Observation of Diffuse Gamma-Ray with Electron-Tracking Compton Imaging Camera Loaded on Balloon

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• Electron-Tracking Compton Camera
• Flight Model Detector
• Balloon Experiment & Results
• Summary
Sensitivity of X/Gamma-ray observations

Photo Absorption → Compton → Pair Creation

10^3 eV → 10^4 → 10^5 → 10^6 → 10^7 → 10^8 → 10^9 → 10^10 → 10^11 → 10^12

keV → MeV → GeV → TeV

erg/(cm^2 sec)

1 mCrab

Integral IBIS

COMPTEL

EGRET

Air Cherenkov

NeXT

JEM-X

Glast (2008)

ASCA

CHANDRA, NEWTON

All sky survey

Good

Bad

1'' ~ 1' ~ 1°

1°

1°

< 0.1°

< 0.1°

Pointing

All Sky

All Sky

All Sky

Pointing

Δθ

ΔΩ
Electron-Tracking Compton Imaging

- gaseous TPC: Tracker
  - track and energy
  - of recoil electron
- Scintillator: Absorber
  - position and energy
  - of scattered gamma

Reconstruct Compton scattering event by event

- 1 photon $\Rightarrow$ direction + energy
- Large FOV ($\sim 3\,\text{str}$)
- Kinematical background rejection

\[
\cos \alpha_{\text{geo}} = \vec{g} \cdot \vec{e}
\]

\[
\cos \alpha_{\text{kin}} = \left(1 - \frac{m_e c^2}{E_\gamma}\right) \sqrt{\frac{K_e}{K_e + 2m_e c^2}}
\]

The performance of the prototype was reported by H. Kubo in 2004 IEEE NSS.
Sub-MeV gamma-ray Imaging
Loaded-on-balloon Experiment

10cm cube camera @ Sanriku (Sep. 1st 2006)
- Operation test @ balloon altitude
- Observation of diffuse cosmic/atmospheric gamma
  ~200 photons during 3 hours
  (100 keV~1MeV)

30cm cube camera
- Observation of Crab/Crg X-1

40cm cube camera
- Long duration observation with super pressure balloon

50cm cube camera
- All sky survey (load on a satellite)
SMILE-I gondola

- Plastic scinti.
- GSO scinti.
- TPC
- Preamplifier
- NIM module
  - Shaper
  - DAC
- VME module
  - CPU
  - ADC
  - telemetry
  - scaler
- FPGA encoding board
- Regulator
- Bessel
- Battery
- Ballast

Size: 1.45×1.2×1.55m³
Weight: 397 kg
Power: ~350 W
No posture control!!
Tracker
- Gas: Xe 80% + Ar 18% + C₂H₆ 2%
- 1atm, sealed
- Gain: ~35000
- Drift velocity ($V_d=400\text{V/cm}$):
  - measured: 2.5cm/μsec
  - simulation: 2.48cm/μsec
- Volume: 10×10×14 cm³
- Energy resolution:
  - ~45% (22.2keV, FWHM)
- Position resolution: ~500μm

Absorber
- Scintillator: GSO(Ce)
- Pixel size: 6×6×13 mm³
- Photo readout: H8500 (HPK)
- DC/HV: EMCO Q12N-5
- A unit consists of 192 pixels, 3 PMTs, 3 DC/HV and 4 preamplifier
- 4 channels readout with resistive chain (H. Sekiya et al., NIM, 2006)
- Bottom: 3×3 PMTs
- Side: 3×2 PMTs × 4
- Energy resolution:
  - ~11% (662keV, FWHM)
- Flat Panel PMT H8500

Recoil electron

Flat Panel PMT H8500
MeV gamma-ray imaging

$^{137}\text{Cs (662keV)} \sim 50\text{cm from window, 600 - 724keV}$

- Energy resolution : $\sim 12\%$ (662 keV, FWHM)
- Detection efficiency : $2.5 \times 10^{-4}$ (356 keV)
  $5.0 \times 10^{-5}$ (662 keV)
Flight

Sanriku Balloon Center (JAXA)
Launch at Sep. 1st 2006

05:26 turn on
06:11 launch
08:56 level-flight start
12:59 turn off
13:20 cut off
13:45 landing
14:32 recovery
**Gamma-ray rate & spectrum**

**Rate of Gamma-ray event**
- 100~900 keV
- All direction ~1000
- in FOV (3 str) ~450

**Energy Spectrum**
- 32~35 km level flight
- 3.5 hours (live ~3h)
- in FOV event
  - ~200 events

*GEANT4 ⇒ ~200 events*
**Growth curve**  
Dependence of Count rate on Atmospheric depth

- **Cosmic** \( \phi_c = \phi_d + \phi_s \)
  - directory incoming component: Gamma-rays are attenuated by atmosphere
    \[ \phi_d = A \times \exp \left( - \frac{z}{\tau_{\text{tot}}} \right) \]
  - scattered component: Gamma-rays are scattered in atmosphere before reaching the detector
    \[ \phi_s = p(E, z) \times \phi_d \]

- **Atmospheric** \( \phi_A \)

The component of the interaction of charged particle and atmosphere
\[ \phi_A = B \times z \]

- \( z \): atmospheric depth
- \( \tau_{\text{tot}} \): mean free path
- \( p(E, z) \): correction factor
- \( A, B \): free parameter
We confirmed the results of past observations!!
Dependence of total flux on zenith angle

- 100~900 keV
- 32~35km, 3.5h
- 5.5~8.5 g/cm²

The HWHM of effective area is about 60° (GEANT4)

Preliminary

Ling (1975)
300 keV
7.0 g/cm²
For Next Balloon Experiment

30cm cube TPC

K. Ueno’s talk (N33-5)

Large area GSO array

The Development is going on!!

Tracks of cosmic muon
**Summary**

- We develop an Electron-Tracking Compton Camera.
- The flight model detector for SMILE-I
  - Energy resolution: \( \sim 12\% \) for 662 keV @ FWHM
  - Detection efficiency: \( \sim 2 \times 10^{-4} \) for 356 keV
  - Field Of View: \( \sim 3 \text{str} \)
- The first balloon was launched on September 1\(^{st}\), 2006 from Sanriku-Balloon-Center (ISAS/JAXA).
- The balloon flight lasted 7 hours, and the level flight continued during 4 hours at the altitude of 32-35 km.
- Our detector was stable at the balloon altitude.
- The experiment is the first observation using ETCC at the balloon altitude.
- There were \( \sim 1000 \) gamma-ray events in this flight, and \( \sim 200 \) gamma-ray events in FOV during the level flight.
- We confirmed the past observations of the fluxes of diffuse cosmic and atmospheric gamma-rays.
- Our detector realized a large FOV and a high S/N at the balloon altitude.
Thank you!