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Correlated radio/X-ray behaviour of Cyg X-3*

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PoS(EXPReS09)018

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In order to test the recently proposed classification of the radio/X-ray states of the X-ray binary Cyg X-3, we present an analysis of the radio data available for the system at much higher spatial resolutions than used for defining the states. The radio data set consists of archival VLBA data at 5 and 15 GHz and new e-EVN data at 5 GHz. In the X-ray regime we use data that are quasi-simultaneous with radio, monitoring and pointed RXTE observations. We find that when the radio emission from both jet and core is globally considered, the behaviour of Cyg X-3 at milliarcsecond scales is consistent with that described at arcsecond scales. However, when the radio emission is disentangled in a core component and a jet component the situation changes. It becomes clear that in active states the radio emission from the jet is dominating that from the core. This shows that in these states the overall radio flux cannot be used as a direct tracer of the accretion state.

Science and Technology of Long Baseline Real-Time Interferometry:
The 8th International e-VLBI Workshop, EXPReS09
June 22 - 26 2009
Madrid, Spain

[*] An extended version of this paper was submitted to MNRAS.
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1. Introduction

Cygnus X-3 (Cyg X-3) is an exotic X-ray binary system (XRB) discovered in the X-ray band at the end of the 1960s. The nature of the compact object is unknown, circumstantial evidence existing for both a black hole and a neutron star. Strong evidence points toward a Wolf-Rayet star companion. The system is at a distance of 7–9 kpc and has an orbital period of 4.8 h.

In the radio band the system shows flares of different amplitudes, the strongest of them reaching up to a few tens of Jy at cm wavelengths (e.g. [9]). During these outbursts, Cyg X-3 reveals the presence of relativistic jets (e.g. [7, 6], with a complex structure that was clearly resolved on a few occasions [5, 3, 10]. Based on arcsec-scale radio observations [11, 12, 13] identified four distinct radio states of the system: quiescent (flux densities ~ 100 mJy), minor flaring (< 1 Jy), major flaring (> 1 Jy), and quenched (< 30 mJy).

Recently, based on the relationship between the radio and soft X-ray emissions, [8] have revisited the classification of the radio states proposed in [11, 12, 13], and identified six radio/X-ray states for Cyg X-3: quiescent, minor flaring, suppressed, quenched, major flaring, and post-flare (Fig. 1, upper left panel). In this study we aim to test the validity of the proposed classification scheme using high-resolution radio data.

2. Observations

We observed Cyg X-3 with the e-EVN at 5 GHz on five occasions, in 2007 Jun and 2008 Apr (Fig. 1). The data rate transfer was 256 Mbps for the run in 2007 and 512 Mbps for the rest. During the observations the target did not vary significantly in flux density with the exception of the run on 2007 Jun 25 when a smooth gradient was recorded during the first two hours. For future observations, we note that with proper planning, it is possible to trigger on the pre-flare quenched state to observe a major flare at high resolution right from the onset to the end. The e-VLBI technique, with its rapid turnaround time would then allow to optimize the response to such an outburst by modifying the observing strategy in real time as necessary to best track the development of the flare. Furthermore, it can offer the practical possibility to observe more ephemeral states (like perhaps the post-flare) in which the system spends only days to weeks.

In order to maximize the size of the sample to be used in the study we complemented the recent e-VLBI observations with archival VLBA and previous e-VLBI data. Whenever 5 GHz data were not available, we used 15 GHz observations.

In the X-ray domain we used RXTE ASM/PCA/HEXTE data taken quasi-simultaneously (i.e. within one day) with the radio observations. Following the methodology and nomenclature used in [8], the resulting absorbed X-ray spectra were classified according to their shape and flux at 20 keV.

3. Milliarcsecond behaviour

Fig. 1, upper right panel, shows the relation between the soft X-ray and radio emissions when both the contribution of the jet and core are taken into account in the radio band. In the same figure, in the bottom right panel, the contribution of the jet to the radio flux density has been

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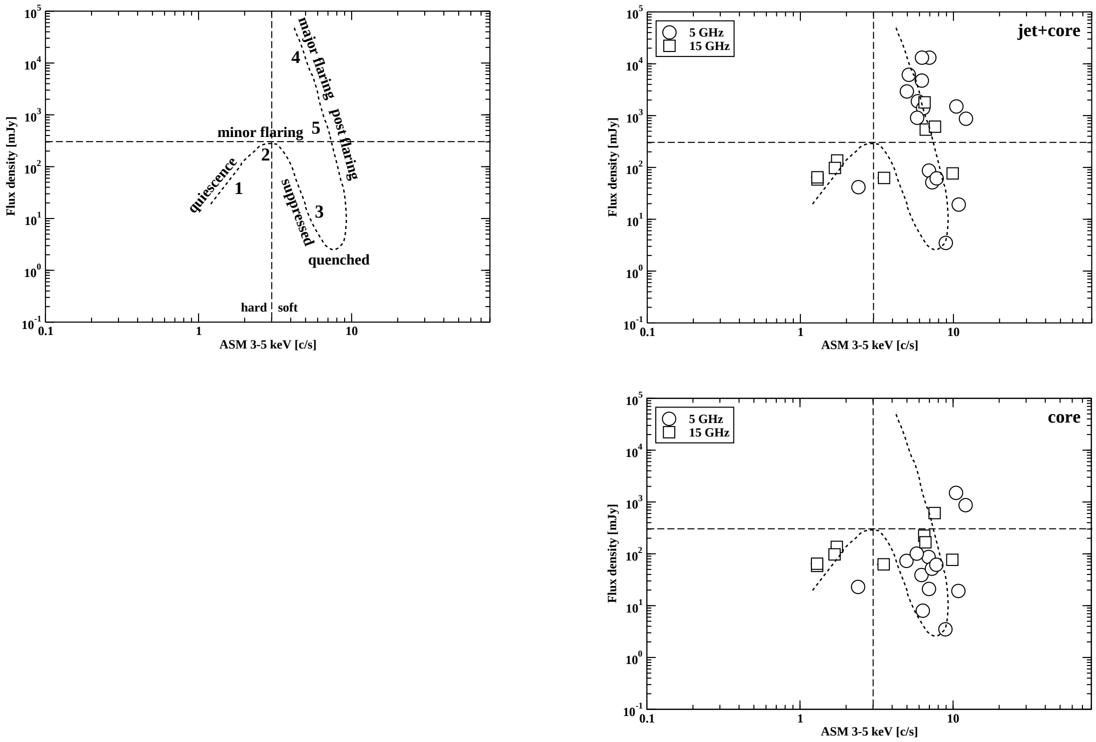

Figure 1: *Upper left*: The radio/X-ray states of Cyg X-3 as proposed by [8]. The numbers correspond to the X-ray spectral group. The transition levels at 3 counts s^{-1} and 300 mJy are chosen to coincide with those used in [8]. The curved dashed line is a guide for the eye and mirrors the trend found by [8]. *Upper right*: Quasi-simultaneous radio/X-ray emission of Cyg X-3 when the radio emission of core and jet are both considered. *Bottom right*: The same as upper right panel, but this time only the radio emission from the core of the system is taken into account.

removed. The superimposed dashed lines should be taken as guides for the eye and reflect the model of the radio/X-ray states of Cyg X-3 as proposed by [8]. With respect to Fig. 1, upper right panel, acknowledging the small number of observations, the mas scale behaviour of Cyg X-3 does seem consistent with the arcsec scale one reported by [8], at least from the point of view of the overall distribution of points and the normalization.

When the radio emission originating in the jet is removed we obtain the plot represented in Fig. 1, bottom right panel. The trend in the distribution of the points observed at mas scale in Fig. 1 upper right panel is lost. Basically what happens is that the data in Fig. 1 corresponding to the major flare/post-flare states, in which the jet emission is dominant, are shifted towards lower radio flux densities thus blurring the classification of the states, roughly speaking, beyond and below the ad-hoc X-ray and respectively radio transition levels. While these states may be able to be classified via their X-ray spectra, the radio emission cannot be used as a diagnostic here. The important conclusion is that since in active states most of the radio emission is not coming from the core then during the outbursts the overall radio flux is not a direct tracer of the accretion state. However, when the overall radio emission is considered we do observe an anti-correlation/trend between the radio and X-ray emissions in the flare/post-flare states (Fig. 1, upper right). A possible explanation can be articulated by invoking the shock-in-jet model which was successfully applied to the light curves of Cyg X-3 [4] and the truncated disc model of the X-ray states [1]. In the soft X-ray states the innermost region of the accretion disk is relatively close to the compact object and slowly recedes further away as the outburst proceeds. As the disc gets colder the level of the soft X-rays is decreasing, while the corona starts to build up leading to an increase in the hard X-rays. Therefore stronger radio flares, which tend to peak at later times, will be associated with states in which the accretion disc is truncated further away from the compact object, where the soft X-ray levels are lower and the hard X-ray levels are higher.

4. Conclusions

It was found that the behaviour of Cyg X-3 at mas scales, as probed here, is well described by the radio/X-ray classification scheme proposed by [8] based on arcsec scale radio observations, when the whole contribution of the system to the radio flux density is taken into account (i.e. radio emission from both jet and core).

However, when the contribution of the jet to the total radio flux density is removed, and therefore only the radio emission corresponding to the core is considered, the situation changes significantly. What is obvious is that when Cyg X-3 is in an active state (for sure during the major flaring and most of the post-flaring states) the observed radio flux density at cm wavelengths is dominated by the emission from the jet. Hence the data imply that during these states there is no unambigous connection between the accretion state and the total radio emission.

Acknowledgments

EVN is a joint facility of European, Chinese, South African and other radio astronomy institutes funded by their national research councils. e-VLBI developments in Europe are supported by the EC DG-INFSO funded Communication Network Developments project "EXPReS", Contract No. 02662. NRAO is a facility of the NSF operated under cooperative agreement by Associated Universities, Inc. The X-ray data were provided by the ASM/RXTE teams at MIT and at the RXTE SOF and GOF at NASA's GSFC. AS is supported by the European Community via contract ERC-StG-200911.

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