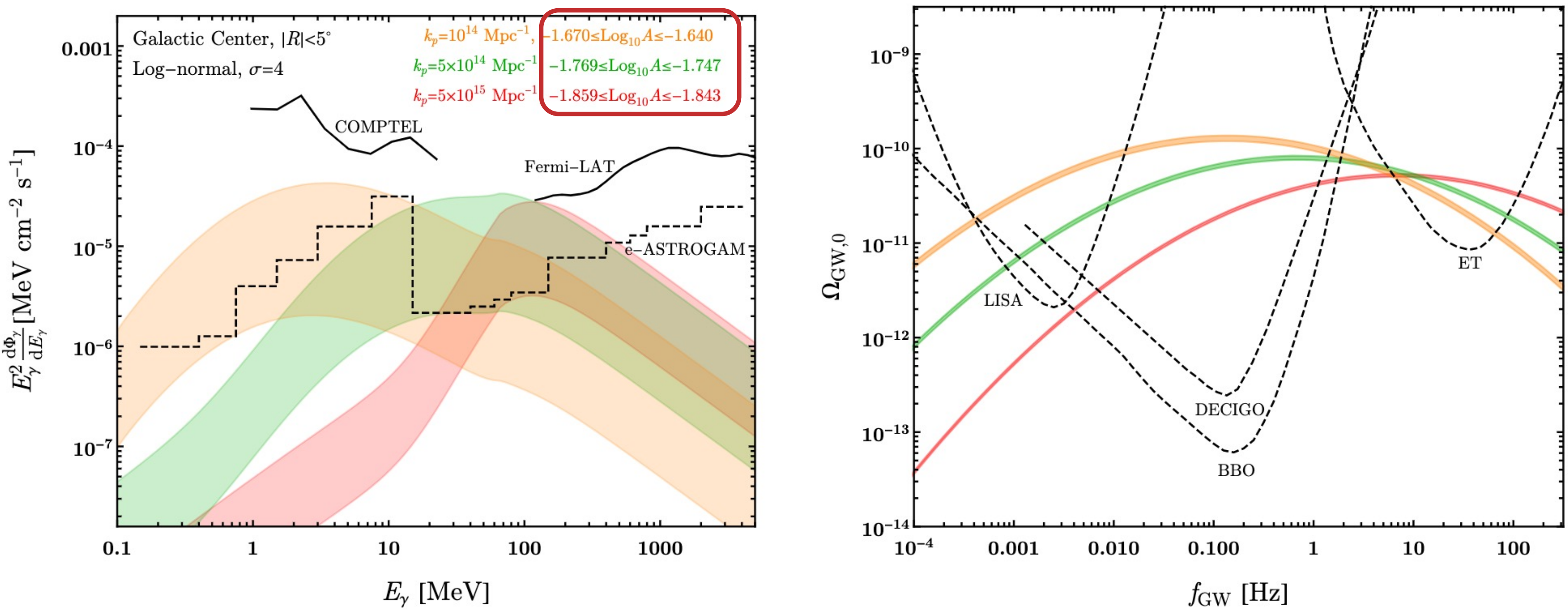
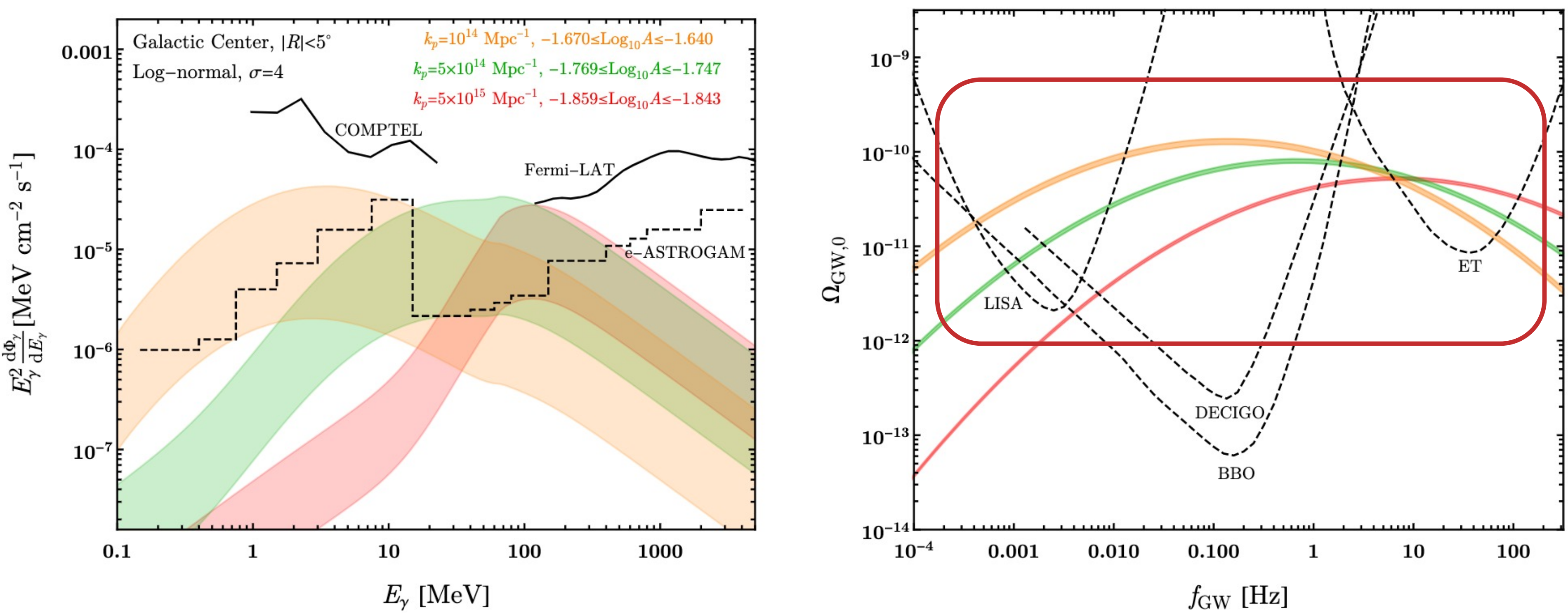


- Upper bound for A : Existing bounds (Gamma-ray, $f_{\mathrm{PBH}} \leq 1$)
- Lower bound for A : Above e-Astrogam Sensitivity

Correlations between gamma-ray and GW signals



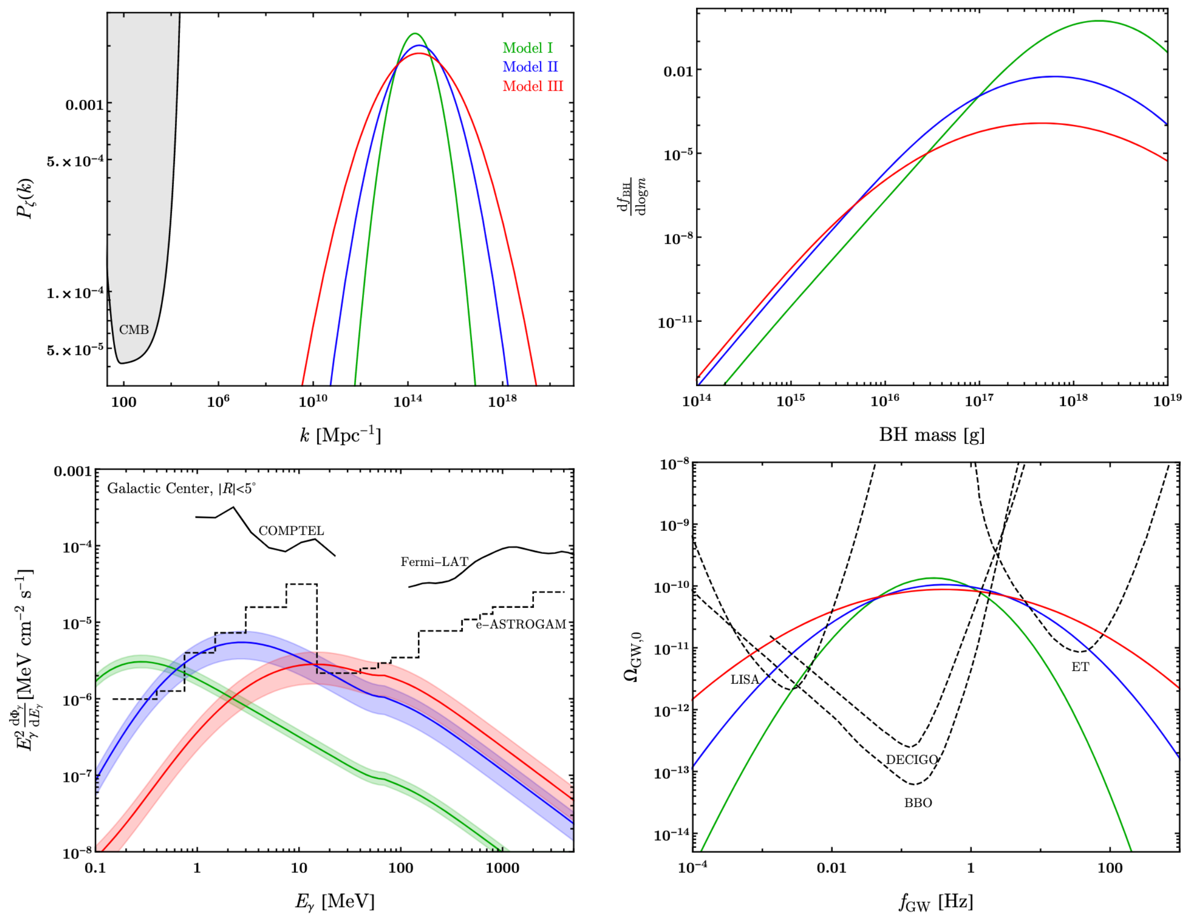
- For the $P_\zeta(k)$ that gives visible gamma-ray signal, the companion GW signals are within the future GW experiments sensitivities!

Question:

How well can we measure the three $P_\zeta(k)$ parameters?

Three examples of $P_\zeta(k)$

Model	σ	k_p [Mpc^{-1}]	$\log_{10} A$	$A(2\pi\sigma^2)^{-\frac{1}{2}}$	$f_{\rm BH,total}$	$m^{\rm peak}$ [g]	σ_m	$\gamma_{\rm eff}$
I	2	2×10^{14}	-1.933	2.327×10^{-3}	1.0	1.8×10^{18}	0.76	3.6
II	3	3×10^{14}	-1.820	2.013×10^{-3}	1.4×10^{-2}	6.1×10^{17}	1.0	2.8
III	4	3×10^{14}	-1.737	1.827×10^{-3}	3.7×10^{-4}	4.5×10^{17}	1.2	2.0



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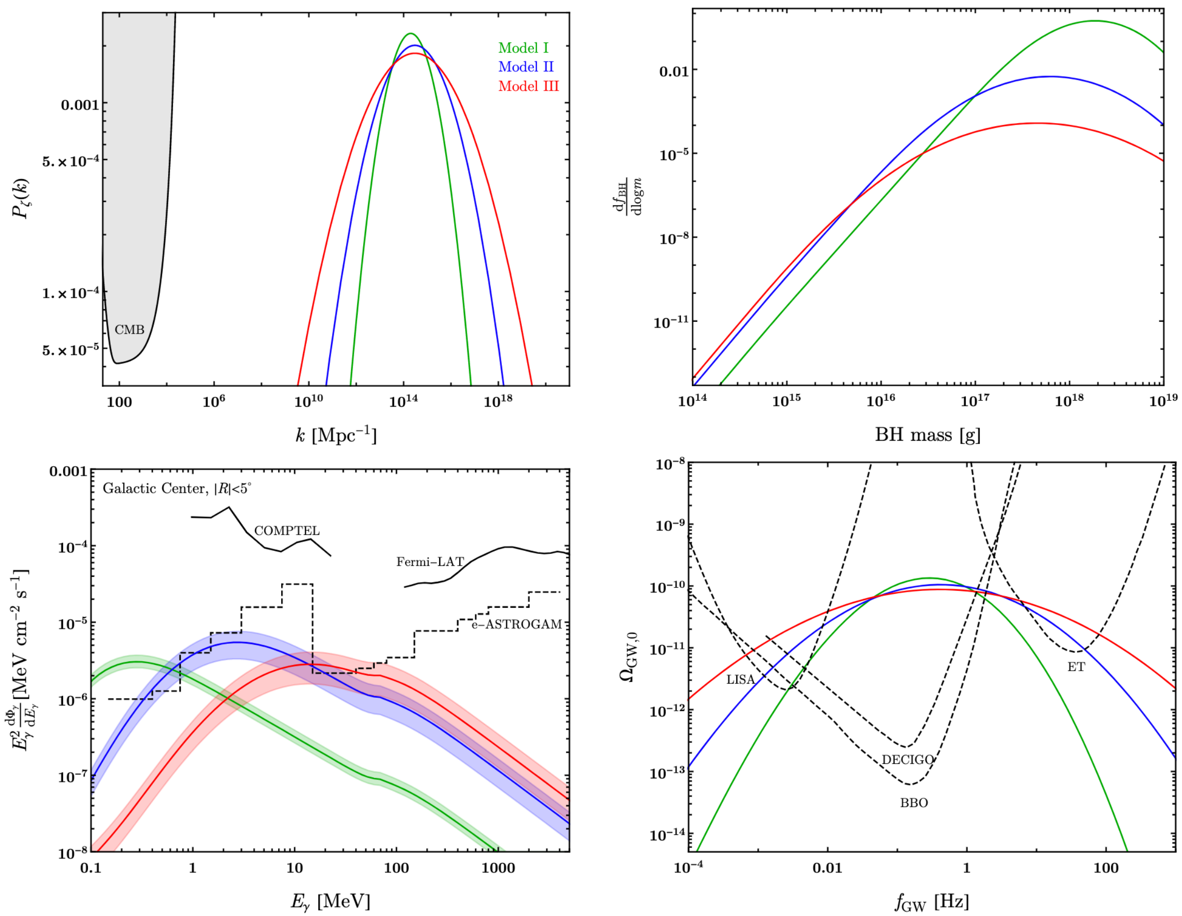
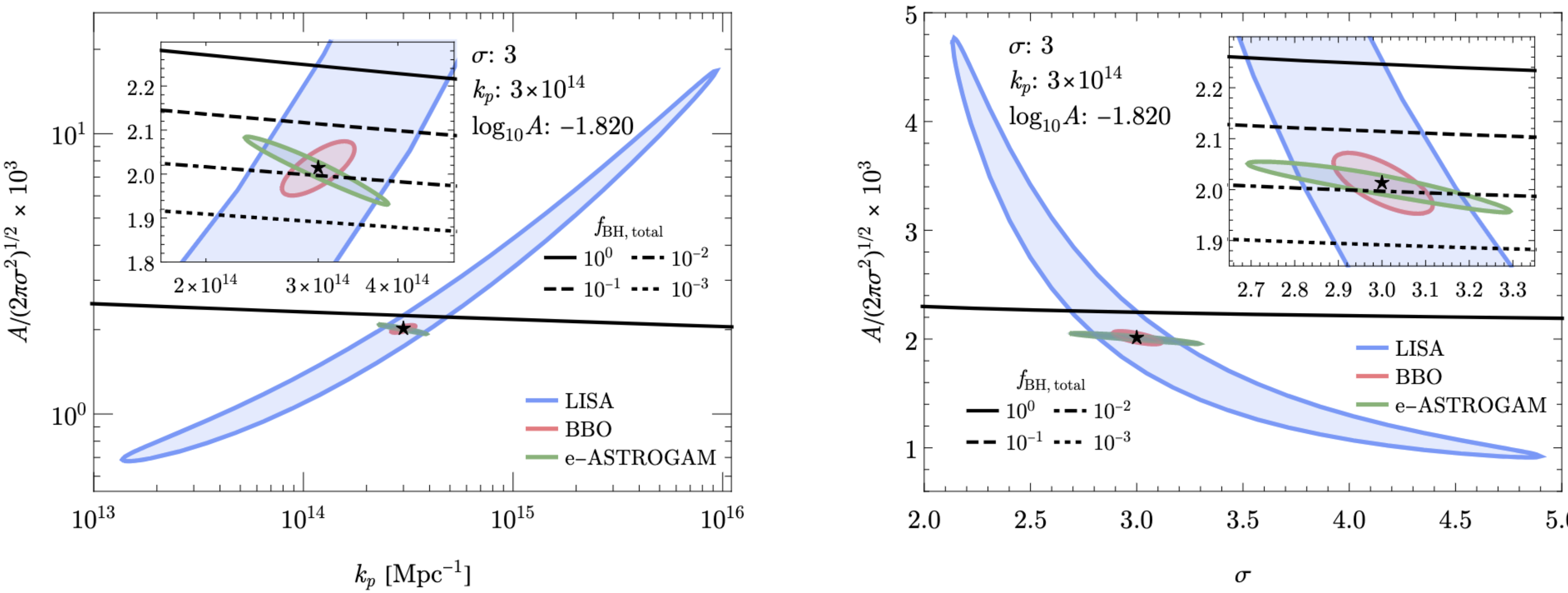


Likelihood Analysis for Model II



- The 2σ contours for each experiment assuming the log-normal curvature perturbation in case of Model II
- Thanks to the anti-correlation between the two data-sets, we can measure $P_{\zeta(k)}$ parameters very precisely

CONCLUSIONS

Conclusions

- If we get to see the Hawking radiation at e-ASTROGAM from primordial black holes produced by curvature perturbations, we will see the GW signal produced by the same perturbations at future GW detectors

- This leads to a smoking gun signal for distinguishing the PBH from other gamma-ray sources

- Correlating the gamma-ray and GW signals allows a precise measurement of the primordial curvature power spectrum

Future Work

- If we observe gamma-rays from asteroid-mass PBHs, from the photon spectrum we can tell the existence of a dark sector particle that decays or annihilates to photons

- Asteroid-mass PBH is a good source to look for dark sector

THANK YOU