Part IV

Cataclysmic Binaries and their Role in Stellar Evolution

https://doi.org/10.1017/S0252921100100727 Published online by Cambridge University Press

BINARY STARS AND SS433

Remo Ruffini
Istituto di Fisica "G.Marconi" - Università di Roma, Italy

ABSTRACT

Some of the most unique experimental features of the source SS433 are outlined as well as some implications of the theoretical models of this source.

The fact that as many as 10^9 stars in our galaxy may be members of multipole systems make the theoretical study of binary sources one of the most important in the entire field of astronomy and astrophysics. Moreover, since all type of stellar population are member of binary systems the study of such binaries gives as well basic information about the Hertzsprung Russell diagram and evolution of a single star. In particular the knowledge of the binary parameters, such as the orbital period and the velocity of each one of the component, allows to infer the value of the star masses of their radii and their luminosity. Beyond any doubt the entire study and discovery of white dwarfs can be considered a clear success, a biproduct of this type of research. In order to pursue the theoretical analysis of these binary systems our entire field of applied mathematics has been developed reaching classical results on the equilibrium configurations of self gravitating fluids in rotation.[1,2] All these classical works have become in recent years of paramount importance for the understanding of an entire new branch of high energy astrophysics: the binary X-ray sources. Unlike usual binaries, in this case, one of the star is a gravitationally collapsed star; either a neutron star or a black hole. The matter falls from the

Z. Kopal and J. Rahe (eds.), Binary and Multiple Stars as Tracers of Stellar Evolution, 373–388.

normal star into the deep potential well of the collapsed companion star. Under these circumstances a large emission of X-rays ($dE/dt \simeq 10^{38}$ erg/sec) can occur.(3) The development of X-ray astronomy by the group of Riccardo Giacconi has allowed the identification of a large variety of such binary X-ray sources. It has been possible for the first time to measure the masses of neutron stars(4) and to meet the necessary conditions required for the positive identification of a black hole in Cygnus XI.(5)

A second field of research which has also shown remarkable progress in recent years thanks to the ample use of radiotelescopes,(6) radars and satellites(7) and atomic clocks,(8) is that of testing general relativistic effects within the weak gravitational fields of the solar system. Specifically conceived and directed experiments have tested such effects as time delay in the propagation of signals in a gravitational field, light deflection, gravitational redshifts and planetary motions(9) to such accuracy that general relativity has become the most viable theory of gravity consistent with experimental tests.

What one would like to have in the future is a mixture of these two fields of research, namely, clean and precise tests of general relativistic effects like those in the solar system, but in the strong gravitational field of a gravitationally collapsed object. Such a goal more than likely cannot be achieved with binary X-ray sources since there the most relativistic region of the gravitational field is occupied by matter accreting from the normal companion star.

An important step towards this goal has been achieved by the discovery of the binary pulsar PSR 1913+16. This system has given the first clear evidence of the existence of gravitational waves in nature.(10) Progress is also currently being made in developing suitable experiments for the detection of gravitational waves on the earth.(11) Other important systems in this context may be the X-ray burst sources in globular clusters or in the galactic bulge(12) and possibly SS433. In the following, we will limit our attention to the system SS433.

SS433 was originally observed in the sixties by Stephenson and Sanduleak in a search for stars with strong hydrogen emission lines and was the 433rd object in their list.(13) In 1978, it was identified(14,15) with a point-like radio source located at the center of the supernova remnant W50, initially discovered by Holden and Caswell;(16) radio studies done by several groups(17) have since given a very detailed map of W50 and of SS433. In 1978, Clark and Murdin(15) had proposed the identification of SS433 with the X-ray source A1909+04 discovered in 1975 by the Ariel 5 satellite.(18) The total flux in the optical region was estimated to be

https://doi.org/10.1017/S0252921100100727 Published online by Cambridge University Press

$L_{opt} \simeq 10^{37}$ erg/sec, the one in radio to be $L_{radio} \simeq 10^{31 \div 32}$ erg/sec, and the one in X-rays to be $L_X \simeq 10^{35}$ erg/sec. Except for the anomalous abundance and strength of the emission lines, nothing peculiar had been observed until that time, not even in the energetics of the system, with the possible exception of a low value of the X-ray flux compared to the one for binary X-ray sources.

What has made this system unique is the spectroscopic analysis of the optical spectrum done by Ciatti, Mammano and Vittone[19] of the Asiago Observatory; they showed the existence of strong anomalous emission lines moving from night to night by an amount $\Delta\lambda$ 50 Å! These lines were attributed at that time by Mammano and co-workers to a magnetic splitting of the H_α line by a strong magnetic field (10^{7-8} Gauss). Further investigation by various research groups throughout the world has shown some regular patterns in the shift of the lines as a function of time and finally an overall periodicity of $P \simeq 164$ days with a very specific pattern (Fig. 1).[20,21] Analogous moving emission lines have been observed around H_β, H_γ and in higher series of the hydrogen spectrum.[22,23]

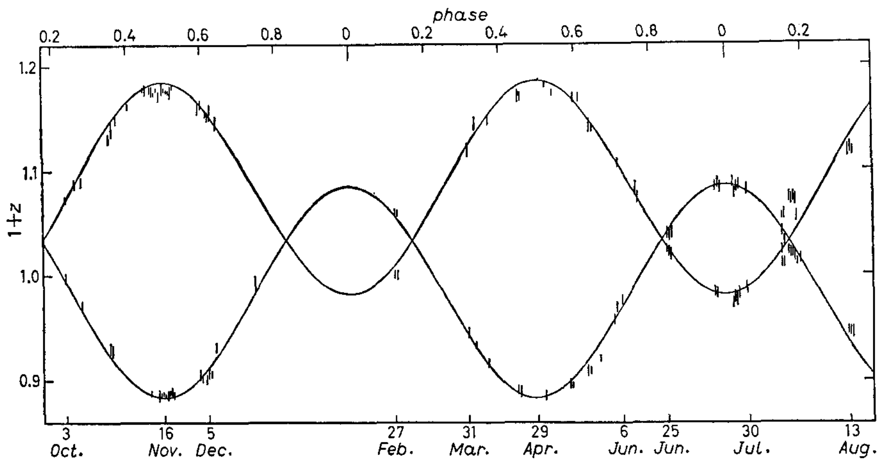

Figure 1. The 164 day modulation of the shifted lines of SS433 during 1978-1979. For details see refs. (18), (19) and (29).

Before discussing theoretical models for SS433, let us review some of the points on which everyone agrees.

(1) SS433 is a relativistic system. The widely accepted hypothesis of kinematical (and possibly gravitational) effects can be clearly inferred

https://doi.org/10.1017/S0252921100100727 Published online by Cambridge University Press

by the magnitude of the shifts in Fig.1. It is well known that the frequency shift observed by an observer with four-velocity u_{obs} emitted by a source with four-velocity u_{em} is simply given by:

$$\nu_{obs}/\nu_{em} = (u^{\alpha} k_{\alpha})_{obs} / (u^{\alpha} k_{\alpha})_{em} \tag{1}$$

where k is the wave four-vector propagating from the emitter to the observer. If the shifts are due uniquely to the kinematic effect of two motions of equal speed in opposite directions, we have:

$$\lambda_{\substack{red\\blue}} /\lambda_{o} = (1 \pm v/c \cos\psi)\,(1-v^2/c^2)^{-1/2} \tag{2}$$

and the fact that $(\lambda_{red} + \lambda_{blue})/2\,\lambda_o \simeq 1.036$ is a direct measure of the γ factor of the special relativistic Doppler formula. If the shifts are due to a general relativistic effect (see below), there will be an additional gravitational redshift. Therefore, for the first time, either in "bulk" is observed to be moving inside our own galaxy at a relativistic speed or matter in "bulk" is observed to be moving around a gravitationally collapsed object with high regularity.

(2) The relativistic effects are modulated in time with a period $T_p \simeq 164$ days.

(3) SS433 has to be a gravitationally collapsed object. Inference of this comes mainly from its association with W50 and on the general grounds of the total energetics of the system. The proof of this last point, however, will be only possible by consistency with a detailed theoretical model.

M. Milgrom[24] in one of the earliest theoretical papers on this subject suggested a variety of possible models explaining the shift of the lines and their time variation in terms of Doppler and possibly gravitational effects. It is interesting to note that at the time of the Milgrom work, the 164 day period in the shift of the moving lines had still not been discovered. Two of the models proposed by Milgrom are still being actively pursued today: the two jet model in which material is ejected in two highly collimated relativistic beams (this model has been proposed independently by Fabian and Rees[25]) and a ring model of material orbiting a collapsed object.

The widely publicized two jet model (Fig. 2) has been discussed by Fabian and Rees,[25] Milgrom,[26] Abell and Margon,[21] Katz,[27] Martin and Rees,[28] and Maraschi and Treves.[29] In this model, matter is moving at an almost relativistic speed $v \simeq 0.26c$ in two highly collimated jets precessing around a fixed axis. This idea has found some support by X-ray and radio observations[17] but, interesting as it is, it fails to be a definite model in more than one respect.

(1) The origin of the acceleration process of matter in these beams and the mechanism by which the speed of the matter in the beams should be kept at an almost constant velocity are not yet determined.

(2) The physical reasons by which the beams are collimated within an angle $\lesssim 2^{\circ}$ are again not determined.

(3) The clock mechanism characterizing the 164 day modulation is also unclear.

(4) The most severe constraint comes, in our opinion, from the overall energy balance in the jets. Every photon of the shifted lines should be emitted by an atom of mass, m, moving at a velocity v=0.26c. The kinetic power of the jets is then given by:

$$W_{kin} \simeq G \cdot V \cdot N_{ph} \cdot 1/2\, mv^2 \cdot P^{-1} \qquad (3)$$

where the number M_{ph} of H_{α} photons emitted in the jets per second is easily computed by the observed flux in the moving lines ($L_{m\ell} \simeq 10^{34}$ erg/sec), $V \geq 1$ is given by (number of atoms in the jets)/(number of atoms emitting H_{α}), $G \geq 1$ takes into account the geometry of the jets and the optical depth of the emitting region and $P \geq 1$ is the number of re-emissions in each hydrogen atom. If one assumes $V \cdot G \cdot P^{-1} = 1$, then $W_{kin} \simeq 10^{41}$ erg/sec. This is an extremely high value for a galactic object.

Let us now consider the other possibility: a ring model. Although the model is still not unique, there are a variety of points which can be explicitly explained, some predictions of the model which can be tested and quantitative estimates and computations which can be done in this theoretical framework.

In the ring model[12,30] the observed shifts in H_{α}, H_{β}, ... lines are explained in terms of a combination of gravitational and Doppler effects associated with matter orbiting a black hole. The mechanism of acceleration of matter up to the observed relativistic velocities is simply accretion through (almost) Keplerian orbits. In order to fit the data the emission has to occur only from two opposite spots in the precessing ring[31] (Fig. 3). If we assume, for simplicity, that photons propagate along straight lines, we can fit the observed data very satisfactorily (see Fig. 1) and the predicted behavior is virtually identical to the one obtained in the two jet model.[31] The radius inferred for the orbit is then r = 50M (wee use c = G = 1) implying that the central object is either a compact neutron star or a black hole. Since the orbits have to be almost Keplerian and unperturbed by electromagnetic fields, we are going to assume in the following that the central object is indeed a black hole. We have proposed some experimental tests to check this (see below).

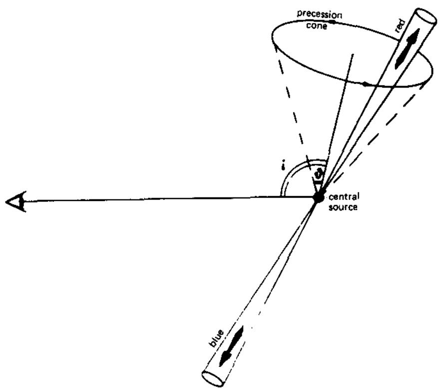

Figure 2. Two jets models for SS433

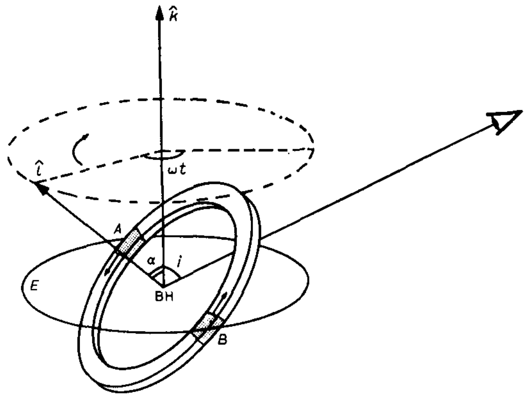

Figure 3. Ring models for SS433

One of the main ideas in the development of this ring model has been to include as many relativistic effects as possible in the treatment with a double purpose: (a) to recognize the self-consistency of the model, and (b) in case of experimental configuration, to clearly point out the most unique features of SS433 from the point of view of relativistic astrophysics.

The 164 day modulation is explained in terms of an additional general relativistic effect: the Lense-Thirring-Wilkins effect.[30] If a black hole of mass M is endowed with a specific angular momentum a = L/M, this effect predicts a precession of the angular momentum $\hat{\ell}$ of the ring with respect to the angular momentum $\hat{K}$ of the black hole by an angle of:

$$\Delta\Omega = 4\Pi\ (a/M)\,(M/r)^{3/2} \tag{4}$$

per revolution, where r is the radius of the emitting ring previously determined by the amplitude of the shifts. This interpretation of the 164 day periodicity, if confirmed, would be the first measurement of the specific angular momentum of the black hole:

$$a/M = 1.2 \times 10^{-7}\ (M/M_{\odot}) \tag{5}$$

Until this point there has been no need to fix the mass of the black hole, since all the results given above scale with the black hole mass. Shaham et al. and Terlevich and Pringle[30] have assumed a black hole

https://doi.org/10.1017/S0252921100100727 Published online by Cambridge University Press

mass of $\sim 10^6$ $M_\odot$ in order to explain the energetics of the observed optical radiation from the moving lines of SS433:

$$L_{ml} = \alpha A \sigma T^4 \qquad (6)$$

where A is the surface area of the line emitting regions, $\alpha \simeq 1$ and T is a suitable temperature for the emission of Balmer lines ($T = 10^4$ °K). Eq. (6) has been obtained under the assumption that the emission occurs by a thermal process: as pointed out in ref. (33), this is not necessarily the case. The existence of such a large mass for SS433 can hardly be explained from an astrophysical point of view. For this reason, we assume in the following that the mass of SS433 is around 10 $M_\odot$, and we overcome the constraint given by Eq. (6) by choosing a different radiation mechanism. Two of the points still to be explored are: (a) why the hydrogen lines are emitted only in a ring, and (b) why only two spots on the ring are observed to emit.

In order to give an answer to these questions, it is necessary to make a model of the emission process of the shifted lines. Since the thermal radiation leads to the constraint given by Eq. (6), namely, to a mass of the gravitationally collapsed object $M \geq 3 \times 10^5$ $M_\odot$, we have explored the possibility that cooperative or stimulated emission takes place. The phenomenon of cooperative or stimulated emission, well known from laboratory physics, can occur only under very restrictive conditions in any astrophysical setting. The fact that a variety of astrophysical systems demonstrating this phenomenon have been found(34) clearly shows that these necessary conditions are fulfilled at least in some cases.

One of the major novelties in an astrophysical setting is that different oscillators will in general have large relative velocities and find themselves separated by large differences of gravitational potential. As a consequence, due both to Doppler shifts (transverse and parallel) and gravitational red or blue shifts, the frequencies of the individual oscillators will differ by an amount larger than the intrinsic width allowed by the cooperative emission process.(33) Some considerations concerning the conditions of population inversion necessary in order to have a cooperative or stimulated emission process at work, have been explored in refs. (36) and (37). Here we focus our attention on the necessary conditions that the gravitational potential and the velocity field of matter have to fulfill in order to have such an emission mechanism working and being observable from infinity.

A first necessary condition in order to have cooperative emission between an oscillator at a point P and an identical one at a point P' is that the two oscillator frequencies related by Eq. (1) fulfill the inequality:

https://doi.org/10.1017/S0252921100100727 Published online by Cambridge University Press

$$|\nu_p - \nu_{p'}| \leq \Delta\nu \tag{7}$$

where $\Delta\nu$ is the width of the cooperative or stimulated emission process.

The elucidate the meaning of this constraint, we present in Fig. 4 the case of a disk of matter in circular orbit around a Schwarzschild black hole of mass M. The dashed region shows the locus of corotating points P' in "frequency contact" with the corotating point P within the bandwidth $\Delta\nu/\nu \lesssim 10^{-2}$. Details are given in ref. (35). We want to point out here that, independent of the numerical value of the width of the cooperative emission process and of the location of the emitting point P, every atom P can be in "frequency contact" with an entire ring-like region in the disk, having a mean radius equal to the distance of the point P from the black hole, and with two almost radially pointing columns. The lasing or masing process can only occur in these regions of "frequency contact" and in directions in which a critical size for the emitting region is reached. This size is dictated by the cooperative mechanism (radiation flux, density of particles, etc.).

A further necessary condition must be fulfilled in order that cooperative or stimulated emission generated in the system be observed in the shape of an emission line by an external observer at point O. All the emitting points need to have constant shifts, with the balancing of Doppler and gravitational effects with respect to the observer at the point O (clearly this equality has to be fulfilled only within the linewidth observed, see Eq. (7)). We define the "regions of constant shift" with respect to the observer O at infinity to be the sets of points P satisfying the following condition:

$$\nu_p / \nu_o = (u^\alpha k_\alpha)_p / (u^\alpha k_\alpha)_o = \text{constant} \tag{8}$$

For the sake of example, we again consider a Keplerian ring around a Schwarzschild black hole;[35] the results for the case of an observer at infinity lying on the disk plane, are shown in Fig. 5.

It is then clear that in order to have the mechanism of cooperative emission working and observable, both necessary conditions given above have to be fulfilled. Stimulated or cooperative emission will be observed only from the intersection of the two sets, namely, regions of "constant shift" and regions in "frequency contact". It is likely that only intersection regions of large enough depth along the line of sight can lead to observable phenomena of amplified emission. The astrophysical setting for the simultaneous fulfillment of the two necessary conditions given above will only occur along selected directions. It is also a matter of course that observations of the same astrophysical system from different directions of sight will lead to different laser or maser patterns.

In the simple case of the Keplerian disk seen edge-on shown in Figs. 4 and 5, the intersection of the two conditions with the above condition of "maximum depth" is found to select two emitting regions in each ring of matter constituting the disk.[35] Going back to the model of SS433, this result is expected to play a fundamental role in the characterization

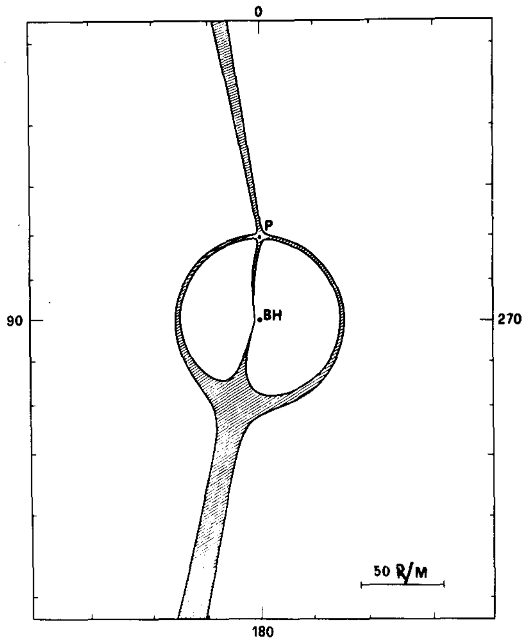

Figure 4. The dashed region is the set of points in a Keplerian disk in "frequency contact" with the point P orbiting the black hole at a distance r=50M. This region consists of points having frequencies within a bandwidth $\Delta\nu/\nu \leq 10^{-2}$ about the frequency ν of the point P. The disk is rotating counter-clockwise (ref. (35)).

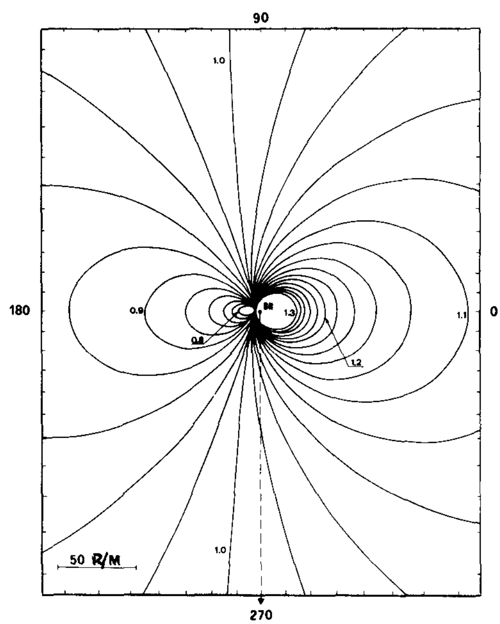

Figure 5. Lines of constant shift for the Keplerian disk of Fig. 4, seen edge-on (the line of sight coincides with the dashed line). Selected numerical values of (1+z) are identicated on the redshifted constant shift lines (z > 0) and on the flueshifted lines (z < 0) (ref. (35)).

https://doi.org/10.1017/S0252921100100727 Published online by Cambridge University Press

of the two emitting regions during the precessing of the ring plane.(31)

In order to give an astrophysical meaning to these considerations and identify the source of energy of the system, we consider the ring as a part of an accretion disk. The structure of this disk should, however, be very different from the ones usually described in the literature for accretion processes in binary X-ray sources.(38) One of the major differences is that the present disk should be at very low temperature near the black hole in order to have, at r = 50 M, emission of the Balmer lines of hydrogen. This is in clear contrast to the traditional models which assume that the X-rays are emitted by matter accreting near the surface of the black hole. Traditionally, the accretion occurs from a companion star overflowing its Roche lobe; the ensuing X-ray luminosity is typically near the critical value

$$L_{crit} = 4\pi\, cGM/k_T \simeq 1.3 \times 10^{38}\ M/M_{\odot}\ \text{erg/sec} \tag{9}$$

where k_T is the opacity due to Thomson scattering. In SS433, the accretion rate implies by the observed fluxes is not necessarily high enough to require a violent Roche-lobe flow from the possible companion star.(39)

The main assumptions of the model are:(12)

(a) The X-ray flux is not generated near the glack hole but in a shell at redius $r_o = (10^3 \div 10^4)$ M.

(b) Since $L < L_{crit}$ for $r < r_o$ the distribution of matter is assumed to the disk-like with an angular velocity very near to the Keplerian one.

(c) The structure of the magnetic field is almost toroidal and exerts minimal viscosity, implying small accretion rates in the inner part of the disk.

(d) The temperature of the disk is assumed to be monotonically increasing outward starting from zero temperature at the black hole surface(38) all the way up to $T_o \simeq 10^{6\div7}$ °K at $r \simeq r_o$.

(e) Finally, in a region $r \gg r_o$, the accreting material is heated up ($T \simeq 10^4$ °K); from this region the unshifted optical lines and the optical and infrared continuum should be emitted.

It is important also to stress that, unlike the traditional models, in the Fang Li Zhi-Ruffini model, the accretion rate M is not considered to be constant in the disk, but is a function of the radial coordinate. The loss of mass will occur from the surface of the disk either as "coronal outflow" or in jets of material of high temperature and low density.(40) This material should be responsible for the observed jet structure in radio emission.

https://doi.org/10.1017/S0252921100100727 Published online by Cambridge University Press

An attempt to integrate the full equations in order to describe the structure of the disk has been made by W. Stoeger.[40] But independently of the details of the complete treatment, some important and general results can be obtained by the study of some idealized situations in which analytical treatment can be applied. It has been shown in fact by Rosner, Ruffini and Vaiana[41] and, independently, by Fang Li Zhi[42] that the narrowness of the recombination region in the inner part of the disk can be explained in a natural way and quantitatively determined both in a magnetized and an α -viscosity law approach to the disk structure (see also ref. (36)). The results clearly show a temperature gradient in the inner part of the disk and the possible existence of a recombination layer at $r \simeq 50$ M. This is the reason why mainly a ring of matter should be visible in the optical region as expected from the kinematical analysis given above. The sharpness of the temperature transition can be also an important ingredient in generating both the inversion of population levels and the pumping mechanism for the cooperative emission process.[36,37]

We would like now to point out some possible general relativistic tests which can be checked on SS433 and could help in establishing the validity of the ring models. It has been pointed out that both the jet model and the disk model can explain the observed features of SS433 at least from a kinematical point of view. The correlation of simultaneous variations in the blue and redshifted lines, especially on short time scales,[20] finds a very natural explanation in the disk model as due to small changes in the position of the emitting zones. Quite apart from these features, there is a "gedanken" process which, in principle, could give a very important test of the strong field treatment of general relativity and, at the same time, of the correctness of the ring geometry in SS433.

In the fit of Fig. 1, the observed photons are supposed to propagate along straight lines from the emissing regions to the observer.[31] If we generalize this treatment, taking into proper account the light deflection by the central object, we have at least two additional paths to the observer in addition to the direct ones (see Fig. 6). These paths originate from photons being emitted from the points A and B and arriving at infinity after a strong deflection near the unstable orbit $r = 3$ M (paths undergoing a total deflection $> 180^{\circ}$ have not been considered, since they are expected to give rise to negligible intensity). The complete relativistic treatment,[43] including the numerical integration of the null geodesic equation:

$$\frac{d^2u}{d\phi^2} = 3u^2 - u \tag{10}$$

https://doi.org/10.1017/S0252921100100727 Published online by Cambridge University Press

(where $u = M/r$ and ϕ is a polar angle in the photon orbital plane), induces in the predicted behavior of the shifted lines the deformation given by the solid curves of Fig. 7; of course, this effect should not occur in the jet model since in that case the shifted lines are supposed to originate far from the central object (dashed curves of Fig. 7). The predicted asymmetry between the blueshifted and the redshifted lines could be checked experimentally.

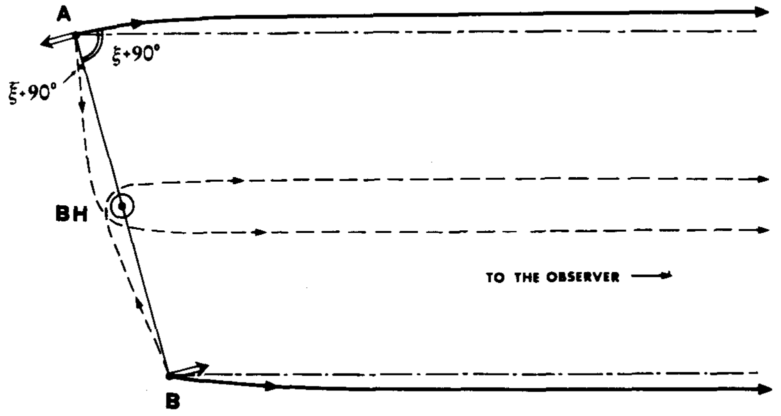

Figure 6. Selected trajectories of a photon in a Schwarzschild geometry reaching an asymptotic observer. The solid curves refer to the trajectories going from the emitting regions A and B (Fig. 3) directly to the observer. The dashed curves refer to trajectories being highly deflected by the black hole near the unstable orbit r = 3 M, represented here by the circle around the black hole. The dot-dashed straight lines refer to the rectilinear photon propagation used to obtain the fit of Fig. 1 (ref. (35)). Clearly the observed shifts of photons propagating along the direct or the highly deflected paths are very different (Fig. 7).

The two inner curves, with smaller shifts and complicated modulations, originate from photons reaching the observer along the two highly deflected paths in Fig. 6. The detection, even if sporadic, of these shifted lines (they are expected to be much fainter than the other shifted lines) could constitute a fundamental check of the strong field effects of general relativity.

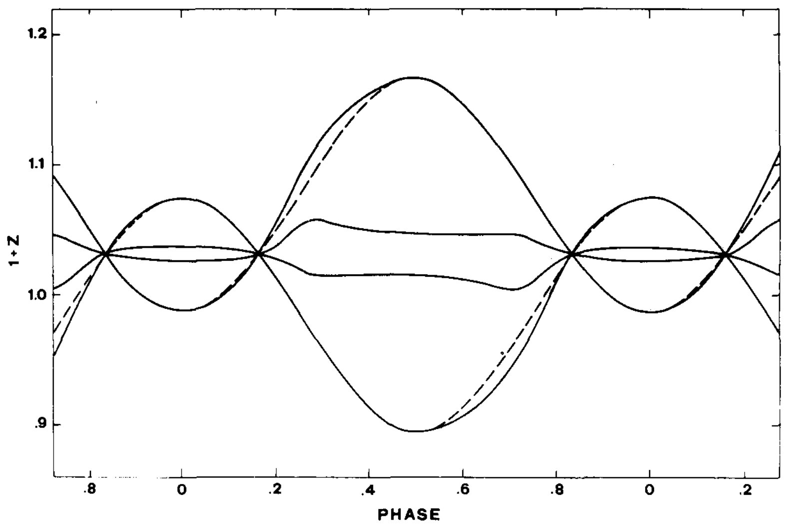

Figure 7. The predicted modification of the sinusoidal behavior of the shifted lines, in a ring model, due to general relativistic effects are here plotted as a function of phase. The dashed curves represent the corresponding behavior obtained within the jet model. The two inner curves, with smaller shifts and complicated modulations, originate from photons being highly deflected by the black hole near r 3 M. The opposite modulation (phase increasing from left to right) can also occur for the opposite sign of the black hole spin (ref.(43)).

Another relativistic effect is expected in SS433 in the case in which the precession of the emitting ring has to be ascribed to the Lense-Thirring coupling between the angular momentum of the emitting ring and the spin of the black hole. If matter is accreting into the black hole, the spin of the black hole is expected to change and, in turn, the precession period due to the Lense-Thirring effect, as given by Eq. (4), is going to change. Following the above assumption that the dissipation process in the inner part of the disk are small and that matter moves in almost Keplerian orbits, we can infer that the infalling mass M_{in} will carry in the angular momentum corresponding to the last stable orbit:[43]

$$\Phi_{LSO} \simeq \Delta M_{in} (Mr_{LSO})^{1/2} \cos\alpha' (1-3M/r_{LSO})^{-1/2} \times \left[1-3 \cos \alpha'(a/M)(M/r_{LSO})(1-2M/r_{LSO})(1-3M/r_{LSO})^{-1}\right] \qquad (11)$$

where the radius r_{LSO} is given by:

$$r_{LSO} \simeq 6M\left[1 - \frac{2\sqrt{2}}{3\sqrt{3}}\left(\frac{a}{M}\right)\cos\alpha'\right] \qquad (12)$$

and the angle $0 \leq \alpha'(r=r_{LSO}) \leq \alpha(r=50M)$ (see Fig. 3), since the effective potential in the θ-direction tends to constrain the orbital motion close to the equatorial plane of the black hole. The corresponding change in the Lense-Thirring period is given by (L is the spin of the black hole)

$$\frac{\Delta T_P}{T_P} \simeq \frac{\Delta a}{a} + \frac{1}{2}\frac{\Delta M}{M} \simeq \frac{\Delta L}{L} \simeq \frac{\Phi_{LSO}}{L} \qquad (13)$$

since, for the orbits considered here, the second term can be neglected.

Then from any observed change in the precession period T_P, the corresponding accretion rate M_{in} into the black hole can be inferred:

$$\dot{M}_{in} \simeq (3.2 \div 5.0) \times 10^{-10}\left(\frac{M}{M_\odot}\right)^2\left[\frac{|\dot{T}_P|}{10^{-2}T_P yr^{-1}}\right] M_\odot yr^{-1} \qquad (14)$$

This result could be of great relevance in order to estimate important parameters in the models of SS433, e.g. the ratio of matter accreting versus the one ejected in the Fang Li Zhi-Ruffini model.

In all the above considerations, the radius r at which the shifted lines are emitted is assumed to be constant in time. Viceversa, a change in the radius r of the emitting regions will also produce a change of the observable precession period. In this case, however, the orbital velocity of the emitting matter will also change the amplitude of the frequency separation in the shifted lines.

The recent discovery of a change in the 164 day period clearly agrees with the picture presented above. From the observed value $\dot{T}_P \simeq 0.01$ days/day, we can directly infer an accretion rate, $\dot{M}_{in} \simeq (0.7 \div 1.1) \times 10^{-9}\ (M/M_\odot)^2\ M_\odot yr^{-1}$, implying for masses $\lesssim 10$ M a subcritical accretion regime as in the hypothesis of our model. It goes without saying that confirmation of our explanation and the eventual observation of the other predicted relativistic effects would represent an extremely important test of general relativity and of the existence of a black hole in SS433.

REFERENCES

1. See e.g. Kopal, Z. "Close binary systems" Chapman and Hall, London 1959 and references therein.
2. See e.g. Plavec, M. "Mass exchange and Evolution of Close binaries" in Advances in Astronomy and Astrophysics Vo.6-1968 and reference therein.
3. Giacconi, R., Ruffini, R.: "Physics and astrophysics of neutron stars and black holes", Proc. International School "Enrico Fermi" (Varenna, Italy), 1978, North Holland, Amsterdam.
4. See e.g.: Bahcall, J.N.: 1978, Am. Rev. As. Ap. 16, 241.
5. Rhoades, C.E., Ruffini, R.: 1974, Phys. Rev. Lett. 32, 324.
6. Fomalont, E.B., Sramek, R.A.: 1976, Phys. Rev. Lett. 36, 1475.
7. Shapiro, I.I., et al.: 1977, J. Cheophys. Res. 82, 4329.
8. Williams, J.G., et al.: 1976, Phys. Rev. Lett. 36, 551; Shapiro, I.I., Counselman, C.C., King, R.W.: 1976, Phys. Rev. Lett. 36, 555.
9. See e.g.: Will, C.M. in "General Relativity: an Einstein centenary survey", Hawking, S.W. and Israel, W., editors, 1979, Cambridge University Press.
10. Taylor, J.H., Fowler, L.A., McCulloch, P.M.: 1979, Nature 277, 437.
11. See e.g.: Amaldi, E., et al.:
12. Ruffini, R.: 1979, Nuovo Cimento Lett. 26, 239.
13. Stephenson, C., Sanduleak, N.: 1977, Ap. J. Suppl. 33, 439.
14. Seaquist, E., et al.: 1978, IAU Circular n.3256.
15. Clark, D., Murdin, P.: 1978, Nature 276, 44.
16. Holden, D.J., Caswell, J.L.: 1969, MNRAS 143, 407.
17. Seward, P., Grindlay, J., Seaquist, E., Gilmore, W.: 1980, Nature 287, 806;
    Hjellming, R.M., Johnston, K.J.: 1981, Ap. J. 246, L141;
    Geldzahler, B., Pauls, T., Salter, C.: 1980, As. Ap. 84, 237 and references therein.
18. Seward, F., Page, C., Turner, M., Pounds, K.: 1976, MNRAS 175, 39P.
19. Ciatti, F., Mammano, A., Vittone, A.: 1978, IAU Circular, n.3305.
20. Ciatti, F., Mammano, A., Vittone, A.: 1980, As. Ap. 85, 14.
21. Margon, B., et al.: 1979, Ap. J. 230, L41;
    Bedogn, R., et al.: 1980, As. Ap. 84, L4.
    Abell, G., Margon, B.: 1979, Nature, 279, 701.
    Margon, B., et al.: 1979, Ap. J. 233, L63.
22. Margon, B., Grandi, S.A., Downes, R.A.: 1980, Ap. J. 241, 306 and references therein.
23. Allen, D.: 1979, Nature 281, 284;
    McAlary, C., McLaren, R.: 1980, Ap. J. 240, 853.
24. Milgrom, M.: 1979, As. Ap. 78, L9.
25. Fabian, A.C., Rees, M.J.: 1979, MNRAS 187, 13P.
26. Milgrom, M.: 1979, As. Ap. 78, L17.

27. Katz, J.I.: 1980, Ap.J. 236, L127.
28. Martin, P.G., Rees, M.J.: 1979, MNRAS 189, 19P.
29. Maraschi, L., Treves, A.: 1979, preprint.
30. Amitai-Milchrub, A., Piran, T., Shaham, J.: 1979, Nature 279, 505; Terlevich, R., Pringle, J.: 1979, Nature 278, 219.
31. Ruffini, R., Stella, L.: 1980, Nuovo Cimento Lett. 27, 529.
32. Lense, J., Thirring, H.: 1918, Phys. Z. 19, 156; Wilkins, D.: 1972, Phys. Rev. D5, 814.
33. Ruffini, R.: "Gravitationally collapsed objects", 1979, Proc. Second M. Grossman Meeting, in press.
34. This phenomenon has been widely observed in radio wave lengths (Maser). See e.g.: Moran, J.M., Radio observations of galactic masers, in: Frontiers of Astrophysics, ed. Avrett, E.H. (Harvard U.P., 1976). The multipole fragmentation of the maser sources observed in Astrophysical systems (see e.g.: Genzel, R., et al.: 1978, As. Ap. 66, 13 and references therein), could be originated by the fulfillment of the necessary conditions presented here and in ref. (33)).
35. Ruffini, R., Stella, L.: 1980, Phys. Lett. 93B, 107.
36. Fang Li Zhi, Ruffini, R., Stella, L.: "SS433: Background for a relativistic model", 1981, Vistas in Astronomy, in press.
37. Stoeger, W.: 1981, preprint.
38. See e.g.: Lightman, A.P., Shapiro, S.L., Rees, M.J.: 1978, in ref. (1), and references therein.
39. Crampton, D., Cowley, A.P., Hutchings, J.B.: 1980, Ap. J. 235, L131.
40. Stoeger, W.: 1981, preprint.
41. Rosner, R., Ruffini, R., Vaiana, G.: 1980, preprint.
42. Fang Li Zhi: 1981, MNRAS 194, 177.
43. Ruffini, R., Song,D.J., Stella, L.: 1981, As. Ap.,in press.
44. Collins, II G.W., Newsom, G.H.: 1980, IAU Circular n.3547; Margon, B., Anderson, S.: 1981, IAU Circular n.3626.