Probing the Dark Matter Particle Spectrum with the Dark Matter Power Spectrum

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Work in collaboration with Stefano Profumo, Piero Ullio and Marc Kamionkowski
What do we know?

Compelling cosmological evidence that nonbaryonic (non Standard Model) dark matter exists.
Weakly Interacting Dark Matter

- $\Omega_d h^2 = 0.113$

- Lightest Dark Particle (LDP) stable over cosmological timescales.

- Thermally produced dark matter should have Fermi-scale annihilation cross section. If interacts with SM must be “Weakly Interacting”.
Dark-Sector Couplings to Standard Model Particles

This Talk:

- **The point**: While we know something about the properties of the LDP the interactions of other (unstable) particles of the dark sector are unknown. Can we hope learn something about them?

- **Example**: a charged Next-Lightest Dark Particle (NLDP) and its impact on the matter power spectrum
A Charged NLDP

- **Modified Density Perturbations**: GR Perturbation Theory about a smooth FRW Universe

- **NLDP Decays**: $\phi^\pm \rightarrow \chi \pm ...$

- Can modify evolution of density perturbations in early Universe.

\[ \dot{\delta}_\chi = -\theta_\chi - \frac{1}{2} \dot{h} + \lambda_m \frac{\rho_\phi a}{\rho_\chi^2 T} (\delta_\beta - \delta_\chi) \]

- **Continuity Equation**
- **Gravity**
- **Decay**
Effect of Charged NLDP?

- **Before Decay**: The NDLP couples to the photon-baryon fluid! NLDP perturbation modes that enter the horizon **oscillate** rather than grow. These modes source the LDP modes and thus **suppress growth** of dark-matter perturbations.

- **After Decay**: Dark-Matter modes that enter the horizon **grow** under the influence of gravity, as in the standard case.
Effect of Charged NLDP?

$k = \begin{array}{ccc}
30 \text{ Mpc}^{-1} & 3 \text{ Mpc}^{-1} & 0.3 \text{ Mpc}^{-1} \\
\text{Dark Matter (Standard Case)} & \text{Dark Matter (w/Charged NLDP)} & \text{Charged Matter (Baryons+NLDP)}
\end{array}$

$\tau = 3.5 \text{ yr}$
$f_\phi = 1$

KS and Marc Kamionkowski
$f_{\phi} < 1$

$\Delta^2(k) = \frac{k^3 P(k)}{2\pi^2}$

Suppression by a factor $(1 - f_{\phi})^2$ in the linear power spectrum.
Particle Theory Models? $f_\phi = 1$

- Long lifetime? Very Weak coupling?
  - **SuperWIMPS**
    
    J. Feng et al. (2003) (See talk by F. Takayama on Monday!)

- **Gravitational Decay** can get lead to cosmologically interesting lifetimes.

- May solve the small-scale structure problem with charged-decay for lifetimes of order years.
  
  Or if substructure is found constrain these models!
Particle Theory Models? $f_\phi < 1$

- Supersymmetric Dark Matter Models with the LDP=neutralino and NLDP=stau. $\tilde{\tau} \rightarrow \chi + \ldots$

- The stau coannihilation region ($m_{\chi_1^0} \approx m_{\tilde{\tau}_1}$) of the MSSM can give the observed WMAP relic abundance.

- If $\Delta m < m_{\tau}$ The stau is long-lived because it decays via 4-body processes

$$\tau^{(4)} \propto (\Delta m)^{-8}$$

Stefano Profumo, KS, Piero Ullio and Marc Kamionkowski

Particle Theory Models? $f_\phi < 1$

Only the stau can play the role of a quasistable charged particle (with cosmologically interesting lifetimes) in the MSSM.
Other Signatures

- Production of neutralinos at the LHC if they are Bino-like.
- Production and trapping of long-lived staus at the LHC of ILC.
- Direct Detection of neutralinos possible.
- Indirect detection is unlikely.
- Might observe these effects with the high-redshift Cosmic 21-cm Power Spectrum
Summary

- The properties of dark-sector particles are not known.
- Example: A charged NLDP could have interesting effects on the matter power spectrum.
- Stau is a good candidate in the MSSM.
- Direct Detection. LHC/ILC.
- 21-cm fluctuations.