Future Gamma-Ray Experiments in the CTA Era

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Sexten 2017: Gamma-Ray Astrophysics with CTA

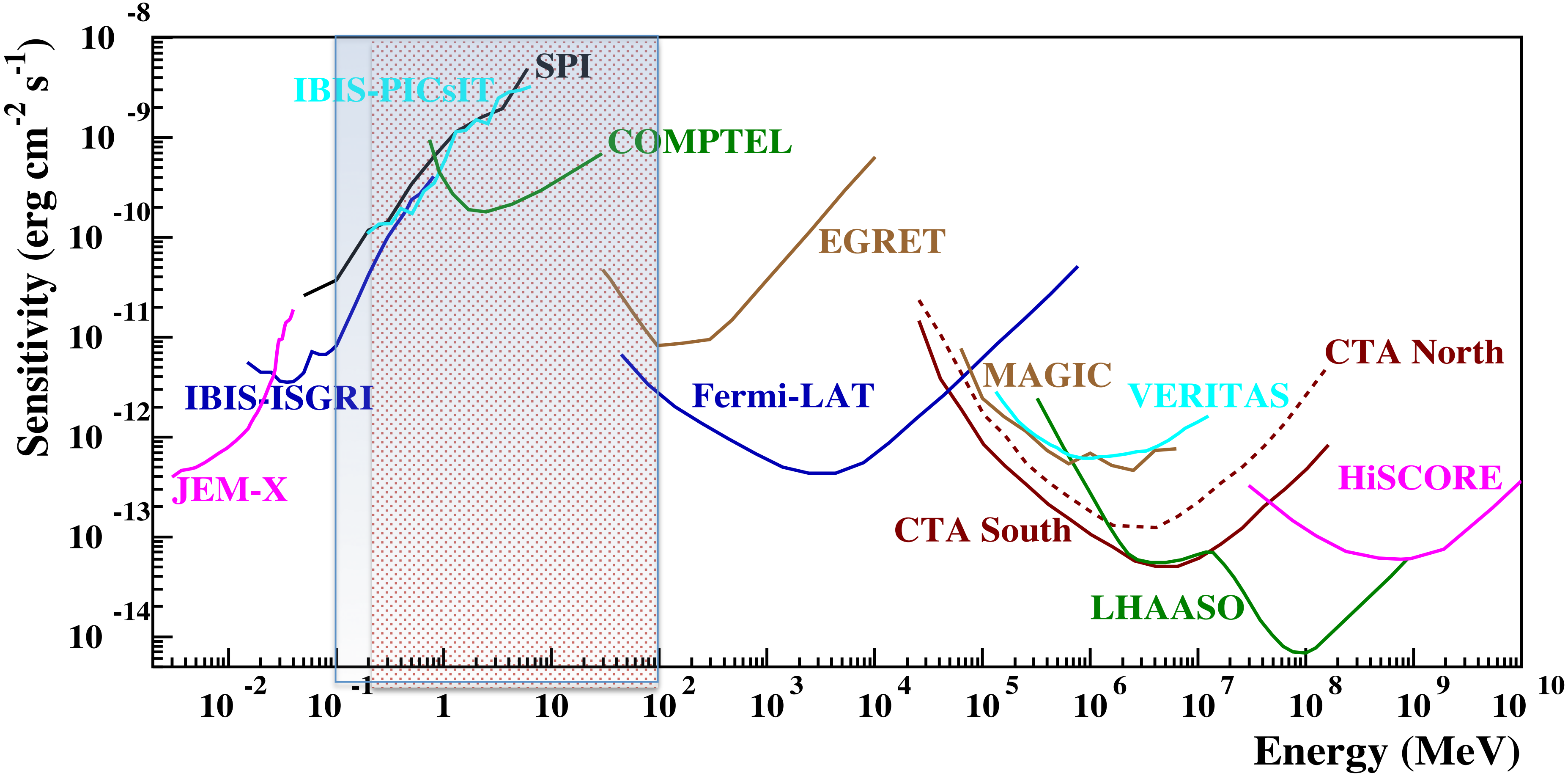
28 July 2017

future gamma-ray experiments with CTA ?

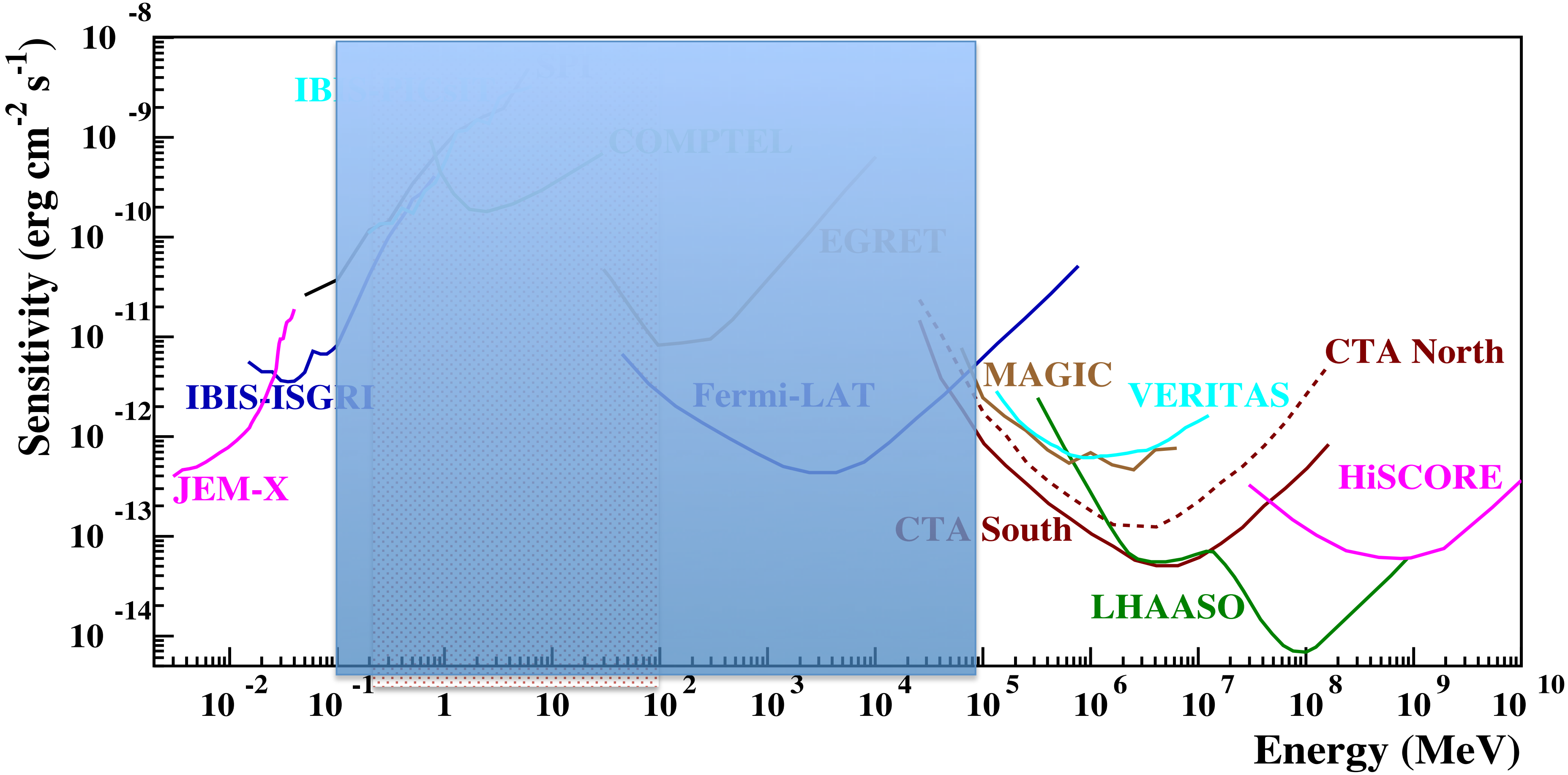
- space
  - ???

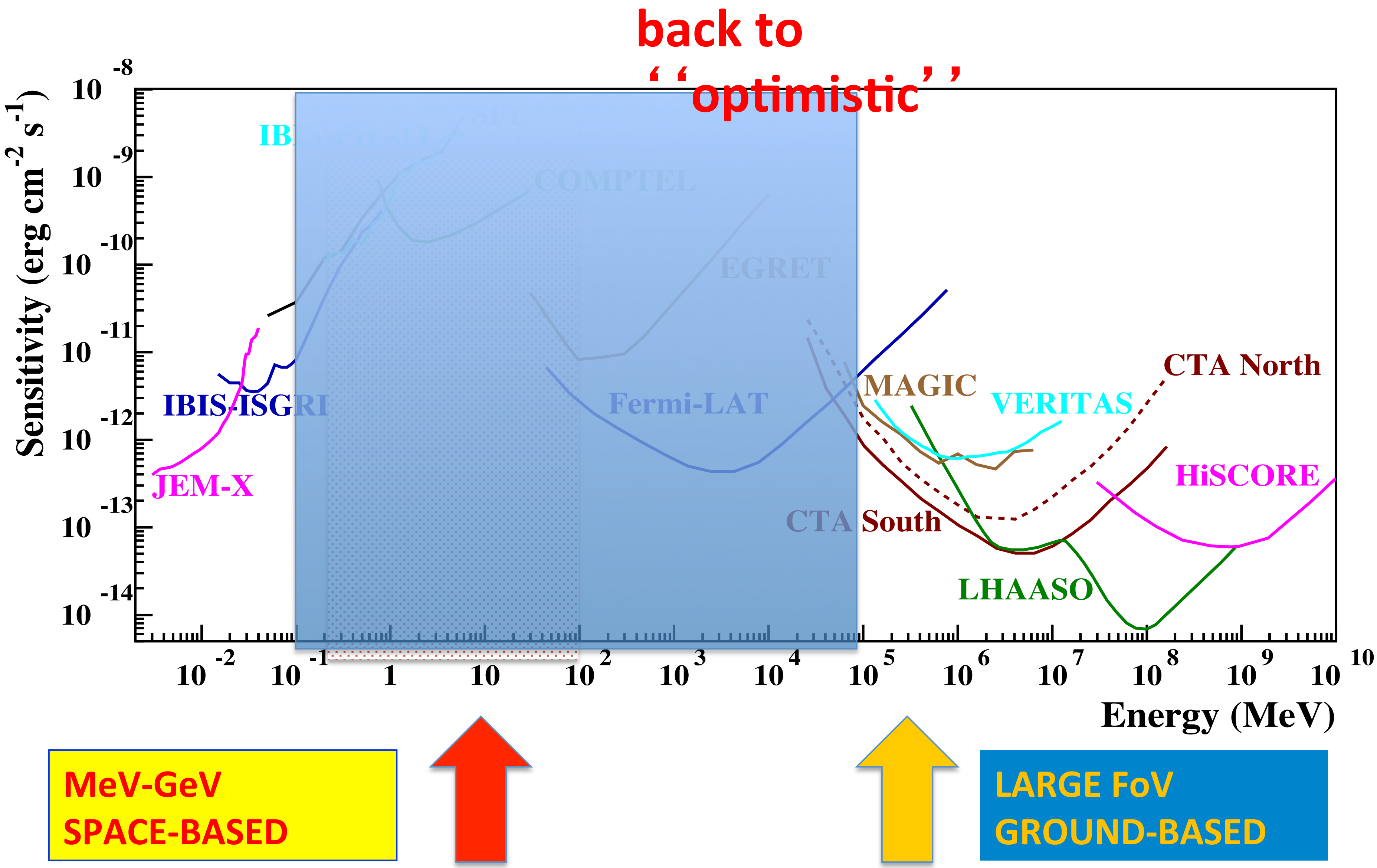
- ground-based, wide FoV
  - HAWC (North)
  - LHAASO
  - ???

‘‘optimistic’’


Sensitivity (erg cm^{-2} s^{-1})
Energy (MeV)
SPI
IBIS-PICsIT
COMPTEL
EGRET
IBIS-ISGRI
JEM-X
Fermi-LAT
MAGIC
VERITAS
CTA North
CTA South
HiSCORE
LHAASO

‘ ‘pessimistic’ ’





back to
' 'optimistic' '
Sensitivity (erg cm^{-2} s^{-1})
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JEM-X
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CTA South
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HiSCORE
LHAASO
MeV-GeV
SPACE-BASED
LARGE FoV
GROUND-BASED

future gamma-ray experiments with CTA?

- space
  - ???

- ground-based, wide FoV
  - HAWC (North)
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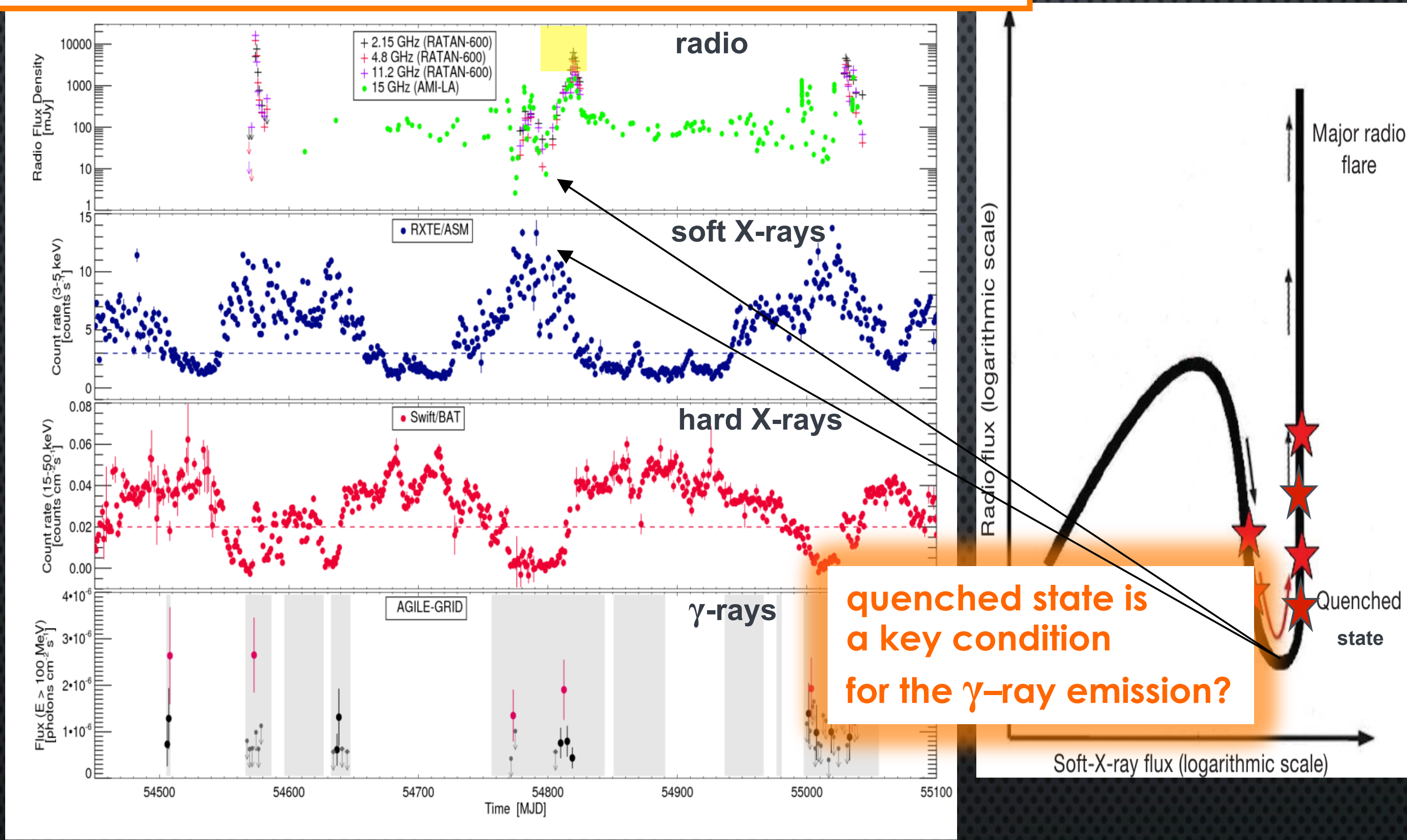
future gamma-ray experiments with CTA?

- space
  - e-ASTROGRAM (AMEGO)
- ground-based, wide FoV
  - HAWC (North)
  - LHAASO
  - a new Southern 100 GeV-100 TeV experiment

- ‘‘new life’’ for the MeV range
- add the GeV
  (join with MeV, ASTROGAM idea)
- a very large number of astrophysical reasons
- clear evidence today that the MeV-GeV region is at the heart of particle acceleration for both leptonic and hadronic processes
- not only an almost unexplored range,
  but the crucial connection of VHE astrophysics with the rest of the world.

Cygnus X-3

Multi-wavelength light curve (December 2007 → September 2009)



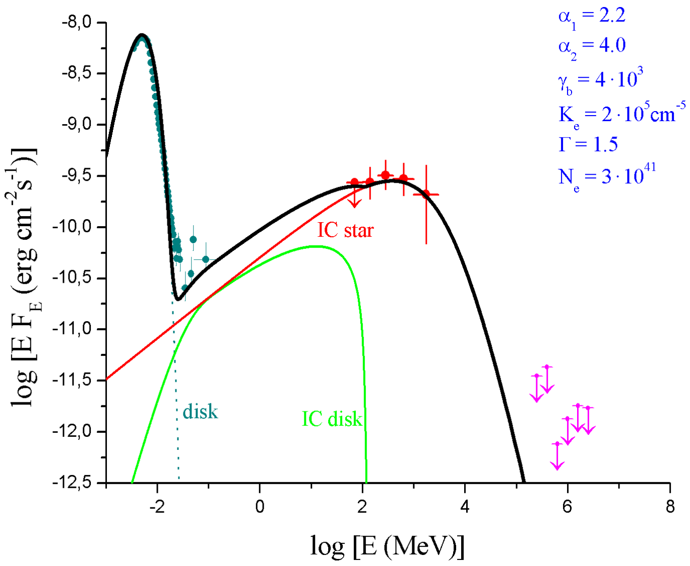
Repetitive multi-frequency emission pattern:

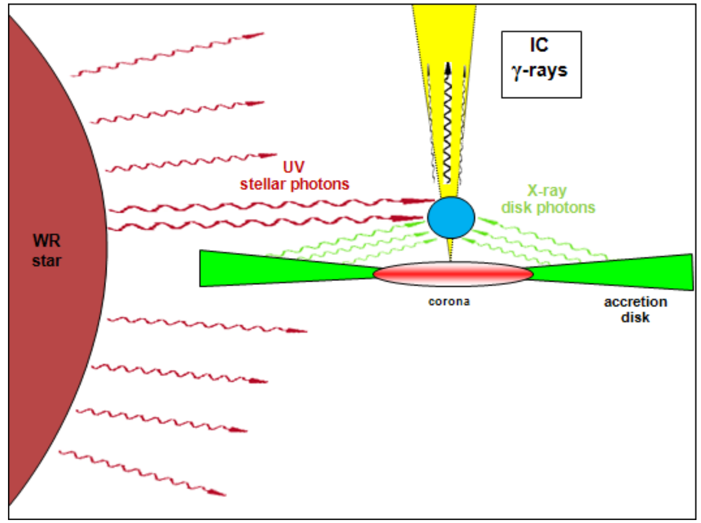
- **STRONG ANTICORRELATION** between hard X-ray and γ-ray emission: γ-ray activity associated with sharp/local minima in the hard X-ray light curve (*Swift*/BAT count rate ≤ 0.02 counts cm^{-2} s^{-1})
- γ-ray flares coincident with soft spectral states (*RXTE*/ASM count rate ≥ 3 counts s^{-1})
- γ-ray flares around hard-to-soft or soft-to-hard spectral transitions

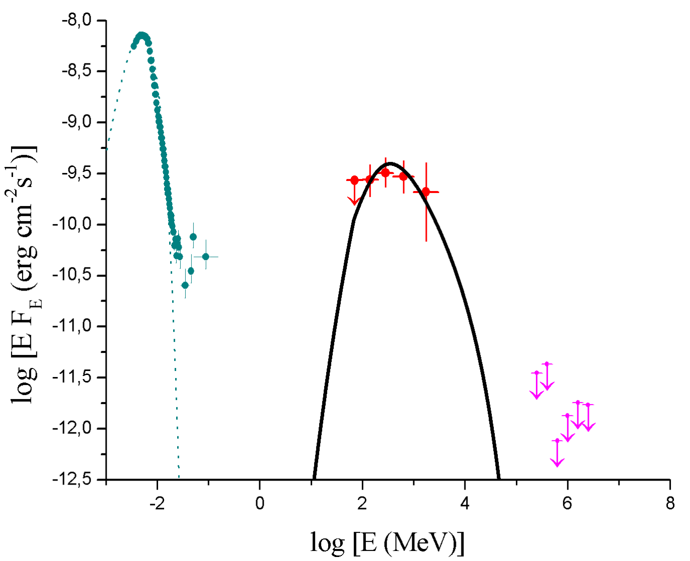
(Piano et al. 2012)

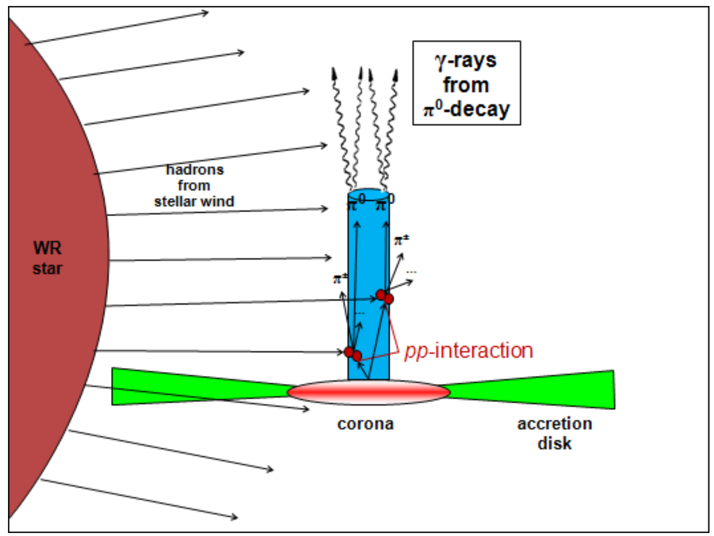
Cygnus X-3

(Piano et al., A&A, 545 A110, 2012)









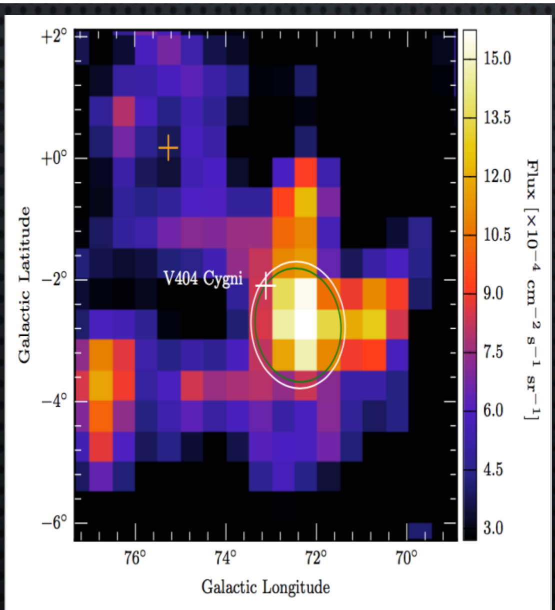
V404 Cygni

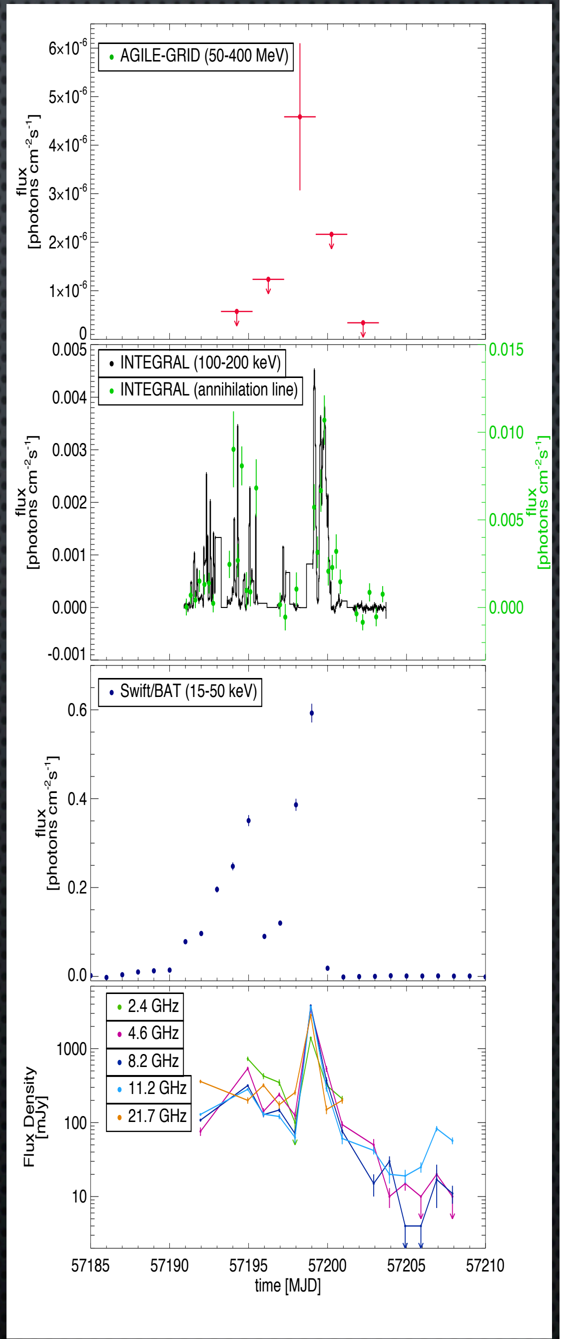
After ~26 years of quiescence →
active phase in June 2015

High Energy γ-ray flare (50-400 MeV) coincident with outbursts in:

- radio
- X-ray
- soft γ-rays (continuum & 511 keV annihilation line)

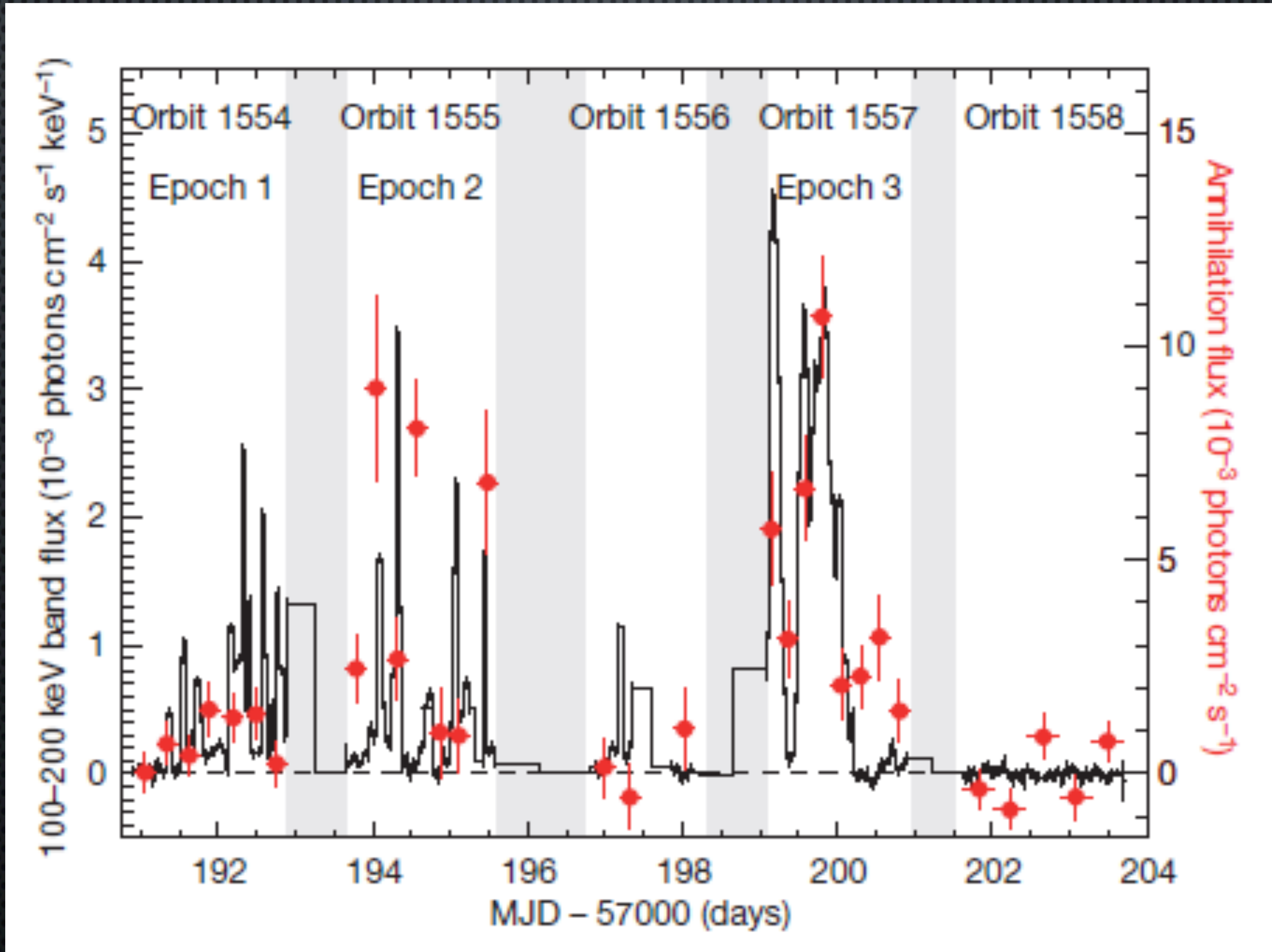
AGILE 2-day intensity map (50-400 MeV)





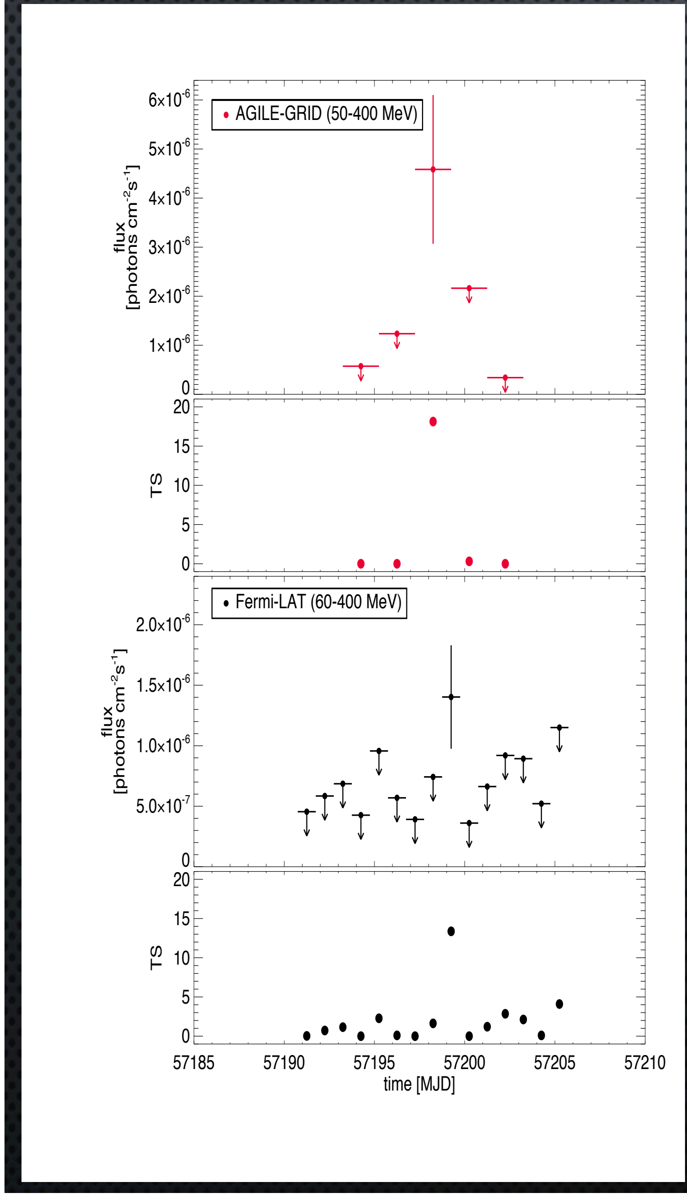
V404 Cygni

(Siegert etal., 2016)

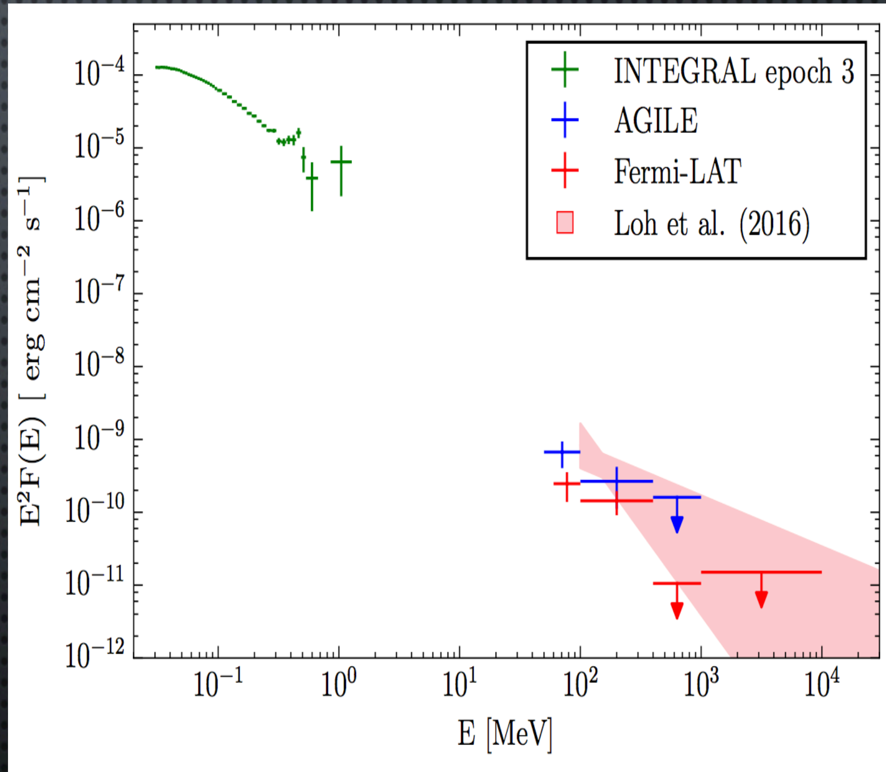


V404 Cygni

AGILE (50-400 MeV) simultaneous
with Fermi-LAT (60-400 MeV)



Simultaneous flaring SED

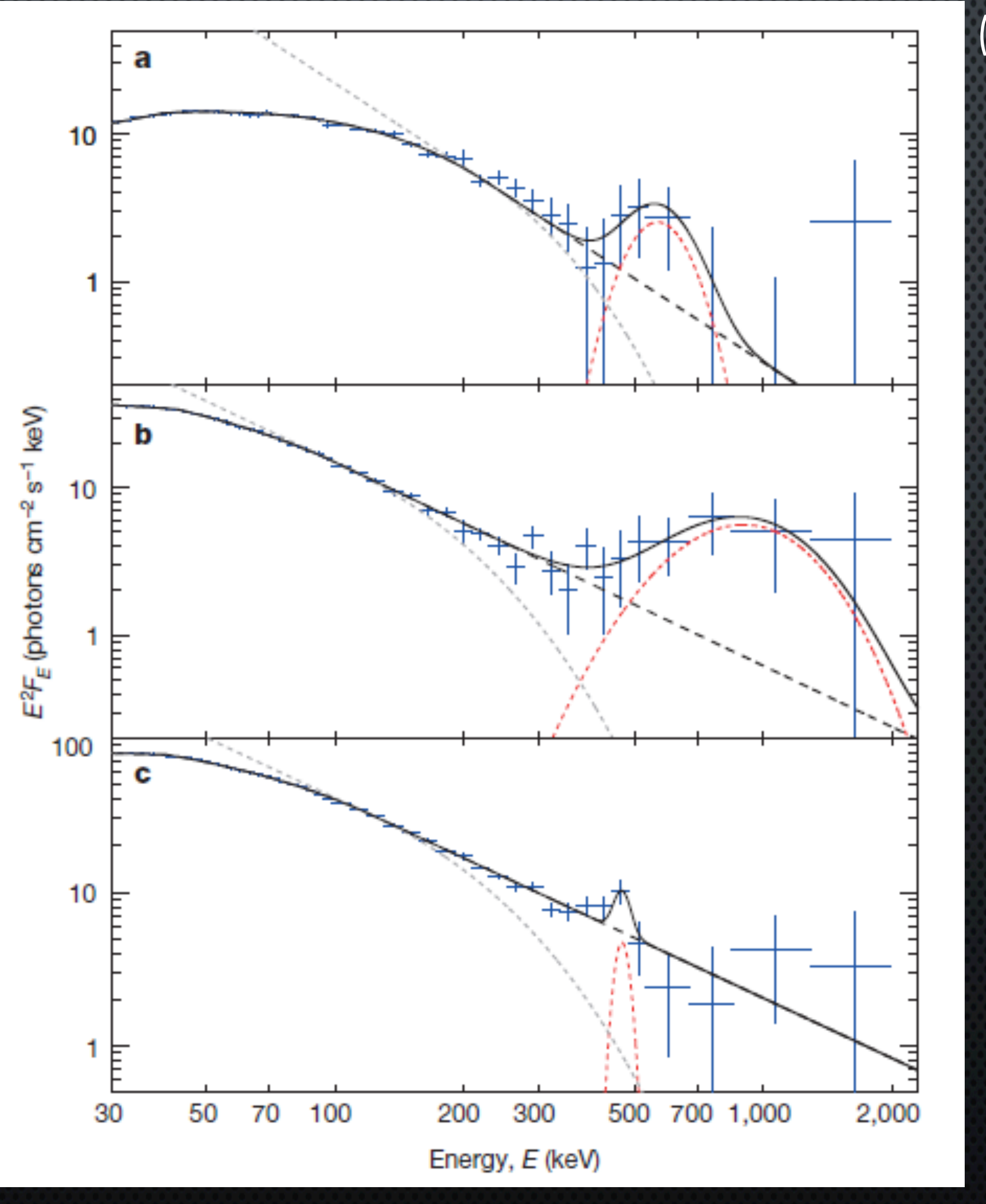


Soft emission in HE γ-rays:
no detected activity above 400 M

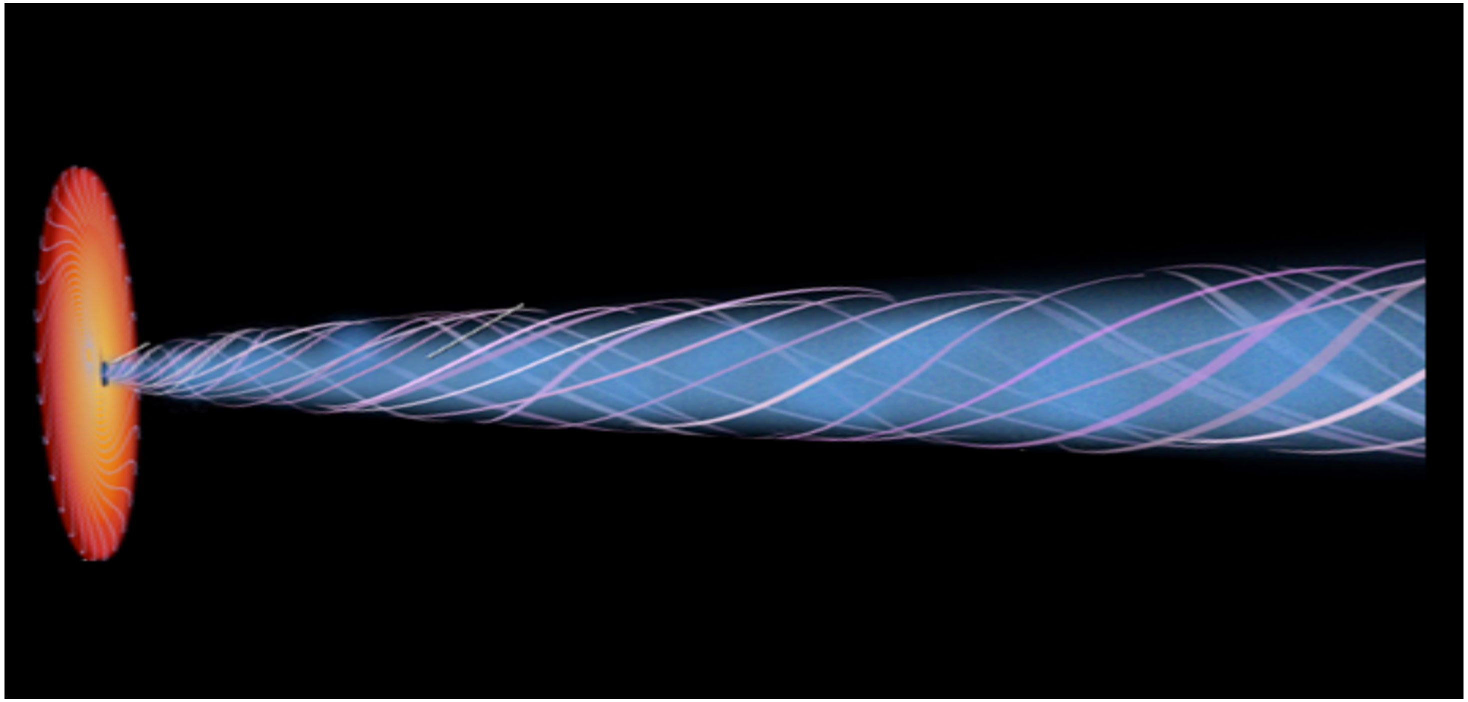
(Piano et al. ApJ 839, 84, 2017)

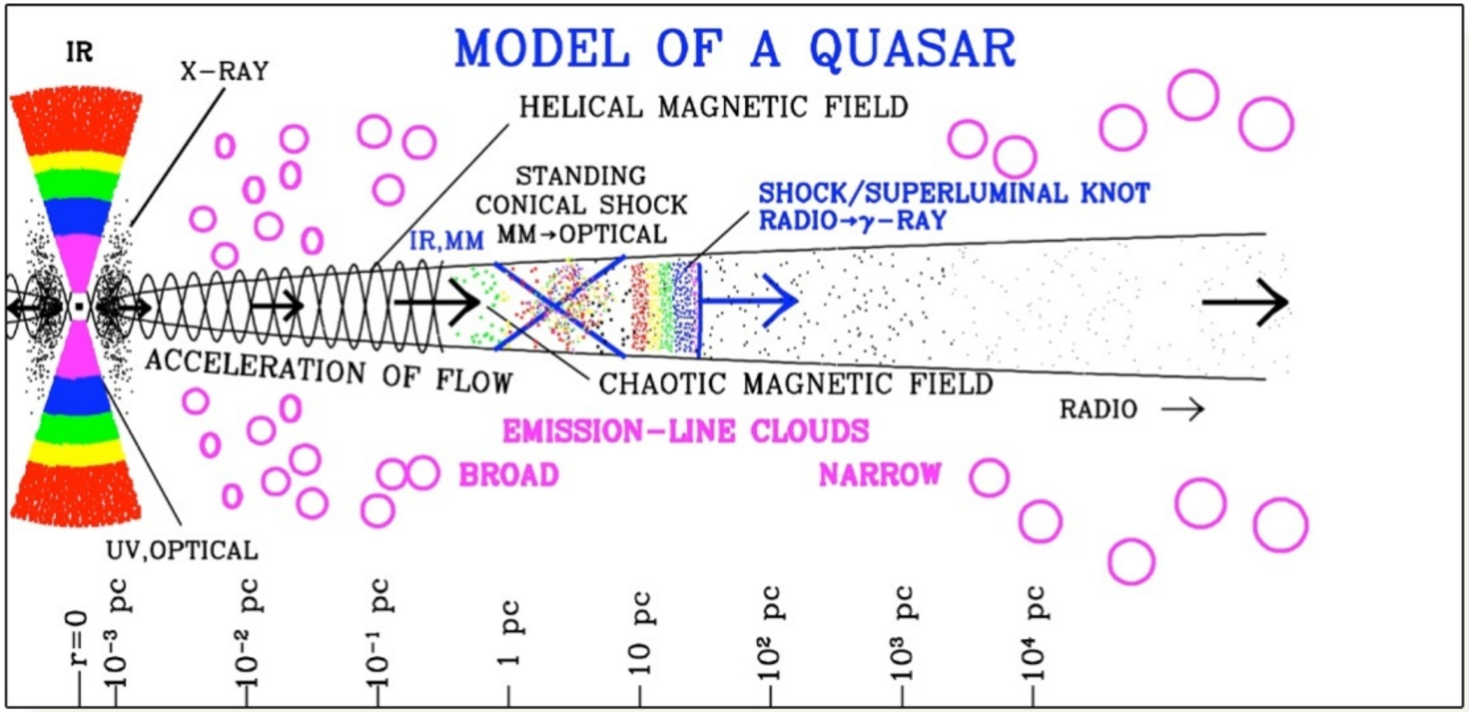
V404 Cygni

(Siegert etal., 2016)

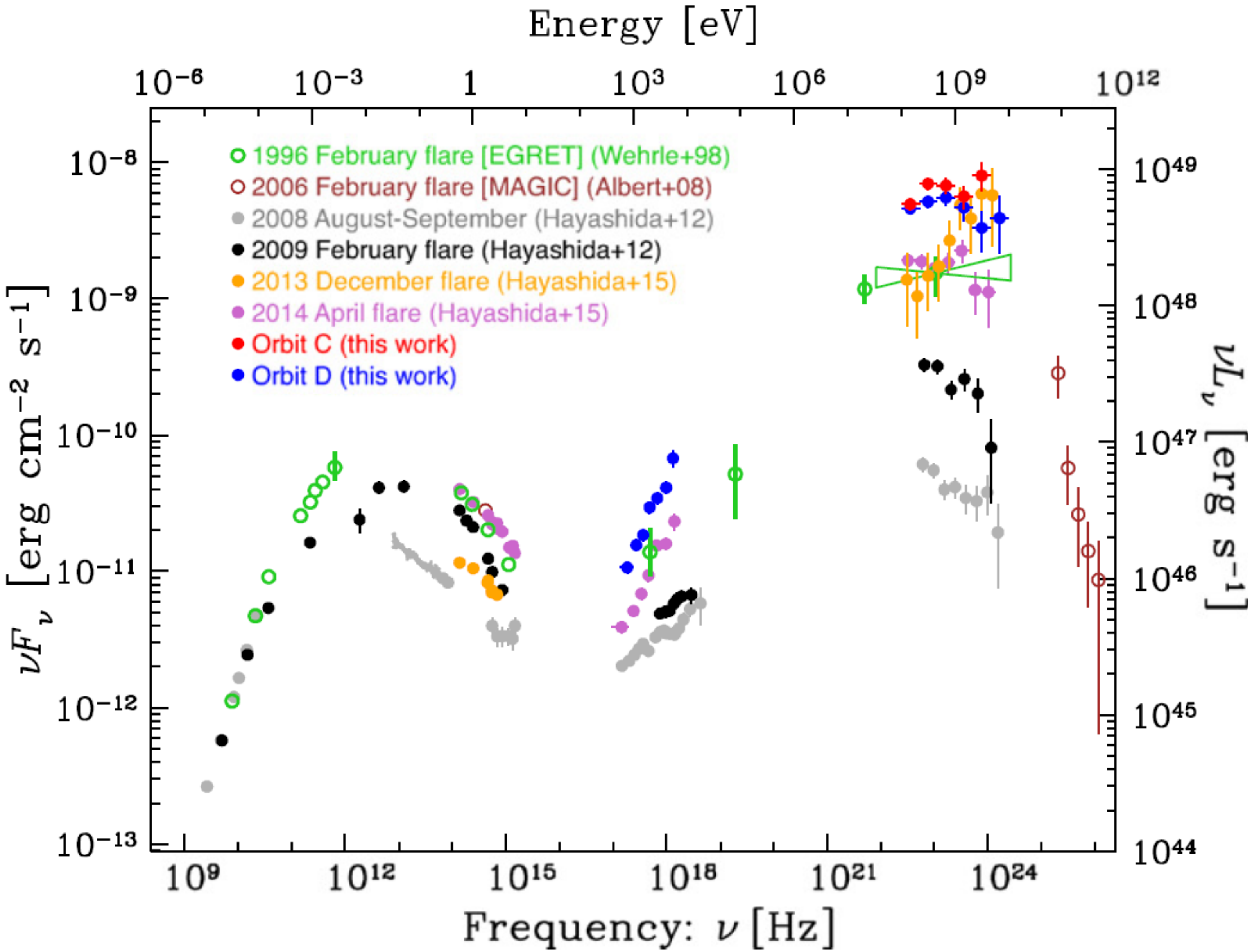


period 3

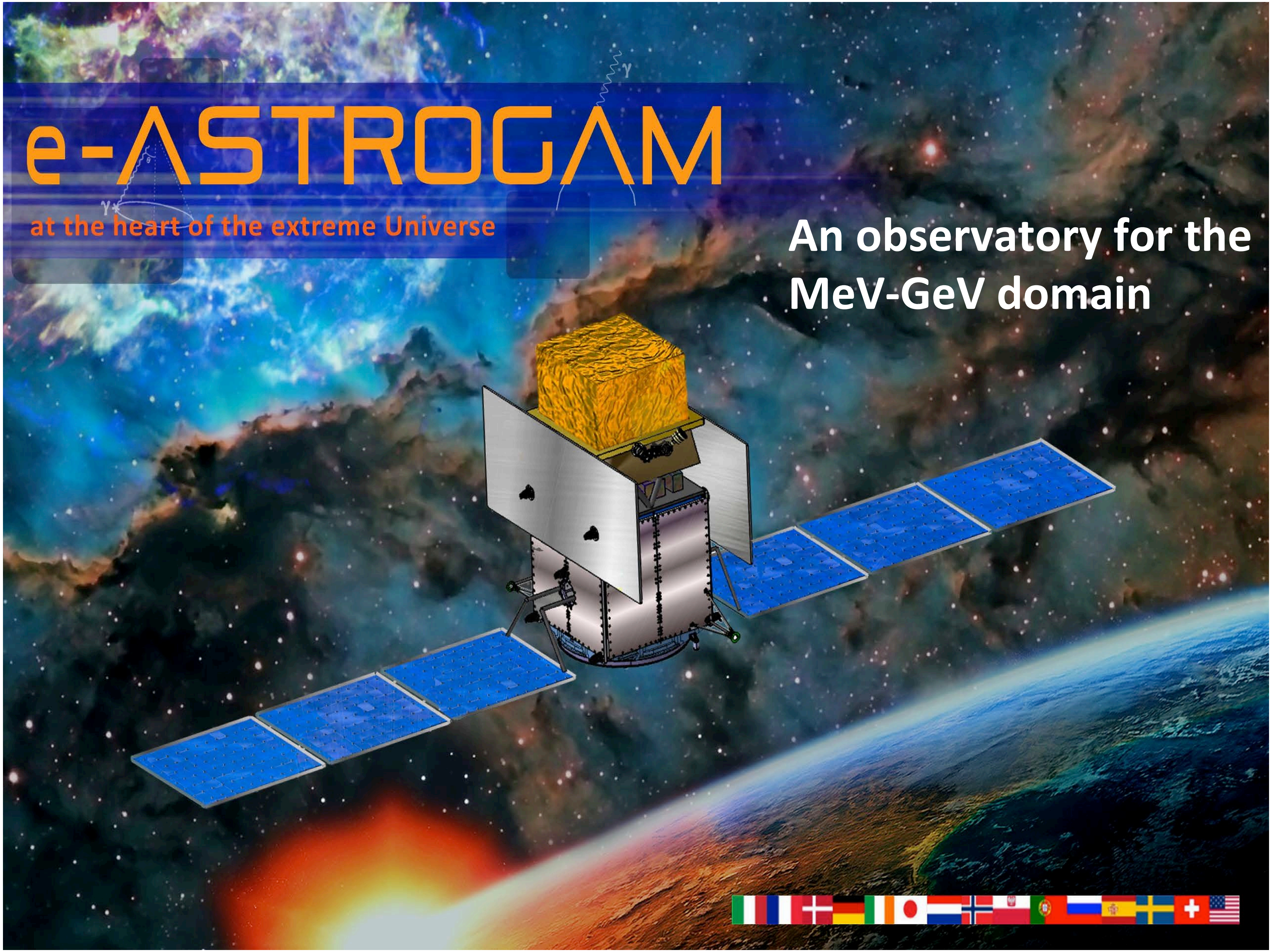



MODEL OF A QUASAR
IR
X-RAY
HELICAL MAGNETIC FIELD
STANDING
CONICAL SHOCK
MM→OPTICAL
SHOCK/SUPERLUMINAL KNOT
RADIO→γ-RAY
IR,MM
ACCELERATION OF FLOW
CHAOTIC MAGNETIC FIELD
RADIO →
EMISSION-LINE CLOUDS
BROAD
NARROW
UV,OPTICAL
r=0
10⁻³ pc
10⁻² pc
10⁻¹ pc
1 pc
10 pc
10² pc
10³ pc
10⁴ pc

The case of blazars: 3C 279 (Ackermann etal. 2016)



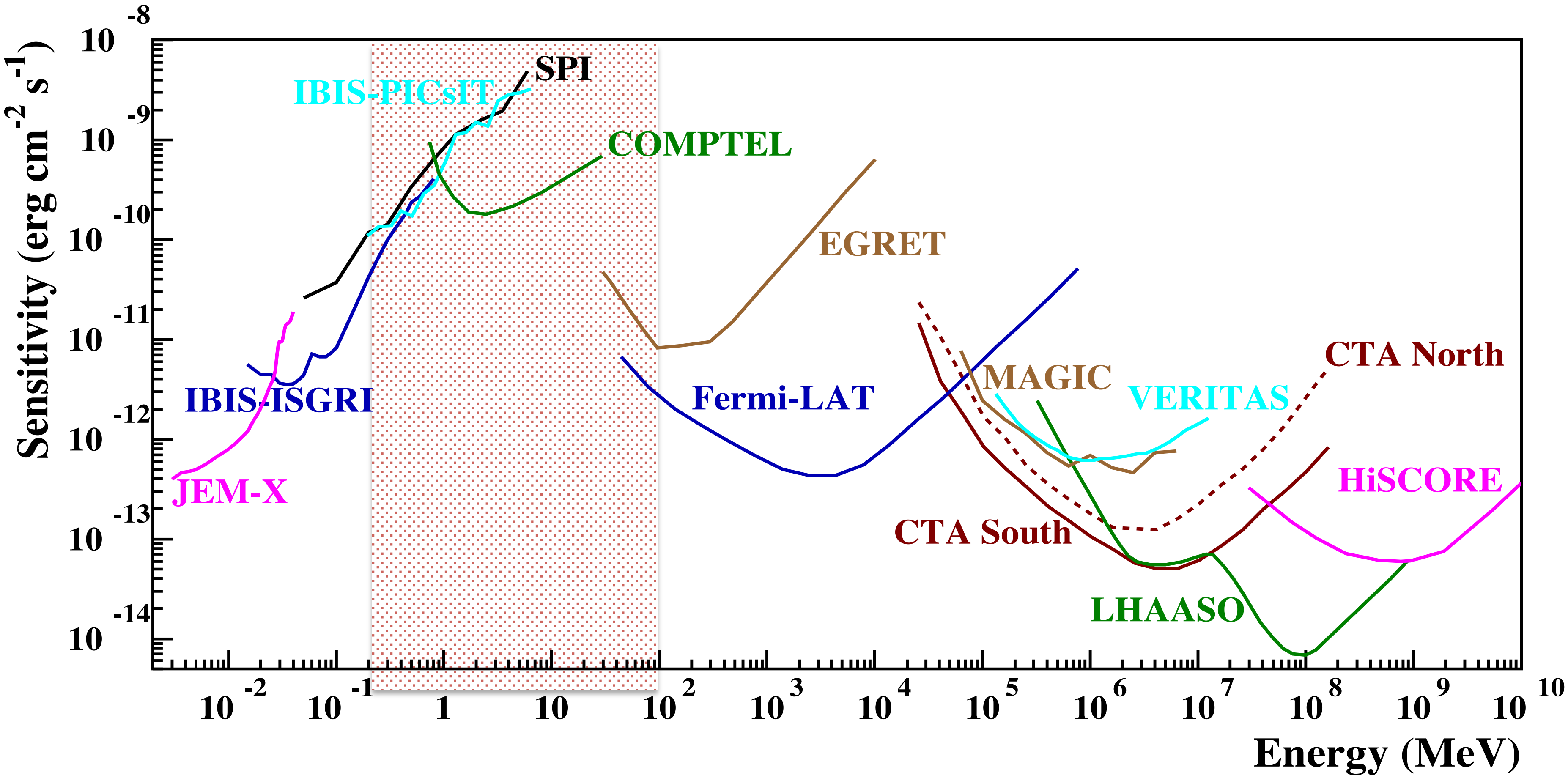
How can we live now without a high-sensitivity MeV experiment ?


e-ASTROGAM
at the heart of the extreme Universe
An observatory for the
MeV-GeV domain

e-ASTROGAM history

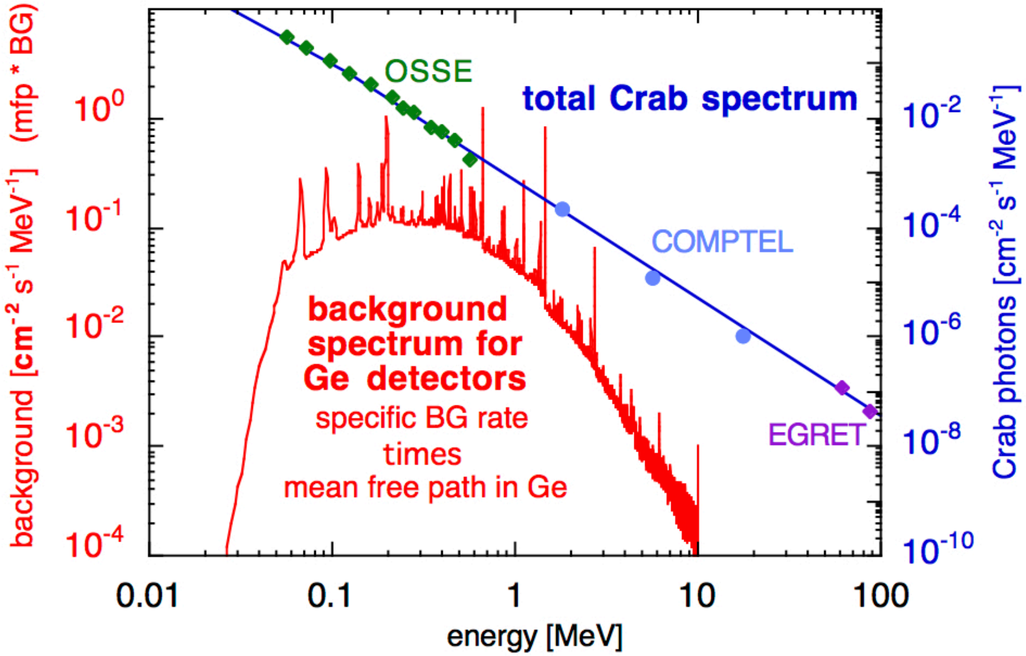
- born from the merging of ASTRO-MeV and Gamma-Light concepts in 2014
- ASTROGAM proposed in 2015 to ESA M4 (it passed the first evaluation, not selected for Phase-A)
- e-ASTROGAM (enhanced-ASTROGAM) proposed in 2016 to ESA M5

The MeV/sub-GeV domain

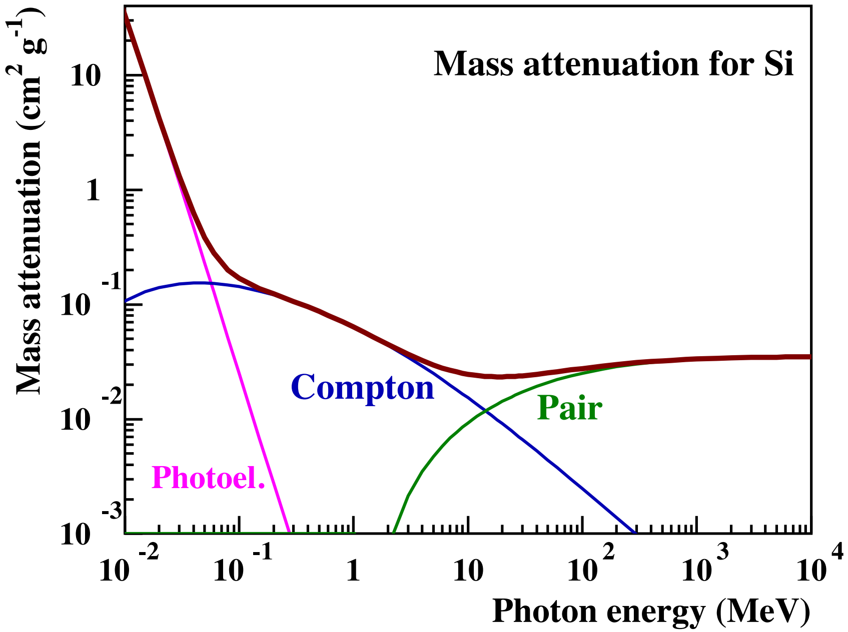


- Worst covered part of the electromagnetic spectrum (only a few tens of steady sources detected so far between 0.2 and 30 MeV)
- Many objects have their peak emissivity in this range (GRBs, blazars, pulsars...)
- Binding energies of atomic nuclei fall in this range, which therefore is as important for HE astronomy as optical astronomy is for phenomena related to atomic physics

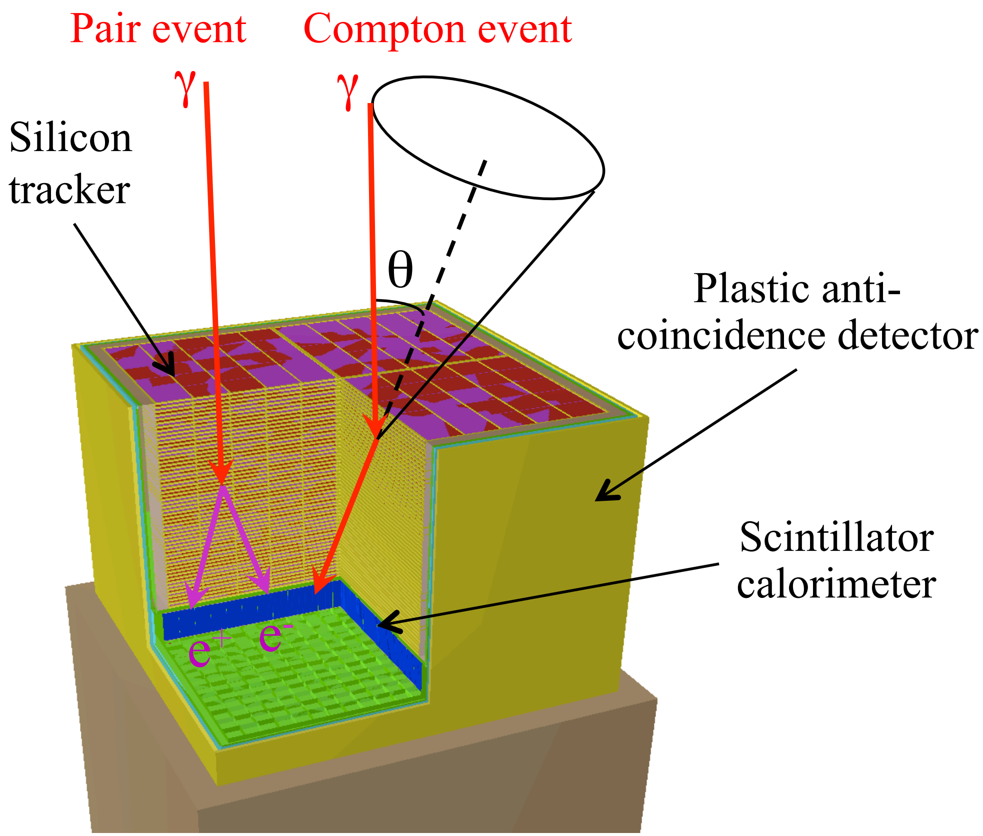
Observational challenges

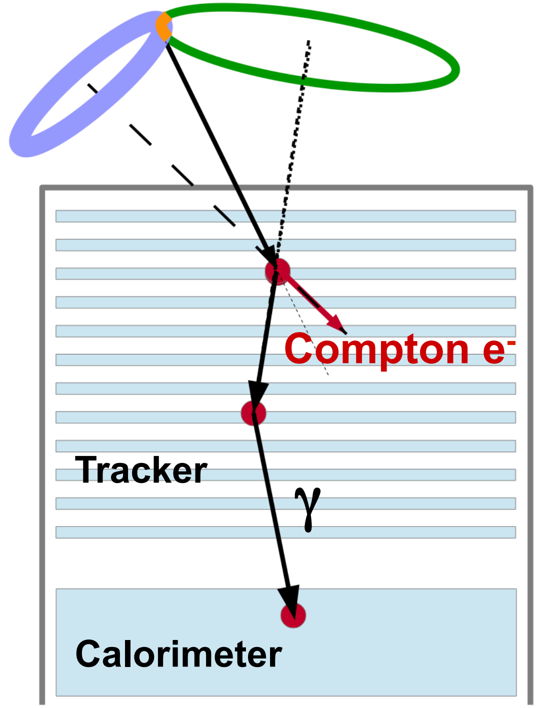


- ☺ The MeV range is the domain of nuclear γ-ray lines (radioactivity, nuclear collision, positron annihilation, neutron capture)
- ☹ Strong instrumental background from activation of space-irradiated materials
- ☹ Photon interaction probability reaches a minimum at ~ 10 MeV
- ☹ Three competing processes of interaction, Compton scattering being dominant around 1 MeV
  ⇒ complicated event reconstruction



How to measure gamma rays in the MeV-GeV?

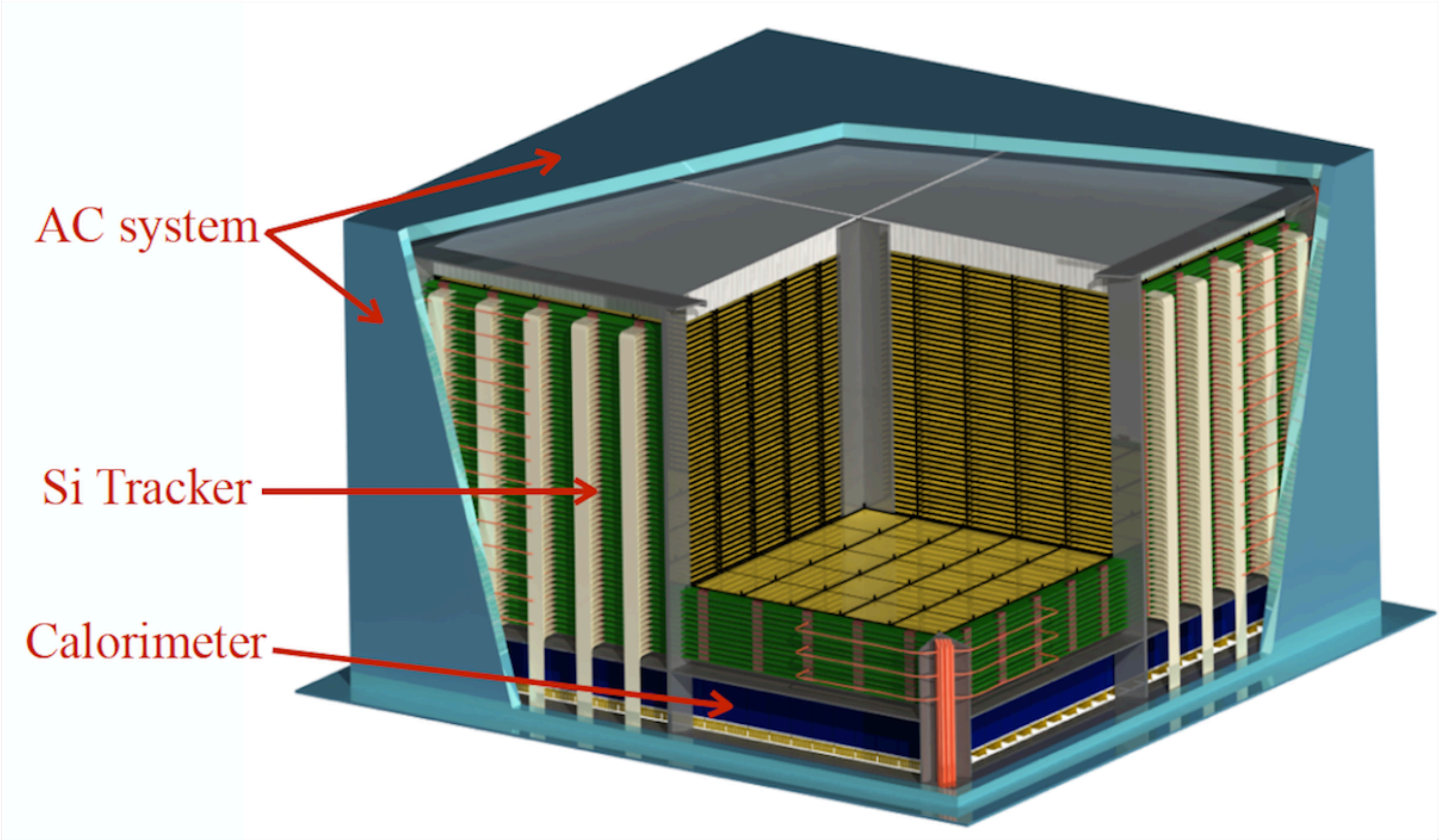




Tracked Compton event

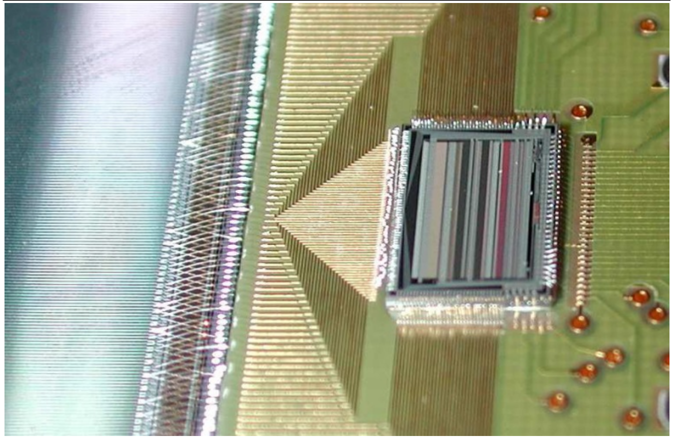
- **Tracker** – Double sided Si strip detectors (DSSDs) for excellent spectral resolution and fine 3-D position resolution ($1 m^2$, 500 μm thick, 0.3 Xo in total)
- **Calorimeter** – High-Z material for an efficient absorption of the scattered photon ⇒ CsI(Tl) scintillation crystals readout by Si drift detectors or photomultipliers for best energy resolution. 8 cm (4.3 Xo)
- **Anticoincidence detector** to veto charged-particle induced background ⇒ plastic scintillators readout by Si photomultipliers

e-ASTROGAM: the payload

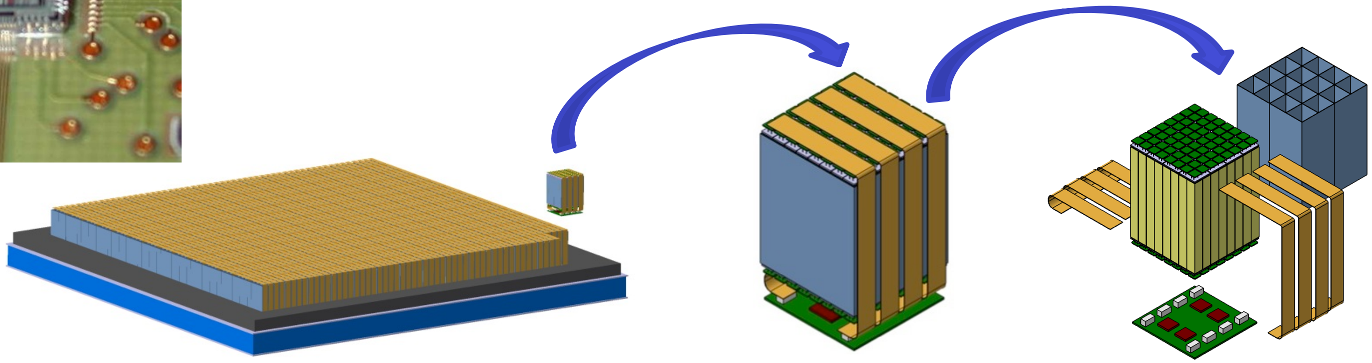


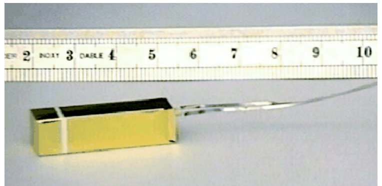
e-ASTROGAM: the payload

Detail of the detector-ASIC bonding in the AGILE Si Tracker

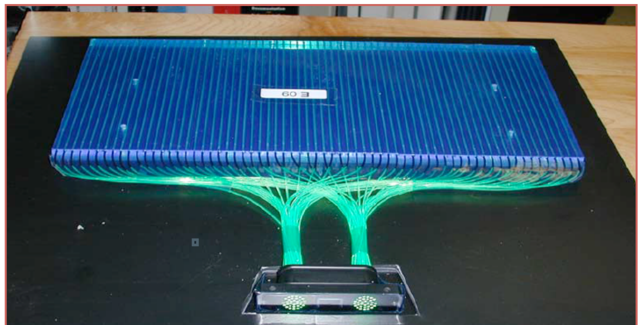


- **Tracker**: 56 layers of 4 times 5×5 DSSDs (5 600 in total) of 500 μm thickness and 240 μm pitch
- DSSDs bonded strip to strip to form 5×5 ladders
- Light and stiff mechanical structure
- Ultra low-noise front end electronics





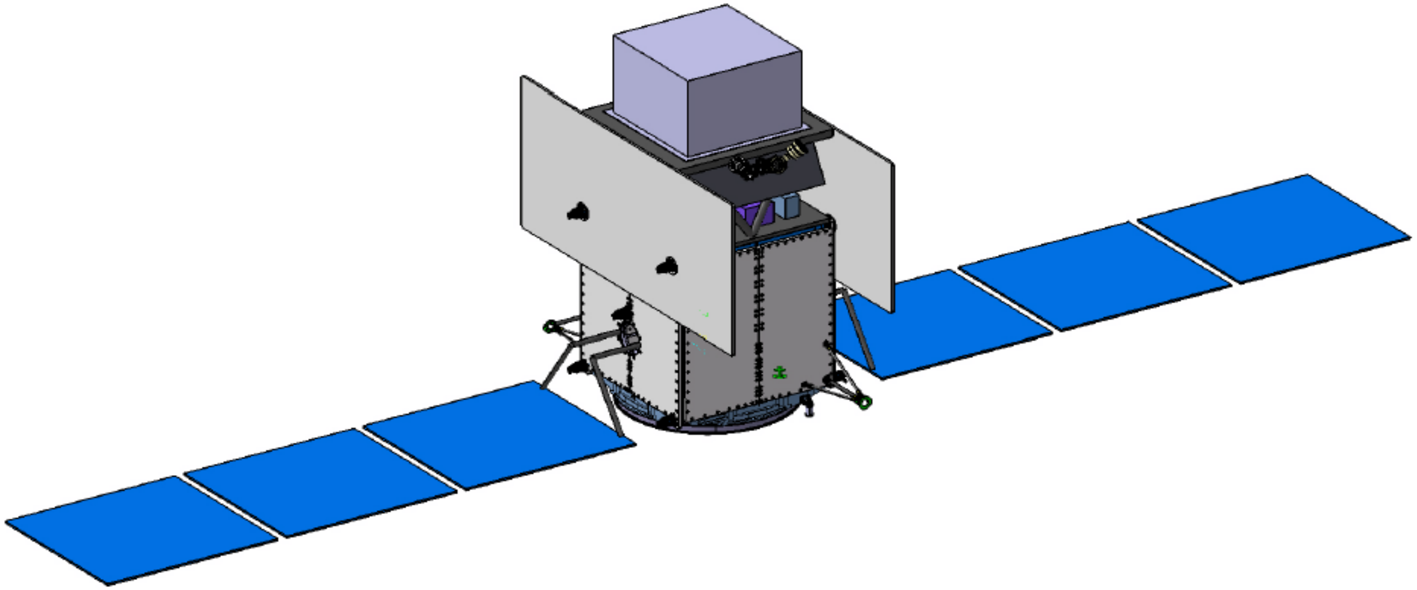
PICSiT CsI(Tl) pixel



Fermi/LAT AC system

- **Calorimeter**: 33 856 CsI(Tl) bars coupled at both ends to low-noise Silicon Drift Detectors
- **ACD**: segmented plastic scintillators coupled to SiPM by optical fibers
- **Heritage**: AGILE, Fermi/LAT, AMS-02, INTEGRAL, LHC/ALICE…

e-ASTROGAM: spacecraft & satellite



Mass of the satellite: ~2.5 ton
Mass of the payload: ~900 kg
Power consumption: ~1100 W

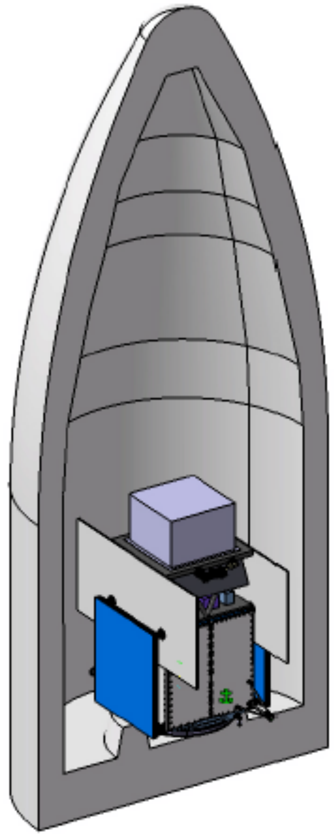
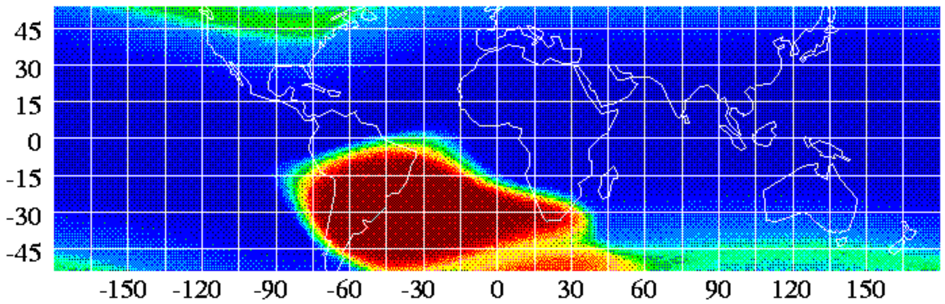
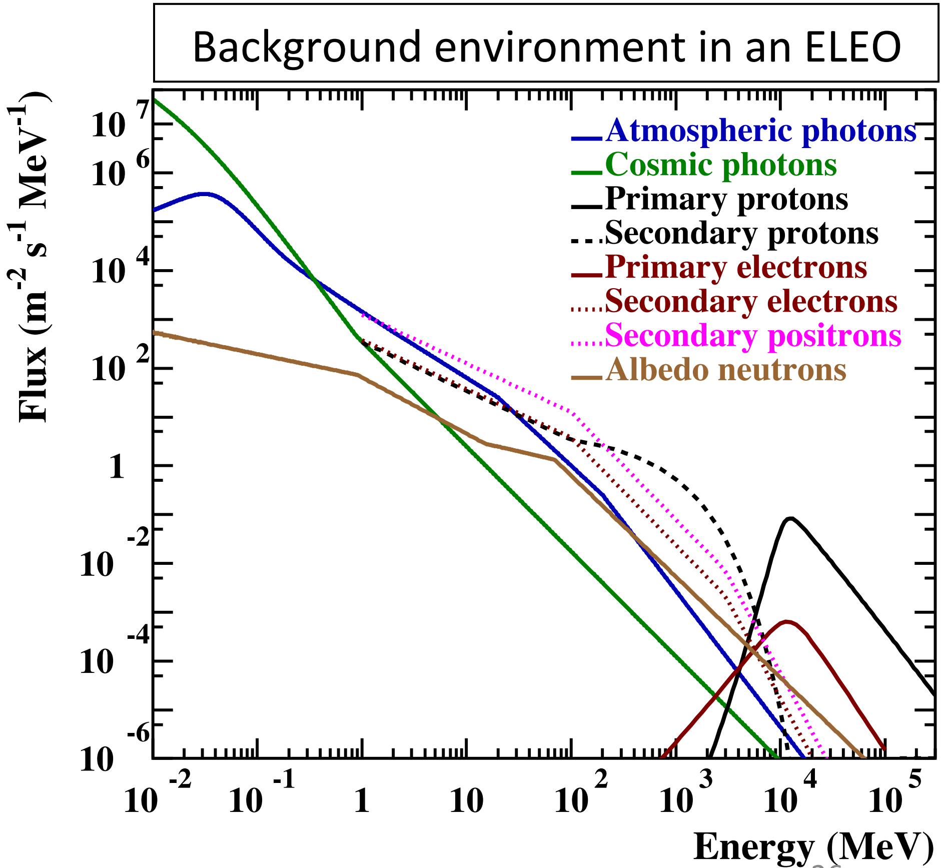


Figure 20: e-ASTROGAM under Ariane 6.2 fairing in upper position.

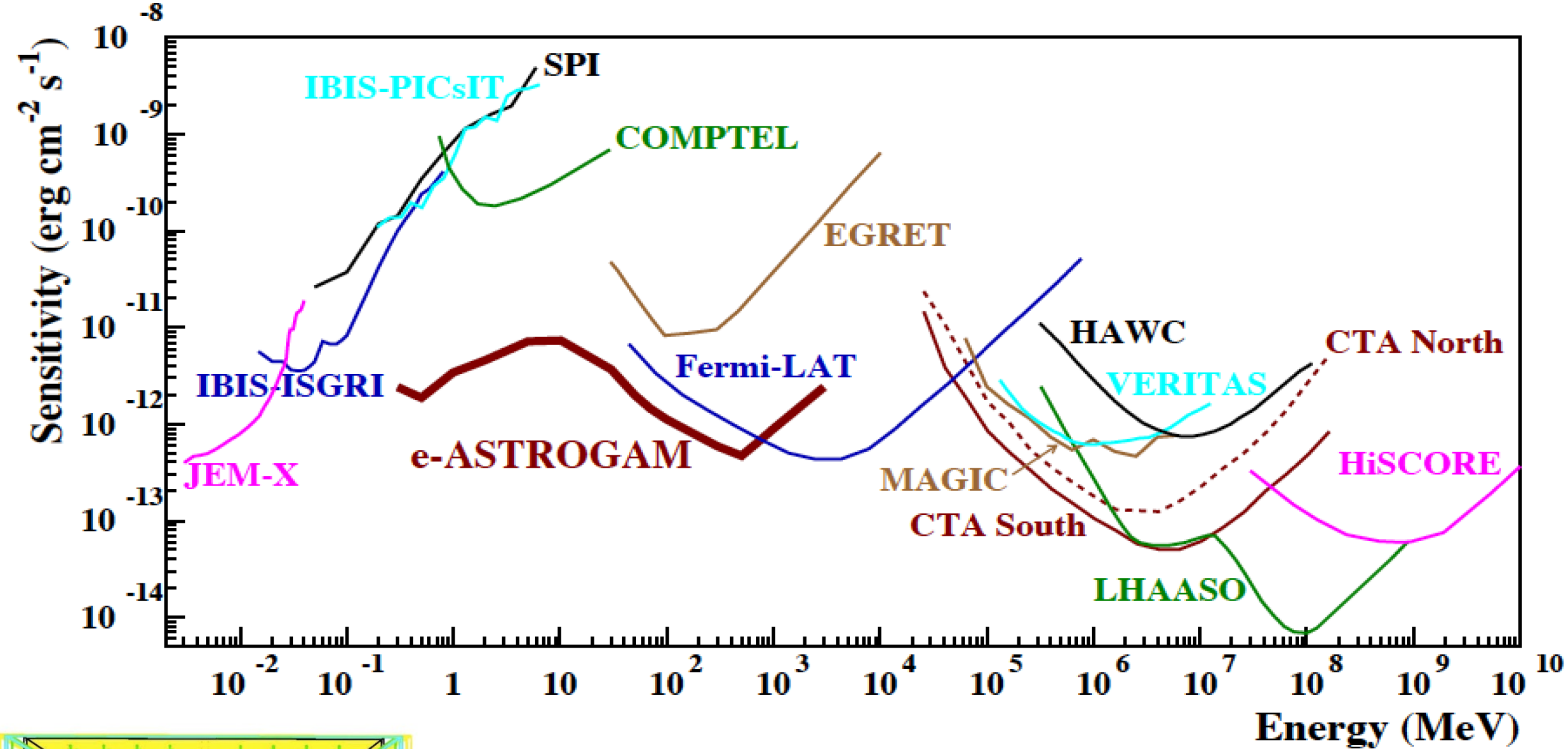
e-ASTROGAM: mission profile

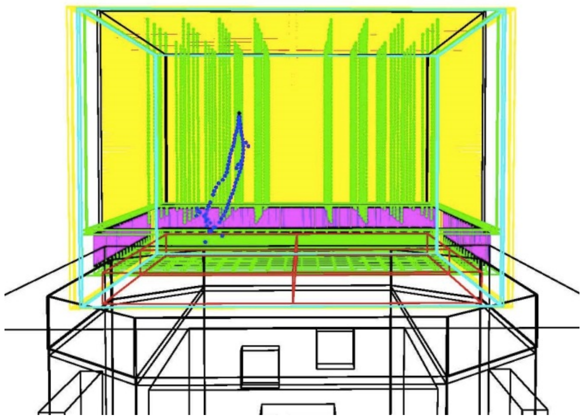
- **Orbit** – Equatorial (inclination *i* < 2.5°, eccentricity *e* < 0.01) low-Earth orbit (altitude in the range 550 - 600 km)
- **Satellite communication** –
ESA ground station at Kourou
+ ASI Malindi station (Kenya)
- **Data transmission** – via X-band (available downlink of 10 Mbps)
- **Observation modes** – (i) zenith-pointing sky-scanning mode, (ii) nearly inertial pointing, and (iii) fast repointing to avoid the Earth in the field of view
- **In-orbit operation** – 3 years duration + provisions for a 2+ year extension





e-ASTROGAM: performance assessment

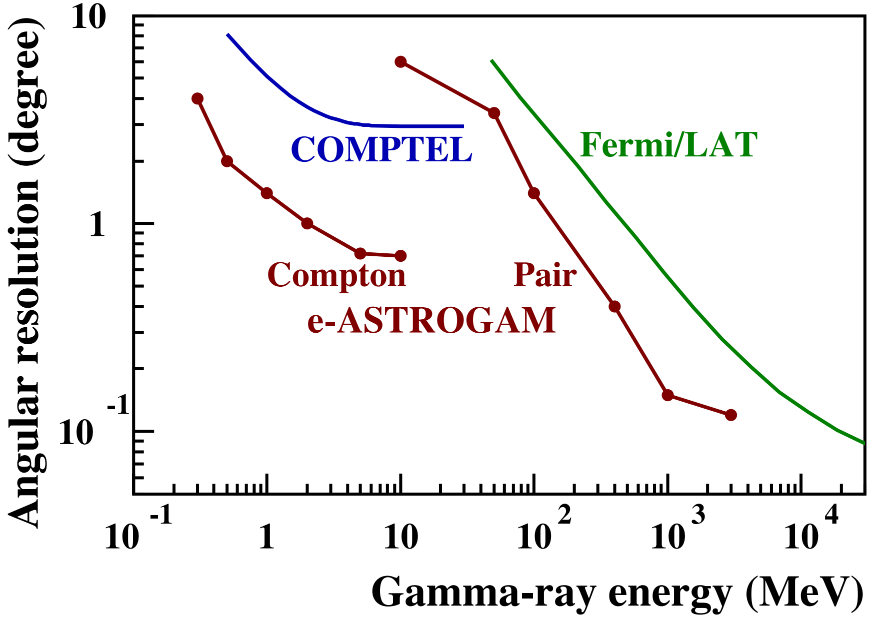




- e-ASTROGAM performance evaluated with **MEGAlib** (Zoglauer et al. 2006) and **Bogemms** (Bulgarelli et al. 2012) – both tools based on Geant4 – and a detailed numerical mass model of the gamma-ray instrument

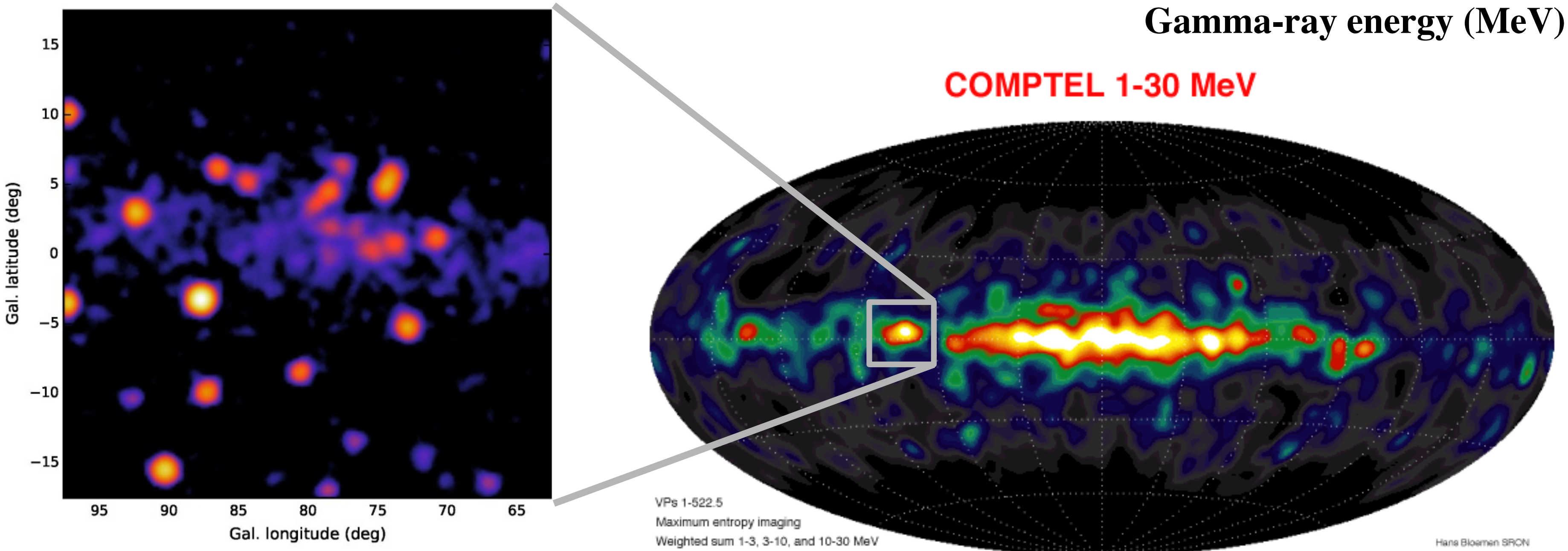
Angular resolution

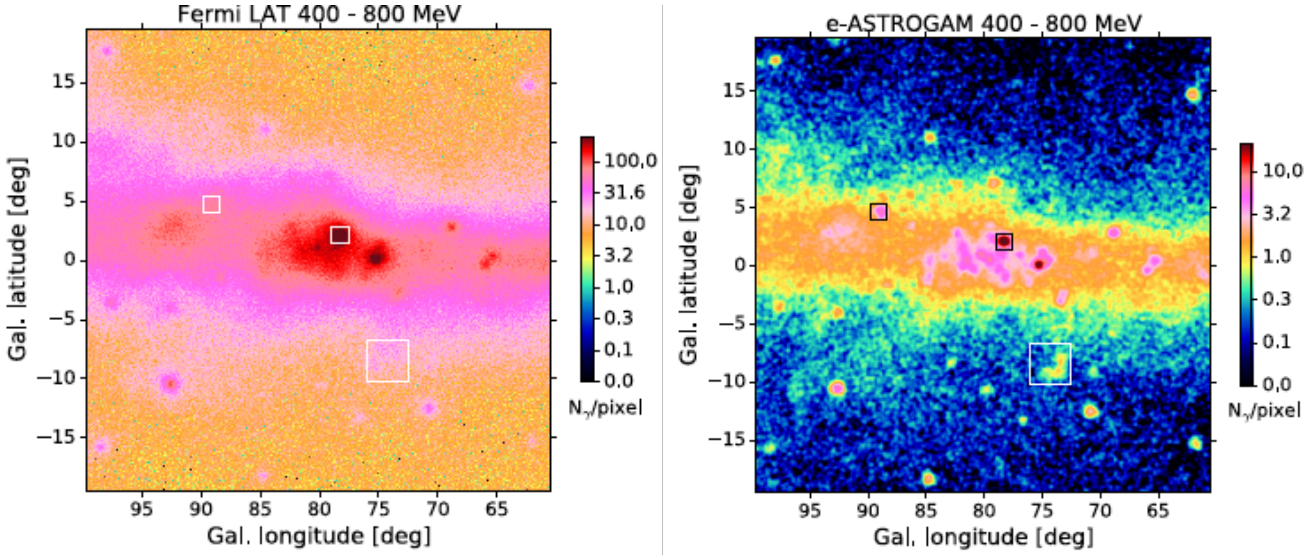
- Angular resolution improved close to the physical limits



Cygnus region in the 1 - 3 MeV energy band with the e-ASTROGAM PSF (extrapolation of the 3FGL source spectra to low energies)

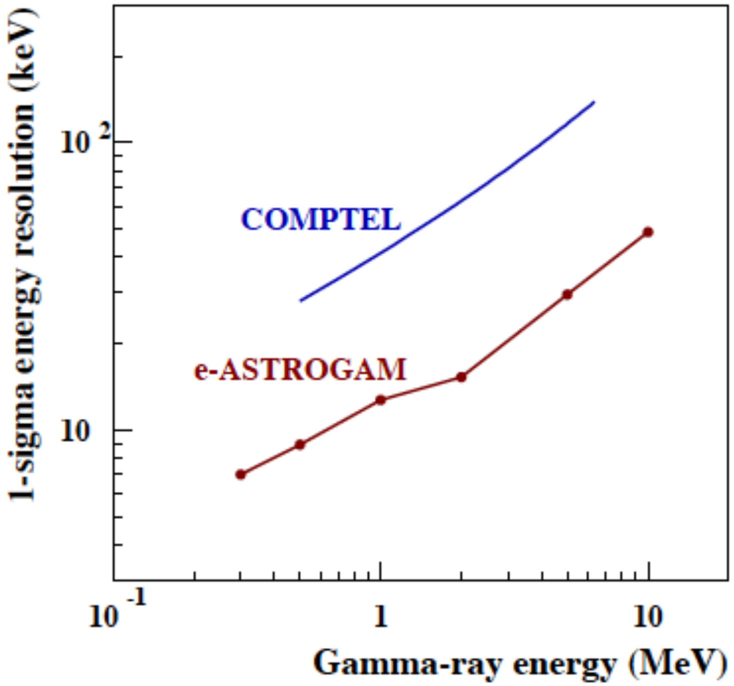
COMPTEL 1-30 MeV





Energy resolution

ΔE/E (Gamma-ray imager)	2.5% at 1 MeV 30% at 100 MeV
ΔE/E (Calorimeter burst)	< 25% FWHM at 0.3 MeV < 10% FWHM at 1 MeV < 5% FWHM at 10 MeV

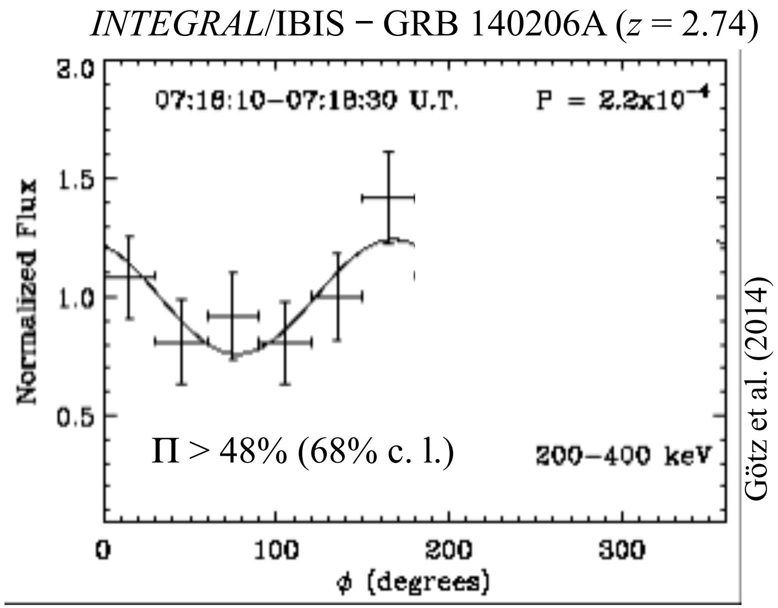


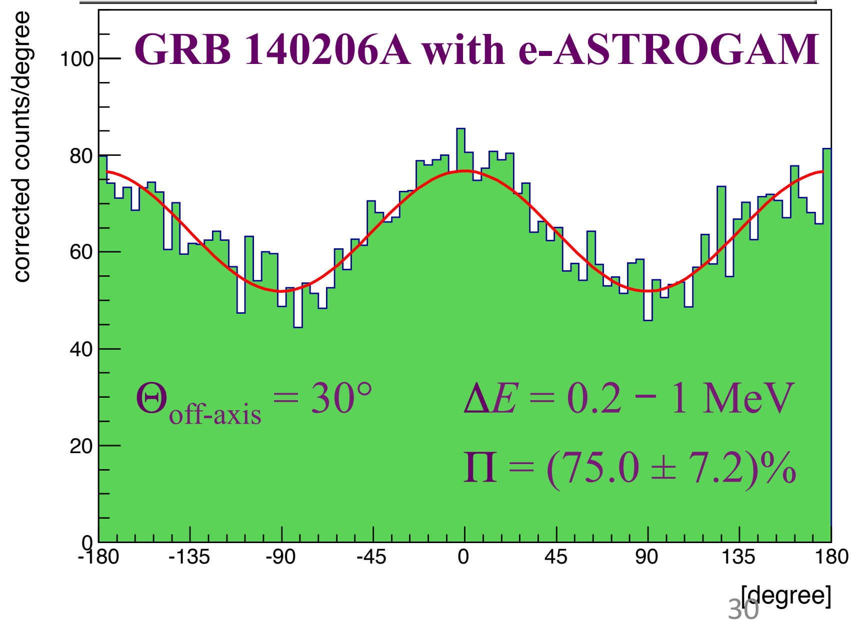
Gamma-ray polarization

- γ-ray polarization in **objects emitting jets** (GRBs, Blazars, X-ray binaries) or with **strong magnetic field** (pulsars, magnetars) ⇒ magnetization and content (hadrons, leptons, Poynting flux) of the outflows + radiation processes

- γ-ray polarization from **cosmological sources** (GRBs, Blazars) ⇒ fundamental questions of physics related to Lorentz Invariance Violation (vacuum birefringence)

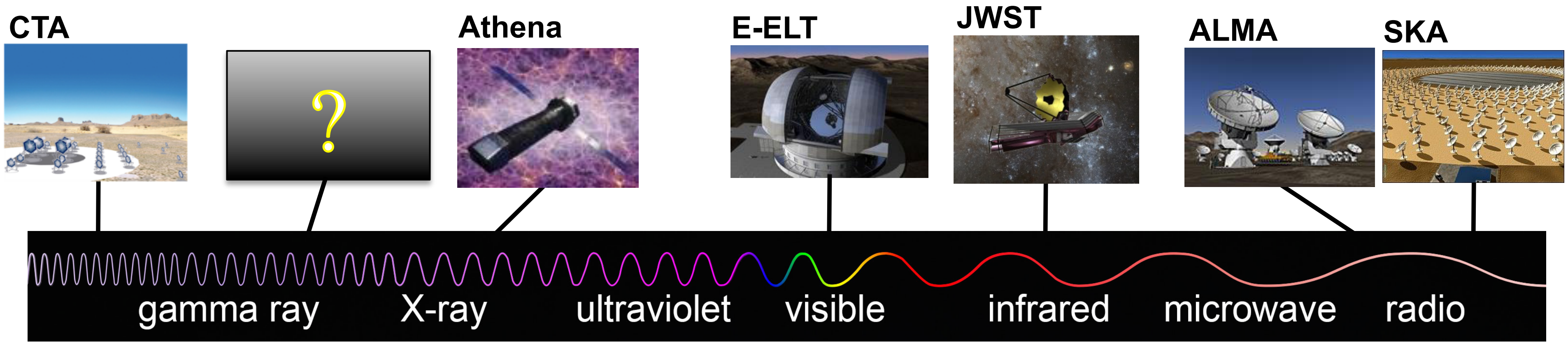
✓ e-ASTROGAM will measure the γ-ray polarization of ~ **200 GRBs per year** (promising candidates for highly γ-ray polarized sources)



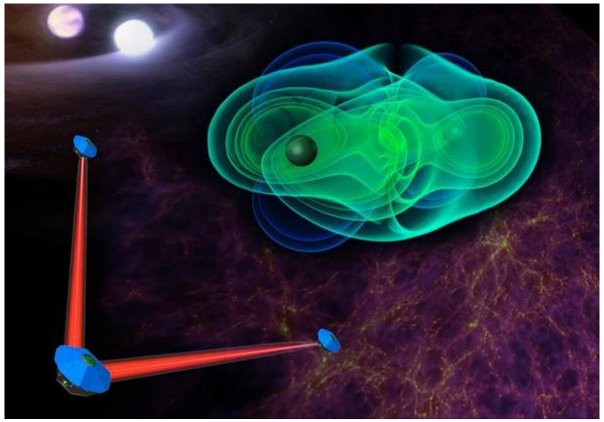


Science with e-ASTROGAM

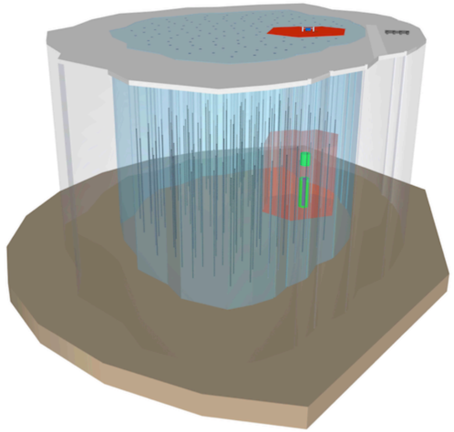
γ-ray astronomy/astrophysics in context



eLISA – Gravitational waves



IceCube-Gen2 – Neutrinos



New Astronomies:
gravitational waves,
neutrinos

- Need for a sensitive, wide-field γ-ray space observatory operating at the same time as facilities like SKA and CTA, as well as eLISA and neutrino detectors, to get a coherent picture of the transient sky and the sources of gravitational waves and high-energy neutrinos: e-ASTROGAM

Instrument characteristics

- Best PSF in MeV-GeV
  - Resolve sources
- Calorimetric measurements of MeV lines with high resolution:
  - Positron detection (511 keV line)
  - Measurements of isotopical contents
  - Hadronic collisions of LECR with molecular clouds
- Capability of measuring polarization (marks Compton interactions at the sources and magnetic fields)
- SED resolution in the GeV range: allows to reconstruct the "pion bump", characteristic of the decay $\pi^o \rightarrow \gamma\gamma$ and thus an indicator of hadronic processes

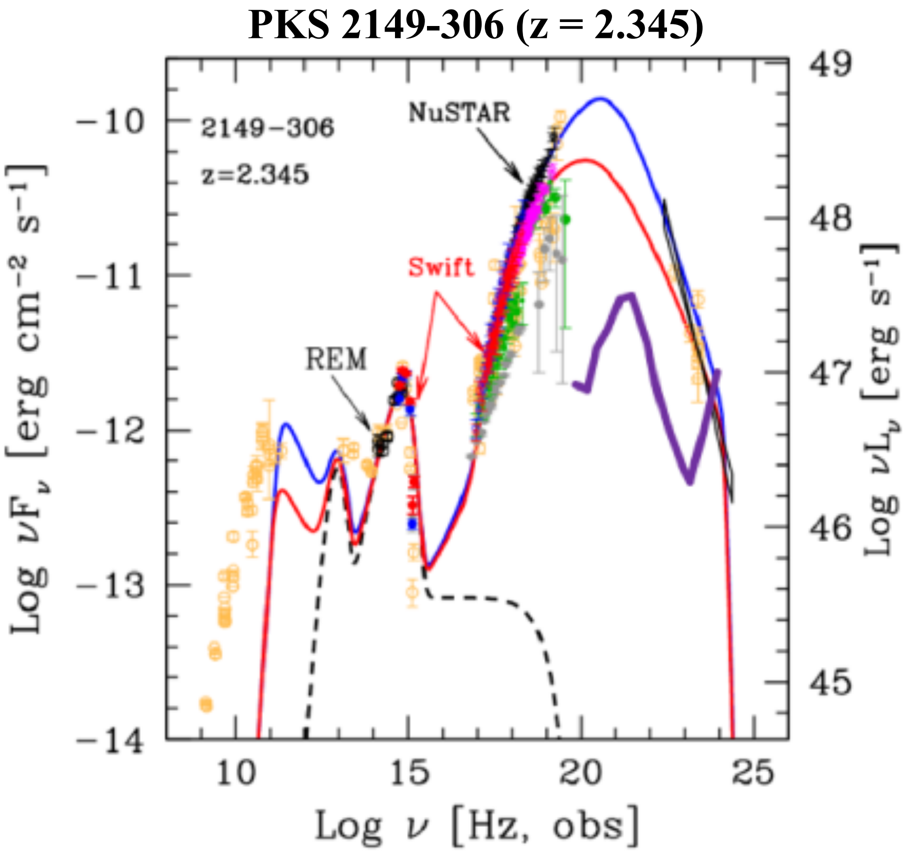
e-ASTROGAM core science

1. **Processes at the heart of the extreme Universe: prospects for the Astronomy of the 2030s**
   - Determine the composition (hadronic or leptonic) of the outflows and jets (polarimetric capability and spectroscopy)
   - Identify the physical acceleration processes in these outflows and jets (e.g. diffusive shocks, magnetic field reconnection, plasma effects), that may lead to dramatically different particle SED;
   - Clarify the role of the magnetic field in powering ultrarelativistic GRB jets, through time-resolved polarimetry and spectroscopy.
   - Multimessenger astronomy in the 2030s. Joint detection of gravitational waves.
2. The origin and impact of high-energy particles on galaxy evolution, from cosmic rays to antimatter
3. Nucleosynthesis and the chemical enrichment of our Galaxy

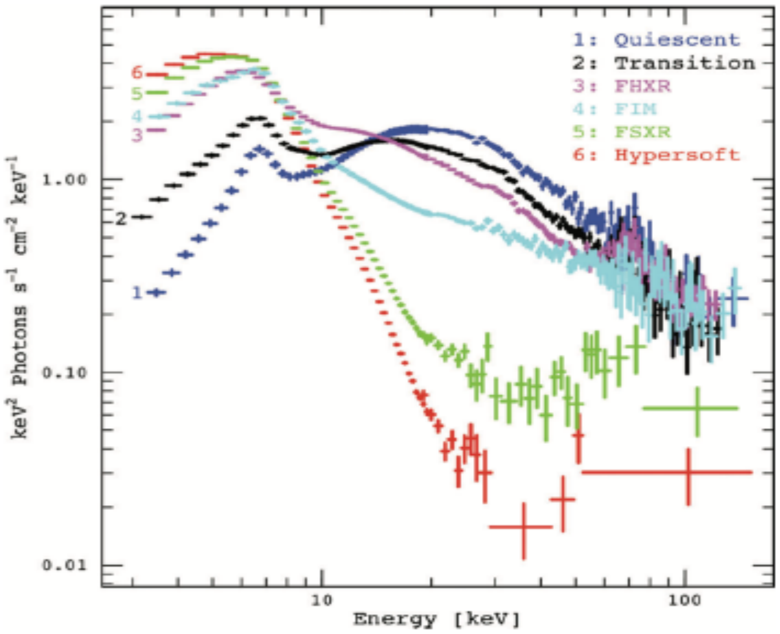
e-ASTROGAM core science topic #1

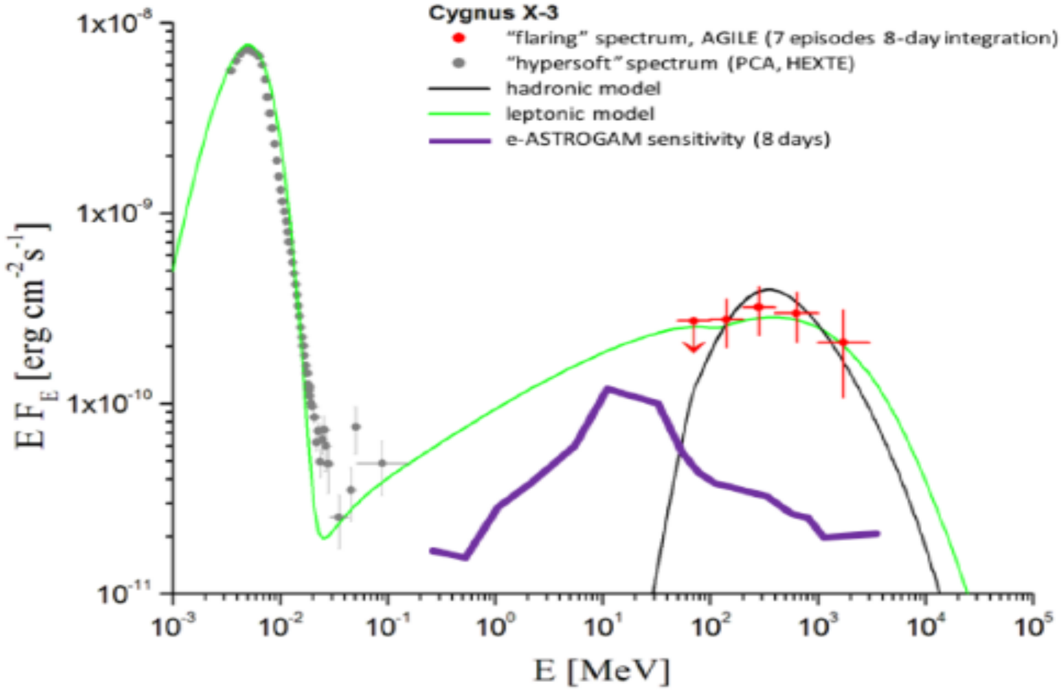
At the heart of the extreme Universe

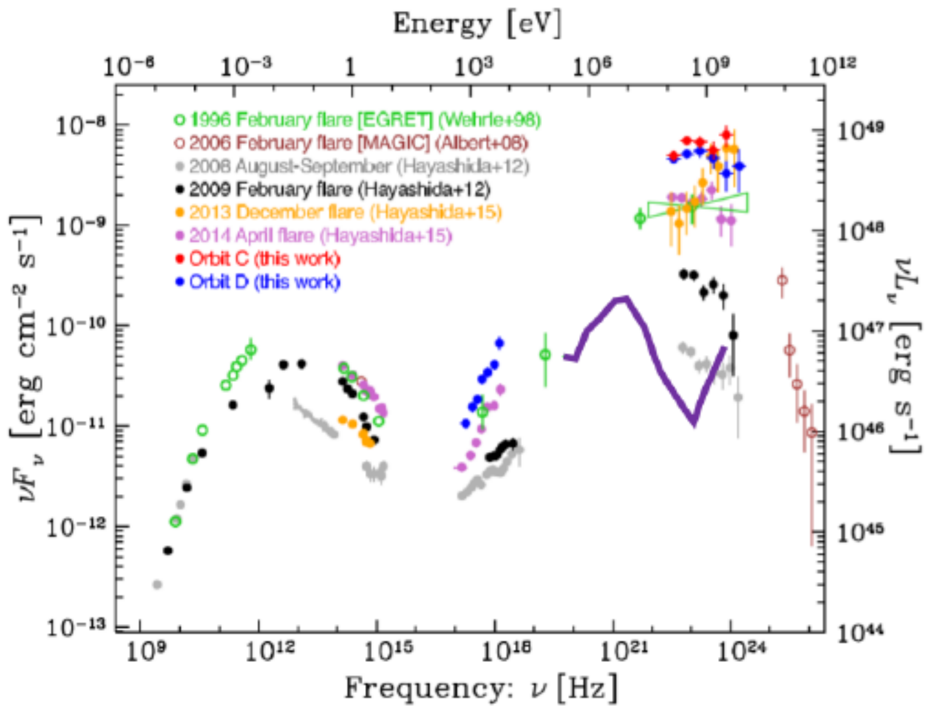
- *Launch of ultra-relativistic jets in **GRBs**? Ejecta composition, energy dissipation site, radiation processes?*
- *Can short-duration GRBs be unequivocally associated to **gravitational wave** signals?*
- *How does the accretion disk/jet transition occur around supermassive black holes in **AGN**?*
- *Are BL Lac blazars sources of **UHECRs** and high-energy **neutrinos**?*



✓ With its wide **field of view**, unprecedented **sensitivity** over a large spectral band, and exceptional capacity for **polarimetry**, **e-ASTROGAM** will give access to a variety of extreme **transient** phenomena



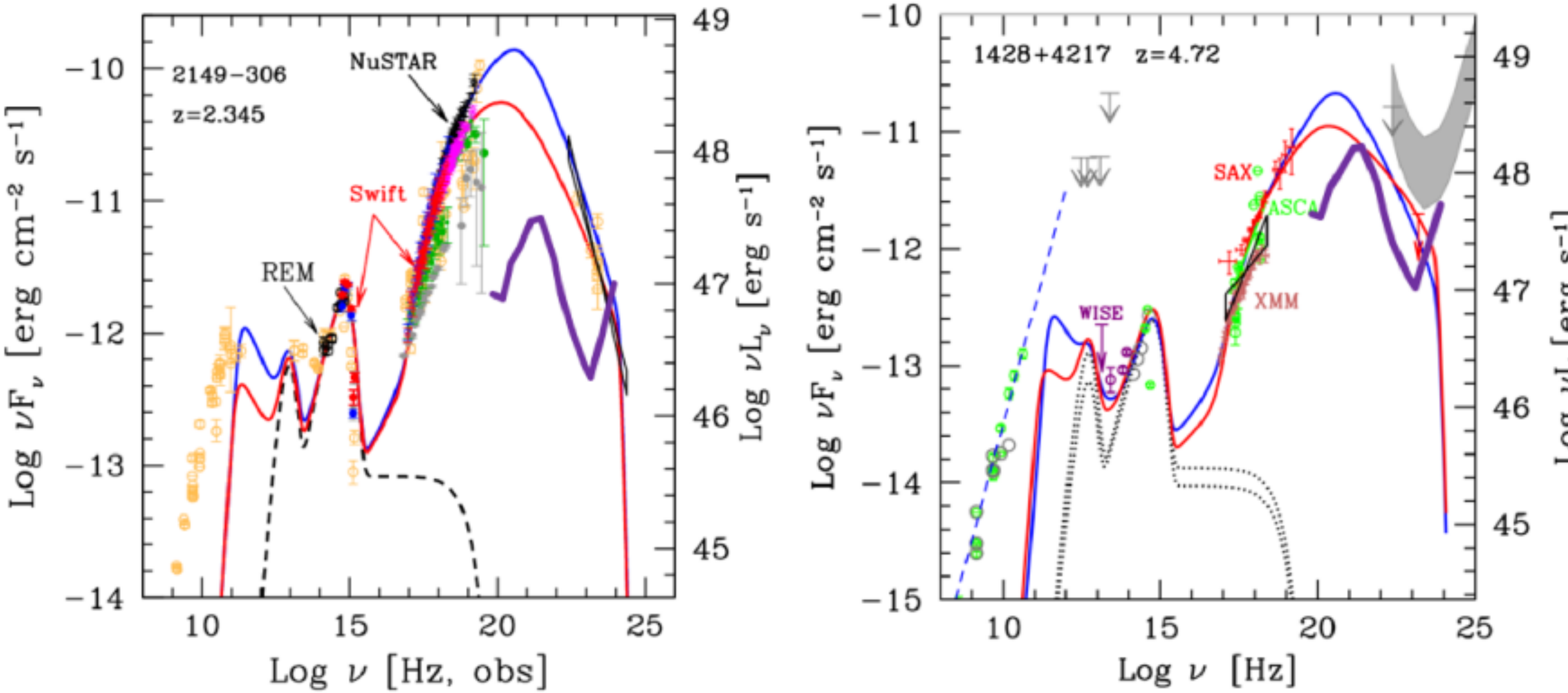




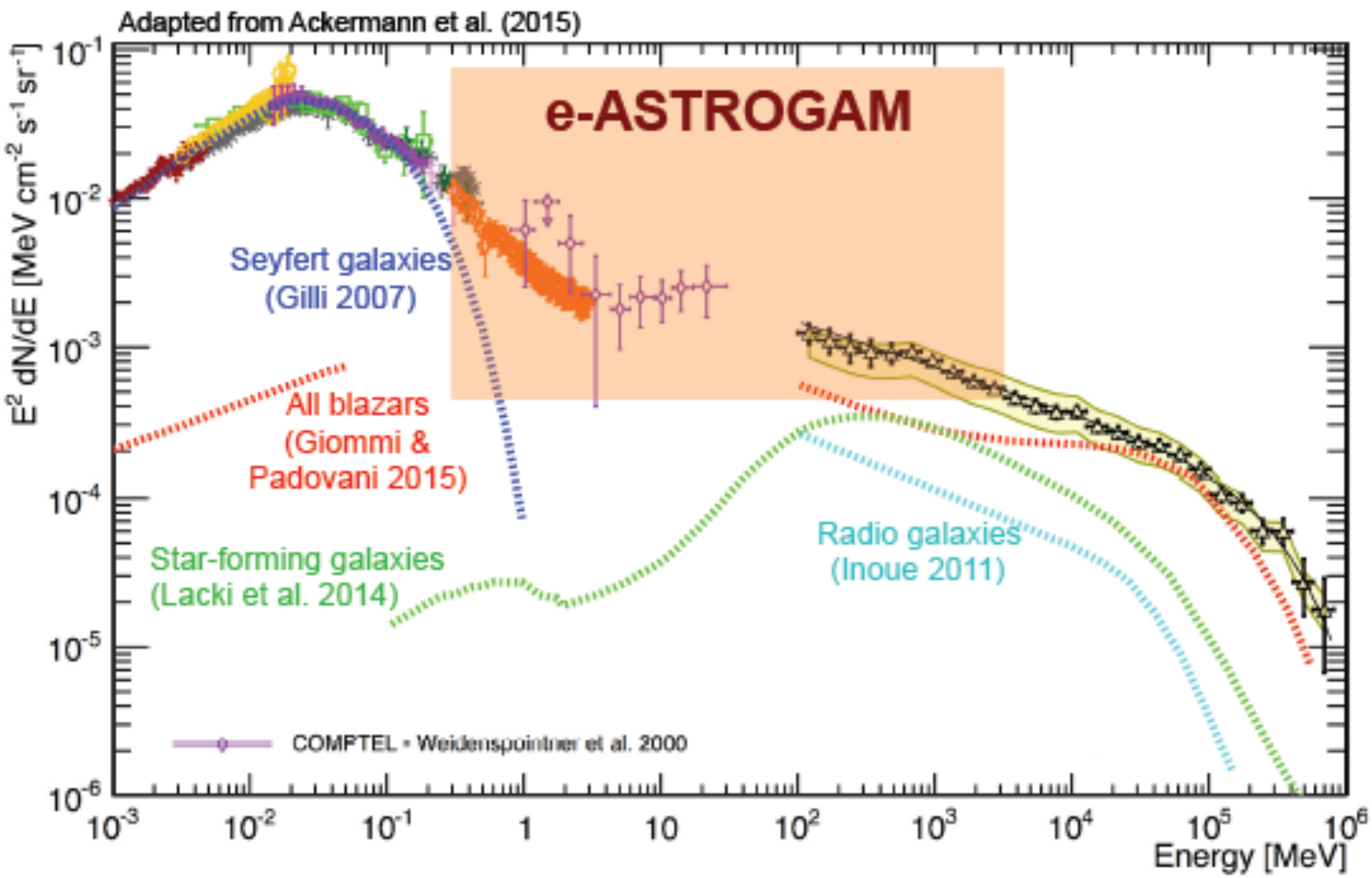
Relativistic jets; flares

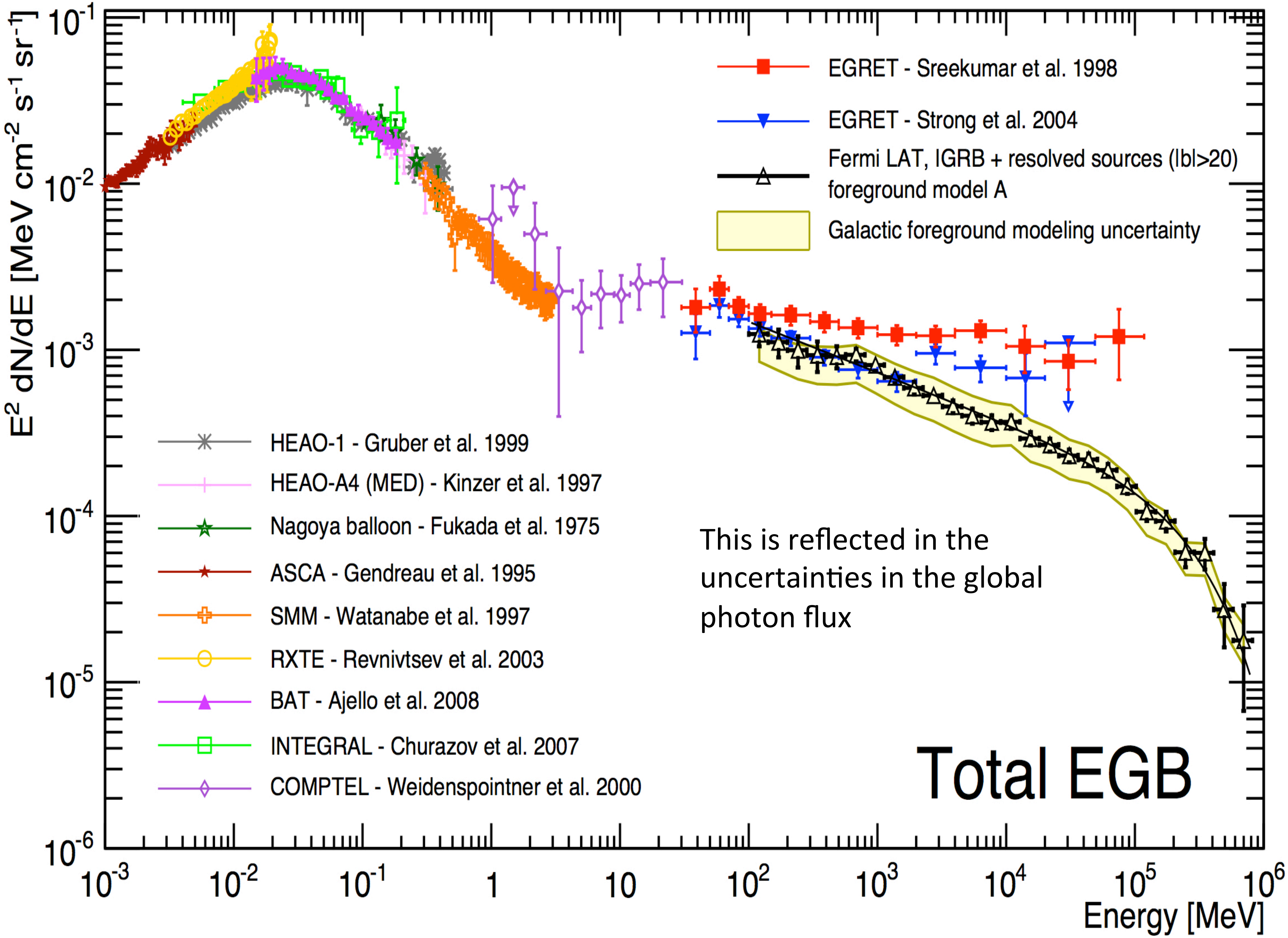
Figure 5: SED from a collection of different spectral states of the FSRQ 3C 279 showing a dramatic gamma-ray flaring activity, including the minute-timescale episode detected by Fermi in June 2015 [13]. The purple solid line is the 3σ e-ASTROGAM sensitivity calculated for a 50 ks exposure.

MeV blazars; cosmology at z up to 4.5



A huge blazar population and the extragalactic gamma-ray bkg





This is reflected in the uncertainties in the global photon flux

Gamma-ray bursts and the new Astronomy of GW and neutrino astrophysics

- Threshold at 30 keV using the Calorimeter
- **200 GRB/year detectable**
  - Localized within 0.1-1 deg, and the information can be processed onboard
  - 42 GRBs/year with a detectable polarization fraction of 20%;
  - 16 GRBs/year with a polarization fraction of 10%
- Possible detection of electromagnetic counterparts of impulsive GW events
  - MeV likely to be the threshold
  - Possible associations GRB/GW
- MeV possible threshold also for the counterparts of neutrino bursts

e-ASTROGAM core science: 2

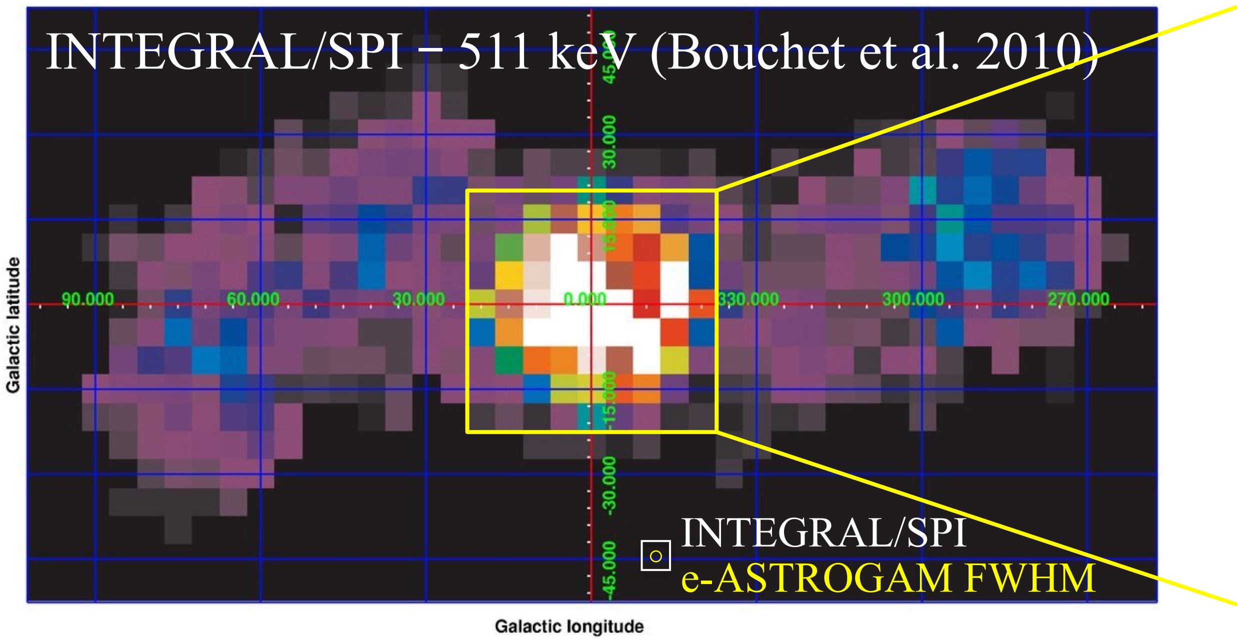
1. Processes at the heart of the extreme Universe: prospects for the Astronomy of the 2030s
2. **The origin and impact of high-energy particles on galaxy evolution, from cosmic rays to antimatter**
   - origin & propagation of LECR, CR diffusion in interstellar clouds and their impact on gas dynamics and state; wind outflows and their feedback on the Galactic environment (e.g., Fermi bubbles, Cygnus cocoon).
   - detect line emissions from 511 keV up to 10 MeV, thus:
     - origin of the gamma-ray and positron excesses toward the IG;
     - determination of the astrophysical sources of the local positron population. As a consequence e-ASTROGAM will provide a key contribution to the search for DM
3. Nucleosynthesis and the chemical enrichment of our Galaxy

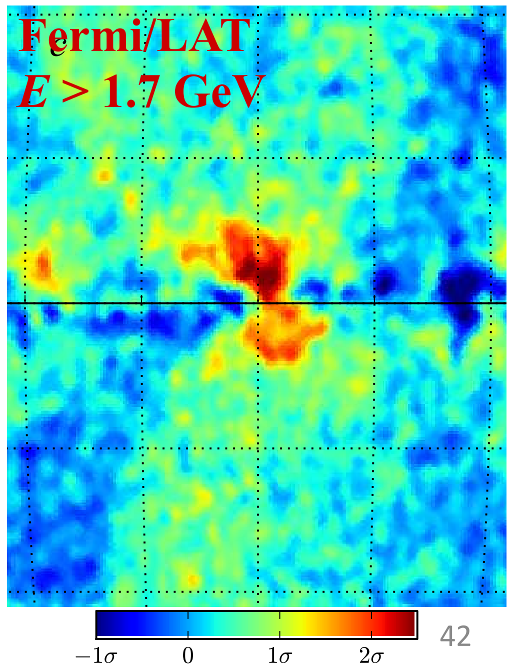
e-ASTROGAM core science topic #2

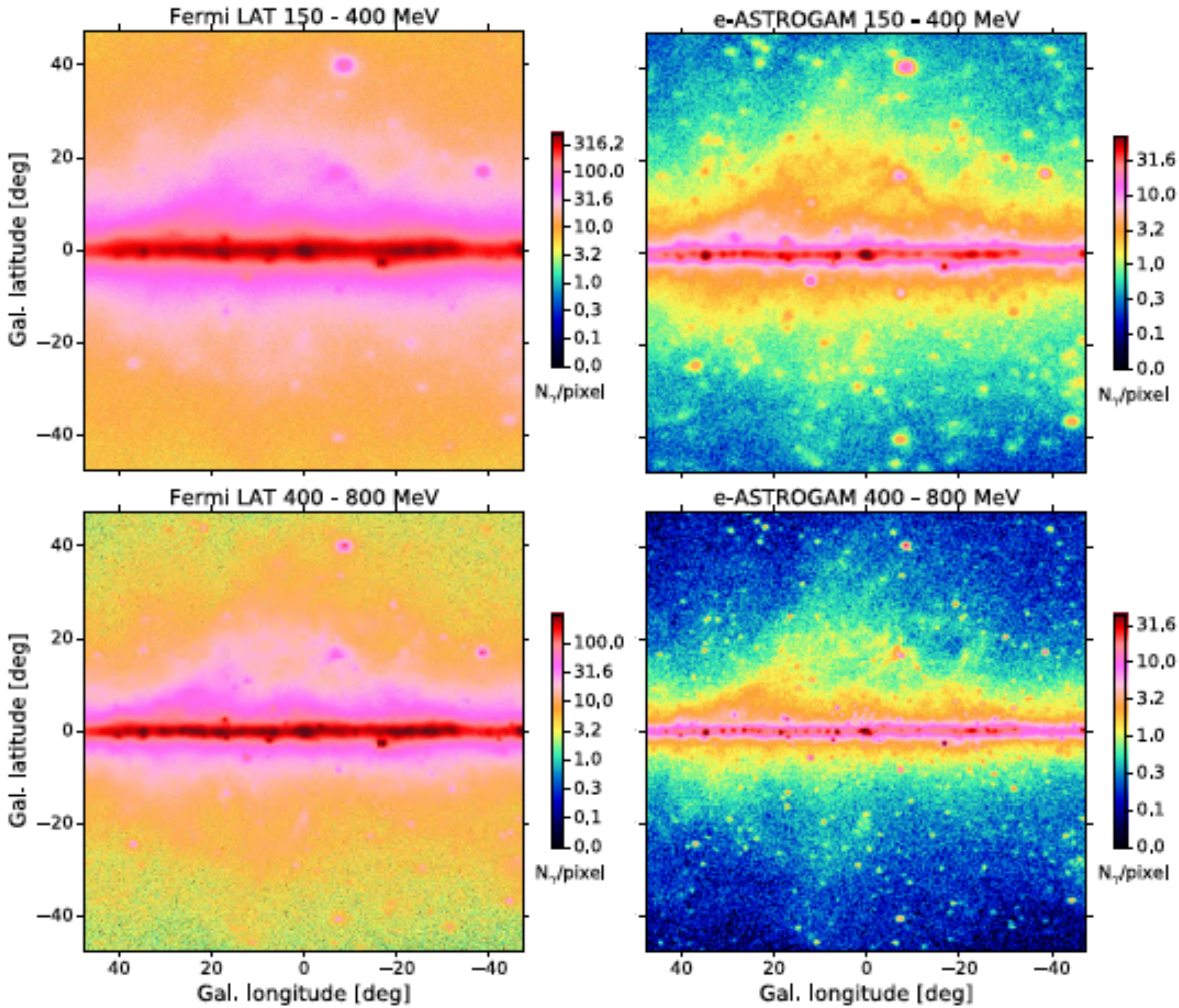
The high-energy mysteries at the Inner Galaxy

- *Origin of the* ***Fermi Bubbles*** *and of the* ***511 keV emission*** *from the Galaxy's bulge? Are these linked to a past activity of the central* ***supermassive black hole****? What is causing the* ***GeV excess*** *emission from the center region?*

✓ With a **sensitivity** and an **angular resolution** in the MeV – GeV range significantly improved over previous missions, **e-ASTROGAM** will enable a detailed **spectro-imaging** of the various high-energy components







Fermi LAT 150 - 400 MeV
e-ASTROGAM 150 - 400 MeV
Fermi LAT 400 - 800 MeV
e-ASTROGAM 400 - 800 MeV
Gal. latitude [deg]
Gal. longitude [deg]
Nγ/pixel
316,2
100,0
31,6
10,0
3,2
1,0
0,3
0,1
0,0

Cosmic rays in the Inner Galaxy; acceleration in SNRs

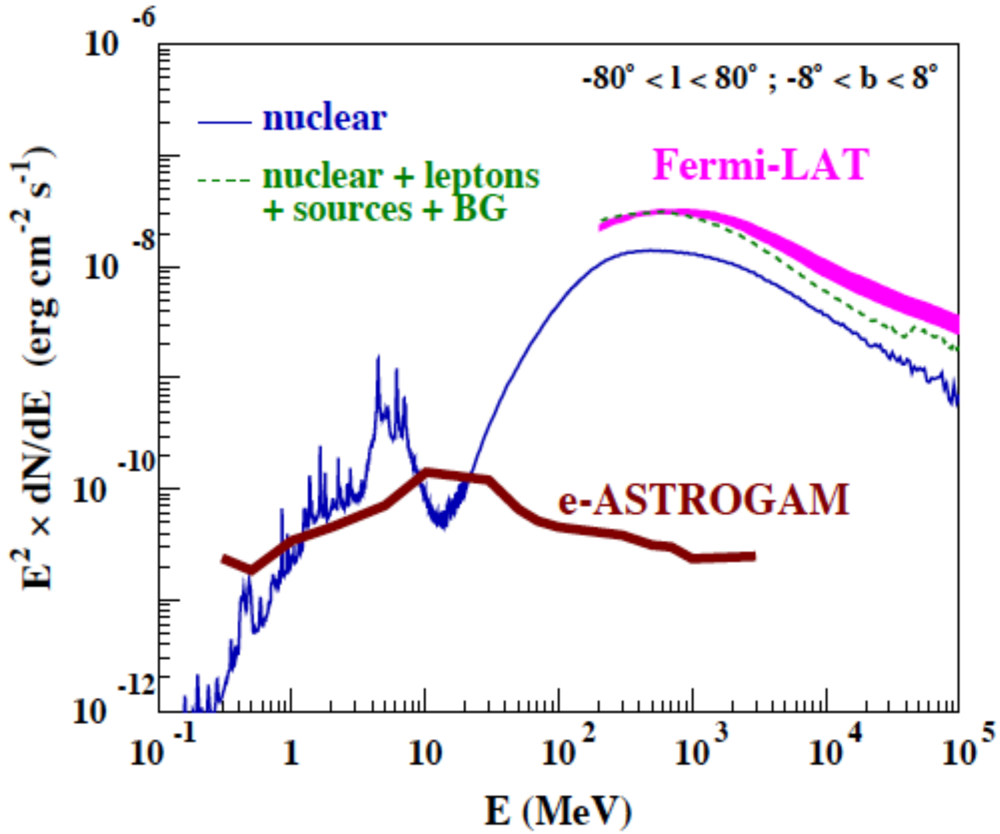
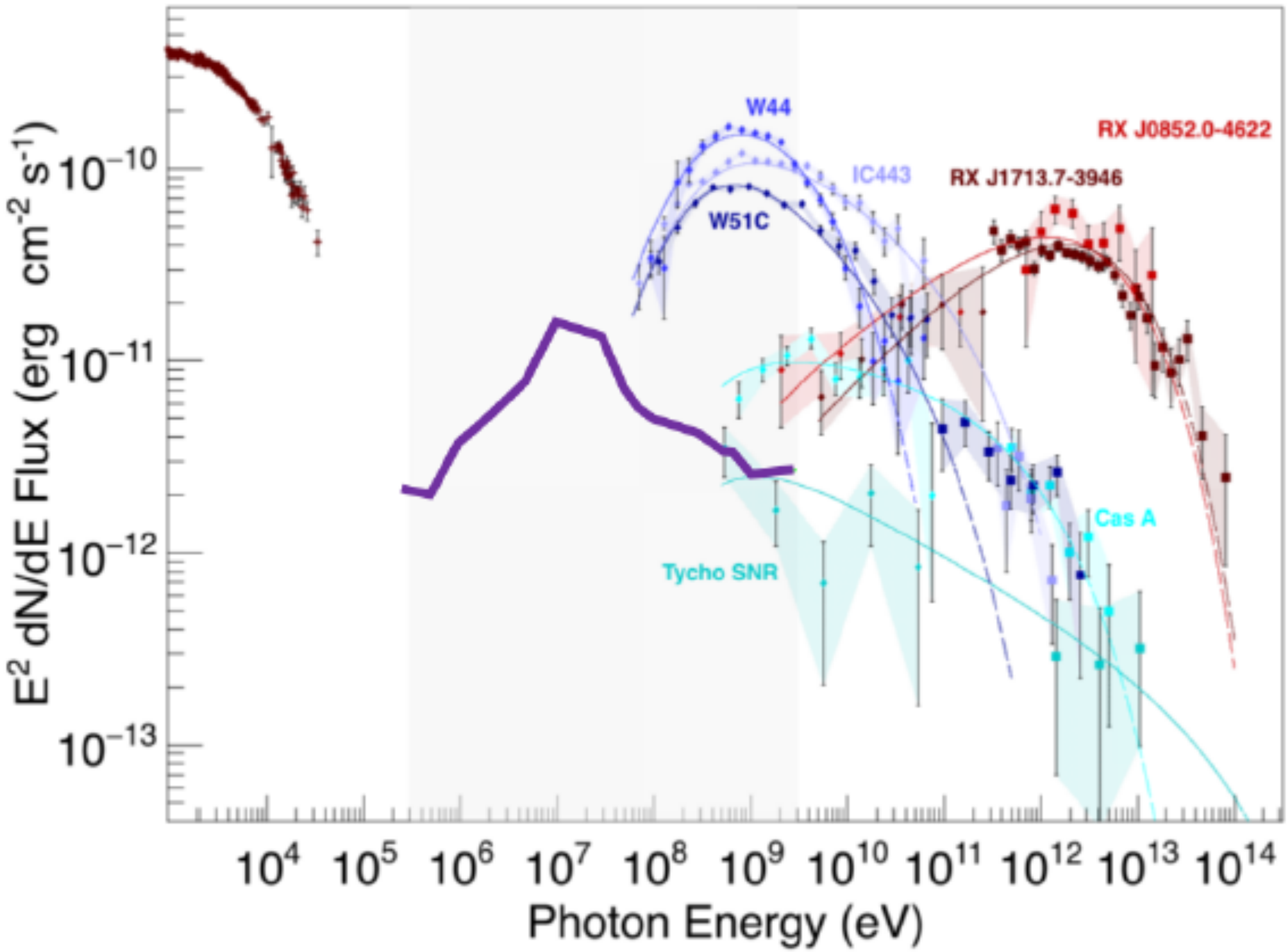


Figure 9: Predicted γ-ray emission due to nuclear interactions of CRs in the Inner Galaxy. The γ-ray line emission below 10 MeV is due to LECRs ([24]). The 1-year sensitivity of e-ASTROGAM (for Galactic background) is superimposed.

Cosmic rays in the Inner Galaxy; acceleration in SNRs



Antimatter and Dark Matter

- Unique sensitivity to the 511-keV line
- Sensitivity to many classical positron sources: can determine if the PAMELA/AMS positron excess is due to nearby pulsars

- The MeV region is the missing ingredient to determine the photon background from the Inner Galaxy: clarify if there is a photon excess (which might be due to DM, new particles)
- The MeV region is where the bulk of photons from WIMPs below 100 GeV is expected
- In some models, MeV dark matter

e-ASTROGAM core science: 3

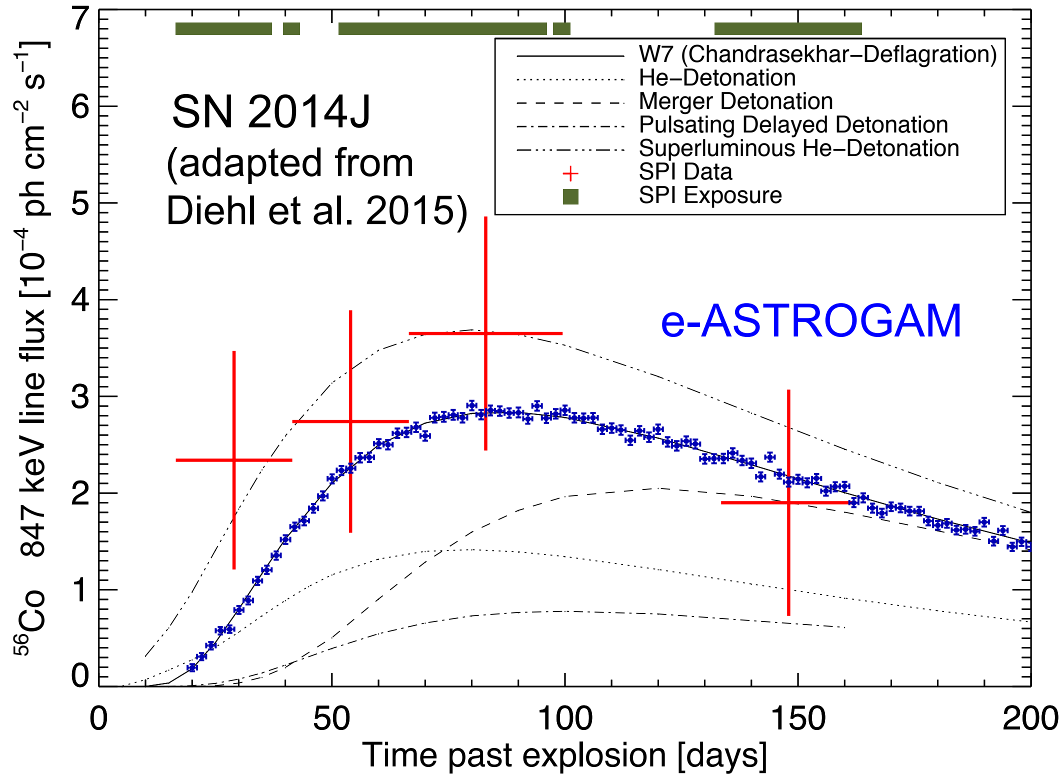
1. Processes at the heart of the extreme Universe: prospects for the Astronomy of the 2030s
2. The origin and impact of high-energy particles on galaxy evolution, from cosmic rays to antimatter
3. **Nucleosynthesis and the chemical enrichment of our Galaxy**
   - What are the progenitor system(s) and explosion mechanism(s) of thermonuclear SNe?
   - What do we need to understand before using SN Ia for precision cosmology?
   - How do core-collapse supernovae (CCSNe) explode, and what is the recent history of CCSNe in the Milky Way?
   - How are cosmic isotopes created in stars and distributed in the interstellar medium?

e-ASTROGAM core science topic #3

Supernovae, nucleosynthesis, and Galactic chemical evolution

- *How do thermonuclear and core-collapse SNe explode? How are cosmic isotopes created in stars and distributed in the interstellar medium?*

✓ With a remarkable improvement in **γ-ray line sensitivity** over previous missions, **e-ASTROGAM** should allow us to finally understand the progenitor system(s) and explosion mechanism(s) of **Type Ia SNe** (^{56}Ni, ^{56}Co), the dynamics of **core collapse** in massive star explosions (^{56}Co, ^{57}Co), and the history of **recent SNe** in the Milky Way (^{44}Ti, ^{60}Fe...)



e-ASTROGAM Observatory science (1)

Type	3-yr	New sources
Total	~ 860-1210	~ 600 (including GRBs)
Galactic sources (< 30 MeV)	~ 50-100	~ 50
Galactic sources (> 30 MeV)	~ 200-300	~ 100
MeV-Blazars	~ 100	~ 100
GeV-Blazars	~ 300-400	~ 100
Other AGNs (< 10 MeV)	~ 20-30	~ 10-20
Supernovae	~ 4-5	~ 4-5
Novae	~ 0-1	~ 0-1
GRBs	~ 200-300	

e-ASTROGAM Observatory science (2)

- **Diffuse Galactic gamma-ray background**
- **Pulsars and millisecond pulsars**
- **PWNe**
- **Magnetars**
- **Galactic compact binaries**
- **Classical novae**

e-ASTROGAM Observatory science (3)

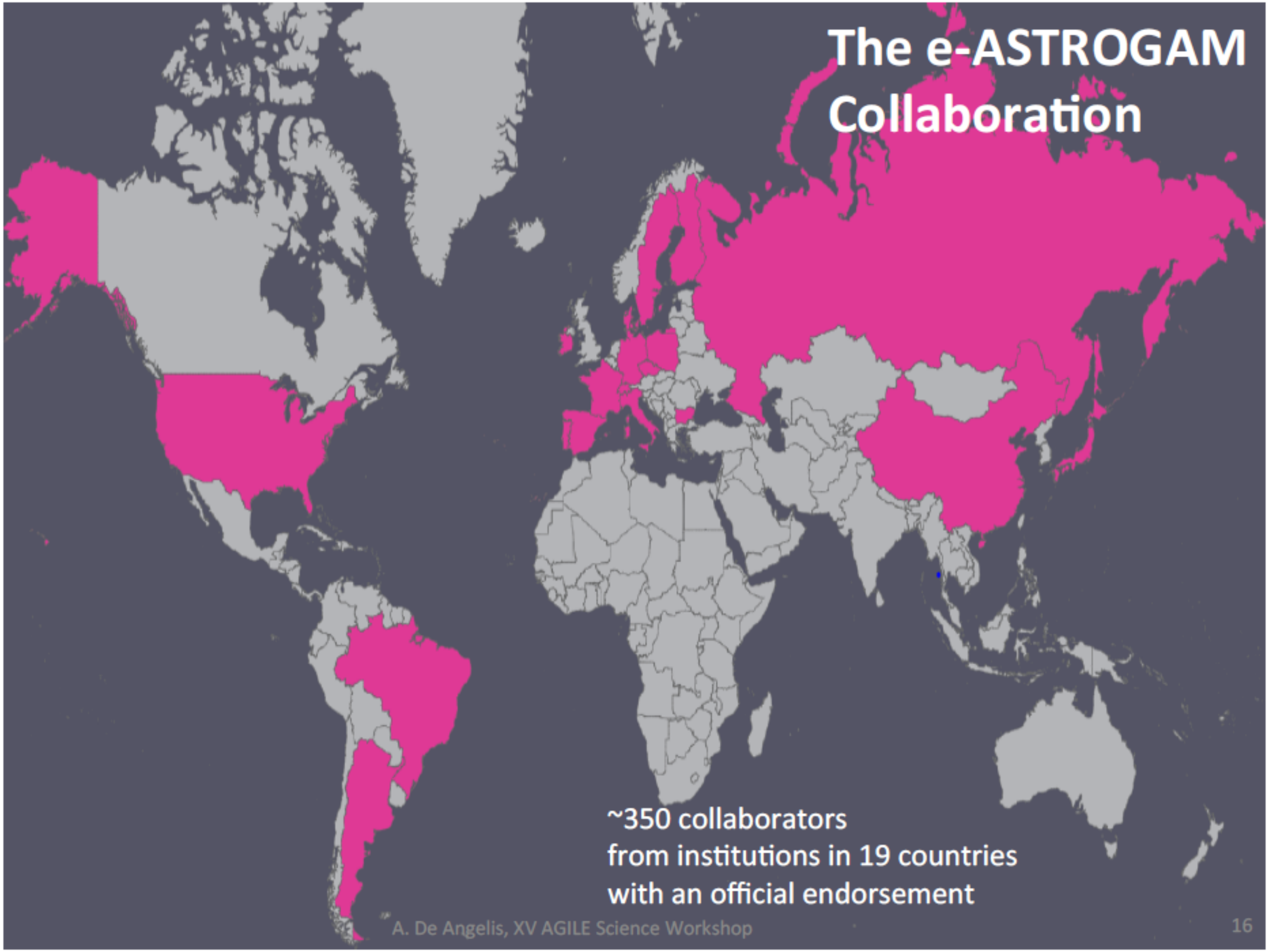
- **Interstellar shocks**
- **Blazar population studies**
- **Studies of the propagation of gamma rays over cosmological distances**
- **Solar flares and contribution to “SpaceWeather“**
- **Terrestrial Gamma-Ray Flashes**

Proposal submitted to ESA M5 on Oct 5, 2016

It passed a first ESA selection, included in a list of 13 candidates (July 2017)

Expected launch ~2028

Simulations being improved; a program for prototypes testing in 2017-2018.


The e-ASTROGAM Collaboration
~350 collaborators
from institutions in 19 countries
with an official endorsement
A. De Angelis, XV AGILE Science Workshop
16

The e-ASTROGAM Collaboration (at the proposal time)

Principal investigator: Alessandro De Angelis, INFN/INAF Padova, U. Udine, Italy; LIP/IST, Portugal
Co-I: Vincent Tatischeff – CSNSM (CNRS/IN2P3) Paris, France; Univ. Paris Sud

INFN, INAF, U. Padova, U. & Polit. Bari, U. Roma Tor Vergata, U. Siena, U. Udine, U. Trieste

CSNSM, APC, CEA/Irfu, IPNO, LLR, CENBG, LUPM, IRAP

U. Mainz, KIT/IPE, U. Tübingen, U. Erlangen, RWTH Aachen, U. Potsdam, U. Würzburg, MPE

DPNC UniGe, ISDC, Univ. Geneva, PSI

ICE (CSIC-IEEC), IMB-CNM (CSIC), IFAE-BIST, Univ. Barcelona, CLPU & Univ. Salamanca

KTH and Univ. Stockholm

Czech Technical Univ., Prague; University of Coimbra, LIP and IST Lisboa; Univ.Sofia

DTU Copenhagen

Univ. College Dublin, Dublin City Univ.

Space Research Center of PAS Warsaw

NASA GSFC, NRL, Clemson Univ., Washington Univ., Yale Univ., Univ. Maryland, UC Berkeley

Ioffe Institute, St. Petersburg

University of Tokyo

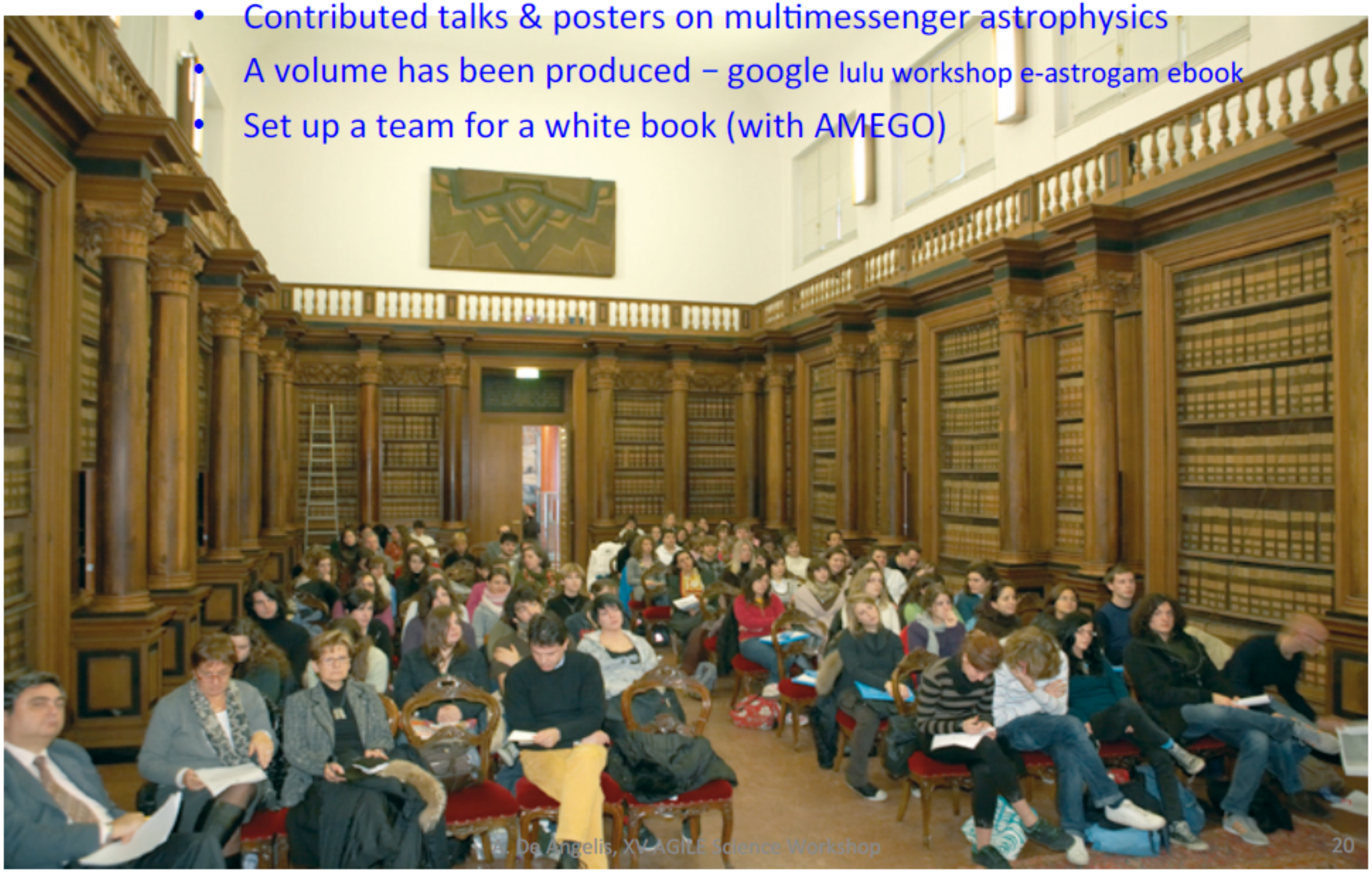
CBPF Rio de Janeiro

Endorsements from national agencies/ delegations to ESA

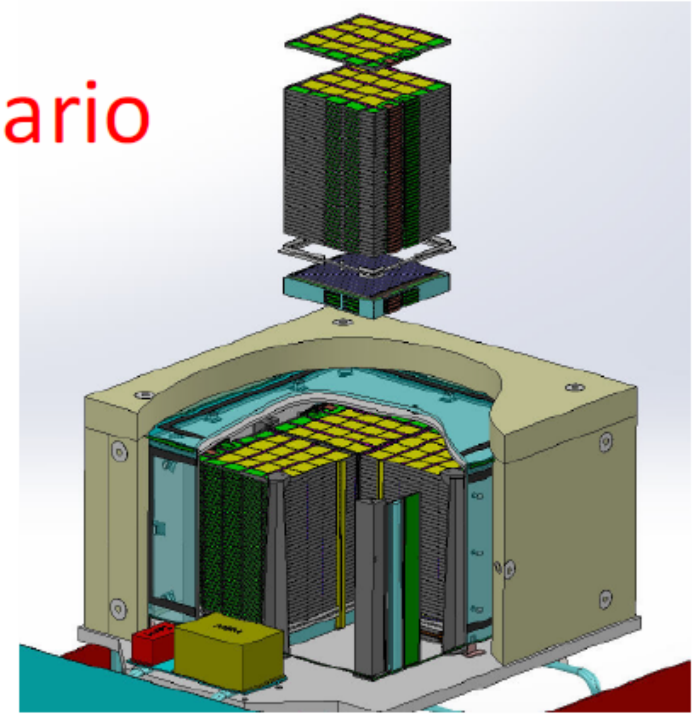
- ASI (Italy)
- CNES (France)
- DLR (Germany)
- (Switzerland)
- Swedish National Space Board (Sweden)
- National Space Agency/DTU (Denmark)
- Spanish Research Agency (Spain)
- Polish Space Agency
- FCT (Portugal)
- NASA (US)

First e-ASTROGAM Science Workshop

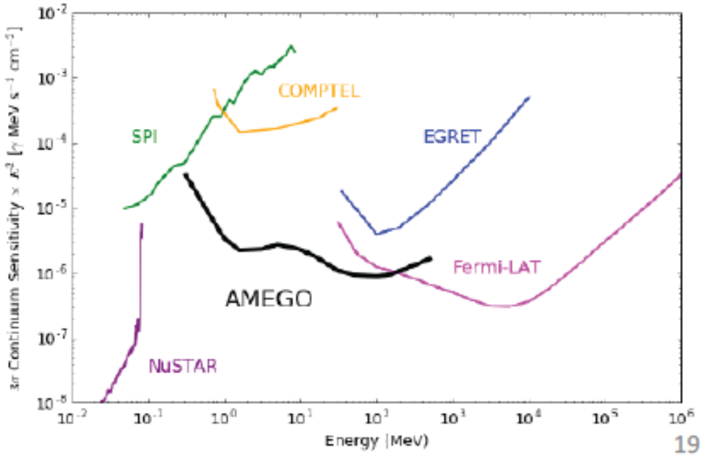
- Padova, Feb 28 - Mar 2, 2017
- Contributed talks & posters on multimessenger astrophysics
- A volume has been produced – google lulu workshop e-astrogam ebook
- Set up a team for a white book (with AMEGO)



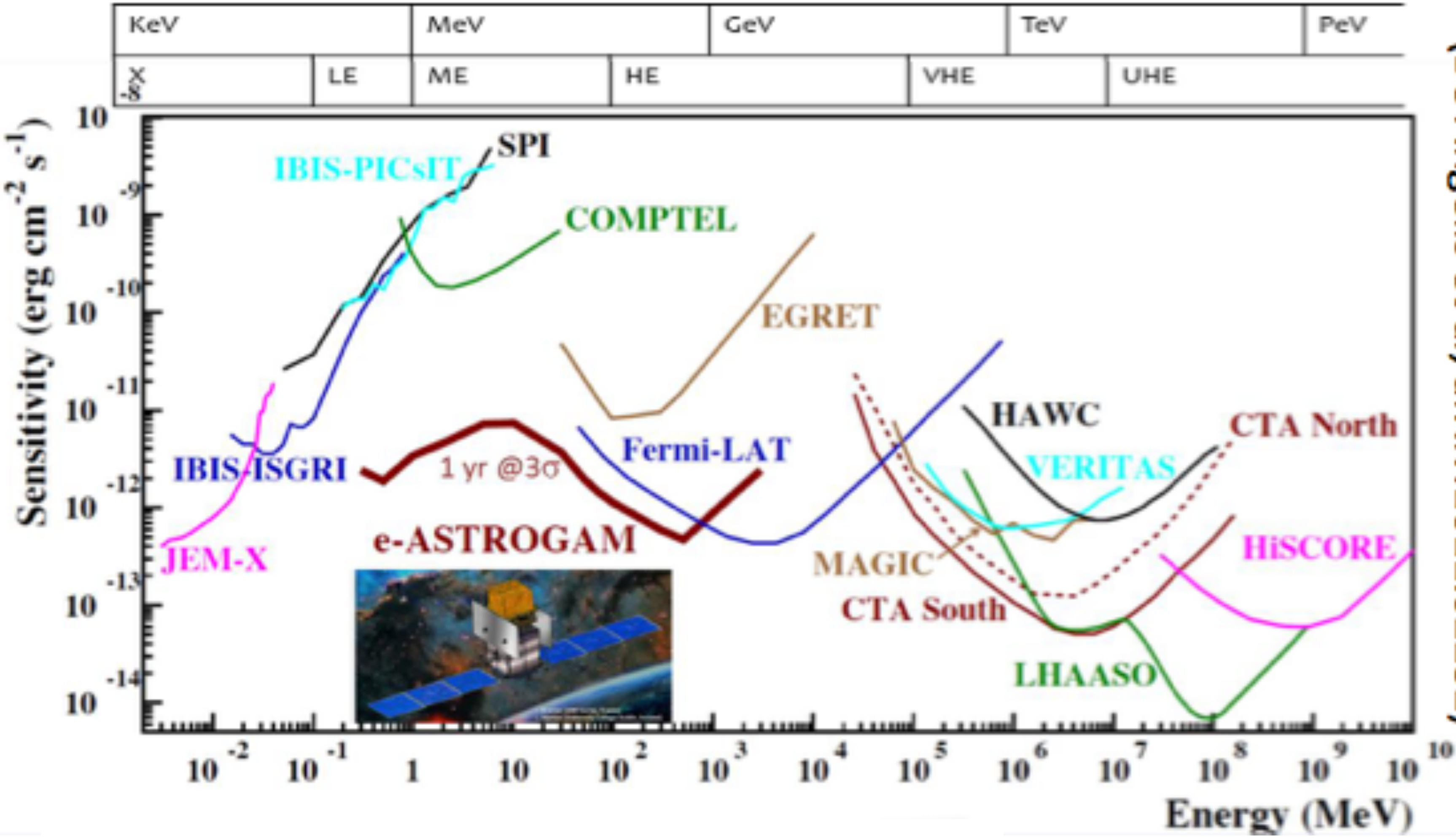
The international scenario



- The All-sky Medium Energy Gamma-ray Observatory AMEGO, a similar project from NASA, started evaluation in Dec 2016
- PI is Julie McEnery, NASA GSFC (the old Fermi team); several e-ASTROGAM collaborators are co-I
- If approved, launch in 2028

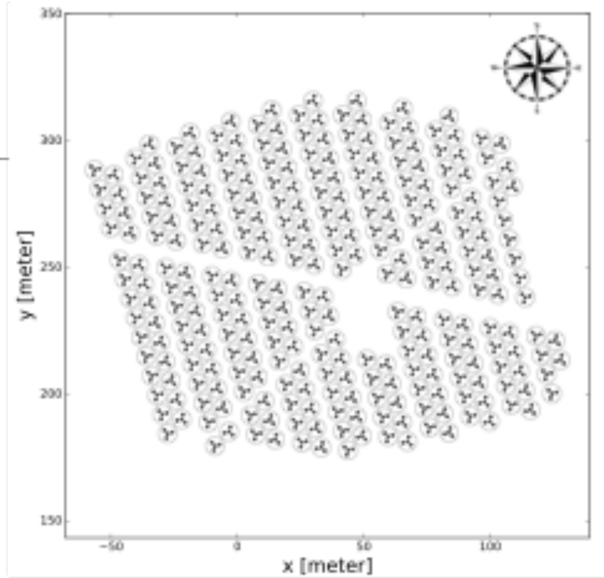


Gamma-ray experiments



(De Angelis et al, arXiv:1611.02232)

Northern Hemisphere: HAWC

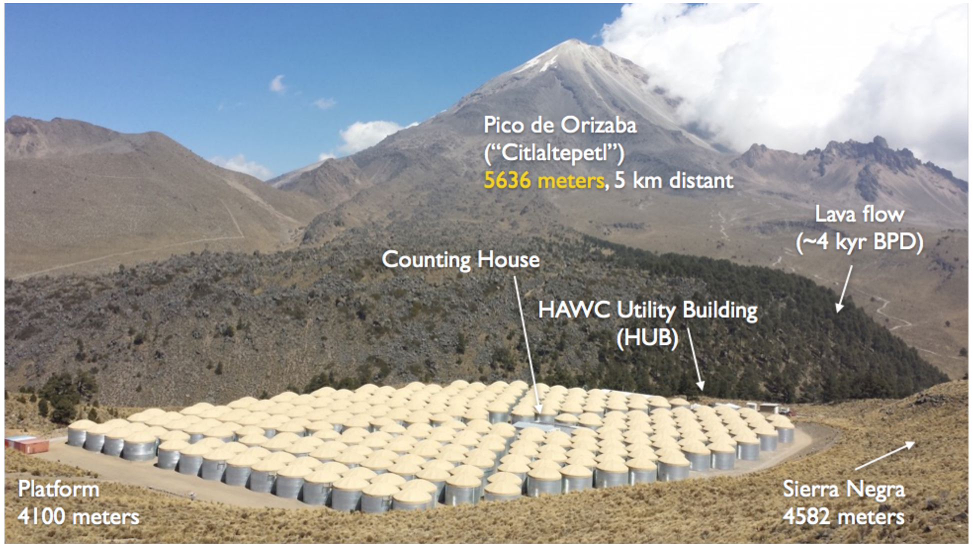


The **H**igh **A**ltitude **W**ater **C**herenkov Gamma-ray Observatory (HAWC) is up and running

Goals: observe gamma rays and cosmic rays from half the sky each day between 100 GeV and 100 TeV

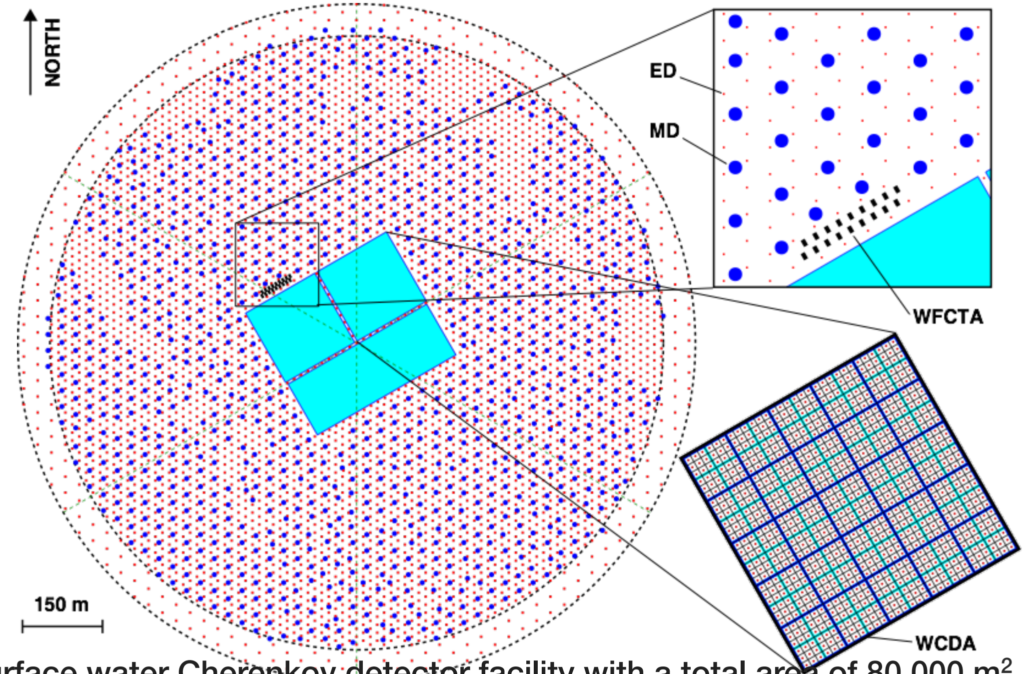
- 4100 meters above sea level
- 19°N latitude (Galactic Center at 48° zenith)
- 300 water tanks, 1200 large photocathode area PMTs 1/6th of sky in instantaneous field of view

- Instrumented Area: 22,000 m^2 ≈140 X 140 m^2
- Coverage factor: ≈60 %
- 10 kHz event rate



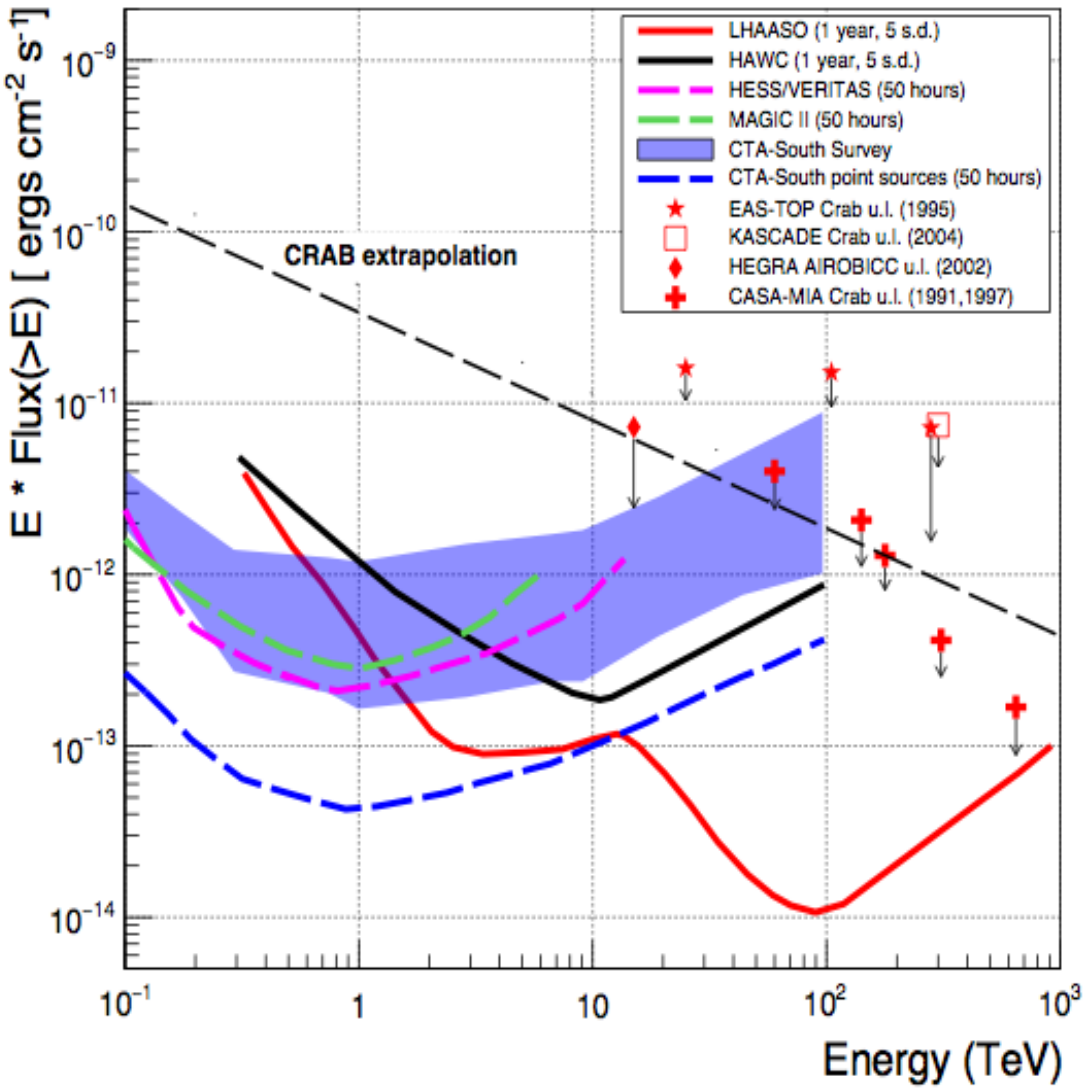
Northern Hemisphere: LHAASO

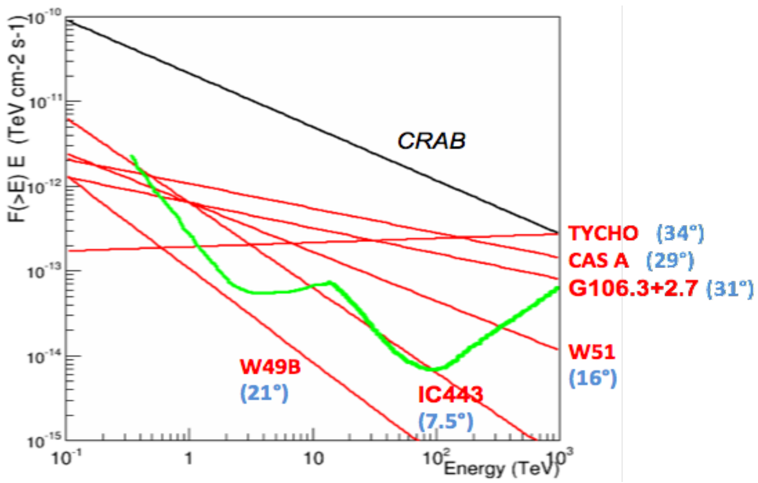
- 1.3 km^2 array, including 5195 scintillator detectors 1 m^2 each, with 15 m spacing.
- An overlapping 1 km^2 array of 1171, underground water Cherenkov tanks 36 m^2 each, with 30 m spacing, for muon detection (total sensitive area ≈ 42,000 m^2).



- A close-packed, surface water Cherenkov detector facility with a total area of 80,000 m^2.
- 18 wide field-of-view air Cherenkov (and fluorescence) telescopes.
- Neutron detectors

Gamma-Ray Astronomy with LHAASO





LHAASO will observe at TeVs, with high sensitivity, >40 of the sources catalogued by Fermi-LAT at lower energy, monitoring the variability of >20 AGNs.

Southern Hemisphere: ALPACA

Andes
Large area
PArticle detector for Cosmic ray physics
and Astronomy

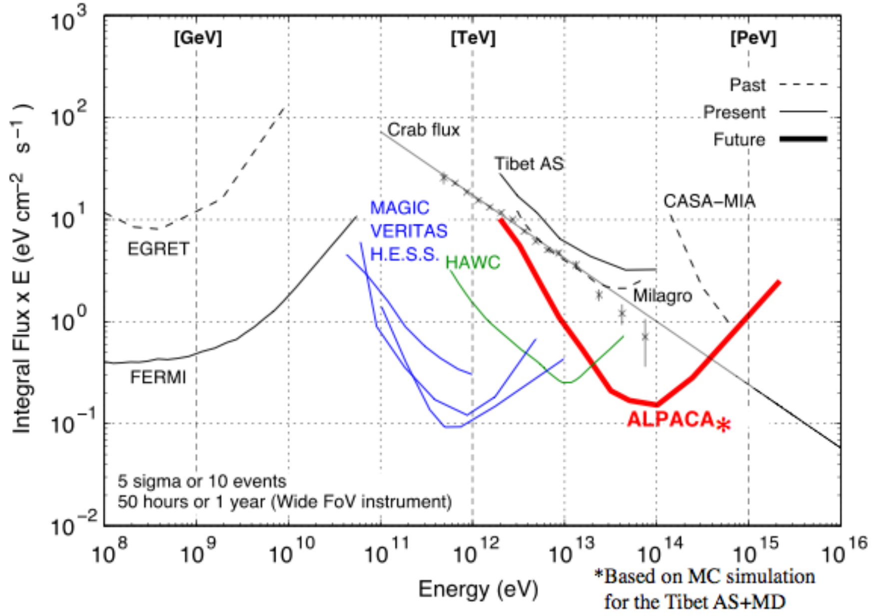
Location: 4,740 m above sea level (16°23′S, 68°08′W)

# of scintillation detectors	1 m² x 401 detectors
Effective area of	~83,000 m²
modal energy	~5TeV
angular resolution	~0.2 @100 TeV
energy resolution	~30% @100TeV
field of view	~2 sr

CR rejection power >99.9%@100 TeV
(γ ray efficiency ~ 90 %)

MD Array 56m² x 96 detectors
- Effective area for muons ~5400m²
- CR rejection power >99.9% @100TeV (gamma ray efficiency ~90%)

Tibet ASγ experiment moved from Tibet to Bolivia



Southern Hemisphere: LATTES

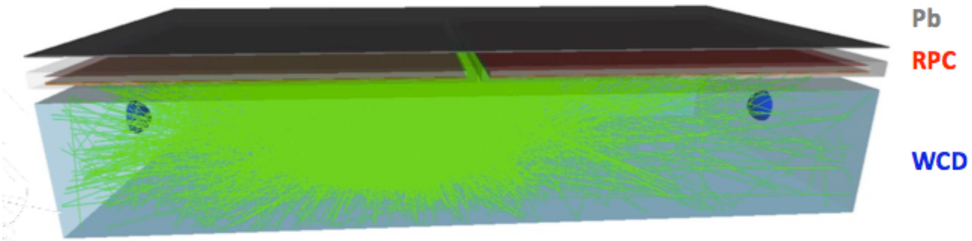
arXiv:1607.03051

P. Assis, U. Barres de Almeida, A. Blanco, R. Conceicao, B. D'Ettorre Piazzoli, A. De Angelis, M. Doro, P. Fonte, L. Lopes, G. Matthiae, M. Pimenta, R. Shellard, B. Tome'

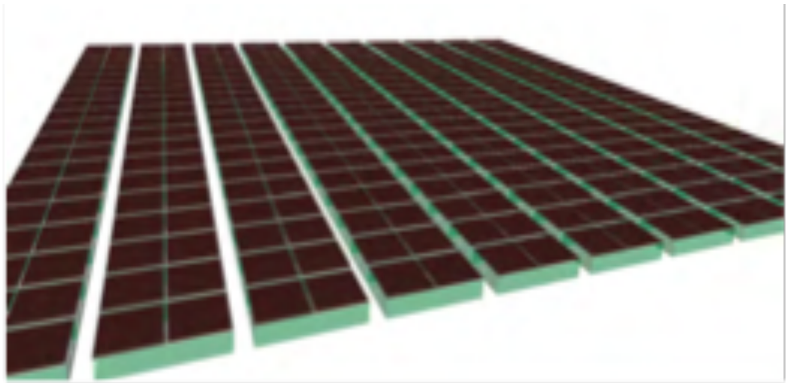
An array of hybrid detectors constituted by

1. one Water Cherenkov Detector (WCD) with a rectangular horizontal surface of 3 m × 1.5 m and a depth of 0.5 m, with signals read by PMTs at both ends of the smallest vertical face of the block.

2. On top of the WCD there are two MARTA RPCs, each with a surface of (1.5 × 1.5) m^2 and with 16 charge collecting pads. Each RPC is covered with a thin (5.6 mm) layer of lead.



- Thin lead plate (Pb)
  - 5.6 mm (one radiation lenght)
- Resistive Plate Chambers (**RPC**)
  - 2 RPCs per station
  - Each RPC with 4x4 readout pads
- Water Cherenkov Detector (**WCD**)
  - 2 PMTs (diameter: 15 cm)
  - Dimensions: 1.5 m x 3 m x 0.5 m



Possible limit: fragility of glass RPCs

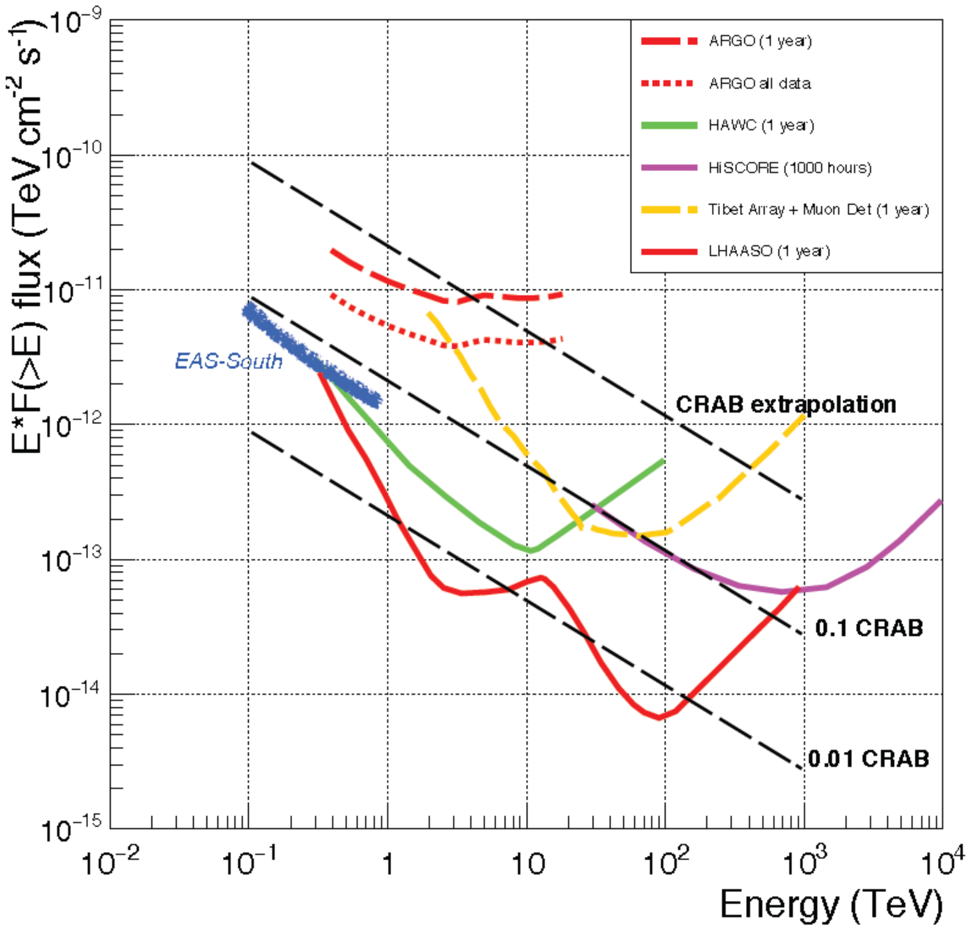
Southern Hemisphere: STACEX

(Di Sciascio, Piano, Montini, Santonico, Tavani, 2017)

Calorimetric approach with a double layer of RPCs (with lead layer in between) to enhance the conversion of secondary photons.

- A RPC carpet of 100 x 100 m^2 at least
- bakelite RPCs (ARGO-like)
- fully 'analog' read out

A study is underway in Rome to investigate the sensitivity of a RPC carpet operated at extreme altitude.



CTA and a new Wide FoV observatory

(Di Sciascio et al. 2017)

A future Wide FoV Observatory to be useful to CTA needs:

- $\approx$ 5x - 10x greater sensitivity below TeV
- Lower energy threshold ($\approx$ 100 - 300 GeV)
- Ability to detect extragalactic transient (AGN, GRBs)
- *Southern hemisphere site*

★ Is this possible ?

Minimum Detectable Gamma-Ray Flux (1 year):

$$MDF \propto \frac{\sqrt{\Phi_{bkg}}}{\Phi_\gamma} \cdot \frac{1}{R \cdot \sqrt{A^\gamma_{eff}}} \cdot \sigma_\theta \cdot \frac{1}{Q}$$

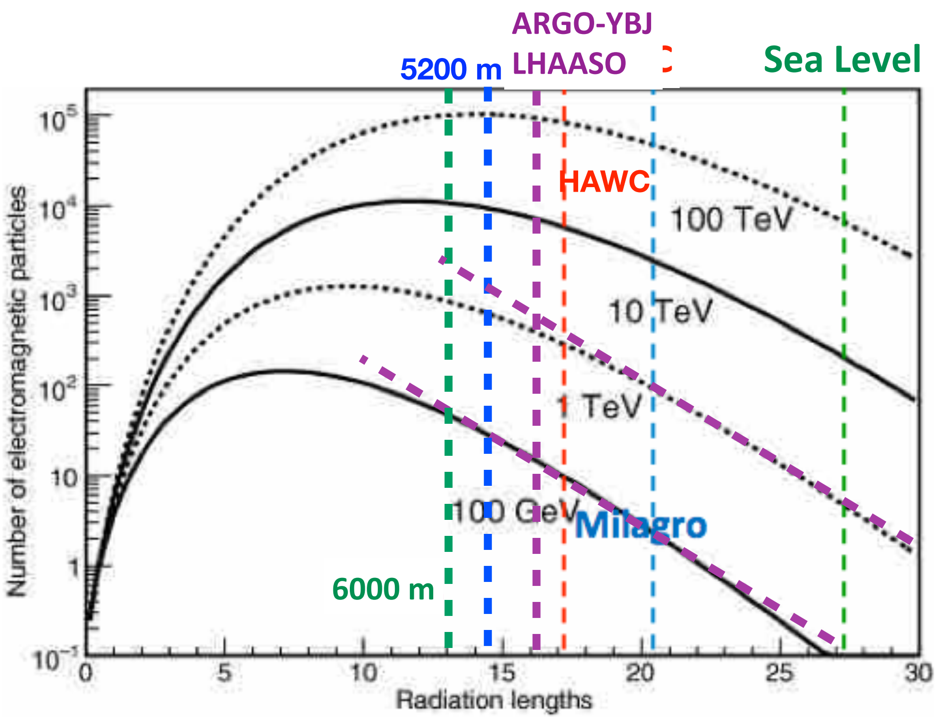
Φ_{bkg} = integral background flux
Φ_γ = integral photon flux
σ_θ = angular resolution

$$R = \sqrt{\frac{A^\gamma_{eff}}{A^{bkg}_{eff}}}$$

$$Q = \frac{\text{fraction of surviving photons}}{\text{fraction of surviving hadrons}}$$

Lowering the energy threshold: high altitudes

(Di Sciascio et al. 2017)



Showers of all energies have the same slope after shower maximum: ≈1.65x decrease per r.l. .
So, for all energies, if a detector is located one radiation length higher in atmosphere, the result will be a ≈1.65x decrease of the detectable energy.

HAWC (4100 m asl)
ARGO-YBJ/LHAASO (4400 m asl) = 1, 1 energy thr.
Chacaltaya (5200 m asl) ≈2x, ≈3x energy thr.
6000 m asl ≈3x, ≈5x energy thr.

increase in size **decrease in en. thr.**

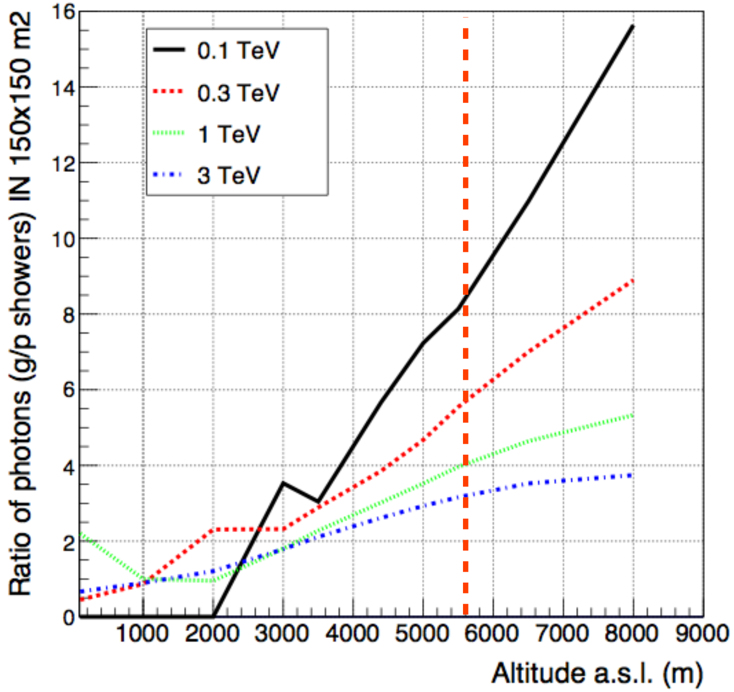
This imply that the effective areas of EAS detectors increases at low energies.

Lowering the energy threshold:

- Extreme altitude (>4400 m asl)
- Detector and layout
- Coverage
- Detection of secondary photons

Secondary photons (Di Sciascio, Piano, Montini, Santonico, Tavani, 2017)

gamma rays dominate the particles on ground (≈7:1 for 100 GeV γ-showers at 4300 m asl)



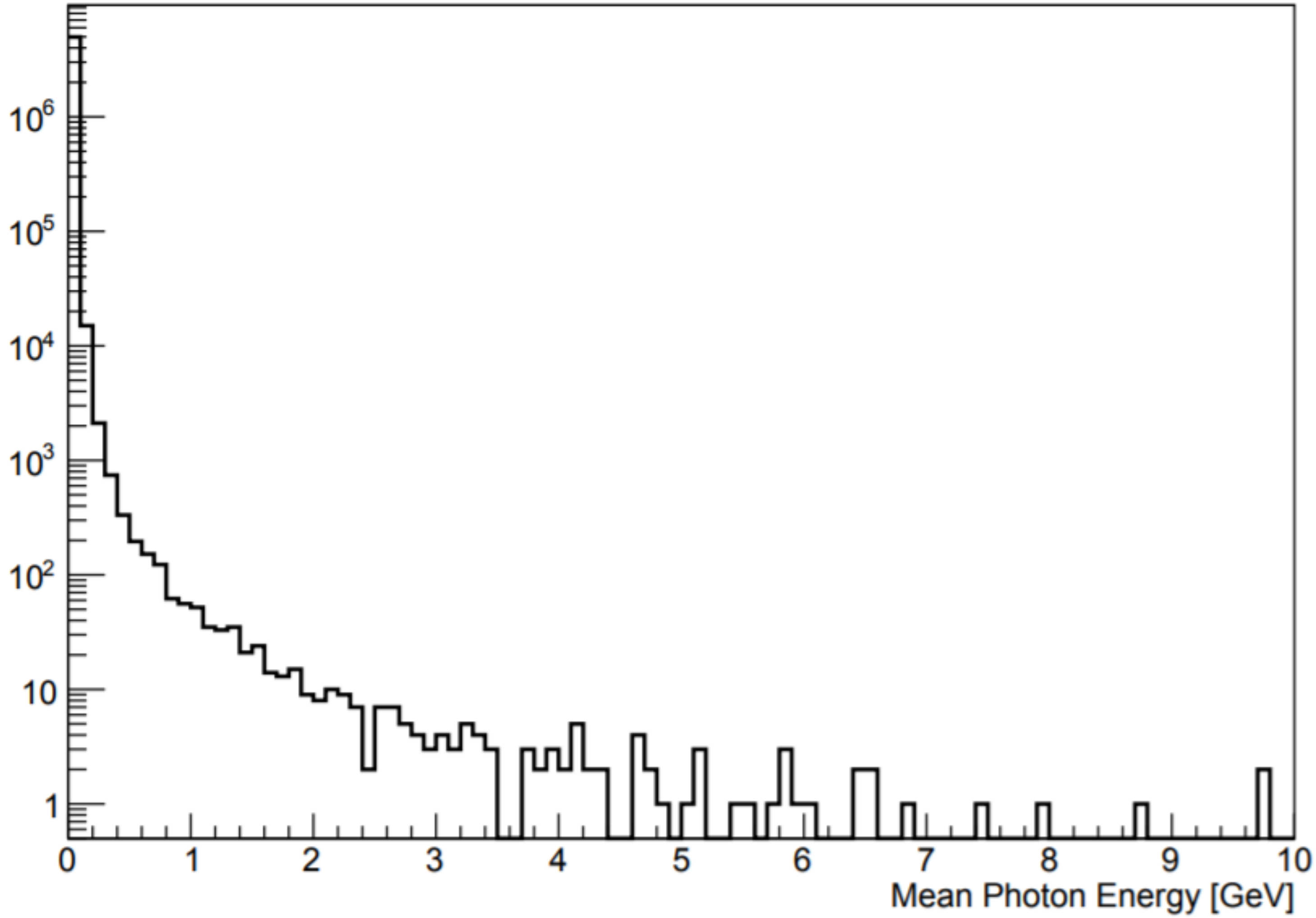
In γ-showers the ratio Nγ/Nch decreases if the comparison is restricted to a small area around the shower core.
For instance, we get Nγ/Nch ≈3.5 at a distance *r* < 50 m from the core for 100 GeV showers.

The number of secondary photons in γ-showers exceeds the number of gammas in p-showers with increasing altitude.

Detection of secondary photons very important to lower the energy threshold and to improve the angular resolution

Secondary gamma-rays, simulation, input 100 GeV, shower at 5,000 m of altitude

(Di Sciascio, Piano, Montini, Santonico, Tavani, 2017)



The drive for a Southern wide-FoV experiment

- With the right sensitivity (less than 100 mCrab at 100 GeV) would be extremely valuable for CTA.
- It is doable by a combination of techniques for the low-energy (100 GeV) and higher energies above TeV (join groups and ideas)
- Better if positioned at 5000 m for energy threshold and sensitivity
- Competitive cost.

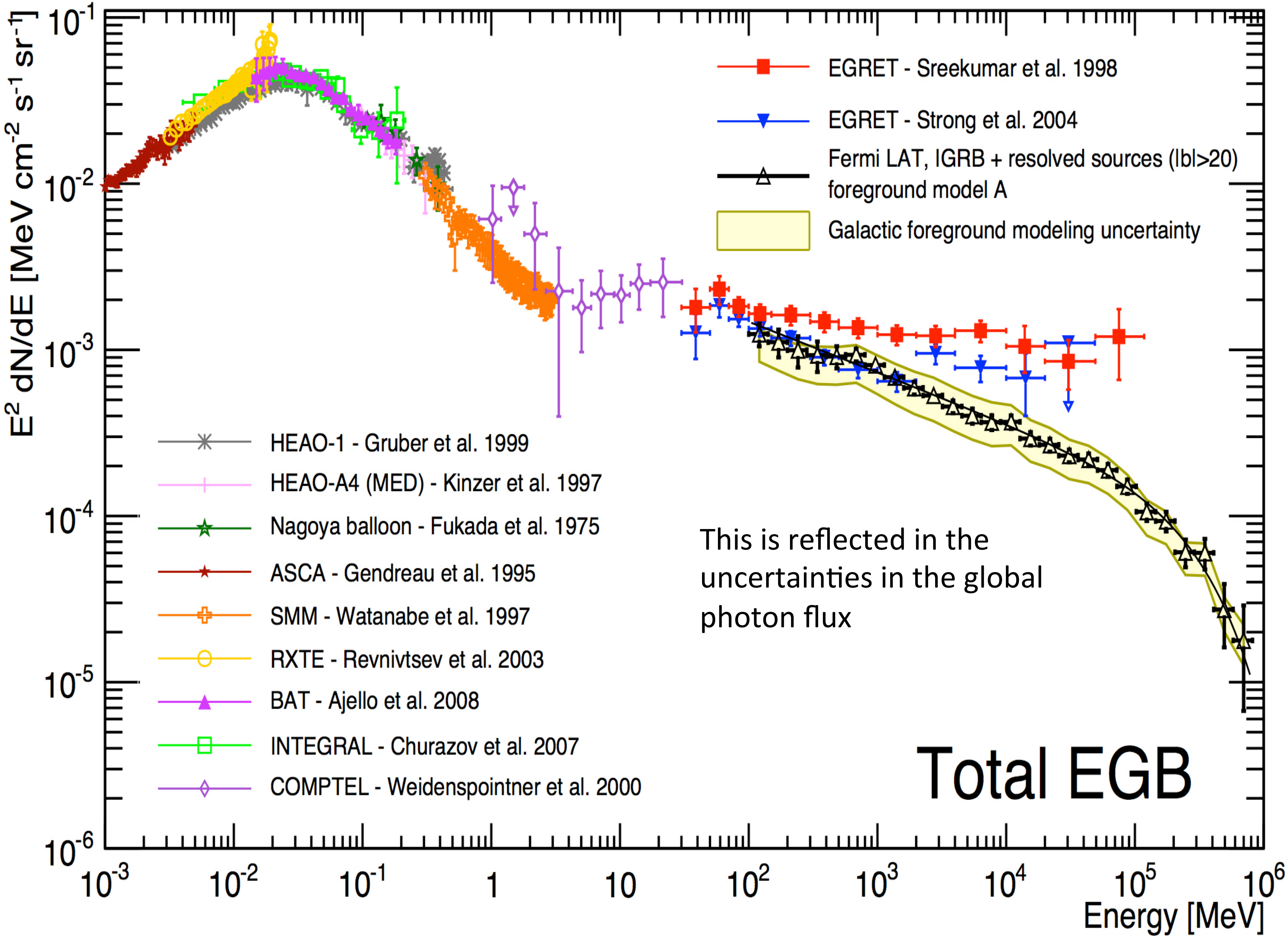
Conclusions

- **Gamma-ray astrophysics from space and the ground has an enormous potential for the next decade: it is up to our community to make it real.**

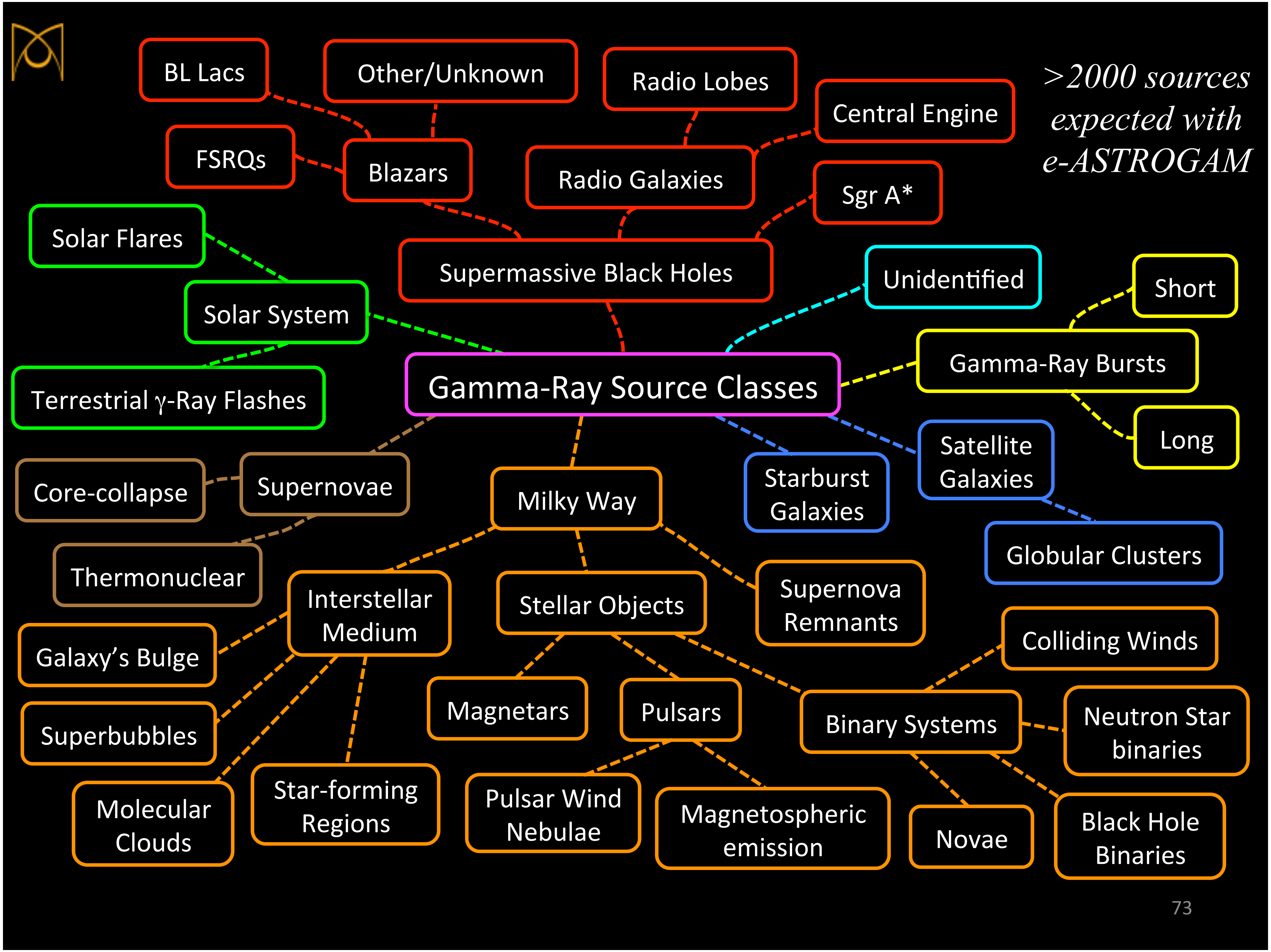
- **The MeV-GeV range is of crucial importance being at the heart of many fundamental processes: e-ASTROGAM and AMEGO are real chances for a new space mission complementary to CTA**

- **A Southern large FoV TeV experiment is needed, with a strong push to low-energy sensitivity**

Back-up slides

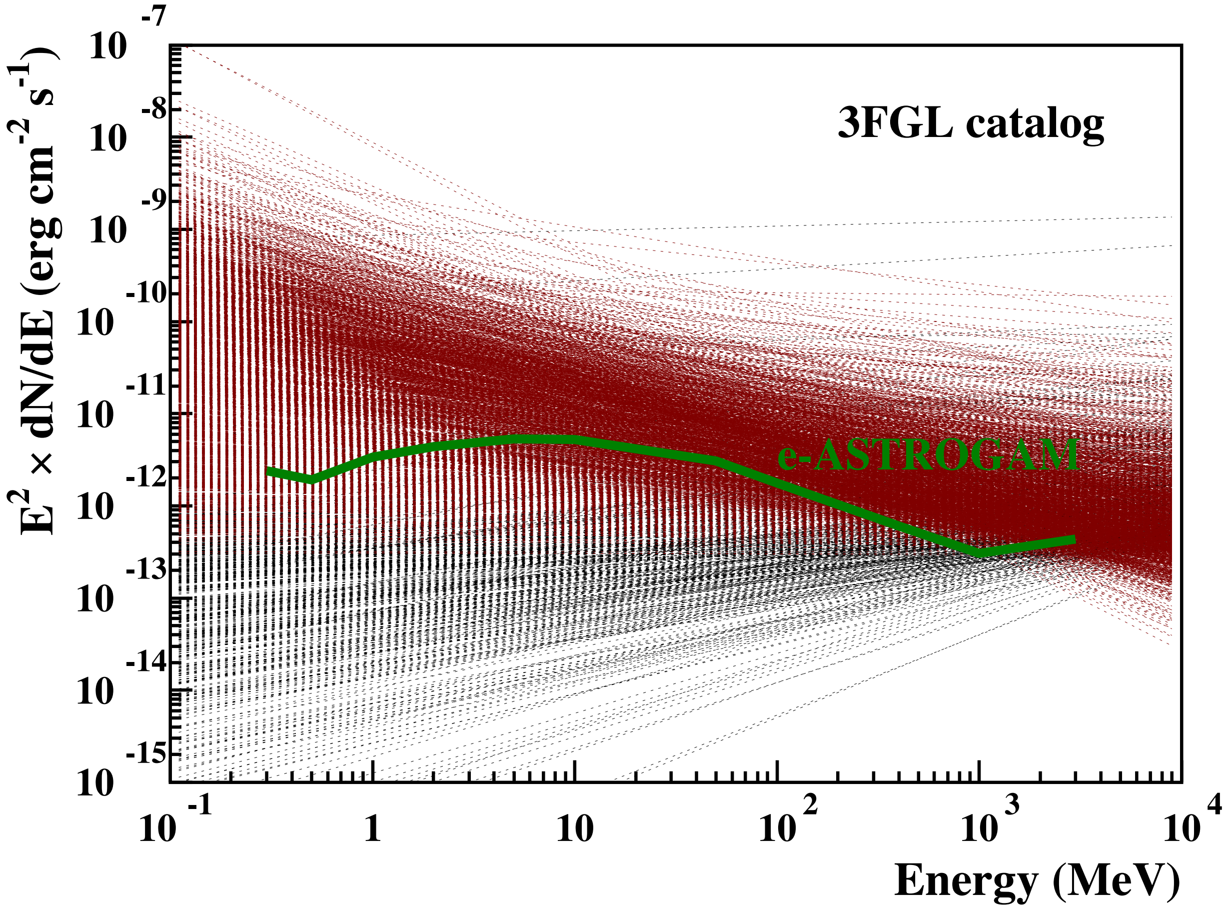


This is reflected in the uncertainties in the global photon flux


>2000 sources expected with e-ASTROGAM
Gamma-Ray Source Classes
Supermassive Black Holes
Blazars
BL Lacs
FSRQs
Other/Unknown
Radio Galaxies
Radio Lobes
Central Engine
Sgr A*
Unidentified
Gamma-Ray Bursts
Short
Long
Solar System
Solar Flares
Terrestrial γ-Ray Flashes
Supernovae
Core-collapse
Thermonuclear
Milky Way
Starburst Galaxies
Satellite Galaxies
Globular Clusters
Interstellar Medium
Galaxy's Bulge
Superbubbles
Molecular Clouds
Star-forming Regions
Stellar Objects
Magnetars
Pulsars
Pulsar Wind Nebulae
Magnetospheric emission
Supernova Remnants
Binary Systems
Colliding Winds
Neutron Star binaries
Novae
Black Hole Binaries

e-ASTROGAM discovery space

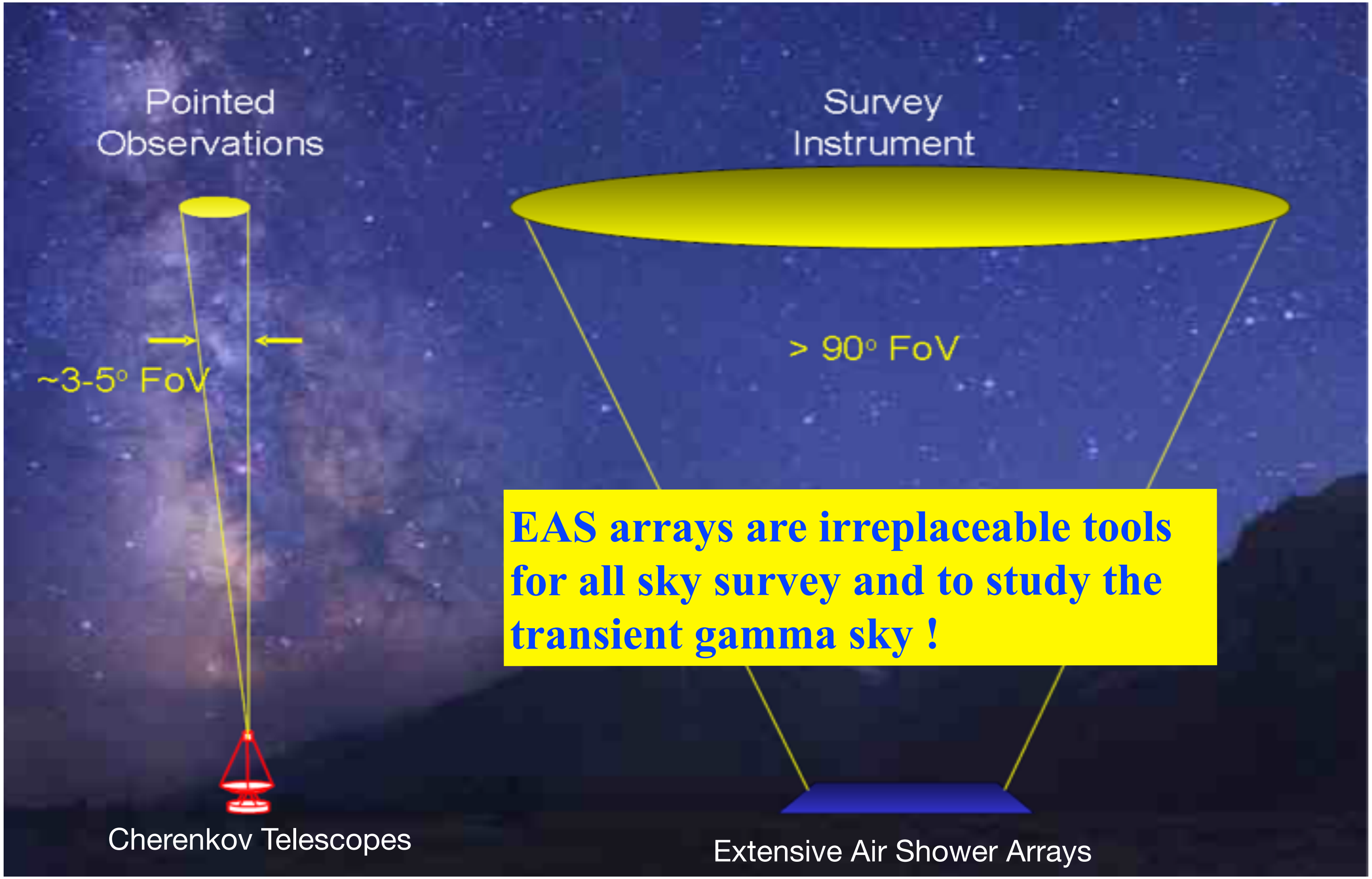
- Over 3/4 of the sources from the 3rd *Fermi* LAT Catalog (3FGL), 2415 sources over 3033, have power-law spectra (E_γ > 100 MeV) steeper than E_γ^{-2}, implying that their peak energy output is below 100 MeV



- These includes more than 1200 (candidate) blazars (mostly FSRQ), about 150 pulsars, and nearly **900 unassociated sources**
- Most of these sources will be detected by **e-ASTROGAM** ⇒ large discovery space for new sources and source classes

Status of e-ASTROGAM
The e-ASTROGAM Collaboration

Pointed and Survey Instruments



We need to know

★ Which are the sources of CRs ?

- which acceleration mechanism? ➜ injection spectrum
- total energy in CRs
- maximum energy of accelerated particles

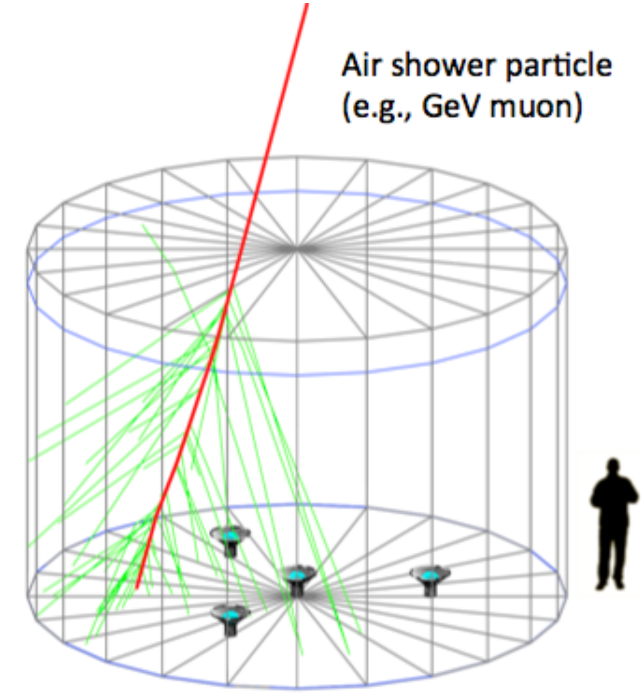
★ How do CRs propagate ?

- magnetic field in the Galaxy
- spatial distribution of sources
- spatial distribution of CRs
- injected ➜ observed spectrum

★ Which is the chemical composition of CRs ?

Water Cherenkov Method

- Robust and cost-effective surface detection technique
- Water tanks: 7.3 m radius, 5 m height, 185 kL purified water
- Tanks contain three 8” R5912 PMTs and one 10” R7081-HQE PMT looking up to capture Cherenkov light from shower front



Final tank deployed: December 15, 2014

Wide Field of View Cherenkov Experiments

One of the main component of LHAASO is the array of Wide Field of View Cherenkov Telescopes WFCTA.

The goal: measurement of the CR energy spectrum and composition in the range 10^{13} - 10^{18} eV

Why Cherenkov telescopes at high altitude ?

(1) Measure EASs near maximum development points to reduce fluctuations.

High altitude:

(2) Use an unbiased trigger threshold for heavy components of primaries.

(3) Low energy theshold and wide energy range ($10^{13} \rightarrow 10^{18}$ eV).

Cherenkov signal:

(4) Measure the electromagnetic component which is less dependent on hadronic interaction models than the muon component.

(5) Good separation capability between the different masses.

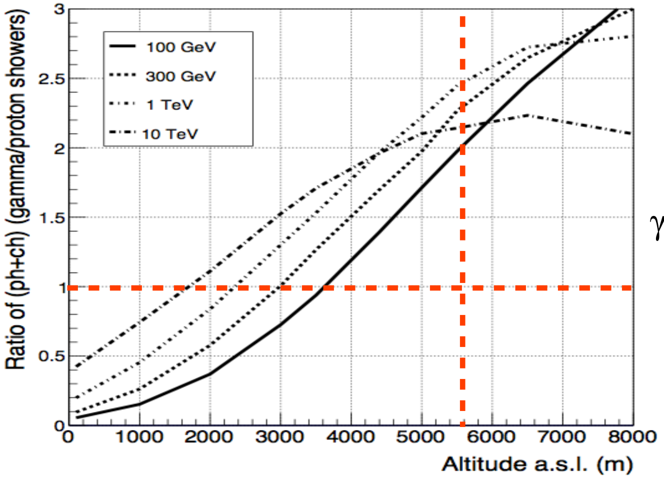
(6) Good energy resolution (<20%).

Chin. Phys. C 38, 045001 (2014)
Phys. Rev. D 92, 092005 (2015)

Observation modes: Cherenkov and Fluorescence Light in Phase-II

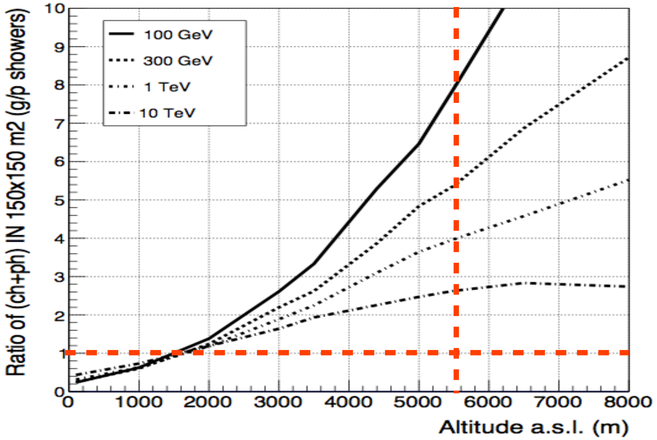
γ/p detection efficiency

High altitude → rejection of the background 'for free' !



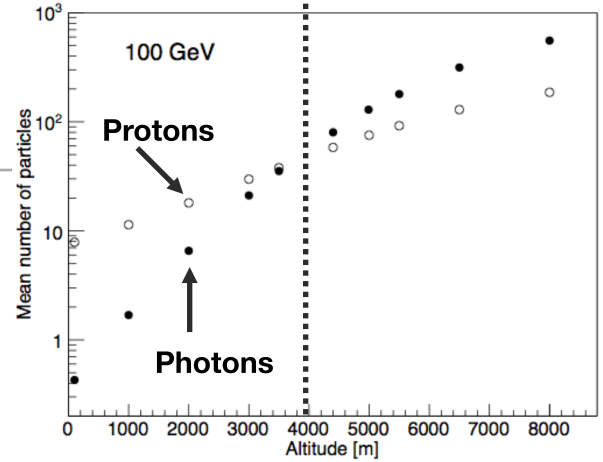
$$R = \sqrt{\frac{A^{\gamma}_{eff}}{A^{bkg}_{eff}}}$$

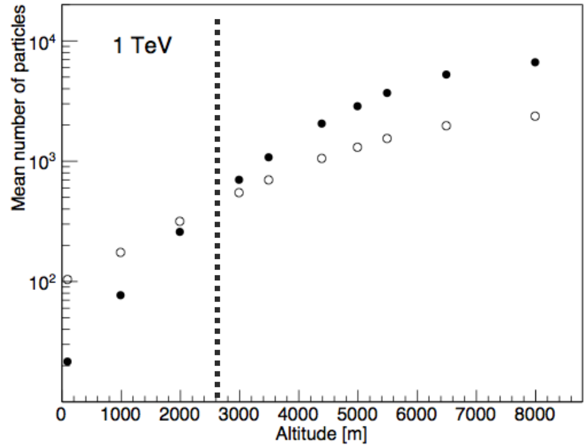
γ/hadron relative trigger efficiency

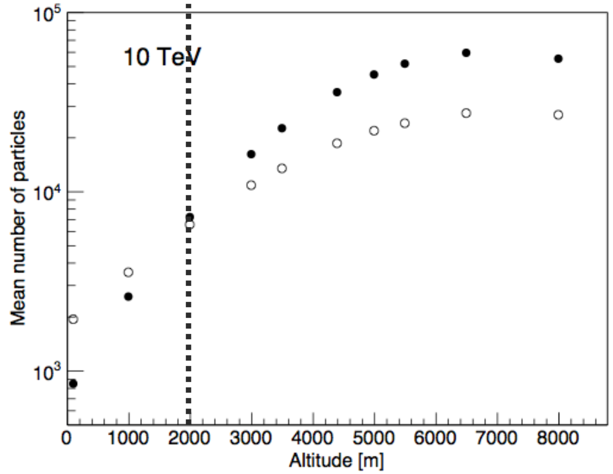


The number of particles in γ-showers exceeds the number of particles in p-showers at extreme altitude.

Trigger probability of a detector larger for γ-showers than for p-showers at extreme altitude.



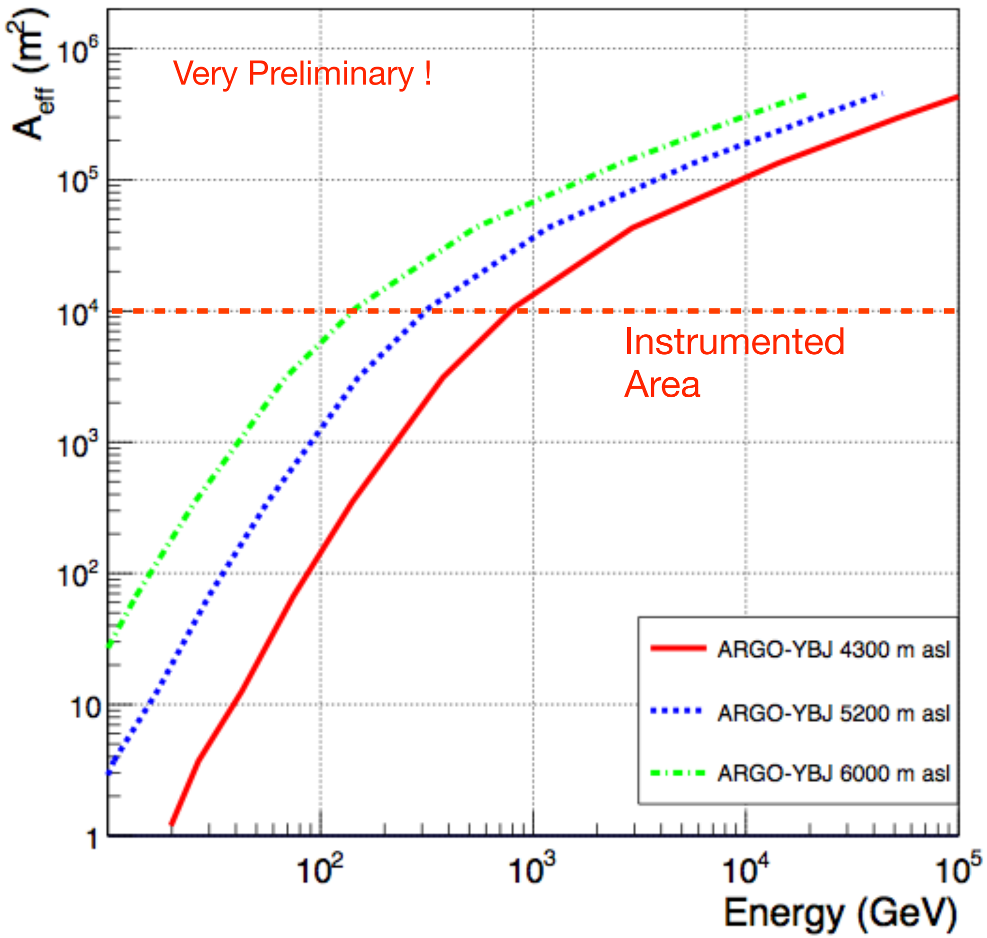




Effective Area

The Effective Area is function of

- Number of charged particles
- Dimension and coverage of the detector
- Trigger Logic



Effective Areas at 100 GeV:

≈ 1000 m^2 at 5200 m asl
≈ 5000 m^2 at 6000 m asl

Effective Areas at 300 GeV:

≈ 10,000 m^2 at 5200 m asl
≈ 20,000 m^2 at 6000 m asl

detailed calculations under way !