All-sky Survey High Resolution Air-shower telescope project (ASHRA)

ASURA (阿修羅)
• A god of Indian myth.
• A statue of National treasure at Kofuku temple in Nara.
• He has 3 faces and 6 arms.

ASHRA Collaboration
Makoto Sasaki
ICRR, Univ. Tokyo
ASHRA Collaboration

Now 23 collaborators in 14 institutes


ICRR Univ.Tokyo, KEK, Max Planck Institute for Astrophysics, Toho Univ., Univ.Tokyo, National Astronomical Observatory, Nagasaki Institute of Applied Science, Waseda Univ., Tokyo University of Science, Yokohama National Univ., Tokyo Metropolitan Univ., Tohoku Univ., Tokyo Institute of Technology
Motivation

Discovery of New Very High Energy Phenomena in the Universe

Neutrino object

Transient object, Faint object

New particle & interaction
New Stage of AS Imaging Technique

- **All-sky Survey**
  - Chance of discovery
  - Complete shower shape

- **Higher resolution**
  - Point source
  - Connection with Astronomy
  - Primary particle (flavor) ID

- **Simultaneous detection**
  - Cerenkov & Fluorescence
  - TeV- , EHECR, EHE-
Progress of Optics

- **TA … Davies-Cotton**
  - FOV ~ 16 ″ / Telescope
  - Focal spot size ~ 0.3 ″

- **ASHRA … Baker-Nunn**
  - FOV ~ 50 ″ / Telescope
  - Focal spot size ~ 0.01 ″
Progress of Imaging Device

**TA … PMT+ADC**
- 16 \( \times \) 16 = 256 pixels/tele.
- Pixel res. \( \sim \) 1 \( \mu \)
- 256 outputs / 256 pixels

**ASHRA … IIT+SS-Imager**
- 3K \( \times \) 3K~10M pixels/tele.
- Pixel res. \( \sim \) 0.015 \( \mu \) (=1’)
- 4 outputs / 10M pixel
ASHRA Detector

• **Station**
  - 3 stations in a desert
  - 12 telescopes / station
  - All-sky (2 \( \pi \) sr) / 80M pixels

• **Telescope**
  - 4 Sub-telescopes / telescope

- Air-tight box
- Electrostatic IIT
- Corrector lens
- Trigger system
- Light guide
- Opt. filter
- Reflector
- Support
- Air cond.
Optics with FOV 50° & Spot size 0.01°

- **Modified Baker-Nunn**
  - 3 collector lens
  - Spherical reflector
  - Focal sphere
  - Feasible fabrication
  - Flexible optimization

F/0.74

NIMA in press.
Collector lens

- Sag curve is smooth.
- Max sag 6mm or 2mm.
- Acrylic internal absorption is negligible @ $\lambda > 300$ nm.
- Anti-reflective coat $\Rightarrow$ Reflectivity < 0.5%

\[ NIMA \text{ in press.} \]
Photoelectric Imaging Pipeline

with High Resolution, High S/N, and Self-trigger

Device

<table>
<thead>
<tr>
<th>Function</th>
<th>Lens IIT</th>
<th>Amp IIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gain</td>
<td>x10 lens</td>
<td>Amp</td>
</tr>
<tr>
<td>Require</td>
<td>$10^2$</td>
<td>$10^3$</td>
</tr>
<tr>
<td>Achieve</td>
<td>130 μm</td>
<td>13 μm</td>
</tr>
<tr>
<td></td>
<td>70 μm</td>
<td>7 μm</td>
</tr>
<tr>
<td>Status</td>
<td>Producing</td>
<td>Purchased</td>
</tr>
</tbody>
</table>

Light Split & Control

<table>
<thead>
<tr>
<th>Splitters</th>
<th>Delay IIT</th>
<th>Gate IIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Split</td>
<td>200ns DL</td>
<td>On / Off</td>
</tr>
<tr>
<td></td>
<td>$10^2$</td>
<td>$10^3$ / 0</td>
</tr>
<tr>
<td></td>
<td>13 μm</td>
<td>13 μm</td>
</tr>
<tr>
<td></td>
<td>7 μm</td>
<td>7 μm</td>
</tr>
</tbody>
</table>

Developed with 1997-1998 grant
Trigger

Cerenkov Trigger
- Trigger
- Pixel Det.
- 128 x 128
- Discri. (X)
- Discri. (Y)
- Decision (FPGA)

L1-Trigger
- Global Gate
- < 30 ns

L2-Trigger
- DAQ Request
- < 300 ns

Split & Control
- Gate-IIT
- 20~100 ns

SS-Imager
- Electric Shutter
- DAQ
- < 4 µs (<100pix)

Fluo. Trigger
- Trigger
- Pixel Det.
- 128 x 128
- Discri. (X)
- Discri. (Y)
- Pre-Trigger
- 3D Track Finder

L1-Trigger
- Macro-cell Gate
- < 30 ns

L2-Trigger
- DAQ Request
- < 50 µs

Split & Control
- Gate-IIT
- ~100 µs

SS-Imager
- 2D Electric Shutter
- DAQ
- < 100 µs

Constrains:
- Night Sky BG ~0.02pe/10ns/TrgPix
- p-AS (>3TeV) ~1 kHz/Tele.
Observation of EHECR

<table>
<thead>
<tr>
<th>Threshold</th>
<th>Events/yr</th>
</tr>
</thead>
<tbody>
<tr>
<td>$10^{19}$eV</td>
<td>1324</td>
</tr>
<tr>
<td>$10^{19.5}$eV</td>
<td>259</td>
</tr>
<tr>
<td>$10^{20}$eV</td>
<td>33</td>
</tr>
</tbody>
</table>
Observation of TeV-

- Energy threshold ~ 1 TeV @ 1600m alt
- No need of time-sharing
  => Better pointing accuracy.
Observation of EHE

<table>
<thead>
<tr>
<th>Model</th>
<th>Events/yr</th>
</tr>
</thead>
<tbody>
<tr>
<td>GZK</td>
<td>1.9</td>
</tr>
<tr>
<td>AGN-jet</td>
<td>25.9</td>
</tr>
<tr>
<td>AGN-core</td>
<td>5.4</td>
</tr>
<tr>
<td>GRB</td>
<td>1.6</td>
</tr>
<tr>
<td>TD</td>
<td>0.3</td>
</tr>
<tr>
<td>Z-burst</td>
<td>1.3</td>
</tr>
</tbody>
</table>
Plan & Targets

2002 2003 2004 2005 2006 2007

- **Phase 0**
  - R&D @ Akeno
  - TeV \(\gamma\) observation with IIT,proto.
  - Crab peak
  - Production & test of sub-telescope proto.

- **Phase 1**
  - 1 sta. @ Utah?
  - All-sky survey
    - TeV \(\gamma\), EHE \(\gamma\)

- **Phase 2**
  - + 2 sta. @ Utah?
  - Full all-sky observation
    - TeV \(\gamma\), EHE \(\gamma\), UHECR
Summary

1. Matured techniques in other fields are newly applied.
   - Modified Baker-Nunn optics with $50 \, \square \, \text{FOV}$ and $< 1'$ spot size
   - Photoelectric image pipeline with self-trigger control
   - 2D pixel trigger and CMOS image sensor

2. Highly competitive with excellent cost-performance

<table>
<thead>
<tr>
<th>Start Year</th>
<th>ASHRA 3sta.</th>
<th>Auger</th>
<th>IceCube</th>
<th>TA 3sta.</th>
<th>AGASA</th>
<th>HiRes</th>
</tr>
</thead>
</table>

|-----------------------------|-------------------------------|-------------------|-------------------|-------------|----------|----------|

<table>
<thead>
<tr>
<th>Point Accuracy(°)</th>
<th>0.01~0.02</th>
<th>1~2</th>
<th>0.4</th>
<th>0.6~1.0</th>
<th>1.0~2.0</th>
<th>0.5~0.8</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Protons / yr (&gt;10^{20} eV)</th>
<th>34</th>
<th>41</th>
<th>--</th>
<th>10</th>
<th>1</th>
<th>6</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>yrs / yr (&gt;10^{16} eV)</th>
<th>AGN</th>
<th>GZK</th>
<th>2~7</th>
<th>16</th>
<th>8</th>
<th>--</th>
</tr>
</thead>
</table>

| Cost ($) | 12M | 50M | 100M | 25M | 2M | 6M |
Hyper Links
EHE Neutrino Objects

- Proton-acceleration site
  - 1 arcmin. mesh
  - NGC4261 by optical & radio

- GZK mechanism
  - 2.7K-CMB
  - Earth
  - UHECR

- Optically thick/dark object
  - "Cocoon" of an AGN-jet
Gamma Ray Burst

Beppo-SAX identified GRB with ~3 arcmin. resolution.

=> Multi-wavelength Analysis (1997~)

Optically thick region

Central engine

Internal shocks

External shocks

Luminosity

GRB

Afterglow

Kinetic energy

Shock dissipation

ASHRA with ~1 arcmin. resolution. => A new trigger?
Particle Physics Aspects

- TD test with TeV- & UHE- flux
  - Sigl, Lee, & Coppi

- Double Bang by Tau Neutrino
  - 1° resolution

- Extra Dimension
  - Interaction Length

- Earth-skimming Tau Neutrino
Intrinsic Advantage of FD

1. Development measurement

2. Geometrical reconstruction

=> VHE- panicked identification

=> High precision pointing

Stereo analysis
Pixel Resolution & AS Image

- < 1 arcmin at E > $10^{18.5}$ eV
- 0.3 arcmin at E ~ $10^{20}$ eV
1. Discovery of a point source with $\Delta$ and $\Pi$.
2. Plot of $X_{\text{max}}$ vs deflection angle.
3. Understand from data:
   - Magnetic field
   - AS fluctuation

Source: 10 Mpc away
E=$10^{20}$ eV

- Proton
- Fe
- Neutrino

Commercial 16-in X-ray IIT
Commercial Light Guide (or “periscope”)
Trigger imager

128 × 128 pixels
Pad readout
Projection onto X & Y
CMOS Image Sensor
with 2D e-shutter

XY address
2D e-shutter
Macro-cell readout
128 × 128 macro-cells

Reset & Write Operation:
Select each Macrocell with XSELn & YSELn

Read Operation:
Select a macrocell with XADR and YADR, then apply ReadCLK
Prototype of CMOS Image Sensor

- Submitted to VDEC
  - 3×3 macro-cells
    - Unit of
      (Reset, Shutter) & Readout
  - 4×4 pixels/macro-cell

1 macro-cell

Total : 3×3 macro-cells
Successful Observation of Simulated TeV- $\gamma$

5ns pulsed YAG laser @ dist. 2km

Real event

MC
Baseline Design of Telescope Array

He kindly drew a Japanese flag on top of the TA station in his talk.
TA Electronics

TA Electronics/Online Group
Makoto SASAKI
sasakim@icrr.u-tokyo.ac.jp

SIGNAL FINDER

DSP: Signal Finding

To/From Track Finder

CSI: 16bit-Dynamic range
LCS < 1p.e./ADC-sample
VLSI: Cost performance

ADC: 12bit-5MH z

TRACK FINDER

DSP: Track Finding

HV Distributer

14bit Control & Monitor
256ch TA Prototype @ Akeno
Run started in Sep. 2002
HiRes3 R&D

- The mirror, formerly known as m18
- The Laser, currently in Millard county
- Infrastructure – generator, office shelter…
高解像度による感度の向上

- ピクセル S/N:
  - (集光面積/角解像度)\(^{1/2}\)
  - AS横広がりが無視できる場合のみ

イベント中最大のピクセル S/N の平均

AS横広がり無視の場合の予測

\[ t \triangleq L, S \triangleq L, B \triangleq L^3 \quad t \triangleq L, S \triangleq L^2, B \triangleq L^3 \]