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Review of Indirect WIMP Search Experiments

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Abstract

Observational evidence for dark matter can be explained by Weakly Interacting Massive Particles (WIMPs). These dark matter particle candidates could indirectly be detected through the observation of signals produced as part of WIMP annihilations or decays. Latest results from indirect searches for WIMPs are reviewed. Current and planned experiments are presented and their prospects and discovery potential discussed.

Keywords: Dark Matter, Indirect Searches

1. Introduction

Despite overwhelming evidence that it composes the vast majority of the mass in the Universe, dark matter's particle properties literally remain in the dark. Identifying the mysterious nature of dark matter is one of today's most pressing scientific problems and is being sought for using colliders, direct-detection experiments, and powerful indirect detection techniques. WIMPs – Weakly Interacting Massive Particles (denoted χ) are attractive candidates for dark matter and naturally arise in many theories beyond the standard model of particle physics, which were developed to explain the origin of electroweak symmetry breaking and solve the gauge hierarchy problem [1].

This review is structured in the following way. Evidence for dark matter and expected signals are discussed first, followed by a review of experiments and recent results. Prospects for the detection of WIMPs with existing and proposed experiments are discussed before concluding.

2. Evidence for dark matter and signals

2.1. Evidence for dark matter

Evidence for the existence of dark matter can be obtained at all scales from the motion of stars in dwarf spheroidal galaxies, galactic rotation curves, virial velocities in clusters of galaxies, gravitationally lensed galaxies, baryon acoustic oscillations (BAO), to imprints on the cosmic microwave background (CMB). N-body simulations of dark matter can reproduce observed large scale structures in our universe and can also be used to obtain expected dark matter distributions in Milky Way like galaxies. Dark matter only simulations yield spherically symmetric halo density profiles $\rho(r)$, which describe the average dark matter density as function of the distance r from the Galactic center. The impact of baryons, the behavior for small r (cusp-core problem), and the impact of sub-structure are still topics of debate. Figure 1 summarizes the observational evidence and lists astronomical objects that are expected to contain high dark matter densities and therefore are natural targets for indirect searches.

2.2. Thermal relic

If dark matter is a WIMP that is a thermal relic of the early Universe, then its total self-annihilation cross section averaged over the velocity distribution $\langle\sigma_A v\rangle$ is revealed by the observed dark matter abundance. Evolution of the number density n is determined by the competition between production and annihilation with stan-

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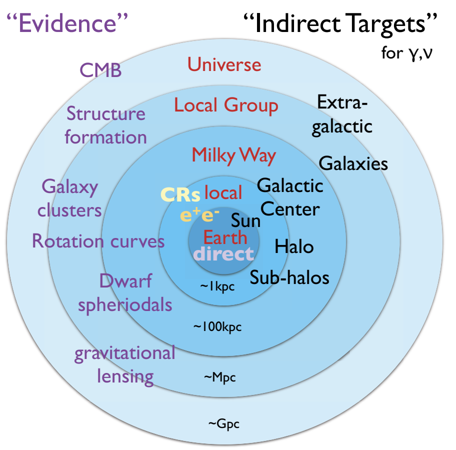

Figure 1: Observational evidence for dark matter and potential target that are expected contain significant amounts of dark matter.

dard model particles.

$$\frac{dn}{dt} + 3Hn = \frac{d(na^3)}{a^3 dt} = \langle\sigma_A v\rangle \left(n_{eq}^2 - n^2\right) \quad (1)$$

The Hubble parameter, H, provides a measure of the universal expansion rate and n_{eq} is the equilibrium abundance $n_{eq} = g_\chi (mT/(2\pi))^{3/2} \exp(-m/T)$. In equilibrium n decreases exponentially as the Universe expands and cools. When the χ abundance becomes very small, equilibrium can no longer be maintained and WIMPs freezes out [2], setting the natural scale for $\langle\sigma_A v\rangle$.

2.3. Indirect Detection

Indirect signals from WIMP annihilations depend on the square of the dark matter density, ρ, the annihilation products, and propagation effects. As an example we discuss the differential neutrino flux from WIMP annihilations of mass m_χ, which is given by:

$$\frac{d\Phi}{dE}(E, \phi, \theta) = \frac{1}{4\pi} \frac{\langle\sigma_A v\rangle}{2m_\chi^2} \sum_f \frac{dN}{dE} B_f J(\Delta\Omega) \quad (2)$$

where $\frac{dN}{dE}$ is the differential neutrino multiplicity per annihilation weighted by the branching fraction B_f. This annihilation part encodes the particle physics in form of the energy spectrum. Intrinsic WIMP properties could be derived from spectral shapes, as well as the WIMP mass identified via end-point analyses. The "Astrophysics factor" J has a characteristic spacial dependence. J is the integral over the line of sight (los) of the squared WIMP density over the integration solid angle $\Delta\Omega$, defined as

$$J(\Delta\Omega) = \int_{\Delta\Omega(\phi,\theta)} d\Omega' \int_{\rm los} \rho^2(r(l,\phi'))dl(r,\phi') \quad (3)$$

Note, that the dark matter annihilation cross sections could be velocity-dependent [3].

Expected fluxes of other cosmic messenger particles (γ-rays, $\bar{p}$/p, $e^\pm$, ...) can be obtained similarly, but often require extensive modeling of diffusion and propagation effects. WIMPs can be searched for with all these messengers, but γ-rays and neutrinos provide best detection prospects as spectral and directional information can be directly linked to the WIMP annihilations. Searches in the CMB are not discussed here [4].

3. Instruments

PAMELA – Payload for Anti-Matter Exploration and Light-nuclei Astrophysics, is a satellite-borne magnetic spectrometer attached to the Resurs-DK1 satellite. Charged particles passing through the instrument aperture are deflected by the field of a neodymion-iron-boron permanent magnet. The resulting curvature of charged particle trajectories is measured precisely by a tracking system consisting of 6 plane double-sided silicon micro-strip tracker and depends on the particle charge and magnetic rigidity ($R = pc/|Z|e$). The energy and interaction topology of particles is measured with a sampling imaging calorimeter, in which pairs of orthogonal ministrip silicon sensor planes are interleaved with tungsten absorber plates. The main purpose of the calorimeter is to distinguish $e^\pm$ from $p/\bar{p}$ and He. Plastic scintillation counters act as an anti-coincidence system to reject particles that have entered through the sides of the instrument. Further detector components are a time of flight system, neutron calorimeter, and bottom scintillator [5].

Fermi-LAT – The Fermi Large Area Telescope is a pair-conversion telescope and the primary instrument on the Fermi Gamma-ray Space Telescope launched on June 11, 2008. It consists of three detector subsystems: (1) A tracker/converter with 18 layers of paired silicon strips detectors interleaved with tungsten foils, (2) An 8 layer CsI(Ti) scintillation crystals calorimeter, (3) plastic scintillator tiles and wavelength-shifting fibers as anti-coincidence detector. Fermi-LAT is sensitive in the energy range of 20 MeV – 300 GeV. Fermi-LAT observations started in August 2008 and first analyses were performed with the `Pass 6` data event analysis scheme designed prior to launch. `Pass 7` has been improved