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Test of SS 433 Models

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We present an observational test to distinguish between two alternative SS 433 models.

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1. INTRODUCTION

Among the competing models (Fabian and Rees, 1979; Milgrom, 1979; Cohen and Struble, 1980) for SS 433, there are two which involve a rotating neutron star. (Of special interest here, such an object is characterized by superstrong magnetic fields $B \approx 10^{12}$ G at its poles.) One model (Abell and Margon, 1979) involves relativistic jets of collimated material ejected from the polar regions with speed $V \approx 0.27c$. The other involves collimated high-velocity material falling toward the polar regions of the star. Both theories give red- and blue-shifted spectral lines which vary sinusoidally with a 164-day period (Abell and Margon, 1979). Both theories attribute this period to that of a rotating neutron star [in a binary system with an orbital period of 13.1 days (Abell and Margon, 1979; Margon, 1980).

With the outgoing model, the spectral line shifts are attributed to the Doppler effect, with the blue-shifted lines emanating from jet material moving toward the observer and away from the magnetic pole, while the source of the red-shifted lines is material moving away from the observer and away from the opposite magnetic pole. No generally accepted collimation or acceleration mechanism is identified with this model.

With the infalling model (Cohen and Struble, 1980) the radiating material is collimated by the neutron star's converging magnetic field lines and is accelerated by its gravitational field (accretion from its binary companion).

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If B is negligible ($B \ll 10^{12}$ G), the spectral line shifts are due to both gravitational red-shifts and to the Doppler effect. Unfortunately, this difference in red- and blue-shift mechanisms does not give a clear observational basis for distinguishing between the two models. The infall model (Cohen and Struble, 1980) gives a gravitational line broadening because component parts of the radiating source region have different gravitational potentials (Cohen and Struble, n.d., summarized in Margon, 1981, 1984; Aller, 1963).

On the other hand, VLA radio observations have suggested outwardly moving blobs of material (Margon, 1981). At this time, however, there is no clear correlation between such radio emission and the 164-day and 13.1-day periods associated with the optical line emission.

One of the important differences between the two models is that the radiating material in the case of the incoming model is in a radiative source region in the superstrong magnetic field domain ($B \approx 10^{12}$ G) (Cohen and Kuharetz, 1992; Cohen *et al.*, 1988). With the outgoing model the magnetic field strength in the radiative source region is relatively low ($B \ll 10^{12}$ G). We exploit this difference to give a possible observational test to distinguish between the two models.

2. RED AND BLUE SHIFTS

To obtain an observational test of the two models, i.e., the infalling and outgoing jet models, we note (for a given atom) that the red- and blue-shift frequency ratio ν_2/ν_1 is independent of the particular (unshifted) spectral line which is examined. As noted previously, the spectral line shifts can be obtained from (Cohen and Struble, 1980; Schrödinger, 1956)

$$\frac{\nu_2}{\nu_1} = \frac{k_u}{k_r} \frac{U^u|_2}{U_v|_1} = \frac{\lambda_1}{\lambda_2} \tag{1}$$

where k_u is the wave vector of the radiation and U^u is the velocity vector of the observer or emitting region.

It is convenient to take the average of the red- and blue-shifted spectral values at any time, since this is essentially constant, independent of the point in time within the 164-day cycle of SS 433; i.e.,

$$\frac{\lambda_+ + \lambda_-}{2\lambda_e} = U_e^0 \tag{2}$$

which follows from equation (1). Here λ_+ is the red-shifted and λ_- is the blue-shifted wavelength, λ_e is the emitted wavelength from the source region, and U_e^0 is the timelike component of the source region four-velocity. Here,

λ_+ and λ_- can be obtained from simultaneous observations of the red- and blue-shifted radiation.

We note that the spectral lines are also shifted due to the magnetic field. The relative magnetic shifts can be different for different spectral lines. This difference is most evident if such spectral lines are in different spectral series. (The hydrogen spectrum will be considered here.)

In particular, an estimate of the ratio of the emitted wavelength λ' (in the presence of the superstrong magnetic field) and the emitted wavelength λ (in the absence of the magnetic field) is given by

$$\frac{\nu'}{\nu}=\frac{\lambda}{\lambda'}=1-\frac{\frac{4}{3}(x^2/n)(1-n^3/m^3)}{1-n^2/m^2} \tag{3}$$

where

$$x^2=(0.0487)^2(10^{12}/B) \tag{4}$$

$x=a/a_0$, $a=(\hbar c/eB)^{1/2}$ is the electron cyclotron radius, $a_0=0.528$ Å is the Bohr radius, m corresponds to the initial quantum state and n to the final quantum state (which determines the spectral series), and B is in Gauss.

Equation (3) is obtained by combining the following equations:

$$E_n=\frac{\text{const}}{n^2}; \qquad E'_n=E_n+\Delta E_n \tag{5}$$

$$\frac{\nu'}{\nu}=\frac{E'_n-E'_m}{E_n-E_m} \tag{6}$$

and (Cohen and Kuharetz, 1992; Cohen *et al.*, 1988)

$$\frac{\Delta E_n}{|E_n|}=\frac{4}{3}\frac{x^2}{n} \tag{7}$$

Here the primed terms denote quantities in the presence of a superstrong magnetic field B of the order of 10^{12} G.

Table I shows the order of magnitude of the wavelength shifts expected based on the ratio

$$\left(\frac{\lambda'}{\lambda}\right)_{nm}=R_{nm} \tag{8}$$

for spectral transitions from the m to the n states.

Table I. Wavelength Ratio R_{nm} for Transitions in Hydrogen in Superstrong Magnetic Fields, $B \approx 10^{12}$ G, Compared to Zero Field

Lyman	Balmer	Paschen
$R_{12} = 1.0037$	—	—
$R_{13} = 1.0034$	$R_{23} = 1.0020$	—
$R_{14} = 1.0033$	$R_{24} = 1.0018$	$R_{34} = 1.0014$
$R_{15} = 1.0033$	$R_{25} = 1.0018$	$R_{35} = 1.0013$
$R_{16} = 1.0032$	$R_{26} = 1.0017$	$R_{36} = 1.0012$

Examples of the order of magnitude of the wavelength shift $\Delta\lambda$ to be expected based on the R_{nm} values in Table I for spectral lines in the Lyman, Balmer, and Paschen series are as follows (Semat and Albright (1972), p. 226):

Lyman:

$$\Delta\lambda_{12} = (R_{12} - 1)(1215.68) = 4.5\ \text{Å}$$

$$\Delta\lambda_{13} = (R_{13} - 1)(1025.83) = 3.5\ \text{Å}$$

Balmer:

$$\Delta\lambda_{23} = (R_{23} - 1)(6562.79) = 13.1\ \text{Å}$$

$$\Delta\lambda_{24} = (R_{24} - 1(4861.33) = 8.8\ \text{Å}$$

Paschen:

$$\Delta\lambda_{34} = (R_{34} - 1)(18{,}751.1) = 26\ \text{Å}$$

$$\Delta\lambda_{35} = (R_{35} - 1)(12{,}818.1) = 15\ \text{Å}$$

3. CONCLUSION

A possible test to distinguish between the two models for SS 433 (the outgoing versus the infalling model) is to examine the ratio R_{nm} of the shifted wavelength λ' to the unshifted wavelength λ for each hydrogen spectral line. If this ratio is not constant, it would be consistent only with the infall model (i.e., in the superstrong magnetic field domain considered here). If the ratio R_{nm} is the same for each spectral line, then the test cannot distinguish between the two models. Such observational tests are presently being explored.

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