Variability in Quiescent Neutron Stars

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Why We Care

• Neutron stars are one possible terminal phase for massive stellar evolution.
• Studying neutron stars allows us to study the behavior of matter at conditions not otherwise observed.
• Particle accelerators do not allow us to study observe matter at simultaneous high densities and low temperatures.
• These conditions are important to our understanding of fundamental physics.
Neutron Stars

- Highly dense stellar remnants of supernovae, the gravity of which are balanced by neutron degeneracy pressure. Neutron stars have radii of ~10-15 km, masses of ~1.5 M☉, and core densities greater than that of an atomic nucleus.
Accretion

- The accumulation of dust and gaseous matter by a massive body, due to gravitational force.
Quiescence

- The state of a massive body not actively accreting.
Measurement of Neutron Star Radii

- We use X-ray emission to make experimental measurements of neutron stars.
- We will be using data from the Chandra X-Ray telescope.
Measurement of Neutron Star Radii

- Photon Counts
  - Actual data collection from X-Ray telescopes

- Spectral Flux vs. Energy
  - Presents physical mechanisms.

- Radii
  - Key parameter for understanding equations of state
Spectral Flux in Quiescence

- There are two components of these emissions:
  - Thermal (surface/atmospheric)
  - Power Law (unknown cause)
Thermal Emission

- Blackbody-like radiation is one mode of measuring radii of massive astronomical bodies.
- This thermal component of radiation is emitted from atmosphere of the neutron star.
Thermal Mode

• Blackbody Radiation:

$F = \sigma T_{\text{eff}}^4 \left( \frac{R_\infty}{D} \right)^2$

• Gives:

$R_\infty = \frac{R_{NS}}{\sqrt{1 - \frac{2GM}{c^2 R_{NS}}}}$

Rutledge, et al. (1999)

→ Hydrogen Atmosphere Model
Power Law Emission

• At energies $\geq 2$ keV, a hard power law dominates.

$$A(E) = K(E)^{-\alpha}$$

• The origin is unknown, but it may be due to accretion onto magnetosphere and/or comptonization.
Variability

- Repeated measurements of neutron stars show variability.
Variability in Cen X-4: problems for measuring the radius

Power law variation was expected, but data from Cen X-4 also shows a variable thermal component. This data cannot be modeled without varying the thermal component. Cackett, et al. (2010)
Variability in CX1 in NGC 6440

Observed two years after accretion outburst. Cackett, et al. (2005)

<table>
<thead>
<tr>
<th>Color</th>
<th>Photon Energy (keV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Red</td>
<td>0.3- 1.5</td>
</tr>
<tr>
<td>Green</td>
<td>1.5- 2.5</td>
</tr>
<tr>
<td>Blue</td>
<td>2.5- 8.0</td>
</tr>
</tbody>
</table>

Observed three years later.
Current Project

• To understand the thermal component variability and implications for measuring neutron star radii.
• Distance to globular clusters is more accurately known than to binary systems elsewhere in the Galaxy.
• Another observation of NGC 6440 has been made by the Chandra X-Ray telescope. This and other data will be studied for variability.