Mem. S.A.It. Vol. 83, 186

Memorie della

AGILE highlights

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Abstract. AGILE is an ASI space mission in joint collaboration with INAF, INFN and CIFS, dedicated to the observation of the gamma-ray Universe. We present here an overview of AGILE highlights during the first 4 years of operations. The study of galactic gamma-ray transients with AGILE already brought very important results, such as the first confirmation of gamma-ray emission above 100 MeV from a colliding wind massive binary system in the η-Carinae region, and of episodic transient gamma-ray flaring activity from Cygnus X-1 and Cygnus X-3 microquasars. The AGILE MCAL also detects surprisingly bright Terrestrial Gamma-ray Flashes (TGFs) in the Earth upper atmosphere up to 40 MeV and above, on millisecond timescales. The AGILE discovery of Crab Nebula variability above 100 MeV announced on September 2010 has astonished the scientific community. This finding was confirmed the next day by the NASA Fermi Observatory. Gamma-ray data provide evidence for particle acceleration mechanisms in nebular shock regions more efficient than previously expected from current theoretical models.

Key words. Gamma-rays: observations - catalogs

1. Introduction

AGILE (Astrorivelatore Gamma ad Immagini LEggero) (Tavani et al. 2009a) is an ASI mission with INFN, IASF-CNR e CIFS participation, devoted to gamma-ray astrophysics in the 30 MeV – 50 GeV energy range, with simultaneous X-ray imaging capability in the 18–60 keV band. The satellite was launched on April 23rd, 2007, from the Indian base of Sriharikota. The AGILE Data Center (ADC), part of the ASI Science Data Center located in Frascati, Italy, is in charge of all the scientific oriented activities related to the analysis, archiving and distribution of AGILE data. Thanks to its sky monitoring capability and fast ground segment alert system, AGILE is substantially improving our knowledge on various known gamma-rays sources, such as supernova remnants and black hole binaries, pulsars and pulsar wind nebulae, blazars and Gamma Ray Bursts. Moreover, AGILE has contributed to the discovery and study of new galactic gamma-ray source classes, of peculiar star systems and of mysterious galactic gamma-ray transients. The AGILE mission is also giving a crucial contribution to the study of the terrestrial gamma-ray flashes (TGFs) detected in the Earth atmosphere.

On September 2010 AGILE detected a powerful gamma-ray flare from the Crab Nebula (Tavani et al. 2011), and due to its rapid alert system, made the first public an-

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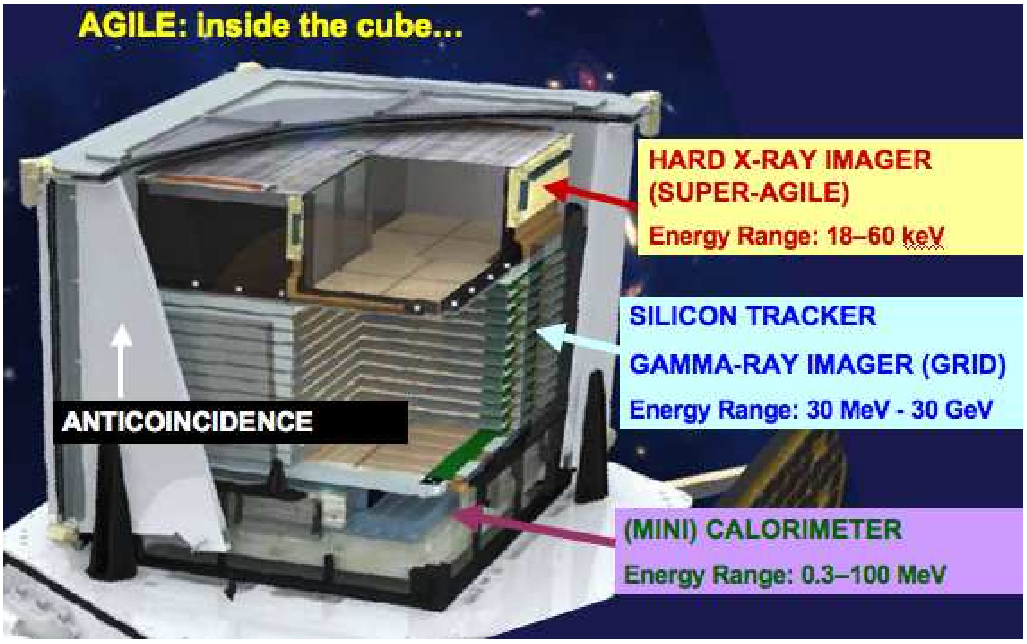

Fig. 1. The AGILE instrument

nouncement on September 22, 2010 (Tavani et al. 2010). This finding was confirmed the next day by the NASA Fermi Observatory (Buehler et al. 2010). AGILE also detected an earlier episode of flaring from the Crab Nebula in October, 2007. Astronomers have long believed the Crab to be a constant source from optical to gamma-ray energies, an ideal standard candle. Current theoretical models for particle acceleration mechanisms in nebular shock regions will need to be substantially revised.

2. The AGILE instrument

AGILE is the first of a new generation of high-energy space missions based on solid-state silicon technology. The AGILE instrument shown in Fig.1 is a first and unique combination of a gamma-ray (AGILE-GRID) (Barbiellini et al. 2001; Prest et al. 2003) and a hard X-ray (SuperAGILE) detectors (Feroci et al. 2007), for the simultaneous detection and imaging of photons in the 30 MeV - 50 GeV and in the 18 - 60 keV energy ranges. The instrument is completed by a calorimeter (energy range 250 keV - 100 MeV) (Labanti et al. 2006) and by an anti-coincidence system (Perotti et al. 2006). Its good angular resolution, 0.1 - 0.2 degrees in gamma-rays and 1-2 arcminutes in X-rays, the very large field of view ($\sim$ 3 sr) as well as its small dead time (100 μs), makes AGILE a very good instrument to study persistent and transient gamma-ray sources.

3. The AGILE data center and data flow

AGILE Telemetry raw data (Level-0) are down-linked every $\sim$ 100 min to the ASI Malindi ground station in Kenya and transmitted first to the Telespazio Mission Control Center at Fucino, and then to the **AGILE Data Center (ADC)**. ADC is in charge of all the scientific oriented activities related to the analysis, archiving and distribution of AGILE data. It is part of the ASI Science Data Center (ASDC) located in Frascati, Italy, and it includes scientific personnel from both the ASDC and the AGILE Team.

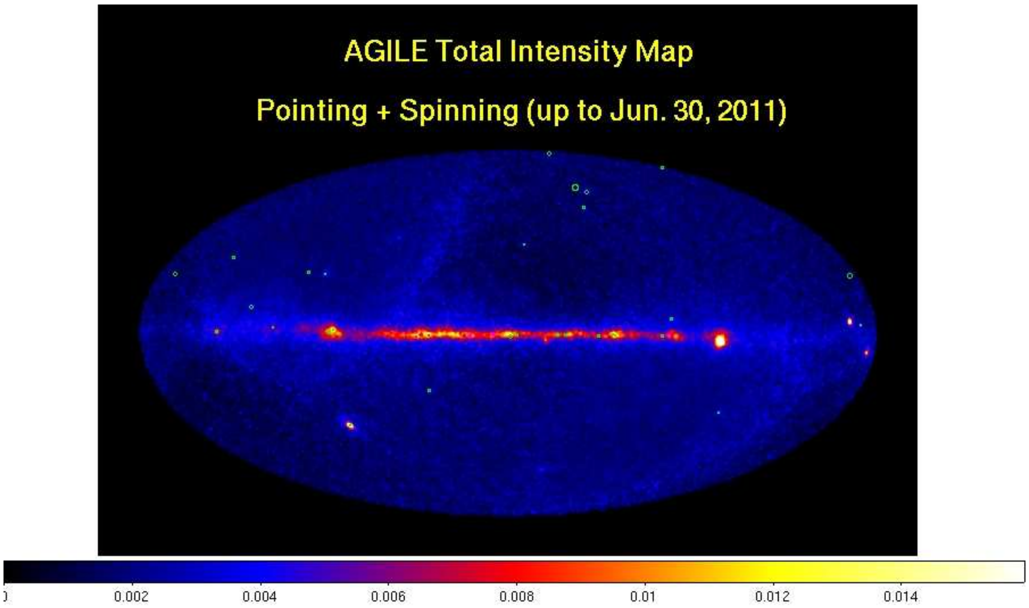

Fig. 2. Whole sky AGILE intensity map (ph cm^{-2} s^{-1} sr^{-1}) in Galactic coordinates and Aitoff projection, for energies $E > 100$ MeV, accumulated during the first 4 years of observations (pointing + spinning observing modes). Green circles: AGILE First Catalog source positions (Pittori et al. 2009).

Raw data are routinely received at ADC within $\sim$ 5 min after the end of each contact, archived and transformed in FITS format through the AGILE Pre-Processing System (Trifoglio et al. 2008), and routinely processed using the scientific data reduction software tasks developed by the AGILE instrument teams and integrated into an automatic quick-look pipeline system developed at ADC. The AGILE-GRID ground segment alert system is distributed among ADC and the AGILE Team Institutes and it combines the ADC quick-look (Pittori et al. 2011) with the GRID Science Monitoring system (Bulgarelli et al. 2009) developed by the AGILE Team. Automatic alerts to the AGILE Team are generated within ~ 100 minutes after the TM down-link start (T0) at the Ground Station. GRID Alerts are sent via email (and sms) both on a contact-by-contact basis and on a daily timescale. This fast ground segment alert system is very efficient, and leads to alerts within $\sim$ (2-2.5) hours from an astrophysical event. Refined manual analysis on most interesting alerts are performed every day (quick-look daily monitoring). Public AGILE data and software are available at the ADC web pages at ASDC[1]. More details on the ADC organization and tasks will be given in a forthcoming publication (Pittori et al. 2011).

During the first $\sim$ 2.5 years AGILE was operated in “pointing observing mode”, characterized by long observations called Observation Blocks (OBs), typically of 2-4 weeks duration, mostly concentrated along the Galactic plane following a predefined Baseline Pointing Plan. On November 4, 2009, AGILE scientific operations were reconfigured following a malfunction of the rotation wheel occurred in mid October, 2009. The satellite is currently operating regularly in “spinning observing mode”, surveying a large fraction (about 70%) of the sky each day. The instrument and all the detectors are operating nominally producing data with quality equivalent to that obtained in pointing mode. The AGILE Guest Observer Program has not suffered any interruption. Fig.2 shows the total gamma-ray intensity above 100 MeV as ob-

[1] *http://agile.asdc.asi.it*

served by AGILE up to June, 2011, during the first $\sim$ 4 years of observations (pointing plus spinning).

The AGILE First Catalog of high-confidence γ-ray sources detected by the AGILE satellite during observations performed during the first year of operations (Pittori et al. 2009) is overlayed on the image in Fig.2. The AGILE First Catalog includes 47 high-significance γ-ray sources for energies greater than 100 MeV and it results from a conservative analysis, with a high-quality event filter optimized to select γ-ray events within the central zone of the instrument Field of View (radius of 40°). A new analysis on the complete data archive, reprocessed with the latest available software and calibrations, for the release of a new AGILE source catalog is ongoing.

4. AGILE highlights during the first four years

We present here an overview of the AGILE science highlights during the first four years of operations, up to May 2011.

AGILE blazar highlights: On December 3-4, 2009 the AGILE satellite in spinning observing mode detected the strongest gamma-ray flare for energy greater than 100 MeV ever observed to date (Striani et al. 2009a, 2010a). The flaring source is the flat spectrum radio quasar 3C 454.3, with an estimated isotropic luminosity of about 6×10^{49} erg s^{-1}. Integrating from 2009-12-02 06:30 UT to 2009-12-03 08:30 UT, a quick-look maximum likelihood analysis yielded a source flux of $\sim$ (1.8 $\pm$ 0.4) 10^{-5} ph cm^{-2} s^{-1} (E $>$ 100 MeV). This flux value greatly exceeds the value previously reported by AGILE in (Striani et al. 2009b), showing a rapid increase ($\sim$ 80%) of the gamma-ray flux of the source in 24 hours.

On June 19, 2010 a very intense γ-ray emission from the peculiar Flat Spectrum Radio Quasar 4C 21.35 at redshift z=0.432, has been reported by AGILE (Striani et al. 2010b) and Fermi (Iafrate et al. 2010). Flaring activity was also detected in the previous few days by the MAGIC at energy greater than 100 GeV, together with a NIR flux increase. Following the AGILE alert, six Swift Target of Opportunity observations were performed between June 20 and 23, 2010. Optical polarimetric observations during the gamma-ray flare, and optical follow-up were also reported. During the June 17-19, 2010 gamma-ray flare the source has shown a flux increase of a factor 2 with respect to the previous 48 hours of AGILE data and a factor of 50 with respect to the previous quiescent state. The source spectral energy distribution (SED) including both quiescent and flaring γ-ray data is shown in Fig.**??**, together with multi-wavelength data and preliminary modeling. A paper is in progress on AGILE data analysis and multi-wavelength follow up (Pittori et al., in progress).

As it has been observed by EGRET and confirmed by Fermi, AGILE detects only few objects with flux greater than 100 $\times$ 10^{-8} ph cm^{-2} s^{-1} above 100 MeV. Whether this is due to selection effects or there is a subclass of blazars with peculiar characteristics is still an open question. Moreover AGILE observations have brought to light a more complex behaviour of blazars with respect to the standard models, indicating the presence of two emission components in any BL Lacs, and the possible contributions of an hot corona as source of seed photons for the External Compton in FSRQs, see also (Vercellone et al. 2010b). The study of multiwavelength correlations is the key to understand the structure of the inner jet and the origin of the seed photons for the Inverse Compton process (Vercellone et al. 2008), (Vercellone et al. 2009), (Donnarumma et al. 2009).

AGILE pulsars and pulsar wind nebulae highlights: the first AGILE Catalog includes the detection of all the 6 already known EGRET pulsars, see also (Pellizzoni et al. 2009a), and 2 new confirmed pulsars: PSR J2229+6114, providing a reliable identification for the previously unidentified EGRET source (Pellizzoni et al. 2009b), and the GO source PSR J2021+3651, see (Halpern et al. 2008), plus several other pulsar candidates. From the independent timing analysis performed by the AGILE Pulsar working group, up to now data were published for a total of

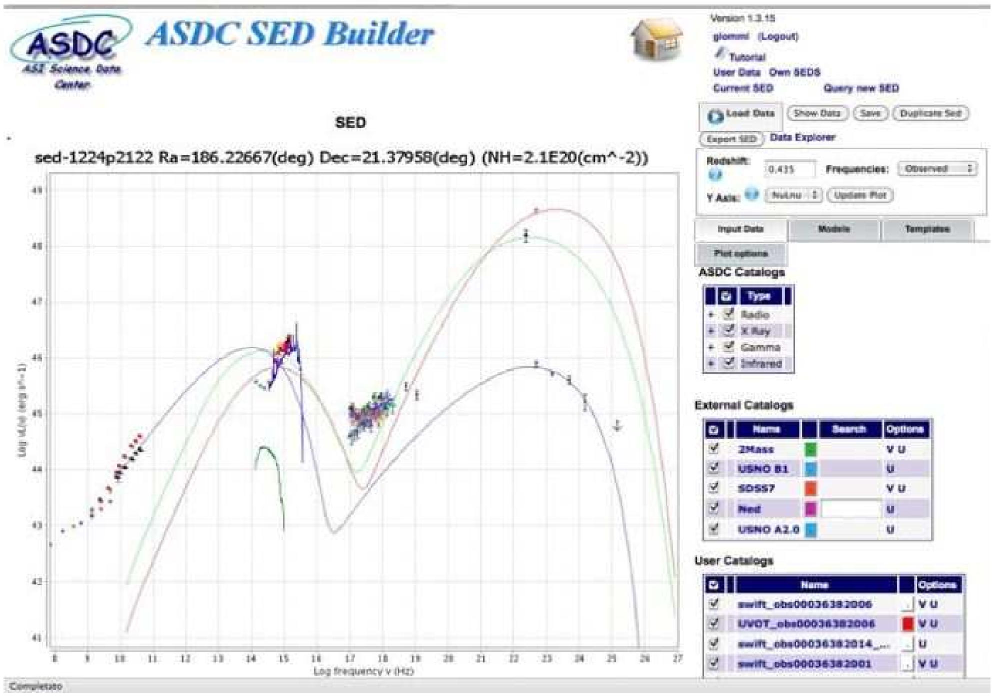

Fig. 3. Spectral energy distribution (SED) of the FSRQ 4C 21.35 obtained by using the ASDC multi-mission archive and SED builder tool. It includes both quiescent and flaring γ-ray data, together with multi-wavelength data and our preliminary SED modeling (Pittori et al., in progress).

7 new AGILE pulsar sources (Pellizzoni et al. 2009b). Among the newcomers from timing analysis (not present in the first Catalog) there is the remarkable PSR B1509-58 with very high rotational energy losses, with a magnetic field in excess of 10^{13} Gauss and the powerful millisecond pulsar B1821-24, in the globular cluster M28. Structured energy-dependent peaks (more than two) are evident in pulsar light curves, and multiple gap models may be invoked. The full exploitation of the AGILE $\simeq$ 100 MeV band, where the AGILE exposure is competitive with that of Fermi, is in progress.

Pulsars are also known to power winds of relativistic particles that can produce bright nebulae by interacting with the surrounding medium. The AGILE detection of gamma-ray emission from the Vela Pulsar Wind Nebula, described in the Science paper "Detection of Gamma-Ray Emission from the Vela Pulsar Wind Nebula with AGILE", (Pellizzoni et al. 2010) is the first experimental confirmation of gamma-ray emission (E > 100 MeV) from a pulsar wind nebula. This result constrains the particle population responsible for the GeV emission and establishes a class of gamma-ray emitters that could account for a fraction of the unidentified galactic gamma-ray sources.

AGILE galactic transients highlights: The study of galactic gamma-ray transients is an "hot topic" for the AGILE mission, which brought already very important results. AGILE has provided the first confirmation of gamma ray emission from a colliding wind massive binary system in the eta-Carinae region, a phenomenon only speculated but never observed before (Tavani et al. 2009b).

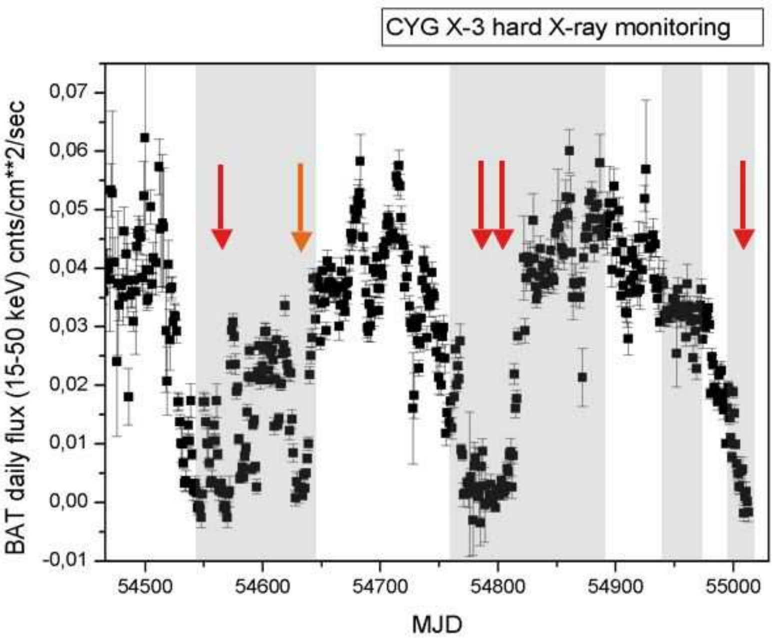

Fig. 4. Hard-X-ray flux from Cygnus X-3 as monitored by the Burst Alert Telescope (BAT) on board NASA's Swift spacecraft, between 1 January 2008 and 30 June 2009. The red arrows mark the dates of major gamma-ray flares of Cygnus X-3 as detected by the AGILE instrument (Tavani et al. 2009c).

Episodic transient gamma-ray flaring activity for a source positionally consistent with Cygnus X-1 microquasar was reported twice by AGILE (Bulgarelli et al. 2009; Sabatini et al. 2010a,b). Remarkably, AGILE also detects several gamma-ray flares from Cygnus X-3 microquasar and also a weak persistent emission above 100 MeV from the source for the first time (Tavani et al. 2009c). There is a clear pattern of temporal correlations between the gamma-ray flares and transitional spectral states of the radio-frequency and X-ray emission: flares are all associated with special Cygnus X-3 radio and X-ray/hard X-ray states. As shown in Fig.4, gamma-ray flares occur either in coincidence with low hard-X-ray fluxes or during transitions from low to high hard-X-ray fluxes, and usually appear before major radio flares.

Crab Nebula variability: During 2010 the AGILE discovery of Crab Nebula variability above 100 MeV has astonished the scientific community (Tavani et al. 2011; Abdo et al. 2011). Astronomers have long believed the Crab to be a constant source from optical to gamma-ray energies, an ideal standard candle. However, on September 2010 AGILE detected a giant gamma-ray flare, see Fig.5, and due to its rapid alert system, made the first public announcement on September 22, 2010 (Tavani et al. 2010). This finding was confirmed the next day by the Fermi Observatory (Buehler et al. 2010). AGILE detected a flare from the Crab also in October, 2007 and in sect 6.1 of the First AGILE Catalog paper (Pittori et al. 2009), it was reported that anomalous flux values observed from the Crab in 2007 were under investigation.

Astronomers have long believed the Crab to be a constant source from optical to gamma-ray energies, an ideal standard candle. Gamma-ray data provide evidence for particle accel-

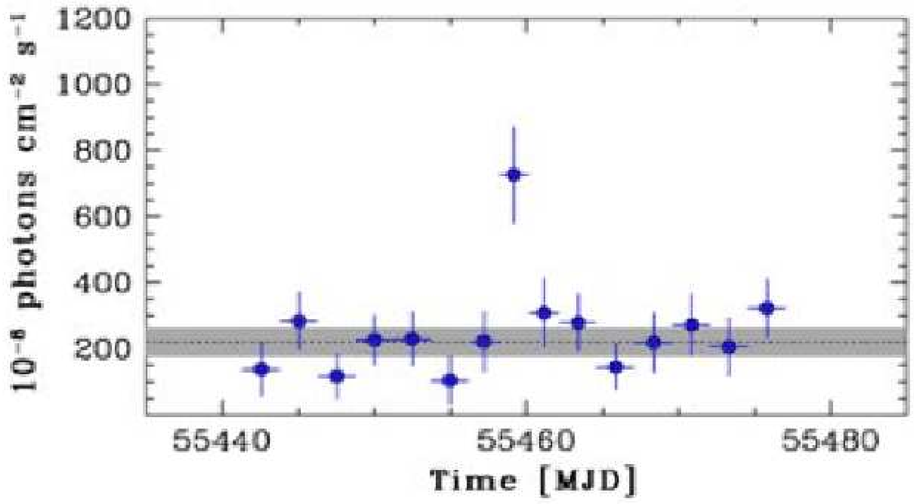

Fig. 5. The Crab Nebula flare in September 2010, as observed by AGILE at energies above 100 MeV, (Tavani et al. 2011).

eration mechanisms in nebular shock regions more efficient than previously expected from current theoretical models.

Impulsive events: AGILE GRBs and TGFs: The X-ray imager SuperAGILE detects several GRBs in its energy band (18-60 keV) at a rate of about 1 per month (Del Monte et al. 2008), while the AGILE MCAL observes about 1 GRB per week in the energy range 0.7-1.4 MeV on several time scales (Marisaldi et al. 2008). At GRID energies only three confirmed GRBs with high energy component $E >$ 50 MeV were observed up to now (Giuliani et al. 2008).

The AGILE MCAL also detects very interesting events on timescales < 5 ms up to 40 MeV and above, which are currently under study as "Terrestrial Gamma-Ray Flashes" (TGF) (Marisaldi et al. 2010). TGFs are phenomena of terrestrial atmospheric origin only lasting a few milliseconds that are likely associated to very intense tropical thunderstorms.

5. Conclusions

The study of cosmic gamma-rays in the energy range from a few tens of MeV to a few tens of GeV is only possible from space due to atmospheric absorption, and it is fundamental for our understanding of the most energetic phenomena occurring in nature. With the successful launch of the new generation gamma-ray space ASI telescope AGILE on April 2007, followed by NASA Fermi/GLAST on June 2008, gamma-ray astrophysics entered a new era. In several cases gamma-ray data provide evidence for particle acceleration mechanisms more efficient than previously expected from current theoretical models. Gamma-ray emission from cosmic sources at these energies is intrinsically non-thermal, and the study of the wide variety of gamma-ray sources, such as Galactic and Extragalactic compact objects, and of impulsive gamma-ray events such as far away GRBs and very near TGFs, provides a unique opportunity to test theories of particle acceleration, and radiation processes in extreme conditions and it may help to shed light on the foundations of physics itself.

6. Discussion

JIM BEALL: Can you please clarify the relationship between the X-ray dip, the γ-ray flare, and the radio flare in Cygnus X-3?

CARLOTTA PITTORI: Gamma-ray flares above 100 MeV occur either in coincidence with **low** hard-X-ray states or during transitions from low to high hard-X-ray fluxes, and usually appear **before** major radio flares.

WOLFGANG KUNDT Comment: I would like to remind that η-Carinae has been intepreted as a possible evolved triple-star system.

Acknowledgements. We acknowledge support from the ASI grants I/089/06/2 and I/042/10/0.

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