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Search for Gamma-rays from Lightest Kaluza-Klein Particle Dark Matter with GLAST

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on behalf of GLAST LAT Dark Matter and New Physics Working Group

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The Gamma-Ray Large Area Space Telescope (GLAST), scheduled to be launched in 2007, is the next generation satellite for high-energy gamma-ray astronomy. The Large Area Telescope (LAT), GLAST main instrument, has a wide field of view (> 2 sr), a large effective area and a 20 MeV - 300 GeV energy range. It provides excellent high-energy gamma-ray observations for Dark-Matter searches. Here we study the possibility to detect gamma-rays coming from Lightest Kaluza-Klein Particle (LKP) annihilations in the context of the minimal Universal Extra Dimensions (UED) models. We perform the analysis for different LKP masses and for a Galactic Center (GC) Navarro, Frenk and White (NFW) halo model modified by a boost factor parameter. Finally we give an estimate of the background to obtain the expected total gamma-ray flux and the corresponding expected GLAST sensitivity.

1 Introduction

The nature of the Cold Dark Matter (CDM) is probably one of the most outstanding open questions in present day Cosmology. It has been a subject of special interest to high-energy physicists, astrophysicists and cosmologists for many years. According to a wealth of observations and arguments, such as excessive peculiar velocities of galaxies within clusters of galaxies or gravitational arcs, it can make up a significant fraction of the mass of the universe. On the galactic scale, dark matter halos are required to explain the observed rotation curves in spiral galaxies or the velocity dispersion in elliptical galaxies. Virtually all proposed candidates require physics beyond the standard model of particle physics and could be detected through stable products of their annihilations: energetic neutrinos, antiprotons, positrons, gamma-rays etc. Supersymmetric extensions of the standard model of particle physics provide a natural candidate for CDM in the form of a stable uncharged Majorana fermion (Neutralino). However, Kaluza-Klein (KK) Dark Matter in the framework of Universal Extra Dimensions (UED) has been proposed [1] as an interesting alternative scenario and received much attention in recent years.

Hereafter, we briefly report on the potential of the GLAST high-energy gamma-ray telescope to detect KK Dark Matter indirectly through their annihilation in the halo of the galaxy.

2 The Gamma-ray Large Area Space Telescope (GLAST) mission

GLAST is an international satellite-based observatory that will study the gamma-ray Universe [a]. Its main instrument, the Large Area Telescope (LAT), is a modular 4x4-tower pair-conversion telescope instrumented with a plastic anticoincidence shield which vetoes charged cosmic rays, a tracker of silicon strip planes with foils of tungsten converter followed by a segmented CsI electromagnetic calorimeter. A photon traversing the tracker will have some probability of converting into the tungsten foils, thus forming an electron-positron pair, subsequently tracked

[a] For more details, see the GLAST website at: http://glast.gsfc.nasa.gov/

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by the silicon strip detectors. The reconstructed trajectories of this pair, together with their energy deposition in the calorimeter, allows to reconstruct the direction and energy of the incident gamma-ray photon. The main characteristics of the full LAT detector, i.e. the effective area, point spread function and energy dispersion, have been obtained from detailed Monte Carlo studies and parameterized by a series of functions: the Instrument Response Function (IRF) [b]. The LAT takes much of its basic design concept from its predecessor EGRET but the energy range (20 MeV-300 GeV and above), field-of-view (greater than 2 steradians) and angular resolution will provide the LAT with a factor ~30 better sensitivity. This improvement should allow the LAT to detect several thousands of new high-energy sources and shed light on many issues left open by EGRET.

A detailed description of GLAST science prospects and an introduction to the experiment can be found in [2]. The LAT is now completed, and represents the largest silicon strip detector ever built. It will undergo environmental testing soon, and then will be handed to the spacecraft vendor for integration.

GLAST is scheduled for launch in September 2007.

3 Kaluza-Klein Dark Matter with GLAST in minimal universal extra dimensions models

Models with extra spatial dimensions predict a tower of Kaluza-Klein (KK) particles for every field that propagates in the higher dimensional bulk. In universal extra dimensions models (UED), all standard model fields propagate and it is natural to attempt to identify one of these KK particles with dark matter.

Here, we will consider the simplest, five-dimensional model with one compactified UED on an S^1/Z_2 orbifold of radius R. As the extra dimensions are compactified on orbifolds, a discrete symmetry, called KK parity, is preserved and ensures the stability of the lightest KK particle (LKP). Then, as the LKP is neutral with respect to the SM gauge groups with a mass (which is inversely proportional to the compactification radius R) at the weak scale, an excellent dark matter candidate naturally emerges in a stable WIMP with relic density naturally in the right range [1]. In supersymmetric theories superpartners differ in spin by 1/2, while in scenarios with extra dimensions, the excited KK states have the same spin as their ground state standard model partners. A one-loop calculation shows that the LKP is likely to be associated with the first KK excitation of the photon, more precisely the first excited KK state of the hypercharge gauge boson B. The $B^{(1)}$ relic density depends on the mass spectrum and the coannihilation channels. It was shown [1] that the limit from the Wilkinson Microwave Anisotropy Probe (WMAP) of $\Omega_{CDM}h^2 = 0.12 \pm 0.02$ corresponds to $500\ GeV \lesssim m_{B^{(1)}} \lesssim 1000\ GeV$ where h is the Hubble constant. The lower bound on the $B^{(1)}$ mass in UED models excludes any possibility of gamma-ray line signal from UED models with GLAST ($E_\gamma \lesssim$ 300 GeV) and we will therefore concentrate on continuum spectra.

Unlike the supersymmetric case, charged lepton production is not helicity suppressed and then, the suppression factor associated to Majorana fermion dark matter does not apply. At tree level, the branching ratios for $B^{(1)}$ pairs annihilation are [1] quark pairs (35%), charged lepton pairs (59%), neutrinos (4%), charged (1%) and neutral (0.5%) gauge bosons, and Higgs bosons (0.5%).

We will consider the primary gamma-rays from cascading decays of $q\bar{q}$ final states and, as proposed in [3], we will also consider secondary gamma-rays from radiative photon emission of high-energy charged leptons and the semi-hadronic decays of τ leptons. For primary gamma-rays, we will use the approximation of Fornengo et al [4], who have used the Pythia Monte Carlo

[b] http://www-glast.slac.stanford.edu/software/IS/glast_lat_performance.html

code to parametrize $dN_\gamma^{q,\tau}/dE$ for quarks and τ leptons with a center of mass energy of 1 TeV. Using DarkSusy [5] simulations, we checked that the approximations was still valid for the energy range we have considered ($m_{B^{(1)}} = 500, 800$ and $1000\ GeV$). We neglect the few percent going into W, Z, and Higgs final states. For secondary gamma-rays from charged leptons, we will use de analytic computation given in Bergström et al [3].

Following [6], the differential gamma-ray flux from dark matter particle annihilation in the GC can be written as

$$\Phi_\gamma = \frac{1}{4\pi} \frac{\langle N_\gamma \sigma v \rangle}{2 m^2_{B^{(1)}}} \int_{\Delta\Omega} \int_{\text{line of sight}} \rho^2(l) \ \ dl(\psi)\ d\Omega$$

where the integral runs along the line of sight, in a direction making an angle ψ respect to the direction of the GC and $\Delta\Omega$, the angular acceptance of the detector. $m_{B^{(1)}}$ is the mass of the LKP and N_γ is the total number of photons per annihilation above a given energy threshold E_{th}. The annihilation cross section $\langle \sigma v \rangle$ can be computed in the non relativistic expansion limit ($\langle \sigma v \rangle \simeq a + bv^2$) from [1]. Here we are only concerned with the annihilation into fermions f which, is given by $< \beta \sigma_{B^{(1)}B^{(1)} \to f\bar{f}} >_{v \to 0} = 0.518 \times (1\ TeV/m_{B^{(1)}})^2\ pb$. In order to separate the factors depending on the profile from those depending only on particle physics, we introduce the quantity $J(\psi)$, as defined in [6] and $\overline{J}(\Delta\Omega)$, the average of $J(\psi)$ over a spherical region of solid angle $\Delta\Omega$, centered on $\psi = 0$. We can then express the differential flux from a solid angle $\Delta\Omega$ as

$$\frac{d\Phi_\gamma}{dE_\gamma} = 1.4\ 10^{-8}\ \frac{dN_\gamma}{dE} \left(\frac{1\ TeV}{m_{B(1)}} \right)^4 \bar{J}(\Delta\Omega) \times \Delta\Omega \ \ m^{-2}\ s^{-1}$$

The details of the dark matter distribution in the Galactic halo remains rather uncertain. Numerical N-body simulations favor cuspy halos, with radial density distributions ranging from r^{-1} to $r^{-1.5}$ in the inner regions [7,8]. Bearing these uncertainties in mind, we will assume a moderately cuspy (r^{-1}) Navarro, Frenk and White (NFW) profile with a boost factor b. The boost factor parameter allows for deviation from a pure NFW profile (for which $b = 1$). It can be as high as 1000 in case of adiabatic compression effects [9].

The total number of photons per $B^{(1)}B^{(1)}$ annihilation is given by $dN_\gamma/dE = \sum_i B_i dN\gamma^i/dE$ where the sum is over all processes that contribute to primary and secondary gamma-rays with B_i the corresponding branching ratio.

In the left panel of Fig.1 we show (for comparison with Bergström et al [3]) the differential spectra we computed for a 800 GeV LKP with a boost factor $b \simeq 200$ in considering a region of 10^{-5} sr around the GC. We also show the various contributions to the differential flux as discussed above. In the right panel, we plotted the (normalized) differential spectra obtained for a 500, 800 and 1000 GeV LKP as compared with a E^{-2} spectra and a typical mSUGRA neutralino of 500 GeV. We clearly see that in the energy range we have considered for GLAST (5 GeV-300 GeV) the differential flux of the KK particle is close to a E^{-2} spectrum which is typical from standard astrophysical source : the connection with ground based Cherenkov arrays will be needed to disentangle both KK signal from standard astrophysical one. We can also see that the KK spectral shape is weakly dependent on the $B^{(1)}$ mass and we will only consider the 500 GeV LKP spectra in our simulations.

4 Simulations and preliminary LAT sensitivity to Kaluza-Klein Dark Matter

Using the differential spectra obtained for a 500 GeV LKP as described in the previous section, we performed a full detector simulation including the latest IRF, orbit dependent effects, dead time and South Atlantic Anomaly for one year operation. Using a modeling of the astrophysical sources, we simulated a 30 degree radius FOV centered at the GC with a NFW dark matter profile and $m_{B^{(1)}} \simeq 500$ GeV. We also simulated the diffuse background based on GALPROP

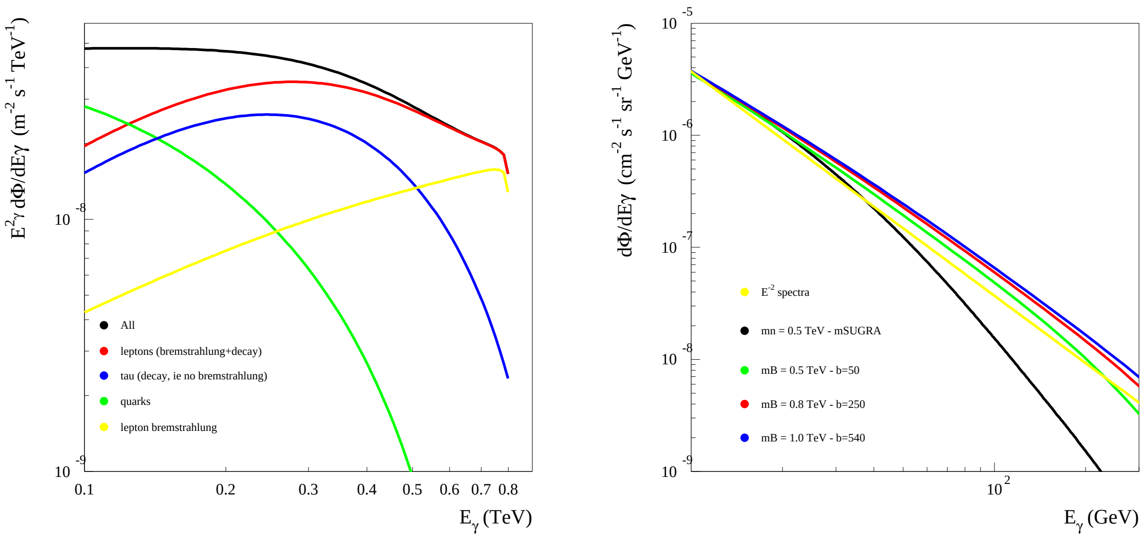

Figure 1: Various contributions to the differential spectra (left) for a 800 GeV LKP and 500,800 and 1000 GeV spectra (right) as compared with E^{-2} and typical mSUGRA neutralino of 500 GeV differential spectra.

code (point source substracted). For $E_{th} = 5$ GeV and $\Delta\Omega = 0.84\ sr$, the total integrated flux leads to the 5 σ sensitivity flux $\Phi_\gamma(\Delta\Omega, E_\gamma \geq E_{th}) = 4\ 10^{-4}\ m^{-2}\ s^{-1}$. For comparison, a NFW profile with a 500 GeV LKP leads to $\Phi_\gamma(\Delta\Omega, E_\gamma \geq E_{th}) = 2\ 10^{-5}\ m^{-2}\ s^{-1}$ which shows that a moderate boost factor of $b \simeq 20$ is needed to reach the 5 σ sensitivity.

5 Conclusions

In this paper we computed a preliminary GLAST-LAT sensitivity to indirect gamma-ray signature of KK dark matter, based on the best simulations currently available to the LAT collaboration. Despite its dependancy on a still unprecisely known background, our estimate shows that the GLAST telescope, should be capable of searching for Kaluza-Klein dark matter in the energy range $E_\gamma \geq 5$ GeV with moderate boost factors. However, due to the $\sim E^{-2}$ spectral shape of the KK spectra in the energy range we considered, joint observations with ground based Cherenkov arrays (continuum and gamma-ray lines) will be needed to disentangle KK signal from the signal of a standard astrophysical source.

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