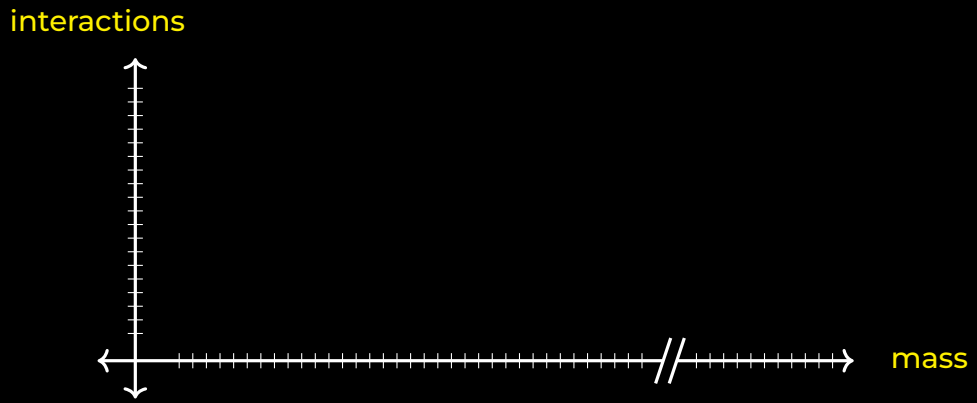
Massachusetts Institute of Technology

CLOSE ENCOUNTERS OF THE PRIMORDIAL KIND

The final frontier for black holes as dark matter

Benjamin V. Lehmann
MIT Center for Theoretical Physics

The dark matter parameter space



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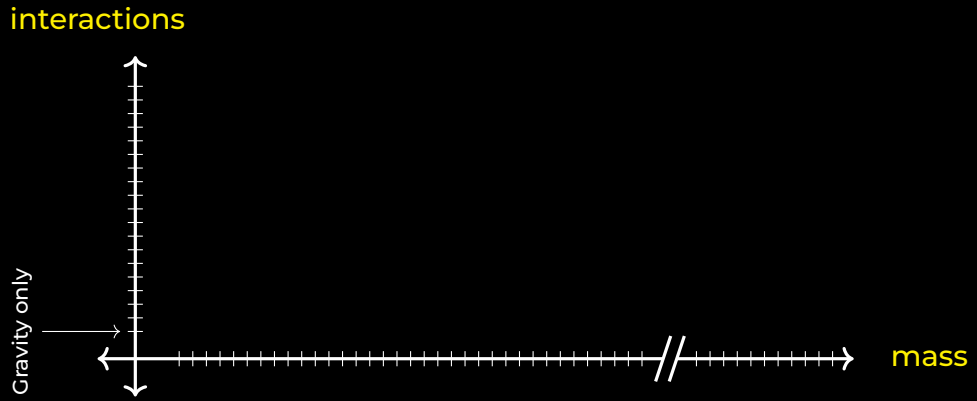

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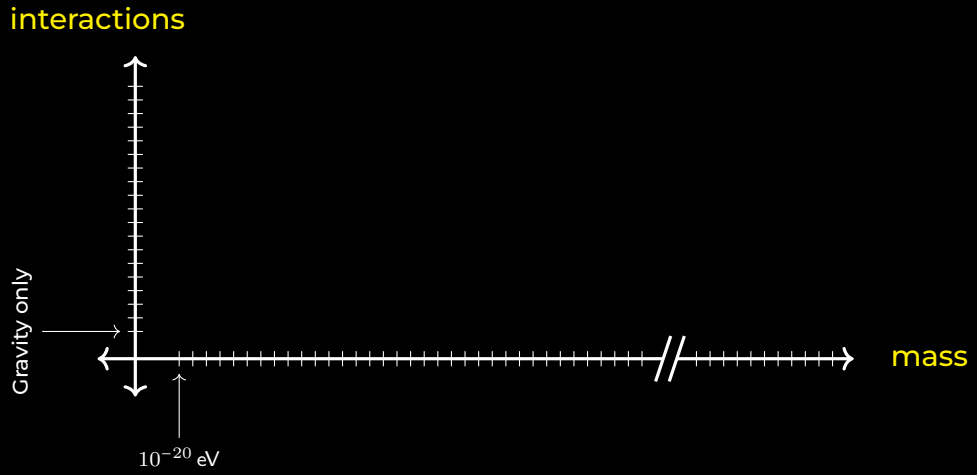

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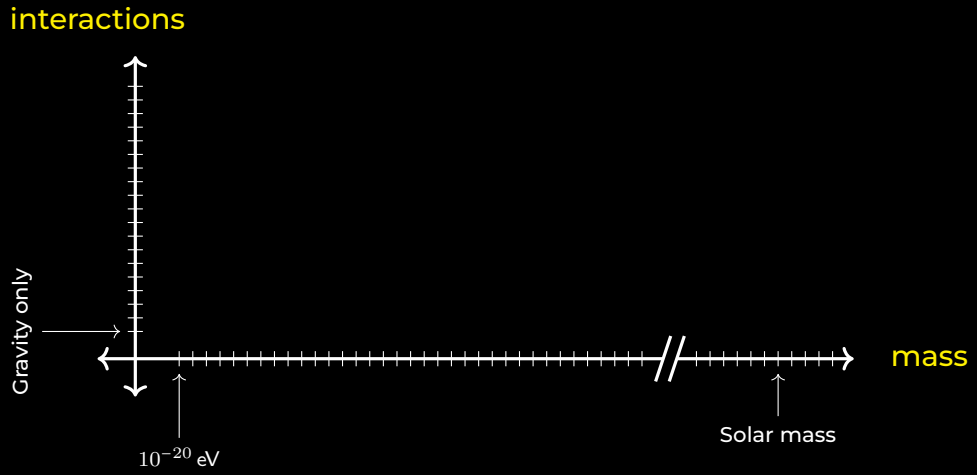

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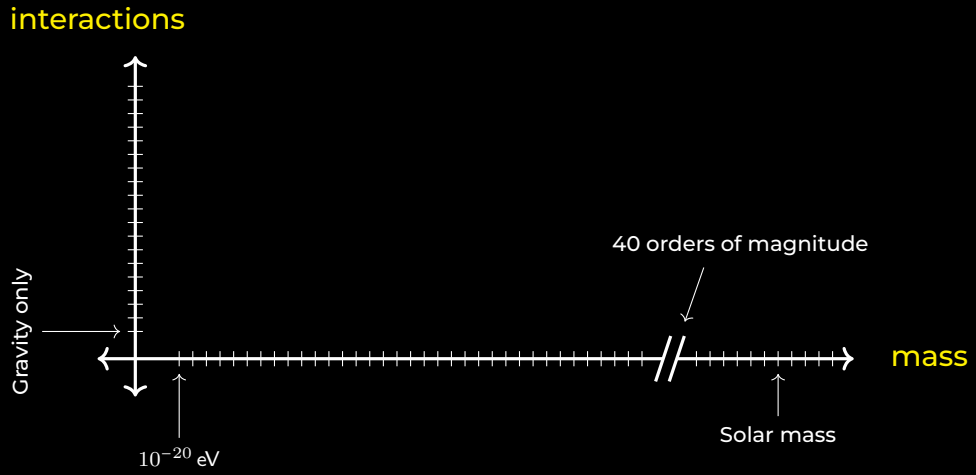

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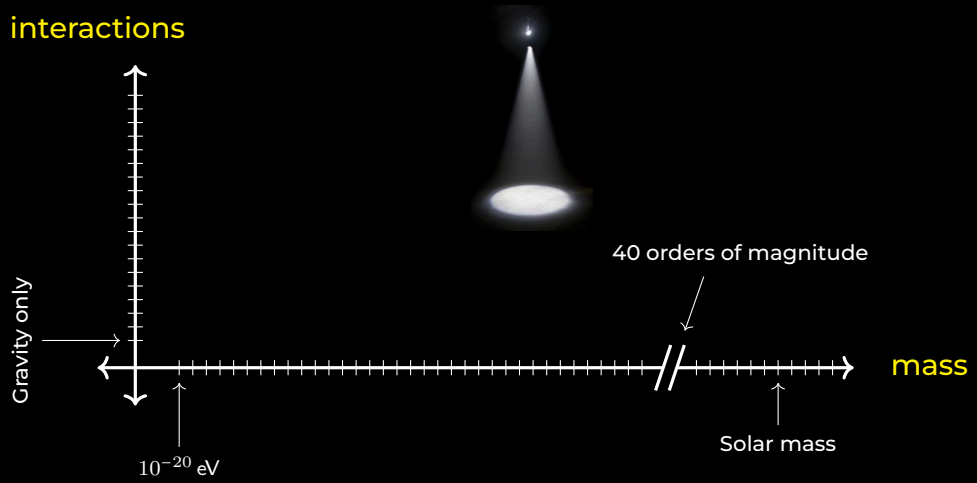

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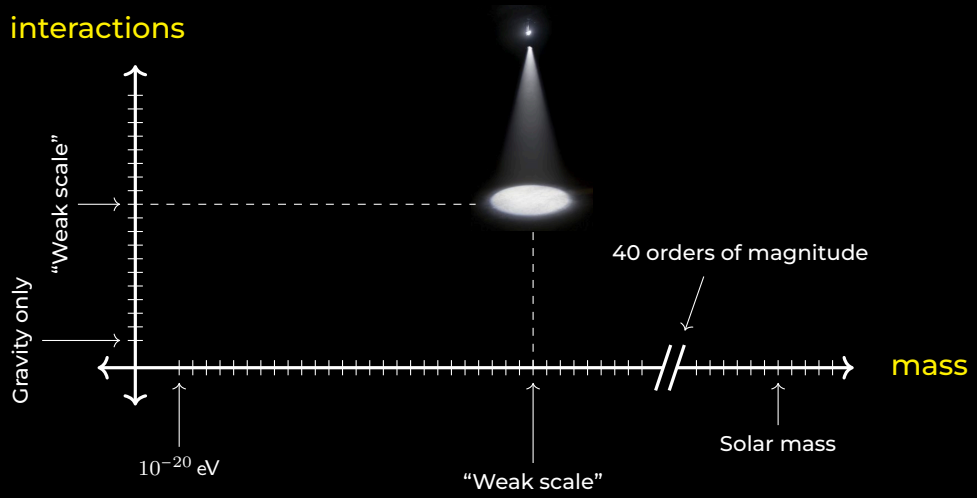

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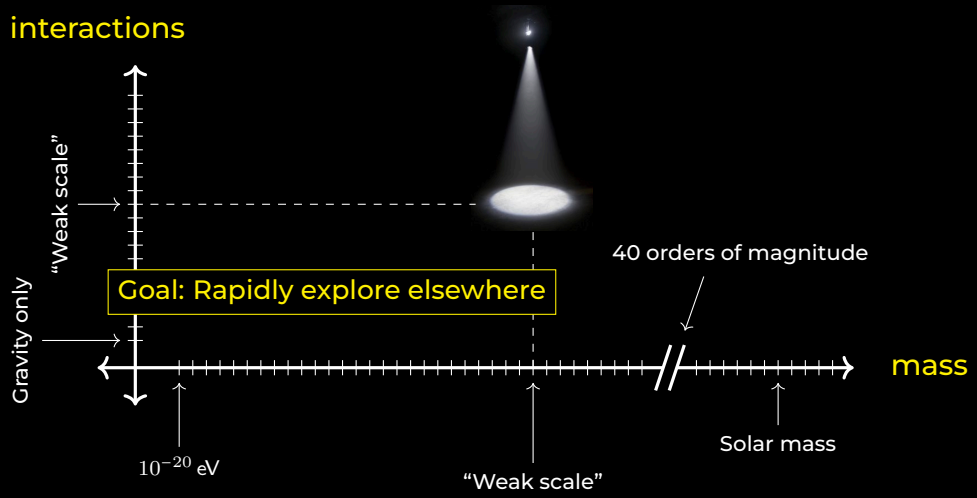
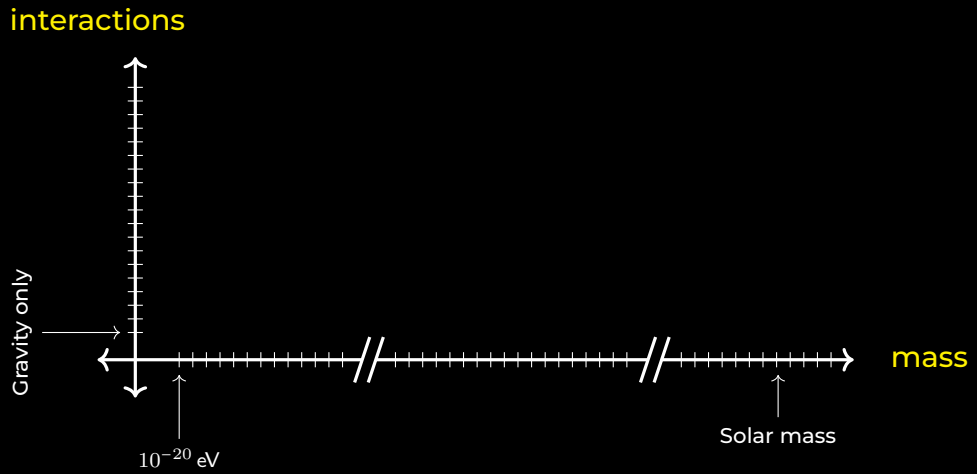


Is dark matter made of particles?



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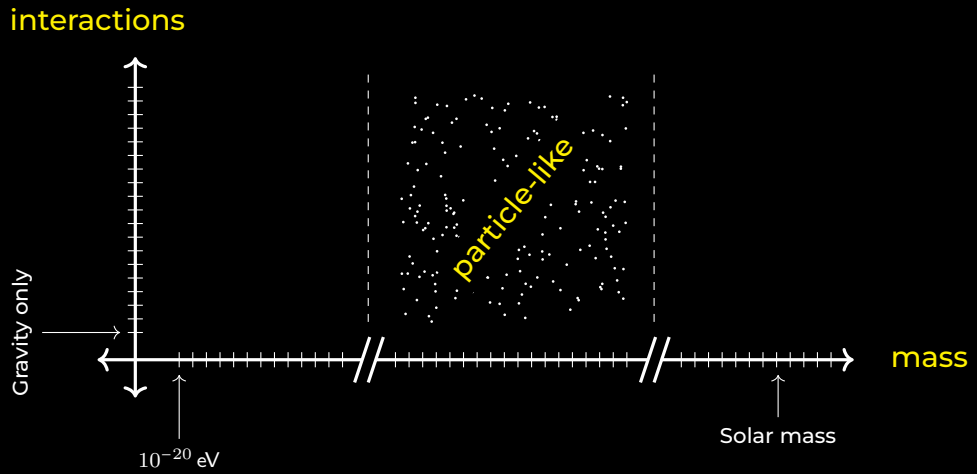

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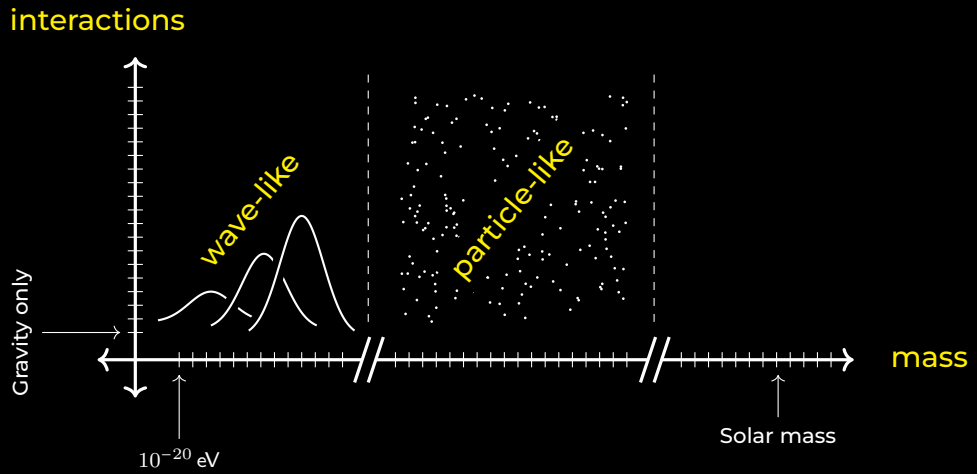

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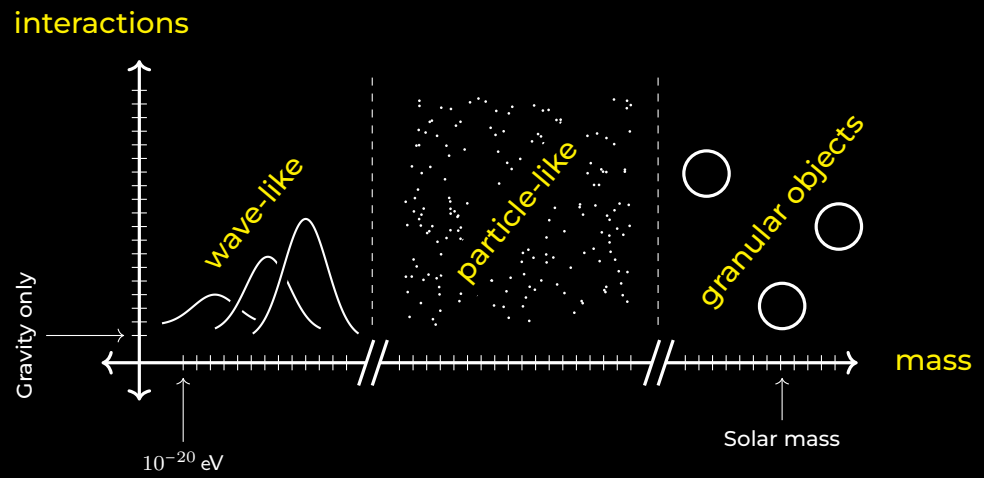
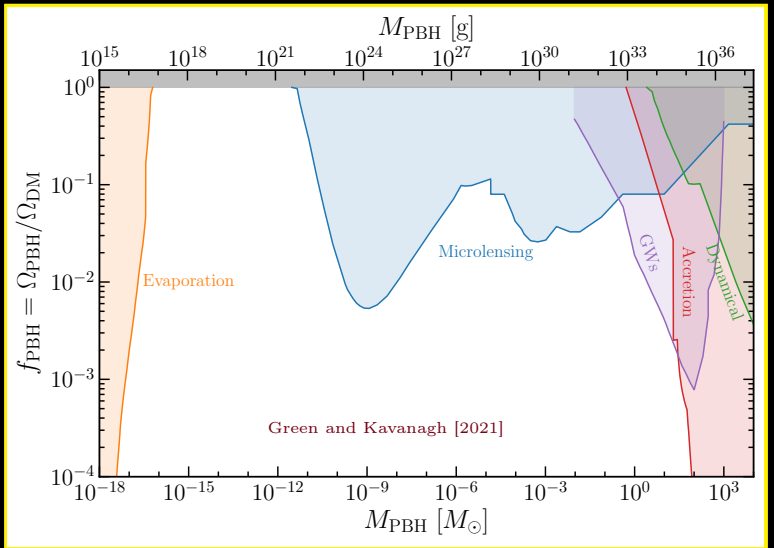


Primordial black holes as dark matter



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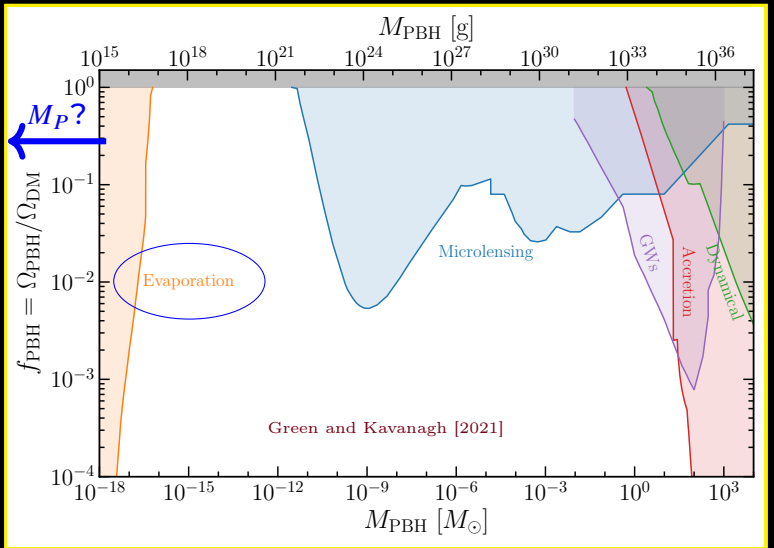

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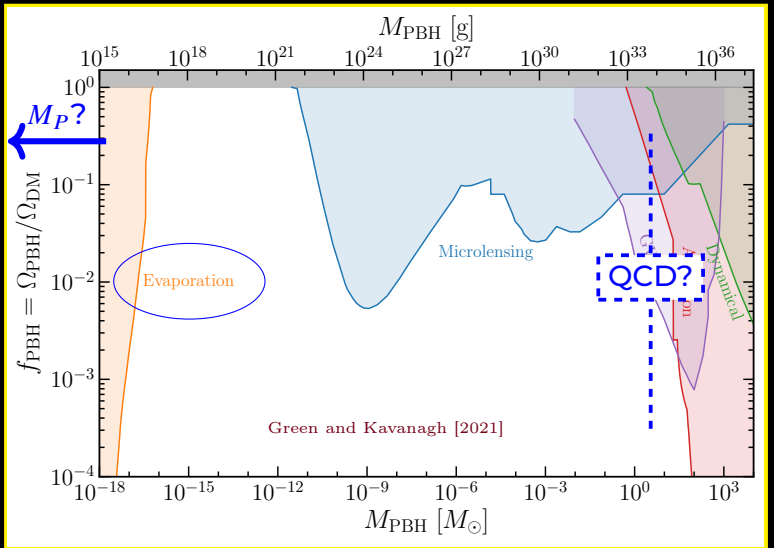

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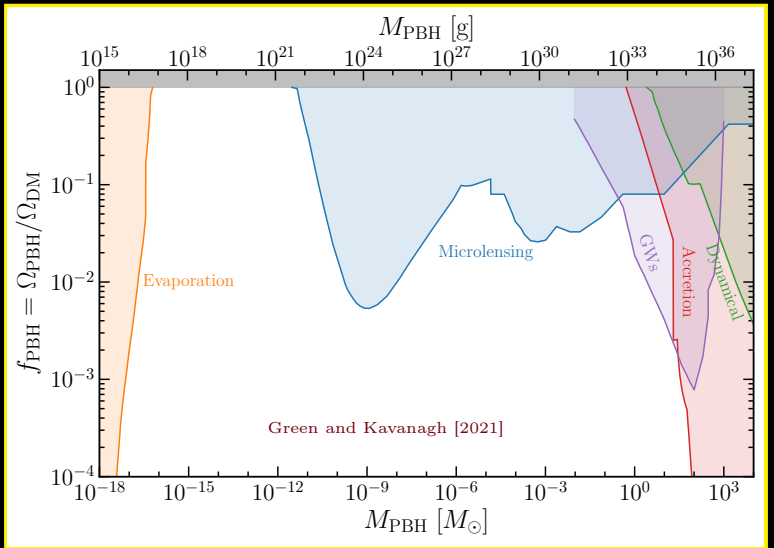
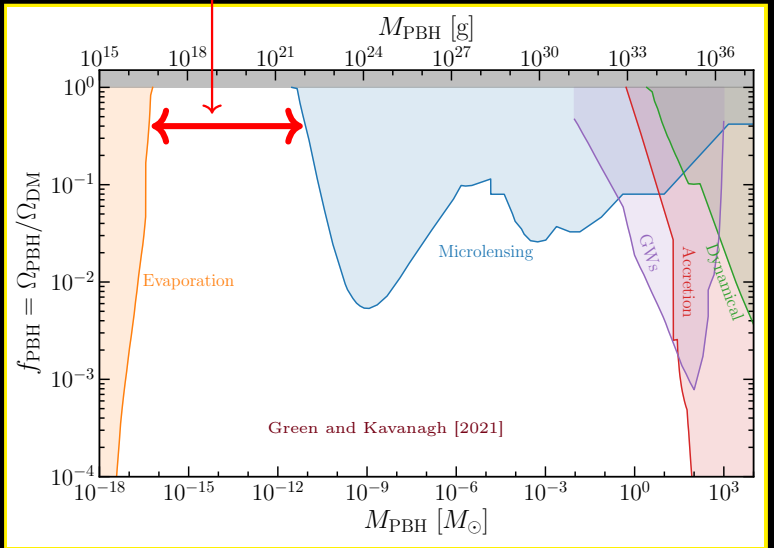
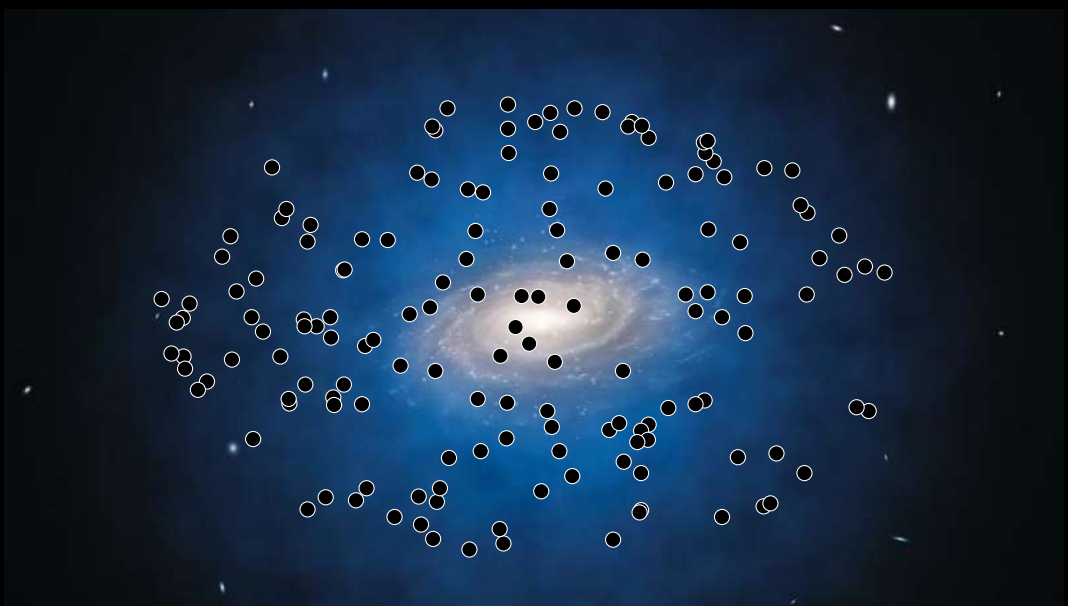


Primordial black holes as dark matter

mainly in “asteroid mass” range



Looking for dark matter black holes



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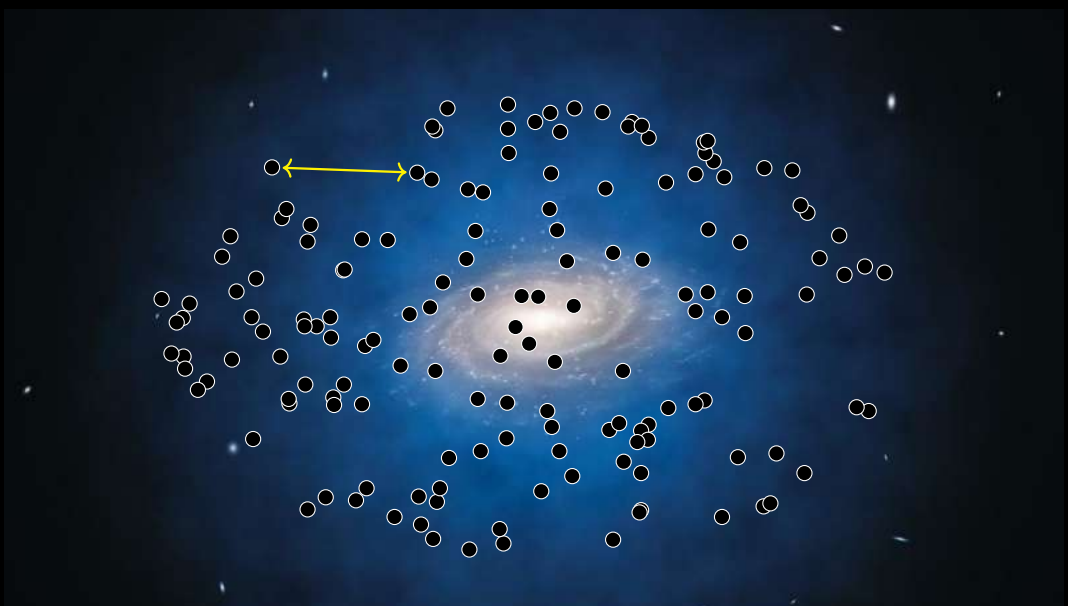

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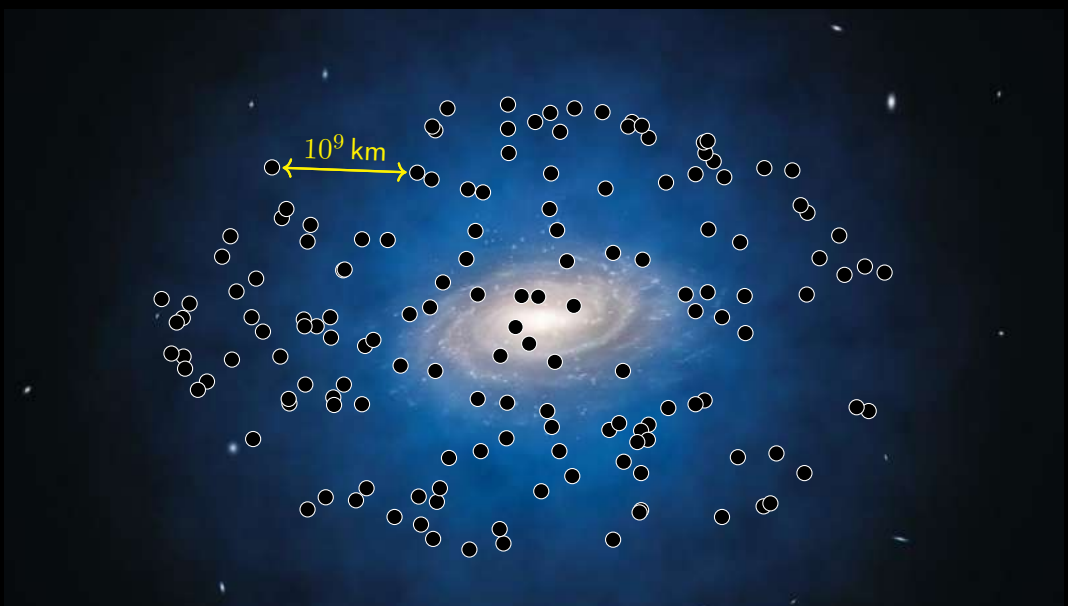

Black hole detectors?

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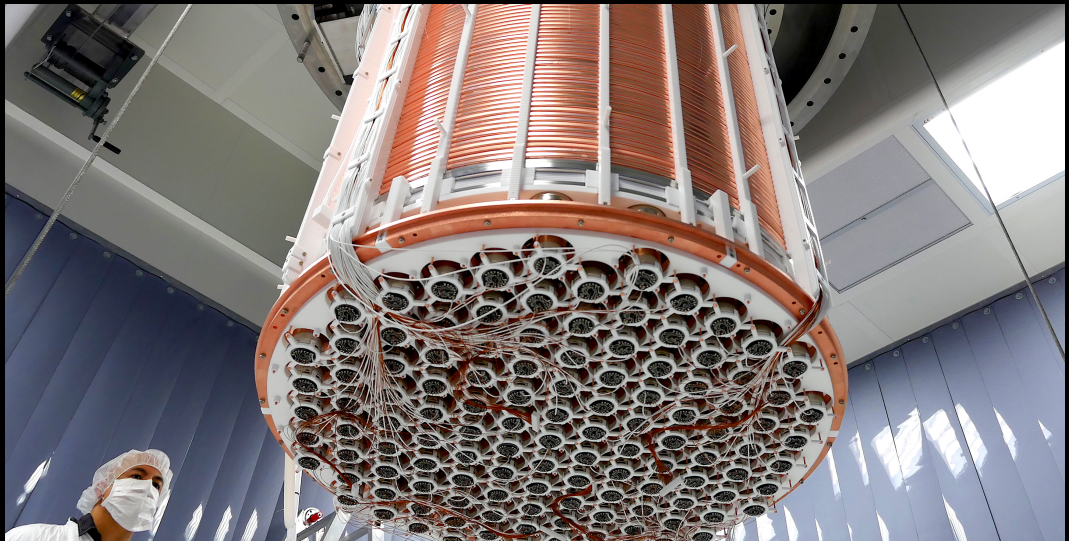

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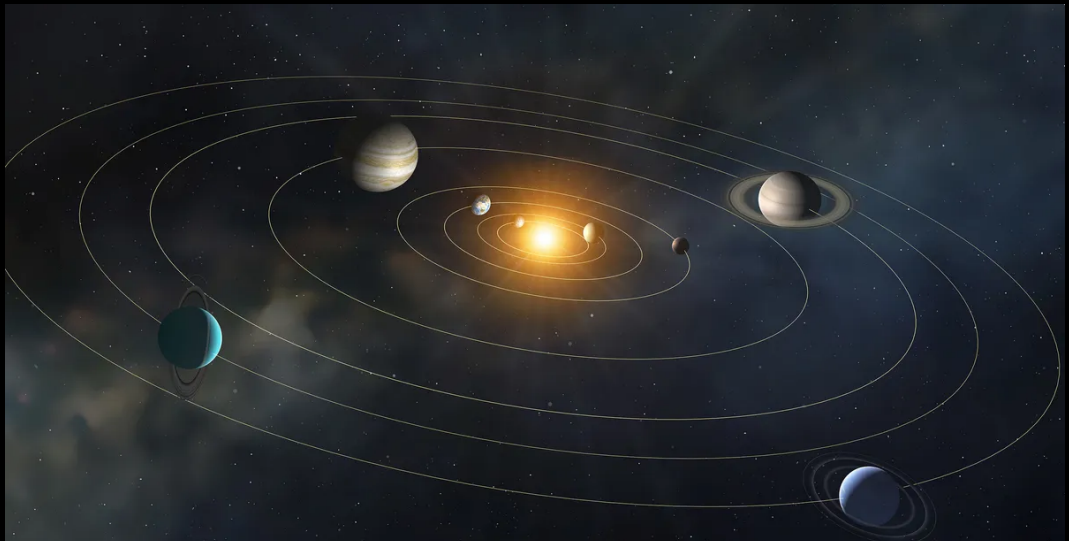
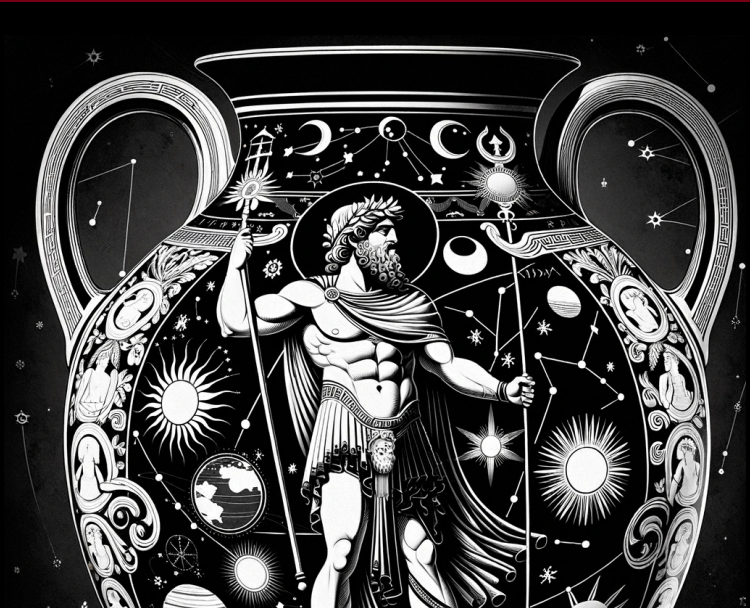


Ephemerides



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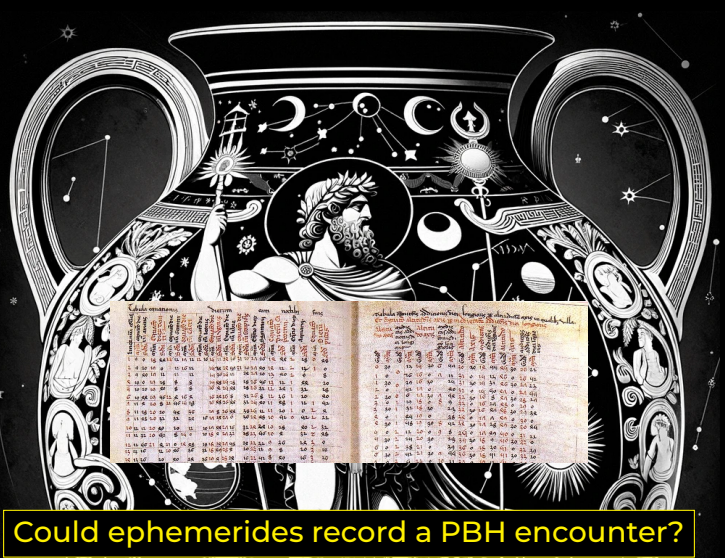
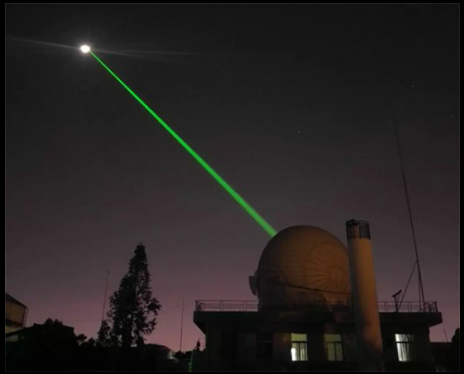


Could ephemerides record a PBH encounter?

Precision measurements in the Solar System

Precision measurements in the Solar System



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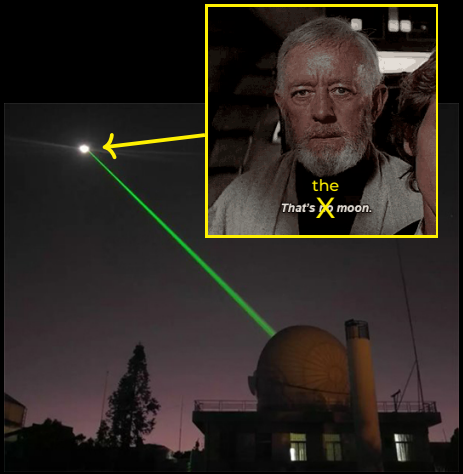

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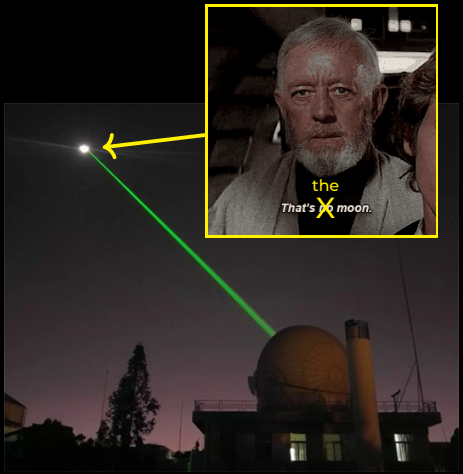

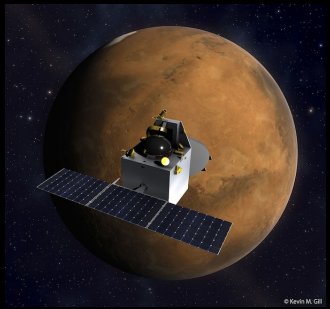

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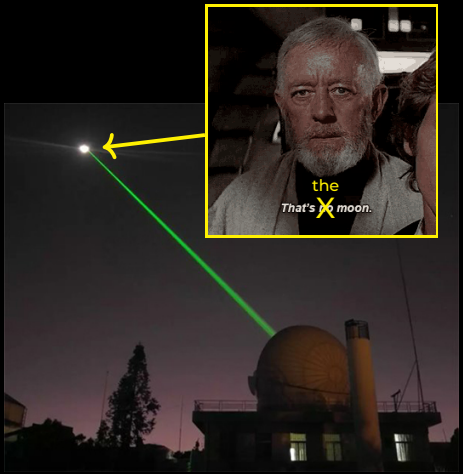

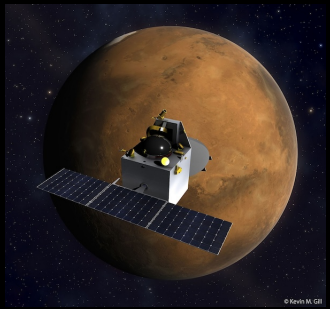

Mars orbiters have had $\mathcal{O}(10\,\mathrm{cm})$ precision for $\mathcal{O}(20\,\mathrm{yr})$!

Could we see a black hole?

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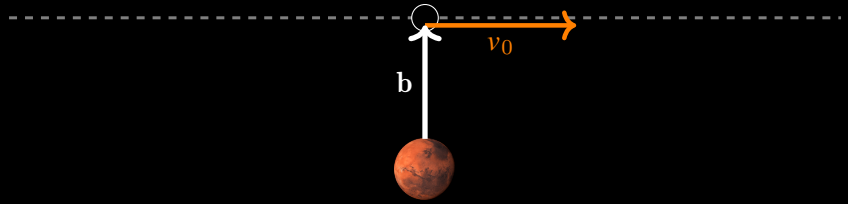

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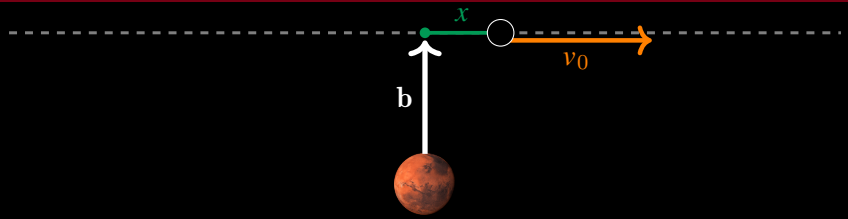

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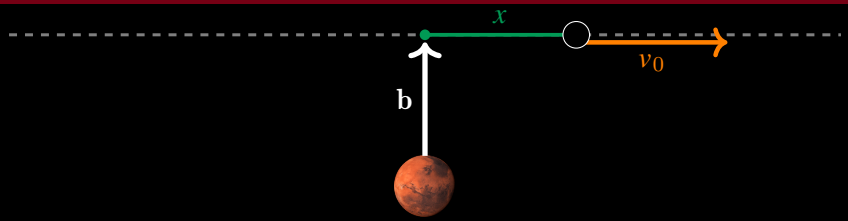

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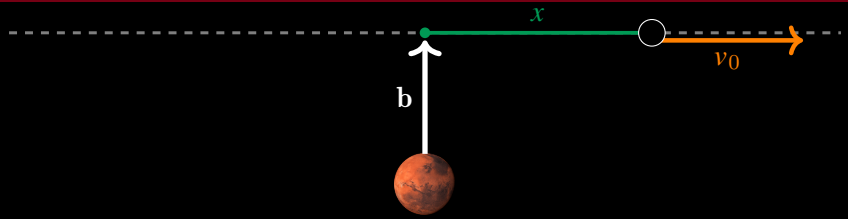

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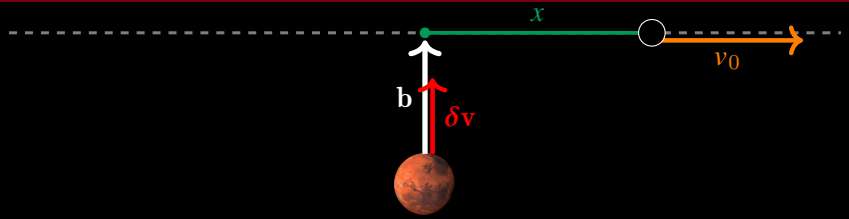

$$\delta \mathbf{v} \simeq \int \frac{\mathrm{d}x}{v_0} \frac{G M_{\mathrm{PBH}} \mathbf{b}}{(\mathbf{b}^2 + x^2)^{3/2}} = \frac{2 G M_{\mathrm{PBH}}}{v_0 b^2} \mathbf{b}$$

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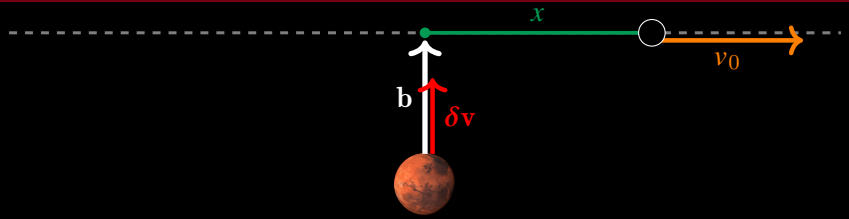

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$$\delta r = \delta v \times \Delta t \gtrsim \sigma_r$$

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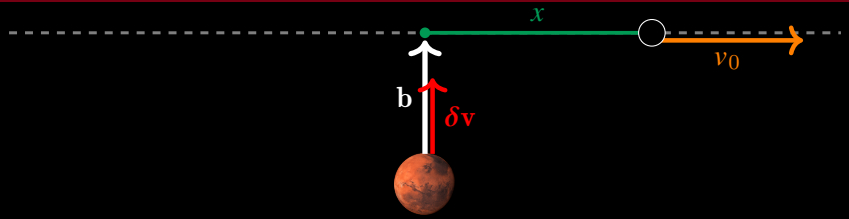

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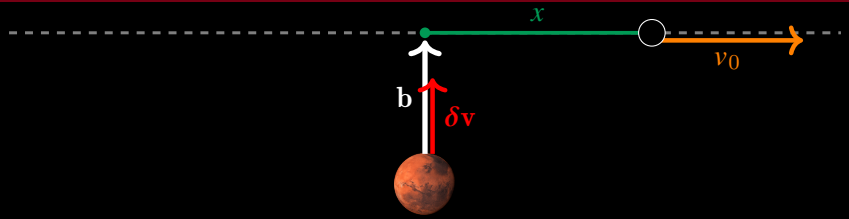

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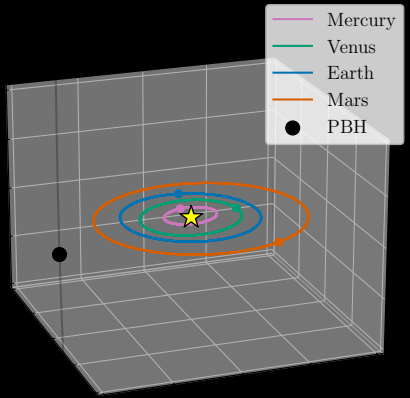
$$\delta r = \delta v \times \Delta t \gtrsim \sigma_r \qquad b_{\rm max}(\Delta t) = \frac{2 G M_{\rm PBH}}{v_0 \sigma_r} \times \Delta t$$

~ 1 detectable per $\Delta t_{\rm min} \approx 26\,{\rm yr} \left(\frac{M_{\rm PBH}}{10^{20}\,{\rm g}} \right)^{-1/3} \left(\frac{\sigma_r}{0.1\,{\rm m}} \right)^{2/3}$

Simple simulations



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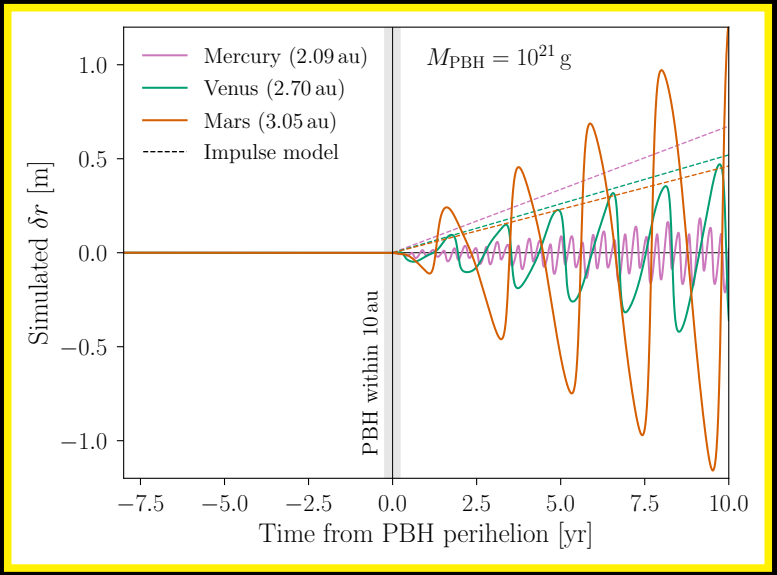
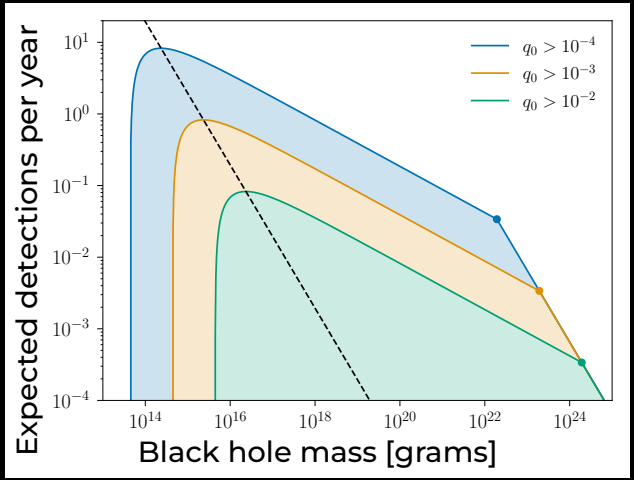


Rates and constraints



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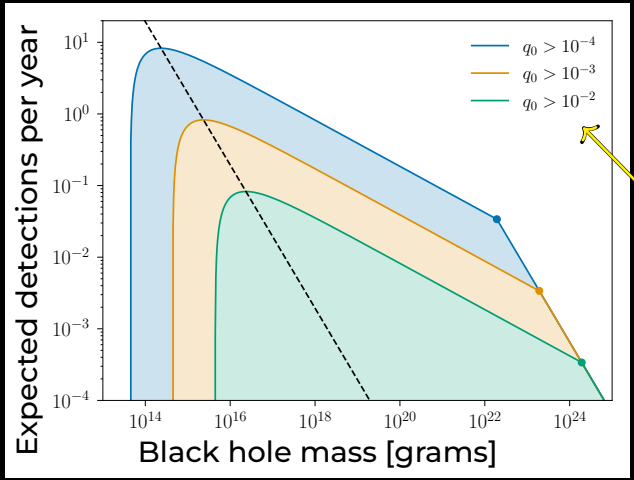
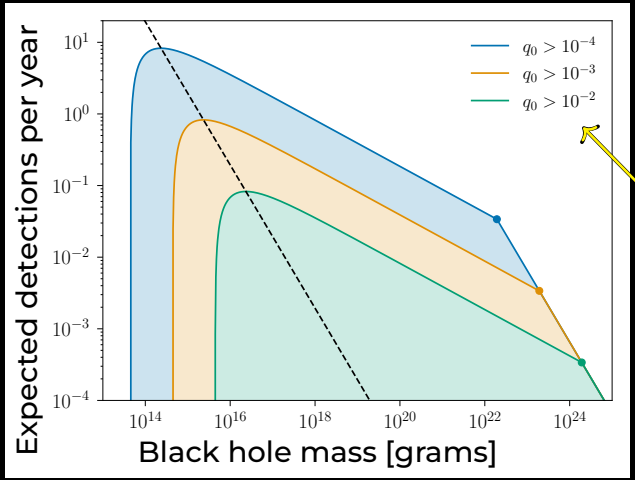


Small-signal sensitivity

Rates and constraints



Small-signal sensitivity

(Depends on data & simulation quality)

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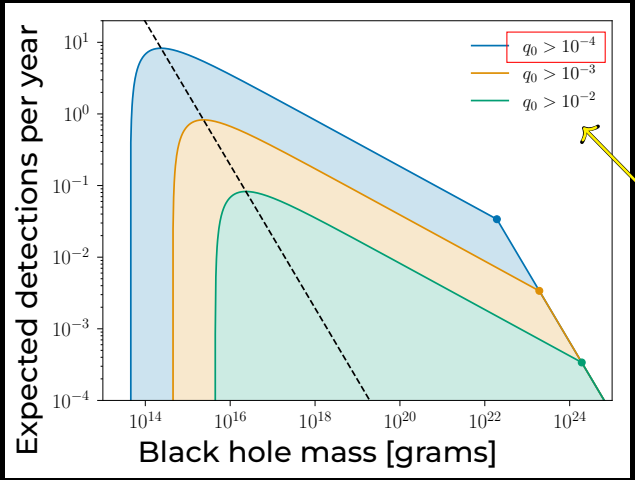
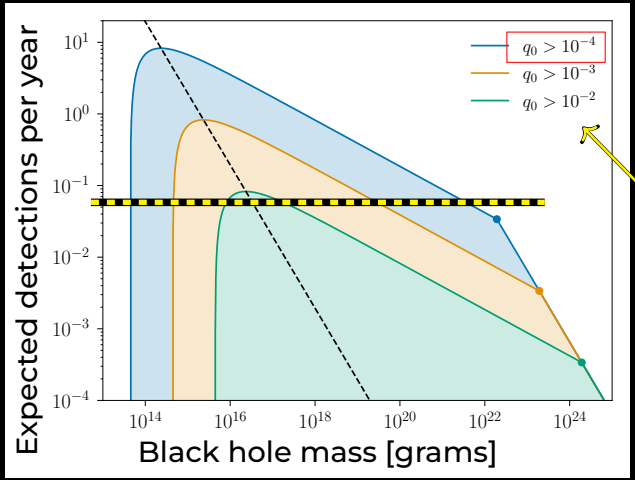


LIGO-like
data analysis

Small-signal
sensitivity

(Depends on data & simulation quality)

Rates and constraints



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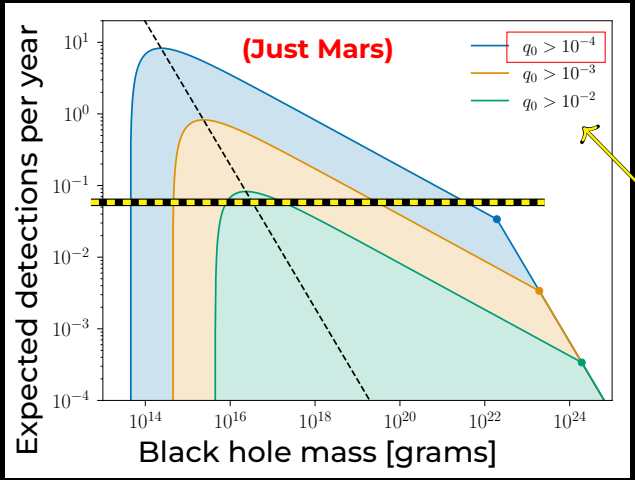

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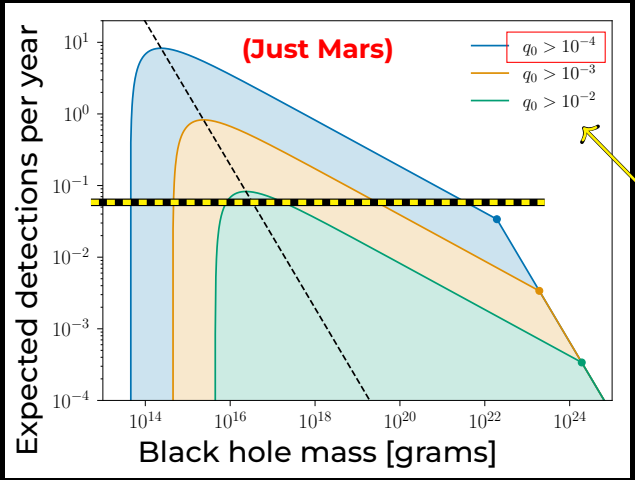

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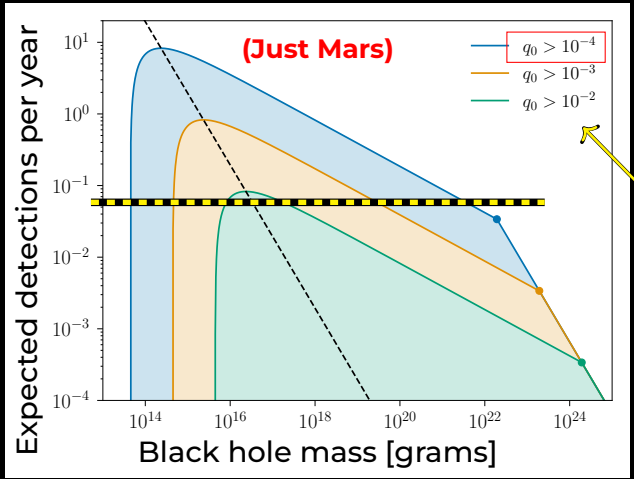
(Depends on data & simulation quality)

This is possible—

Rates and constraints



LIGO-like
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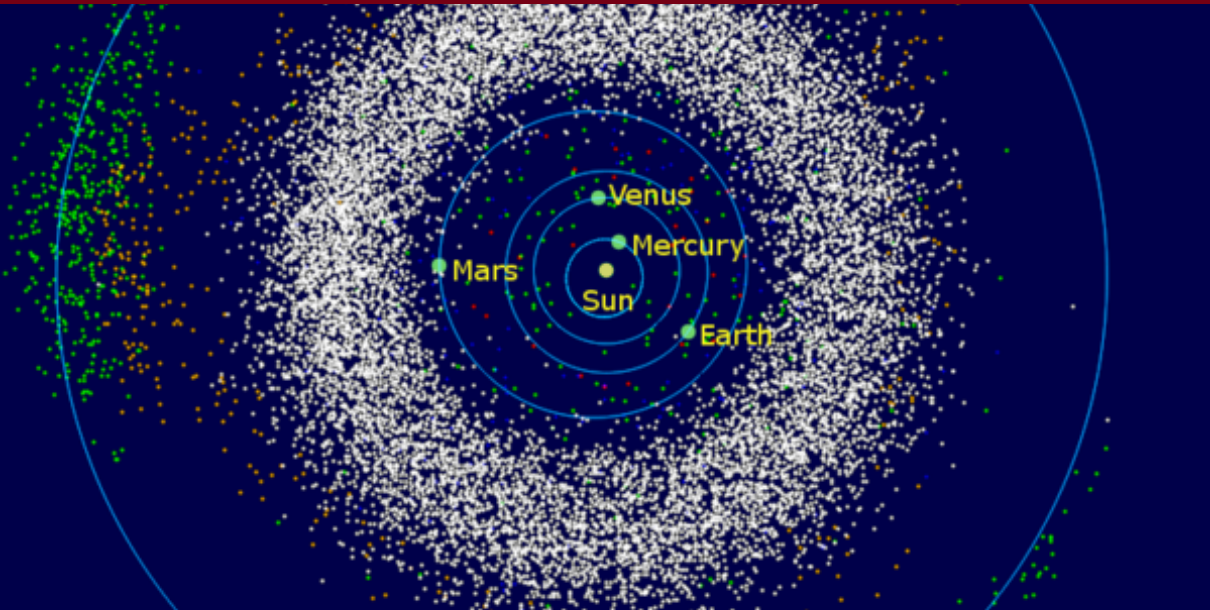
(Depends on data & simulation quality)

This is possible—with full-scale simulations

Precision Solar System modeling



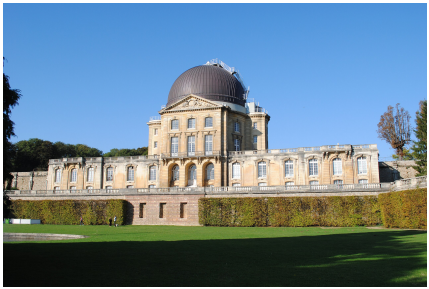
Precision Solar System modeling

JPL DE441 model

Venus
Mercury
Sun
Earth

Precision Solar System modeling

JPL DE441 model



Paris Observatory INPOP21a

Precision Solar System modeling

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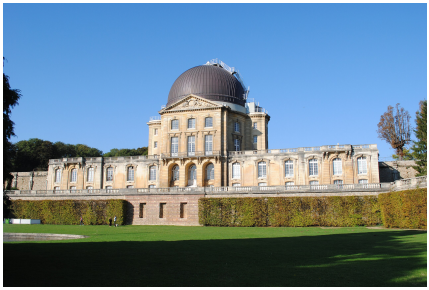

Paris Observatory INPOP21a

Including >2M objects, tidal dissipation, relativity…

Precision Solar System modeling

JPL DE441 model

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Including >2M objects, tidal dissipation, relativity…

Rai had lots of ideas to help make this a reality

Binaries as paleo-detectors

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For a low flux, use a long exposure

Binaries as paleo-detectors

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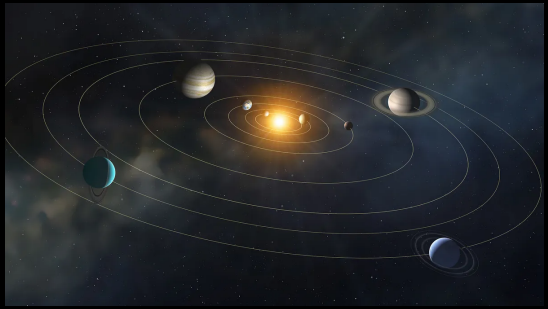

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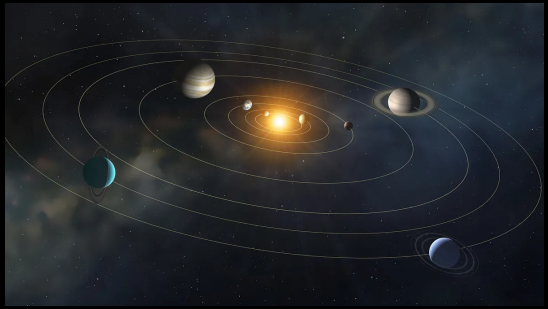
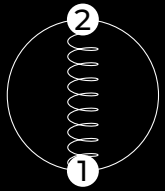


Dynamical exchange



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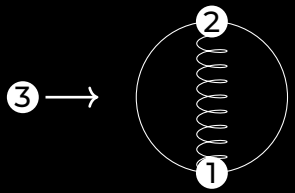
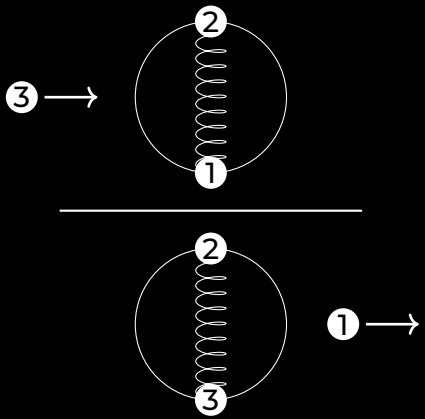
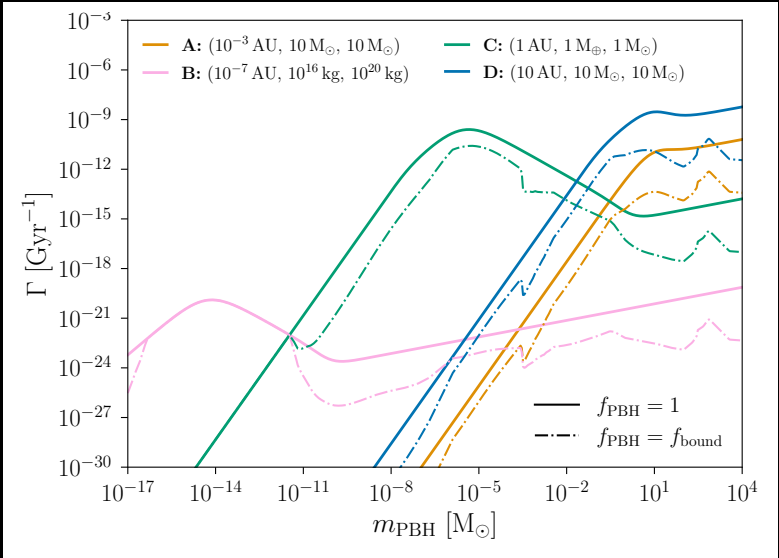


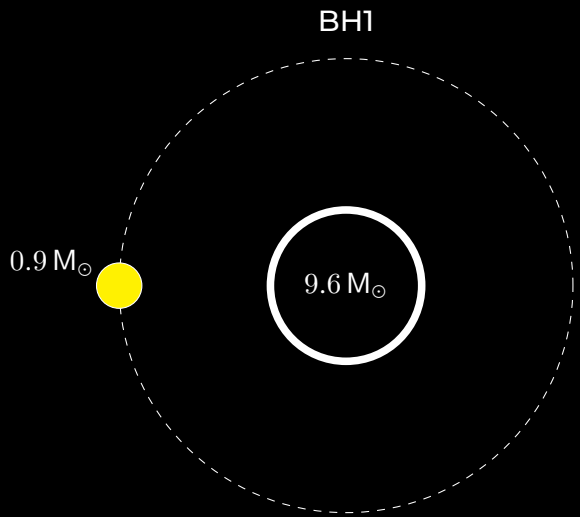
Dynamical exchange



Exchange rate



Gaia BH1, BH2, BH3



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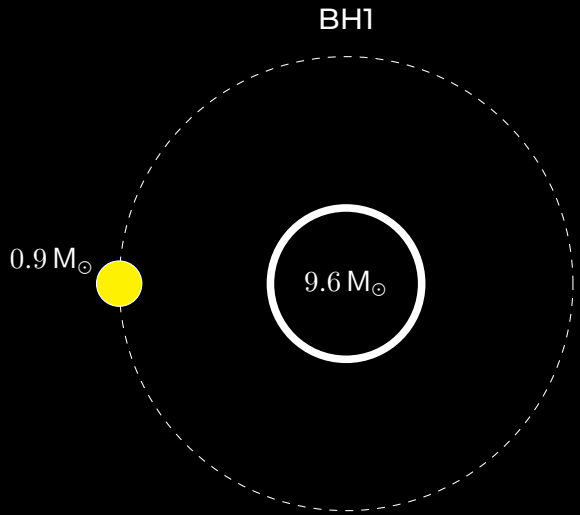
(M, a) would require a common-envelope phase



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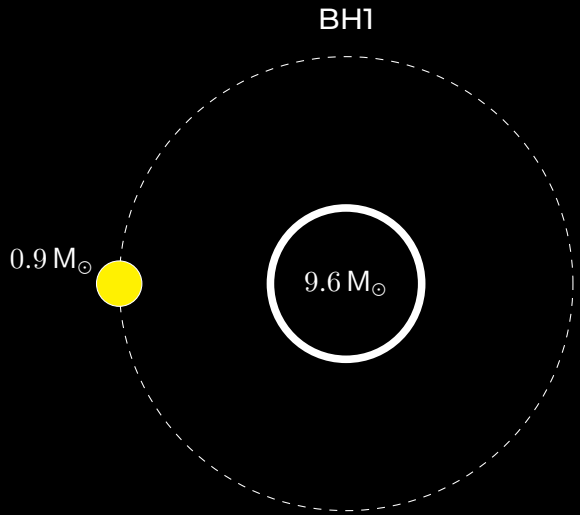
In tension with chemistry



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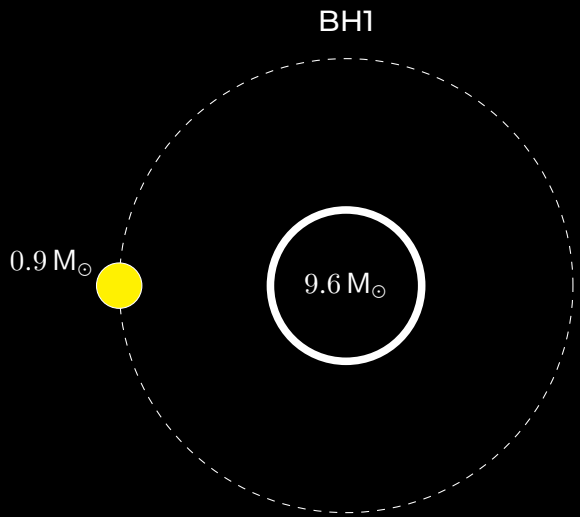

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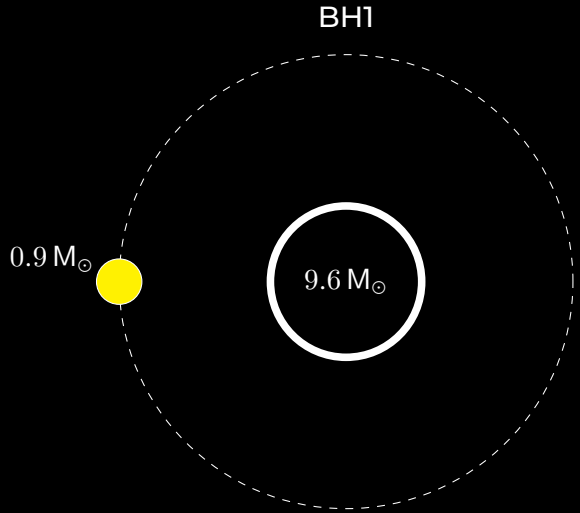
Exchange?

In-situ: 10^{-10}–10^{-8} Gyr^{-1}



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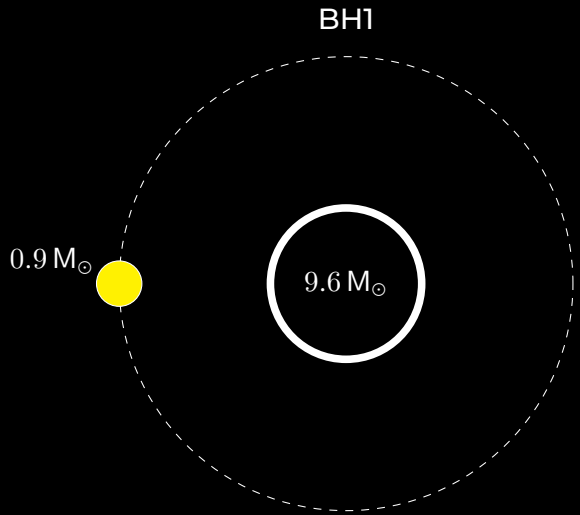

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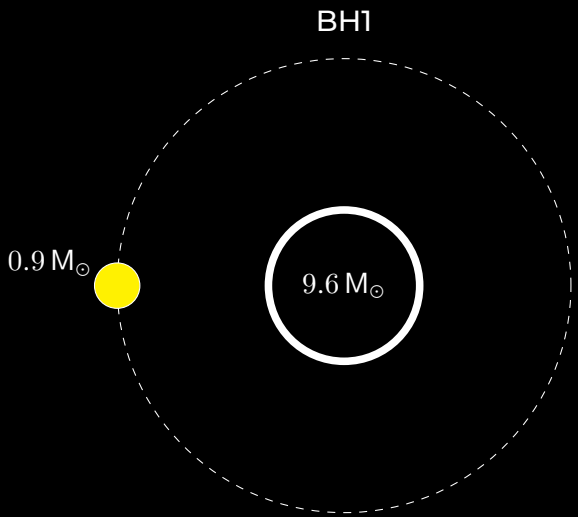

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PBHs: 10^{-8}–10^{-6} Gyr^{-1}

Gaia BH1, BH2, BH3

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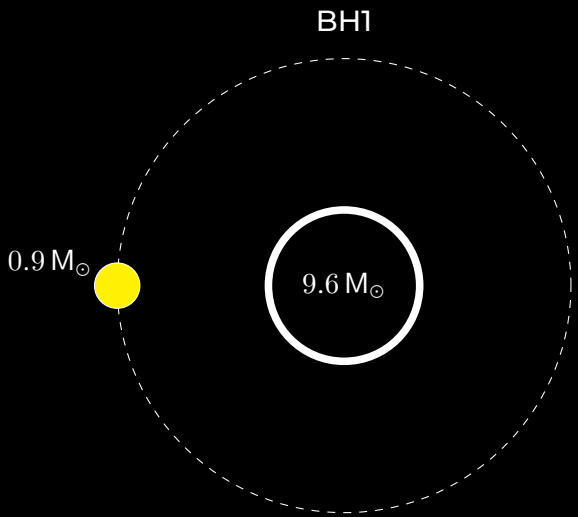
In tension with chemistry



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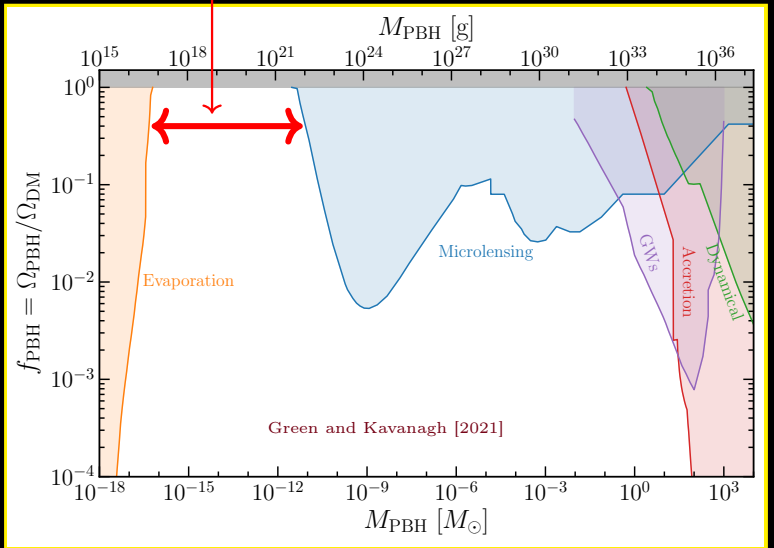
~matches

Primordial black holes as dark matter

mainly in “asteroid mass” range



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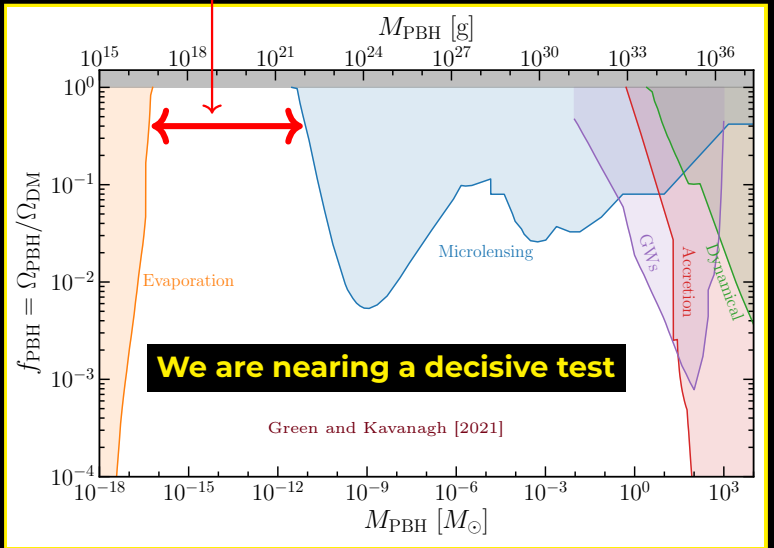


PBHs produce spectral distortions?
(Sometimes!)
① Gravitational Sunyaev-Zeldovich
② Photons?
③ Heavy DM
Gravitational SZ effect
Ordinary SZ: CMB
CMB
Tgas ~ 10 keV
n(ω)
ΔI/I ~ 10^-3
200 GHz
2309.15925 [König]
Can this happen to a cosmic GW bkgd?
M_PBH = 10^-16 M☉
f_PBH = 1
Low-energy g. depleted (1%)
Can this be used to probe PBHs?
Challenge: spectral precision ≪ CMB
THE NORTH FACE