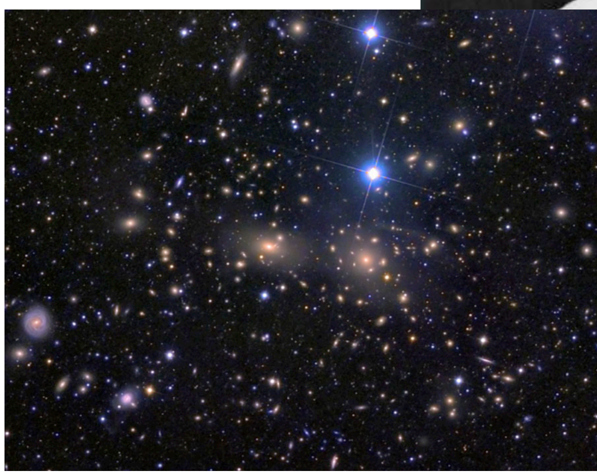
Primodial Black Hole Dark Matter

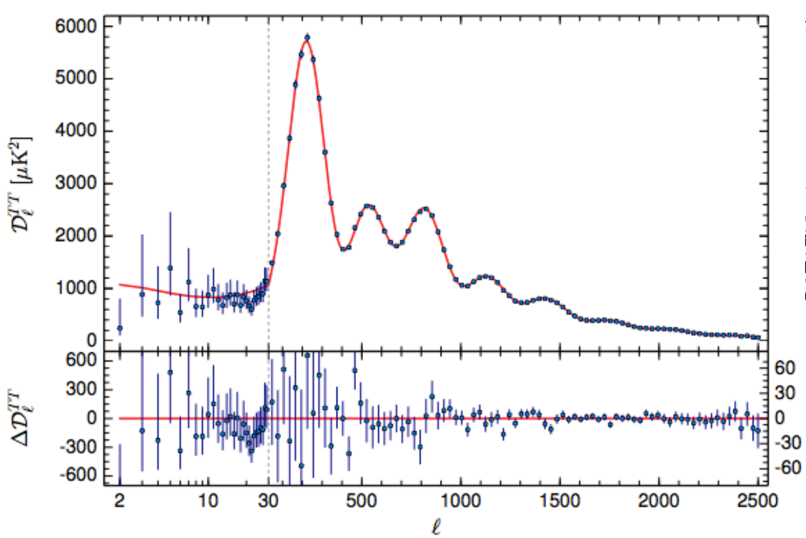
Raphael Flauger

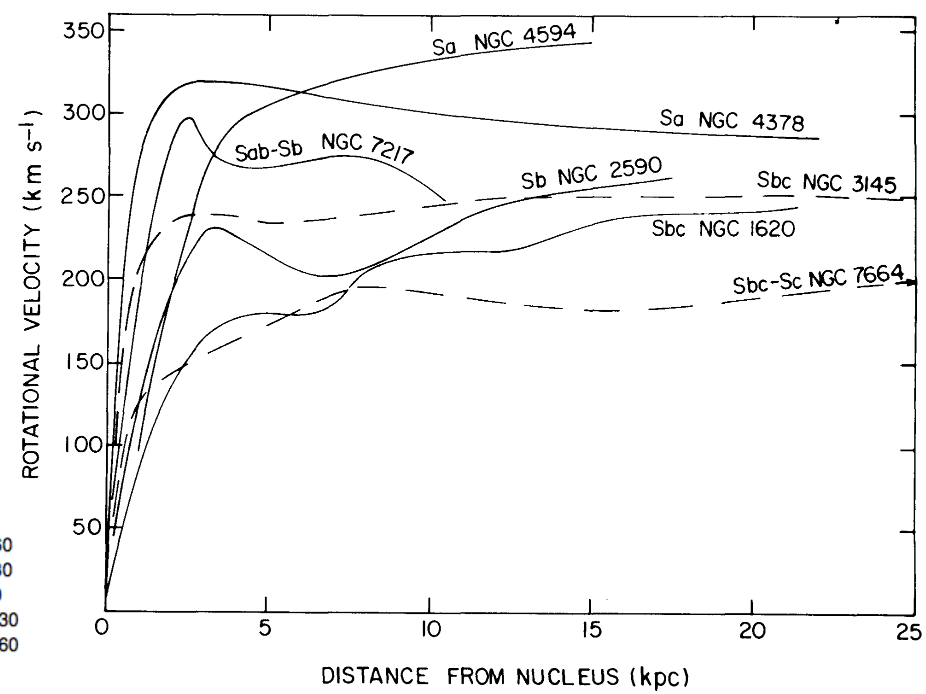
Dark Matter in Southern California 2017, Caltech, August 30, 2017

Introduction

We have compelling evidence that dark matter exists...







Introduction

... but we don’t know whether dark matter consists of

- WIMPs

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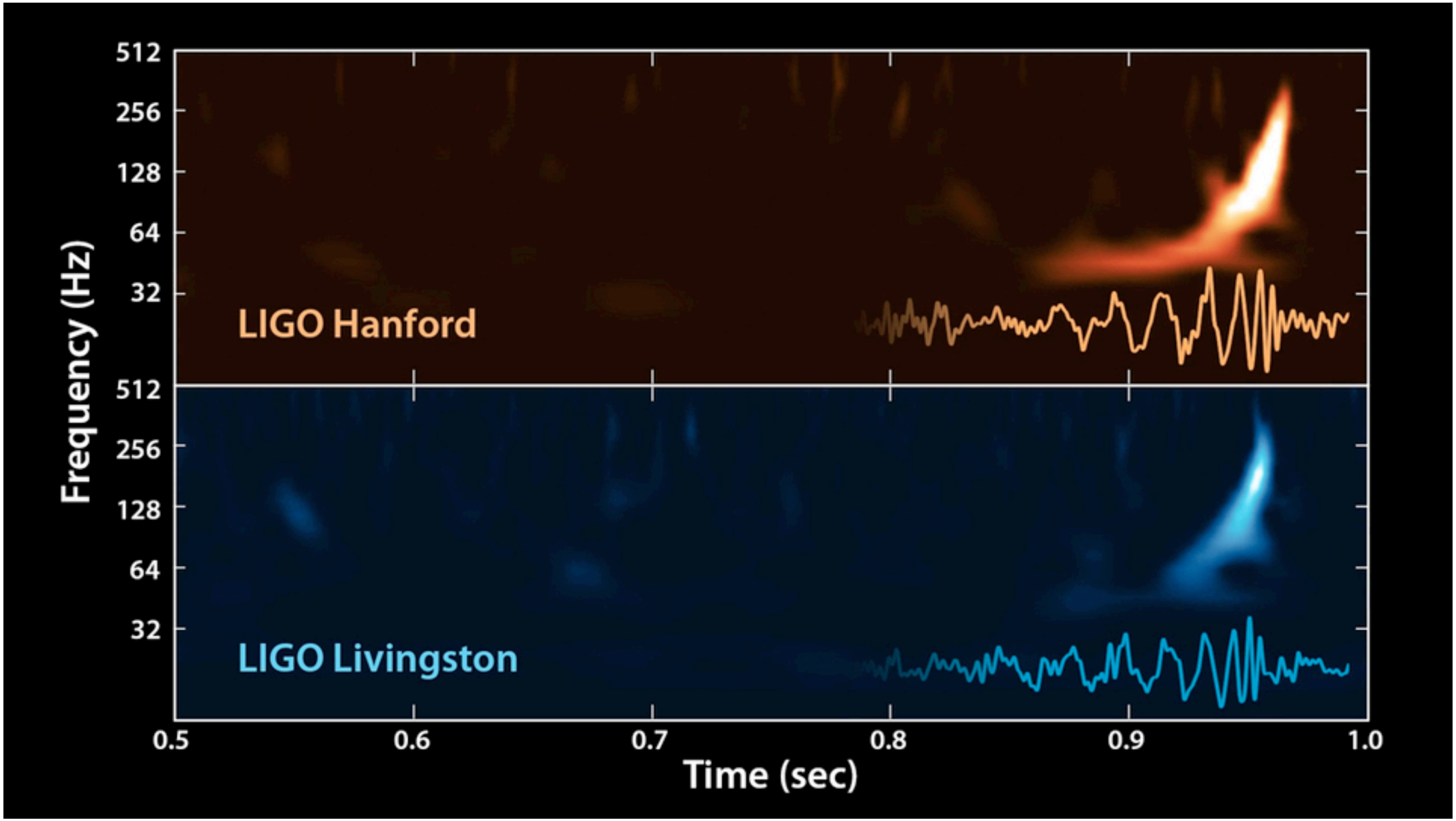
- WIMPs
- axions
- SIDM
- neutrinos
- ...
- primordial black holes

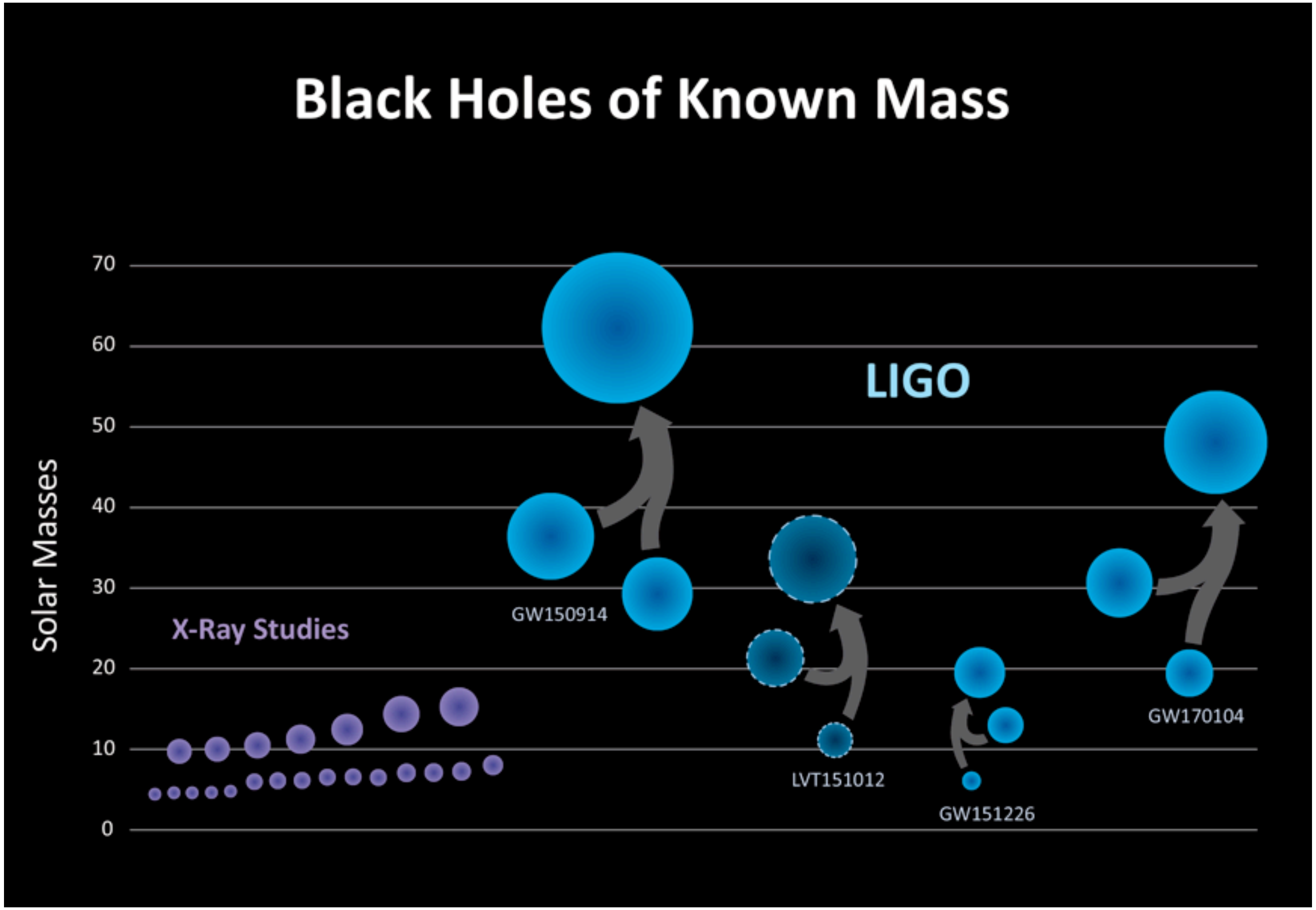
LIGO

LIGO has detected gravitational waves from binary black hole mergers



LIGO

The detected black holes are perhaps more massive than expected



LIGO and Dark Matter

Could LIGO be seeing mergers of primordial black holes that make up all the dark matter?

(Bird, Cholis, Muñoz, Ali-Haïmoud, Kamionkowski, Kovetz, Racanelli, Riess, 2016)

- Expected rates agree with the rates estimated by LIGO.
- Consistent with observational constraints on primordial black holes at the time of writing.

LIGO and Dark Matter

Merger rates

$$\sigma = \pi \left(\frac{85\,\pi}{3} \right)^{2/7} R_s^2 \left(\frac{v_{\rm pbh}}{c} \right)^{-18/7}$$

$$\Gamma \simeq V n^2 \sigma v_{\rm pbh}$$

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For Milky Way like halo

$$\Gamma \simeq 1.1 \times 10^{-4}\, \rho_{0.002}\, v_{\rm pbh-200}^{-11/7}\, {\rm Gpc}^{-3}\, {\rm yr}^{-1}$$

much smaller than rate $2{-}53\,{\rm Gpc}^{-3}\,{\rm yr}^{-1}$ inferred by LIGO.

LIGO and Dark Matter

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In substructure as high as

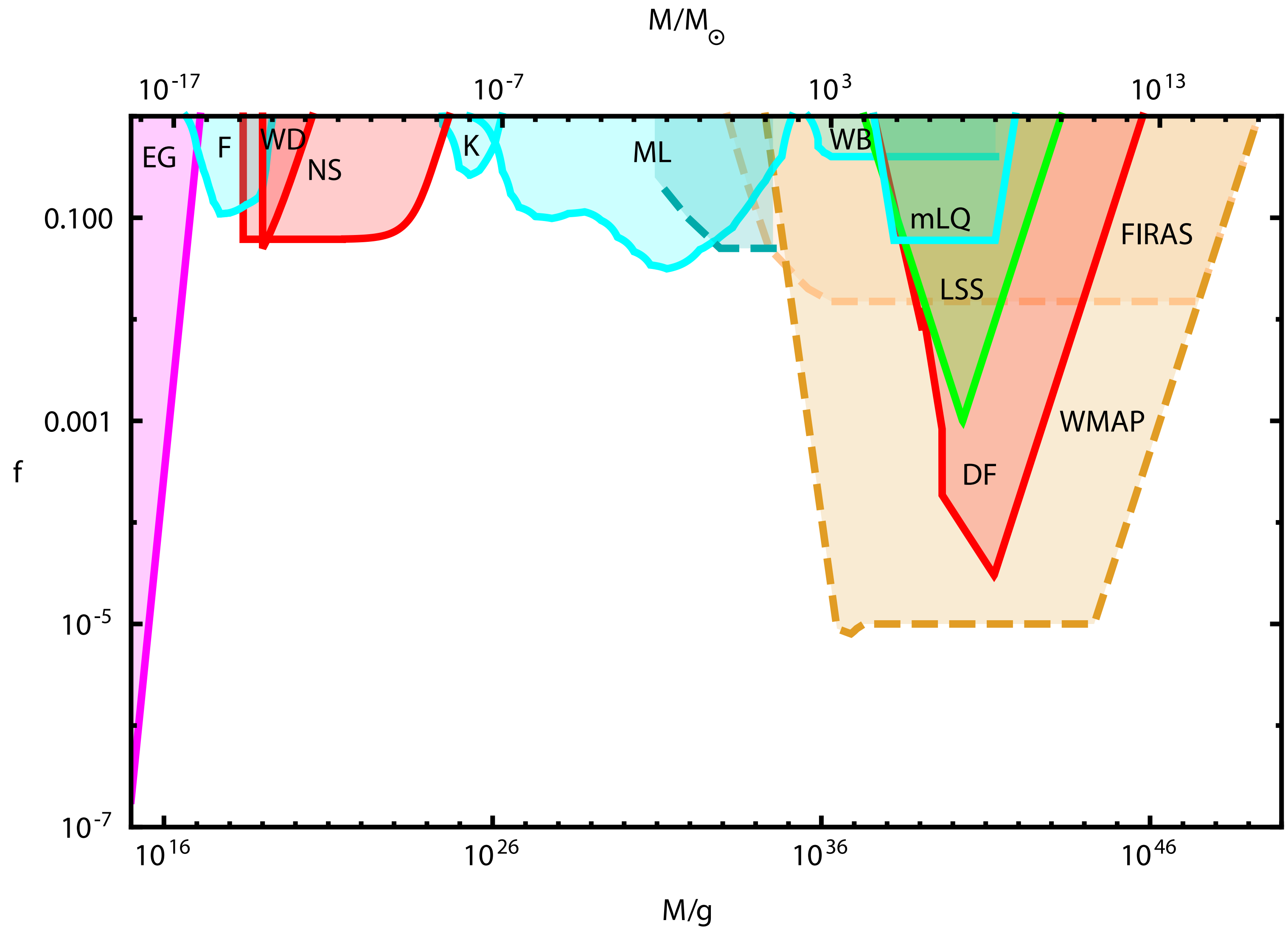
$$\Gamma \simeq 700\,{\rm Gpc}^{-3}\,{\rm yr}^{-1}$$

More refined estimates appear consistent with LIGO rates.

(Bird, Cholis, Muñoz, Ali-Haïmoud, Kamionkowski, Kovetz, Racanelli, Riess, 2016)

LIGO and Dark Matter

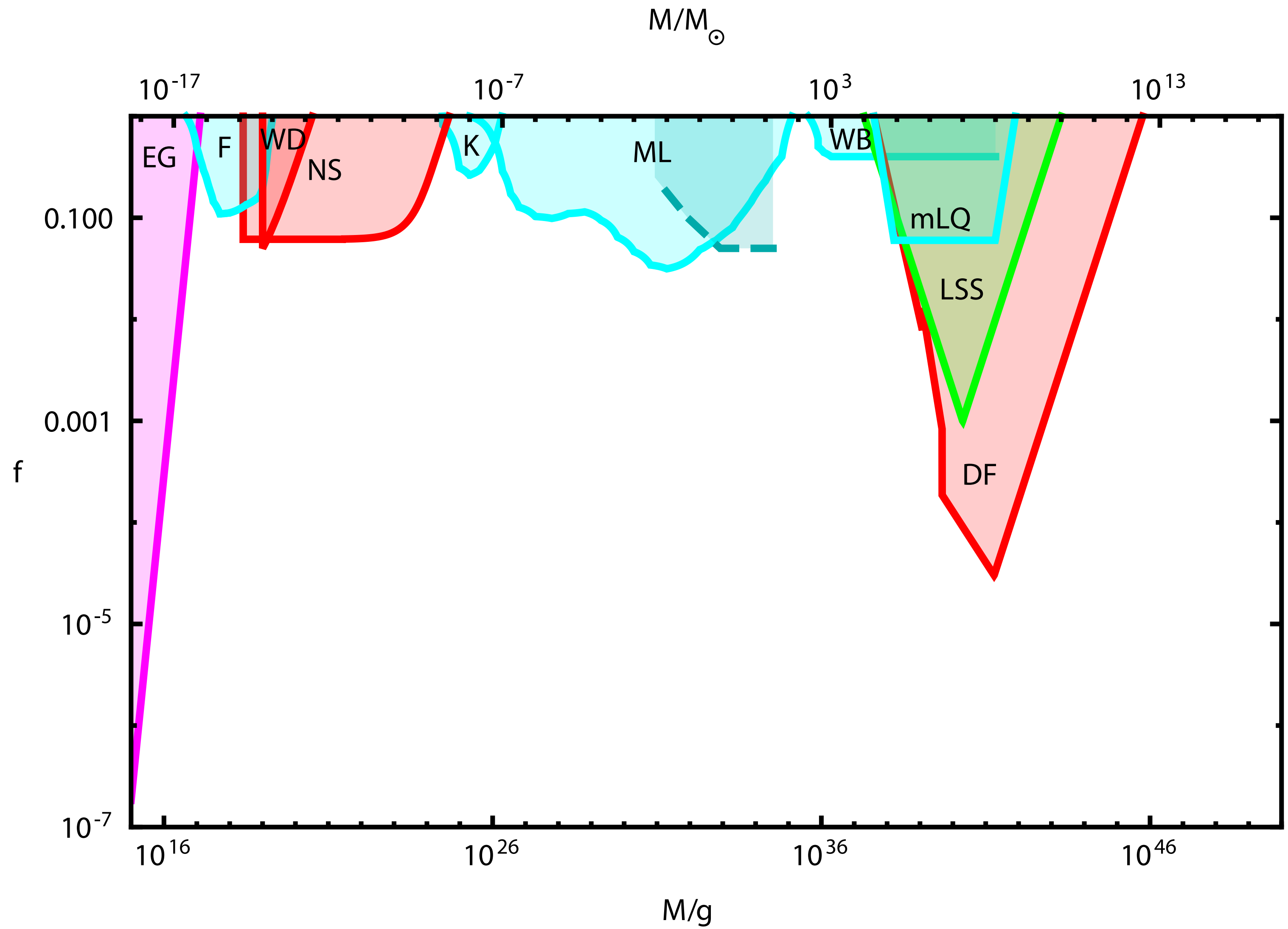
Constraints



adapted from Carr, Kühnel, Sandstad, 2016

LIGO and Dark Matter

Constraints



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LIGO and Dark Matter

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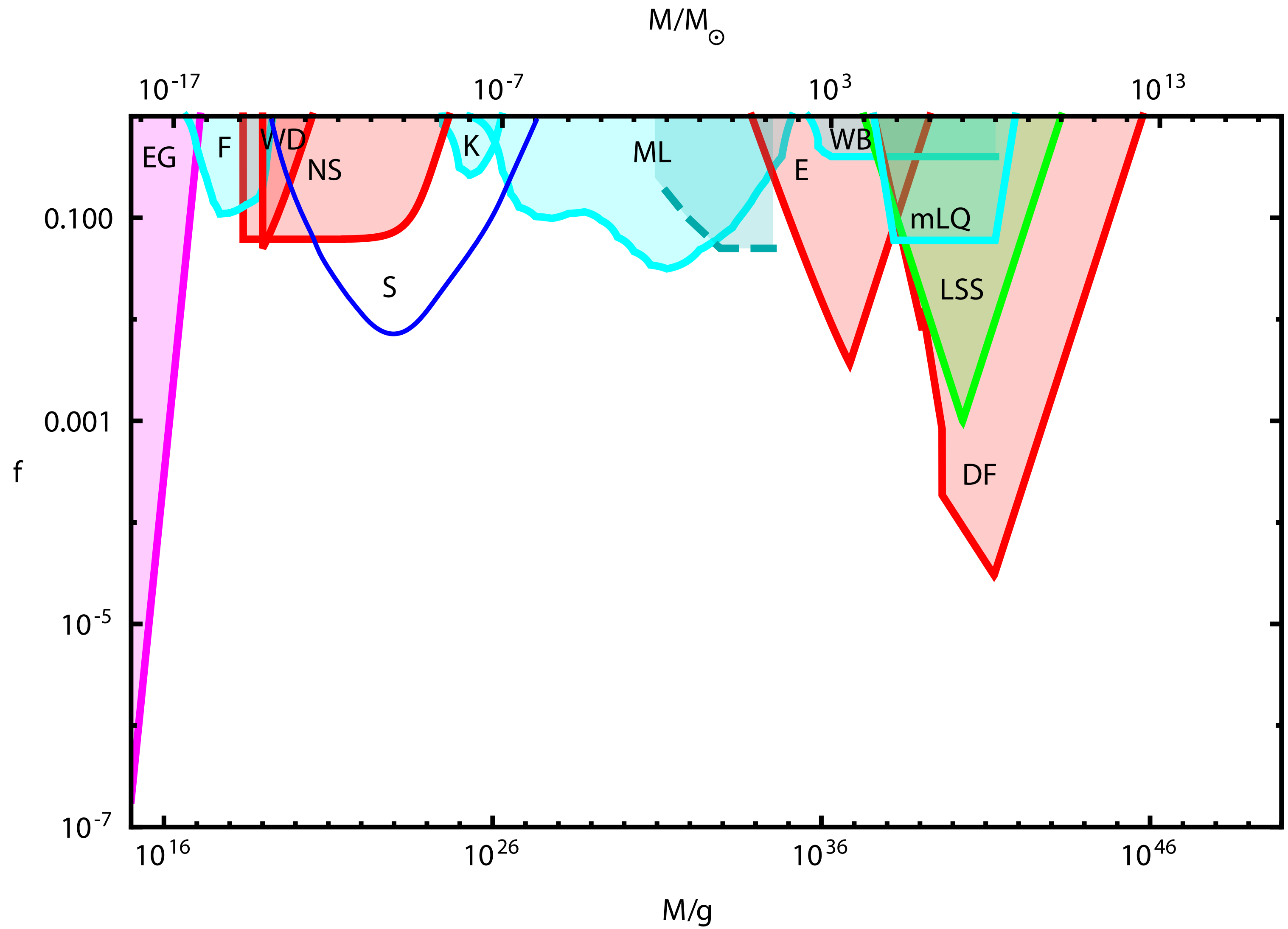


adapted from Carr, Kühnel, Sandstad, 2016
Brandt, 2016
Niikura et al., 2017

CMB Constraints

Spectral distortions

e^- p He

γ dark matter

ν cosmological constant

- Coulomb interactions
- Compton scattering
- Double-Compton scattering
- Bremsstrahlung

lead to black body spectrum

CMB Constraints

Spectral distortions

- photon number changing processes freeze out below

$$z < \text{few} \times 10^6$$

injection of photons/energy generates μ

- energy is no longer efficiently exchanged below

$$z < 10^5$$

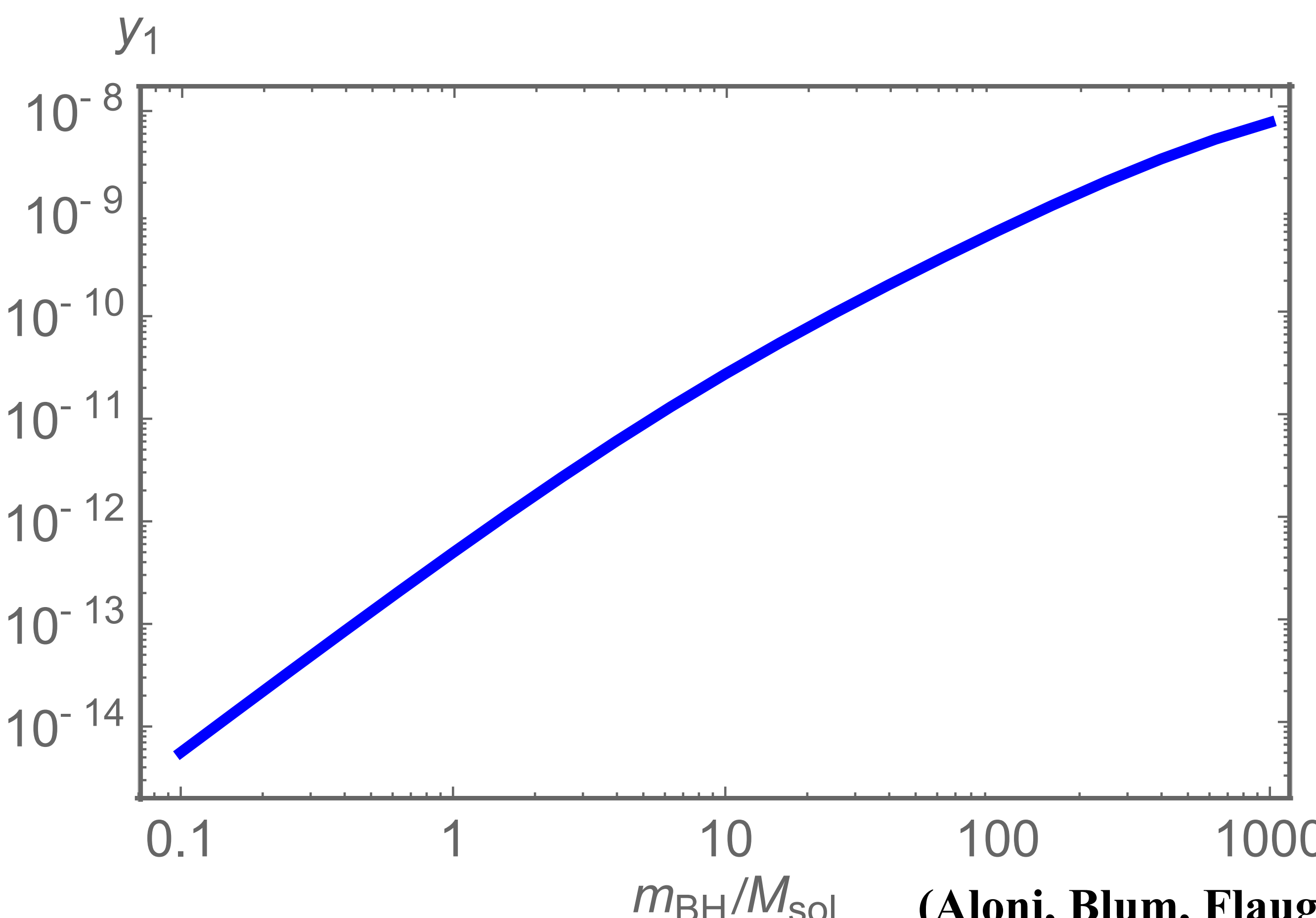
intermediate and y-distortions

Accretion onto primordial black holes predominantly generates y-distortion

(Ricotti, Ostriker, Mack, 2007)

CMB Constraints

Spectral distortions



(Aloni, Blum, Flauger, 2016)

easily compatible with FIRAS bound

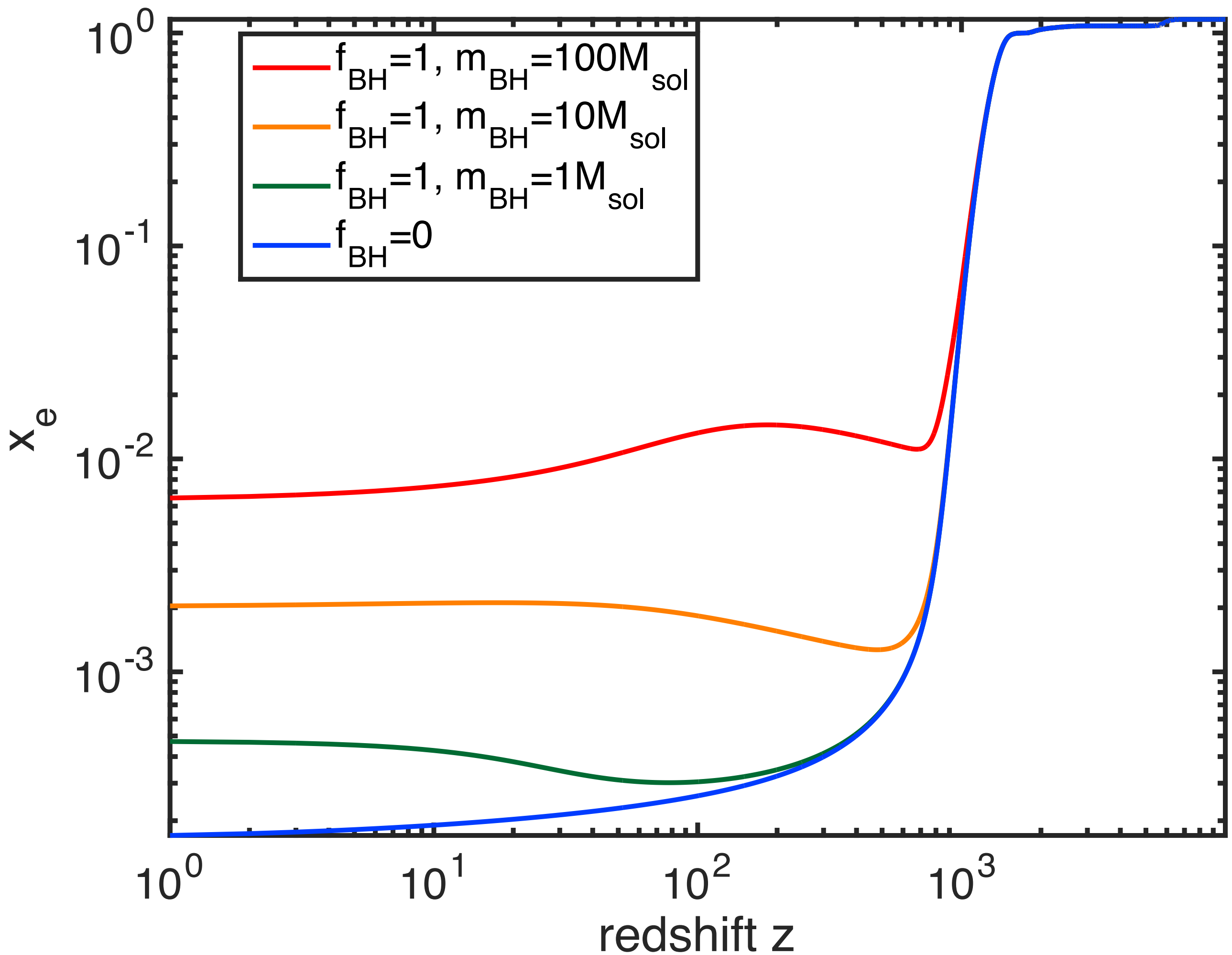
$$y < 1.5 \times 10^{-5} \text{ at } 95\%\text{CL}$$

CMB Constraints

Anisotropies

Accretion onto primordial black heats the plasma and ionizes hydrogen.

(Aloni, Blum, Flauger, 2016)

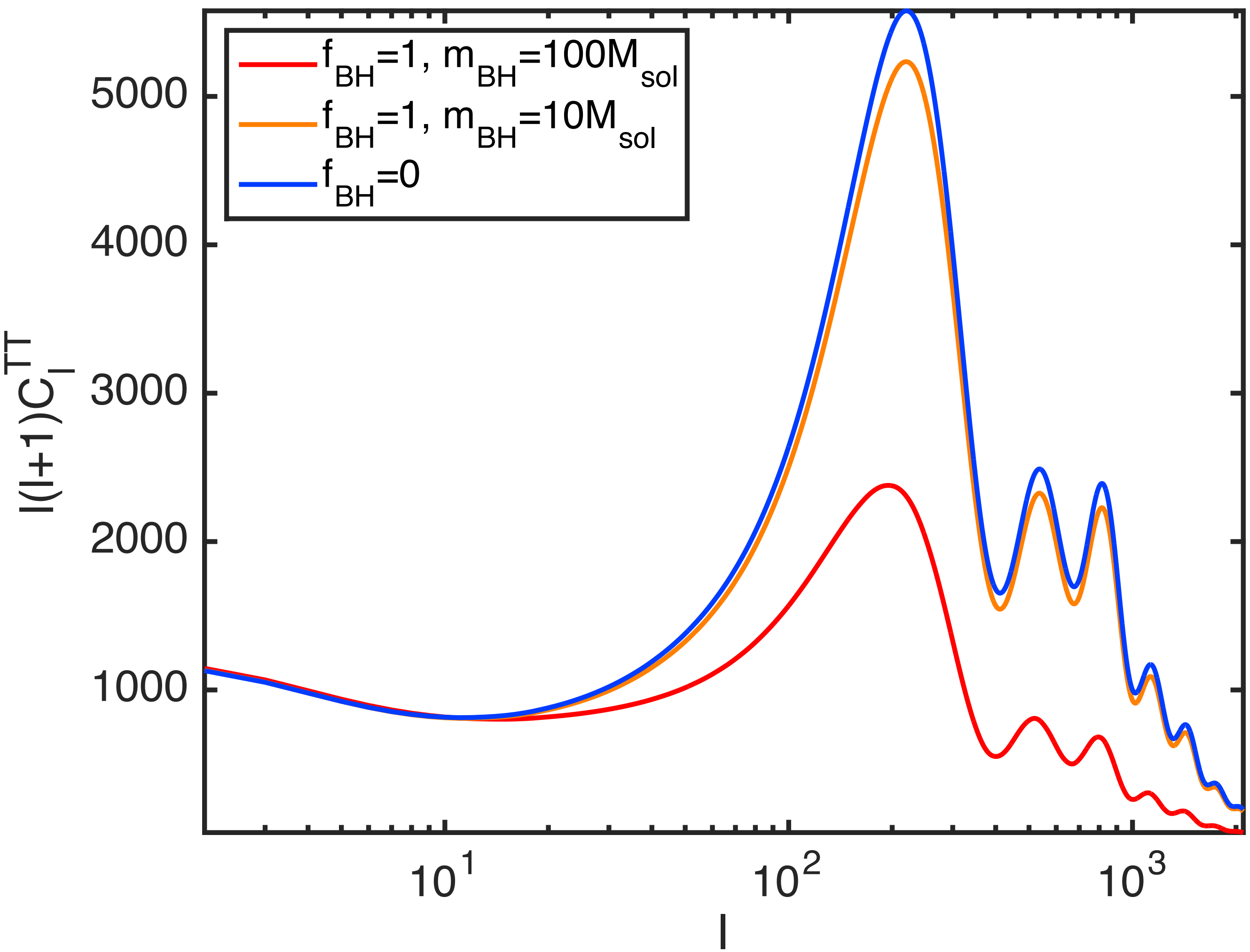


CMB Constraints

Anisotropies

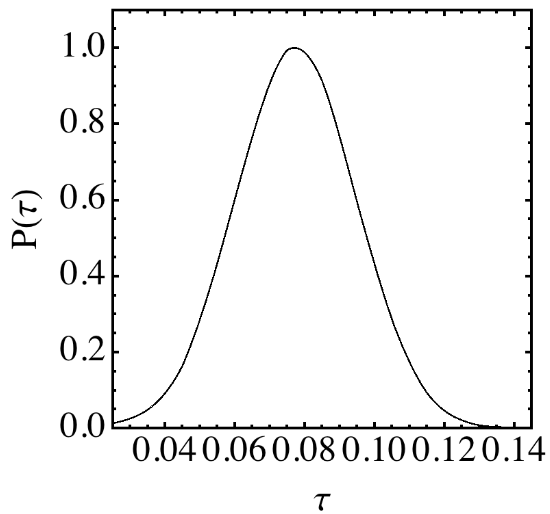
Modified ionization history leads to modified temperature and polarization anisotropies

(Aloni, Blum, Flauger, 2016)

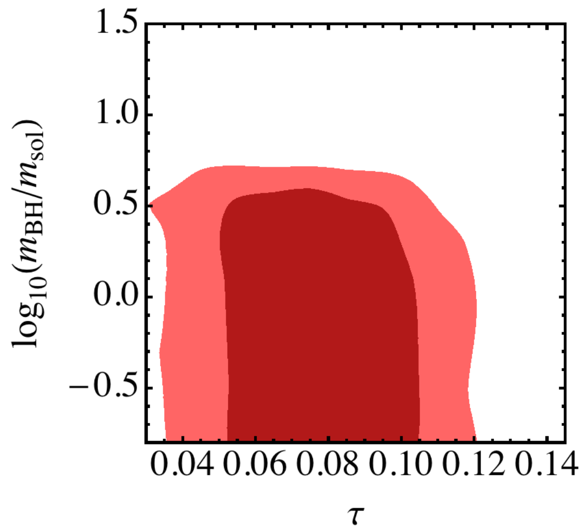


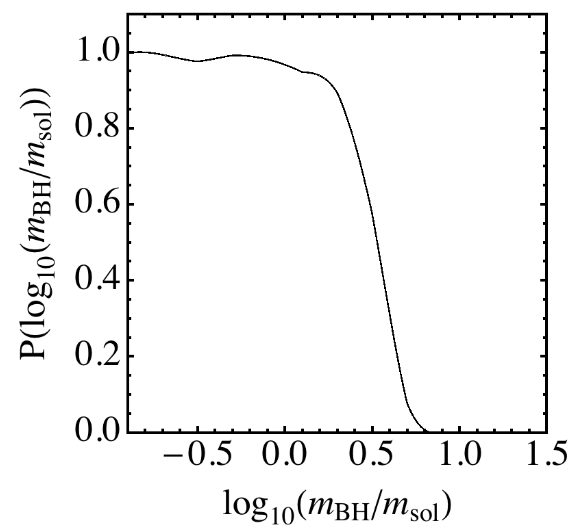
CMB Constraints

Anisotropies



$M_{\rm pbh} > 5 M_{\rm sol}$
disfavored by
Planck 2015 data





CMB Constraints

Anisotropies

Caveat

- the accretion rate is very uncertain

Accretion as modeled by Ricotti, Ostriker, Mack

$$M_{\rm pbh} < 5 M_{\rm sol}$$

Accretion as modeled by Ali-Haïmoud, Kamionkowski

$$M_{\rm pbh} < 100 M_{\rm sol}$$

Accretion as modeled by Poulin et al.

$$M_{\rm pbh} < 2 M_{\rm sol}$$

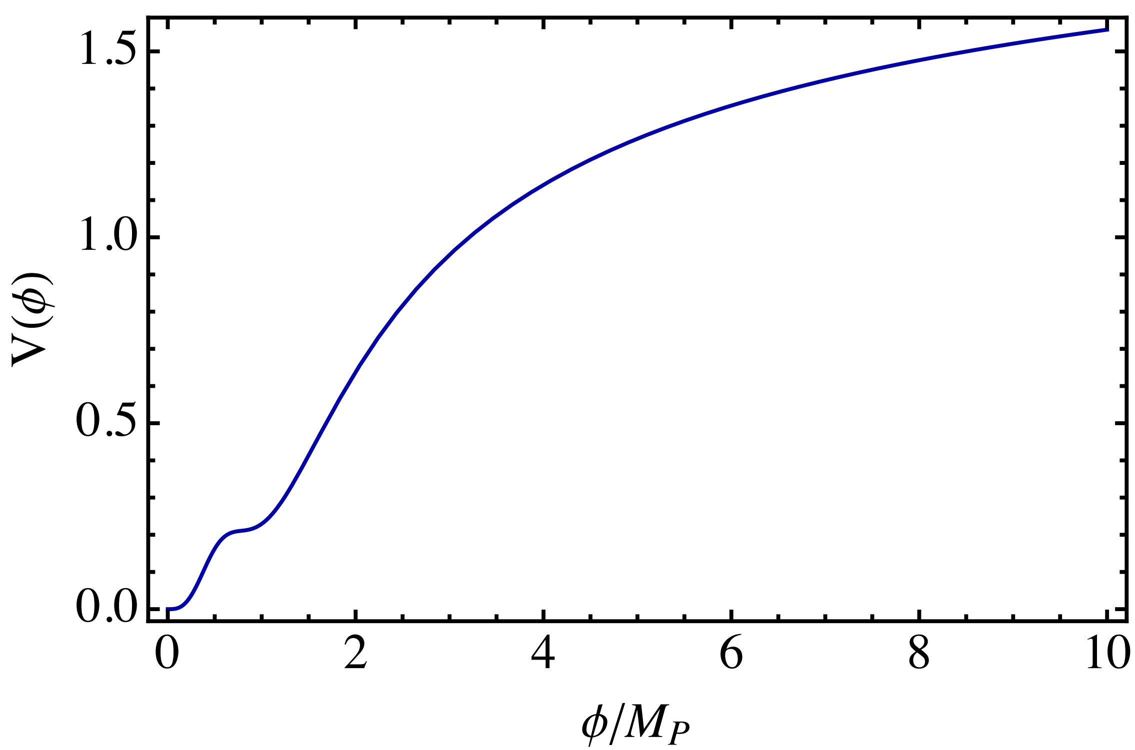
Formation

Primordial black holes can form

- during inflation if $\epsilon \approx 0$ because

$$\Delta^2_{\mathcal{R}}(k) = \frac{H^2(t_k)}{8\pi^2 \epsilon(t_k)}$$

e.g.



Formation

Primordial black holes can form

- during inflation if $\epsilon \approx 0$ because
- during reheating
- during a phase transition
- ...

Even though there are several mechanisms that can lead to formation of primordial black holes, none naturally predicts 30 solar masses.

Conclusions

- The idea that LIGO might have seen gravitational waves from black holes that make up the dark matter is intriguing.
- It seems disfavored by data, but a firm conclusion would require a better understanding of accretion onto these black holes.
- Assuming a nearly monochromatic initial mass function, what is the expected mass function at late times?
- The idea is testable as it predicts high eccentricities, absence of EM counterpart, low spin, origin in low mass halos, a stochastic gravitational wave background

Thank you