

Modeling the multi-wavelength spectrum of the γ -ray source LSI+61°303

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Abstract.

Considerable interest has centered around LSI+61°303 since 1977 when it was discovered to be variable radio source and proposed to be the counterpart of a COS-B γ -ray source. The radio light curve exhibits outbursts whose periodicity corresponds to the optical periodicity of the orbital motion. LSI+61°303 has been also identified as an x-ray source and an MeV γ -ray source. The various observations in different wavebands from radio wavelengths through to γ -rays are summarized here. A new emission model is constructed which is strongly constrained by the multi-waveband data.

1 Introduction

LSI+61°303 is one of a small but important group of radio emitting x-ray binary systems. It was discovered to be a strong, variable radio source (Gregory and Taylor (1978)) and proposed to be the counterpart of the COS-B γ -ray source 2CG0135+01. It was then identified with its Be star optical counterpart (Gregory et al. (1979)). The radio light curve exhibits outbursts whose periodicity is consistent with the optical periodicity of the orbital motion (Hutchings and Crampton (1981)).

In this paper the various observations of LSI+61°303 in radio, infrared, optical, soft and hard x-rays, and γ -rays are considered to determine the spectrum from radio to γ -rays. These basic properties are then interpreted in terms of a quantitative model which interprets the radio and x-ray through γ -ray emission as synchrotron and inverse-Compton emission components. More details and refinements to the model are presented in Leahy (2001, in preparation).

2 The Data

LSI+61°303 has been observed on numerous occasions in various wavebands from radio through γ -ray. The radio ob-

servations are summarized in Ray et al. (1997). That paper presents two frequency (2.25 and 8 GHz) observations from 1994 January to 1996 February. Flux and spectral index lightcurves are given for the whole period as well as phase-averaged flux and spectral index lightcurves. They find an outburst period of 26.69 ± 0.02 days, significantly different from the period of 26.496 ± 0.008 days given by Taylor and Gregory (1984). The radio outburst is modelled in detail by Peracaula (1997). Here the concern is mainly the properties of the non-outburst emission in order to constrain the relativistic electron population around the compact object. This emission has a mean minimum flux of 17 mJy at 83 GHz and a 2.25-8.3GHz spectral index of $\alpha = 0.5$, where as the outburst emission has a mean peak flux of 160 mJy at 83 GHz and a spectral index of $\alpha = 0.0$.

Optical observations (Hutchings and Crampton (1981)) give period, K , e and ω with large uncertainties. Marti and Paredes (1995) summarize previous optical observations which indicate the primary star is Be star with $T_{eff} = 22500$ K. They then use infrared observations to constrain the nature of the circumstellar disk of material around the primary star. The temperature of the disk was taken to be 17500K, then the density of the disk is given by the parameters in Table 1 of that paper.

Previous x-ray through γ -ray flux measurements are summarized in Harrison et al. (2000). One of the important results of that paper was the identification of a nearby QSO which had contaminated a number of previous flux measurements of LSI+61°303 (including the Comptel and OSSE measurements, but not the EGRET measurement). They measured the flux of the QSO and of LSI+61°303 with the RXTE/PCA and RXTE/HEXTE, so that the flux from LSI+61°303 could be reliably determined. Previous measurements with ROSAT and with ASCA, both imaging instruments, were not contaminated by the QSO flux.

Long-term monitoring of LSI+61°303 has been carried out by the All-Sky-Monitor (ASM) on board RXTE (Leahy (2001)): that data gives the best orbital period determination and also the best determination of the orbital x-ray light

curve.

LSI+61°303's x-ray spectrum is previously best determined by the ASCA satellite (Leahy et al. (1997)). The 0.5-10 keV x-ray spectrum has $\alpha = 0.70 \pm 0.07$ and $\alpha = 0.82 \pm 0.07$ in the two ASCA observations. More extensive flux measurements are from ROSAT and RXTE/PCA (Harrison et al. (2000)). The mean PCA 2-10 keV flux for 10 pointings is $1.1 \times 10^{-11} \text{ erg cm}^{-2} \text{ s}^{-1}$, which is higher by a factor 2 than the ASCA 2-10 keV flux. The mean ROSAT 0.5-2 keV flux for 9 pointings is $2 \times 10^{-12} \text{ erg cm}^{-2} \text{ s}^{-1}$, which is higher by a factor 1.3 than the ASCA 0.5-2 keV flux. The derived ROSAT flux is sensitive to the column density to LSI+61°303, which has been determined by the ASCA spectrum ($6 \times 10^{21} \text{ cm}^{-2}$). The above indicates that the ASCA flux was from a low flux part of the orbital cycle.

The PCA flux is the most representative for the orbital cycle average of LSI+61°303 and also not sensitive to the assumed column density. The EGRET 100 MeV flux is also representative of the orbital cycle average. The derived PCA-EGRET spectral index, assuming a power law, is $\alpha = 0.69$, consistent with the ASCA values but better determined due the wide energy range. The other high energy measurements which are contaminated by the nearby QSO are not considered here.

Figure 1 shows the x-ray and γ -ray flux measurements plotted against energy. These have all been converted to the common set of units of νf_ν using a common spectral index of $\alpha = 0.69$. The ASCA data are lower than the PCA data, consistent with coming from a low flux part of the orbital cycle. However the ROSAT data sample a wide range of orbital phase and should be representative of the orbital cycle. So there is evidence for either: a turndown in the spectrum below about 2 keV; or a column density variation with orbital phase that was not detected with ASCA due to the very limited time sampling; or some combination of the above. A higher column density would mean a larger correction to the ROSAT fluxes to get absorption corrected fluxes, which could bring the fluxes up to agree with the power law extrapolation from higher energies.

3 The Model

Previous studies (e.g. Harrison et al. (2000), Leahy et al. (1997), Peracaula (1997)) have determined that the radio emission is synchrotron and the x-ray through γ -ray emission is inverse-Compton in origin. The x-ray light curve is smoothly modulated with a peak at constant orbital phase (Leahy (2001)), whereas the radio light curve shows large outbursts and variable orbital phase (e.g. Ray et al. (1997)). Comparison of x-ray and radio light curves (Harrison et al. (2000) and Leahy (2001)) shows that the radio outburst lags the x-ray peak by 0.4 in orbital phase. Thus the radio outburst is suggested here to be associated with a volume of electrons escaping the environment of the compact object, whereas the steady radio emission is from a steady population of electrons associated with those electrons that give the x-ray to γ -ray emission.

Here, the emission from a steady population of relativistic electrons is compared to the data for the steady radio emission and the orbital-cycle average of the x-ray and γ -ray data. A power law inverse Compton emission from 0.5 keV to 100 MeV implies an electron population with energy spectrum index 2.38 over an electron energy range of $6.4 \times 10^{-6} \text{ erg}$ to $2.9 \times 10^{-3} \text{ erg}$, using the photon energy distribution and photon flux from the primary star for a temperature of 26500K and luminosity of $1.33 \times 10^{38} \text{ erg/sec}$. The orbital radius was calculated for different primary star masses, but numbers given here are for the case of primary mass of $10 M_{sun}$. The electron energy range giving the radio emission is $1.5 \times 10^{-5} B^{-0.5} \text{ erg}$ for 1.46GHz to $1.8 \times 10^{-4} B^{-0.5} \text{ erg}$ for 200GHz, with B the magnetic field in Gauss. The synchrotron spectrum should have the same index as the x-ray to γ -ray spectrum if it is optically thin. The quiescent radio $\alpha = 0.5$ is similar to the x-ray to γ -ray $\alpha = 0.69$. The reason it is slightly flatter could be due to optical depth effects for the synchrotron or due to energy losses steepening the part of electron spectrum responsible for the inverse-Compton emission. Optical depth in the radio will flatten the radio spectrum (reduce α).

The normalization of the x-ray to γ -ray spectrum gives the total number of emitting electrons, 2.6×10^{43} , and the total energy in these electrons, $5.4 \times 10^{38} \text{ erg}$. The inverse Compton lifetime of the electrons is in the range $1.5 \times 10^3 \text{ s}$ to $6.9 \times 10^5 \text{ s}$, much shorter than synchrotron loss times, which range from 900 days to 11000 days. The acceleration process needs to be rapid enough ($< 1.5 \times 10^3 \text{ s}$) in order that there is no spectral break in the electron energy spectrum in the observed x-ray to γ -ray range.

The normalization of the radio spectrum depends on the number of radio emitting electrons and the magnetic field. For a field of 1 Gauss, the number of radio emitting electrons is 4.3×10^{42} , and the total energy in these electrons is $1.5 \times 10^{38} \text{ erg}$. These are smaller than values derived from the inverse-Compton emission by factors of 3.6 to 6. This may indicate that: i) the magnetic field is smaller by a factor of about 3 (requiring more energy and a larger number of radio emitting electrons); or ii) the majority of the inverse Compton emitting electrons are in a high density region, so that the synchrotron emission from those electrons is optically thick over most of the observed radio band, whereas the remainder of the electrons are in a much lower density region, so the synchrotron emission is optically thin. For example, if the dense region has a field of 1 Gauss, and has a size of 0.01 times the semi-major axis, all synchrotron emission below 220 GHz would be optically thick and thus strongly suppressed. If the low density region emits 20 mJy at 5GHz in a field of 0.1 Gauss and is to remain optically thin it must be more extended than 0.8 times the semi-major axis.

Thus there should be an extended region in the binary system with a small but significant fraction of the total electron population. This region is responsible for the quiescent level of radio emission in the system. The compact region around the compact object can contain the majority of the electrons and produce most of the inverse Compton emission but will

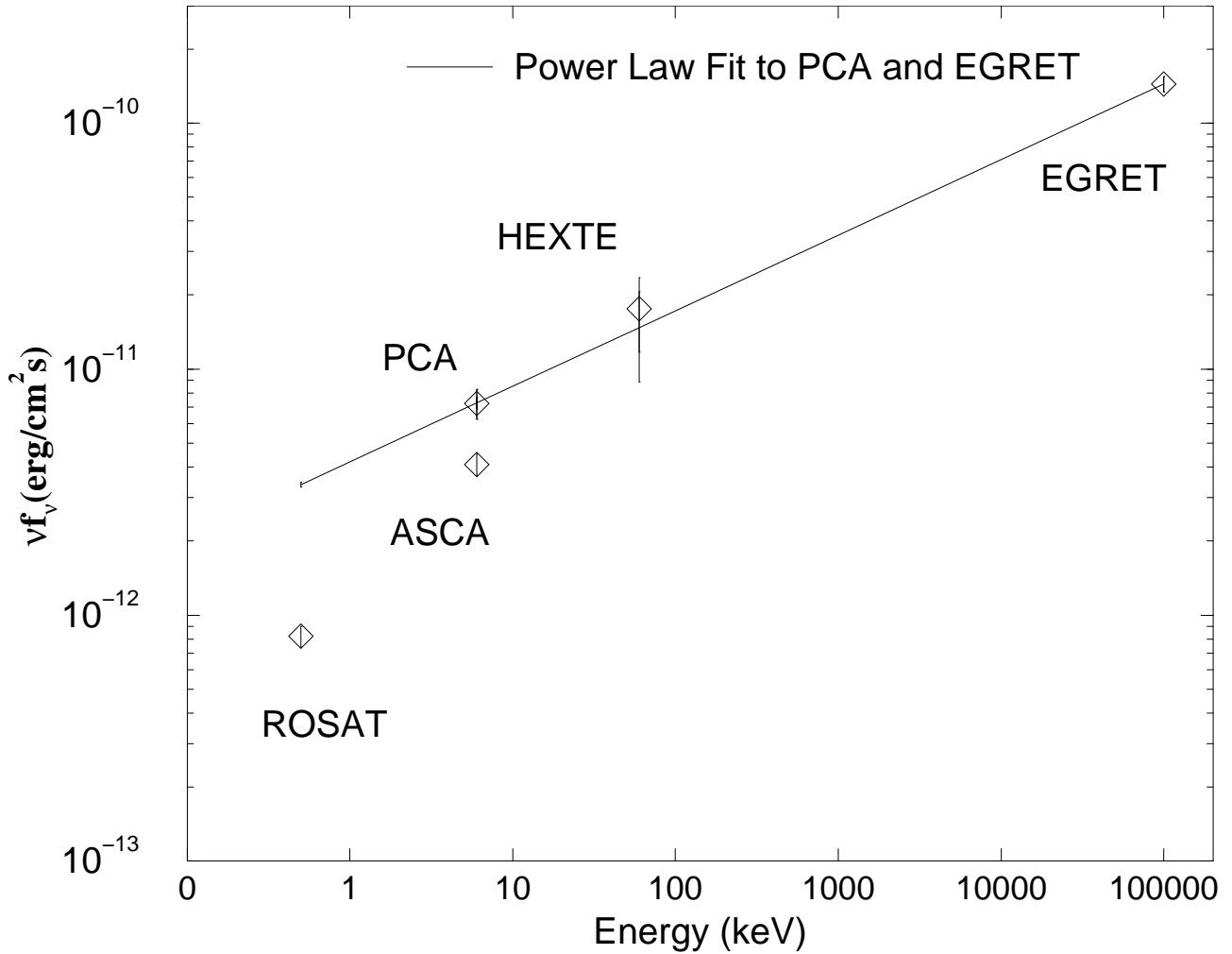


Fig. 1. Soft x-ray to *gamma*-ray flux measurements of LSI+61°303

be very optically thick to radio synchrotron emission. The relativistic electrons around the compact object will have a high pressure. It exceeds the thermal pressure of the gas in the circumstellar disk in which the compact object orbits by 2-3 orders of magnitude. However, the dynamic pressure due to the motion of the compact object through the circumstellar disk is large enough to balance the pressure of the relativistic electrons and thus provide confinement. Magnetic fields may also provide confinement, but are much more complicated to assess. Balancing the dynamic pressure with the electron pressure yields the size of the electron volume as a function of orbital distance to the primary star. This size is small near periastron, indicating good confinement. However it increases rapidly near apastron, thus providing a mechanism to allow the radio outbursts. That is, rapid reduction in confinement pressure allows escape of a large fraction of the relativistic electrons near apastron. This is in accord with the phasing of the radio and x-ray light curves (Leahy (2001), Harrison et al. (2000)), which has the radio outburst on average at orbital phase 0.4, with periastron defined as phase 0.0.

The rapid expansion of the relativistic electrons is accompanied by adiabatic losses which change the electron spectral index by 1 below the energy where inverse Compton losses dominate. This flattens the radio spectral index by 0.5, in agreement with observations.

4 Discussion

In summary, the model presented here for the LSI+61°303 system is as follows. Relativistic electrons are accelerated in the environment of a pulsar orbiting the primary Be star. The acceleration process needs to be rapid enough ($< 1.5 \times 10^3$ s) in order that there is no spectral break in the electron energy spectrum in the observed x-ray to γ -ray range. Most of the electrons are confined to a small volume and emit inverse Compton x-rays and gamma-rays. This small volume is optically thick over the observed radio spectral range. A small but significant fraction of the electrons is not confined to this small volume, but is spread throughout the binary system and contributes to the quiescent radio emission, with spec-

tral index similar to that of the x-rays and gamma-rays. The radio outburst occurs near apastron on the outward journey of the pulsar through the circumstellar disk as the confining pressure on the relativistic electrons decreases fairly rapidly. These relativistic electrons expand rapidly. The resulting adiabatic losses have the effect on the radio spectrum of changing the spectral index by 0.5. The electrons then continue to expand and escape the circumstellar disk. The time evolution of the outburst from just prior to peak of the radio flux onward is well described by the modelling of the radio outbursts given in Peracaula (1997).

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