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SHORT-TERM RADIO VARIABILITY OF CYGNUS X-1

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In this note we report high time resolution radio photometry of the high mass X-ray binary and classical black hole candidate Cygnus X-1. The results presented here are a by-product of an observational program carried out several years ago. At that time, our primary goal was to obtain high sensitivity images of the extended radio emission around Cygnus X-1 (Martí et al. 1997). In addition to these results, the observed data can provide a radio light curve of Cygnus X-1 with time resolution of a few minutes and extending for several hours. The short-term variability of Cygnus X-1 remains practically unexplored at radio wavelengths. Therefore, we are confident that the data presented in this note will help improve this situation.

The radio counterpart of Cygnus X-1 was originally discovered by Tananbaum et al. (1972) and Hjellming (1973). At centimetric wavelengths, this source has a rather stable radio emission at the 10–20 mJy level with a very flat spectral index (Fender et al. 2000). The radio luminosity of the system displays a $\sim$ 30% amplitude modulation with the orbital period of 5.6 d, together with a long-term modulation on time scales of 150 d (Pooley et al. 1999). Here we study the Cygnus X-1 radio light curve with time resolution much higher than in most previous studies.

Our observations were carried out on 1996 April 11 (JD 2450185) with the interferometer Very Large Array (VLA) of the National Radio Astronomy Observatory (NRAO) in New Mexico (USA). The array had its 27 antennas in its C configuration and operated at the wavelength of $\lambda = 6$ cm. In this configuration, the longest baselines extend over 3.4 km equivalent to 57 kλ thus providing an angular resolution of about $4''$. The data were processed using the AIPS package of NRAO following the common procedures for connected radio interferometry. The amplitudes of the visibilities were calibrated by observing 1331+305 for a few minutes at the beginning of the run. The adopted flux density at 6 cm of this VLA primary calibrator is close to 7.5 Jy. We also observed the unresolved source 2007+404, before and after each of the Cygnus X-1 scans, to be used as the phase calibrator. Cygnus X-1 was found to be bright enough to self-calibrate its visibility data in phase using a simple point source model. This step allows us to get rid of most atmospheric phase instabilities. Our final radio light curve has been produced using the AIPS task DFTPL applied on the self-calibrated data. This task performs the

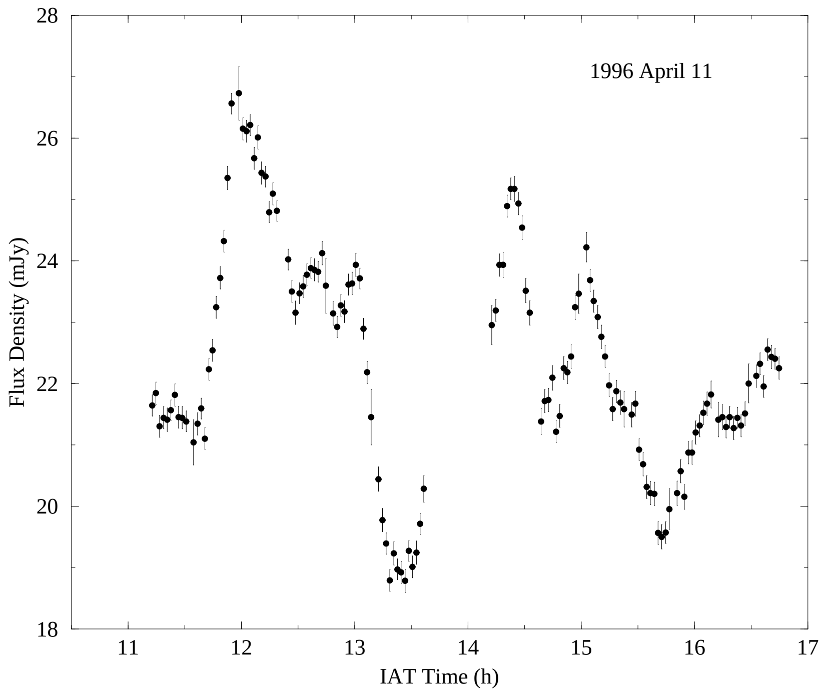

Figure 1. Radio light curve of Cygnus X-1 at the wavelength of 6 cm on 11 April 1996. The data points have been averaged every 120 s. The source has a variability amplitude of $\sim 30\%$ on time scales of one hour. The horizontal axis is labelled in International Atomic Time (IAT) whose difference with Universal Time in 1996 was close to 30 s

direct Fourier transform of the measured visibilities as a function of time for an arbitrary point in the sky, i.e., the Cygnus X-1 position in our case. This Fourier transform is a real quantity that gives the flux density of any point source at that point. No significant nearby confusing sources were present in the array field of view, that is limited by the beam of the individual antennas (FWHM $\sim 10'$). In fact, Cygnus X-1 was the brightest source in the field of view.

In Fig. 1, we present the final radio light curve of Cygnus X-1 for several hours in 11 April 1996. The radio emission of the system is clearly variable with several radio flares in time scales of hours. The variability amplitude observed is close to $\sim 30\%$. This is remarkably similar to that exhibited by Cygnus X-1 during its X-ray flares, which often last from hours to days. The only X-ray coverage of Cygnus X-1 simultaneous with our radio data is that provided by the All Sky Monitor (ASM) on board the Rossi X-ray Timing Explorer satellite posted on the web. Unfortunately, the ASM fluxes are too scarce to check if there is any correlation or anti-correlation between radio and X-ray variability at this time resolution.

The plot in Fig. 1 also suggests a possible recurrence period of the radio flares close to 1 h. These flaring events are also reminiscent of the radio and infrared oscillations observed in the microquasar GRS 1915+105 (see e.g. Mirabel et al. 1998). These events are interpreted in terms of repeated ejections of pairs of relativistic synchrotron emitting plasmons every half an hour or so. It is thus very likely that we are seeing the same phenomenon in Cygnus X-1. The rise time of an individual flare is about 20 minutes with an amplitude of ~ 5 mJy. From light travel time arguments, this implies an upper limit of 3.6×10^{13} cm (2.4 AU) for the size of the radio emitting region. At a distance of 2.5 kpc and assuming a flat spectral index, the corresponding brightness temperature is $\geq 4 \times 10^8$ K, i.e., consistent with non-thermal synchrotron emission. Further concurrent radio and X-ray observations with high time resolution are required to better clarify the tentative suggestions of this paper. The hypothesis of repeated ejection of synchrotron plasmons will be tested in the future, when the very sensitive Expanded Very Large Array (EVLA) becomes available.

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