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Hard X-rays from Be star LSI +61°303

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Abstract. We show that the hard X-ray emission from the X-ray source LSI +61°303 can be due to inverse Compton scattering of optical photons from the Be star by the relativistic electrons responsible for the observed radio emission.

Key words. X-ray source – Be star – LSI +61°303

1. Introduction

The optical object LSI +61°303 is a Be star binary with an orbital period of 26.5 days. The Be star is of spectral type B0-B0.5 V and the orbit has an eccentricity of ∼0.6 (Hutchings & Crampton 1981). X-ray emission was observed from the object (Bignami et al. 1981) and it is suggested that the secondary is a compact object (white dwarf, neutron star or black hole). The maximum X-ray emission occurs when the compact object passes, at periastron, through the gas disk given out by the Be star (Taylor et al. 1996).

Radio emission from LSI +61°303 was first observed by Gregory & Taylor (1978). The radio emission reaches a peak and then decays. The radio emission occurs after every periastron passage of the compact object, when the Be star has a gas disk, and each flare lasts several days. The radio emission has been measured at several frequencies (Taylor & Gregory 1984; Ray et al. 1997 and references therein) and the spectrum can be fitted with a power law of the form $S \propto \nu^{-\alpha}$ where ν is the radio frequency (Ray et al. 1997); the spectral index α varies during an outburst, with a negative value near the peak of radio emission and with positive values subsequently. The spectral index reaches an average value of ∼0.3 (Taylor et al. 1996; Ray et al. 1996) during the later stages of the flare. It is suggested that the radio emission is synchrotron radiation from relativistic electrons in a bubble also containing plasma and that high energy electrons, responsible for the radio emission, are accelerated near the compact object during its periastron passage (Taylor & Gregory 1984). Acceleration of high energy particles is suggested by Taylor & Gregory (1984) to occur due to super critical accretion on to the compact object, while Apparao (2000b) suggests that the shock due to supersonic motion of the compact object through the dense Be star gas disk accelerates the high energy particles. The negative value for the index at the peak of the outburst is attributed to the presence of plasma in the bubble. Paredes et al. (1991) assume that high energy electrons are injected into a bubble or "plasmon" over a few days and which expands, in order to explain the observed radio intensity variations; they express the electron spectrum as a power law with an index $p = 1.6$. Apparao (1999) has suggested that the plasmon formed near the periastron, floats to the top of the Be star gas disk due to buoyancy and subsequently expands in the wind of the Be star; the peak of the radio emission is reached when the bubble becomes optically thin to the radio emission. This picture accounts for the observed (see Paredes et al. 1991 and references therein; Tavani et al. 1996; Ray et al. 1997) radio intensity dependent delay in the radio maximum, compared to that of the X-ray maximum. We shall adopt the picture suggested by Paredes et al. (1991) and Apparao (1999) in this paper. VLBI observations (Taylor et al. 1992; Massi et al. 1992) have shown a double radio source with the sources expanding with a velocity of 640 $\mathrm{km\,s^{-1}}$.

The low energy X-ray emission in the 0.5–4 keV range is estimated to be in the range 10^{33} $\mathrm{erg\,s^{-1}}$ and 10^{34} $\mathrm{erg\,s^{-1}}$ at periastron (Bignami et al. 1981; Taylor et al. 1996; Harrison et al. 2000) using a distance of $d \simeq 2.3$ kPc. The hard X-ray emission (20–200 keV) from the object was obtained by Tavani et al. (1996) and Strickman et al. (1998) using data from BATSE and OSSE instruments aboard the CGRO satellite and by Harrison et al. (2000) with RXTE satellite in the 15–40 keV range. Harrison et al. (2000) find the flux from LSI 61°+303 without contamination from the nearby quasar 0241+62. The energy in the hard X-ray emission is estimated to be about 5 10^{34} $\mathrm{erg\,s^{-1}}$. The observed spectrum of the hard X-ray emission shown in Fig. 1. Gamma rays with energy at about 5 MeV and with energy $\gtrsim$30 Mev have also been observed in the region (Perotti et al. 1980; van Dijk et al. 1996; Kniffen et al. 1997), but there is some

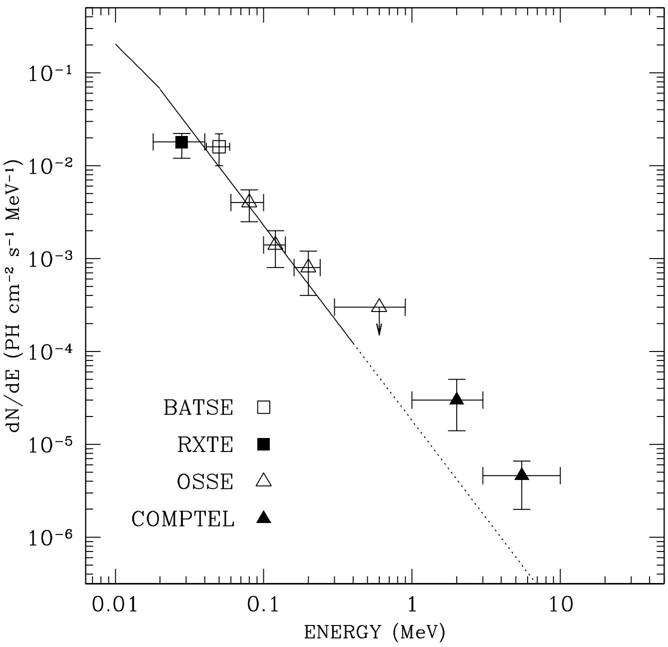

Fig. 1. The hard X-ray spectrum of LSI +61°303. The observed points are taken from Tavani et al. (1996) and Harrison et al. (2000) The line is the calculated inverse Compton spectrum

doubt as to its association with the source LSI +61°303, as the quasar 0241+62 is close and cannot be ruled out as the source. The X-ray flux is correlated with the radio flux (Tavani et al. 1996; Leahy et al. 1997; Harrison et al. 2000), though the peaks of the two emission are separated in phase (Taylor et al. 1996; Harrison et al. 2000).

The nature of the compact object in the binary LSI +61°303 is not yet established. If it is a neutron star or a black hole, a comparison with other X-ray emitting Be star binaries with early spectral type and comparable periastron distances (cf. Be star binaries with neutron stars A0538-66, A0535+26; see Apparao 1994) shows that the low energy X-ray emission is far too small. The object does not show the characteristic small time variability of black holes. The low energy X-ray flux is consistent with the compact object being a white dwarf; the hard X-ray flux observed then has to come from some other source.

Harrison et al. (2000) have argued that the X-ray emission cannot be synchrotron emission from high energy electrons, since the peak emissions of X-rays and radio are out of phase. Taylor et al. (1996) have suggested that the low energy X-ray emission can be due to inverse Compton scattering of the stellar photons by the high energy electrons responsible for the radio emission. That the hard X-ray emission can be from the same process has also been suggested (Apparao 2000a; Harrison et al. 2000). In this note we calculate the hard X-ray flux due to inverse Compton scattering of the Be star photon emission, from the high energy electrons responsible for the radio emission and compare there calculations with observations.

2. Inverse Compton scattering

The Be star is of spectral type B0-B0.5 V (Hutchings & Crampton 1981). Its bolometric luminosity is $\sim 10^{38}$ erg s^{-1}. The surface temperature T is taken to be 31 500 K (Straizys & Kuriliene 1981) and the maximum photon emission is at a photon energy $\epsilon_{\rm m} \sim 10$ eV. Using the period of the system and the eccentricity given above the periastron distance is $\sim 3\ 10^{12}$ cm.

The radio emission is, as mentioned earlier, attributed to an expanding bubble of high energy electrons accelerated near the periastron. The radio spectrum is expressed $S(\nu) = K\ \nu^{-\alpha}$ where K and α are constants. The spectrum of electrons emitting the radio radiation is $N_{\rm e} = K_{\rm e}\ E^{-p}$, where E is the energy of the electron and $p = 2\alpha + 1$. $K_{\rm e}$ is given by (de Jaegar & Harding 1992),

$$K_{\rm e} = \frac{4\pi d^2 K (6.26\ 10^{18})^{(1-p)/2}}{(1.17\ 10^{-22})\alpha(p) B^{(p+1)/2}}, \tag{1}$$

where B is the magnetic field and $\alpha(p)$ is a slowly varying function given by Lang (1980). The inverse Compton scattering of the photons from the Be star (taken as a blackbody spectrun with the temperature given above) from the high energy electrons gives high energy photons whose power is given by (see Rybicki & Lightman 1979),

$$\frac{{\rm d}P}{{\rm d}V{\rm d}t{\rm d}\epsilon_s} = D\frac{C\pi r_0^2 (kT)^{(p+5)/2} F(p) \epsilon_{\rm s}^{-(p-1)/2}}{h^3 c^2}. \tag{2}$$

P is the power in the scattered photons in erg s^{-1}. h is the Planck constant, k is the Boltzman constant, c is the velocity of light and r_0 is the radius of the electron. $\epsilon_{\rm s}$ is the energy of the scattered photon. V is the volume of emission and the expression for $F(p)$ is given by Lang (1980). D is the dilution factor for the radiation from the Be star given by (Ambartsumyan 1958),

$$D = \frac{1}{2}\left[1 - \sqrt{1-(R/r)^2}\right]. \tag{3}$$

R is the radius of the Be star. C is given by,

$$C = \frac{K_{\rm e}}{(mc^2)^{(p-1)} V}, \tag{4}$$

mc^2 is the rest energy of the electron. Using the radio flux at 2.25 GHz as ~ 230 mJy (Ray et al. 1997), $p = 1.6$, $B = 1$ G (Paredes et al. 1991), $R = 4\ 10^{11}$ cm (Straizys & Kuriliene 1981) and $r = 3\ 10^{12}$ cm (the periastron distance), the inverse Compton spectrum is calculated using the Eqs. (1–4). The differential spectrum of the scattered radiation is (note that the volume of emission V and the distance to the source cancel out while obtaining the source values from the observed radio emission and obtaining the photon flux at the earth from the source emission),

$$N_{\rm HX} = 1.3\ 10^{-4} \epsilon_{\rm s}^{-1.6}\ \ \text{photons cm}^{-2}\ \text{s}^{-1}\ \text{MeV}^{-1}. \tag{5}$$

The calculated spectrum (5), however, has a cutoff, due to the finite lifetime (see Taylor & Gregory 1982) of the high energy electrons in the photon field of the Be star. The high energy electron spectrum has a break at a Lorentz factor γ_c, which can easily be calculated and is given by

$$\gamma_c = \frac{4\pi mc^2 v_d r}{L\sigma}. \quad (6)$$

Here v_d is the drift velocity of the electron bubble in the radial direction, L is the luminosity of the Be star, r is the distance of the bubble from the star and σ is the Thomson scattering cross section. The drift velocity v_d near the binary system is unknown; the velocity of the radio lobes is measured to be ∼640 km s^{-1} (Taylor et al. 1992; Massi et al. 1992), while closer to the binary system, Taylor & Gregory (1982) suggest $v_d \gtrsim 10^8$ cm s^{-1}. Using the latter value, $\gamma_c \simeq 43$. The scattered photon spectrum will have a break at $\epsilon_c \sim \gamma_c^2\ \epsilon_m$ which is ∼0.02 MeV, and the photon power law index will increase by 0.5 (Pacholzyk 1970) at ϵ_c. The inverse Compton spectrum will be then of the form given below,

$$N_{HX} = 1.3\ 10^{-4} \epsilon_s^{-1.6} \quad \text{for } \epsilon_s \lesssim 0.02 \text{ MeV} \quad (7)$$

and

$$N_{HX} = 1.8\ 10^{-5} \epsilon_s^{-2.1} \quad \text{for } \epsilon_s \gtrsim 0.02 \text{ MeV}. \quad (8)$$

These spectra, along with the observed values (Tavani et al. 1996; Harrison et al. 2000), are shown in Fig. 1. Since LSI +61°303 is not bright in the hard X-ray region, the observed values given in Fig. 1 are averages from observations made around the periastron.

3. Discussion

It is seen that the observed hard X-ray spectrum between 20 keV and 200 keV is adequately explained by the scattering of photons from the Be star by the electrons responsible for the radio emission. The process suggested here does not explain the observed flux in the 1–10 MeV range as seen from the extension of the spectrum given by Eq. (8) above and another explanation needs to be sought for their origin. Harrison et al. (2000) have suggested that the observed flux at 100 MeV by the EGRET satellite (Kniffen et al. 1997) can be from the inverse Compton process. The flux calculated from Eq. (8) for this energy range is also lower than the observed value. It is however possible, as mentioned in the introduction, that this flux may not be from LSI +61°303 but from the neighbouring quasar.

The present calculation suggests that there is a break in the X-ray spectrum around 20 keV. With the existing data, it is not possible to observe this break because of the dimness of the source in the hard X-ray region. Future observations with better statistics may be able to establish the break.

In the present calculation we have used the peak radio intensity to obtain the intensity of high-energy electrons. The radio electrons, as mentioned earlier, are accelerated around the periastron and the plasmon starts its adiabatic expansion after the escape from the Be star gas disk, which occurs on the order of a day. In the adiabatic expansion, the high energy electrons lose energy and the value of K_e will change (Shklovsky 1960). It is clear, however, from the radio peak occuring several days after the periastron that the high energy electrons survive several days. The decrease in K_e will result in the decrease of the inverse Compton scattered photons and the hard X-ray intensity will depend on the radio intensity. In Fig. 1 we have compared the calculated values of hard X-ray intensity with observed values, which are average values in the orbital phase around periastron. Clearly, detailed simultaneous phase-related observations of hard X-ray intensity and radio intensities are needed to establish the relation between the two.

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