Title: Searching for the Dark Universe

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Abstract: For nearly a century, we have known that the majority of matter in the universe is not luminous. In the past few decades we have come to be certain that this matter is not only not luminous but not made out of any of the particle ever observed in a laboratory. I will describe the ongoing hunt for this matter and the prospects for the discovery in the next decade. I will further discuss recent claims the dark matter may have been discovered in various signals, and prospects for resolving these claims in the next few years. Finally I will touch on the idea of "dark forces," the idea of an expansive dark sector that is much greater than a single dark particle.
THIS IS THE ERA OF LAMPPPOSTS
Is your model a WIMP?

- yes: Is it a neutralino?
  - yes: Is it the usual KSVZ or DSVZ axion?
  - no: Sounds weird

- no: do you invoke new states or forces to explain one of DAMA, CoGeNT, PAMELA, Fermi excesses, etc?
  - yes: has the paper been cited a large number of times?
  - no: Sounds crazy
A STRONG CP PROBLEM

\[ \Theta \hat{G}_{\nu \nu} \rightarrow \frac{a}{f_a} \hat{G}_{\nu \nu} \]

idea -> make \( \Theta \) a field

QCD effects generate potential that relaxes \( \Theta \) (a) to 0

The axion acquires a mass \( m_a \approx \frac{m_\pi f_\pi}{f_a} \approx 0.6 \text{ meV} \left( \frac{10^{10} \text{GeV}}{f_a} \right) \)
COUPLINGS TO OTHER MATTER

\[ \frac{a}{f_a} G_{\mu \nu} G_{\mu \nu} \rightarrow \frac{a}{f_a} F_{\mu \nu} F_{\mu \nu} \]
For a thermal relic, you learn precisely one number; namely the annihilation cross section

\[ \langle \sigma v \rangle_{\text{ann}} \approx 3 \times 10^{-26} \text{ cm}^3 \text{sec}^{-1} \]

\[ \approx \frac{\alpha^2}{(200 \text{GeV})^2} \]
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$$<\sigma v>_{ann} \approx 3 \times 10^{-26} \text{ cm}^3\text{sec}^{-1} \approx \frac{\alpha^2}{(200\text{GeV})^2}$$
SUSY Spectrum, 1984

Lawrence Hall, Savasfest 2012
(cf Matt Reece talk LHCP2013)
• IMHO good to think generally about DM models because conventional wisdom on the weak scale has not proven itself reliable

• So, even if it is a WIMP, it needn’t look or act as we anticipated

• Light WIMPs, very heavy WIMPs, hidden sector DM…
SO WHAT ABOUT THE SEARCH FOR WIMPS?

Evolution of the WIMP–Nucleon $\sigma_{SI}$

- Z-exchange models (hep-ph/0209262)
- Higgs-exchange models (hep-ph/1109.2604)

Coherent neutrino scattering signals

Slide from J Feng
MAJORANA TRIPLET: LOOP MEDIATED

Hill + Solon '13; Hill + Solon '14
• This era will answer the question: does the dark matter couple at $O(0.1-0.01)$ to the Higgs boson

• But perfectly plausible WIMPs can have very weak nucleon interactions
HAVE WE FOUND DARK MATTER ALREADY?

![Graphs and images related to dark matter detection](image-url)
A LINE AT 3.55(ish) KeV

DETECTION OF AN UNIDENTIFIED EMISSION LINE IN THE STACKED X-RAY SPECTRUM OF GALAXY CLUSTERS

Esra Bulbul\textsuperscript{1,2}, Maxim Markevitch\textsuperscript{3}, Adam Foster\textsuperscript{1}, Randall K. Smith\textsuperscript{1} Michael Loewenstein\textsuperscript{2}, and Scott W. Randall\textsuperscript{1}

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\textsuperscript{2} NASA Goddard Space Flight Center, Greenbelt, MD, USA.


An unidentified line in X-ray spectra of the Andromeda galaxy and Perseus galaxy cluster

A. Boyarsky\textsuperscript{1}, O. Ruchayskiy\textsuperscript{2}, D. Iakubovskyi\textsuperscript{3,4}, and J. Franse\textsuperscript{1,5}

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\textsuperscript{5}Leiden Observatory, Leiden University, Niels Bohrweg 2, Leiden, The Netherlands
Bulbul et al

3.57 ± 0.02 (0.03) XMM-MOS Full Sample 6 Ms

3.51 ± 0.03 (0.05) XMM-PN Full Sample 2 Ms

Boyarsky et al

Passes the Toro test
DECAYING DARK MATTER

- Sterile neutrino $N \rightarrow \nu + \gamma$

- R-parity violating gravitino
  $\tilde{g} \rightarrow \nu + \gamma$

- Also R-parity violating axino, ...

- For bosonic DM axions (or axion-like particles) would decay $a \rightarrow \gamma\gamma$

from talk by Ruchayskiy, April 2014
A NEW FORCE

Dark matter

Dark force carrier

maybe look for this?
FIG. 5: The layout of the experimental setup — see text for details.

Bjorken, Essig, Schuster, Toro

APEX, HPS, Darklight... - searches for new physics at the $\lesssim$GeV scale
SEARCHES FOR DARK FORCES

Bjorken, Essig, Schuster; Toro ‘08

Curtin, Essig, Gori, Shelton ‘14
THIS IS A STORY OF LAMP POSTS
THE SEARCH FOR DARK MATTER

- Finding dark matter is hard because it’s dark and we don’t know what it is
- In this era, we will learn important qualitative results about dark matter, whether or not it is found
- We have many well motivated lamp posts being pursued, and there are tremendous prospects in the coming decade
- But it may be that the lamp post that best illuminates dark matter is still unconsidered