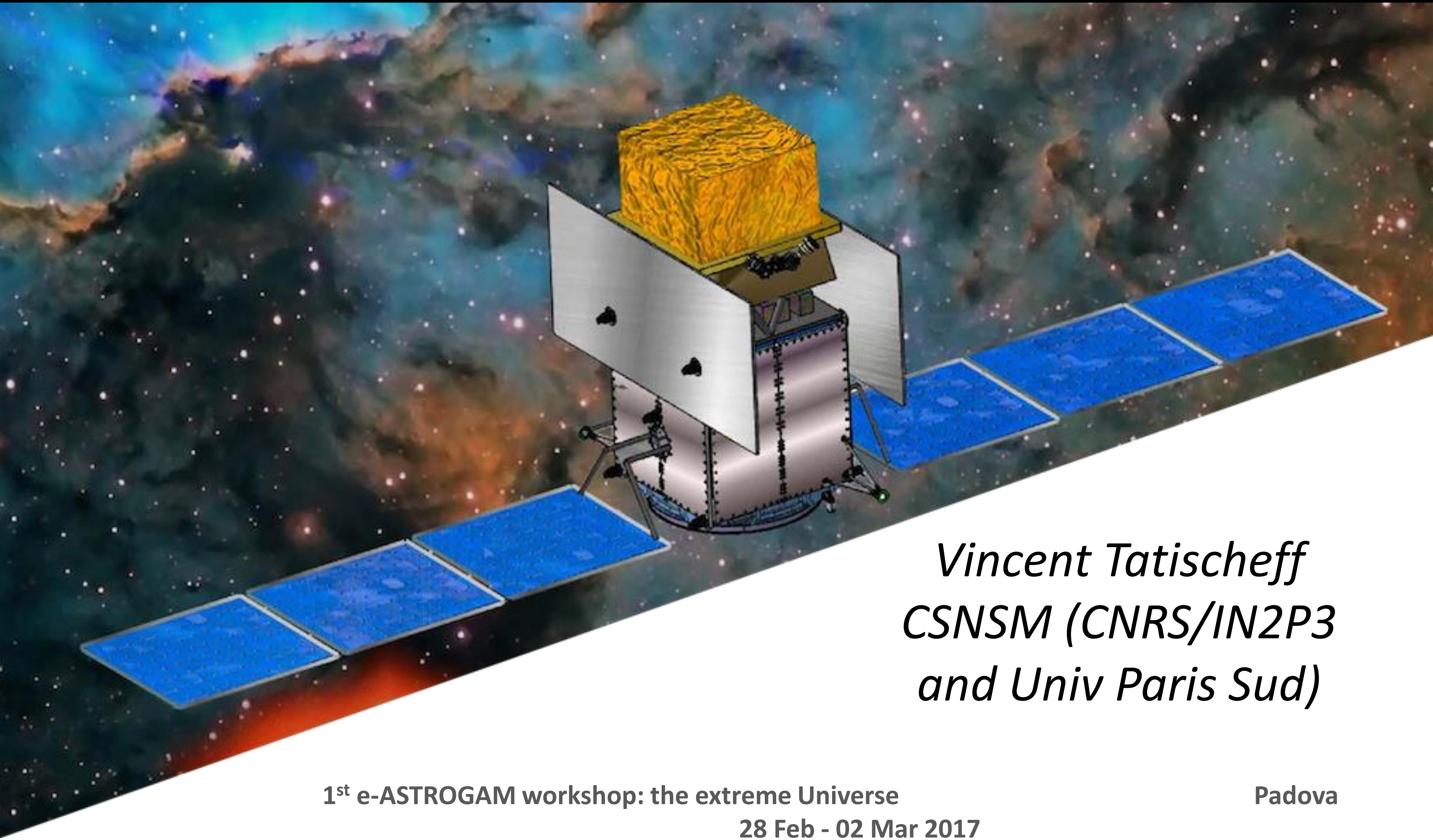
e-ASTROGAM
Instrument and spacecraft

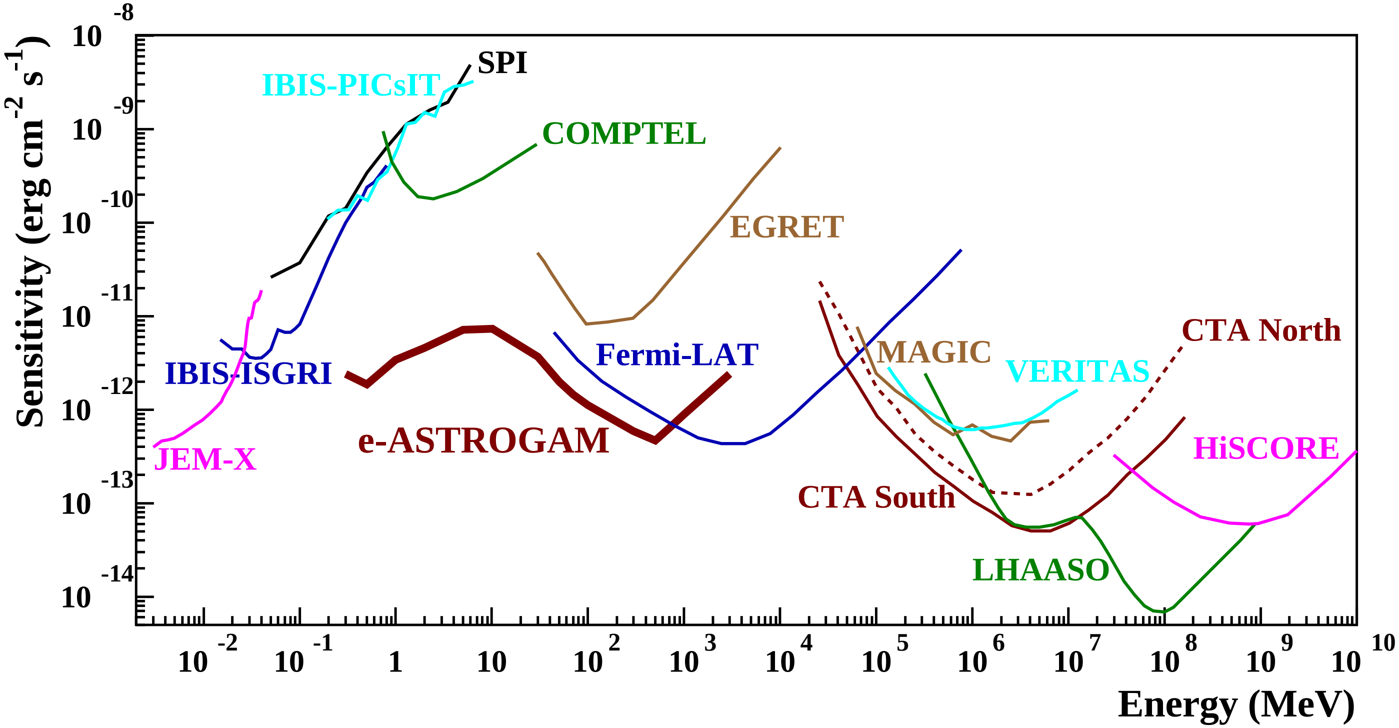


Vincent Tatischeff
CSNSM (CNRS/IN2P3
and Univ Paris Sud)

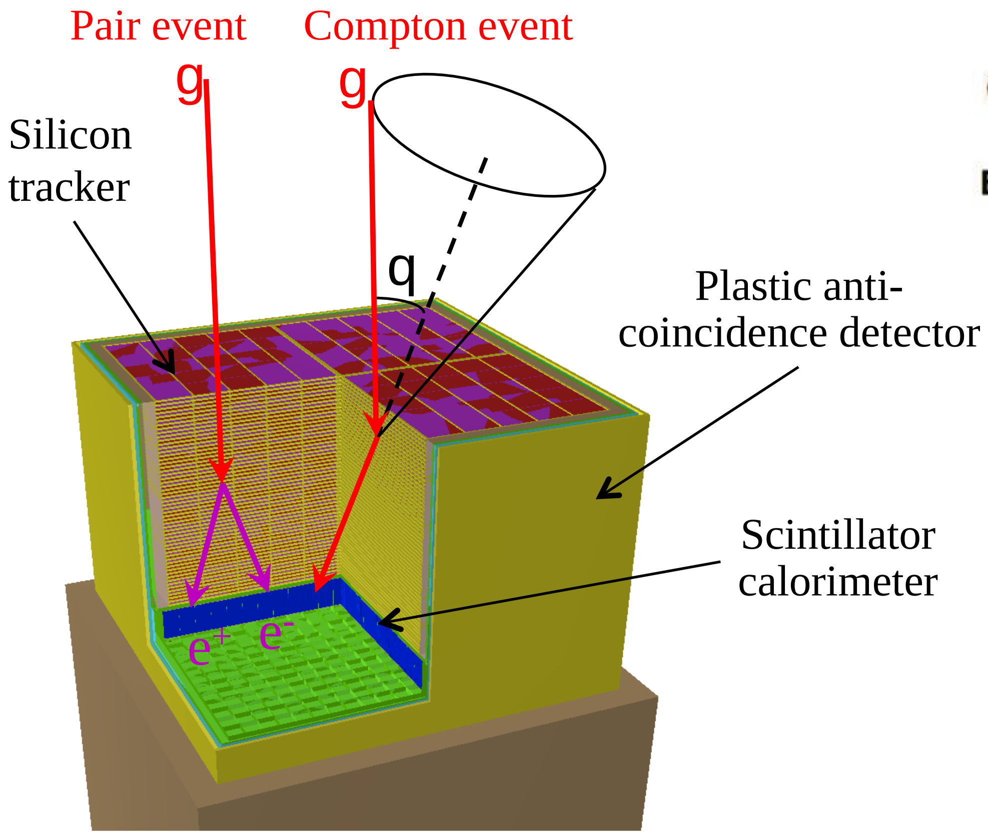
1st e-ASTROGAM workshop: the extreme Universe **Padova**
28 Feb - 02 Mar 2017

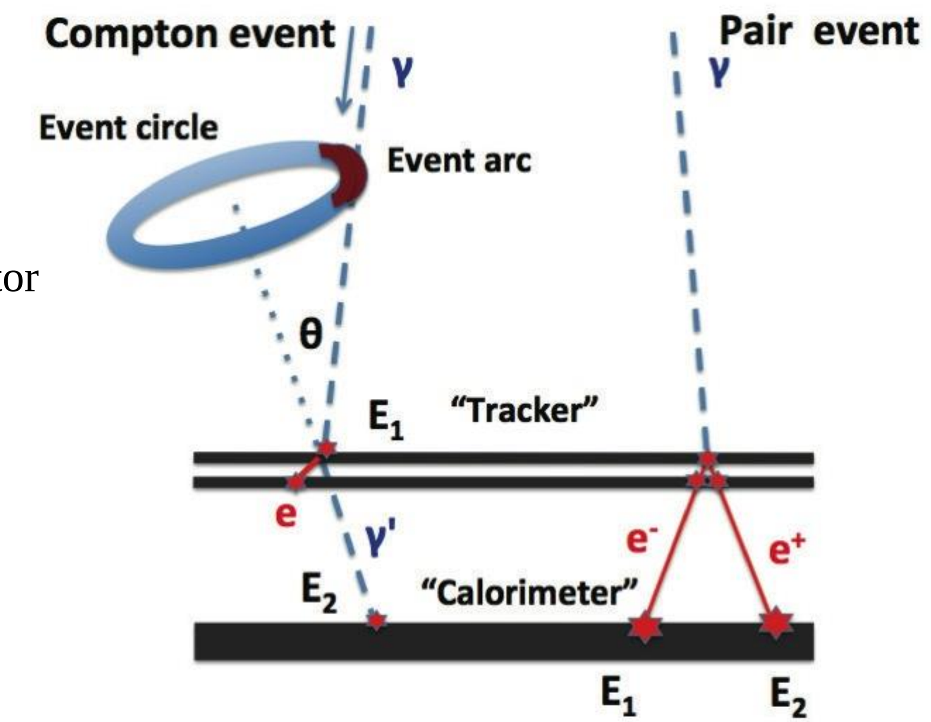
e-ASTROGAM Scientific requirements

1. Cover most of the energy range of space-based γ-ray astronomy (0.2 MeV – 3 GeV)
2. Achieve a sensitivity better than that of CGRO/COMPTEL by a factor of 50 – 100 in the important range 1 – 30 MeV
3. Fully exploit gamma-ray polarization for both transient and steady sources
4. Improve significantly the angular resolution (to reach, e.g., ~ 10' at 1 GeV)
5. Achieve a very large field of view (~ 2.5 sr) ⇒ efficient monitoring of the γ-ray sky
6. Enable sub-milisecond trigger and alert capability for transients



e-ASTROGAM 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 Silicon Tracker

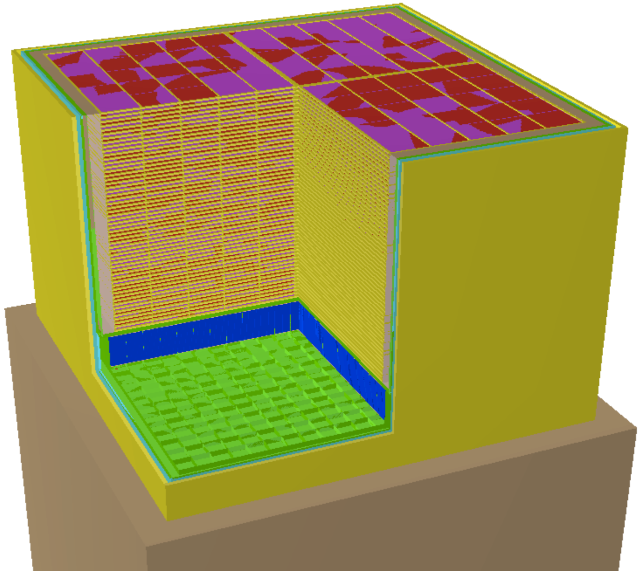
- 56 layers of 4 times 5×5 double sided Si strip detectors = 5600 DSSDs
- Each DSSD has a total area of 9.5×9.5 cm^2, a thickness of 500 μm, a strip width of 100 μm and pitch of 240 μm (384 strips per side), and a guard ring of 1.5 mm
- Spacing of the Si layers: 10 mm
- The DSSDs are wire bonded strip to strip to form 5×5 2-D ladders

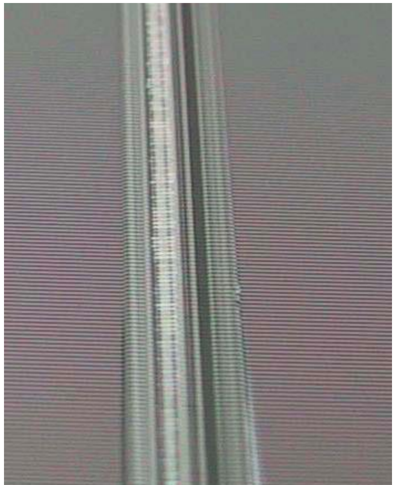
⇒ 860 160 electronic channels

- DSSD strips connected to ASICs through a pitch adapter

⇒ 26 880 IDeF-X ASICs (32 channels each)

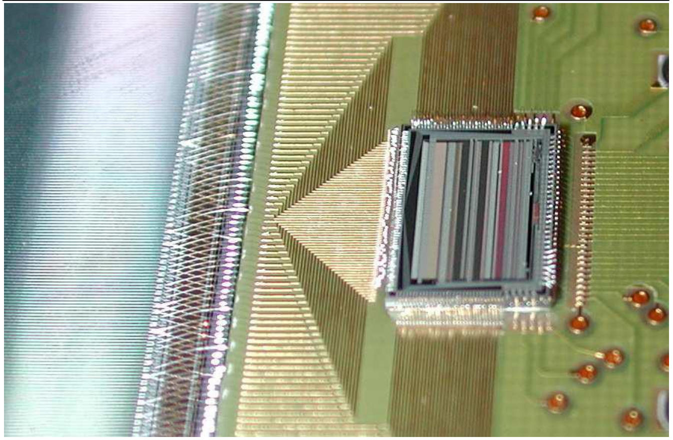
⇒ Power budget = 688 W (800 μW/channel)



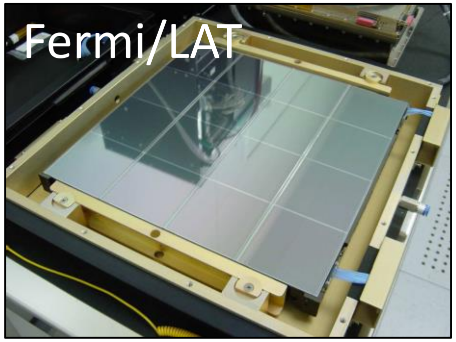


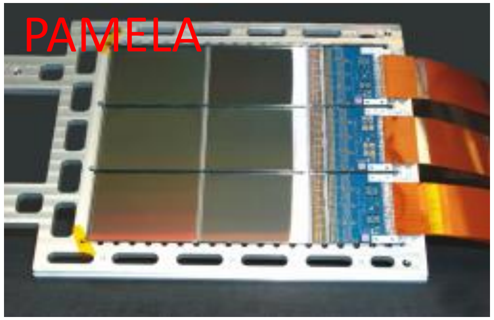
Si strip bounding in Fermi/LAT

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

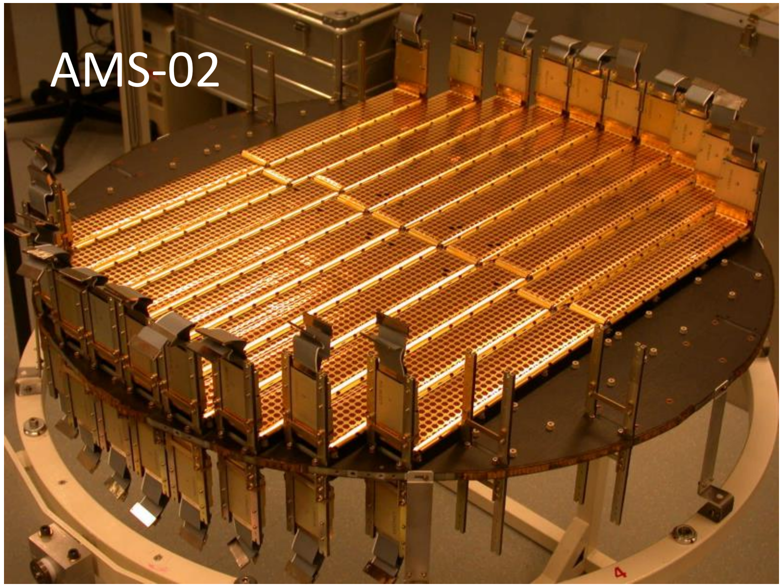


- DSSDs are widely used in particle physics experiments, e.g. LHC/ATLAS+CMS
- Ladders of wire-bonded SSSDs in Fermi/LAT and AGILE, and of wire-bonded DSSDs in PAMELA and AMS-02



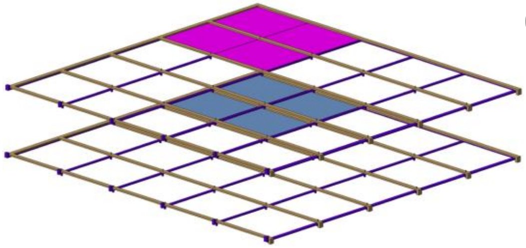


- **Main technology challenges**:
  - (i) Mechanical structure (no material between the Si layers) and 2-D bonding
  - (ii) Thermal control (FEE areas in the temperature range -10° – 0° C)
  - (iii) Front-end electronics (noise not to exceed a few keV FWHM)

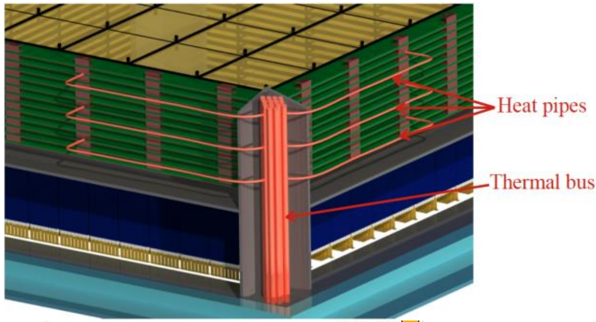


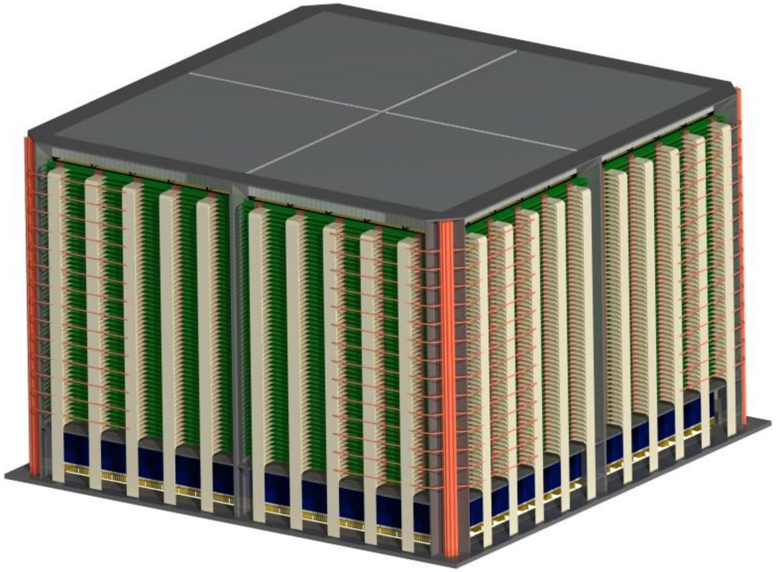
e-ASTROGAM Tracker mechanics - thermal control

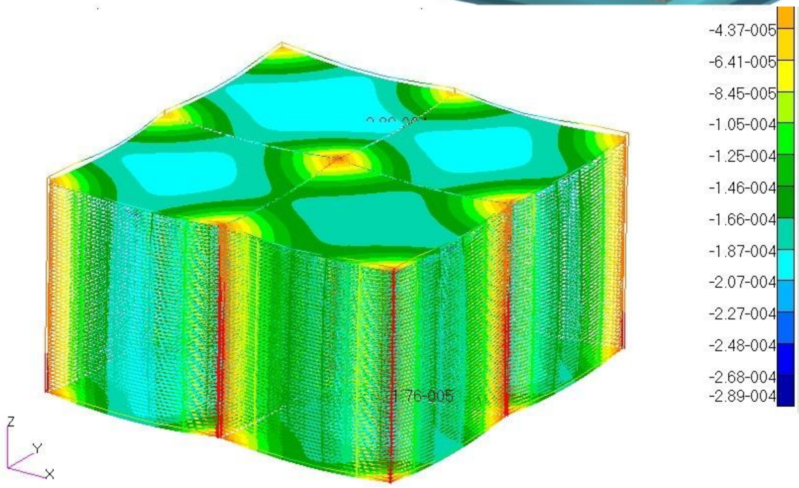
- Structure of a detection plane made of two frames sandwiching the Si detectors, with the support rods parallel to the DSSD strips to enable wire bonding



- Detailed structural calculations including both static and modal analyses $\Rightarrow$ maximum vertical displacement of 280 μm
- **Thermal control**: heat pipe technology to channel the electronics-generated heat to external radiators



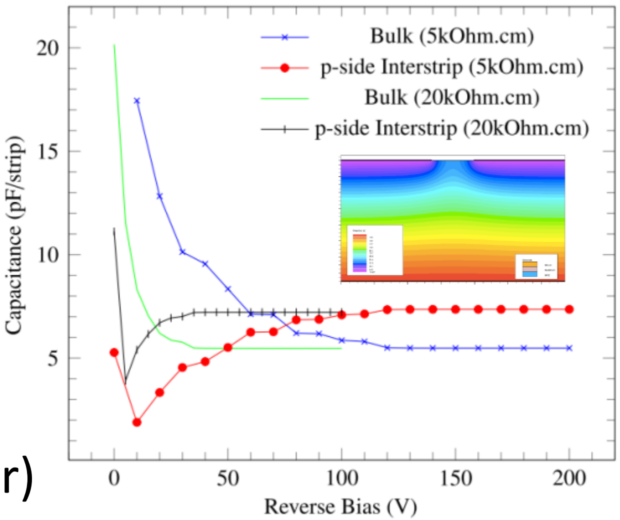


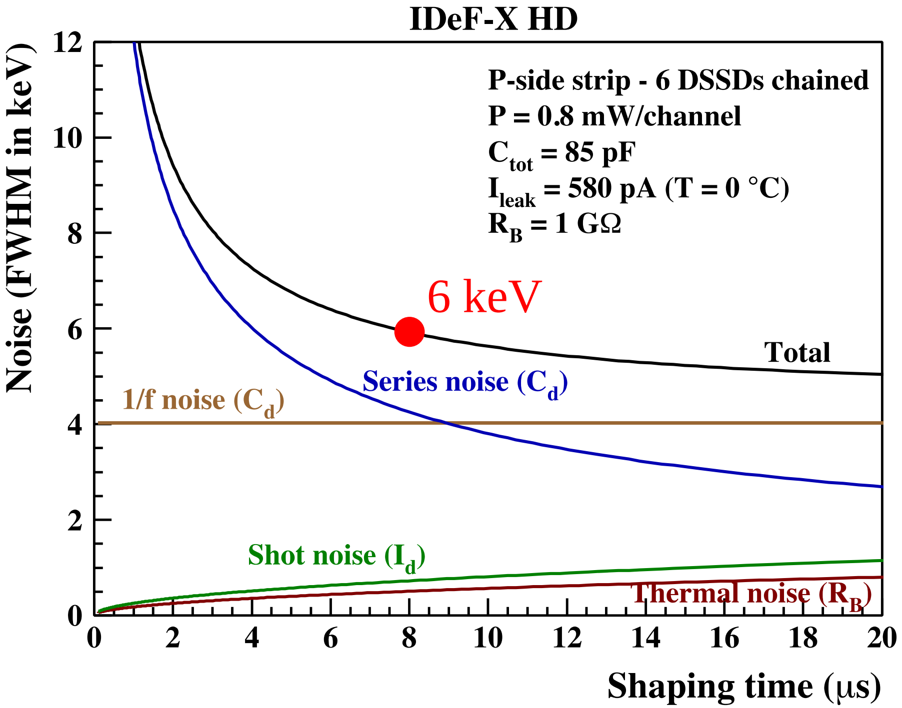


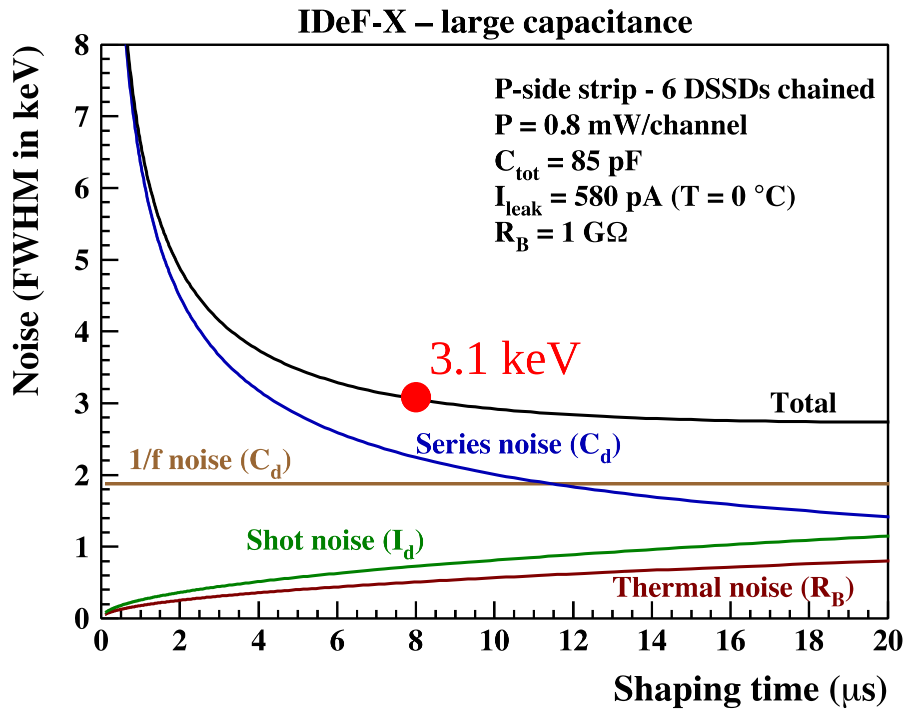
e-ASTROGAM Tracker FEE

- FEE ASIC: ultra low-noise (AMS CMOS 0.35 μm), space-qualified (Solar Orbiter/STIX) IDeF-X HD (CEA/Irfu)
- SILVACO's Tcad semiconductor toolkit to simulate the electrical behavior of the DSSDs (C_d, I_{leak}…)

⇒ Predicted electronic noise: $\Delta E \sim 6$ keV (for $\tau = 8$ μs) with IDeF-X **HD**, $\Delta E = 3.1$ keV with IDeF-X optimized for **large capacitance** (new space-qualified preamplifier)

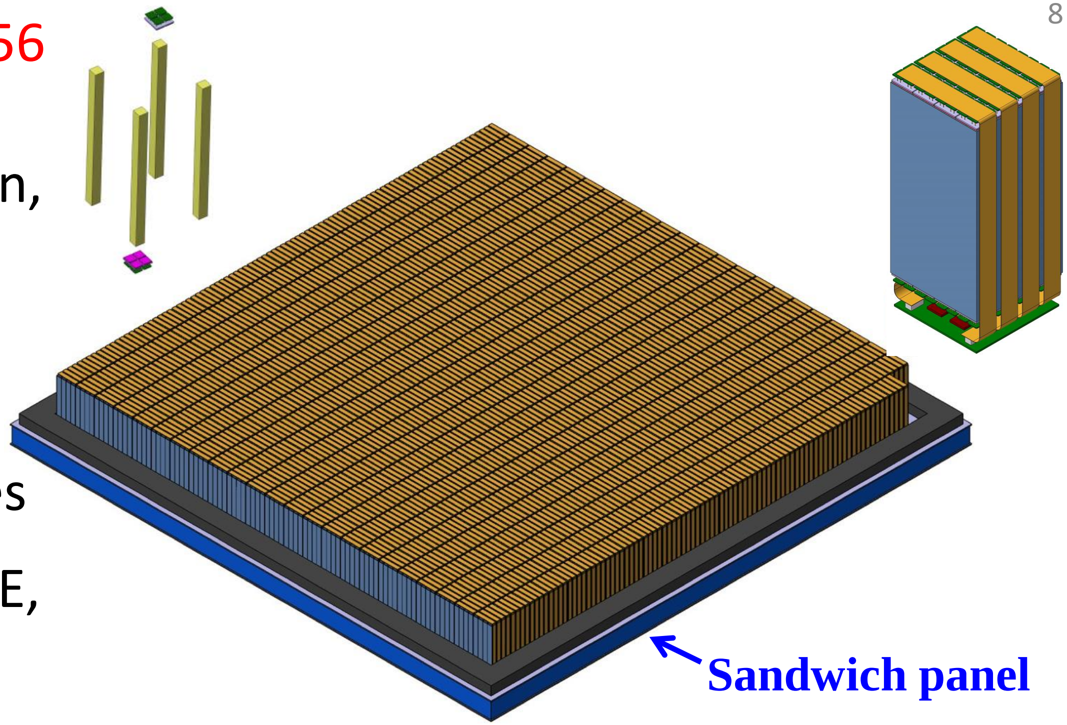


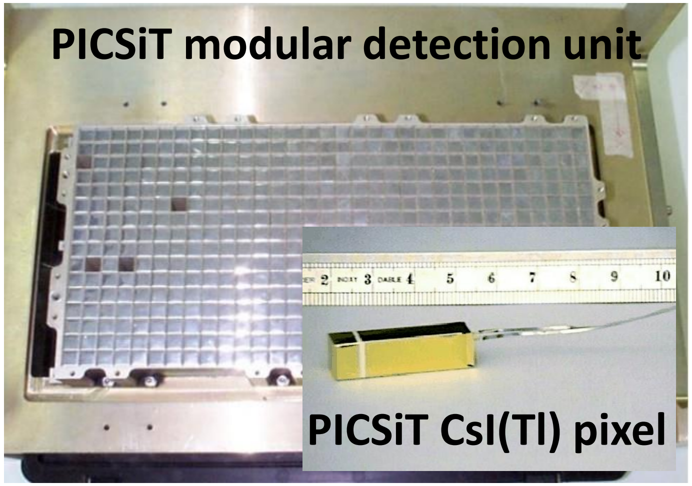


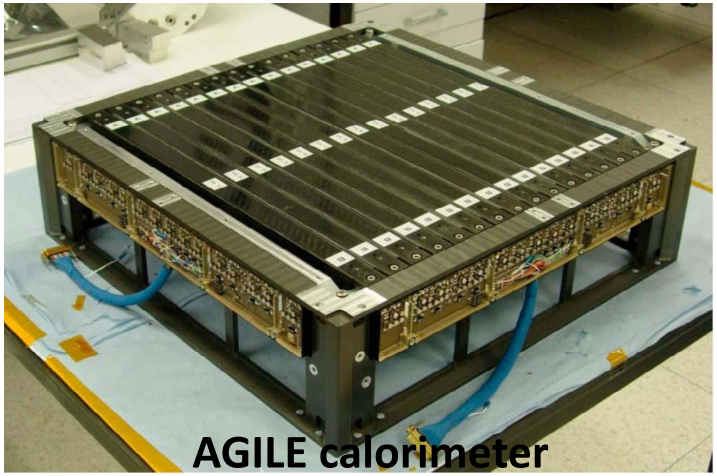


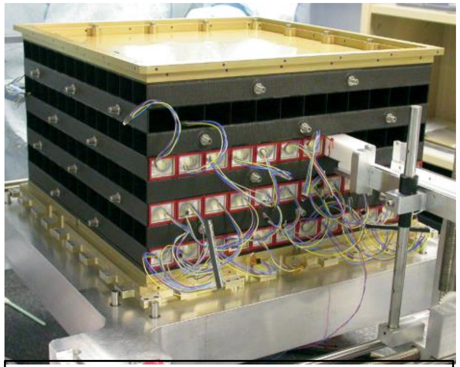
e-ASTROGAM Calorimeter

- Pixelated detector made of 33 856 CsI(Tl) scintillator bars of 8 cm length and 5×5 mm^2 cross section, glued at both ends to low-noise Silicon Drift Detectors (SDDs)
- Calorimeter formed by the assembly of 529 (23×23) modules
- **Heritage**: INTEGRAL/PICsIT, AGILE, Fermi/LAT, LHC/ALICE





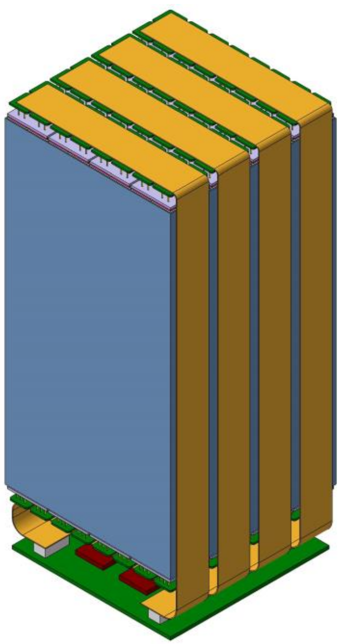


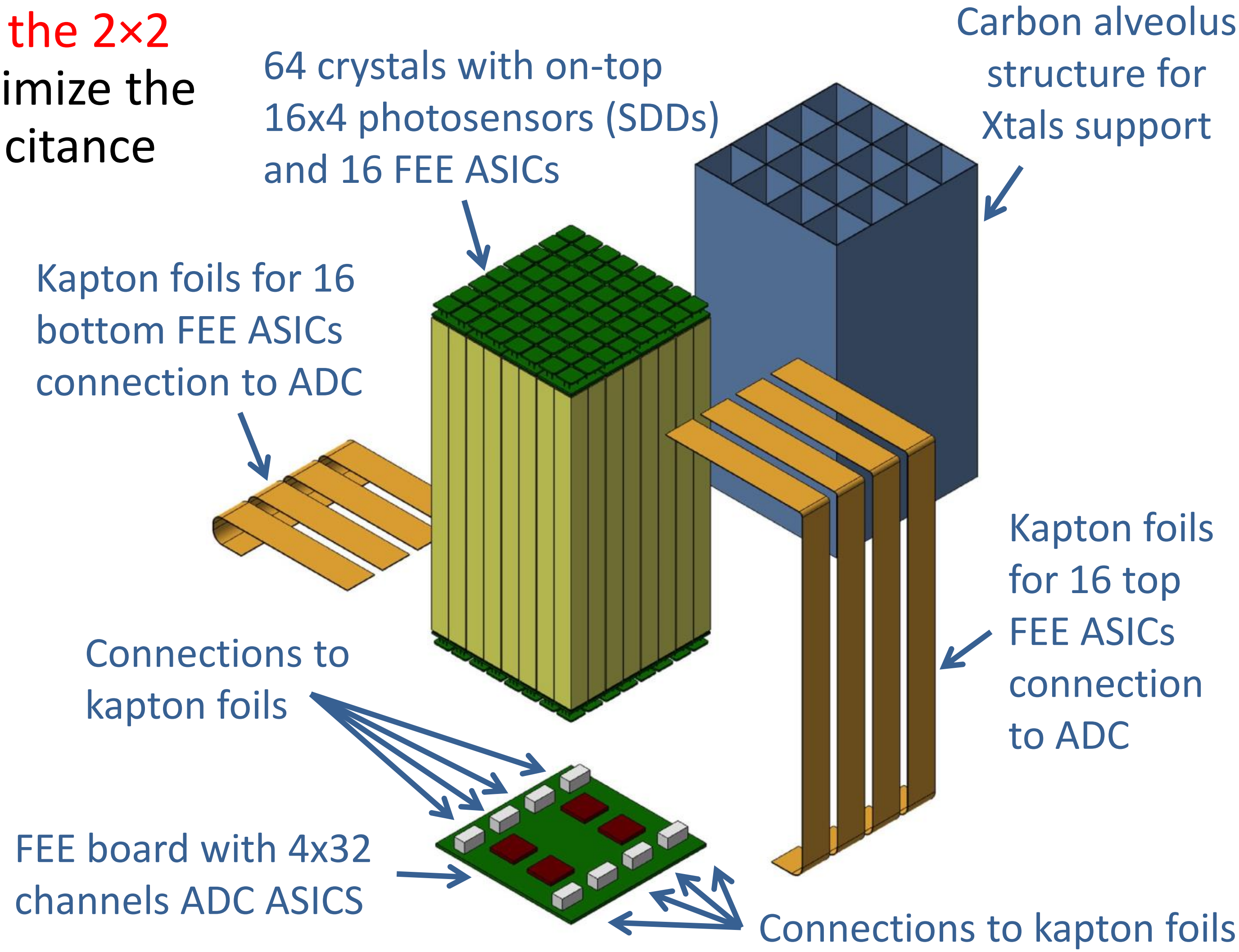

Fermi cal. module

e-ASTROGAM Calorimeter module

- FEE ASIC: modified version of the ultra low-noise VEGA ASIC (INFN) with 4 channels (instead of 32) and an increase of the shaping-amplifier dynamics
- ASICs mounted on the 2×2 SDD boards to minimize the bonding stray capacitance

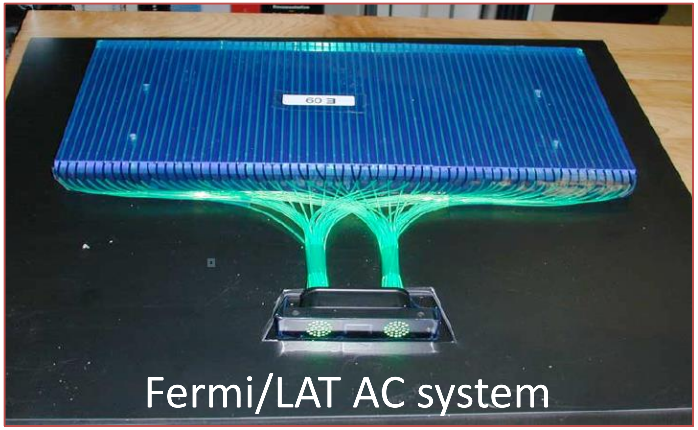
Calorimeter module



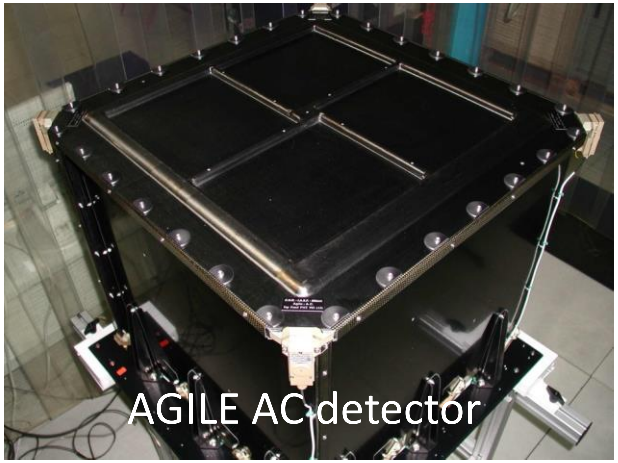


e-ASTROGAM Anticoincidence system

- **Upper-AC** system formed by large panels of plastic scintillators covering 5 faces of the instrument (6 plastic tiles per lateral side and 9 tiles for the top = 33 tiles total)



Fermi/LAT AC system



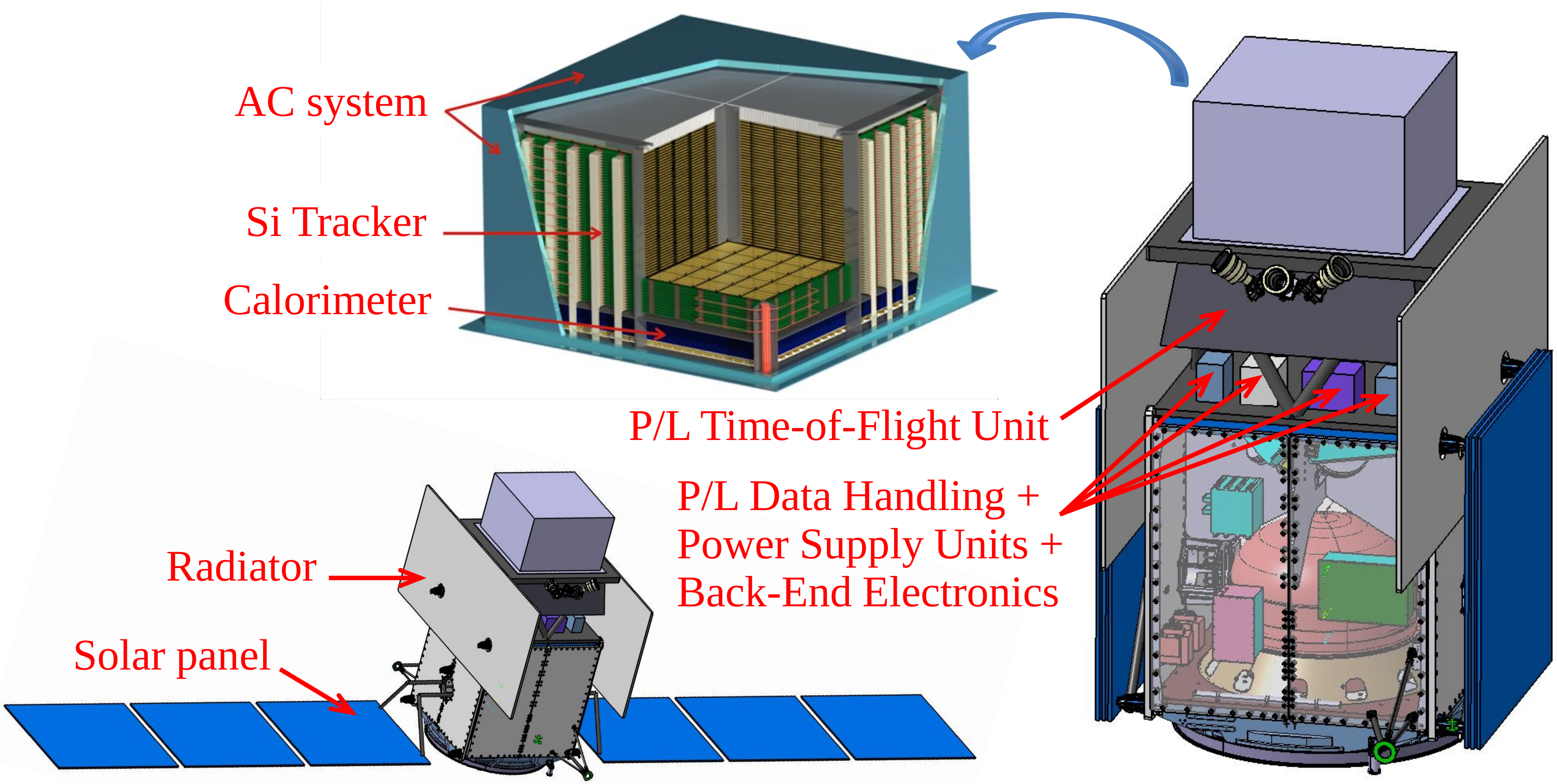
AGILE AC detector

- Wavelength shifting optical fibers buried in trenches convey the scintillation light to Si photomultipliers (e.g. the B-Series SiPMs of the SensL© company)
- The SiPM signals are readout by the space-qualified VATA64 ASICs from Ideas©
- **Heritage**: Fermi/LAT, AGILE

- **Time-of-Flight** system formed by two scintillator layers separated by 50 cm below the instrument to reject the particle background from the platform
- **Heritage**: AMS, PAMELA

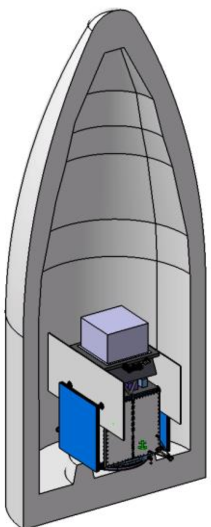
e-ASTROGAM Satellite

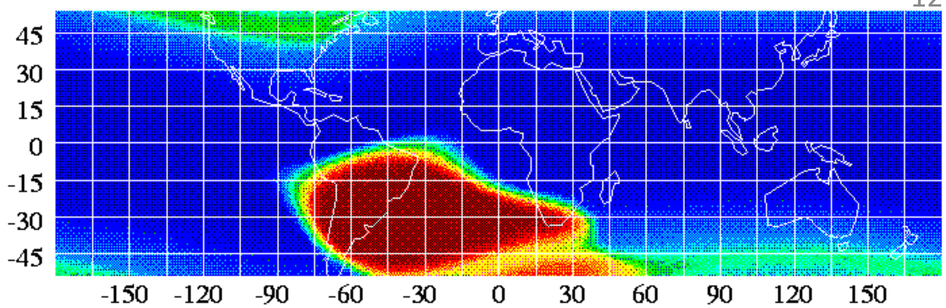
- Arrangement of the **Thales Alenia Space PROTEUS 800** platform developed in the frame of the SWOT CNES/NASA program
- Spacecraft dry mass 2.4 t. Telescope mass 1.2 t (with mat. & syst. margins)

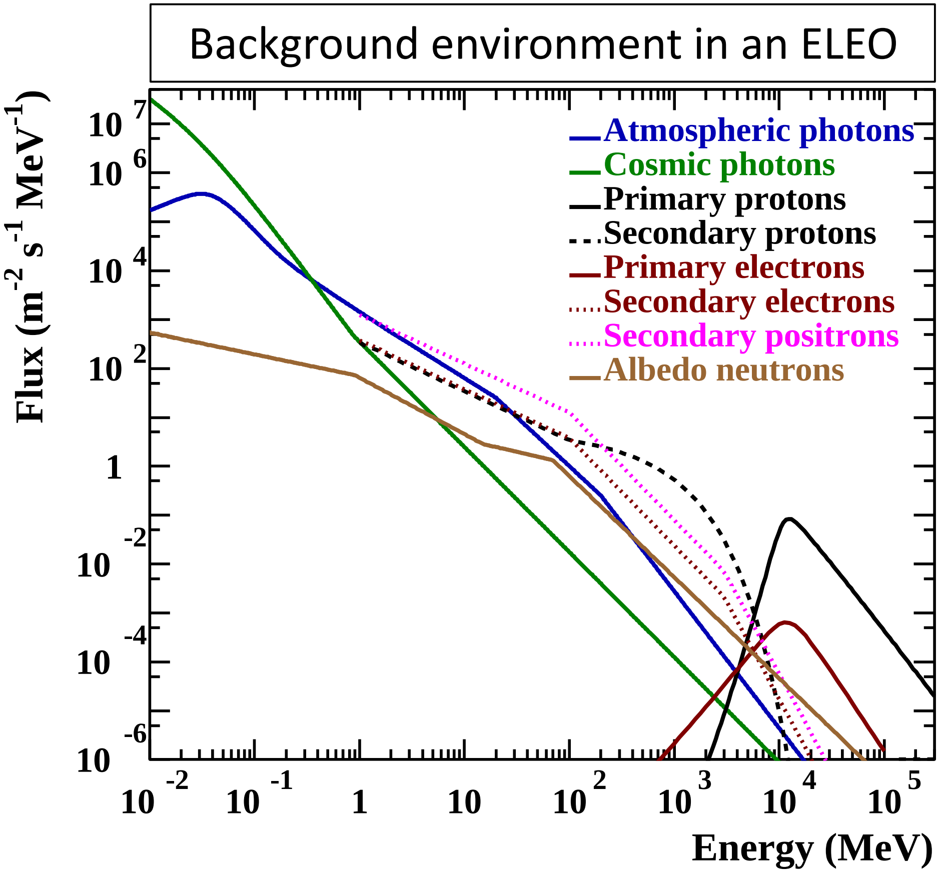


Mission profile

- **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



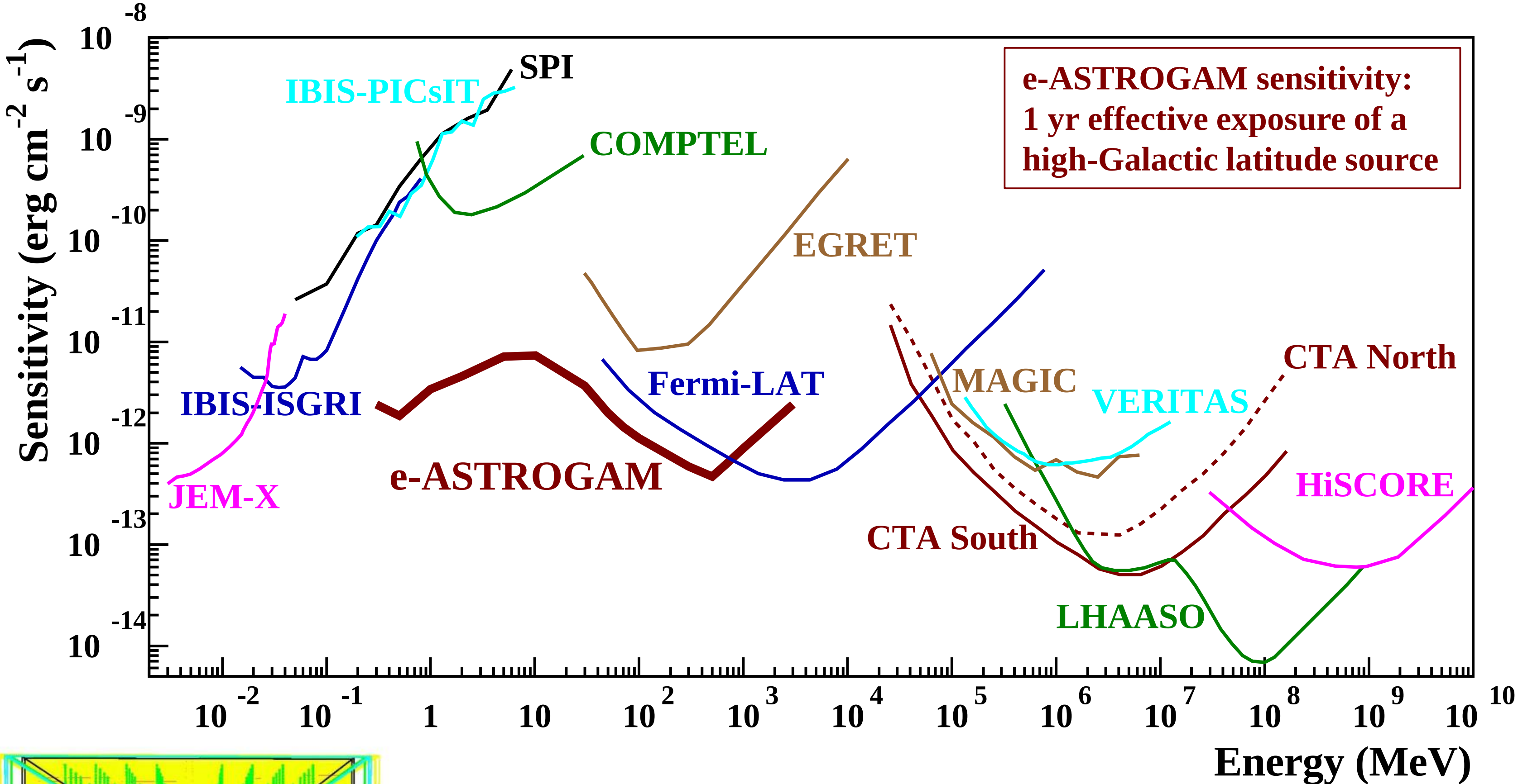


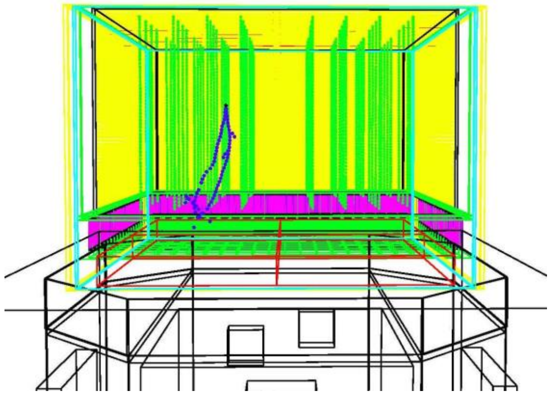


Threats

- No major threats: no active mechanical system, no active cooling…
- Full redundancy of the platform, as well as of the Payload Data Handling Unit and the Power Supply Unit
- Due to the payload modular design, a single failure of an element would cause only a small reduction of the overall performance
- Possible descoping options:
  - Tracker – reduce the number of Si layers
  - Calorimeter – replace 4 CsI(Tl) crystals of 5×5 mm^2 cross section by one of 1 cm side (loss of spatial resolution to be studied)
    33 856 → 8 464 crystals

e-ASTROGAM Performance assessment





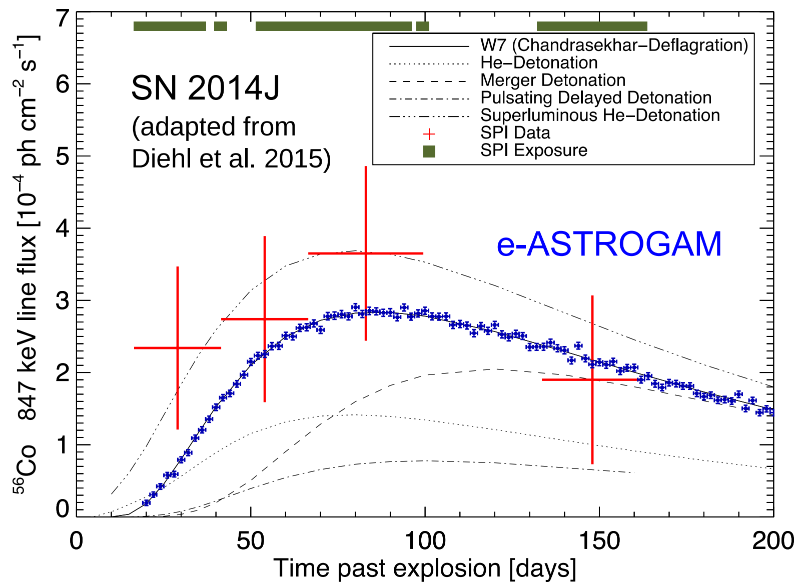
- e-ASTROGAM performance evaluated with **MEGAlib** (Zoglauer et al. 2006) and **Bogemms** (Bulgarelli et al. 2012) – both tools based on Geant4 – and a detailed numerical mass model of the gamma-ray instrument (talk by V. Fioretti)

e-ASTROGAM Line sensitivity

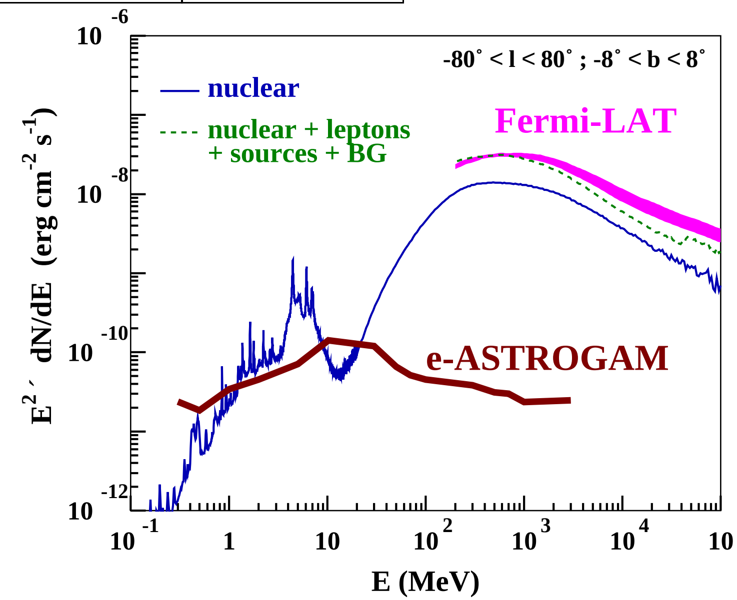
E (keV)	FWHM (keV)	Origin	SPI sensitivity (ph cm^{-2} s^{-1})	e-ASTROGAM sensitivity (ph cm^{-2} s^{-1})	Improvement factor
511	1.3	Narrow line component of the e+/e- annihilation radiation from the Galactic center region	5.2 ´ 10^{-5}	4.1 ´ 10^{-6}	13
847	35	^{56}Co line from thermonuclear SN	2.3 ´ 10^{-4}	3.5 ´ 10^{-6}	66
1157	15	^{44}Ti line from core-collapse SN remnants	9.6 ´ 10^{-5}	3.6 ´ 10^{-6}	27
1275	20	^{22}Na line from classical novae of the ONe type	1.1 ´ 10^{-4}	3.8 ´ 10^{-6}	29
2223	20	Neutron capture line from accreting neutron stars	1.1 ´ 10^{-4}	2.1 ´ 10^{-6}	52
4438	100	^{12}C line produced by low-energy Galactic cosmic-ray in the interstellar medium	1.1 ´ 10^{-4}	1.7 ´ 10^{-6}	65

⇒ R. Diehl
⇒ E. Churazov
⇒ R. Diehl
⇒ M. Hernanz
⇒ J. Kiener

- **SN Ia:**

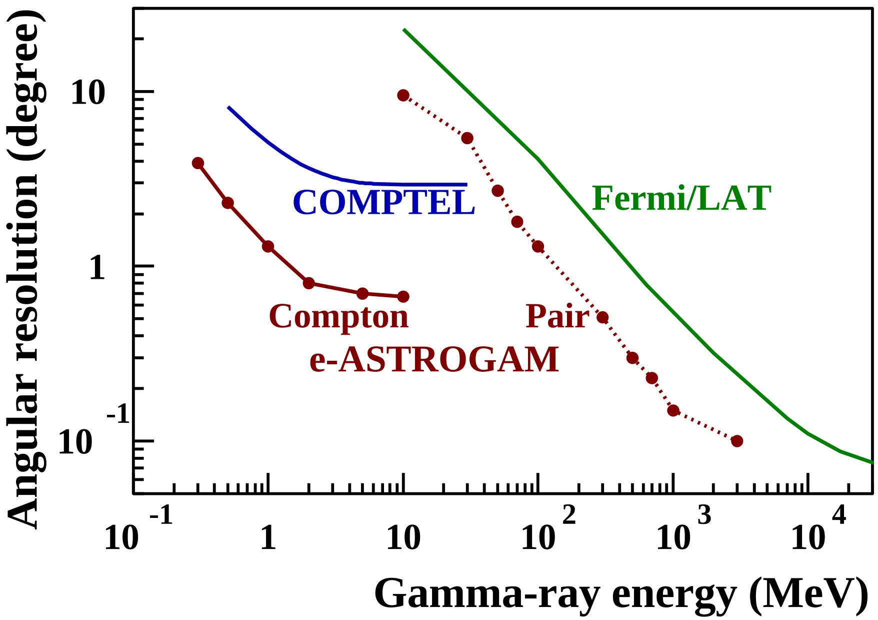


- **LECR:**

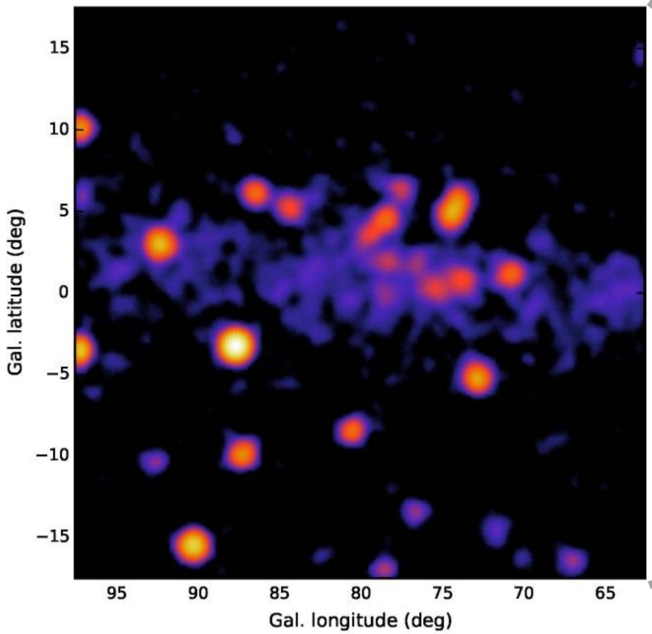


Angular resolution

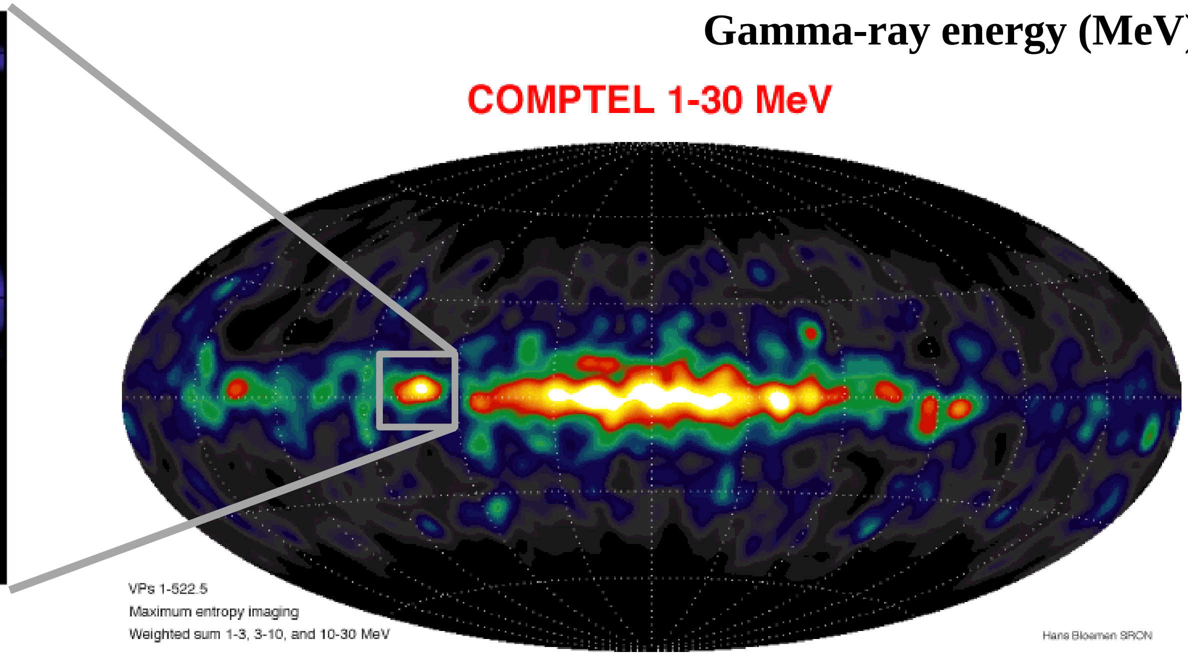
- Angular resolution improved close to the physical limits (Doppler broadening, nuclear recoil)



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

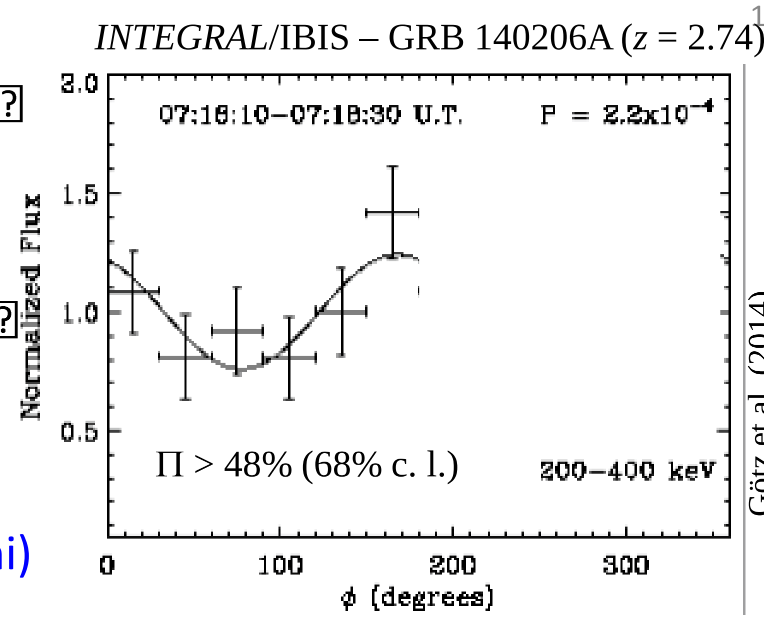


COMPTEL 1-30 MeV



Polarization

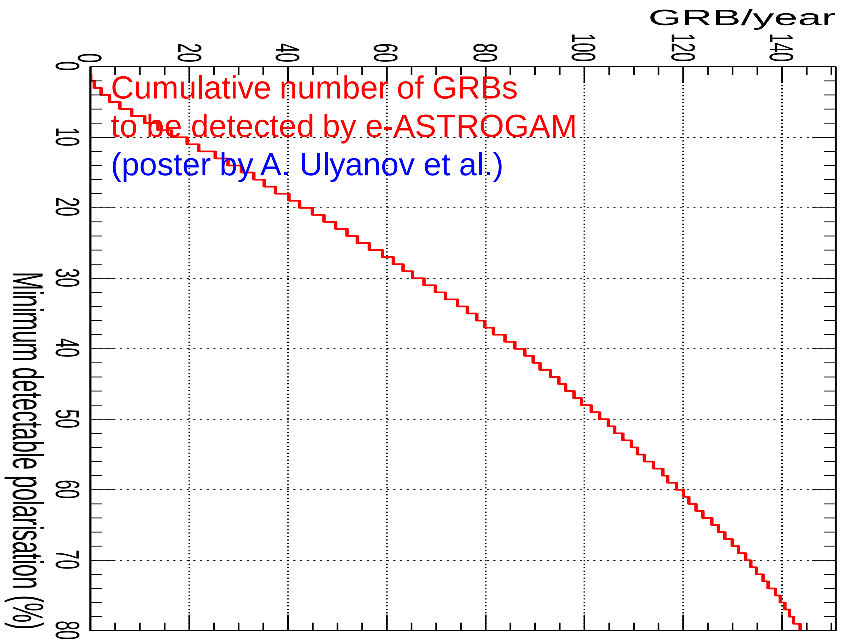
- Achievable Minimum Detectable Polarization
  MDP_{99} = 10% for a 10 mCrab source in 1 yr ⍰
  pulsars, magnetars, PWN, X-ray binaries

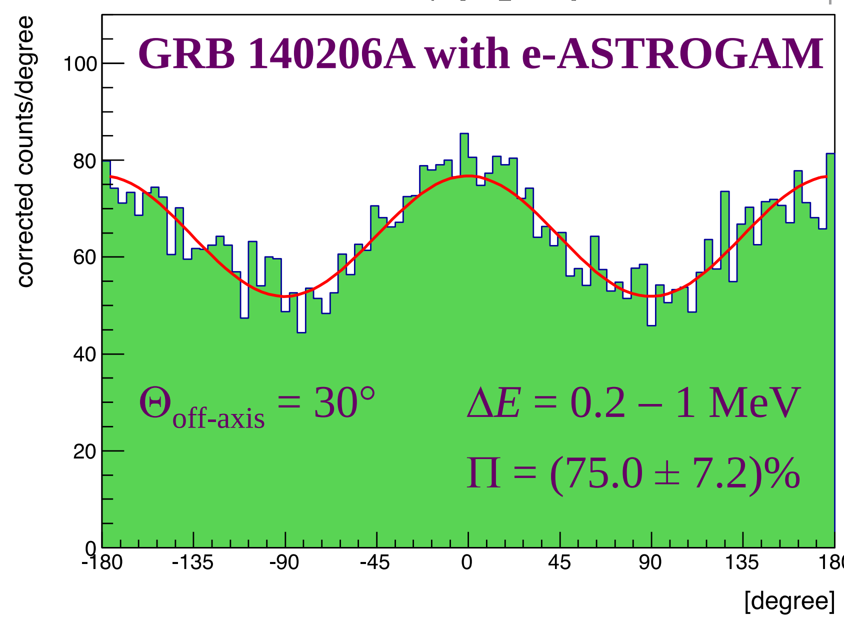


- e-ASTROGAM will measure the γ-ray polarization of ~ 100 **GRBs** per year ⍰
  jet composition + geometry, LIV etc…

- **Blazars** ⍰ leptonic vs hadronic models

(talks by C. Gouiffès, A. Shearer, D. Bernard, R. Mignani)



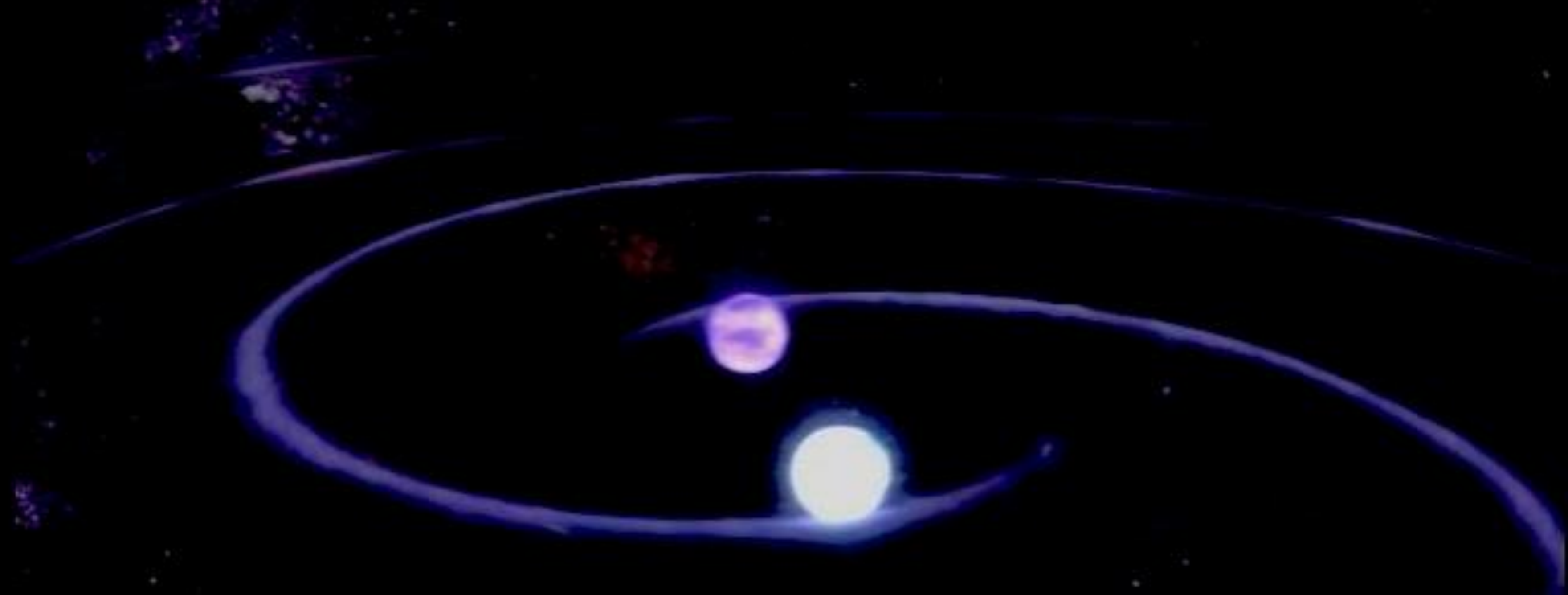


e-ASTROGAM

Conclusions

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

- **The simulated performances show that the mission has a great potential for science...**



Extra slides

Dimension, mass, power budgets

PAYLOAD MASS BUDGET		Predicted Mass [kg]	Maturity margin	Predicted mass + maturity margin [kg]
Silicon Tracker	Silicon tiles	59.0	5%	62.0
	FEEs, harness, glue	152.0	20%	182.4
	Mechanics	51.5	20%	61.8
Calorimeter	Crystals	305.0	5%	320.3
	FEEs, harness, housing	77.0	20%	92.4
Anticoincidence	Upper AC (Plastic, FEEs, mechanics)	76.0	20%	91.2
	ToF (Plastic, FEEs, mechanics)	60.0	20%	72.0
Electronic boxes	ST, Cal, AC Back-end electronics (BEEs)	30.0	20%	36.0
	PDHU	10.0	20%	12.0
	PSU	15.0	20%	18.0
Thermal control	Thermal harness	20.8	20%	25.0
Harness		22.0	20%	26.4
TOTAL		**878.3**		**999.4**

- Instrument dimension:
  120 x 120 x 78 cm^3
- Mass of the thermal control = thermal harness at payload level (based on CNES PASO simulations)

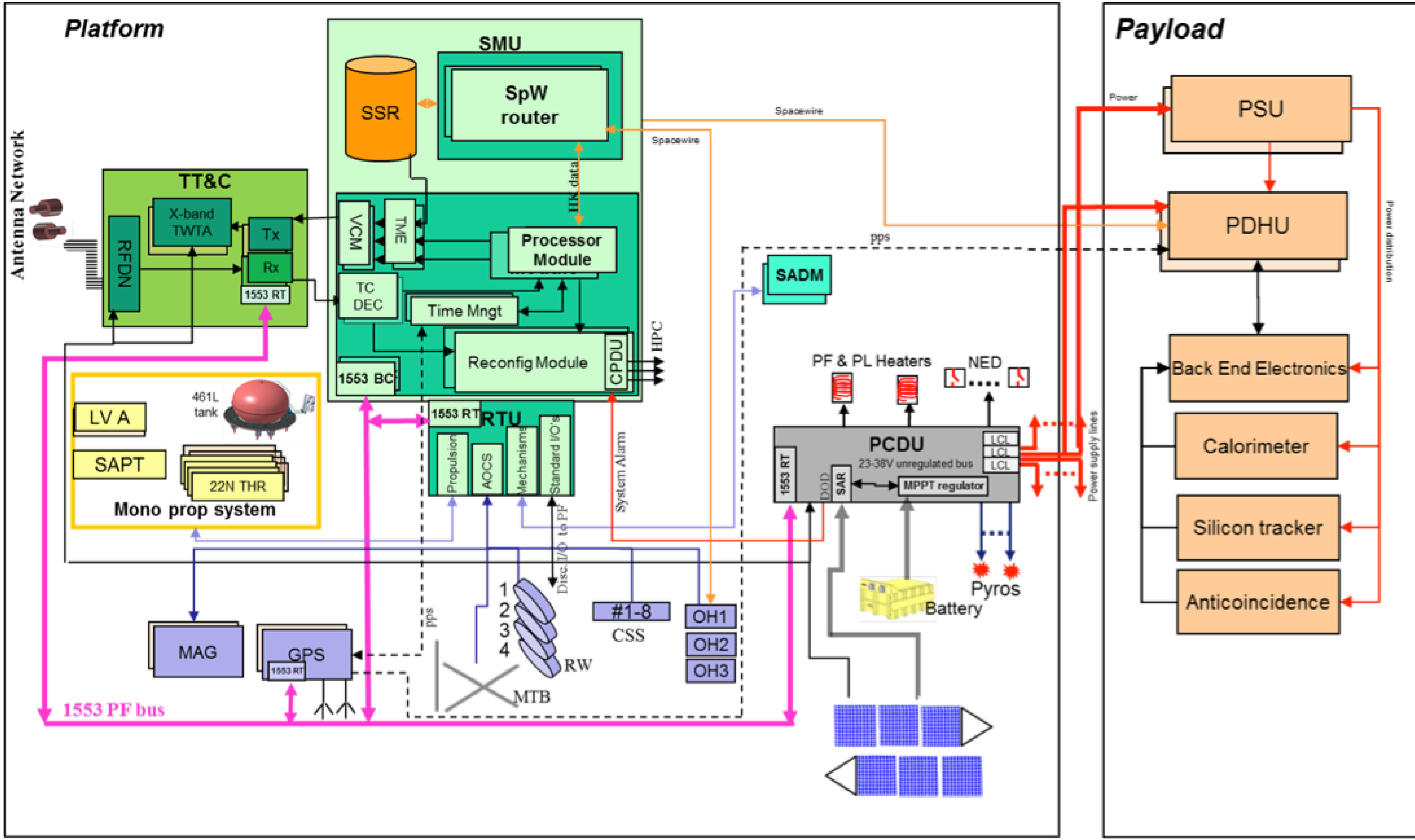
PAYLOAD POWER BUDGET	Design [W]	Margin	Total [W]
Silicon Tracker	688.1	20%	825.8
Calorimeter	28.4	20%	34.1
Anticoincidence (AC + ToF)	17.5	20%	21.0
Tracker, Calorimeter, AC BEEs	50.0	20%	60.0
PDHU	20.0	20%	24.0
PSU	273.0	20%	327.6
Heaters	40.0	20%	48.0
TOTAL	**1117.1**		**1340.5**

e-ASTROGAM Telemetry budget

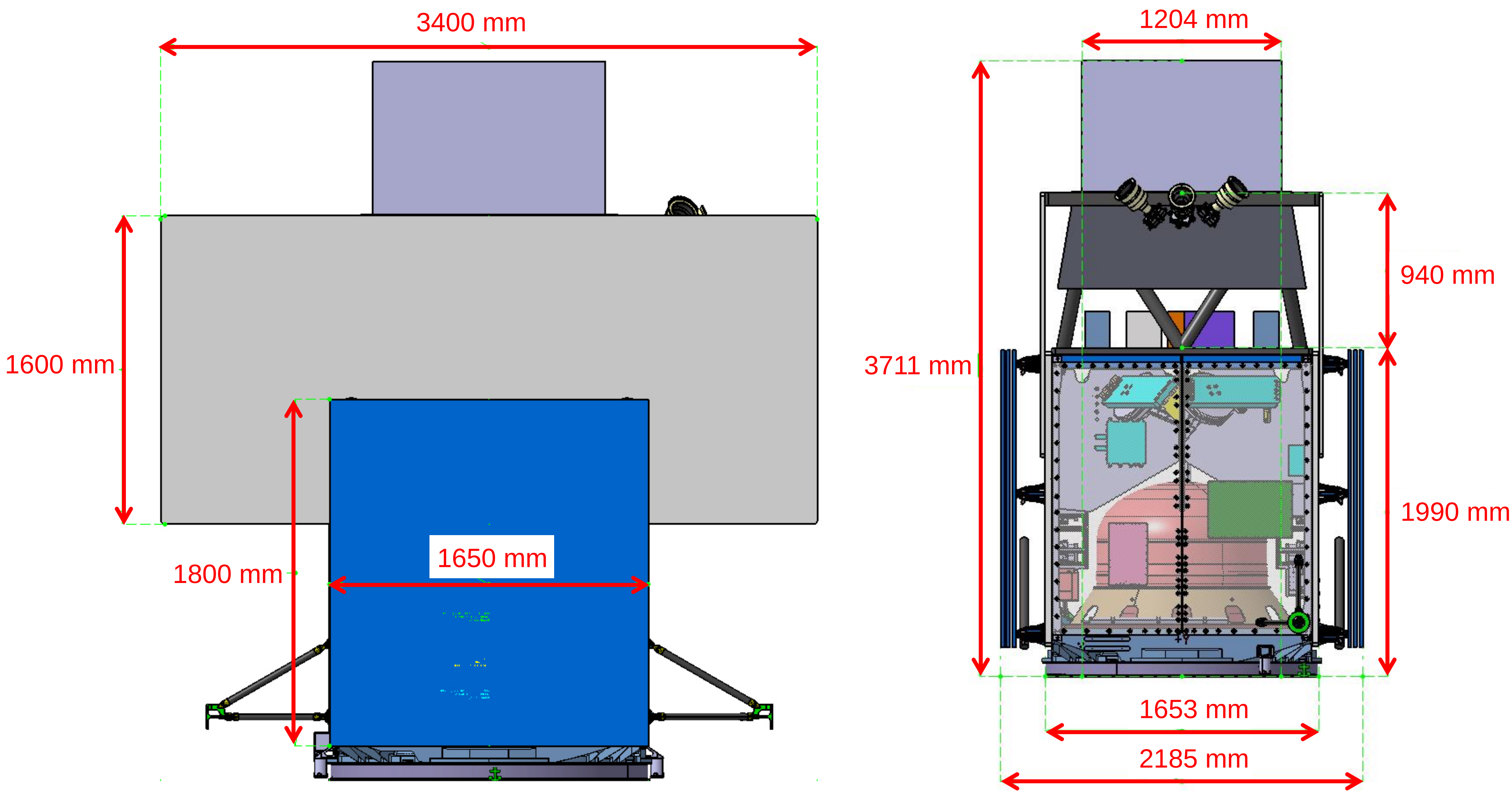
Data acquisition source	Average acquisition rate (kbps)	Notes
P/L HKs	40.0	50.000 HK parameters coded with 16 bits; sampling time: 20s
P/L engineering reports	0.1	TC acceptance/execution reports, anomaly reports, memory dump reports etc.
Gamma-ray Compton events (AC, Silicon Tracker, and Calorimeter data)	739.2	Average output event rate: 2800 Hz; average event packet length: 264 bits
Gamma-ray Pair events (AC, Silicon Tracker, and Calorimeter data)	2000.0	Average output event rate (>10MeV): 200 Hz; average event packet length: 10 kbits
Silicon Tracker Scientific ratemeters	32.0	2000 ratemeters (1 for each ladder); Integration time: 1s
Calorimeter Burst data	140.0	2 TGF/orbit (10s including pre-burst & post-burst); 1 GRB/day (100s including pre-burst & post-burst); average event rate: 16 kHz
Calorimeter Scientific ratemeters	10.4	Spectra of 13 energy channels between 30 keV - 200 MeV; integration time: 10ms; 8 bits per energy bin
AC Scientific ratemeters	6.7	5 ratemeters (1 for each AC side); integration time: 1ms; 8 bits per energy bin
Total (kbps)	2968.4	
Margin 20%	593.7	
Total with margin (kbps)	3562.1	

⇒ ~ 2.5 Gbytes per orbit (before data compression by a factor > 2.6)

e-ASTROGAM Avionics

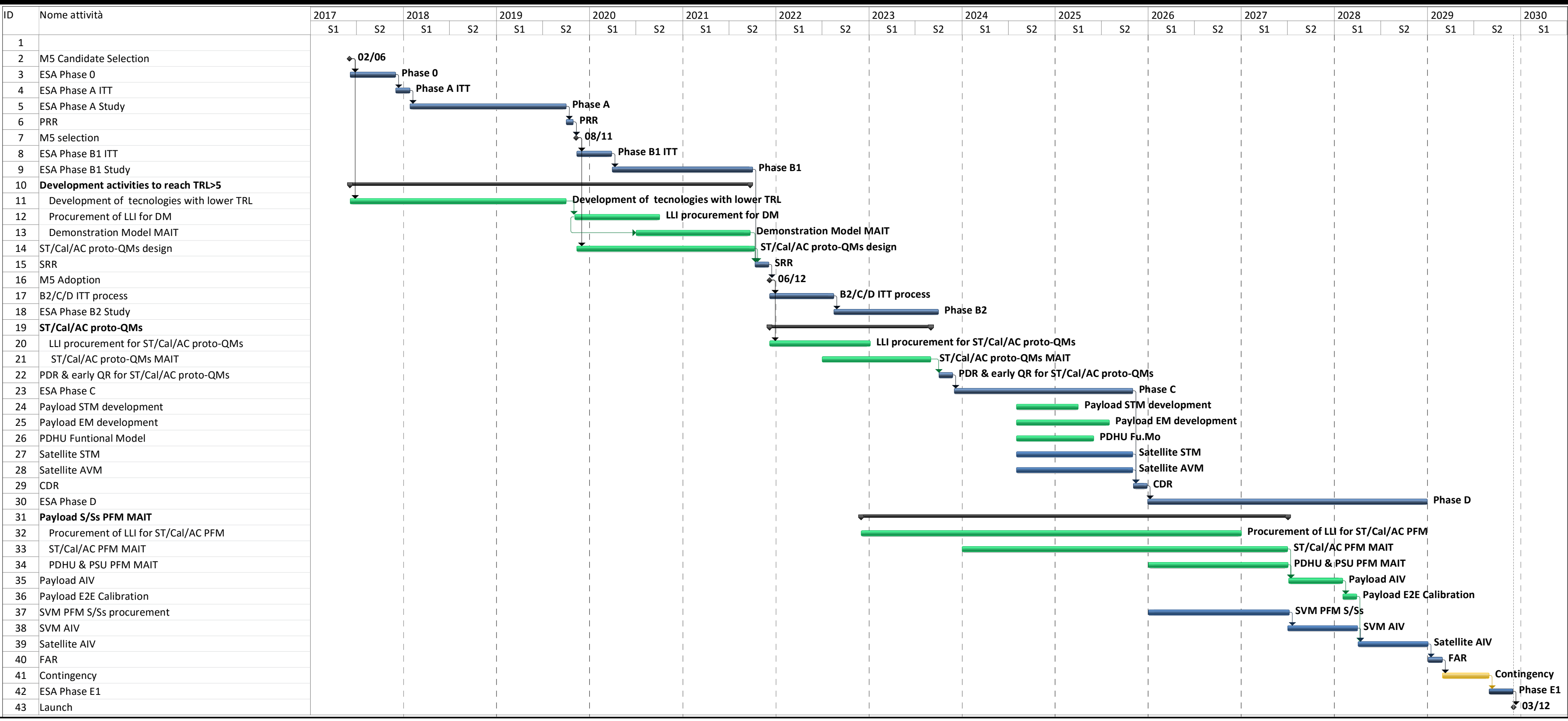


e-ASTROGAM Dimensions



- **Double-sided silicon strip detectors** esa
  - *Number*: 5 600 → 7 500 with prototypes, models and spare detectors
  - *Possible manufacturers*: Hamamatsu (Jp.), FBK (It.), IMB-CNM (CSIC, Esp.)
  - *Screening, characterization*: (+ ?)
- **Silicon Tracker FEE ASIC** esa
  - *Number*: 26 880 → 36 000 with prototypes and models
  - *Manufacturer*: AMS under coord. of CEA (prod., backend process)
- **Calorimeter Crystals** esa
  - *Number*: 33 856 → 45 000 with prototypes, models and spare detectors
  - *Possible manufacturers*: Saint-Gobain Crystals, Detect Europ (Amcrys)
  - *Screening, characterization*:
- **Calorimeter silicon drift detectors**
  - *Manufacturer*: FBK under coordination of INFN Trieste (232 wafers of 6'')
- **Calorimeter FEE ASIC**
  - *Manufacturer*: AMS under coordination of Politecnico di Milano

e-ASTROGAM Schedule - models



❑ Planning to accommodate the mass production involved in the P/L implementation

- **Definition phase** (A/B1; S2-2017/S2-2021): test benches, prototyping (TRL >5), design proto-QMs
- **Phase B2** (S2-2021/S2-2023): development and qualification of proto-QMs => start P/L subsystem mass production after PDR
- **Phase B2/C/D** (S2-2022/S1-2028): mass production for P/L S/S PFMs, P/L AIV, P/L E2E calibration
- **Phase D/E1** (S1-2026/S2-2029): SVM S/S PFM, SVM AIV, Satellite AIV, Contingency (6 m), Launch

e-ASTROGAM Costing

e-ASTROGAM cost at completion for ESA

Activity	Cost estimates (million € ec 2016)		Notes
1. Launch (S/C adaptor included)		73	Ariane 6.2
2. Spacecraft		144	Based on platform costing
Project Office and Engineering	36		
SVM products	84		
AIT Platform + AIV Satellite	24		
3. ESA contribution to P/L		60	Procurement of silicon detectors, CsI crystals, and Tracker ASICs
4. ESA contribution to Science Data Center		20	
5. Ground Segment (MOC)		42	
6. Ground Segment (SOC)		42	
7. ESA internal cost		57	15% of the ESA cost for items 1 - 6
8. Contingency		44	10% of the ESA cost for items 1 - 7
TOTAL COST FOR ESA		**482**	

Contribution to P/L development by national agencies

SUB-SYSTEMS	Cost (M€)	Programmatic involvement
P/L SYSTEM	20	Italy, France, Germany, Switzerland, Spain, Sweden, Poland, Ireland, Denmark
TRACKER	30	Italy, Switzerland, France, Germany, Spain, Denmark
CALORIMETER	20	France, Germany, Italy, Ireland, Spain
ANTICOINCIDENCE	10	Germany, Sweden, Spain
DATA HANDLING & POWER SUPPLY	10	Germany, Poland, France
TOTAL P/L	**90**	

Contribution to e-ASTROGAM science and operation by national agencies

	Cost (M€)	Programmatic involvement
CONTRIBUTION TO SCIENCE DATA CENTER	5	All
MALINDI GROUND STATION (3 YEARS)	6	Italy
TEAM SUPPORT	20	All
TOTAL	**31**	