Neutrino Telescope Array (NTA)

Towards Survey of Astro $\nu_\tau$ Sources

July 25 KEK Seminar
What if one had better Sensitivity and accurate Pointing Info?
Neutrino Telescope Array

NTA

Ashra-1 + NuTel

Aim/Scientific Goal

Clear Discovery and Identification of Nonthermal Hadronc Processes in the Universe, be it Galactic, Extragalactic, or Cosmogenic.
Neutrino Telescope Array

NTA

I. Intro: Earth-skimming $\nu_\tau$ Method

II. “My” NuTel Effort

III. Ashra-1: 1st Search for GRB $\nu_\tau$

IV. NTA: a New Collaboration
   * Plan & “Size”  * Performance  * Organization
   * Comparison: Auger/IceCube; GZK Quest

V. Conclusion: Call for Collaboration!!
Window of Opportunity

Conventional $\nu$ Detector

? Still Survives

UHECR $\nu$ Detector

Cline, Stecker, astro-ph/0003459

a plot I first used ~ 2002
Detection Mechanism

Earth-Skimming $\nu_\tau$ Method

$\tau$ Appearance!

Cross Section
$\sim E^{1.4}$

$\tau$ Decay: Air Shower
$\rightarrow$ ns Cherenkov

$\nu_e$: electron energy mostly absorbed in mountain
$\nu_\mu$: no extensive air shower
What I learned 8/2001

Vannucci Visit to NTU

- Earth Center Opaque for $E > 10^{14}$ eV $\nu$ !?
- Mountain-Valley $\nu_\tau$ Detection Concept

I asked whether he already had funding ...

after - checking literature (e.g. Fargion)
- passing it thru NTUHEP PIs

I hired Alfred Huang in Fall (start simulations)
(had to convince him ...)

Hawaii Site also came out from Vannucci visit ...

from Colloquium 3/2004 @ KIAS
Hawaii Big Island as Site: happened as *gotcha*

- Courtesy visit to CosPA-1 [Fred Lo]
  - Hawaii is known good Astro Site
  - Stood together in front of Hawaii map
  - *Snap:* Big Mountains w/ 40 km sep.

Mt. Hualalai: M. Alfred Huang

Good view of Mauna Loa
Situated at dryer west side
Mauna Loa provide long base line
~ 90 km wide and 4 km high

GWS Hou & MA Huang, astro-ph/0204145
P Yeh et al., MPLA 19 (2004) 1117  [CosPA 2003 WS]

from Colloquium 3/2004 @ KIAS
Three simulation stages

1. Mountain simulation: $\nu_\tau \rightarrow \tau$
   - $\nu$ + N cross-section
   - inelasticity
   - energy loss of tau

2. Air shower simulation:
   $\tau \rightarrow$ Cherenkov photons
   - $\tau$ decay mode
   - CORSIKA detailed air shower simulation vs. fast simulation

3. Detector performance simulation
   - light propagation + Q.E.
   - pixelization for triggers
   - reconstruction
Preliminary Reconstruction

- Reconstruction: Minimize $\chi^2$ for $x,y,\theta,\phi$, and $E$

  - Two Detectors Separated by $\sim 100$ m (“stereo”)
Possibility for Reconstruction

- Angular Error within 1°
- Energy Error ~ 40%
- Reconstruction Efficiency > 90% if triggered
NuTel electronics (2002-2003)

Signal-sharing plate
Hamamatsu 8x8 MPMT

PMT → Preamp. → FADC

16-channels preamplifier

10 bit x 40 MHz ADC

Trigger daisy chain

Trigger → cycle RAM → buffer RAM → DAQ

Front-end electronics
Inside cPCI (PXI) chassis

16 DCM boards (512 channels) inside PXI chassis

MAPMT

NTA — Astro $\nu_\tau$
George W.S. Hou (NTU)
Fresnel lens system not good enough

- The spot all isn’t small, ~ 5mm. This is Chromatic issue. Spot with multi-wavelength is 2~3 times spot with single wavelength.
- The main way to lower the chromatic aberration is to use different material. However there are very few UV transparent material.
- Cytop is the best to eliminate dispersion (high Abbe no.), also high T(%) its spot size ~3mm, but it is expensive and lens will become fatter due to low index.

<table>
<thead>
<tr>
<th></th>
<th>Cytop</th>
<th>PMMA</th>
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<tr>
<td>Refraction index</td>
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<td>1.49</td>
</tr>
<tr>
<td>Abbe’s number</td>
<td>90</td>
<td>55</td>
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</table>

To sum up, all spot size are less than the channel size of MAPMTs, it meets the threshold but not good enough. Any possible errors can make spots larger. So we changed to other design.
Proposal for CosPA-1 Renewal (4 yr) filed 9/2013

1/2004 up Mauna Loa

George W.S. Hou (NTU)
**NuTel**

- NuTel is the first experiment *dedicated* to earth skimming for $\tau$ appearance
- PeV cosmic $\nu_\tau$ rate is $\sim 0.5$ event/year

- First set of two telescopes ready
- VHECR observation in Taiwan: prototype deployment in 2009 indicates high light background at Mei-Fong

- But it got cut out in CosPA II in Spring 2004 ... and we could not restore it, after several tries ... so I continued it on a shoestring ...
Aspherical Corrector Lens mainly eliminate spherical aberration.

Help from KEK

Schmidt Mirror System

D: 1.6 m, finally we made 1.8 m

Curved image surface

### Schmidt Mirror System Parameters

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<th>Surface #</th>
<th>Surface Name</th>
<th>Surface Type</th>
<th>Y Radius</th>
<th>Thickness</th>
<th>Glass</th>
<th>Refract Mode</th>
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<td>Infinity</td>
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#### Conic const (k) and Polynomials

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<th>-2.904e-017</th>
<th>-2.607e-023</th>
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1/26/2010
NuTel went on a shoestring budget since 2004...
Mountain line of Chi-Lai

F.O.V.
Set-up of Observational Tent
Image around the focal plane
Waiting for sunrise before leaving
NuTel

- NuTel is the first experiment dedicated to earth skimming for $\tau$ appearance
- PeV cosmic $\nu_\tau$ rate is $\sim 0.5 \text{ event/year}$
- First set of two telescopes ready
- VHECR observation in Taiwan: prototype deployment in 2009 indicates high light background at Mei-Fong
- We learned challenge of mountain operation
  $\Rightarrow$ Tried pair up with CRTNT (曹臻) ... they evolved ...
- Synergy w/ Ashra-1 (reconnect 9/2012) $\Rightarrow$ (Ashra) NTA
• Ashra-1 succeeded in demonstrating power of **Earth-Skimming $\nu_\tau$ Method**

(Courtesy Makoto Sasaki)
Optical Air-shower Detector

Progress of Resolution $\times$ FOV

Fly’s Eye (1981-1993)

HiRes (1994-2006)

Ashra-1

Virgo Cluster
4deg $\times$ 4deg

2m$^2$ mirror
256ch PMT

Image Tube + CMOS

4deg/pix $\times$ All-sky
P M T

1deg/pix $\times$ 28deg
P M T

1.2min/pix $\times$ All-sky

NTA — Astro $\nu_{\tau}$

George W.S. Hou (NTU)

7/25 @ KEK 26
Ashra-1 Pipeline Trigger & Readout

Same Fine Image to Multiple Triggers

Optical 4s
BG 200ns
CR 200ns

Photoelectric Image Pipeline (PIP)

Multi-Messenger Approach with One Detector System

1st imaging air-shower with self-triggered I.I.
20” Photoelectric Lens Imaging Tube (PLI)

**Large:** World largest I.I.

**Fine:** FWHM = 40-60μm @output window

**Stable:** No performance degradation for 3.5 years

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Input Diameter φ500mm

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Output Diameter φ25mm

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Y. Asaoka, M. Sasaki, NIMA 647 (2011) 34

**Performance of a 20-in. photoelectric lens image intensifier tube**

Voichi Asaoka*, Makoto Sasaki

Institute of Cosmic Ray Research, University of Tokyo, Kashiwa, Chiba 277-8582, Japan

**Article Info**

Article history:

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Available online 20 May 2011

Keywords:

Detection

Monte Carlo simulation

Electromagnetic calorimeter

β decay experiment

**Abstract**

We have evaluated a 20-in. photoelectric lens image intensifier tube (PLI) to be used on the spherical focal surface of the Aosta light collector, where Aosta stands for All-day Sensory High Resolution Neutron Detector, an uncommonly optimal collective sampling that images an shower produced by very high energy cosmic ray particles in a 42°-diameter field of view with a resolution of 50% accuracy. The PLI is ideally useful in image intensifier, due to the great effective photoelectric area of 20 in. diameter and reduced an image size to less than 1 in. diameter using the electric lens effect. This enables us to use a solid-state image to take focal surface images in the Aosta light collector. Thus, PLI is a key technology for the Aosta experiment to measure a much lower shower cost in comparison with other experiments using photomultiplier arrays at the focal surface. In this paper, we present the design and performance of the 20-in. PLI.

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Improving QE and Precision
Ashra-1

**PIP & PLI Installation @ Mauna Loa**

*Fine Imager for AS*

*Fine Imager for Optical Flash*

Test of PIP

Installation of PLIs

20-in Photoelectric Lens Image Intensifier (PLI)

[Y. Asaoka & M. Sasaki, NIM, A647 (2011) 34]
Segment Mirror Installation @ Mauna Loa

Mount Seg. Mirrors

Spot Size RML 0.19 mm
Corresponds to 0.46 arcmin after adjusting all segments

All Light Collector Optical System on ML Ready

Al+Al$_2$O$_3$-coat: UV enhanced

Reflection > 85%
Ashra Observational Site: Mauna Loa

3300 m a.s.l., 35 km from MK
77% mono, 27% stereo
2~3 arcmin image

Nice Coverage and Precision as Particle Monitor
Ashra-1: 1\textsuperscript{st} Search for GRB $\nu_\tau$

GRB081209A

Swift GRB Alert during Commissioning

First Check for PeV-EeV Tau Neutrino from a GRB

OBSERVATIONAL SEARCH FOR PeV–EeV TAU NEUTRINO FROM GRB081203A

Y. Aita¹, T. Aoki¹, Y. Asaoka¹, T. Chonan¹, M. Jobashi¹, M. Masuda¹, Y. Morimoto¹, K. Noda¹, M. Sasaki¹, J. Asoh², N. Ishikawa², S. Ogawa², J. G. Learned³, S. Matsuno³, S. Olsen³, P.-M. Binder⁴, J. Hamilton⁴, N. Sugiyama⁵, and Y. Watanabe⁶

(Ashra-1 Collaboration)

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² Department of Physics, Toho University, Funabashi, Chiba 274-8510, Japan
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⁴ Department of Physics and Astronomy, University of Hawaii at Hilo, Hilo, HI 96720-4091, USA
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Received 2011 April 29; accepted 2011 June 10; published 2011 June 28

ABSTRACT

We report the first observational search for tau neutrinos (ντ) from gamma-ray bursts (GRBs) using one of the Ashra light collectors. The Earth-skimming ντ technique of imaging Cherenkov τ showers was applied as a detection method. We set stringent upper limits on the ντ fluence in PeV–EeV region for 3780 s (between 2.83 and 1.78 hr before) and another 3780 s (between 21.2 and 22.2 hr after) surrounding GRB081203A triggered by the Swift satellite. This first search for PeV–EeV ντ complements other experiments in energy range and methodology, and suggests the prologue of “multi-particle astronomy” with a precise determination of time and location.
The Clear Discovery and Identification of Non-thermal Hadronic Process in the Universe

Air Shower Imaging Detector for Neutrinos

**Neutrino Telescope Array Letter of Intent:**

A Large Array of High Resolution Imaging Atmospheric Cherenkov and Fluorescence Detectors for Survey of Air Showers from Cosmic Tau Neutrinos in the PeV-EeV Energy Range

Makoto Sasaki\(^1\), George Wei-Shu Hou\(^2\)

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VHEPA 2014: Start forming collab.  →  VHEPA 2015: Design & Proposal
Table 1. Coordinates and FOV coverage of the Ashra NTA sites.

<table>
<thead>
<tr>
<th>Site ID</th>
<th>Location</th>
<th>X [km]</th>
<th>Y [km]</th>
<th>Z [km]</th>
<th>FOV [sr]</th>
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<tbody>
<tr>
<td>Site0</td>
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<td>0.000</td>
<td>0.00</td>
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<td>13.82</td>
<td>1.70</td>
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</tr>
</tbody>
</table>
- Huge **Target** Mass
  (> 100 km$^3$-weq)
- Huge **Atmos.** Mass
  (area > 1000 km$^2$)
- Mountains Shield BG

**Need Collaboration**
NTA Light Collector (LC)

Light Collector (LC)
Schmidt Optics with $\phi 1.5m$ pupil
FOV $28^\circ = \text{focal sphere } \phi 50cm$

Detector Unit (DU)
4 LCs watching same FOV
Superimposed 4 images
⇒ Effective pupil size = $\phi 3m$

⇒ Concept:
Ashra-1 x 1.5 scaled-up + same trigger & readout

12 DU's per $\pi$ coverage

Need at least 30 DU's for Coverage

Need Collaboration
Earth-skimming \( \tau \) Shower Imaging Method

- **Mauna Loa**
  - NTA Site1 (Ashra-1 ML)
  - Fluor. Light
  - Distance suitable for shower development: \( \sim 30 \) km

- **Mauna Kea**
  - **Huge Mass!**
    - Volume > 3,200 km\(^3\)
    - Mass > 9.3 \( \times 10^{12} \) ton
  - **Distance suitable for shower development:** \( \sim 30 \) km

- **Ashra-1 already demonstrated this method!**

**Reminders**:
- CR BG
- Shielding BG

**NTA — Astro \( \nu_\tau \)**

George W.S. Hou (NTU)

7/25 @ KEK
Three simulation stages

1. Mountain simulation: $\nu_\tau \rightarrow \tau$
   - $\nu + N$ cross-section
   - inelasticity
   - energy loss of tau

2. Air shower simulation:
   - $\tau \rightarrow$ Cherenkov photons / fluorescence
   - $\tau$ decay mode
   - CORSIKA detailed air shower simulation vs. fast simulation

3. Detector performance simulation
   - light propagation + Q.E.
   - pixelization for triggers
   - reconstruction

sophisticated “Ashra-1” det.

LOI at hand (submit soon)
NTA Simulated Event

Central (Site0): Fluorescence

Mauna Loa (Site1): Cherenkov

R00264/E00052: $E_\nu = 10^{17.0}$ eV, $E_\tau = 10^{16.8}$ eV, $E_{\text{show}} = 10^{16.7}$ eV

Elevation = $-6.4^\circ$, Azimuth = $347.6^\circ$

Mauna Loa (Site1)
Hualalai (Site3)
Central (Site0)
Mauna Kea (Site2)

$N_{pe}^{\text{tot}} = 4035$ (C:1363, F:2672), $R_{p}^{\text{min}} = 1.8$ km, $R_{x}^{\text{min}} = 5.4$ km

Simple Fit => Pointing Accuracy
Site0 + Site1: $\delta \theta = 0.08^\circ$
1. We use the $\nu_\tau$ distribution from CTEQ4 [14], inelasticity parameter from [13], and parameterize energy loss in Earth by [12, 15].

2. We use $\tau$ decay from TAUOLA and air-shower generation of Gaisser-Hillas + NKG [16].

3. For detector simulation, we incorporate light collection and throughput with simplified triggering logic. Event reconstruction is not yet implemented.

Assumed FOV

| LC:   | $32^\circ \times 32^\circ$ |
| Trigger Pixel: | $0.5^\circ \times 0.5^\circ$ |
| Sensor Pixel:   | $0.125^\circ \times 0.125^\circ$ |

trigger conditions:

- Number of detected photoelectrons per LC > 61.
- S/N estimated in track-associated 4 pixels × 64 pixels box (air-shower track included) > 4 [17].
What if one had better Sensitivity and accurate Pointing Info?
IceCube PeV Events

$E^2 \phi(\nu_e + \nu_\mu + \nu_\tau) = 3.6 \times 10^{-8} \text{ GeV sr}^{-1} \text{ cm}^{-2} \text{ s}^{-1}$

Should be Measured $\sim E_{\text{dep}}$
NTA Differential Sensitivities

LOI at hand

NTA Survey Depth: $z \sim 0.15$ (2 Glyr) for GRB$\nu$ flux (Hümmert al., 2012)
NTA $\nu_\tau$ Survey Performance

NTA can observe Galactic Center

- Duty 10-20% from Ashra-1
- $\nu_\tau$ pointing accuracy $< 0.2^\circ$
- FOV Elevation $30^\circ \times$ Azimuth $360^\circ$
- For GRB$\nu$
- Survey Depth $z < 0.15$ (2 Gyr)
NTA Diffuse Sensitivity (3 yr)

NTA Survey Depth: $z \sim 0.15$ (2 Gyr) for GRBν flux (Hümer et al., 2012)
Differential limits to diffuse flux of UHEν

Single flavour (90% CL)

ν limits
- Full IceCube (2 yr)
- Auger (6 yr)
- ANITA-II (28.5 days)
- ASHRA NTA (3 yrs) (expected)

Cosmogenic ν models
- p, Fermi-LAT bound
- Fe, FR II & SFR evol.
- p & mixed

 Astrophysical sources
- AGN ν
- Waxman-Bahcall

IceCube PeV ν's

NTA Observation?

GZK-ν

Pierre Auger PRELIMINARY

E² dN/EdE [GeV cm² s⁻¹ sr⁻¹]
The Quest for GZK Neutrino

\[ p^+ + \gamma_{CMB} \rightarrow \Delta^+ \rightarrow n + \pi^+ \]
\[ \pi^+ \rightarrow e^+ + \bar{\nu}_\mu + \nu_\mu + \nu_e \]

ARA

ARIANNA

CR Composition Issue

Jordan Hanson @ VHEPA2014
March 2014 @ Kashiwa, Tokyo Univ.
Composition compared with astrophys. scenarios

GZK spectrum maybe Smaller than “planned”

Limiting energy of sources combined with GZK describes composition data best
Q1: GZK effect or Exhausted Sources?

GZK suppression

maxium energy scenario

$E_{\text{max}}^p \sim 10^{18.6} \text{ eV} \Rightarrow E_{\text{max}}^\text{Fe} \sim 10^{20} \text{ eV}$

Of fundamental astrophysical importance: $E_{\text{max}}$ of sources? Standard Fermi acceleration?
Differential limits to diffuse flux of UHEν

Single flavour (90% CL)

ν limits
- Full IceCube (2 yr)
- Auger (6 yr)
- ANITA-II (28.5 days)
- ASHRA NTA (3 yrs) (expected)

Cosmogenic ν models
- p, Fermi-LAT bound
- Fe, FR II & SFR evol.
- p & mixed

Astrophysical sources
- AGN ν
- Waxman-Bahcall

Pierre Auger PRELIMINARY

NTA Observation?
NTA \( \nu_\tau \) Survey Performance

Target is not Diffuse, but "nearby" Point Sources

NTA can observe Galactic Center

NTA Exposure

Duty 10-20\% from Ashra-1

\( \nu \) pointing accuracy < 0.2\°

FOV Elevation 30\° \( \times \) Azimuth 360\°

For GRB\( \nu \)

Survey Depth \( z < 0.15 \) (2 Glyr)
NTA Organization

250 people, 39 institutions, 11 countries

490 people, 18 countries

NTA Projected: ≤ 10 countries
NTA Organization

Goal

Schedule

NTA Projected: $\leq$ 10 countries

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</tr>
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Collaboration Needed

At least 30 DUs for Coverage, 100 Myen each

12 DU's per $\pi$ coverage
NTA Projected: ≤ 10 countries

Initial Meeting 11/2012

Near-term Timeline

LOI at hand (submitted) → VHEPA2014 (March) Call for Collaboration → Proposal/TDR “2015”

funding ~ 2 yrs; construction ~ 5 yrs
use Ashra-1 for test/sci
萬事具備，
只欠東風。
Clear Discovery and Identification of Nonthermal Hadronic Processes in the Universe, be it Galactic, Extragalactic, or Cosmogenic.

Call for Collaboration

Collaborators Welcome!!

send mail to wshou@phys.ntu.edu.tw if interested to join mailing list
Tau Deflection & Decay Energy After Propagation in Rock

$$\log_{10} (\Delta \text{Angle} [\text{rad}])$$

$$E_{\nu_{\tau}} = 10^{15} \text{ eV}$$

$$E_{\nu_{\tau}} = 10^{19} \text{ eV}$$
Optical Fiber Transmission System

Coadds coarse images from light collectors & distribute to trigger sensors

Pipeline

#1

4m

Optical Coupler

#2

#3

#4

Optical Fiber Bundle

To Cerenkov Trigger

To Fluorescence Trigger

- 64x64 fibers (0.5mmf)
- 0.67deg-FOV / fiber

Light collectors can be easily appended to the trigger.

Sensitivity can be reinforced when more budget is available.
Now Test for Fluor. Trigger @ Akeno