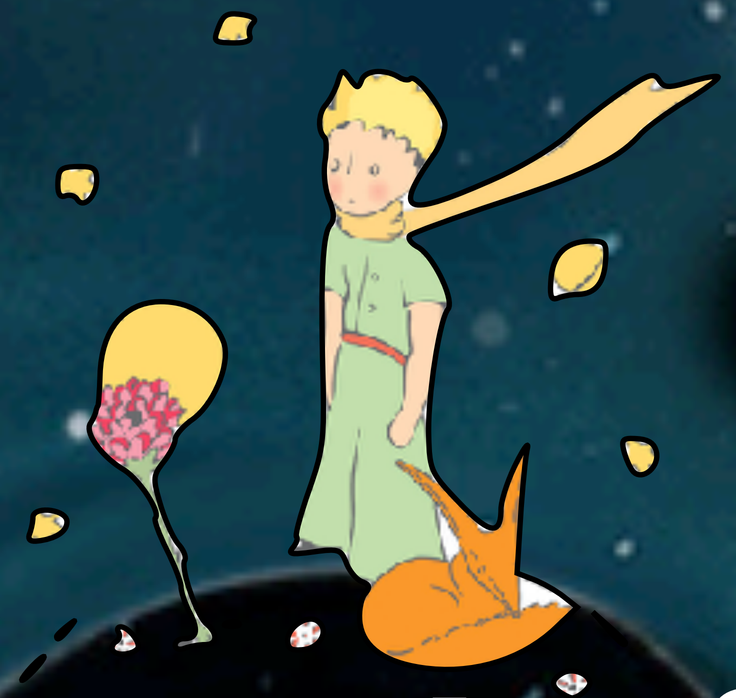
Sébastien Clesse
Université Libre de Bruxelles (ULB)



The Quest of Subsolar (Primordial) Black Holes

Background picture: artist view of GW190521 by Ingrid Bourgault

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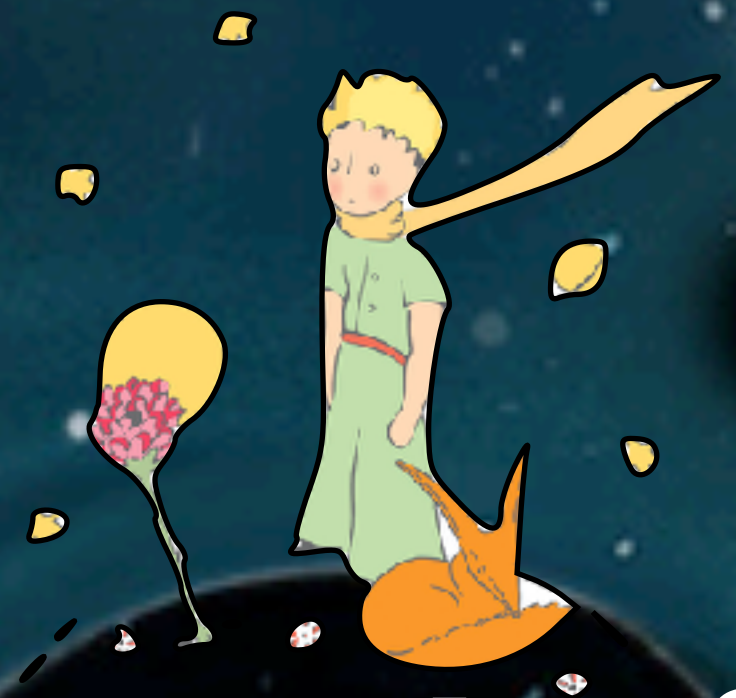
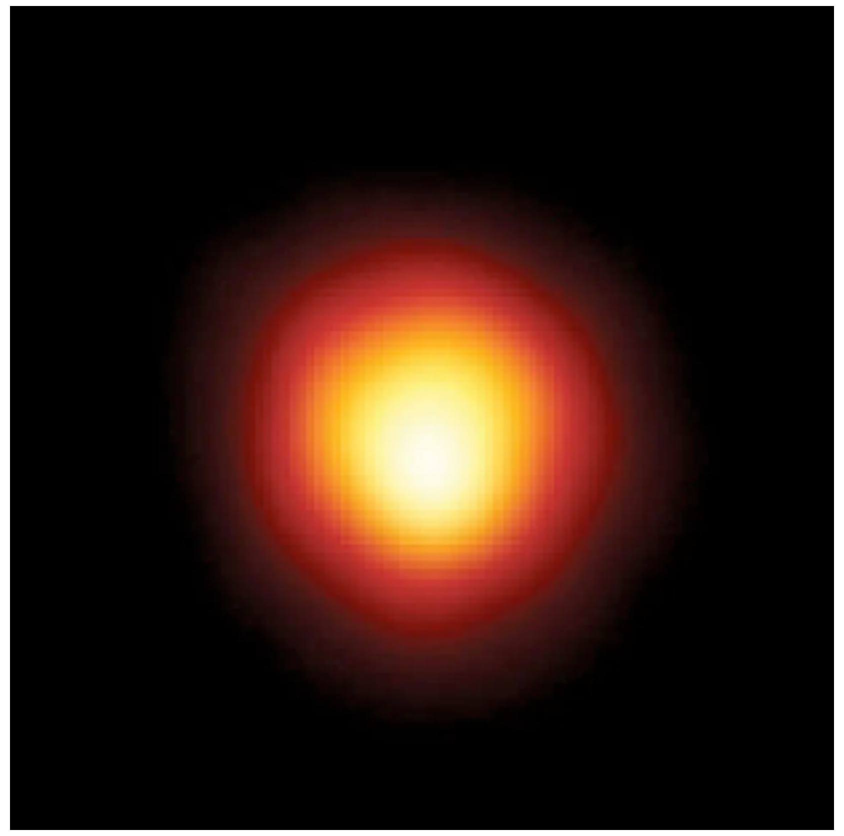


The Quest of Subsolar (Primordial) Black Holes

Essential is invisible to the eyes
(A. de Saint-Exupéry, Le petit Prince)

Background picture: artist view of GW190521 by Ingrid Bourgault

Massive **stars**



Supernovae,
core collapse

+

Neutron Star
1.2-2 $M_\odot$

or

Black Hole

5-60 $M_\odot$

Never lighter than 1 $M_\odot$


Massive stars
Supernovae,
core collapse
+
Neutron Star
1.2-2 M⊙
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5-60 M⊙
Never lighter than 1 M⊙
Inhomogeneities
from the Big-Bang
If O(1), collapse
in the early Universe
Primordial black holes
Cloud of
dark matter particles
If dissipative, collapse
in the late Universe
Dark Matter black holes


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Can have any mass, including smaller than one solar mass


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Our target

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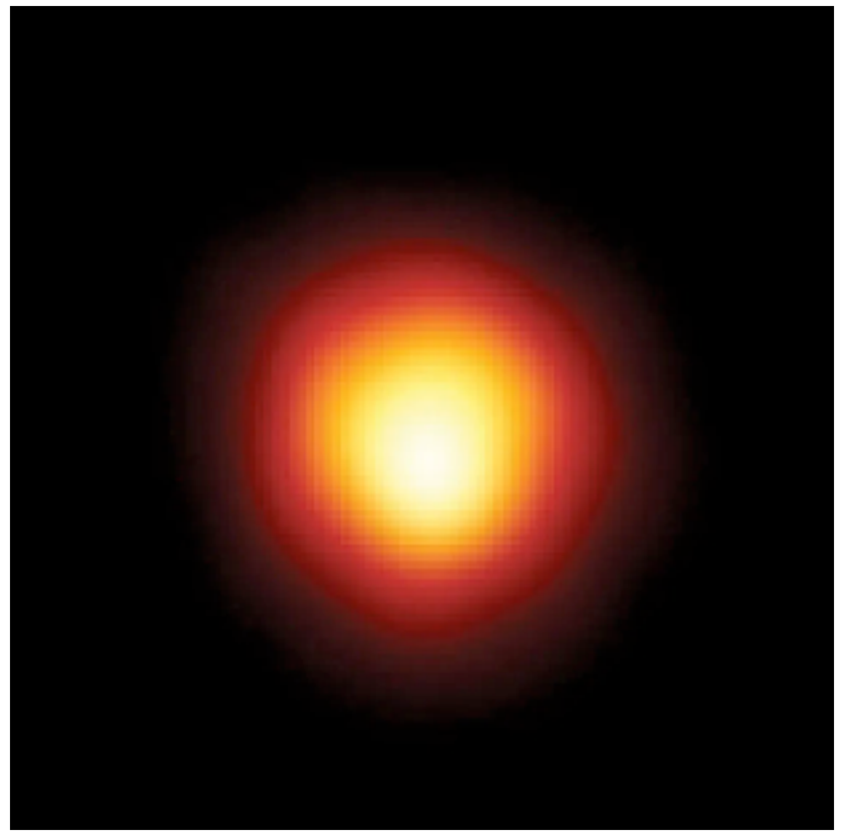

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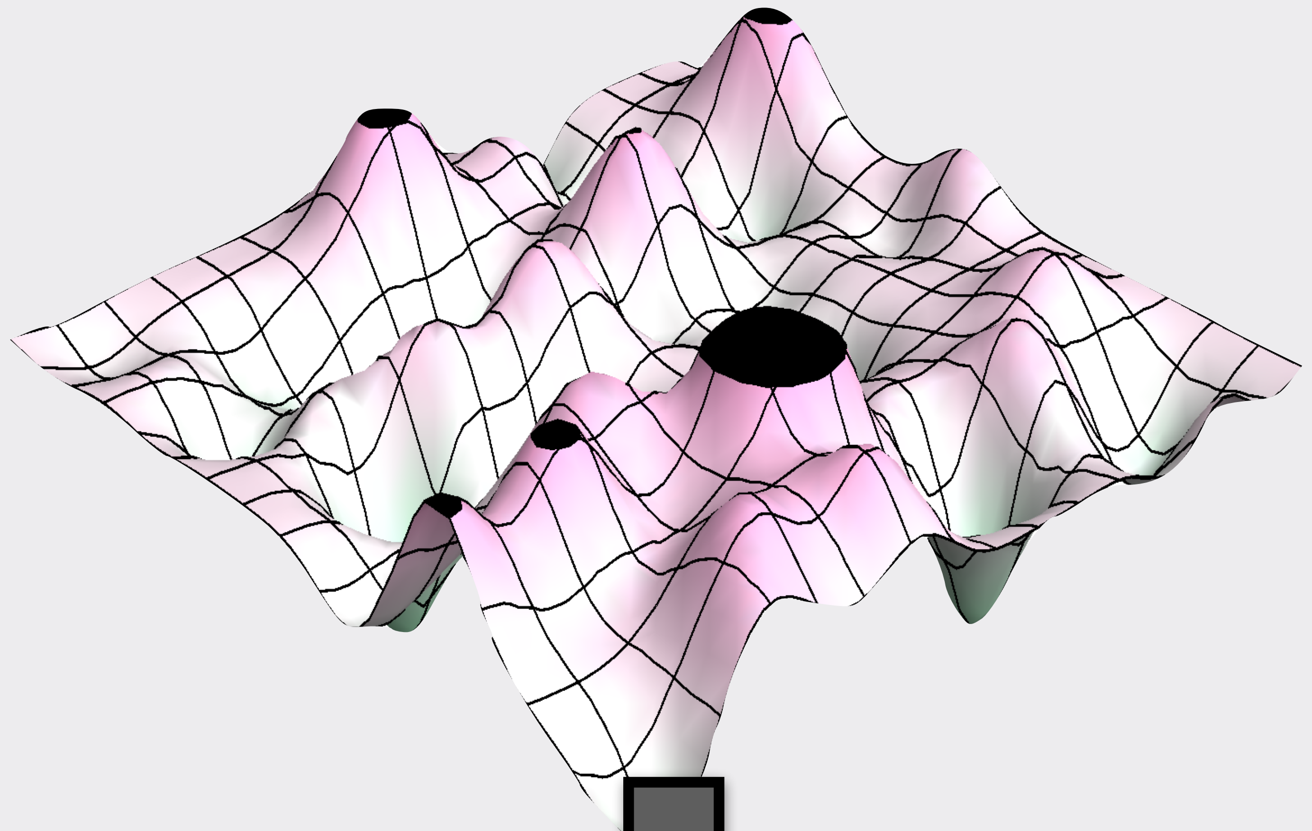

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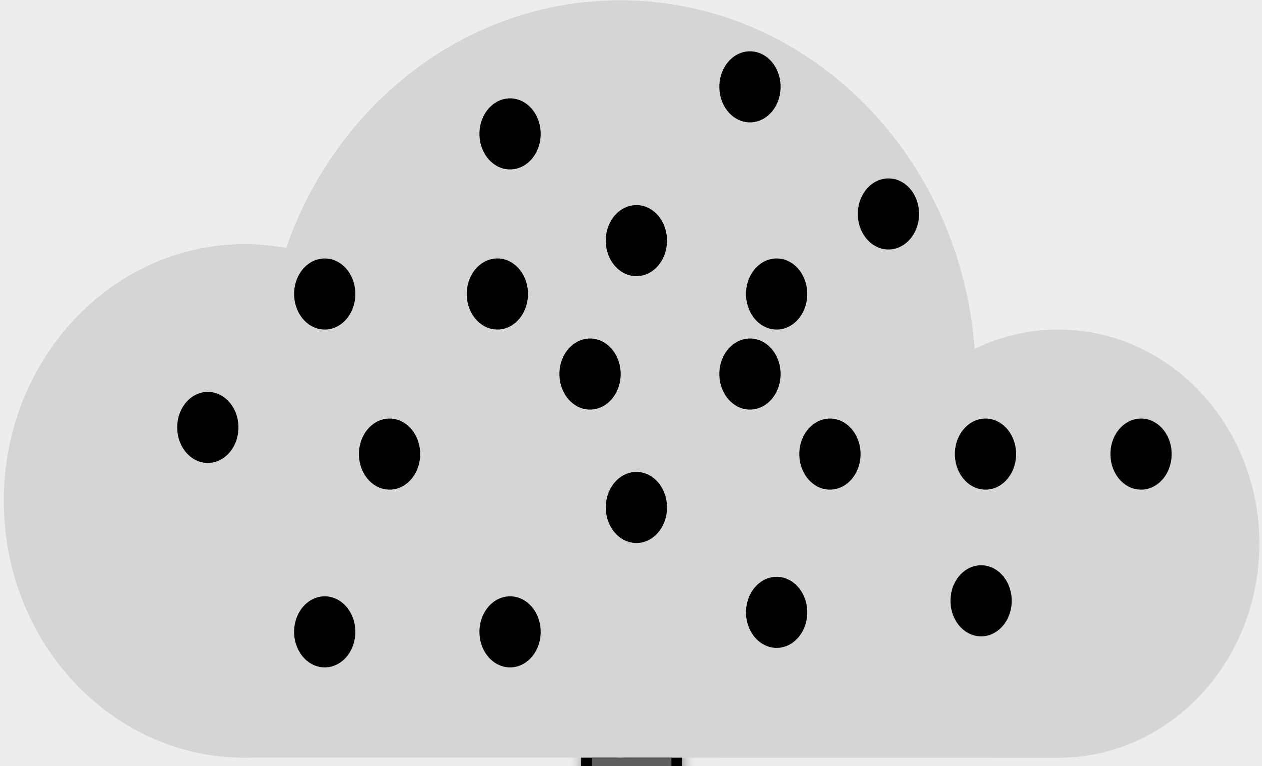

If dissipative, collapse
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Dark Matter black holes

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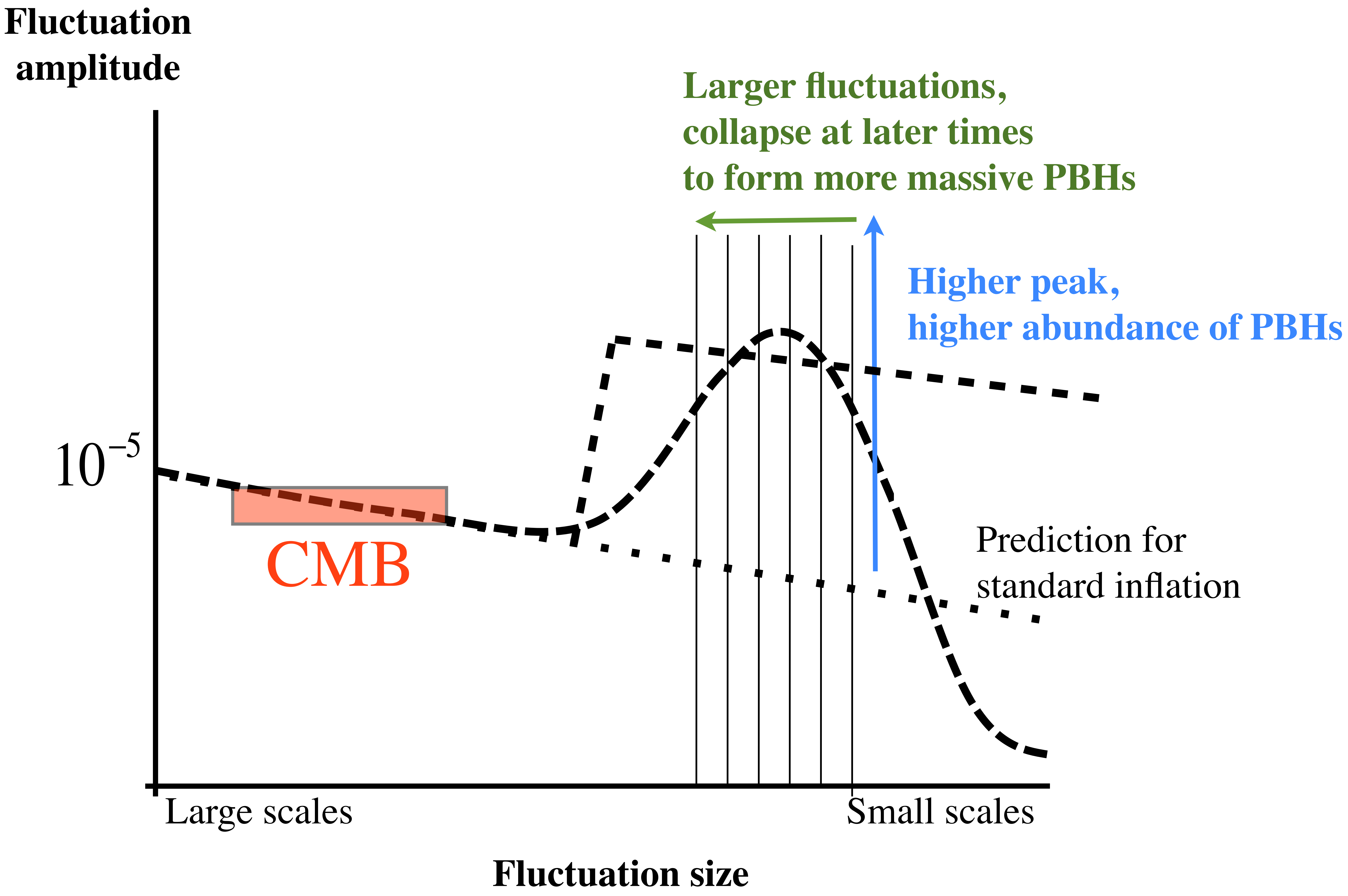
Our target

A simple but fine-tuned process…



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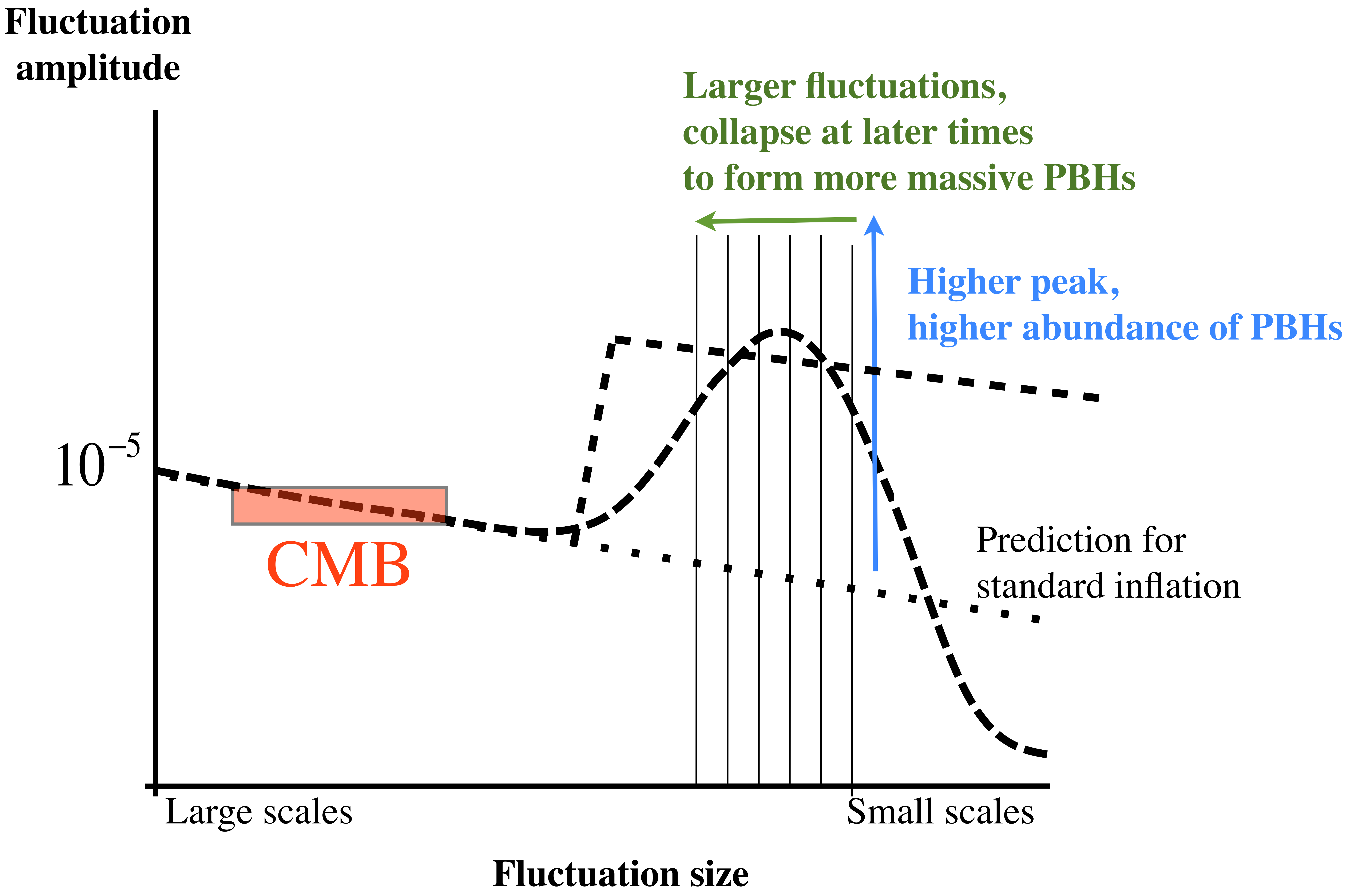

For *Gaussian* perturbations, the density of PBH depends **exponentially** on the threshold (δ_{cr}) and fluctuation amplitude :

$$\beta \equiv \frac{\rho_{\rm PBH}^{\rm form}}{\rho_{\rm cr}} = {\rm erfc}\left(\frac{\delta_{\rm cr}}{\sqrt{\mathcal{P}_\delta}}\right) \approx \sqrt{\frac{2}{\pi}}\frac{\sqrt{\mathcal{P}_\delta}}{\delta_{\rm cr}} {\rm e}^{-\frac{\delta_{\rm cr}^2}{2\mathcal{P}_\delta}}$$

PBHs do not have the same mass

Double fine-tuning problem!

...linked to the QCD epoch

From *known* thermal history:

- **Chandrasekhar** mass ~ **Horizon** mass at **QCD epoch**
- Change in the **number of relativistic degrees of freedom**
- **Equation of state** reduction
- **Critical threshold** is **reduced**
- Formation of **(sub)solar-mass PBHs** is **boosted**

Byrnes, Hindmarsh, Young, Hawkins, 1801.06138
Carr, S.C., Garcìa-Bellido, Kühnel, 1906.08217

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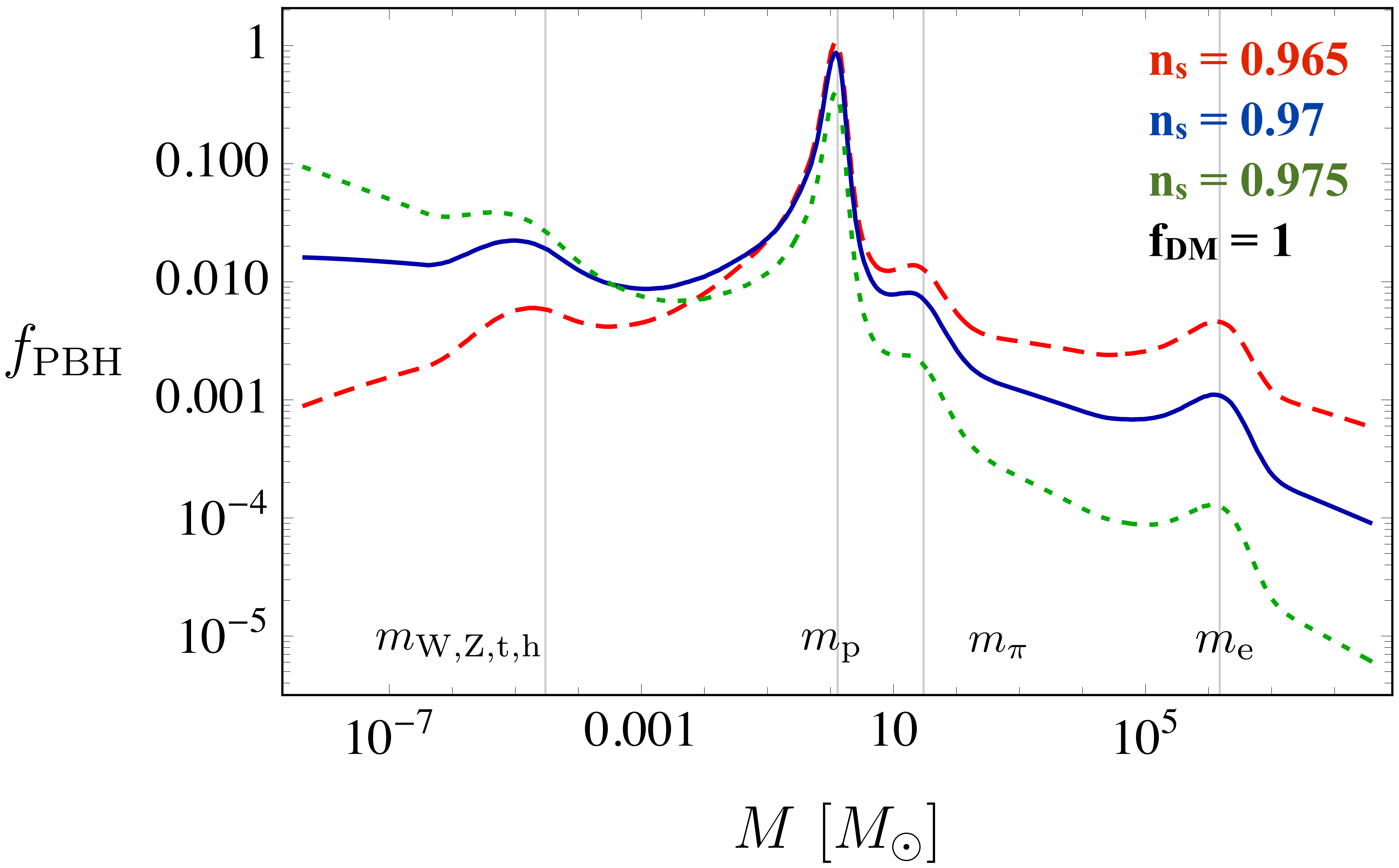
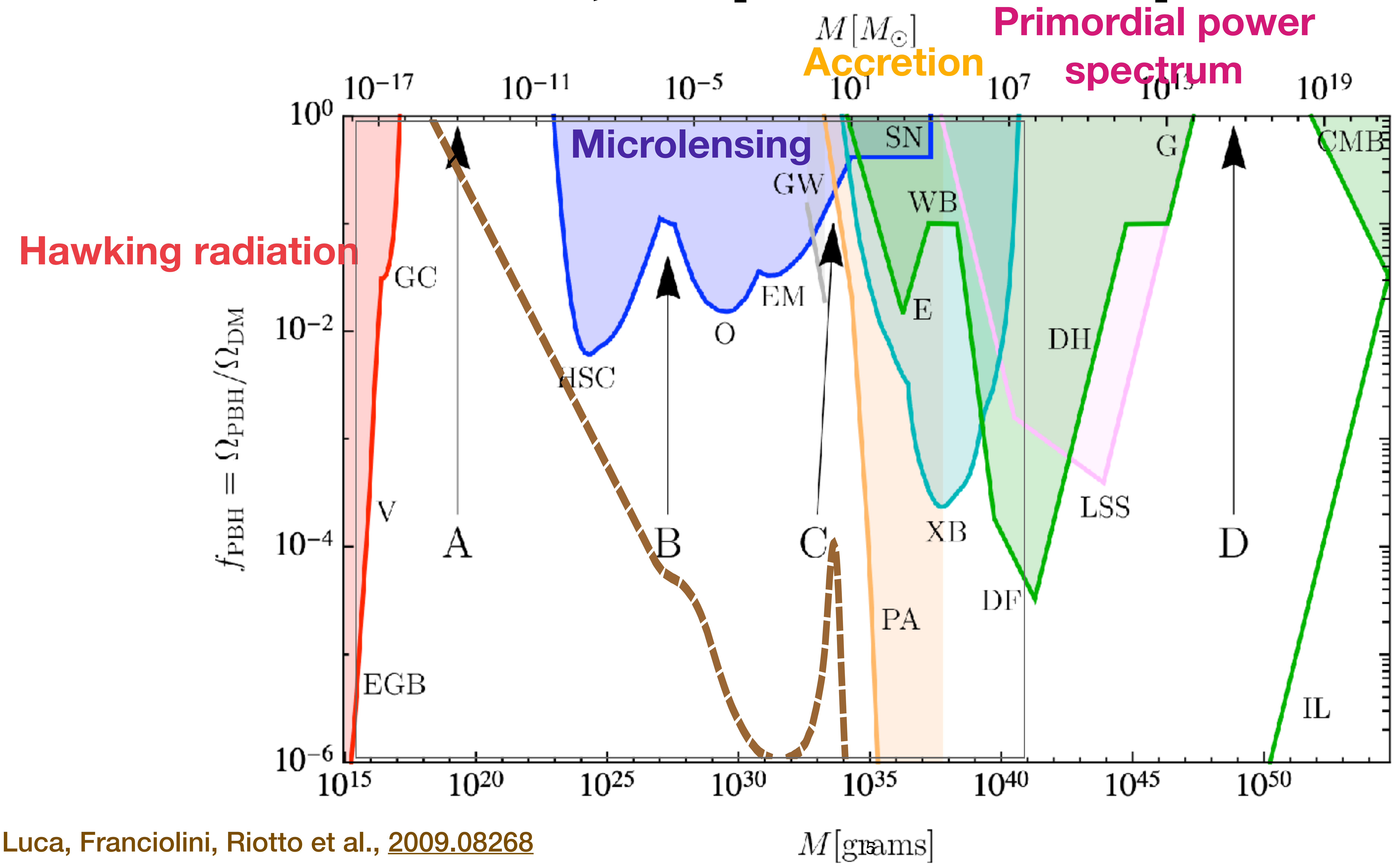


✓ **Inevitable**
✓ **Naturally** leads to **stellar-mass** PBHs
◉ But does **not** solve the **abundance/transition** problems

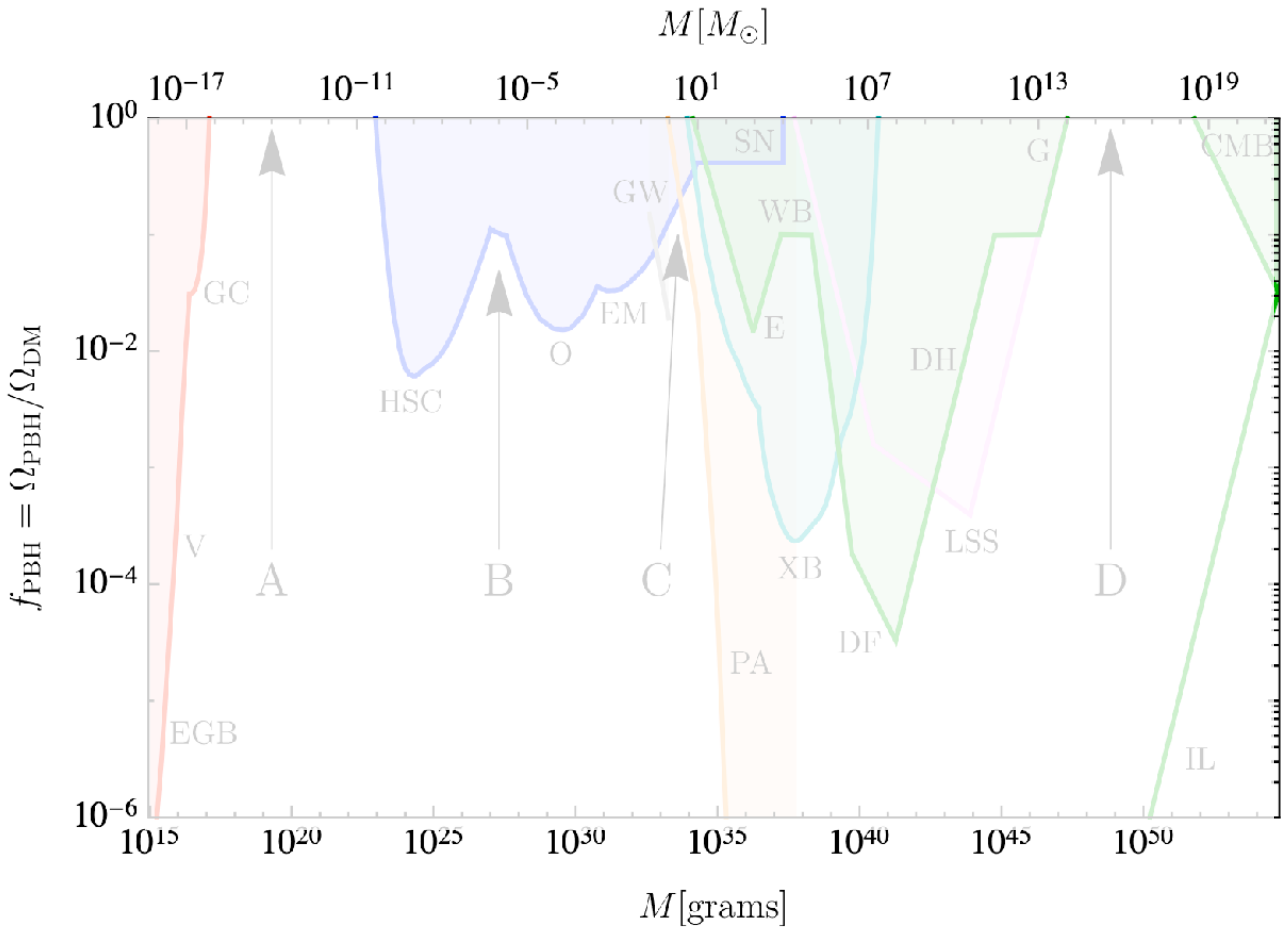
Limits vs clues, a question of point of view



Carr & Kuhnel, 2006.02838

De Luca, Franciolini, Riotto et al., 2009.08268

Limits vs clues, a question of point of view



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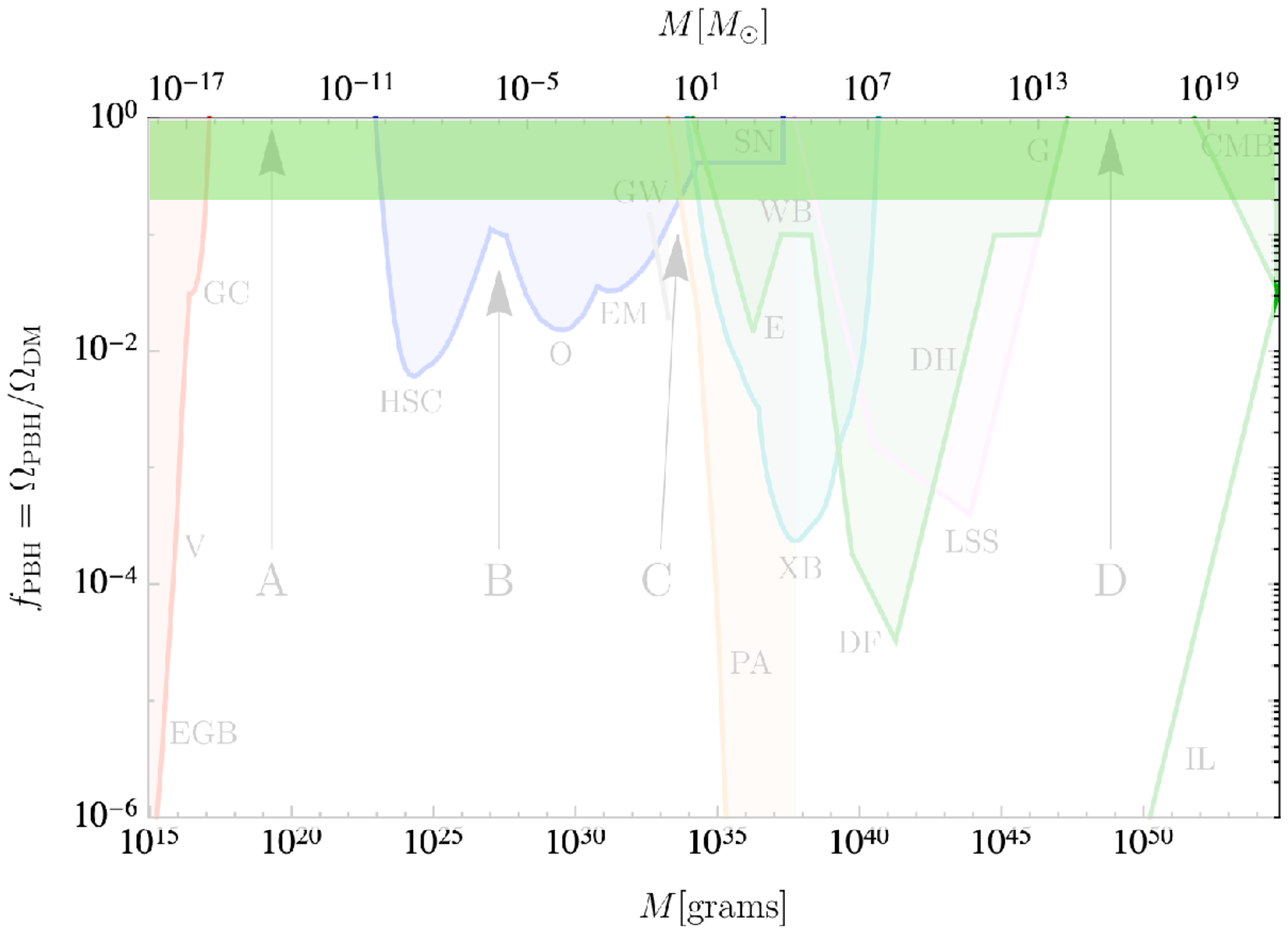

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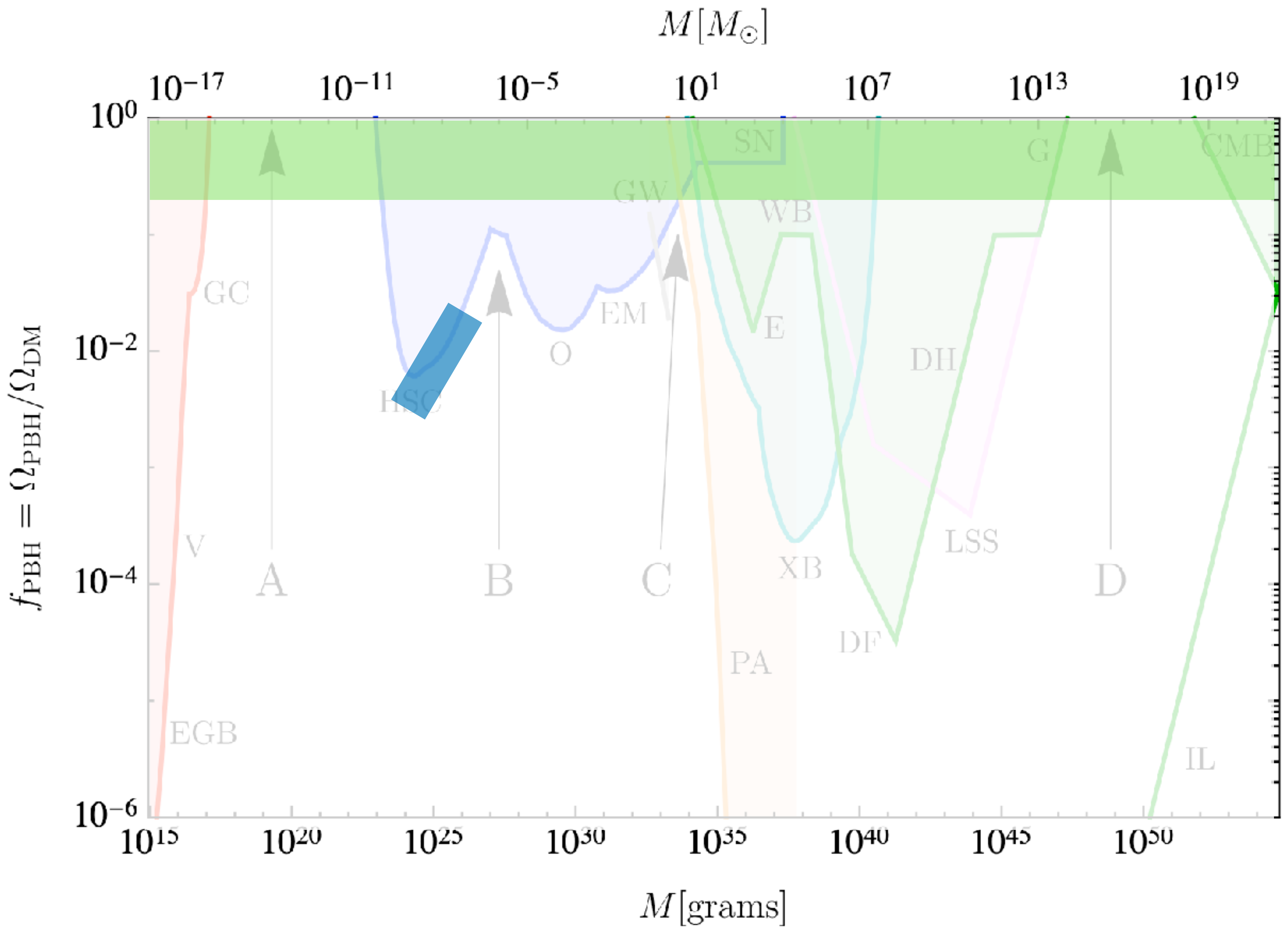

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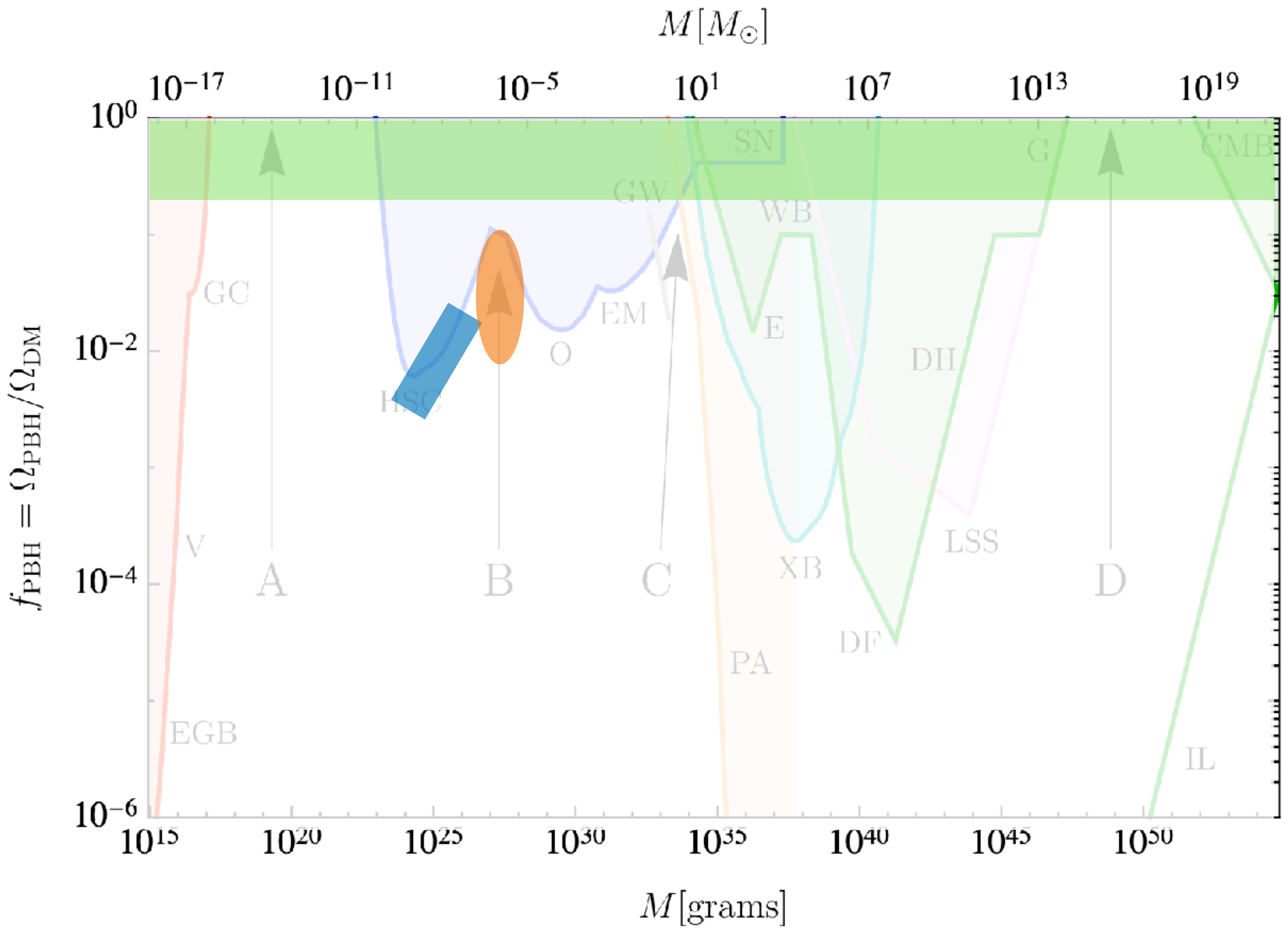

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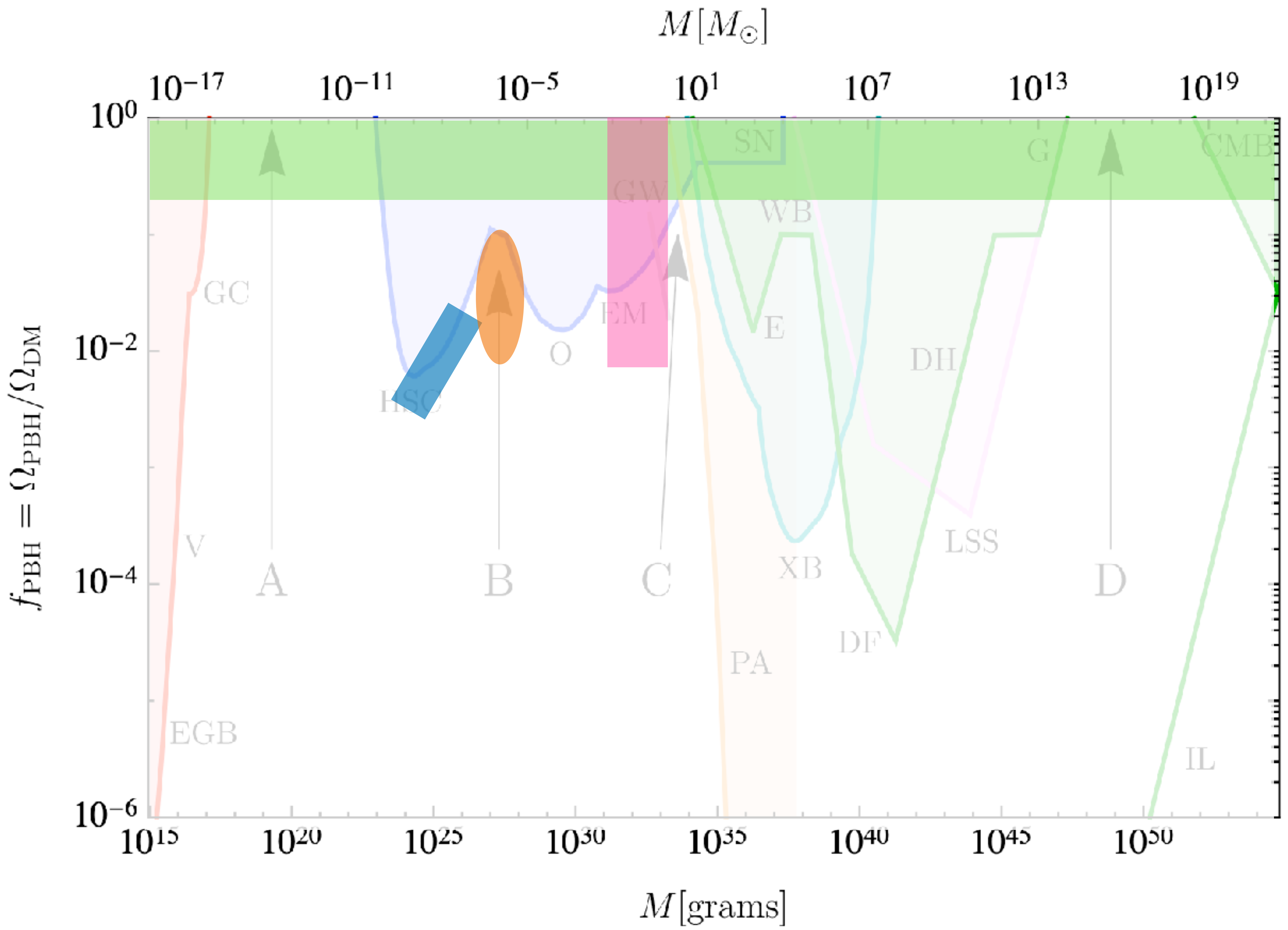

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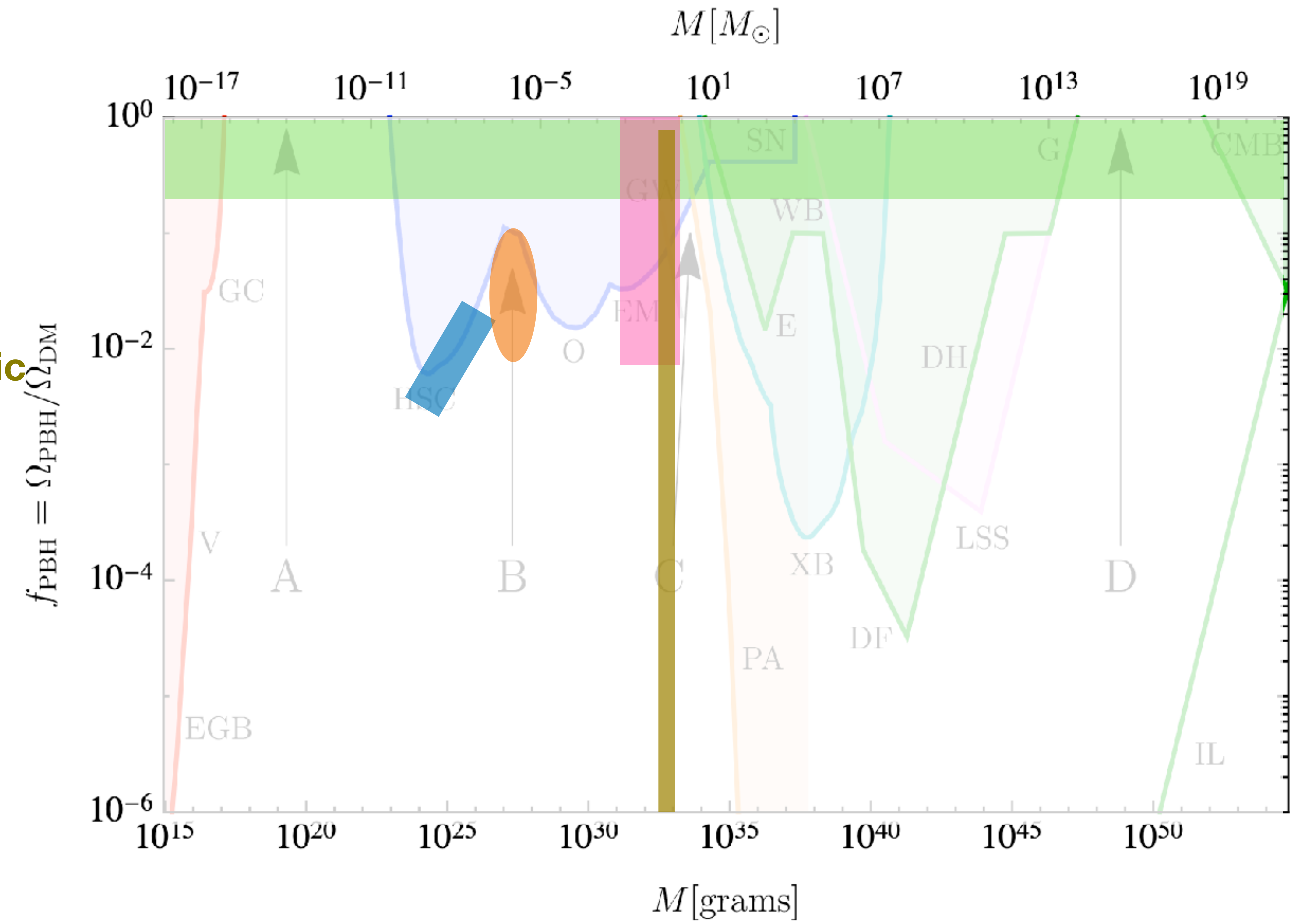

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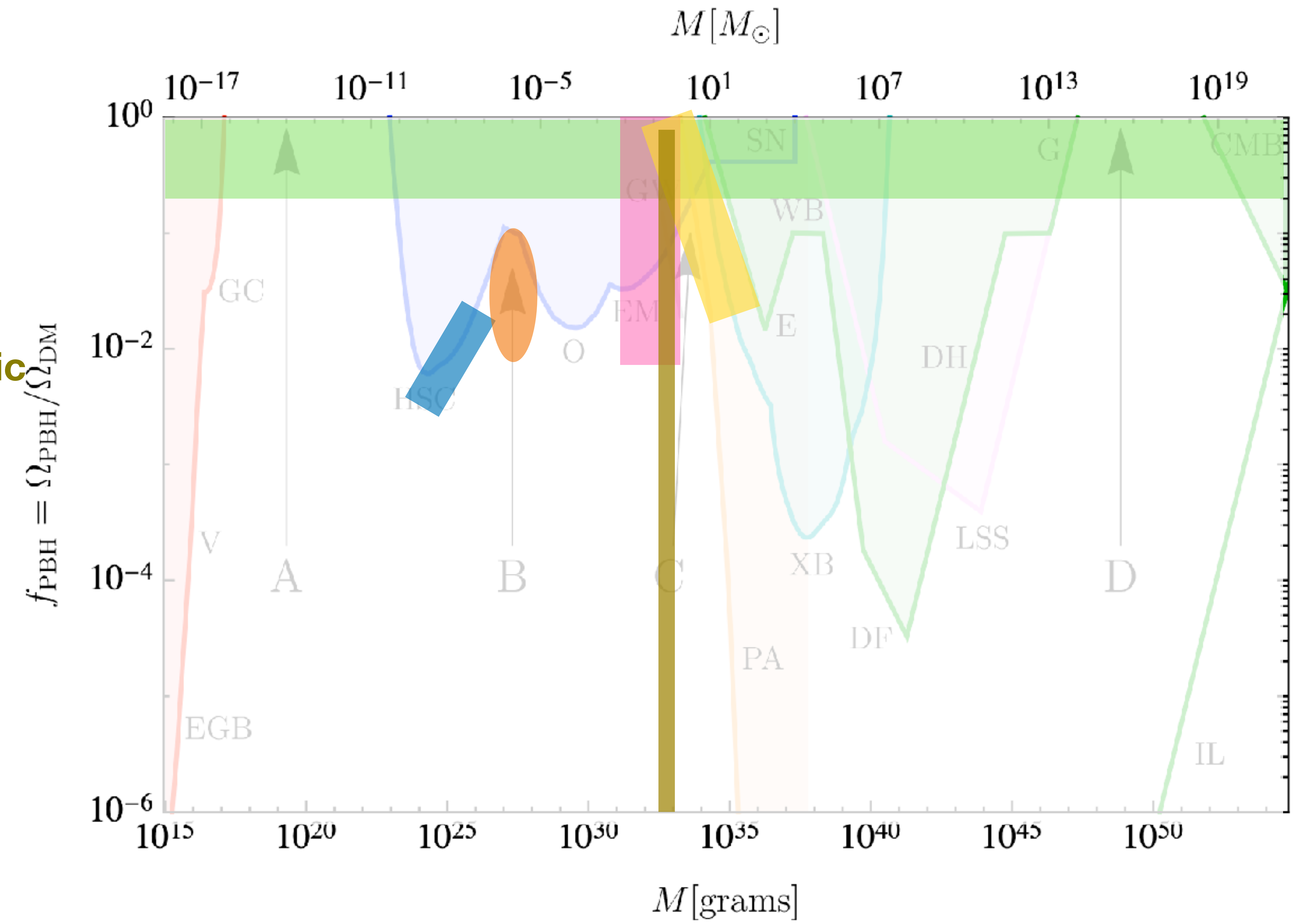

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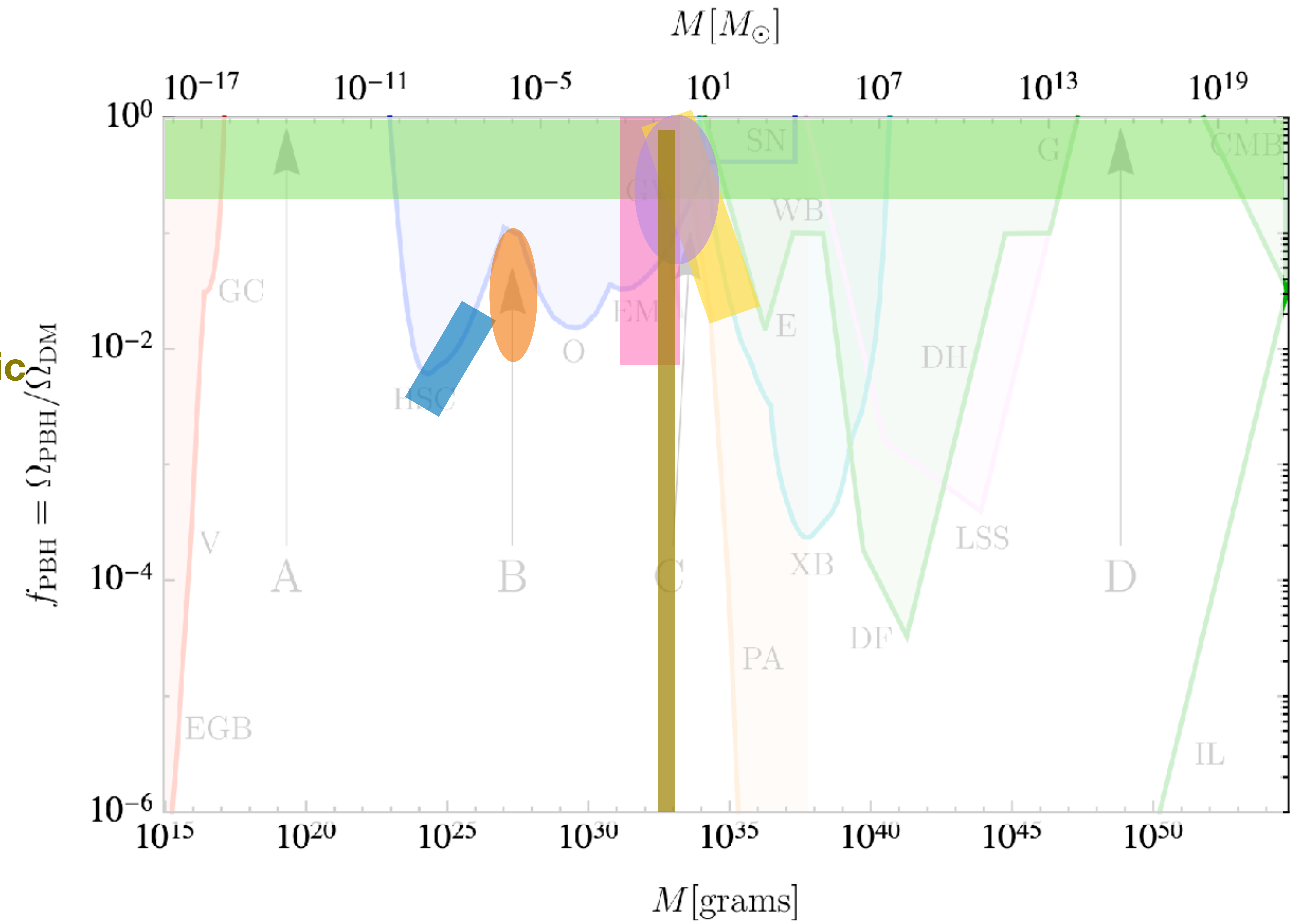

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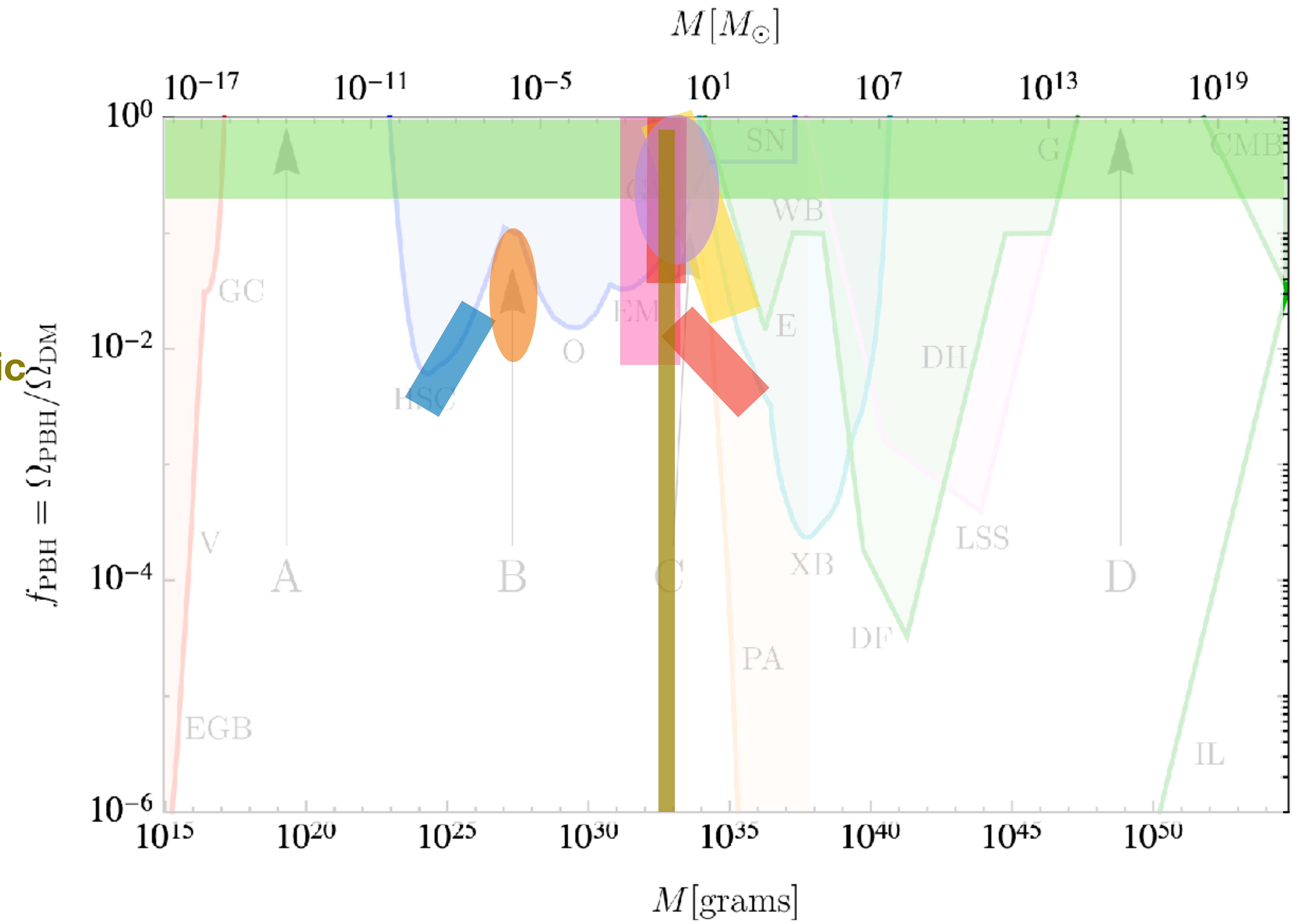

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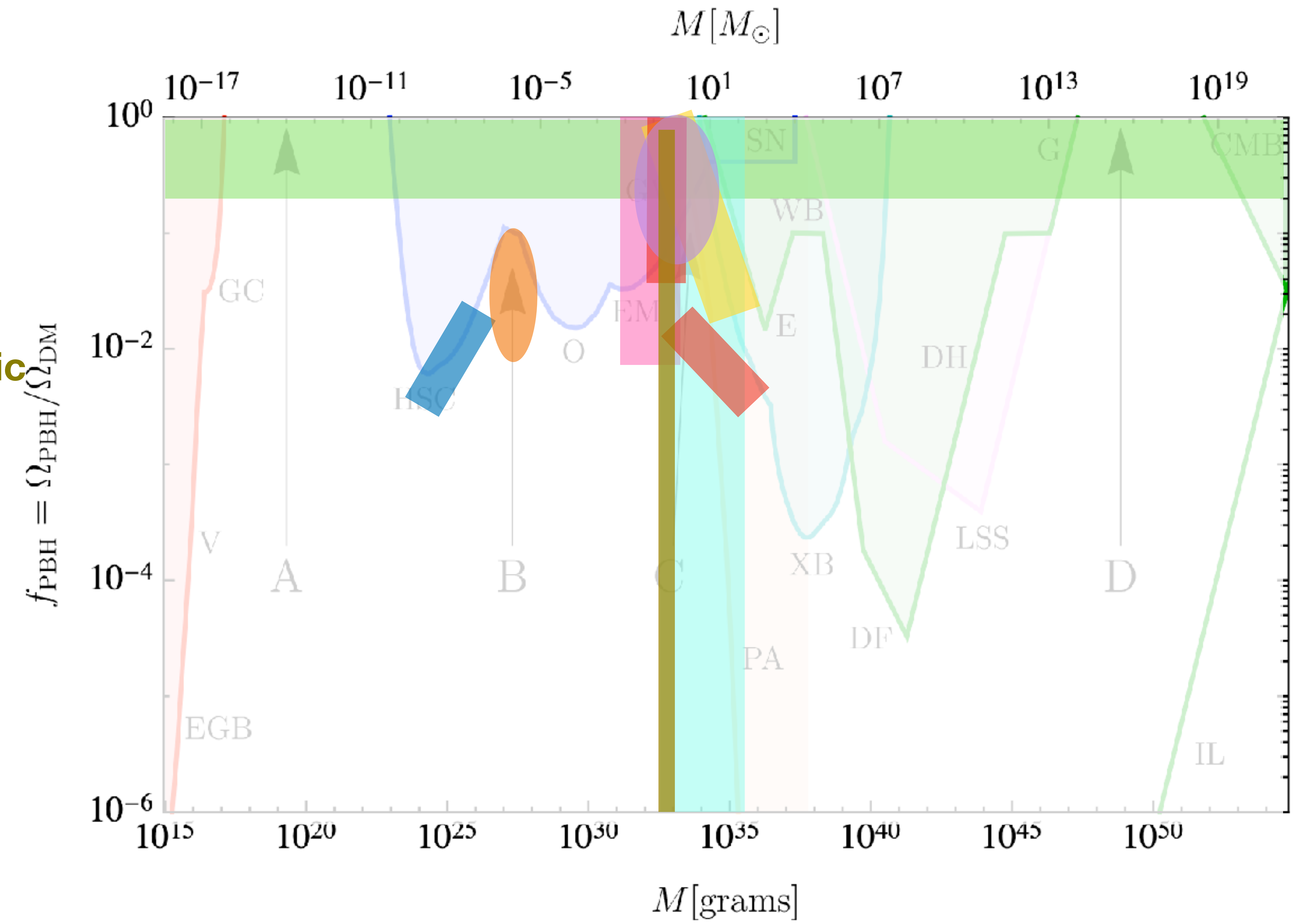

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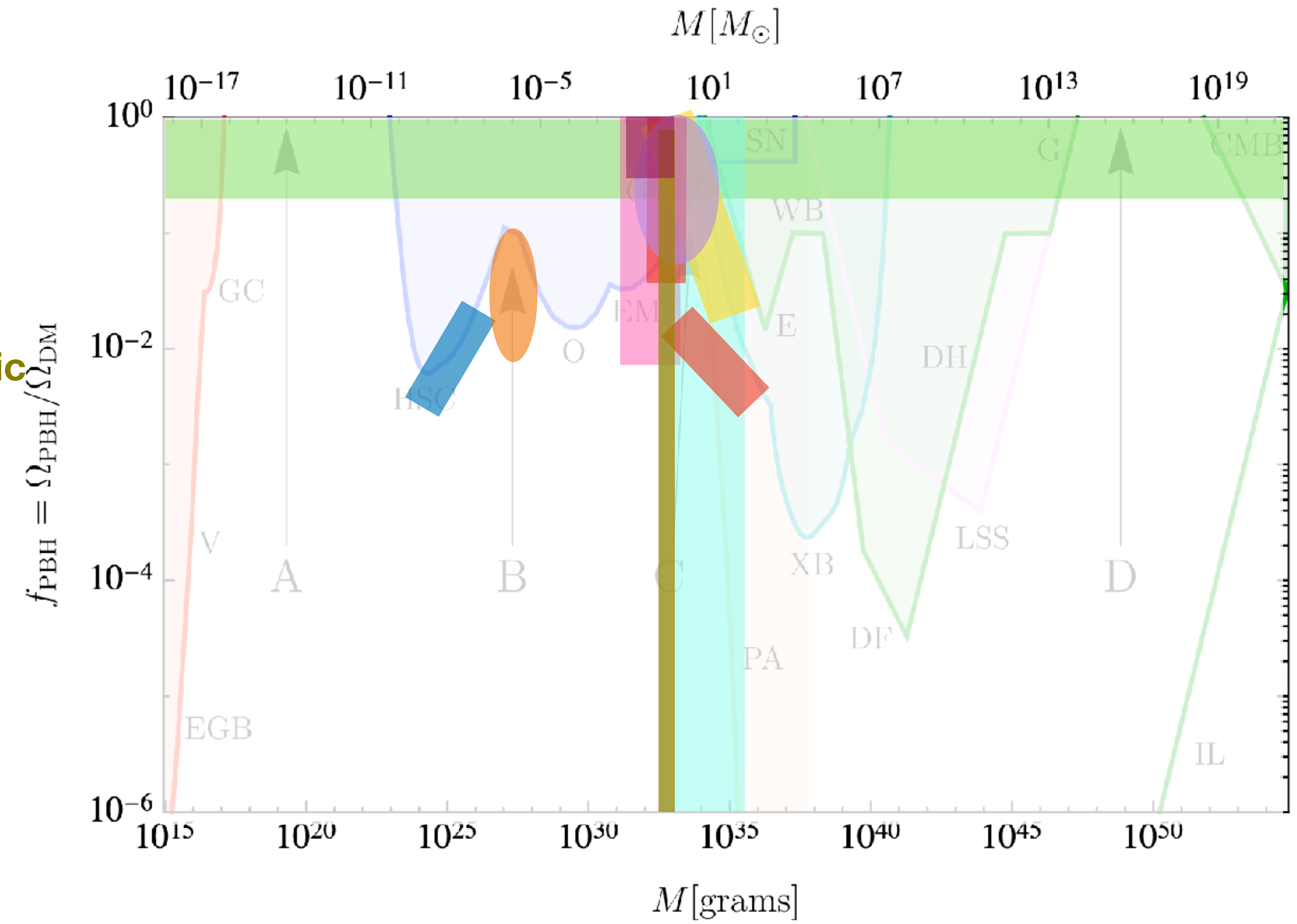

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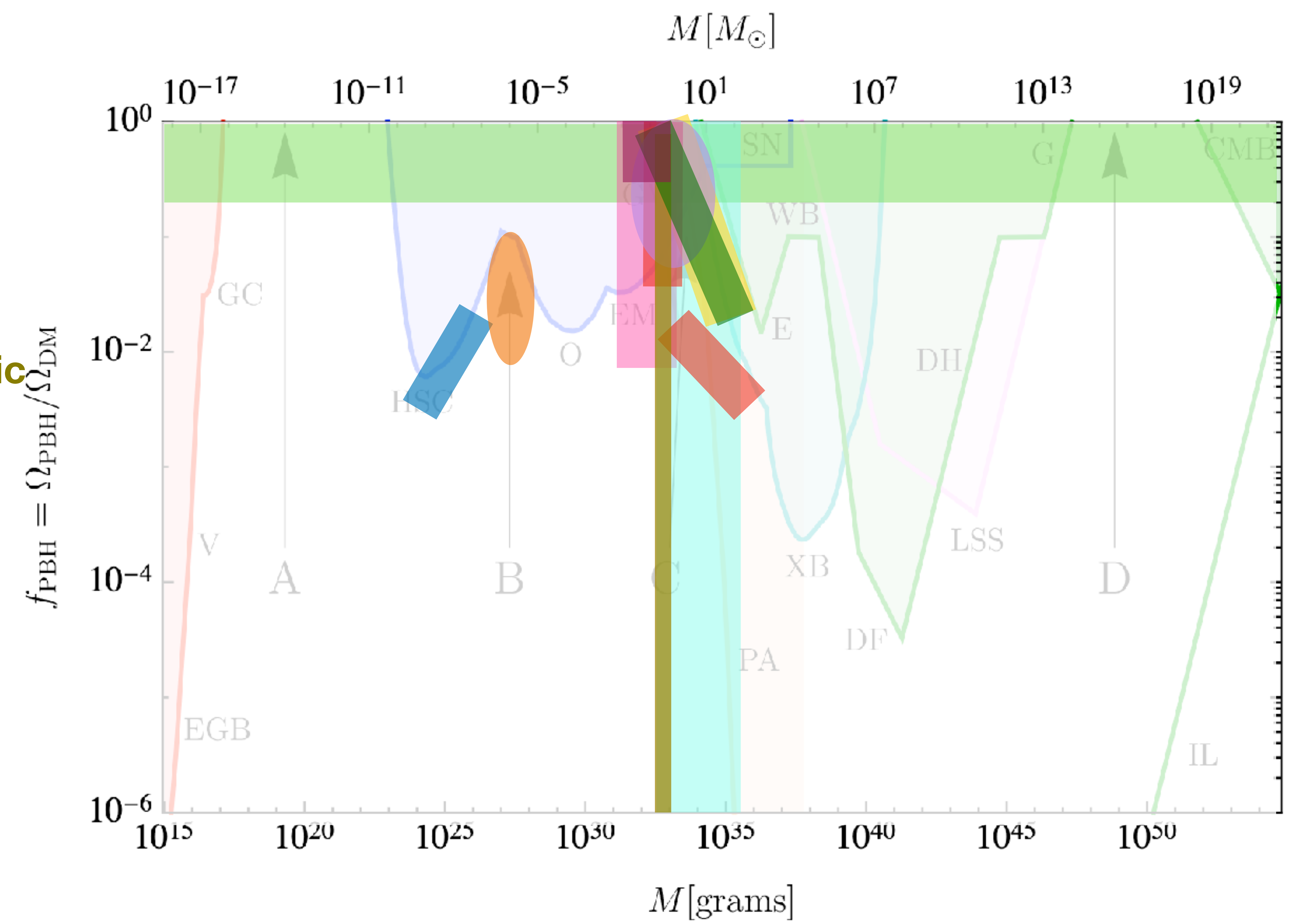

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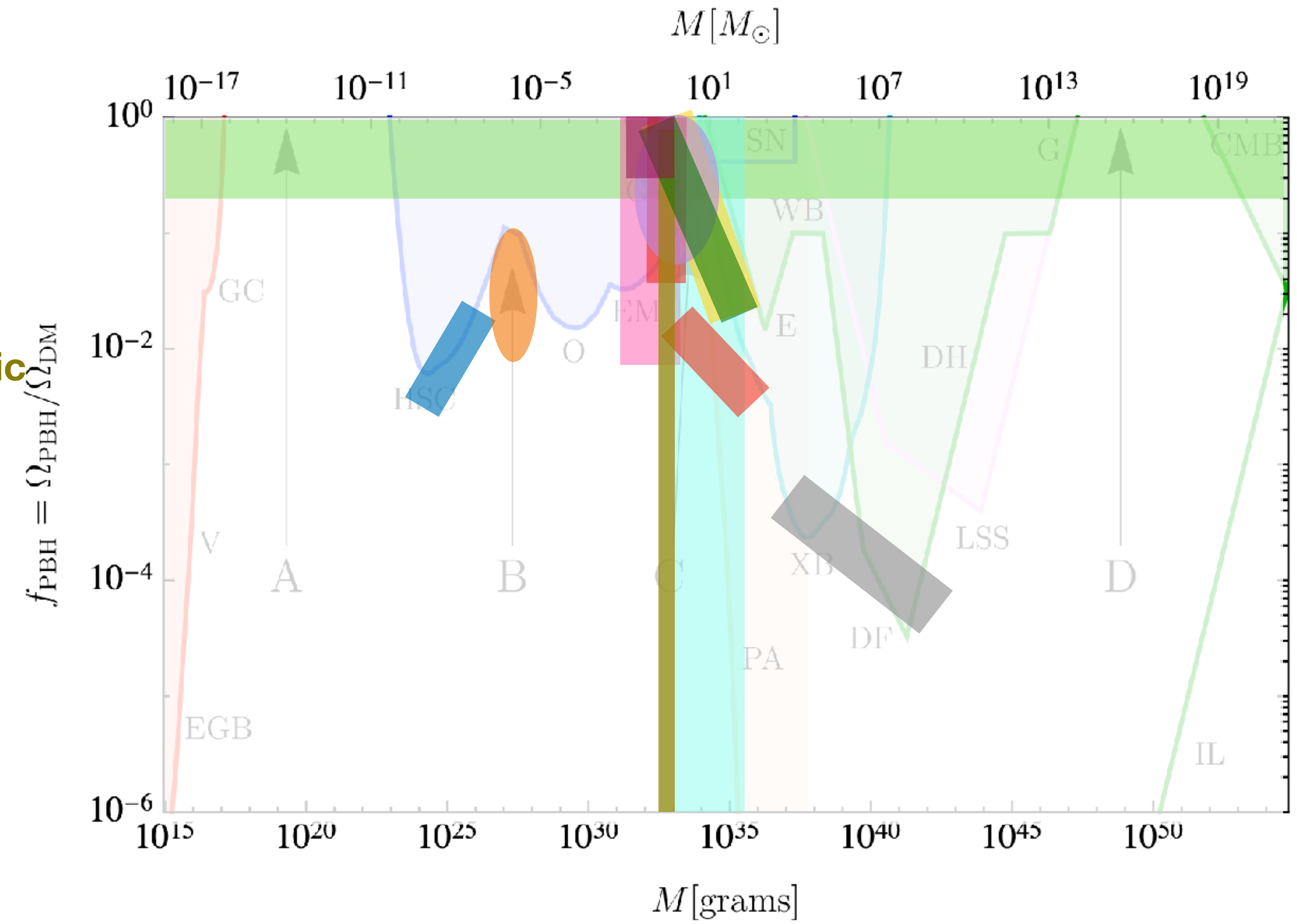

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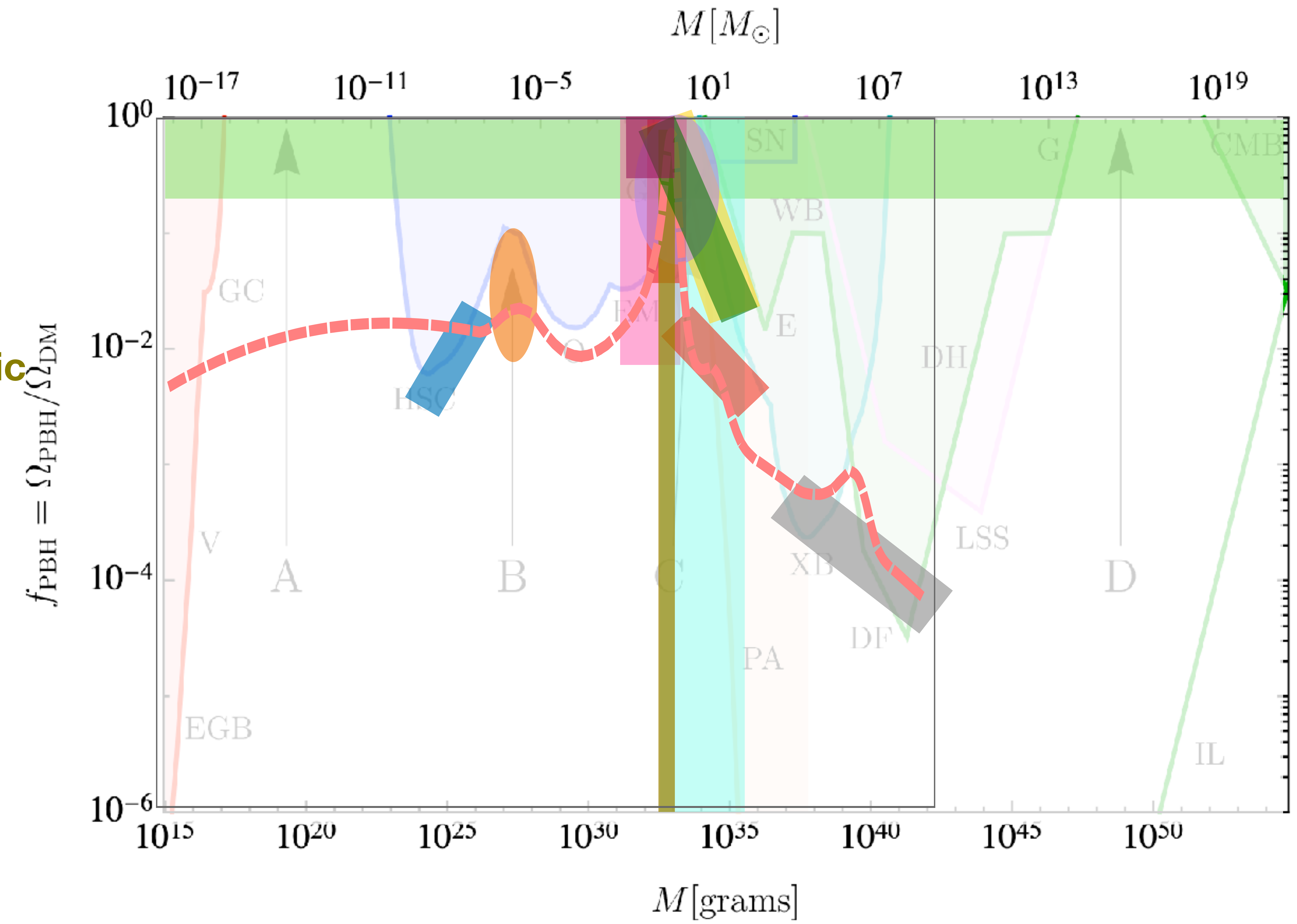


Continuous Waves

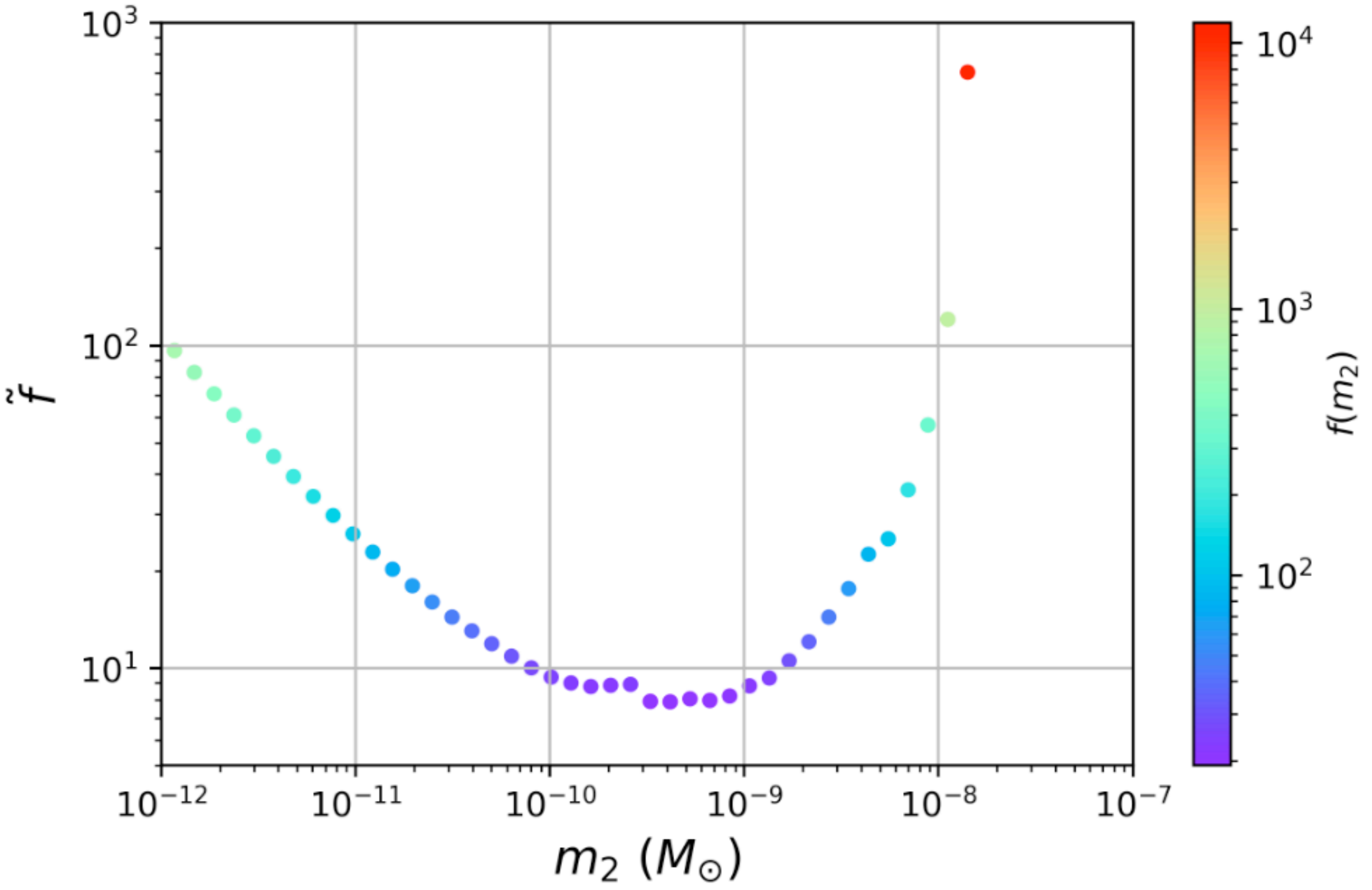

Continuous Waves
Stochastic Background


Continuous Waves
Stochastic Background
Individual mergers

Continuous Waves
Stochastic Background
Individual mergers
Bursts from encounters


Continuous Waves
Stochastic Background
Primordial GW background
Individual mergers
Bursts from encounters

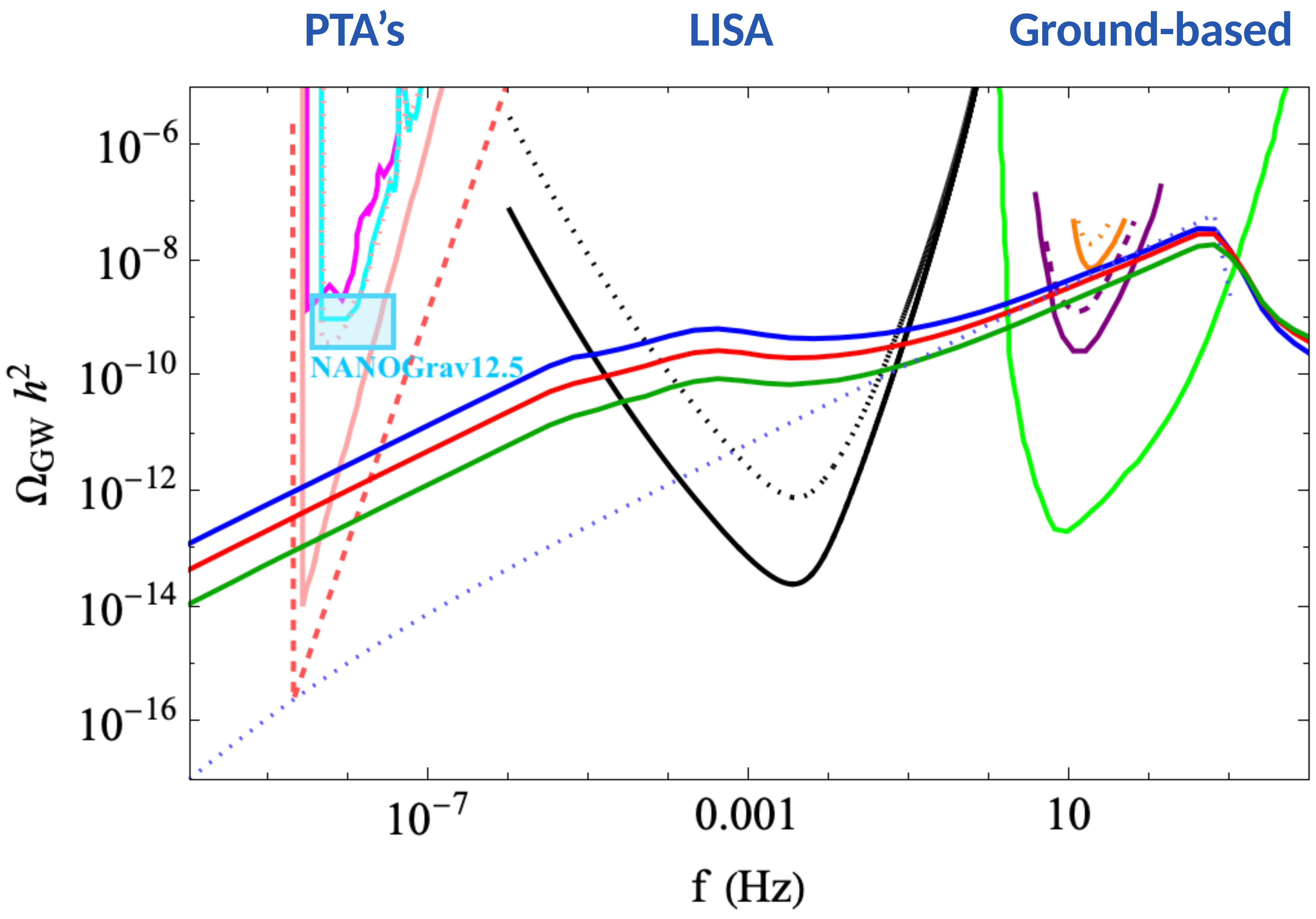
Continuous waves from planetary-mass PBHs



O3 limit
Miller, SC. et al
2110.06188

Boosted GW background from subsolar PBHs

Gravitational-wave background from early PBH binaries:



[E. Bagui, SC, 2021]

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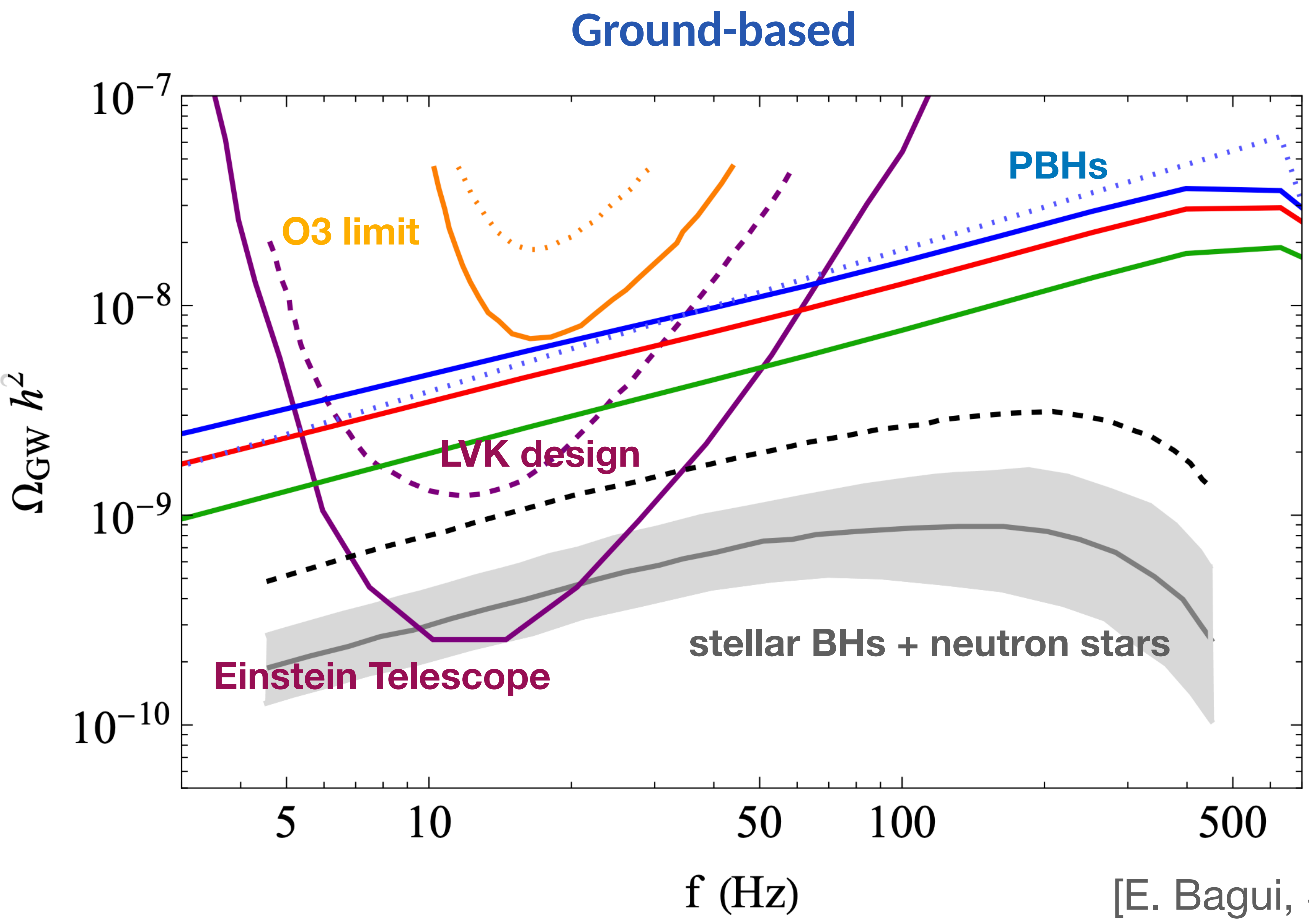

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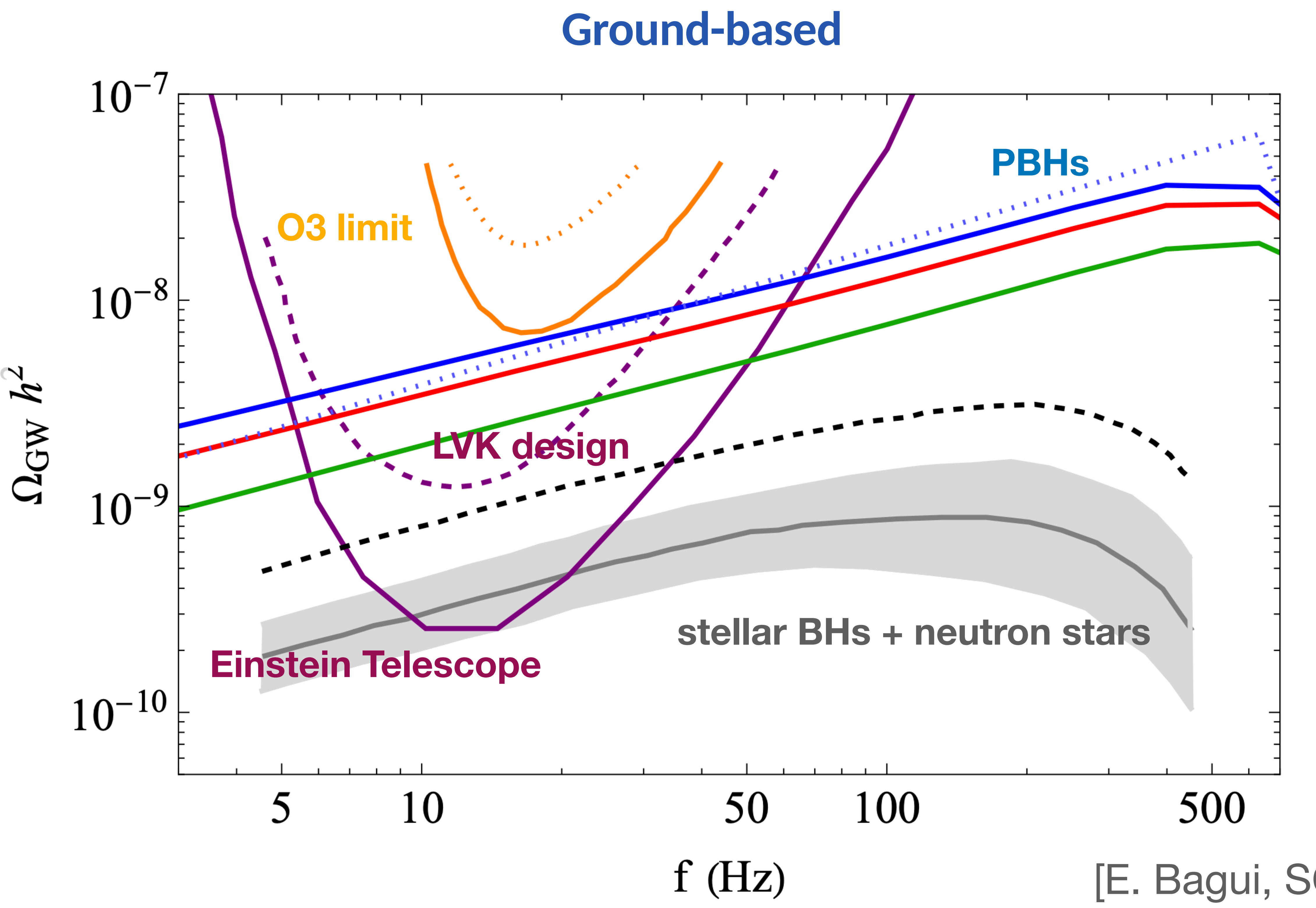

[E. Bagui, SC, 2021]

Well **above stellar BH predictions** due to **solar-mass + planetary-mass** binaries

At the limit of being detected by LIGO/Virgo !

Subsolar black hole mergers

In O2 data, Phukon, SC, et al, 2105.11449

TABLE I. The candidates of the search with a SNR > 8 and a FAR < 2 yr^{-1}. We report here the FAR, $\ln \mathcal{L}$, the UCT time of the event (date and hours), template parameters that pick the events and the associated SNRs.

FAR [yr^{-1}]	$\ln \mathcal{L}$	UTC time	mass 1 [$M_\odot$]	mass 2 [$M_\odot$]	spin1z	spin2z	Network SNR	H1 SNR	L1 SNR
0.1674	8.457	2017-03-15 15:51:30	3.062	0.9281	0.08254	-0.09841	8.527	8.527	-
0.2193	8.2	2017-07-10 17:52:43	2.106	0.2759	0.08703	0.0753	8.157	-	8.157
0.4134	7.585	2017-04-01 01:43:34	4.897	0.7795	-0.05488	-0.04856	8.672	6.319	5.939
1.2148	6.589	2017-03-08 07:07:18	2.257	0.6997	-0.03655	-0.04473	8.535	6.321	5.736

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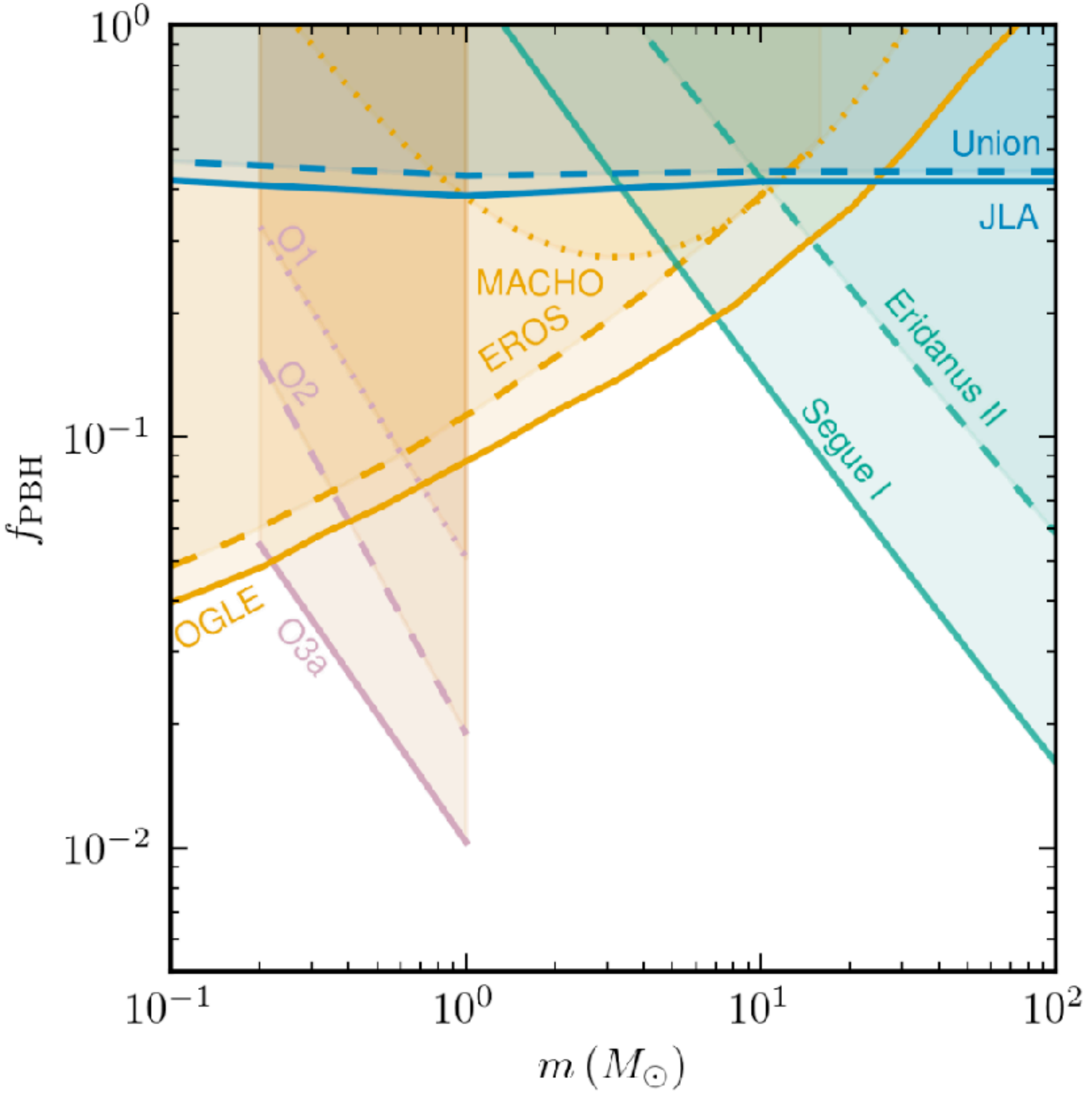
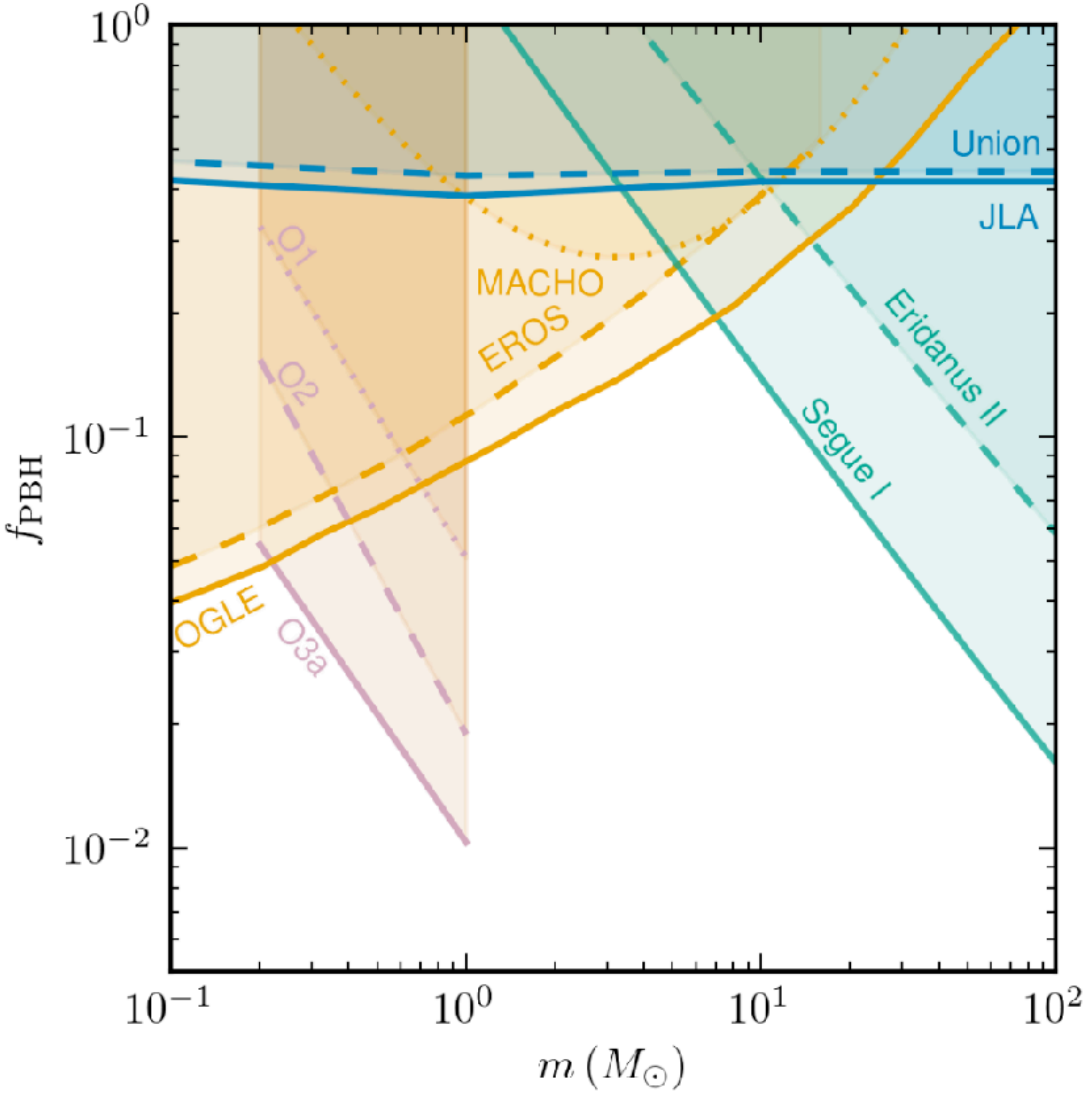
Noise or tip of the iceberg ?

Subsolar black hole mergers



LVK, 2109.12197

Subsolar black hole mergers

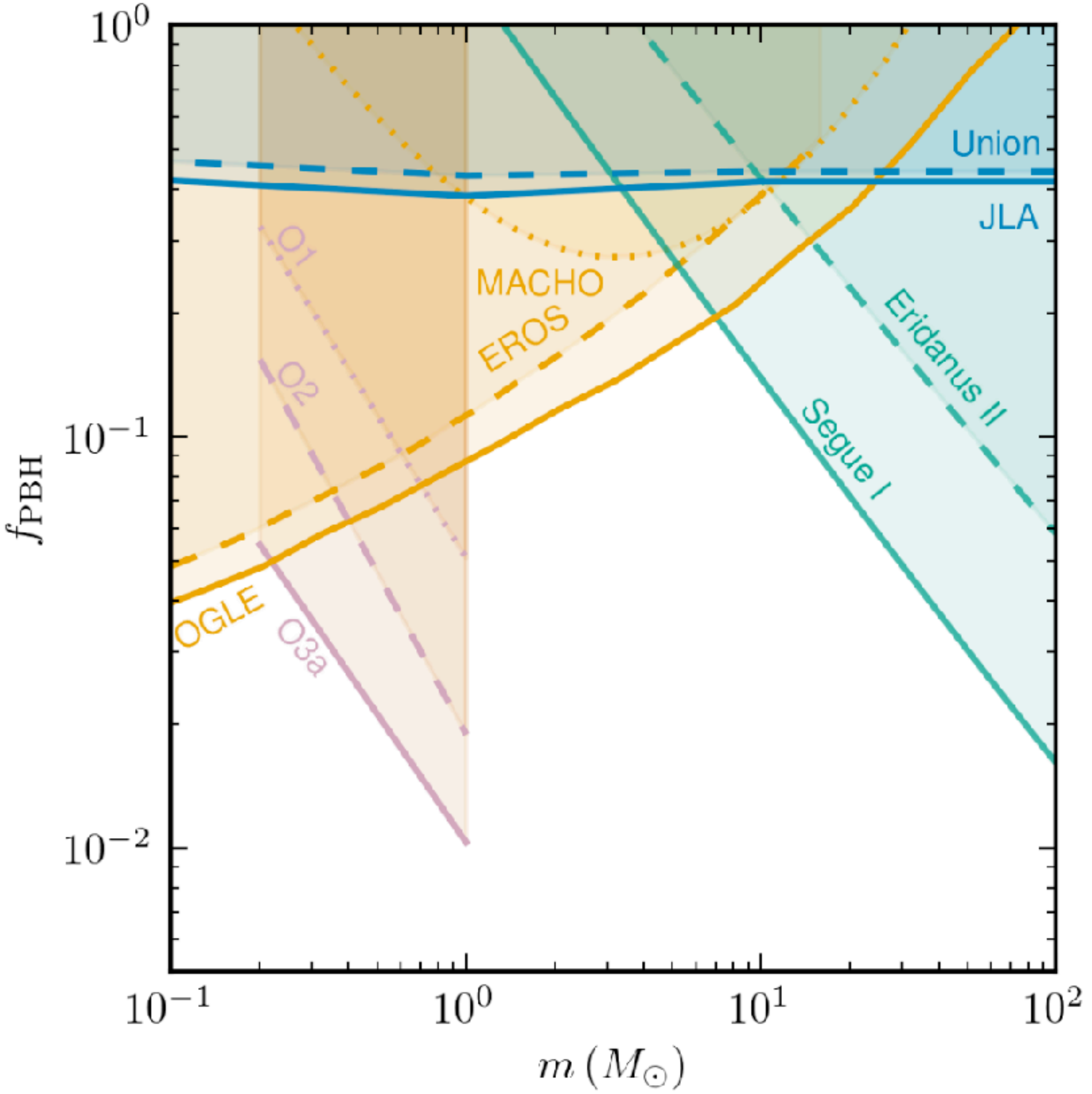


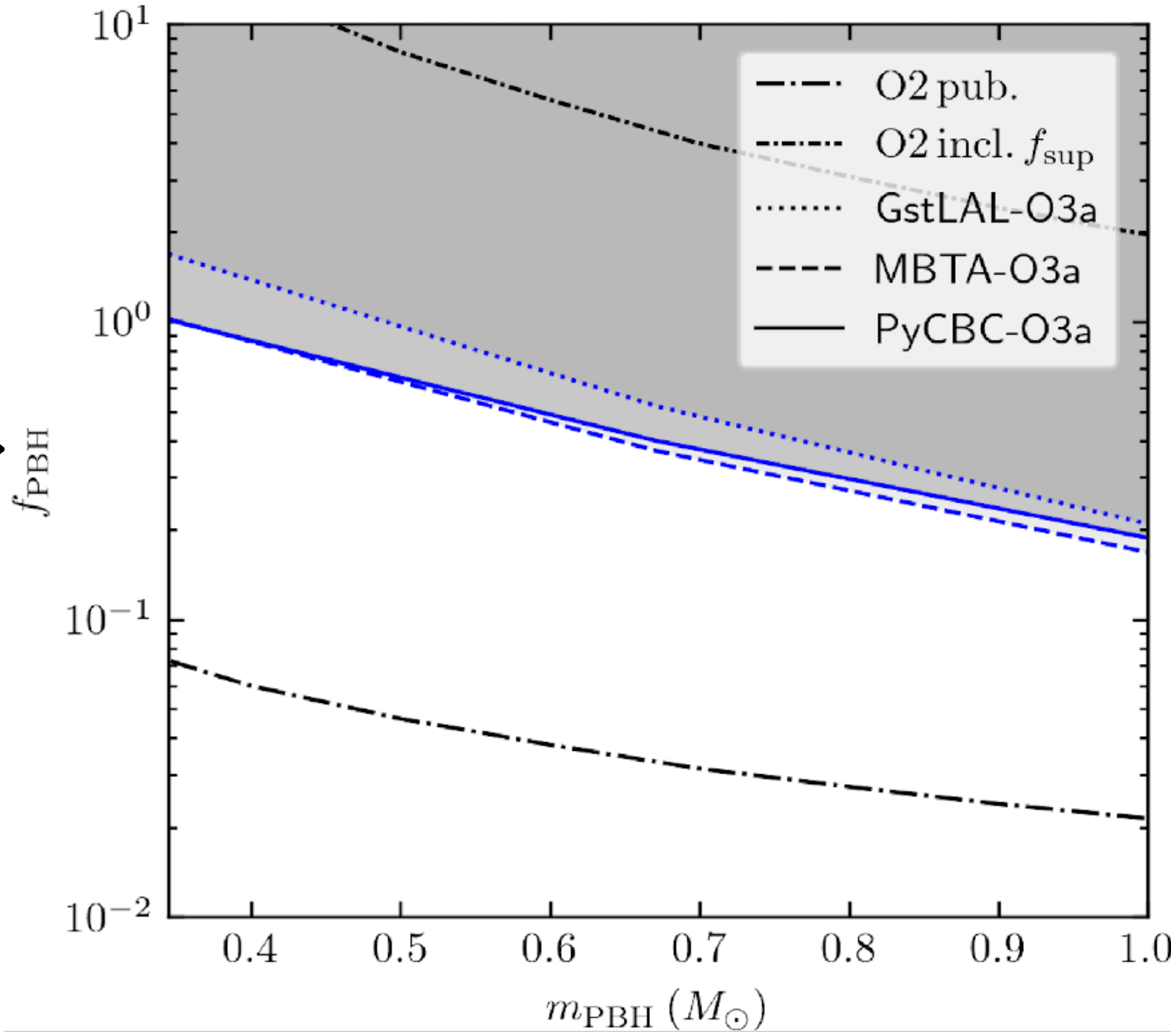
LVK, 2109.12197

But… Poisson effect in a black hole sea!

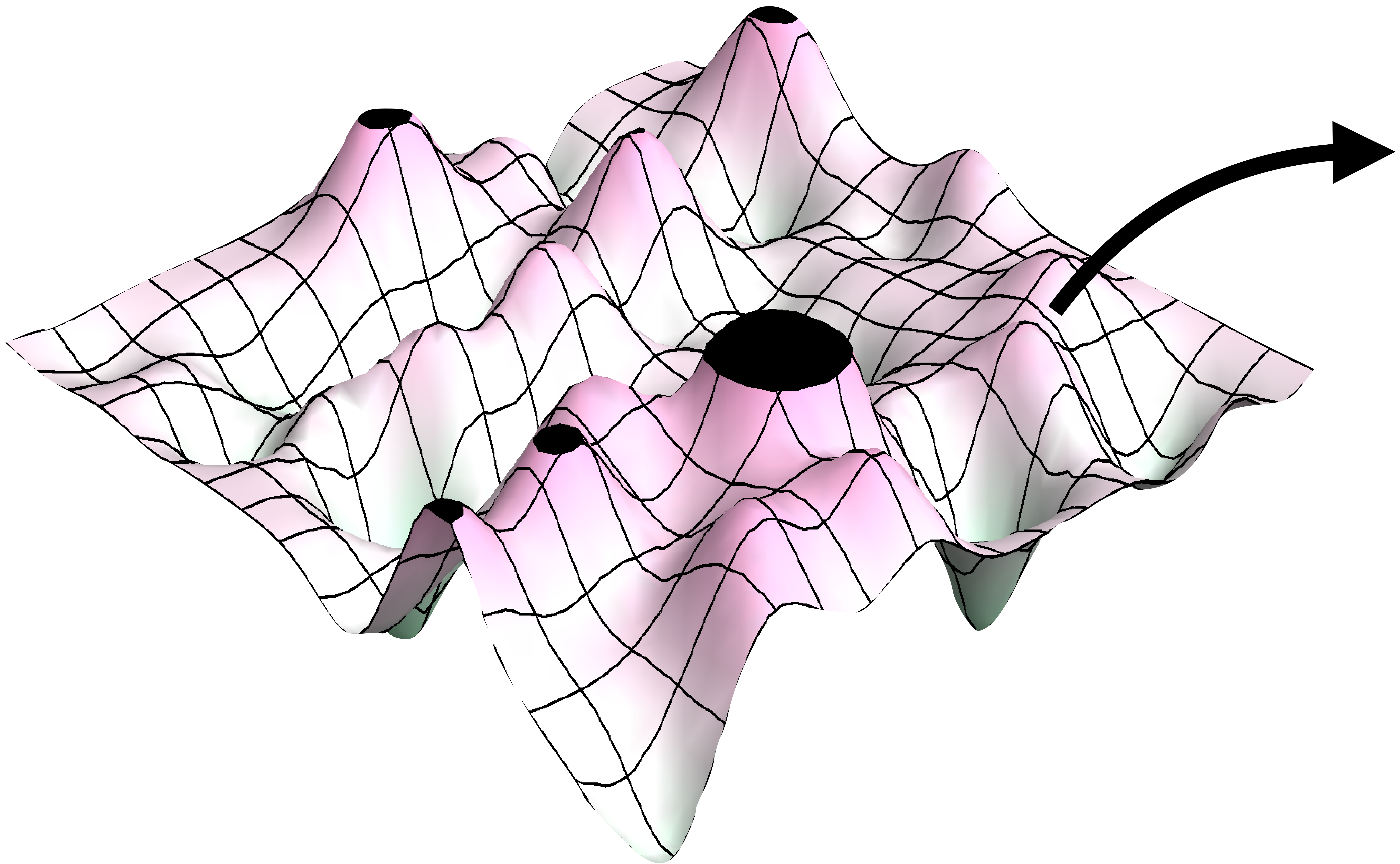
Do not include
merger rate suppression
due to PBH clusters
inevitably induced
by Poisson fluctuations

Subsolar black hole **mergers**



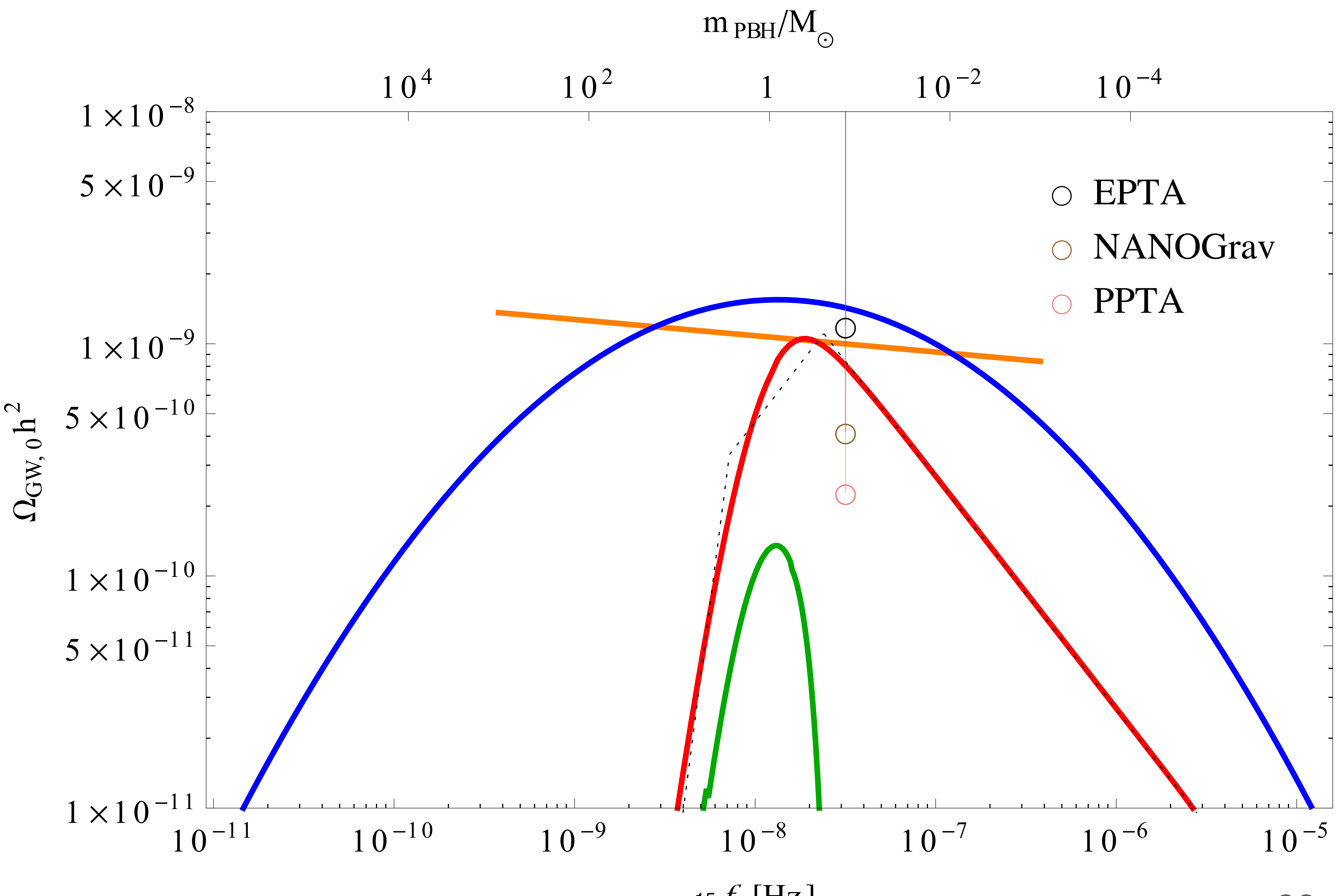


GW background from density perturbations



Source gravitational-waves (at 2nd order)

GW background from density perturbations



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SC, Garcia-Bellido, Orani, 2018

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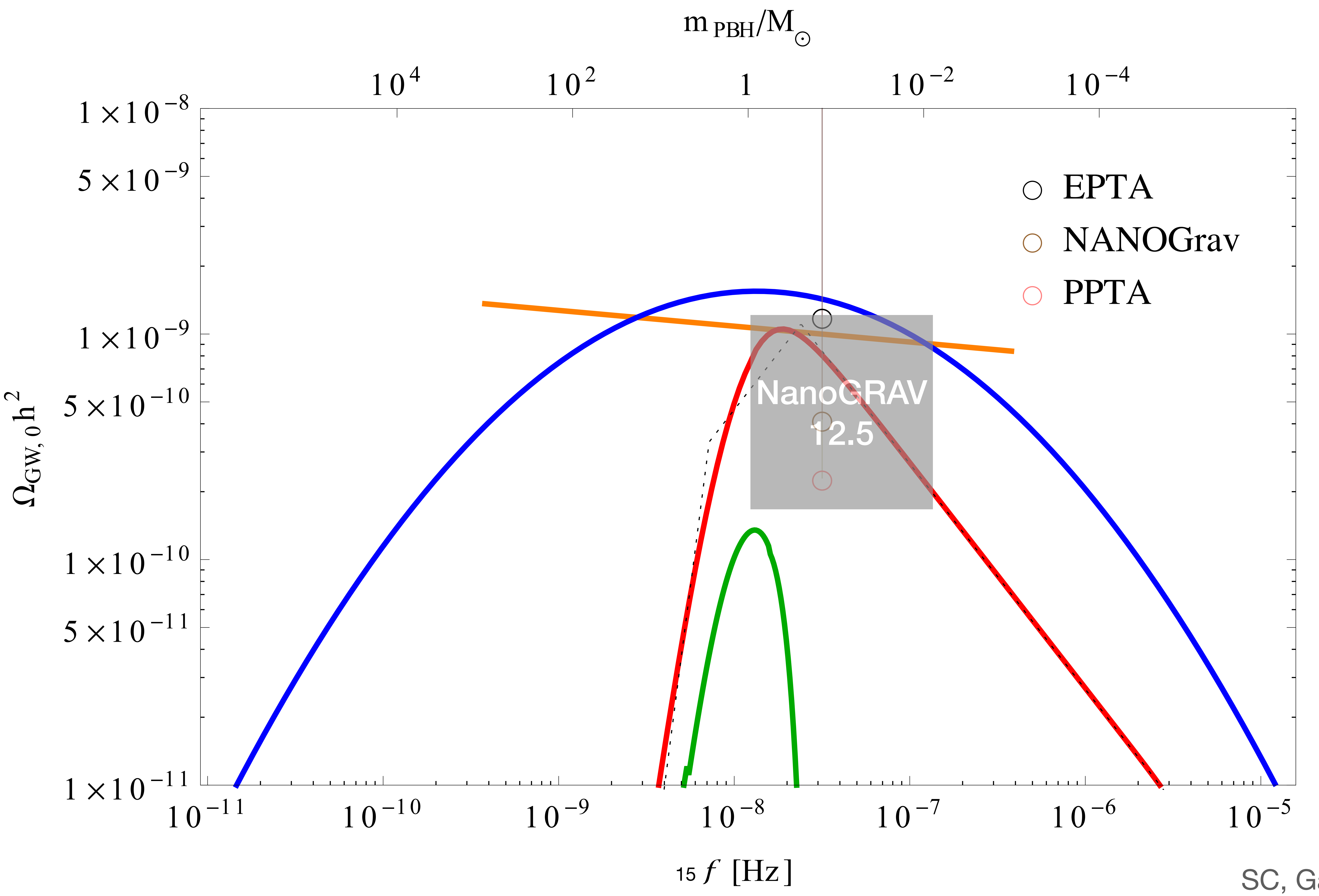
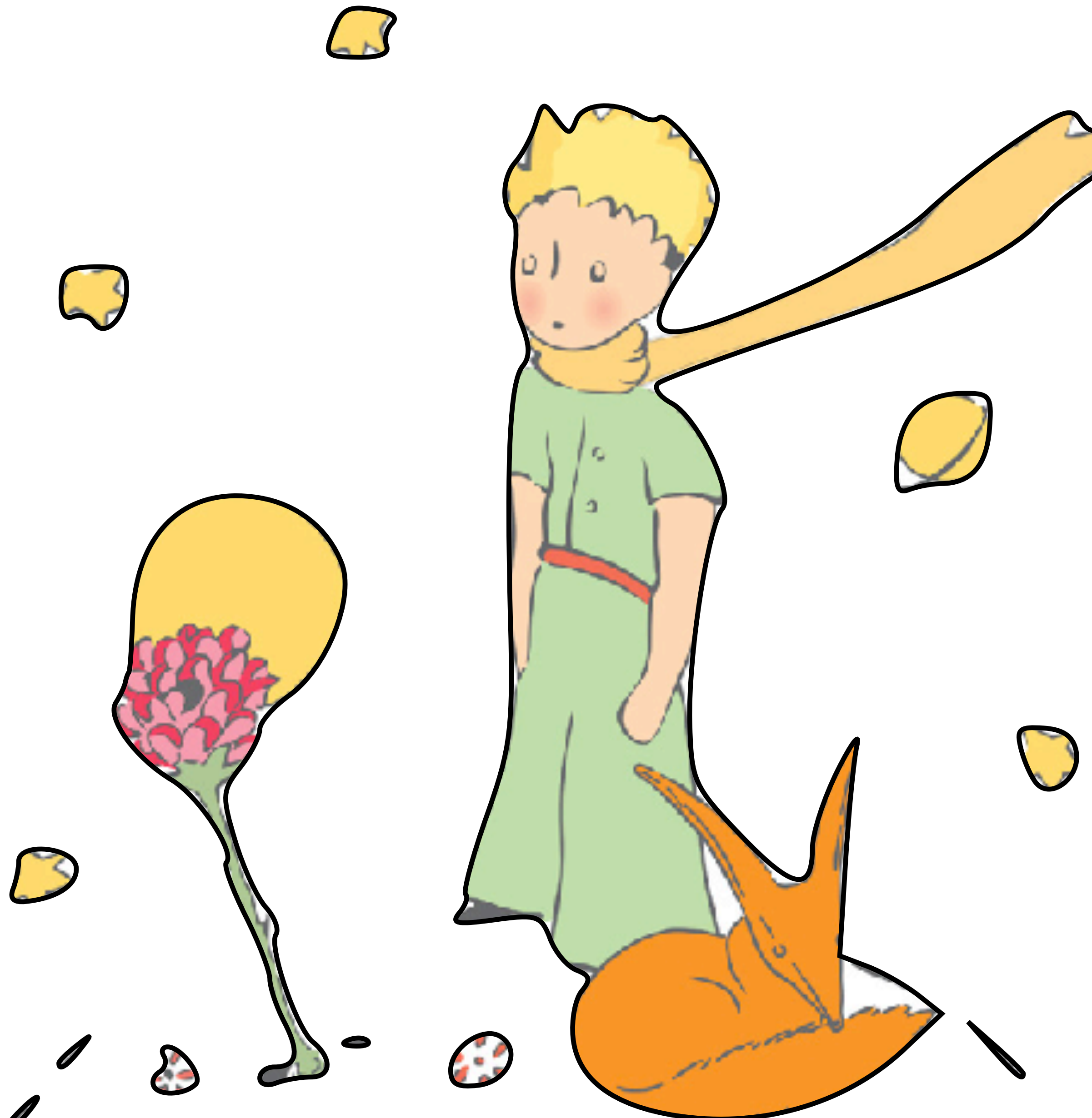


SC, Garcia-Bellido, Orani, 2018

Conclusion



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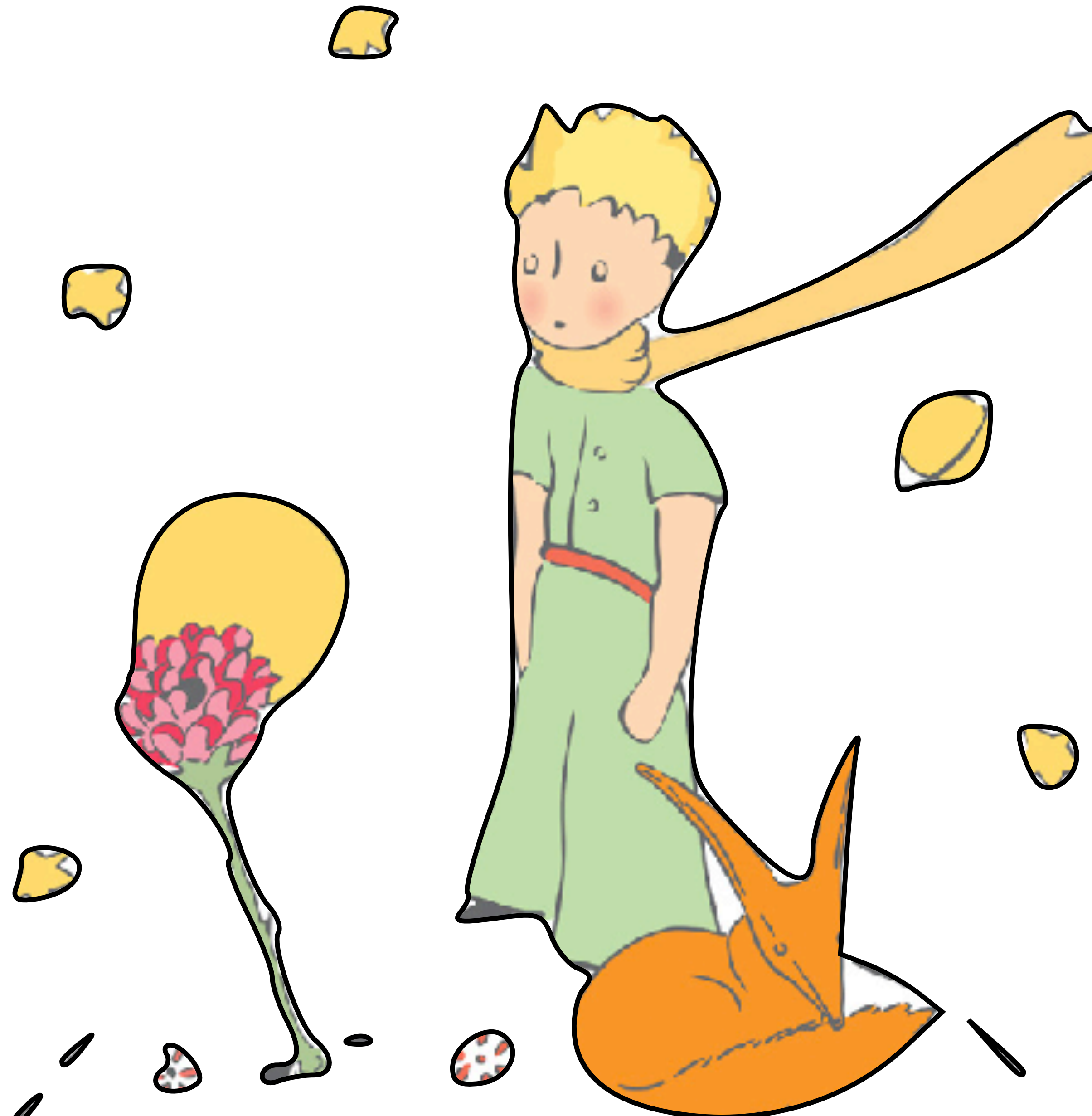

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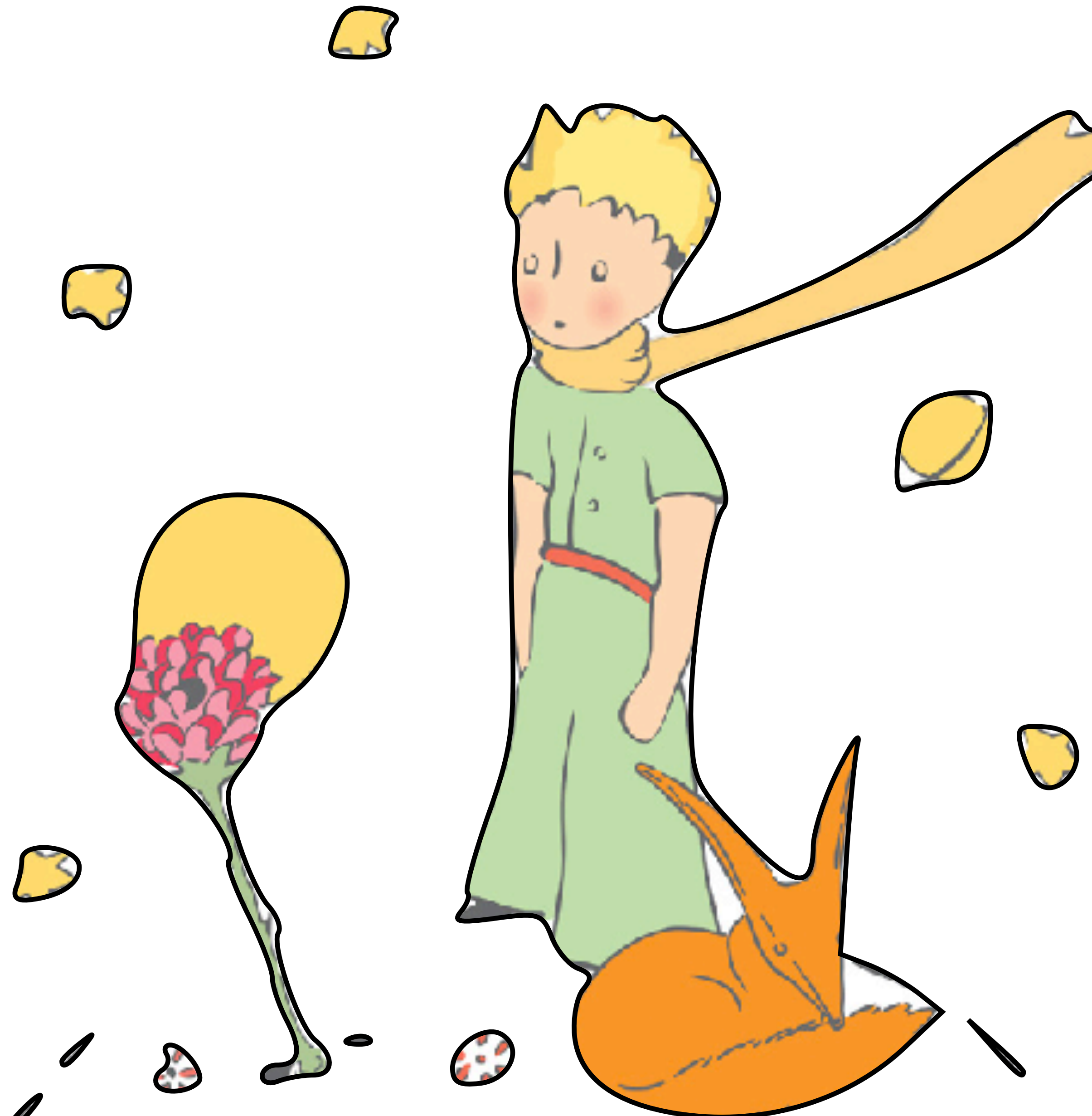

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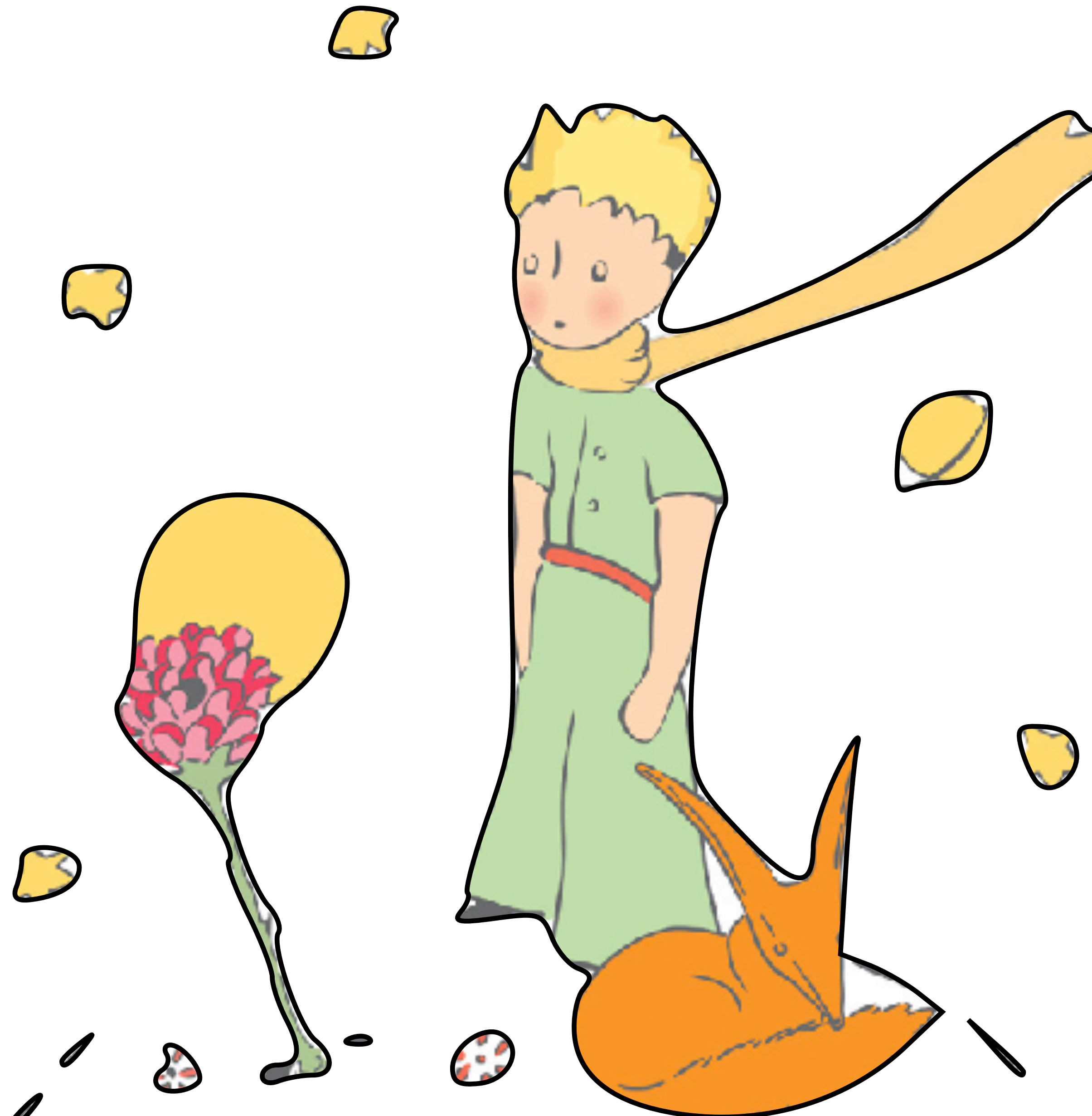

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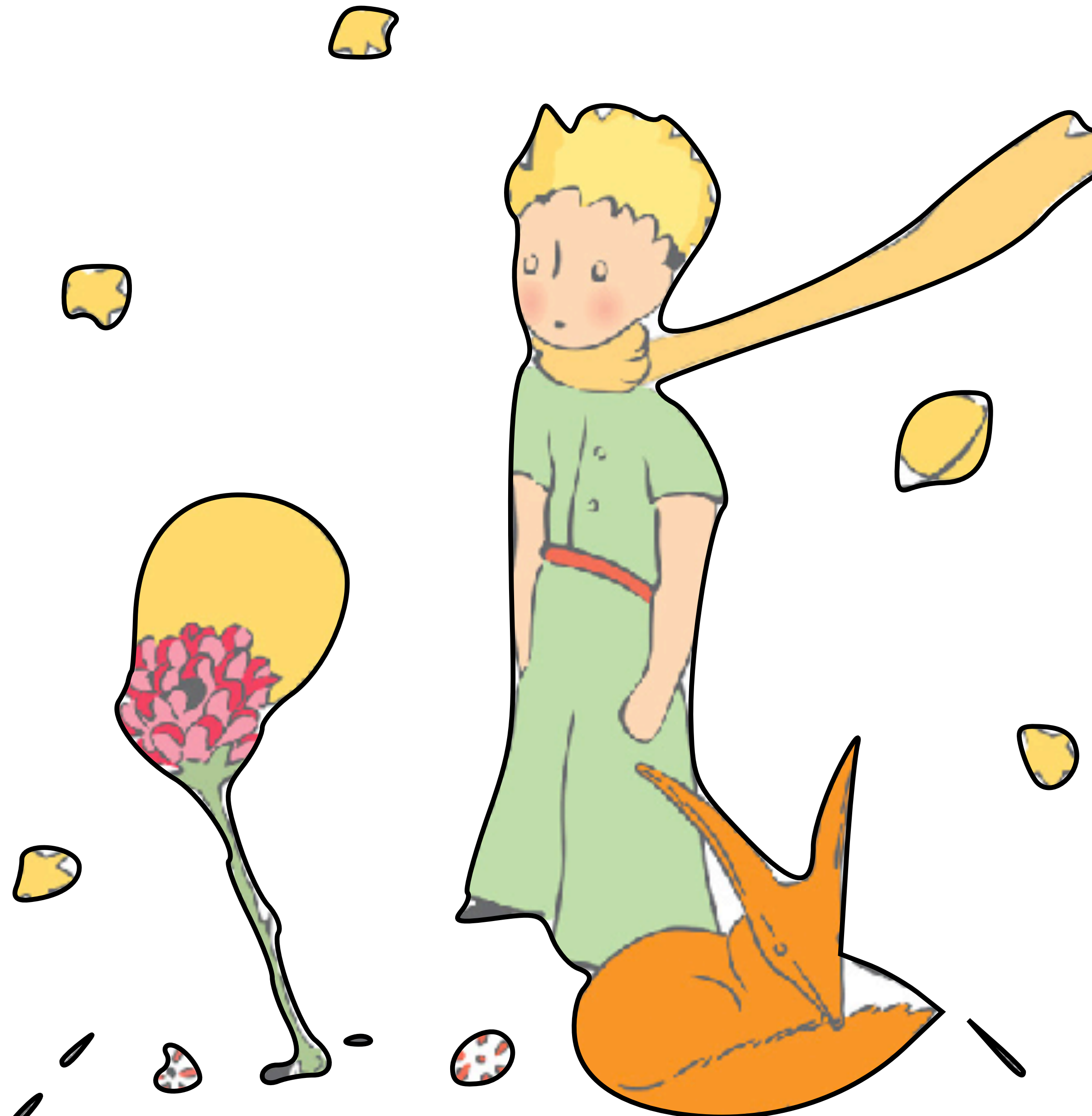

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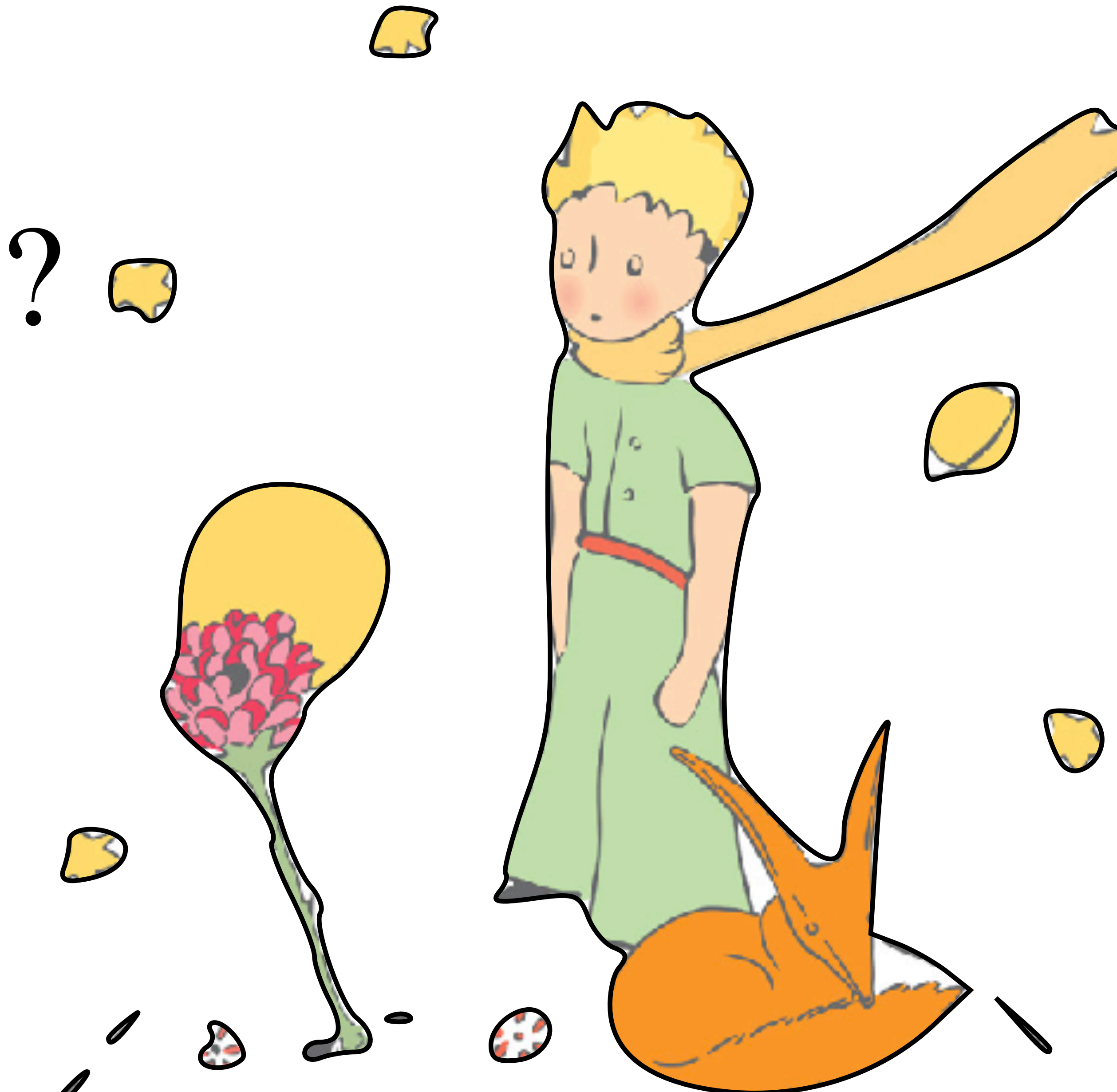

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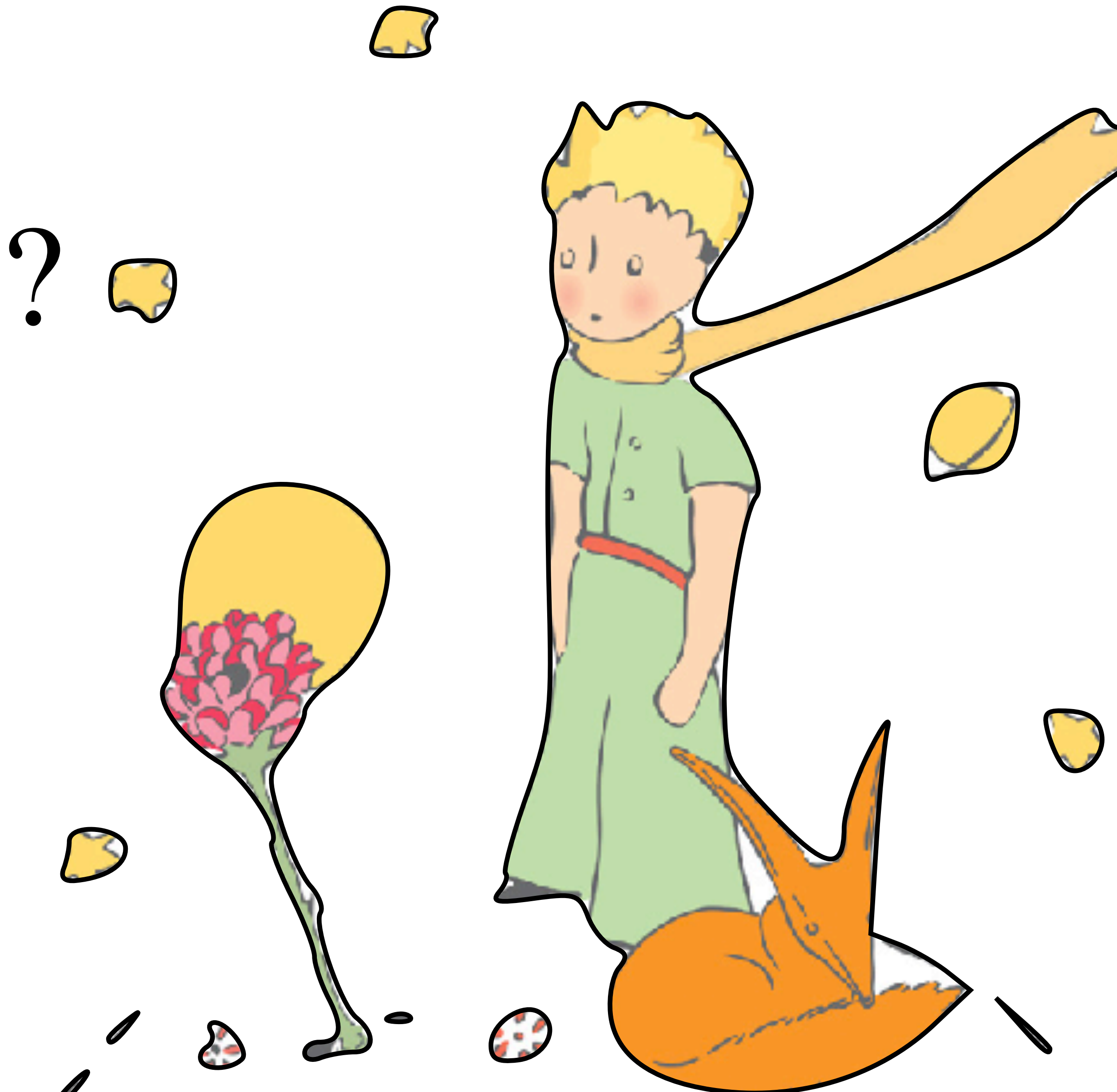

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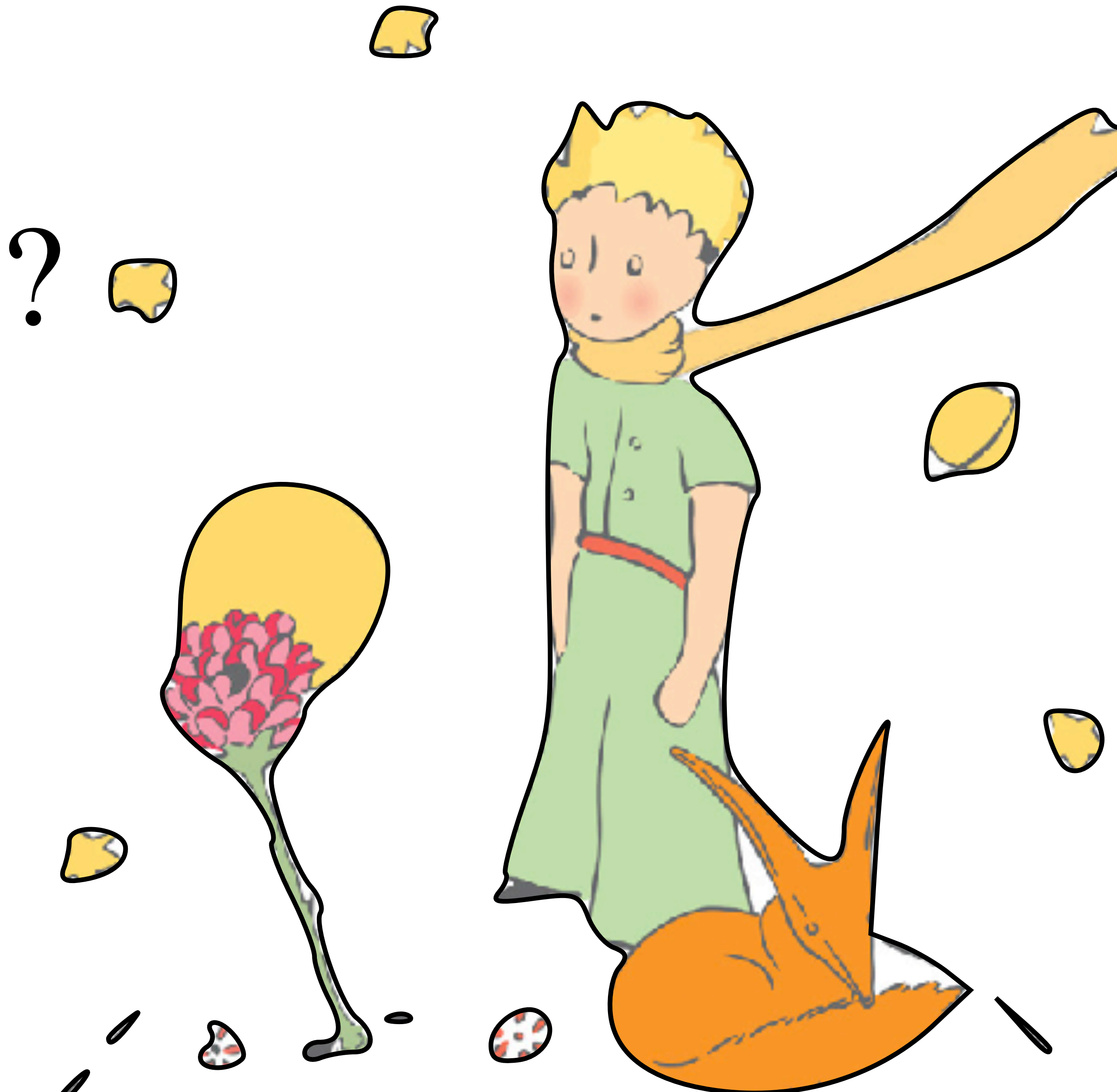

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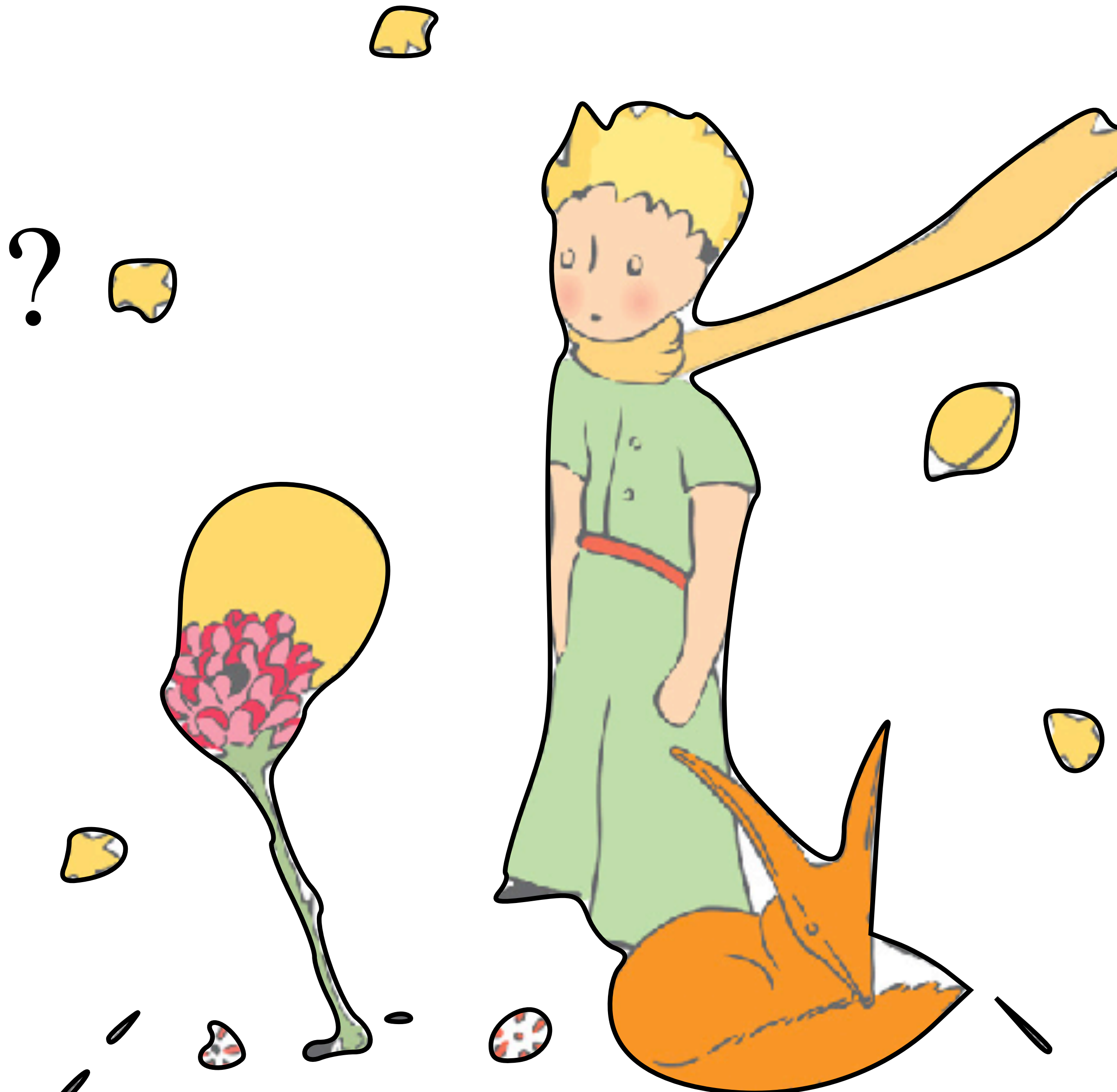

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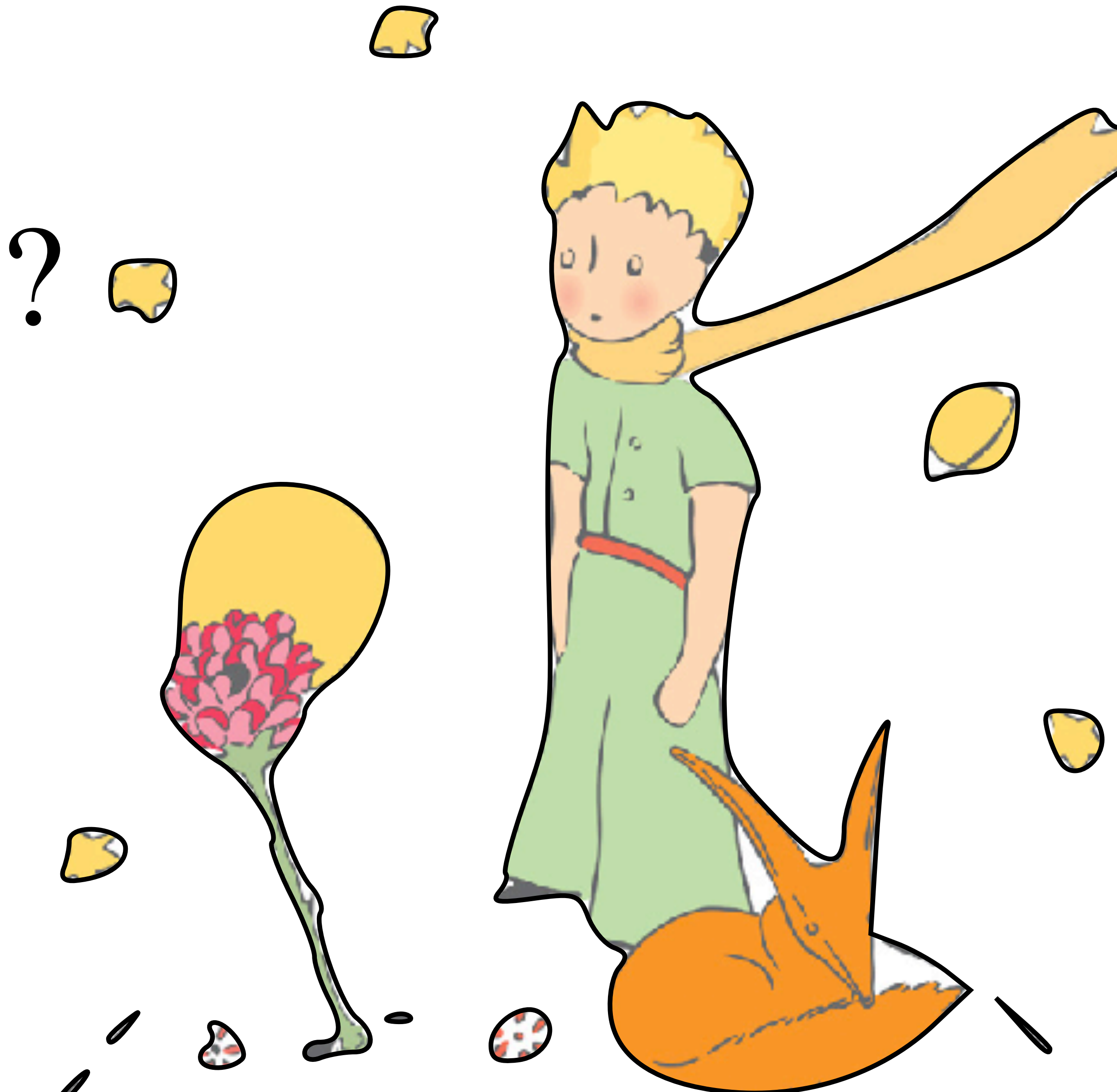

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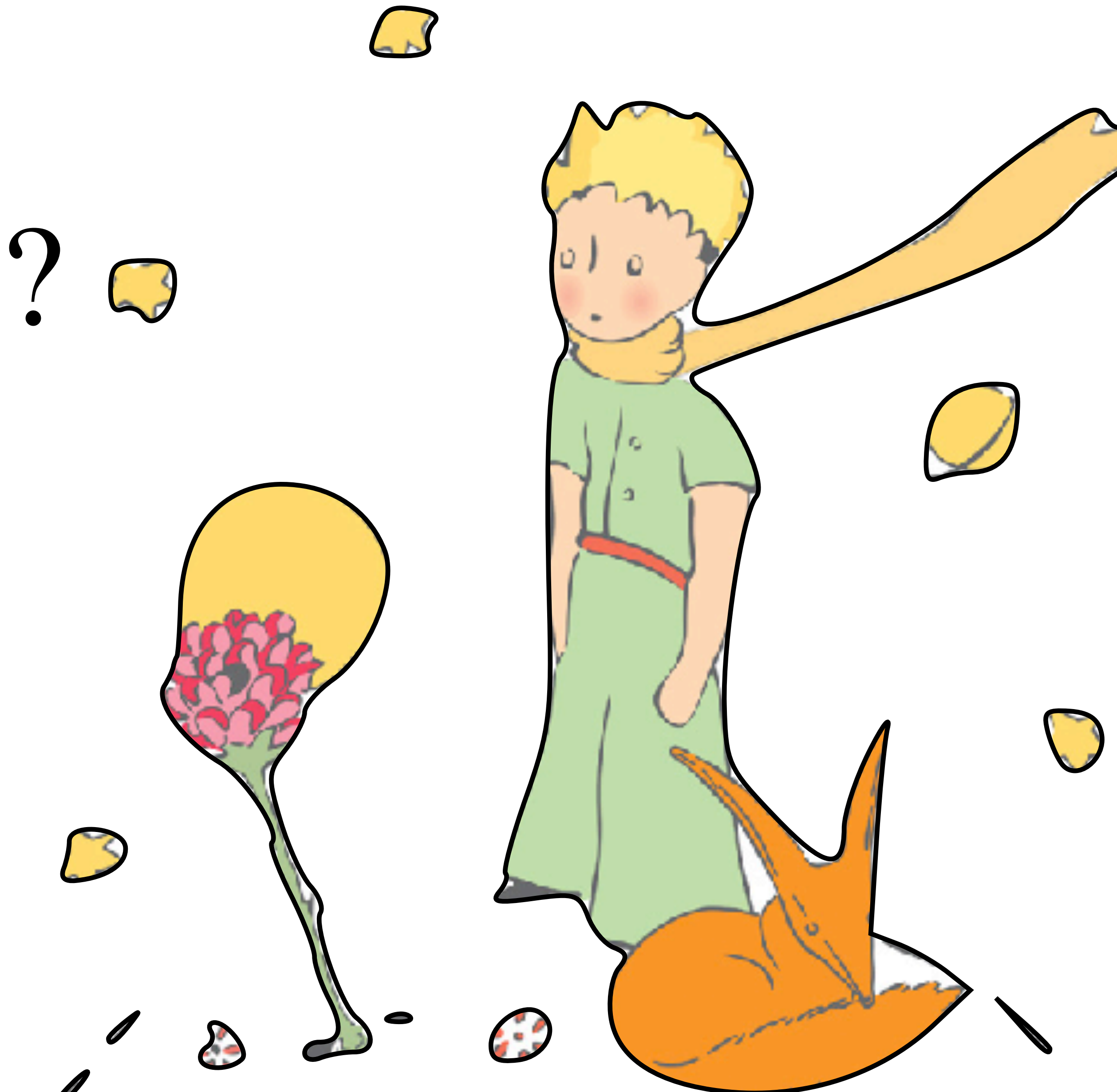

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