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DESY

March 21, 2015
JPS meeting
Waseda University
Cherenkov Telescope Array

- Observations of gamma rays in 20 GeV – 100 TeV band
  - Cherenkov light from electromagnetic shower produced by interaction of gamma rays with atmosphere
- Large collection area by placing many telescopes
  - x10 better sensitivity
- Wide energy band coverage by three different sizes of telescopes
  - Large-sized telescope (LST): Φ = 23 m, 20 GeV – 1 TeV, 4 telescopes
  - Medium-sized telescope (MST): Φ = 10 – 12 m, 0.1 – 10 TeV, ~20 telescopes
  - Small-sized telescope (SST): Φ = 4 – 7 m, 1 – 100 TeV, 30 – 70 telescopes
SST-2M Design Concept

- **Dual mirror design with small pixel photon sensor**
  - Small pixel (~6 mm) photon sensor to reduce camera cost
    - Multi-anode photomultiplier or SiPM
    - High density readout electronics (ASIC)
  - Schwarzschild-Couder (SC) optics
    - Short focal length to realize small plate scale
      - Technically challenging
    - Large field of view
      - Longer telescope spacing (larger collection area)

- **Gamma-ray Cherenkov Telescope (GCT)**
  - Collaboration of Australia, France, Germany, Japan, Netherlands, UK
## SST-2M Camera Design

### SST-2M Camera Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>32 mod</td>
<td></td>
</tr>
<tr>
<td>FOV for 0.18°/pixel (36 mm/°)</td>
<td>8.6°</td>
</tr>
<tr>
<td>FOV for 0.28°/pixel (23 mm/°)</td>
<td>13.4°</td>
</tr>
<tr>
<td>Angular pixel size for FOV=10°</td>
<td>0.21°</td>
</tr>
<tr>
<td># of pixels per camera</td>
<td>2,048</td>
</tr>
<tr>
<td>Power consumption per camera (FE)</td>
<td>350 W</td>
</tr>
<tr>
<td>Weight per camera (FE+SiPM)</td>
<td>11 kg</td>
</tr>
<tr>
<td>Total cost (FE+SiPM) for 50 CAMs*</td>
<td>$7.2M</td>
</tr>
</tbody>
</table>

*Assuming $20/ch, which does not explicitly include labor for mechanical module assembly and calibrations.

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Front-End (FE) electronics module

- 32 modules
- 2048 channels
- ~31 cm
- 9°
Comparison with Single-Mirror Camera

SST-1M camera
- 38 cm
- 9.1°
- 108 modules
- 1296 pixels
- 0.26° (24 mm)/pixel

SST-2M camera
- ~31 cm
- 9°
- 32 modules
- 2048 channels
- 0.18° (6.2 mm)/pixel
GCT Camera Electronics

- Camera module
  - Front-end electronics
- Backplane
- DAQ board
  - Trigger REQ
  - Trigger ACK
  - Data storage
    - raw data, command (UDP)
    - SPI control/monitor

- Photo sensor
  - × 16
- Peripherals
  - LEDs, fans, temps
- Peripheral board

Photo sensor connects to Front-end electronics, which in turn connects to Backplane. The Backplane is connected to DAQ board, where data is processed and stored. The DAQ board has connections for triggering and data communication. Peripherals like LEDs, fans, and temperature sensors are connected to the peripheral board.
GCT Camera Electronics

- Camera module
  - Front-end electronics
  - Photo sensor
- Backplane
  - x 16
- DAQ board
- Data storage
- raw data, command (UDP)
- SPI control/monitor
- Trigger REQUEST
- Trigger ACKNOWLEDGE

Peripherals
- LEDs, fans, temps
- Peripheral board

CTA: Cherenkov Telescope Array
GCT Camera Electronics

Camera module

Front-end electronics

Photo sensor

•

× 16

DAQ board

Trigger REQ

Trigger ACK

Data storage

raw data, command (UDP)

SPI control/monitor

Peripheral board

Peripherals

LEDs, fans, temps
GCT Camera Electronics

Camera module

Front-end electronics

Backplane

Peripherals

LEDs, fans, temps

Peripheral board

Data storage

raw data, command (UDP)

SPI control/monitor

Photo sensor

× 16

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GCT Camera Electronics

Camera module

Front-end electronics

Backplane

Photo sensor

Peripheral board

Peripherals

LEDs, fans, temps

Camera module

Front-end electronics

Backplane

Photo sensor

Peripheral board

Peripherals

LEDs, fans, temps

GCT Camera Electronics

CTA cherenkov telescope array

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GCT Camera FEE Design

designed by G. Varner (Hawaii)
GCT Camera FEE Specifications

❖ **Requirements**
- Waveform sampling at ~ 1 GSa/s
- Signal bandwidth > 380 MHz
- Cross-talk < 1%
- **Look-back time: > 12 µs**
  - For coincidence between telescopes
- Dynamic range: > 9 bits
- Readout (dead) time: < 30 µs
- Trigger timing: < 4 ns
- Trigger segment: 0.1° x 0.1° ~ 0.2° x 0.2°

❖ **TARGET ASIC**
- Switched capacitor array for high speed waveform sampling
- Integrated digitization circuits and trigger circuits
  - Reduction of components and cost, increase reliability
- Internal bias generator
  - All digital interface
- Low power consumption: ~70 mW/channel including FPGA
TARGET ASIC Development

- TARGET ASIC is required to minimize cost and PCB space
  - while realizing GHz sampling and digitization, and trigger
- Current status of development
  - Waveform recording and digitization satisfy requirements
  - Trigger performance needs improvements due to interference from waveform recording
    - Separate ASIC for trigger and preamp

TARGET ASIC Development

- Photo sensors → Preamp → Trigger → Digitization → Data → L0 trigger
- New TARGET ASIC
  - Photo sensors → New Trigger ASIC → Preamp → Trigger → Digitization → Data → L0 trigger

New Trigger ASIC
TARGET Performance

Waveform recording linearity

Minimum detectable pulse: 3.1 mV
σ = 0.6 mV

Trigger performance with sampling OFF

Waveform recording resolution

CTA小口径望遠鏡用焦点面検出器の試作器開発
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Development of Photo sensor

- **Silicon photomultiplier**
  - High photon detection efficiency (PDE)
  - Low bias voltage (50–70 V)
  - Robust compared with phototubes
  - Crosstalk needs improvement
    - Trade off with PDE
    - Factor of >10 improvement with 10-15% loss of PDE
  - Packaging density is getting better with Through Via Silicon technology
    - 4-side buttable
    - 200 µm gap between pixels
  - It is a default choice for all dual-mirror telescopes in CTA

- **R&D is almost over**
  - 6 mm sensor is being evaluated
  - Prototype with correct pixel size (6.3–6.7 mm) will be fabricated and tested

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CTA小口径望遠鏡用焦点面検出器の試作開発
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DAQ and Slow Control Software

- **libTARGET (2013 –)**
  - C++ and Python libraries for lab tests of TARGET ASICs
  - Was not designed for multiple modules or high trigger rates

- **libCHEC (2014 –)**
  - Based on libTARGET, but fast DAQ, slow control, and event display functionality was written from scratch
  - C++ and Python libraries
  - Makes use of C++11, CMake, Boost, CFITSIO, ROOT6, SWIG, Google Protocol Buffer, and ZMQ
  - 32 UDP sockets are connected to 32 camera modules
    - For raw data transfer and slow control of camera modules
  - Still under development, being tested with CHEC-M in a lab
First GCT camera prototype is assembled and being tested

- FEE module level tests completed
- Integrated camera test in progress
Camera Commissioning

- First GCT camera prototype is assembled and being tested
  - FEE module level tests completed
  - Integrated camera test in progress

*FEE modules*

*FEE module test bench*

*Camera prototype (full scale)*

*Camera prototype (back side)*

*Photon pulse from camera prototype*
Summary and Plans

❖ Waveform sampling capability of TARGET-7 is satisfactory
  ✤ Trigger performance will be fixed by CCTV
❖ Characterization and improvement of SiPM ongoing
  ✤ R&D is almost over
❖ System test ongoing for the first camera prototype

❖ Plans
  ✤ CCTV is out of fab and will be tested soon
  ✤ Prototype sensor will be fabricated after completion of 6 mm sensor testing
  ✤ Prototype production of complete GCT telescope ongoing