Behind the Scenes of the Universe

The Worldwide Race to Discover Dark Matter

Gianfranco Bertone

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“If we were to regard Syrius and Procyon as double stars, the change of their motion would not surprise us.” F.W. Bessel (1844)
“The phenomena of varying motions of stars seem also to possess interest in relation to our knowledge of the physical constitution of the Universe.” F.W. Bessel (1844)
Evidence for Dark Matter

Evidence for the existence of an unseen, “dark”, component in the energy density of the Universe comes from several independent observations at different length scales:

- Rotation Curves
- Clusters of galaxies
- CMB
- Type Ia Supernovae
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![Diagram of an iceberg representing dark matter with 85% in the dark matter section, 7% in diffuse gas, and 1% in stars.](image-url)
A modern view of the Galaxy
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What do we know?

An extraordinarily rich zoo of non-baryonic Dark Matter candidates! In order to be considered a viable DM candidate, a new particle has to pass the following 10-point test:

1) Abundance ok?
2) Cold?
3) Neutral?
4) BBN ok?
5) Stars OK?
6) Collisionless?
7) Couplings OK?
8) $\gamma$-rays OK?
9) Astro bounds?
10) Can probe it?
Dark Matter candidates
Dark Matter candidates

• Neutralino?

[Image of an iceberg with a large portion submerged in water]
Dark Matter candidates
Like ancient geographers..

So geographers, in Afric maps,
With savage pictures fill their gaps,
And o'er unhabitable downs
Place elephants for want of towns.

Jonathan Swift (1667 - 1745)
Dark Matter candidates

WIMPs
Weakly Interacting Massive Particles

Natural Candidates: Arising ‘as a bonus’ from theories addressing the fundamental problems of particle physics

Ad-Hoc Candidates: Postulated to solve the DM Problem

Others
• Axions, Sterile Neutrinos, SuperWIMPs, WIMPless, Axino, Q-balls, etc.
Dark Matter searches

Colliders

Direct Detection

Indirect Detection
The worldwide race
Indirect Detection

Dark Matter annihilates into particles of the Standard Model

Dark Matter
Ordinary matter

Particles of the Standard Model annihilate into Dark Matter

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Simulating Galaxy Formation
Simulating Galaxy Formation

$z=11.9$

800 x 600 physical kpc

Diemand, Kuhlen, Madau 2006
Including baryons (= gas and stars)

z=99.00

Evolution of the gas density (blue), temperature (red) and metalliccy (green)

2 kpc

Agertz et al. (2009)
The gamma-ray Sky

A Tentative Gamma-Ray Line from Dark Matter Annihilation at the Fermi Large Area Telescope

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Abstract. The observation of a gamma-ray line in the cosmic-ray fluxes would be a smoking-gun signature for dark matter annihilation or decay in the Universe. We present an improved search scheme for such signatures in the data of the Fermi Large Area Telescope (LAT), concentrating on energies between 20 and 300 GeV. Besides updating to 43 months of data, we use a new data-driven technique to select optimized target regions depending on the profile of the Galactic dark matter halo. In regions close to the Galactic center, we find a 4.5σ indication for a gamma-ray line at Eγ = 130 GeV. When taking into account the look-elsewhere effect the significance of the observed excess is 3.2σ. If interpreted in terms of dark matter particles annihilating into a photon pair, the observations imply a dark matter mass of m₁ = 129.8 ± 2.4 GeV and a partial annihilation cross-section of ⟨σv⟩₁ → γ = (1.37 ± 0.32 GeV⁻¹) × 10⁻²⁷ cm³ s⁻¹ when using the Einasto dark matter profile. The evidence for the signal is based on about 50 photons; it will take a few years of additional data to clarify its existence.
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Reg3 (SOURCE), $E_\gamma = 129.4$ GeV

Signal counts: 68.7 (4.59σ)
80.5 - 208.5 GeV
p-value=0.51, $\chi^2_{\text{red}} = 20.1/21$

Counts

Counts - Model

$E$ [GeV]
How to cross-check?

The HESS-II telescope in Namibia
Direct Detection
Principle and Detection Techniques

DM Scatters off nuclei in the detector

Detection of recoil energy via ionization (charges), scintillation (light) and heat (phonons)

Adapted from Baudis 2007
e.g. *Xenon100*...
\[
\frac{dR}{dE_R}(E_R) = \frac{\rho_0}{m_\chi m_N} \int_{v>v_{min}} v f(\vec{v} + \vec{v}_e) \frac{d\sigma_{\chi N}}{dE_R}(v, E_R) d^3\vec{v}
\]
Direct Detection

Differential Event Rate

\[
\frac{dR}{dE_R}(E_R) = \frac{\rho_0}{m_\chi m_N} \int_{v>v_{min}} vf(\vec{\nu} + \vec{\nu}_e) \frac{d\sigma_{\chi N}}{dE_R}(v, E_R) d^3 \vec{\nu}
\]

Particle Physics  Astrophysics
Status of Direct Searches

A rapidly evolving field of research. The CDMS II results have been released in April 2013!

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Dark Matter Searches at the LHC
Dark Matter Searches at the LHC

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Beyond the Standard Model

The Standard Model provides an accurate description of all known particles and interactions, however there are good reasons to believe that the Standard model is a low-energy limit of a more fundamental theory.

To explain the origin of the weak scale, extensions of the standard model often postulate the existence of new physics at ~100 GeV.

On the left, schematic view of the structure of possible extensions of the standard model.
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So far only constraints (no discovery)
What if we discover new particles?

What we can realistically hope to achieve with accelerator data

What we really need to identify neutralinos with dark matter

Fraction of Dark Matter in the form of neutralinos

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Complementarity with Astroparticle experiments

What we can achieve with a combination of accelerator and direct detection data

What we really need to identify neutralinos with dark matter

Fraction of Dark Matter in the form of neutralinos

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• Many new ideas and collaborations arose from the Dark Matter program that ends next week, thanks to the director and the KITP staff for hosting us!