Isolated sector production from primordial BHs

Hannah Tillim

Oxford University (supervisors J. March-Russell & S. M. West)

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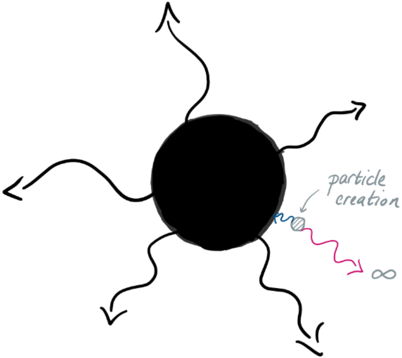
Dark Matter from Primordial Black Holes

O. Lennon, J. March-Russell, R. Petrossian-Byrne, H. Tillim,
Black Hole Genesis of Dark Matter, *JCAP* **1804** (2018), arXiv:1712.07664

Isolated sector DM

- The WIMP paradigm - requires couplings between sectors - much of the parameter space now explored
- Important to explore alternatives

"Isolated"
Interactions with SM purely gravitational

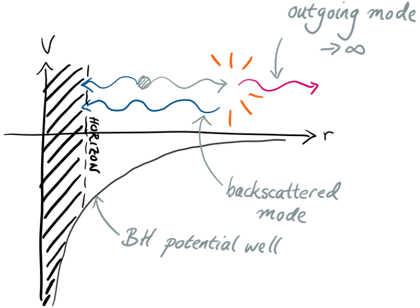


- Production mechanisms (freeze-out, freeze-in) not applicable to isolated sectors
- Coupling to gravity → Hawking radiation

Hawking radiation

Hawking temperature:

$$T_{\rm BH} = \frac{M_{\rm Pl}^2}{8\pi M_{\rm BH}}$$



Hawking radiation rate:

$$\mathrm{d}\left(\frac{\mathrm{d}N_{s,i}}{\mathrm{d}t}\right) = \sum_{\ell,h} \frac{(2\ell+1)}{2\pi} \frac{\Gamma_{i,s,\ell,h}(\omega)}{\exp(\omega/T(t)) + (-1)^{(2s+1)}} \mathrm{d}\omega$$

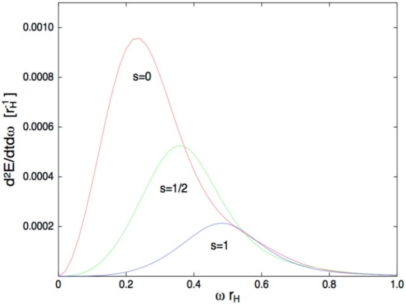
S. Hawking, Commun.Math.Phys. 43 (1975) 199-220
D. Page, Phys. Rev. D13 (1976) 198206

Hawking radiation

$$\rightarrow N_{s,i} \simeq \frac{f_{s,i} g_{s,i}}{2e_{\rm T}} \left(\frac{M_0}{M_{\rm Pl}}\right)^2 \begin{cases} 1 & (T_0 > m_i/d_s) \\ d_s^2 T_0^2/m_i^2 & (T_0 < m_i/d_s) \end{cases}$$

Spin	e_s	f_s
0	7.24×10^{-5}	6.66×10^{-4}
1/2	4.09×10^{-5}	2.43×10^{-4}
1	1.68×10^{-5}	7.40×10^{-5}
3/2	5.5×10^{-6}	2.1×10^{-5}
2	1.92×10^{-6}	5.53×10^{-6}

$$e_T = \sum_{i,s} g_{i,s} e_{i,s}$$



Setup

- **Model:**
  - Population of micro pBHs with near-uniform initial density n_0
  - Any other initial energy density is SM radiation (no DM)
  - DM is single species, long-lived, sub-Planckian massive particles, spin ≤ 2
- **Simplifying assumptions:**
  - All Schwarzschild
  - All masses $= M_0$
  - $T_0 > v_W$

Setup

$$\frac{\mathrm{d}\rho_{\mathrm{BH}}}{\mathrm{d}t} + 3H\rho_{\mathrm{BH}} = -e_{\mathrm{T}}\frac{M_{\mathrm{Pl}}^4}{M^2}n$$

$$\frac{\mathrm{d}\rho_{\mathrm{rad}}}{\mathrm{d}t} + 4H\rho_{\mathrm{rad}} = +e_{\mathrm{T}}\frac{M_{\mathrm{Pl}}^4}{M^2}n$$

$$H(t)^2 = 8\pi(\rho_{\mathrm{BH}} + \rho_{\mathrm{rad}})/3M_{\mathrm{Pl}}^2$$

$$\frac{\mathrm{d}M}{\mathrm{d}t} = -\frac{M_{\mathrm{Pl}}^4}{M^2}\sum_{s,i} e_{s,i}g_{s,i} \equiv -e_{\mathrm{T}}\frac{M_{\mathrm{Pl}}^4}{M^2}$$

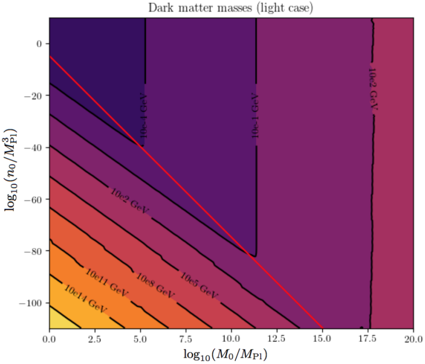
- Fast vs. slow evaporation
- Light vs. heavy DM
- Yield $Y_i \equiv n_i/s_{\mathrm{tot}}$

Light DM results

$$Y_i^{\text{slow}} \simeq \frac{1}{2}\frac{f_{s,i}g_{s,i}}{g_*^{\frac{1}{4}}e_{\text{T}}^{\frac{1}{2}}}\left(\frac{M_{\text{Pl}}}{M_0}\right)^{\frac{1}{2}}$$

$$Y_i^{\text{fast}} \simeq \frac{1}{2}\frac{f_{s,i}g_{s,i}}{g_*^{\frac{1}{4}}e_{\text{T}}}\left(\frac{n_0}{M_{\text{Pl}}^3}\right)^{\frac{1}{4}}\left(\frac{M_0}{M_{\text{Pl}}}\right)^{\frac{5}{4}}$$

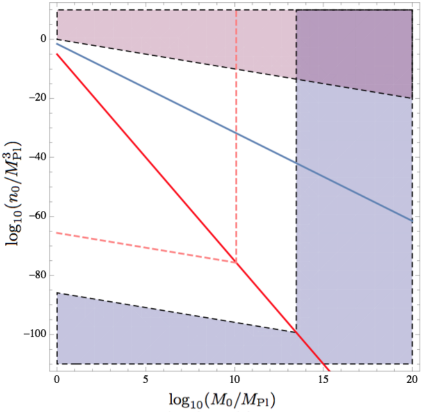
- $Y \times m_{\text{DM}} = 0.43$ eV



Light DM constraints

Constraints for single real $s = 0$ dof *before* free-streaming constraint is imposed.

- red line: $B_0 = 1$
- blue line: one pBH per initial Hubble patch
- blue shaded regions: $T_{RH} < 3\,\mathrm{MeV}$
- pink, dotted line: $T_{RH} = 200\,\mathrm{GeV}$.
- upper purple region: $\rho_{BH}(0) > M_{\mathrm{Pl}}^4$.



Free streaming: excludes most of light region (for $s < 3/2$)

Thermalisation

Ongoing work with J. March-Russell, S. M. West

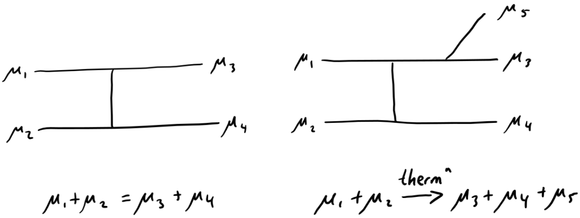
Thermalisation

- Emitted with non-thermal spectrum and very high energy tail
- Underpopulated compared to equilibrium density
- Require redistribution of energy $(2 \to 2)$ and particle creation $(2 \to 3 \ldots)$

Kinetic	$f(p) = 1/(\exp[-(E-\mu)/T] \pm 1)$
Thermal	$T_i = T$
Chemical	$\sum \mu_i^{\text{in}} = \sum \mu_j^{\text{fin}}$

- Other studies in this direction: S. Davidson & S. Sarkar arXiv:0009.078v3; M. Garny et. al. arXiv:1810.01428, S. Heeba; F. Kahlhoefer & P. Stöcker arXiv:1809.04849, ...

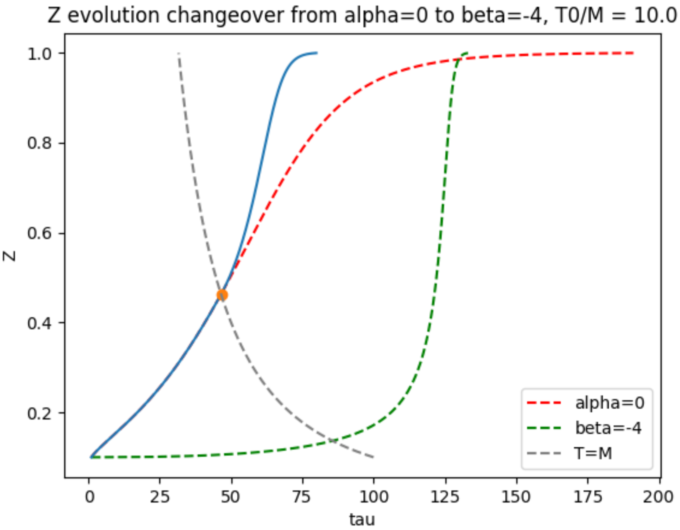
Thermalisation



- Kinetic, thermal and 'partial chemical' → evolution to full chemical
- Boltzmann equation governs evolution - depends on a collision term

$$\dot{n} + 3Hn = \frac{g}{\pi^2} \int \mathrm{d}^3 p \mathbf{C}[f]$$

Thermalisation: interim results



What's next

- Robust model-independent framework for estimating thermalisation timescales
- Concrete pheno of permanently underpopulated sectors
- Application to pBH production model to reopen light DM case

Thank you!

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