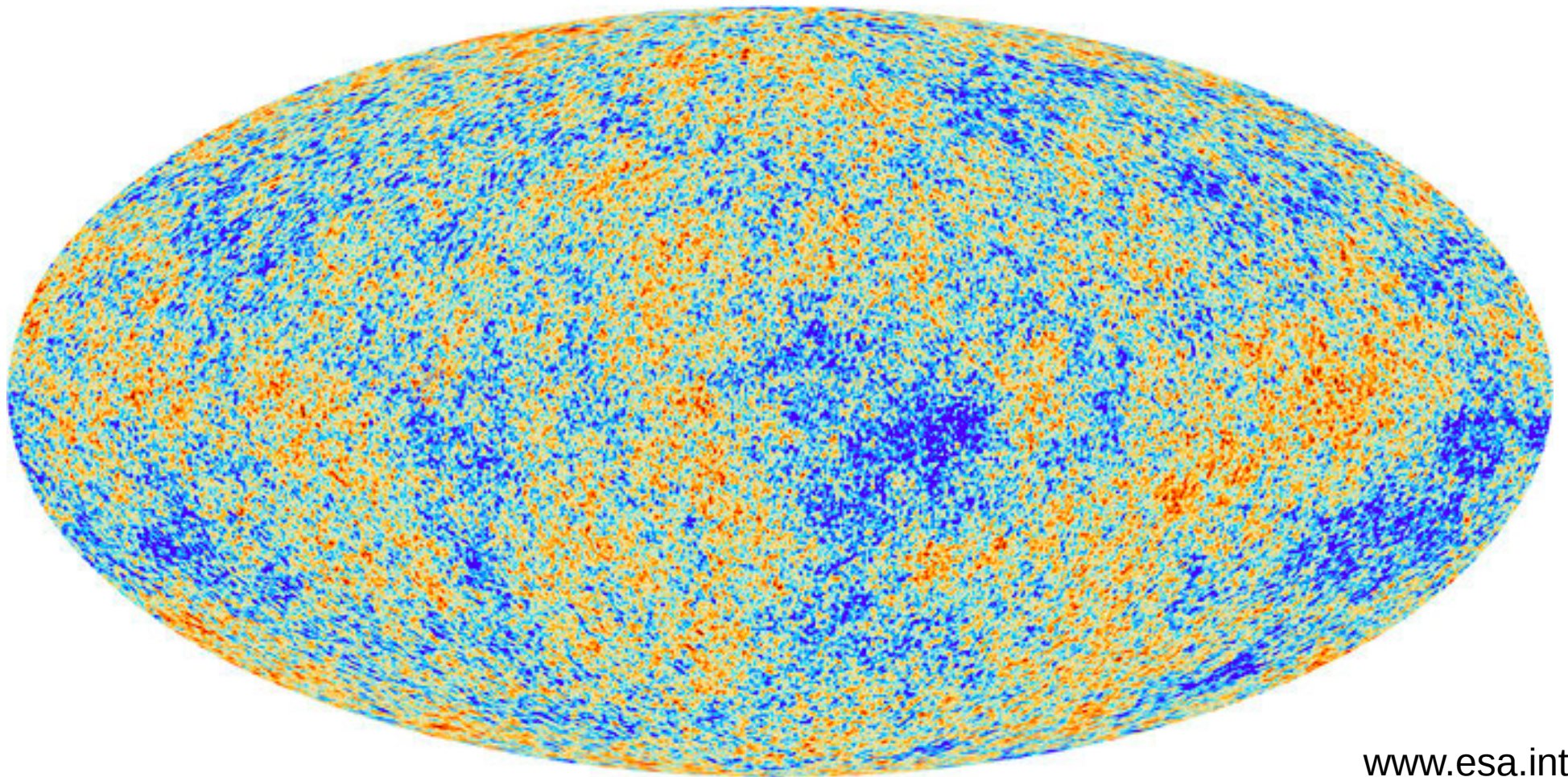


# Planck Constraint on Relic Primordial Black Holes

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Based on: Clark, Dutta, Gao, Strigari, and Watson; arXiv: 1612.07738 (Phys. D95 (2017), 083006)



# Primordial Black Holes (PBHs)

- LIGO measurements of black holes

Abbott, et al, [LIGO Scientific and Virgo Collaborations]; arXiv:1602.03837

- Formed in the early Universe

Hawking; Mon. Not. Roy. Astron. Soc. 152, 75 (1971)

- Possible Dark Matter Candidate

Carr, Kohri, Sendouda, and Yokoyama; arXiv:0912.5297

# Hawking Radiation Energy Injection

$$\begin{aligned}\frac{dE}{dV dt} &= \dot{M}_{\text{BH}} c^2 n_{\text{BH}} \\ &= \frac{\dot{M}_{\text{BH}}}{M_{\text{BH}}} \rho_c c^2 \Omega_{\text{BH},0} (1+z)^3\end{aligned}$$

$$\dot{M}_{\text{BH}} = -5.34 \times 10^{25} F(M_{\text{BH}}) M_{\text{BH}}^{-2} \text{g}^3 \text{s}^{-1}$$

# Intergalactic Medium Interactions

- Hydrogen Ionization

$$I_{X_i}(z) = f_i(E, z) \frac{dE/dV dt}{n_H(z) E_i}$$

- Lyman-Alpha Excitations

$$I_{X_\alpha}(z) = f_\alpha(E, z) (1 - C) \frac{dE/dV dt}{n_H(z) E_\alpha}$$

- Medium Heating

$$K_h(z) = f_h(E, z) \frac{dE/dV dt}{n_H(z)}$$

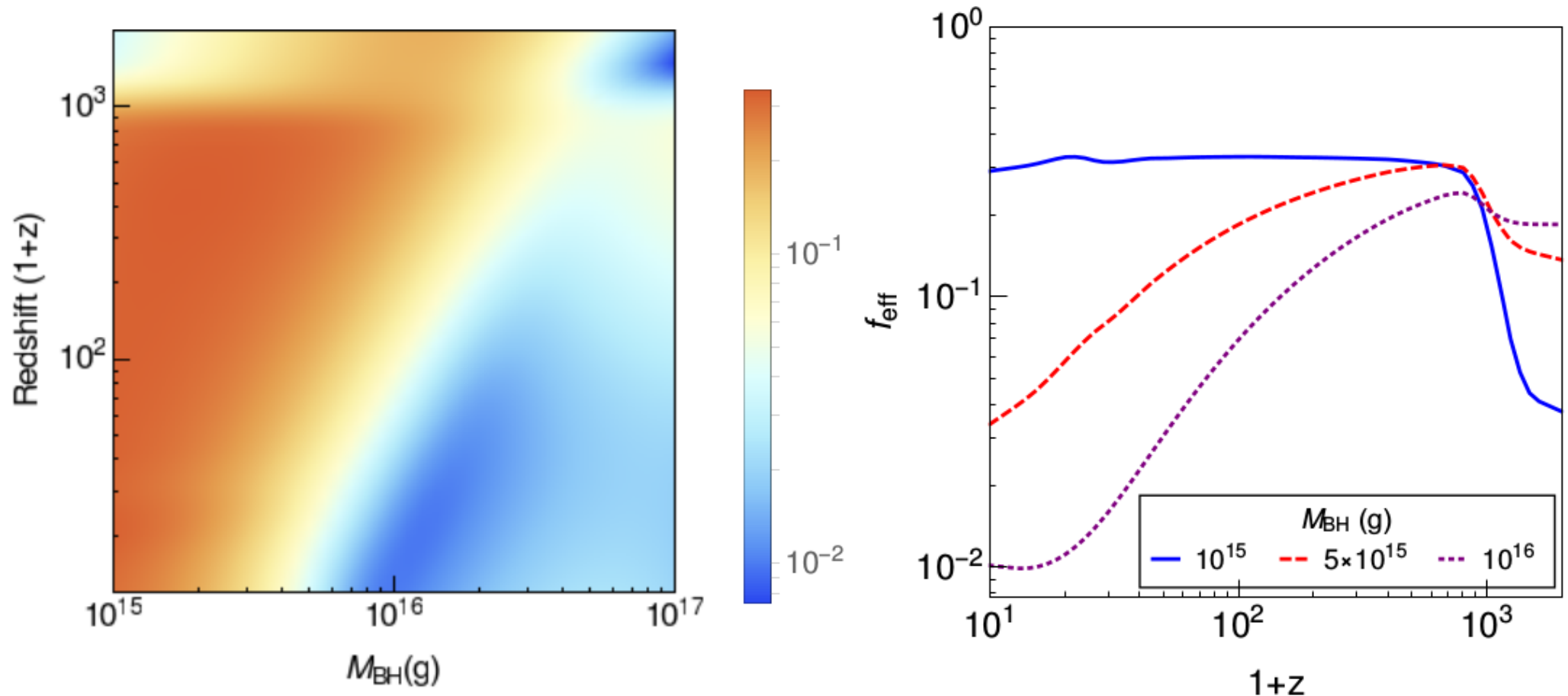
Liu, Slatyer, and Zavala; arXiv:1604.02457

Belotsky and Kirillov; arXiv:1409.8601

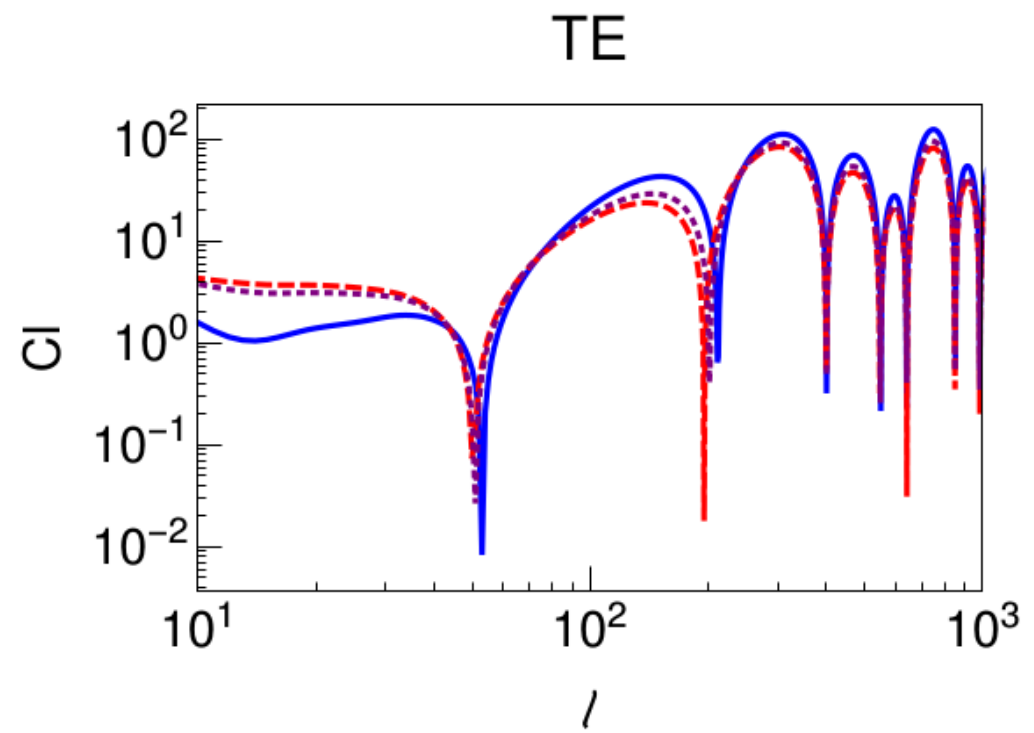
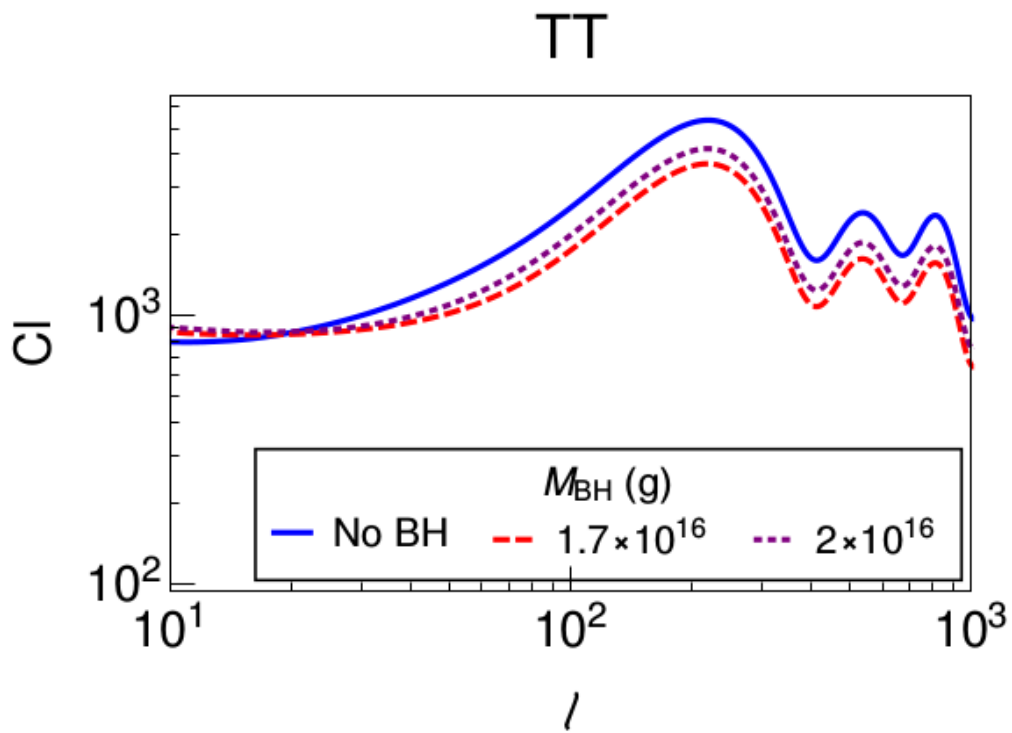
Slatyer; arXiv:1211.0283

# Effective Efficiency

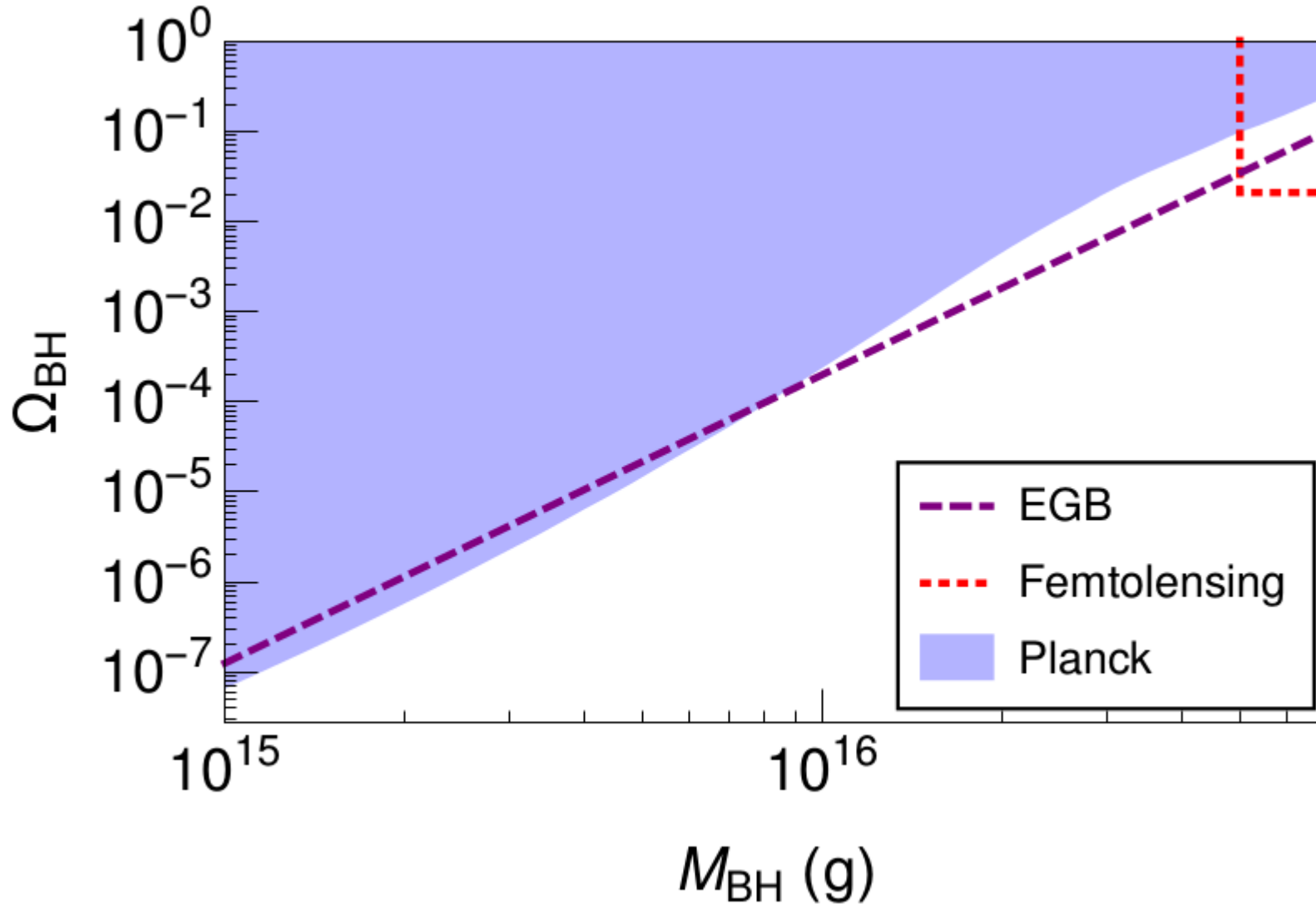
$$f_{c,\text{BH}}(M_{\text{BH}}, z) = \frac{\sum_i \int_0^\infty g_i f_i f_{c,i}(E, z) \left( \frac{dN}{dE dt}(E) \right)_i dE}{\sum_i \int_0^\infty g_i f_i \left( \frac{dN}{dE dt}(E) \right)_i dE}$$



# CMB Anisotropies



# PBH Density Constraints



Thank You