Neutron Star Science with the X-ray Surveyor

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Open Questions Neutron Star Astrophysics

• The Nature of Dense Matter
• The Evolution and Effects of Magnetic Fields
• Observations of Neutron Star Mergers
Open Questions in QCD and Dense Matter

- Expect quark degrees of freedom at $\sim 3 \rho_{ns}$
- But the interactions of quark matter?
- Strangeness? (e.g., hyperons?)
Why is Dense Matter of interest to Astrophysics?

- Supernova Mechanism
- Neutron Star/Black Hole Division
- Coalescing Neutron Stars:
  - Gamma-ray Bursts
  - Gravitational Waves

Movie credit: Luciano Rezzolla
Using Neutron Stars for QCD

- Neutron star mass-radius relation maps faithfully to EoS
- Measure radii and control systematics
- Make measurements using new methods
What do the Radii Data Tell Us?

Neutron Star (M,R) relation maps faithfully to the EoS $P(\rho)$

Lattimer & Prakash 2001; Ozel & Psaltis 2009
Measurement of Radii

TARGETS

• Little/no accretion disk emission
• Little/no magnetospheric emission
• Low magnetic field

Method: Broadband Spectroscopy

\[ R^2 = \frac{F D^2}{\sigma T^4} \left( 1 - \frac{2GM}{Rc^2} \right) \]
The Radius Measurement from qLMXBs

Chandra observations of U24 in NGC 6397 at five different quiescent epochs

Chandra’s angular resolution has been essential for globular clusters

Guillot et al. 2011
Radius Measurement using Thermonuclear Bursts

![Graph showing time vs. flux and color temperature for Burst #32]

- **Time (s)**: 0 to 40
- **Flux (10^-7 erg cm^-2 s^-1)**: 0 to 2.0
- **Color Temperature (keV)**: 1.0 to 4.0
- **Normalization (km/10 kpc)^2**: 10^2 to 10^6
Radius Measurement using Thermonuclear Bursts

![Graph showing Flux versus Color Temperature for 4U 1724-207]
Radius Measurement using Thermonuclear Bursts

\[ L_{\text{Edd}} = \frac{4 \pi G c M}{\sigma_T (1 + X)} \left( 1 - \frac{2 G M}{R c^2} \right)^{1/2} \]
Neutron Star Radius Results

Six Burst Sources

Six+one qLMXBs

Ozel et al. 2015
Measurement of Radii

Graph showing the relationship between Mass ($M_\odot$) and Radius (km) with labeled curves:
- Redshift
- Eddington Limit
- Surface Emission
Expected Lines from NS Surfaces

• Observing line features are difficult but doable
• Settling time very short: look in the right places
• Account for line broadening effects
• Have sensitivity and energy resolution
Expected Lines from NS Surfaces

Line redshifts and widths are a function of the NS compactness
Searches so far have failed

Need Collecting Area
Radius Measurements from Pulse Profiles

\[ f_{NS}=600\text{Hz} \]
\[ M=1.6 \, M_\odot; \, R=10 \, \text{km} \]

\[ \frac{(2-20 \, \text{keV})}{(1-2 \, \text{keV})} \]

\[ \text{Color} \]

\[ \text{Flux} \]

\[ \text{Phase} \]

NICER
Mysteries of Magnetic Fields
Spectral Features: p cyclotron line
Simulated 750 ks X-ray spectrum of 1E 1048.1-5937 with Chandra

15 ks with the X-ray Surveyor
The Need for an X-ray Surveyor

- Neutron star science questions interest a broad physics/astrophysics community
- Large collecting area is key for progress
- As is energy resolution for lines, spectral distortions
- Angular resolution for crowded fields
- Time resolution allows bright burst spectroscopy