THE e-ASTROGAM MISSION

Filling the gap between MeV and GeV
~ *eASTROGAM* and *CAST* ~

Kazuhiro Nakazawa（U.Tokyo）

15-16 Dec. 2016 "The extreme Universe viewed in very-high-energy gamma rays 2016" @ ICRR

This talk is supported by…

eASTRAOGAM Collaboration (for ESA-M5)

Alessandro De Angelis, Vincent Tatischeff, Marco Tavani, Uwe Oberlack, Isabelle Grenier, Lorraine Hanlon, Roland Walter, Andrea Argan, Peter von Ballmoos, Andrea Bulgarelli, Immacolata Donnarumma, Margarita Hernanz, Irfan Kuvvetli, Mark Pierce, Alessio Aboudan, Giovanni Ambrosi, Denis Bernard, Elisa Bernardini, Andrea Borgna, Marica Branchesi, Andrei Bykov, Martina Cardillo, Paolo Coppi, Domitilla De Martino, Roland Diehl, Michele Doro, Valentina Fioretti, Stefan Funk, Gabriele Ghisellini, Eric Grove, Clarisse Hamadache, Dieter Hartmann, Masaaki Hayashida, Gottfried Kanbach, Jurgen Kiener , Jurgen Knodlseder, Philippe Laurent, Olivier Limousin, Karl Mannheim, Mario Nicola Mazziotta, Julie McEnery, Sandro Mereghetti, Gabriele Minervini, Alexander Moiseev, Aldo Morselli, Kazuhiro Nakazawa, Piotr Orleanski, Josep Maria Paredes, Barbara Patricelli, Jean Peyre, Giovann Piano, Martin Pohl, Harald Ramarijaona, Riccardo Rando, Ignasi Reichardt, Marco Roncadelli, Fabrizio Tavecchio, David Thomson, Alexei Ulyanov, Xin Wu, Andrei Zdziarski, Andreas Zoglauer

AND

CAST ex-WG → to reform as RG (ISAS/JAXA)

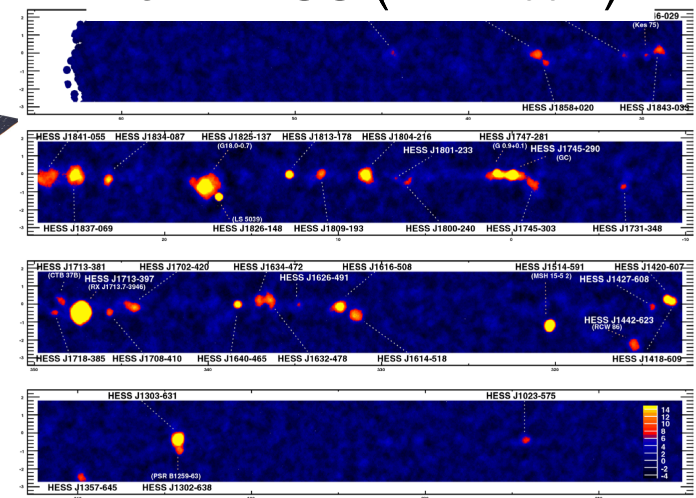
Tadayuki Takahashi, Shin Watanabe, Motohide Kokubun, Yuto Ichinohe, Takeshi Takashima, Takefumi Mitani (ISAS/JAXA), Makoto Tashiro, Yukikatsu Terada (Saitama U), Toru Tamagawa (RIKEN), Masaharu Nomachi (Osaka U), Yasushi Fukazawa, Tsunefumi Mizuno (Hiroshima U), Yasunobu Uchiyama (Rikkyo Univ.) and Teruaki Enoto (RIKEN) et al.

1-1: A New era in high-*E* astro-physics

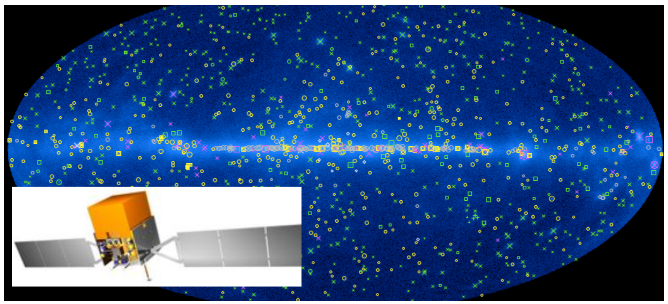
X-ray to GeV, TeV, new all-sky surveys and high-sens. probes came about.

examples …

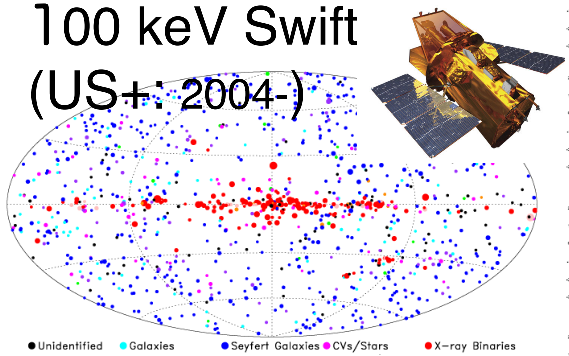
TeV HESS (Int.: 2004-)



GeV : Fermi (US+:2008-)

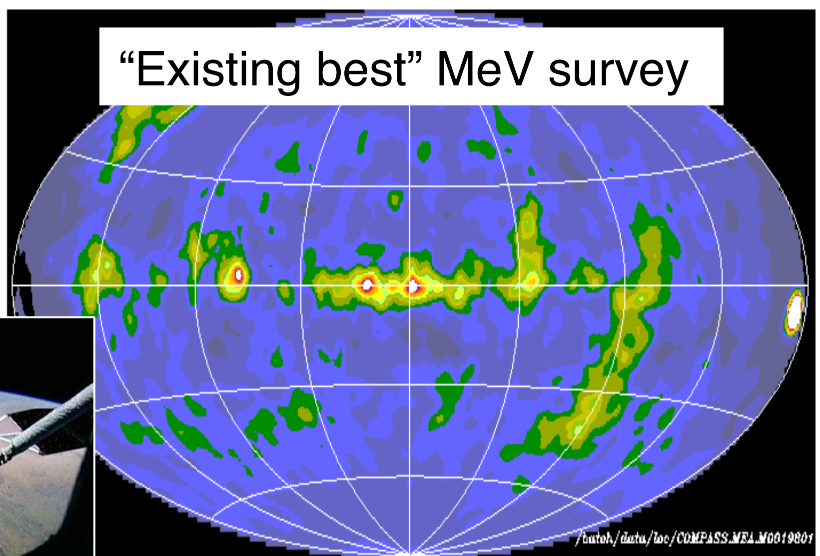


100 keV Swift (US+: 2004-)

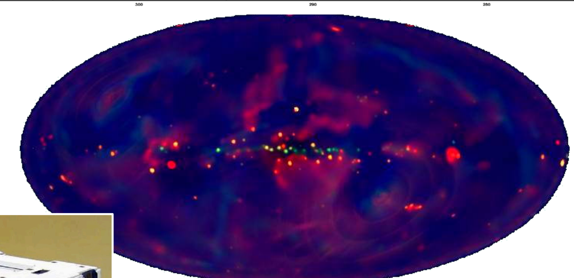


… but not *yet* in MeV

MeV COMPTEL (1990-2000)



X-ray



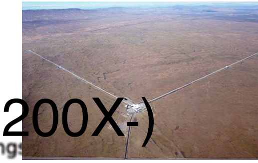
MAXI (Jp: 2009-)

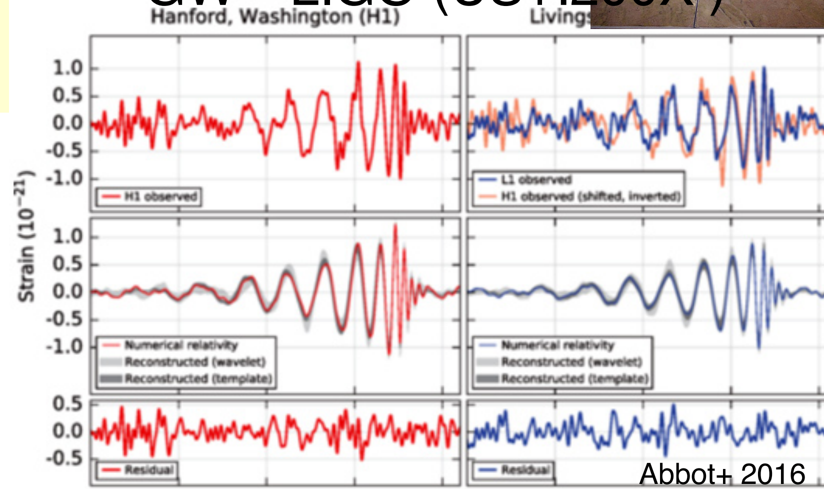
1-1: A New era in high-*E* astro-physics

With GW, neutrino, as well as radio, optical, X-ray, GeV, a time domain astronomy is also coming (soon)

examples …

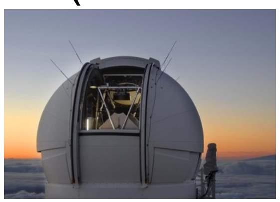
GW LIGO (US+:200X-)

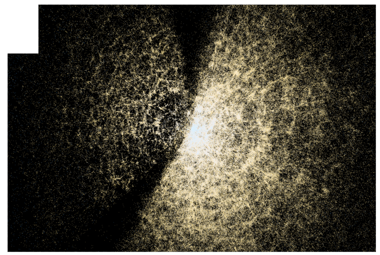




Abbot+ 2016

Opt. SDSS (US+:1999-)

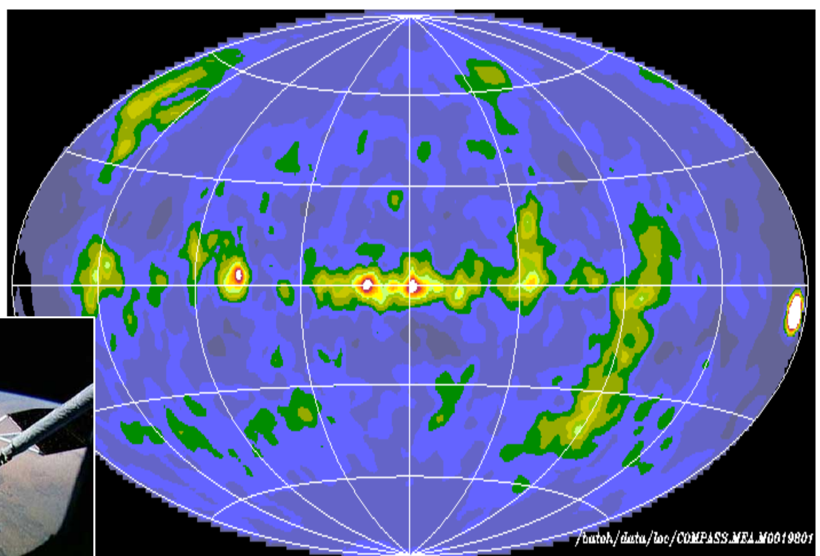




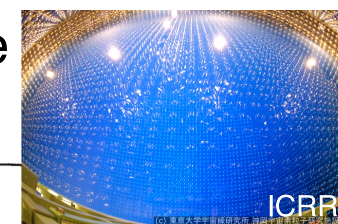
Pan-STARRS (US: 2008-)

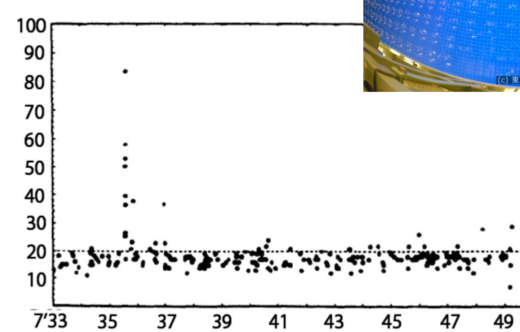
… but *far away* in MeV

MeV
COMPTEL
(1990-2000)



Neutrino
Kamiokande
(JP+:1986-)





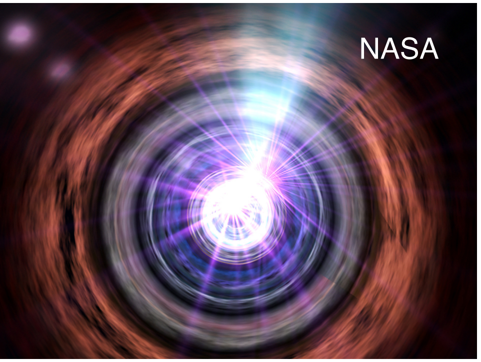
Hirata+ 1987

1-2: Sciences *left* around MeV to sub-GeV

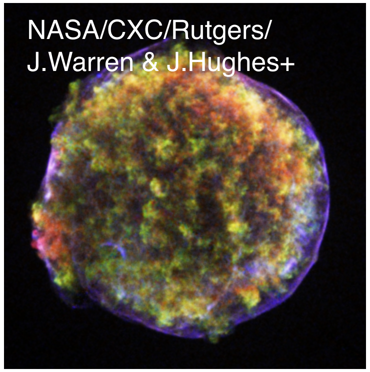
Motivation： Non-thermal energy in the Universe
Extream physics/Unknown phenomena
SN and metal synthesis etc …

Many science, “Only MeV to sub-GeV can access”

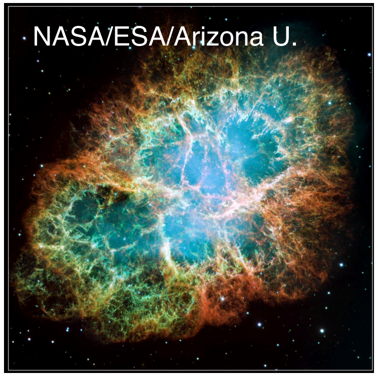
- Many “left-over” from Suzaku, Swift (HXR), Fermi, HESS (Gev, TeV) etc.
  → MeV to sub-GeV is needed to resolve the issue (AGN, jet, NS, BHB..)
- Many science only MeV can do → Nuclear gamma-ray lines related



AGN, Jet : non-thermal E



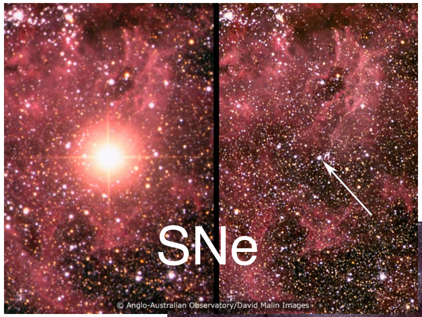
SNe

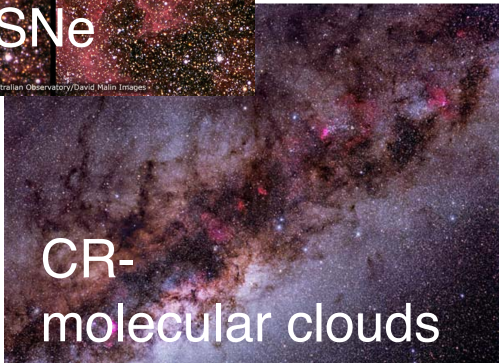


Extream

+GRB

DM



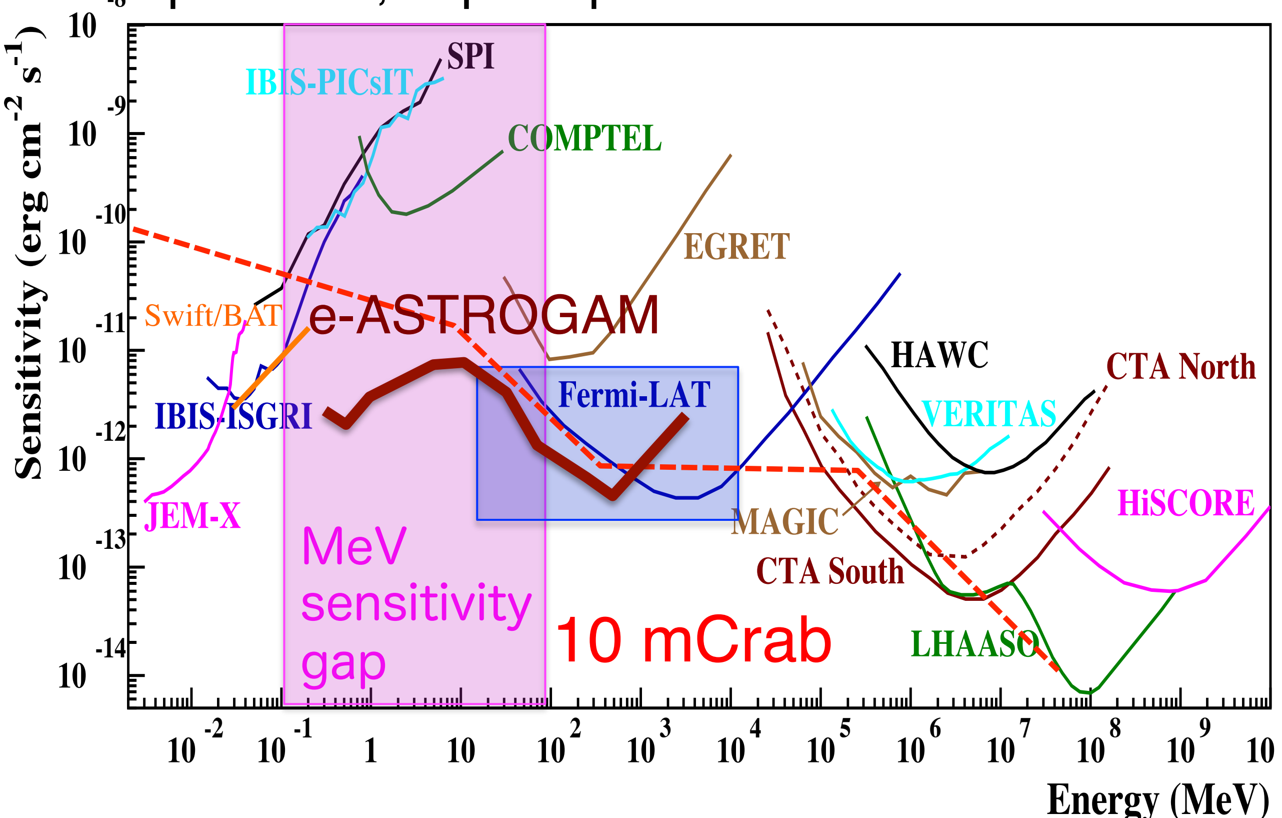


1-3: eASTROGAM = Explore the Frontier

- Clear Sensitivity Gap exists **around 0.1-100 MeV**
- *Swift, Fermi, with ~1000 sources* → for “Astronomy” ~10 mCrab sens. needed
- *Fermi* → “need low-GeV sensitivity with better Δθ”
- New-gen. Compton telescopes with good Δθ for MeV is emerging
  (Hitomi-SGD (Si-CdTe), COSI (Ge-strip balloon), etc.),
  can also adopt pair telecope mode, in principle

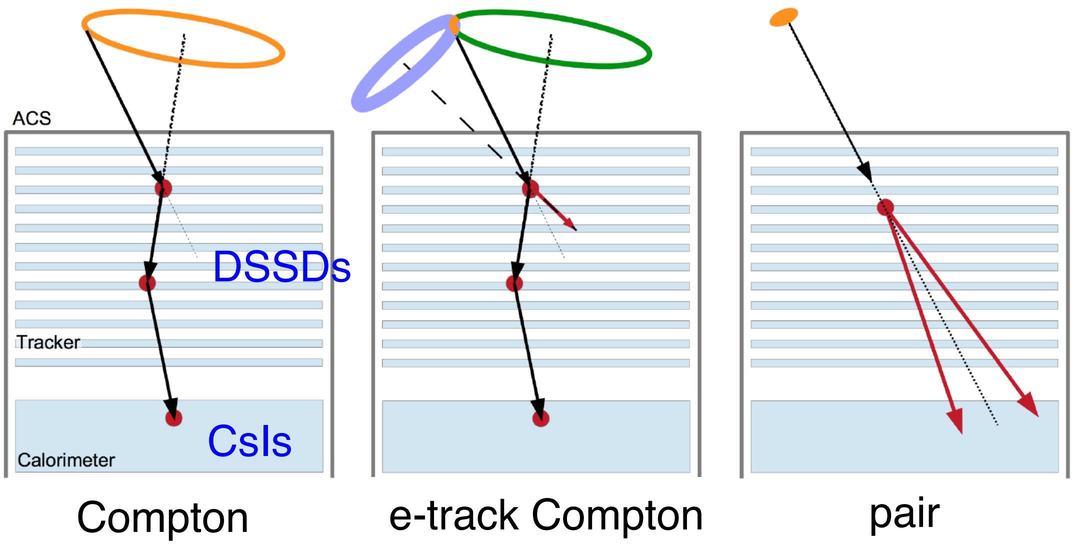
The next step forward
- 0.2-1000 MeV band with
- 10 mCrab sens.
- with wide-FoV

is needed!
→ eASTROGAM

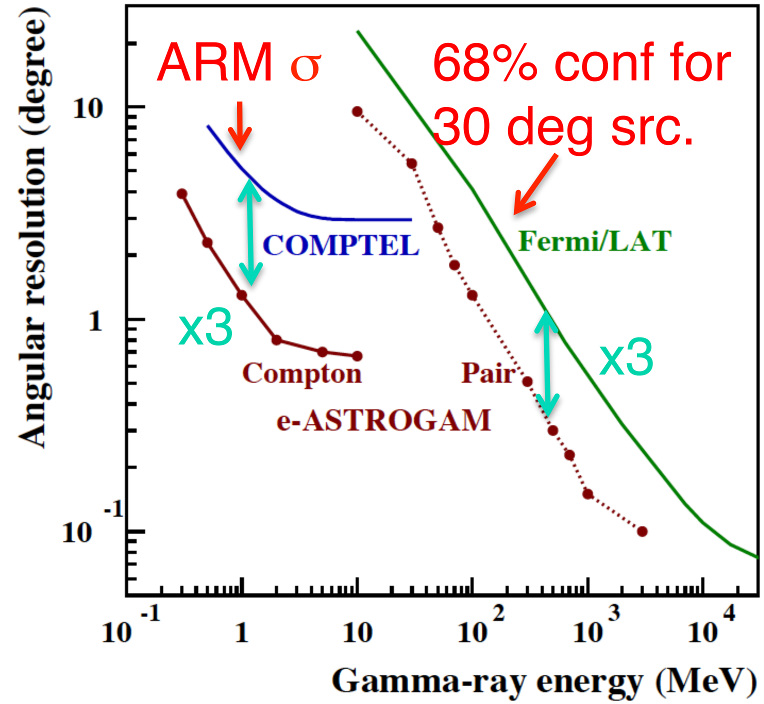


1-3: eASTROGAM = Explore the Frontier

3 DAQ modes



Angular resolution



- Combination of DSSD + CsI arrays
  - new-gen. Compton Telescope
  - converter-free pair Telescope

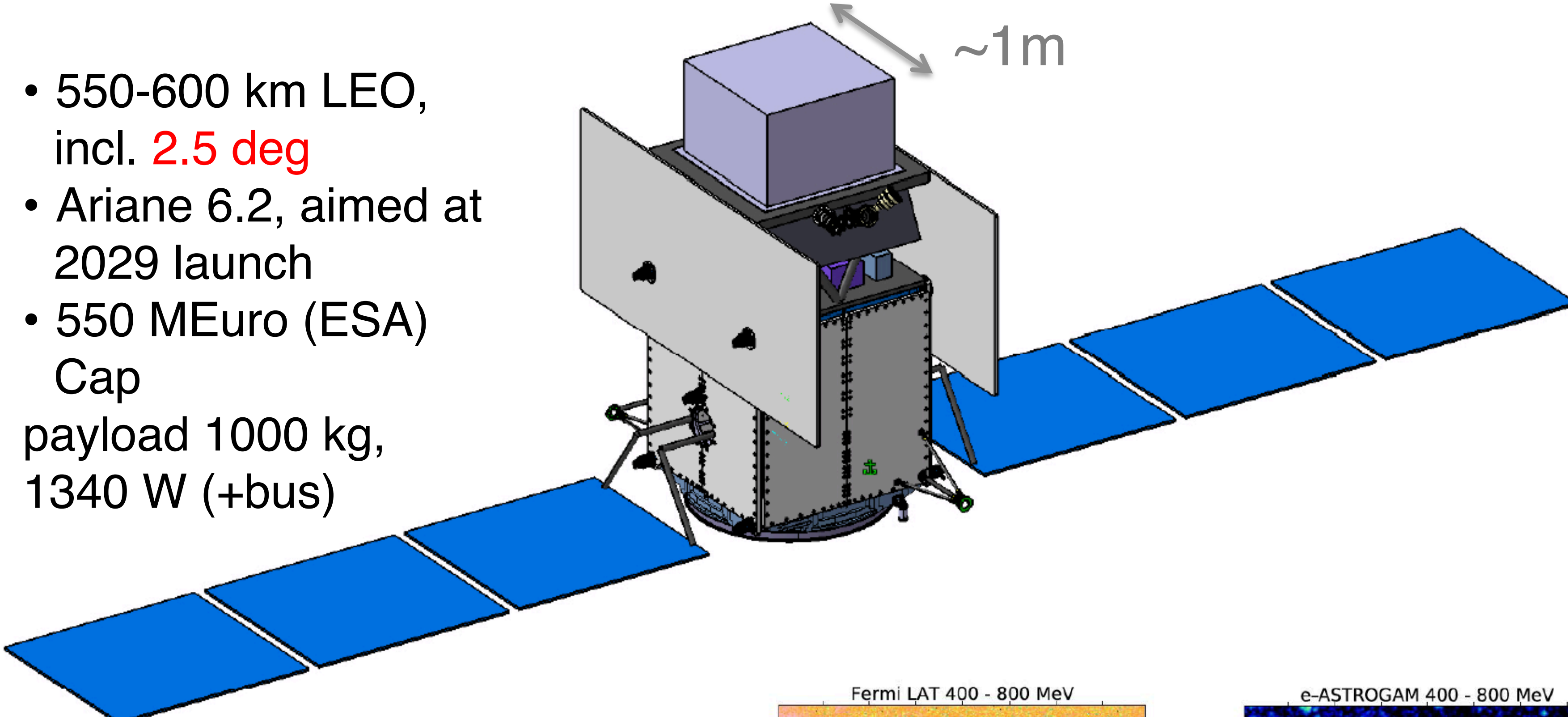
BOTH for better angular-resolution

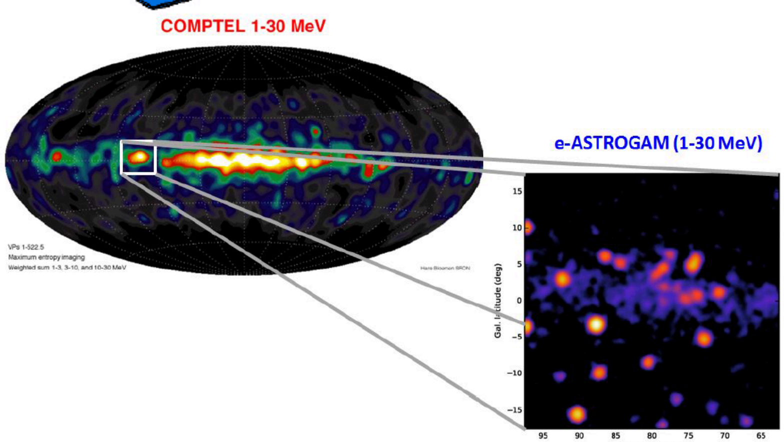
→ better sensitivity on 0.2 MeV – 10 GeV

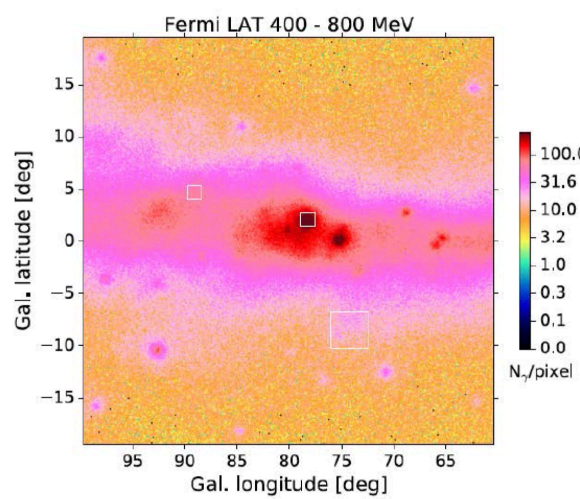
1-4: eASTROGAM proposed for ESA-M5

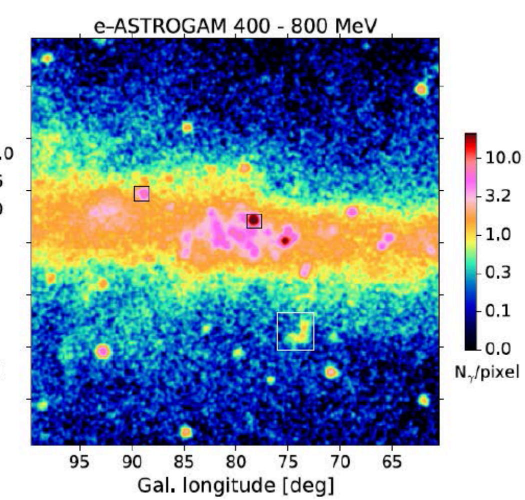
- 550-600 km LEO, incl. 2.5 deg
- Ariane 6.2, aimed at 2029 launch
- 550 MEuro (ESA) Cap

payload 1000 kg,
1340 W (+bus)







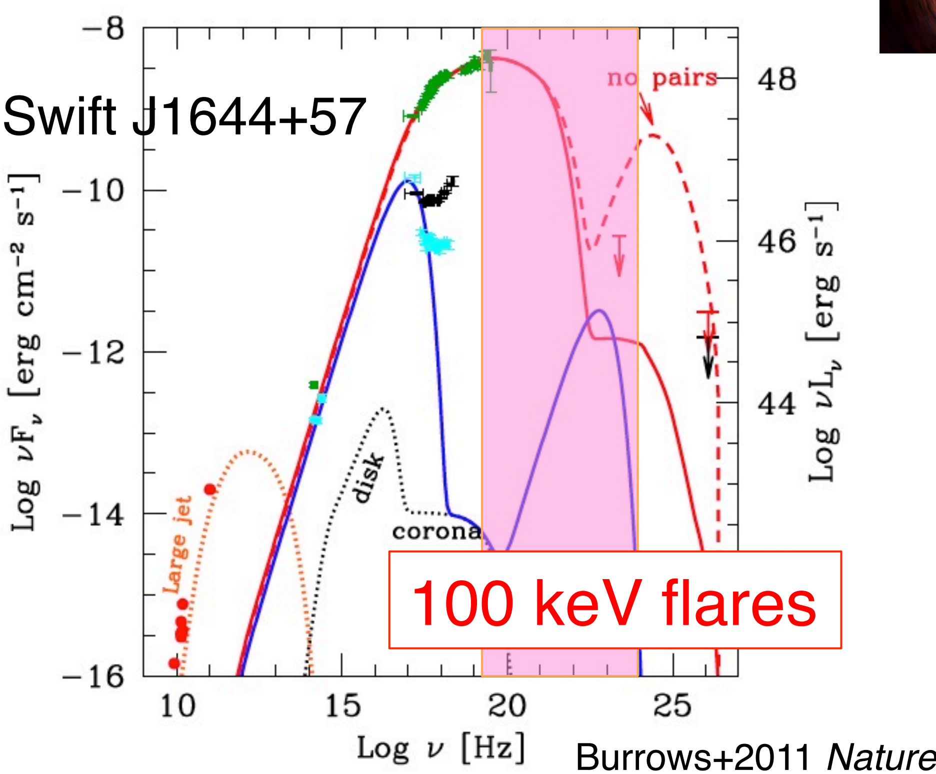


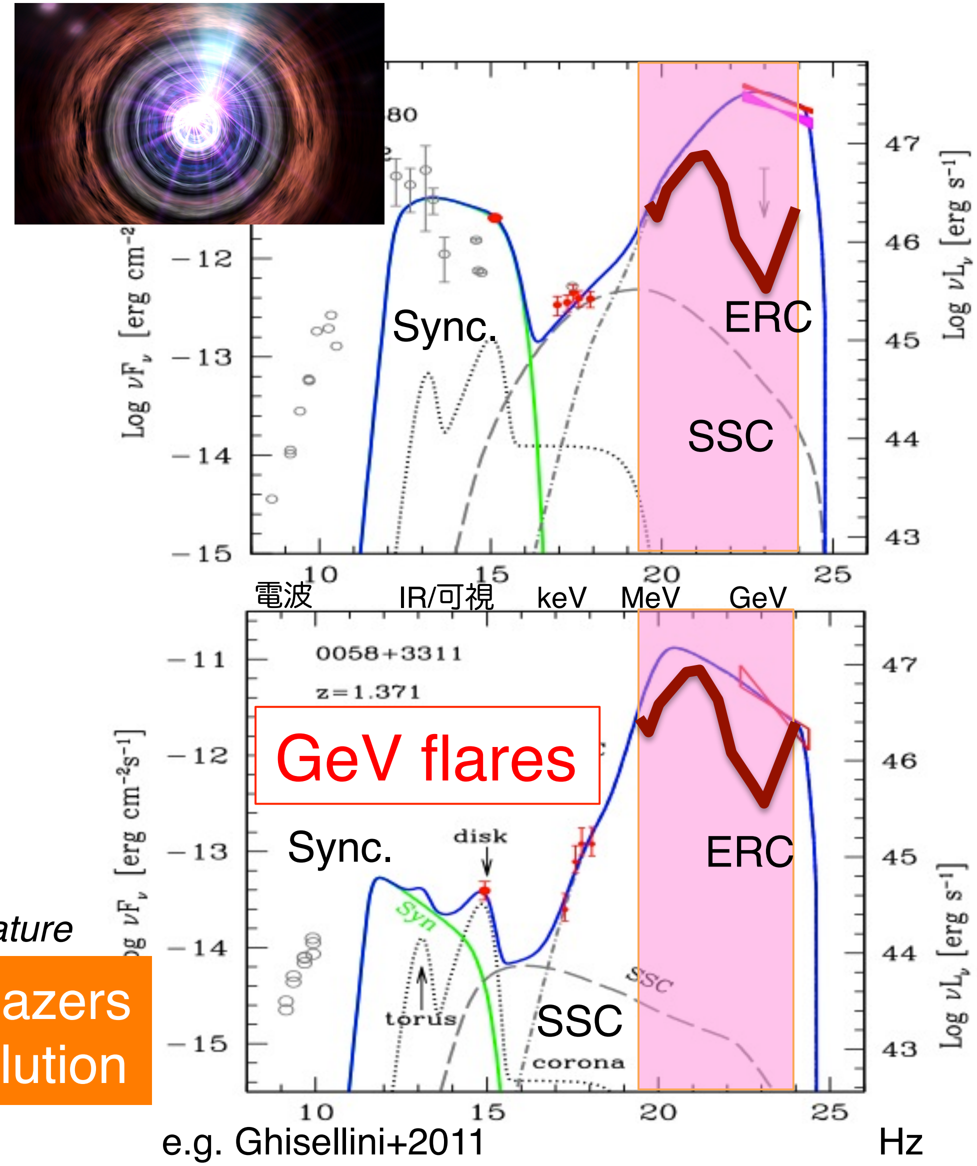
2. MeV – sub-GeV all-sky science

from proposal document

2-1 AGN jet and flare-ups

BL Lac and FSRQ: the strongest accelerator in the universe

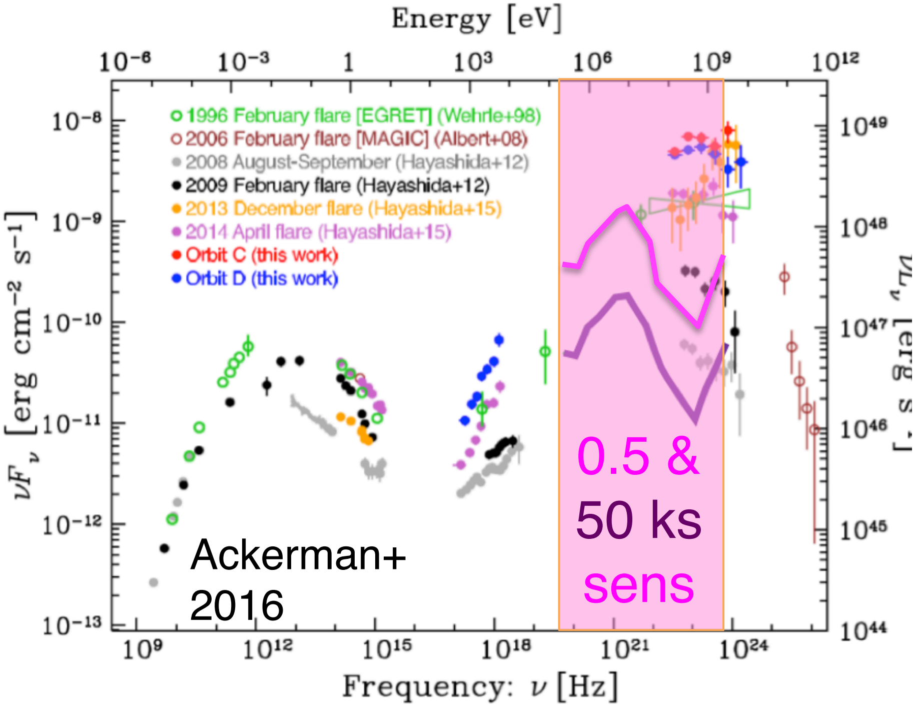




eASTROGAM will see > 100 of MeV-blazers up to z ~ 4.5 → radio-laud vs quiet evolution

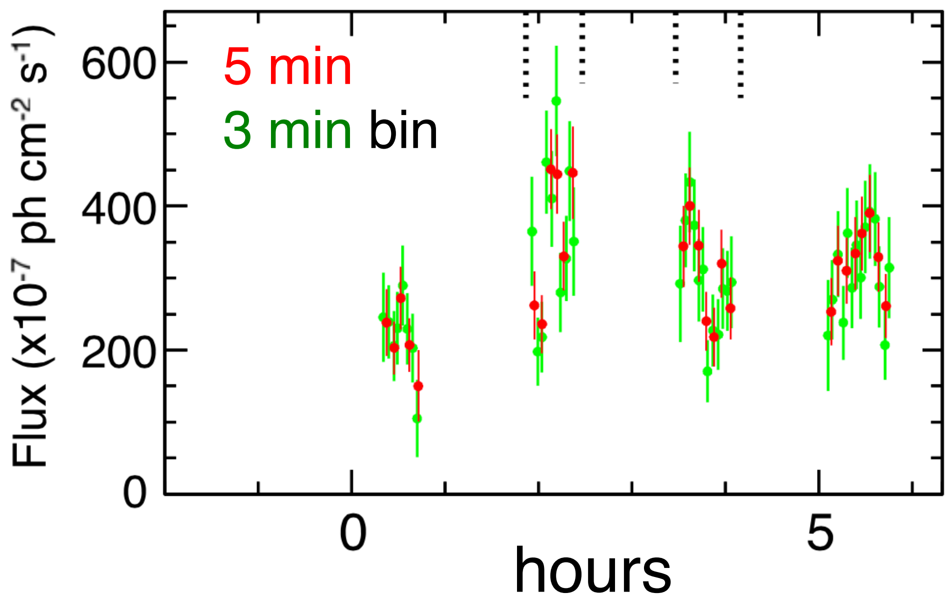
2-1 AGN jet and flare-ups

SED of 3C279 flares



3C279 light curve > 100 MeV

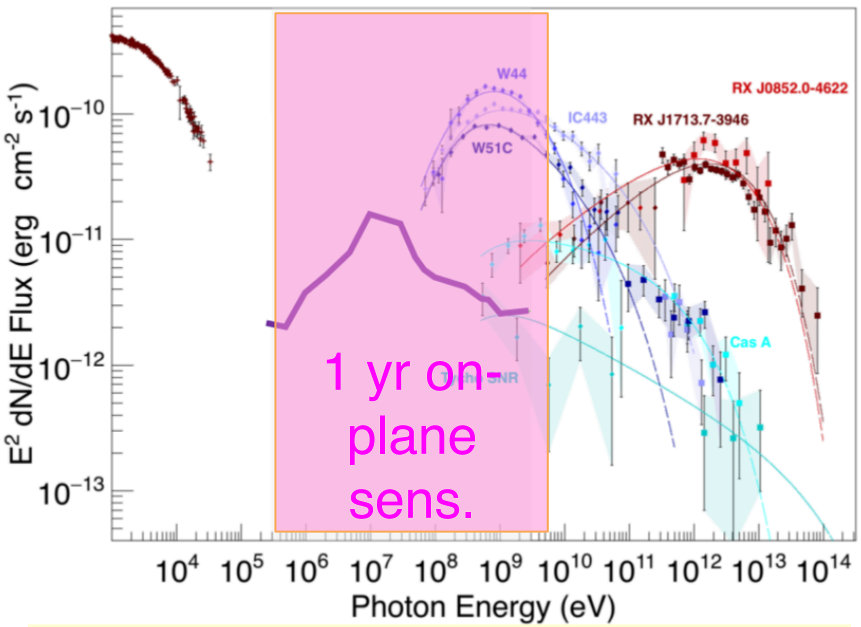
Fermi LAT obs.



- Origin (SSC or ERC of what ?) → SED and polarimetry
- very short time-variability → search for megnetic recconection -like feature?
- hadronic or electron? → SED (and polarimetry?)

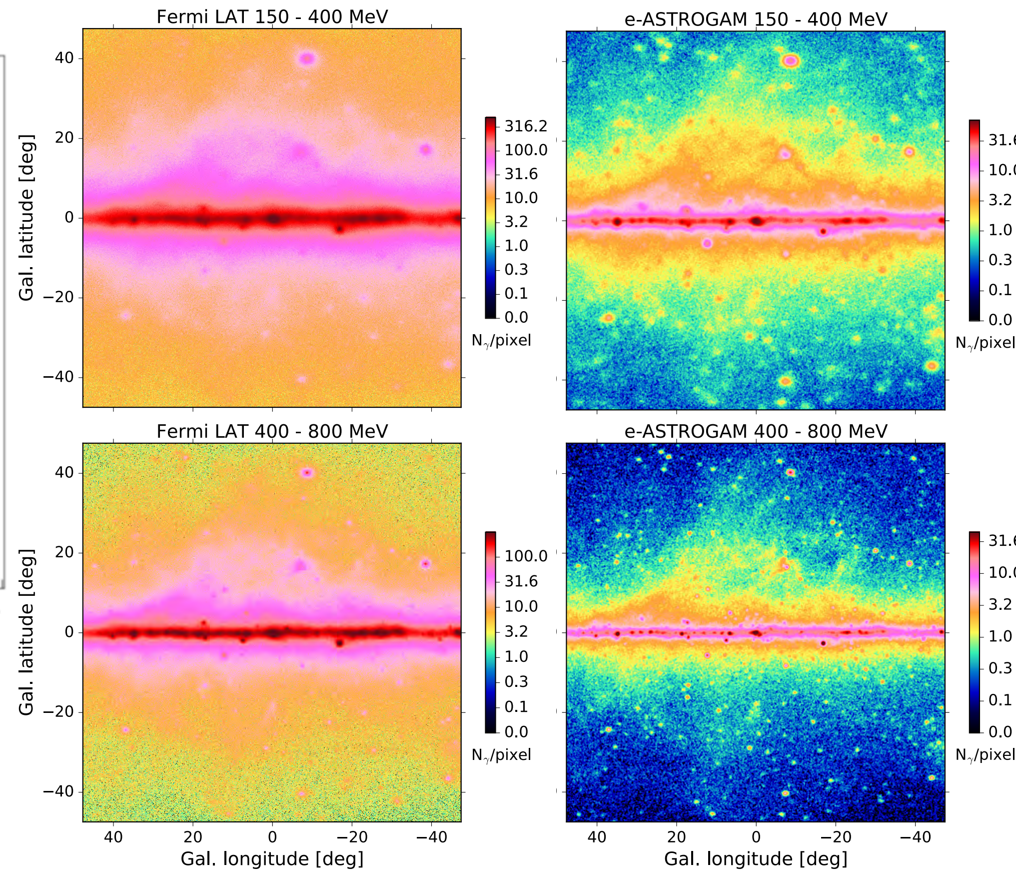
2-2 Cosmic-ray accelarations

GeV SNR SED



- GeV SNRs → SED, even space resolved (Δθ 0.1 deg) + nuclear lines
- Better Δθ at sub-GeV for M-cloud CR study

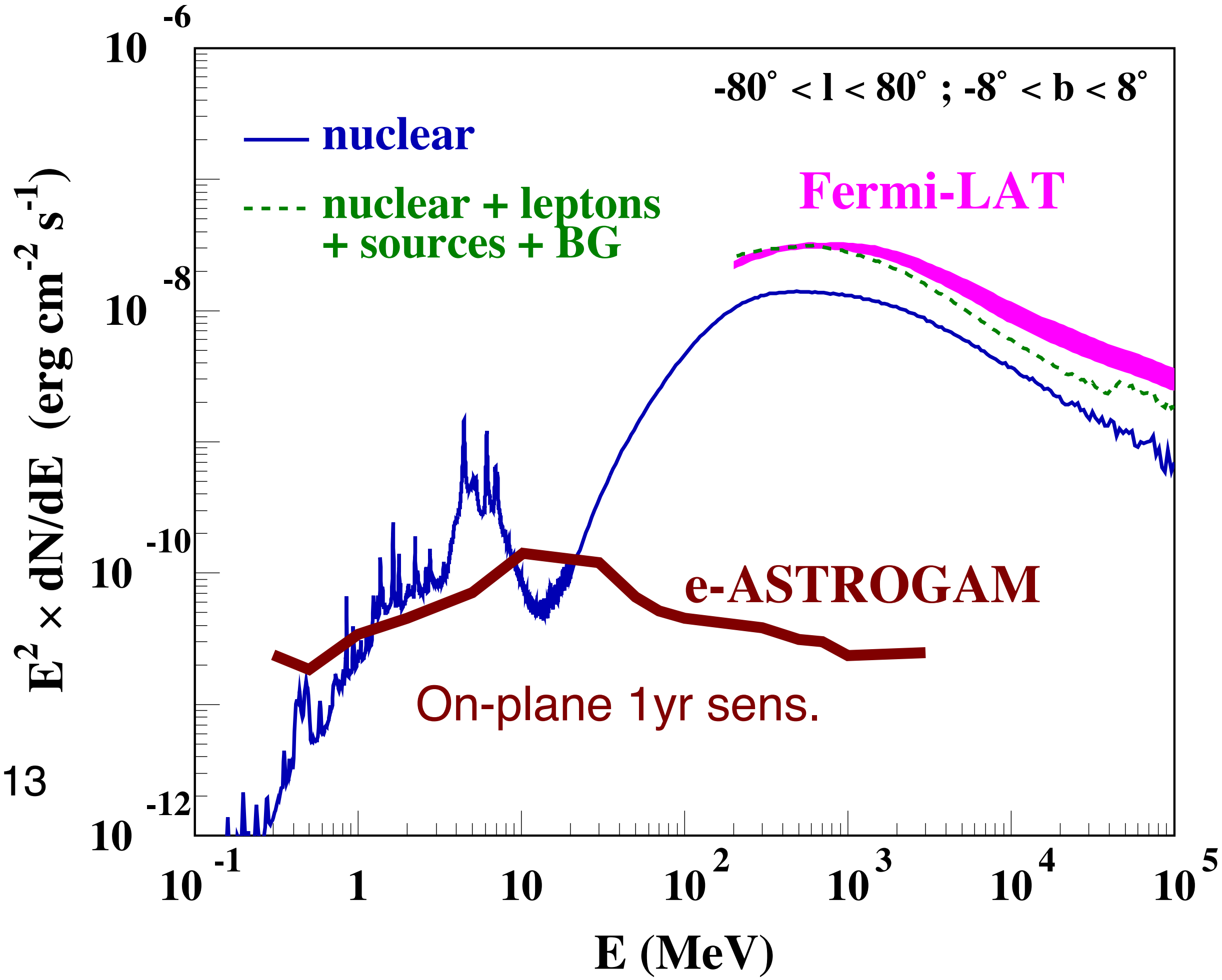
CR - molecular cloud interaction



4 yr Fermi vs 1 yr eASTROGAM

2-2 Cosmic-ray accelarations

On-plane
MeV survey
for LE-CRs

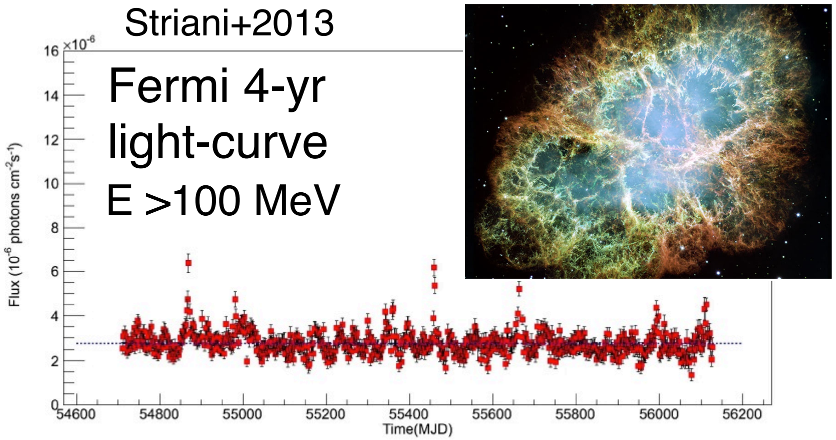


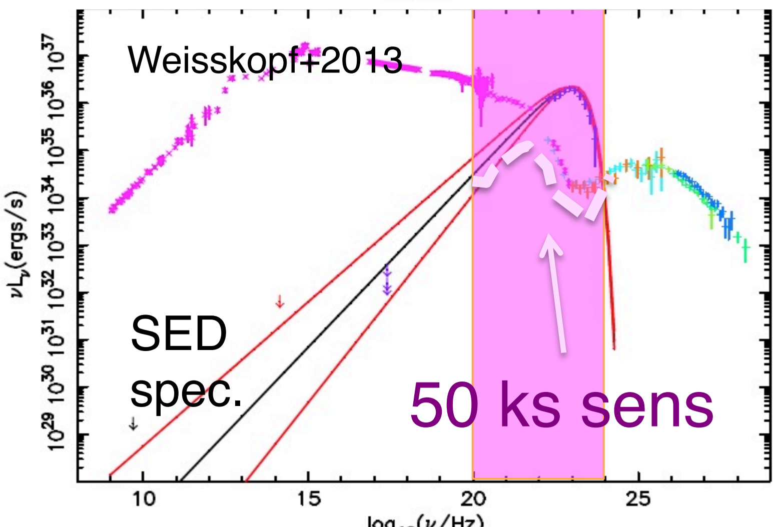
Benhabiles-Mezhoud+ 2013

can also detect, prompt MeV lines from low-energy CR, interacting with M-Clouds. → MC ionization, CR propagation …

2-3 Time domain: Pulsar Wind & Magnetors

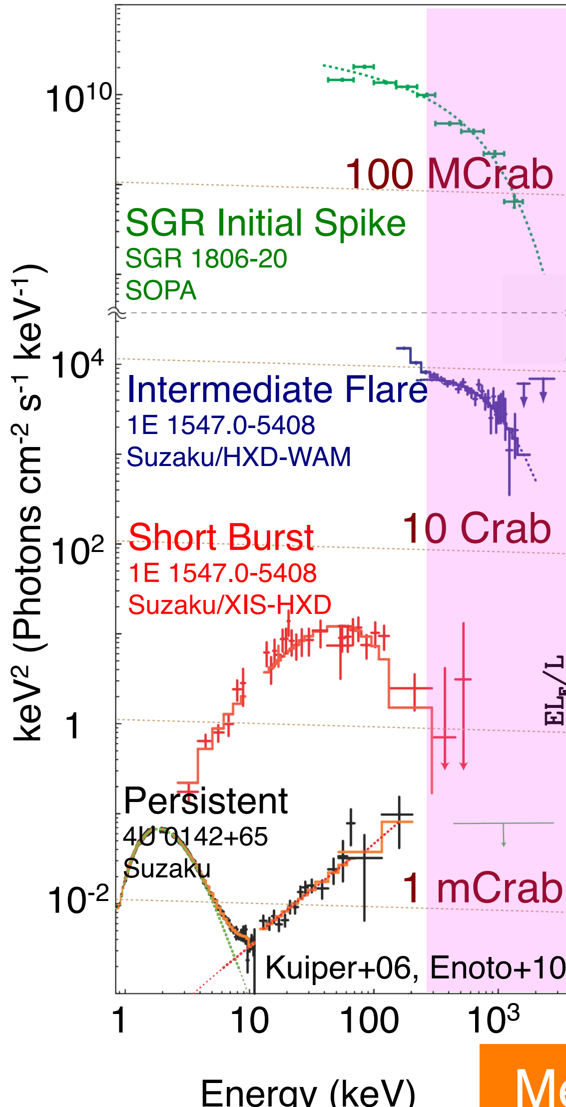
Crab GeV flare





How to acc. Electrons up to PeV in ~day. Reconnection ?

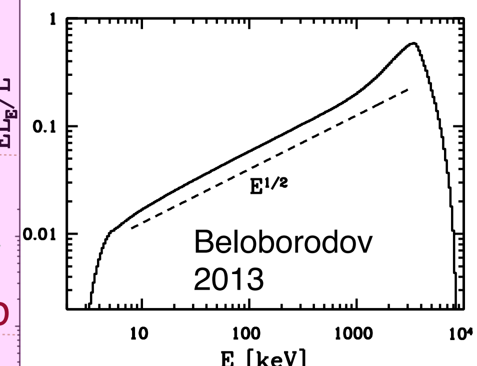
Magnetors



⇒ 511 keV !

Enigmatic HXR

⇒MeV peak?

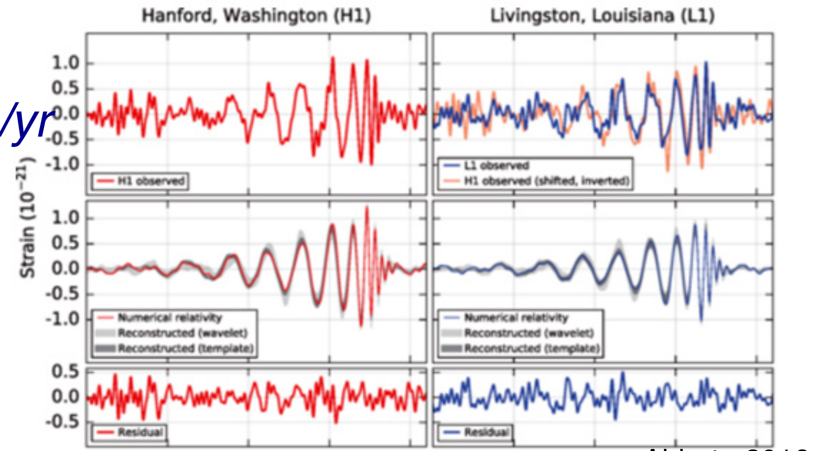


MeV all-sky needed

2-4 Multi-messenger Astronomy

eASTROGAM has “wide-filed of view” → Good synergy with GW and Neutrino detectors.

Fermi-GBM : 240 GRBs/yr

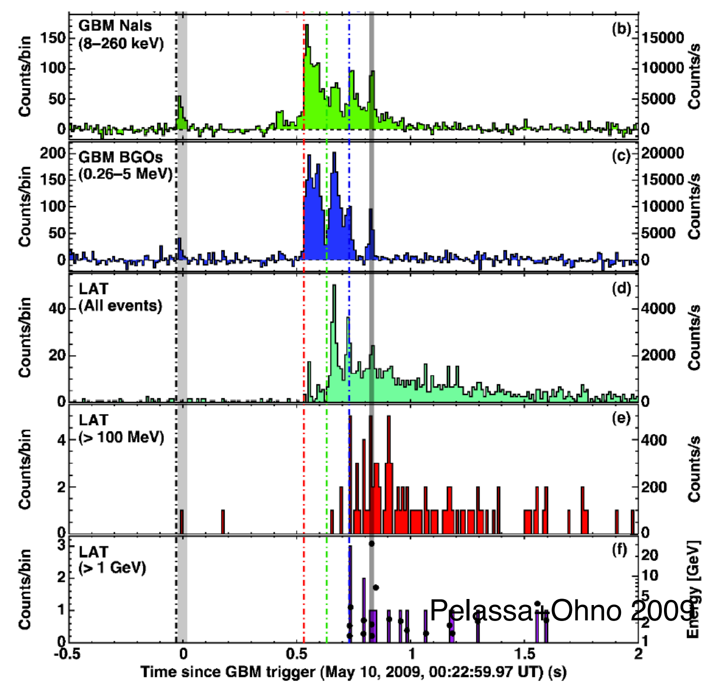


Abbot+ 2016

- GRBs: CsI array trigger. ~200 GRBs/yr
  If bright, with $\Delta\theta$ = 0.1-1 deg with Compton/Pair reconstruction.

- ~40 (16) GRBs/yr with polarimetry, if 20 (10)% polarized

- Binary NS merger : synery with GW and eASTROGAM
  - *up to 1.4/yr* detection “GW && Short GRB” (Patriceli+2016) *could be 1 per 3-4 year?*

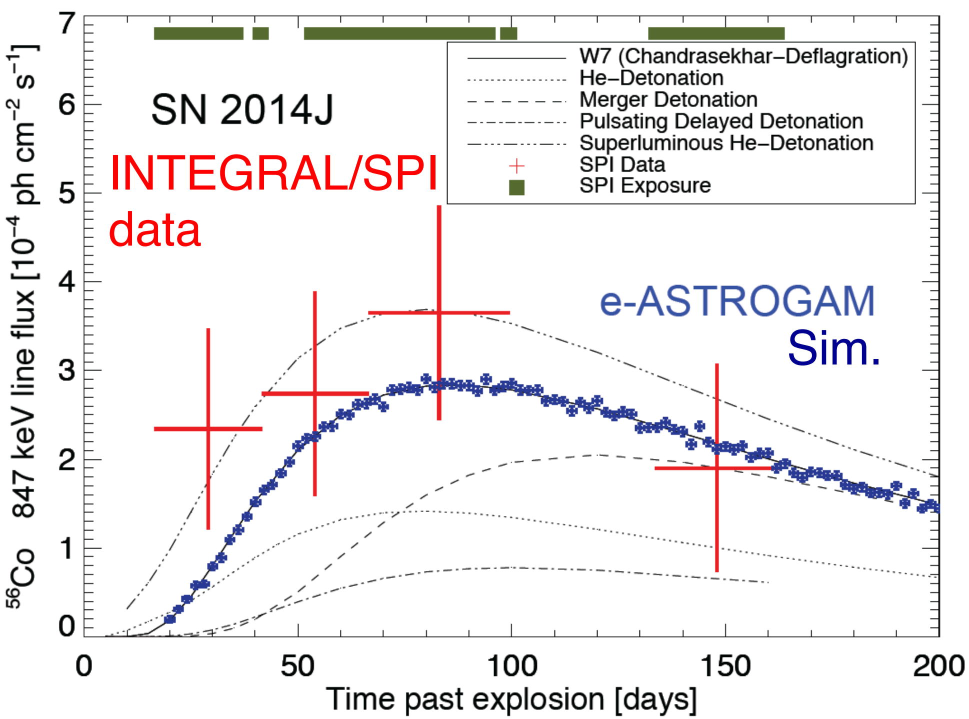


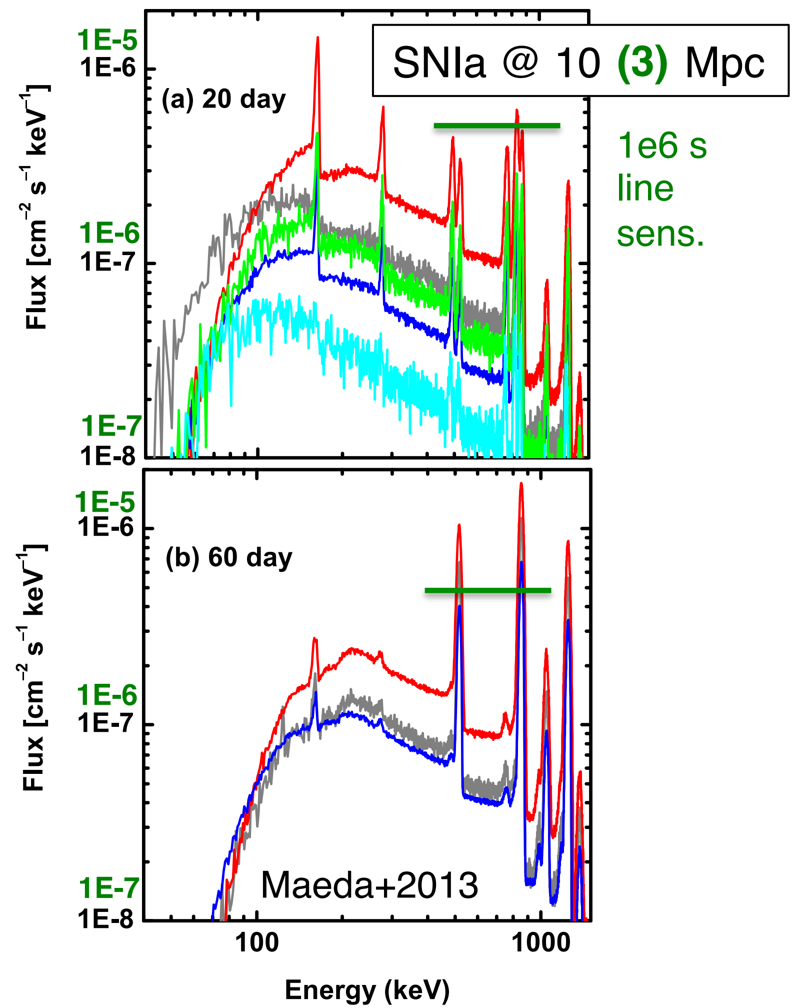
Pelassa+Ohno 2009

2-5: Time domain: SN-Ia + SN II

SNIa ^{56}Ni synthesis amount

847 keV light curve



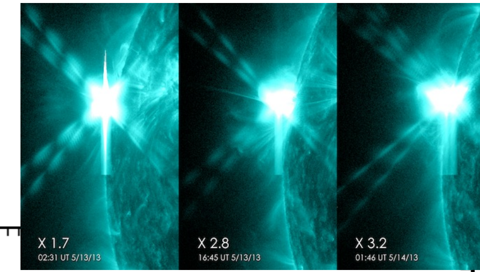


→ eASTROGAM will detect 10+/-3 SNIa in 3 years

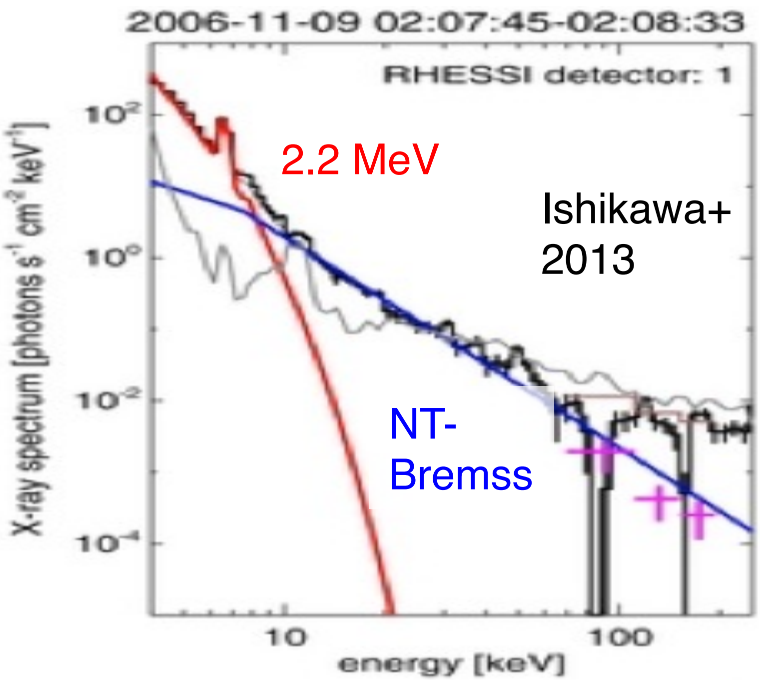
SNIa senario has diversity. 56Ni is “key” to see models

SN II also *will* be observed, also 26Al, as well as Nova

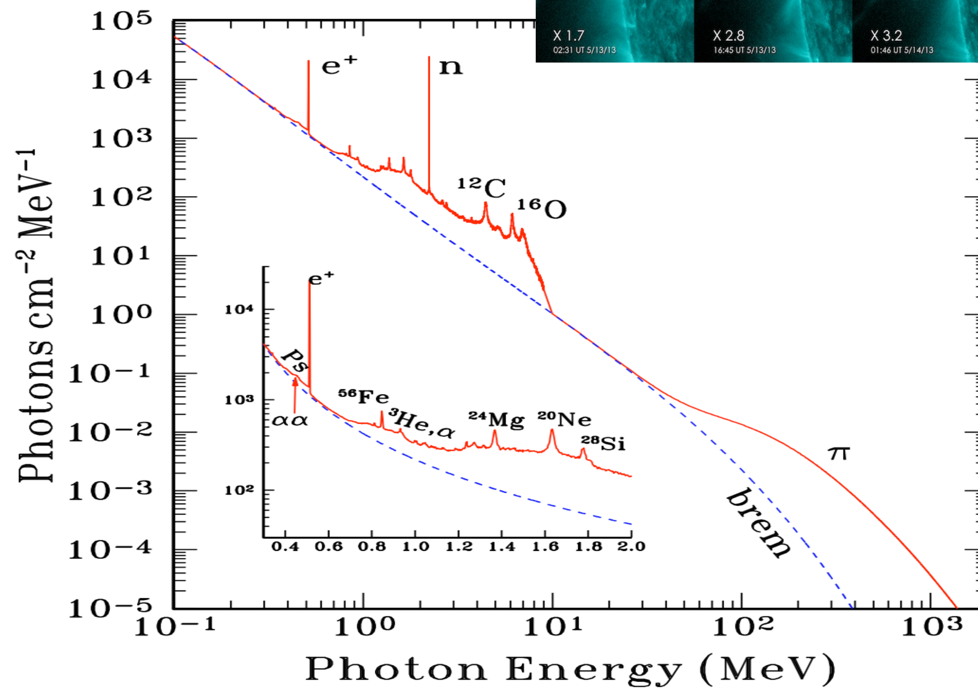
2-7：solar flares



Obs (RHESSI)



Models



- 2.2 MeV lines from flares → proton acc.
- ^{12}C, ^{16}O prompt lines also appear → proton energy
- polarimetry in rim-flares → acceleration axis?

3. Mission design

from proposal document

3-1 e-ASTROGAM requirements

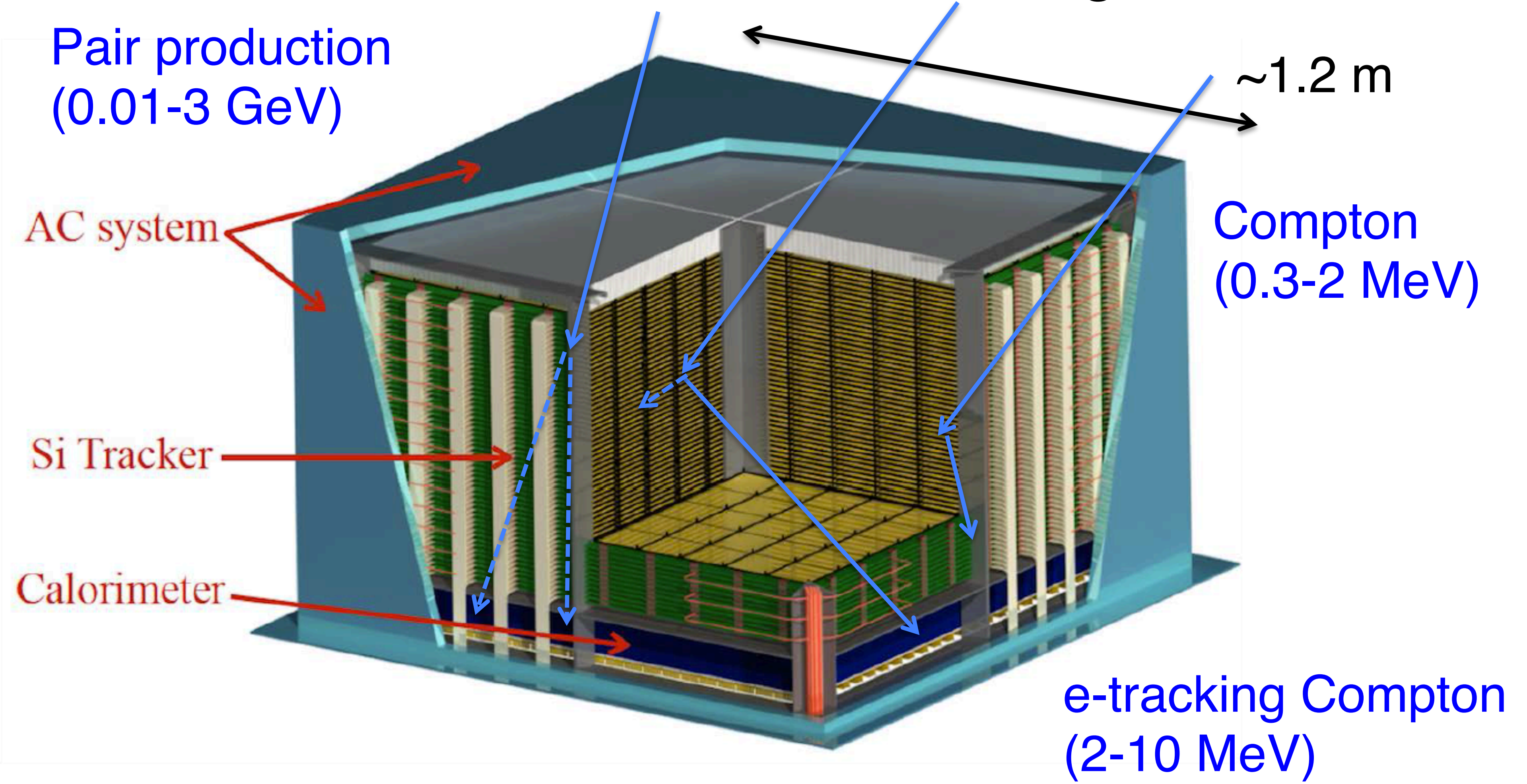
enegy range : 0.3 MeV – 3 GeV (Compton + pair)
(30 keV – 200 MeV (GRB with CsI array))

$\Delta\theta$: 1.5 deg @ 1 MeV (ARM FWHM),
1.5 deg @ 100 MeV (68% contaminant)
0.2 deg at 1 GeV (68% contaminant)

Sensitivity : 2—5 x10^{-5} MeV/cm^2/s
1 MeV – 500 MeV (10^6 s expo.)

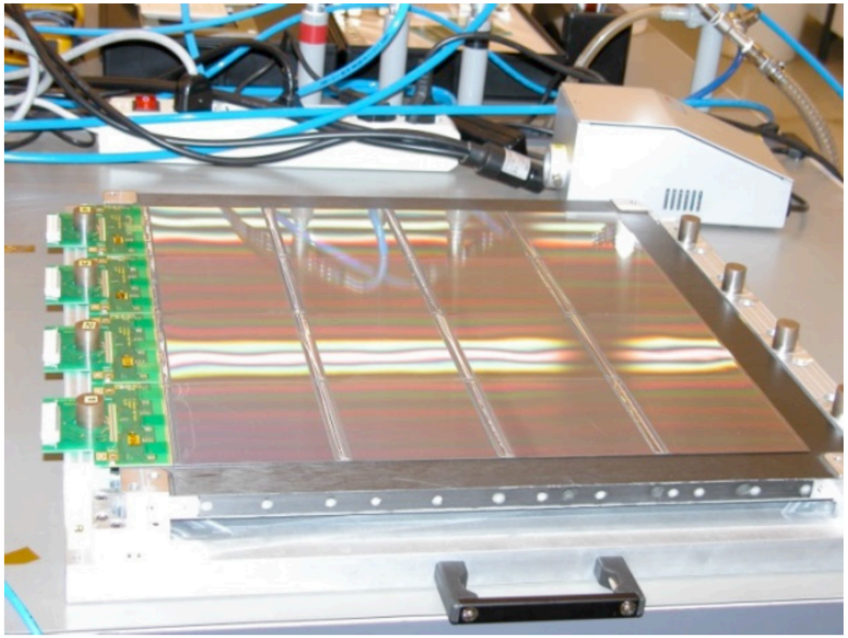
Line sens. : 5x10^{-6} ph/cm^2/s @ 511 keV (10^6 s expo.)
: 5x10^{-6} ph/cm^2/s @ 847 keV
: 3x10^{-6} ph/cm^2/s @ 4.44 MeV

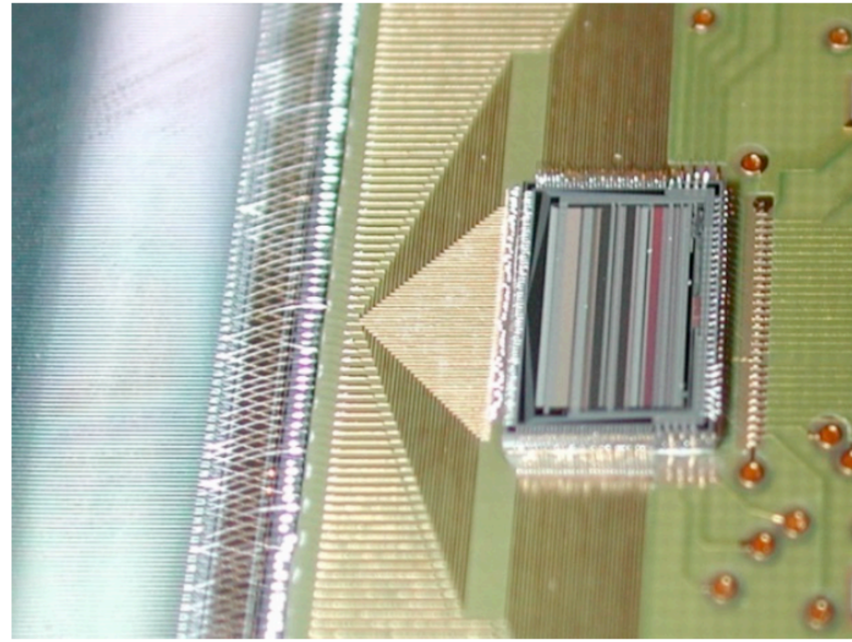
3-2 e-ASTROGAM design



- 9.5x9.5 cm² DSSD in 10x10 tiling, with 0.5 mm^t, 240um pitch x 56 layers → 2.8 cm Si
- 8500 cm² of 8cm long CsI in 5x5 mm→ 8 cm CsI
- with anti-co. plastic

3-3 Si-Tracker

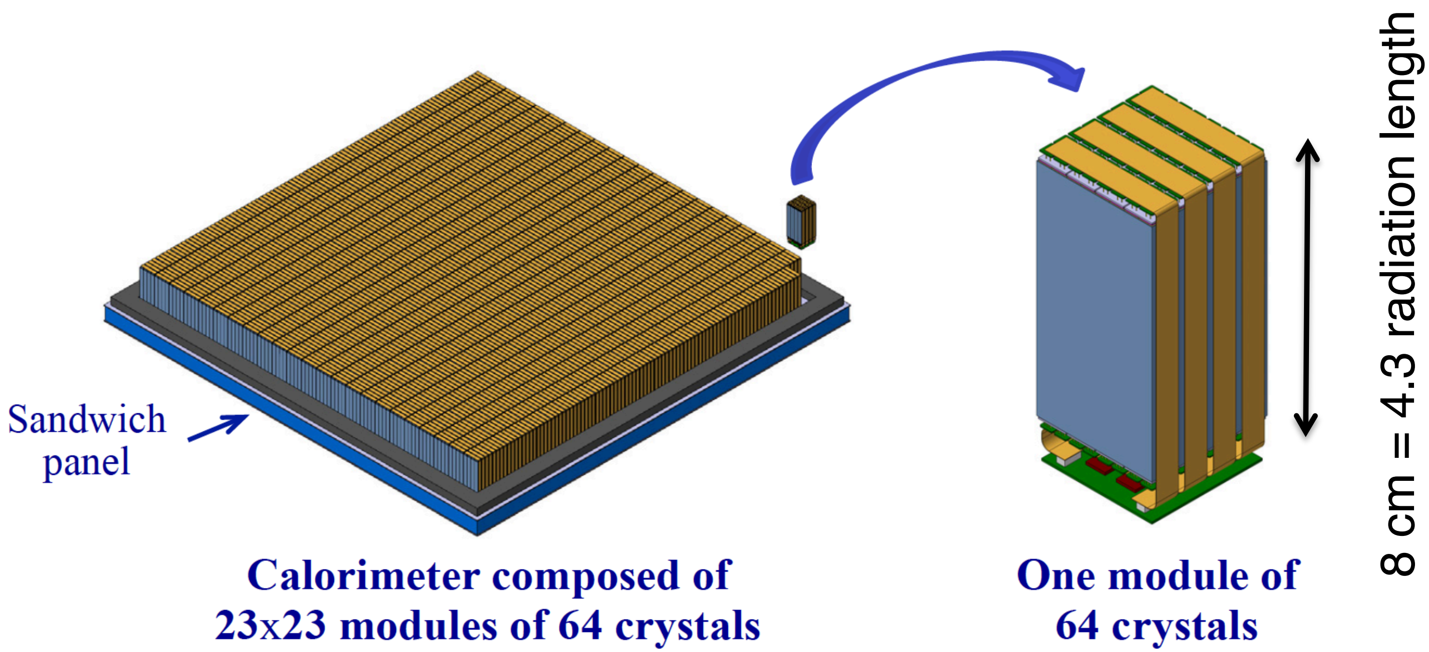




- 9.5x9.5 cm^2 DSSD in 10x10 tiling, with 0.5 mm^t, 240um pitch x 56 layers ("Silicon Radiation Sensors" or "HPK")
- 2.8 cm total thickness → 0.3 ratiation length
- dE < 6 keV (FWHM)

  - I_{leak} = 96 pA/strip at T = 0 C (or 36 pA/strip at T = -10 C). 85 pF/strip.
  - 860,160 DSSD signals are read by a total of 26,880 IDeF-X HD ASICs

3-4 Caloriemeter



- 33,856 bars of **CsI(Tl)** of 8 cm thich and 5x5 mm^2 cross section, read out by **silicon drift detectors (SDDs)** at both ends,
- array of 529 (= 23x23) modules comprising each 64 crystalsl (4.3 radiation length), read-out with VEGA ASIC
- FWHM of 4.5% at 662 keV, dZ ~ 5mm FWHM

3-5 Anti-Coincidence Detector

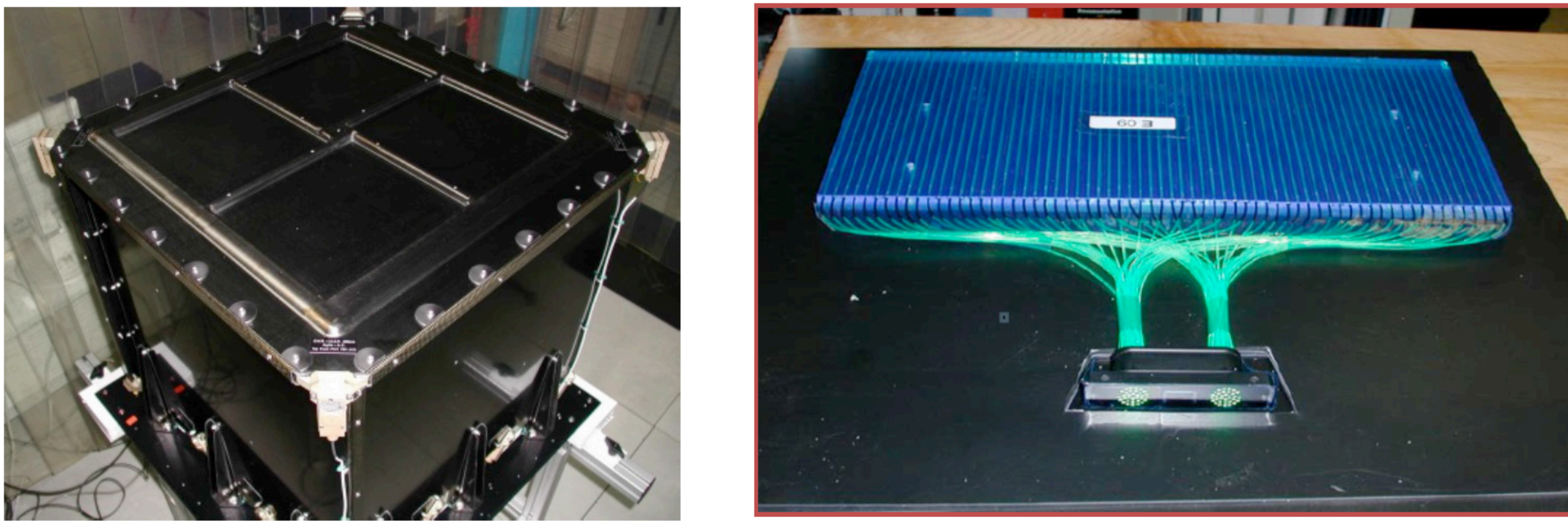
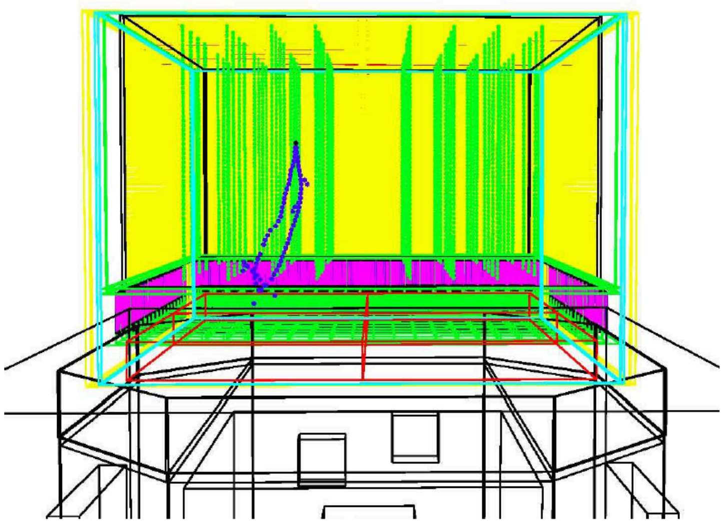
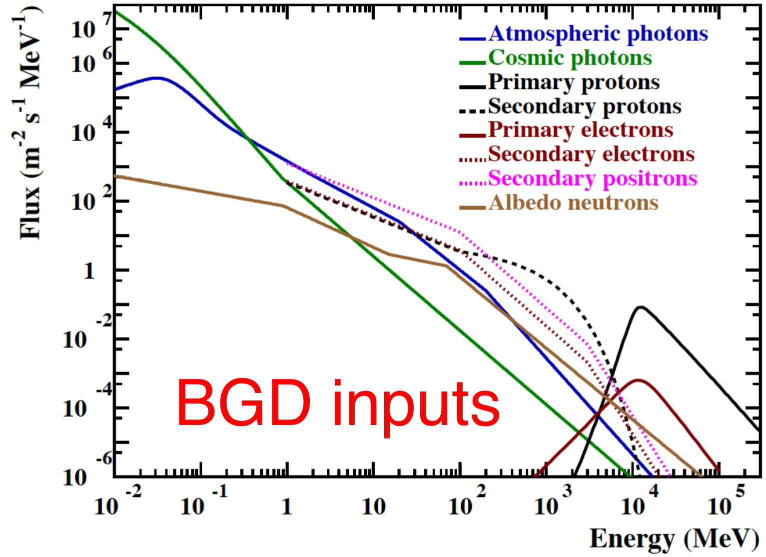


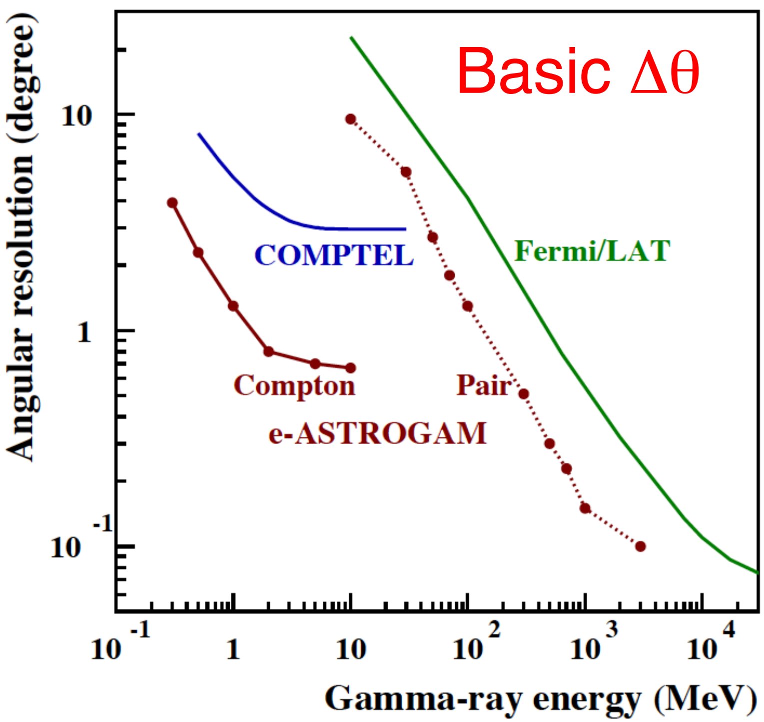
Figure 13: *Left panel* - AGILE AC detector flight unit. *Right panel* - Scintillator tile detector assembly (shown unwrapped) of the Fermi/LAT AC. The green wavelength-shifting fibers carry light to the optical connector in the foreground.

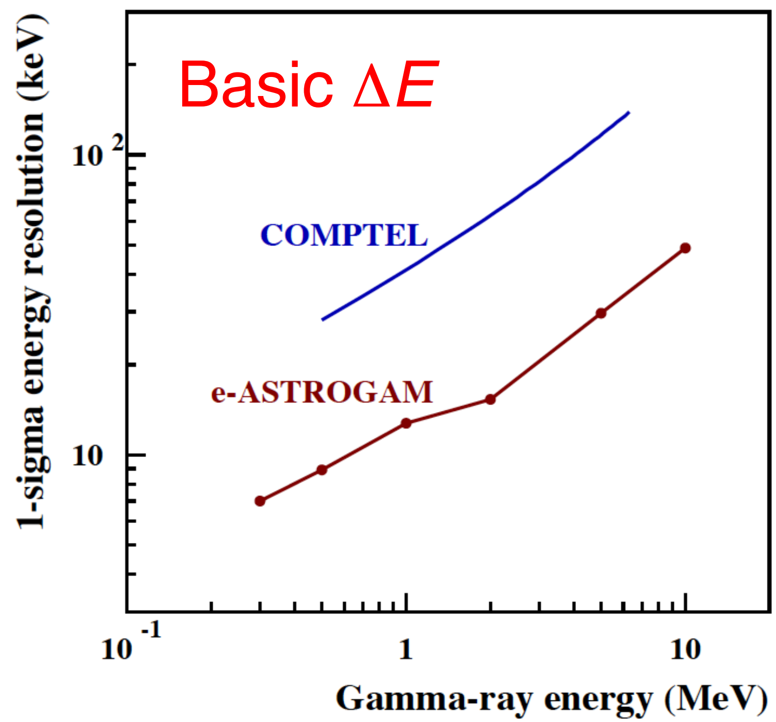
- total active area of about 4.7 m^2.
- silicon photomultipliers (SiPM) by optical fibers
- detection inefficiency < 1e-4

3-6 Performance









3-6 Performance

… A few new idea

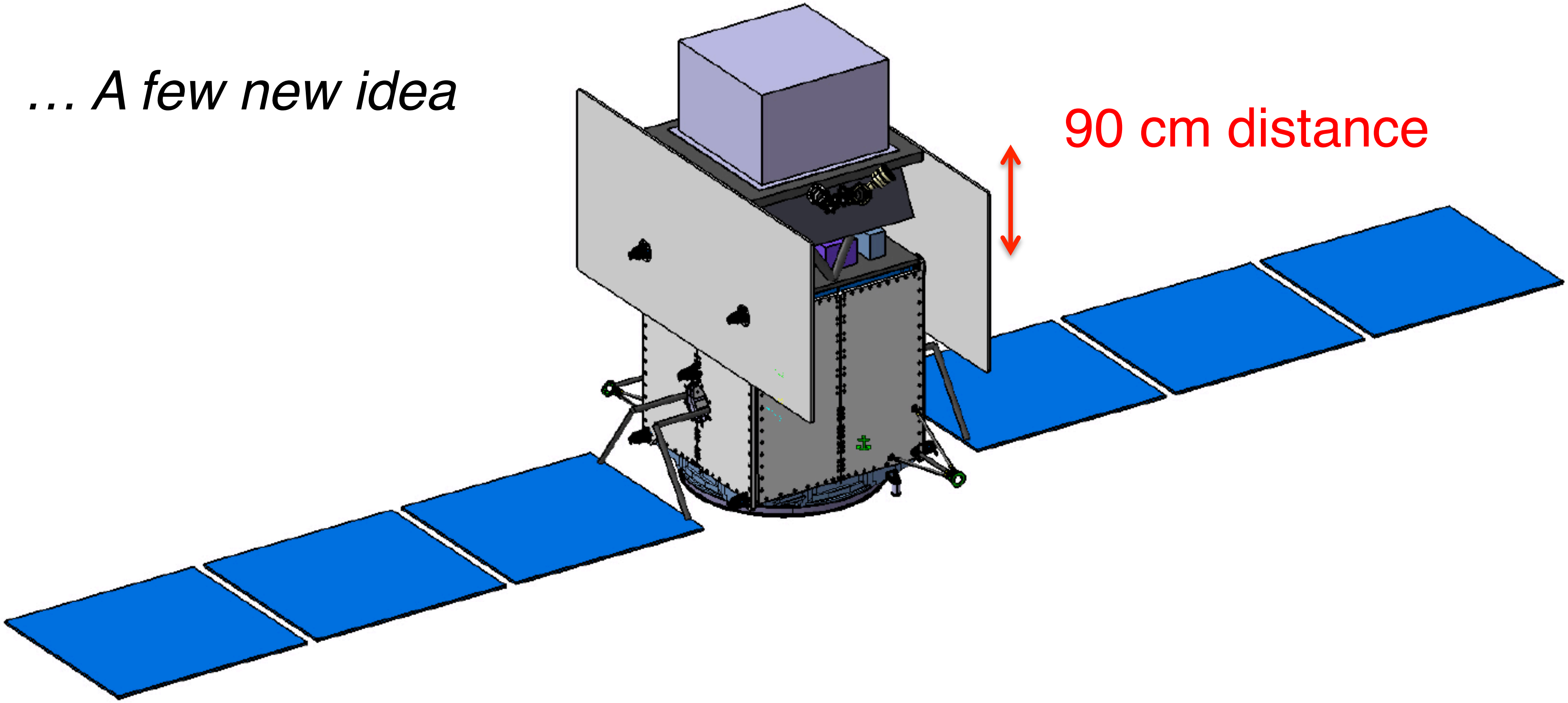
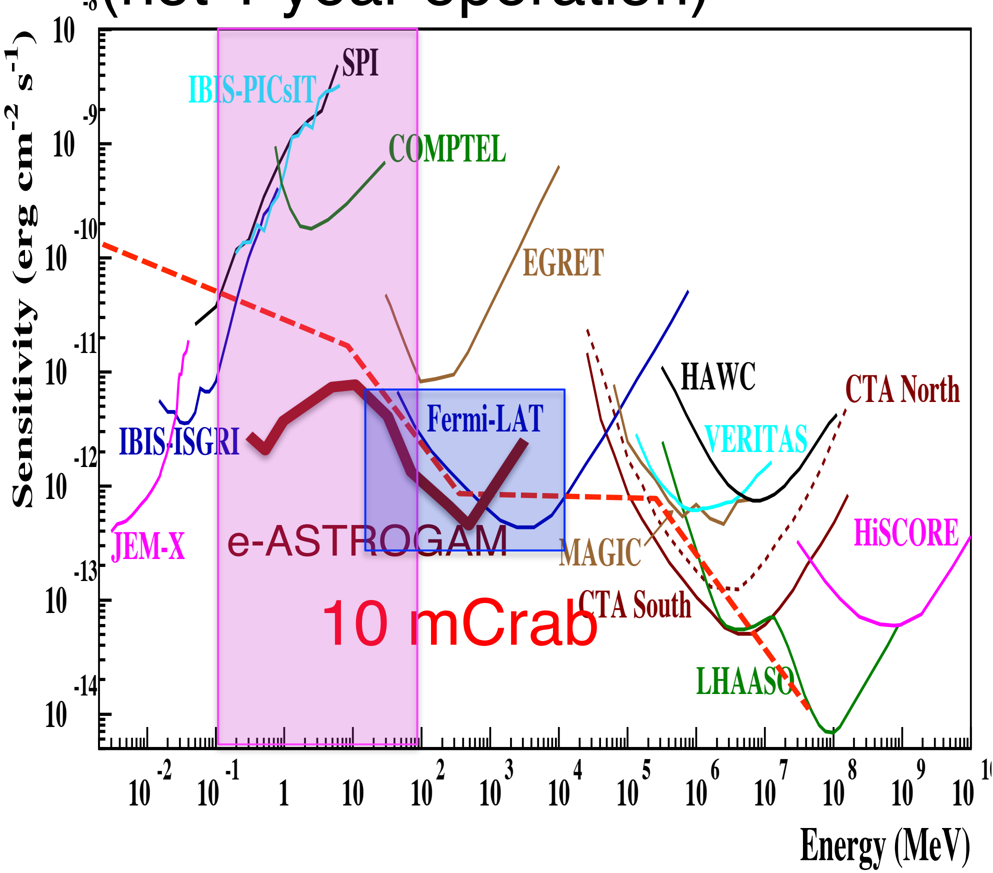


Fig. 19: e-ASTROGAM spacecraft in deployed configuration.

3+2 year operation

3-4 Sensitivity estimation

Comtinuum: 1 year exposure (not 1 year operation)



Line: 1 Ms 1 σ (not 1 year operation)

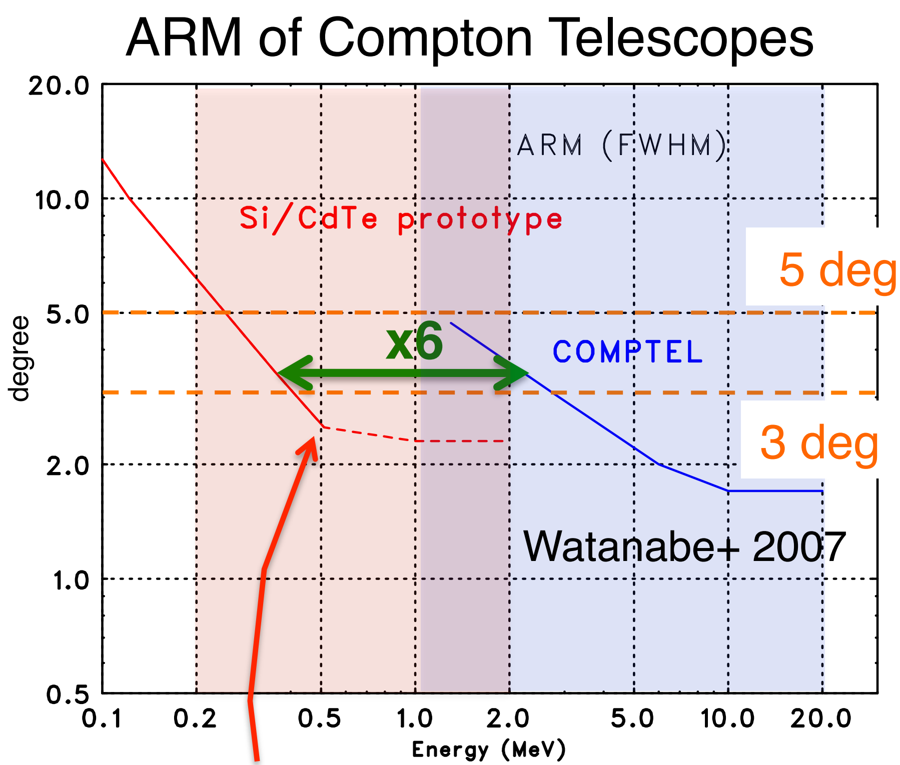
E (keV)	FWHM (keV)	e-ASTROGAM sensitivity (ph cm^{-2} s^{-1})	Improvement vs SPI
511	1.3	4.1×10^{-6}	13
847	35	3.5×10^{-6}	66
1157	15	3.6×10^{-6}	27
1275	20	3.8×10^{-6}	29
2223	20	2.1×10^{-6}	52
4438	100	1.7×10^{-6}	65

4. Other Missions

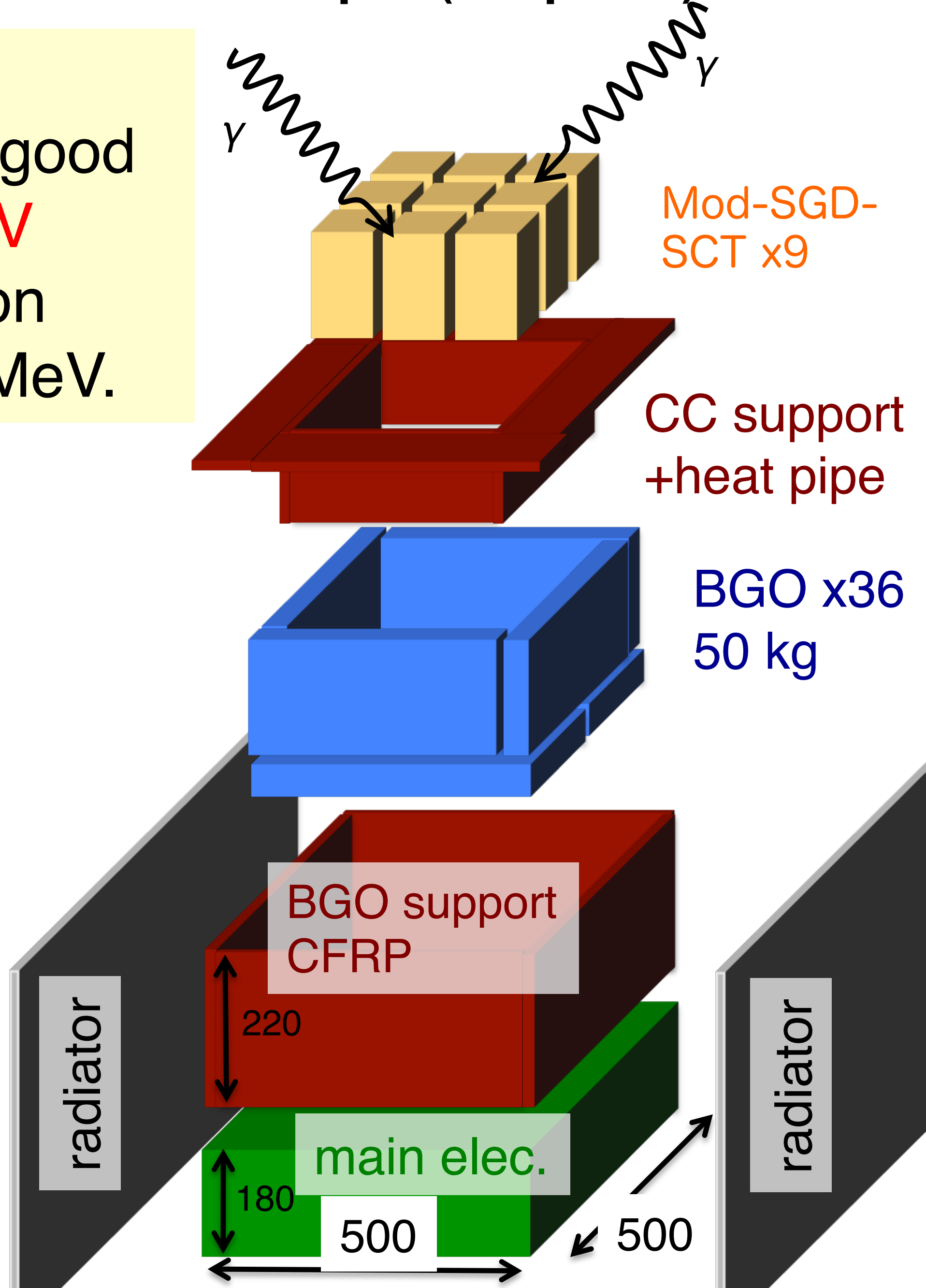
4-1 CAST mission concept (Japan)

Basic concept

- Si-CdTe Compton Camera → good ΔE, good $\Delta\theta$. Good at sub-MeV
- More photon → smaller mission (~50 cm) to cover 0.1– a few MeV.

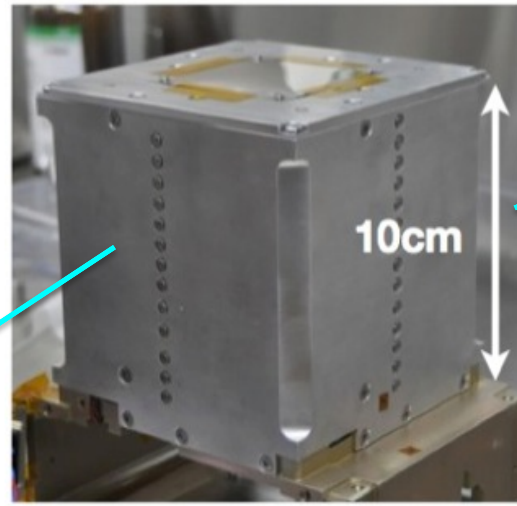


Experimental results (not sim.)



4-1 CAST mission concept (Japan)

Based on heritage from "Hitomi"
Soft Gamma-ray Detector

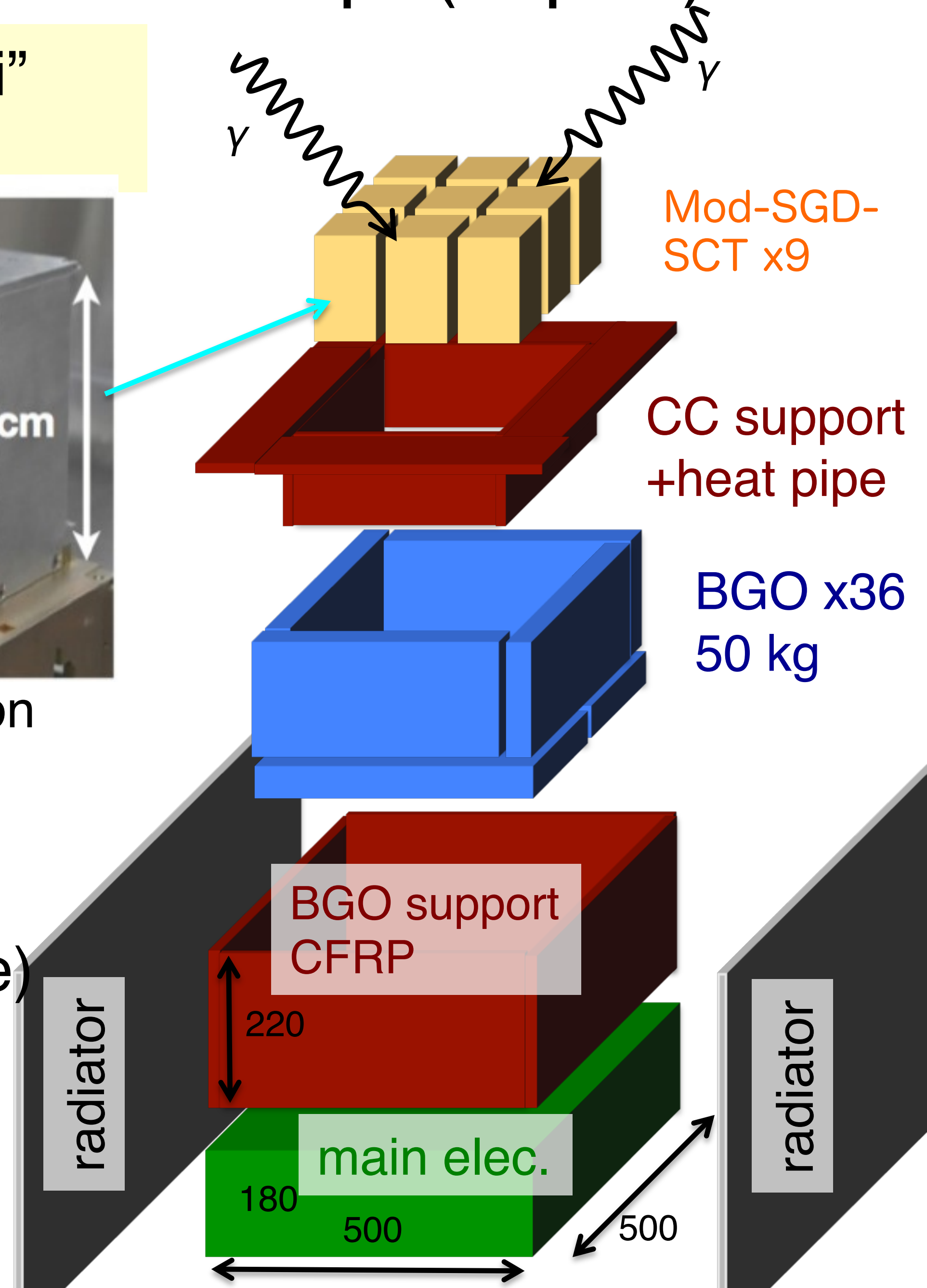


Si-CdTe Compton Camera

next step will be

- ballooning (for low BGD)
- e-tracking (with new Si-device)

** there is also a u-TPC based e-tracking MeV Compton camera, by Tanimori-group*

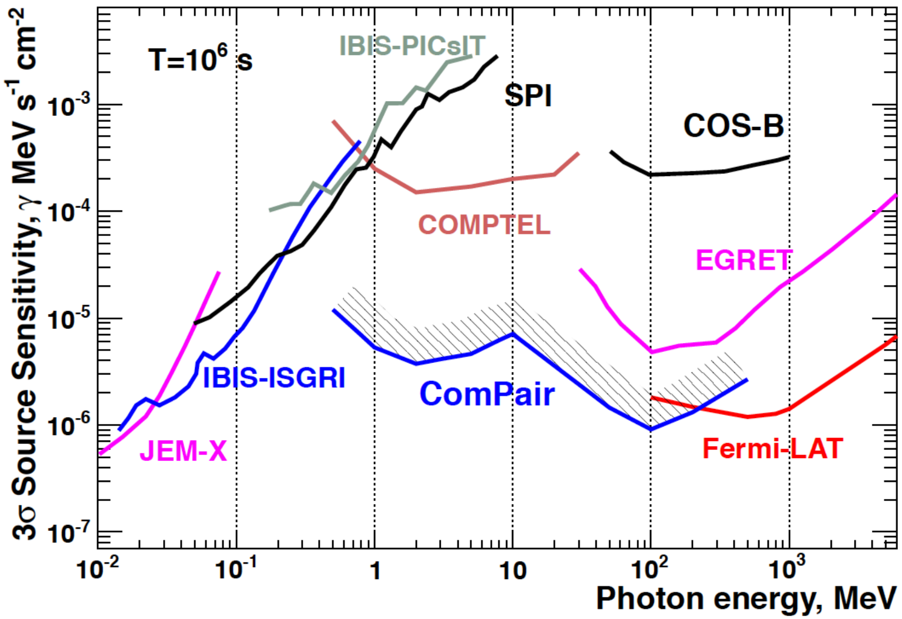


4-2 COMPAIR (US, for MIDEX?)

Concept

Add CZT layer between DSSDs and CsI calorimeter

Both, Compton mode and Pari-mode (0.5-100 MeV)



Moiseev+ 2016

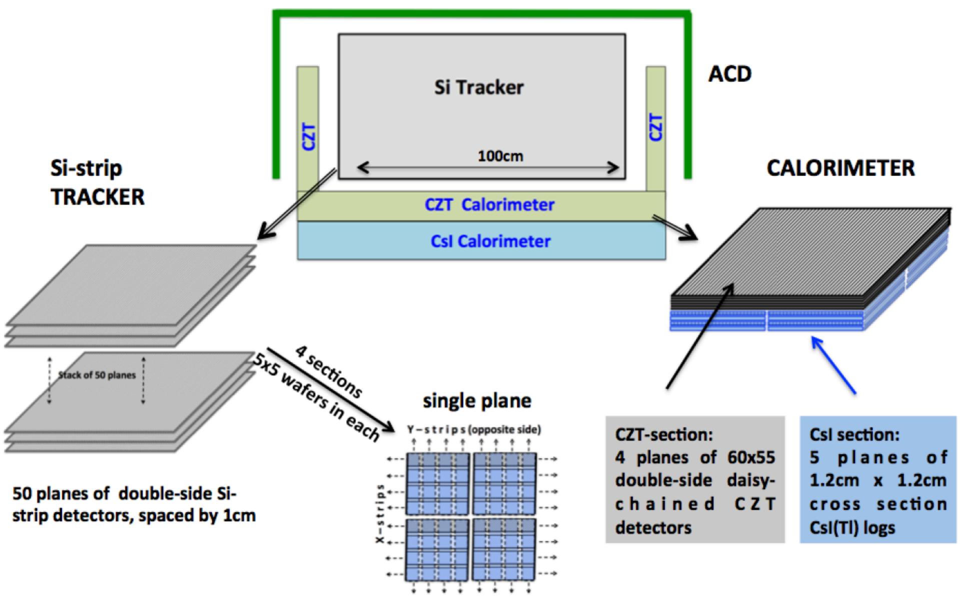


Figure 1: Conceptual design of ComPair

5 Summary

- MeV – GeV is a frontier in high-energy astronomy
- eASTROGAM (for ESA-M5 2029 launch) uses, DSSD-tracker + segmented-CsI calorimeter. Operates with combined
  - (orthodox) Compton telescope
  - electron-tracking Compton telescope
  - converter-less pair telescope
- Desinged for "better than 10 mCrab" sensitivity, and with low-E $\Delta\theta$ improvements over Fermi-LAT, at 0.3 MeV— 30 MeV
- CAST is another plan, focussed on sub-MeV to make it small → we will renew it, incoporating electron-trcking new Si-device
- COMPAIR is similar to eASTROGAM, with CZT middle layer.

For MeV, we will hold a small WS at Kyoto on 2019/2/27-28