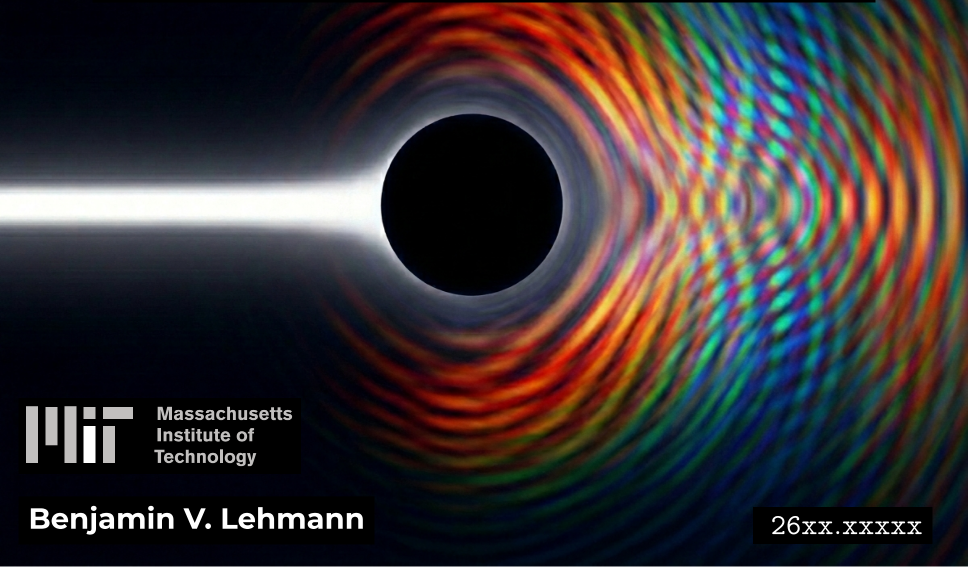
X-ray femtolensing probes asteroid-mass black holes



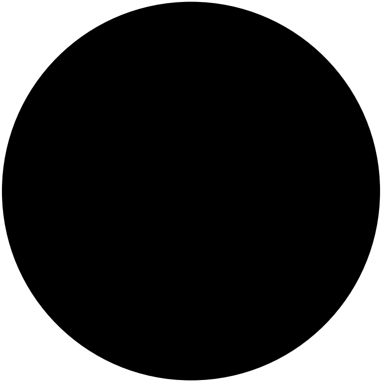
Massachusetts Institute of Technology

Benjamin V. Lehmann

26xx.xxxxx

Is dark matter black holes?

The minimal DM candidate



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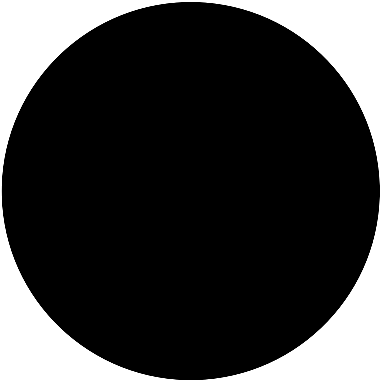

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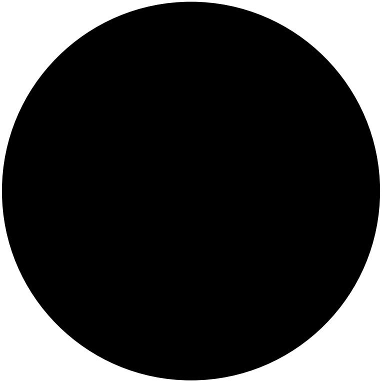

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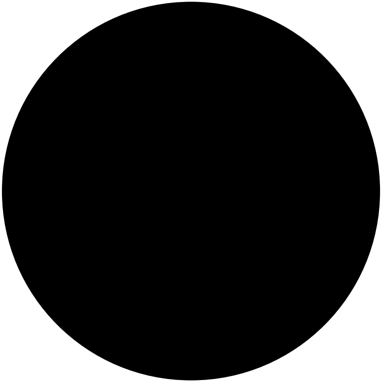

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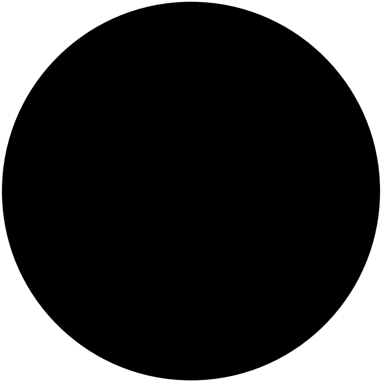

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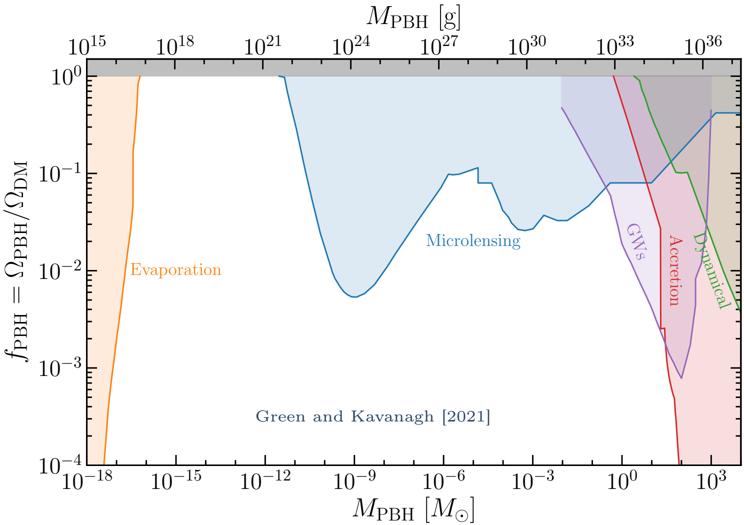
(and a proxy for granular DM, but not for this talk)

Primordial black holes as DM



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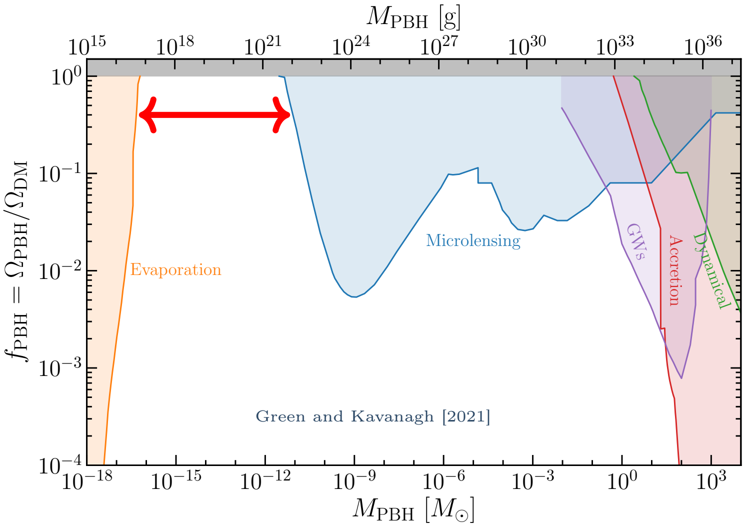

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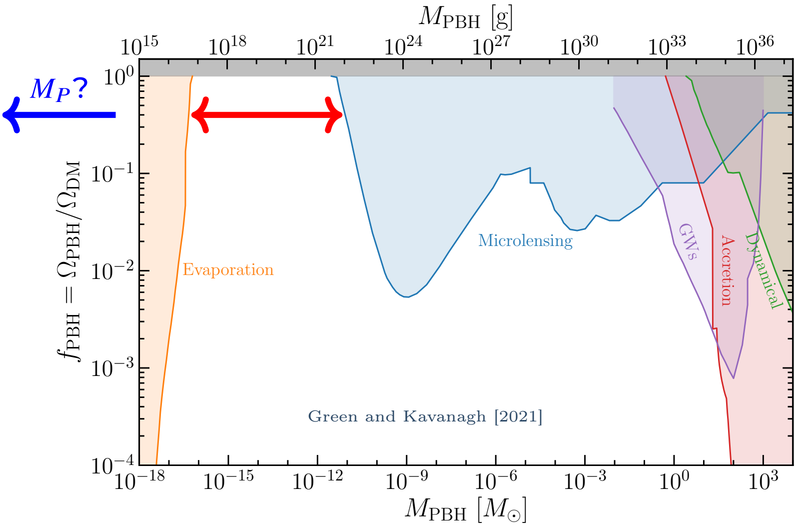

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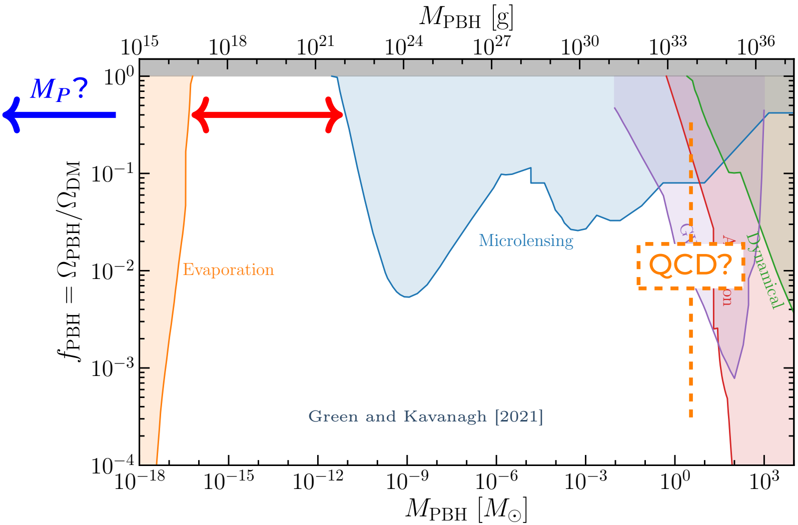

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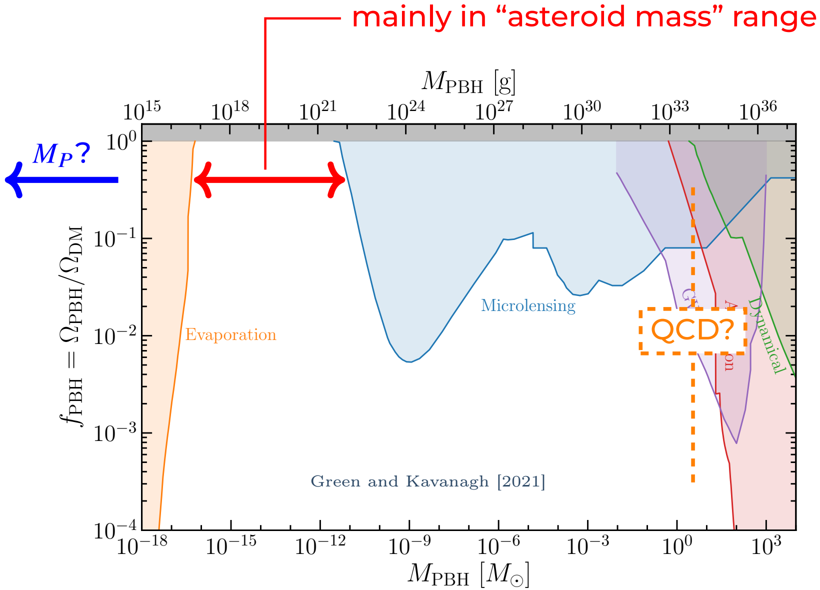
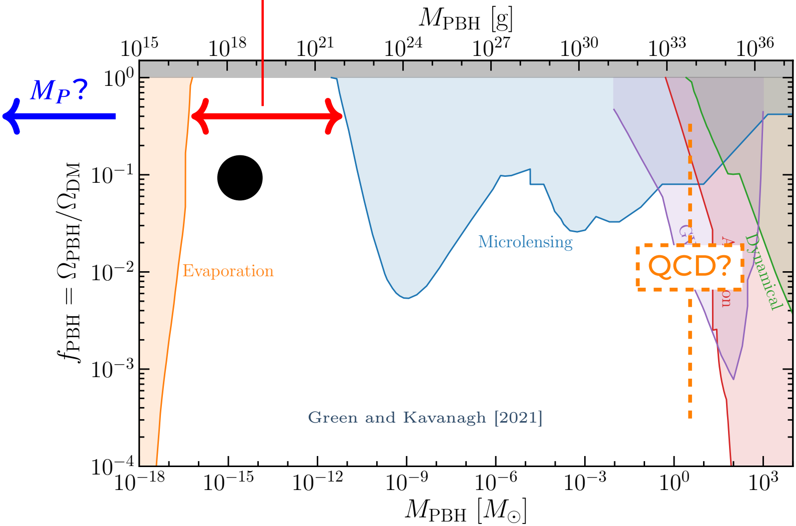


Primordial black holes as DM

mainly in "asteroid mass" range



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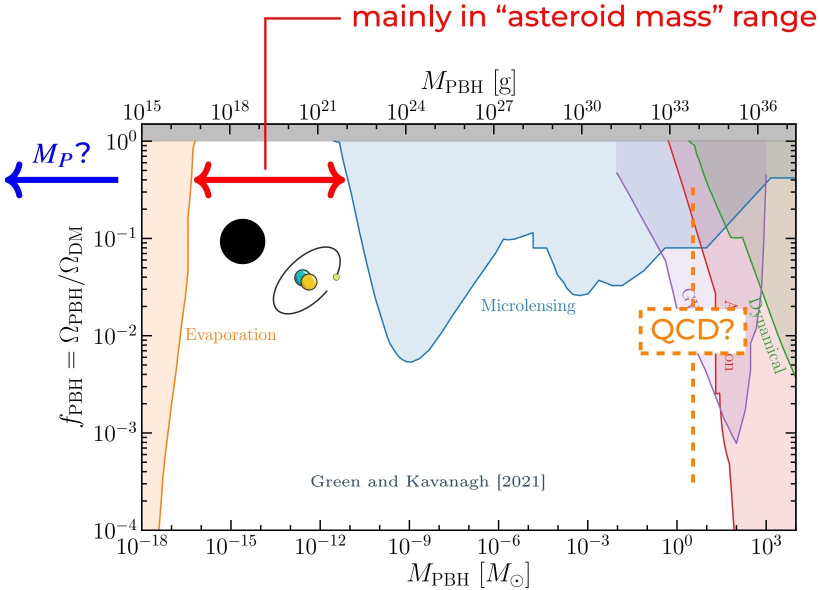

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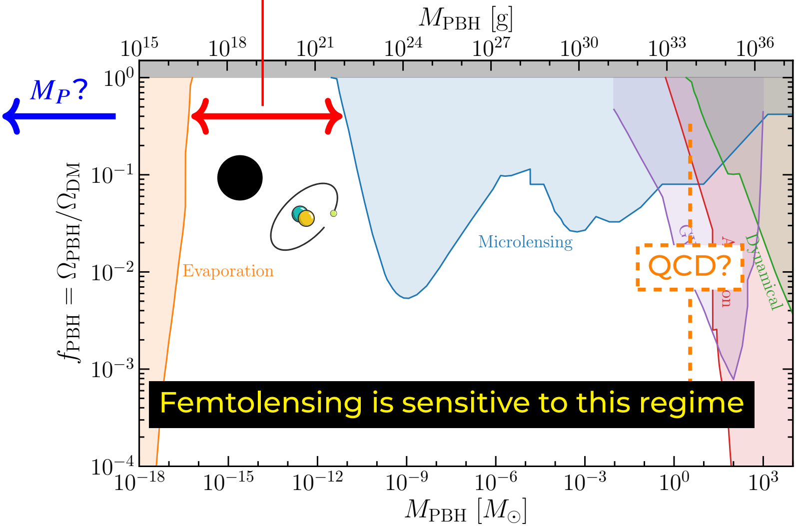
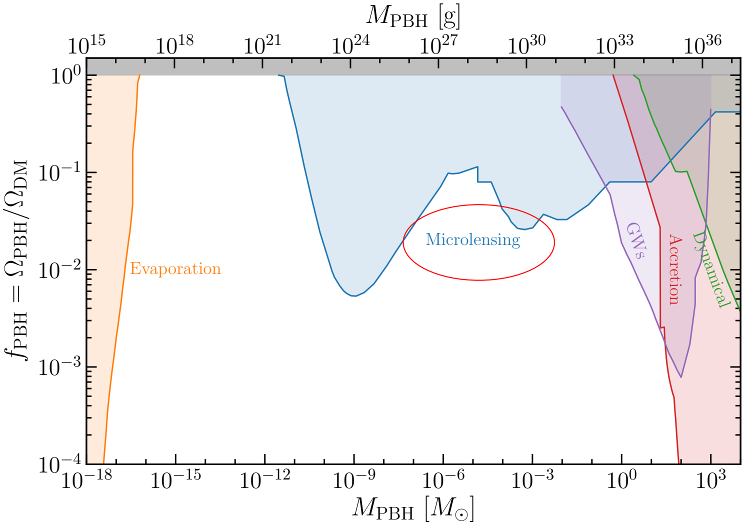


Microlensing



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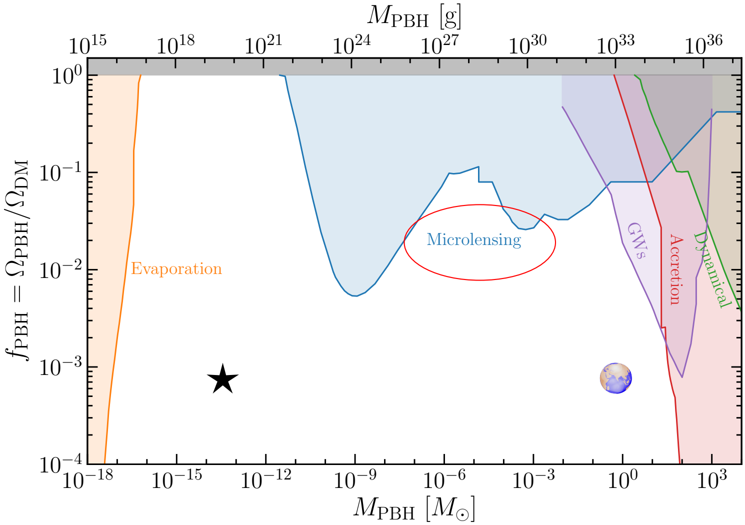

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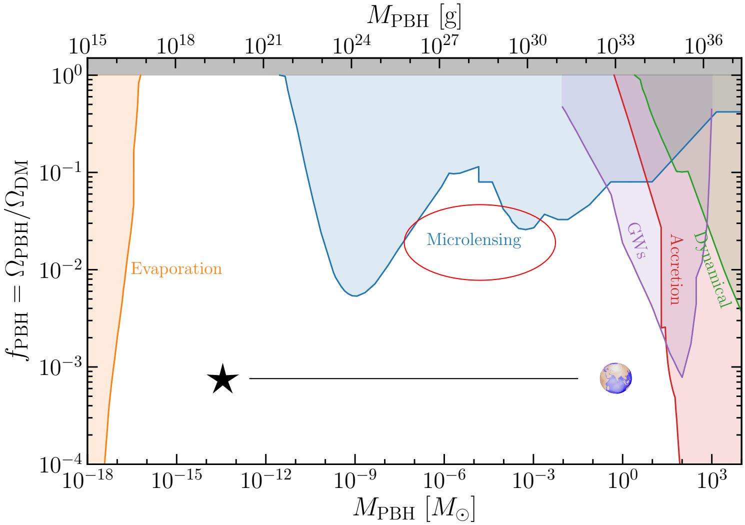

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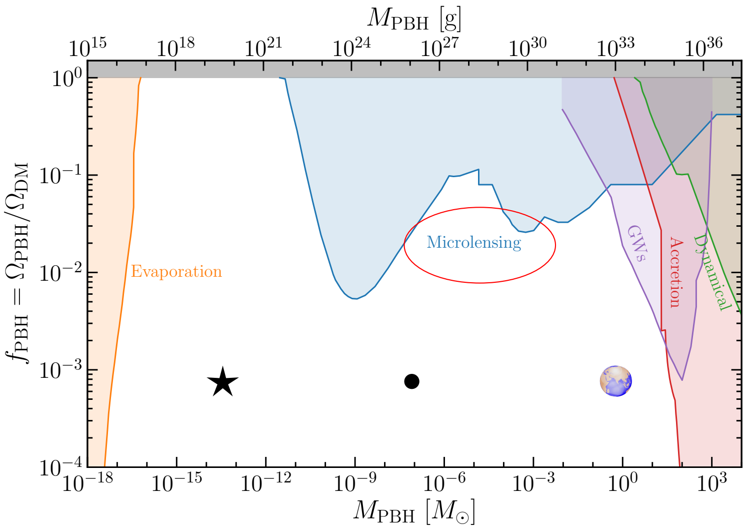

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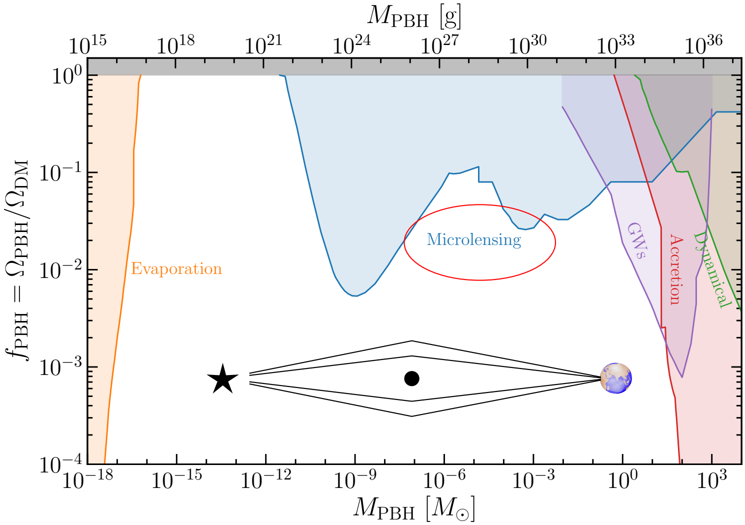

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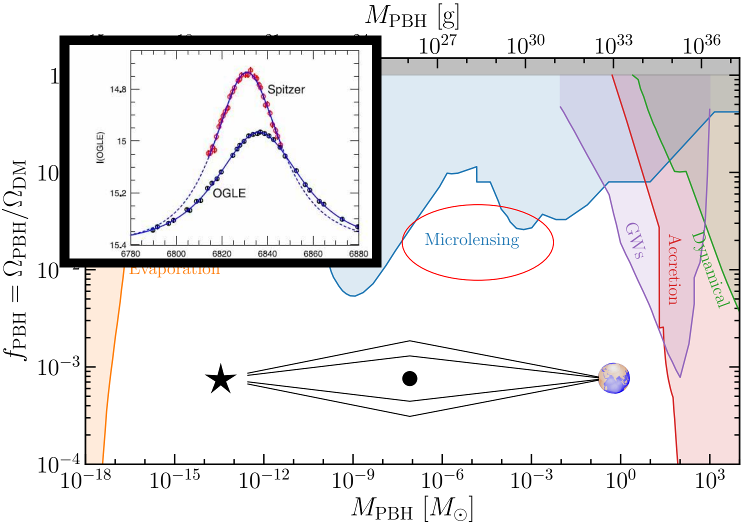

Why isn't microlensing enough?

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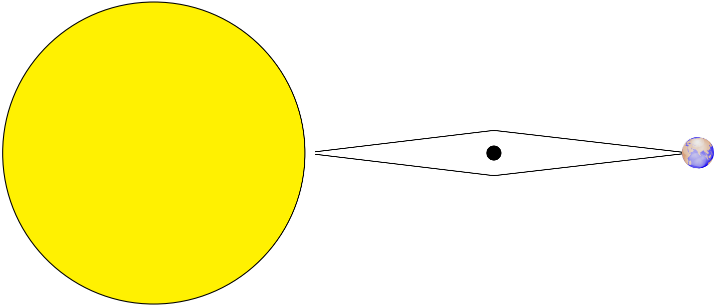

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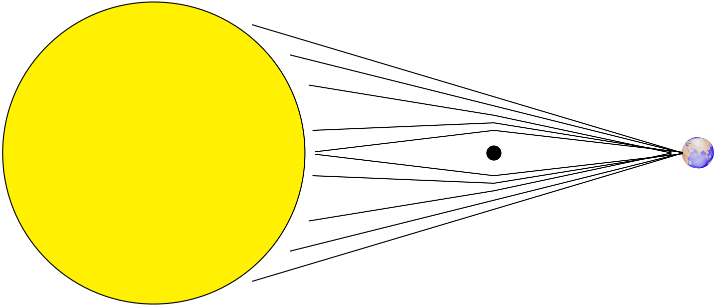

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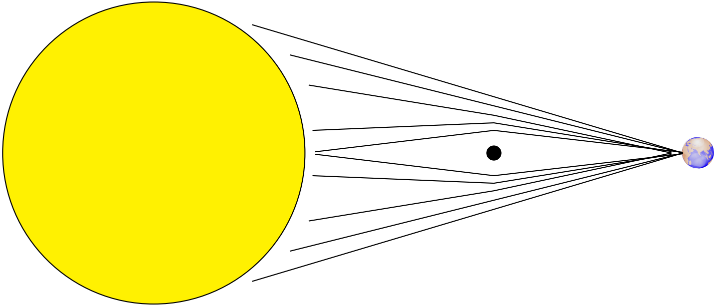

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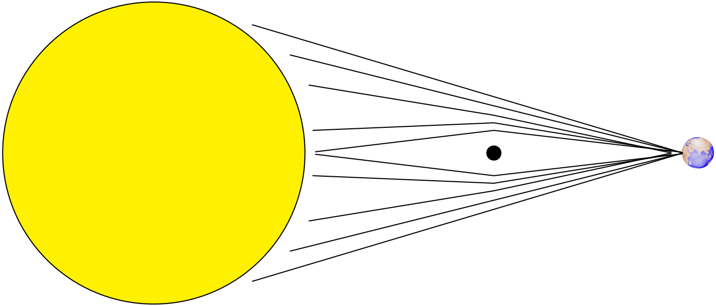

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X-ray microlensing

Shorter wavelengths, smaller sources

Tamta+ 2405.20365

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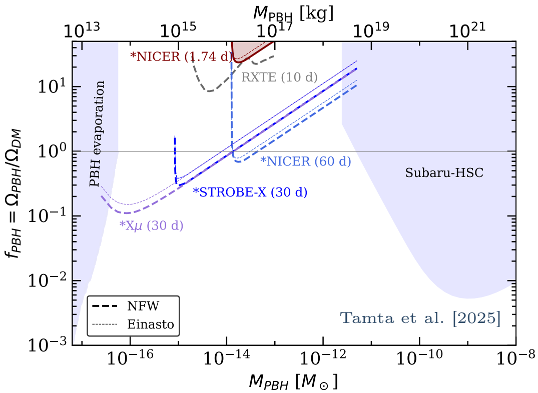

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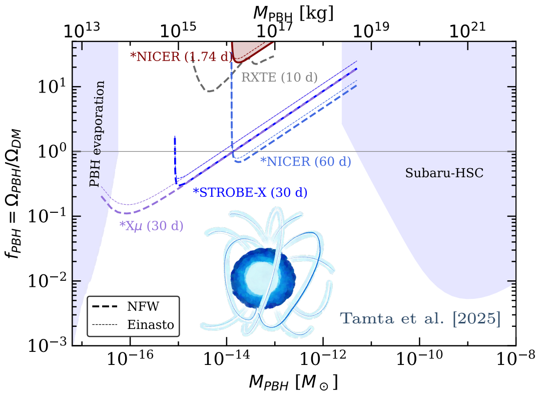

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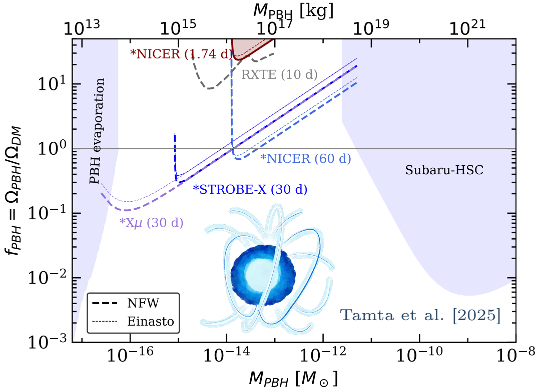
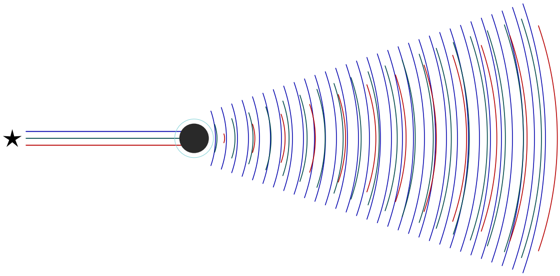


Still impractical due to intrinsic source variability

Tamta+ 2405.20365

Interference maxima are **spatially separated** by color



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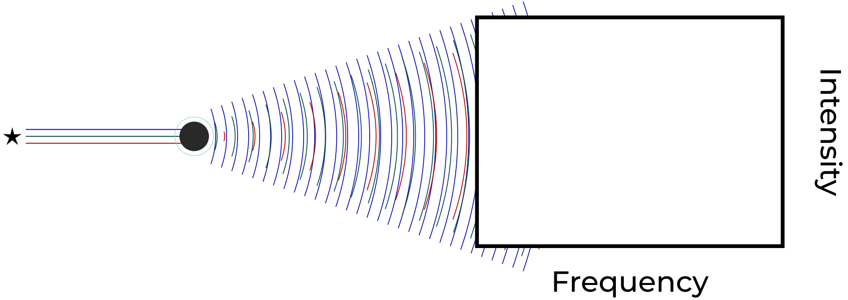

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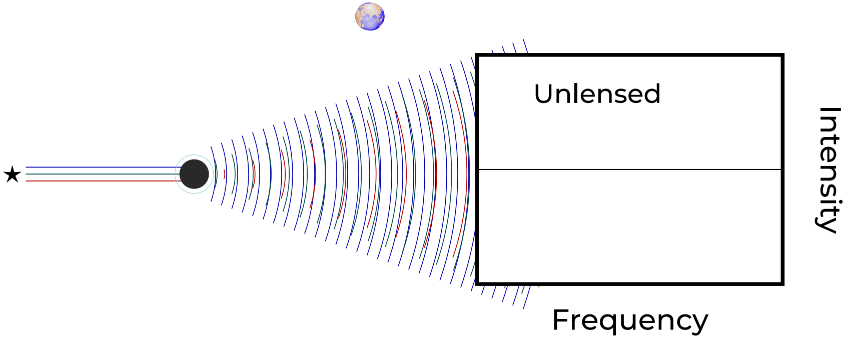

*Femto*lensing

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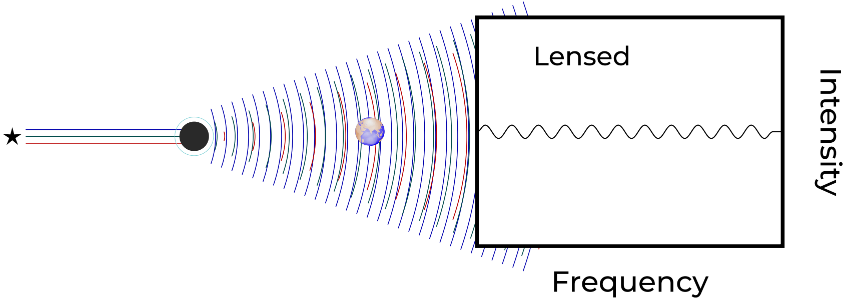

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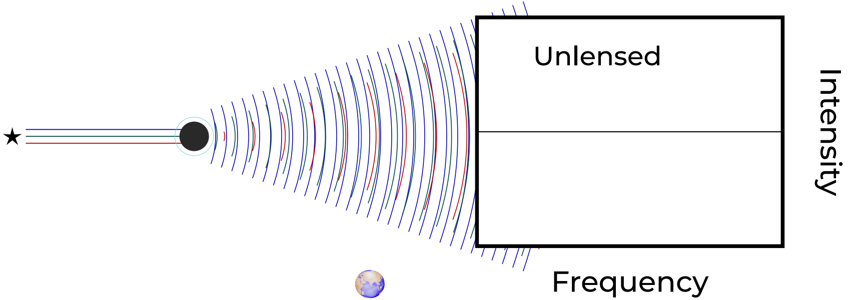

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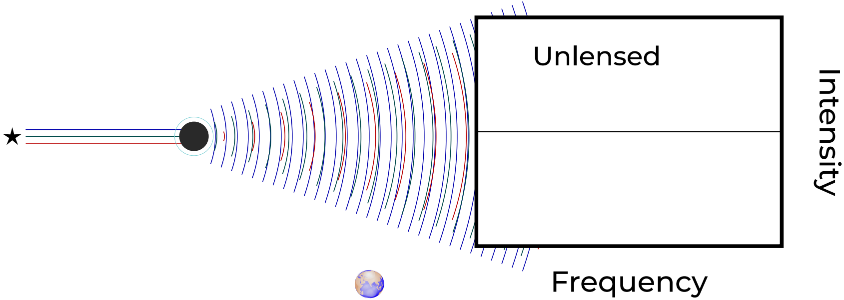

Intrinsic variability is **much less problematic**

Femtolensing regimes

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Wave-optics parameter

$$w \equiv 4GME_\gamma$$

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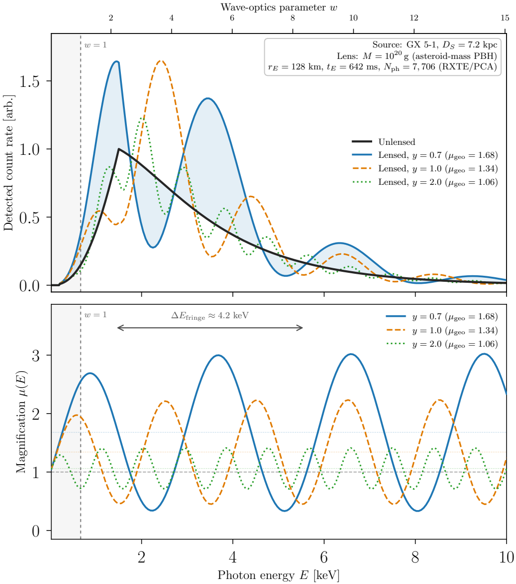
Point-source magnification

$$\mu(w,y) = \frac{\pi w}{1-e^{-\pi w}}\left|{}_1F_1\!\left(\frac{iw}{2}, 1; \frac{iwy^2}{2}\right)\right|^2, \quad y = b/r_E$$

Femtolensed spectra



Present and future data

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RXTE

1995–2012

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RXTE

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NICER

2017–present

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Athena

2037?

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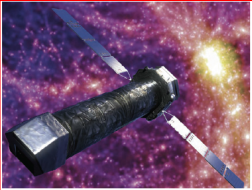
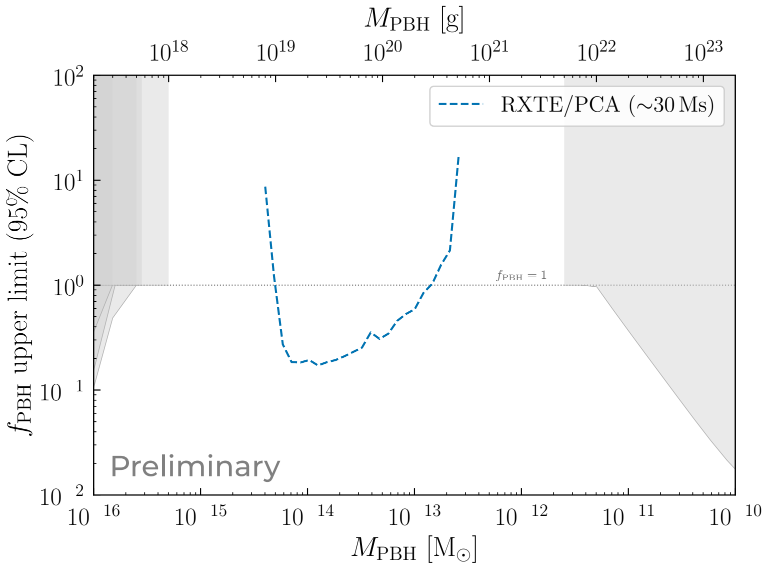


2037?

Lots of archival data is already available!

Could we already set a bound?

Rossi X-ray Timing Explorer (RXTE)



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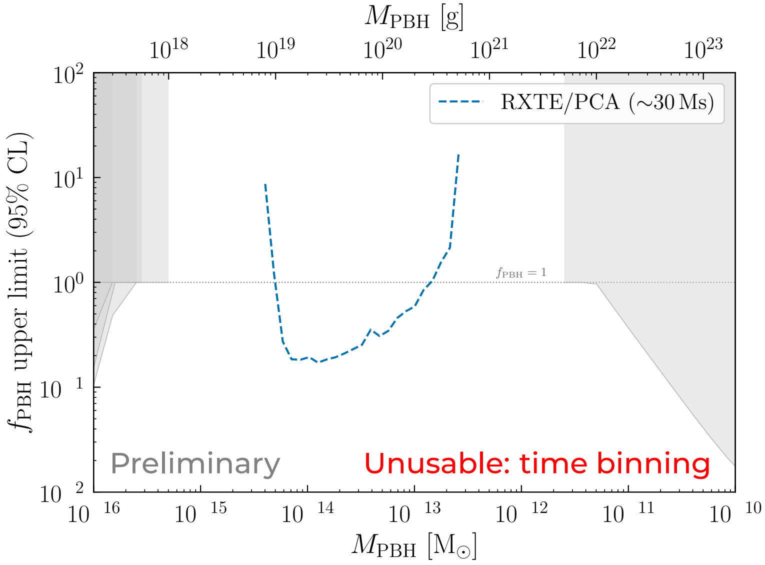

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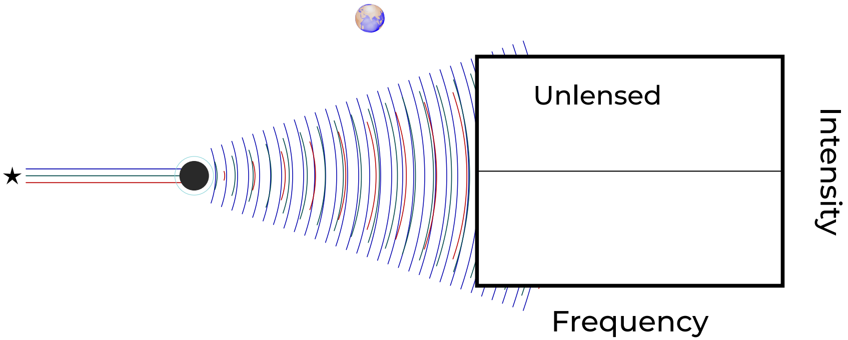
Event time dependence



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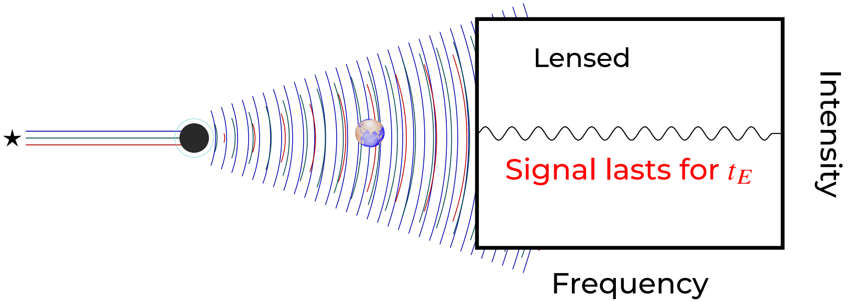

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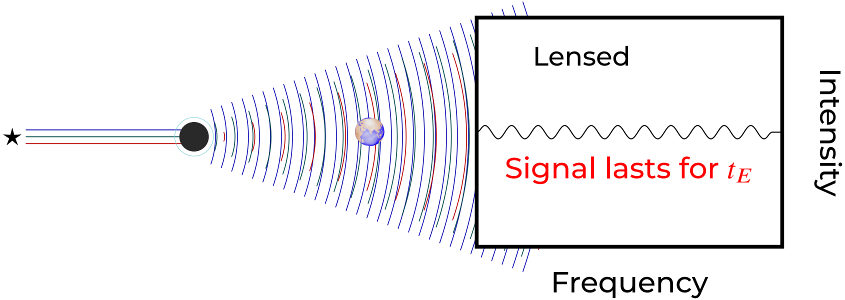

$$r_E = D_L \sqrt{4GM \frac{D_{LS}}{D_L D_S}}$$

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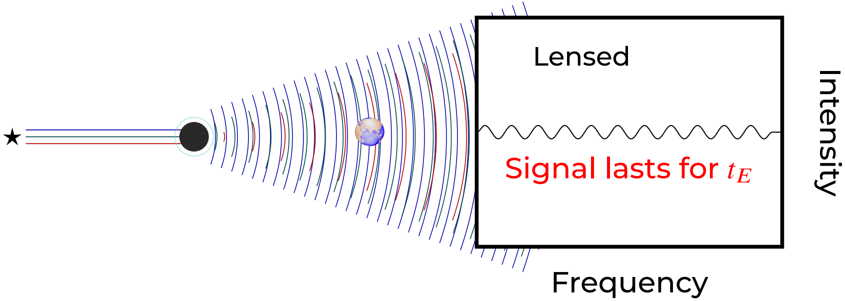

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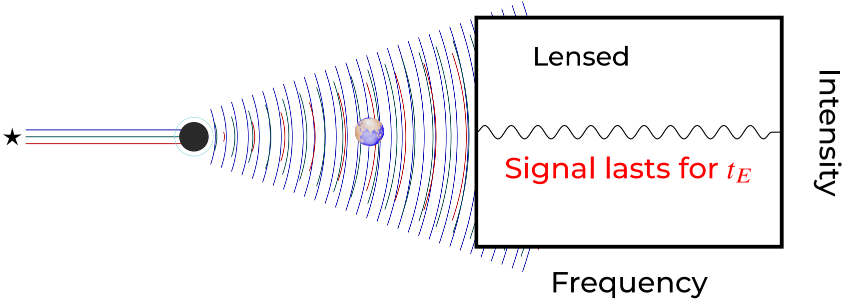

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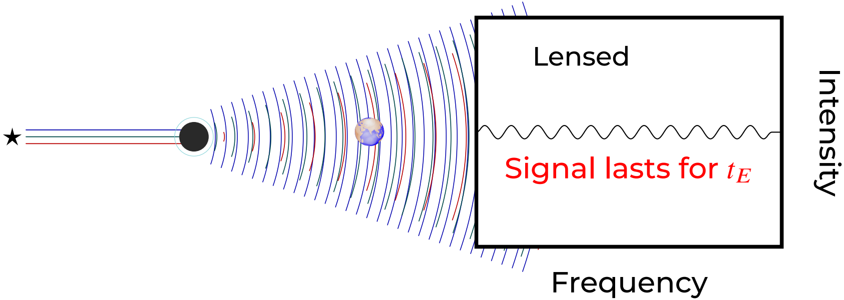

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Most RXTE data is in $16\,\mathrm{s}$ bins!

NICER data

Neutron Star Interior Composition Explorer

2017–present

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- Band: 0.2–$12\,\mathrm{keV}$

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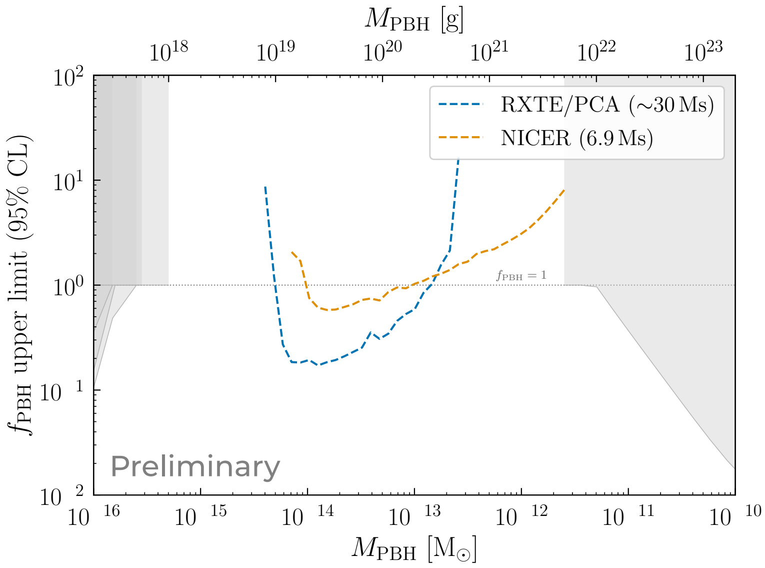
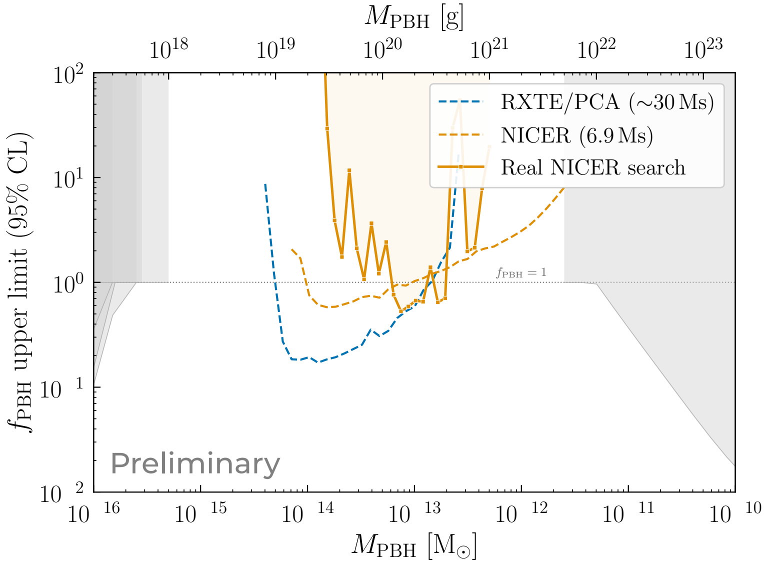

M_{PBH} [g]
10^{18}
10^{19}
10^{20}
10^{21}
10^{22}
10^{23}
RXTE/PCA (∼30 Ms)
NICER (6.9 Ms)
$f_{\mathrm{PBH}} = 1$
f_{PBH} upper limit (95% CL)
10^{2}
10^{1}
10^{0}
10^{-1}
10^{-2}
Preliminary
10^{-16}
10^{-15}
10^{-14}
10^{-13}
10^{-12}
10^{-11}
10^{-10}
M_{PBH} [$M_\odot$]

NICER: real search



Advanced Telescope for High Energy Astrophysics

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Athena

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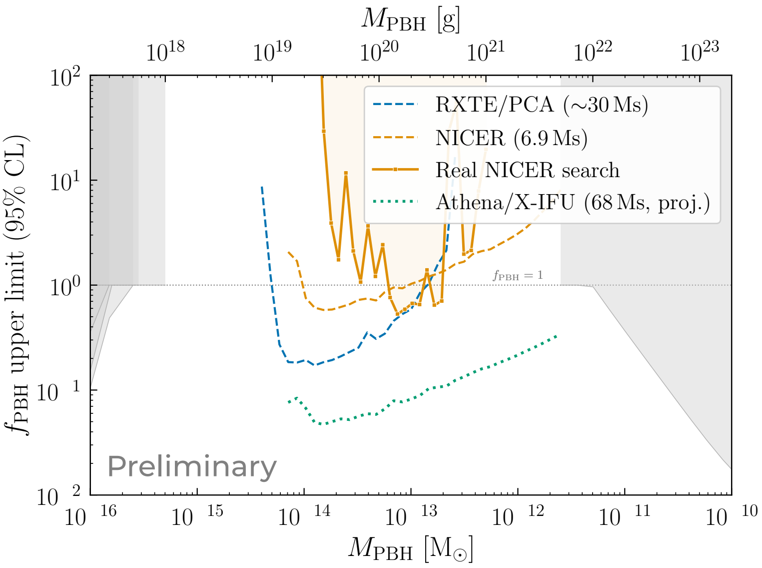
“Super-NICER” — ESA SPC adoption expected next year

Athena projection



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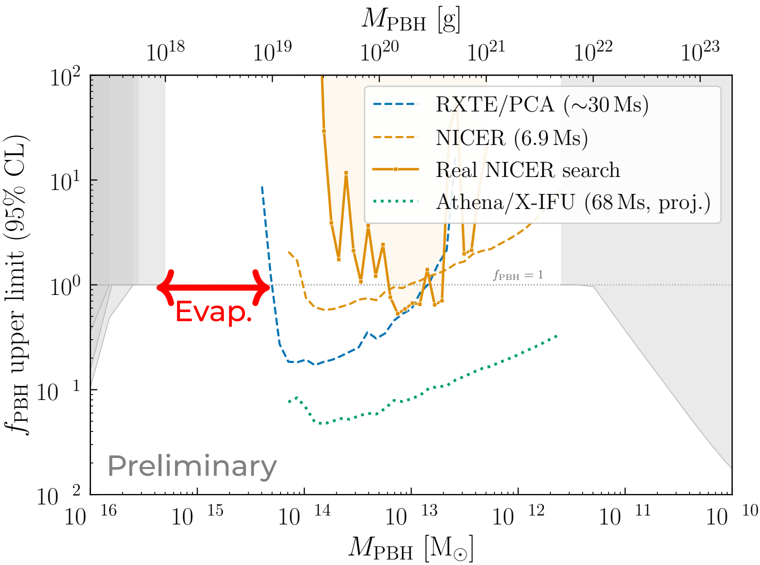
Athena projection



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Conclusions

We can start testing the asteroid-mass range **today**

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NICER

(Already effective)

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Other compact objects will escape this bound

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Other compact objects will escape this bound

But black holes can't hide forever!

References I

A. M. Green and B. J. Kavanagh. Primordial Black Holes as a dark matter candidate. *J. Phys. G*, 48(4):043001, 2021. doi: 10.1088/1361-6471/abc534.

M. Tamta, N. Raj, and P. Sharma. Entering the window of primordial black hole dark matter with x-ray microlensing. *Phys. Rev. D*, 111(4):043043, 2025. doi: 10.1103/PhysRevD.111.043043.