DARK MATTER IN MANY FORMS

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Ordinary matter $\Leftrightarrow \sim 4\%$ of closure density; dark matter $\Leftrightarrow (23 \pm 4)\%$.

Ordinary matter exists in several stable forms: p, n (when incorporated into nuclei), e^-, three flavors of neutrinos $[\tau(\nu_{2,3}) \gg \tau(\mathrm{Universe})]$.

We could expect dark matter to exhibit at least as much variety.

Today: Motivations for multiple forms of dark matter; detector signatures.

- Observed space-time (4-dimensional) and rank (4) of Standard Model group SU(3) $\otimes$ SU(2) $\otimes$ U(1) $\ll$ maximum number of dimensions (10) in superstring theories or rank of groups (16) in such theories.

- At least two well-motivated dark matter candidates already (axions and neutralinos); long-lived next-to-lightest superpartner in some SUSY variants.

Cast as wide a net as possible for dark matter.

STABLE OBSERVED MATTER

Simplest GUT with each family in a single representation: SO(10).

Baryon number B and lepton number L are combined in a single charge $B-L$ conserved in SO(10); quarks have $B-L=1/3$ while leptons have $B-L=-1$. No separate labels for B and L.

Color SU(3) is responsible for existence of qqq configurations.

Protons (uud) are long-lived in comparison with $\tau(\text{Universe})$ as long as SO(10) gauge bosons mediating (e.g.) $ud \to \bar{d}e^+$ are heavy enough.

Also exist nonperturbative configurations (sphalerons) enabling $ud \Leftrightarrow \bar{d}e^+$ transitions but they are only operative at and above electroweak temperatures.

Free neutrons are just barely unstable ($m_e + m_{\nu_e} + m_p < m_n$) but become stable when incorporated into some nuclei $\Rightarrow$ richness of ordinary matter.

Decay rates of two heavier neutrino species in Standard Model should be of order $G_F^2 \alpha m_\nu^3 m_\ell^2/16\pi^2 \gg \tau(\text{Universe})$. Could not have anticipated three quasi-stable neutrino species without understanding existence of quark-lepton families. Neutrinos do contribute a non-dominant amount to the dark matter of the Universe.

OLD, NEW QUANTUM NUMBERS

Imagine a TeV-scale effective symmetry SU(3) $\otimes$ SU(2) $\otimes$ U(1) $\otimes$ G, where G could be SUSY with R-parity, extra-dimensional excitations with Kaluza-Klein parity, little Higgs models with T-parity, Technicolor, or some other group.

Possible types of matter:

Type of matter	Std. Model	G	Example(s)
Ordinary	Non-singlet	Singlet	Quarks, leptons
Mixed	Non-singlet	Non-singlet	Superpartners
Shadow	Singlet	Non-singlet	E_8' of $E_8 \otimes E_8'$

Ordinary matter could be singlets under G even if subconstituents were non-singlets (e.g., in composite-Higgs models).

Many dark matter scenarios involve mixed matter, such as superpartners or particles with odd KK- or T-parity.

Mixed-matter scenarios may be different if G is more general than a “parity.”

Shadow matter may not interact with ordinary matter *at all* except gravitationally.

DETECTOR SIGNATURES

Axion dark matter has not received the attention it deserves. RF cavity searches going slowly: Large range of frequencies still to be scanned with enough sensitivity.

Dark matter with non-singlet SM charges but more than a Z_2 (parity) symmetry in the BSM group G may exist in several stable forms.

Neutrino dark matter's contribution to Ω is largely a question of the absolute mass of neutrinos, on which neutrinoless double beta decay will shed some light.

Even in SUSY there are scenarios in which NLSP decays to LSP over a non-prompt distance, anywhere from a typical b path length on up.

Detectors need to be ready for kinks or vees with unexpected flight paths and for accumulation of high-energy stable particles produced in pairs at high energies.

Could imagine charged and neutral quasi-stable candidates split by so little that they charge-exchange with detector and leave a track looking like a dashed line.

Dark matter with non-zero charges purely in hidden sector will respond to gravitational probes (LISA): A. Adams and J. S. Bloom, astro-ph/0405266.

Exploring full range of dark matter possibilities will test our ingenuity!

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A partial bibliography:

- A. Bottino *et al.*, Nucl. Phys. Proc. Suppl. **113**, 50 (2002).
- G. Dudas, G. Gelmini, and P. Gondolo, PL B **529**, 187 (2002).
- G. Dudas *et al.*, PR D **67**, 023505 (2003).
- J. L. Feng *et al.*, PR D **70**, 063514 (2004).