Scientific Justification

The luminous early-type star LSI $+61^\circ 303$ is one of the most unusual stellar systems in the Galaxy. Discovered to be a radio source by Gregory and Taylor (1978), it also emits at far-infrared, x-ray and γ-ray wavelengths (Waters et al. 1988; Taylor et al. 1995; Fichtel et al. 1994). The radio emission takes the form of regular, non-thermal outbursts with a period of 26.51 days (Taylor and Gregory 1984). The periodicity was confirmed from radial velocity observations (Hutchings and Crampton 1981) and has been attributed to eccentric motion of a gravitationally-collapsed companion around a rapidly rotating B0Ve star. This periodic outburst has since been detected in the optical (Mendelsen and Mazeh 1994), infra-red (Paredes et al. 1994) and x-ray (Paredes et al. 1997). The radio outbursts from LSI $+61^\circ 303$ last for about ten days, with a rise to peak flux density over a period of about two days. The strength of the outbursts is modulated over a 4-year cycle (Gregory et al. 1989), reaching a maximum flux density of $\sim$300 mJy at the peak of the cycle.

While classed as a radio-emitting, massive x-ray binary system, even among this class of rare objects LSI $+61^\circ 303$ stands out as unique. Chief among the distinctive properties of LSI $+61^\circ 303$ is the relative luminosity of x-ray and γ-ray emission. Compared to all other x-ray binary systems that have typical luminosities of $10^{36} - 10^{38}$ erg/s in the KeV range, the x-ray luminosity of LSI $+61^\circ 303$ is low, about 10^{34} erg/s. However compared to other objects, LSI $+61^\circ 303$ is a prodigous emitter at γ-ray energies, , with a luminosity of 10^{37} erg/s; LSI $+61^\circ 303$ would be more properly referred to as a γ-ray binary system. This shift of the characteristic photon production energy from x-ray to γ-ray wavelengths indicates a fundamental difference in the energy production mechanism compared to other massive x-ray binary systems.

Several models have been proposed to explain the properties of LSI $+61^\circ 303$, and the production of relativistic particles giving rise to the outburst; including supercritical accretion at periastron passage (Taylor and Gregory 1984), relativistic shock interaction from a young pulsar wind (Maraschi and Treves 1981) and pair-production from γ-rays (Vestrand 1983). No observations have yet been able to discriminate between these models, or suggest a different hypothesis. The unique nature of LSI $+61^\circ 303$ lends it particular importance as an x-ray binary system. Understanding the underlying causes that give rise to its unique properties is likely to yield important insights into the nature of the radio-emitting x-ray binary phenomenon as a whole.

LSI $+61^\circ 303$ has been observed on several occasions with ground-based VLBI (Taylor et al. 1992; Massi et al. 1993; Paredes et al. 1998; Peracaula et al. 1998). However, a consistent picture of the dynamical evolution of the outburst structure has yet to emerge. Early observations indicated a slow expansion of a synchrotron plasmon to overall dimensions of a few mas at velocities of $\sim$ 400 km/s. More recently expansion velocites of $\sim$ 2000 km/s (Paredes et al.) and 18000 km/s (Peracaula et al.) have been reported. Peracaula et al. find evidence for rapid expansion and brightening on sub-mas scales and deceleration of the ejecta upon reaching dimensions over 1 mas. In all cases, unresolved components are present that produce correlated flux densities of several 10's of mJy on global baselines. The outbursts of LSI $+61^\circ 303$ are known to begin optically-thick at the very early stages, then reach an optically-thin stage well before peak flux density. The relative inportance of evolving source geometry versus energetic particle production during the rise to peak flux is still unknown.

The primary difficulties with the VLBI studies is the inability to effectively image the evolving structure of the outburst. Since LSI $+61^\circ 303$ rises from quiescent levels to peak flux density over an interval of 48 hours, dynamical imaging of the outburst requires that (u,v) coverage is sufficient to construct an image of the source structure on a time scale of about three hours. A ground-based VLBI observation of three hours provides only one-dimensional (linear) (u,v) coverage, due to the largely east-west nature of global baselines. This results in a poorly defined image with resolution in only one direction.

The rapidly changing baseline orientation of Space VLBI provides the only means to an unambiguous picture of the dynamical evolution of the outburst ejecta from LSI $+61°303$. Knowledge of the expansion velocity and shape of this ejecta is a critical discriminant of the theoretical models. We propose to observe LSI $+61°303$ with the HALCA satellite in concert with an array of sensitive ground radio telescopes to map the dynamical evolution of a strong outburst. This will be done by using the rapidly changing earth-space baselines to obtain a sequence of several images, each with duration of a few hours, over the 48 hour rise time of a major outburst.

Technical Details

Previous VLBI observations indicate structure in LSI $+61°303$ on sub-milliarcsecond scales, along with unresolved components (figure 1). From these observations we expect correlated flux on the largest space-earth baselines of at least $\sim$30 mJy during the later stages of the outbursts, and probably much higher (of order 100 mJy) during the rise to peak flux. To detect fringes on these baselines requires a baseline sensitivity of $\sim$10 mJy. For a bandwidth of 16 MHz, a coherence time of 400 seconds and a system efficiency of 88 between HALCA and GRT's with SEFDs lower than $\sim$ 70 Jy. By using Phase-Cal tones to calibrate both the phase and group delays of the two 16 MHz HALCA observing bands we can relax the required GRT SEFD to $\sim$ 100 Jy. This implies a GRT array of phased-VLA, Green Bank, Usuda, Effelsberg, and Cambridge. In addition, we would like to include the Torun GRT for improved ground u-v coverage to better constrain the source model. Together with HALCA, this array gives good (u,v) coverage on time-scales of a few hours.

Recent analysis of the periodicities in the outburst timing and strength allow us to predict the time of the onset and the strength of outbursts with sufficient accuracy to effectively schedule the observations. Such a situation is unique to LSI $+61°303$. From this analysis we can predict that throughout 1999 LSI$+61°303$ will be the close to peak of the 4-year cycle (see figure 2); thus the source will be in a strong oubursting state for the entire year.

LSI$+61°303$ is circumpolar or nearly circumpolar for all the proposed GRT's, allowing us to observe continuously for a 48 period, and thus image the expansion of the outburst ejecta throughout the entire rise in flux. We have analysed the quality of (u,v) coverage obtained during 1999, and there are two periods when good tracking is available, and when the spacecraft constraints allow good continuous (u,v) coverage. The optimum period is during September 1999. The predicted dates of outburst during that month are $13^{\rm th}$ to $15^{\rm th}$. An allsky (u,v) coverage plot for a 24 hour period on 15 September 1999, is shown in figure 3. In the region of the source ($2.6^{\rm h}$, $+61°$) the (u,v) coverage is continuous and 2-dimensional. Although not quite as good, a second choice would be late January (18–20) or February (13–15) 1999.

References

Fichtel C.E., Bertsch D.L., Chiang J., et al., 1994, ApJS **94**, 551

Gregory P.C., Taylor A.R., Crampton D., et al., 1979, AJ **84**, 1030

Gregory P.C., Huang-Jian Xu, Backhouse C.J., Reid A., 1989, ApJ **339**, 1054

Hutchings, J.B., Crampton, D. 1981, PASP **93**, 486

Maraschi L., Treves A., 1981, MNRAS **194**, 18

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

Mendelson, H. and Mazeh, T., 1994, MNRAS **267**, 1

Paredes J.M., Marziani P., Martí J., et al., 1994, A&A **288**, 519

Paredes J.M., Martí J., Peracaula M., Ribó M., 1997, A&A **320**, L25

Paredes J.M., Massi M.., Estalella R., Peracaula M., 1998, A&A (in press)

Peracaula M., Gabuzda D.C., Taylor A.R., 1998, A&A **330**, 612

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

Taylor A.R., Kenny H.T., Spencer R.E., Tzioumis A., 1992, ApJ **395**, 268

Vestrand W.T., 1983, ApJ **271**, 304