The AGILE On-Board Kalman Filter

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Abstract

On-board reduction of particle background is one of the main challenges of space instruments dedicated to gamma-ray astrophysics. We present in this paper a discussion of the method and main simulation results of the on-board background filter of the Gamma-Ray Imaging Detector (GRID) of the AGILE mission. The GRID is capable of detecting and imaging with optimal point spread function gamma-ray photons in the range 30 MeV – 30 GeV. The AGILE planned orbit is equatorial, with an altitude of 550 km. This is an optimal orbit from the point of view of the expected particle background. For this orbit, electrons and positrons of kinetic energies between 20 MeV and hundreds of MeV dominate the particle background, with significant contributions from high-energy (primary) and low-energy protons, and gamma-ray albedo photons. We present here the main results obtained by extensive simulations of the on-board AGILE-GRID particle/photon background rejection algorithms based on a special application of Kalman filter techniques. This filter is applied (Level-2) sequentially after other data processing techniques characterizing the Level-1 processing. We show that, in conjunction with the Level-1 processing, the adopted Kalman filtering is expected to reduce the total particle/albedo-

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photon background rate to a value ($\leq 10-30$ Hz) that is compatible with the AGILE telemetry. The AGILE on-board Kalman filter is also effective in reducing the albedo-photon background rate, and therefore contributes to substantially increase the AGILE exposure for gamma-ray point-like sources.

Key words: Gamma-Ray Instruments; Kalman filter.

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1 The AGILE Scientific Instrument

AGILE (*Astro-rivelatore Gamma a Immagini LEggero*) is a Scientific Space Mission [1] supported by the Italian Space Agency (ASI) and jointly developed with participation of the Italian Institute of Astrophysics (INAF) [1], and by the Italian Institute of Nuclear Physics (INFN) and Italian space industry. AGILE is dedicated to high-energy gamma-ray astrophysics, and is planned to be operational during the first half of 2007. The AGILE scientific program emphasizes a quick response to gamma-ray transients and multiwavelength studies of gamma-ray sources.

The AGILE scientific instrument is highly innovative and allows simulta-

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[1] The AGILE scientific management and several subsystem developments have been carried out during the years 1998-2004 in the Institute for Space Astrophysics (IASF) of the Italian Research Council (CNR). Since 2005, IASF became part of INAF.

neous observations in the hard X-ray and in the γ-ray bands. The AGILE Gamma-Ray Imaging Detector (**GRID**), that is sensitive in the 30 MeV – 30 GeV energy range, consists of a 12-plane Silicon-Tungsten Tracker, based on the state-of-the-art technology of Silicon microstrip [2], and a Cesium Iodide Mini-Calorimeter. The additional hard X-ray detection capability is provided by the Super-AGILE detector (sensitive in the energy range 15 – 45 keV) consisting of an additional plane with four Silicon detectors and a light coded mask system positioned on top at the distance of 14 cm. The detector core consisting of Super-AGILE, Silicon Tracker and Mini-Calorimeter (see Fig. 1) is surrounded by a segmented Anticoincidence System. A complex data acquisition system is provided by dedicated electronic boards and by the central Data Handling (DH) unit positioned below the instrument. The AGILE instrument is described in detail in ref. [1]. For our purpose, it is important to consider the physical characteristics of the AGILE photon pair converter, i.e., of the Silicon Tracker consisting of a total of 12 planes, with two Si-layers per plane providing the X and Y coordinates of charged particles. The fundamental Tracker detector units are Silicon tiles of area 9.5×9.5 cm^2, microstrip pitch equal to 121 μm, and thickness 410 μm. The first 10 planes are made of four elements: an Aluminum honeycomb layer (of height 1.2 cm), a Tungsten layer for gamma-ray conversion (245 micron corresponding to 0.07 X_0), and two Si-layers with microstrips orthogonally configured. For each plane there are $2 \times 1,536$ readout microstrips. Since the GRID trigger requires at least three Si-planes to be activated, two more Si-planes are inserted at the bottom of the Tracker without the Tungsten layers. The total readout channel number for the GRID Tracker are **36,864**. Both digital and analog information (charge deposition in Si-microstrip) is processed by the integrated TAA1 chips. The total distance between mid-planes is equal 1.9 cm (optimized by Montecarlo

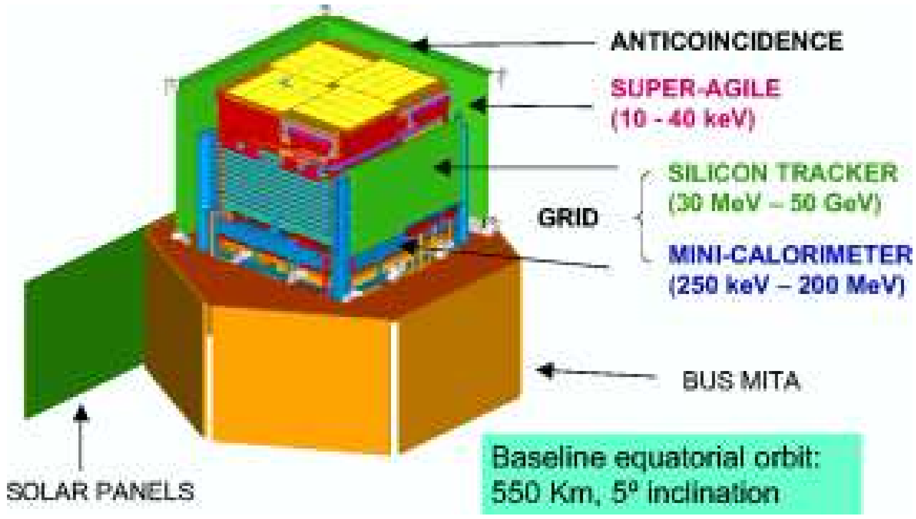

Fig. 1. Schematic representation of the core of the AGILE scientific instrument. The instrument size is $\sim 63 \times 63 \times 58.5$ cm^3 for a total payload weight of ~ 130 kg (including the electronic boxes positioned in the upper part of the spacecraft).

simulations), and the GRID total *on-axis* radiation length is $\sim 0.8\ X_0$. The adopted configuration of the Tracker ensures an optimal compromise between the requirement of a large photon pair-conversion probability and the necessity of a relatively thin converter between planes to increase the angular resolution determined by event topology.

2 The Cosmic-Ray Background

One of the main difficulties for operating space instruments dedicated to gamma-ray astrophysics is represented by the relatively large background induced by primary and secondary cosmic-rays that are present for any low-Earth orbit (LEO). The background particles (mostly electrons/positrons and protons) can produce in the GRID event topologies similar to those of cosmic gamma-rays above 20-30 MeV. The interaction of the primary cosmic rays with Earth's atmosphere produces lower energy secondaries, such as protons, electrons, positrons, with kinetic energies less than 1 GeV. Due to the terrestrial magnetic field at the AGILE orbit, the distribution of charged secondary particles capable of reaching the AGILE Tracker (mainly electrons/positrons and low-energy protons) is almost isotropic. Furthermore, an additional contribution to the background is provided by the *albedo photons*, i.e., gamma-rays produced by the cosmic-ray interactions in the upper atmosphere and originating mainly from the directions of the terrestrial limb [3,4].

The baseline orbit of the AGILE Mission is ideal from the point of view of the expected particle background: it will be circular and equatorial with an altitude near 550 km. For this orbit, by taking into account data from the SAS-2 [5] and Beppo-SAX [6] missions, and spectral data from AMS [7] and MARYA [8], the expected total particle background rate above 10 MeV (outside the South Atlantic Anomaly) that we adopted for the AGILE-GRID background model (see ref. [12] and references therein) is

$$\Phi_{part} \simeq 10^{-1} \text{ particles cm}^{-2} \text{ s}^{-1} \text{ sr}^{-1},$$

which is, in any case, several orders of magnitude larger than the expected cosmic gamma-rays flux above 100 MeV that depends on the pointed sky region (see refs.[9], [10] and [11]),

$$\Phi_\gamma \simeq (10^{-5} - 10^{-4}) \text{ photons cm}^{-2}\text{s}^{-1}\text{sr}^{-1}.$$

Our estimates of the expected albedo-photon background we refer to ref. [12] (see also refs.[3],[4]).

The AGILE on-board Data-Handling (DH) system [13,14] is designed to reduce a good fraction of the particle and albedo-photon background that would otherwise saturate the telemetry channel for scientific data. The downlink

telemetry rate during the $\sim$ 10 min duration of satellite visibility from the ASI ground station in Malindi (Kenya) will be 512 kbit/s. The main task of the AGILE DH system is therefore to provide an on-board event filtering reducing the background rate by a factor of more than 100, i.e., to a value within a factor of 10 - 100 of the cosmic gamma-ray photon rate. This translates (for the AGILE conditions) into achieving a total event rate, comprehensive of cosmic gamma rays and background events of $\lesssim$ 30 Hz.
The residual background events (mostly low-energy electrons and positrons and residual high energy protons) will be further reduced on the ground by a more complex software processing.

The on-board Data-Handling system processes the events through a complex trigger procedure consisting of hardware and software levels. The Level-1 hardware trigger accepts only the events producing particular configurations of hit segmented Anticoincidence panels and Tracker planes, as described in [12–14]. The adopted Level-1 trigger procedure is aimed at obtaining an unprecedently large field of view of $\sim$ 3 sr. This Level-1 hardware trigger level, because of its simplicity, is able to process a high event rate. It was tested with dedicated Monte Carlo simulations (using the numerical code GEANT 3.21) showing that it will provide an output event rate of about 100 Hz, therefore reducing the initial particle background by a factor of 10-100 (see ref. [12]).

The Level-2 software trigger [15] is divided in two steps: Level-2/Step-1 and Level-2/Step-2. The first step consists of a set of software algorithms that, by analyzing the event morphology based on cluster identification, analog information, and topology, will be able to decrease further the charged particles background rate to an estimated level of about 30 Hz. The details on this step of processing and its Monte Carlo testing can be found in [15]. However, the residual background event rate after the Level-2/Step-1 trigger may be too large for the capabilities of the AGILE telemetry transmission. A further processing step is necessary to reduce the background events. In particular, this additional processing is required to efficiently reduce the albedo-photons that can be distinguished from the cosmic gamma-rays on the basis of their incoming direction.

In the following, we present and discuss the algorithm for the Level-2/Step-2 AGILE trigger based on a simplified on-board geometrical and physical reconstruction of GRID events. The aim of the Level-2/Step-2 trigger is to obtain the direction of the incident photons for their on-board selection. Furthermore, an additional reduction of the charged particle background is obtained as discussed in the following sections.

We adopt a technique that we judge to be an optimal compromise between reliability of track reconstruction and on-board computational performance of our Data Handling unit. The method is based on a special implementation of the Kalman Filter (KF) technique that turns out to be very effective in providing a *global* characterization of particle tracks in the Tracker. Obviously, on-board tracing of particle trajectories can be obtained by several algorithms. In case of AGILE, the analog signal in the Silicon 121 μm microstrips can be produced by the electron/positron pairs materialized after a gamma-ray interaction as well as by other spurious or very low-energy secondary photon interactions. The signal provided by the latter component tends to spoil the simplicity of the photon pair production. In order to achieve an optimal track *identification and reconstruction* we tried to implement several algorithms compatible with our DH performance and GRID hardware setup. We concluded that the special Kalman Filter technique presented here is an optimal technique for the AGILE gamma-ray imager. With this method, we obtain not only a characterization of single and combined tracks identified by the KF, but also a selection in the first 2-3 planes including the interaction vertex of the special hits belonging to these tracks. The KF is adopted also for other important features, including the proper treatment of multiple scattering vs. measurement errors, and trajectory projection with actual vs. predicted hit treatment. The resulting on-board reconstruction of the incoming photon direction turns out to be then a product of a global and not only local analysis of the event topology. This fact adds substantial reliability to the AGILE on-board photon direction reconstruction.

3 The Kalman filter

Kalman Filter (KF) algorithms [16], [17], [18] are quite efficient for the gamma-ray event analysis of Silicon detectors. We developed a dedicated algorithm aimed at the *on-board* data analysis of background and gamma-ray data events. In this section, we briefly summarize the main features of the KF that turn out to be of interest for applications to the AGILE-GRID event filtering.

Unlike traditional pattern recognition algorithms, the KF typically updates the candidate track information during the track-finding process and predicts as precisely as possible the next hit to be found along a trajectory. This capability is used to merge into an unique recursive algorithm the track-finding procedure and the fitting of track parameters.

In the KF basic algorithm the electron trajectory is treated as an evolving system, the planes representing the "hits" of this evolution for which the algorithm acquires information on the system. A state vector (p_k), which describes the system at the $k-$th plane, has two components: the position (x_k) and the tangent of the track direction ($\tan\theta_k$). The evolution law of the state vector is :

$$p_k = Fp_{k-1} + w_k \tag{1}$$

where F is a matrix that operates the geometrical projection from a plane to the next, and w_k is the deviation due to multiple scattering. This last effect is described by the Q matrix:

$$Q = cov(w_k) \tag{2}$$

The errors associated to p_k are described by the covariance matrix :

$$C_k = cov(p_k - p_k^{true}) \tag{3}$$

where p_k^{true} contains the true values of the system at the plane k . For every plane, we have a measure of the particle passage (m_k). The measurements are described by the following relation:

$$m_k = Hp_k + \mu \tag{4}$$

where H is the transformation from vector p_k to the measure and μ is the measurement error described by the matrix:

$$V = cov(\mu) = \begin{pmatrix} \sigma^2 \end{pmatrix} \tag{5}$$

The estimate of the system vector is articulated in three phases called *Prediction, Filtering* and *Smoothing.*

- *Prediction*: it consists of a prediction of the more probable state of the system at plane k based on the knowledge of the state of the system on previous planes.
- *Filtering*: Starting from the first plane, the position and direction of the electron on every plane is estimated on the basis of the track obtained in the previous planes. This estimate is corrected taking into account the coordinate of the hit closest to the estimated position.
- *Smoothing*: Starting from the last plane, the track is corrected on every plane on the basis of the hits on the planes lying below. In this way the position and direction of the particle passage on the first plane is determined using the information of the entire track.

In our case the prediction corresponds to the geometrical projection of the state vector from plane $k-1$ to plane k:

$$p_k^{proj} = F p_{k-1} \tag{6}$$

The error on p_k^{proj} is a combination of the errors on p_{k-1} (projected at plane k) and the multiple scattering effects:

$$C_k^{proj} = F C_{k-1} F^T + Q \tag{7}$$

A measure on plane k is an independent information of the state vector on plane k, which can be combined with p_k^{proj} with a weight inversely proportional to the respective errors:

$$p_k = C_k[(C_k^{proj})^{-1} p_k^{proj} + H^T V^{-1} m_k] \tag{8}$$

where:

$$C_k = [(C_k^{proj})^{-1} + H^T V^{-1} H]^{-1} \tag{9}$$

These operations constitute the *Filtering*. It is then possible to insert the measures on the next planes to create a track.

The *Smoothing* process carries backward the information. This processing, analogous to the Prediction and Filtering process, is performed through a gain matrix on the $k-$th plane:

$$A_k = C_k F^T (C_{k+1}^{proj})^{-1} \tag{10}$$

The state vector then becomes:

$$p_k^{smooth} = p_k + A_k (p_{k+1}^{smooth} - p_{k+1}^{proj}) \tag{11}$$

and it has an uncertainty described by the matrix :

$$C_k^{smooth} = C_k + A_k (C_{k+1}^{smooth} - C_{k+1}^{proj}) A_k^T \tag{12}$$

Also these operations have to be performed iteratively, proceeding backward from the last plane to the first. The final vector p_k^{smooth} on the generic plane k will contain the informations coming from all the available measurements. In the Kalman filter computation it is also possible to define a χ^2 that gives an estimate of the goodness of fit. The residuals on each plane are defined as:

$$r_k = m_k - H p_k^{smooth} \tag{13}$$

The matrix with which the residuals are weighted is:

$$R_k = V - HC_k^{smooth}H^T \tag{14}$$

It is then possible to calculate the χ^2 parameter defined as:

$$\chi_k^2 = r_k^T R_k^{-1} r_k \tag{15}$$

It is therefore possible to associate at every fitted track a total chi square (χ_{rec}^2), given by the sum of the χ_k^2 on each plane. If the combination of the AGILE tracker hits gives rise to more than two possible tracks, corresponding to the pair e^+/e^- originating from the photon conversion vertex, the χ_{rec}^2 parameter can be used to choose the best pair of reconstructed tracks. In this way the Kalman filter is used not only as a fitting technique, but *also as a track finder*. Furthermore, the association between the track projections in the ZX and ZY-views can be performed on the basis of the χ_{rec}^2.

4 The Kalman filter for AGILE

The Kalman Filter technique described in the previous section satisfies the crucial requirement for an AGILE-GRID on-board reconstruction. Indeed, it provides good results without needing a large amount of CPU time, since it performs a track finding and fitting with a small number of basic operations. The AGILE on-board version of the algorithm, which we call **Kalmaex** (Kalman-Express), is a simplified version of the complete Kalman Filter algorithm (that we apply to the ground analysis of events). The Kalmaex is based on the following characteristics:

- only the first four hit planes are considered, and the minimum required number of hit planes is three;
- the Kalman filter matrices are calculated only once at the beginning of the process and are kept constant, using as input a fixed value of the track energy;
- the number of combinations of analyzed clusters is limited to the possible combinations on the first two hit planes. On the following planes only the nearest cluster to the projected position is considered;
- for each event and for each view the best track is selected on the basis of the minimum χ^2 factor. A second track is selected only if the ratio of the two χ^2 factors is below a certain threshold parameter;
- an estimate of the original photon direction is then obtained by a 3D track association.

The method requires fixing a value of the trajectory energy in advance. This important parameter (that can be changed by a Telecommand) was determined by extensive Montecarlo simulations of the Tracker behavior to both gamma-ray photon and background events. The best value adopted in our calculations is $E_t = 300\ MeV$. For simplicity, we do not use any energetic information obtainable from the Mini-Calorimeter. Our simulations show that, at this level of fast on-board processing, we do not improve the Kalmaex performance by a refinement obtained for E_t by the use of the Mini-Calorimeter that can be missed by inclined trajectories. The Kalmaex constitutes the Level-2/Step-2 of the on-board AGILE trigger, and is implemented in the AGILE Data Handling system. In the following, we present the results of the algorithm performance tests that we have obtained by Monte Carlo simulations.

5 Monte Carlo simulation results

5.1 Angular resolution

We have applied the Kalmaex algorithm on a set of simulated tracker events induced by both background particles and gamma-ray photons, obtained with the Monte Carlo code GEANT 3.21 [12]. We find that the Kalmaex technique gives good results in terms of angular resolution, the precision in the direction evaluation being only $\sim 30\%$ worse than that obtained with the on-ground processing based on the complete algorithm, as shown in figure 2.

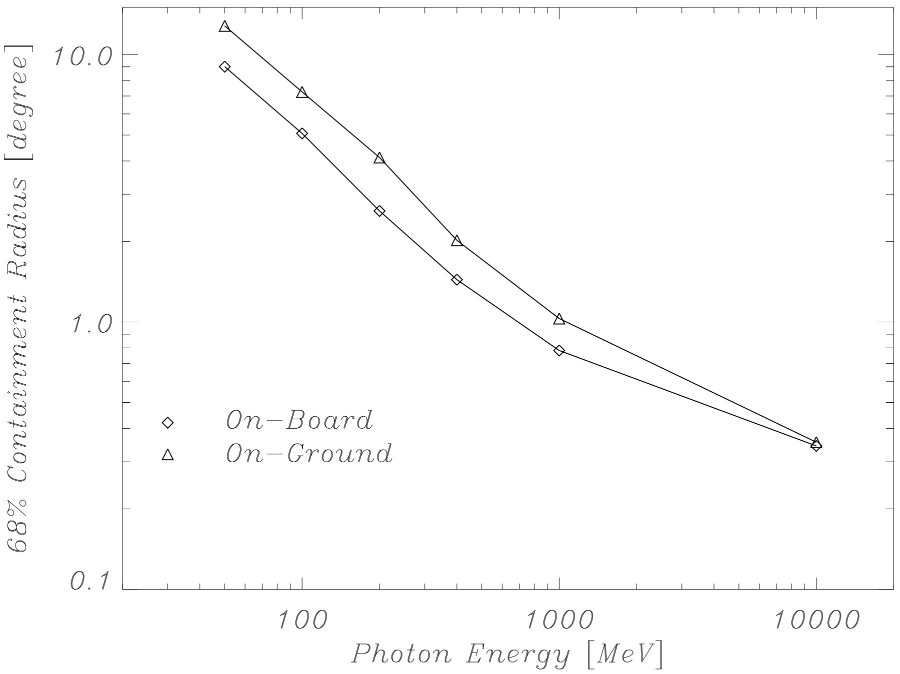

Fig. 2. The 68% containment radius in degrees of reconstructed photons as a function of energy (in MeV). The two lines refer to the on-board (upper line) and on-ground reconstruction algorithm for on-axis photons.

The strong dependence on energy in figure 2 is due to multiple scattering effects which affect mostly the less energetic tracks.

5.2 Albedo-photon rejection

The algorithm has then been applied to a set of simulated photons with direction distribution and energy spectra that reproduce the albedo photons, when the Earth is partially in the AGILE field of view. The photons arrival directions are reconstructed in order to discriminate the gamma rays produced in the Earth atmosphere. Figure 3 shows an example of the distribution of the angular separations (s) between the derived photon direction and the Earth-center direction.

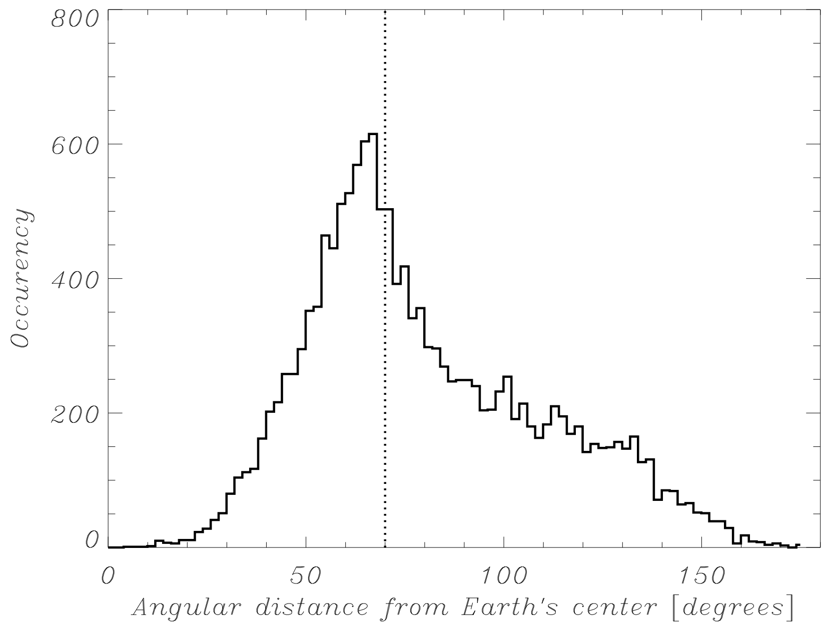

Fig. 3. Distribution of angular distances (in degrees) between Earth's center and albedo-photons reconstructed directions (Albedo-2 case).

The maximum of the distribution corresponds to the atmospheric limb which

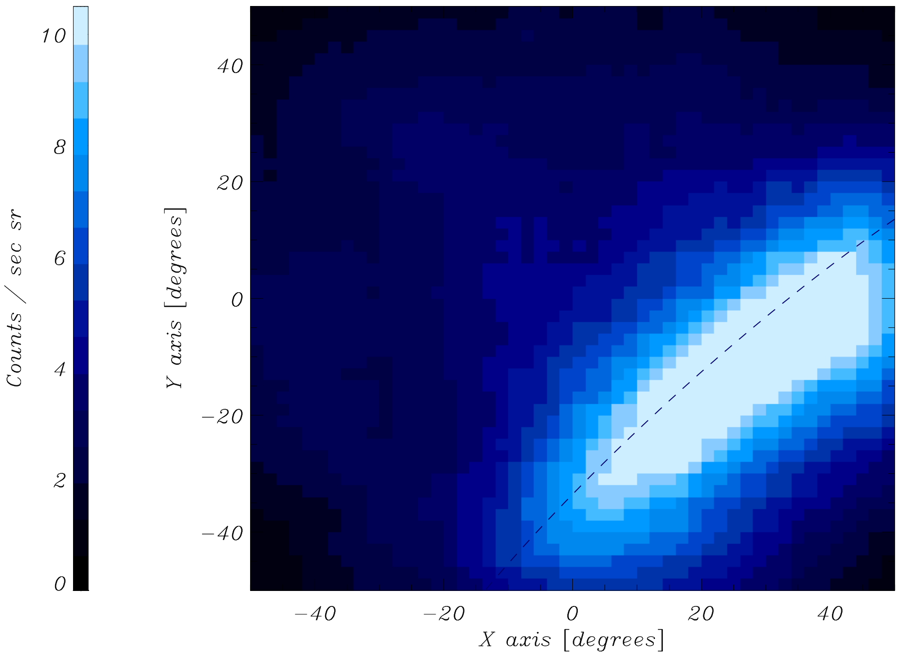

Fig. 4. Simulated counts map of the gamma-rays detected on-board in the AGILE-GRID field of view with the Earth covering a substantial fraction of the field of view (Albedo-2 case). Labels are in degrees.

in this simulation is seen at $s = 67°$ (corresponding to an AGILE altitude of 550 km). The reconstructed image of the Earth in the AGILE field of view is shown in figure 4. A cut of the events with s less than $70°$ can eliminate about 80% of the albedo photons, allowing to send in the telemetry channel the remaining events to the ground where they will be further analyzed by more refined algorithms. The expected rate of albedo photons depends on the position of the Earth in the AGILE FOV. We have examined four different possible configurations that can be described in terms of the angles $\theta_\oplus$ and $\phi_\oplus$, which identify the direction of the Earth center in instrumental coordinates:

- *Albedo-1*: ($\theta_\oplus = 180°$, $\phi_\oplus = 0°$), AGILE pointing at the Zenith;
- *Albedo-2*: ($\theta_\oplus = 90°$, $\phi_\oplus = 315°$), AGILE pointing perpendicular to the

Zenith;

- *Albedo-3*: ($\theta_{\oplus} = 135°$, $\phi_{\oplus} = 315°$), Earth at the edge of the AGILE FOV;
- *Albedo-4*: ($\theta_{\oplus} = 45°$, $\phi_{\oplus} = 0°$), Earth covering most of the AGILE FOV.

In Table 1 we report our results for the expected albedo photon rates, for three different Earth positions with respect to the AGILE FOV, before and after the Kalmaex filtering.
In figures 5 and 6 we show respectively the energy spectra and the distribution of incidence angles of the albedo photons before and after the KALMAEX filtering with the condition $s > 70°$ on Albedo-2 photons.

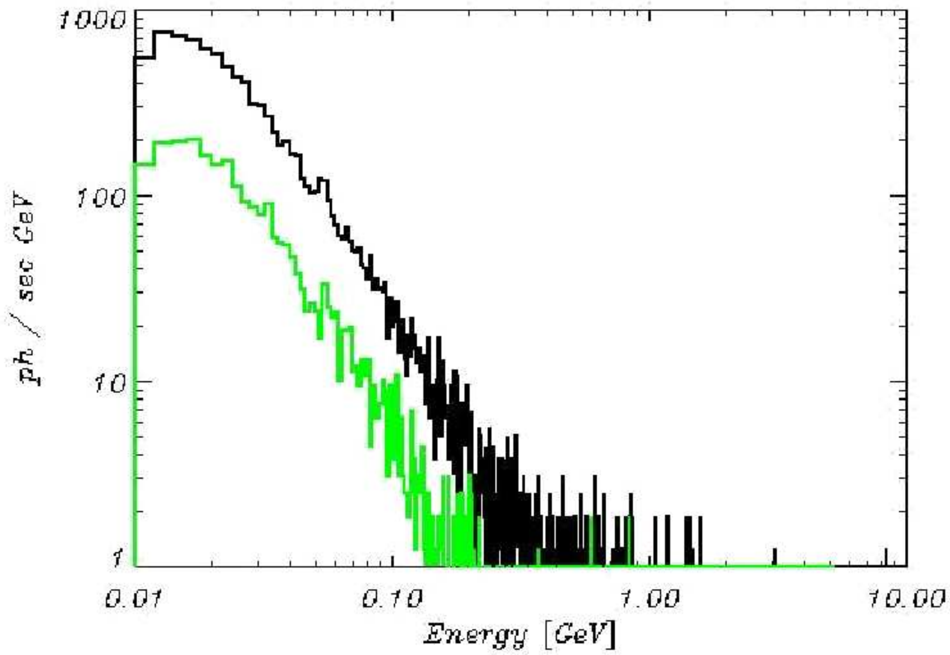

Fig. 5. Energy spectra of albedo photons before (upper curve) and after (lower curve) the KALMAEX filtering for the Albedo-2 configuration.

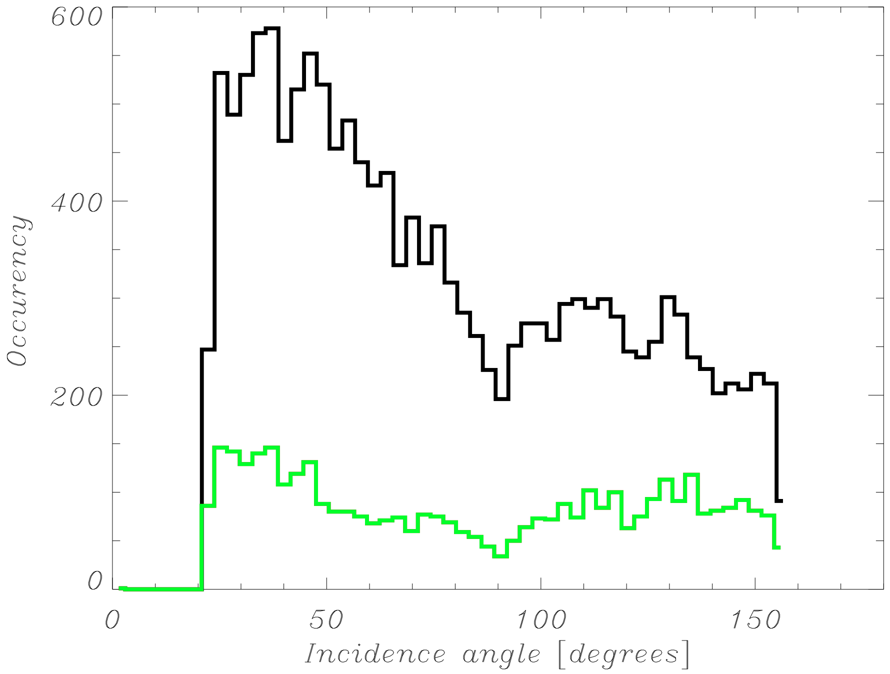

Fig. 6. Distribution of angles of incidence of albedo photons before (upper curve) and after (lower curve) the KALMAEX filtering for the Albedo-2 configuration. An angle of incidence equal to 0° corresponds to the on-axis direction. The Agile field of view is $\sim 60°$.

5.3 Charged Particles Rejection

The Kalmaex algorithm is also able to further reduce the background due to charged particles. The quantity χ^2_{rec} (defined in section 3) derived by the Kalmaex algorithm can be used as a "quality factor" of the reconstructed events. If the reconstruction process is applied to charged background particles AGILE-GRID events, we find that the distribution of χ^2_{rec} is very different from that expected from cosmic gamma-ray photons. A cut of events based on the value of χ^2_{rec} can reduce significantly the particle background. Table 2 shows the effect of this cut on different kind of particle background events.

Table 1

Cuts on albedo-photons for different AGILE-Earth configurations.

Earth Position	Albedo-photon Rate (Hz)		
(instr. coord.)	before Kalmaex	after Kalmaex ($s > 70°$)	after Kalmaex ($s > 80°$)
Albedo-2	19.2	10.5	7.98
Albedo-3	14.6	13.9	13.0
Albedo-4	24.5	4.45	2.21

Table 2

Residual particle background event rates (in Hertz) based on different cuts of the χ^2_{rec} factor.

Background	Step-1	$\chi^2_{rec} < 7000$	$\chi^2_{rec} < 3000$
Electrons	3.73	1.61	1.01
Positrons	7.07	3.01	2.01
Primary Protons	1.77	0.929	0.701
Secondary Protons	0.732	0.402	0.331
Tot Particle	**13.3**	**5.95**	**4.05**

This cut has obviously a further effect also on albedo photons, as shown in Table 3. In the same table we show also the event rates after a “soft” sequence of cuts corresponding to the condition: $s > 70°$ and $\chi^2_{rec} < 7000$, and an “hard” one corresponding to: $s > 80°$ and $\chi^2_{rec} < 3000$. The final result for the Level-2/Step-2 on-board AGILE trigger on particle background is summarized in figure 7.

Table 3

Residual albedo-photon event rates (in Hertz) based on cuts for different AGILE-Earth configurations. "Soft" refers to the results after both cuts $\chi^2_{rec} <$ 7000 and $s > 70°$, while "hard" refers to the cuts $\chi^2_{rec} < 3000$ and $s > 80°$.

AGILE-Earth configuration	Step-1	$\chi^2_{rec} < 7000$	$\chi^2_{rec} < 3000$	"soft"	"hard"
Albedo 1	14.7	5.69	3.53	5.69	3.53
Albedo 2	19.2	10.1	7.50	4.89	2.14
Albedo 3	14.6	5.50	3.43	5.35	3.19
Albedo 4	24.5	15.6	12.3	1.85	0.393

5.4 Effect on gamma-ray photons

The adopted Kalmaex is optimized to cut the albedo photons and to partially reduce the particle background with "light" event cuts. Obviously, a crucial required feature of the Kalmaex is to have a minimum impact on photons coming from gamma-ray sources.

We extensively checked and tested the Kalmaex performance with optimized parameters on gamma-ray photons in the energy range 30 MeV - 30 GeV. The results are shown in table 4.

We also note that the possible self-veto caused by inclined photons whose secondaries "backsplash" on the Mini-Calorimeter turns out to be much reduced, according to our Montecarlo simulations, compared to the EGRET veto configuration. The AGILE event geometry and Anticoincidence segmentation as well as the shallowness of the Mini-Calorimeter configuration reduces

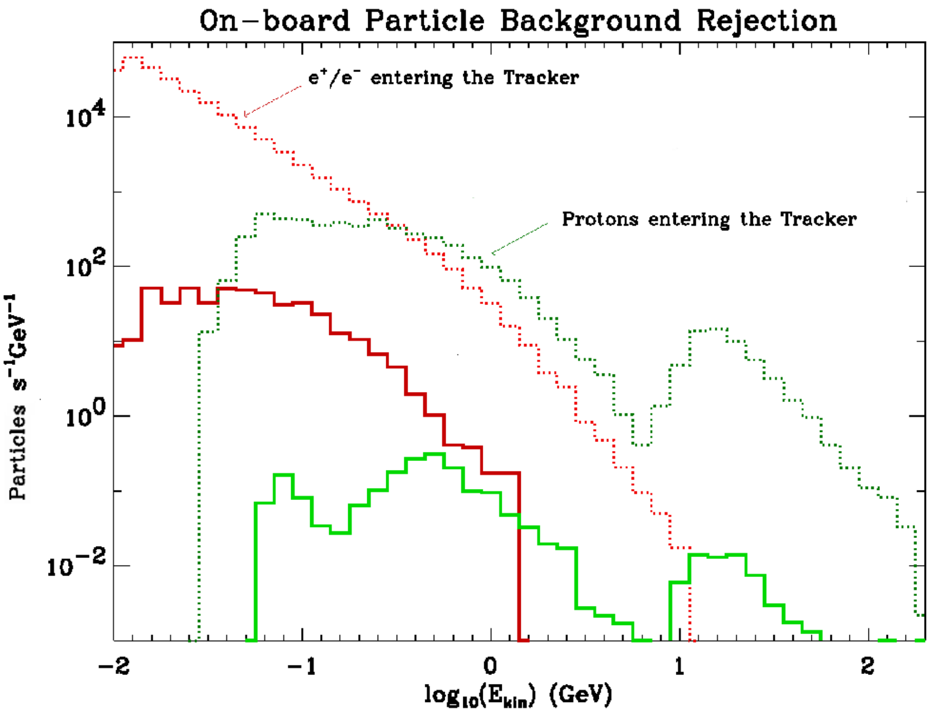

Fig. 7. Energy spectra of different particle background components for the AGILE-GRID. *Dashed lines:* original flux of background particles. *Solid lines:* residual background after the Level-2/Step-2 trigger described in this paper (Upper curve: electrons and positrons, Lower curve: Protons).

substantially the backsplash self-veto.

6 Conclusions

Our results indicate that a simplified Kalman filter algorithm can be implemented by the AGILE DH system, and that it can be used efficiently for an on-board reduction of particle and albedo-photon background events. The overall background event rate is here calculated for a variety of possible conditions to be of the order of 10 Hz. The adopted Kalmaex algorithm and the general Level-2 AGILE-GRID trigger logic is flexible enough to adjust to a

Table 4

Acceptance for photon events at different energies.

Photon Energy	$\chi^2_{rec} < 7000$	$\chi^2_{rec} < 3000$
50 MeV	92.1 %	86.5 %
100 MeV	95.0 %	93.2 %
200 MeV	96.9 %	95.7 %
1 GeV	94.3 %	93.7 %
3 GeV	92.9 %	92.4 %
10 GeV	91.6 %	91.2 %

large number of unexpected background conditions [12–14].

In this paper we showed that the Kalmaex algorithm is particularly effective in reducing on board the number of albedo-photons that constitute a non-negligible component of the background for AGILE. The obtained on-board reduction will lead to the acquisition of data also during a substantial fraction of the passage of the Earth limb across the AGILE-GRID field of view. The resulting AGILE exposure will be therefore increased compared to the case of abrupt data cutoff as the Earth enters in the field of view. Considering the utmost importance of obtaining as large as possible gamma-ray exposures of astrophysical sources, our results are highly significant for the AGILE Mission.

The Kalmaex algorithm discussed in this paper completes the sequence of trigger filtering techniques adopted for the AGILE-GRID from Level-1 to Level-2 (refs. [12,15]). The design of the overall trigger logic is aimed at reducing the particle/albedo-photon background by a substantial amount: particle rates are reduced by a factor between 100 and 1000, whereas albedo-photon rates are reduced by a factor ~ 10. Further reduction of background events will be achieved by event analysis on the ground that will be described in future papers.

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