
Toward Ultra Short Gamma Ray Burst Ground Based Detection, SGARFACE status

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Abstract

We present the status and motivation of the Short GAMMA Ray Front Air Cherenkov Experiment (SGARFACE) which will be operated parallel to standard Very High Energy γ -ray observations using the Whipple 10m telescope. SGARFACE is sensitive to 100MeV-10GeV γ -ray bursts with durations ranging from 100ns to 100 μ s providing a fluence sensitivity as low as few $10^{-9}\text{erg} \cdot \text{cm}^{-2}$. Preliminary data taking started in November 2002.

1. Introduction

Gamma-ray bursts observed with space-based detectors span a wide range of durations limited by the detector integration time to time scales $t \geq 1\text{ms}$. Satellite-based detectors are not efficiently triggered by pulses with time scales shorter than $\sim 1\text{ms}$ because their effective collection area is too small to allow for faster time sampling of signals with typical fluences. Nevertheless, among the detected bursts, millisecond and sub-millisecond variability is common (Walker & Schaefer 2000).

A front of low energy γ -rays entering the Earth's atmosphere results in the development of small electromagnetic cascades at $\sim 20\text{km}$ altitude. Each of them produces Cherenkov light spread over an area of $\sim 500\text{m}$ in radius at ground level. The Cherenkov light from all the showers should give a detectable glow extending over $\sim 2^\circ$ centered on the direction of the burst (figure 1.). The diffuse night sky background (our sensitivity limitation) of collected over such a solid angle during $\sim 10\mu\text{s}$ is comparable to the Cherenkov light yield from a few 100MeV γ -ray burst with a fluence of $10 \gamma\text{-ray} \cdot \text{m}^{-2}$. This also corresponds to the fluence sensitivity of a space-based detector with collection areas of $\sim 1\text{m}^2$. Going toward shorter time scales, the noise contamination is reduced and atmospheric Cherenkov detectors gain in sensitivity following the square root of the burst duration. The fluence sensitivity for a 100 ns burst of 1 GeV γ -rays is $\sim 0.1\gamma\text{ray} \cdot \text{m}^{-2}$ (Krennrich et al., 2000). The timing and imaging analysis allows to remove the dominant

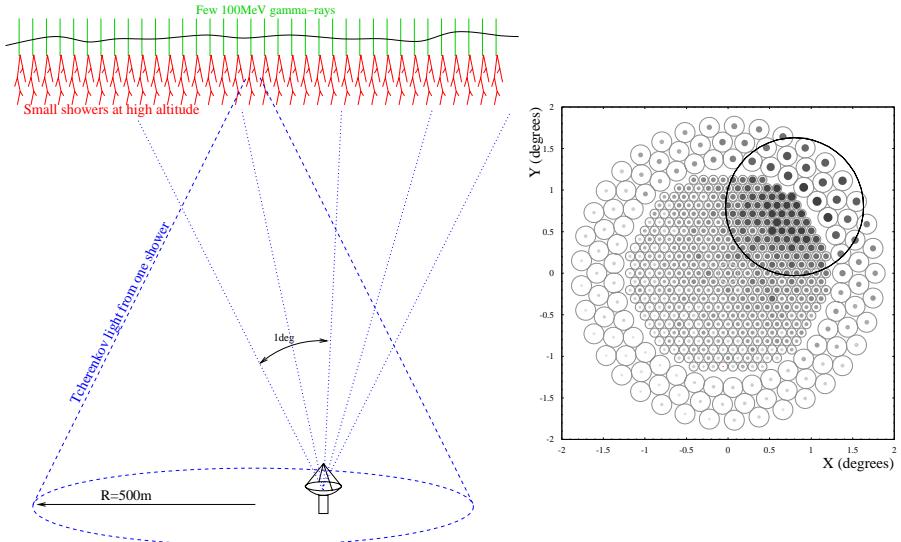


Fig. 1. In an imaging telescope, γ -ray bursts should appear as a Cherenkov glows.

100ns – 10 μ s background due to atmospheric scintillation produced by ultra-high-energy cosmic-ray showers. The features of the multi- γ -ray front initiated shower images are unique. Both the light distribution and the time structure of the Cherenkov light image are centered on the direction of the burst and should be symmetric. We are not aware of any phenomenon capable of producing fake signals and we expect the technique to allow background free detection of bursts.

SGARFACE is the first ground-based experiment using the imaging and time sampling to search for ultra-short bursts of γ -rays. The Whipple observatory 10 m γ -ray telescope will be used to collect the Cherenkov light and form the image. After discussing the design and status of SGARFACE, we will review some of its motivations.

2. SGARFACE

The photomultiplier signals coming from the Whipple 10 m (Finley et al. 2001) Imaging Atmospheric Cherenkov Telescope are duplicated before they reach the standard electronic system used for TeV observations. This allows to carry out a search for bursts at the same time the telescope is used for VHE-astronomy. The signals (see figure 2.) are sent to the Trigger I modules for digitization and subsequent real time-analysis in Field Programmable Gate Arrays (FPGAs). Each time the FPGAs detects a potentially interesting pulse, they send a signal to a coincidence unit (Trigger II module).

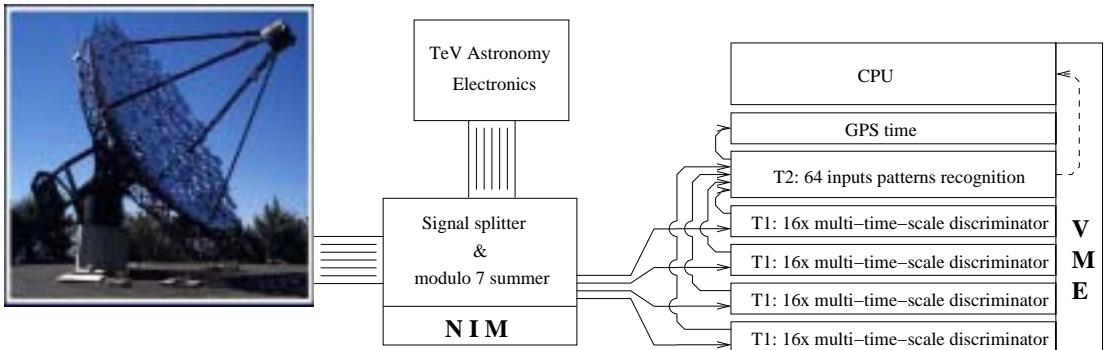


Fig. 2. General scheme of the SGARFACE electronics.

2.1. Splitter summer modules

Since the glow produced by a γ -ray burst is quite extended (1deg.), it is possible to sacrifice the high angular resolution provided by the Whipple 10m telescope camera ($\sim 0.13^\circ$) to cost effectiveness. The splitter summer has been designed to produce the analog sum of seven neighboring photomultiplier signals providing an effective angular resolution of $\sim 0.4^\circ$. A passive splitter preserves the bandwidth of the standard Whipple 10m electronics and reduce their amplitude by about 10%. Each NIM module consists of five boards. Each board takes the inputs of seven signals and provides 1 output channel for SGARFACE. A total of 55 boards are necessary for the complete operation of SGARFACE on the Whipple 10m telescope.

2.2. Trigger-I, multi time scale discriminators

Since the duration of the pulse to be detected is not known a priori, the trigger decision must depend on the integrated signal over a range of time scales. The integral of the signal over time is derived by continuously summing the difference between the values at the input and output of a "first-in-first-out" register stack through which the digitized signal amplitudes are driven at a 50MHz rate. In the SGARFACE design, the signal is integrated over 3 contiguous time windows and a trigger signal is formed when the three integral values exceed a predefined threshold at the same time. This design allows the suppression of frequent short (less than 40ns) Cherenkov pulses produced by single particle induced cosmic-ray showers. This logic is replicated in a cascade providing sensitivity over time windows of width 60ns, 180ns, 540ns, 1620ns, 4860ns and 14580ns. Trigger signals from each time scale are sent to the coincidence unit which can issue a global trigger. The multi-time-scale discriminators are 16-channel VME-based boards.

Hence, 4 Trigger-I modules are sufficient for the entire experiment. The digital signal processing is done by a re-programmable Xilinx FPGA for each channel. After a trigger occurs the local computer can read out the data present in the multi-time-scale discriminator logic.

2.3. Trigger-II, topological trigger

The Trigger-II is designed to take 64 asynchronous inputs. Only one such module is necessary for the operation of SGARFACE. It can be made sensitive to 64 overlapping sectors in order to reduce the accidentals rate. For each sector, the number of inputs in a high state is calculated and compared to a multiplicity threshold. When any of the 64 sectors reach the trigger conditions a global trigger signal is issued. This signal is used to freeze the trigger-I modules and hold the pulse information. It is also used to generate an interrupt to notify the local computer that new data is available to be read. The design of the Trigger-II module is very similar to the Trigger-I. The logic is implemented in a single Xilinx FPGA chip.

2.4. Present status

As of November 2002, the complete system of 11 signal splitter modules is installed and working as well as three Trigger-I boards and the trigger-II module. While final tunings are made on the boards, various data taking strategies are being explored and we expect to start taking data continuously in January 2003. The first data taken toward the sky were encouraging and figure 4. shows a cosmic ray event. From left to right the image acquired on time scales ranging from 60ns to $15\mu\text{s}$ are displayed and the traces under each image show the pulse profile from each channel smoothed to the appropriate time scale.

3. Science perspective

Searching for γ -ray bursts ultra-short durations has not been explored yet with good sensitivity(Halzen et al. 1991). Sub-millisecond structures in Gamma-Ray Bursts have been reported by various authors. Bursts of γ -ray with durations of less than $100\mu\text{s}$ have also been suggested as a possible signature of the existence of primordial black holes. In a quite different domain, some pulsars show giant radio pulses with durations of few microseconds which could have γ -ray counterparts.

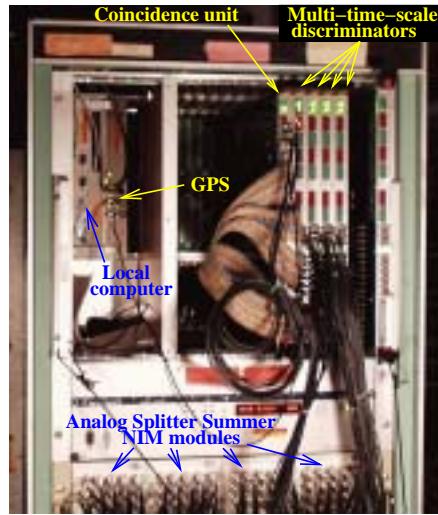


Fig. 3. The SGARFACE electronics installed in the Whipple 10m telescope electronics room.

3.1. Primordial Black Holes

The process of black hole evaporation leads to a violent explosion accompanied by γ -ray emission. The time scale and details of this explosion are mostly unknown and depend on particle physics. However, the total energy emitted is largely model independent $\sim 5 \times 10^{34}$ ergs and a large fraction of that likely dissipated into γ -rays. Short explosions of primordial black-holes could be detected with SGARFACE as far as 250 pc from Earth. Depending on the time scale, SGARFACE individual burst fluence sensitivity will be up to 100 times better than that of space based-detectors like GLAST compensating for the smaller field of view and duty cycle.

3.2. Pulsar giant pulses

Giant radio Pulses from the Crab pulsar reach up to 2000 times the fluence of the average single pulse. It was recently shown (Sallmen et al. 1999) that giant radio pulse from the Crab pulsar have typical durations of a few microseconds and less. Searches for counterparts of giant pulses in optical, X-ray and low energy γ -ray (Patt 1999) proved unsuccessful. EGRET was not sensitive to individual pulses with 2000 times the average pulsed gamma-ray fluence. Rare microsecond bursts correlated with short giant radio pulses could not be excluded (Ramana-murthy 1998; Ramanamurthy 1995). SGARFACE sensitivity is such that a 100ns to $10\mu\text{s}$ burst would be detectable at $E > 0.25\text{GeV}$ gamma-rays if giant pulses were to occur at γ -ray energies and exceed the average γ -ray fluence of a single

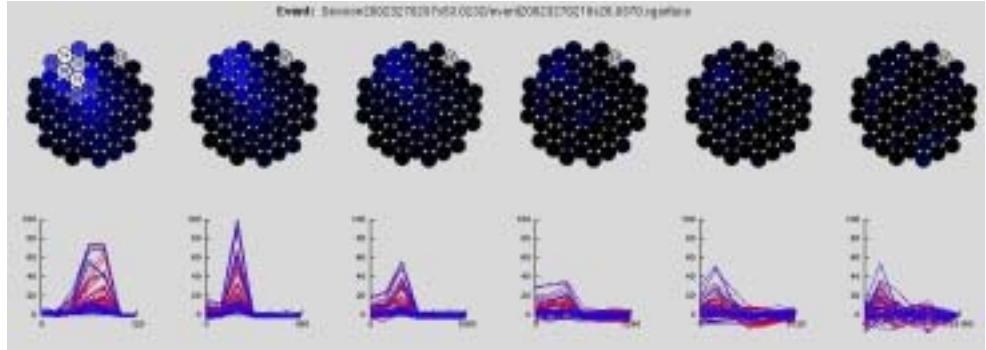


Fig. 4. A cosmic ray shower seen on the event display. The integration time-scale ranges from left to right from 60ns to 15 μ s. The pulse recorded by each channel is shown in the lower part smoothed to the time scale corresponding to the image. The vertical scale is arbitrary.

pulse by a factor of 1000 or more. SGARFACE clearly matches the observed time scales of giant pulses and the relative fluence increases seen in the radio. Another good candidate for this search is PSR1937+21 which is the fastest known millisecond pulsar (1.56ms) and exhibits giant radio pulses with amplitudes larger than 1000 times the average pulse amplitude.

4. Conclusion

With the installation of SGARFACE at the Whipple 10m telescope, its sensitivity will be expanded to GeV photon bursts of 0.1 μ s to 100 μ s. SGARFACE is expected to have a fluence sensitivity of 500 times that of EGRET for microsecond bursts of GeV photons. Data taking should start before the end of 2002 and will be the object of an interesting search for sub-millisecond γ -ray signal with possible implications for primordial black holes and pulsar giant pulses.

5. References

- Walker, K.C. and Schaefer, B.E., 2000, ApJ, 537:264-269.
- Krennrich, F., LeBohec, S. and Weekes, T.C., 2000, ApJ, 529:506-512.
- F.Halzen et al., 1991, Nature, Vol. 353: 807-814.
- Sallmen et al., 1999, ApJ, 517: 460.
- Patt et al. 1999, ApJ, 522: 440.
- Ramanamurthy et al., 1998, ApJ, 496: 863.
- Ramanamurthy et al. 1995, ApJ, 450: 791.
- Lundgren et al. 1995, ApJ, 453: 433.