The Observation of Diffuse Cosmic and Atmospheric Gamma Rays with an Electron Tracking Compton Camera loaded on a Balloon

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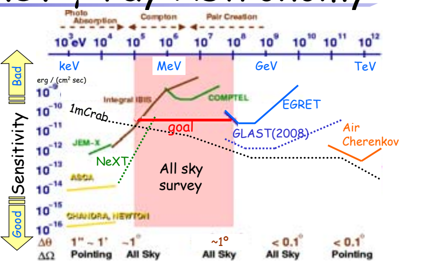
1. Observation in MeV γ-ray Astronomy

◆ Universe in MeV gamma ray

- Nucleosynthesis
  - SNR : Radio-isotopes
  - Galactic plane : ^{26}Al (1.8), ^{60}Fe (1.173/1.333)
- Acceleration
  - Jet (AGN), GRB :
    - Synchrotron radiation
    - Inverse Compton scattering
- Strong Gravitational Potential
  - Black Hole : accretion disk, π^0-decay
- Etc.
  - gamma-ray pulsar, solar flare
  - Annihilation (0.511), neutron capture (2.2)

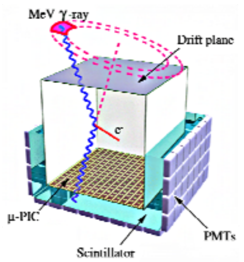


◆ Past Observations

- COMPTEL (CGRO) : Double Compton Imaging
  COMPTEL discovered ~30 steady sources in all sky.
  The observation was obstructed by many backgrounds,
  so that the actual sensitivity was lower than the designed one.
- IBIS, SPI (INTEGRAL) : Coded Aperture Imaging
  The sensitivity is nearly equal to that of COMPTEL in MeV region.

Goal :
All sky survey by a new detector, which has a 10 times better sensitivity than that of COMPTEL.

2. Electron Tracking Compton Camera



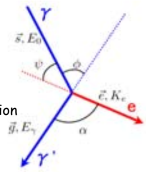
◆ Electron Tracking Compton Camera (ETCC)

The camera consists of a gaseous time projection chamber, which detects the track and energy of the recoil electron, and a scintillator, which detects the absorption point and the scattered gamma-ray energy. By the detection of the direction of the recoil electron, we can reconstruct the Compton scattering completely and obtain the fully ray-traced gamma-ray image.

$$E_0 = E_\gamma + K_e$$

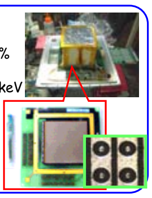
$$\vec{s} = \left(\cos\phi - \frac{\sin\phi}{\tan\alpha}\right)\vec{g} + \frac{\sin\phi}{\sin\alpha}\vec{e}$$

- E_0: Energy of the incident gamma-ray
- $\vec{s}$: Direction of the incident gamma-ray
- $\vec{g}$: Unit vector of the scattering direction
- $\vec{e}$: Unit vector of the recoil direction
- ϕ : Scattering angle
- α : Differential angle between $\vec{g}$ and $\vec{e}$



Tracker (μ-TPC)

- volume : 10×10×15 cm³
- gas: Xe 80% + Ar 18% + C_2H_6 2%
  1 atm, sealed, 3.97 g/cm³
- energy resolution : ~45% @ 22keV
- position resolution : ~400μm
- gas gain : ~30000
  (GEM:~10, μ-PIC:~3000)
- Drift velocity : ~2.5 cm/μsec
- dE/dX (MIP) : 5.3 keV/cm



Absorber (GSO:Ce scinti.)

- pixel size : 6×6×13 mm³
- Bottom : 3×3 PMTs
- Side : 3×2 PMTs × 4 sides
- energy resolution : ~11% @ 662keV

◆ Background Rejection

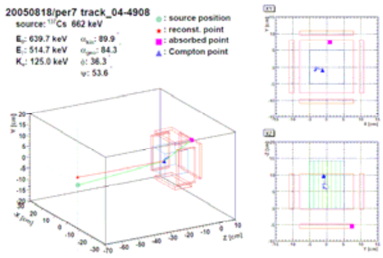
The angle α between the scattering direction and the recoil direction is measured geometrically

$$\cos\alpha_{geo} = \vec{g}\cdot\vec{e},$$

and also this angle is obtained by the calculation using the energies of the recoil electron and the scattered gamma-ray

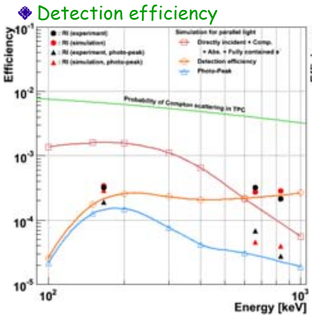
$$\cos\alpha_{kin} = \left(1 - \frac{m_e c^2}{E_\gamma}\right)\sqrt{\frac{K_e}{K_e + 2m_e c^2}}.$$

Therefore we can select the good events of which the kinematical calculated angle is consistent with the measured one. Because of the background rejection by the angle α, the electron tracking Compton imaging fits for the MeV gamma-ray astronomy, whose serious problem is the obstruction by background.

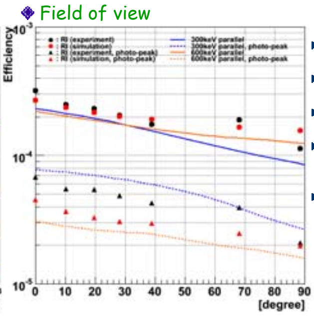


3. Performance of 1st FM Detector

◆ Detection efficiency

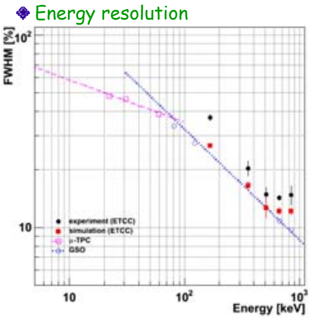


◆ Field of view

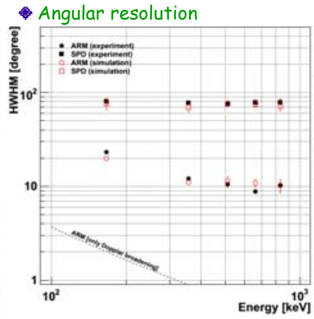


- Energy range
  100 keV ~ 1 MeV
- Detection efficiency
  ~2×10^{-4}
- FOV
  ~π str
- Energy resolution
  ~14%
  (662keV, FWHM)
- Angular resolution
  ARM : ~9°
  SPD : ~80°
  (662keV, HWHM)

◆ Energy resolution

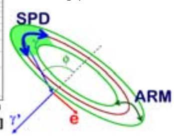


◆ Angular resolution



Angular Resolution Measure (ARM) is the accuracy of the scattering angle.

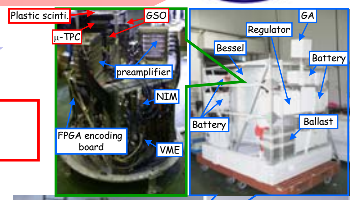
Scatter Plane Deviation (SPD) is the accuracy of the determinant of the scattering plane.

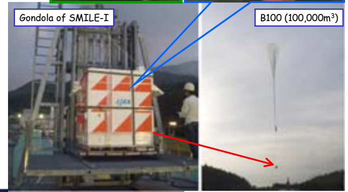


4. 1st Flight of SMILE

◆ Sub-MeV gamma-ray Imaging Loaded-on-balloon Experiment

- 10cm cube camera
  - Operation test @ balloon altitude
  - Observation of diffuse cosmic/atmospheric gamma
- 30cm cube camera
  - Observation of Crab/Cyg X-1
- 40cm cube camera
  - Long duration observation with super pressure balloon
- 50cm cube camera
  - All sky survey (load on a satellite)

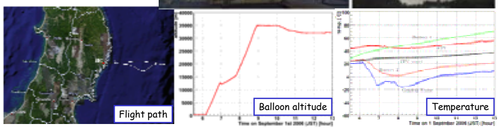




◆ 1st Flight of SMILE

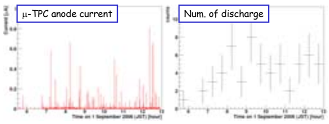
On September 1st 2006, SMILE-I was launched from Sanriku Balloon Center (ISAS/JAXA).

- 05:26 Turn On (Compton camera mode)
- 06:11 Launch
- 08:56 Level flight
- 12:06 Charged particle tracking mode
- 12:34 Compton camera mode
- 12:59 Turn off
- 13:20 Cut from the balloon
- 13:45 Landing on the sea
- 14:32 Recovering



◆ Status of μ-TPC

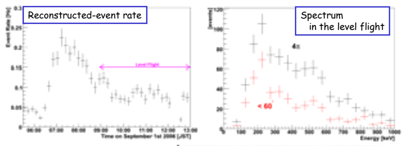
- There were several small discharges but no abnormal current.
  ⇒ The TPC was under the stable operation.
- The discharge rate increased after the launch of the balloon, and it looked constant after the Pfotzer Maximum.
  ⇒ We consider these discharges were caused by the primary heavy cosmic-rays, such as He or C ions.



5. Results

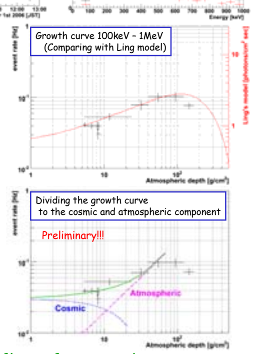
◆ Detection of gamma-ray event

- Number of the reconstructed events
  ~2000 events during this flight
  ~800 events in the level flight
  ~420 downward events (zenith < 60°)
  at 32~35 km during the live time of 3 h
- Reconstructed event rate
  maximum rate at near the Pfotzer Maximum
  roughly constant during the level flight
- Spectrum
  slightly excess at ~511 keV
  ⇒ due to the interaction between CR and vessel

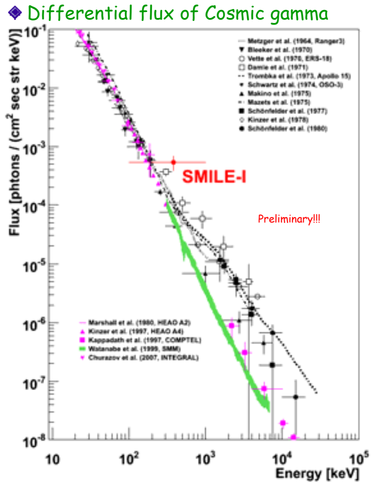


◆ Growth curve

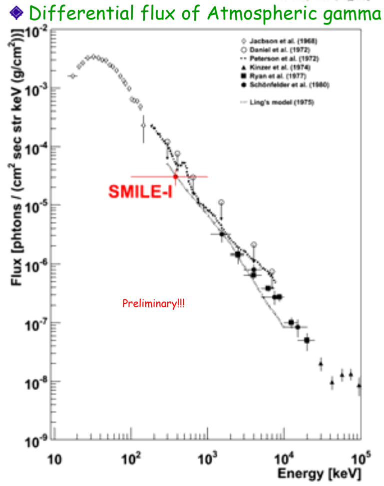
- Comparing with Ling's model (J. Geophys. Res. 1975)
  Depth dependence of our result was well consistent
- for obtaining the flux of cosmic/atmospheric gamma ray…
  atmospheric gamma:
  assumed it proportional to the atmospheric depth
  cosmic gamma:
  considering the attenuation of the atmosphere
  correcting the effect of scattering
  in overlying atmosphere using Geant4 simulation
  ⇒ We obtain the fluxes by fitting our growth curve



◆ Differential flux of Cosmic gamma

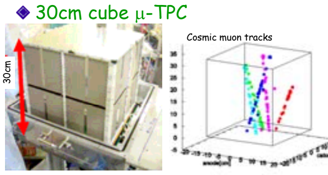


◆ Differential flux of Atmospheric gamma



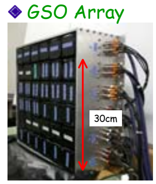
6. Present Work for Next Balloon

◆ 30cm cube μ-TPC

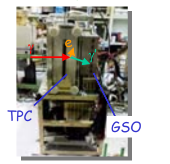


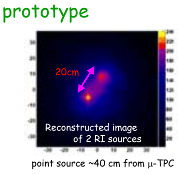
- 30cm cube TPC
  Succeeded in the observation of the track of cosmic muon
- GSO:Ce Pixel Scintillator Array
  Finished the construction and the calibration
- Larger ETCC prototype
  30×30×15cm³ TPC + 30×30cm² GSO ⇒ already operated
  with 30cm cube TPC ⇒ Now going
- for next balloon experiment
  Started the design

◆ GSO Array



◆ 30cm MeV camera prototype





point source ~40 cm from μ-TPC