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


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, 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 a 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 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.

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 (<200 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

<table>
<thead>
<tr>
<th>Parameter</th>
<th>LOFT-P Requirements</th>
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<tbody>
<tr>
<td>Effective Area</td>
<td>Large Area Detector (LAD) 170 cm² (peak)</td>
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<tr>
<td>Spectral Resolution</td>
<td>2-30 keV</td>
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<tr>
<td>Energy Range</td>
<td>&lt; 240 eV to 6 keV</td>
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<tr>
<td>Pointing Accuracy</td>
<td>1 arcmin</td>
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<tr>
<td>Time Resolution</td>
<td>1 ns</td>
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Mission Design

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 minimum altitude of 650 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 IM7-6552 composite laminates.
- **Communication 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 solar arrays, 7.2 m² 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 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.

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. 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 m² 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 lead-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.

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

References