NUTATIONAL EFFECTS IN SS 433*

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Abstract. The nutation effects of an accreting disk around SS 433 are analyzed within the framework of the fully relativistic model of Fang and Ruffini.

1. Introduction

The theoretical interpretation of the shifts in the moving lines of SS 433 ((Mammano *et al.*, 1980; Margon *et al.*, 1980), presenting large asymmetries between the blue (λ_{-}) and the redshifted lines (λ_{+}) with respect to the lines at rest give the SS 433 is a relativistic system which has a periodic change in moving lines.

In order to explain the observed shifts in Hα, Hβ, etc. lines, at least two basic geometries have advanced (Milgram, 1979): in one (the 'twin jet' model), the emission comes from two highly collimated beams moving at a speed $v/c \simeq 0.25$ away from a central source, in the other (the 'ring' model), the emission occurs from two opposite points of a ring orbiting a gravitationally collapsed object at a radius of $\sim 45M$ (Fang and Ruffini, 1979; Ruffini and Stella, 1980a). And the possible processes of stimulated emission in the ring model have been considered at work in SS 433 (Ruffini and Stella, 1980b).

In the ring model the modulations in the amplitude of the shifted lines with a period of $\sim 164^{d}$ is assumed to a precessional effect of the ring around the compact object and the observational data (Frasca *et al.*, 83) is well fitted by the general relativistic line shift equation (Ruffini and Stella, 1980a), a combination of gravitational and Doppler shift

$$1 + Z^{\pm} = (1 - 3M_1/r)^{-1/2}\{1 \pm (M_1/r)^{1/2}\cos\delta[\tan^2\xi + (1 - 2M_1/r)^{-1/2}]\}, \tag{1}$$

where the + (−) sign refers to the red (blue) shifts, and

$$\cos\delta = (\cos i \sin\alpha - \sin i \cos\alpha\cos\varphi)(1 - \sin^2 i \sin^2\varphi)^{-1/2}, \tag{2}$$

$$\sin\xi = \sin i \sin\varphi, \tag{3}$$

with the following values of parameters in Equations (1) and (2):

$$r \simeq 45M_1, \; (i, \alpha_0) = (65.^\circ 7, 54.^\circ 0) \quad \text{or} \quad (36.^\circ 0, 24.^\circ 3).$$

Further analysis of the spectroscopical data of the shifted lines has shown significant statistical deviation from a simple sinusoidal behaviour in the modulations of the shifted

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TABLE I

The relevant short period modulations (Frasca *et al.*, 1983)

Period	Amplitude		Difference of phase
	Z_+	Z_-	
$6^{\mathrm{d}}.29$	0.0080	0.0075	$\sim 180°$
$5^{\mathrm{d}}.84$	0.0049	0.0041	$\sim 180°$

lines with a period of $\sim 164^{\mathrm{d}}$ (Newsom and Collins, 1980, a, b, 1981; Wagner *et al.*, 1981; Katz *et al.*, 1982; Mammano *et al.*, 1983). According to the observational data analysis of Frasca *et al.* (1983), the relevant modulations in the shifted lines among many periodic modulations are given in Table I. The square module of these amplitudes corresponding to the $\sim 6^{\mathrm{d}}$ periodicities gives a relation (Mammano, 1982)

$$|A_{6.28}|^2 \simeq 3\,|A_{5.84}|^2\,. \tag{4}$$

The aim of this talk is to show these $\sim 6^{\mathrm{d}}$ periodicities can be accounted for by a nutational effect induced by the companion star on the accretion disk, initially introduced in the ring model, in the binary system model for SS 433. If it is confirmed, this effect will establish unequivocally the binary nature of the system.

2. Model

From the analysis of spectroscopical data (Crampton *et al.*, 1980, 1981) and the photometric data (Margon *et al.*, 1980, 1983), it has been inferred that the SS 433 is very probably a member of a binary system with a period $P \sim 13^{\mathrm{d}}.08$. Therefore we make a binary system simply introducing a companion star into ring model (see Fang and Ruffini, 1979; or Fang *et al.*, 1981).

In our model the accretion disk in the binary system are formed by a succession of precessional rings inclined at the same angle α with respect to the orbital plane. The perturbational modes generated at the border of the accretion disk are then assumed to propagate down to the inner emitting ring by viscosity (see Meritt and Petterson, 1980; Hatchett, 1981).

Each ring will generally experience a torque due to the coupling of its quadrupole moment with the tidal field of the companion star, M_2. This torque which can be calculated from the transport law of the spin angular momentum of a ring in the gravitational field of the companion star is the origin of the nutation type perturbations of a ring and determines the quadrupole angular velocity of a ring. In the Newtonian limit, the torque can be expressed by the equation

$$\frac{\mathrm{d}L^i}{\mathrm{d}t} = -\varepsilon_{ijk} R_{\mathrm{kolo}} f_{jl} \equiv N^i\,, \tag{5}$$

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where L^i is the spin angular momentum of the ring,

$$f_{jl} = \int \rho(x^j x^l - \tfrac{1}{3}r^2\delta_{jl})\, d^3x$$

is the reduced quadrupole moment tensor, and the Riemann curvature tensor R_{kolo} is given by

$$R_{\mathrm{kolo}} = \partial^2\Phi/\partial x^k\, \partial x^l, \tag{6}$$

where Φ is the Newtonian potential of the companion star defined by

$$\Phi(x, y, z) = -M_2/[(x - x_R)^2 + (y - y_R)^2 + (z - z_R)^2]^{1/2}.$$

The (X_R, Y_R, Z_R) is the coordinate of the companion star.

In order to describe a ring in the binary and evaluate the perturbations on a ring due to the torque defined in Equation (5), we introduce three systems of coordinates (see Figure 1):

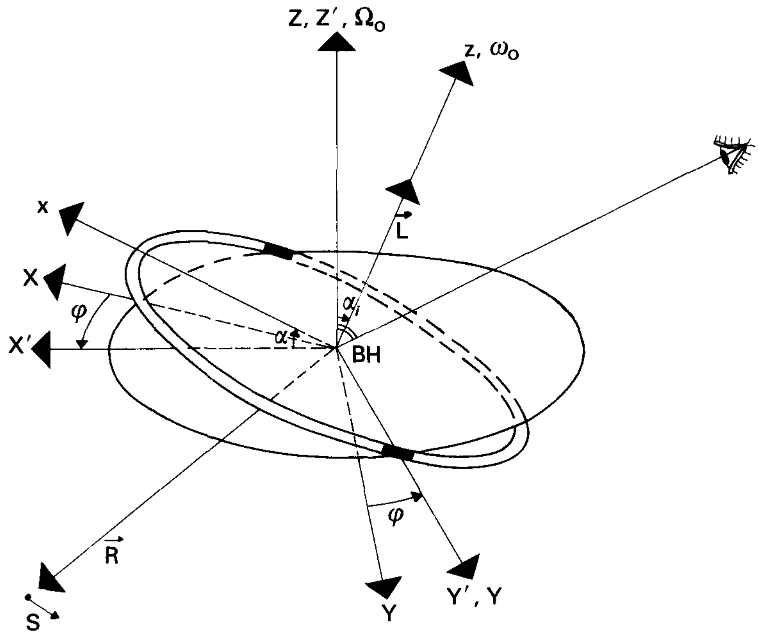

Fig. 1. A coordinate system (X', Y', Z') is defined with its origin at the centre of the ring, with the Z'-axis normal to the binary orbital plane and the Y'-axis along the line of the nodes, defines as the intersection between the binary orbital plane and the plane of the ring. The ring's local plane is also defined with the y-axis coincident with Y'-axis and the x-axis in the plane of the ring. The plane of the ring is inclined by an angle α with respect to the binary orbital plane. The centre of the companion star rotates in the $X - Y$ plane with an angular velocity ω and is identified by the position R. Finally we define a non-rotating coordinate (X, Y, Z), still with its origin at the centre of the ring, with $Z = Z'$ and the Y-axis, initially intersecting the nodes, forming an angle with respect to the Y'-axis. The line-of-sight from the Earth to the centre of the ring substent the Z-axis by an angle i.

(i) The fixed system (X, Y, Z) with its origin at the center of the ring, the Y-axis initially along the line of nodes defines as the intersection between the binary orbit and the plane of the ring, and the X-axis in the plane of the binary.

(ii) The ring's local frame (x, y, z) has the y-axis coincident with the nodal line, the x-axis in the plane of the ring and α is the inclination angle between the plane of the binary orbit and the plane of the ring.

(iii) The moving (rotating) system (X', Y', Z') still has its origin at the center of the ring with the axis $Z' = Z$ and the Y'-axis which is always along the line of node, displaced from the Y-axis by the angle φ given by the precession and nutation of the ring in the binary system. The (X, Y, Z) coordinate system is fixed with respect to the asymptotic inertial frame at rest at infinity. The center of companion star lies in the $X - Y$ plane.

We now assume that the ring is precessing at a rate $\Omega_p \sim 2\pi/164^{\mathrm{d}}$ and the angular velocity of the binary system is $\omega \simeq 2\pi/13\overset{\mathrm{d}}{.}08$. Using Equation (5) in (X, Y, Z) coordinate system in which we are doing the observations, we can evaluate the perturbations induced by the companion star on the angles α and φ. If we write the change of angles (see Cogotti *et al.*, 1983) as

$$\alpha(t) = \alpha_0 + \alpha_N(t)\,, \qquad \varphi(t) = \varphi_0 + \Omega_p t + \varphi_N(t)\,;$$

and assume $|\alpha_N(t)| \ll |\alpha_0|$ and $|\varphi_N(t)| \ll |\varphi_0 + \Omega_p t|$, then after simple calculations, we obtain the perturbations of angles α_N and φ_N as

$$\alpha_N(t) = \Omega_Q[2(\omega - \Omega_p)]^{-1} \tan\alpha_0 \cos[2(\omega - \Omega_p)t - 2\varphi_0 + \psi_1]\,,$$

$$\varphi_N(t) = \Omega_Q[2(\omega - \Omega_p)]^{-1} \cos[2(\omega - \Omega_p)t - 2\varphi_0 + \psi_2]\,, \tag{7}$$

where Ω_Q is the angular velocity of the quadrupole precession defined by

$$\Omega_Q = -\frac{3}{4}\left(\frac{\omega}{\omega_0}\right) \omega M_2/(M_1 + M_2) \cos\alpha_0\,. \tag{8}$$

The ω_0 is the angular velocity of a ring. One can easily see that the sign of quadrupole angular velocity is highly dependent on the sign of the angular velocity of a ring. The phases ψ_1 and ψ_2 in Equation (7) are the difference of phases introduced by the propagation processes. Since the angular velocity of these perturbations on angles, $2(\omega - \Omega_p)$, is larger than the angular velocity of the total precession, we can say the perturbation is nutation.

3. Applications to the Foruma of the Line Shift

According to the observational data of Ciatti *et al.* (1983), the sum of the red- and blue-shift, $Z^+ + Z^-$, is time independent up to the relevant Fourier component (see also Frasca *et al.*, 1983), we may assume that the radius of the emitting ring is constant. In order to demonstrate the effect of nutational perturbation on the shifted lines, we expand the relativistic formula given in Equation (1) in terms of $(M_1/r)^{1/2}$ and α_N and

φ_N given in Equation (7). Keeping the expansion terms up to the order of $(M_1/r)^{3/2}$ and choosing linear terms of α_N and φ_N only, we have for the expressions of the shifted lines $1 + Z^{\pm} = 1 + Z_0^{\pm} + \Delta Z^{\pm}$, where

$$1 + Z_0^{\pm} = (1 - 3M_1/r)^{-1/2}[1 \pm (M_1/r)^{1/2} \times \times (\cos i \sin \alpha_0 - \sin i \cos \alpha_0 \cos(\Omega_p t + \varphi_0))] \quad (9)$$

is the usual formula for the line shift with long term precessional rate $\Omega_p = 2\pi/163\overset{\mathrm{d}}{.}34$ and, according to Cogotti *et al.* (1983), the $\Delta Z^{\pm}$ terms are

$$\begin{aligned}\Delta Z^{\pm} = \pm\{&+A_1(2\Omega_p)\cos(2\Omega_p t + 2\varphi_0) - A_2\{3\Omega_p)\cos(3\Omega_p t + 3\varphi_0) + \\ &+ A_3(2\omega - 2\Omega_p)\cos[2(\omega - \Omega_p)t + \Theta_3] + \\ &+ A_4(2\omega - \Omega_p)\cos[(2\omega - \Omega_p)t - \Theta_4] - \\ &- A_5(2\omega - 2\Omega_p)\cos[(2\omega - 3\Omega_p)t - \Theta_5] - \\ &- A_6(2\omega)\cos(2\omega t + \Theta_6) - A_7(2\omega - 4\Omega_p)\cos[2\omega - 4\Omega_p)t + \Theta_7] - \\ &- A_8(2\omega + \Omega_p)\cos[(2\omega + \Omega_p)t - \Theta_8] + \\ &+ A_9(2\omega - 5\Omega_p)\cos[(2\omega - 5\Omega_p)t - \Theta_9]\}\,,\end{aligned} \quad (10)$$

where A_i, $i = 1, \ldots, 9$, are the amplitudes given by

$$\begin{aligned}A_1 &= \tfrac{1}{2}\Gamma(M_1/r)^{3/2}\sin^3 i \cos i \sin \alpha_0\,, \\ A_2 &= \tfrac{1}{4}\Gamma(M_1/r)^{32}\sin^3 i \cos \alpha_0\,, \\ A_3 &= \Gamma(M_1/r)^{1/2}\,\Omega_Q[2(\omega - \Omega_p)]^{-1}\cos i \sin \alpha_0[1 + \tfrac{1}{2}M_1/r(1 + \cos^2 i)] \times, \\ &\times [(1 + \tan^4 \alpha_0) - 2\cos \Delta\psi \tan^2 \alpha_0]^{1/2}\,, \\ A_5 &= \tfrac{1}{2}\Gamma(M_1/r)^{1/2}\,\Omega_0[2(\omega - \Omega_p)]^{-1}\sin i \cos \alpha_0[1 + \tfrac{3}{4}(M_1/r) \times \\ &\times (1 + \tfrac{1}{3}\cos i)][(1 + \tan \alpha_0) + 2\cos \Delta\psi \tan^2 \alpha_0]^{1/2}\,, \\ A_6 &= \tfrac{1}{4}\Gamma(M_1/r)^{3/2}\,\Omega_Q[2(\omega - \Omega_p)]^{-1}\sin^2 i \cos i \sin \alpha_0(5 + 4\cos \Delta\psi)^{1/2}\,, \\ A_7 &= \tfrac{1}{4}\Gamma(M_1/r)^{3/2}\,\Omega_Q[2(\omega - \Omega_p)]^{-1}\sin^2 i \cos i \sin \alpha_0(5 - 4\cos \Delta\psi)^{1/2}\,, \\ A_8 &= \tfrac{1}{8}\Gamma(M_1/r)^{3/2}\,\Omega_Q[2(\omega - \Omega_p)]^{-1}\,\mathrm{Am}^{-3} i \cos \alpha_0[(9 + \tan^4 \alpha_0) - \\ &- 6\cos \Delta\psi \tan^2 \alpha_0]^{1/2}\,, \\ A_9 &= \tfrac{1}{8}\Gamma(M_1/r)^{3/2}\,\Omega_Q[2(\omega - \Omega_p)]^{-1}\sin i \cos \alpha_0[(9 + \tan^4 \alpha_0) + \\ &+ 6\cos \psi \tan^2 \alpha_0]^{1/2}\,;\end{aligned} \quad (11)$$

where the symbol $\Gamma = (1 - 3M_1/r)^{-1/2}$ and $\Delta\psi = \psi_1 - \psi_2$. The first two amplitudes A_1 and A_2 are the Fourier harmonics of Ω_p and all the rest are the combinations between $(2\omega - 2\Omega_p)$, the nutational rate, and Ω_p. The phases Θ_i, $i = 3, \ldots, 9$, are given by

$$\Theta_3 = \psi_1 - 2\varphi_0\,,$$

$$\Theta_4 = \arctan\{[\tan^2\alpha_0 \cos(\psi_1 - \varphi_0) - \cos(\psi_2 - \varphi_0)] \times$$
$$\times [\tan^2\alpha_0 \sin(\psi_1 - \psi_0) - \sin(\psi_2 - \varphi_0)]^{-1}\},$$
$$\Theta_5 = \arctan\{[\tan^2\alpha_0 \cos(\psi_1 - 3\varphi_0) - \cos(\psi_2 - 3\varphi_0)] \times$$
$$\times [\tan^2\alpha_0 \sin(\psi_1 - 3\varphi_0) - \sin(\psi_2 - 3\varphi_0)]^{-1}\},$$
$$\Theta_6 = \arctan[(\sin\psi_1 + 2\sin\psi_2)(\cos\psi_1 + 2\cos\psi_2)^{-1}],$$
$$\Theta_7 = \arctan\{[\sin(\psi_1 + 4\varphi_0) - 2\sin(\psi_2 + 4\varphi_0)] \times$$
$$\times [\cos(\psi_1 - 4\varphi_0) - 2\cos(\psi_2 - 4\varphi_0)]^{-1}\},$$
$$\Theta_8 = \arctan\{[\tan^2\alpha_0 \cos(\psi_1 + \varphi_0) - 3\cos(\psi_2 + \varphi_0)] \times$$
$$\times [\tan^2\alpha_0 \sin(\psi_1 + \varphi_0) - 3\sin(\psi_2 + \varphi_0)]^{-1}\},$$
$$\Theta_9 = \arctan\{[\tan^2\alpha_0 \cos(\psi_1 - 5\varphi_0) + 3\cos(\psi_2 - 5\varphi_0)] \times$$
$$\times [\tan^2\alpha_0 \sin(\psi_1 - 5\varphi_0) + 3\sin(\psi_2 - 5\varphi_0)]^{-1}\}. \quad (12)$$

We can then conclude from the above relations that the combination of the precession of the disk and the nutation due to the tidal torque exerted by the companion star leads to the modulations in the shifted lines.

4. Applications to the SS 433

4.1. The fit of the observational data

In order to evaluate the amplitudes of the frequency shifts $\Delta Z^{\pm}$ given by Equation (10), we have determine the parameters r, i, α_0, $\Delta\psi$, and Ω_Q. We use the assumed angular velocity of the disk by $\Omega_p \simeq 2\pi/163\overset{\mathrm{d}}{.}34$ (Mammano *et al.*, 1983) and binary period as $p \simeq 13\overset{\mathrm{d}}{.}08$ (Crampton *et al.*, 1980). According to the recent data analysis of observations

TABLE II

The nine amplitudes of modulations, given in Equation (11), and their corresponding periods are given

H	T (days)	$\|A_i\|$
$2\Omega_p$	81.7	0.0043
$3\Omega_p$	54.4	0.0004
$2\omega - \Omega_p$	6.29	0.0078
$2\omega - 3\Omega_p$	5.84	0.0045
$2\omega - 2\Omega_p$	6.06	0.0036
2ω	6.54	2×10^{-5}
$2\omega - 4\Omega_p$	5.64	4×10^{-5}
$2\omega + \Omega_p$	6.81	6×10^{-5}
$2\omega - 5\Omega_p$	5.45	3×10^{-5}

(Mammano *et al.*, 1982; Frasca *et al.*, 1983) and the relation given in Equation (4), we obtain the only viable values of parameters as $(i, \alpha_0) \simeq (65\overset{\circ}{.}7, 54\overset{\circ}{.}0)$, $\Delta\psi \simeq 127\overset{\circ}{.}3$ at $r \simeq 45M_1$. It is interesting that the set $(i, \alpha_0) \simeq (65\overset{\circ}{.}7, 54\overset{\circ}{.}0)$ is obtained both for the $\sim 164^d$ periodicity and for the nutation of $\sim 6^d$ periods. Finally we can evaluate the value of Ω_Q in Equation (11), using the experimental value for the amplitude of the $6\overset{d}{.}28$, by $\Omega_Q \simeq 2\pi/83\overset{d}{.}8$. In Table II we give the amplitudes and the corresponding periods of the modulation in Equations (11) and (10).

4.2. A DISCUSSION ON THE BINARY PERIOD

The value of the total precessional angular velocity has been determined quite accurately by a variety of observations. Although the binary period of $13\overset{d}{.}08$ which is first reported by Crampton *et al.* (1980) is widely circulated, it is interesting to analyze strictly the value of the binary period.

According to the data analysis of the observations (Frasca *et al.*, 1983) the significant amplitudes occur at periods of $6\overset{d}{.}29$ and $5\overset{d}{.}84$. In Table III and Table IV we give the values of the expected periodicities in ΔZ corresponding to the above major modulations. The co-precessional case (Table III) corresponds to the results of Giles *et al.* (1980) that they obtained the binary period as $11\overset{d}{.}8$, and the counter-precessional case (Table IV) is similar to the results of Crampton *et al.* (1980).

TABLE III

The periodicities of the three principal harmonics given in Equation (10) are given as a function of selected values of the binary period for a corotating precessional period of 164^d

$\Omega_p > 0$			
H \ P	$12\overset{d}{.}11$	$11\overset{d}{.}68$	$11\overset{d}{.}27$
$2\omega - \Omega_p$	6.28	6.06	5.84
$2\omega - 2\Omega_p$	6.84	6.28	6.05
$2\omega - 3\Omega_p$	6.81	6.84	6.28

TABLE IV

Same as Table III, for a counter-rotating precessional period

H \ P	$13\overset{d}{.}08$	$13\overset{d}{.}62$	$14\overset{d}{.}22$
$2\omega - \Omega_p$	6.28	6.54	6.81
$2\omega - 2\Omega_p$	6.06	6.28	6.54
$2\omega - 3\Omega_p$	5.84	6.05	6.28

We assume that the total precessional angular velocity of the disk mainly from the quadruple precessional velocity given in Equation (8), i.e. $\Omega_p \sim \Omega_Q = -\frac{3}{4}(\omega/\omega_0)\omega M_2/(M_1 + M_2)\,|\cos\alpha_0|$. We used $|\cos\alpha_0|$ instead of $\cos\alpha_0$ to give sign of rotational disk to ω_0. According to this relation we know the following thing that the sign of Ω_p is directly related to the sign of ω_0, the rotation of the disk. If ω_0 and ω have the same sign, the precession is now counter-precession, but ω_0 has opposite sign to ω, the Ω_p has co-precession with ω. If the widely used $\sim 13^d$ period which is confirmed by Katz *et al.* (1982) is correct, ω_0 has the same sign of ω and binary system has counter-precessional angular velocity. It is worth noting that, since $\Omega_Q \sim 2\pi/83^d$ and $\Omega_p \sim 2\pi/164^d$, the required additional angular velocity may be $\Omega_{add} \sim 2\pi/164^d$ and the sign of Ω_{add} may be opposite to Ω_Q, if Ω_p is obtained by additional combination of many precessional mode.

4.3. The Masses of the Binary System

From the amplitude of the nutational period we have determined the numerical value of $\Omega_Q \simeq 2\pi/83\overset{d}{.}8$. By the equation for Ω_Q in Equation (8) with known values of parameters we obtain the relation

$$\frac{M_1}{M_\odot} \simeq K(r)/[1 - K(r)\,(M_2/M_\odot)^{-1}]\,, \tag{13}$$

where $K(r) \simeq 3.4 \times 10^7\,(r/45M_1)^{-3/2}$ and, as usual, r is the radius of the disk. Combining the above equation with the mass function of Crampton and Hutchings (1981)

$$\frac{M_2^3}{(M_1 + M_2)^2} \simeq 13M_\odot\,. \tag{12}$$

We can infer constraints on the masses of the system (see Table V).

TABLE V

Here are shown for selected values of the radius of the accretion disk around a compact object, the masses of binary system (M_1 for the compact object and M_2 for the companion star), the interstellar distance R, and velocities (v_1 for the velocity of the compact object and v_2 for that of the companion star). Reading from the top of the table, all the data are obtained by the assumption $v_1 \sim v_{orb} \simeq 195$ km s^{-1} (see Crampton and Hutchings, 1981) and, reading from the bottom, we have assumed $v_2 \sim v_{orb}$

M_1/M	M_2/M	R (cm)	r (cm)	v_2 (km s^{-1})	
3.1×10^8	1.0787×10^6	1.10×10^{15}	4.84×10^{15}	5.60×10^4	7.16×10^{13}
1.76×10^6	3.467×10^4	1.98×10^{14}	1.17×10^{14}	9.88×10^3	2.30×10^{13}
3.04×10^4	1.088×10^3	5.13×10^{13}	2.02×10^{14}	5.44×10^3	7.23×10^{12}
1.79×10^3	3.96×10^2	2.11×10^{13}	2.64×10^{13}	8.82×10^2	5.84×10^{12}
74.56	62.31	8.39×10^{12}	4.97×10^{12}	2.33×10^2	4.13×10^{12}
52	52	7.65×10^{12}	4.13×10^{12}	1.95×10^2	4.13×10^{12}
15.59	30.01	5.81×10^{12}	2.3×10^{12}	1.01×10^2	4.43×10^{12}
1.16	15.07	4.1×10^{12}	7.7×10^{11}	15	1.00×10^{13}
M_2/M	M_1/M	R (cm)		V_1 (km s^{-1})	r (cm)

We see from the table that the possibility that SS 433 is a very massive black hole (see, e.g., Terlevich and Pringle, 1979;. Amitai-Milchgrub *et al.*, 1979; and Shaham, 1980) can be discarded on the ground of the above formulae. We are probably dealing with stars of mass $\lesssim 50M_\odot$ both in the case of collapsed object and that of the companion star. It is also worth stressing that the disk should have dimensions comparable to the interstellar distance.

5. Conclusions

In this article we have considered as a model of SS 433 a binary system which consists of companion star, compact object and accretion disk around a compact object,

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processing with a period of $\sim 164^d$. We have considered the nutational effects on the disk induced by a companion star with a binary period of $\sim 13^d$. Within the ring model, the theoretical expressions for the $\sim 6^d$ modulations in the shifted lines are obtained.

In the background of our model we have reached general conclusions:

(1) Strong and independent evidence for the binary nature of the system obtained from the different Fourier components of the 6^d periodicities.

(2) The sense of the precessional angular velocity of the disk is opposite to that of binary angular velocity which has the same sign of angular velocity of the disk.

(3) The presence of an extended disk of dimensions comparable to the separation distance of the system.

(4) Evaluation of the masses of the system.

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