Out of the Chorus Line: What Makes 1E1207.4-5209 a Unique Object?

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Abstract. The discovery of deep spectral features in the X-ray spectrum of 1E1207.4-5209 has pushed this Isolated Neutron Star (INS) out of the chorus line, since no other INS has shown significant features in its X-ray continuum. On August 2002, *XMM-Newton* devoted a two-orbit TOO observation to this target with the aim to better understand the nature of such spectral features, using much improved statistics. Indeed, the 260 ksec observation yielded 360,000 photons from 1E1207.4-5209, allowing for a very sensitive study of the temporal and spectral behaviour of this object.

1. Introduction

Neutron star atmosphere models predicted the presence of absorption features depending on atmospheric composition, but high quality spectra, collected both by *Chandra* and by *XMM-Newton*, did not yield evidence for any feature (see Pavlov et al. 2002a and Becker and Aschenbach 2002 for recent reviews). INS spectra are well fitted by one or more black-body curves with, possibly, a power law contribution at higher energies, but with no absorption or emission features. The spectrum of 1E1207.4-5209, on the contrary, is dominated by two broad absorption features seen, at 0.7 and 1.4 keV, both by *Chandra* (Sanwal et al., 2002) and *XMM-Newton* (Mereghetti et al., 2002). To better understand the nature of such features, *XMM-Newton* devoted two orbits, for a total observing time of 257,303 sec, to 1E1207.4-5209. In the two MOS EPIC cameras the source yielded 74,600 and 76,700 photons in the energy range 0.2 - 3.5 keV, while the pn camera recorded 208,000 photons, time-tagged to allow for timing studies. Analysis of this long observation, while confirming the two phase-dependent absorption lines at 0.7 and 1.4 keV, unveiled a statistically significant third line at ~2.1 keV, as well as a possible fourth feature at 2.8 keV. The nearly 1:2:3:4
ratio of the line centroids, as well as the phase variation, naturally following
the pulsar B-field rotation, strongly suggest that such lines are due to cyclotron
resonance scattering (Bignami et al. 2003). A recent software release, based on
a better characterization of the EPIC instrument, prompted us to revisit the
data. While the spectral analysis results confirm and strengthen the conclusions
of Bignami et al. (2003), the temporal and spatial analysis yielded interesting
new results which we shall briefly outline (see De Luca et al. 2003 for details).

2. Timing Analysis

After converting the arrival times of the 208,000 pn photons to the Solar System
Barycenter, we searched the period range from 424.12 to 424.14 ms using both a
folding algorithm with 8 phase bins and the Rayleigh test. The best period value
and its uncertainty ($P = 424.13076 \pm 0.00002$ ms) were determined following the
procedure outlined in Mereghetti et al. (2002). Comparing the new period
measurement of 1E 1207.4–5209 with that obtained with Chandra in January
2000 (Pavlov et al. 2002b), we obtain a period derivative $\dot{P} = (1.4 \pm 0.3) \times 10^{-14}$
s s$^{-1}$. However, Fig. 1 (left panel) shows that the $\dot{P}$ value rests totally on the
first Chandra period measurement. Using only the 3 most recent values, the
period derivative is unconstrained. Thus, we cannot exclude that the observed
spin-down, based on only a few sparse measurements, be affected by glitches
or Doppler shifts induced by orbital motion. Questioning the object’s $P$ would
have far reaching consequences for the understanding of 1E1207.4-5209 since the
serious discrepancy between the pulsar characteristic age ($\tau_c \sim 5 \times 10^5$ yrs) and
the SNR age ($\tau_{SNR} \sim 7$ kyrs) is entirely based on the value inferred from the
measurements summarized in Fig. 1 (left panel).

To study the energy dependence of the pulse profile, we divided the data
in four channels with approximately 52,000 counts each: 0.2–0.52 keV, 0.52–0.82
keV, 0.82–1.14 keV and 1.14–3.5 keV. The pulse profiles in the different energy
ranges (Fig. 1, right panel) show a broad, nearly sinusoidal shape, with a pulsed
fraction varying from $\sim 3$ to $\sim 11$ % in the four energy intervals. It is worth
noting that the minimum pulsed fraction is found in the 0.20-0.52 keV energy
range, the only portion of the spectrum free from absorption lines. Indeed,
Fig. 1 (right panel) is an independent confirmation of the findings of Bignami
et al (2003) who ascribed the source pulsation to the absorption lines phase
variation.

Finally, comparing the shapes of the light curves of Fig. 1 (right), we see
for the first time a phase shift of nearly 90° between the profile in the lowest
energy range (<0.52 keV) and those at higher energies.

3. Optimizing the X-ray position

To derive the sky coordinates of 1E 1207.4–5209 we computed independently
for the MOS1 and MOS2 cameras the boresight correction to be applied to the
default EPIC astrometry. We used the Guide Star Catalog II (GSC-II$^1$) to select,

$^1$http://www-gsss.stsci.edu/gsc/gsc2/GSC2home.htm
amongst our \( \sim \)200 serendipitous detections, 6 sources with a stellar counterpart to be used to correct the EPIC astrometry. The rms error between the refined X-ray and GSC-II positions is \( \sim \)1 arcsec per coordinate. The resulting MOS1 position of 1E 1207.4–5209 is \( \alpha_{J2000} = 12h10m00.91s, \delta_{J2000} = -52°26′28.8″ \) with an overall error radius of 1.5 arcsec. The MOS2 position is \( \alpha_{J2000} = 12h10m00.84s, \delta_{J2000} = -52°26′27.6″ \), with an uncertainty of 1.5 arcsec, fully consistent with the MOS1 coordinates.

4. Search for the optical counterpart

The field of 1E 1207–5209 was observed with the 8.2-meter UT-1 Telescope (Antu) of the ESO VLT (Paranal Observatory). Observations were performed with the the FOcal Reducer and Spectrograph 1 (FORS1) instrument. Images were acquired through the Bessel V and R filters for a total integration time of \( \sim2 \) and 3 hrs, respectively. Fig. 2 shows the inner portion of the combined FORS1 V-band image centered on the target position, with the MOS1 and MOS2 error circles superimposed. A faint object (marked with the two ticks in Fig. 2) is detected just outside the southern edge of the MOS1 error circle and showed variability along the time span covered by our observations. In any case, its position falls more than 2 arcsec away from the intersection of the MOS1/MOS2 error circles, which we regard as the most probable region.

No candidate counterpart is detected within the MOS1/MOS2 error circles down
to R $\sim 27.1$ and V $\sim 27.3$, which we assume as upper limits on the optical flux of 1E 1207−5209. For the X-ray derived interstellar absorption ($A_V = 0.65$) and a distance of 2 kpc, the measured u.l. rule out any hypothetical “normal” stellar companion other than a very low-mass main sequence star. If we assume that 1E 1207-5209 is indeed isolated, we can derive a neutron star optical luminosity $\leq 3.4 \times 10^{28}$ erg s$^{-1}$ or $\leq 4.6 \times 10^{-6}$ of its rotational energy loss, a value similar to those of middle-aged INSs. Since the VLT flux upper limits are $\geq 100$ higher than the extrapolation of the XMM-Newton blackbody (De Luca et al. 2003), they can not constrain the optical spectrum.

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