Large Observatory For x-ray Timing

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

Chris Tenzer (IAAT, University of Tübingen)
on behalf of the LOFT Consortium
# LOFT Organization Structure

<table>
<thead>
<tr>
<th>LOFT ESA Payload Manager</th>
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<td>A. Short (ESA)</td>
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<td>C. Corral van Damme / M. Ayre (ESA)</td>
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<td>D. Lumb (ESA)</td>
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## Study lead

| Jan-Willem den Herder (SRON, The Netherlands) |

## Project Manager

| Enrico Bozzo (ISDC, Switzerland) |

## System Engineering/Payload

| Marco Feroci (INAF-IASF Roma & INFN Tor Vergata, Italy) |

## Science Team

<table>
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<tr>
<th>Luigi Stolla (INAF-OAR, Italy)</th>
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<td>Peter Jonker (SRON, The Netherlands)</td>
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## Large Area Detector (LAD)

| Silvia Zane (MSSL, United Kingdom) |

## Wide Field Monitor (WFM)

<table>
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<tr>
<th>Soren Brandt (DTU, Denmark)</th>
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<td>Margarita Homanz (IEEC-CSIC, Spain)</td>
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## Scientific and Instrument Simulations

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<tr>
<th>Jörg Wilms (Univ. of Erlangen-Nuremberg, Germany)</th>
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## Digital Electronics

| Andrea Santangelo (Univ. of Tübingen, Germany) |

## Silicon Detectors

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Chris Tenzer - IAAT, University of Tübingen
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### LOFT ESA Study Scientist

- **D. Lumb** (ESA)

**on behalf of scientists from:**
- Brazil
- Canada
- Czech Republic
- Denmark
- Finland
- France
- Germany
- Greece
- Ireland
- Israel
- Italy
- Japan
- the Netherlands
- Poland
- Spain
- Switzerland
- Turkey
- United Kingdom
- USA

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- **Joan in’t Zand** (SRON, The Netherlands)
  - **Digital Electronics**
  - **Silicon Detectors**
- **Andrea Santangelo** (Univ. of Tübingen, Germany)
- **Martin Pohl** (Univ. of Geneva, Switzerland)
- Andrea Vacchi (INFN, Italy)

Chris Tenzer - IAAT, University of Tübingen
L1 Slot

ATHENA: X-ray Observatory (formerly IXO)
JUICE: Mission to Jupiter and its moons
(formerly EJSM-Laplace)
NGO: Gravitational Waves Observatory
(formerly LISA)

M3 Slot

EChO: (Exoplanet Characterisation Observatory)
STE-QUEST: (Space-Time Explorer and Quantum
Equivalence Principle Space Test)
MarcoPolo-R: return a sample of material from a
primitive near-Earth asteroid
LOFT: Large Observatory for X-ray Timing

9.3.2012: Call for S-class missions, launch in 2017
M3 (LOFT) ESA Programmatic

Anticipated Mission Timeline (if further selected)

Following this Call for Missions, four new M missions, one of which being LOFT, have been recommended by the Space Science Advisory Committee (SSAC) for further assessment. These candidate M missions for the 2022 launch slot will enter a competitive process according to the following schedule:

- Assessment Phase in 2011-2013
- Down selection to enter in Definition Phase in 2013
- Definition Phase completed by 2014
- Adoption of M3 mission in 2015
- Start of Implementation Phase by the end of 2015
- Launch by 2022.

Goal of the Assessment Phase (2011-2013)

The objective of the Assessment Phase is to provide all the elements for enabling the down-selection process, in particular the space segment definition for meeting the assigned science objectives, the implementation schedule, the mission Cost at Completion, the technology readiness evaluation and the implementation risk assessment.
LOFT will address
Fundamental Question 3.3
“Matter under extreme conditions”
in ESA’s Cosmic Vision program

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 Core Science

Strong Gravity

Dense Matter

Observatory Science

To match ESA Cosmic Vision Theme: Matter under extreme conditions

- Does matter orbiting close to a Black Hole event horizon follow the predictions of General Relativity?
- What is the Equation of State of matter in Neutron Stars?
Observatory Science

LOFT lifetime: 4 years

~50% of the time LOFT will be Observatory for virtually all classes of relatively bright sources (> few \times 10^{-12} \text{erg/cm}^2/\text{s}): including

- 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

Chris Tenzer - IAAT, University of Tübingen
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 localize X-ray transients and impulsive events and monitor spectral state changes, triggering follow-up observations and provide important science in its own.
LOFT in one Plot

Chris Tenzer - IAAT, University of Tübingen
LOFT current configuration

Industrial study by Thales Alenia Space - Italia

folded

Solar Array

LAD

WFM

Bus

Chris Tenzer - IAAT, University of Tübingen
LOFT Instruments

**LAD:**
16 Detectors per Module
21 Modules per Detector Panel
6 Detector Panels per LAD

**WFM:**
4 Units
2 Cameras per Unit
4 detectors per Camera

Chris Tenzer - IAAT, University of Tübingen
## Large Area Detector Requirements

<table>
<thead>
<tr>
<th>Item</th>
<th>Requirement</th>
<th>Goal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Effective area</td>
<td>$4 \text{ m}^2 @ 2 \text{ keV}$, $8 \text{ m}^2 @ 5 \text{ keV}$, $10 \text{ m}^2 @ 8 \text{ keV}$, $1 \text{ m}^2 @ 30 \text{ keV}$</td>
<td>$5 \text{ m}^2 @ 2 \text{ keV}$, $9.6 \text{ m}^2 @ 5 \text{ keV}$, $12 \text{ m}^2 @ 8 \text{ keV}$, $1.2 \text{ m}^2 @ 30 \text{ keV}$</td>
</tr>
<tr>
<td>Calibration accuracy area</td>
<td>$15%$</td>
<td>$10%$</td>
</tr>
<tr>
<td>Energy range</td>
<td>$2 - 50 \text{ keV}$</td>
<td>$1 - 50 \text{ keV}$</td>
</tr>
<tr>
<td>Energy resolution</td>
<td>$260 \text{ eV} @ 6 \text{ keV}$, $200 \text{ eV}$ (singles, $40%$), $2 \text{ keV}$ above $30 \text{ keV}$ (allows for binning)</td>
<td>$200 \text{ eV} @ 6 \text{ keV}$, $160 \text{ eV}$ (singles, $40%$)</td>
</tr>
<tr>
<td>knowledge energy scale</td>
<td>$10^{-2}$</td>
<td>$0.8 \times 10^{-2}$</td>
</tr>
<tr>
<td>Collimated FoV (FWHM)</td>
<td>$1 \text{ degree}$</td>
<td>$0.5 \text{ degree}$</td>
</tr>
<tr>
<td>Transparency of collimator</td>
<td>$\sim 1%$ at $30 \text{ keV}$</td>
<td>$0.5%$ at $30 \text{ keV}$</td>
</tr>
<tr>
<td>Flat top</td>
<td>$12 \text{ arcmin}, \pm 2%$</td>
<td>$12 \text{ arcmin}, \pm 1%$</td>
</tr>
<tr>
<td>Time resolution</td>
<td>$10 \mu\text{s}$</td>
<td>$7 \mu\text{s}$</td>
</tr>
<tr>
<td>Absolute time</td>
<td>$1 \mu\text{s}$</td>
<td>$1 \mu\text{s}$</td>
</tr>
<tr>
<td>Dead time</td>
<td>$&lt; 1%$ @ $1 \text{ Crab}$, $&lt; 10%$ @ $10 \text{ Crab}$</td>
<td>$&lt; 0.5%$ @ $1 \text{ Crab}$, $&lt; 5%$ @ $10 \text{ Crab}$</td>
</tr>
<tr>
<td>Calibration knowledge</td>
<td>Less than the statistical precision of power spectrum for 1 day at $15 \text{ Crab}$ (TBC)</td>
<td>Factor 2 better</td>
</tr>
<tr>
<td>deadtime</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Background</td>
<td>$&lt; 10 \text{ mCrab}$</td>
<td>$&lt; 5 \text{ mCrab}$</td>
</tr>
<tr>
<td>Background knowledge</td>
<td>$10%$</td>
<td>$5%$</td>
</tr>
<tr>
<td>Max flux (continuous, no loss of info)</td>
<td>$&gt; 500 \text{ mCrab}$</td>
<td>$&gt; 500 \text{ mCrab}$</td>
</tr>
<tr>
<td>Max flux (continuous, re-binned)</td>
<td>$15 \text{ Crab}$</td>
<td>$30 \text{ Crab}$</td>
</tr>
</tbody>
</table>
# Wide Field Monitor Requirements

<table>
<thead>
<tr>
<th>Item</th>
<th>Requirement</th>
<th>Goal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Location accuracy</td>
<td>1 arcmin</td>
<td>0.5 arcmin</td>
</tr>
<tr>
<td>Angular resolution</td>
<td>5 arcmin</td>
<td>3 arcmin</td>
</tr>
<tr>
<td>Sensitivity (5 μ)</td>
<td>1 Crab (1 s)</td>
<td>0.2 Crab (1 s)</td>
</tr>
<tr>
<td></td>
<td>5 mCrab (50 ks)</td>
<td>2 mCrab (50 ks)</td>
</tr>
<tr>
<td>Calibration accuracy (sensitivity)</td>
<td>20 %</td>
<td>15 %</td>
</tr>
<tr>
<td>Field of view</td>
<td>50% of the accessible part of the sky of the LAD</td>
<td>Same, as improvement of the sensitivity is the prime goal</td>
</tr>
<tr>
<td>Energy range</td>
<td>2 – 50 keV</td>
<td>1 – 50 keV</td>
</tr>
<tr>
<td>Energy resolution</td>
<td>500 eV</td>
<td>300 eV</td>
</tr>
<tr>
<td>Energy scale knowledge</td>
<td>4%</td>
<td>1%</td>
</tr>
<tr>
<td>Number of energy bands for compressed images</td>
<td>8</td>
<td>16</td>
</tr>
<tr>
<td>Time resolution</td>
<td>300 sec for normal</td>
<td>150 sec for normal</td>
</tr>
<tr>
<td></td>
<td>10 μsec for triggered</td>
<td>5 μsec for triggered</td>
</tr>
<tr>
<td>Absolute time calibration</td>
<td>1 μsec</td>
<td>1 μsec</td>
</tr>
<tr>
<td>duration for rate triggers</td>
<td>0.1 sec - 60 sec</td>
<td>0.1 - 60 sec</td>
</tr>
<tr>
<td>Rate meter data</td>
<td>10 msec</td>
<td>8 msec</td>
</tr>
<tr>
<td>Transient event down-link</td>
<td>&lt; 3 hours (2 orbits)</td>
<td>&lt; 1.5 hour (1 orbit)</td>
</tr>
<tr>
<td>Availability of triggered WFM data</td>
<td>3 hours</td>
<td>1.5 hours</td>
</tr>
<tr>
<td>Onboard memory</td>
<td>5 min @ 100 Crab</td>
<td>10 min @ 100 Crab</td>
</tr>
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# The LOFT Mission Profile

<p>| | |</p>
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<tbody>
<tr>
<td><strong>Orbit</strong></td>
<td>Low earth ($\leq 600$ km), equatorial ($\leq 5^\circ$), circular</td>
</tr>
<tr>
<td><strong>Launcher</strong></td>
<td>Soyuz from Kourou</td>
</tr>
<tr>
<td><strong>Satellite Mass</strong></td>
<td>$\sim 2000$ kg (with margins)</td>
</tr>
<tr>
<td><strong>Satellite Power</strong></td>
<td>$\sim 1800$ W (with margins)</td>
</tr>
<tr>
<td><strong>Slew rate</strong></td>
<td>$&gt;6^\circ$ /minute</td>
</tr>
<tr>
<td><strong>Telemetry</strong></td>
<td>8 Mbps</td>
</tr>
<tr>
<td><strong>Ground Stations</strong></td>
<td>Kourou, Malindi</td>
</tr>
<tr>
<td><strong>Nominal Lifetime</strong></td>
<td>4 years</td>
</tr>
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</table>
The LOFT Technologies

1. Large Area Silicon Drift Detectors

2. Capillary plates X-ray collimators
The Key to LOFT: 
low weight/power/volume per unit effective area

Capillary Plate Collimator
(\sim 3 \text{ kg/m}^2)

Silicon Drift Detector
(\sim 1.3 \text{ kg/m}^2)

Readout electronics
(\sim 2.5 \text{ kg/m}^2)

Mechanical support, Power Distribution, Interfaces, …

\sim 8 \text{ mm}
The Large Area Silicon Drift Detector for LOFT

A heritage of the ITS of the ALICE experiment at the Large Hadron Collider (CERN)

INFN Trieste, in collaboration with Canberra Inc., designed, built, tested and calibrated 1.5 m² of SDD detectors, now operating since ~2 years.

Mature Technology. High TRL. Proven mass production.

LOFT Baseline

Thickess \[450 \mu m\]

Monolithic Active Area \[76 \text{ cm}^2\]

Drift time \[<5 \mu s\]

Single-channel area \[0.3 \text{ cm}^2\]

Chirs Tenzer - IAAT, University of Tübingen
The Working Principle of the LOFT Si Drift Detector

Si bulk

read-out anodes

35 mm

~1 mm

Chris Tenzer - IAAT, University of Tübingen
The Working Principle of the LOFT Si Drift Detector

- Si bulk
- X-ray
- charge
- read-out anodes
- signal
- Single events (∼45%)
- ∼1 mm
- 35 mm

Chris Tenzer - IAAT, University of Tübingen
The Working Principle of the LOFT Si Drift Detector

Double events (~55%)

Single events (~45%)

Chris Tenzer - IAAT, University of Tübingen
The development of LOFT Si Drift Detector

**2009**

ALICE spare model - discrete read-out - *Room Temperature*

**2010**

1st LOFT Prototype

Fe$^{55}$ source (5.9-6.4 keV)

**2011**

2nd LOFT Prototype
Si Drift Detectors and Capillary Plate Collimators

Chris Tenzer - IAAT, University of Tübingen
The LOFT capillary plate collimator at Univ. of Leicester

The MIXS-C model during vibration tests at RAL

Courtesy G.W. Fraser, Univ. of Leicester
Critical Mission Parameters Linked to Calibration

- Background / Radiation Environment
- Source Confusion
- Absolute Pointing Knowledge and Stability
- Degradation of Energy Resolution due to Radiation Damage
- Temperature Stability

A possible approach

Our real goal: avoid spurious modulation in count rate from celestial sources, due to varying LAD response within a given observation. The satellite will point whatever we will define as LAD boresight to a direction which is APE off-set from the source, oscillating at TBD (1-10 Hz?) "high frequency" with amplitude RPE and at TBD (<10^{-5} Hz?) "low frequency" with amplitude APD.

Even if LAD had a perfectly triangular response, what we really need is that such response will vary by less than TBD% for an angular range ±(RPE/2) around APE.

This suggests a large FOV science requirement RPE FOV APE.

FOV
APE
RPE

M. Feroci - MSSL 29.02.2012

3rd LOFT consortium meeting - MSSL
28th-29th Febr 2012
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Baseline collimator

5 mm thick, 80 µm pore size, 10 µm wall (80% OAR)
(and on a single tile -> higher effective area)

Tighter requirement on RPE (<10 arcsec)

Baseline collimator

5 mm thick, 80 µm pore size, 10 µm wall (80% OAR)
(and on a single tile -> higher effective area)

Tighter requirement on RPE (<10 arcsec)
Critical Items for Calibration

Critical Parameters for Ground and in-Flight Calibration

• Effective area as $f(Energy)$ (10 m$^2$ @ 8 keV)

• Energy resolution as $f(Energy)$ (@ 6 keV: Singles 200eV, Overall 260 eV)

• Knowledge of energy scale (1e-2), Temperature effects

• Collimator performance as $f(Angle, Energy)$ (measured up to 50 keV)

• Dead time, pileup effects as $f(Countrate)$
LOFT Web Page

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

- Mission info
- Simulation Tools
- Project status updates
- Public Outreach

2nd LOFT Science Meeting:
24-27.9.2012 Toulouse

LOFT International Support Team:

Chris Tenzer - IAAT, University of Tübingen
LOFT is a simple mission, relying on solid hardware heritage, offering both breakthrough and observatory science.

LOFT is one of the 4 mission concepts selected by the ESA Advisory Structure as a candidate in CV-M3

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

Thank you