THE GAMMA-RAY SKY UNDER A "NEW" LIGHT

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During the last year the Gamma-Ray sky has glowed of new light: the PAMELA experiment, the Pierre Auger Observatory, the AGILE satellite, and the Fermi Gamma-ray Space Telescope are contributing in an unprecedented way to the unveiling of the cosmic distribution of gamma-ray sources and their viable relation with cosmic rays. The Alpha Magnetic Spectrometer, to be launched next July 2010, will add, for the first time, a precious energetic window, up to a few TeV, to this exciting investigation. We analyze the perspectives of AMS results and the possibilities for the detection of Galactic and Extragalactic gamma-ray astrophysical sources like Pulsars, Microquasars, Gamma-Ray Bursts, and Active Galactic Nuclei.

Keywords: Gamma-ray photons; AGN; Pulsars; GRBs.

1. Results from Cosmic Rays and γ-ray Observatories

The Gamma-ray investigation of the sky is a relatively new field of research, which has reached a gorgeous development during the last few years. In less than a year, in particular, the PAMELA experiment, the Pierre Auger Observatory, the AGILE satellite, and the Fermi Gamma-Ray Space Telescope have contributed to our knowledge in an unprecedented way. Soon (current launch date: July 29, 2010), the Alpha Magnetic Spectrometer will be located on the International Space Station, adding, for the first time, a "new" observation high-energy "window" from the Space.

PAMELA measured the positron/electron ratio[1]. Low energy data show a depletion of positrons compared to other previous experiments (e.g. HEAT, AMS) and also with respect to the secondary production models. This depletion could be explained by the effect of charge drift in the solar modulation of electrons and positrons[2–4]. Otherwise, the higher energy data ($\mathrm{E} > 9\,\mathrm{GeV}$), as confirmed by other observatories, show a positron fraction excess. Positrons might also originate in objects such as pulsars and microquasars or through dark matter annihilation, which would be "primary sources". Unfortunately, these data from PAMELA are insufficient to distinguish between astrophysical primary sources and dark matter annihilation[5].

The Pierre Auger Observatory measured, since 2007, 57 events with $E > 57$ EeV, among which 27 were found to be in correlation with AGN positions within a distance of 71 Mpc[6], while on average only 5.6 were expected for isotropic distribution. This indicates that the highest energy cosmic rays are extragalactic and supports the conclusion that the observed suppression in the cosmic ray spectrum is due to the GZK effect rather than to the exhaustion of the acceleration power of their sources. Besides, being most of the 27 AGN mentioned above of Sy1 and Sy2 type, their characteristics of missing relativistic jets[7] brings to the hypothesis of the possible existence of a new class of objects: very intense, short-duration AGN flares capable of accelerating the highest energy cosmic rays, resulting from the tidal disruption of a star or from a disk instability[8].

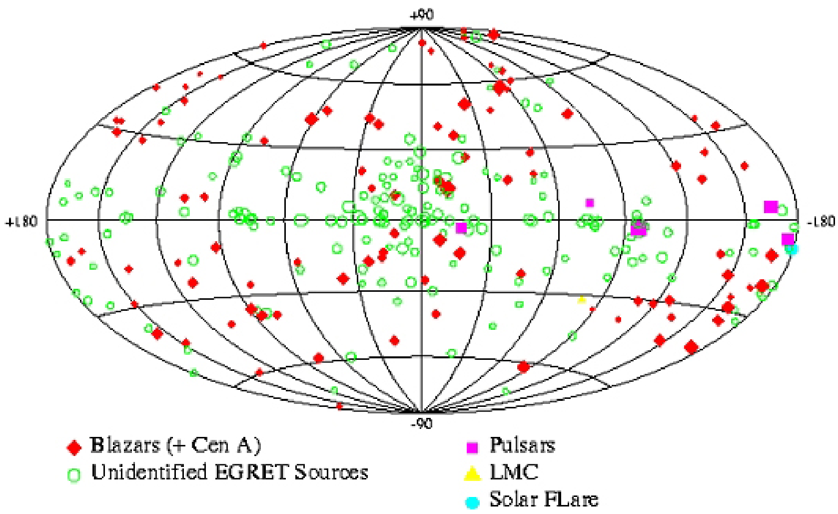

Fig. 1. The EGRET sky (E>100 MeV) in Galactic coordinates[9].

The EGRET gamma-ray telescope on-board the Compton Gamma Ray Observatory (CGRO, 1991–2000) detected 271 sources, many of which remained unidentified despite searches in the full electromagnetic spectrum[9]

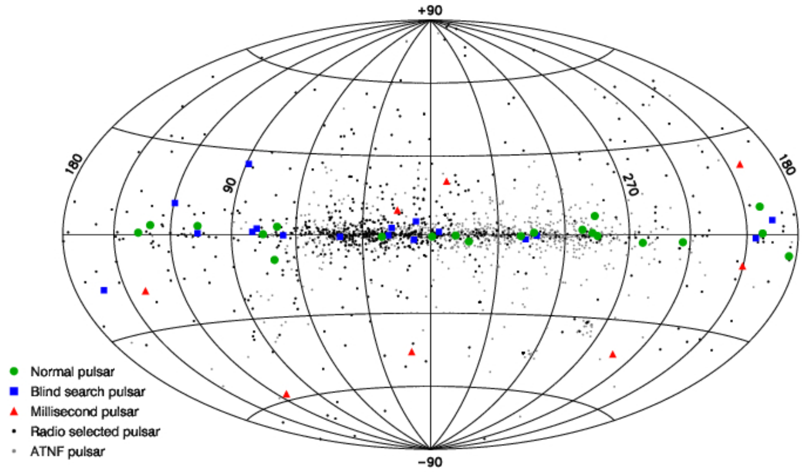

Fig. 2. The Fermi pulsar sky map in Galactic coordinates[13].

(Fig. 1). Among the identified sources 60 are blazars. Many of the 170 EGRET unidentified sources are thought to be of galactic origin because of their lack of variability and concentration along the galactic plane. A large fraction of these have been suspected to be pulsars despite deep radio and X-ray searches often failing to uncover pulsed emission, even when the gamma-ray source were coincident with supernova remnants or pulsar wind nebulae. The lack of radio pulsations has usually been explained as the narrow radio beams missing the line of sight toward the Earth.

The Fermi Gamma-Ray Space Telescope, launched on June 2008, detected 106 sources having high-confidence associations with known blazars and radio galaxies, which constitute the Large Area Telescope (LAT) Bright AGN Sample (LBAS). Fermi-LAT, 17 years after the launch of the CGRO, is revealing also new classes of GeV gamma-ray pulsars. It has recently discovered 16 radio-quiet gamma-ray pulsars[10], and 16 millisecond gamma-ray pulsars[11] (MSPs). Before Fermi, the only radio-quiet pulsar known was Geminga[12]. The First LAT Catalog of Gamma-ray Pulsars[13] has just been published (Fig. 2). Moreover, on September 2, 2009 Fermi detected the most energetic photon (33 GeV) ever revealed from a GRB[14].

The AGILE satellite, launched on April 2007, is a fully Italian (small) mission. AGILE recently detected pulsed gamma-ray emission from the powerful MSP B1821-24 in the globular cluster M28[15], and also the microquasar LSI+61303 was observed[16].

2. The Alpha Magnetic Spectrometer: AMS-02

The AMS-02 experiment will operate at energies ranging from one GeV to a few TeV and will reveal photons by means of two gamma-ray detection modes: a) conversion mode, and b) single-photon mode[17]. The conversion mode implies that the gamma-ray photon is converted in, or before, the tracker (STD) into a e^+–e^- pair, whereas in the single-photon mode the photon is converted in the electromagnetic (EM) calorimeter (ECAL) and produces an EM-shower. The probability that a high energy photon converts into a pair in the tracker is 20%, while 80% is the probability that such photon produces an EM-shower directly reaching the ECAL.

Exposure maps[18] have been calculated both for the conversion mode (Fig. 3, *Left*) and the single-photon mode (Fig. 3, *Right*). The observation time considered is of 355.7 days (5 precession periods in one year). The South Atlantic Anomaly has also been taken into account. For the tracker, the dependency of the effective area from the angle of incidence, for a total opening angle of 45.6°, has been considered in the case of photons with E = 32 GeV. The acceptance is of 0.060 m^2 sr. For the ECAL the opening angle is of 23.1° and the acceptance value of 0.073 m^2 sr.

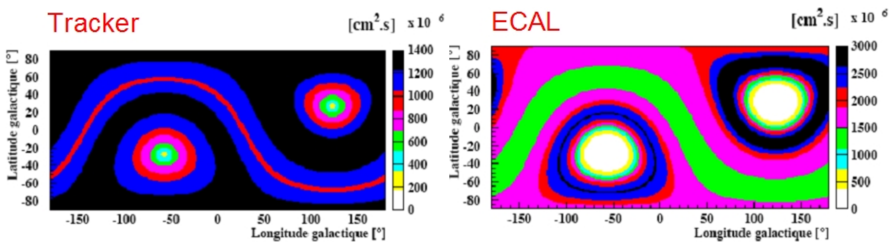

Fig. 3. Integration time: 355.7 days. *Left*: Exposure map simulated for the conversion mode. *Right*: Exposure map simulated for the single-photon mode.

3. AMS-02 compared with EGRET and Fermi

From a comparison[19] among the technical characteristics of EGRET, Fermi and AMS-02 (Table 1) we can see as AMS-02 is going to be highly competitive with both EGRET and Fermi. AMS-02 will have a chance to observe the most brilliant blazars, as EGRET did, but pushing to higher energies. AMS-02 in particular will be able to provide significant measurements of γ-ray fluxes also above 100 GeV, covering an energy range never reached so far from the Space: >100 GeV, up to a few TeV. Only Cherenkov telescopes on Earth, in fact, have reached TeV energies, although with viewing angles of only a few degrees. As a further important plus the ECAL and STD will definitely provide a better energy resolution than ever so far.

Table 1. Comparison among EGRET, Fermi, and AMS-02 (adapted from Ref. 18).

Experiment	EGRET	Fermi	AMS (ECAL)	AMS (STD)
Effective area peak (cm^2)	1300	10000	3500	550
Energy range (GeV)	0.03–30	0.03–300	1–1000	1–1000
Field of view (sr)	0.6	2.4	0.4	1.6
Angular res. (10 GeV, σ_{68})	0.5°	0.12°	2.5°	0.1°
Angular res. (≥100 GeV, σ_{68})		0.04°	0.9°	0.016°
Energy res. (10 GeV, σ(E)/E)	12%	7%	3%	2%
Energy res. (≥100 GeV, σ(E)/E)		10%	1.5%	5%
Sensitivity (10^{-10} cm^{-2} s^{-1}) (>10 GeV, 1 yr, 5σ)	120	1.5	120	60

It is worth mentioning a hot topic concerning Gamma-ray Bursts (GRBs). EGRET revealed emission over 1 GeV from 3 GRBs. Surprisingly, Fermi-LAT has observed so far only about 10 GRBs. The open question is then: do GRBs really not emit at energy higher than a few tens of GeV, or are the highest energy photons suppressed by some physical mechanism? One of the hypothesis concerns the possible absorption of such photons by the Extragalactic Background Light (EBL[20]).

4. Pulsars

Three general classes of models have been discussed for γ-ray pulsars: 1) *polar cap models*[21] - the particle acceleration and γ-production taking place in the open field line region within one stellar radius from the magnetic pole; 2) *outer gap models*[22] - the interaction region lying in the outer magnetosphere in vacuum gaps associated with the last open field lines; 3) *slot gap models*[21] - the polar cap rim acceleration extending to many stellar radii. In the polar cap models a sharp turnover is expected in the few to 10 GeV energy range due to the attenuation of the γ-ray flux in the magnetic field[23].

A simulation of AMS-02 measurements for the Vela pulsar[19] (Fig. 4, *Left*) shows that, in the energy range from 5 to 50 GeV, it is possible the distinction between the two models (polar cap and outer gap) of γ emission. Fermi observed Vela[24], whose spectrum (Fig. 4, *Right*, compared with EGRET data[25]) fitted with a power law with a simple exponential cut-off located at about 3 GeV, excludes models radiating from the near-surface polar cap zone. The observation of the Crab[26] performed by AMS-02 (Fig. 5) would also add useful information to the physical interpretation of its broadband spectral behavior.

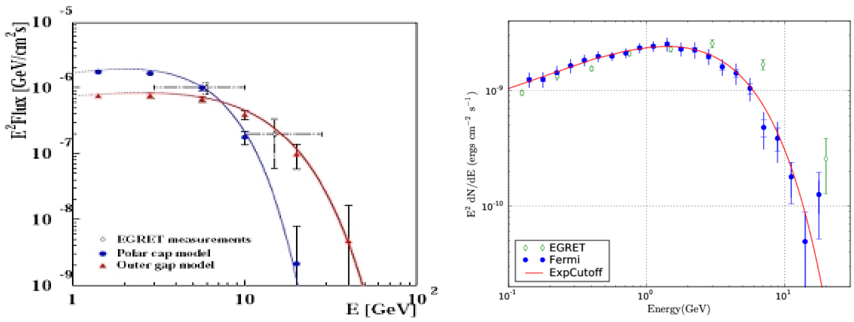

Fig. 4. *Left*: Simulation of the Vela pulsar spectrum as it should be observed by AMS-02[19]. *Right*: Spectrum of the Vela pulsar observed by Fermi[24]. EGRET data points (diamonds[25]) are shown for comparison.

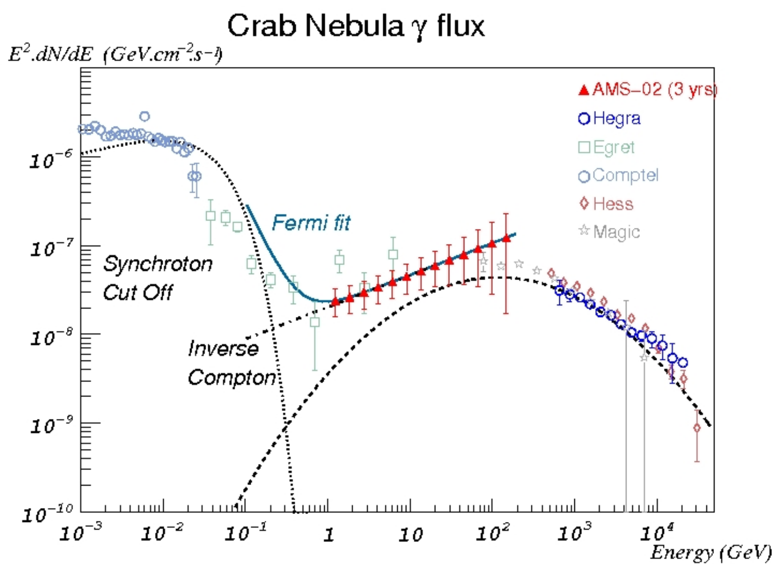

Fig. 5. Simulation of the Crab pulsar spectrum as it should be observed by AMS-02[26].

5. Conclusions

The huge gamma-ray progress, that has been developing during the last few years is going to be further enriched by the forthcoming AMS-02 experiment. Due to its large acceptance ($\sim$0.5 m^2 sr) and long duration of data taking (at least 3 years and surely longer as concerns photons) AMS-02 will have the great chance of observing both Galactic and Extragalactic astrophysical sources at high energies up to a few TeV, for the first time, from the Space. Moreover, thanks to the potentialities of both its tracker (0.4 Xo) and its calorimeter (16.3 Xo), it will be able to reach jointly an unprecedented energy and spatial resolution.

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