Black Holes & Dark Matter

Alvise Raccanelli

MARIE CURIE ACTIONS
European Commission
H2020

Did LIGO detect Dark Matter?

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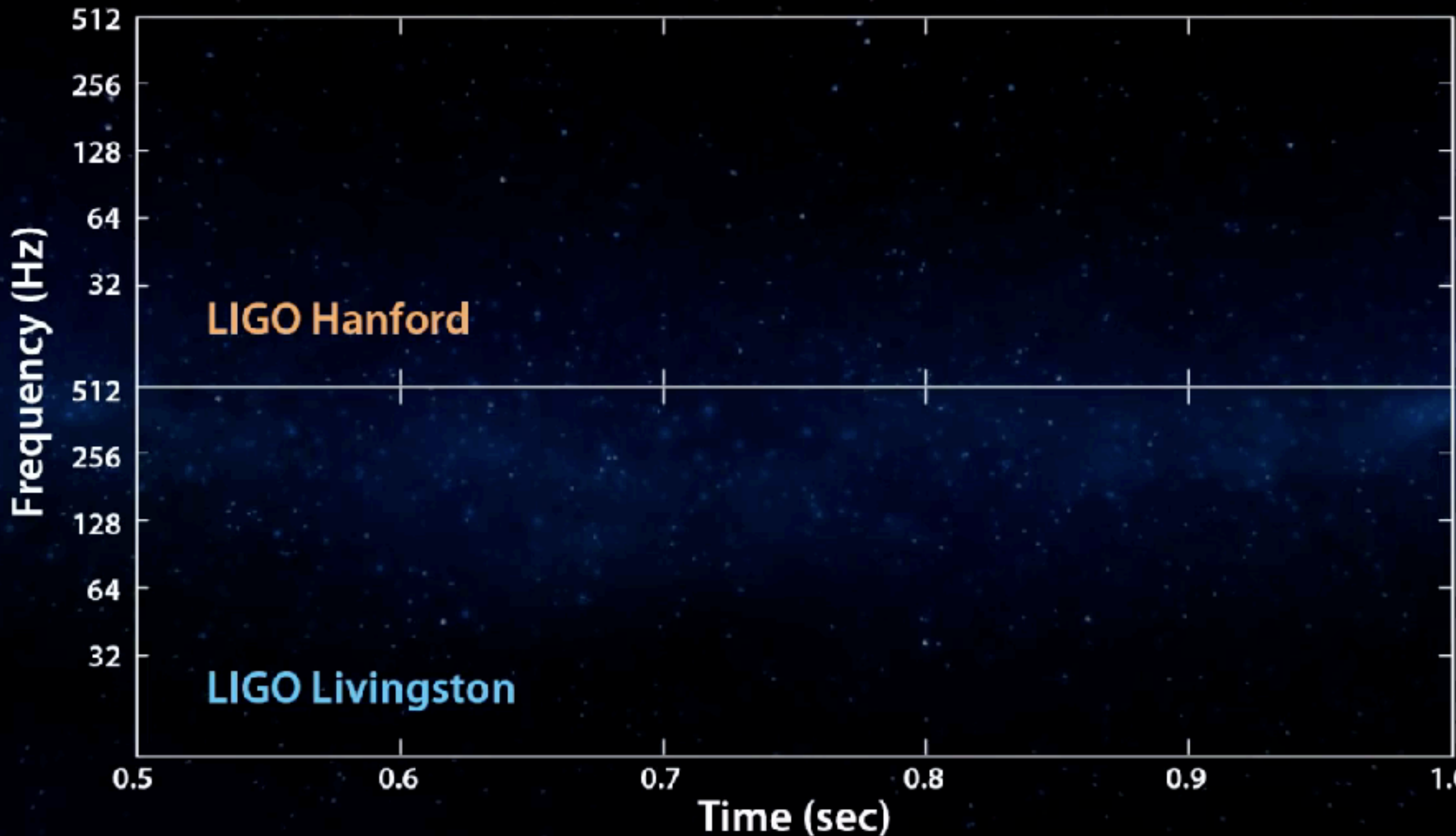
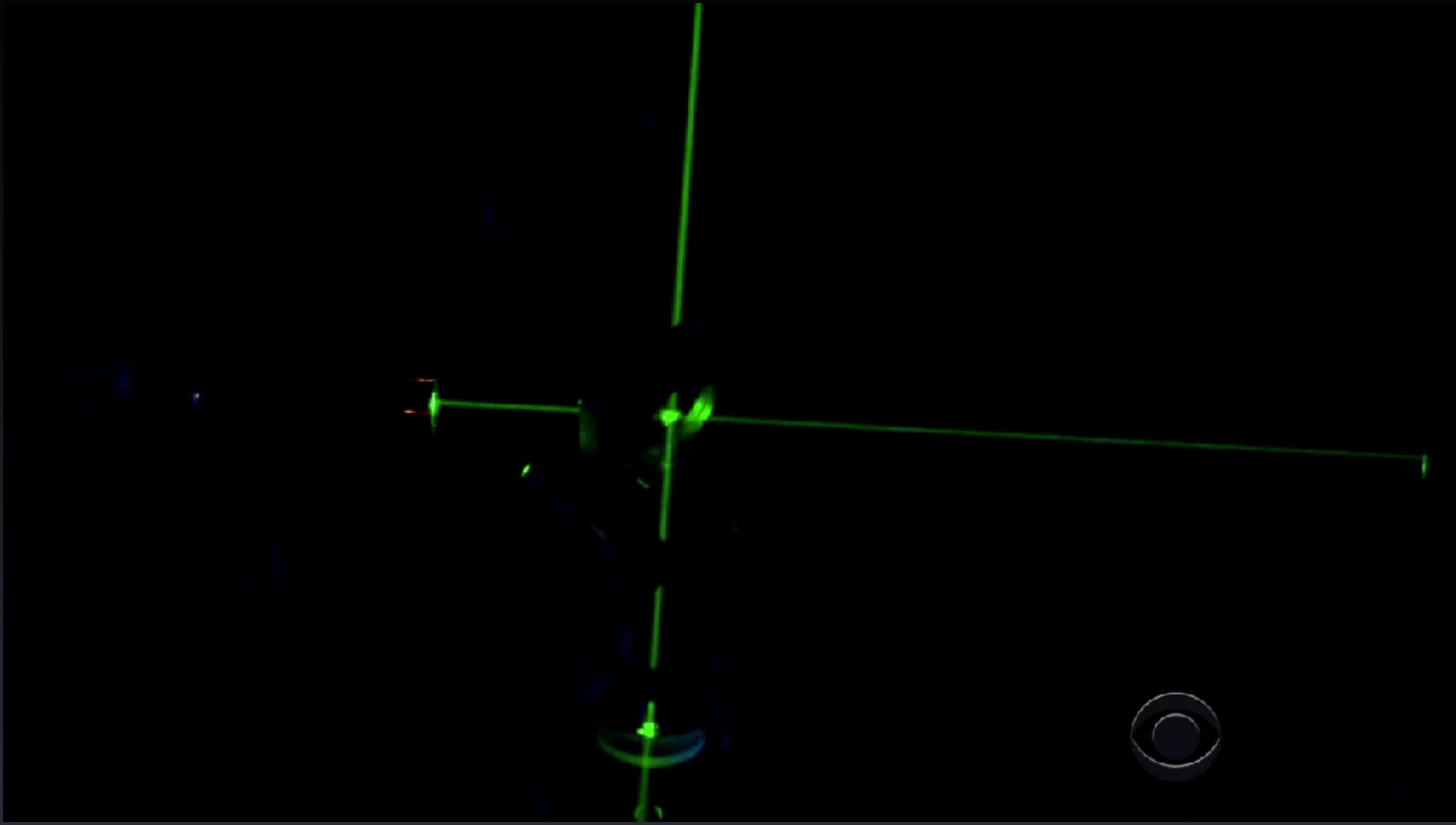
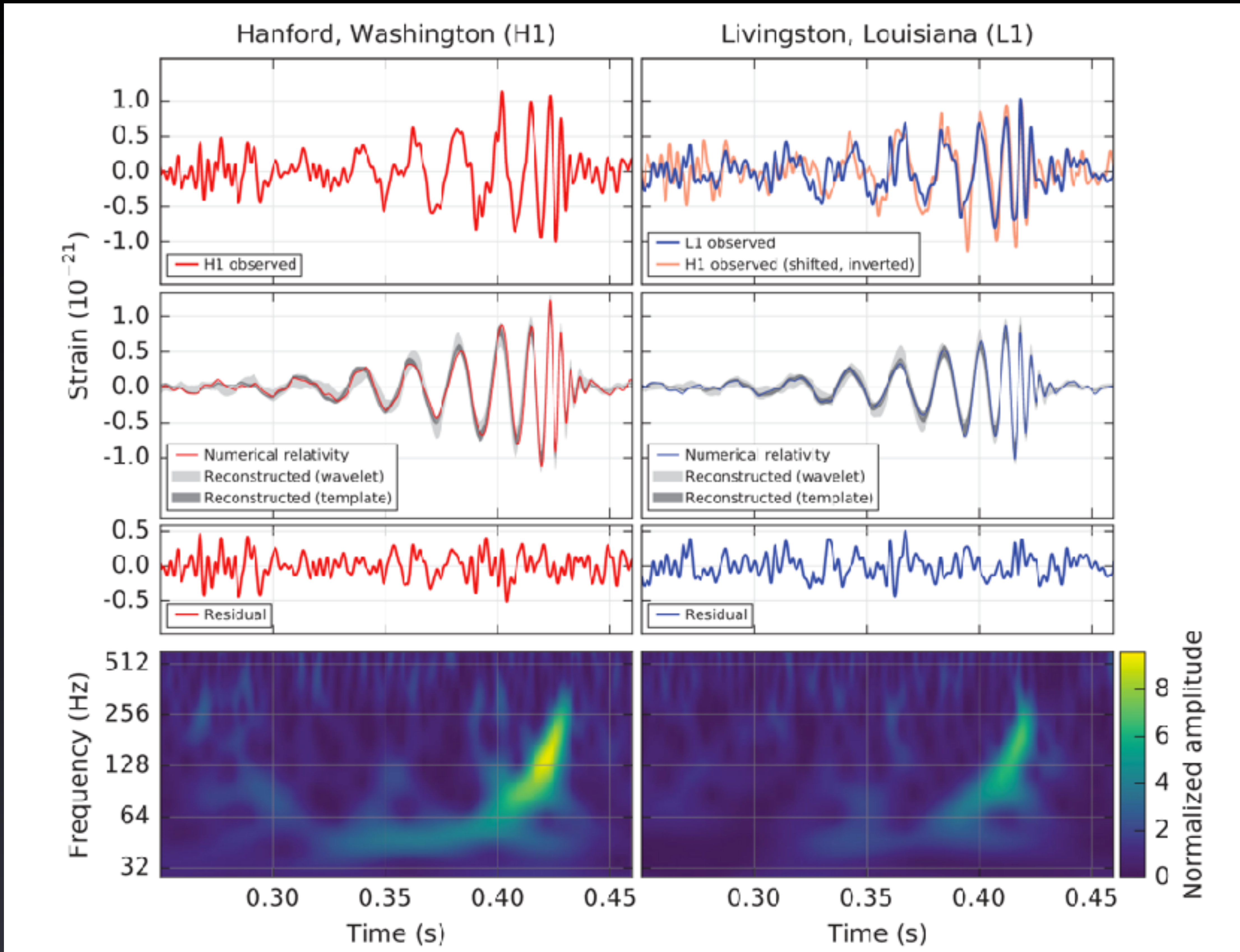


Frequency (Hz)
512
256
128
64
32
LIGO Hanford
512
256
128
64
32
LIGO Livingston
0.5
0.6
0.7
0.8
0.9
1.0
Time (sec)





Hanford, Washington (H1)
Livingston, Louisiana (L1)
Strain (10^{-21})
H1 observed
L1 observed
H1 observed (shifted, inverted)
Numerical relativity
Reconstructed (wavelet)
Reconstructed (template)
Residual
Frequency (Hz)
Normalized amplitude
Time (s)

Binary BHs

$\sim 30\text{-}30 M_\odot$

?

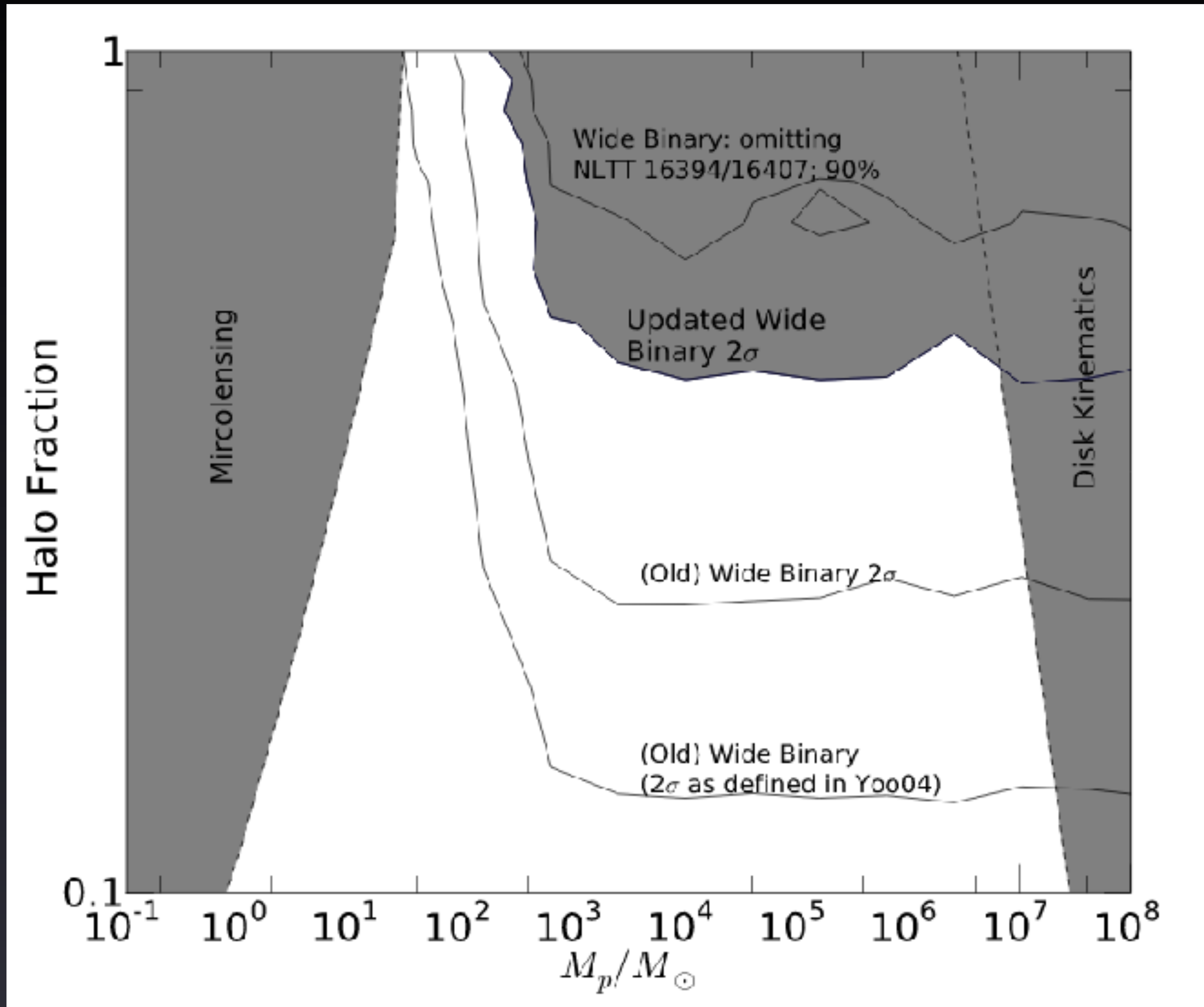
Dark Matter

Cold Dark Matter

Self-Interacting?

Dark Matter

Primordial Black Holes ?



Quinn et al. 2009

Did LIGO detect DM?

Did LIGO detect dark matter?

Simeon Bird,* Ilias Cholis, Julian B. Muñoz, Yacine Ali-Haïmoud, Marc Kamionkowski, Ely D. Kovetz, Alvise Raccanelli, and Adam G. Riess[1]

[1] *Department of Physics and Astronomy, Johns Hopkins University, 3400 N. Charles St., Baltimore, MD 21218, USA*

We consider the possibility that the black-hole (BH) binary detected by LIGO may be a signature of dark matter. Interestingly enough, there remains a window for masses $10\,M_\odot \lesssim M_{\rm bh} \lesssim 100\,M_\odot$ where primordial black holes (PBHs) may constitute the dark matter, if constraints from CMB spectral distortions can be avoided. If two BHs in a galactic halo pass sufficiently close, they radiate enough energy in gravitational waves to become gravitationally bound. The bound BHs will rapidly spiral inward due to emission of gravitational radiation and ultimately merge. Uncertainties in the rate for such events arise from our imprecise knowledge of the phase-space structure of galactic halos on the smallest scales. Still, reasonable estimates span a range that overlaps the $2-53$ Gpc^{-3} yr^{-1} rate estimated from GW150914, thus raising the possibility that LIGO has detected PBH dark matter. PBH mergers are likely to be distributed spatially more like dark matter than luminous matter and have no optical nor neutrino counterparts. They may be distinguished from mergers of BHs from more traditional astrophysical sources through the observed mass spectrum, their high ellipticities, or their stochastic gravitational wave background. Next generation experiments will be invaluable in performing these tests.

Physical Review Letters, 116, 20

Constraints

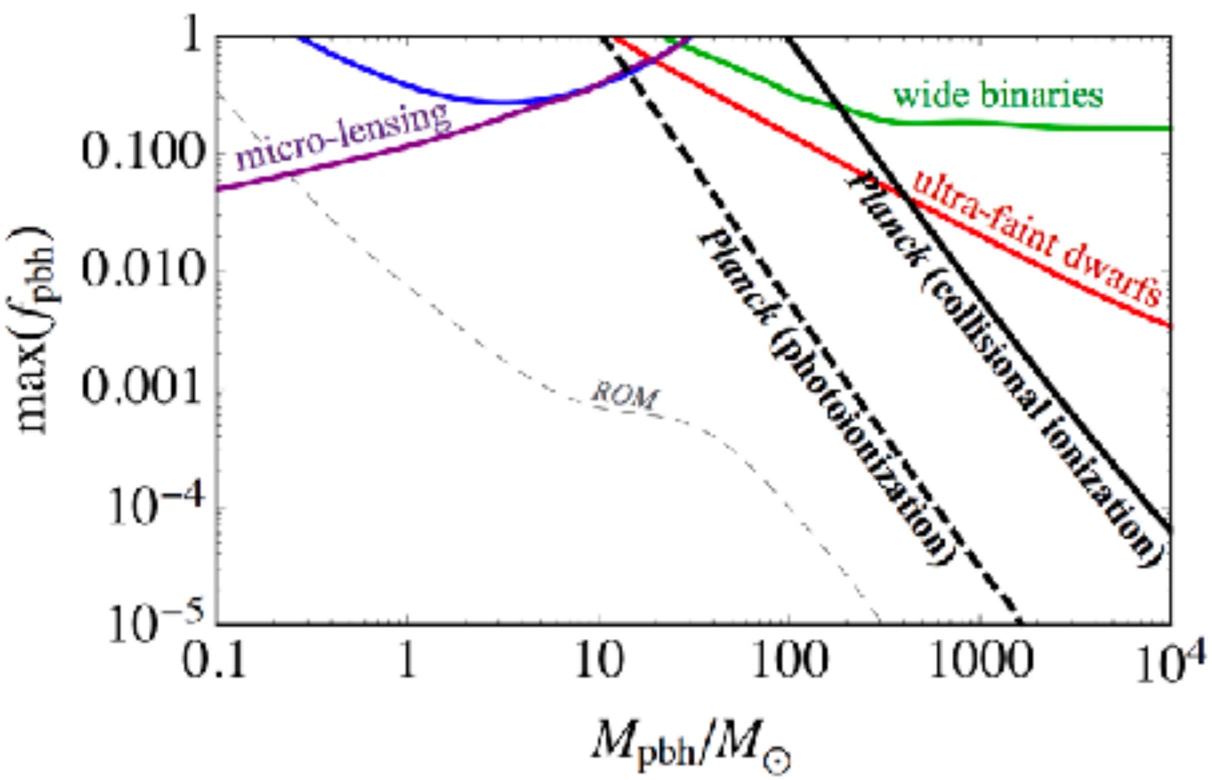
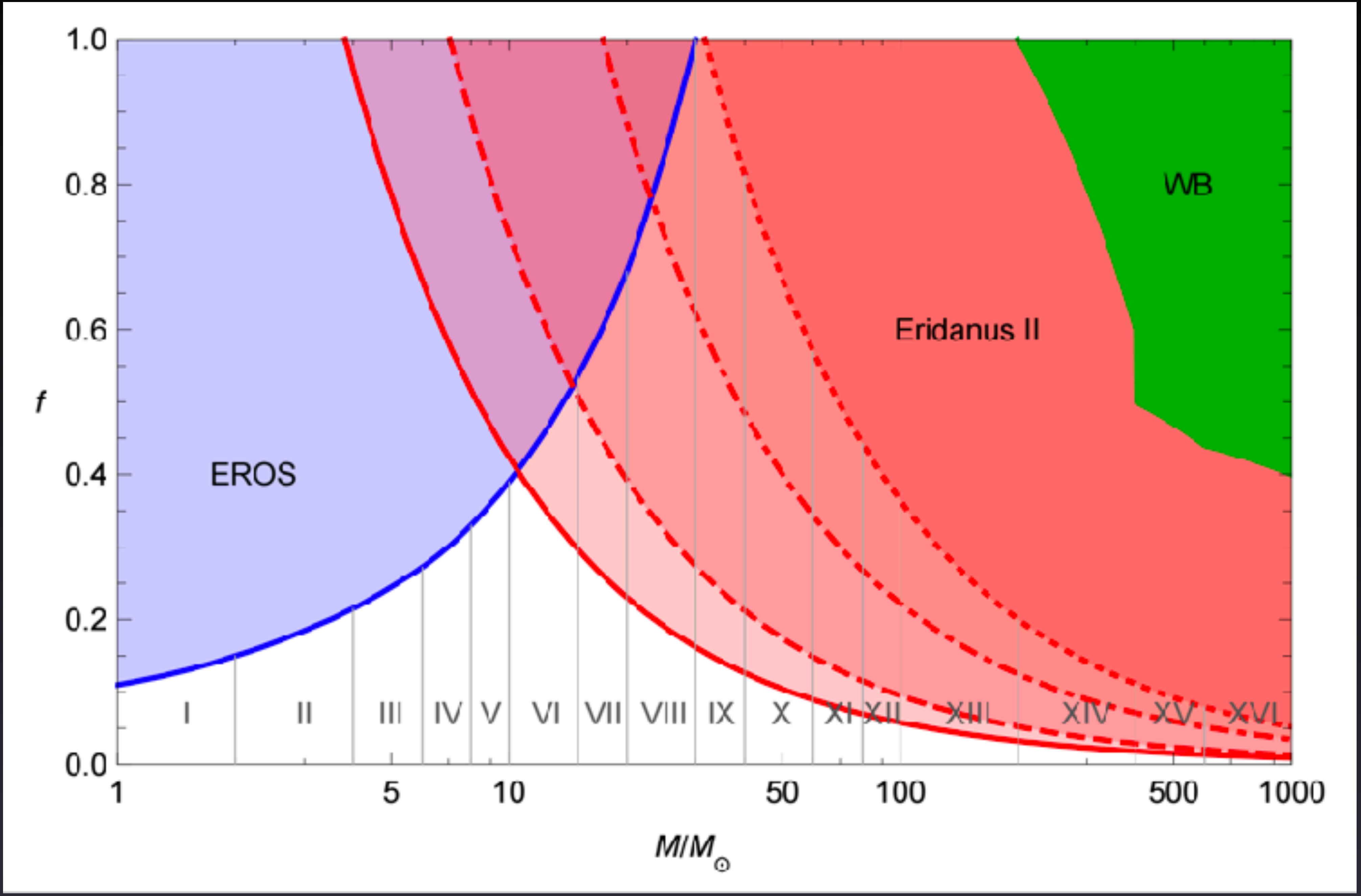


FIG. 14. Approximate CMB-anisotropy constraints on the fraction of dark matter made of PBHs derived in this work (*thick black curves*). The "collisional ionization" case assumes that the radiation from the PBH does not ionize the local gas, which eventually gets collisionally ionized. The "photoionization" case assumes that the local gas is ionized due to the PBH radiation, up to a radius larger than the collisional ionization region, yet smaller than the Bondi radius. The former case is the most conservative, as collisional ionization leads to a smaller temperature near the black hole horizon, hence a smaller luminosity, and weaker bounds. The correct result lies somewhere between these two limiting cases. For comparison, we also show the CMB bound previously derived by ROM (*thin dashed curve*), as well as various dynamical constraints: micro-lensing constraints from the EROS [15] (*purple curve*) and MACHO [14] (*blue curve*) collaborations (but see Ref. [53] for caveats), limits from Galactic wide binaries [17], and ultra-faint dwarf galaxies [54] (in all cases we show the most conservative limits provided in the referenced papers).

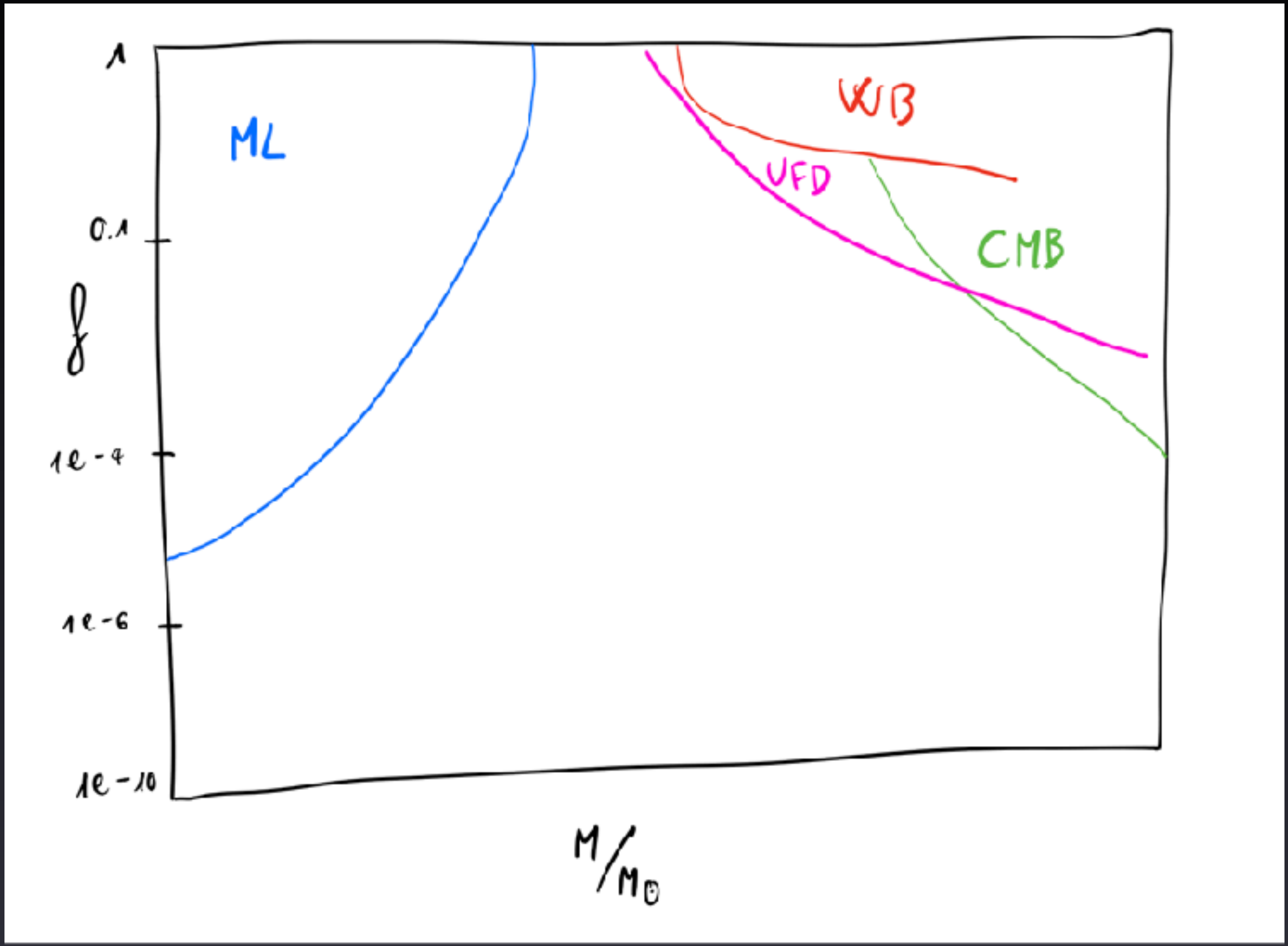
Ali-Haimoud & Kamionkowski 2017

Constraints



Carr et al. 2016

Constraints



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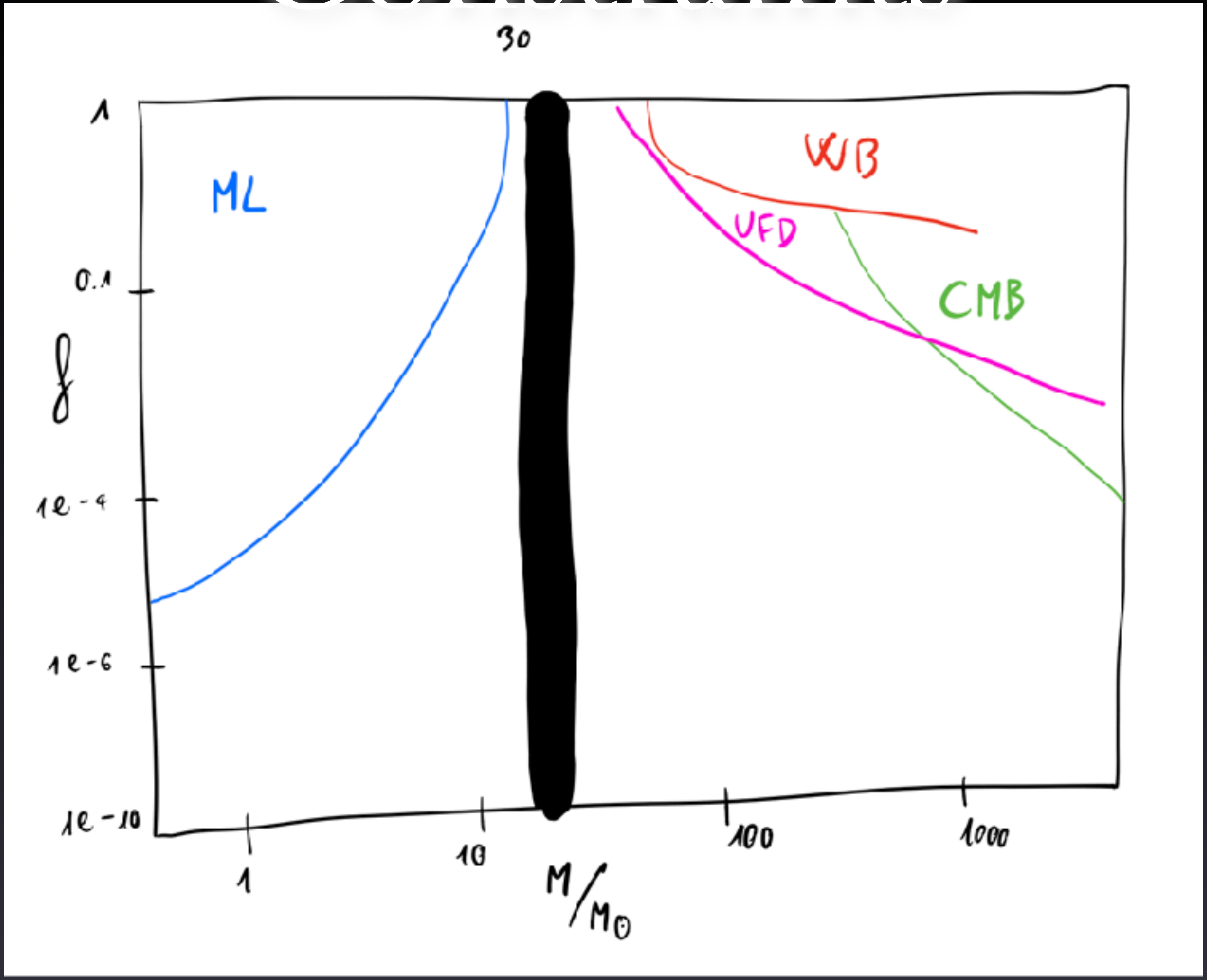

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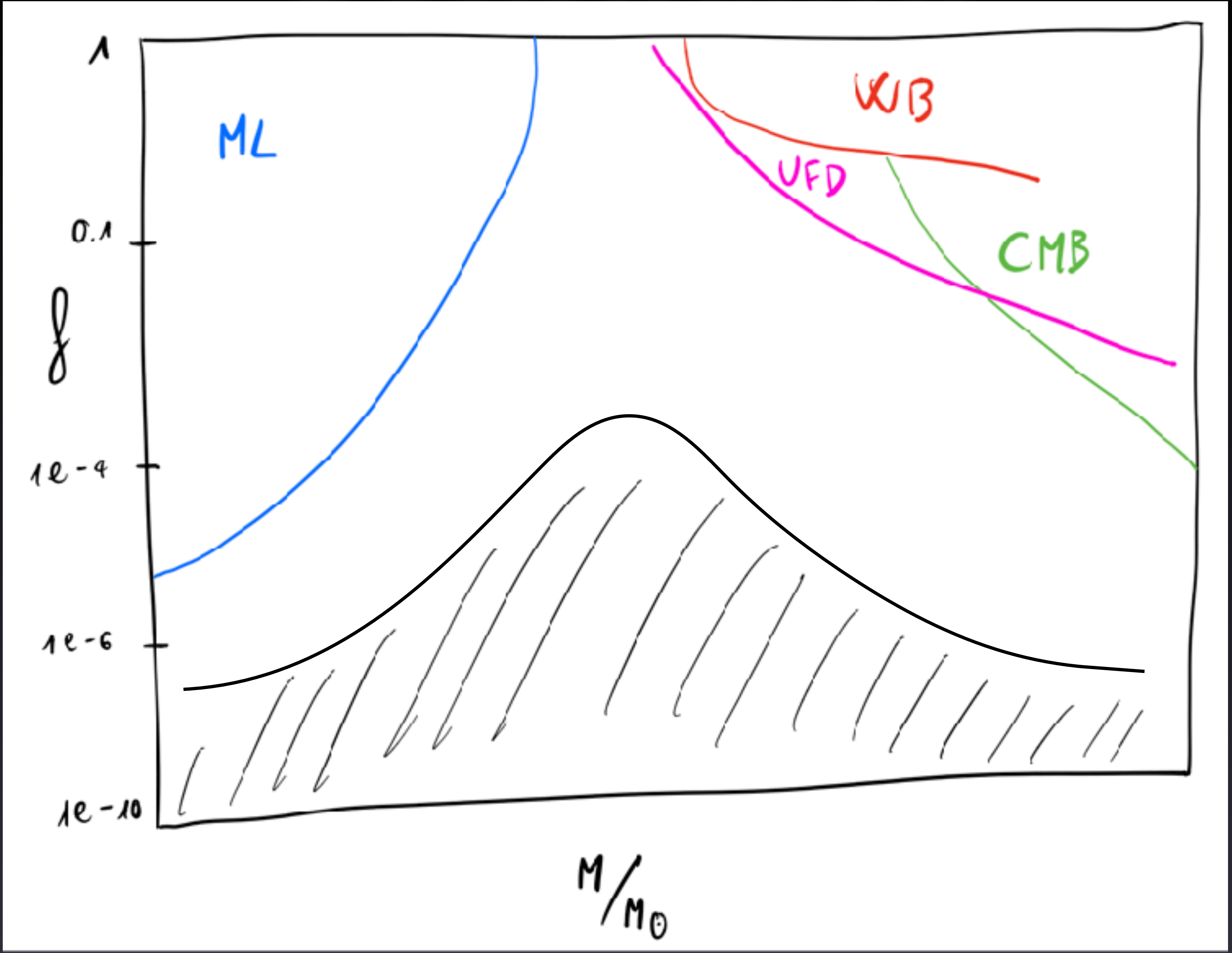

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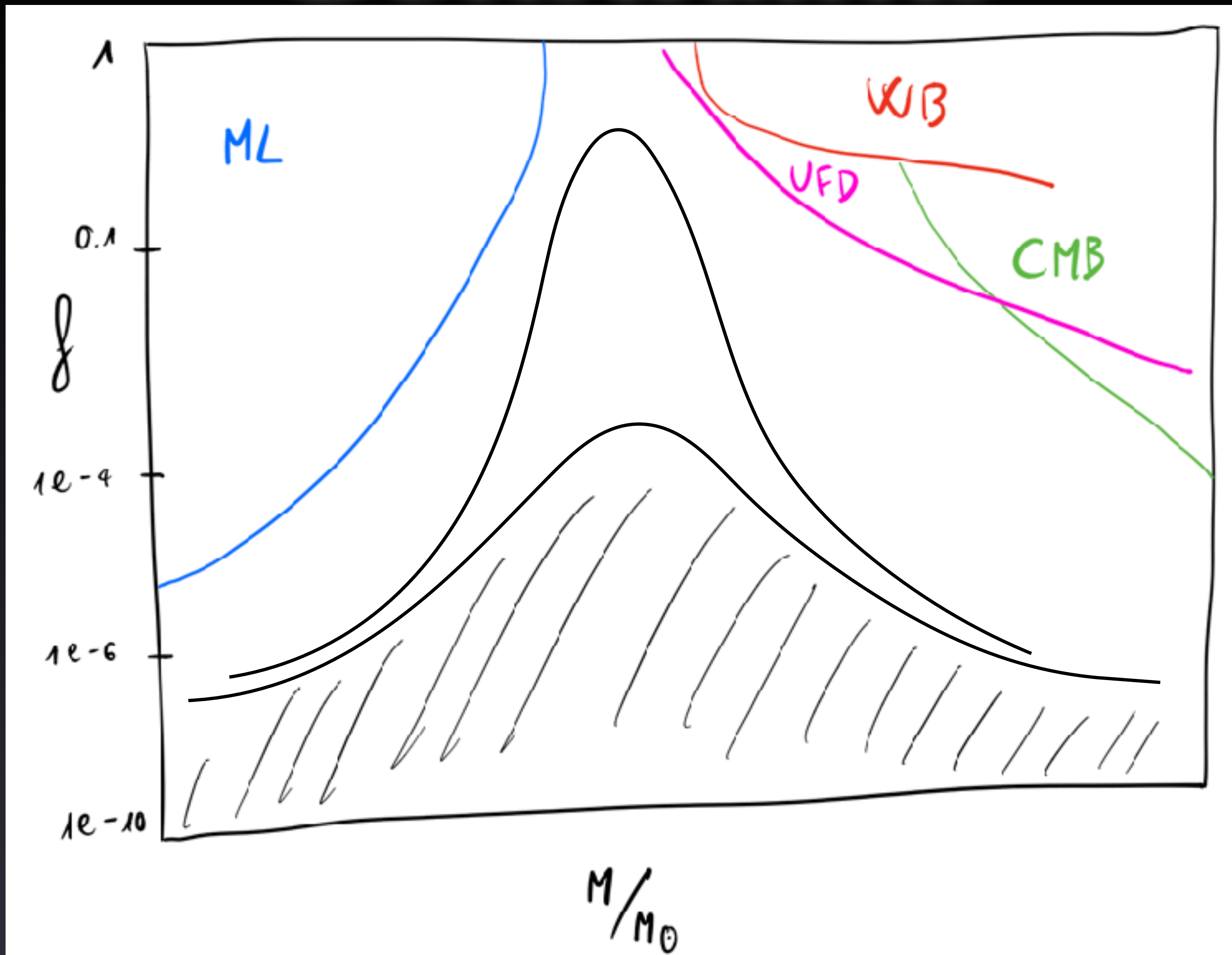

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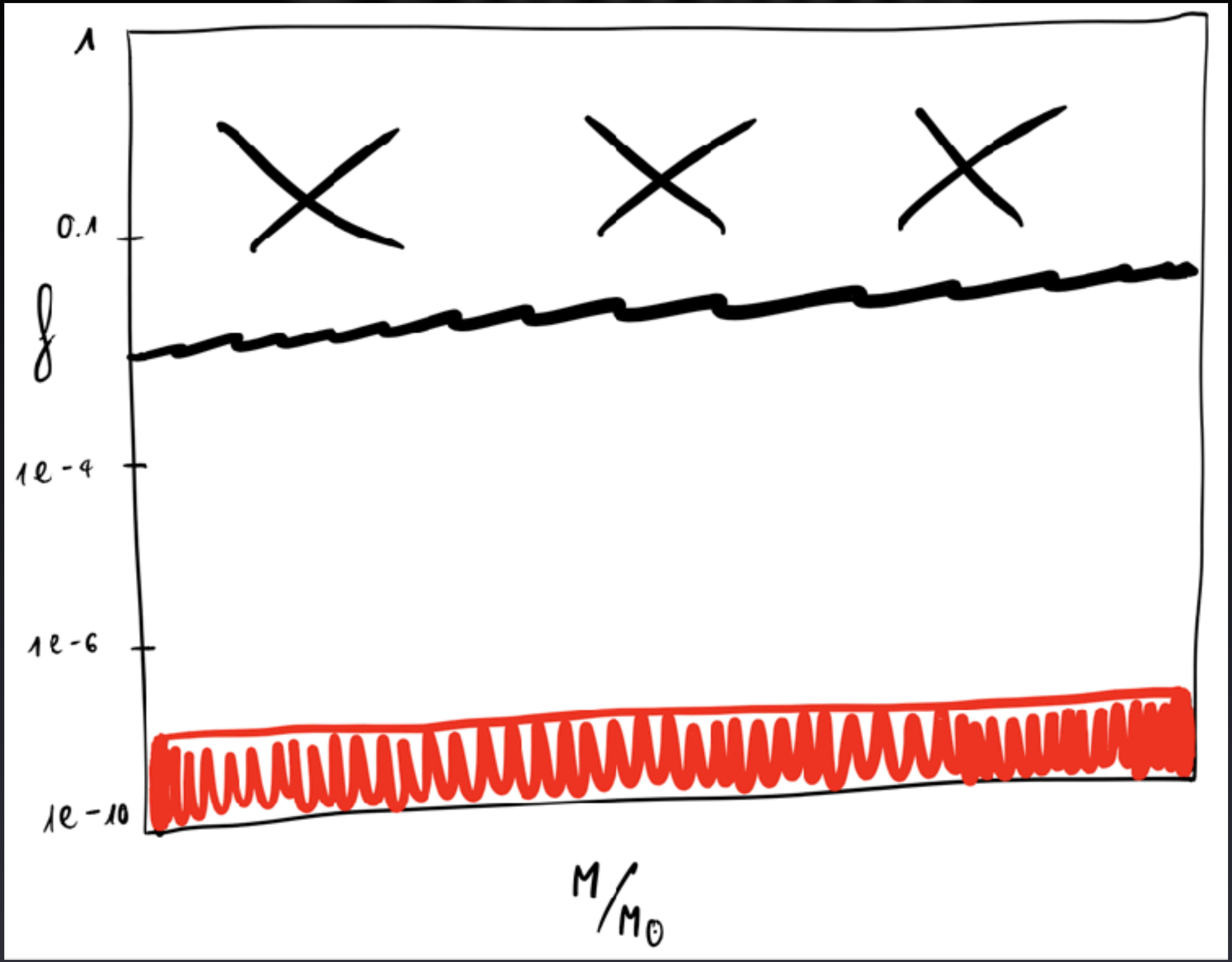
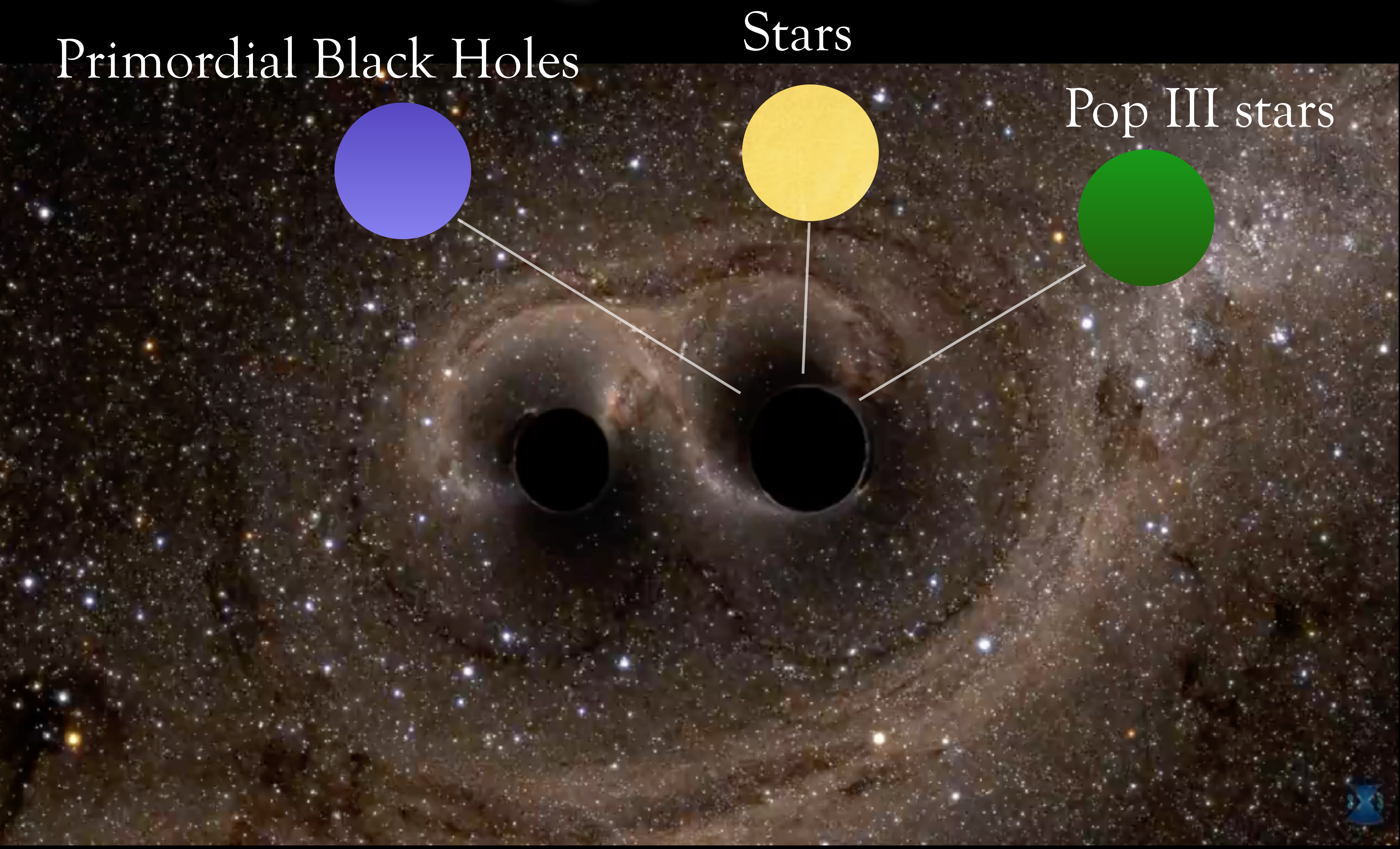
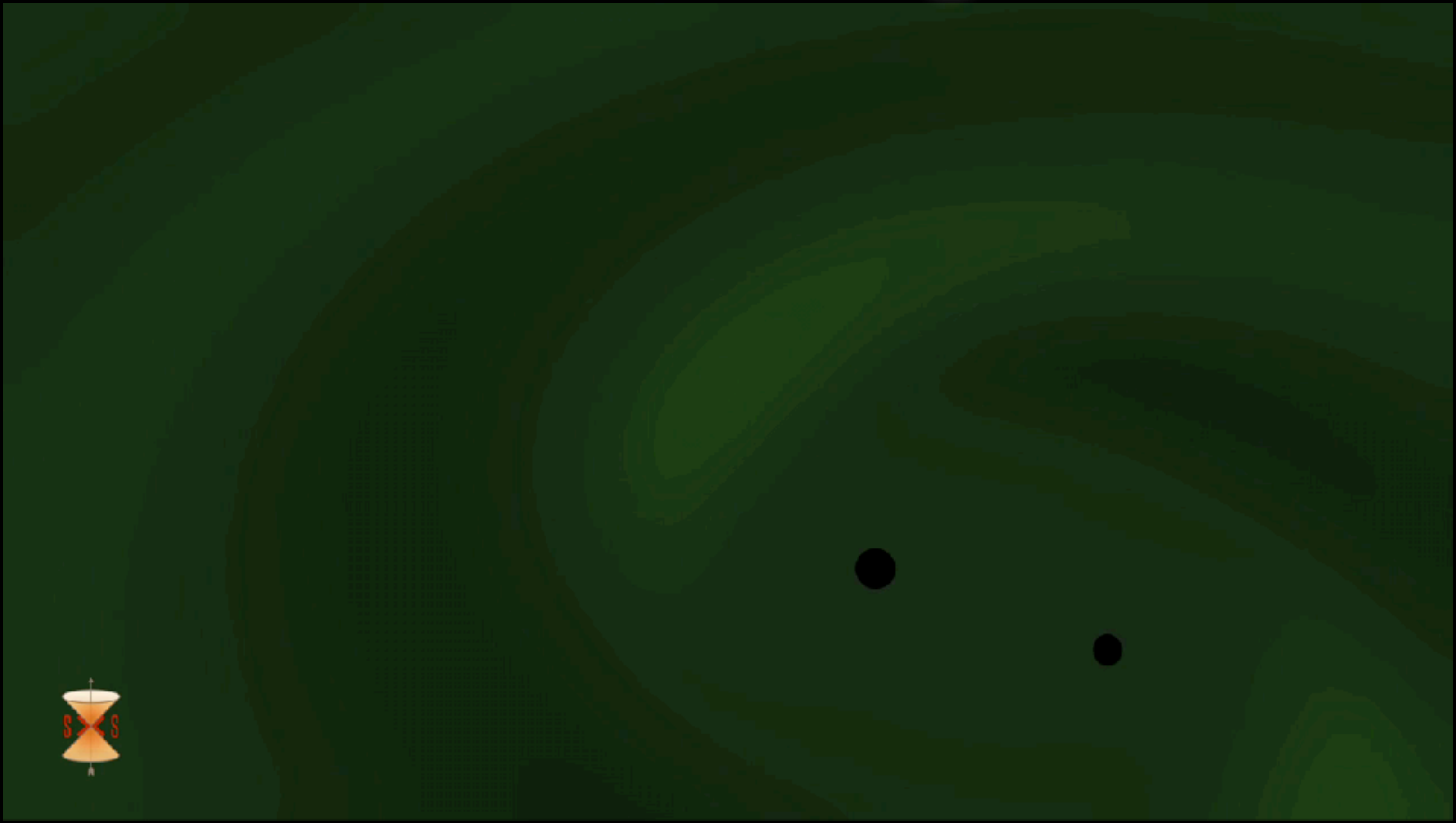


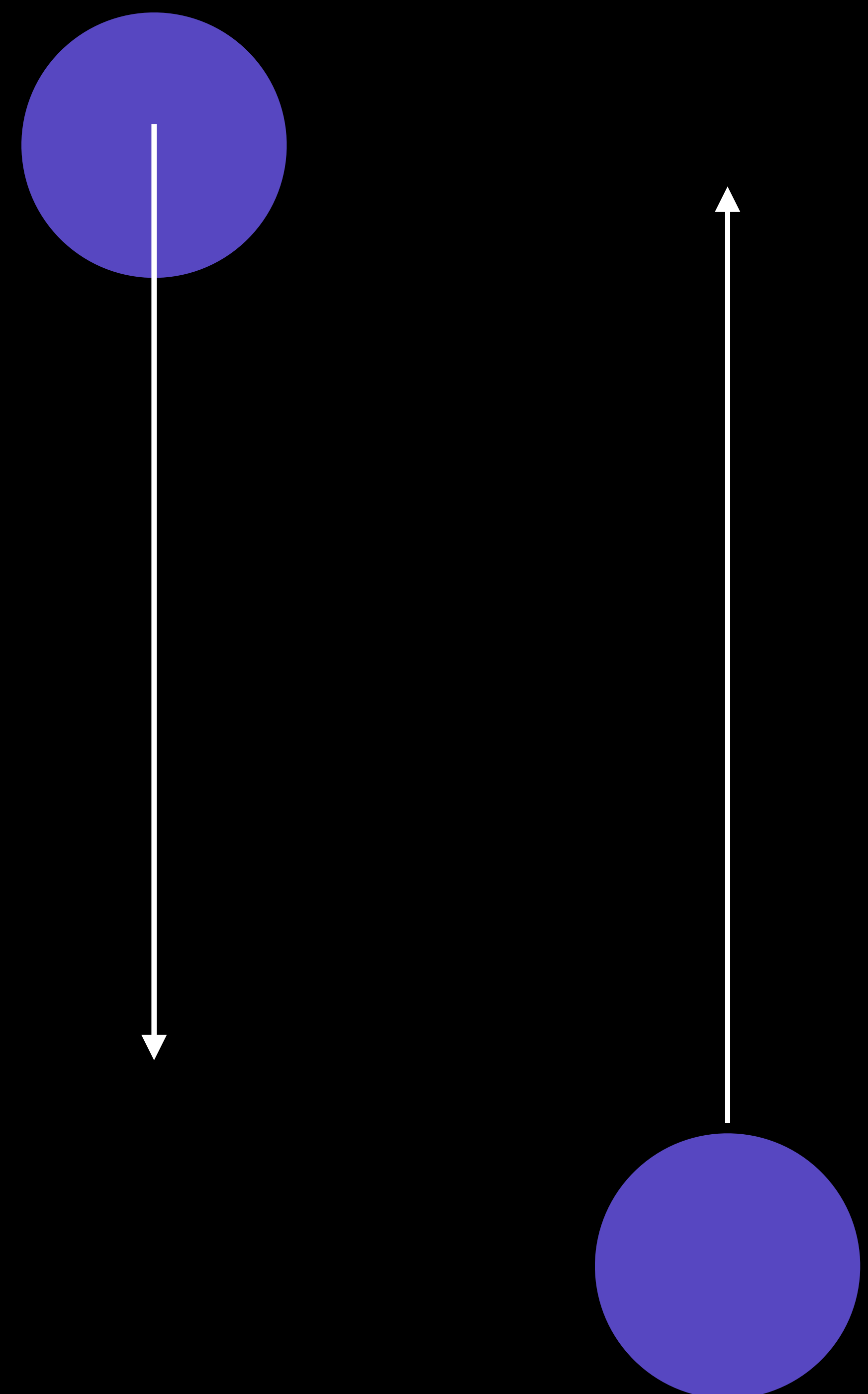
Progenitors ?



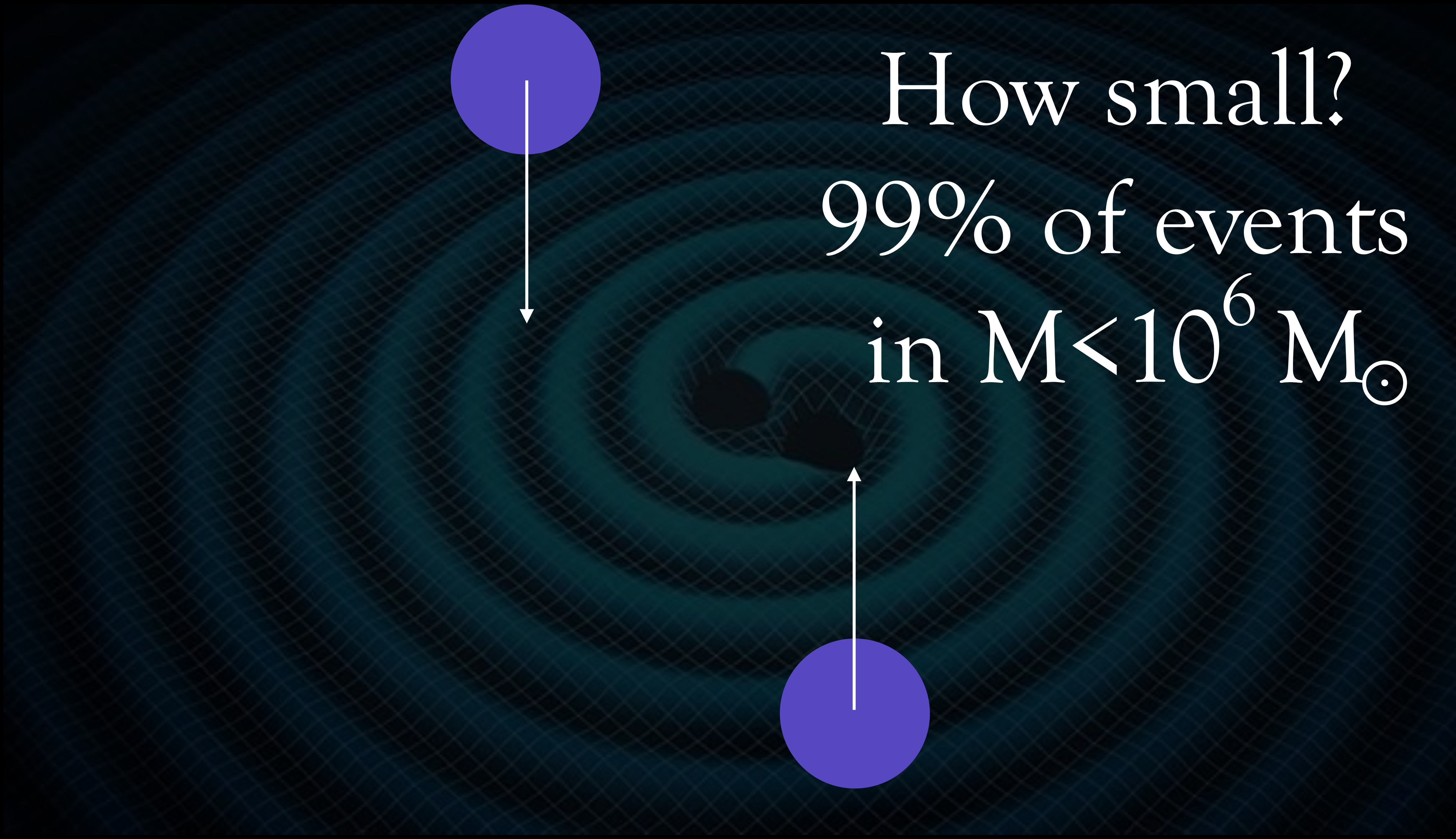
BBH merger



Big halos



Small halos



How small?
99% of events
in $M < 10^6\, M_\odot$

Progenitors ?

Determining the progenitors of merging black hole binaries

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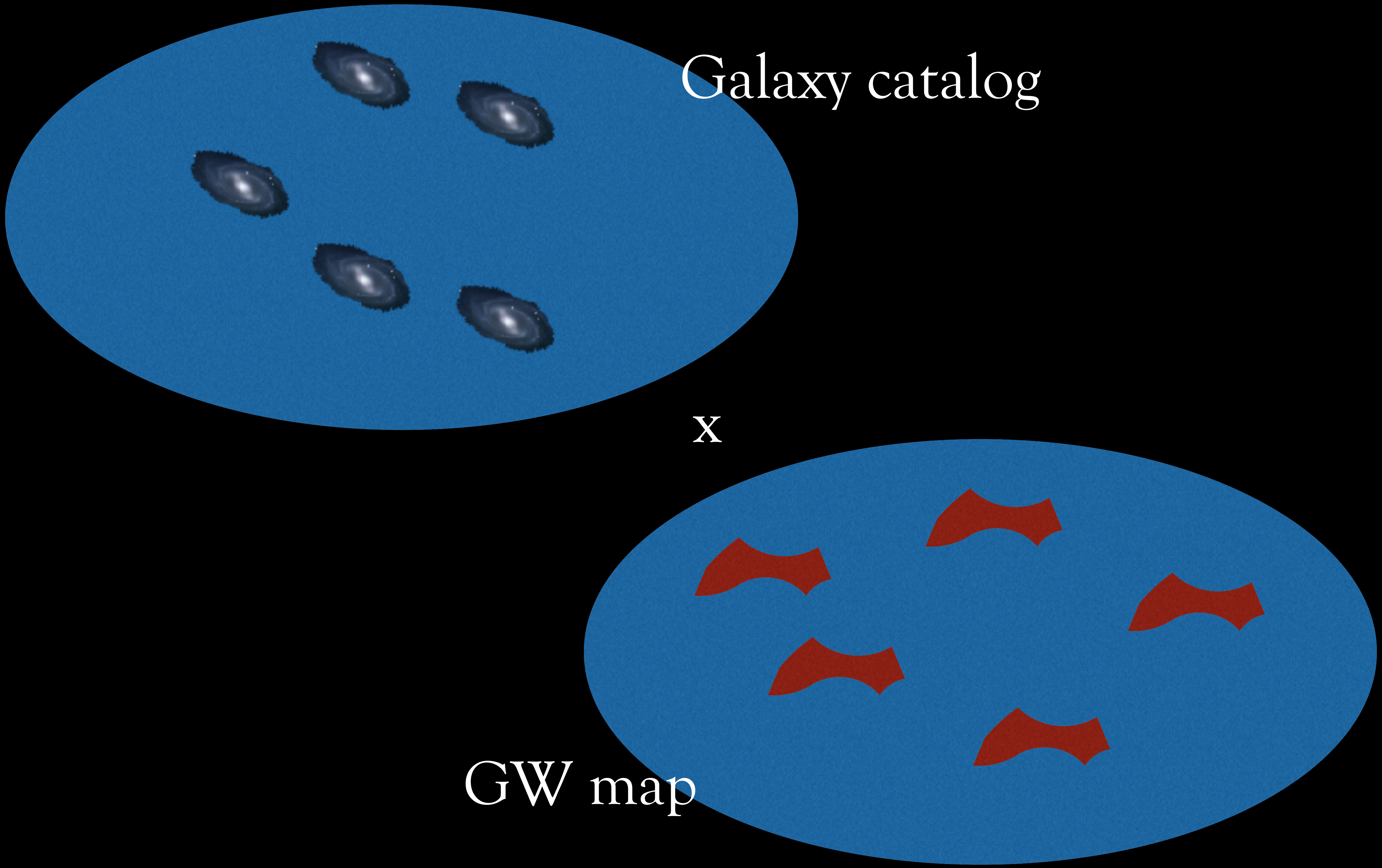
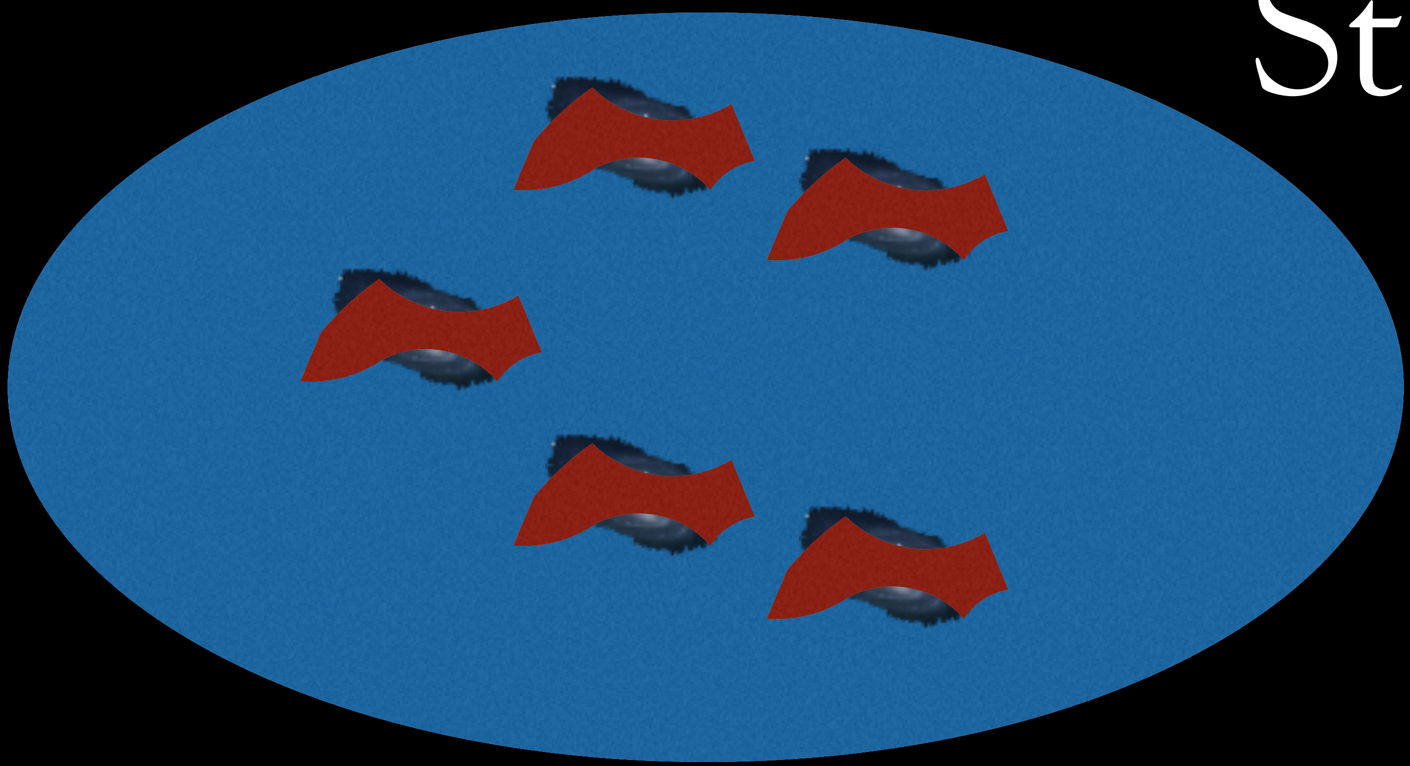
Johns Hopkins University, 3400 N. Charles St.,
Baltimore, MD 21218, USA

We propose a method for determining the progenitors of black hole (BH) mergers observed via their gravitational wave (GW) signal. We argue that measurements of the cross-correlation of the GW events with overlapping galaxy catalogs can determine if BH mergers trace the stellar mass of the Universe, as would be expected from mergers of the endpoints of stellar evolution. If on the other hand the BHs are of primordial origin, as has been recently suggested, their merging would be preferentially hosted by lower biased objects, and thus have a lower cross-correlation with star-forming galaxies. Here we forecast the expected precision of the cross-correlation measurement for current and future GW detectors such as LIGO and the Einstein Telescope. We then predict how well these instruments can distinguish the model that identifies high-mass BH-BH mergers as the merger of primordial black holes that constitute the dark matter in the Universe from more traditional astrophysical sources.

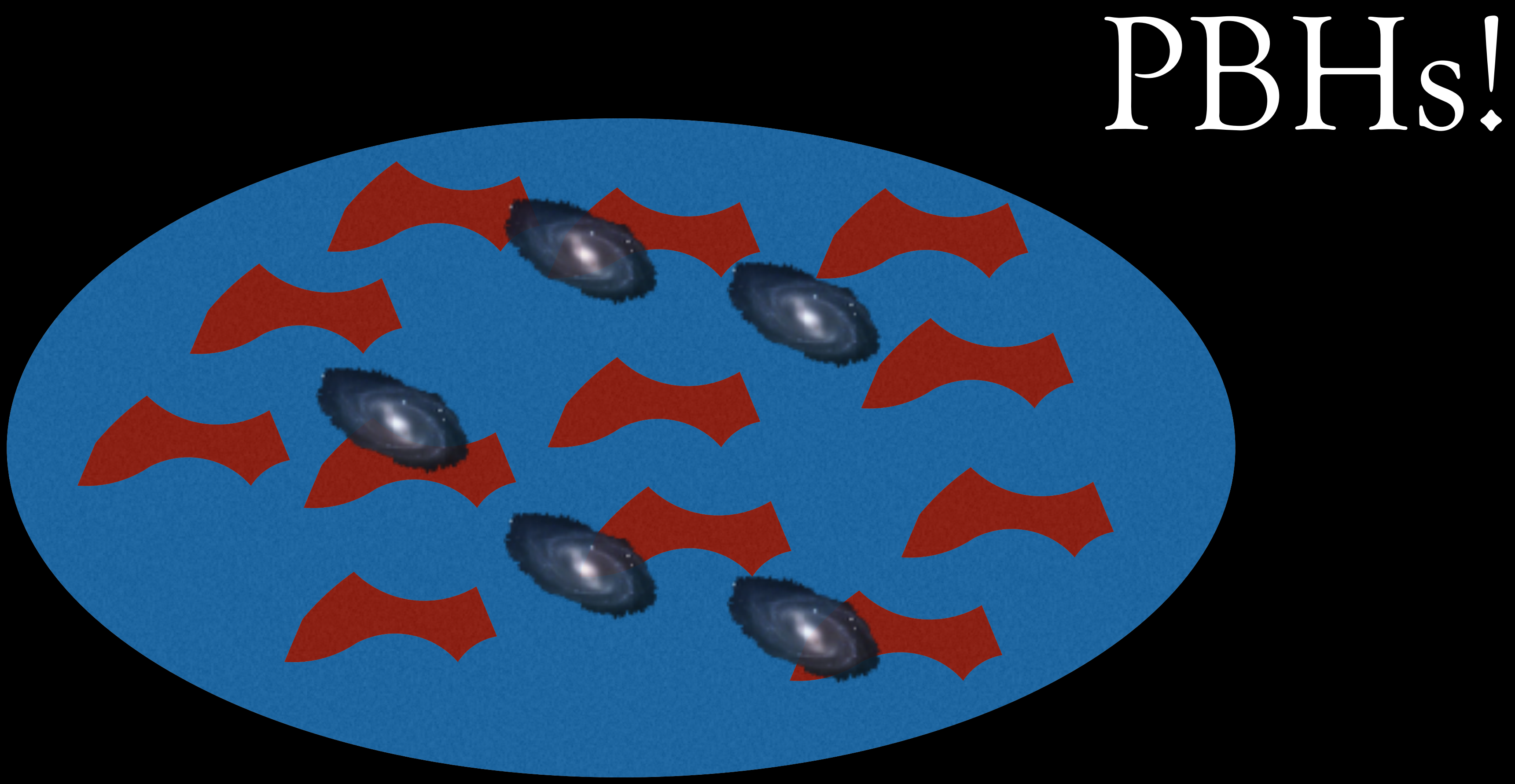
Cross-correlations



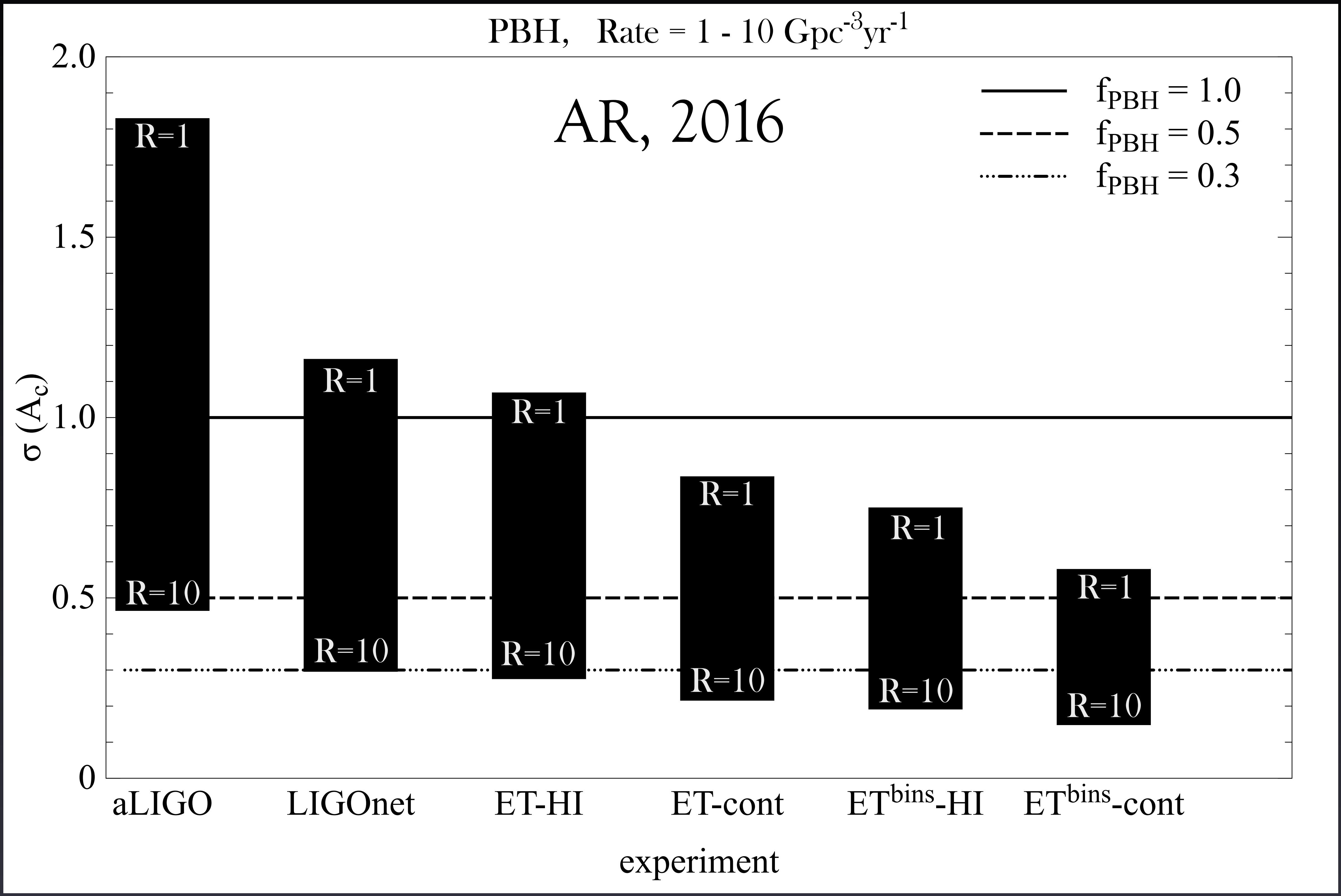
Cross-correlations



Cross-correlations



PBH-galaxy



PBH, Rate = 1 - 10 Gpc-3yr-1
AR, 2016
fPBH = 1.0
fPBH = 0.5
fPBH = 0.3
σ (Ac)
2.0
1.5
1.0
0.5
0
R=1
R=10
aLIGO
LIGOnet
ET-HI
ET-cont
ETbins-HI
ETbins-cont
experiment

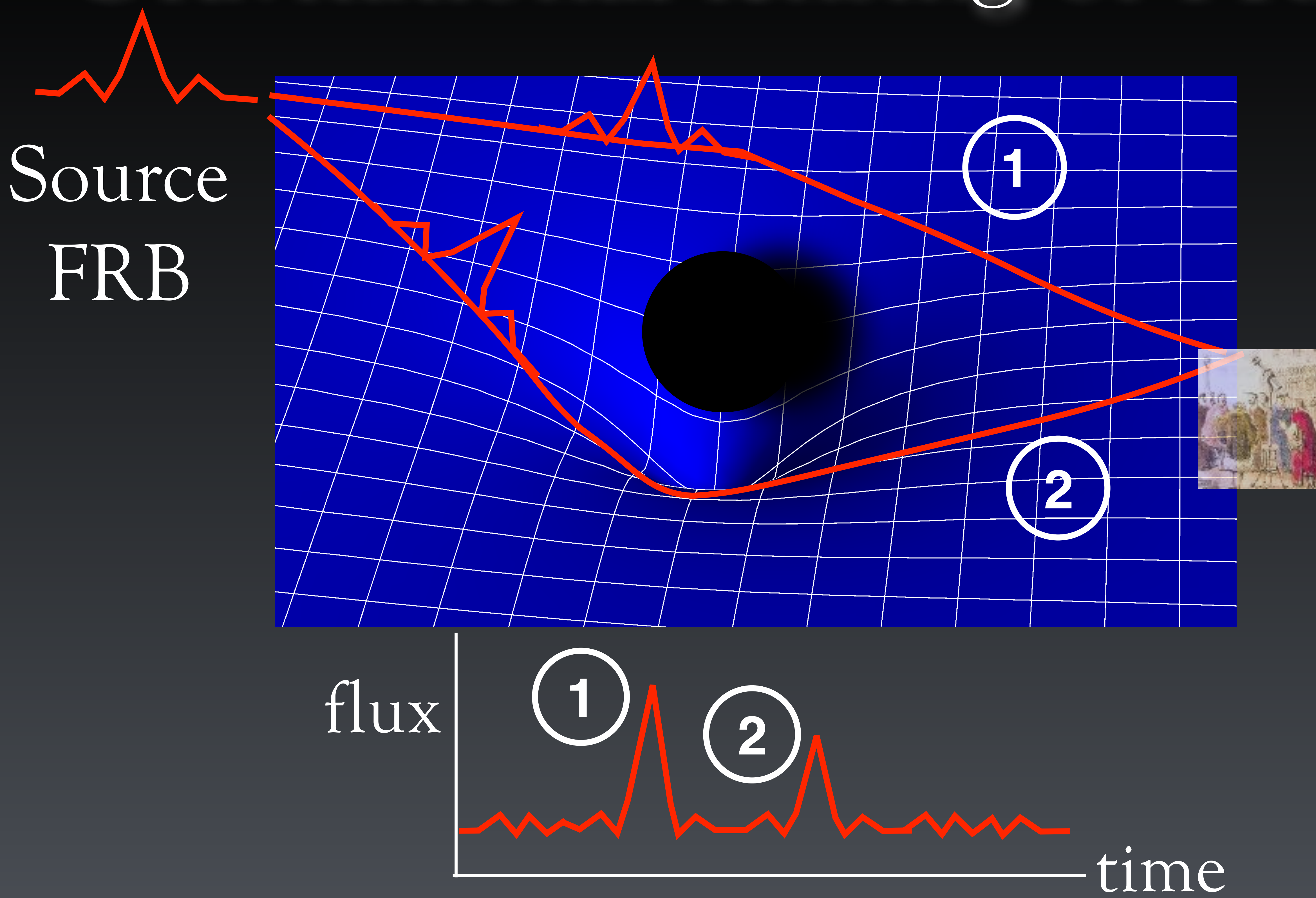
PBH - Other probes

Eccentricity (Cholis et al., 2016)

FRB lensing (Munoz et al., 2016)

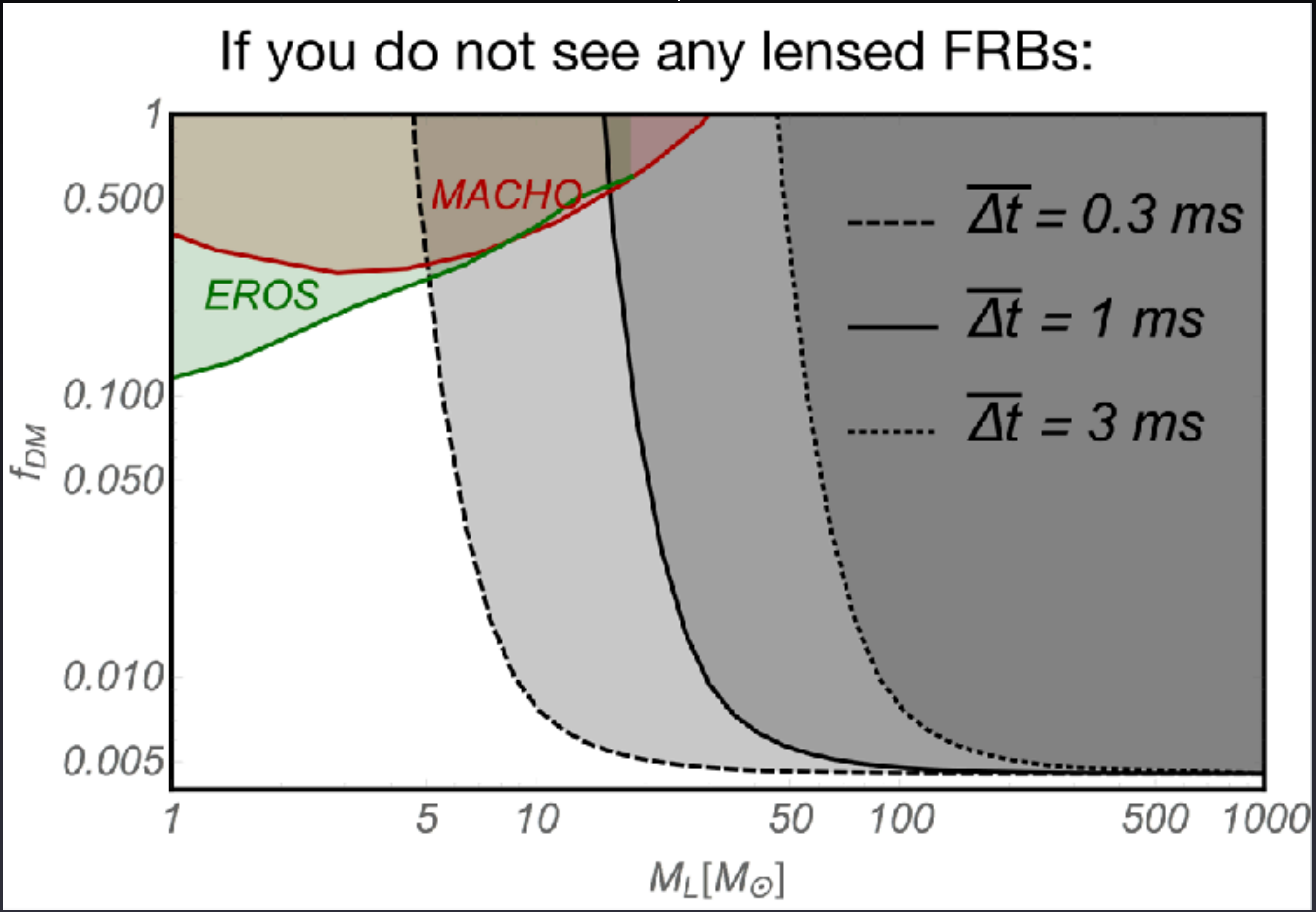
BHMF (Kovetz et al., 2016)

Gravitational lensing of FRBs



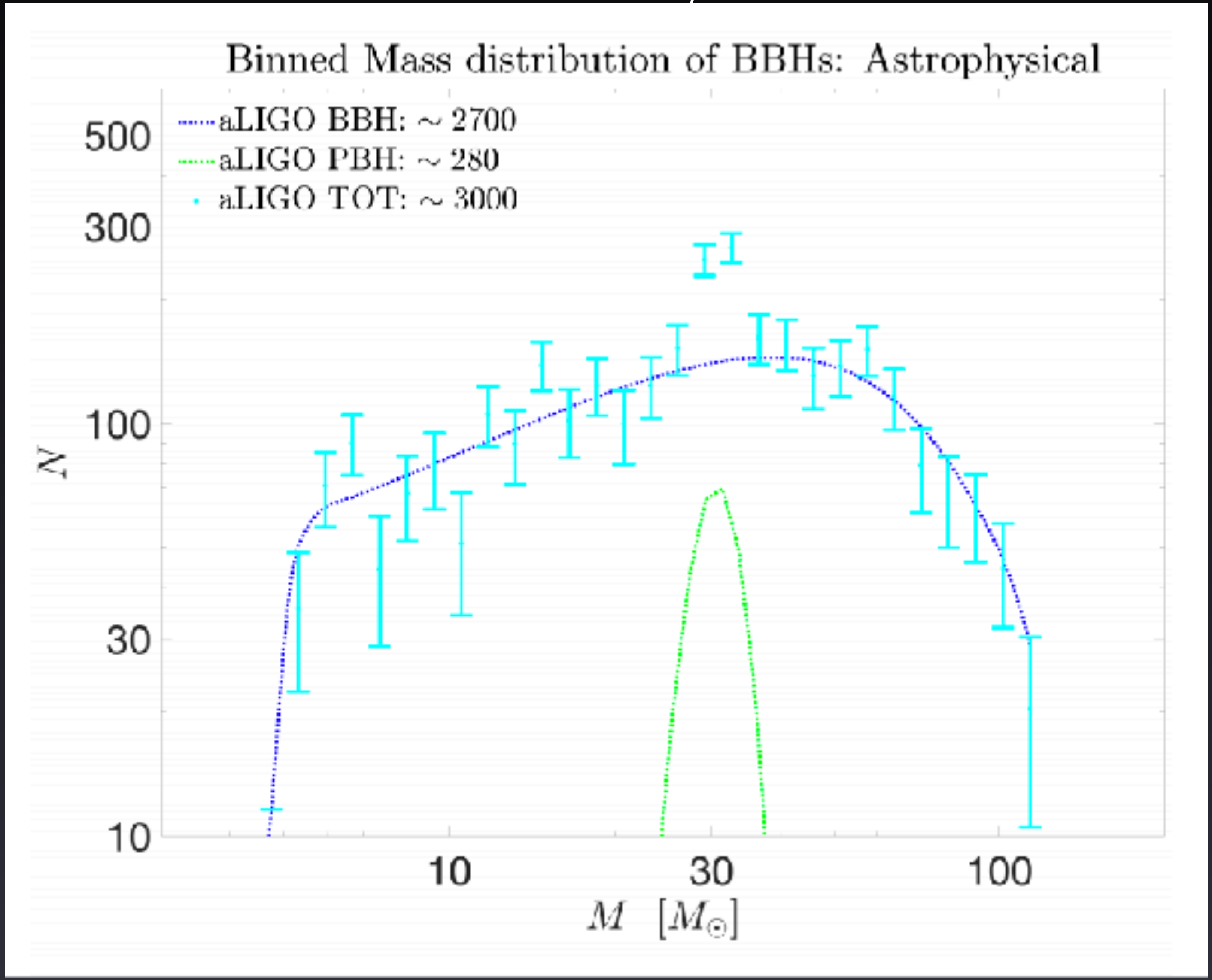
PBH - FRB lensing

Munoz et al., PRL 2016



PBH - BH mass function

Kovetz et al., 2016



Conclusions

'At the moment our idea is just an idea,' Dr Bird told MailOnline. 'It's possible, but we don't know whether or not it is really true...it's an exciting possibility!'

'It's a plausibility argument which at the moment you cannot disprove,' Professor Peter Meszaros, an astronomer at Pennsylvania State University told **New Scientist**.

Conclusions

PBHs as DM are not ruled out

It is worth investigating more

In any case we will learn something

Conclusions

I am working on constraints on neutrino mass (and something else) from cosmology, come see me if interested

(with L. Verde, R. Jimenez, C. Pena-Garay, F. Simpson, F. Villaescusa Navarro)

Thank You