Young Neutron Stars and Their Environments
IAU Symposium, Vol. 218, 2004
F. Camilo and B. M. Gaensler, eds.

LSI +61°303: A Pulsar Wind Nebula in a Binary?

D. A. Leahy

University of Calgary, Alberta T2N 1N4, Canada

Abstract. LSI +61°303 outbursts are modeled as a pulsar wind nebula expanding inside the environment provided by the Be companion star's stellar wind and photon flux. A set of equations describing the system is developed and solved numerically for representative sets of parameters. Emission in X-rays through gamma-rays is due to inverse Compton emission from relativistic electrons around the pulsar. The radio emission is due to synchrotron emission of varying optical depth, which yields a varying spectral index. The peak of X-ray emission is near periastron and the peak of the radio emission is near apastron, due to reduced confining pressure on the relativistic electron cloud and its subsequent rapid expansion.

1. Introduction

LSI +61°303 is an unusual radio emitting X-ray binary system. Leahy (2001) gives a review of its properties. The radio source LSI +61°303 is highly variable, exhibiting outbursts every 26.496 days which have rise times of ~1 day and last ~10 days (Gregory & Taylor 1978). Two-frequency radio monitoring indicates a flat spectral index, and the emission has been interpreted as optically-thin synchrotron radiation for most of the outburst, with indication that the source becomes self-absorbed for a short time at the beginning of the outburst rise (Taylor & Gregory 1984). VLBI observations show that at its maximum size the emitting region has a dimension of $\sim 5\times10^{13}$ cm, and an expansion velocity $(2.0-6.4)\times10^{7}$ cm s^{-1} (Massi et al. 1993). The phase of peak flux varies between 0.4 – 1.0 of the radio ephemeris (phase 0 arbitrarily defined as MJD 43366.275, period equal to 26.496 days), most often occurring at phase ~0.6 (Paredes et al. 1990; Ray et al. 1997).

2. Pulsar wind expansion in the binary system

The basic model used here for LSI +61°303 is: electrons are accelerated to relativistic energies by a pulsar in orbit around the Be primary star. The flux of stellar photons interacts with the power law distribution of relativistic electrons to produce a broad power law distribution of photons from X-ray through γ-ray energies. The same electrons radiate synchrotron photons in the 1 GHz to 200 GHz range. The eccentric orbit of the pulsar and its associated relativistic electron cloud result in the moderate modulation of the X-ray through γ-ray flux. The radio outburst is much more highly variable in intensity than the X-ray and is due to a rapidly expanding cloud of relativistic electrons.

https://doi.org/10.1017/S0074180900181021 Published online by Cambridge University Press

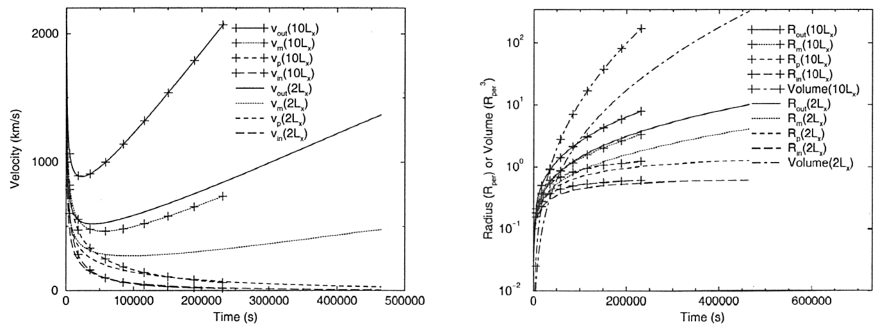

Figure 1. Velocity vs. time for the expansion (left); radius and volume vs. time for the expansion (right).

The sound speed in the relativistic electron region (called a bubble here) is large ($c/3$) so the interior of the bubble is homogeneous in pressure. The relativistic particle energy, E, inside the bubble increases which drives the bubble expansion via internal pressure $P = E/3V$. The exterior pressure is provided by the Be stellar wind. The bubble expansion is calculated numerically and illustrated for four points on the bubble surface: the innermost point facing the Be star, the outermost point, a point at constant distance (equal to the pulsar distance at the time of bubble growth initiation), and at the point midway between the inner and outer points. For the cases illustrated the energy injection rates were 2 and 10 times L_x, with L_x the observed X-ray luminosity.

Figure 1 shows the resulting expansion of the bubble vs. time: velocities, sizes and timescales are obtained which agree well with those deduced for the radio outburst (Peracaula 1997). At early phases the bubble is very optically thick to synchrotron, so that the radio flux only rises a few days after the X-ray flux, as observed. At radio peak the bubble is at large distance from the Be star so that the inverse Compton emission has fallen. This model can explain the observed features of the X-ray, γ-ray and radio emission from LSI +61°303 (Leahy 2004).

Acknowledgments. This work supported by the Natural Sciences and Engineering Research Council of Canada.

References

Gregory, P. C., & Taylor, A. R. 1978, Nature, 272, 704

Leahy, D. A. 2001, A&A, 380, 516

Leahy, D. A. 2004, A&A, 413, 1019

Massi, M., Paredes, J.M., Estalella, R., & Felli, M. 1993, A&A, 269, 249

Paredes, J. M., Estalella, R., & Rius, A. 1990, A&A, 232, 377

Peracaula, M. 1997, PhD thesis, University of Barcelona

Ray, P., Foster, R., Waltman, E., Tavani, M., & Ghigo, F. 1997, ApJ, 491, 381

Taylor, A. R., & Gregory, P. C. 1984, ApJ, 283, 273