CANGAROO-III and beyond

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“CANGAROO”

Collaboration of Australia and Nippon for a Gamma Ray Observatory in the Outback

Woomera, South Australia
CANGAROO team

- University of Adelaide
- Australian National University
- Ibaraki University
- Ibaraki Prefectural University
- Konan University
- Kyoto University
- STE Lab, Nagoya University
- National Astronomical Observatory of Japan
- Kitasato University
- Shinshu University
- Institute of Space and Astronautical Science
- Tokai University
- ICRR, University of Tokyo
- Yamagata University
- Yamanashi Gakuin University
Brief history of CANGAROO

- 1987: SN1987A
- 1990: 3.8m telescope
- 1990: ICRR-Adelaide Physics agreement
- 1992: Start obs. of 3.8m tel.
- 1994: PSR 1706-44
- 1998: SNR1006
- 1999: 7m telescope
- 2000: Upgrade to 10m
- 2001: U.Tokyo-U.Adelaide agreement
- 2002: Second and third 10m tel.
- 2004: Four telescope system
Why Woomera?

- NZ: too wet, not many clear nights
- Woomera:
  - Former rocket range and prohibited area...infra-structure and support
  - Adelaide group was operating BIGRAT

ELDO rocket Launch site in '60s

BIGRAT
(BIcentennial Gamma RAy Telescope)
CANGAROO-II telescope

- Upgraded in 2000 from 7m telescope completed in 1999
- 114 x 80cm CFRP mirror segments in parabola (*first plastic-base mirror in the world!*)
- Focal length 8m
- Alt-azimuth mount
- 552ch imaging camera
- Charge and timing electronics

Tanimori et al., ICRC 1999
CFRP mirror & tuning system

80cmφ, 5.5kg

CANGAROO-II camera

- 3° FOV
- R4124UV (Hamamatsu)
- 0.115° pixel
- Lightguide
- 16PMTs/module
CANGAROO-II Electronics
CANGAROO-II & -III

CANGAROO-II

7m (1999)

10m (2000)

CANGAROO-III
Woomera: 2004 March
Basic specifications of telescopes

- **Location:**
  - 31°06’S, 136°47’E
  - 160m a.s.l.

- **Telescope:**
  - 114×80cmφ FRP mirrors (57m², Al surface)
  - 8m focal length
  - Alt-azimuth mount

- **Camera:**
  - T1: 552ch (2.7° FOV)
  - T2, T3, T4: 427ch (4° FOV)

- **Electronics:**
  - TDC+ADC

Mori et al., Snowbird WS (1999)
GFRP mirrors and tuning system

Tuning using star images via a CCD camera

Before tuning

After tuning

Ohishi et al., ICRC 2003
Spot size

- T1: 0.20°
- T2: 0.21°
- T3: 0.14°
- T4: 0.16°

Point Spread Function (FWHM)

Image of a star on camera observed by a CCD camera

(measured at construction time)
CANGAROO-III camera

<table>
<thead>
<tr>
<th></th>
<th>T1</th>
<th>T2, T3, T4</th>
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<tbody>
<tr>
<td>FOV</td>
<td>3°</td>
<td>4°</td>
</tr>
<tr>
<td>Num. of pixels</td>
<td>552</td>
<td>427</td>
</tr>
<tr>
<td>Weight</td>
<td>~110 kg</td>
<td>~110 kg</td>
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<tr>
<td>Size of PMT</td>
<td>½”</td>
<td>¾”</td>
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<tr>
<td>Pixel arrangement</td>
<td>square</td>
<td>hexagonal</td>
</tr>
<tr>
<td>HV polarity</td>
<td>negative</td>
<td>positive</td>
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<tr>
<td>HV supply unit</td>
<td>1ch/16 PMTs</td>
<td>1ch/1 PMT</td>
</tr>
</tbody>
</table>

R3479 (Hamamatsu)

Lightguide (T1/T234)
PMT gain uniformity and linearity

Lightguide design

Winstone cone cross section

Efficiency vs. incident angle

Kajino et al., ICRC2001
High voltage control & monitor
Camera calibration

Blue LED flasher at the reflector center

Blue LED flasher in the camera box

Patterned screen

Yamaoka et al., ICRC2003
CANGAROO-III Electronics (2)

Discriminator and summing module (DSM)

Trigger logic
CANGAROO-III Electronics (3)

ADC linearity

Single photoelectron spectrum measured with DSM and ADC
Telescope control

Telescope control unit

Position data (every 100ms)

RS-232C

Position command (alt-azimuth)

Driving control PC

Remote command/position data/NTP

Local area network

Hayashi et al., ICRC2003
Star tracking

Star position error observed by a CCD camera

- CCD X-axis (degree)
- CCD Y-axis (degree)
- RMS deviation: 0.013 degree

PMT size: T3

Hear Kiuchi’s talk!
Construction of CANGAROO-III

<table>
<thead>
<tr>
<th>Year</th>
<th>T1</th>
<th>T2</th>
<th>T3</th>
<th>T4</th>
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<tr>
<td>1999</td>
<td>1</td>
<td>6</td>
<td>3</td>
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<tr>
<td>2003</td>
<td>11</td>
<td>12</td>
<td></td>
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</tr>
<tr>
<td>2004</td>
<td></td>
<td></td>
<td>3</td>
<td></td>
</tr>
</tbody>
</table>

- **Construction**: Green circle
- **Observation**: Orange line
- **Observation start**: Red circle
- **Tuning**: Blue line
- **Expansion to 10m**: Green square

**4-telescope stereo**
Sample of 4-fold stereo events

Data: 2004 March
Global trigger system

- Before: “software trigger”
  - Each telescopes triggered independently
- Now: “hardware stereo”
  - Requires at least 2 telescopes
- If no coincidence ⇒ Reset
  - Dead time ×1/100

\[ \Delta t = \frac{d}{c} < 500 \text{ns} \]

Diagram:
- Telescopes
- 150m Opt.fiber
- Trigger
- 650ns
- Coincidence
- Opt.fiber
- Trigger
- Event number
- Telescopes
- Turnaround ~2.5μs
- Wait time ~5μs
Effect of global triggers

Muon events are removed!
Beyond CANGAROO-III

- In the near future
  - Improvement of old T1 and others

- In the long range
  - No unified plan yet...
  - Started brainstorming, technical and physical considerations...
Where should we go?

- Lower Energy
- Higher sensitivity
- Higher Energy
- Wider coverage
- Wide FOV camera
- Large reflector/high altitude
- Wider coverage
- Higher Energy
- Large effective area
A case study: array of telescopes

- How to achieve large effective area in modest cost?
- Large span array with wide cameras?
Lateral distribution of light

- Tail is extended beyond 150m!
Array span vs. effective area

- 6° FOV camera
- Gamma-ray energy: 100 GeV, 1 TeV, 10 TeV
Summary

- CANGAROO-III is a system of 10m imaging Cherenkov telescope build by Japanese-Australian collaboration.

- We have been carrying out 4-telescope stereo observations of sub-TeV gamma-rays since 2004 March. Now we have incorporated a global trigger system to reduce muons.

- We are studying the next-generation telescopes. One option could be a large-span array of telescopes to increase the effective area.