SuperAGILE: The X-ray Monitor of the AGILE Gamma-ray Mission

M. Feroci\textsuperscript{1}, E. Costa\textsuperscript{1}, E. Del Monte\textsuperscript{1}, I. Lapshov\textsuperscript{1}, M. Mastropietro\textsuperscript{1}, E. Morelli\textsuperscript{2}, M. Rapisarda\textsuperscript{3}, A. Rubini\textsuperscript{1}, P. Soffitta\textsuperscript{1}, G. Barbiellini\textsuperscript{4}, F. Longo\textsuperscript{4}, M. Prest\textsuperscript{4}, E. Vallazza\textsuperscript{4}, A. Argan\textsuperscript{5}, S. Mereghetti\textsuperscript{5}, M. Tavani\textsuperscript{5}, S. Vercellone\textsuperscript{5}, and A. Morselli\textsuperscript{6}

\textsuperscript{1}Istituto di Astrofisica Spaziale, CNR, Rome, Italy
\textsuperscript{2}Istituto TESRE, CNR, Bologna, Italy
\textsuperscript{3}ENEA - Frascati, Italy
\textsuperscript{4}INFN - Sezione di Trieste, Italy
\textsuperscript{5}Istituto di Fisica Cosmica "G. Occhialini", CNR, Milan, Italy
\textsuperscript{6}Univ. Roma "Tor Vergata" and INFN - Sezione di Roma 2, Italy

ABSTRACT

SuperAGILE is the X-ray stage of the AGILE gamma-ray mission. It is devoted to monitor X-ray (10-40 keV) sources with a sensitivity better than 10 mCrabs in 50 ks and to detect X-ray transients in a field of view of 1.8 sr, well matched to that of the gamma-ray tracker, with few arc-minutes position resolution and better than 5 \( \mu \)s timing resolution. SuperAGILE is designed to exploit one additional layer of four Si microstrip detectors placed on top of the AGILE tracker, and a system of four mutually orthogonal one-dimensional coded masks to encode the X-ray sky. The total geometric area is 1444 cm\(^2\). Low noise electronics based on ASIC technology composes the front-end read out. We present here the instrumental and astrophysical performances of SuperAGILE as derived by analytical calculations, Monte Carlo simulations and experimental tests on a prototype of the silicon microstrip detector and front-end electronics.

Key words: X-rays; Instrumentation.

1. INTRODUCTION

AGILE (“Astrorivelatore Gamma ad Immagini LEggero”, Tavani et al. 2000 and Barbiellini et al. 2000) is the first mission of the Program of Small Missions of the Italian Space Agency (ASI). The main goal of AGILE is to monitor the gamma-ray sky in the energy range between 30 MeV and 50 GeV, with a large field of view (~3 sr), good sensitivity, good angular resolution and good timing (dead time lower than 100 \( \mu \)s for the gamma-ray detector).

AGILE is scheduled for launch by the beginning of 2003 in an equatorial ~100 minutes orbit, for a nominal lifetime of 2 years. It will use the ASI base in Malindi as a ground station. The satellite mass will be about 200 kg (~65 kg of payload) and the power available to the payload is about 65 W. The scientific telemetry will be able to transmit approximately 300 Mbit of data to ground at each passage over the Malindi ground station.

The AGILE payload (Mereghetti et al. 2000) is composed of a Si tracker, containing 14 planes of Si microstrip detectors (121 \( \mu \)m pitch), interleaved with tungsten layers used as a photon pair converter (each layer is 0.07 radiation length - \( X_0 \)). At the bottom of the Si tracker a mini-calorimeter - two planes of CsI bars, for a total on-axis radiation length of 1.5 \( X_0 \) - is in charge of the total absorption of the created pairs. The same detector, however, can be used for independent detection and triggering of high energy (300 keV - 200 MeV) transient events. The hard X-ray section, SuperAGILE, is located on top of the Si-tracker. All the above parts are surrounded by an anticoincidence made of a 6-mm thick (5-mm on the top shield), segmented plastic scintillator.

2. THE SUPERAGILE ASSEMBLY

SuperAGILE is basically composed of a Detection Plane (DP), a Collimator equipped with a Coded Mask, a Front-End Electronics and an Interface Electronics (SAIE). Table 1 resumes the main SuperAGILE characteristics and Figure 1 shows its appearance (see also Soffitta et al. 2000 for a more extensive description).

The DP is composed of 4 detection units (DUs), placed on a single Al honeycomb plane support, so that two of them sample the X-direction and the
other two are devoted to the Y-direction. Each DU is composed of 4 Si microstrip tiles, bonded in pairs so that the effective length of each strip is approximately 19 cm. They are read-out through a set of IDE AS-XAA1 chips, based on ASIC technology, 12 for each of the DUs. The collimator (present baseline: 500 µm thick Carbon Fiber field separators, coated with a 75 µm Gold layer) is mounted on the same tray supporting the DP, and in turn supports the 4 orthogonal, one-dimensional coded masks. The coded masks have been designed based on an Hadamard sequence, with a 50% covering factor. They will be manufactured either in Gold or in Tungsten, 100 µm thick. The SAIE is in charge of interfacing SuperAGILE with the AGILE Data Handling System, allowing an event-by-event transmission with better than 5 µs timing resolution. The energy information will be provided in the extended energy range between 1 and 64 keV, with 64 channels, to allow for a finer threshold calibration at low energies, and exploit for calibration purposes the Tungsten fluorescences at ∼58 keV.

The combined capabilities of the SAIE and the AGILE Data Handling (see also Morselli et al. 2000) will allow the transmission to ground of a relatively large set of scientific housekeeping data, including ratemeters and detector images. In particular, the AGILE Data Handling will be able to perform a continuous automatic search for transient events (e.g., gamma-ray bursts) on timescales from 1 ms to 100 s. Once a transient event is triggered onboard, the Data Handling will be able to provide attitude-corrected sky images for it, determining the location of the transient source on the sky. The possibility to distribute in almost real time the coordinates of a transient event through a fast link (e.g., TDRSS or similar) is currently under study.

3. LABORATORY TESTS ON PROTOTYPES

The most critical items for the SuperAGILE design were the signal-to-noise ratio at low energies (i.e., around 10 keV) and the power consumption. For this reason extensive laboratory tests have been performed on the ASIC chips planned to be used as front-end electronics: the XA1.3 chip, precursor of the XAA1 chip, especially developed by IDE AS for SuperAGILE. The results of these tests (see Del Monte et al. 2000 for a detailed discussion) show that the electronic noise can be reduced to less than 4 keV (FWHM) and the power consumption to less than 1 mW per channel (SuperAGILE includes 6144 independent electronic channels). The same tests have shown a critical dependence of several chip characteristics (gain, offset, strip address and others) from the temperature.

Table 1. Characteristics of SuperAGILE

| Characteristic                  | Value                                      |
|--------------------------------|--------------------------------------------|
| Detector Type                  | Silicon Strips                             |
| Basic Detection Unit           | 4 Si tiles, 19 cm x 19 cm                  |
| Total geometric Area           | 1444 cm²                                   |
| Nominal Energy Range           | 10-40 keV                                  |
| On-axis Effective Area         | 320 cm² (13 keV)                           |
| Detector Strip Size            | 121 µm                                     |
| Detector Thickness             | 410 µm                                     |
| Energy Resolution (FWHM)       | ∼3-4 keV                                   |
| Timing Accuracy                | ∼5 µs                                      |
| Collimator Materials           | 75 µm Gold-coated Carbon Fiber             |
| Mask Size                      | 1444 cm²                                   |
| Mask-Detector Distance         | 14 cm                                      |
| Mask Transparency              | 50%                                        |
| Mask Material                  | Gold or Tungsten                           |
| Mask Thickness                 | 100 µm                                     |
| Mask Element Size              | 242 µm                                     |
| Field of View (FWZR)           | 107° x 68°                                 |
| On-axis Angular Resolution     | 5.9 arcmin                                 |
| Source Location Accuracy       | ∼1-2 arcmin for bright sources             |

Figure 1. Schematic view of the SuperAGILE structure
4. SENSITIVITY

We studied the sensitivity and expected astrophysical performances by means of analytical calculations and Monte Carlo simulations. In Figure 2 we present the map of the SuperAGILE effective area for two individual DUs over their field of view (FOV), for a monochromatic 13.1 keV photon beam (this energy corresponds to the peak in the area vs. energy relation). The area of two orthogonal units is presented, showing the overlap of their FOV, providing an effective bi-dimensional source location capability within the central 60° x 60° part of the FOV, in addition to the one-dimensional location capability for the further ∼20°. The maximum effective area at the center of the FOV is ∼80 cm², thus giving a maximum of 320 cm² when the four units are considered together.

In Figure 3 the 5-σ sensitivity is presented for sources with Crab-like energy spectra, for an integration time of 50 ks, over the full 10-40 keV energy range. The sensitivity is presented as a function of the source location within the field of view, along the two directions. It is worth noticing the wide central part of the FOV with slowly variable sensitivity, allowing for an excellent use of most of the FOV for source monitoring purposes.

5. EXPECTED ASTROPHYSICAL PERFORMANCES

In this section we present the expected performances of SuperAGILE for few interesting classes of hard X-ray sources. In Figure 4 we show the sensitivity (5-σ in 50 ks) as a function of energy. On the same plot we show the typical energy spectrum of the X-ray binary pulsar Her X-1, as observed by BeppoSAX near the maximum of the 35-day cycle (Dal Fiume et al., 1998), showing that SuperAGILE will be able to provide accurate energy spectra for this and similar sources, also when it goes to its periodic minimum (a factor ∼3 fainter). As a result of the long pointings (∼2 weeks) driven by the gamma-ray tracker, SuperAGILE will point the same source(s) for the same long time, thus providing both accurate energy spectra over such a long integration time as well as a monitoring of the fluxes and energy spectra over much shorter timescales. In Figure 4 we also show the observed energy spectra (in a flare and in a dip state) of the Galactic microquasar GRS 1915+105 (Feroci et al. 1999). Also in this case the SuperAGILE sensitivity is perfectly suited to allow both spectral and temporal variability studies. It is worth noticing that the galactic microquasars are among the primary targets also for the gamma-ray tracker and will likely be pointed several times over the AGILE lifetime.

In Figure 5 we show the SuperAGILE capability in studying fast hard X-ray transients, as the short recurrent bursts from the Soft Gamma-ray Repeaters (e.g., Aptekar et al. 2000). The plot clearly shows that also in 250 ms SuperAGILE can provide detailed energy spectra of such events. The wide field of view of SuperAGILE is very well suited for a monitoring of the activity of these sources, that are mostly concentrated towards the galactic center, thus allowing to trigger pointed observations when they undergo periods of intense bursting activity. Furthermore, the giant flares from these sources (e.g., Feroci et al. 2000) are very good candidates for emission of rapid and intense flashes of gamma-rays and SuperAGILE can provide the Tracker with an accurate position of...
a possible new soft gamma-ray repeater manifesting itself with a giant flare, as the source of the 1979 March 5th event did.

Finally, Figure 6 shows the source location capability of SuperAGILE for gamma-ray bursts. The plot simulates the sky image of the SuperAGILE detection of GRB 980425, a relatively weak and soft gamma-ray burst in the BeppoSAX sample. Although the simulation assumes an event at 15° off-axis in both X and Y directions, the detection is highly significant and allows for a very good source location determination, as can be seen by the right-hand panels where the sky image is zoomed-in. This capability motivated the set-up of the onboard triggering and source localization system for SuperAGILE (see Sec. 2).

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