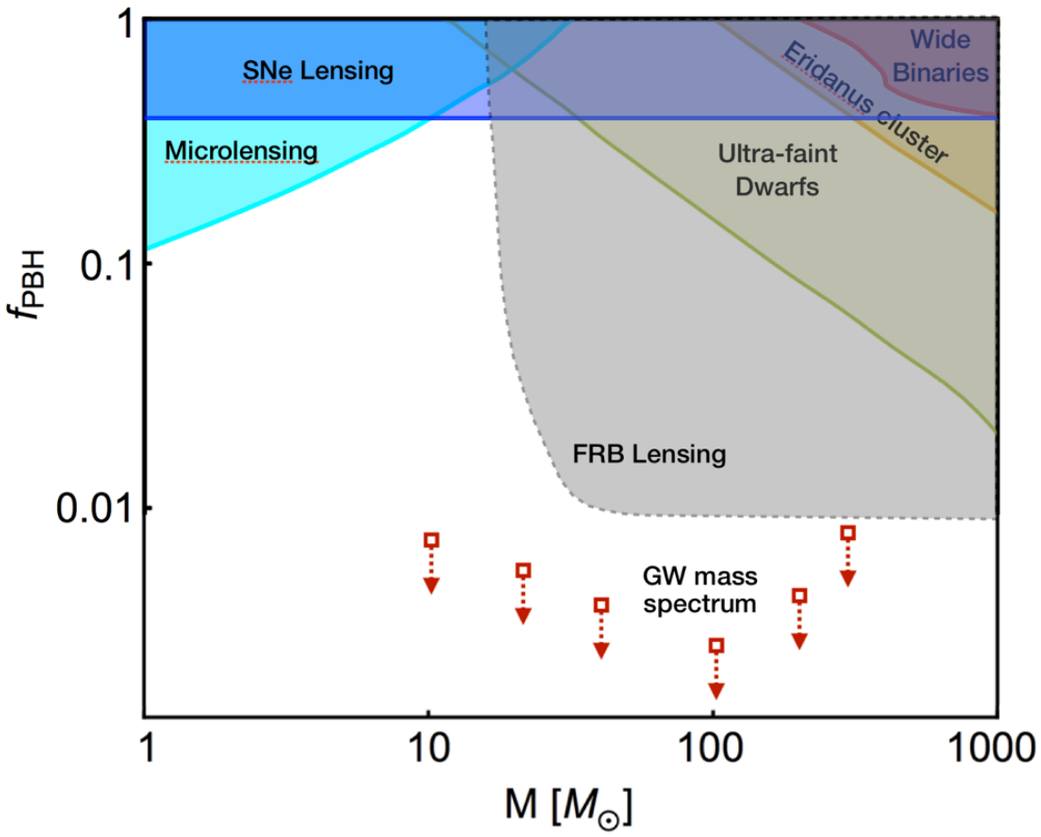
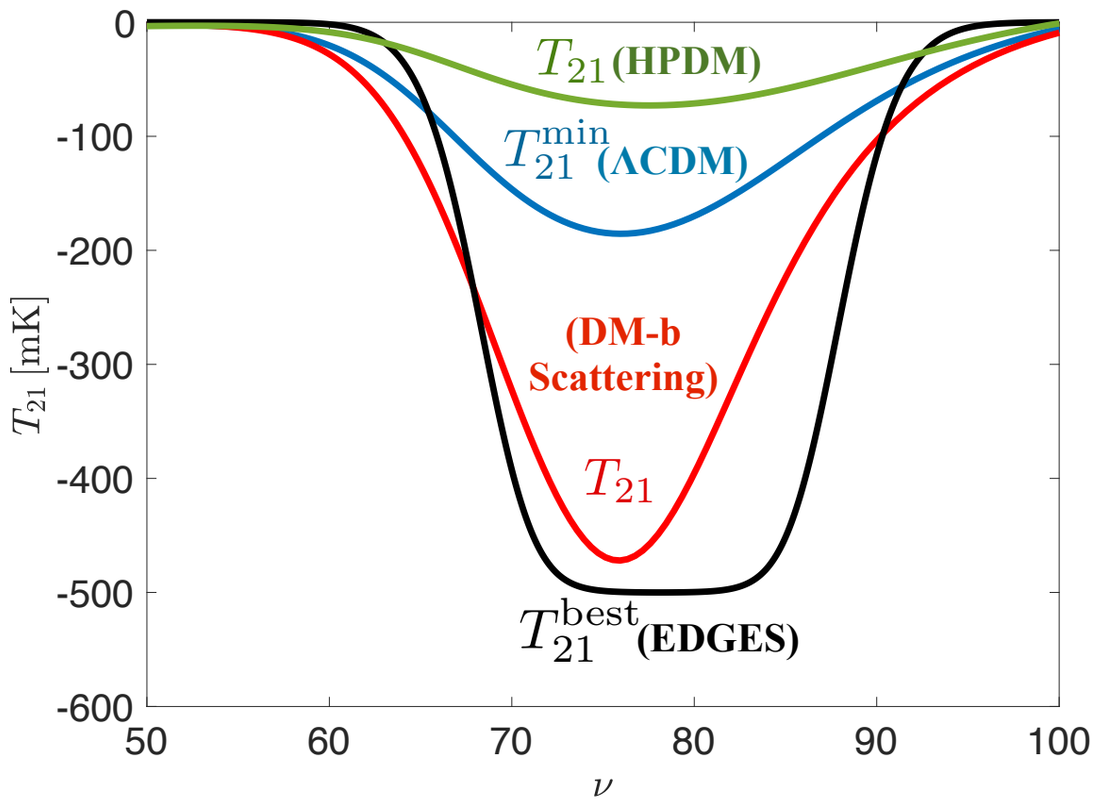
New Cosmological Probes of the Lightest and Heaviest Dark

Ely D. Kovetz
Johns Hopkins University





Based on: arXiv:1603.00464, arXiv:1605.01405, **arXiv:1605.00008**, arXiv:1606.07437, arXiv:1611.01157, **arXiv:1705.09182**, **arXiv:1709.06576**, **arXiv:1809.09627**

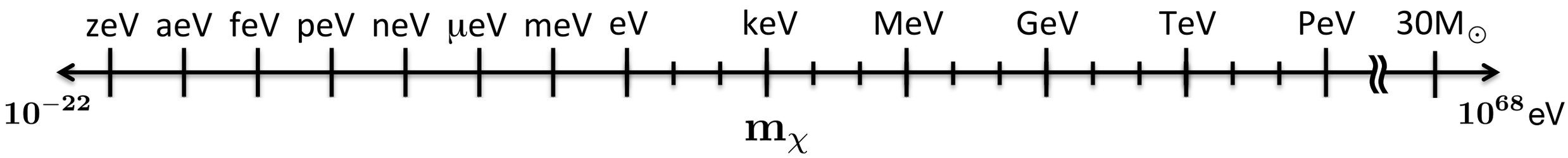
with: **Y. Ali-Haïmoud**, S. Bird, P. Breysse, I.Cholis, **L. Ji**, **M. Kamionkowski**, **J. Muñoz**, A. Raccanelli, A. Riess

Based on: arXiv:1509.00029, arXiv:1807.11482, arXiv:1808.00001, **arXiv:1809.01139**

with: Y. Ali-Haïmoud, R. Barkana, K. Boddy, **I. Cholis**, V. Gluscevic, M. Kamionkowski, **D. Kaplan**, V. Poulin

The Dark Matter Landscape

(adapted from: “US Cosmic Visions: New Ideas in Dark Matter 2017 : Community Report”, Battaglieri et al., arXiv:1707.104591)



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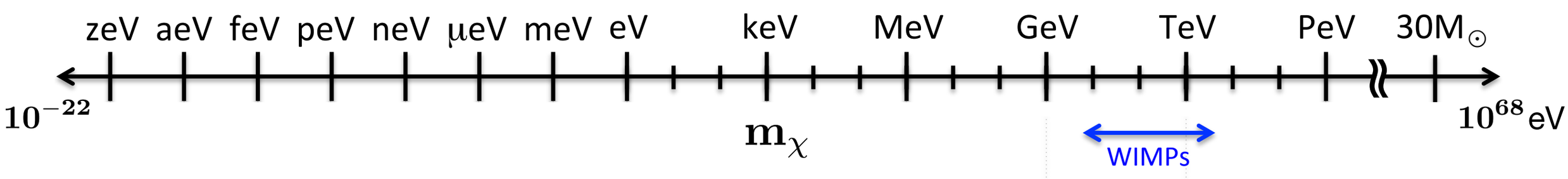

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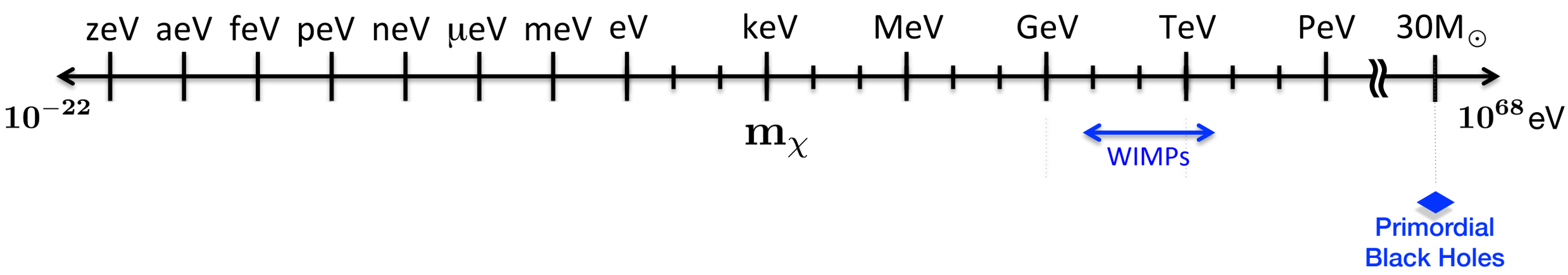

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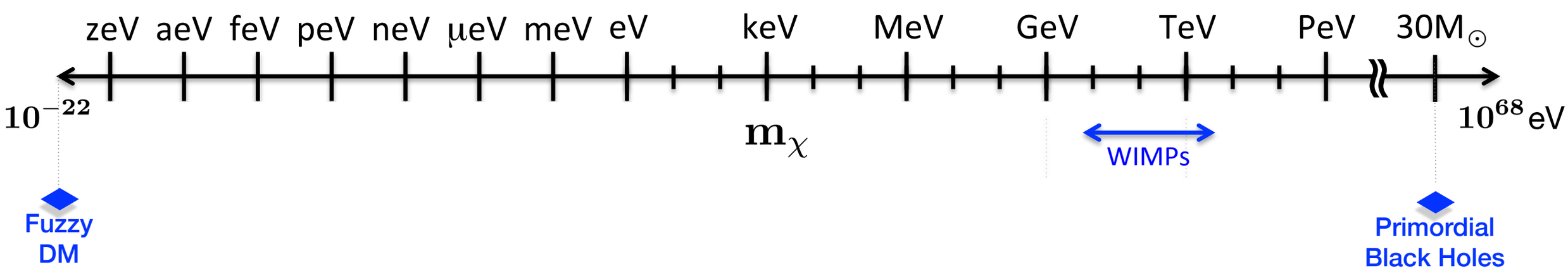

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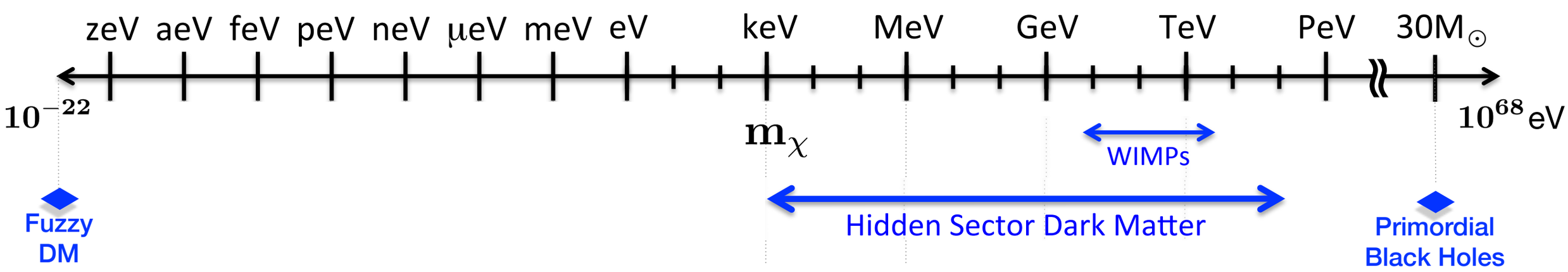

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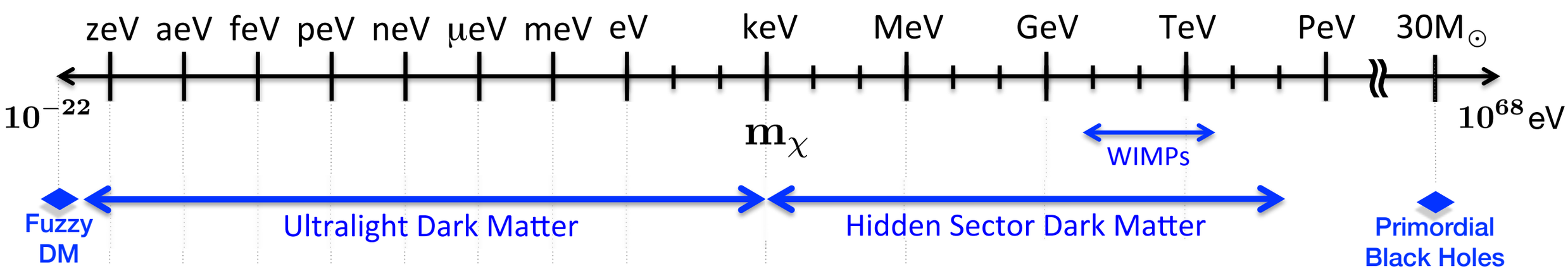

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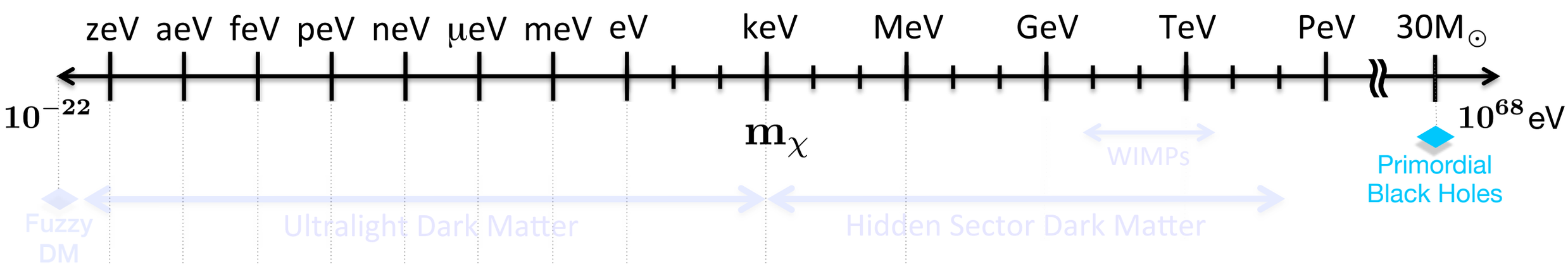

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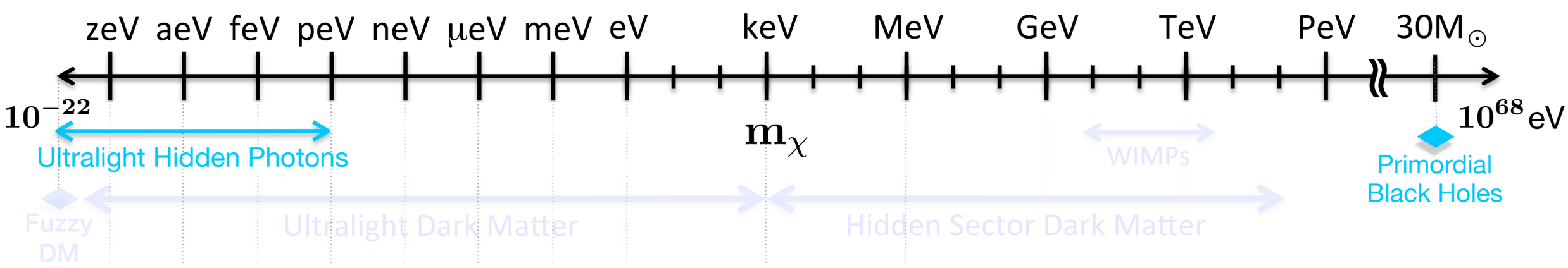

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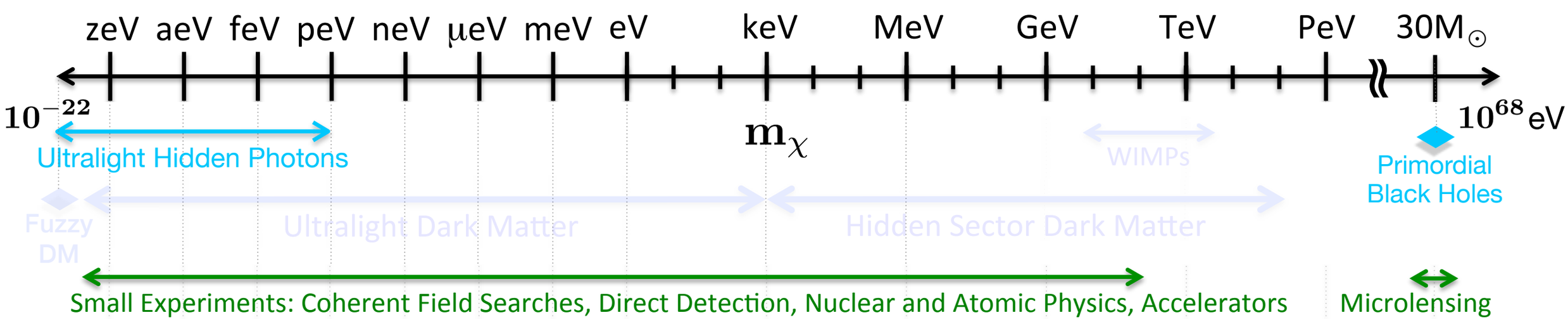

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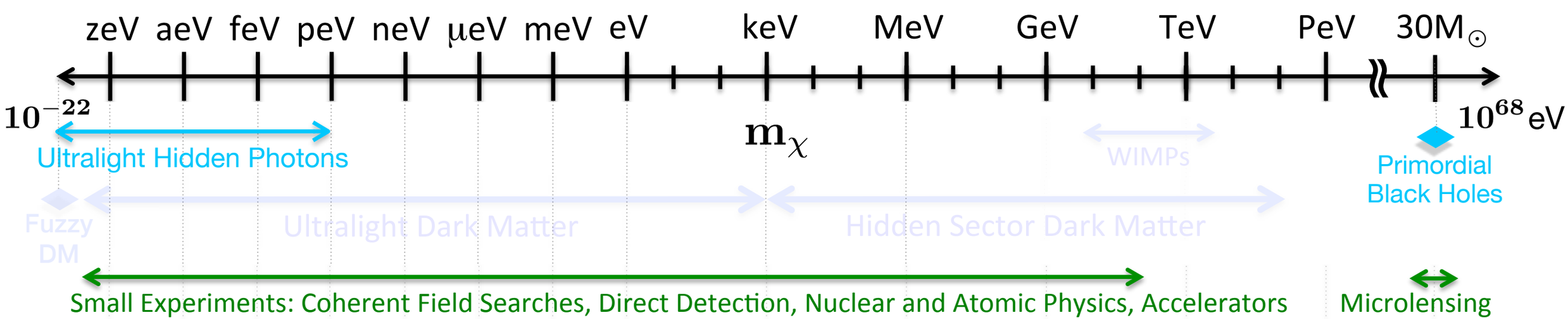
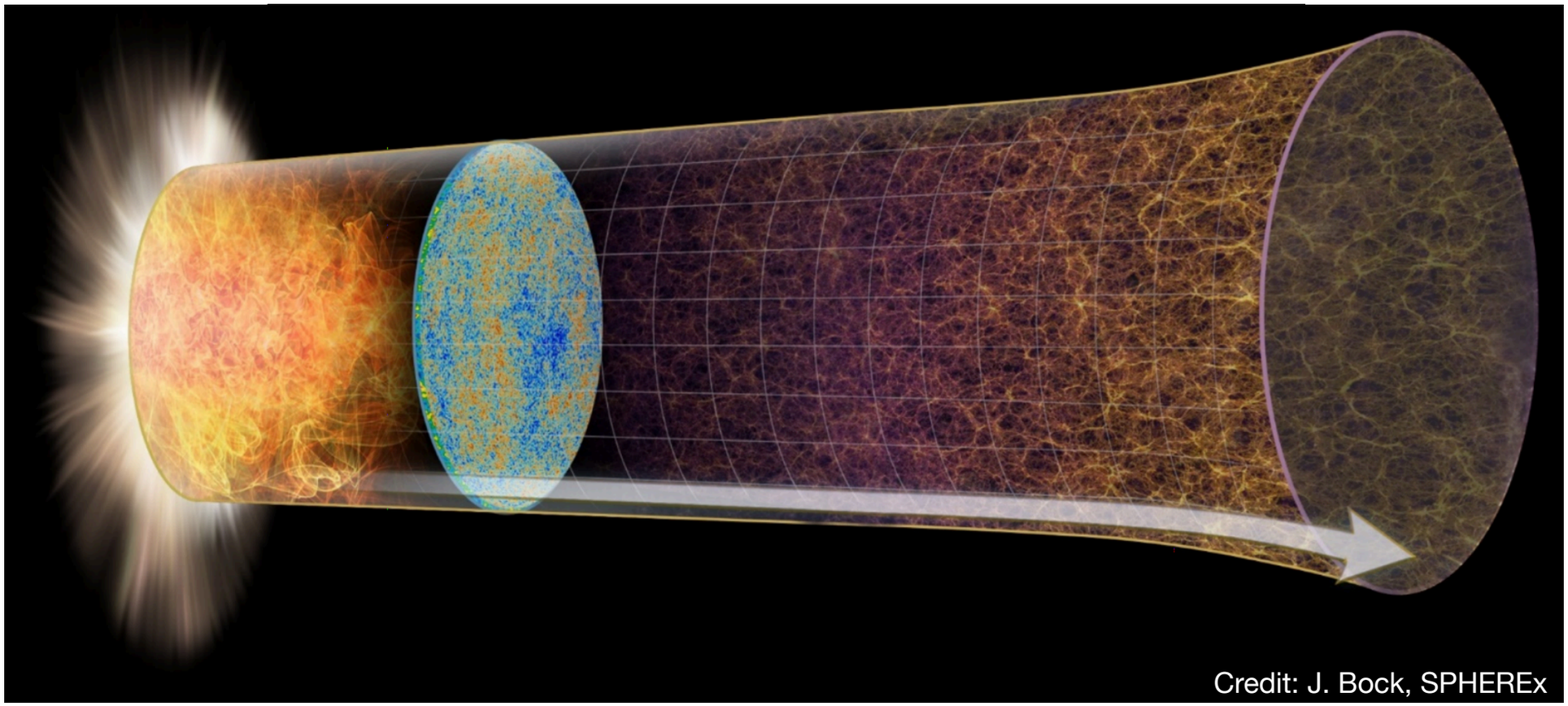
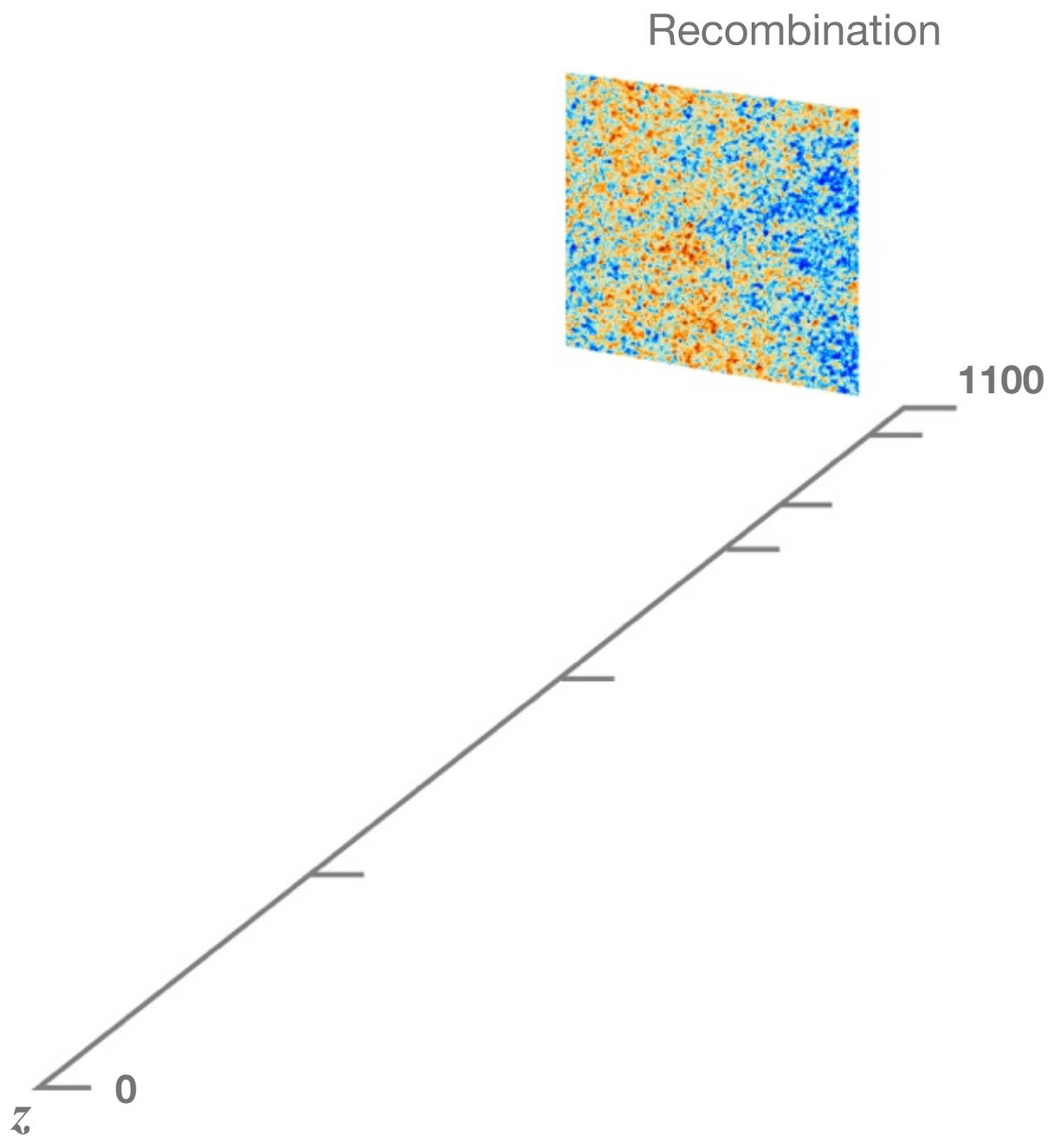




The Observable Universe: A Multi-Layer Detector



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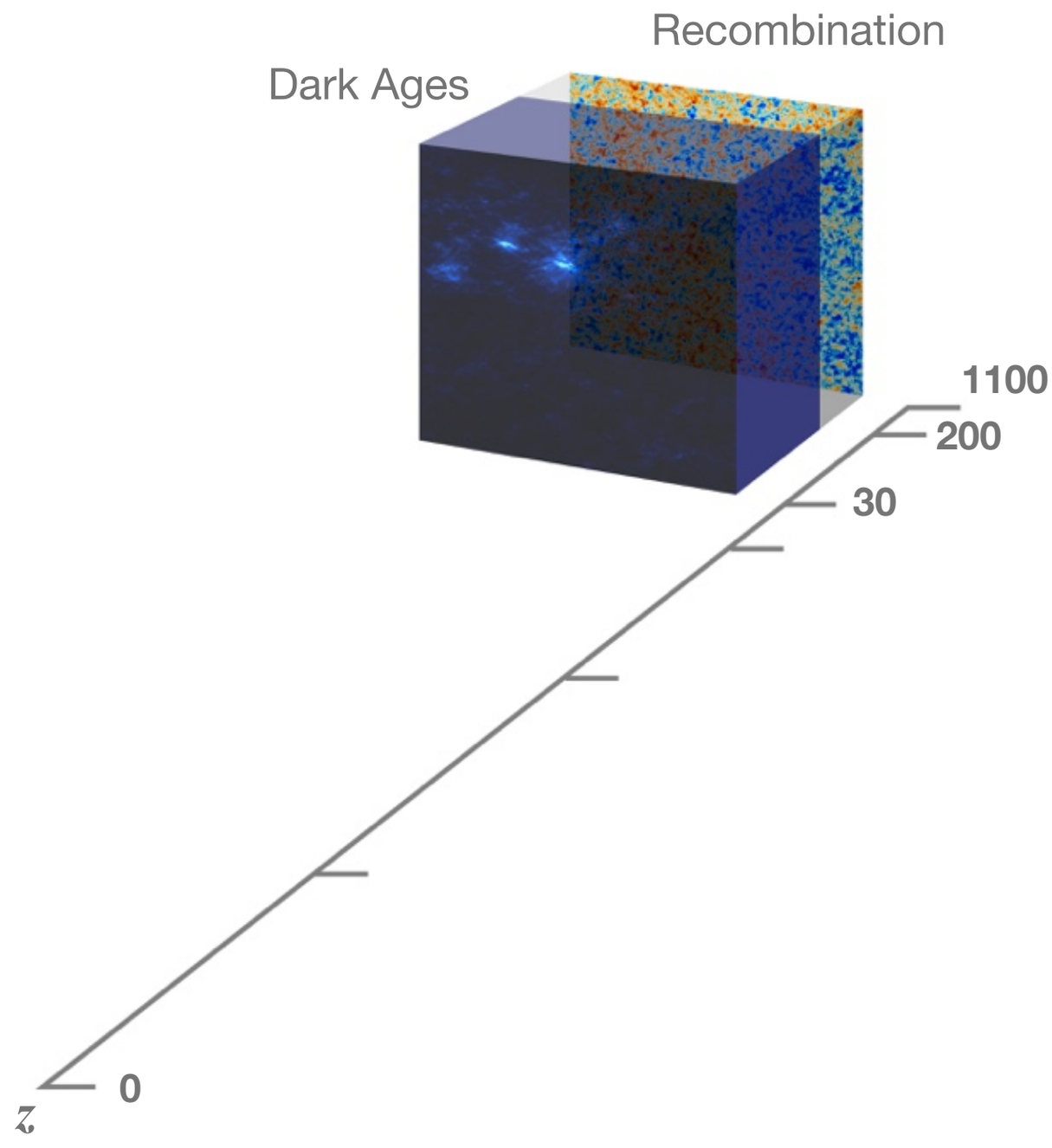

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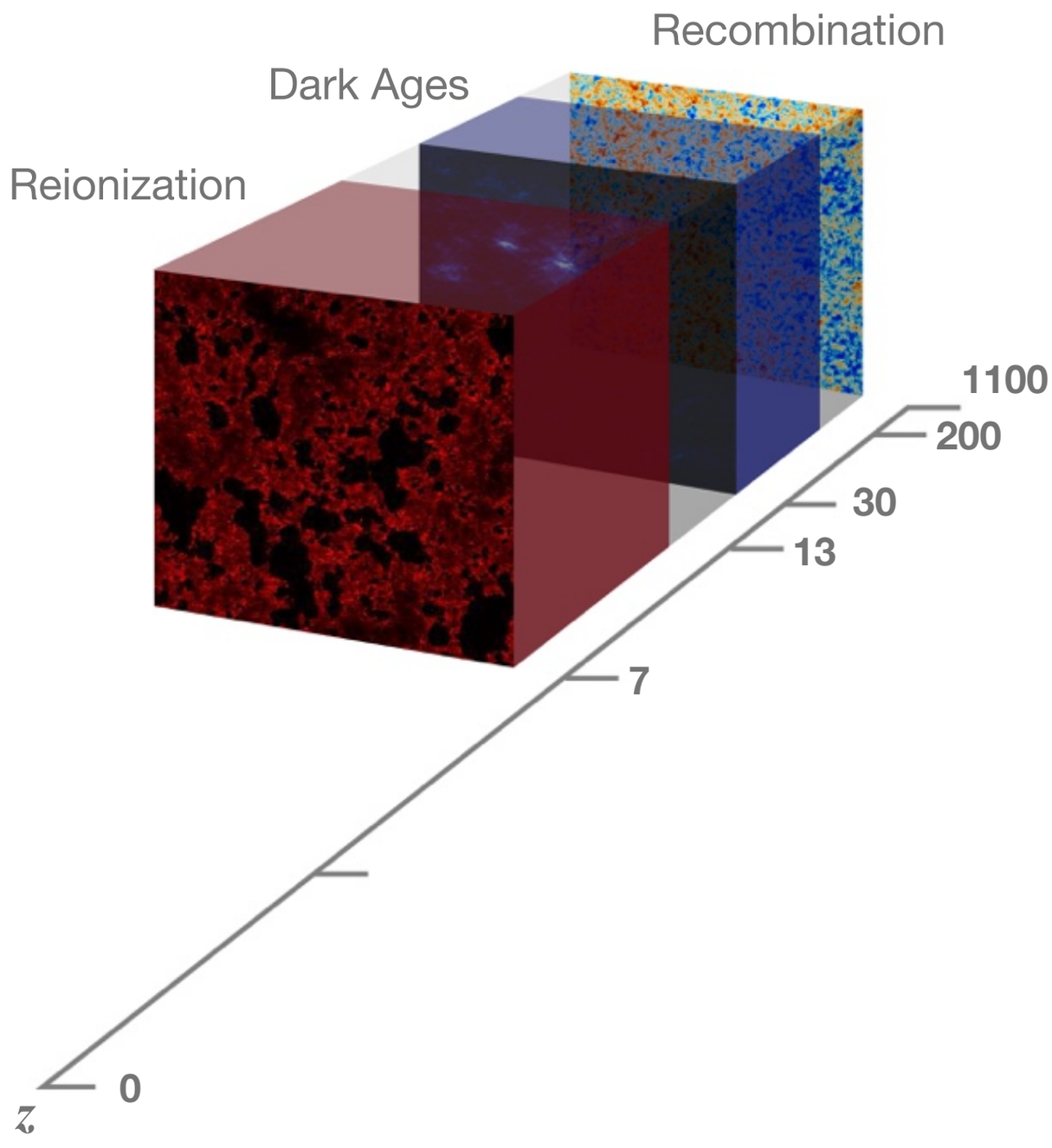

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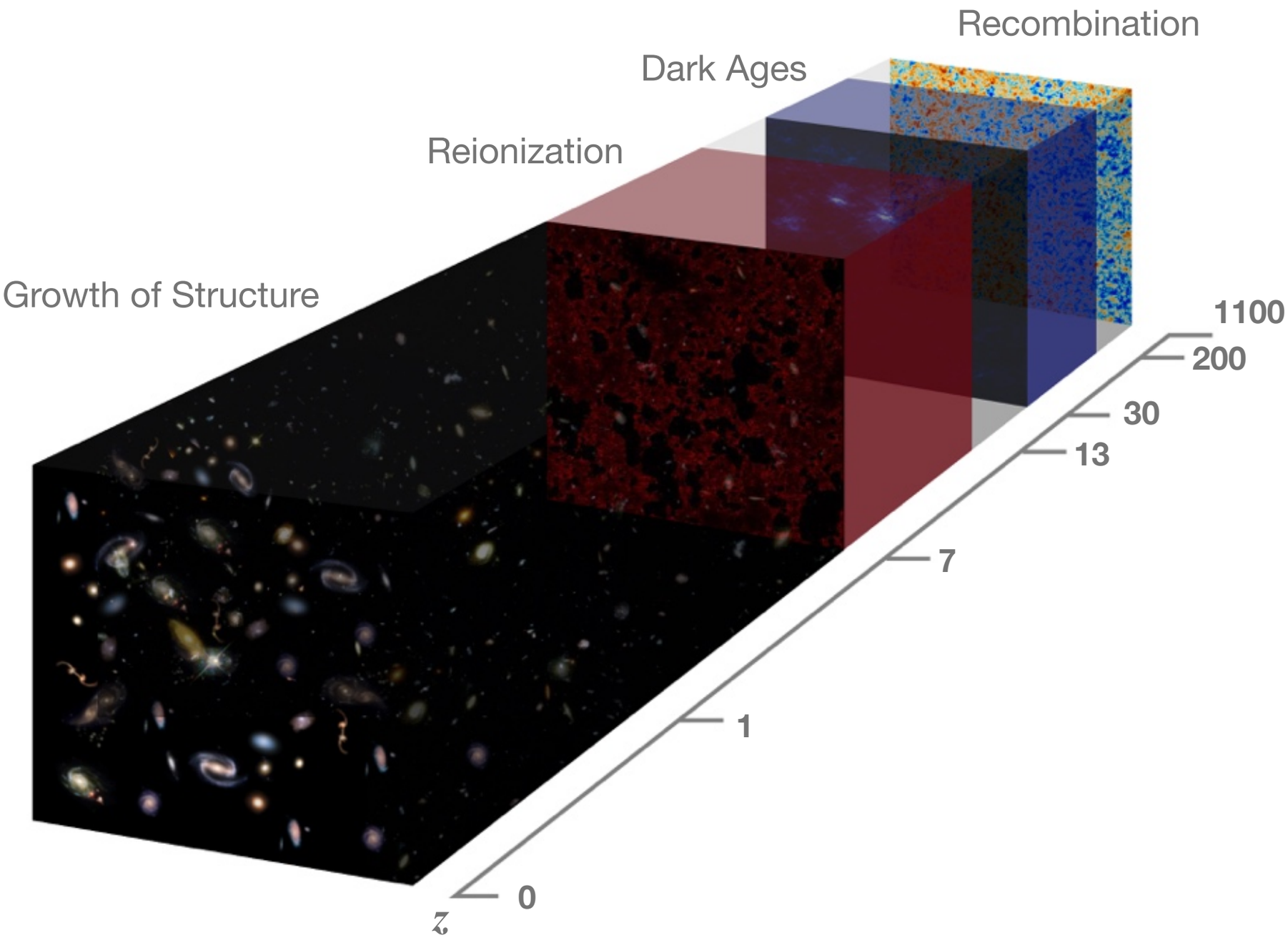

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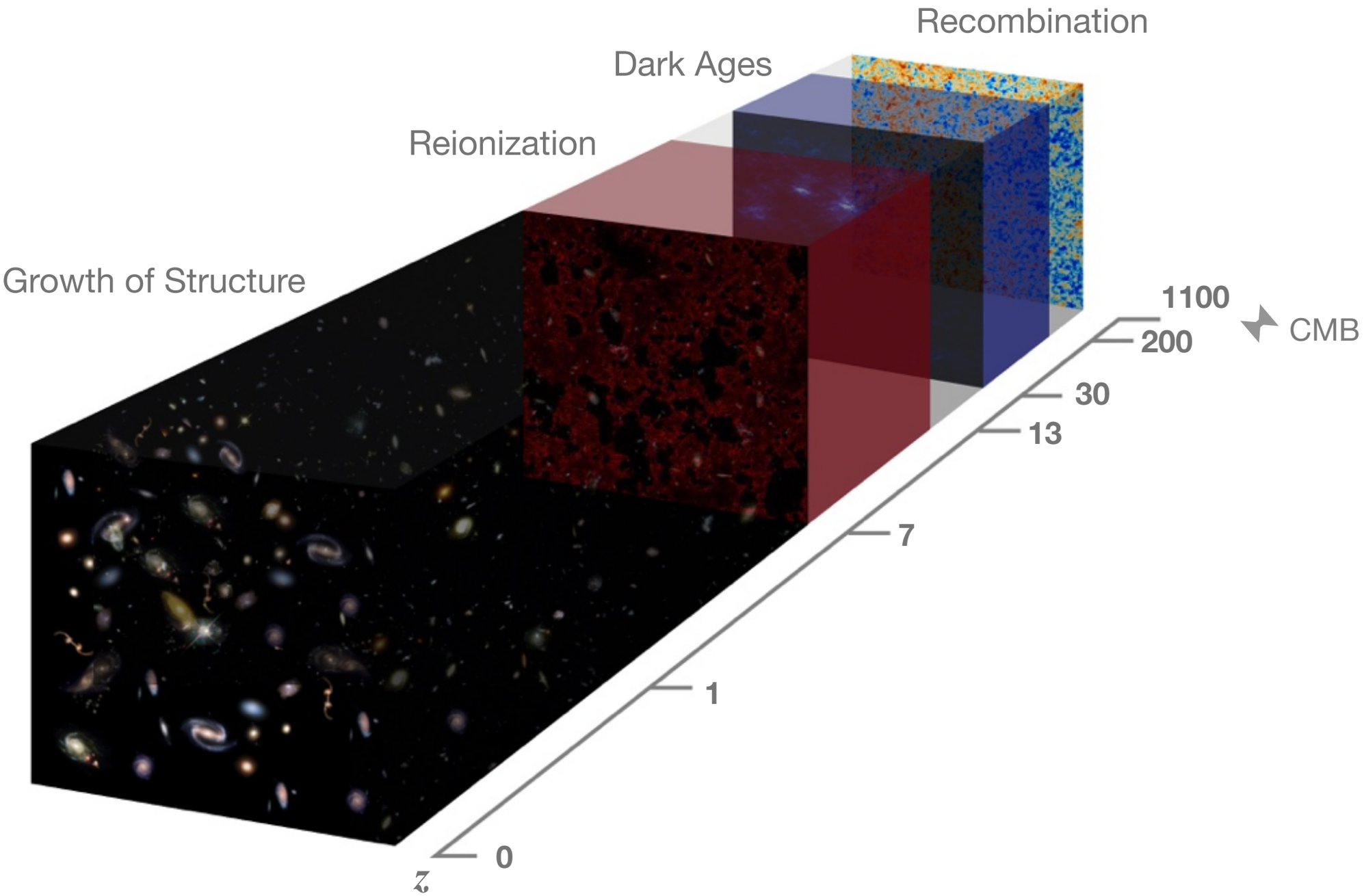

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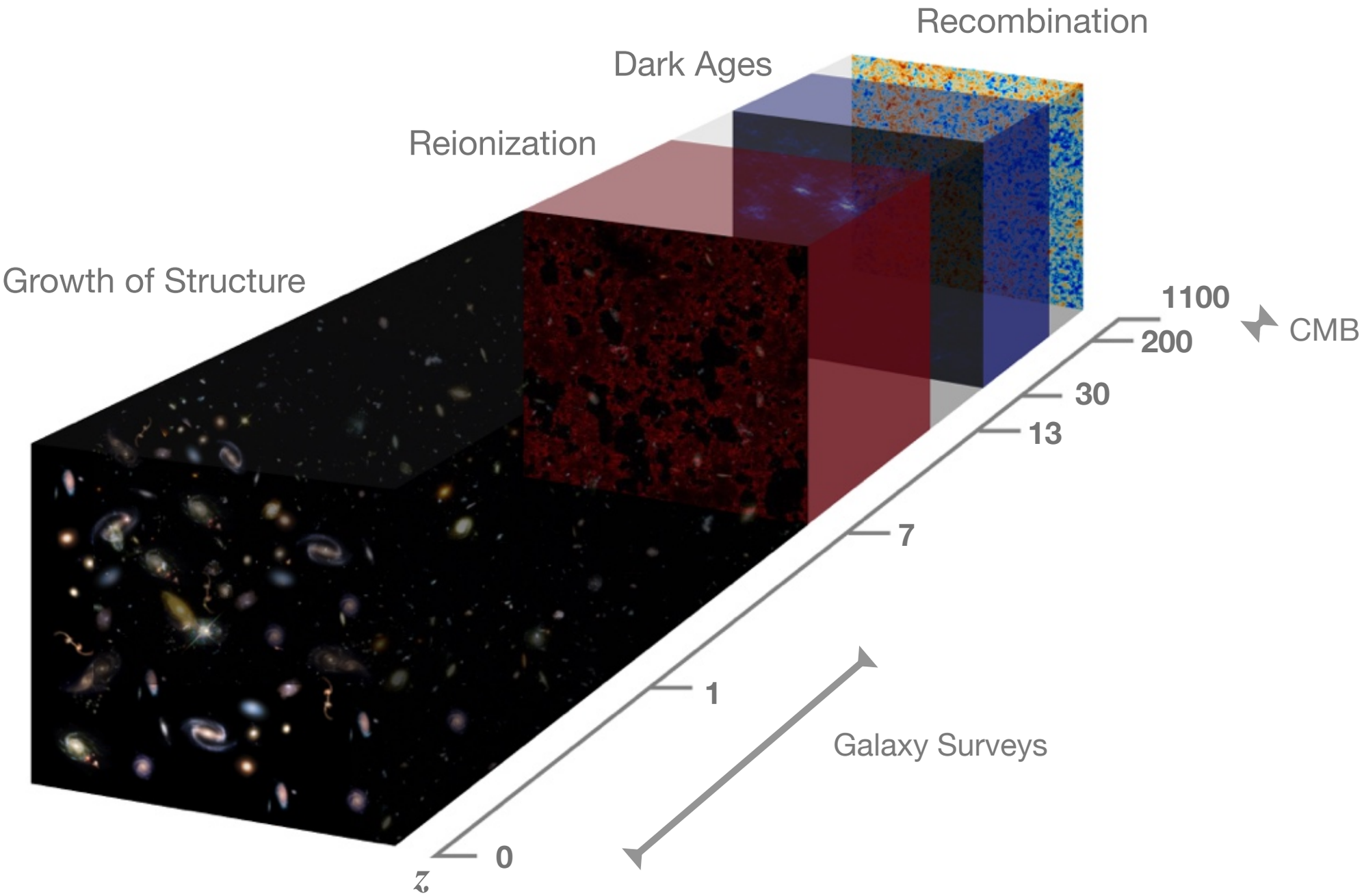

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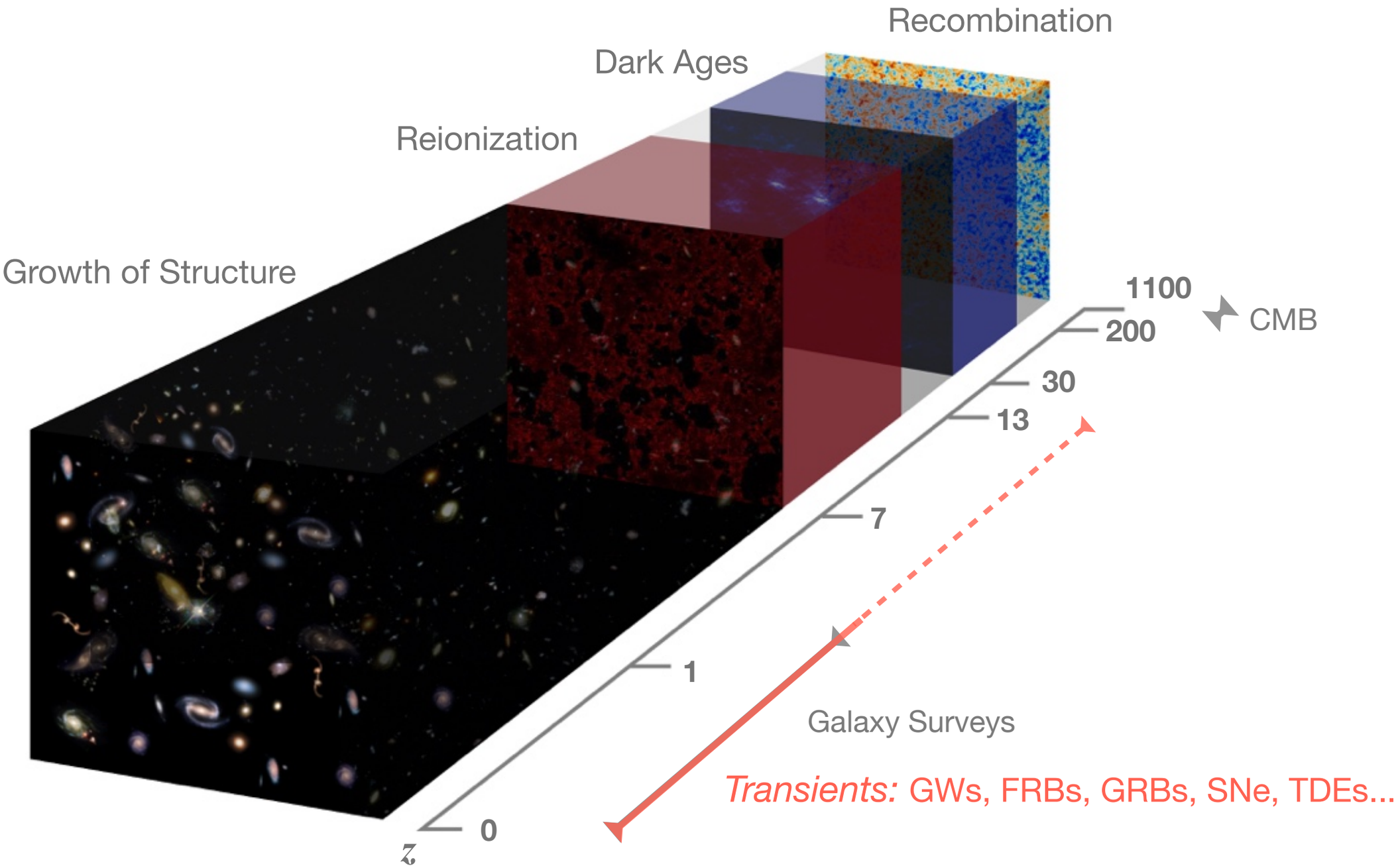

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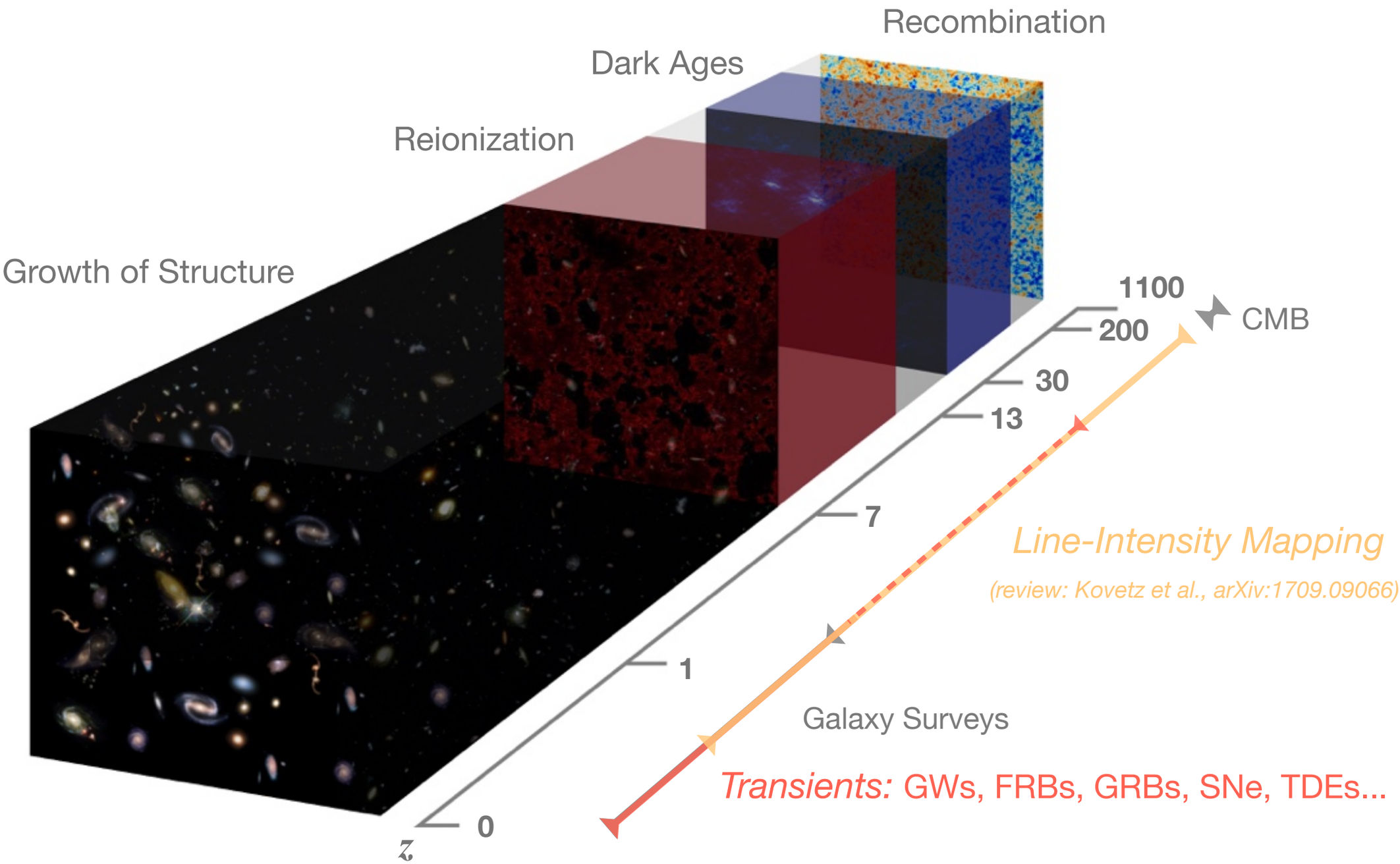

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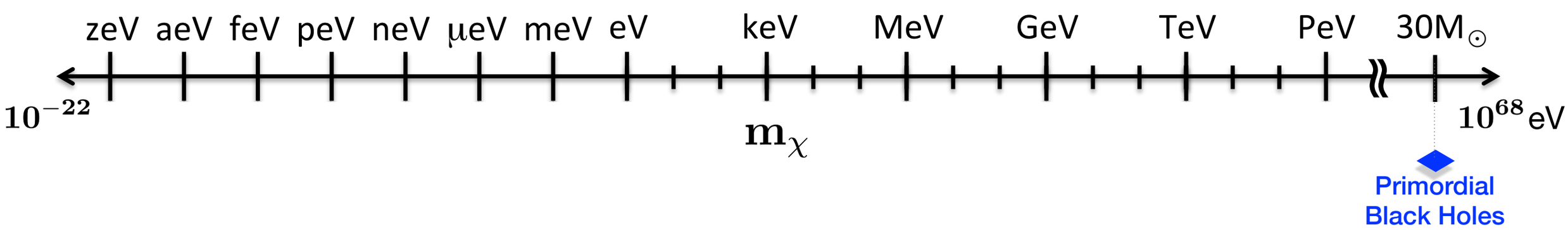
(adapted from Battaglieri et al., arXiv:1707.04591)



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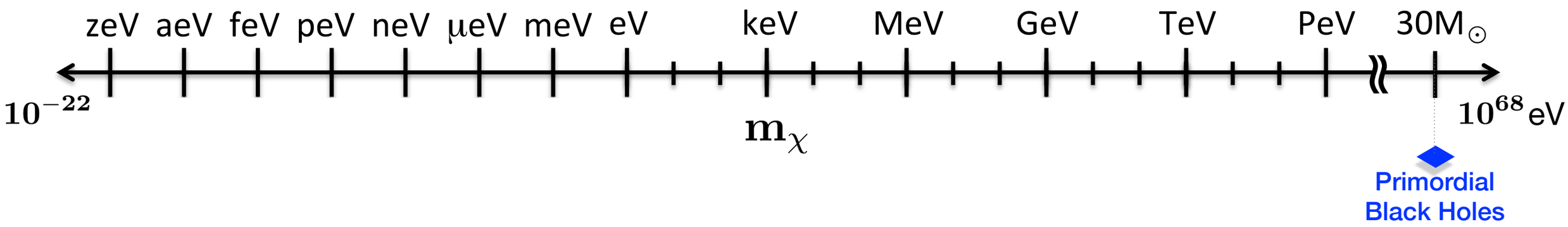

On September 14, 2015:

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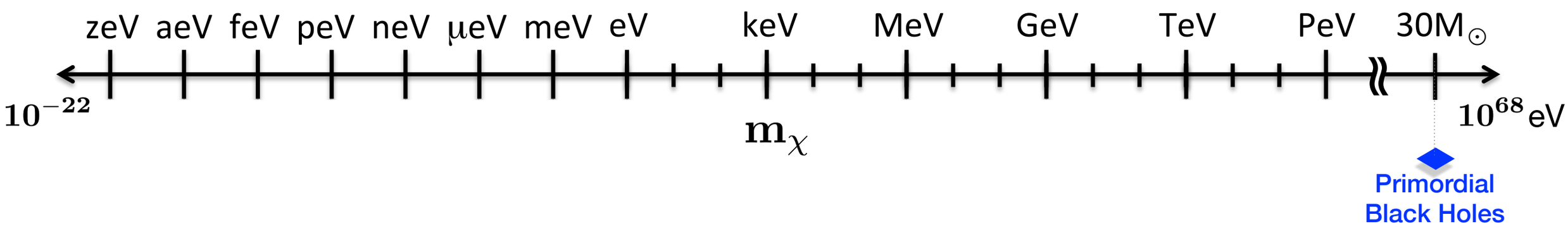

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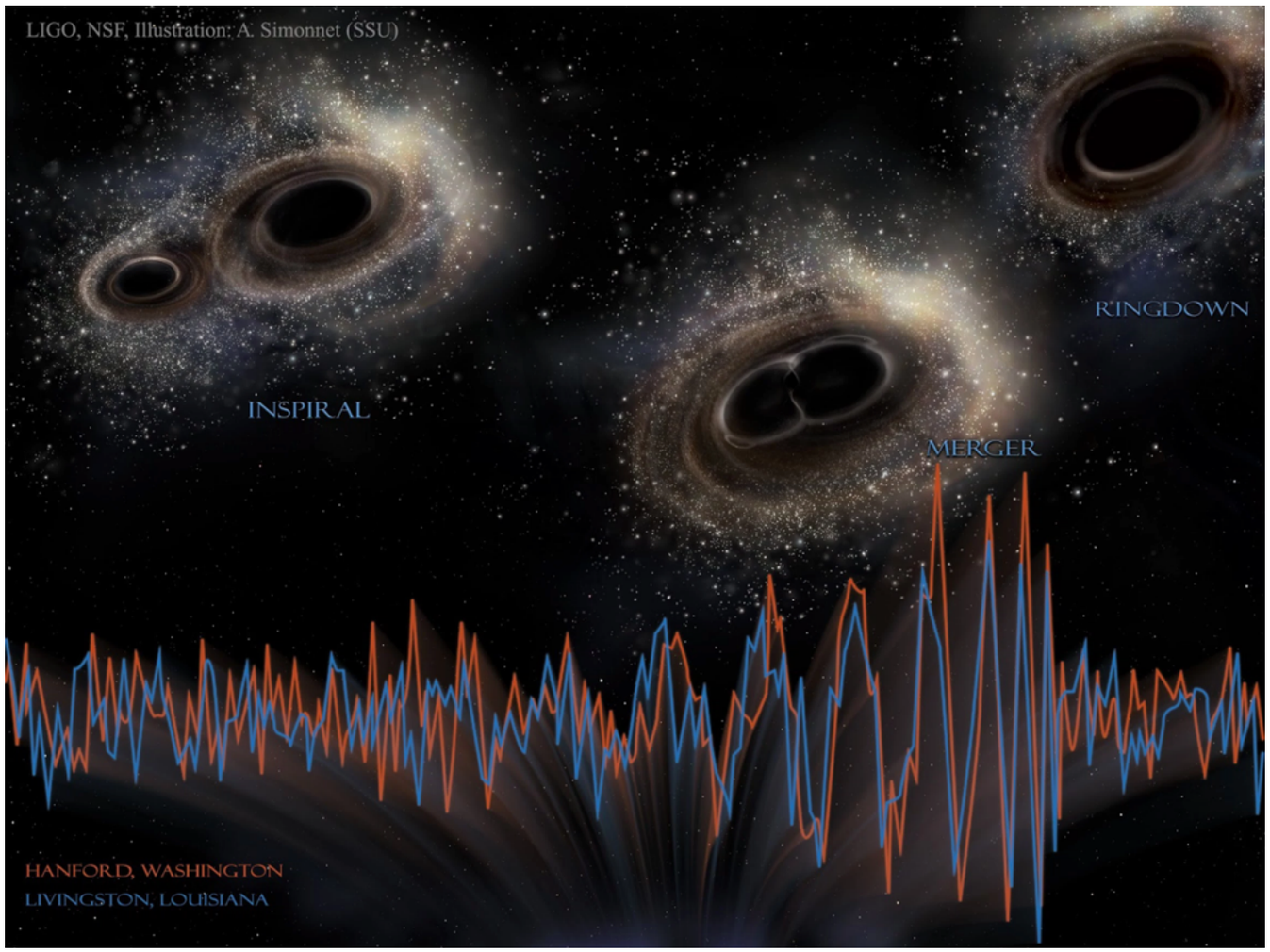

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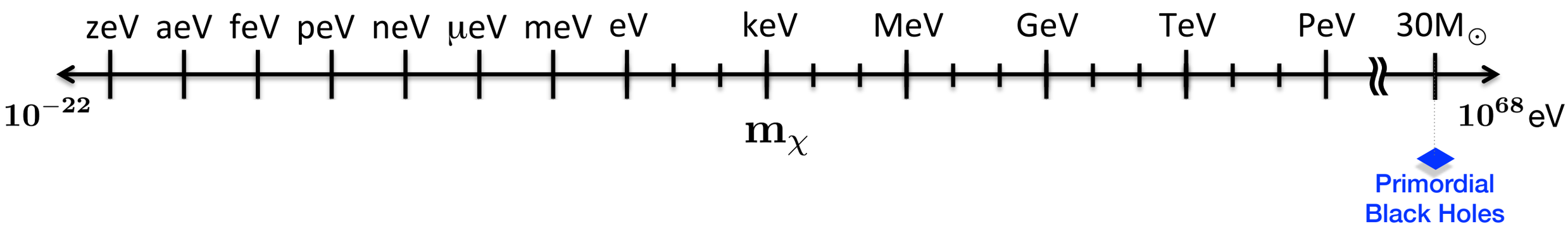

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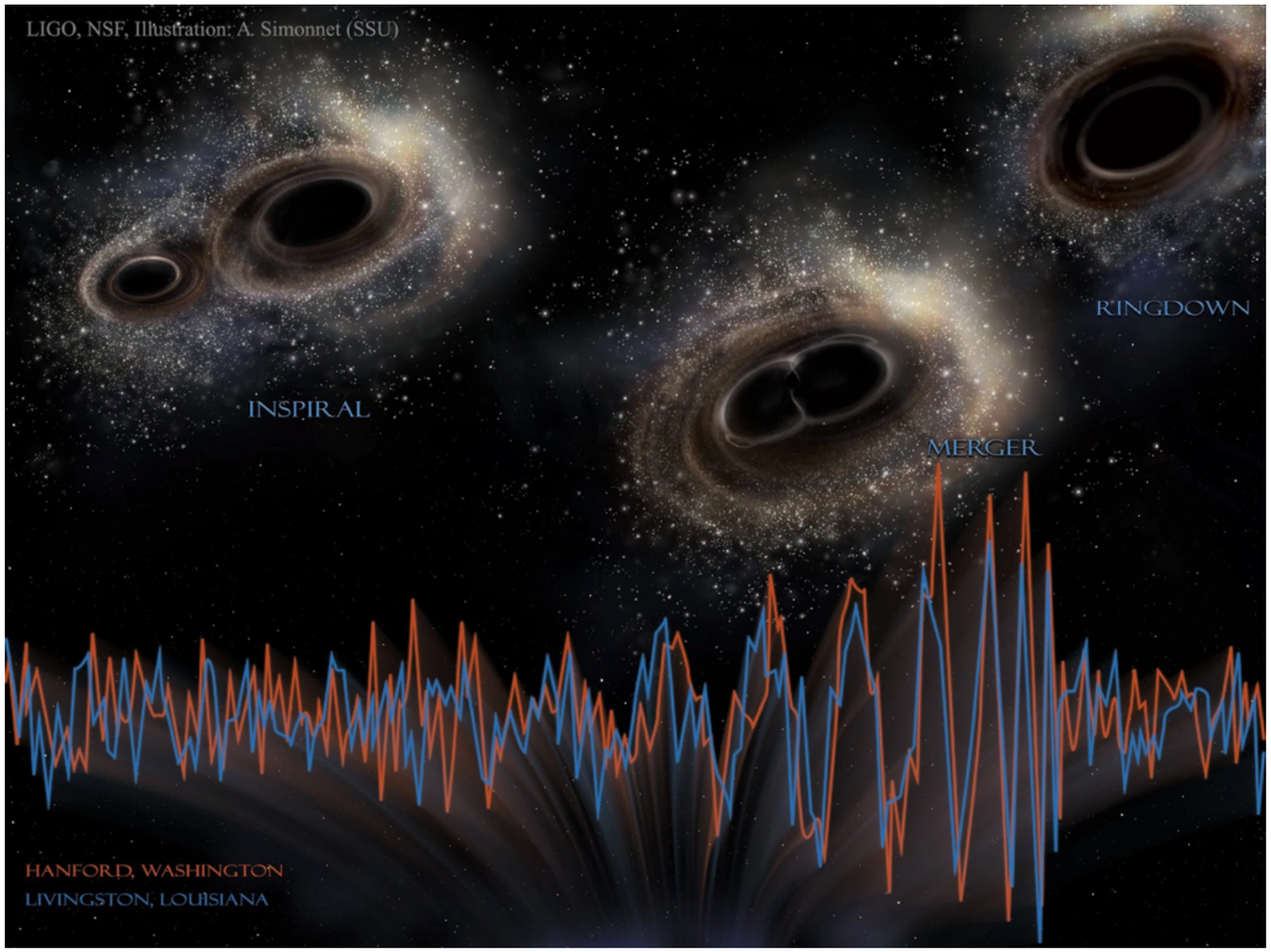
Lots of information....



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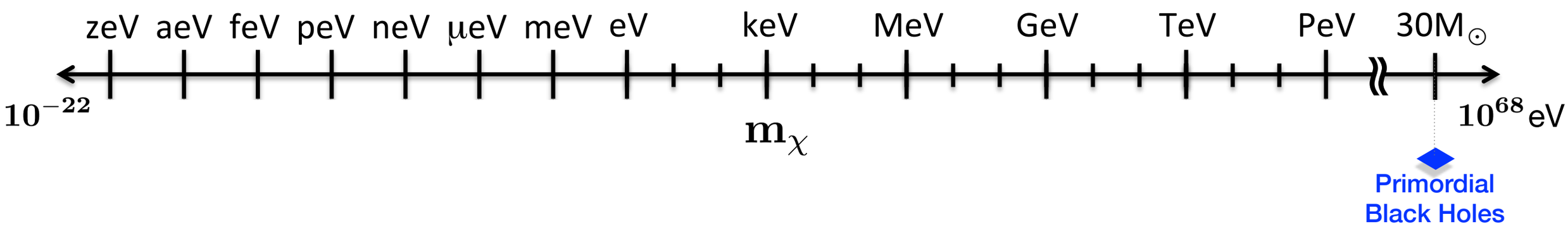

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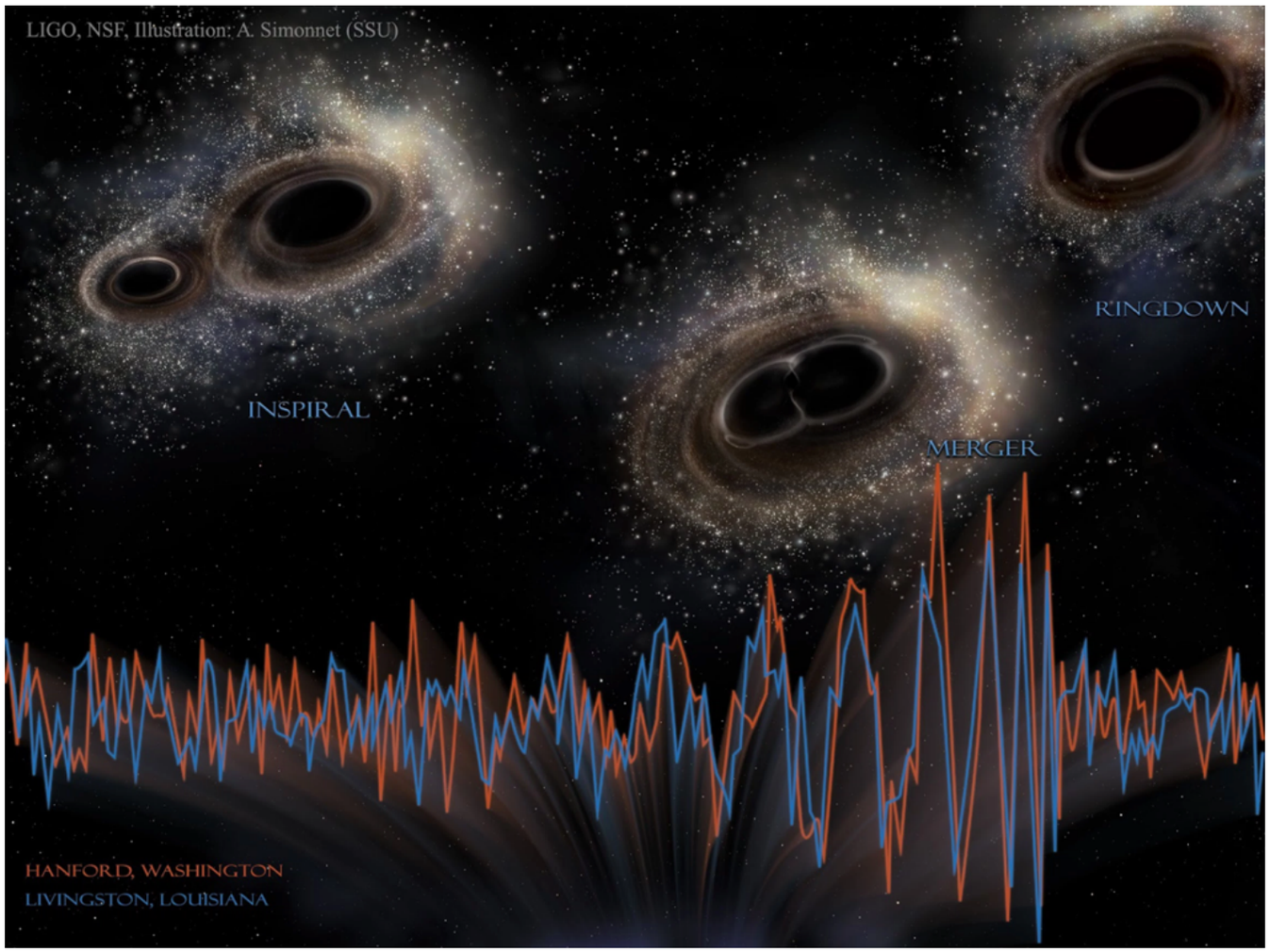
Black hole masses: ~ $29, 36 M_\odot$



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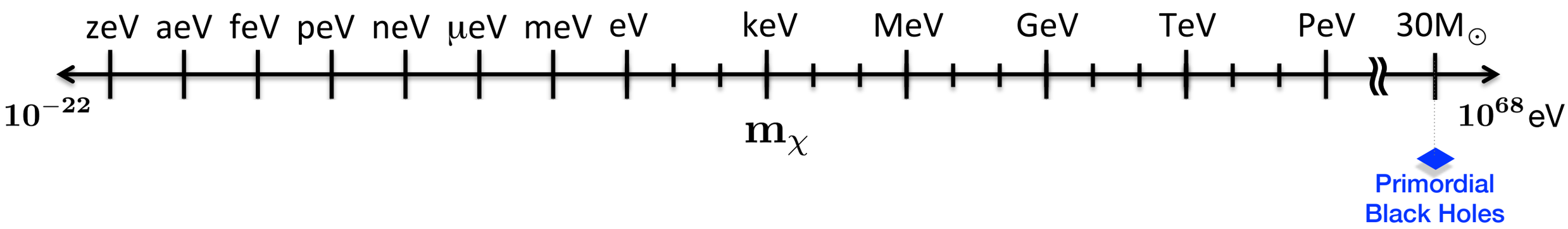

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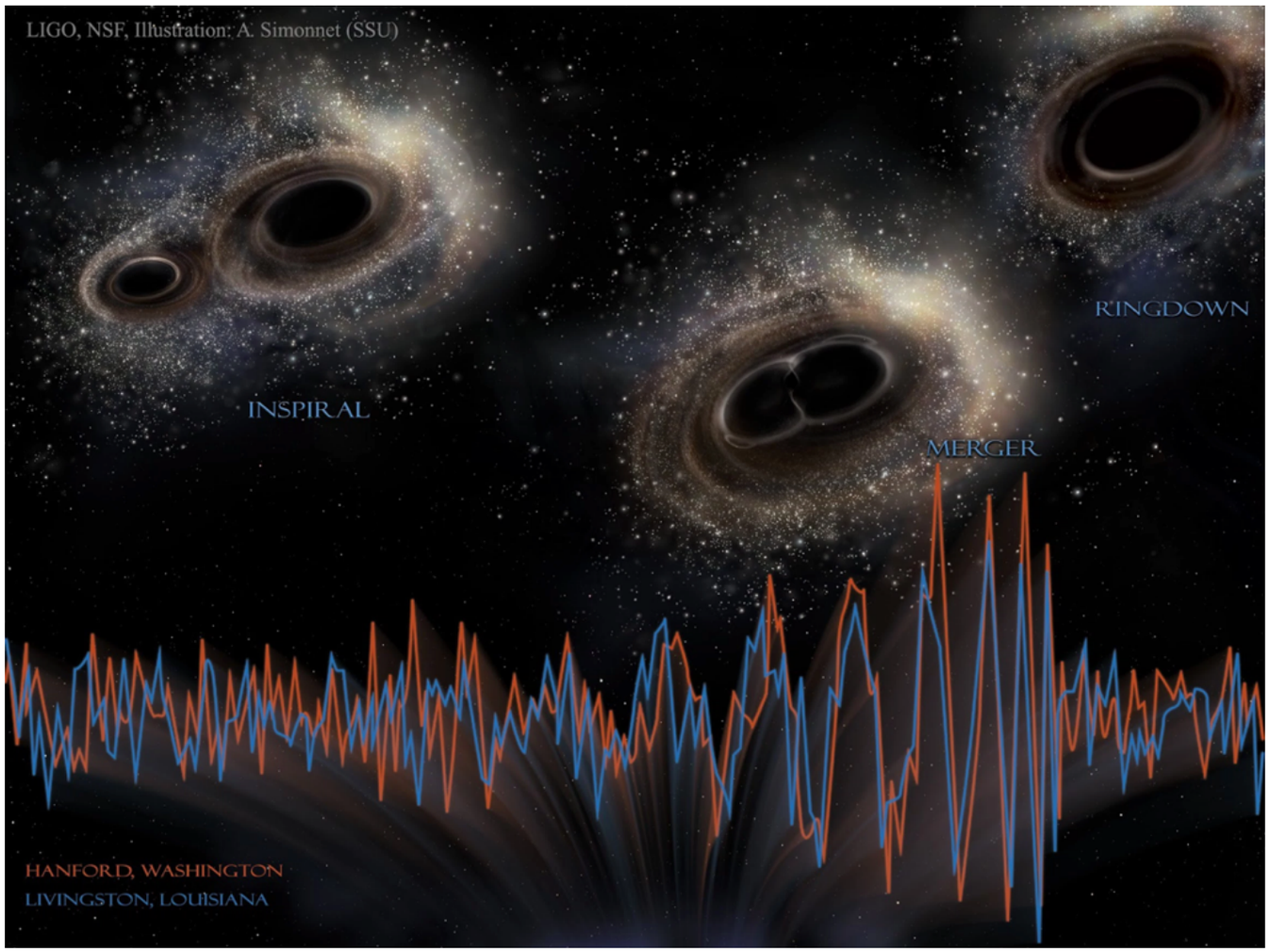
Could these be primordial?

Zel'dovich & Novikov (1967), Hawking (1971), Carr & Hawking (1974)...



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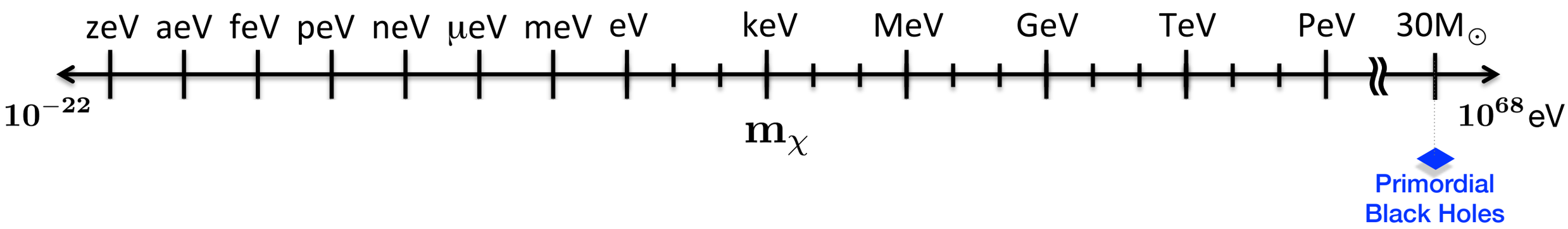

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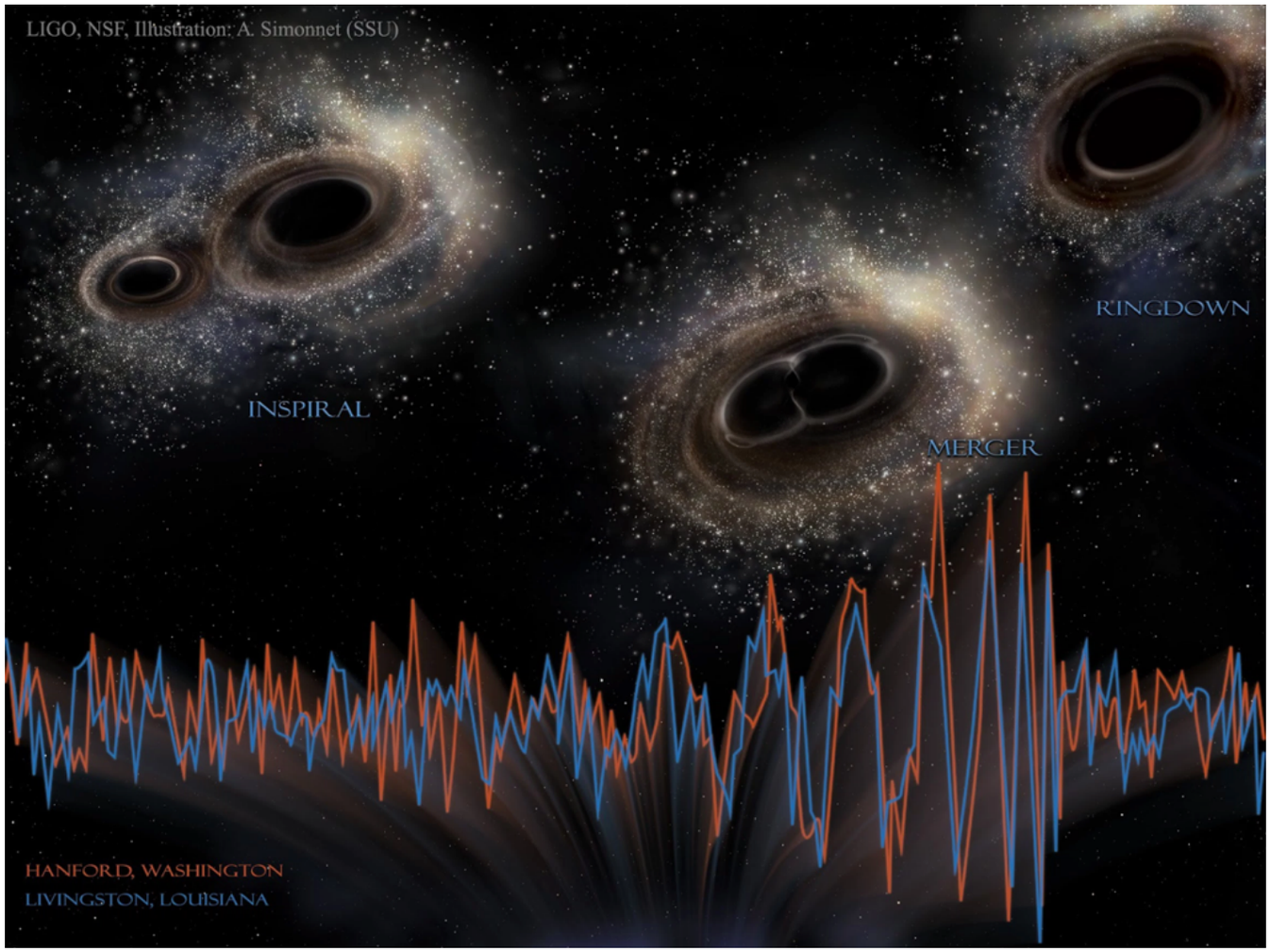
Did LIGO detect Dark Matter?

Bird,..., **EDK**,... et al., Phys. Rev. Lett. 116 (2016)



What's the Status with Current Observations?

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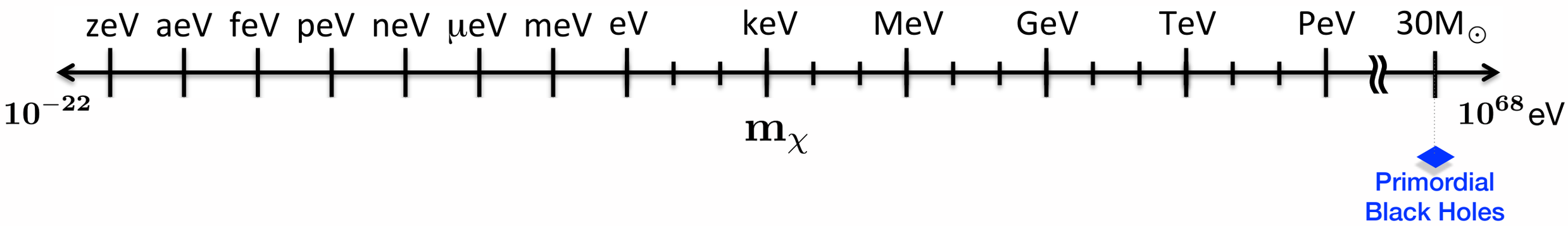

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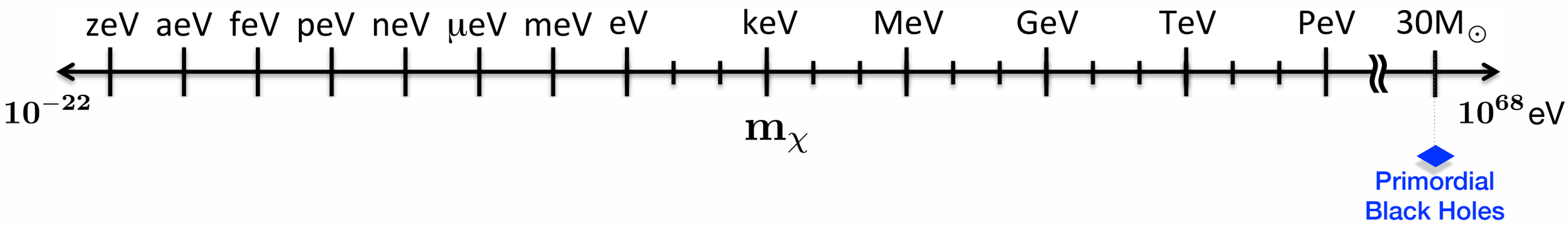
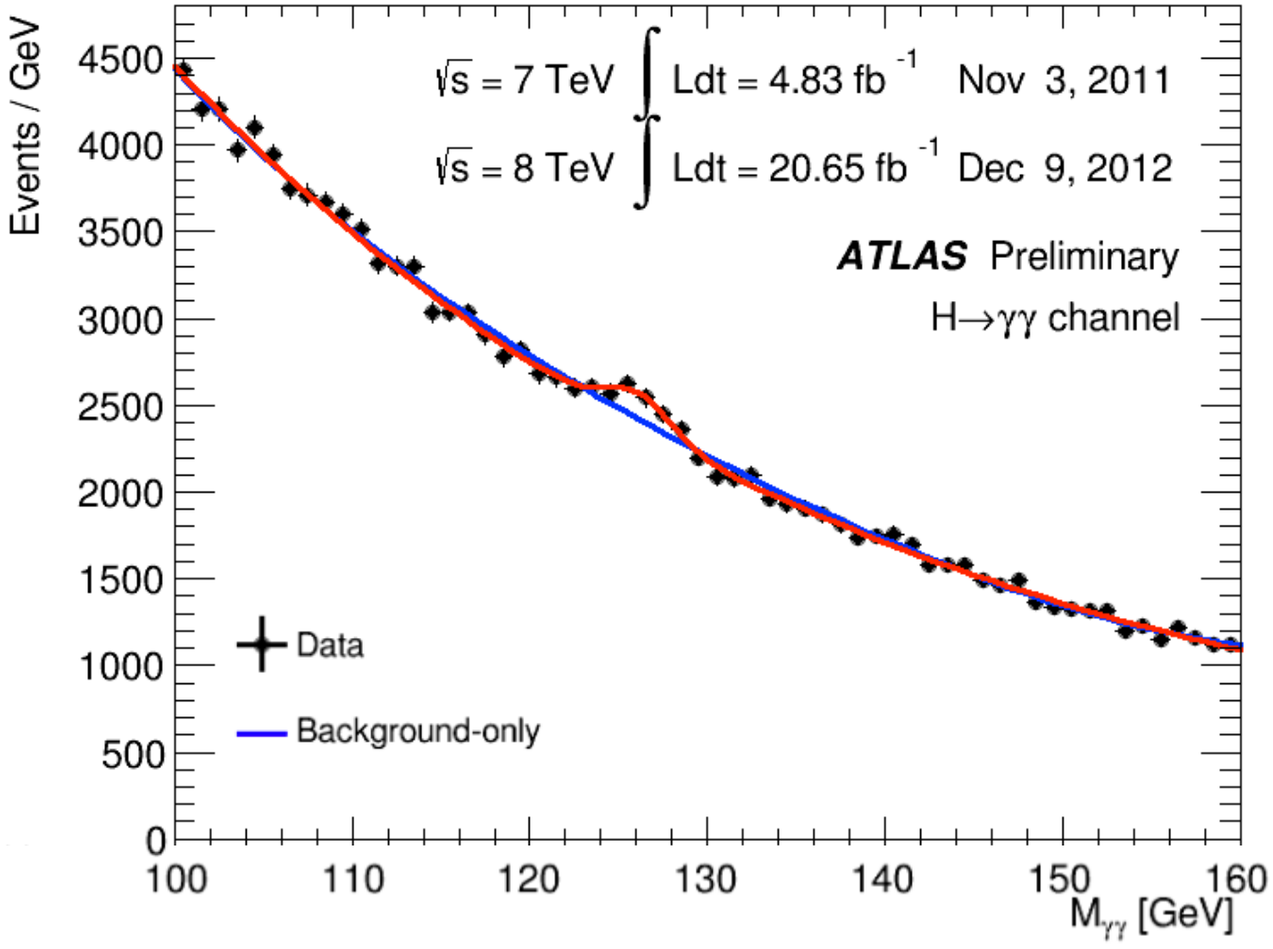


LHC (ATLAS) First Two Runs



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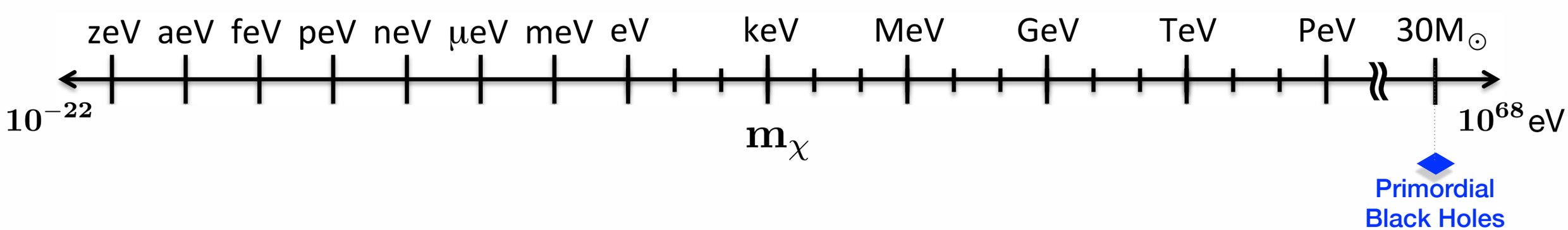

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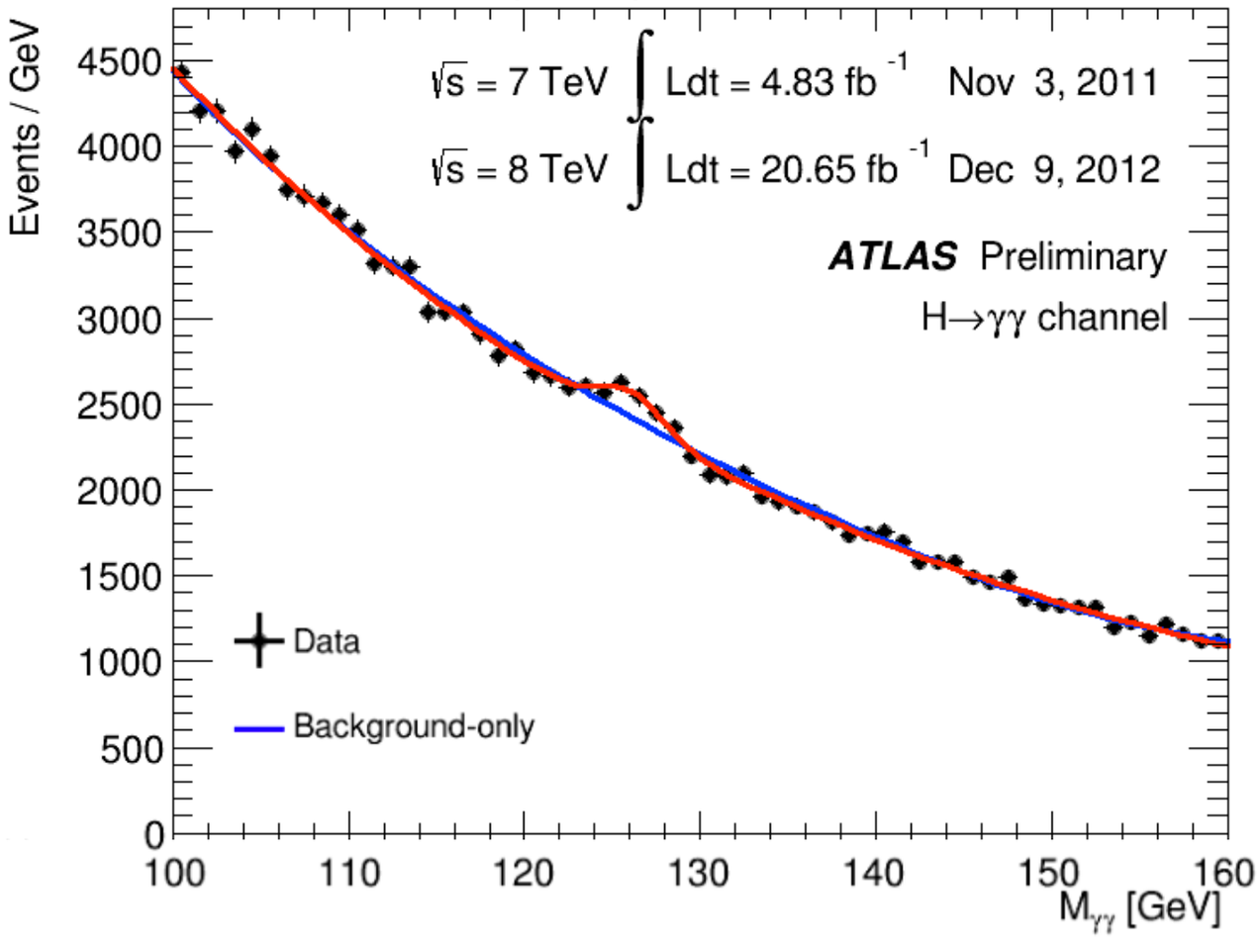
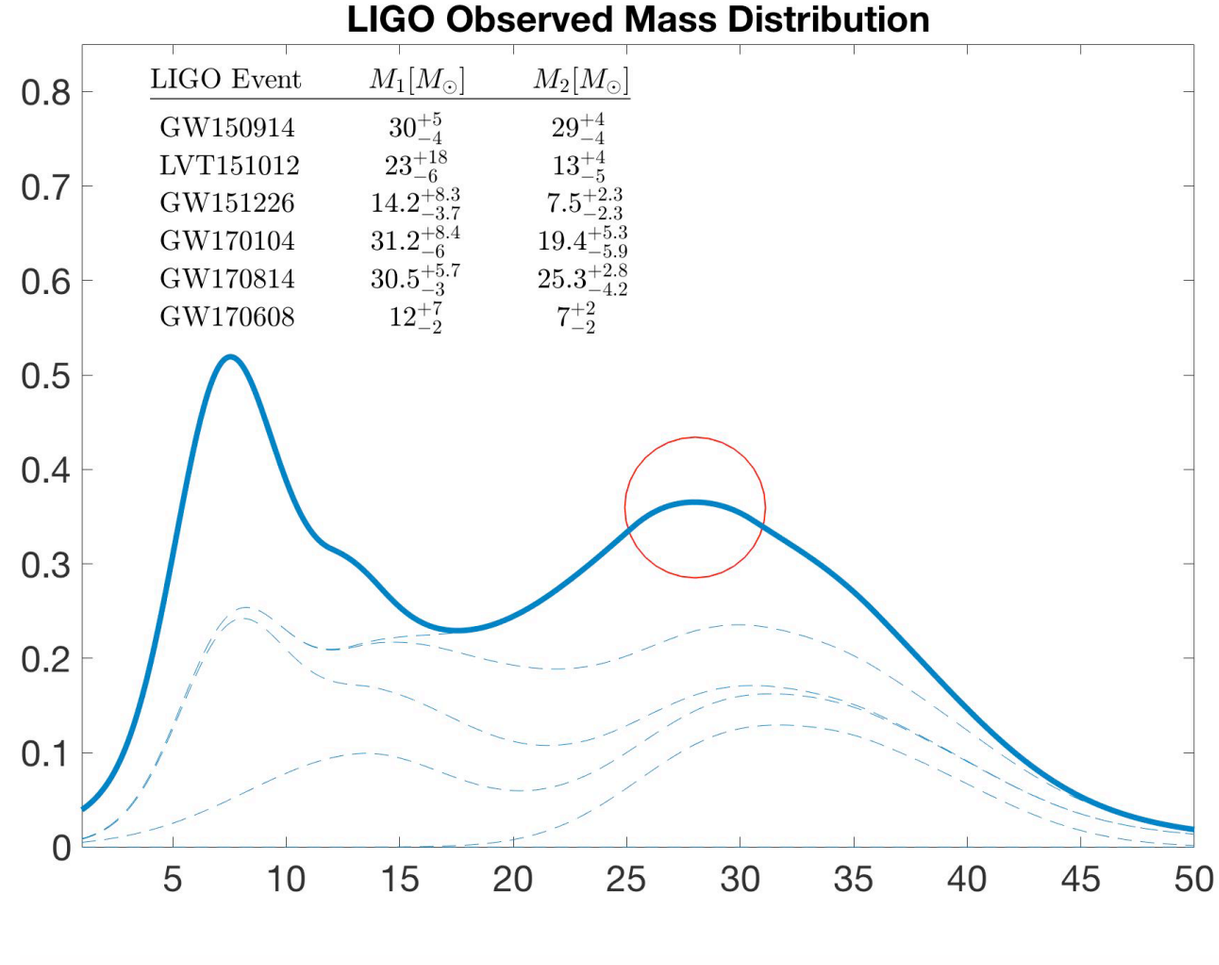


LIGO Observed Mass Distribution



Searching for PBH Dark Matter

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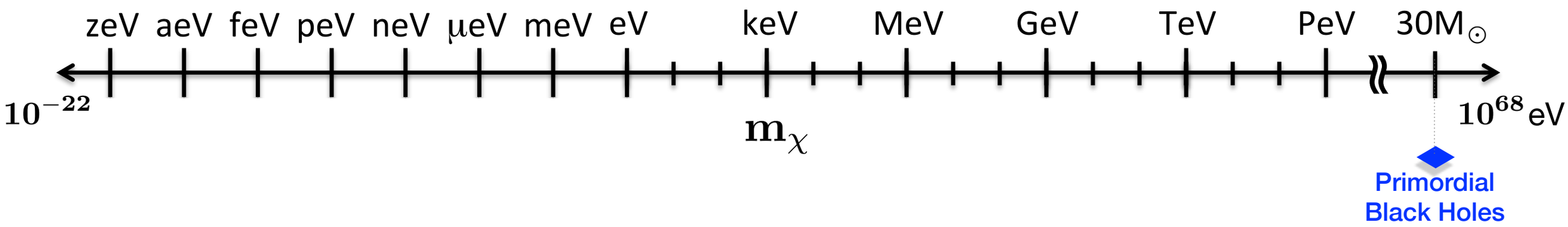

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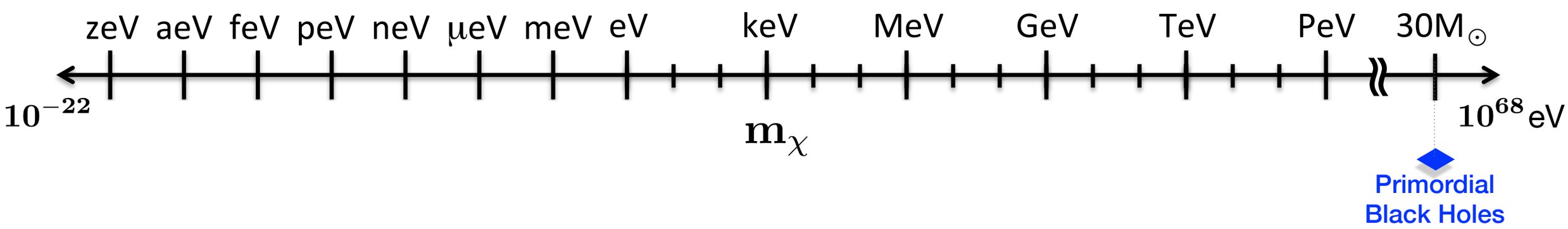

Search techniques:

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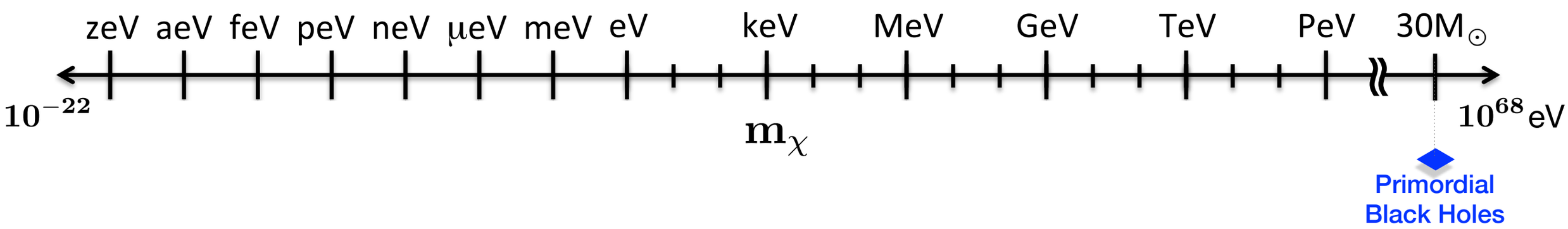

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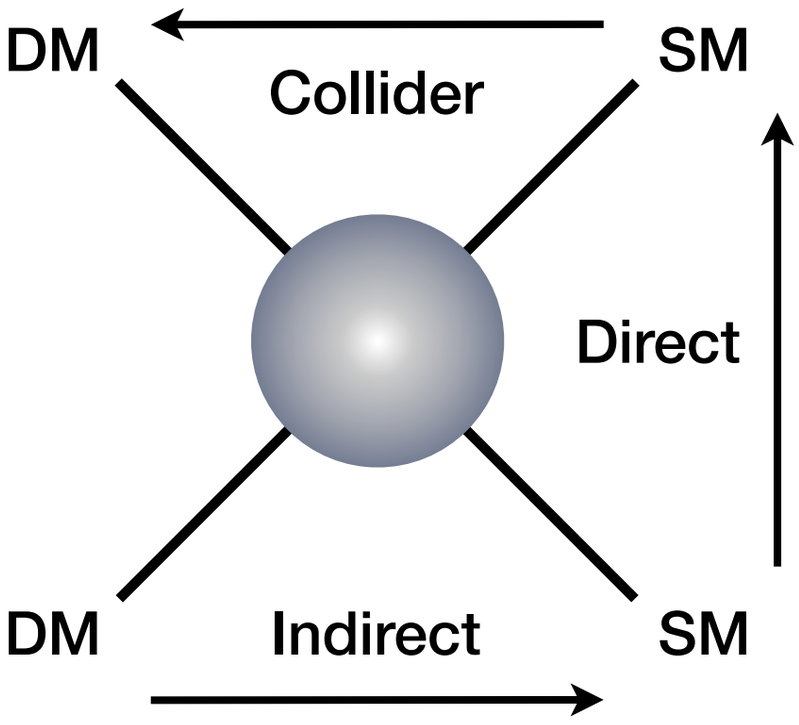

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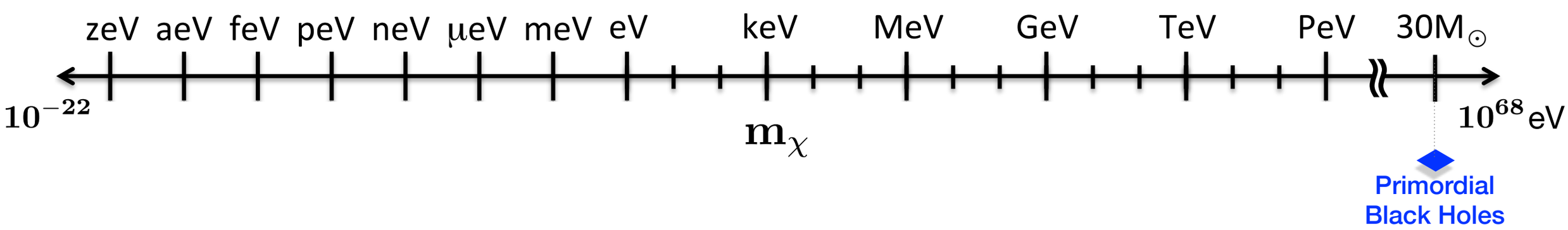

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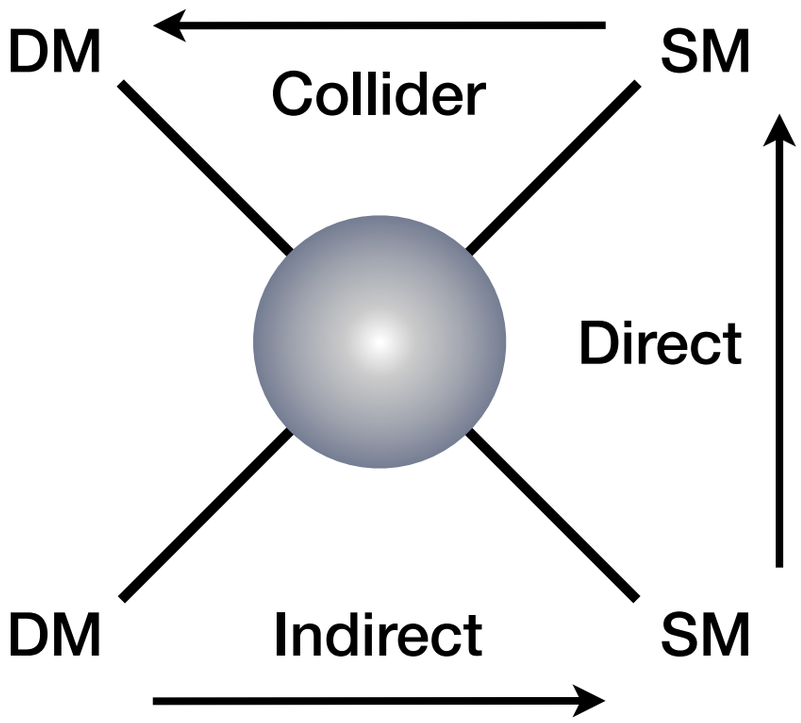

Similarly...

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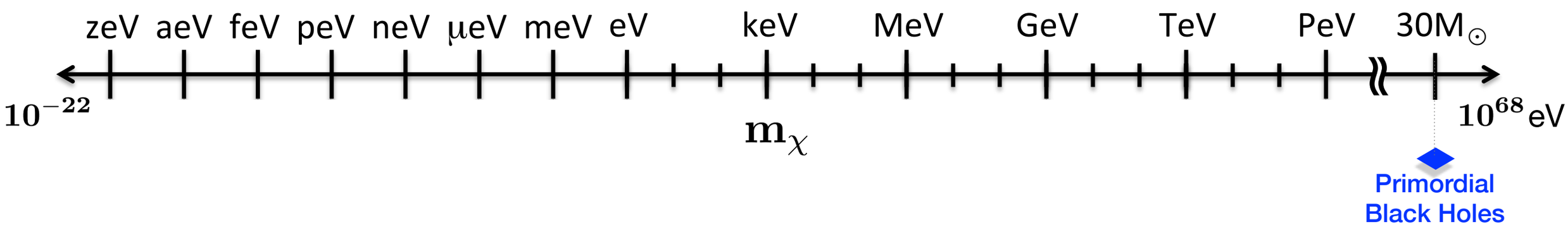

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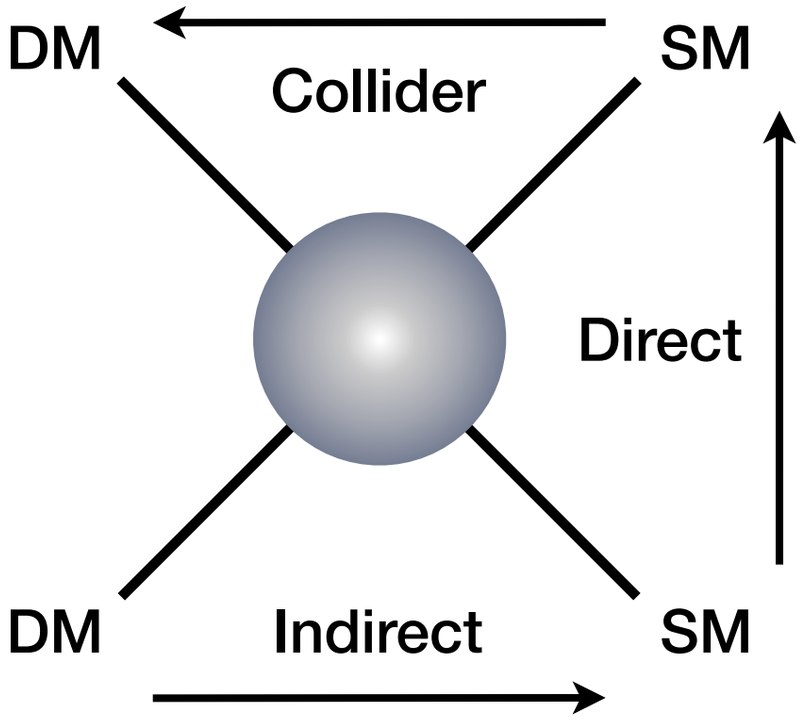
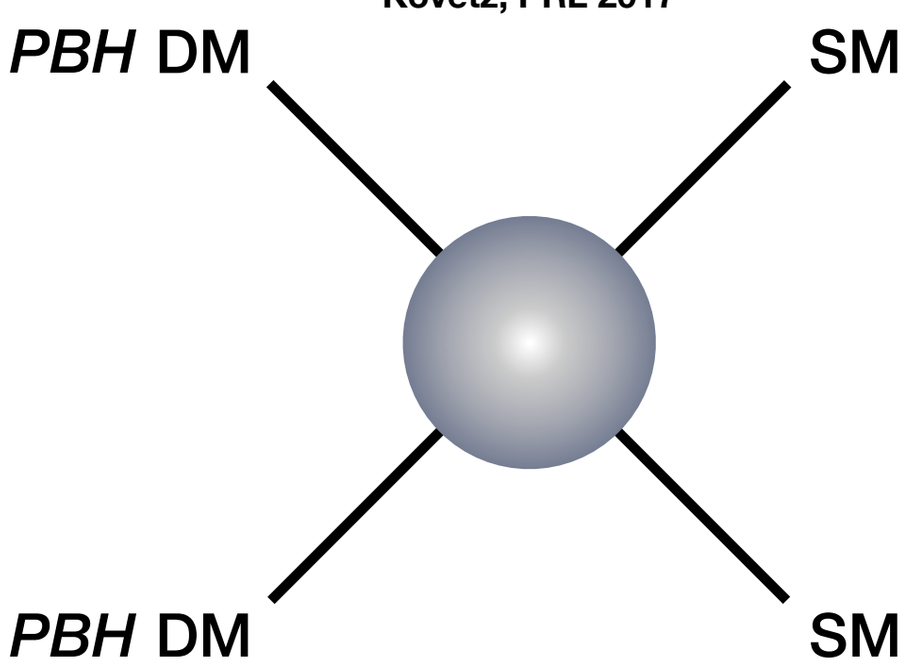


Similarly...

Kovetz, PRL 2017



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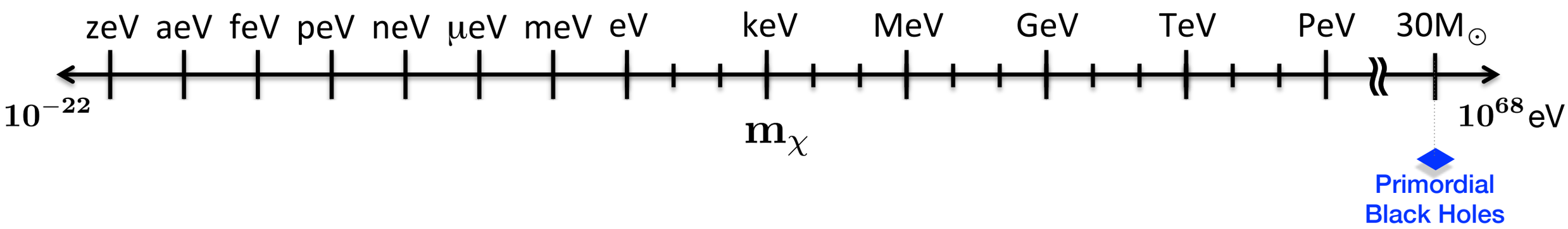

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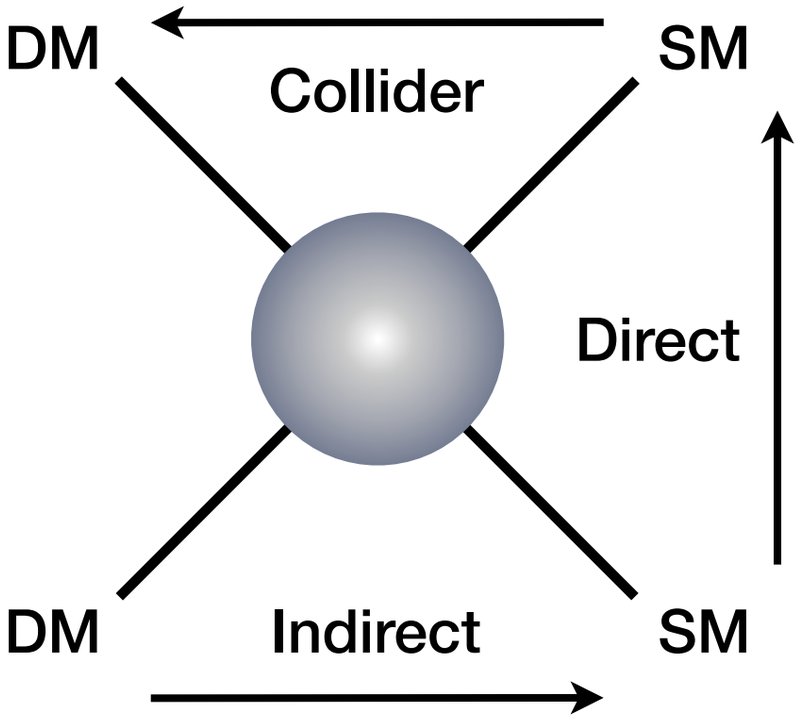

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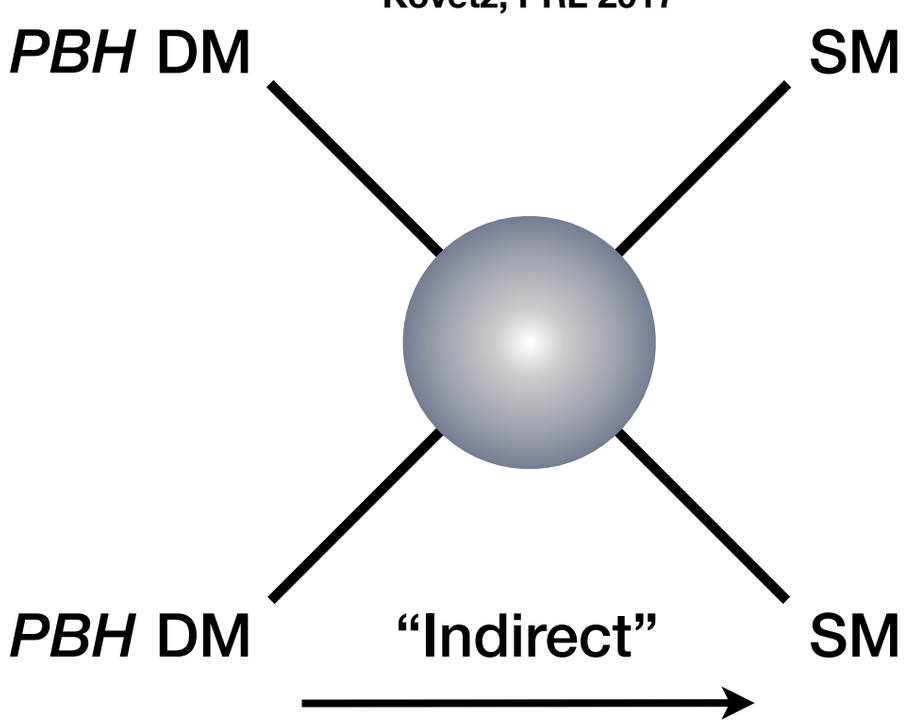
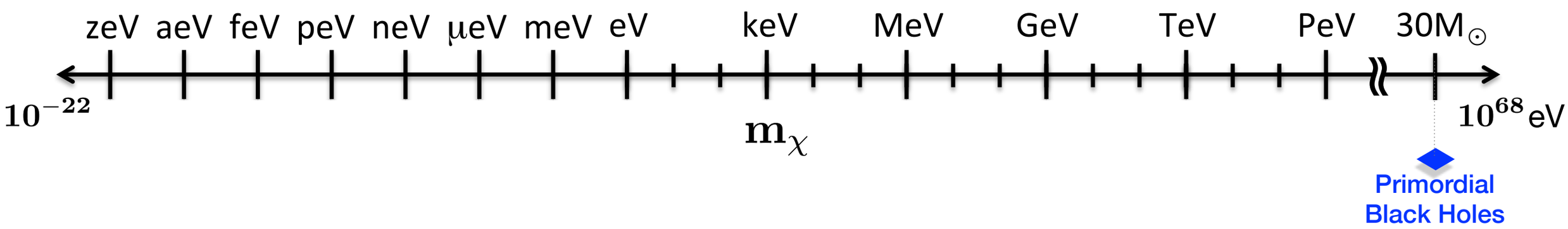
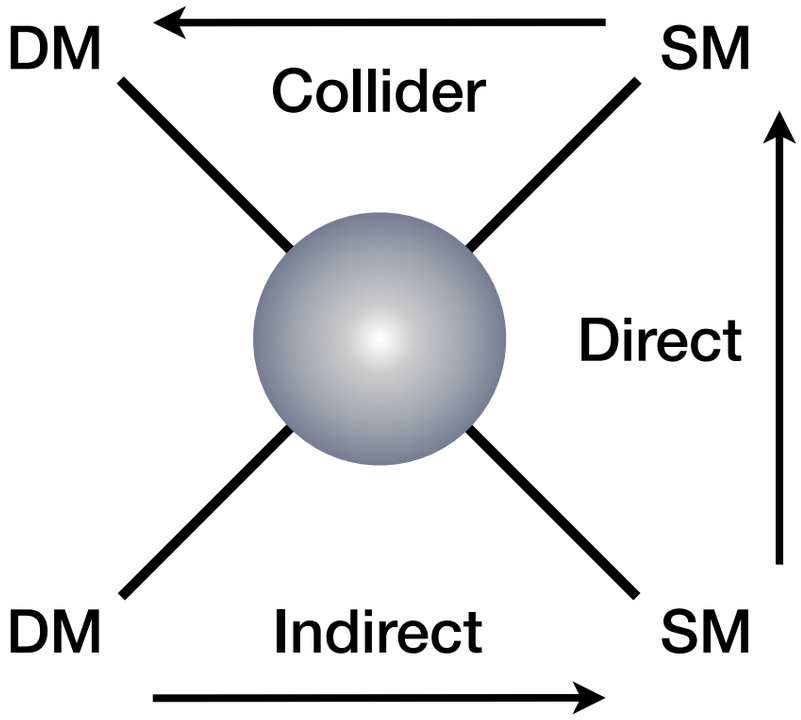


Searching for PBH Dark Matter

(adapted from Battaglieri et al., arXiv:1707.04591)

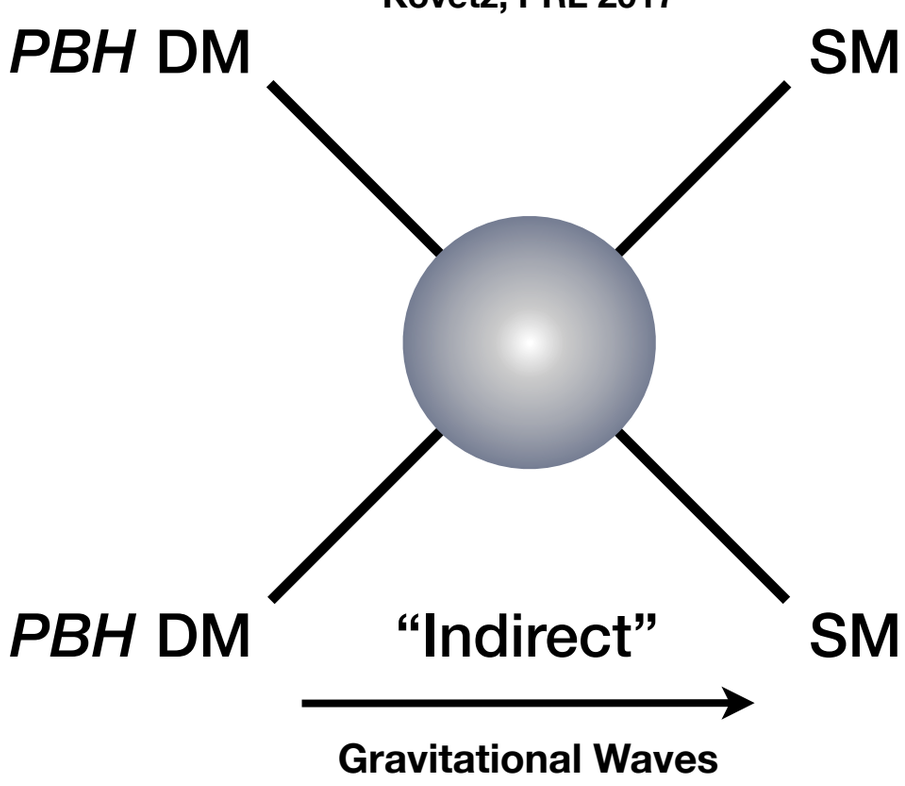


Search techniques:



Similarly...

Kovetz, PRL 2017



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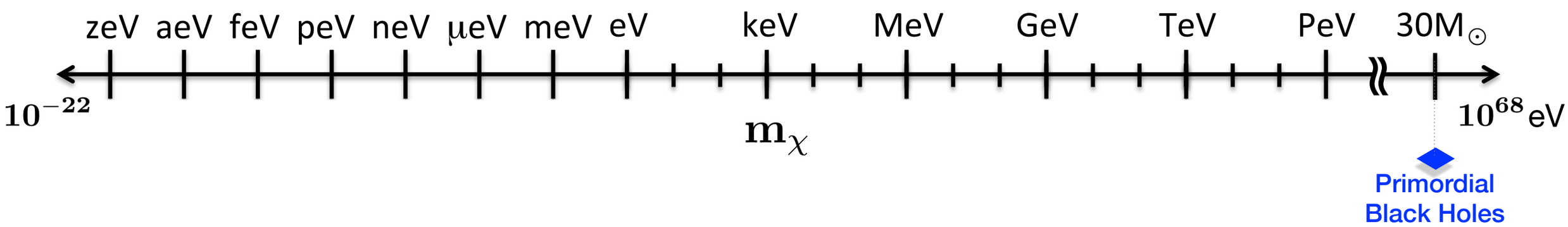

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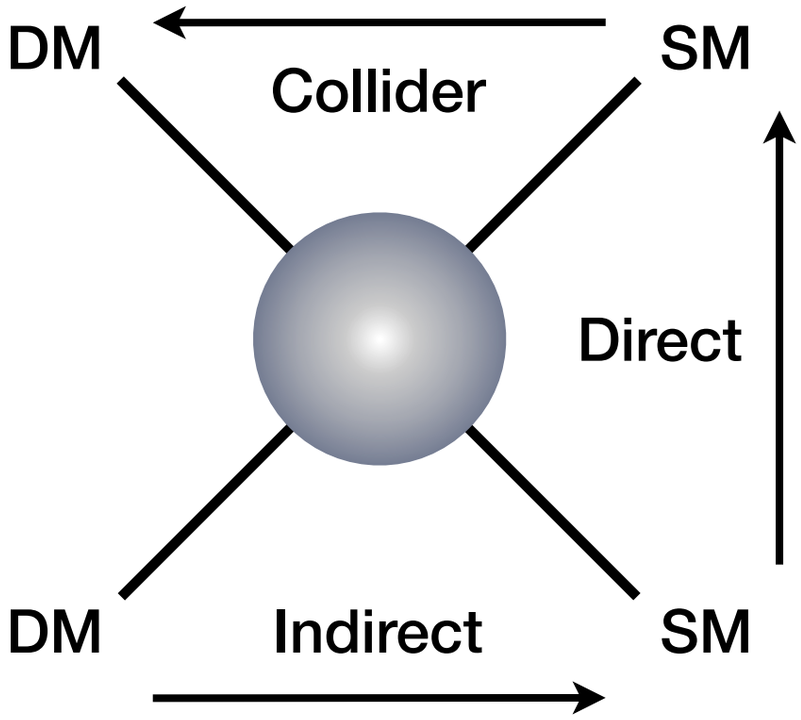

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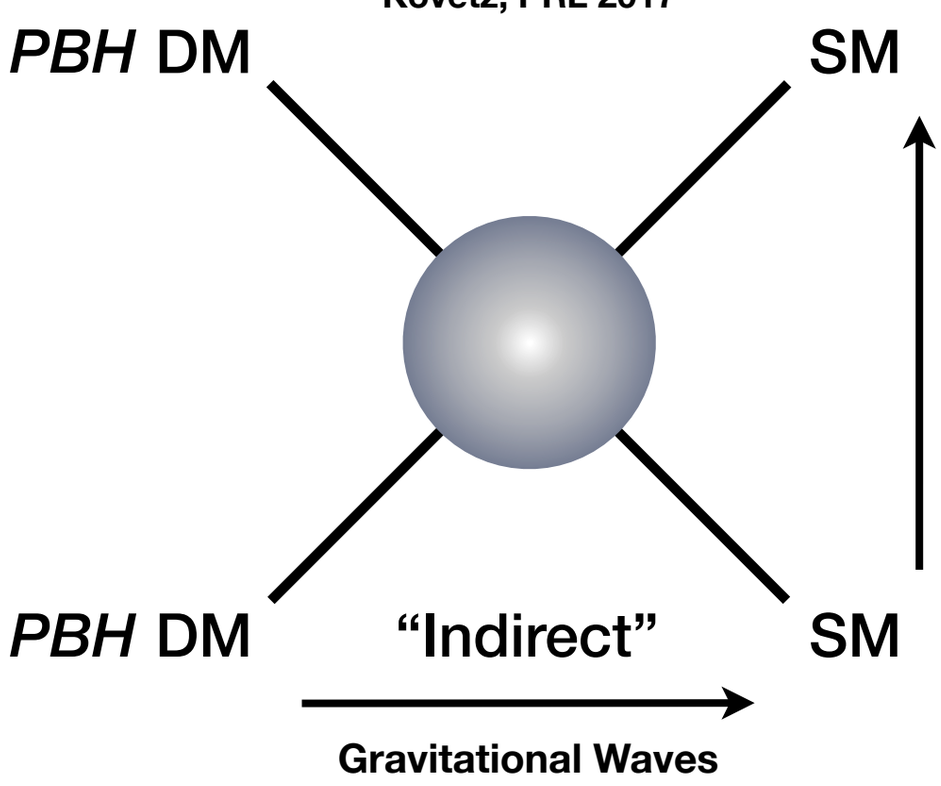

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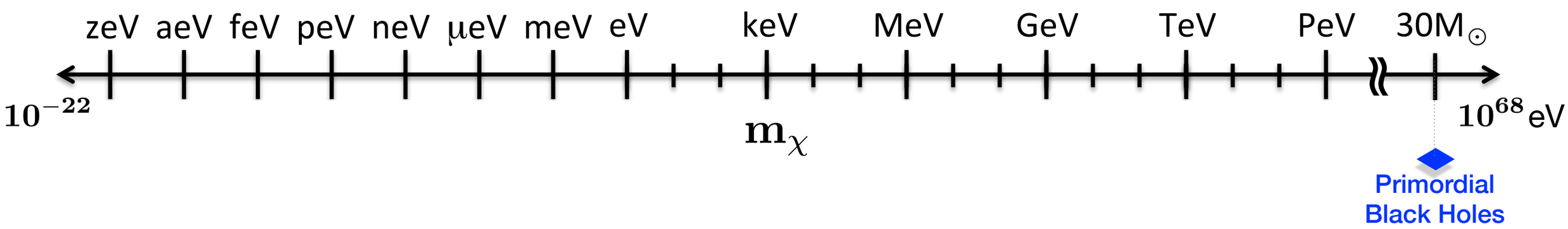

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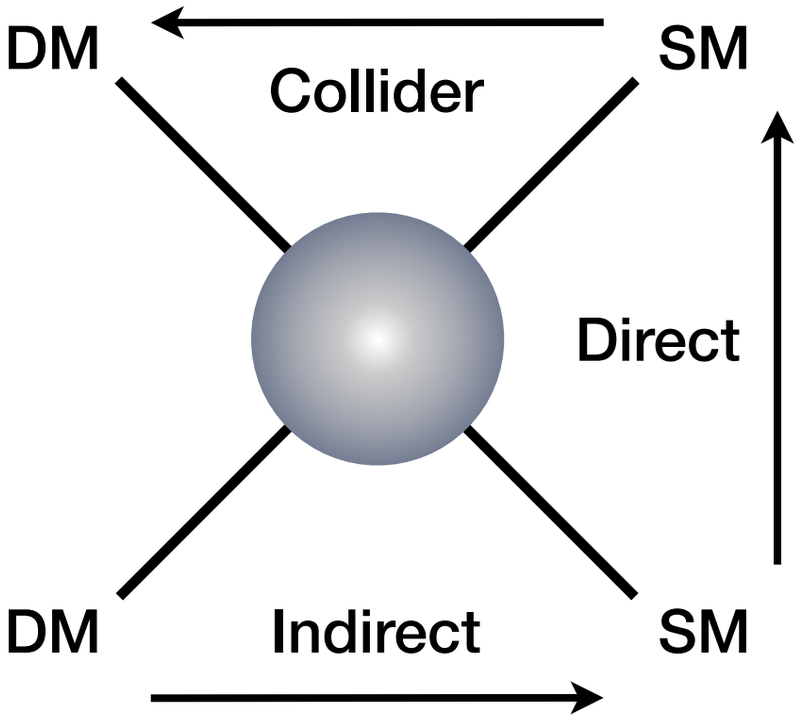

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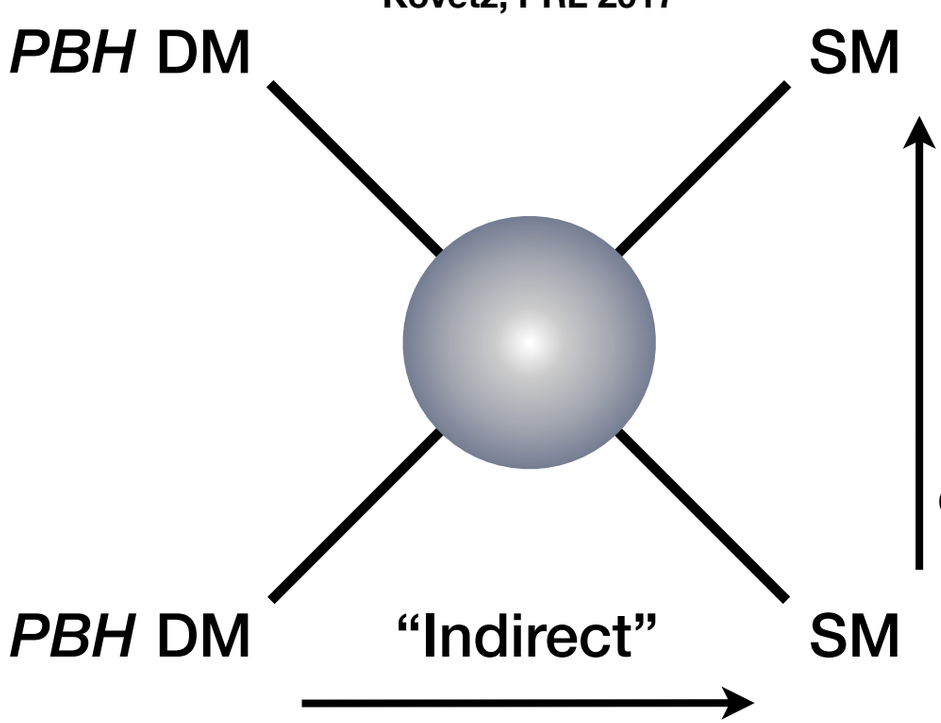
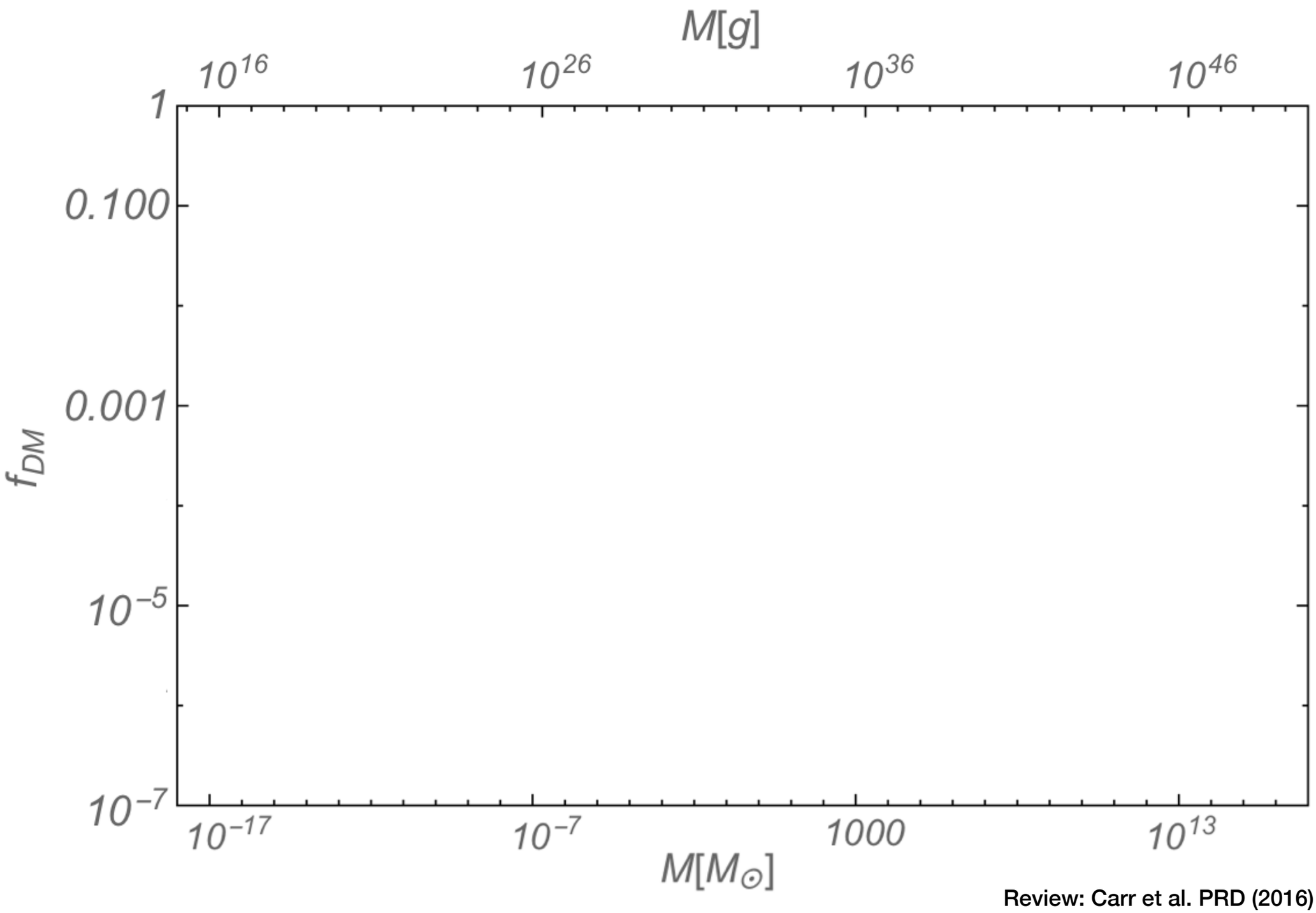


"Direct":

CMB
Microlensing
Wide Binaries
Ultra-Faint Dwarfs
Fast Radio Bursts
Gamma Ray Bursts
.
.
.

PBH Dark Matter: Existing Constraints



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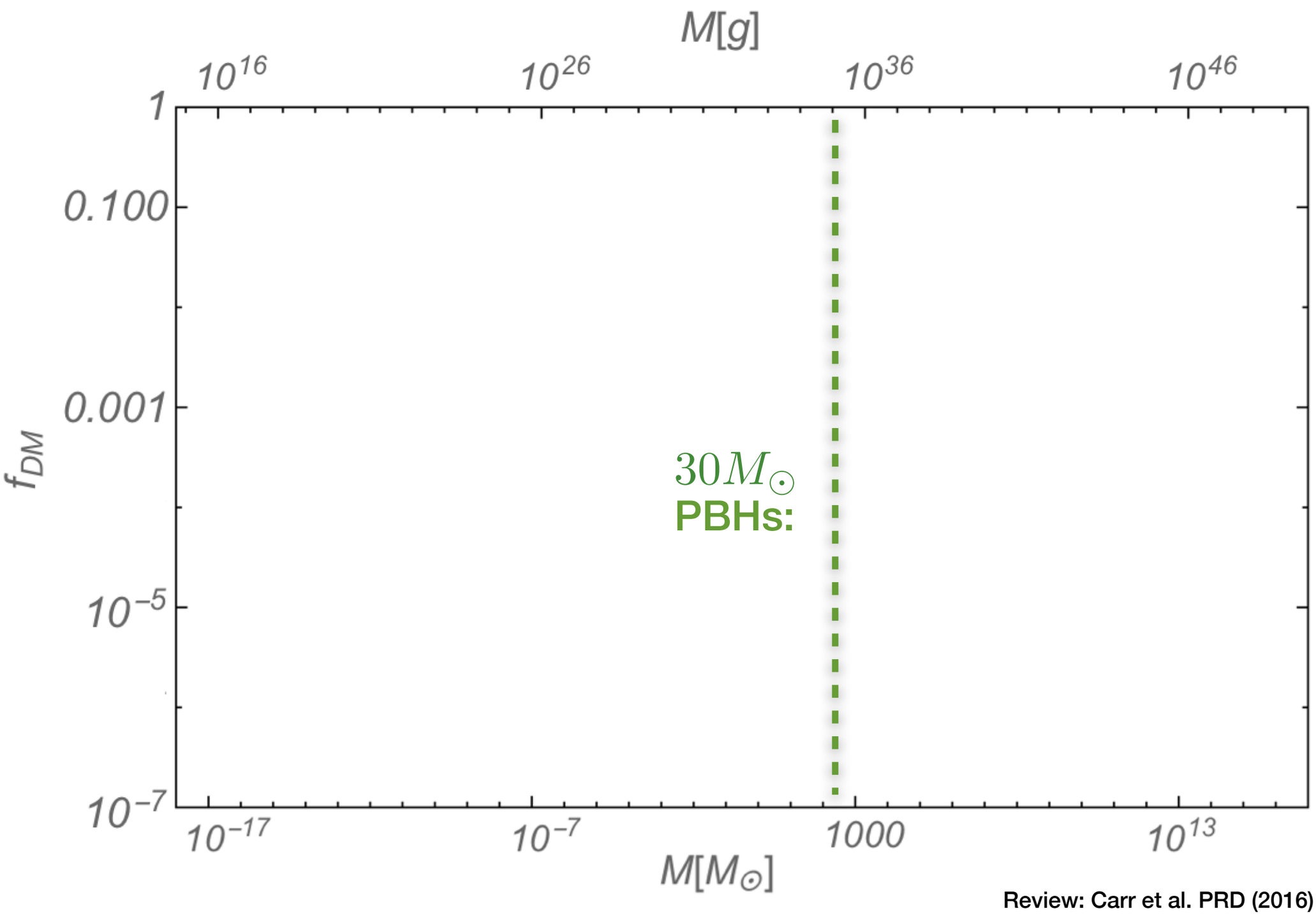

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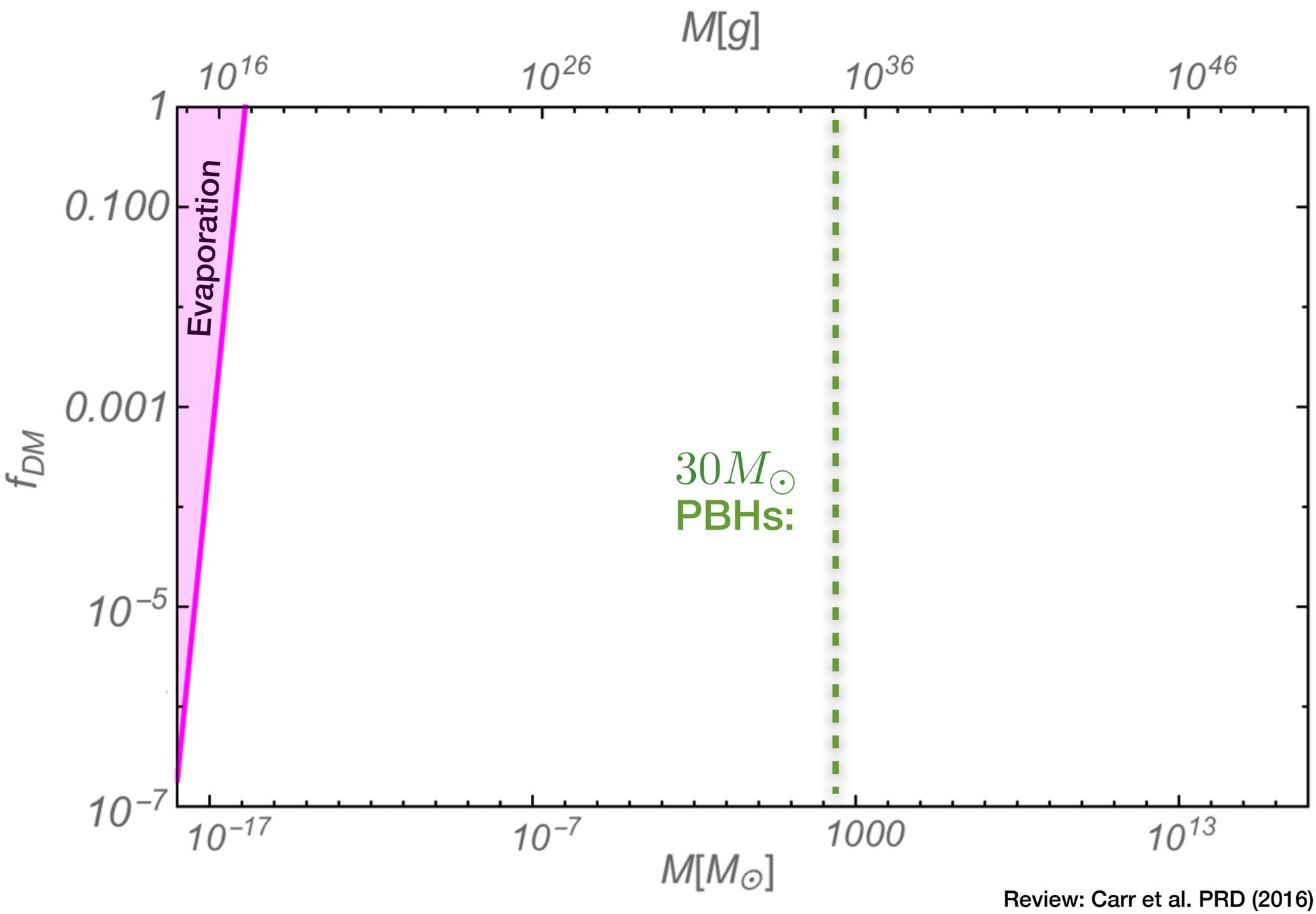

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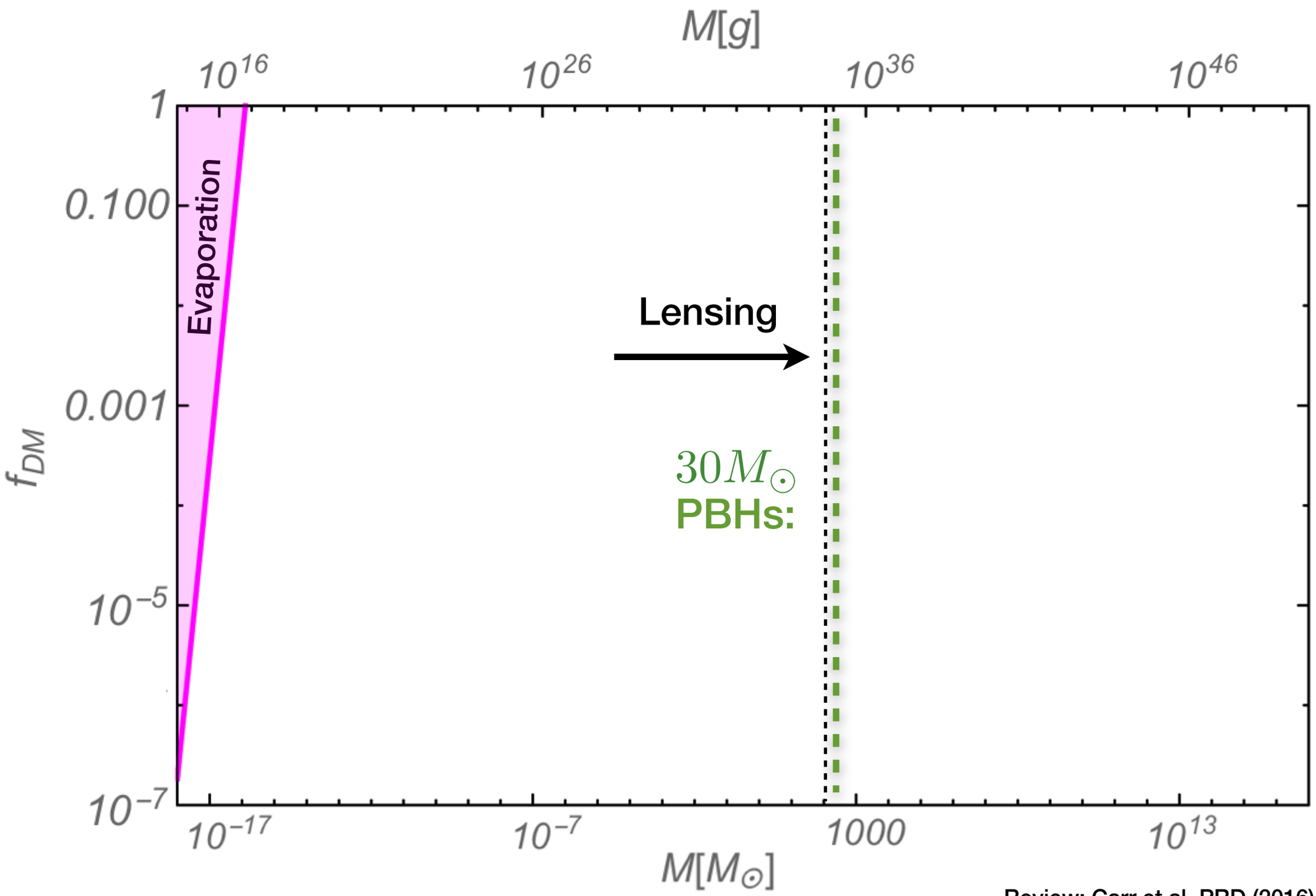

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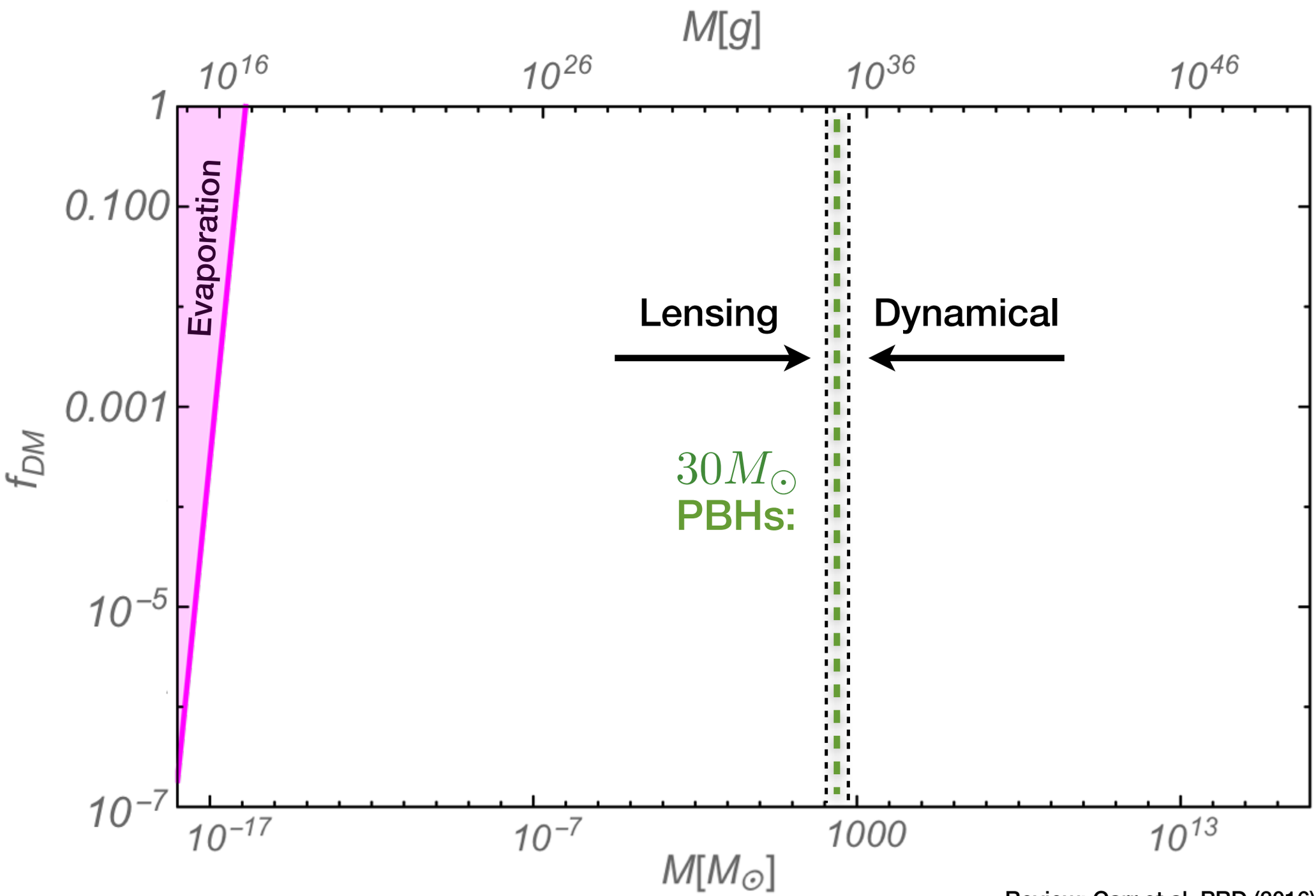

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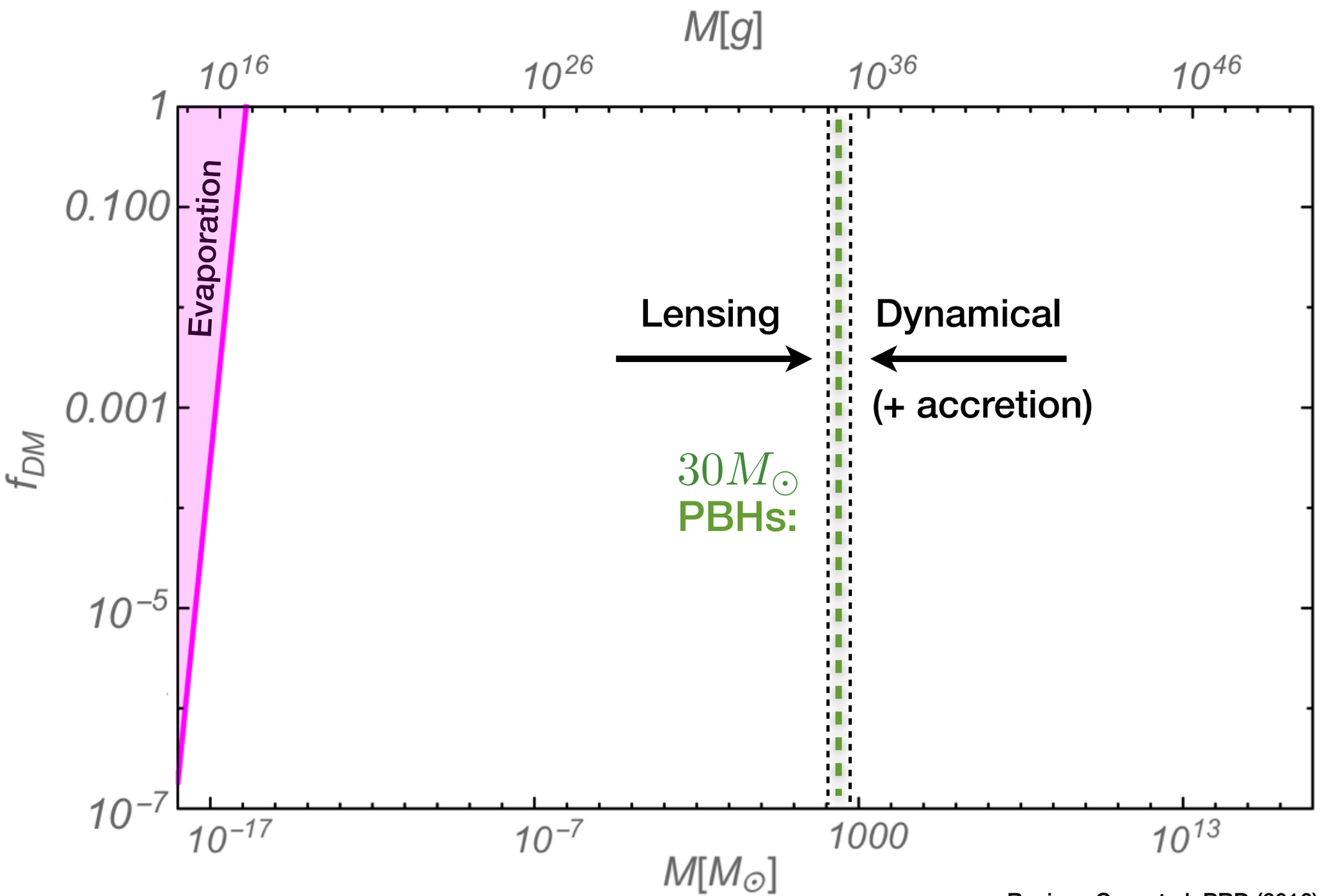

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Microlensing: Illustration

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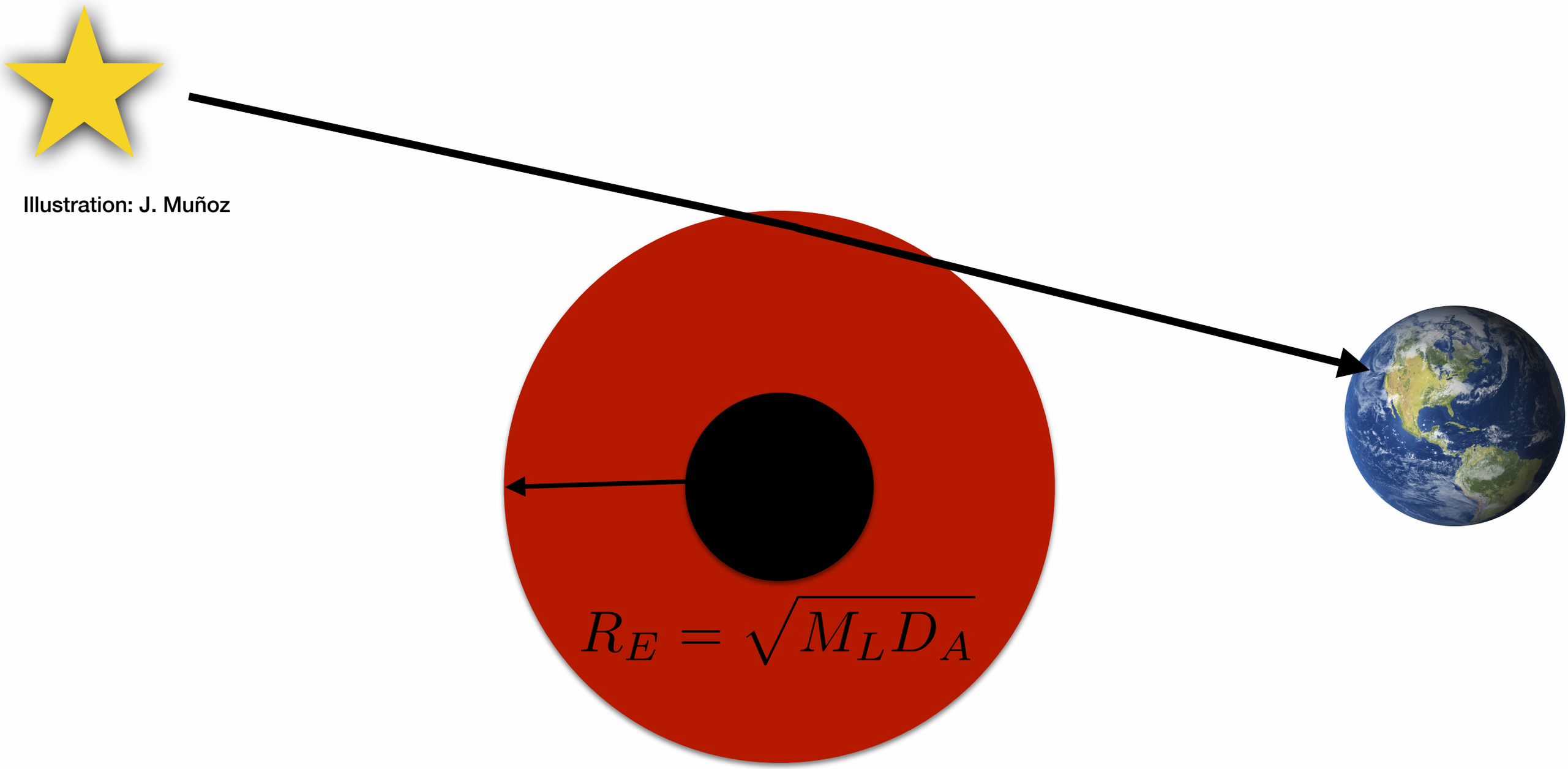
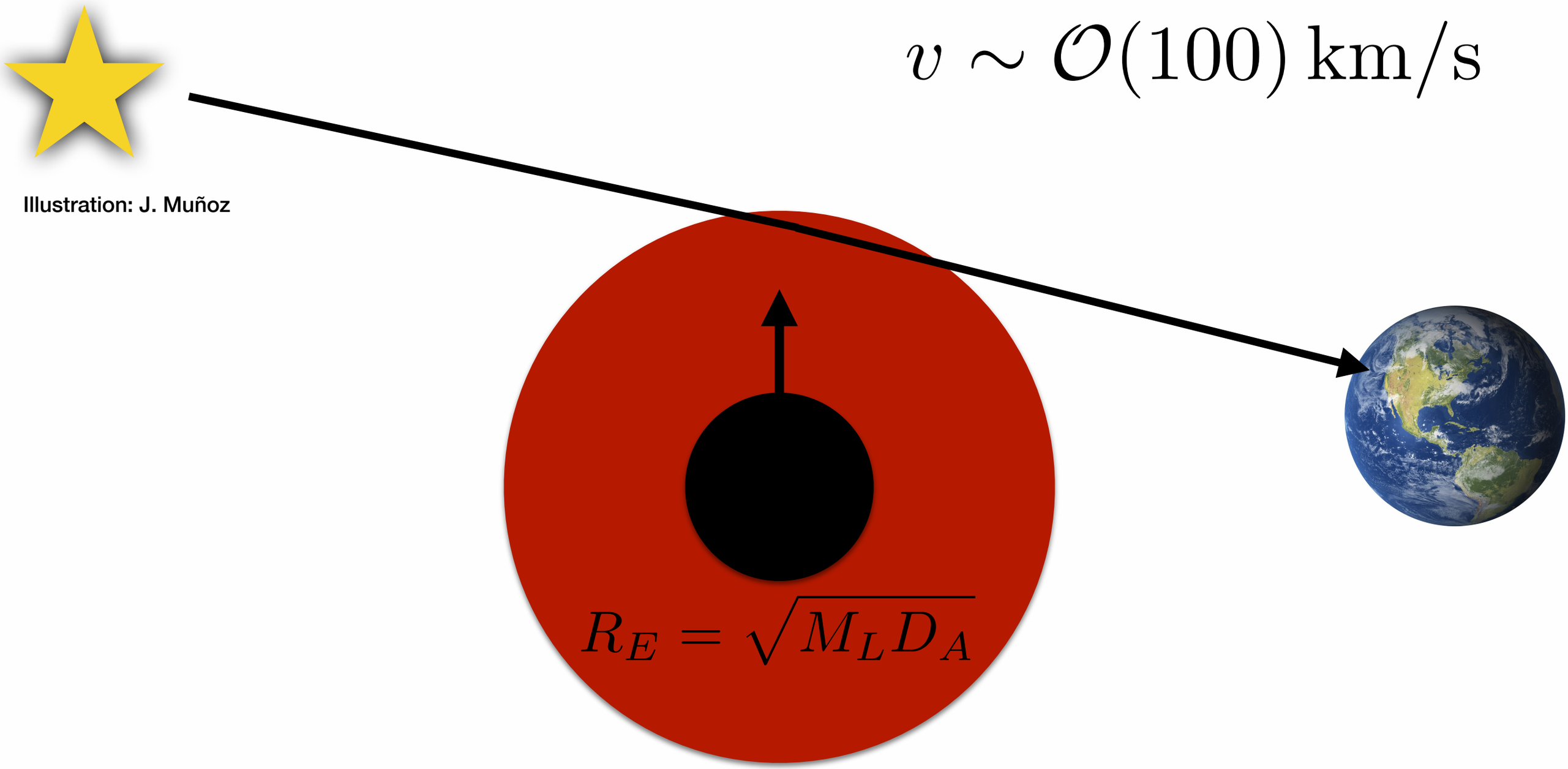


Illustration: J. Muñoz

Microlensing: Illustration

$$v \sim \mathcal{O}(100)\,\mathrm{km/s}$$



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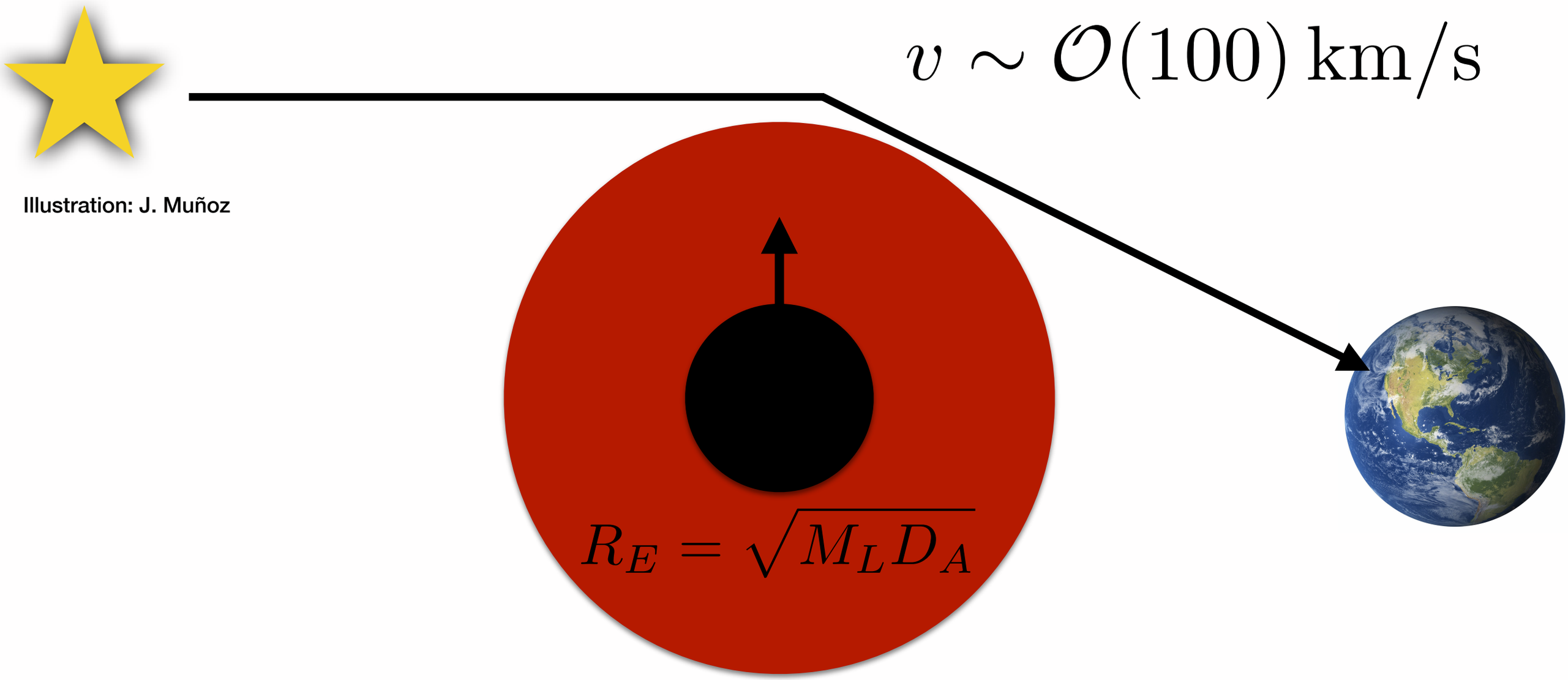

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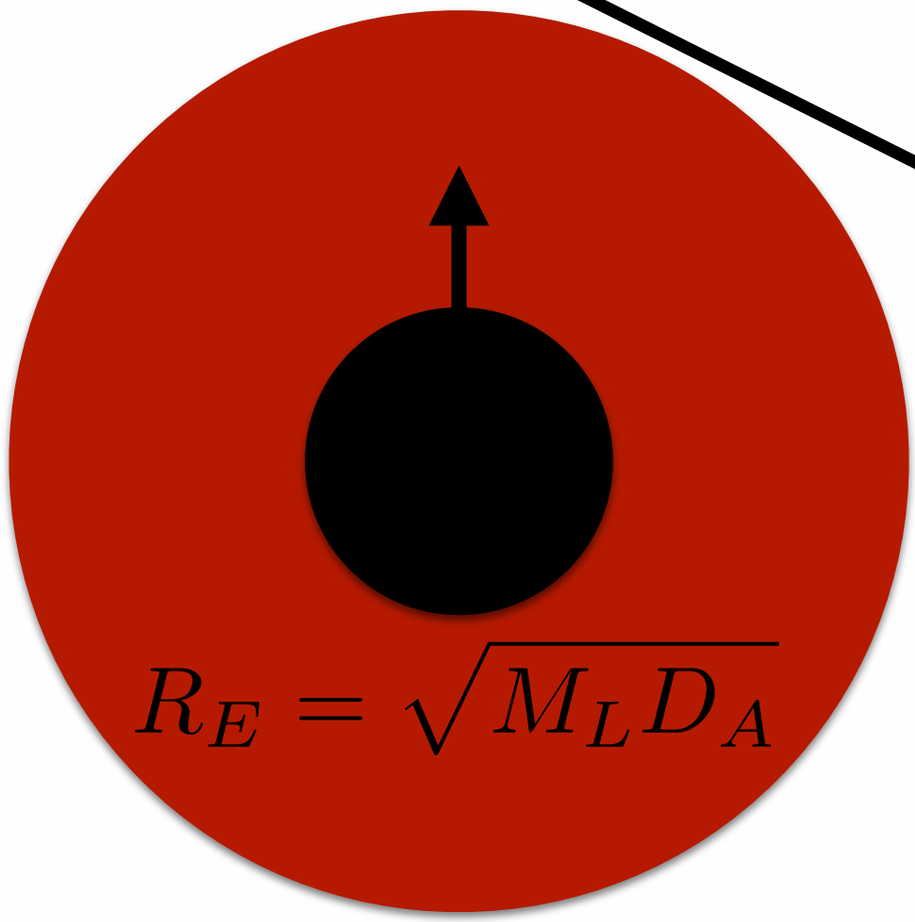
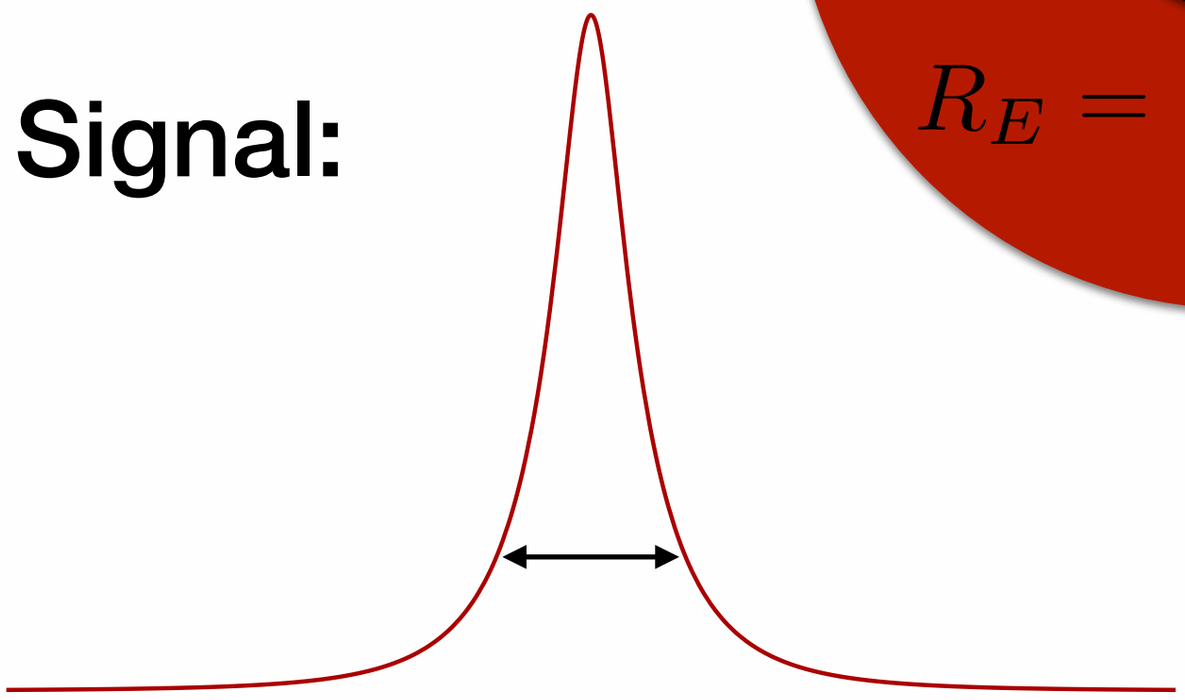


Signal:



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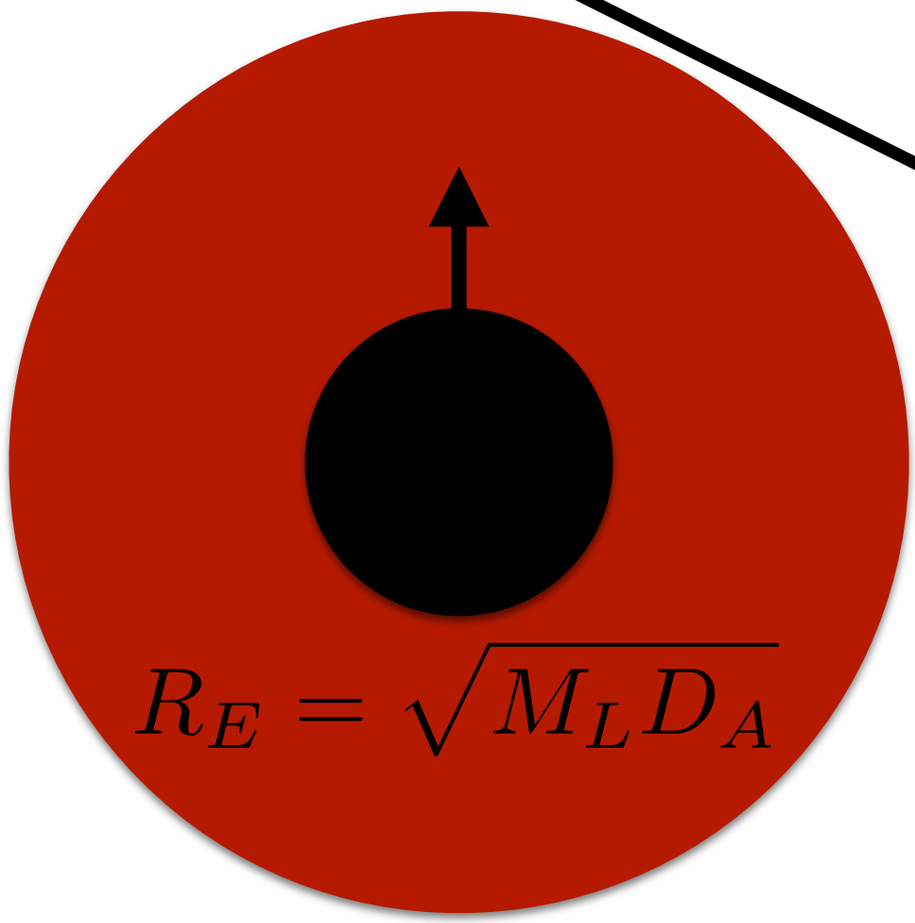

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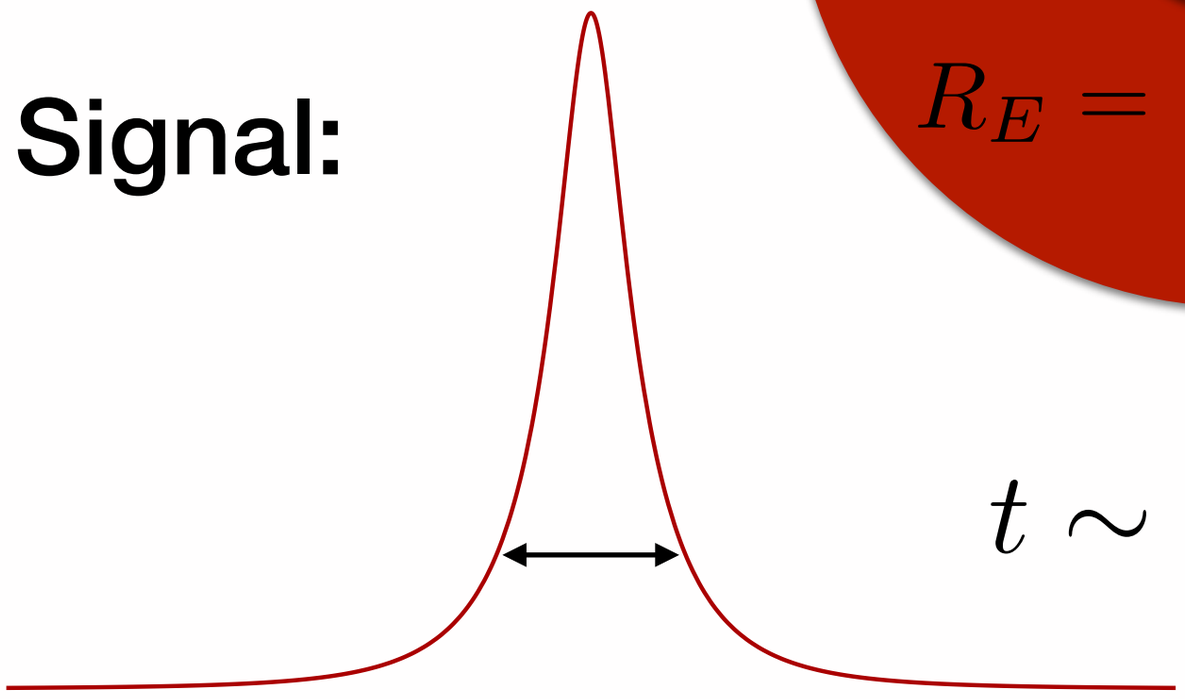
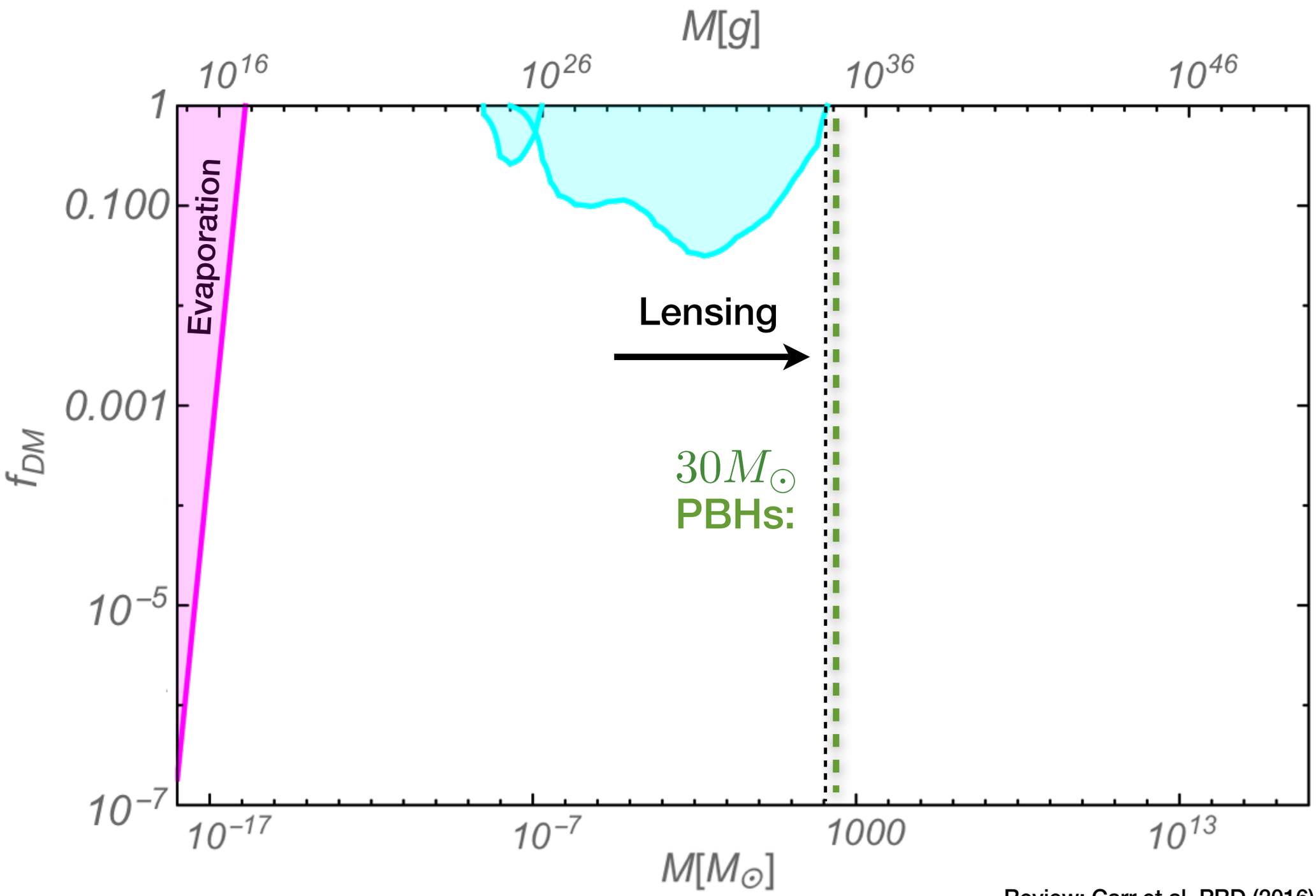


$$t \sim \frac{R_E}{v} \sim \mathrm{yrs} \times \sqrt{\frac{M_L}{10\,M_\odot}}$$

PBH Dark Matter: Existing Constraints



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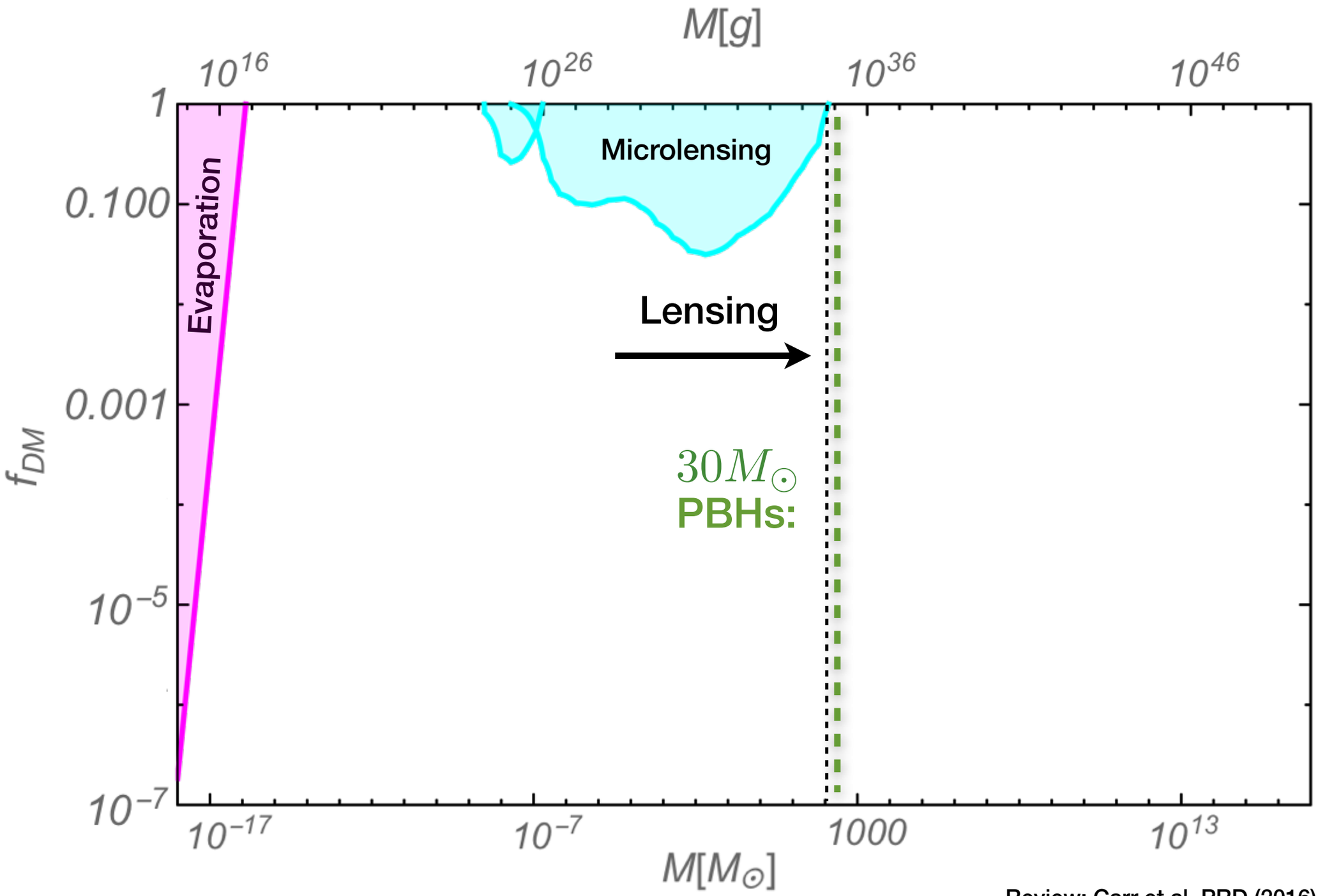

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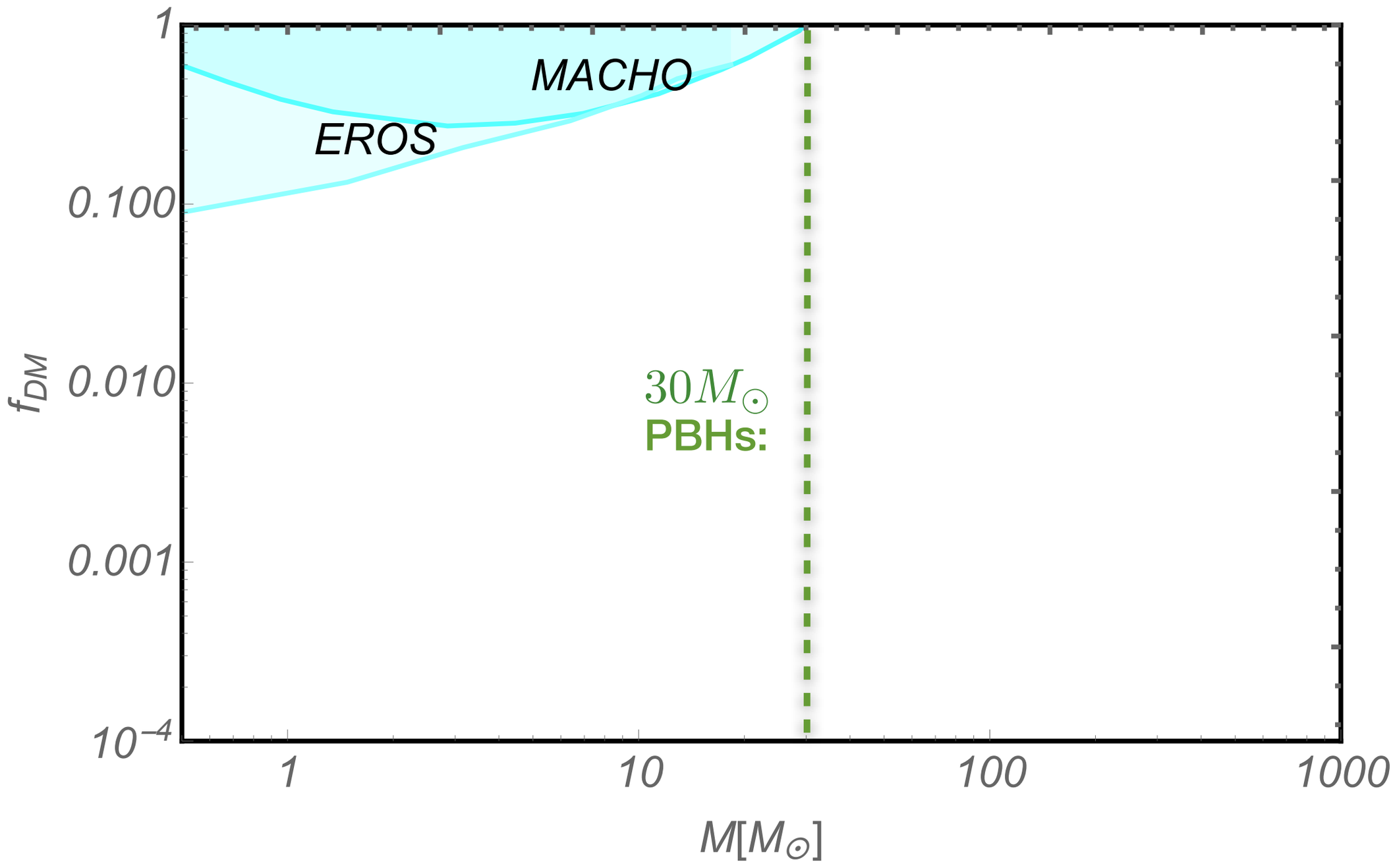
PBH Dark Matter: The “LIGO Window”



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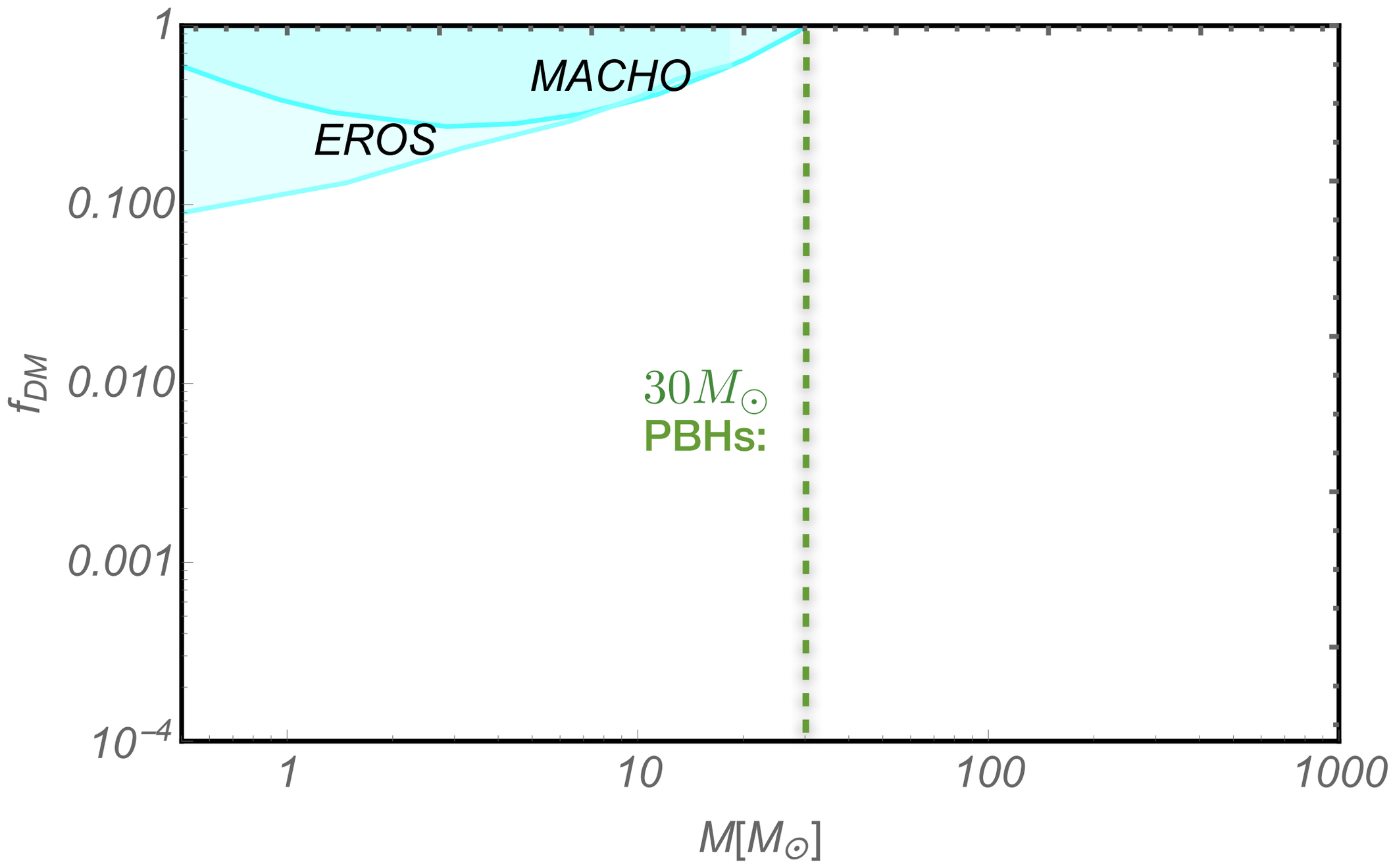

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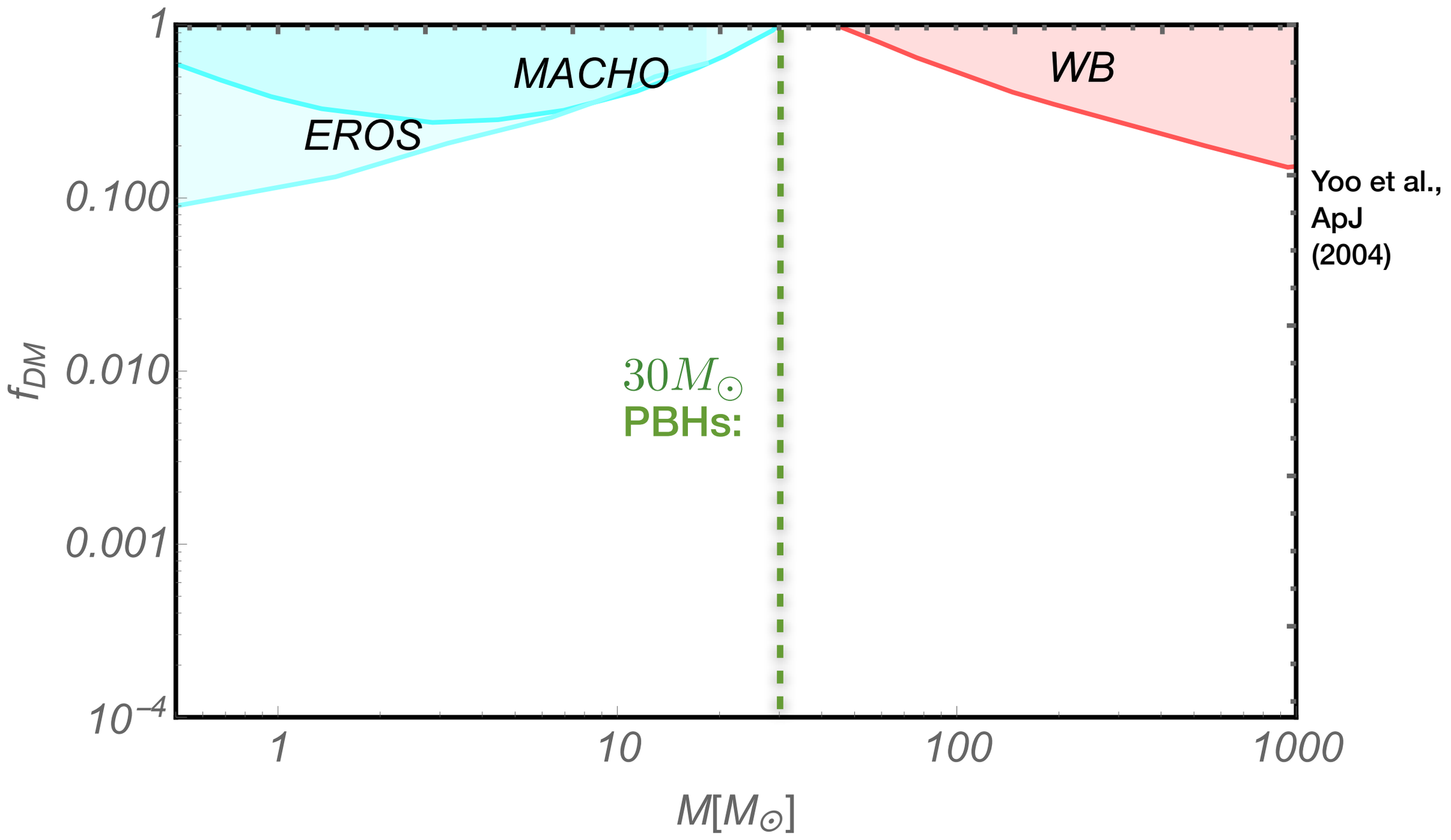

Yoo et al., ApJ (2004)

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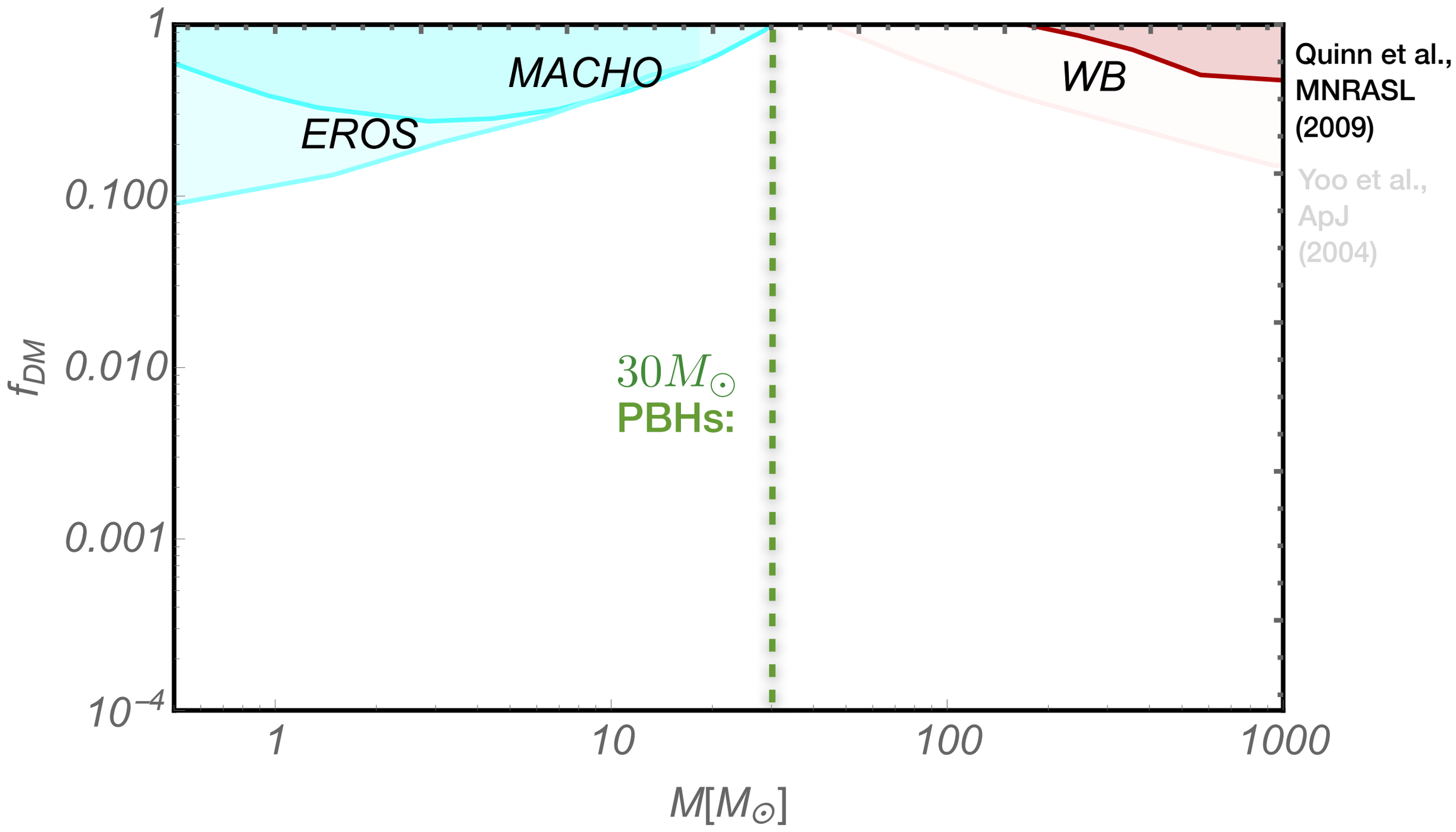

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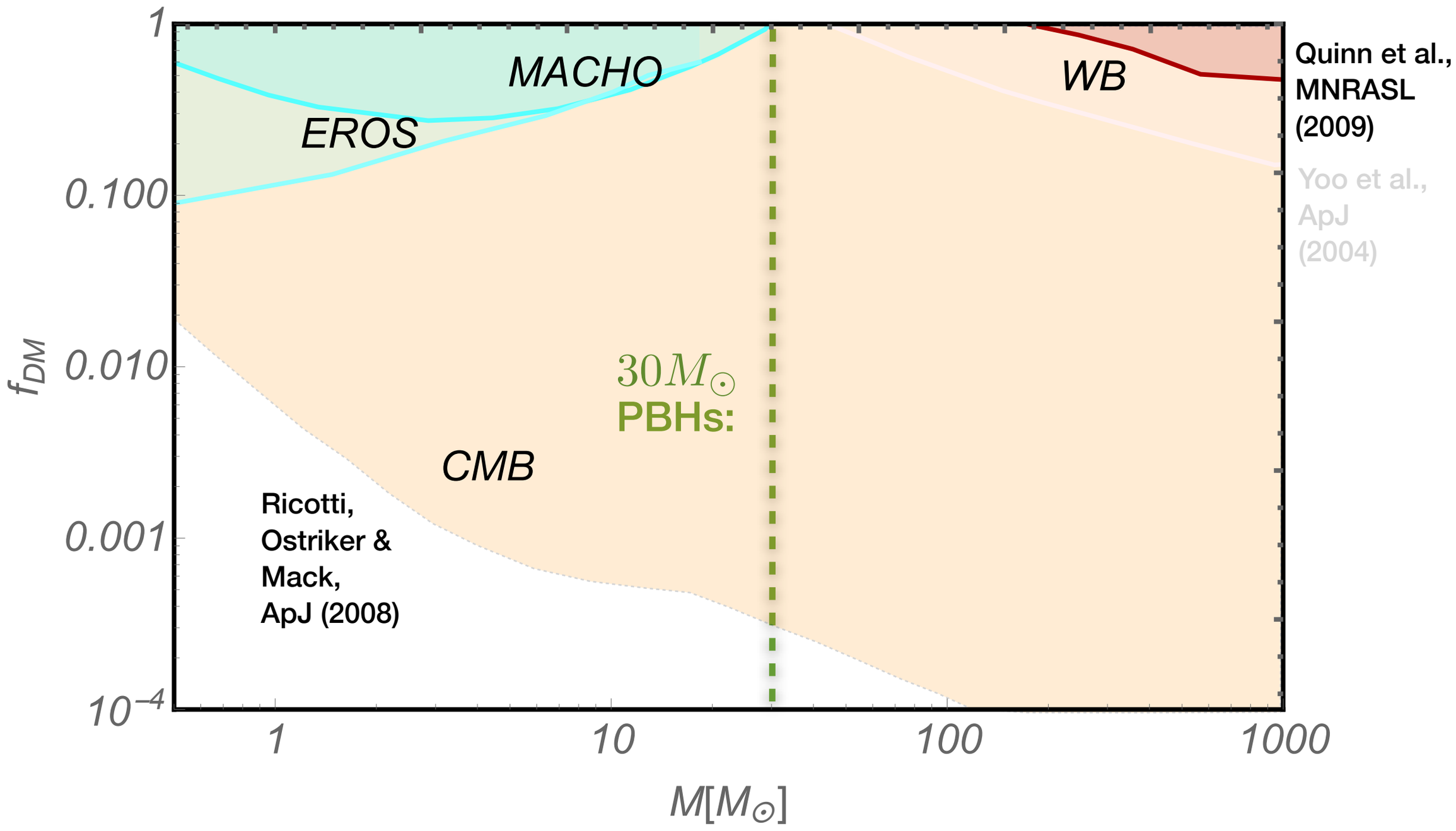

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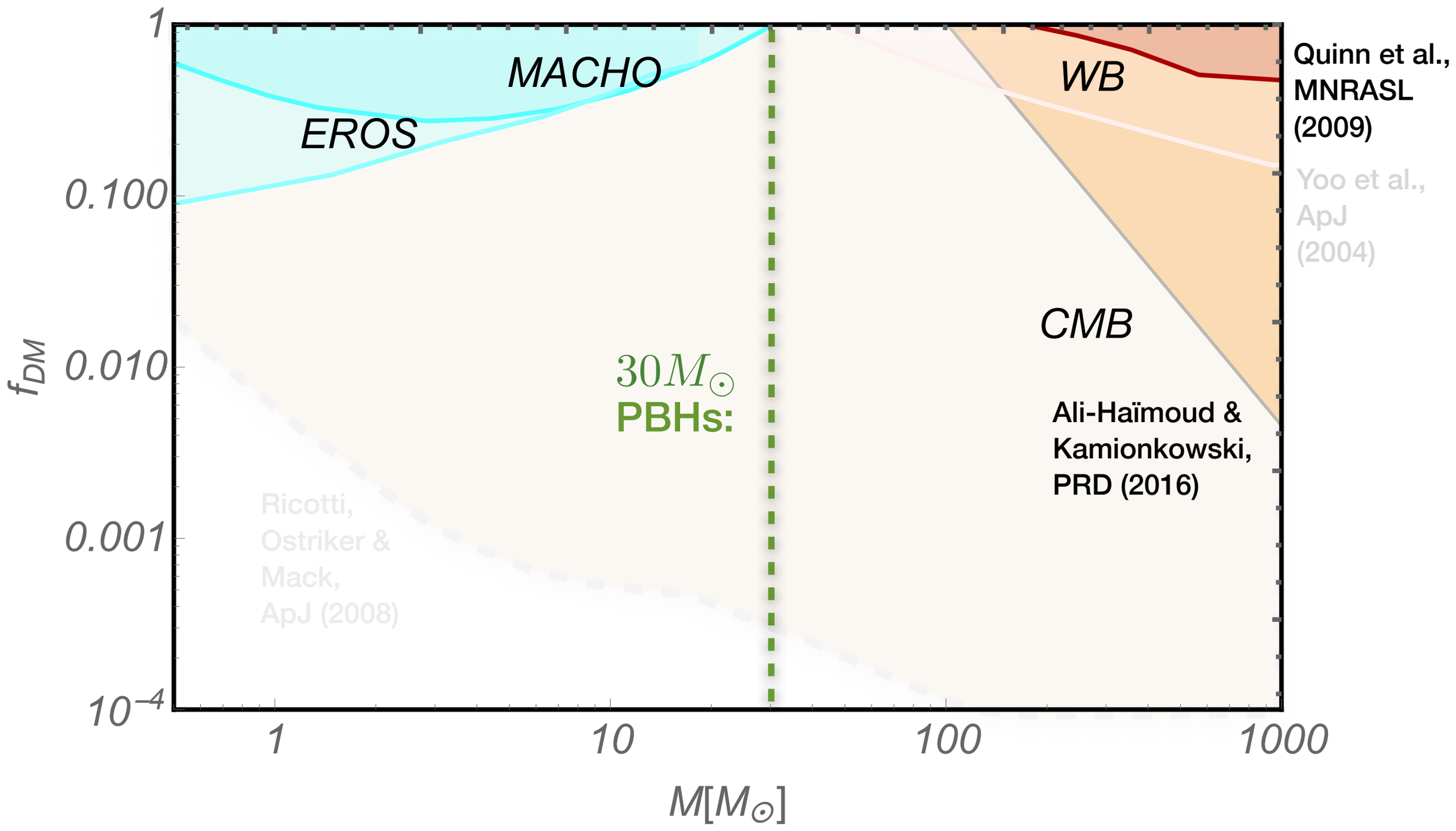

Outline

Ely Kovetz
GGI, Oct. 2018

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- Indirect Detection of PBH DM: Gravitational Waves

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- 21cm at Cosmic Dawn: a DM Detector

Indirect Detection: GWs from Merging PBHs

(Bird et al., PRL 116 (2016))

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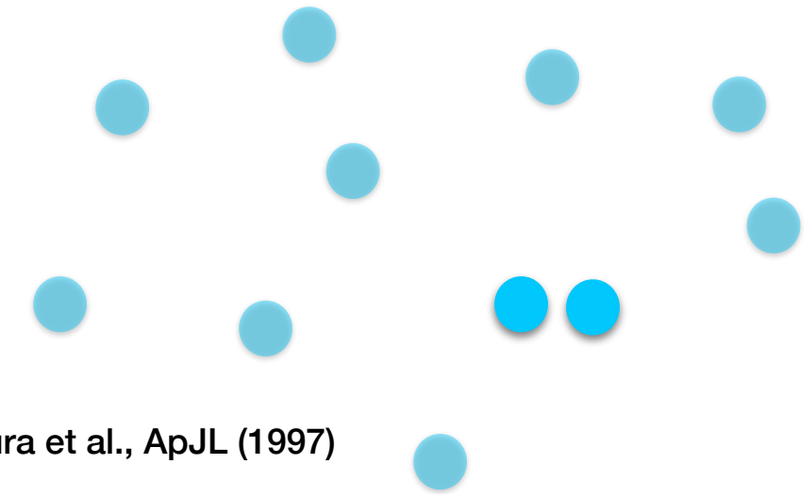

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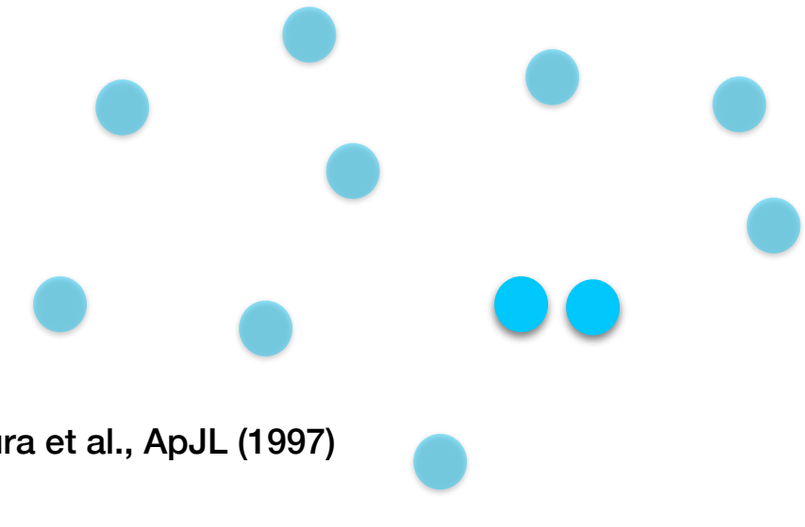

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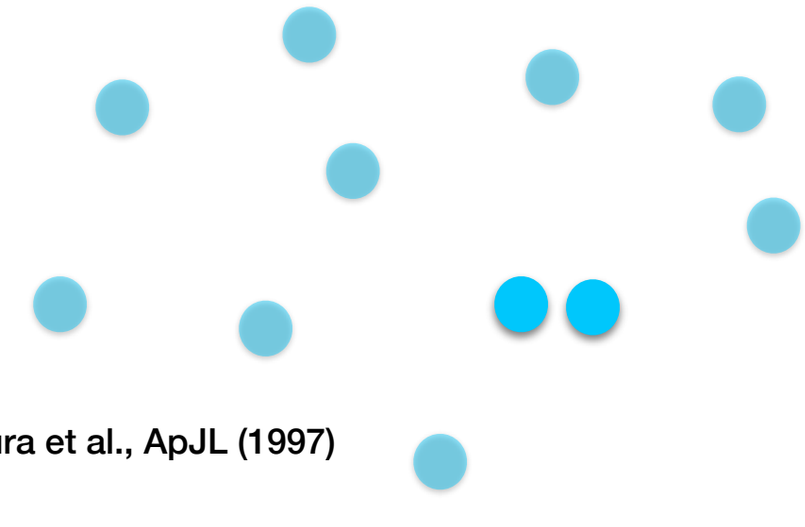

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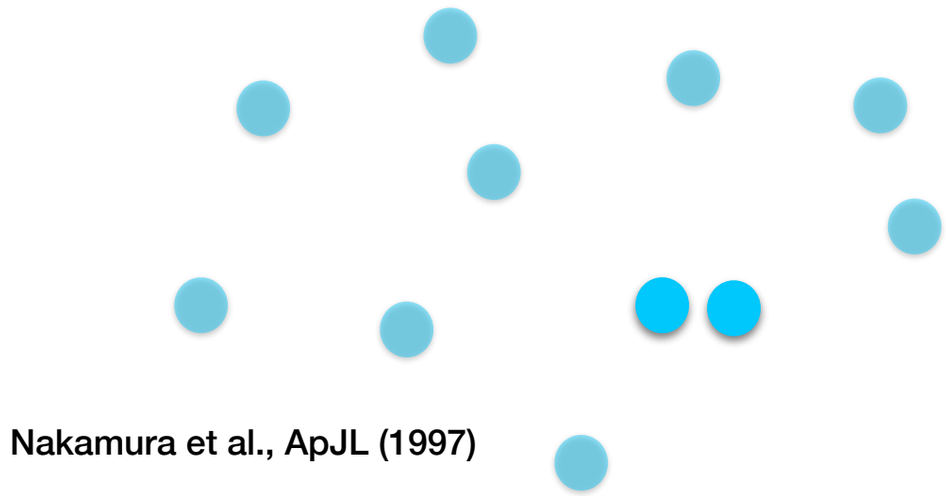

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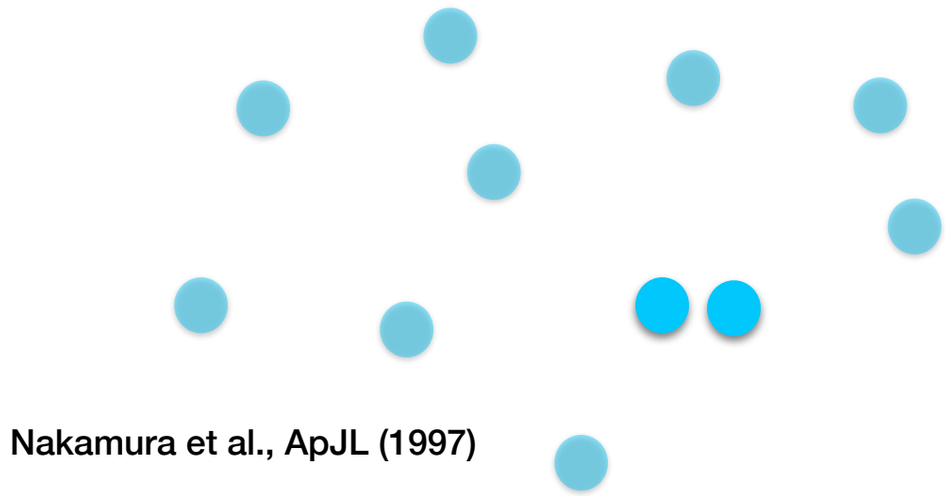

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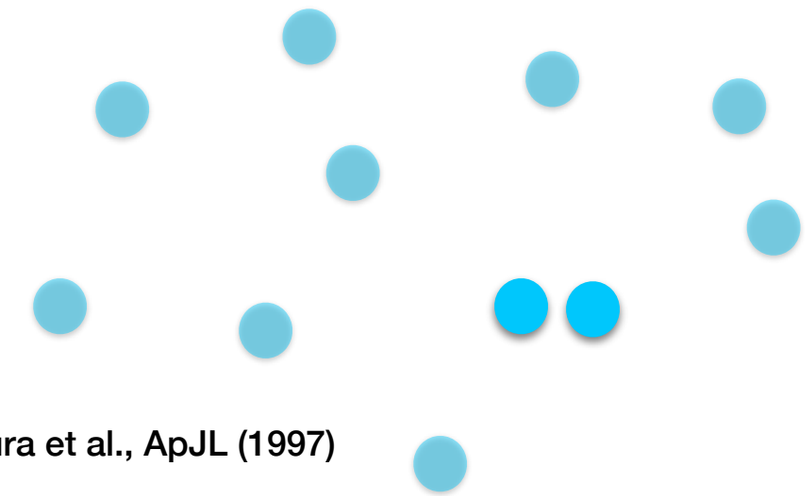

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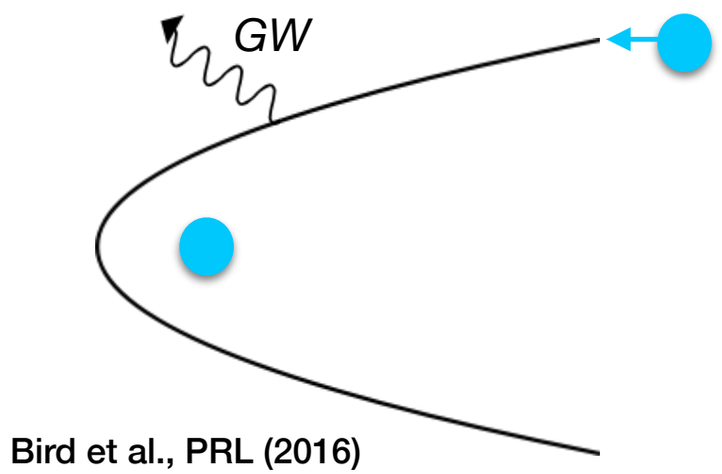

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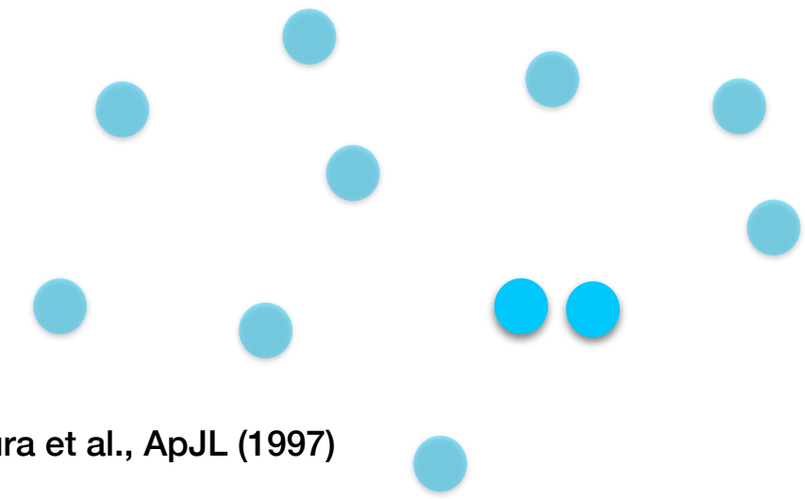

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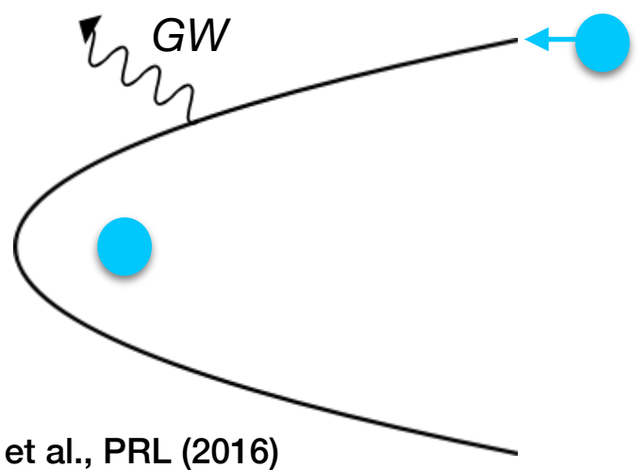

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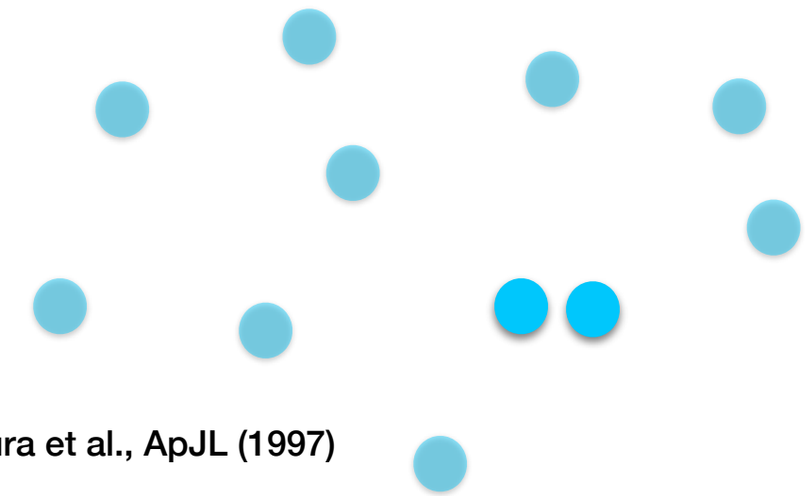

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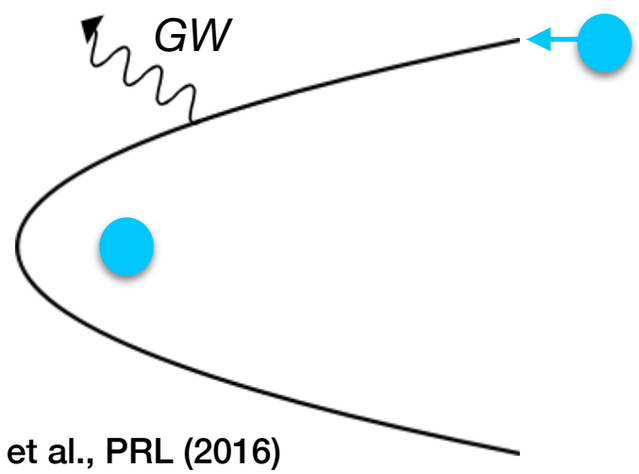

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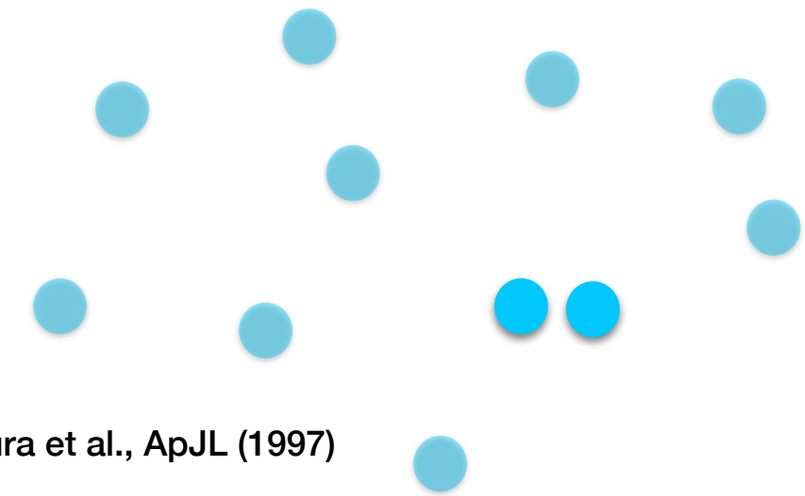

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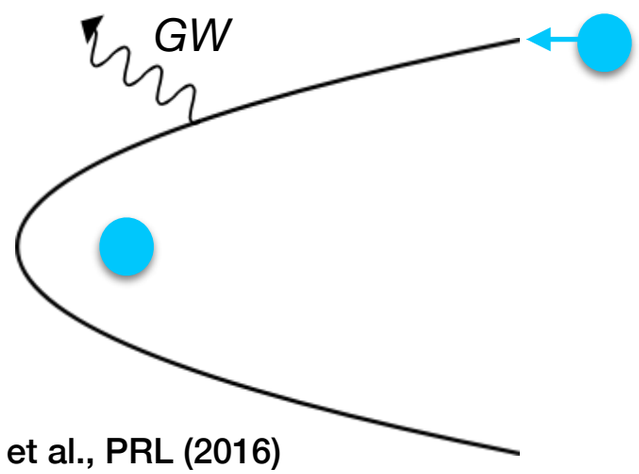

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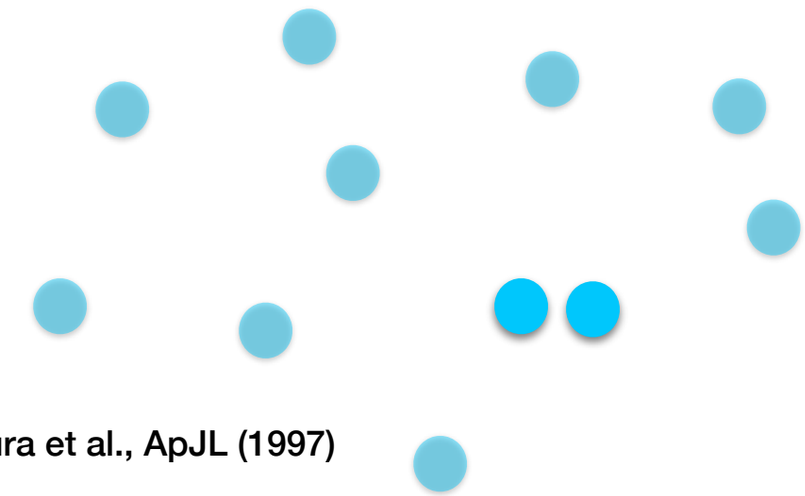

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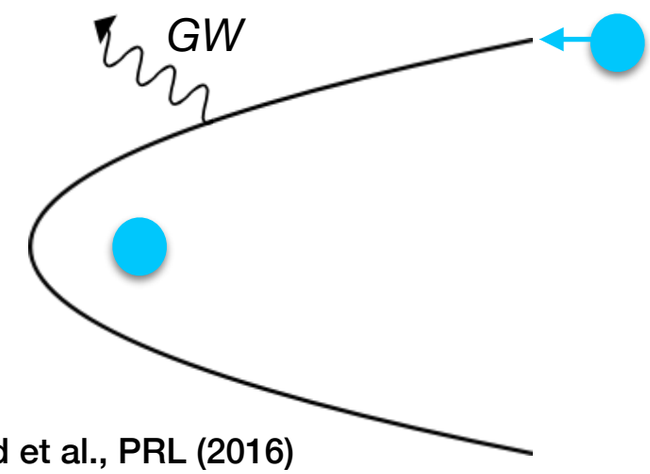


Bird et al., PRL (2016)

Indirect Detection: GWs from Merging PBHs

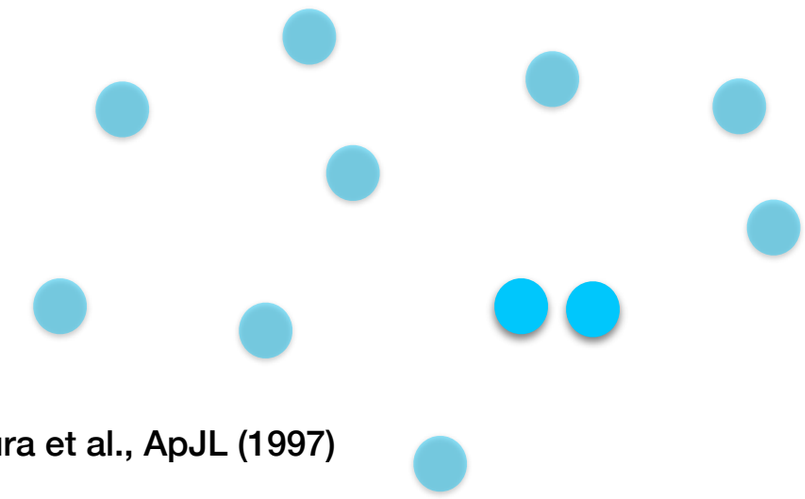
(Bird et al., PRL 116 (2016))

How do PBH ***binaries*** form?

1) PBHs can become bound early on:

- Quite numerous (if account for all of DM)
- Wide distribution of merger times
- Possibly disrupted by present day?

Ali-Haïmoud, **EDK** and Kamionkowski, PRD (2017)



Nakamura et al., ApJL (1997)

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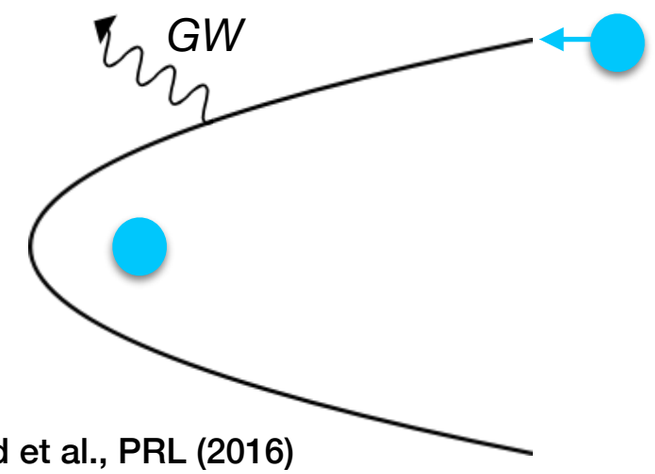

Bird et al., PRL (2016)

- Total merger rate consistent with LIGO estimate: $\mathcal{V}_{\rm LIGO} = 0.5 - 12\ {\rm Gpc}^{-3}\ {\rm yr}^{-1}$

Q: Does PBH Dark Matter have testable GW predictions?

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A: Yes!

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(orbital eccentricities, stochastic background, spatial clustering...)

Cholis, EDK et al., PRD (2016)

Mundic, Bird & Cholis, PRL (2016)

Raccanelli, EDK et al., PRD (2016)

Raidal et al., JCAP (2017)

Wang et al., PRL (2018)

The GW mass spectrum: Background

(EDK et al., PRD 2017)

Observed mass spectrum with 5 years of advanced LIGO data:

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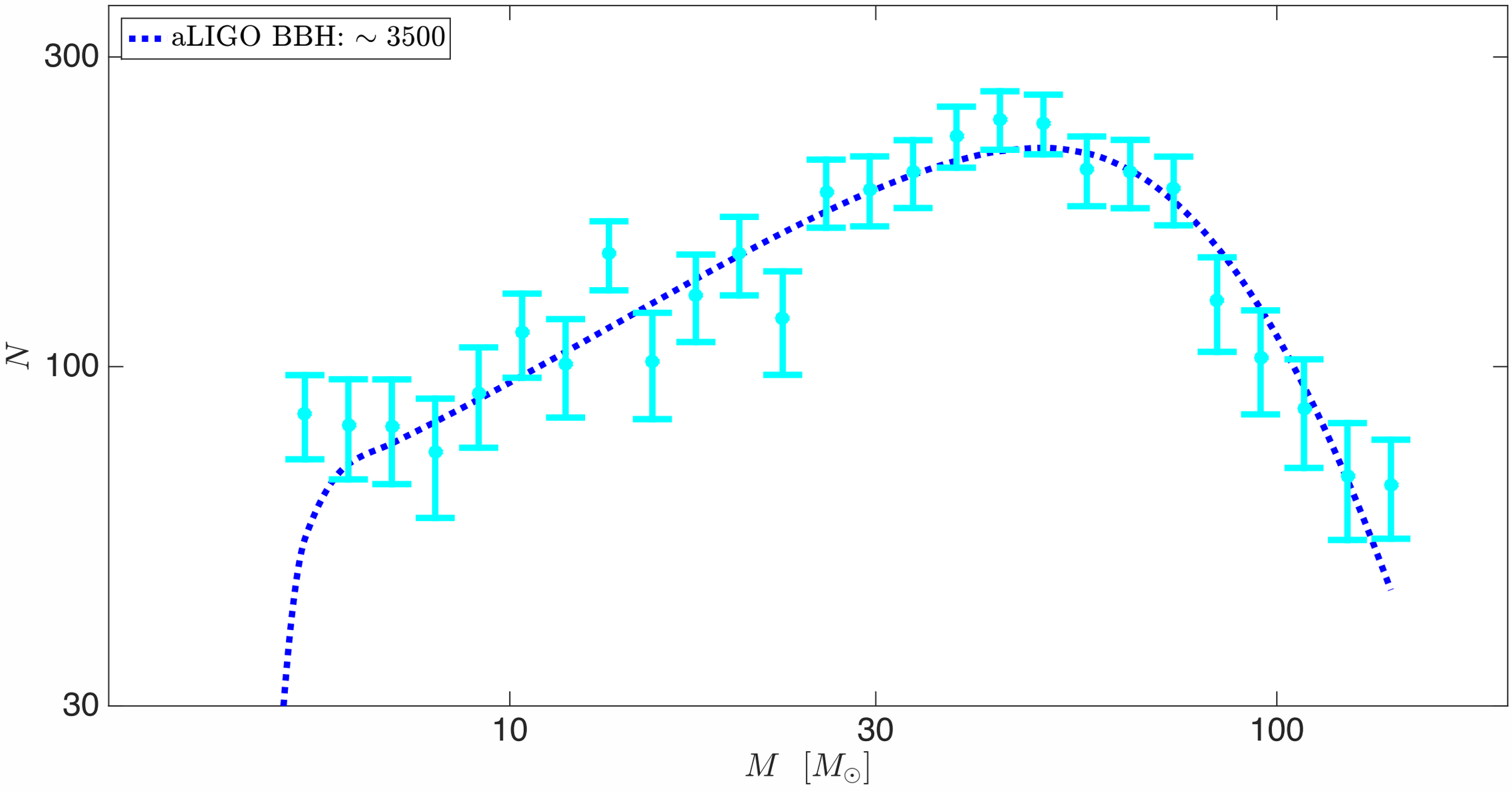
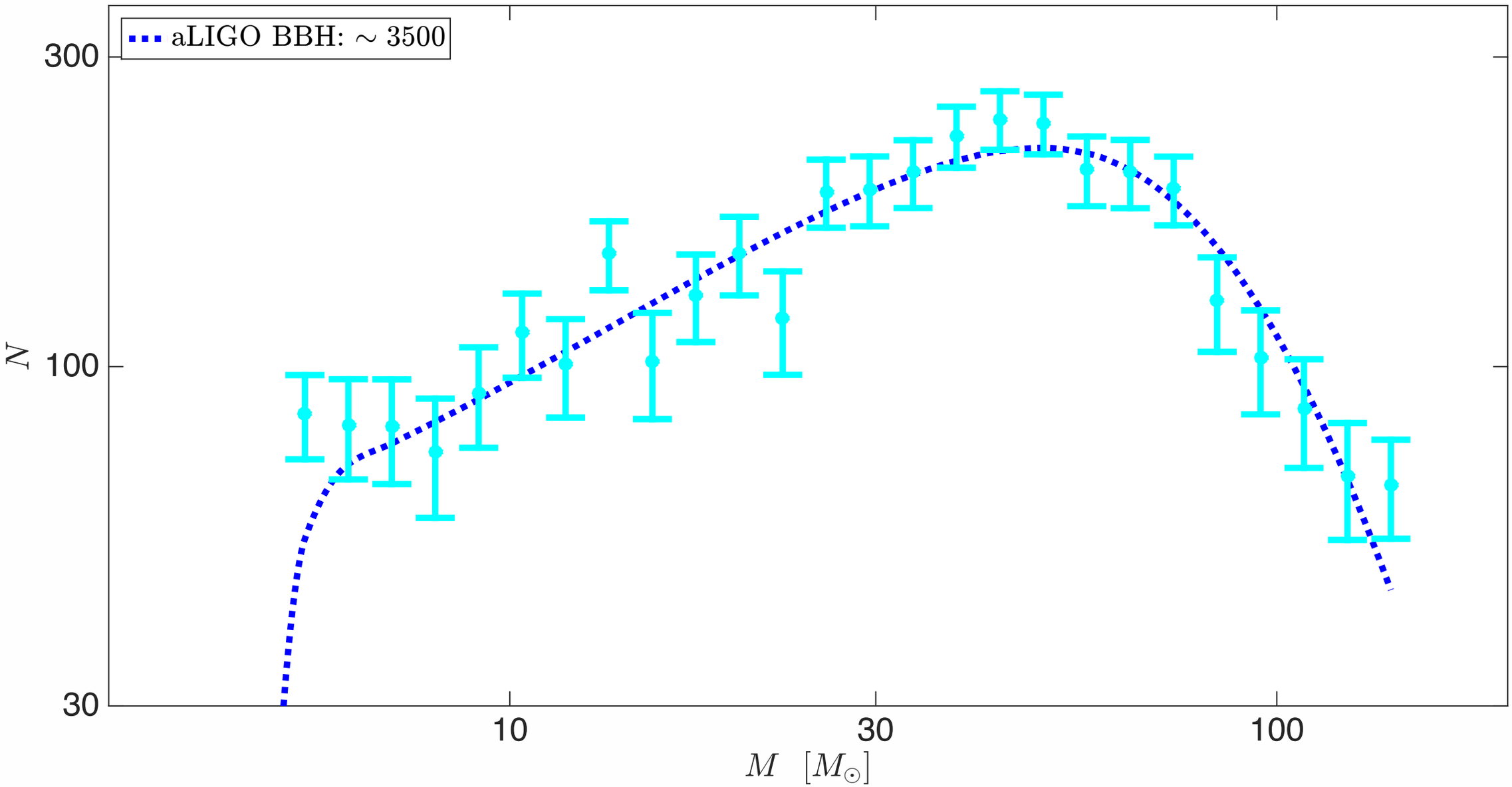


The GW mass spectrum: Background + “Signal”

(EDK et al., PRD 2017)



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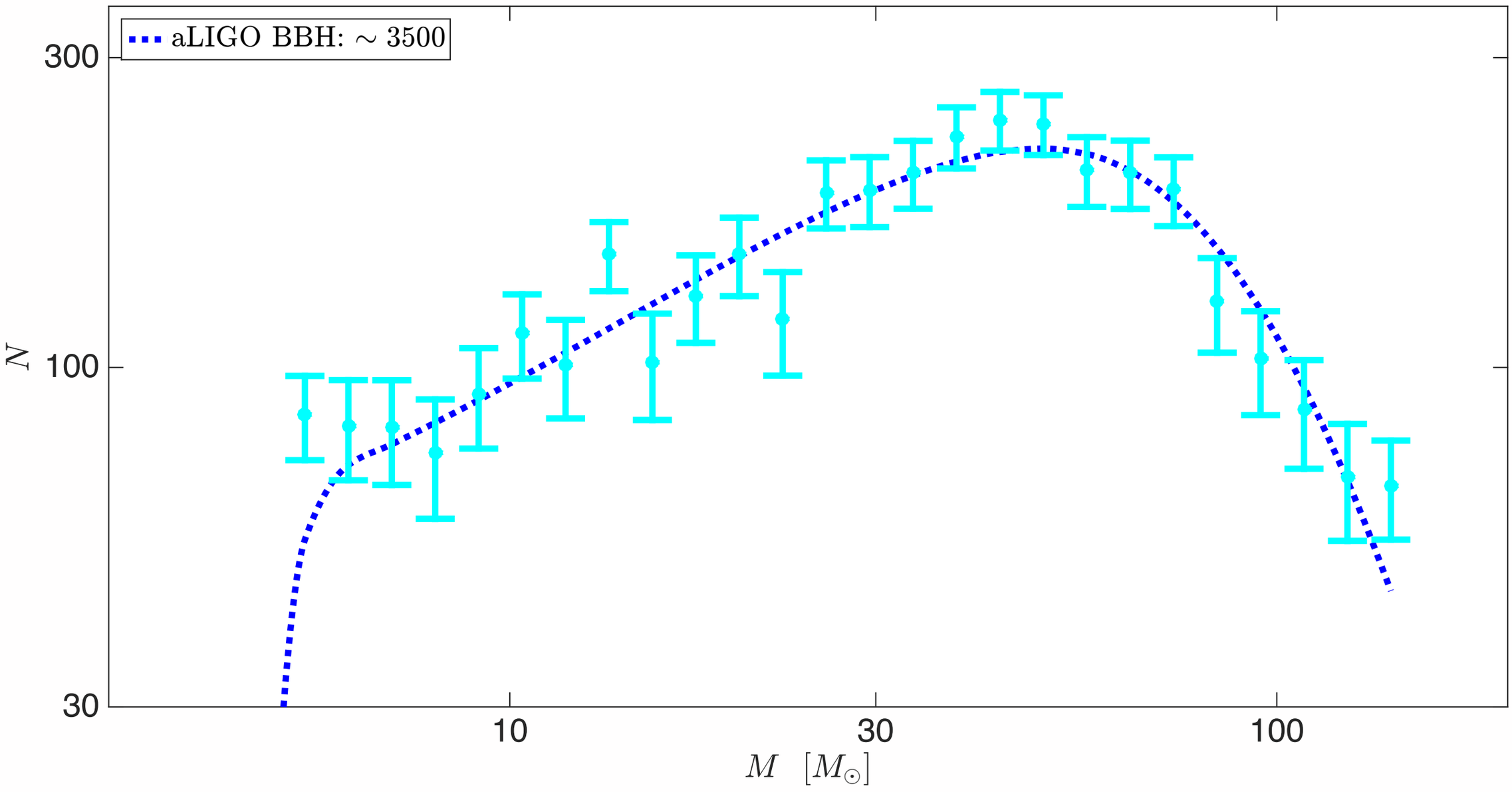

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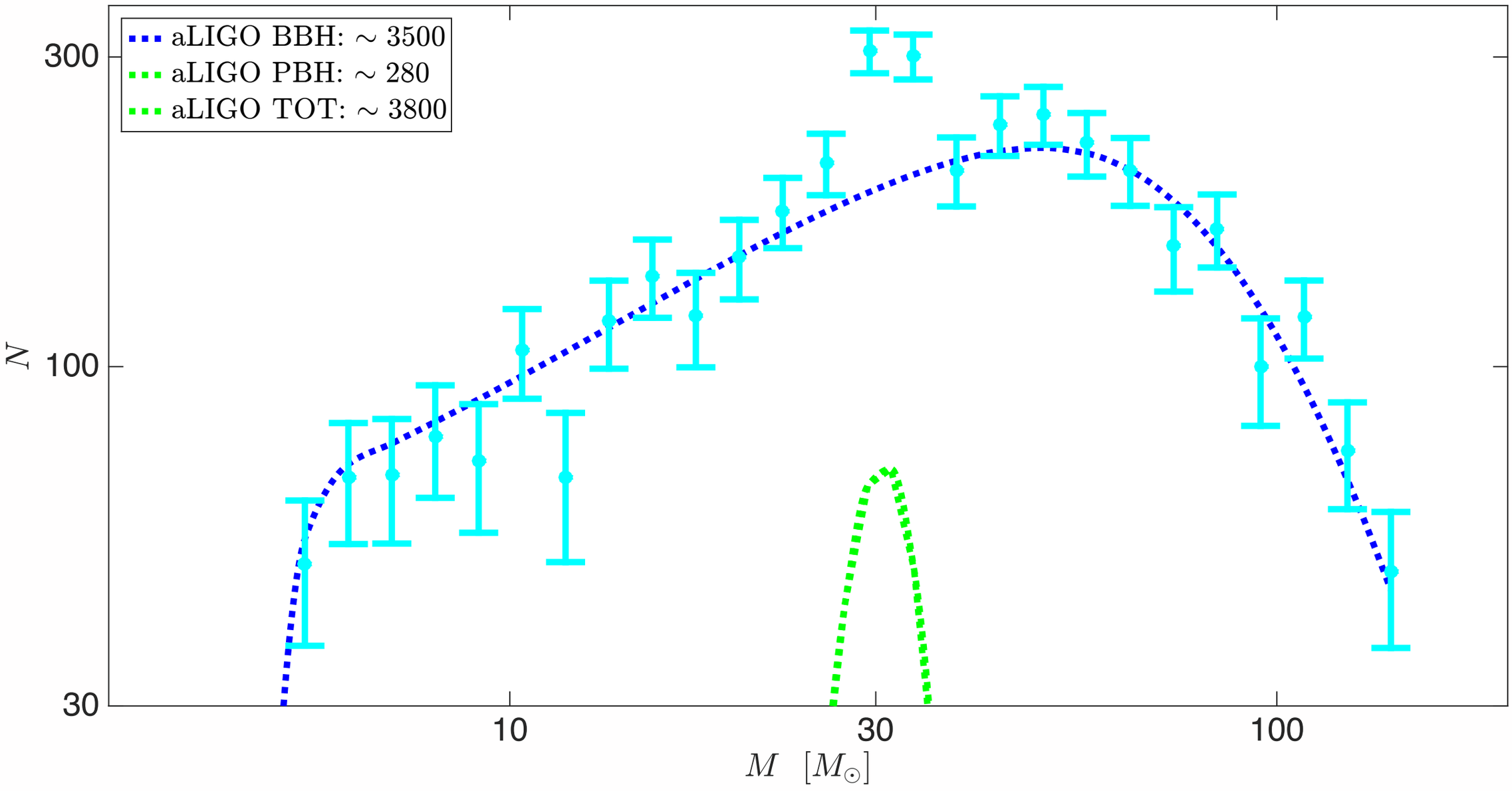

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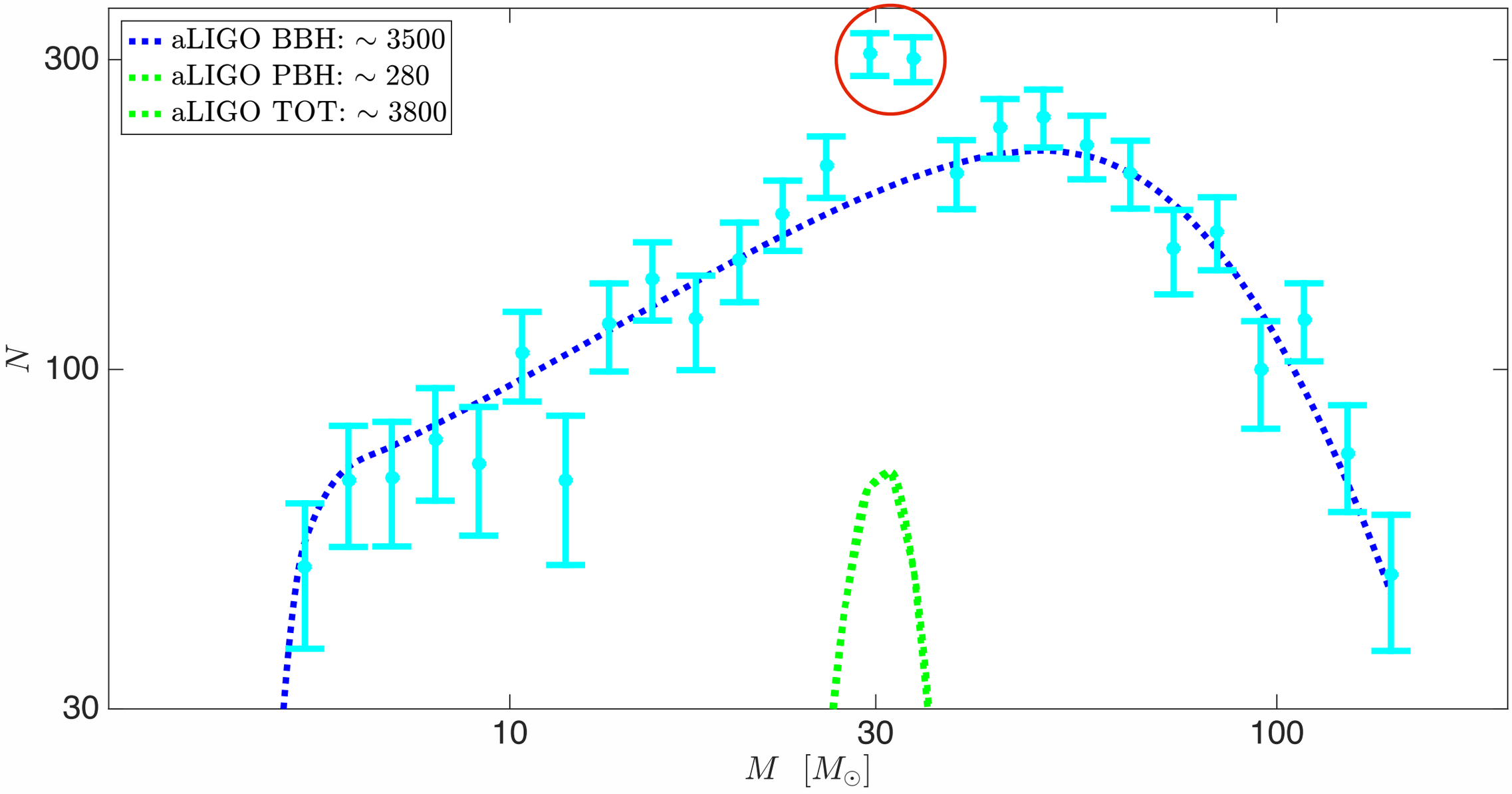

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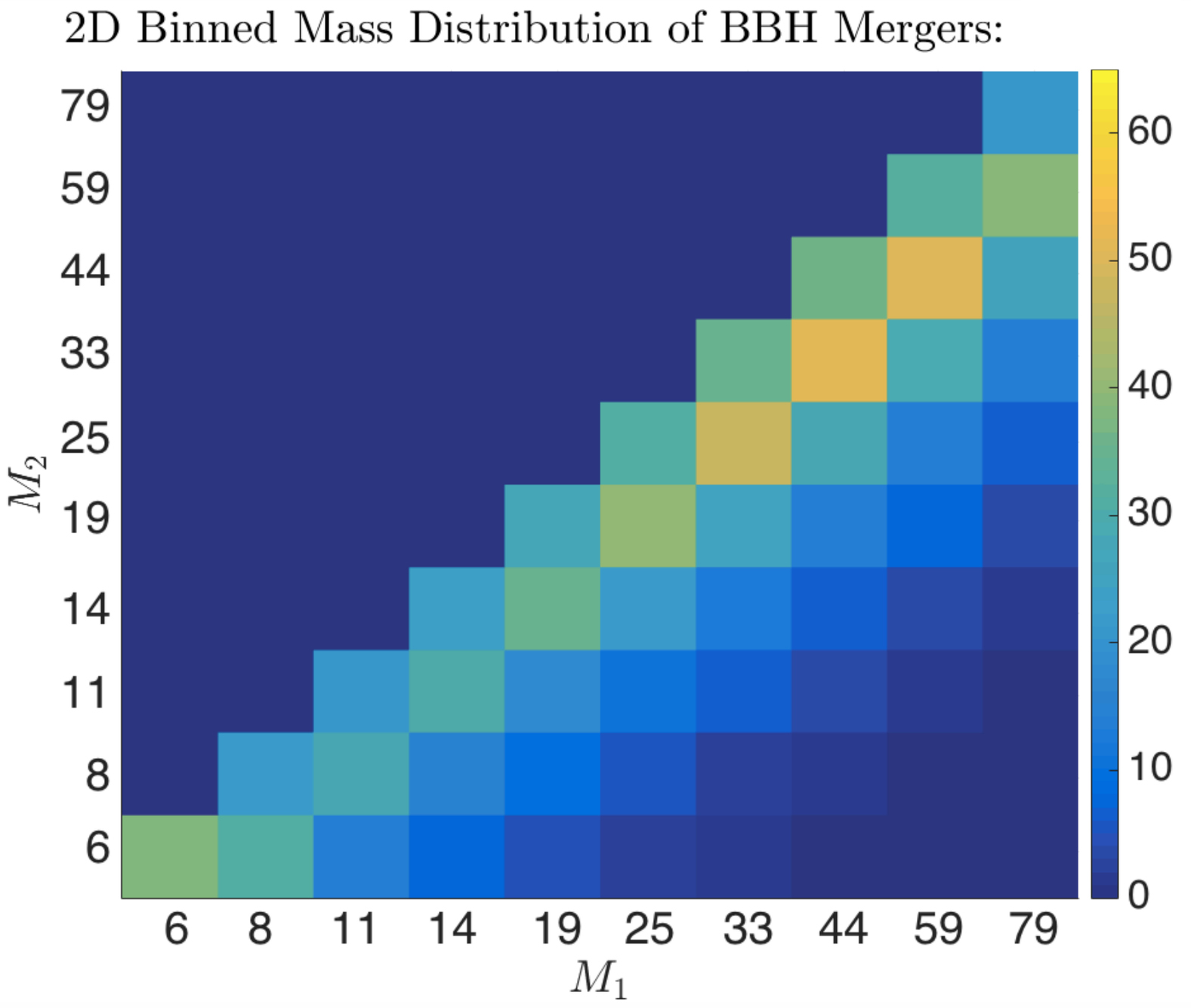

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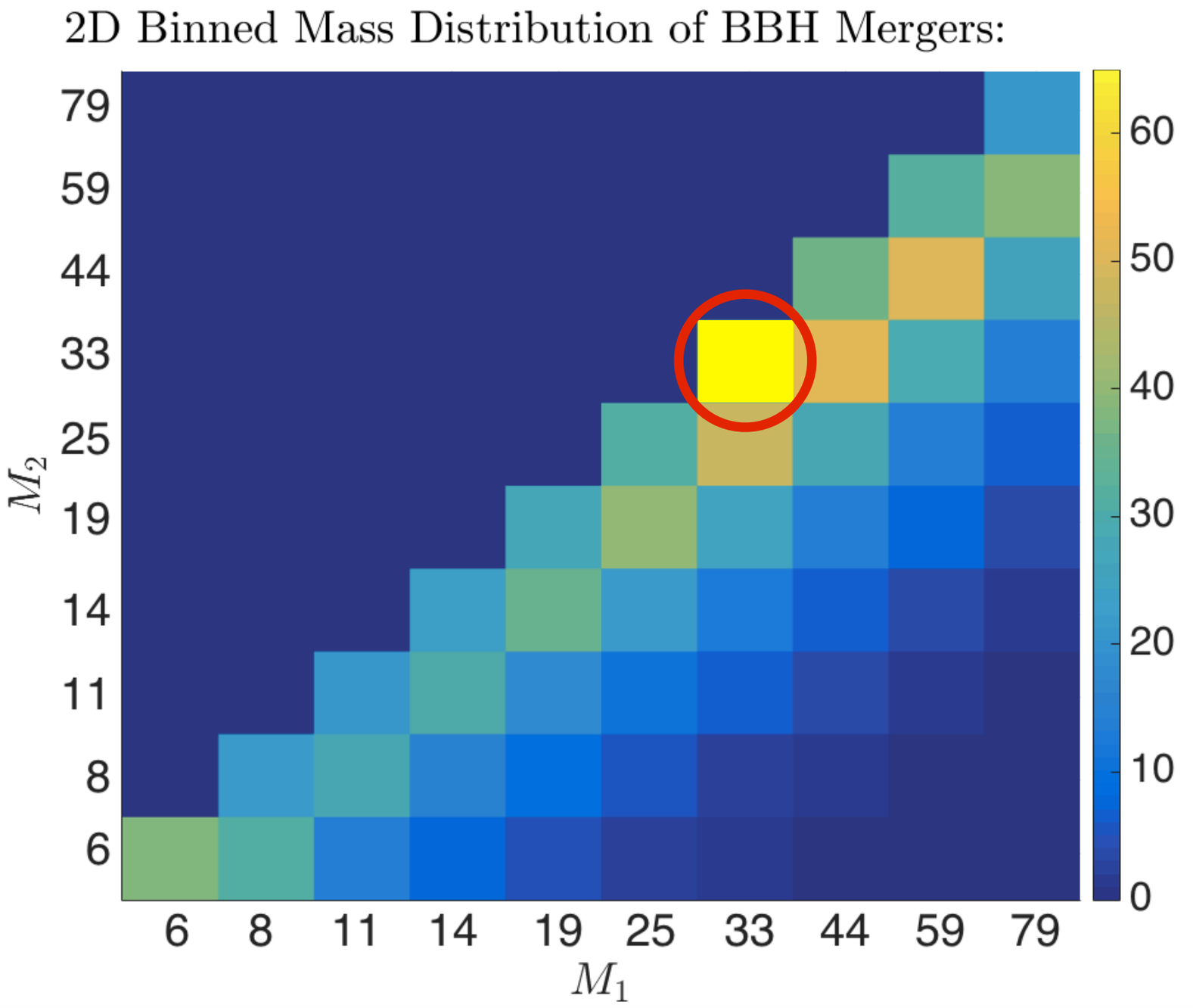

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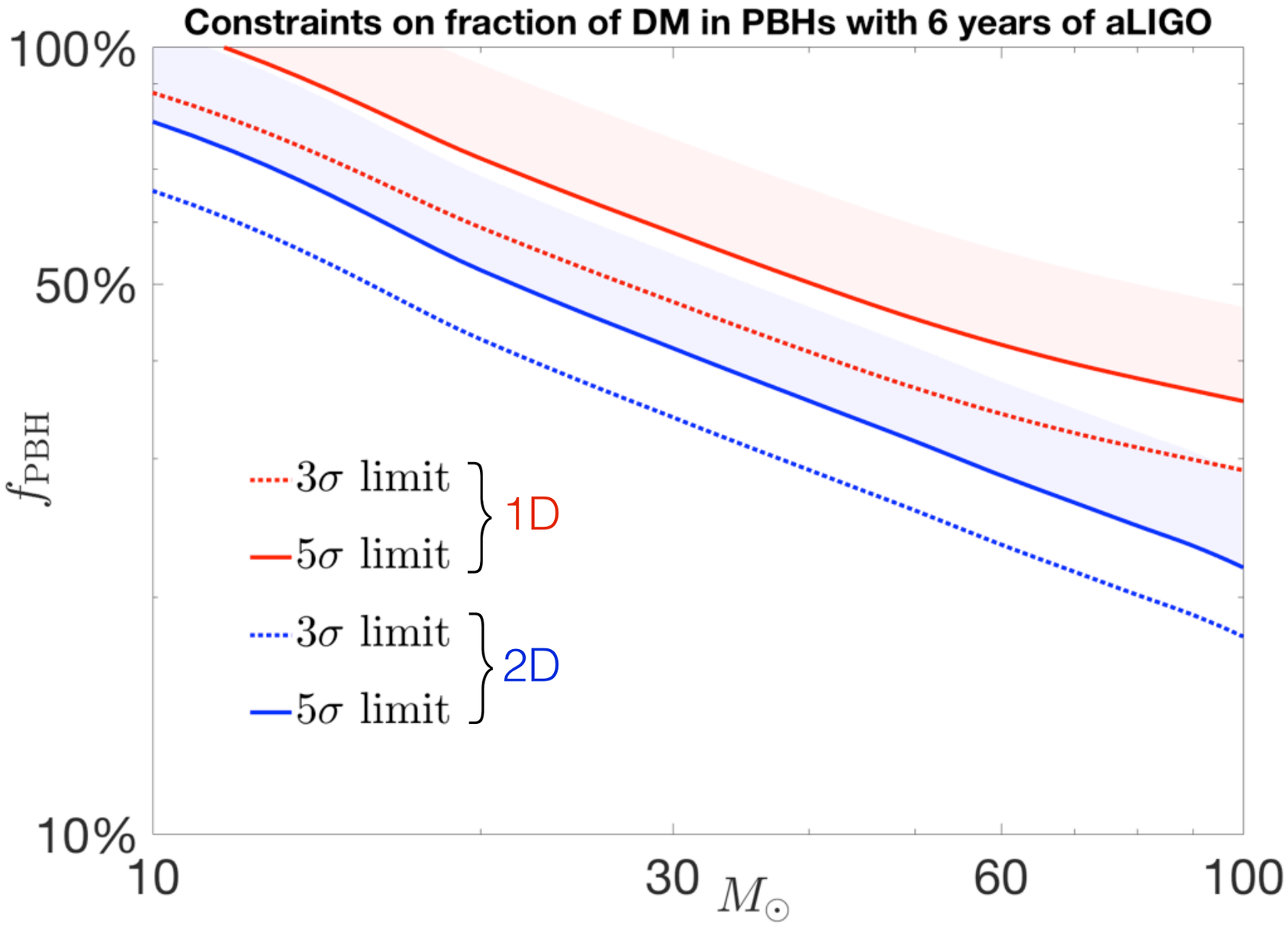

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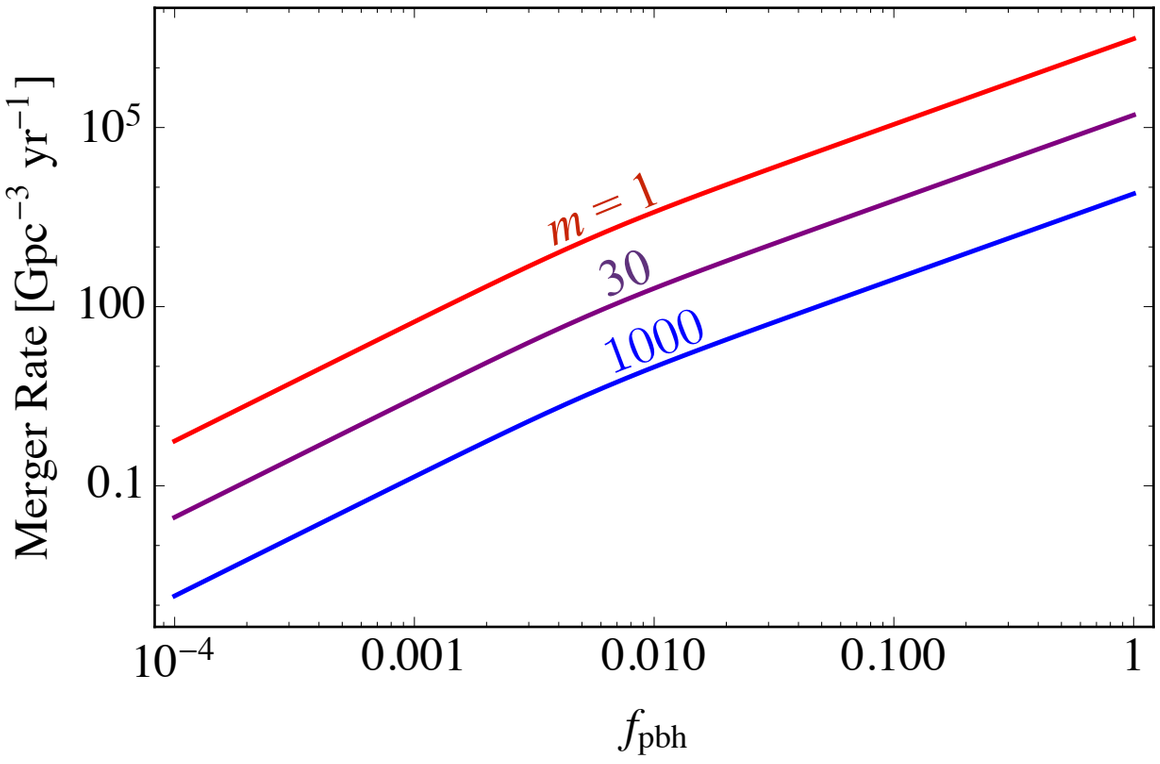

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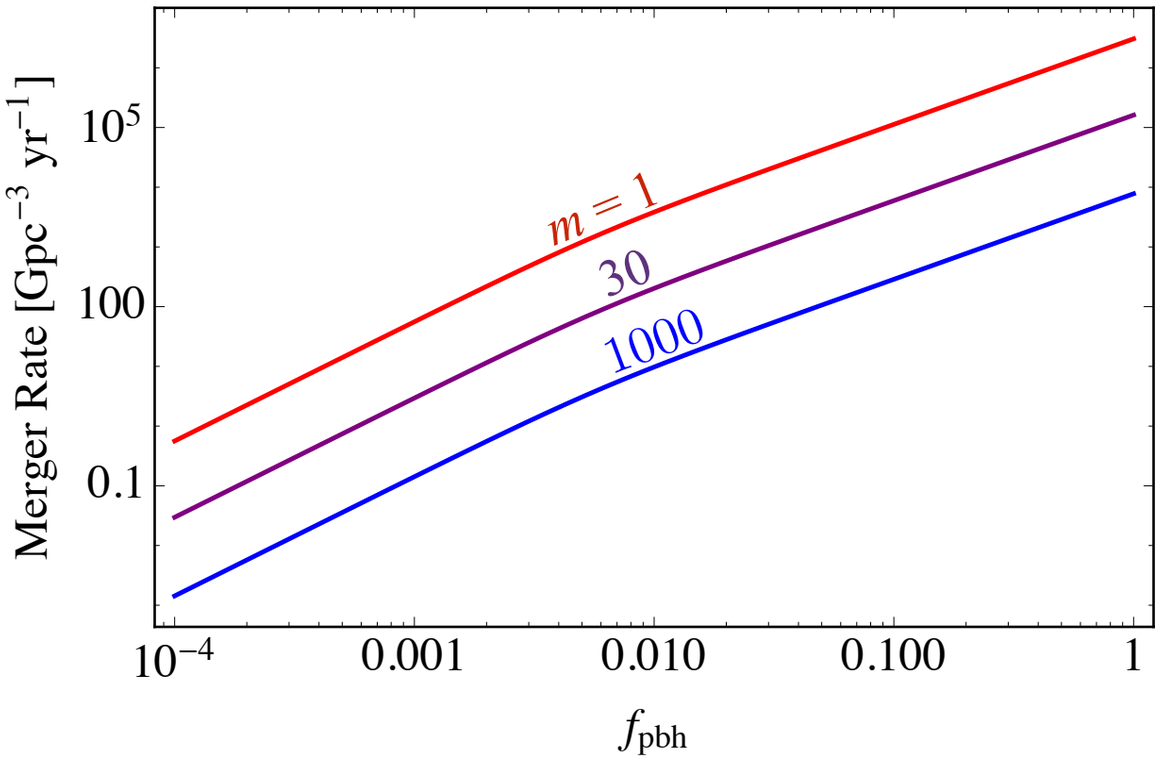

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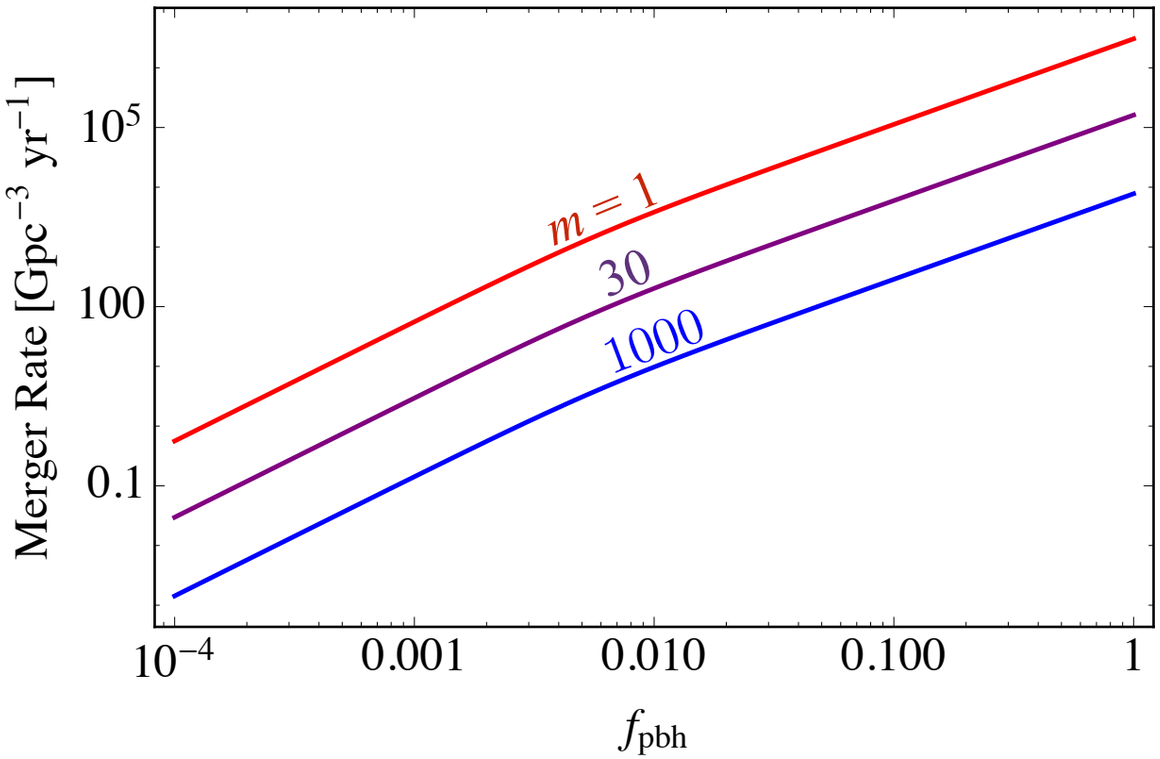

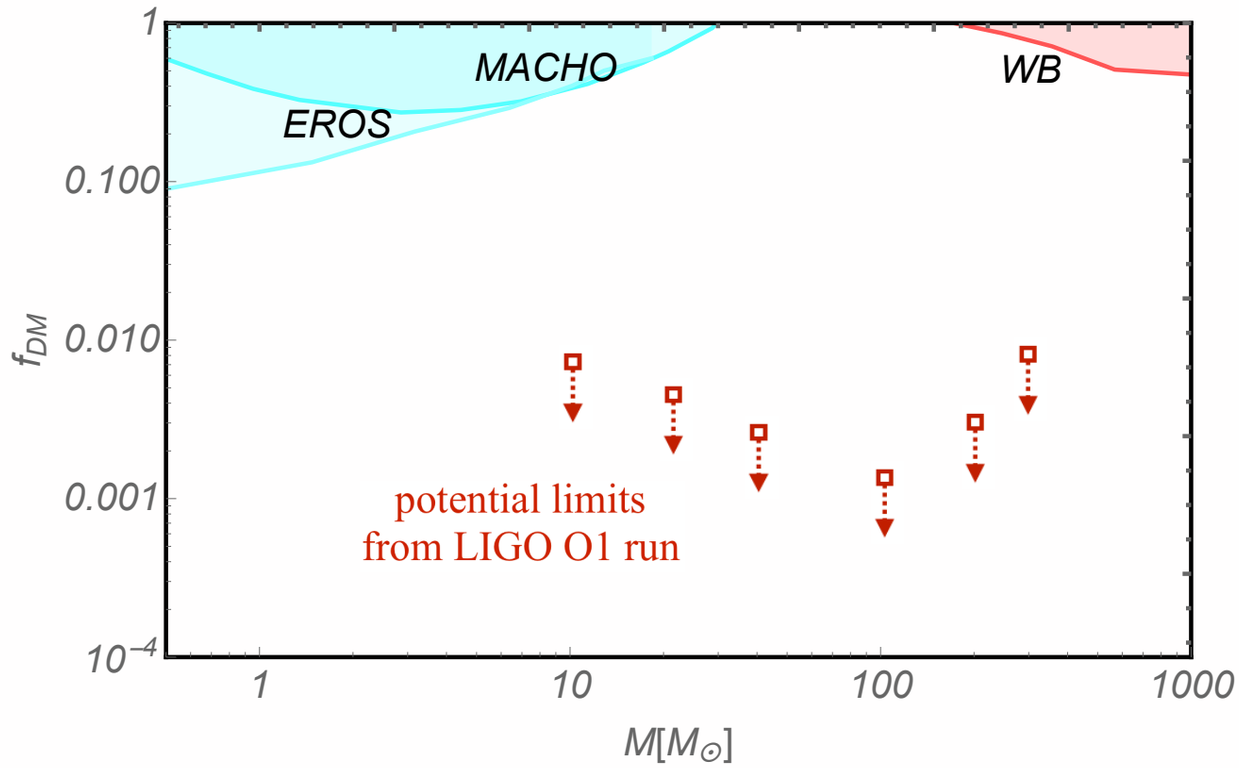

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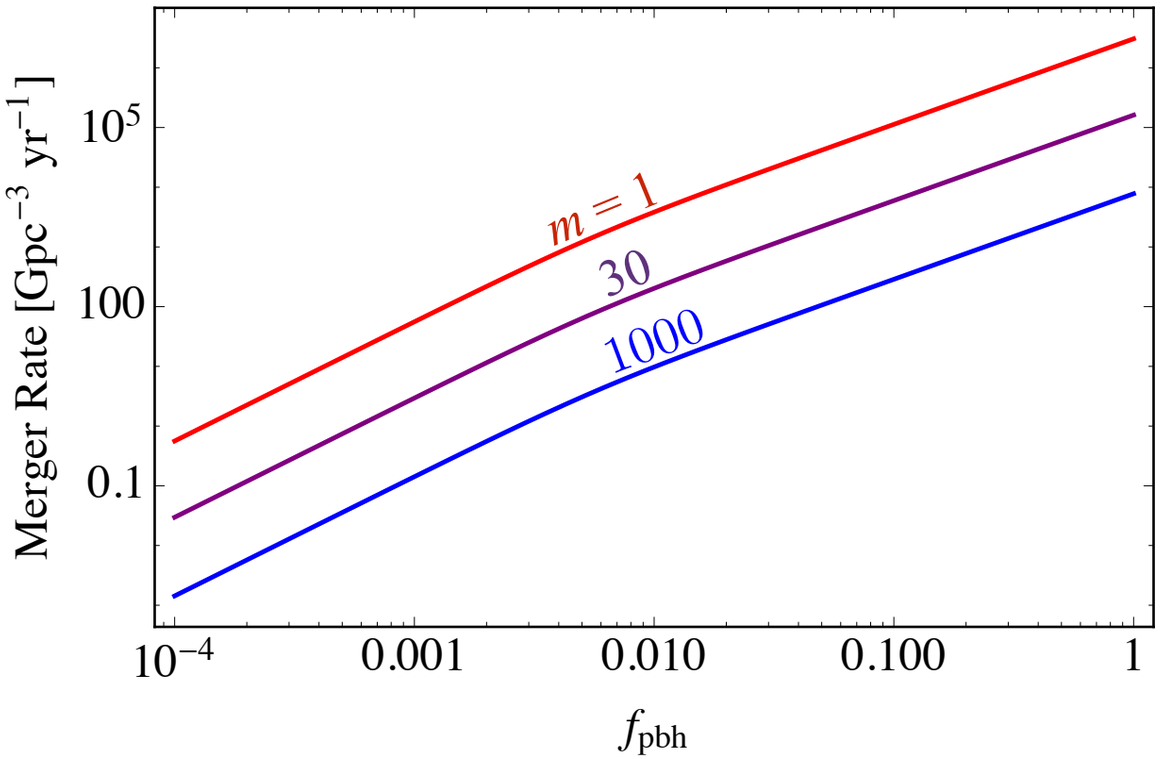

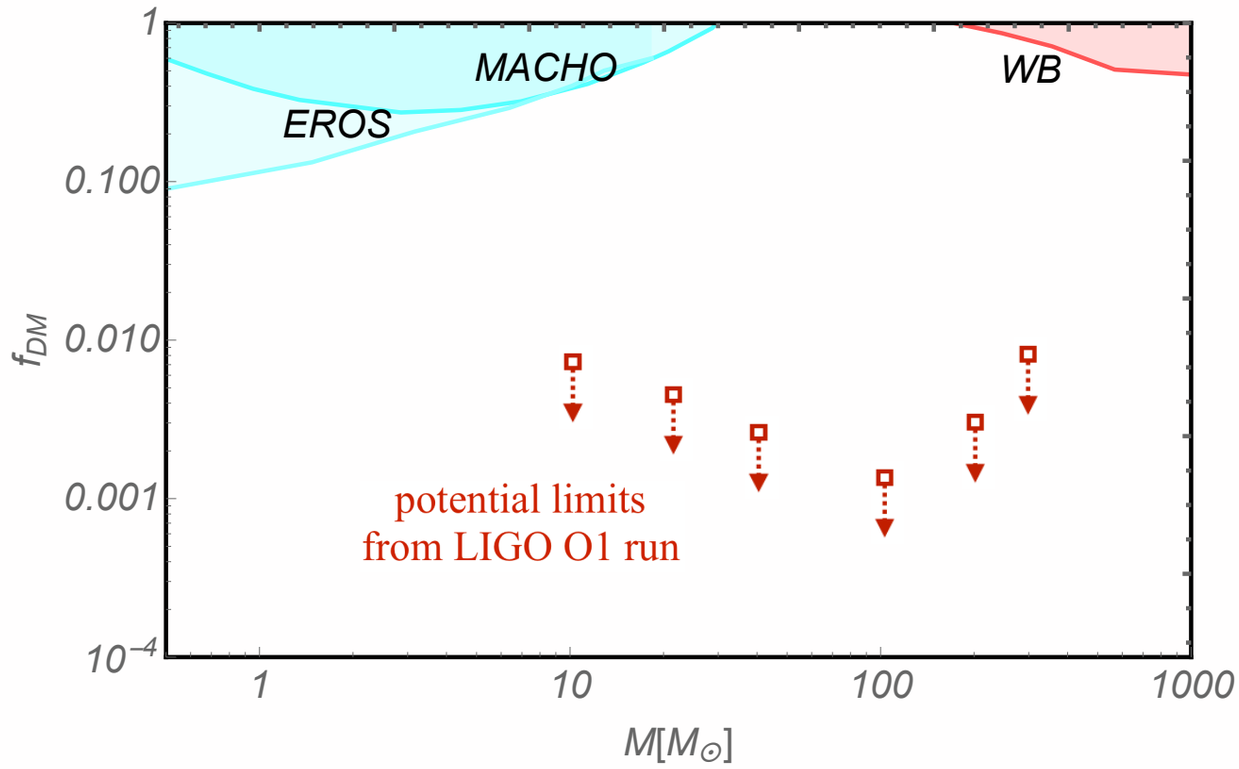

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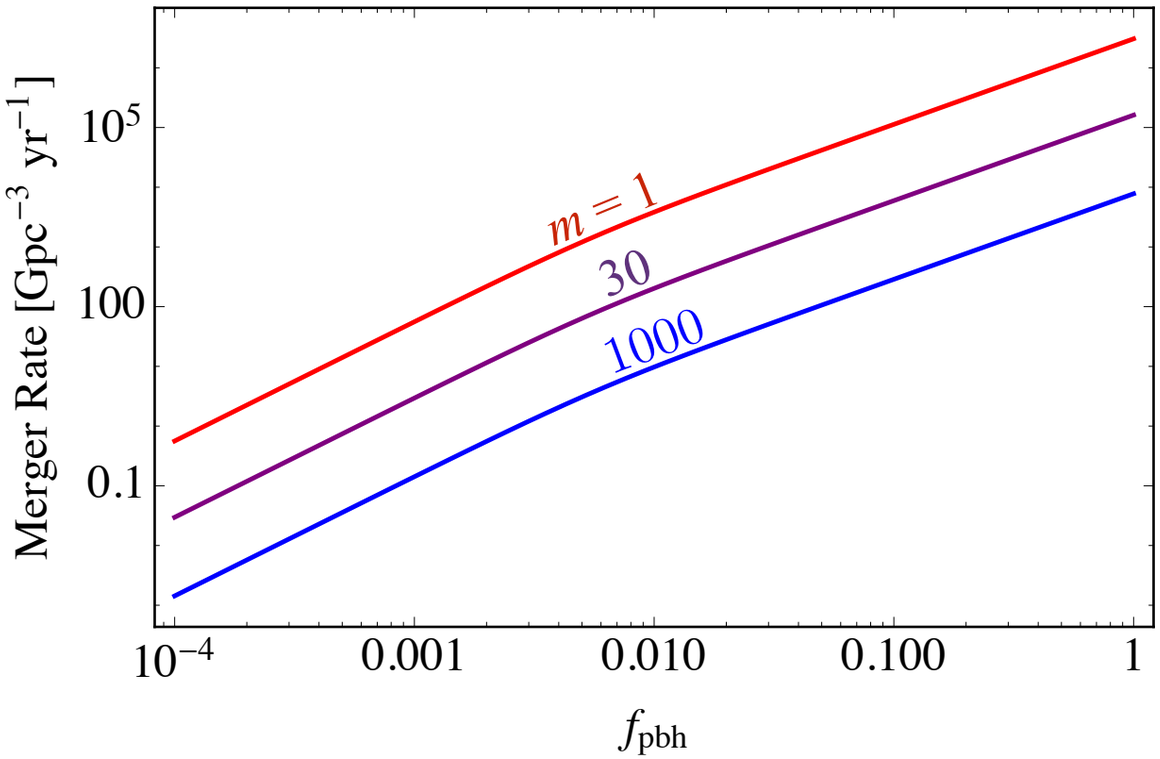

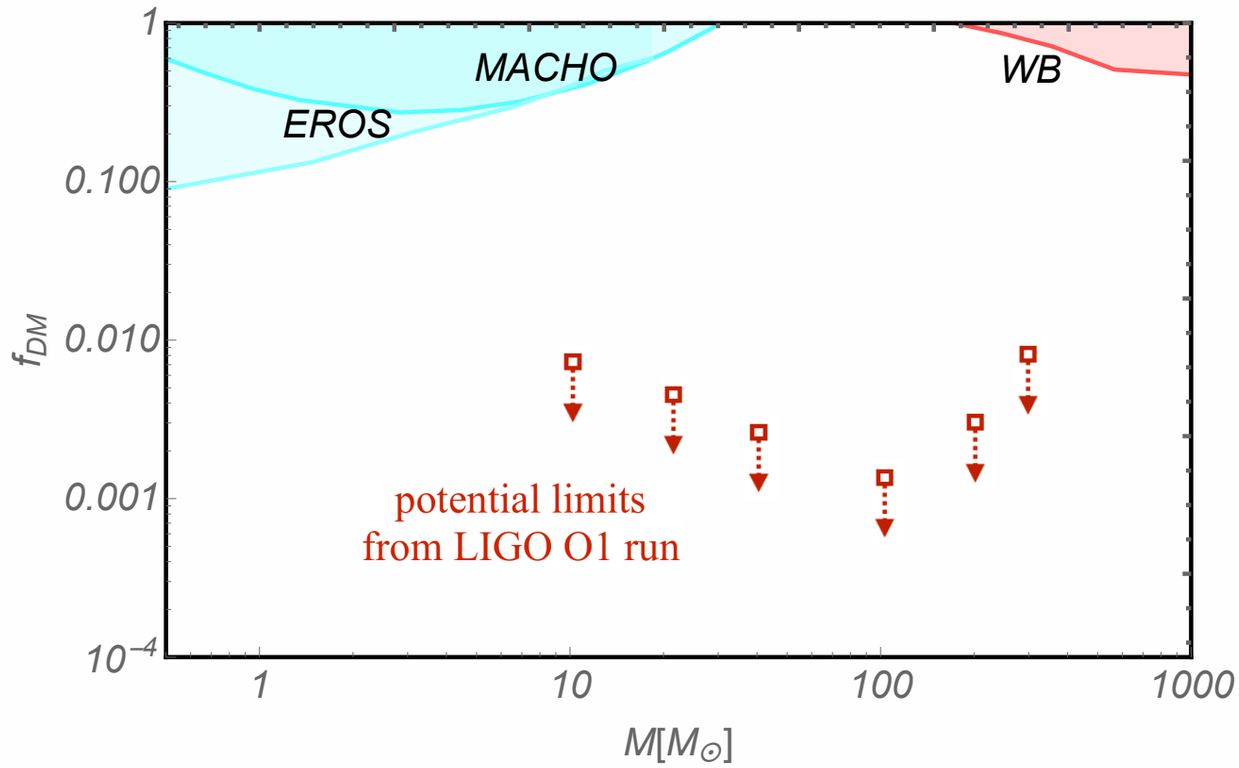

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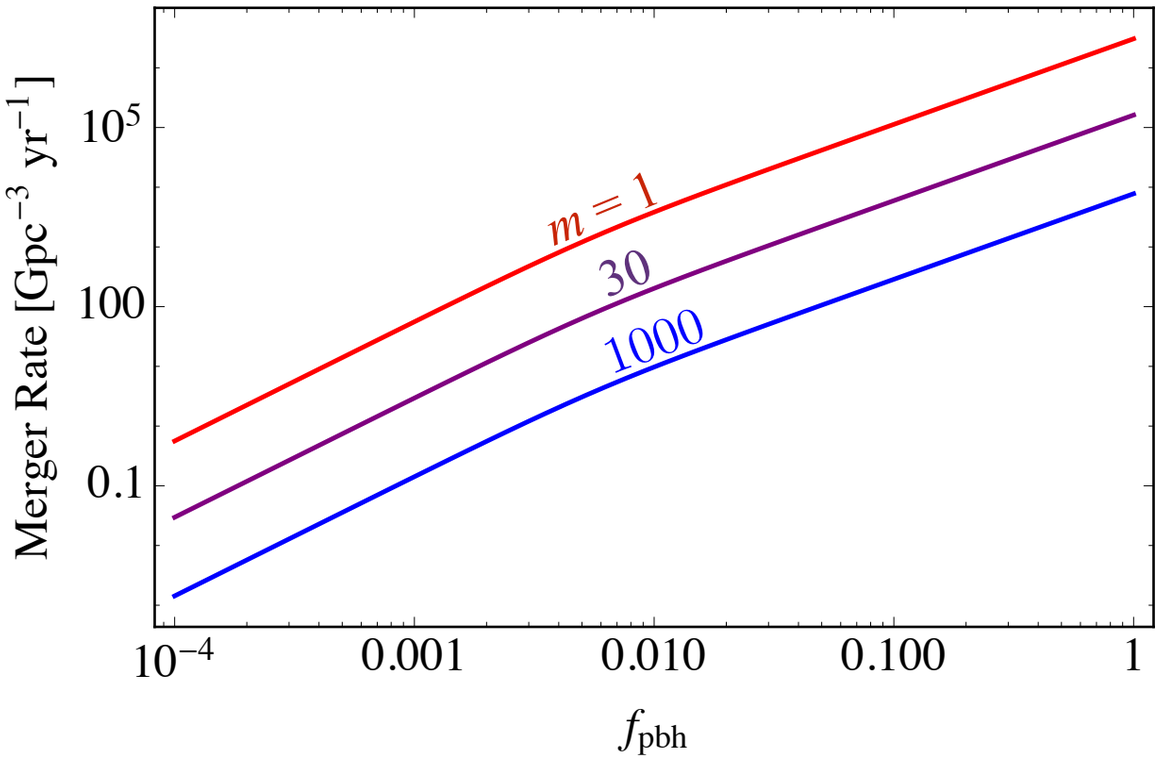

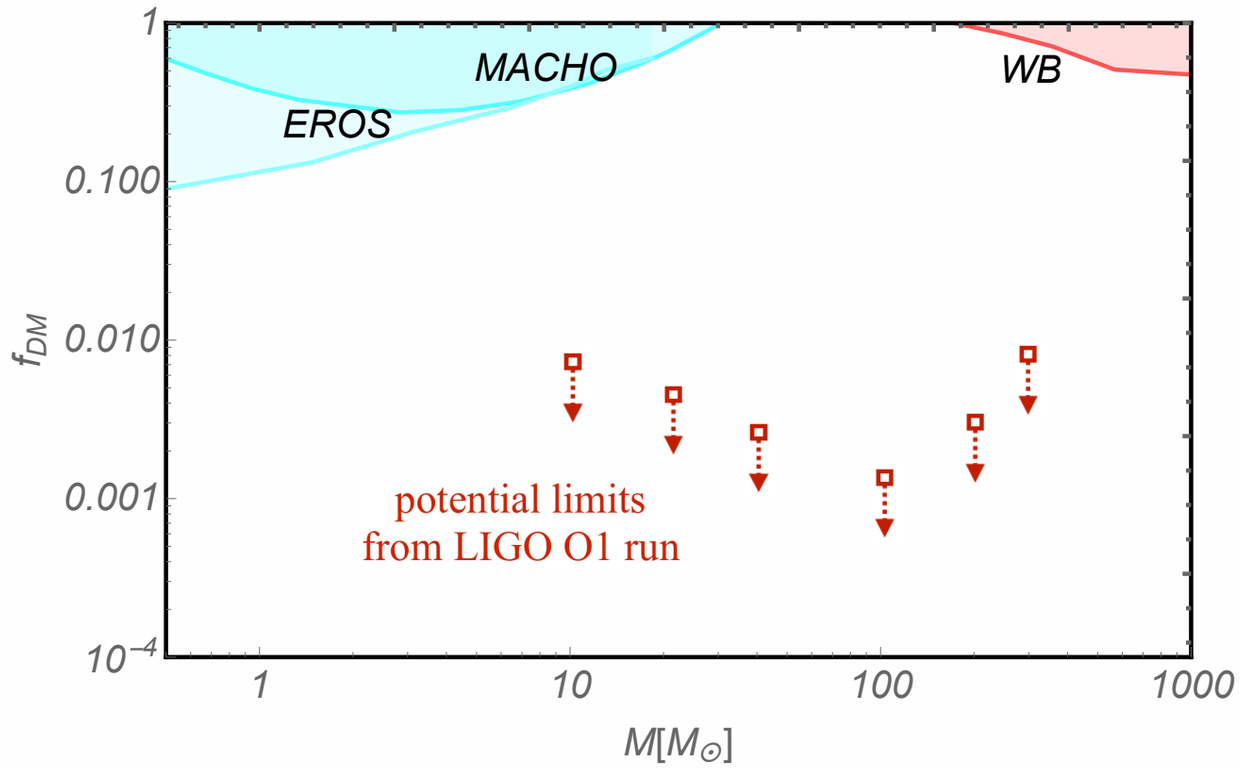

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Outline

Ely Kovetz
GGI, Oct. 2018

- Indirect Detection of PBH DM: Gravitational Waves

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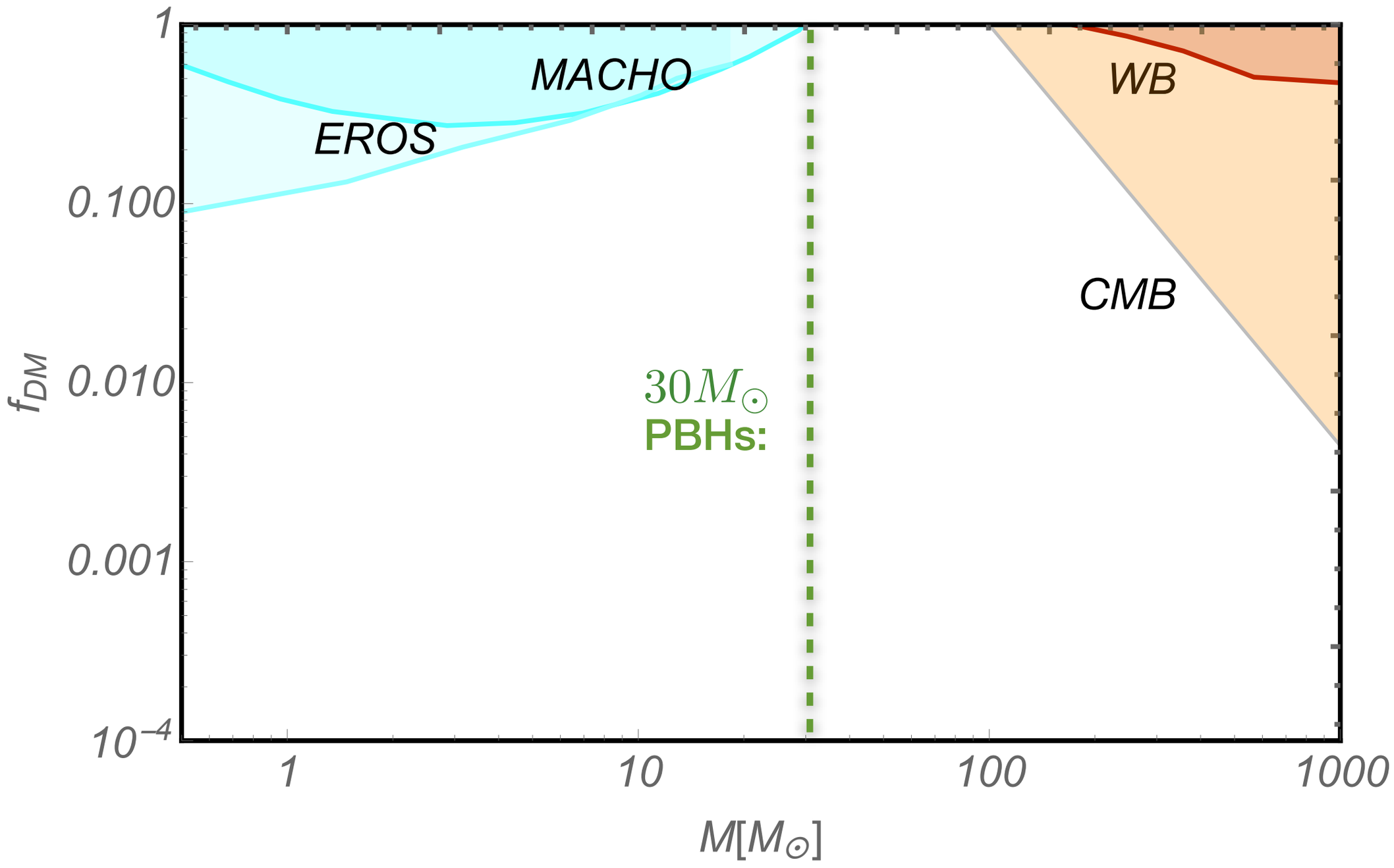
- Direct Detection of PBH DM: beyond Microlensing

Direct Detection: New Probes of PBH DM

Can we do better than with microlensing of stars?



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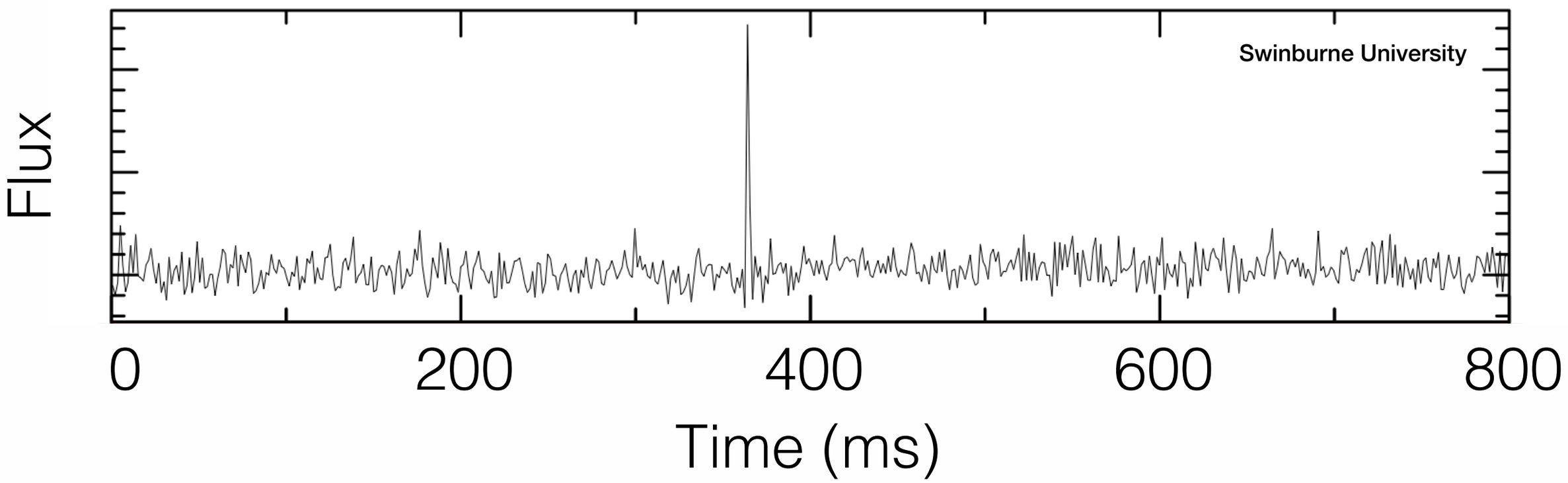

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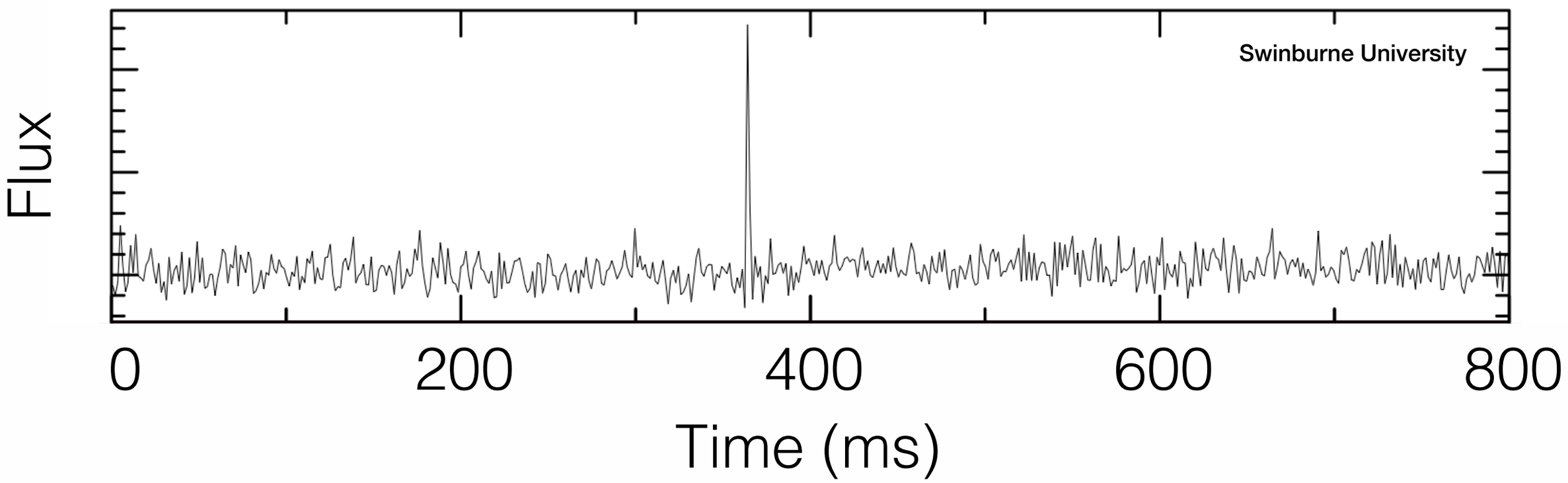

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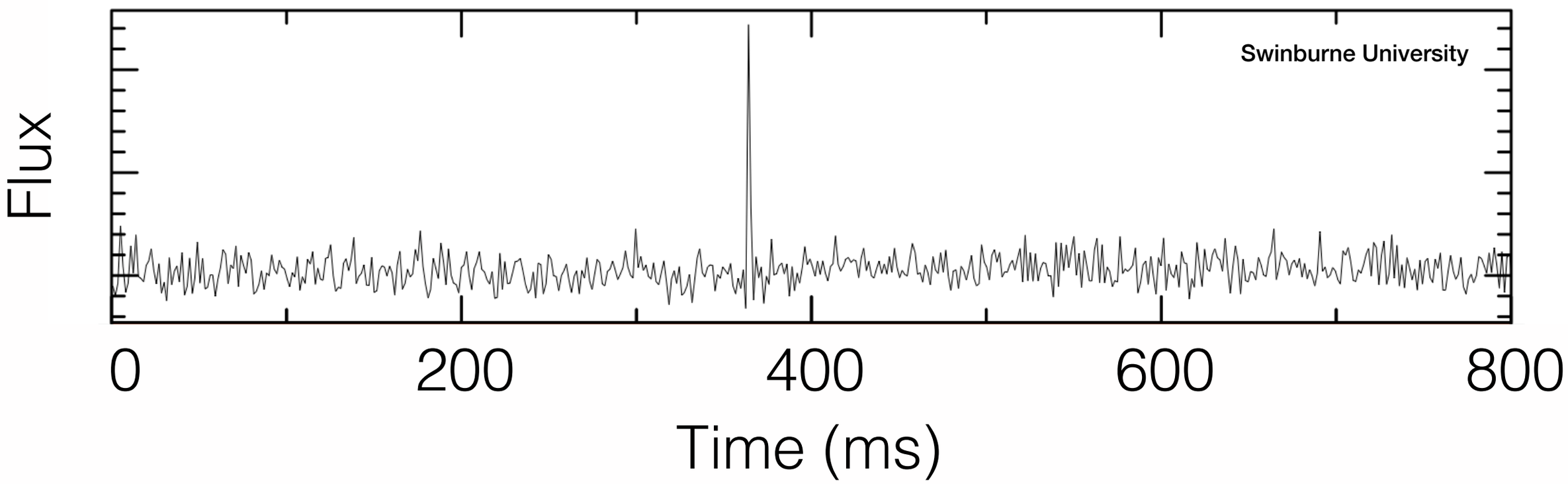

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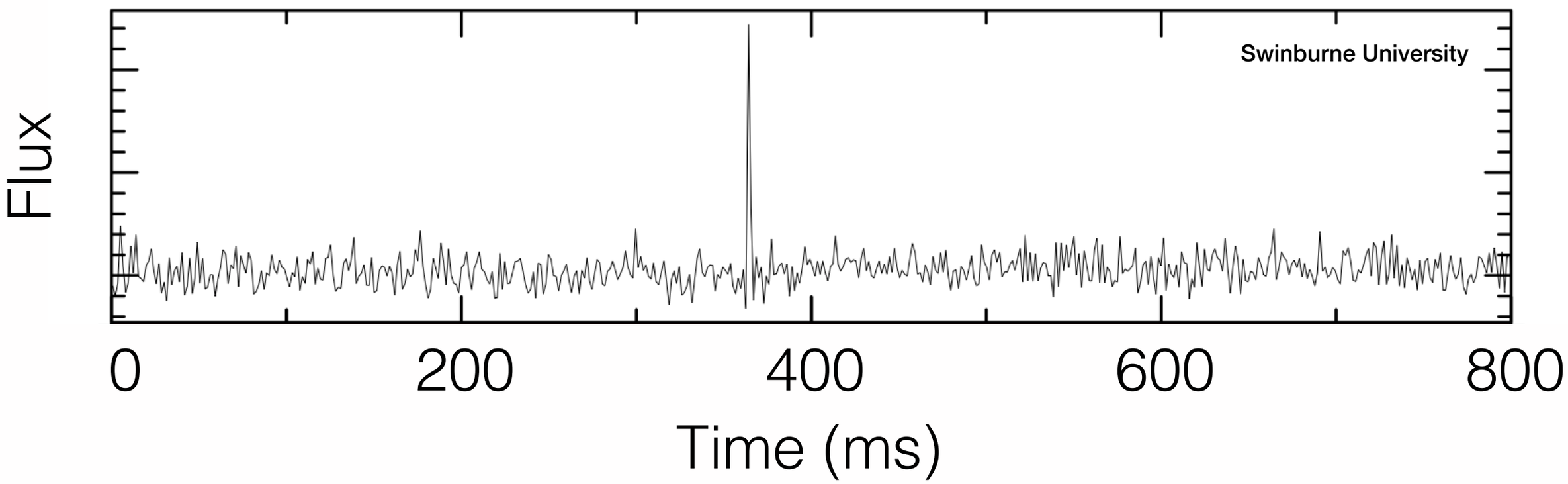

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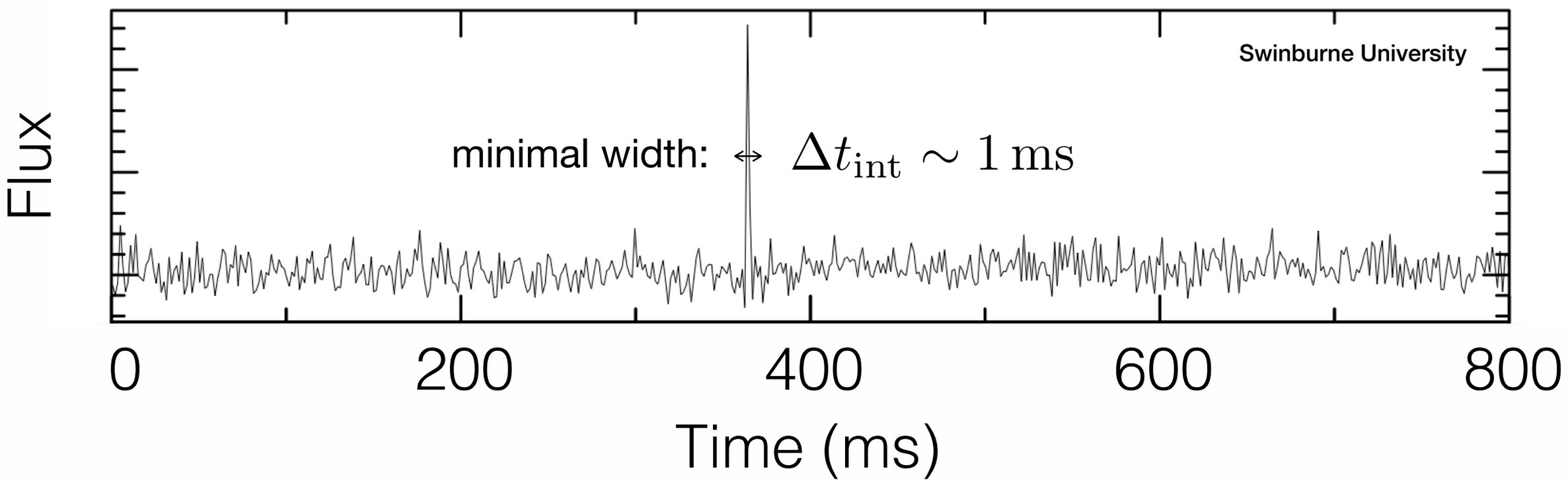

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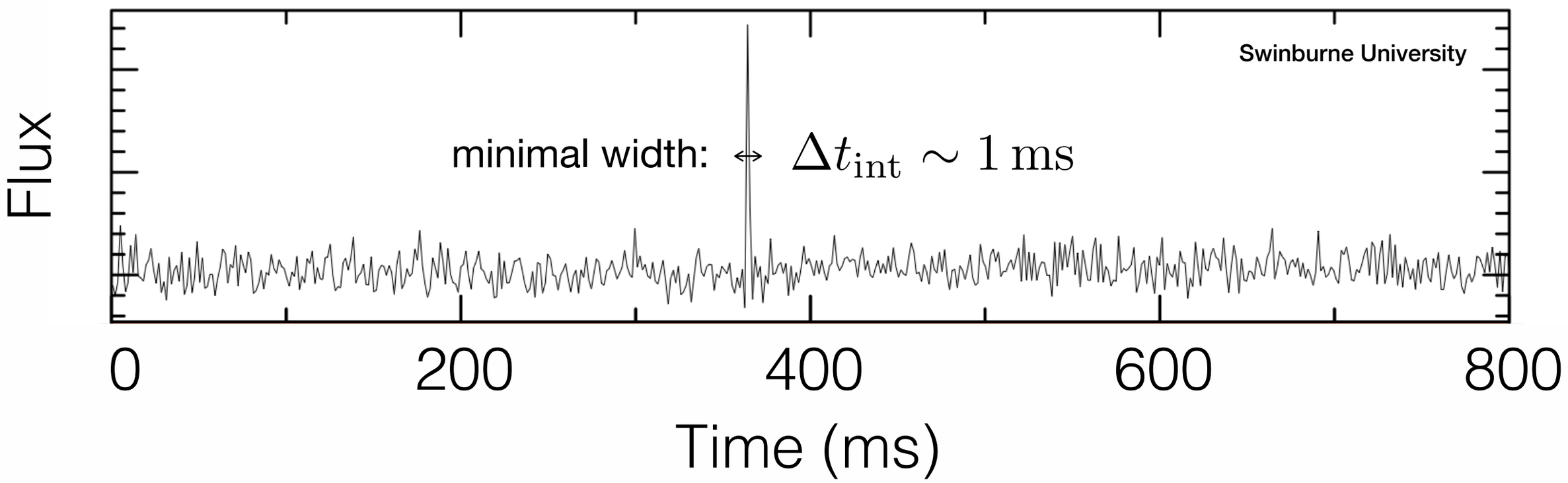

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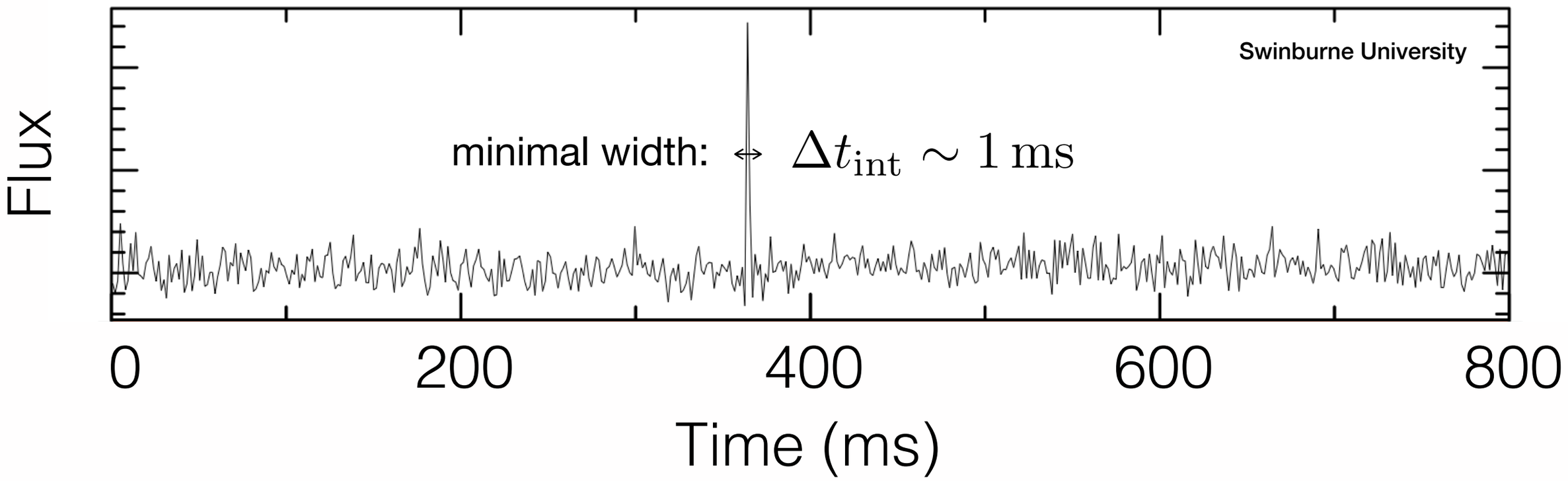

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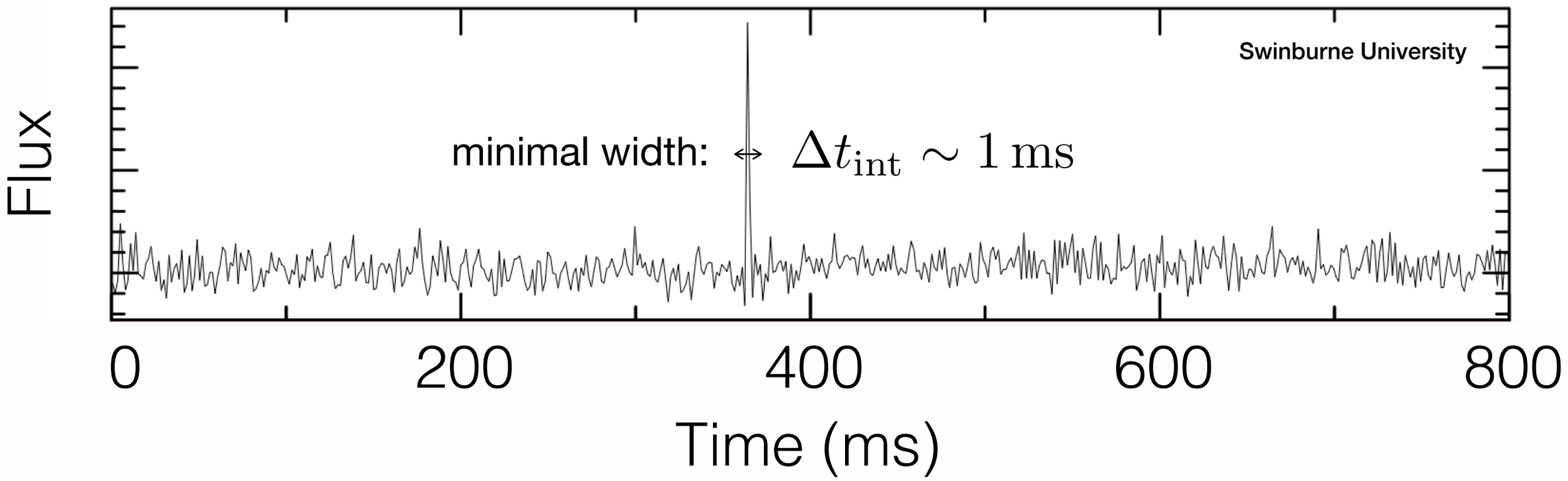

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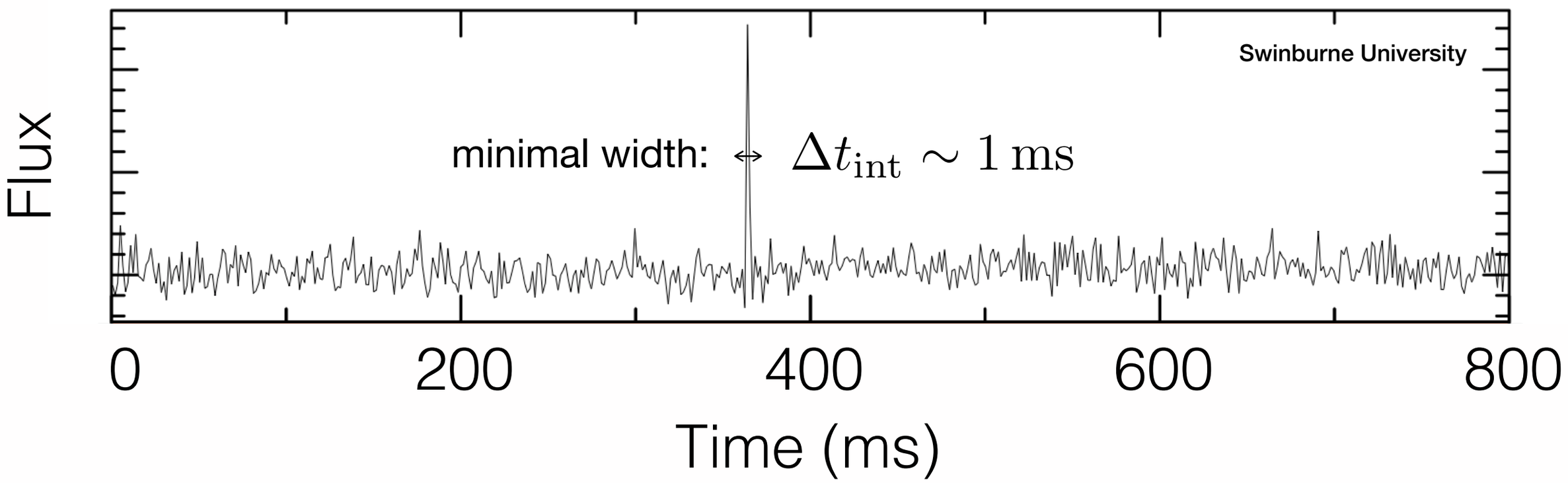

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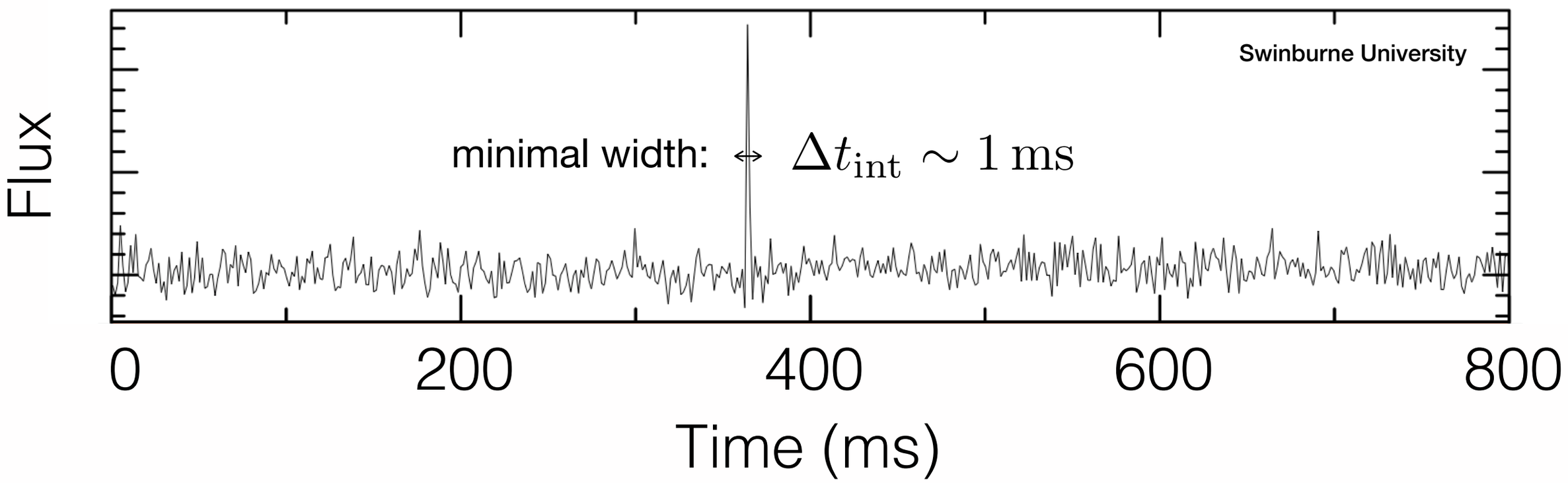

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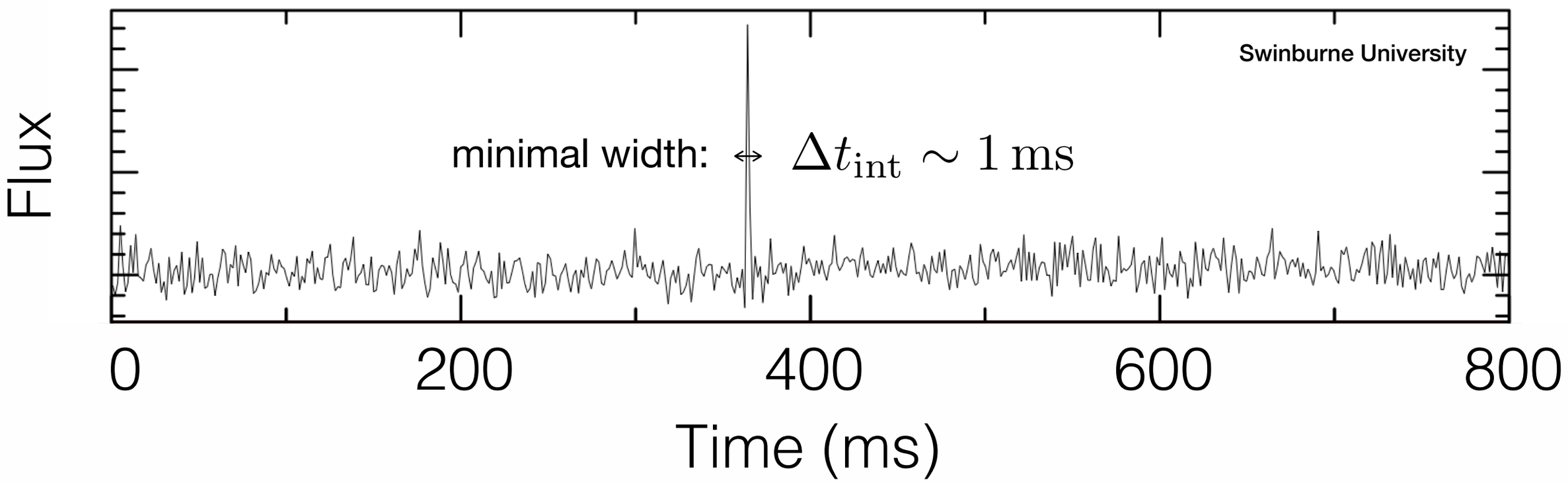

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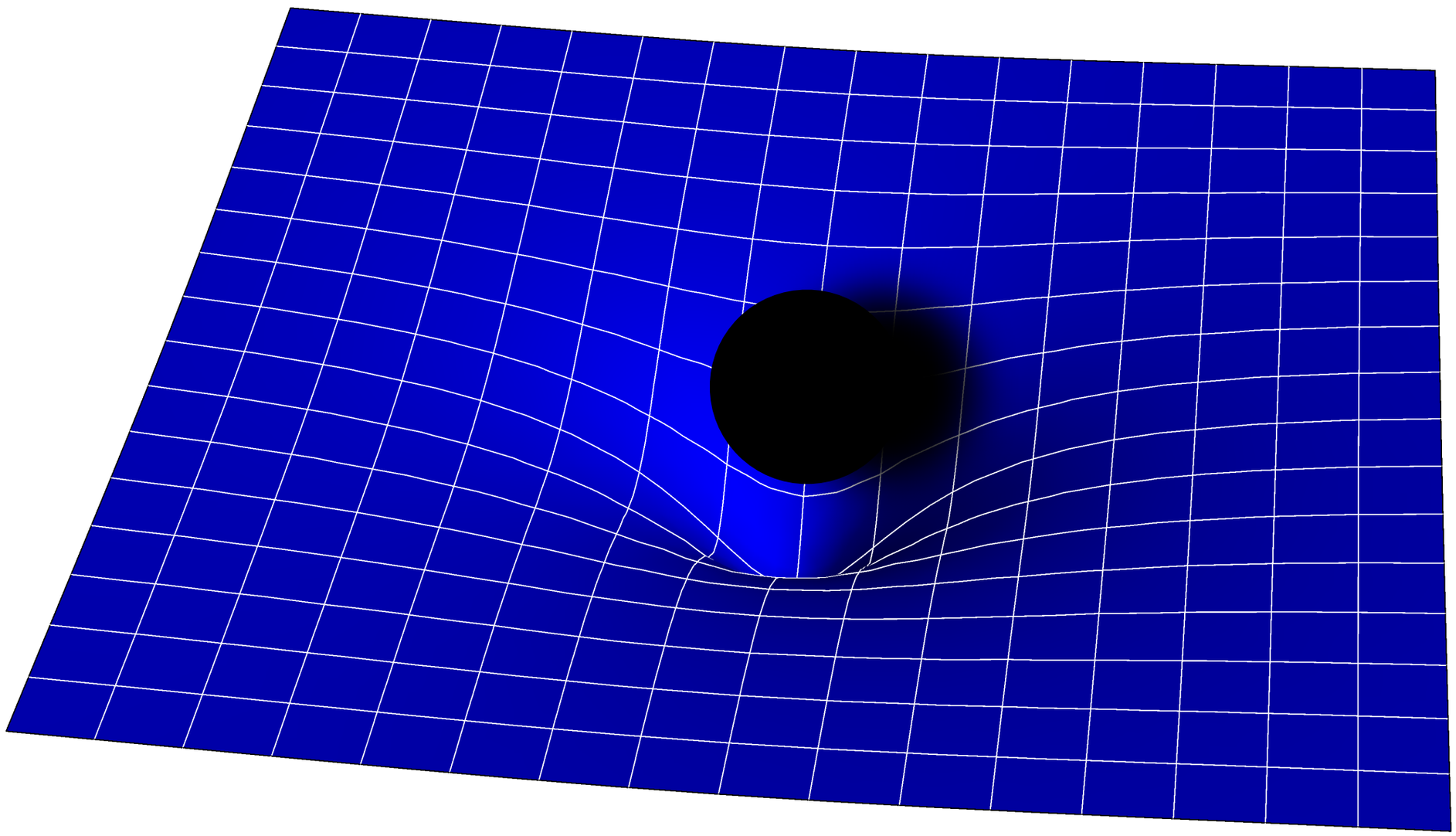

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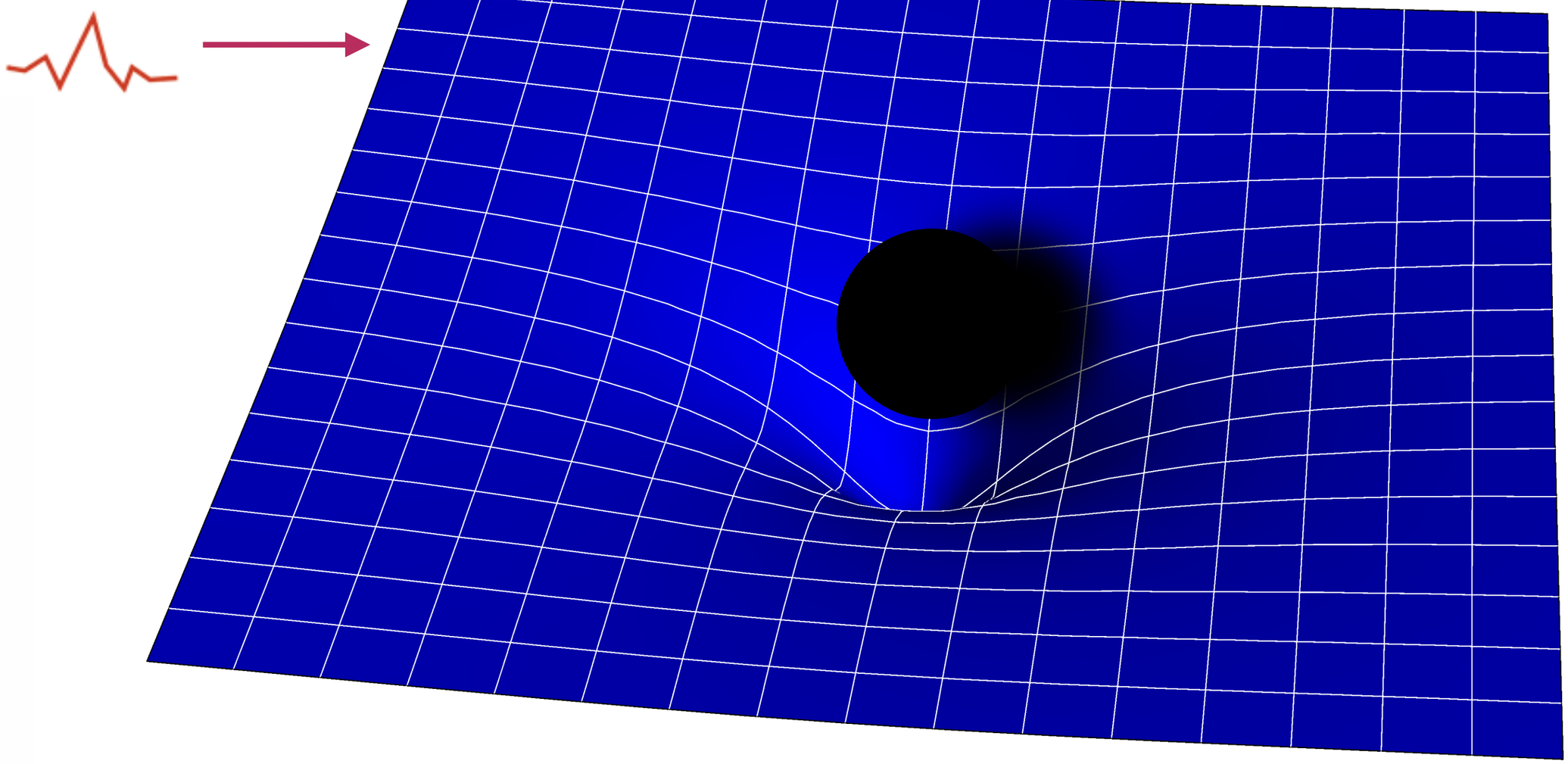
Source FRB



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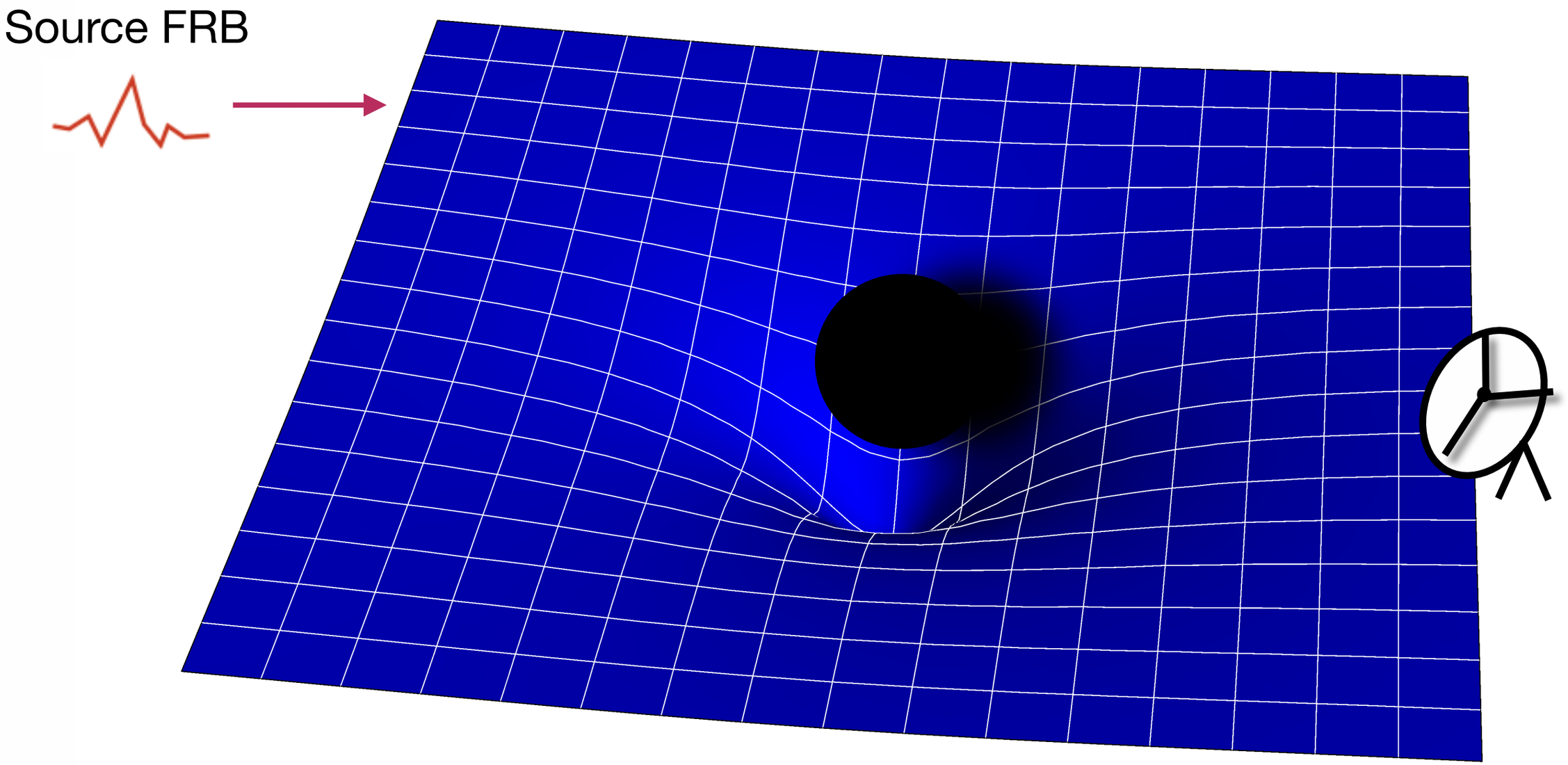

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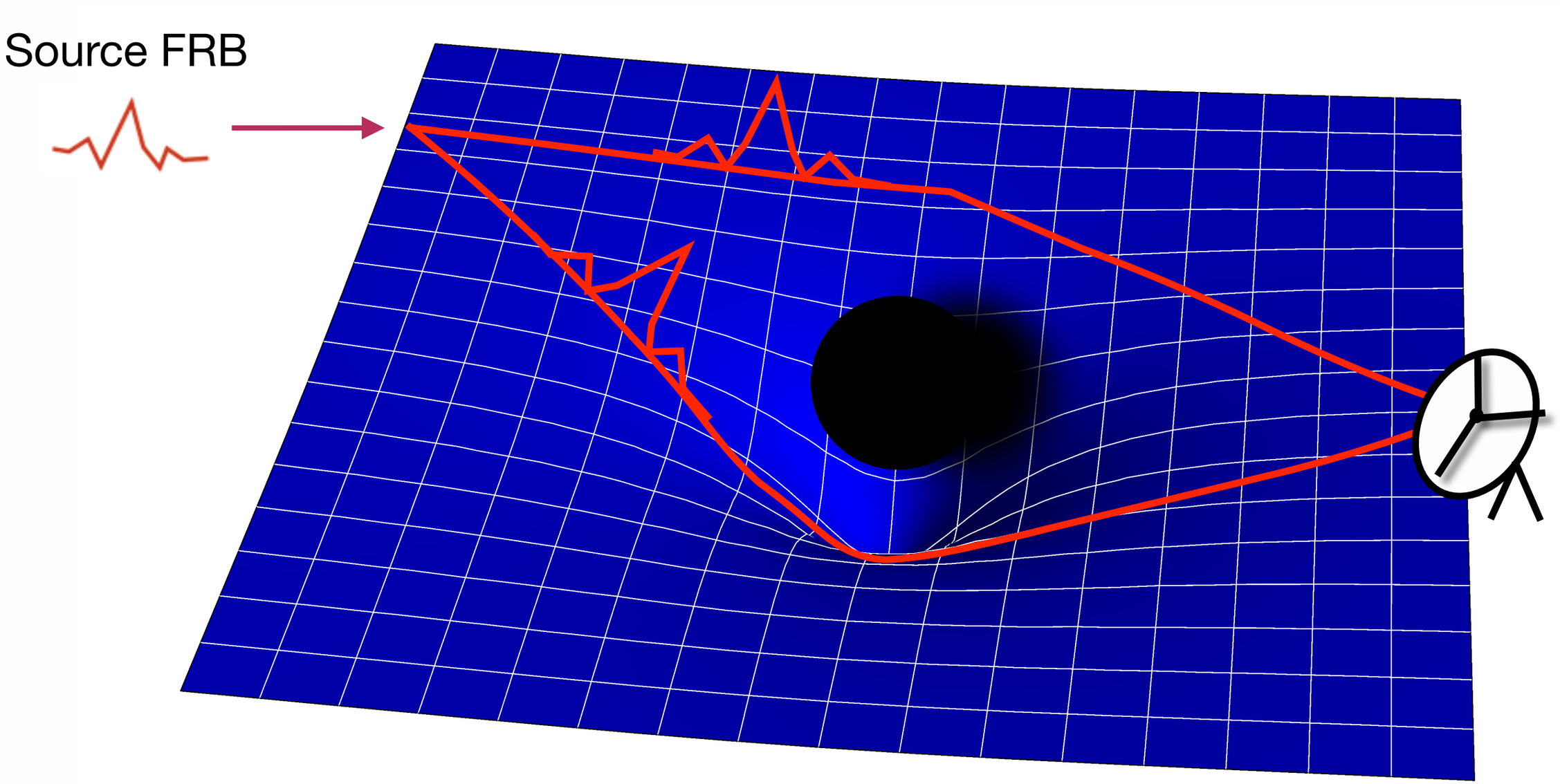

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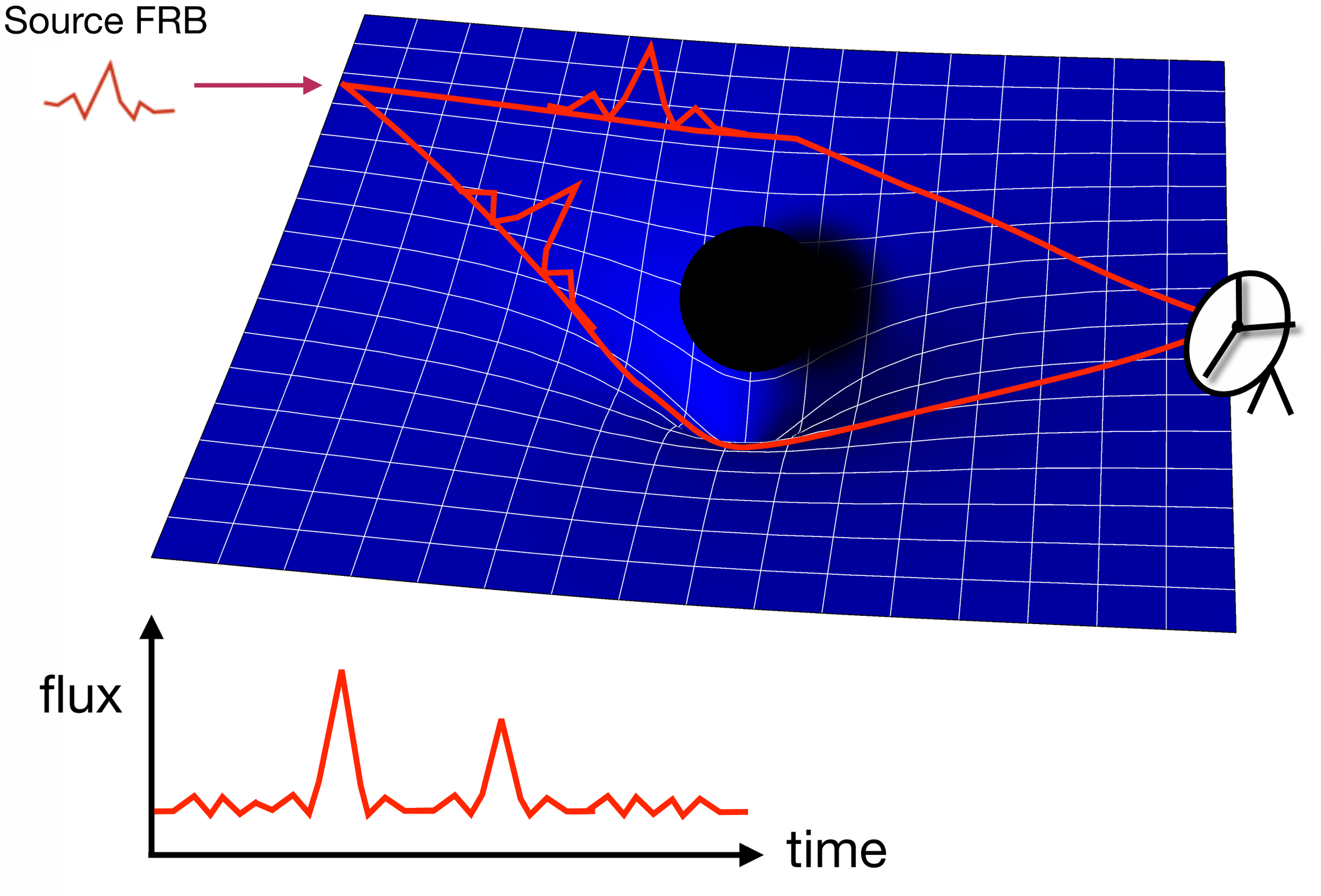

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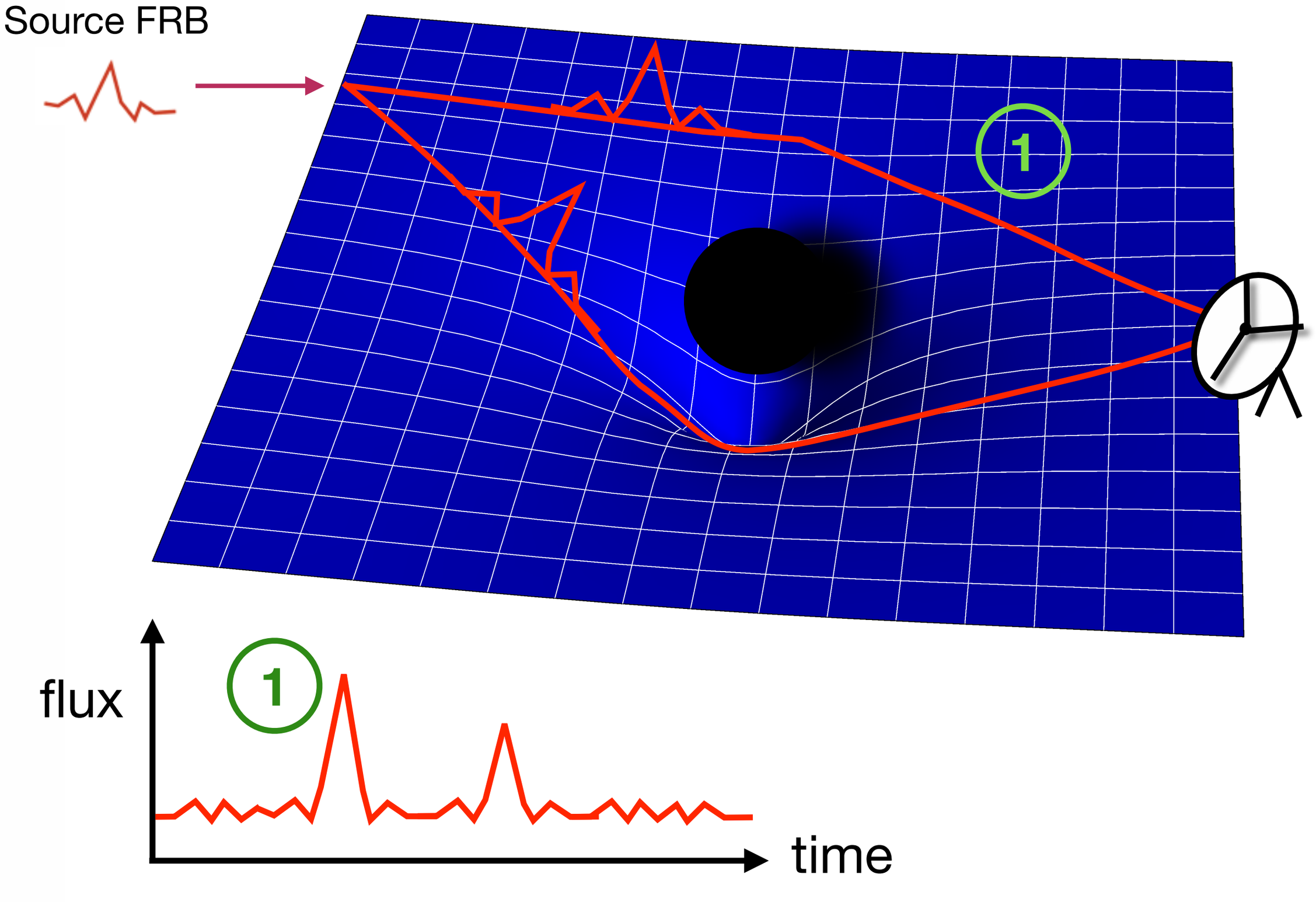

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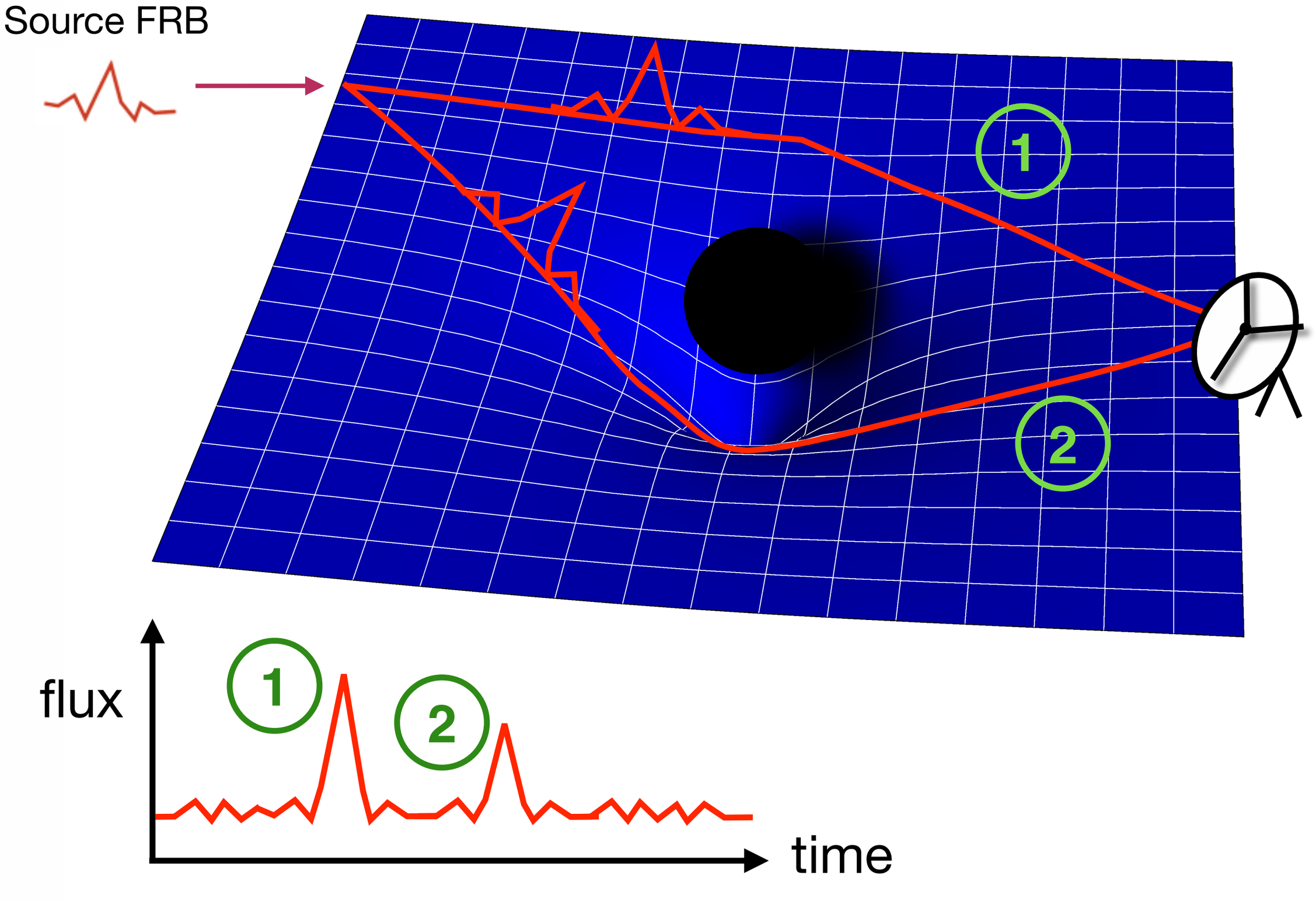

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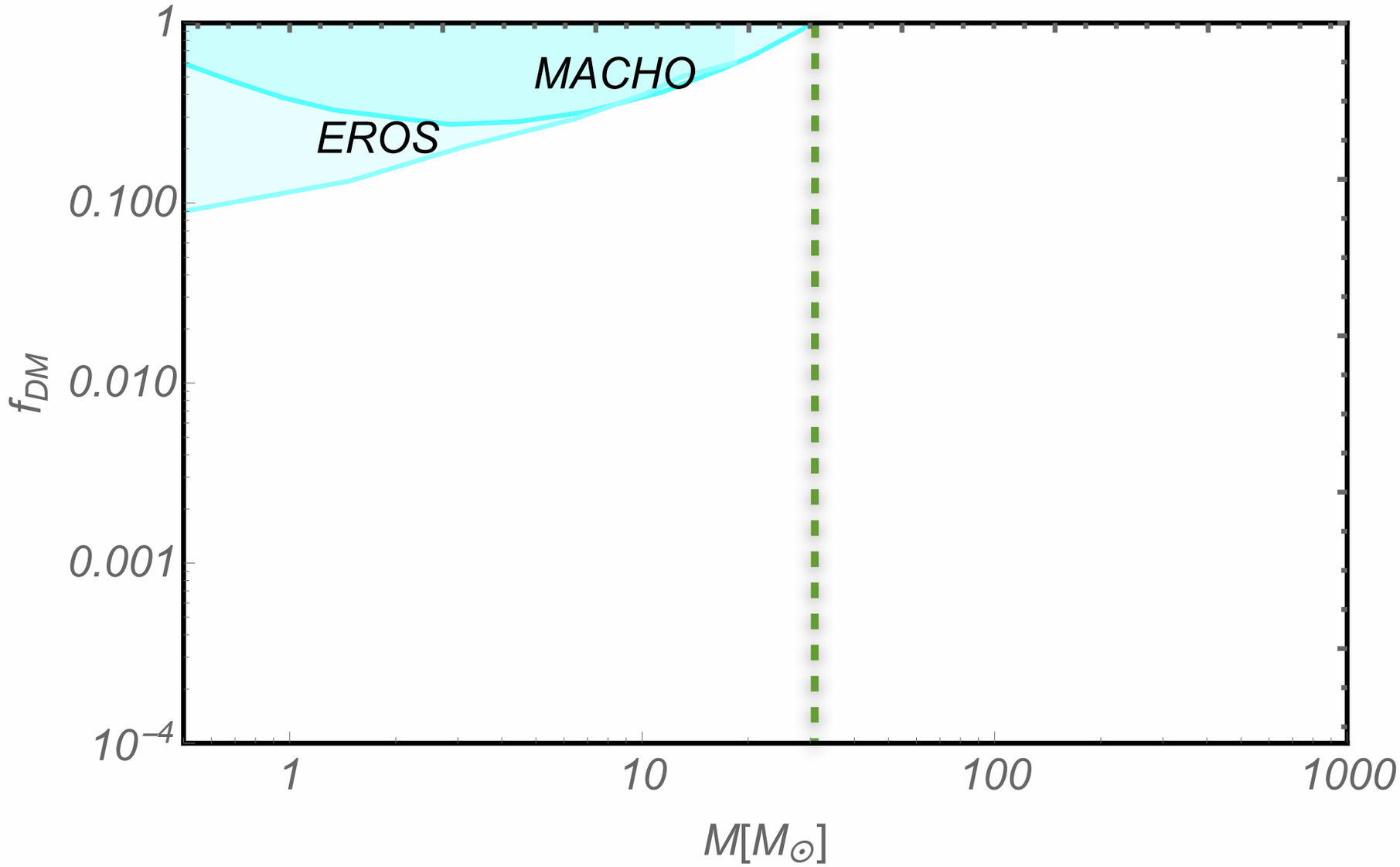

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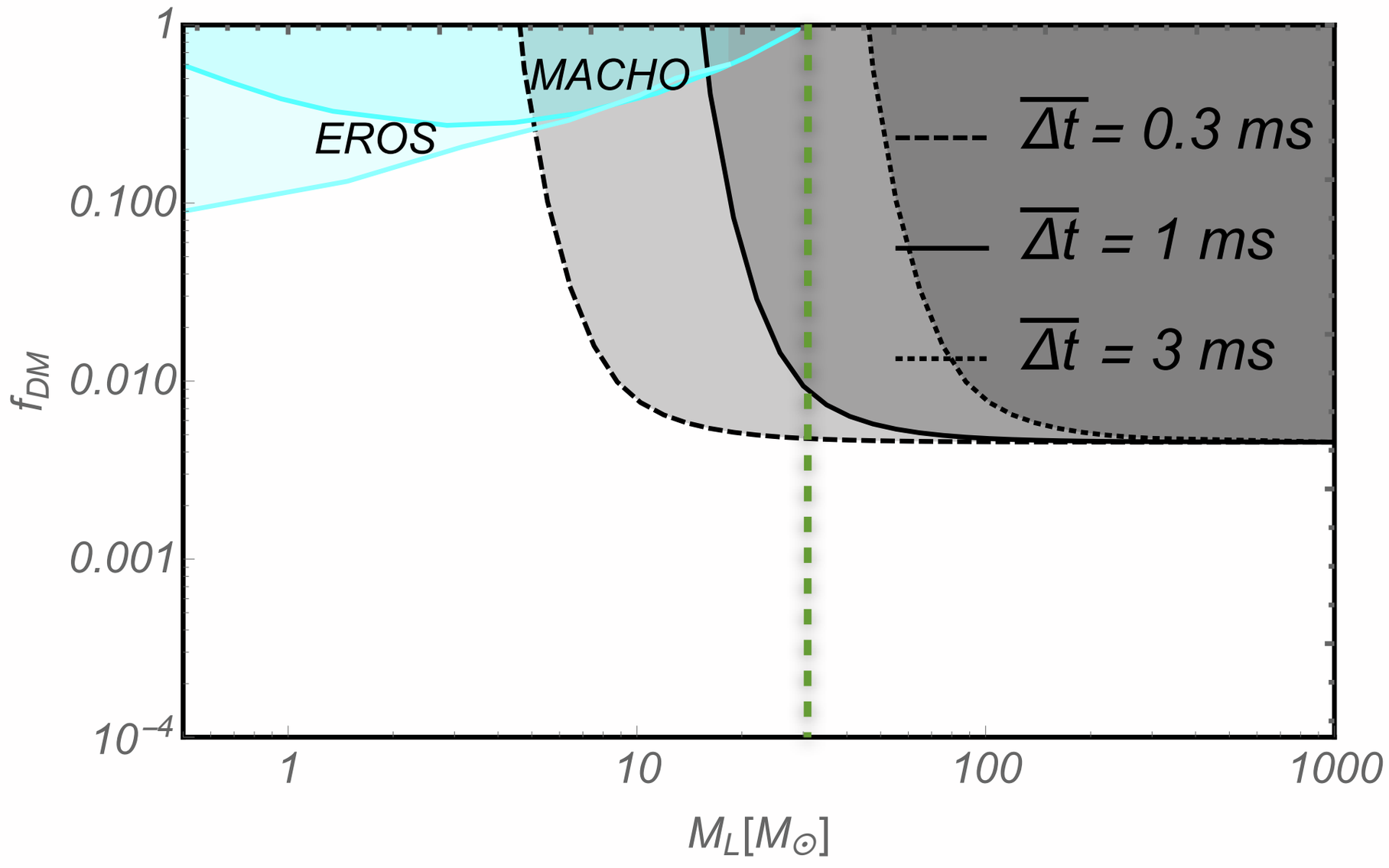

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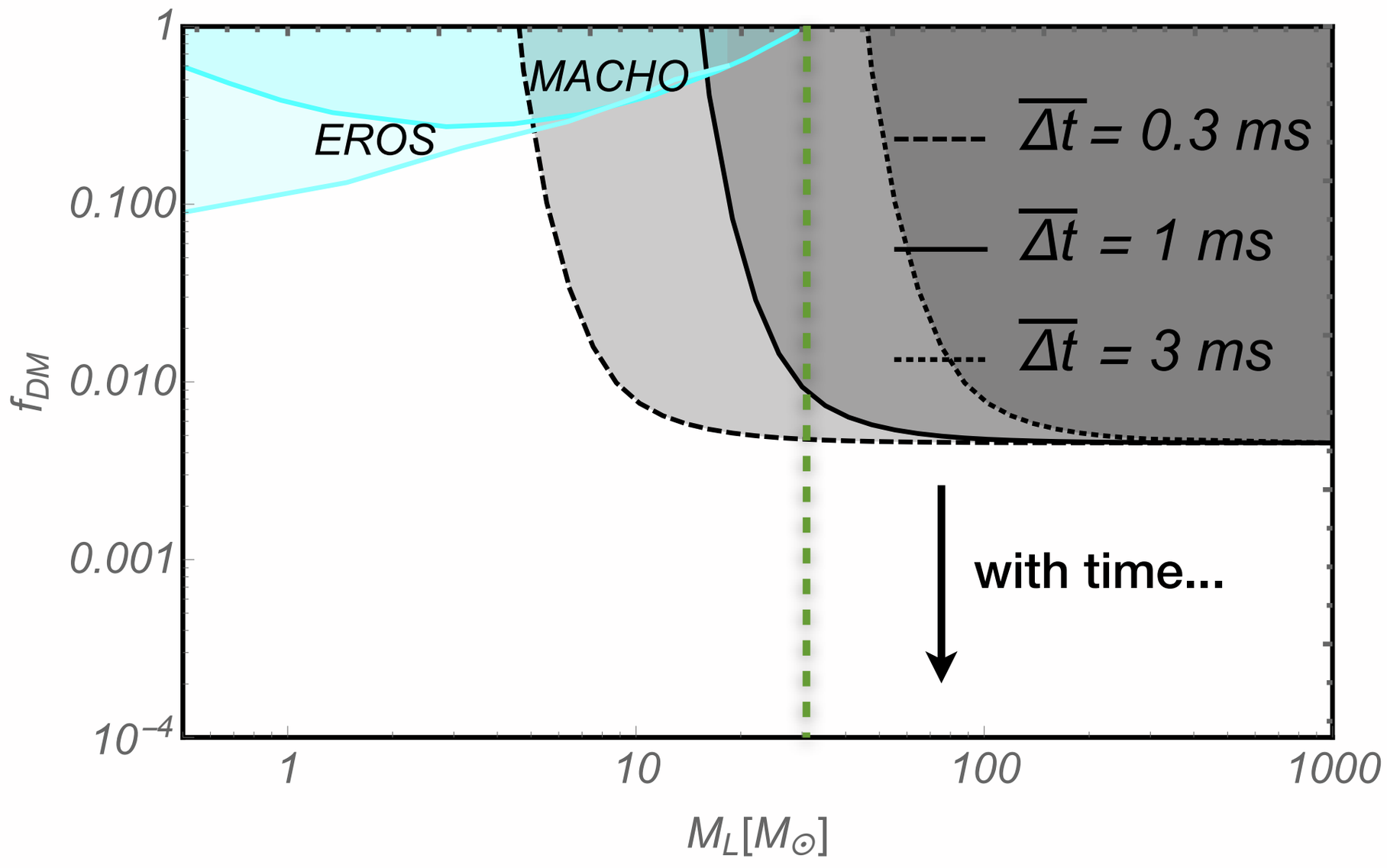

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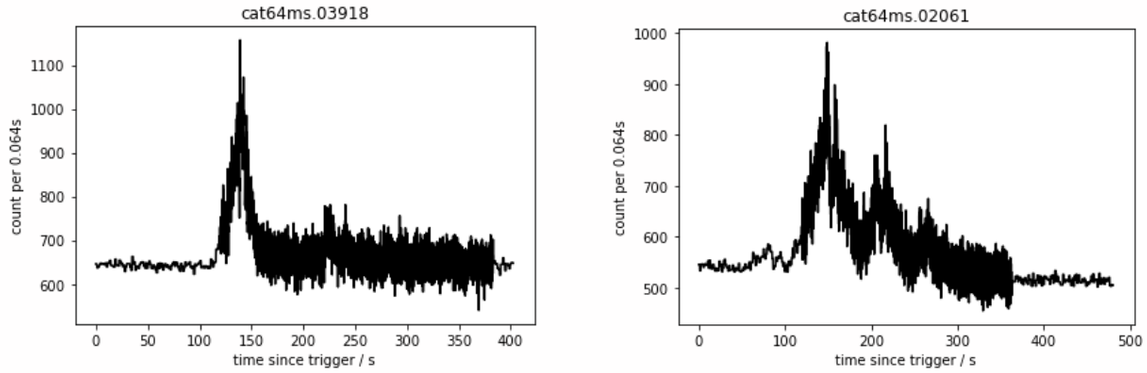

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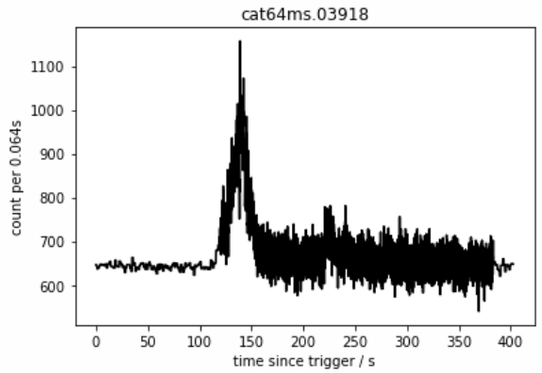

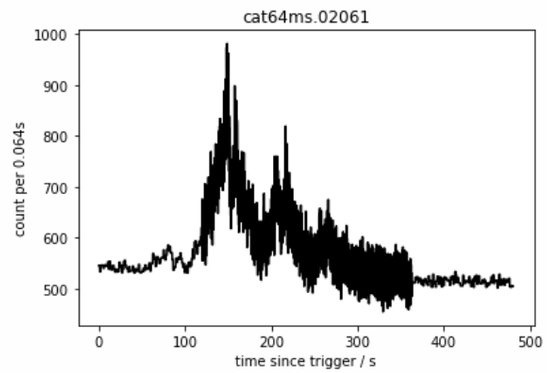

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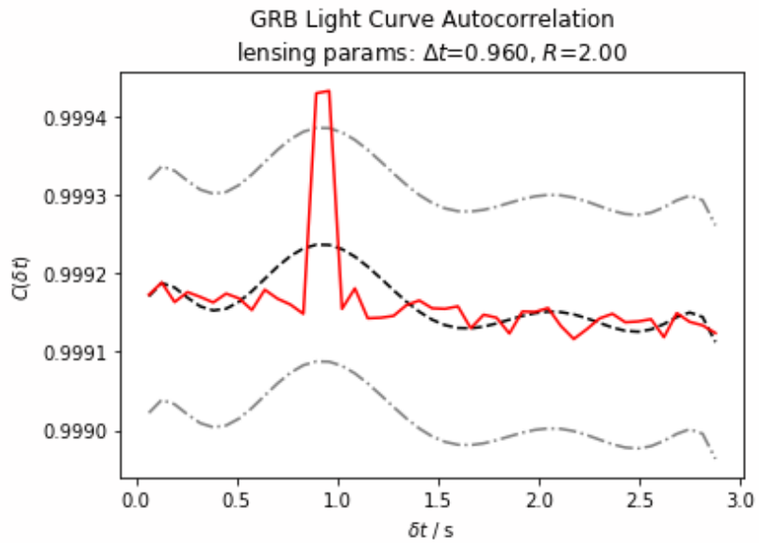

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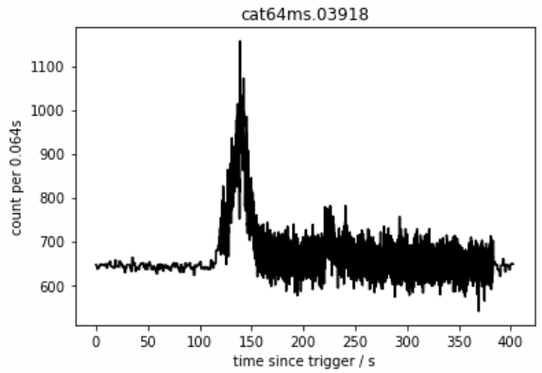

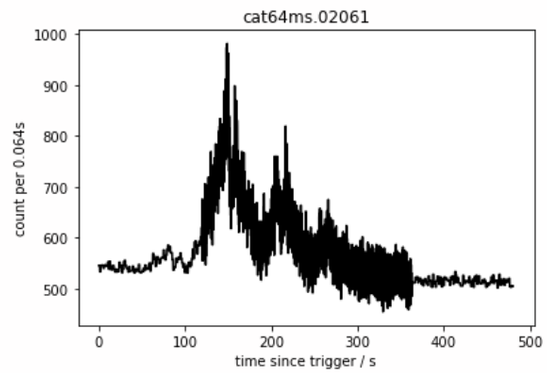

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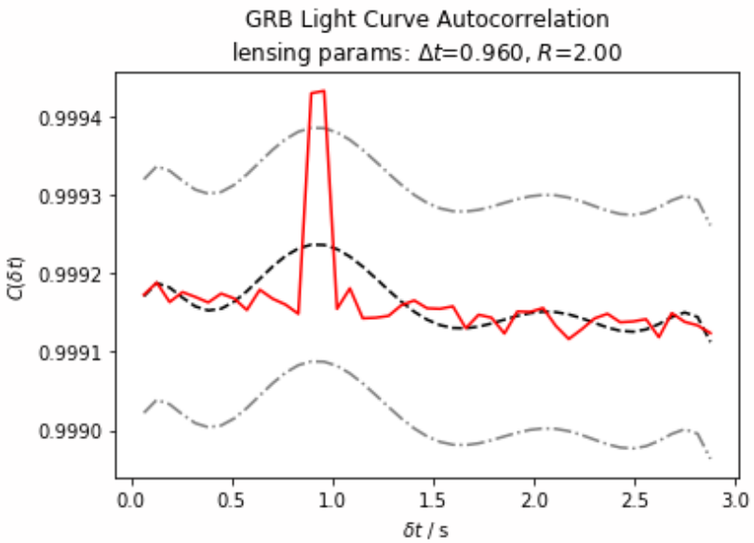
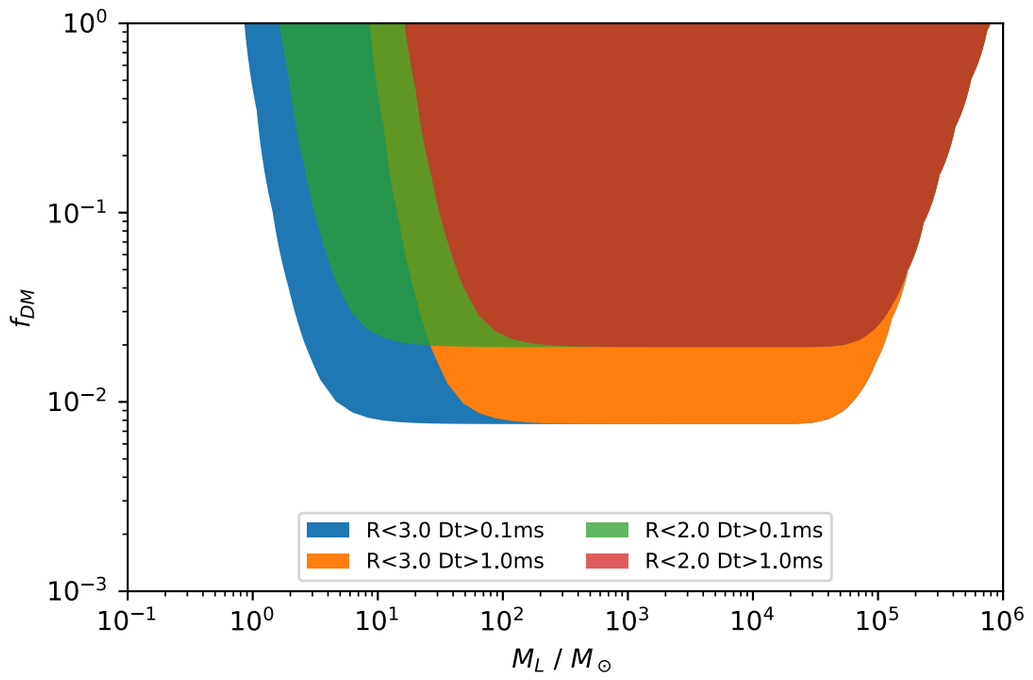


With future observatories:



PBH DM LIGO Window: Constraints Tightening!

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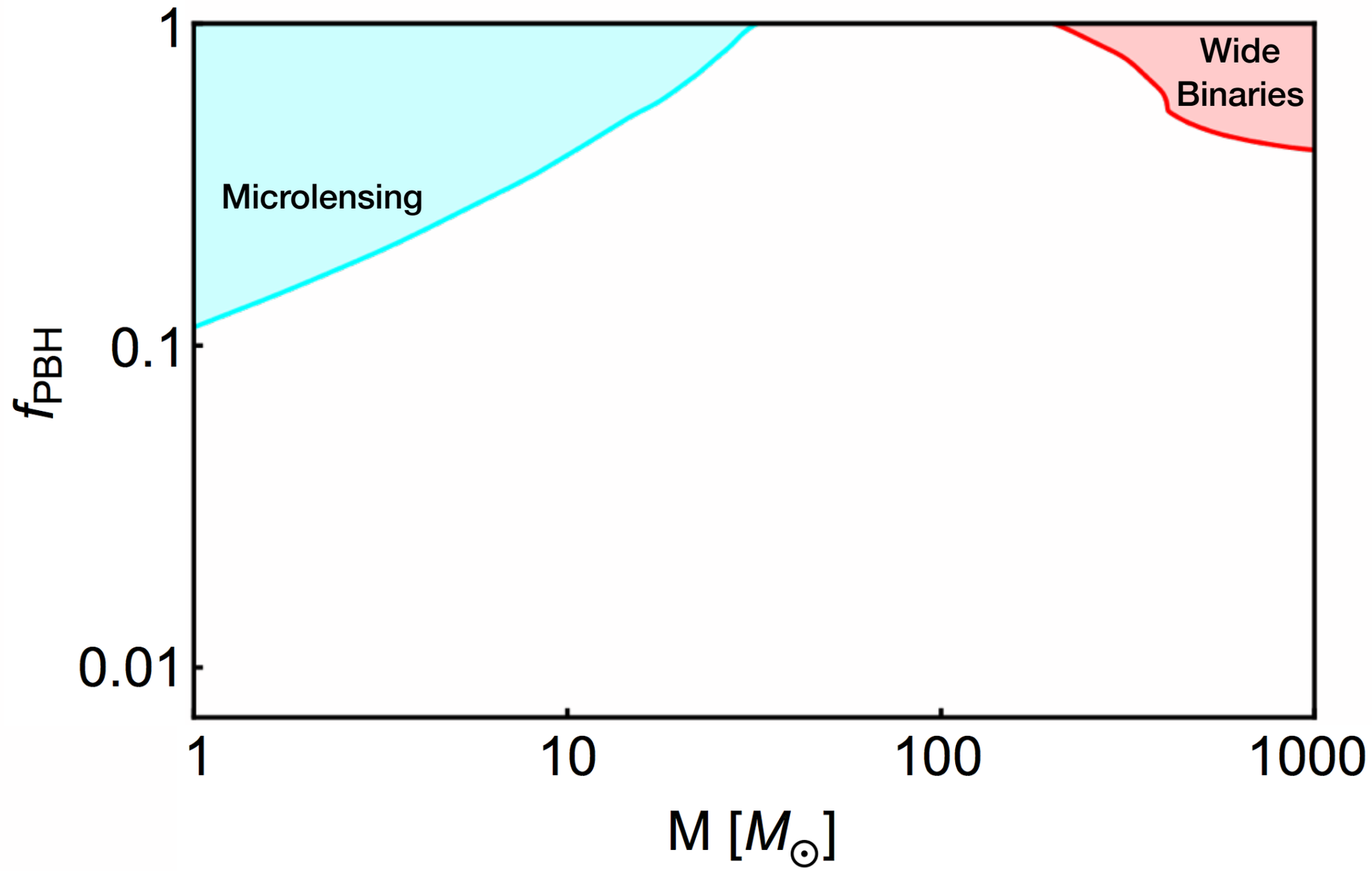

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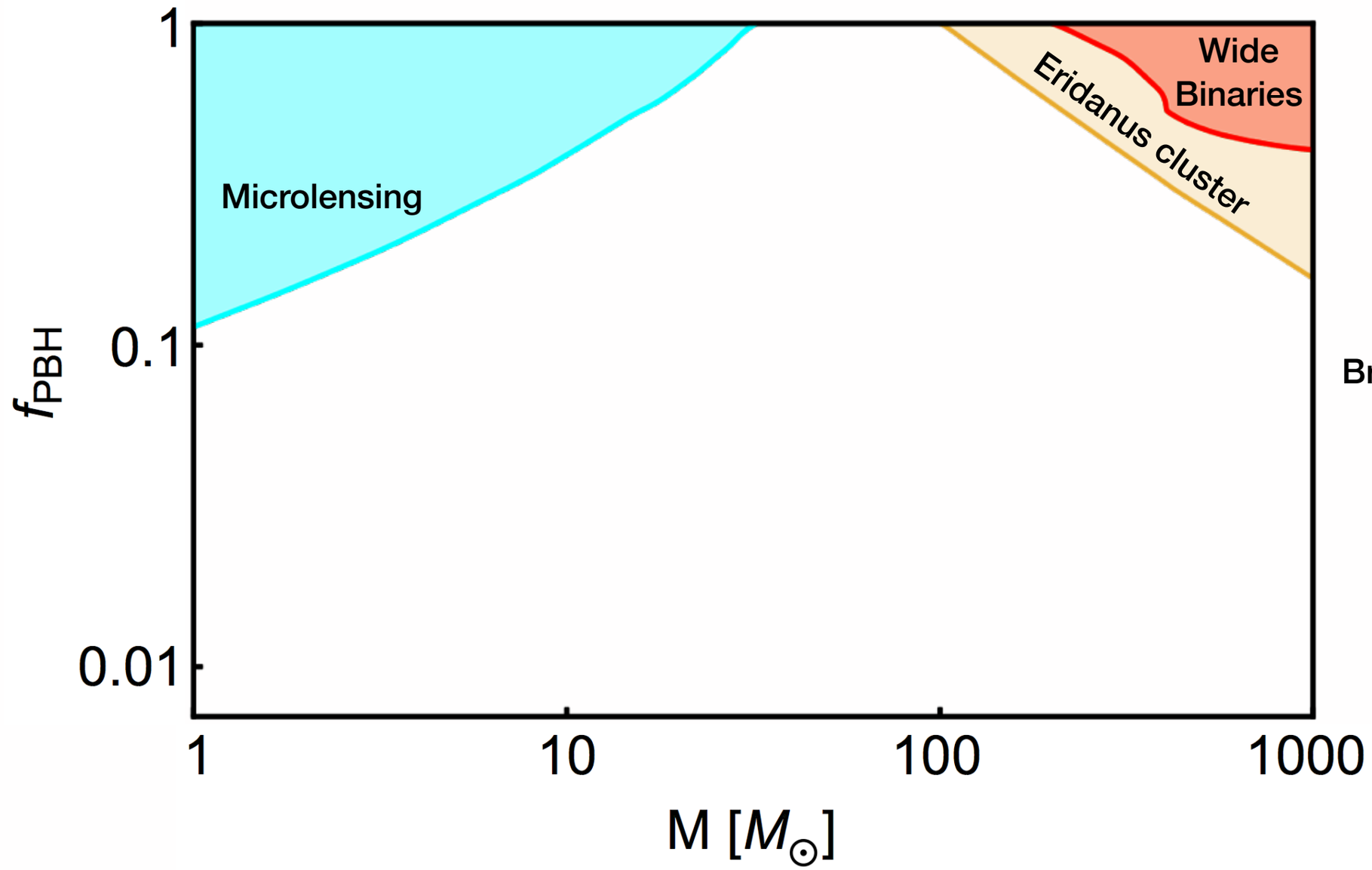

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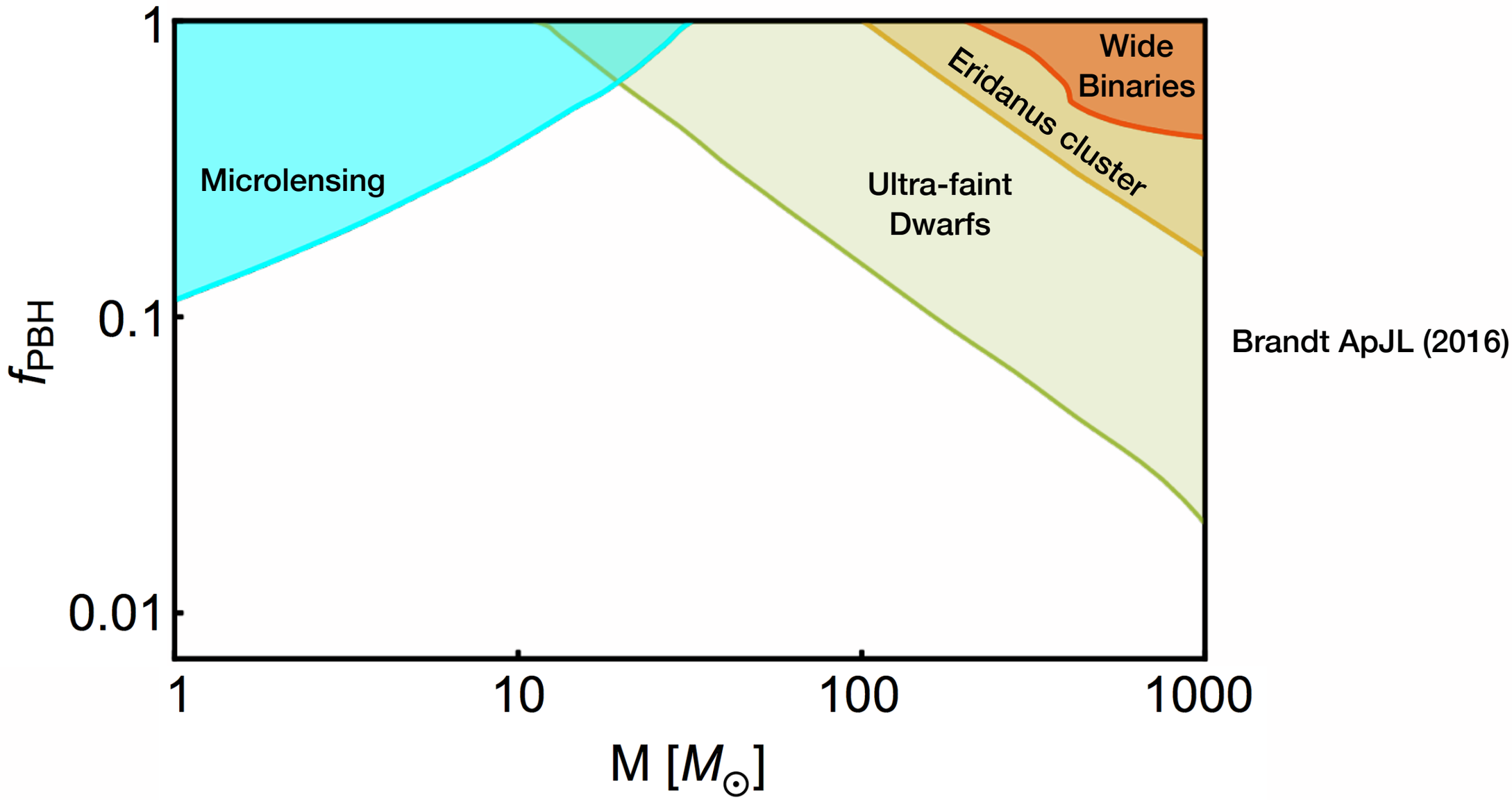

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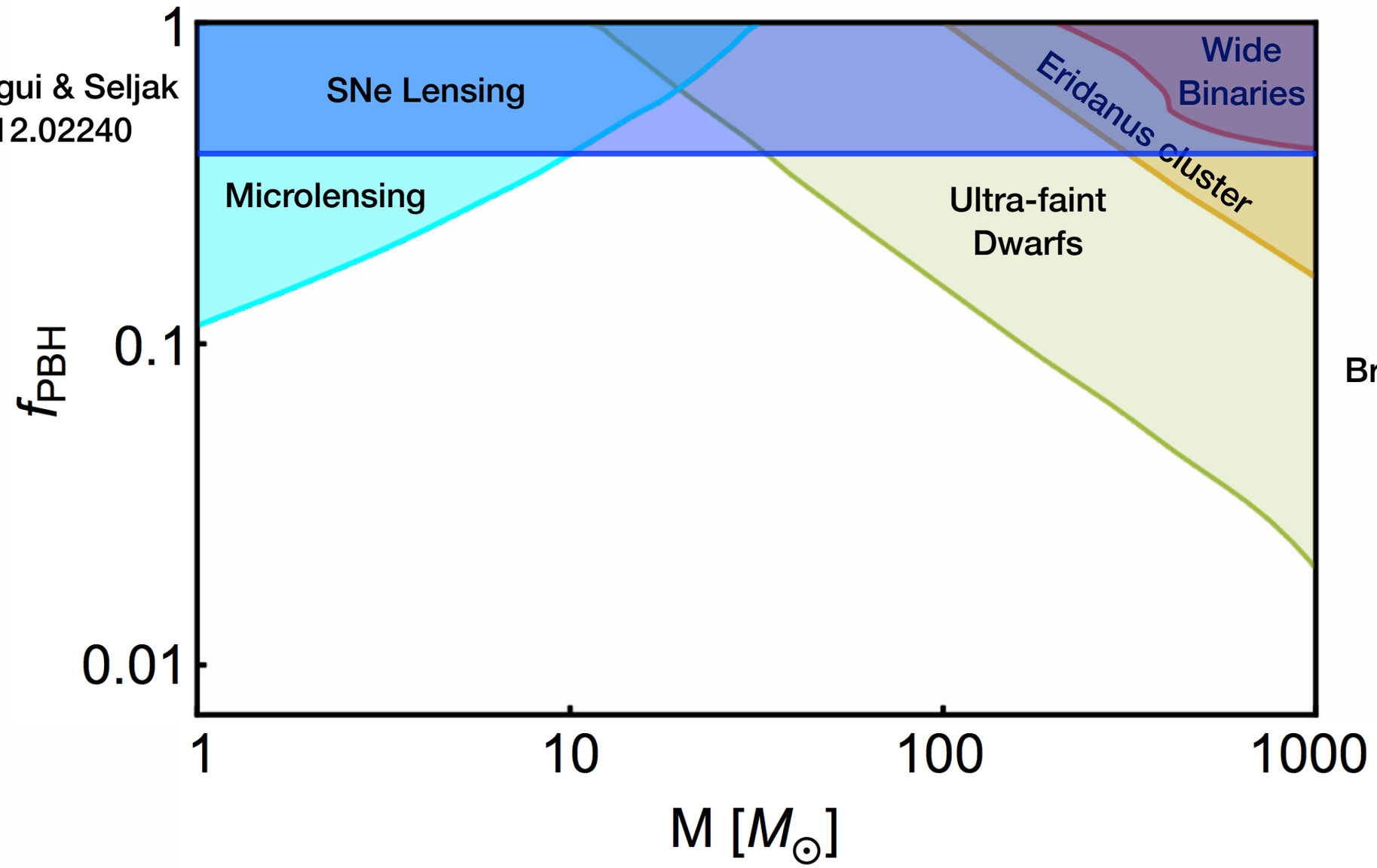

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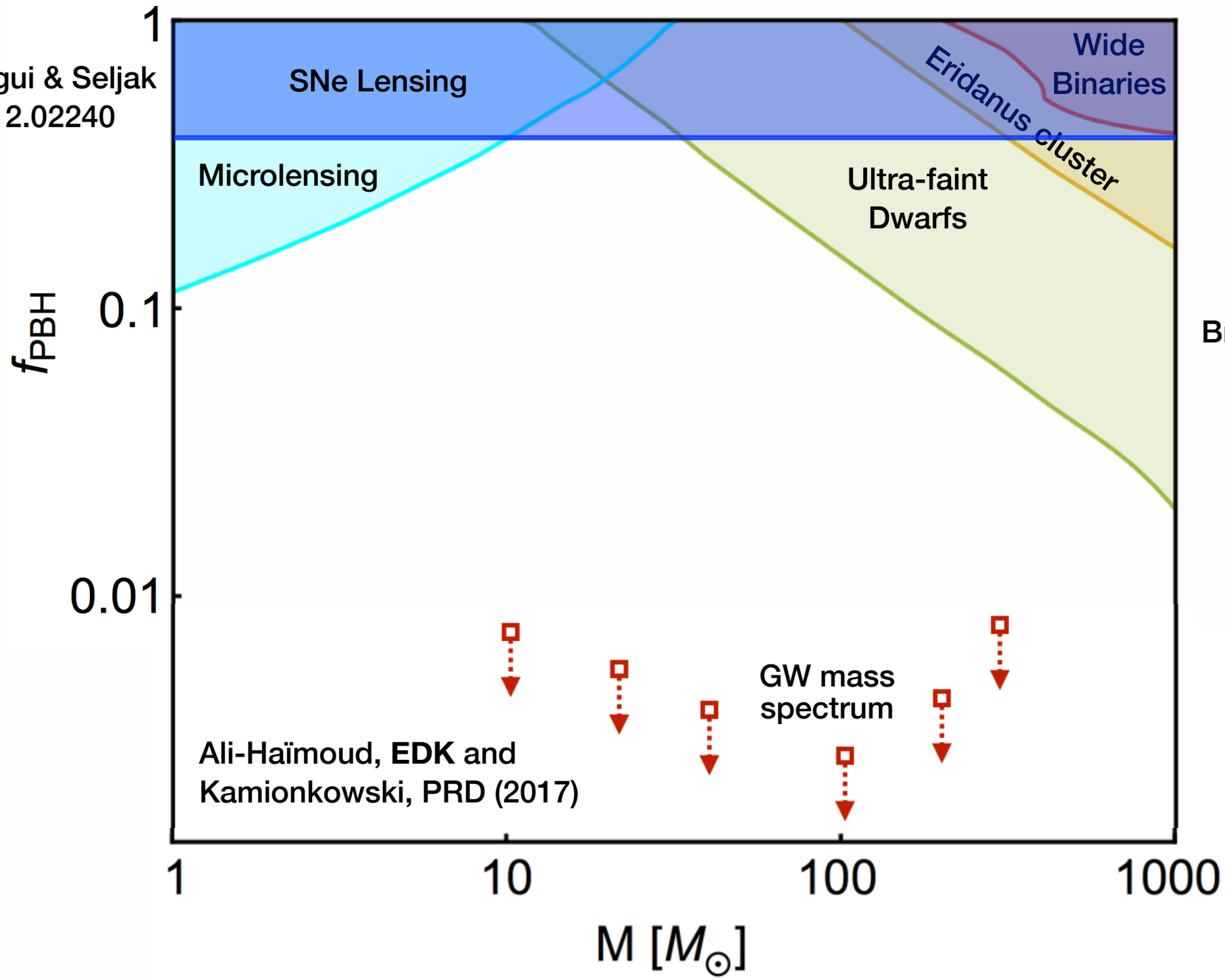

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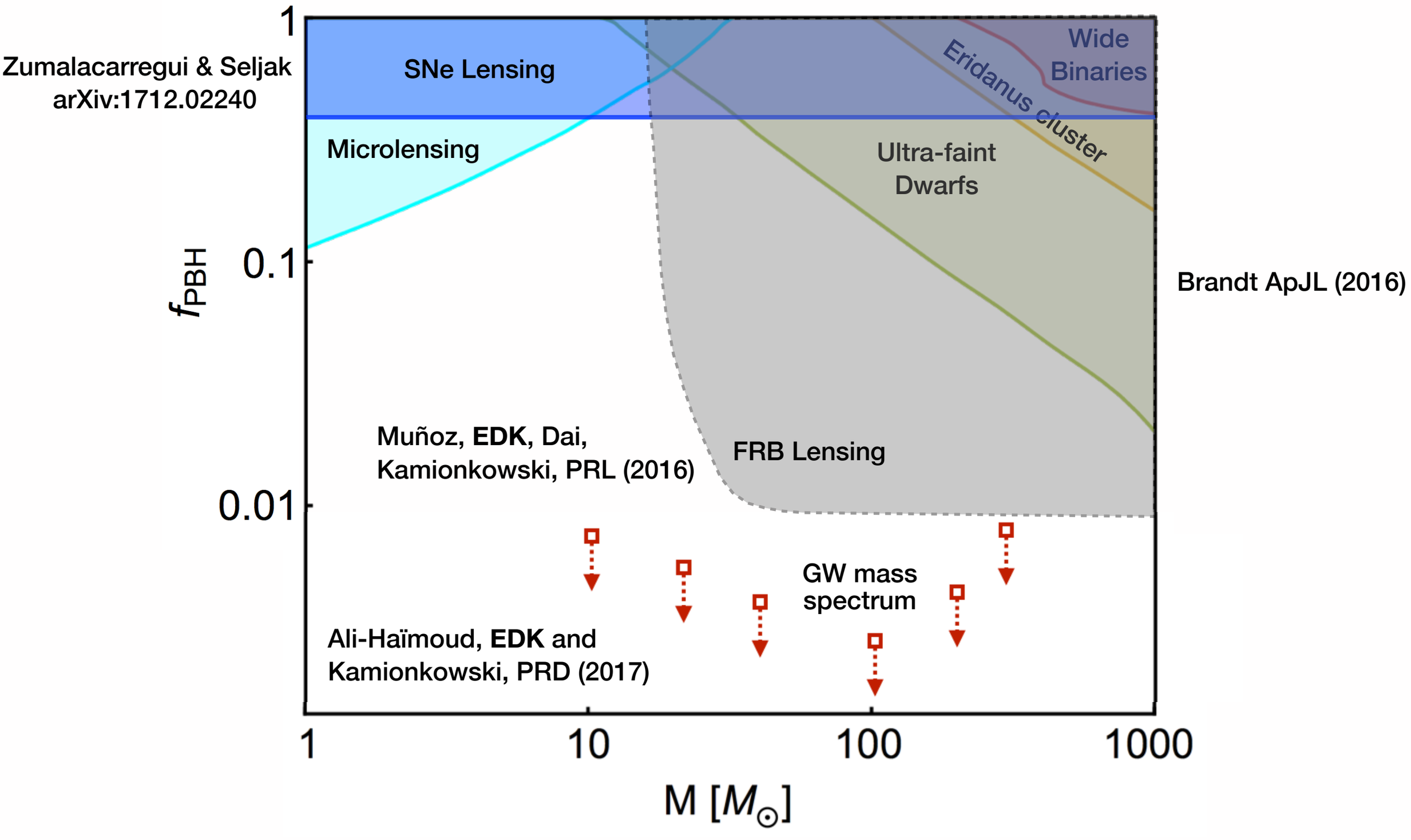

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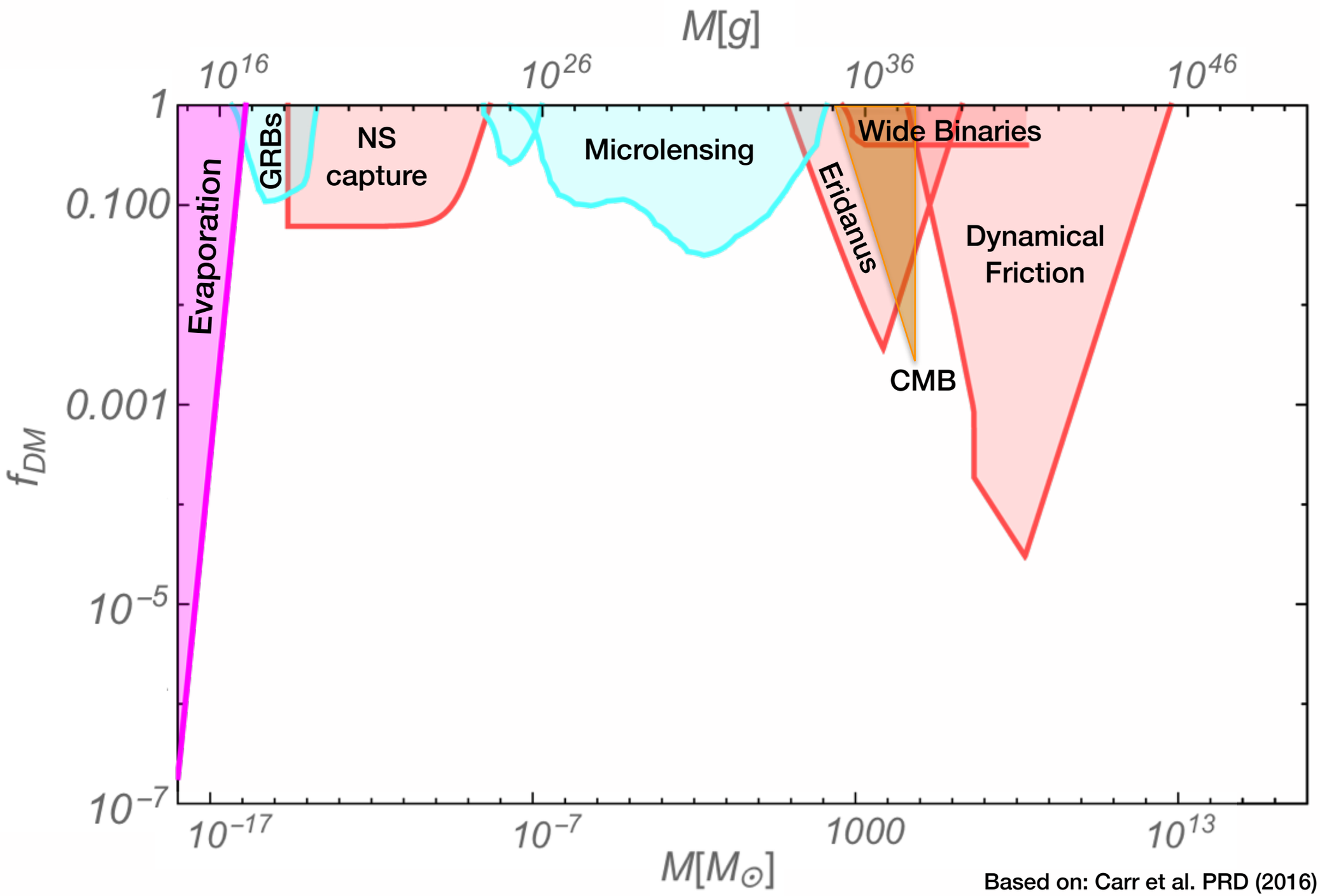

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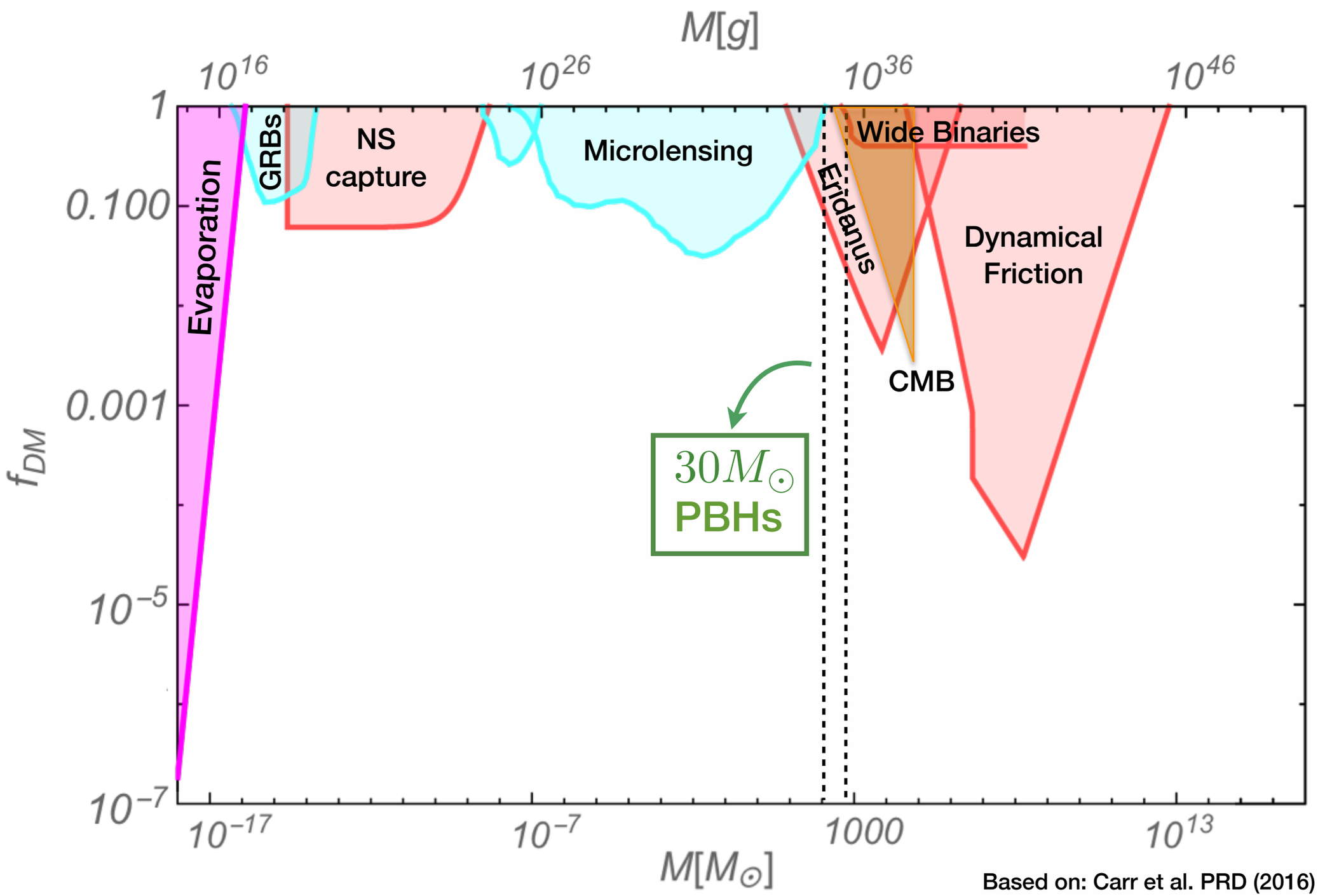

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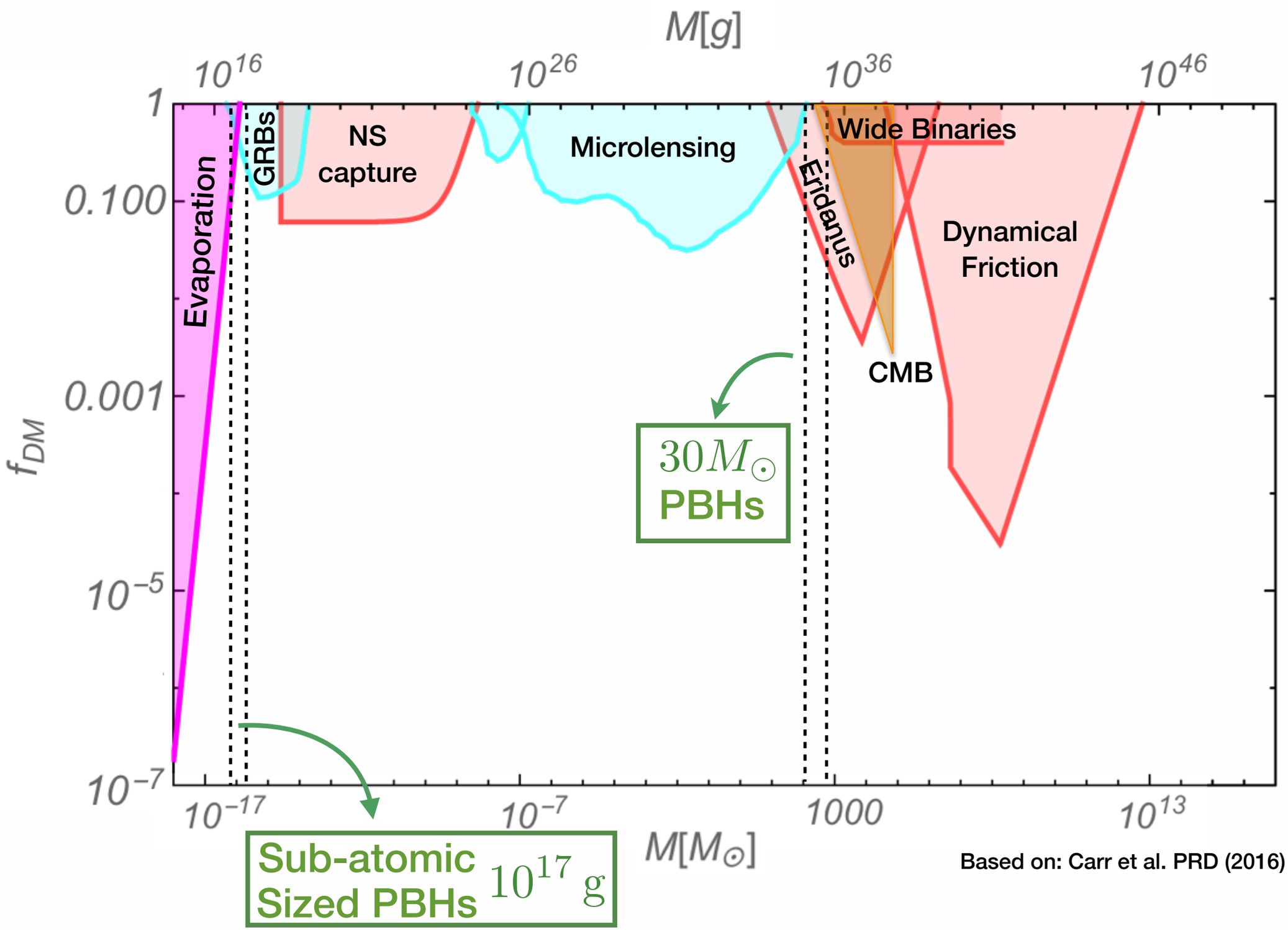

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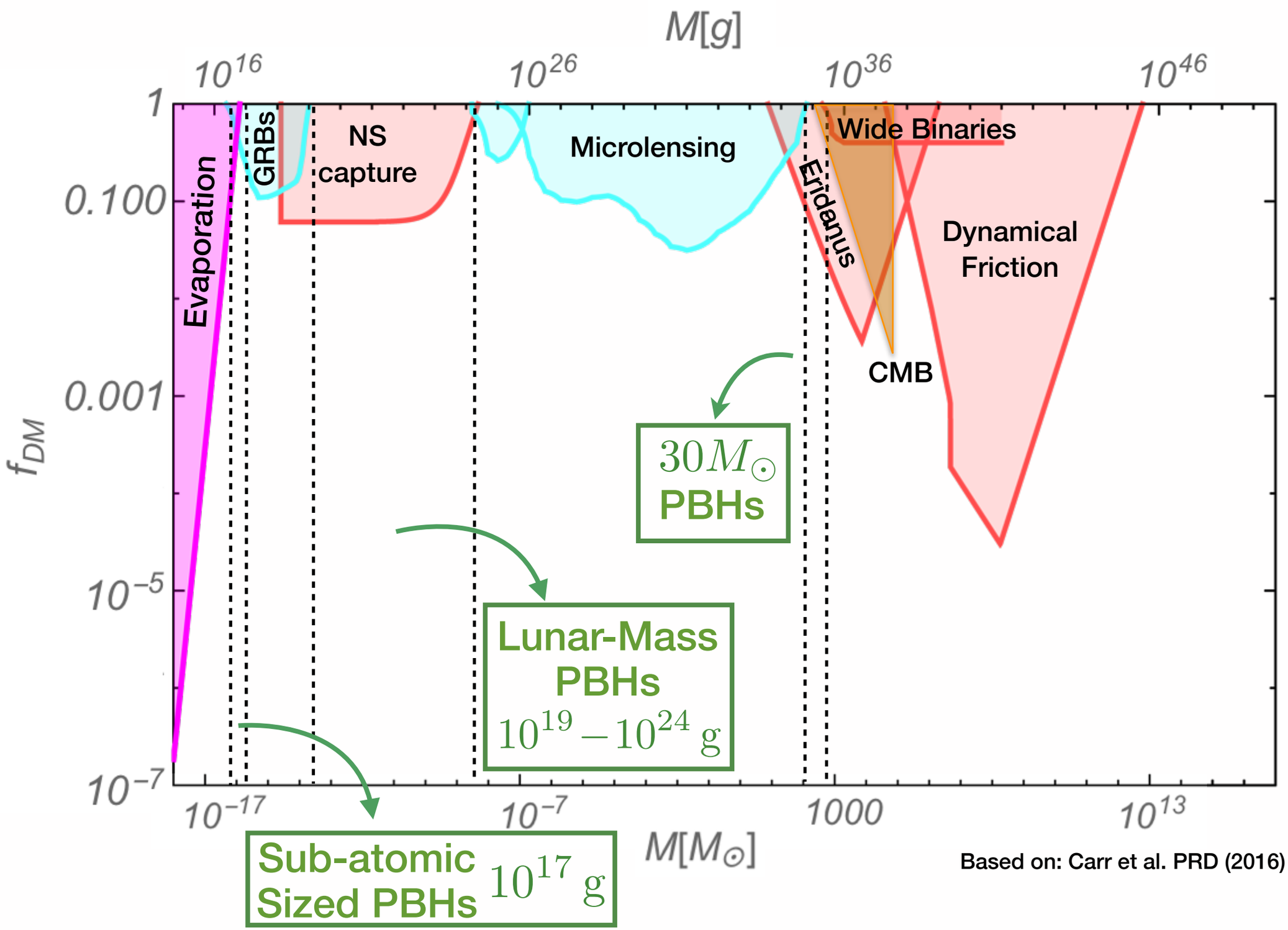

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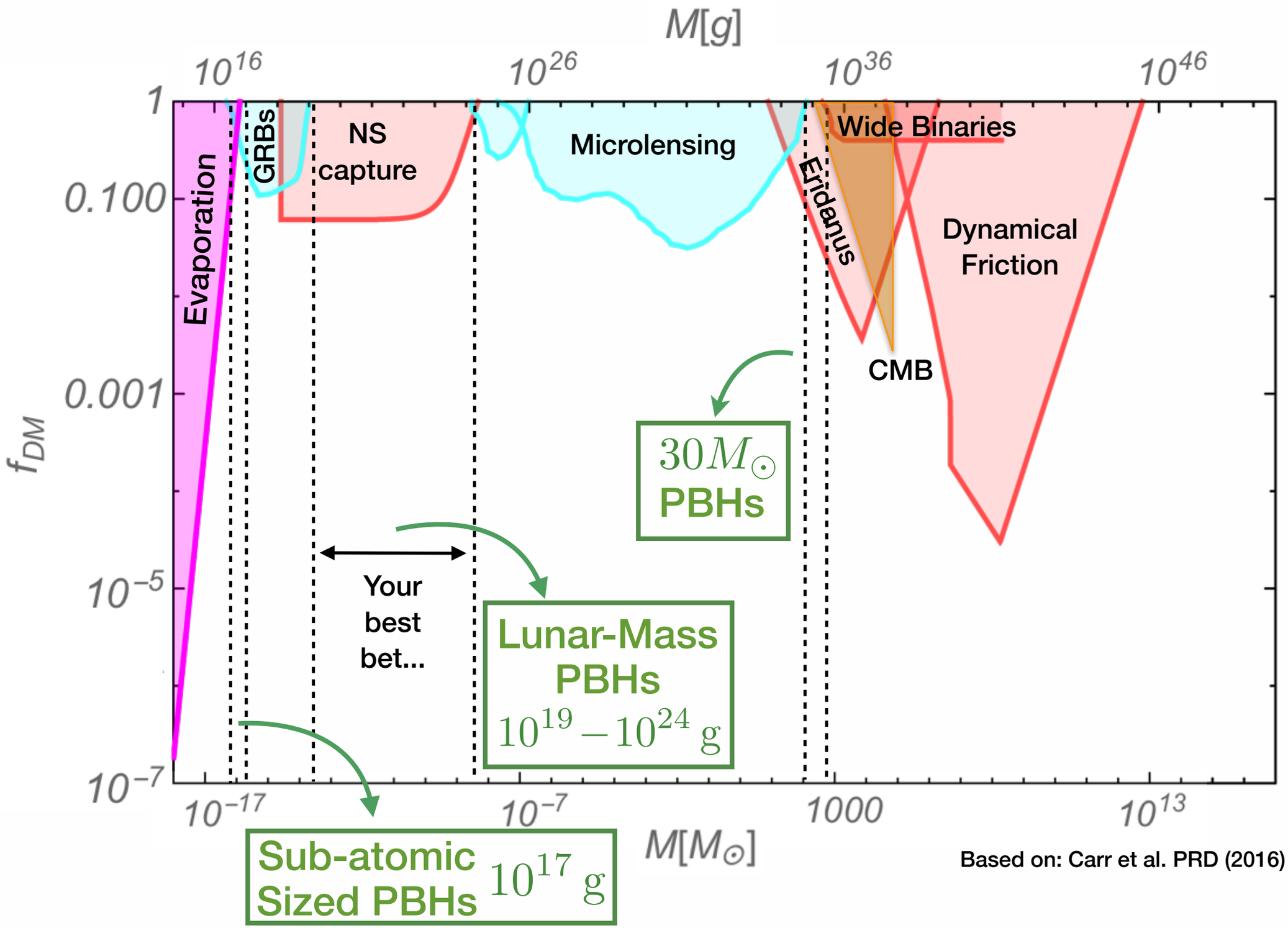

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Ely Kovetz
GGI, Oct. 2018

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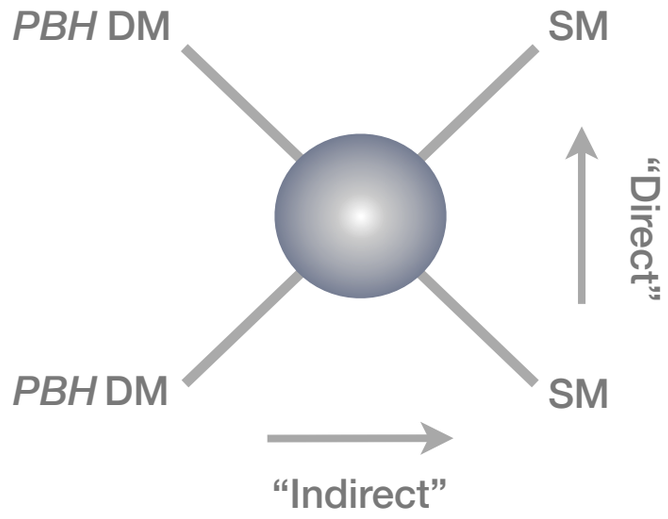

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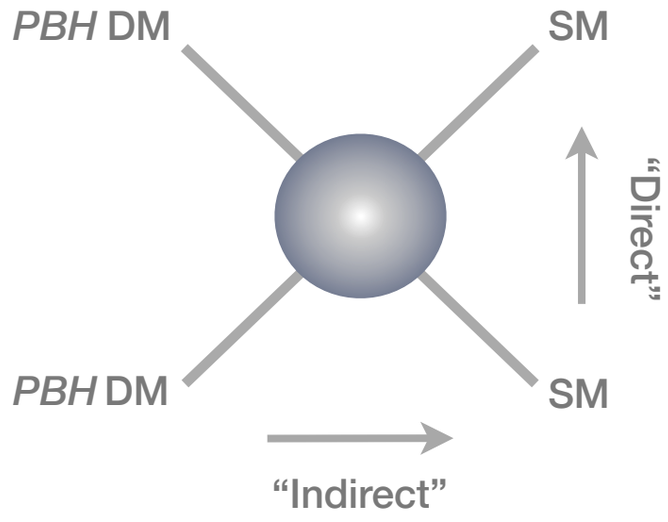

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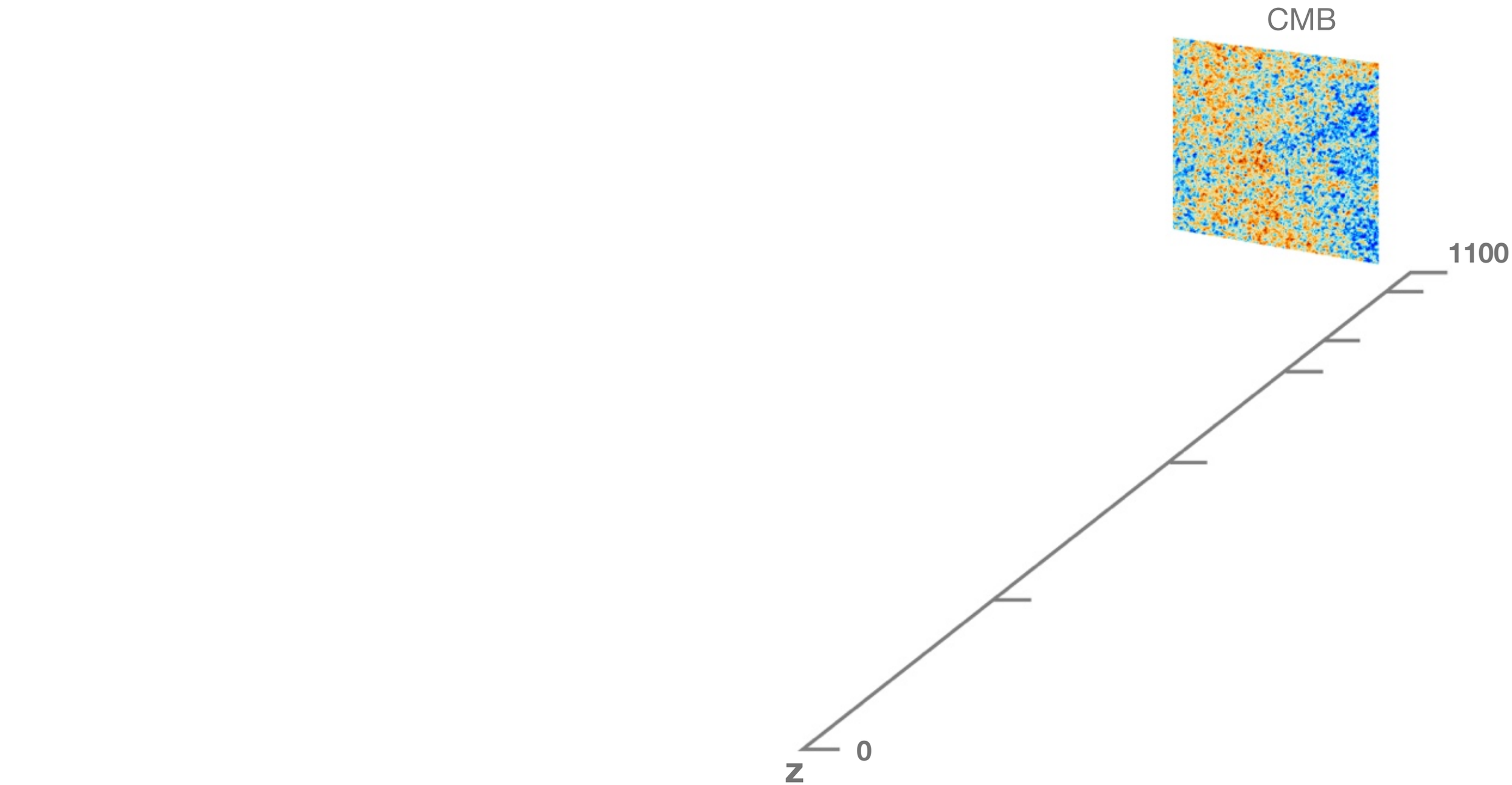

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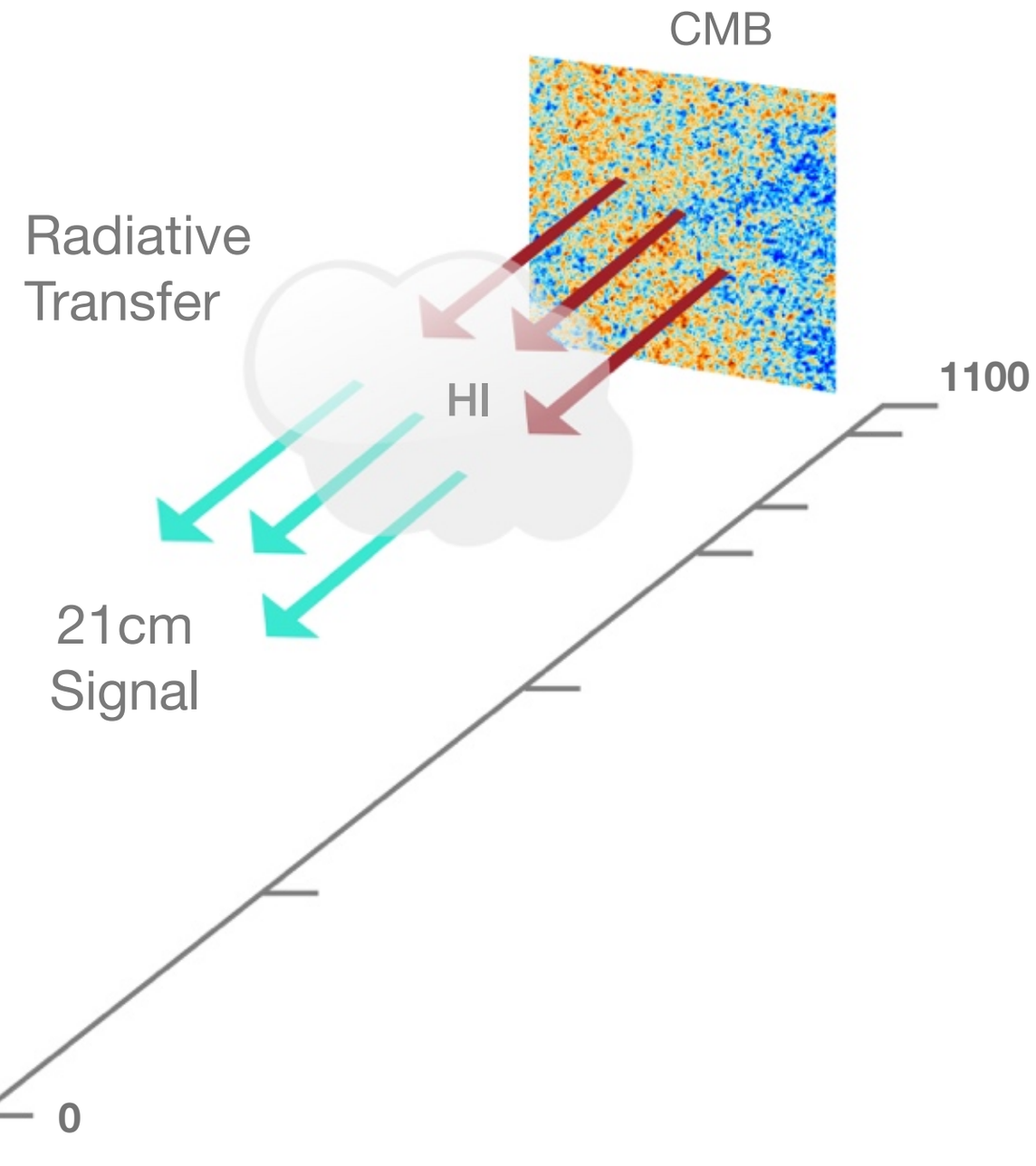

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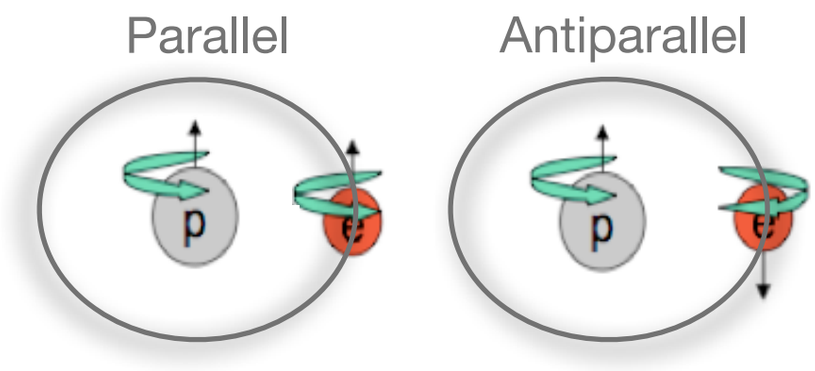

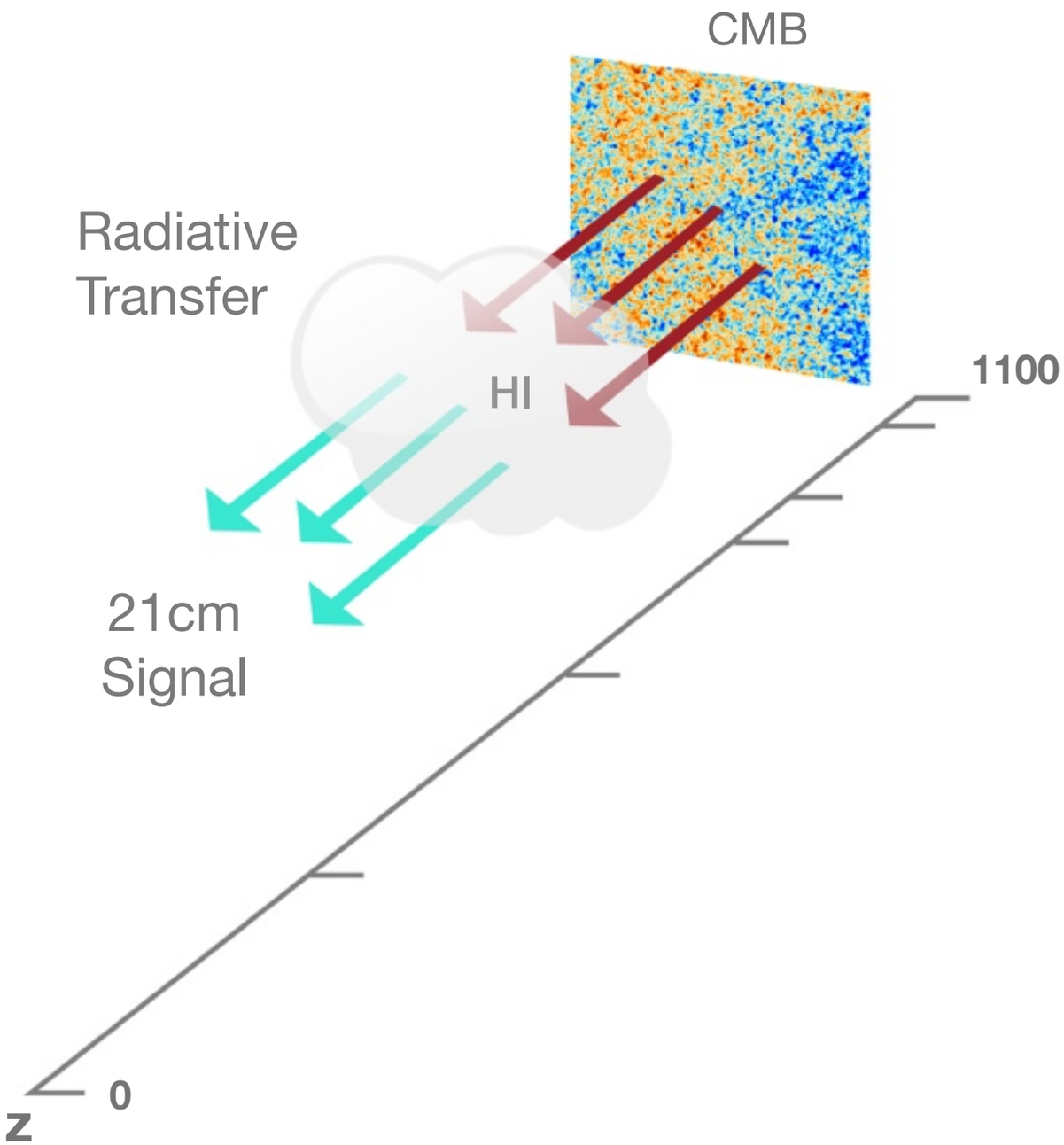

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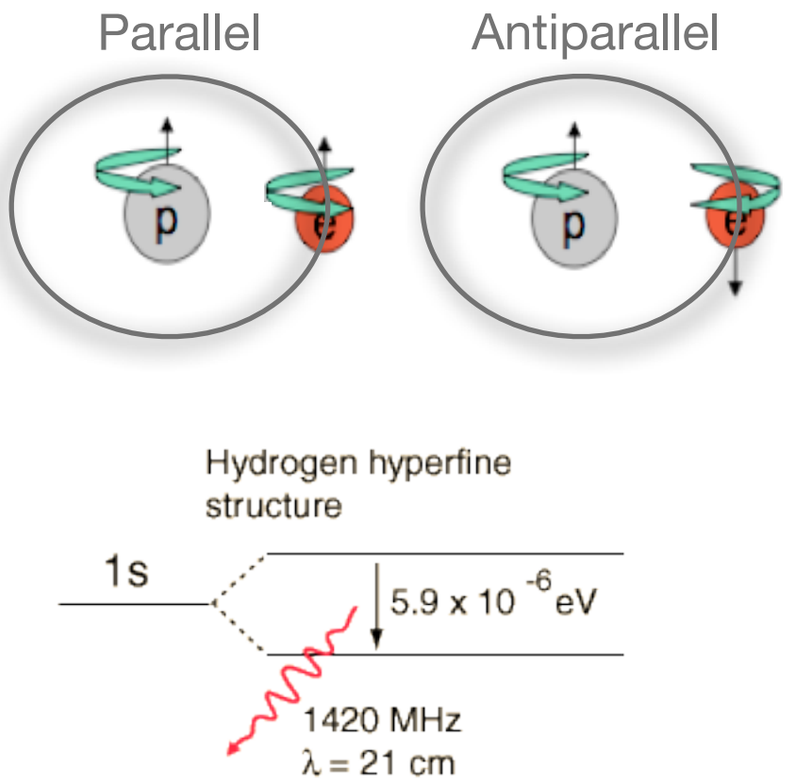

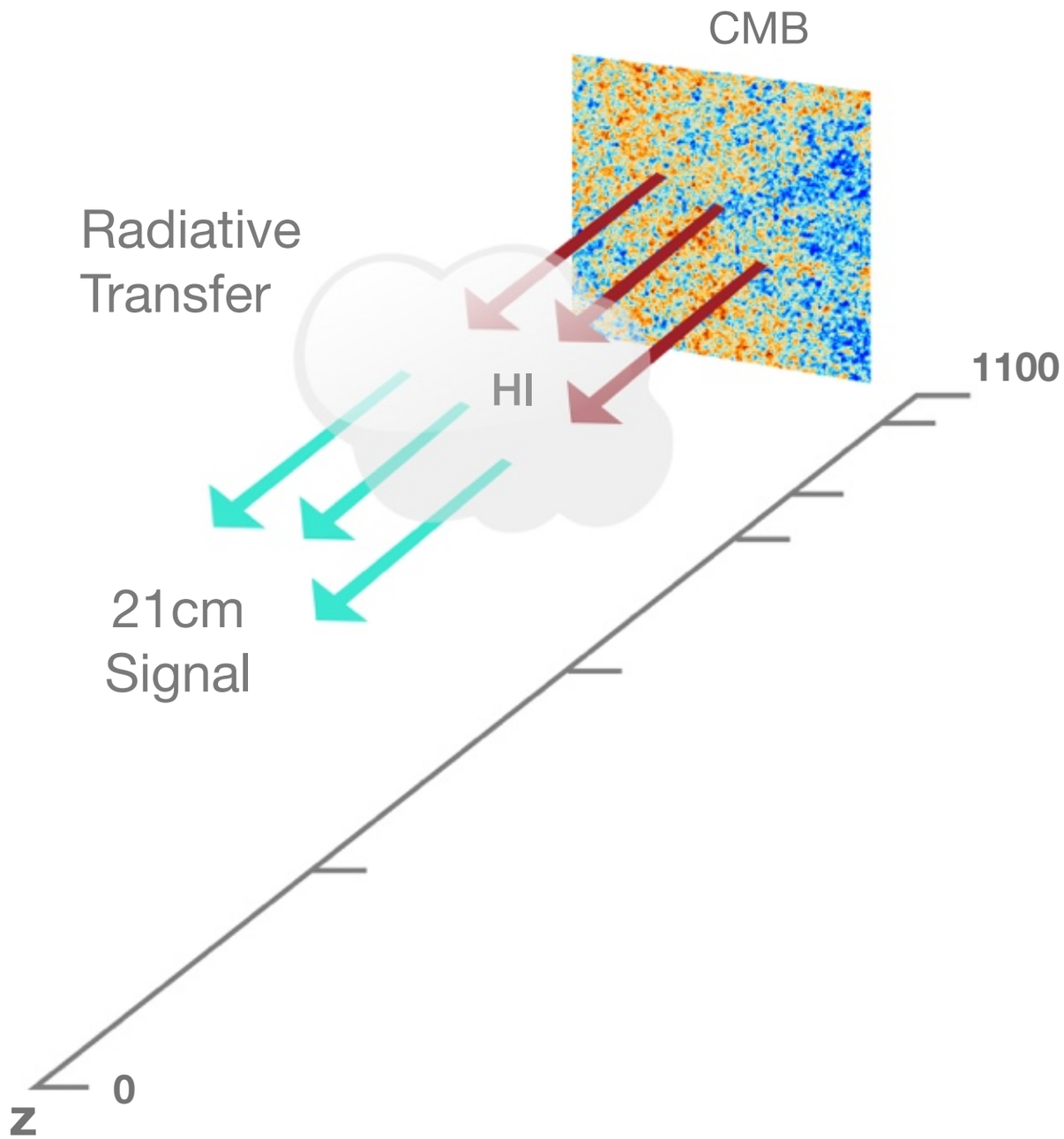

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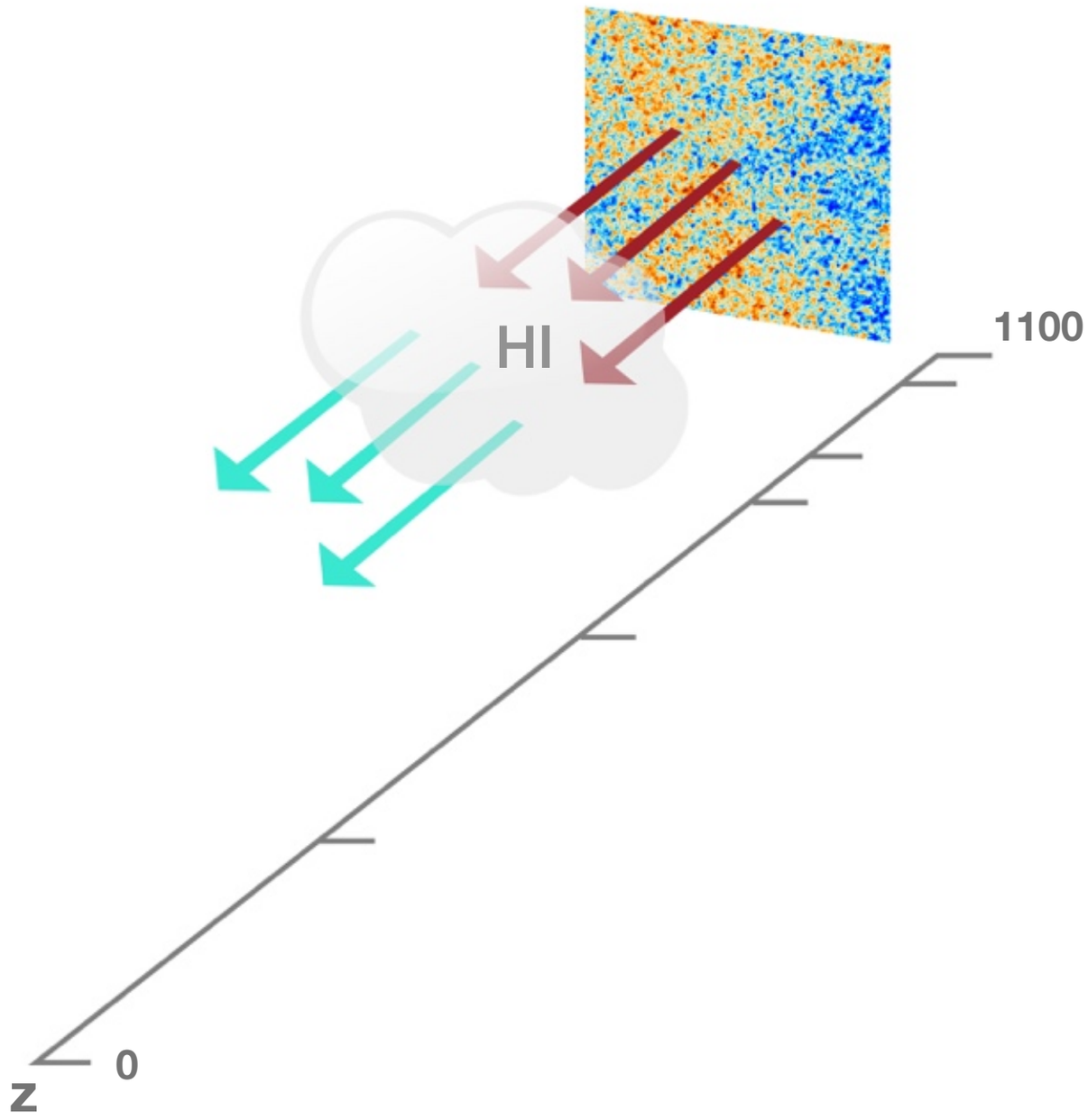

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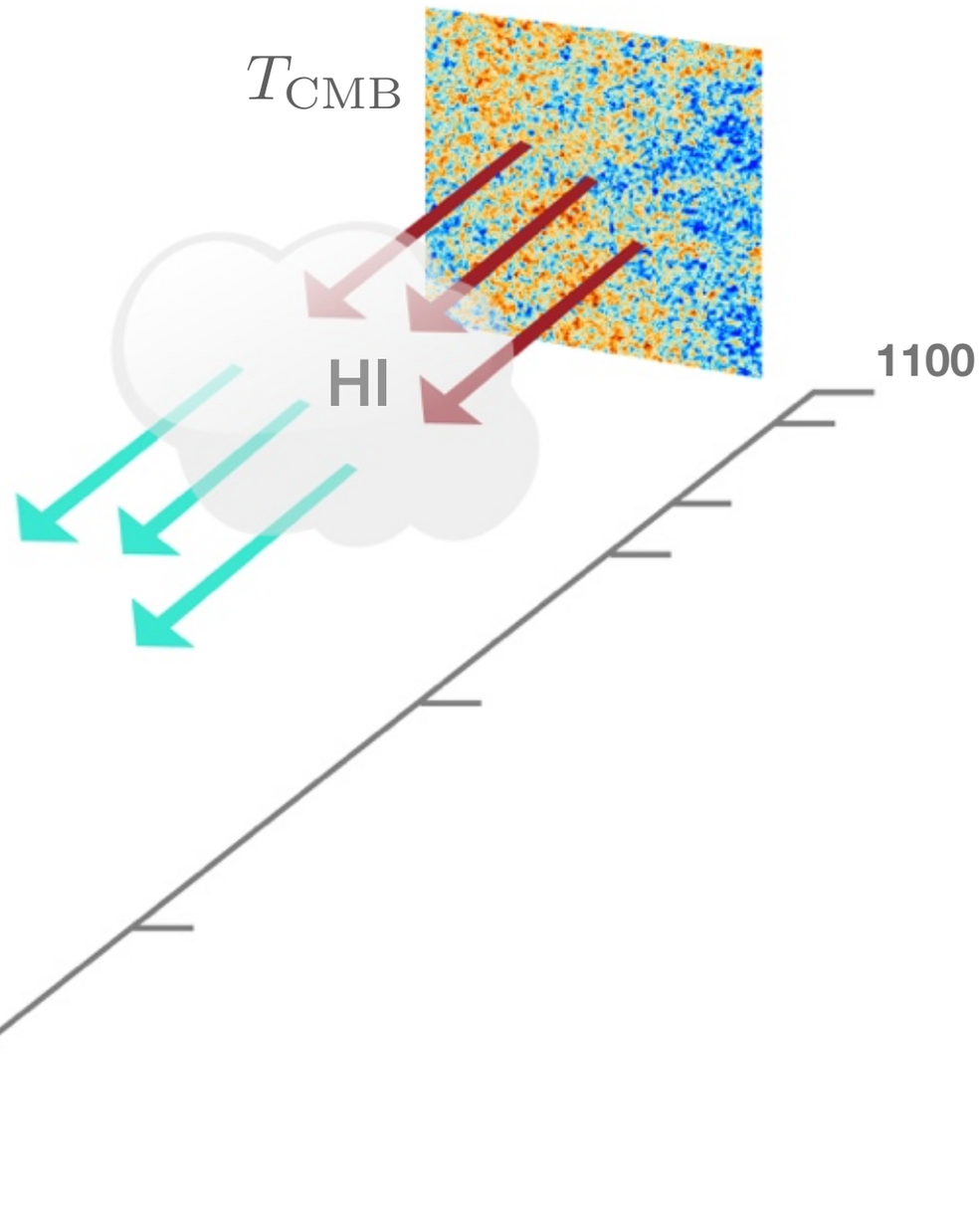

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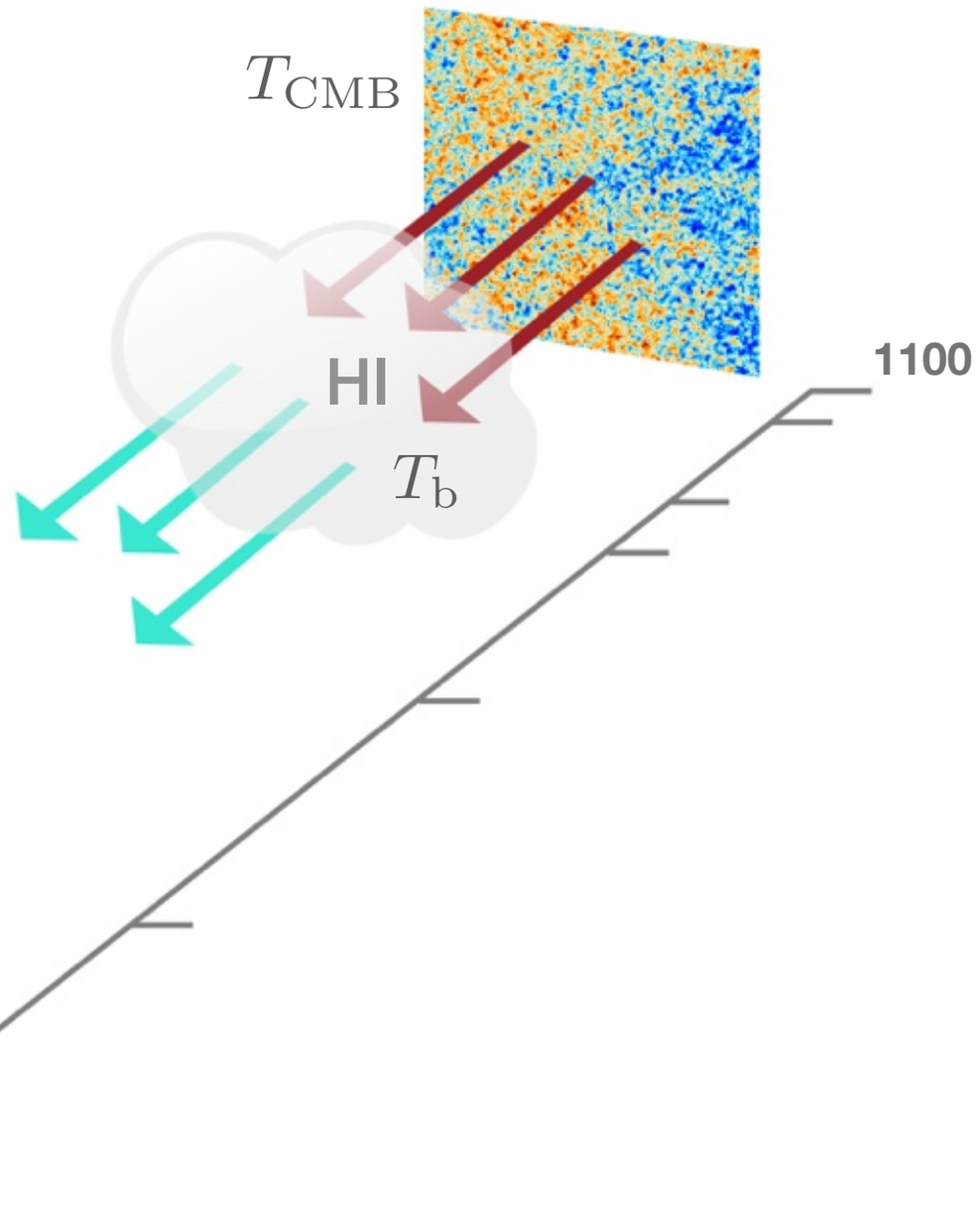

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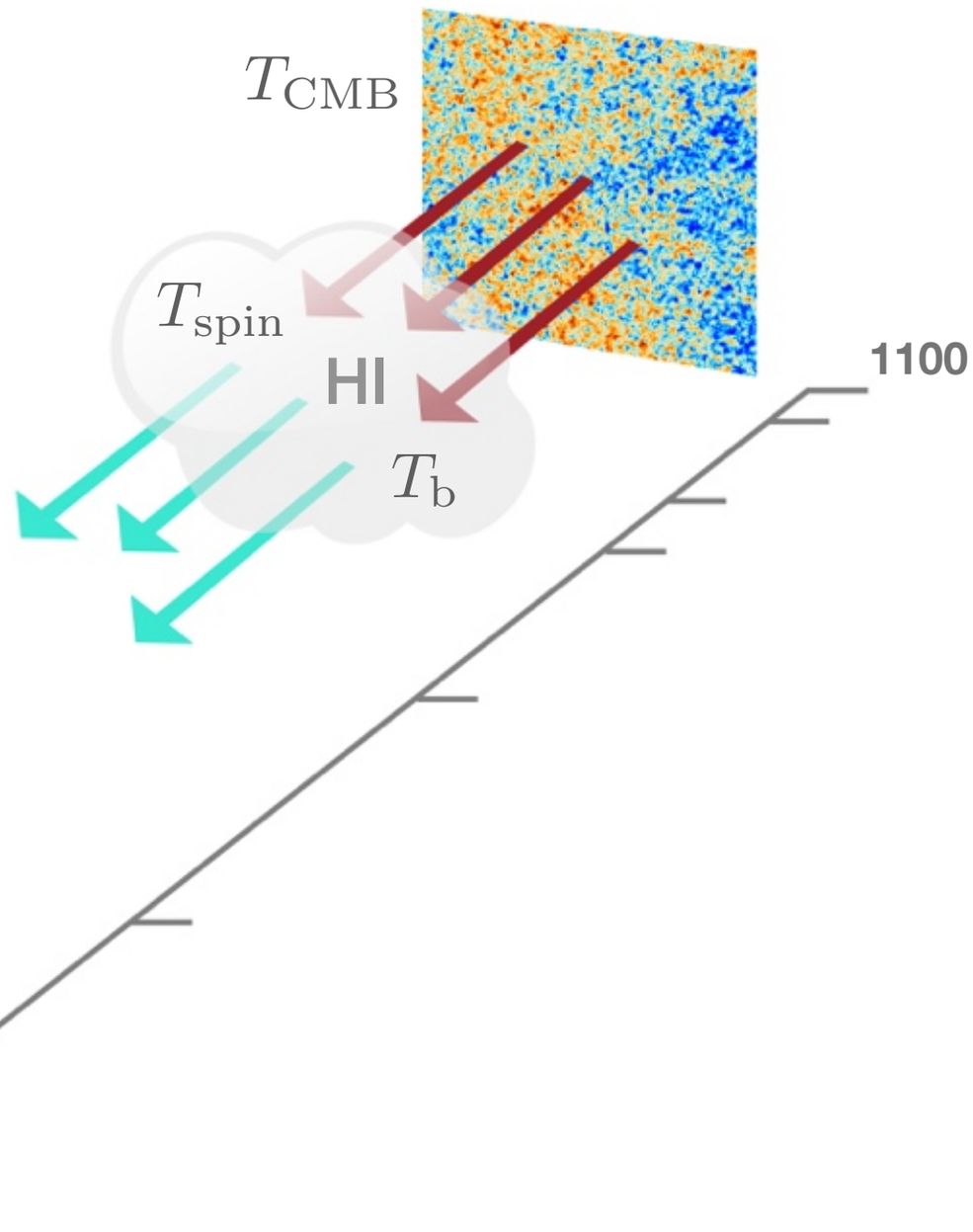

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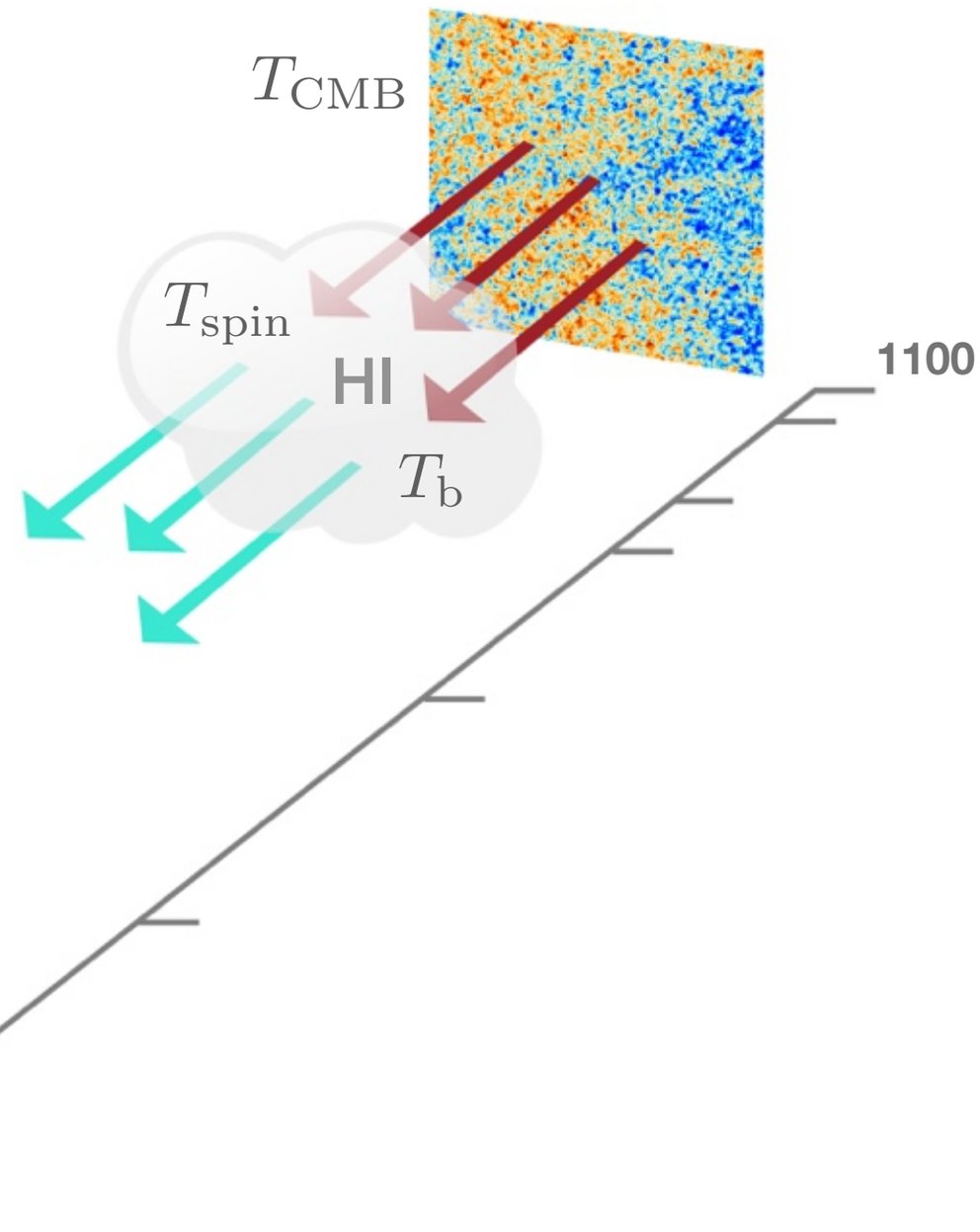

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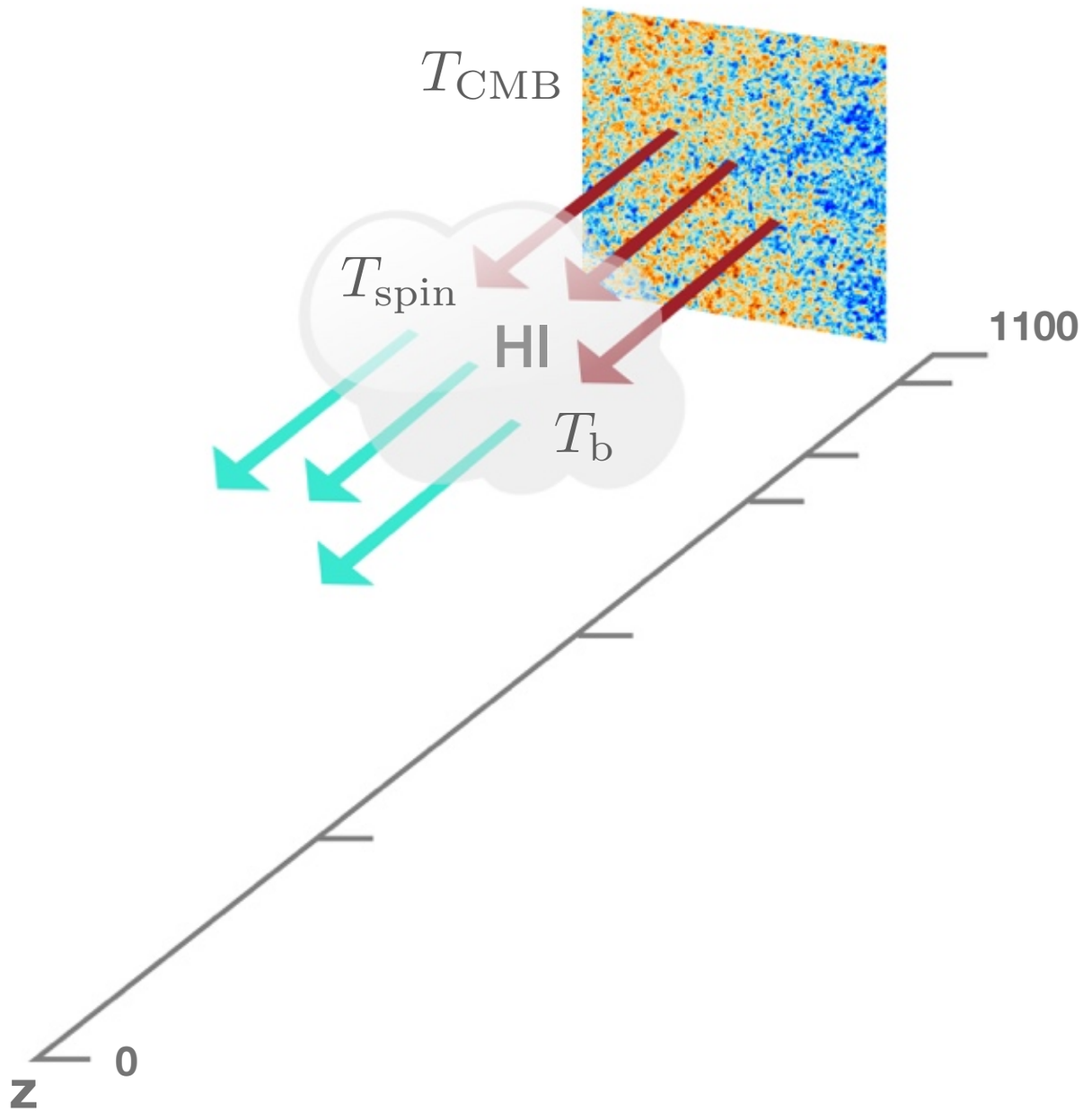

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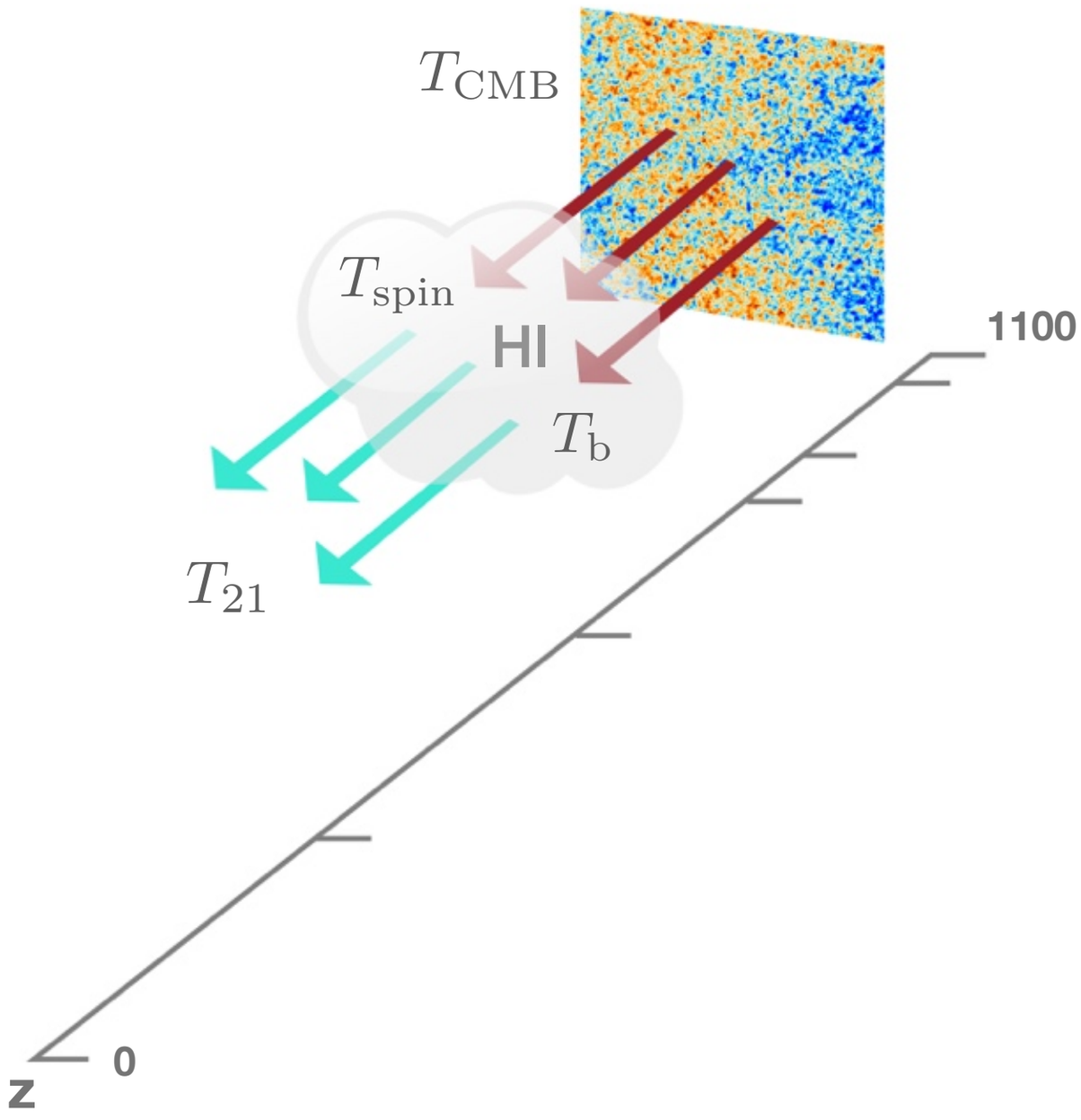

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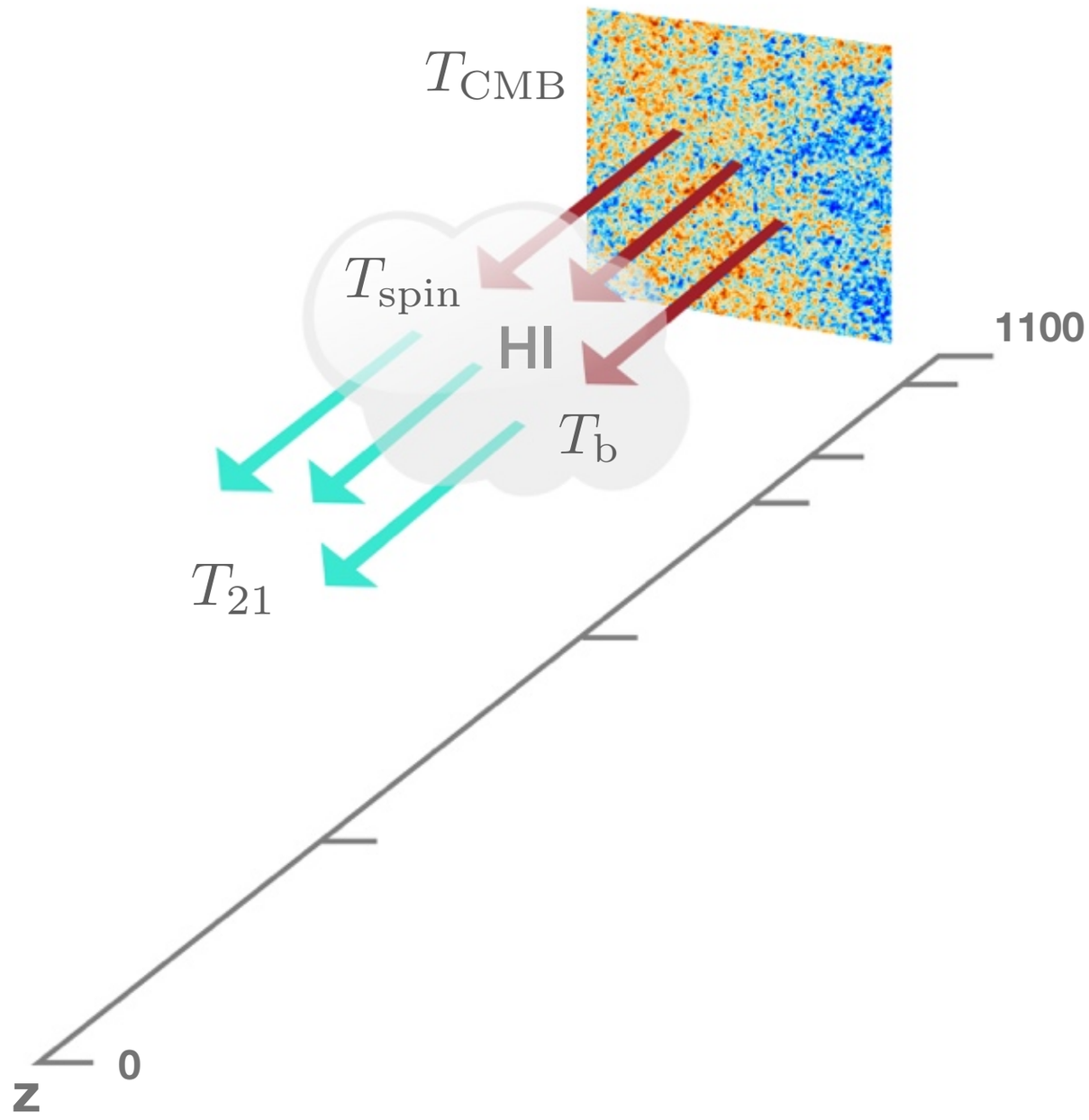

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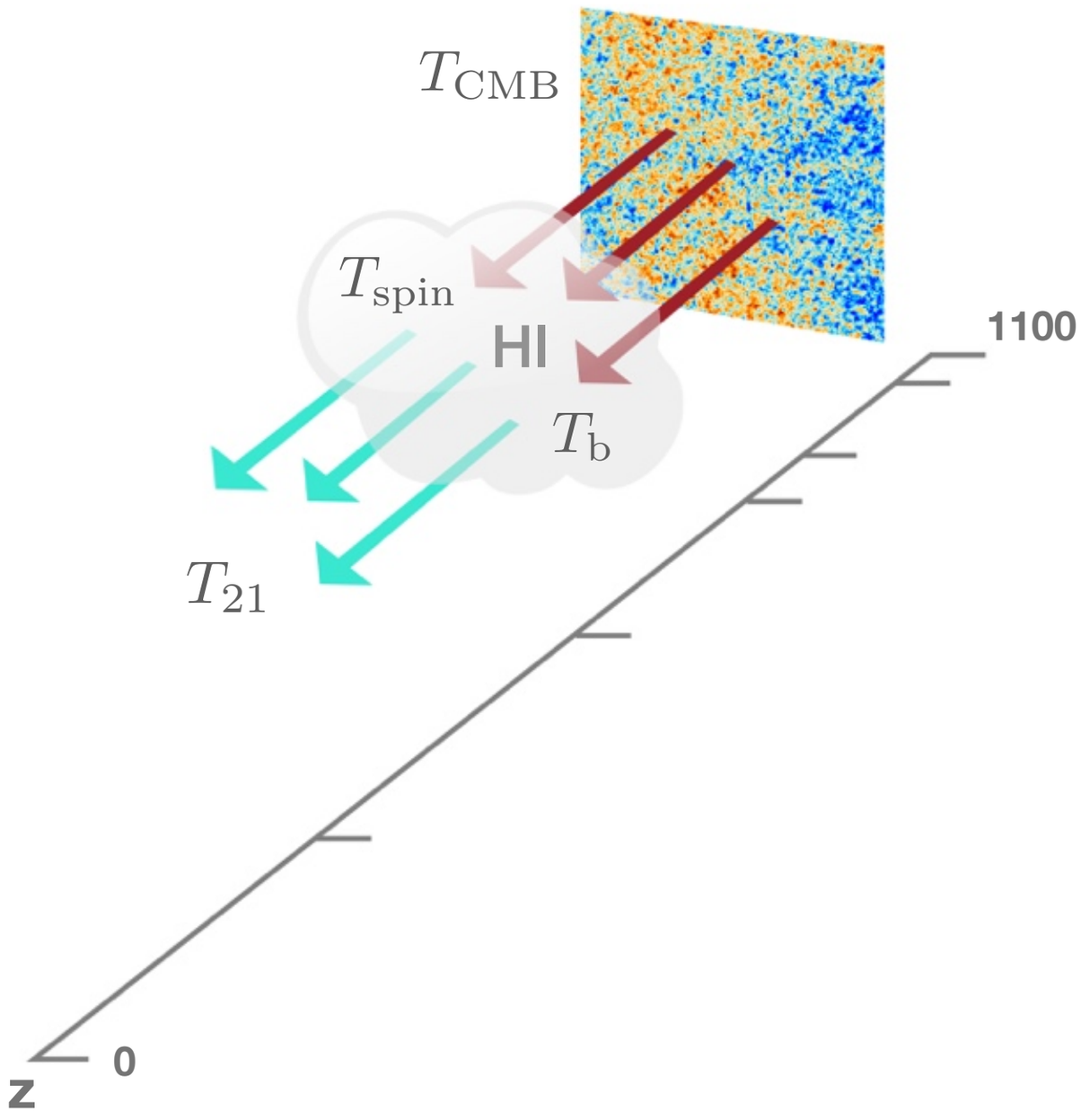

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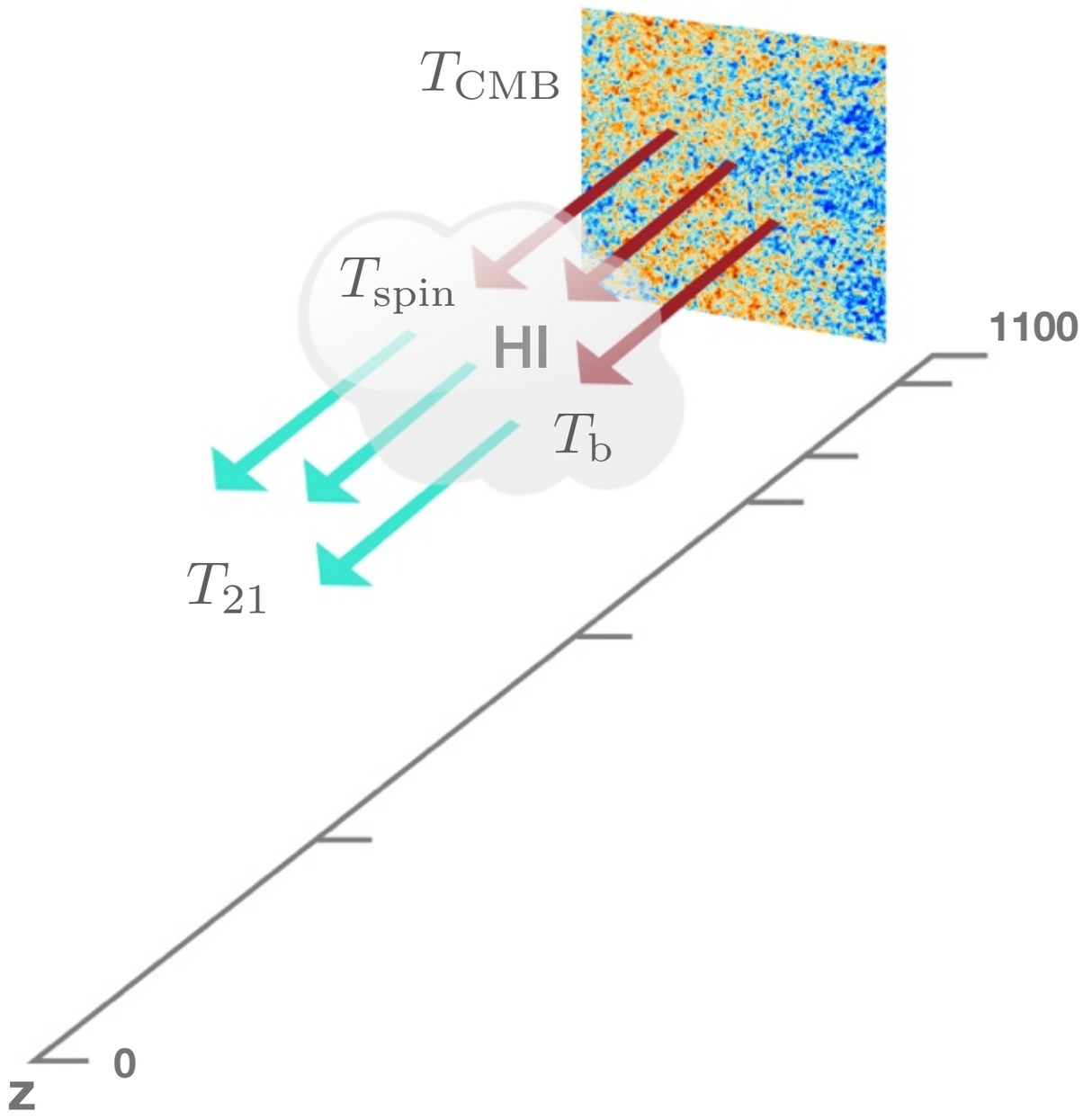

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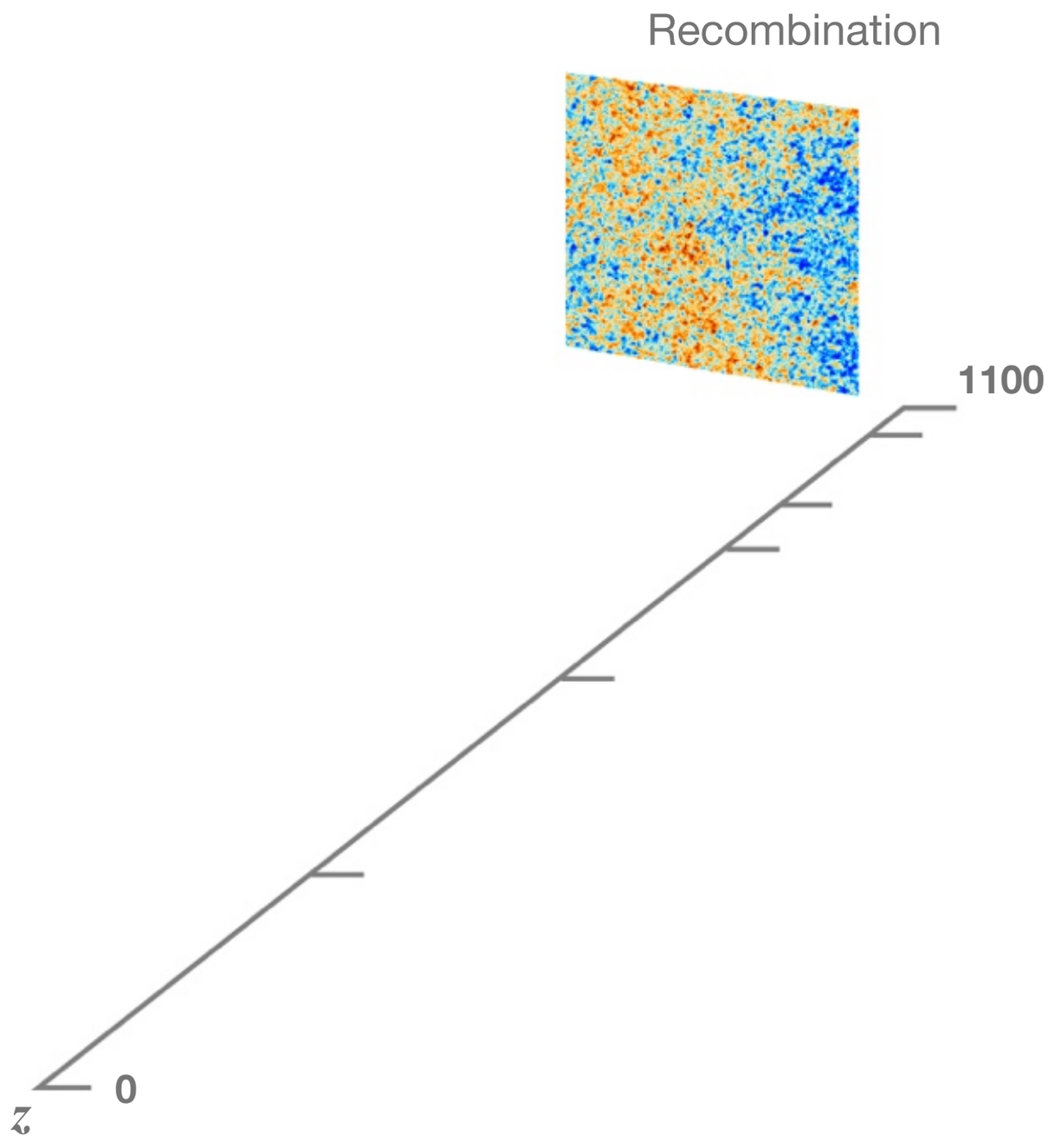
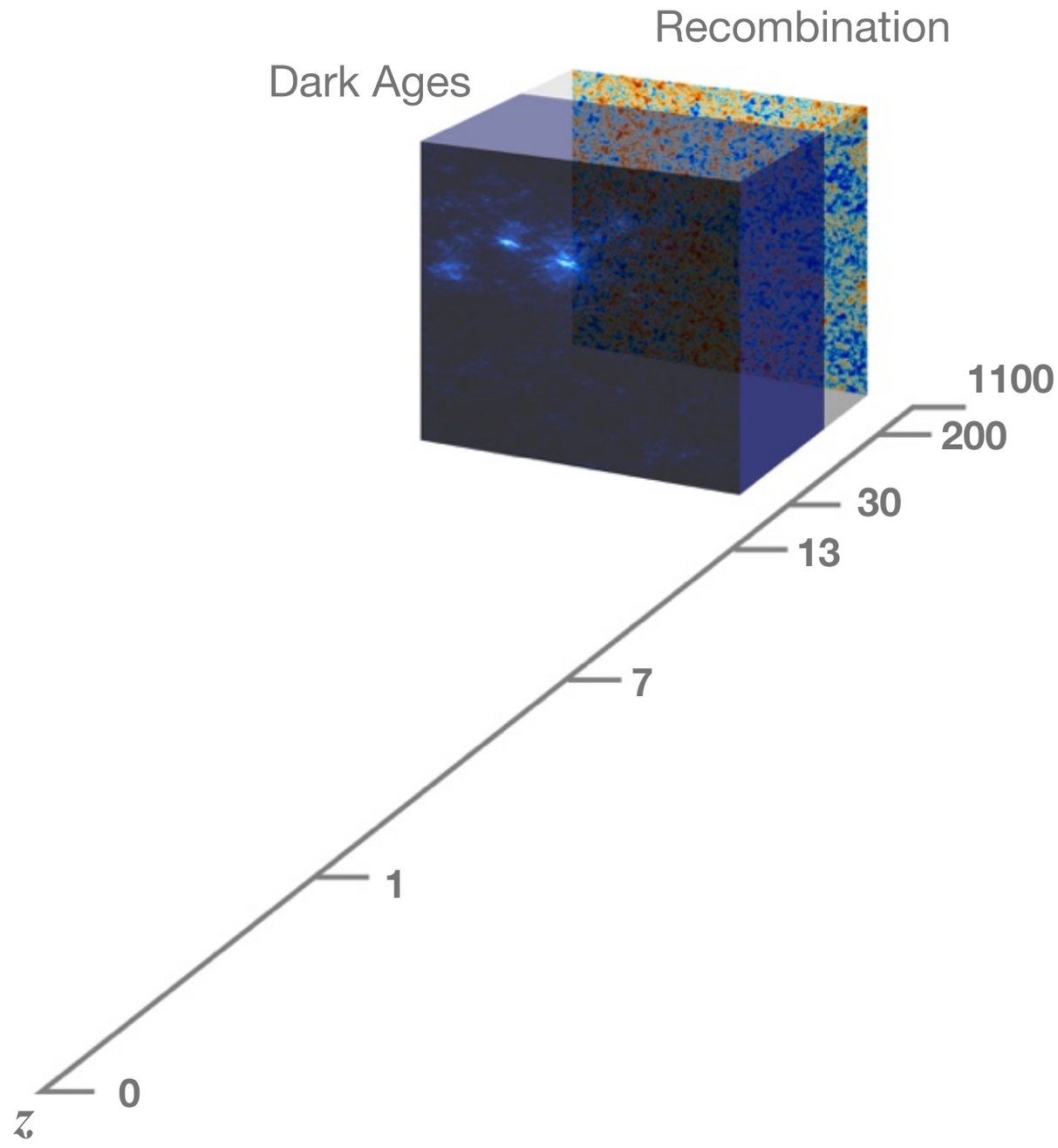


It's Always Darkest before the (Cosmic) Dawn



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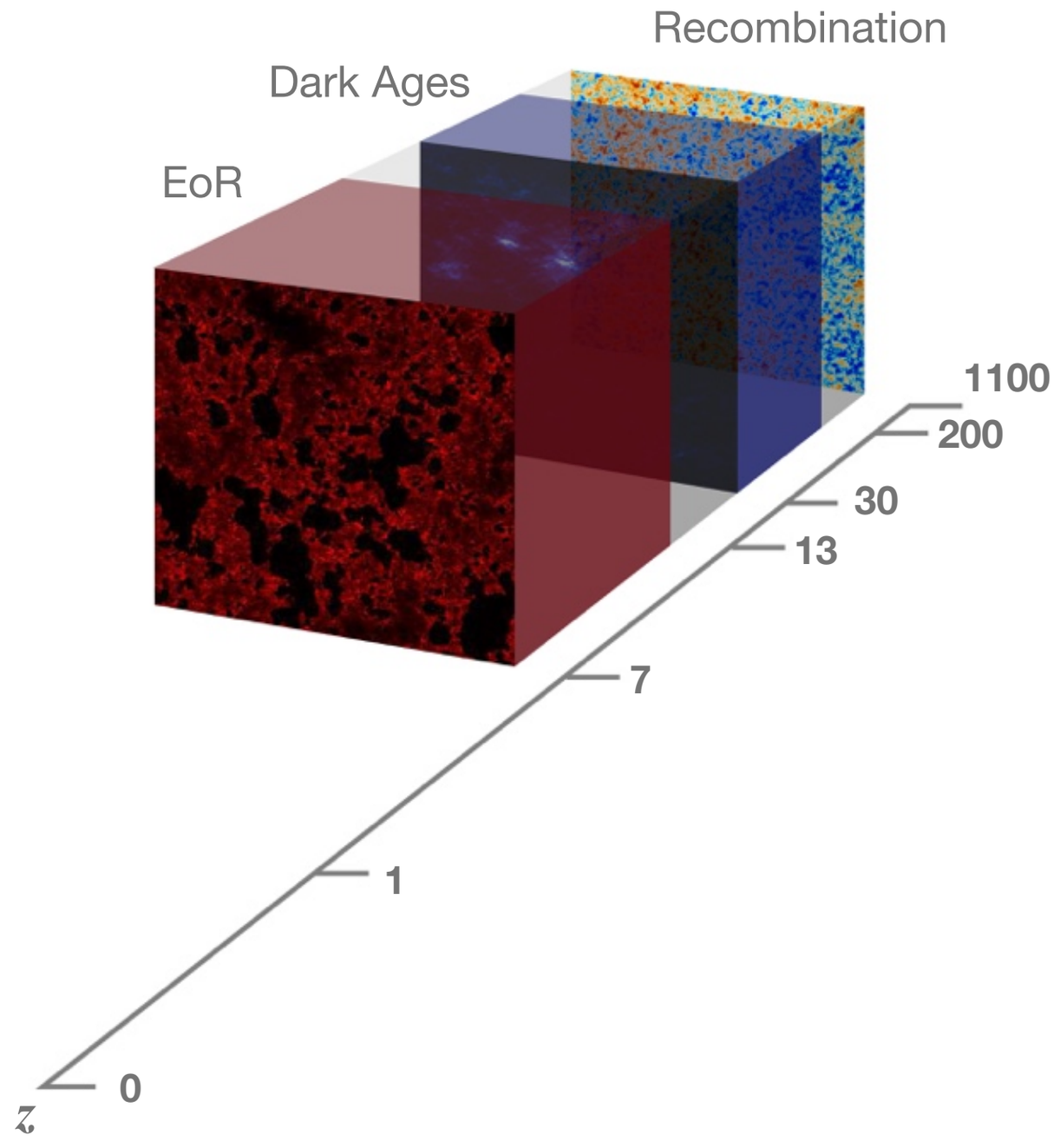

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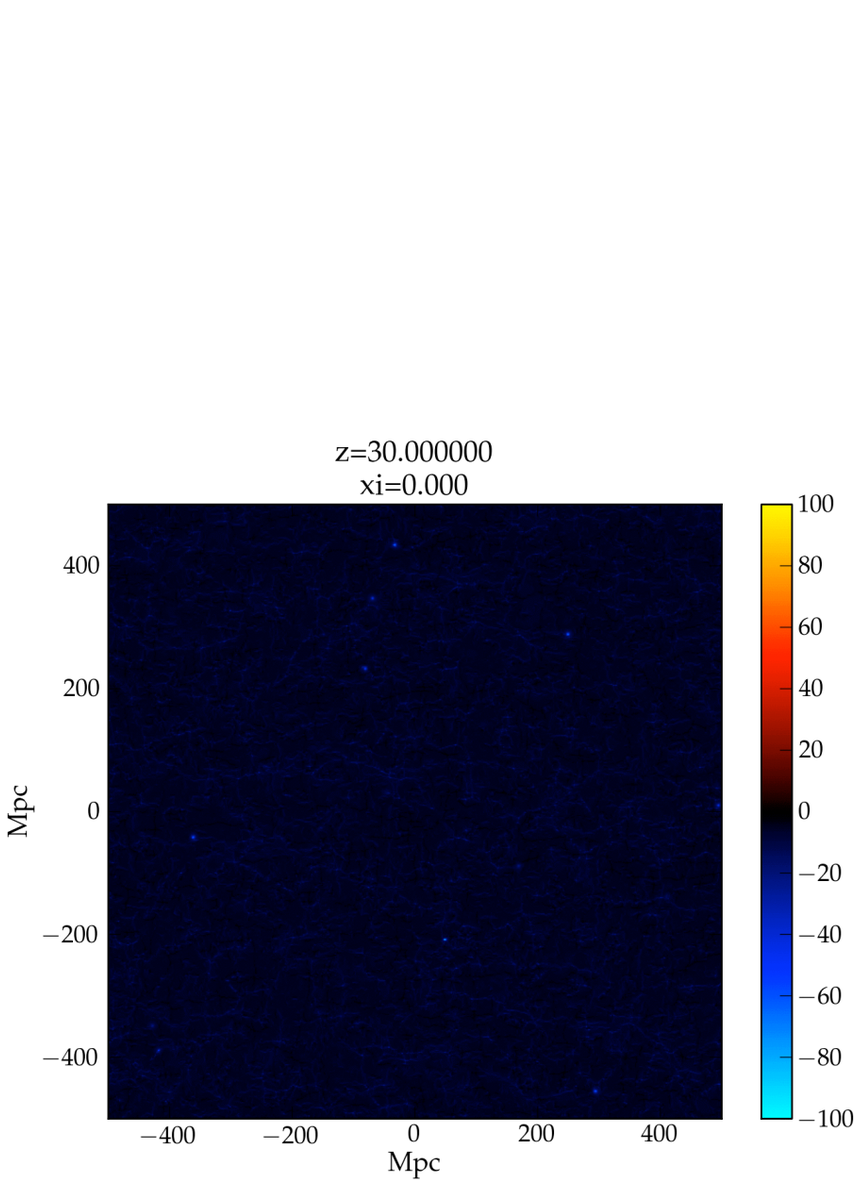
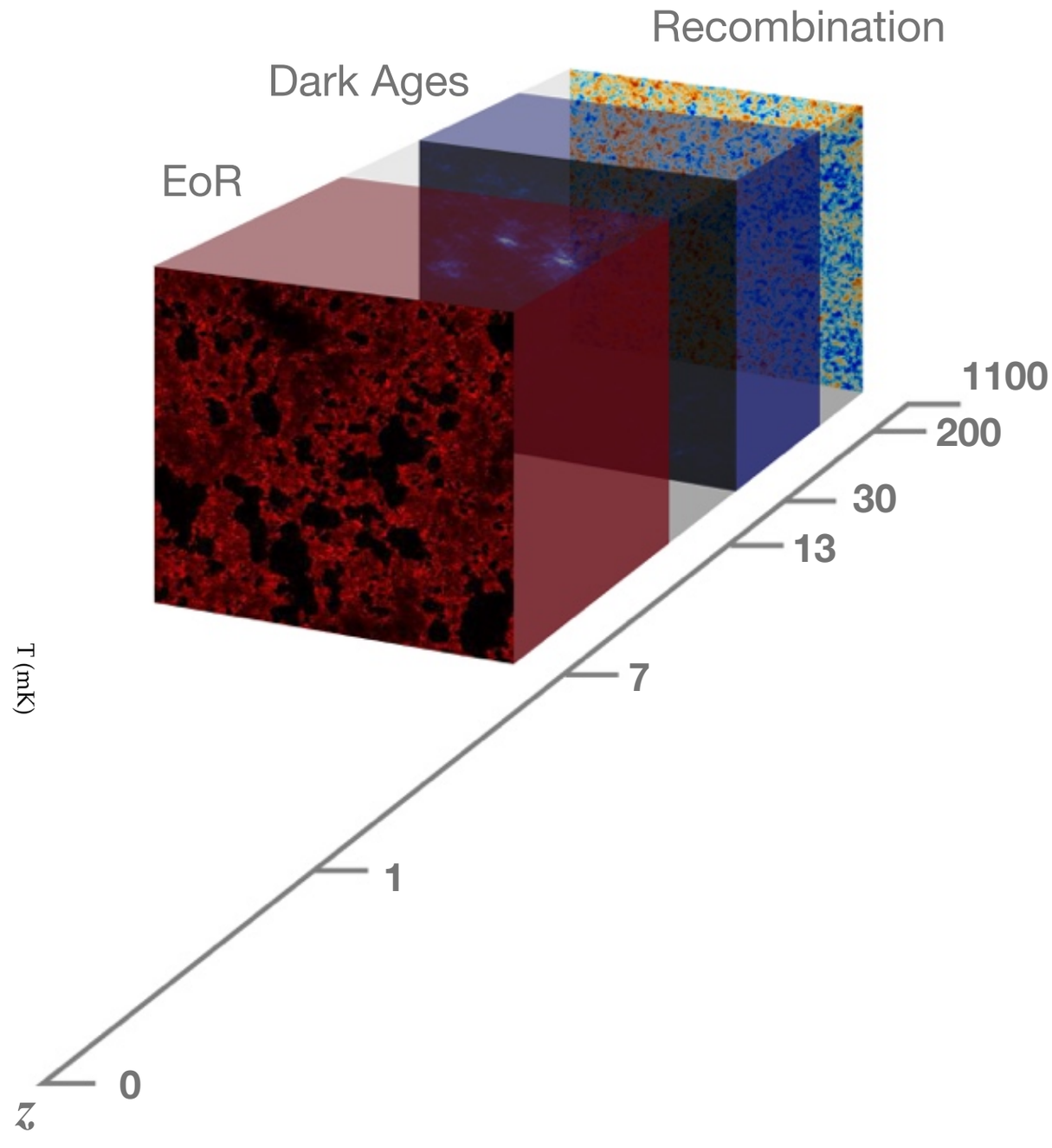


Credit: Mário Santos



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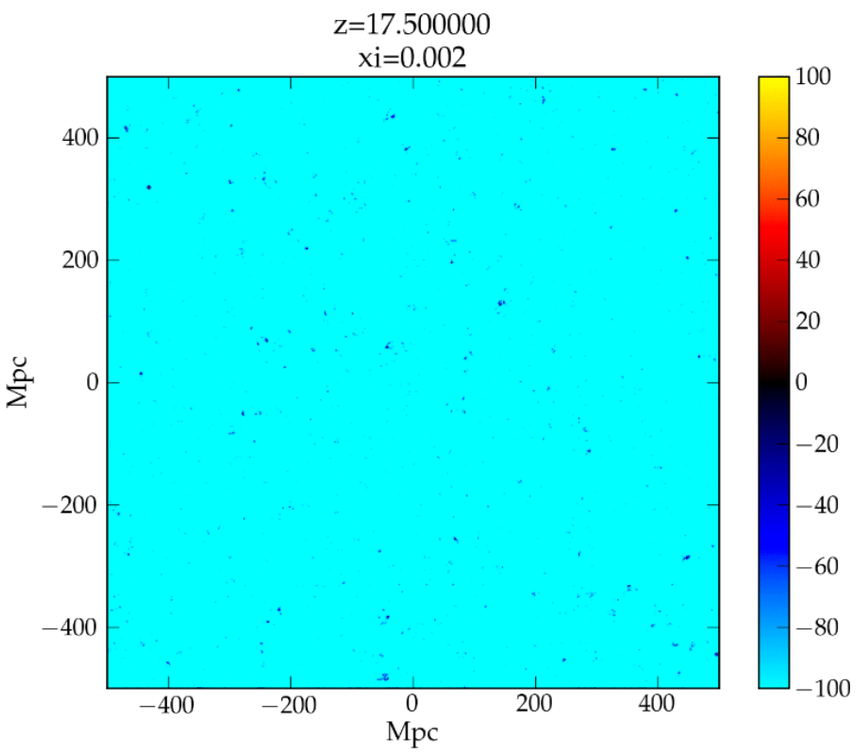

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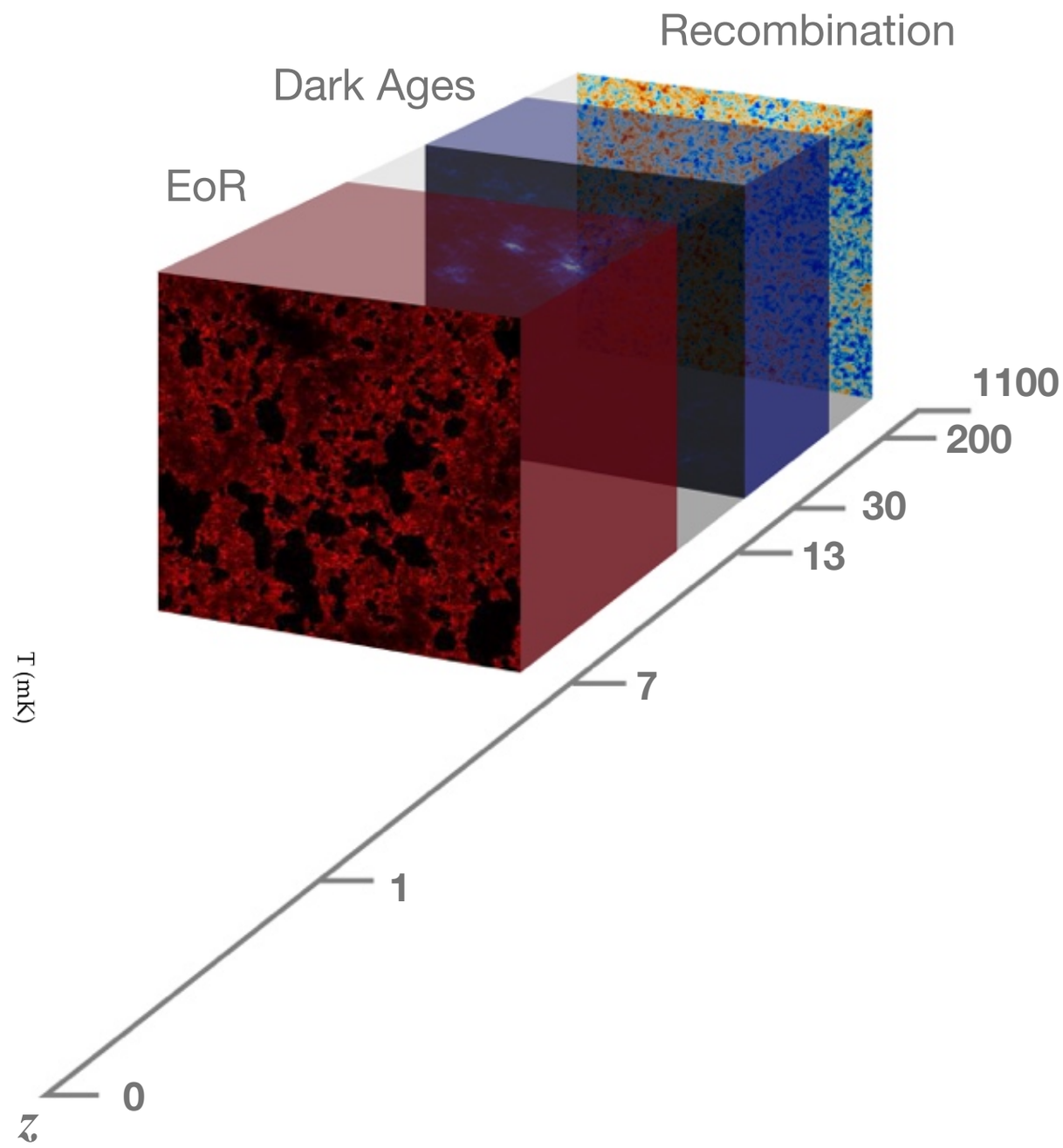

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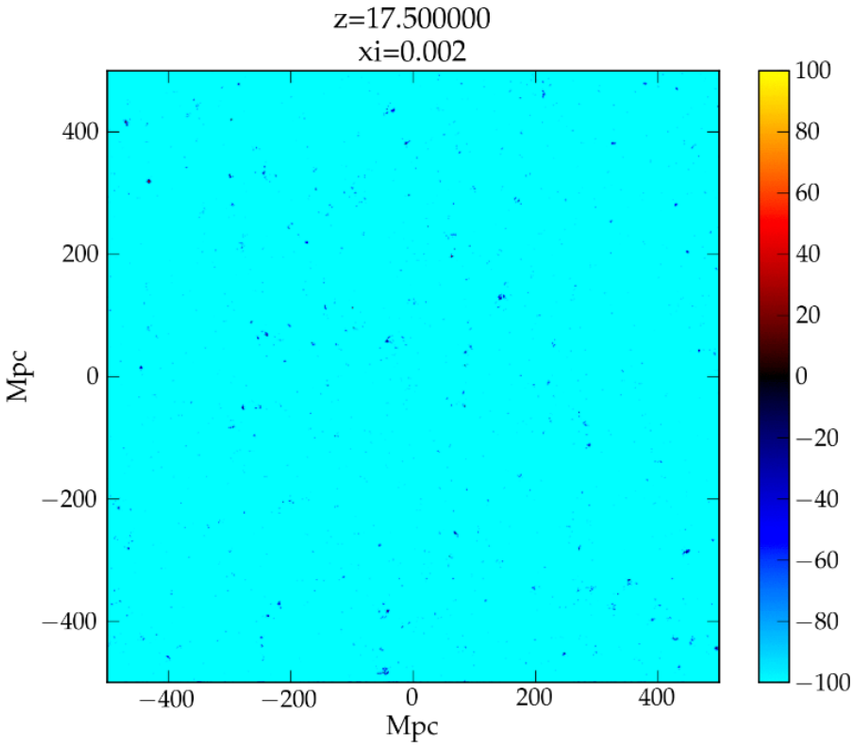

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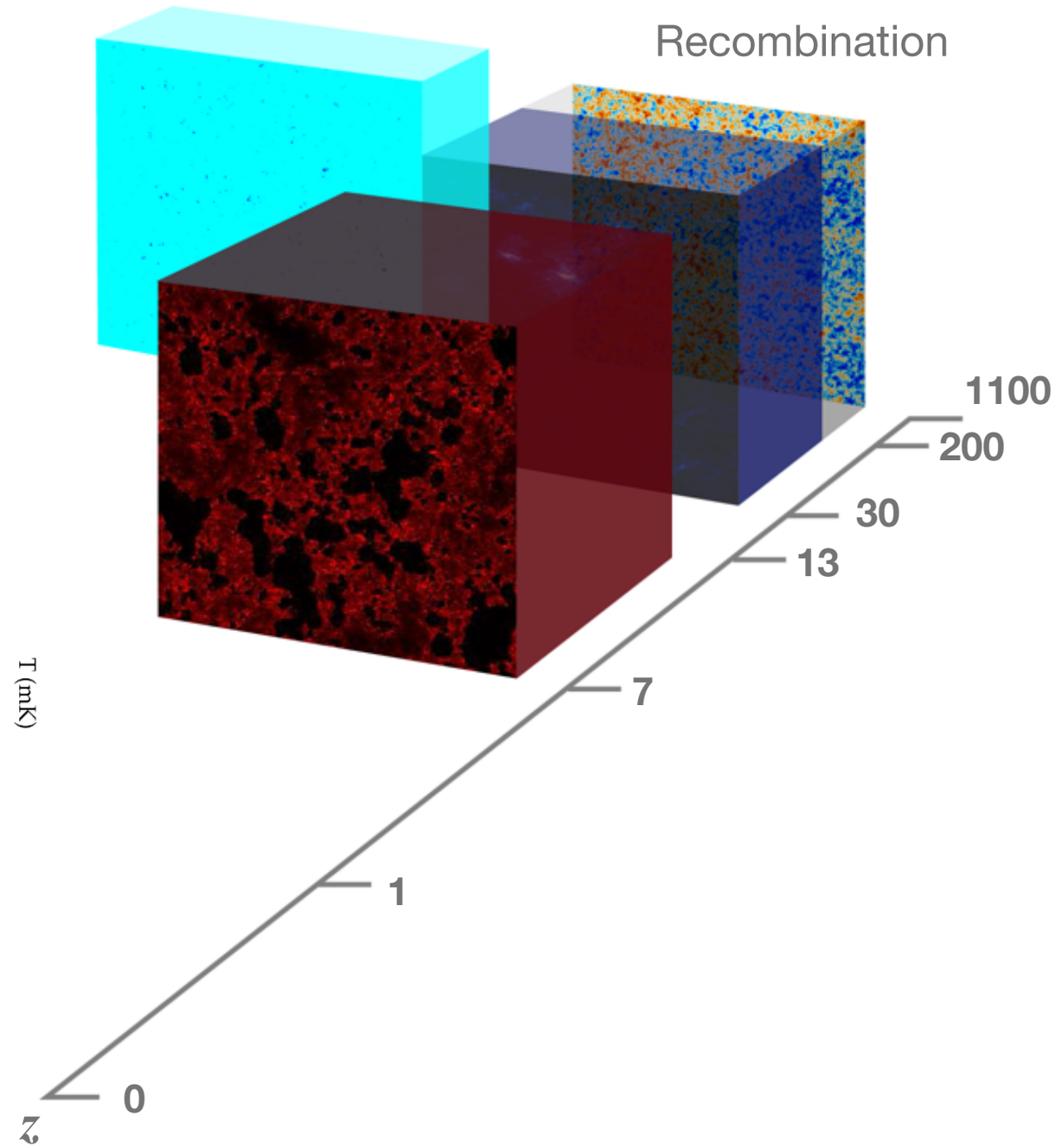

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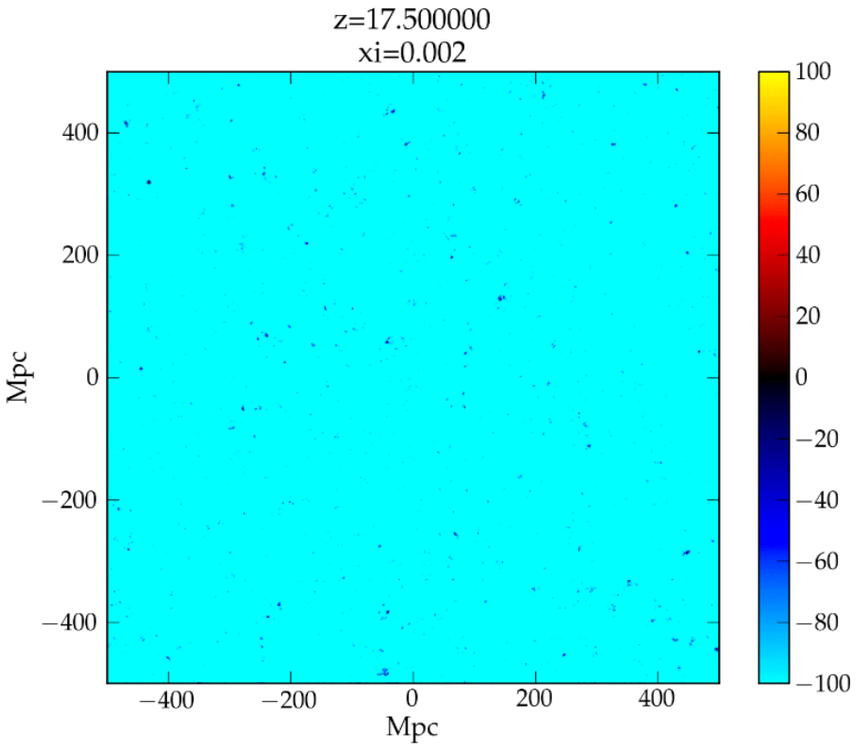

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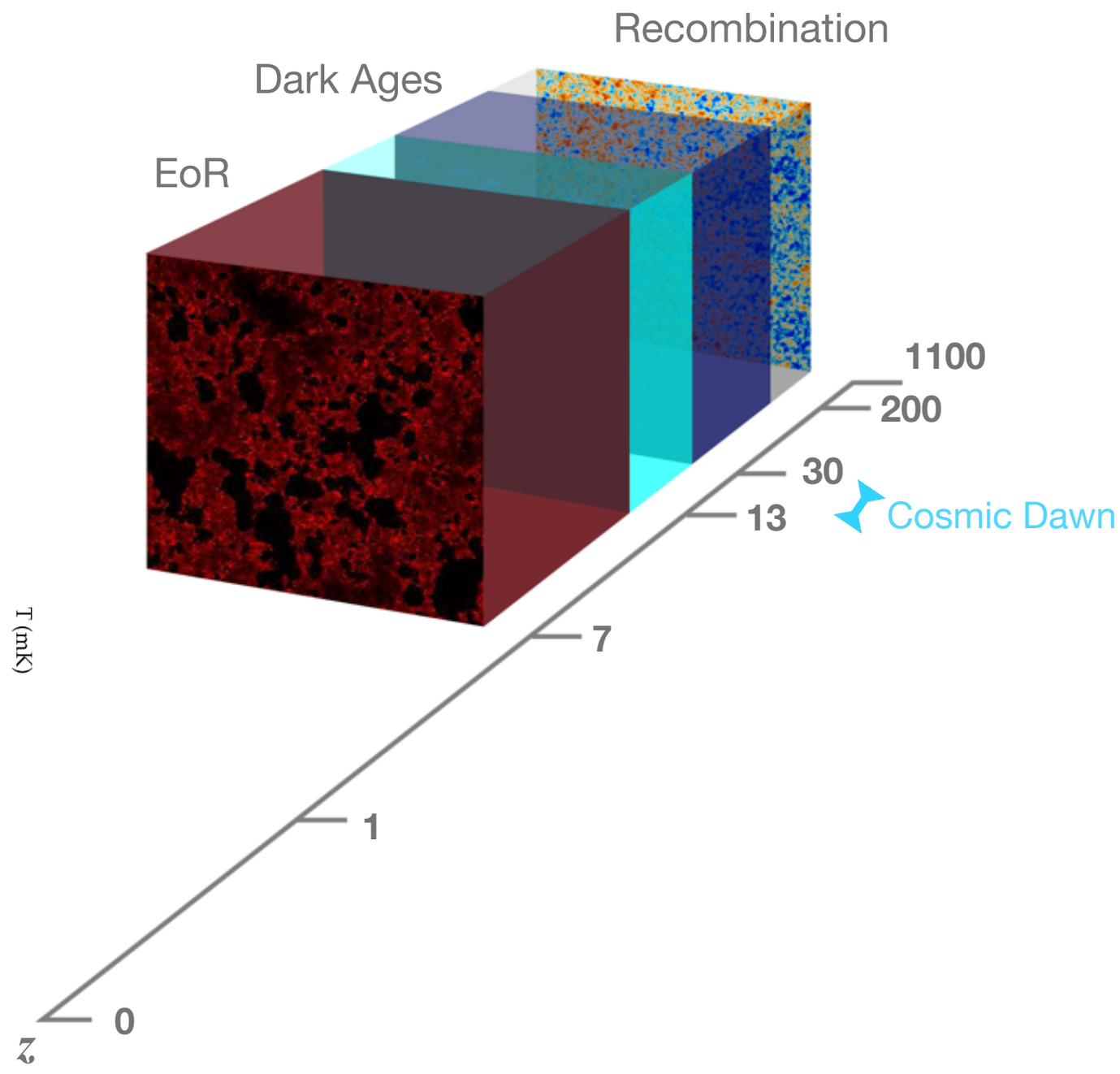
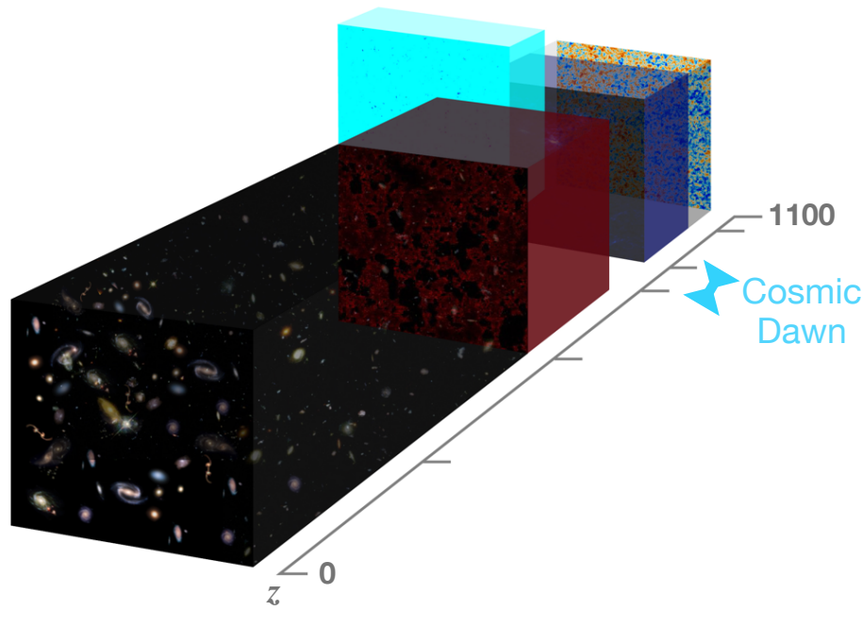


EDGES: First Claimed Detection of Cosmic Dawn



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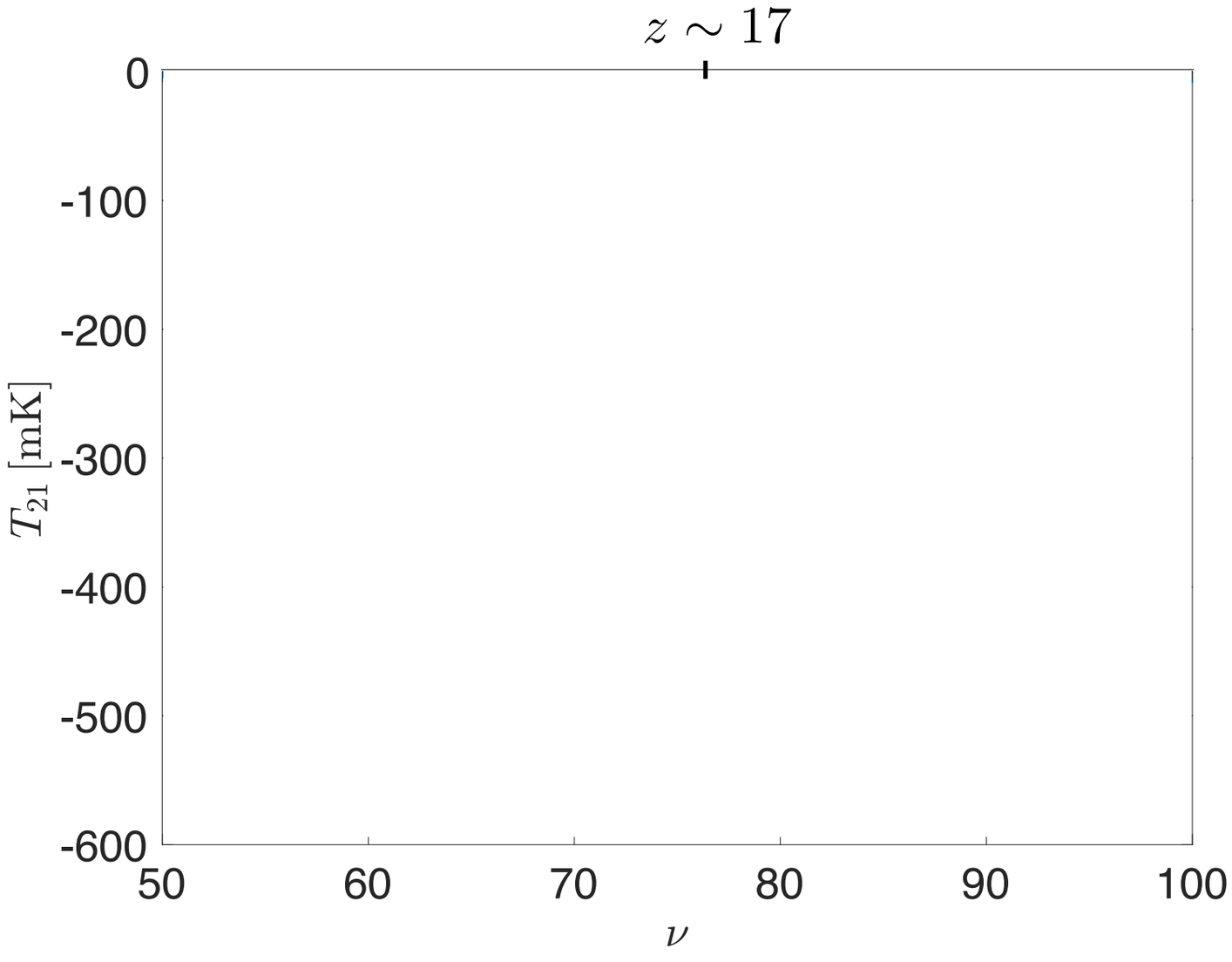

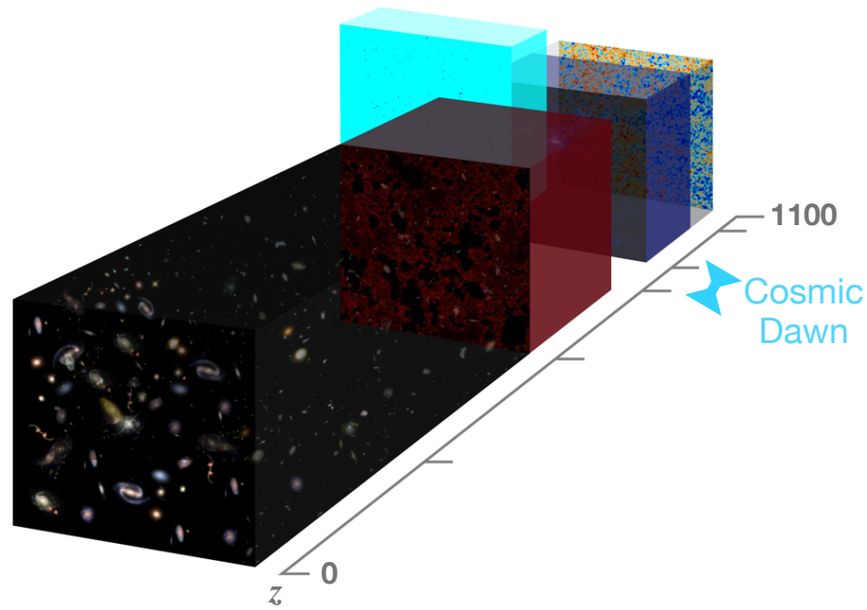

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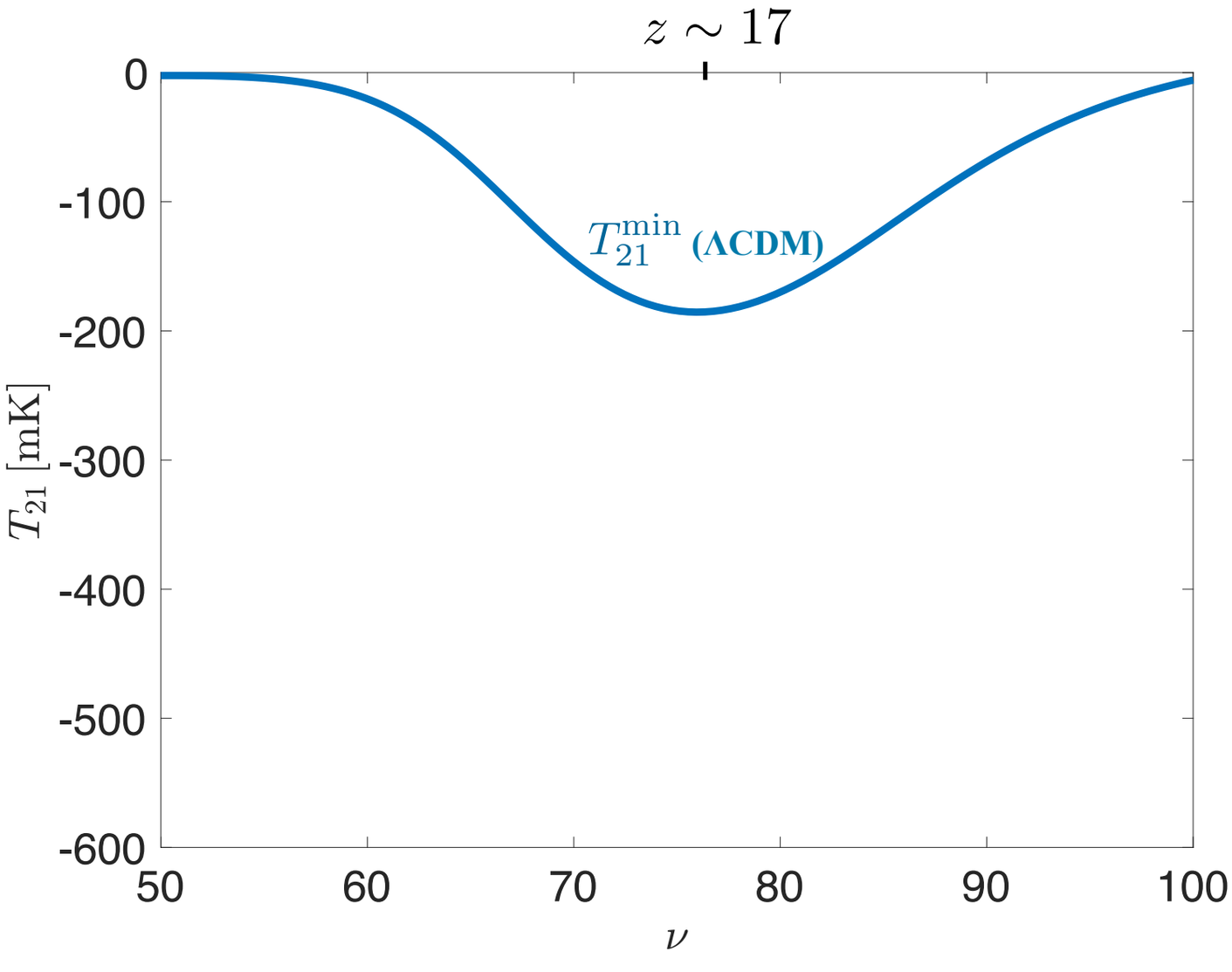

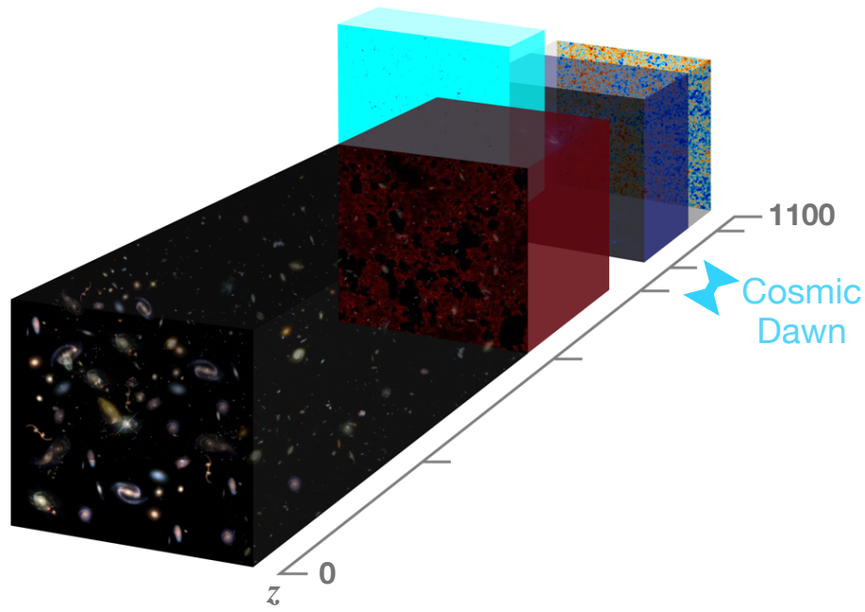

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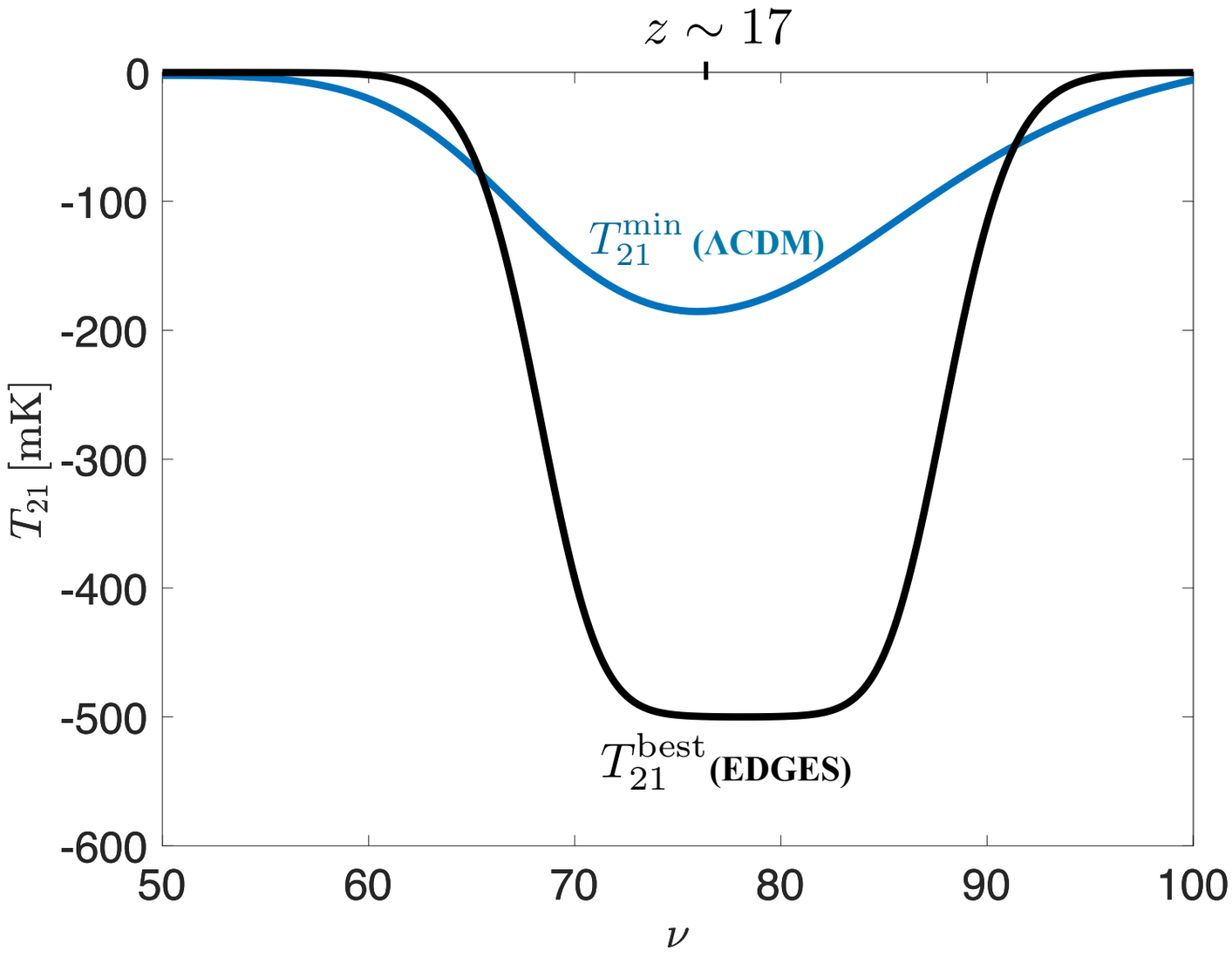

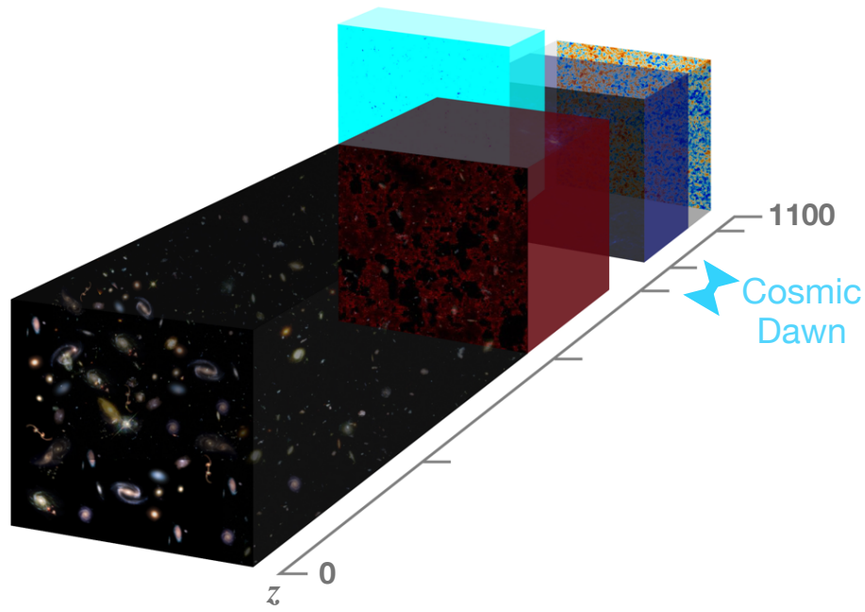

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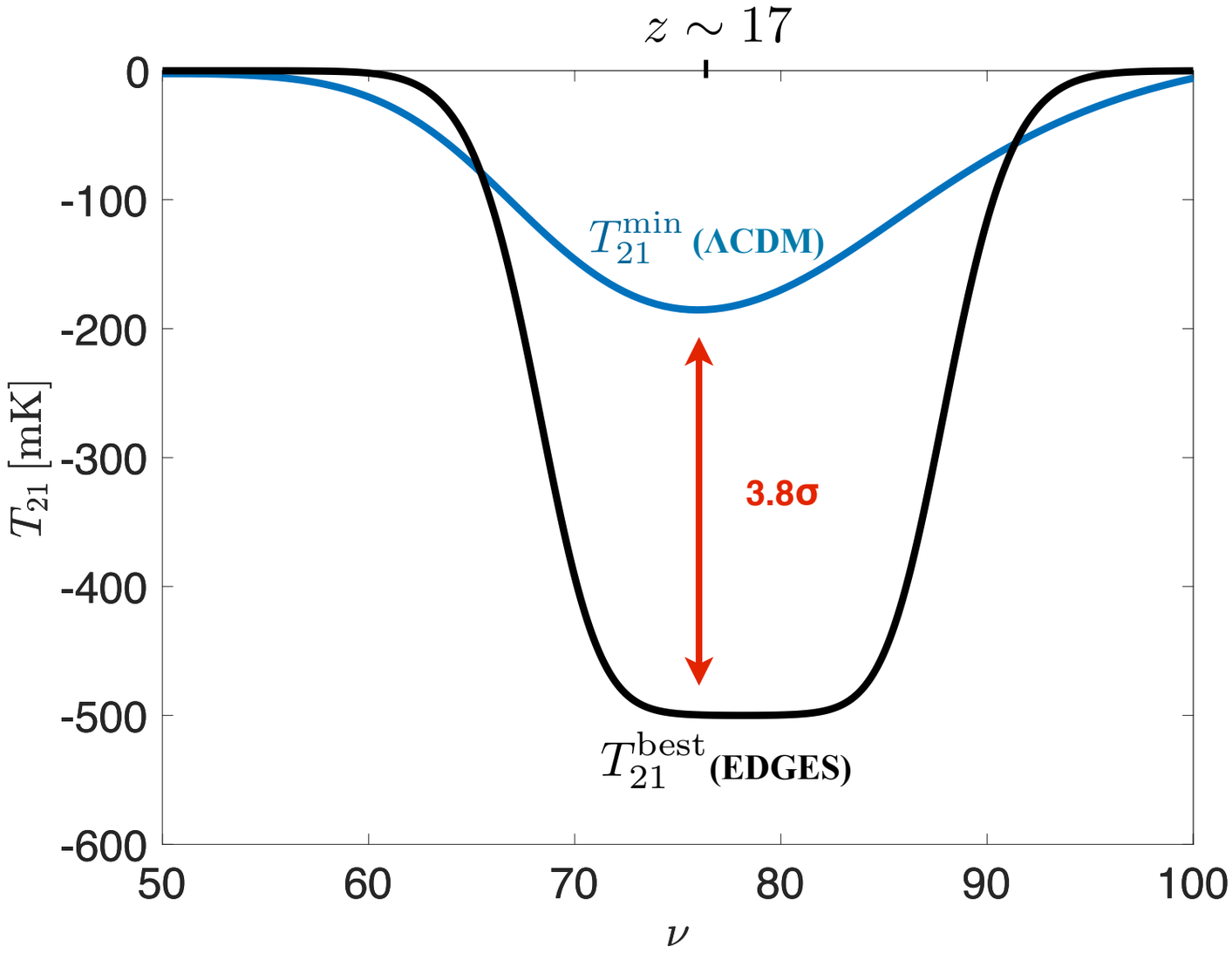

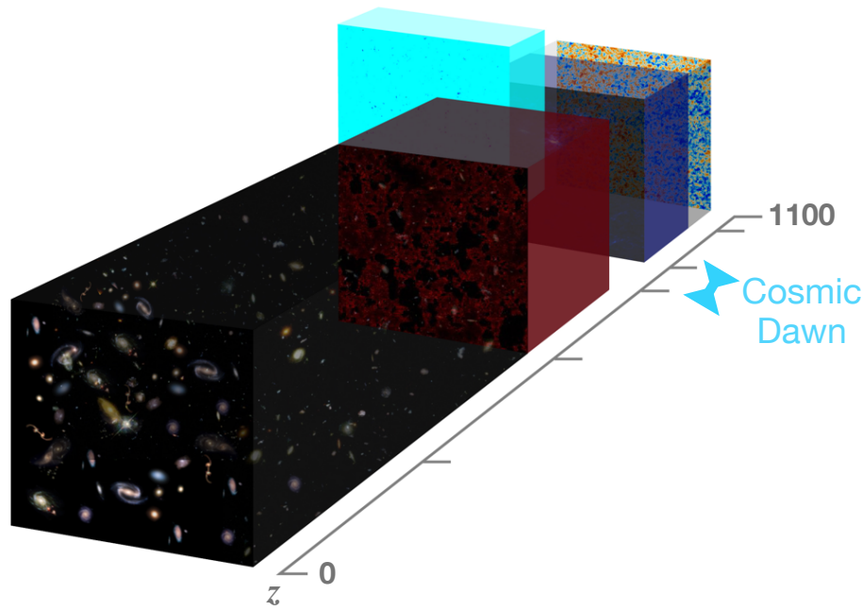

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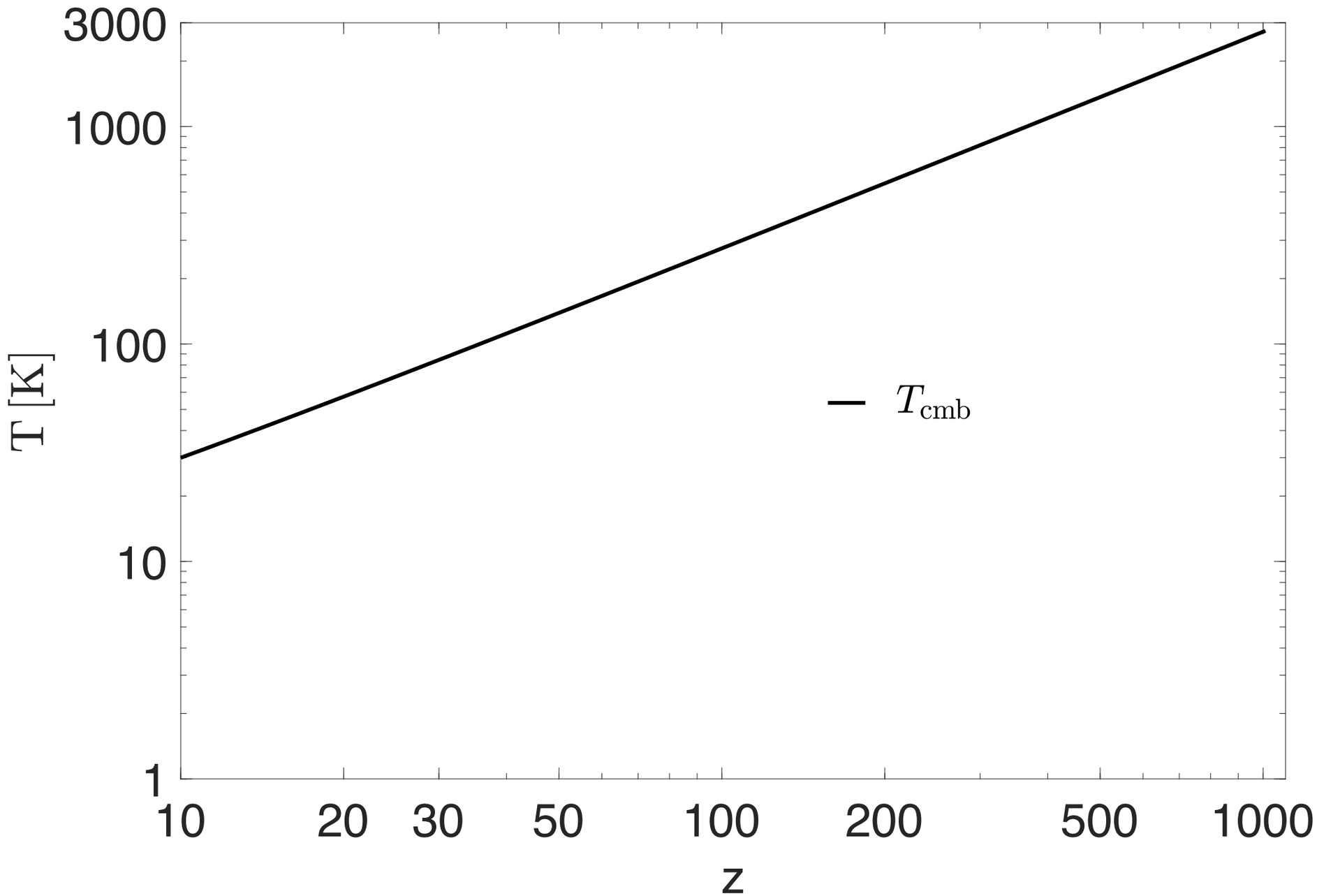

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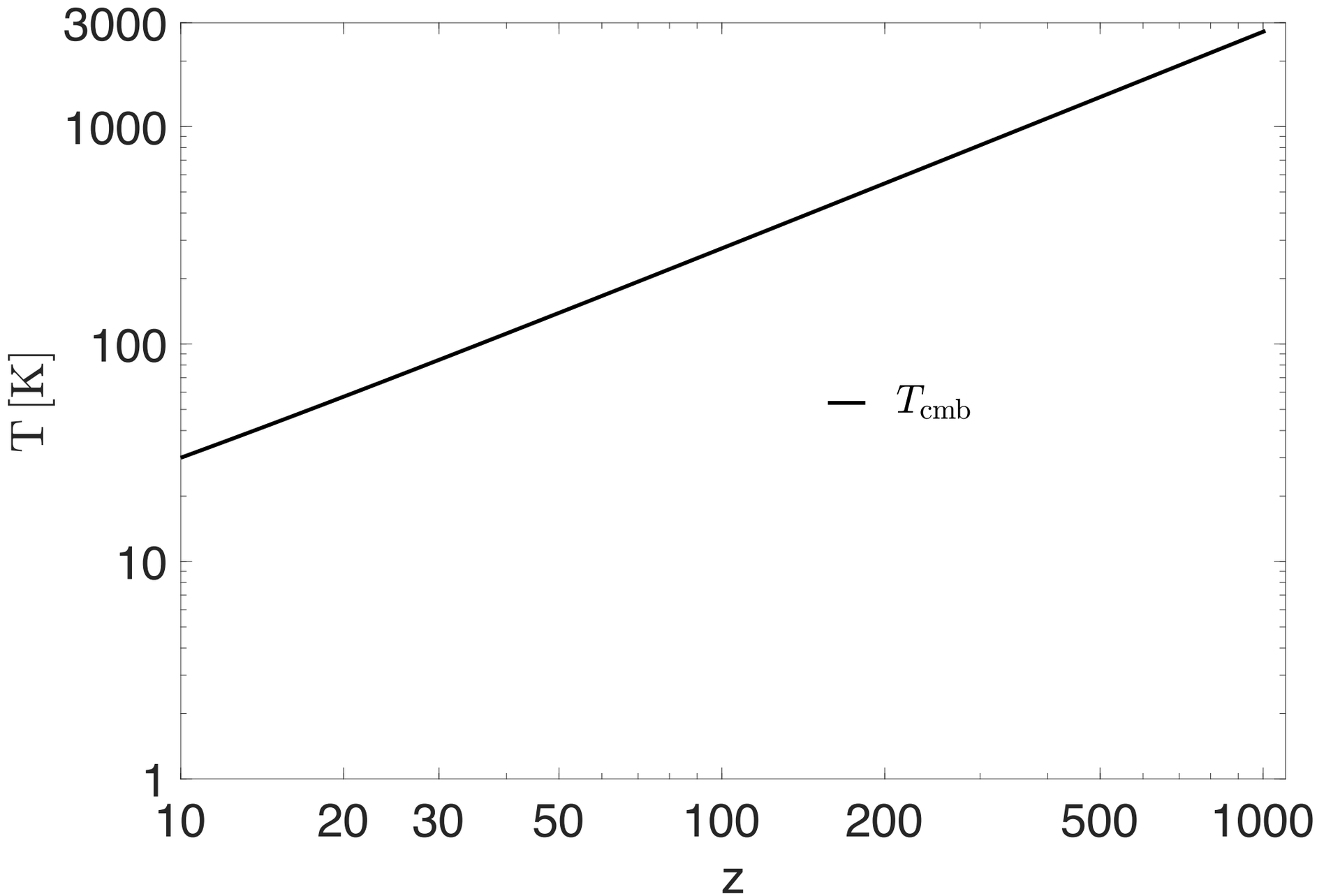

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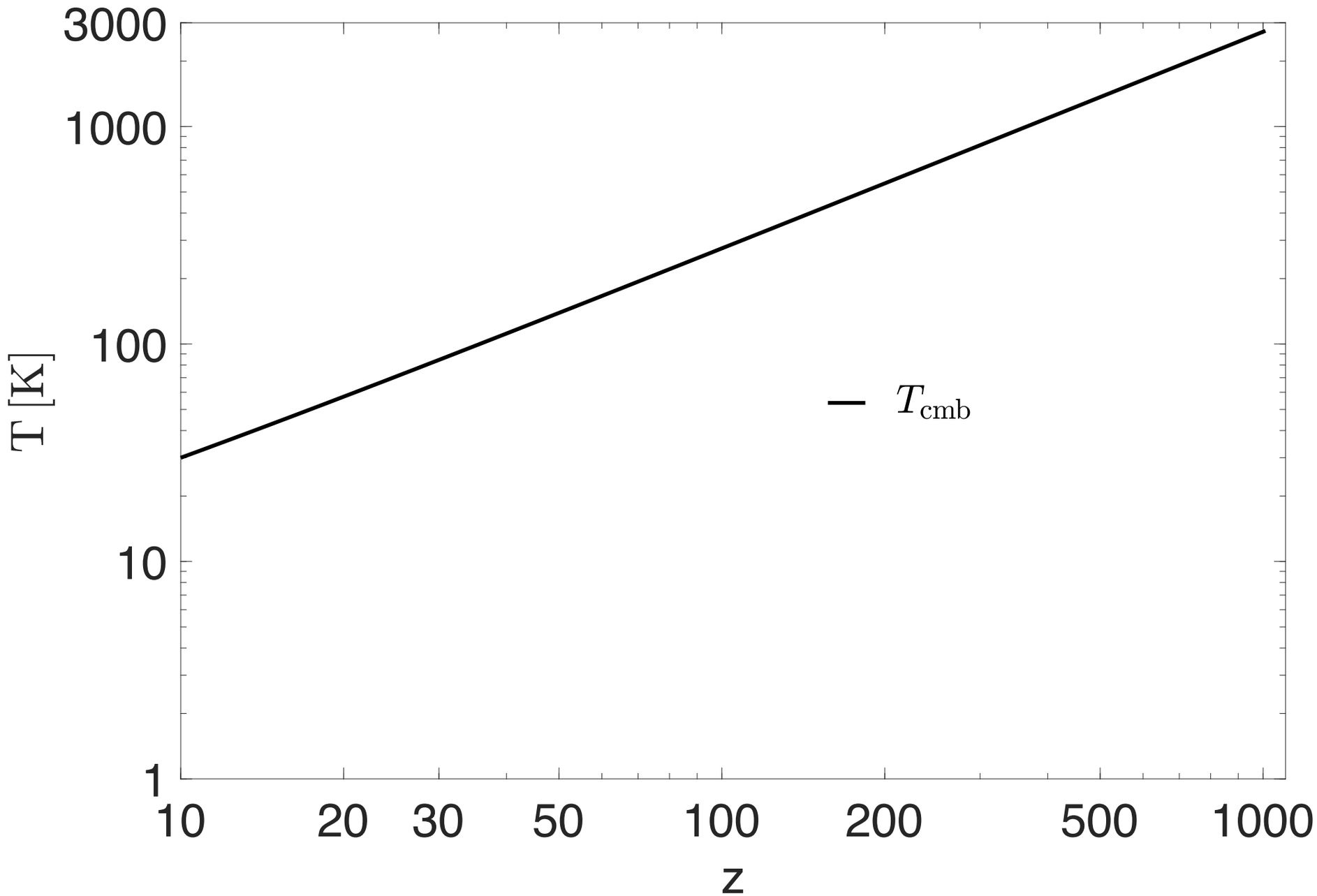

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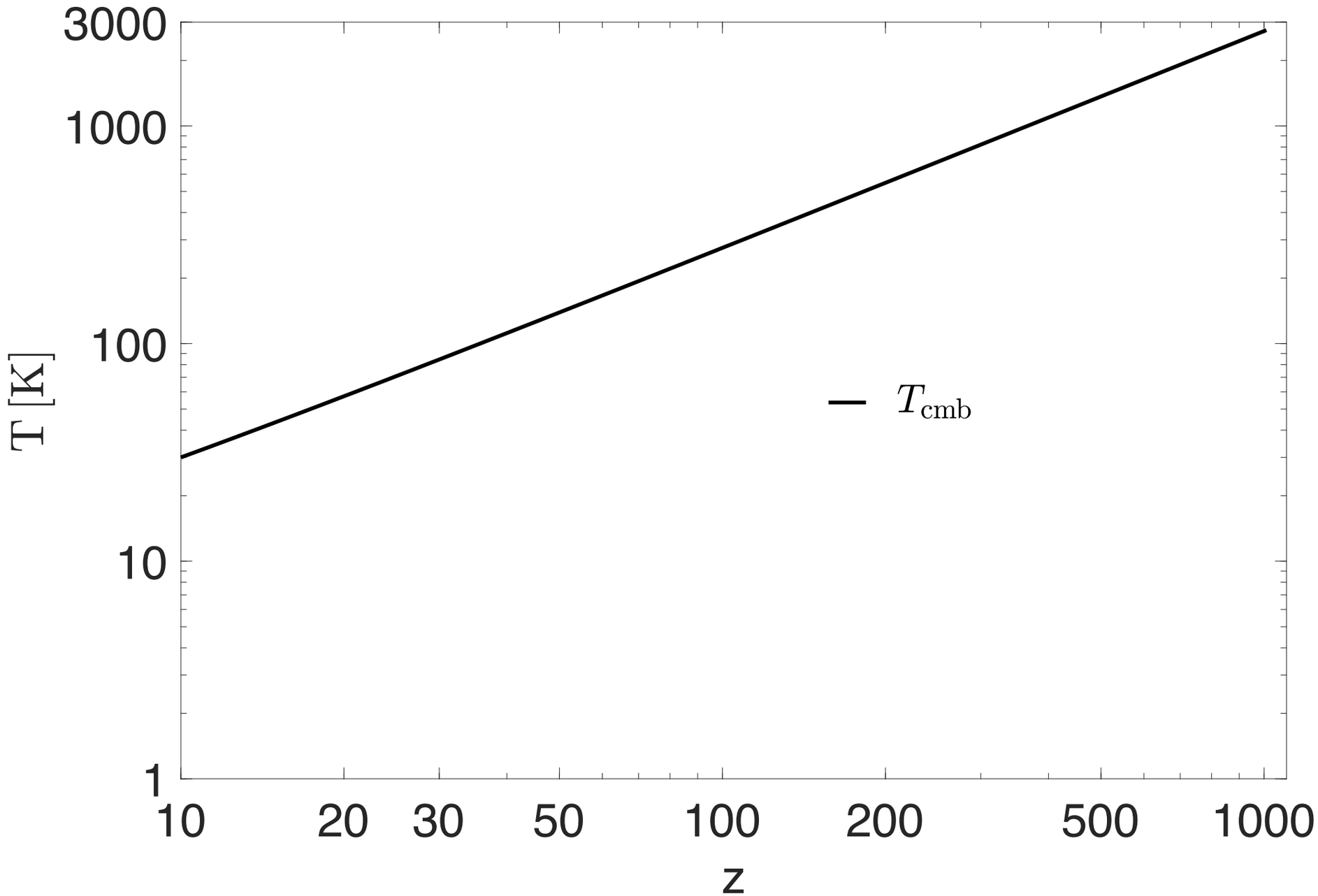

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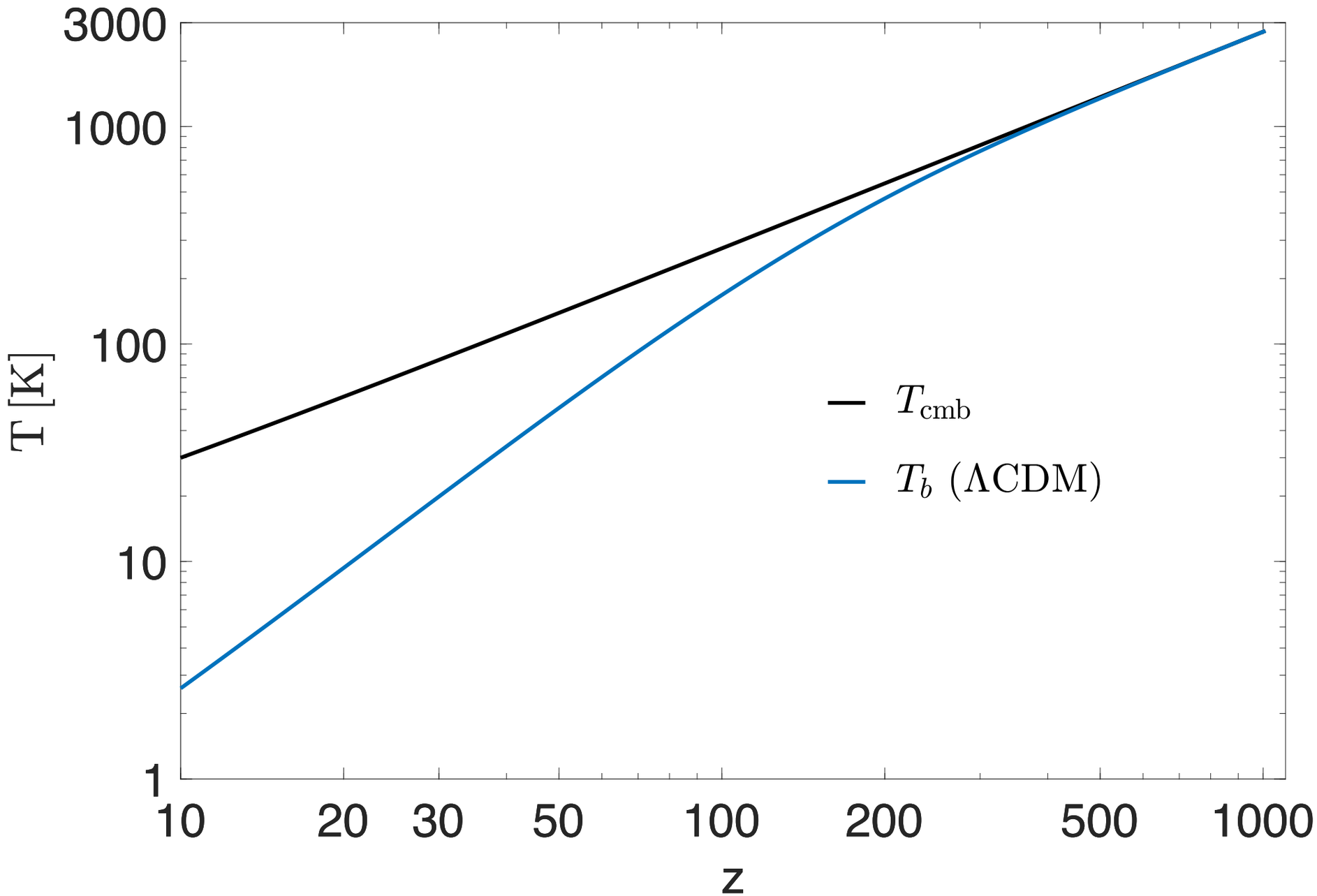

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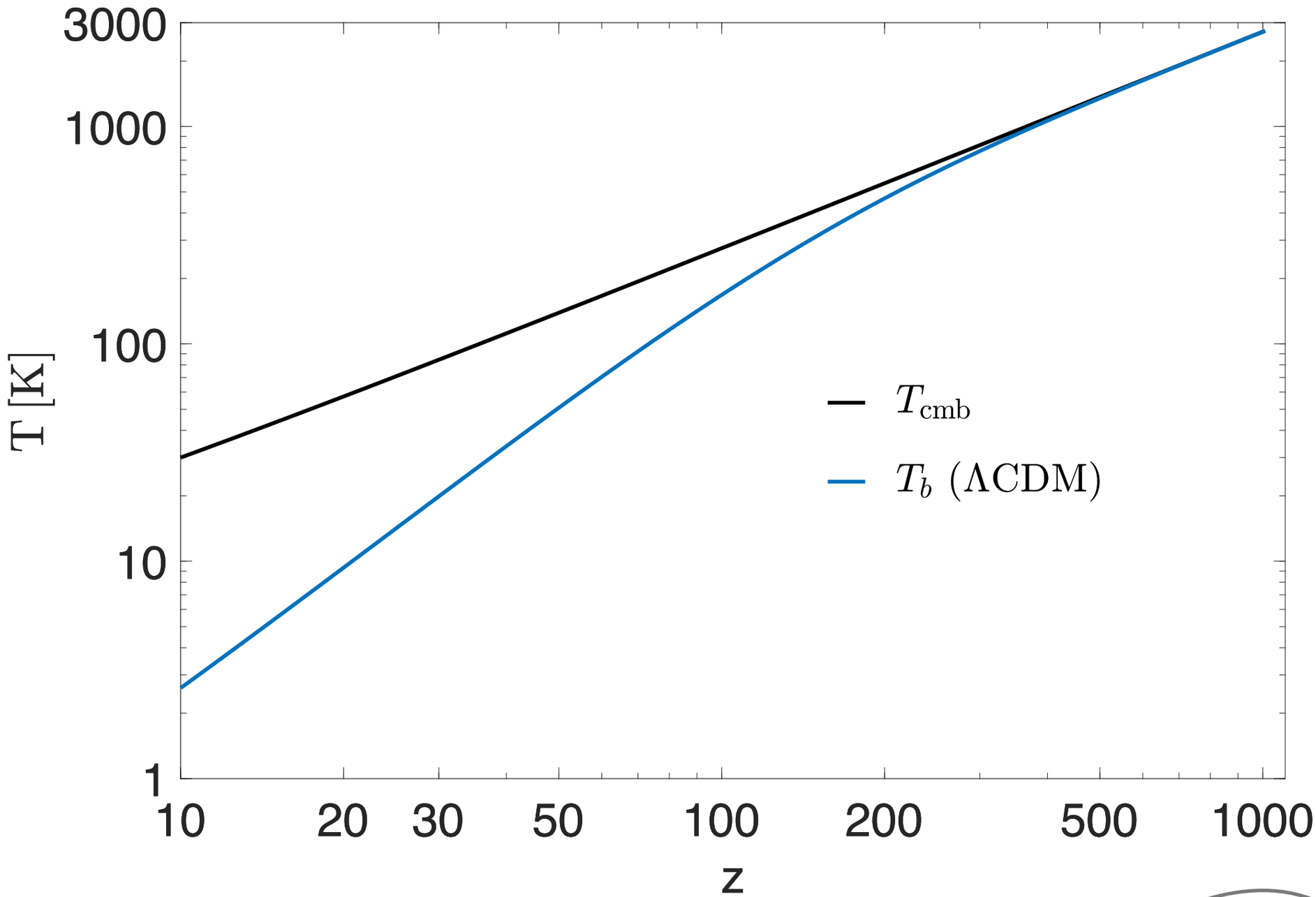

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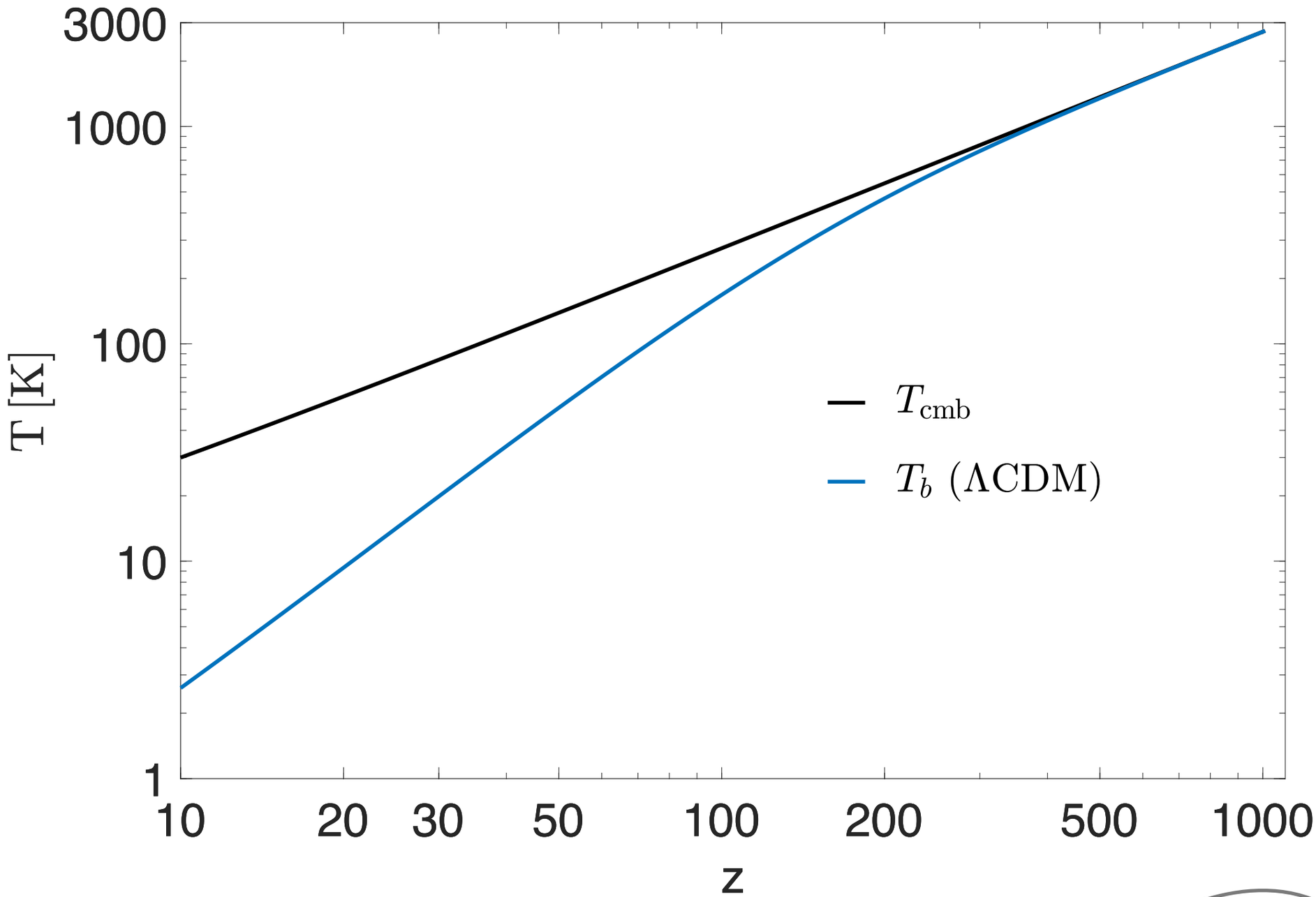

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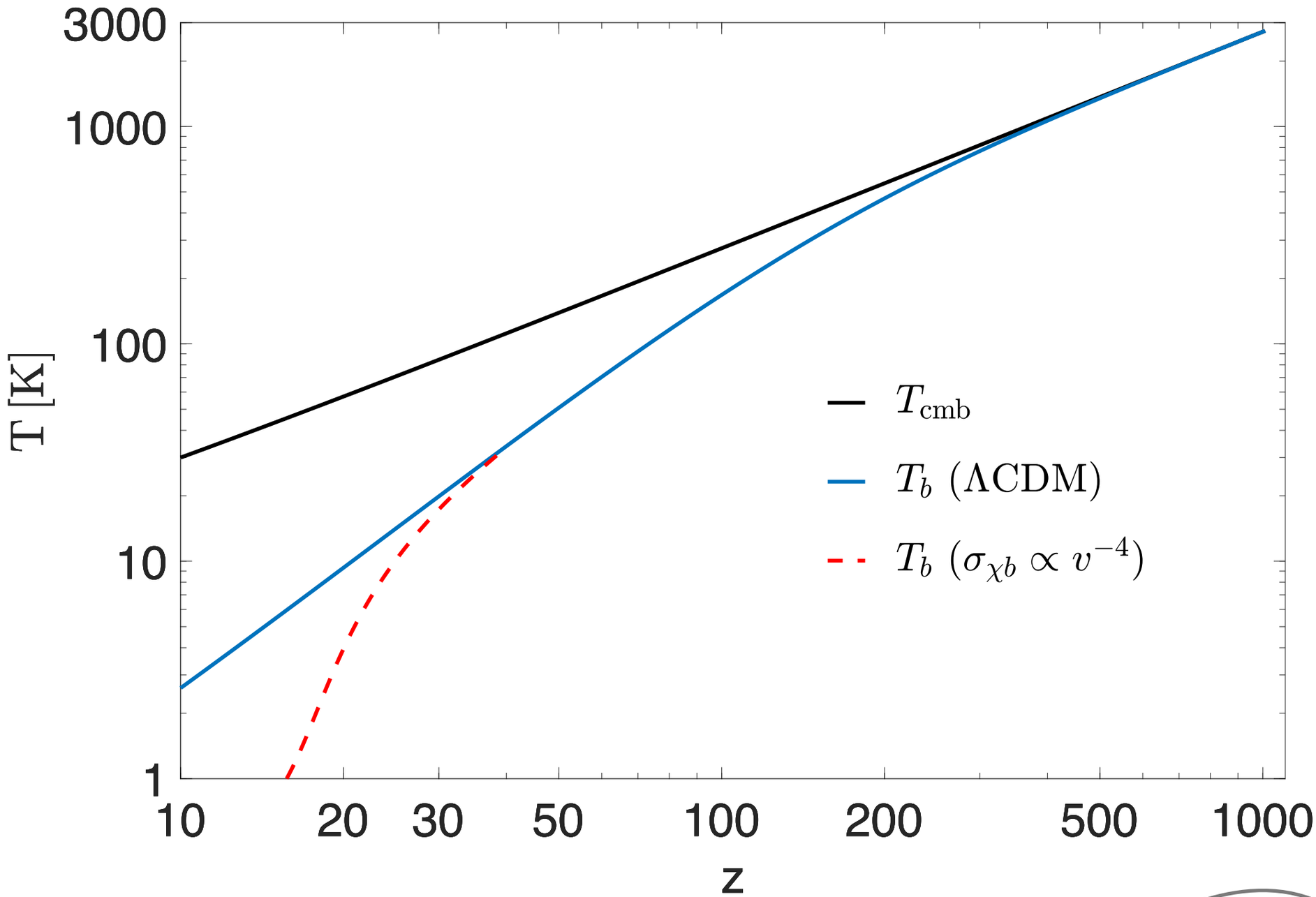

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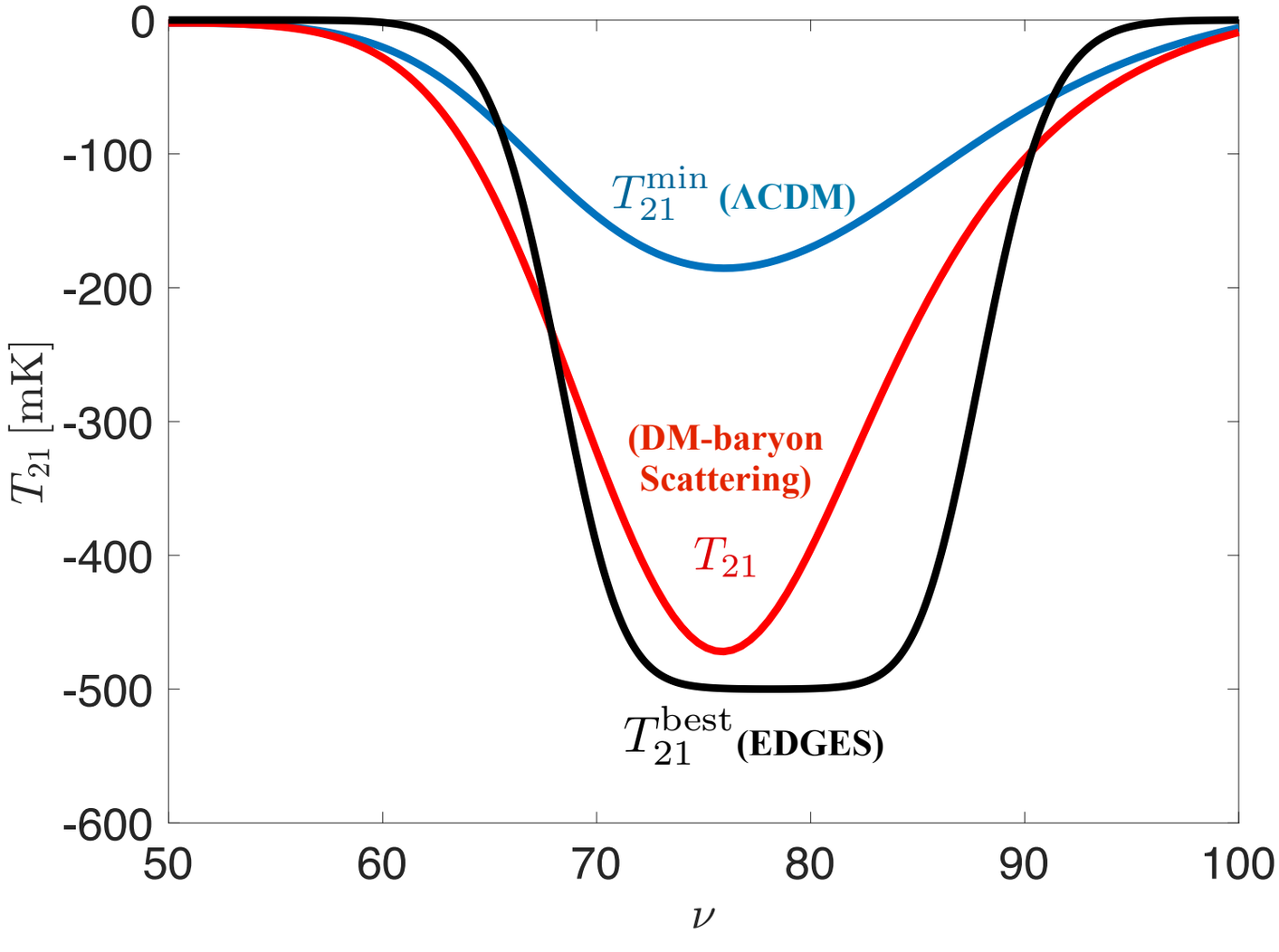

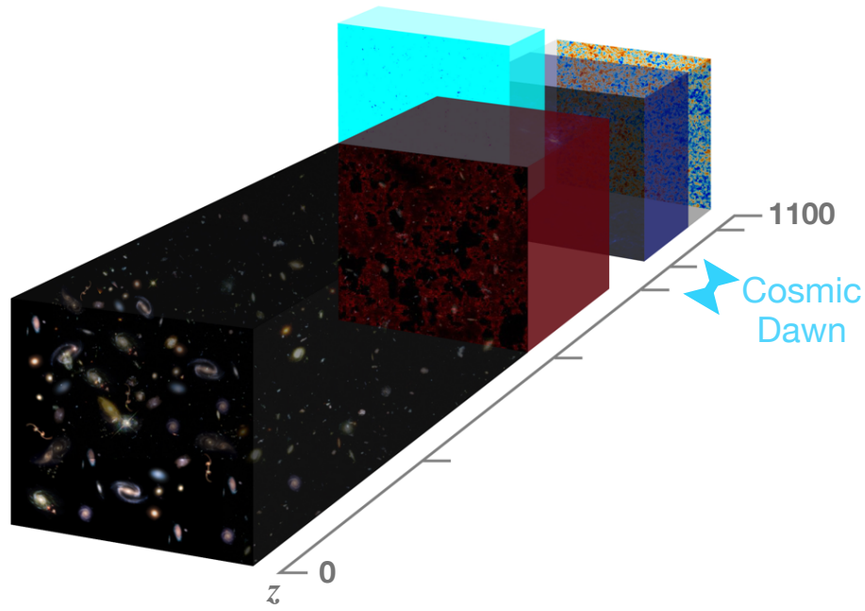

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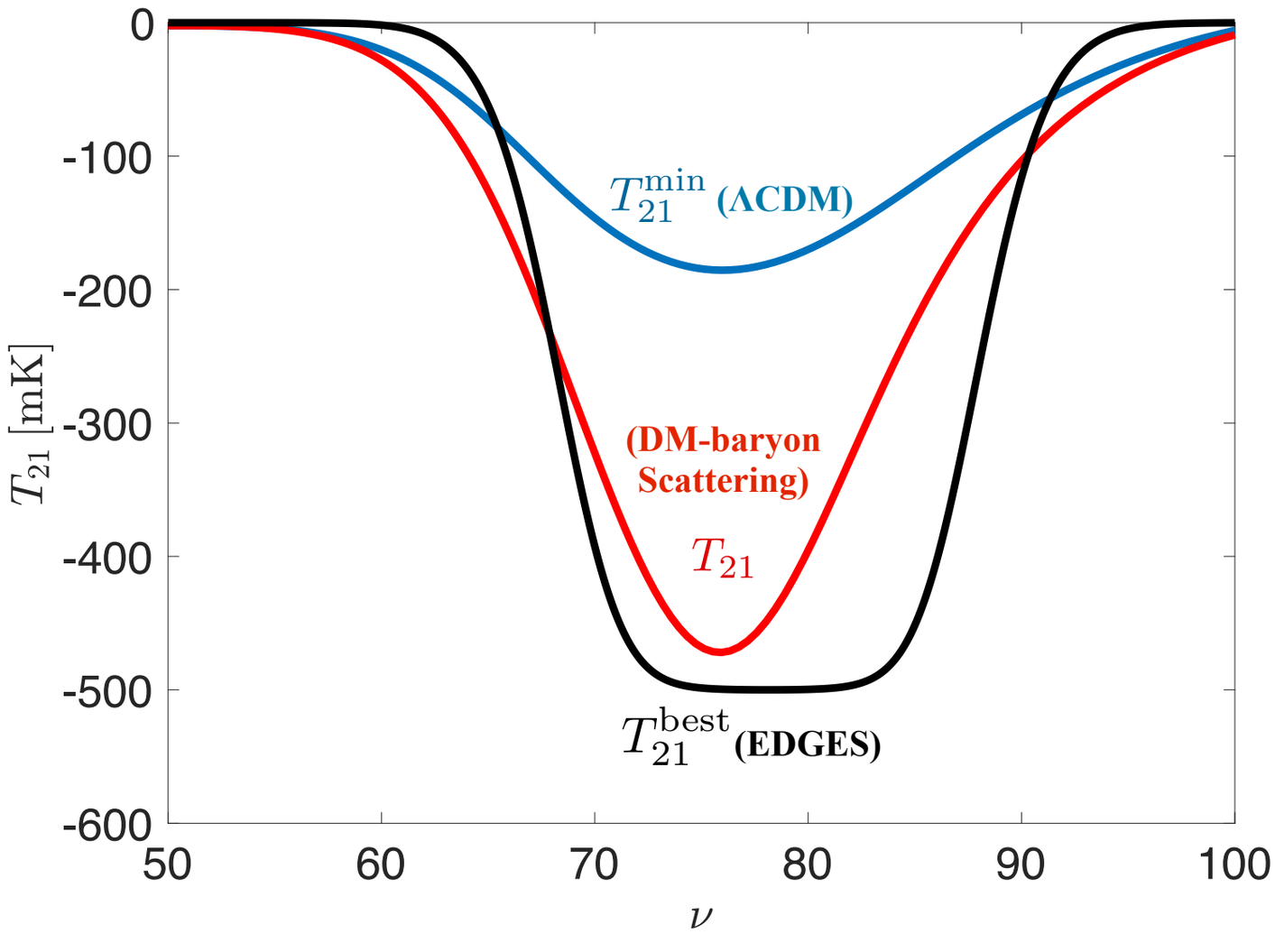

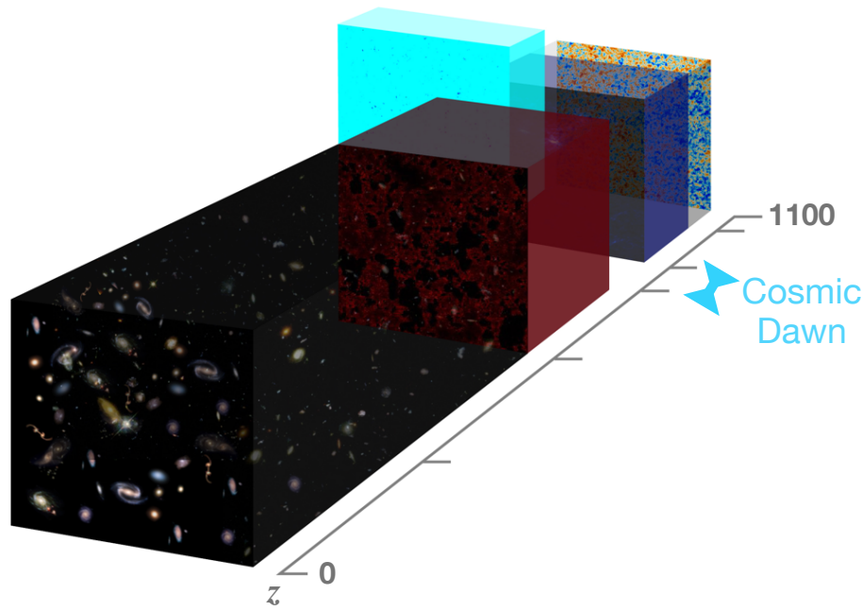

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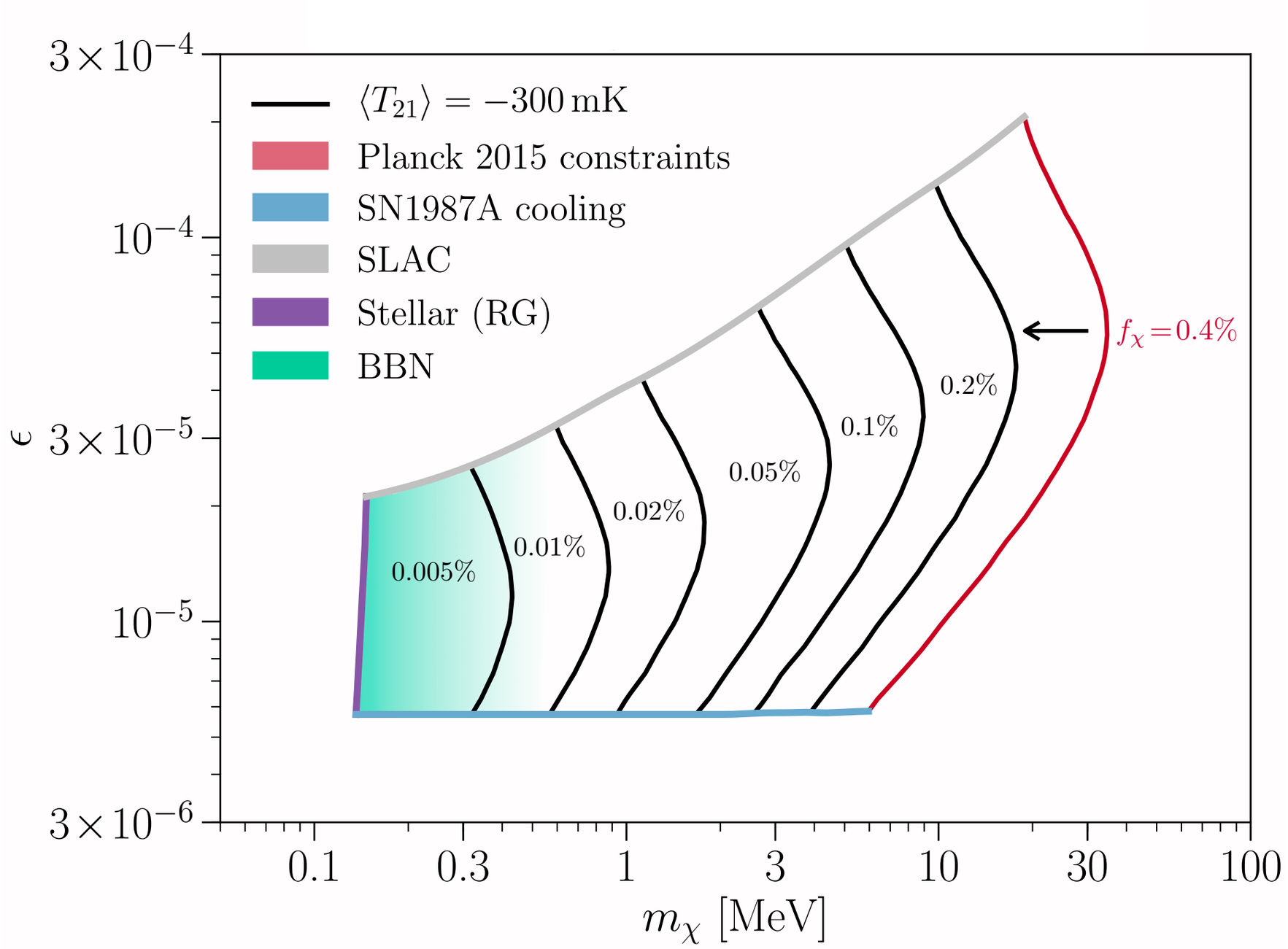

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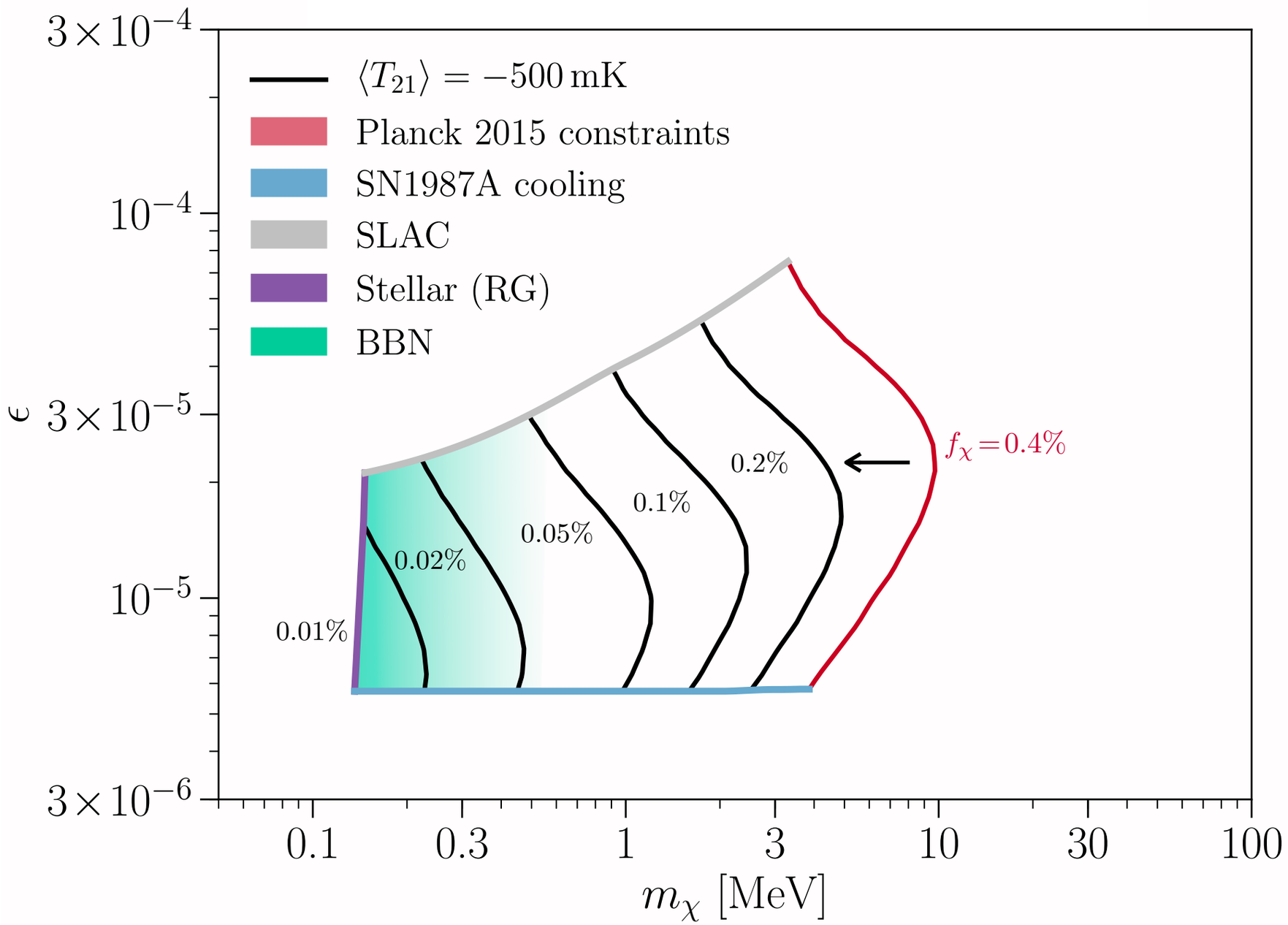

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Hidden photons couple to the standard model electric current:

$$\mathcal{L} = -\frac{1}{4}F_{\mu\nu}F^{\mu\nu} - \frac{1}{4}\tilde{F}_{\mu\nu}\tilde{F}^{\mu\nu} + \frac{m^2}{2}\tilde{A}_\mu\tilde{A}^\mu - \frac{e}{(1+\varepsilon^2)^{1/2}}J^\mu\left(A_\mu + \varepsilon\tilde{A}_\mu\right)$$

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Effect governed by the plasma frequency (= *effective SM-photon mass*):

$$\text{At } z = 17: \qquad \omega_p = \left(\frac{4\pi n_e \alpha}{m_e}\right) = 1.7\times10^{-14}\left(\frac{n_e}{2\times10^{-7}\,\text{cm}^{-3}}\right)^{1/2}\ \text{eV}$$

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The baryon temperature is then:

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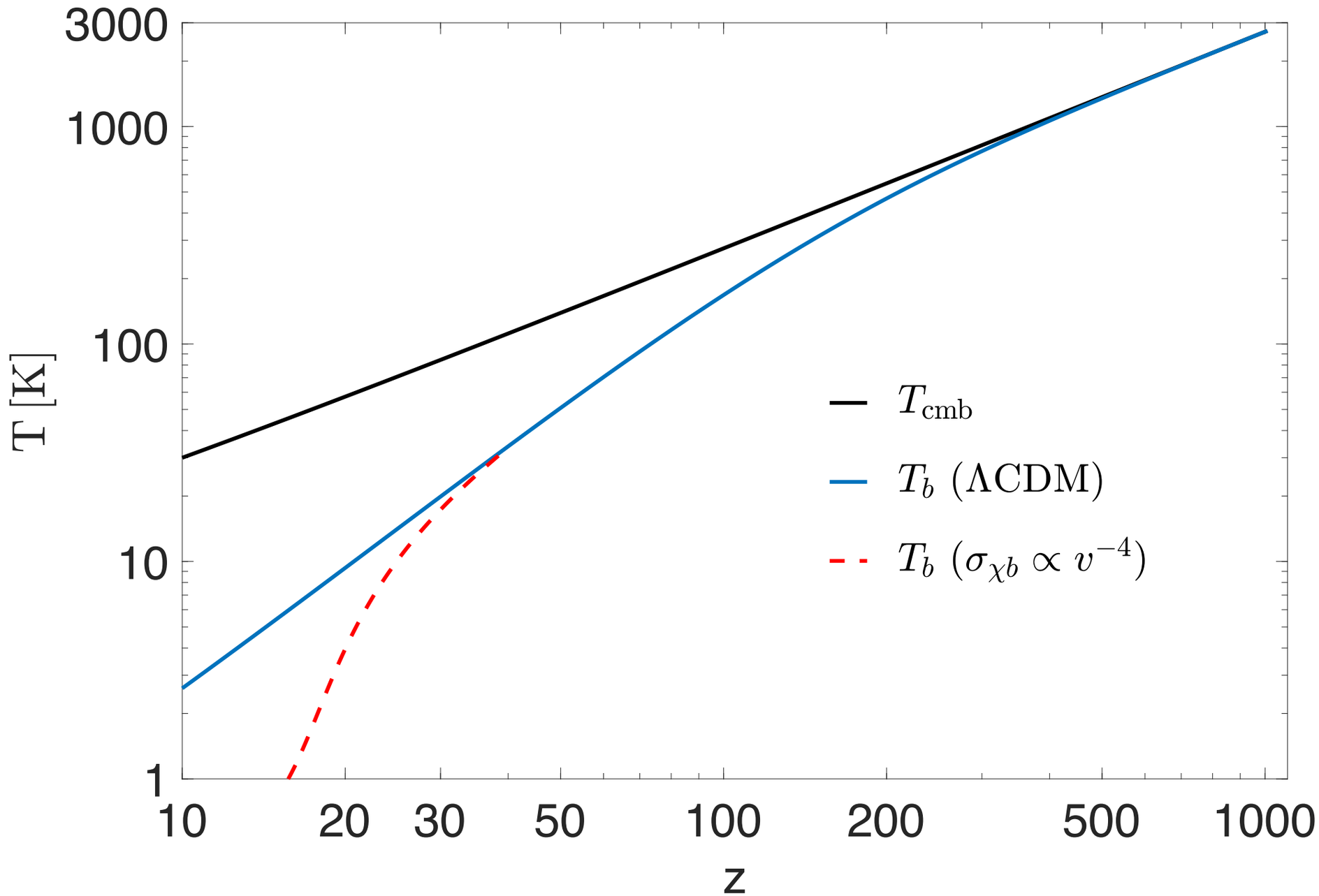

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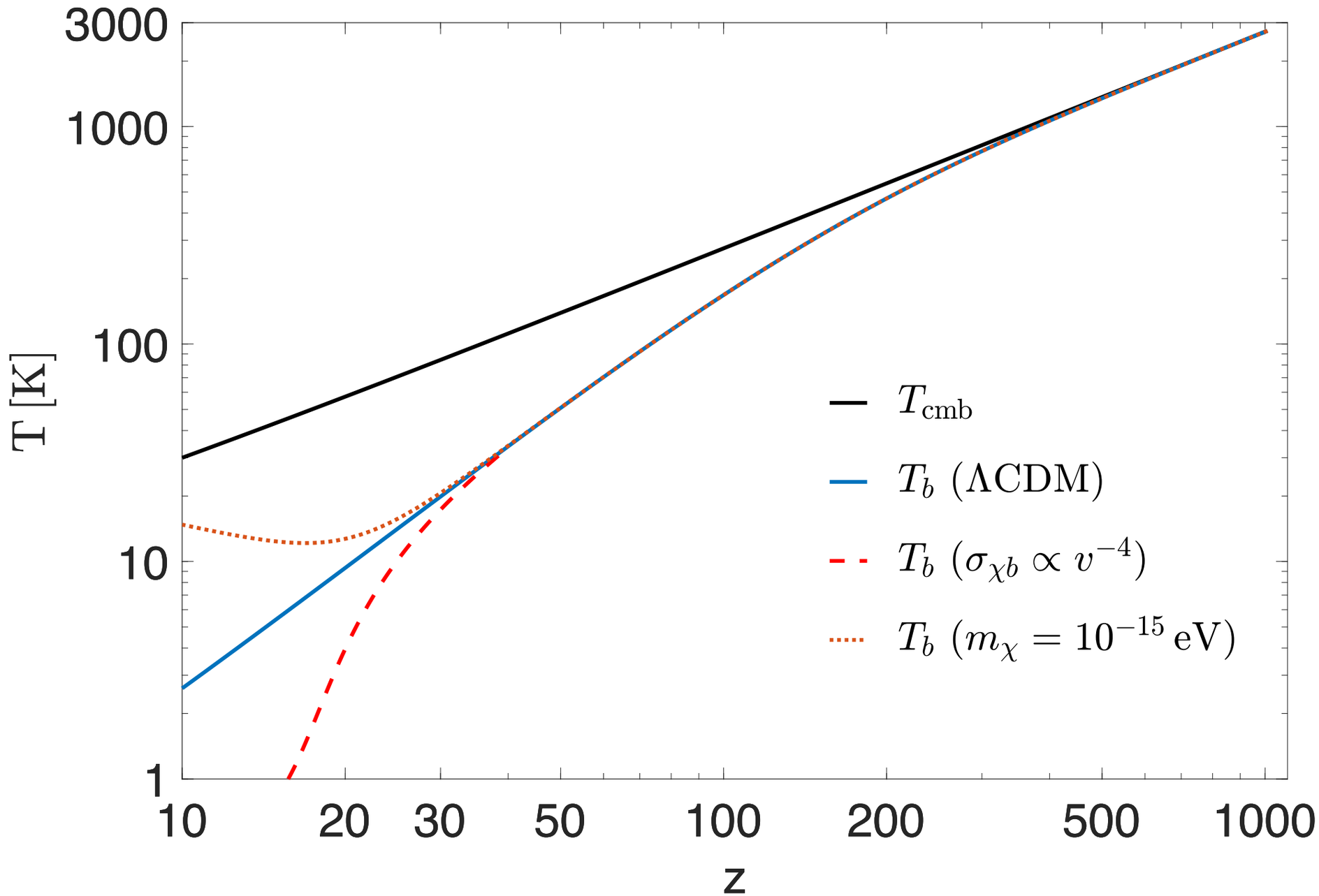

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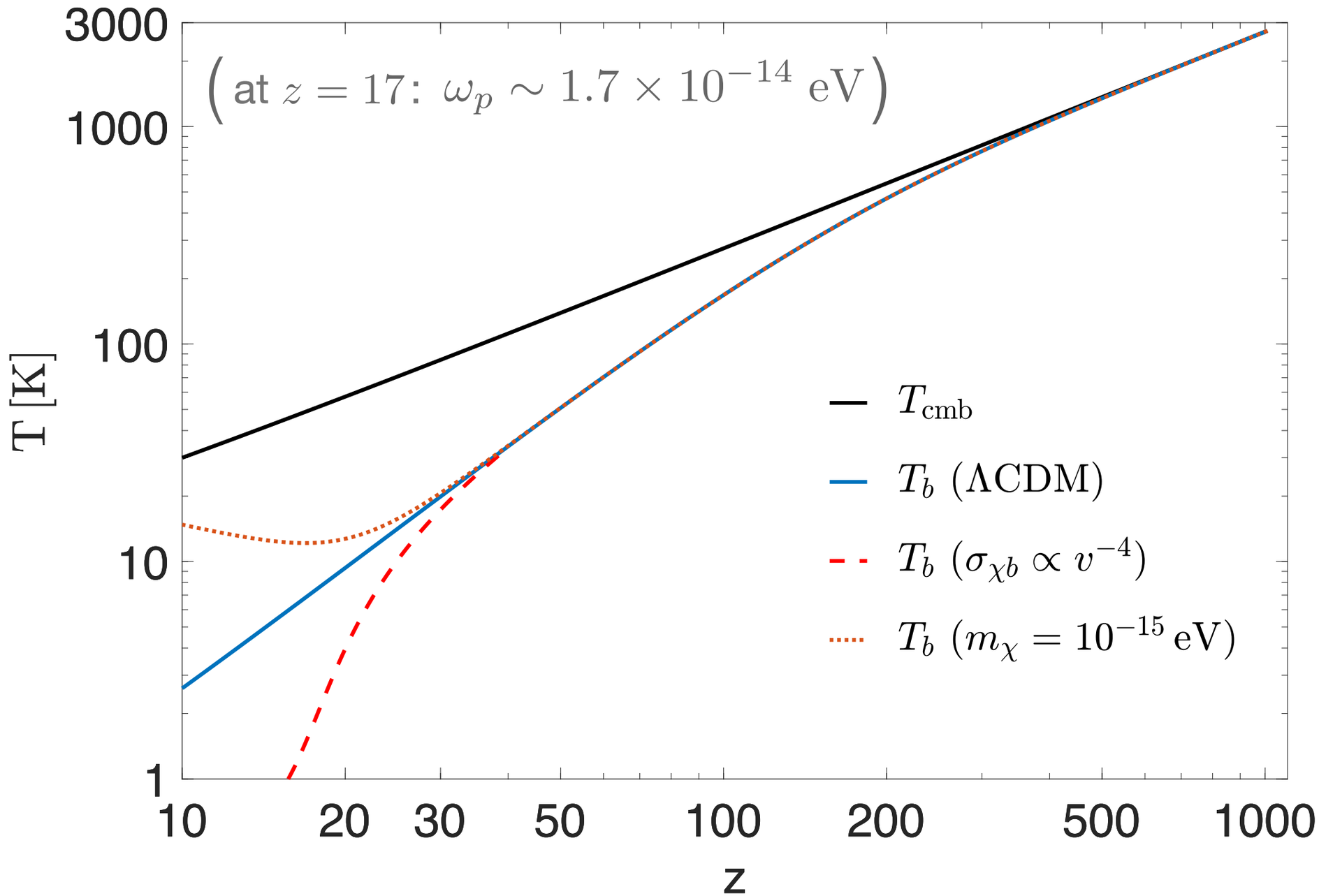

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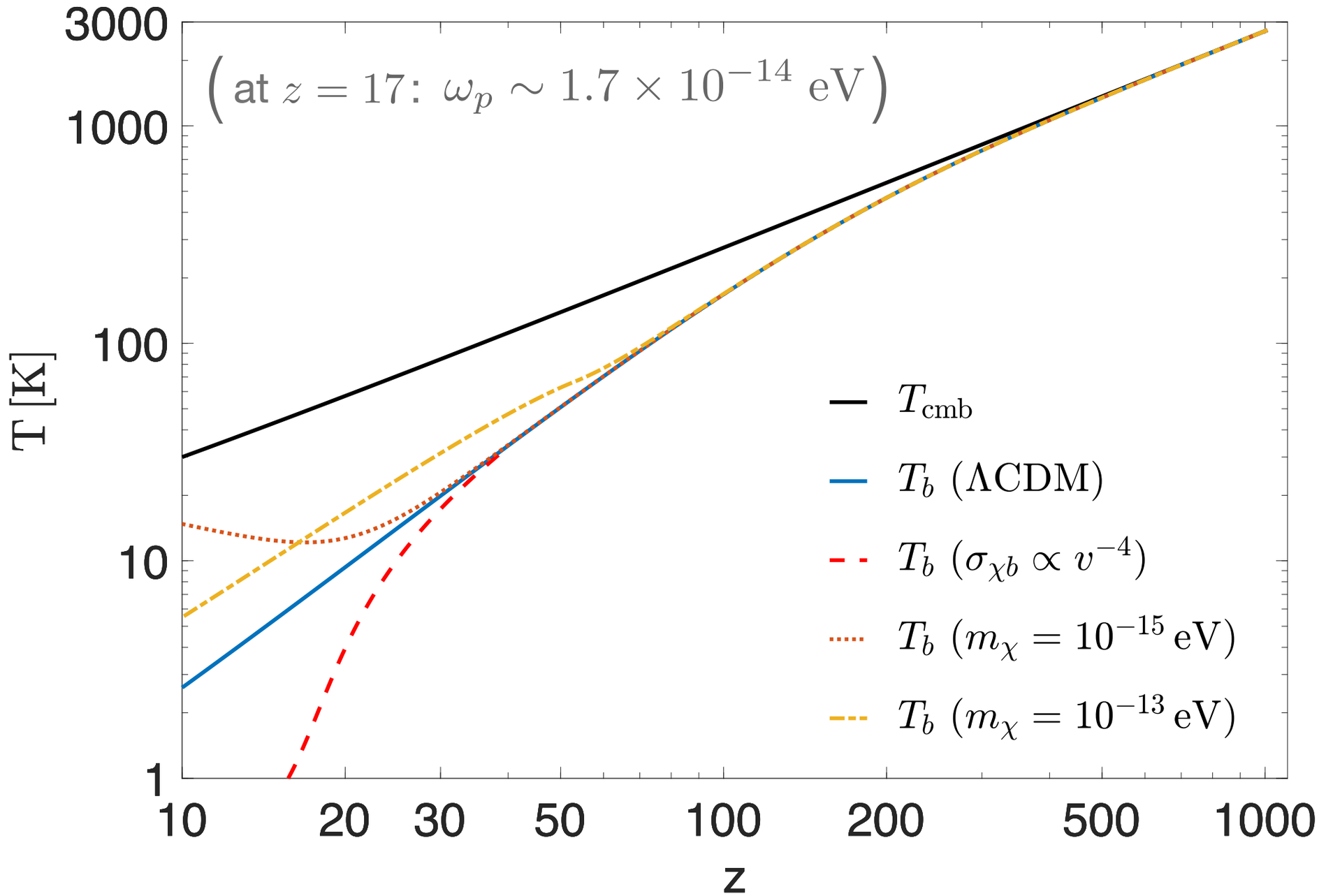

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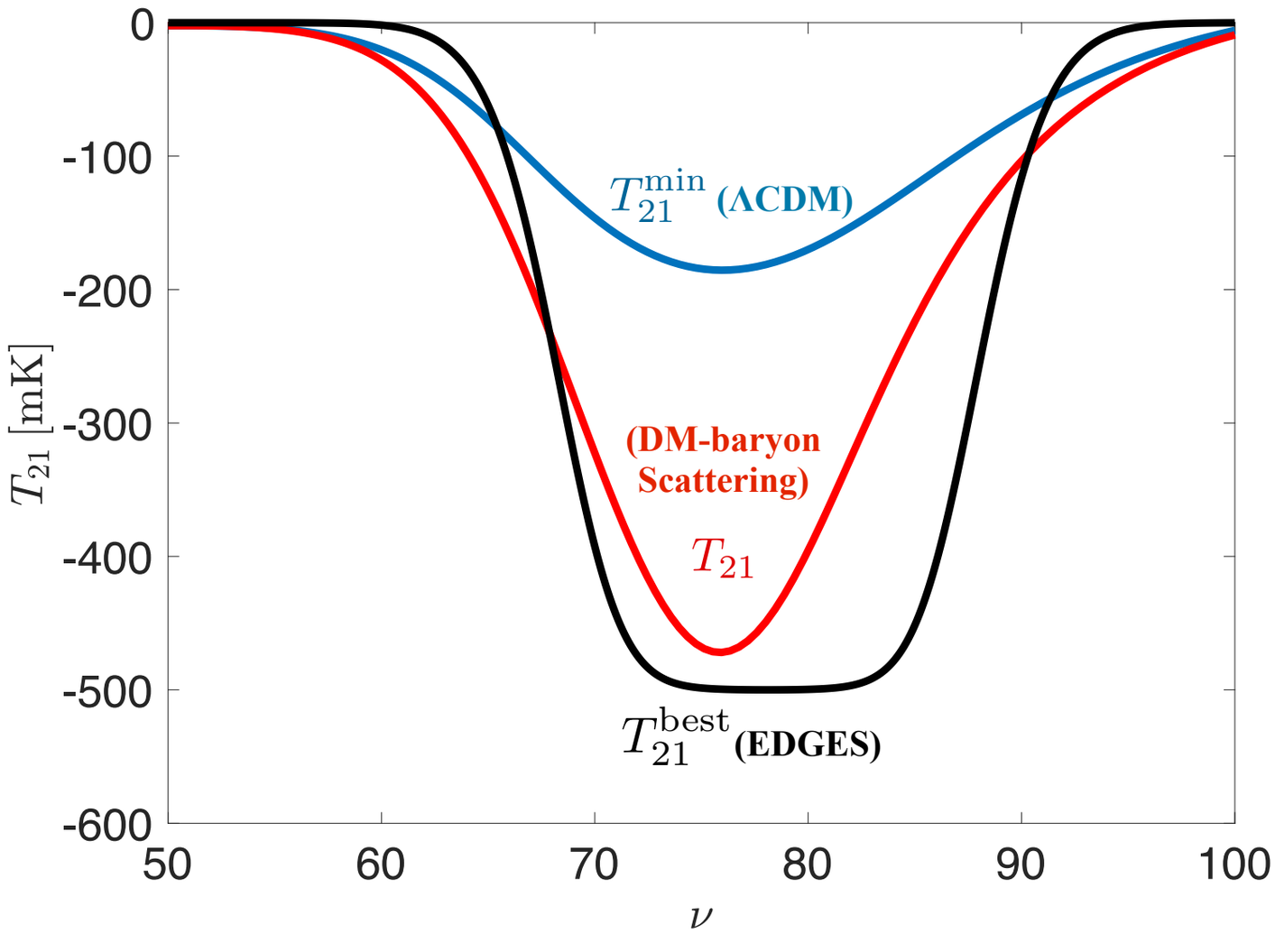

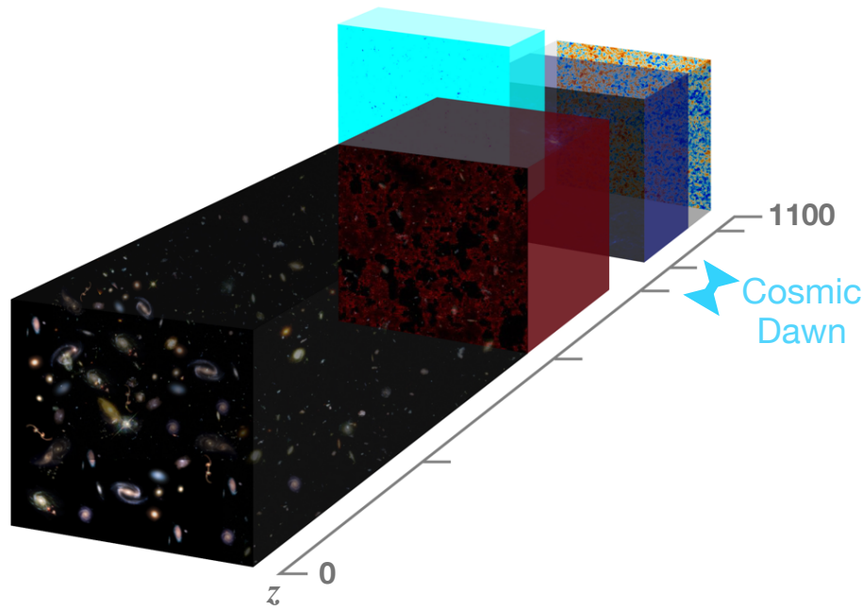

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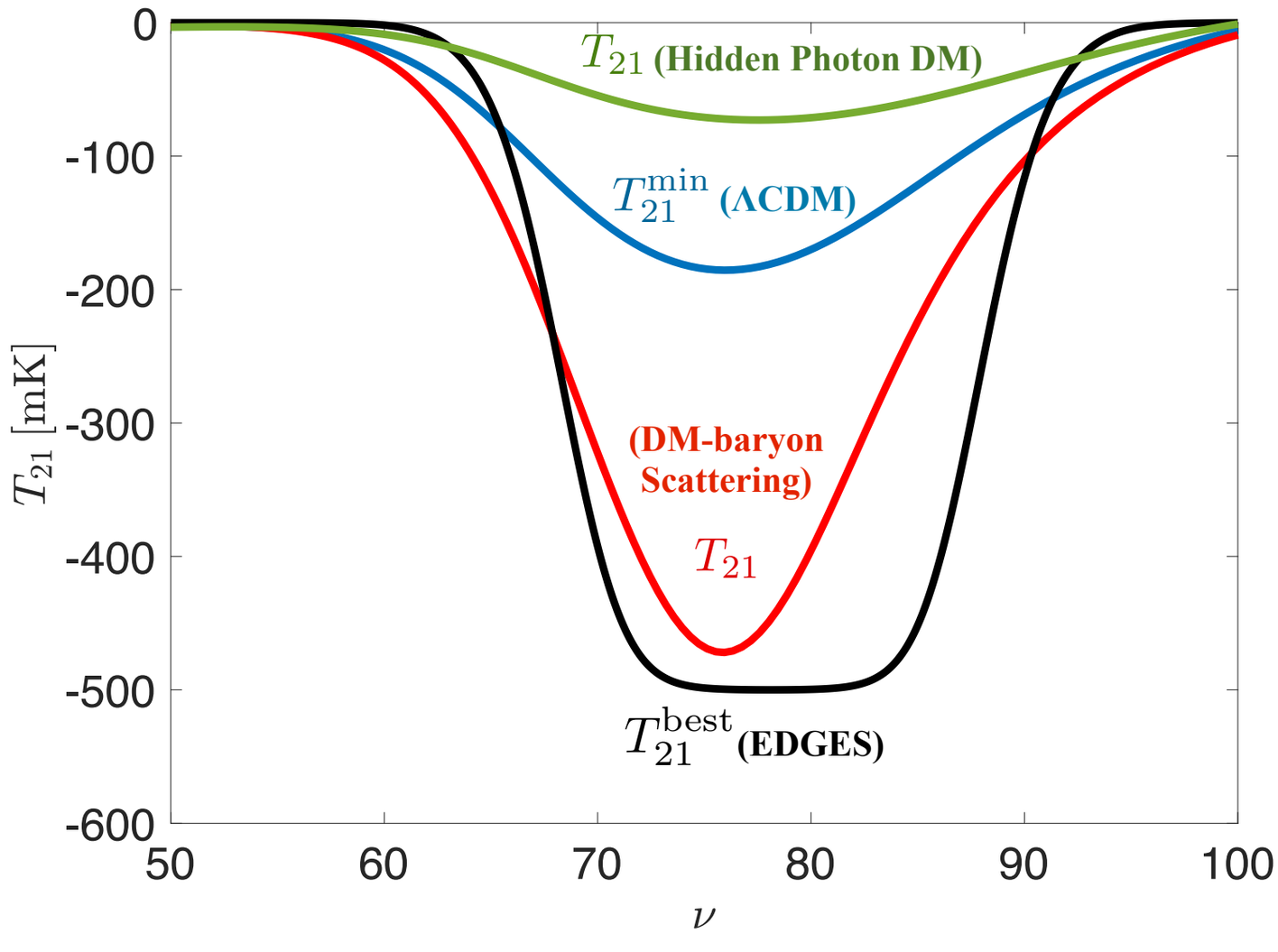

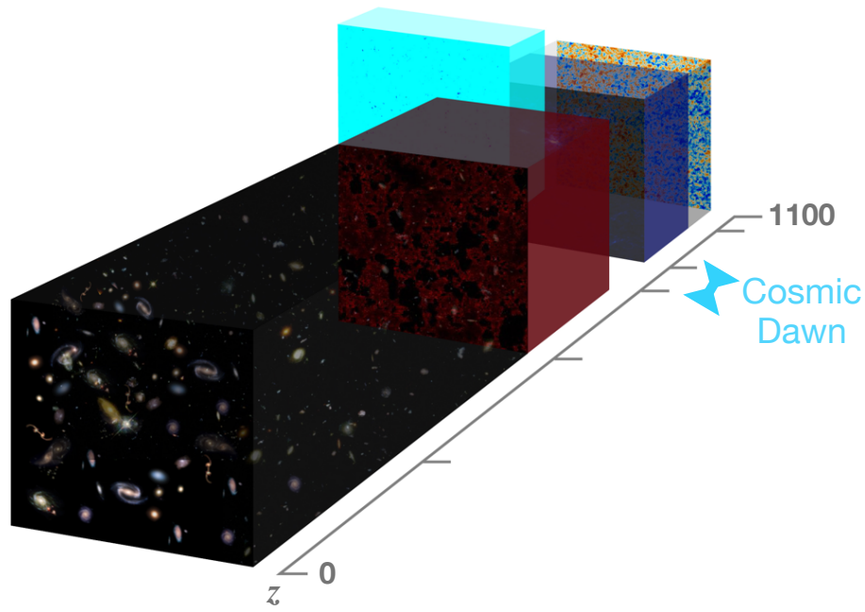

Ultra-Light Hidden-Photon Dark Matter

(EDK, Cholis and Kaplan, arXiv:1809.01139)

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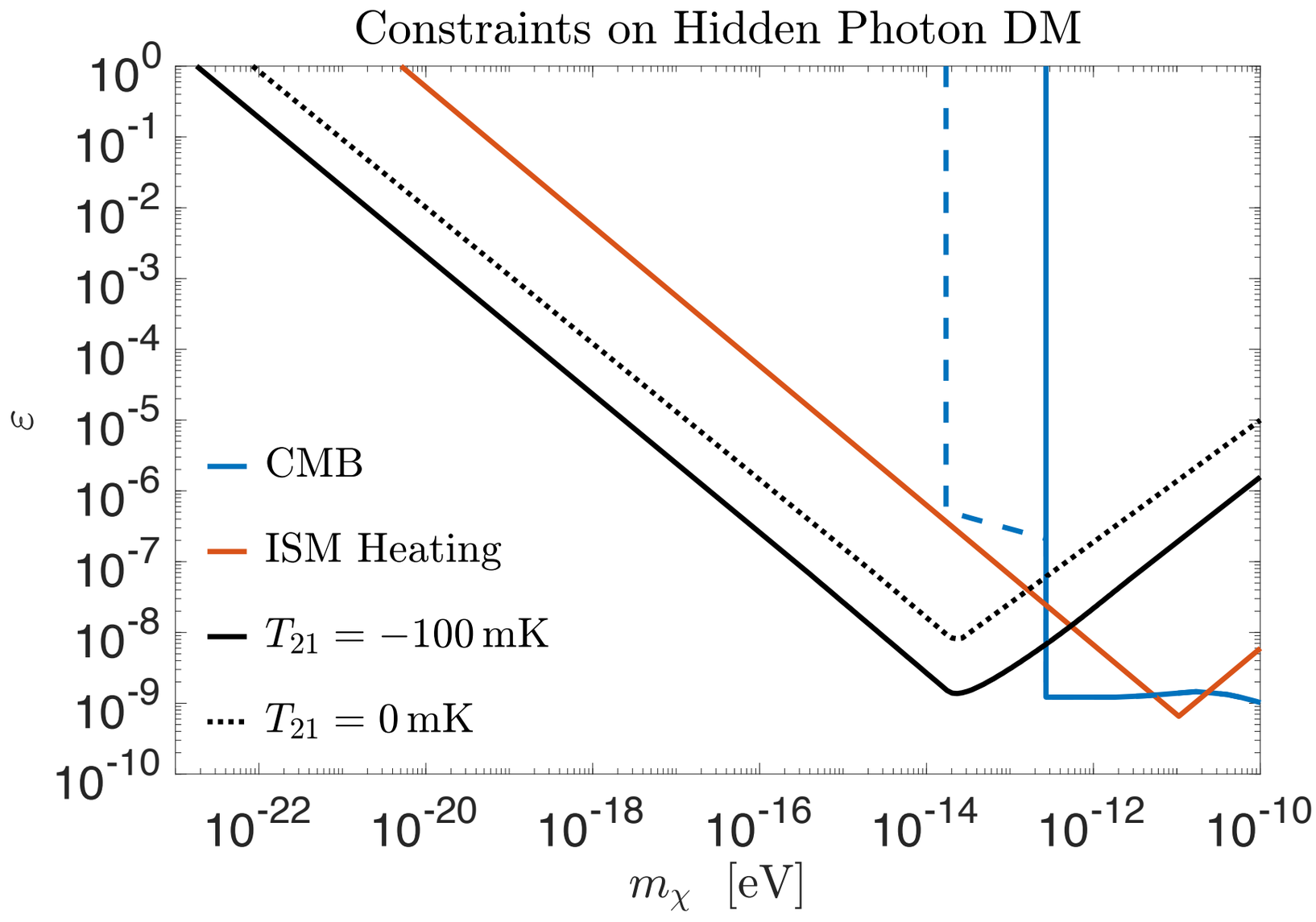

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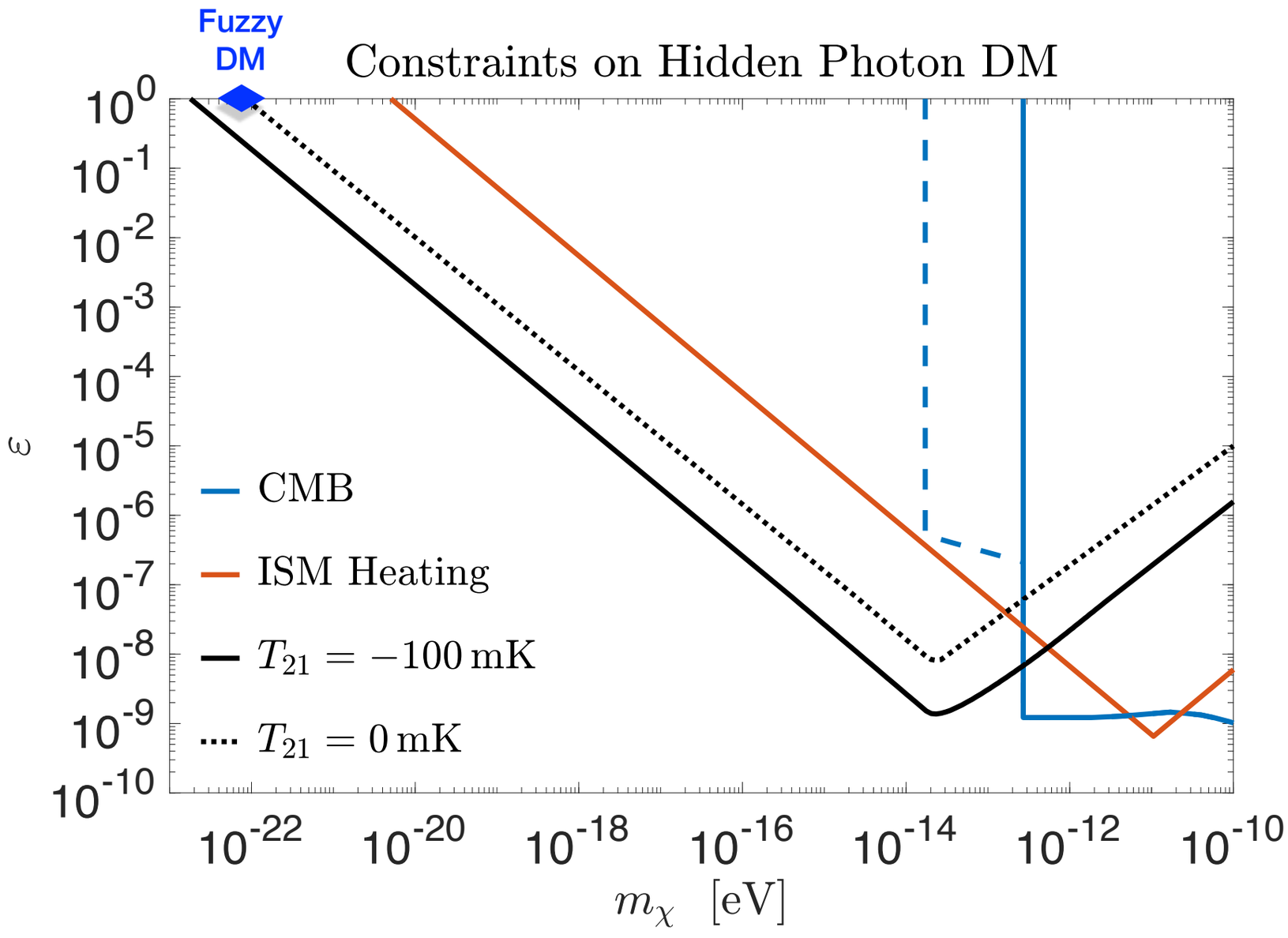
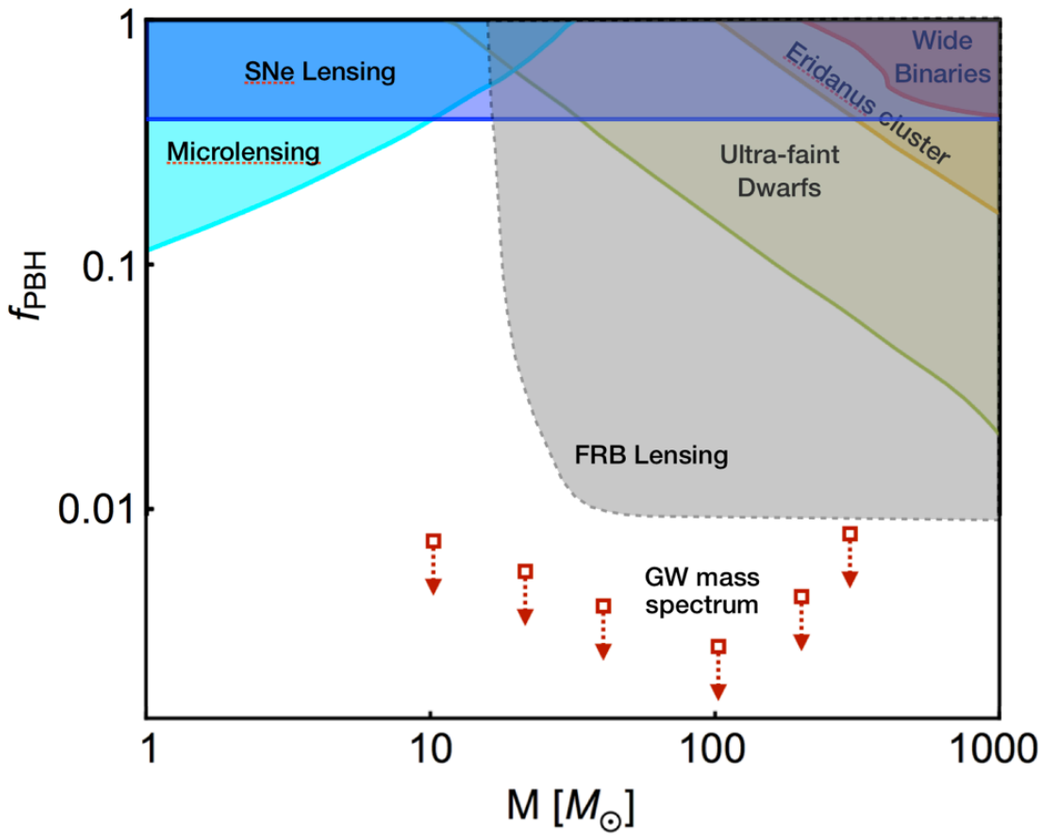
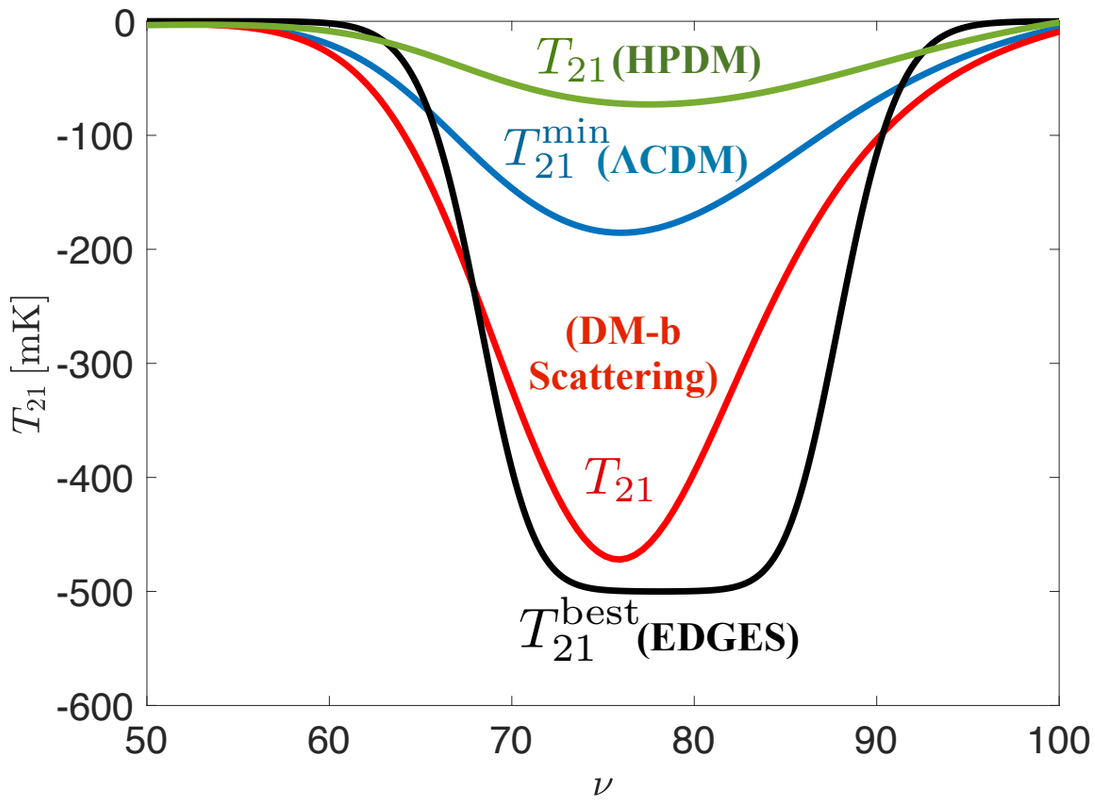


Thank You!

Ely D. Kovetz
Johns Hopkins University





Based on: arXiv:1603.00464, arXiv:1605.01405, **arXiv:1605.00008**, arXiv:1606.07437, arXiv:1611.01157, **arXiv:1705.09182**, **arXiv:1709.06576**, **arXiv:1809.09627**

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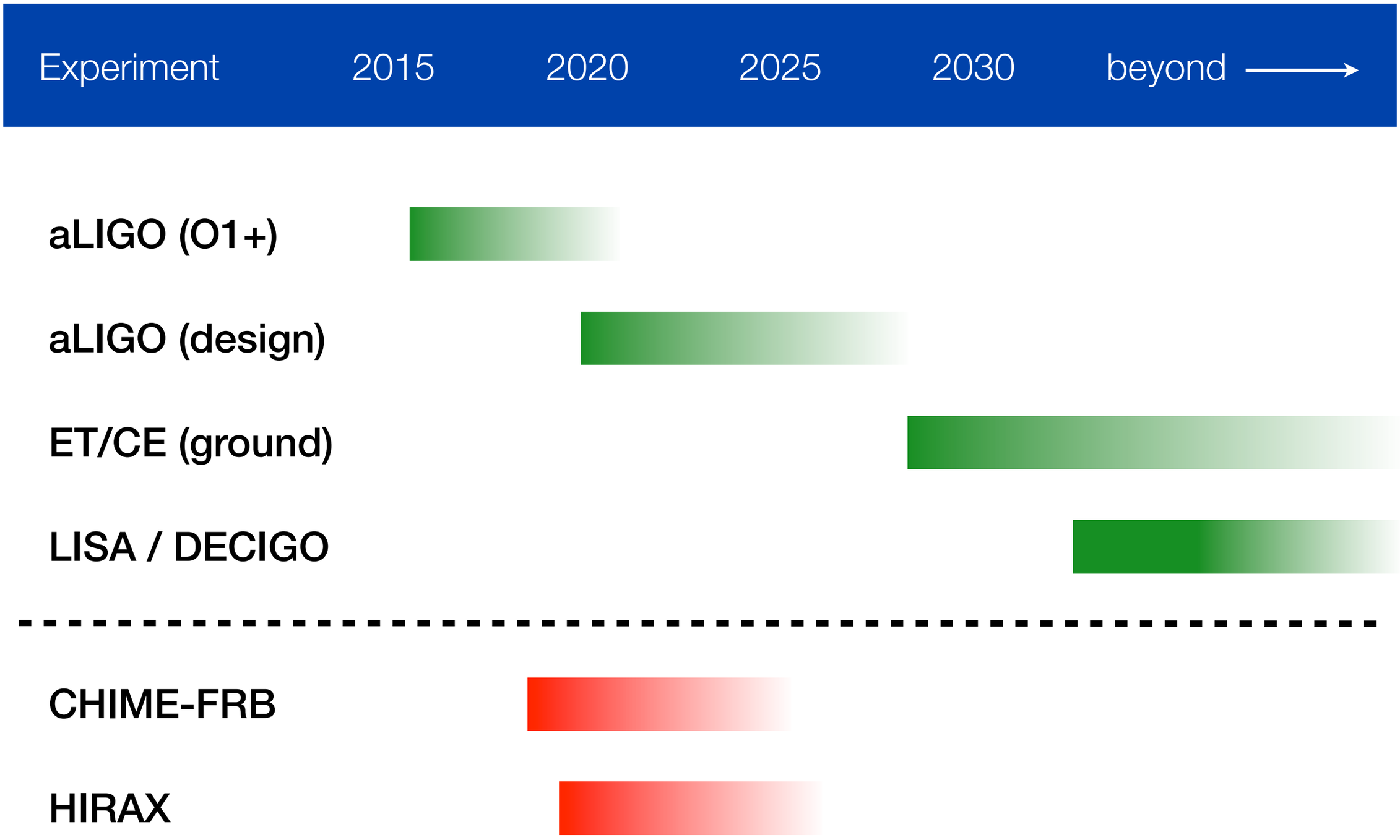
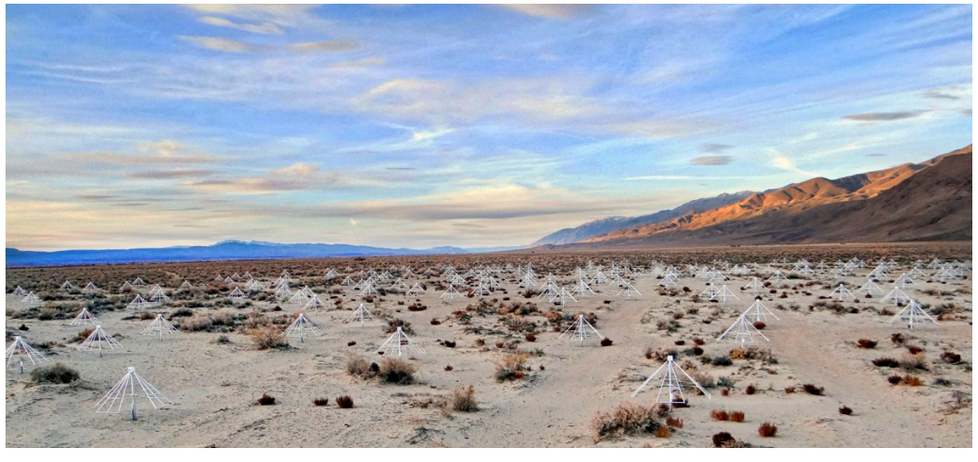
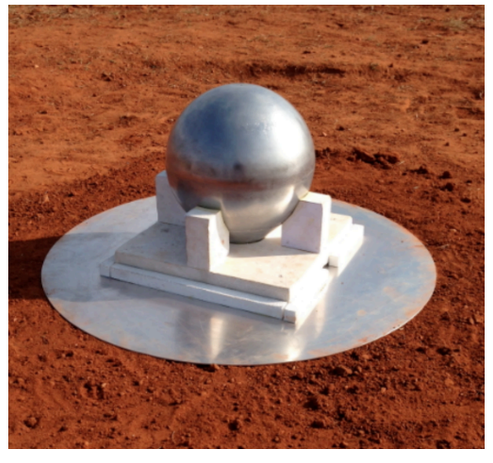
Observational Outlook: Timeline



Experimental Outlook

- 21cm global signal: LEDA, PRIZM, SARAS2...





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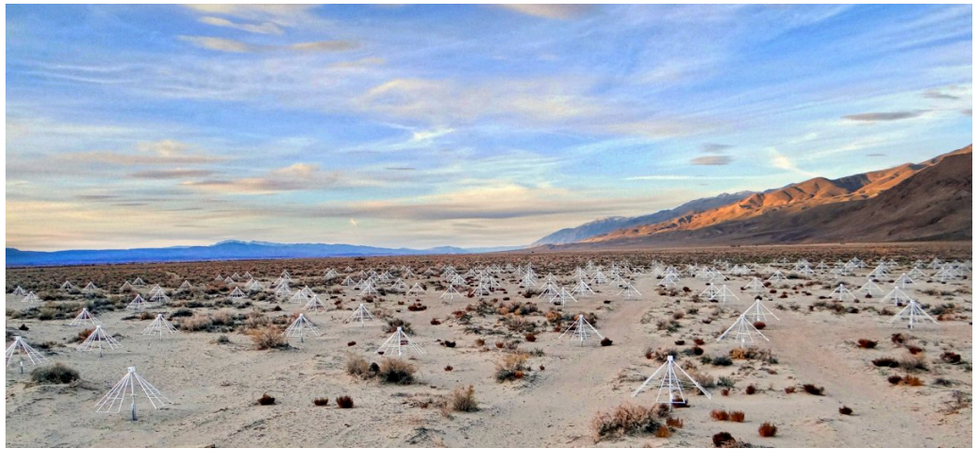

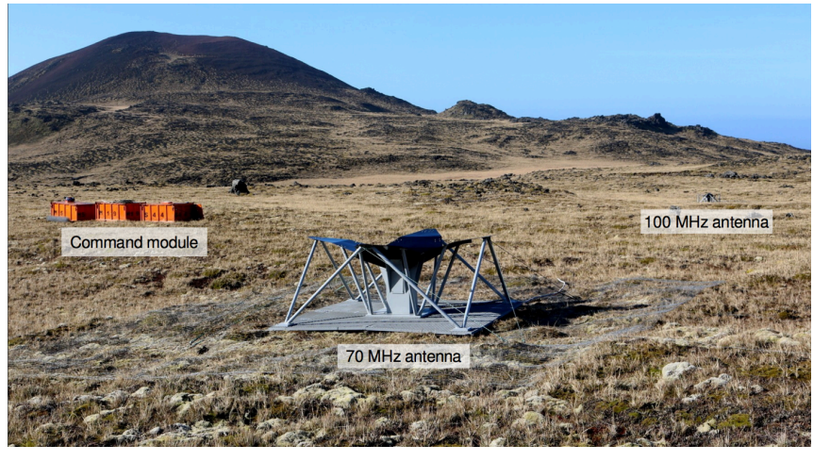

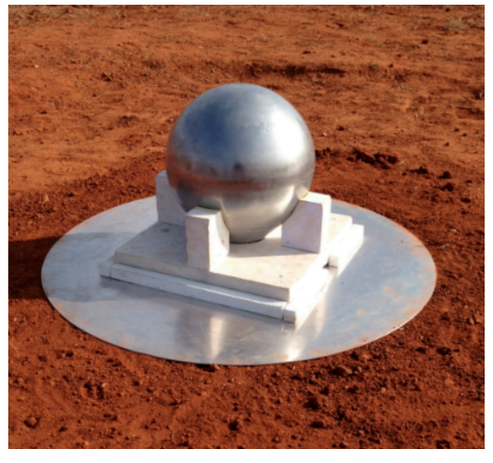

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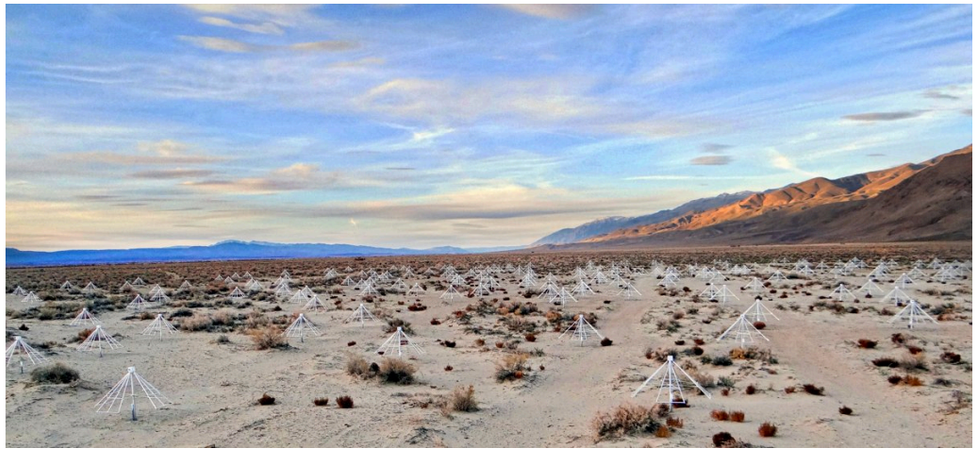

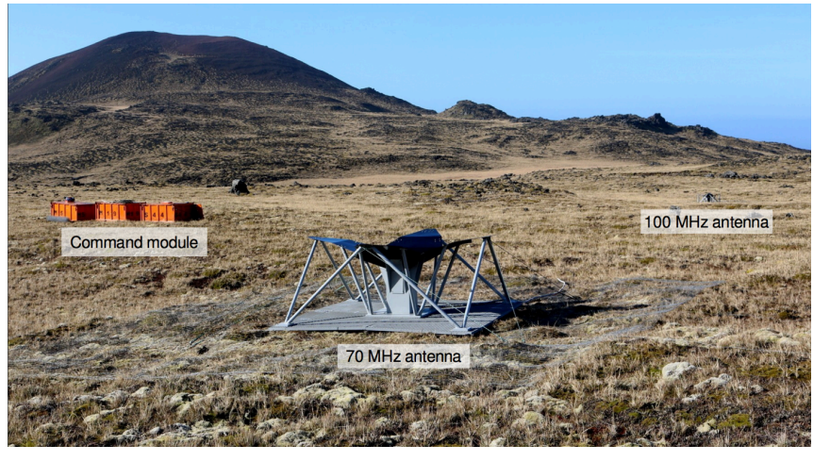

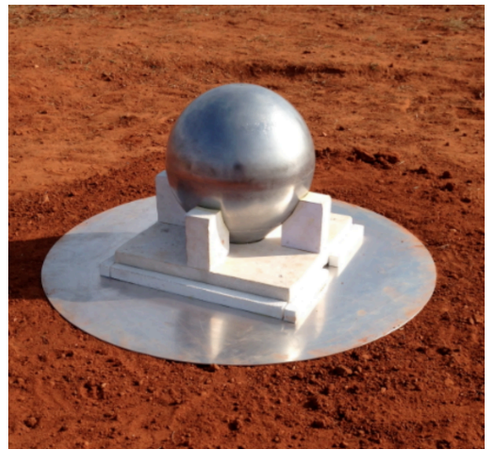

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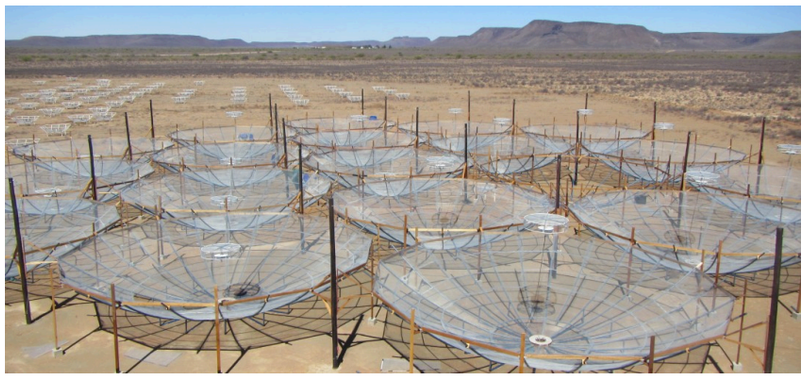

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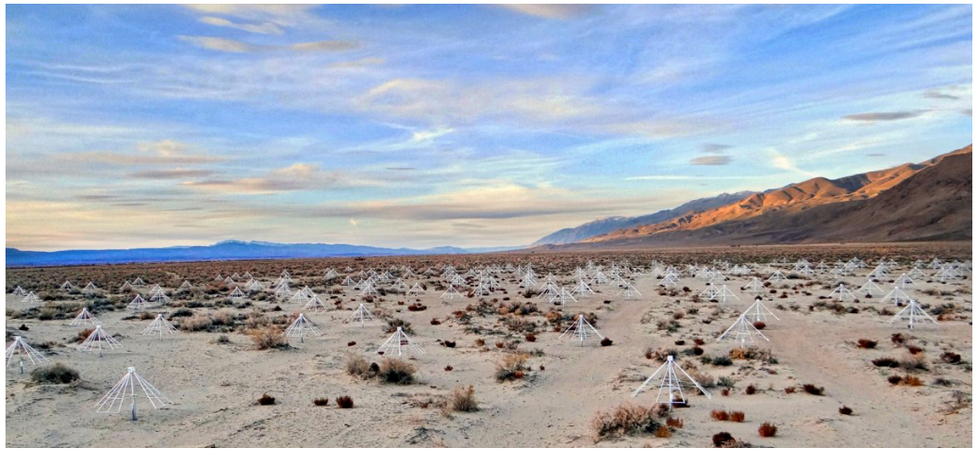

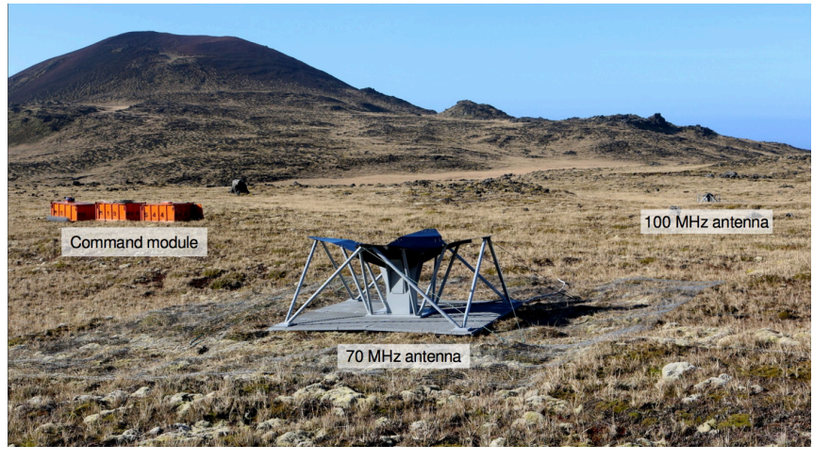

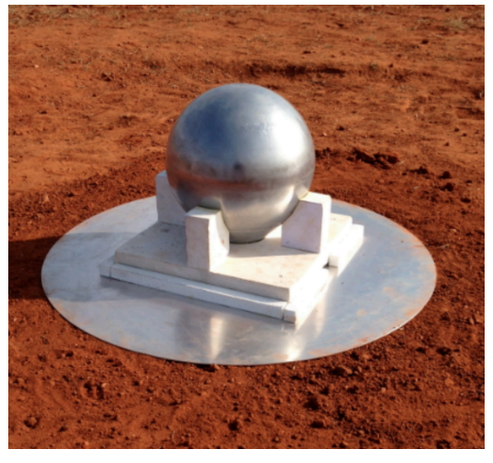

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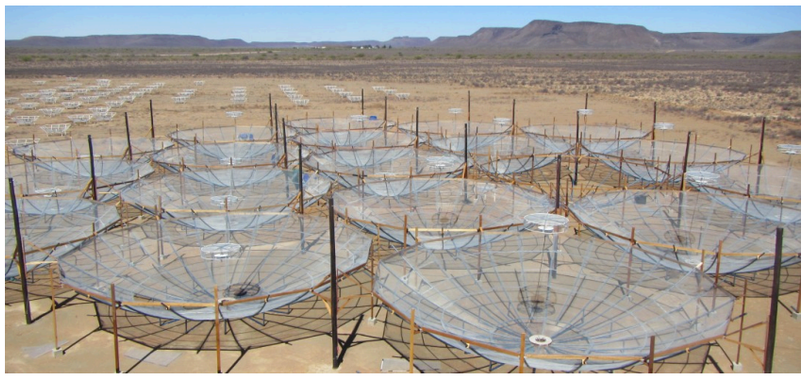

If EDGES is correct, power spectrum signal should be x10 higher than expected.

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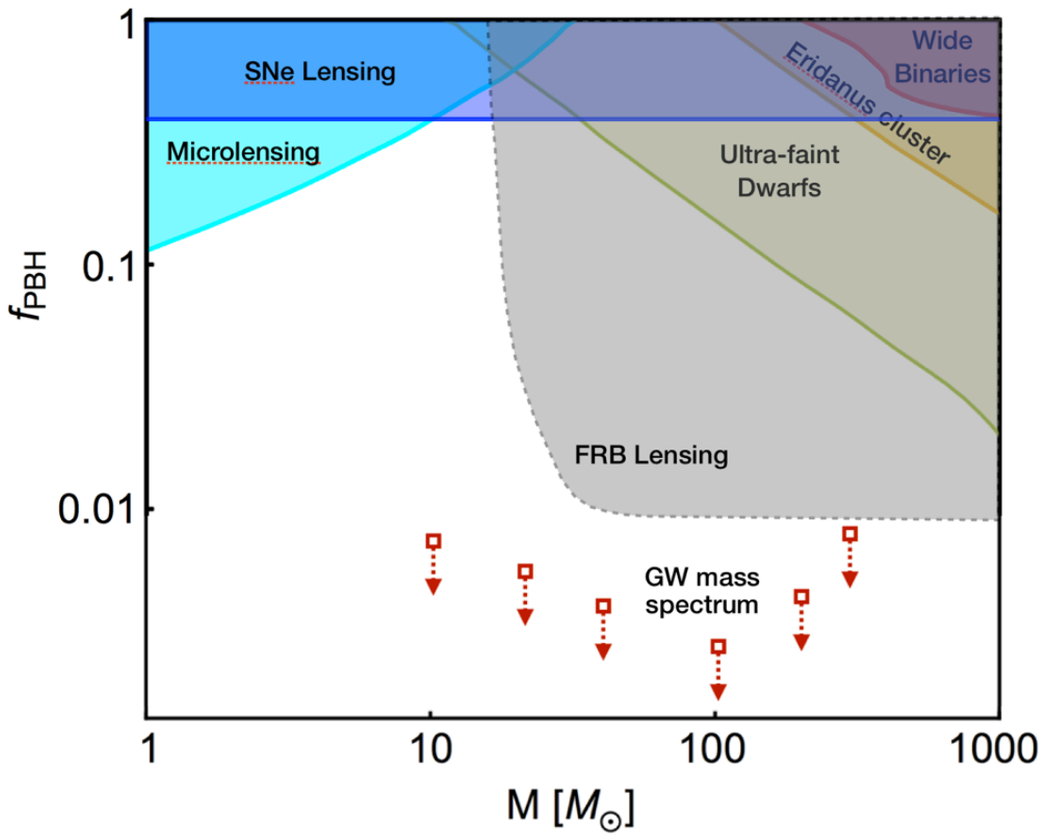

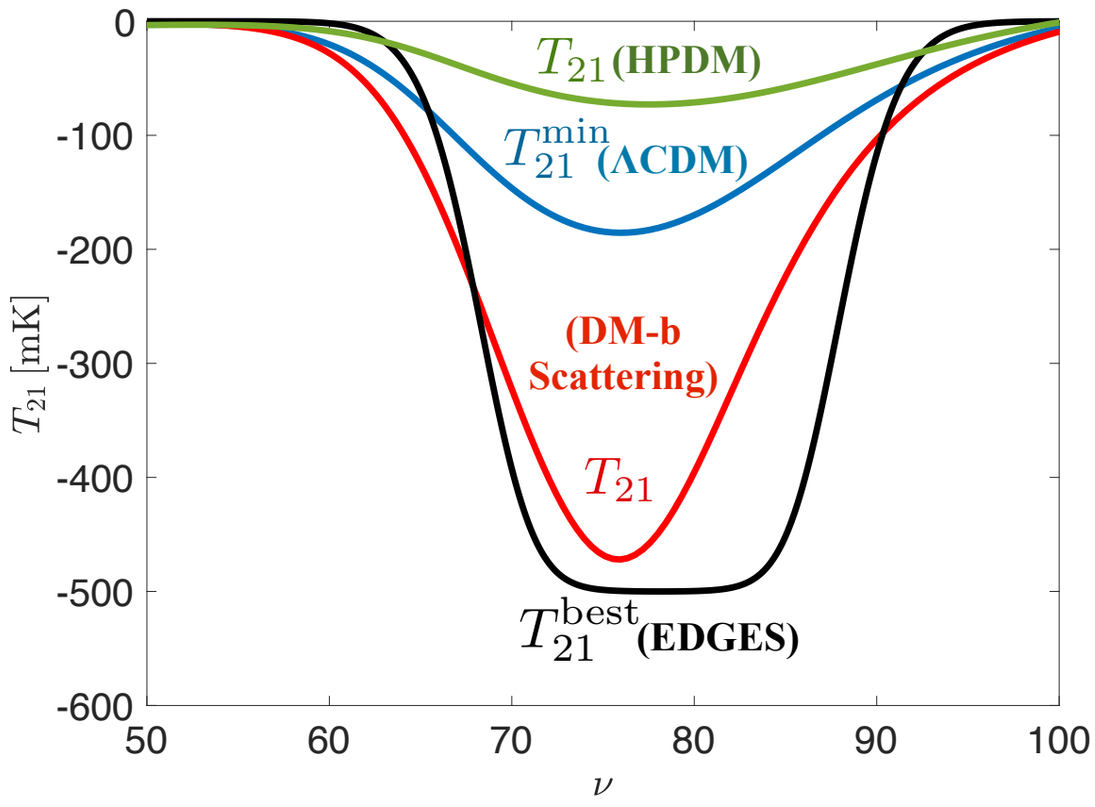

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