# High-Energy Gammas from the giant flare of SGR 1806-20 of December 2004 in AMANDA

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**Abstract.** We show in this paper the analysis of the AMANDA-II data looking for events correlated with the giant flare observed in December 27th 2004 from the Soft Gamma-ray Repeater 1806-20. This flare was more than two orders of magnitude brighter than any previous flare of this kind and saturated the satellite gamma detectors that observed it. If a hard component of gamma-rays was present in the event, these would produce detectable rates of muons in underground detectors like AMANDA. Moreover, high-energy neutrinos could also have been emitted in quantities large enough to produce a signal in this detector. The unblinding of the data showed no signal, so upper limits were set both to the gamma-ray and the neutrino fluxes.

## 1. Introduction

Soft Gamma-ray Repeaters (SGRs) are X-ray pulsars which emit X-ray bursts lasting $\sim$0.1 s during sporadic active periods. The typical luminosities of these bursts is $10^{41}$ erg/s. However, there are rare occasions in which giant flares (in X-rays and soft-gamma rays) are observed, with luminosities thousands of times higher than normal bursts. Three of these giant flares had been observed until 1998 [1]. On December 27th 2004, a giant flare of soft-gamma rays and hard X-rays coming from the Soft Gamma-ray Repeater 1806-20 saturated several satellite gamma-detectors [2, 3, 4]. This was the brightest transient event ever observed in the Galaxy.

The most accepted theory to describe SGRs is the "magnetar" model. According to this model, these objects are very-rapidly-rotating neutron stars, with extremely high magnetic fields ($B \sim 10^{15}$ G, two orders of magnitude larger than in normal neutron stars). Along time scales of the order of tens of years, these strong magnetic fields build up an increasing stress in the star. When the stress on the star crust is too strong, it fractures. This produces a starquake which liberates enormous quantities of energy in X-rays and $\gamma$-rays as the magnetic field rearranges [5].

The energy spectrum of the Dec. 2004 flare can be described as the sum of a black-body spectrum and a power law [6], which would indicate a relevant component of high-energy ($\sim$TeV) emission. High-energy gammas would produce showers when interacting at the top of the Earth's atmosphere. These showers would be muon-poor, but some of the many photons produced in these interactions would produce pions. The decay of these pions would yield muons which can reach underground detectors like AMANDA [7].

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High-energy neutrino fluxes have been also predicted by some authors [8, 9], if there is a significant baryonic outflow. In this case, neutrinos could also reach underground neutrino detectors and produce a signal.

## 2. The AMDANDA detector

The AMANDA neutrino telescope [10] consists of a three dimensional array of 677 Optical Modules (OMs). An Optical Module is basically a photomultiplier and its electronics housed in pressure-resistant glass sphere. These OMs are distributed along 19 strings buried 1500-2000 m deep in the Antarctic ice.

The main aim of this experiment is the detection of cosmic neutrinos. The principal signature is given by high-energy neutrinos interacting in the surroundings of the detector and producing a relativistic muon which would emit Cherenkov light when traveling in the ice. Events are recorded when at least 24 OMs register a signal within 2 $\mu$s. The information of the position and the time of the photons hitting the photomultipliers is used to reconstruct the direction of the neutrino. As we have mentioned before, the main motivation in this analysis is the search for muons produced indirectly in the showers induced by gamma-rays interacting in the top atmosphere. Since the source was above the horizon, the effective area for TeV photons is one order of magnitude higher than for neutrinos. However, there is no way to distinguish between both possibilities in case of the observation of a muon.

## 3. Analysis

Since both the time and the position of the burst can be well constrained, the enormous background of muons produced by cosmic rays in the atmosphere can be effectively reduced.

There are two variables to optimize in this analysis: the width of the time window and the angular size of the search cone. In order to prevent a possible bias in the analysis, we perform the optimization of the selection criteria with the data blinded, which is particularly relevant when small signals are expected, as it is our case.

The duration of the burst was ~0.6 s. However, this window had to be widened in order to account for the dispersion in the times given by the satellites [11, 12, 2, 4, 13], calculated at the location of the detector. The chosen window, once these facts were taken into account is 1.5 s around UT 21h 30m 26.6s of December 27th.

The next step is to determine the best search cone. This is done by optimizing the so-called Model Discovery Factor (MDF) [14], defined as

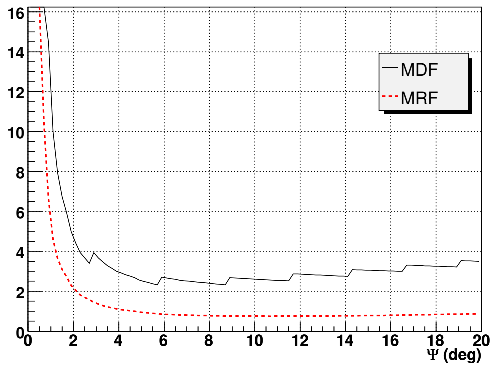
$$MDF = \frac{\mu(n_b, CL, SP)}{n_s} \tag{1}$$

where $\mu$ is the Poisson mean of the number of signal events which would result in rejection of the background hypothesis, at the chosen confidence level $CL$, in $SP\%$ of equivalent measurements. $n_s$ and $n_b$ are the number of signal and background events, respectively.

The background was determined using on-source, off-time, real data (the data $\pm10$ minutes around the burst is kept blinded). It was also checked that the detector rate on December 27th was stable (rate~90 Hz, close to the AMANDA average).

The signal is simulated in order to estimate the angular resolution and the effective area of the detector. With the codes CORSIKA-QGSJET01 [15] and ANIS [16], we generated photons and neutrinos, respectively, with energies ranging from 10 TeV to $10^5$ TeV. The secondary muons are propagated up to the detector and reconstructed.

The dependence of the MDR on the search cone is shown in figure 1 (left). It can be seen in that plot that the optimum size corresponds to a radius of 5.8°. The expected background for such a cone, during 1.5 s is 0.06 events, at the location of the source.



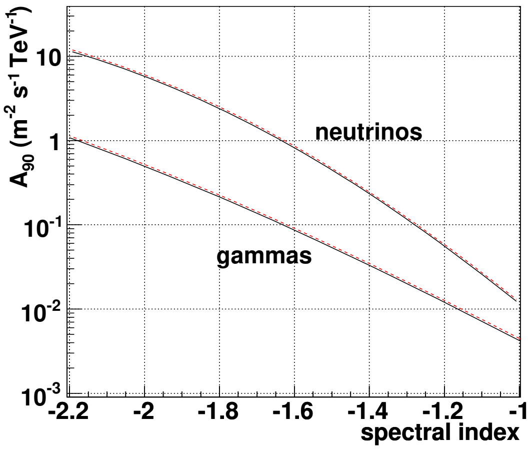




**Figure 1.** Left: Model Discovery Factor (solid, black) and Model Rejection Factor (dashed, red) as a function of the radius of a circular angular acceptance window, for an $E^{-1.47}$ spectrum. Right: Sensitivity (dashed, red) and limit (solid, black) to the normalization constant in the flux of gammas (lower line) and neutrinos (upper line), as a function of the spectral index, assuming a flux $\phi(E) = A\ (E/\mathrm{TeV})^{\gamma}$.

## 4. Results

Once the optimum selection criteria were found, the data were unblinded. However, no event was found correlated with the burst. Therefore, upper limits were set, based on the effective area of the detector. Assuming a power law spectrum $\frac{dN}{dE} < A_{90}(E/\mathrm{TeV})^{\gamma}$, the limits on the normalization constant of the flux of gamma-rays and neutrinos are shown in figure 1 (right), as a function of the spectral index. This means, for instance, limits of 0.05 (0.5) $\mathrm{TeV}^{-1}$ $\mathrm{m}^{-2}$ $\mathrm{s}^{-1}$ for $\gamma = -1.47$ $(-2)$ in the gamma flux and 0.4 (6.1) $\mathrm{TeV}^{-1}$ $\mathrm{m}^{-2}$ $\mathrm{s}^{-1}$ for $\gamma = -1.47$ $(-2)$ in the high-energy neutrino flux (at 90% CL).

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