# Prospect towards Survey of Astronomical $\nu_\tau$ Sources

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By separating $\nu_\tau \to \tau$ conversion from $\tau$-shower generation, the Earth-skimming $\nu_\tau$ method allows for huge target mass and detection volume simultaneously. In part motivated by recent IceCube astrophysical PeV neutrino events, the planned NTA observatory will have three site stations watching the air mass surrounded by Mauna Loa, Mauna Kea, and Hualalai on Hawaii Big Island, plus a site station at the center watching the lower night sky. Sensitivities equivalent to $> 100$ km$^3$ water and pointing accuracy of $< 0.2°$ can be achieved with Cherenkov-fluorescence stereoscopic observation for PeV-EeV neutrinos that is almost background-free. With design based on experience from the operating Ashra-1 detector, and the goal of clear discovery and identification of astronomical $\nu_\tau$ sources, a new International Collaboration is being formed to probe for cosmic proton accelerators.

## Prologue

The IceCube experiment announced three PeV scale astrophysical neutrino events: at $1.04 \pm 0.16$ PeV ("Bert") and $1.14 \pm 0.17$ PeV ("Ernie") [1], respectively, and the highest-energy neutrino ever observed [2], around 2 PeV ("Big Bird"). Spectacular as these are, the theme we explore in this article is: What if one had better *sensitivity* and accurate *pointing* information?

## 1. Introduction: Astronomy to $\nu$-Astronomy

Astronomy is as old as humankind. But after staring for eons with our bare eyes, the telescope expanded the human sight, eventually allowing us to realize just how unimaginably vast our Universe really is. This was further enriched by expanding beyond the "visible" light spectrum, to the extent that we have giant radio telescope arrays on Earth, and exquisite optical, X-ray or $\gamma$ ray telescopes in orbit. But as the 2002 Nobel prize was awarded for the pioneering X-ray telescope work, a totally new type of observational tool was also recognized: "the detection of cosmic neutrinos" [3] by Ray Davis, and by Masatoshi Koshiba.

The word "neutrino", meaning "small neutral one" in Italian, was coined by Fermi, in part because the name "neutron" was already taken. The particle was introduced by Pauli to salvage energy conservation in $\beta$ decay. But even as bold a person as Pauli feared that he had introduced a "ghost" particle [4] that seemed impossible to detect. However, Fermi put it to good use in writing down the first theory, the Fermi theory, of weak interactions, i.e. $n \to p + e^- + \bar{\nu}$. Decades later, after observation of reactor neutrinos by Cowan and Reines [3], Davis the chemist went deep underground and mined Sun-produced gems, i.e. radioactive $^{37}$Ar converted from $^{37}$Cl by $\nu_e$ produced by the Sun's internal nuclear furnace.

Koshiba's method is more optoelectronic. He also went underground, but rather than tons of "dry-cleaning fluid", he had tons of clear, pure water, watched by many 20 inch photomultiplier tubes (PMTs) that surround the tank. With this setup, he detected the Cherenkov light from electrons streaming through the water, which were themselves scattered off by solar $\nu_e$s through $\nu_e + e^- \to \nu_e + e^-$ scattering. The directional nature of this scattering allows us to "see" the Sun, from underground and "at night", fulfilling the prophetic words "Nothing is hidden from its heat" of David the shepherd. Koshiba's more pioneering discov-

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ery came, however, from further afield: neutrinos from SN1987A, the supernova (SN) explosion in the Great Magellanic Cloud (seen on Earth) on February 24, 1987. Considering that the KamiokaNDE experiment was built — and went underground — for the purpose of searching for proton decay (NDE standing for Nucleon Decay Experiment), the experiment lucked out because this is the closest recorded SN since Galileo's invention of the telescope (hence, the 1604 Kepler's supernova). The electronic nature of detection meant they could record a pulse of 11 neutrino events in the detector, and extra-solar neutrino astronomy was born. The 10–20 MeV neutrino burst was consistent with SN theory, was confirmed by other detectors, and are extra-galactic in origin.

As our minds echo with another prophetic line from the same Psalm of David, "their lines go out through all the Earth", we reflect on the contrast of cosmic neutrinos as probes versus photons and cosmic rays (CR). The chargeless and weakly interacting neutrinos are the most penetrating, travel in straight lines and unaffected by magnetic fields, hence can point back to far away sources, the *cosmic accelerators*. Uncovering such would uncover nonthermal acceleration involving protons [5].

For observing neutrinos on Earth, counting solar and SN neutrinos as "done", and the "atmospheric neutrinos" (neutrinos produced by CR debris produced in the atmosphere) as "nuisance", the next main objective is to detect genuine cosmic neutrinos from very far away sources, and these would have to be extremely energetic, because of the rapid fall-off of the CR flux with energy. Thus, to catch the low flux, current and developing neutrino telescopes are all of "km$^3$" size or beyond. The leading detector is the spectacular IceCube [6] experiment mentioned in Prologue, operating beneath 1.5 km of Antarctic ice, with a full km$^3$ of pristine ice instrumented with more than five thousand 10 inch PMTs. The full detector was completed at end of 2010, and the aforementioned PeV neutrino announcement has turned a new page in neutrino astronomy: the start of genuine neutrino astrophysics.

For the direct pursuit of ultra high energy cosmic rays (UHECR) at and above $10^{18}$ eV energies, the current leading detector is the Auger experiment [7], covering a detection area of $\sim$ 3000 km$^2$. The detector was completed in 2008 and has been taking data since, and one of the main targets is the search for so-called GZK [8] neutrinos, which arise through the "$\Delta$" conversion of UHE ($10^{19}$ eV or above) cosmic protons by interaction with the cosmic microwave background (CMB) radiation,

$$\begin{aligned} p + \gamma_{\rm CMB} &\to \Delta^+ \\ &\to n + \pi^+(\to \nu_\mu \mu^+[\to e^+ \nu_e \bar{\nu}_\mu]) \\ &\to n + e^+ + \nu_e \bar{\nu}_\mu \nu_\mu, \end{aligned} \tag{1}$$

hence necessarily diffuse. But contrasting this UHECR approach with water tanks and fluorescence detectors, with the IceCube approach of water Cherenkov detection of cosmic neutrinos, we are reminded of some gap or window between PeV to EeV ($10^{15}$ eV to $10^{18}$ eV), which lacks a dedicated experiment. It is quite amazing that, with over a dozen years of successful deployment of these humongous detectors, this window remains rather open. The discovery of PeV neutrinos by IceCube suggests a supra-PeV neutrino spectrum, making it imperative to explore this region in earnest.

Astronomical high-energy neutrinos should be produced at the accelerators through charged pion production in collisions with radiation fields or the ambient matter, in reactions such as:

$$\begin{aligned} &p + \gamma \to \Delta^+ \to \pi^0 + p,\ \pi^+ + n; \\ &p + \text{nucleus} \to \pi^{\pm,0} + X. \end{aligned} \tag{2}$$

The discovery of the proton accelerators in the Universe is just revealing the above particle reaction processes around the acceleration sites. The secondary PeV-EeV neutrinos are the direct evidence of the acceleration and must point to the accelerators. The secondary $\gamma$ rays produced from the $\pi^0$ could also indicate the evidence and give direction, but we must distinguish them from $\gamma$ rays generated through the inverse-Compton process. The detection of both particles would be fascinating, as it would explore the accelerators in the Universe in the context of multi-partilce or multi-messenger approach. The photopion ($p\gamma$) reaction is typically the main neutrino generation process, where extragalactic sources like jets and cores of active galactic nuclei (AGN) and $\gamma$-ray burst (GRB) jets have been widely studied. Some sources like starburst galaxies (SBGs) and other candidates in our galaxy may emit neutrino flux mainly through the hadronuclear ($pp$) reaction [9, 10]. For many astronomical objects, ambient photons are expected to be in the UV region. In that case, the kinetic threshold for photopion production through delta resonance is in the range of several PeV.

In this article we emphasize a neutrino detection method that targets this PeV to EeV region with greater sensitivity, and with great pointing accuracy. These capabilities would bring one truly into the neutrino astronomy era, and the technique is based on the so-called Earth-skimming $\nu_\tau$ method.

## 2. Earth-skimming $\nu_\tau$ Method and NuTel

The Earth-skimming (ES) and mountain-pentrating $\nu_\tau$ detection method, and its utility towards cosmic neutrino detection, combine quite a few amazing facts.

- Whenever protons are accelerated, pions are produced (Eq. (2)). The decay chain of charged pions, as illustrated in the second half of Eq. (1), implies that the $\nu_e : \nu_\mu : \nu_\tau$ ratio is 1 : 2 : 0 at production. However, one astonishing fact we learned through precise measurements of atmospheric neutrinos is that $\nu_\mu$ oscillates into $\nu_\tau$ with near maximal mixing [11], implying that this ratio turns into 1 : 1 : 1 at cosmic distances. Cosmic hadron acceleration implies $\nu_\tau$ flux.
- Reactor and solar neutrinos are ghostly [4], but as neutrino cross section grows with energy, very high energy (VHE) $\nu_\tau$s can convert in the Earth or a mountain, and the produced $\tau$ maintains direction and traverses with minimal interaction, and upon emerging it would then decay and shower (except for $\tau \to \mu\bar{\nu}_\mu\nu_\tau$ mode) in the atmosphere. In contrast, for $\nu_e$, the electron shower is absorbed in mountain/Earth, while the converted muon from $\nu_\mu$ does not shower. Thus, this Earth-skimming $\nu_\tau$ shower technique is unique to the $\tau$ neutrino.
- A UV telescope placed on a mountain several 10 km downstream can catch the Cherenkov pulse from the $\tau$ shower (hence the name "NuTel").
- Further advantages of the method are: mountain/Earth as shield of cosmic ray secondaries, precise arrival direction determination, and negligible atmospheric neutrino background.

The magic works for two large mountains separated by a $\sim$ 10 km or wider valley (see Fig. 1). These points were raised around 2000 [12] (see also Refs. [13] and [14]), but brought to our attention by François Vannucci [15] in 2001, and through which (for a more personal discussion, see Ref. [16]) we realized the excellent site of Hawaii Big Island: two big mountains (Mauna Loa and Mauna Kea, each above 4000 m) separated by $\sim$ 40 km! On top of that, these are well known sites for astronomy, making it perfect for placing the UV telescope up 2000 m or higher. The third highest peak, Mount Hualalai at 2521 m offers a third site [14].

The NuTel project [14, 17] was launched in early 2000s, with the aim of observing Cherenkov radiation from $\nu_\tau$-originated air showers. The original goal was to place a telescope up Mauna Loa (or Hualalai) to watch Mauna Kea (or Mauna Loa). There are three stages for the simulation:

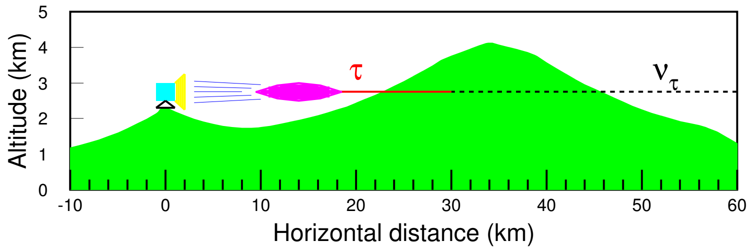


Fig. 1. Illustration of $\nu_\tau \to \tau$ conversion inside a mountain and the detection technique. The projection is a slice through Hualalai and Mauna Loa of Hawaii Big Island.

(1) Mountain: $\nu_\tau \to \tau$ conversion cross section, inelasticity, energy loss;

(2) Shower: $\tau$ decay modes, detailed vs fast simulation;

(3) Detector Performance: light propagation and quantum efficiency, trigger, reconstruction.

For reconstruction, it was deemed necessary to place two telescopes $\sim$ 100 m apart for stereo view, and utilizing a cluster-based trigger algorithm. It was found that angular error would be $< 1^\circ$, shower energy resolution was decent, and reconstruction efficiency was good when triggered.

The MAPMT-based readout electronics and DAQ system was developed and built within a year, but the bottleneck was optics. A EUSO-like Fresnel lens was found impractical, and discussions went on to adopt the optical system from Ashra, where Sasaki *et. al* also proposed [18] the Earth-skimming $\nu_\tau$ method with a fluorescence telescope array. This became inherited as the basic technique of Ashra-1 and Neutrino Telescope Array, as discussed in next sections. In any case, while NuTel is the first experiment dedicated to Earth-skimming $\tau$ appearance, it did not reach physics running, the Achilles heel being the event rate estimated at 0.5 event/year. Because of this, the proposal was rejected in Spring 2004, and could not be restored even after several tries. The optics was developed further, however, and eventually two 1.8 m Schmidt mirror systems were built. The first one went up Mei-Fong at 2100 m in Taiwan, Summer 2009, to watch 3000 m peaks at night. But due to the difficulty of mountain operation and funding, the NuTel project was effectively terminated in 2010.

## 3. Ashra-1 and 1$^{\text{st}}$ Search for GRB $\nu_\tau$

As we shall describe, Ashra-1 succeeded in demonstrating the Earth-skimming $\nu_\tau$ method.

The All-sky Survey High Resolution Air-shower detector [19] Phase I, or Ashra-1 (see Fig. 2), was developed slightly earlier but in a similar time frame as NuTel, with the ambitious aim of "multi-messenger astronomy" [20, 21], i.e. optimized for the detection of VHE particles. Let us recall the development of optical air shower detectors. In the early 1990s, detectors such as Fly's Eye had 4° per PMT with all-sky coverage. By the late 1990s to the 2000s, HiRes had 1° per PMT with 28° coverage per telescope. In contrast, based on the developments of imaging tube plus CMOS camera, Ashra-1 has 1.2 arcmin. per pixel but all-sky coverage.

Starting from an optical system with 42° field-of-view (FOV), the Ashra-1 Light Collector (LC, see Fig. 3) has total resolution of $\sim$ 3 arcmin., and can cover Mauna Kea surface at 35 km distance from Mauna Loa. Combined with a high resolution imaging system with trigger,

Fig. 2. The Ashra-1 main and sub stations at the Mauna Loa site.

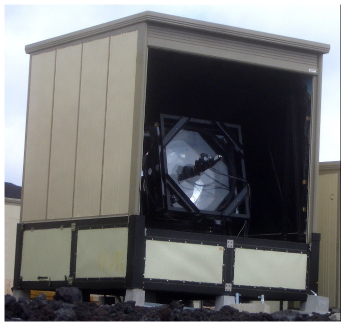

Fig. 3. An Ashra-1 light collector towards Mauna Kea.

very cost-effective pixels compared with conventional PMT arrays are achieved. With each of its 12 Detector Units (DU) consisting of several aligned LCs, Ashra-1 can observe the entire sky with arcminute resolution.

Ashra-1 takes a multi-messenger approach with one detector system. The key technical feature is the use of electrostatic rather than optical lenses to generate convergent beams (the 20 inch Photoelectric Lens Image, or PLI tube [22], the world's largest image intensifier), demagnifying to 1 inch at focal surface, enabling high resolution over a wide FOV. The electron optics of photoelectric lens imaging links wide angle precision optics [23], with improved quantum efficiency and precision, to the image pipeline [24]. The Photoelectric Image Pipeline (PIP) splits the focal image into trigger/image capture devices after amplification, sending the same fine image to multiple triggers. This allows the simultaneous measurement of three phenomena on different time scales, i.e. Cherenkov emission (ns), fluorescence ($\mu$s), and starlight (s), without sacrificing the S/N ratio.

The demonstration phase has been running since 2008 at the Mauna Loa Observation Site (ML-OS) at 3300 m above sea level on Hawaii Big Island, with 77% mono and 27% stereo. With alert for GRB081203A given by SWIFT satellite, Ashra-1 succeeded in the first search for PeV-EeV $\nu_\tau$s originating from a GRB [25] with the Earth-skimming $\nu_\tau$ technique using one LC, setting stringent limits. Moreover, Ashra-1 has achieved the best-yet instantaneous sensitivity in the 100 PeV energy region subsequent to a January 2012 trigger upgrade.

Ashra-1 will return its attention to more technical demonstration and the multi-messenger exploration of the PeV–EeV Universe, as well as the principal demonstration of neutrino detection with the wide angle optical air-shower detector array. The observation of PeV astronomical neutrinos by IceCube certainly provides a new impetus. So let us now unfold the NTA project, Neutrino Telescope Array, which joins the concept of NuTel with the technological development of Ashra-1.

## 4. Neutrino Telescope Array (NTA): Detector and Performance

Based on Ashra-1 performance, we aim at forming a new collaboration, Neutrino Telescope Array (NTA) an air shower imaging neutrino detector for

Aim/Scientific Goal :

Clear Discovery and Identification of Nonthermal Hadronic Processes in the Universe, be it Galactic, Extragalatic, or Cosmogenic.

A Letter of Intent (LOI) is at hand [26], which is still being improved.

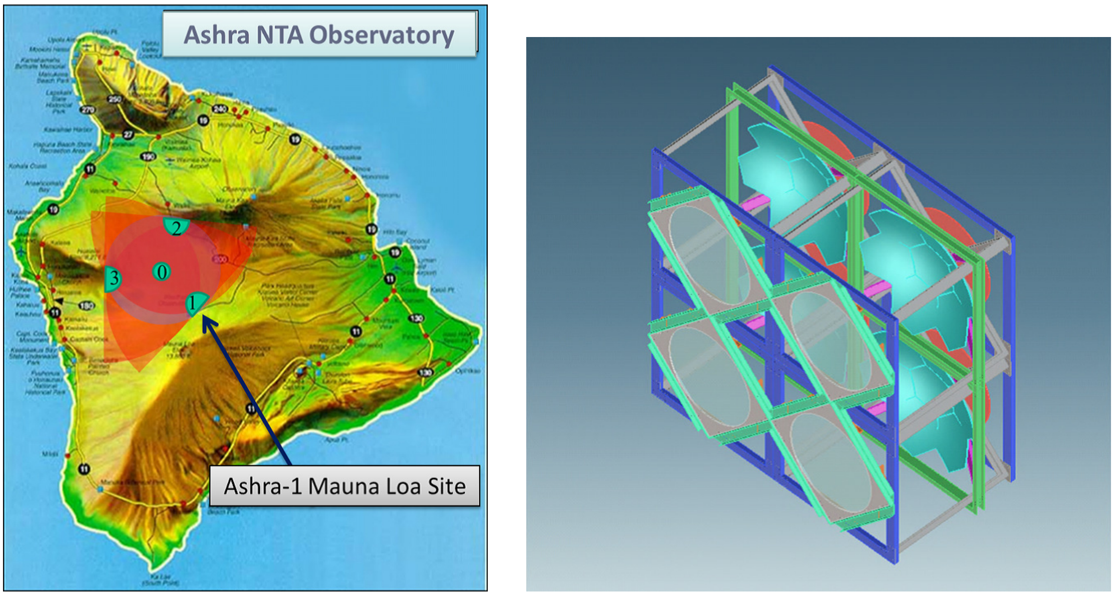


Fig. 4. (left) NTA observatory layout on Hawaii Big Island, where overlay of semi-circles illustrate view from Site1–3; (right) Detector Unit of four same Light Collectors.

As stated in Prologue and Introduction, stimulation has come from the IceCube experiment, which has recently reported [1, 2] the "first indication of an astrophysical neutrino flux". They observe three fully contained $\nu$-induced particle showers with deposited energy $\sim$ 1–2 PeV, which provides great motivation for exploring the PeV-EeV region.

— *What if one had better Sensitivity and accurate Pointing?* —

With better than 0.2° pointing accuracy, NTA would be able to discern the origins of such events.

Site Plan and Size

As shown in Fig. 4 (left), the planned NTA observatory consists of four sites: Site0–Site3, where the x-y-z coordinates and corresponding FOV coverage are given in Table I. Site1–Site3 are the vertices of an equilateral triangle with sides of 25 km, and observe the total air mass surrounded by Mauna Kea, Mauna Loa, and Hualalai; the central Site0 can potentially have full-sky coverage.

VHE $\nu_\tau$s can convert in Earth/mountain, reappear as $\tau$s and produce air showers upon decay in the atmosphere, and the Cherenkov photons are detected [12–14]. By separating $\nu_\tau \to \tau$ conversion from subsequent air shower generation, detection is possible while preserving the huge target mass required for the initial interaction. Currently, Ashra-1 operates on Site1, or ML-OS, with view of Mauna Kea, which is a huge mountain equivalent to $10^4$ km$^3$ of ice for converting $\nu_\tau$ to $\tau$, but it also serves as a shield to CR background. The distance between Mauna Kea and Loa allows a 30 km range for shower development. Ashra-1 has demonstrated [25] the ES-$\nu_\tau$ technique with this configuration, but NTA would augment it with the fluorescence [18] ability of Site0, plus two other mountain sites. The huge target mass ($>$ 100 km$^3$), huge atmospheric mass (shower volume, with area $>$ 1000 km$^2$) and mountain as background shield imply a rather large footprint for NTA, and conceptually quite different from IceCube and Auger. The footprint calls for a new International Collaboration.

Each site has a group of DUs, each of which has 4 LCs (Fig. 4 (right)) instrumented with se-

Table I. The x-y-z coordinates and FOV coverage of the NTA sites used in the simulation, where the z-axis points to zenith and y-axis points north, and z-coordinates are from topography data. Site1–Site3 form an equilateral triangle, with Site0 at the geometric center and defined as the origin. Site1 is located at ML-OS (on Mauna Loa) and Site2 at 25 km distance from ML-OS in the direction of the Kilohana Girl Scout Camp.

| Site ID | Location | X [km] | Y [km] | Z [km] | FOV [sr] |
|---|---|---|---|---|---|
| Site0 | Center | 0.000 | 0.00 | 2.03 | $\pi$ |
| Site1 | Mauna Loa | 9.91 | $-10.47$ | 3.29 | $\pi/2$ |
| Site2 | Mauna Kea | 4.12 | 13.82 | 1.70 | $\pi/2$ |
| Site3 | Hualalai | $-14.02$ | $-3.35$ | 1.54 | $\pi/2$ |

gmented mirrors. The NTA LC concept is scaled up from Ashra-1 by 1.5, but uses the same trigger and readout. The LCs use Schmidt optics, with pupil of 1.5m, and FOV of 32° means 50 cm at focal sphere. 4 LCs with same FOV and superimposed images give a DU with effective pupil size of 3m. 12 DUs are needed per $\pi$ solid angle coverage. Thus, from Table I, at least 30 DUs are needed. The construction, deployment and operation of these DUs spread out at four distant sites further defines the need for NTA to be an International Collaboration.

Pointing Accuracy

Pointing accuracy is a main strength of NTA, both because of high pixelization, and because of the ES-$\nu_\tau$ method. NTA performance studies are based on Ashra-1 experience, where some details can be found in the LOI [26]. Detailed detector design studies are currently underway.

We estimate our ability to trace showers back to their origins, which is a very important feature in light of the IceCube events. The simulation steps are very similar to Sec. 2, except that one now also has the fluorescence capability of Site0. One has better light propagation and quantum efficiencies, but the highlight is the much higher pixelization development of the Ashra-1 detector.

First, we use PYTHIA to model neutrino interactions. The $\tau$ with respect to the parent $\nu_\tau$ angle, $\Delta\theta_\tau$, is less than 0.3 arcmin. for $E_\tau > 1$ PeV. The NTA detector design is optimized for this.

Second, we use GEANT4 to evaluate the deflection of $\tau$ as it propagates within the Earth, adopting the parametrization of [27] to estimate energy loss, where radiative energy loss is dominant. Bremsstrahlung, $e^+e^-$ pair production, and photonuclear interactions are all included. To validate the simulation, we compared the energy dependence of $\beta$ particle bremsstrahlung, pair production, and photonuclear interaction to results of Ref. [27]. The $\beta$ energy dependence agreed well for the first two processes, but we found that GEANT4 produced smaller values for photonuclear interactions at higher energies and the ratio of values approached a factor of three at $10^8$ GeV. Investigating further, we wrote a toy Monte Carlo simulation for photonuclear interactions in which the energy dependence of the $\beta$s was reproduced to within $\pm 30\%$ accuracy.

Next, to estimate the deflection due to $\tau$ decay, we use TAUOLA and take account of $\tau$ polarization. The deflection angle is less than 1 arcmin. if the energy of the secondary particle is higher than 13 TeV. TAUOLA showed that the probability of a deflection greater than 1 arcmin. for $\tau$s with PeV energy is very small. We adopt this assumption throughout our air-shower analysis.

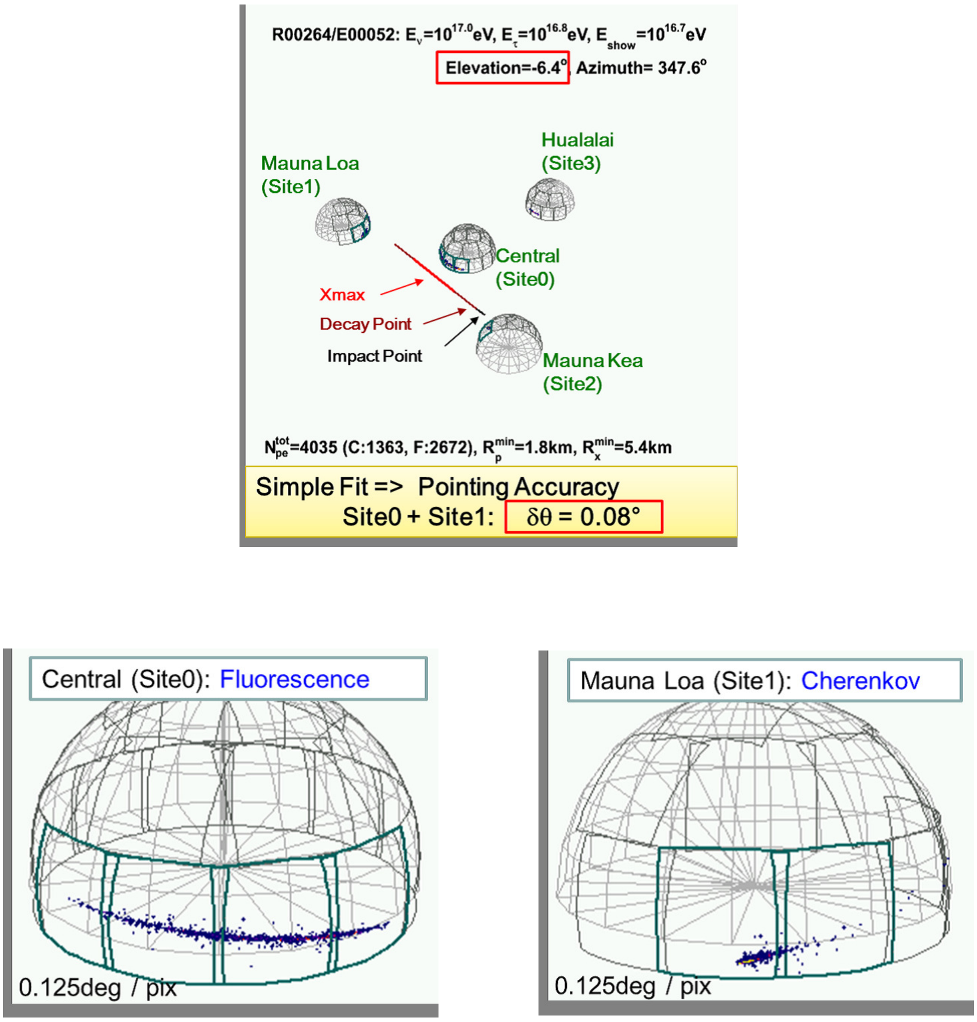


Fig. 5. A simulated $\tau$ shower event generated by an Earth-skimming $\nu_\tau$ carrying primary $E_{\nu_\tau} = 10^{17}$ eV: (top) Global hit map view in the NTA system; (bottom left) fluorescence image of air shower taken by Site0, and (bottom right) Cherenkov image from the same event taken by Site1. The trigger pixel and fine image FOVs are $0.5^\circ \times 0.5^\circ$ and $0.125^\circ \times 0.125^\circ$, respectively.

Finally, the hadron air-shower direction is evaluated using CORSIKA. We compare the direction of the parent particle (charged pion) at shower max to that of $e^\pm$, the dominant producers of Cherenkov photons. The angle between the average direction of $e^\pm$ and the parent particle is found to be within $0.1^\circ$ at 1 PeV. The energy resolution is found, by MC simulation, to be several 10%.

We conclude that the arrival direction of PeV-scale $\nu_\tau$s is within $0.1^\circ$ of the original direction of the generated hadron air-shower. The accurate reconstruction of arrival direction by means of fine imaging will be a very powerful technique in the determination of point sources of PeV $\nu_\tau$s.

## Performance and Sensitivity

To simulate the performance of the NTA detector, we assume each DU has $32^\circ \times 32^\circ$ total FOV, $0.5^\circ \times 0.5^\circ$ for trigger pixel FOV, and $0.125^\circ \times 0.125^\circ$ image sensor pixel FOV. According to Table I, the Site0 system consist of 12 DUs, which covers the solid angle of $\pi$ sr in the lower elevation angle regions (can be extended to full-sky coverage). The remaining sites have

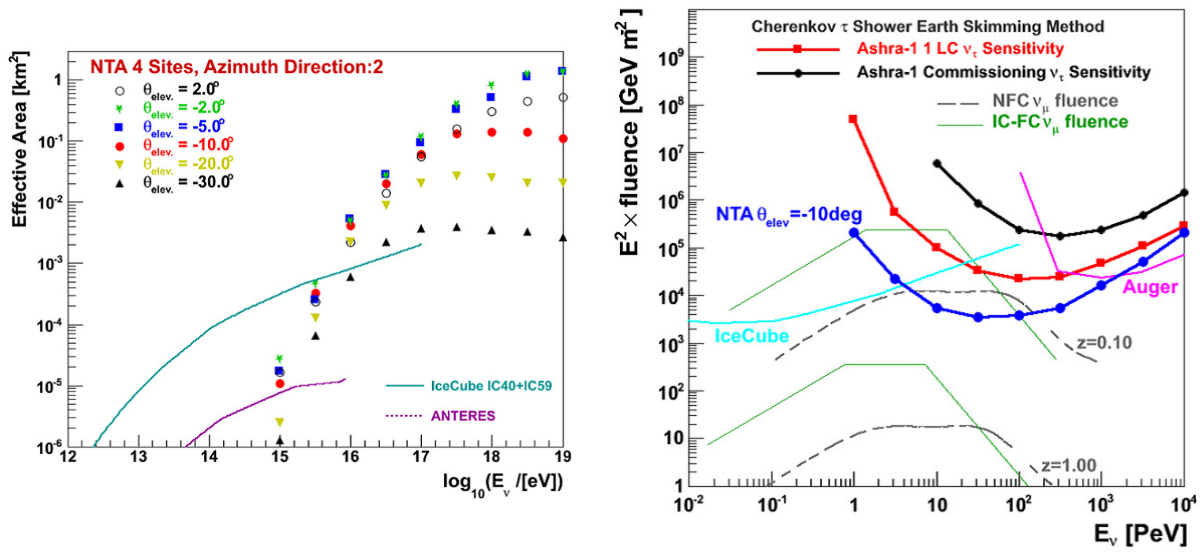


Fig. 6. (left) Estimated effective detection area for $\nu_\tau$ from a point source with azimuthal arrival direction corresponding to Mauna Loa ($\phi_2$) with respect to the central Site0, and dip angles 2.0° (black open circle), $-2.0°$ (green star), $-5.0°$ (blue filled box), $-10.0°$ (red filled circle), $-20.0°$ (yellow filled triangle), and $-30.0°$ (black filled triangle); (right) Differential sensitivities calculated as Feldman-Cousins 90% CL limit for various LC designs and $\theta_{\rm elev} = -10°$, in comparison with (earlier) published sensitivities of IceCube and Auger, together with theoretical models (dashed lines for Ref. [33]).

only 6 DUs in the lower elevation angle region covering $\pi/2$ sr. The bottom edge of the lower elevation angle region is defined to be $-9°$ (below the horizon).

In our simulation program, we take density profile of the Earth, use the $\nu_\tau$ distribution from CTEQ4 [28], inelasticity parameter from [29], and parameterize energy loss in Earth by [27, 30]. We use $\tau$ decay from TAUOLA and air-shower generation of Gaisser-Hillas + NKG [18]. We use a constant average $\nu_\tau$ energy fraction of 40% (lab frame) from $\tau$ decays, without taking into account the energy distribution. The error from this approximation is found to be negligible. For detector simulation, we incorporate light collection and throughput with simplified trigger logic. Event reconstruction is not yet implemented. All candidate events must satisfy the trigger conditions:

(1) number of detected photoelectrons per LC $> 61$;

(2) $S/N$ estimated in track-associated $4 \times 64$ pixel box (air-shower track included) $>$ 4 [31].

A simulated event with primary $\nu_\tau$ energy $E_{\nu_\tau} = 10^{17}$eV, elevation angle $-6.4°$ exiting from Mauna Kea and arrival direction towards Mauna Loa, consistent with the above conditions, is shown in Fig. 5. A combined simple fit to Site0 + Site1 gives an error for $\nu_\tau$ arrival direction reconstruction at 0.08°. Our estimates for effective detection area for $\nu_\tau$ from a point source is illustrated for Mauna Loa site for various dip angles on left side of Fig. 6, with similar result for Hualalai site. The effective detection area turns on sharply above PeV.

The IceCube PeV neutrino events clearly call for higher sensitivity searches with more accurate pointing ability. In particular, the PeV to EeV window should be *measured*. NTA fits the bill. Note that IceCube events do not [32] preclude the possibility of additional supra-PeV

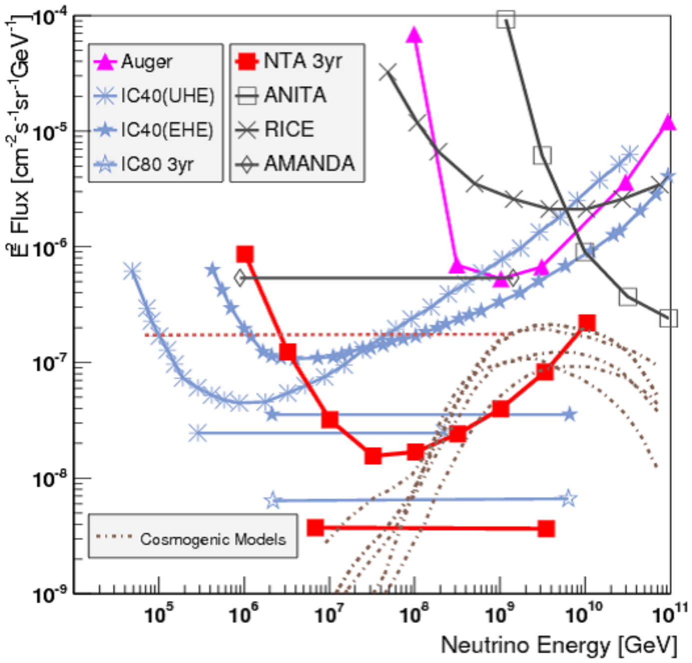


Fig. 7. Diffuse sensitivity of NTA with 3 year observation (maroon squares), together with cosmogenic neutrino flux models and related efforts.

sources. We show on right side of Fig. 6 the differential sensitivity for NTA, compared side by side with IceCube and Auger capabilities (for illustration only). The solid theoretical fluence curve is ruled out by IceCube, but subsequent models for GRB neutrino flux, e.g. Ref. [33], can be probed by NTA. Given the PeV neuntrino events observed by IceCube, this search is now mandatory.

The power of NTA is to survey $\nu_\tau$ point source objects with the best-yet sensitivity in the detection solid angle for $\nu_\tau$ defined as $-30^\circ < \theta_{\rm elev} < 0^\circ$ and $0^\circ < \phi_{\rm azi} < 360^\circ$, and for 10 PeV $< E_{\nu_\tau} <$ 1 EeV. Fig. 6 (right) shows that the NTA survey depth can reach $z \lesssim 0.15$, of order 2 billion lightyears. The location of NTA on Hawaii Big Island allows us to survey the Galactic Center (GC) for more than several hundred hours each year, assuming the standard 10–20% duty cycle.

NTA sensitivity for diffuse $\nu_\tau$ flux (maroon squares) for 3 year ($\sim 9.5\times10^6$ s) observation is given in Fig. 7, assuming duty cycle of 10% and trigger conditions as above. We refer further discussion on angular resolution and background simulation to the LOI [26].

As can be seen from Fig. 6 (right) and Fig. 7, although the Auger and IceCube results shown may not be the latest, their trend is indicated. Auger has studied its capabilities with UHE-$\nu$s. Because of the already fixed Auger detector configuration, its best sensitivity is around $10^{18}$ eV [34], complementary to that of IceCube around $10^{15}$ eV. But, the fact that IceCube sees several astro-$\nu$s at PeV energy, one expects a spectrum to be probed between IceCube and Auger sensitivities. This is precisely where NTA fits in, with great pointing accuracy to pick out point sources within 2 Glyrs. After all, the real target is not the diffuse source, such as GZK-$\nu$s (though partially probed, see Fig. 7), but nearby astrophysical Point Sources. Direct observation of such sources with the ES-$\nu_\tau$ technique would reveal the existence of hadron acceleration mechanisms, and open a new chapter in CR and neutrino astrophysics.

## 5. Organization: Forming a New Collaboration

The IceCube Collaboration operating at the South Pole consists of $\sim 250$ people, and 39 instiutions from 11 countries. The corresponding numbers for the Auger Collaboration, operating on the Pampas in Argentina, are $\sim 500$ people from 18 countries. We have estimated that a minimum of 30 Detector Units (DUs) are needed for the coverage given in Table I for NTA, distributed over four mountain sites on Hawaii Island, assuming the DU FOV to be $32° \times 32°$. Each DU would require four Light Collectors (LCs), one trigger and readout unit. The estimated cost per DU, based on Ashra-1 experience, is $\sim$100M yen. Allowing for some infrastructure and site preparation, but not running and maintenance costs, a crude cost estimate is 5000M yen for the construction of NTA. We estimate therefore, given the size and challenge of the project, that NTA eventually would be a Collaboration consisting of up to 10 countries. But how would this Collaboration form?

As we design the NTA instruments and explore site options, collaboration organization has started, although one is still in the chicken & egg phase: one probably would need a major funding contribution at more than 50% total cost to start attracting international collaborators, and only then (when some manpower has materialized) would one be able to seriously devise a schedule towards the scientific goal. Currently, we have a small International Executive Board (IEB) of national representatives from Japan, Taiwan and U.S., with national affairs handled domestically. Initial meetings started since late 2012, but other groups are invited to join. The time frame for the proposed project will be determined both by budgetary and scientific considerations. 2015 would be the pivotal year to not only discuss the design and plans of the project, but also major decisions on hardware implementation towards the Project Proposal. Funding efforts would likely take 2 more years. If Japanese core funding is received in time, we hope to start experimental operations using at least part of Site0 and Site1 by 2018. Ashra-1 would continue to run for both testing and scientific purposes. The expected construction time for full NTA would be of order 5 years.

## 6. Conclusion

The "cosmogenic" neutrino flux arising from Eq. (1), which one can see in Fig. 7, are the famed GZK neutrinos. There is an ongoing list of experiments aiming for this "grail": ANITA, ARA, ARIANNA, etc. There were some worries in the "CR Composition" issue raised by Auger [35], suggesting that the CR composition moves away from protons towards iron, starting around $10^{18.6}$ eV. This would deplete the expected GZK flux. Altough the issue remains [36], it is also more complex [37].

With the GZK neutrino in backdrop, we assert that the scientific goal of

"*Clear Discovery and Identification of Nonthermal Hadronic Processes in the Universe, be it Galactic, Extragalatic, or Cosmogenic.*"

is reachable, and in view of the IceCube PeV astro-$\nu$ events, it has become mandatory. A Collaboration, the NTA, is needed to achieve this. Our current situation can be succinctly summarized by the famous words from the Three Kingdoms period (reading much better in Chinese, or kanji):

"*Every Thing is Ready,*
*Except the Easterly Wind.*"

The Easterly Wind of yens. Or could it be in a different currency?

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