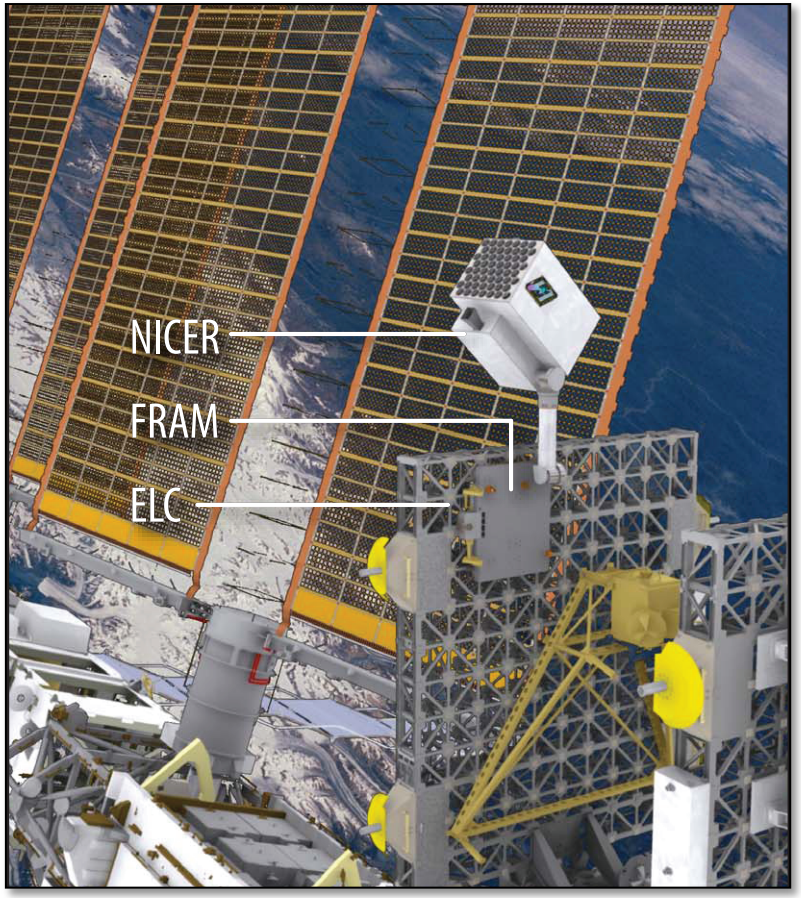
NICER
Neutron star Interior Composition ExploreR
Keith Gendreau, NASA GSFC
Principal Investigator
NASA
GSFC
MIT KAVLI
INSTITUTE

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
- ***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

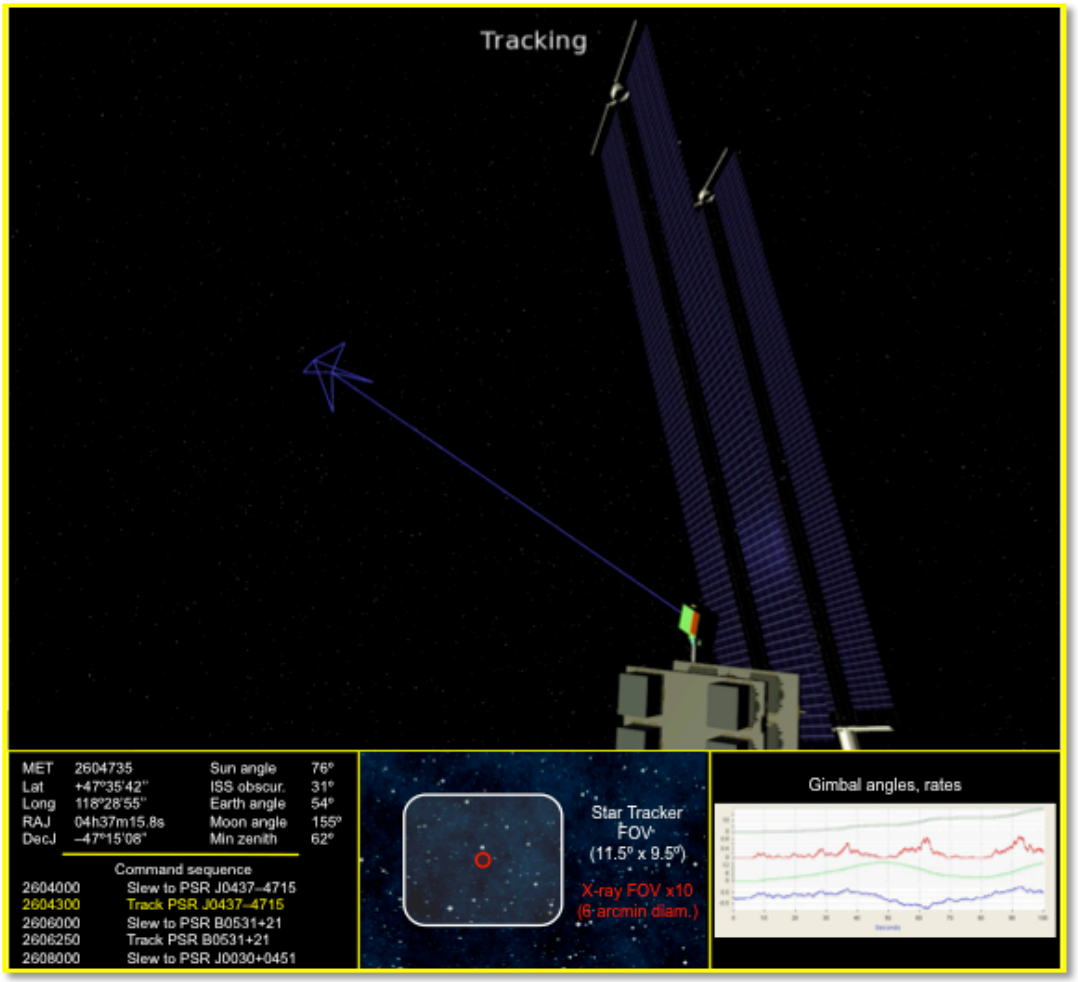
An established platform and a benign environment

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.

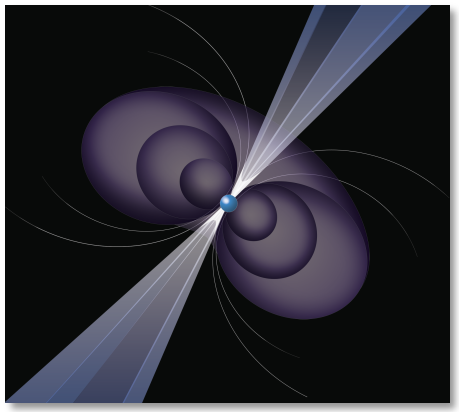


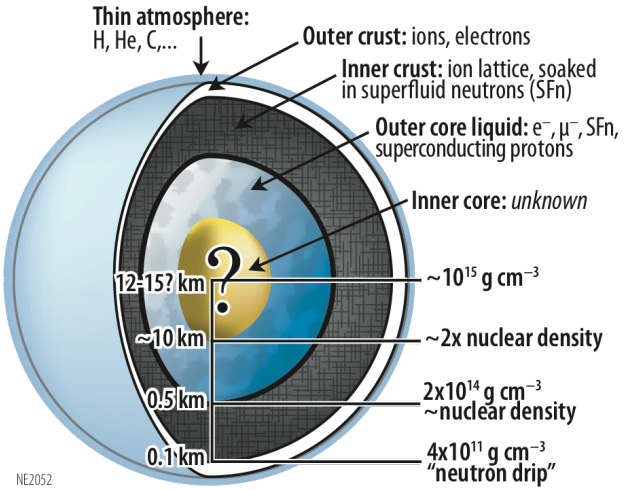
Science Objectives

NICER

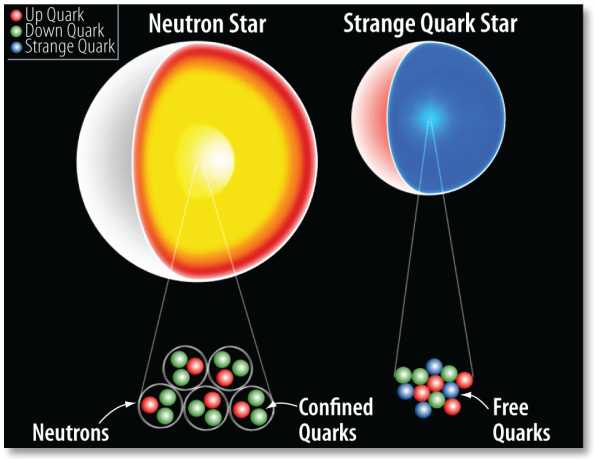
Neutron stars — Unique environments in which all four fundamental forces of Nature are simultaneously important.

- 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.





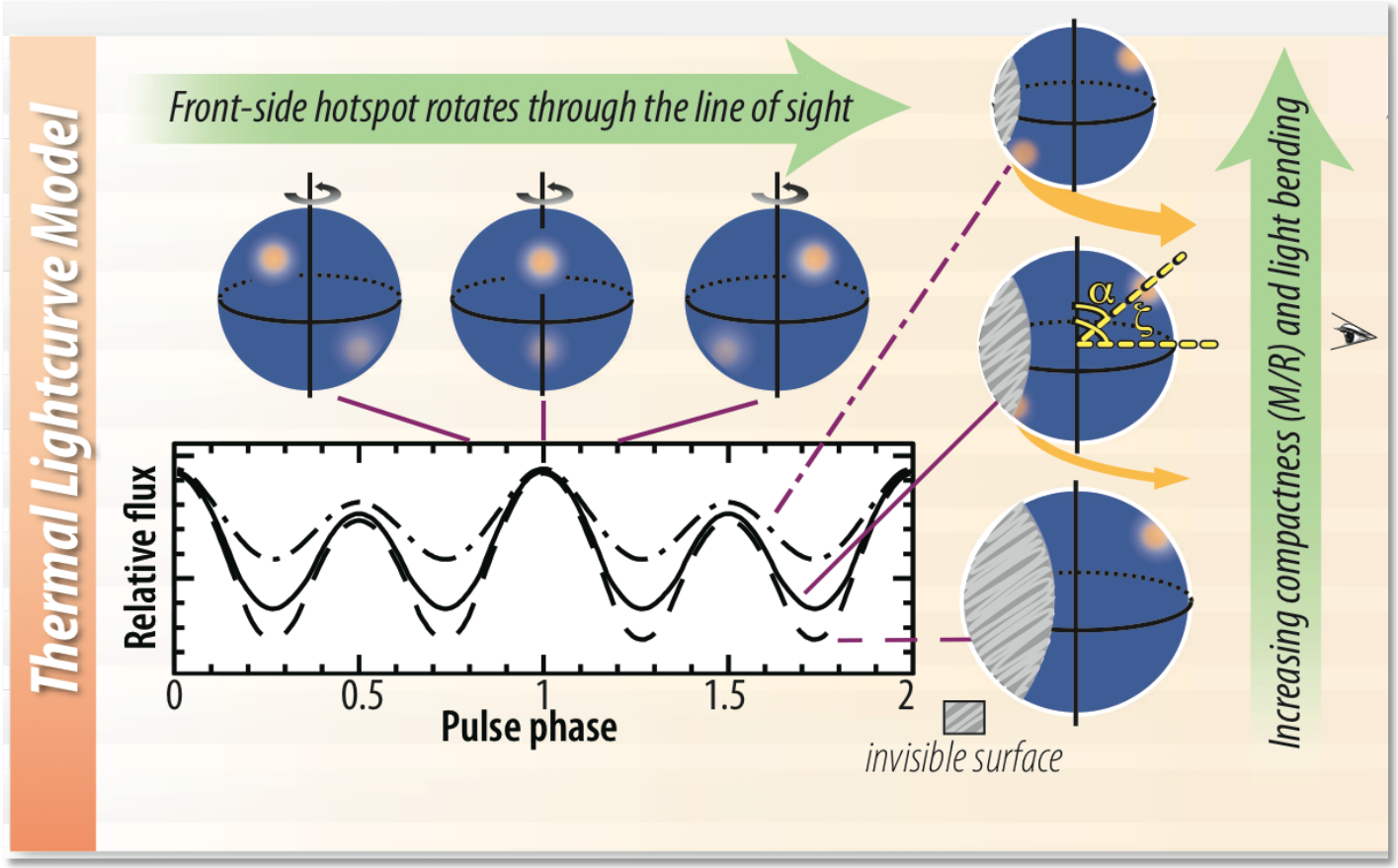
Objective	Measurements
Structure — Reveal the nature of matter in the interiors of neutron stars	Neutron star radii to ±5%. Cooling timescales
Dynamics — Uncover the physics of dynamic phenomena associated with neutron stars	Stability of pulsars as clocks. Properties of outbursts, oscillations, and precession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



Science Measurements

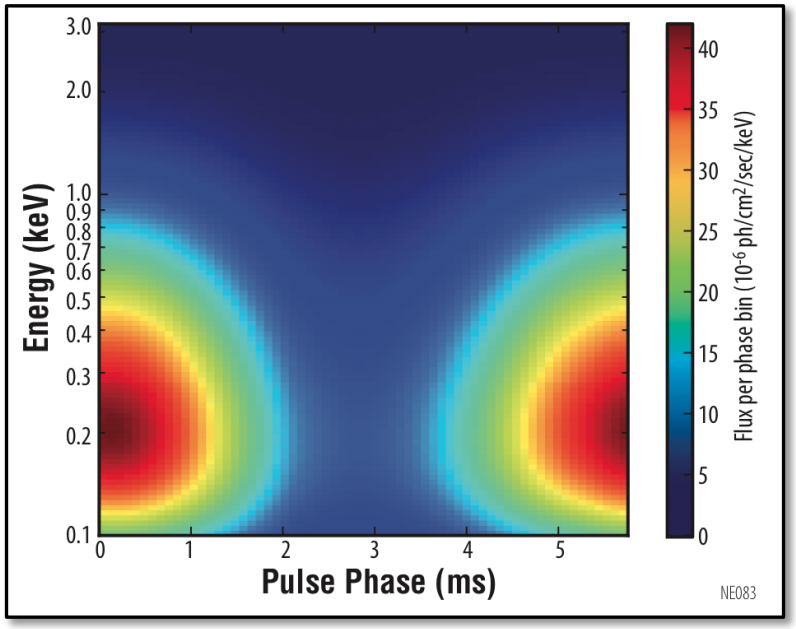
NICER

Reveal stellar structure through lightcurve modeling, long-term timing, and pulsation searches

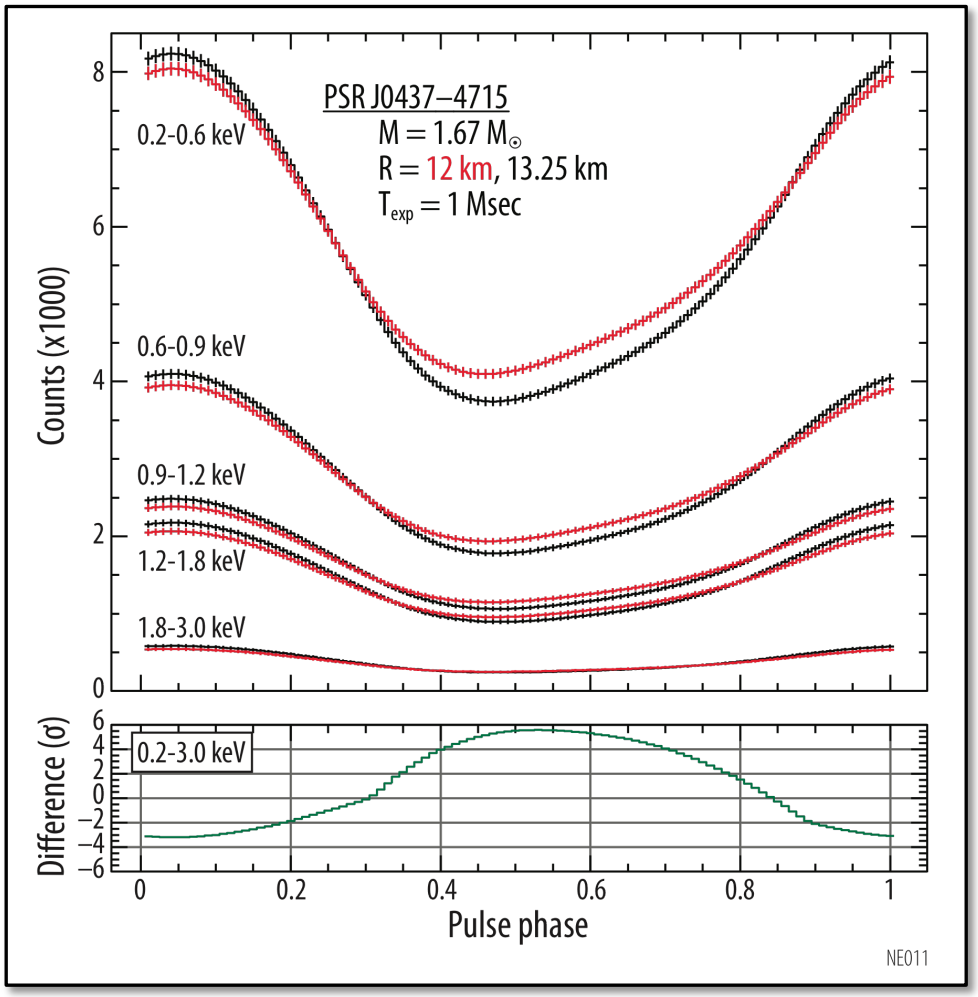


Lightcurve modeling constrains the compactness (*M*/*R*) and viewing geometry of a non-accreting millisecond pulsar through the depth of modulation and harmonic content of emission from rotating hot-spots, thanks to gravitational light-bending…

Science Measurements (cont.)



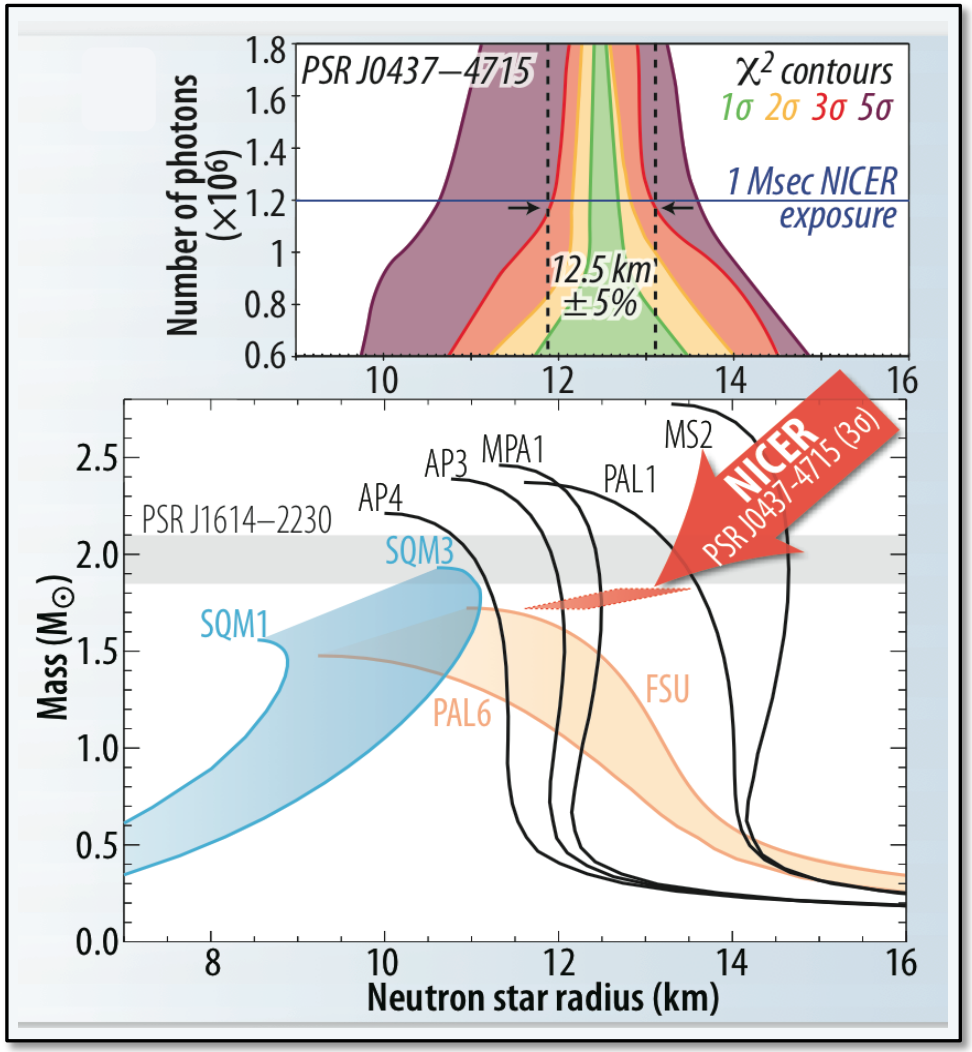
… while phase-resolved spectroscopy promises a direct constraint of radius *R*.



Science Measurements (cont.)

Simulations demonstrate how well an assumed neutron star radius can be recovered. The ±5% (3σ) measurement goal is attained in less than 1 Msec.

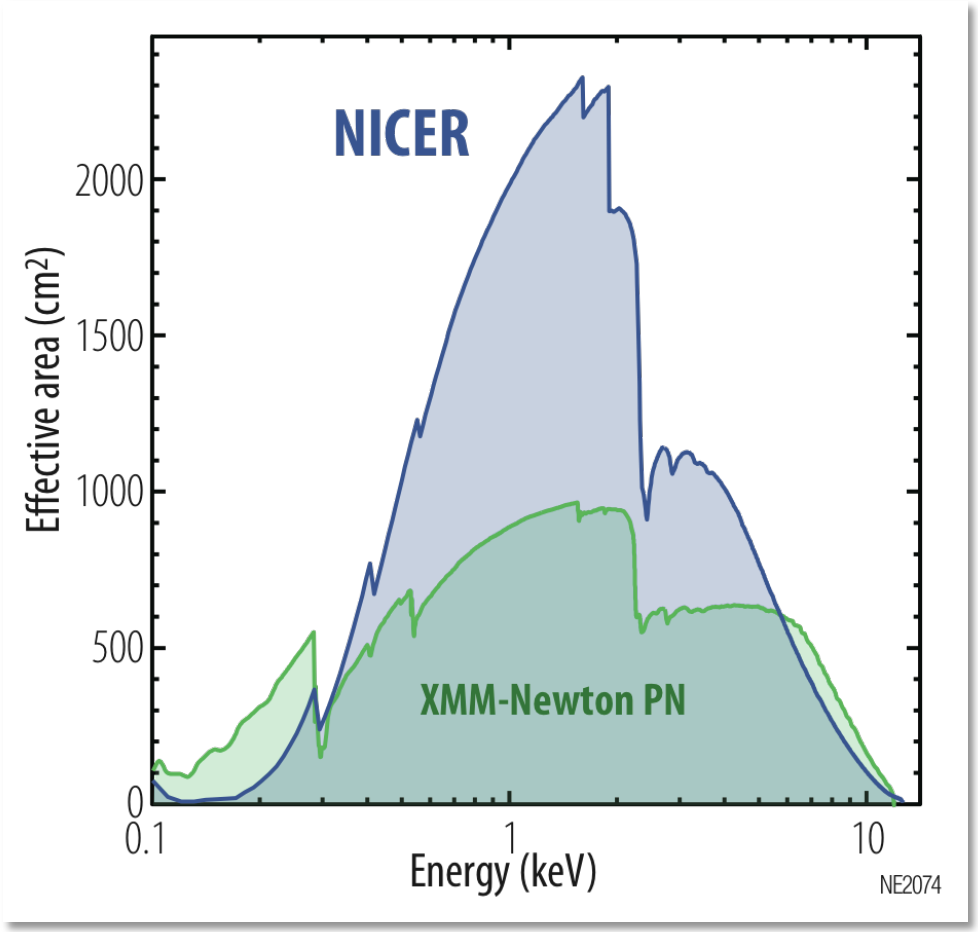
The resulting allowed regions in the *M-R* plane rule out proposed families of neutron star equations of state. The best mass measurements alone can't distinguish among competing models.



Instrument Performance

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

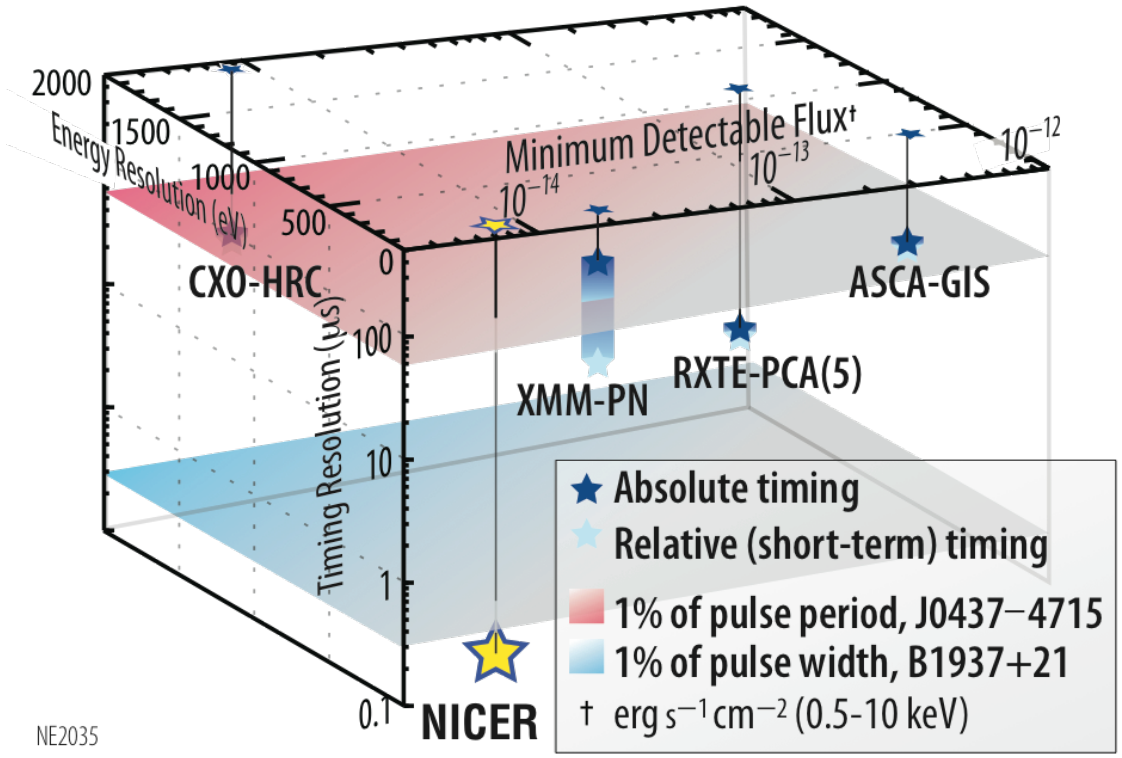
- ***Bandpass:*** 0.2–12 keV
- ***Effective area:***
  > 2000 cm^2 @ 1.5 keV,
  600 cm^2 @ 6 keV
  2x XMM-Newton for soft X-ray timing
- ***Energy resolution:***
  85 eV @ 1 keV,
  137 eV @ 6 keV
  Similar to XMM and Chandra
- ***Time-tagging resolution:***
  < 300 nsec (absolute)
  ~25x better than RXTE
  ~100–1000x better than XMM
- ***Spatial resolution:*** 5 arcmin diam. non-imaging FOV
- ***Background:*** Dominated by diffuse cosmic 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

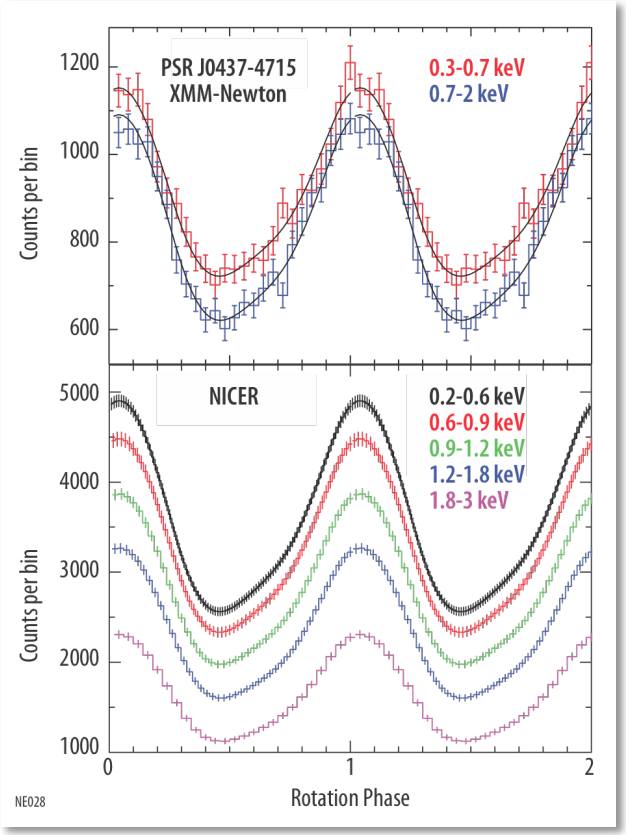


Instrument Performance (cont.)

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

NICER offers a combination of capabilities not available in any existing mission.

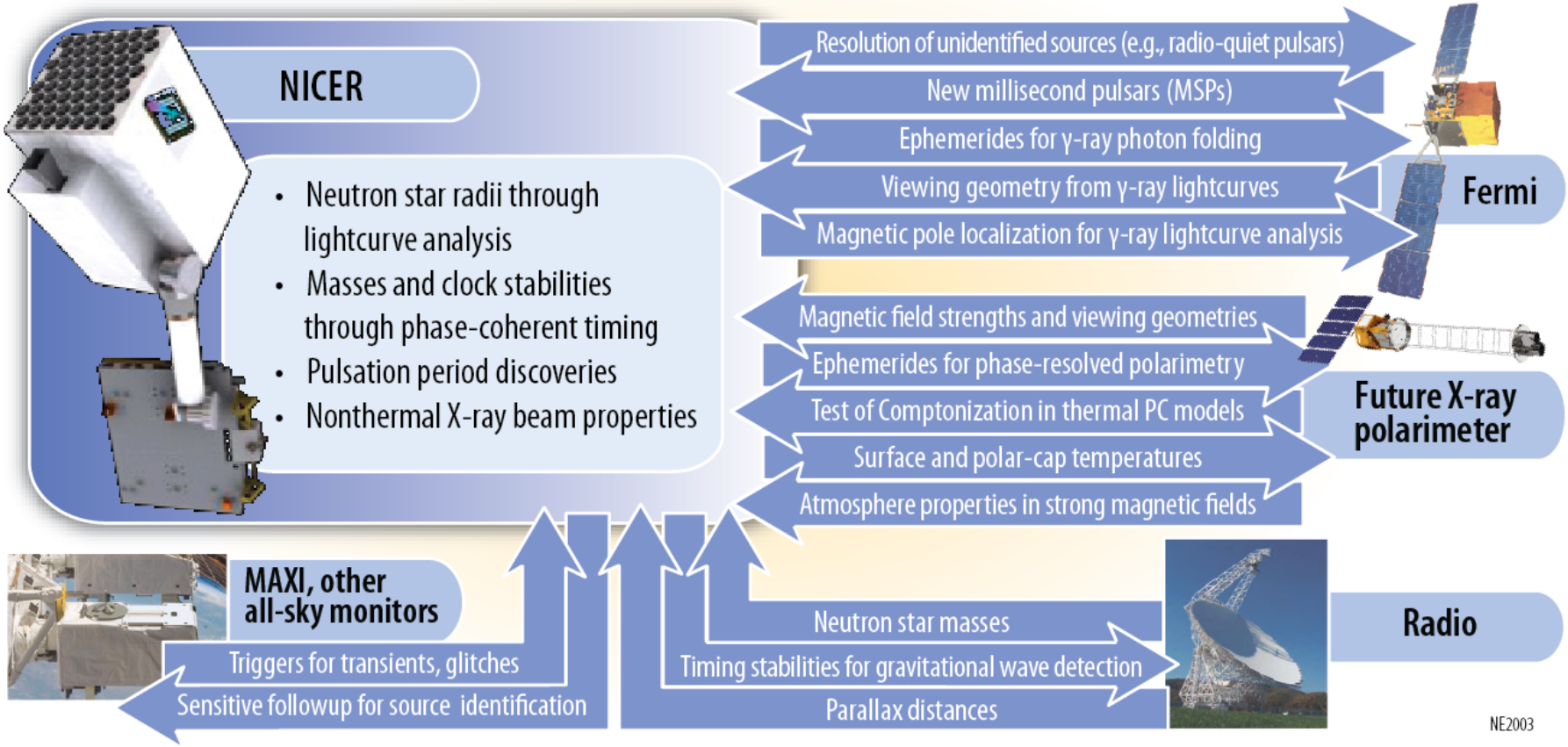




"Best effort" XMM and NICER lightcurves for key target PSR J0437–4715.

Neutron Star Science Synergies

Interplay between multiwavelength capabilities amplifies scientific returns from all

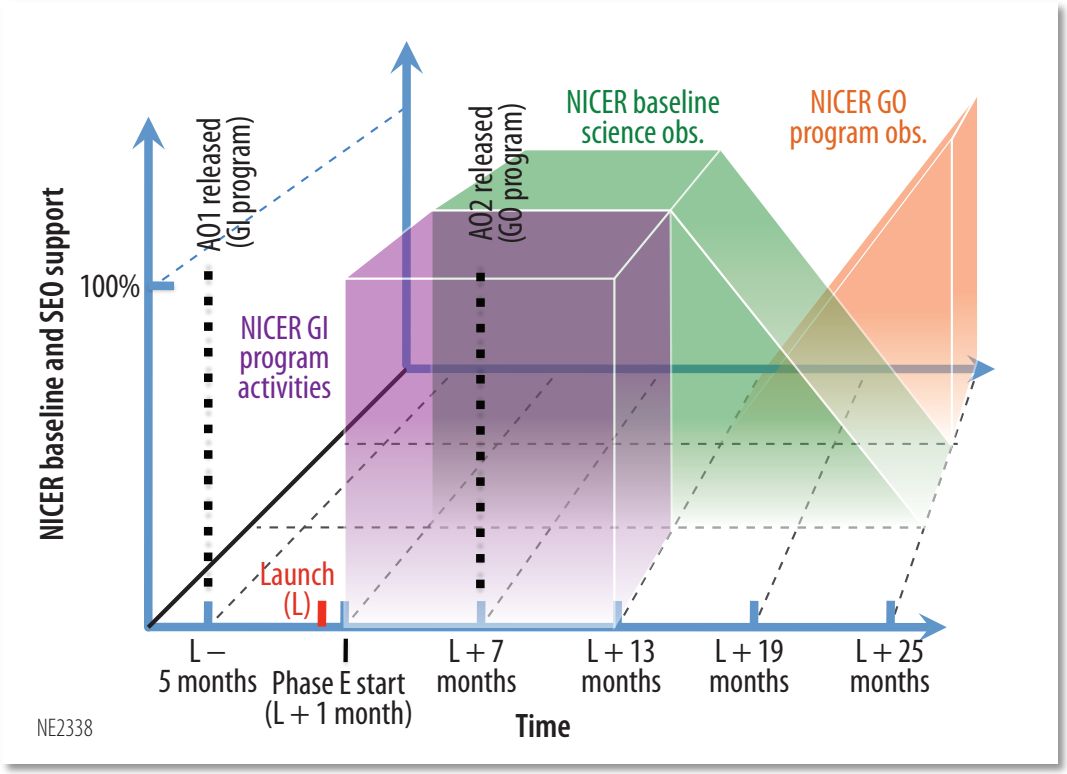


Proposed Guest Investigator/Guest Observer Program

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

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

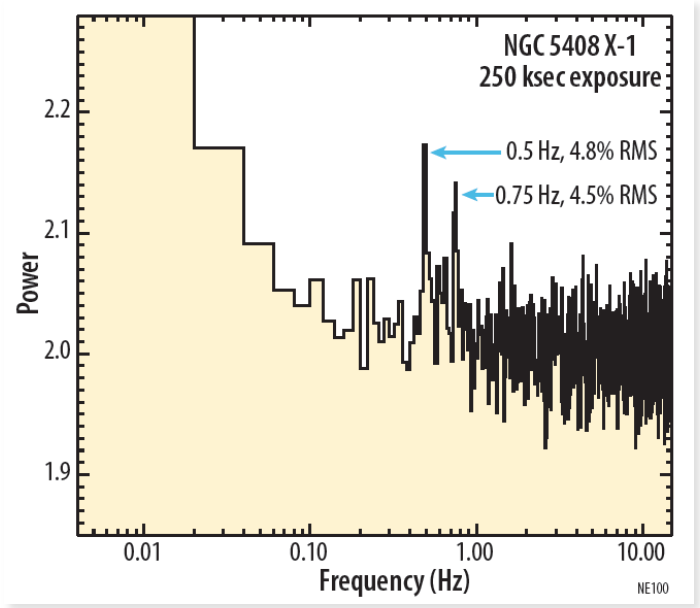
- In Year 1, support for corollary neutron star research: theory & complementary multiwavelength observations
- In Year 2, solicitation of proposals for guest observations with NICER, not necessarily targeting neutron stars.

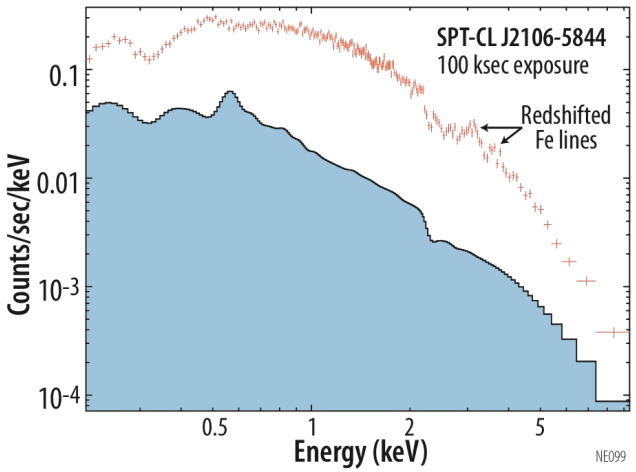


Proposed Guest Investigator/Guest Observer Program (cont.)

Sample science enabled by the NICER GO program

Black holes of all sizes are probed through soft continuum spectroscopy to constrain spins in stellar-mass binaries, power spectra of QPOs to definitely establish *ultraluminous X-ray sources* as intermediate-mass black holes, and relativistic reflection lines to discriminate among AGN models.





Redshifted Fe lines from ***galaxy clusters*** reveal star-formation history and poorly understood feedback processes that drive galaxy evolution. (*Left*) A z = 1.18 line is seen well above the diffuse X-ray back-ground (*blue*).

Plus…

- Temporal and spectral variability studies of ***bright coronal stars*** can be conducted on much shorter timescales than previously possible
- The interplay of accretion processes and gravitational radiation in ***double-degenerate systems*** can be studied through QPOs in "polars" and long-term timing of SN Ia progenitors
- Emission lines and soft excesses in ***high-mass X-ray binaries*** probe field strengths, accretion geometry, and long-term spin evolution.