The Search for Dark Matter: Direct and Indirect Methods

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Topics

1. Current evidence for dark matter—DM06 results

2. Cold and warm dark matter
   a. Problems with cold dark matter
   b. Some evidence for warm dark matter from dSpn’s

3. Search for sterile neutrinos

4. Indirect search for WIMP’s—Some current results

5. Direct search for SUSY cold dark matter
   a. Techniques to search
   b. Results from cryogenic detectors
   c. Results from xenon detector

6. Prospects for the future
   a. Next two years $\sim 10^{38} \text{ pb}$
   b. New detectors Super CDMS and LUX

Summary

Some slides taken from DM+DE 06 Proceeding,

NSF/DOE DARK SAG $\sim 100 \text{ M}$
for decade
Overview

Advisory Committee Members

Meeting program

Talks online: http://www.physics.ucla.edu/hep/dm06/dm06.htm

Chapter 1  Precision Cosmology and Dark Energy

- Precision Cosmology: Successes and Challenges – Joel R. Primack
- Dark Energy from Vacuum Fluctuations – S.G. Djorgovski and V.G. Gurzadyan
- Measuring the Dark Energy Equation of State – Amol Upadhye
- The Cosmic Ionization History as a Probe of Dark Matter Decay and Annihilations – Xuelei Che

Chapter 2  Evidence for Dark Matter: Dark Galaxies and Streams

- Catching a Bullet: Direct Evidence for the Existence of Dark Matter – D. Clowe, S.W. Randall and M. Markevitch
- The Common Origin of Luminous Dark Matter – C. Balazs
- Limits on the Machos from EROS-2 – J. Rich for the EROS-2 Collaboration

Chapter 3  Warm Dark Matter and Sterile Neutrinos

- Evidence for Sterile Neutrinos Which Could Be Part of Dark Matter – David O. Caldwell
- Sterile Dark Matter and Reionization – Alexander Kusenko

Chapter 4  Indirect Detection of Dark Matter

- Understanding Limitations in the Determination of the Diffuse Galactic γ-ray Emission – Igor Moskalenko, Seth W. Digel, Troy A. Porter, Olaf Reimer, Andrew Strong
- Probing Supersymmetric Parameters with Astrophysical Observations – Dan Hooper
- The Search for Milky Way Halo Substructure WIMP Annihilations Using the GLAST LAT – Larry Wai
- Constraining the Early Hubble Rate Using Cosmic Antiprotons – Mia Schelke, Riccardo Catena, Nicolaio Fornengo, Antonio Masiero, Massimo Pietroni

Pomela Launched June 2006

Project = D e+ 1p study for Dark Matter.
<table>
<thead>
<tr>
<th>Year</th>
<th>Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>~1933</td>
<td>F. Zwicky observes fast galaxies in clusters; suggests missing mass in cluster is the cause</td>
</tr>
<tr>
<td>~1960s</td>
<td>Astronomers realize that galaxies have fast moving stars in halo; suggest dark matter is the cause</td>
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<tr>
<td>~1980</td>
<td>Suggestions for MOND to explain rotation curves by modifying Newtonian gravity [1][2]</td>
</tr>
<tr>
<td>~1998</td>
<td>Experiments on SN1A reports at dark matter meeting; indication of accelerating universe; dark energy is suggested cause</td>
</tr>
<tr>
<td>~2003</td>
<td>WMAP data strongly supports both dark matter and dark energy components of the universe</td>
</tr>
<tr>
<td>~2005</td>
<td>SDSS observes Baryon acoustic oscillations; provides additional proof for dark matter</td>
</tr>
<tr>
<td>2006</td>
<td>New results on cooling acoustic clusters</td>
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* Several independent measurements of $\Omega_{DM}$ suggest a single origin: cold dark matter

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In 1912, Einstein was still trying to provide astronomers to test various astrophysical consequences of his new ideas on gravitational lensing. Erwin Freundlich was one of the few astronomers who actively engaged in such work. In spring 1912, Einstein, then a professor in Prague, visited Berlin where he met Freundlich, who was working at the Königliche Sternwarte, the Royal Observatory. It is quite possible that the issue was discussed at a meeting with Freundlich. At any rate, Einstein did the gravitational lensing calculations during his Berlin visit as evidenced by notes found in a small notebook dated to the period 1910 to 1914 (8) (Fig. 1). These calculations appear interspersed between various notes referring to Berlin appointments and addresses during his visit from 13 to 22 April 1912 (9). Notes on the gravitational lensing effect are contained in the pages of the notebook and primarily deal with (i) the possibility of a double image of the source as a result of gravitational light bending and (ii) the magnification of the intensity of these images. Einstein started by sketching the geometrical constellation of gravitational lensing with a light-emitting source and a lensing star separated by a distance $R$ (Fig. 1). An observer is located at distance $R'$ from the lens along the axis formed by the light source and lens and at a small distance $r$ off of this axis. Einstein then wrote down the basic lensing equation

$$ r = \rho \frac{R + R'}{R} - \frac{R' \alpha}{\rho} $$

(1)

which expresses the condition that a light ray passing the lens at a distance $\rho$ will reach the observer. According to Einstein's 1911 paper (7), the light ray is bent by an angle $\alpha / \rho$, where $\alpha$ depends on the mass of the lens and differs by a factor of 2 from the value following from general relativity. Introducing dimensionless units, Einstein arrived at the quadratic equation for $\rho$ labeled (1) in his notes (Fig. 1). The two solutions to this quadratic equation correspond to the fact that a light ray can reach the observer after passing either side of the lens.

Considering the apparent brightness of the two images, Einstein also correctly calculated the magnification factor for the intensity of the deflected light [labeled (3) in Fig. 1]. On the following pages in the notebook, Einstein further discussed this magnification factor, transforming the bracketed expression of the equation labeled (3) in Fig. 1 into the form

$$ \sqrt{1 - \frac{1}{\rho^2}} $$

(2)

1912 (1913)
Masses of Galaxy and Cluster

Possible by Dark Matter

Telescope
Hubble Space

Gravitational Lens

~ 2000 light years

"S"
CHALLENGES TO CDM ON GALAXY SCALES

- Too much dark matter in halo centers?
- Not enough dark matter around ellipticals?
- Halo substructure issues?
- Halo and galaxy merging history?
- Angular momentum issues?
- Does CDM correctly predict galaxy number density (luminosity function)?
- Halo occupation statistics ok?
- morphology, kinematics, and colors?
- formation and evolution?
Systematic properties of DM -- II
--minimum mass, scale, dispersion?

- Red line: constant mass DM halo,
  - $M \sim 4 \times 10^7 M_\odot$
- apparent lower mass boundary
- Some data are old, central $M/L$ only

Figure from astroph-0602186
The "WIMP Miracle"

The amount of dark matter left over is inversely proportional to the annihilation cross section:

\[ \Omega_{DM} \sim \frac{1}{\langle \sigma_A V \rangle} \]

If we take \( \sigma_A = \frac{k \alpha^2}{m^2} \), then

\[ \Omega_{DM} \sim m^2 \]

and

For \( \Omega_{DM} \sim 0.1 \),

\[ M \sim 100 \text{ GeV} - 1 \text{ TeV}. \]

Cosmology alone tells us we should explore the weak scale.
I. INTRODUCTION

Some issues in, India.

Some issues in, India.

PACS numbers: 12.60.Jv, 95.35.+d, 98.35.Cg

...amplitude signal in the Galaxy... small-scale clumps outside the bulge. The results obtained are crucial for calculations of the dark matter annihilation signal in the Galaxy... It is shown that the Galactic disc provides the dominant contribution to the galactic destruction of dark visibly... It is shown in the Galactic disc provides the dominant contribution to the galactic destruction of dark visibly... The results obtained are crucial for calculations of the dark matter annihilation signal in the Galaxy... The results obtained are crucial for calculations of the dark matter annihilation signal in the Galaxy... The results obtained are crucial for calculations of the dark matter annihilation signal in the Galaxy...
The Signal and Backgrounds on Earth

Detecting Dark Matter
Some best in xenon, some best in argon. Fiducial volume.

- Multiply recoils
- S2/S1
- Scintillation intensity
- Secondary pulse shape
- Primary scintillation intensity
- Primary scintillation
- Experimental handles (argon, xenon)

WARP, ADM, XENON, ZEPLIN

2-Phase Noble Liquids
Final setup with veto ZEPFILN II

In lead shield to be placed

Veto Simulator

Liquid
Data analysis in progress (Jan 2005).

Physics data taking in progress (>1200K day on tape).

Detector fully operational (March 2006).

ZEPHER II operation underground at Boulby Mine, UK.

USA, UK, Saar W, Saar M, and Marse.
Volume
in 30x the
volume
the detector
1000 kg (100x)

SUPERDMS: Phased approach to 1-ton

NEXT STEPS: Work with 4.1 to 4.7

SiOCl4 - a great new tool
Project Description

2006 Funds, 3rd Quarter, NSF # 2006

LUX

Xenon + US EPOC

Pompeii 418, 419, Herculaneum, 2005
Figure 3.1: Over view of the LUX detector system. Shown are the 6 m OD water tank with storage and recovery vessels, a LN storage vessel, and electronics and equipment racks atop a work platform. (right) Cutaway view of the LUX detector. Shown are the central cryostat, the central muon veto, the central cryostat, for liquid Xe, two cylindrical cooled Xe chambers and finally the 6 m OD water tank with storage and recovery vessels, a LN storage vessel, and electronics and equipment racks atop a work platform.
Figure 6.1. (right) Limits (90%CL) on the WIMP-nucleon scalar cross section for the leading current direct detection experiments: Edelweiss, ZEPLIN I and CDMS II. A preliminary analysis of the recent XENON10 data (discussed in Section 7) is also shown. Several of the latest theoretical models are represented by the lower shaded regions (blue [Ruiz 2006], red [Ellis 2006]), and the red [Masiero 2004] and blue crosses [Baltz 2004]. Projected goals of SuperCDMS 25 kg (goal in 2012), and for the LUX 300 kg detector (goal in 2009) are shown. (left) The event rate, (dashed lines) integrated above a threshold, evts/kg/day, (lines) differential, evts/keVr/kg/day, for mass 100 GeV WIMP at a spin independent cross section of $\sigma = 2.0 \times 10^{-45}$ cm$^2$ on Xe, Ge and Ar targets.
Spin-dependent WIMP limits

Why are we doing this deep underground?
Because of the large $A^2$ variation, $Xe, Ce, Ar$ provide interesting target to use to test for the $A^2$ dependence. Well-understood detection properties to compare signals need a complement of detectors with different $A^2$ and $Xe$.

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Comparison</th>
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<tbody>
<tr>
<td>Requires range of target $Xe$ detectors</td>
<td>$Xe$ N/A, $Ar$ N/A ~ 1.0</td>
</tr>
<tr>
<td>(4$^9$ - 1.0$^{10}$ dp) as big as this building: We don't know the size until we measured.</td>
<td>Very hard to do.</td>
</tr>
<tr>
<td>Requires a very large DRIFT like detector:</td>
<td>Very hard to do.</td>
</tr>
<tr>
<td>Great stability over long time. Effective if few percent detection requires</td>
<td>Discriminated Signal</td>
</tr>
<tr>
<td>Comment</td>
<td>Measurement</td>
</tr>
</tbody>
</table>

How to prove that Dark Matter has been detected.
1. **Dark matter is REAL**—not modified (MOND)
   - Standard model fits all data (now B^0's mixing)
   - Very tight constraints on SUSY or any devised from model
   - (B^0's → μμ very important)

2. **What is dark matter type?**
   - a. Cold dark matter fits data, but has problems
      (WIMPs/Axions)
   - b. Warm dark matter fits some data
      (Sterile neutrinos)
   - Theory of SUSY WIMPs seems confused now.

3. **Direct search** for dark matter particles (WIMPs)
   - Incredible progress now:
     a. Cryogenic
     b. Li Xe
     c. Li Ar
     - Ge ...to Super CDMS
     - ZEPLIN/XENON to one-ton detector size
     - big progress now
     - 4 detectors proposed or in operation

   **Other methods promising**
   - **Possible progress** 10^{-7} Pb (2007)—10^{-8} Pb (2008)—10^{-10} Pb (by 2012)

4. **Indirect search**—GLAST has good chance to see, but requires clumps of dark matter and low background? : PAMELA DATA!
   - Other \( \bar{\nu} \), e^+, etc.

5. **Powerful new underground labs:**
   - SNOLAB (2007)
   - DUSEL (2010?)
   - Important for low background search

6. **To prove dark matter detection need several needed** \( A^2 \) range of detectors
   - Ar, Ge, Xe, etc.

**GOOD CHANCE TO DISCOVER DARK MATTER 2007—2010**

Compliments and extends **LHC**

**8th Dark Matter and Dark Energy 08: Marina Del Ray, February 2008**

Miami 2006  
December 11-17, 2006  
Fort Lauderdale, FL
Evolution of Direct Searches

Schematic of the possible future of the dark matter search (R. Gaitskell)

LUX Coll. mkg at VELA
Jan 10/11 2007

Good Chance to
Discover Dark Matter
Particles in Near Future