Thermal dark matter and Primordial Black Holes

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Prelude

- Early universe cosmology may lead to the formation of the primordial black holes (PBHs).
- The total dark matter (DM) maybe consists of the 'particle DM' and the PBHs.
- It's useful to define the quantity, $f_{\rm PBH} \equiv \Omega_{\rm PBH}/\Omega_{\rm DM}$, where, $\Omega_{\rm PBH}$ is the current density parameter for the PBHs, and, $\Omega_{\rm DM}$ is the density parameter for the total dark matter as observed today.
- Formation of 'particle DM' halos around the PBHs may lead to observable gamma-ray signals as a result of dark matter self annihilations. (**Mack et al. 2007; Ricotti et al. 2007, 08; Ricotti & Gould 2009; Scott & Sivertsson 2009**)

Dark Matter density profile around PBH

$$\rho(\tilde{r}) = \frac{8}{\tilde{r}} \int_0^\infty d\beta_i \beta_i \int_0^\infty d\tilde{r}_i \tilde{r}_i \rho_i(\tilde{r}_i) f(\beta_i, \tilde{r}_i) \left(\frac{1}{\tilde{r}_i} - \beta_i^2 \right)^{3/2} \int_{\sqrt{\mathcal{Y}_m}\Theta(\mathcal{Y}_m - 0)}^1 \frac{dy}{\sqrt{y^2 - \mathcal{Y}_m}}$$

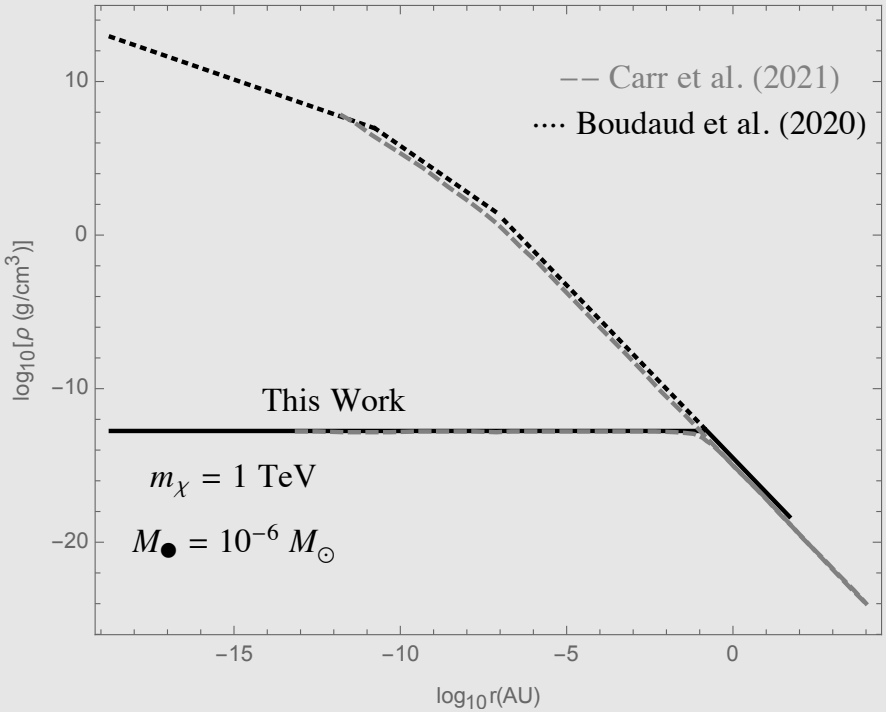
$f(\beta_i, \tilde{r}_i)$ is the fraction of dark matter particles with velocities between β_i and $\beta_i + \mathrm{d}\beta_i$ given by

$$4\pi\beta_i^2 \mathrm{d}\beta_i f(\beta_i, \tilde{r}_i) = \frac{4\pi\beta_i^2}{(2\pi\sigma_i^2)^{3/2}} \exp\left(-\frac{\beta_i^2}{2\sigma_i^2} \right) \mathrm{d}\beta_i$$

$$\mathcal{Y}_m = 1 + \frac{\tilde{r}^2}{\tilde{r}_i^2} \left[\frac{1}{\beta_i^2} \left(\frac{1}{\tilde{r}_i} - \frac{1}{\tilde{r}} \right) - 1 \right], \qquad \tilde{r} = r/r_{\mathrm{Sch}}, \qquad r_{\mathrm{Sch}} = 2GM_\bullet/c^2.$$

Boudaud et al. (2021), arXiv: 2106.07480v2

Dark Matter density profile around PBH



$$\rho(r) \sim \begin{cases} r^{-3/4} & r < r_A \\ r^{-3/2} & r_A < r < r_B, \\ r^{-9/4} & r_B < r < r_C, \\ 0 & r > r_C \end{cases}$$

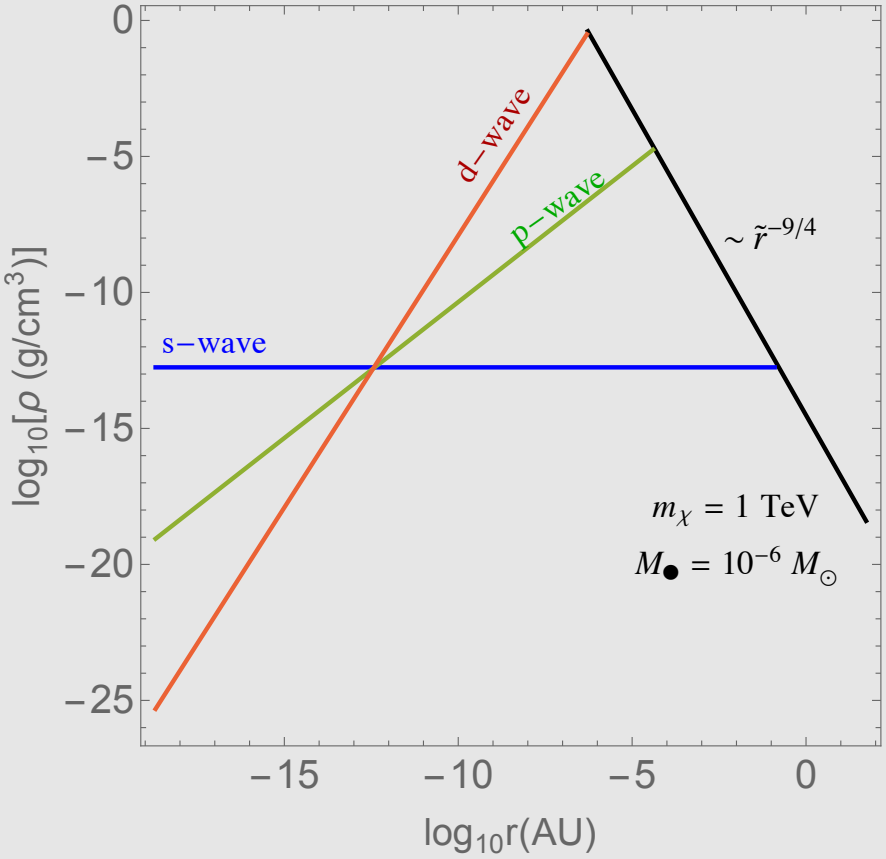
Eroshenko et al. (2016), arXiv: 1607.00612v2

Boudaud et al. (2021), arXiv: 2106.07480v2

Carr et al. (2021), arXiv: 2011.01930v4

Effect of DM self-annihilation

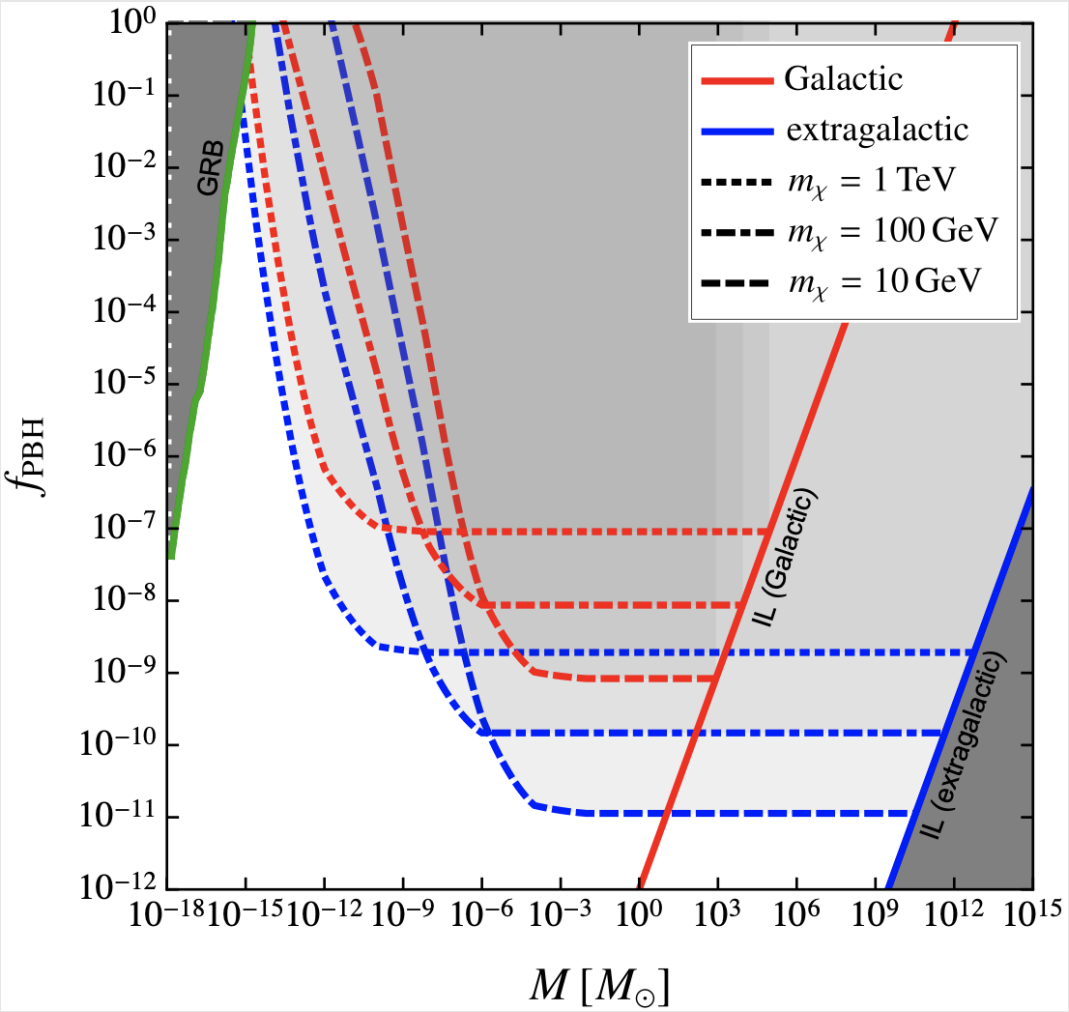
- **Expansion of thermally averaged annihilation cross-section**
  $\langle \sigma v \rangle = \langle \sigma_s + \sigma_p v^2 + \sigma_d v^4 + \cdots \rangle$.
- The core density of the DM halo near the PBH is set to have a maximum value by the DM annihilations $\rho_{\rm Max} \sim \frac{m_\chi}{\langle \sigma v \rangle t_{\rm halo}}$.



The s-wave: Black holes and WIMPs can't coexist

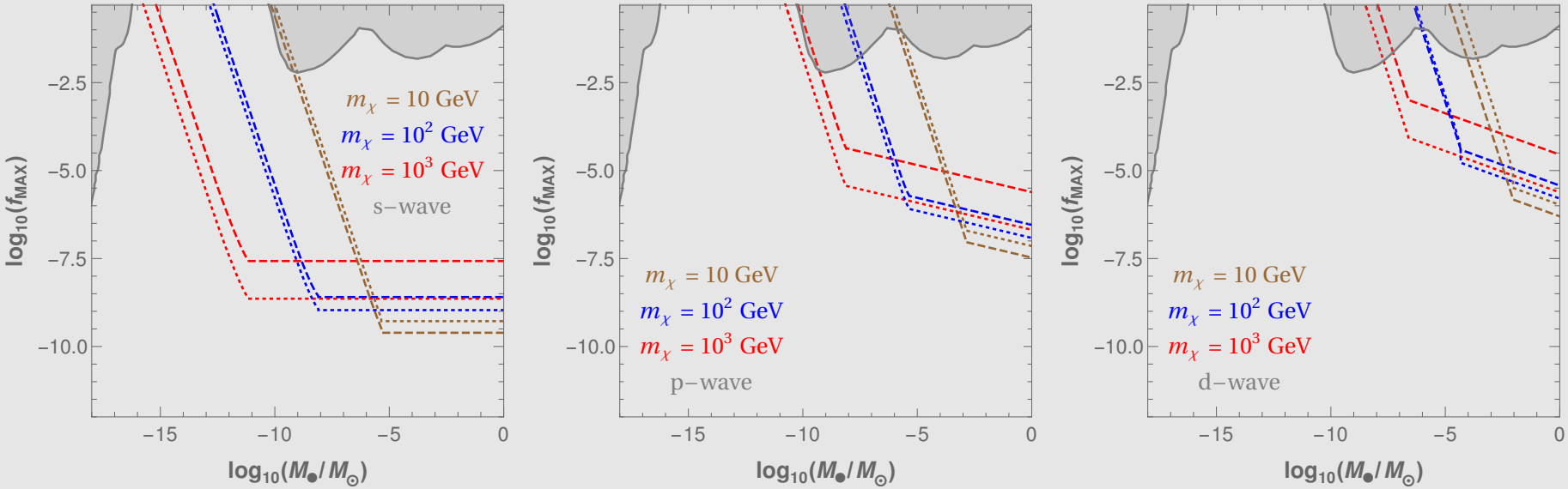
- "Primordial Black Holes as Dark Matter: Almost All or Almost Nothing", Lacki & Beacom (2010).
- "WIMPs and stellar-mass primordial black holes are incompatible", Adamek et al. (2019): For DM mass $10 - 10^3$ GeV, $f_{\rm PBH} \lesssim 10^{-9}$.
- "Black Holes and WIMPs: All or Nothing or Something Else", Carr et al. (2020), arXiv: 2011.01930v4.

The s-wave: Black holes and WIMPs can't coexist



Carr et al. (2021), arXiv: 2011.01930v4

Motivation: p- and d-wave



Conclusions

- The p-wave and d-wave case helps in amelioration of the bounds on f_{PBH}, making those very interesting scenarios.
- Notably, the p-wave freeze-out scenario is very common in the Beyond Standard Model scenario.
- For p-wave and d-wave dark matter with non-zero s-wave contribution, we observe s-wave behavior beyond a characteristic radius.

Thank You!