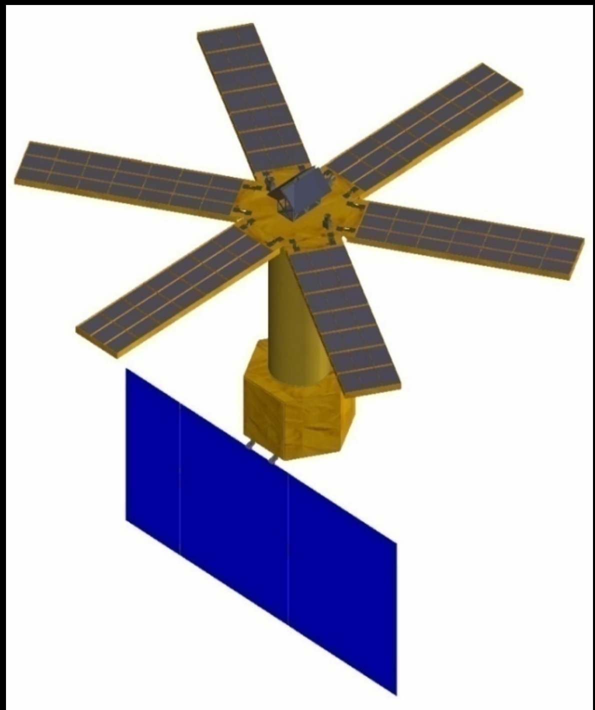
LOFT

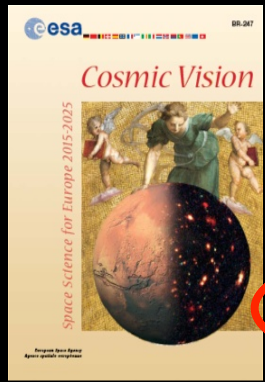
the Large Observatory For x-ray Timing

Jan-Willem den Herder (SRON, Utrecht, The Netherlands)
Marco Feroci (INAF/IAPS, Rome, Italy)

on behalf of the LOFT Consortium

LOFT: the Large Observatory For x-ray Timing





3. What are the fundamental physical laws of the Universe?

3.1 Explore the limits of contemporary physics

Use stable and weightless environment of space to search for tiny deviations from the standard model of fundamental interactions

3.2 The gravitational wave Universe

Make a key step toward detecting the gravitational radiation background generated at the Big Bang

3.3 Matter under extreme conditions

Probe gravity theory in the very strong field environment of black holes and other compact objects, and the state of matter at supra-nuclear energies in neutron stars

LOFT Consortium: national representatives:

Jan-Willem den Herder	SRON, the Netherlands
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Luigi Stella	INAF/OAR-Rome, Italy
Michiel van der Klis	Univ. Amsterdam, the Netherlands
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Juhani Huovelin	Univ. of Helsinki, Finland
Paul Ray	Naval Research Lab, USA
Joao Braga	INPE, Brazil
Tad Takahashi	ISAS, Japan

LOFT Science Team composed of scientists from:

Australia, Brazil, Canada, CzechRepublic, Denmark, Finland, France, Germany, Greece, Ireland, Israel, Italy, Japan, theNetherlands, Poland, Spain, Sweden, Switzerland, Turkey, United Kingdom, USA

The LOFT Mission

LOFT is specifically designed to exploit the diagnostics of very rapid X-ray flux and spectral variability in compact objects, yielding unprecedented information on strongly curved spacetimes and matter under extreme conditions of density and magnetic field strength.

LOFT will investigate variability from submillisecond QPO's to years long transient outbursts.

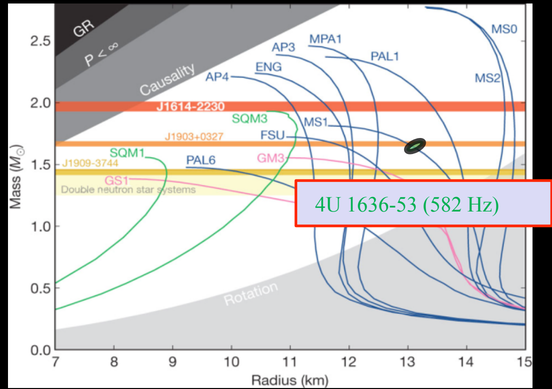
The LOFT LAD has an effective area ~20 times larger than any largest predecessor, uniquely combined with a "CCD-class" energy resolution.

The LOFT WFM has a few steradian field of view at soft X-rays to discover and localise X-ray transients and impulsive events and monitor spectral state changes, triggering follow-up observations and providing a wealth of science in its own.

The LOFT Science

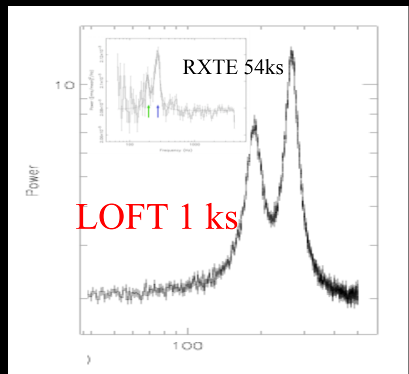
Neutron Star Structure and Equation of State of ultradense matter:

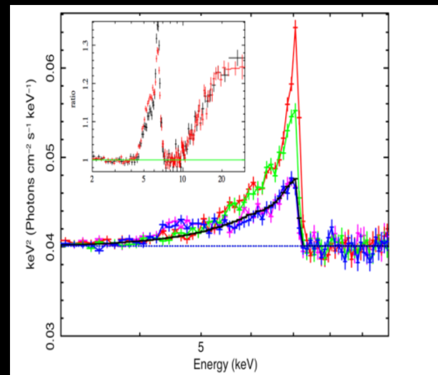
- neutron star mass and radius measurements
- neutron star crust properties



Strong gravity and the mass and spin of black holes

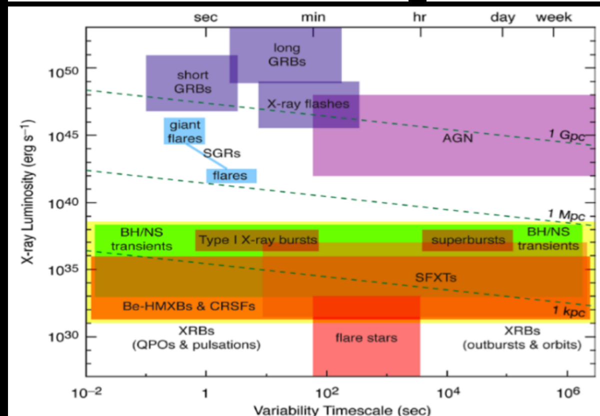
- QPOs evolution and in the time domain
- Fe line reverberation studies in bright AGNs
- Relativistic precession





Observatory Science, for virtually all classes of relatively bright sources, including:

X-ray bursters, High mass X-ray binaries, X-ray transients (all classes), Cataclismic Variables, Magnetars, GRBs, Nearby galaxies (SMC, LMC, M31, …), AGNs …



Science goals: EoS

EOS1 Constrain the Equation of State of supranuclear-density matter by the measurement, using three complementary types of pulsations, of mass and radius of at least 4 NS with an instrumental accuracy of 4% in mass and 3% in radius. .

EOS2 Provide an independent constraint on the EoS by filling out the accreting NS spin distribution through discovering coherent pulsations down to an amplitude of about 0.4% (2%) rms for a 100 mCrab (10 mCrab) source in a time interval of 100 s, and oscillations during type I bursts down to typical amplitudes of 1% (2.5%) rms in the burst tail (rise) among 35 NS covering a range of luminosities, inclinations and binary orbital phases.

EOS3 Probe the interior structure of isolated NSs by observing seismic oscillations in Soft Gamma-ray Repeater intermediate flares

Science goals: Strong Field Gravity

SFG1 detect strong-field GR effects by measuring epicyclic motion in high frequency QPOs from at least 3 black hole X-ray binaries.

SFG2 Detect disk precession due to relativistic frame dragging with the Fe line variations in low frequency QPOs for 10 NSs and 5 BHs

SFG3 Detect kHz QPOs at their coherence time, measure the waveforms and quantify the distortions due to strong-field GR for at least 10 NSs covering different inclinations and luminosities.

SFG4 Measure the Fe-line profile and carry out reverberation mapping of 5 BHs in binaries to provide BH spins to an accuracy of 5% of the maximum spin (a/M=1), constraining fundamental properties of stellar mass black holes and of accretion flows in strong field gravity.

SFG5 Measure the Fe-line profile of 30 AGNs, and carry out reverberation mapping of the 8 AGNs most suitable for the latter purpose, to provide BH spins to an accuracy of 20% of the maximum spin (10% for fast spins) and measure their masses with 30% accuracy, constraining fundamental properties of supermassive black holes and of accretion flows in strong field gravity.

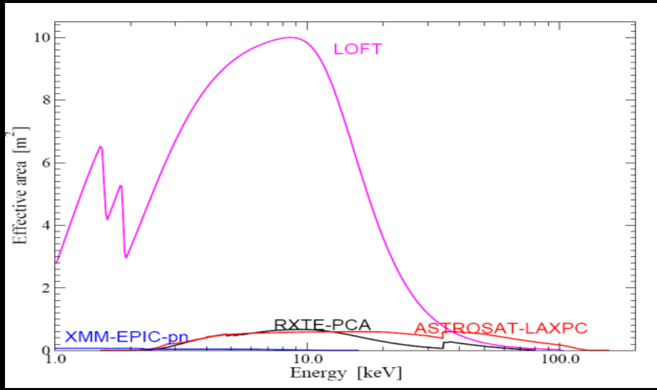
observing program

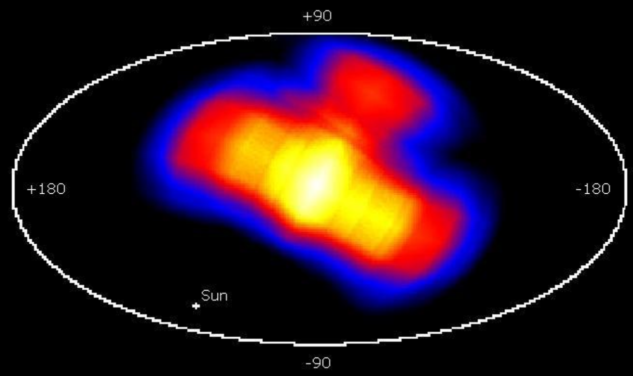
4-years Breakdown: 21 Ms core science + ~30 Ms for observatory science

Source Type	TOO	Sources	Pointings	Total Time (ks)	Science Goal
BH transient outbursts	Yes	4	800	2400	SFG1,2,4
Persistent BH	No	2	400	1600	SFG 1,2,4
AGN	No	30	50	8000	SFG 5
Msec pulsar outburst	Yes	3	250	1000	EOS1, SFG2,3
NS transient bright outburst	Yes	3	250	1800	EOS 1,2 SFG 3
Persistent bright NS	No	12	350	4800	EOS 1,2 SFG 2,3
NS transient weak outburst	Yes	6	6	120	EOS 2
Persistent weak NS	No	14	14	280	EOS 2
Bursters	Yes	10	40	1000	EOS 2

A 4 year mission will guarantee a > 99% probability to detect two BHCT with HF QPO and two Accreting Millisecond X-ray Pulsar and a 95% probability to detect 3

The LOFT Instruments





LAD – Large Area Detector	
Effective Area	4 m^2 @ 2 keV 8 m^2 @ 5 keV 10 m^2 @ 8 keV 1 m^2 @ 30 keV
Energy range	2-30 keV primary 30-80 keV extended
Energy resolution FWHM	260 eV @ 6 keV 200 eV @ 6 keV (45% of area)
Collimated FoV	1 degree FWHM
Time Resolution	10 μs
Absolute time accuracy	1 μs
Dead Time	<1% at 1 Crab
Background	<10 mCrab (<1% syst)
Max Flux	500 mCrab full event info 15 Crab binned mode

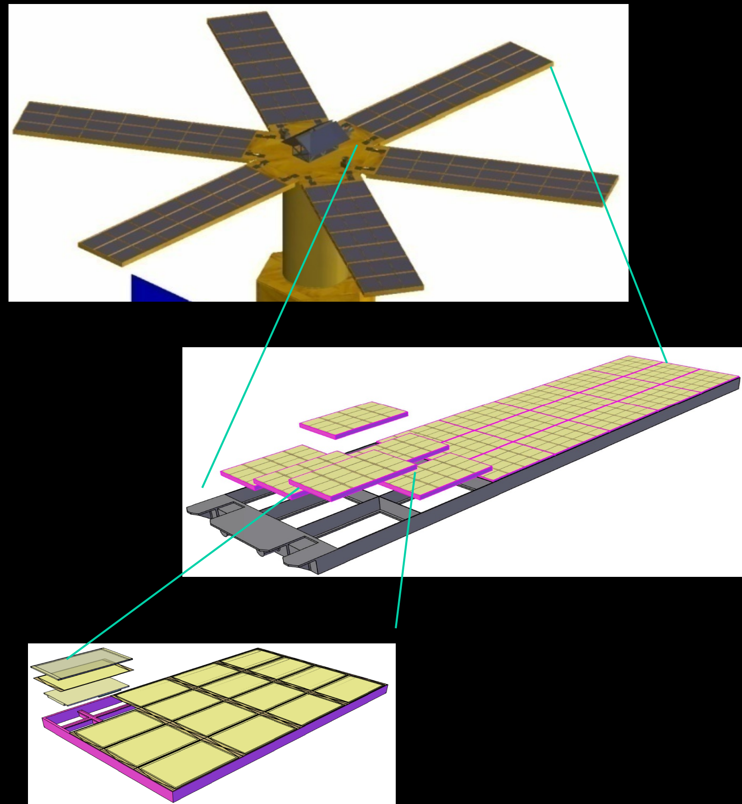
WFM- Wide Field Monitor	
Energy range	2-50 keV primary 50-80 keV extended
Active Detector Area	1820 cm^2
Energy resolution	300 eV FWHM @ 6 keV
FOV (Zero Response)	180°x90° + 90°x90°
Angular Resolution	5' x 5'
Point Source Location Accuracy (10-σ)	1' x 1'
Sensitivity (5-σ, on-axis) Galactic Center, 3 s Galactic Center, 1 day	 270 mCrab 2.1 mCrab
Standard Mode	5-min, energy resolved images
Trigger Mode	Event-by-Event (10μs res) Realtime downlink of transient coordinates

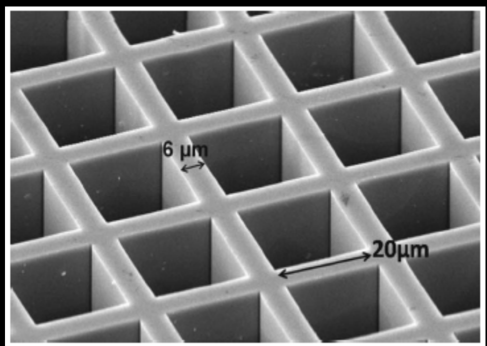
The Large Area Detector (LAD)

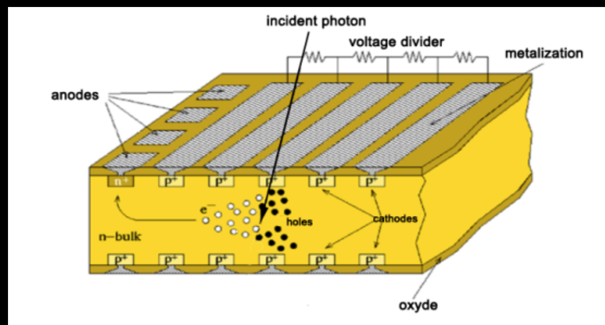
Fully modular/redundant by design
(126 independent modules)

Fine detector segmentation
(5×10^5 read-out channels, 0.3 cm^2 each, deadtime and the pile-up minor issues).

Driving Technology:
large-area Silicon Drift Detectors and capillary plate collimators.

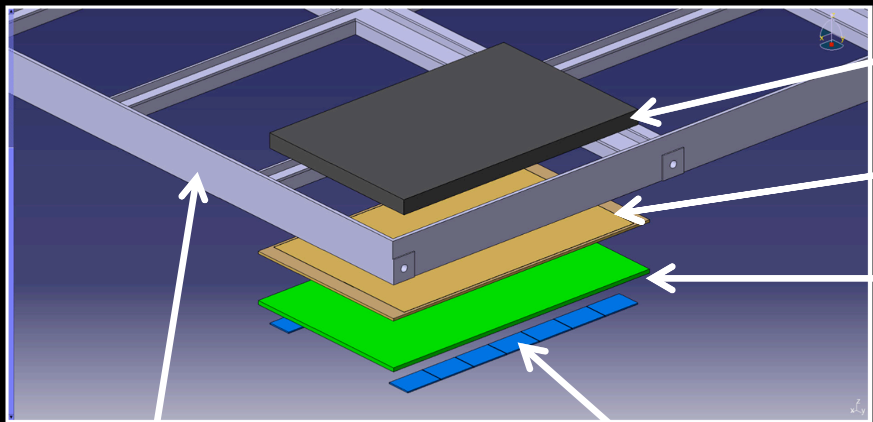






The Key to LOFT:
low weight/power/volume per unit effective area
126 modules, each with 16 SDDs (18 m^2) = 2016 SDDs
CCD class resolution

~10 mm



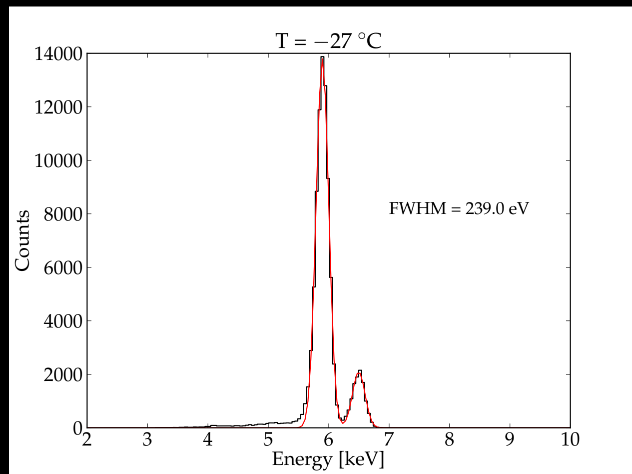
Capillary Plate Collimator
(~6 kg/m^2)

Silicon Drift Detector
(~1.3 kg/m^2)

Readout electronics
(~2.5 kg/m^2)

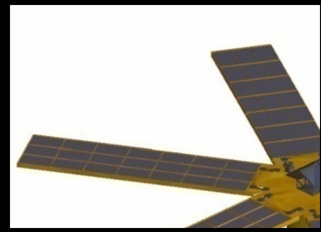
Mechanical support, Power Distribution, Interfaces, …

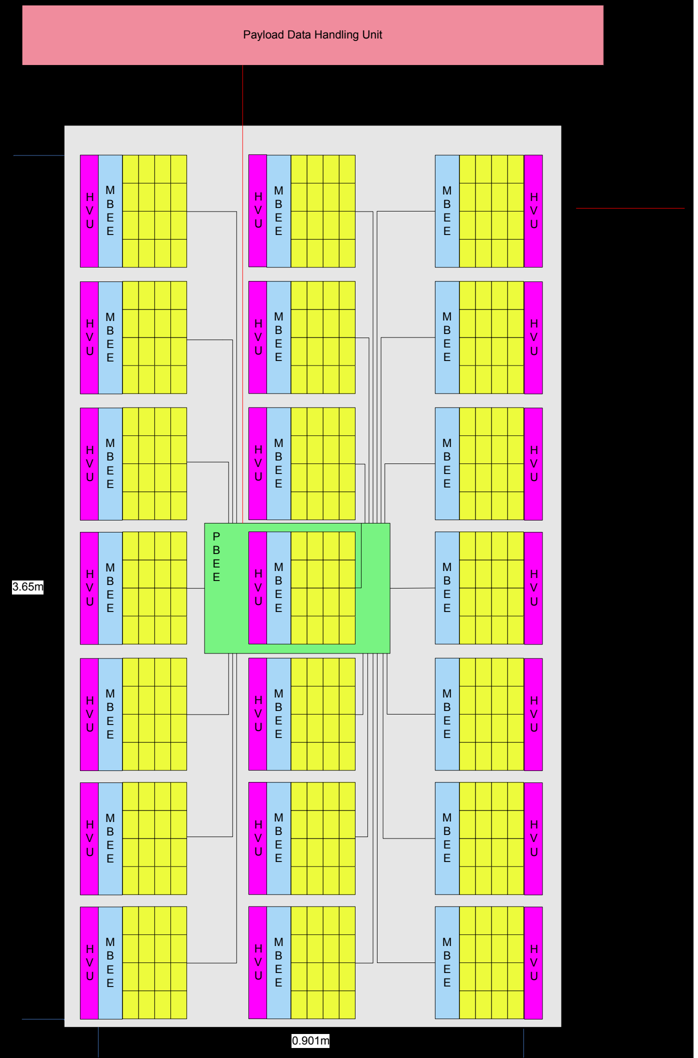
ASICs (mixed signal)



Key characteristics

- ~ 125 modules with16 detectors
- Each detector integrated with FEE (analog to digital)
- HV (1.3 kV) and electronics per module
- A panel backend electronics per ~ 20 modules on a panel
- 2 or 5 panels
- Mass: 1182 kg (margin included)
- Power:1208 W (margin included)





background

Simulated sources in a GEANT mass model:

1. Cosmic diffuse X-ray background

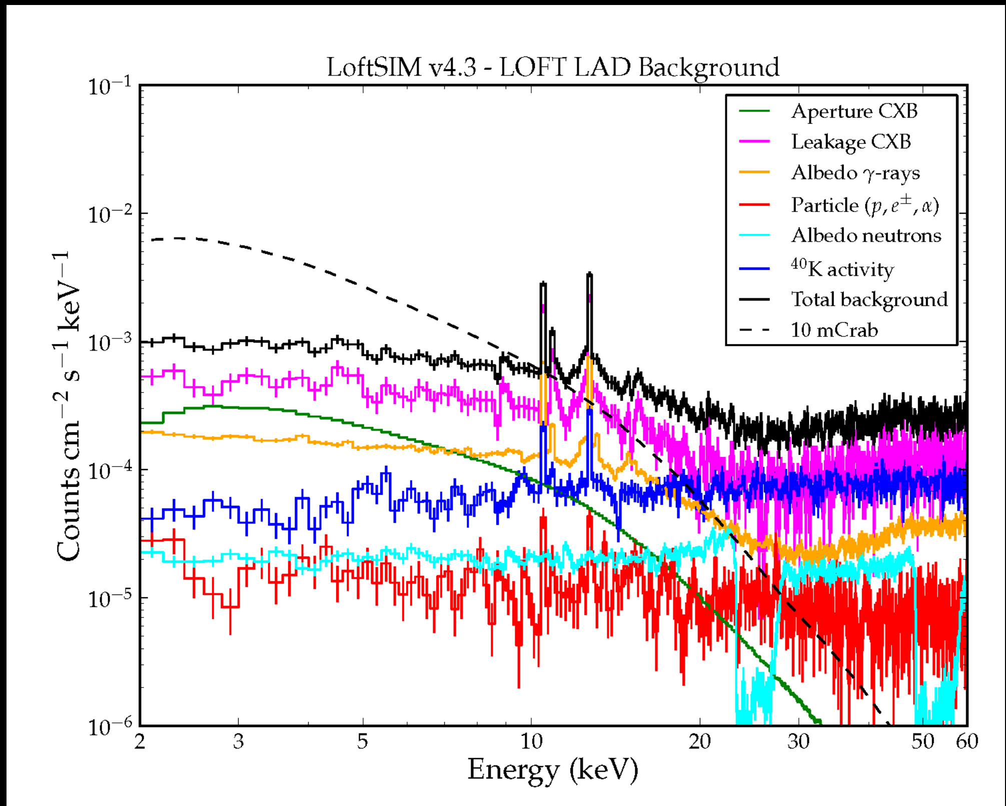
2. Earth albedo gamma-rays

3. Residual primary cosmic rays

4. "Secondary", Earth atmosphere generated, cosmic rays

5. Earth albedo neutrons

6. Potassium natural radioactivity (collimator)

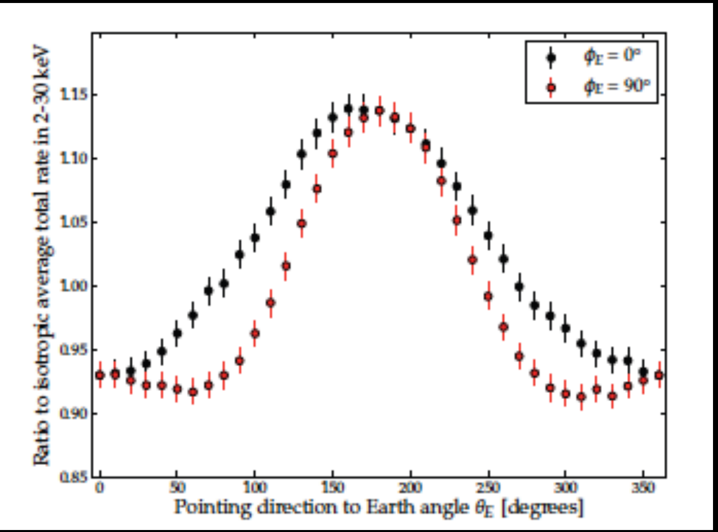


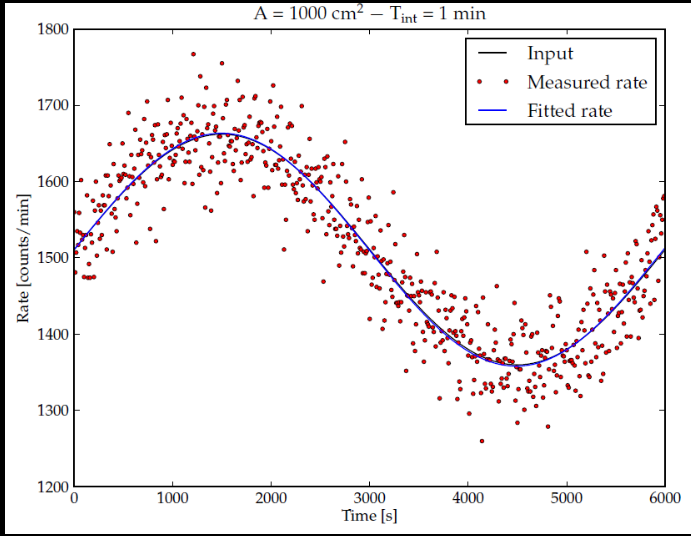
Background: knowledge

LAD background is dominated (>80%) by high energy photons of CXB and Earth albedo "leaking" through the collimator: steady and predictable

modulation of the background due to the different spectrum of CXB and Albedo as function of orbit and pointing. Max modulation is 20% (cf. factor 2-3 of RXTE)

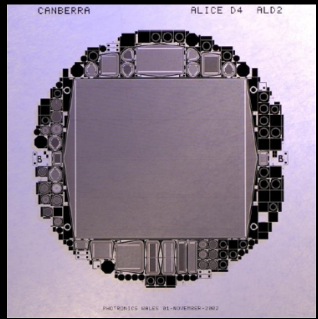
One module blocked (<1% of the area) tomonitor the non-aperture background (90% of total), providing an independent modelling of the background variation with 0.3% accuracy over the orbital timescale.

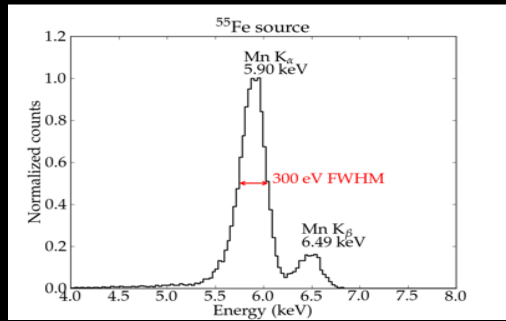


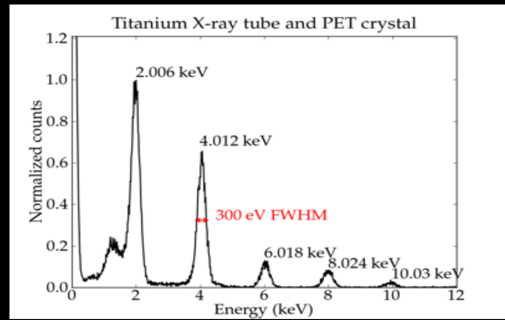


SDD development (INAF/FBK)

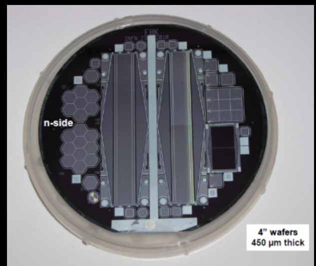
ALICE
(2002)

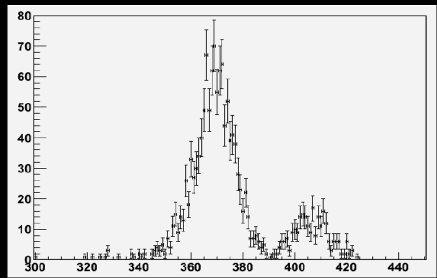


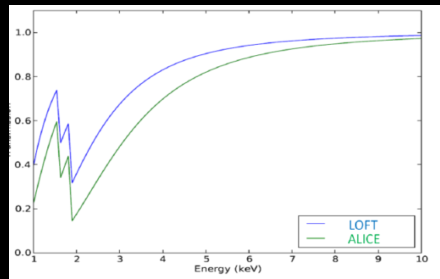




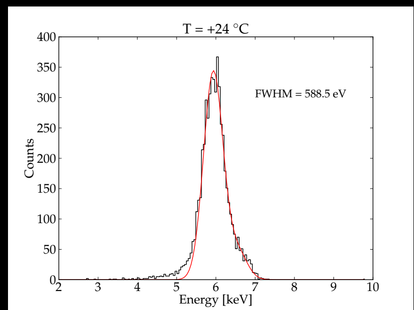
FBK-1
(2010-11)

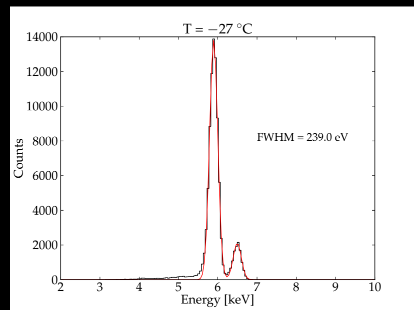




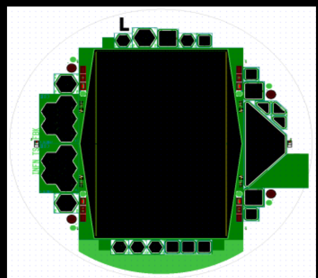


FBK-2
(2011-12)



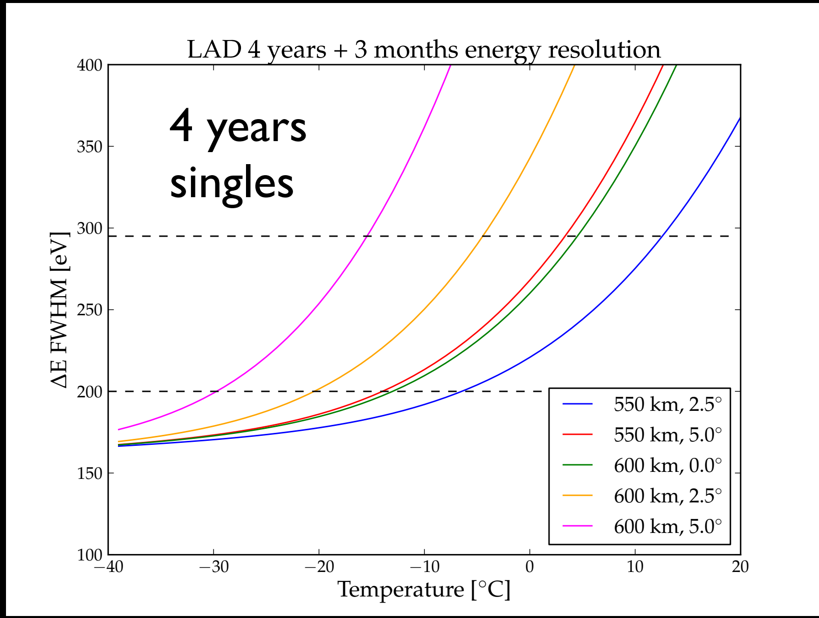


FBK-3
(end-2012)

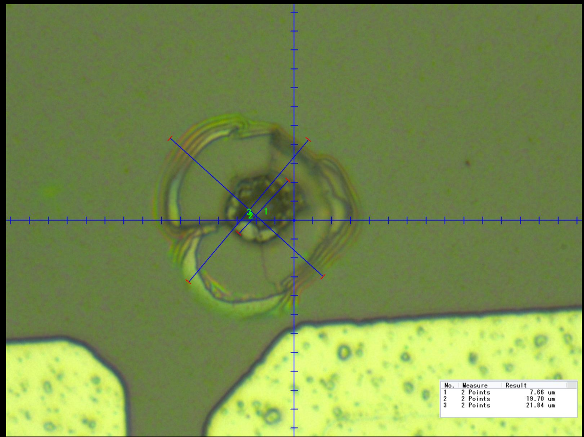


SDD operations

Radiation damage for 550 km, *i* < 2.5° dominated by initial leakage current. Contributions from soft protons and NIEL due to orbit < 10% and 5%. Temperature < -7 degree C



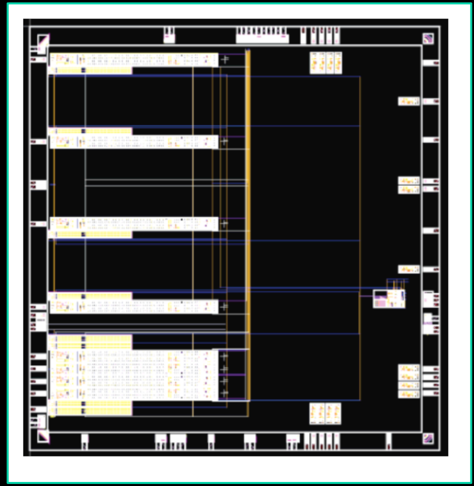
Micro meteorites: < 2 % of area at EOL (worst case analysis)



ASIC and collimator development

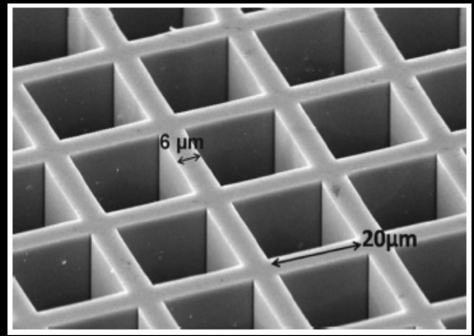
ASIC development (IRAP, France)

- First design (analog part) demonstrated performance
- Design ongoing for integrated digital part



Collimator development (Leicester & Photonis)

- Same technology as for BeppiColombo MIXS instrument (MCP leadglass, rectangular pores, OAR of 66%)
- Optimization ongoing (open area fraction)



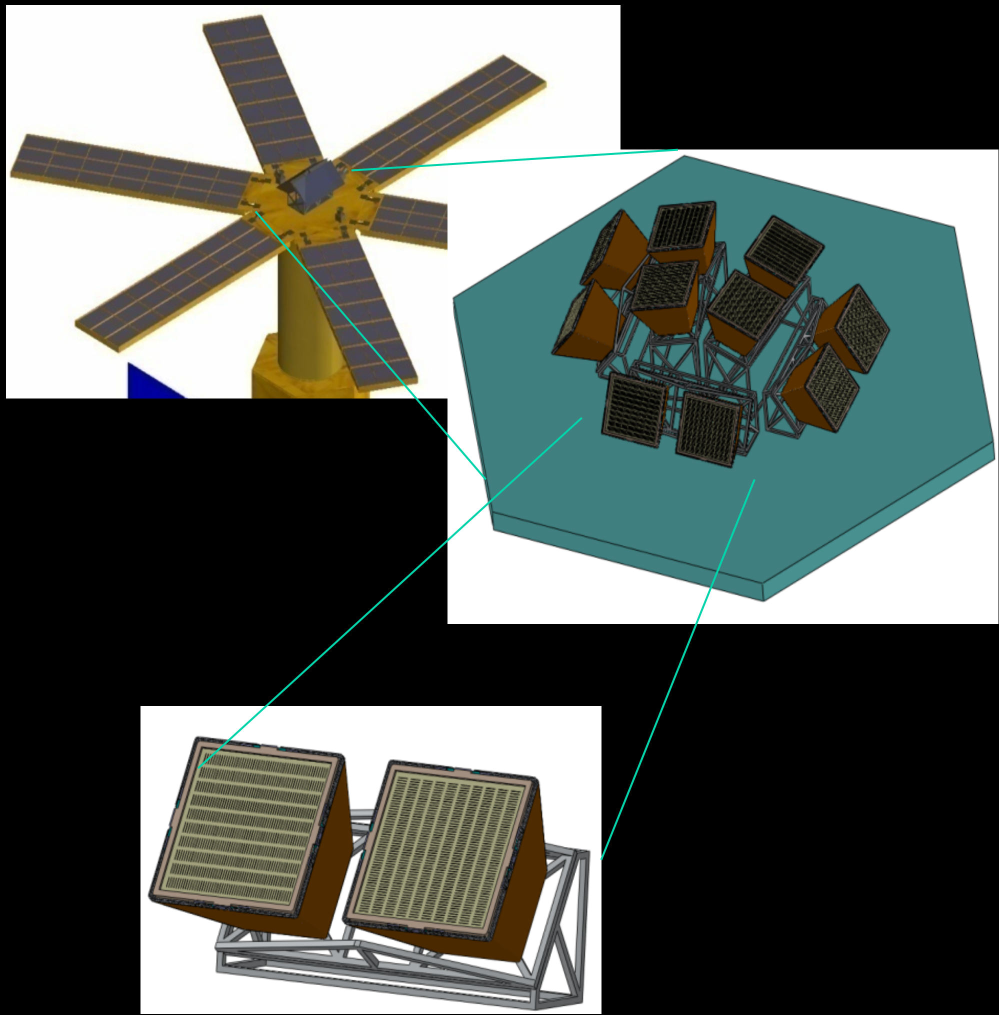
The Wide Field Monitor (WFM)

5 Independent Units, each one composed of 2 cameras.

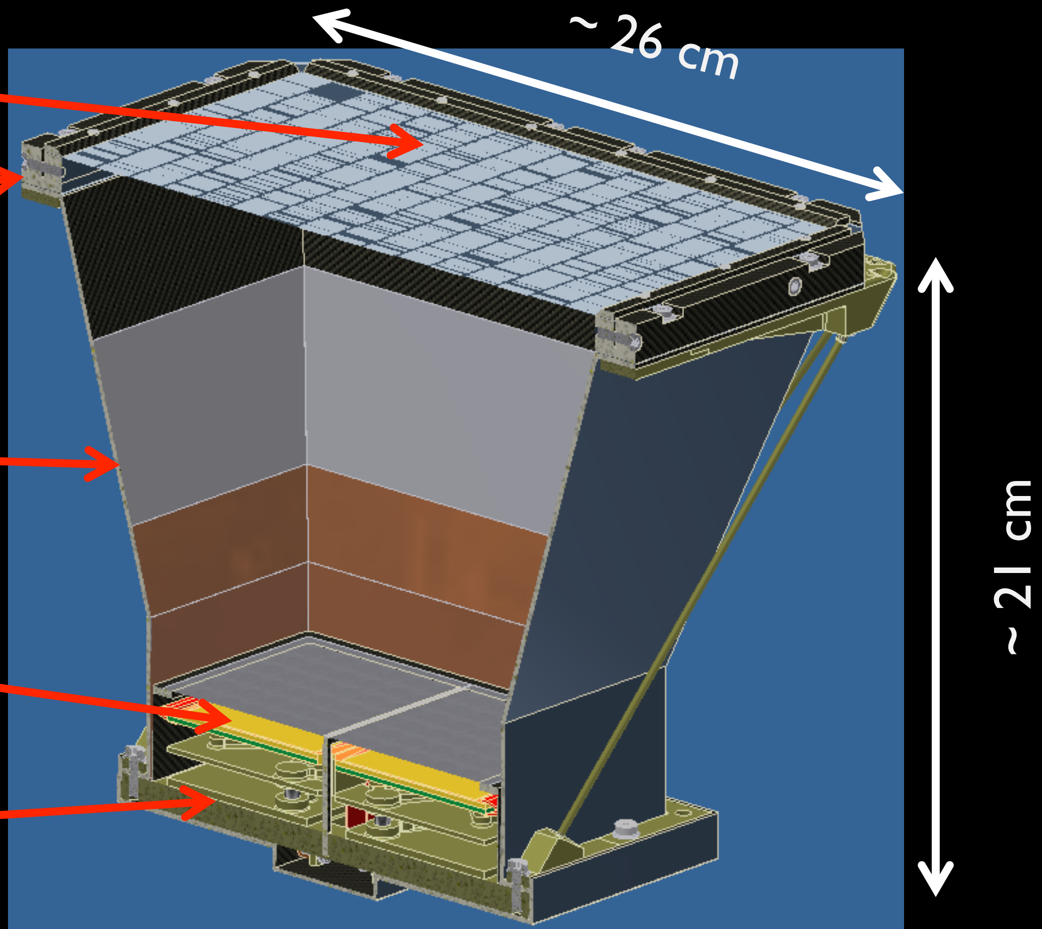
WFM FoV covers >50% of the (LAD-accessible) sky at any time, in the 2-50 keV energy range

Onboard triggering, imaging and coordinate distribution of transient events.

Driving Technology:
large-area Silicon Drift Detectors (same as LAD) and coded masks.

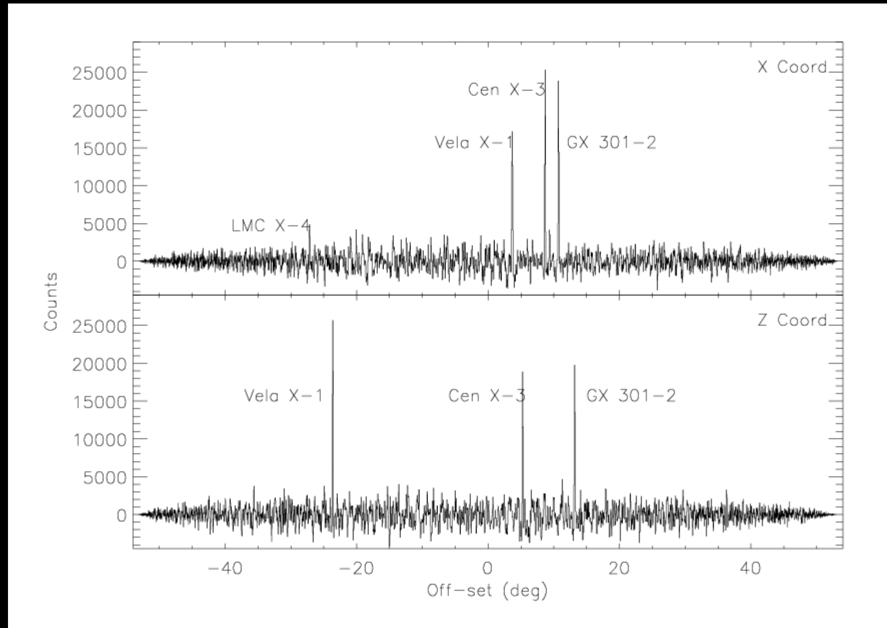


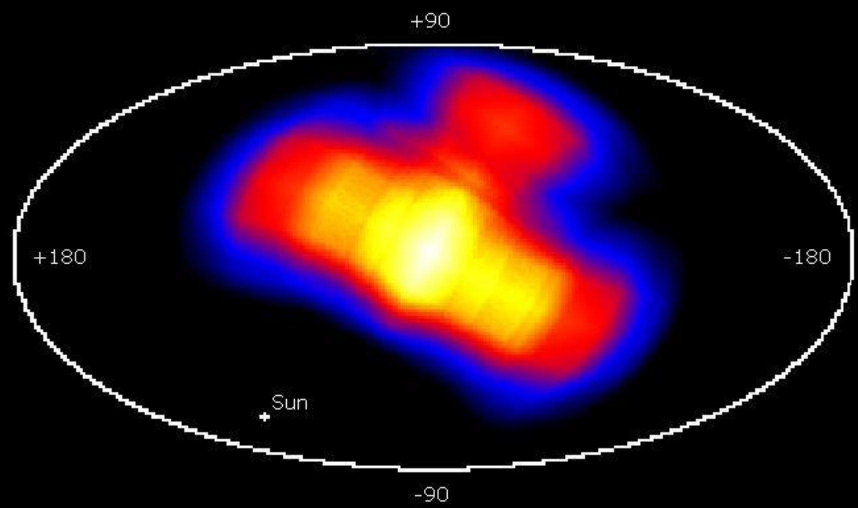
The Key to LOFT:
Coded mask (1 dimensional) using SDD



Key characteristics

- 5 sets of two orthogonal cameras: sky coverage per pointing 50%
- Sensitivity (5 σ) (1 s: 1 Crab; 50 ks: , 5 mCrab)
- Similar SDD to achieve low energy threshold and spectral resolution (2 – 80 keV)
- Onboard trigger and position
- VHF broadcast (< 30 sec to user community)
- Mass: 139 kg (margin included)
- Power: 110 W (margin incldded)

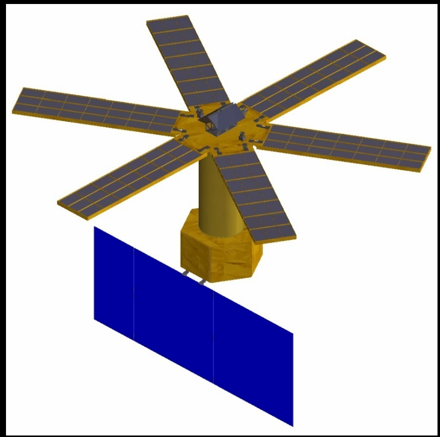


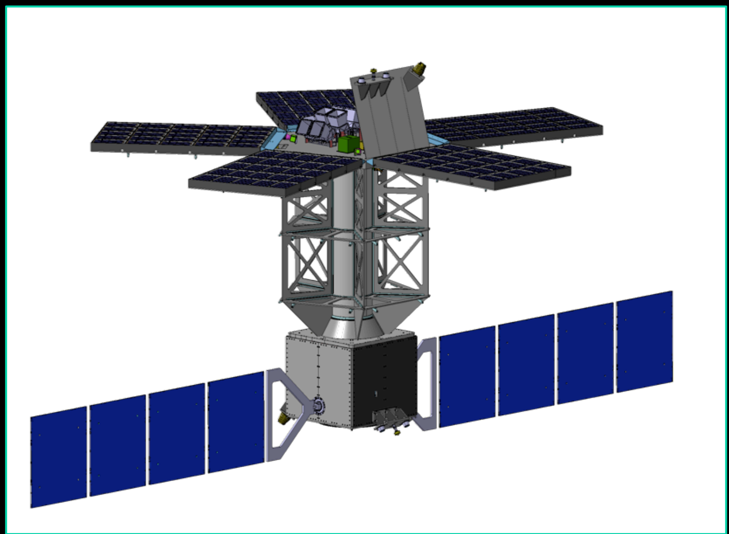


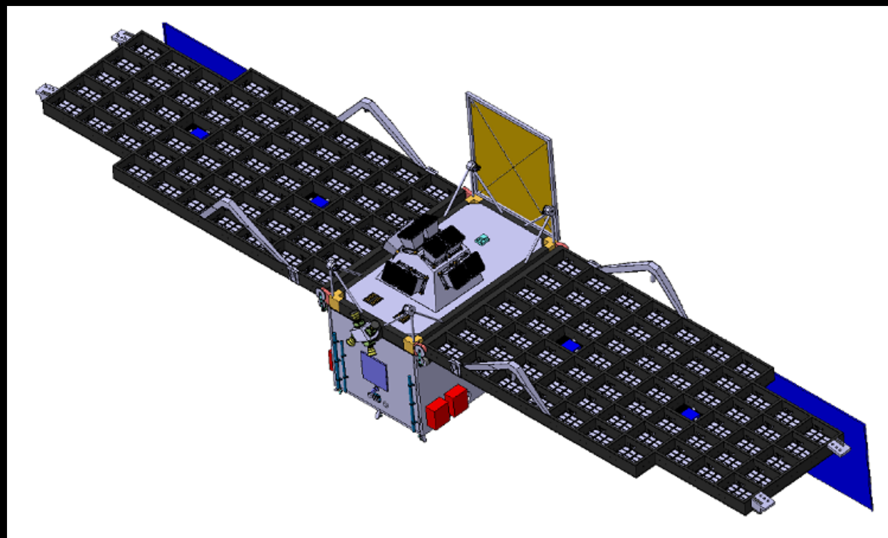
Mission

- ESA Medium Class mission (M3 candidate) – currently in Phase A study (5 compete for down select to single mission end 2013
- Launch date: 2022-2024 timeframe
- Soyuz launcher
- Low Earth orbit, 2 ground stations
- 4+1 years mission lifetime
- 2 instruments and science data centre provided by community (= we)

configuration not yet frozen







Science-related Mission Features

Pointing:

- 3-axis stabilized (LAD response stability)
- LAD accessible sky fraction >50% (R), >75% (G)
- Galactic Center visibility: >35% (R), >65% (G)
- Up to 2 slews per orbit (“night-time” observations)
- ToOs : within 8 hrs (working hours) and 24 hrs (otherwise)

Low-Earth Orbit (equatorial: 550 km, <2.5°)

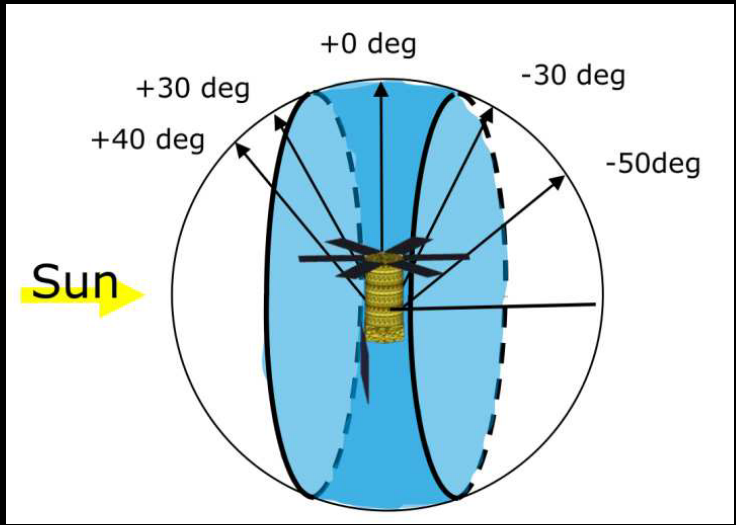
- spectral resolution (reduce radiation damage)
- reduce background (modulation)

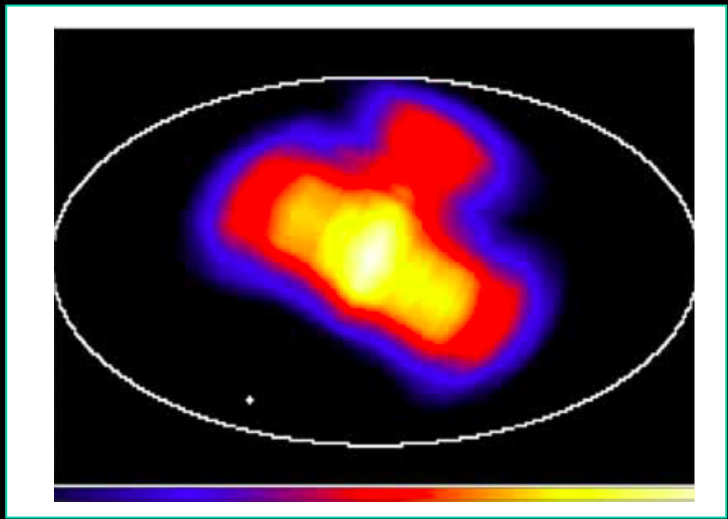
Data and Telemetry:

- Downlink per orbit: 6.7 Gbit (X-band, Kourou and Malindi)
- Flex TM share between LAD and WFM
- Fast delivery of GRB/transient coordinates (VHF network)

Sky visibility

- field of regard (good spectral resolution ± 30° (50% of sky) and extended field of regard around +30/-70°
- Major challenge: thermal environment for large range of pointings in LEO: T_{SDD} < -6° C, gradient < 10°
- sky visibility of the galactic center ~ 35 %
- Unique FoV of WFM to monitor large fraction of the sky



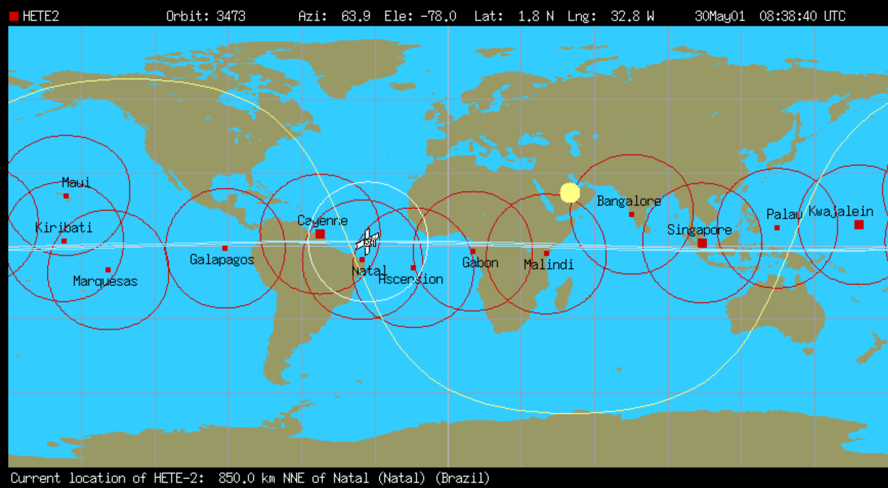


Burst Alert System

Added Burst Alert System

- Automatic triggers onboard
- Data available within 1.5 – 3 hour from detection
- For bright events time and position broadcasted to user community (< 30 s)
- VHF system with set of ground stations (community supplied)
- 150 ± 30 GRB / year
- ~ 5000 Type-1 Xpray bursts / year

malindi



What next ….

- Provide technical information to ESA (September)
- providenthe yellow book for ESA (November)
- Create support (this meeting, EWAS)
- Advice by ESA advisory structure (AWG, FWG, …)

See also http://www.isdc.unige.ch/loft

LAD team:

France, Germany, Italy, Switzerland, United Kingdom

WFM team:

Denmark, Finland, France, Germany, Italy, Netherlands, Poland, Spain, United Kingdom

GS team:

Denmark, France, Germany, Italy, Netherlands, Spain, Switzerland, United Kingdom