Narrow absorption features in the X-ray spectra of isolated Neutron Stars

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Abstract

We co-added the available XMM-Newton RGS spectra for each of the isolated X-ray pulsars RX J0720.4-3125, RX J1308.6+2127 (RBS 1223), RX J1605.3+3249 and RX J1856.4-3754 (four members of the "Magnificent Seven") and the "Three Musketeers" Geminga, PSR B0656+14 and PSR B1055-52. We confirm the detection of a narrow absorption feature at 0.57 keV in the co-added RGS spectra of RX J0720.4-3125 and RX J1605.3+3249 (including most recent observations). In addition we found similar absorption features in the spectra of RX J1308.6+2127 (at 0.53 keV) and maybe PSR B1055-52 (at 0.56 keV). The absorption feature in the spectra of RX J1308.6+2127 is broader than the feature e.g. in RX J0720.4-3125. The narrow absorption features are detected with 2σ to 5.6σ significance. Although very bright and frequently observed, there are no absorption features visible in the spectra of RX J1856.4-3754 and PSR B0656+14, while the co-added XMM-Newton RGS spectrum of Geminga has not enough counts to detect such a feature. We discuss a possible origin of these absorption features as lines caused by the presence of highly ionised oxygen (in particular OVII and/or OVI at 0.57 keV) in the interstellar medium and absorption in the neutron star atmosphere, namely the absorption features at 0.57 keV as gravitational redshifted (g_r=1.17) OVIII.

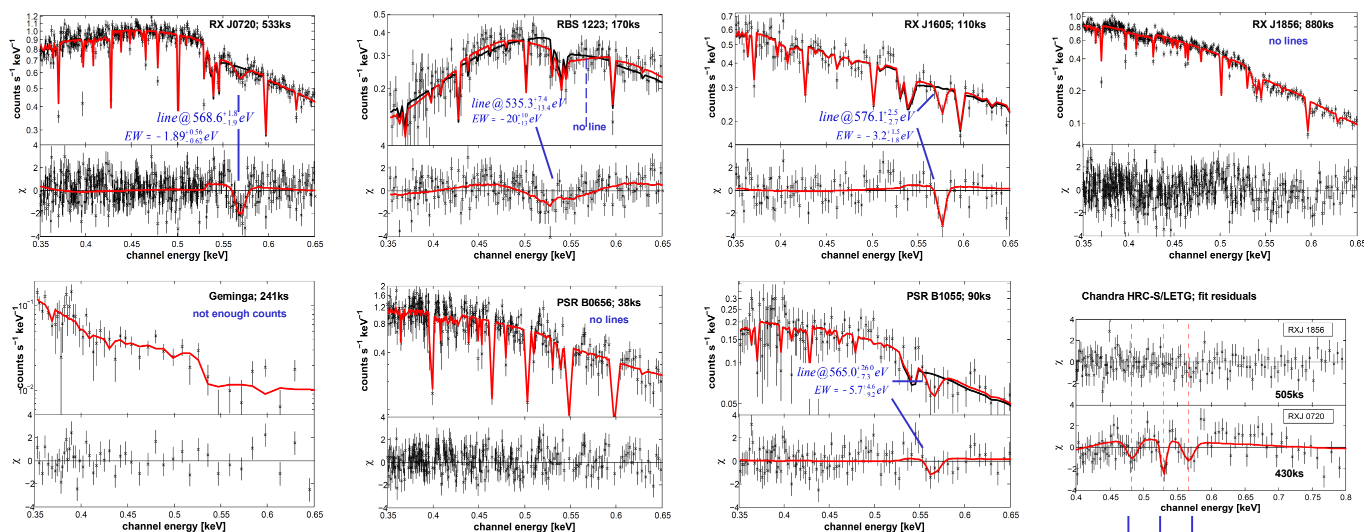

Fig. 1: Co-added RGS spectra of those isolated neutron stars, that are frequently observed and bright enough to detect possible narrow absorption features, that may originate from the neutron star atmosphere. In the case of RX J0720 we find one narrow absorption feature in the RGS spectra (@568 eV) and maybe two further features in the co-added Chandra HRC-S/LETG spectra (@480eV of unknown origin or redshifted OVII and 530eV from neutral oxygen from the ISM). These features are absent in the spectra of RXJ 1856 (both, RGS and HRC) and eg. PSR B0656 (RGS).

Interpretation

Due to gravity, spectral lines appear redshifted, hence offer us the opportunity to measure the compactness. Hambaryan et al., 2009 found an absorption feature at 569 eV in the co-added RGS spectra of RX J0720, that would either fit to the Kα lines of He-like oxygen (OVII), mixed with absorption lines from OVI at rest (ISM), or to the Lyα line of OVIII with a grav. redshift gr=1.17. Then, OVII would appear at 480 eV with the same redshift. Maybe such a line is found in the co-added HRC spectra of RX J0720 (Hohle et al., MNRAS, in press and Fig. 1). Van Kerkwijk et al. (2004) found a similar feature at 576 eV in the co-added RGS spectra of RX J1605, that could be confirmed by us. The features in the spectra of both neutron stars (NSs) would fit to the different transitions of OVII at rest (1s2p1P1@573.95 eV and 1s2p3P1,2@568.63 eV), however only the resonance transition should be appear in absorption (alternatively, these lines are caused by redshifted OVIII Lyα absorption with slightly different compactness). We investigated the spectra of the other isolated NSs (see spectra above and Hohle et al., MNRAS, in press) – some NSs exihbit these lines, whereas in some cases these lines are absent. Currently it is not known whether the absorption features are caused by the ISM (that would require a significant overabundance of ionised oxygen, see Tab. 1), a circumstellar cloud/disk or from the NS atmosphere. A cloud/disk would account for some properties of the so-called optical excess in the case of RX J0720 (Hambaryan et al., 2009) , but a disk surrounding three (RX J0720, RX J1605 and maybe PSR B1055) out of seven investigated objects seems unlikely. **Since the binding energy depends on the B-field, pulse-phase resolved spectroscopy of high resolved spectra (eg. with ASTRO-H/SXS) would unambiguously probe the origin of these lines. A change of the B-field by a factor of two (since we see different parts of the NSs surface, while rotating), would change the line widths by 20-40% (Mori and Haily, 2006). This is almost possible with RGS even today. From line shift, we could constrain the equation of state for matter at super-nuclear densities (see Fig. 2). Only in two cases (RX J1856 & RX J0720) we can give constrains on the radius (for the latter with large errors). Thus, we need more suitable targets that will be discovered with the eROSITA instrument.**

	line EW [eV]	N_{OVII} [cm⁻²]
RX J0720	$-1.89^{+0.57}_{-0.62}$	3×10^{16}-10^{19}
RX J1605	$-3.2^{+1.5}_{-1.8}$	3×10^{16}-10^{20}
PSR B1055	$-5.7^{+4.6}_{-9.2}$	$>10^{16}$

Tab. 1: Fitted equivalent widths (EWs) and corresponding column densities (Futamoto et al., 2004) assuming that the absorption features are pure and not a blend (note, the features are likely superimposed by OVI).

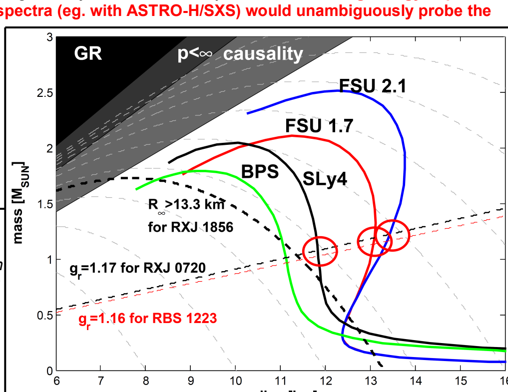

Fig. 2 M/R diagram with stable configurations of mass and radius of some equations of state (EoS) (G. Shen et al, 2010a, 2010b, 2011 and Hänsel & Potekhin, 2004). Walter et al. (2010) gives R_∞ >13.3 km for RXJ1856 (black dashed line) and from (possible) red-shifted OVIII lines in the co-added RGS and Chandra spectra of RXJ0720 we obtain g_r=1.17 (black dashed line). For RBS 1223 M/R = 0.087 (Hambaryan et al. 2011, A&A, accepted), hence g_r=1.16 (red dashed line). These values are consistent with EoSs in the M/R diagram that are indicated by red circles. Hence, we can exclude the BPS EoS and all EoSs dealing with strange matter (see also Lattimer 2010).

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Acknowledgements

MMH thanks the DFG for financial support through SFB/TR-7 "Gravitational Wave Astronomy"