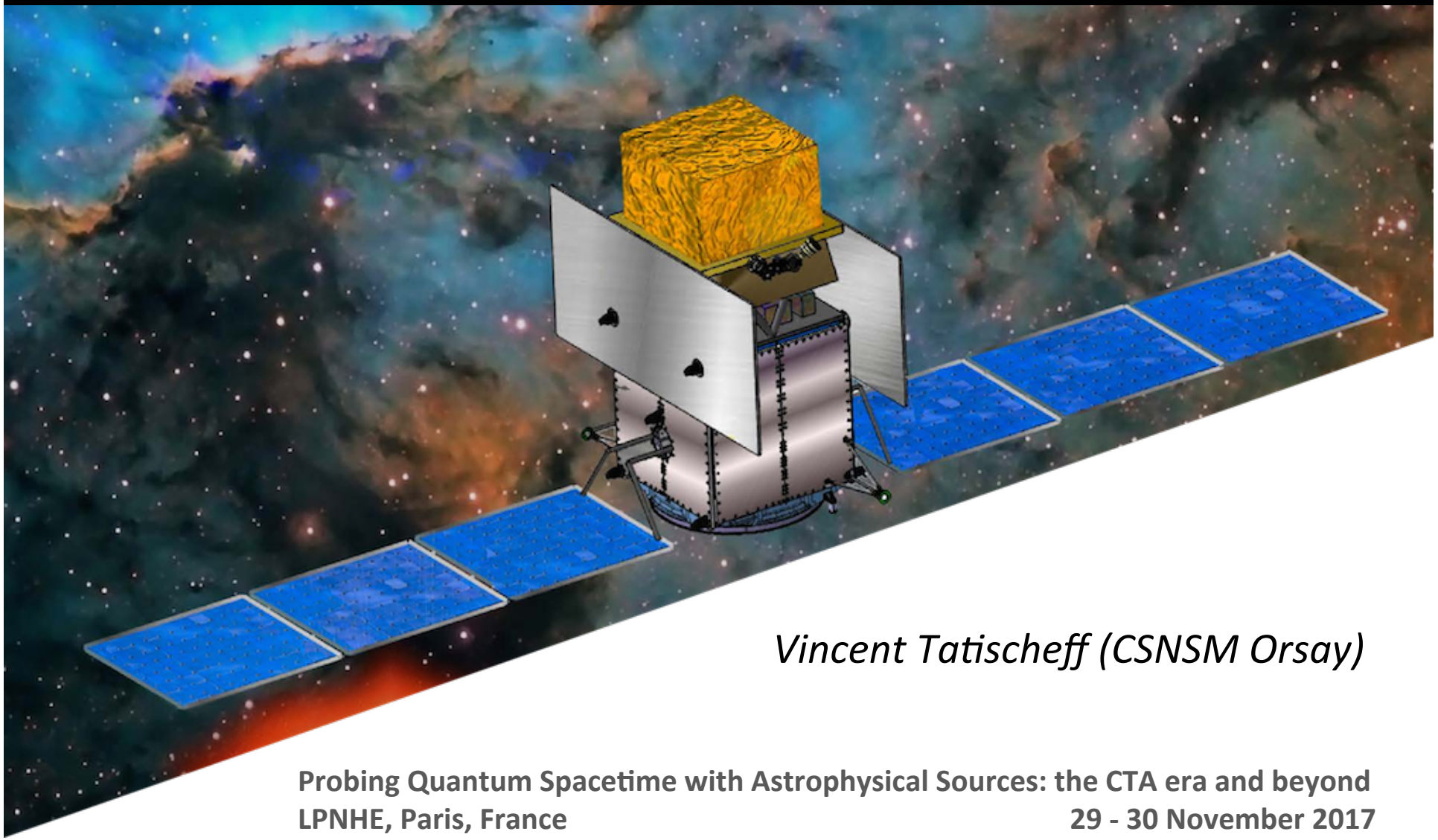
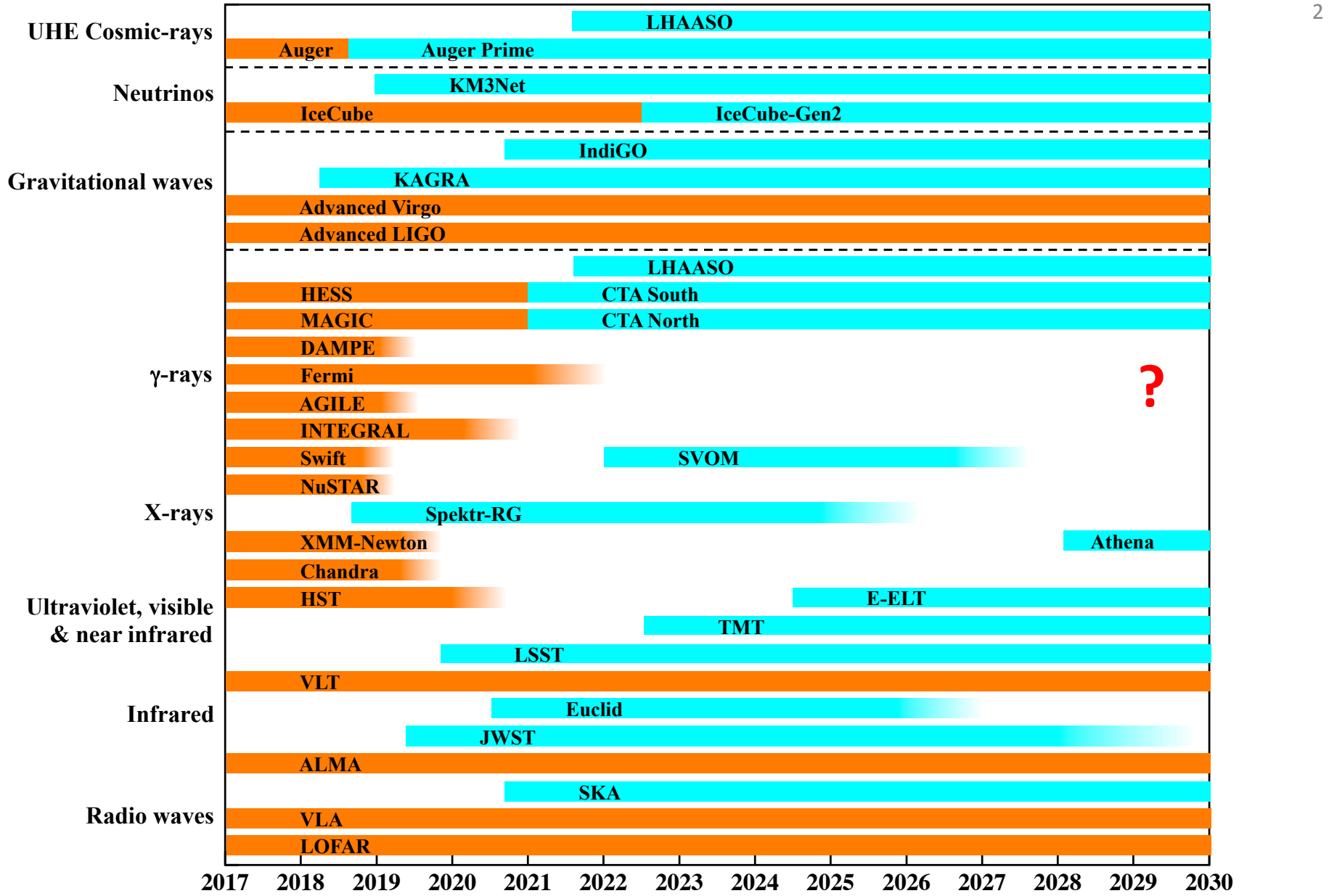
e-ASTROGAM and the future of gamma-ray space astronomy



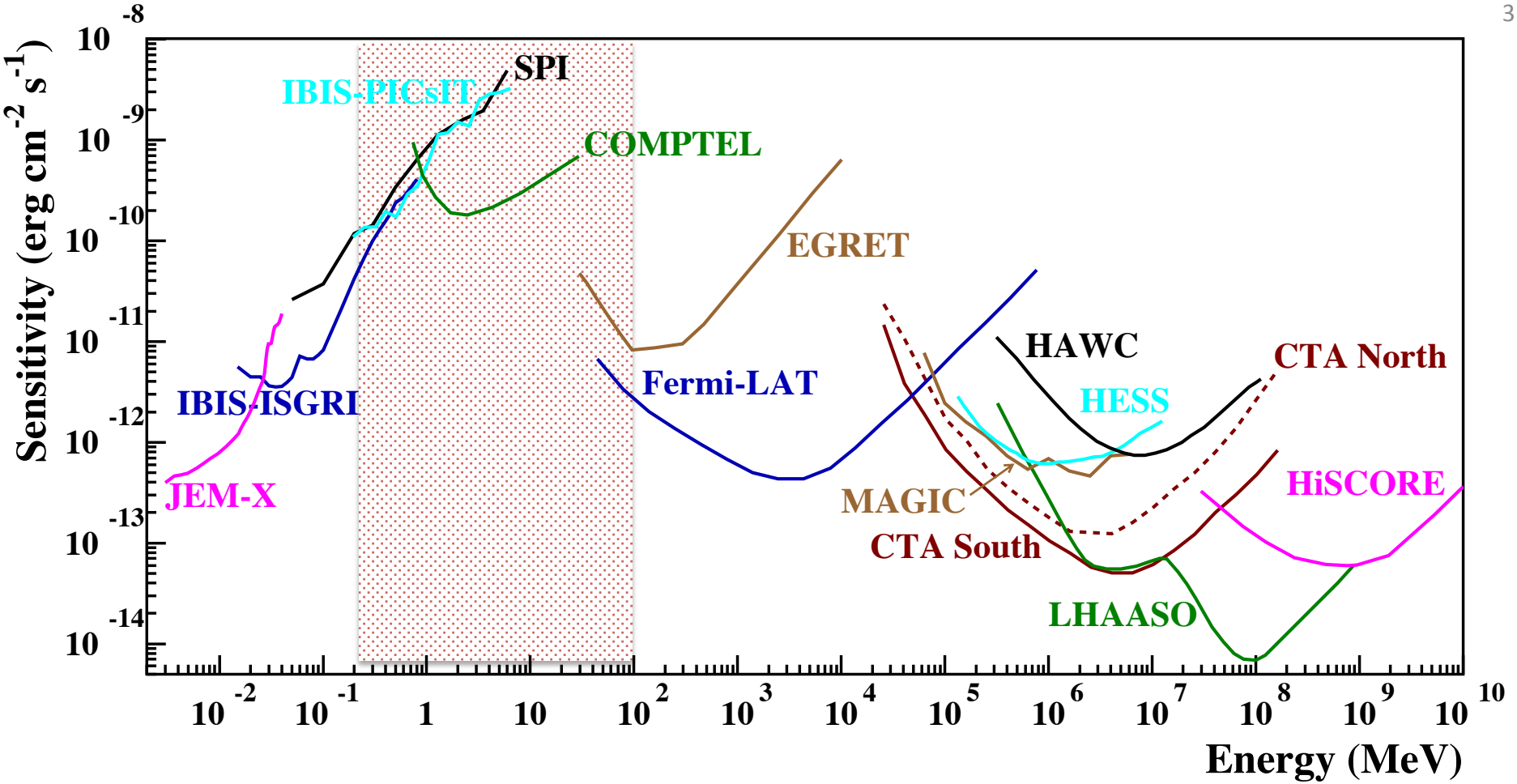
Vincent Tatischeff (CSNSM Orsay)

Probing Quantum Spacetime with Astrophysical Sources: the CTA era and beyond
LPNHE, Paris, France **29 - 30 November 2017**

Multi-wavelength/messenger context

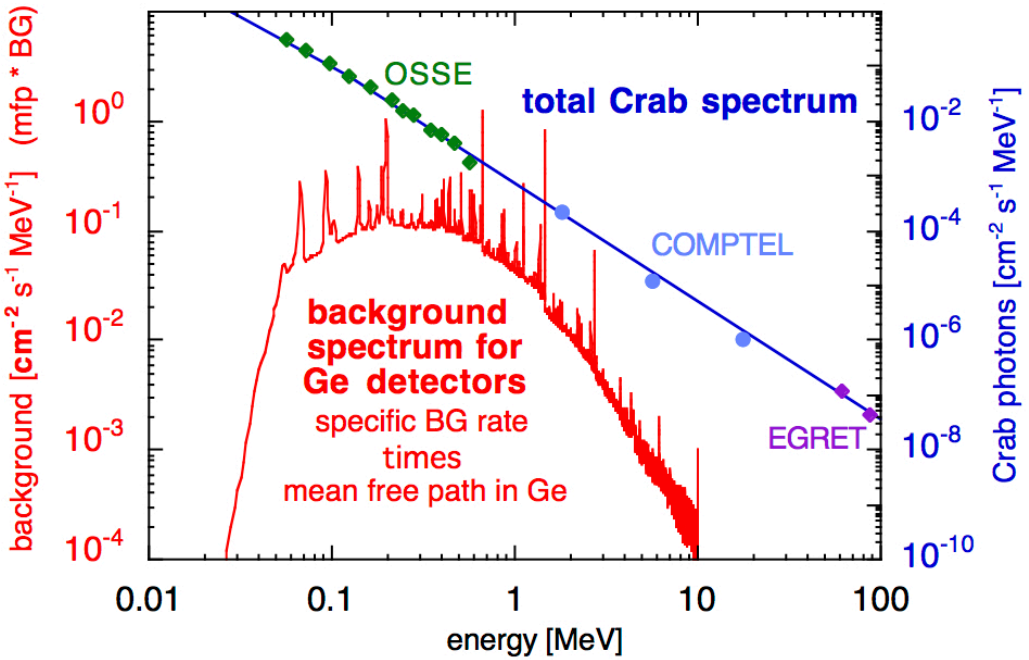


The MeV/sub-GeV domain



- 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...)

Observational challenges

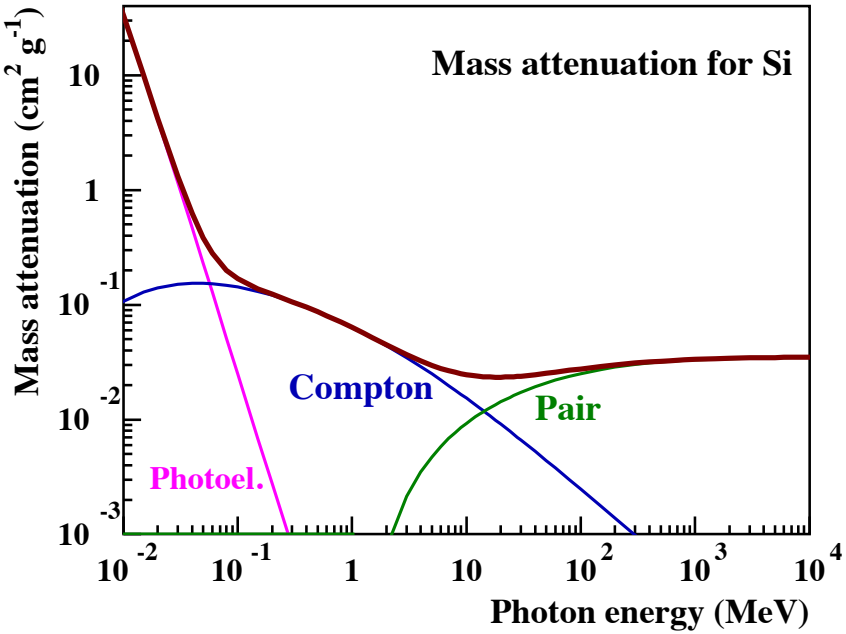


☺ The MeV range is the domain of nuclear γ-ray lines (radioactivity, nuclear collision, positron annihilation, neutron capture)

☹ Strong instrumental background from activation of space-irradiated materials

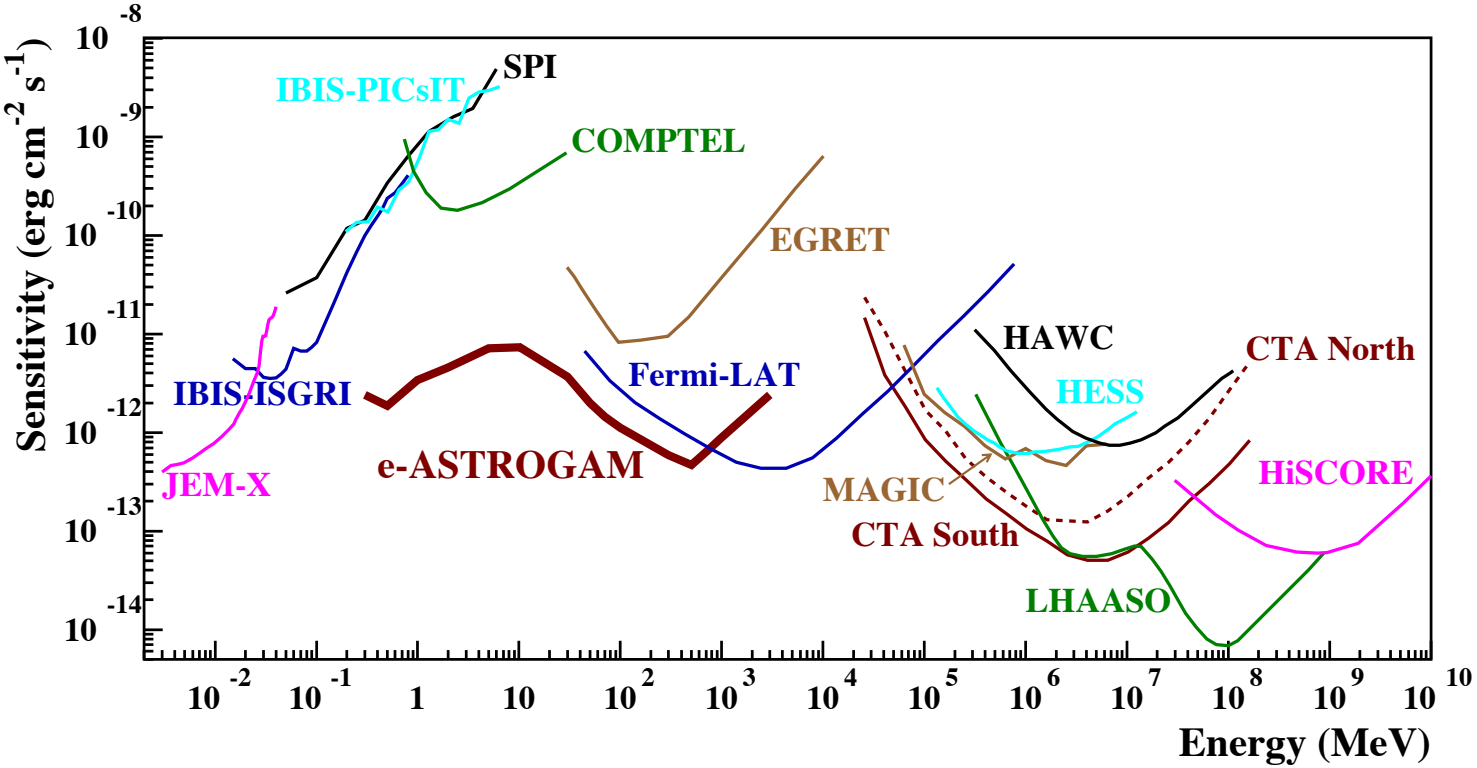
☹ Photon interaction probability reaches a minimum at ~ 10 MeV

☹ Three competing processes of interaction, Compton scattering being dominant around 1 MeV
⇒ complicated event reconstruction



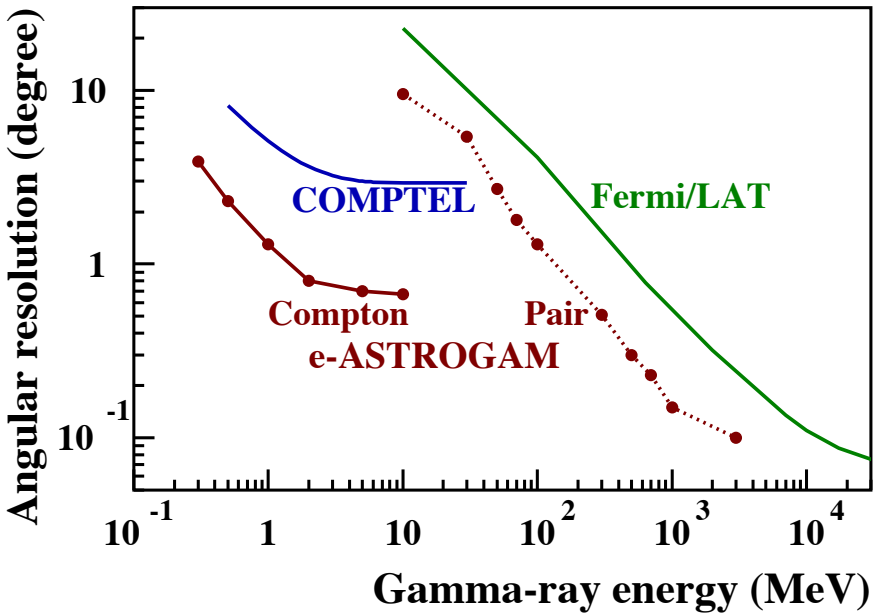
Scientific requirements

1. Excellent sensitivity in the 1-30 MeV energy range (better than CGRO/COMPTEL by a factor of 50 - 100)
2. Gamma-ray polarization for both transient and steady sources
3. Unprecedented angular resolution (e.g., ~ 10' at 1 GeV)
4. Large field of view (~ 2.5 sr) ⇒ efficient monitoring of the γ-ray sky
5. Sub-millisecond trigger and alert capability for transients

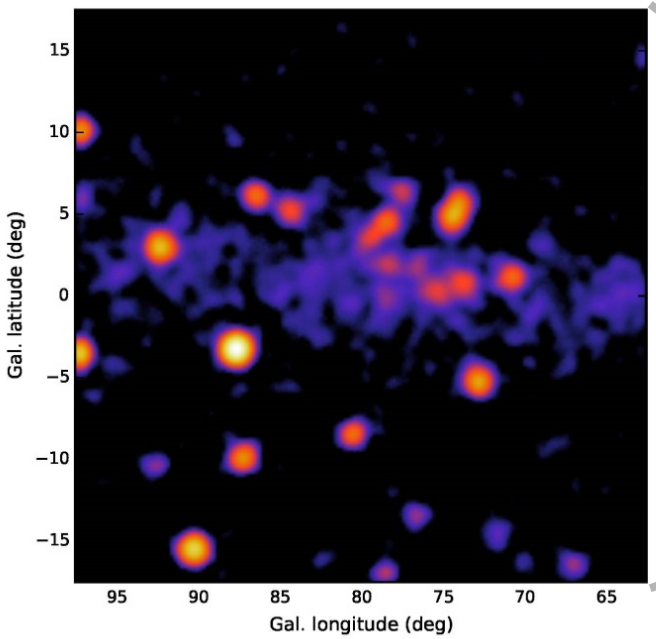


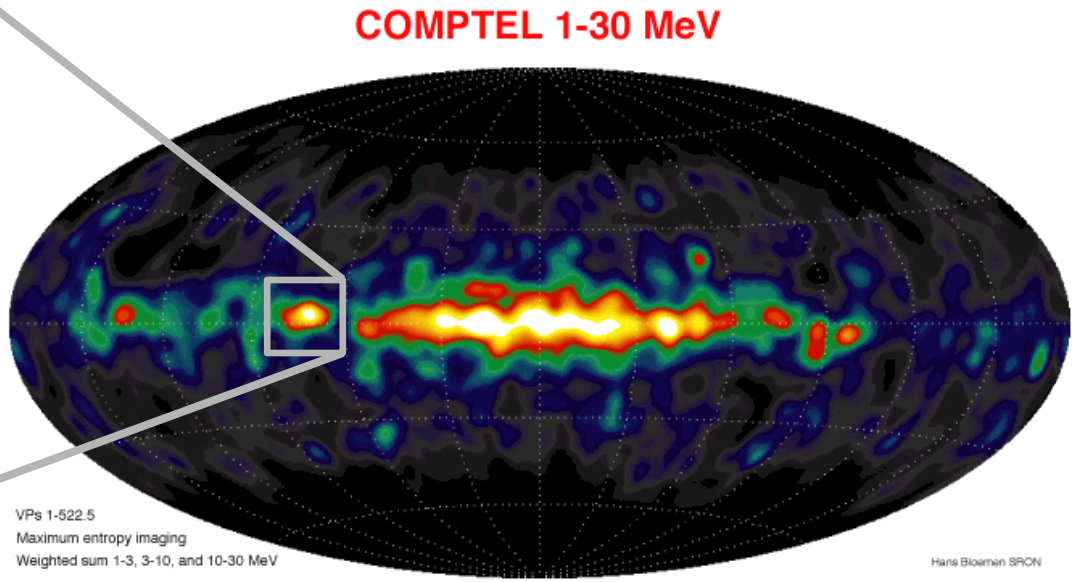
Angular resolution

- 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)



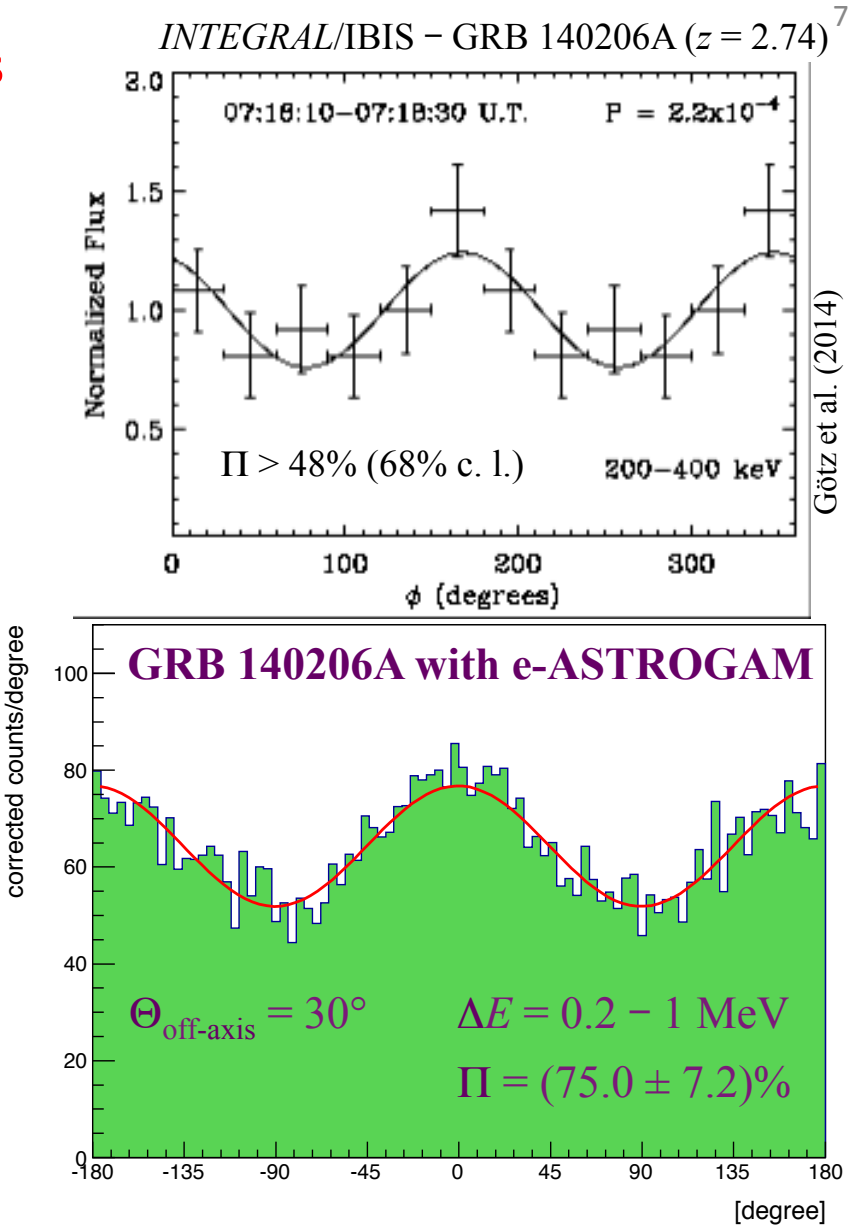


Gamma-ray polarization

- 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)



Core science motivation

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

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

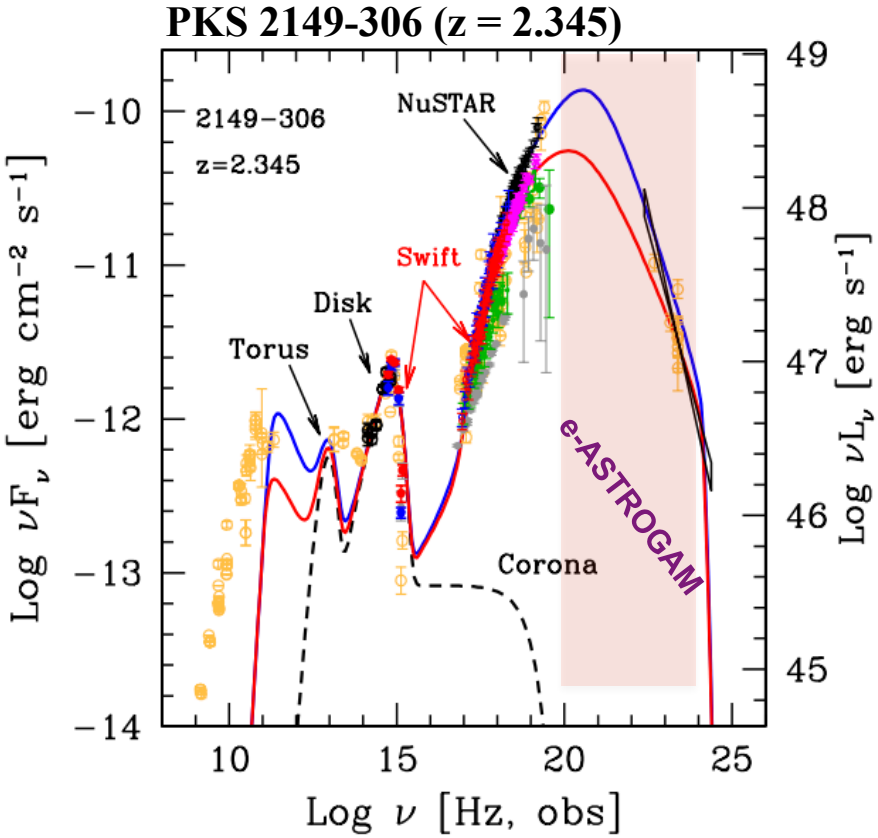
3. **Supernovae, nucleosynthesis** & **cosmic evolution** of matter

\+ ... tests of Lorentz Invariance Violation (polarization, time tagging of 1 μs, spectral range covering 4 orders of magnitude)

Core science topic #1

Jet & acceleration from GRBs and supermassive BHs at high z

- *Why did the most luminous **jetted AGN** with mass > 10^9 $M_\odot$ formed earlier than non-jetted AGN?*
- *Launch of ultra-relativistic jets in **GRBs**? Ejecta composition, energy dissipation site, radiation processes?*
- *Are BL Lac blazars AGN sources of high-energy **neutrinos** and **UHECRs**?*
- *Are some short GRBs associated with **gravitational waves** from neutron star/ black hole mergers?*



✓ **e-ASTROGAM**: wide **field of view**, unprecedented **sensitivity**, **polarimetry**
⇒ access to a variety of extreme **transient** phenomena

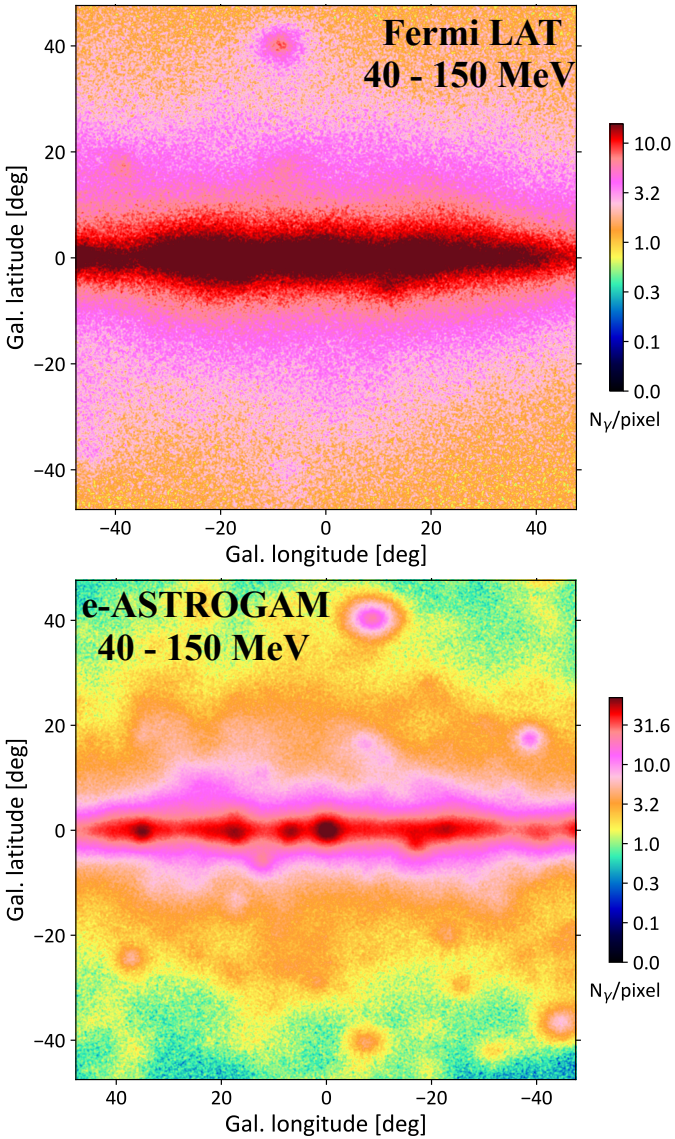
- More than 1000 AGN detections up to z > 6
- (1.2 - 18) NS-NS mergers per year with gravitational waves

Core science topic #2

Origin & 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 CRs in the self regulation of the **Galactic ecosystem** (star formation, galactic winds, magnetic field growth...)?*
- *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:** detailed **spectro-imaging**, thanks to the significantly improved **sensitivity** and **angular resolution** in the MeV − GeV range



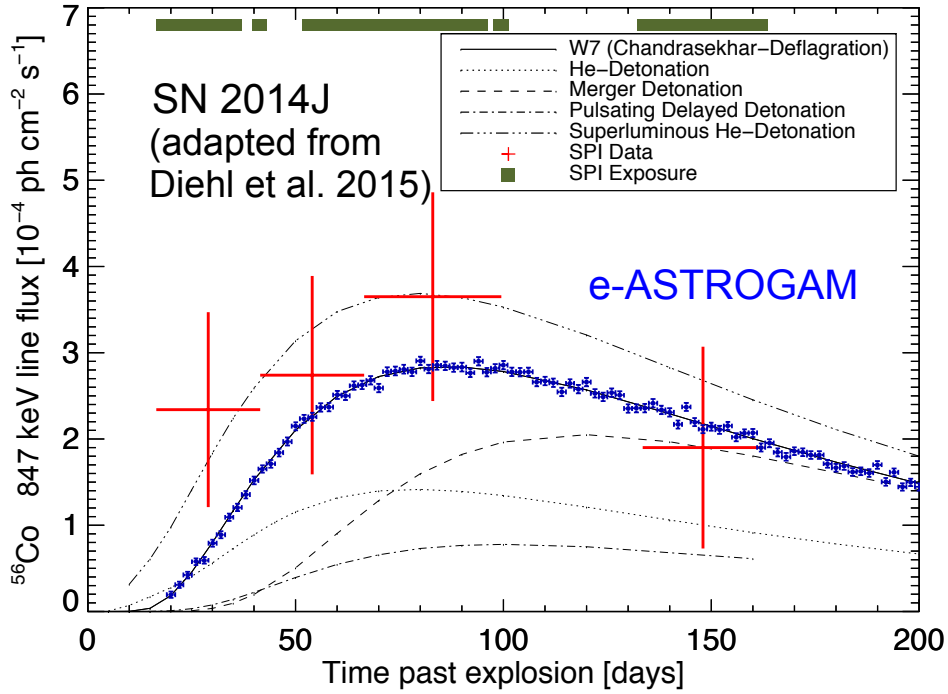
Core science topic #3

Supernovae, nucleosynthesis & cosmic evolution of matter

- *Progenitor system(s) & explosion mechanism(s) of **thermonuclear SNe**? Standard candles for **precision cosmology**?*
- *Diversity of **core-collapse** events? Formation of black holes & neutron stars?*
- *How are cosmic isotopes **created in stars and supernovae**, distributed in the ISM and recycled into new stars?*

✓ **e-ASTROGAM**: excellent **sensitivity** for detection of key **γ-ray lines** ⇒

- Mass and evolution of ejected ^{56}Ni/^{56}Co in a dozen of SN Ia
- ^{44}Ti radioactivity from all young Galactic SNRs & SN 1987A
- Deep survey of the ^{26}Al, ^{60}Fe and positron annihilation radiations



e-ASTROGAM observatory in context

High-redshift blazars, high-accretion AGN

Supernova remnants & PeVatrons

Supernovae, (kilo)novae, nucleosynthesis

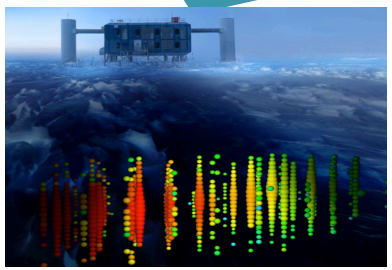
Cosmic rays & the interstellar medium (tracing gas & cosmic-ray feedback)

GRBs, merger events & other transients (polarization)

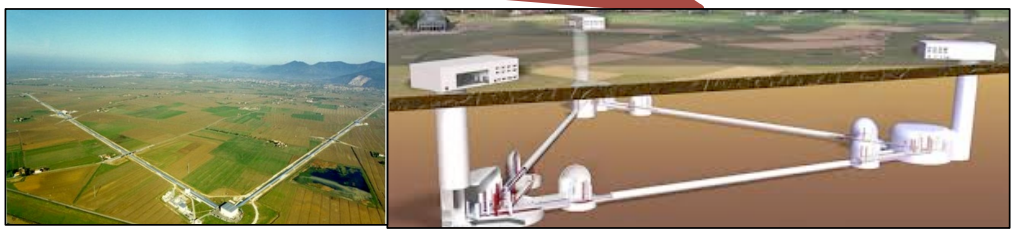
Fundamental physics

X- & γ-ray binaries, microquasars

Pulsars, magnetars (polarization)

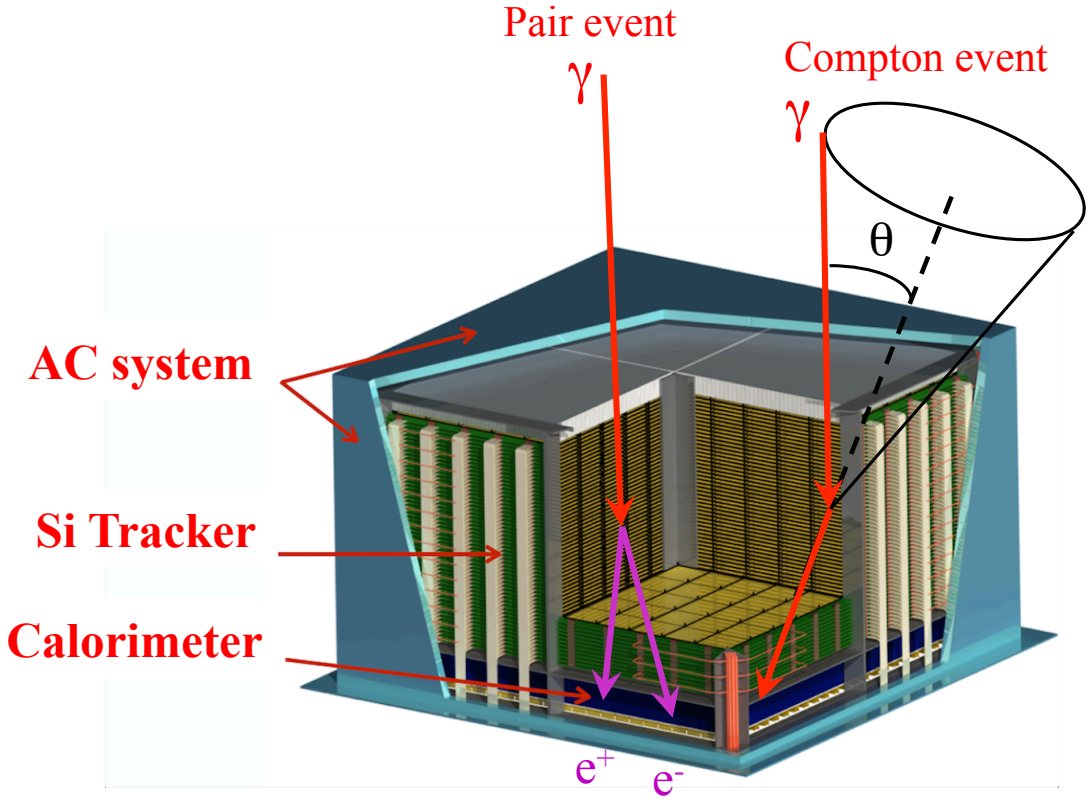


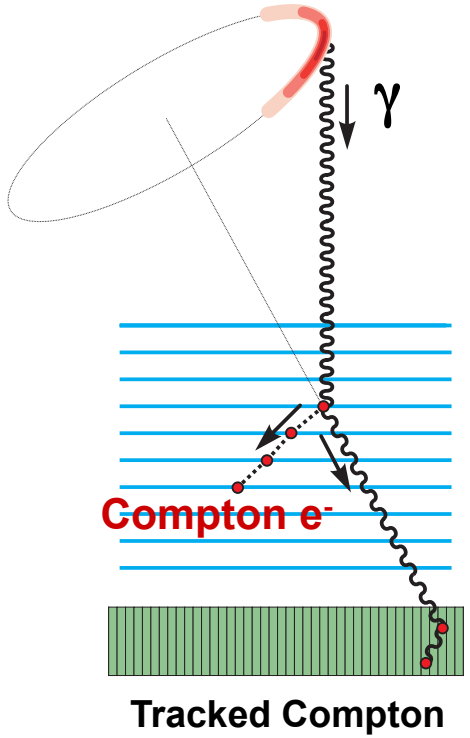
IceCube/KM3NeT



LIGO/Virgo, KAGRA, INDIGO, European Pulsar Timing Array, Einstein Telescope, Cosmic Explorer, LISA

Measurement principle

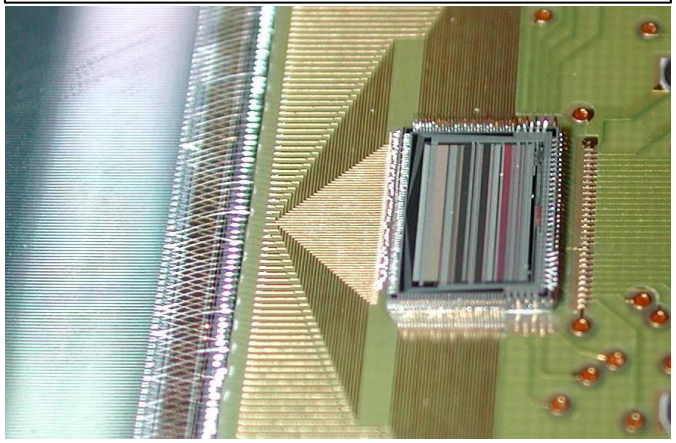




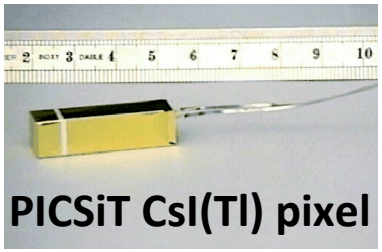
- **Tracker** – Double sided Si strip detectors (DSSDs) for excellent spectral resolution and fine 3-D position resolution
- **Calorimeter** – High-Z material for an efficient absorption of the scattered photon ⇒ CsI(Tl) scintillation crystals readout by Si Drift Diodes for better energy resolution
-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

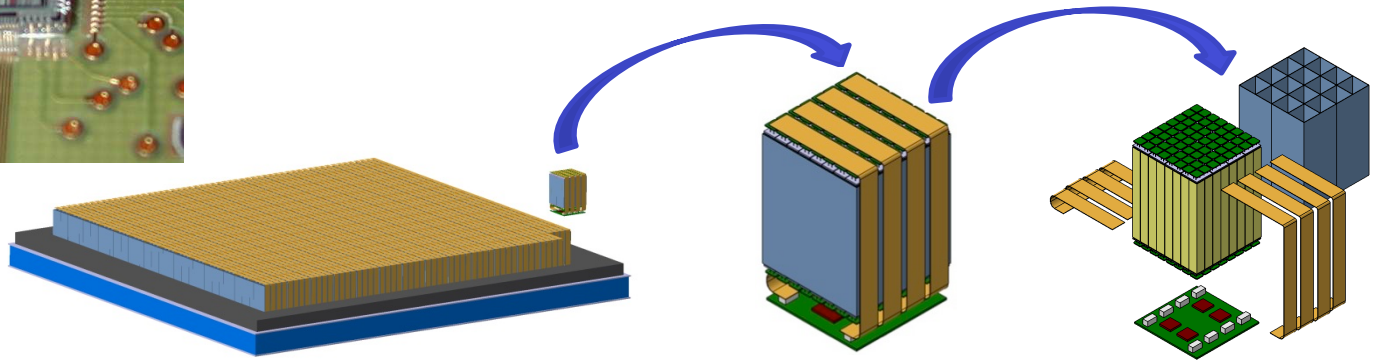
e-ASTROGAM payload

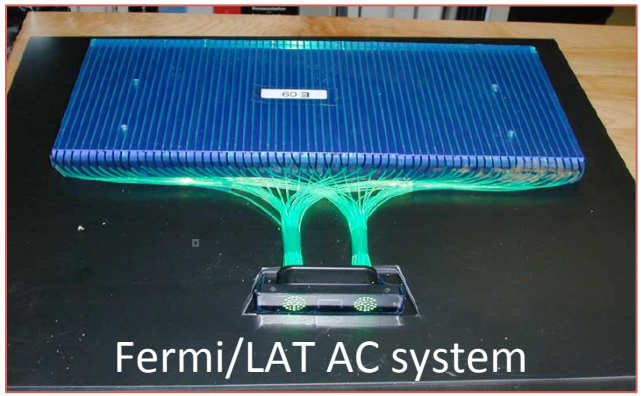
Detail of the detector-ASIC bonding in the AGILE Si Tracker



- **Tracker**: 56 layers of 4 times 5×5 DSSDs (5600 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

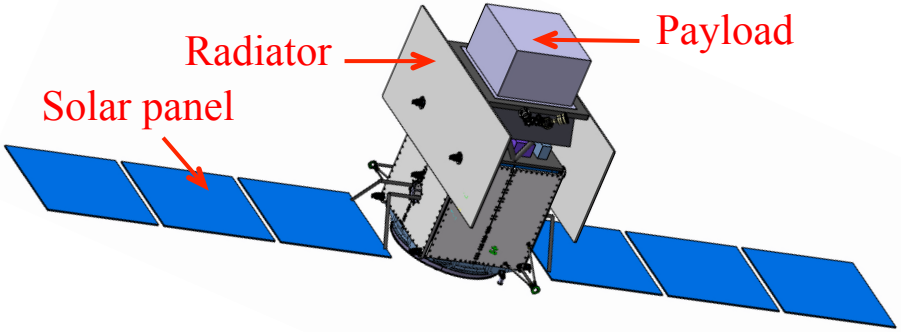


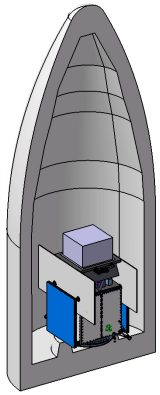


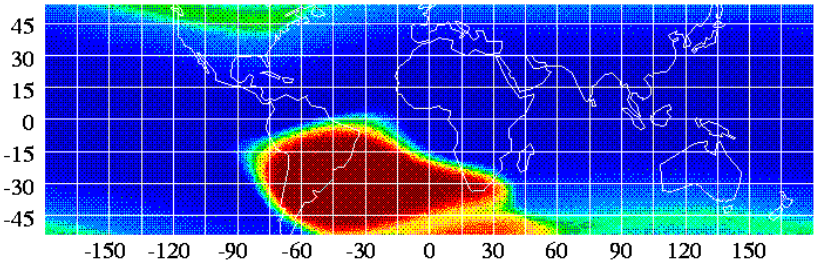


- **Calorimeter**: 33 856 CsI(Tl) bars coupled at both ends to low-noise Silicon Drift Detectors
- **ACD**: segmented plastic scintillators coupled to SiPM by optical fibers
- **Heritage**: AGILE, Fermi/LAT, AMS-02, INTEGRAL, LHC/ALICE…

Satellite and mission profile

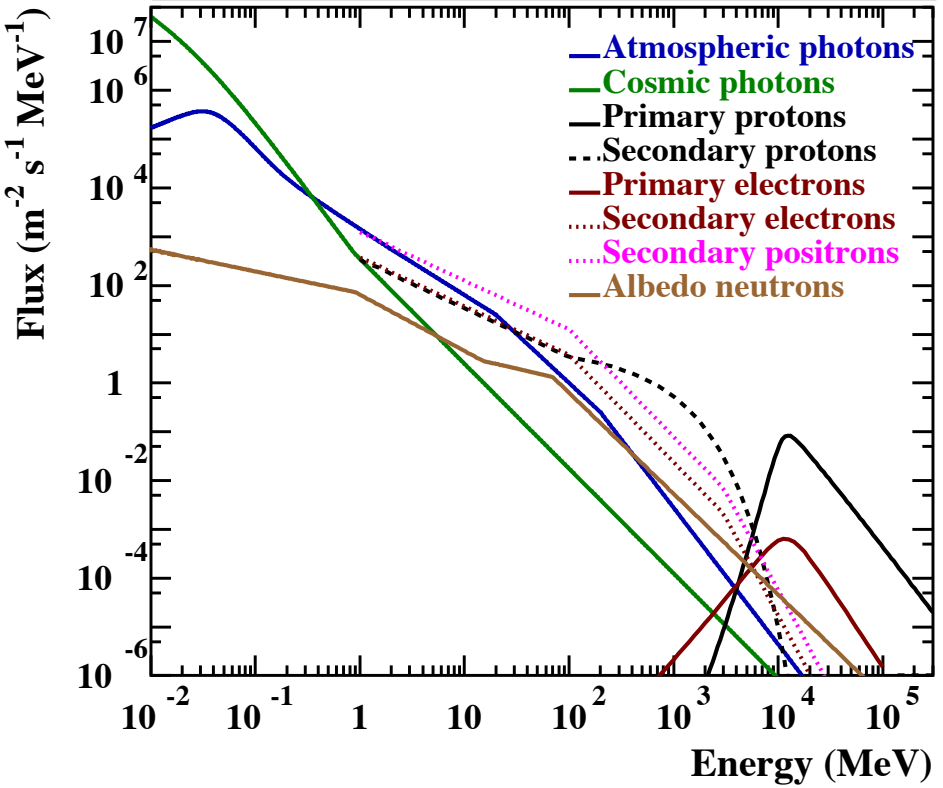




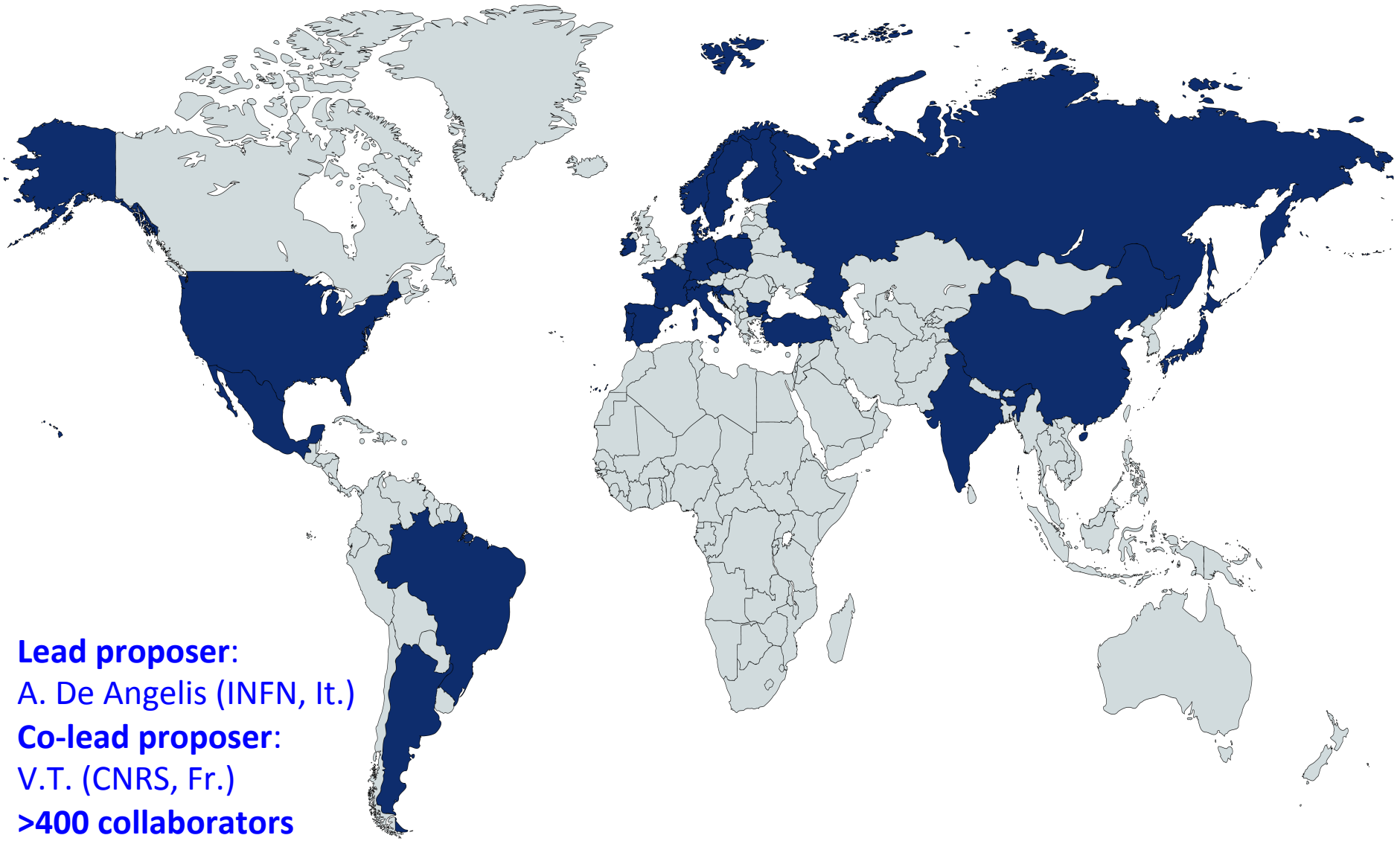


- **Platform** – Thales Alenia Space PROTEUS 800 (SWOT CNES/NASA)
- **Orbit** – Equatorial (inclination $i < 2.5°$, eccentricity $e < 0.01$) low-Earth orbit (altitude in the range 550 - 600 km)
- **Launcher** – Ariane 6.2
- **Observation modes** – (i) zenith-pointing sky-scanning mode, (ii) nearly inertial 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 Collaboration

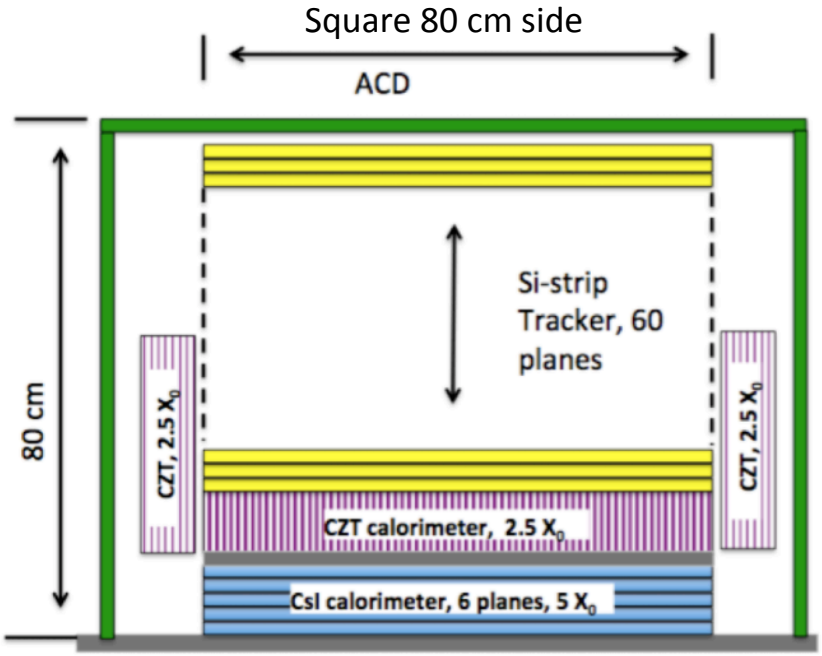


Lead proposer:
A. De Angelis (INFN, It.)
Co-lead proposer:
V.T. (CNRS, Fr.)
>400 collaborators
from institutions in 24 countries; Science White Book just published (224 authors; 194 pages)

All-sky **M**edium **E**nergy **G**amma-ray **O**bservatory

NASA/GSFC, G. Wash. Univ., Clemson Univ., NRL, UC Berkeley, Wash. Univ., UNH, NASA/MSFC, UAH, USRA, OSU, UIUC, UNLV, UDel, UCSC, SLAC, Stanford, UNF, Yale, RICE, INFN, Pisa Univ., Padova Univ., Stockholm Univ., INAF, LIP, Udine Univ., Rome Univ., CSNSM

Si Tracker
DSSD in 60 layers with 1 cm spacing. Strip pitch 0.5 mm.



Anticoincidence Detector
Plastic scintillator shell for charged particle rejection.

CZT Calorimeter
Drift configuration with single layer array of 0.6 cm x 0.6 cm x 2 cm bars surrounding lower tracker layers.

CsI Calorimeter
Hodoscopic arrangement of 1.5 cm x 1.5 cm CsI bars in 6 layers with SiPM sensors.

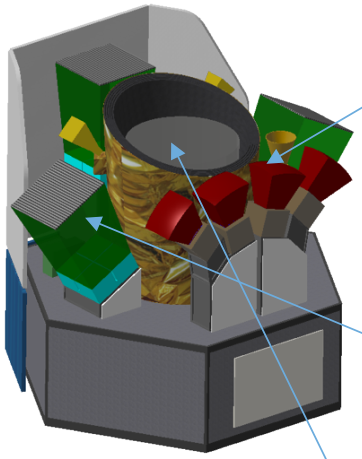
Mission and spacecraft design can build on development for ComPair

Designed for a NASA Probe mission

- ***THESEUS*** is a submitted project to ESA for the M5 slot. The expected selection for phase A will be announced early 2018, for an expected launch date as early as 2029.

- ***THESEUS*** **Core Science is based on two pillars:**
  - probe the **physical properties of the early Universe**, by discovering and exploiting the population of high redshift GRBs.
  - provide an **unprecedented deep monitoring** of the soft X-ray transient Universe, providing a fundamental contribution to multi-messenger and time domain astrophysics in the early 2030s (synergy with aLIGO/aVirgo, eLISA, ET, Km3NET and EM facilities e.g., LSST, E-ELT, SKA, CTA, ATHENA).

THESEUS Payload



- Autonomous platform, with rapid repointing capabilities
- Low Earth Orbit (~600 km), low inclination (<5°)
- Fast ground communication for alert dissemination

Soft X-ray Imager: a set of four « Lobster Eye » telescope with an overall field of view of 1 sr, <arcmin localization accuracy, working in the 0.3-6 keV energy range. One order of magnitude more sensitive than previous wide field instruments. Provided by an UK led consortium

X-Gamma ray Imaging Spectrometer : three coded mask telescopes with a focal plane composed by a combination of Si and CsI detectors (possibility of polarization measurements). Sensitive in the 2 keV to 20 MeV, with an (up to) 4 sr field of view, a source location accuracy of 5 arc min. Provided by a consortium led by Italy.

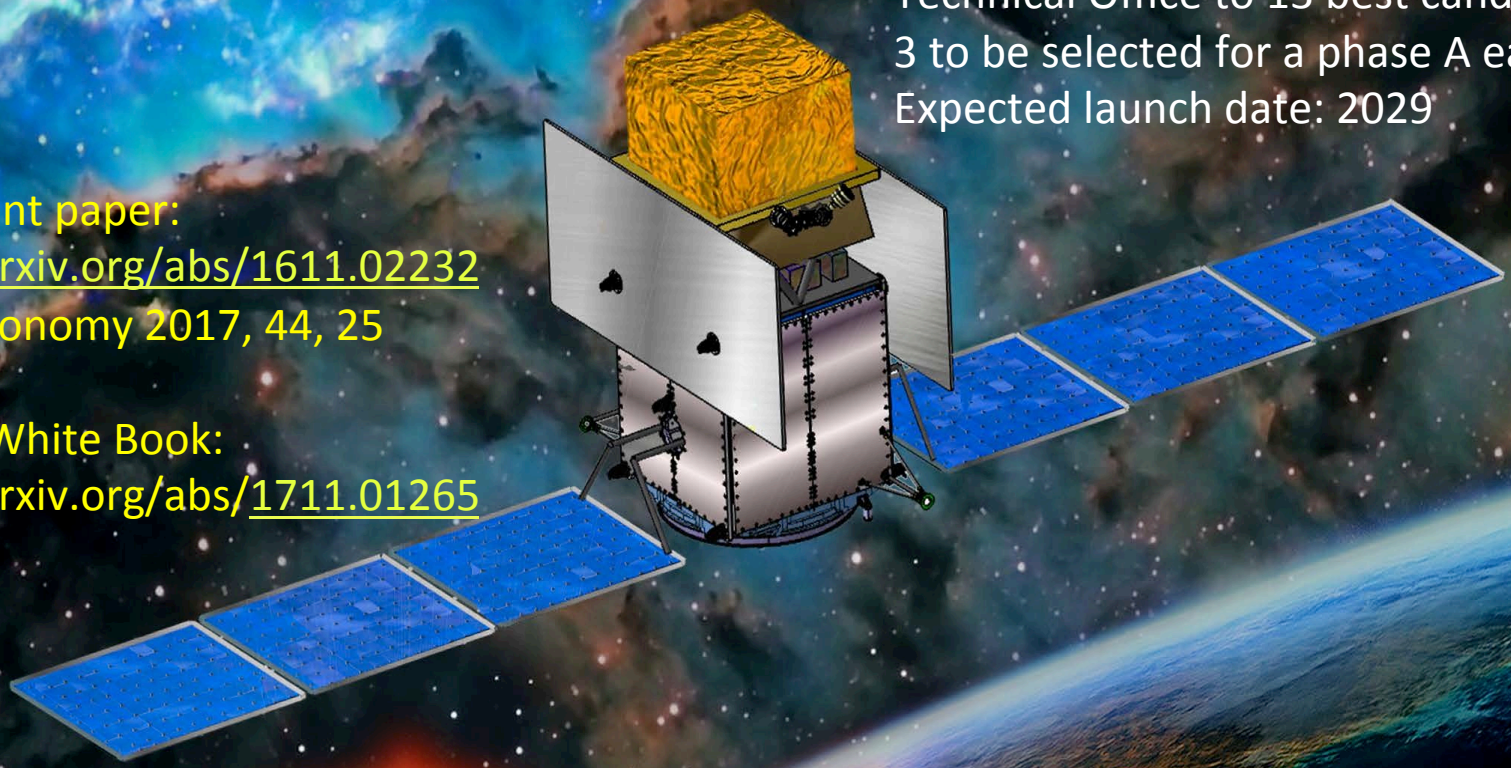
Near Infra-Red Telescope for rapid on-board follow-up with a 0.7 m primary mirror, sensitive in the 0.7-1.8 µm range, with a 10x10 arc min field of view and moderate spectroscopic capabilities (goal of 500). Provided by a consortium lead by France.

http://www.isdc.unige.ch/theseus/

e-ASTROGAM

at the heart of the extreme Universe

M5 proposal down-selected by ESA's Technical Office to 13 best candidates ⇒
3 to be selected for a phase A early 2018
Expected launch date: 2029



Instrument paper:
https://arxiv.org/abs/1611.02232
Exp. Astronomy 2017, 44, 25

Science White Book:
https://arxiv.org/abs/1711.01265

http://eastrogam.iaps.inaf.it