SS 433 AS A MAGNETIC X-RAY BINARY

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ABSTRACT

In this paper we expand upon a proposed model for SS 433. Specific attention is given to the manner in which the light travel time within the system places constraints upon the geometrical parameters defining the system. Consideration is also given to the physical situation which exists in the high Doppler shift emitting region. Implications of recent observations of "a 13-day" period spectral and light variability upon the central source are briefly discussed.

Since the announcement by Margon et al. (1979a) that the anomalous lines in the spectrum of SS 433 could be interpreted as highly Doppler shifted Balmer and Neutral Hydrogen lines, this object has received a remarkable amount of attention. Previous to this announcement, it had been listed by Stephenson and Sanduleak (1977), and had been noted by Seaquist et al. (1978) as a radio source, Marshall et al. (1978) as an X-ray source and Clark and Murdin (1978) as positionally coincident with the supernova remnant W50. Margon et al. (1979b) have placed the object at a distance in excess of 3.5 kpc while Liebert et al. (1979) have measured the absolute fluxes of various components of the spectra. Abell and Margon (1979) have fit the periodic behavior of the highly Doppler-shifted line spectrum with a kinematic model having a period of about 164d, an orbital inclination of either 17° or 78° and possessing radial beams inclined to the rotation axis of the orbit by either 78° or 17°. Collins and Newsom (1979) have shown that all these data are consistent with the picture of a magnetically accelerated stellar wind arising in the primary of an X-ray binary. Their model suggests that the beams arise when the magnetically accelerated particles pass through the region of cool gas and perhaps dust located in the orbital plane of the system beyond the Stromgren sphere of the X-ray binary (see fig. 1). In this paper we shall note some of the further implications of the model.

Since the orientation of the beam with respect to the radius vector will depend on the complicated hydromagnetic interaction of the beam with the cool gas, we have let the orientation β (see fig. 2) be arbitrary within the range $-\pi/2 < \beta < \pi/2$. The radial

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velocity then becomes

$$v_r = v[\sin(\alpha+\beta)(\cos\theta \cos\phi \sin i + \sin\theta \cos i) + \cos(\alpha+\beta) \sin\phi \sin i] \quad (1)$$

where ϕ = o occurs when the intersection of the magnetic and orbital

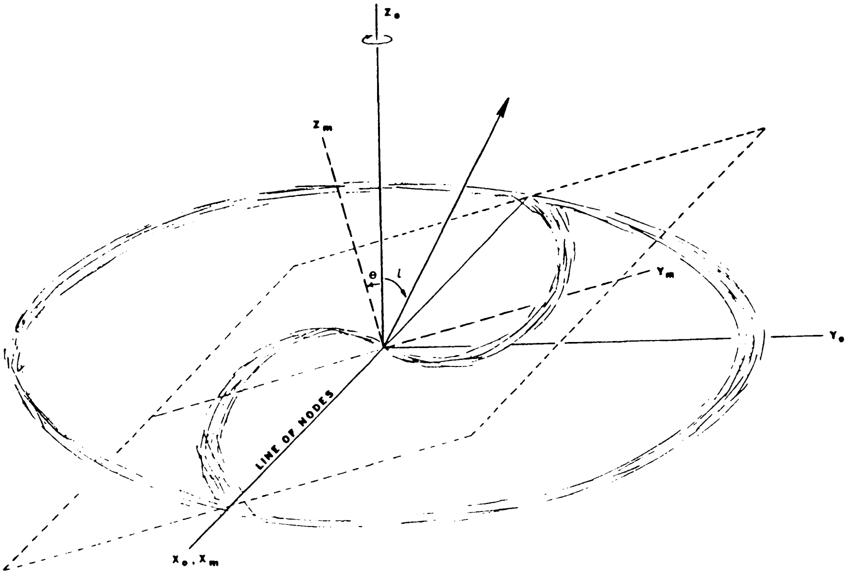

Fig. 1. Particle Beams Accelerated From X-Ray Binary Encounter Gas Disk at the Intersection of Magnetic and Orbital Planes.

planes is in the plane of the sky. In the disk model the beams will be produced at the nodes and hence $\alpha = 0$. It is clear from eq. 1 that in the Abell-Margon model ($\beta = 0$, $\alpha = \pi/2$) an ambiguity in i and θ exists as equation 1 is invariant under the transformation [$i = \pi/2 - \theta$, $\theta = \pi/2 - i$] (Note: our θ is the complement of Abell and Margon's angle). For a wide range of β limited by possible values of θ (i.e. $12° < |\beta| < 90°$, $\alpha = 0$), only $i = 17°$ will preserve the observed amplitude and phase difference between the maximum and first crossing point. Indeed only a combination of $|\alpha+\beta| = \pi/2$ produces the ambiguity in θ and i.

Because the beams occur at a large distance from the central binary in this model, a substantial light travel time effect exists. This causes the beams to display equal radial velocities at a time slightly later than when their motion is across the line of sight. Thus a net positive redshift with respect to the average of the extreme should occur at the crossing point. In the case where $\alpha = 0$, this addition shift is given by

$$\Delta Z = -\frac{4\pi}{P}\left(\frac{v\gamma}{Rc^2}\right) \sin^2 i \sin\phi_c \, [\cos\beta \cos\phi_c - \sin\beta \cos\theta \sin\phi_c] \quad (2)$$

where ϕ_c is the value of the phase at the first crossing after maximum, P is the beam period, $\gamma = (1-v^2/c^2)^{-1/2}$ and R is the radial

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distance from the binary to the point of beam emission. Since the crossing points are symmetrically placed about $\phi=\pi$, the measured values of the redshift increments ΔZ at the two crossing points provide sufficient information to specify β and R. Thus measurement of these values is of the utmost importance, although the day to day "flickering" in radial velocity will require that a mean curve be derived from several cycles. The specification of these parameters places significant constraints on the physical situation in the beam-radiating region.

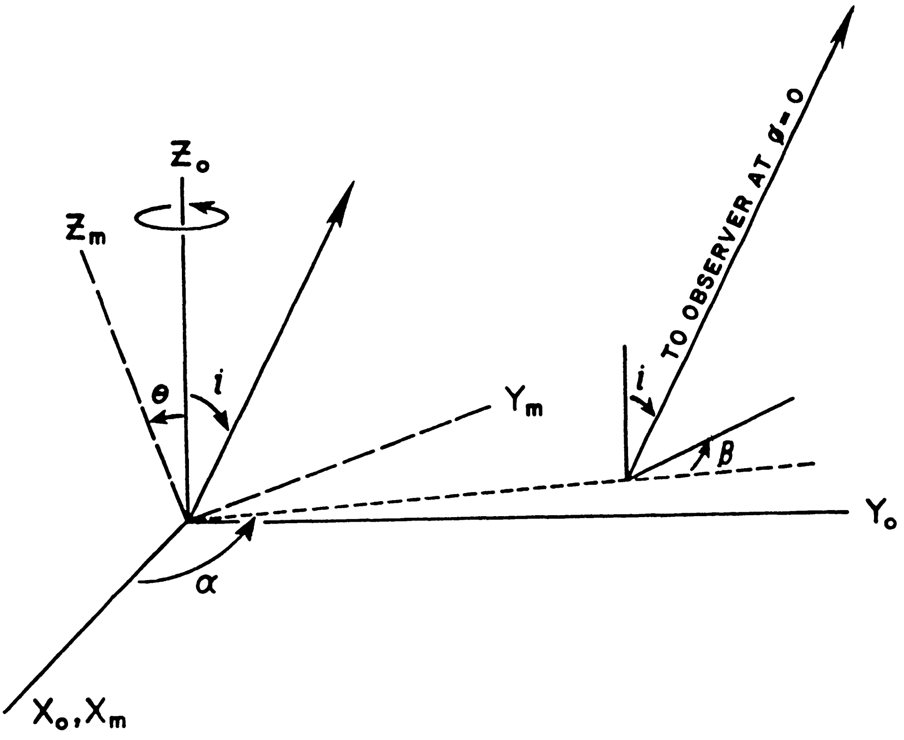

Fig. 2. Coordinate Frame for X-Ray Binary Model

Before passing to considerations of the nature of the central binary source itself, it is worth describing conditions in the beam. Several authors (e.g. Liebert et al. 1979) have concluded that the atoms radiating in the beam have a velocity of about 80,000 km/sec. This, combined with the daily variation and implied maximum recombination time, present a picture of a 33 Mev proton beam incident on a cool gas with a density of at least 10^8 particles/cc. Although collisionally produced electrons will pass through a speed resonance with the beam protons producing a recombination spectrum in the moving frame, the bulk of the line spectrum appears to be formed via a charge exchange reaction with atomic hydrogen. Each incoming 33 Mev proton undergoes about 10^4-10^5 radiative captures during its lifetime

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in the disk. Thus with plausible values for the mass outflow (i.e. about $10^{-8} M_\odot$/yr) it is possible to match the observed line intensities. A more detailed treatment of the beam physics is presently being completed.

Lastly we must make certain that the physical situation required by the beam does not present an impossible situation for the central binary. Plausible beam densities (Collins et al. 1980) and the known particle energies imply a magnetic field of about a gauss at the point where the beam reaches its maximal energy. Collins and Newsom (1979) show that this places minimal constraints upon the stellar mass of the primary required to contain the field. We originally suggested that the beam motion was driven by the orbital motion of the binary system itself but were rather concerned that the 160 day period was vastly longer than that of any known X-ray binary. Recent observations by Crampton et al. (1979) of a 13 day spectroscopic variation of the unshifted Hα component and apparent confirmation of a similar photometric light variation (Kemp and Arbabi 1979) would seem to rule out orbital motion as the direct driving force. Using an inclination of 17° and the mass function of Crampton et al. (1979), a very approximate calculation indicates that a magnetically distorted sychronously rotating primary would precess with a period of about 1/2 year. In this case the orbital motion would still be the ultimate source of the beam energy, but it would be supplied via the precession. Further work is in progress to strengthen the quantitative aspects of this argument.

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DISCUSSION FOLLOWING COLLINS, NEWSOM AND BOYD

Massey: How do you reconcile your model with the wealth of other observed properties--the unshiften emission lines, for example?

Collins: Only time has constrained me from dealing with the additional observed properties, all of which to date do not appear to be in conflict with this picture. For instance, much of the unshifted emission spectrum arises from the quiscent material in the disk which has been ionized by the beam. However we do not rule out the possibility than a component may arise within the central binary system inself since such a spectrum is not uncommon in other X-ray binaries.

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