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The Fermi Gamma-Ray Sky

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Abstract. Lanched in June 2008, Fermi is a very successful mission. Its Large Area Telescope (LAT) is a powerful instrument to study the gamma-ray sky. The Italian community is contributing to the LAT data analysis through INAF, INFN and ASI.

Key words. Gamma-Ray Astronomy – Space Mission – High-Energy Astrophysics

1. Introduction

Gamma-ray astronomy is currently enjoying a golden age. For the first time in the history of high energy astrophysics, the sky is covered 24h a day by two gamma-ray telescopes. The two space missions are AGILE, a small mission operated by the Italian Space Agency (ASI), together with INAF and INFN, and Fermi, formerly known as Glast, a larger NASA mission with a significant contribution by ASI, INAF and INFN.

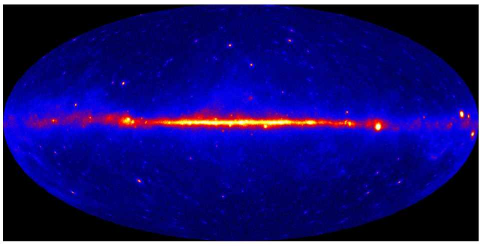

Fig. 1. Fermi image of the gamma-ray sky.

2. Highlights from Fermi LAT

Launched in June 2008, the GLAST/FERMI mission is fulfilling its promises. In 20 months of operation the Fermi Large Area Telescope Atwood et al. (2009) reached the 100 Billion trigger mark. However, this does not mean that Fermi LAT recorded 100 Billions high-energy gamma-ray photons. Unfortunately, the majority of the triggers is to be ascribed to cosmic rays, much more numerous than high-energy gamma-ray photons. Usually, cosmic ray signals are an unavoidable source of background for gamma-ray telescopes, however, Fermi LAT was able to take advantage of its cosmic ray triggers to measure the spectrum of the cosmic electrons and positrons with great accuracy Abdo et al. (2009a).

The most astounding result of the LAT observations is the extraordinary sharpness of its gamma images, as shown in Figure 1 with a picture of the whole sky after 1 year of Fermi operation.

The first Fermi catalogue Abdo et al. (2010a) numbers more than 1400 sources belonging to different celestial families such as pulsars and pulsar wind nebulae, micro quasars, Supernova Remnants (SNRs), globu-

Send offprint requests to: P. A. Caraveo lar clusters, normal galaxies, active galaxies, gamma ray bursts.

Data gathered during the mission's first year of operation represent a major step in studying neutron stars gamma-ray emission. Fermi unveiled the existence of two dozens radio-quiet neutron stars pulsating in gamma-rays without any radio signal (Abdo et al. 2009b; Saz Parkinson et al. 2010), discovered emission by very fast pulsars spinning hundred times per second Abdo et al. (2009c) and detected pulsating emission by about thirty "normal" radio pulsars Abdo et al. (2010b).

The discovery of 16 Geminga-like, radio-quiet neutron stars Abdo et al. (2009b) during the first 6 months of Fermi operation, was ranked second among the 2009 ten most important achievements by Science magazine. Radio-quiet neutron stars were already known, Fermi just confirmed their existence also thanks to the powerful blind search techniques which were developed Atwood et al. (2006).

By studying Geminga back in the 90's, Bignami and Caraveo (1996) suggested that many of the unidentified gamma sources were radio-quiet pulsars. Indeed, the majority of radio-quiet pulsars detected by Fermi coincide with unidentified sources detected by EGRET in the 90's Hartman et al. (1999) confirming our hypotheses.

Many historical problems have, indeed, been solved in the first year of Fermi operations. New data explained the behavior of LSI 61°303, a binary system marked by periodic radio emissions Abdo et al. (2009d). In 1981, while studying source COS-B CG135+01, we discovered its X emissions and suggested that LSI 61°303 could be responsible for the gamma-ray emission Bignami et al. (1981). This is indeed the case.

New data solved also the case of CygX-3, a binary system in which a small black hole takes 4,8 hours to orbit around a massive star. CygX-3 is considered a micro quasar because, sporadically, it becomes the brightest radio source in the sky, showing that the black hole environment can accelerate particles very efficiently. In 1977, analyzing the NASA SAS-2 satellite data the source was tentatively seen, but never confirmed. The new gamma instruments helped locating it: AGILE perceived four times the presence of a variable source compatible with the CygX-3 position Tavani et al. (2009) while Fermi revealed variable emissions on longer spans of time together with the source orbital modulation during its activity periods Abdo et al. (2009e). So, after 32 years the AGILE and Fermi observations were published almost simultaneously on Nature and Science magazines, confirming an old model proposed in 1977 Bignami et al. (1977).

Apart from turning neutron stars and black holes into brilliant sources of gamma-rays, particles accelerated in neutron stars' magnetosphere can escape to power pulsar wind nebulae. Already observed in X rays, PWNe can be detected in gamma rays too at least in the case of more powerful pulsars like the Crab Abdo et al. (2010c) or Vela pulsar (Abdo et al. 2010d; Pellizzoni et al. 2010).

Supernova Remnants have been detected as extended sources of gamma radiation (Abdo et al. 2009f, 2010e) making it possible to discriminate between hadronic and leptonic acceleration processes and to test the acceleration mechanism initially proposed by Enrico Fermi back in 1949.

In March 2010 a transient source was detected in the Cygnus region. The concurrent appearance of Nova V407 Cyg (Figure 2), positionally consistent with the Fermi LAT transient source, made the case for the first detection of gamma-ray emission from a Nova Abdo et al. (2010f)

Christening 2009 as the "Neutron Stars years" does not downplay the Fermi outstanding results in other fields. Active galaxies, AGNs, have been detected by the hundreds Abdo et al. (2010g). Emission by such galaxies is characterized by extreme variability Abdo et al. (2010h) and, in order to understand their behavior, a multiwavelength approach, encompassing gamma, X-ray, optical and radio observations, is needed Abdo et al. (2010i).

The constant coverage assured by Fermi and AGILE instruments and the data close monitoring enables scientists to follow the sources behavior in real time and alert other

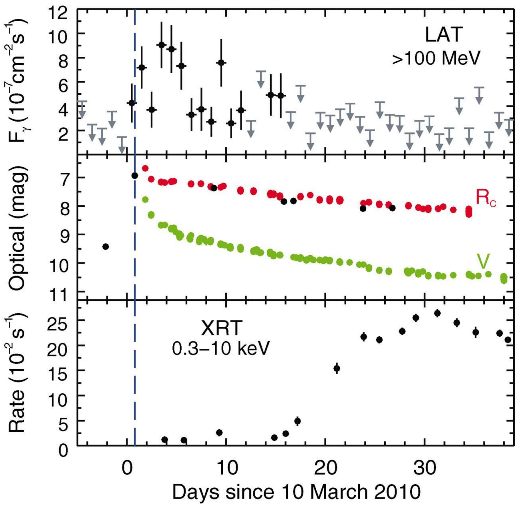

Fig. 2. Daily flux measurements for Nova V407 Cyg in gamma-rays (upper panel), optical (central panel) and X-rays (botton panel).

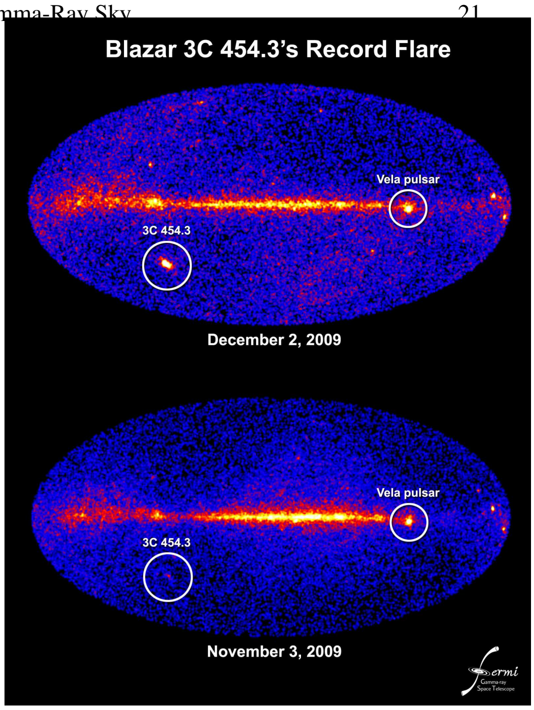

Fig. 3. Extreme variability measured for 3C454.3 in December 2009.

instruments when needed. A few particularly turbulent galaxies are monitored 24h a day. On December 2009, 3C454.3 was for a few days the brightest source in the gamma sky (see Figure 3), a rare occasion to study the emission mechanisms working in its jets Ackermann et al. (2010).

Neither are to be overlooked the gamma bursts lasting for few seconds or even fractions of a second, marking the destruction of massive stars and the birth of stellar mass black holes. Such explosions free incredible amounts of energy funneled in jets. The extreme conditions reached within those jets accelerate particles to very high energy triggering the production of copious gamma-ray emission.

Such explosions took place billions of years ago when our Universe was younger and our Sun, with its planetary system, was yet to come. Photons can travel for billions of years and represent a perfect test bed for one of the general relativity axioms: light's constant speed. According to Einstein's theory, all kind of electromagnetic radiation travel at the same speed, while according to other theories the more energetic photons could be slowed down by an hypothetical space-time sponge-like structure. Gamma-ray bursts produce photons on a wide energy range, so a simple test was performed using a short GRB recorded on May 10, 2009, by AGILE, Fermi and Swift (3 instruments with an important Italian contribution). Supposing that all photons started together seven billion years ago, limits on the difference in arrival times between the least and the most energetic photons were estimated, and wiped out the Cosmic Foam theory Abdo et al. (2009g).

The results described are just the tip of the iceberg. Much more can be mined from the Fermi LAT data which are freely available together with the software tools to perform standard analysis.

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