Warm dark matter from a gravitational freeze-in in extra-dimensions

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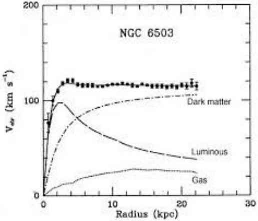
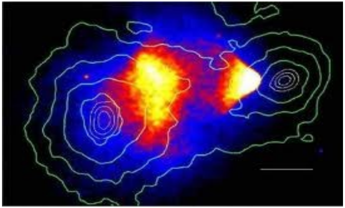
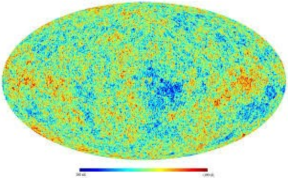
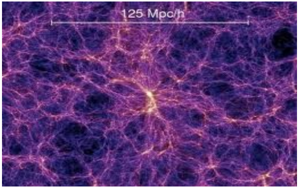
What we know









gravitational evidence for dark matter on all scales: rotation curves, clusters, large scale structure, CMB

$$\Omega h^2 \approx 0.12$$

All evidence is gravitational!

What if gravity is the only interaction of a dark matter particle?

Ideas discussed in the literature

- Planckian interacting dark matter 1511.03278
- gravitational production during inflation e.g. 1804.07471
- ...

common theme: very heavy dark matter with no associated observable

Can we keep simplicity of idea (gravitational interacting particle as dark matter) and allow for more interesting observational consequences?

Extra-dimensions

Nice feature: the UV-problems we introduce are similar to the ones we have with GR anyways

- one large extra-dimension/warped extra-dimension with two branes a la Randall-Sundrum
- only gravity propagates in 5th dimension
- all matter (SM and DM) on the brane

Production mechanism

Crucial part of interaction:

$$\mathcal{L} \supset \sum_i \frac{1}{\Lambda} T_{\mu\nu} h_i^{\mu\nu}$$

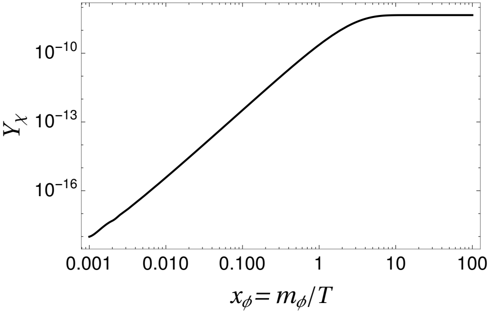
infinite tower of KK gravitons with increasing mass

- model characterized by three parameters
  - dark matter mass m_{DM}
  - first graviton mass m_1
  - strength of interaction Λ
- for $\Lambda = \mathcal{O}(\text{TeV})$ freeze-out possible
  possible but strongly constrained by LHC searches de Giorgi, SV 21
- for $\Lambda \gg 1$ TeV freeze-in production possible
  more about this option $\rightarrow$ rest of this talk

The idea: Freeze-in

- very weak interaction strength
- initially DM not part of the high energy plasma in the early Universe
- interactions too slow to reach equilibrium
- slow build up of population as Universe expands

$$\frac{\mathrm{d}Y_\chi}{\mathrm{d}x_\phi} = \frac{1}{3H}\frac{\mathrm{d}s}{\mathrm{d}x_\phi}\left[-\frac{\Gamma}{s}Y_\phi + \ldots\right]$$



Freeze-in extra-dimensions

- KK-graviton branching ratio to DM is $\mathcal{O}(10^{-2})$
  $\rightarrow$ thermalization hard to avoid if KK-gravitons part of plasma
  $\Rightarrow$ freeze-in of KK-gravitons that decay to DM later (sequential freeze-in)
- contributions from whole KK-tower needs to be taken into account

$$\frac{dY}{dT} = -\sum_i \frac{\gamma_i}{HsT}\mathcal{B}(h_i \to \bar{\psi}\psi)$$

- nice analytic approximations for sum over masses and temperature integral possible for all parameter ranges

e.g. for $m_1 \ll T_R$: $\quad Y \approx 4 \times 10^{-6} \frac{M_{Pl} T_r^2}{m_1 \Lambda^2}$

What are the signature?

- preferred parameters hard to test in experiments
  - LHC ✗
  - fifth force searches ✗
- parameters can be tested by cosmological observations
  - structure formation (warm dark matter) ✓
  - BBN ✓

Warm dark matter 101

Note: Simplified arguments!

- KK-gravitons long-lived and redshift as matter
  $\rightarrow$ DM produced with momentum $p \gg T_{SM}$
  $\Rightarrow$ warm dark matter with non-thermal velocity distribution
- free streaming erases structures smaller than distance traveled since production

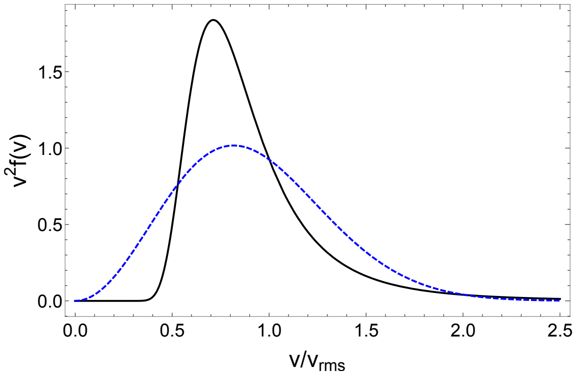
$$\lambda_{FS} = \int_1^{a_{prod}} da \frac{v(a)}{H(a)}$$

- warm dark matter $\rightarrow \lambda_{FS}$ at the edge of observational limits
  $\Rightarrow v_{today} \lesssim 7$ m/s
- velocity of particle produced from decay of heavy parent is

$$v_{0,i} \approx \frac{m_i}{2m_{DM}} \frac{a_d}{a_0} = \frac{m_i}{2m_{DM}} \left(\frac{g_0}{g_d}\right)^{1/3} \frac{T_0}{T_d}$$

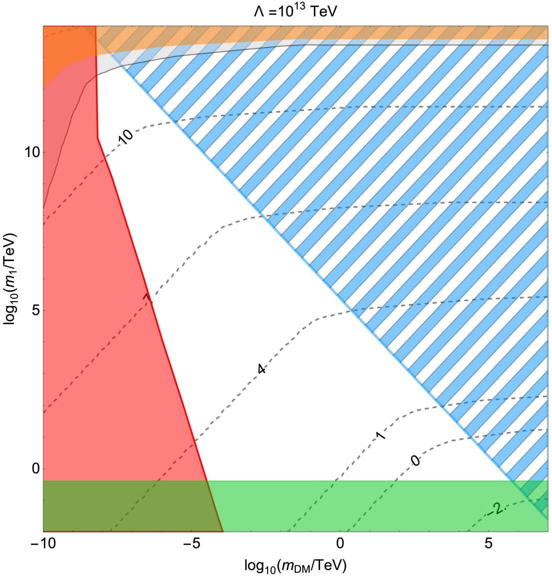
- $\Rightarrow$ can compute v (or $f(v)$) if we know when DM is produced

Velocity distribution



- typically limits reported for thermal distribution
- complicated analysis of structure formation needed for full picture
- approximate limit by comparing v_{rms}

Parameter space freeze-in



Summary

- dark matter can be produced by gravitational freeze-in in extra-dimensional models
- very high Λ possible
- freeze-in largely unconstrained by experiments
- parts of parameter space excluded by cosmology (warm dark matter)
  improvements of test of warm dark matter expected in next years