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Status of the Ashra Project

M. Sasaki[a], Y. Aita[a], Y. Arai[e], Y. Asaoka[a], T. Chonan[g], S. Dye[h], R. Fox[j], S. Fukagawa[b], G. Guillian[h], J. Hamilton[i], Y. Hsiung[j], M. Huang[k], M. Jobashi[a], T. Kimura[c], H. Kuze[b], J. Learned[h], N. Manago[a], S. Matsuno[h], K. Noda[a], Y. Ogawa[f], A. Okumura[a], N. Sugiyama[d], M. Wang[j], Y. Watanabe[g] and M. Yasuda[g] for the Ashra collaboration
(a) ICRR, Univ. Tokyo, (b) Chiba Univ., (c) Ibaraki Univ., (d) NAOJ, (e) KEK, (f) Toho Univ., (g) Tokyo Inst. Tech., (h) Univ. Hawaii Manoa, (i) Univ. Hawaii Hilo, (j) National Taiwan Univ., (k) National United Univ.
Presenter: Sadakazu Haino (sasakim@icrr.u-tokyo.ac.jp), jap-sasaki-M-abs1-he15-oral

The All-sky Survey High Resolution Air shower detector (Ashra) is primarily designed to elucidate transient objects such as Gamma Ray Bursts not only detecting optical lights but also simultaneously TeV γ, PeV neutrinos, and EeV cosmic rays. Ashra records images in unprecedented arc-minute detail of high-energy cosmic particle interactions in the atmosphere using new wide angle high resolution optics, Image Intensifier and CMOS technology. A first run of data taking with prototype versions of the optical and the trigger systems took place in 2004-2005, allowing us to evaluate the performance of the systems and to approach an analysis strategy. Full configuration of the Mauna Loa site will be reached by 2006. We will illustrate the summary of the Ashra project and the pilot data with the analysis for optical transient and TeV γ-ray search.

1. Introduction

Cosmic Gamma Ray Bursts (GRBs) seem to be the most relativistic phenomenon observed so far. There is much observational evidence that GRB outflows are highly relativistic and collimated. Phenomena responsible for GRB, however, expecially for the central engine, have not been unambiguously identified yet. In order to proceed with understand the physics of GRB one needs to observe them also in wavelengths different than γ-rays. It is natural to expect that GRB should be accompanied by bright optical flashes [1]. Systematic study of optical flashes accompanying GRB could impose important limits for theories explaining bursts mechanism and their energy engines. The jet opening angle has been inferred for several GRBs, and appears to range from 2° to 30° [2]. Therefore, the true GRB rate must be approximately more than 100 times that detected by satellite experiments such as BATSE, HETE-2, INTEGRAL, and Swift. It remains an open question what these off-axis afterglows should look like. It is also quite likely that other particles in addition to γ-rays are emitted in the GRB events. For instance, it was pointed out that fireball model of GRB is closely related to extragalactic cosmic rays [3], ultra-high-energy cosmic rays [4][5][6], and high-energy neutrinos [7]. There are important suggestions that bursts of very-high energy γ with the energy of $\sim$1-10 TeV, which are associated with GRBs and originated from inverse compton cooling [10] and synchrotron radiations from protons accelerated to ultra-high energy [11] in the jets. Since cosmological GRBs seem to be a relatively homogeneous population of sources with a narrow luminosity function [8][9], GRBs can also serve to explore cosmology.

The rapid identification of new transients is essential for a search of this nature. Also, the simultaneous detection of very high energy γ-rays, νs and optical afterglows enables revealing the physics mechanism in the GRBs as well as examining the particle acceleration in the expanding fireball model in detail. The Ashra detector is primarily designed to elucidate the origin and nature of high energy astronomical phenomena of transients such as GRBs.

2. System Overview

The activities herein contribute to the technology development and demonstration of the All-sky Survey High Resolution Air-shower detector (Ashra; http://www.icrr.u-tokyo.ac.jp/$\sim$ashra) for the advancement of particle

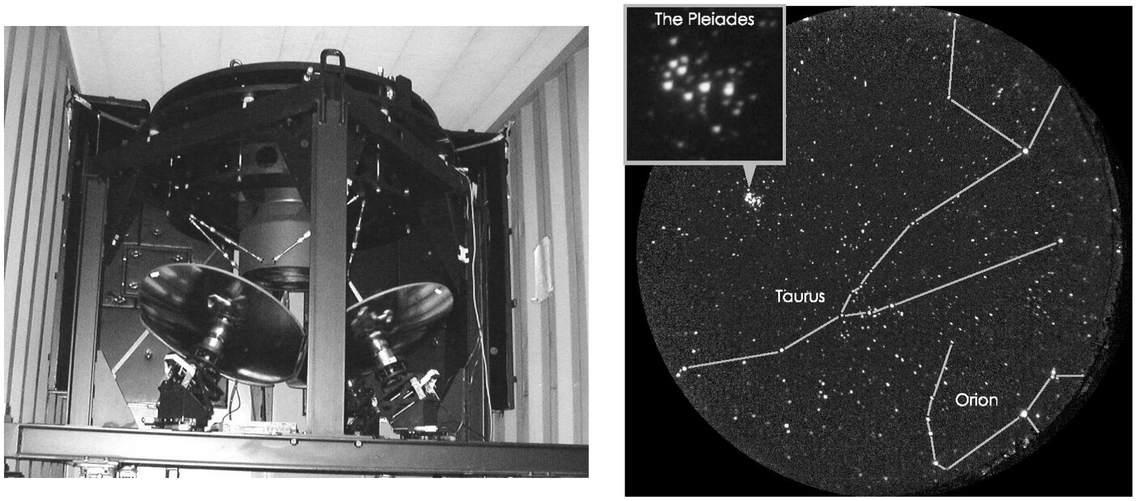

Figure 1. The 2/3 scale Ashra prototype telescope operated on Haleakala (left). Example of a 50-degree FOV image in which the constellation of Taurus and Orion can be clearly identified (right). The inset of a 2-degree square window shows a close-up view of the Pleiades.

astrophysics. Ashra records images in unprecedented arc-minute detail of high-energy cosmic particle interactions in the atmosphere using new CMOS technology. Tracks of nitrogen fluorescence and beams of Cherenkov radiation reveal the arrival direction, energy, and identity of cosmic rays (neutrinos, nuclei and gamma rays) over an energy range of 7 orders of magnitude, from TeV to EeV scale and beyond. Ashra sees not only near horizontal air showers due to neutrinos, but those showers exiting the nearby mountains due to conversion of traversing tau neutrinos, and includes a view of the Galactic Center region. Moreover, the detector can be used to seek optical flashes from Gamma Ray Bursts, providing early alert to telescopes for more detailed observation, particularly those located nearby. Ashra consists of three high-altitude (3 km) stations to be incrementally installed at Mauna Loa, Hualalai, and Mauna Kea on the island of Hawaii. Each station, separated by 30–40 km, observes the entire moonless night sky with 12 detectors. In the Ashra optics, UV photons from air showers and directly from GRBs are collected using modified Baker-Nunn optics [12] [13]. A detector utilizes three or four 2.2 m projected diameter spherical reflectors for viewing a 0.5 sr region of sky. Detector images pass through a photoelectric pipeline for trigger processing and recording on 4 mega-pixel CMOS sensors. Covering the sky with 48 M pixels, roughly a thousand-fold improvement over presently employed technology, represents resolution measured in arc minutes rather than degrees (as achieved with photomultipliers). This unprecedented pixelization provides shower reconstruction with better pointing accuracy (arc-minutes), improved energy determination, and an extension of the range to which distant high energy showers can be detected (because of being able to resolve shorter tracks on the sky).

The increased pixelization will pay off in energy, particle type discrimination, origin direction and effective volume. The most unique feature of Ashra however is the ability to serve as simultaneous detector for both the long duration (100 μs) fluorescent events and short (few ns) air Cherenkov events, not possible with earlier instruments. The problem of integrating background light over long times is solved by an image delay system to the CMOS sensors, and a moving electronic shutter driven from a parallel multi-anode photomultiplier trigger. The major gain here is the ability to monitor the whole sky continuously for extended (dark) periods, making an unprecedented search for new point (and time varying) sources such as the numerous gamma ray

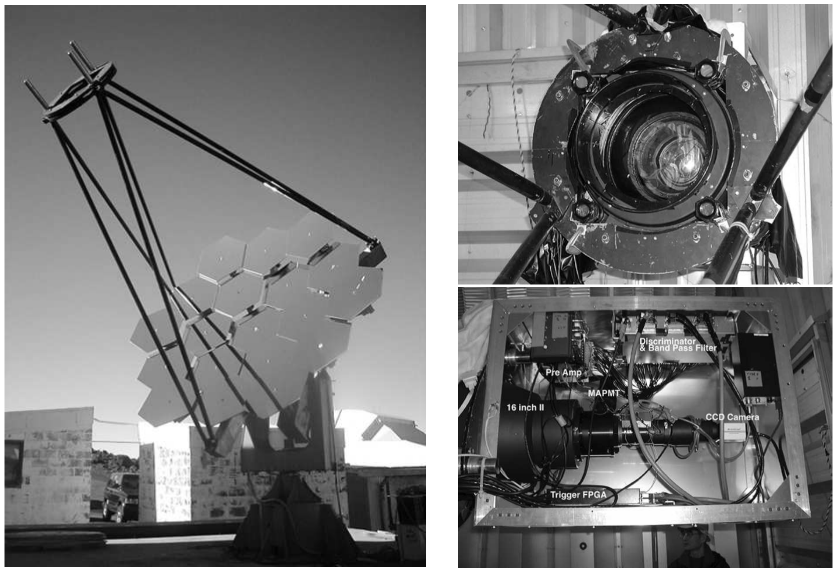

Figure 2. Altazimuth telescope with 3m diameter of mirror system at Haleakala observatory for testing self-trigger of the image pipeline for TeV γ-rays. (left). The focal sphere of image intensifier mounted on the telescope (upper right). The image pipeline and the peripheral units mounted on the telescope (lower right).

bursts, soft gamma ray repeaters, unidentified EGRET sources and so on. Note that the effective area of Ashra for such a search is much larger than water Cherenkov based detectors.

The photoelectric image pipeline consists of focal sphere image intensifire (FIIT), relay lens systems, self-triggered IIT (STIIT) providing the functions of splitting light and making optical delay, trigger image sensor, and high resolution CMOS image sensor. Using multiple stage pipeline and 3-way light splitter allows us image transportation to the CMOS image sensor with enough gain without sacrificing the fine image resolution, self-trigger for short time phenomena like atmospheric Cherenkov signal, and a commercial CCD chip on a board to continuously catch untriggered light images. Since the examined resolution at the focal surface is much better than the required one, four light guides after sub-telescopes, which can be connected into one STIIT, significantly contributes to high cost-performance of this system. Following the light splitter, a proximity focused IIT is equipped to make delay for the trigger decision time using the scintilation light on phosphor P-46, of which 10%-decay-time is 200 ns. The gated II after the delay II makes a role of "high speed shutter" by controling the voltage supplied between the photocathode and the micro channel plate (MCP) using the gate signal from the trigger device.

All Ashra systems now exist in the prototype stage and first versions have been assembled on Haleakala since Fall 2004 (Fig.1). Land acquisition on Mauna Loa via the University of Hawaii is almost established. It is planned to install the first station on Mauna Loa beginning in 2005 and completed in 2006.

3. Test Observations

The fine resolution (arcminutes) in the wide field of view (0.5 sr) have been already demonstrated using the 2/3-scale model (Fig.1). Adding those, we successfully made a cross-observation of the field covering the HETE-2 WXM error box of GRB041211 continuously between the time 1h7m before GRB041211 and that 1h41m after GRB041211 taking 2000 images covering the WXM error box every 5 s with 4 s exposure time.

We detected no new objects in the WXM error box resulting the 3-sigma limiting magnitudes are stringently derived (GCN Report #2846, see also http://www.icrr.u-tokyo.ac.jp/∼ashra/GRB041211/). We also succeeded in two more world-earliest cross-observations with Swift (GRB050502b, GCN Report 3333) (GRB050504, GCN Report 3348).

A demonstration alt-az mounted air Cherenkov detector on Haleakala is in place and has also been collecting data with the image pipeline and the self-trigger system (Figure 2). We have already confirmed the peak of TeV γ-rays from Crab nebula to be more than 5 σ after detailed analysis. We have taken data for TeV γ-rays from Mkr421 and Mkr501 for the observation time of several tens hours respectively in good weather conditions. Also recently we have been ready for making cross-observations of TeV γ-rays associated with GRB within 10 seconds after appropriate alert from a satellite.

In conclusion, the prototype detectors have fairly met all our specifications of wide angle high resolution optics and image pipeline. We are thus confident to proceed with the construction of the full-scale detector station system at Mauna Loa as the first phase.

Figure 3. The full-scale Ashra light collector unit mount under the ajustment in a room (left). Site location view toward Mauna Kea from the Ashra phase-1 observation site at Mauna Loa (right).

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