Gravitational Wave Constraints on Burdened Primordial Black Holes

In collaboration with Basabendu Barman and Oscar Zapata [*JCAP*(2024)]

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Prepared for : Hearing beyond the standard model with cosmic sources of gravitational waves

Non-Standard Cosmology: Role of PBH

- Production of particulate Dark Matter through Hawking radiation of PBH (also PBH as DM candidate)
- Production of BSM states through Hawking radiation whose decay admits Baryon Asymmetry
- Entropy injection through Hawking radiation
- Modification of the Hubble parameter dependence:

$$H(a) = \sqrt{\frac{\rho_{Rad}(a) + \rho_{PBH}(a)}{3M_{PL}^2}}$$

- Production of Gravitational Waves

Memory Burdened PBH

- The existing semiclassical framework : PBH is a classical object radiating quantum particles
- Semiclassical framework looses accuracy as it looses at most half of its initial mass
- Backreaction: quantum information retained in the system acts back on it leading to its stabilisation
- The evaporation rate decreases and quantified as a function of the PBH entropy

Ingredients of PBH Evaporation

- Important Parameters:

  1. PBH initial mass (M_{in})
  2. $\beta = \dfrac{\rho_{PBH}^{in}}{\rho_{Rad}^{in} + \rho_{PBH}^{in}}$
  3. q is the fraction of M_{in} when the memory effect kicks in
  4. k is a measure of the "strength" of the memory effect

Rate of Mass Loss

- The PBH entropy : $S = \frac{M_{BH}^2}{2M_P^2}$

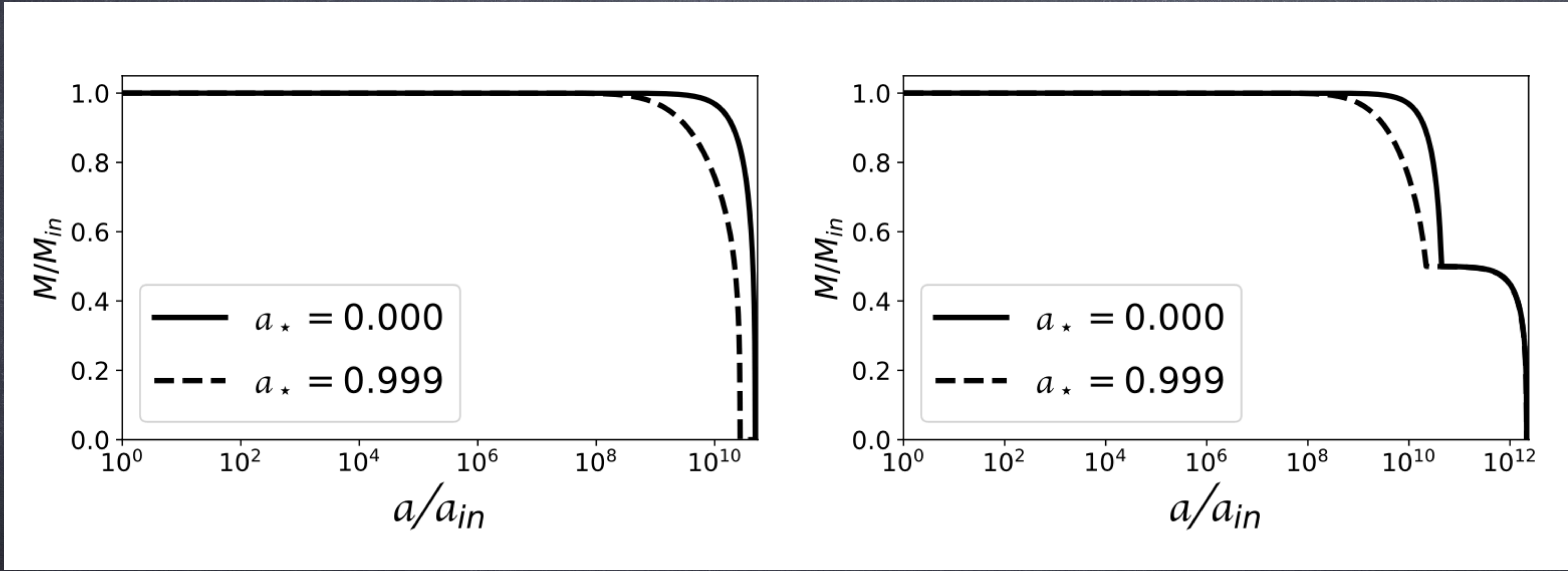
- Semiclassical rate : $\frac{dM_{BH}}{dt}|_{SC} = -\,\epsilon(a_\star, M_{BH})\frac{M_P^4}{M_{BH}^2}$

- Memory Burdened rate : $\frac{dM_{BH}}{dt}|_{MB} = -\,\epsilon(a_\star, M_{BH})\frac{M_P^4}{M_{BH}^2} \times \frac{1}{S^k}$

Dvali, Eisemann, Michel, Zell *PRD(2020)*;
Thoss, Burkert, Kohri *MNRAS(2024)*;
Alexandre, Dvali, Koutsangelas *PRD(2024)*

- The goal of this work is to constrain the value of k

M_{BH} as a function of scale factor(a)



FRISBHEE*

Gravitational Waves from PBH evaporation

- Graviton emission from PBH leads to production of gravitational waves (Schwarzschild case)

$$\Omega_{\rm GW}(f_0) = \frac{1}{\rho_c}\frac{d\rho(f_0)}{d\ln f_0} = \frac{g_h\,\pi}{2\,M_P^4\,\rho_c}\,f_0^4\int_{t_{\rm in}}^{t_{\rm ev}} dt\,\frac{M_{\rm BH}(t)^2\,n_{\rm BH}(t)}{\exp\left[2\pi\,f_0\,M_{\rm BH}(t)/(a(t)\,M_P^2)\right]-1}$$

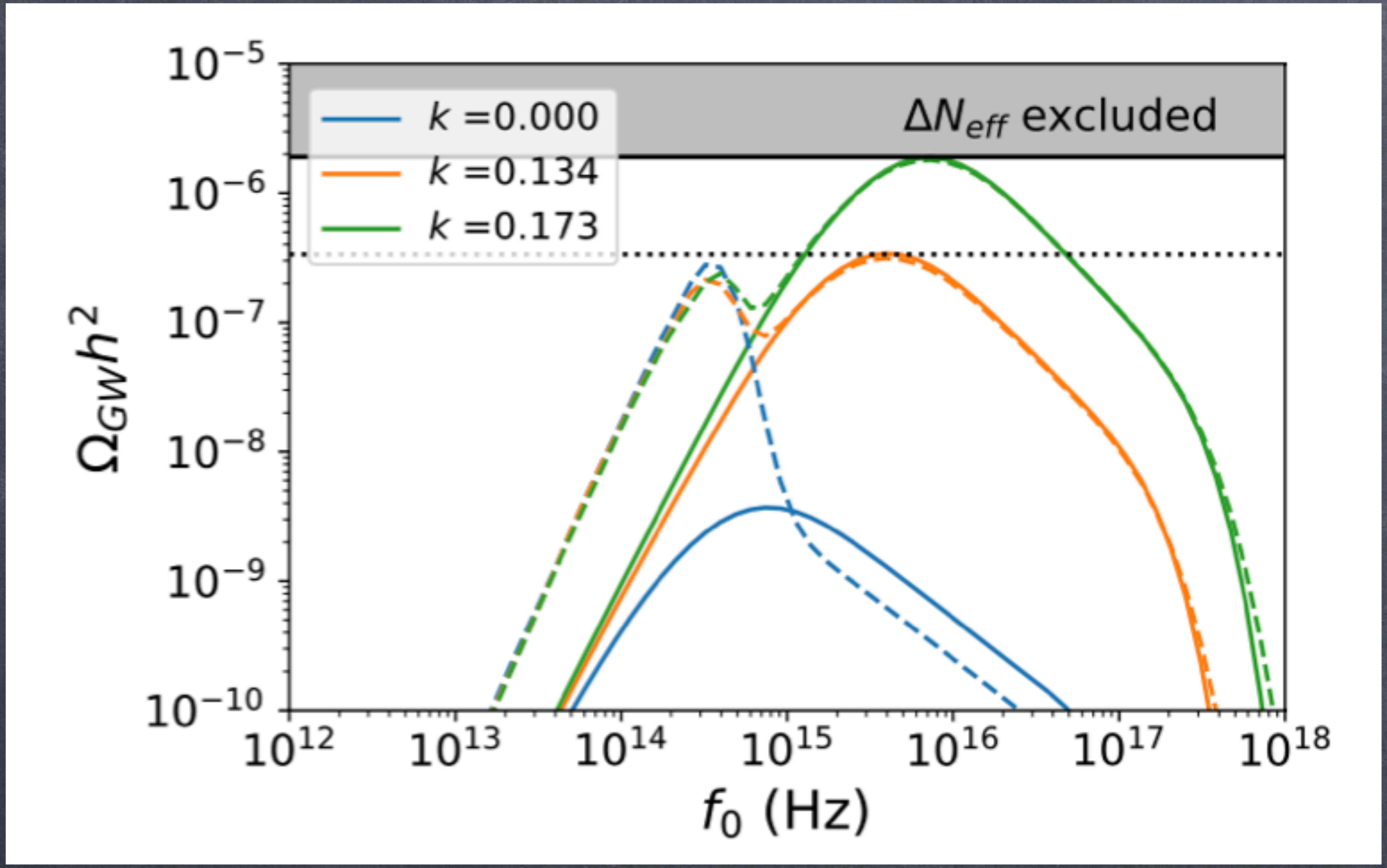
Inomata, Kawasaki, Mukaida, Terada, Yanagida *PRD(2020)*

- MB effect leads to over-production of GWs

- Bound from Cosmic Microwave Background Radiation

$$\int\frac{df_0}{f_0}\,h^2\,\Omega_{\rm GW}(f_0)\lesssim 5.62\times10^{-6}\,\Delta N_{\rm eff} \approx \Omega_{\rm GW}\,h^2(f_0)\lesssim 5.62\times10^{-6}\,\Delta N_{\rm eff}$$

Gravitational Wave Enhancement

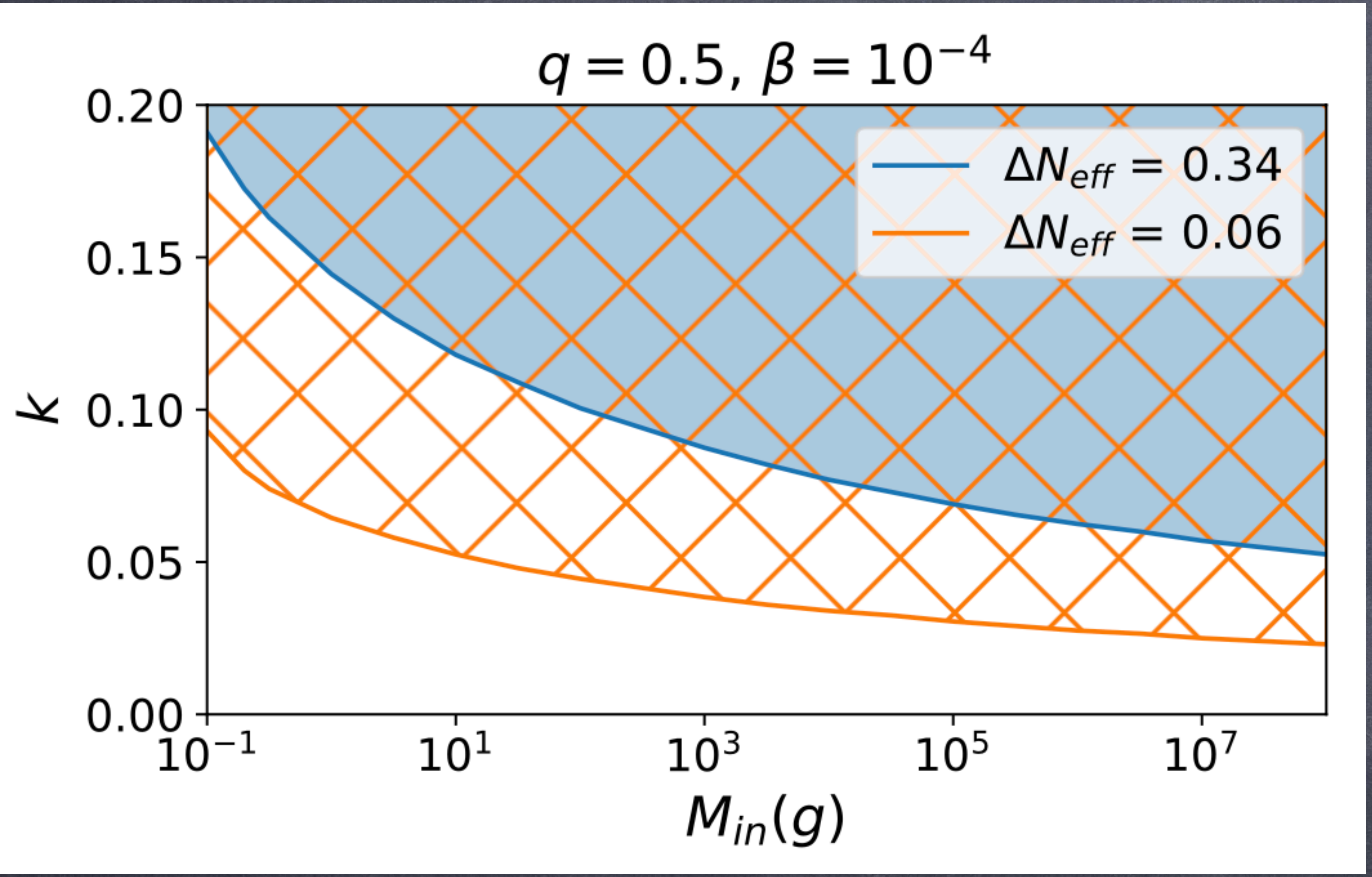


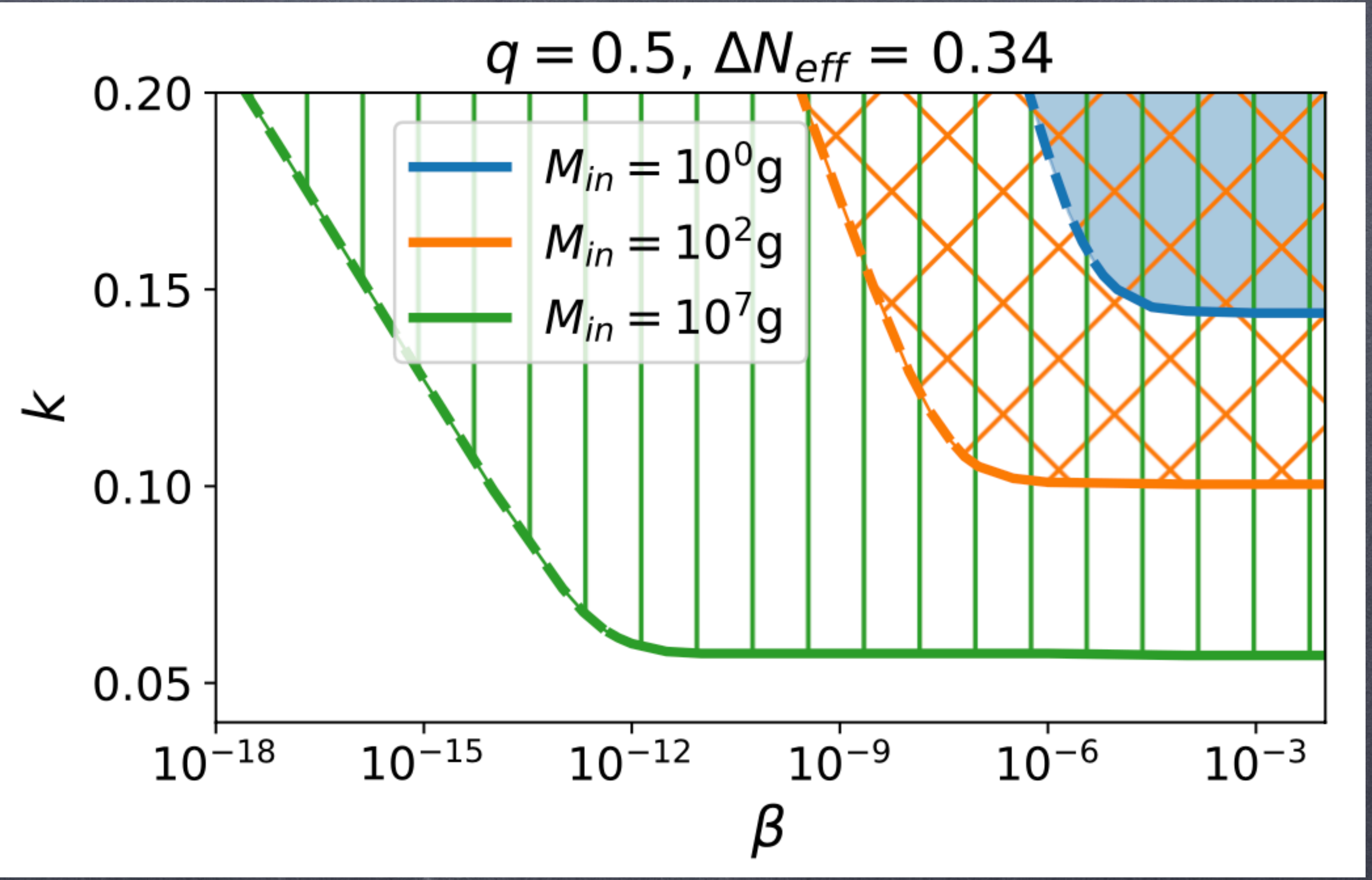
Benchmark Values

- $M_{in} = 10^2\ g$
- $q = 0.5$
- $\beta = 10^{-9}$

- Black solid (dotted) line $\rightarrow$ $\Delta N_{eff} = 0.34(0.06)$
- Solid (dashed) coloured lines $\rightarrow$ Schwarzschild (Kerr) PBH

Constraints on k





Conclusion: MB effect is quite stringently constrained
And will be probed further with CMB-S4

Acknowledgements

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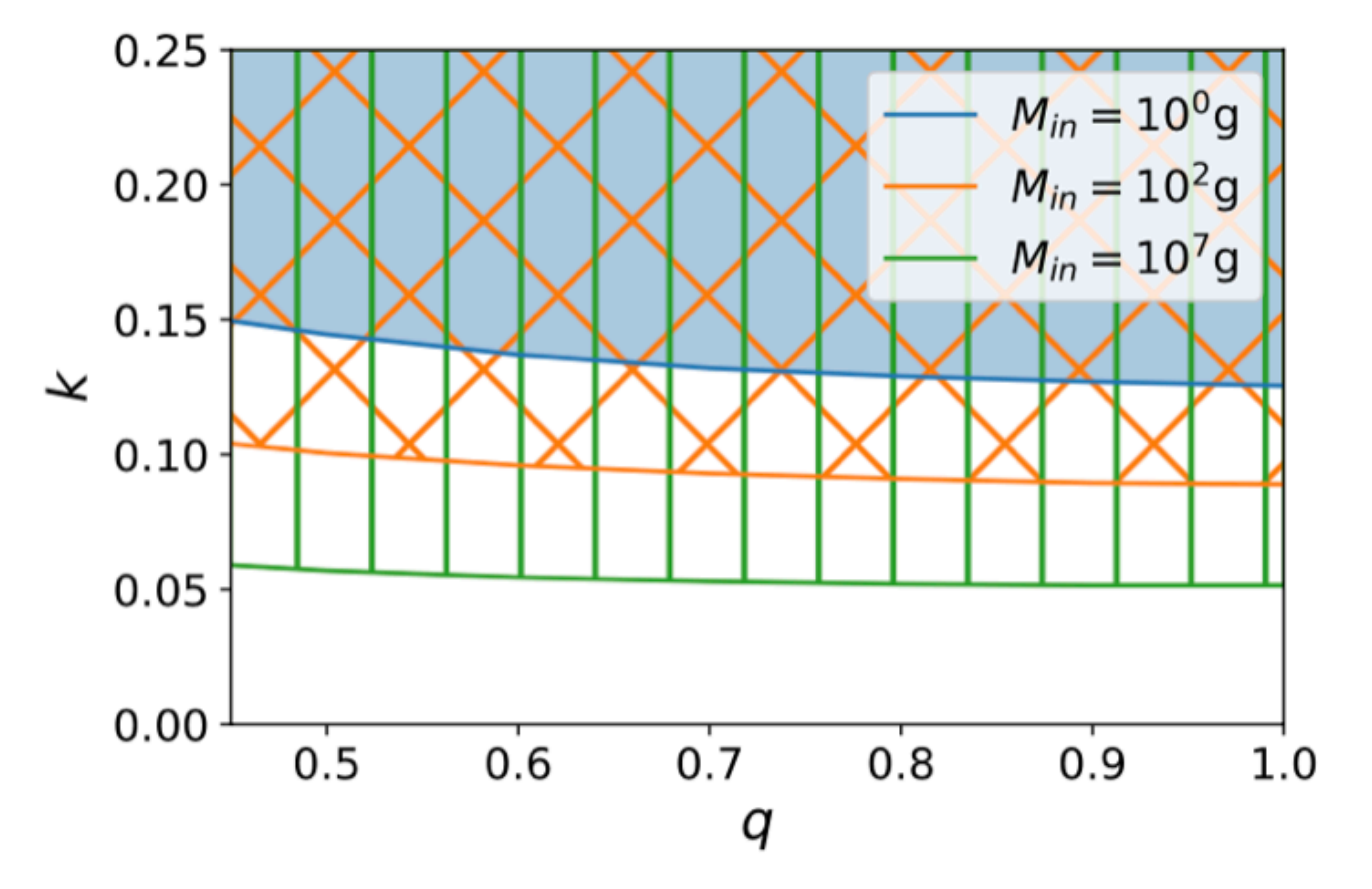
Thank you for your attention

Additional Slides



Additional Slides