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Apparent Relativistic Motion in Cygnus X-3

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Abstract. Weak and strong flaring has been observed at cm-wavelengths on Cygnus X-3. The weak flares seem to have different statistical properties to those of the strong flares. Previous observations have shown the ejection of radio emitting blobs at around 0.3c following major flares. However recent VLBA observations show apparent superluminal expansion and contraction during weak flaring.

1. Radio Jets in X-ray Binaries

A small number (~ 7) of the known radio emitting X-ray binary stars have been found to have jets (Fender et al. 1997). VLA, MERLIN and VLBI observations have shown velocities of knots in the jets to range from 0.26c (SS 433) to 0.9c (GRS1915+105 and GRO J1655−40), giving rise to pronounced superluminal effects in the latter cases. Expansion at 0.3c has been found in Cyg X-3 following strong (several Jy) flares (but see poster paper presented by Mioduszewski et al., these Proceedings, p. 351). Major flaring episodes on Cyg X-3 occur 1 to 2 times per year, last 2–3 weeks and are followed by long periods of quiescent emission at around 100 mJy. Also notable is the quenching episodes to levels of less than 20 mJy immediately before major flares (Waltman et al. 1996). This paper however concentrates on weak flaring (0.1–1 Jy) which occurs at times between the major flaring episodes.

2. Weak Flaring in Cyg X-3

Flux density data from the Green Bank (GBI) monitoring program (E. Waltman, priv. comm.), and the Jodrell Bank MERLIN and broad-band interferometer (BBI) were used (Spencer et al. , in prep.) to investigate the statistical properties of the flares over a range of flux densities. The first order structure function $\rho(\tau) = <(S(t) - S(t+\tau))^2>$ was formed for 6-month long sections of the GBI data and for daily runs with the MERLIN and BBI. Plots of $\log(\rho)$ vs. $log(\tau)$ have the general form of a noise floor followed by a rise to a plateau at large τ. The slope of the rising section is related to the slope of the power spectrum and can be used to characterize the data. In addition simple falling exponentials were fitted to flares, by identifying by eye the occurrence of a flare and then fitting for the decay time for each flare.

Plots of structure function slope and decay time vs. flux show that the lower flux density flares events (≤ 1 Jy) have narrower flares and less steep slopes as summarized in Table 1. Weaker flares vs. are thus dominated by shorter lived events and hence have spectral components at higher frequencies.

3. VLBA Observations

VLBA observations were made on 1995 May 7 at 15 GHz. Observations of Cyg X-3 were interlaced with frequent scans on 2005+403. Solutions from the

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Table 1. Flare properties vs Flux

RMS flux density (Jy)	Slope of structure function	Width to half flux (days)
< 0.5	0.92 ± 0.08	0.72 ± 0.12
$0.5 - < 1$	1.36 ± 0.19	1.34 ± 0.20
> 1	1.27 ± 0.14	1.82 ± 0.18

latter were extrapolated to those of Cyg X-3 in a pseudo-phase reference manner (Newell et al. 1997). The observations were proposed to take place during quiescence, however two weak flares (peak flux 0.3 Jy) occurred during the run, as revealed by total flux measurements with the GBI (at 2.3 and 8.3 GHz) and at 15 GHz with the Cambridge 5-km (Pooley, priv. comm.) The duration of each flare was $\sim$ 1 hour, and are therefore similar to the events described above. The VLBA data were split into 10 and 20 minute duration scans and a map made of each scan in order to facilitate imaging a highly variable source. The measured visibilities on the short (< 30 M λ) baselines were consistent with the total flux density.

Rather surprisingly the source was found to be unresolved (< 1 mas) in the inter-flare quiescent periods, and resolved ($\sim 2.2 \times 1.6$ mas) during the flares. The apparent size of the source thus changed rapidly. In fact there appears to be no transition period where the object grew or shrunk in size, as shown by both the maps and by inspection of the visibilities. Apparent expansion *and* contraction velocities for the major axis were found to be several c, exceeding 4.8c and 6.8c for the second flare. The quiescent compact component seems to be present at the center of the source at all times.

However the evidence is that an actual expansion is not taking place, but rather that an outburst occurs with the illumination of a surrounding nebula or shell. Certainly the data are not consistent with the ejection of radio knots in a jet in the usual way (Ogley et al. 1997). For example a gamma-ray burst from Cyg X-3 could give rise to an electron-positron cascade at a distance of around 1 light hour from the binary. This could then radiate via the synchrotron mechanism at radio wavelengths. Adiabatic and collision losses would then allow the shell to decay, revealing the compact quiescent component. Further VLBA observations have recently taken place to try to confirm these strange results.

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