Be/X-ray Binary Science for Future X-ray Timing Missions

Colleen A. Wilson-Hodge

For future missions, the Be/X-ray binary community needs to clearly define our science priorities for the future to advocate for their inclusion in future missions. In this talk, I will describe current designs for two potential future missions and Be X-ray binary science enabled by these designs. The Large Observatory For x-ray Timing (LOFT) is an X-ray timing mission selected in February 2011 for the assessment phase from the 2010 ESA M3 call for proposals. The Advanced X-ray Timing ARray (AXTAR) is a NASA explorer concept X-ray timing mission. This talk is intended to initiate discussions of our science priorities for the future.

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Colleen A. Wilson-Hodge
NASA/MSFC

14 July 2011

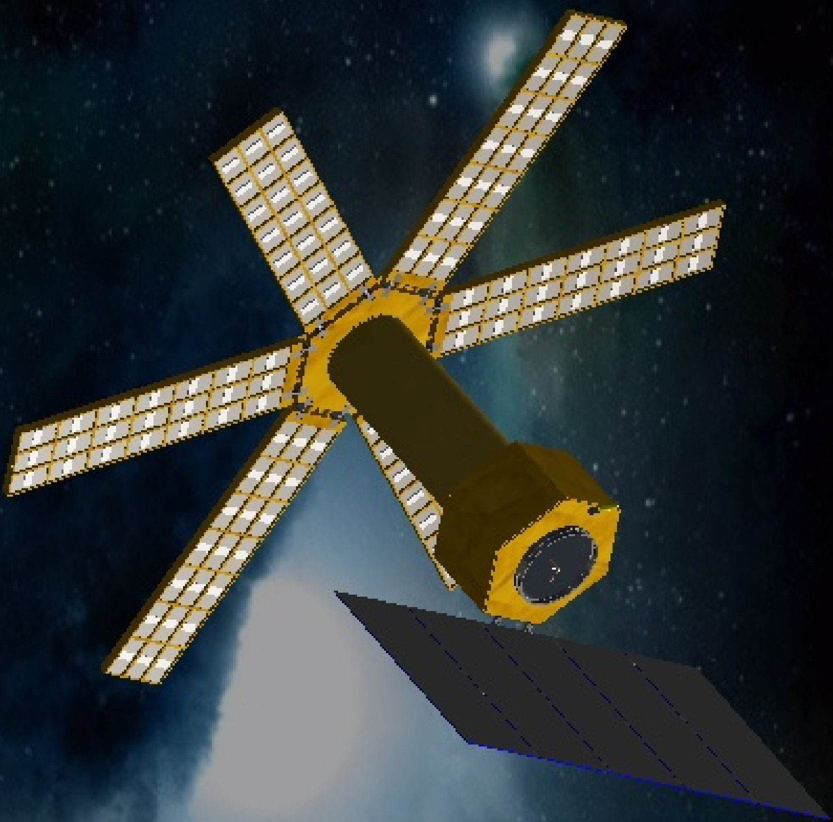
Introduction

- New X-ray timing missions are in development: LOFT, AXTAR, etc.
- What Be/XRB science cannot be done with current missions?
- What are the requirements to achieve that new science?
- Now is the time – if we make a strong science case, we can impact requirements of new missions!

Outline

- Missions
  - Large Observatory for X-ray Timing (LOFT)
  - Advanced X-ray Timing Array (AXTAR)
- Science

LOFT
Large Observatory For x-ray Timing



A mission proposal selected by ESA
as a candidate CV M3 mission
devoted to X-ray timing
and designed to investigate
the space-time around collapsed objects

Proposal PI:
Marco Feroci (INAF/IASF-Rome, Italy

ESA Assessment study lead:
Jan-Willem den Herder (SRON-The Netherlands)

The LOFT Mission

LOFT is specifically designed to exploit the diagnostics of very rapid X-ray flux and spectral variability that directly probe the motion of matter down to distances very close to black holes and neutron stars, as well as the physical state of ultradense matter.

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

The LOFT LAD has an effective area ~20 times larger than its largest predecessor (the Proportional Counter Array onboard RossiXTE) and a much improved energy resolution.

The LOFT WFM will discover and localise X-ray transients and impulsive events and monitor spectral state changes, triggering follow-up observations and providing important science in its own.

The LOFT Science Drivers

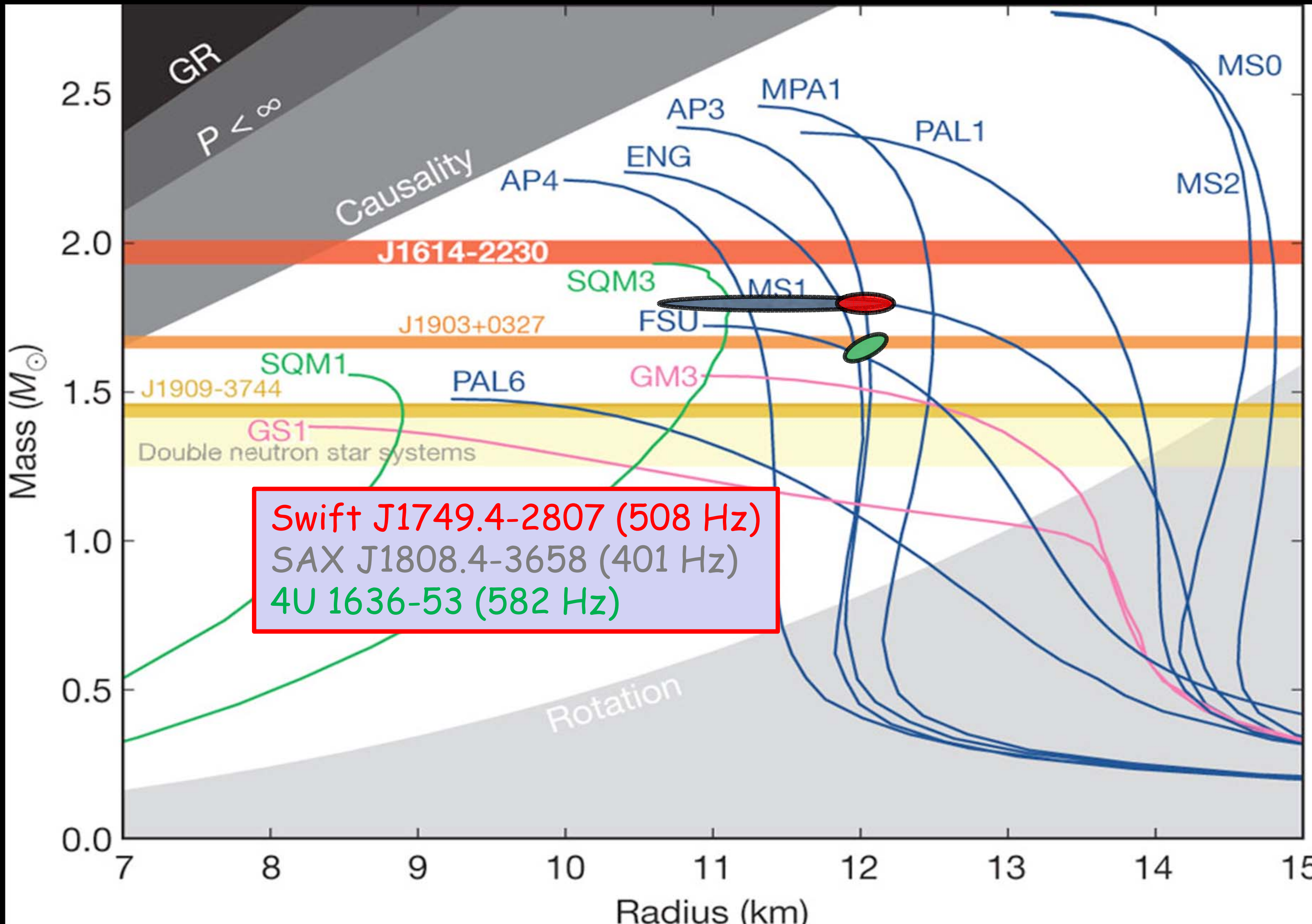
Neutron Star Structure and Equation of State of ultradense matter:

- neutron star mass and radius measurements to 5% uncertainty (90% confidence level)
- neutron star crust properties

Strong gravity and the mass and spin of black holes

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

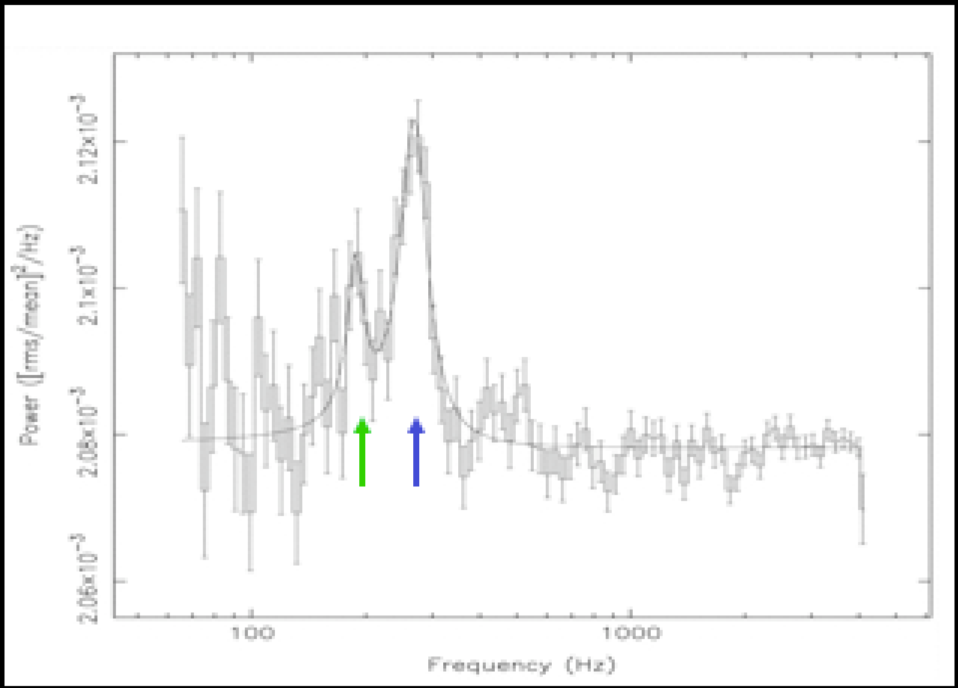
LOFT Constraints to NS EOS from M-R measurements



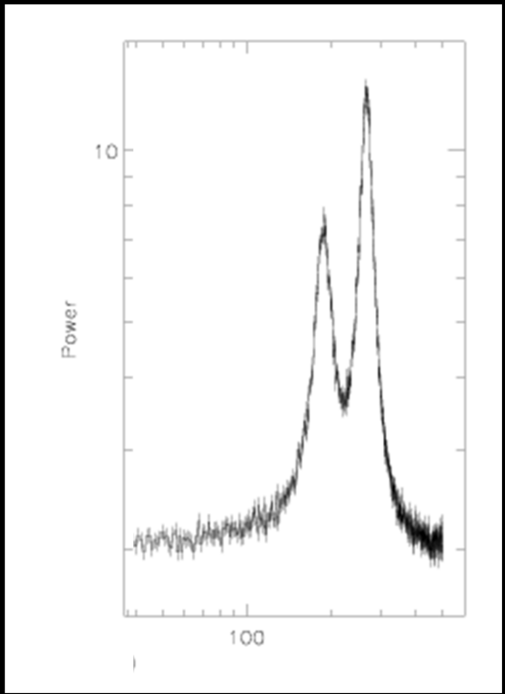
from Demorest et al. 2010

The high frequency QPOs in the BHC XTE J1550-564

ν_1=188 Hz, ν_2=268 Hz, frac rms ν_1= 2.8%, frac rms ν_2=6.2% (Miller et al. 2001), flux = 1 Crab, RXTE Exposure 54 ks, significance ~3-4σ.



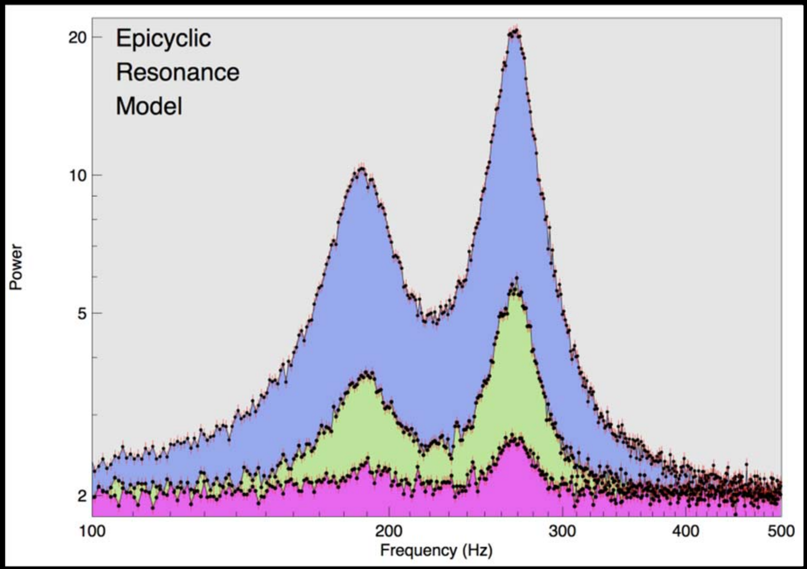
LOFT simulation: Texp=1 ks

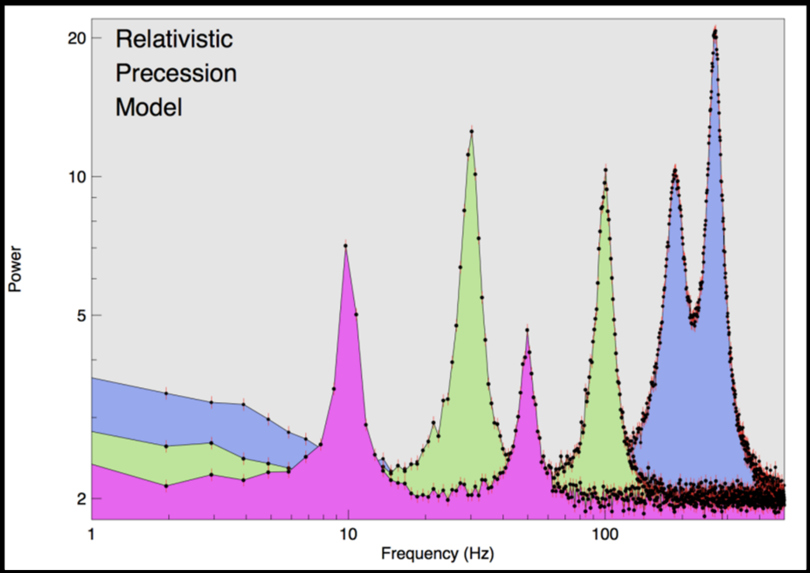


LOFT study of the QPO evolution with flux and fractional rms

Epicyclic Resonance Model
(Abramowicz & Kluzinak 2001)

Relativistic Precession Model
(Stella et al 1999)





Once the ambiguity of the interpretation of the QPO phenomena is resolved, the frequency of the QPOs will provide access to general relativistic effects (e.g, Lense-Thirring or strong-field periastron precession) and to the mass and spin of the black hole.

The LOFT Observatory

As for RXTE/PCA (but at much higher sensitivity), with a high flexibility in its observing program, LOFT will also be an Observatory for virtually all classes of relatively bright sources.

These include:

X-ray bursters,

High mass X-ray binaries

X-ray transients (all classes)

Cataclismic Variables

Magnetars

Gamma ray bursts (serendipitous)

Nearby galaxies (SMC, LMC, M31, …)

Bright AGNs

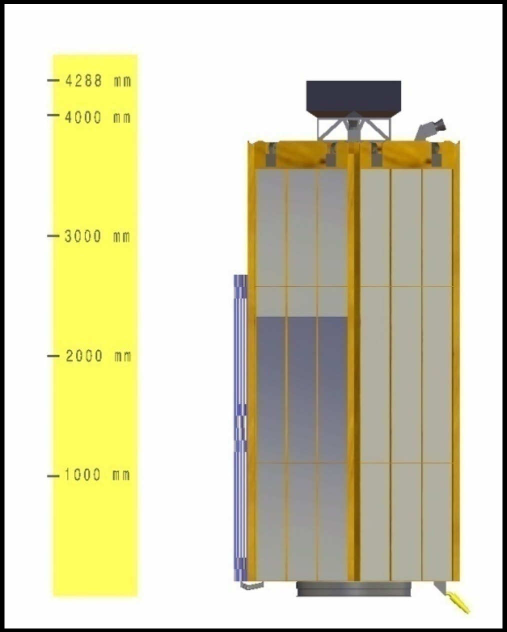
…

The LOFT Scientific Requirements

Parameter	Requirement	Goal
LAD		
Energy range	2–30 keV (nominal) 2-50 keV (expanded)	1–40 keV (nominal) 1–60 keV (expanded)
Effective area	12 m^2 (2-10 keV) 1.3 m^2 (@30 keV)	15 m^2 (2-10 keV) 2.5 m^2 (@30 keV)
Energy resolution (FWHM, @ 6 keV)	<260 eV (all events) <200 eV (40% of events)	<180 eV (all events) <150 eV (40% of events)
Field of view (FWHM)	<60 arcmin	<30 arcmin
Time resolution	10 μs	5 μs
Dead time	<0.5% (@ 1 Crab)	<0.1% (@ 1 Crab)
Background	< 10 mCrab	< 5 mCrab
Maximum source flux (steady, peak)	>300 mCrab, >15 Crab	>10 Crab, > 30 Crab
WFM		
Energy range	2-50 keV	1-50 keV
Energy resolution (FWHM)	<300 eV	<200 eV
Field of view	>3 steradian	>4 steradian
Angular resolution	5 arcmin	3 arcmin
Point source localization	1 arcmin	0.5 arcmin
Sensitivity (5 σ, 50 ks)	2 mCrab	1 mCrab
Sensitivity (5 σ, 1 s)	0.5 Crab	0.2 Crab

The LOFT satellite

Industrial study by Thales Alenia Space - Italia



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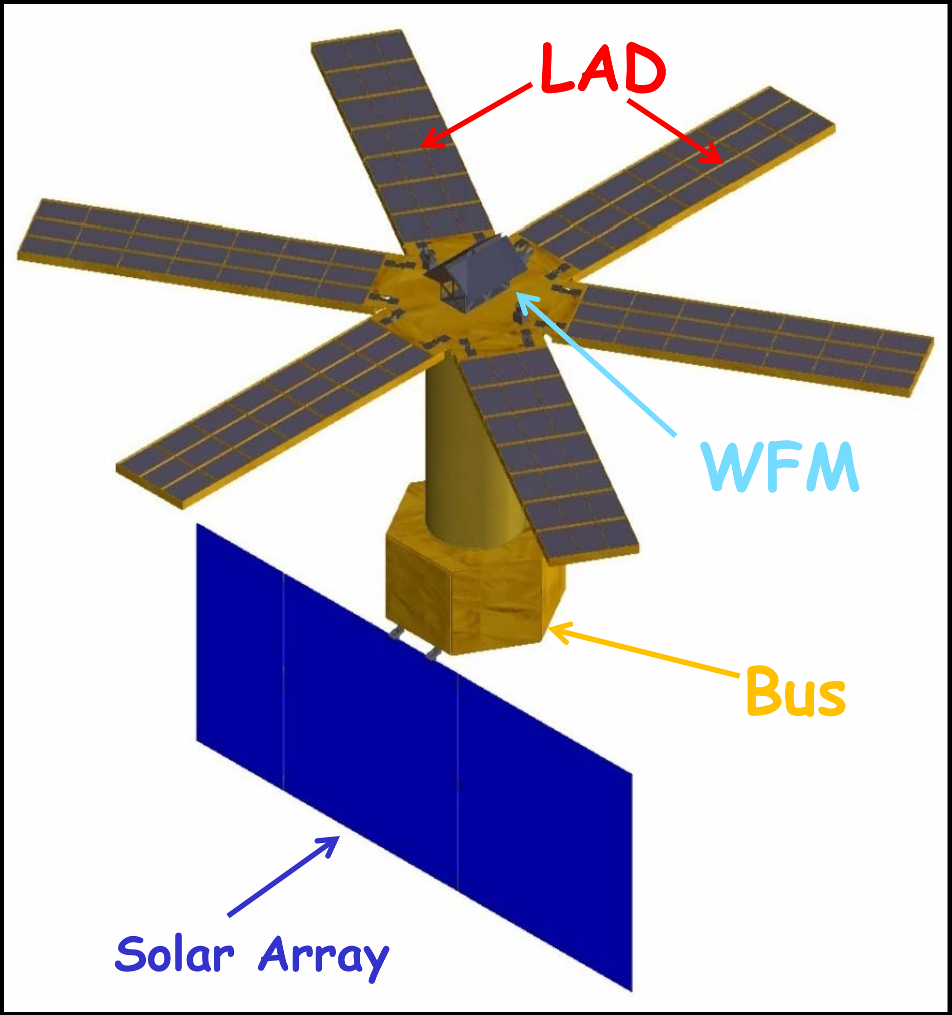
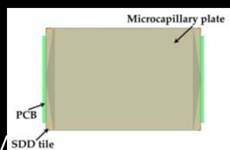
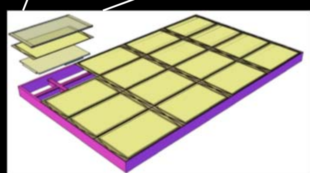


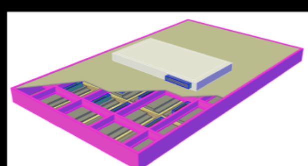
The Large Area Detector (LAD) for LOFT

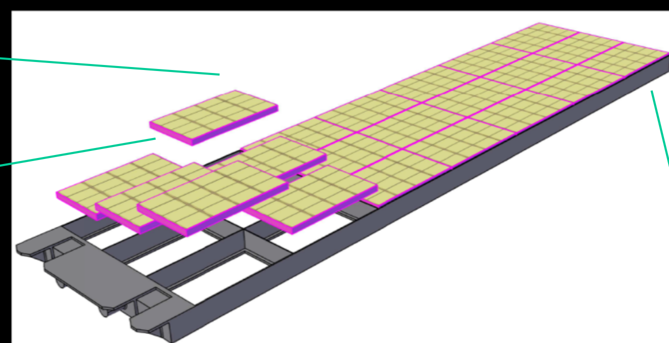
A fully modular and redundant approach:

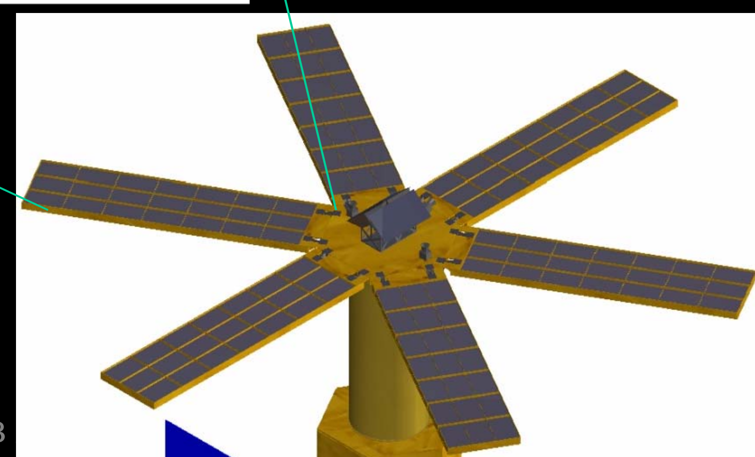
16 independent detectors per Module
21 independent Modules per Detector Panel
6 independent Detector Panels per LAD









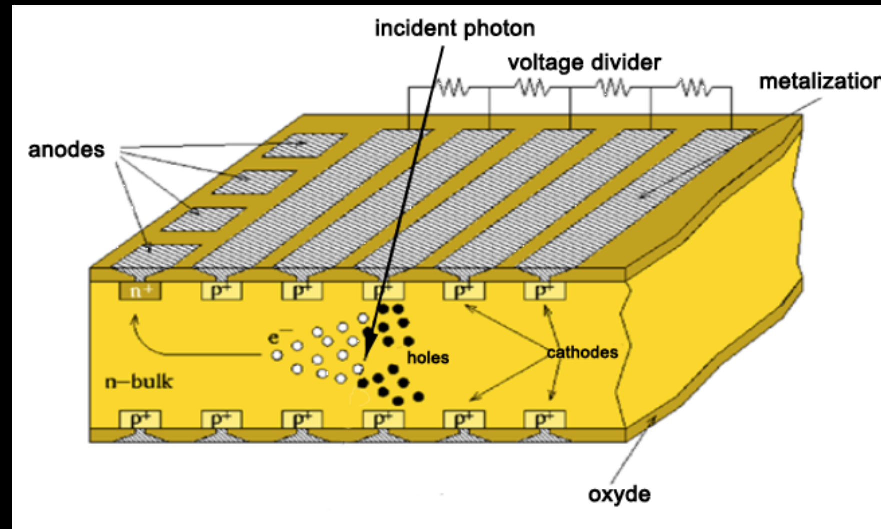


The Large Area Si Drift Detector for LOFT

- A series of cathodes create a linear electric drift field towards a series of anodes

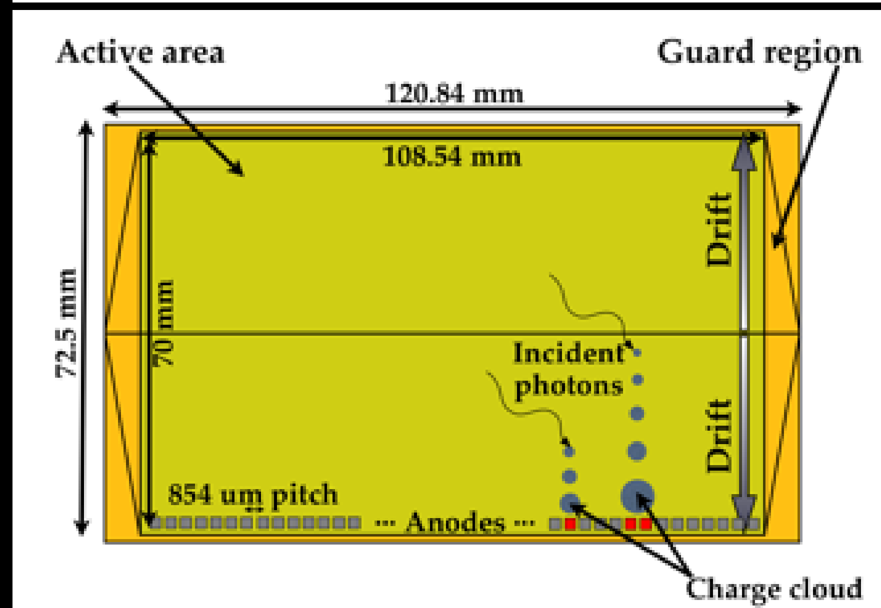
- Electrons-holes pairs are focused on the middle plane of the detector and drift towards the anodes

- The collecting area is decoupled from the sensitive area → low noise



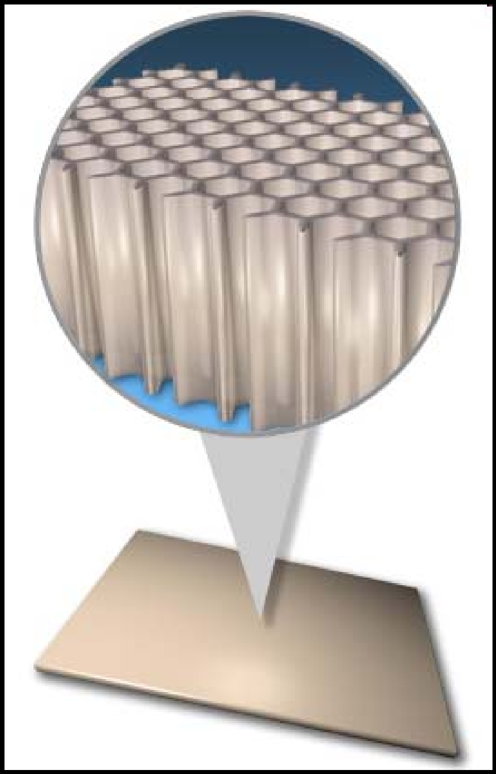
LOFT Baseline

Thickness	450 μm
Monolithic Active Area	76 cm^2
Anode Pitch	854 μm
Drift length	35 mm
Drift time	<5 μs
Single-channel area	0.3 cm^2

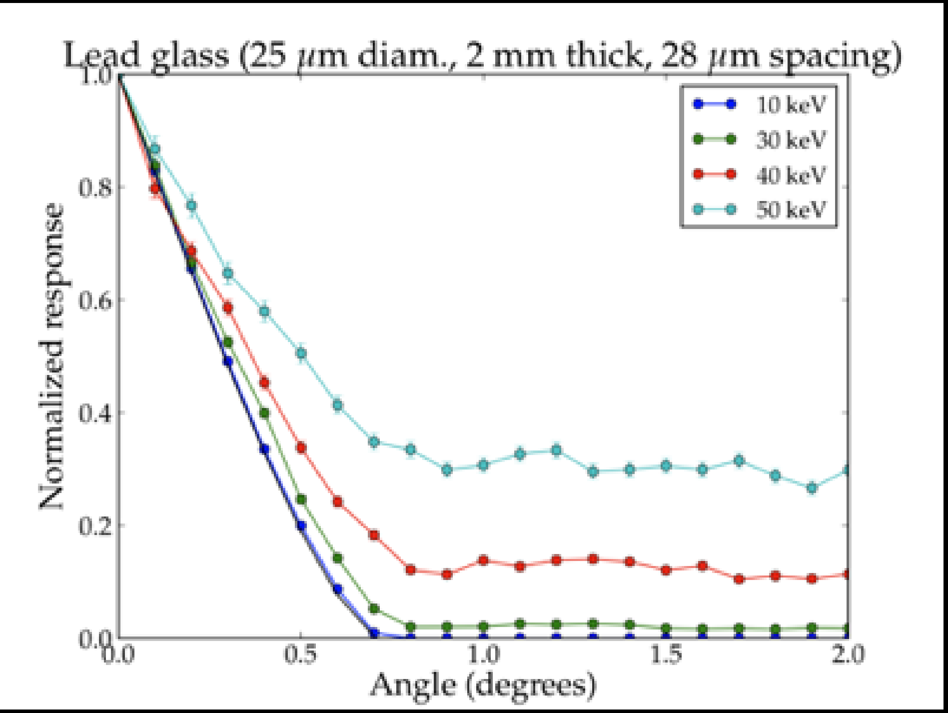


Capillary-plate Collimator

Lead-glass microcapillary plates are commercially available. Customization possible. LOFT baseline: FOV to ~43′ FWHM (2 mm thickness, 25 μm hole dia, 28 μm pitch, Open Area Ratio 80%). Heritage: Microchannel Plates (e.g., Chandra).



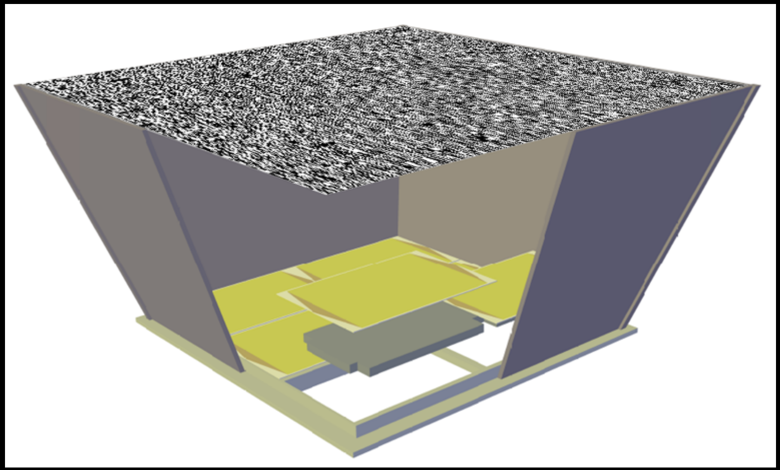
Collimation vs Energy:
GEANT Montecarlo simulations

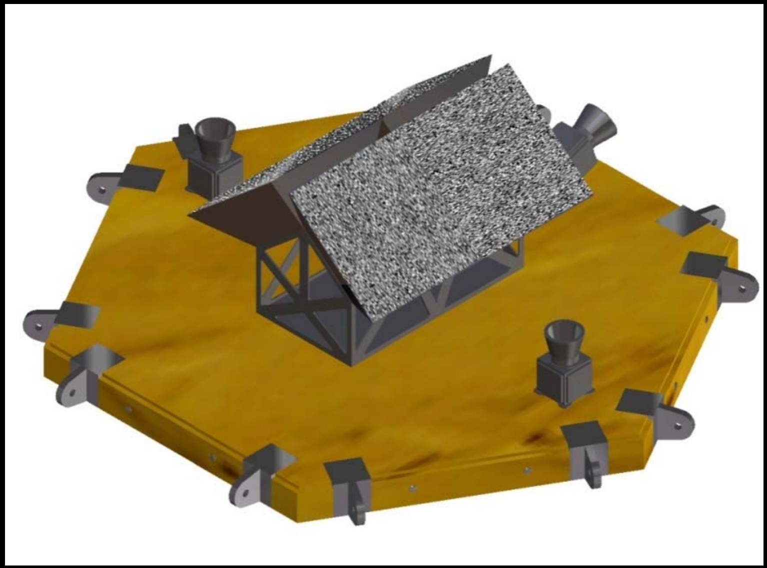


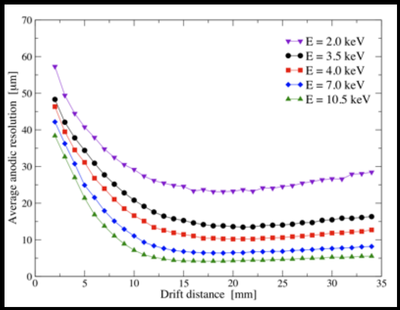
The Wide Field Monitor for LOFT

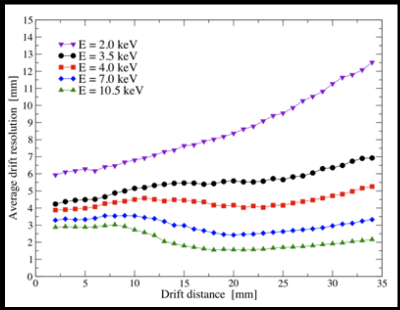
Based on the same type ofSi detectors as the Large Area Detector

but finer pitch (300 μm):
<60μm 1D position resolution
coarse (~3mm) 2D resolution



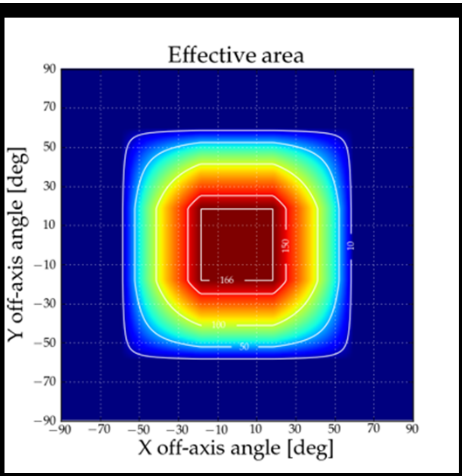






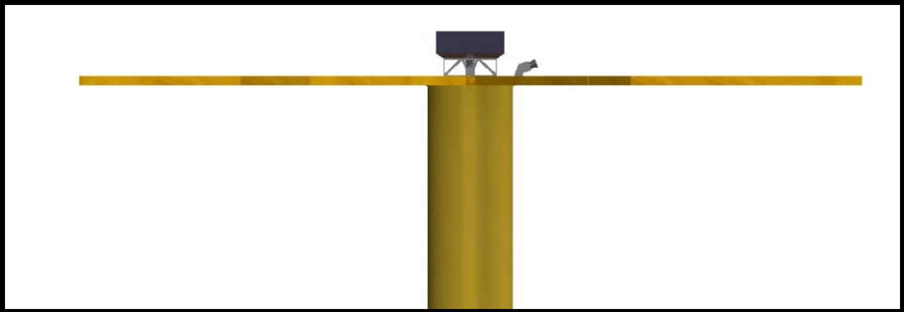
4 units

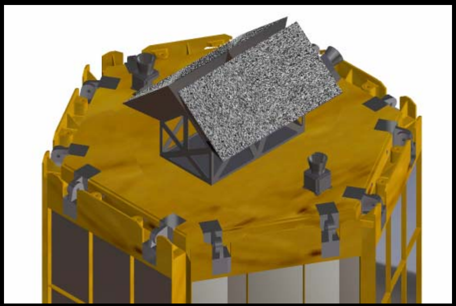
FoV, 1 unit:
0.4 sr FC
2.9 sr PC



The Wide Field Monitor for LOFT

Parameter	Single Unit	Overall WFM
Energy	2-50 keV	2-50 keV
Geometric Area	400 cm^2	1600 cm^2
Energy Resolution FWHM	< 350 eV	< 350 eV
Field of View Fully Coded	0.40 sr	0.80 sr
Partially Coded	2.90 sr	3.95 sr
Zero Response	118°	154°
Angular Resolution	5' x 2°	5' x 5'
Point Source Location Accuracy (10σ, 1D)	< 1' x 20'	< 1'x1'
On-axis sensitivity at 5σ in 1 s	610 mCrab	430 mCrab
On-axis sensitivity at 5σ in 50 ks	2.7 mCrab	1.9 mCrab
Total Power (w/margins)		14 Watts
Total Weight (w/margins)		37 kg

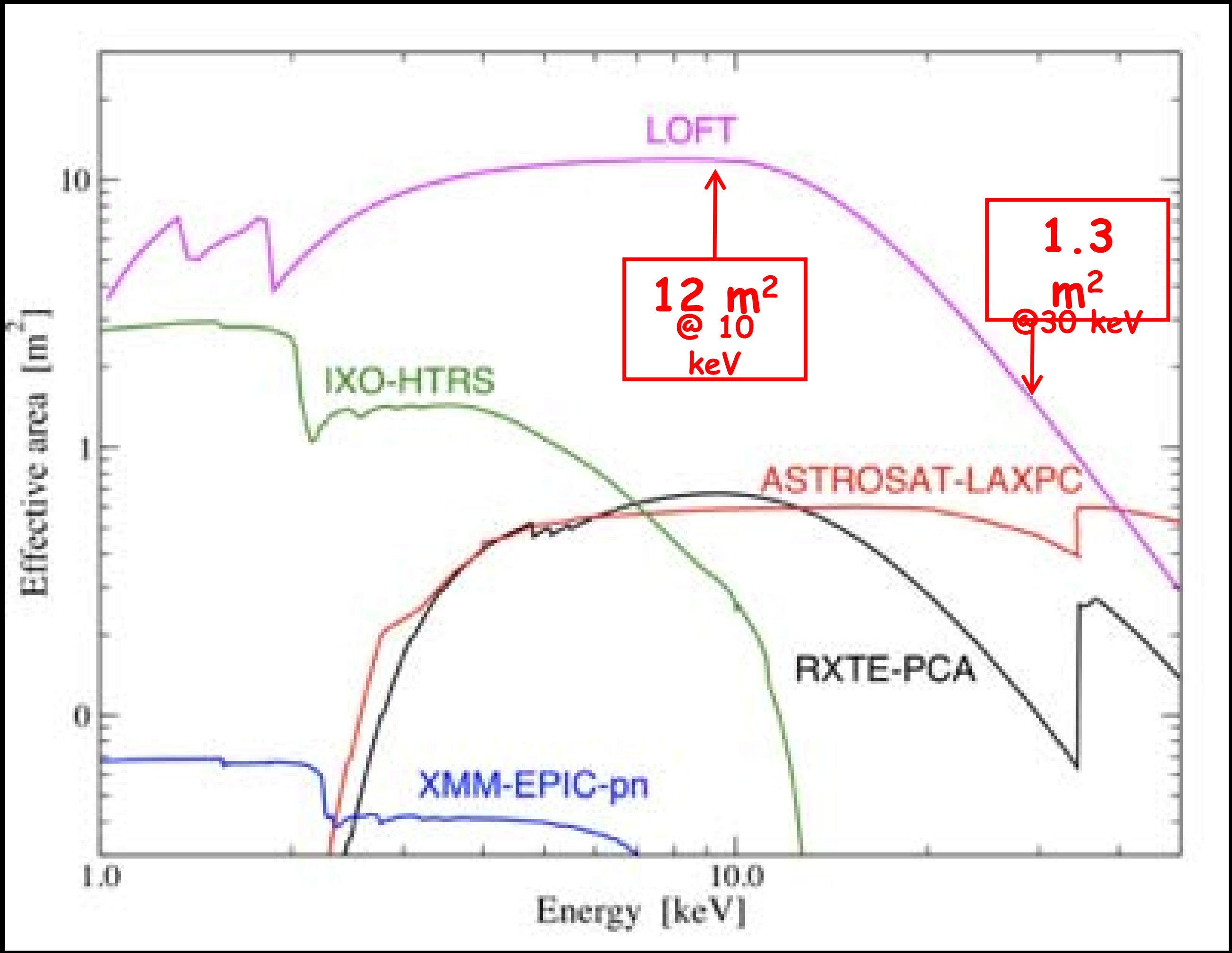




The LOFT Baseline Overview

Detector	450 μm thick SDD
Energy Range	2-30 keV (2-50 keV extended range)
Field of View	43 arcmin
Geometric Area	18 m^2
Effective area (@8 keV)	12 m^2 (20x RXTE/PCA)
Energy Resolution	<260 eV (<200 eV for 40% of the area)
Time Resolution	5 μs
Crab Count Rate	3×10^5 cts/s
Deadtime	<0.03% for 1 Crab
Sensitivity	1 mCrab/1s
Supporting Experiment:	Wide Field Monitor (4 sr)
Satellite Mass	~1800 kg
Telemetry	<700 kbps
Orbit	Low-Earth (Vega launcher)

LOFT in context



Advanced X-ray Timing Array (AXTAR)

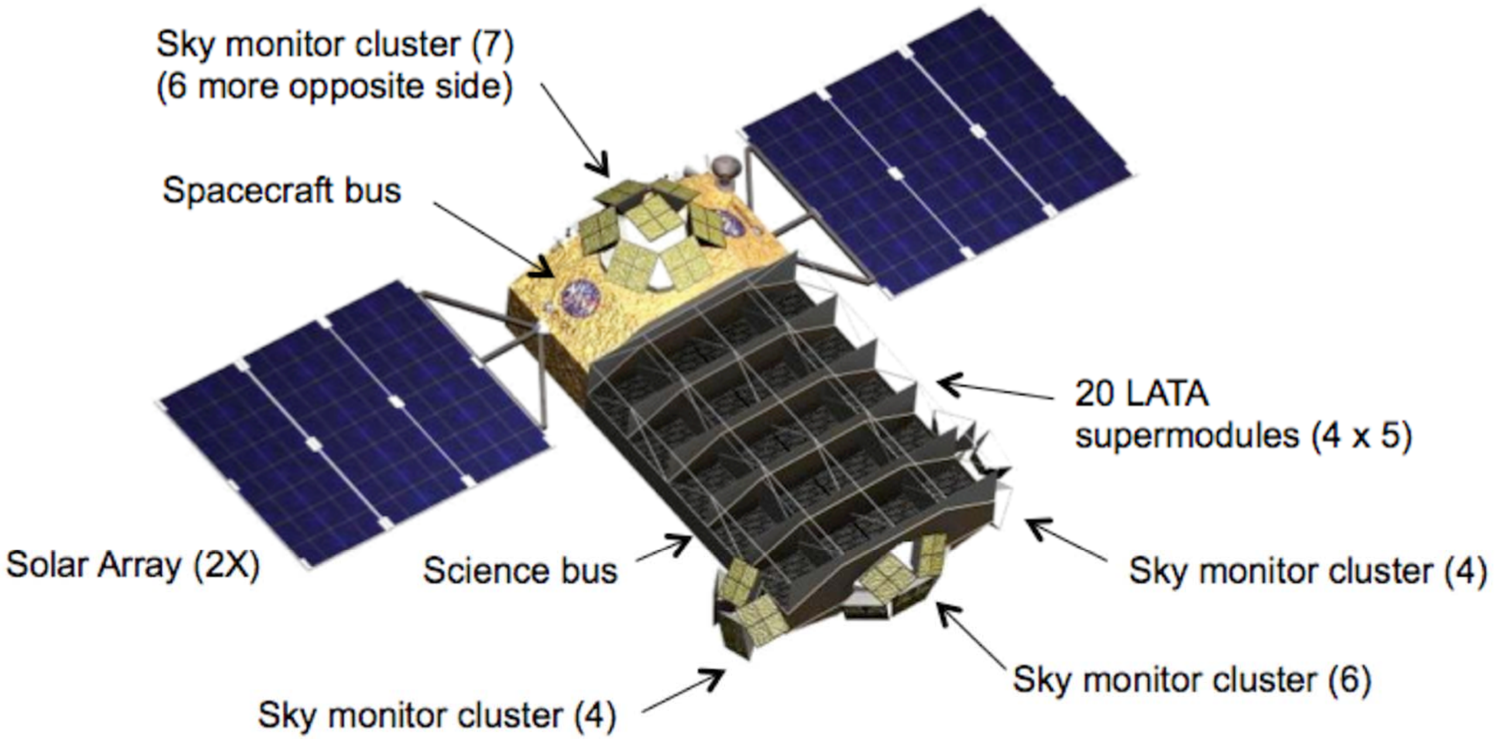
A US Medium sized Explorer (MIDEX) Mission Concept

Deepto Chakrabarty (MIT),
Paul Ray (NRL),
Colleen Wilson-Hodge(NASA/MSFC)

AXTAR Primary Science Objectives

- 5-10% measurement of NS radius from X-ray burst oscillation light curves
  - constrain the equation of state for ultra-dense matter
- Understand the effects of General Relativity and dependence on mass and spin for high frequency QPOs in black hole binaries
  - Sensitivity at E>10 keV to 0.1% RMS amplitude

The Advanced X-ray Timing Array (AXTAR)



Taurus II fairing

AXTAR Technical Requirements

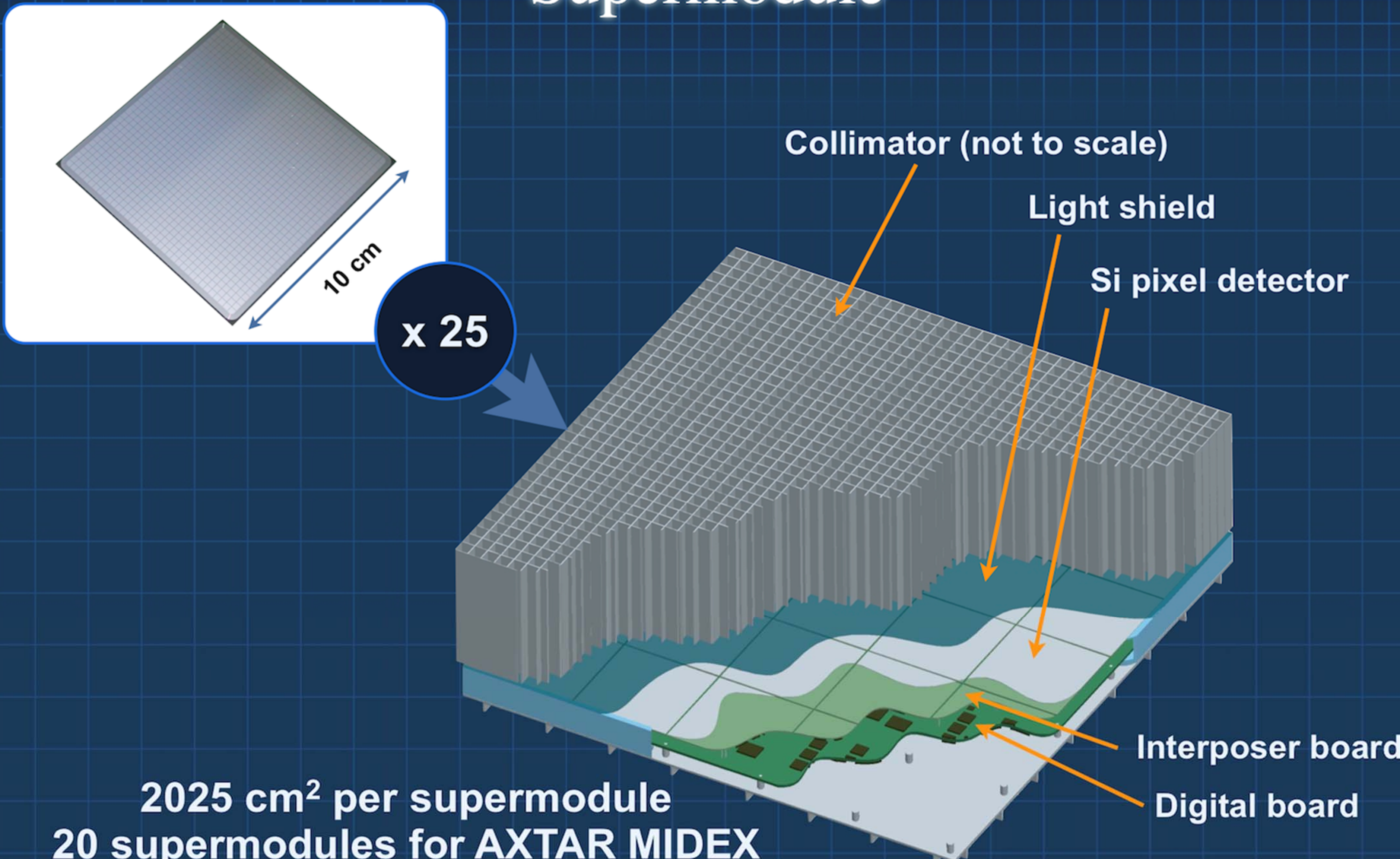
- Effective area > 3 m^2 (RXTE was 0.6 m^2)
- Energy Range: Below 2 keV to at least 30 keV
- Achieve high count rates with minimal deadtime
- Fast response to transients and state changes; flexible scheduling
- Sky monitor to provide triggers and context, plus stand alone science.

Table 1. Mission Requirements

Parameter	Baseline	Drivers	Technology Factors
		Large Area Timing Array (LATA)	
Effective Area	3.2 m^2	NS radius, BH QPOs	Mass, cost, power
Minimum Energy	1.8 keV	Source states, absorption meas., soft srcs	Detector electronics noise
Maximum Energy	>30 keV	BH QPOs, NS kHz QPOs, Cycl. lines	Silicon thickness
Deadtime	10%@10 Crab*	Bright sources, X-ray bursts	Digital elec. design, pixel size
Time Resolution	1 μs	Resolve ms oscillations	Shaping time, GPS, Digital elec.
		Sky Monitor (SM)	
Sensitivity (1 d)	< 5 mCrab*	Faint transients, multi-source monitoring	Camera size/weight/power
Sky Coverage	> 2 sr	TOO triggering, multi-source monitoring	# cameras vs. gimbaled designs
Source Location	1 arcmin	Transient followup	Pixel size, camera dimensions
		AXTAR Mission	
Solar Avoidance Ang.	30°	Access to transients	Thermal/Power design
Telemetry Rate	1 Mbps	Bright sources	Ground stations/TDRSS costs
Slew Rate	> 6° min^{-1}	Flexible scheduling, fast TOO response	Reaction wheels

*1 Crab = 3.2×10^{-8} erg cm^{-2} s^{-1} (2–30 keV)

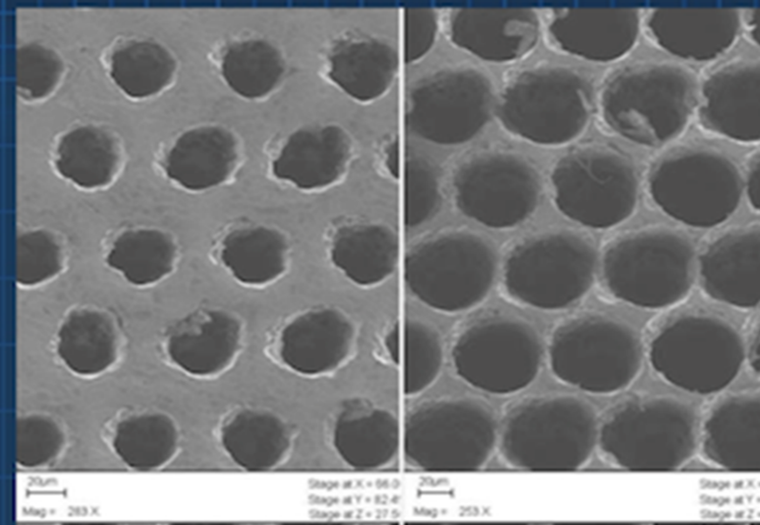
Large Area Timing Array (LATA) Supermodule

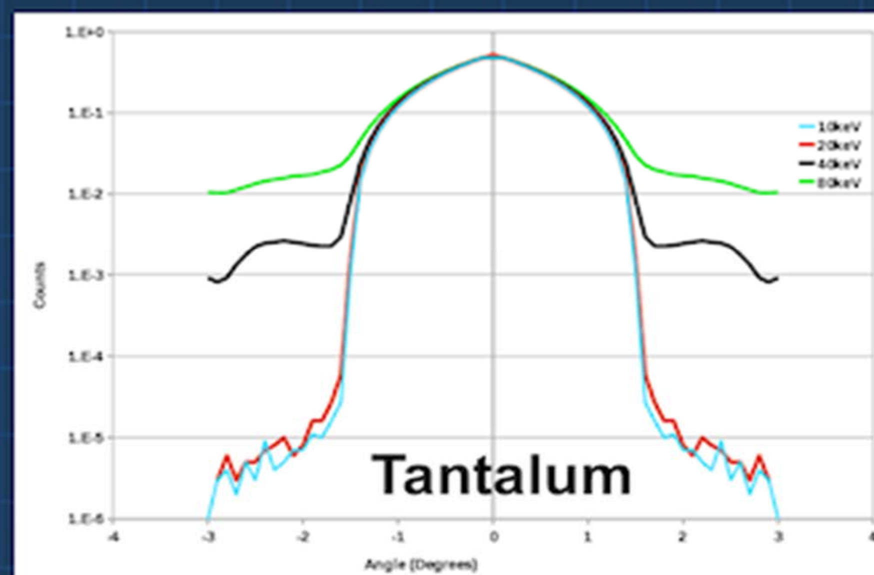


2025 cm^2 per supermodule
20 supermodules for AXTAR MIDEX

Tantalum Collimators

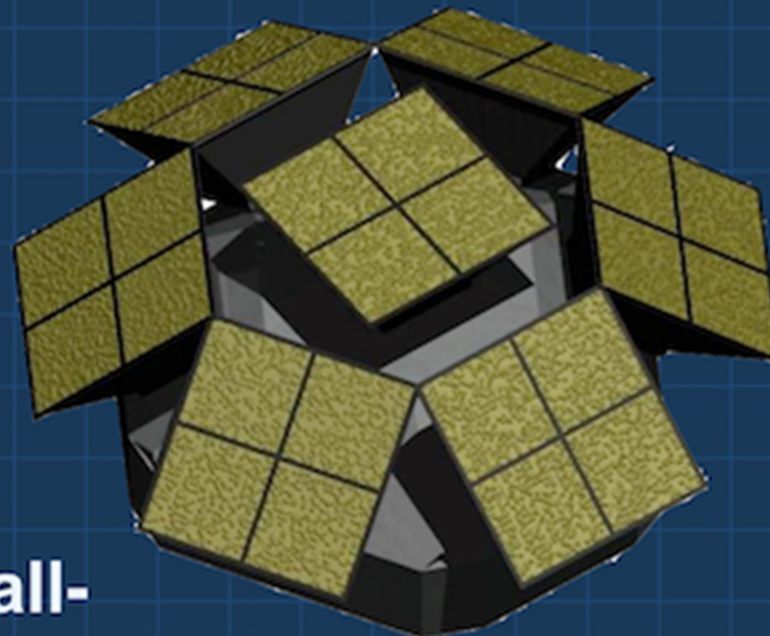
At NRL, we have been developing alternatives by micromachining tantalum plates (see photo at right). We have achieved aspect ratios of 30:1 in 2-mm thick tantalum sheets. Collimators made in this way have the potential to significantly enhance the performance of the LAD. Tantalum has much higher stopping power than lead-glass, providing greatly improved rejection of the diffuse X-ray background and bright sources outside the field of view. This improvement is particularly dramatic at the higher energies (> 15 keV). Such alternative collimators will need to be evaluated by weighing their performance benefits relative to the resources required such as additional costs and mass.





Sky Monitor (SM)

- Same Si pixel detectors provide 2-d imaging when paired with a coded mask
  - Arcminute source localizations
  - ~300 cm^2 area per camera
  - few mcrab sensitivity (1 day), 20x better than RXTE/ASM

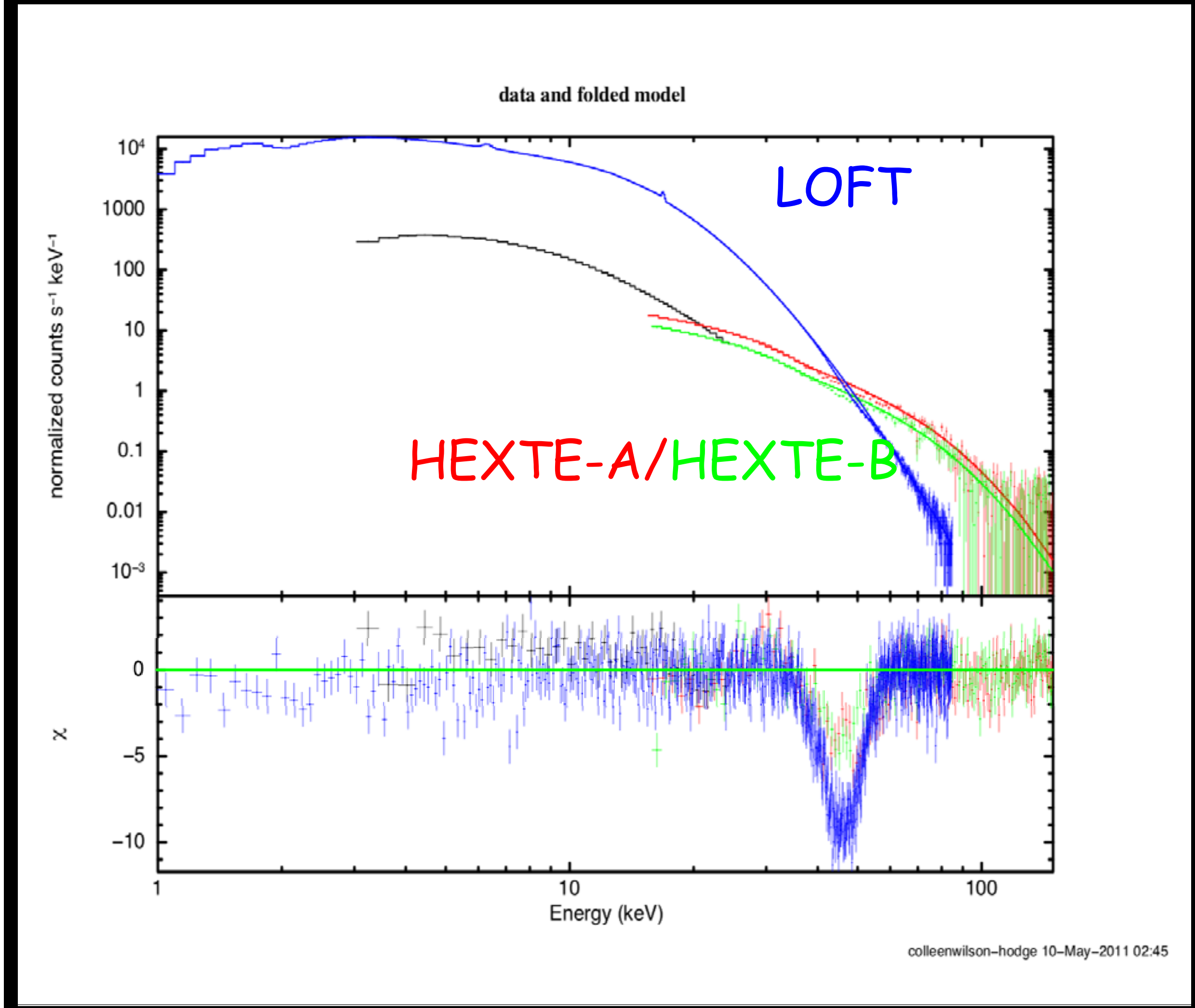


- 32 cameras could provide all-sky *continuous* coverage
  - Timescales from ms to years
  - Reduced MIDEX configuration being studied by MIT

Observations LOFT or AXTAR can perform for accreting pulsars

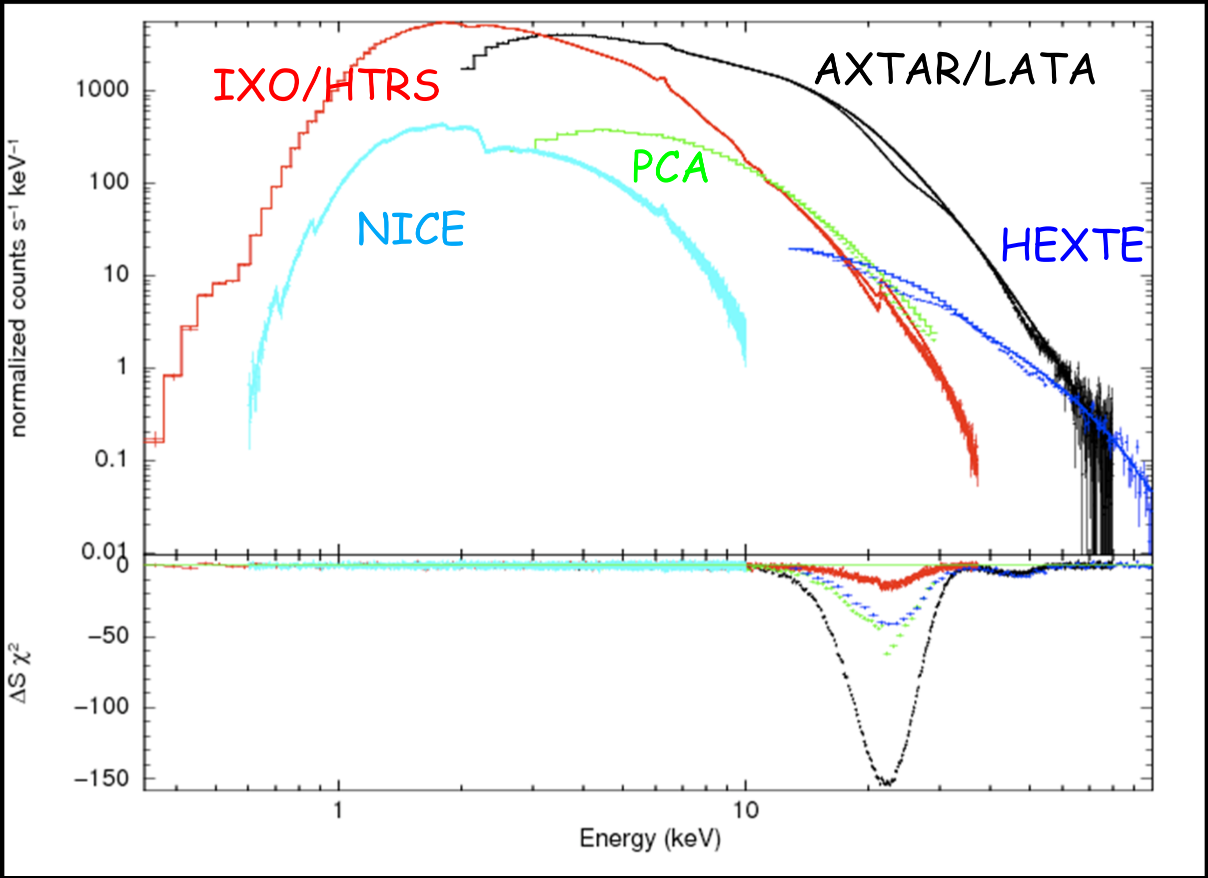
- Observations
  - Measure cyclotron lines.
  - Monitor phase connected spin parameters.
  - Determine precise fluxes during and between outbursts.
  - Track pulse profile variations.
  - Search for QPO.
- Instrument needs
  - Broad energy range
  - Good timing capability
  - Regular monitoring observations
  - Quick ToO activation
  - Very high count rate statistics
  - Imaging/small fov

LOFT Cyclotron line simulations



- A0535+26 RXTE observation Aug 28, 2005
- Cyclotron Line detected at 48 keV
- PLCUT model for continuum: index = 1.02, Ecut = 12.6 Efold = 20.6
- 2-10 keV Flux 7×10^{-9} erg cm^{-2} s^{-1}
- LOFT 10ks spectrum simulated in XSPEC using response with (DE=300 eV 3-60 keV)

AXTAR Cyclotron line simulations



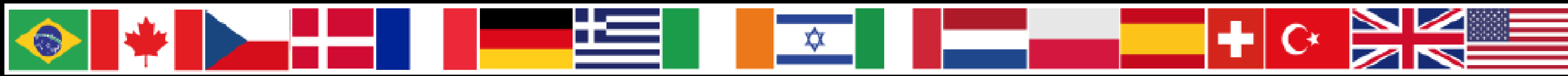
- A0535+26 RXTE observation Aug 28, 2005
- Line detected at 48 keV
- PLCUT model for continuum: index = 1.02, Ecut = 12.6 Efold = 20.6
- Added line @ 24 keV with V0332+53 parameters
- 2-10 keV Flux 7×10^{-9} erg cm^{-2} s^{-1}

Questions for Discussion

- What new science can we do for BeXRB with 3.2 m^2 (AXTAR) or 12 m^2 (LOFT)?
- What is the most important energy range for BeXrB science?
- For the AXTAR Sky Monitor or the LOFT Wide-field monitor – what time resolution is needed?
- Other questions?

Backup

The (current) LOFT Consortium



The LOFT Coordination Team: M. Feroci (*Coordinator*, INAF, Italy), D. Barret (IRAP, France), T. Belloni (INAF, Italy), J. Braga (INPE, Brazil), C. Budtz-Jorgensen (DTU, Denmark), S. Campana (INAF, Italy), T. Courvousier (Univ. Geneve, Switzerland), M. Hernanz (IEEC, Spain), R. Hudec (Prague Techn. Univ., Czech Republic), G.L. Israel (INAF, Italy), P. S. Ray (NRL, USA), A. Santangelo (Univ. Tuebingen, Germany), L. Stella (INAF, Italy), A. Vacchi (INFN, Trieste, Italy), M. van der Klis (Univ. Amsterdam, The Netherlands), D. Walton (MSSL, UK), A. Zdziarski (N. Copernicus, Poland)

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The LOFT Mission Profile

Orbit	Low earth (600 km), equatorial (<5°), circular
Launcher	Vega from Kourou
Satellite Mass	1800 kg (with margins)
Satellite Power	1800 W (with margins)
Slew rate	4° /minute
Telemetry	650 kbps
Ground Stations	Kourou, Malindi
Nominal Lifetime	2+2 years