Constraining WIMP Properties at future direct detectors

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TeVPA, Stanford, July 2009

Based on work in collaboration with Roberto Trotta (Imperial College, London)
Milky Way Dark Matter Distribution

Including substructure, local density probably not less than 1/2 the canonical value

Vogelsberger et al., MNRAS 2009

Measured distribution of speeds near solar circle implies 10% variation relative to multivariate gaussian fit

Kamionkowski & Koussiappas 2008

Xue et al. 2008 uses population of 2000 BHB stars out to 60 kpc

\[ M(< 60 \text{ kpc}) = 4.0 \pm 0.7 \times 10^{11} M_\odot \]

\[ M_{\text{vir}} = 1.0^{+0.3}_{-0.2} \times 10^{12} M_\odot \]
RAVE escape velocity constraints

\[ f(|v| \mid v_{\text{esc}}, k) \propto (v_{\text{esc}} - |v|)^k, \quad |v| < v_{\text{esc}} \]

\[ f(|v| \mid v_{\text{esc}}, k) = 0, \quad |v| \geq v_{\text{esc}}, \]

Smith et al.,
Algorithm

Generate los velocity data sets and analyze with spherical jeans equation

MW potential given by bulge, (spherical) disk, and halo components

Free parameters:
1) Bulge scalelength
2) Velocity anisotropy of stars
3) 5 parameter DM halo model

$$\rho(r) = \frac{\rho_0}{(r/r_0)^a[1+(r/r_0)^b]^{(c-a)/b}}$$

$$\phi_{\text{disk}} = -GM_{\text{disk}}(1 - e^{-b_{\text{disk}}/r})/r.$$ 

Metropolis-hastings method determines parameters, subject to escape velocity constraints

Xue et al., 2008

\[ \sigma_{\text{los}}(r) = 111 \text{ km s}^{-1} e^{-r/354\text{ kpc}} \]
Constraining WIMP mass

10^3-10^5 kg/day exposure for Ge

Low mass WIMPs more strongly constrained

Anne Green, JCAP 0807:005,2008

Constraints on Milky Way Halo Parameters

With 2000 halo stars and local escape velocity data, project about 20% constraint on the (smooth) local dark matter density.
Projections for 1 tonne Xe

Approx. 300 (100) events for 50 (500) GeV WIMP

Assuming the incorrect local density leads to a 15 (5) sigma bias in the reconstruction for low (high) mass WIMPs

New Local Density Result

As determined from following data sets:
1) Terminal velocities
2) VBLI high mass SF regions
3) Cepheid PMs from Hipparcos
4) Local surface density
4) BHB stars
5) Satellite dynamics

For Einasto profile, local dark matter density is $0.385 \pm 0.027 \text{ GeV cm}^{-3}$
(Similar result for NFW)

Catena & Ullio 2009
Further improvements

Dark Matter Halo Triaxiality/
Non-maxwellian DF

``Complementarity``

Astrophysical ``backgrounds``


Cabrera, Krauss, Wilczek PRL 1985
Neutrino Coherent Scattering

Cross Section: \[ \sigma \sim G_f^2 Q_w^2 E_\nu^2 F(Q^2)^2 \]

Weak charge: \[ Q_w^2 = N - (1 - 4\sin^2 \theta_w)Z \]

Coherence condition: \[ [\text{three-momentum}] \times [\text{nuclear radius}] \leq 1 \]

Implies sensitivity to neutrinos \( \sim 10 \text{ MeV} \)

Fundamental prediction of the Standard Model, but not yet detected

Freedman 1974 PRD, Tubbs & Schramm 1975
Neutrino Coherent Scattering Rates at Direct Dark Matter Detectors

Figure 3. Number of events above a threshold recoil kinetic energy for four target nuclei. For both the diffuse supernova and atmospheric event rates, the sum of all contributing neutrino flavors are shown. As an additional note, the analysis above just accounts for neutrino-nucleus coherent scattering. In principle it would also be possible to detect these same fluxes via neutrino-electron elastic scatterings [8]. For this channel the largest rate is due to the solar pp reaction. For example, from pp scatterings on Xe a flat spectrum of electron recoil events is expected at $\sim 0.1$ events per ton-yr with energies up to $\sim 600$ keV.

3. Implications for WIMP-Nucleon Cross Section Constraints

In the absence of backgrounds the expected upper limit on the WIMP-cross section simply scales linearly with the detector. For example a ten times greater exposure will imply a ten times stronger upper limit on the cross section. In the presence of backgrounds, however, the projected limits on the cross section must be modified. Dodelson [26] has provided a simple formalism for estimating the upper limit on the cross section, which is given by:

$$\sigma_{\text{WIMP}} \leq \frac{1}{N_{\text{events}}} \left( \frac{E_{\text{kin}}}{m_{\text{nucleon}}} \right)^2 \left( \frac{N_{\text{influence}}}{R_{\text{geomagnetic}}} \right)$$

where $\phi_p(A)$ is the flux of primary protons (nuclei of mass A) outside the influence of the geomagnetic field and $R_p(A)$ represents the filtering effect of the geomagnetic field. Free and bound nucleons are treated separately because propagation through the geomagnetic field depends on magnetic rigidity (total momentum divided by total charge) whereas particle production depends to a good approximation on energy per nucleon. A proton of rigidity $R_{\text{GV}}$ has total energy per nucleon $E_{\text{GeV}} = \sqrt{R^2 + m_{\text{nucleon}}^2}$ whereas the corresponding relation for helium is $E_{\text{GeV/A}} = \sqrt{R^2/4 + m_{\text{nucleon}}^2}$.

The neutrinos come primarily from the two-body decay modes of pions and kaons and the subsequent muon decays. The decay chain from pions is:

$$\pi^\pm \rightarrow \mu^\pm + \nu_\mu (\bar{\nu}_\mu)$$

$\downarrow$

$$e^\pm + \nu_e (\bar{\nu}_e) + \bar{\nu}_\mu (\nu_\mu)$$

Solar Neutrinos

ATM Neutrinos

SN Neutrinos

Monroe and Fisher PRD 2008
Strigari, NJP 2009
Conclusions

- Present and future confluence of astronomical/underground data
- Incorporating all data sets important for interpreting WIMP detections/limits
- In the (bad news) of lack of WIMP signal, interesting neutrino signals are observable