JET RADIO EMISSION IN CYGNUS X-1 AND ITS ORBITAL MODULATION

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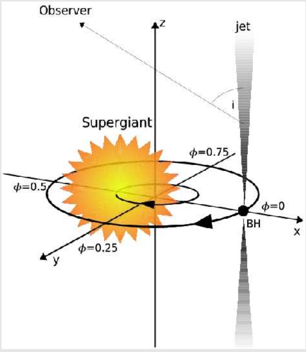
ABSTRACT

We present a revised wind absorption model to explain orbital modulation present in the jet radio emission of Cygnus X-1. Our model successfully explains the presence and characteristics of the radio orbital modulation in Cyg X-1. The jet in the model is curved, owing to assumed geometry we could obtain more modulation for extended emission profiles and a frequency dependent phase shift. We have tested different jet emission profiles among which the double-power-law profile was in agreement both with theoretical models and observations. Our results are consistent with the scenario according to which, jet in Cyg X-1 has double structure composed of the non-relativistic dark outer layer and a mildly relativistic inner spine. The outer jet is our candidate for the dark jet that powers the ISM shell around Cyg X-1. Our model also successfully explained the lack of radio orbital modulation in Cyg X-3.

INTRODUCTION



A schematic representation of Cygnus X-1 in the phase ϕ = 0. The center of mass is located inside the secondary.

- Cyg X-1 is a high-mass X-ray binary with the orbital period of 5.6 d, containing a black hole and the O9.7 Iab supergiant.
- The radio emission of Cyg X-1 is due to the synchrotron process in a relativistic jet moving with a velocity of ~0.6c (Stirling et al. 2001). It has a flat spectrum at 10-20 mJy in the hard spectral state.

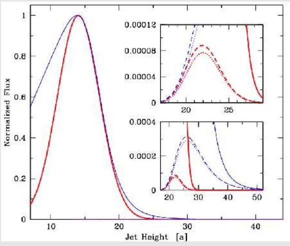
Observed values of modulation depth (MD) and phase shift (PS)

	15GHz	8.3GHz	2.25GHz
MD	0.304±0.029	0.138±0.039	0.045±0.044
PS	0.153±0.035	0.176±0.056	0.316±0.155

OBJECTIVES

- Examine the radio modulation produced by the jet motion in the wind for different inclination angles and wind and jet parameters.
- Explain why the modulation depth and time lag of the minimum with respect to the superior conjunction depend on frequency

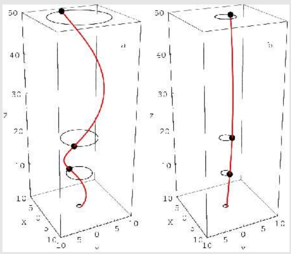
MODEL



Example of the double-power-law profile (thick blue solid curve) in comparison with the Gaussian profile (thick red solid curve). The transmitted profiles at 8.3 GHz from ϕ=0 (dotted curves) and ϕ =0.5 (dashed curves) are heavily absorbed and are shown in the two insets. (a - orbital separation)

- We constructed a phenomenological jet model that includes the jet geometry and emission profile.
- The radio emission is absorbed via free-free mechanism in the completely ionized wind of the companion star
- Because of the relatively low initial velocity and acceleration the jet is slow and lags behind the black hole
- The emission at a given frequency along the jet has a double-power-law profile.
- High frequency emission profiles are located lower on the jet than the low frequency profiles.
- The wind absorption model is based on the model presented in the paper by Brocksopp, Fender & Pooley (2002)

RESULTS



The geometry of the jet for low and a high acceleration a) 5 x 10^2 cm s^{-2}, b) 5 x 10^3 cm s^{-2}. The black hole orbit is shown in the XY plane, and three circles above it show the jet orbit at the height of z = 10, 20 and 50 a.

- The model reproduces an orbital modulation in radio light curves, when the jet travels in the wind of the secondary star
- The frequency dependent distribution of profiles along the jet produces the differences in modulation depth
- The jet curvature introduces the time delay in light curves
- Our estimates of the jet velocity and its acceleration, required to obtain proper jet curvature are ~3.4-9x10^8 cm/s and ~4-6x10^3 cm/s^2 respectively, for inclination angle in the range 30°-60°.
- At face value there is a contradiction between the observed jet velocity, and velocity and acceleration obtained in our model.
- The contradiction disappears when instead of one outflow there are two.

CONCLUSIONS

Jet in Cyg X-1 is in the form of two flows of different particles.

- Non-relativistic dark jet, composed of electrons and protons, emitted by a MHD mechanism of a magnetic field anchored in an accretion disc. It gives the main contribution to the energy budget. In AGNs the flow is related to the large jet observed on kiloparsec-scales that fuels the radio lobes and hotspots.
- A beam of relativistic particles, produced in the inner regions of the MHD flow. Particles carry only small fraction of total energy. The inner flow is believed to be responsible for the VLBA AGN paresc-scale jets and for the observed superluminal motion.
- The outer MHD jet confines and heats the inner plasma.
- Outer curved flow is the candidate for the dark jet which *may* dominate the power output of the stellar black hole in Cyg X-1 (Gallo et al. 2005)
- The two flow model for microquasars has been introduced by Ferreira et al. (2006). It is based on the two-flow model for extragalactic radio jets proposed in the late 80's by Sol, Pelltier & Asséo (1989).

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