The absorption structures in spectra of 1E1207.4-5409 seen by Suzaku

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Abstract

We observed the strange X-ray "pulsar" 1E1207.4-5409 using Suzaku and investigated its spectral structures. 1E1207.4-5409 is an X-ray source near the center of the SNR G296.5+10.0. Soft X-ray observations by Chandra and XMM-Newton reported "harmonic" absorption structures at about 0.7, 1.4, and 2.1 keV (also might be at around 2.8 keV) in the energy spectrum (Bigmani et al. 2003, Luca et al.2004). The origin of these structures has not clarified yet. If these structures could be due to proton-cyclotron resonance, the magnetic field should be in the range of B$\sim 10^{14}$G, and it would serve as a strong support for the existence of magnetar. Suzaku made observations of this strange source twice and obtained spectral data displaying similar absorption structures at about 0.7, 1.4 and 2.1 keV.

Key words: Pulsars: individual (1E1207.4-5209) — Stars: neutron

1. Introduction

An isolated neutron star (INS) 1E 1207.4-5209 (hereafter 1E1207) near the center of SNR G296.5+10.0 (PKS 1209-51/52) is an unique object among INSs. The monitor of 1E1207's radio-quiet X-ray pulsation proposed that the period have hardly changed. This result shows that the age of this object has far exceeded the age of the SNR. Gotthelf et al. 2007 presents the possibility that 1E1207 is born spinning slowly with weak magnetic field. Moreover, the previous observations of XMM-Newton and Chandra showed absorption lines at 0.7, 1.4, and 2.1, (also 2.8) keV (e.g., Sanwal et al. 2002; Mereghetti et al. 2002; Bignamet al. 2003). If they are electron cyclotron lines, they suggest magnetic field of B $\sim 810^{10}$ G. On the other hand, if they are due to proton cyclotron resonance, magnetic field would be B $\sim 1.6 \times 10^{14}$ G, this suggests that 1E1207 is a magnetar (e.g., Bignamiet al. 2003). Alternatively, there are reports that the structures at 2.1, 2.8 keV are insignificant and the others are due to transitions of hydrogen like O / Ne ions in the stellar atmosphere with a similar strong magnetic field (e.g., Mori et al. 2006). Here we analyzed its recent period variation and the absorption structure seen a low energy spectrum by observing with Suzaku. 1E 1207 was observed twice with Suzaku. The Suzaku observations were done in the Normal mode and the Parallel-sum (P-sum) mode. In the P-sum mode, the pixel data from multiple rows are summed in the Y-direction on the CCD, and read by the row. The time resolution is 8 s/1024 $\sim$ 7.8 ms. The property of each observation is summarized in Table 1.

Table 1. The observational property.

	1st Obs.	2nd Obs.
Obs. ID	401030010	401030020
Obs. time	2006/07/30 13:18	2007/02/15 04:48
(UT)	$\sim$ 2006/08/01 03:15	$\sim$ 2007/02/16 15:20
Exposure	70.1(Normal)	49.8(Normal)
	26.2(P-sum)	50.0(P-sum)
Remarks	XIS nominal	XIS nominal
	SCI off	SCI on

2. Timing analysis

We analyzed the P-sum mode data, and search for the period with epoch-folding technique. Similar asymmetric pulses are seen as shown by Chandra and Newton results. The pulse period was evaluated to be 0.424130±0.000001 s by the analysis. Although the error is rather large, the pulse period does not significantly change comparing with the previous results, and hence this supports the scenario that 1E 1207 is older than SNR G296.5+10.0.

3. Spectral analysis

Spectral structures were clearly detected in the acquired spectrum of 1E1207 when we analyze XIS1 data of the second observation. We analyzed the data based on the assumption of cyclotron resonant scattering of electrons or protons in a strong uniform magnetic field.

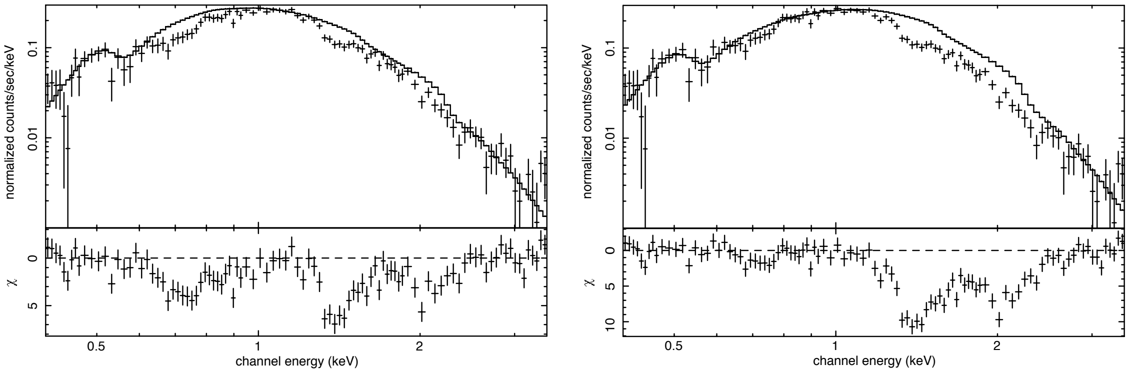

Fig. 1. The XIS1 spectrum of the second observation plotted together with the best-fitting continuum models. Left: 2BB with the best-ft value of Bignami et al. (2003). Right: 2BB with free temperatures.

Energy of an electron in uniform magnetic field $\boldsymbol{B}$ along the z-axis may be given by

$$E = \left(n' + \frac{1}{2}\right)\frac{e\hbar}{m_{\rm e}c}B - 2\mu_{\rm B}\boldsymbol{\sigma}\cdot\boldsymbol{B} + \frac{P_z^2}{2m_{\rm e}} \qquad (1)$$

where $\mu_{\rm B} = e\hbar/2m_{\rm B}c$ is the Bohr magneton, $B = |\boldsymbol{B}|$, $\sigma_{\rm z} = \pm 1/2$, and $n' = 0, 1, 2, \cdots$. The electronic momentum parallel to $\boldsymbol{B}$, $P_{\rm z}$, could be ≈ 0; i.e., electrons are likely to be cold due to the synchrotron cooling. The electronic energy is therefore allowed to have discrete values, $E_{\rm n}$, being harmonically spaced Landau levels in the non-relativistic case. Here,

$$E_{\rm n} = \frac{e\hbar B}{m_{\rm e}c}n \qquad (n = 0, 1, 2, \cdots) \qquad (2)$$

Then, harmonic absorption-line like structures could be generated due to the resonant scattering among the Landau levels. We attempted to fit the absorption lines up to the third harmonic with Gaussian line profile. We employed Xspec 11.3.2ag. It was able to explain a continuous element by two black body (BB), and the absorption structure fitted with gaussian absorption (gabs). In addition, the energy ratio of three lines was fixed at 1:2:3. Table 2 shows the best-fit parameters of the fittings with a 2 Black-body (denoted as "2BB" hereafter) as the continuum together with three *harmonic* lines.

Table 2. The best-fit parameters. $E_{\rm a}$ represents the centroid energy of the fundamental (the first harmonic) line.

	Fit-1	Fit-2
nH [10^{22}cm^{-2}]	0.11 (Fixed)	0.11 (Fixed)
kT_1 [keV]	0.163 (Fixed)	$0.10\,^{+0.02}_{-0.01}$
kT_2 [keV]	0.319 (Fixed)	0.31 ±0.01
$E_{\rm a}$ [keV]	0.71 ±0.01	0.71 ±0.01
χ^2 / d.o.f.	97.1 / 91	89.3 / 89
Null hypo. Prob.	0.31	0.47

The left panel of Figure 1 shows the XIS1 spectrum together 2BB using the best-fit parameters reported in Bignami et al. (2003). The spectral structures can be seen with *harmonic* separations in the residual (the bottom panel). In this case the Suzaku data give almost the same result for line structures as those reported in Bignami et al. (2003) at $0.71 \times j$ with j =1, 2, and 3 (see the left column of Table 2) (Fit-1). We made the other fit (Fit-2) with the model consisted of 2BB (with free temperatures) and three *harmonic* lines with a free centroid energy of the first line, and obtained an acceptable (better) fit shown in the right column of Table 2. The right panel of Figure 1 displays the spectrum and the best-ft continuum model obtained by the above fitting. The first line at around 0.71 keV looks shallower than that of Fit-1. A possible explanation could be that spawned photons due to the scattering at the higher harmonics collect at about the fundamental energy and then make it shallow. Many previous works suggest this possibility (e.g., Araya & Harding (1999)).

In the case of the proton cyclotron resonant scattering dominates, anomalous magnetic moment should be in consideration. The resonance energies may be given by

$$E_{\rm n} \approx \left(n + \frac{1}{2} \mp 1.4\right)\frac{e\hbar B}{m_{\rm p}c} \qquad (n = 0, 1, 2, \cdots) \qquad (3)$$

Therefore it is unlikely to expect exactly harmonic structure; instead the ration would be $(1 : 2 : 2.79 : 3 \cdots)$. We fixed the energy ratio of four Gauss absorption lines expected as above. However, resulting fit is not good and does not constrain physical parameters either. The current data are likely in favor of the electronic cyclotron scattering as an explanation of the spectral structures.

4. Conclusion

1E 1207.4-5209 was observed twice with Suzaku and *harmonic absorption lines* were seen in the data, but the first line looked shallower than that in the previous reports. Our analysis shows that electronic cyclotron scattering is preferable.

References

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