Heavy warm dark matter from supercooling

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In collaboration with Yann Gouttenoire and Filippo Sala

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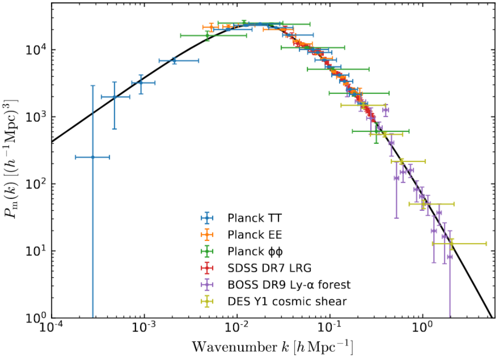
Non-Cold Dark Matter



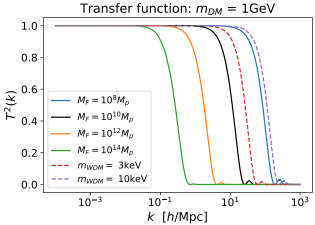
- Planck Collab. 1807.06205

High speed DM at late times $\rightarrow$ suppression of small scale structure

DM Velocity

For standard WDM:

$$v(t_{\rm eq}) \approx 9 \times 10^{-5} \left(\frac{3\ \mathrm{keV}}{m_{\rm WDM}}\right)^{4/3}$$



- IB et al. 2004.14773

Can be used as a proxy for other scenarios.
Future constraint $m_{\rm WDM} \sim 10$ keV.

Examples

1. DM from evaporating PBHs - e.g. Fujita et al. 1401.1909
2. Inflaton Decay - Ballesteros et al. 2011.13458
3. Freeze-in - e.g. Ballesteros et al. 2011.13458
4. Super-WIMP Decay - e.g. Decant et al. 2111.09321

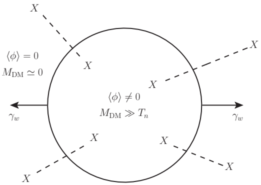
Phase Transition

Question

Can we get Non-Cold DM from a phase transition?

Also see Monday's talk by Christian Döring (2107.10283) for an alternative way a PT can affect structure.

Phase Transition



Particles gaining a mass during a PT $\rightarrow$ boosted in the plasma frame.

$$\mathcal{L} \supset \lambda\phi^2 X^2$$

Can we use this to get NCDM? No, due to small $m_{\rm DM}/T_{\rm RH}$.

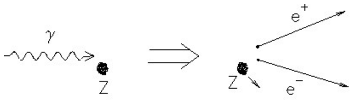
Problems:

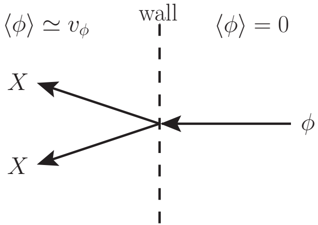
1. DM does not get a large enough momentum kick unless $\lambda \gg 1$.
2. DM comes back into kinetic equilibrium after the PT.

Phase Transition

- Simplest idea didn't work.
- We need to go to a slightly more complicated DM scenario.
- Eventually we get $m_{\mathrm{DM}} \sim 10^8$ GeV Non-Cold DM from a FOPT.

DM production





Instead produce DM at the wall - Azatov, Vanvlasselaer, Yin 2101.05721

$$\mathcal{L} \supset \frac{1}{2} m_{\rm DM}^2 X^2 + \frac{1}{4}\lambda \phi^2 X^2$$

We can have $m_{\rm DM} \gg \langle\phi\rangle \sim m_\phi$.

Probability

$$P(\phi \to X + X) = \frac{\lambda^2 v_\phi^2}{96\pi^2 m_{\rm DM}^2} \qquad \text{for} \quad \gamma_{\rm wp} \sim \frac{T_n M_{\rm Pl}}{T_{\rm RH}} \gtrsim \frac{L_w m_{\rm DM}^2}{T_n}$$

DM Abundance and velocity

Assuming zero initial abundance (possible because $m_{\rm DM} \gg T_{\rm RH}$):

$$Y_{\rm DM} \approx \frac{\lambda^2 v_\phi^2}{m_{\rm DM}^2} \left(\frac{T_n}{T_{\rm RH}} \right)^3 \simeq \frac{0.43\ {\rm eV}}{m_{\rm DM}}$$

Two solutions possible for $\Omega_{\rm DM}$.

1. Rad Dom: $T_n \simeq T_{\rm RH} > T_{\rm infl}$.
2. Vac Dom: $T_{\rm RH} \simeq T_{\rm infl} > T_n$.

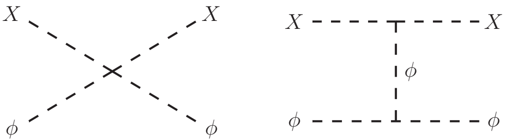
In a subset of parameter space late time velocity of DM also large.

DM velocity

From $\gamma_{\rm DM} \approx m_{\rm DM}/T_n$ one finds

$$v(t_{\rm eq}) \approx \frac{T_\gamma^{\rm eq}\, m_{\rm DM}}{T_{\rm RH}\, T_n}$$

This is compared to the limit $v(t_{\rm eq}) \lesssim 10^{-4}$ from standard WDM models.

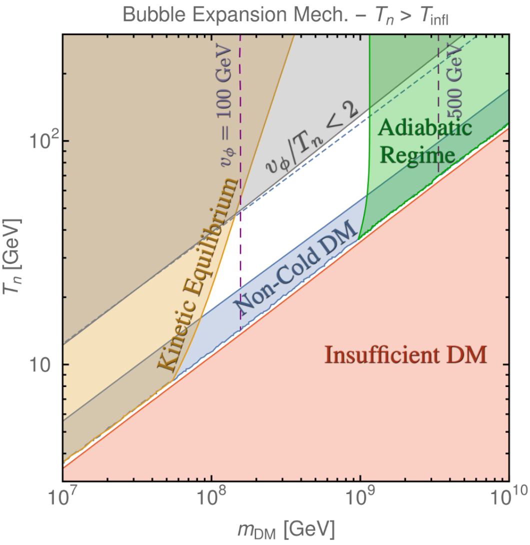


We need to avoid momentum loss

$$n_\phi \sigma(X\phi \to X\phi) v_{\rm rel} \frac{\delta p_{\rm DM}}{p_{\rm DM}} = n_\phi \frac{\lambda^2}{16\pi \hat{s}} < H.$$

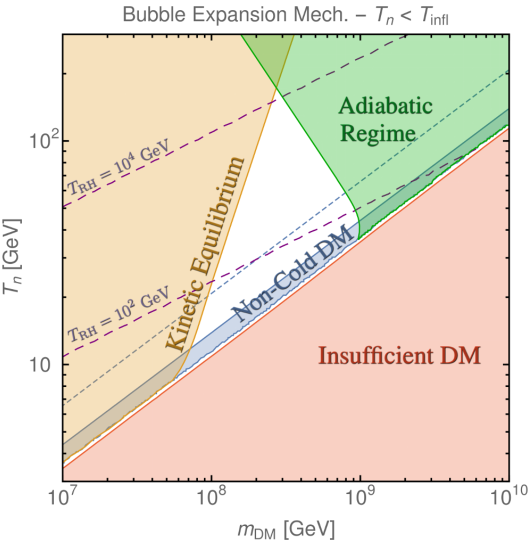
- Large $\hat{s}$ helps us.
- For $T \lesssim m_\phi \approx T_{\rm RH}$, $n_\phi \propto {\rm Exp}[-m_\phi/T]$.

Results



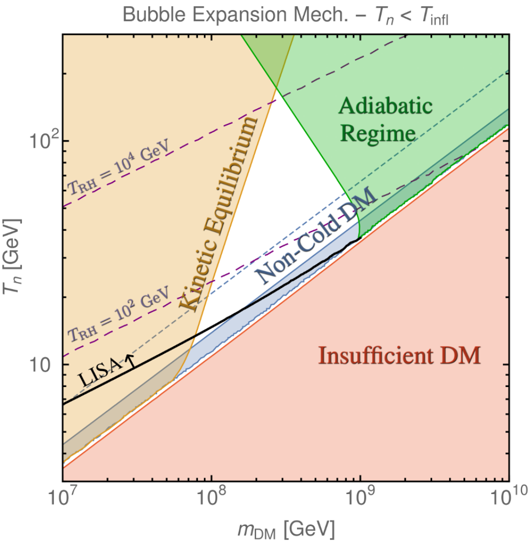
Phase transition during radiation domination.

Results



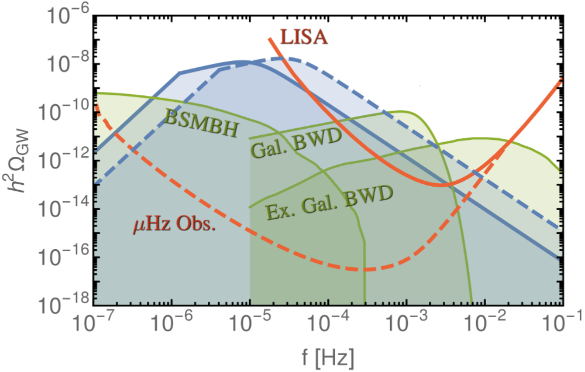
Phase transition during vacuum domination.

Results



Phase transition during vacuum domination.

Gravitational Waves

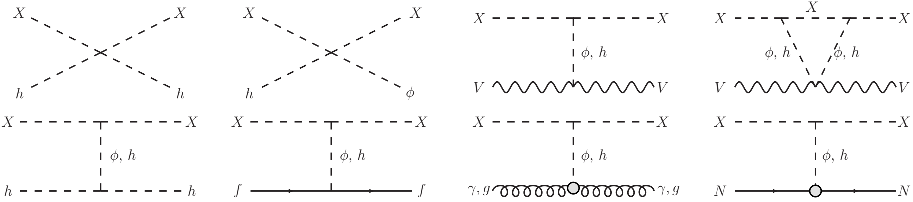


$m_{\rm DM} = 5 \times 10^8$ GeV, $\lambda = 1$, $\Lambda_{\rm vac} = 10^{-2} v_\phi^4$

$$f_{\rm peak} \propto T_{\rm RH}$$

Interactions with the SM

The ϕ can decay via a portal $\mathcal{L} \supset -\lambda_{h\phi}\phi^2|H|^2$.



These can also sap DM momentum. However it is easily possible to have $\lambda_{h\phi}$ small enough to avoid this while allowing for rapid ϕ decay.

Concluding Remarks

Conclusion

- Using Azatov/Vanvlasselaer/Yin production mechanism showed non-cold DM from a PT is possible.
- Generic signal: Ω_{GW} peaked towards the IR of the LISA sensitivity together with suppression of small scale structure.
- Crucial: ϕ not charged under a gauge symmetry.
- Z_2 for ϕ should be broken to avoid domain walls.
- If Z_2 for X also broken we get some indirect detection.
- Unobservable via direct detection.