Galactic Bulge Monitor with Ashra-1 and NTA detectors

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The Ashra phase-1 (Ashra-1) detector has been developed to efficiently take fine images of air-shower (AS) Cherenkov (CE) and fluorescence (FL) light induced by the Earth-skimming ν_τ and γ-ray ASs. Based on the Ashra-1 performance, we have planned a new extension, i.e. Neutrino Telescope Array (NTA), an AS imaging ν and γ-ray observation system for *Clear Discovery and Identification of Non-thermal Hadronic Processes in the Universe.* Four NTA stations are to be deployed on Mauna Loa at 3000-3500 m a.s.l. (NTA Summit Array layout). Using the four stations, NTA can watch the air volume surrounding Mauna Loa including the surface of Mauna Loa, the largest volcano, Hawaii Island and sea around it to efficiently detect CE and FL light from ν_τ ASs with both short and long decay lengths and γ-ray ASs. From the detailed MC studies, the NTA ν_τ sensitivity is sufficient to probe Pevatorons, an extension of the IceCube detected astrophysical neutrino flux and predictions of the cosmogenic neutrino flux. The point-back accuracy is evaluated to be within 0.2° with respect to the original direction of the PeV-scale ES ν_τ's. As the first step observation with the minimal systematic deployment, we propose to monitor 10 TeV-10PeV γ-rays from the Galactic bulge with Ashra-1 as well as Earth-skimming ν_τ's with NTA simultaneously to clearly identify the Pevatrons and comprehensively understand the emission process there. The effective detection area of Ashra-1 and NTA for the Galactic bulge γ-rays with the energies around 1 PeV is more than 10 and 100 times respectively larger than that of a ground array with 500m scale.

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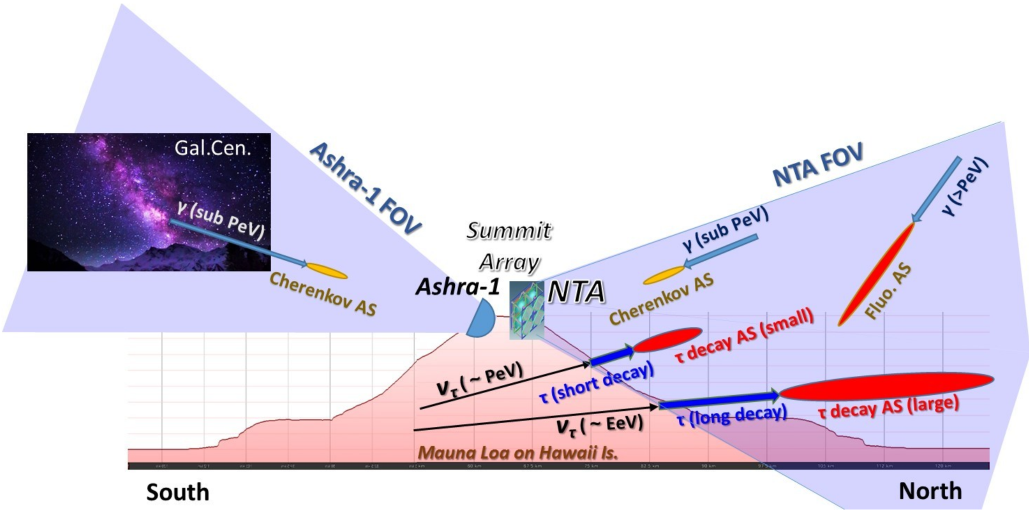

Figure 1: Concept of imaging observation of PeV ν's, γ-rays, and nuclei with Ashra NTA Summit Array. Simultaneously 6 Ashra-1 light collectors watch our Galactic bulge. NTA can check the coincidence of the ES-ν_τ's with gamma-ray events by Ashra-1.

1. Introduction

Combined detection of PeV ν's and γ's from an accelerator provides indispensable identification of the location and the physics mechanism i.e. $p+\gamma \to \Delta^+ \to \pi^0 + p,\ \pi^+ + n;\ p + \text{nucleus} \to \pi^{\pm,0} + X,$ which can clearly reveal the long-standing unresolved origin(s) of cosmic rays. Recently several suggestive observations have been independently made [1, 2, 3]. Such a "multi-particle" paradigm [4] can be performed by Ashra NTA with the single unique detector system [5].

In 2002, Sasaki *et al.* presented the distinctive potential of the Earth-skimming tau ν (ES-ν_τ) technique [15]. It enjoys a large target mass by detecting air-showers (ASs) produced by τ decays in the air. The τ's, produced by ν_τ's that interact with the Earth matter, traverse, and emerge out of a mountain or the ground decaying and generating ASs. Adding to the good detection sensitivity for for ν's, the advantages are perfect shielding of cosmic ray secondaries, precise arrival direction determination, and negligible background from atmospheric ν's [16]. The Ashra detector can efficiently image AS Cherenkov (CE) and fluorescence (FL) light generated from ES-ν_τ and γ ASs in the effective volume of air in the field of view (FOV) (Figure 1). The unique point is the resolution better than 0.1° yielding strong hadron rejection as selecting γ's both with FL and CE light.

2. From Ashra-1 to Ashra NTA

The Ashra Phase 1 (Ashra-1) [17] light collector (LC) achieves the total resolution of $\sim$ 3 arcminutes (0.05 °) covering 42° FOV. The key feature is the use of electrostatic rather than optical lenses to generate convergent beams with the 20 inch Photoelectric Lens Imaging tube (PLI) [18] demagnifying to 1 inch at focal surface, enabling high resolution over a wide FOV [19]. The following trigger readout Photoelectric Image Pipeline (PIP) [20] can image and read out three in-

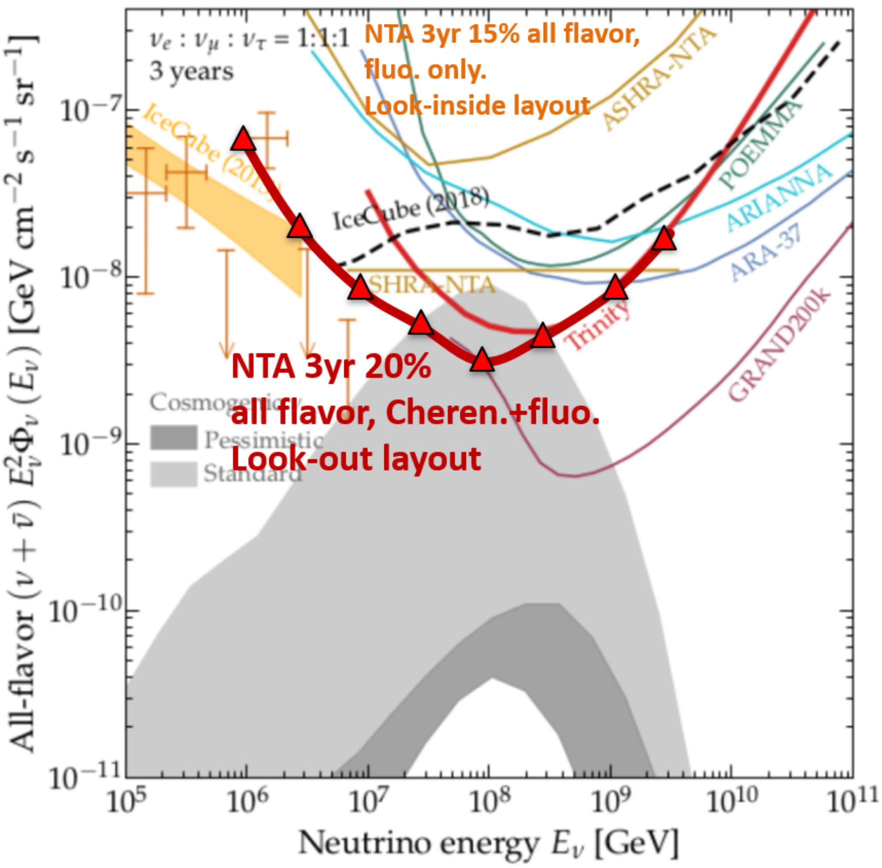

Figure 2: Sensitivity of Ashra with only fluorescence mode, that including far-Cherenkov mode and other experiments, neutrino flux predictions, and existing flux constraints. Figure adapted from [21].

dependent phenomena on different time scales, i.e. AS CE emission (ns), AS FL (μs), and starlight (s), without sacrificing the S/N ratios. The demonstration phase has been operated since 2008 at the Mauna Loa Observation Site at 3300 m asl. on Hawaii Island. With alert for GRB081203A given by SWIFT satellite, Ashra-1 succeeded in the first search for PeV-EeV ν_τ's originating from a GRB with the ES-ν_τ technique setting stringent fluence limits [22]. The updated ES-ν_τ limits from 1863 hours observation will be published soon [23].

Based on Ashra-1 performance, we have planned a new extention, i.e. Ashra Neutrino Telescope Array (NTA), which is an AS imaging ν and γ observation system for the aim/scientific goal [5]: *Clear Discovery and Identification of Nonthermal Hadronic Processes in the Universe, be it Galactic, Extragalatic, or Cosmogenic.* By optimizing the layout of the NTA stations to enhance the detection sensitivity for ES-ν_τ's around 1 PeV from the detailed simulation studies [5, 16], four NTA stations are to be deployed on Mauna Loa at 3000 - 3500 m asl (NTA Summit Array), watching the air volume surrounding Mauna Loa including the surface of Mauna Loa, the largest volcano, to efficiently detect CE and FL light generated from τ ASs with both short and long decay lengths and γ ASs (Figure 1). The reconstructed AS images with fine resolution is powerful not only in the determination of point sources of PeV ν_τ's but also FL observation for γ ASs above PeV with the

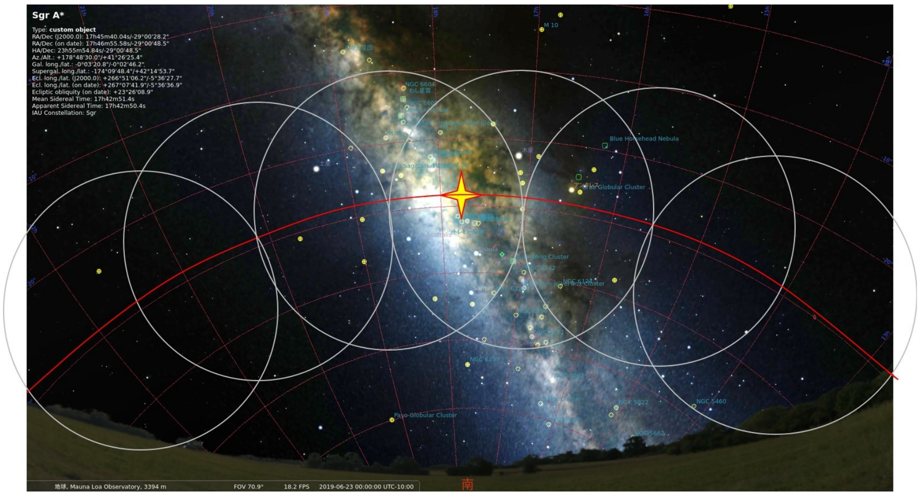

Figure 3: Simulated southern sky at the Mauna Loa site at 0:00 on June 23, 2019. The cross star indicates the location of the Galactic center(GC). The track of GC (arc) and the FOV of the rearranged Ashra-1 light collectors (circles) are also shown.

large effective area (Figure 1). Figure 2 shows a comparison of NTA's total ν_τ detection sensitivity with that of NTA with only fluorescence mode [5] Trinity [21], GRAND [6], POEMMA [7], ARIANNA [8], and ARA-37 [9]. Also shown are predictions of the cosmogenic neutrino flux [10], measurements of the astrophysical neutrino flux with IceCube [11], and the recent limits from IceCube [12], AUGER [13], and ANITA [14]. The NTA ν_τ sensitivity is sufficient to probe Pevatorons, an extension of the IceCube detected astrophysical neutrino flux and predictions of the cosmogenic neutrino flux. Adding that the unique combination among CE and FL observations for both ES-ν_τ's and γ with NTA will truly identify Pevatron(s) and open up new types of search for ν's and γ's in the wide energy range.

As the first step, the combination between Ashra-1 light collectors and new NTA detector units is useful to realize the comprehensive observation both with TeV-PeV γ-rays and PeV ν's. Six Ashra-1 LCs will be realigned for the FOV centers to be on the arc of the Galactic Center trajectory optimizing the monitoring coverage and the stereoscopic observation efficiency as shown in Figure 4. Therefore we will arrange the fields of view so that their fields of view overlap by half of the field of view of adjacent telescopes as shown in Figure 4. As a result, the total rate of the stereoscopic observation can be more than 70% of the fully-covered trajectory in the sky. We estimate the annual observable time to be 1150 hours $\times\varepsilon_w$ during nights without moon in the south, where the weather efficiency $\varepsilon_w > 90\%$ according to the Ashra-1 experience, which is more than 50 times better than HESS achieved i.e. 227 hours for Sgr A* in 10 years [2]. The series of 6 Ashra-1 LC FOVs can monitor AS CE light of γ-rays arrived from the Galactic bulge (GB) or central region. Another advantage of the detection of γ-rays with Ashra-1 is the large zenith-angle method. The GB trajectory experiences the zenith angle larger than 50 degrees (70 degrees), which corresponds to the distance to the shower max larger than 9 km (26 km) and the threshold energies higher than 16 TeV (240 TeV). This situation is useful to check the cut-off energy in the γ-ray spectrum in the Galactic bulge or central region as well as the large monitoring FOV and efficiency. Once

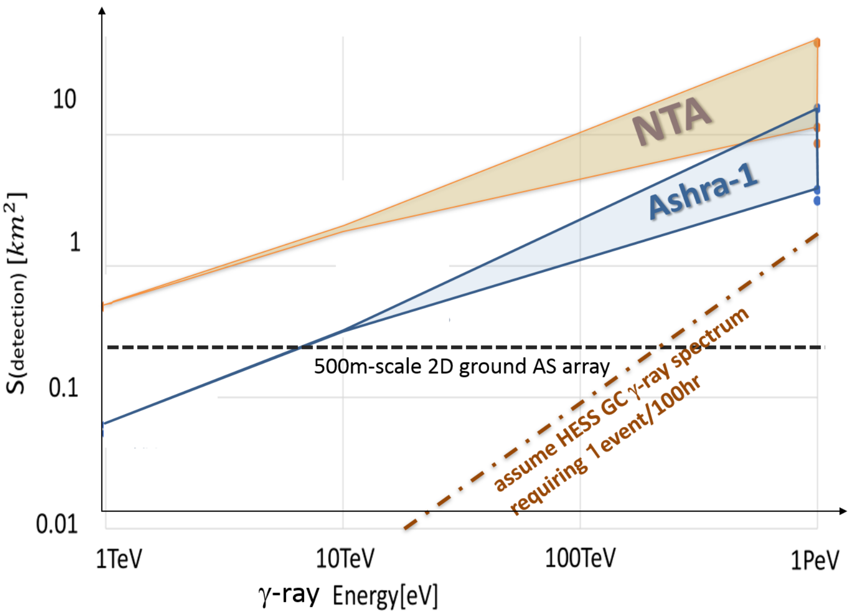

Figure 4: The γ-ray effective detection area versus energies comparing with NTA, Ashra-1 (bands), and 500m-scale 2D ground AS array (dash). Requirement of 1 events/100hr-observation assuming HESS GC γ-ray spectrum (dot-dash) [2] is also shown.

the northward NTA units detect ν's from the same source direction as γ-rays, we can discuss the physics of the occurrence of γ-rays and ν's more concretely than ever.

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