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Dark Matter Searches with GLAST

Lawrence Wai

Stanford Linear Accelerator Center
2575 Sand Hill Road
Menlo Park, CA 94025
U.S.A.

representing the GLAST LAT Collaboration

Abstract. Indirect detection of particle dark matter relies upon pair annihilation of Weakly Interaction Massive Particles (WIMPs), which is complementary to the well known techniques of direct detection (WIMP-nucleus scattering) and collider production (WIMP pair production). Pair annihilation of WIMPs results in the production of gamma-rays, neutrinos, and anti-matter. Of the various experiments sensitive to indirect detection of dark matter, the Gamma-ray Large Area Space Telescope (GLAST) may play the most crucial role in the next few years. After launch in late 2007, The GLAST Large Area Telescope (LAT) will survey the gamma-ray sky in the energy range of 20MeV-300GeV. By eliminating charged particle background above 100 MeV, GLAST may be sensitive to as yet to be observed Milky Way dark matter subhalos, as well as WIMP pair annihilation spectral lines from the Milky Way halo. Discovery of gamma-ray signals from dark matter in the Milky Way would not only demonstrate the particle nature of dark matter; it would also open a new observational window on galactic dark matter substructure. Location of new dark matter sources by GLAST would dramatically alter the experimental landscape; ground based gamma ray telescopes could follow up on the new GLAST sources with precision measurements of the WIMP pair annihilation spectrum.

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INTRODUCTION

Some of the most exciting discoveries in the history of physics may be just around the corner. In the next 5-10 years the particle nature of dark matter may very well be discovered by colliders, direct detection, and/or indirect detection, if the dark matter is composed primarily of Weakly Interacting Massive Particles (WIMPs). Of course, there are other possibilities for particle dark matter, as summarized in the following table:

TABLE 1. non-baryonic particle dark matter candidates

	production mechanism	**mass scale**	**observation methods**
axions	non-thermal	$\approx 10^{-5}$ eV	radio wave conversion
neutrinos	big-bang thermal	≈ 0.1 eV	large scale structure
WIMPs	big-bang thermal	≈ 100 GeV	direct/indirect detection, collider production

The WIMP hypothesis is the favorite, mainly because of the simple big-bang thermal production mechanism, but also because WIMPs are accessible to colliders, direct detection, and/or indirect detection. These complementary experimental methods will

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provide crucial clues in the exploration of the putative new underlying symmetry which prevents the dark matter particles from decaying. The favorite symmetry at the present time is SUperSYmmetry (SUSY), but there are other possibilites, as summarized in the following table:

TABLE 2. WIMP candidates motivated from particle physics

motivation	WIMP name	particle type	stability principle
supersymmetry	lightest SUSY particle	Majorana fermion	R-parity conservation
left-right asymmetries	iso-singlet neutral lepton	Majorana fermion	no mixing with neutrinos
extra dimensions	lightest Kaluza-Klein particle	fermion or boson	universal extra dimension

The Large Hadron Collider (LHC) will start operating in 2007; if the underlying particle dark matter symmetry allows for new strongly interacting particles at the TeV scale (e.g. gluinos from supersymmetry), then the new strongly interacting particles should be produced copiously and subsequently decay into pairs of dark matter particles which can be detected by "missing momentum" measurements in the LHC detectors.

Indirect detection of dark matter has the potential to provide crucial information on the physics of particle dark matter which cannot be obtained by direct detection or collider production experiments. The reason is that indirect detection depends upon pair annihilation of the relic dark matter which we know must exist as an integral part of the observed astrophysical structures in the universe, whereas direct detection depends upon WIMP-nucleon scattering at the earth, and collider experiments rely upon WIMP pair production. All three techniques are nearly completely complementary to each other in terms of dark matter source location and dark matter interaction mechanism, as summarized in the following table:

TABLE 3. WIMP detection experiment classes

	WIMP location	WIMP interaction	observation methods
direct detection	Earth's surface	WIMP-nucleus scattering	underground detectors
colliders	irrelevant	WIMP pair production	LHC, ILC detectors
indirect detection	earth, sun, galaxy	WIMP pair annihilation	gamma, neutrino, anti-matter observatories

The idea of using gamma-rays to detect particle dark matter has a long history [1]. A new era in gamma-ray astronomy will be opened with a successful launch of the Gamma-ray Large Area Space Telescope (GLAST) in late 2007. GLAST may be the single most important experiment in the area of indirect detection of dark matter for several years to come, as compared to anti-matter or neutrino observatories, or ground based gamma-ray observatories. The reason is that gamma-rays have a high detection efficiency, unlike neutrinos, and gamma-rays also travel in straight lines, unlike anti-matter, which permits the "imaging" of the dark matter sources. A large fraction of the WIMP annihilation gamma-rays are expected to fall into the "sweet spot" of the GLAST energy range ≈ 1 GeV, which is below the threshold of ground based gamma-ray observatories.

The GLAST Large Area Telescope (LAT) [2] consists of a tracking detector, calorimeter, and anti-coincidence detector. The tracking detector is composed of 36 layers of Silicon strip detectors interleaved with Tungsten foils, and serves as the target for converting the gamma-rays as well as measuring the tracks of the conversion electron-positron pair. The calorimeter is composed of 8 layers of stacked Cesium Iodide crystal logs readout with PIN photodiodes at both ends of each log. The anti-coincidence detector is composed of overlapping plastic scintillator tiles readout with PMTs via wavelength shifting fibers. At the time of writing of this paper, the LAT has been accepted by NASA for integration with the observatory. The launch of GLAST into low earth orbit is scheduled for fall 2007.

The LAT is designed to present an effective area of ∼10000 square centimeters with a field of view covering ∼1/6 of the full sky. The standard mode of operation will be a continuous scan of the sky. The energy threshold is 20 MeV and gamma-ray energies up to 300 GeV can be measured. The angular resolution for the LAT is significantly better than that of EGRET (factor of at least a few), as is the energy resolution, especially above 10 GeV. The mission lifetime is designed for 5 years. The resulting point source sensitivity ($\sim 3 \times 10^{-9} cm^{-2} s^{-1}$) is better than that of EGRET by a factor of 30 (below 10 GeV) to 100 (above 10 GeV).

If some of the gamma-rays observed by EGRET originated in pair annihilation of WIMPs, then GLAST has an excellent chance to independently demonstrate the existence of particle dark matter. In any case, because indirect detection of dark matter offers a complementary method for probing the underlying symmetry preventing the decay of dark matter particles, sources consistent with WIMP annihilation radiation located by GLAST will be compelling targets for future gamma-ray observatories.

The dark matter sources available to GLAST may be categorized into 4 classes: galactic center, galactic halo, galactic satellites, and extragalactic. Two gamma-ray sources found by EGRET may have contributions from WIMP pair annihilation: 1) the "GeV-excess" found in the galactic diffuse [3], and 2) the source at the galactic center (3EG J1746-2851). Of course, WIMP pair annihilation is only one of several possible explanations, and GLAST should be able to rule out or confirm the various hypotheses. The hypotheses for the galactic diffuse "GeV-excess" include:

- contribution from diffractive proton scattering [4]
- inverse Compton scattering from a larger than local cosmic ray electron flux [5]
- WIMP annihilation

The most convincing signature for WIMP annihilation would be $\gamma - \gamma$ and/or $\gamma - Z^0$ spectral lines. As a back-of-the-envelope estimate, consider the high latitude region $|b| >$10deg ($|b| >$30deg for $|l| <$30deg), 5 years of GLAST data, and the galactic diffuse background predicted by GALPROP within ΔE/E=0.235 at $E = M_{WIMP}$. If we assume that tree-level WIMP annihilation contributes to 30% of the galactic diffuse flux for $E > .01 M_{WIMP}$ and a line branching fraction of 0.1%, then the significance (# line counts/sqrt(# bkgd counts)) as a function of WIMP mass is shown in figure 1.

The EGRET gamma-ray source at the galactic center [6] may have contributions from particle dark matter radiation. The source may or may not be coincident with the supermassive black hole; at high energies ($>$ 5GeV) the source appears to be offset [7]. The hypotheses for the galactic center source include:

- cluster of pulsars

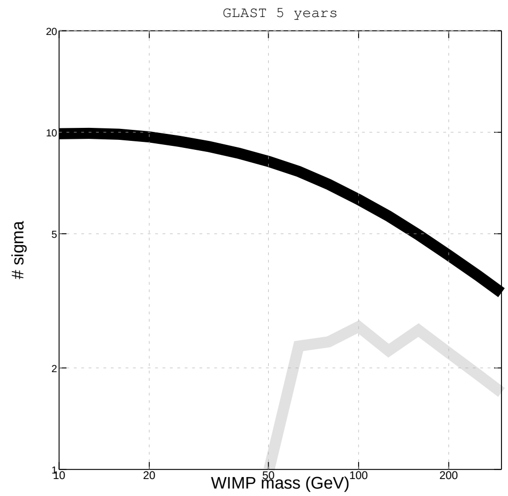

FIGURE 1. #sigma vs WIMP mass for a line branching fraction of 0.1%; grey is for $\gamma - Z^0$ and black is for $\gamma - \gamma$. The assumptions are given in the text.

- inverse Compton scattering from an electron source
- accretion onto the supermassive black hole
- WIMP annihilation

The main signatures for the WIMP annihilation hypothesis will be the spectrum, spatial location and extent, lack of variability, and lack of counterparts. The most convincing signature for WIMP annihilation will come from the energy spectrum, e.g. GLAST should be able to search for a cutoff of the source spectrum at the mass of the WIMP. However, due to the complex astrophysics present in the galactic center region, we may ultimately need to observe WIMP annihilation lines in order to lay the question to rest; this may require going "beyond-GLAST" due to suppression of the line branching fractions. The results of the LHC, the next round of direct detection experiments, and GLAST will basically shape the requirements for the next generation of dark matter detection experiments. Around 2010 we should be ready to formulate the requirements for the new experiments, whether they be on the ground, in space, and/or underground.

REFERENCES

1. J. E. Gunn, B. W. Lee, I. Lerche, D. N. Schramm and G. Steigman, Astrophys. J. **223**, 1015 (1978); F. W. Stecker, Astrophys. J. **223**, 1032 (1978); J. Silk and M. Srednicki, Phys. Rev. Lett. **53**, 624 (1984); J. Silk and H. Bloemen, Astrophys. J. **313**, L47 (1987); G. Lake, Nature **346**, 39 (1990); L. Bergström, P. Ullio and J. H. Buckley, Astropart. Phys. **9**, 137 (1998).
2. W.B. Atwood et. al., NIM A342, 302 (1994); E.D. Bloom et. al., Space Sci.Rev. **75**, 109 (1996); N. Gehrels and P. Michelson, Astropart. Phys. **11**, 277 (1999)
3. S. D. Hunter et al., Astrophys. J. **481**, 205 (1997).
4. T. Kamae, T. Abe, & T. Koi, Astrophys. J. **620**, 244 (2005).
5. A. W. Strong, I. V. Moskalenko, & O. Reimer, Astrophys. J. **613**, 962 (2004).
6. H. A. Mayer-Hasselwander et al., Astron. & Astrophys. **335**, 161 (1998).
7. D. Hooper & B. L. Dingus, Phys. Rev. D **70**, 3007 (2004).