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Primordial Black Hole Evaporation and Dark Matter Production

MultiDark 19

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Based on: arXiv:2107.00013 and arXiv:2107.00016 both in PRD "Editors suggestion"

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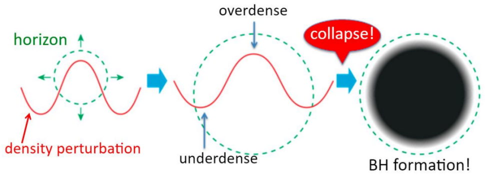
Primordial Black Holes

- Hypothetical black holes formed before stellar formation.
- Come from extremely dense matter fluctuations in the early Universe.
- These density perturbations are not produced in standard slow roll inflation.



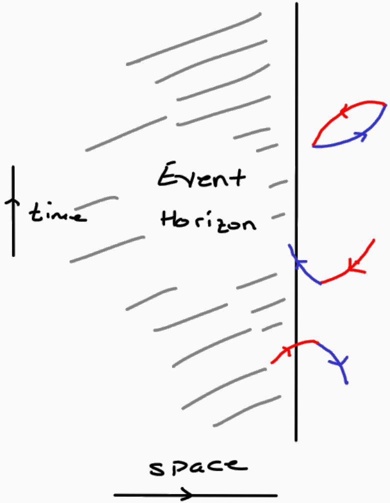
[picture borrowed from N. Kitajima]

Hawking radiation

- Hawking radiation gives a lifetime to all BHs

$$t_{\rm ev} \sim (M_{\rm BH}^{\rm in})^3/(3M_{\rm pl}^4)$$

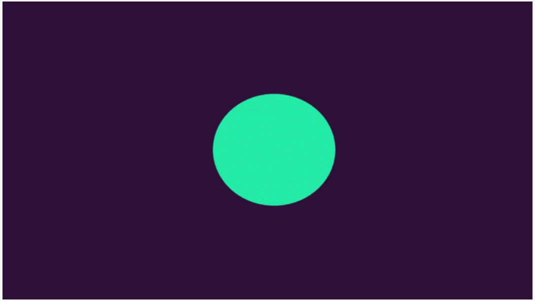
- Since $t_{\rm univ.} \sim 13 \times 10^9\,{\rm yr}$ PBHs with $M_{\rm BH}^{\rm in} \lesssim 10^{14}\,{\rm g}$ would no longer exist.
- Stable BHs will contribute to $\Omega_{\rm DM} h^2$ (Not the topic of this talk).
- However BHs radiate all particles, regardless of interactions, so they could produce non-interacting dark matter!



Black Hole evaporation is a very efficient way to produce dark matter!

Pessimist's motivation to study it:

- We have a way of producing dark matter which doesn't require any interactions other than gravity.
- This would be very difficult to test.
- arXiv:2107.00013 is dedicated to this, where we fully track the coupled system in probably the most precise way.



Black Hole evaporation is a very efficient way to produce dark matter!

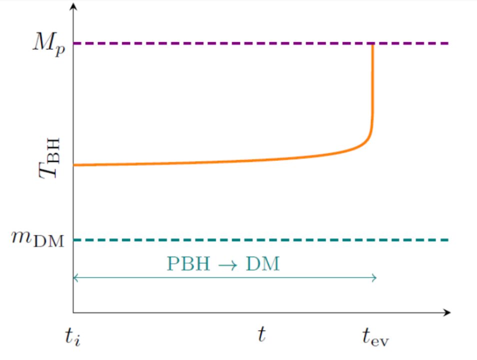
Optimist's motivation to study it:

- Many models predict interactions between the SM and dark matter.
- Current and near future experiments may even measure this interaction.
- Dark matter detection could be an indirect probe into PBH's in early Universe.
- arXiv:2107.00013 is dedicated to this, where we make use of the code developed and now include an interacting dark matter model.

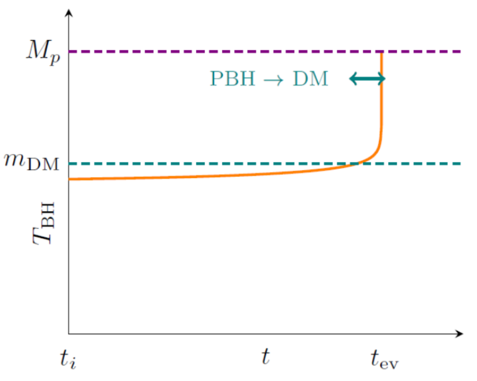
Any particles with $m_{\rm DM} < M_{\rm p}$ will be emitted

- Two separate regimes of particle production for stable particles

$$N_{\rm DM} \approx \frac{120\zeta(3)}{\pi^3}\frac{g_i}{g_\star(T_{\rm BH})}\frac{M_{\rm BH}^2}{M_{\rm pl}^2}\,.$$

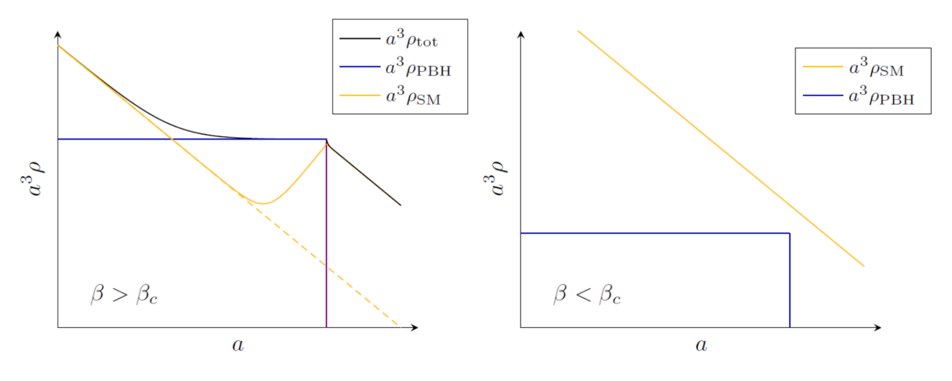


$$N_{\rm DM} \approx \frac{15\zeta(3)}{8\pi^5}\frac{g_i}{g_\star(T_{\rm BH})}\frac{M_{\rm pl}^2}{m_{\rm DM}^2}$$



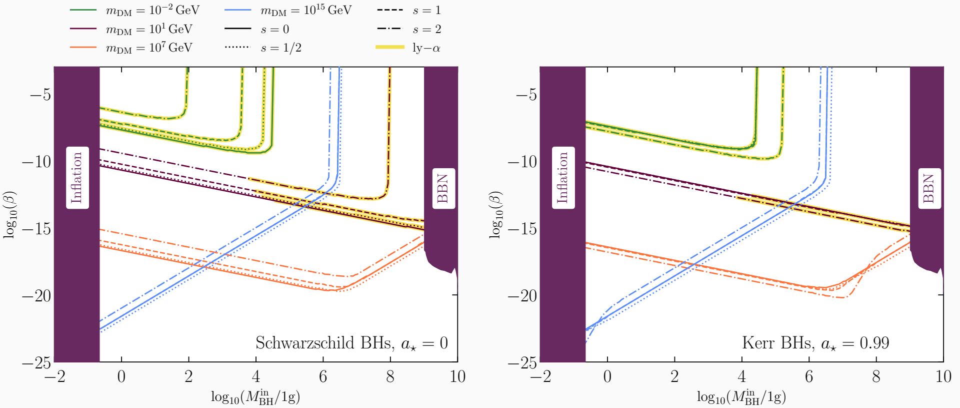
Primordial black hole abundance

- PBH abundance is parameterized by $\beta \equiv \frac{\rho^{i}_{\rm BH}}{\rho^{\rm i}_{\rm tot}}$
- PBHs could dominate in early times



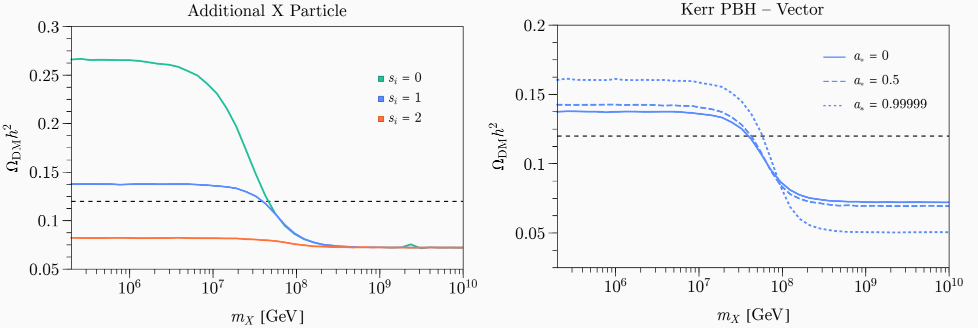
Dark Matter from just PBHs

- We calculate $\Omega_{\rm DM} h^2$ for different particle spins.
- Additional, for spinning BHs ($a_\star \neq 0$).



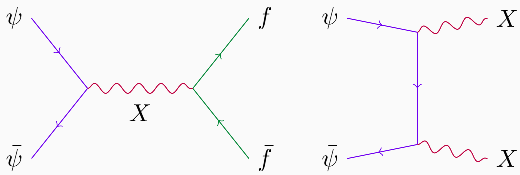
Effect of extended dark sectors

- Multiple particles are predicted in many BSM models, with dark matter being the lightest one.
- Consider one extra particle and fermionic DM, $X \to 2\mathrm{DM}$.



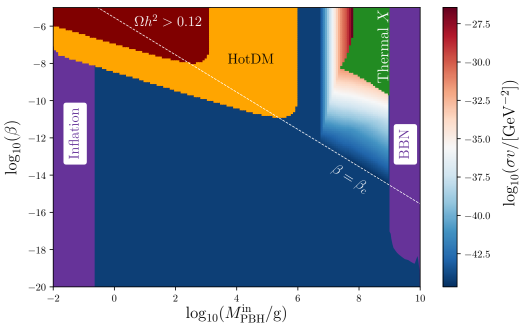
Freeze-In Dark Matter with PBHs

We considered a vector-mediated, fermionic dark matter model

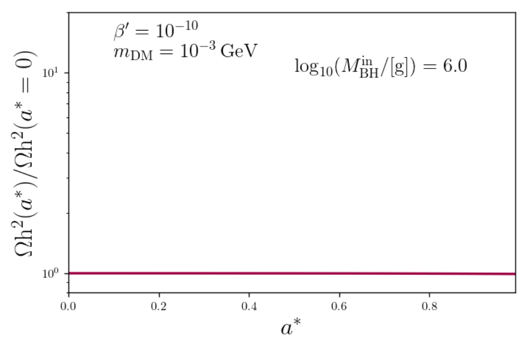


and systematically explore the parameter space

Here $m_{\rm DM} = 1$ MeV and $m_X = 1$ TeV



- The way PBHs reheat the thermal plasma depends on $a_\star$.
- This can mean that $T^{\mathrm{univ.}} \sim m_X$ for longer.
- On this resonance is when more DM particles are produced through standard freeze-in.

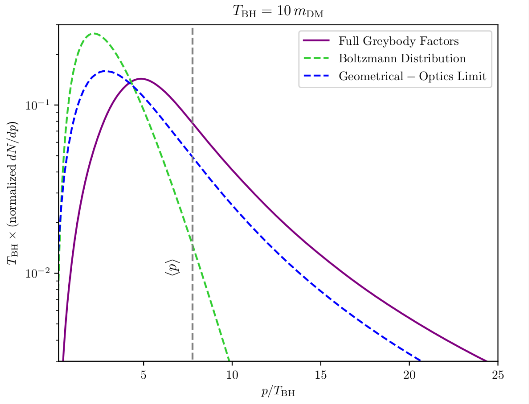


Current work: improving warm dark matter limits

- In our previous work, we performed a naive estimation for the warm dark matter constraint.

$$\langle p_{\mathrm{DM}} \rangle = \int p_{\mathrm{DM}} \frac{\mathrm{d}\mathcal{N}_{\mathrm{DM}}}{\mathrm{d}p_{\mathrm{DM}}}$$

$$v_0 = \left(\frac{a_{\mathrm{ev}}}{a_0} \right) \frac{\langle p_{\mathrm{DM}} \rangle}{m_{\mathrm{DM}}}$$

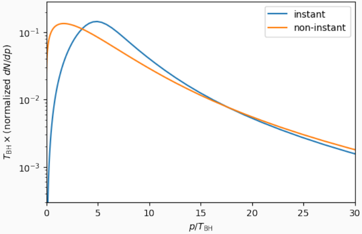


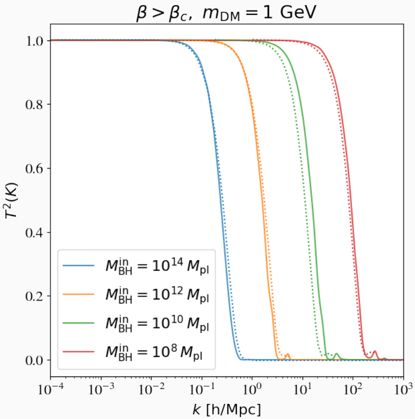
Current work: using our code with a CMB calculator

- Baldes et. al (2020) already performed an analysis with CLASS.
- Which includes phase-space effects from non-instantaneous evaporation

$$P_\chi(k) = P_{\rm CDM}(k)\, T_\chi^2(k)$$

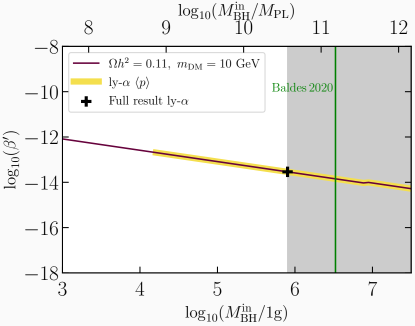
$$\frac{\mathrm{d}N}{\mathrm{d}p} = \int_0^\tau \mathrm{d}t' \frac{a(\tau)}{a(t)} \times \frac{\mathrm{d}^2 N}{\mathrm{d}p'\mathrm{d}t'}\left(p\frac{a(\tau)}{a(t)}, t\right)$$





Current work: using our code with a CMB calculator

- Previously only done with approximate phase spaces and with Schwarzchild BHs.
- Our code keeps track of all emitted particles and when.
- We've already seen effects on fermion dark matter with Schwarzchild and we expect greater effects for Kerr BHs.



Conclusions

- PBHs could have been a big player in the Early Universe.
- If heavy BSM particles exist, evaporating BHs will produce them.
- This is a really efficient way of producing non-interacting dark matter.
- On the other hand, the detection of dark matter would have implications for the fairly unconstrained region of $M_{\rm PBH} \sim [10^{-1}, 10^{9}]\,{\rm g}$.
- With our code, available on GitHub, we have started a program of understanding the dynamics at play with interacting dark matter and PBH evaporation.

From Inflation to BBN: the PBH playground

- Particle injection from PBH evaporation during nucleosynthesis has severe consequences for BBN.
- CMB limits on Hubble scale during inflation, which limits the scale of density fluctuations.
- Green constraints come from gravitational waves of simultaneous PBH evaporation.