



# MeVガンマ線による宇宙探査

高田 淳史 (京大理)



# MeV gamma-ray astronomy

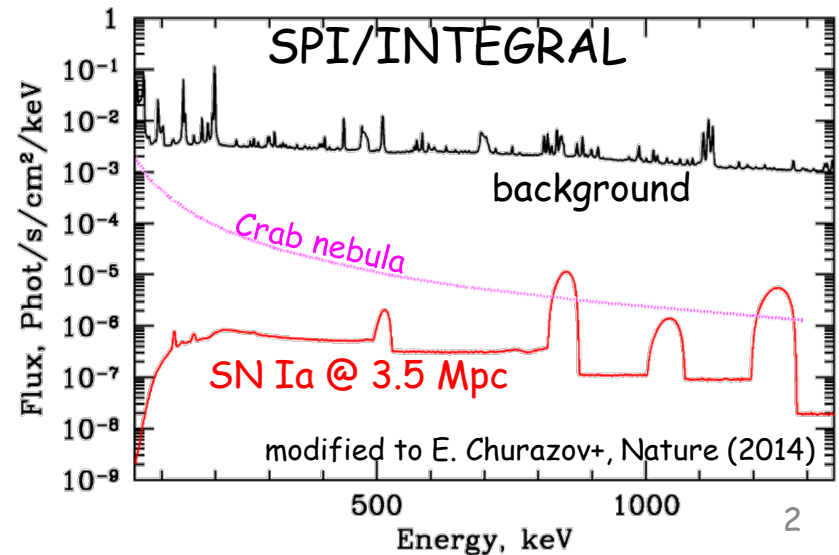
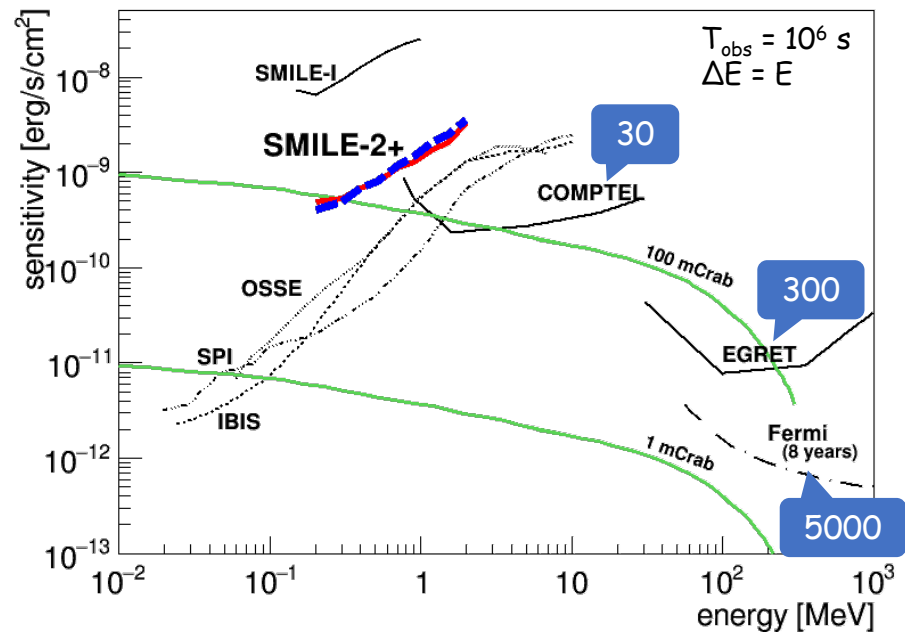
## ➤ Line gamma-ray

- Short-lived RIs  
 $^{56}\text{Ni}/^{56}\text{Co}$ ,  $^{44}\text{Ti}$   
 $\Rightarrow$  nucleosynthesis
- RI with lifetime of  $\sim 10^6$   
 $^{26}\text{Al}$ ,  $^{60}\text{Fe}$   
 $\Rightarrow$  diffusion in galaxy
- Electron-positron annihilation
- De-excitation of  $^{12}\text{C}^*$ ,  $^{16}\text{O}^*$   
 $\Rightarrow$  low-energy CR

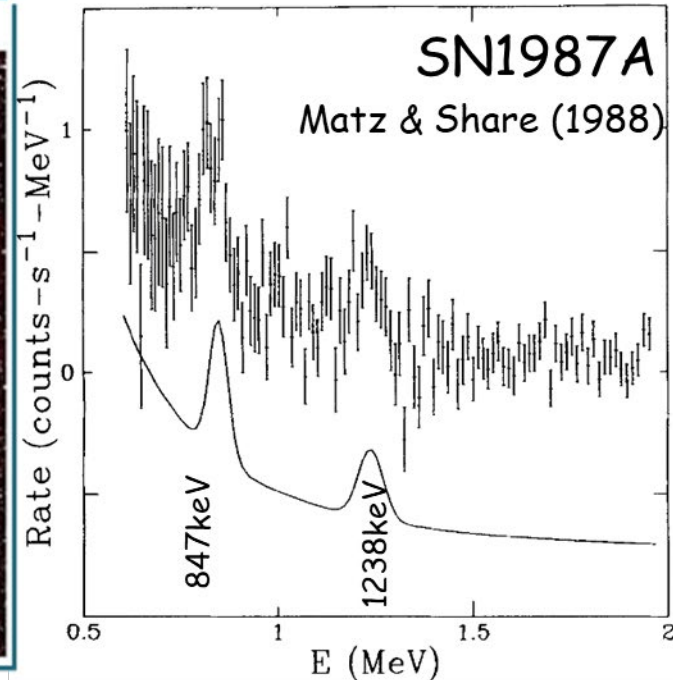
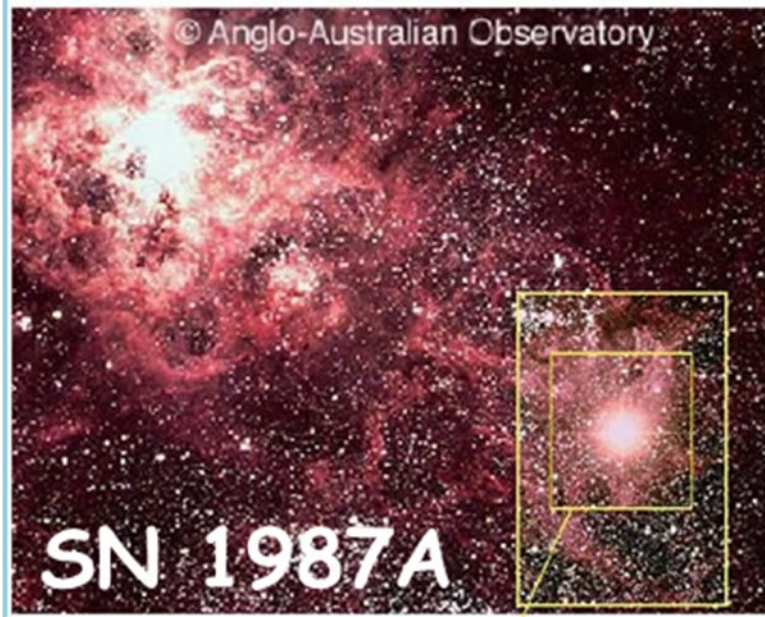
## ➤ Continuum component

- Synchrotron + Inverse Compton
- $\pi^0$ -decay  
 $\Rightarrow$  particle acceleration
- Hawking radiation ( $\sim 10^{16-17}$  g)
- Annihilation of DM  
 $\Rightarrow$  new physics

S/N needs to be improved  
to increase detection sensitivity

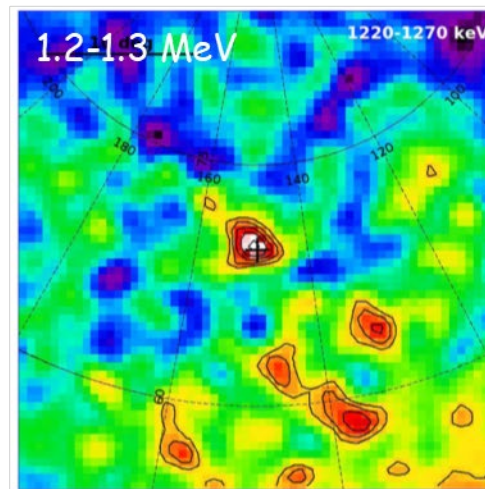
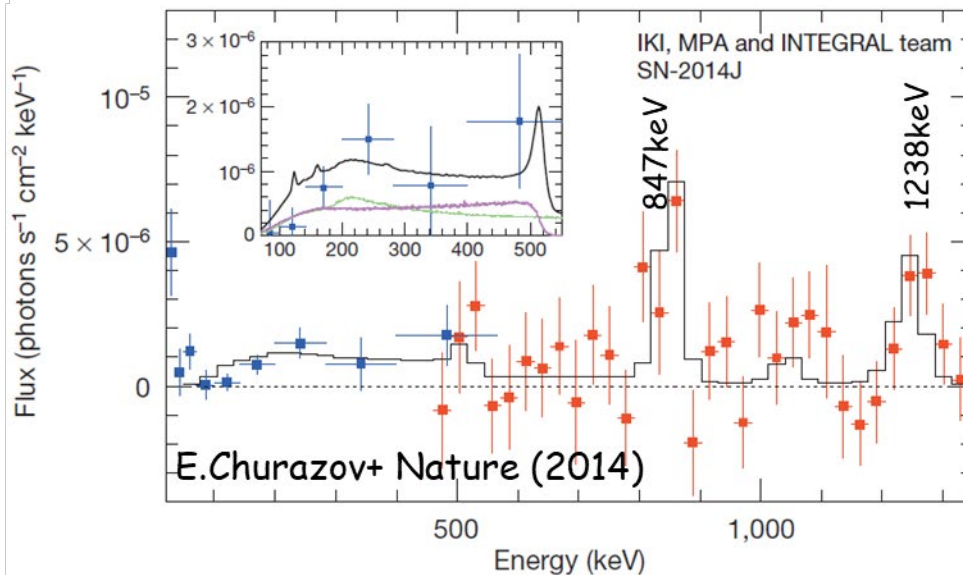


# 大マゼラン星雲の超新星1987A



## Broad band SN2014J spectrum and the model (day 75)

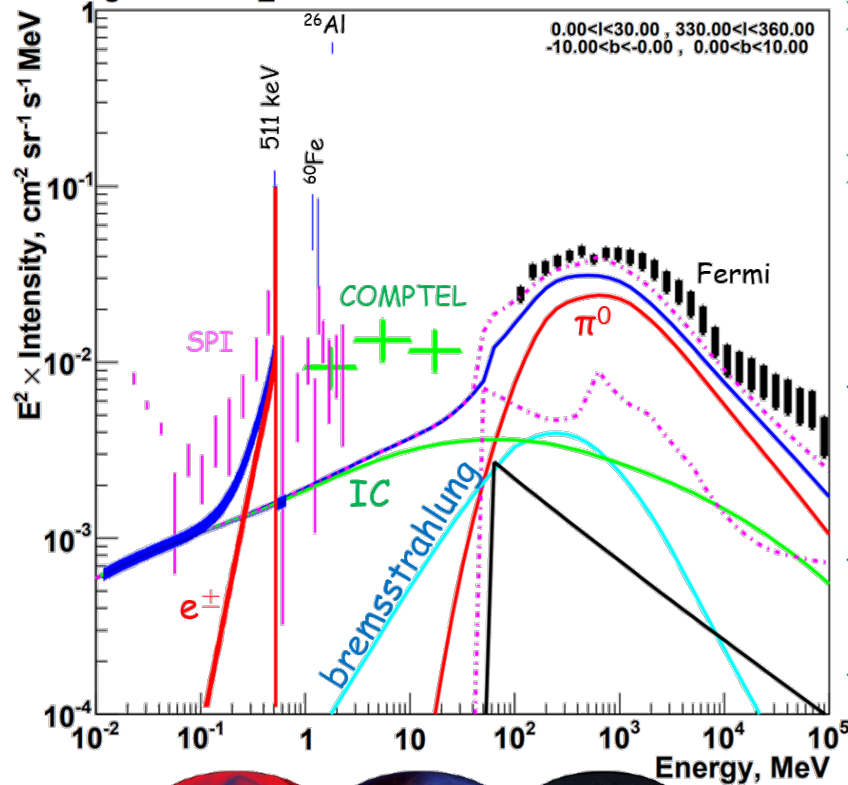
Fluxes of 847 and 1238 keV lines + continuum below 511 keV



# Galactic diffuse gamma-rays

galdef ID 54\_z04LMS

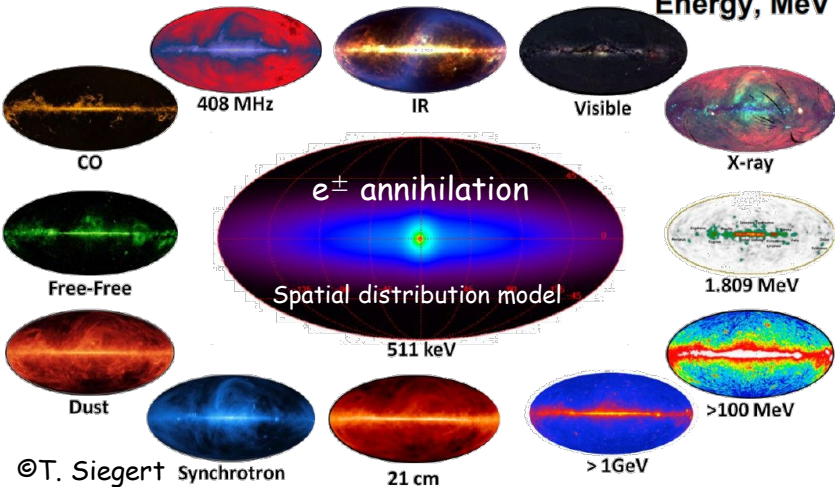
modified of A. W. Strong (2011)



- **Continuum in MeV band**
  - Stronger intensity than expectation of IC
  - Characteristic emission in MeV band
- **Annihilation line of  $e^\pm$** 
  - Origin of positron is unknown
  - Spatial distribution different from other band



- ◆ **Dark matter** intensity  $\propto$  density<sup>2</sup>
  - annihilation or decay of light WIMPs
  - > electron, positron, gamma-ray
- ◆ **Primordial black holes** intensity  $\propto$  density
  - $\sim 10^{16-17}g \Rightarrow$  Hawking radiation at  $\sim$ MeV
- ◆ **Convolved point source** Concentrate to galactic plane
  - Bright objects in MeV are unknown
- ◆ **Interaction between CR and ISM** Concentrate to galactic plane
  - expectation is 1/10 of intensity by IC



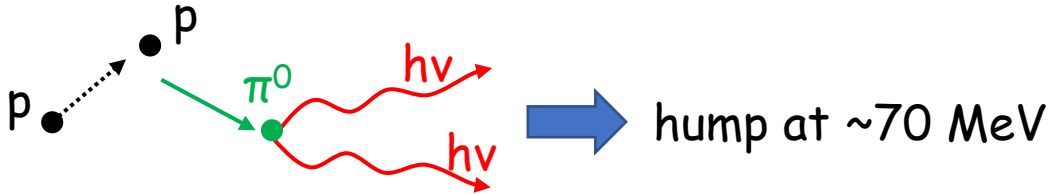
Our galaxy is common galaxy  
Center region is bright in MeV



**Extragalactic diffuse gamma-ray will have same radiation component.**

# Low-energy Cosmic-ray

➤ Production of  $\pi$ -meson  $\Rightarrow$  over  $\sim 300$  MeV



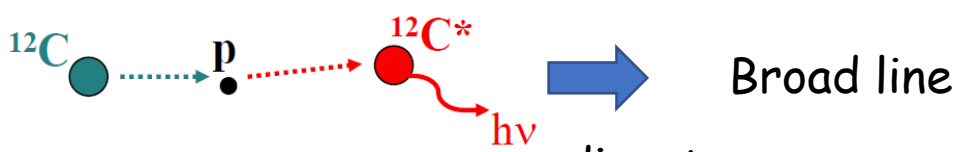
hump at  $\sim 70$  MeV

Energy spectrum at  $< 50$  MeV is important

➤ Excitation of nuclei  $\Rightarrow < 100$  MeV



Narrow line

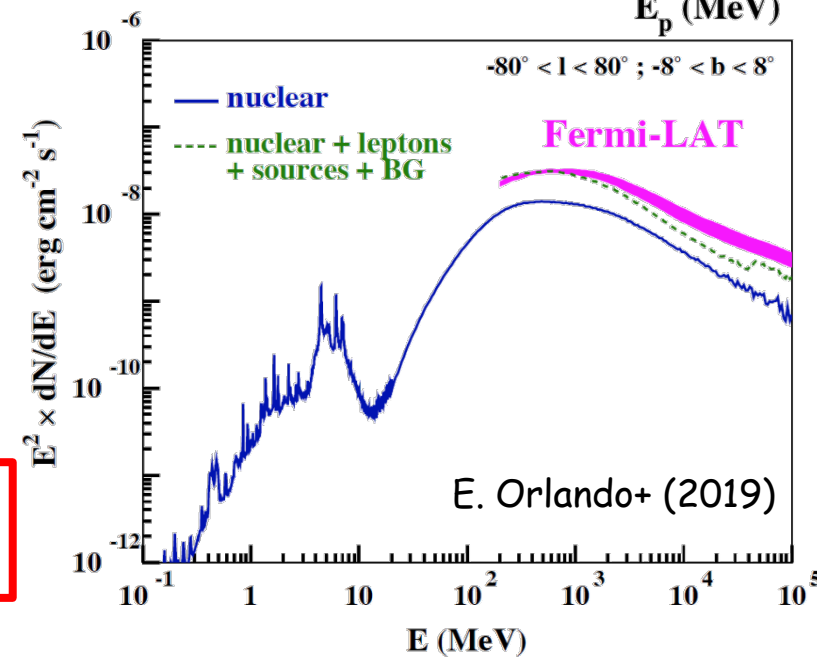
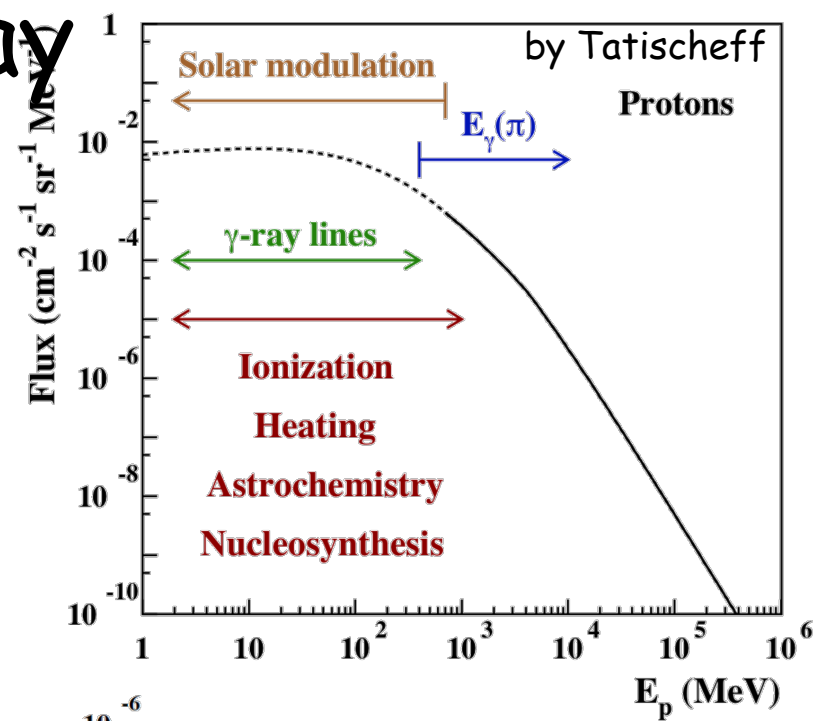


Broad line

$^{12}\text{C}^*$  4.439 MeV  
 $^{16}\text{O}^*$  6.129 MeV  $\Leftrightarrow$  direct measurement of total amount of low-energy CR

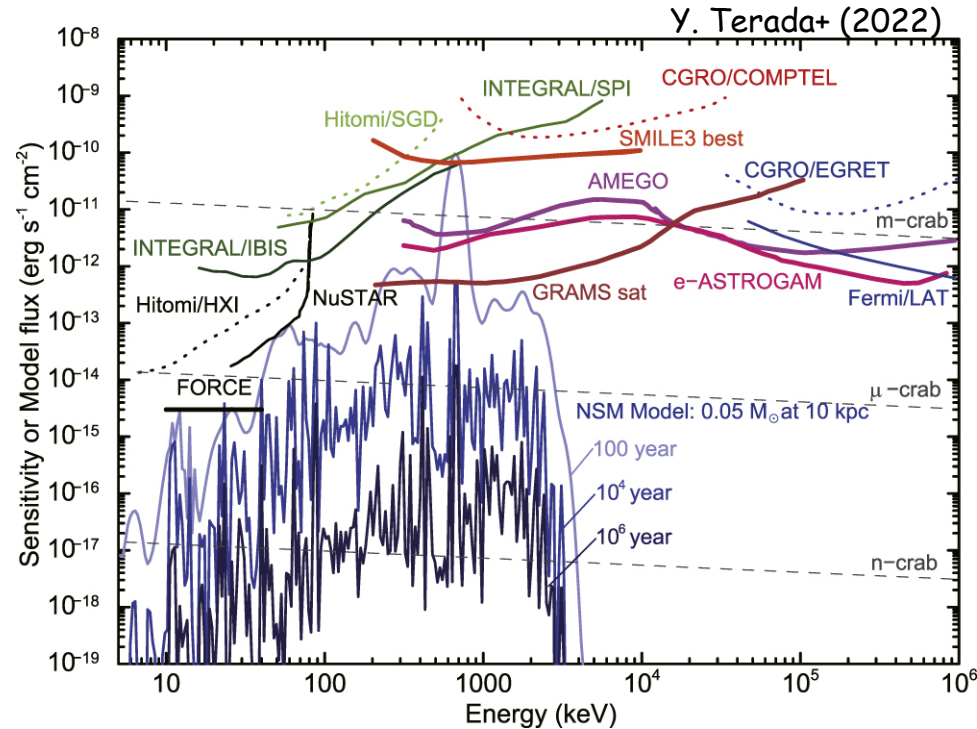
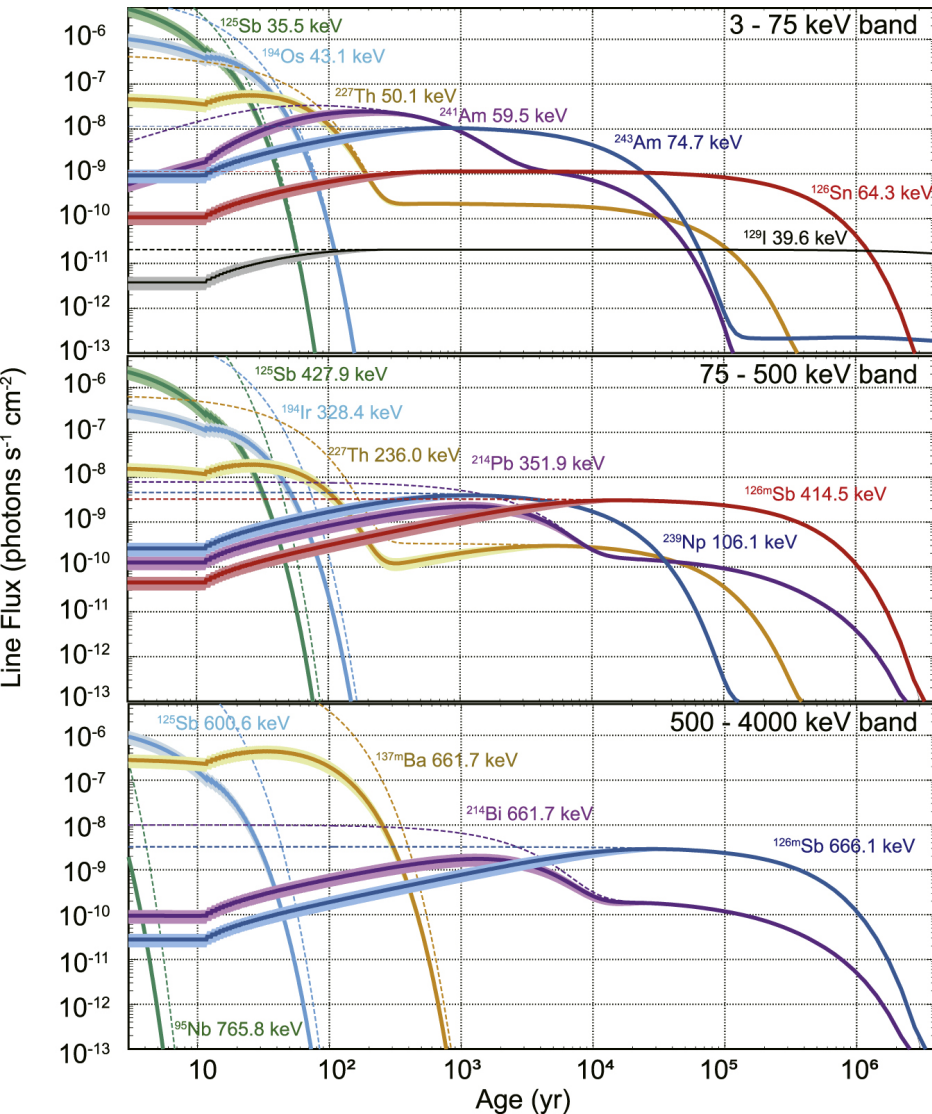
Characteristic structure @ 3-10 MeV

MeV gamma-ray is a very important probe for the existence of low-energy CR.



# History of Galactic NS-merger

Y. Terada+ (2022)

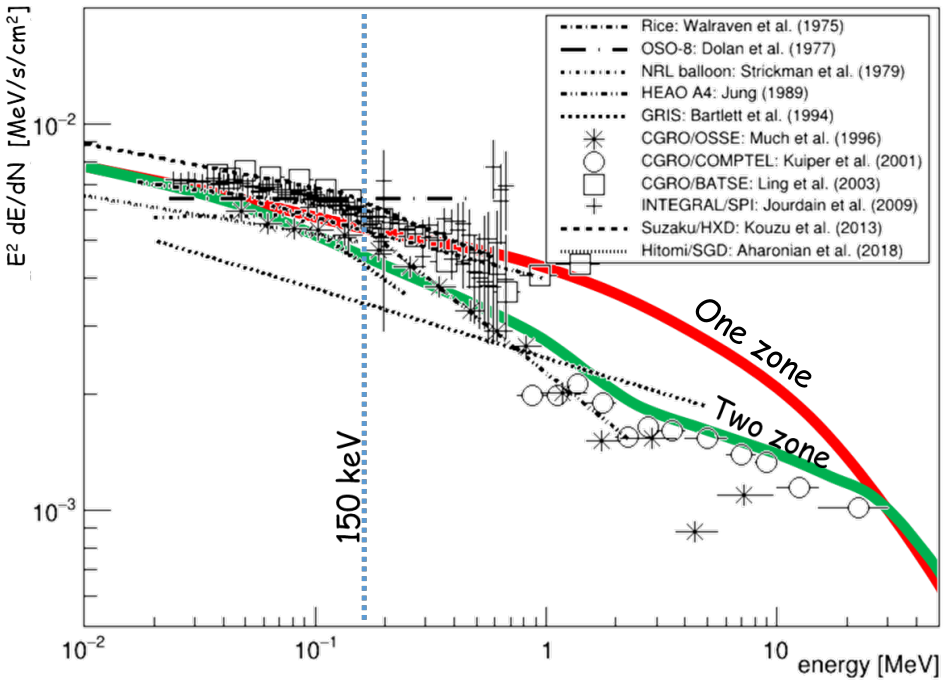
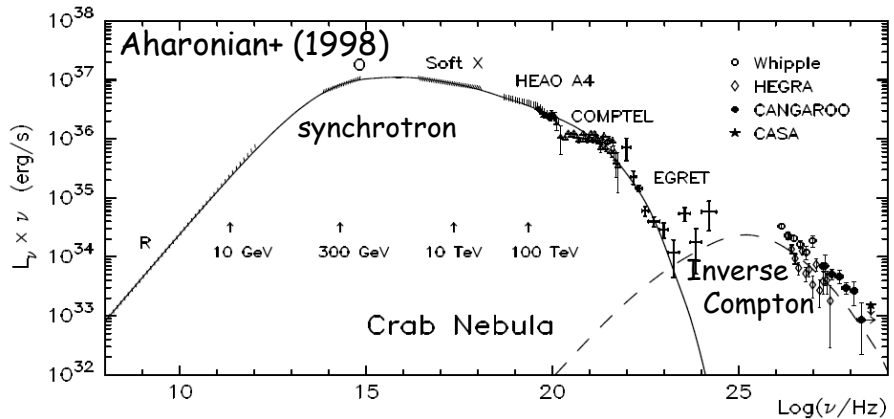
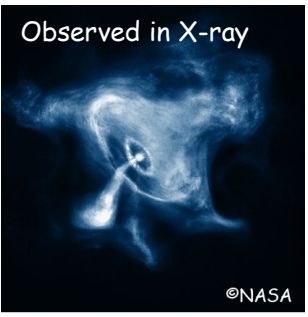


Y. Terada+ (2022)

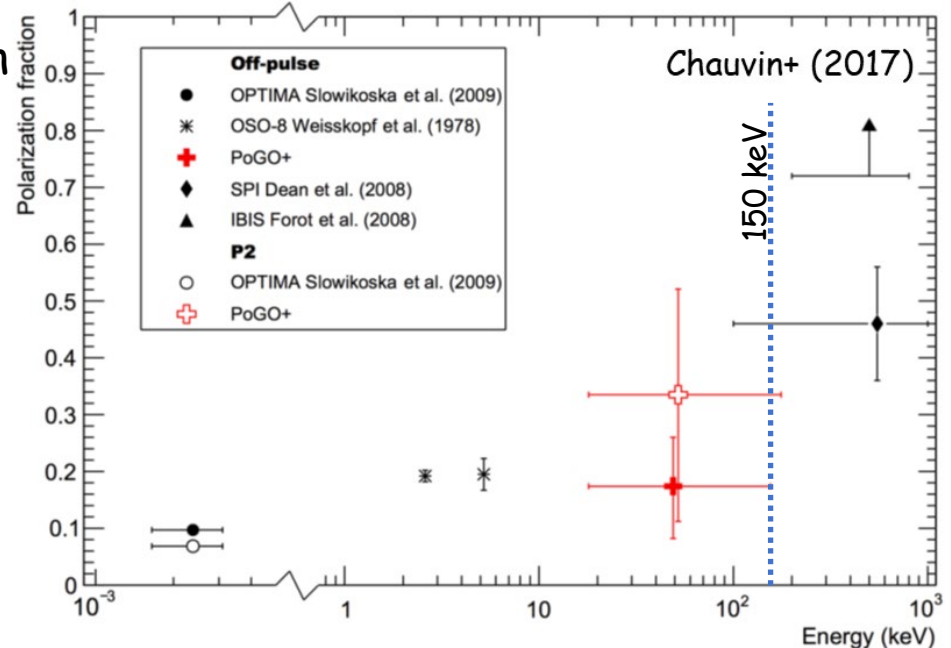
RIs produced by r-process in NS merger  
 -> If NS-merger occurred in our galaxy,  
 line gamma-rays from remnant would  
 be detected.

Observation of line gamma-rays  
 become searching past NS-merger.

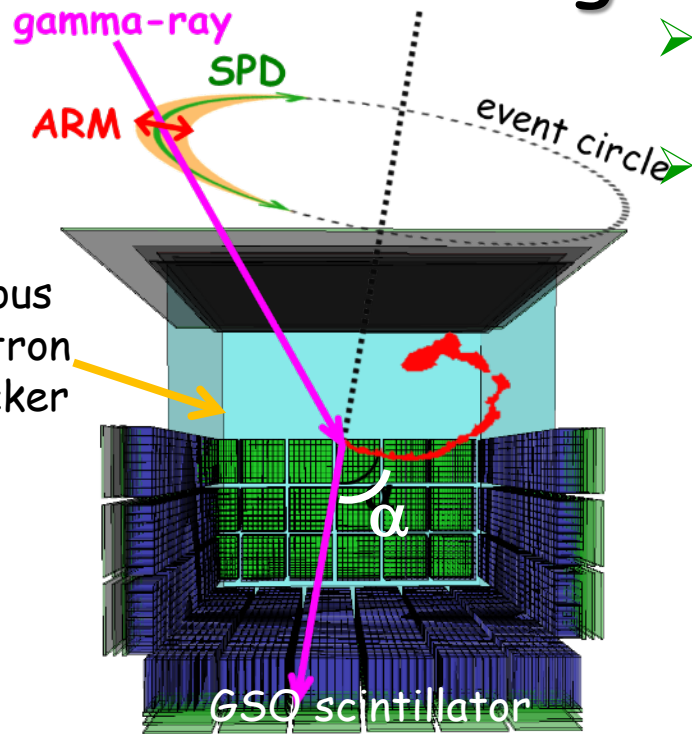
# Crab nebula



- Radiation in MeV
  - > Synchrotron by PeV electron
- Observations suggest...
  - hard @ 1-30 MeV? Kuiper+ (2001)
  - break at ~150 keV? Jourdain+ (2009)
- Some suggest that the observed spectrum is the sum of radiation from different regions. Aharonian (1998) Lyutitov+ (2019)
- Crab nebula is a point source in MeV
  - > Detailed energy spectrum @ ~1 MeV



# Electron-tracking Compton camera (ETCC)



## Gaseous tracker

Track & energy of recoil electron

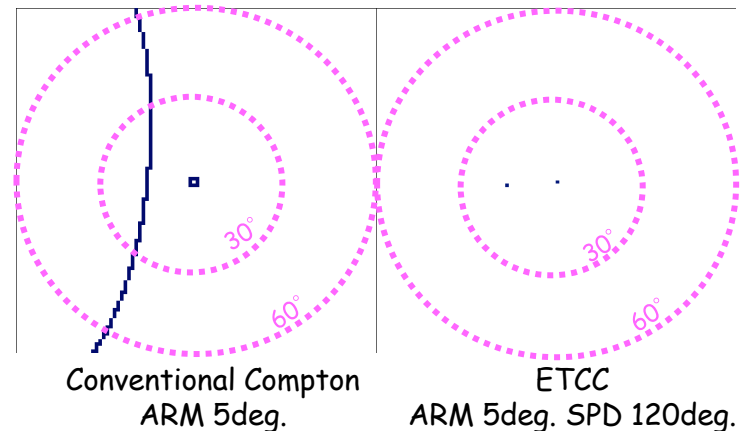
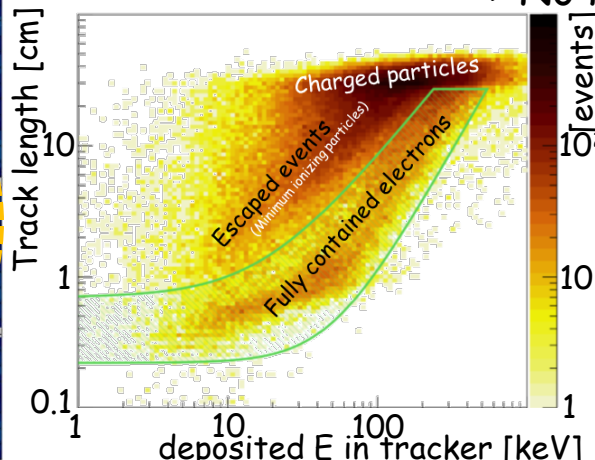
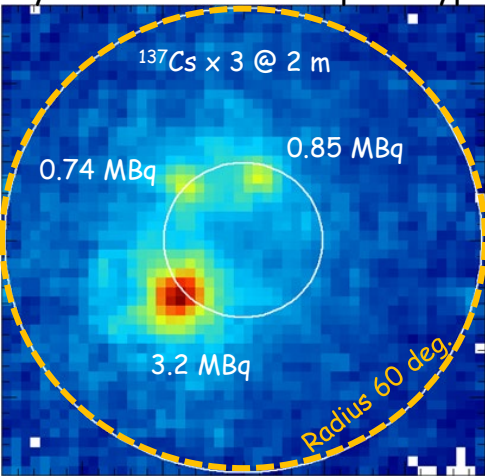
## pixel scintillator array

position & energy of scattered gamma

Reconstruct Compton scattering with momentum conservation

- **Bijection function**  
-> same as ordinary telescopes
- PSF with same definition as ordinary telescopes  
-> Gamma-rays outside region of interest are eliminated simple ON-OFF method.
- **Compton kinematical test with angle  $\alpha$**   
**Particle identification with  $dE/dx$**   
-> No heavy VETO & large FoV of 3 sr

Obtained gamma-ray image by 30 cm-cubic ETCC prototype





# Sub-MeV/MeV gamma-ray Imaging Loaded-on-balloon Experiments

- ✓ **SMILE-I** (Sep. 2006, Sanriku, 4h)
  - Observation of atmospheric/diffuse cosmic gammas
  - Background rejection with particle identification

Effective area 1 mm<sup>2</sup>  
Xe + Ar 1 atm

A. Takada+, ApJ (2011)

- ✓ **SMILE-2+** (Apr. 2018, Alice Springs, 26h)
  - Detected galactic center region ( $\sim 8\sigma$ ), Crab ( $\sim 4\sigma$ )
  - Obtained by ON-OFF method

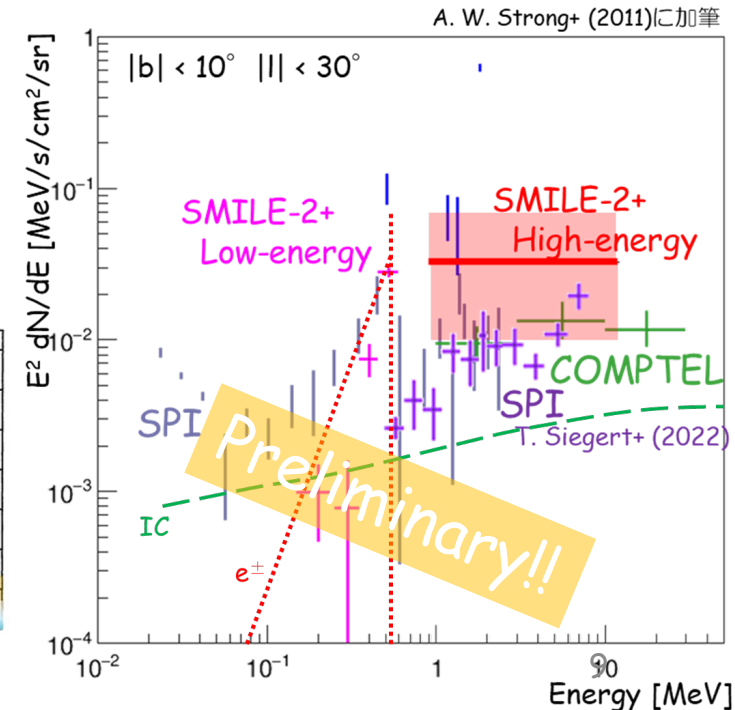
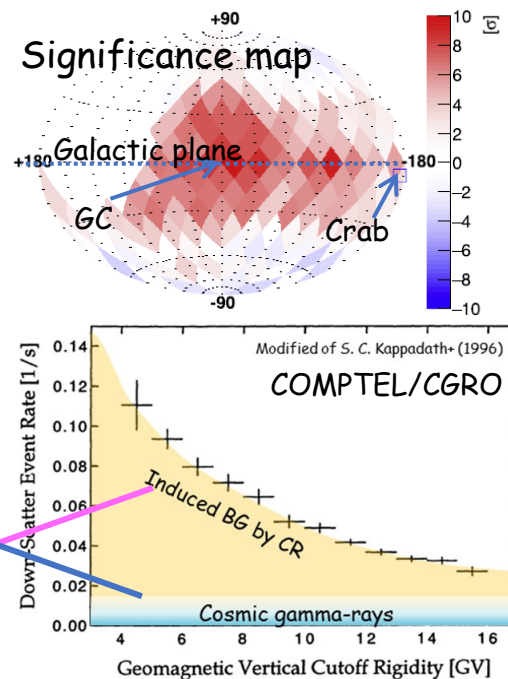
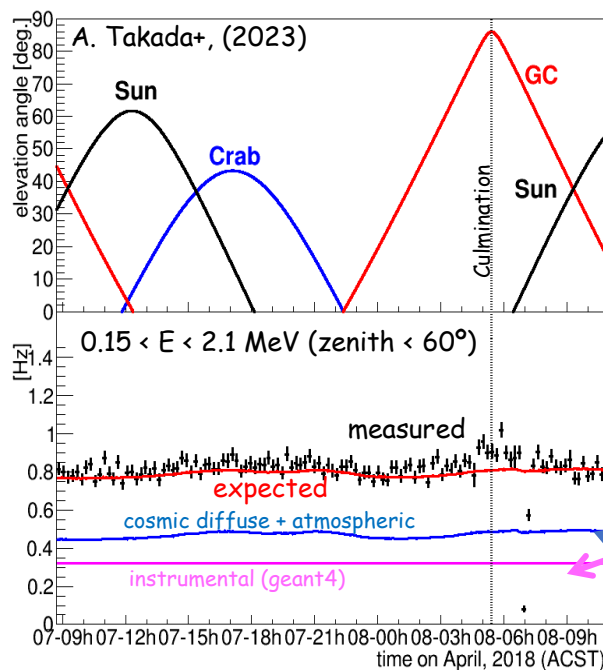
Effective area 1 cm<sup>2</sup>  
Ar 2 atm

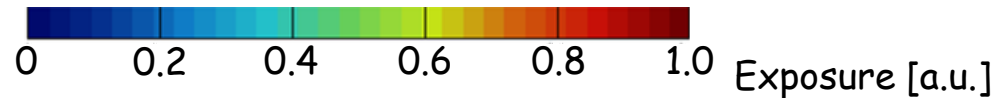
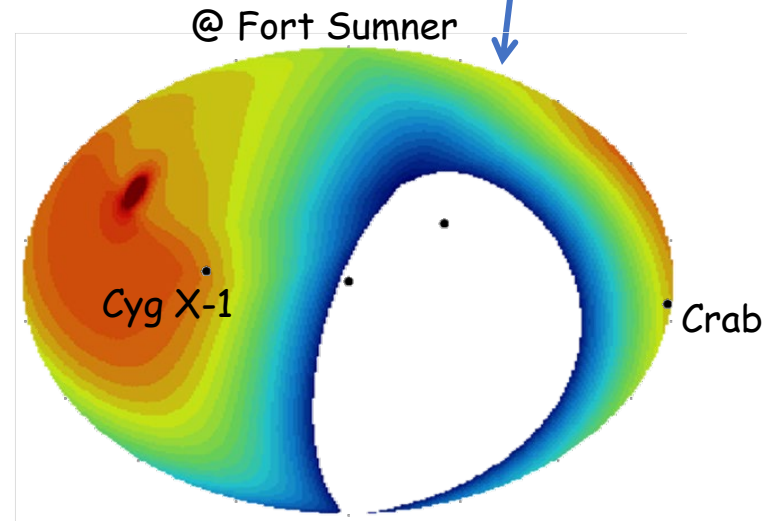
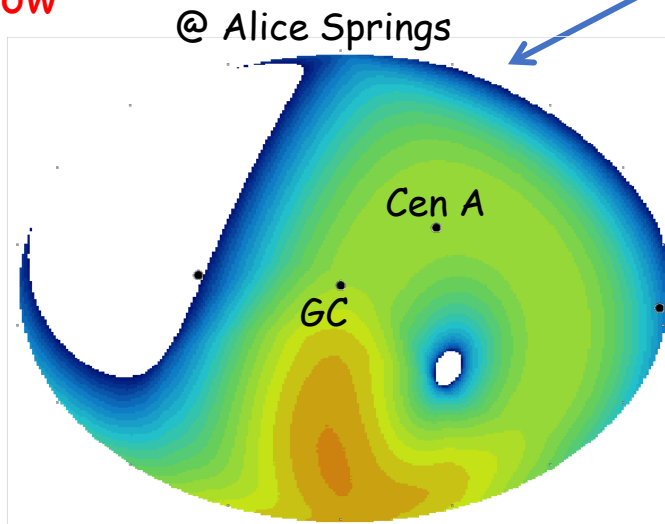
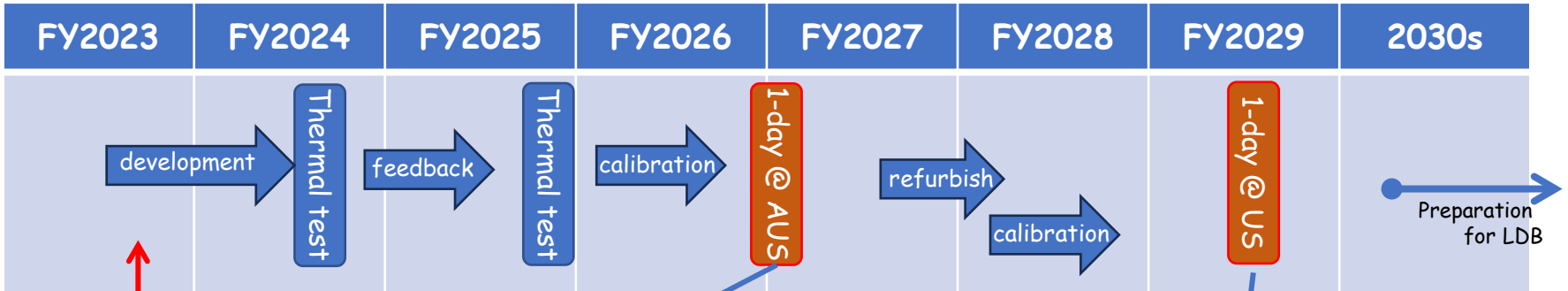
T. Tanimori+, J. Phys CS (2020)

A. Takada+, ApJ (2022)

T. Ikeda+, submitted (2023)

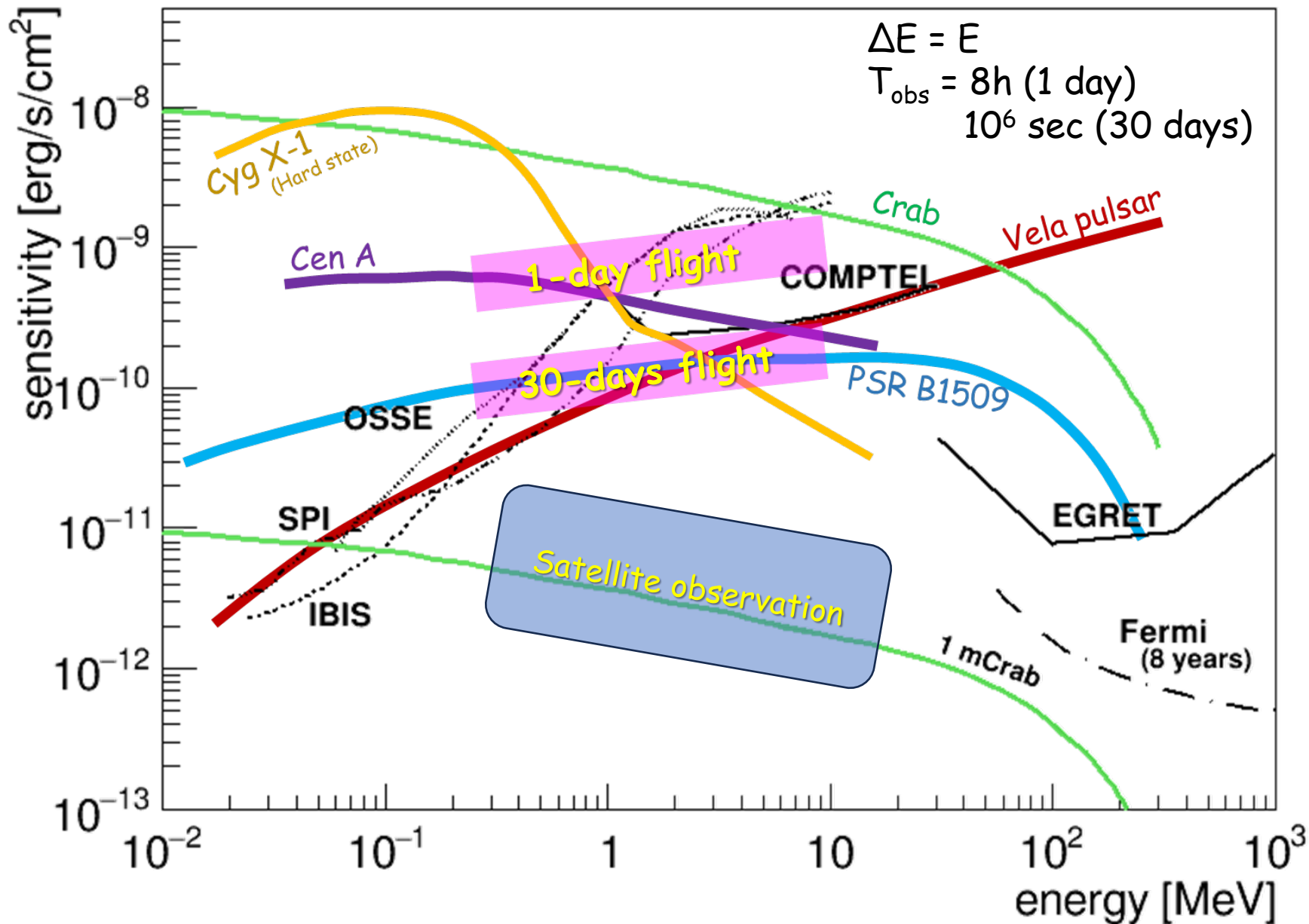
Demonstrations are completed -> scientific observation **SMILE-3**





- 2027 spring : 1-day flight @ Australia (ISAS)
  - > Galactic Center region
- 2029 fall : 1-day flight @ US (NASA)
  - > Cyg X-1 • Crab & test flight for Long duration balloon
- 2030s : Long duration balloon (NASA)
  - > Galactic Center region • Cen A • Sky of southern hemisphere

# Expected detection sensitivity



Thank you for your attention!  
<http://www-cr.scphys.kyoto-u.ac.jp>

