Search for Dark Matter with GLAST [*]

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Abstract

The detection of exotic cosmic rays due to pair annihilation of dark matter particles in the Milky Way halo is a viable techniques to search for supersymmetric dark matter candidates. The study of the spectrum of gamma-rays, antiprotons and positrons offers good possibilities to perform this search in a significant portion of the Minimal Supersymmetric Standard Model parameter space. In particular the EGRET team have seen a convincing signal for a strong excess of emission from the Galactic center that has no simple explanation with standard processes. We will review the limits achievable with the experiment GLAST taking into accounts the LEP results and we will compare this method with the antiproton and positrons experiments.

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The detection of exotic cosmic rays due to pair annihilation of dark matter particles in the Milky Way halo is a viable techniques to search for supersymmetric dark matter candidates. The study of the spectrum of gamma-rays, antiprotons and positrons offers good possibilities to perform this search in a significant portion of the Minimal Supersymmetric Standard Model parameter space. In particular the EGRET team have seen a convincing signal for a strong excess of emission from the Galactic center that has no simple explanation with standard processes. We will review the limits achievable with the experiment GLAST taking into accounts the LEP results and we will compare this method with the antiproton and positrons experiments.

The EGRET team [1] have seen a convincing signal for a strong excess of emission from the galactic center, with I(E) x E^2 peaking at $\sim$2 GeV, and in an error circle of 0.2 degree radius including the position l = 0° and b = 0°.

This is a particular aspect of a more general problem of the diffuse Galactic gamma-ray emission [2] that also outside the galactic center reveals a spectrum which is harder than expected. As can be seen in figure 1, the spectrum observed with EGRET below 1 GeV is in agreement with the assumption that the cosmic ray spectra and the electron-to-proton ratio observed locally are uniform, however, the spectrum above 1 GeV, where the emission is supposedly dominated by π°-decay, is harder than that derived from the local cosmic ray proton spectrum [3]. Many different approaches are trying to solve this problem; one option is the relaxation of the assumption that the local cosmic ray electron spectrum is not representative for the entire Galaxy and it is on average harder than that measured locally. Another possibility is that there is some variability in the spectral indices of SNR cosmic ray sources (for a discussion see [4]). Here we will connect the problem of the GeV excess with the problem of the missing dark matter in the Universe and we will examine the possibility to disentangle this effect with the future space γ-ray
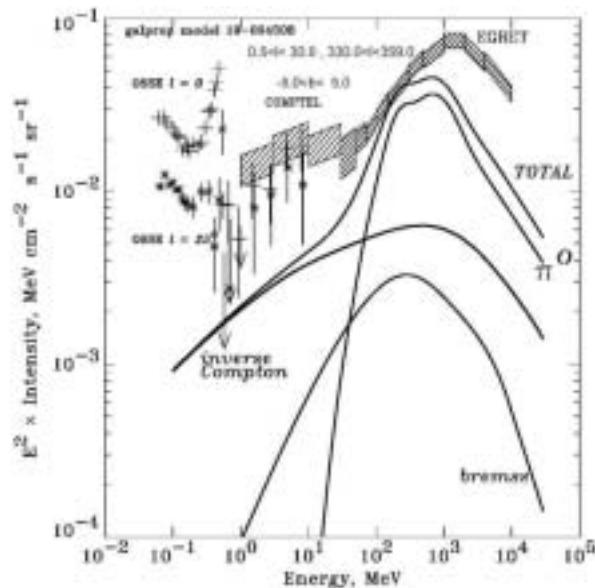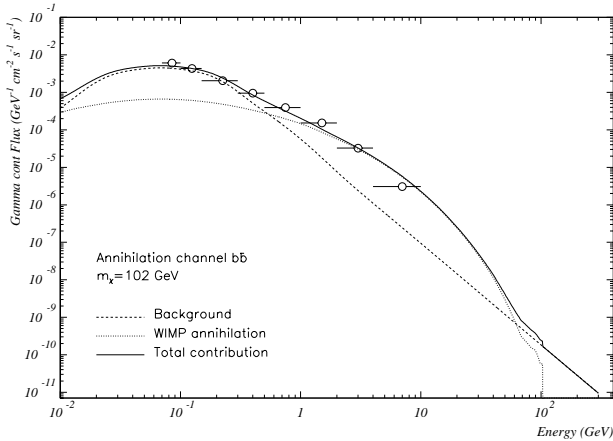

Figure 1. *Gamma-ray energy spectrum of the inner galaxy (300° $\geq$ l $\leq$ 30°) compared with what is expected for standard propagation models*

Figure 2. *Gamma-ray energy spectrum of the inner galaxy (300° ≥ l ≤ 30°) compared with what is expected for standard propagation models*

and cosmic ray experiments.

Over the last years our knowledge of the matter and energy content of the universe has improved dramatically. Astrophysical measurements from several experiments are now converging and a standard cosmological model is emerging. The most significant new data come from recent measurements of the cosmic microwave background radiation (CMBR)[5] and measurements of the Hubble flow using distant supernovae[6].

Current data favor (see for example [7]) a flat universe with a cosmological constant $\Omega_\Lambda = 1 - \Omega_m$ and a total matter density of about 40%±10% of the critical density of the Universe, with a contribution of the baryonic dark matter less then 5%. The remaining matter should be composed of some yet-undiscovered matter form, such as Weakly Interacting Massive Particles (WIMP); a good candidate for WIMP's is the Lightest Supersymmetric Particle (LSP) in R-parity conserving supersymmetric models.

The motivation for supersymmetry at an accessible energy is provided by the gauge hierarchy problem [8], namely that of understanding why $m_W \ll m_P$, the only candidate for a fun-

damental mass scale in physics. This difference introduces problems because one must fine-tune the bare mass parameter so that is almost exactly cancelled by the quantum correction in order to obtain a small physical value of m_W. This seems unnatural, and the alternative is to introduce new physics at the TeV scale and to postulate approximate supersymmetry[9], where boson and fermion partners naturally induce cancellations in quantum corrections in case

$$|m_B^2 - m_F^2| \le 1 TeV$$

.

This is also the reason to expect that, if supersymmetry is real, it might be accessible to the current generation of accelerators and in the range expected for a cold dark matter particle.

The minimal supersymmetric extension of the Standard Model (MSSM) [10] has the same gauge interactions as the Standard Model; most often its phenomenology is simplified by reducing its parameter space to only six parameters: the higgs mixing parameters μ that appears in the neutralino and chargino mass matrices, the common mass for scalar fermions at the GUT scale m_0, the gaugino mass parameter $M_{1/2}$, the trilinear scalar coupling parameter A, the ratio between the two vacuum expectation values of the Higgs fields defined as $\tan \beta = v_2/v_1 =< H_2 > / < H_1 >$ and the mass of the pseudoscalar Higgs m_A.

The LSP is expected to be stable in R-parity conserving versions of the MSSM, and hence should be present in the Universe today as a cosmological relic from the Big Bang [11]. R-parity is a discrete symmetry related to baryon number, lepton number and spin:

$$R = (-1)^{3B+L+2S}$$

It is easy to check that R=+1 for all Standard Model particles and R=-1 for all their supersymmetric partners. There are three important consequences of R conservation: (i) sparticle are always produces in pairs; (ii) heavier sparticles decay into lighter sparticles and (iii) the LSP is stable because it has no allowed decay mode.

The LSP is expected also to be neutral, because with an electric charge or strong interaction, it would have condensed along with ordinary

baryonic matter during the formation of astrophysical structures, and should be present in the Universe today in anomalous heavy isotopes [12]. This leaves as candidates a sneutrino with spin 0, the gravitino with spin 3/2 and the neutralino χ that is a combination of the partners of the γ, Z and the neutral Higgs particles (spin 1/2).

Searches for the interactions of relic particles with nuclei rule out sneutrinos with masses lighter than few TeV [13], while the gravitino could constitute warm dark matter with a mass around 1 keV. So the best candidate for cold dark matter appears to be the neutralino χ. The experimental LEP lower limit on m_χ is [14]

$$m_\chi \geq 50 \ GeV$$

As m_χ increases, the LSP pair annihilation rate in dark structures decreases, but, as we will show below, up to $\sim 300 \ GeV$, the distortion of the spectrum of the diffuse gamma ray background due to a neutralino induced component up to the neutralino mass can be a possible signature of the existence of the LSP[15].

How can this kind of signal be seen?

In figure 2 is shown the EGRET data from the Galactic center, the diffuse gamma ray background flux expected from the standard interactions and propagation models of cosmic ray protons and electrons and an example of the flux due to neutralino annihilation in the dark matter halo. In this case the signal is for a ~ 100 GeV neutralino and for the $b\bar{b}$ annihilation channel (the spectral shape of the other channels is very similar).

The total flux is:

$$\phi_\gamma = N_b \phi_b + N_\chi \phi_\chi, \tag{1}$$

where N_b and N_χ are normalizations parameters for the standard and exotic flux, respectively. N_b is associated to the interstellar medium column density $n(l)$, integrated along the line of sight.

The background flux can be written in the following way:

$$\phi_b(E_\gamma) = Em(E_\gamma)/\left(cm^2 sr\right) \tag{2}$$

$$N_b = \int_{l.o.s} \frac{dl}{4\pi} n(l)/\left(cm^{-2} sr^{-1}\right) \tag{3}$$

where $Em(E_\gamma) \ [GeV^{-1}s^{-1}]$ is the emissivity per hydrogen atom, which gives the number of secondary photons with energy E_γ, emitted per unit time and unit energy. The two main production mechanisms for the background are through the π^0 production and the inverse compton scattering. We have considered two channels for the π^0 production, i.e. primary p and He. The processes are of the type:

$$p + X \to .. \to \pi^0 \to 2\gamma, \tag{4}$$

$$He + X \to .. \to \pi^0 \to 2\gamma$$

where X can be interstellar H or He nucleus. We have simulated the spectrum using the Galprop computer code [16]. The WIMP flux ϕ_χ in eq.(1) originates from the annihililation of a couple of generic WIMPs, of mass m_χ, in allowed tree-level final states, of which the leading channels are usually $b\bar{b}, c\bar{c}, t\bar{t}, W^+W^-, Z^0Z^0$. Light quark states are suppressed by m_f^2/m_χ^2 in the annihilation cross section, where m_f is the intermediate fermion mass. Higgs bosons annihilation states are included, allowing for their decay into particles for which we do simulate. The continuum gamma ray flux coming from a direction that forms an angle ψ with the direction of the Galactic center can be written as:

$$\phi(E, \psi) = \frac{2\sigma v}{4\pi m_\chi^2} \int_{l.o.s} \rho^2(l) dl(\psi) \tag{5}$$

where m_χ is the WIMP mass, σv is the total annihilation cross section times the relative velocity of the two annihilating WIMPs (in the galactic halo $v/c \sim 10^{-3}$) and $\rho(l)$ is the WIMP mass density along the line of sight. Contributions along the line of sight are then summed. The equation (5) can be factorized into two pieces, one depending only on the cross section and the WIMP mass, and the other one depending on the WIMP distribution in the galactic halo. This factor depends in a crucial way from the halo model used. We now write the differential flux ϕ_χ of eq.(1), in units of $cm^{-2}s^{-1}sr^{-1}GeV^{-1}$, as:

$$\begin{aligned} \phi_\chi(E, \psi) &= 1.87 \cdot 10^{-11} \left(\frac{2\sigma v}{10^{-29}cm^3 s^{-1}}\right) \times \\ &\quad \times \left(\frac{10 GeV}{m_\chi}\right)^2 \cdot \left(\frac{dN}{dE}\right) \end{aligned} \tag{6}$$

where dN/dE is the the number of photons produced per unit energy in each intermediate annihilation channel. We then introduced the dimensionless function $J(\psi)$ that encodes the dependence from the halo density profile:

$$J(\psi) = \frac{1}{8.5Kpc}\left(\frac{1}{0.3GeV/cm^3}\right)\int \rho^2(l)dl(\psi) \quad (7)$$

In such a way the adimensional normalization factor N_χ of eq.(1) is then precisely $J(\psi)$. Actually we have averaged the value of $J(\psi)$ over a solid angle $\Delta\Omega$ around the direction determined by the angle ψ:

$$\langle J(\psi)\rangle_{\Delta\Omega} = \frac{1}{\Delta\Omega}\int J(\psi)d\Omega \quad (8)$$

where we have chosen the same EGRET region around the galactic center of $\Delta\Omega = 2.15\cdot 10^{-3}\,sr$.

As it can be seen from figure 2, the fit to the data greatly improve when a neutralino component is added. Of course this cannot be assumed as evidence for the existence of supersymmetry particles as the dark matter component of the halo, but as an indication that more experiments with greater sensitivity and exposure are needed.

In the next session we present one future possibility, i.e. the experiment GLAST.

1. The Gamma-ray Large Area Telescope GLAST

The standard techniques for the detection of gamma-rays in the pair production regime energy range are very different from the X-ray detection.

For X-rays detection focusing is possible and this permits large effective area, excellent energy resolution, very low background. For gamma-rays no focusing is possible and this means limited effective area, moderate energy resolution, high background but a wide field of view. This possibility to have a wide field of view is enhanced now, in respect to EGRET, with the use of silicon detectors, that allow a further increase of the ratio between height and width, essentially for two reasons: a) an increase of the position resolution that allow a decrease of the distance between the planes of the tracker without affecting the angular resolution, b) the possibility to use the silicon
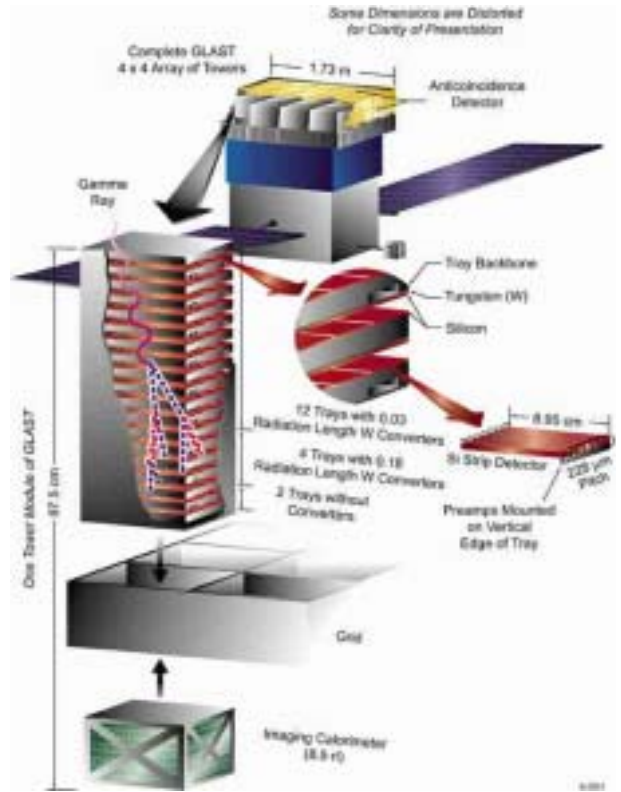

Figure 3. *The GLAST instrument, exploded to show the detector layers in a tower, the stacking of the CsI logs in the calorimeter, and the integration of the subsystems.*

detectors themselves for the trigger of an events, with the elimination of the Time of Flight system, that require some height. The Gamma-ray Large Area Space Telescope (GLAST)[19], has been selected by NASA as a mission involving an international collaboration of particle physics and astrophysics communities from the United States, Italy, Japan, France and Germany for a launch in the first half of 2006. The main scientific objects are the study of all gamma ray sources such as blazars, gamma-ray bursts, supernova remnants, pulsars, diffuse radiation, and unidentified high-energy sources. Many years of refinement has led to the configuration of the apparatus shown in figure 3, where one can see the
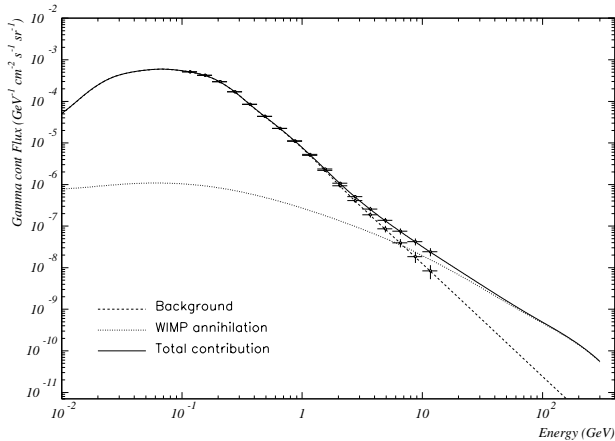
Figure 4. *Total photon spectrum from the galactic center from standard propagation models and from one neutralino annihilation models and the kind of statistical errors that it is expected in three years with GLAST.*

4x4 array of identical towers each formed by: • Si-strip Tracker Detectors and converters arranged in 18 XY tracking planes for the measurement of the photon direction. • Segmented array of CsI(Tl) crystals for the measurement the photon energy. • Segmented Anticoincidence Detector (ACD). The main characteristics, shown in figures 5 to 8, are an energy range between 20 MeV and 300 GeV, a field of view of ~ 3 sr, an energy resolution of $\sim 5\%$ at 1 GeV, a point source sensitivity of $2\mathrm{x}10^{-9}$ (ph cm^{-2} s^{-1}) at 0.1 GeV, an event deadtime of 20 μs and a peak effective area of 10000 cm^2, for a required power of 600 W and a payload weight of 3000 Kg.

The list of the people and the Institution involved in the collaboration together with the on-line status of the project is available at *http://www-glast.stanford.edu*. A description of the apparatus can be found in [20] and a description of the main physic items can be found in [21].

In figure 4 is shown the total photon spectrum from the galactic center from standard propaga-
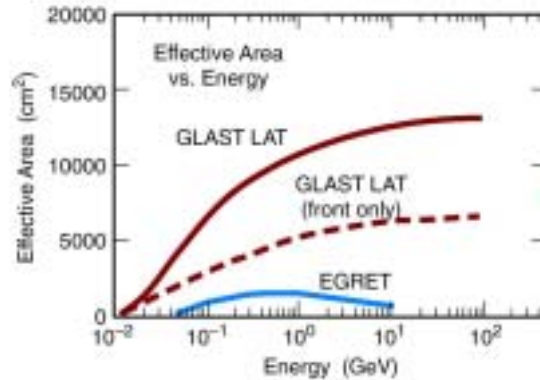

Figure 5. *GLAST effective area as a function of energy including all background and track quality cuts compared with EGRET's one*
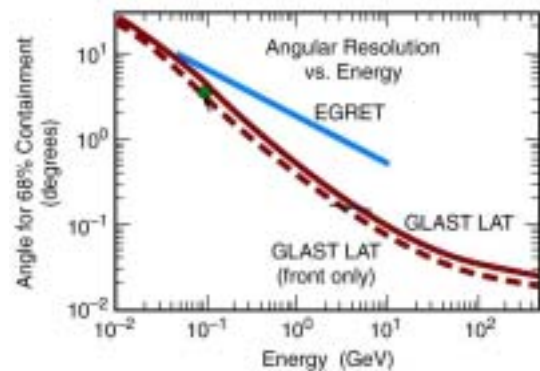

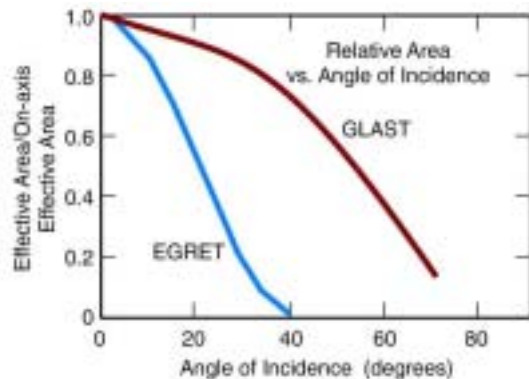Figure 6. *GLAST angular resolution.*

Figure 7. *GLAST relative effective area for 1 GeV photons as a function of the zenith angle*
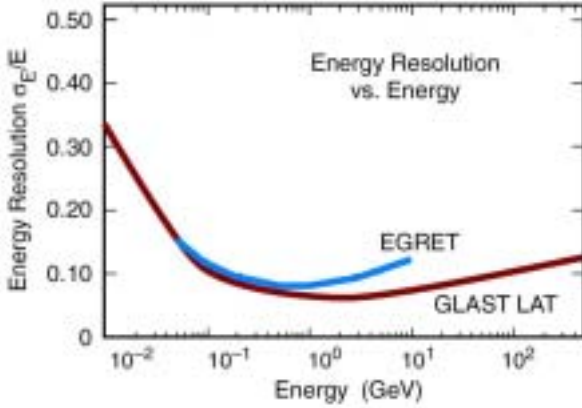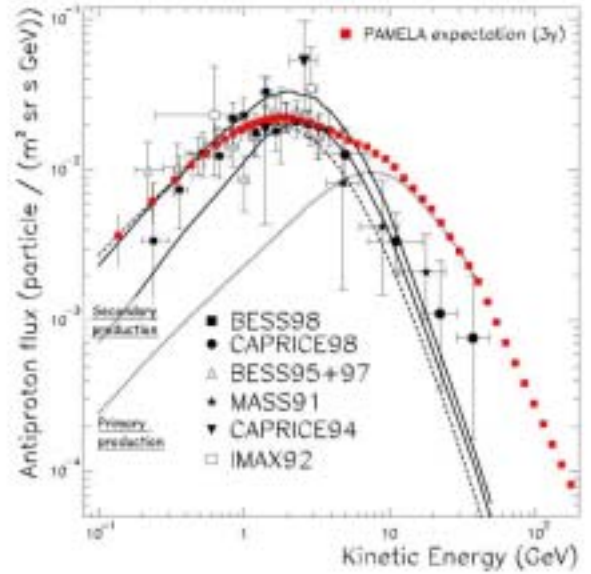
Figure 8. *GLAST and EGRET energy resolution*

Figure 9. *Distortion of the secondary antiproton flux induced by a signal from a heavy neutralino. The PAMELA expectation in the case of exotic contributions are shown by black squares*

tion models and from one neutralino annihilation models and the kind of statistical errors that it is expected in three years with GLAST in the case of a moderate value of $J(\psi)$ (~ 500) which is within the allowed ranges of both the modified isothermal and cuspy halos. This effort will be complementary to a similar search for neutralinos looking with cosmic-ray experiments like the next space experiments PAMELA[24] and AMS[25] at the distortion of the secondary positron fraction and secondary antiproton flux induced by a signal from a heavy neutralino.

2. Conclusion

The gamma-ray space experiment GLAST is under construction. Its time of operation and energy range is shown together with the other space X-ray satellite and gamma-ray experiments in figure 11. Note that it will cover an interval not covered by any other experiments. Note also the number of other experiments in other frequencies that will allow extensive multifrequency studies. In the last decade, ground-based instruments have made great progress, both in technical and scientific terms. High-energy gamma rays can be observed from the ground by experiments that detect the air showers produced in the upper atmosphere. In 12 the GLAST sensitivity is compared
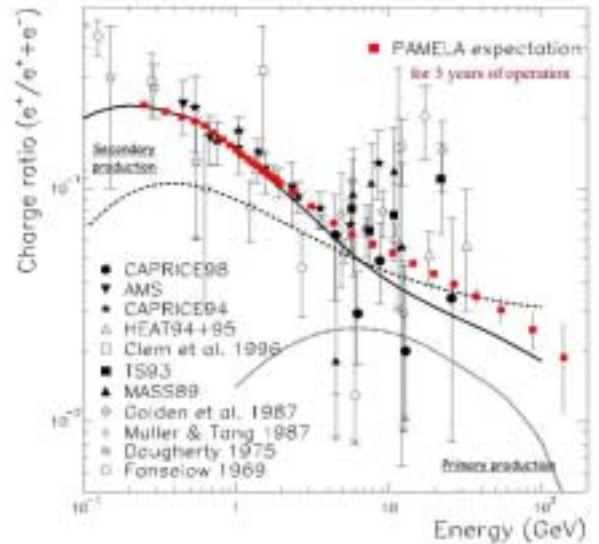

Figure 10. *Distortion of the secondary positron fraction The PAMELA expectation in the case of exotic contributions are shown by black squares*
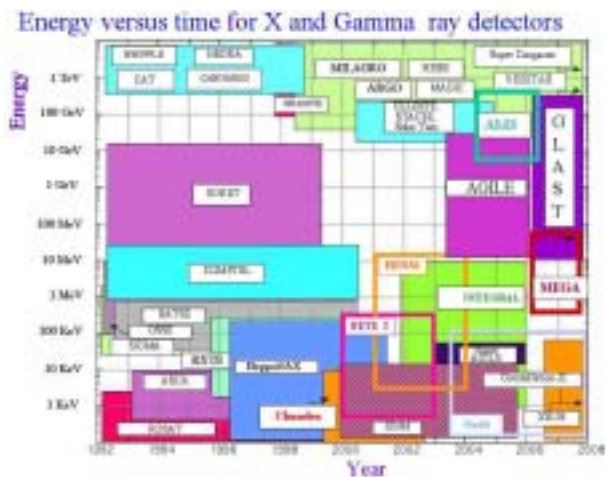
Figure 11. *Timeline schedule versus the energy range covered by present and future detectors in X and gamma-ray astrophysics.*

Figure 12. *Sensitivity of present and future detectors in the gamma-ray astrophysics.*

with the others present and future detectors in the gamma-ray astrophysics range is shown. The predicted sensitivity of a number of operational and proposed Ground based Cherenkov telescopes, CELESTE, STACEE, VERITAS, Whipple is for a 50 hour exposure on a single source. EGRET, GLAST, MILAGRO, ARGO and AGILE sensitivity is shown for one year of all sky survey. The diffuse background assumed is $2 \cdot 10^{-5}\ photons\ cm^{-2} s^{-1} sr^{-1} (100\ MeV/E)^{1.1}$, typical of the background seen by EGRET at high galactic latitudes. The source differential photon number spectrum is assumed to have a power law index of -2, typical of many of the sources observed by EGRET. Above 1GeV the GLAST sensitivity shown is not limited by background, but rather by the requirement that the number of source photons detected is at least 5 sigma above the background. The AMS sensitivities is from [30]. Note that on ground only MILAGRO and ARGO will observe more than one source simultaneously. The Home Pages of the various instruments are at *http://www-hfm.mpi-hd.mpg.de/CosmicRay/CosmicRaySites.html.*
As is shown in [31], indirect dark matter searches

and traditional particle searches are highly complementary and, in the next few years, many experiments will be sensitive to the various potential neutralino annihilation products. These include under-ice and underwater neutrino telescopes, atmospheric Cerenkov telescopes, high altitude extensive air showers detectors and the already described space missions GLAST, PAMELA together with AMS. In many cases, these experiments will improve current sensitivities by several orders of magnitude and probably, as it is shown in [31], " all models with charginos or sleptons lighter than 300 GeV will produce observable signals in at least one experiment in the cosmologically preferred regions of parameter space with $0.1 < \Omega_\chi h^2 < 0.3$ " before LHC.

Acknowledgements

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