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Subgalactic Structure
Suppression in the MSSM

Based on S.P., K. Sigurdson, P. Ullio and M. Kamionkowski, PRD 71 (2005) 023518

XXXXth Rencontres de Moriond
ELECTROWEAK INTERACTIONS AND UNIFIED THEORIES
The CDM Paradigm

- **Collisionless** (suff. weakly interacting)
- **Cold** (non-rel. at thermal decoupling)

- Acoustic peaks in the CMB Temperature Anisotropies
- The Large Scale Structure of the Universe
- Dark Matter dominated Halos
THE GALACTIC SUBSTRUCTURE PROBLEM

- Number of $\Lambda$CDM predicted dwarf galactic satellites much larger than observed (small scale crisis)

*M31 (NGC224)*

Andromeda Galaxy
THE GALACTIC SUBSTRUCTURE PROBLEM

Dwarf galaxies satellites in the Milky Way

N-body simulations prediction ($\Lambda$CDM)

ASTROPHYSICS

- Anomalous gas clusters with suppressed star formation processes
- Photoionization
- Primordial small-scale power supp. through inflation potential

PARTICLE PHYSICS

- Warm Dark Matter
- Self-interacting Dark Matter
- Strongly Affect DM microphysics hence larger scale structure

- **Produce** DM (totally or partially) from charged particles decays
CHARGED PARTICLES DECAYS & DM

- DM (collisionless) Particle $\chi$
- Charged particle $\phi \rightarrow \chi + ...$

- The Universe (the “horizon”) expands
- Structures start to grow when their size crosses the horizon
- Before decay, $\phi$ is coupled to the baryons-photons fluid, small scale supp.
- After decay (larger scales), track DM

Particle Physics Variables:

$(\tau_\phi, f_\phi)$

*See: K. Sigurdson and M. Kamionkowski, PRL 92 (2004) 171302*
To suppress sub-galactic scales:

$\tau_\phi \sim \text{age of the Universe when the mass enclosed in a Hubble volume is } O(\text{Galactic Mass Scale})$

$\tau_\phi \sim O(\text{few years})$

Decrease $f_\phi \rightarrow$ increase $\tau_\phi$

*See: K. Sigurdson and M. Kamionkowski, PRL 92 (2004) 171302
Can we fulfill all these conditions within the minimal SUSY extension of the SM, with a (possibly detectable) Neutralino LSP?

*See: S.P., K.Sigurdson, P.Ullio and M.Kamionkowski, PRD 71 (2005) 023518*
In the MSSM, if the $\phi \rightarrow \chi + \varphi$ decay mode is allowed

$$\Gamma \sim O \left( 1 \text{ GeV} \right)$$

$$\tau_\phi \sim O \left( 10^{-24} \text{ s} \right)$$

If $m_\phi < m_\chi + m_\varphi$

- Super-CKM suppression (Squarks)
- Phase space (multi-body decays)

- CHARGINO
- STOP
- STAU

ONLY MSSM VERY-LONG-LIVED CHARGED PARTICLE CANDIDATE!

*See: S.P., K. Sigurdson, P. Ullio and M. Kamionkowski, PRD 71 (2005) 023518
GOOD NEWS!! Stau is often the NLSP in SUSY-GUT inspired models

- Quasi degenerate staus are required in the coannihilation region of mSUGRA to suppress the $\chi$ relic abundance (coupled $\chi$-stau freeze-out)

- mAMSB with low common sfermions soft-breaking mass $m_0$

- mSUGRA with non-universal, GUT-inspired gaugino masses (higgsino like $\chi$)

*See: S.P., K.Sigurdson, P.Ullio and M.Kamionkowski, PRD 71 (2005) 023518*
**HOW TO TEST THE SCENARIO**

- **Direct & Indirect $\chi$ Detection**
- **Charged tracks or water tank trapping at the LHC**

**Lyman-$\alpha$ forest**

$k/h \sim 0.1 - 10 \text{ Mpc}^{-1}, \quad z=4$

(non-linear regime)

- $n_s=1, \alpha_s=0$
- $n_s=1, \alpha_s=-0.025$
- $\tau=13 \text{ yr}, f_s=1/5$

Running spectral index

~ charged particle decay effect

- $k/h \sim 0.1 - 10 \text{ Mpc}^{-1}$
- $k/h \sim 1-100 \text{ Mpc}^{-1}$

**21-cm Power Spectrum**

between $z \sim 30-200$, neutral hydrogen absorbs the CMB at $\lambda = 21 \text{ cm}$

$\Delta^2(k) \sim 1-100 \text{ Mpc}^{-1}$

(linear regime)

Distinguish various ($\tau_{\phi}, f_{\phi}$) scenarios & R.S.I !!!
CONCLUSIONS

✓ Subgalactic Structure Problem: **CDM overpredicts Galactic Dwarf Satellites**

✓ Ways out: resort to “exotic” astro-frameworks, or alter the (C)DM particle properties

✓ A well motivated **SUSY scenario** gives an elegant solution to the small scale crisis

✓ A **year-long-lived charged Stau** couples to the baryons-photons plasma until it decays, suppressing small scale structures up to the Galactic size

✓ The scenario is **predictive**, and it will be cross-tested at

   - Direct & Indirect **Dark Matter searches**
   - **CERN LHC**
   - **Lyman-α surveys**
   - Upcoming measurements of the **21-cm PS**

*See: S.P., K.Sigurdson, P.Ullio and M.Kamionkowski, PRD 71 (2005) 023518*
THE PARTICLE PHYSICS SETUP

**Candidates**

- Gravitino or KK Graviton & O (100 TeV) Masses
  - Only non-thermal production
  - Arbitrary $f_φ$
  - No detection hopes

- MSSM Neutralino & very long lived, charged Next-to-LSP
  - Thermally production of both $φ$ and $χ$
  - $f_φ$ is output of the particle physics model
  - Might give detectable DM signals

*See: S.P., K.Sigurdson, P.Ullio and M.Kamionkowski, PRD 71 (2005) 023518*
OPEN ISSUES IN THE STANDARD LORE

- Cusps in Dark Halos (often not observed, e.g. in low-surface brightness dwarves)
  \[ \rho \propto r^{-\alpha} \quad 1 < \alpha < 1.5 \]

- Excessive concentration (e.g. in barred spirals)
  \[ c = r_{200} / r_{halo} \]

- Excessive loss of angular momentum in the baryon infall -> too small disks

- Number of galactic satellites much larger than observed (small scale crisis)