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Search for Short Bursts of Gamma Rays with SGARFACE

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Abstract: The Short GAmma Ray Front Air Cherenkov Experiment (SGARFACE) is designed to search for bursts of γ rays above 200 MeV lasting from 1 ns to 16 μs. The custom-designed trigger and data-acquisition system is coupled to the camera on the Whipple 10m telescope, an air-Cherenkov telescope in southern Arizona. The experiment has operated for more than 3 years during which time about 1 million events were recorded. Rejection of the cosmic-ray background and of atmospheric phenomena is accomplished through time-resolved imaging of the recorded Cherenkov light. Potential sources of bursts of γ rays are the final explosion of primordial black holes within about 200 pc and γ-ray emission accompanying giant radio pulses. Results of the search for explosions of primordial black holes will be presented.

Introduction

The SGARFACE experiment is designed to search for bursts of γ rays on time scales from 1 ns to 16 μs and with energies above 200 MeV [5]. Bursts of γ rays with this energy may result from the evaporation of primordial black holes or from emission associated with giant radio pulses from pulsar-wind nebulae, as has been observed in the optical band for the Crab Nebula [12].

It has been suggested [4] that black holes of mass M emit real particles with an energy spectrum of a black body at temperature $T \propto M^{-1}$. This means that black holes loose mass by radiation and in the absence of accretion will evaporate completely in $10^{64}(M/M_\odot)^3$ years, where $M_\odot \approx 2 \times 10^{33}$g is the Solar mass. At the present time, black holes with an initial mass of $4.5 \times 10^{14} g$ [8] would be in the final stage of explosion. The types and energy spectra of the emitted particle are well understood below the QCD confinement temperature of $T_c \approx 160$ MeV, corresponding to a hole mass of 6.6×10^{13} g [9]. Above this temperature, it is unknown whether individual elementary particles will be emitted, or if a phase transition of the surrounding vacuum occurs and a thermodynamic model of the emission is required. The most extreme thermodynamic model is that of [2], where the density of states increases exponentially with mass, $\propto m^{-5/2} e^{m/T_c}$, and during the final explosion 6×10^{34} erg are released during approximately 100 ns [10]. Of this, 10^{34} erg would be emitted by γ-rays of around 250 MeV energy. It is possible that the evaporation would not continue past the Planck mass of 2.2×10^{-5} g, reducing the amount of released energy [7].

On the other hand, in the standard model the number of radiated particle species available is well defined, and the evaporation proceeds slower and reaches higher temperatures. The final explosion would last about 1 s with γ-ray of greater than 400 GeV energy being emitted [3, 1].

The SGARFACE experiment [6] is now operating as part of the Whipple 10 m telescope, an imaging air-Cherenkov telescope (ACT) located in southern Arizona [13]. The location of the Whipple 10 m telescope is 31.6804° latitude, 110.8790° W longitude, and 2312 m a.s.l. The air-Cherenkov technique has a detection area of $\approx 2 \times 10^5$ m^2 for single γ-ray primaries. At sub-GeV energies, the Cherenkov emission from one γ ray is not detectable, but a wavefront of near-simultaneous sub-GeV γ-rays produces a detectable signal. The angular distribution of Cherenkov photons of these low-energy γ-ray wavefronts is smooth with an angular extend of $\approx 1^\circ$ RMS. The width of the angular distribution is due to multiple scattering and proportional to E^{-2}, where E is the energy of the secondary e$^{\pm}$. The burst image would appear nearly identical to detectors separated by hundreds of km. This idea was used by [11] to search for the γ-ray emission from evaporating black holes using the 10 m telescope. The cosmic-ray background was eliminated by requiring a second telescope, located 400 km away, to trigger simultaneously. No coincidences were detected, setting an upper limit of 0.04 explosions/pc^3/yr. In contrast, the SGARFACE experiment uses only a single ACT. Here, background rejection of cosmic rays, as well as other events caused by atmospheric phenomena, is achieved by the time-resolved imaging of the Cherenkov wavefronts.

Description of the Experiment

The camera on the Whipple 10 m telescope consists of 380 close-packed PMTs covering a 2.4° field of view. The signal used for SGARFACE is split off the cables via passive couplers before the 10 m electronics. To reduce cost and complexity of the SGARFACE system, clusters of seven nearest-neighbor pixels are summed into 55 channels, each viewing ≈0.4° of the sky. This angular resolution is sufficient to image the extended Cherenkov images produced by bursts of γ rays. The channels are sampled by a flash analog-to-digital (FADC) converter at an interval of 20 ns and with memory depth of 35 μs. To preserve all photo-electrons, a capacitor at the FADC input widens very short pulses to about 25 ns. The SGARFACE trigger operates on six time scales, ranging from 60 ns to 14.6 μs, with the discriminator thresholds set conservatively above the night-sky background level. During most of the observations, 7 nearest neighbor SGARFACE pixels were required to exceed this threshold, minimizing accidental triggers.

Summary of Observations

The SGARFACE experiment has operated nearly continuously since March 2003 during routine observations with the Whipple 10 m telescope. A total of 1511 hours lifetime exposure was accumulated with a mean rate of 0.18 Hz. In the PBH search, we require good to very good night-sky conditions, reducing the data set to 1051 hours. The dead-time of the data-acquisition (DAQ) system is 0.316 sec per event, and was 6% of the total operational time. The requirement of good to very good night-sky conditions, implies that the 10 m telescope was taking scientific data and assures a high level of data quality.

The exposure of the sky during the three years of operation is shown in Fig. 1 in equatorial coordinates and in Fig. 2 in galactic coordinates. The bin-size of $4^{\circ 2}$ represents the effective field of view at DEC=0. Long exposures are seen at prominent TeV γ-ray sources: Crab Nebula, Mrk 421, Mrk 501, the Galactic Center, and 1H 1428+428. Near each source location, but offset in right ascension (RA) by ±30 min, is a second long exposure that is used as a control region in the Whipple analysis. The horizontal bands in Fig.1 arise from the nightly 10 minute zenith runs when the telescope is pointed at or near the zenith.

Calibration of the Light-throughput

The detector response to Cherenkov light was calibrated by direct measurement of all components involved. The expected digital-count (dc) per photo-electron (pe) is 0.92± 0.1, where the error is

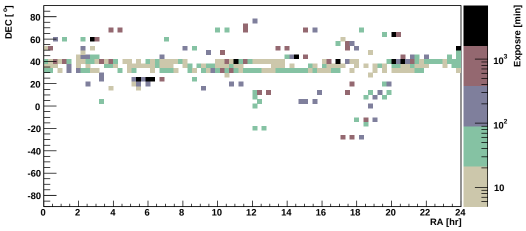

Figure 1: Exposure map of the sky in equatorial coordinates. Bins of less than 5 minute exposure are suppressed. Prominent point of observation are the Crab Nebula (RA 05h34m31.9s DEC+22°00m52.1s, J2000), Mrk 421 (RA 11h04m27.31s DEC+38°12m31.8s), and the Galactic Center (RA 17h45m40.0s, DEC-29°00m28.1s)

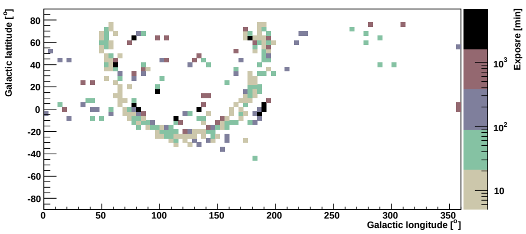

Figure 2: Exposure map of the sky in galactic coordinates. Bins of less than 5 minute exposure are suppressed.

due to systematic uncertainties. As these measurements were done only once and at separate times, a second method was developed to track any instrumental variations. It consists of two parts:

1) The light-throughput of the Whipple 10 m is measured from recorded images of complete muon ring. The ratio of digital-counts to photo-electrons for the 10 m DAQ is shown in Fig.3. Variations in the dc/pe ratio are due to ageing of the PMTs and increase in the high-voltage level. Because of uncertainties in the UV response of the mirrors and PMTs, the dc/pe value is tied to the directly measured value of 3.3±0.3 dc/pe in November 2000.

2) Events that are recorded simultaneously by both, Whipple and SGARFACE, are used to cross-calibrate the light-level between each cluster of pixels. Cosmic rays produce coincident events about 70% of the time, providing a large enough statistical sample to perform a nightly calibration. The average ratio between the two DAQ systems is measured to be 3.54 and is very stable over the three-year time span, as shown in Fig.4.

Using this cross-calibration method, the dc/pe ratio is determined to be 0.93±0.1 at the time of the directed measurement and is in agreement with the direct measurements.

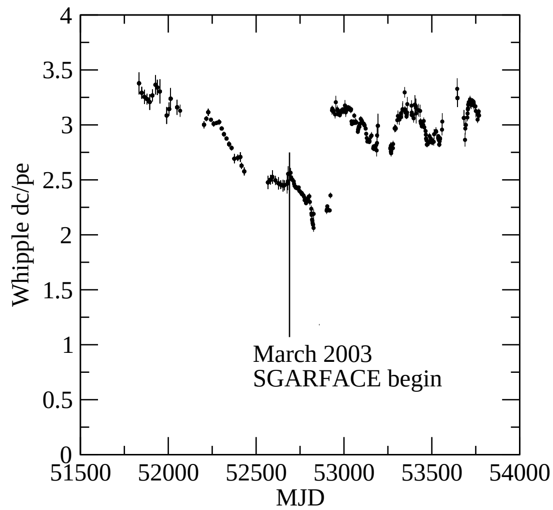

Figure 3: The number of digital counts produced per photo-electron for the Whipple 10 m DAQ.

Search for Bursts

The final analysis of the data is underway. The image shape and timing information of events are parameterized and used in the rejection of background events. Sources of background are cosmic-rays, from which we see direct Cherenkov light and fluorescence emission, and atmospheric backgrounds such as lightning and airport/airplane beacons.

The sensitivity of the instrument to bursts of γ-rays is established through detailed Monte-Carlo simulations. The upper limits on PBH explosion rate will be presented at the conference.

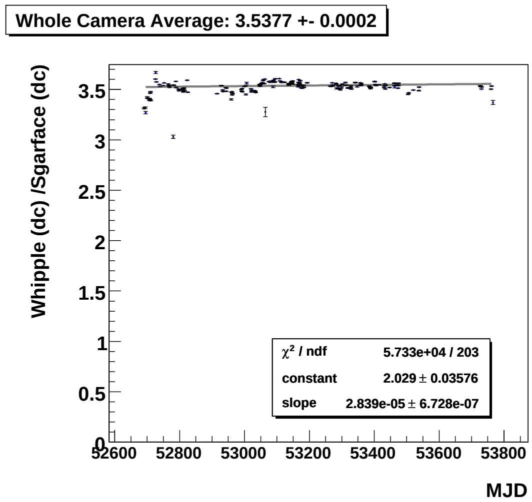

Figure 4: Cross-calibration between Whipple 10 m DAQ and SGARFACE. The number of digital counts (dc) is compared between the two instruments using simultaneously detected cosmic-ray images.

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