# The LIGO Discovery and Massive Compact Dark Matter

**Ely D. Kovetz**
Johns Hopkins University

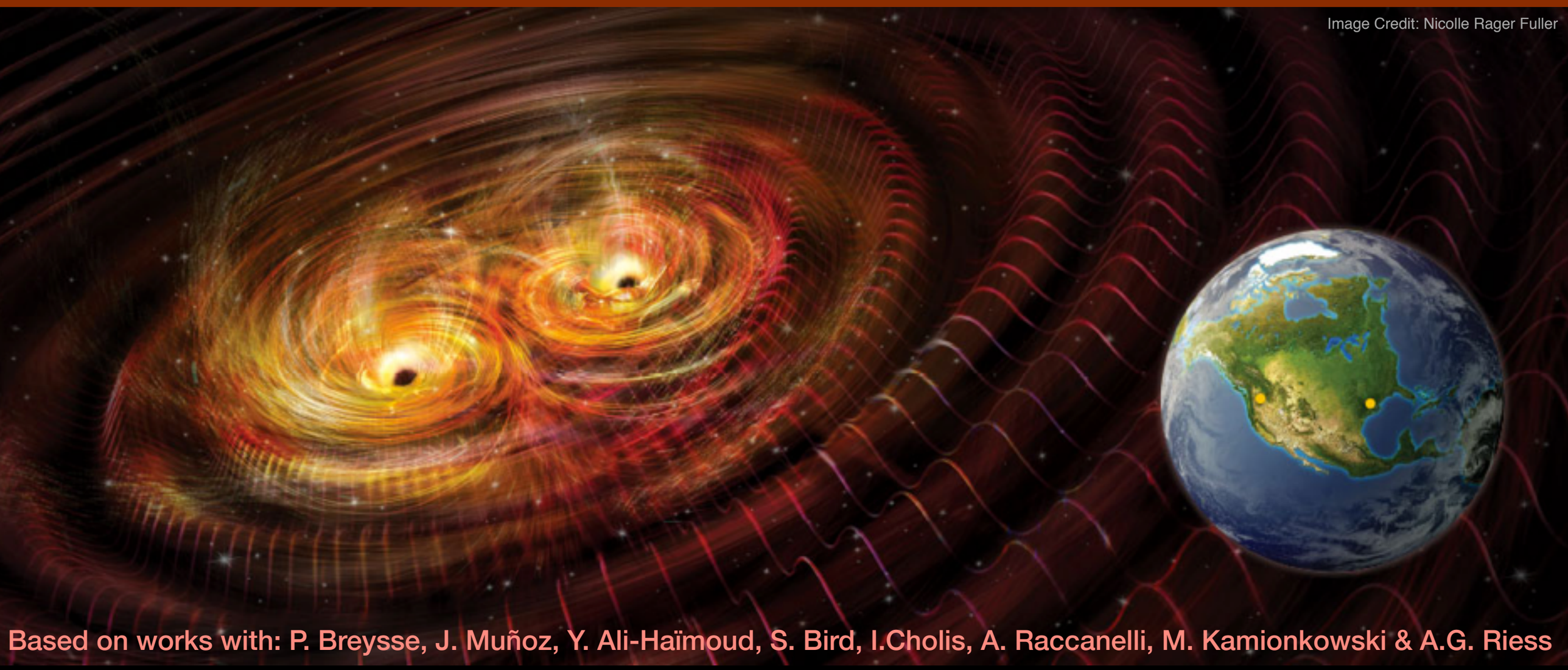
Image Credit: Nicolle Rager Fuller

Based on works with: P. Breysse, J. Muñoz, Y. Ali-Haïmoud, S. Bird, I.Cholis, A. Raccanelli, M. Kamionkowski & A.G. Riess

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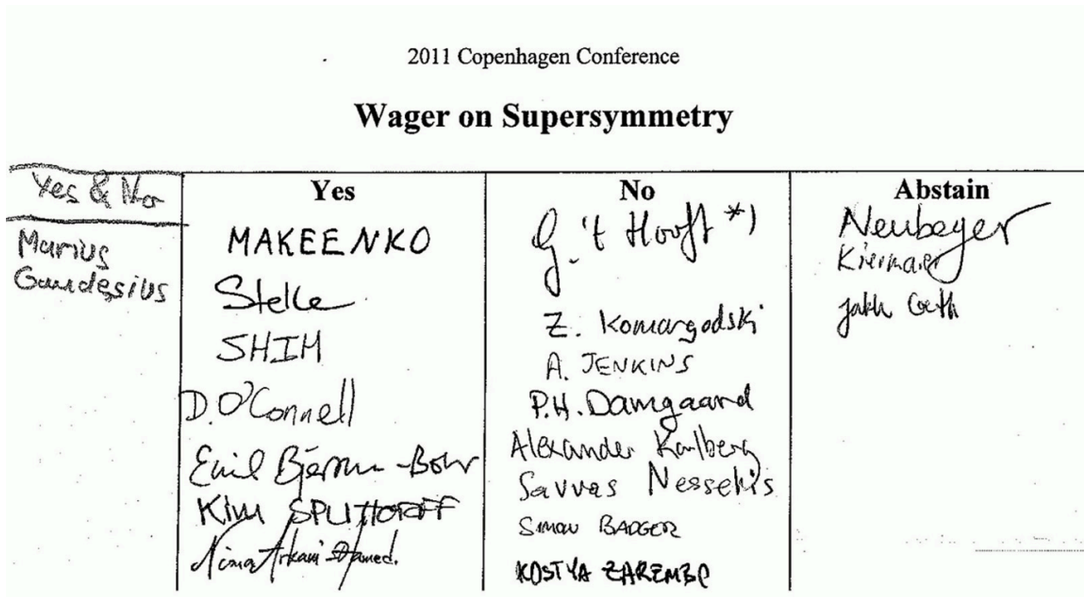

2011 Copenhagen Conference

**Wager on Supersymmetry**

| Yes & No | Yes | No | Abstain |
|---|---|---|---|
| Marius Gundersius | MAKEENKO | G. 't Hooft *) | Neubeyer |
| | Stelle | Z. Komargodski | Kiermaier |
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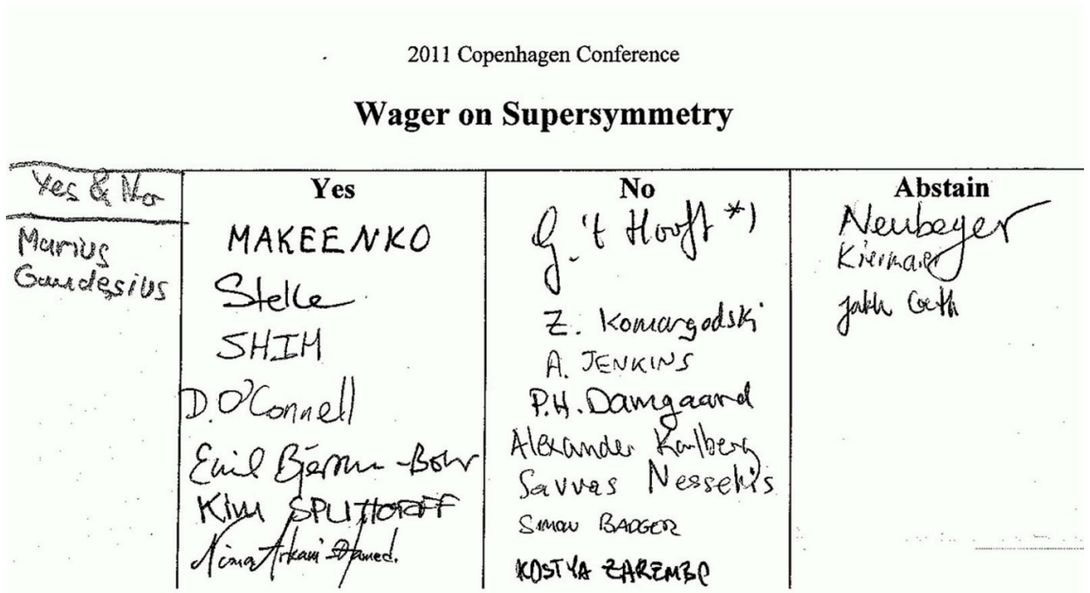

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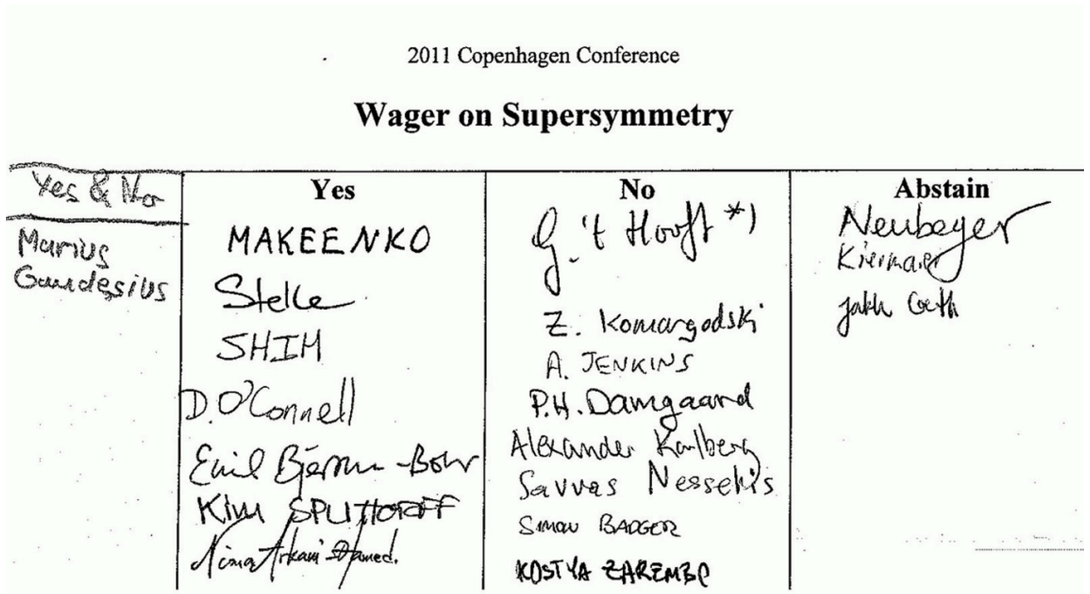

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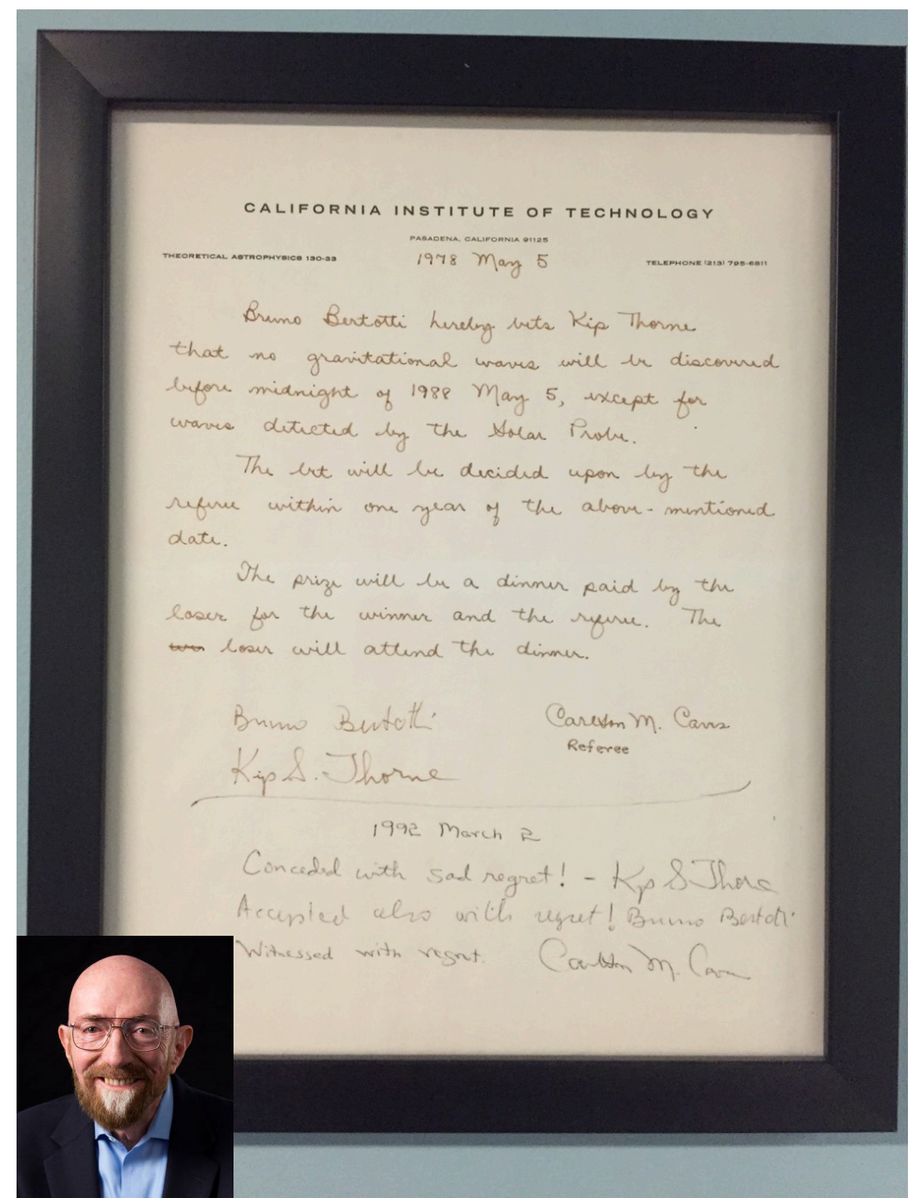

CALIFORNIA INSTITUTE OF TECHNOLOGY

PASADENA, CALIFORNIA 91125

THEORETICAL ASTROPHYSICS 130-33 — 1978 May 5 — TELEPHONE (213) 795-6811

Bruno Bertotti hereby bets Kip Thorne that no gravitational waves will be discovered before midnight of 1988 May 5, except for waves detected by the Solar Probe.

The bet will be decided upon by the referee within one year of the above-mentioned date.

The prize will be a dinner paid by the loser for the winner and the referee. The ~~two~~ loser will attend the dinner.

Bruno Bertotti — Carlton M. Caves, Referee

Kip S. Thorne

1992 March 2

Conceded with sad regret! – Kip S. Thorne

Accepted also with regret! Bruno Bertotti

Witnessed with regret. Carlton M. Caves

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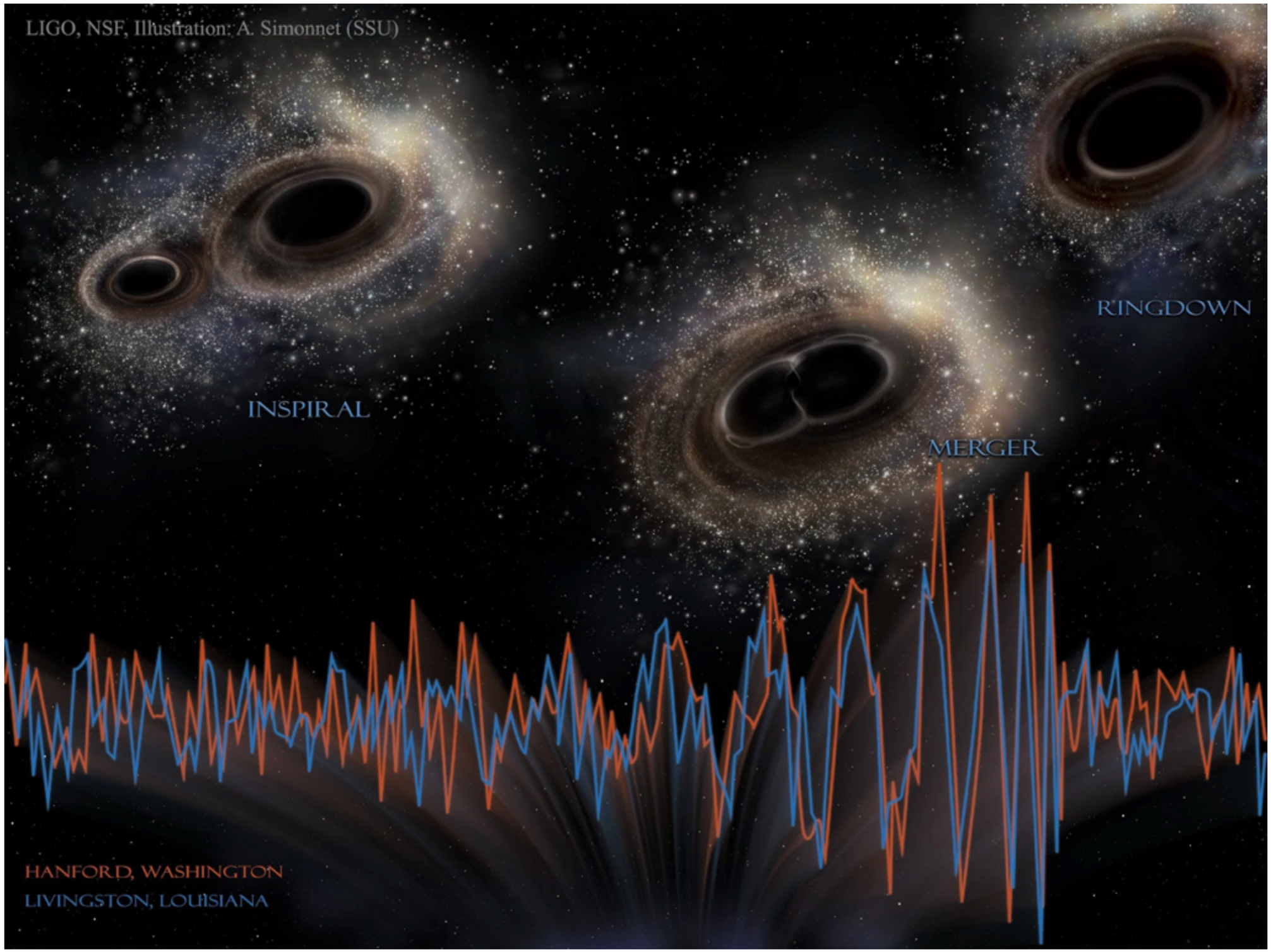

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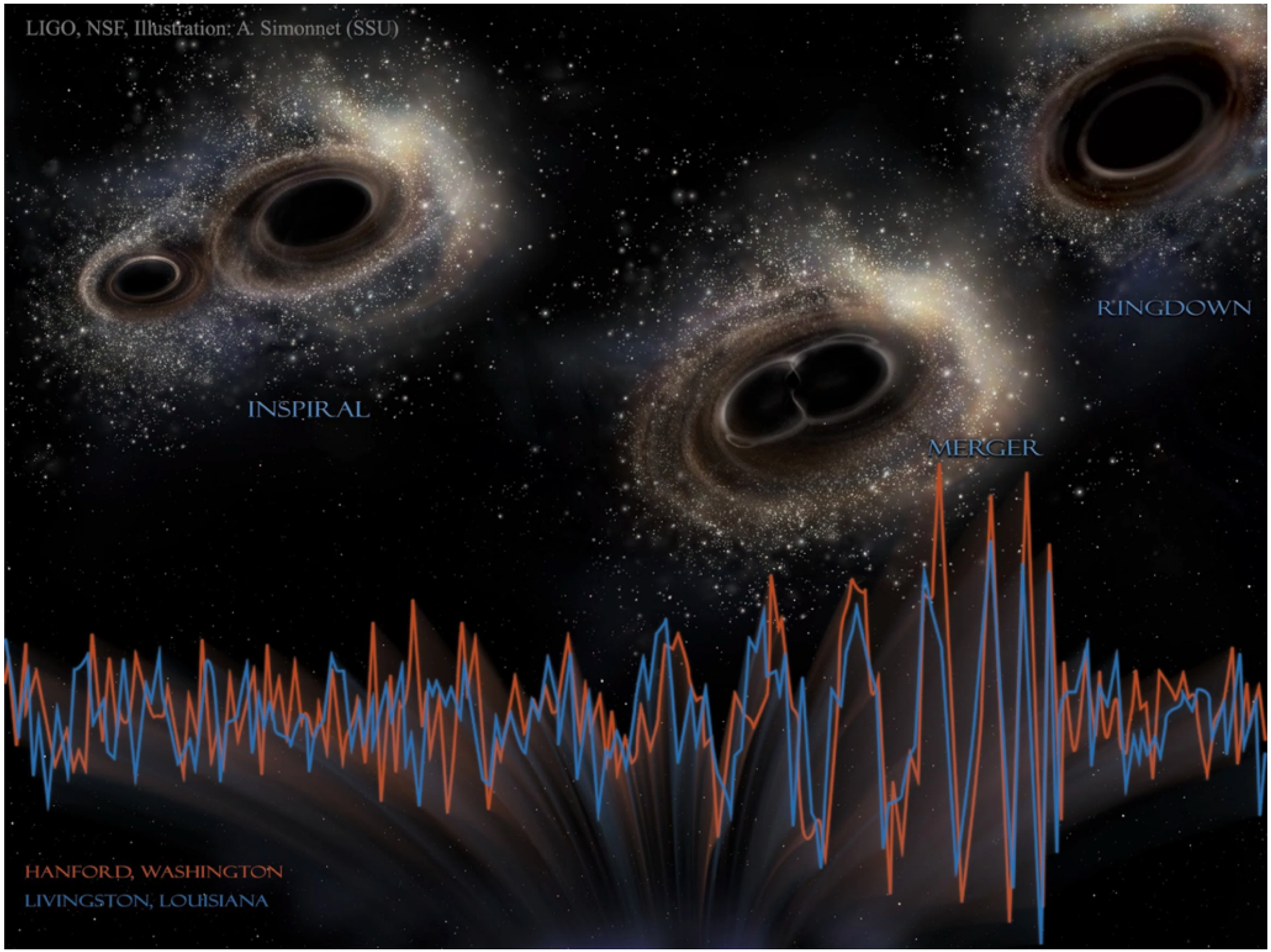

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Could these be primordial black holes?

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- Summary and observational outlook

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**“Did LIGO Detect Dark Matter?”**
**Bird, Cholis, Muñoz, Ali-Haïmoud, Kamionkowski, EDK, Raccanelli & Riess, Phys. Rev. Lett. 116 (2016)**

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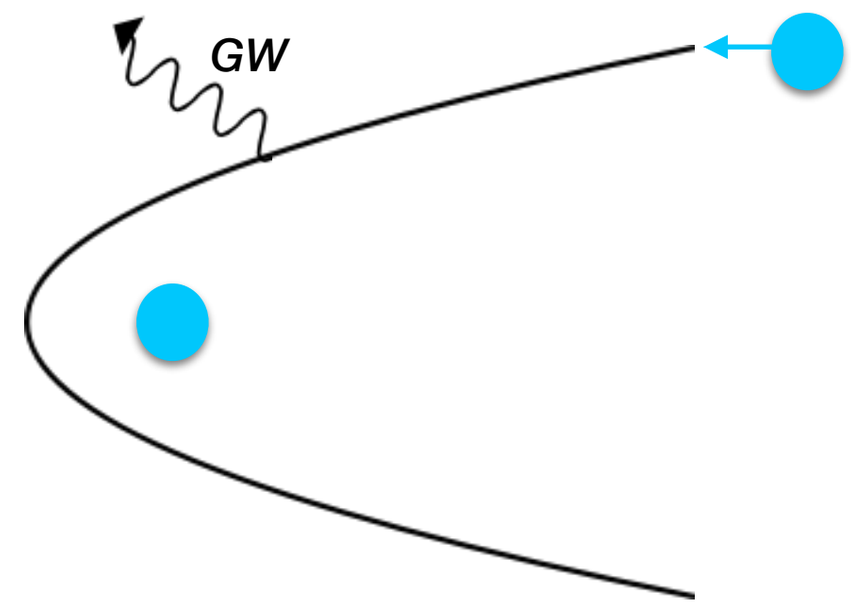

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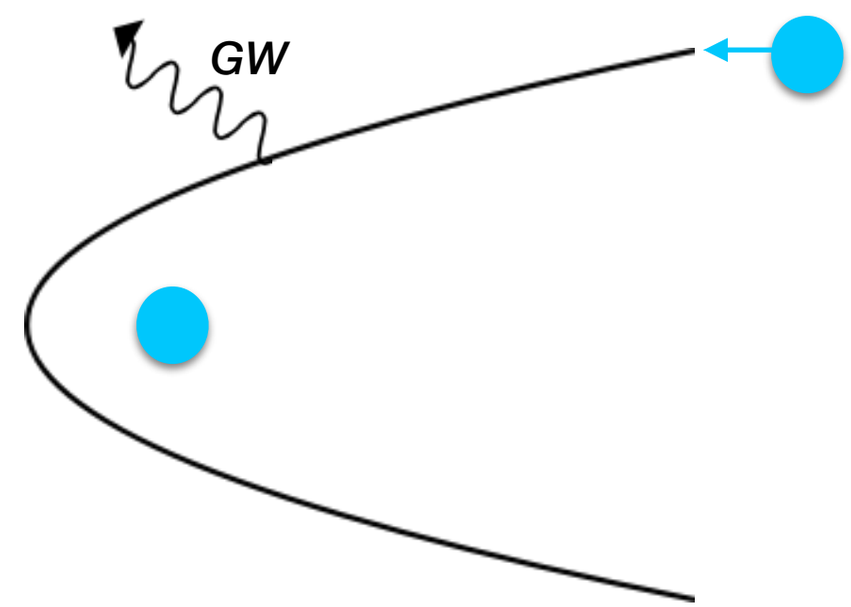

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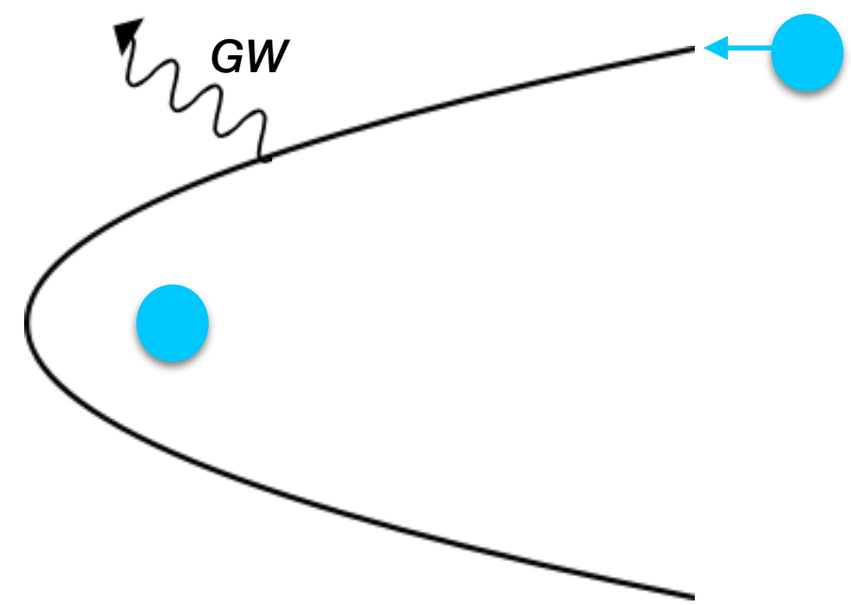

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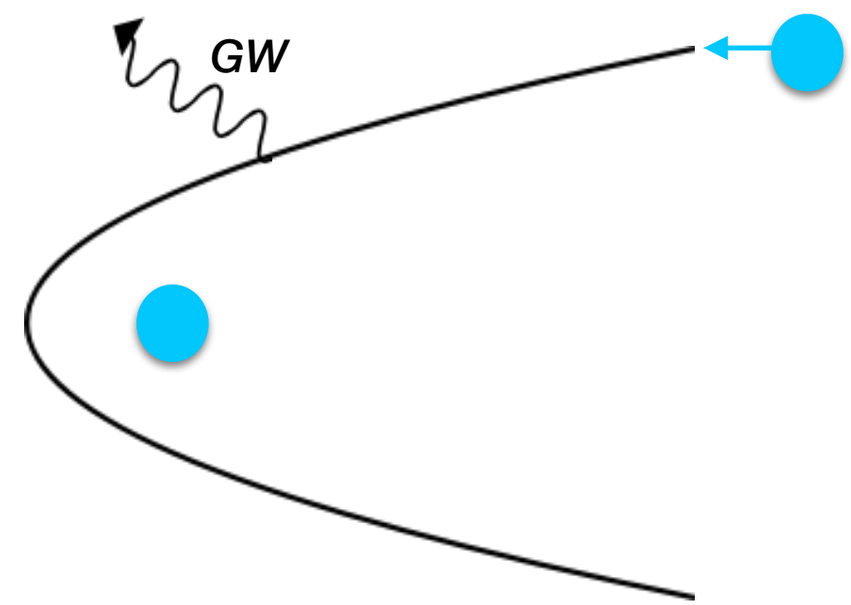

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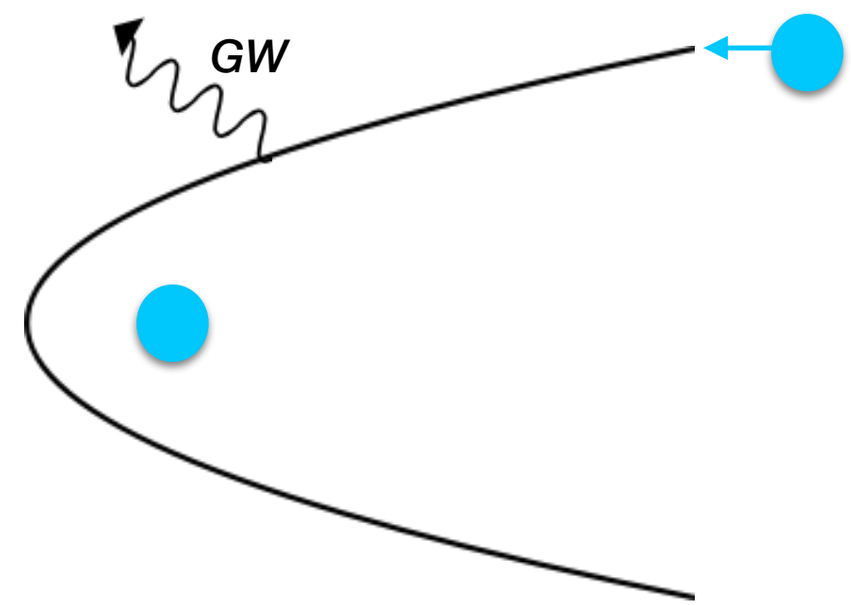


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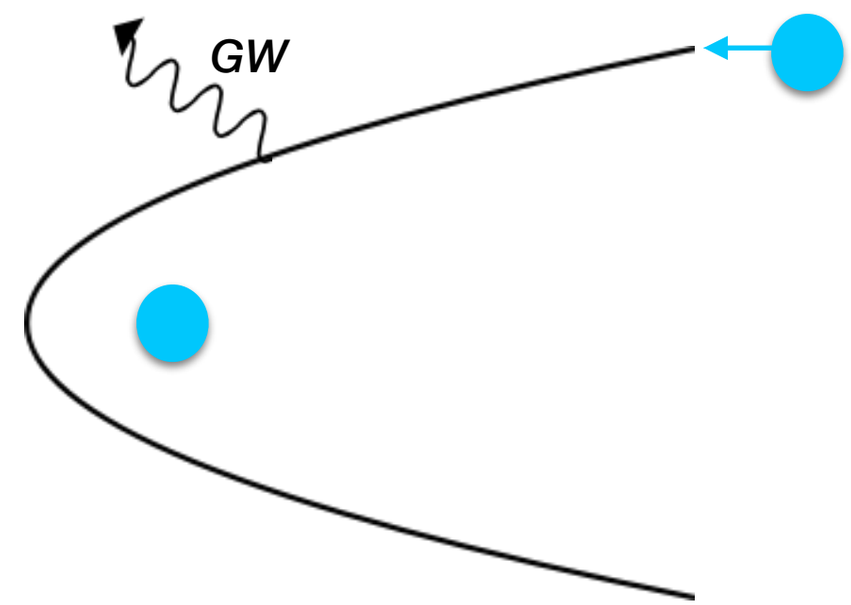


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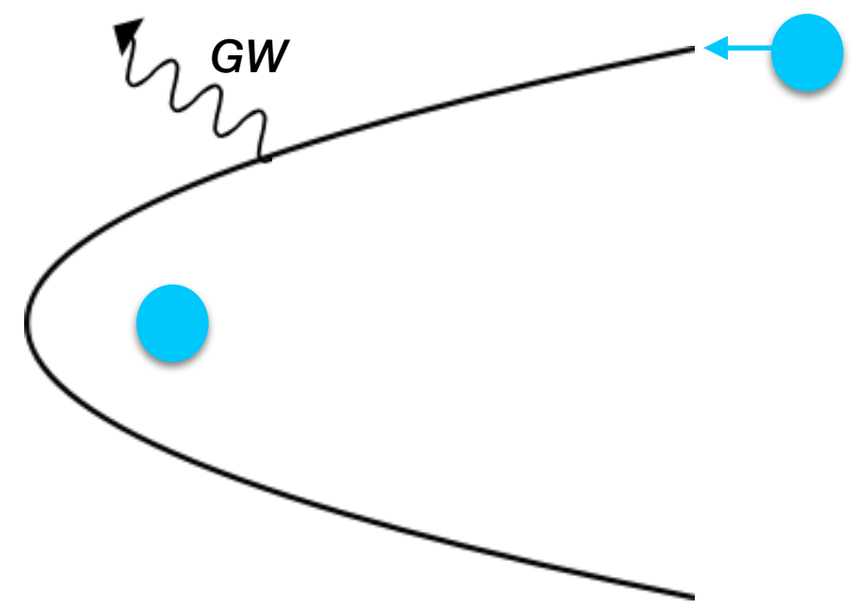


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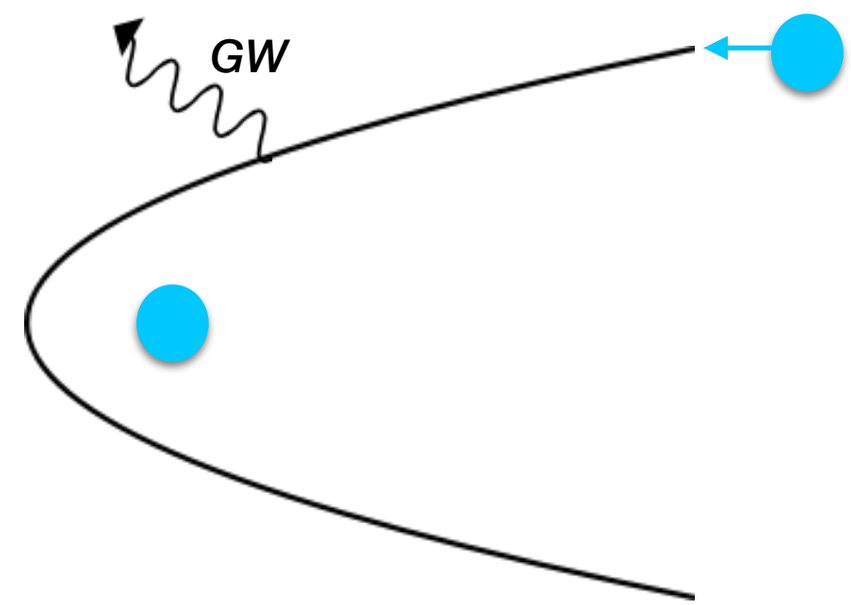


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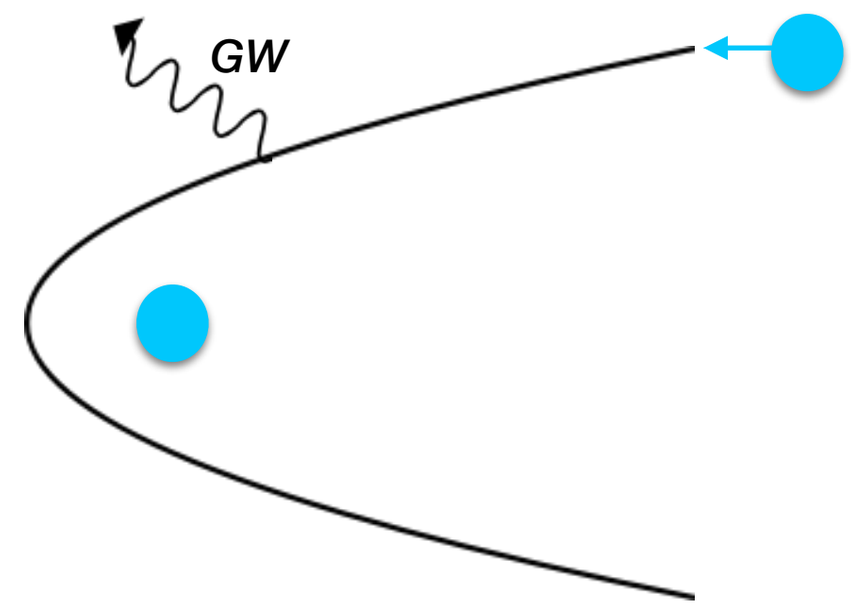


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Three-body interactions/captures: less relevant, much longer timescales.

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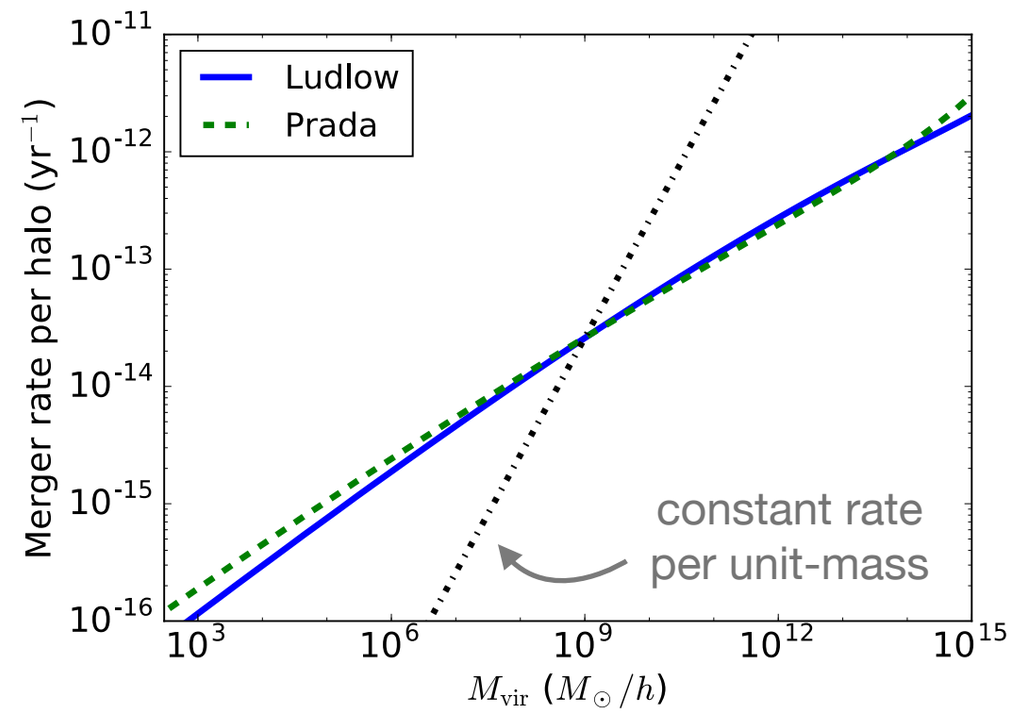

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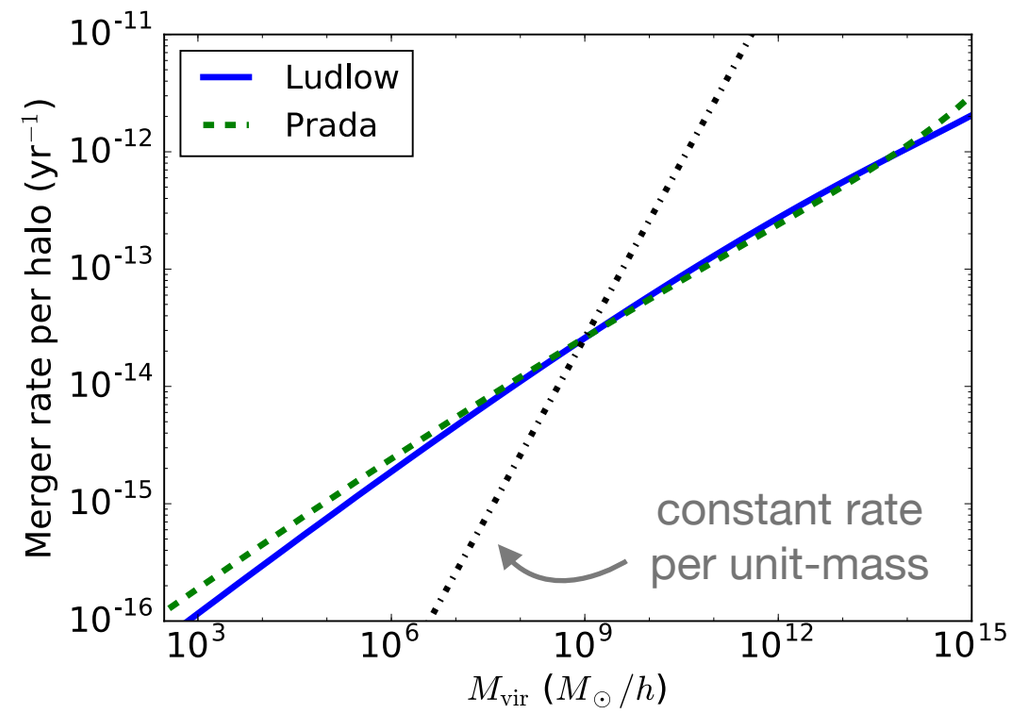


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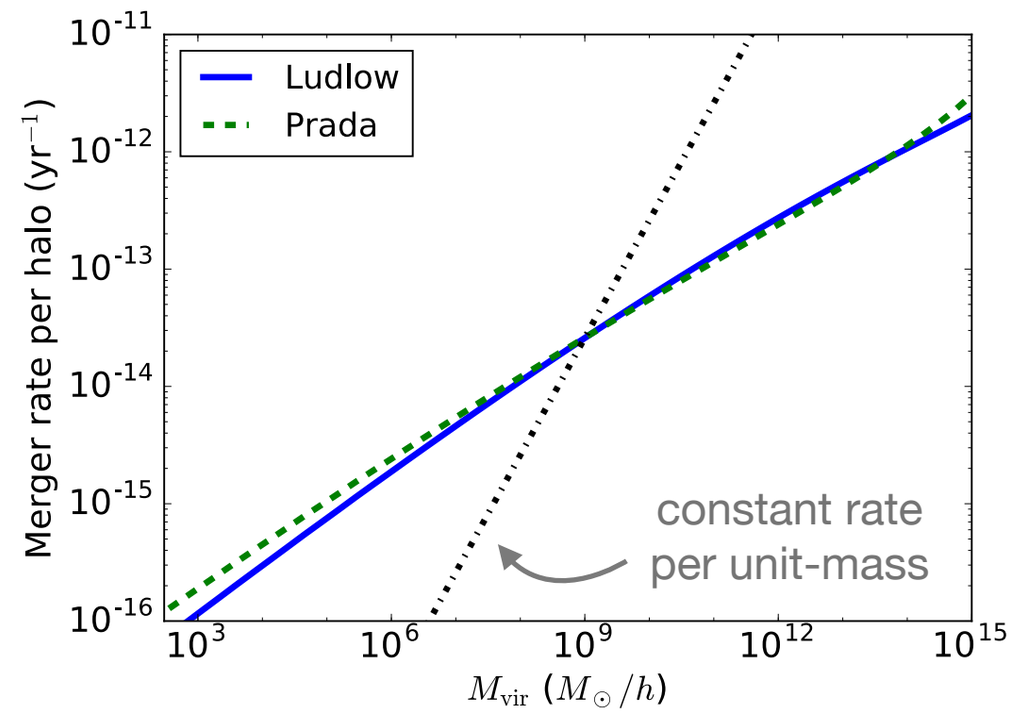


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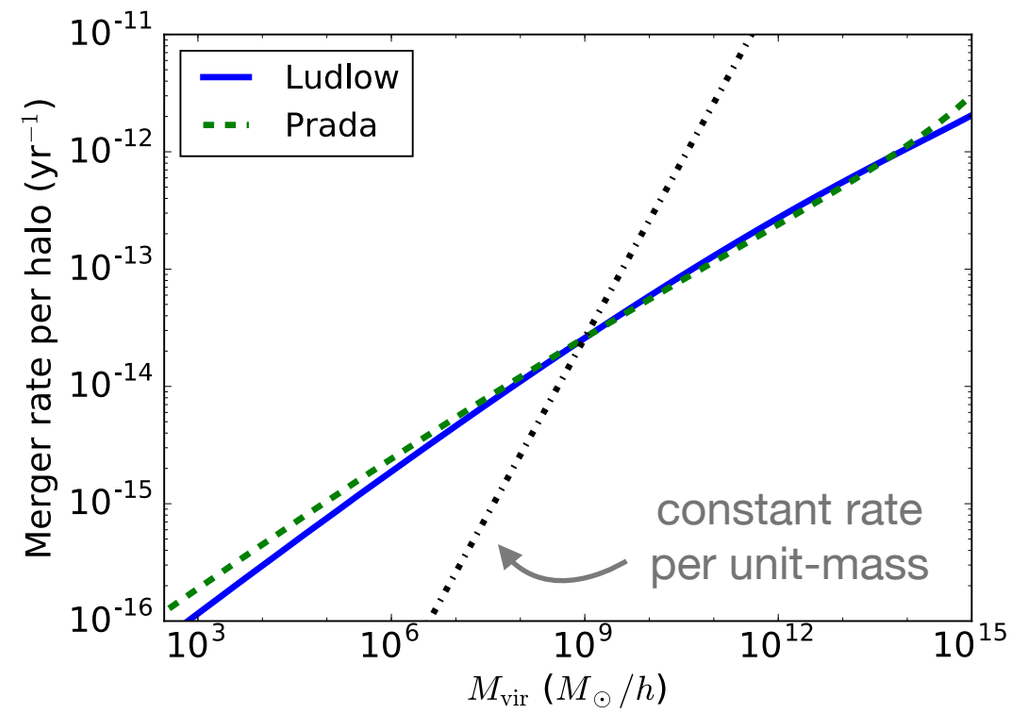


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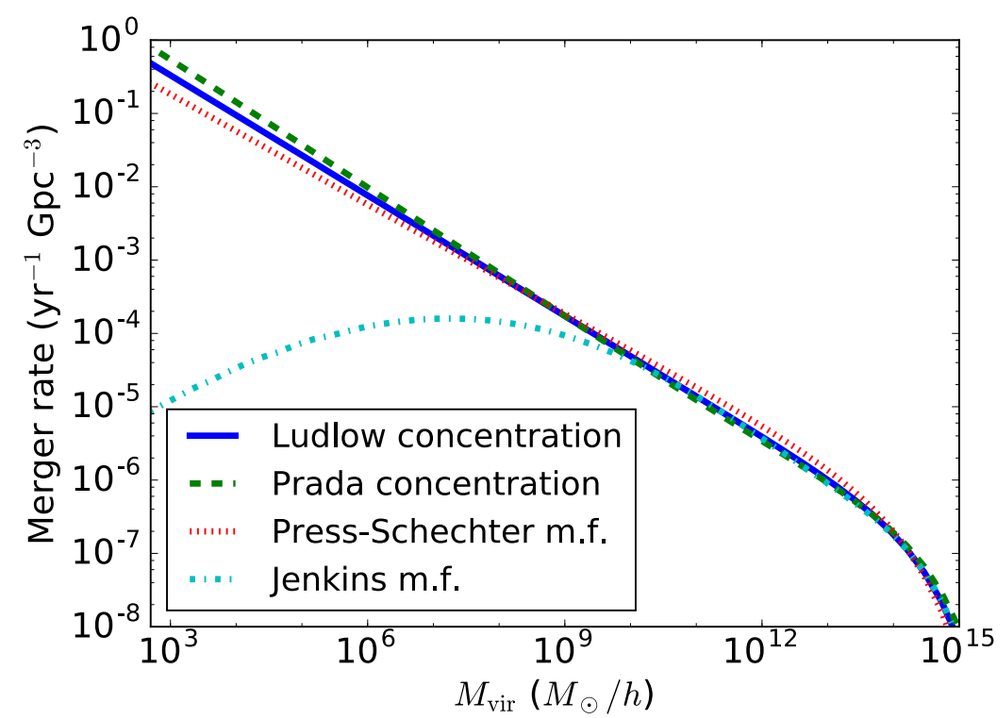

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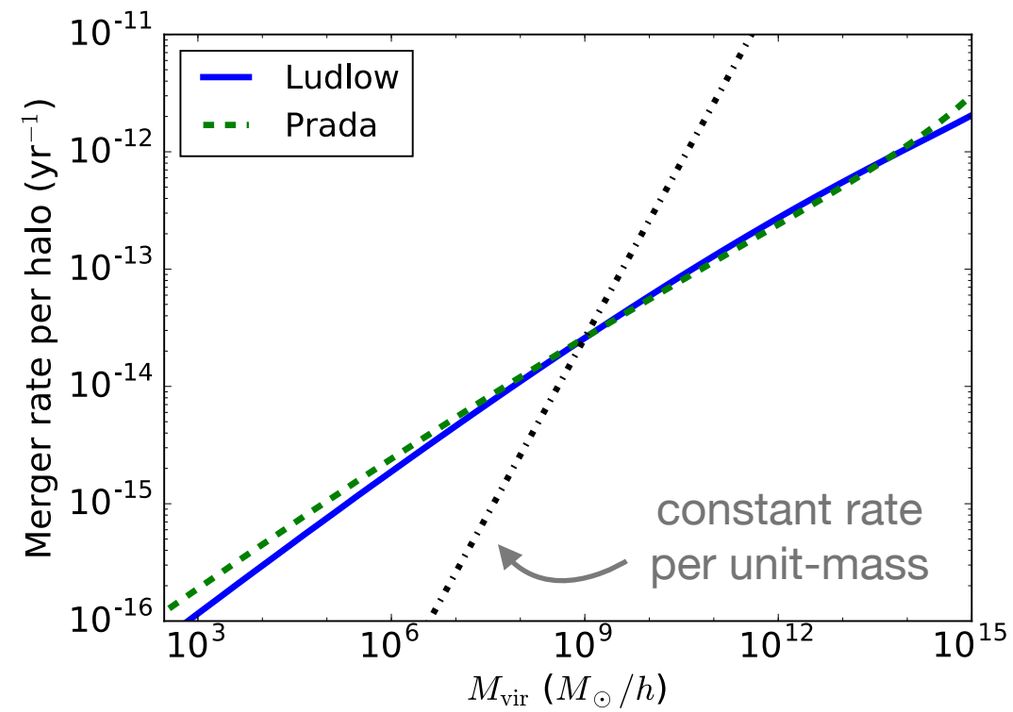


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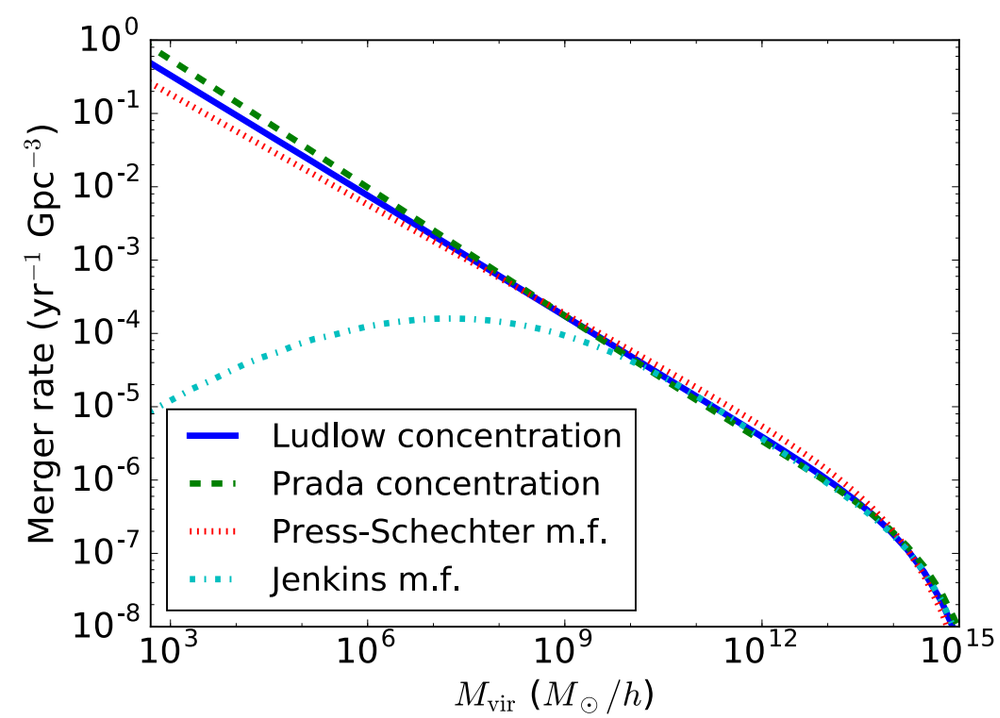


Dominated by smallest halos!!

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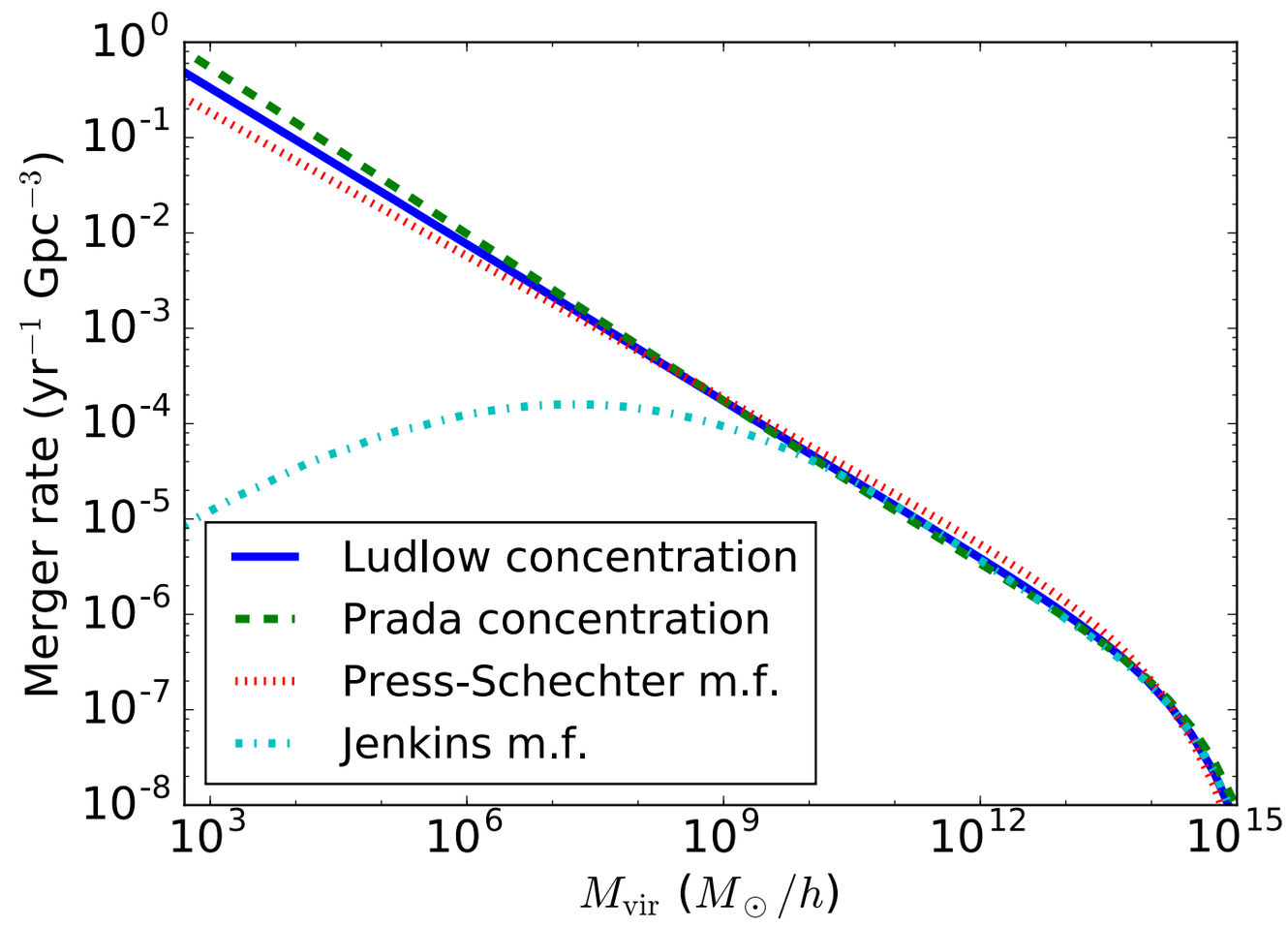

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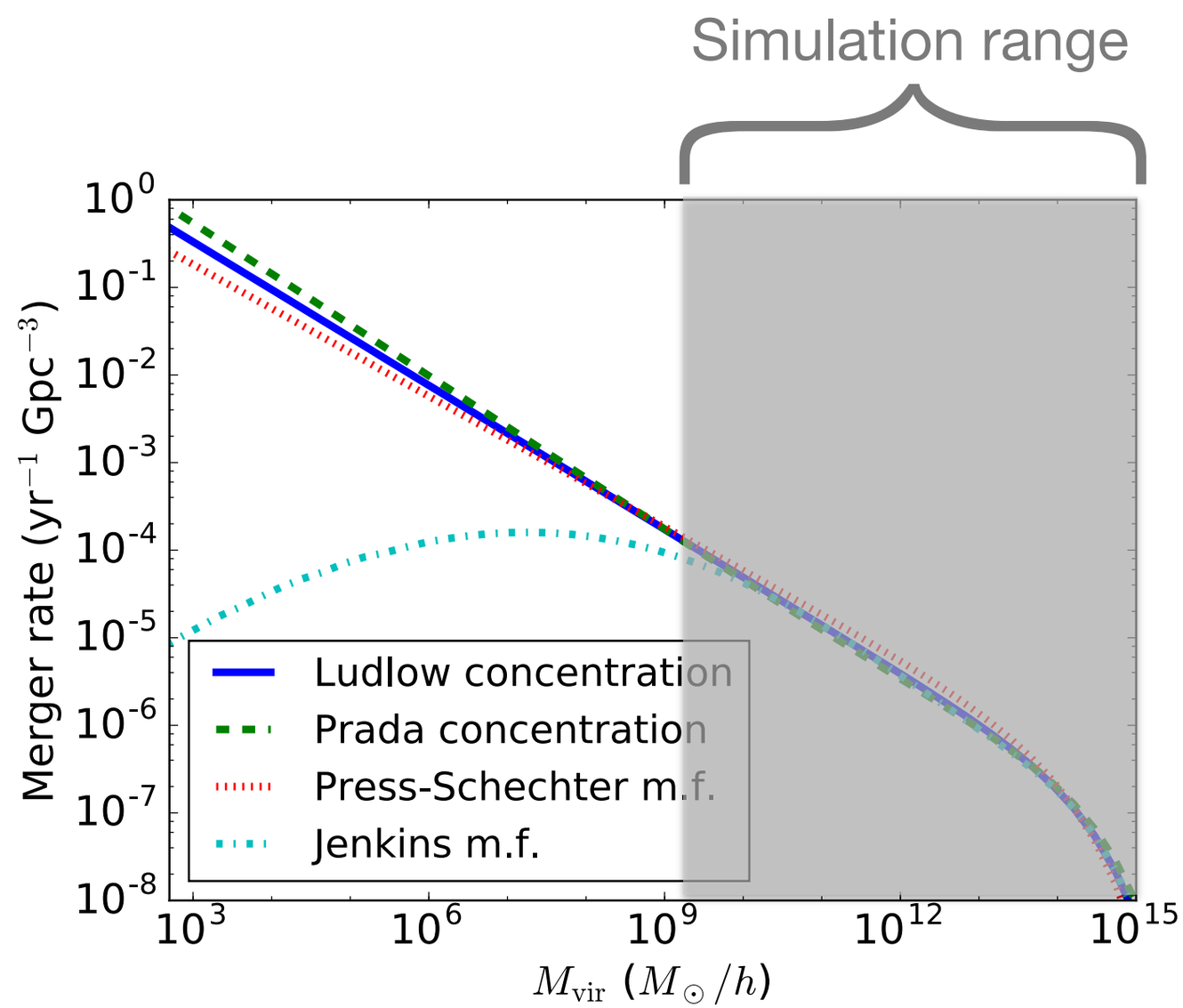

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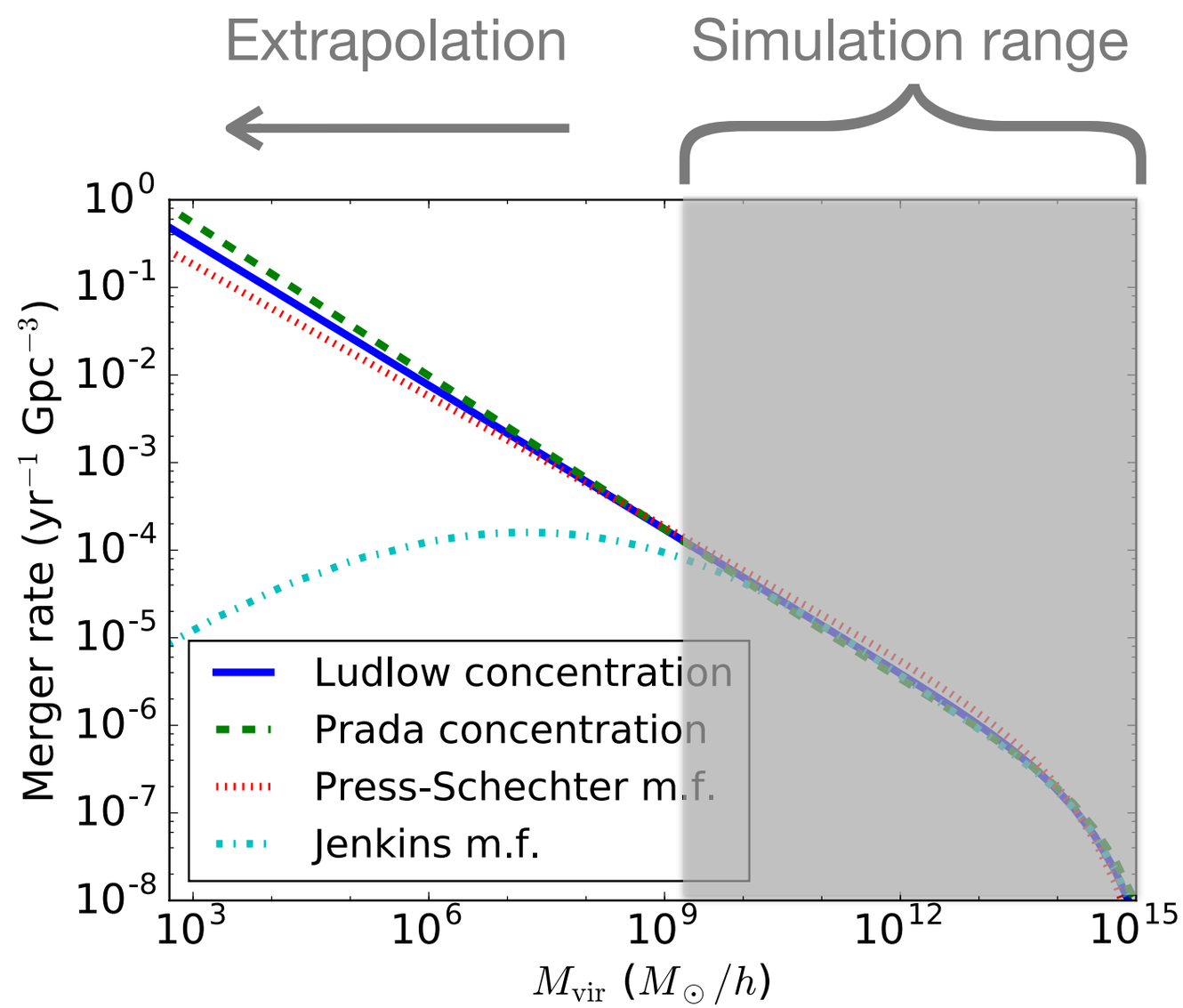

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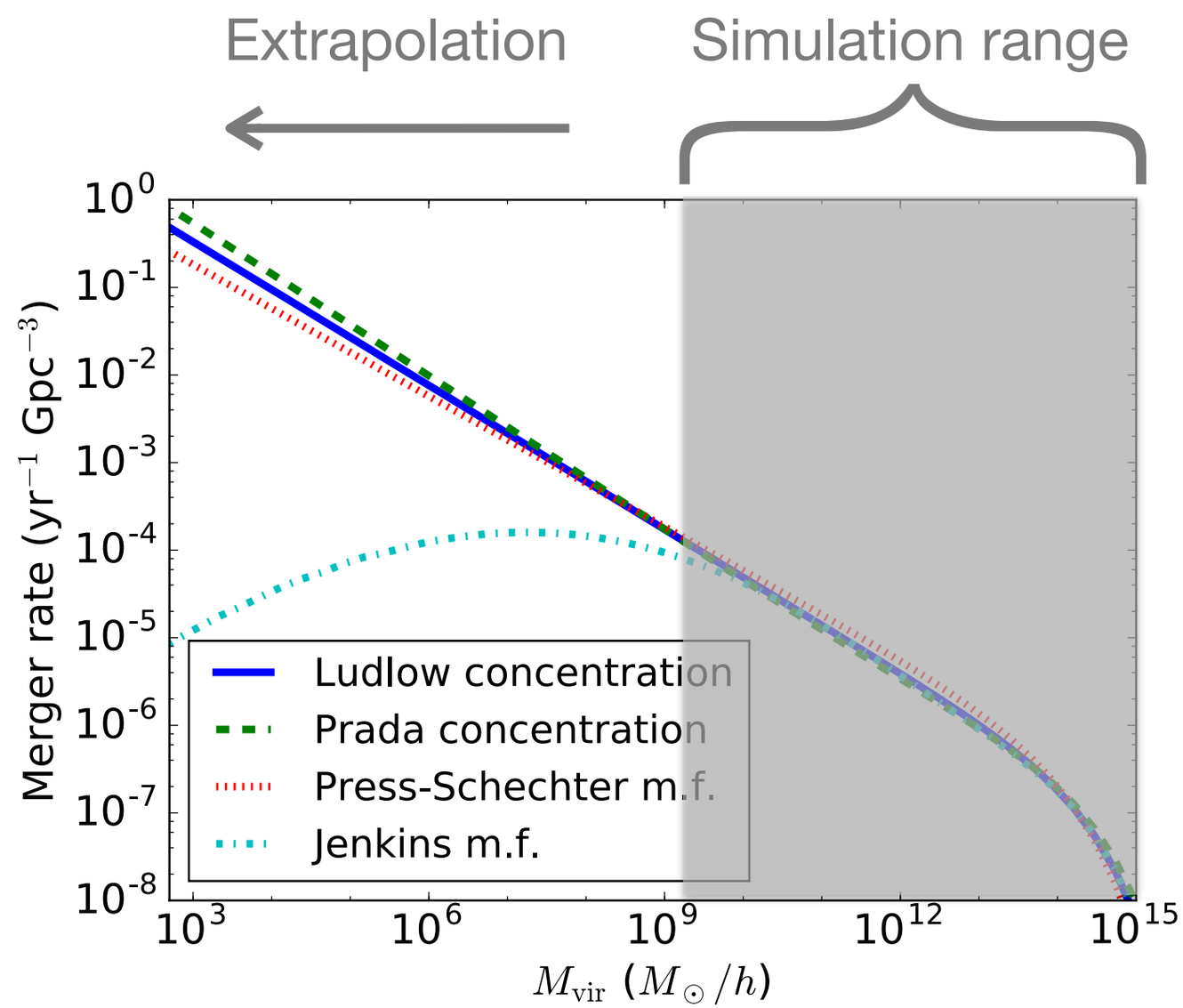
Q: Low mass cutoff?



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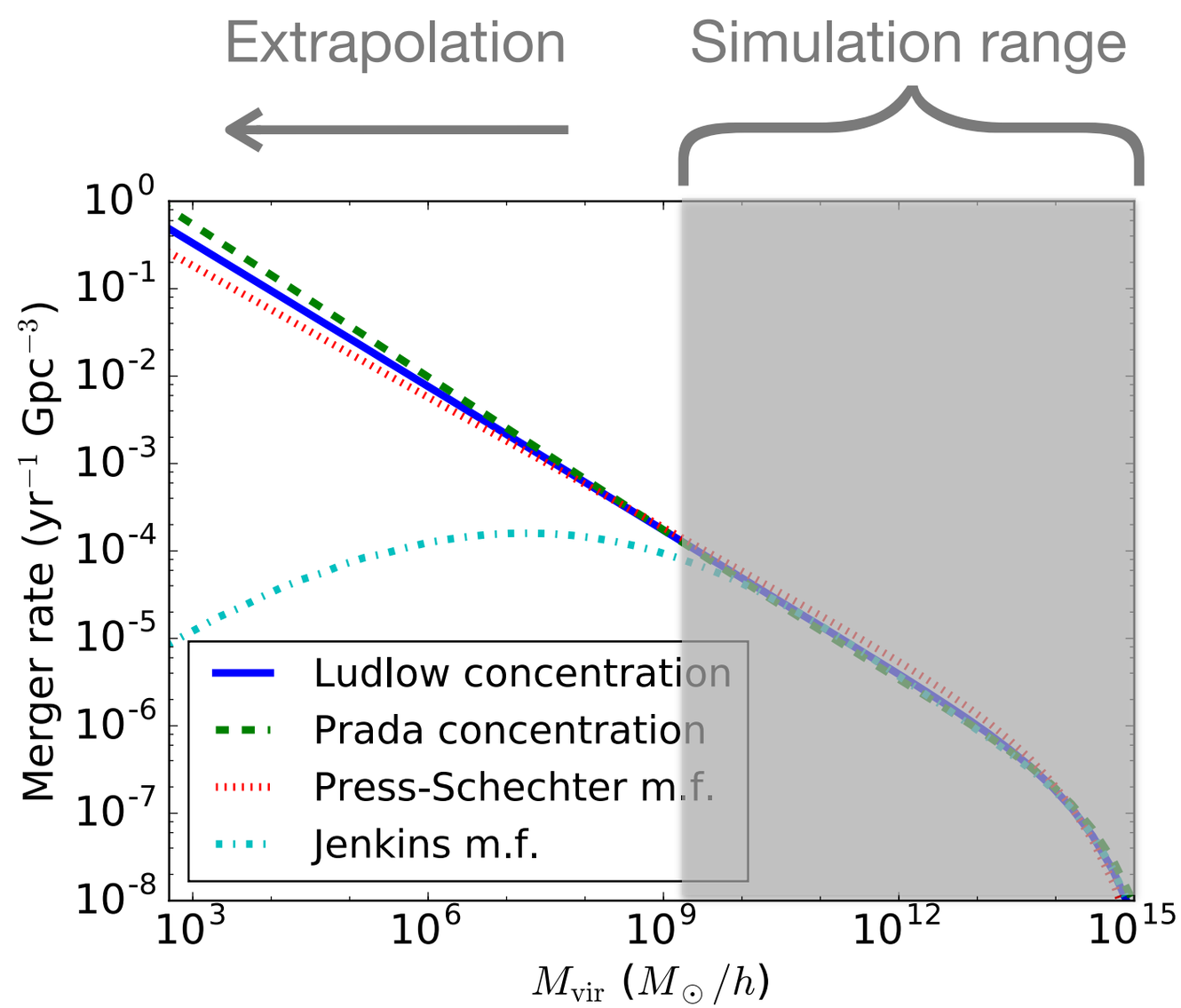

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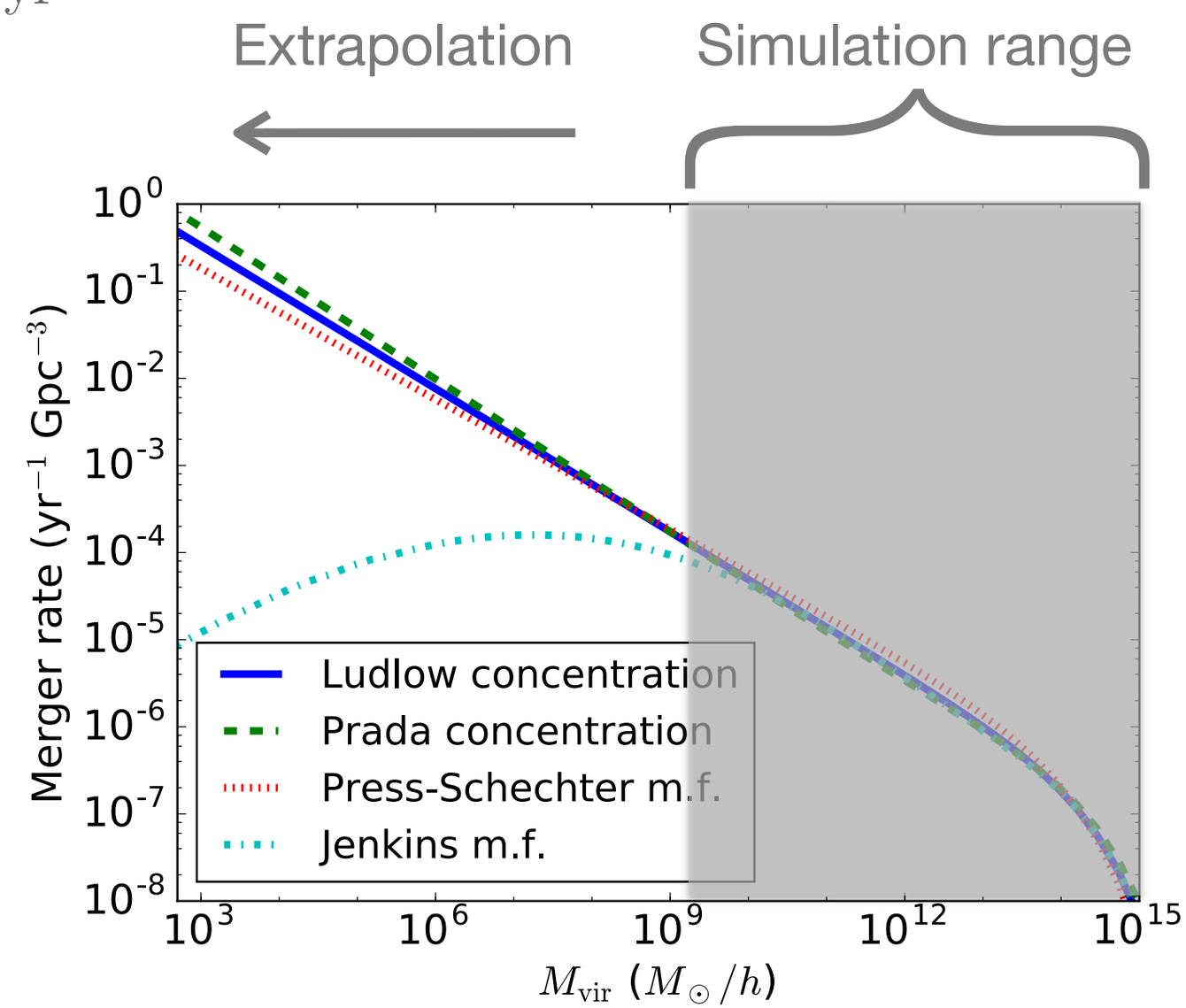

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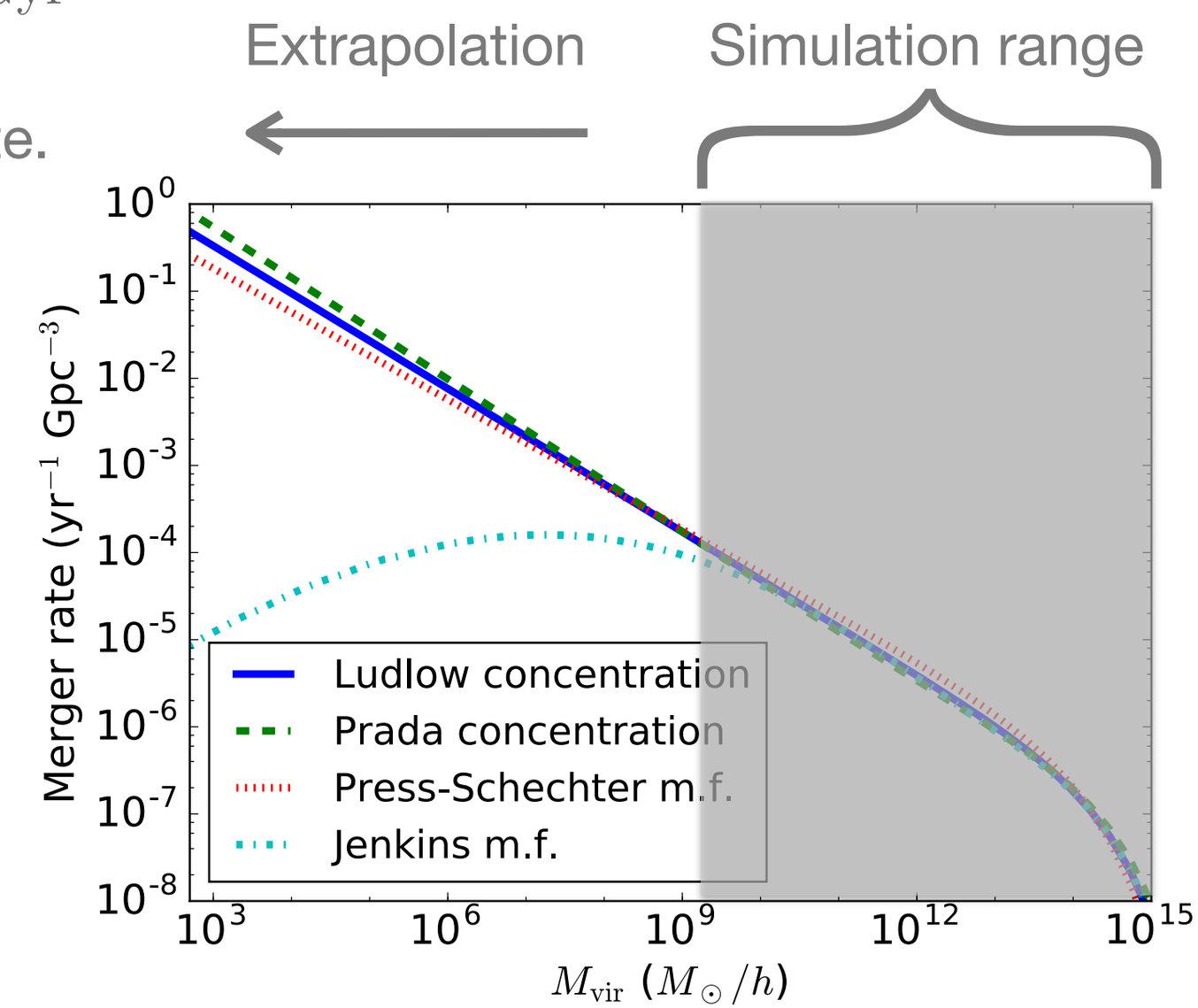

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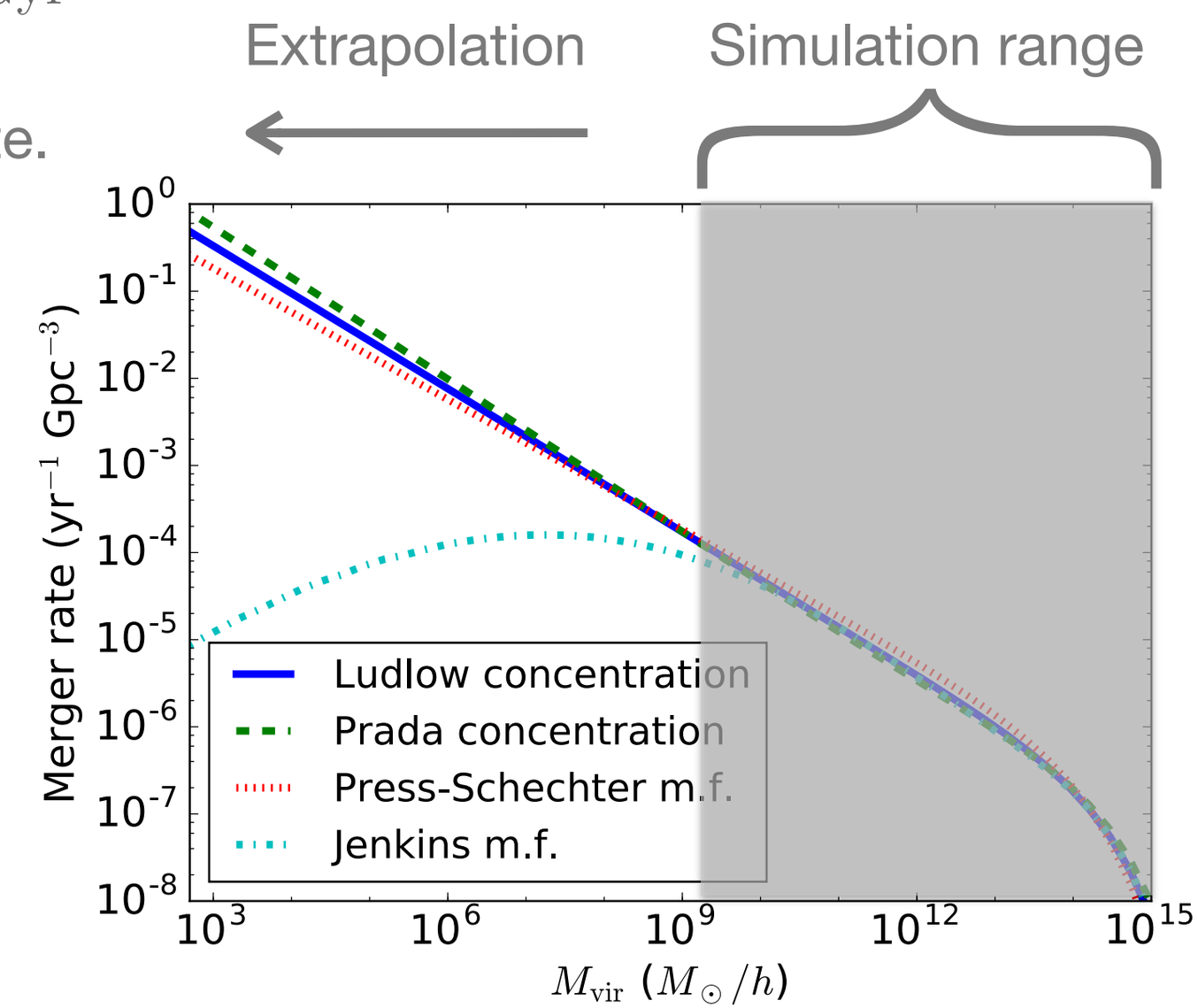

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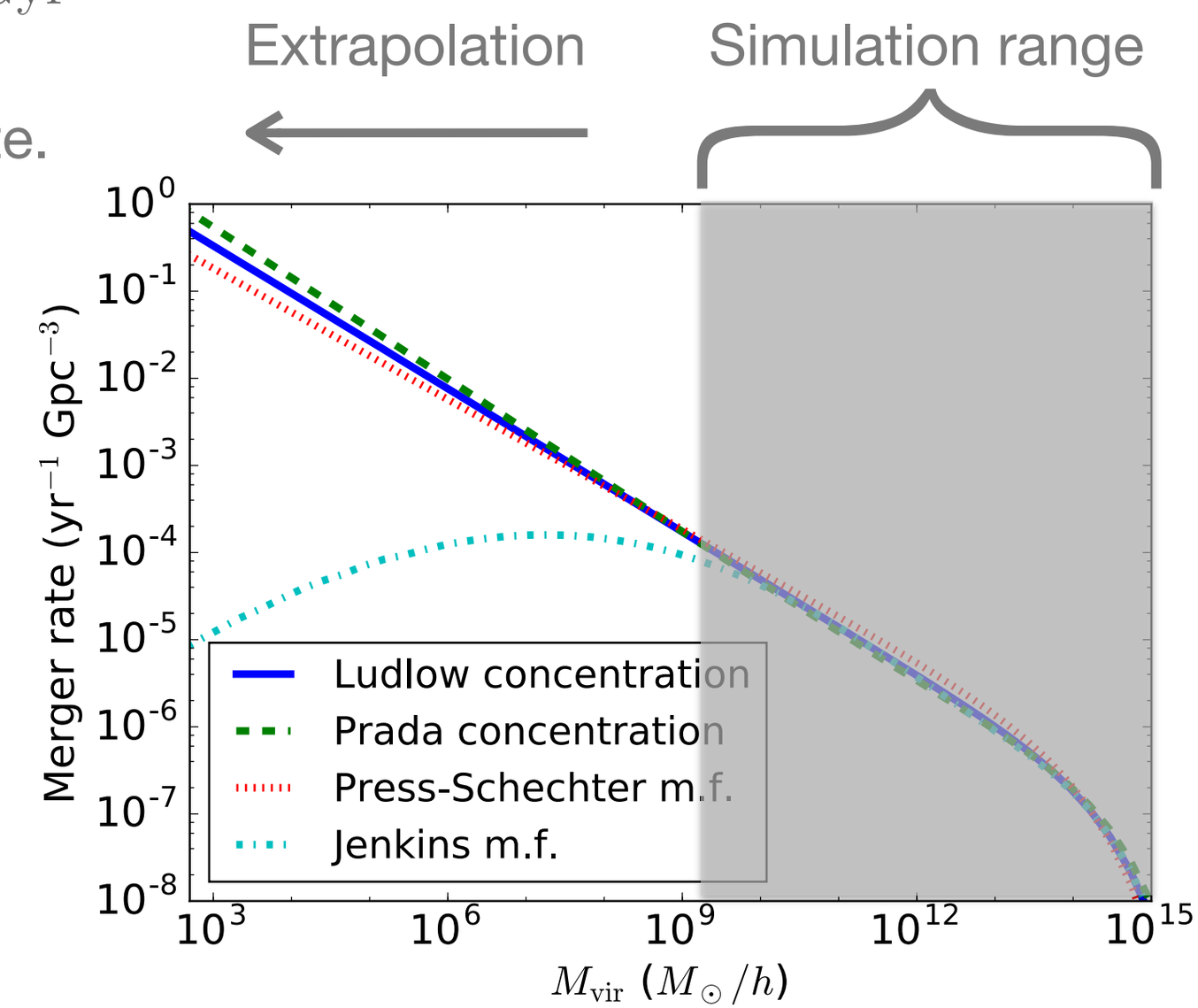

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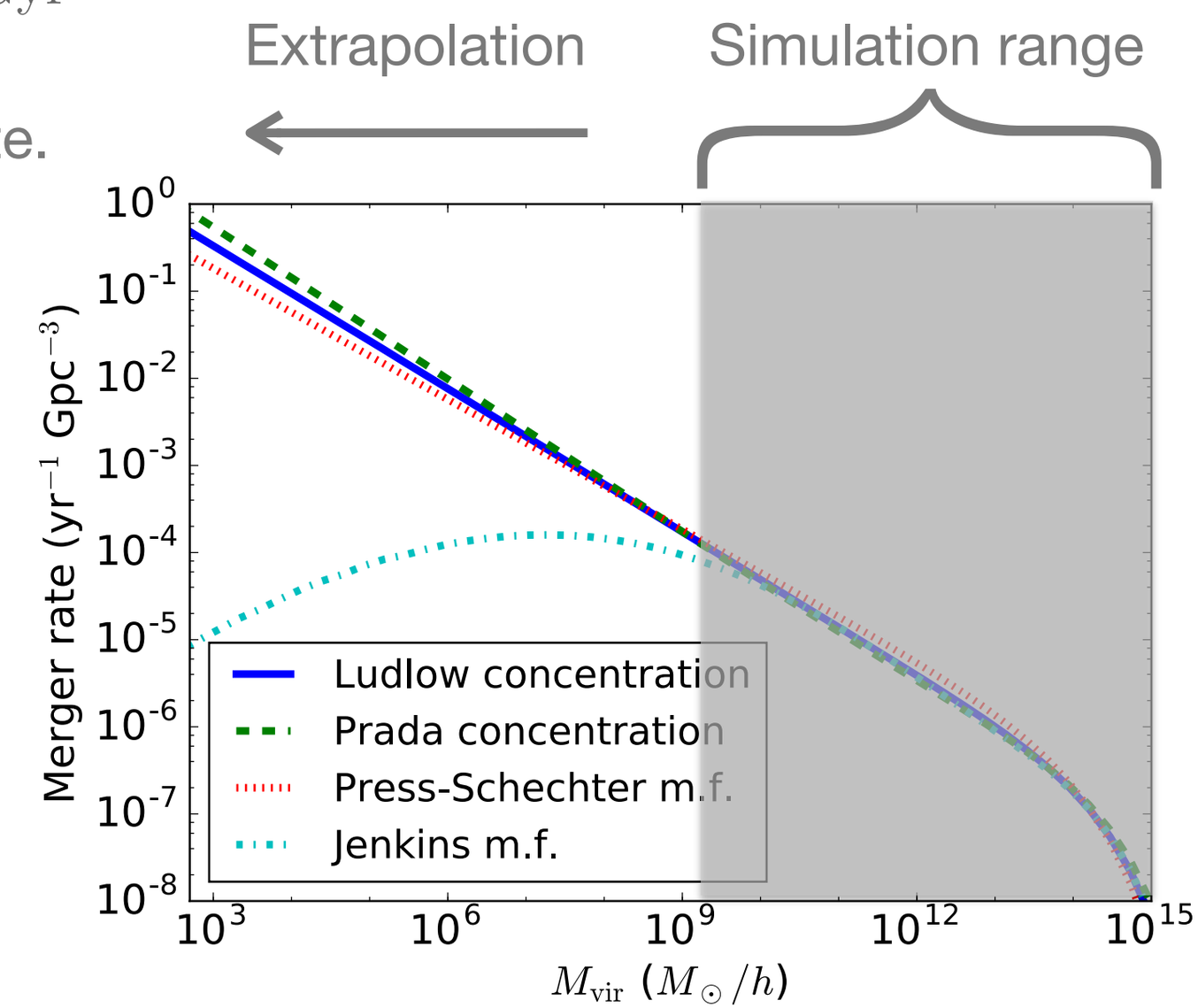

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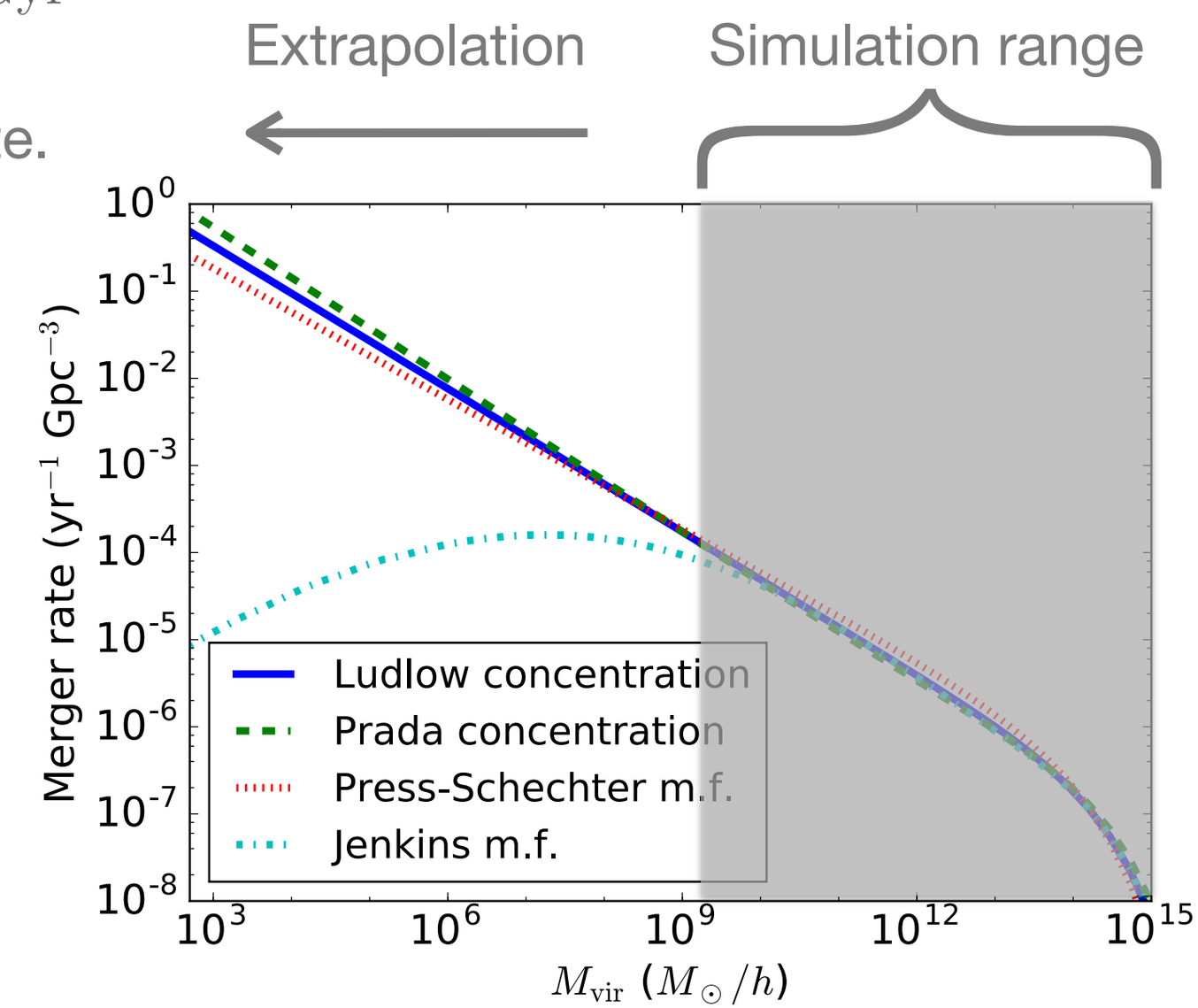

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Next!

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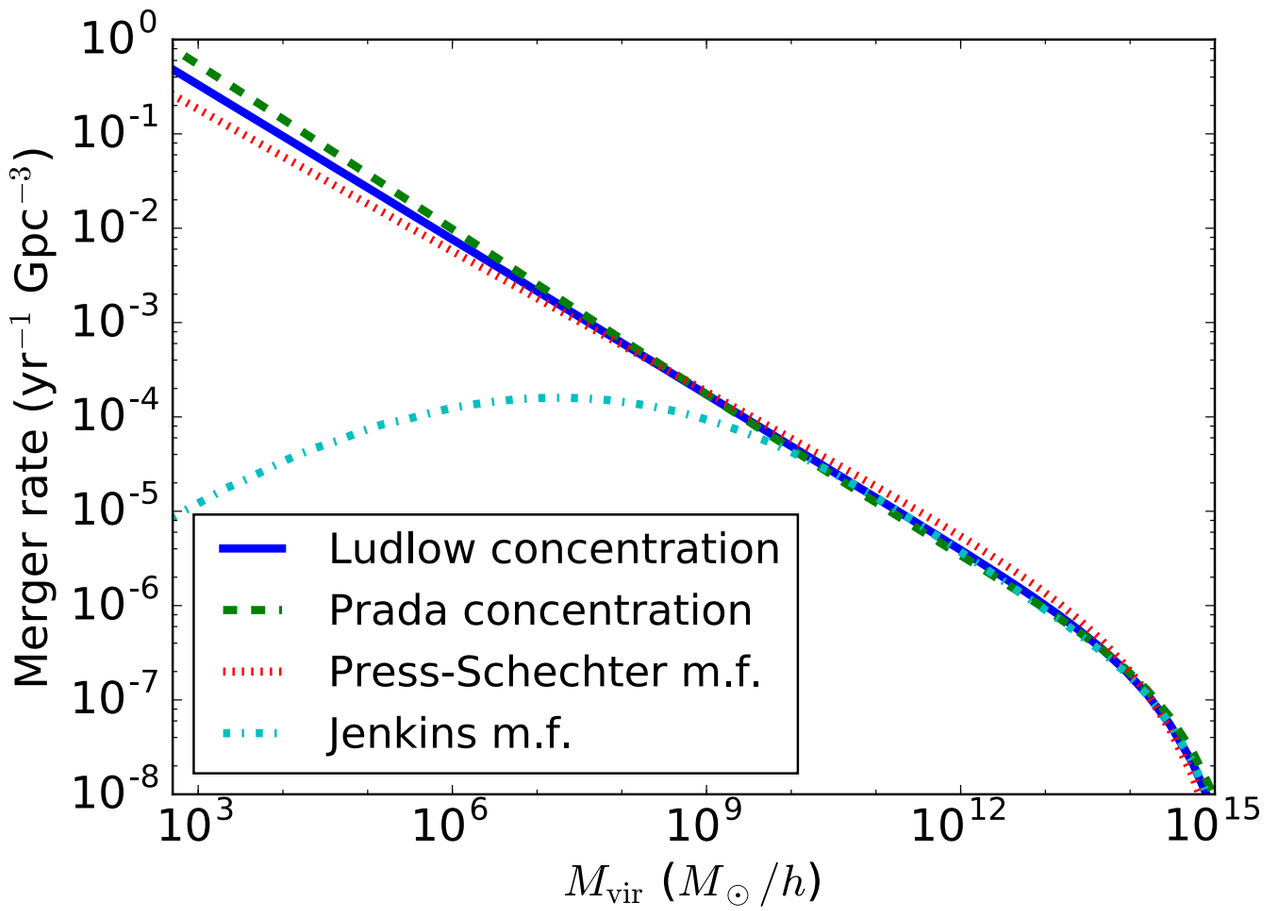

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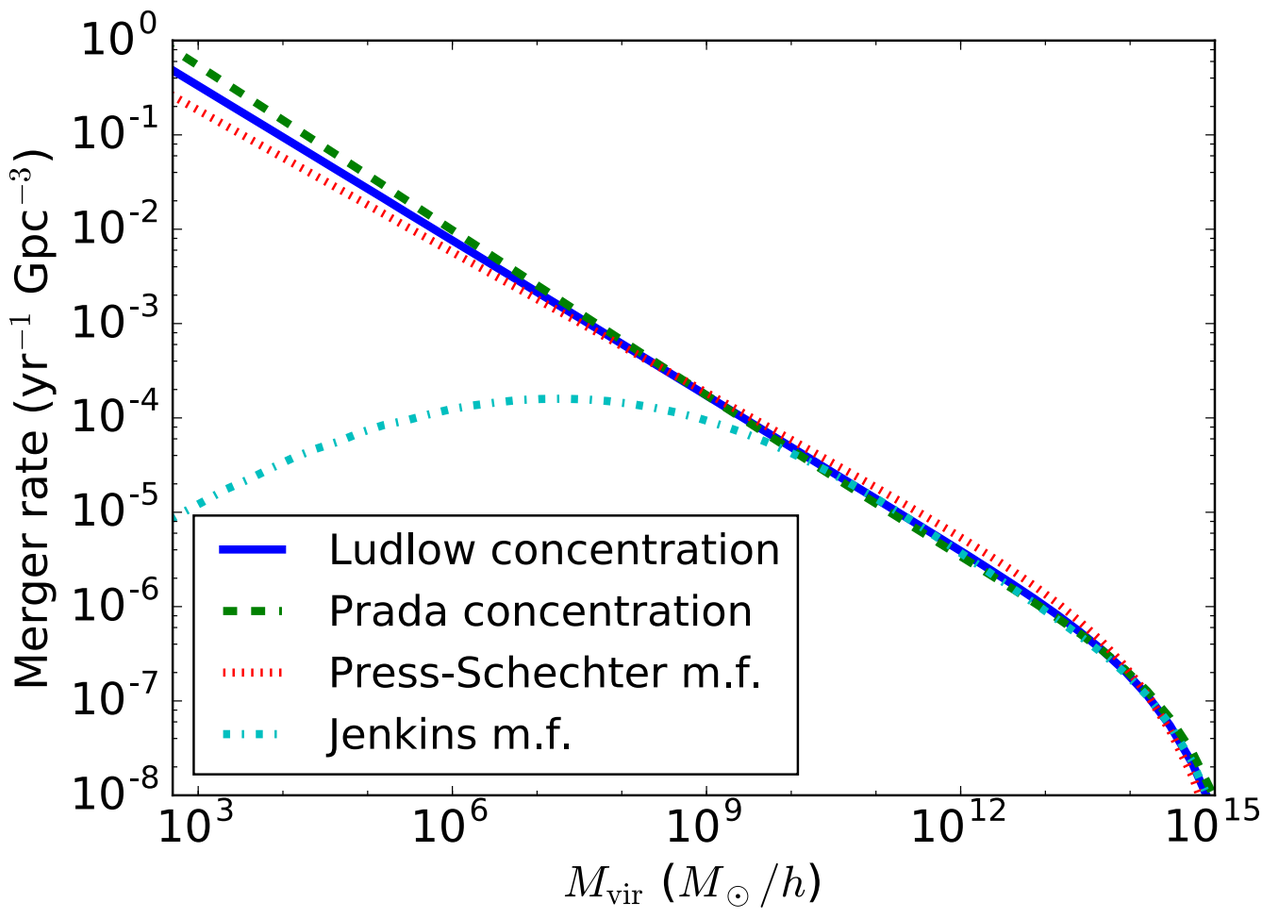


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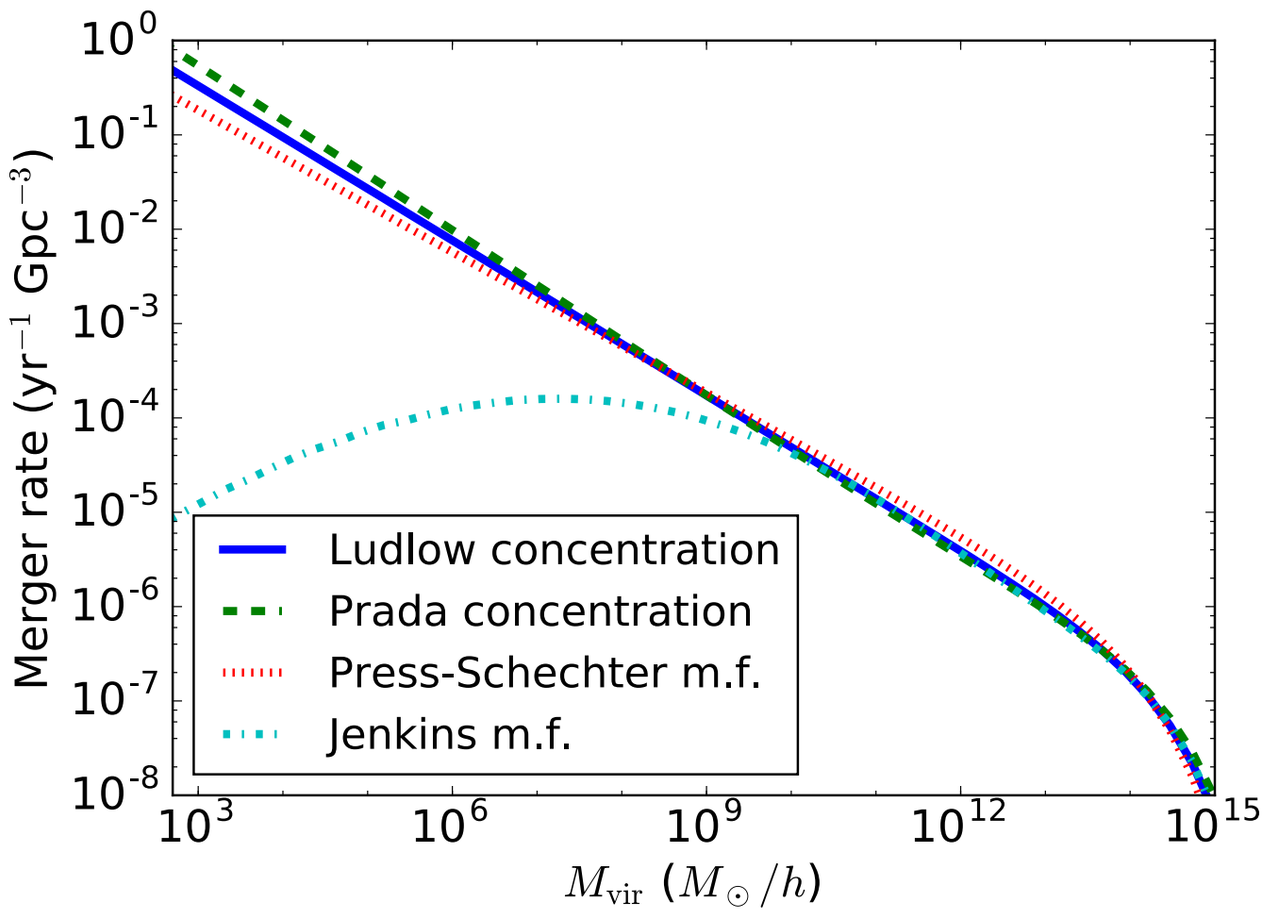


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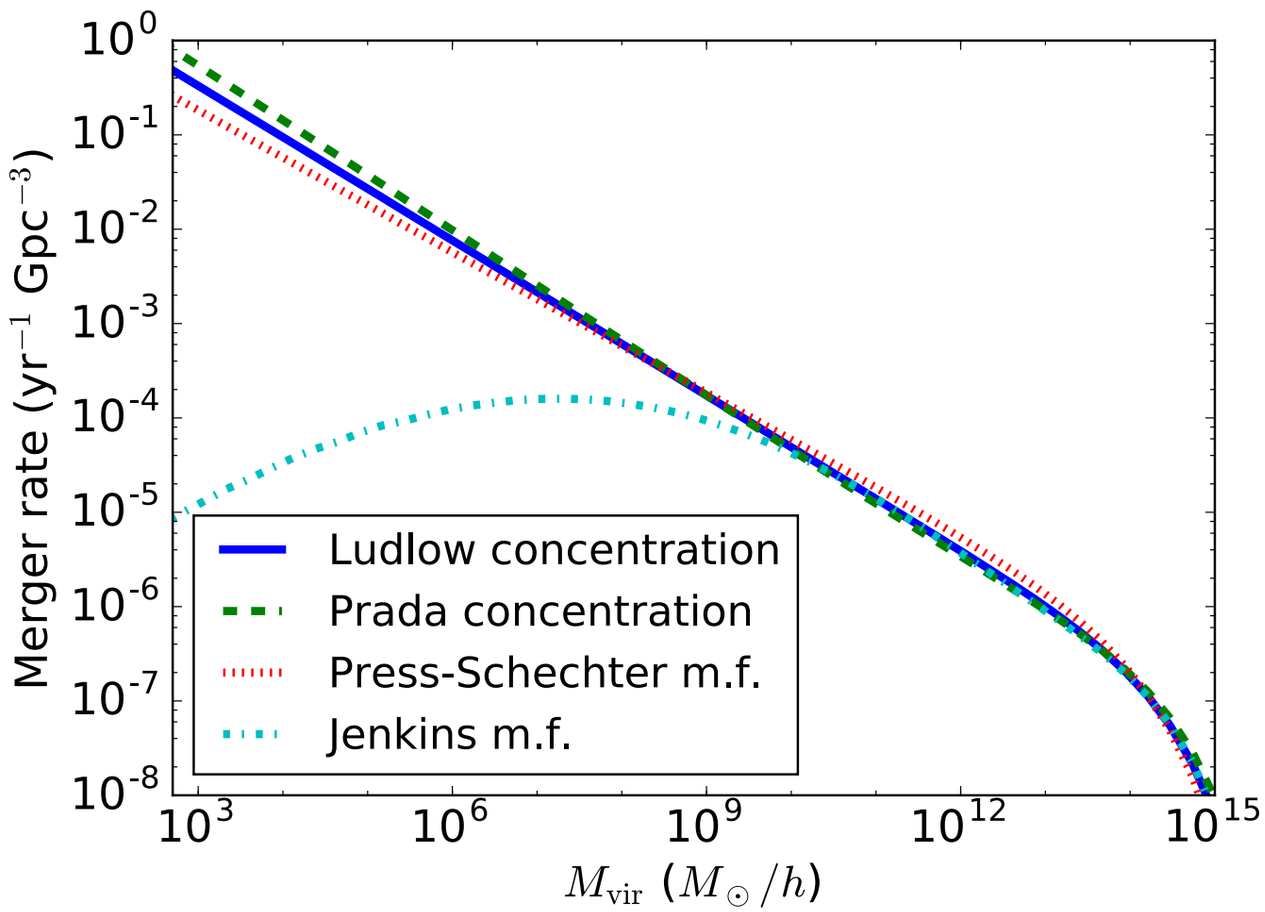


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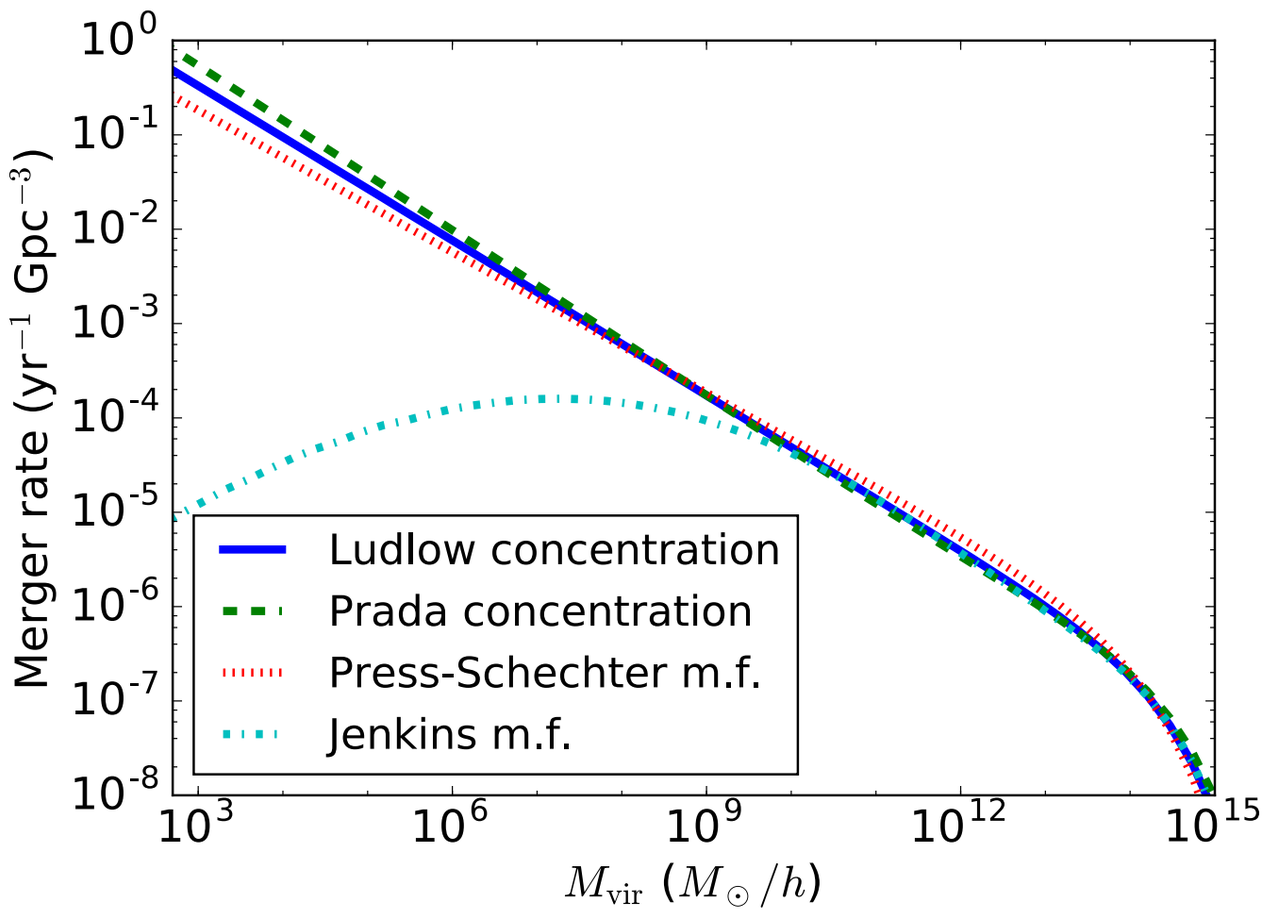


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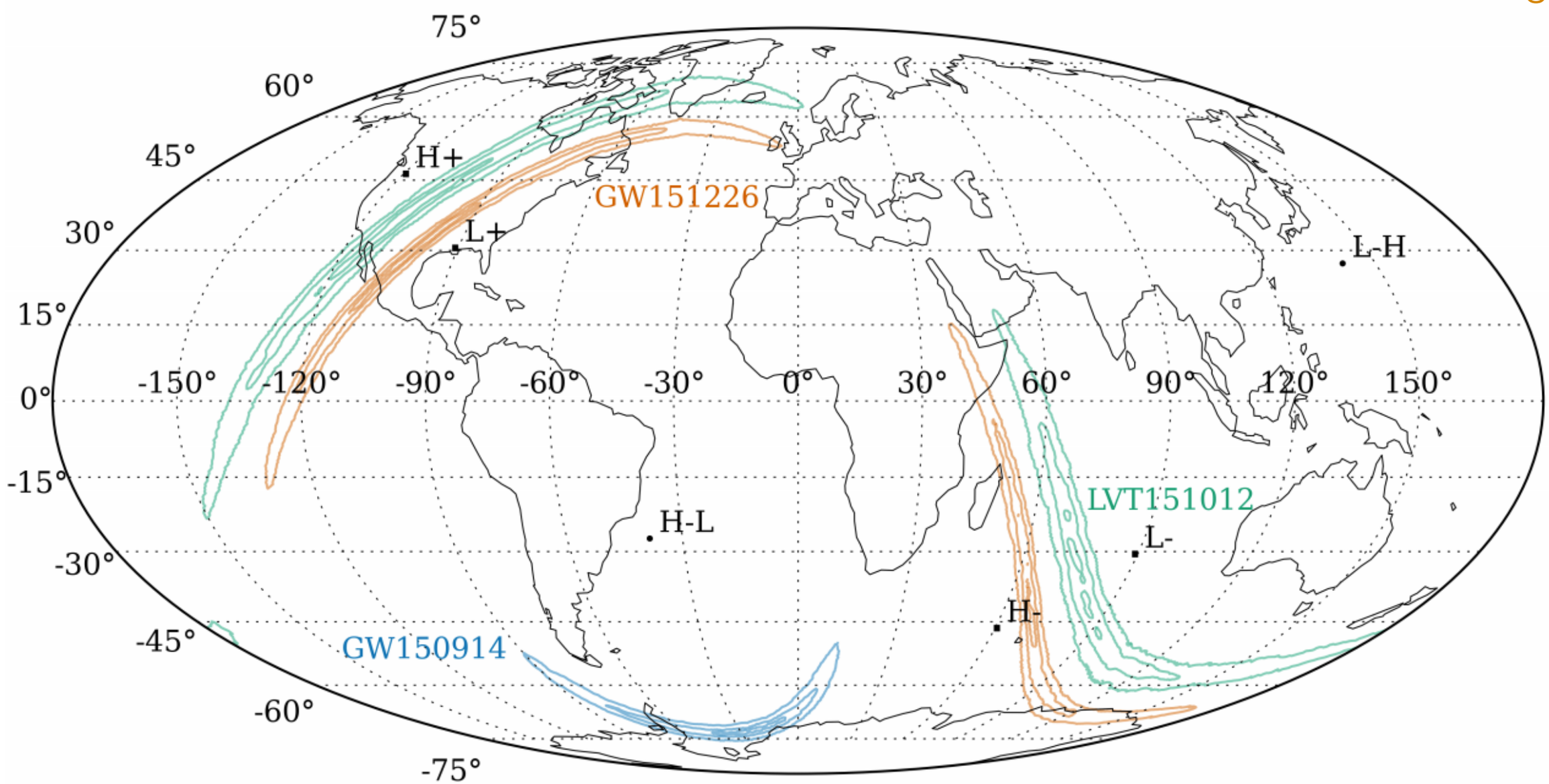


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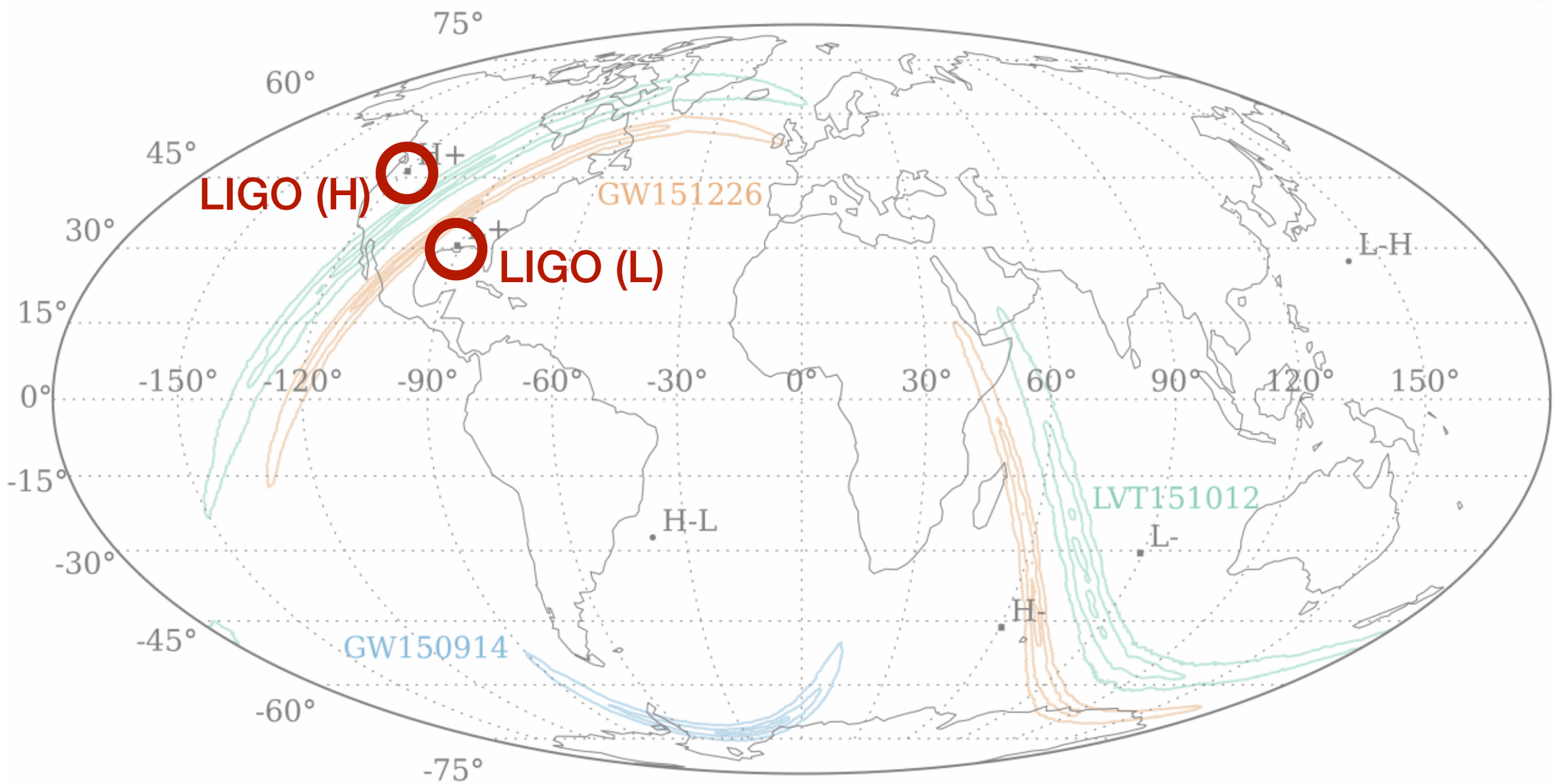


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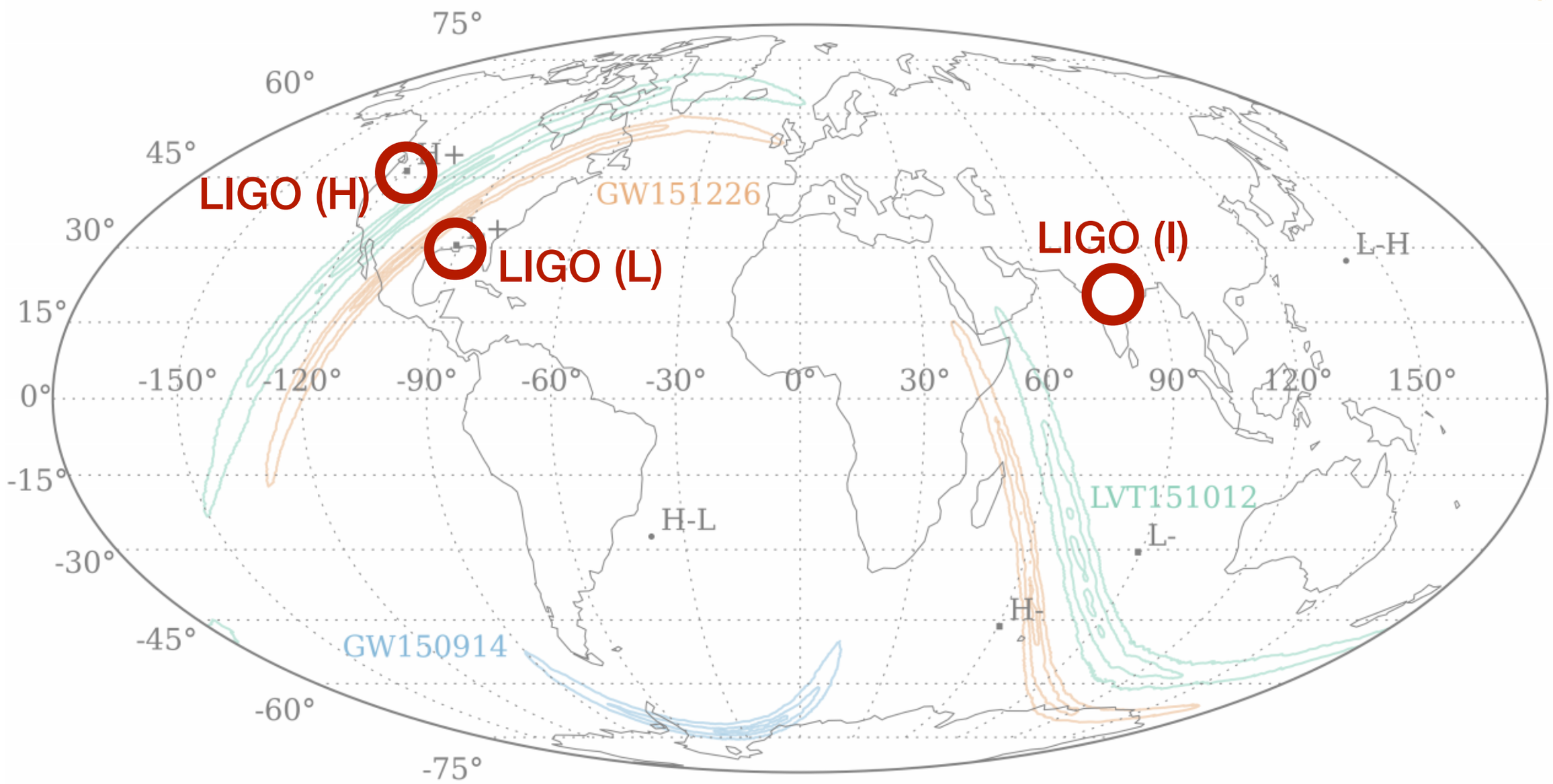


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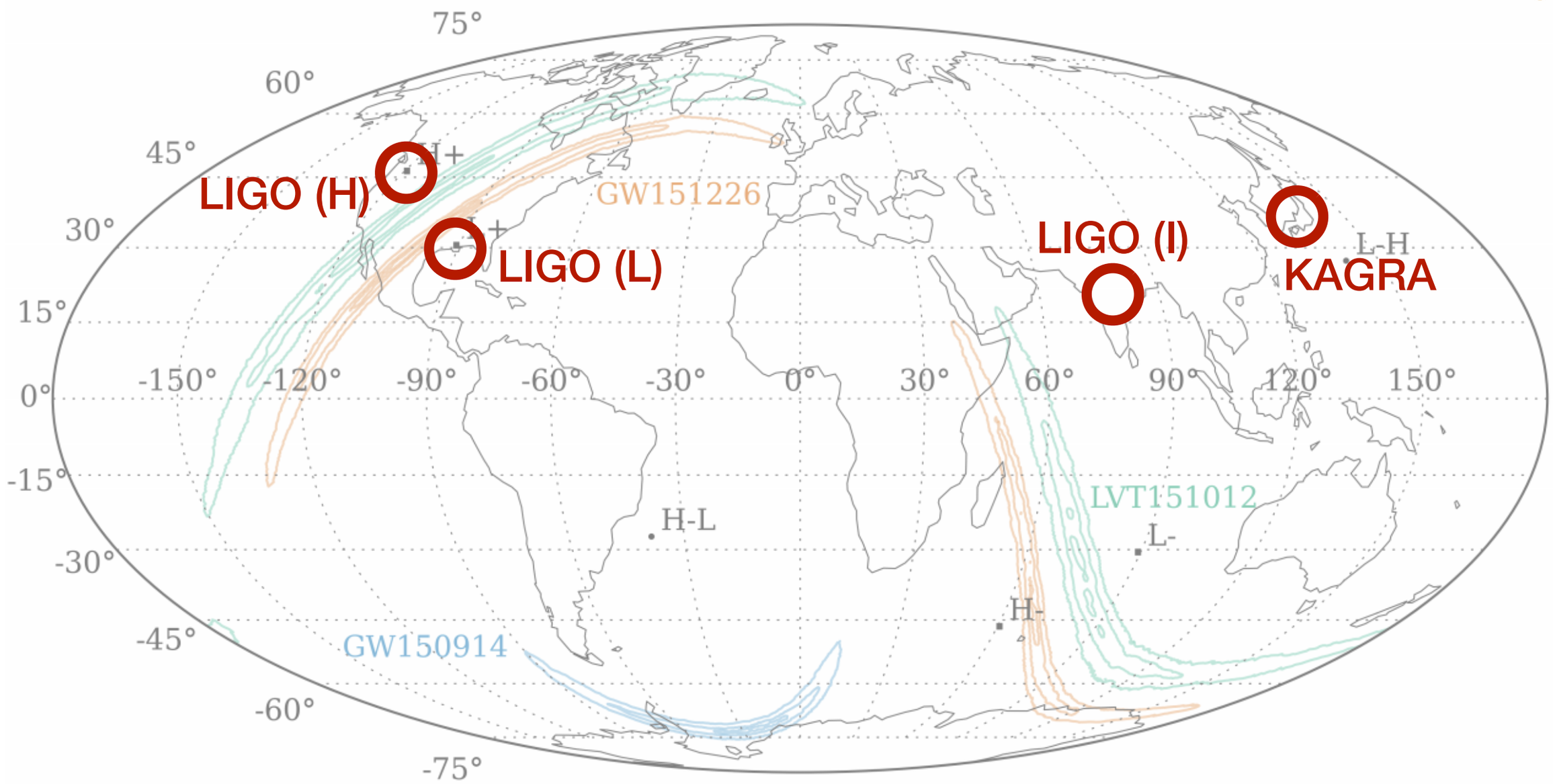


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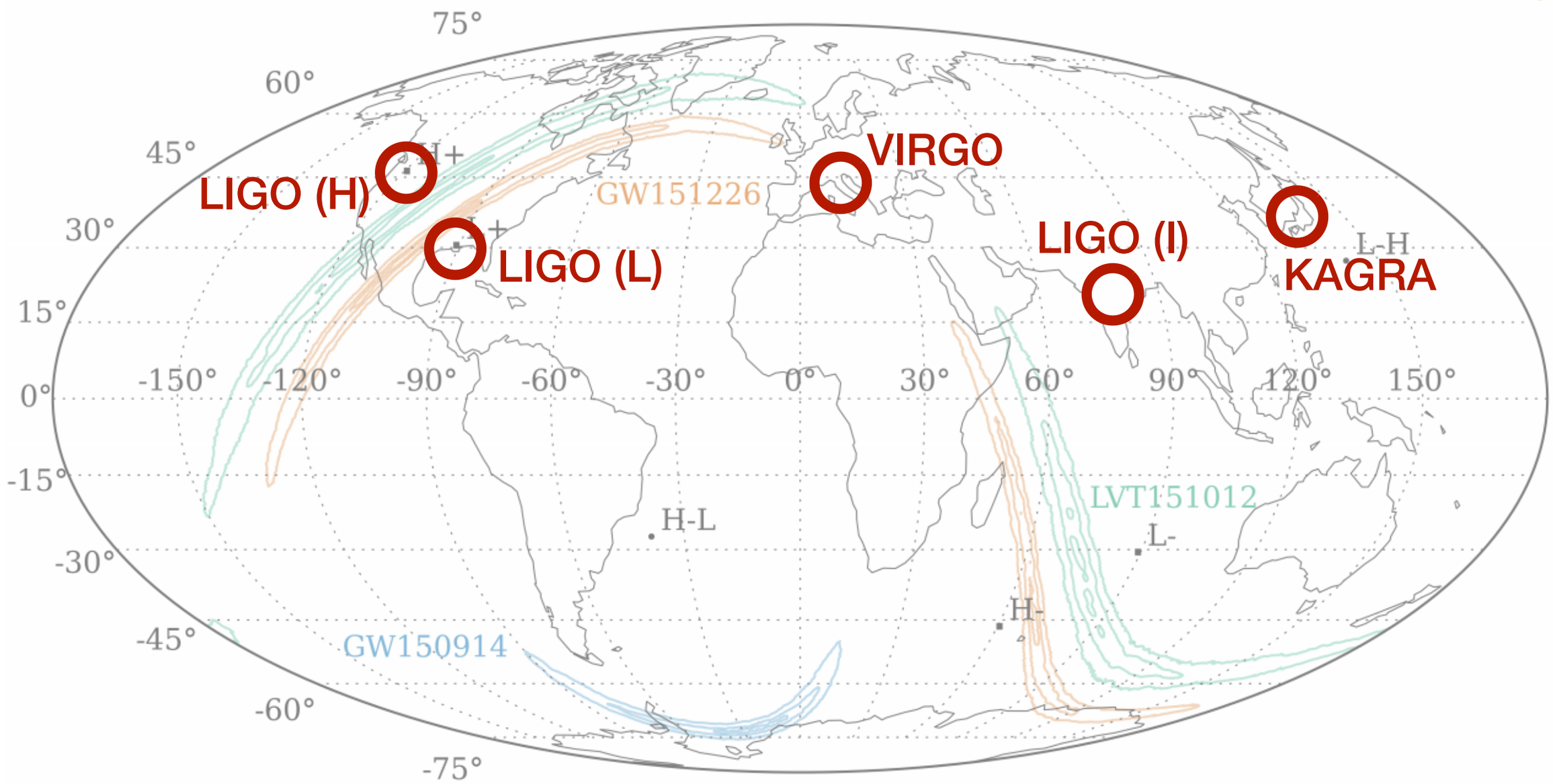


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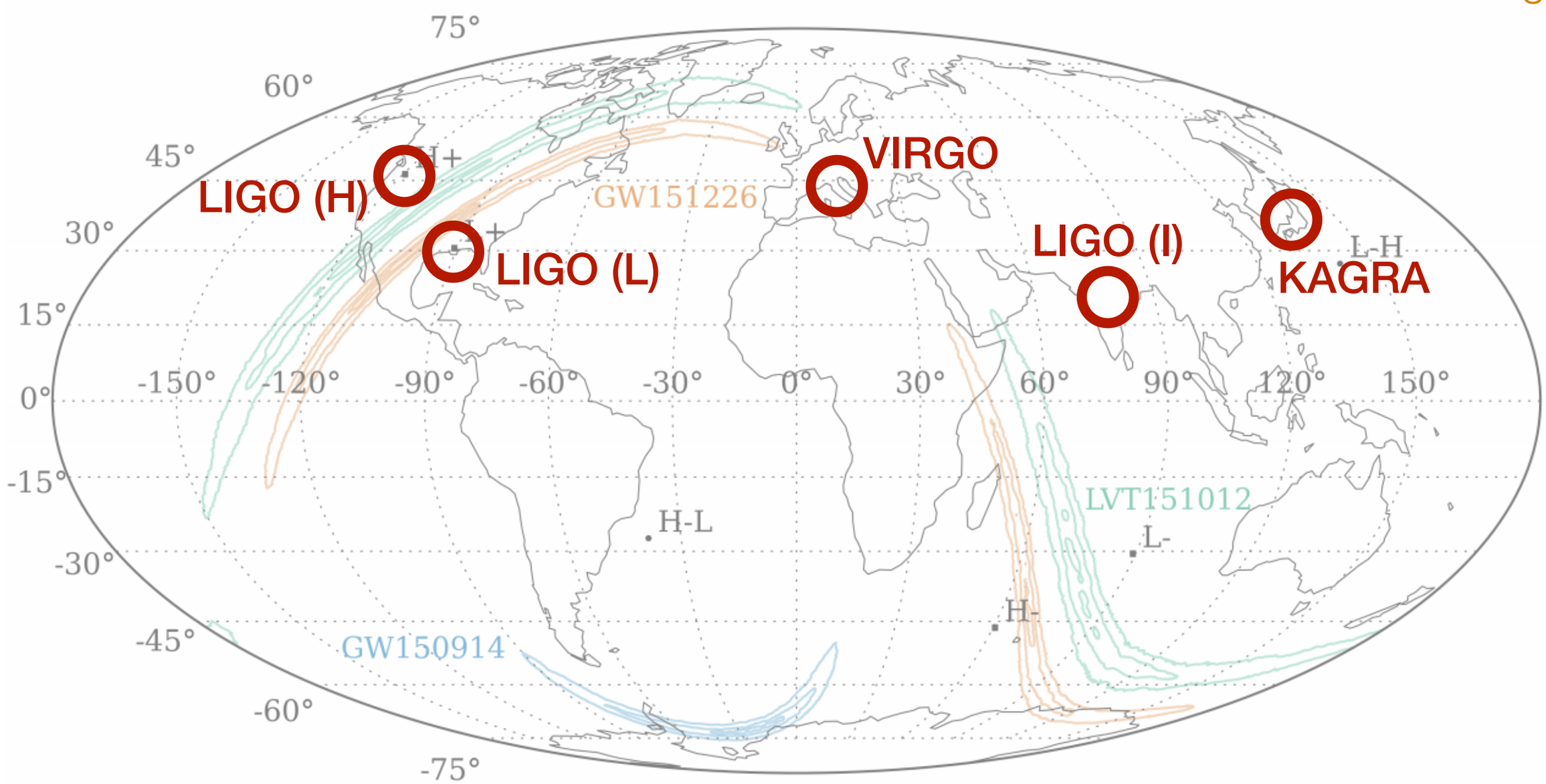


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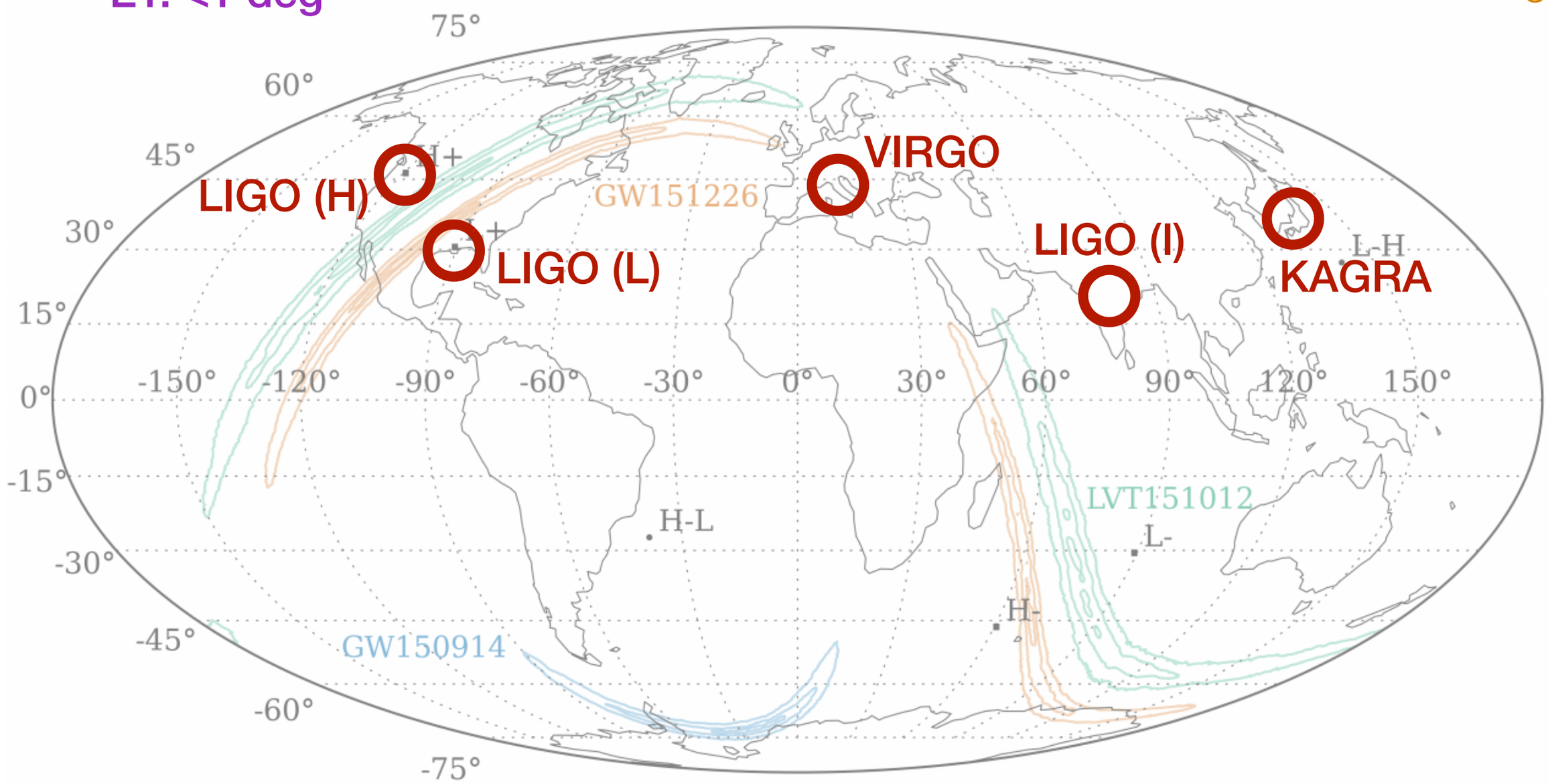


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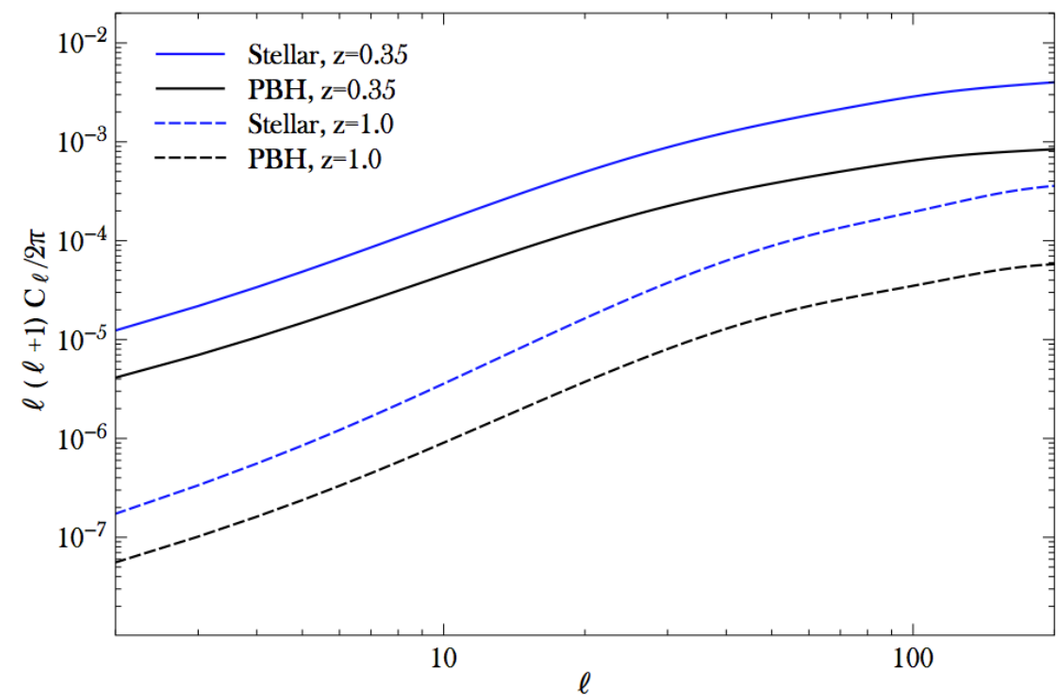

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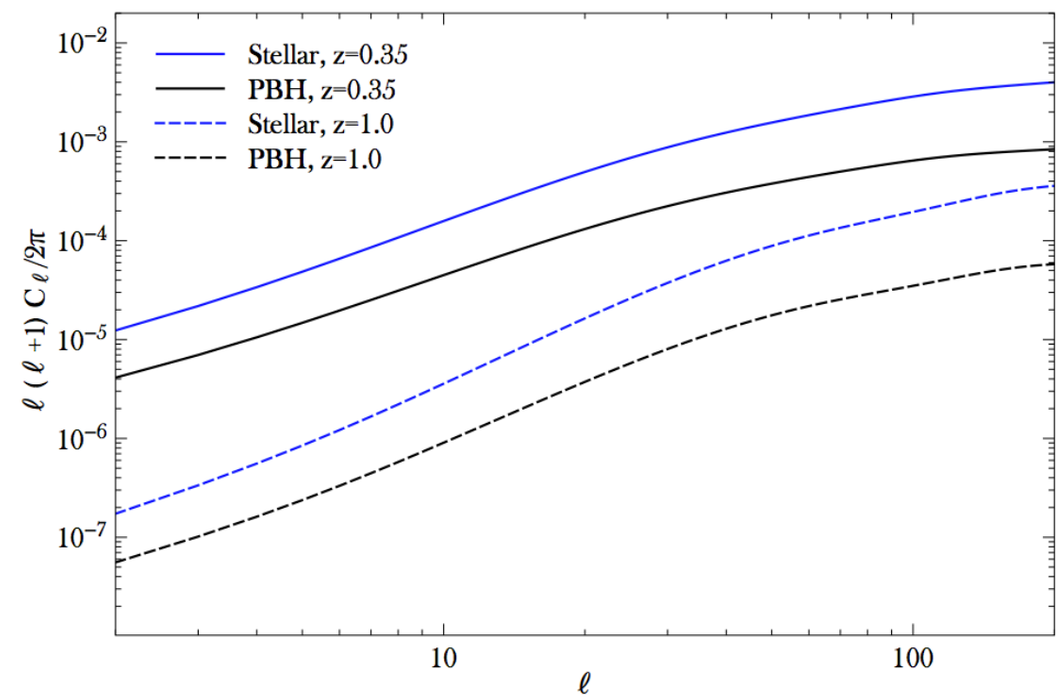

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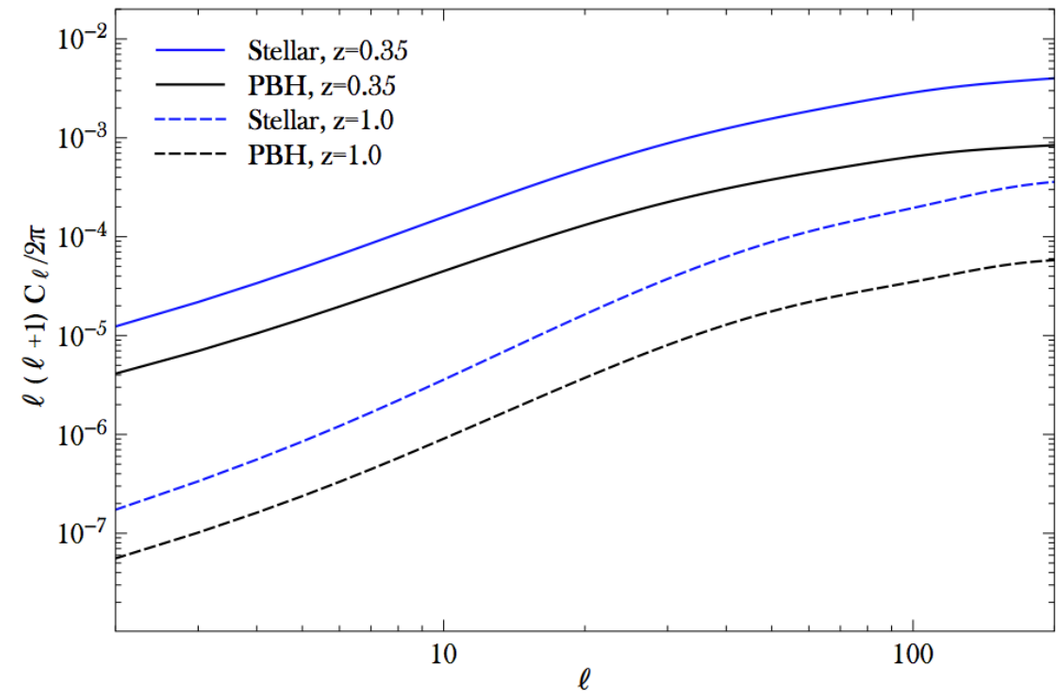


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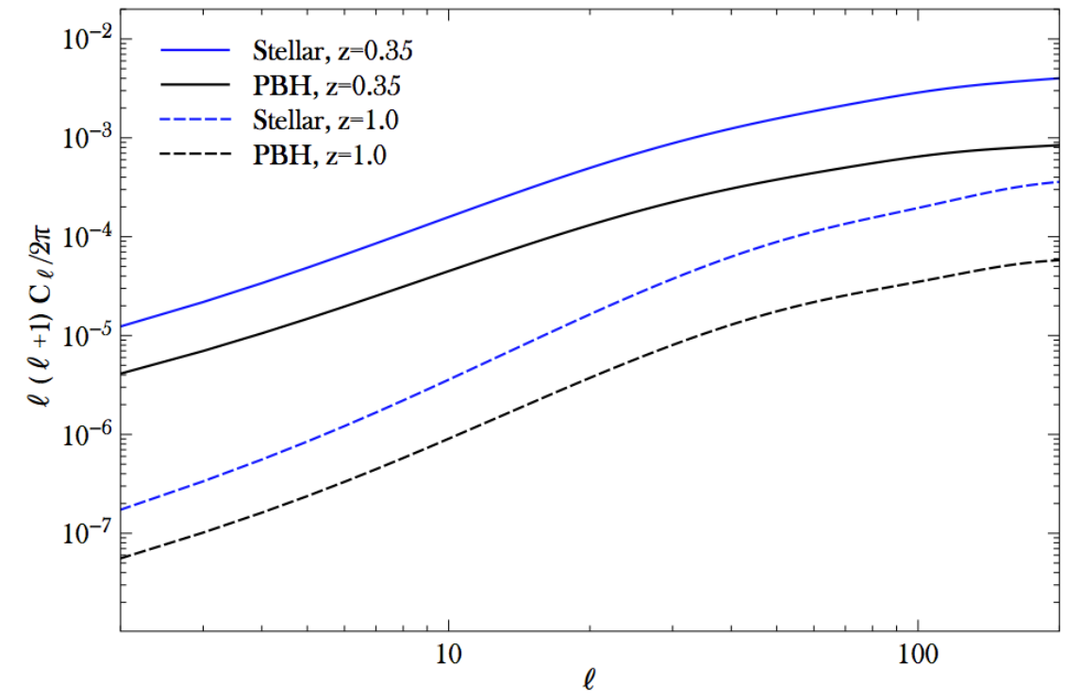


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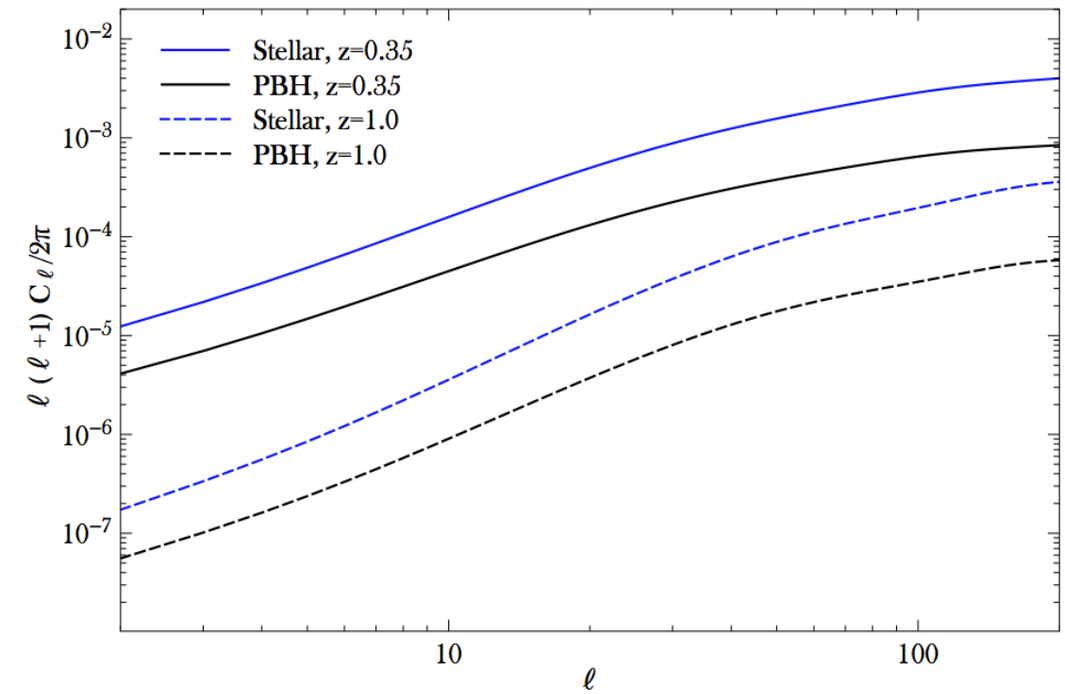


Amplitude proportional to bias: $A_c \propto b^{\mathrm{GW}}$

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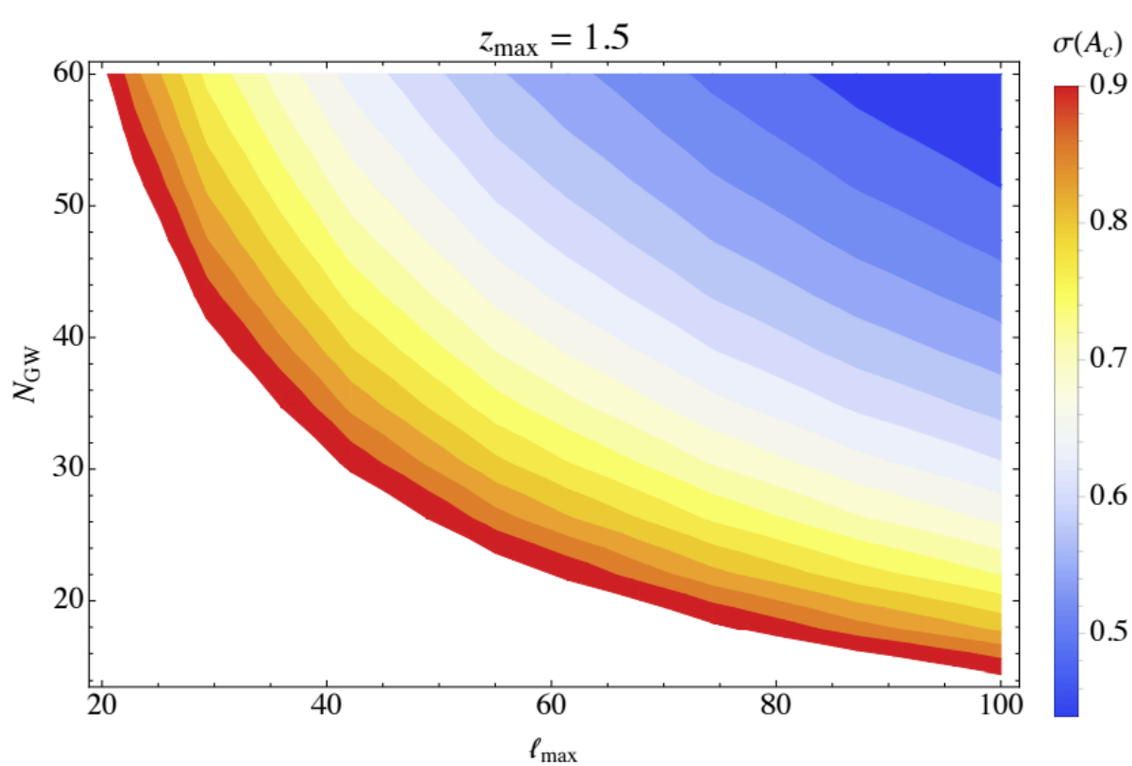

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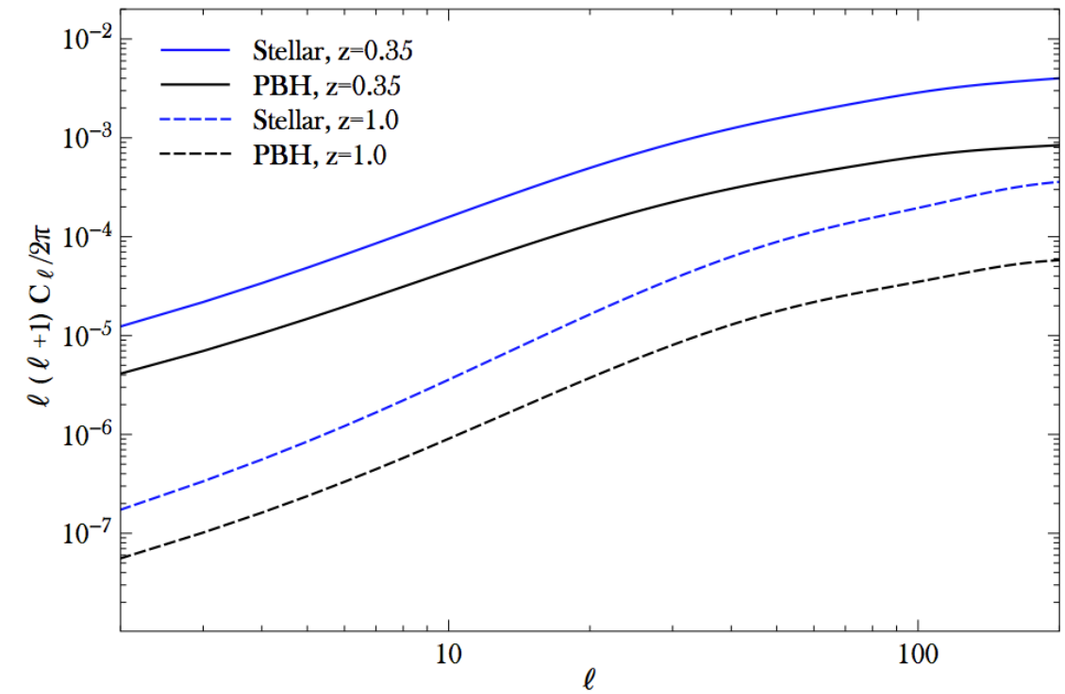


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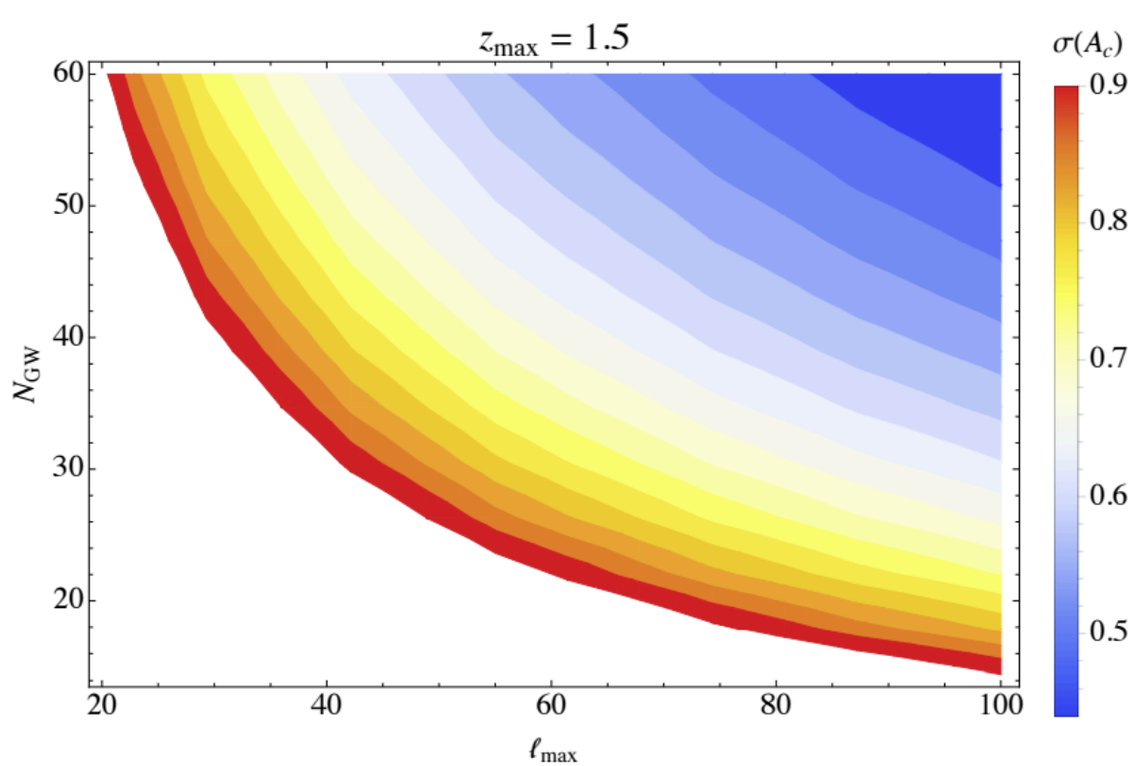


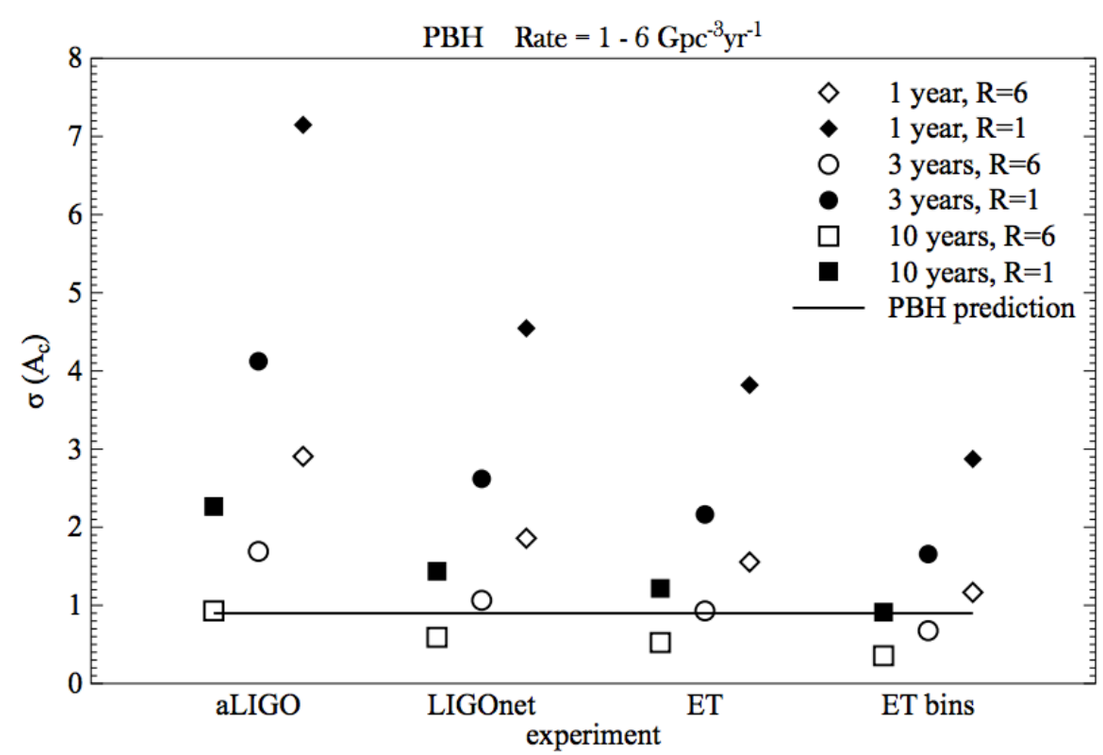

# Determining the Progenitors: Initial Conditions

(Cholis et al., arXiv:1606.07437)

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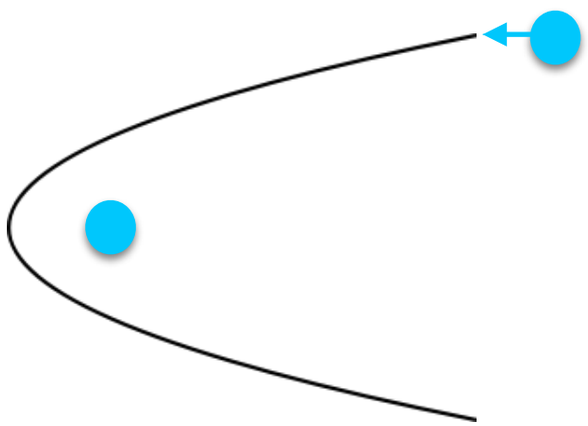

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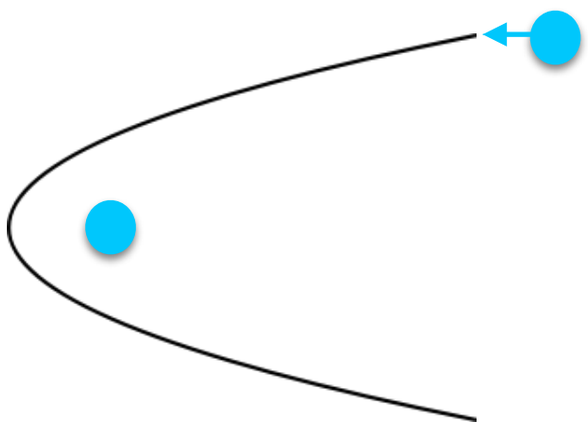

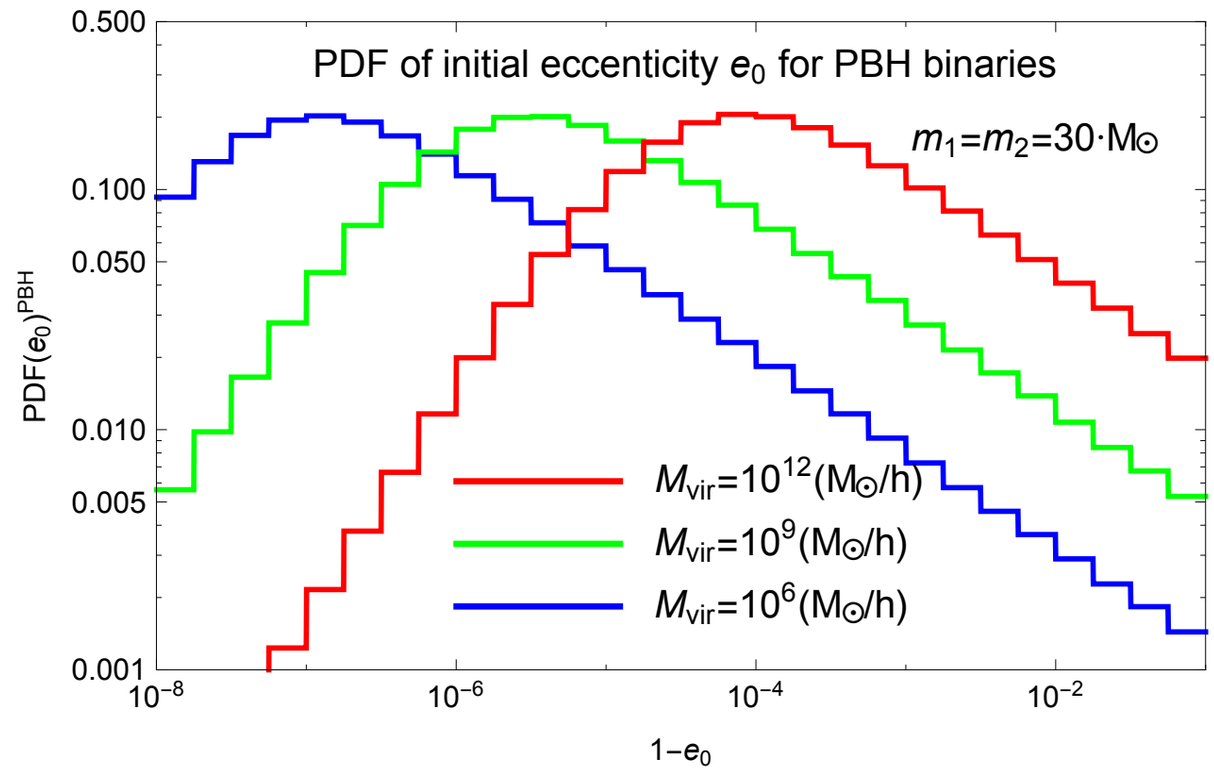

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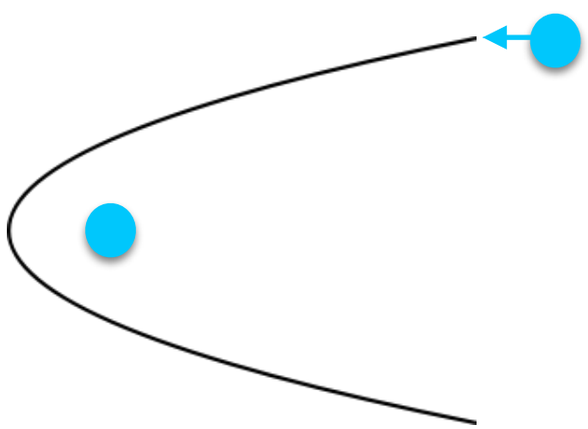

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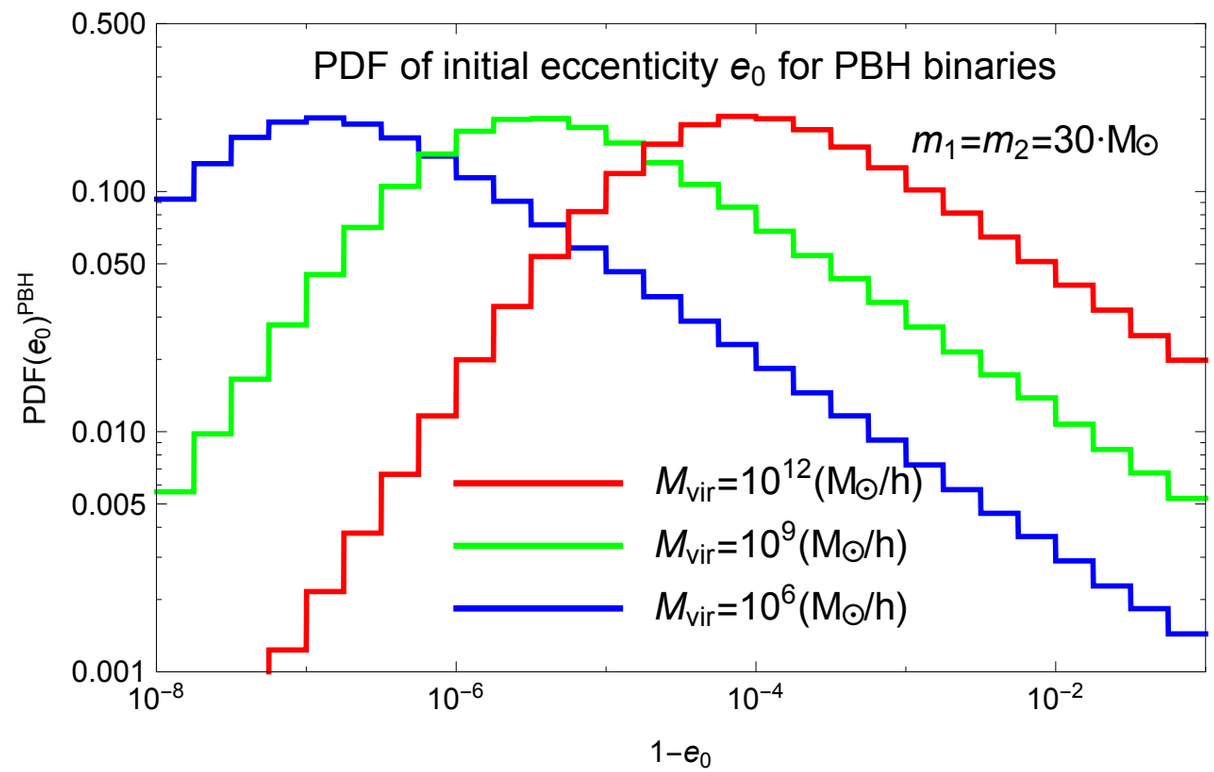

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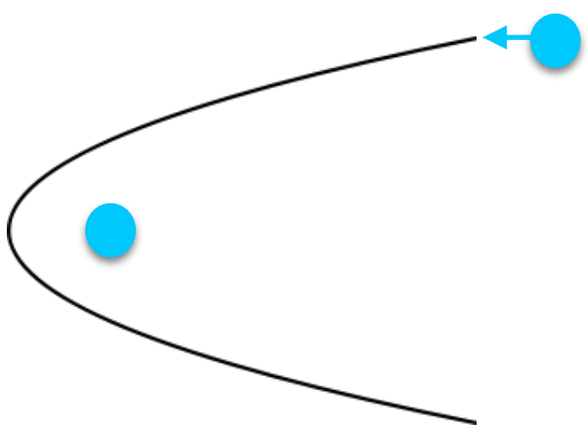

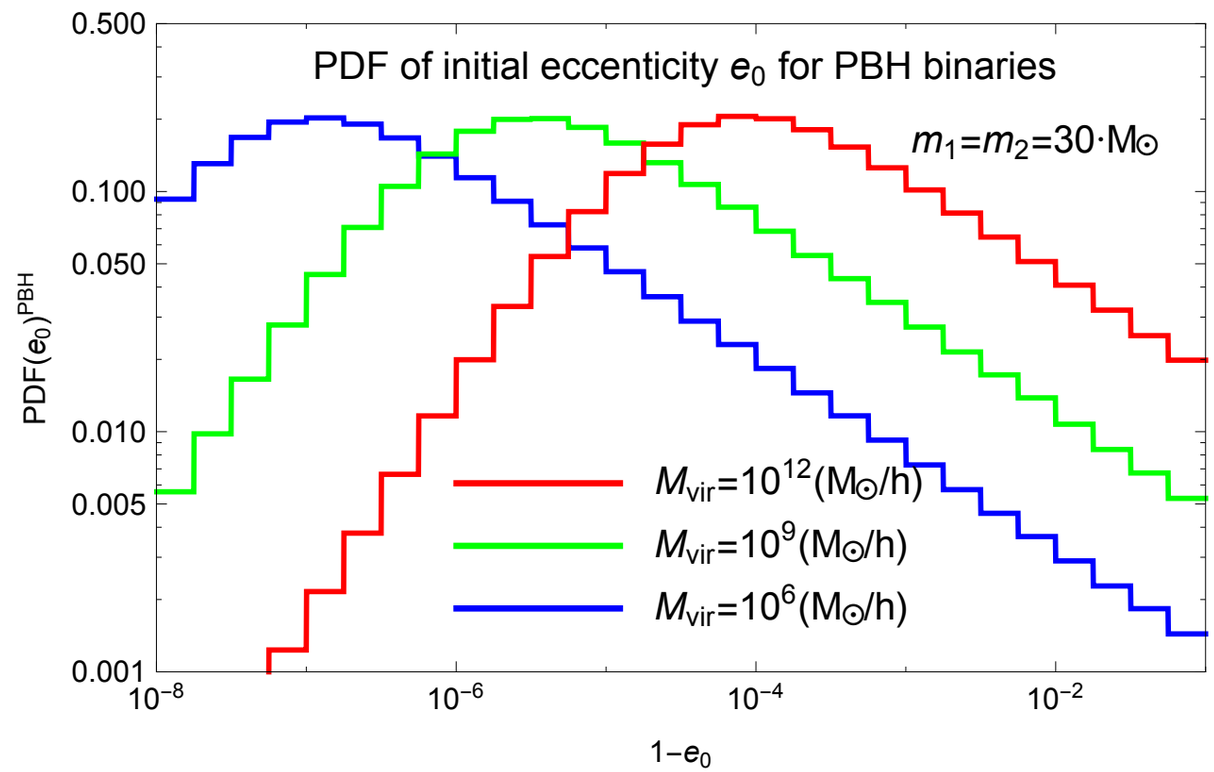


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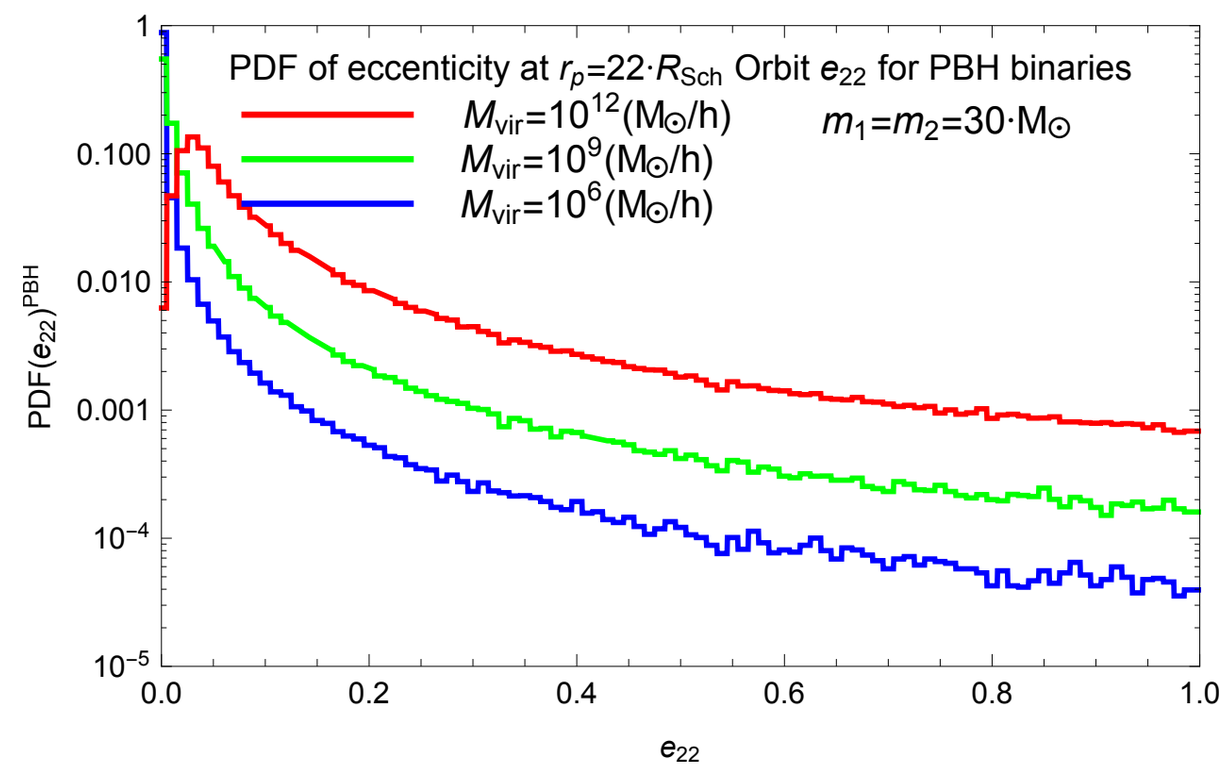

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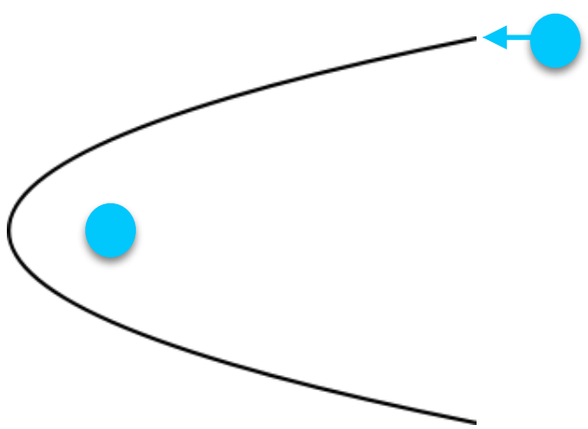

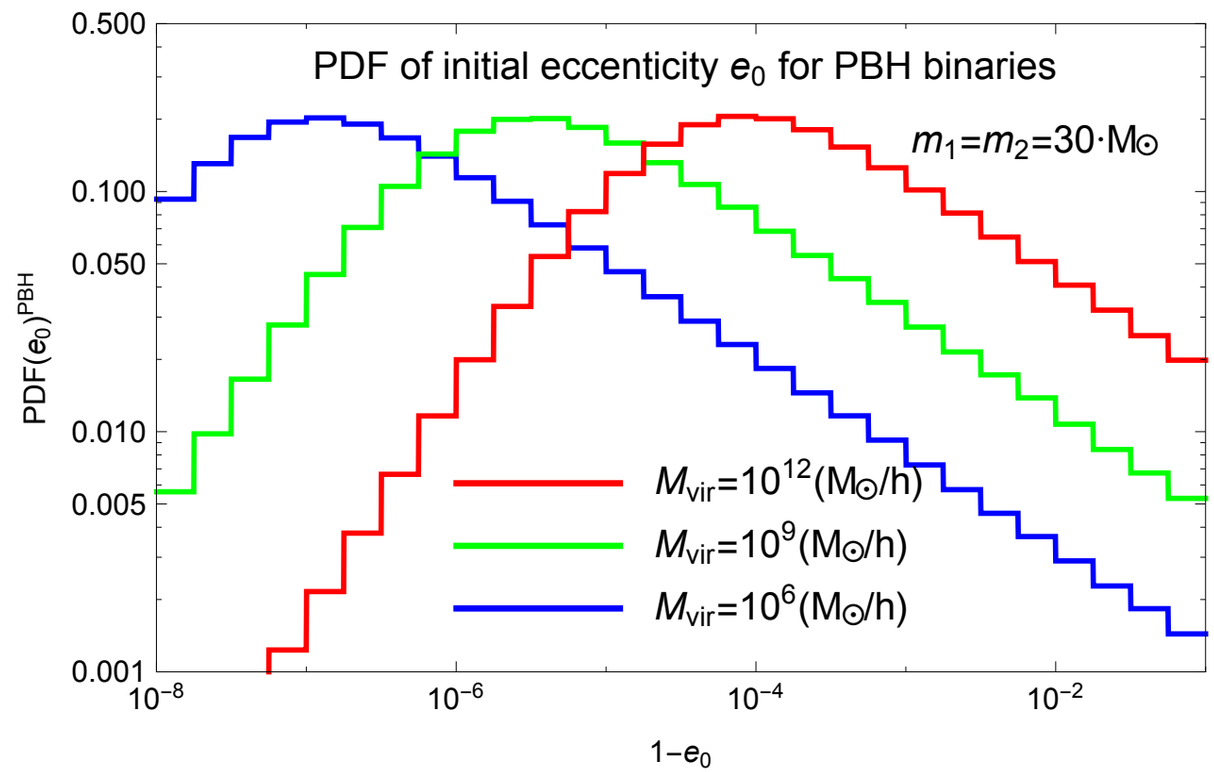


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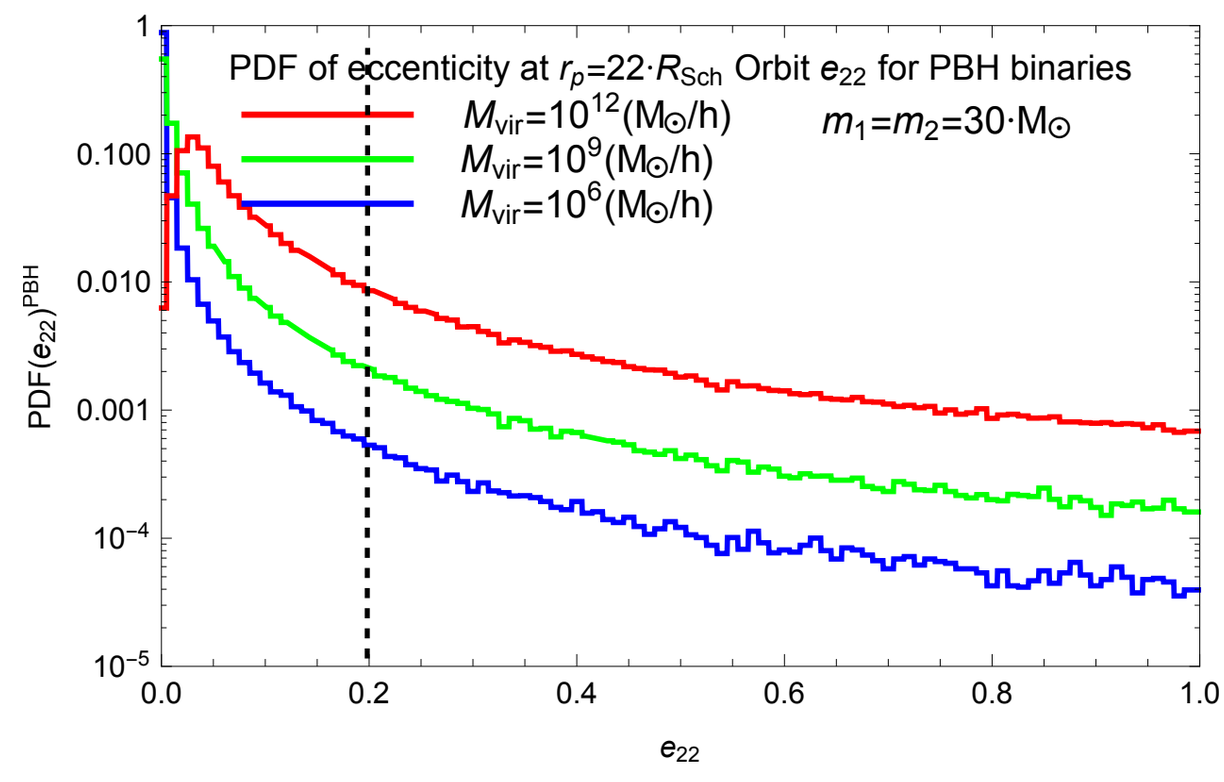
Final eccentricity:

~1% of PBH GW events with detectable final eccentricity:



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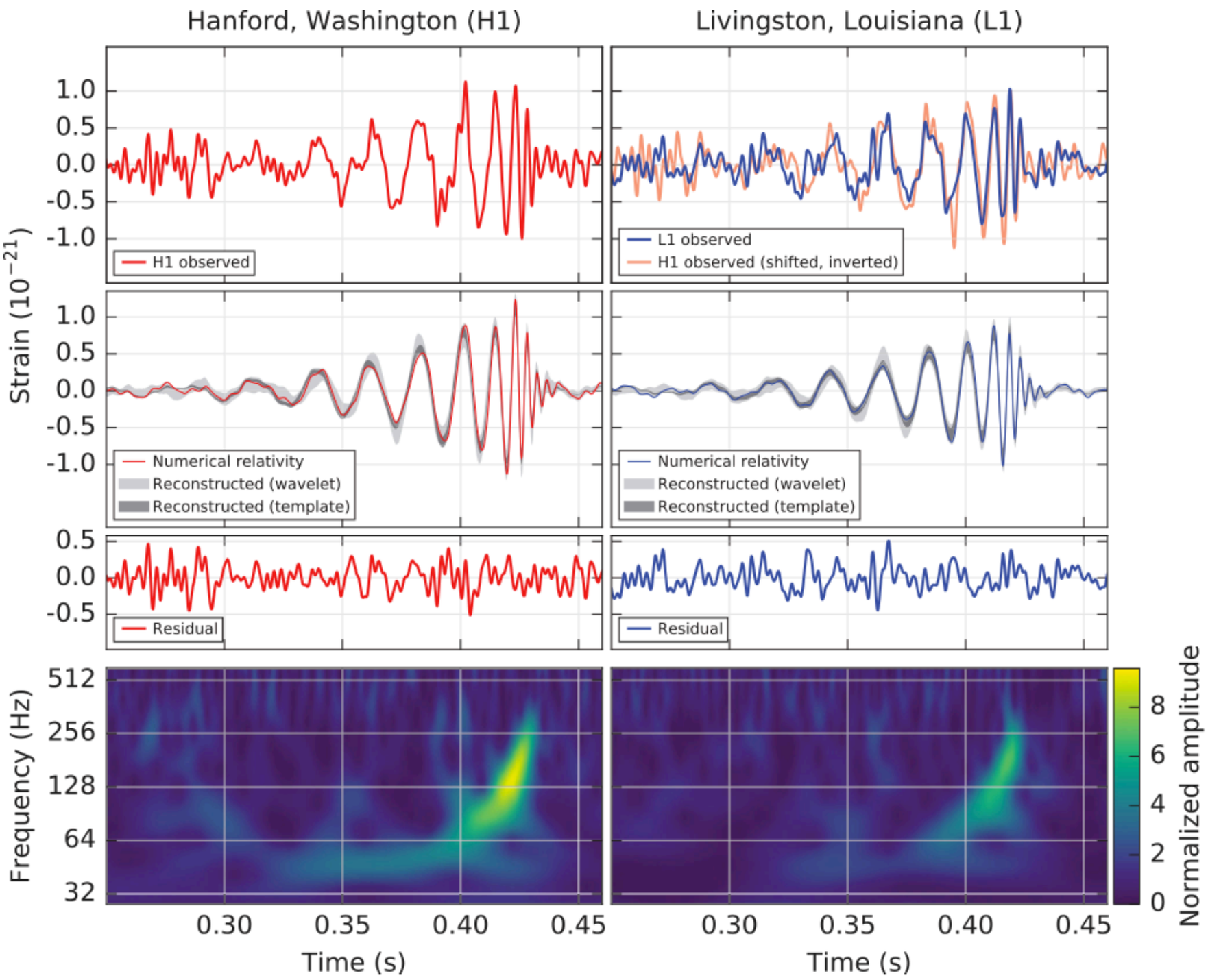

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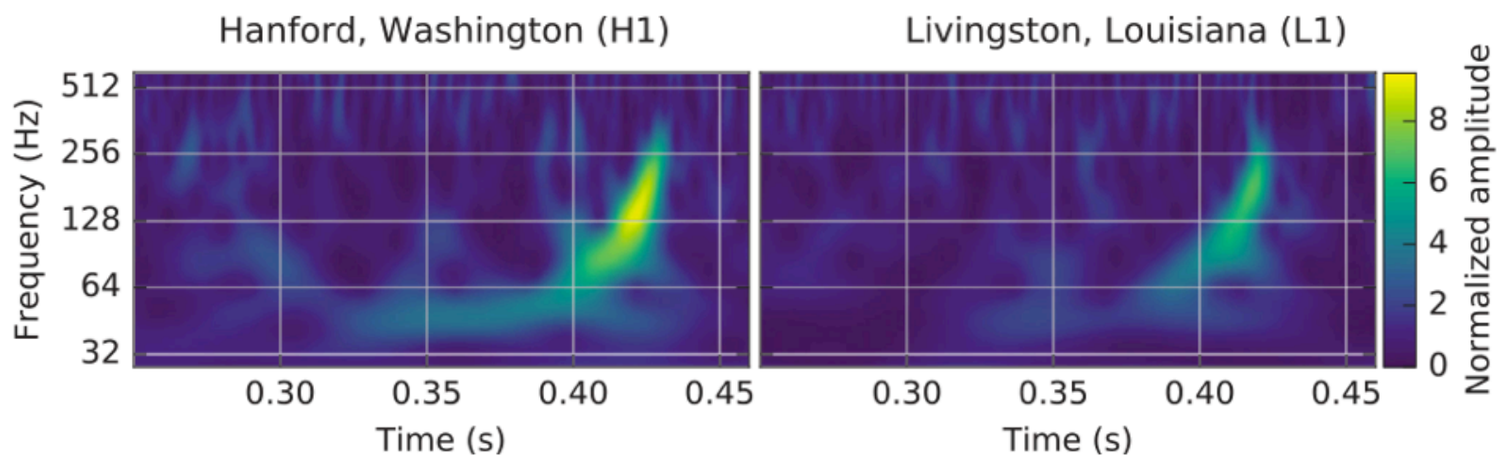

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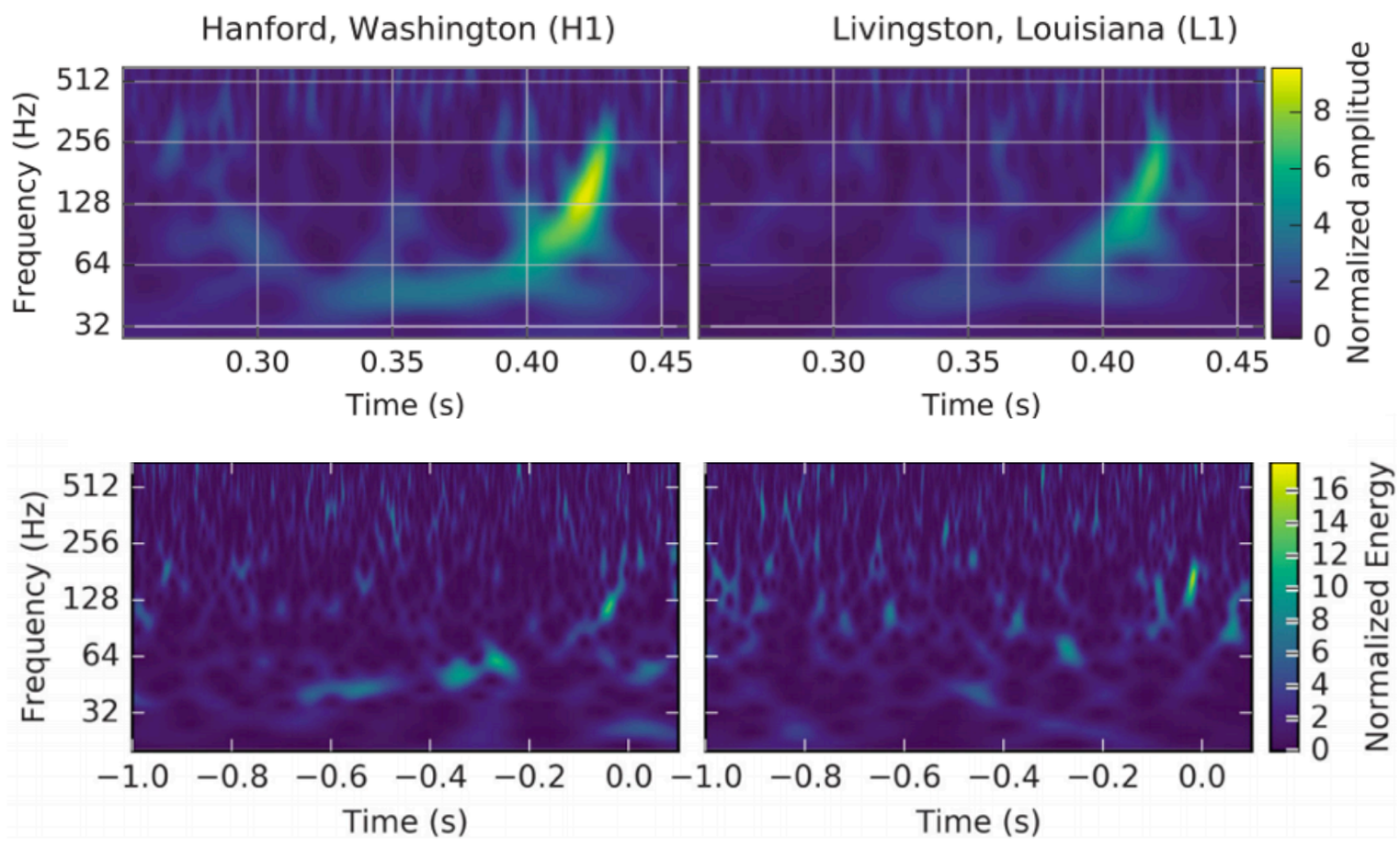

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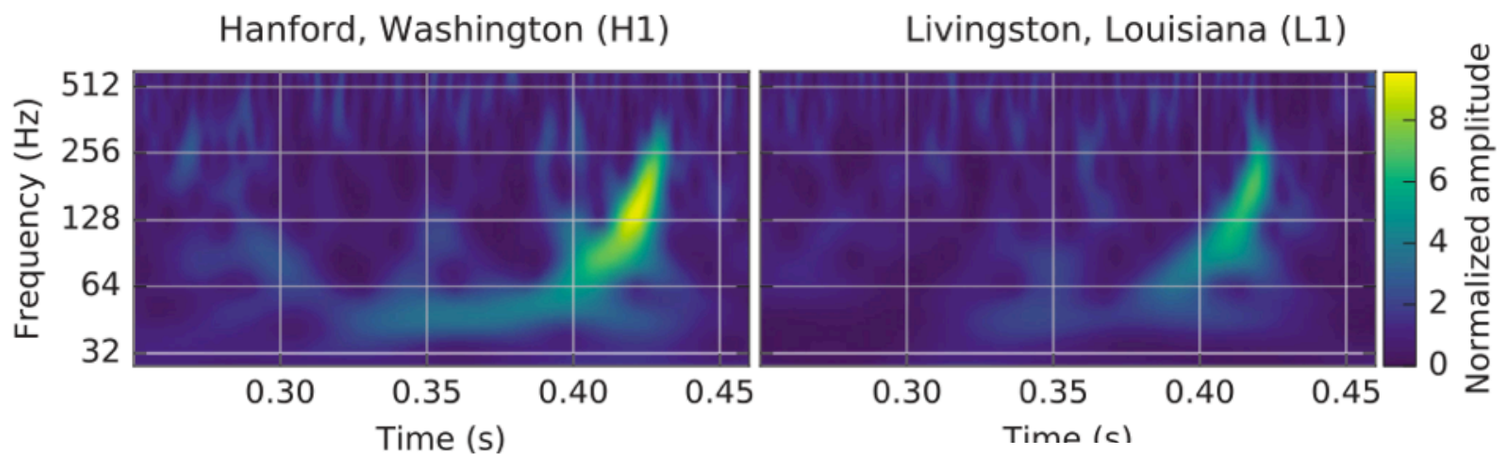


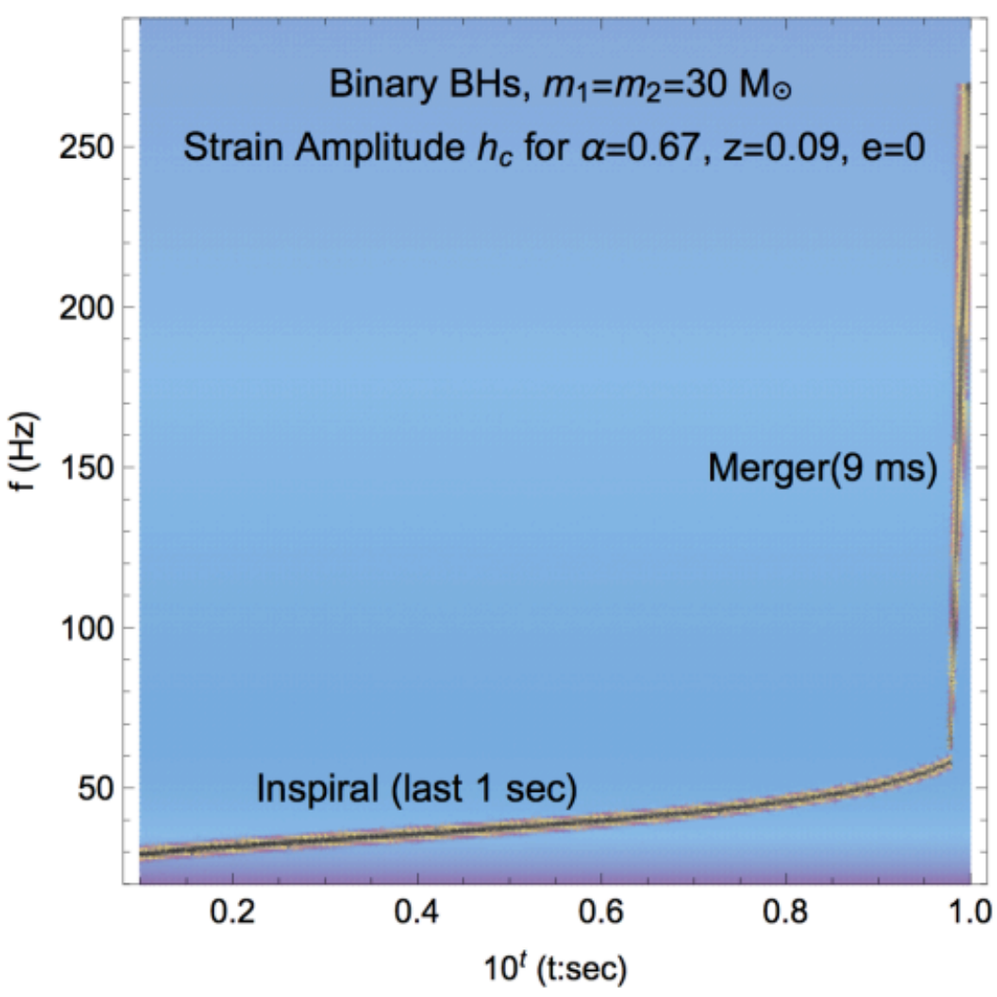


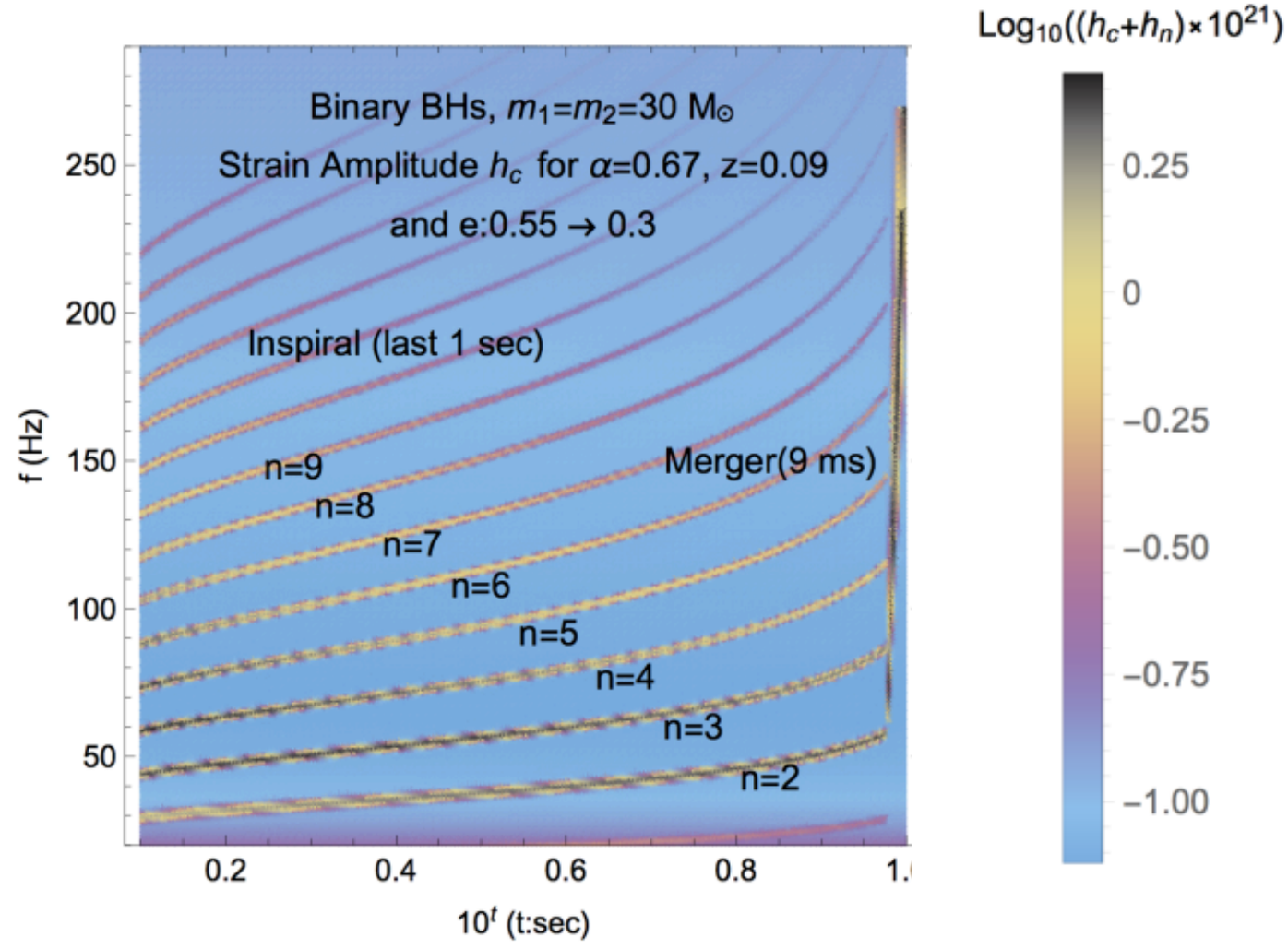

# Orbital Eccentricities in PBH Binaries

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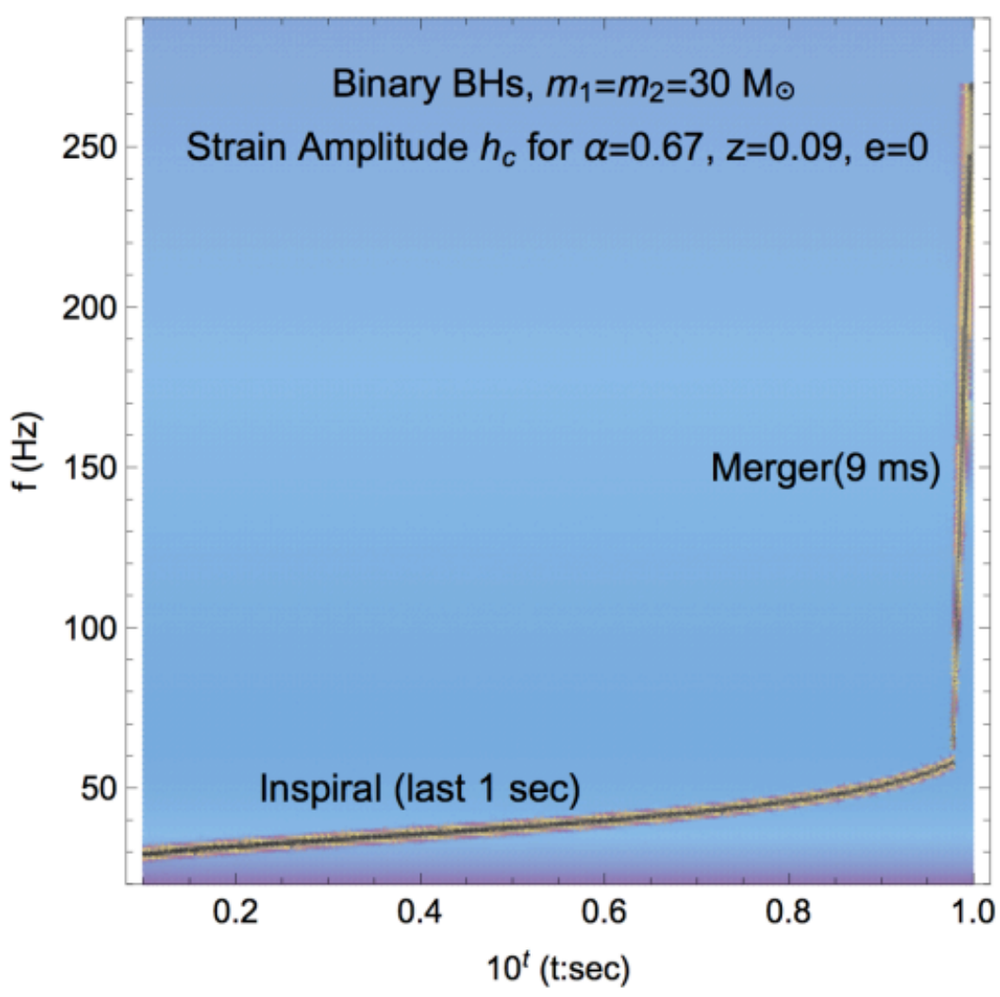
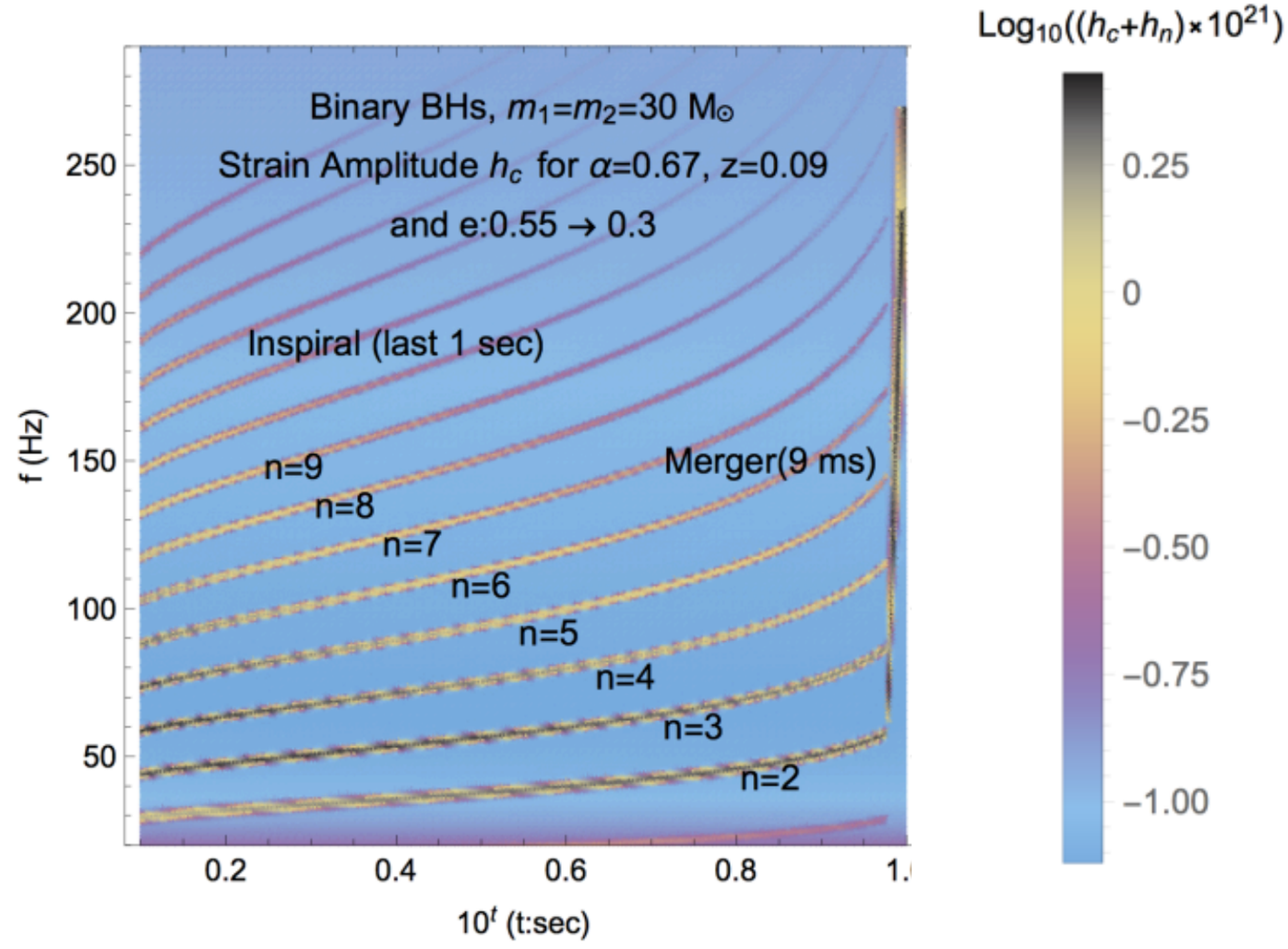
GW signal (+ noise):

| Environment $M_{\rm vir}$ $(M_\odot/h)$ | $R_m(0)^{e_{14}>0.2}$ (Gpc$^3$yr$^{-1}$) | $N^{e_{14}>0.2}$ LIGO 6yr | $N^{e_{14}>0.1}$ ET 10 yr | $N^{e_{14}>0.1}$ ET 10 yr (optimistic) |
|---|---|---|---|---|
| PBHs in $10^6$ | (0.2-4) $\times 10^{-4}$ | $(0.05-1)\times 10^{-1}$ | 0.04-1 | 0.08-2 |
| PBHs in $10^9$ | (0.1-2.5) $\times 10^{-5}$ | $(0.2-5)\times 10^{-3}$ | $(0.2-4)\times 10^{-2}$ | $(0.5-10)\times 10^{-2}$ |
| PBHs in $10^{12}$ | (0.7-20) $\times 10^{-7}$ | $(0.15-3)\times 10^{-5}$ | (0.25-5)$\times 10^{-3}$ | (0.04-0.8)$\times 10^{-2}$ |
| PBHs in $> 10^{2.5}$ | (1-20)$\times 10^{-3}$ | 0.3-5 | 1.5-30 | 3-60 |
| BHs in GC$^{2\rm body}$ | (0.2-2)$\times 10^{-5}$ | (1-10)$\times 10^{-3}$ | 0.1-1 | 0.3-5 |



# Determining the Progenitors: Mass Function

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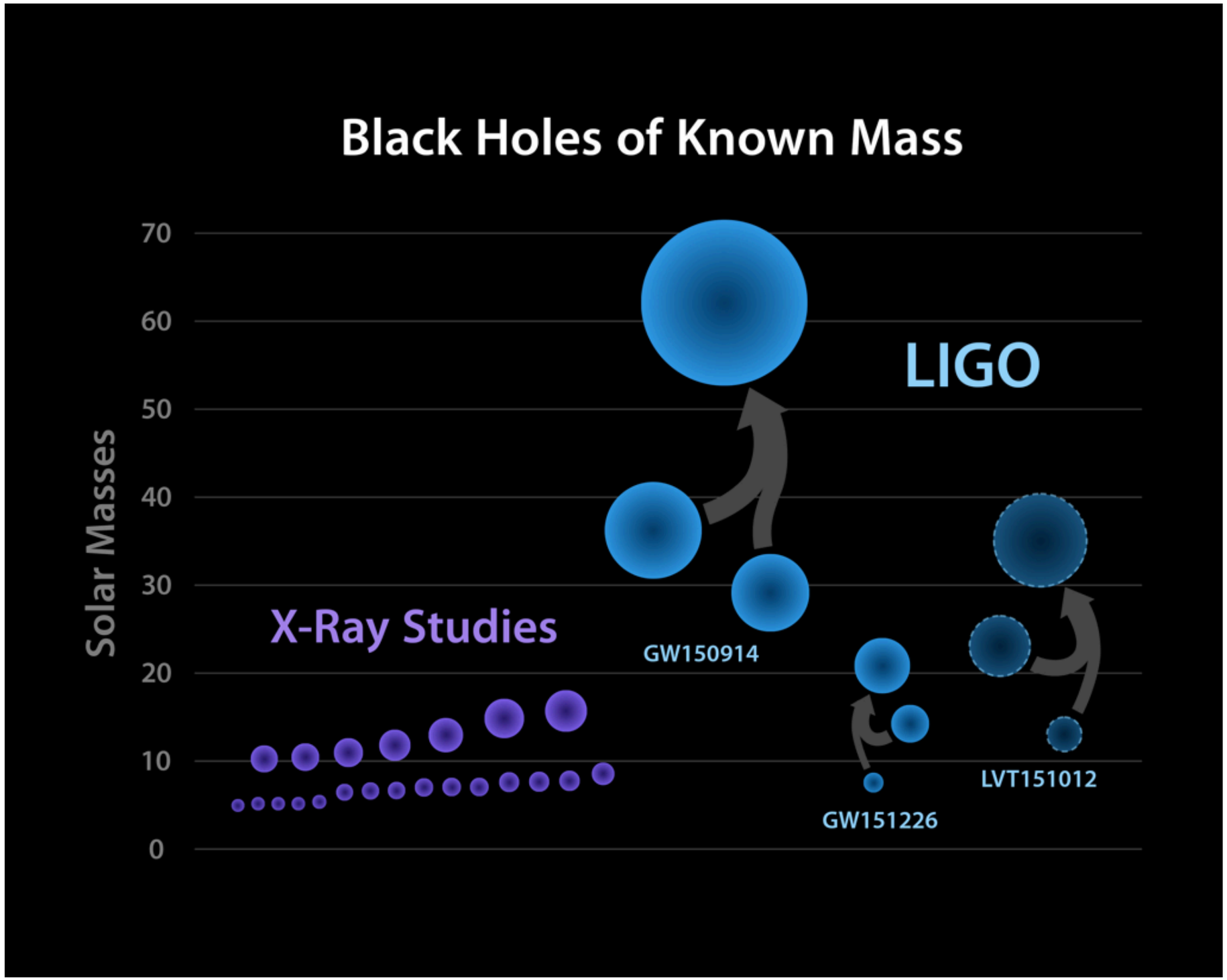


Credit: LIGO

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(EDK, Cholis & Breysse, in preparation)

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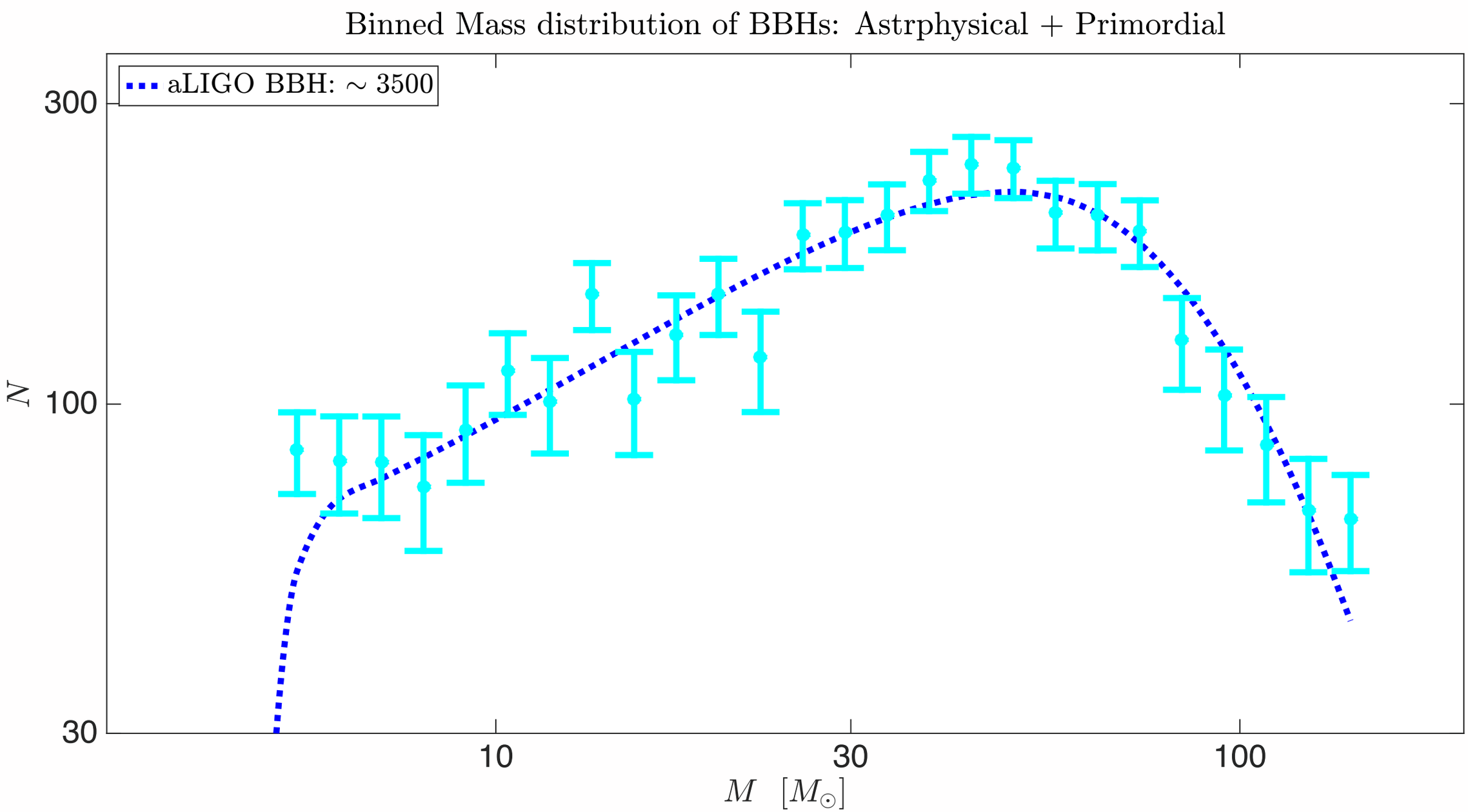

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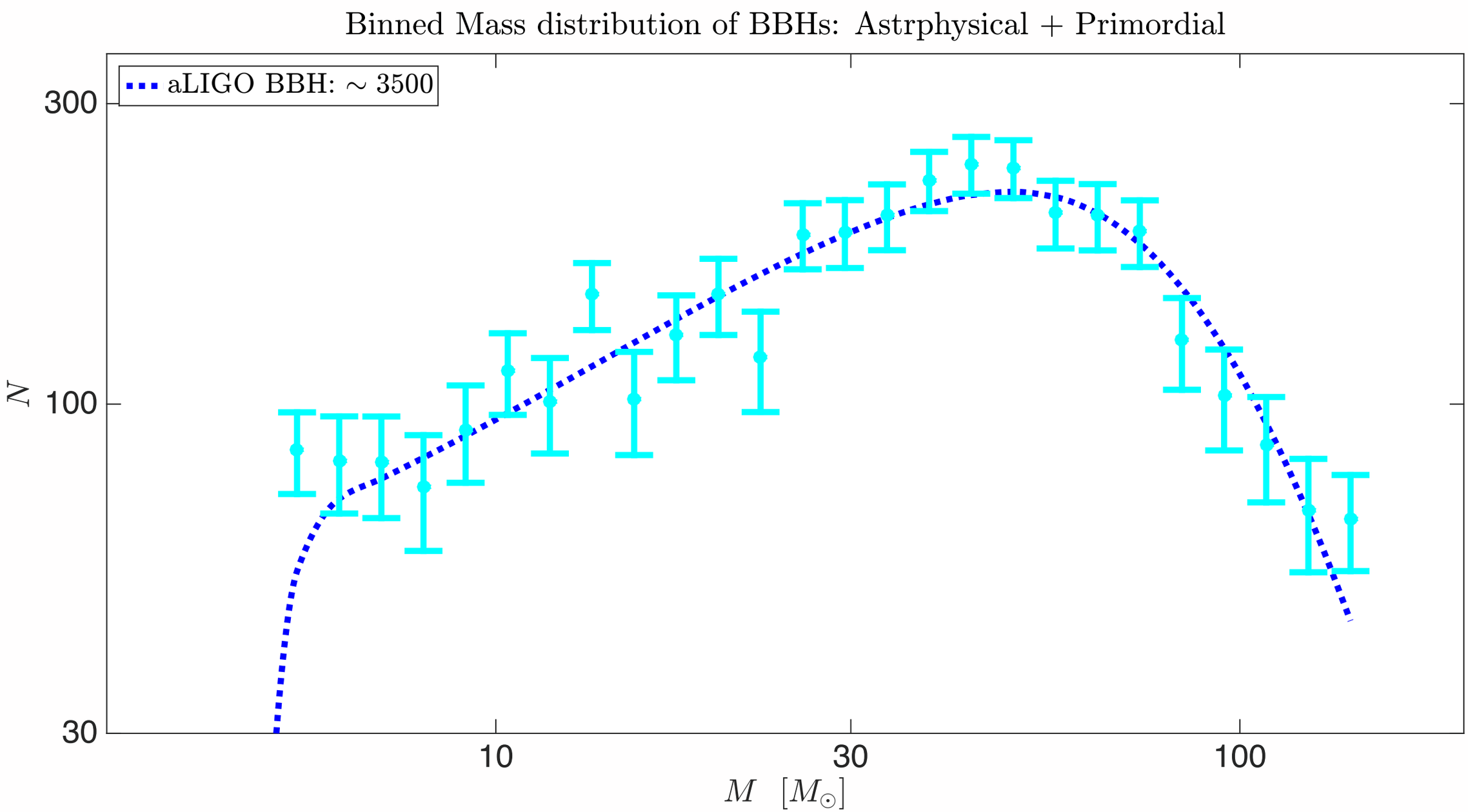

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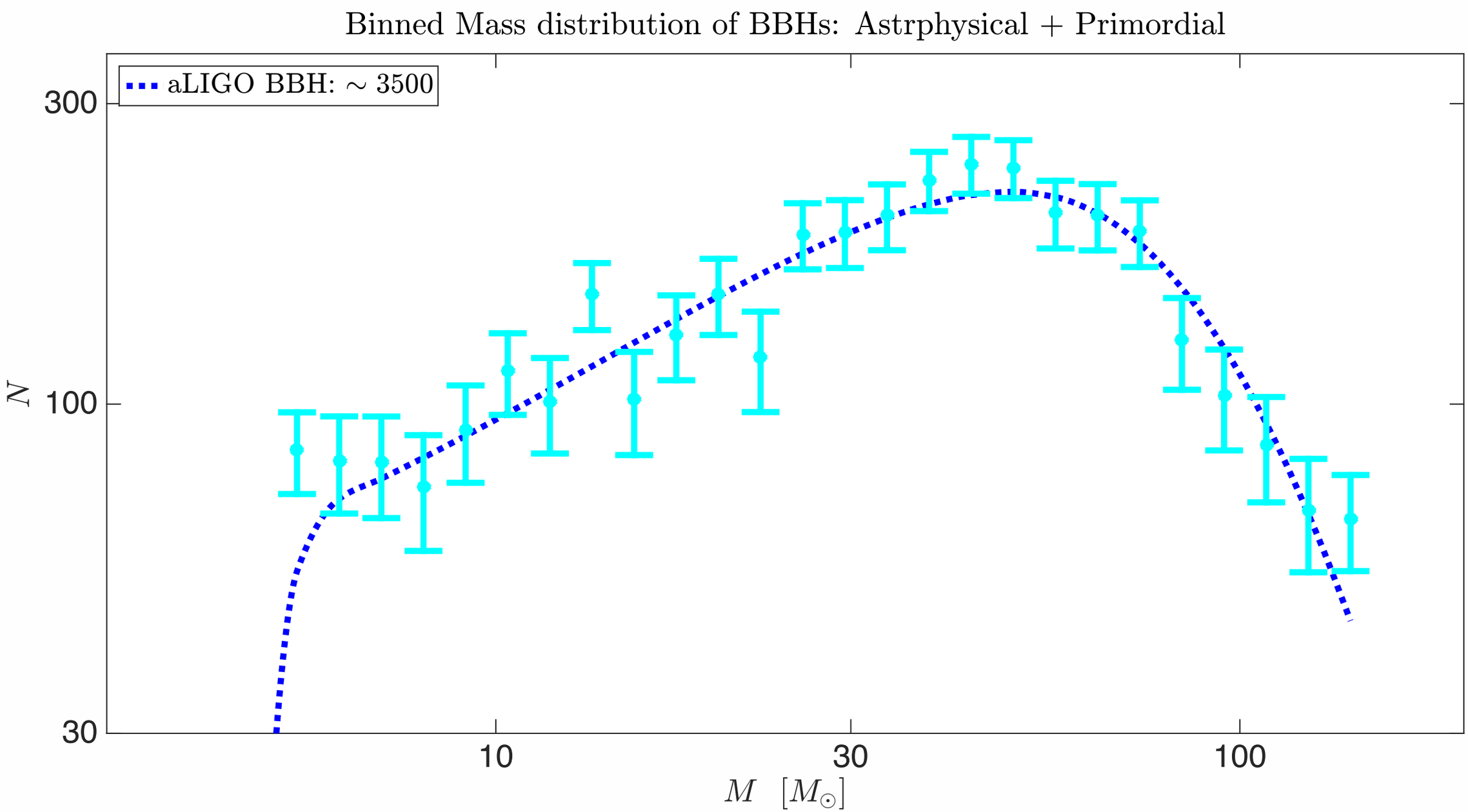

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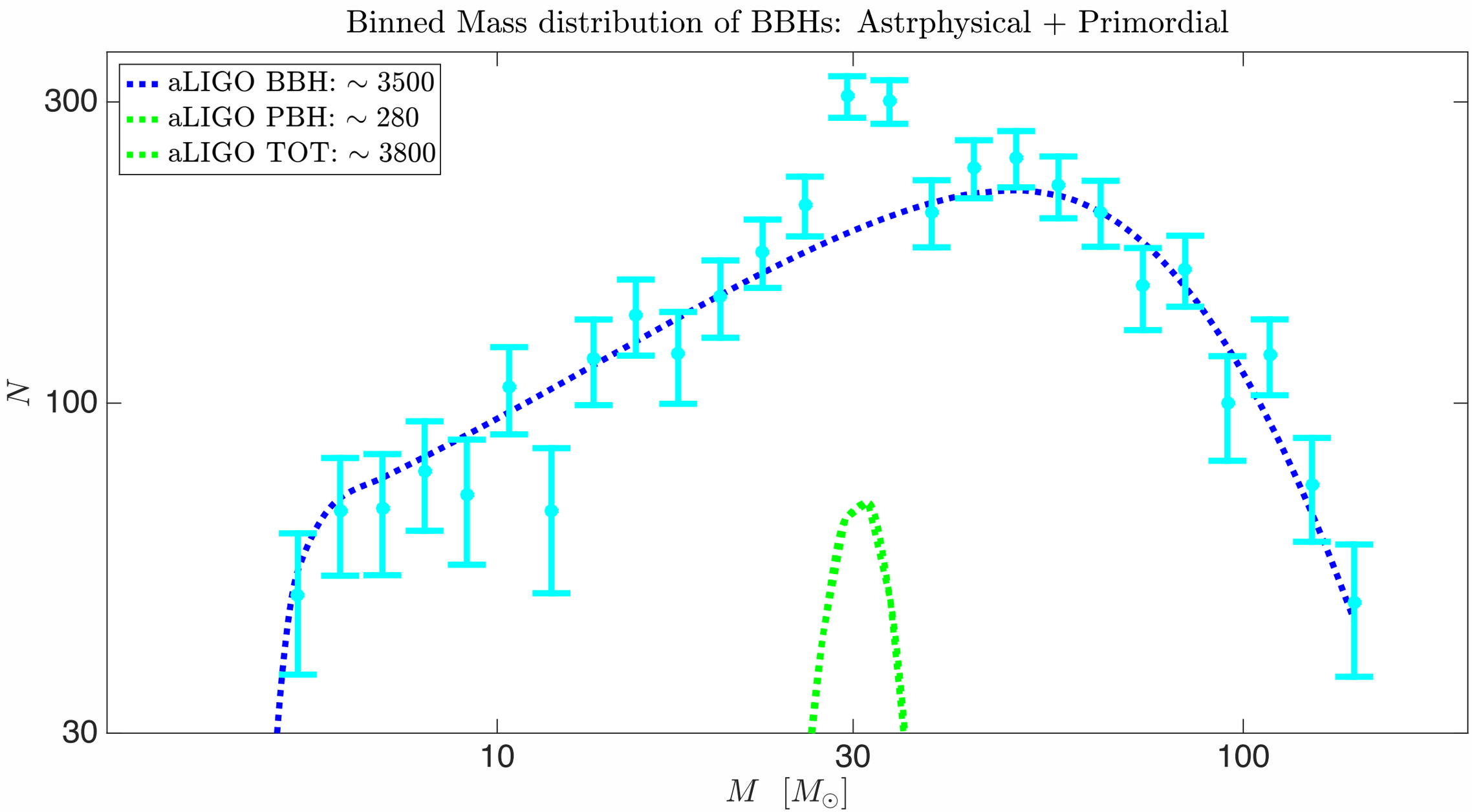

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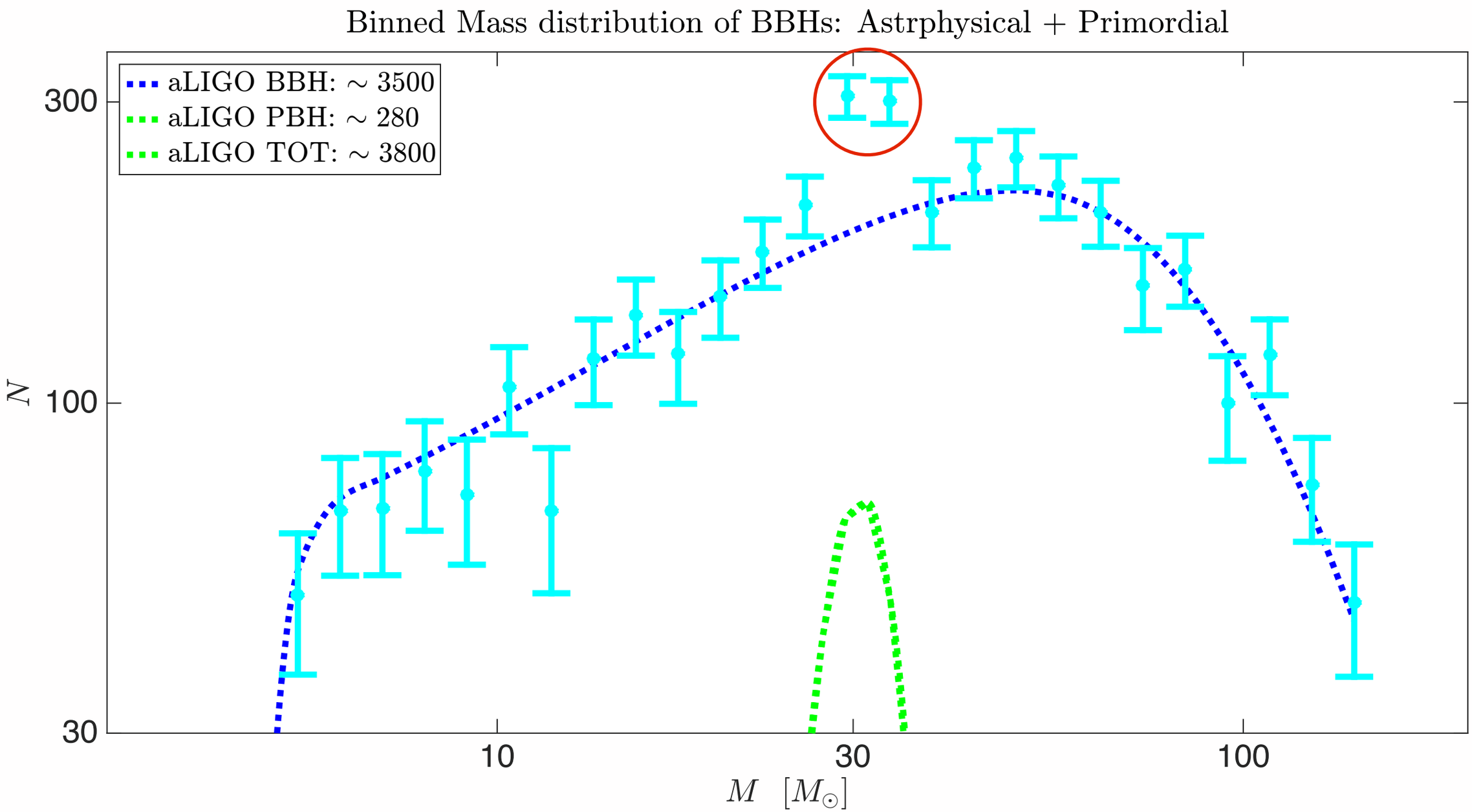

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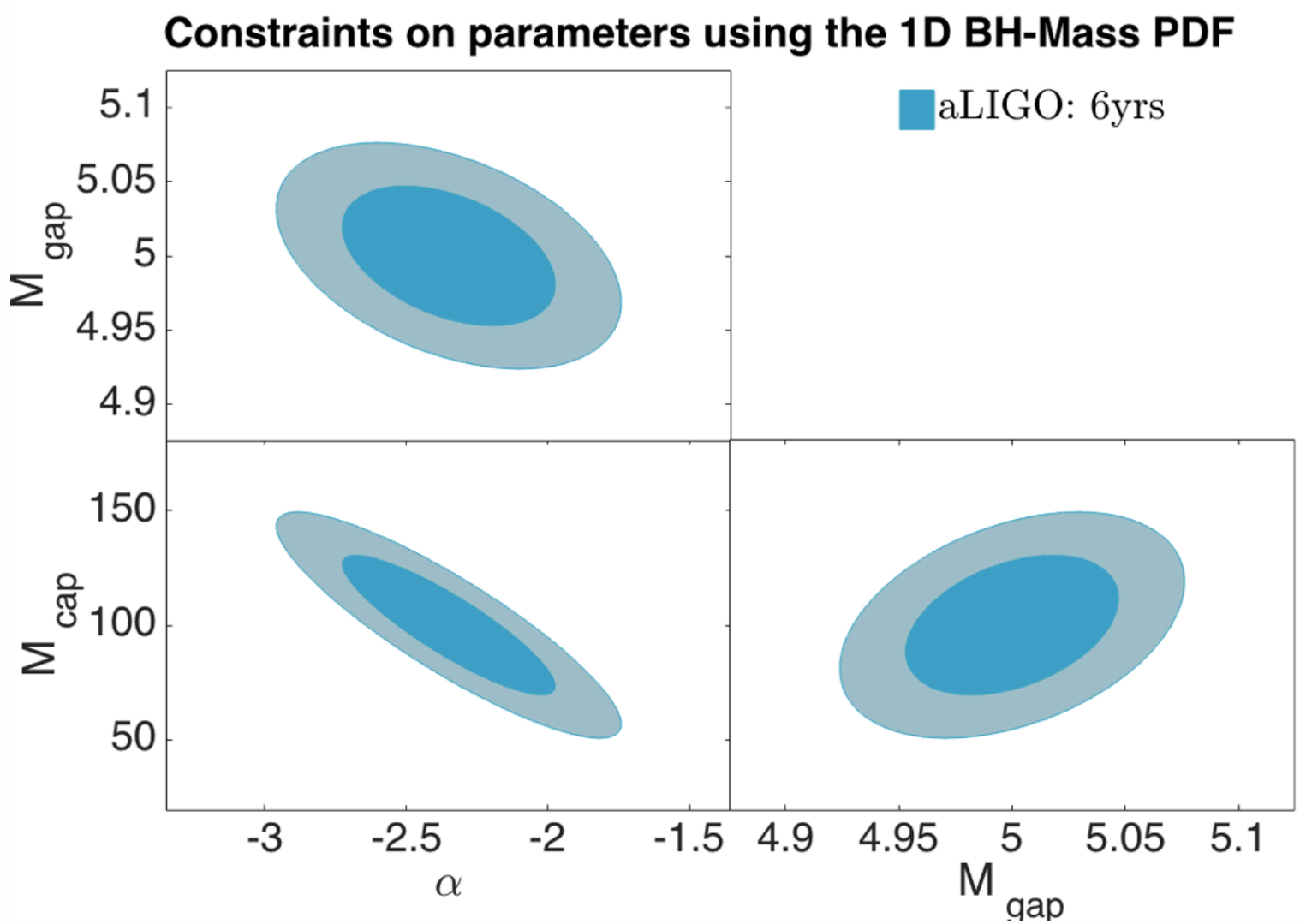

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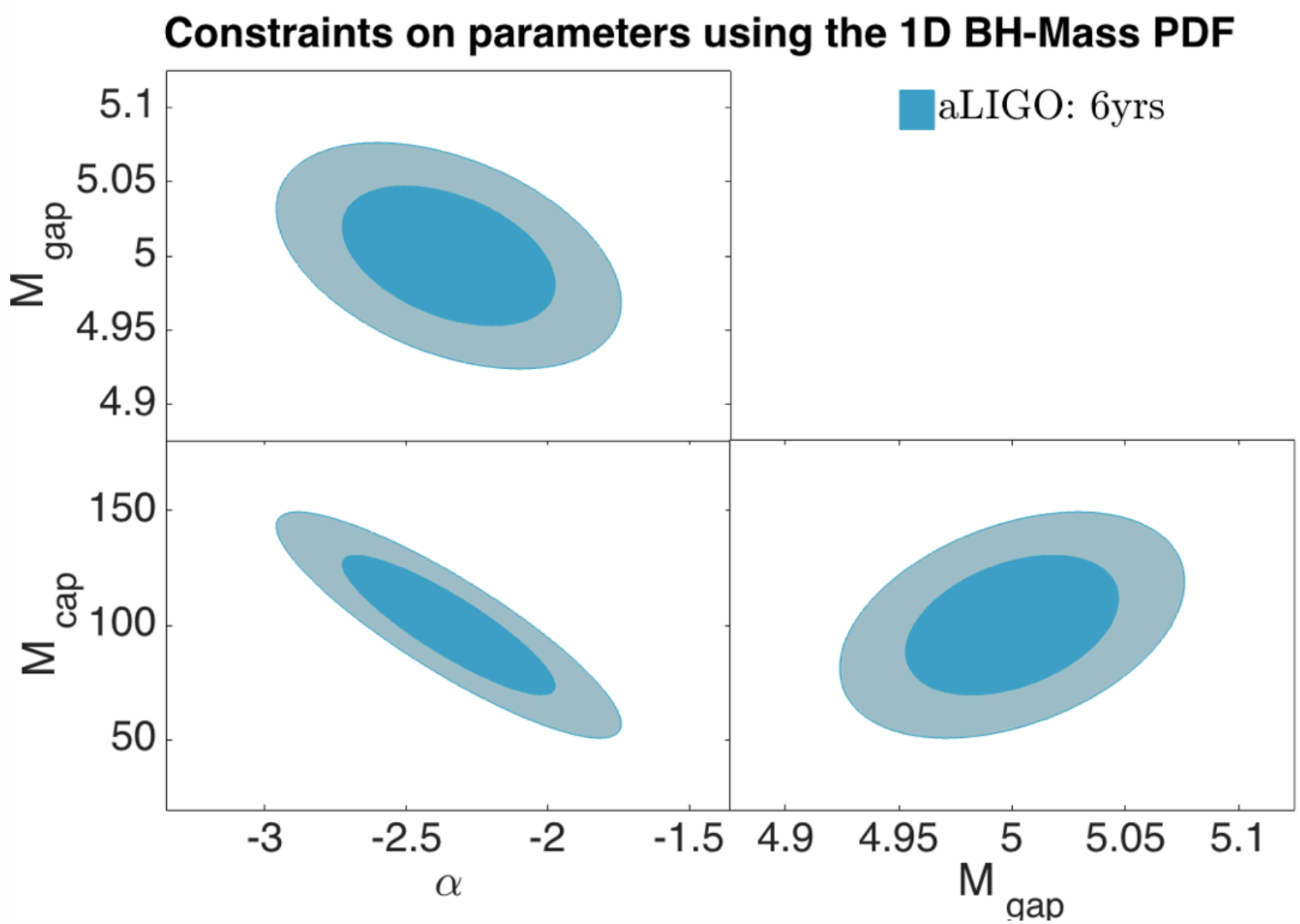

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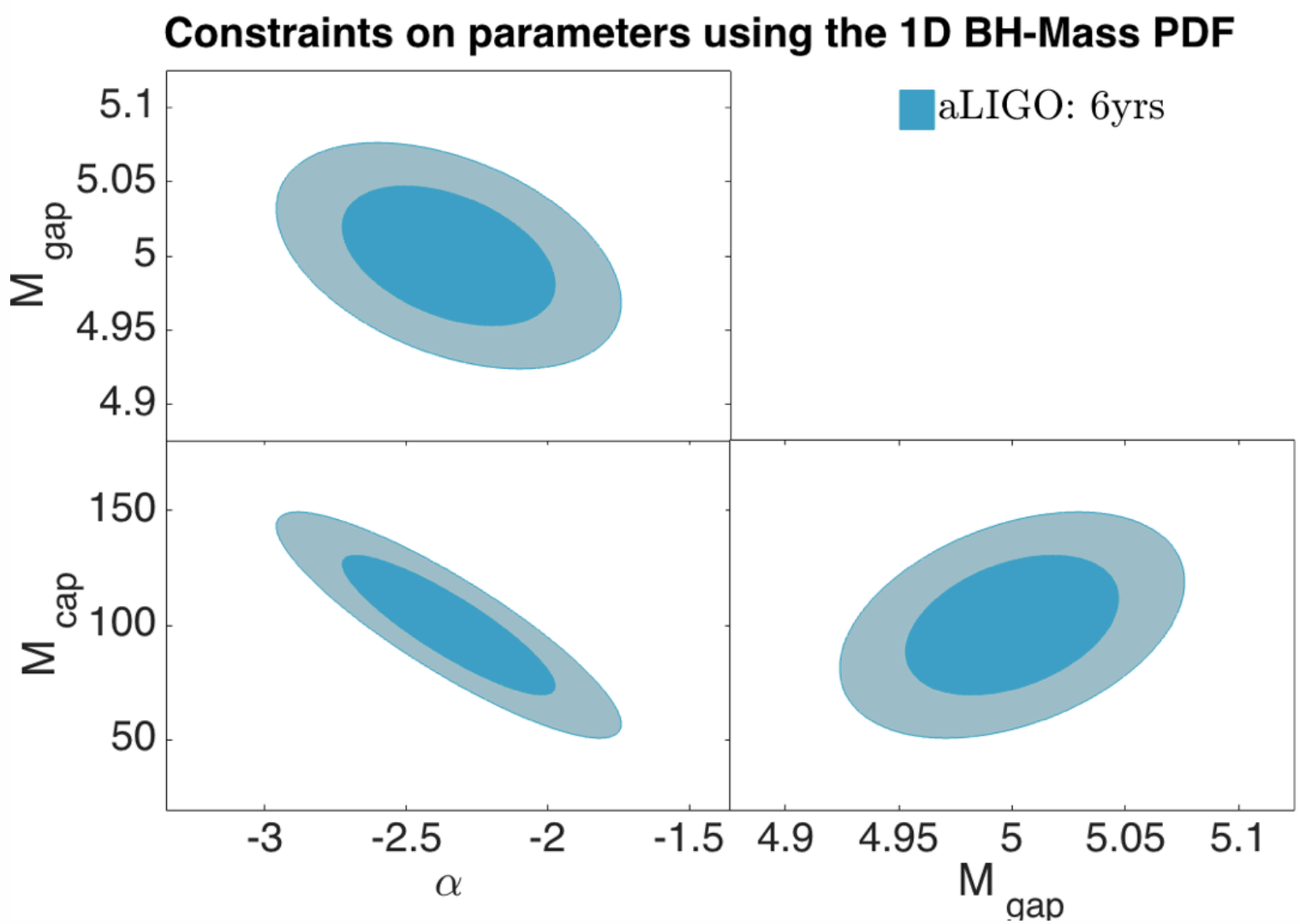

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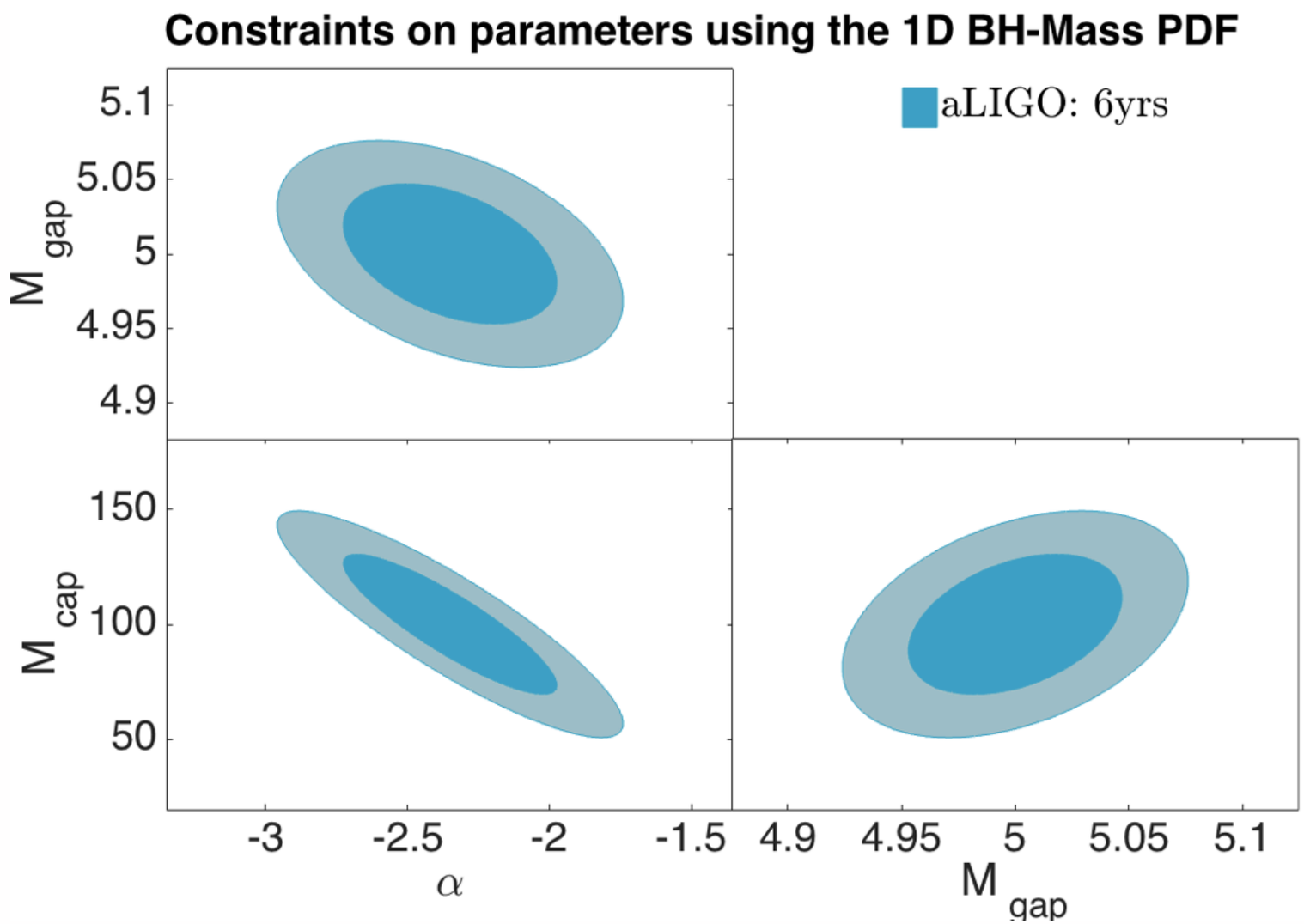

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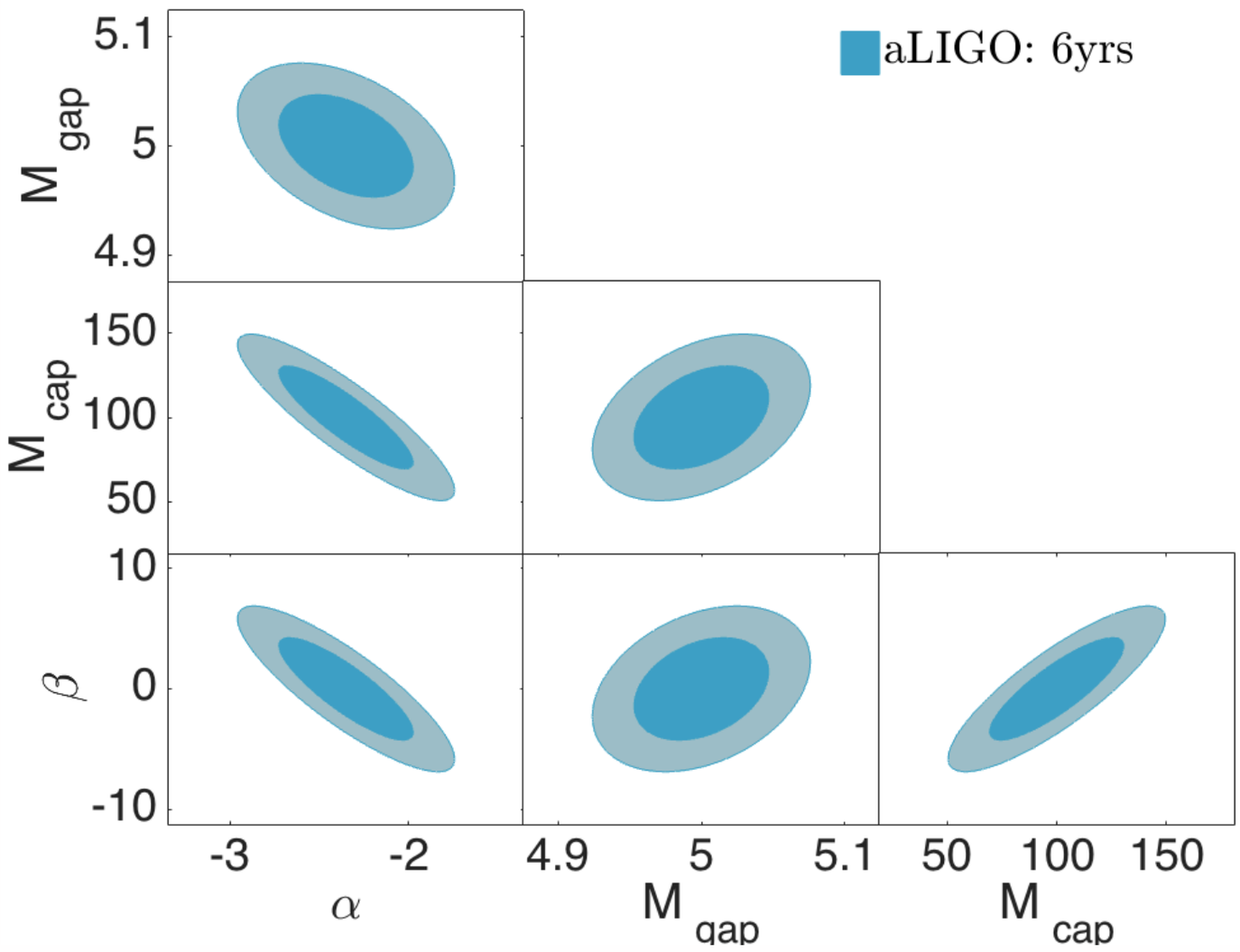

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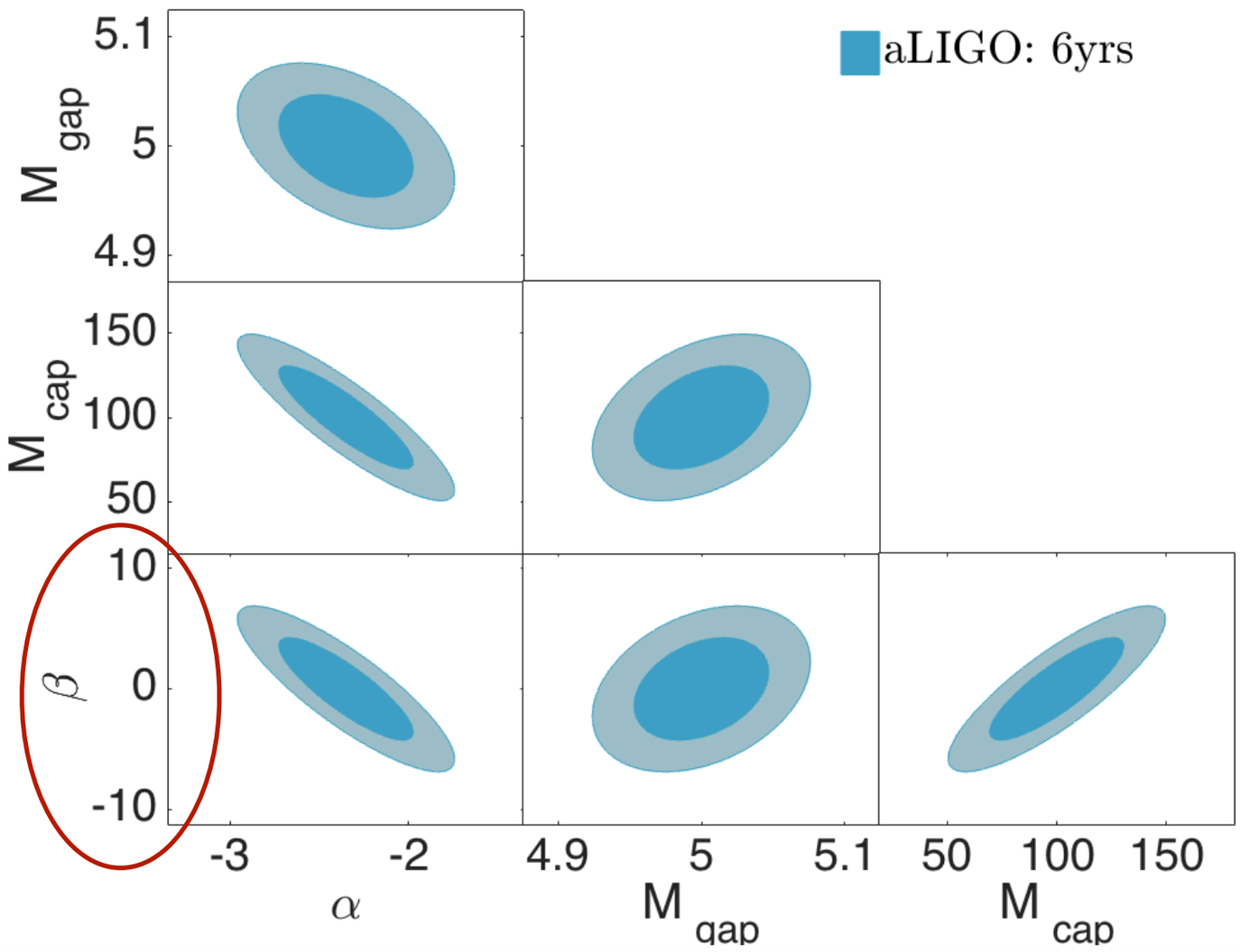

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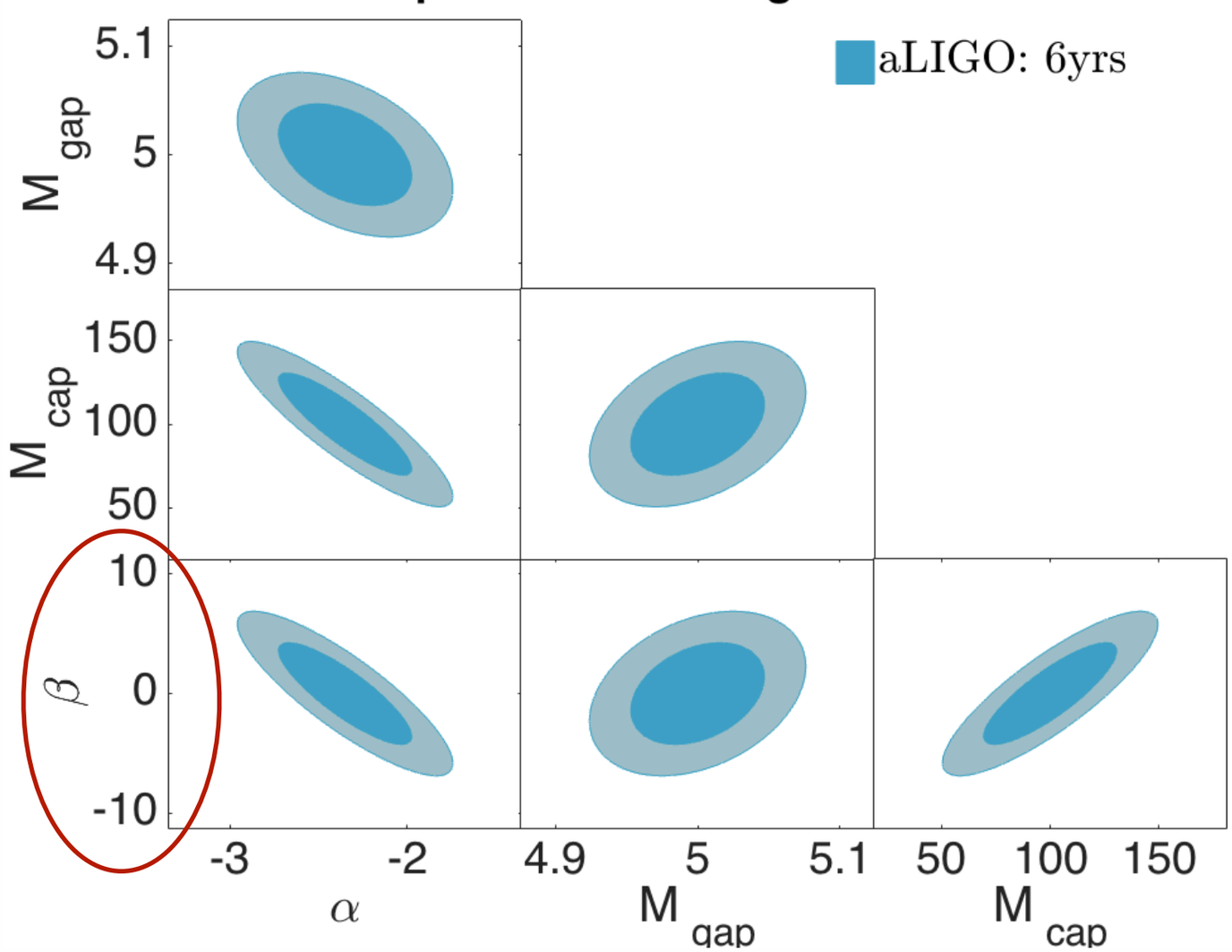


More info
in 2D MF!

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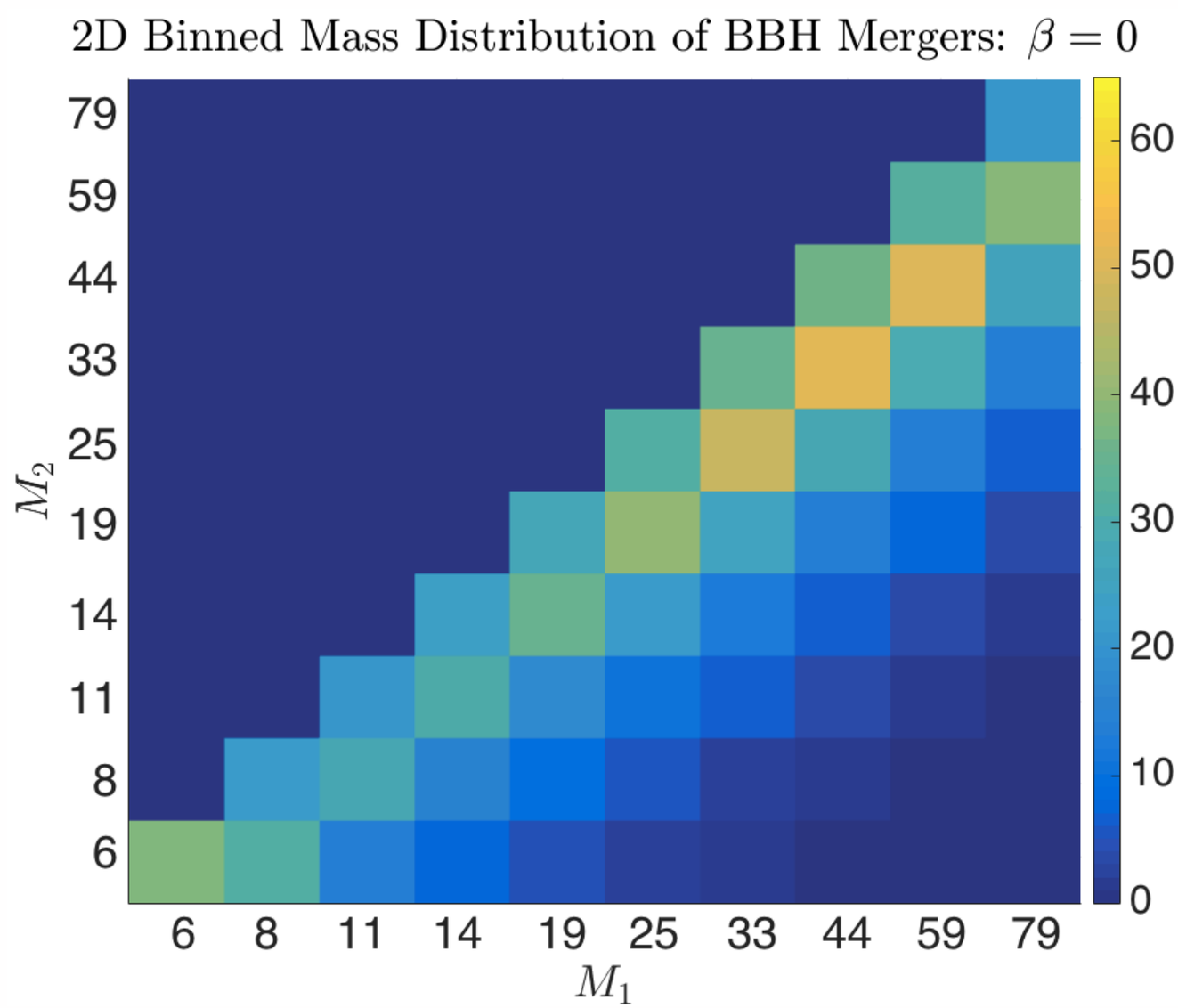

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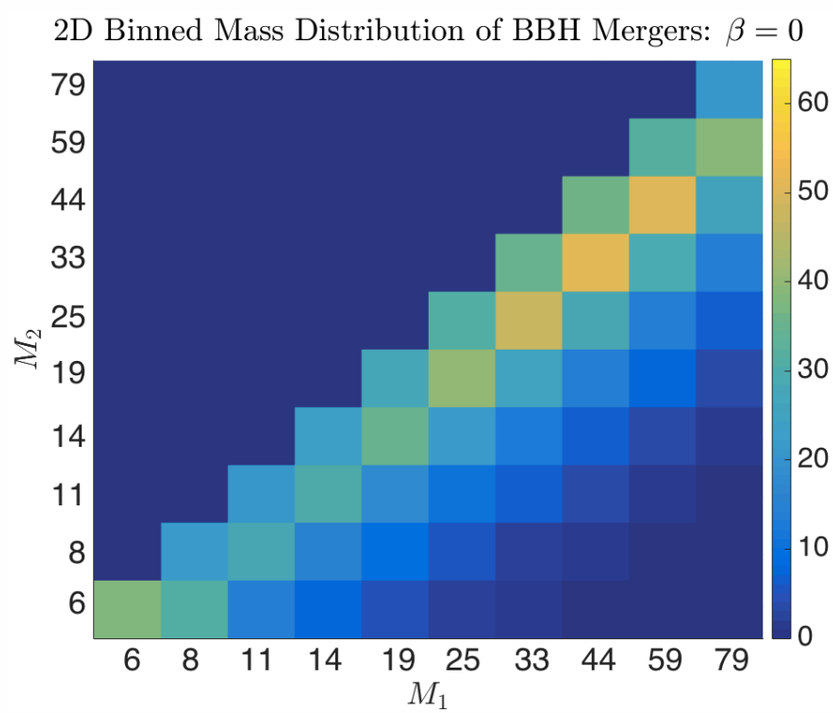

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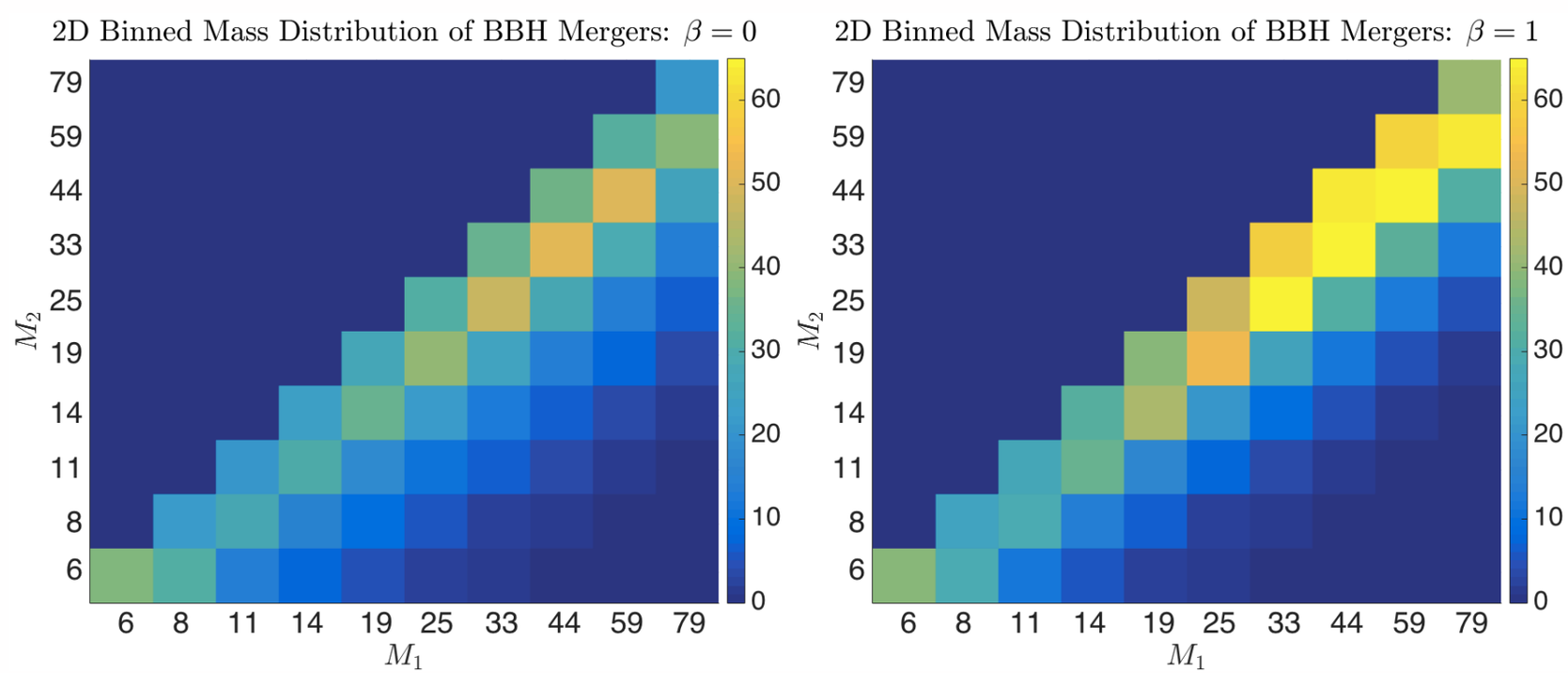

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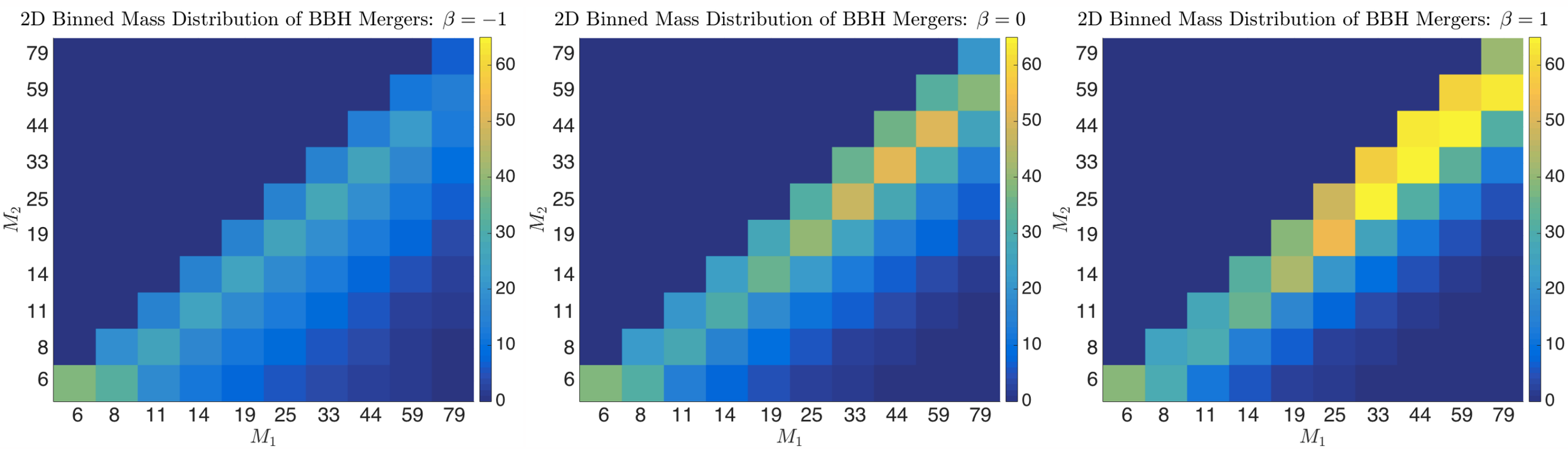

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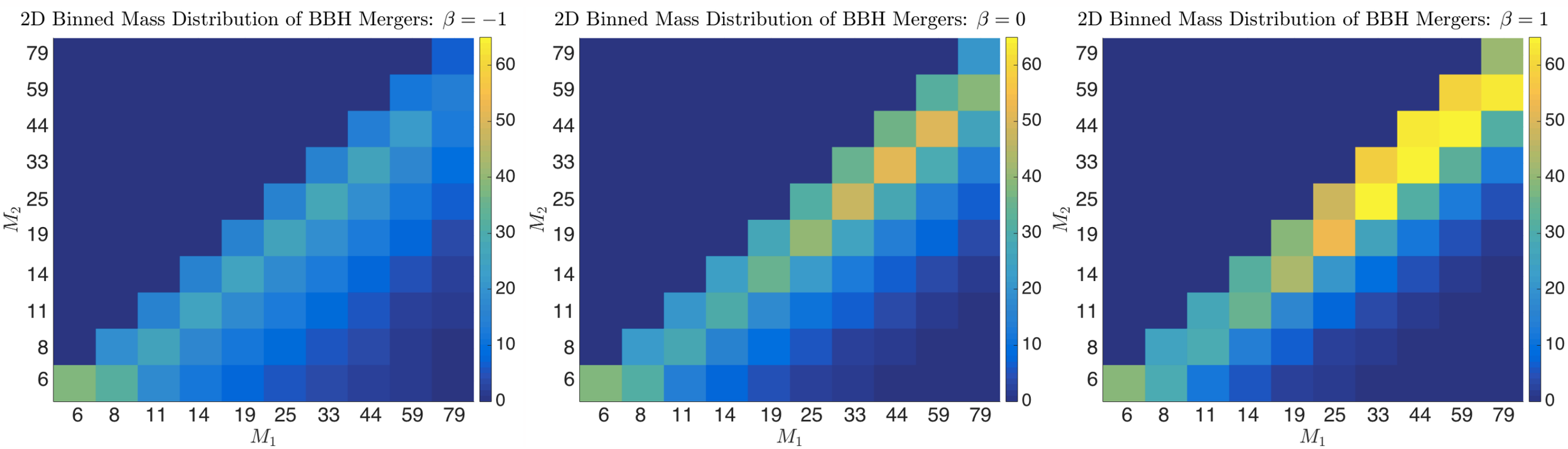

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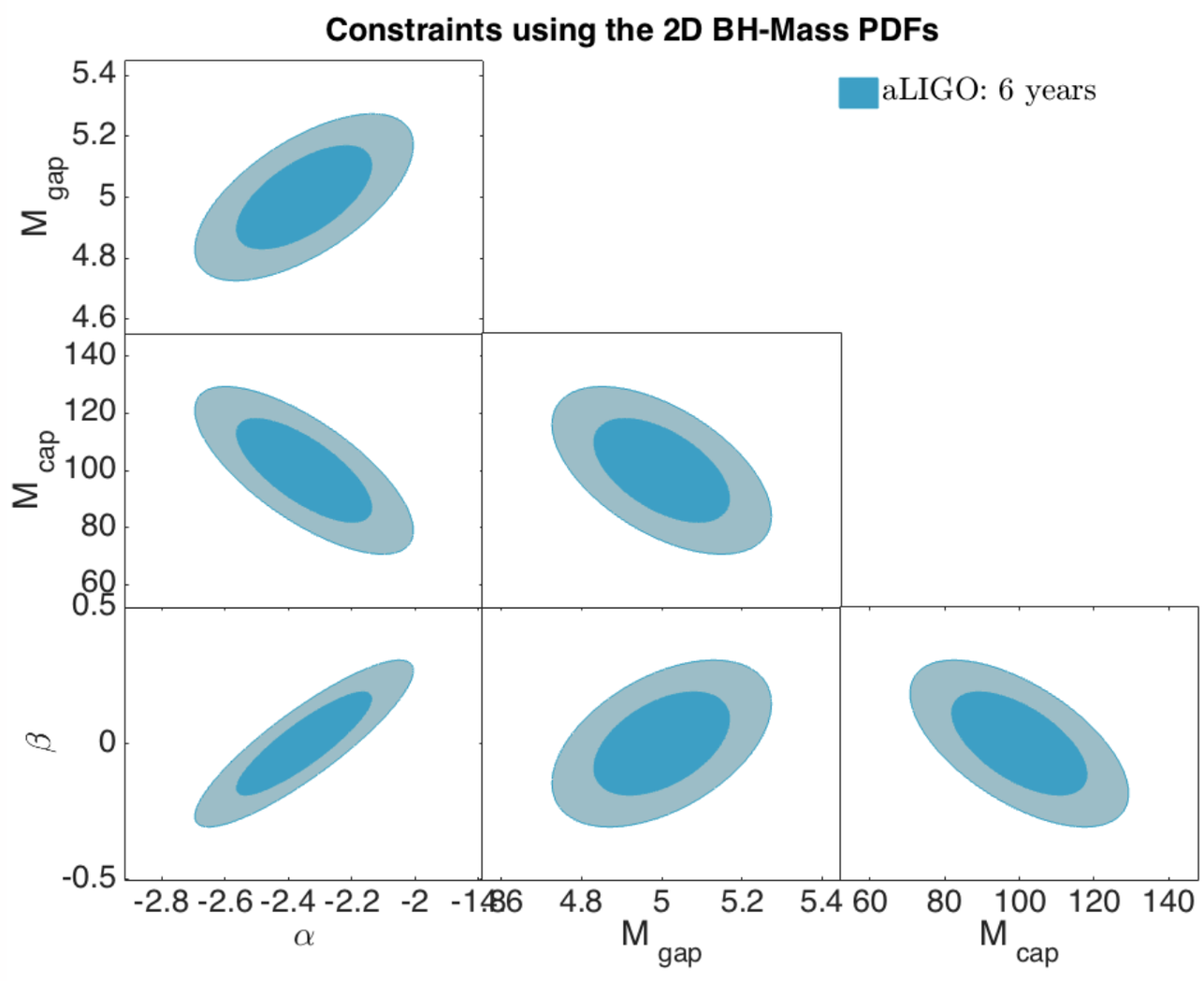

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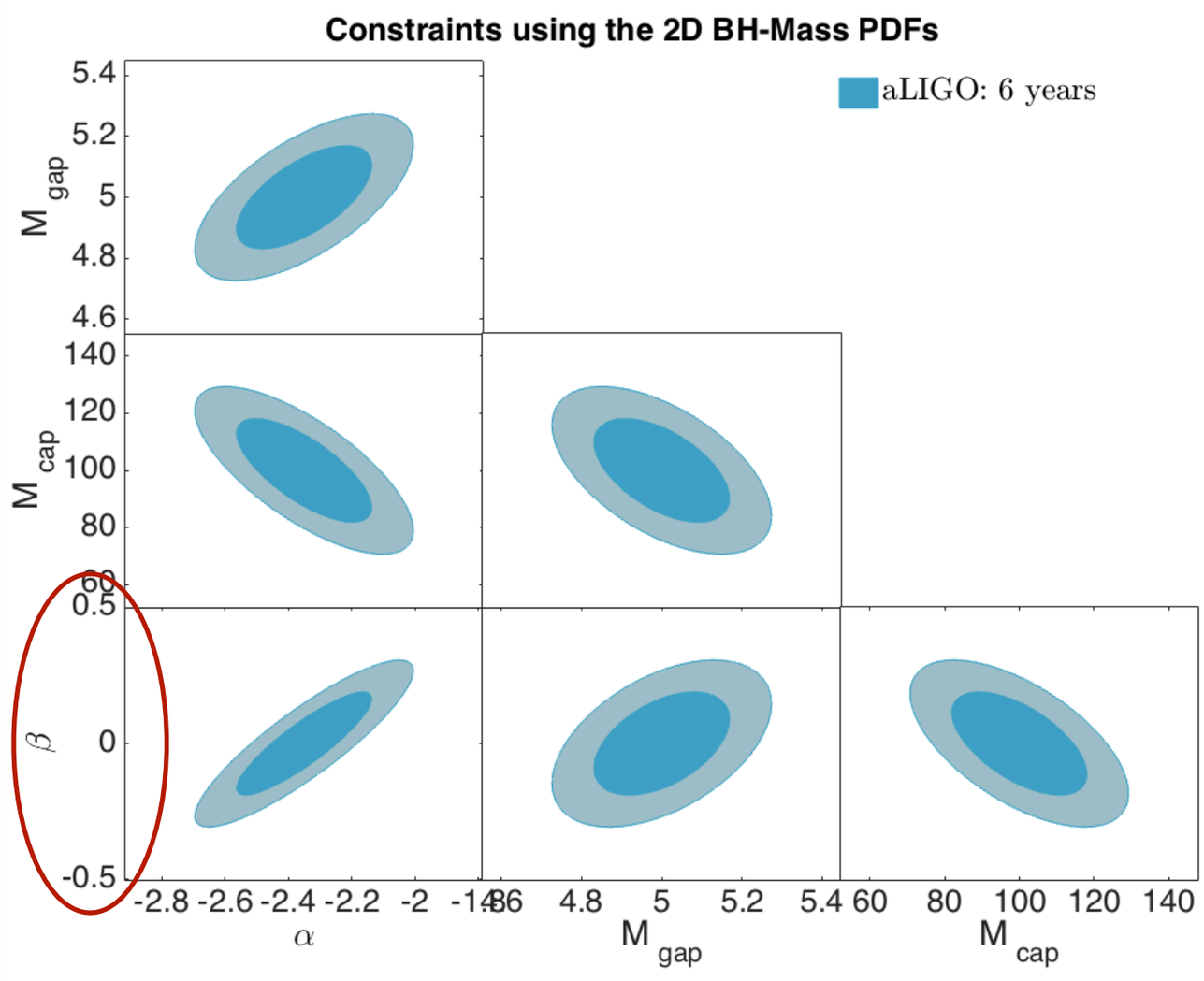

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**“Lensing of Fast Radio Bursts as a Probe of Compact Dark Matter”**
**Muñoz, EDK, Dai & Kamionkowski, Phys. Rev. Lett. 117 (2016)**

# Primordial-Black-Hole Dark-Matter: Constraints

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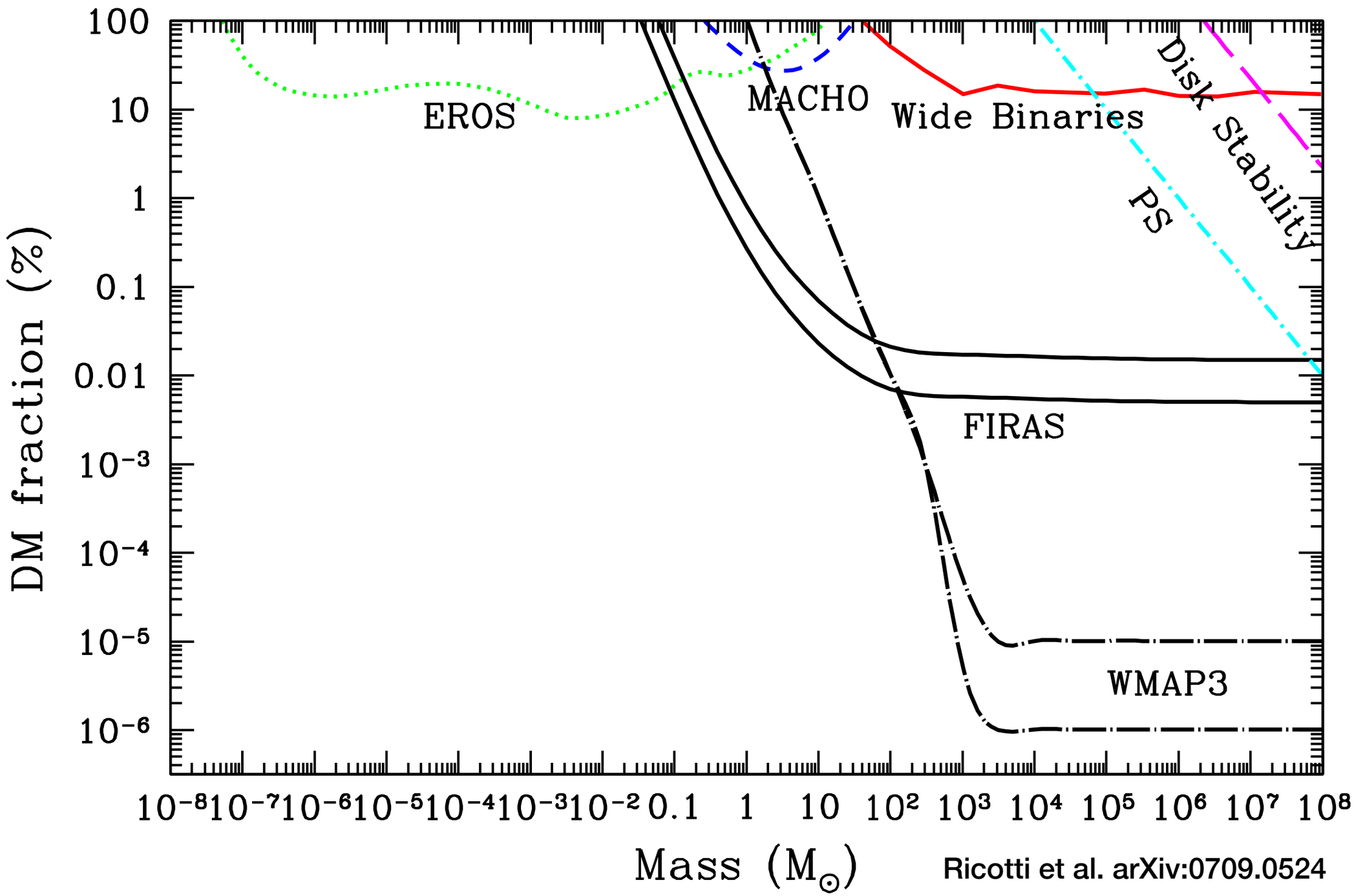


Ricotti et al. arXiv:0709.0524

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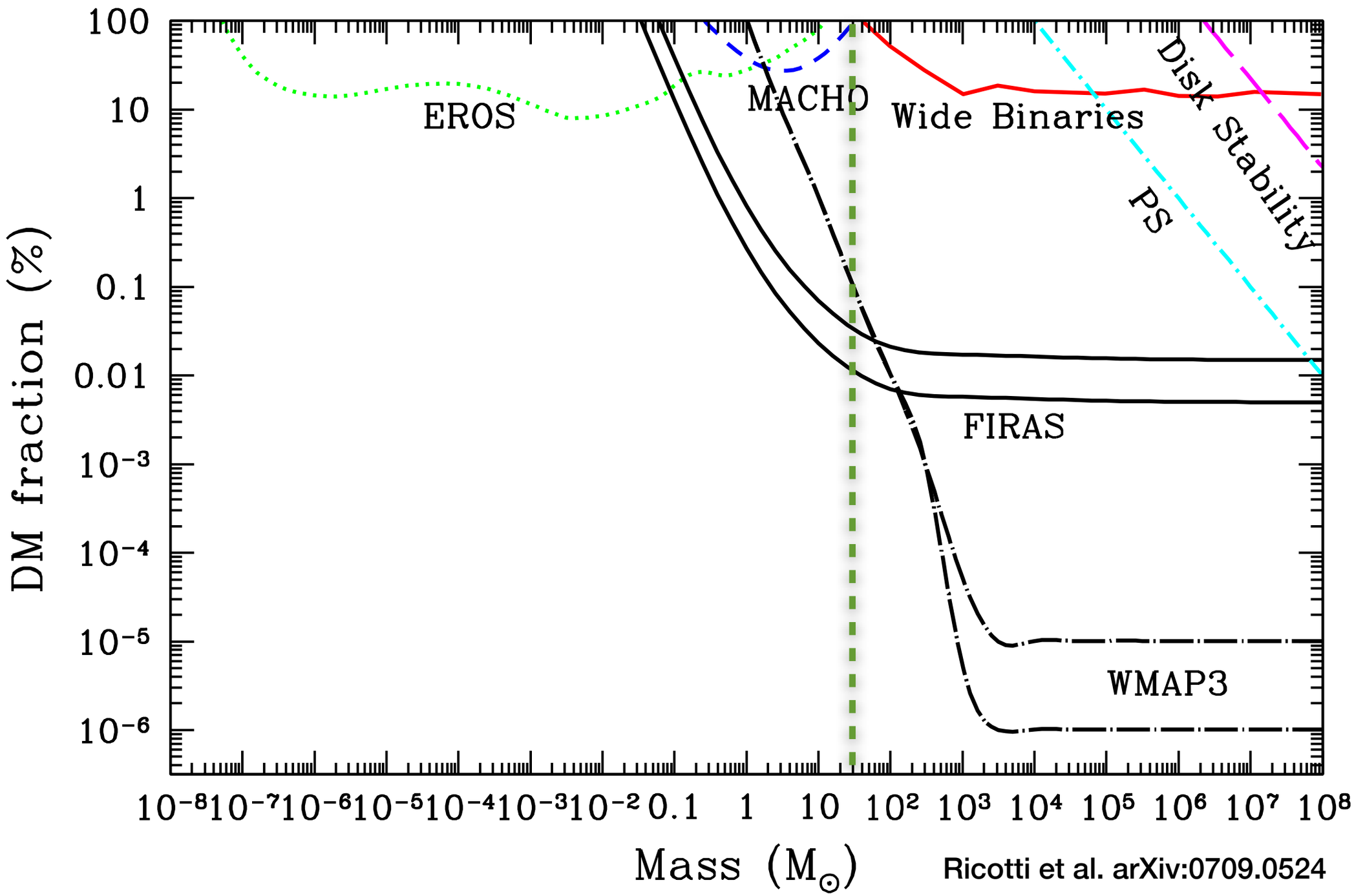


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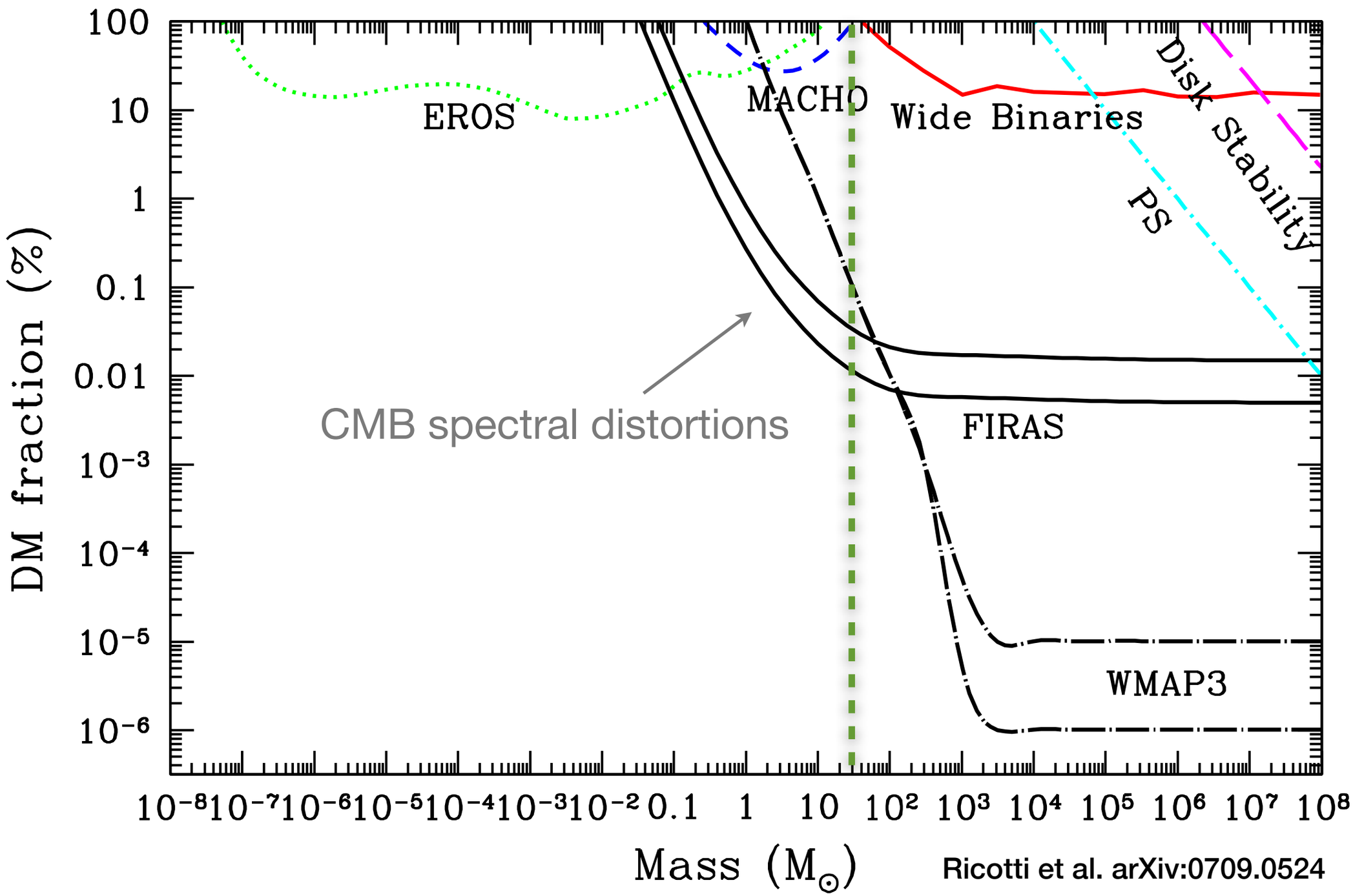


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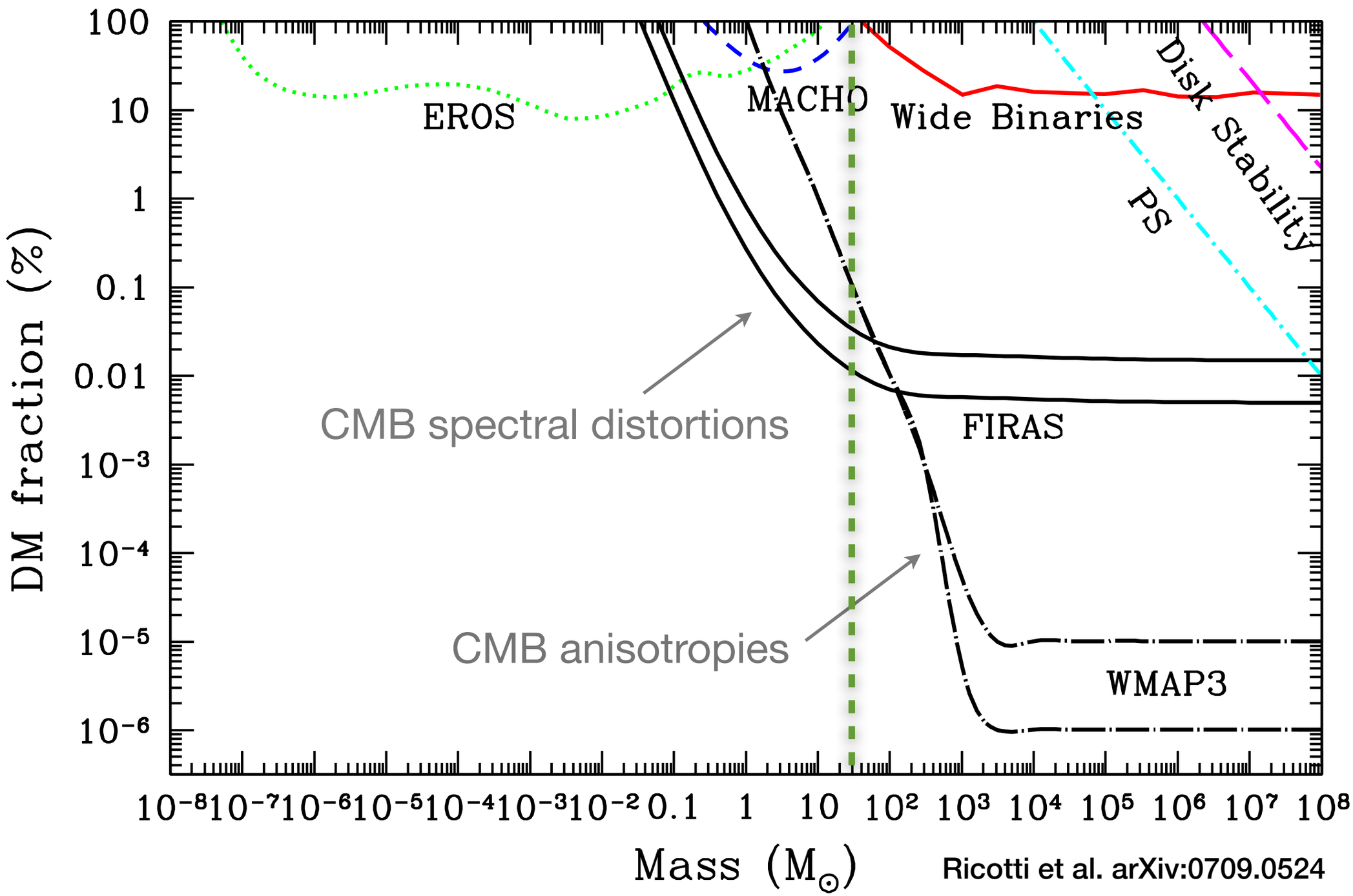


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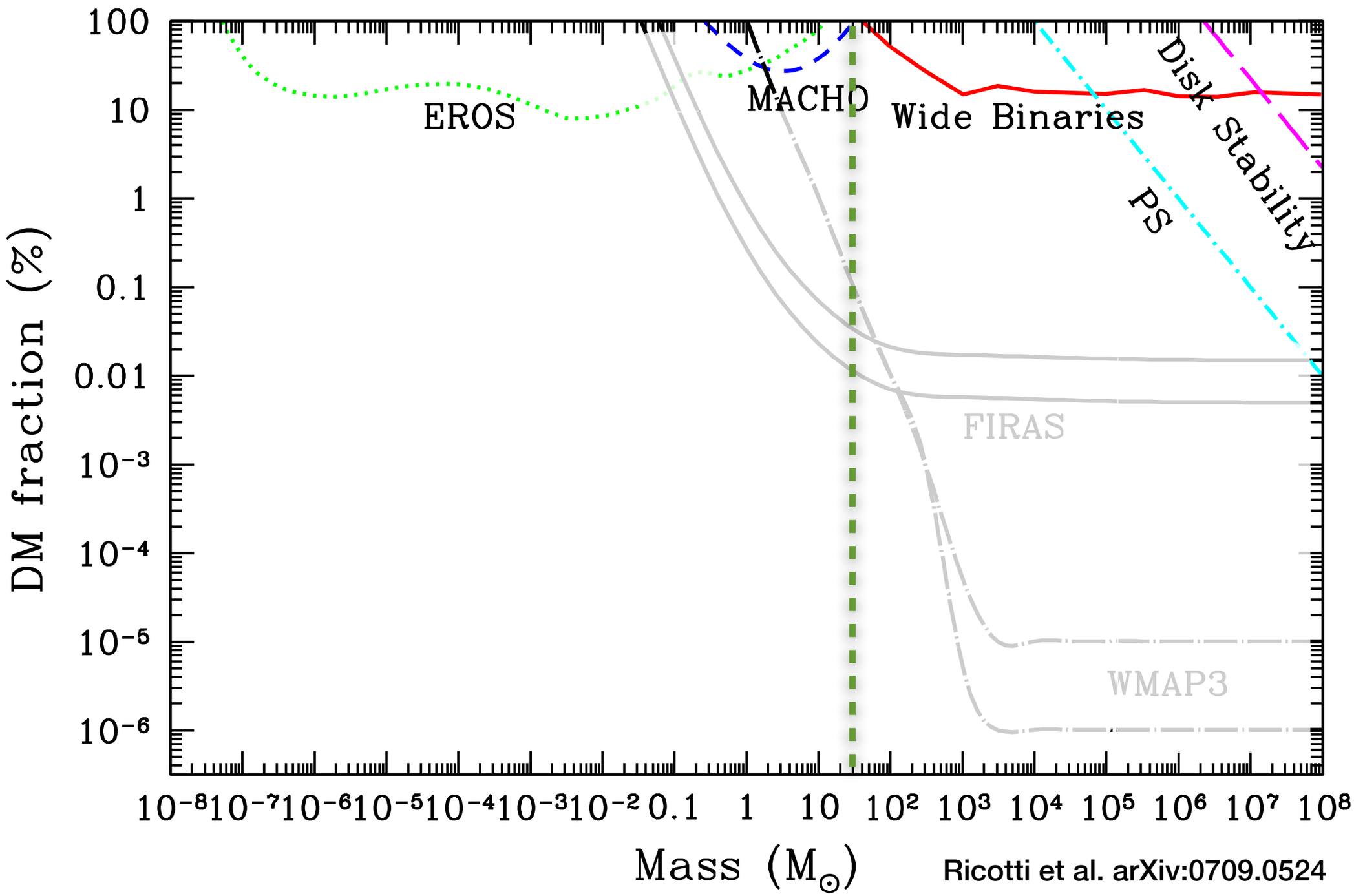


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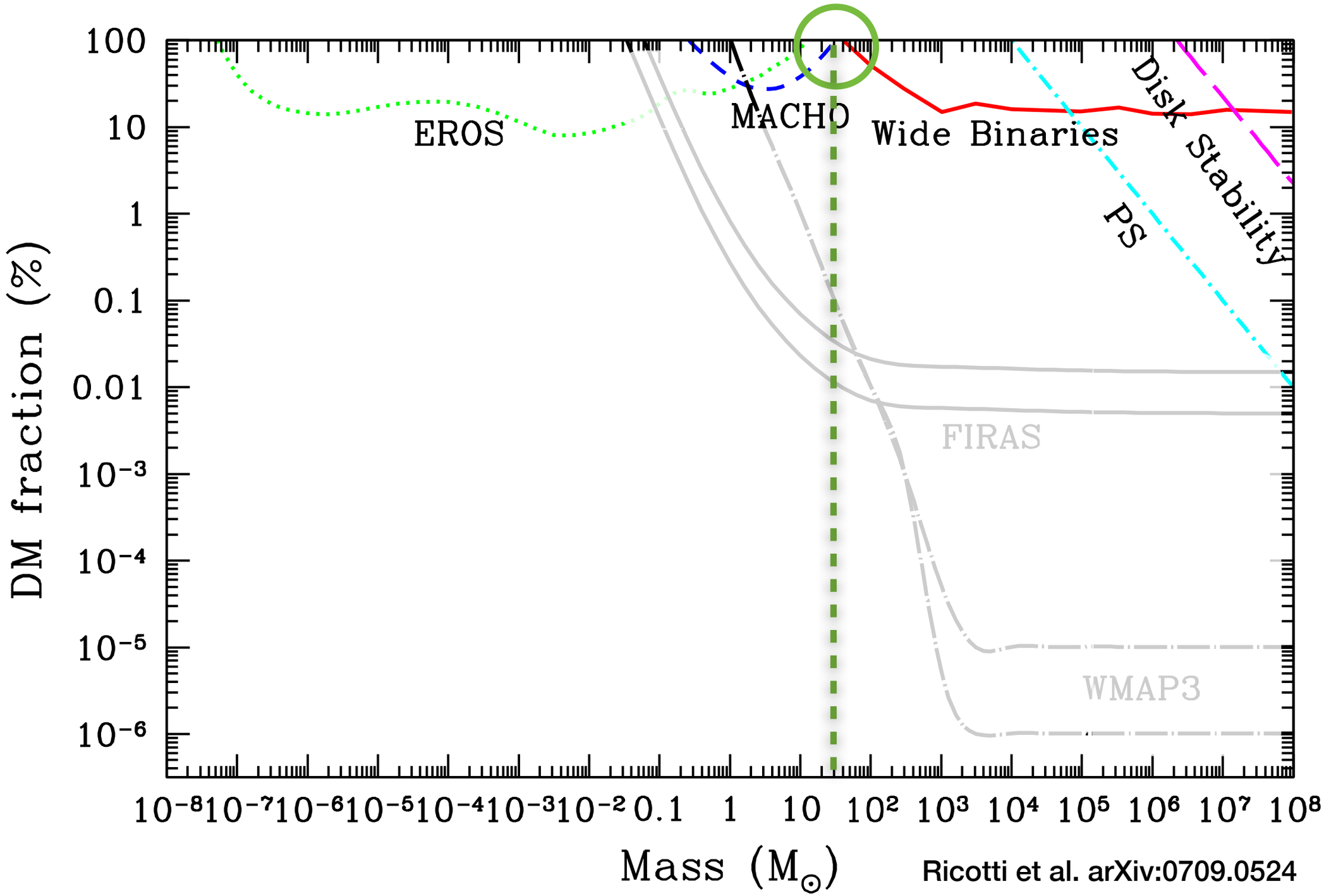


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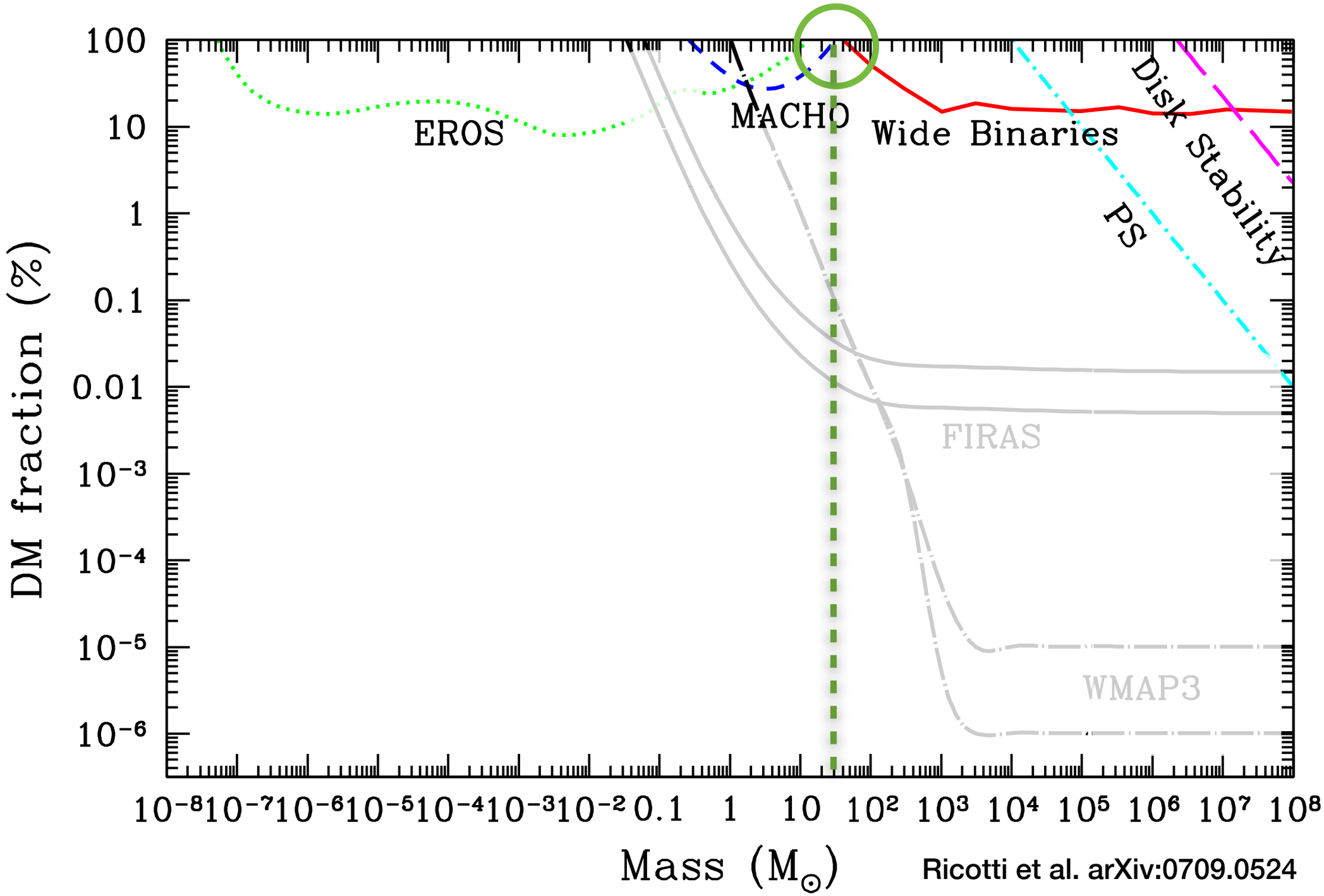


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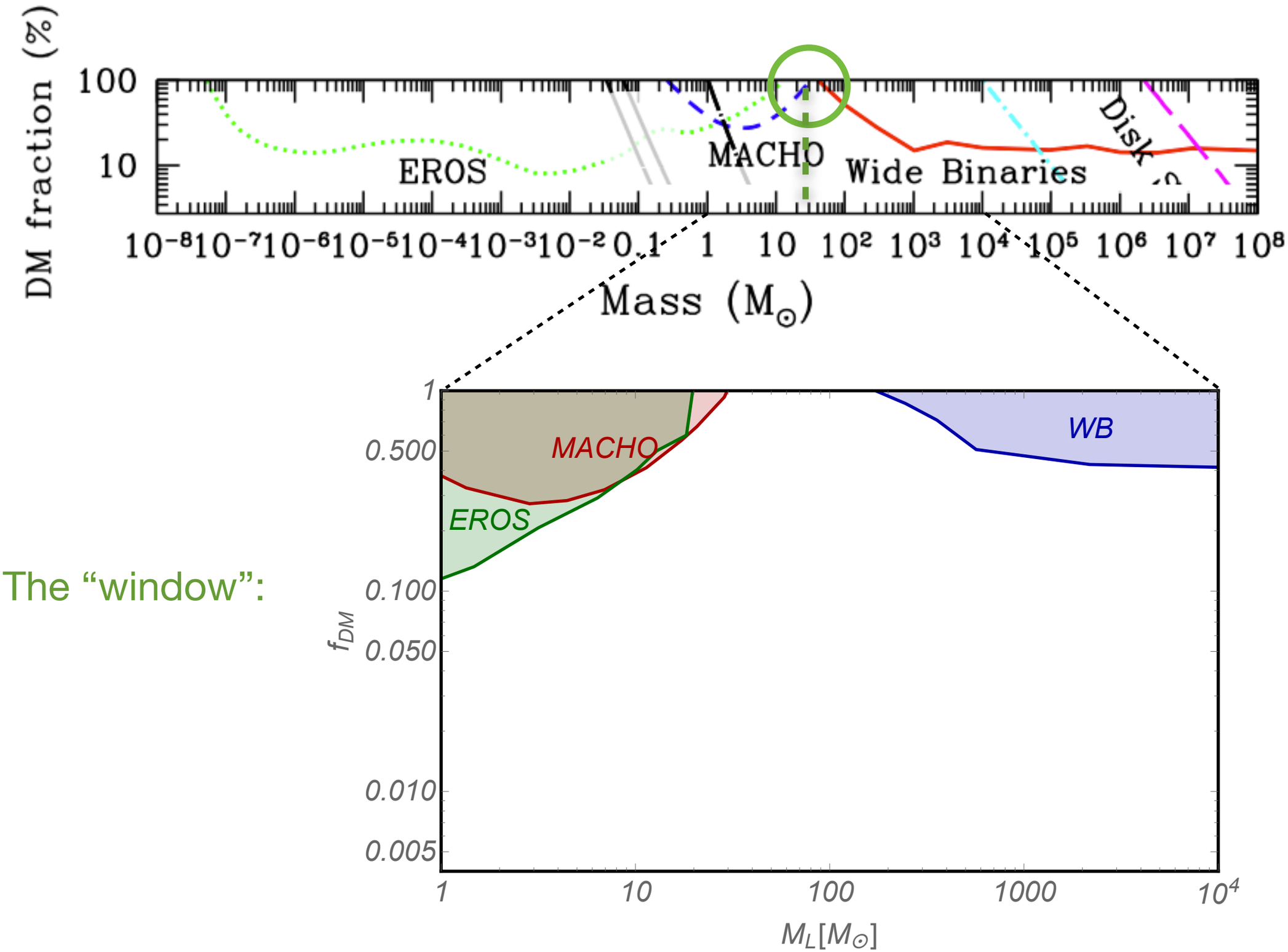
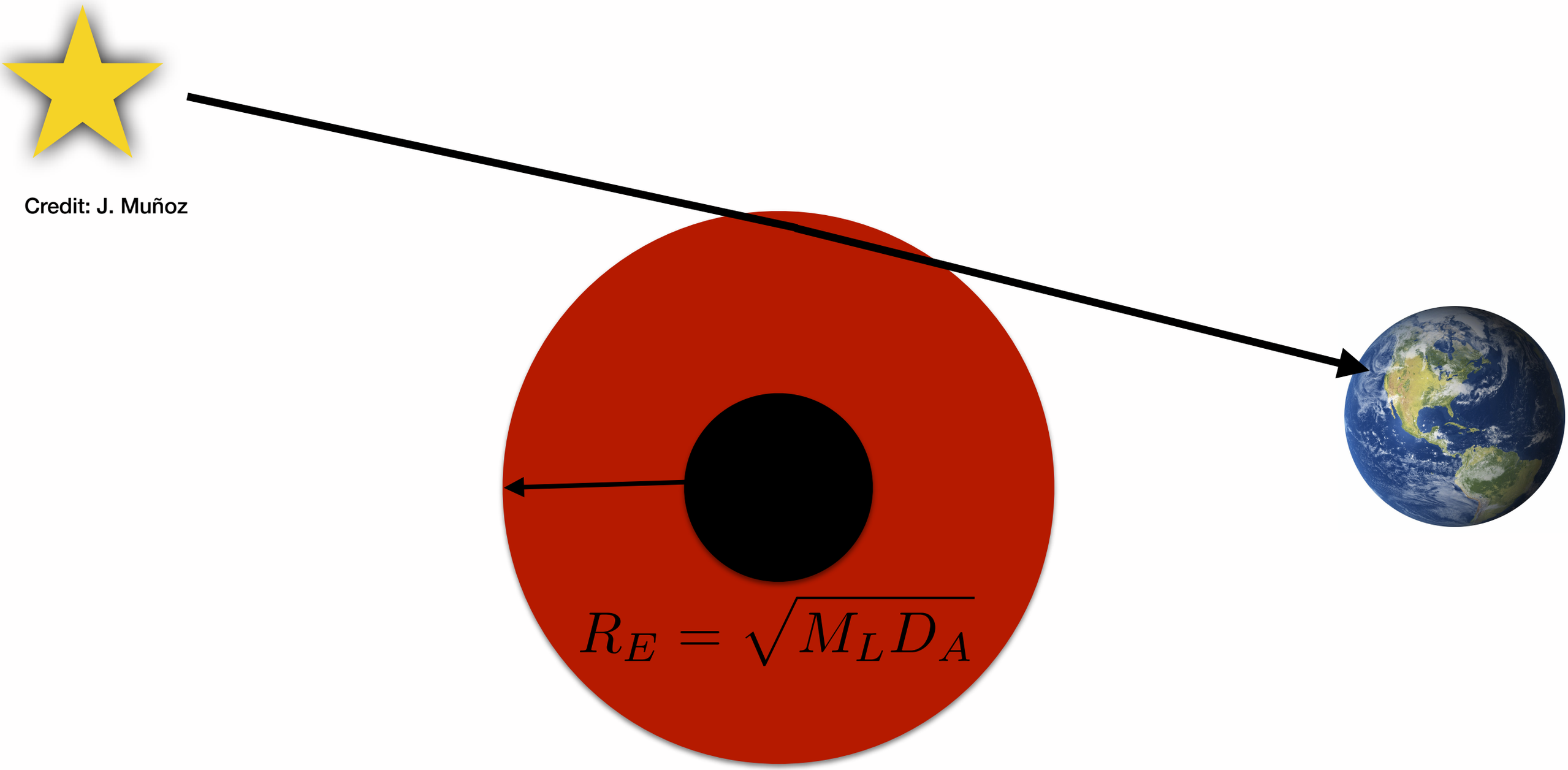



The “window”:

# Microlensing: Illustration

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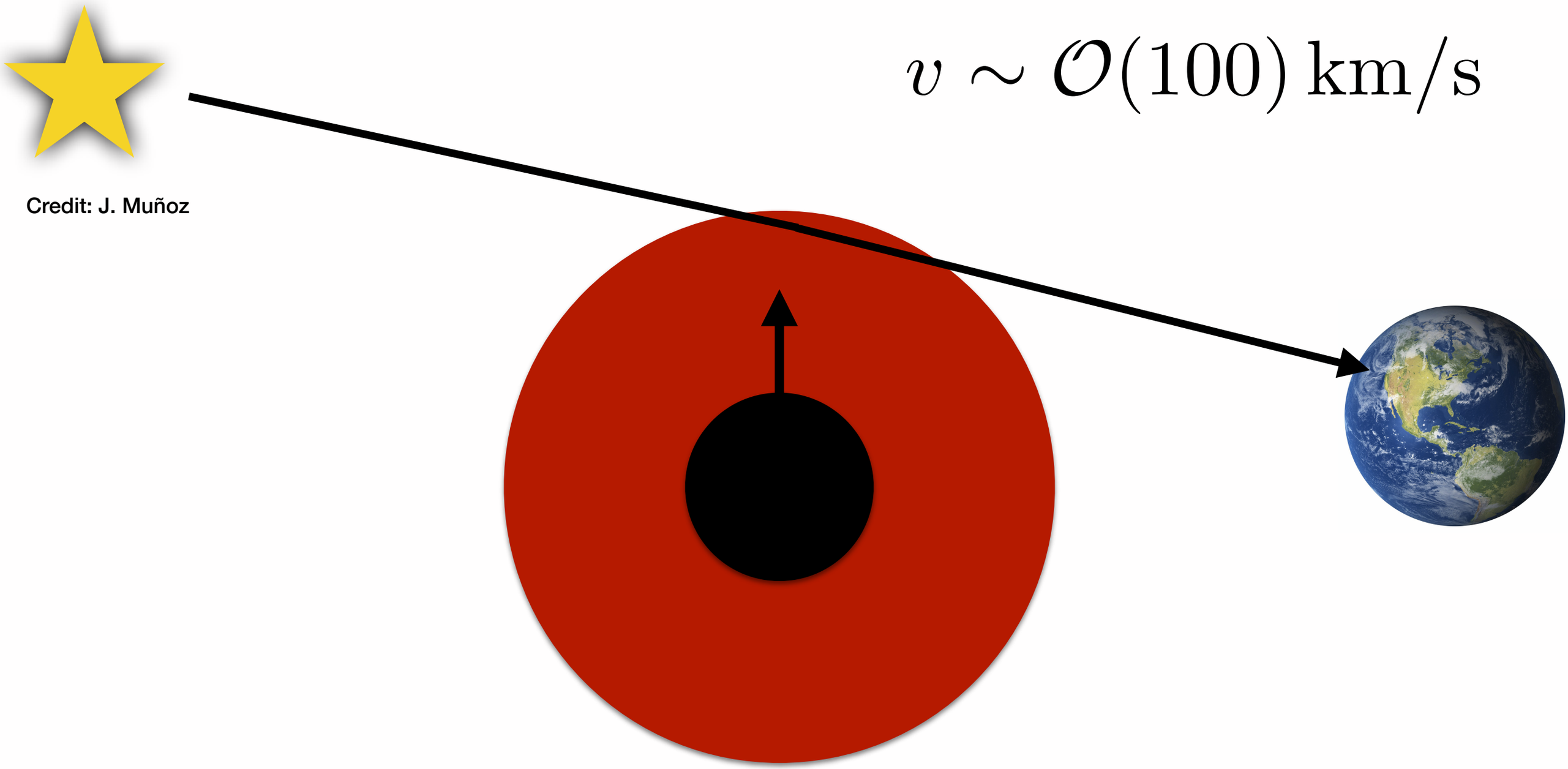


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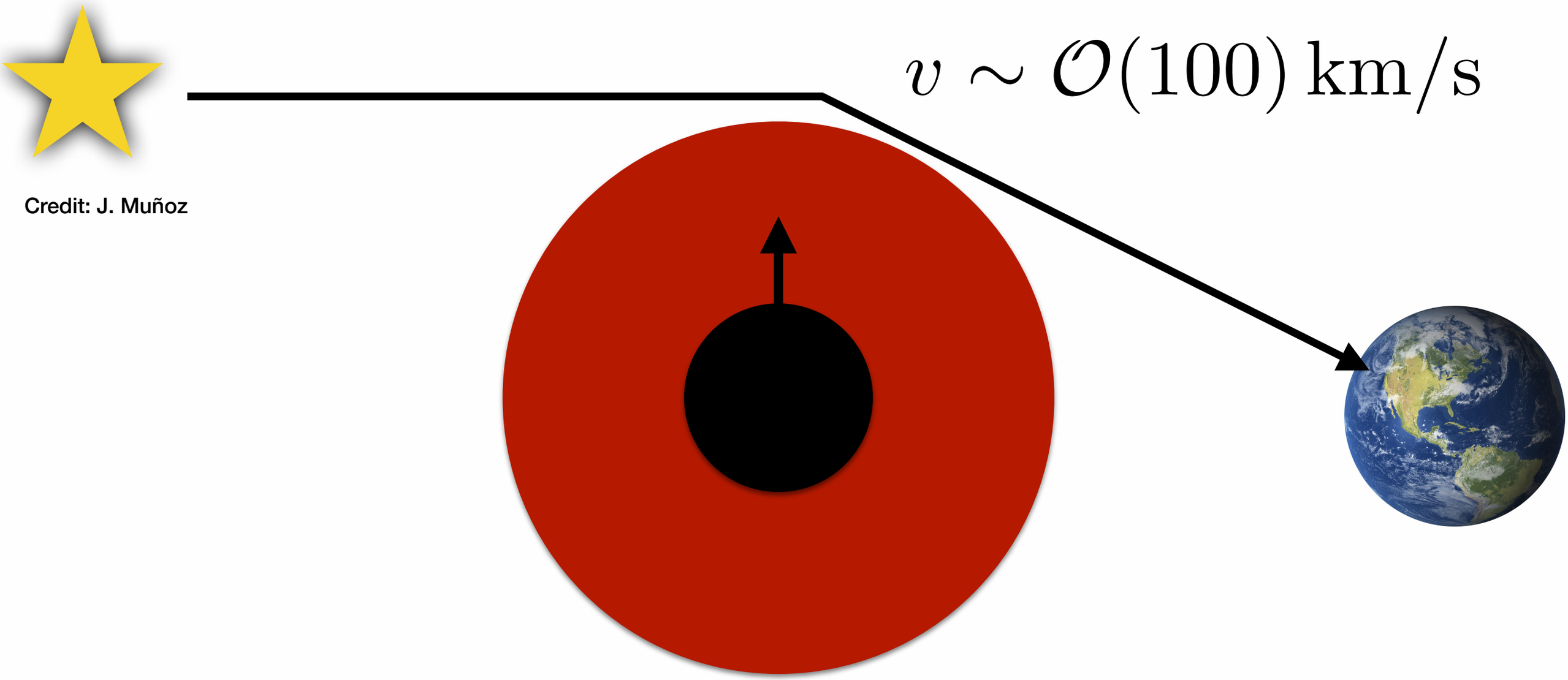


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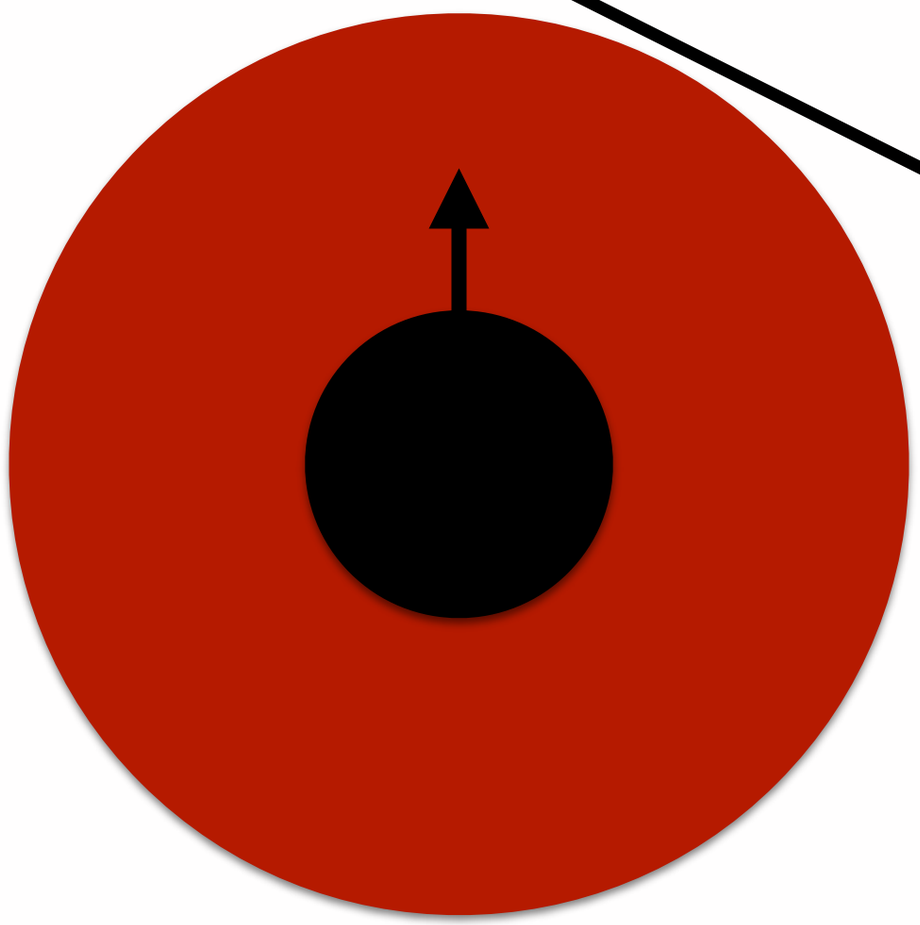
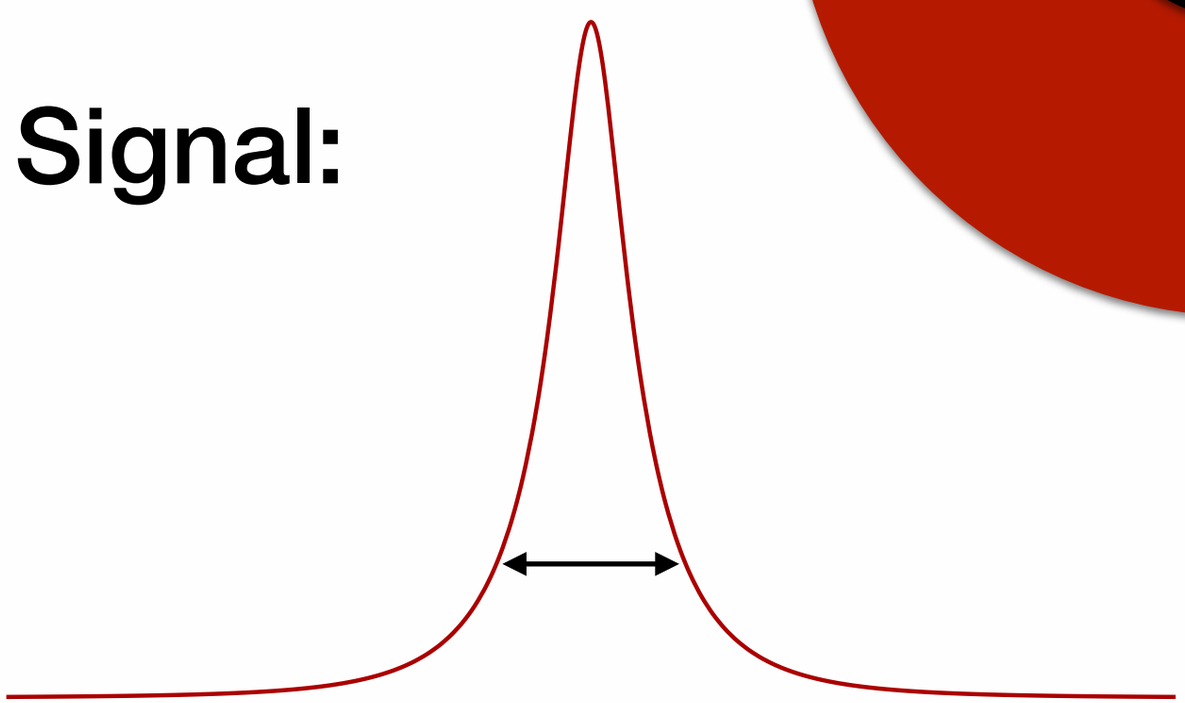
$$v \sim \mathcal{O}(100)\,\mathrm{km/s}$$



Signal:



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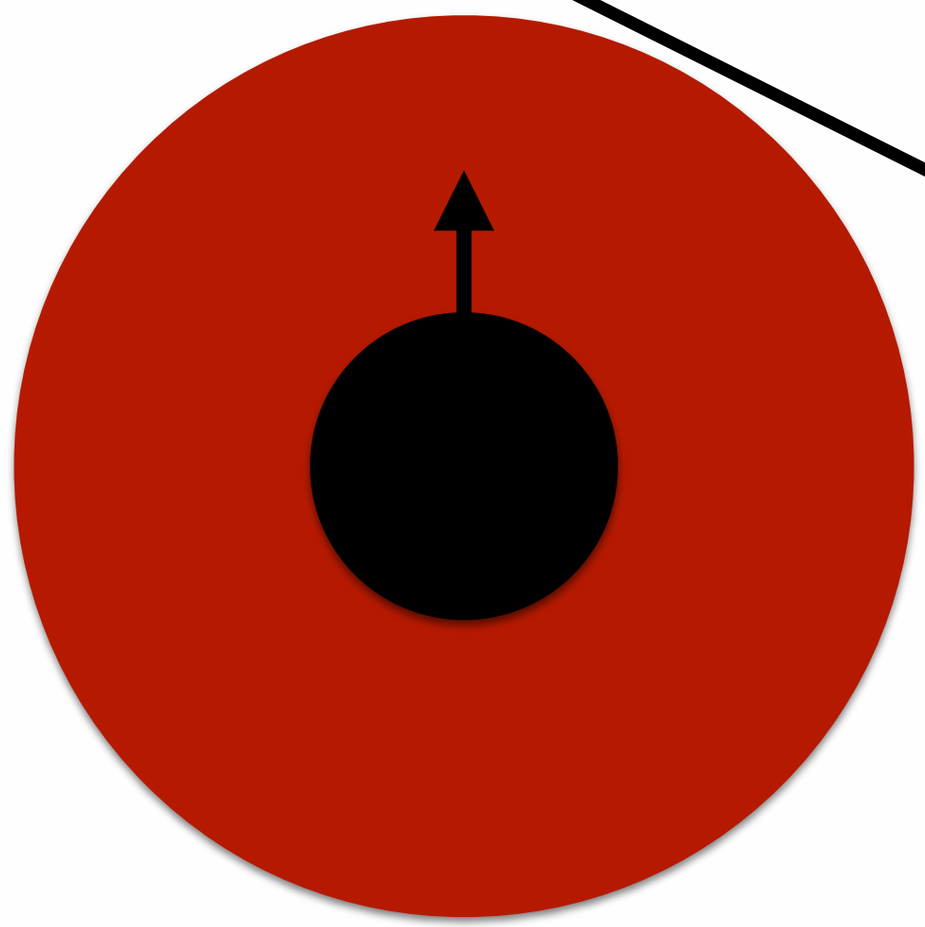

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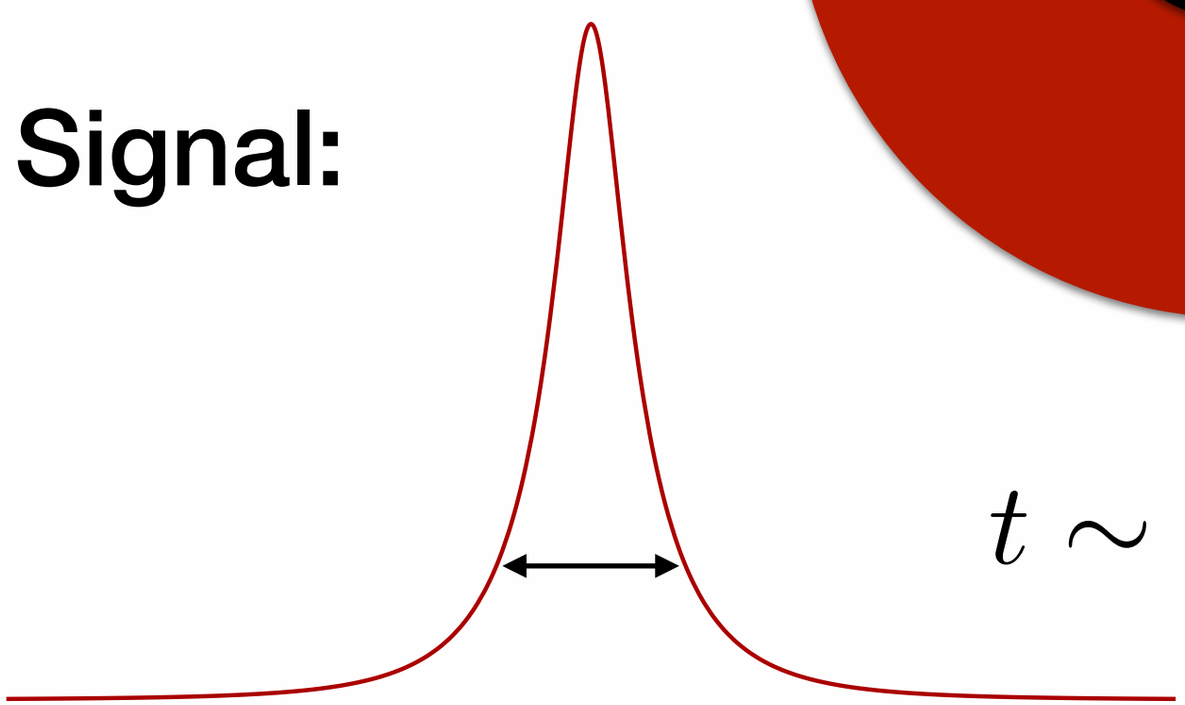

$$t \sim \frac{R_E}{v} \sim \mathrm{yrs} \times \sqrt{\frac{M_L}{10\,M_\odot}}$$

# Fast Radio Bursts

(Muñoz, EDK, Dai, Kamionkowski, PRL 117 (2016))

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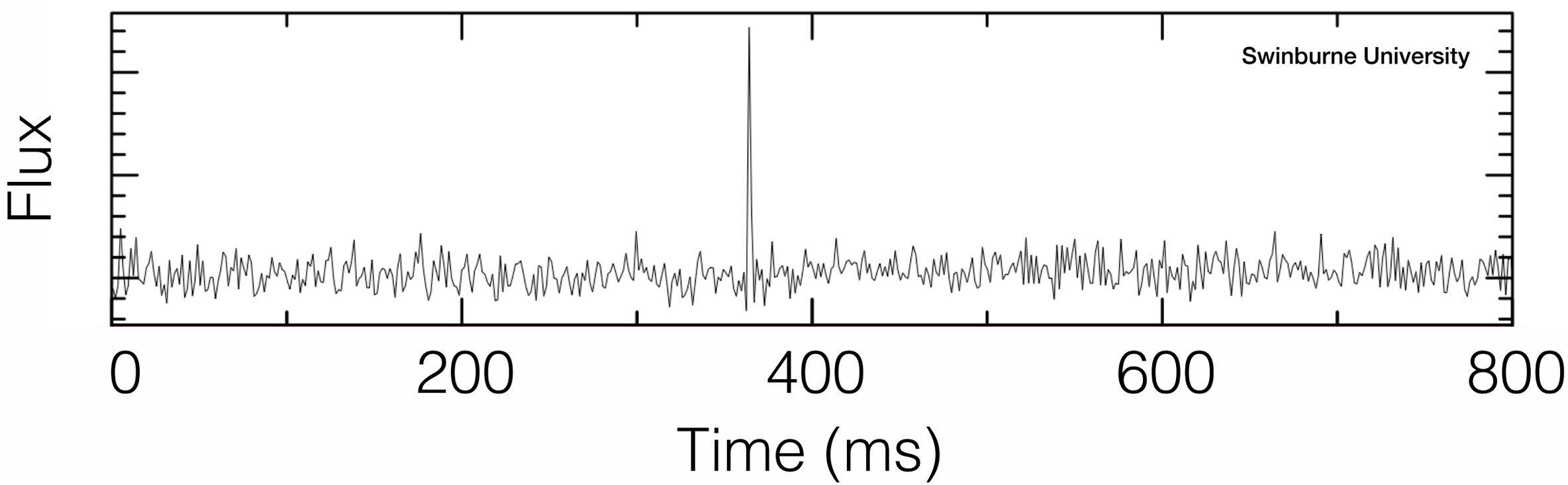

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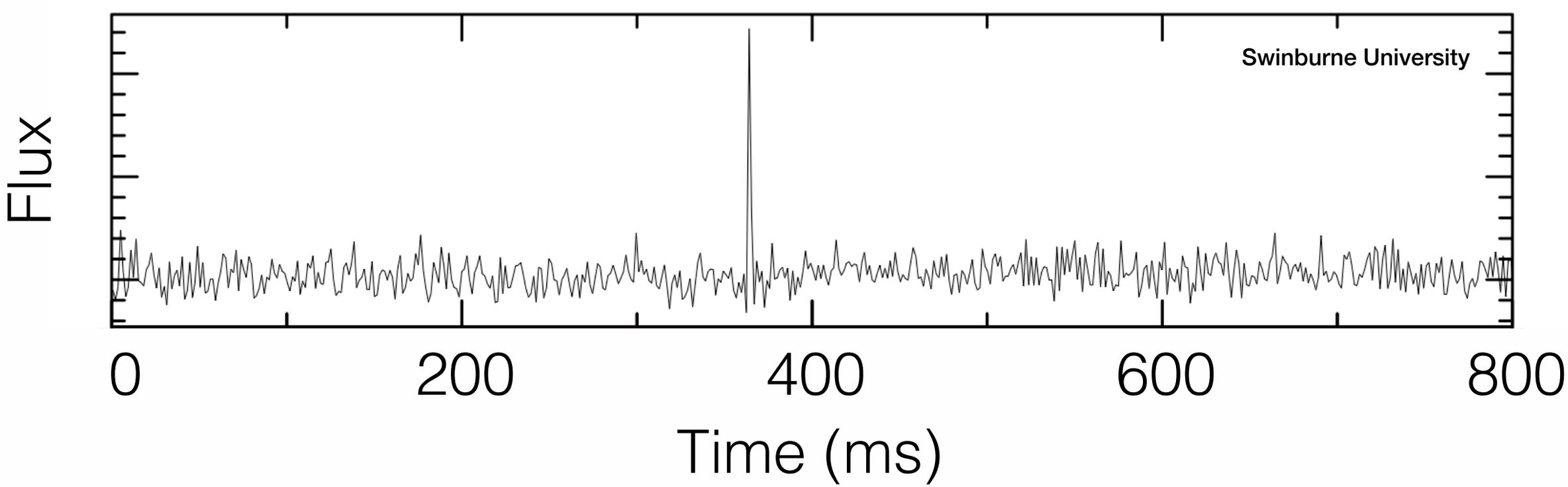

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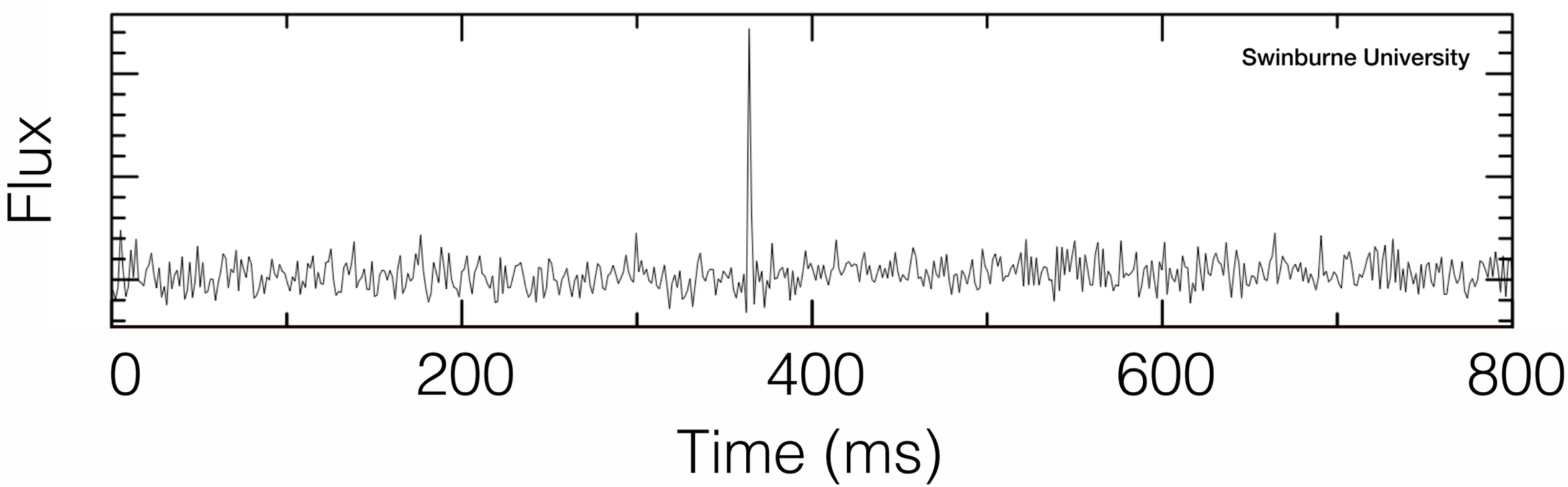

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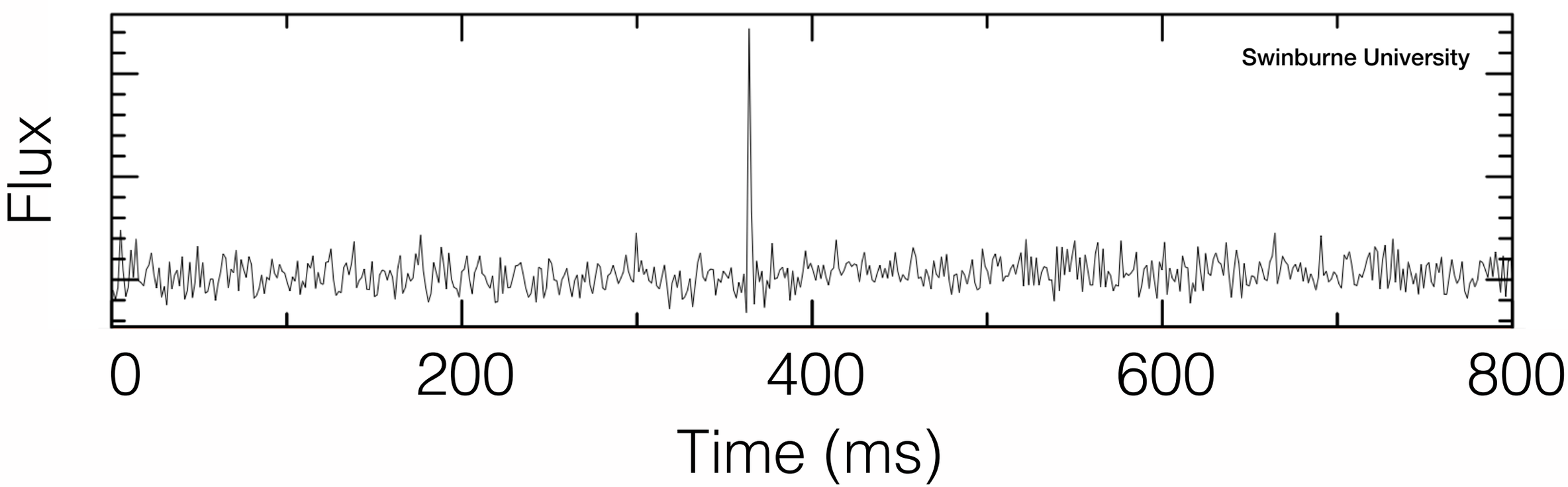

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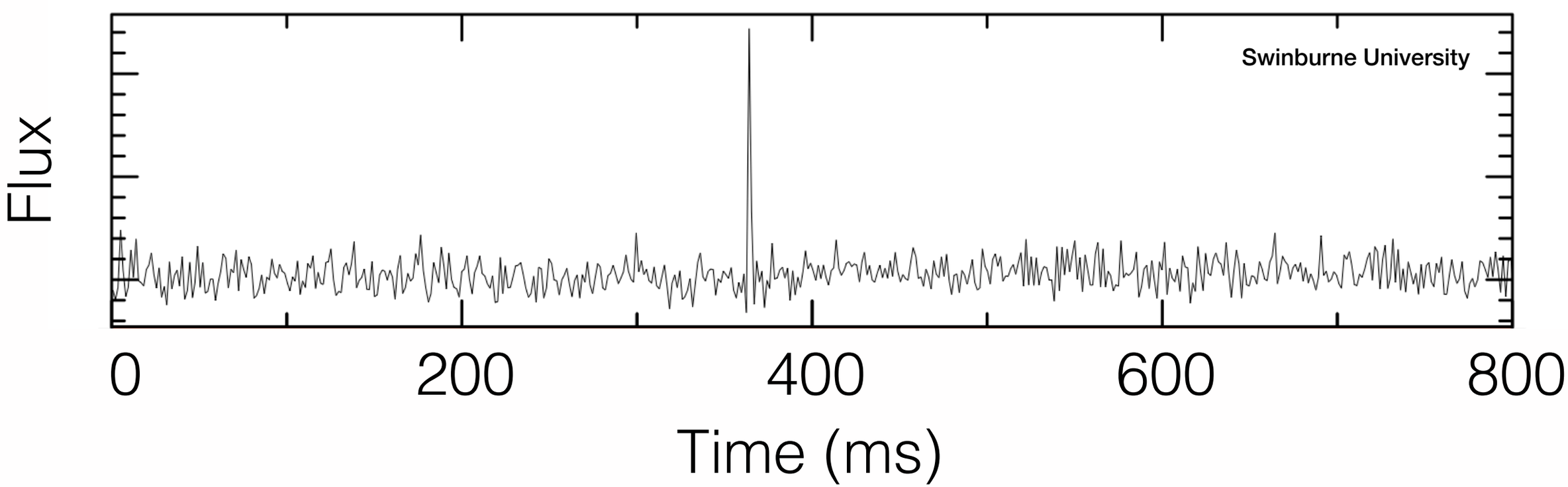

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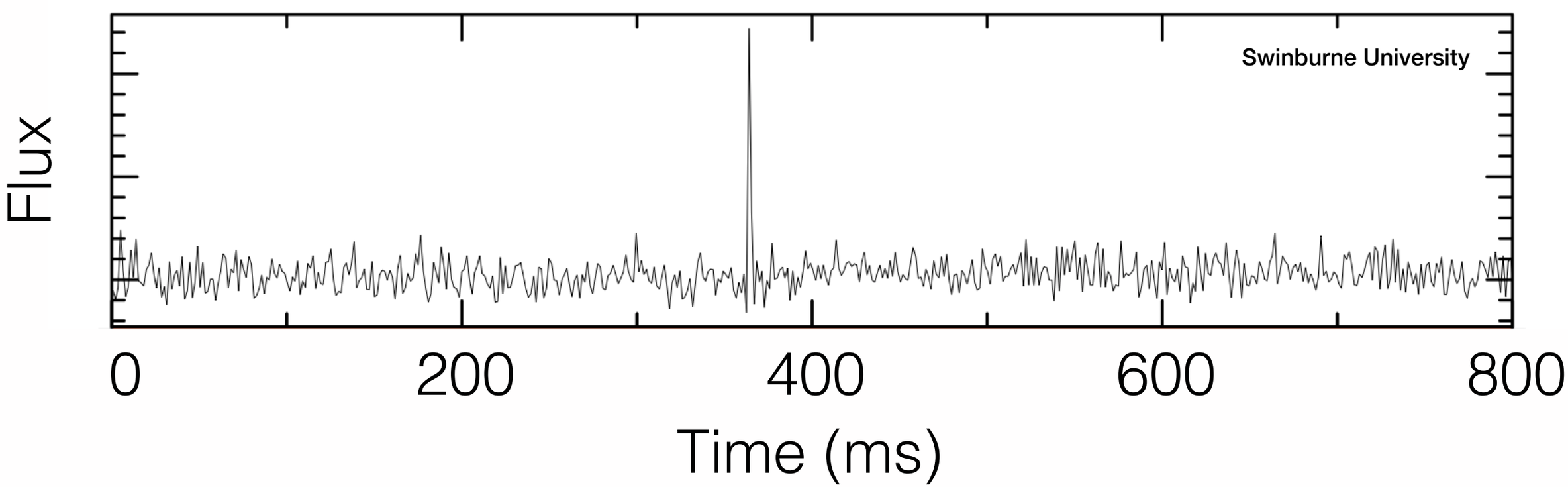

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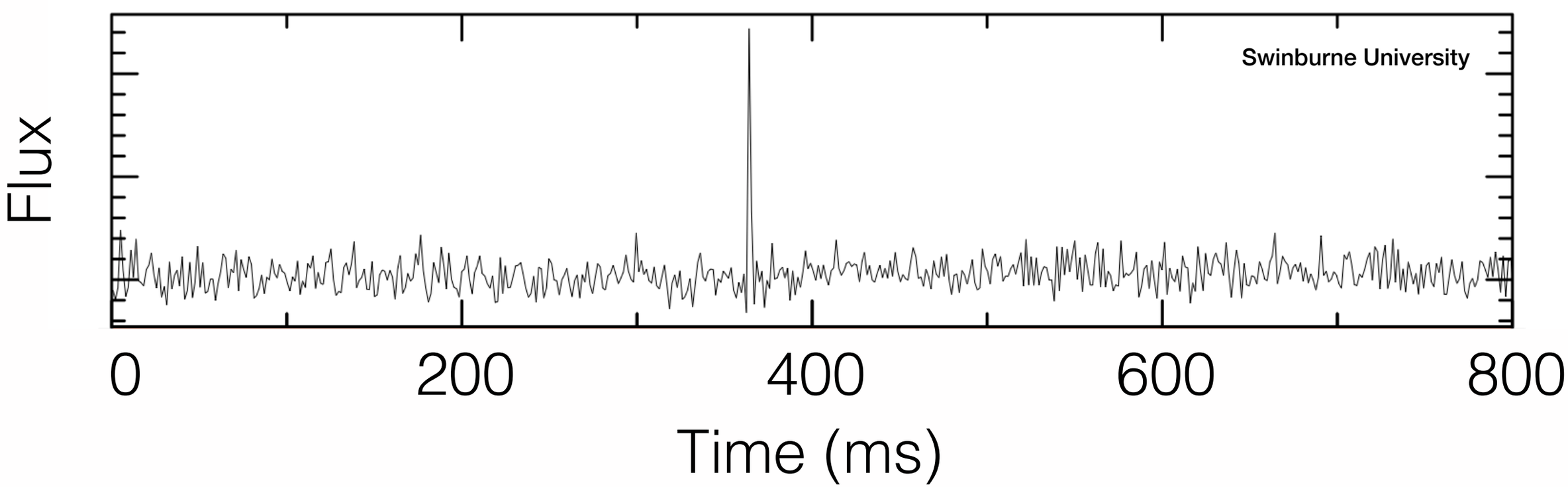

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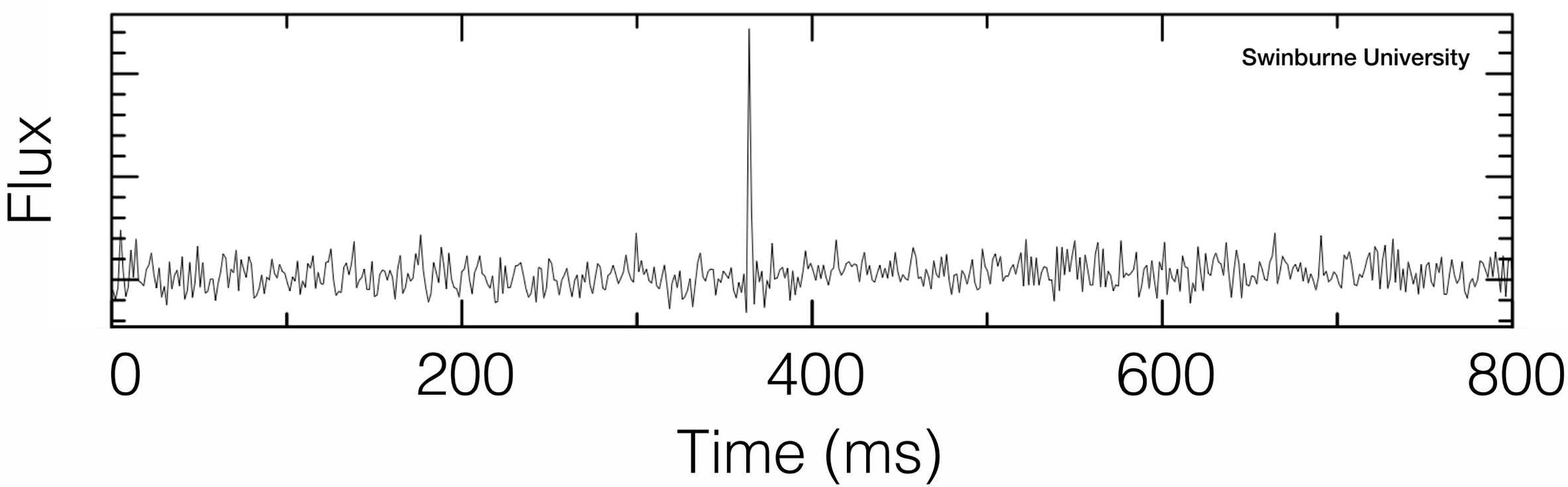

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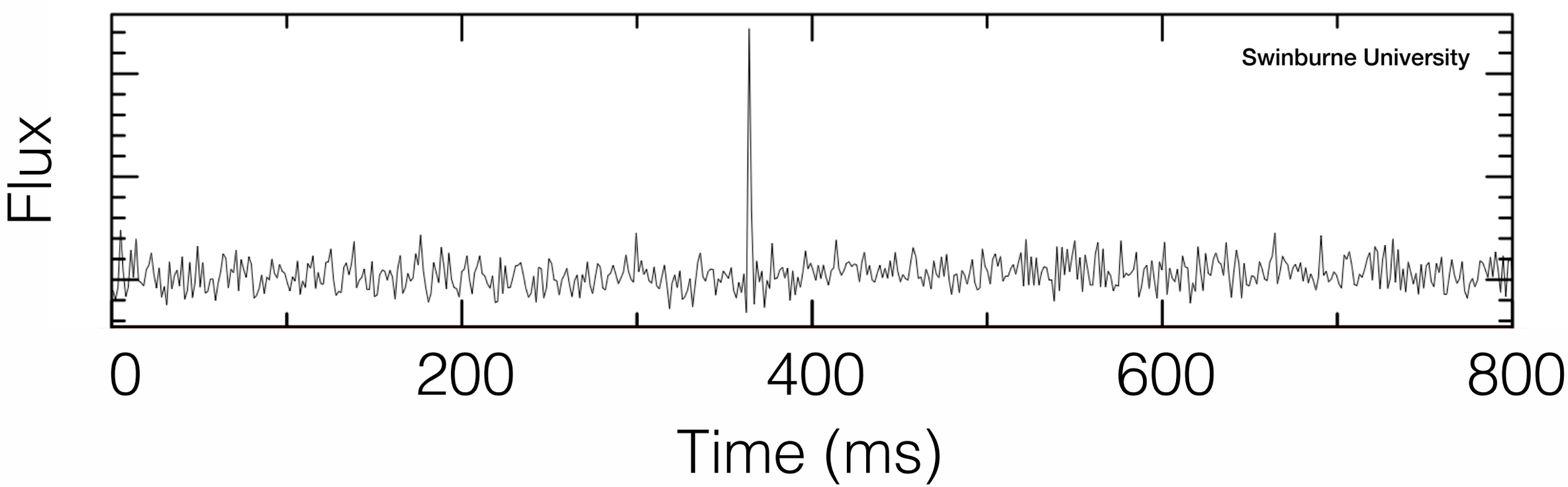

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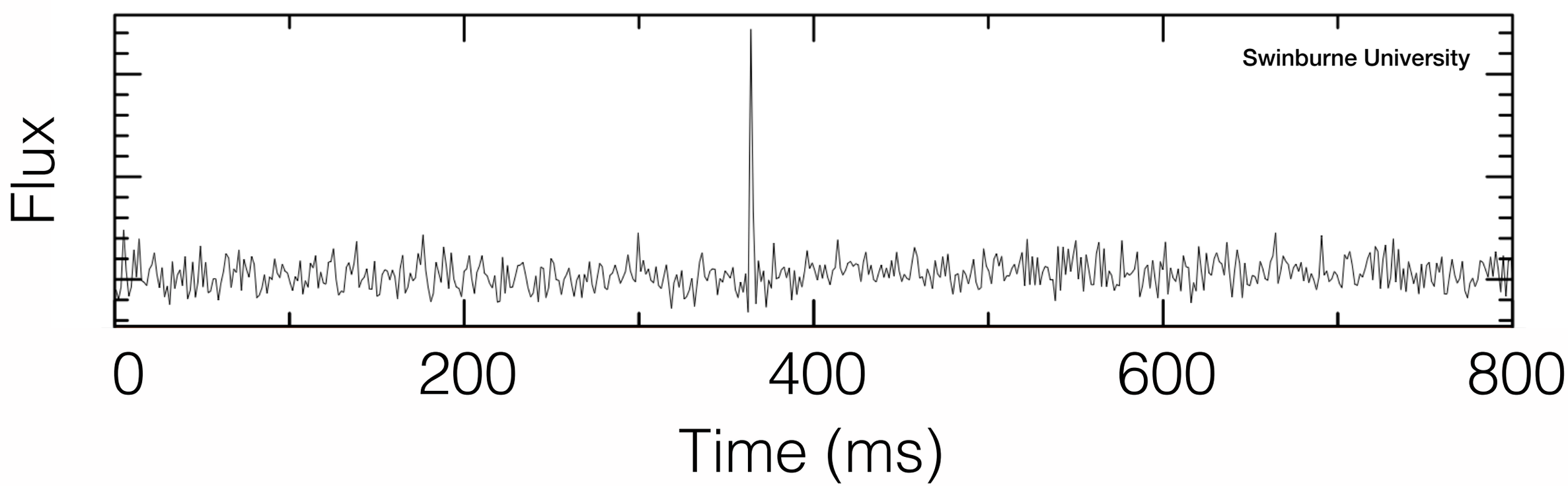

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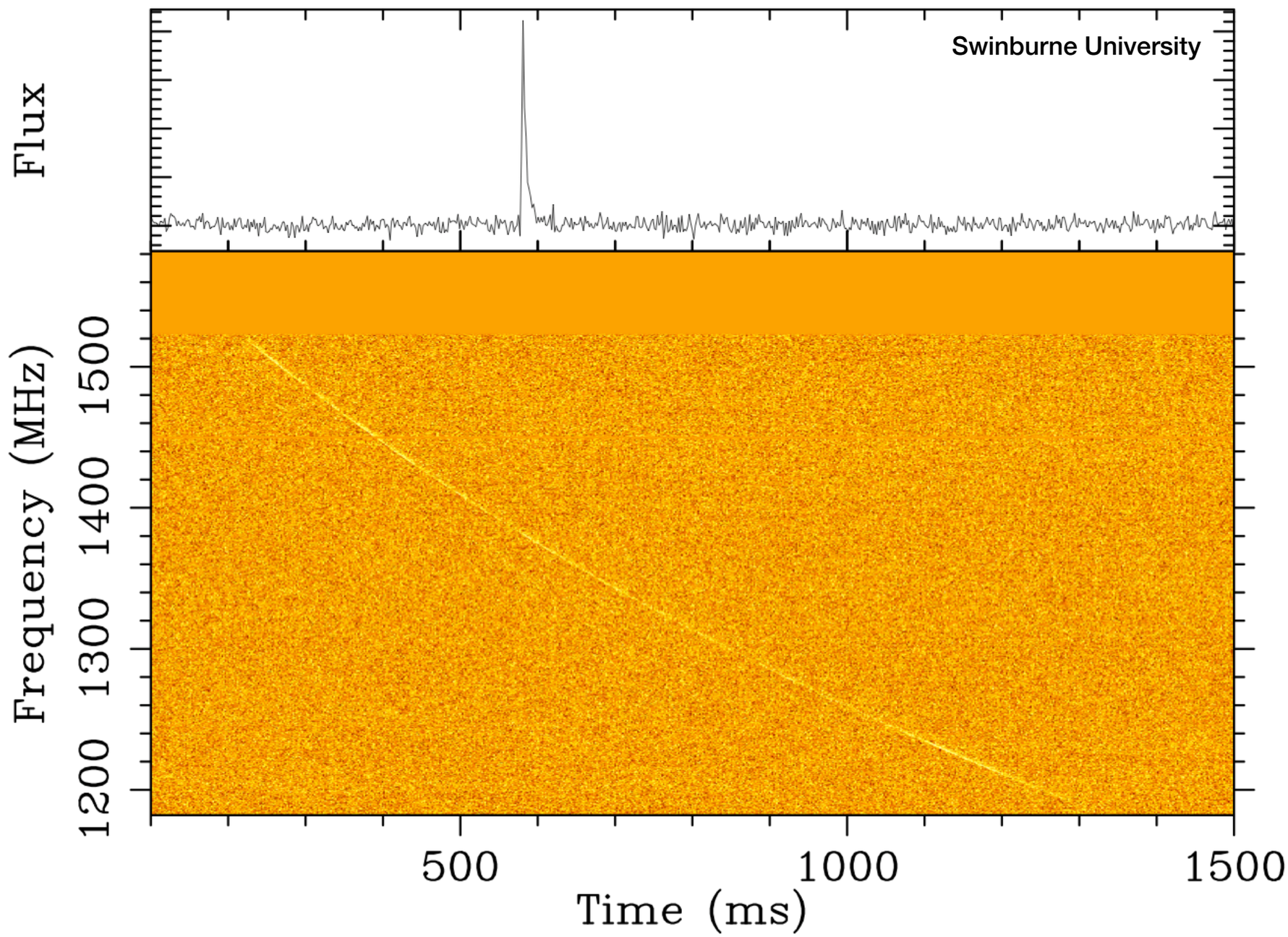

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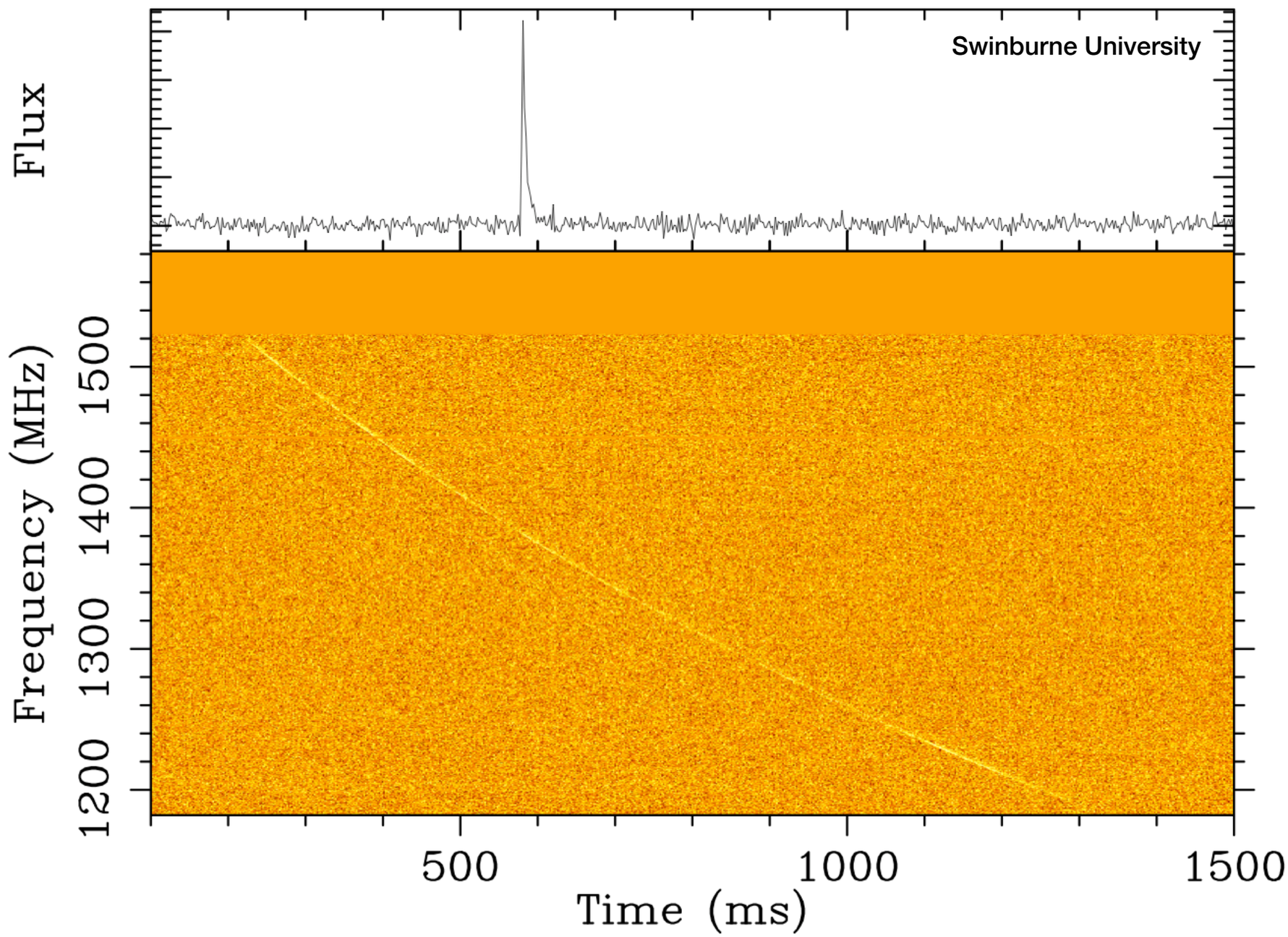

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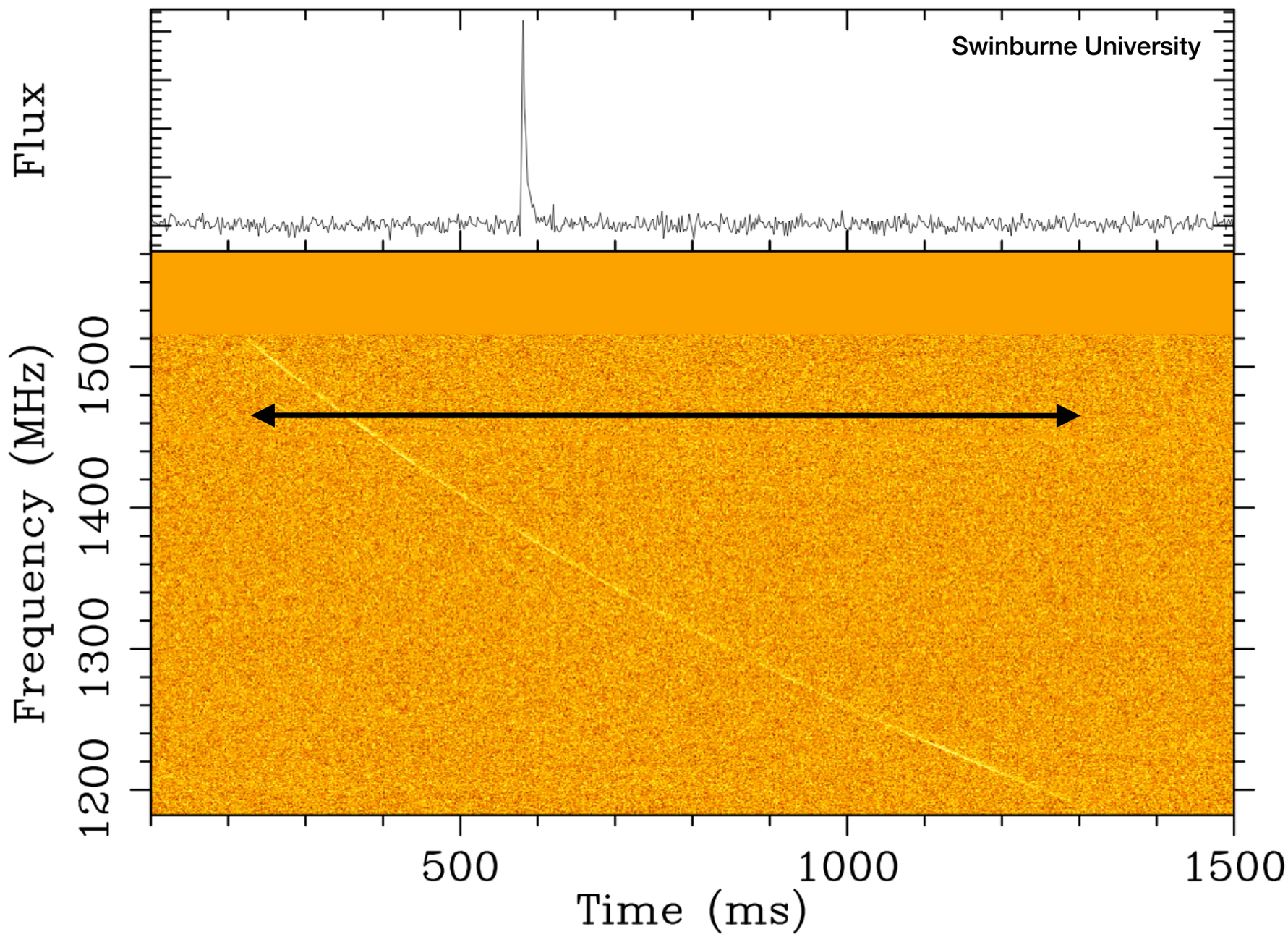

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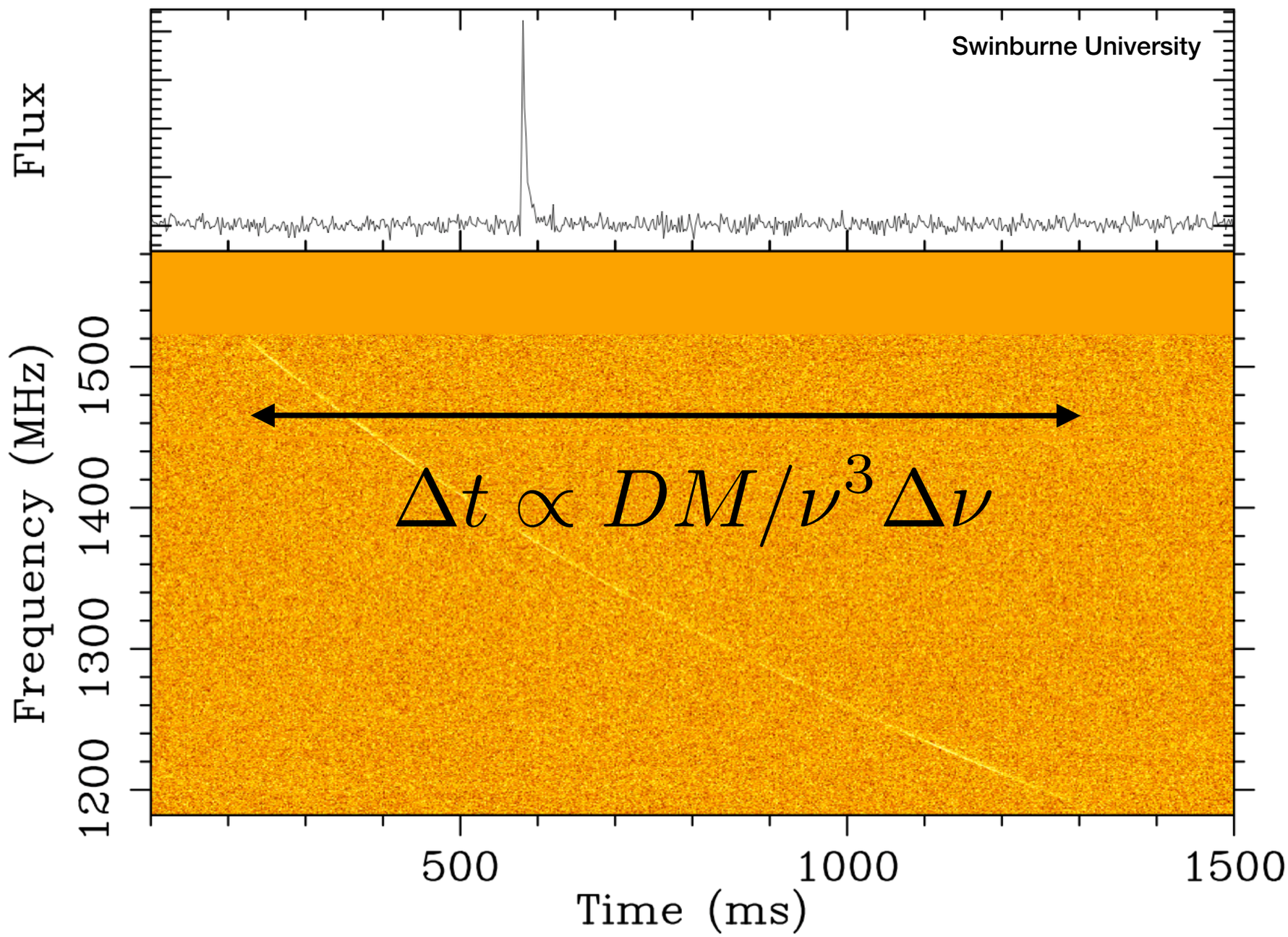

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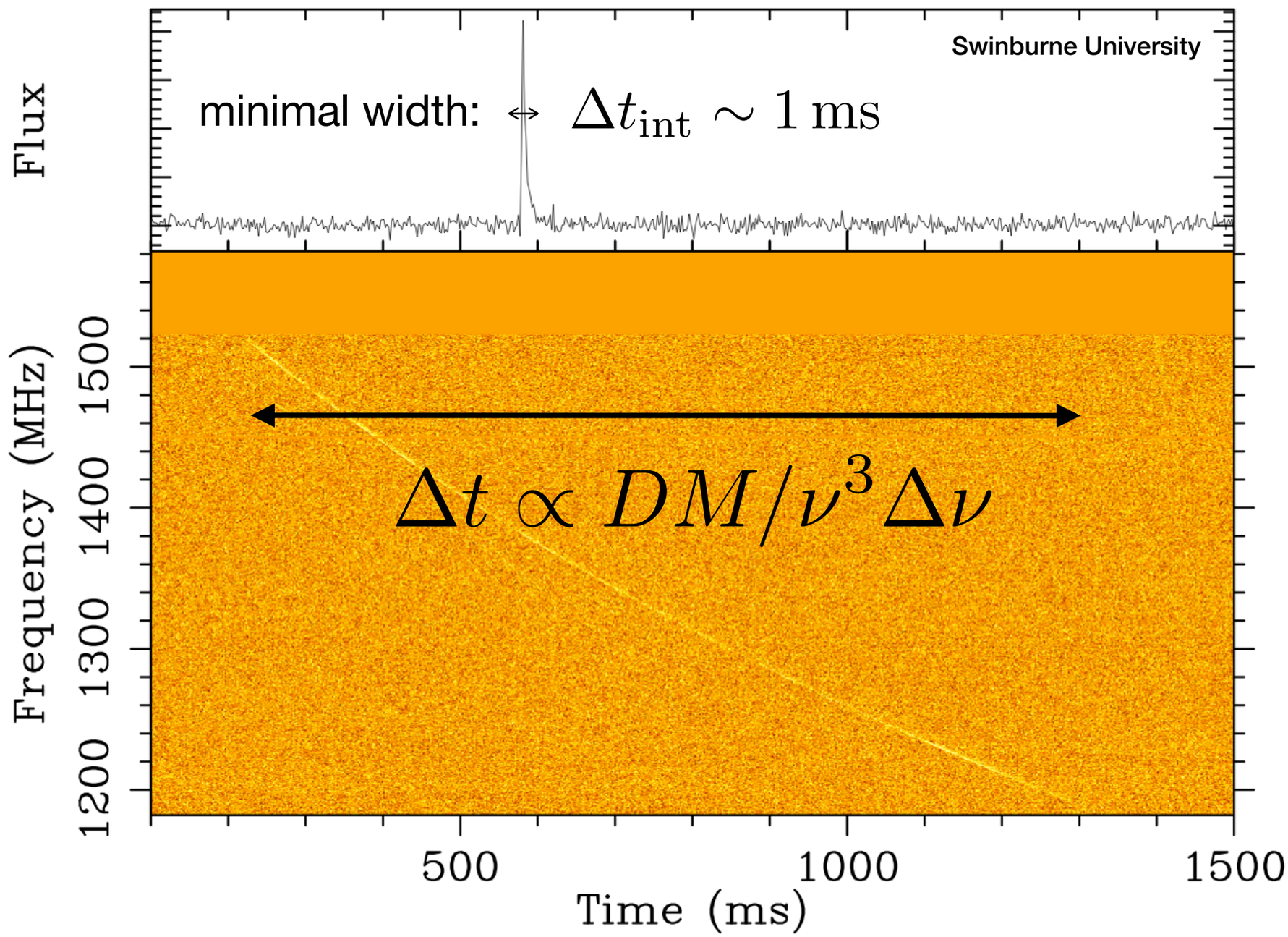

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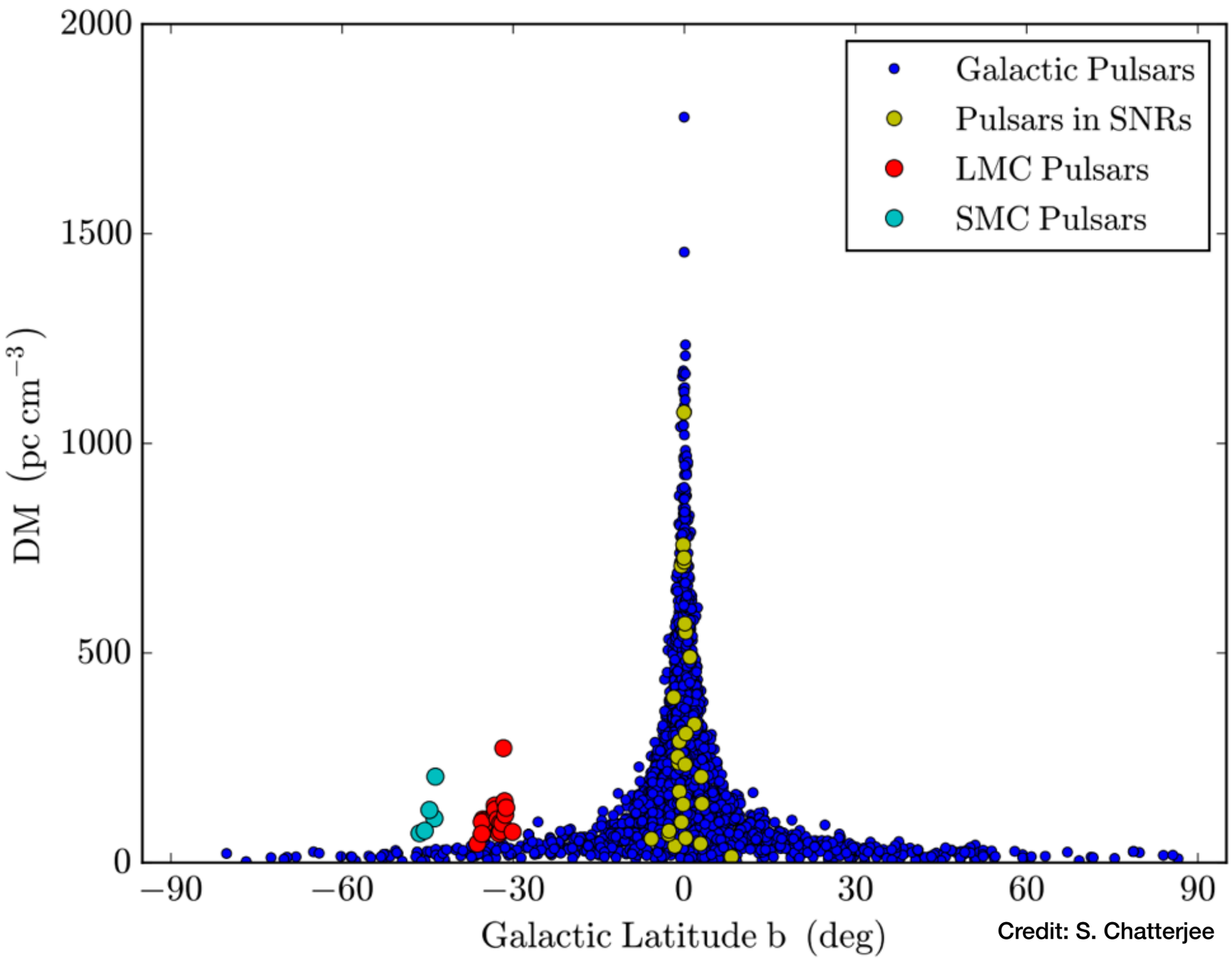


Credit: S. Chatterjee

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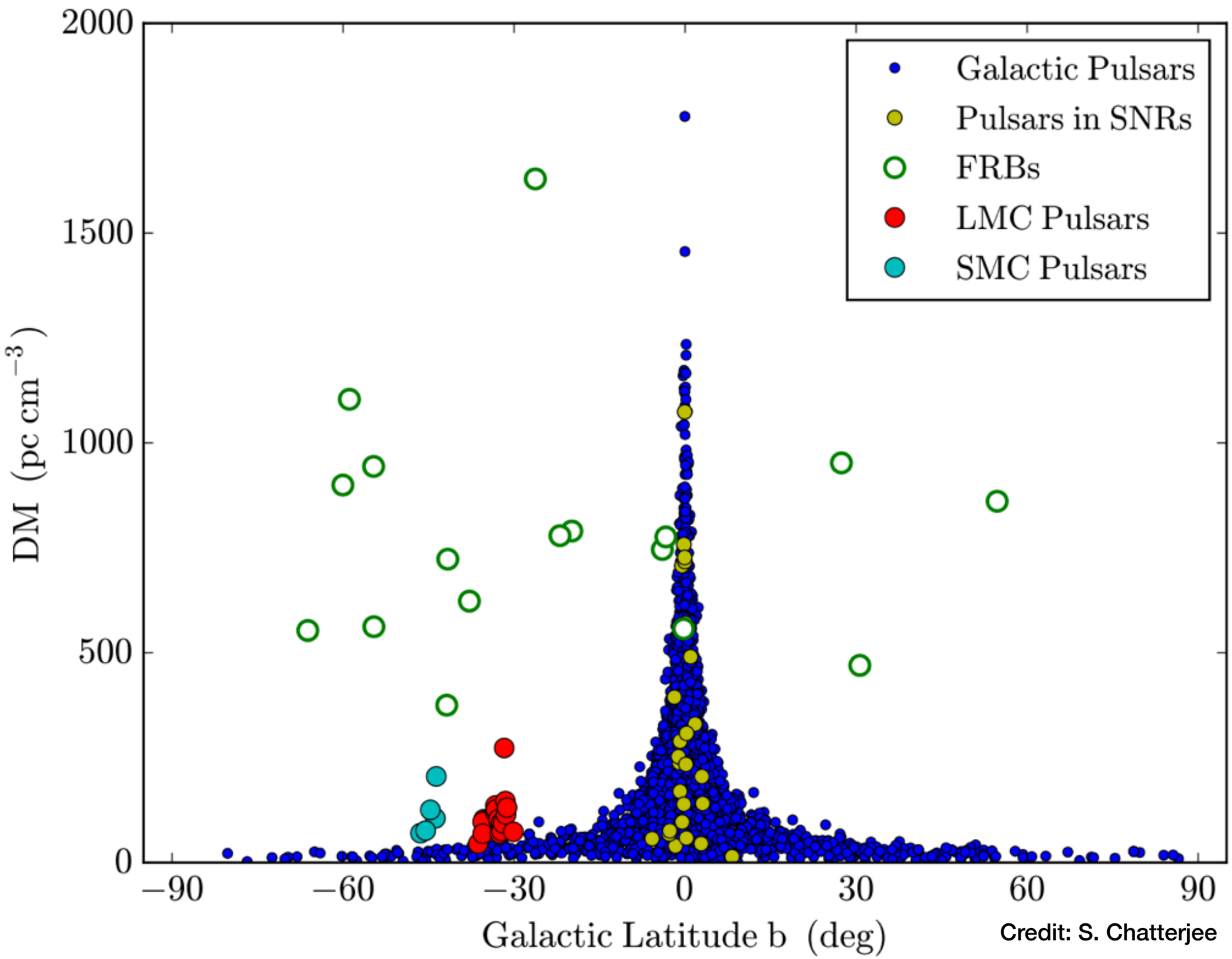


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# Constraining MACHO Dark Matter: FRB Lensing

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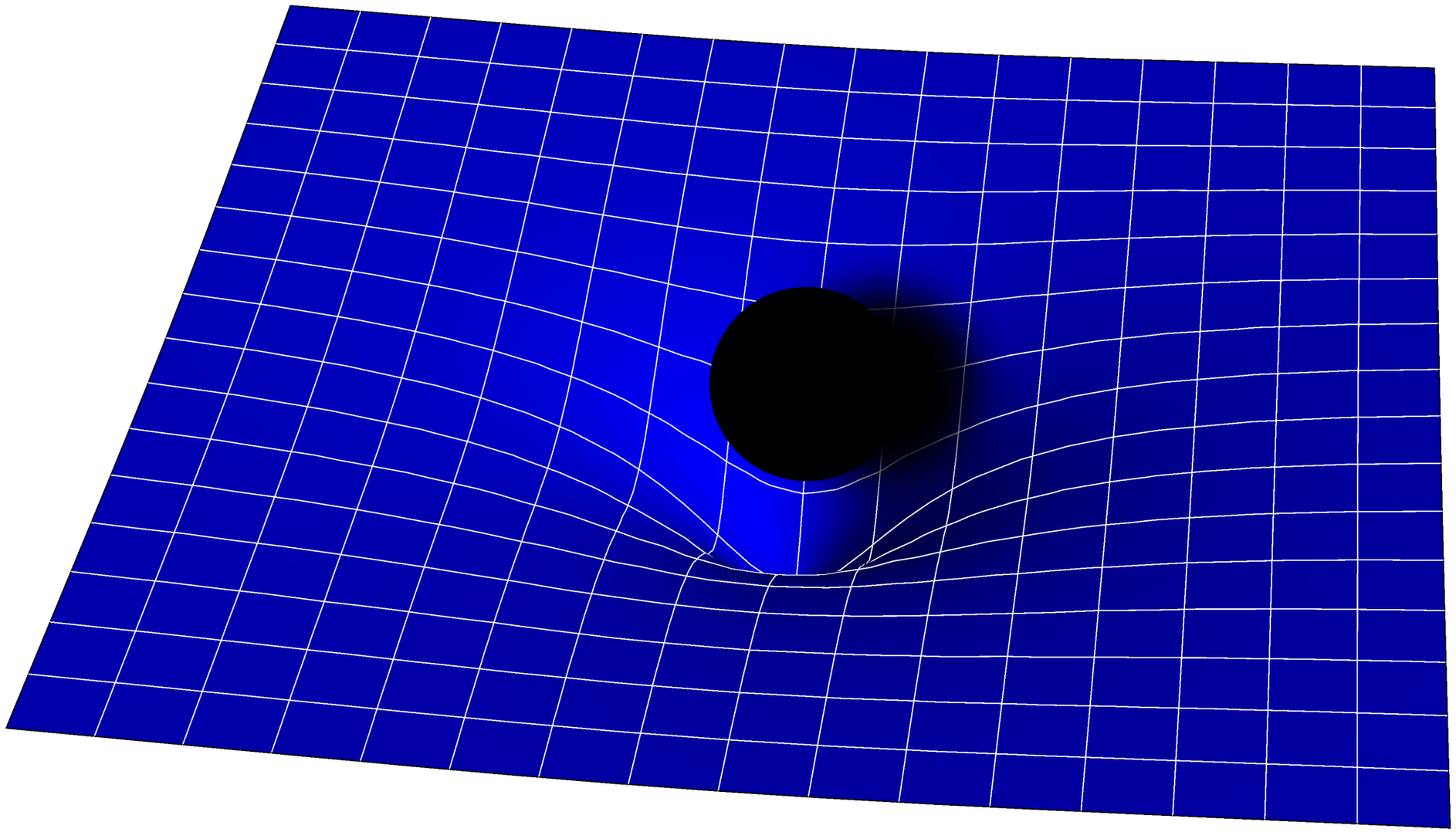

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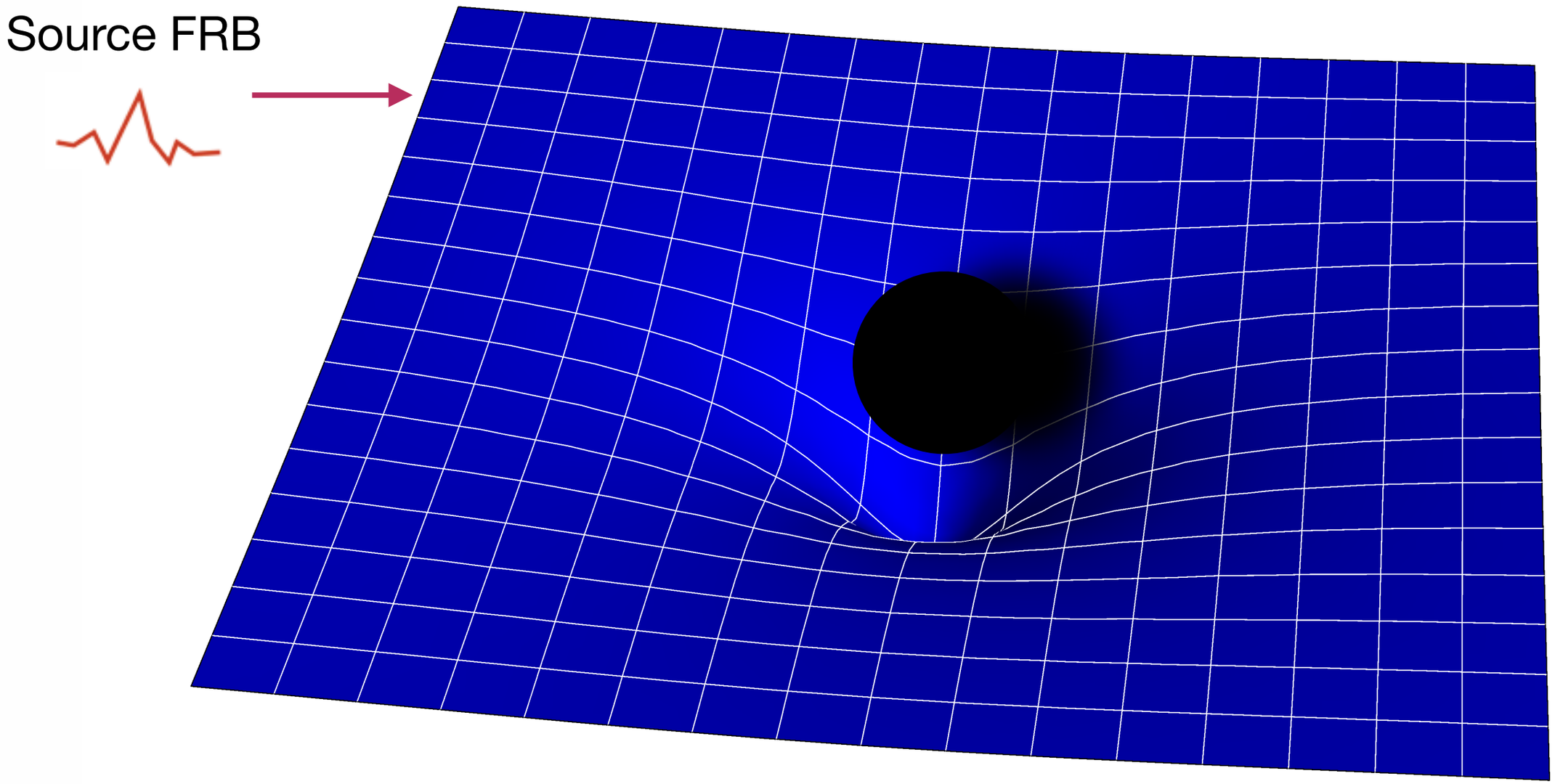


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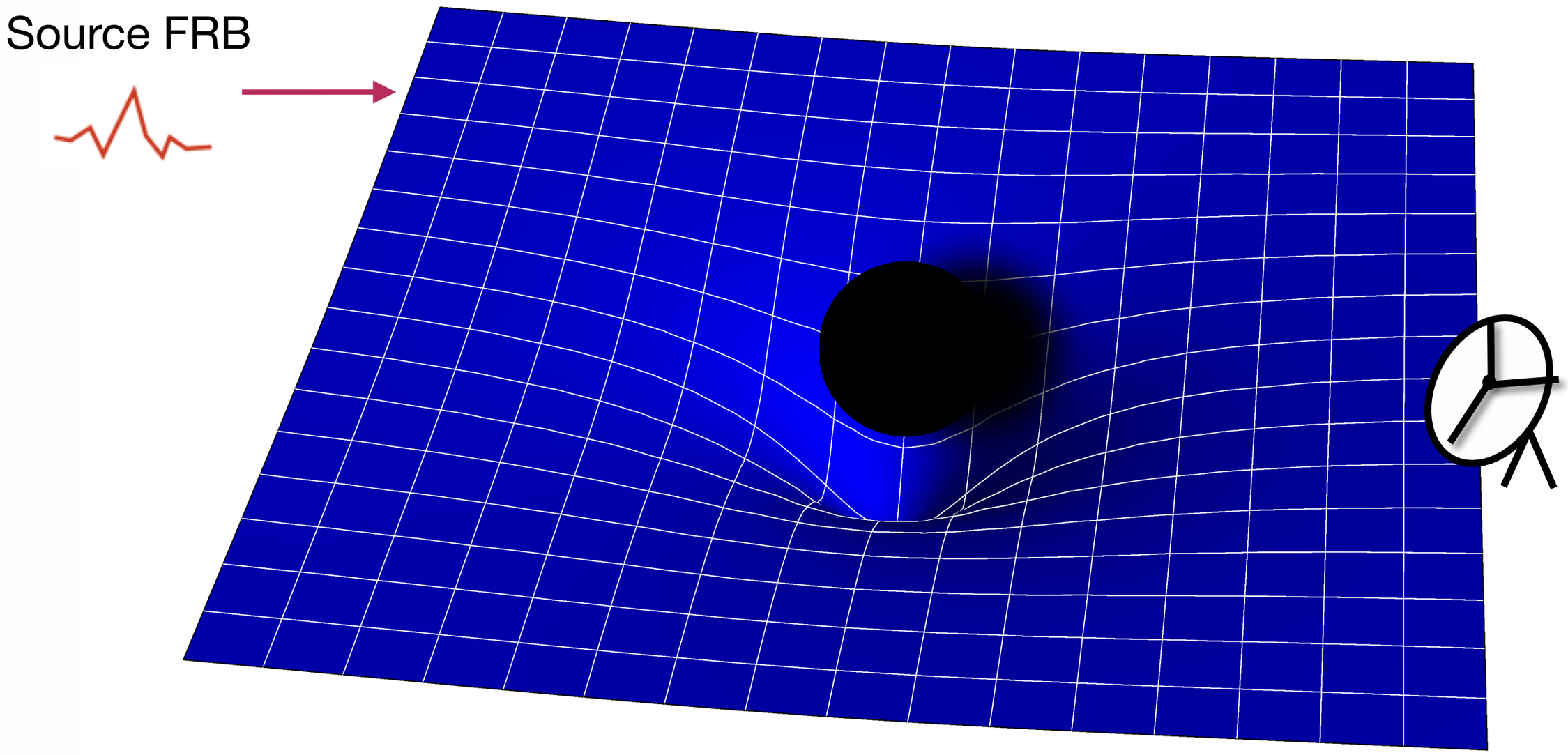


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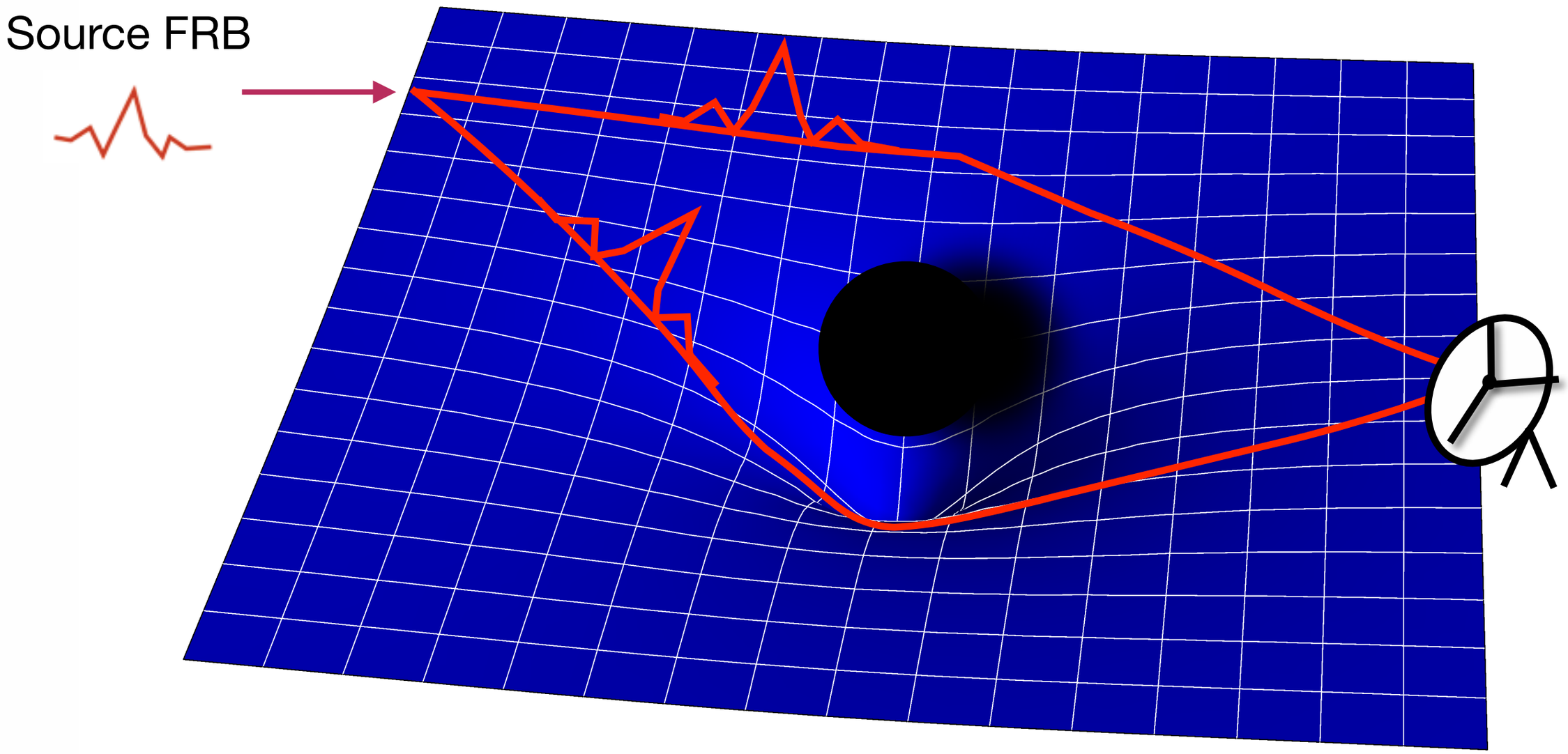


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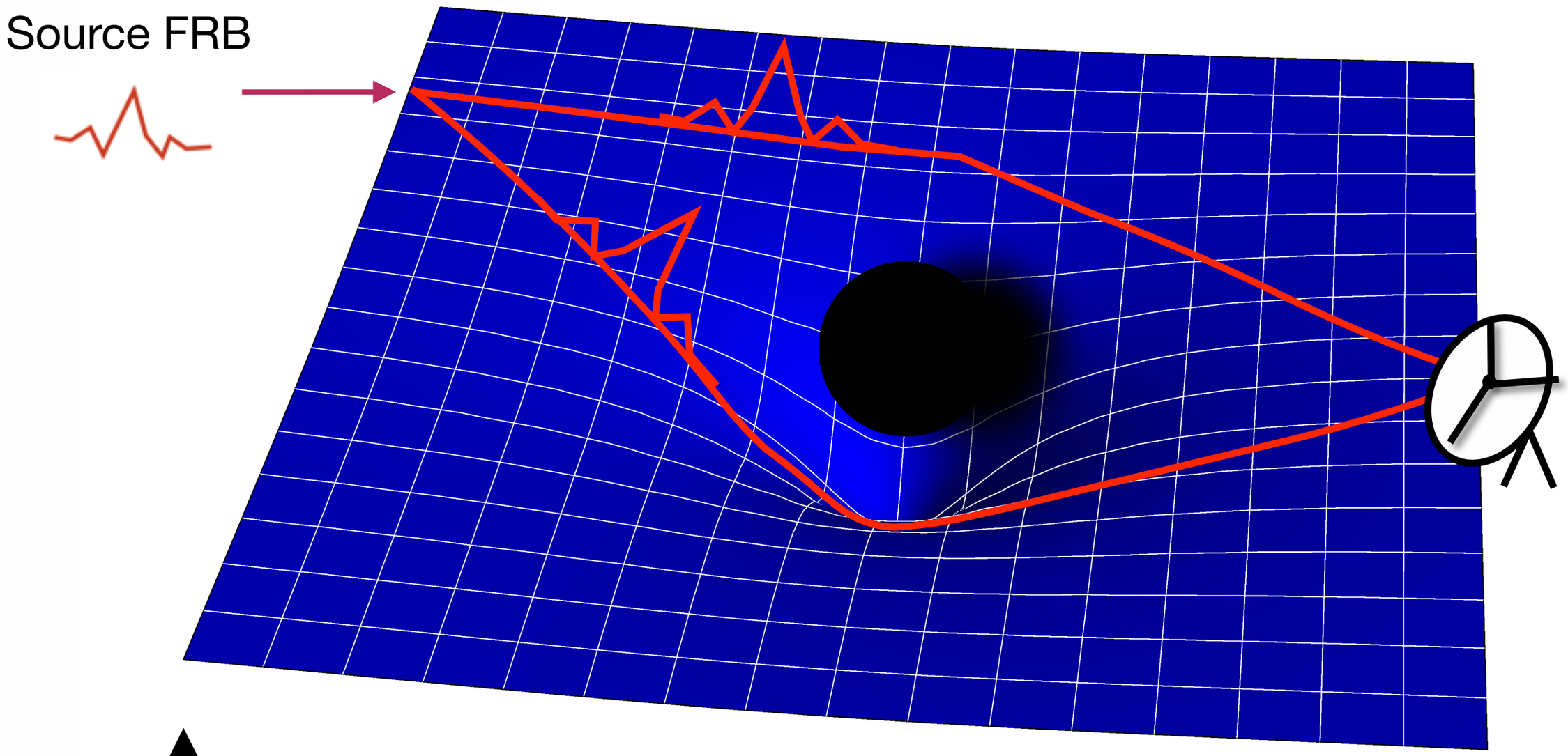


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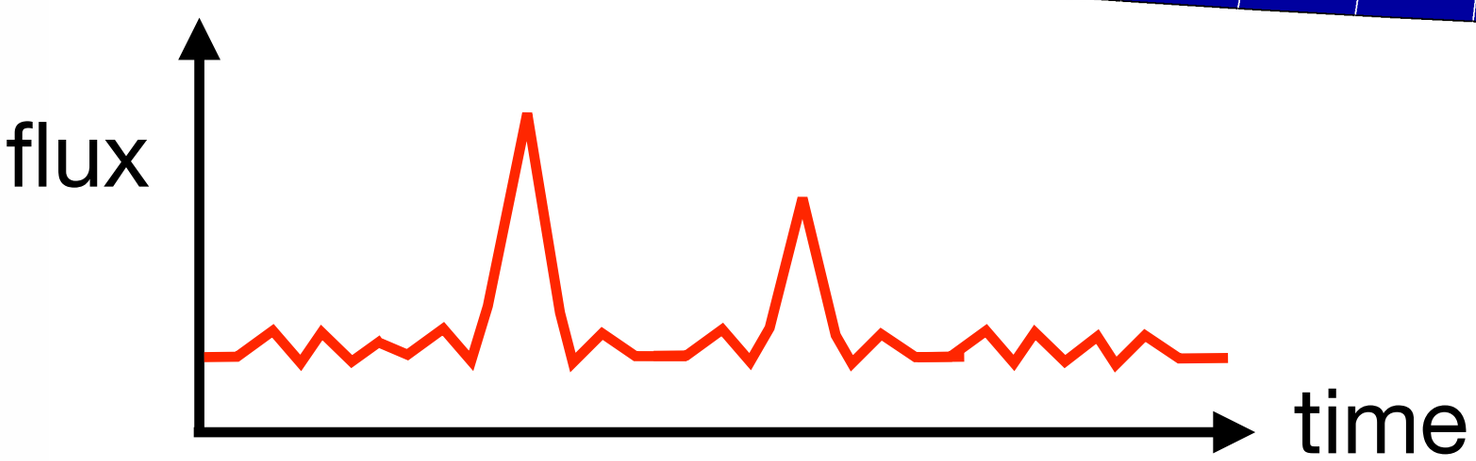

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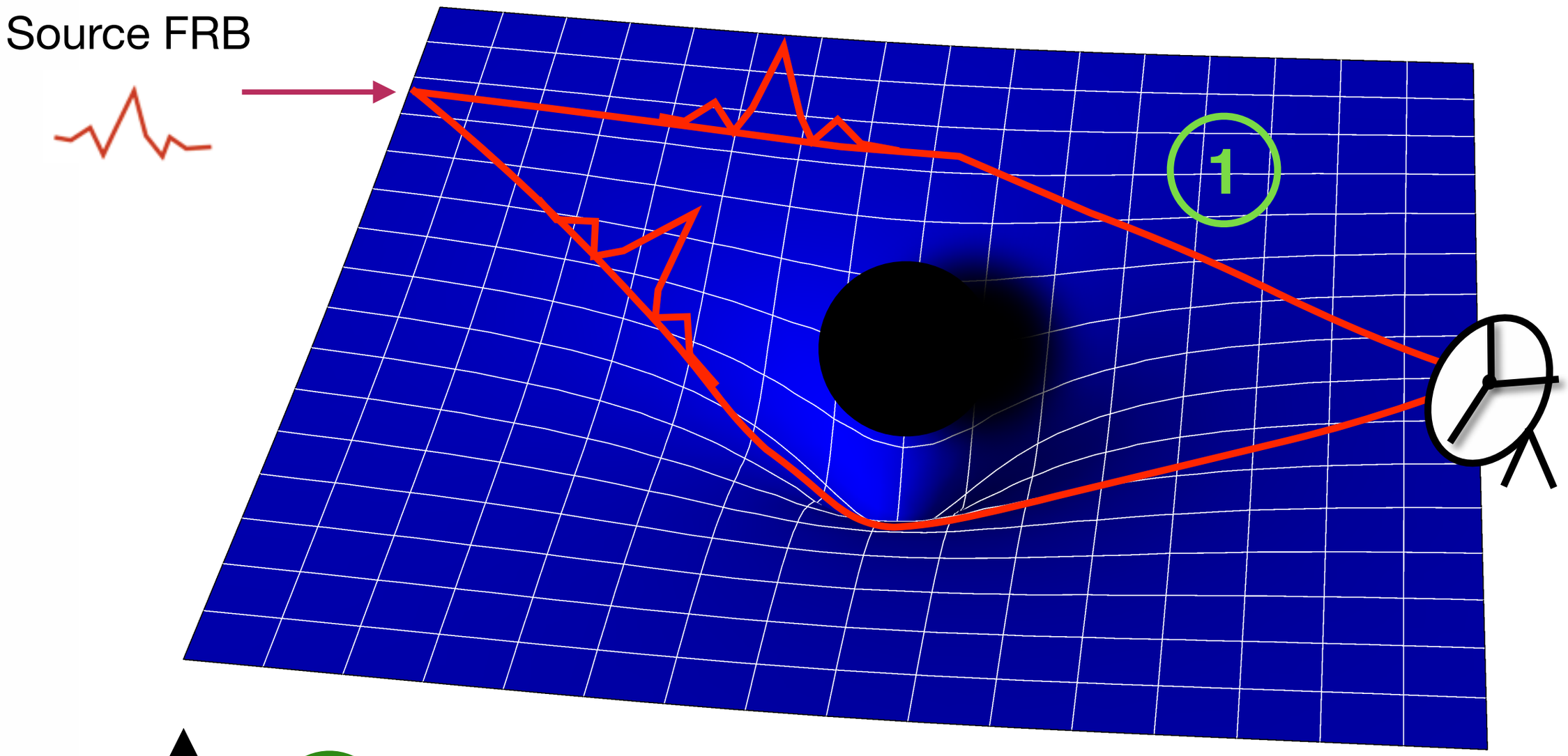


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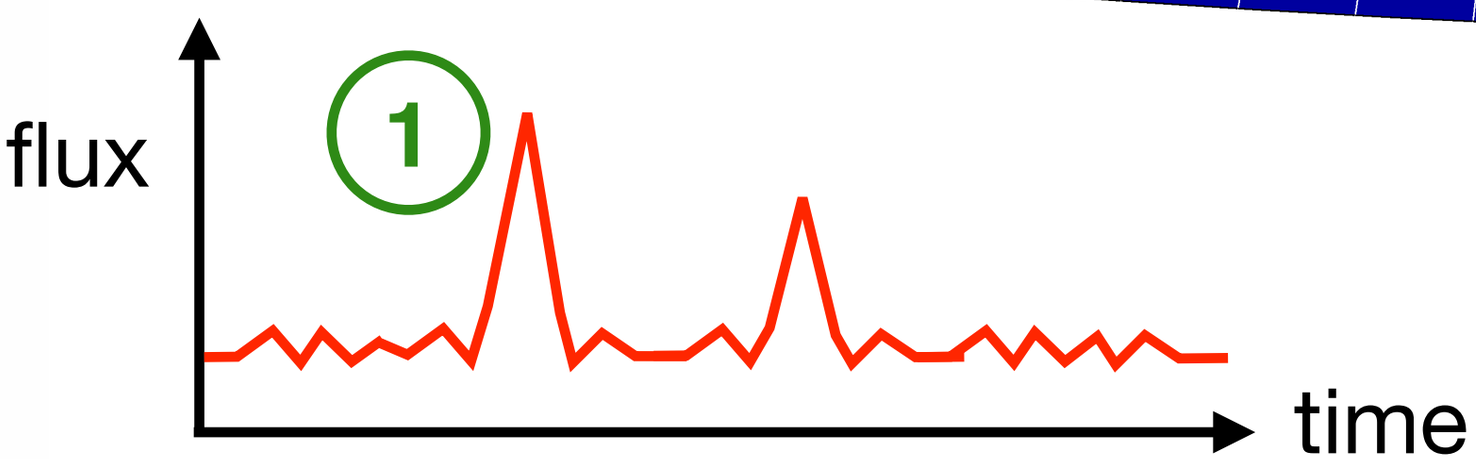

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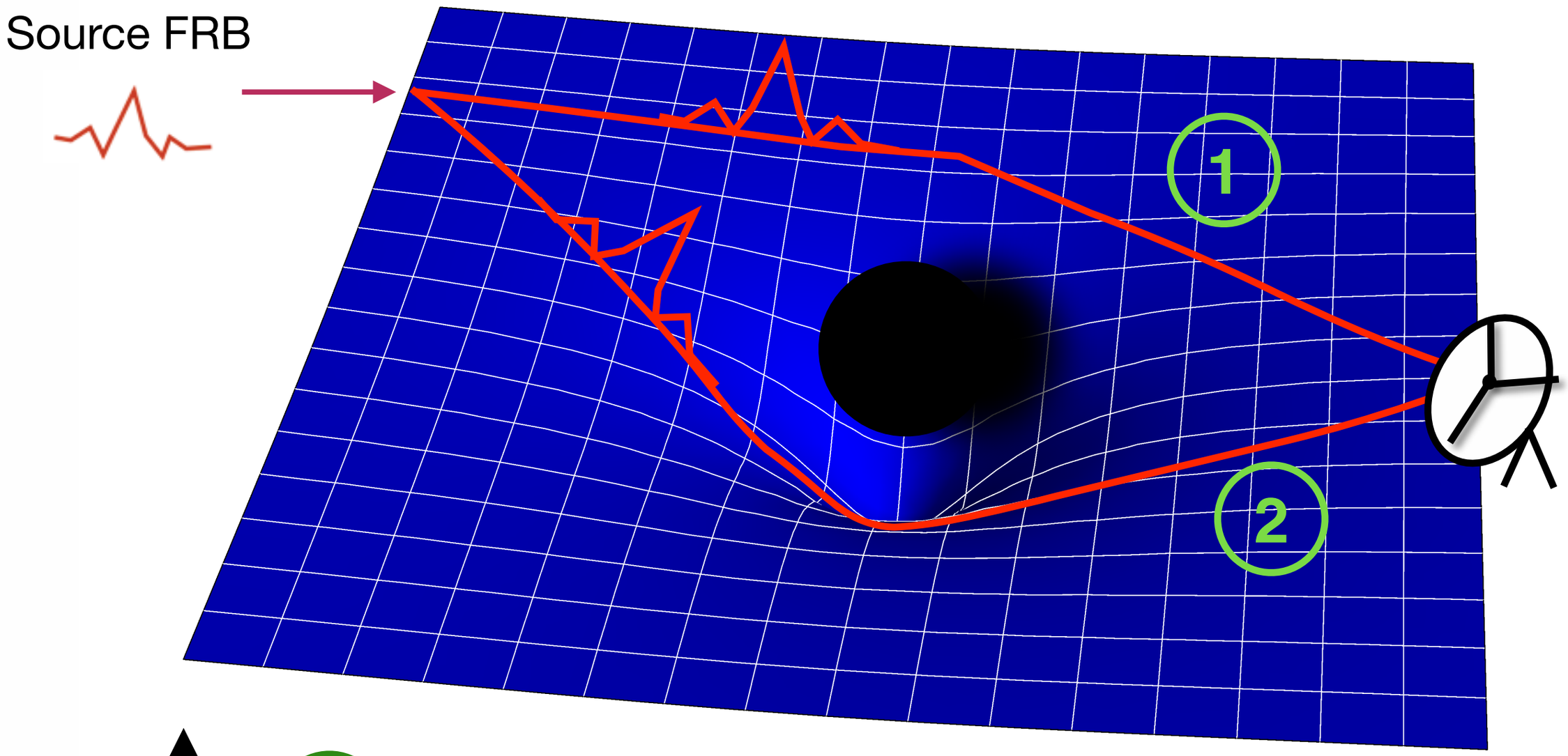


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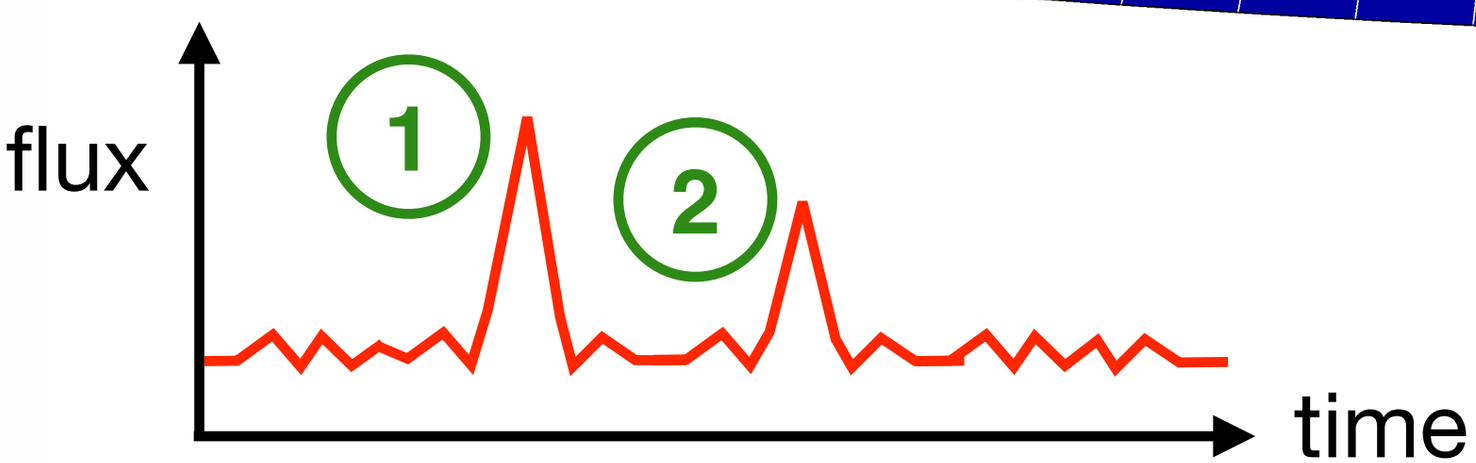

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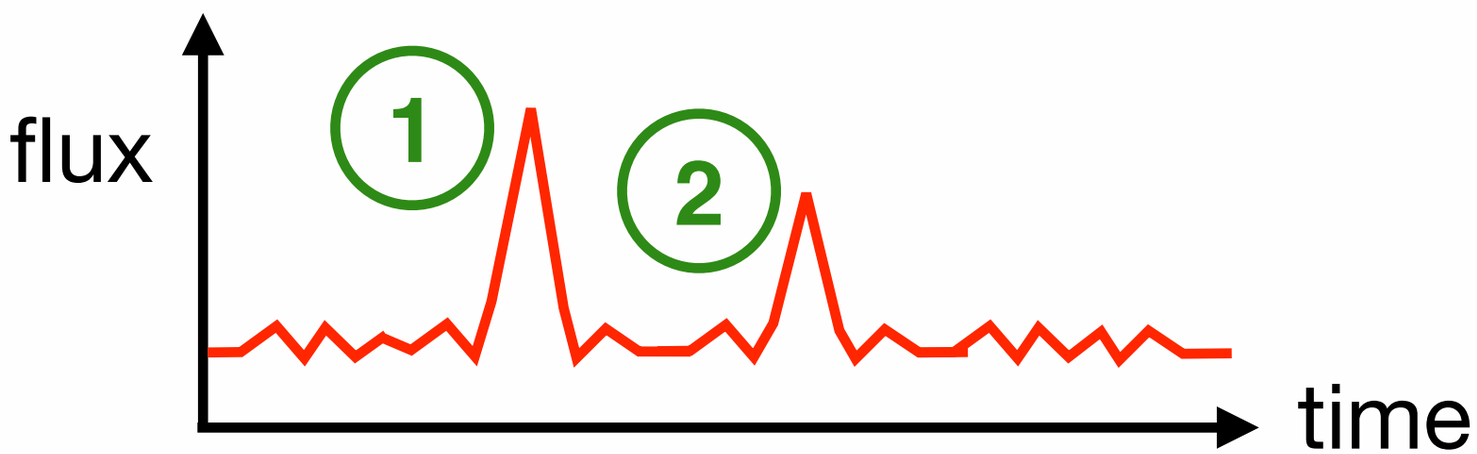

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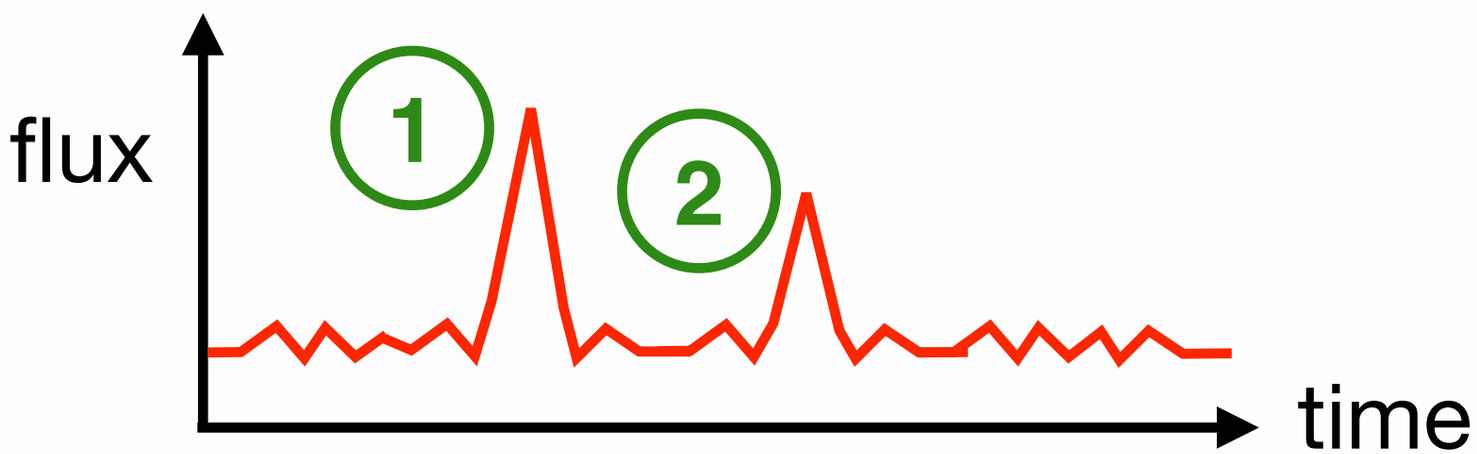


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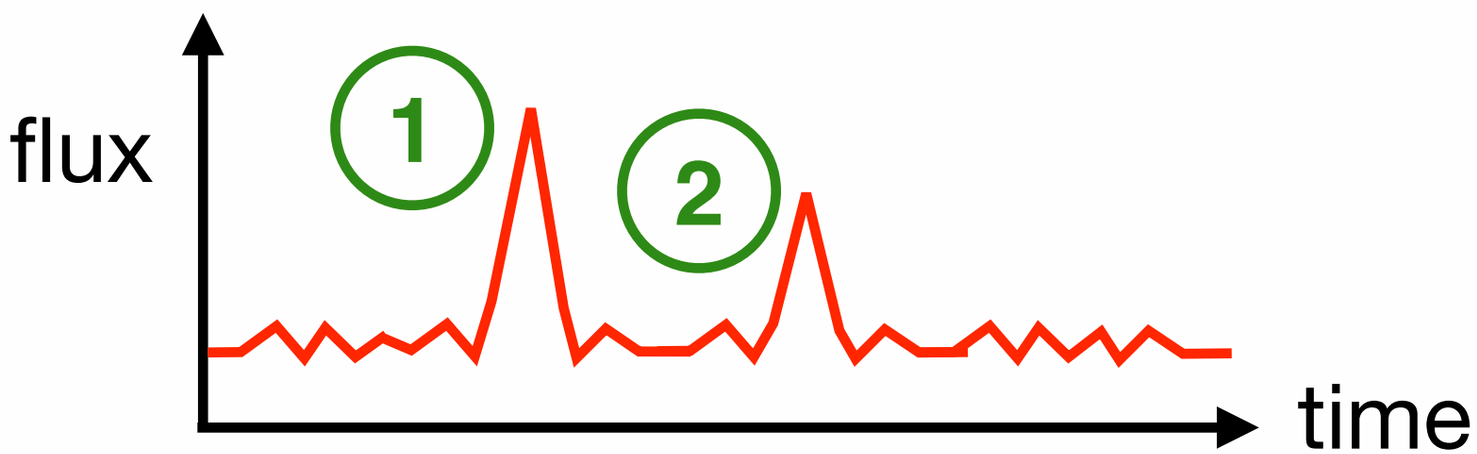


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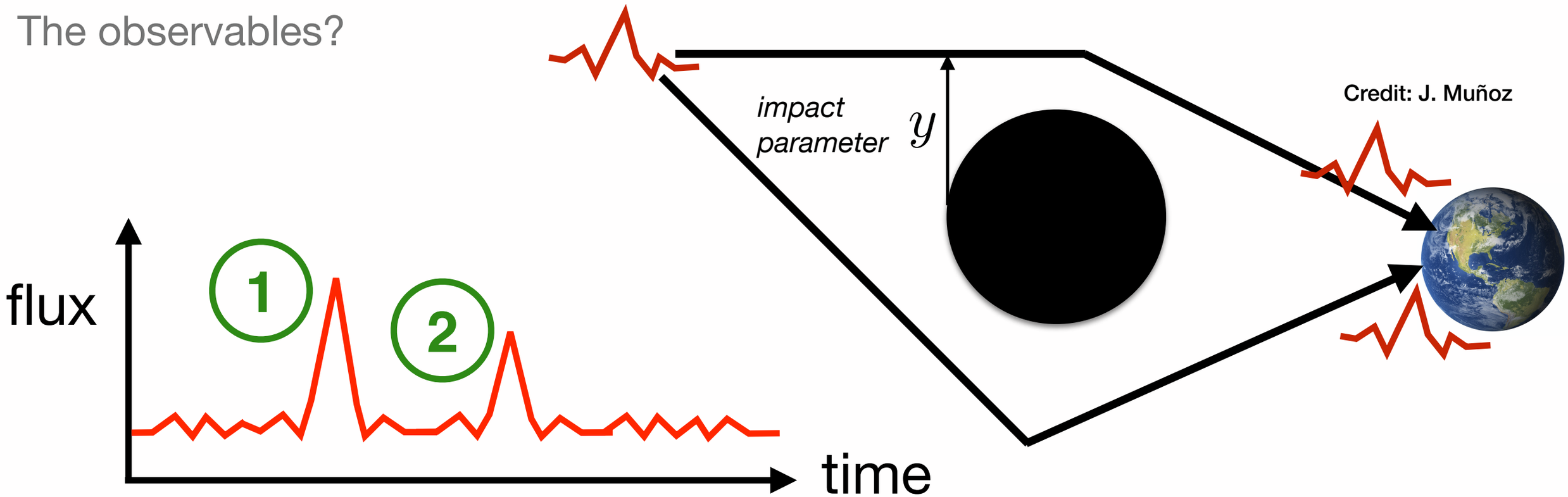


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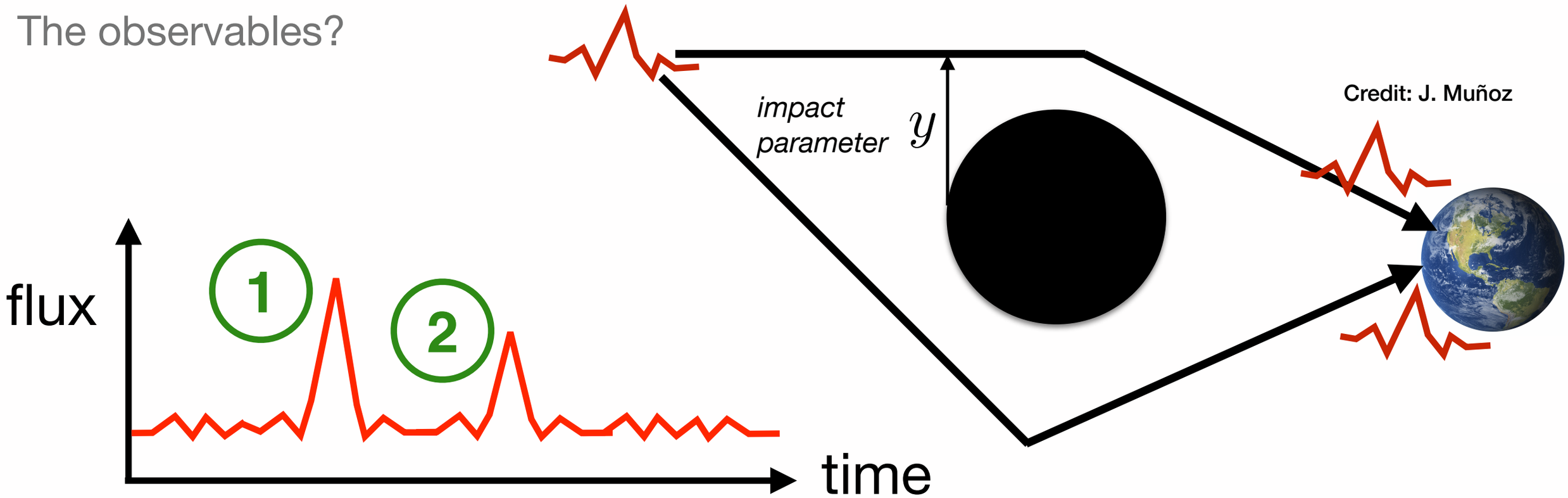


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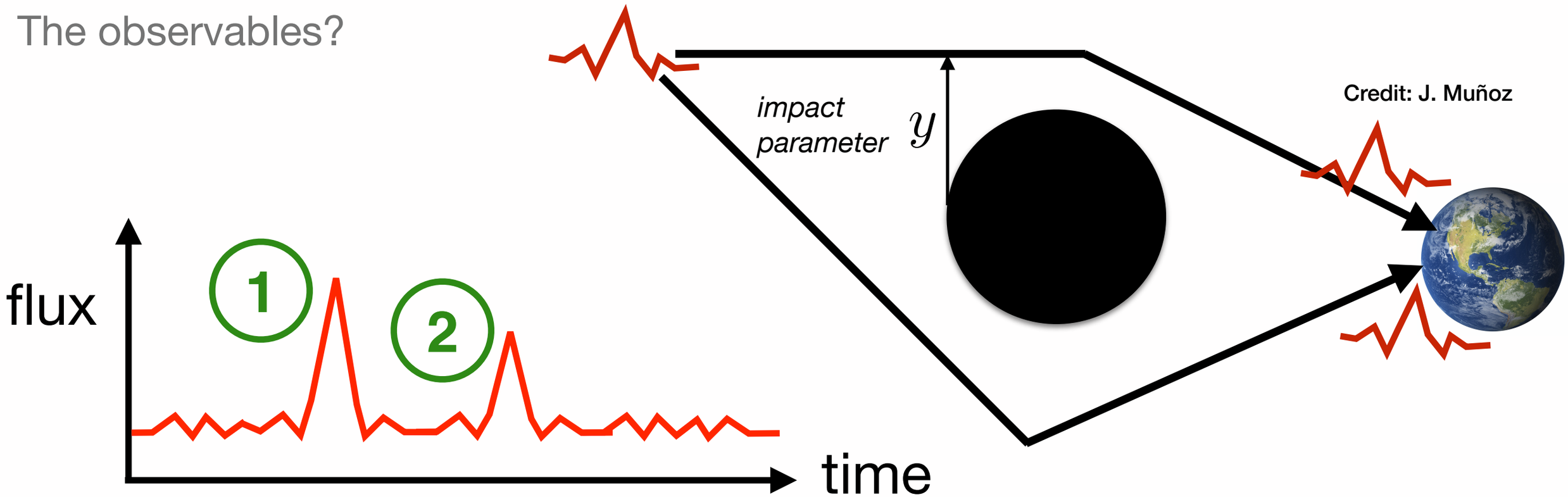


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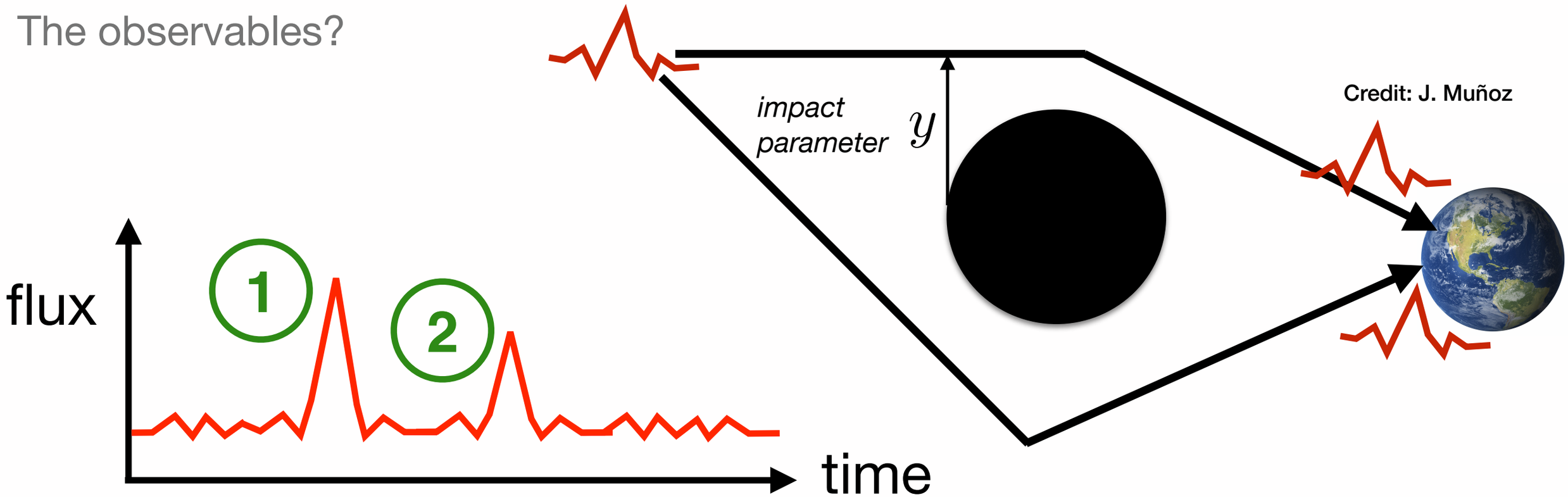


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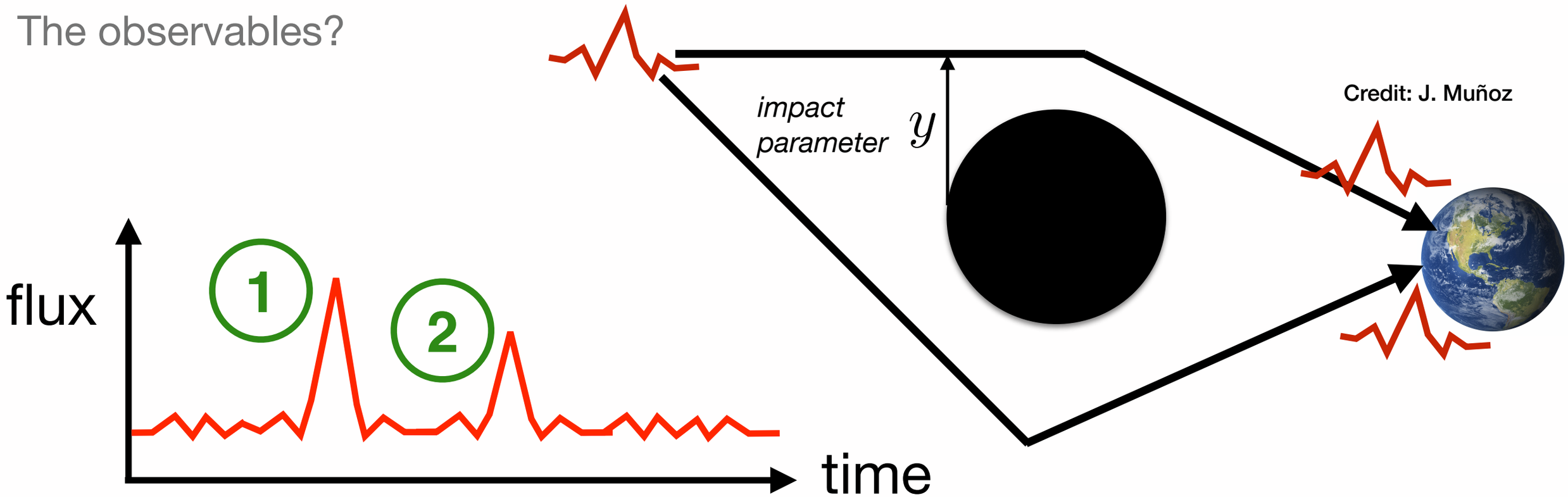


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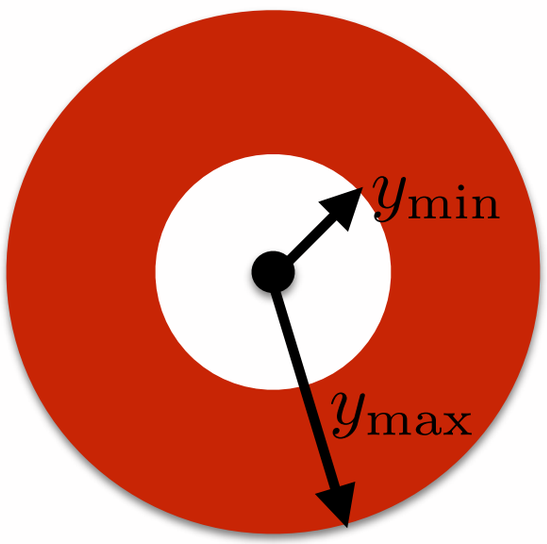


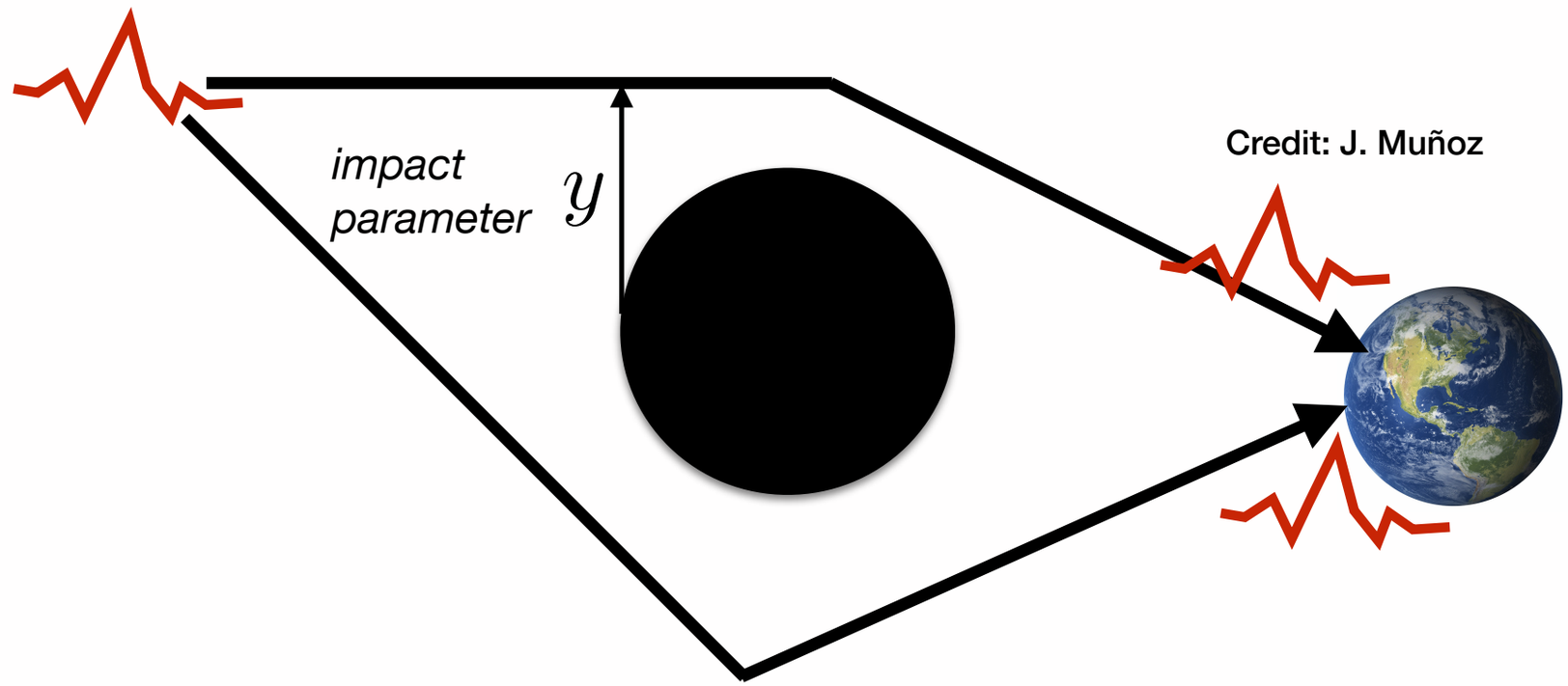


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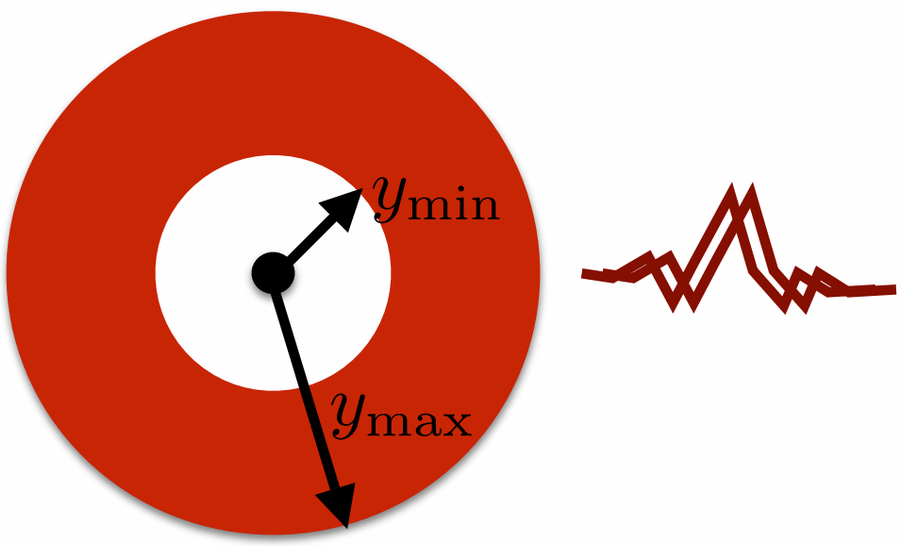


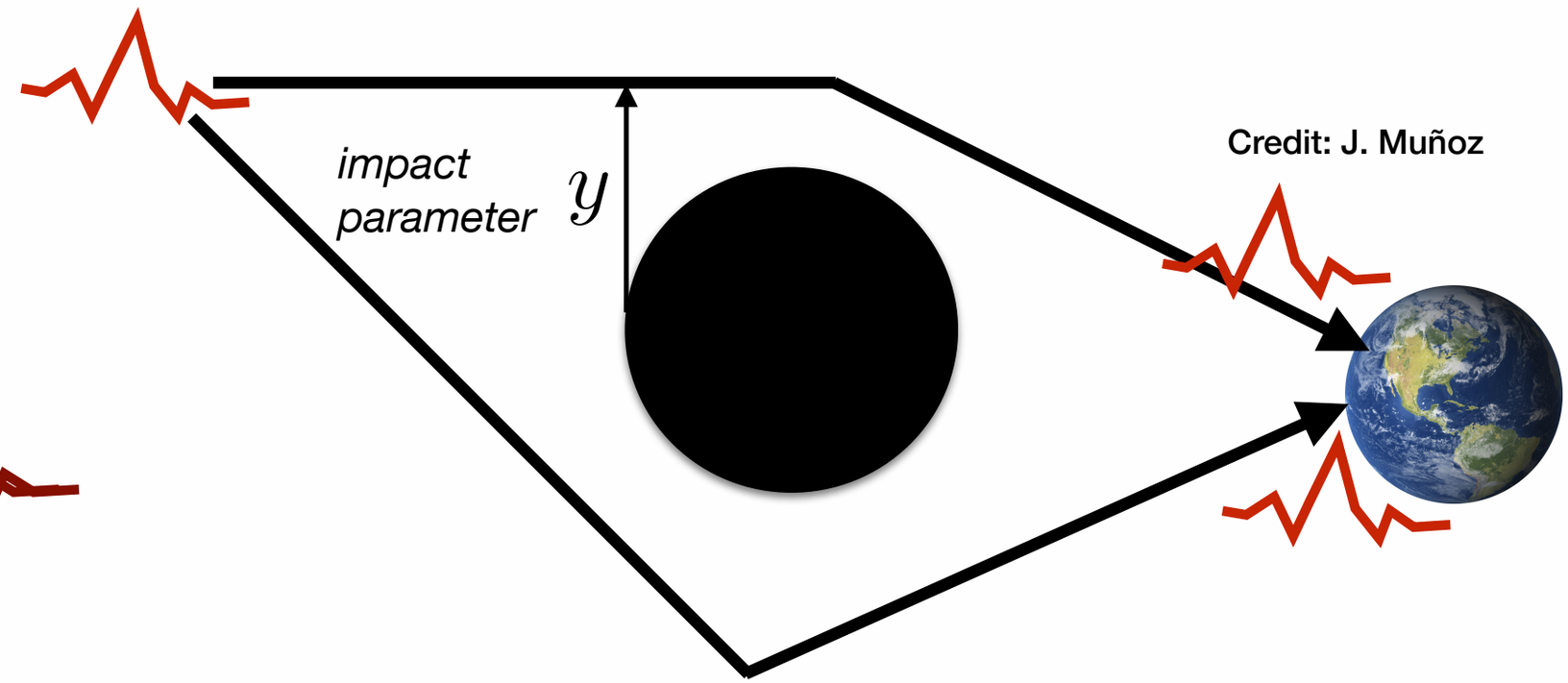


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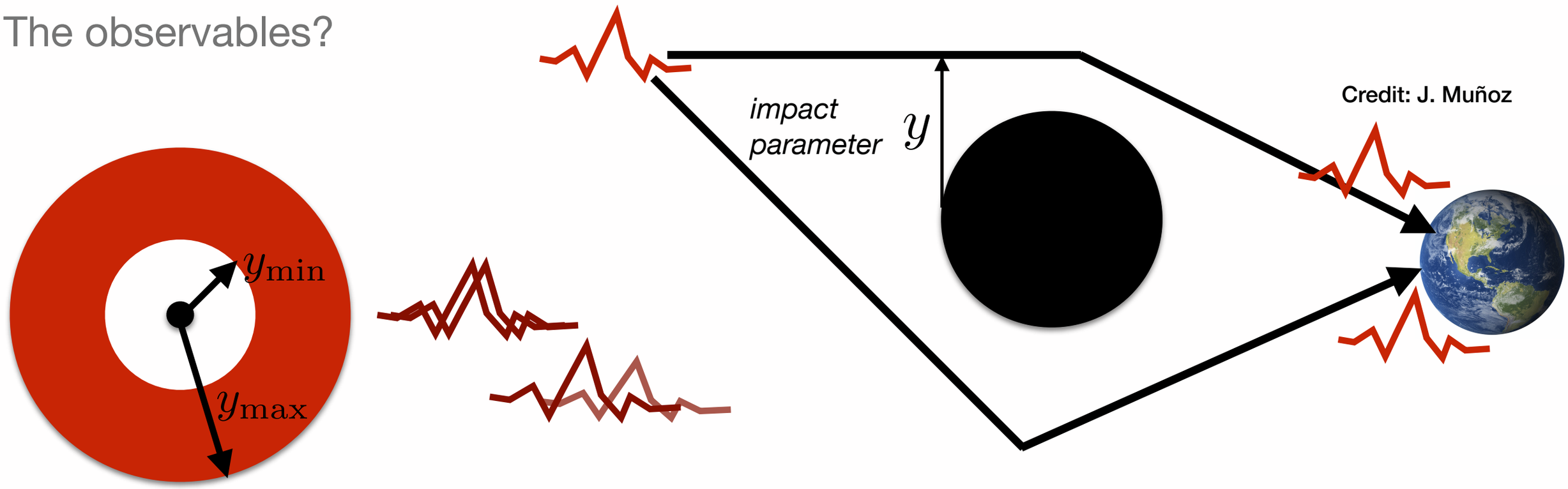


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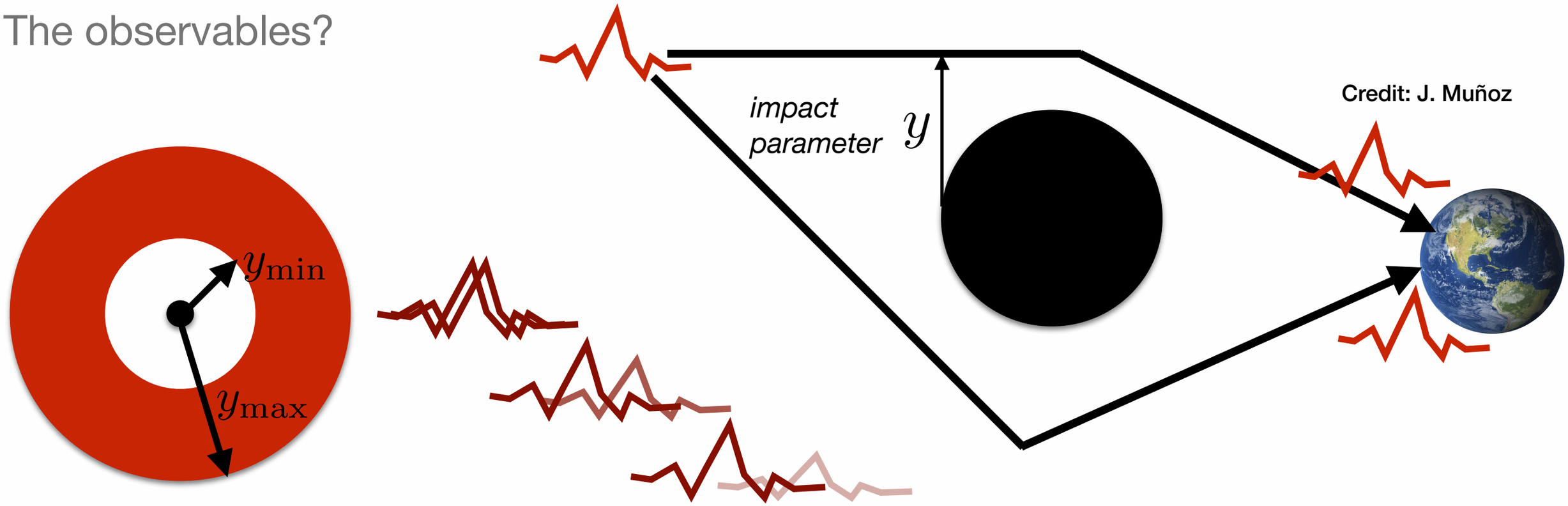


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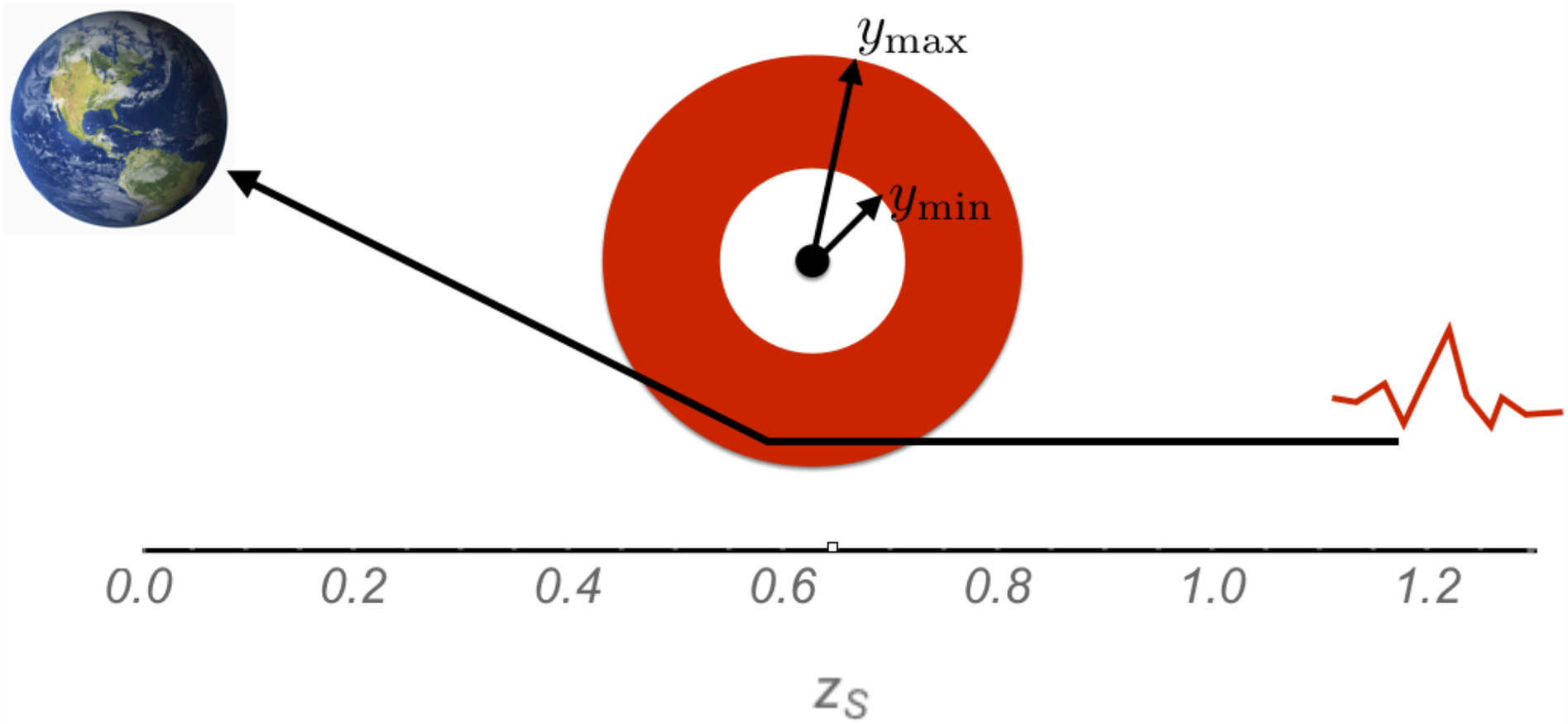

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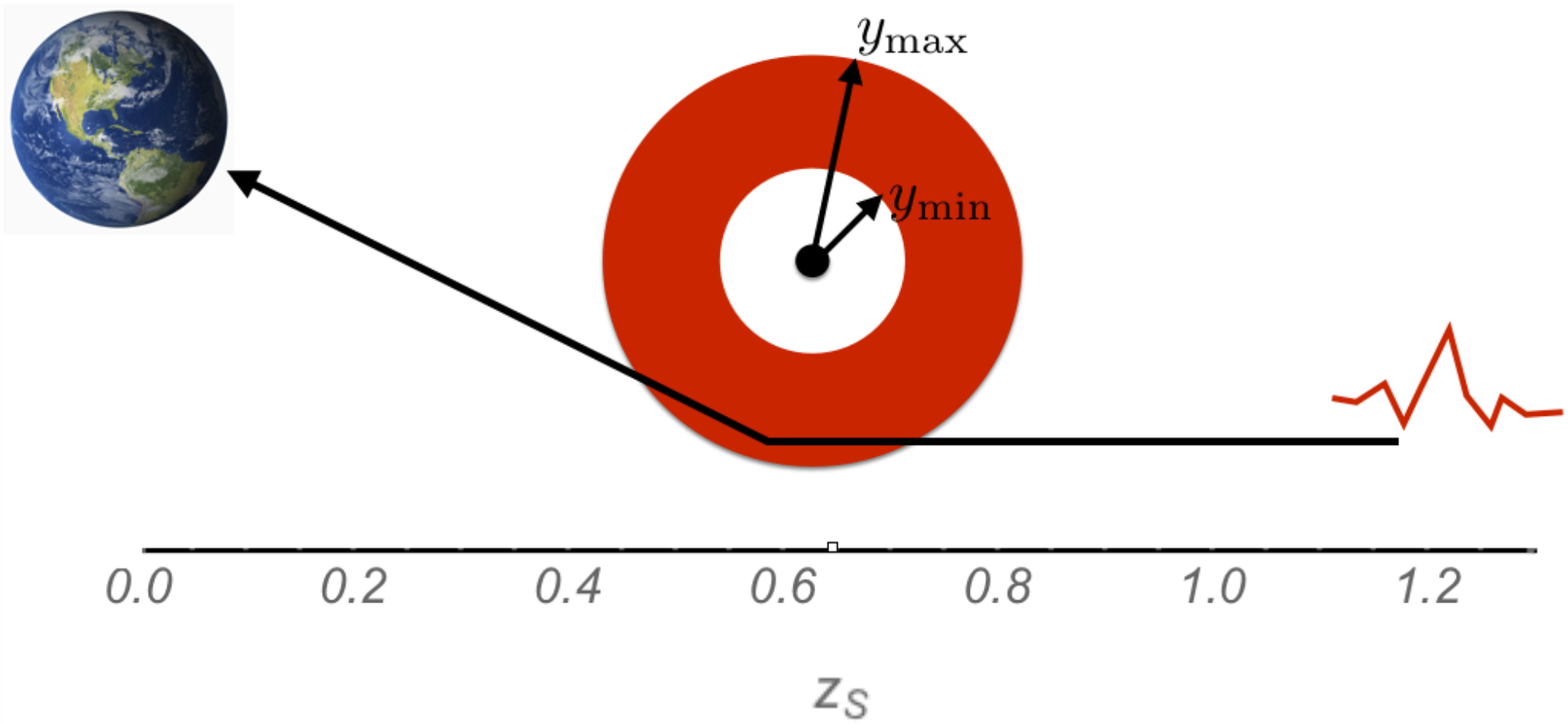

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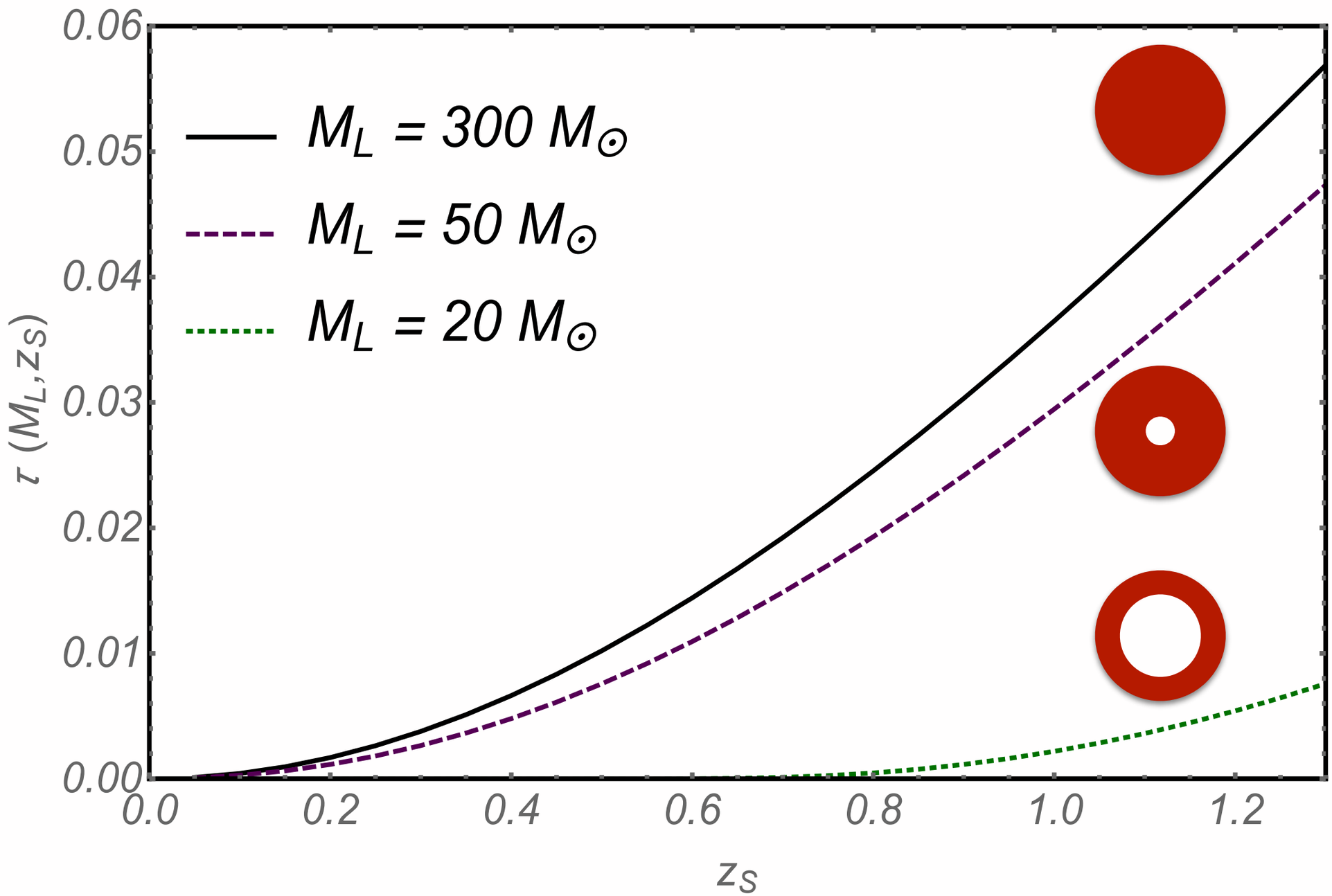

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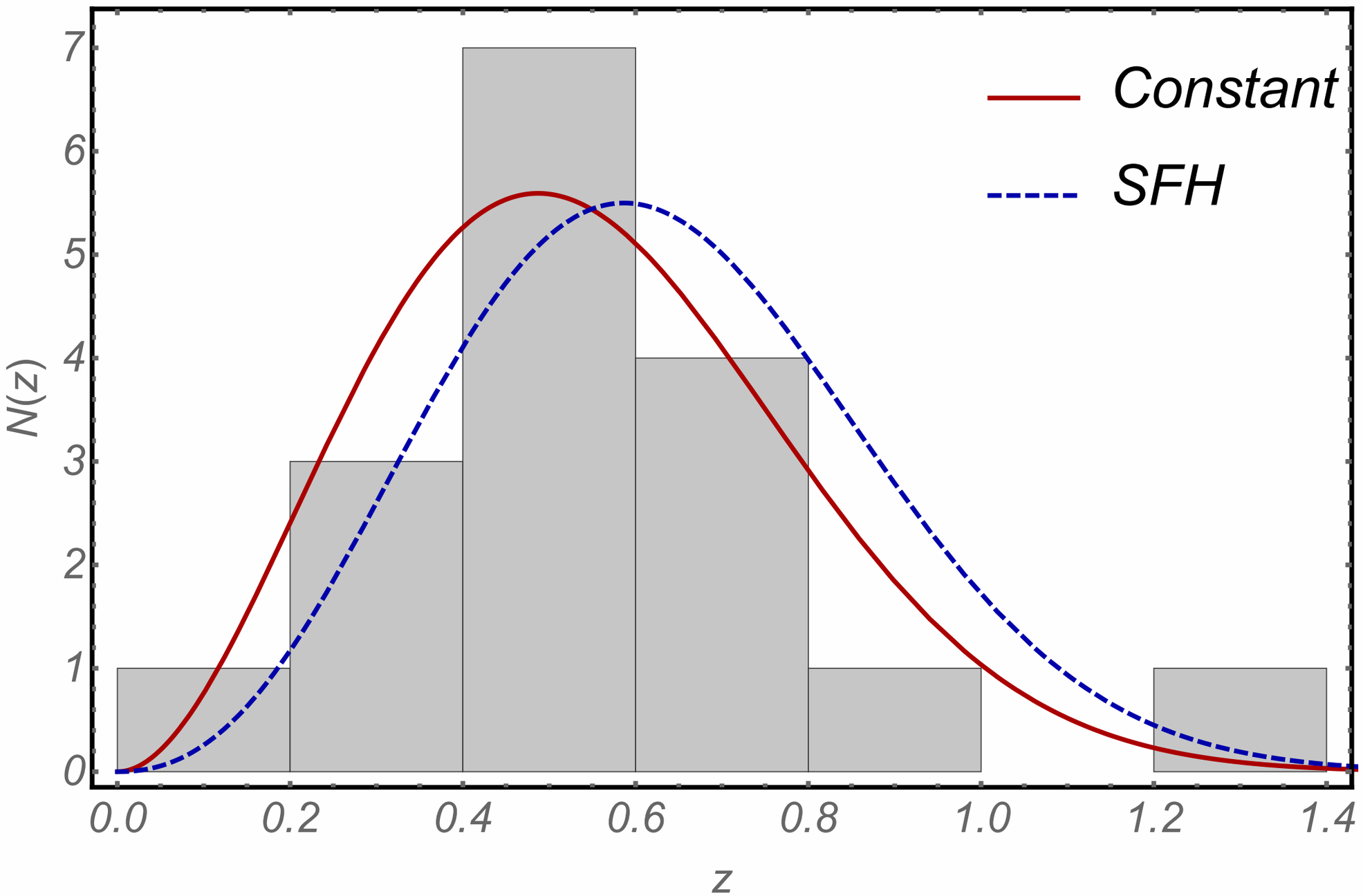

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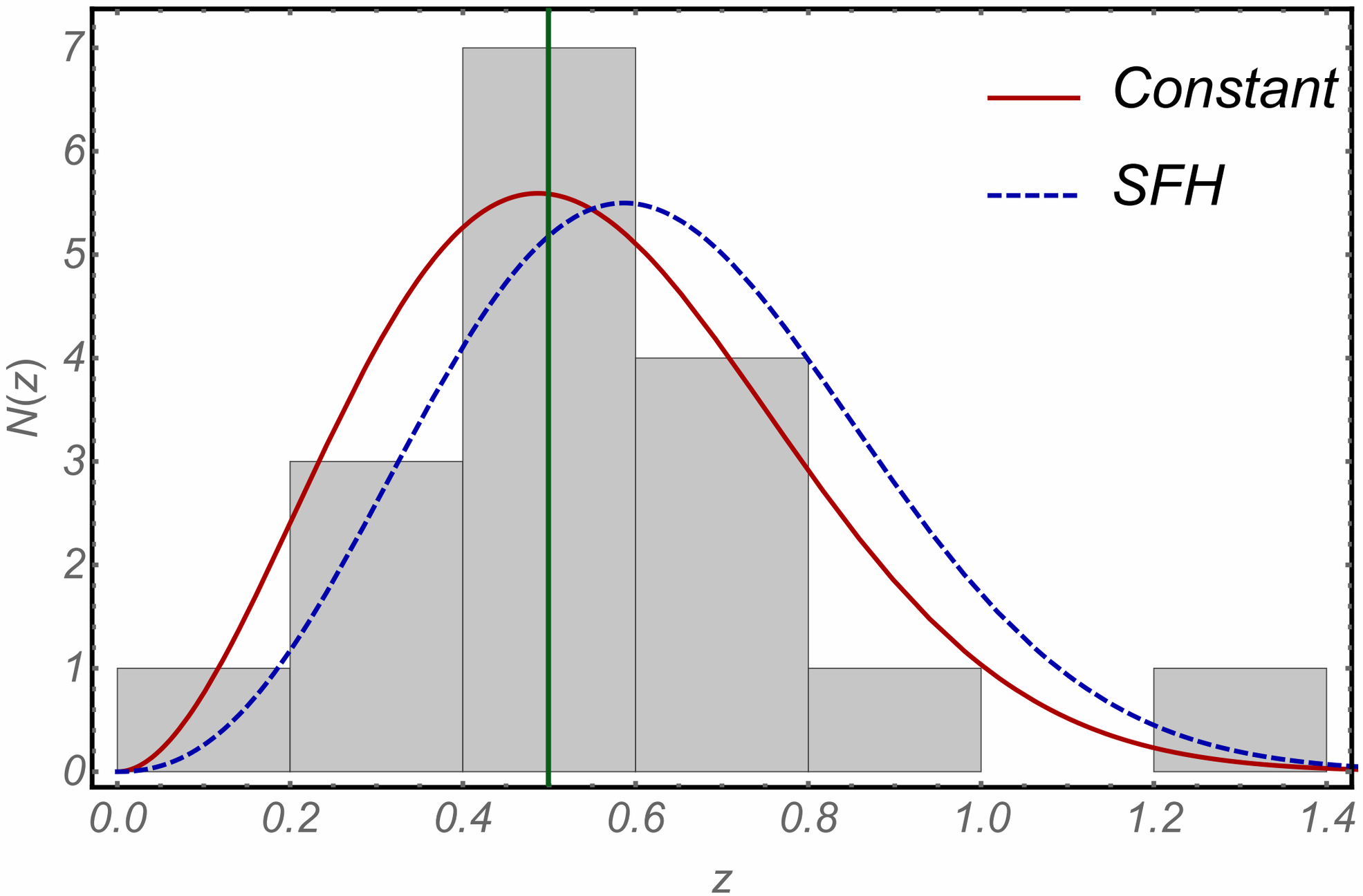

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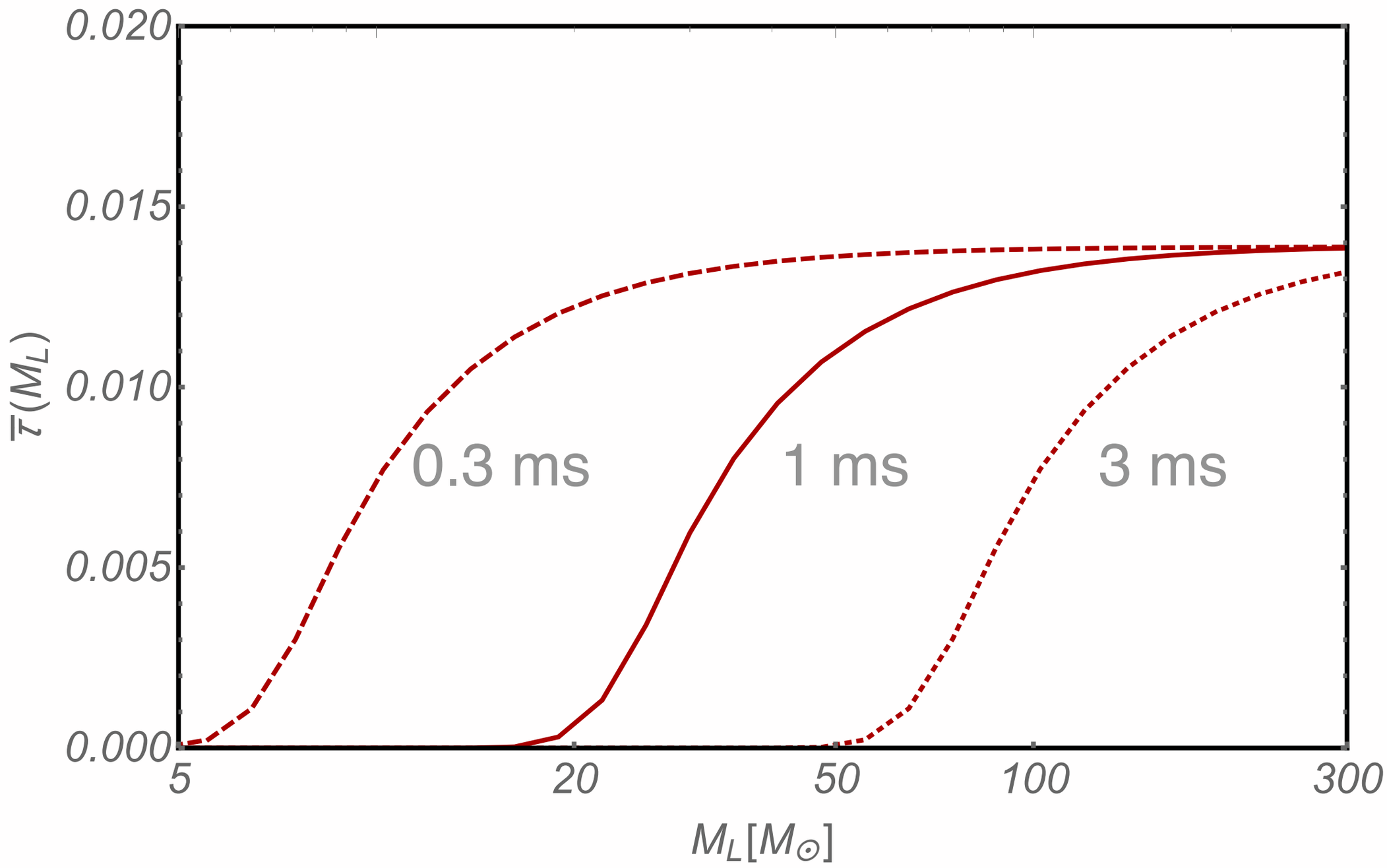

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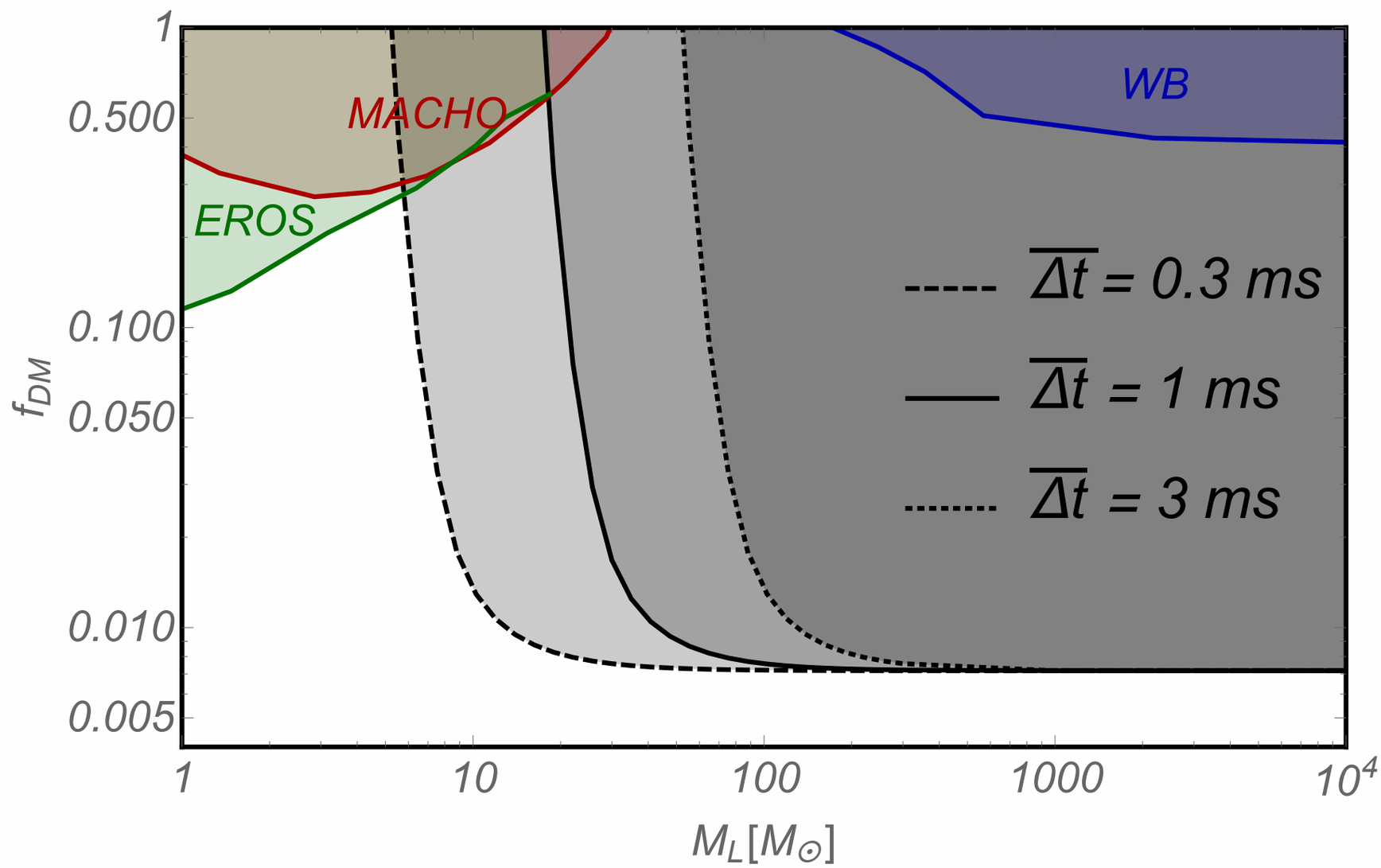

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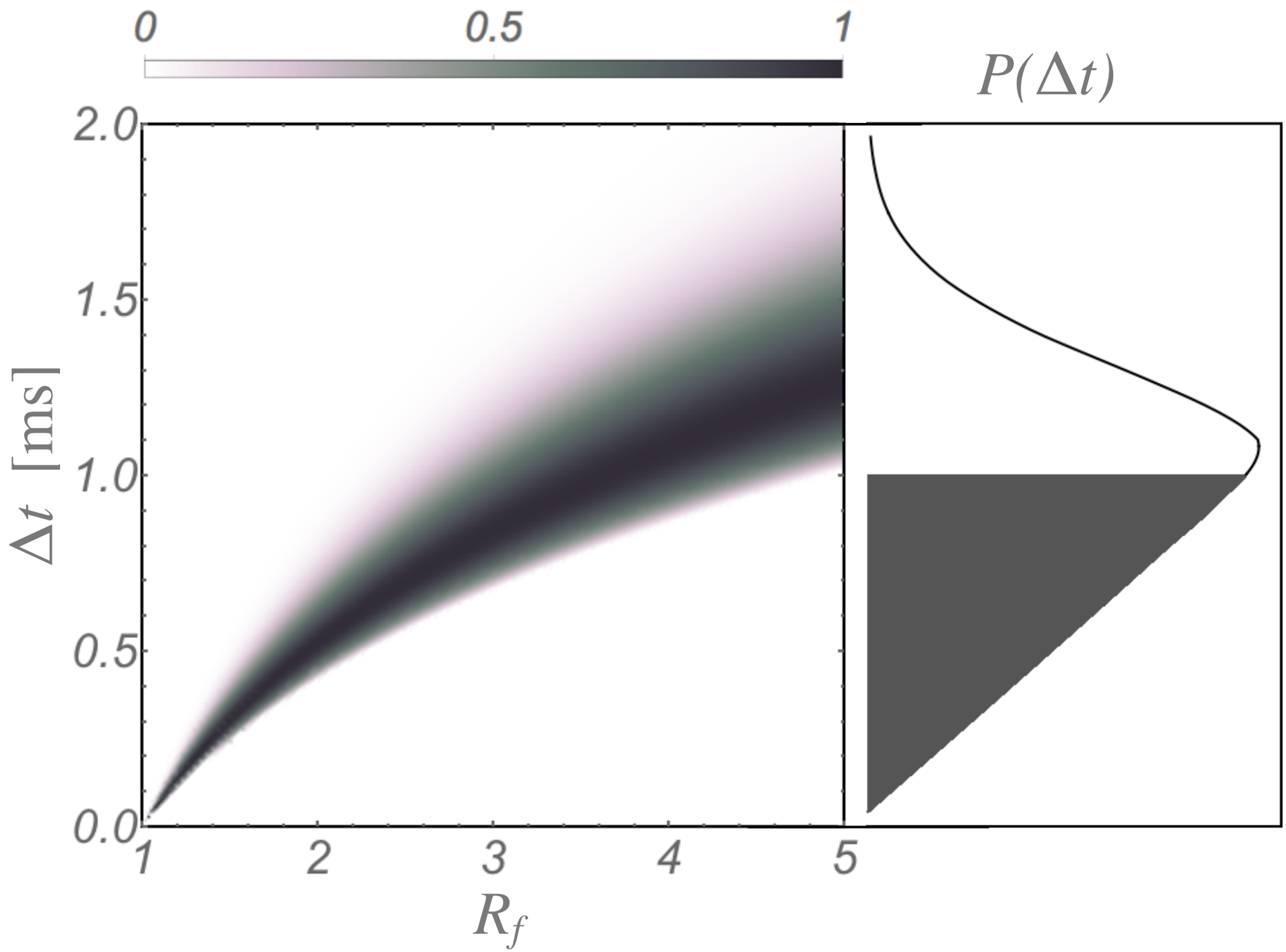

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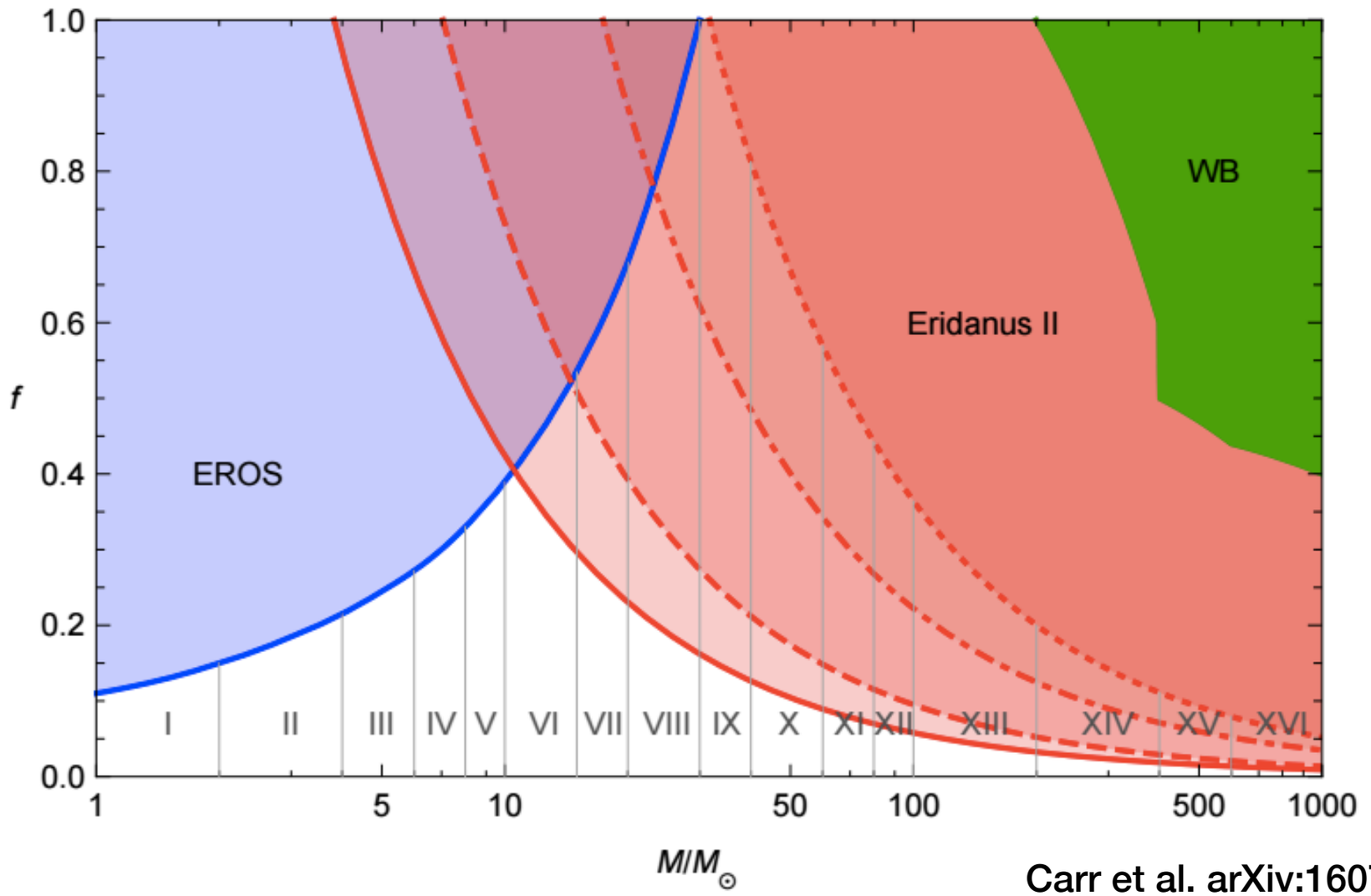


Carr et al. arXiv:1607.06077

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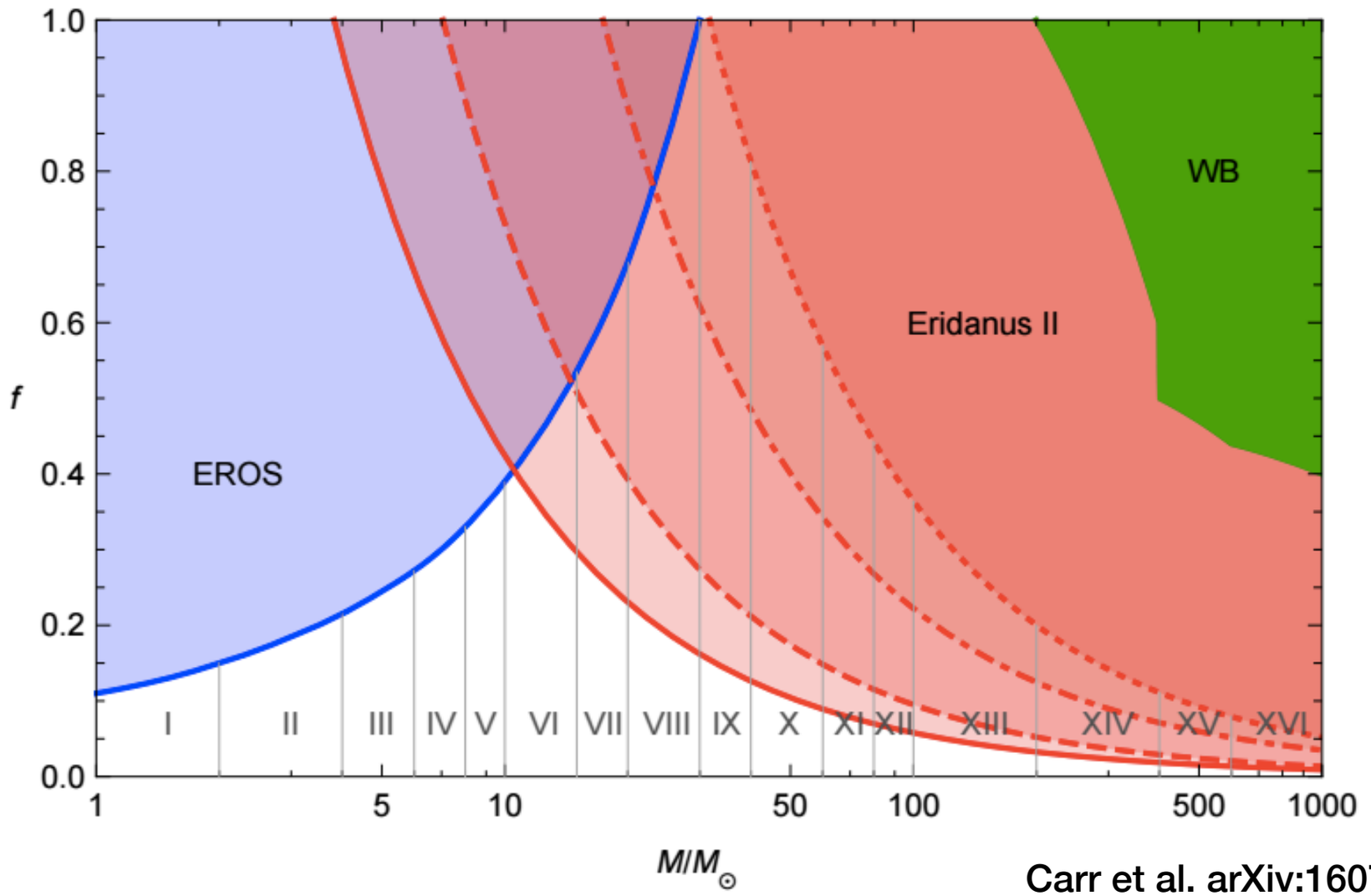


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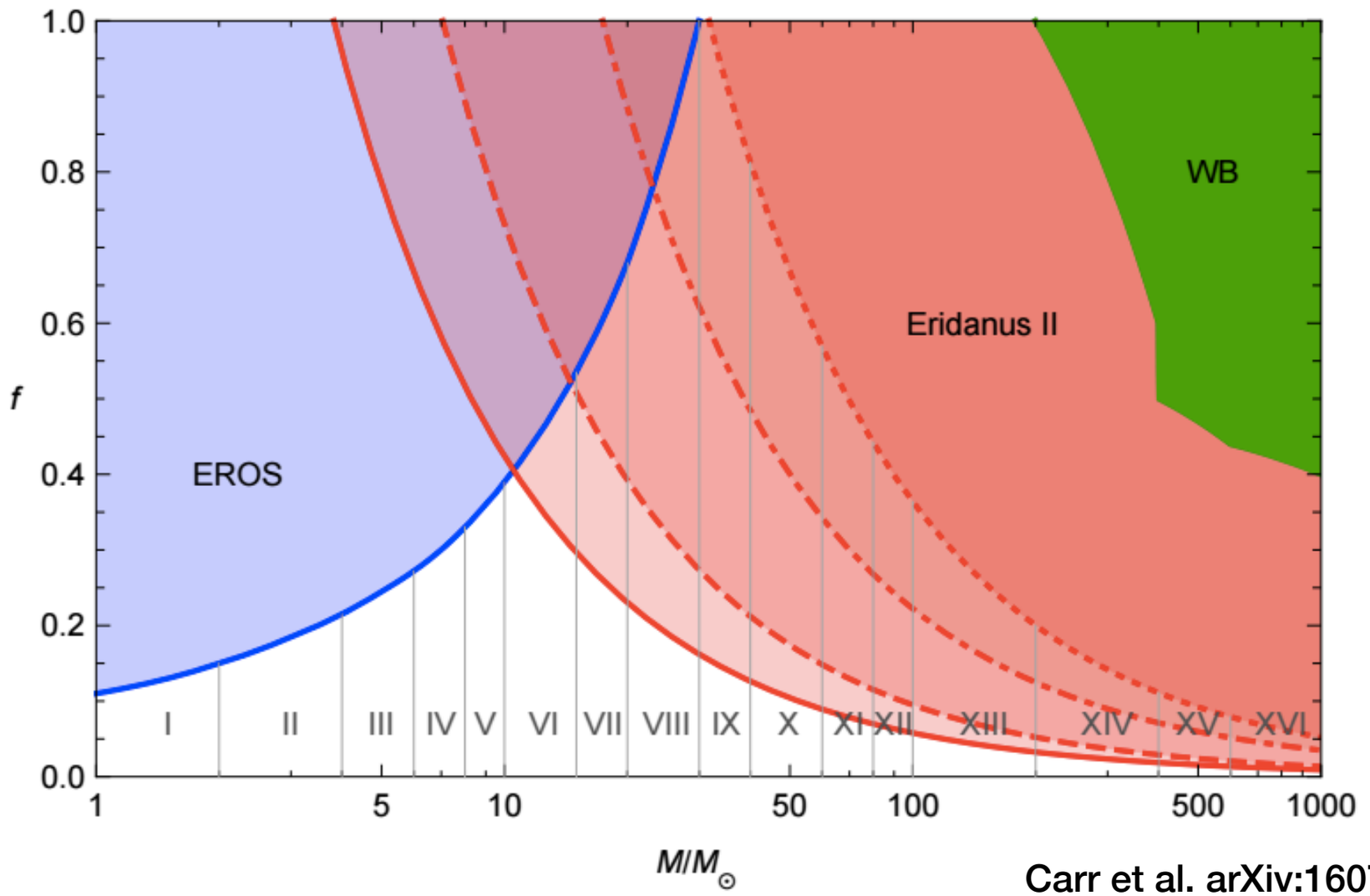


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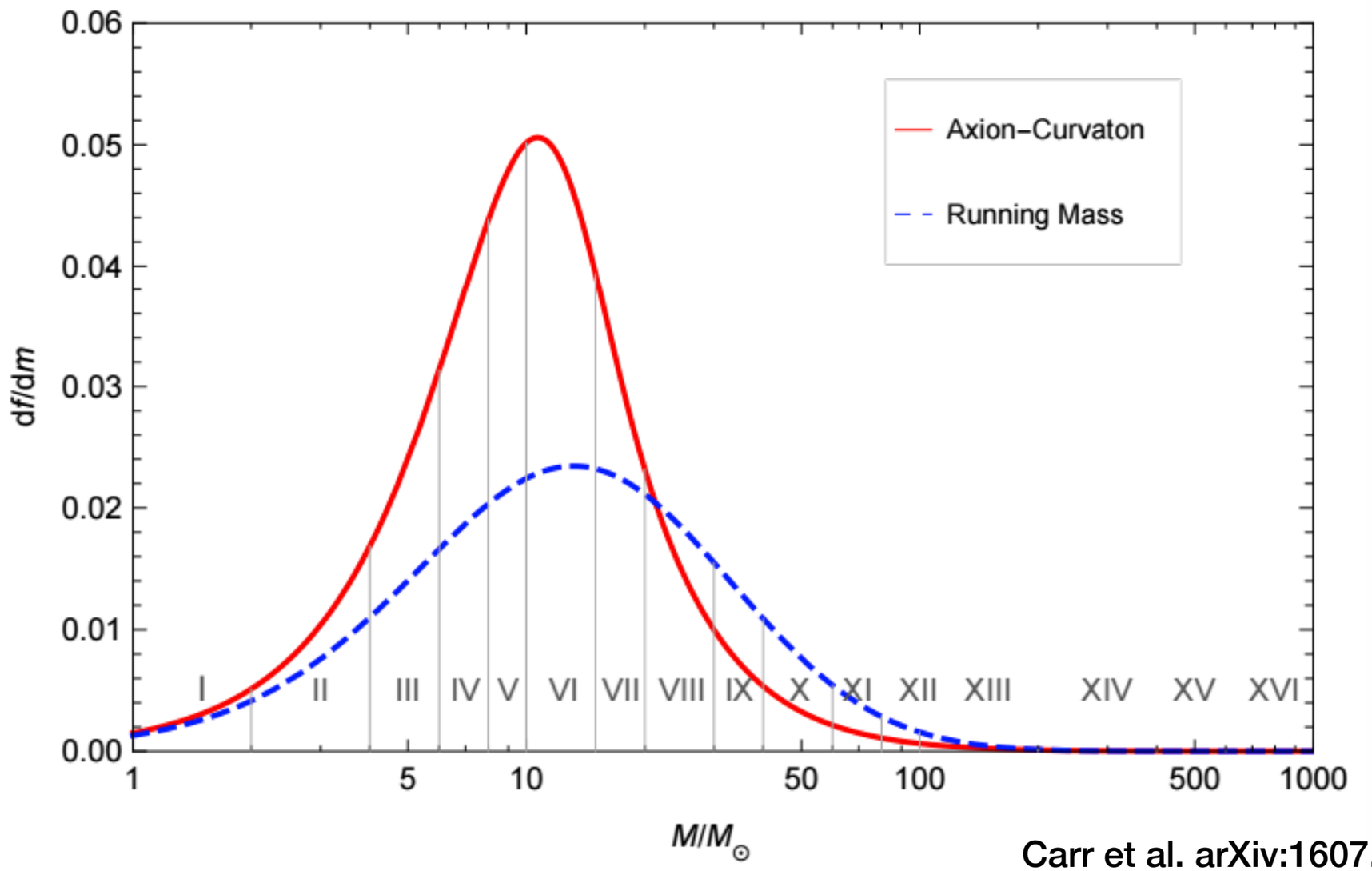


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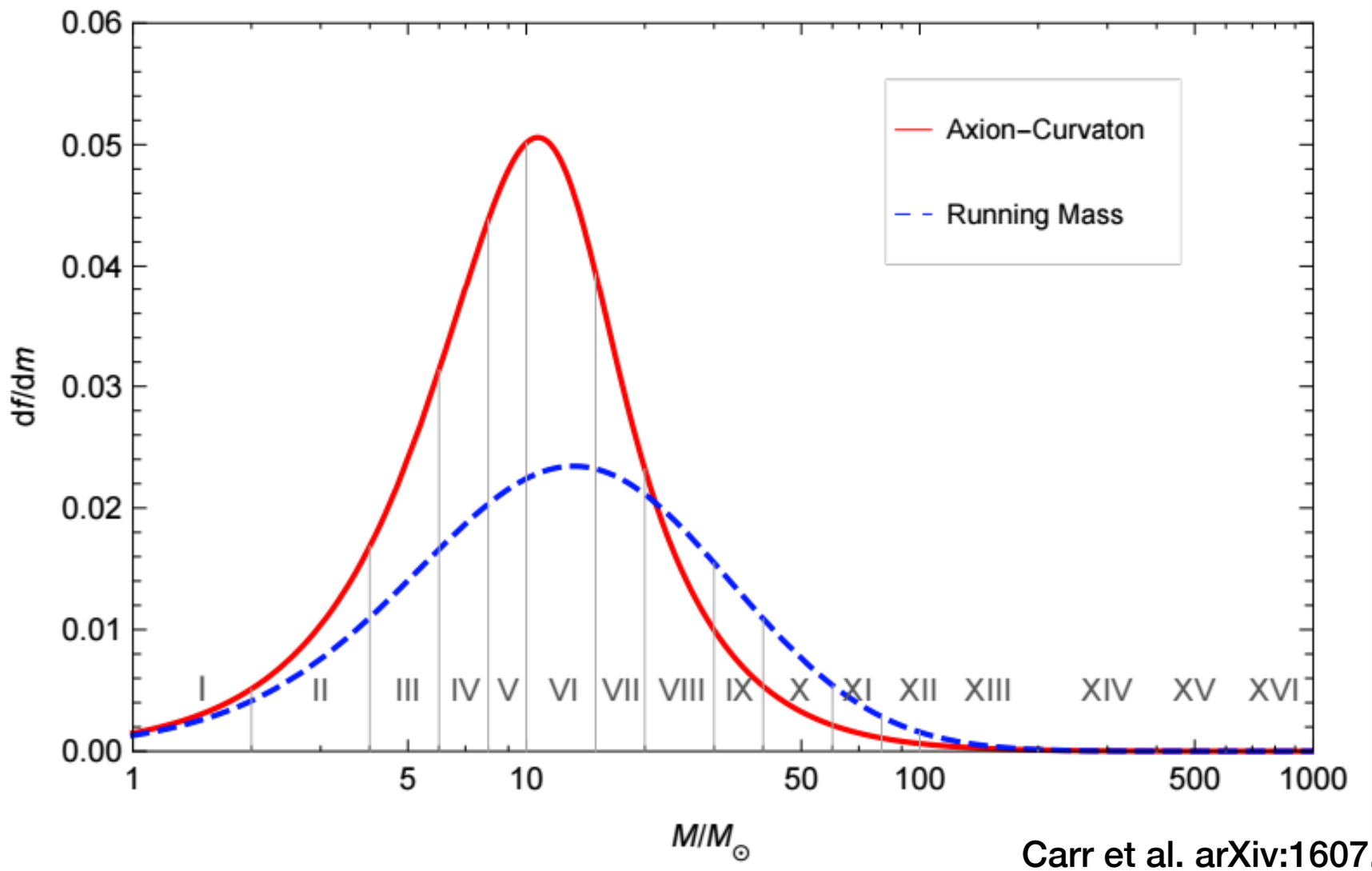


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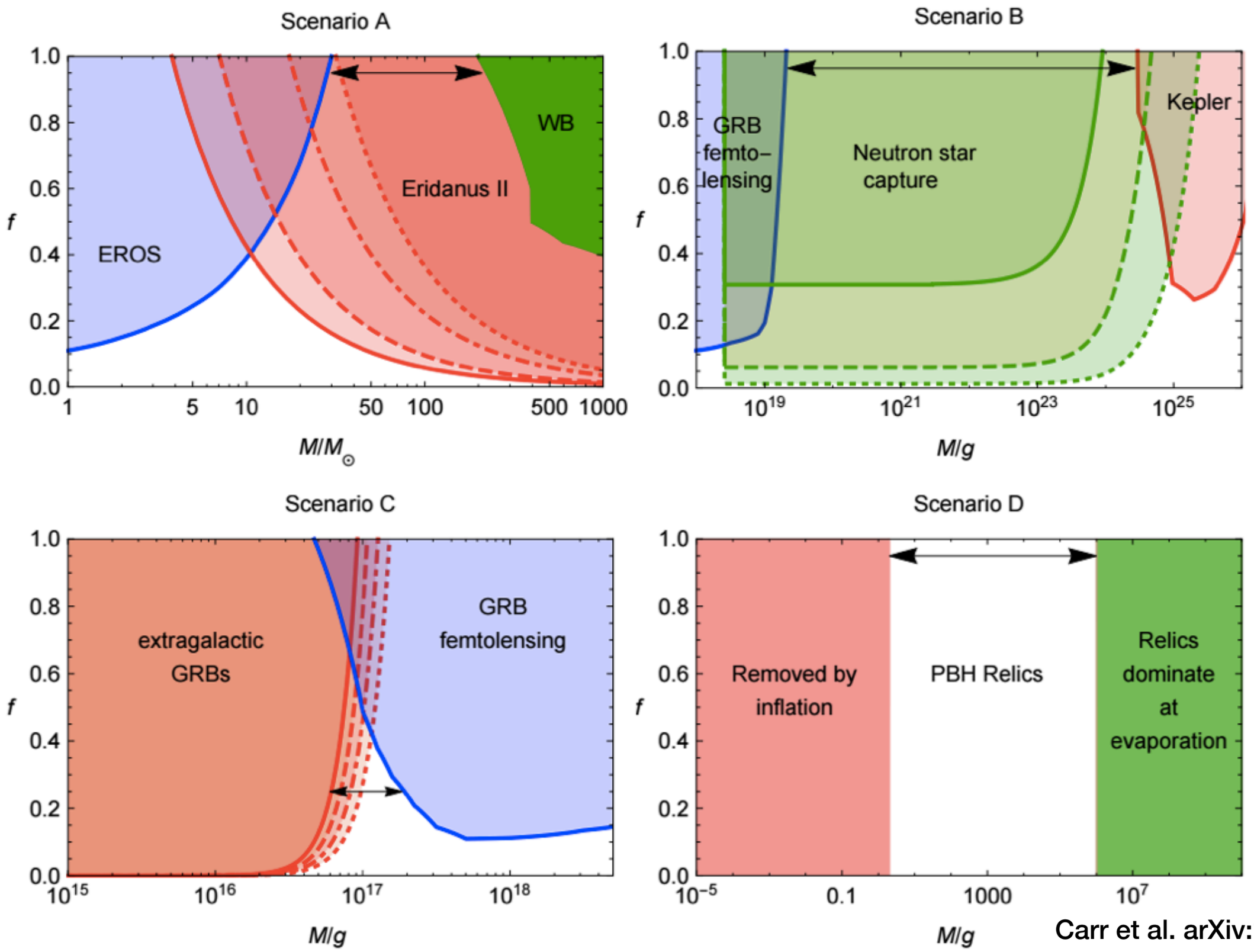
Needs to be done carefully: constraints assume delta-function mass function.

Green arXiv:1609.01143

# Other Windows for PBH Dark Matter

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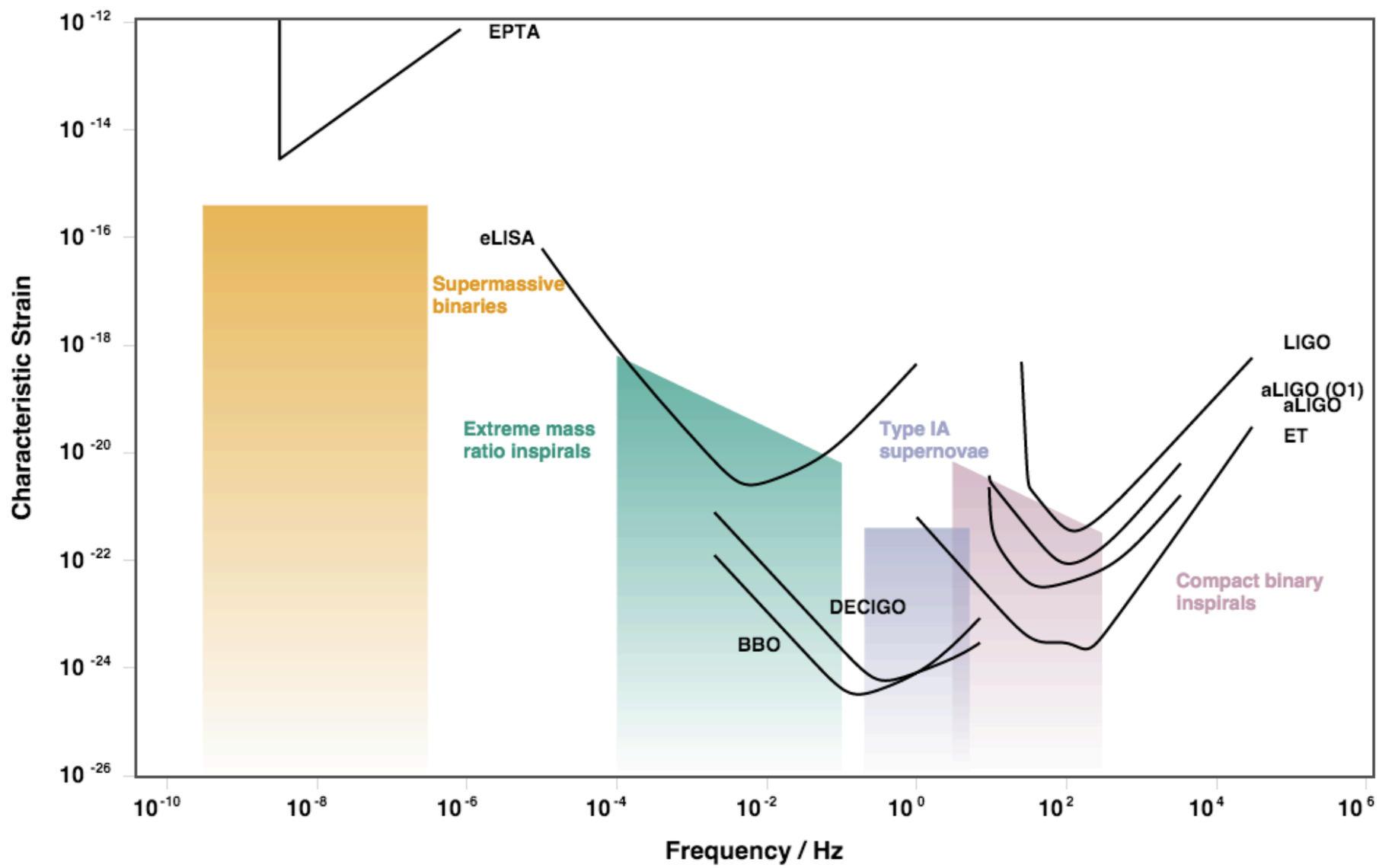

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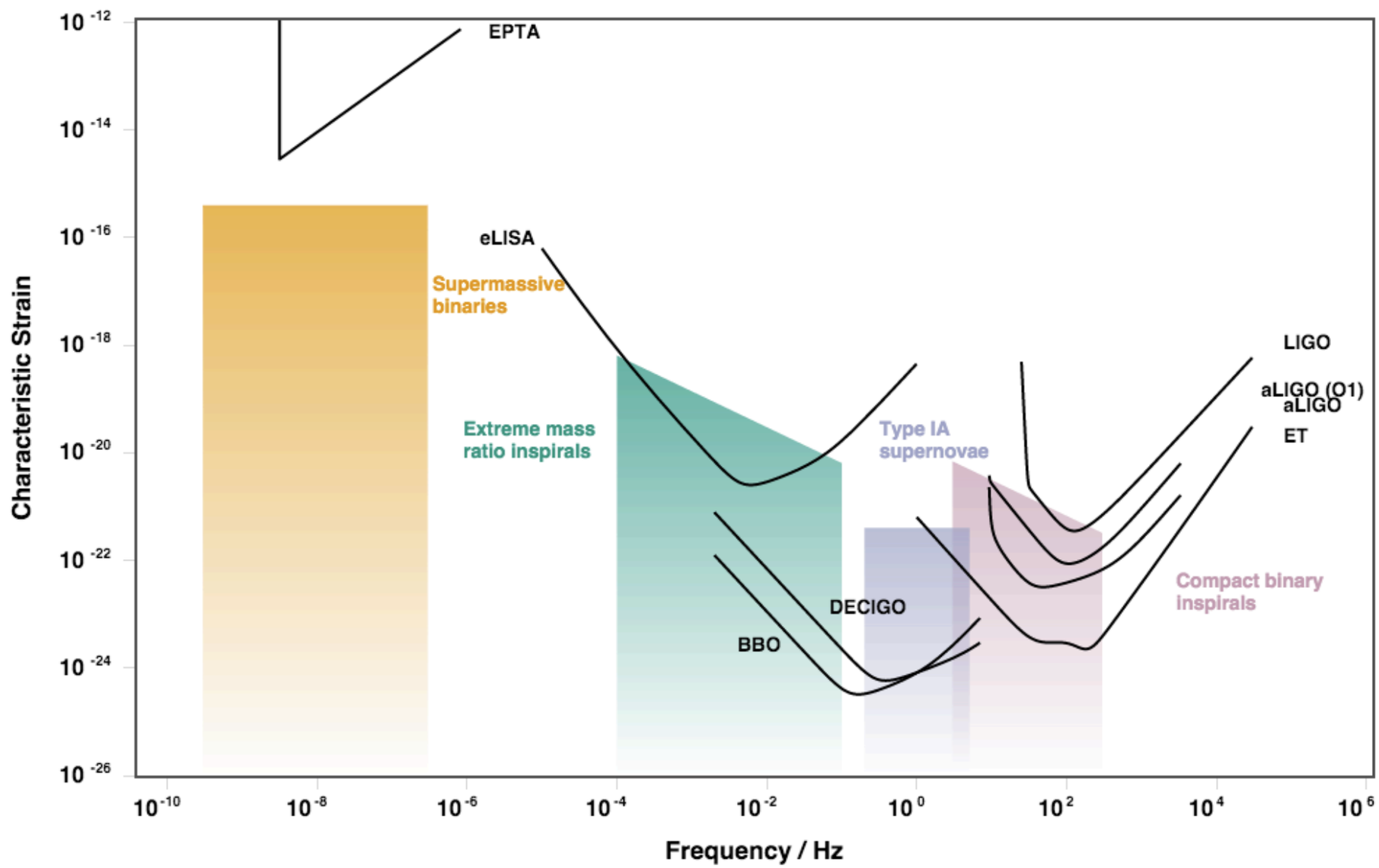


Fast Radio Bursts:

# Observational Outlook

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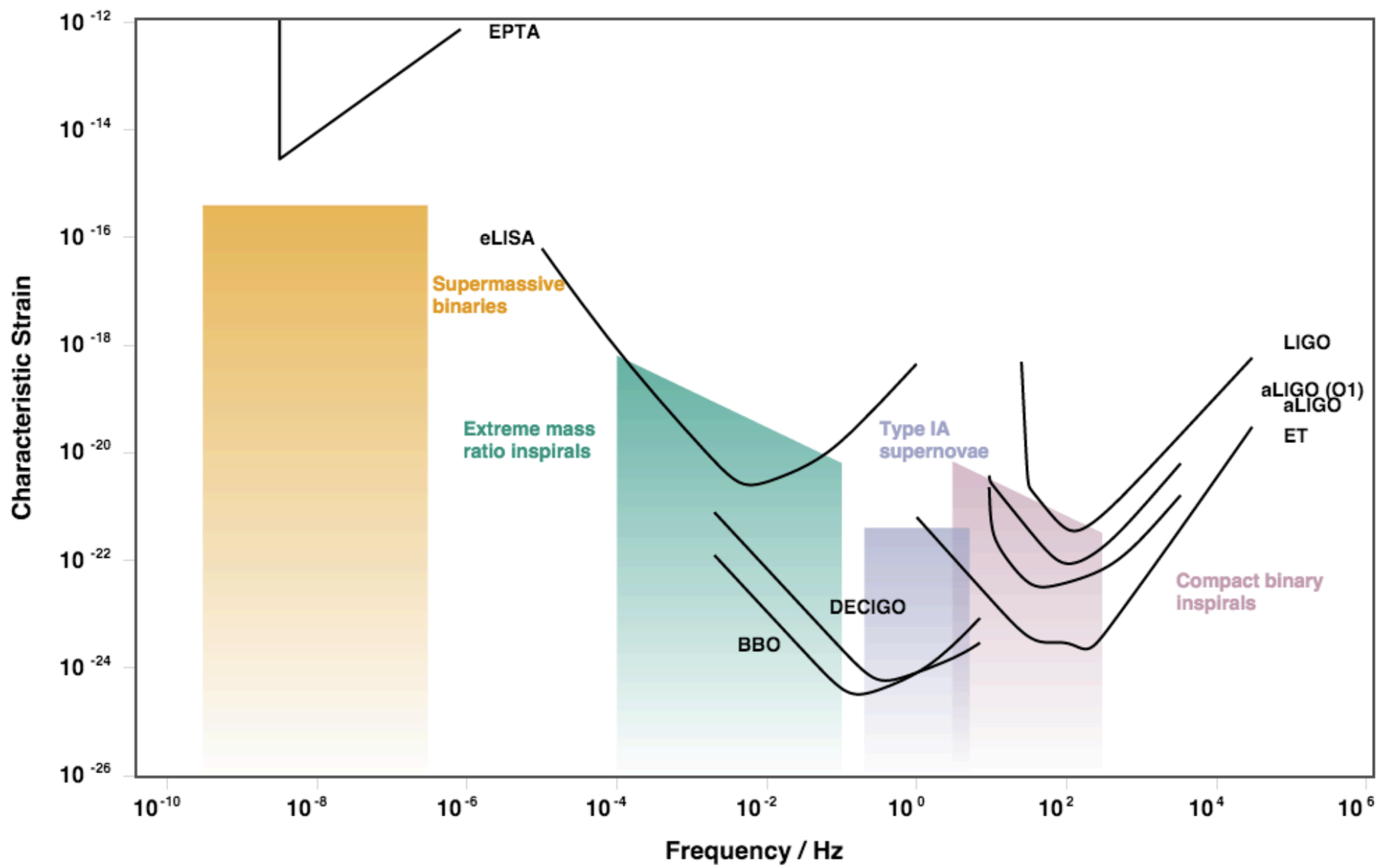


Fast Radio Bursts: Lots of instruments, including CHIME, HIRAX...

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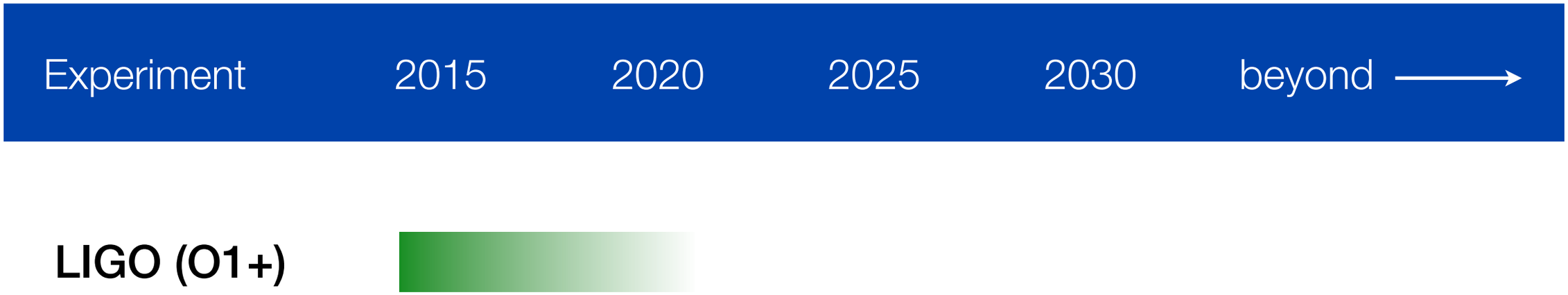
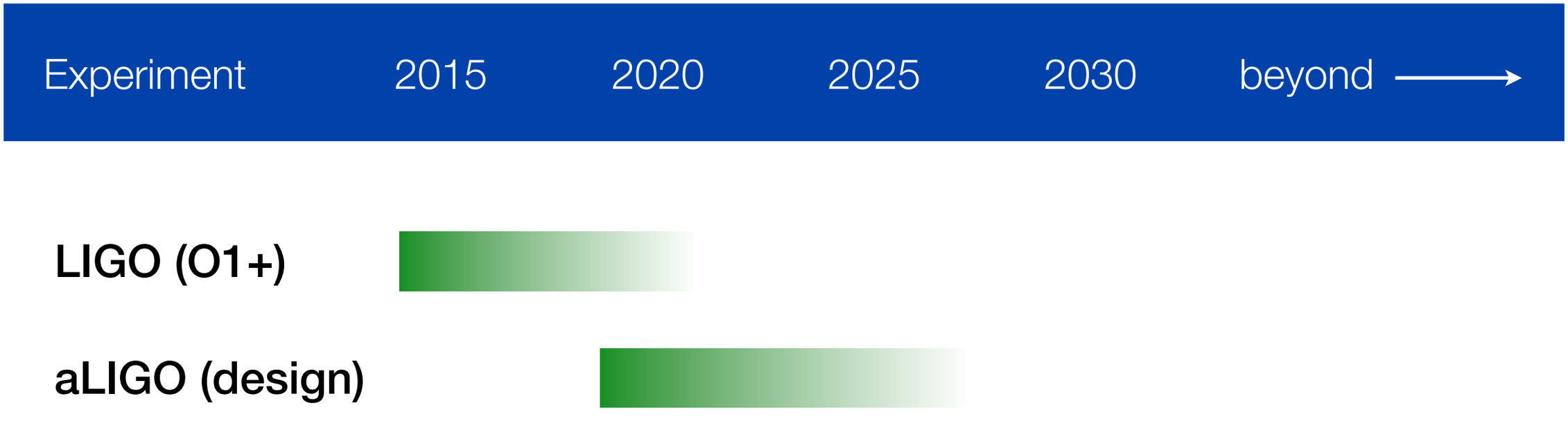
| Experiment | 2015 | 2020 | 2025 | 2030 | beyond → |
|---|---|---|---|---|---|

# Observational Outlook: Experiment Timeline



# Observational Outlook: Experiment Timeline



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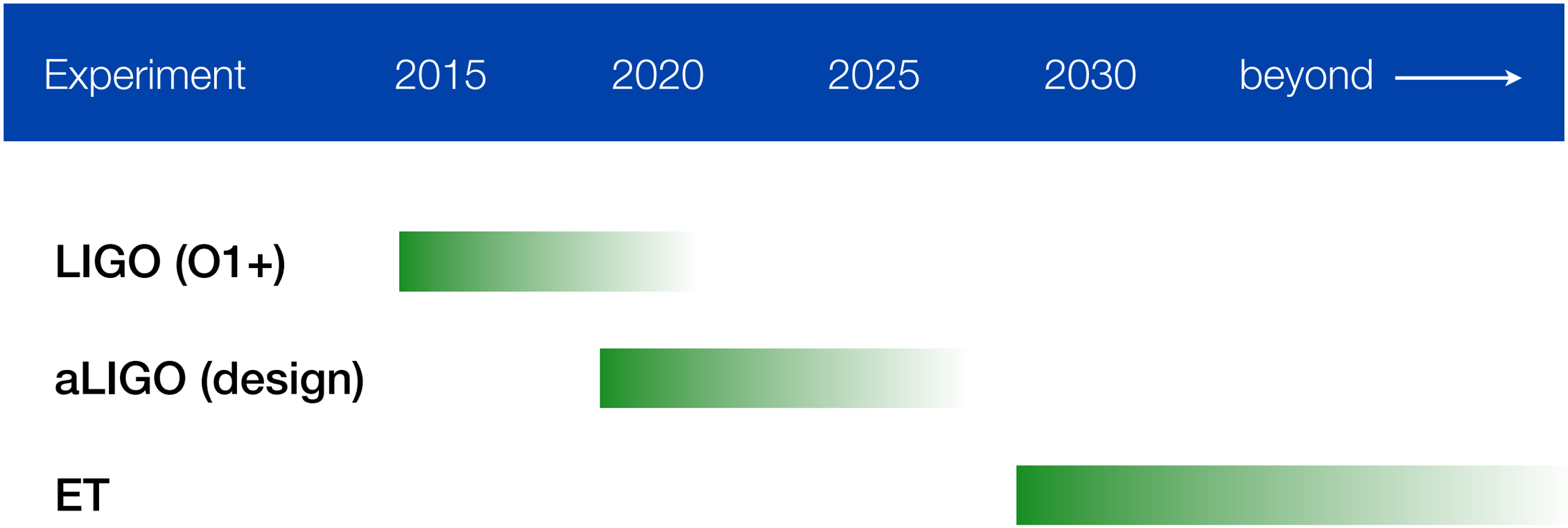
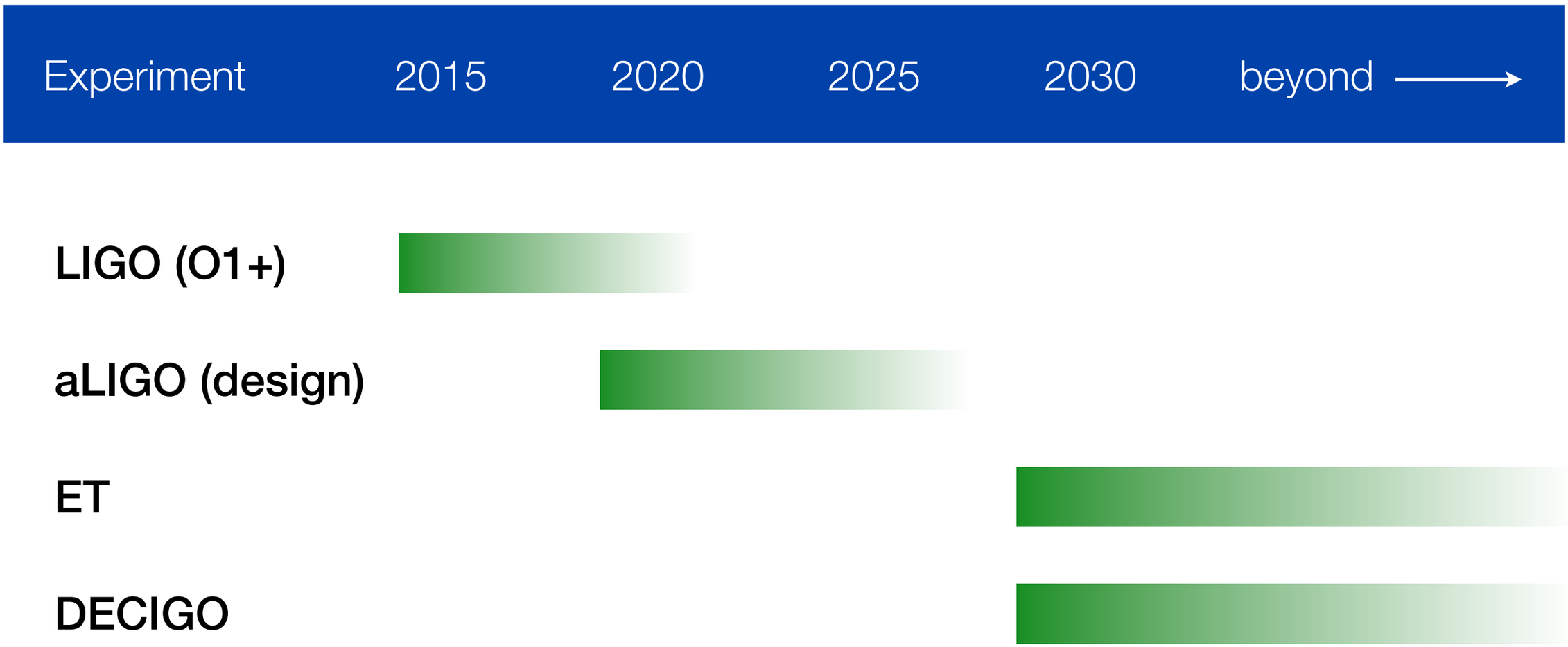


# Observational Outlook: Experiment Timeline



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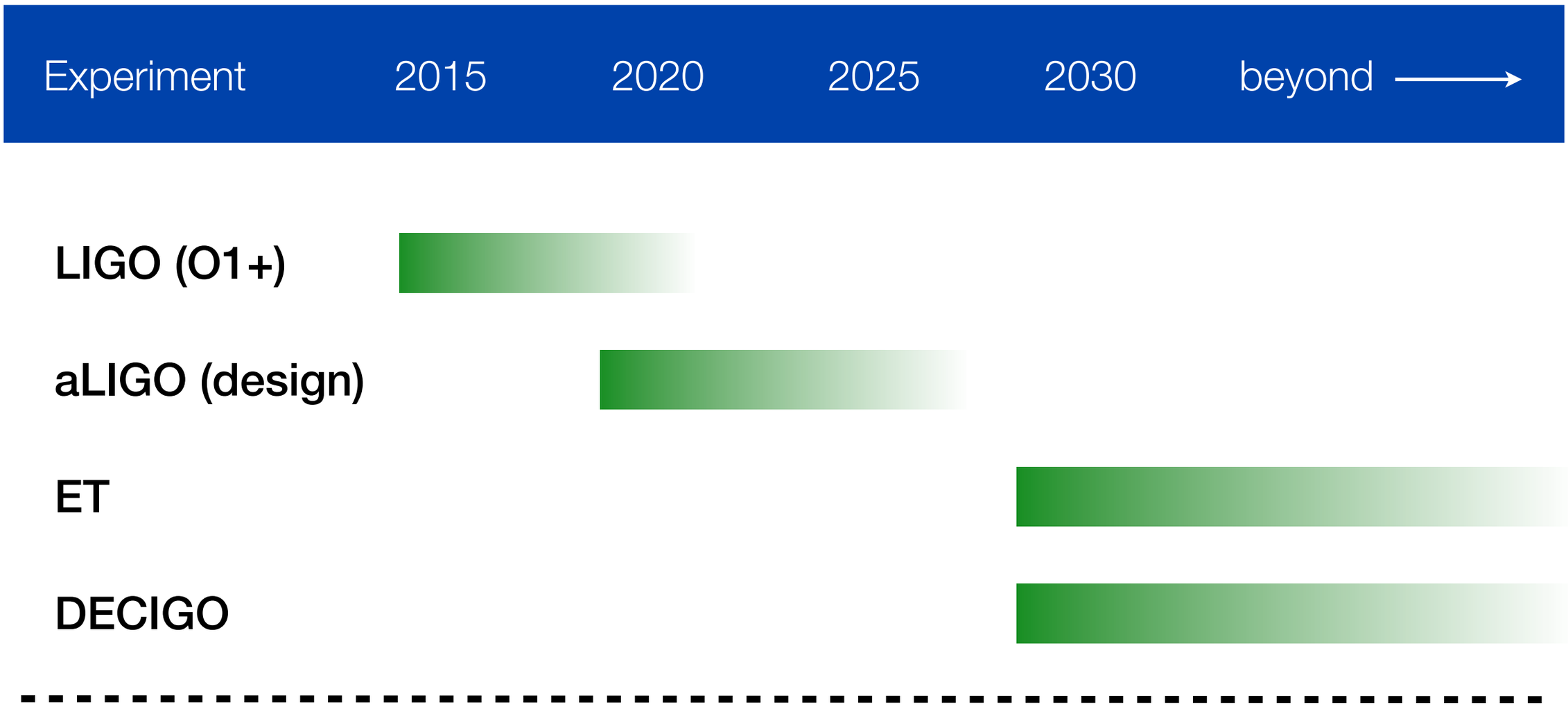
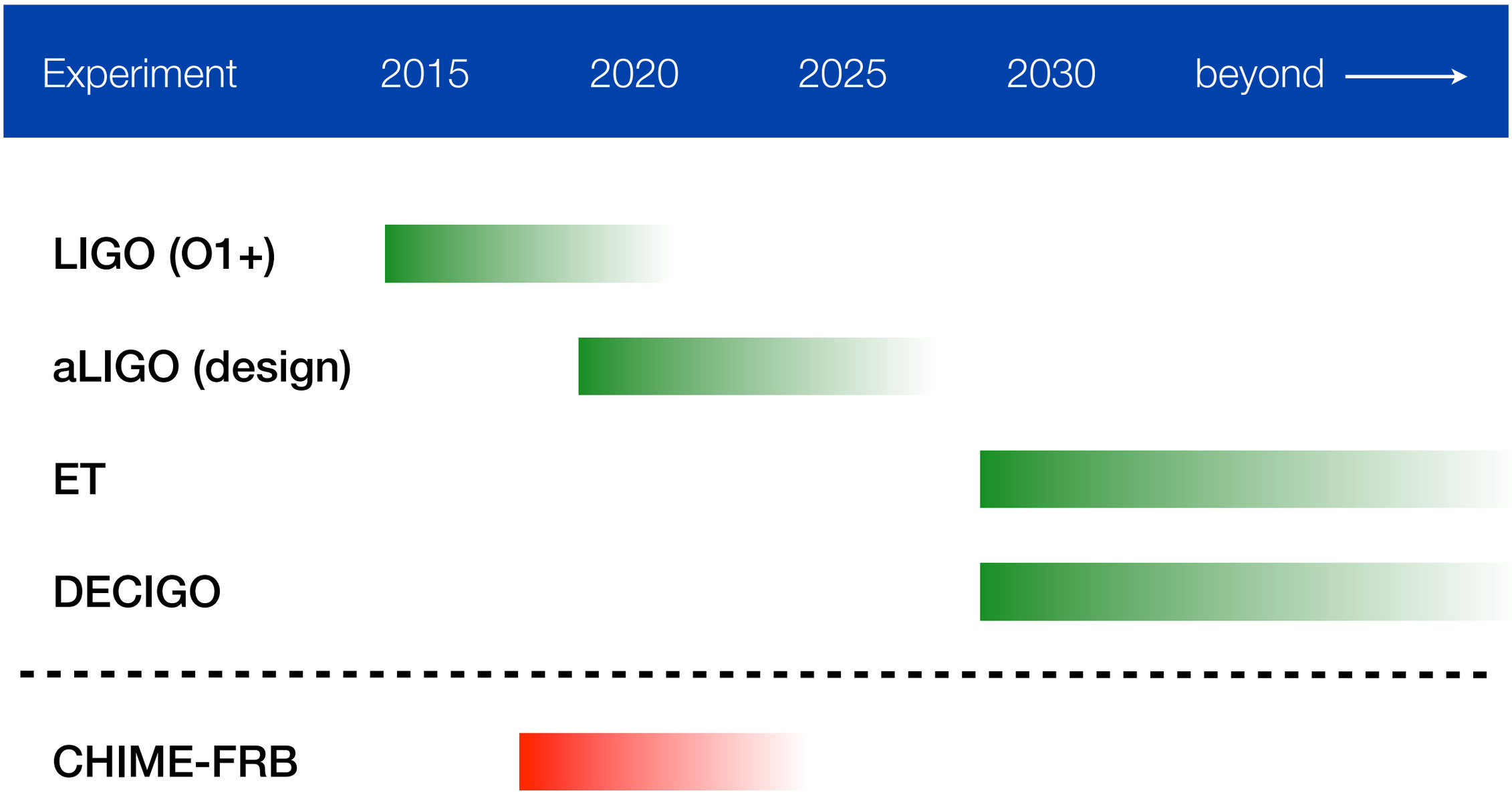


# Observational Outlook: Experiment Timeline



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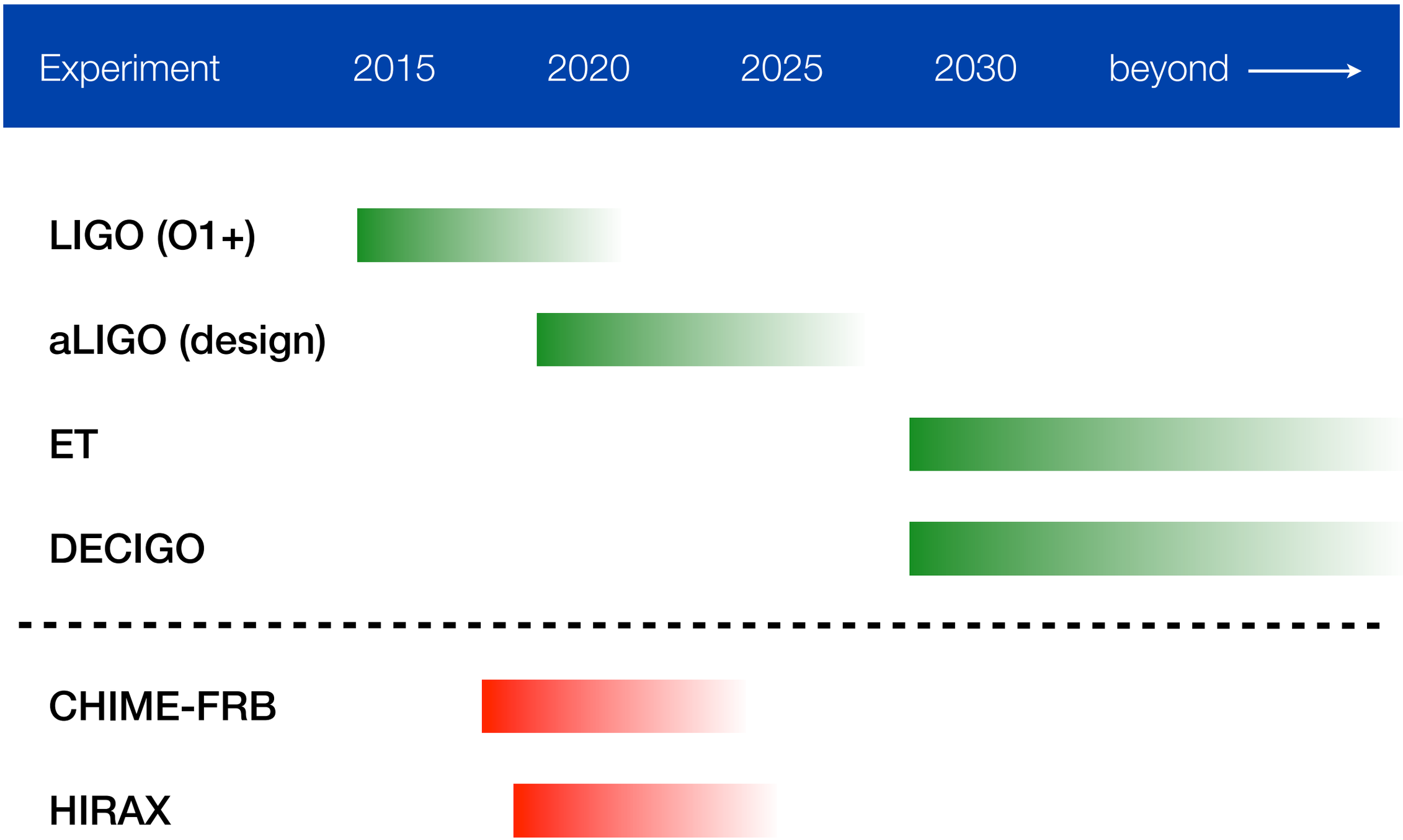

# Conclusion:

# Conclusion: We Can Test if PBHs are Dark Matter

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Theory

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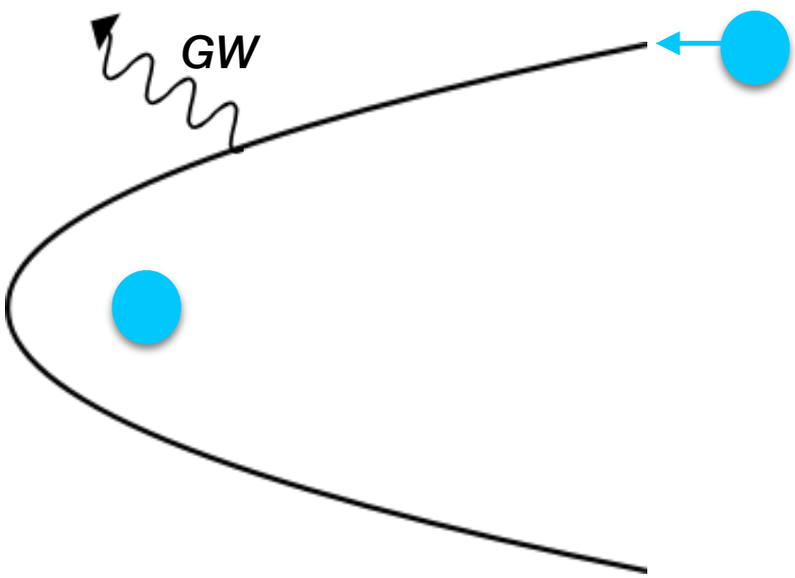

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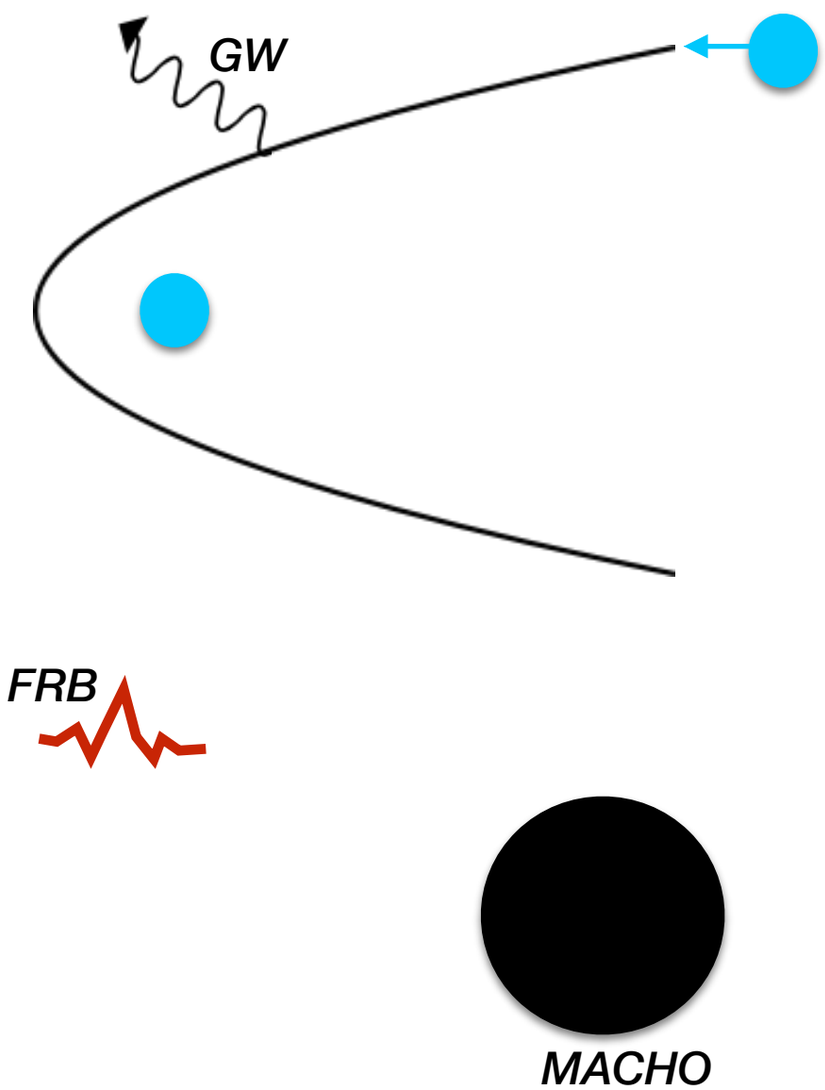

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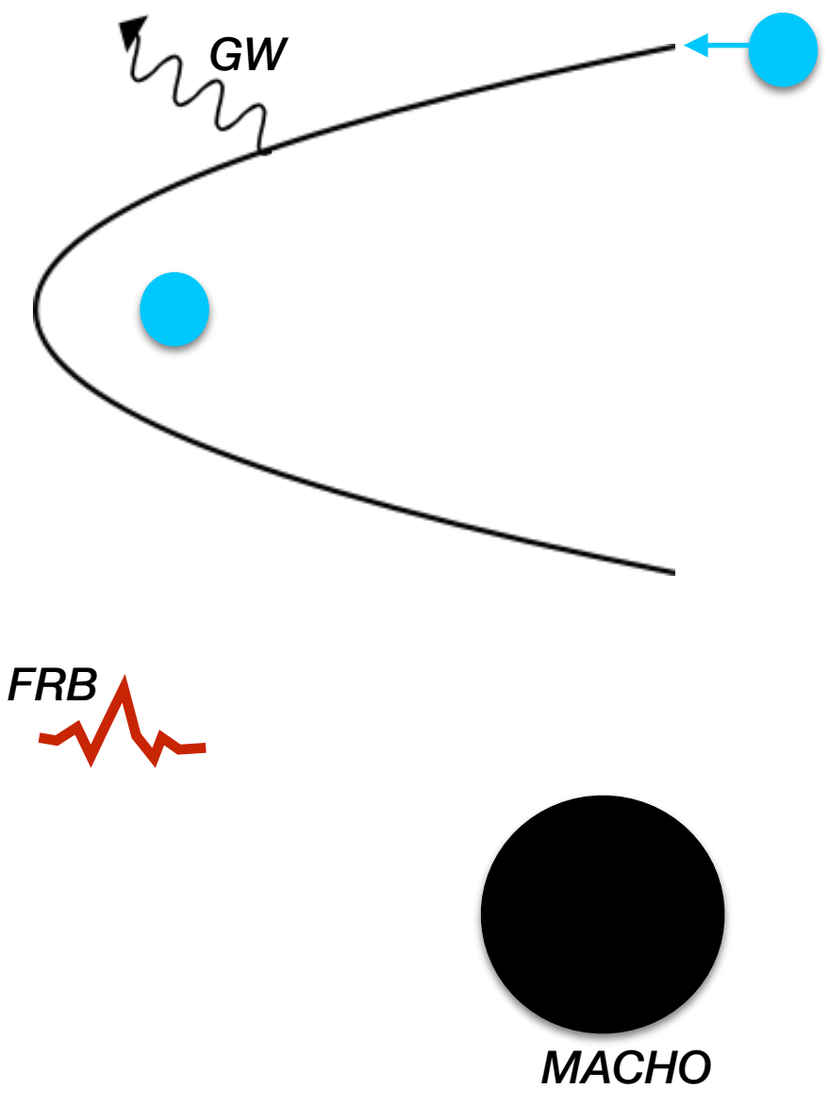


## Experiment

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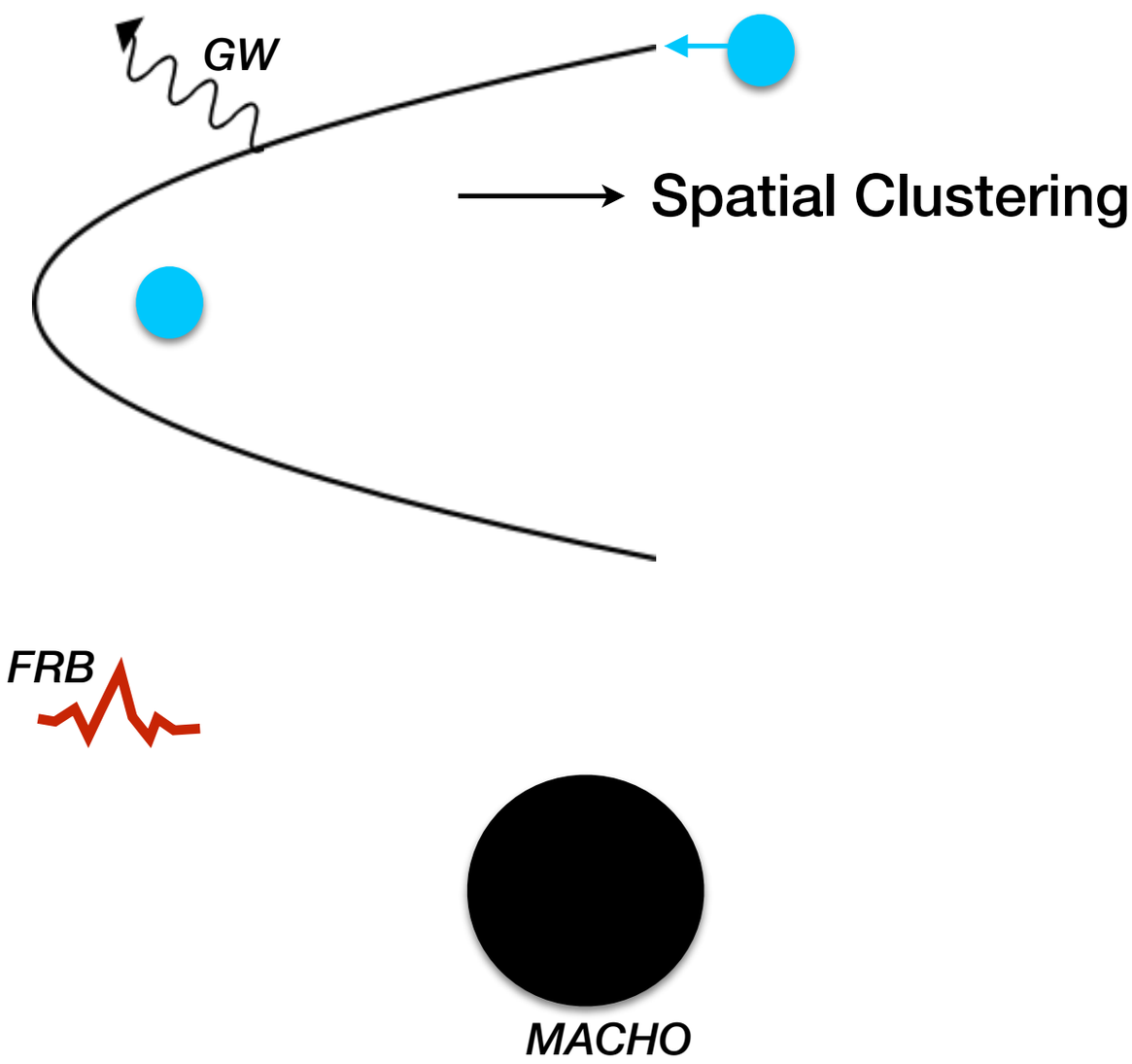
## Theory

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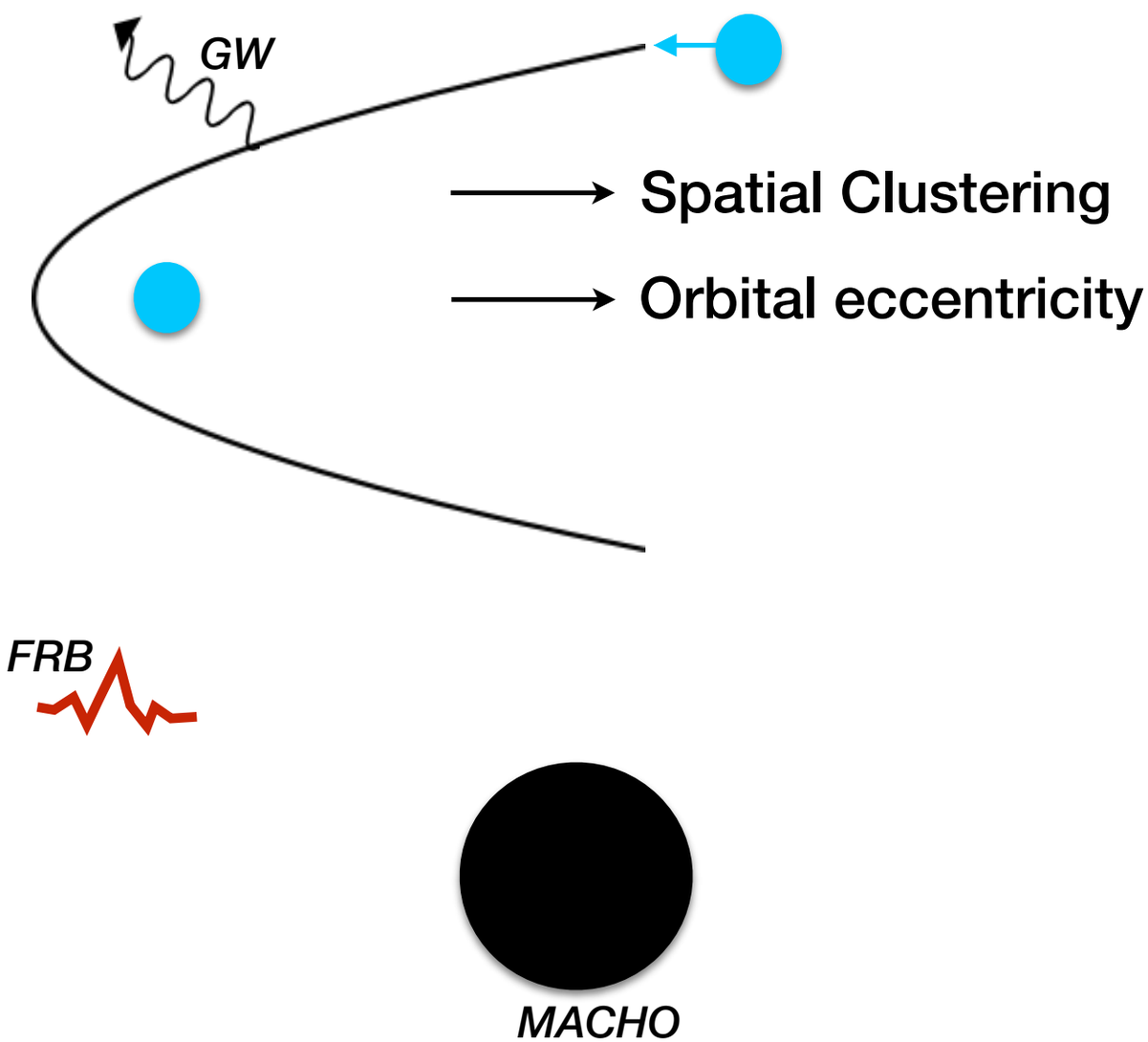


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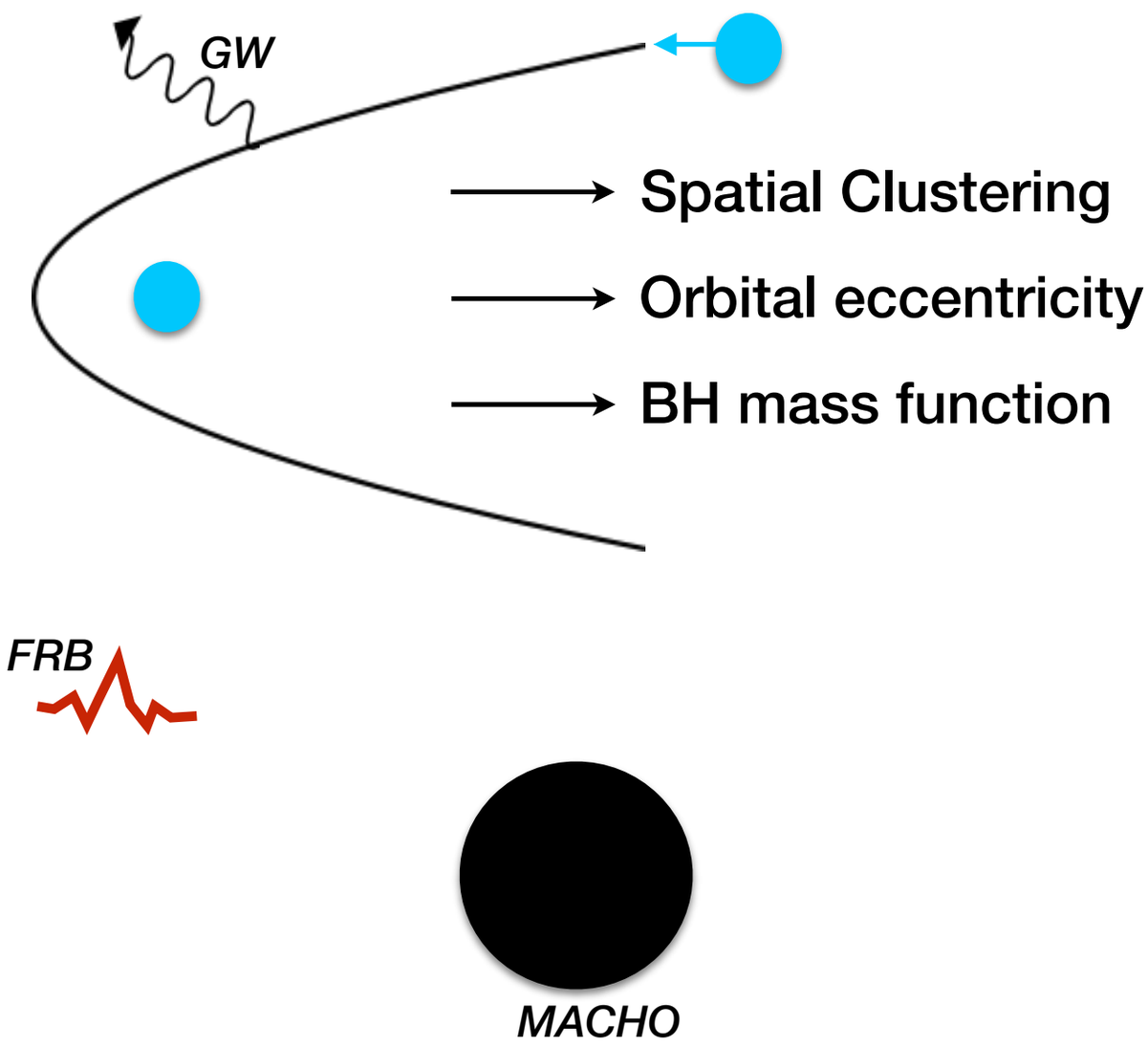


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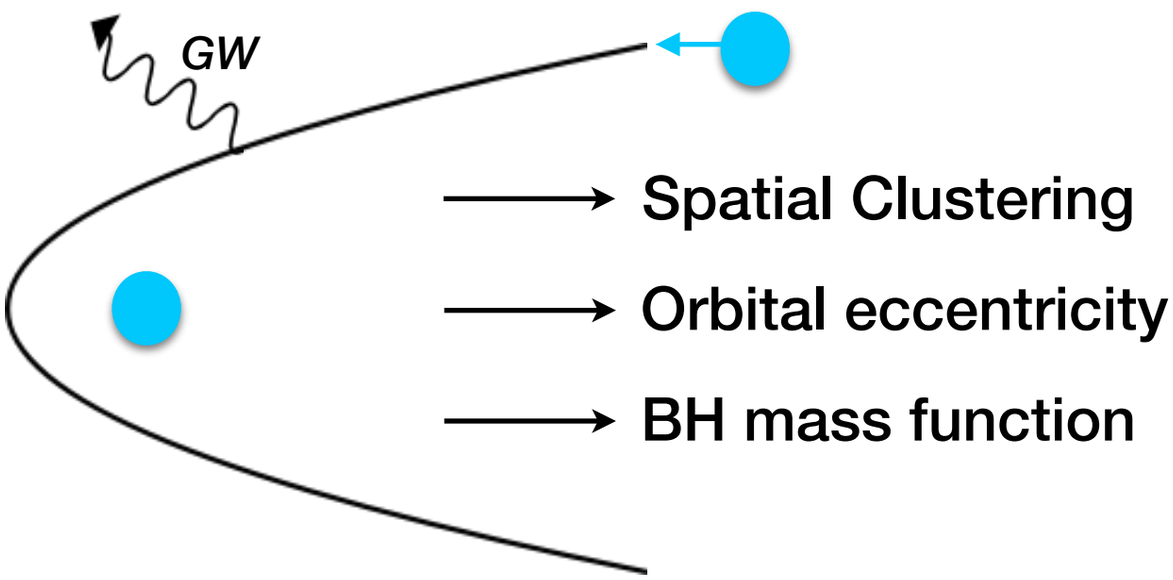


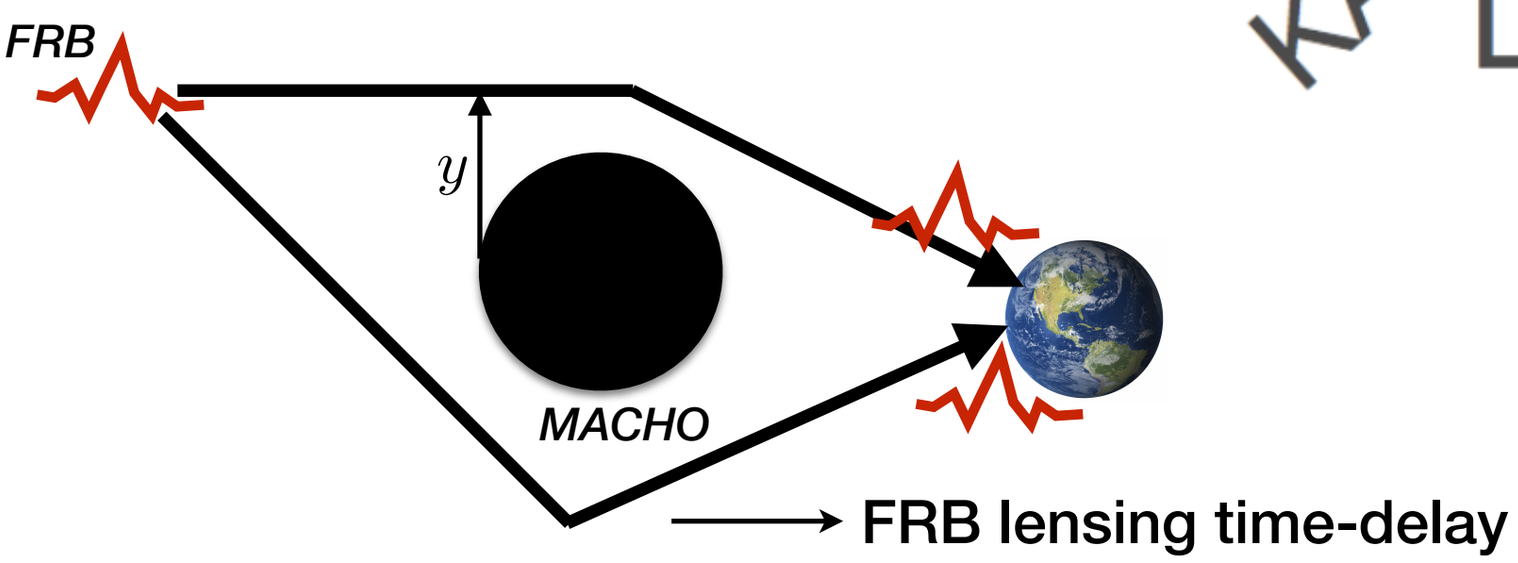


## Experiment

# Thank you!

**Ely D. Kovetz**
Johns Hopkins University

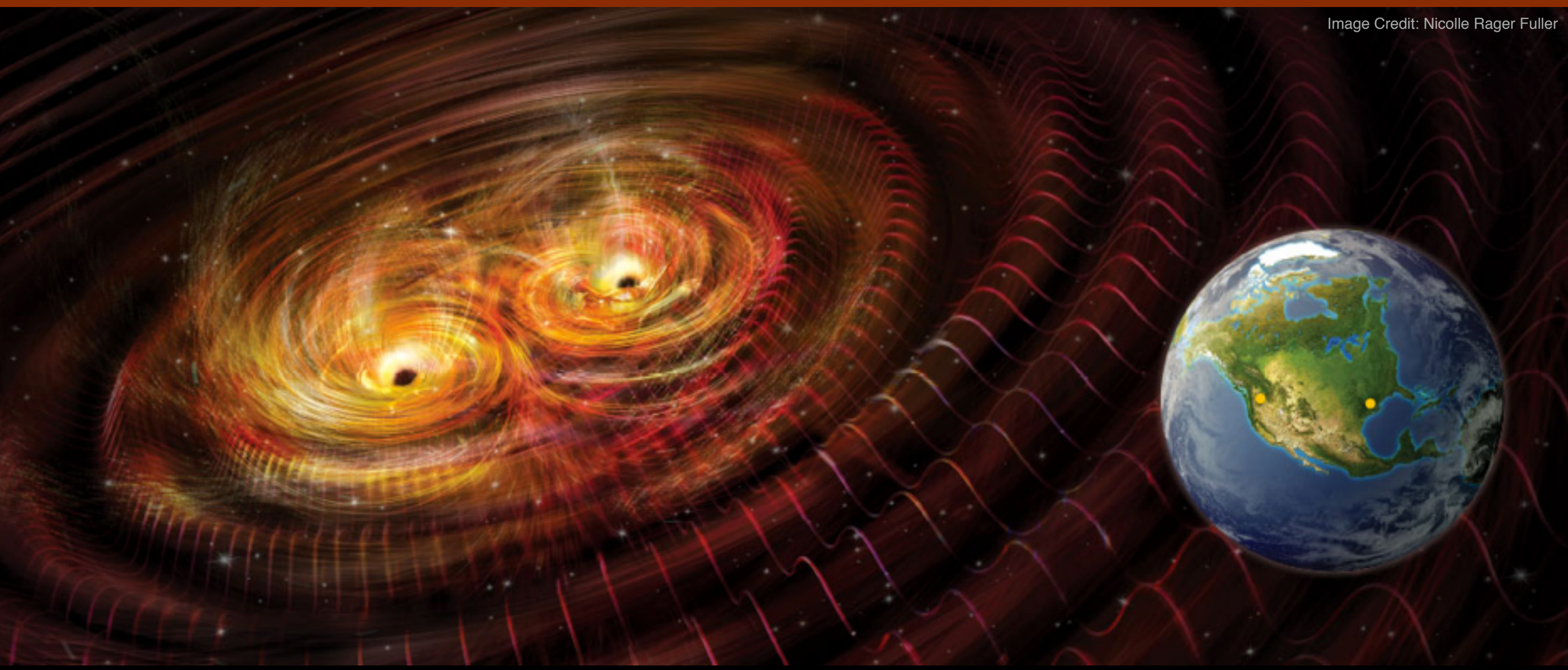

Image Credit: Nicolle Rager Fuller

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**Ely D. Kovetz**
Johns Hopkins University

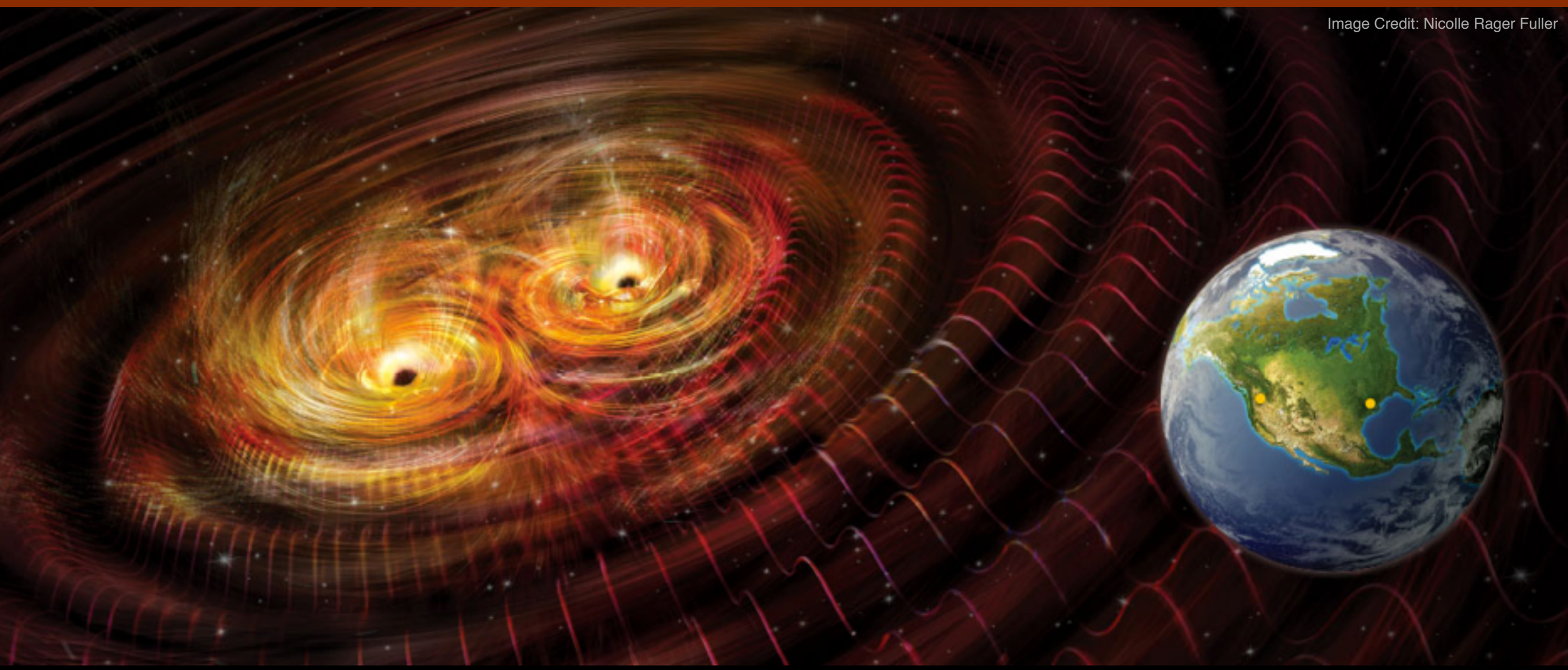

Image Credit: Nicolle Rager Fuller