

# Large Observatory For X-ray Timing (LOFT-P): A Probe Class Mission Concept Study

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## Overview

LOFT-P is a mission concept for a NASA Astrophysics Probe-Class (<\$1B) X-ray timing mission, based on the LOFT M-class concept<sup>1,2,3</sup> originally proposed to ESA's M3 and M4 calls. LOFT-P requires very large collecting area, high time resolution, good spectral resolution, broadband spectral coverage (2-30 keV), highly flexible scheduling, and an ability to detect and respond promptly to time-critical targets of opportunity. Many of LOFT-P's targets are bright, rapidly varying sources, so these measurements are synergistic to imaging and high-resolution spectroscopy instruments, addressing much smaller distance scales than are possible without very long baseline X-ray interferometry, and using complementary techniques to address the geometry and dynamics of emission regions. LOFT-P was presented as an example mission to the head of NASA's Astrophysics Division, to demonstrate the strong community support for creation of a probe-class, for missions costing between \$500M and \$1B. We submitted a white paper<sup>4</sup> in response to NASA PhysPAG's call for white papers: Probe-class Mission Concepts, describing LOFT-P science and a simple extrapolation from the ESA study costs. The next step for probe-class missions will be input into the NASA Astrophysics Decadal Survey to encourage the creation of a probe-class opportunity. We report on a 2016 study by MSFC's Advanced Concepts Office of LOFT-P, a US-led probe-class LOFT concept.

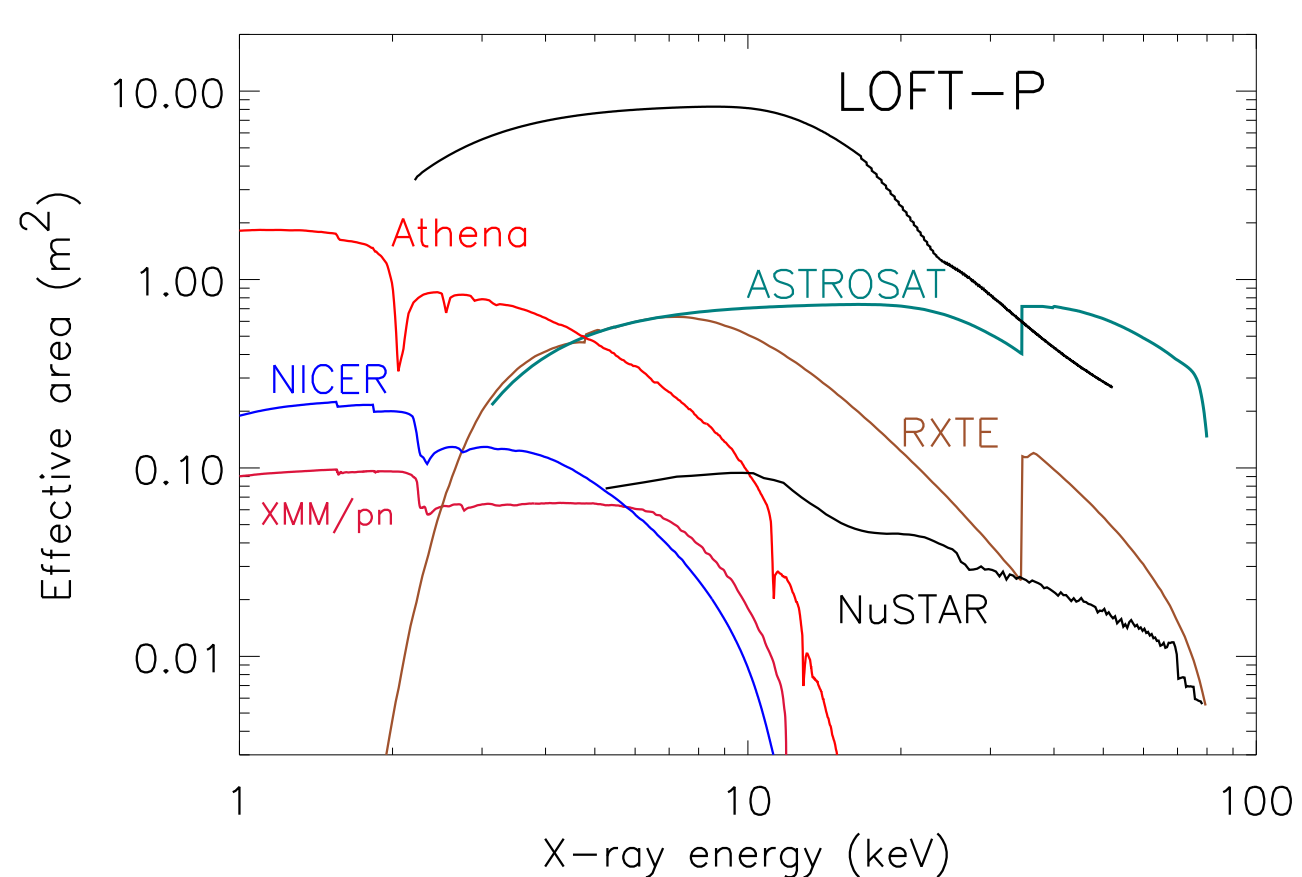


Figure 1: Effective area as a function of area for the LOFT-P LAD baseline concept. Several existing and planned missions are shown for comparison.

## Science Objectives

LOFT-P is a probe-class X-ray observatory designed to work in the 2-30 keV band with huge collecting area (Fig. 1) and good spectral resolution (<260 eV). It is optimized for the study of matter in the most extreme conditions found in the universe and addresses several key science areas including:

- Probing the behavior of matter spiraling into black holes to explore the effects of strong gravity and measure the masses of black holes.
- Using multiple neutron stars to measure the ultradense matter equation of state over an extended range.
- Continuously surveying the dynamic X-ray sky with a large duty cycle and high time resolution to characterize the behavior of X-ray sources over a vast range of time scales.
- Enabling multi-wavelength and multi-messenger studies of the dynamic sky through cross-correlation with high-cadence time-domain surveys in the optical and radio (LSST, LOFAR, SKA pathfinders) and with gravitational wave interferometers like LIGO and Virgo.

Table 1: LOFT-P Mission Requirements

Parameter	Baseline
<i>Large Area Detector<sup>1</sup></i>	
Effective Area	9.5 m <sup>2</sup> @ 8 keV
Energy Range	2-30 keV
Spectral Resolution	< 240 eV @ 6 keV
Deadtime	< 0.1% @ 1 Crab
Time Resolution	10 μs
Collimated field-of-view	1 deg FWHM
Sensitivity (5 σ)	0.1 mCrab in 100 s
<i>Wide Field Monitor<sup>1</sup></i>	
Source Localization	1 arcmin
Angular Resolution	5 arcmin
Energy Range	2-50 keV
Spectral Resolution	300 eV @ 6 keV
Effective Area	170 cm <sup>2</sup> (peak)
Field of view	4.1 steradian
Sky Coverage	50% of LAD accessible sky
Sensitivity (5 σ)	3 mCrab (50 ks)
<i>LOFT-P Mission</i>	
Low Earth Orbit	550 km, < 5 deg inclination
Sky visibility (Field-of-Regard)	> 35% (> 50% extended)
Pointing Accuracy	1 arcmin on 3 axis
Pointing knowledge	5 arcsec
Telemetry Rate	100 Gbit/day
Slew Rate	4 deg/min

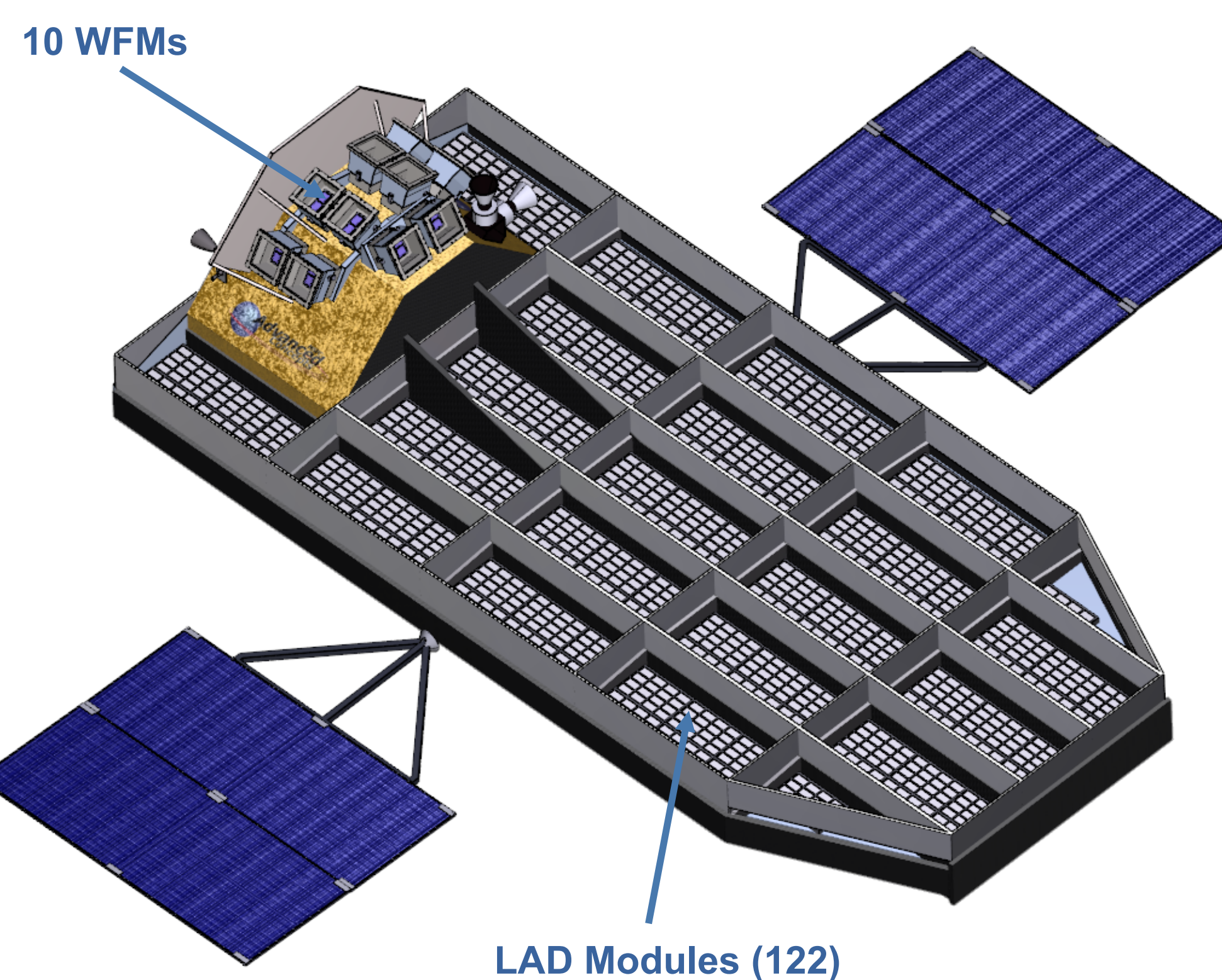


Figure 2: LOFT-P Mission Concept designed for accommodation in a Falcon9 Heavy Launch Vehicle. This concept includes 122 Large Area Detector (LAD) Modules, compared with 126 in the LOFT M3 design, and 10 Wide Field Monitor (WFM) Cameras, with the same number and layout as in the LOFT M3 design.

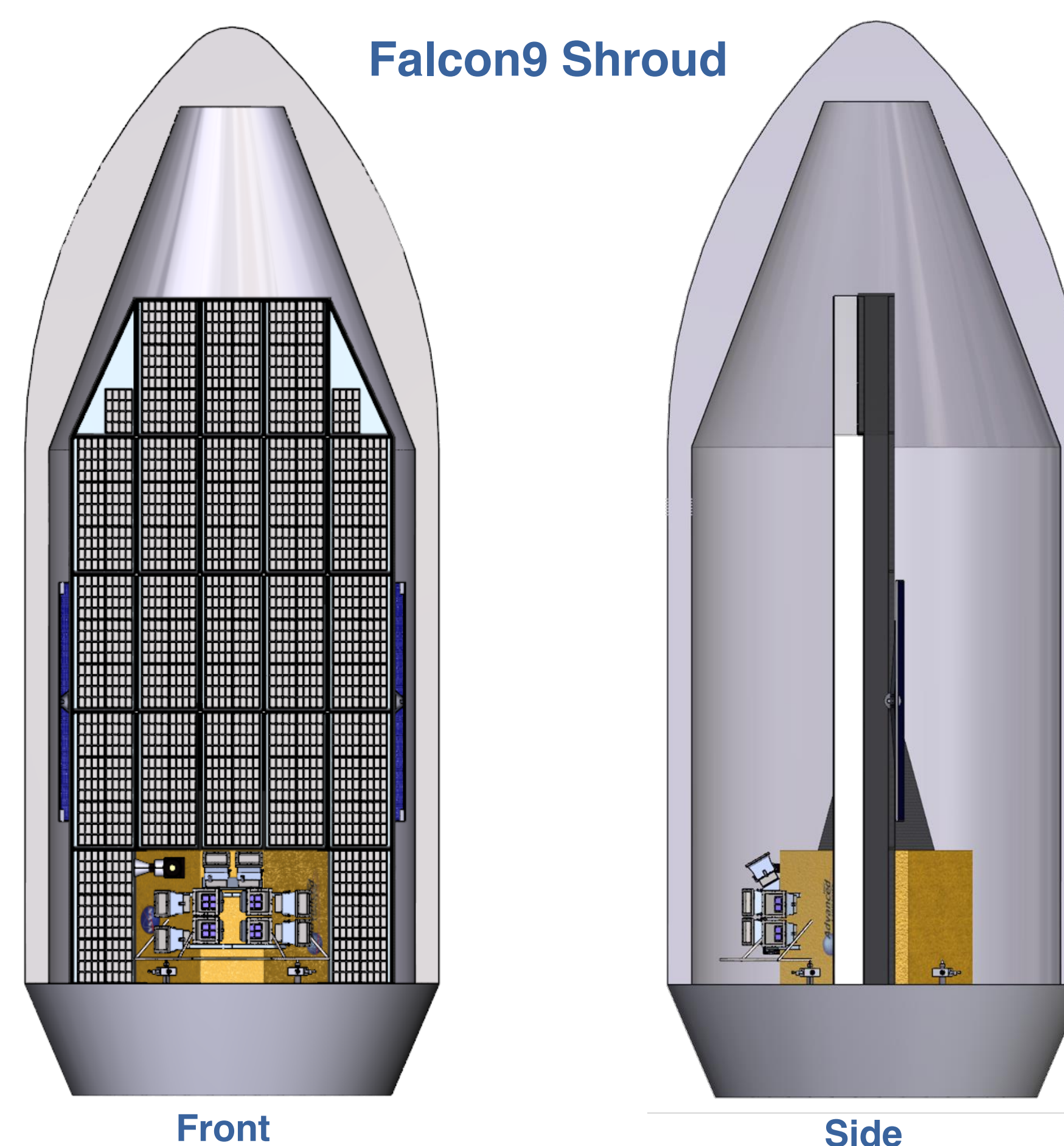


Figure 3: (Below) The LOFT-P mission concept shown in a Falcon-9 shroud. The shaded region is the dynamic envelope.

## Instruments

The LOFT-P mission concept, which has been under study in both the Europe and the US since 2010, comprises two instruments. For purposes of short one-month LOFT-P study, the science requirements (Table 1) and science instruments were assumed to be identical to those for LOFT M3<sup>1,2,3</sup>. We summarize them here. The Large Area Detector (LAD) consists of collimated arrays of silicon drift detectors (SDDs) with a 1-degree field of view and a baseline peak effective area of 10 m<sup>2</sup> at 8 keV, optimized for sub-millisecond timing and spectroscopy of neutron stars and black holes. The unit for the study was a LAD module, comprising a set of 4x4 SDDs and 4x4 leaded-glass microchannel plate collimators, including the module backend electronics, with a radiator for passive cooling and shielding for background reduction. The sensitive Wide Field Monitor (WFM) is a 2-50 keV coded-mask imager (also using SDDs) that acts as a trigger for pointed LAD observations of X-ray transients and also provides nearly continuous imaging of the X-ray sky with a large instantaneous field of view. The WFM for LOFT-P is identical to the LOFT M3 design, with 10 cameras.

## Mission Design

Table 2: LOFT-P Mission Study Parameters

Parameter	Required Value (Goal)
<i>LOFT-P Spacecraft/Mission</i>	
Estimated Launch Year	2027-2030
Mission duration	4 (5) years
Science data downlink	6.7 Gbits (14 Gbits) per orbit
Orbit	LEO, Minimizing time in SAA, < 600 km upper limit, < 5 deg inclination
<i>LAD Module (each)<sup>1</sup></i>	
Basic Mass	6.05 kg
Power	8.25 W
Quantity	120 minimum
Thermal requirement	EoL LAD detector temperature requirement of -10C over nominal FoR; Up to +11 C for extended FoR co-aligned within 3 arcmin
<i>Wide Field Monitor<sup>1</sup></i>	
Basic Mass	9.29 kg
Power	7.56 W
Quantity	10 cameras

Table 3: LOFT-P Master Equipment List

Equipment	Mass (kg)
Structures (incl. LAD frame panel)	2163
Thermal Control	298
Power	191
Communication	11
Command & Data handling	35
Guidance, Navigation, & Control	336
Propulsion	154
Mass Growth Allowance <sup>a</sup>	530
Spacecraft DRY MASS	3720
LAD (122 Modules)	738
WFM (10 cameras, ICU, & harness)	104
Mass Growth Allowance (20%)	168
Total Science Instrument Mass <sup>b</sup>	1011
Total Dry Mass	4730
Propellant (incl. 20% MGA)	940
Total Wet Mass	5670

<sup>a</sup>30% for thermal control; 7% for propulsion system (very high TRL); 20% for all other systems  
<sup>b</sup>Per ESA M3 Study

The LOFT-P spacecraft was designed to meet the requirements in Table 2. The goal of this 1-month study was to take a preliminary look at whether or not a US-led LOFT-P mission would fit within the \$500M-\$1B Probe class (excluding launch vehicle). The study addressed the following:

- **Launch Vehicle and Orbit:** An equatorial orbit with a nominal initial altitude of 550 km was recommended to avoid SAA and minimize station keeping. A Falcon 9 Heavy launch vehicle will easily place LOFT-P into this orbit.
- **Spacecraft Structure:** A monolithic design was selected to minimize complexity. The spacecraft structure will be manufactured using Quasi-isotropic IM-7 8552 composite laminates.
- **Communications System:** An X-band system with a fixed omnidirectional antenna is used for the downlink system. Two ground stations are required to meet the science data download requirements, and 3-4 are needed to meet the science data goals. A secondary VHF burst alert system is included to provide rapid notice of transient events.
- **Power System:** The overall power requirement is 2068W. To meet this requirement, the power system uses two conventional, folding, rigid panel solar arrays, 7.2 m<sup>2</sup> each, and six ABSL 24AH-ABS-DW1001 batteries for energy storage.
- **Avionics & GN&C:** Two redundant flight computers interface to a redundant pair of star trackers and IMUs to provide attitude knowledge to 4". Control momentum gyros and torque rods provide attitude control for inertially pointed observations with better than 1' pointing accuracy.
- **Thermal Control System:** Thermal control can be maintained using passive components. A system level model was run and produced results consistent with LOFT M3 designs.
- **Propulsion System:** A high-TRL propulsion system is included to deorbit the spacecraft at the end of the mission and perform orbit maintenance maneuvers. Secondary purposes include orbit insertion corrections, tip-off damping, collision avoidance, and momentum unloading.
- **Preliminary Cost Estimate:** Two cost estimates were performed, based on the LOFT M3 Yellowbook<sup>1</sup> and based on the results of this study. Mass with contingencies was used. Both cost estimates assumed a NASA-led mission that included full life cycle costs, including labor, instruments, spacecraft, mission operations, and ground data systems. Both estimates included 35% cost reserve. These preliminary estimates allow an additional 15-25% margin with respect to the expected \$1B cap for probe-class missions.

**Preliminary estimates show that LOFT-P is  
feasible as a <\$1B Probe-class mission!**

## References

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2. Feroci, M. et al. "The Large Observatory for x-ray timing (LOFT)," Exp. Astron., 34, 415-444 (2012).
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