Gravitationally Redshifted Absorption Lines in the Burst Spectra of the Neutron Star in EXO 0748-676

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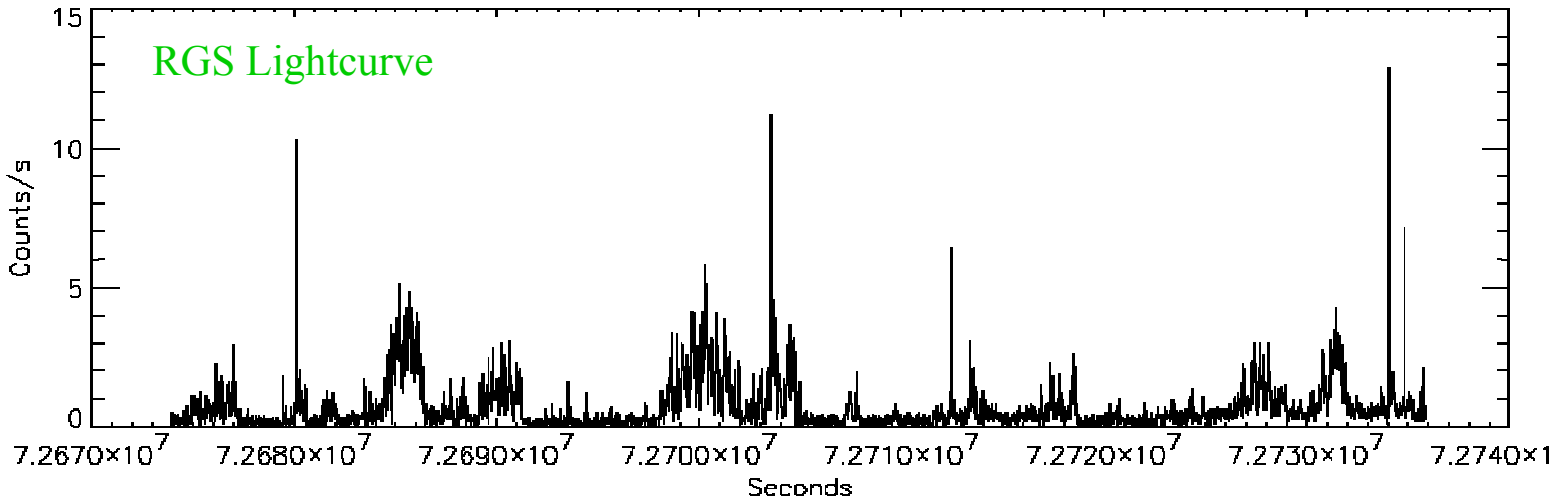
XMM-Newton Observations of EXO 0748-676

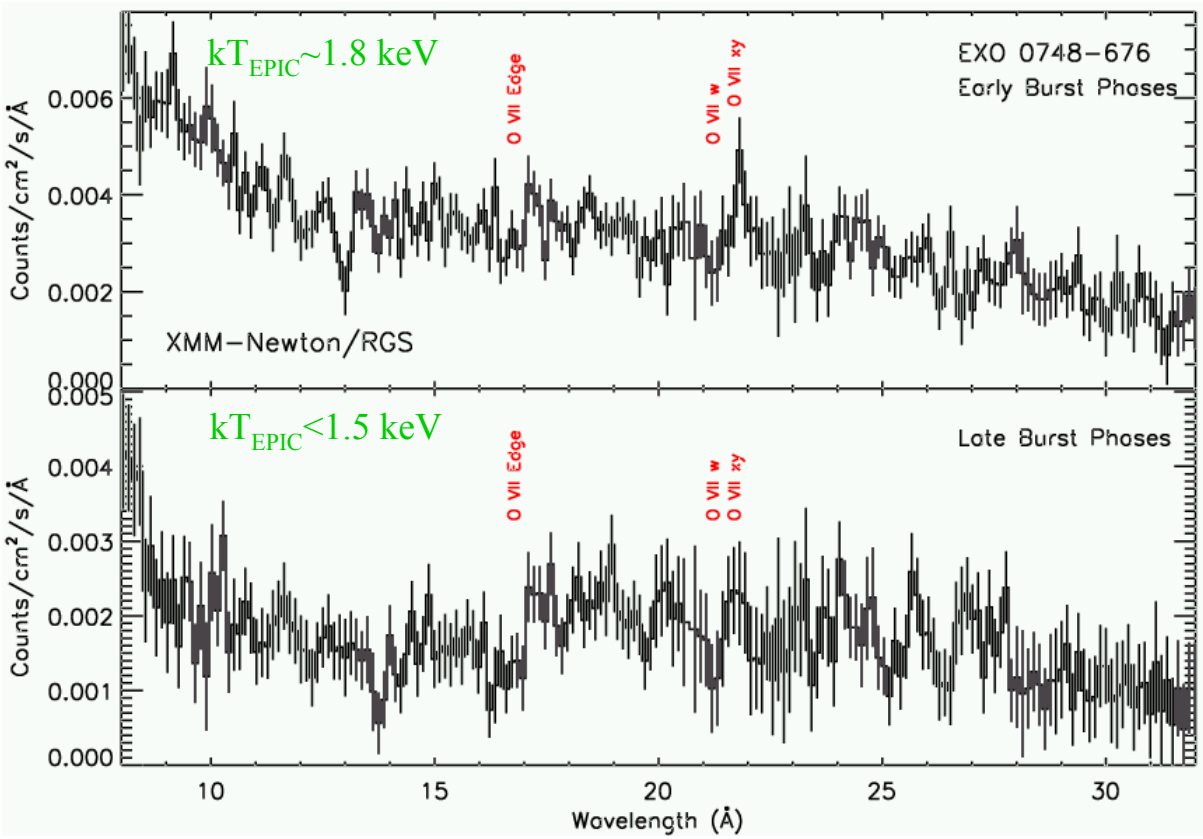
* EXO 0748-676 was observed during commissioning and calibration phases
  - RGS: 335,000 s - EPIC: 39,000 s
* During the frequent X-ray bursts, the neutron star outshines the accretion-generated light by an order of magnitude, while continuing accretion provides a constant source of heavy elements at the neutron star surface

⇨ Excellent opportunity to search for absorption features in the neutron star photosphere



Averaged Burst Spectra

* We collected RGS data for 28 bursts (3200 s), and simultaneous EPIC data for 3 bursts (250 s).
* The EPIC data show evidence of spectral evolution during the bursts. We therefore chose to separate the RGS data into early and late burst phases.

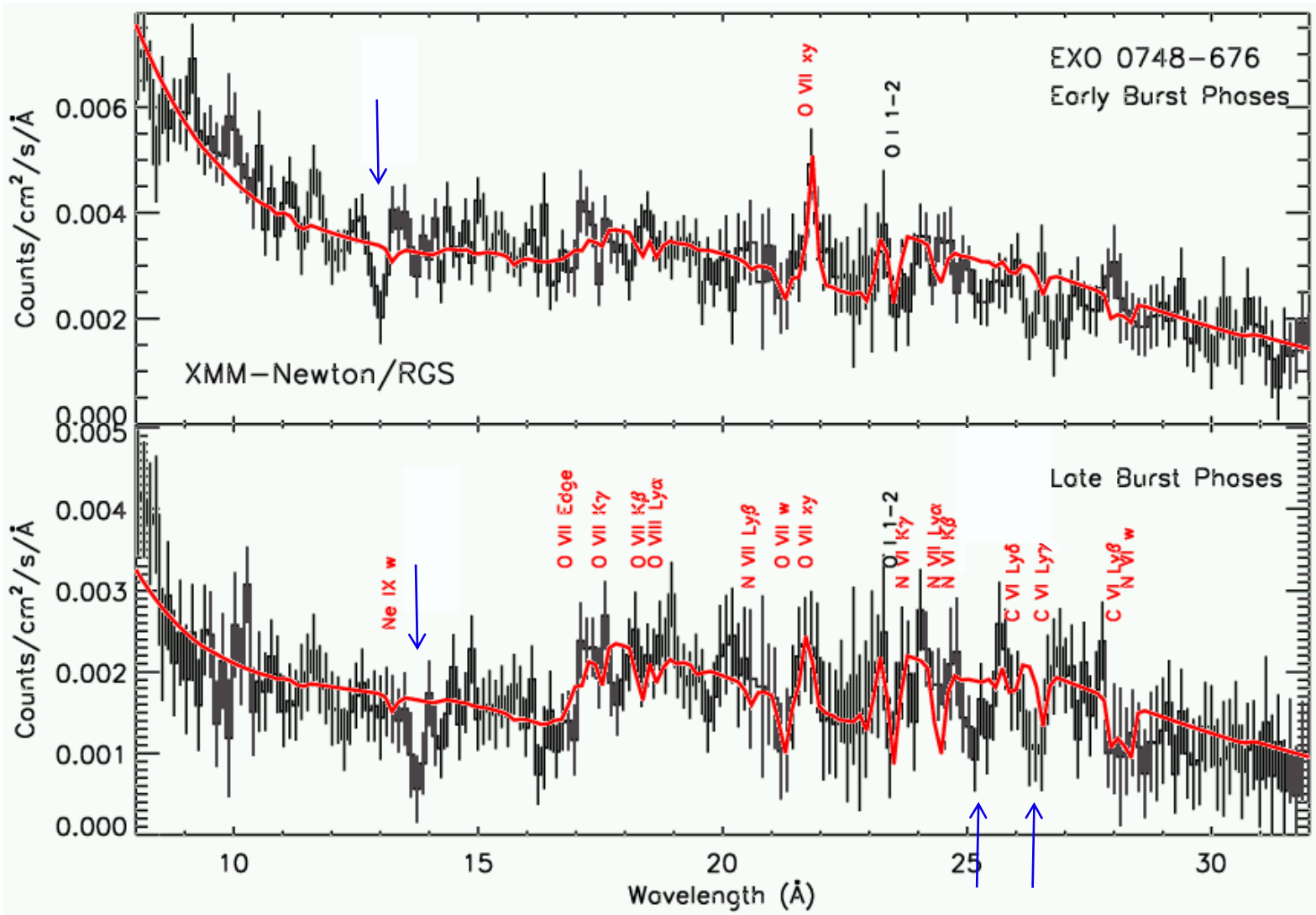


Circumstellar Absorption Spectra

* In order to identify features associated with the neutron star, we must first account for circumstellar absorption.
  - O VII emission line ratios suggest high density photoionized gas
  - O VII absorption features are blue-shifted by v~5000 km/s suggesting bulk outflow
  - Evolution in the absorption-to-emission ratios indicates changes in geometry from spherical to increasingly flat

* We can then use the measured O VII parameters to model the global absorption spectra.
  - The ratio of O VII/O VIII constrains the ionization parameter to $\xi \sim 10$
    $\Rightarrow$ ionization balance for K-shell C, N, O, Ne, Mg, Si & L-shell Fe
  - Assume solar abundances
  - Assuming a constant temperature, the velocity structure for each ion scales from the O VII values

Burst Spectra with Circumstellar Model



Residual Spectral Features

* There are significant residual spectral features at
  - Early: 13.0 Å, (25.3, 26.3, 26.9 Å)
  - Late: 13.75 Å, 25.2 Å, 26.4 Å (17.8, 19.7 Å)

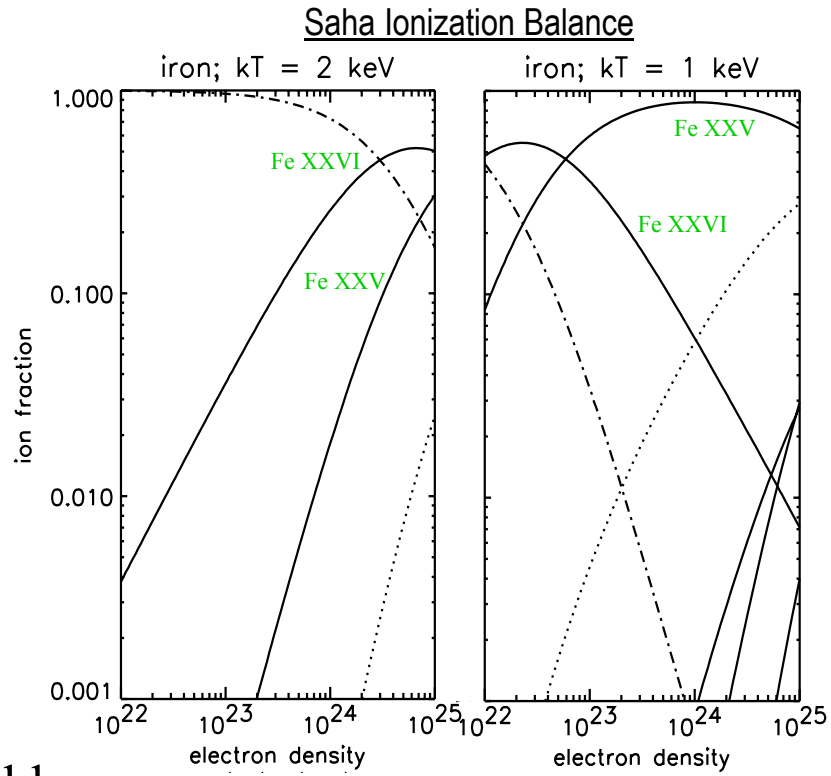
* Excluding Instrumental Explanations
  - The features appear in both RGS instruments
  - The features appear in the early- and late- phase spectra separately
  - There are no similar features in deep exposures of Mkn 421, 3C273, PKS2155-304

* Excluding Circumstellar Explanations
  - The features are inconsistent with absorption in ions at higher ionization parameters
    - Separate ions present at the same ξ would have random velocities
    - For a given line identification, the higher n-level lines and the associated edges are not observed

$\Longrightarrow$ Features must be associated with the Neutron Star

Identifying Absorption Features

* Features are not consistent with simple absorption in Lyman series
* Evolution of the spectral features is key to their identification.
  – Early: Fe XXVI dominates ion balance. Identifying 13.0 Å with Fe XXVI n=2-3 transitions ⇒ z=0.35
  – Late: Fe XXV dominates ion balance. Identifying 13.75 Å with Fe XXV n=2-3 transitions ⇒ z=0.35
* Redshifting O VIII Lyα by z=0.35 would produce a feature between the 25.3, 26.4 Å features – perhaps self-reversed absorption in an extended outflowing atmosphere



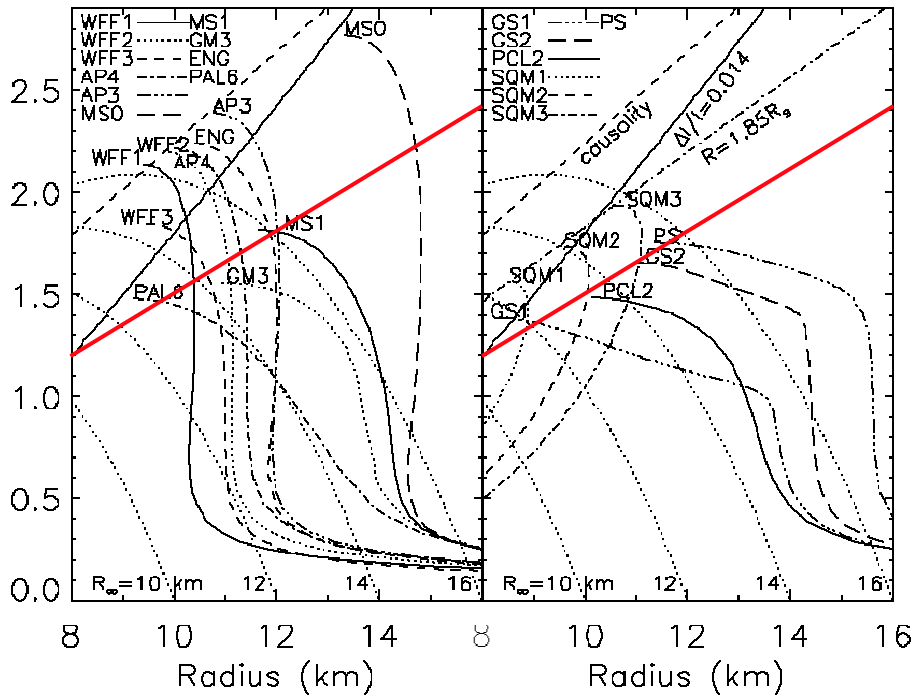
⇒ Three ions all at redshift z=0.35

Summary & Implications

* A gravitational redshift of z=0.35 has been observed in the absorption spectra of the neutron star in EXO 0748-676.

* This imposes quantitative constraints on the equations of state for cold, dense nuclear matter. This redshift is consistent with most models of normal nuclear matter for a mass and radius of

  $M=1.4\text{-}1.8\ M_{\odot}$, R=9-10 km



Reproduced from Lattimer & Prakash (2001)

* Further high-resolution observations of bursting neutron stars should be performed using XMM-Newton, Chandra, and particularly Constellation X.