Indirect search of dark matter

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02/23/2011
Outline

• Astronomical dark matter
• Particle dark matter
• Search for particle dark matter
• Indirect detection
• Recent progress
• Summary and perspective
Evidence of dark matter

Rotation curve of galaxy
van Albada et al. (1985)
Evidence of dark matter

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van Albada et al. (1985)

Gravitational lensing
Clowe et al. (2006)
Evidence of dark matter

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Structure formation
Evidence of dark matter

Rotation curve of galaxy
van Albada et al. (1985)

Gravitational lensing
Clowe et al. (2006)

Structure formation

Cosmological measurement (WMAP7)
Dark matter structure (observation + simulation)

Large scale baryon distribution traces dark matter distribution.

STAGES: Abell901/902

At galactic level, dark matter distribution is in the form of extended halo, with sub and sub-sub halos (hierarchy).

Springel et al. 08
Millennium simulation of dark matter structure

Springel et al.
Structure evolution: cold dark matter

Bottom-up structure formation pattern instead of top-down pattern (fragmentation): cold dark matter

Springel et al. (2006) Nature
CDM simulation vs. galaxy survey
Weak Interacting Massive Particle (WIMP) is a natural candidate
Survey of dark matter in standard model: no one matches

Gondolo, P. (TeVPA08)
Particle candidate of dark matter

Many candidates with mass and cross section spanning many orders of magnitude
Detection of particle dark matter

DM → Indirect detection → high energy photons, neutrinos, anti-matter → SM

DM → Collider detection → missing energy → SM

New Physics

Direct detection
nucleus recoil
Direct detection of dark matter

Detecting the recoil of nucleus through scattering with WIMP

International underground experiments for DM detection

From Q. Yue
Direct detection of dark matter

Many of such experiments, but no confirmed signal
Recently there are several reports on the “candidate signals”

- DAMA annual modulation (Bernabei et al. 2008)
- 2 events by CDMS (Ahmed et al. 2010)
- Some “excess” events by CoGeNT (Aalseth et al. 2010)
Indirect detection of dark matter

Sun

Galaxy

Cluster

Deep extragalactic space and early Universe

WIMP Dark Matter Particles $E_{CM} \sim 100$ GeV

Gamma-rays

W$^+/Z/\gamma$

Neutrinos

$\nu_\mu$, $\nu_\mu \nu_e$

$\pi^+$, $\mu^+$, $e^+$

$\pi^-$, $\nu_\mu$, $\nu_e$

$\mu^-$

$e^-$

$\gamma$

$\gamma$

$\nu_\mu$, $\nu_\mu \nu_e$

$\pi^-$, $\nu_\mu$, $\nu_e$

$\mu^-$

$e^-$

$\gamma$

$\gamma$

$\gamma$

Baltz et al. 2008
Better to search for DM signal in anti-particles due to lower background gamma-rays and neutrinos are also good due to the simple propagation.
Background: Galactic cosmic rays, astrophysical gamma-rays and neutrinos

A. W. Strong
Propagation of Galactic cosmic rays

Major processes of charged particle propagation

- Diffusion ($D, \delta$)
- Convection ($V_c$)
- Reacceleration ($V_a$)
- Fragmentation ($\tau_f$)
- Energy loss ($\tau_l$)
- Decay ($\tau_r$)

\[
\frac{\partial \psi}{\partial t} = Q(x, p) + \nabla \cdot (D_{xx} \nabla \psi - V_c \psi) + \frac{\partial}{\partial p} p^2 D_{pp} \frac{\partial}{\partial p} \times \frac{1}{p^2} \psi - \frac{\partial}{\partial p} \left[ \dot{p} \psi - \frac{p}{3} (\nabla \cdot V_c \psi) \right] - \frac{\psi}{\tau_f} - \frac{\psi}{\tau_r},
\]

Maurin et al. arXiv:0212111
GALPROP: a numerical tool to solve the propagation Equations, with relatively realistic astrophysical inputs (Strong & Moskalenko 1998; Moskalenko & Strong 1998)
Example 1: charged anti-matter cosmic rays

Positron fraction shows hints of excess above ~10 GeV; antiproton/proton ratio is consistent with model
Example 1: charged anti-matter cosmic rays

Positron fraction shows hints of excess above ~10 GeV; antiproton/proton ratio is consistent with model

Supersymmetric DM model can explain the positron data, but is strongly constrained by antiproton data
Example 2: charged anti-matter cosmic rays

Anti-deuteron: Expected perspective of AMS02 and GAPS
Example 3: diffuse gamma-rays

EGRET “GeV excesses” can be reproduced with SUSY DM model
de Boer et al. (2005)
Example 3: diffuse gamma-rays

Still there are constraints from antiproton data

Bergstrom et al. (2006)

Recent Fermi data disfavor the existence of “GeV excesses”

Abdo et al. (2009)
Example 4: neutrinos

At high energies (>10 GeV), only the atmospheric neutrinos are detected. Atmospheric neutrinos can be used to constrain DM models.
Other methods for DM indirect detection

- X-ray emission from synchrotron or bremsstrahlung of electrons
- Radio emission from synchrotron of DM induced electrons
- Sunyaev-Zel’dovich effect
- Big bang nucleosynthesis
- IGM heating and reionization
- 21 cm signal
- Cosmic expansion history
- Dark stars
- ......
Recent progress
Electron/positron excesses

PAMELA: excess of positron, non-excess of antiproton

ATIC/PPB-BETS/Fermi/HESS: excess of electron+positron
Cannot be simply understood as cosmic ray background

To explain simultaneously positron and electron data, we need exotic electron/positron sources.
An anomalous positron abundance in cosmic rays with energies 1.5-100GeV

Implication on DM scenario

gauge boson  quark  lepton

Model independent implications: leptonic; m~TeV; high production rate (Yin, YQ, et al. 2009, PRD)
Assuming the DM origin of the electron/positron excesses, we can further determine the DM parameters quantitatively using a global fitting method.

Liu, YQ, et al. 2010, PRD
arXiv: 0911.1002
Test with gamma-rays: Galactic diffuse

Test with gamma-rays

Papucci & Strumia, arXiv:0912.0742
Test with gamma-rays: Galactic center

Conversely, if we adopt the fact that $e^{\pm}$ excesses come from DM annihilation, we can constrain the DM halo parameters

<table>
<thead>
<tr>
<th>channel</th>
<th>$m_\chi$(TeV)</th>
<th>$\langle \sigma v \rangle$(10$^{-23}$cm$^3$s$^{-1}$)</th>
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<tbody>
<tr>
<td>Model I</td>
<td>$e^\pm$</td>
<td>0.62</td>
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<tr>
<td></td>
<td>$\mu^\pm$</td>
<td>1.5</td>
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$$\rho(r) = \frac{\rho_s}{(r/r_s)^\gamma(1 + r/r_s)^{3-\gamma}}, \quad r_s = r_{\text{vir}}/c_{\text{vir}}(2 - \gamma)$$

Bi et al. 2009, PRD
Test with gamma-rays: clusters

YQ et al., 2010, PRD

<table>
<thead>
<tr>
<th>Name</th>
<th>$z$</th>
<th>$d_L$(Mpc)</th>
<th>R.A.</th>
<th>Dec.</th>
<th>$M_{200}(10^{14}M_\odot)$</th>
<th>$r_{200}$(Mpc)</th>
</tr>
</thead>
<tbody>
<tr>
<td>NGC 4636</td>
<td>0.0031</td>
<td>13.1</td>
<td>12°43'</td>
<td>2°41'</td>
<td>0.25</td>
<td>0.60</td>
</tr>
<tr>
<td>M49</td>
<td>0.0033</td>
<td>14.0</td>
<td>12°30'</td>
<td>8°00'</td>
<td>0.46</td>
<td>0.73</td>
</tr>
<tr>
<td>Fornax</td>
<td>0.0046</td>
<td>19.5</td>
<td>03°39'</td>
<td>−35°27'</td>
<td>1.00</td>
<td>0.95</td>
</tr>
<tr>
<td>Centaurus</td>
<td>0.0114</td>
<td>48.6</td>
<td>12°49'</td>
<td>−41°18'</td>
<td>2.66</td>
<td>1.32</td>
</tr>
<tr>
<td>AWM 7</td>
<td>0.0172</td>
<td>73.6</td>
<td>02°55'</td>
<td>41°35'</td>
<td>4.28</td>
<td>1.54</td>
</tr>
<tr>
<td>Coma</td>
<td>0.0231</td>
<td>99.3</td>
<td>13°00'</td>
<td>27°59'</td>
<td>13.65</td>
<td>2.27</td>
</tr>
</tbody>
</table>

Fermi limb (Abdo et al. 2010)

Fermi upper limits of cluster observation can also set constraint on the model to explain $e^+/-$ excesses
Test with gamma-rays: extragalactic background

YQ, Yue, Zhang & Chen, 2011
Reionization and 21 cm signal

YQ et al. 2010, JCAP
Test with neutrinos: SuperK limits

Hisano et al. 2009, PRD, PLB
A non-thermally produced warm WIMP scenario

• DM is attractive explanation of e+/− excesses
• For DM annihilation, large boost factor is needed
• Gamma-ray, radio and neutrino emission will constrain the scenario

Recall the classical problems of CDM
• Cusp-core problem
• Missing satellite problem

Based on these problems, we proposed a non-thermally produced warm WIMP scenario to reconcile with the current observational data
• Non-thermal production can give relatively large cross section to explain the boost factor
• Warm nature can erase the central cusp and the small halos and avoid the gamma-ray constraints
Summary

• Due to the progress on the experiments, searching for particle dark matter becomes very popular in recent years.

• Several new generation cosmic ray experiments reveal very interesting signals, which stimulate extensive discussions of possible dark matter origin.

• Traditional SUSY DM cannot explain the data.

• Gamma-rays, radio emission and neutrinos also strongly constrain the leptonic DM models to explain the data.
Perspective

• Operating experiments: PAMELA, Fermi, H.E.S.S., MAGIC, VERITAS, ARGO-YBJ, ANTARES, IceCube

• On-going experiments: CALET, AMS02

• Planning experiments: CTA, LHAASO, KM3NET

• Large amount of high quality data ensure us to take a thorough study of the possible DM signals, cross check the models and derive implications on DM candidates
谢谢
Thank you