

# Balloon Observation of the Galactic Center Region with MeV gamma-ray telescope in SMILE-2+

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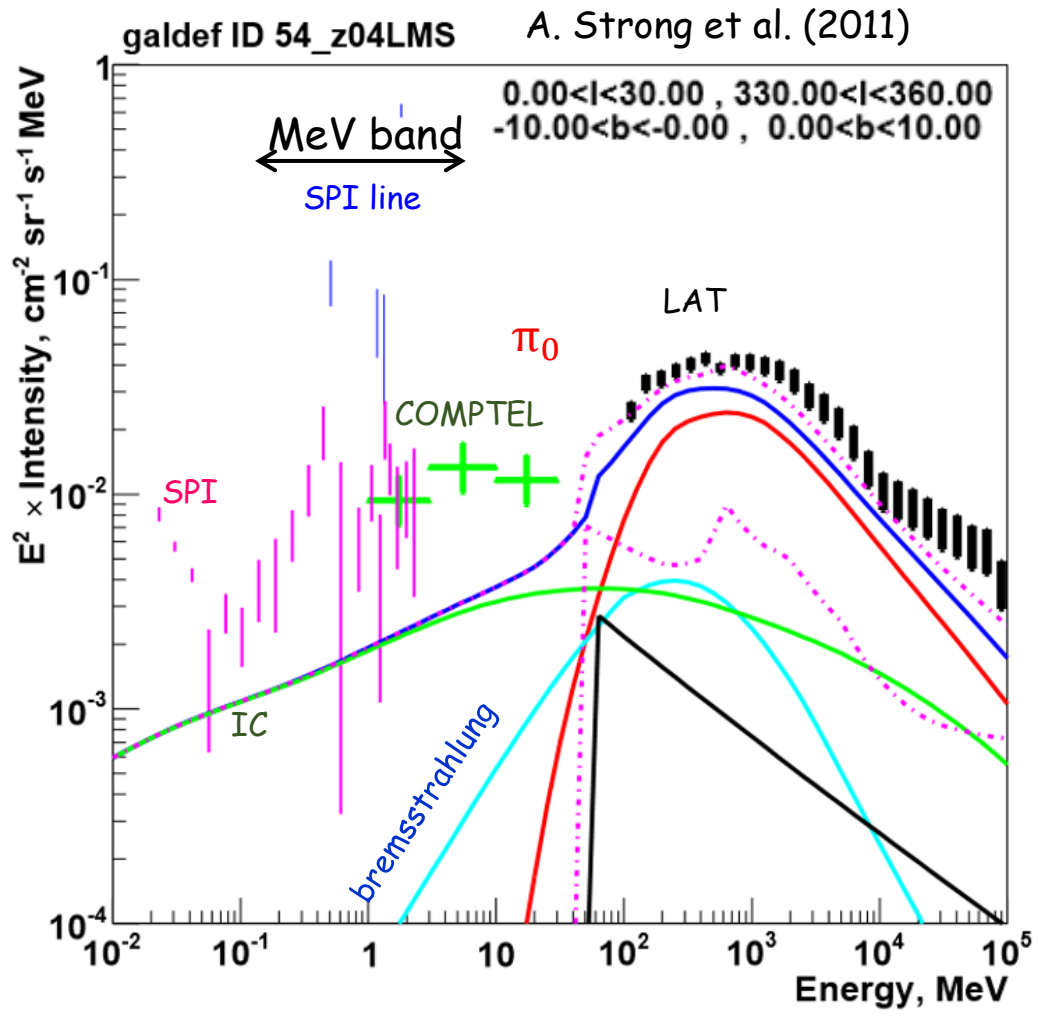
photo : Just before Launching @ Alice Springs, Australia, April 7<sup>th</sup>, 2018

# Contents

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- Galactic Center Region in MeV band
  - to decide emission sources
- Preliminary results of SMILE-2+
- Future work of SMILE-3
- Summary

# Galactic Center Region in MeV band



lack of knowledge of MeV band

data  $\sim 5$ - $10 \times$  theoretical line (IC)

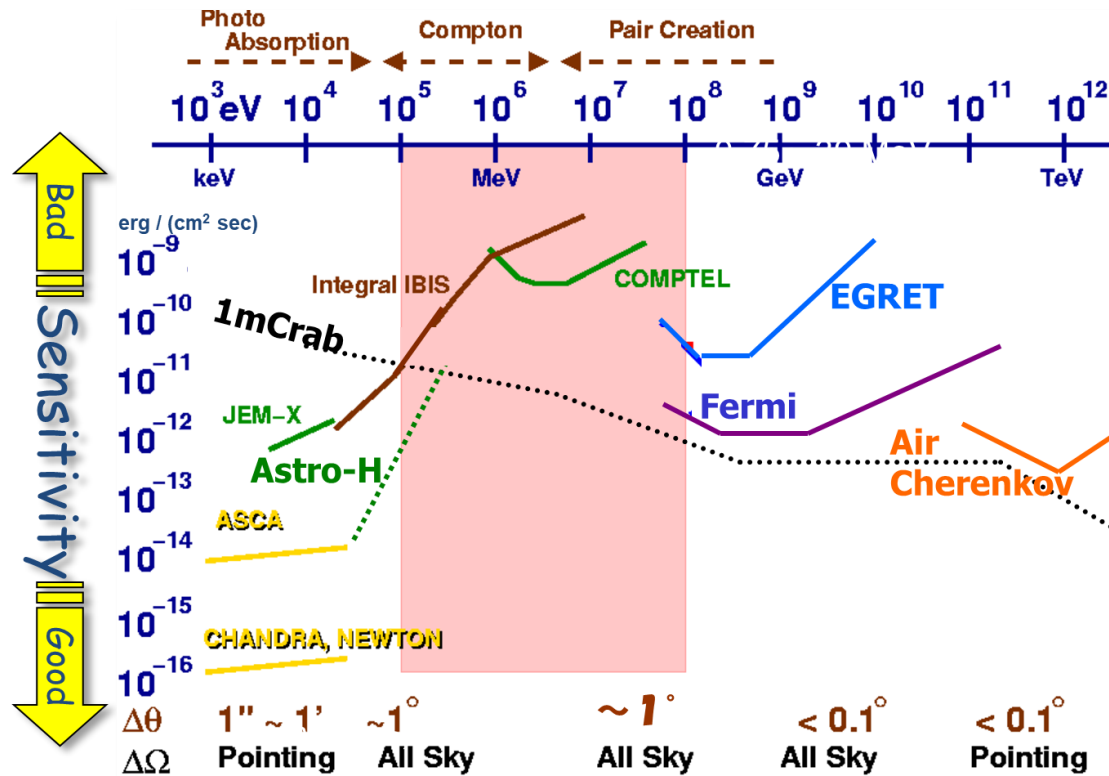
IC: Inverse Compton between cosmic electron and cosmic optical-infrared-microwave background

Possible Candidate

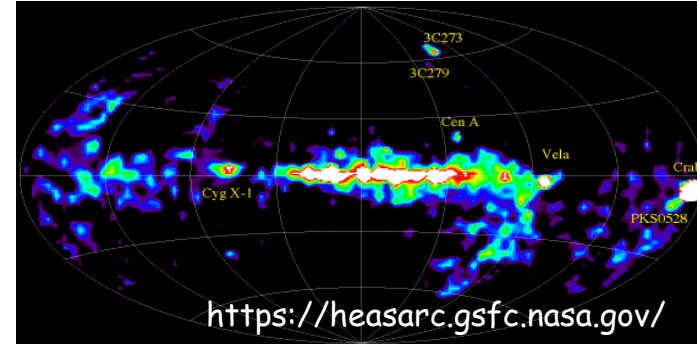
- unidentified point sources ?
- nuclear gamma-rays ?
- light dark matter ?

We cannot decide the emission sources using the observations data until now.

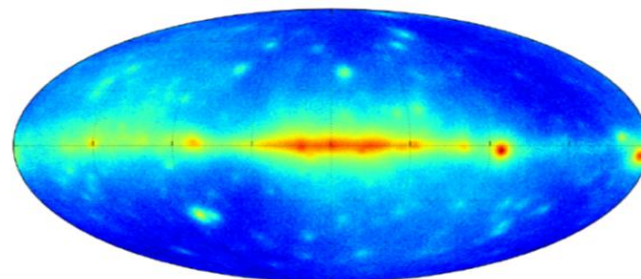
# Problems of Observation in MeV band



Difference in Sky maps  
COMPTEL 1-30 MeV, 32 sources (9 years)



Fermi 30-100 MeV, 198 sources (9 years)



G. Principe et al. (2018)

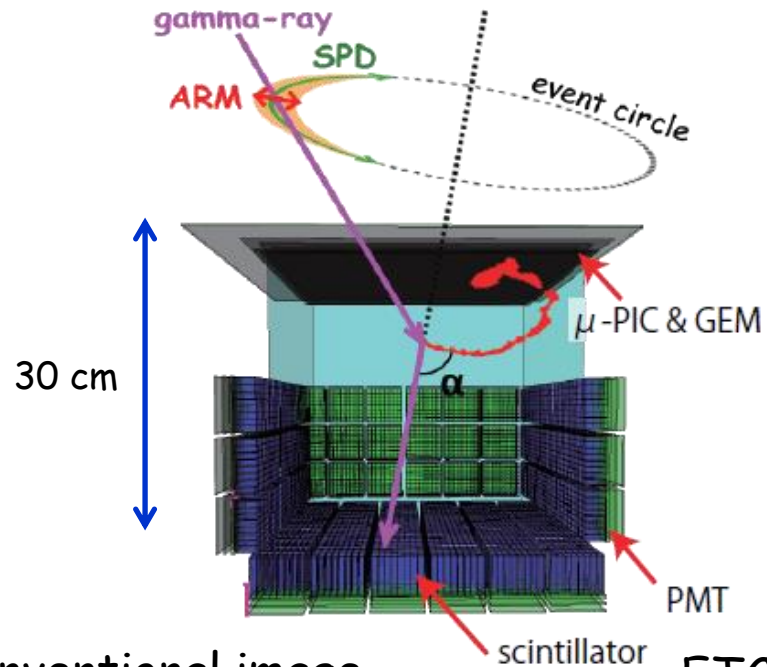
lower sensitivity in MeV band

- Contaminations of point sources (Half Power Radius < several ten degrees)
- huge backgrounds (S/N < 10<sup>-2</sup>)

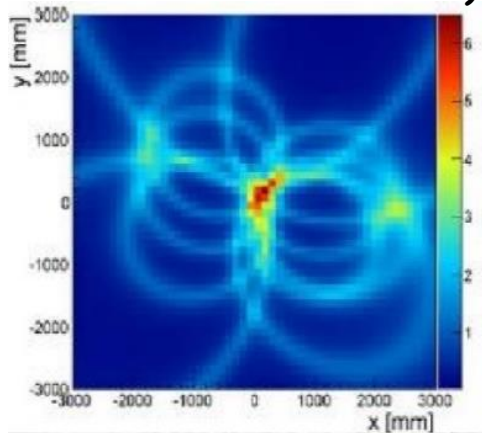
Requirements for the next-generation observation :

- High S/N and High-resolution Image
- Wide-energy-band detection
- Large Field of View

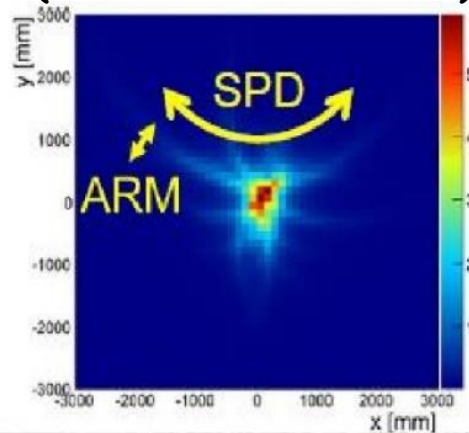
# Electron-tracking Compton Camera : ETCC



Conventional image  
(without e- track info.)



ETCC image  
(with e- track info.)



- **Gaseous TPC** : Scattering Target track and energy of recoil electron
- **Scintillator** : Absorber position and energy of scattered gamma ray



measure all the parameters of Compton-scattering kinematics

- 1 photon  $\rightarrow$  direction and energy
- Large field of view
- strong noise reduction
  - Compton kinematical test with  $\alpha$  angle
  - Particle identification with  $dE/dx$  ratio

# SMILE Project

**SMILE-I @ Sanriku (Sep. 1<sup>st</sup> 2006)** 10 cm cubic, Xe+Ar 1 atm

- Confirmation of operation at the high altitude
  - Observation of diffuse cosmic/atmospheric gamma-ray
    - > ETCC was operated stably @ 35 km
- Results were consistent with past observations A. Takada+, ApJ, 2011

**(30 cm)<sup>2</sup> prototype** only ground tests 30 cm cubic, Ar 1 atm

- Ground cal. -> eff. area :  $\sim 1 \text{ cm}^2$  @ <300 keV
- ARM :  $5.3^\circ$  SPD :  $\sim 100^\circ$  @ 662 keV  
-> PSF :  $\sim 15^\circ$  @ 662 keV T. Tanimori+, ApJ, 2015

**SMILE-2+ @ Alice Springs (Apr. 2018)** 30 cm cubic, Ar 2 atm

- Observation of bright objects G.C. region & Crab nebula
  - eff. area :  $\sim 1 \text{ cm}^2$  @ 300 keV PSF :  $\sim 30^\circ$  @ 662 keV
- > detected G.C region ( $\sim 10\sigma$ ) and Crab nebula ( $\sim 3.5\sigma$ )

**SMILE-3** 30 cm hexagonal column, CF<sub>4</sub> 3 atm

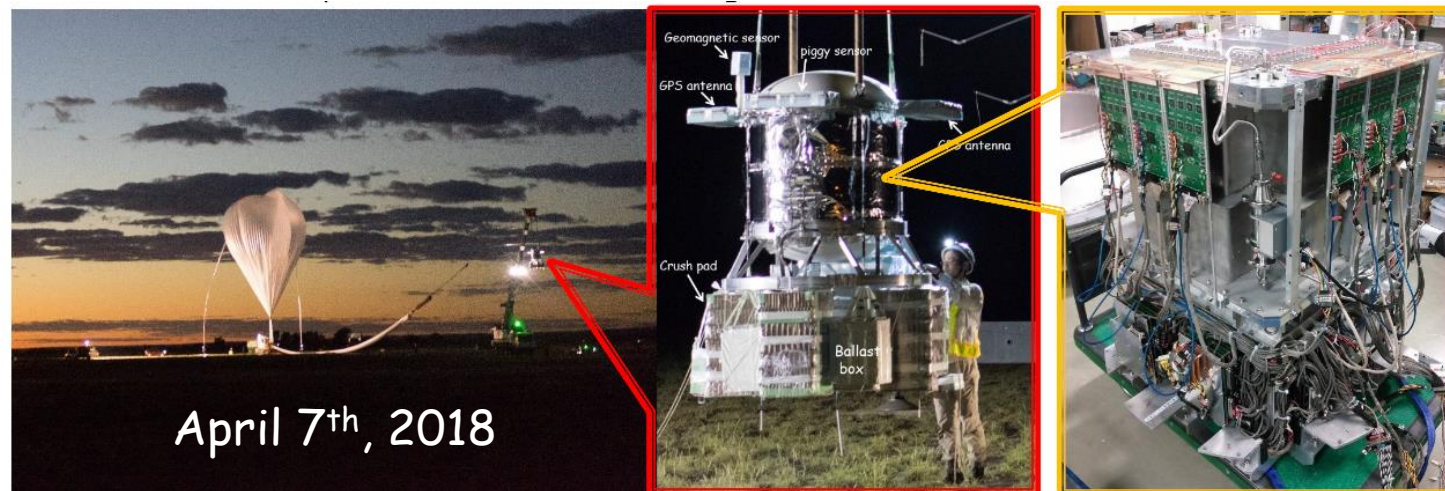
- Scientific observation loaded on a long duration balloon
  - eff. area :  $\sim 10 \text{ cm}^2$  @ <300 keV
- PSF :  $\sim 9^\circ$  @ 511 keV

**All skv survey with a satellite** 50 cm cubic, CF<sub>4</sub> 3 atm

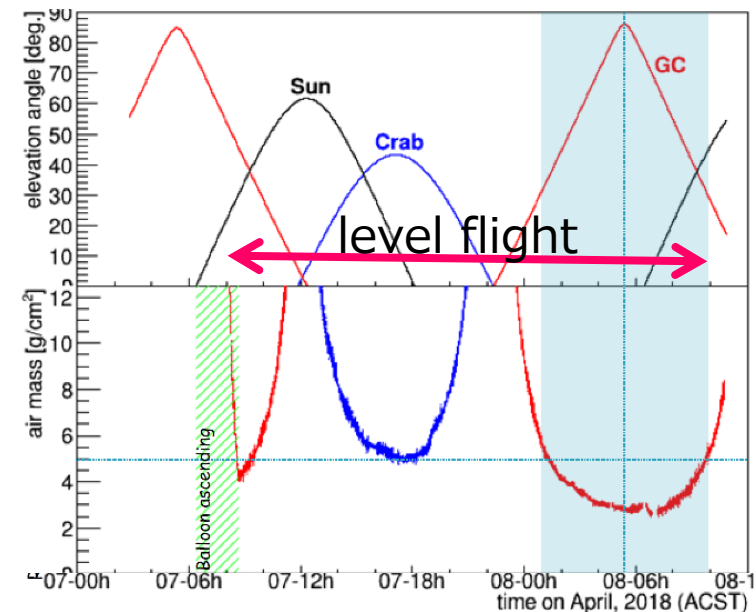
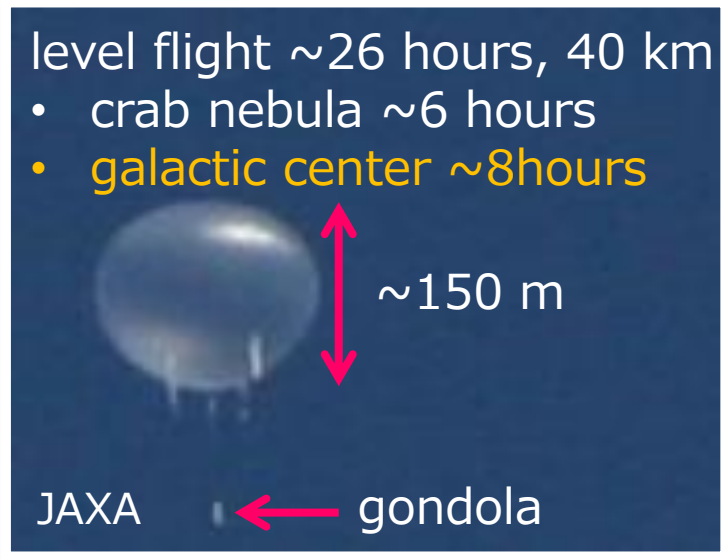
# Aim and Flight Overview of SMILE-2+

**Aim:**  
certification of the imaging spectroscopy of ETCC, using celestial objects

**Targets:**  
511 keV line and Diffuse gamma rays from Galactic Center Region, Cosmic diffuse gamma-rays, and Crab nebula

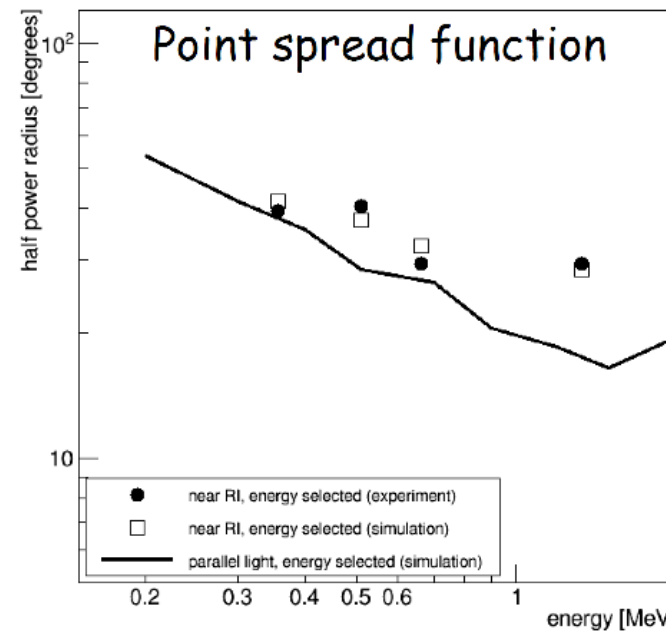
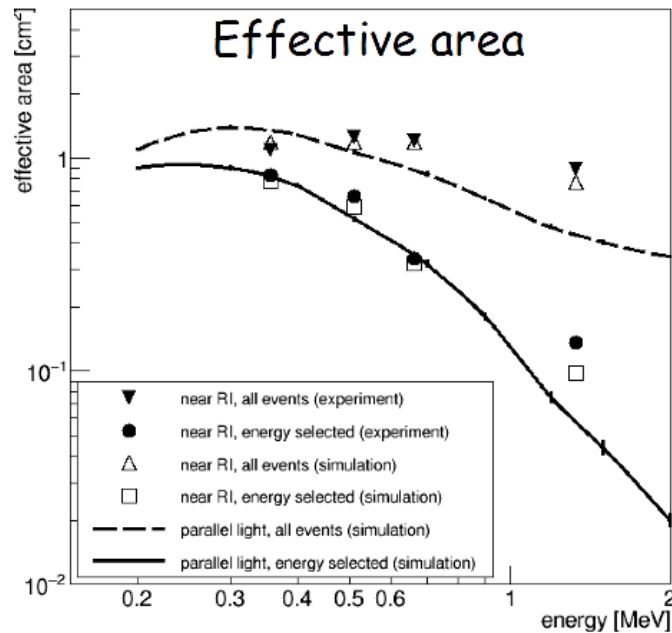
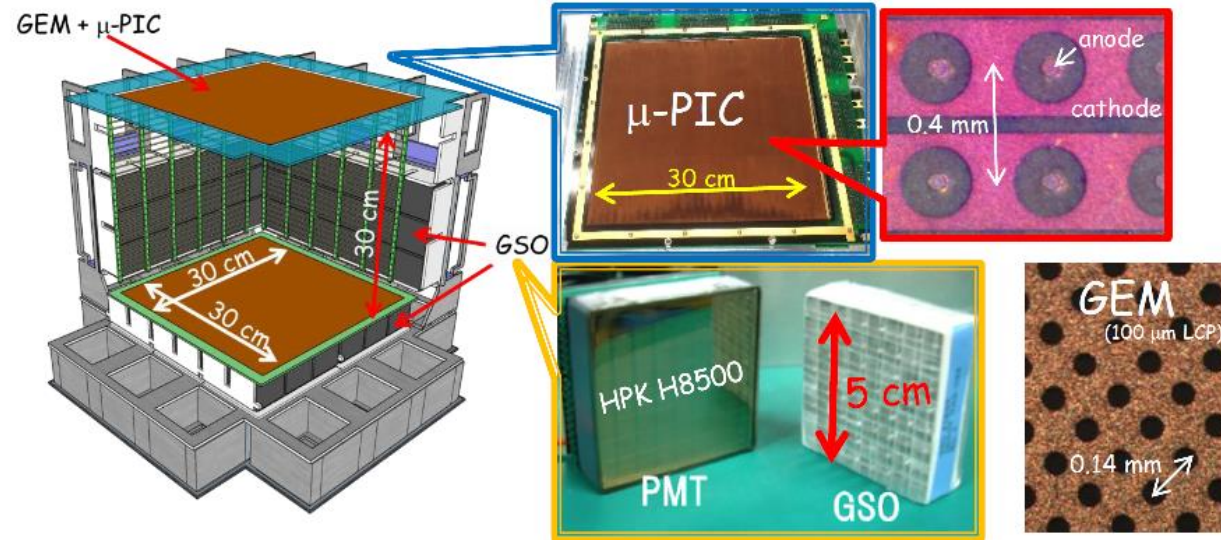
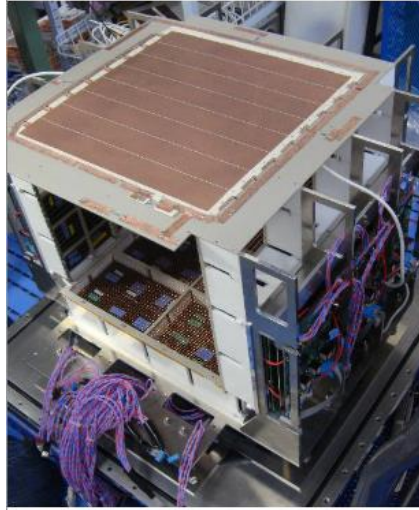


Launched from Alice Springs in Australia



We succeeded in the balloon flight as planned.

# Detector and Performance of SMILE-2+

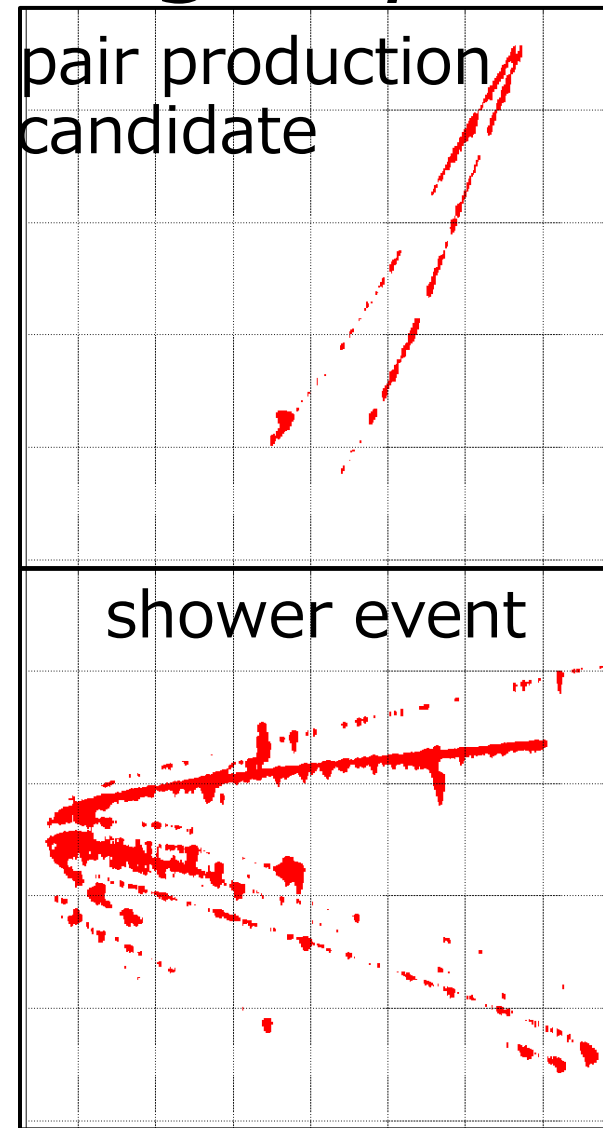
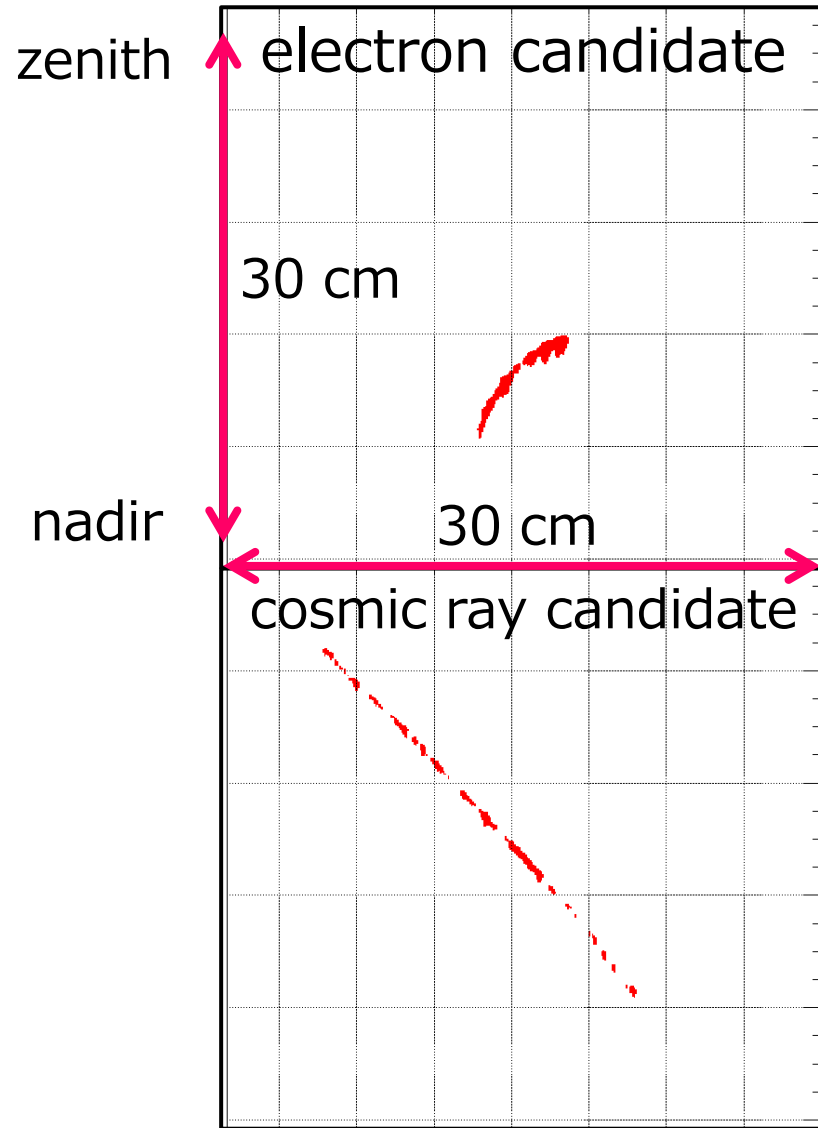


Effective area:  $\sim 1 \text{ cm}^2 @ 0.3 \text{ MeV}$

PSF:  $\sim 30 \text{ deg.} @ 0.6 \text{ MeV}$



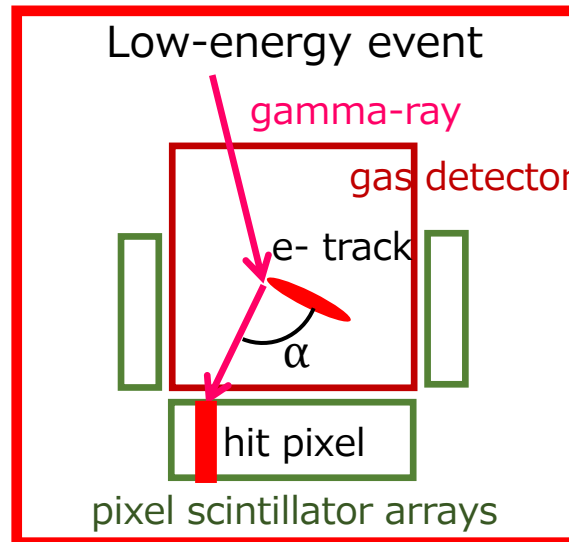
# Obtained tracks of charged particles



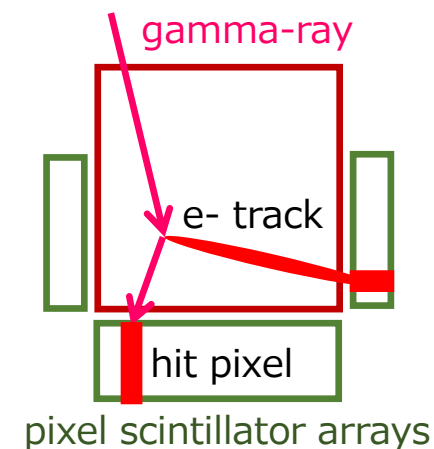
Our gas detector succeeded in getting charged particles.

# Method of Data Analysis

We have Two types of event analysis.  
Here we mainly present Low-energy event.

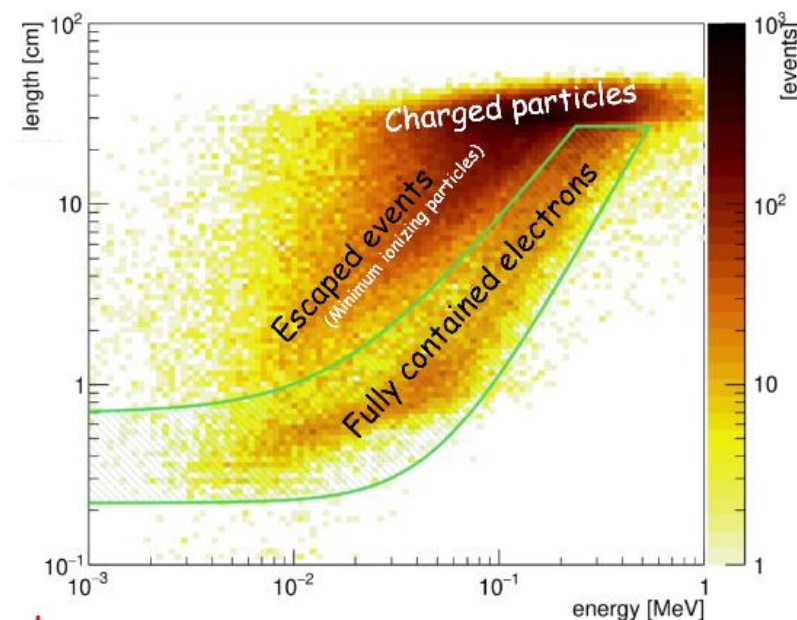


High energy event

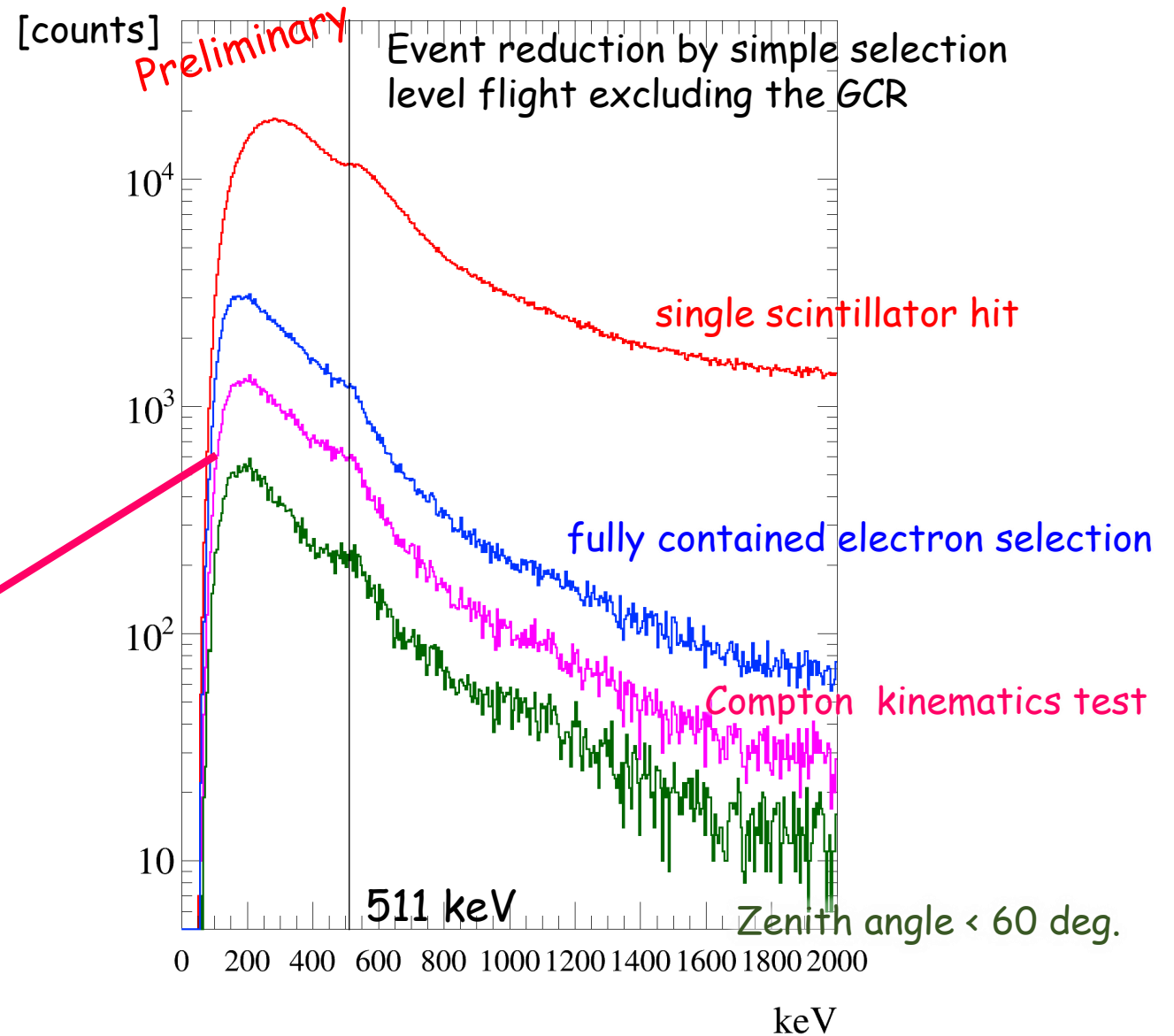
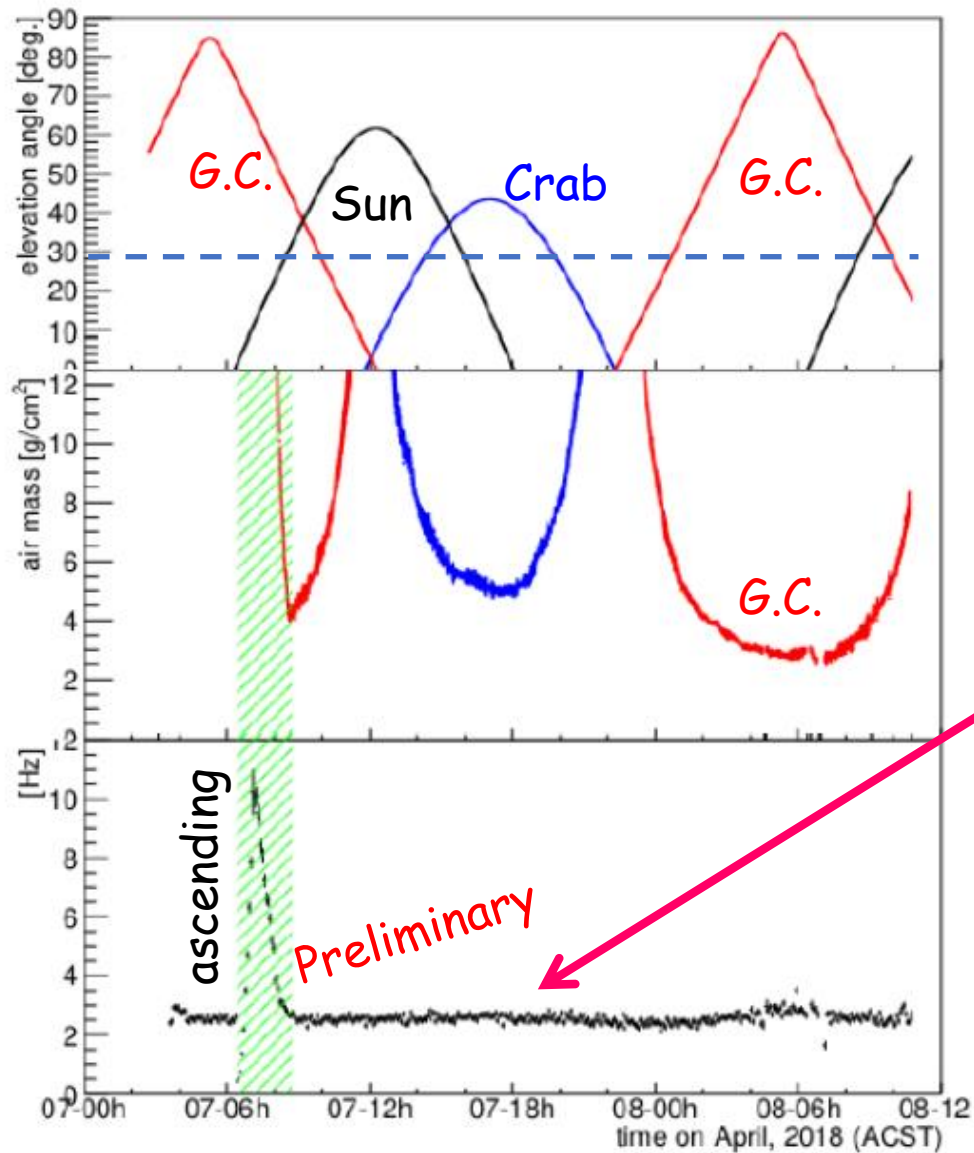


## Event selection

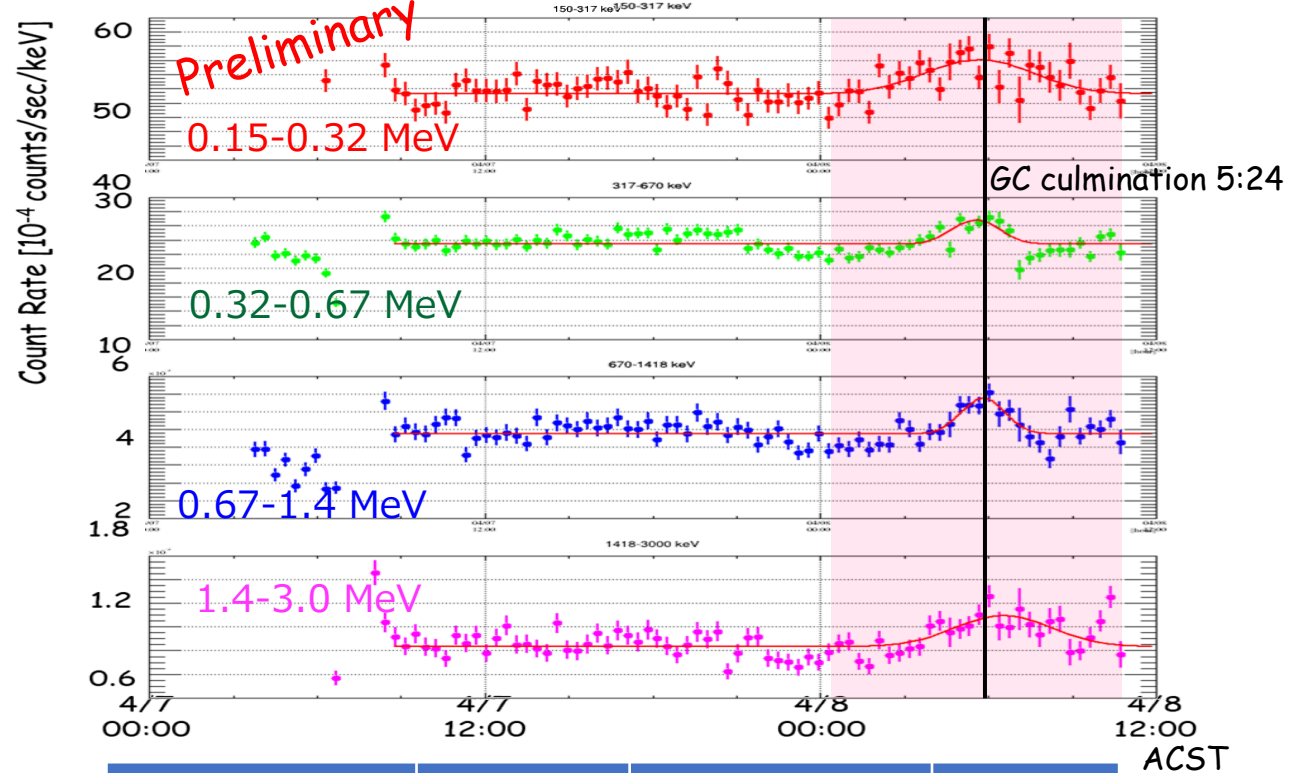
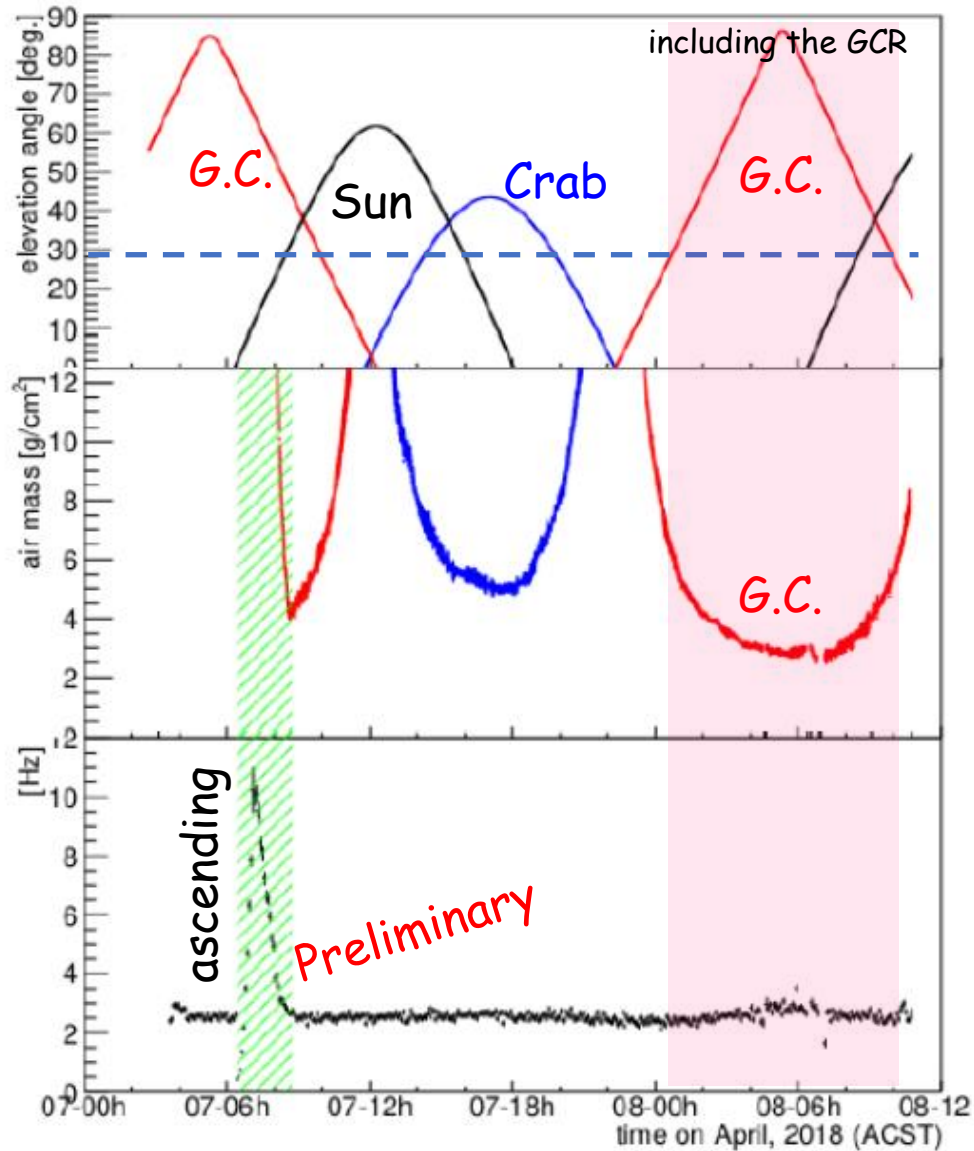
1. single scintillator hit
  2. fully contained electron selection
  3. certification of Compton kinematics  
using a angle selection
- Only simple selection
  - No heavy veto for gamma-rays



# Light curve after event selections



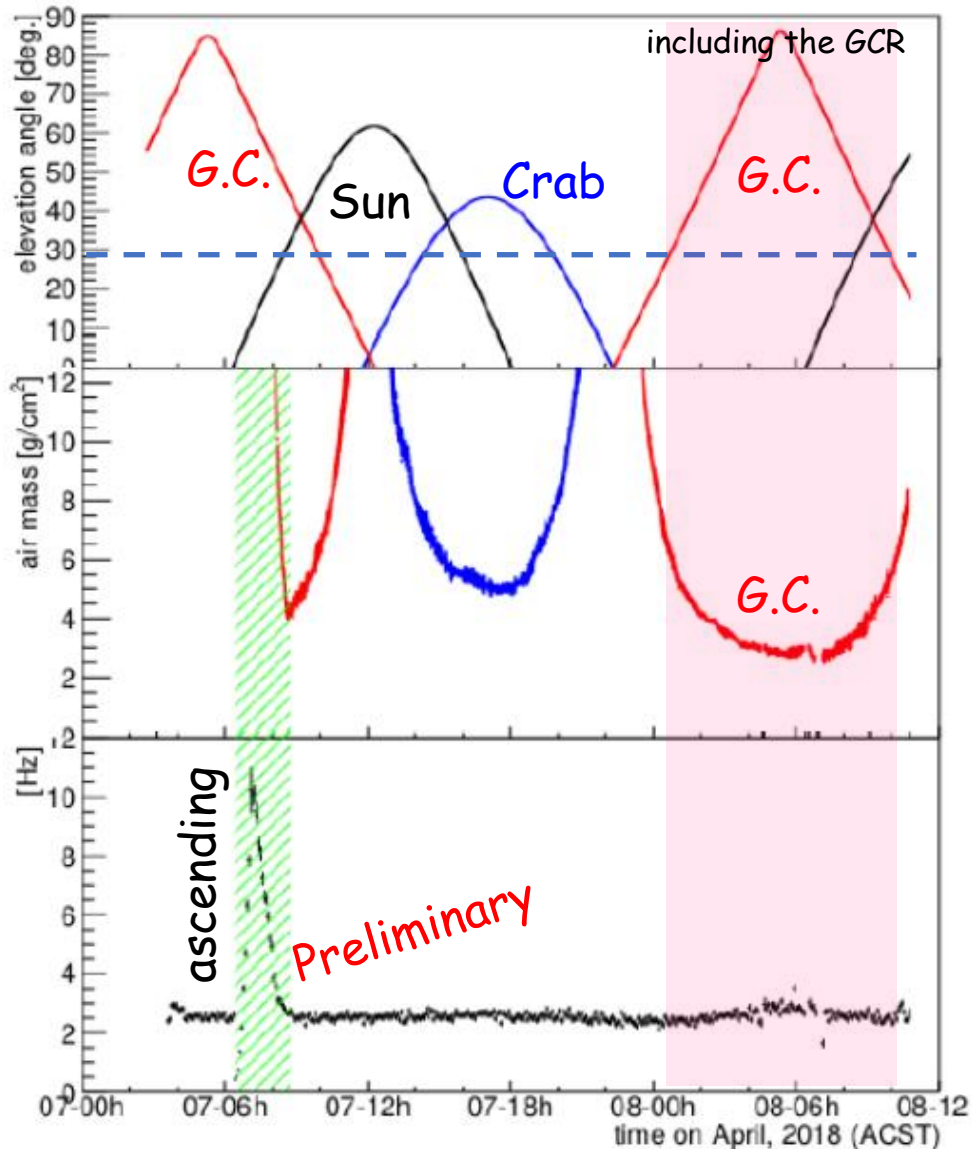
# Light curve after event selections



Energy [MeV]	Peak Time [ACST]	Peak Time Error [min]	Gauss 1 $\sigma$ [min]
0.15-0.32	5:10:32	22.3	116.6
0.32-0.67	5:02:40	11.1	50.7
0.67-1.4	5:18:08	9.8	45.6
1.4-3.0	6:02:42	12.7	103.8

All peak times are consistent with the culmination time.

# Light curve after event selections



- An excess appeared (total:  $\sim 10\sigma$ )  
@ air mass  $< 5 \text{ g/cm}^2$  for GC

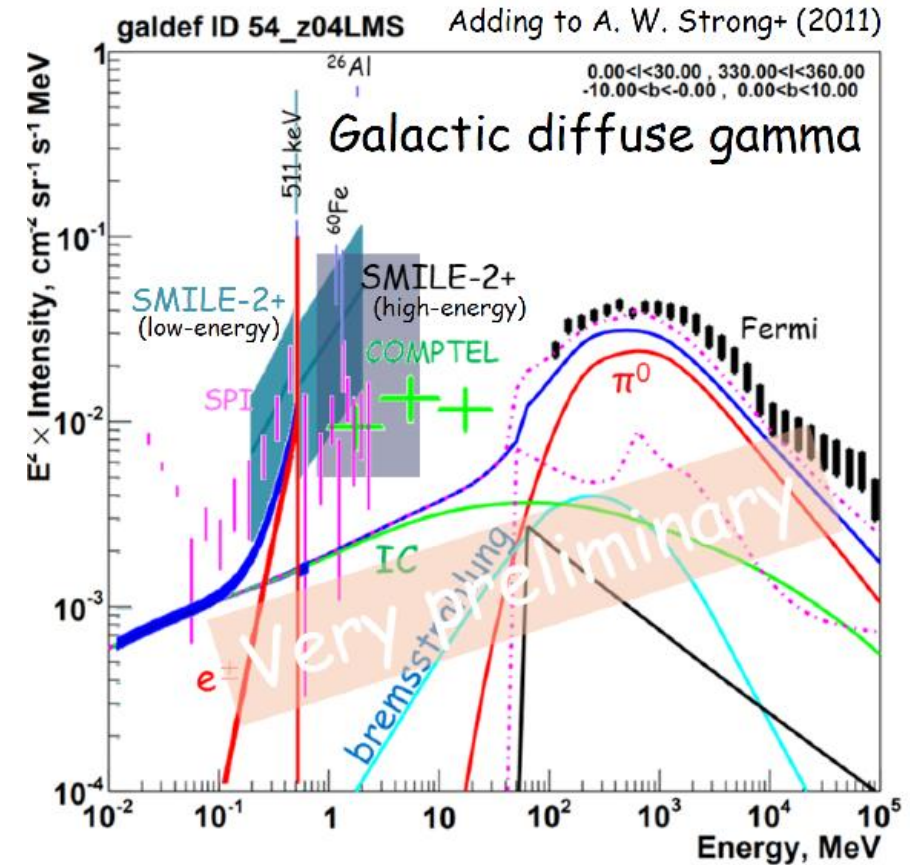
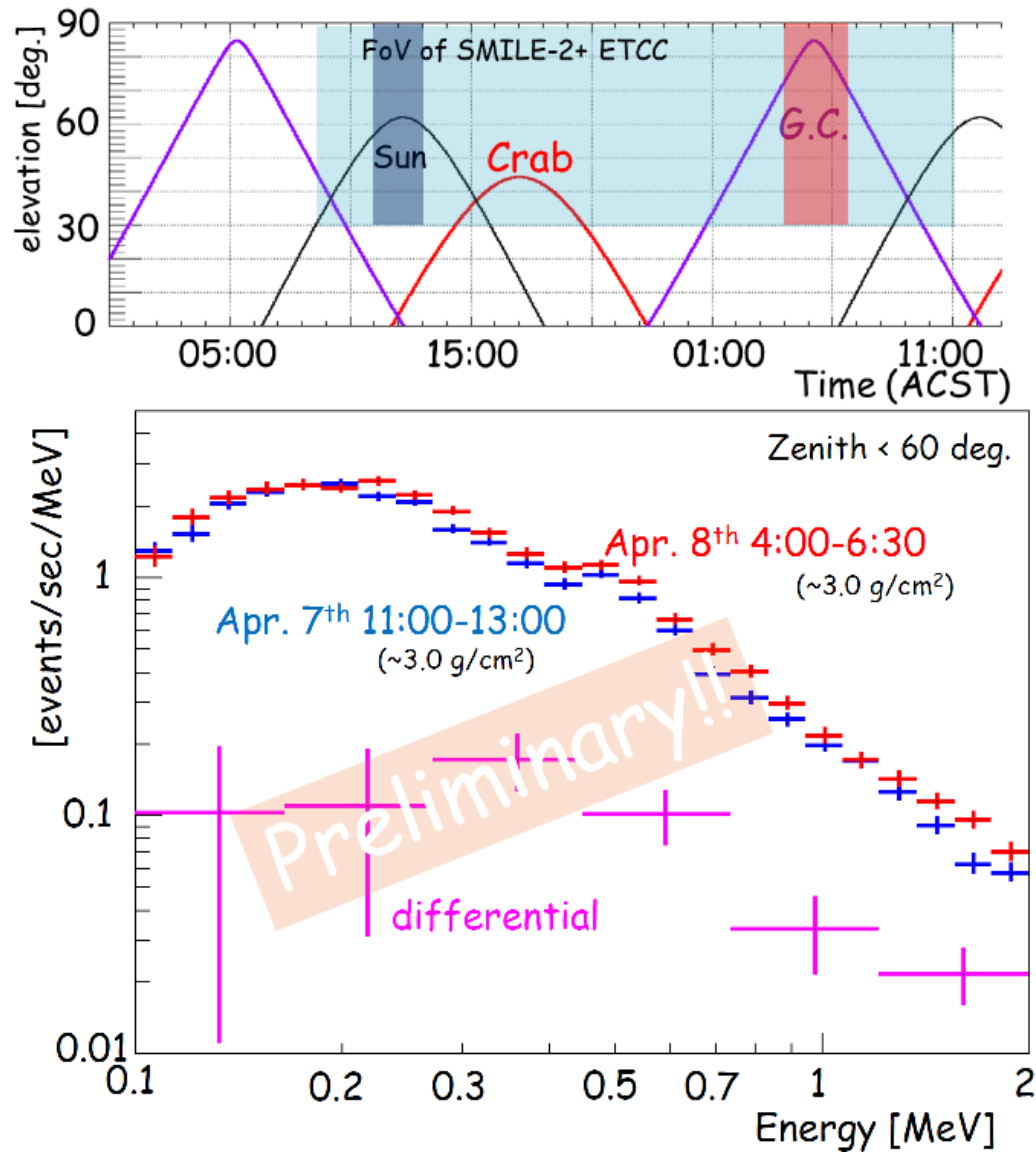
$\sim 0.5 \text{ Hz}$

$\rightarrow 10^{-2 \sim -1} [\text{ph/s/cm}^2/\text{sr/MeV}]$

$\approx$  past observation of  
galactic diffuse gamma

We possibly detected galactic  
center region by simple light curve.

# ON/OFF Analysis and Deconvoluted Spectrum



- Deconvoluted spectrum is consistent with SPI & COMPTEL.
- All of observations in MeV band have **an excess compared with the expected emission.**

# Future work in SMILE-3

What is origin ?

- Unresolved **celestial objects** ?  
-> (Crab @ G.C.)  $\times O(100)$
- Convolution of **some gamma-ray lines** ?  
-> de-excitation lines are not discovered
- Others ?  
-> evaporation of **primordial black holes** Carr+ (2010)  
-> annihilation of **dark matters** Ahn+ (2005)



Celestial-objects origin -> concentrate to galactic plane  
Dark matter origin -> like mass-distribution

● next balloon observation: **SMILE-3**

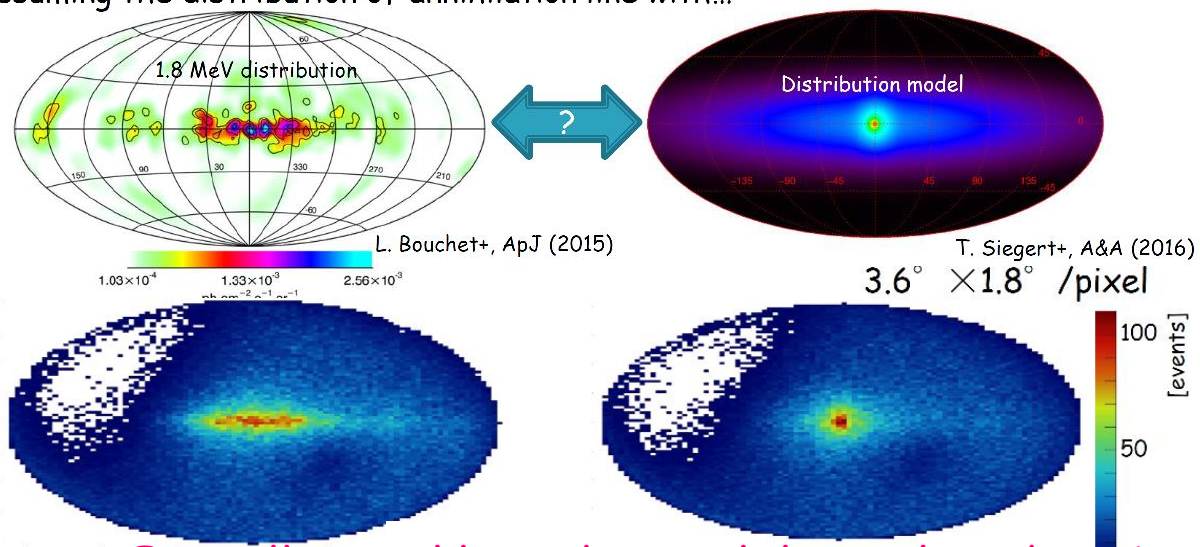
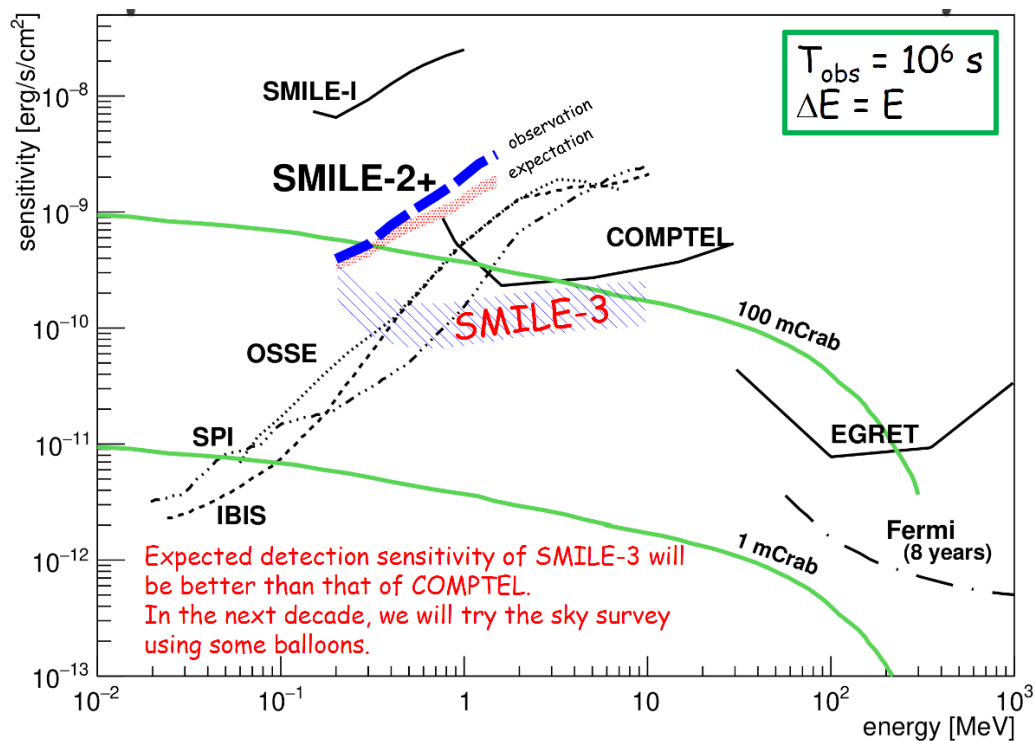
Effective area  $\sim 5 \text{ cm}^2$  @ 0.5 MeV

Spatial resolution  $\sim 10 \text{ deg.}$  @ 0.5 MeV

Altitude 40 km, 30 days, Southern hemisphere

● **SMILE-3 will get  $10^2 - 10^3$  times data than SMILE-2+.**  
**(continuum and annihilation line)**

Assuming the distribution of annihilation line with...



● **SMILE-3 will reveal how the annihilation line distributes.**

# Summary

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- In MeV band in the GCR, observation data is higher than theoretical line (IC). The candidates which make the enhancement are unidentified point sources, nuclear gamma-rays, and light dark matter etc..
- ETCC provides Imaging Spectroscopic and high S/N ( $\sim 1$ ) observations.
- The aim of SMILE-2+ is to certificate imaging performance of ETCC using celestial objects.
- Observation times of the galactic center region were  $\sim 8$  hours.
- Because of High S/N, the light curves have the peaks whose times are consistent with the culmination.
- We expect to reveal both Spectra and Intensity map in SMILE-2+ data.
- Next Balloon observation, SMILE-3 is long duration balloon (one month).  
The sensitivity of SMILE-3 is 5-10 times better than COMPTEL.  
We will get  $10^2 - 10^3$  times data for Galactic diffuse continuum and annihilation line, and reveal how the annihilation line distributes.

Thank you.