Study of the Point Spread Function of AGILE-GRID in spinning mode

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Abstract

The ability of the AGILE gamma-ray imager detector (GRID) to reconstruct the arrival direction of an incident photon is quantified through the Point Spread Function (PSF). In a gamma-ray imaging detector, the PSF depends on the accuracy of the track reconstruction method and it is a function of the photon energy and its incidence angle with respect to the detector axis. Monte Carlo simulations, test beams and in-flight calibrations when AGILE was in Pointing Mode of observation were used to characterize the PSF. Since Nov. 2009, AGILE has been put in the safe Spinning Mode of observation. In order to assess the PSF function in Spinning Mode, we have performed a study based on the aperture photometry technique applied to one of the brightest gamma-ray source, the Crab nebula.

The AGILE spacecraft and its payload

AGILE ("Astrorivelatore Gamma a Immagini Leggero") is an Italian Space Agency (ASI) mission dedicated to the observation of the gamma-ray Universe ([1], [2]). AGILE is a completely Italian mission funded by ASI, built and operated in cooperation with INAF, INFN, CIFS, and with the participation of several Italian companies: Carlo Gavazzi Space, Thales-Alenia Space Italia, Rheinmetall Italia, Telespazio, Galileo Avionica, Mipot. The satellite was launched on April 23rd, 2007, from the Indian base of Sriharikota. AGILE is the first of a new generation of high-energy space missions based on solid-state silicon technology, combining for the first time two sophisticated co-axial instruments: the Gamma-Ray Imaging Detector GRID [4,5], sensitive to photons with energy in the range 30 MeV - 50 GeV, and a hard X-ray detector, sensitive in the range 18 - 60 keV [3]. The instrument is completed by a calorimeter (energy range 250 keV - 100 MeV) [6] and by an anti-coincidence system [7]. Its optimum angular resolution, 0.1 - 0.2 degrees in gamma-rays and 1-2 arcminutes in X-rays, the very large field of view as well as its small dead time (100 microsec), makes AGILE a very good instrument to study persistent and transient gamma-ray sources.

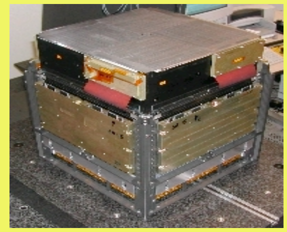

Figure 1: *the AGILE payload. The gamma-ray imager GRID and, on top of it, the hard X-ray Super-AGILE detector.*

AGILE in Spinning Mode

Until Oct. 2009, the AGILE spacecraft was operated in "fixed-pointing" mode, completing 101 pointings. Starting from Nov. 2009, the attitude control system had to be re-configured and the scientific operations changed into the "**spinning observation mode**". The main instrument axis now rotates around the spacecraft Z-axis with an angular velocity v ≈ 0.8 deg/s, thus scanning roughly 70% of the sky every day.

Due to the fixed solar panels configuration, the Sun direction has to be always perpendicular to the solar panel surface. Thus, the regions around the Sun and anti-Sun directions are excluded from the daily scan by the GRID detector. Nevertheless, these exclusion regions shift during the year along the Elliptical plane due to the Earth orbital motion and the whole sky is thus imaged every three months (Fig. 2).

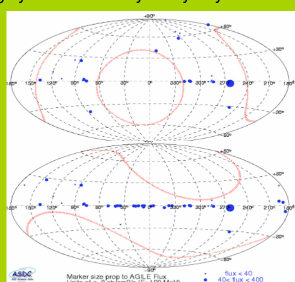

Figure 2: *Sky map in HAMMER-AITOFF projection in Galactic coordinates showing the portion of sky accessible by AGILE in Spinning Mode at two different dates: 2013/01/01 and 2013/04/01. Red lines show exclusion regions around the Sun and Anti-Sun. The First Agile Catalogue Sources [8] are also shown.*

The spinning velocity can be estimated by the attitude of the three spacecraft axes X,Y,Z (in Celestial or Galactic Coordinates) (see Figure 3). Initially, the spacecraft rotation period was of around 6 min. Starting from Feb. 2010, in order to increase the sky GRID daily exposure, the rotation period has been reduced down to an average value of 7.5 min (see Figure 4).

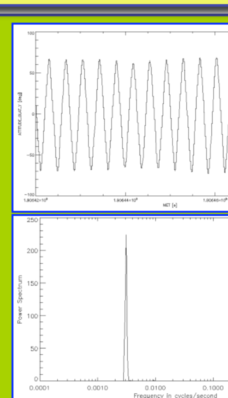

Figure 3: *Upper: AGILE spacecraft Y-axis viewing direction as a function of time, as recorded just after the satellite reconfiguration (2 hours of data taken on Jan 15th, 2010). Right: Power spectrum of the time series shown above. Estimated rotation period: 5.7 min*

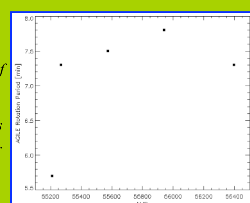

Figure 4: *Rotation period of the AGILE spacecraft in Spinning mode as a function of time.*

Study of the GRID PSF in Spinning

In order to determine the PSF in Spinning Mode, we have performed a study based on the aperture photometry technique [9] using in-flight data taken from Nov. '09 till July '12. The aperture photometry technique is largely used in optical, UV and IR astronomy to determine the instrumental magnitude of a star in not very crowded star fields. The signal from the star is evaluated within a circle centered on the star, while the background counts are evaluated within an annulus centered at the star position and then subtracted to the counts in the signal circle. For our study, we chose as source of gamma-rays one of the brightest ones, the Crab Nebula (1AGL J0535+2205), and two separate energy bands: 100-400 MeV and 400-1000 MeV (Fig. 5).

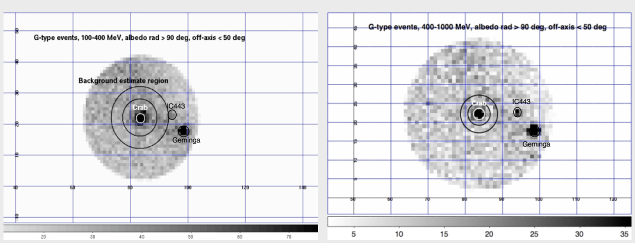

Figure 5: *RA-DEC maps (J2000) of the gamma-like (G-type) events observed by the GRID detector within 20° from the Crab position (RA,DEC (J2000)=83.775°, 22.095°) for 100-400 MeV band (Left) and 400-1000 MeV band (right). G-type events have been selected using the latest AGILE event filter FM3.119 (FM filter). Events from the terrestrial albedo with arrival directions < 90° and with off-axis angles >50 deg have been rejected. The annular regions used for the background estimates are also shown.*

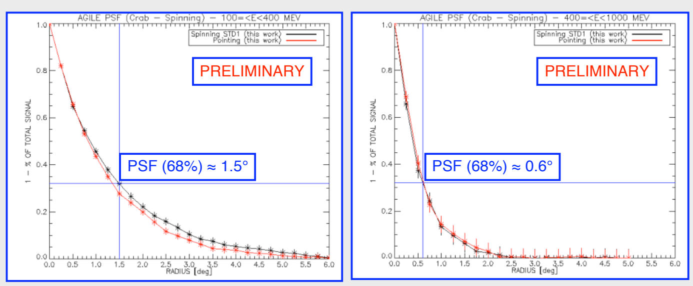

Figure 6: *Left: (1 - % of total signal) as a function of the distance from the Crab position for G-type events with energy between 100 and 400 MeV. Right: the same graph for events in the 400-1000 energy band. On both plots, the red curves show the results obtained for the Pointing period applying the same method [11].*

In order to build the GRID PSF curve, we estimate the source signal density as a function of the angular distance from the source. To do this, the aperture photometry is iteratively applied to several concentric circular annuli centered at the Crab position, whose inner and outer radii increment by 0.25° up to a maximum aperture chosen according to the energy interval under consideration (This method is also known as surface photometry [10]). The background photon density is estimated from an outer annulus, whose internal and external radii are again chosen according to the energy band under consideration (see Fig. 5). From the inverse of the cumulative of the surface photometry distribution (1 - fraction of total source signal), we can estimate the GRID PSF as the value of the radius containing 68% of the total signal contribution (32% for the inverse) (see Figure 6).

Conclusions

In this work, we have evaluated the PSF of the AGILE-GRID detector in Spinning Mode applying the aperture photometry technique to the Crab Nebula gamma-ray source. Two energy bands (100-400 and 400-1000 MeV) have been chosen for this study. For the lower energy band, we have found a slightly larger PSF for the Spinning period with respect to the Pointing observations (also confirmed in [12]), while the Spinning PSF in the higher energy band is consistent with the one observed in Pointing, calculated with the same method.

References

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