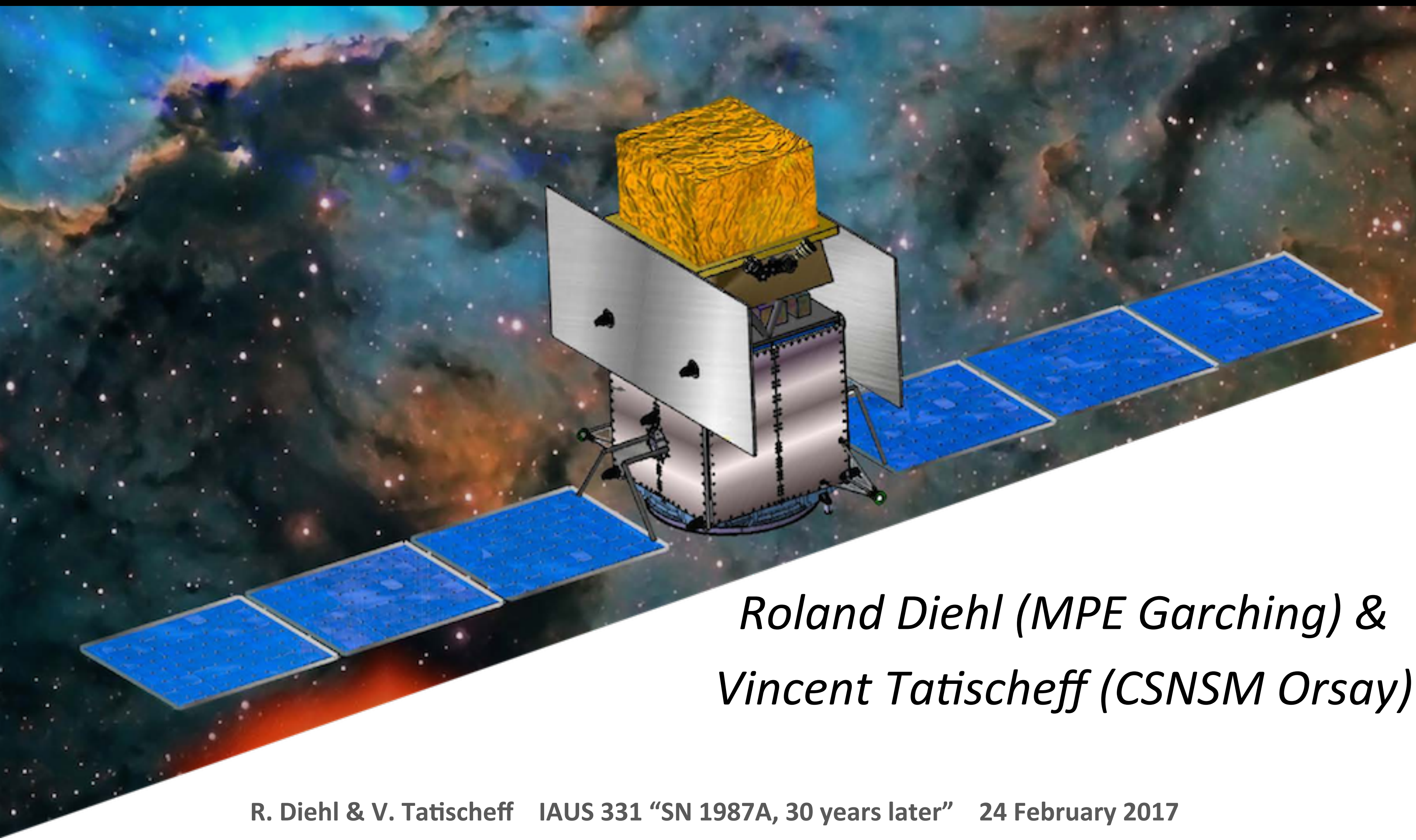
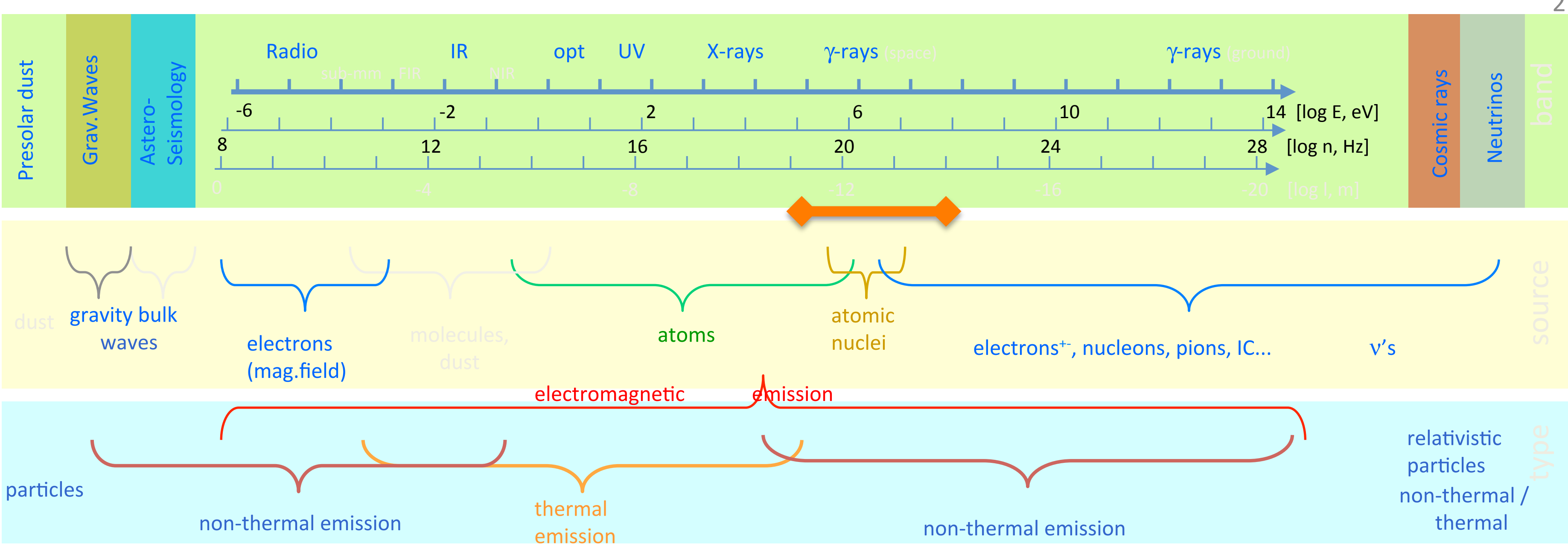
# e-ASTROGAM: towards a new space mission for gamma-ray astronomy



*Roland Diehl (MPE Garching) &*
*Vincent Tatischeff (CSNSM Orsay)*

# e-ASTROGAM The MeV/sub-GeV domain

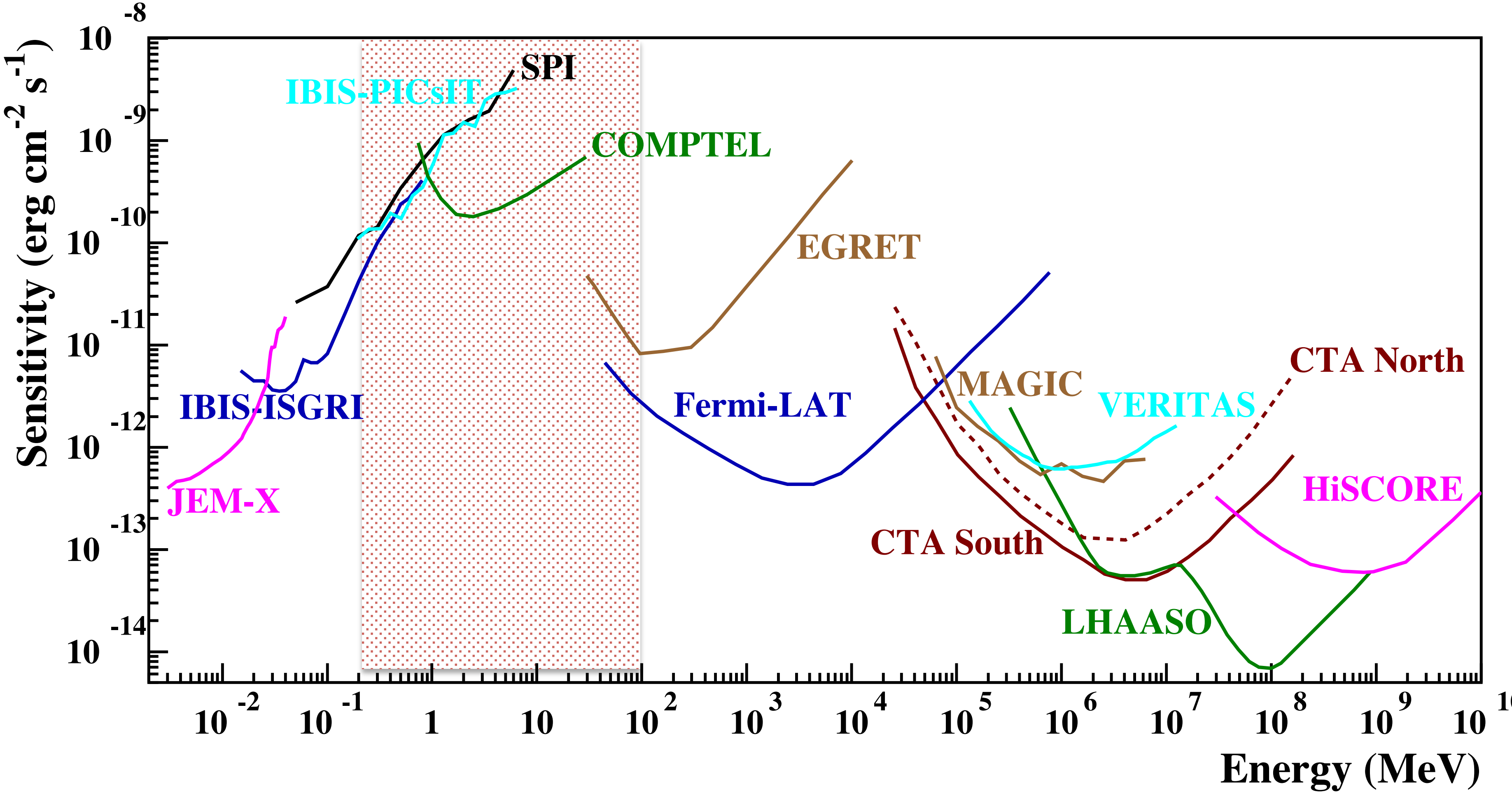





- Unique physics in this part of the electromagnetic spectrum:
  - Nuclear processes (i.e. atomic nuclei excitations)
  - Transition from thermal to non-thermal/relativistic astrophysics, CR acceleration

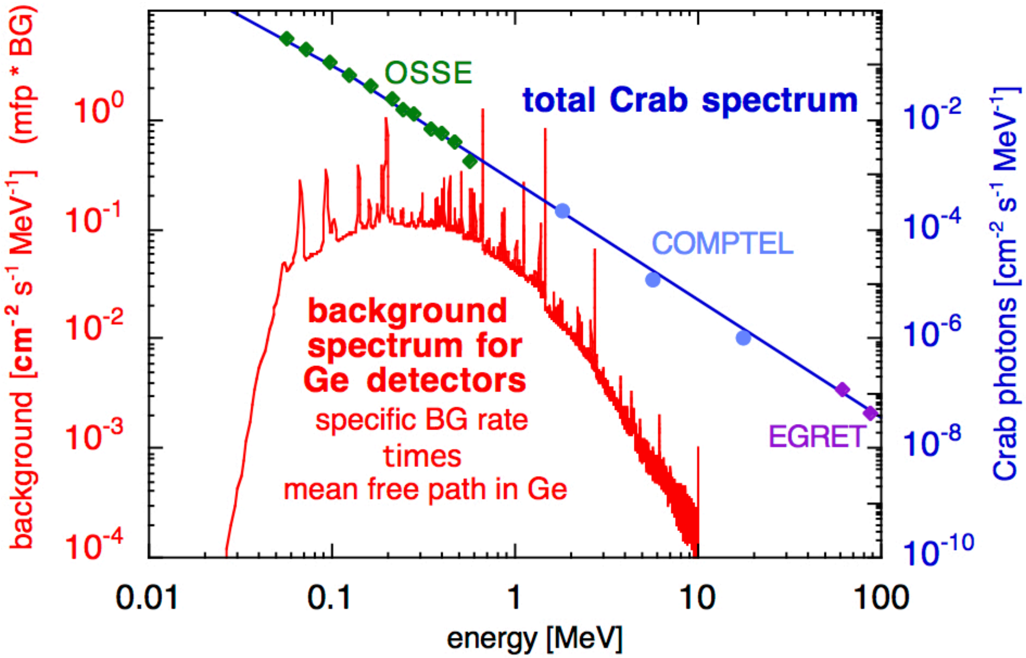
# The MeV/sub-GeV domain



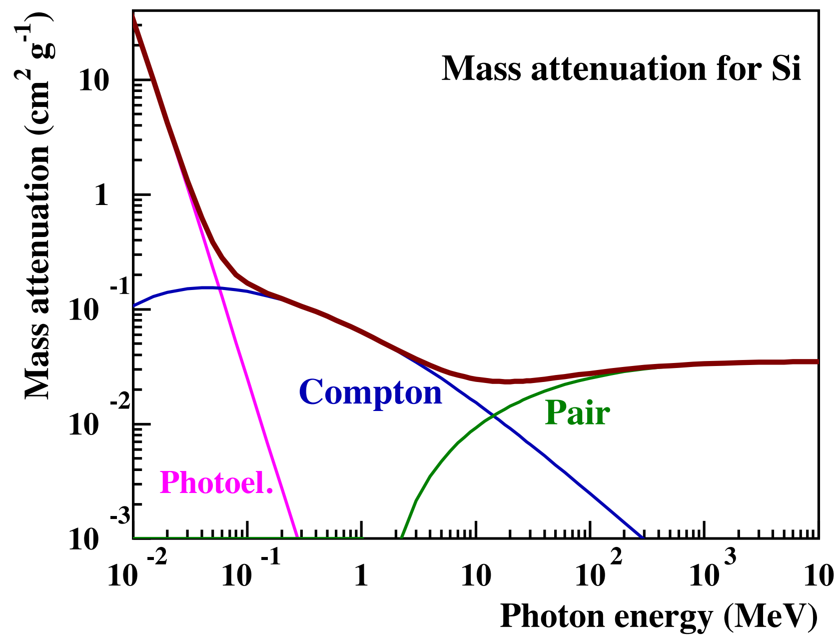



- Worst covered part of the electromagnetic spectrum (only a few tens of steady sources detected so far between 0.2 and 30 MeV)
- Many objects have their peak emissivity in this range (GRBs, blazars, pulsars...)

# e-ASTROGAM Observational challenges

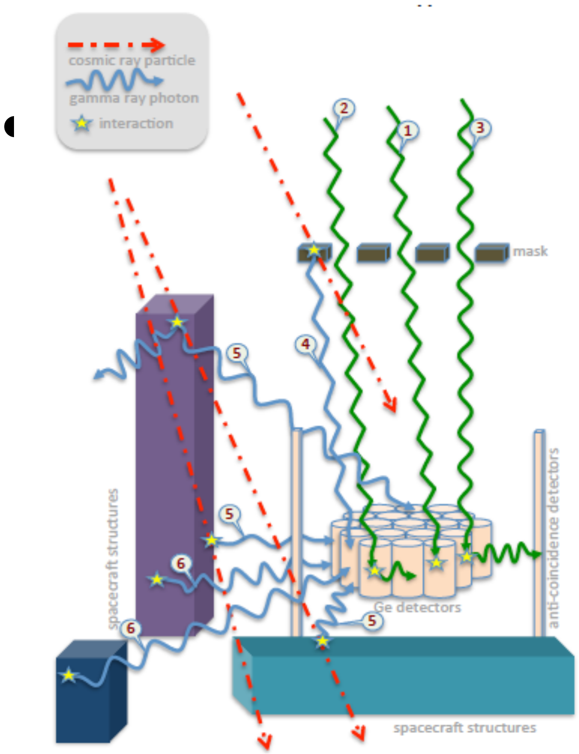


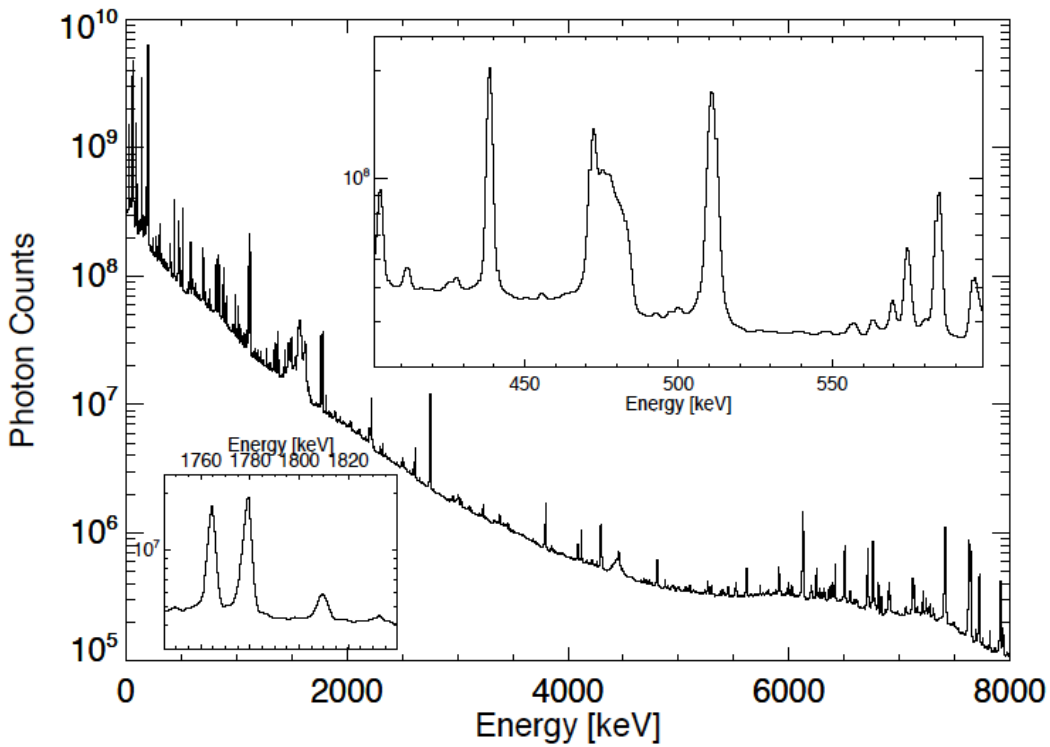

- ☺ The MeV range is the domain of nuclear γ-ray lines (radioactivity, nuclear collision, positron annihilation, neutron capture)
- ☹ Strong instrumental background from activation of space-irradiated materials




- ☹ Photon interaction probability reaches a minimum at ~ 10 MeV
- ☹ Three competing processes of interaction, Compton scattering being dominant around 1 MeV
  → complicated event reconstruction

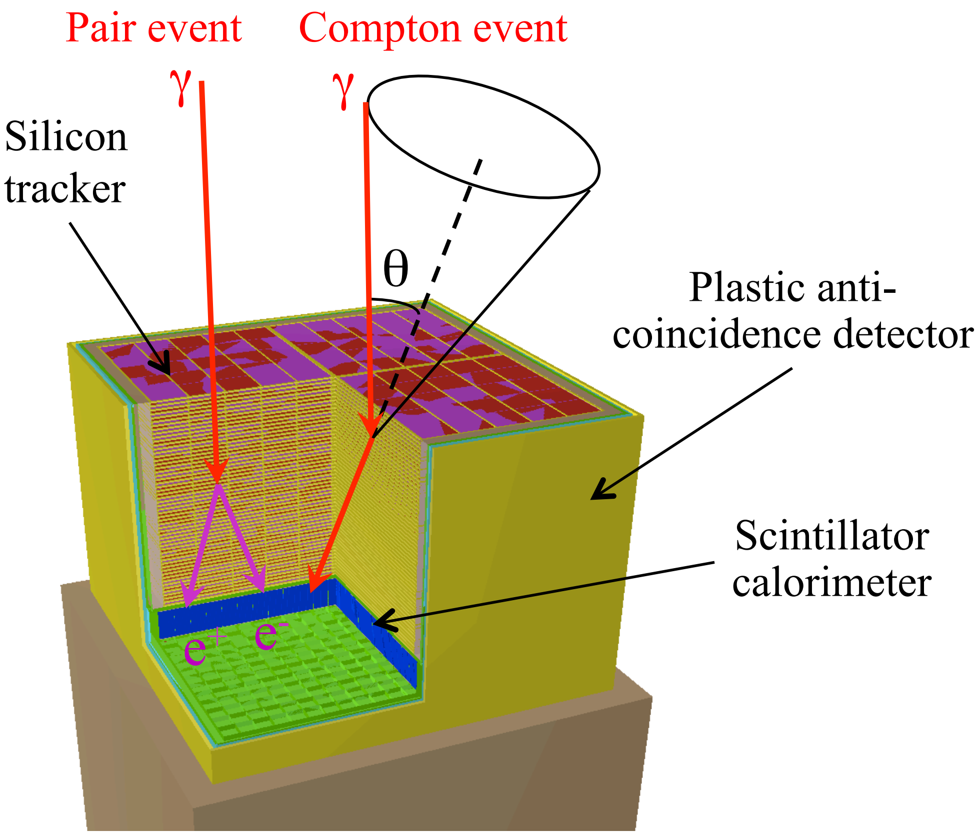
# Gamma ray spectroscopy with SPI: instrumental lines

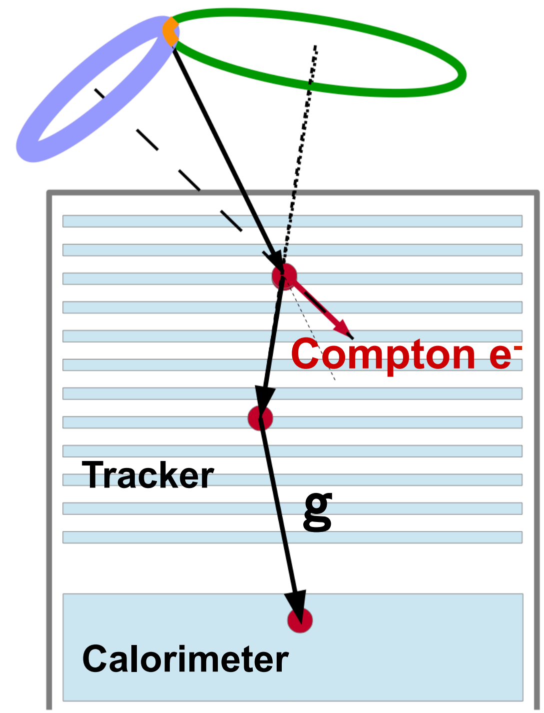


# e-ASTROGAM Measurement principle





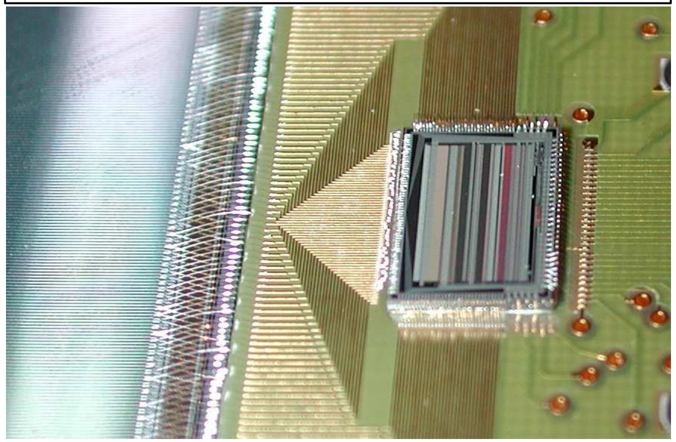

Tracked Compton event

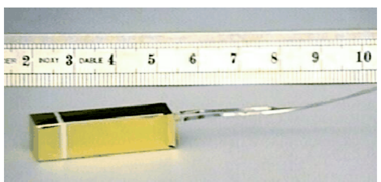
- **Tracker** → Double sided Si strip detectors (DSSDs) for excellent spectral resolution and fine 3-D position resolution
- **Calorimeter** – High-Z material for an efficient absorption of the scattered photon → CsI(Tl) scintillation crystals readout by Si Drift Diodes for better energy resolution
- **Anticoincidence detector** to veto charged-particle induced background → plastic scintillators readout by Si photomultipliers

# e-ASTROGAM Payload

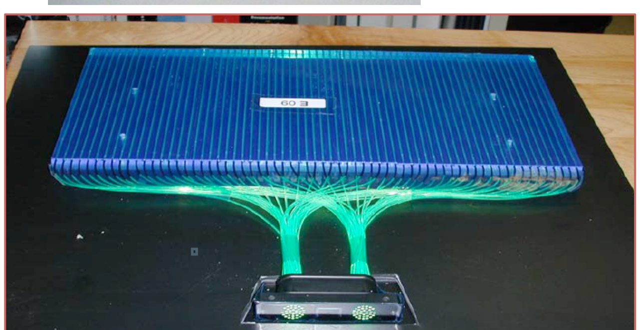


Detail of the detector-ASIC bonding in the AGILE Si Tracker



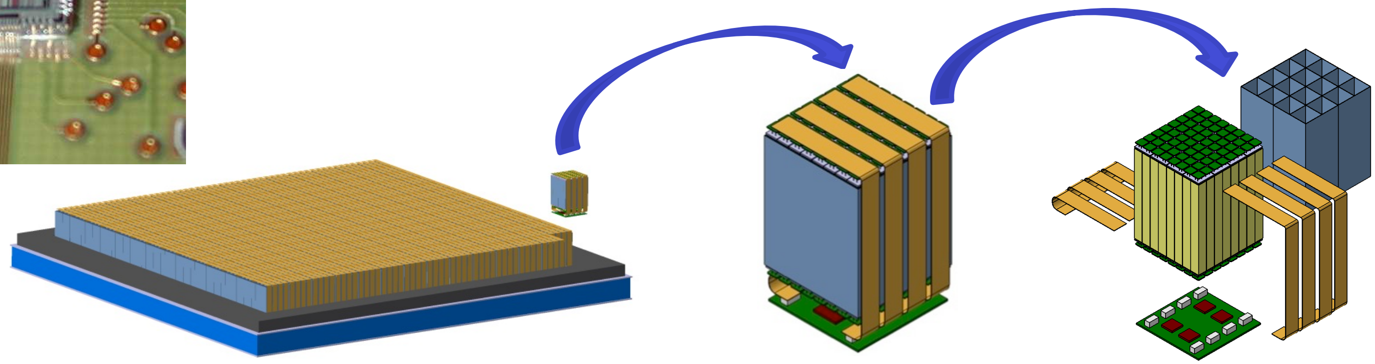


PICSiT CsI(Tl) pixel



Fermi/LAT AC system

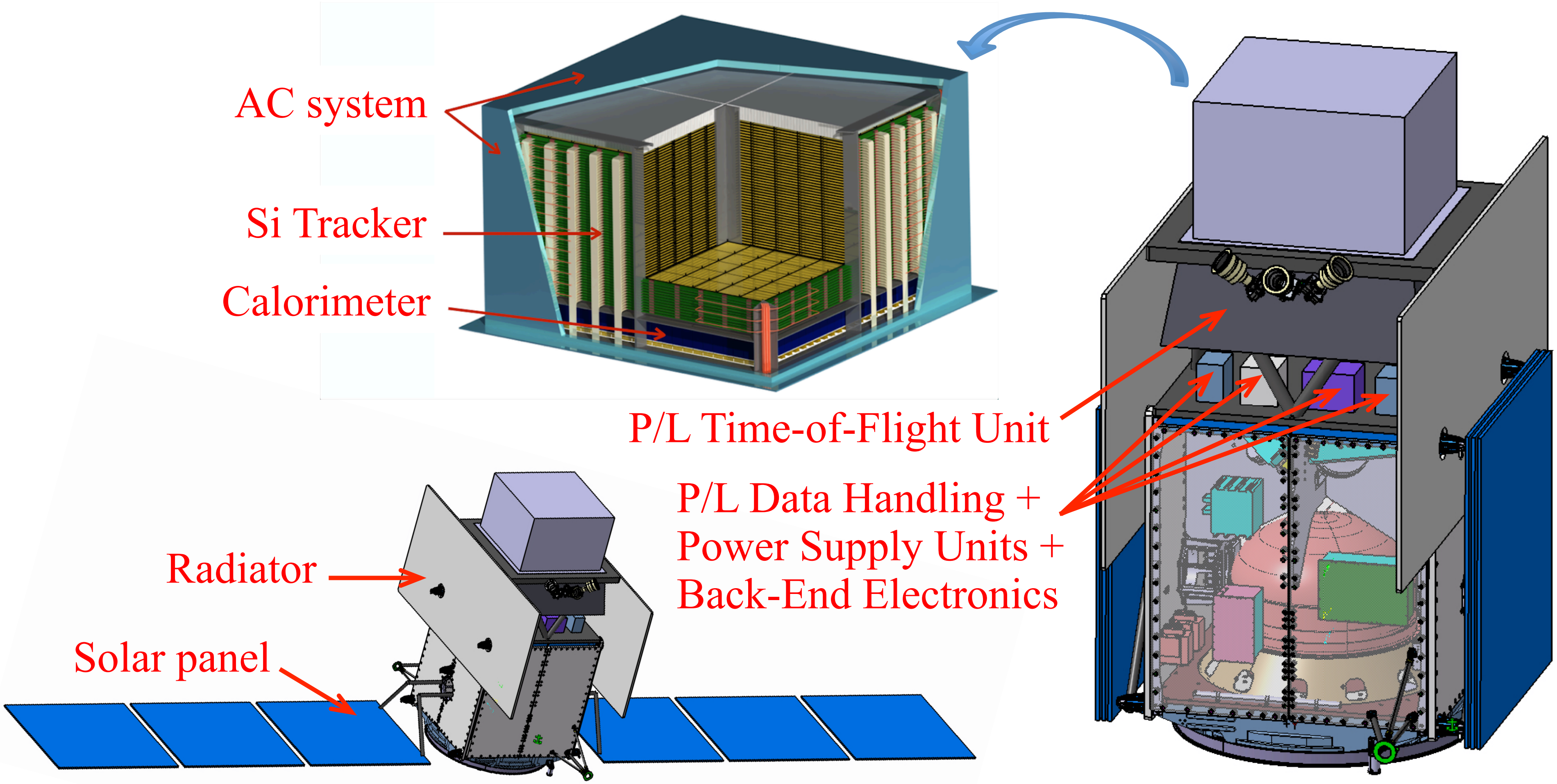
- **Tracker**: 56 layers of 4 times 5×5 DSSDs (5 600 in total) of 500 mm thickness and 240 mm pitch
- DSSDs bonded strip to strip to form 5×5 ladders
- Light and stiff mechanical structure
- Ultra low-noise front end electronics



- **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 Satellite

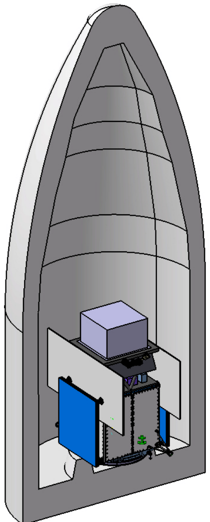
- Arrangement of the **Thales Alenia Space PROTEUS 800** platform developed in the frame of the SWOT CNES/NASA program
- Spacecraft dry mass 2.4 t. Telescope mass 1.2 t (with mat. & syst. margins)

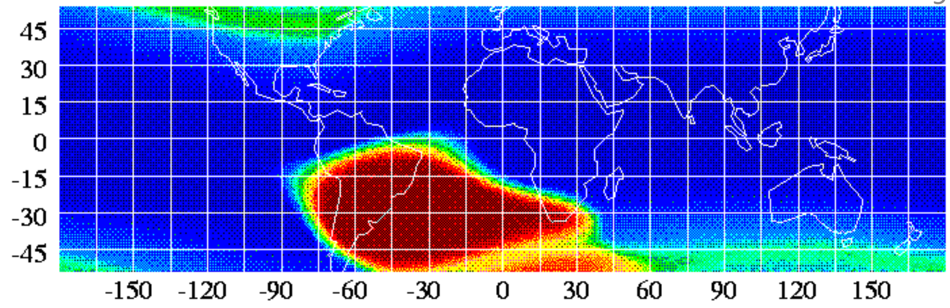


# e-ASTROGAM Mission profile

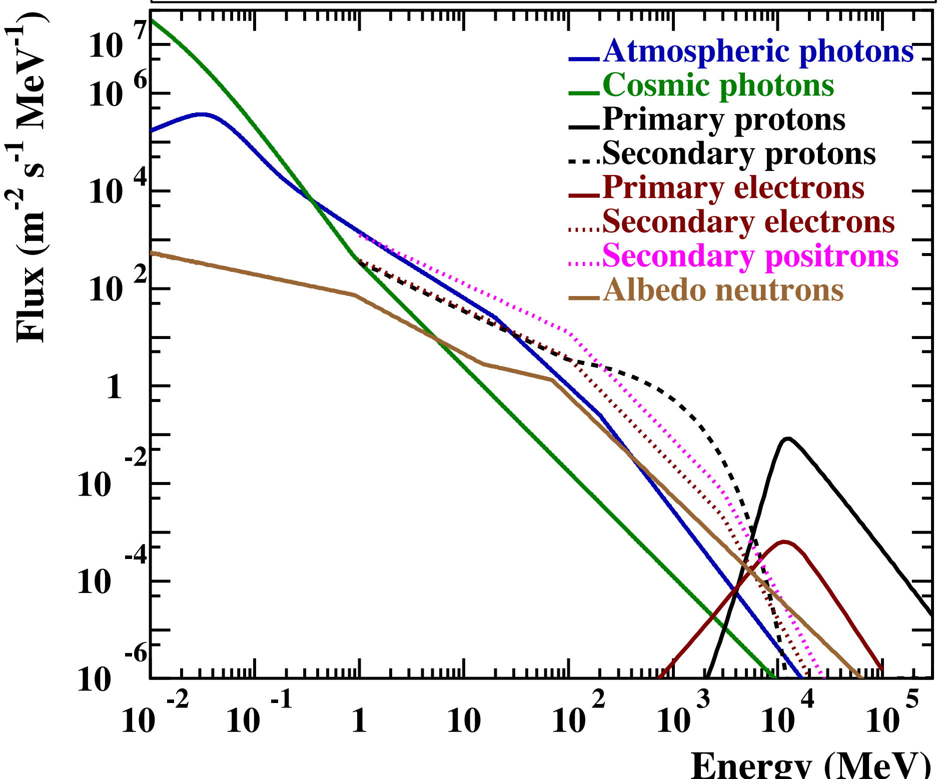


- **Orbit** – Equatorial (inclination $i < 2.5°$, eccentricity $e < 0.01$) low-Earth orbit (altitude in the range 550 - 600 km)
- **Launcher** – Ariane 6.2
- **Satellite communication** – ESA ground station at Kourou + ASI Malindi station (Kenya)
- **Data transmission** – via X-band (available downlink of 8.5 MHz)
- **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

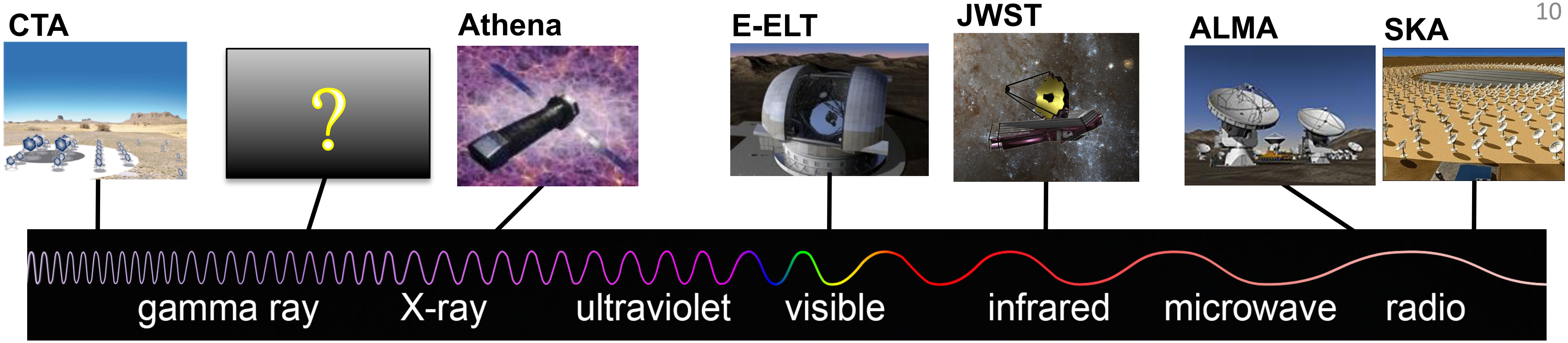




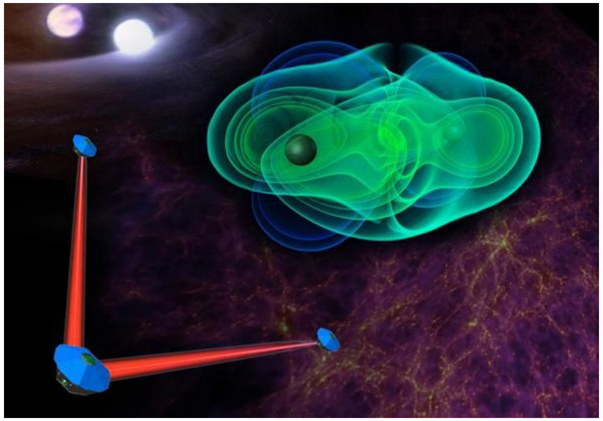

Background environment in an ELEO



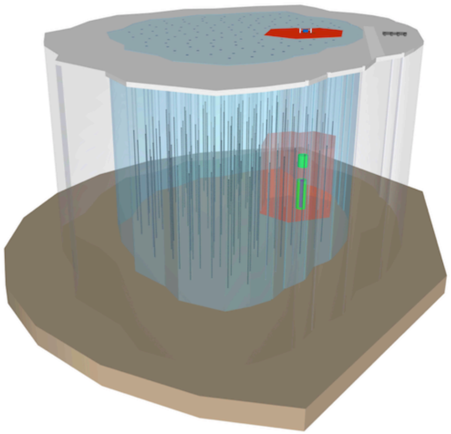
# e-ASTROGAM γ-ray astronomy in context




eLISA – Gravitational waves



IceCube-Gen2 – Neutrinos



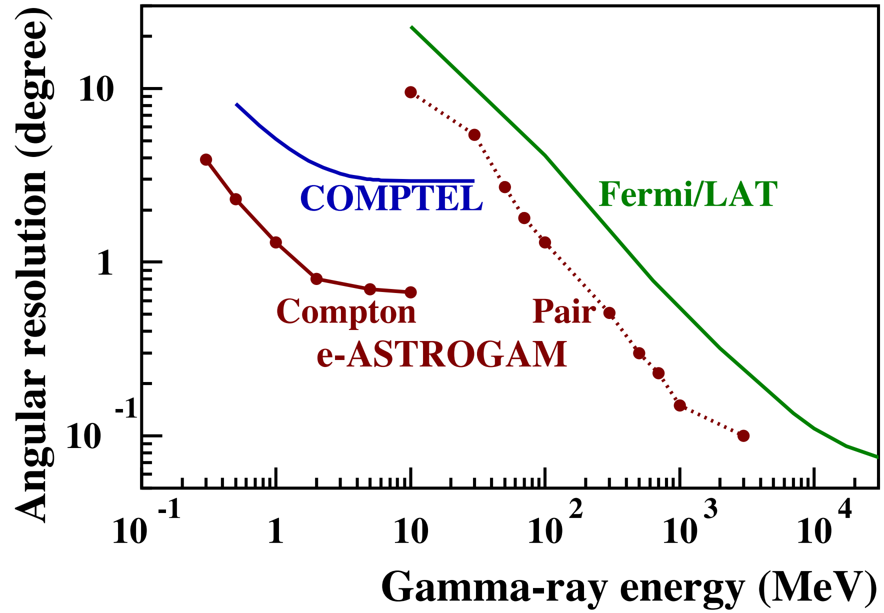
**New Astronomies:**
gravitational waves
neutrinos

- 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

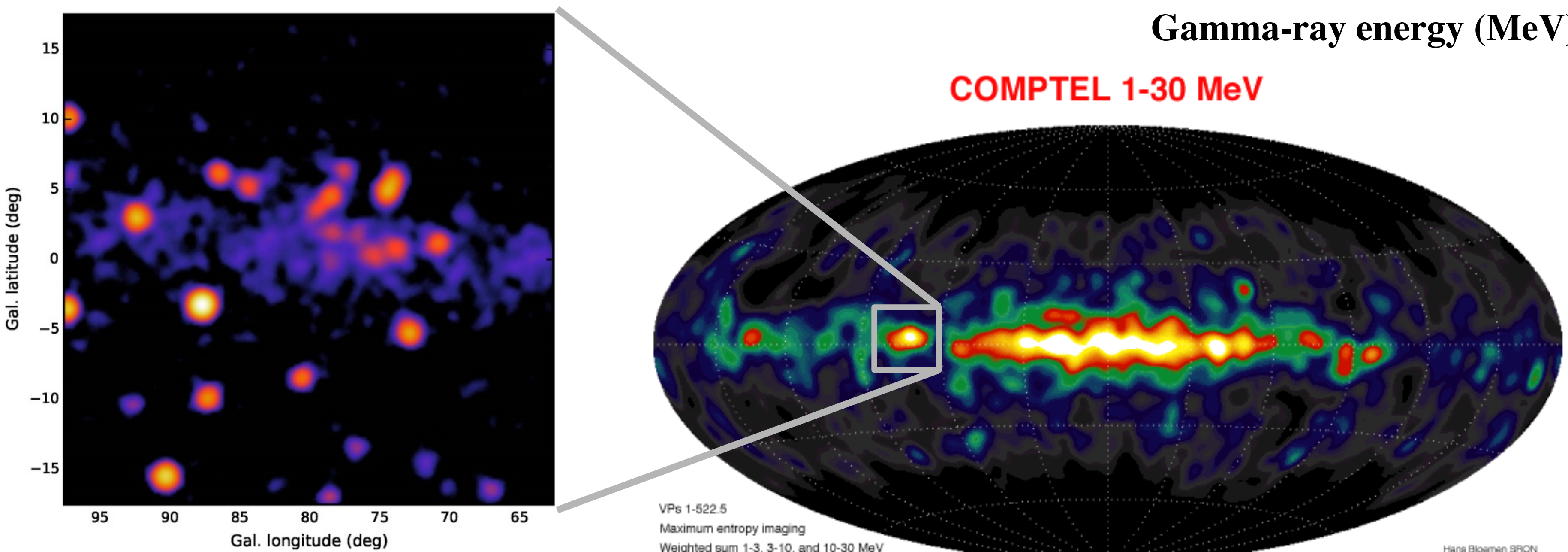
# e-ASTROGAM Angular resolution



- Angular resolution needs to be improved close to the physical limits (Doppler broadening, nuclear recoil)




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

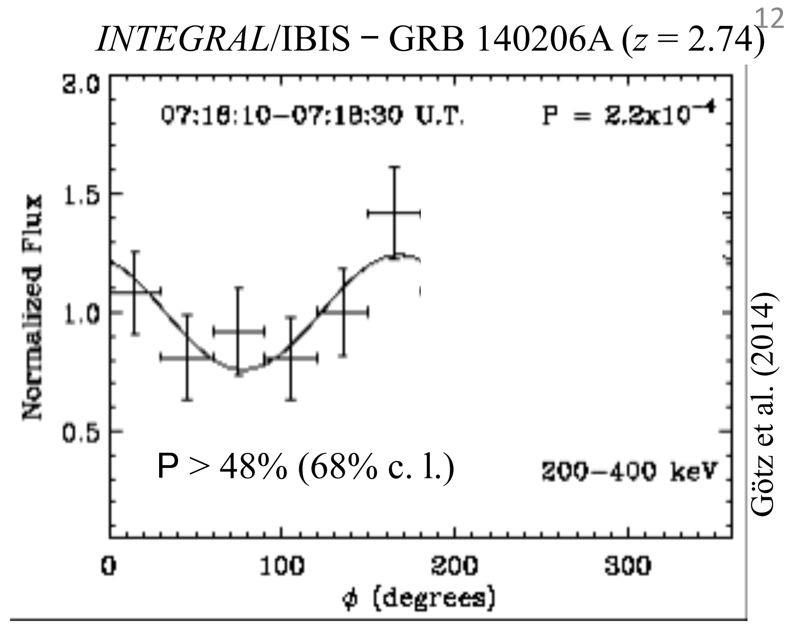


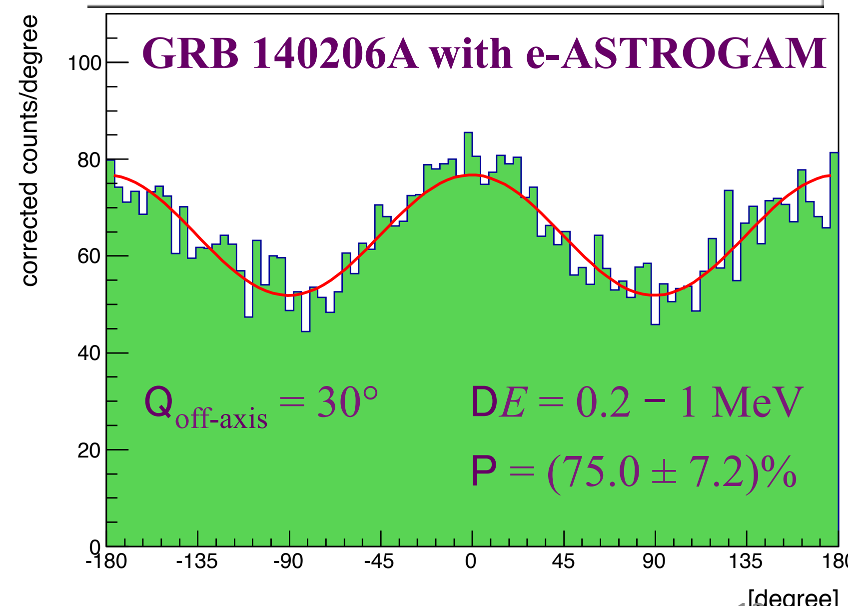
# e-ASTROGAM Gamma-ray polarization

- 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)

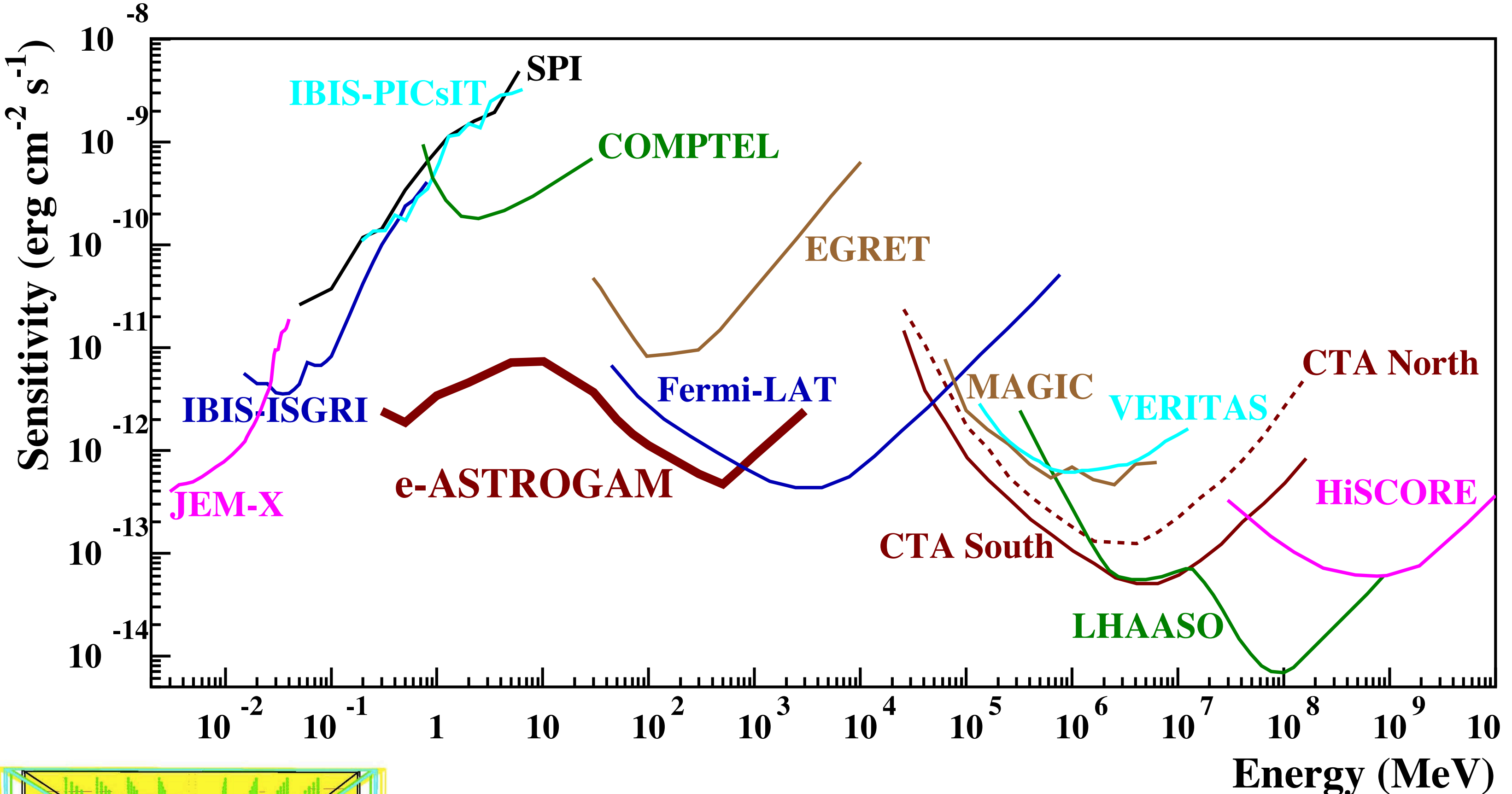
✓ e-ASTROGAM will measure the γ-ray polarization of ~**100 GRBs per year** (promising candidates for highly γ-ray polarized sources)

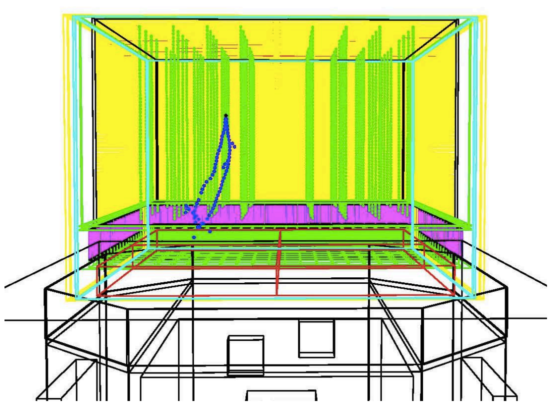


# e-ASTROGAM Performance assessment





- 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

# e-ASTROGAM Core science



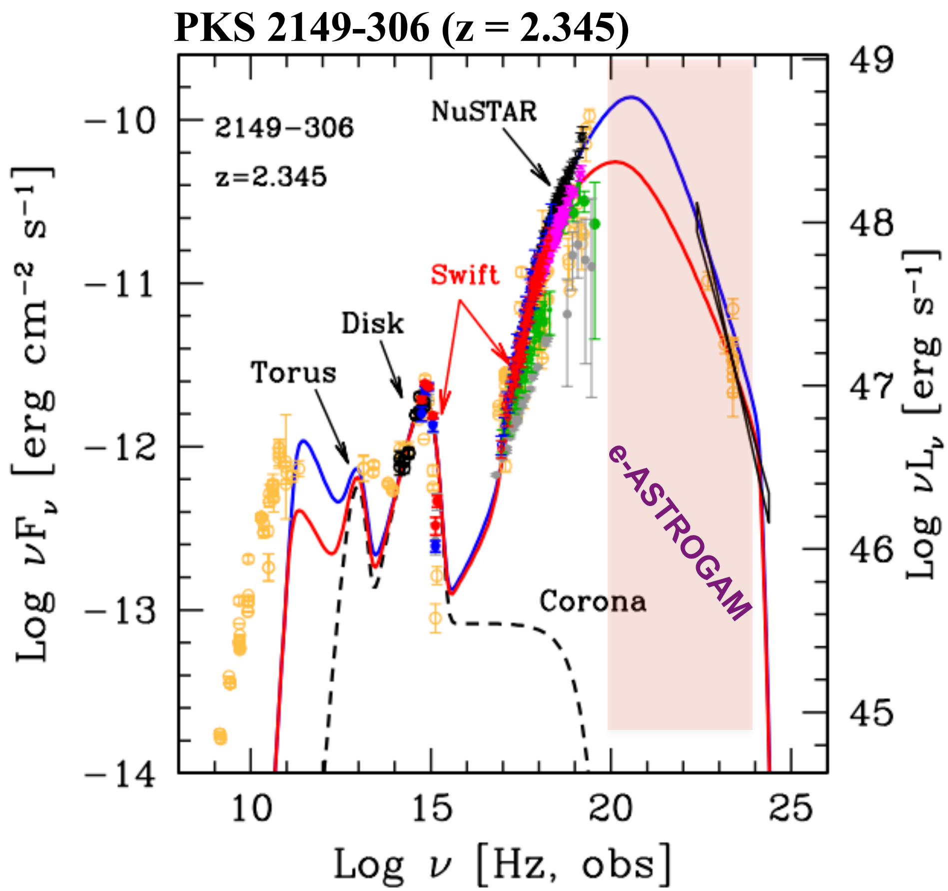
1. **Jet and outflow astrophysics** (compact binaries, gamma-ray bursts, active galactic nuclei) and the link to **new astronomies** (gravitational waves, neutrinos, ultra-high energy cosmic rays)

2. Origin and impact of **high-energy particles** on **Galaxy evolution**, from **cosmic rays** to **antimatter**

3. **Supernovae, nucleosynthesis** and the **chemical evolution of our Galaxy**

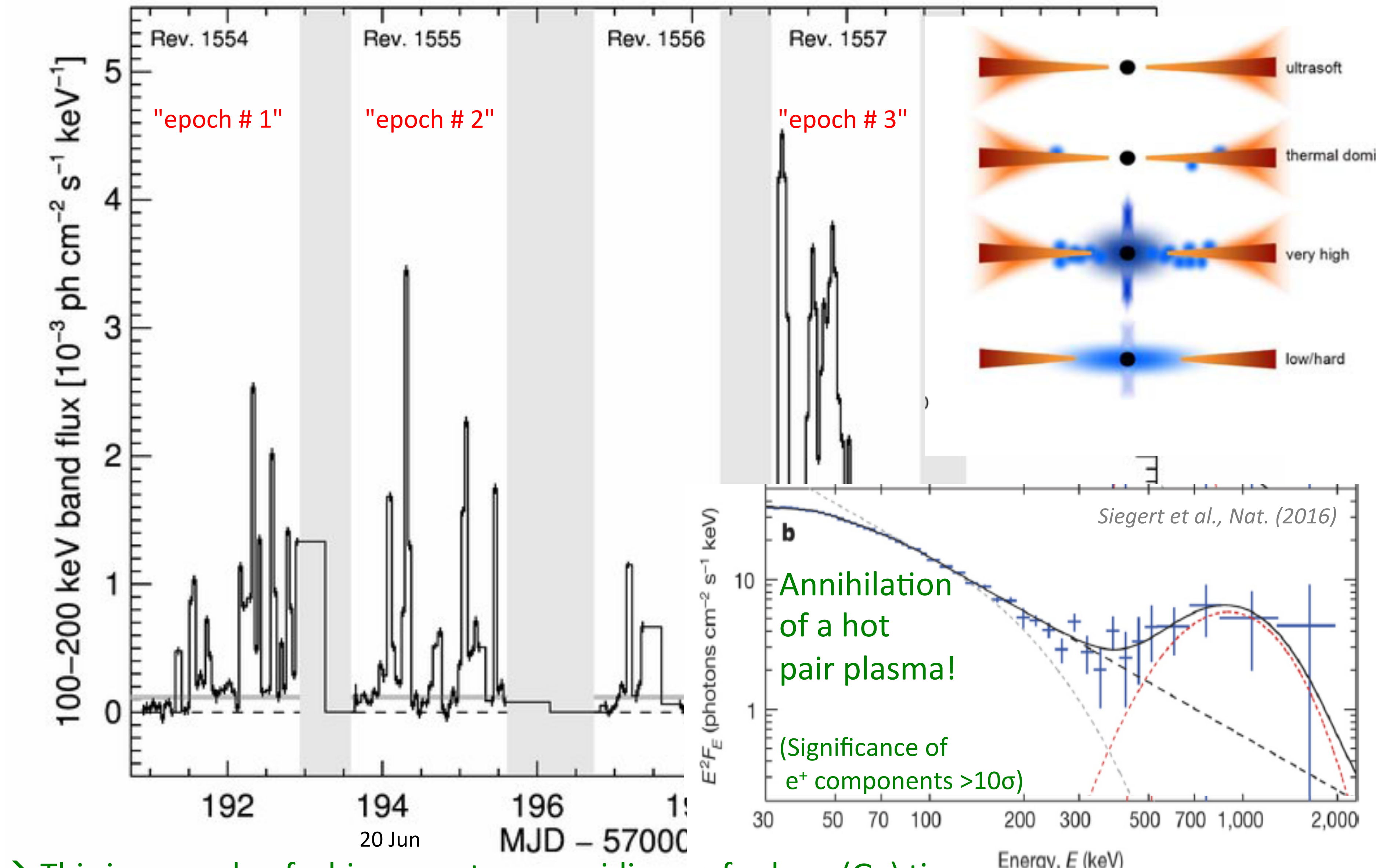
# Jet and outflow astrophysics in the era of new astronomies

- *How does the accretion disk/jet transition occur around* ***Galactic compact objects*** *and supermassive black holes in* ***AGN****?*
- *Are BL Lac* ***blazars AGN*** *sources of* ***UHECRs*** *and high-energy* ***neutrinos****?*
- *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?*




✓ 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

# Flaring of Microquasar V404 Cyg Jun 2015 → γ's from $e^+$!

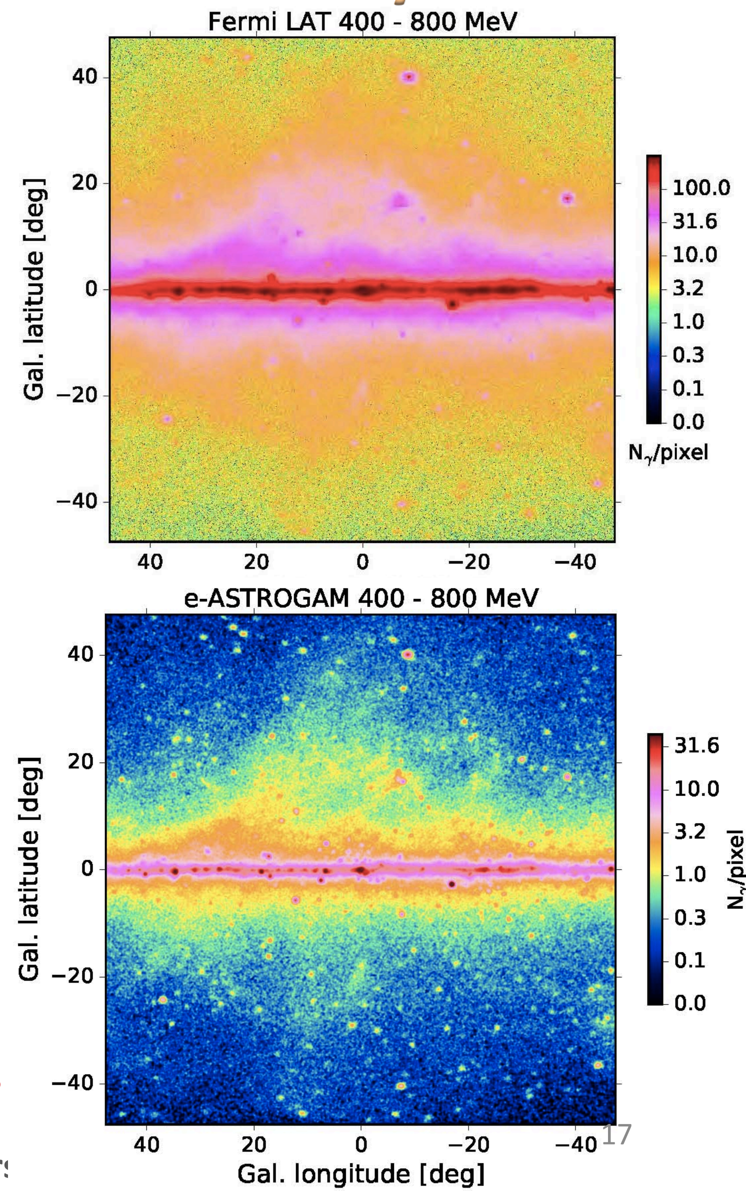



→ This is example of a binary system providing e+ for long (Gy) times

# Origin and impact of high-energy particles on Galaxy evolution

- *What are the energy distributions and fluxes of CRs produced in supernova remnants and propagating in the interstellar medium?*
- *What is the role **of low-energy CRs** in the self regulation of the Galactic ecosystem?*
- *What are the origins of the **Fermi Bubbles** and the **511 keV emission** from the Galaxy's bulge? Are these linked to a past activity of the central **supermassive black hole**?*

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



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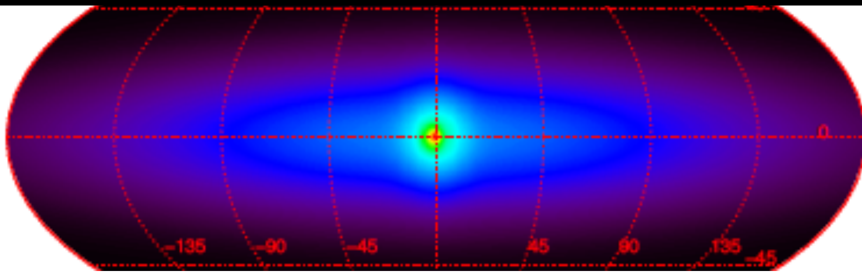
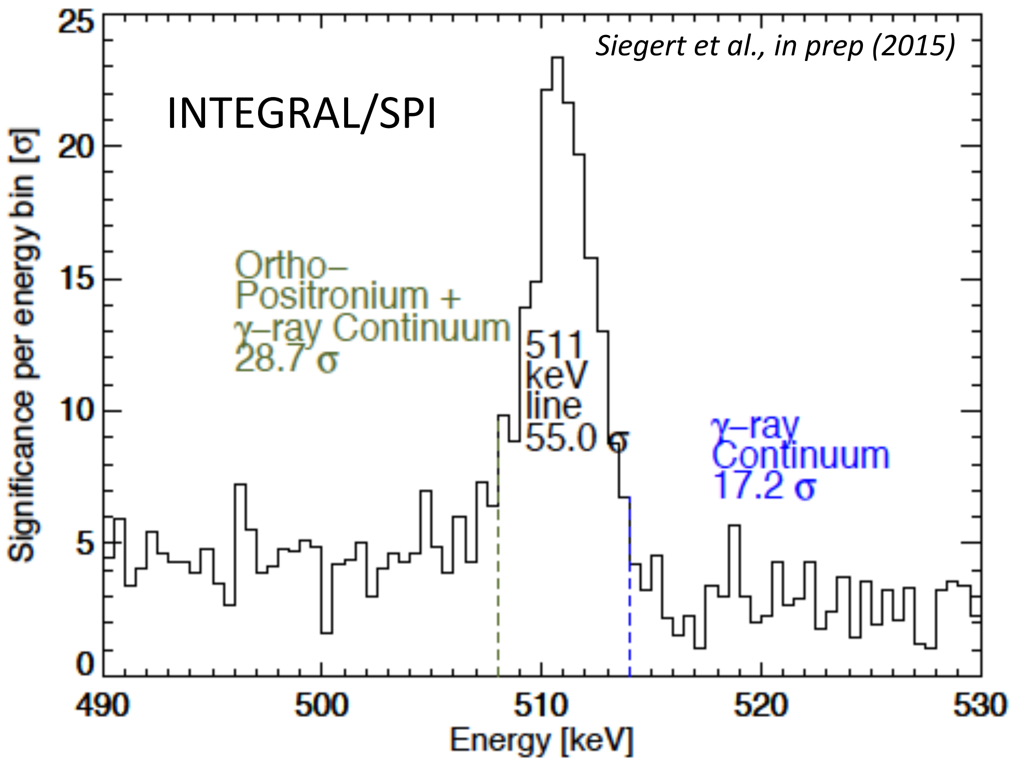
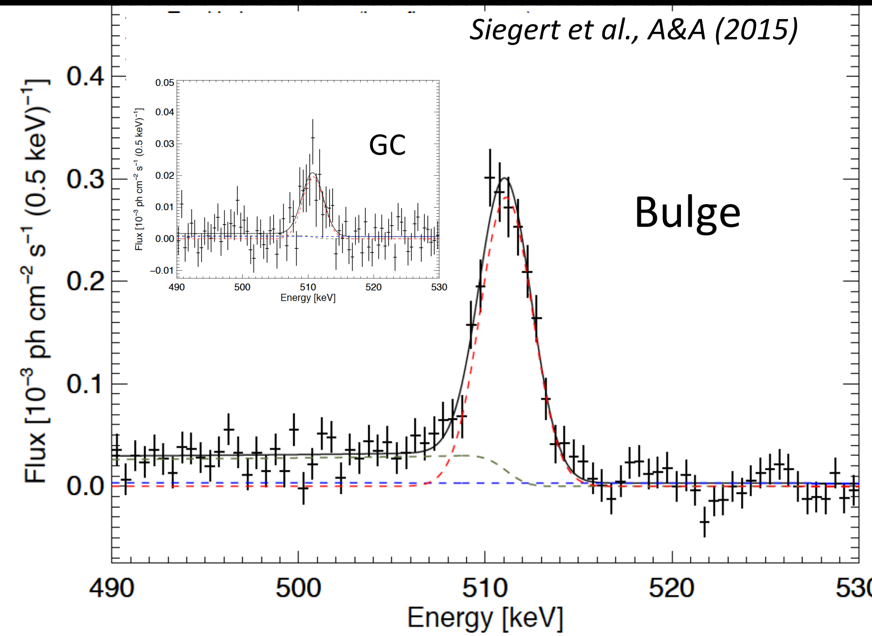
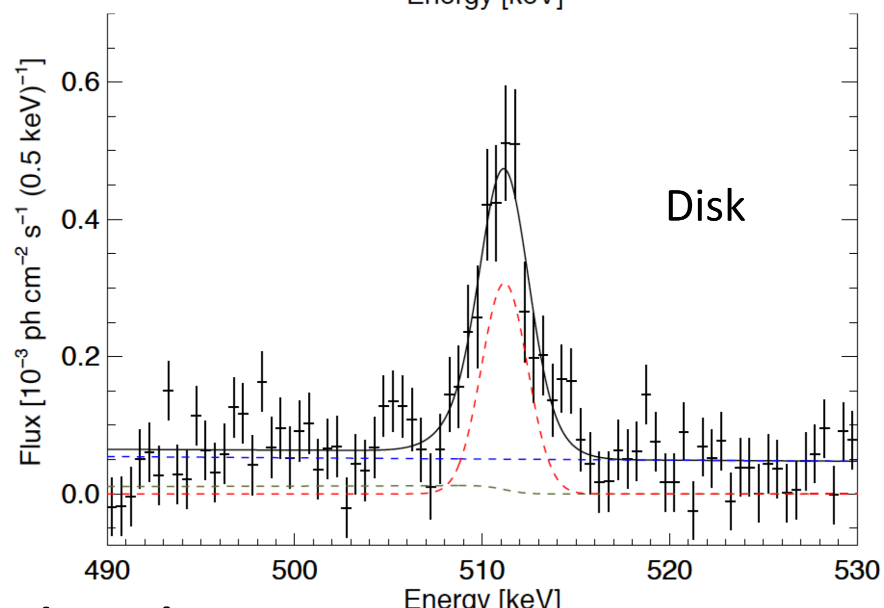
# e-ASTROGAM Understanding Our Galaxy




e+ annihilation spectra from different regions



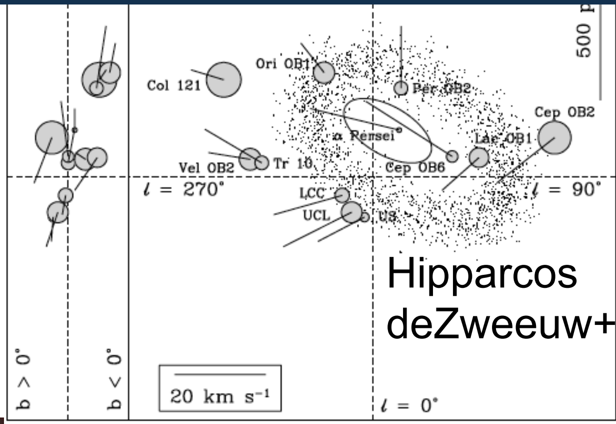




→ Propagation of CRs in the Galaxy's ISM

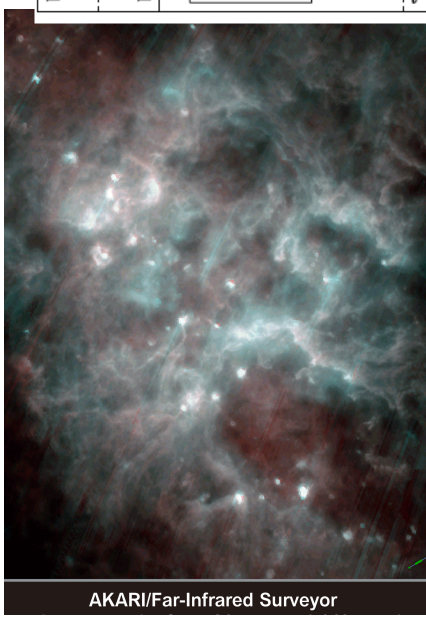
# $^{26}$Al Emission: Groups of Stars, Feedback, Ejecta on Myrs

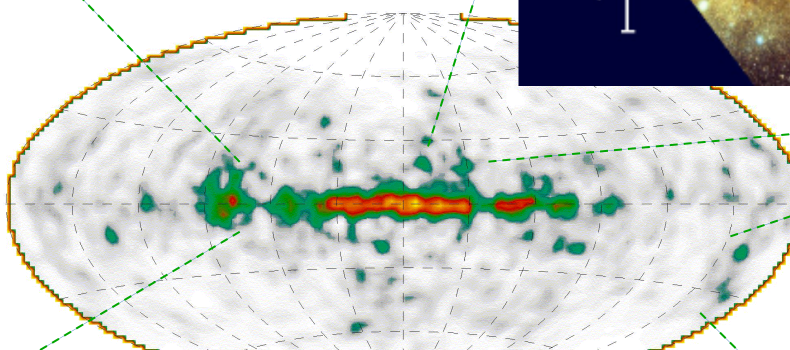
## Nearby and/or rich Groups of Stars:

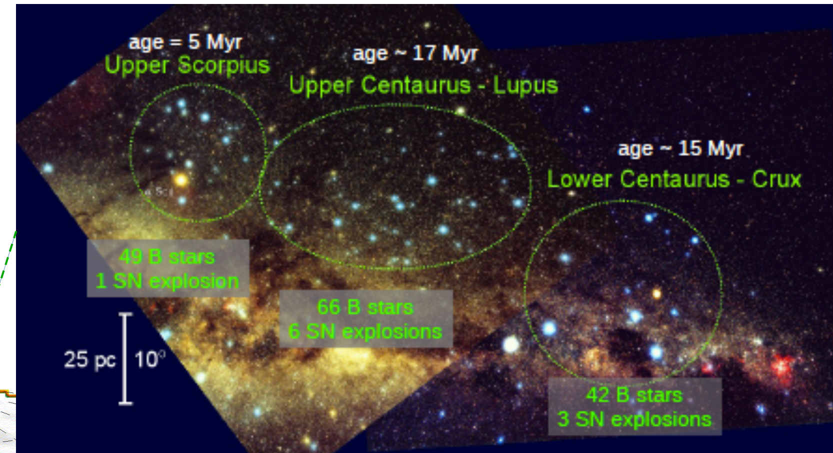
*Test our Models (E, $Y_i$, L, dM/dt) for Consistency*

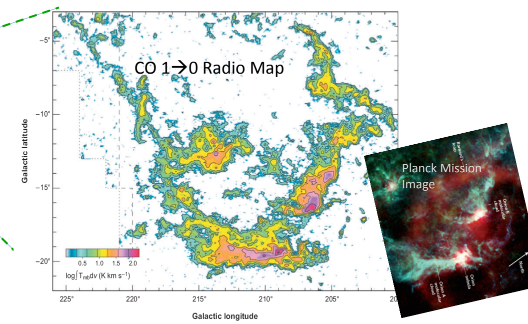


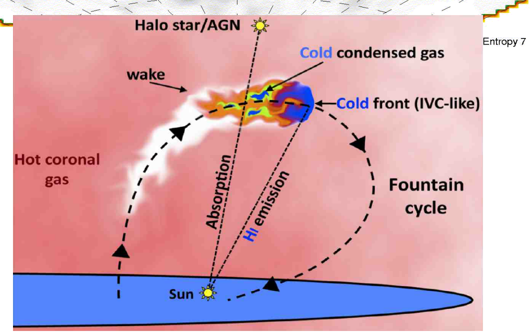

Hipparcos
deZweeuw+'99





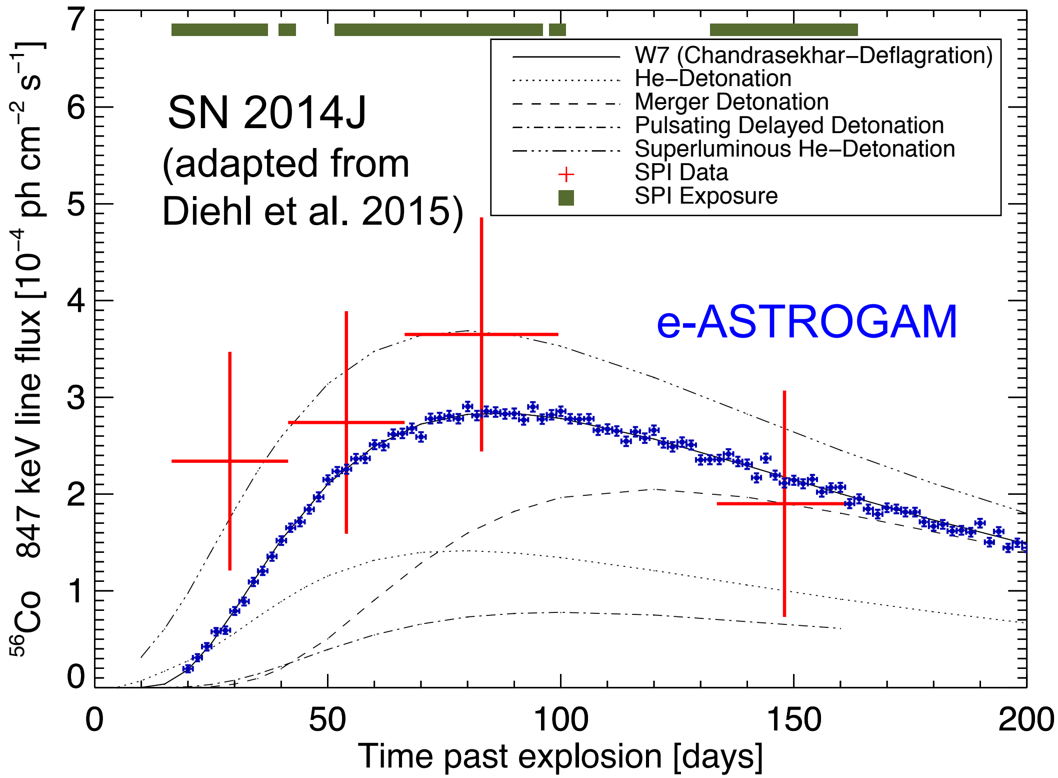




...plus: scale height, chimneys,...

## Supernovae, nucleosynthesis, and Galactic chemical evolution

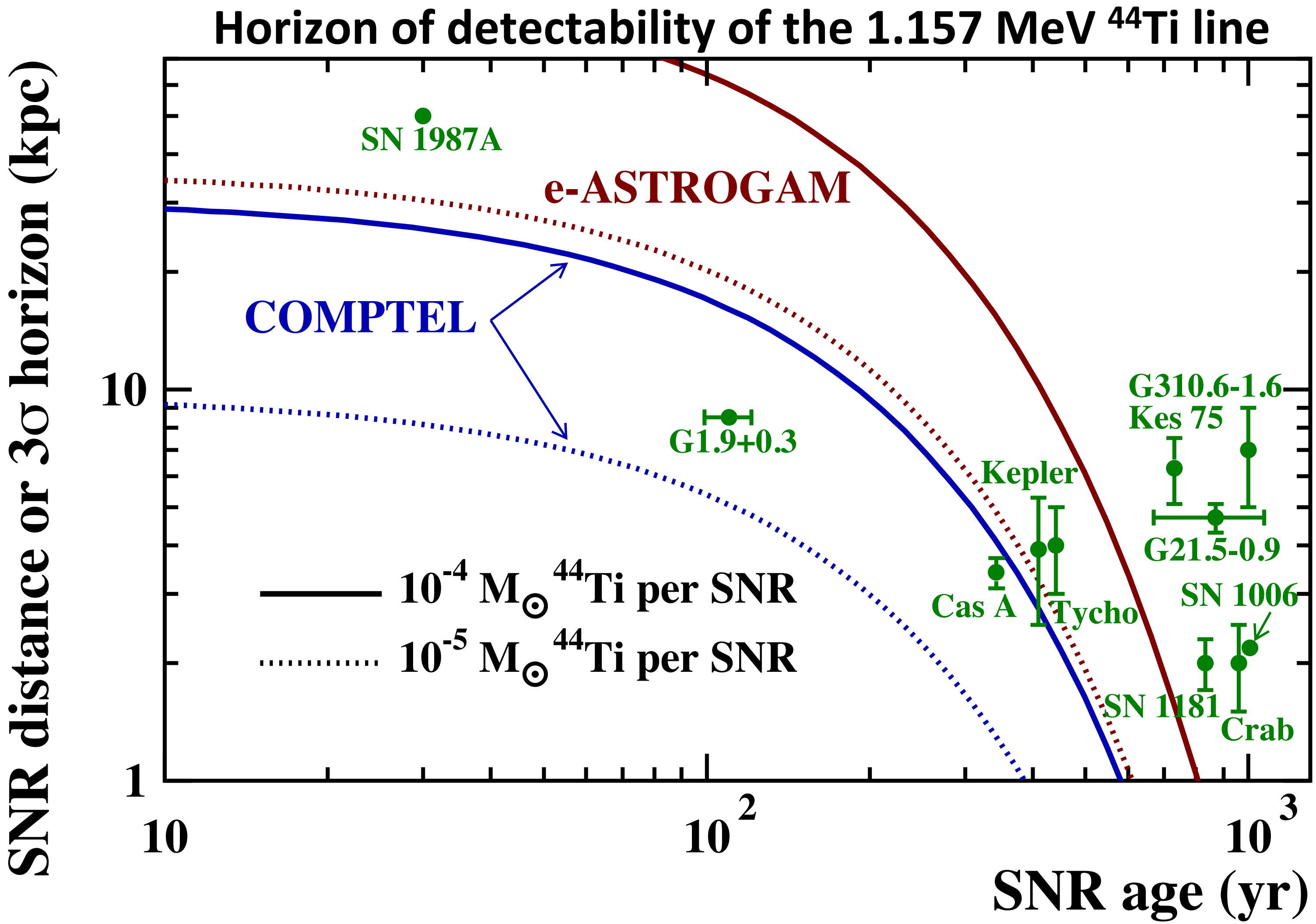
- *How do thermonuclear and core-collapse SNe explode? How are cosmic isotopes created in stars and distributed in the interstellar medium?*

✓ With a remarkable improvement in **γ-ray line sensitivity** over previous missions, **e-ASTROGAM** will shed light on 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, $^{44}$Ti...), and the **mixing processes** of stellar debris into the interstellar medium ($^{26}$Al, $^{60}$Fe)



# Recent SN history with $^{44}$Ti






- e-ASTROGAM should detect ~10 young, $^{44}$Ti-rich SNRs (see The et al. 2006) thus revealing active PeV cosmic-ray accelerators detectable with CTA

# e-ASTROGAM Cosmic-ray acceleration



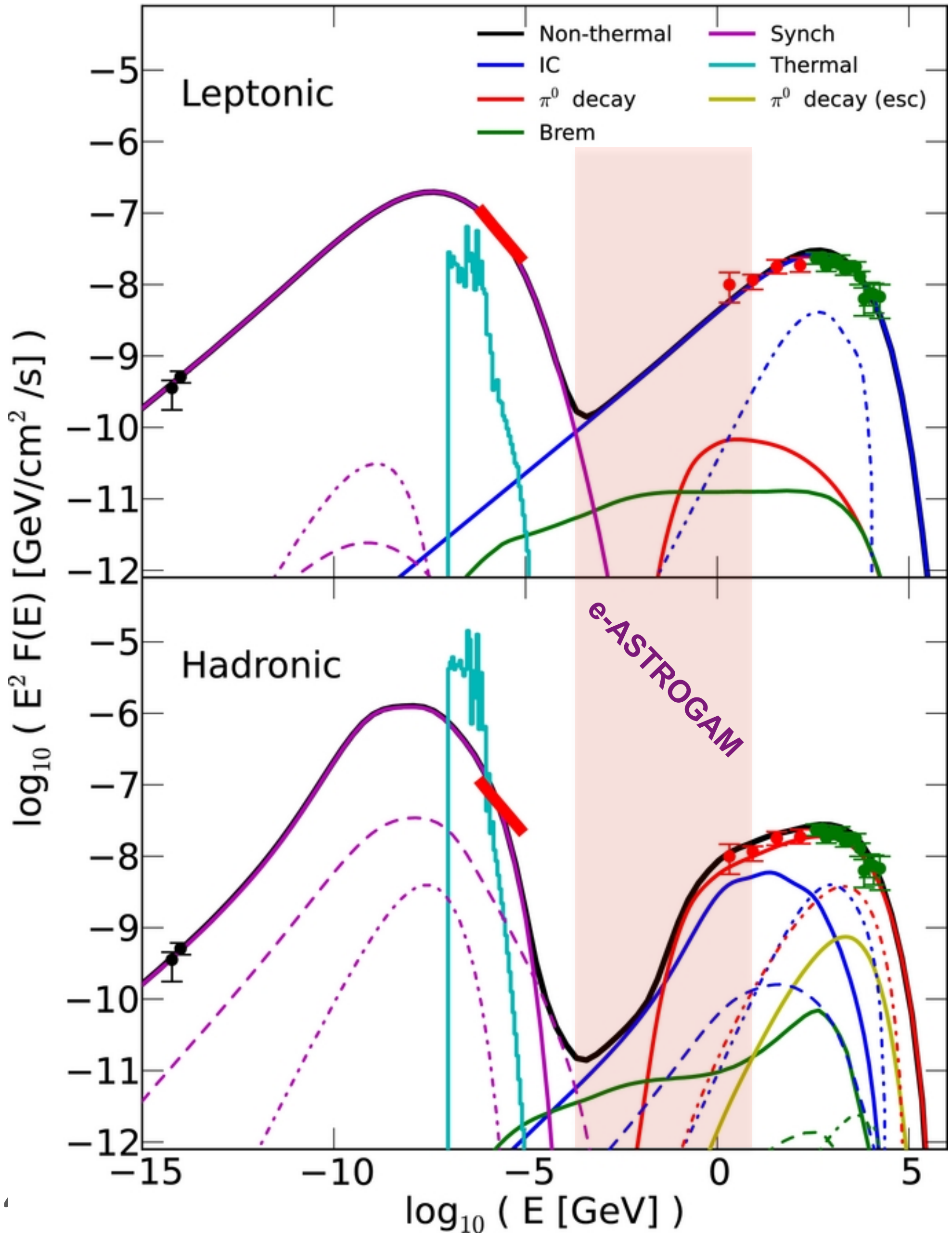
- The 0.2 MeV – 3 GeV band covered by **e-ASTROGAM** is essential to separate the leptonic and hadronic emission components in young SNRs

⇒ Differential injection of electrons and protons into the shock acceleration process

⇒ Acceleration efficiency

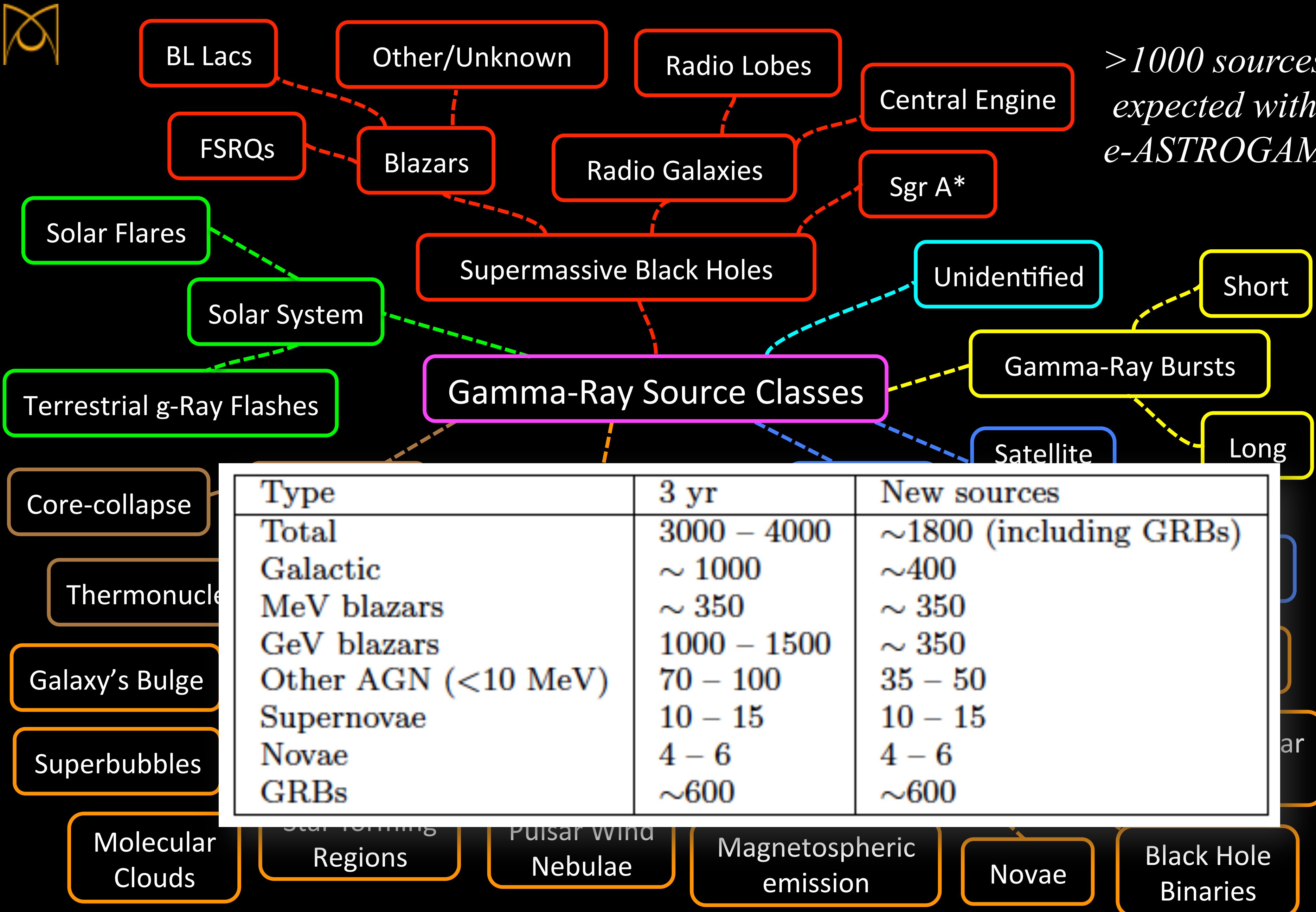
⇒ Turbulent magnetic field amplification

- **e-ASTROGAM**'s sensitivity and PSF are crucial to distinguish the pion emission in older, interacting SNRs from the Galactic background




Vela Jr, Lee et al. (2013)

*>1000 sources expected with e-ASTROGAM*




| Type | 3 yr | New sources |
|---|---|---|
| Total | 3000 – 4000 | ~1800 (including GRBs) |
| Galactic | ~ 1000 | ~400 |
| MeV blazars | ~ 350 | ~ 350 |
| GeV blazars | 1000 – 1500 | ~ 350 |
| Other AGN (<10 MeV) | 70 – 100 | 35 – 50 |
| Supernovae | 10 – 15 | 10 – 15 |
| Novae | 4 – 6 | 4 – 6 |
| GRBs | ~600 | ~600 |

# Collaboration



**Principal investigator**: Alessandro De Angelis (INFN, Italy)

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

DTU

Univ. College Dublin, Dublin City Univ.

Space Research Center of PAS Warsaw

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

Ioffe Institute

University of Tokyo

# e-ASTROGAM Conclusions

- **The MeV / sub-GeV gamma-ray band is potentially one of the richest energy domain of astronomy**

- **e-ASTROGAM will be an essential observatory to study the explosion mechanisms of supernovae, the SN-GRB connection, the recent SN history in the Milky Way, the shock acceleration of cosmic rays... among many other things**

- **The e-ASTROGAM payload is innovative in many respects, but the technology is ready**

- **eASTROGAM has been proposed for ESA's M5 mission (~2030)** *(and just passed the first downselection to ~14 best candidates)*

- *June2017: Selection of 3 Mission Proposals for Phase A Study*