A Spectral Insight into the Physics of Accreting ms Pulsars

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A Spectral Insight into the Physics of Accreting ms Pulsars

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Abstract. The broadened iron lines observed from accreting compact objects are most easily interpreted in terms of reflection onto the accretion disc of the hard X-ray photons emitted by the central source. In this context, such a broadness is due to the relativistic motion of the reflecting plasma, in the deep gravitational well of the compact object, and can thus serve as a probe of the inner radius of the disc. Here we report about the discovery of such features from a couple of accreting millisecond pulsars, and discuss the constraints which can be derived on the magnetospheric radius.

Keywords: accretion, accretion disks – line: profiles – X-rays: binaries
PACS: 97.10.Gz, 97.60.Gb, 97.80.Jp

In the past decade high resolution spectroscopy revealed itself to be one of the most powerful probes of the inner regions of the accretion disc around a compact object. Broad and asymmetric emission lines are in fact observed from a variety of accreting compact objects, such as AGN [see e.g. 1] , Galactic binaries hosting black holes [see e.g. 2] and neutron stars [NS, see e.g. 3]. These features are generally interpreted as fluorescent emission due to the illumination of a geometrically thin, and optically thick, accretion disc, by an external hard X-ray source. Their broadness is thus explained in terms of the relativistic Keplerian motion of the reflecting plasma in the accretion disc, under the gravitational influence of the compact object [4]. Modelling the shape of these lines thus allow to constrain where the disc is truncated near the compact object.

Here, the discovery of broadened reflection features in the X-ray spectra of accreting millisecond pulsar (AMSP) is reported. AMSPs are NSs which accrete from a low mass star, and show pulsations at their ms spin period. According to the recycling scenario [see e.g. 5], they are the progenitors of rotation-powered ms pulsars. As the disc around an accreting pulsar is interrupted by a magnetosphere, modelling the shape of these reflection features allows to constrain where the transition between the disc and the magnetosphere takes place, i.e. the magnetospheric radius. This radius is a key parameter of the theories of accretion onto a quickly rotating objects, and issues such as the magnitude of the accretion torque and the field-disc interaction can be therefore assessed from an observational point of view.

1. REFLECTION FEATURES FROM ACCRETING MS PULSARS

SAX J1808.4-3658 is the cornerstone of AMSPs. It is in fact the first discovered [6], and thereafter most studied member of its class. As every AMSP discovered so far, it is a transient system, and it went six times into outburst since 1996. Its broadband X-ray spectrum is composed of (i) two soft components originating from the disc and from the NS surface, and (ii) an energetically dominating hard component, interpreted as thermal Comptonization in a hot ($kT_e > 35$ keV) medium [see 7, for a review of the spectra shown by AMSPs]. Signatures of disc reflection, such as a 6.5 keV iron emission line and a Compton hump at $\sim$30 keV were also observed using *RXTE* data [8]. The shape of the line has been further investigated thanks to a 44 ks *XMM-Newton* observation [9], which unveiled its intrinsic broadness (see left panel of Fig. 1). If the line is modeled with a Gaussian, a width of $\sigma = 1.1(2)$ keV is in fact obtained. Explaining such a large width in terms of disc reflection of the hard continuum component [4], leads to an estimate of the inner disc radius of 6.0–12.4 R_g (corresponding to 12.4–25.6 km for a 1.4 $M_\odot$ NS). This estimate is perfectly consistent with the requirement that the accretion disc is truncated inside the corotation radius. Accretion theories further relate the inner disc radius to the accretion rate and to the NS magnetic field strength. Given the measured X-ray flux of the source, the inner disc radius thus estimated indicates a magnetic field in the range 1–5$\times 10^8$ G, exactly in the plausible

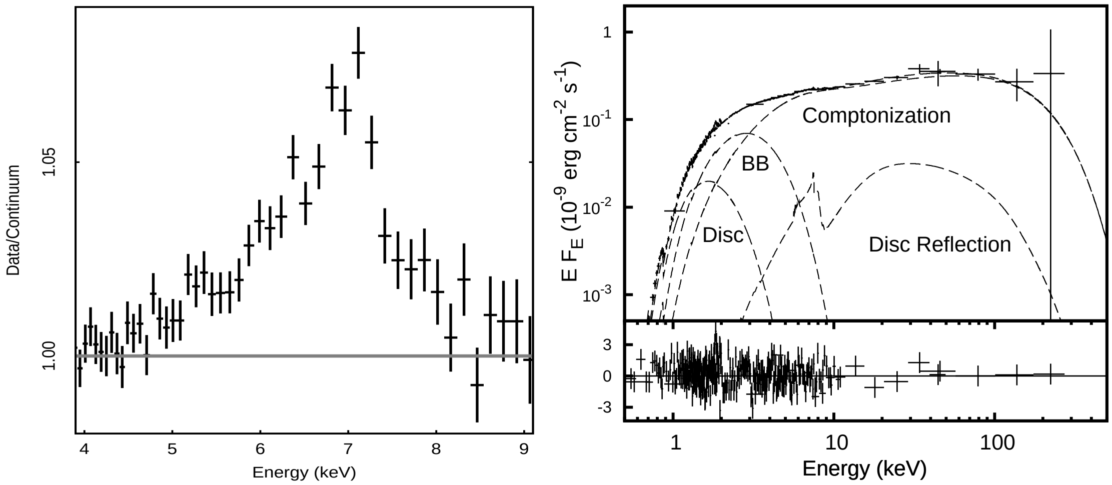

FIGURE 1. Ratio between the 0.5-11 keV *XMM-Newton* spectrum of SAX J1808.4-3658 and the continuum, when the 6.5 keV is not included in the model (left). Simultaneous *XMM-Newton-RXTE* 0.5–150 keV spectrum of IGR J17511-3057, and residuals with respect to a model composed of (i) a multi temperature disc black body, (ii) a single temperature black body, (iii) a Comptonized component, and (iv) a reflection component, blurred by relativistic motion (right).

range (10^8–10^9 G) for the AMSPs to be the progenitors of radio millisecond pulsars [9, 10].

A 70ks *XMM-Newton* observation of the recently discovered source IGR J17511-3057 also showed the presence of a 6.8 keV, moderately broadened, iron line, superimposed to a continuum that has a shape similar than that of SAX J1808.4-3658 [11]. Considering also the 3–150 keV spectrum observed by *RXTE*, the shape of the reflection continuum could be better constrained (see right panel of Fig. 1), indicating an accretion disc extending down to ~ 40 km from the NS. Despite the strength of the line is lower than in the case of SAX J1808.4-3658, similar conclusion can be drawn regarding the geometry of the disc around the accreting pulsar.

Like for other accreting objects, also the X-ray emission of AMSP show the typical clues of disc reflection. The detection of broadened lines from these sources gives the unique opportunity to study the region where the disc is truncated by the magnetosphere of a quickly rotating NS. While the results obtained so far confirm the theoretical expectations on the location of the magnetospheric radius, given the expected magnetic field of a recycled pulsar, future observations will better assess the evolution of the line shape with the mass accretion rate.

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