Planned Missions for X-ray Studies of Millisecond Pulsars: NICER and LOFT

Paul Ray (NRL)
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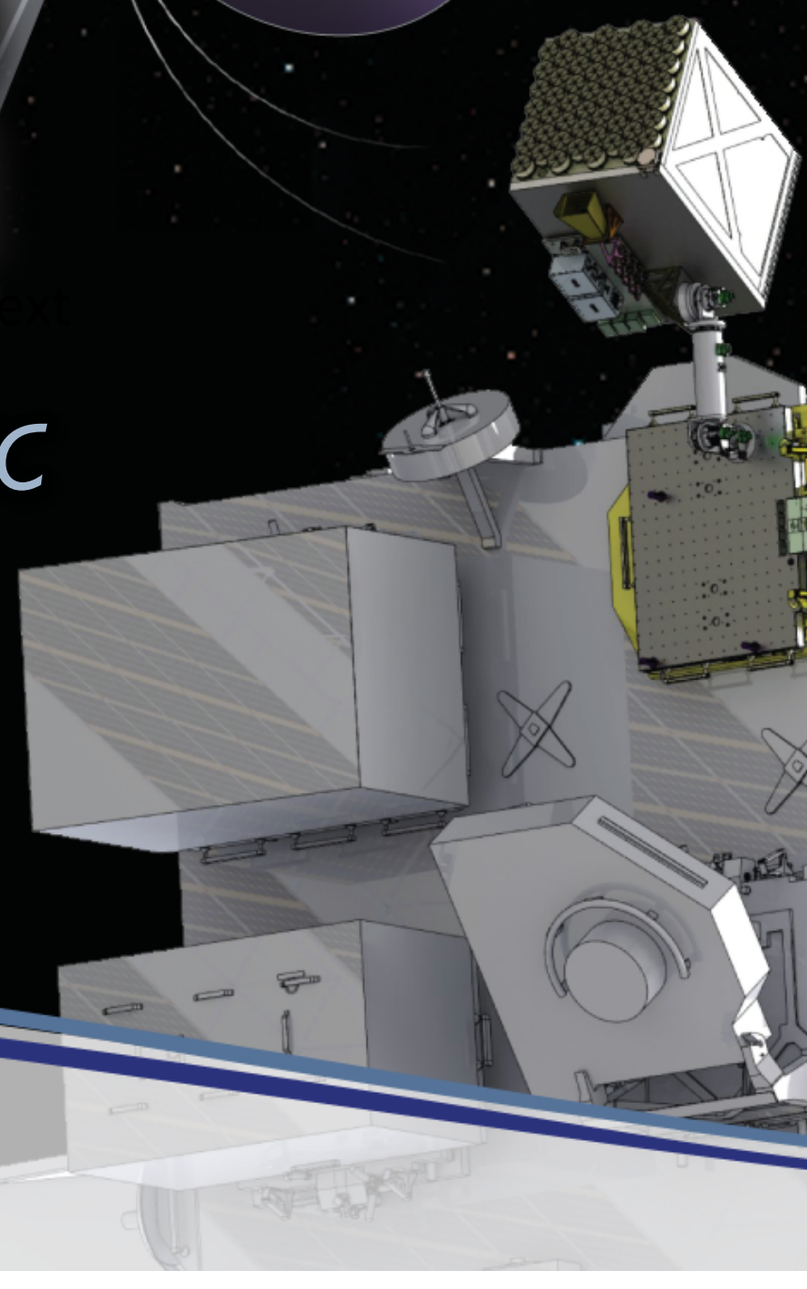
http://heasarc.gsfc.nasa.gov/docs/nicer/

NICER

Neutron star Interior Composition ExplorER

Keith Gendreau, NASA GSFC
Principal Investigator

Zaven Arzoumanian
Deputy PI



NASA

GSFC

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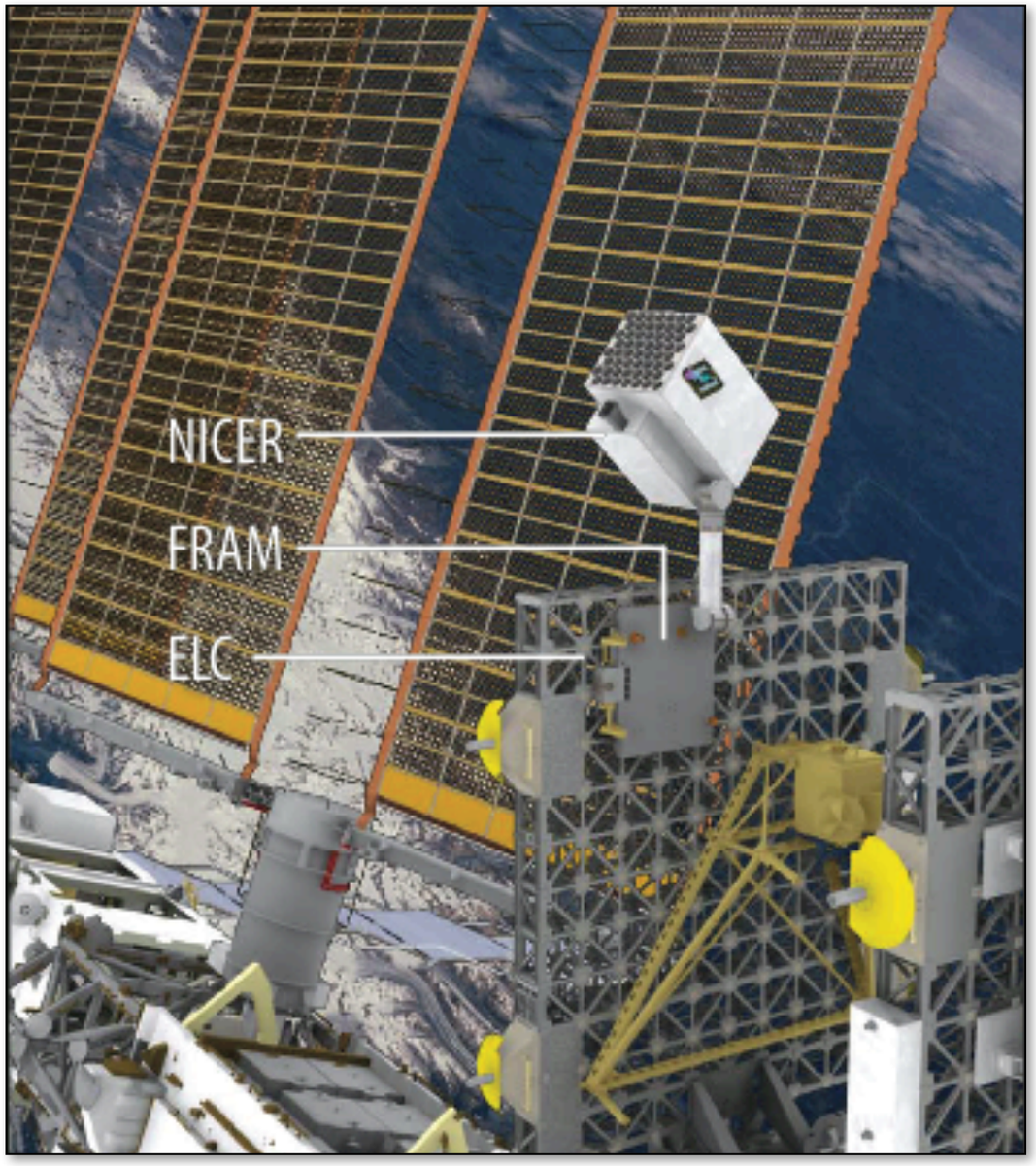
Mission Overview

NICER

Astrophysics on the International Space Station —
Understanding ultra-dense matter through soft X-ray timing

- ***Science:*** A proposed International Space Station (ISS) payload dedicated to the study of *neutron stars*. A fundamental investigation of extremes in gravity, material density, and electromagnetic fields
  - Currently in Phase A
  - Downselect from 2 candidate missions in March of 2013
- ***Launch***: Late 2016, JAXA *HII-B* or U.S. commercial (e.g., SpaceX)
- ***Duration:*** 18 (minimum 12) months, with an optional Guest Observer program
- ***Platform:*** ISS ExPRESS Logistics Carrier (ELC), with active pointing over 2π steradians
- ***Instrument:*** X-ray (0.2–12 keV) "concentrator" optics and silicon-drift detectors. GPS position and absolute time reference to better than 300 ns.



ISS Accomodations

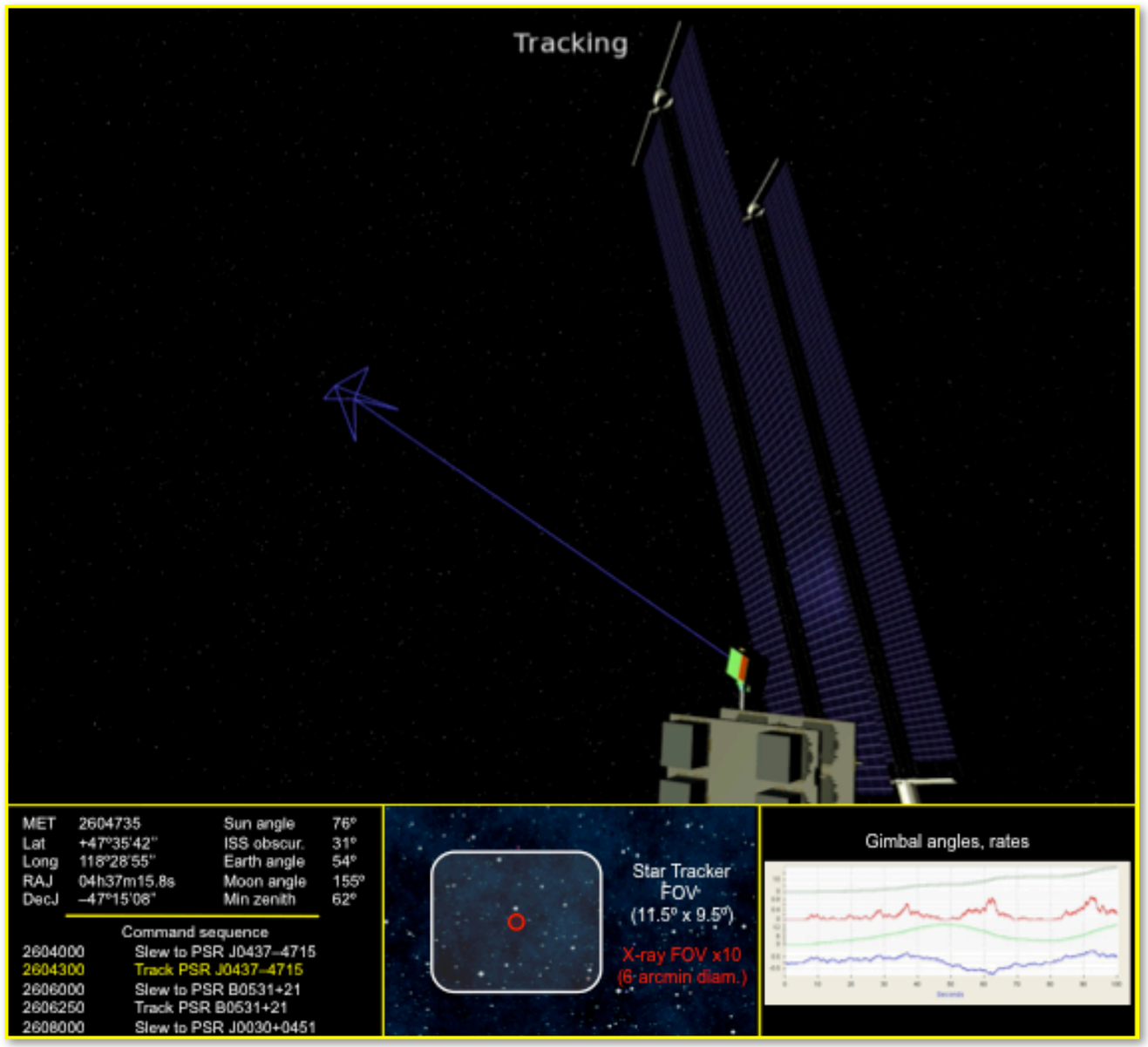
NICER

The ISS offers:

- Established infrastructure (transport, power, comm, etc.) that reduces risk
- Generous resources that simplify design and reduce cost.
- A stable platform for arcminute astronomy

NICER's design:

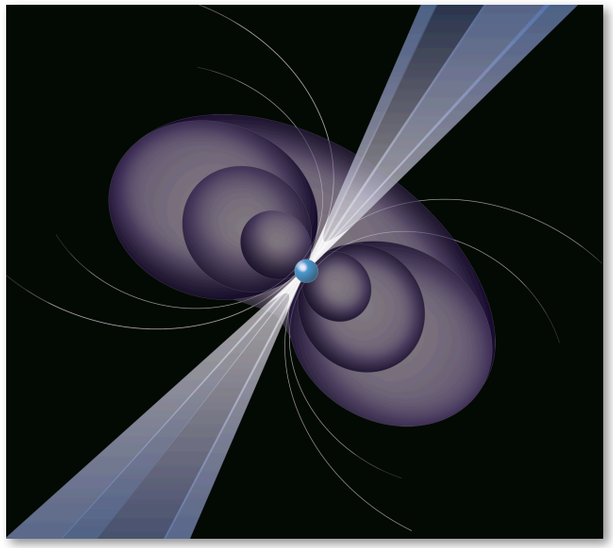
- Is tolerant of ISS vibrations
- Is insensitive to the ISS contamination and radiation environments, with safe-stow capability
- Provides high (> 65%) observing efficiency.

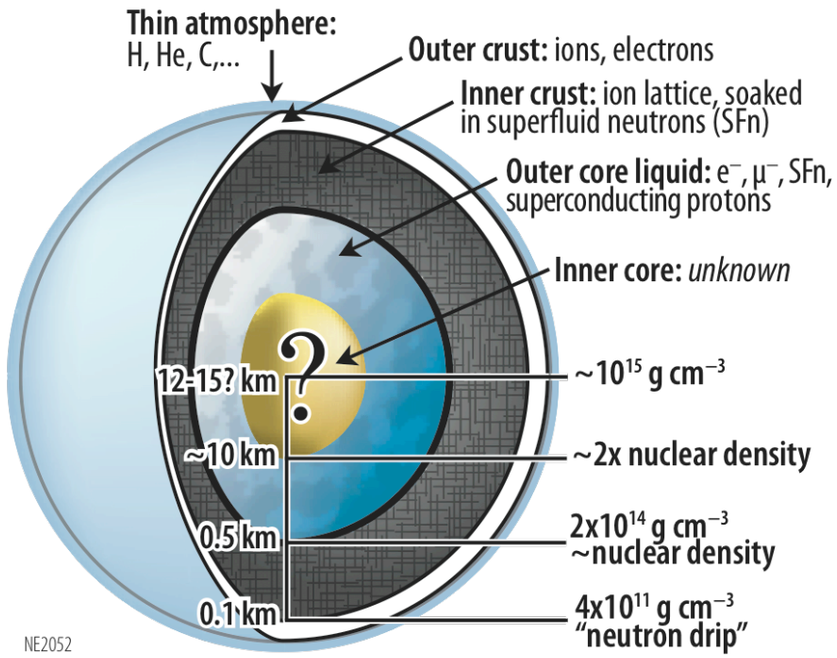


Science Objectives

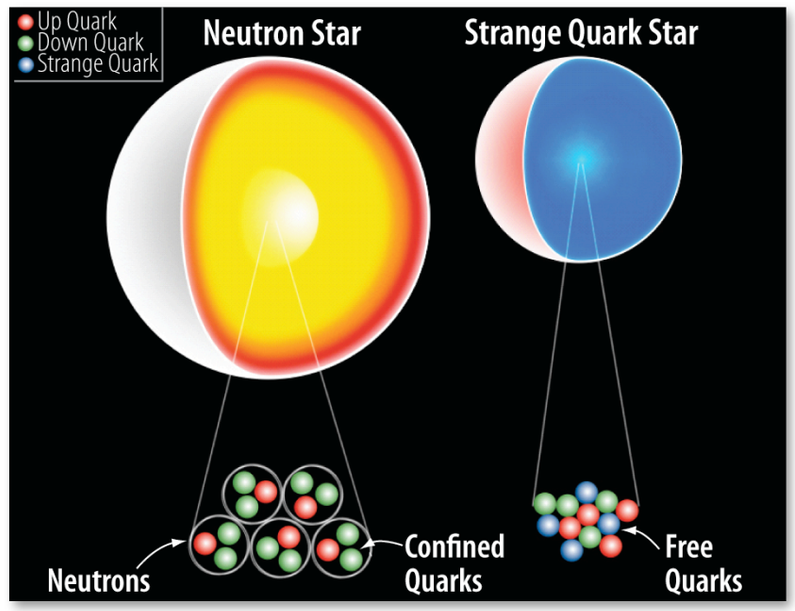
Neutron stars — Unique environments in which all four fundamental forces of Nature are simultaneously important.

- To address NASA and National Academy of Sciences strategic questions
- To resolve the nature of ultradense matter at the threshold of collapse to a black hole
- To reveal interior composition, dynamic processes, and radiation mechanisms of neutron stars.





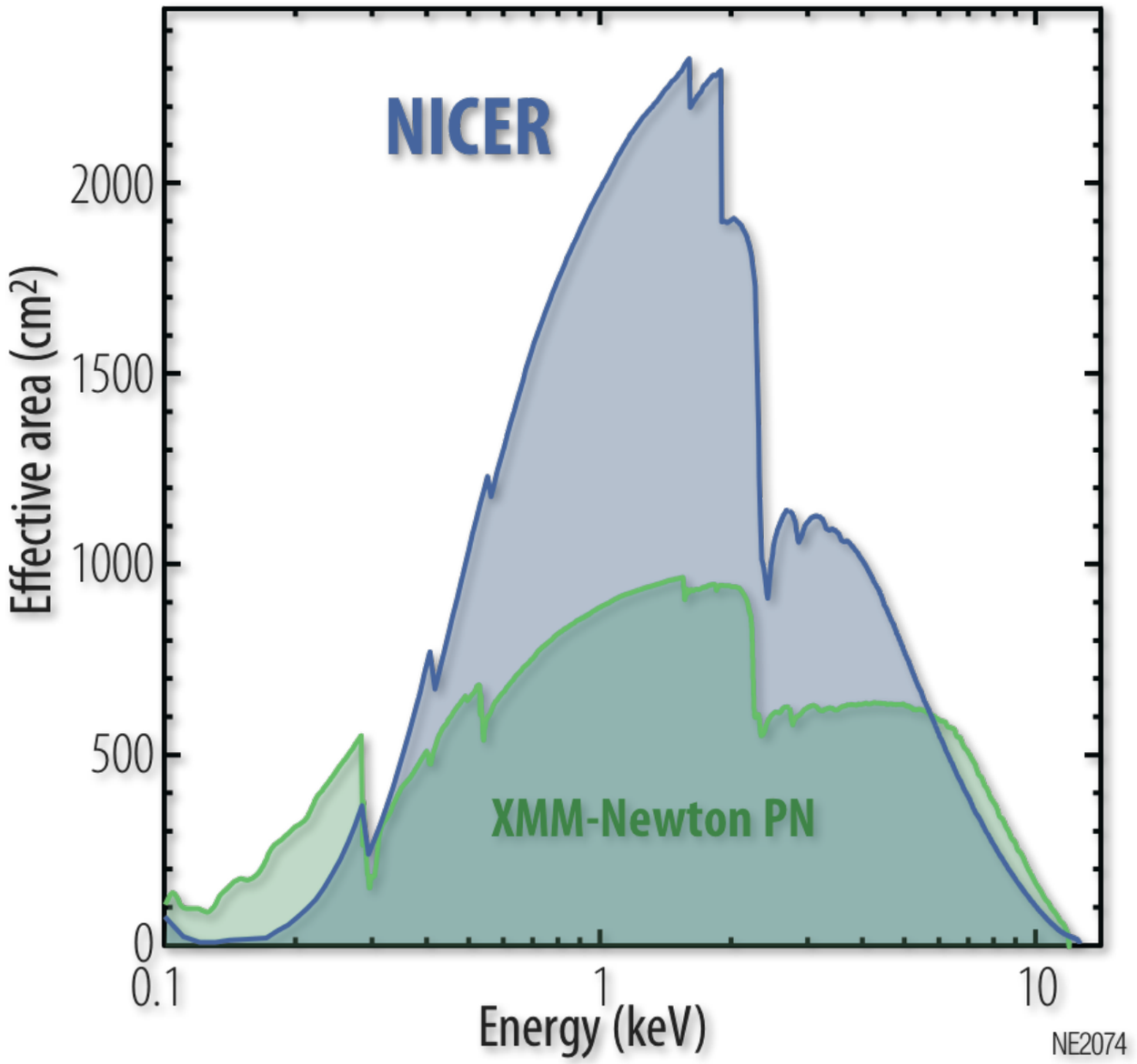
Objective	Measurements
Structure — Reveal the nature of matter in the interiors of neutron stars	Neutron star radii to ±5%. Cooling timescales
Dynamics — Uncover the physics of dynamic phenomena associated with neutron stars	Stability of pulsars as clocks. Properties of outbursts, oscillations, and precession
Energetics — Determine how energy is extracted from neutron stars.	Intrinsic radiation patterns, spectra, and luminosities.



Instrument Performance

High-throughput, low-background soft X-ray timing and spectroscopy

- ***Bandpass:*** 0.2–12 keV
- ***Effective area:***
  > 2000 cm^2 @ 1.5 keV,
  600 cm^2 @ 6 keV
  2x XMM-Newton for soft X-ray timing
- ***Energy resolution:***
  85 eV @ 1 keV,
  137 eV @ 6 keV
  Similar to XMM and Chandra
- ***Time-tagging resolution:***
  < 300 nsec (absolute)
  ~25x better than RXTE
  ~100–1000x better than XMM
- ***Spatial resolution:*** 5’ diam. non-imaging FOV
- ***Background:*** Dominated by diffuse XRB (soft)
- ***Sensitivity:*** 3 x 10^{-14} ergs s^{-1} cm^{-2}
  (0.5–10 keV, 5σ in 10 ksec)
  ~30x better than RXTE,
  ~4x better than XMM



Neutron Star Science Synergies

NICER

Interplay between multiwavelength capabilities amplifies scientific returns from all

NICER

- Neutron star radii through lightcurve analysis
- Masses and clock stabilities through phase-coherent timing
- Pulsation period discoveries
- Nonthermal X-ray beam properties

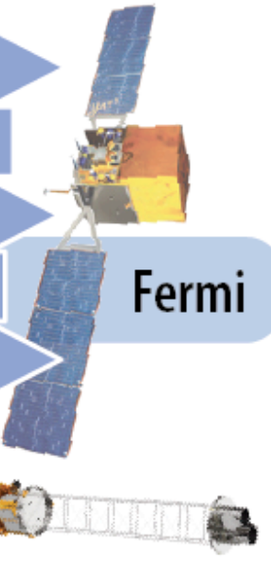
Resolution of unidentified sources (e.g., radio-quiet pulsars)

New millisecond pulsars (MSPs)

Ephemerides for γ-ray photon folding

Viewing geometry from γ-ray lightcurves

Magnetic pole localization for γ-ray lightcurve analysis



Fermi

Magnetic field strengths and viewing geometries

Ephemerides for phase-resolved polarimetry

Test of Comptonization in thermal PC models

Surface and polar-cap temperatures

Atmosphere properties in strong magnetic fields

Future X-ray polarimeter

MAXI, other all-sky monitors

Triggers for transients, glitches

Sensitive followup for source identification

Neutron star masses

Timing stabilities for gravitational wave detection

Parallax distances

Radio

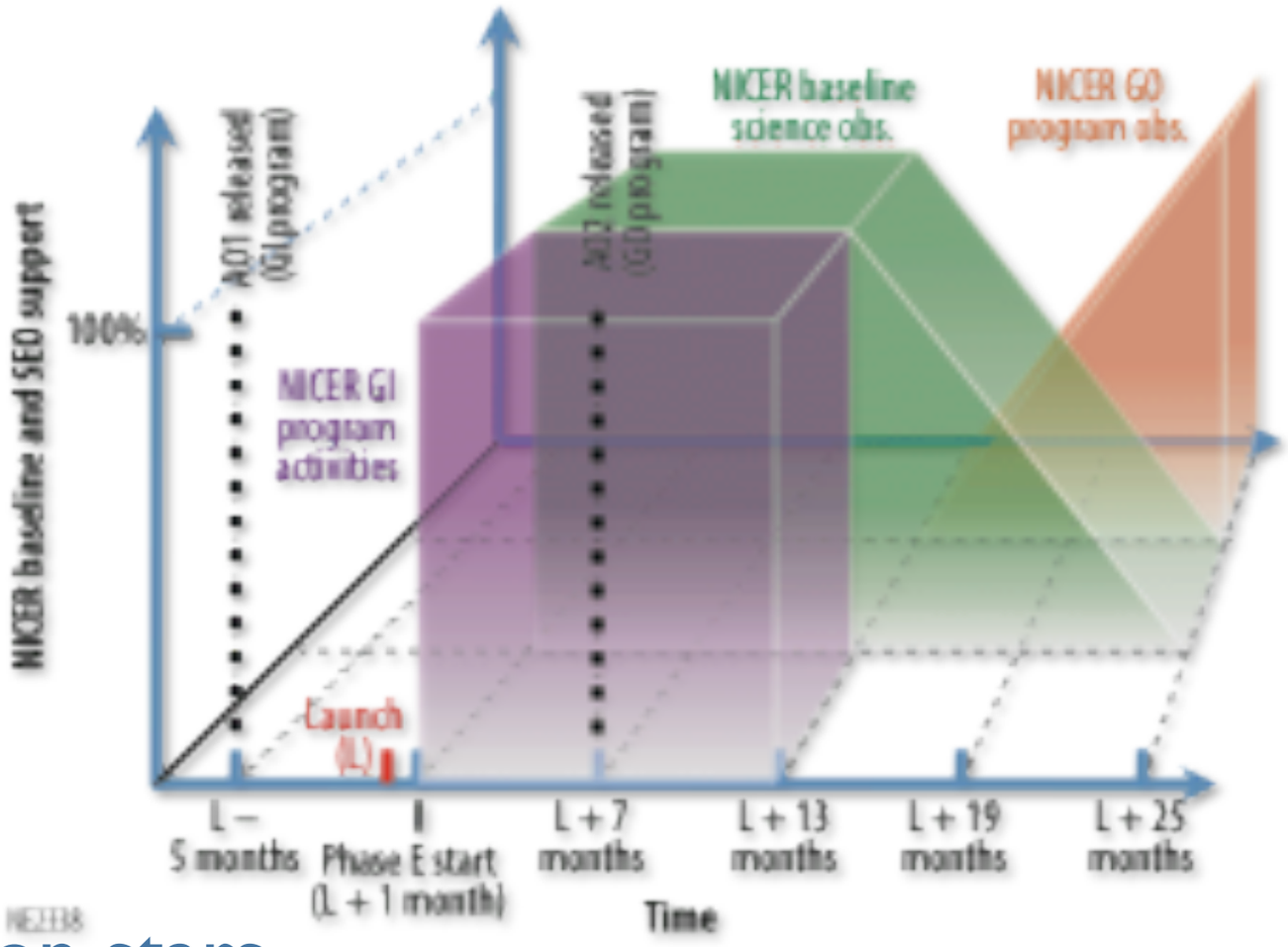
NE2003

Proposed Guest Investigator/Guest Observer Program

X-ray astrophysics beyond neutron stars, continuity of RXTE timing science

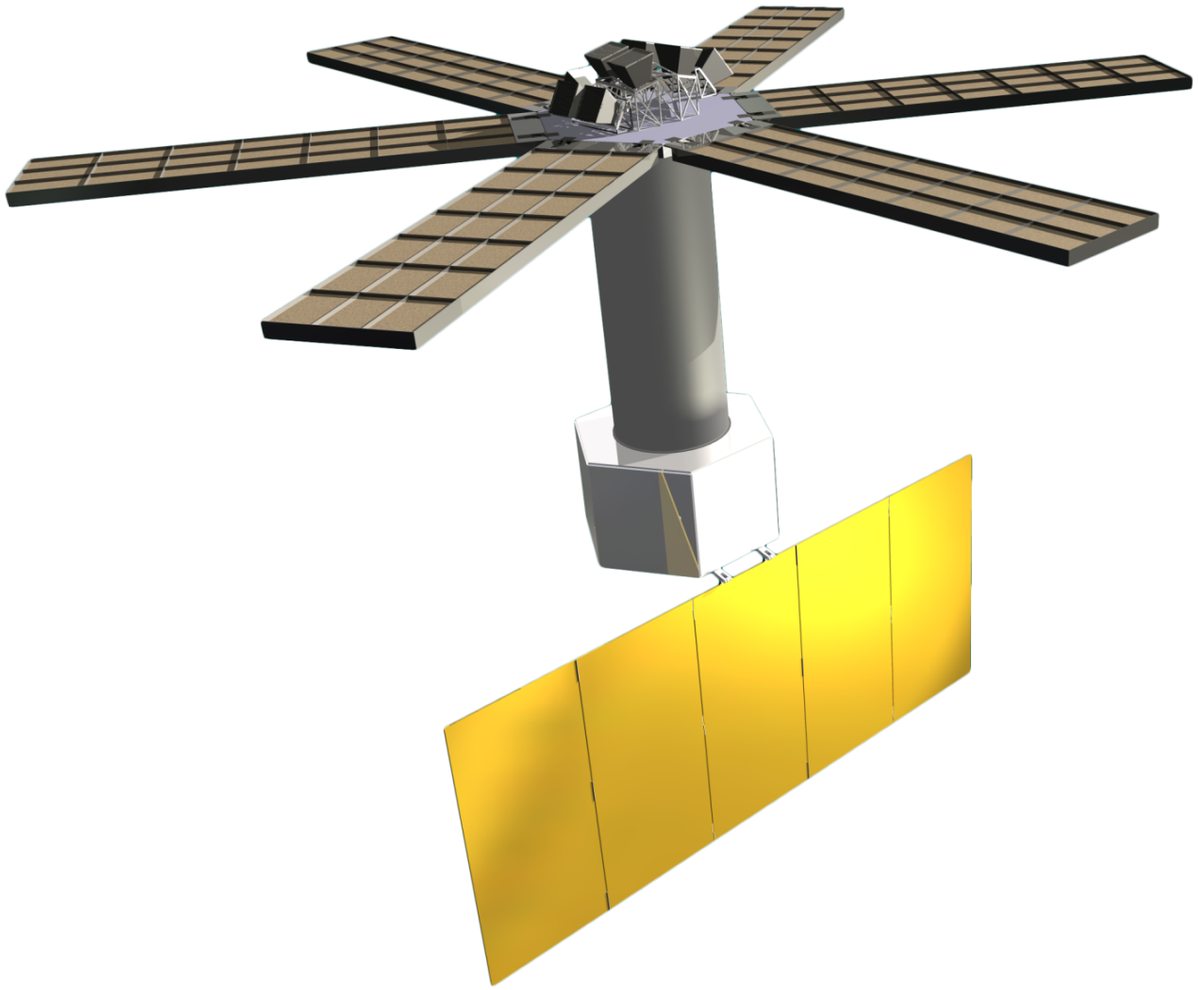
A proposed two-part Guest Investigator/Observer program, modeled after *Swift*:

- In Year 1, support for corollary neutron star research: theory & complementary multiwavelength observations
- In Year 2, solicitation of proposals for guest observations with NICER, not necessarily targeting neutron stars.



Large Observatory For x-ray Timing

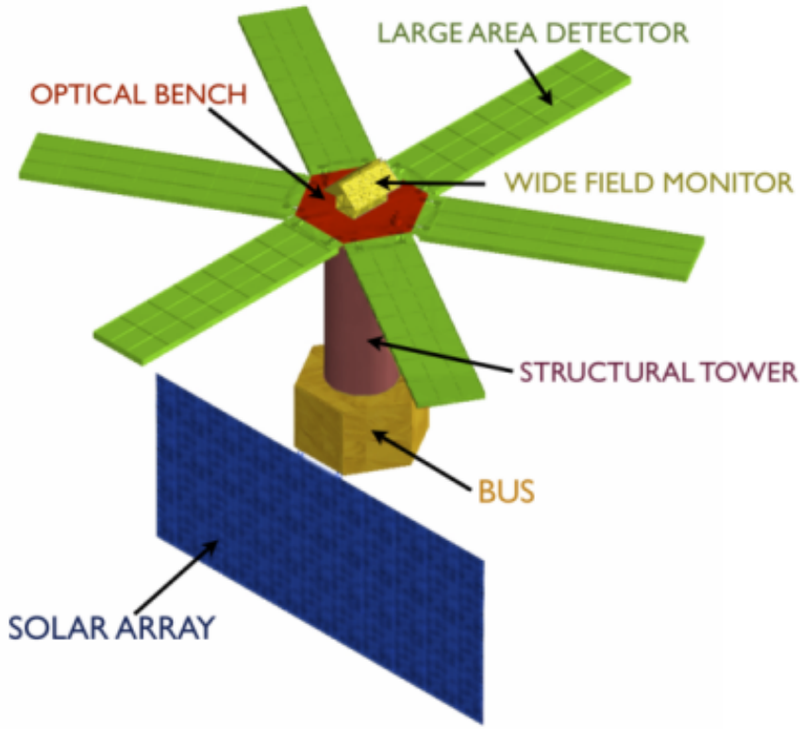
- One of 5 missions in consideration for M3 launch slot under ESA's Cosmic Vision program
  - Launch planned for 2022–2024 on Soyuz into ~600 km, near equatorial orbit ($i < 5°$)
  - Others are EChO, MarcoPolo-R, STE-QUEST, and PLATO (left over from M1,M2 selection)
  - ESA contribution capped at 450 M€
- Currently undergoing assessment phase study
  - Downselect to one M3 mission will occur at end of 2013
- Nominal mission duration 4 years



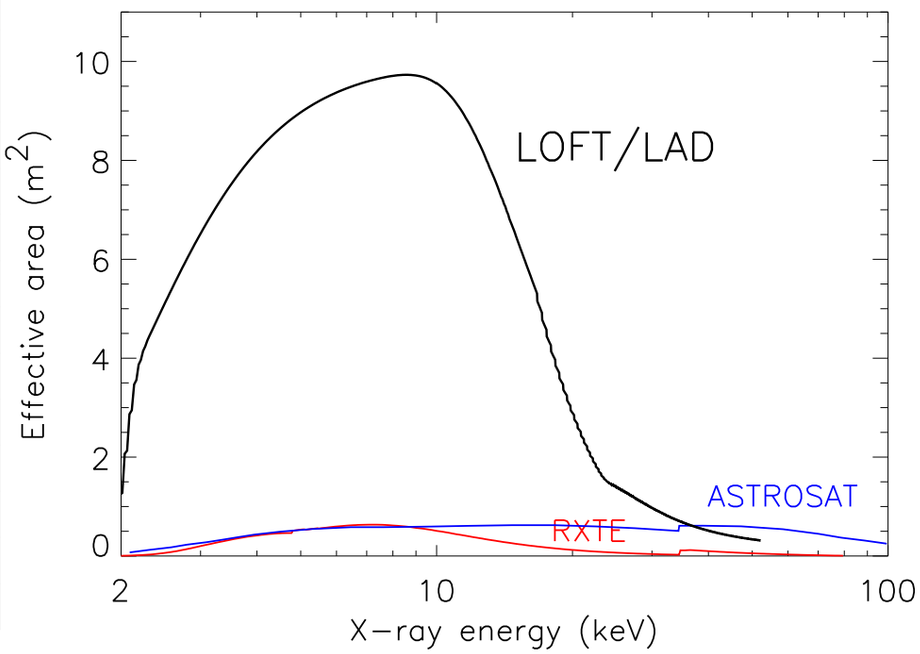
http://www.isdc.unige.ch/loft/

LOFT Payload

- **Large Area Detector (LAD)**
  - 20x area of RXTE PCA
  - 2–30 keV, <260 eV resolution
  - Excellent timing, high rate capability
- **Wide Field Monitor (WFM)**
  - Continuous coverage of large fraction of sky
  - Transient triggering, burst alerts, and stand-alone science

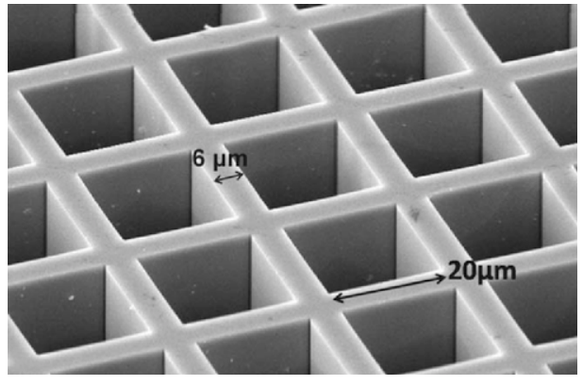


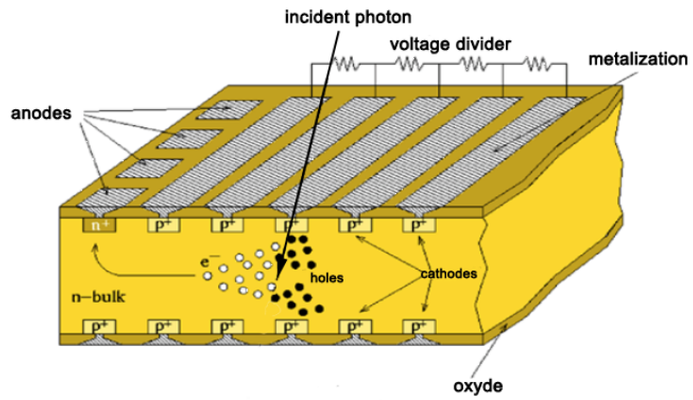
Parameter	LAD	WFM
Detector Type	Silicon Drift Detector	Silicon Drift Detector
Number of Units	7 Panels x 20 Modules x 16 Detectors	5 Units x 2 Cameras/Unit
Effective Area	10.2 m^2 (at 8 keV)	364 cm^2 per Unit
Mask	—	0.25 x 14 mm elements (25% open)
Det. Operating Temperature	< –32 °C	< –20 °C
Energy Range	2–30 keV (30–80 extended)	2–50 keV (50–80 extended)
Energy Resolution	<260 eV (<200 eV single-anode events)	<500 eV @ 6 keV
Spatial Resolution	—	5 arcmin x 5 arcmin
Field of View	1°	180°x90° + 90°x90° (FWZR)
Background	3000 cts/s (1000 cts/s with Ta collimator)	550 cts/s per Unit
Time Resolution	10 μs	300 s (baseline) 10 μs (event-mode)
Typical Data Rate (w/compression)	200/1000 kbps (100/500 mCrab)	50/90 kbps (425 kbps event mode)
Mass (CBE w/contingency)	701 kg (MCP coll.) / 803 kg (Ta coll.)	80 kg
Power (CBE w/contingency)	1222 W	110 W

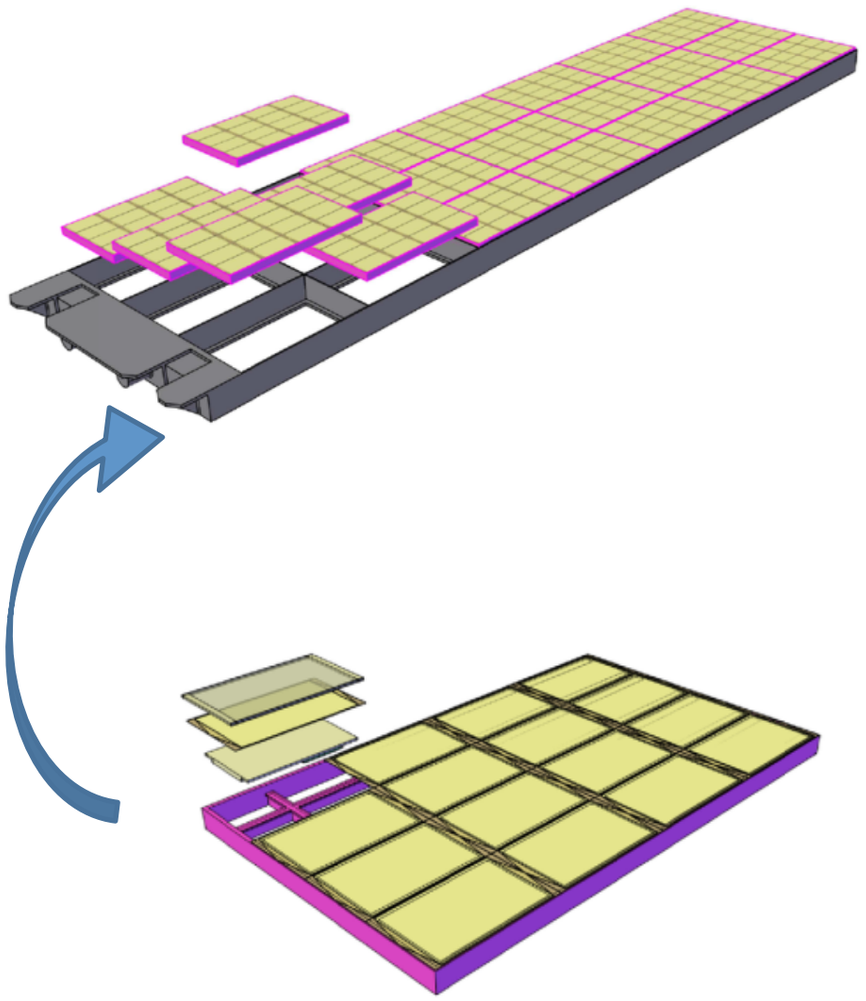


Large Area Detector (LAD)

- Two critical enabling technologies
  - Large area silicon drift detectors (heritage from ALICE experiment at LHC)
    - 11 x 8 cm, 450 μm thick
    - <260 eV energy resolution
  - Thin, light micropore X-ray collimators out of lead-glass
    - MCP heritage including MIXS instrument on BepiColumbo
  - Highly modular
    - 16 detectors/module
    - 21 modules/panel
    - 6 panels in the instrument
- Over 10 m^2 effective area
  - Small deadtime, even on bright sources

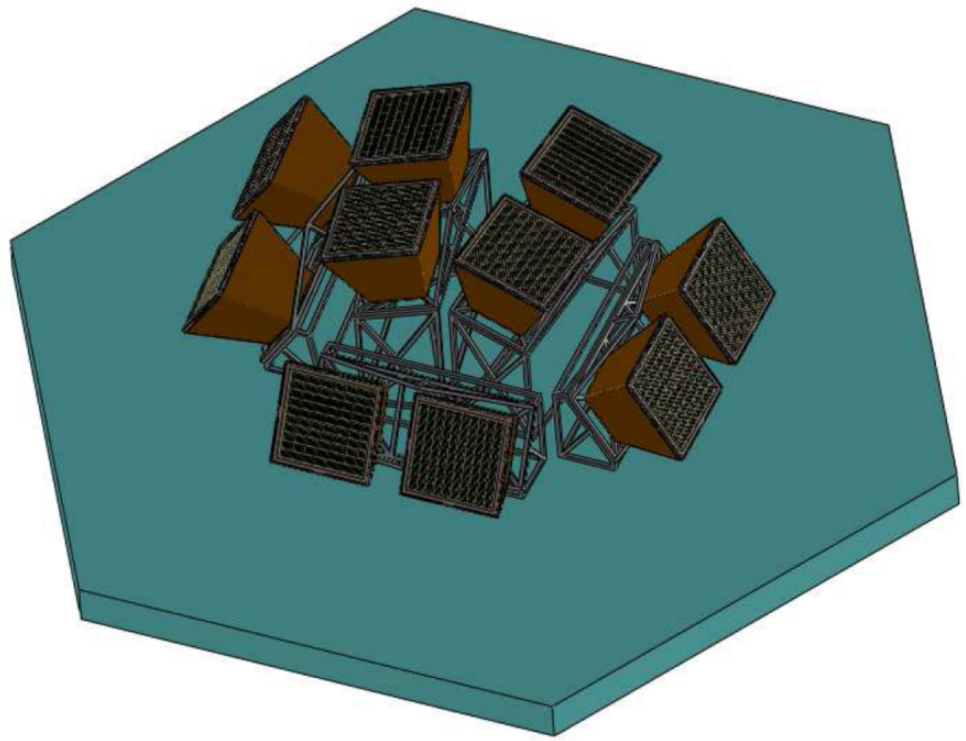


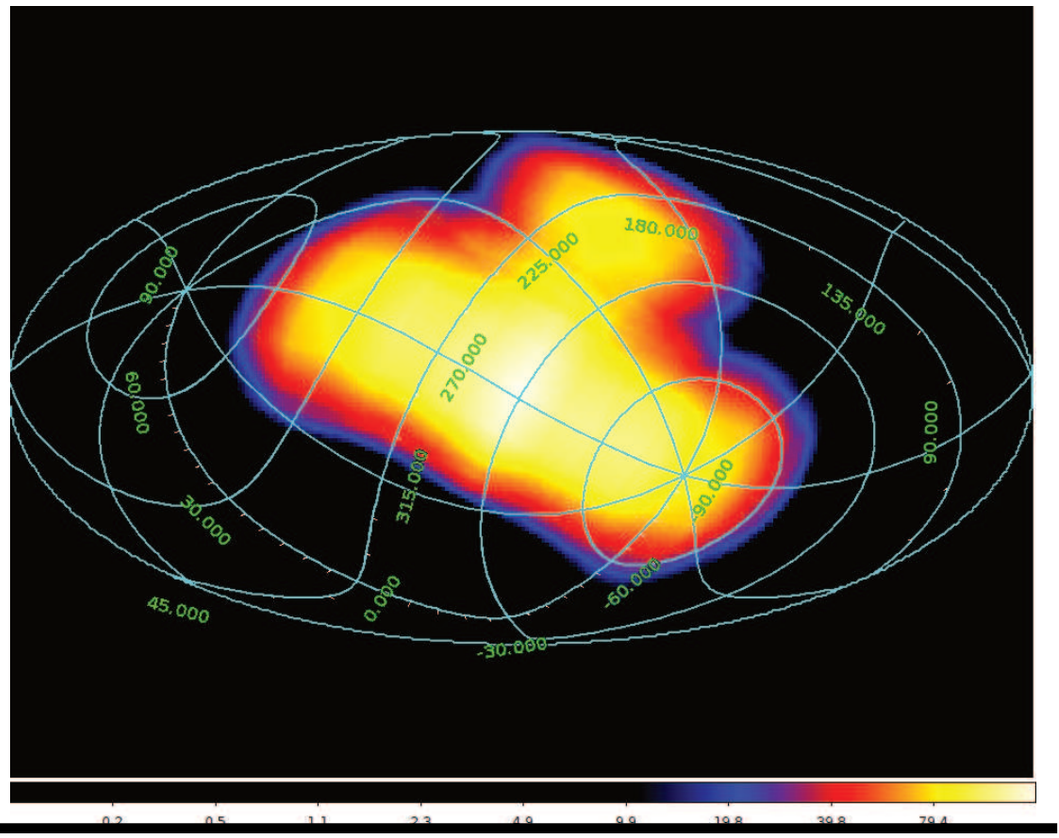




Wide-Field Monitor (WFM)

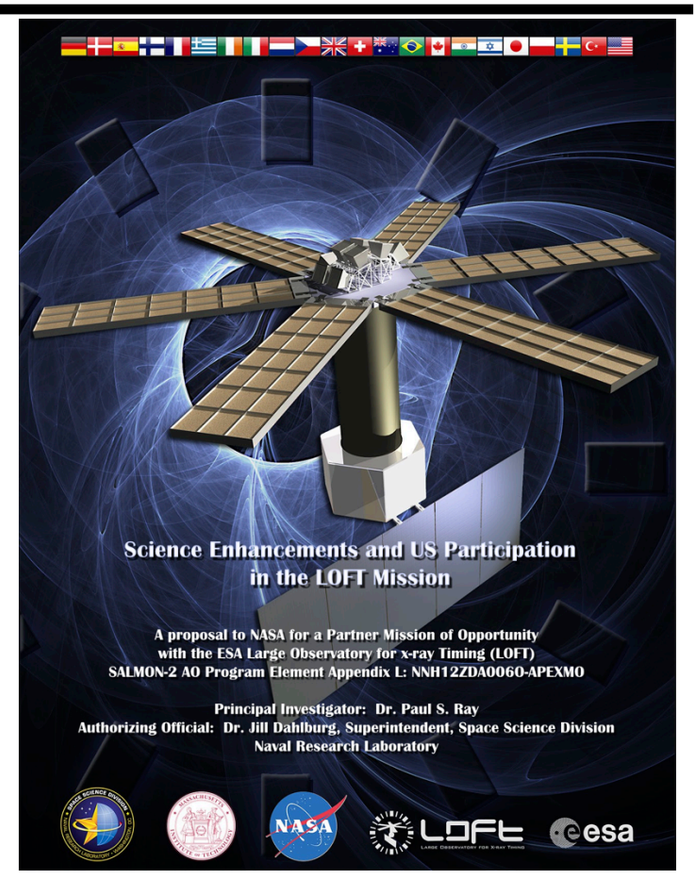
- 5 pairs of crossed 1.5D coded-mask cameras, covering most of LAD accessible sky
  - 180°x90° + 90°x90° (FWZR)
- Based on same SDDs as LAD, but optimized for imaging
  - 2–50 keV
  - 300 eV resolution
  - 5 arcmin spatial resolution (1’ locations)
  - Crab is about 227 cts/s in one camera pair

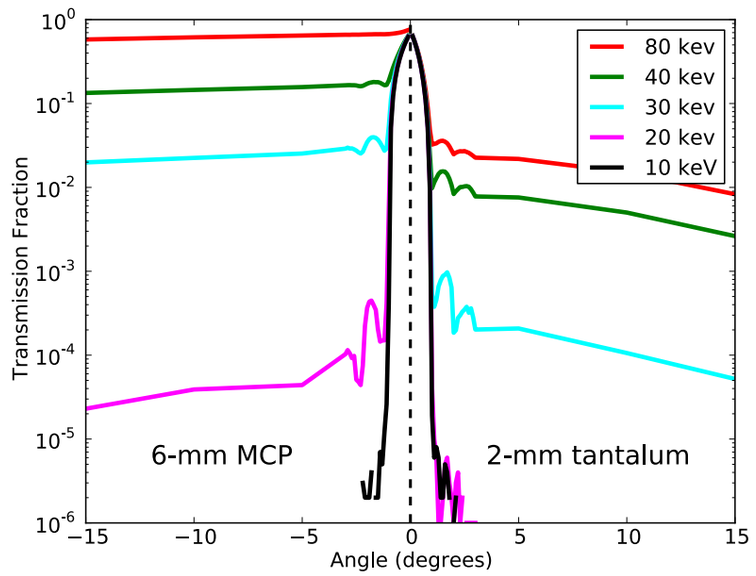




US-LOFT Proposal

- **NASA Mission of Opportunity Proposal submitted 14 December 2012**
  - PI: P. Ray (NRL), with major contributions from MIT, NASA/MSFC, JPL, and NASA/GSFC, plus large US science working group
  - ~$40M for US participation if LOFT is selected by ESA
- **Proposed US Contributions**
  - Tantalum X-ray collimator, which reduces background by factor of 3 and reduces source confusion
  - Additional ground station enables event-mode data from WFM and less compression on LAD bright sources
  - Science team participation leverages US experience with RXTE to improve LOFT
  - Science support and data archive at HEASARC to enable US science
    - Pre and post-launch competitively-funded science program
    - GO program as a Science Enhancement Option (SEO)





Science Objectives

- **Baseline ESA Science**
  - Study of extremes of density, gravity, and magnetic field
  - Equation of state of ultradense matter
  - Testing strong-field general relativity and black hole spin by tracing accretion flows near black holes
  - Observatory Science (50% of observing time)
- **US Enhancements**
  - Reduced background for LAD significantly extends sensitivity to faint sources like active galactic nuclei (AGN) and rotation-powered pulsars
  - Increased telemetry for WFM opens up X-ray sky monitoring to high-resolution time-domain astronomy and multi-wavelength connections

Summary

- Some good prospects for X-ray missions going forward after Chandra, XMM-Newton, & Suzaku
  - NuSTAR
  - ASTROSAT
- and hopefully,
  - NICER
  - LOFT
  - someday maybe an IXO-like mission?