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The Cyclotron Resonance Scattering Features In Neutron Star Binaries Observed By INTEGRAL

Wei Wang

National Astronomical Observatories, Chinese Academy of Sciences, Beijing 100012, China
email: wangwei@bao.ac.cn

Abstract. Cyclotron resonance scattering features (CRSF) are the direct observational evidence for the strongly magnetized neutron stars. Since the first detection of the absorption line in the X-ray source Her X-1 thirty years ago, more than ten sources are indentified as the strongly magnetized neutron stars through detecting CRSFs. INTEGRAL is the new X-ray/gamma-ray mission with good angular resolution, high sensitivity and spectral resolution in the range of 18 C 200 keV, so that it provides us a good chance to detect the CRSFs in neutron star systems. INTEGRAL has confirmed the line features in 5 previous known sources and discovered 4 new candidates. Physical mechanism of CRSFs and accretion physics can be probed with detailed spectral analysis.

Keywords. stars: neutron, X-rays: binaries

1. Introduction

INTEGRAL is the ESA's operational space-based hard X-ray/soft gamma-ray telescope. There are two main instruments aboard INTEGRAL, the imager IBIS and the spectrometer SPI, supplemented by two X-ray monitors JEM-X and an optical monitor OMC. The co-aligned observations allow us to study X-ray pulsars in a wider energy band of 3 − 500 keV. The good spectral resolution and high sensitivity around tens of keV provide a good chance to search for the cyclotron resonance scattering features in neutron star accretion systems.

With the INTEGRAL all-sky survey observations, we have confirmed the previous reported CRSFs in several systems, like 4U 0115+63 (the fundamental energy $E_0 \sim 10-15$ keV, Li *et al.* 2012); Her X-1 ($E_0 \sim 39$ keV, Klochkov *et al.* 2007); V 0332+53 ($E_0 \sim 26$ keV, Kreykenbohm *et al.* 2005); A 0535+26 ($E_0 \sim 45$ keV, Caballero *et al.* 2007); Vela X-1 ($E_0 \sim 27$ keV, Schanne *et al.* 2007). In addition, INTEGRAL observations discovered four new candidates: 4U 2206+54 ($E_0 \sim 30$ keV, Wang 2009); 2S 0114+65 ($E_0 \sim 22$ keV, Bonning & Falanga 2005); RX J0440.9+4431 ($E_0 \sim 32$ keV, Tsygankov *et al.* 2012); and IGR J01583+6713 ($E_0 \sim 35$ keV, Wang 2010a). Assuming the electron absorption line case, we can calculate the magnetic field strength of detected neutron star systems by using the the formula $[B/10^{12}\mathrm{G}] = [E_{\rm cycl}/11.6\mathrm{keV}](1+z)$, where $E_{\rm cycl}$ is the energy of the fundamental line, here $E_{\rm cycl} = 29.6$ keV, and z is the gravitational redshift near the surface of the neutron star. For a canonical neutron star of 1.4 $M_\odot$ with a radius of 10 km, we can take $z \sim 0.3$. Then we derived the magnetic field strength of the accreting magnetized neutron stars in the range of $(1-5) \times 10^{12}$ G.

2. Some Interesting Results

Detailed spectral analysis of CRSFs and the variations can probe the accretion physics near the polar cap regions of X-ray pulsars in binaries. During the 2008 giant outburst, we determined the spin period of the neutron star in 4U 0115+63 at $\sim 3.61430 \pm 0.00003$ s, and a spin up rate during the outburst of $\dot{P} = (-7.24 \pm 0.03) \times 10^{-6}$s d^{-1} (Li *et al.* 2012). And the spectral analysis combined with JEM-X and IBIS confirmed the 5 cyclotron line harmonics in 4U 0115+63 during the giant outburst. In addition, The fundamental absorption line energy varies during the outburst: around 15 keV during the rising phase, and transiting to ~ 10 keV during the peak of the outburst, and further coming back to ~ 15 keV during the decreasing phase. The variations of photon index show the correlation with the fundamental line energy changes: the source becomes harder around the peak of the outburst and softer in both rising and decreasing phases. The possible correlation between X-ray luminosity and the fundamental line energy E_0 is also confirmed. The spectral transition around the peak phase of the outburst should be related to X-ray luminosity. When $L_x > 6.76 \times 10^{37}$ergs s^{-1}, we detect the familiar fundamental CRSF at $E_0 \approx 10$ keV, below this luminosity level, the fundamental line energy changes to be $E_0 \approx 15$ keV.

We identified two cyclotron absorption features around 30 keV and 60 keV in a high mass X-ray binary 4U 2206+54 (Wang 2009). This special source contains a superslow pulsation neutron star with the spin period of ~ 5560 s (Wang 2009, 2010b; Reig *et al.* 2009) and the neutron star shows a spin-down trend with a rate of $\sim 4.9 \times 10^{-7}$ s s^{-1} (Wang 2012; Finger *et al.* 2010). In the standard evolution model of X-ray binaries, this slow pulsation period ($P_{\rm spin} > 1000$ s) cannot be reached except for the much stronger surface magnetic field. Combined with the very fast spin-down rate in the source, we suggested that 4U 2206+54 could be an accreting magnetar which has a magnetic field higher than 10^{14} G! However, we also should re-consider the CRSFs in this source, if the features are explained as electron absorption lines, the derived magnetic field is $\sim 3\times 10^{12}$ G; while in the proton absorption case, the derived magnetic field is about 10^{15} G. Thus the physical nature and origin of 4U 2206+54 is still in dispute at present, requiring further studies.

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