IL NUOVO CIMENTO Vol. 34 C, N. 6 Novembre-Dicembre 2011
DOI 10.1393/ncc/i2011-11084-7

Colloquia: IFAE 2011

# Highlights from Agile, Fermi and Pamela space experiments

S. Germani
*INFN, Sezione di Perugia - Via A. Pascoli, Perugia, Italy*

(ricevuto il 29 Luglio 2011; pubblicato online il 21 Dicembre 2011)

**Summary.** — The last generation of high energy gamma-ray and cosmic-ray space experiments are providing an unprecedented view of the high energy universe allowing continuous progresses in the understanding of astroparticle physics. The main results for Agile, Fermi and Pamela space experiments are presented.

PACS 95.55.Ka – X- and $\gamma$-ray telescopes and instrumentation.
PACS 95.85.Ry – Astronomical observations: Neutrino, muon, pion, and other elementary particles; cosmic rays.

## 1. – Introduction

The $\gamma$-rays and cosmic rays (CR) science topics are extremely interconnected and in many cases they describe the same phenomena from different points of view. Many $\gamma$-ray emitters are also sites of CR acceleration like Super Nova Remntants (SNRs), Pulsar Wind Nebulae (PWNe) and Active Galactic Nuclei (AGN). In fact the $\gamma$ radiation is generated by the accelerated cosmic particles and there is a relation between the charged particles energy spectrum and the resulting high energy photons. Due to interstellar or intergalactic magnetic fields the cosmic rays are diffused and the directional information about the generating source is lost, while $\gamma$-rays point directly to the production site that is also where CR are accelerated. The diffused particles interact with cosmic matter and magnetic fields generating a diffuse $\gamma$-ray emission. So, as for the acceleration, high energy photons can trace the CR propagation. Due to their strict interconnections both $\gamma$ rays and cosmic rays can be used to study cosmic evolution or to investigate the Dark Matter issue.

The study of the high energy sky has witnessed a dramatic revolution in the last years with the recent results from new space experiments, providing information about particle acceleration at high energy. Great improvements have been achieved in the study of cosmic rays concerning their origin, production and propagation. New highlights have been also pointed out in the understanding of the mechanism of particle acceleration in astrophysical objects. These proceedings will concentrate on recent scientific results achieved in the last years by Pamela, AGILE and Fermi.

 

## 2. – The instruments

**2**˙1. *AGILE*. – The Astrorivelatore Gamma a Immagini Leggero (AGILE) experiment is an Italian Space Agency (ASI) mission launched on April 23 2007 in a $\sim$ 550 km equatorial orbit with low inclination angle ($\sim 2.5°$). It combines for the first time a $\gamma$-ray imager (GRID), a pair conversion telescope sensitive in the 30 MeV–30 GeV energy band, with a coded-mask hard X-ray imager (SuperAGILE) in the 18–60 keV band. Details on the detector and performance can be found in [1]. AGILE reaches its optimal performance near 100 MeV with good imaging and sensitivity.

**2**˙2. *Fermi*. – The Fermi satellite was launched on June 11, 2008, from Kennedy Space Center at Cape Canaveral, Florida, into a circular orbit at 565 km altitude and 25.6° inclination. It hosts two instruments: the Large Area Telescope (LAT) [2], a pair conversion gamma-ray telescope covering the energy range from 20 MeV to more than 300 GeV, and the Gamma-ray Burst Monitor (GBM) [3] that covers the lower energy range from 8 keV to 40 MeV.

**2**˙3. *Pamela*. – The PAMELA experiment (a Payload for Antimatter Matter Exploration and Light-nuclei Astrophysics) is a satellite-borne apparatus designed to study charged particles in the cosmic radiation with a particular emphasis on antiparticles. The PAMELA apparatus is inserted inside a pressurized container attached to the Russian Resurs-DK1 satellite and comprises the following subdetectors: a time-of-flight system (ToF), a magnetic spectrometer, an anticoincidence system (AC), an electromagnetic imaging calorimeter, a shower tail catcher scintillator and a neutron detector. Technical details about the PAMELA instrument can be found in [4]. PAMELA has been collecting data since July 11th 2006.

## 3. – The $\gamma$ rays and cosmic rays connection

Super Nova Remnants are among the main candidates for the parent source population of Galactic cosmic rays but, while multiwavelength spectra of SNRs undoubtedly prove the presence of high-energy electrons in the expanding shock-waves, only indirect evidence points to the acceleration of nuclei. The Fermi-LAT detected several middle-aged SNRs (with ages of the order of $10^4$ years) showing interactions with molecular clouds. Their broad-band spectrum is better reproduced by assuming that the $\gamma$ radiation is mostly produced by nucleon-nucleon inelastic collisions [5-8].

Most of the energy lost by pulsars while spinning down goes into the production of a pulsar wind, and its termination shock further accelerates particles, primarily electrons, which produce a pulsar wind nebula. Pulsars and their wind nebulae might therefore significantly contribute to the leptonic fraction observed in cosmic rays. AGILE and the Fermi-LAT detected several events of surprising day-scale variability from the Crab nebula [9,10]. The Spectral Energy Density (SED) for different Crab flare events is shown in fig. 1. The descending part of the SED is interpreted as synchrotron emission from an electron population reaching PeV energies during the flare events which is challenging the acceleration models.

The Fermi-LAT investigated the distribution of CRs at large in the Galaxy through interstellar emission observations. The observations reinforced the so-called CR gradient problem, with the measurement of CR densities larger than expected toward the outer Galaxy [12]; this might be related to some poorly-constrained aspects in the propagation

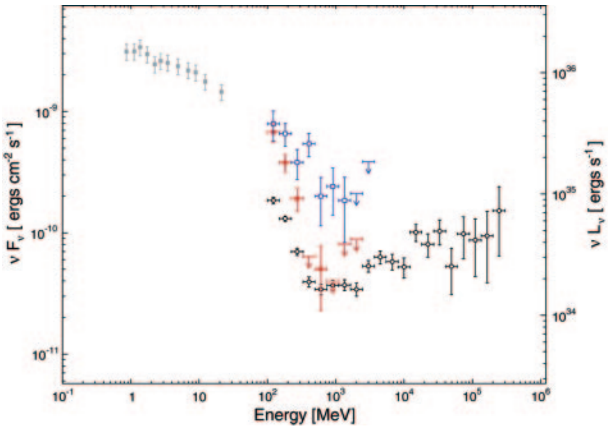


Fig. 1. – Spectral energy distribution of the Crab Nebula. Th color version of this image can be found on-line. Open circles (black) indicate the average spectrum measured by the LAT in the first 25 months of observations. Squares (red) indicate the energy spectrum during the flare of February 2009 (MJD 54857.73 to 54873.73), and open squares (blue) indicate the spectrum in September 2010 (MJD 55457.73 to 55461.73). Low energy (gray) squares indicate historical long-term average spectral data from the COMPTEL telescope, with 15% systematic errors [11]. Arrows indicate 95% confidence flux limits (see [10]).

of particles or to large masses of target gas escaping our observations or to unknown accelerators.

High-energy $\gamma$-ray emission from non-active external galaxies, highlighting different emitting CR populations, is regarded as the main piece of evidence that CRs below $10^{15}$ eV are Galactic in origin. The only non-AGN galaxy detected before the new generation of $\gamma$-ray telescopes was the nearby Large Magellanic Cloud (LMC). The LAT has so far detected $\gamma$-ray emission from the two Magellanic clouds [14, 15], the Andromeda galaxy [16] and from some nearby starburst galaxies [13]. The LMC was the first external galaxy ever resolved in high-energy $\gamma$-rays, leading to the first map of CR acceleration and propagation in a galaxy. The $\gamma$ emission correlates with massive-star formation rather than interstellar gas. This reinforces the idea that the energy for accelerating CRs in galaxies is provided by massive stars, thanks to the catastrophic explosions taking place at the end of their lives and, perhaps, to the collective action of stellar winds in massive-star clusters. The link between the acceleration of particles and massive stars is further supported by the correlation found between the $\gamma$-ray luminosity and the massive-star formation rate shown in fig. 2.

## 4. – Direct cosmic ray measurements

Th PAMELA experiment reported an unexpected rise at high energy for the positron/electron fraction in CRs [17]. The incompatibility of the measurements with pure $e^+$ secondary production led to the interpretation of the results as a possible Dark Matter signature. Fermi measured the first high-statistics spectrum of CR electrons+positrons spectrum between 20 GeV and 1 TeV [18], subsequently extended down to 7 GeV [19]. PAMELA also measured $e^-$ spectrum between 1 and 625 GeV [21] which appears softer than the $(e^- + e^+)$ spectra presented by Fermi but the difference is within the system-

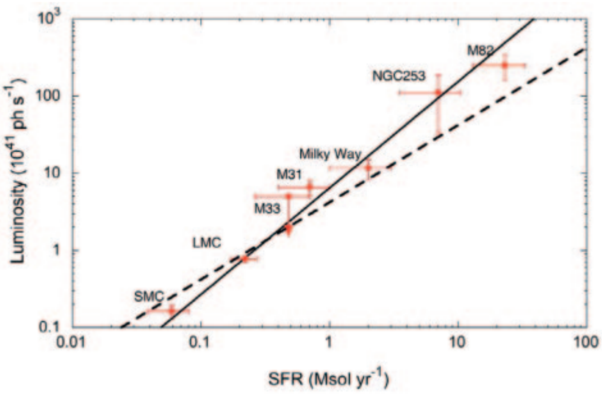


Fig. 2. – Gamma-ray > 100 MeV luminosity *vs.* star formation rate for Local Group galaxies and the starbursts M82 and NGC 253. The lines are power-law fits to the data for the MW, M31, the LMC, and the SMC, for which the slope was free (solid) or fixed to 1 (dashed). For more details see [16].

atic uncertainties. Several studies show that the LAT ($e^- + e^+$) spectrum, along with the positron fraction measured by PAMELA, can be well fitted with the addition of a separate high-energy $e^+$ and $e^-$ component, whose origin might be due to nearby pulsars or annihilation of Weakly Interacting Massive Particles (WIMPs) dark matter. Fermi investigated possible anisotropies in the arrival directions of CR electrons and positrons

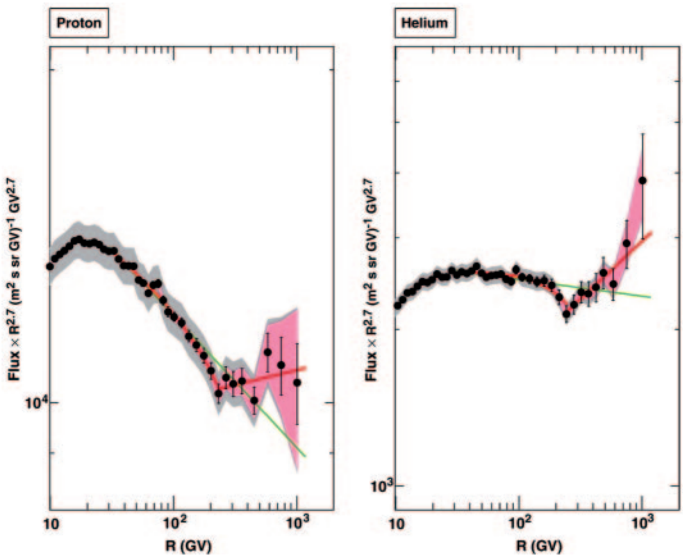


Fig. 3. – (Colour on-line) Proton (left) and helium (right) spectra in the range 10 GV to 1.2 TV. The shaded area represents the estimated systematic uncertainty. The lines represent fits with a single power law in the rigidity range 30 to 240 GV (green) and the fit with a rigidity-dependent power law (30 to 240 GV) plus a single power law above 240 GV (red), respectively (see [24]).

with energy above 60 GeV that could potentially provide important information about their origin. No significant anisotropy has been found so far [20].

The first antiproton flux measurement by PAMELA [22] has been recently updated [23] and it is in agreement with the theoretical expectations but the experimental uncertainty is now smaller than the spread between the models. The new data can be used to further constrain and improve CR generation ad propagation theory.

PAMELA reported precision measurements of the proton and helium spectra in the rigidity range 1 GV–1.2 TV [24] shown in fig. 3. The spectral shapes of these two species are different and cannot be well described by a single power law. Both the proton and helium data exhibit an abrupt spectral hardening at 230–240 GV. These data challenge the current paradigm of cosmic-ray acceleration in supernova remnants followed by diffusive propagation in the Galaxy and could be interpreted as an indication of different populations of cosmic ray sources.

## 5. – Conclusions

The space $\gamma$ and cosmic rays experiments are continuously improving our knowledge of the high energy phenomena in the Universe and are contributing to answer some long-standing open questions. They are also challenging the conventional theories of cosmic rays acceleration and propagation with new and unexpected discoveries.

## REFERENCES


[1] Tavani M. *et al.*, *Astron. Astrophys.*, **502** (2009) 3.
[2] Atwood W. B. *et al.*, *Astrophys. J.*, **697** (2009) 1071.
[3] Meegan C. *et al.*, *Astrophys. J.*, **702** (2009) 791.
[4] Picozza P. *et al.*, *Astropart. Phys.*, **296** (2007) 27.
[5] Abdo A. A. *et al.*, *Astrophys. J.*, **706** (2009) L1.
[6] Abdo A. A. *et al.*, *Science*, **327** (2010) 1103.
[7] Abdo A. A. *et al.*, *Astrophys. J. Lett.*, **710** (2010) L92.
[8] Abdo A. A. *et al.*, *Astrophys. J.*, **712** (2010) 459.
[9] Tavani M. *et al.*, *Science*, **331** (2011) 736.
[10] Abdo A. A. *et al.*, *Science*, **331** (2011) 739.
[11] Kuiper L. *et al.*, *Astron. Astrophys.*, **378** (2001) 918.
[12] Ackermann M. *et al.*, *Astrophys. J.*, **726** (2011) 81.
[13] Abdo A. A. *et al.*, *Astrophys. J. Lett*, **709** (2010) L152.
[14] Abdo A. A. *et al.*, *Astron. Astrophys.*, **512** (2010) A7.
[15] Abdo A. A. *et al.*, *Astron. Astrophys.*, **523** (2010) A46.
[16] Abdo A. A. *et al.*, *Astron. Astrophys.*, **523** (2010) L2.
[17] Adriani O. *et al.*, *Nature*, **458** (2009) 607.
[18] Abdo A. A. *et al.*, *Phys. Rev. Lett.*, **102** (2009) 181101.
[19] Ackermann M. *et al.*, *Phys. Rev. D*, **82** (2010) 092004.
[20] Ackermann M. *et al.*, *Phys. Rev. D*, **82** (2010) 092003.
[21] Adriani O. *et al.*, *Phys. Rev. Lett.*, **106** (2011) 201101.
[22] Adriani O. *et al.*, *Phys. Rev. Lett.*, **105** (2010) 121101.
[23] Adriani O. *et al.*, *Phys. Rev. Lett.*, **102** (2009) 051101.
[24] Adriani O. *et al.*, *Science*, **332(6025)** (2011) 69.