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Hydrogen Spectrum of SS433 System

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We propose that the hydrogen spectrum in intense magnetic fields will help clarify the mechanisms which govern the SS433 system. In ultra high magnetic fields the standard hydrogen spectrum is superimposed on the Landau levels. There is, however, one deep-lying level in hydrogen at an energy of 50 eV to greater than 200 eV, depending on the magnetic field strength typical of neutron stars in x-ray binaries. When this level manifests itself it will give an indication of the magnetic field strength at the location of the radiating material; it could thus support the infall model SS433.

1. INTRODUCTION

The SS433 system of neutron star and its companion has a binary period of about 13 days. What makes this system so unusual is that it displays simultaneously blue- and red-shifted hydrogen spectra; moreover, the blue- and red-shifted spectra cross over and merge into each other at a regular rate, i.e., the blue-shifted spectrum becomes red-shifted and vice versa, the whole pattern repeating itself every 164 days. These features have attracted considerable attention. The spectral lines are quite narrow, indicating that the material which is the source of the light is well-collimated. The amount of red blueshifting also indicates that speeds up to $0.26c$ are attained (Abell and Margon, 1979).

Most models of SS433 (Millgrom, 1981; Margon, 1983) propose that material is expelled from the magnetic poles of the neutron star of SS433 and subsequently radiates. To account for the observed intensities the radiating material must extend over a considerable region and then must be quite far from the neutron star.

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Cohen and Struble (1980, 1982), on the other hand, suggest that material infalls onto the neutron star from its companion. Accelerating under the gravitational influence of the neutron star, this material will reach a speed of $0.26c$ at approximately 100 km above the star. The hydrogen and other material comes in along the magnetic field lines and is collimated or focused as the lines converge. In this picture the observed intensities could be due to a lasing action of the nebula surrounding the binary system.

Both the incoming and outgoing models can account for alternating blue- and red-shifted spectra due to the motion of material along the polar axes as the neutron star rotates or precesses. The infall model has the advantage of an obvious acceleration mechanism and has well-collimated material.

As the hydrogen approaches the magnetoplane of the neutron star, it will experience increasingly intense magnetic fields. At 100 km above the star where the speed of the material should have reached about $0.26c$, the fields should be 10^{10} G or more.

2. HYDROGEN ATOMS IN INTENSE MAGNETIC FIELD

The wave functions of hydrogen atoms in intense magnetic fields become highly distorted along the field direction. As the field strength increases, the cyclotron radius becomes much smaller than the Bohr radius a_0, and the wave function of the atom takes on a pencil shape with the axis along the field direction (Landau and Lifshitz, 1977; Rau and Spruch, 1976; Haines and Roberts, 1969). The cyclotron radius $\rho_c = ch/eB$ is related to the Bohr radius and the magnetic field B measured in gauss by (Rau and Spruch, 1976)

$$\rho_c = a_0(B/2.35E9)^{-1/2}$$

At very high fields, e.g., 2.35×10^{12} G, the ratio of Bohr radius to cyclotron radius squared is 1000. The Coulomb force becomes irrelevant for binding transverse to the magnetic field; it serves to bind the electron to the nucleus along the field direction. In other words, the Coulomb force becomes approximately one-dimensional.

To the extent that $\rho_c \ll a_0$, one can replace $1/r$ in the Coulomb potential with $1/z$ and the resulting spectrum from the z dimension then just consists of the standard hydrogen levels. These levels are superimposed on the Landau levels, which are obtained from the other two dimensions. The curious result is that the high-field result has the same lines as the zero-field result; in this approximation (Landau and Lifshitz, 1977)

$$E_n = -me^4/2h^2n^2$$

The Coulomb denominator is more accurately represented as $1/(z+\rho_m)$, where ρ_m is some small distance corresponding to the cyclotron radius. In this case, although the higher levels are very close to the standard hydrogen levels, there is one very deep-lying level which differs from the standard ones (Landau and Lifshitz, 1977)

$$E_0 = -\frac{2me^4}{h^2}\log^2\left(\frac{a_0}{a_H}\right) = \frac{-me^4}{2h^2}\log^2\left(\frac{h^3 B}{m^2 c|e|^3}\right)$$

where

$$a_H = (h/mw_H)^{1/2}, \qquad w_H = |e|B/mc$$

It has been extensively studied in the variational approximation (Rau and Spruch, 1976). The energy of this level ranges from 50 eV at 10^{10} G to 200 eV at 10^{12} G and gets deeper yet at higher magnetic field strengths.

If this level were measured, say as a transition from a higher energy level, useful information about the magnetic field at the location of the radiating material would be obtained. The model of Cohen and Struble (1980, 1982) predicts that the radiating material should be well within the magnetosphere. A search for this predicted deep-lying level in the soft x-ray region of SS433 may help in deciding between different models of this system.

3. DISCUSSION

Both the infall and outflow models of SS433 can produce a hydrogen spectrum. At first sight, one might think that the infall model would yield a spectrum modified by strong magnetic fields, while the outflow model would yield a normal hydrogen spectrum because radiation is emitted far from the star where the fields are weak.

In this communication we have shown that hydrogen atoms in an ultrastrong magnetic field can produce the same energy levels and corresponding line spectrum as in zero magnetic field limit. Besides this, there arises an additional low-lying level in the strong-field case. Transitions to this level might be observed in the soft x-ray region (50–200 eV) and would support the infall model. If it is not seen, then the observed spectrum is consistent with both models.

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