The Ashra Project

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Abstract: Ashra (All-sky Survey High Resolution Air-shower detector) is a project to build an unconventional optical telescope complex that images very wide field of view, covering 80% of the sky, yet with the angle pixel resolution of a few arcmin, sensitive to the blue to UV light with the use of image intensifier and CMOS technology. The project primarily aims to observe Cherenkov and fluorescence lights from the lateral and longitudinal developments of very-high energy cosmic rays in the atmosphere. It can also be used to monitor optical transients in the wide field of sky. We present the project status, and expected scientific impacts on the observational objectives such as optical transients, unidentified TeV gamma- ray and PeV neutrino sources, and the propagation of EeV cosmic rays.

Overview

Ashra (*All-sky Survey High Resolution Air-shower detector*) [1, 2, 3] is a project to build an unconventional optical telescope complex that images very wide field of view, covering 80% of the sky, yet with the angle resolution of 1.2 arcmin, sensitive to the blue to UV light with the use of image intensifier and CMOS technology. The project primarily aims to observe Cherenkov and fluorescence lights from the lateral and longitudinal developments of very-high energy cosmic rays in the atmosphere. It can also be used to monitor optical transients in the wide field of sky. In 2004 we built prototype telescopes to verify and develop techniques on Haleakala in Hawaii, needed for the development of the full-scale telescopes under construction on Mauna Loa.

Project

The observatory will firstly consist of one main station having 12 detector units and two sub-stations having 8 and 4 detector units. One detector unit has a few light collecting systems with segmented mirrors. The features of the system were studied with a prototype detector unit located on Haleakala. The main station is being constructed on Mauna Loa (3,300 m).

Objectives	Opt. Transients	TeV-γ	Mountain-ν	Earth-skimming-ν	EeV-CR
Detected Light	B-UV	Cherenkov	Cherenkov	Fluorescence	Fluorescence
Energy Threshold	λ=300$\sim$420nm	2 TeV	100 TeV	10 PeV	100 PeV
Flux Limit/Obs. time	15 mag./4s @3σ	5% Crab/1yr@5σ	5 WB-limit/1yr	2 WB-limit/1yr	1600/1yr >10 EeV
Directional Resolution	2 arcmin	6 arcmin	unknown	3 arcmin @ 100 PeV	1 arcmin @ 10 EeV

Table 1: Summary of performance with the full configuration (Ashra-2) of three Ashra sites. For EeV-CRs, trigger requirement is two or more stations. Waxman and Bahcall have calculated a neutrino flux upper limit from astrophysical transparent source, here referred to as the WB-limit. For the observation time for objectives other than optical transients, the realistic detection efficiency is taken into account.

The key technical feature of the Ashra detector rests on the use of electrostatic lenses to generate convergent beams rather than optical lens systems. This enables us to realize a high resolution over a wide field of view. This electron optics requires:

- *image pipeline;* the image transportation from imaging tube (image intensifier) to a trigger device and image sensors of fine pixels (CCD+CMOS), with high gain and resolution, and
- *parallel self-trigger:* the systems that trigger separately for atmospheric Cherenkov and fluorescence lights.

Observational Objectives

optical transients; Ashra will acquire optical image every 5 s after 4-s exposure. This enables us to explore optical transients, possibly associated with gamma ray bursts (GRBs), flares of soft gamma-ray repeaters (SGRs), supernovae explosion, and so on, in so far as they are brighter than $B \simeq 15$ mag, for which we expect 3-σ signals (Fig. 1). The unique advantage is the on-time detection of the events without resorting to usual satellite alerts. 10$\sim$20 events per year are expected in coincidence with the Swift gamma-ray events. The field of view that is wider than satellite instruments allows to detect more optical transients, including an interesting possibility for an optical flash, not visible with gamma-rays.

TeV gamma rays; Atmospheric Cherenkov radiation will be imged by Ashra. Requiring the signal-to-noise ratio (SNR) >5, the system will allow to

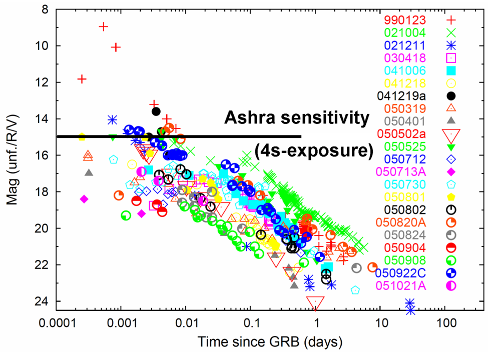

Figure 1: Early light curves (unfiltered, R and V) for a set of GRBs with detections within minutes of the gamma-ray event. All the measurements shown have been taken from GCN circulars (Guidorzi et al. astro-ph/0511032). The limiting magnitude ($\simeq$B) expected with Ashra (4s-exposure) is shown as a horizontal line. There are no observations within 10 s after the GRB events.

explore VHE gamma-ray sources with the energy threshold of 2 TeV at the limiting flux sensitivity of 5% Crab for 1-year observation.

EeV cosmic rays; For fluorescence lights from VHE cosmic rays the effective light gathering efficiency is comparable with that of the High Resolution Fly's Eye detector (HiRes). The arcmin pixel resolution of Ashra provides finer images of longitudinal development profiles of EeV cosmic ray (EeV-CR) air-showers. The resolution of arrival direction with the stereo reconstruction is thus significantly improved and it is better than one arcmin for the primary energy of EeV and higher [4]. This is useful to investigate events clustered around the galactic and/or extragalactic sources. This in turn would give us information as to the strength and coherence properties of the magnetic field

PeV-EeV neutrinos; Ashra may detect Cherenkov and/or fluorescence signals generated from tau-particle induced air-showers that is generated from interactions of tau neutrinos with the mountain and/or the earth. This is identified by peculiar geometry of the air-shower axis. The 1-year detection sensitivity with the full configuration of Ashra is 5 and 2 times larger than the Waxman-Bahcall limit for mountain-produced event (Cherenkov) and earth-skimming event (fluorescence), respectively. The most sensitive energy of around 100 PeV is suitable for the GZK neutrino detection.

The expected performance for each observational object is summarized in Table 1.

Test Observation

We have constructed a 2/3-scale prototype Ashra detector and a 3m-diameter altazimuth Cherenkov telescope on Haleakala to verify the optical and trigger performances. From October 2004 to August 2005 at the observatory, We made good observations for 844 hours out of 1,526 hours of the moonless night time. The efficiency is 55% of the moonless night time and 11% of entire time. This inefficiency is due primarily to bad weather.

The fine resolution (arc-minutes) in the ultra wide field of view (0.5 sr) has already been demonstrated using a 2/3-scale model. Fig. 2 shows an example of a 50-degree FOV image in which the constellations Taurus and Orion can be clearly identified with the 2/3-scale prototype. The inset, a two-degree square window, shows a close-up view of the Pleiades.

Our wide field observation covered the HETE-2 WXM error box at the time of GRB041211. 2,000 images were taken every 5 s with 4-s exposure from the time 1h7m before GRB041211 to 1h41m after GRB041211. We detected no objects showing time variation in the WXM error box. It indicates the 3-sigma limiting magnitudes of B$\sim$11.5 magnitude [5]. This is compared with other observations in Fig. 3 [6] [7]. We also successfully performed two more observations coincident with Swift: GRB050502b [8] and GRB050504 [9].

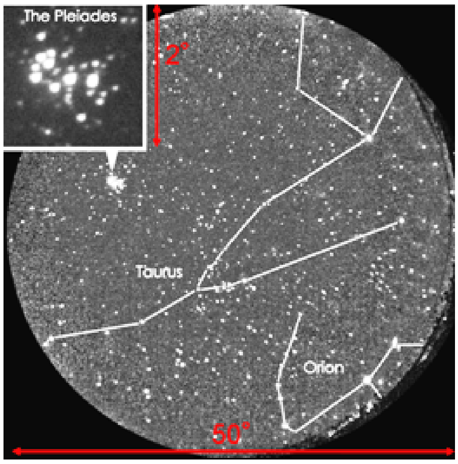

Figure 2: Example of a 50-degree FOV image taken by the Ashra prototype. The solid lines are drawn to indicate the constellations Taurus and Orion. The inset, a two-degree square window, shows a close-up view of the Pleiades.

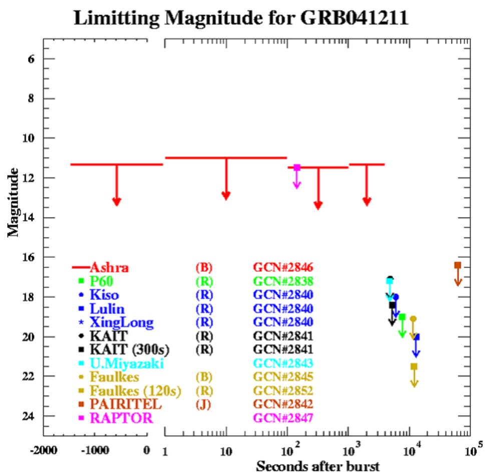

Figure 3: 3-sigma limiting magnitudes of the test observation with the Ashra prototype and comparison with other observations for GRB041211 as a function of time after GRB. Note that the horizontal axis unavoidably stands for time (s) in logarithmic scale after the burst (positive) and in linear scale before the burst (negative).

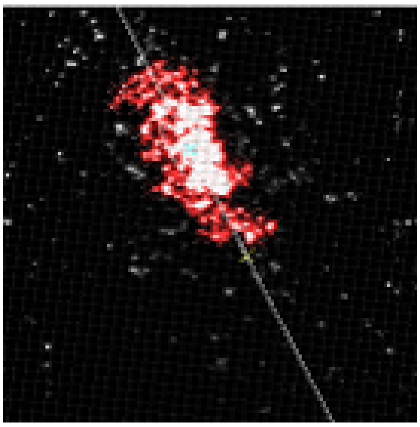

Figure 4: Self-triggered Cherenkov image of air-shower detected by using the Ashra photoelectric image pipeline and a prototype trigger sensor system. This image was taken during tracking Mkr501.

A demonstration of air Cherenkov imaging of high-energy gamma/cosmic ray is shown in Fig. 4 which was taken during observing Mkr501. Separately, we have confirmed the alpha-parameter peak of TeV γ-rays from the Crab nebula to be greater than 5 σ.

Current Status and Plan

After finishing the grading work for the area of 2,419 m^2 at the Mauna Loa site at the end of July 2005, installation of electrical power lines and transformers was performed until the beginning of September. We started the construction of the detector in October 2005 after receiving materials from Japan. Currently, (mid December 2005) a few shelters having motorized rolling doors, acrylic plate windows to maintain air-tightness, and heat-insulating walls and floors have been constructed and positioned on eight construction piers of concrete blocks at the Mauna Loa site. In the shelters, the optical elements of the light collectors have been already installed. The optical performance were checked and adjusted to be optimum with star light images from the pilot observation.

In December 2005, we evaluated the night sky background flux on Mauna Loa using the Ashra light collector installed and aligned in a shelter. The result is fairly consistent with the background in La Palma and Namibia by the HESS group From the star light observations, our understanding of the light correction efficiency to be accurate within 5% level.

In this Ashra-1 experiment, we are performing device installation and specific observation in a step-by-step way to enhance the scientific impacts.

The full Ashra observatory (Ashra-2) will consist of three experimental sites separated by about 30 km on Mauna Loa (3,300 m), Camp Kilohana (2,014 m) on the side of Mauna Kea, and Hualalai (2,320 m) on the island of Hawaii. The full configuration emphasizes the stereoscopic observation Cherenkov and fluorescence lights from air-showers with two or three stations at separated sites as well as the effective detection area for air-showers. The parallax observation for optical transients with two or more stations is also useful for rejecting local background events.

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