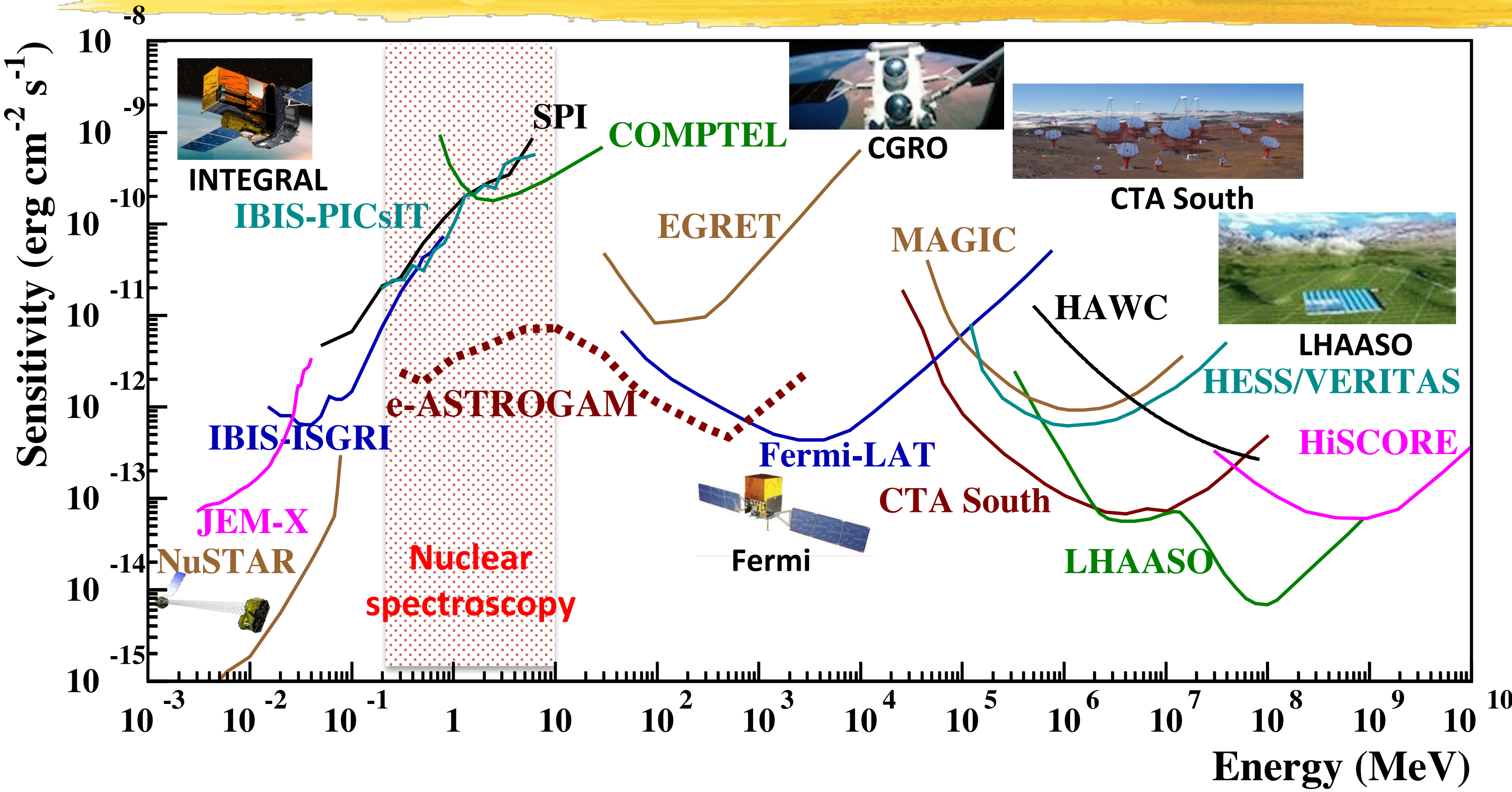
Space qualification of key gamma-ray detector technologies for e-ASTROGAM & AMEGO

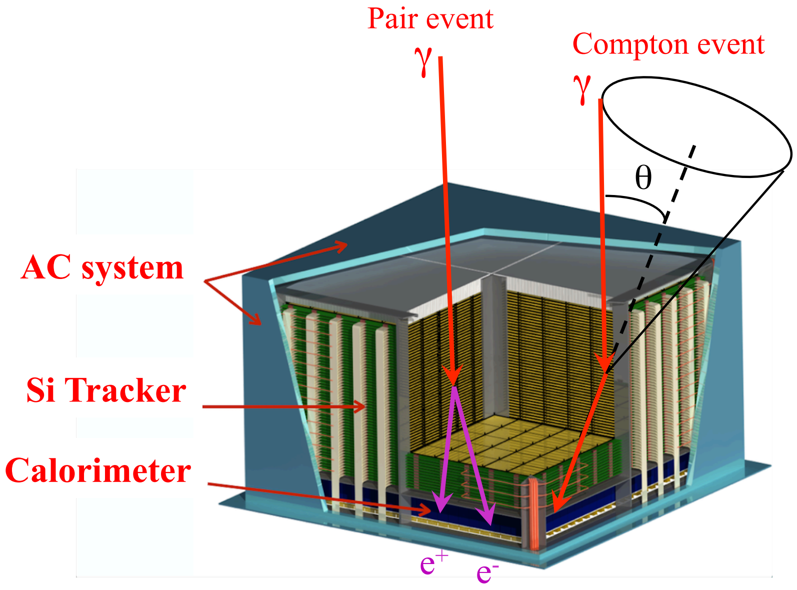
Vincent Tatischeff (IJCLab, France)

Gamma-ray astrophysics in the MeV range

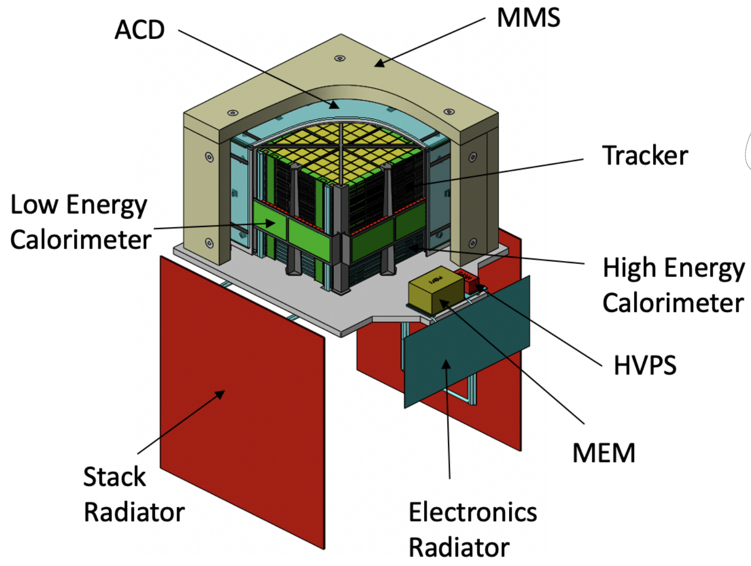


- The MeV gamma-ray range is the domain of **nuclear spectroscopy** and is crucial for **multi-messenger astronomy** (see GW170817)
- Many objects have their **peak emissivity** in this range (GRBs, blazars, pulsars...)
- **But worst covered part of the electromagnetic spectrum** so far: a few tens of steady sources detected in 0.2 - 30 MeV versus 5000+ sources in *Fermi* LAT 4FGL

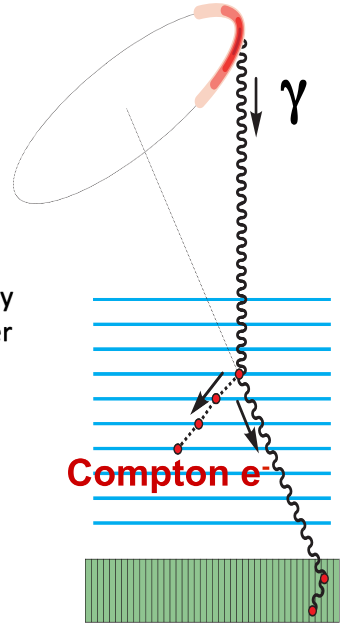
Measurement principle



e-ASTROGAM



AMEGO



Tracked Compton

- **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 photons ⇒ CsI(Tl) scintillators readout by Si Drift Diodes (e-ASTROGAM) or SiPM (AMEGO) + CZT semiconductor bars in the Low Energy Calorimeter of AMEGO
- **Anticoincidence detector** to veto charged-particle induced background ⇒ plastic scintillators readout by Si photomultipliers

e-ASTROGAM & AMEGO

Highly ranked by ESA: "progress is very likely on the major science topics of (a) processes associated with extreme physical conditions [...]; (b) the effects of high-energy particles on galaxies and galaxy evolution; and (c) the varieties of stellar nucleosynthesis at the ends of stellar lifetimes"

- **e-ASTROGAM Instrument**
  - **Tracker**: 56 layers of 4 times (4 towers) 5×5 DSSDs of 500 μm thickness and 240 μm pitch
  - **Calorimeter**: 33 856 CsI(Tl) bars of 5×5×80 mm^3 coupled at both ends to Silicon Drift Detectors
  - **Anti-coincidence detector**: segmented plastic scintillators coupled to SiPM by optical fibers
- **Orbit** - Equatorial (inclination i < 2.5°) low-Earth orbit (altitude in the range 550 - 600 km)
- **Observation modes** - (i) zenith-pointing sky-scanning mode, (ii) nearly inertial pointing, (iii) fast repointing

e-ASTROGAM mission proposed in 2016 for ESA's M5

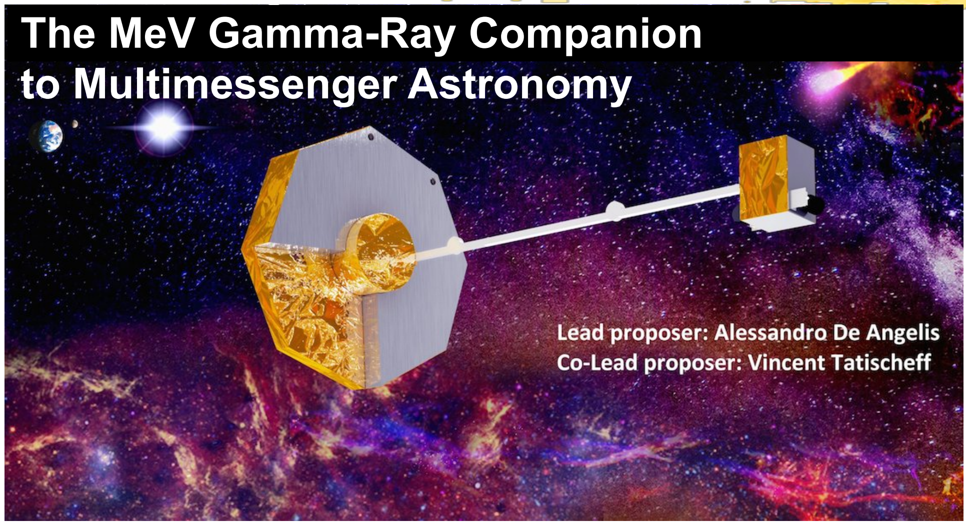
AMEGO

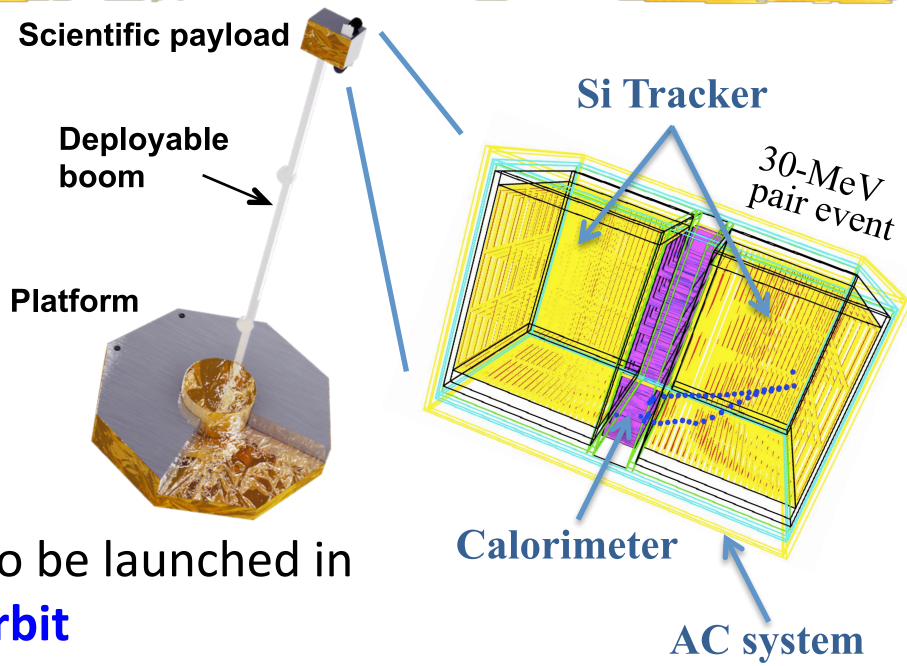
All-sky Medium Energy Gamma-ray Observatory

- **AMEGO Instrument**
  - **Tracker**: 60 layers of 4 times (4 towers) 4×4 DSSDs, 500 μm thickness, 500 μm pitch
  - **Low-Energy Calorimeter**: 3040 CZT bars of 5×5×80 mm^3 with a virtual Frisch-grid readout
  - **High-energy Calorimeter**: 624 CsI(Tl) bars (26×6 layers per tower) of 1.5×1.5×38 cm^3 arranged hodoscopically coupled to SiPMs
  - **Anti-coincidence detector**: 5 panels of 134×87×1.5 cm^3 plastic scintillators coupled to SiPM by wavelength shifting optical fibers
- **Orbit** - 600 km 6° inclined circular orbit
- **Observation modes** - (i) optimized sky-scanning mode, (ii) inertial target pointing

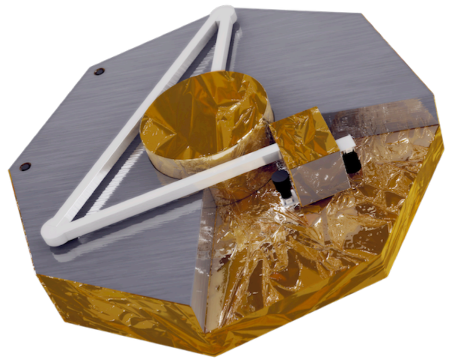
AMEGO designed for a NASA Probe mission (McEnery et al. 2019; Astro2020 Decadal Survey)

All-Sky-ASTROGAM





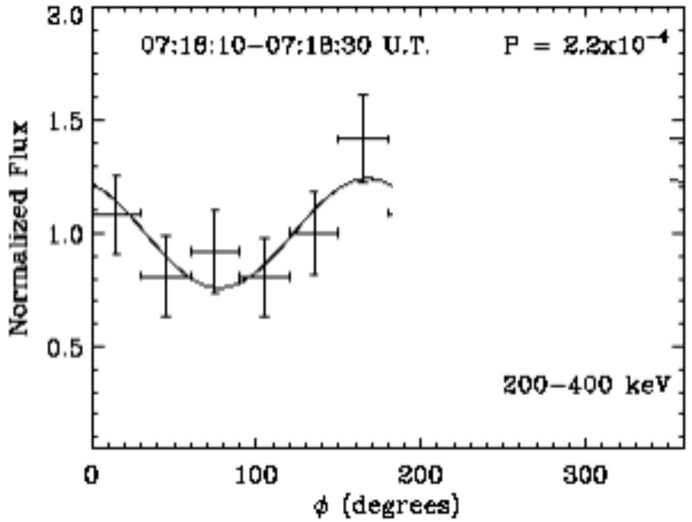
- Proposed in 2019 as **ESA's "Fast" mission** to be launched in 2028 with the ARIEL M4 Mission to an **L2 orbit**
- **All-Sky Gamma-ray Monitor** (0.1 MeV - 500 MeV) with **good localisation** capabilities (e.g. 30 arcmin at 300 MeV) and **excellent sensitivity to polarisation** in the MeV domain
- Gamma-ray Imager (e-ASTROGAM technology, 80 kg) attached to a **deployable boom**
  $\Rightarrow$ **continuous coverage of the whole sky**
  $\Rightarrow$ **reduction of the instrument background** (L2 orbit)
- One of the **last 3 competing missions**, but finally not selected



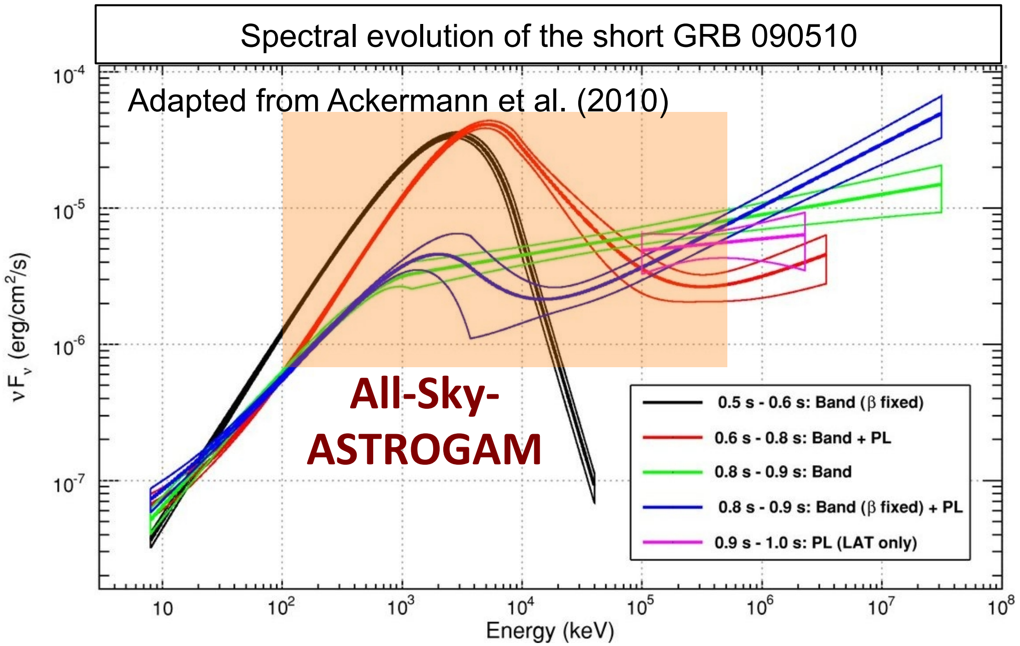
All-Sky-ASTROGAM and Gamma-Ray Bursts

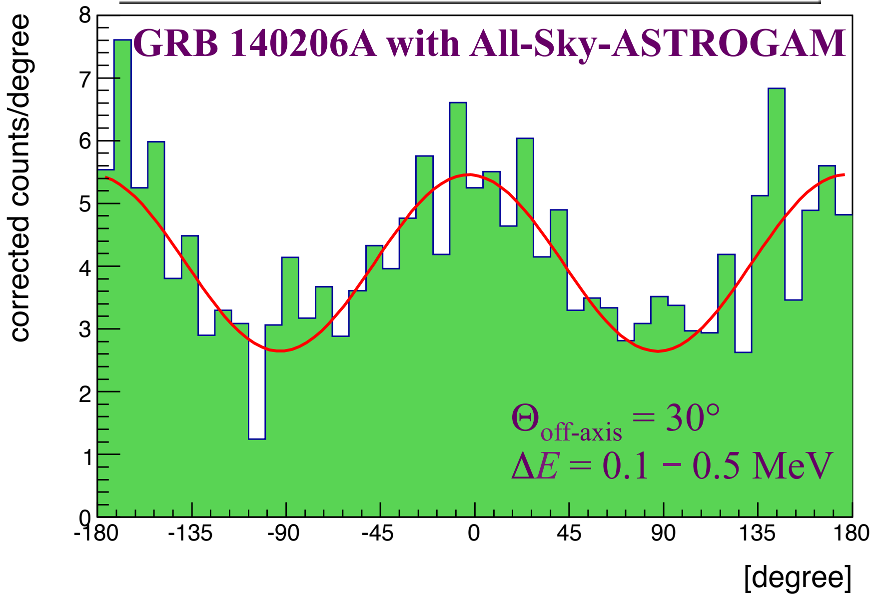
- **Unprecedented gamma-ray polarimetry** for several tens of GRBs per year
  ⇒ **GRB jet physical properties** (B-field), energy dissipation sites, radiation mechanisms...
  ⇒ Test of **Lorentz Invariance Violation** (using vacuum birefringence)
- **Broad-band spectroscopy** with a single instrument

INTEGRAL/IBIS − GRB 140206A ($z = 2.74$)

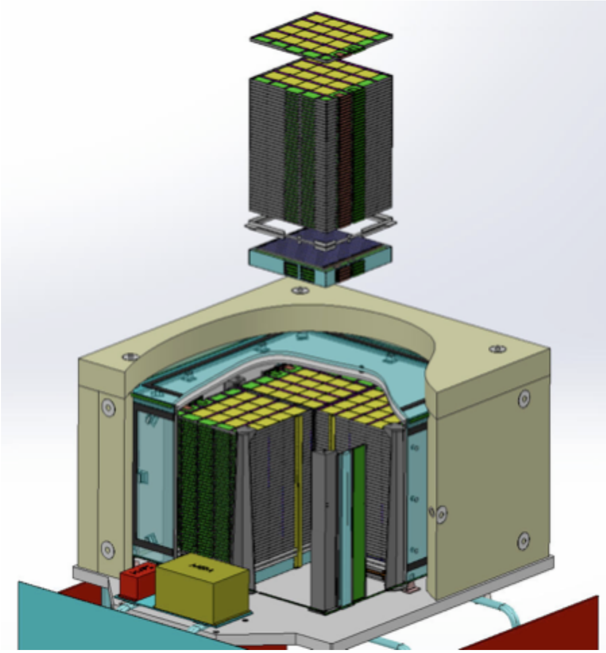


Götz et al. (2014)

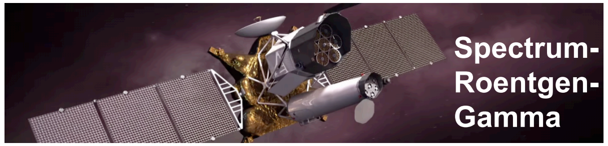




AMEGO & e-ASTROGAM perspectives

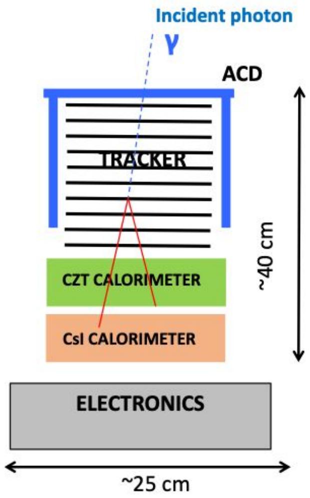


- **AMEGO-X**: smaller version of AMEGO for submission to the upcoming **MidEx call in 2021**, focusing on continuum flux sensitivity for **multimessenger astrophysics** (degraded narrow-line sensitivity - COSI - and polarization capabilities - LEAP)
  - ⇒ Tracker: 40 layers of DSSDs (60 in AMEGO)
  - ⇒ No Low-Energy CZT Calorimeter
  - ⇒ High-Energy Calorimeter: 4 layers of CsI(Tl) (6 in AMEGO)

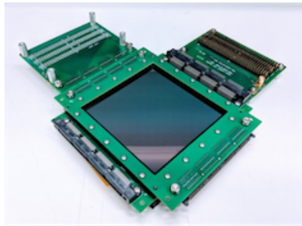


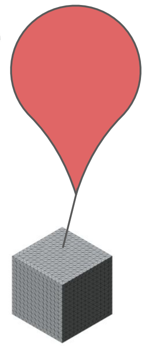
- **European/Russian collaboration for e-ASTROGAM** (project builds on the success of the partnership set up for the INTEGRAL mission)
  - ⇒ Russia: launch (Proton rocket)
  - ⇒ Russia: satellite platform (NPO Lavochkin) similar to that of the SRG mission (payload mass: 1 210 kg; launch mass: 2 712 kg)
  - ⇒ ESA + Ioffe Institute & IKI: development of the gamma-ray telescope
  - ⇒ European & Russian scientists: science program and data analysis

AMEGO Compton prototype

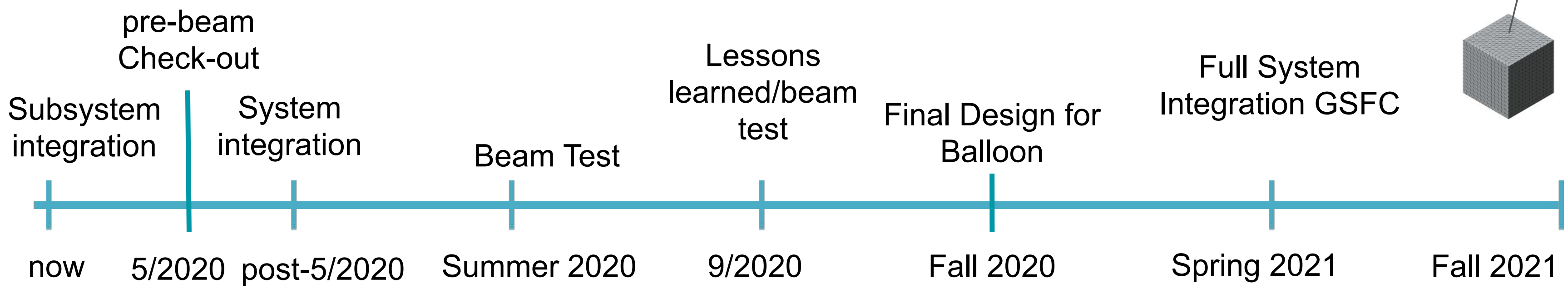


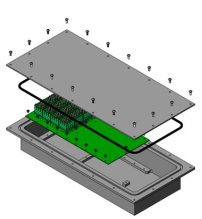
- **Tracker (GSFC/LANL)**: ~10 layers of 4x4 DSSDs (?), 9.5x9.5 cm^2 wafers (Micron Semiconductors TTT13)
- **CZT Calorimeter (GSFC/BNL)**: 16 crates of 4x4 CZT bars, 0.6x0.6x2 cm^3
- **CsI(Tl) Calorimeter (NRL)**: 4 layers of 6 CsI(Tl) logs, 1.7x1.7x10.0 cm3, readout by (SensL J-series) SiPMs
- **Anti-Coincidence Detector (ACD) (GSFC)**: plastic scintillators covering the tracker

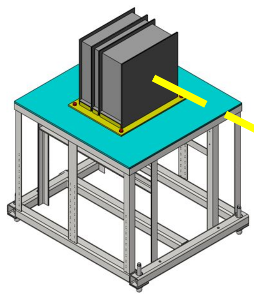


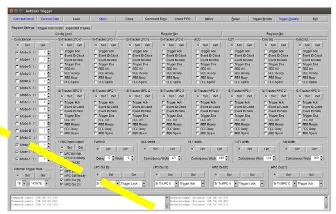


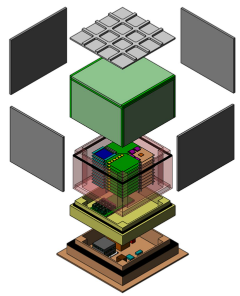
- Pre-Covid timeline (as in Feb 26, 2020, © Regina Caputo):





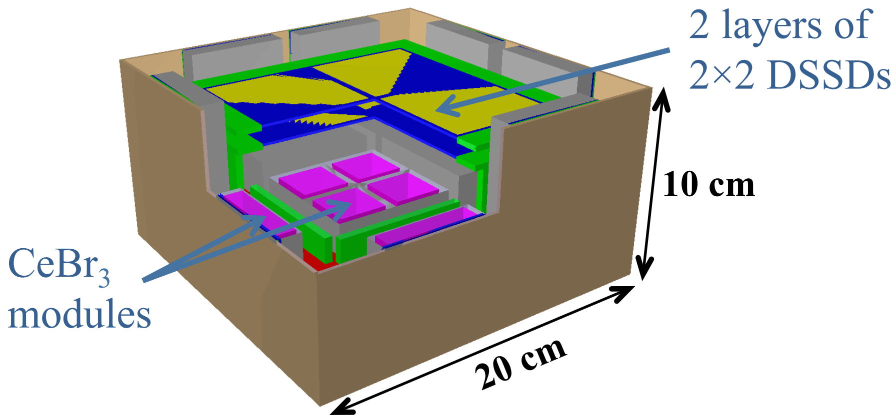


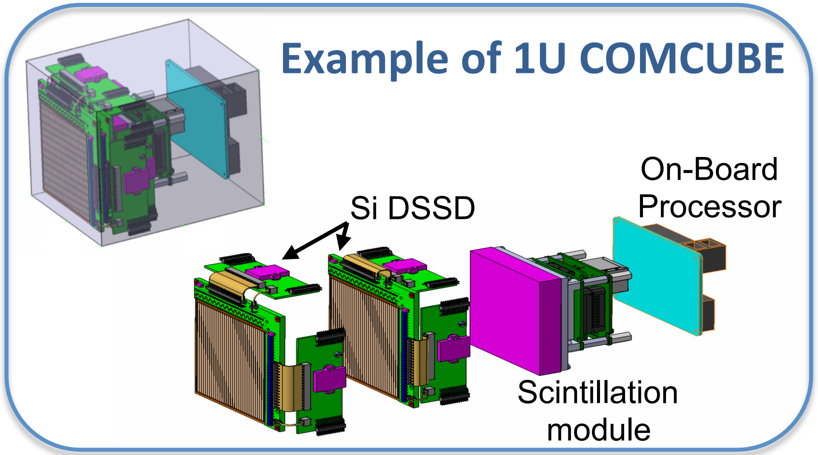




COMCUBE: Compton Telescope CubeSat Prototype

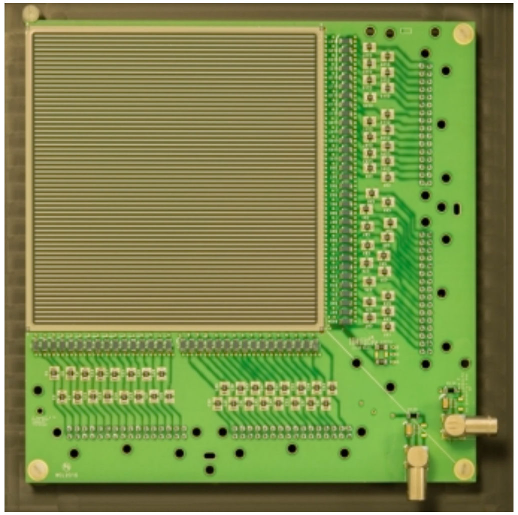
- In-orbit demonstration of a **game-changing GRB polarimeter** based on **e-ASTROGAM/AMEGO technologies**
- AHEAD2020/WP11.2: 1U prototype to be tested in a balloon flight (HEMERA)





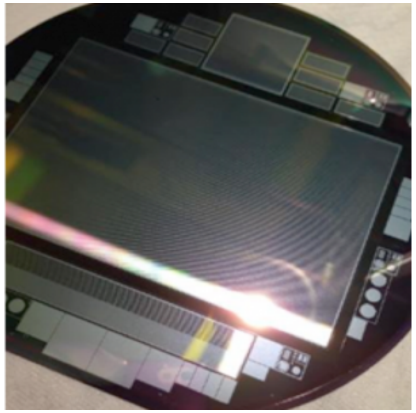
T0: 2/3/2020	T0+6	T0+24	T0+30	T0+33 → T0+36
Design simulation **6 months**	Si DSSDs and calorimeter detector manufacturing **18 months**	Prototype integration&test **6 months**	Balloon experiment **3 months**	Data analysis (AI) **3 months**
LIP IJCLab Mainz UCD	**Si DSSD detectors (D1):** **D1a: CEA** + INFN **D1b:** IJCLab **Calorim. detector (D2):** **D2a:** UCD **D2b:** IJCLab	**UCD** **IJCLab** CEA INFN	**IRAP** + All	**Mainz** LIP

R&Ds relevant to COMCUBE development



Si DSSD (CEA)

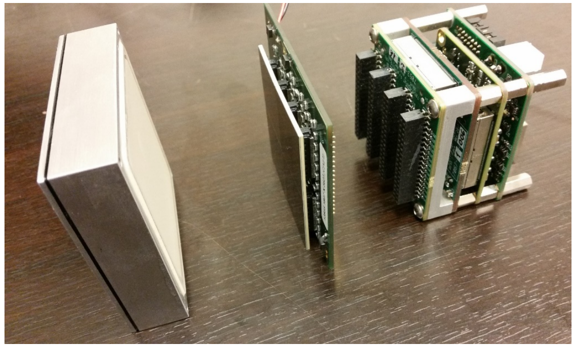
CubeSat with Taiwan / P. Laurent



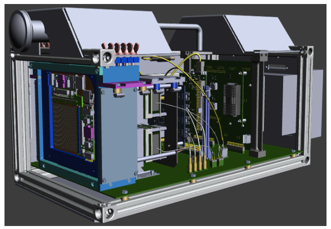
Si DSSD (FBK - INFN)

A. Morselli / V. Vitale

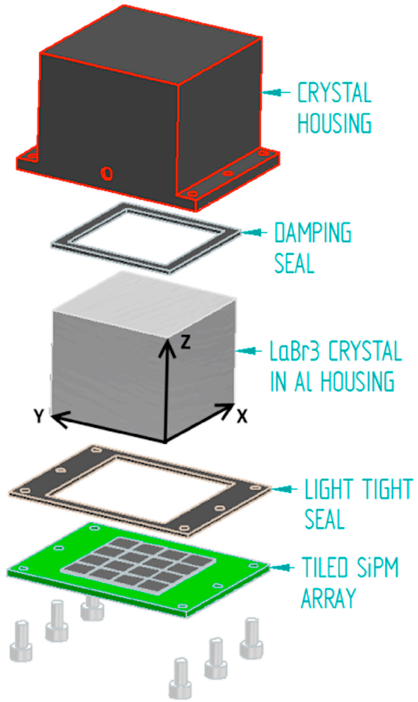
Si DSSD (IJCLab)



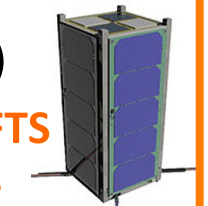
Calorimeter module (IJCLab)



ComptonCAM (nuclear industry)
N. De Séréville / A. Laviron



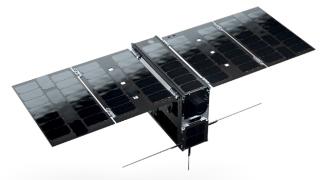
Calorimeter module (UCD)

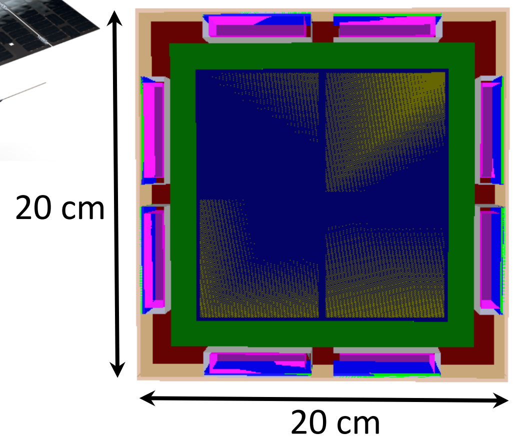


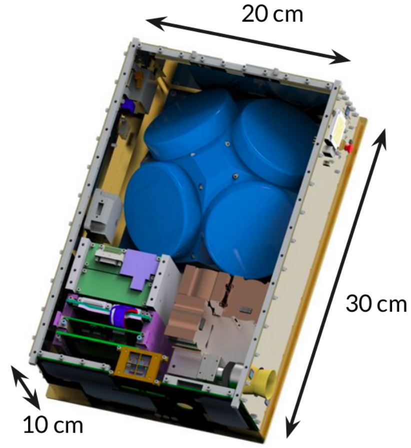
EIRSAT-1, GIFTS
M. Doyle / D. Murphy / A. Uliyanov

COMCUBE as a GRB polarimeter

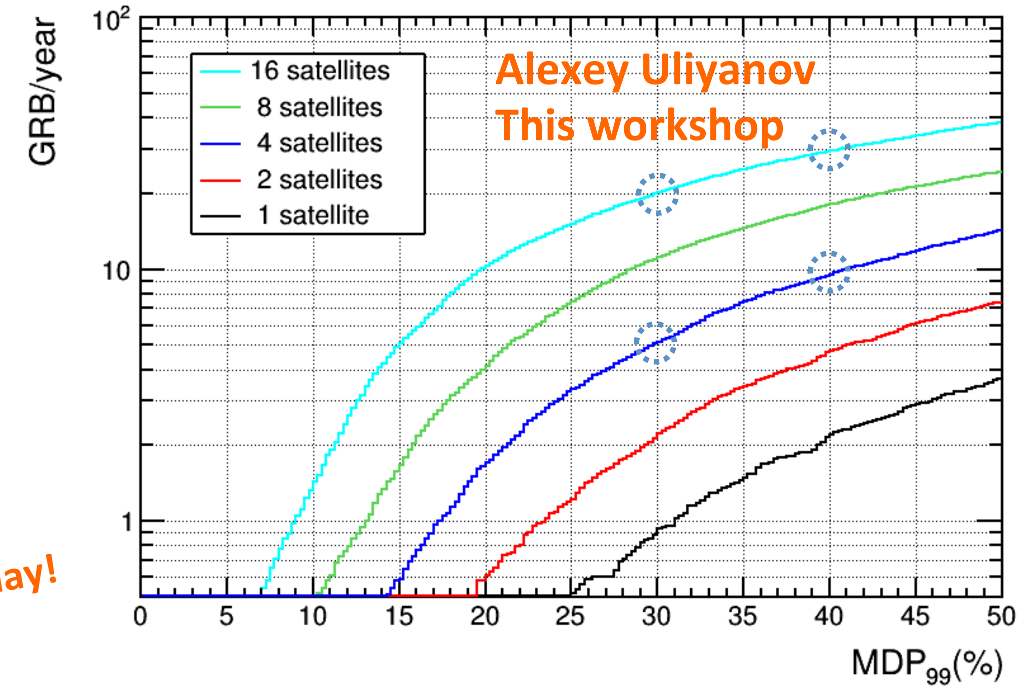
- **6U spacecraft** (like BurstCube)
- Mass of active material: **2.2 kg** ($CeBr_3$ 2.08 kg, DSSD 130 g)
- Number of electronic channels: $CeBr_3$ 768 (64x12), DSSD 512 (8x32x2)
- Photoelectric effective area: ~200 cm^2 at ~100 keV similar to that of CAMELOT
- GRB detection rate of CAMELOT (Werner et al. 2018): ~300 GRBs per year with 9 satellites (all-sky coverage)
- Polarization measurements: assuming 4 (16) satellites in orbit:
  ~10 (30) GRBs/yr detected with MDP_{99}<40%
  ~5 (20) GRBs/yr detected with MDP_{99}<30%







BurstCube



COMCUBE session on Friday!