Status Report about the LeCosPA-Participated Astro-Particle Experiments

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ARA at -200m

The Askaryan Radio Array (ARA)
Detecting Neutrinos in Antarctica
The ARA Collaboration
The Askaryan Radio Array (ARA) is an Ultra High Energy (UHE) Neutrino Detector at the South Pole

At energies above $\sim 10^{19.5}$ eV cosmic rays will interact with CMB photons producing neutrinos

Process is known as the GZK effect

Auger and HiRes measurements of UHE cosmic rays consistent with GZK cut-off

Guaranteed GZK neutrino flux, but how large?

*copy from Jonathan's slides*
Coherent Radio Emission (Askaryan Radiation)

Figure: Detect radio emission from neutrino induced particle cascades in ice
Askaryan Radiation in SLAC

PRL 99, 171101 (2007)
see also:
PRE 62, 8590 (2000),
PRL 86, 2802 (2001),
PRD 72, 023002 (2005)
PRD 74, 043002 (2006)

(copy from Ryan's slides)
Figure: ARA 37 Layout, 37 Stations 200m below the surface ~ 200km² coverage
I. ARA at -200m

DAQ System and Antenna Cluster

**ARA Sub-Station – DAQ**

- 150-850 MHz bandwidth
- 3.2 GSa/s sampling (4x Nyquist)
- Low power consumption
- Autonomous data taking

**Figure:** Each station has 4 string with 16 channels
Build, Test, & Delivery

Figure: Building ARA2 & ARA3 last year
Drilling and Deployment

- Hot water drill creates 6” wide holes
- Holes are pumped dry
- Approaching $\sim 8 \text{ hr} \times \sim 1$ drill crew per 200 m hole
- Instrumentation deployed from greenhouse sled
I. ARA at -200m

Simulation & Expected Sensitivity

- In-house tool called AraSim
- Simulates
  - neutrino interaction
  - radio emission
  - radio propagation
  - instrument response
  - thermal, instrument noise
  - hardware trigger
  - digitized waveforms
- Has been used to calculate trigger-level neutrino sensitivity
II. TAROGE at 1200m

Outline: The Distribution of Experiments

- **UFFO ~550km, Gamma Ray Burst**
- **ANITA ~40km Cosmic Rays, Neutrino**
- **ARA ~-200m, Neutrino**
- **TAROGE ~1km, Cosmic Rays**
TAROGE at 1200~2000m
Cosmic Background Flux

Cosmic ray spectra of various experiment
Building Antenna

Summer intern student from FJU and NCTU making the antenna.
II. TAROGE at 1200m

Testing Antenna

Figure: Summer intern students measure the antenna response.
II. TAROGE at 1200m

LNAs of TAROGE
III. ANITA at 37km

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The ANtarctic Impulsive Transient Antenna (ANITA)
Askaryan Radiation in SLAC

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*copy from Ryan's slides*
III. ANITA at 37km

Flight Path

- Over 65 days of flight over Antarctica
- Over 35 million triggered (noise) events
Results of ANITA II

- A combination of $vxB$ and Fresnel coefficients result in air shower emission being horizontally polarized at the payload.
- ANITA-I detected 16 isolated H-pol candidate UHECR events.
- ANITA-II did not trigger on the H-pol channels —Doh!!
- Still detected 5 UHECR candidate events.
III. ANITA at 37km

Results of ANITA II

- ANITA-II Results

<table>
<thead>
<tr>
<th>Isolated v-pol events</th>
<th>1</th>
</tr>
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<tbody>
<tr>
<td>Expected background events</td>
<td>$0.97 \pm 0.42$</td>
</tr>
</tbody>
</table>

- Combine with efficiency to extract world’s best limit on UHE neutrino flux above $10^{19}$eV
Outline: The Distribution of Experiments

- **UFFO ~550km, Gamma Ray Burst**
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The History of GRB

- Vela
- CAGO of BATSE
- Beppo-SAX
- Swift

**discovery of gamma rays**
Measurement on the Earth
transmission of atmosphere
IV. UFFO at 550km

Measurement on the Earth
Absorption of atmosphere
The History of GRB
The distribution of 2704 GRBs is isotropic, with no concentration towards the plane of the Milky Way.
The History of GRB
Beppo-SAX (1997-2004)
The afterflow of GRBs

Beppo-SAX satellite succeeded in detecting them in X-ray, which after a delay of 20 hours yield sufficiently accurate positions for large ground-based telescope. (William Herschel Telescope)
Gamma Ray Burst (GRB)
Types & Basic Properties

- Typical energy: $10^{51} \sim 10^{54}$ ergs
- Duration: ms $\sim$ minutes
The Potential of GRB
Most Distant of GRB Detected in 2009 (090423)

- The Most Luminous Events Seen in the Universe.
- The Most Distance of Objects until 2009. ($Z \sim 8.23$)
The History of GRB
IV. UFFO at 550km

GRB
Types & Basic Properties

- Short-hard GRBs ($T_{\text{peak}} < 2$ secs): This type originate from the mergers of binary neutron stars (NS-NS, BH-NS). [1, 2, 3, 4, 5]
- Long-soft GRBs: This type originate from the core collapse of massive stellar prorarity (hypernova). [6, 7, 8, 1, 2, 3]
New Project: UFFO pathfinder.

Ultra Fast Flash Observatory
Current Limits of Rapid Response Measurements

Figure: The distribution of UVOT response time. Only 4 events less than 60 secs.
Photon Measurements
Importance of Early Photon Measurements

**Figure:** Left Panel: The fastest-rising light curves are poorly sampled of the early time. Right Panel: The light curves of the decay class. Since the rise time is not known for the decay class bursts, the correlation cannot be tested among all these bursts.
III. Why Should We Need the New Telescope

SWIFT rotates entire spacecraft

UFFO rotates the mirror instead of the spacecraft
UFFO Pathfinder

- Observation of GRBs with early photons from 1 sec after trigger
- Two instruments: SMT(Slewing Mirror Telescope) for UV/optical afterglow, and UBAT(UFFO Burst Alert Trigger) for GRB localization & trigger
- Launched at Apr. 2012 onboard Lomonosov spacecraft
- Size/Mass/Power: 979(L)x409(W)x384(H) / 20kg / 20Watts
IV. UFFO at 550km

UFFO Collaboration
The Operation of UFFO

Figure: UFFO-Pathfinder
The Operation of UFFO

**Figure:** UFFO-Pathfinder

- Xray 5-200keV
The Operation of UFFO

Figure: UFFO-Pathfinder
The Operation of UFFO

Figure: UFFO-Pathfinder
The Operation of UFFO

Figure: UFFO-Pathfinder
The Operation of UFFO (UBAT part)

UFFO Burst Alert & Trigger telescope

Figure: UBAT, sensitive energy range of 10 - 250 keV.
The Operation of UFFO (Coded Mask)

UFFO Burst Alert & Trigger telescope

Figure: Code mask is made by 1 mm thickness tungsten and is pasted by 12.7 µm Kapton tape.
The Operation of UFFO (Coded Mask)

Gamma rays are stopped by mask and form the particular pattern on the detector plane.
The Operation of UFFO (SMT part)
The Operation of UFFO (SMT part)
The Operation of UFFO (SMT part)

IV. UFFO at 550km

Optomechanics

- Ritchey-Chretien type
- 100mm clear aperture
- 17 x 17 arcmin² FOV
- 4 x 4 arcsec² Pixel FOV

F/α 11.4
EFL*: 1,140 mm
Angular resolution: sub-arcsec

Total mass = 953 g
Obscuration ratio (area) = 13%
180(H) x 235(W) x 180(L) mm³

Front

Back

Intensified CCD
The Location of UFFO
Lomonosov

<table>
<thead>
<tr>
<th>Spacecraft &amp; Builder</th>
<th>Lomonosov &amp; FGUM-VNIIEEM</th>
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<tbody>
<tr>
<td>Launch Date</td>
<td>Apr. 2012</td>
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<tr>
<td>Orbit</td>
<td>Circular solar synchronous, height: 550 ± 10 km</td>
</tr>
<tr>
<td>Mass Total/Payload</td>
<td>450 kg / 120 kg</td>
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<tr>
<td>Mission Lifetime</td>
<td>3 years</td>
</tr>
<tr>
<td>Payload</td>
<td></td>
</tr>
<tr>
<td>1. TUS for UHECR (60kg)</td>
<td></td>
</tr>
<tr>
<td>2. UFFO Pathfinder for GRB (20kg)</td>
<td></td>
</tr>
<tr>
<td>3. BDRG for x-rays and gamma-rays detectors (16.5kg)</td>
<td></td>
</tr>
<tr>
<td>4. SHOK for wide field optical camera (11kg)</td>
<td></td>
</tr>
<tr>
<td>5. Magnetometer &amp; EPD for energetic particle detector (5kg)</td>
<td></td>
</tr>
<tr>
<td>6. DEPRON for control of radiation environment (5kg)</td>
<td></td>
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**UFFO PathFinder for GRB**

**TUS telescope for UHECR**

**SHOK**
Works in Taiwan

- A. Thermal Vacuum and Vibration Test.
- B. MAPMT Calibration, YSO crystal intrinsic background measurement and simulation.
- C. Cosmic background simulation. (cosmic ray, diffuse gamma ray, and $e^- \& e^+$)
- D. Alignment and calibration of optical system.
- E. Damage test.
Vibration Test in NSPO (Launch Environment)
Vibration Test in NSPO (Launch Environment)

2011 July, Shock vibration test at NSPO
Thermal-Vacuum Test (space environment)

height: 550 ± 10km, period: 90 minutes
Thermal-Vacuum Test (space environment)

The optical devices of UFFO operated successfully under the rigorous thermal-vacuum cycles, from $+40^\circ$ to $-30^\circ$ and $10^{-7}$ mbar.
MAPMT and Crystal Test

**Figure:** Crystal and MAPMTs
MAPMT Calibration

64 channels MAPMT

Dark box
Background Simulation

- Cosmic ray.
- Diffuse gamma ray.
- $e^+$ and $e^-$.
- Solar wind.
Cosmic Background Flux

Cosmic ray spectra of various experiment
IV. UFFO at 550km

UBAT Model Building

We build the upper UBAT system, which over the MAPMT plane by GEANT4.
IV. UFFO at 550km

Diffuse Gamma Ray Background

10, 20, & 30keV from left to right

50 & 70keV
Diffuse Gamma Ray Background

Low energy photons stop by the wall.
IV. UFFO at 550km

30 keV Photon
Cosmic Ray Background Result

Shower events
IV. UFFO at 550km

Diffuse Gamma Ray Background Result
Protons Hit 1mm Thickness Tungsten Mask

20 MeV  30 MeV  40 MeV
IV. UFFO at 550km

Photons Hit 1mm Thickness Tungsten Mask

The mask cannot stop the high energy photon. In other words, the upper limit of energy range is about 250 keV.
Launch Schedule

Launch time: 2014, August
Outline: The Distribution of Experiments

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- **TAROGE ~1km, Cosmic Rays**
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KIM11, J. LEE11, H. LIM11, E.V. LINDER9,11, T.C. LIU1, NIELS LUND4, K.W. MIN7, G.W. NA11, J.W. NAM1, K. NAM11,
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Valencia, Spain 9University of California, Berkeley, USA 10National United University, Miao-Li 11Ewha Womans University,
Seoul, Korea 12Moscow State University, Moscow, Russia
IV. UFFO at 550km

Cosmic Background Flux

Cosmic ray spectra of various experiment
Askaryan Effect

- Askaryan effect: Neutrinos with energy above $\sim 30$ PeV most efficiently detected with radio
- Delta-ray production, Compton scattering and positron annihilation give charge excess
- Compact bunch moves together
- Long wavelengths add coherently

The South Pole has the perfect combination of ice volume, ice RF-transparency, and existing science infrastructure for this experiment.
IV. UFFO at 550km

References

- http://www.ukaff.ac.uk/movies/nsmerger/
- http://0rz.tw/ty1Cl


IV. UFFO at 550km

Massive Star Collapse (Long-Soft)
Types & Basic Properties

The massive star collapse.
Massive Star Collapse (Long-Soft)
Types & Basic Properties

A massive star with 10-15 solar masses just before its core collapses during a gamma ray burst (GRB) event.
Massive Star Collapse (Long-Soft)
Types & Basic Properties

The core of a massive star just before the inner core (centre) collapses under its own weight in a gamma ray burst (GRB) event.
Massive Star Collapse (Long-Soft)
Types & Basic Properties

The core of a massive star just after the inner core (centre) collapsed to form a black hole in a gamma ray burst (GRB) event.
Massive Star Collapse (Long-Soft)
Types & Basic Properties

The black hole is ejecting the surrounding material as jets (white) from the poles of the black hole towards the star’s surface.
Massive Star Collapse (Long-Soft)

Types & Basic Properties

It says the spin or magnetic field of the black hole forms these jets that are the source of the gamma rays of the GRB, a massive short-lived burst of energy that is 100s of times brighter than an ordinary supernova.
Jet from Massive star Collapse
Types & Basic Properties

A relativistic jet 10 seconds after its creation. Colours, representing density from low to high, are blue, red and yellow.
The Mergers of Binary stars (Short-Hard) Types & Basic Properties

Crashing neutron stars can make gamma-ray burst jets

Simulation begins

Magnetic fields

Neutron stars
Masses: 1.5 suns
Diameters: 17 miles (27 km)
Separation: 11 miles (18 km)

7.4 milliseconds

13.8 milliseconds

Black hole forms
Mass: 2.9 suns
Horizon diameter: 5.6 miles (9 km)

15.3 milliseconds

21.2 milliseconds

Jet-like magnetic field emerges

26.5 milliseconds

Credit: NASA/AEI/ZIB/M. Koppitz and L. Rezzolla
# UBAT Model Building

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<tr>
<th>name</th>
<th>material</th>
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<td>hopper</td>
<td>Aluminum</td>
<td>purple</td>
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<tr>
<td>mask</td>
<td>Tungsten</td>
<td>gray</td>
<td>1 mm</td>
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<tr>
<td>kapton tape</td>
<td>kapton($C_{22}H_{10}N_{2}O_{5}$)</td>
<td>white</td>
<td>0.0127 mm (0.5 mil)</td>
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<tr>
<td>LYSO</td>
<td>LYSO</td>
<td>orange</td>
<td>1.96 mm</td>
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<tr>
<td>reflector</td>
<td>PEN($C_{14}H_{10}O_{4}$)</td>
<td>white</td>
<td>60 μm</td>
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<tr>
<td>electric box</td>
<td>Aluminum</td>
<td>purple</td>
<td>6.4 mm</td>
</tr>
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