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Cir X-1 Revisited: 843 MHz Observations of Cir X-1 and G321·9−0·3*

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Abstract

New high-sensitivity results at 843 MHz are presented for the Circinus X-1 (Cir X-1) and SNR G321·9−0·3 regions. We summarise current observational data for Cir X-1 and discuss appropriate models.

1. Introduction

The discovery in the early 1960s of bright, discrete, X-ray sources showing periodic emission phenomena provided the first conclusive evidence for neutron stars in binary systems (Avrett 1976). With $\sim 5\times 10^{10}$ (Robinson-Saba 1983) binary stars in the Galaxy, one should expect to find many examples of a compact object in close proximity to a supernova remnant (SNR). Unfortunately, that appears not to be the case (Seward 1985) and examples of a close association are quite rare.

Cir X-1 is important, since it contains a compact star and since it lies only 25′ arc away from a well-delineated shell SNR. The best estimate of the distance to Cir X-1 of >8 kpc was derived by Goss and Mebold (1977) using HI absorption during a radio flare.

Cir X-1 must rank beside SS 433 (Ryle *et al.* 1978; Clark and Murdin 1978; Begelman *et al.* 1980) as one of the best astrophysical laboratories for testing models of binary star formation and emission. It emits variably on time scales of fractions of one second to days or years and it shows a well-defined ~16·6-day cycle in its emissivity.

Additionally G321·9−0·3 is an interesting SNR with strong bilateral symmetry in its shell shape—an important fact to be accounted for in models of SNR shell formation.

2. Past Observations and Interpretations

Cir X-1 was first seen as a strong, variable X-ray source (Nolan 1982; Baity *et al.* 1975; Wilson and Carpenter 1976) with a black-body temperature of $T = 3\cdot 7\times 10^7$ K ($kT = 3$ keV). Davison and Tuohy (1975) then suggested that the observed variability resulted from low-energy flaring or from changes in an absorbing medium surrounding the X-ray emission region. Van den Heuvel (1975) calculated that a stellar wind with

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a flow rate of $10^{-3} M_{\odot} \mathrm{yr}^{-1}$ could easily lead to densities which would completely absorb any low-energy emitted X rays.

The idea that a compact star moving in a variously absorbing medium could explain the observed X-ray variability from Cir X-1 was thus born.

In 1975 Clark *et al.* (1975*a*) published a major paper on measurements at 408 and 5000 MHz of southern SNRs in which G321·9−0·3 first featured. The integrated spectral index of the remnant was non-thermal, with $\alpha = -0\cdot34$. On the basis of the diameter of the G321·9−0·3 remnant and a Σ–D relationship they calculated the age of the SNR as 2×10^4 to 10^5 yr and its distance to be 5·5 kpc.

In 1975 Clark *et al.* (1975*b*) proposed in a related paper that Cir X-1 was a runaway binary star flung out of G321·9−0·3 during a supernova explosion and that the compact object in Cir X-1 would probably be in an eccentric orbit around a more massive primary star.

Through 1976 to 1978 Cir X-1 gained a certain notoriety as an X-ray variable emitter because of its large X-ray flares in the 3 to 6 keV energy range (Kaluzienski *et al.* 1976; Holt and Kaluzienski 1980). Abrupt drops in the X-ray emissivity on time scales of 0·07 per day each 16·6 days following flaring activity as strong as three times the intensity of the equivalent emission from the Crab nebula were observed.

Interest in Cir X-1 was heightened when Haynes *et al.* (1976), Whelan *et al.* (1977) and Thomas *et al.* (1978) reported variations in the radio emissivity of Cir X-1 on the same ~16·6-day cycle as that observed in the soft X-ray band. The radio spectrum was variable at the time of a flare and the evidence supported the idea that at lower radio frequencies, say below ~1 GHz, the emission region was optically thick during a radio outburst.

All observations up to that time indicated that Cir X-1 was a point-like object which remained unresolved by all instruments. However, Haynes *et al.* (1978) found a weak radio-emitting region around Cir X-1 which was extended in the direction towards the SNR G321·9−0·3. The full significance of this observation was certainly not realised at the time; only with the results of the present paper does the significance of the 1978 finding become apparent.

Cir X-1 is a variable radio, optical, infrared and X-ray emitter. The wealth of observational data enabled Murdin *et al.* (1980) and Haynes *et al.* (1980*a*) to propose a comprehensive model* for Cir X-1 in which a compact star, probably a neutron star, moves in an eccentric orbit around a large supergiant primary star. Mass dumping into the immediate neighbourhood of the compact star once per orbit was postulated to give rise to the observed variable emissivity.

Glass (1978) questioned the supergiant star hypothesis, arguing instead for a visually weak primary star supplying matter to an accretion disk around the compact star. The surface of the accretion disk supplied the optically variable emission in his model. Argue and Sullivan (1982) appear to have confirmed Glass's work and now suggest a B-type main-sequence star as an optical identification.

3. Observing Cir X-1 and G321·9−0·3 with the MOST

The small angular size of Cir X-1, its southerly declination and its variability make this object a prime candidate for study using the University of Sydney's Molonglo

* This model, which attempted to account for all of the time-variable phenomena seen, is referred to throughout the remainder of this paper as the MH model.

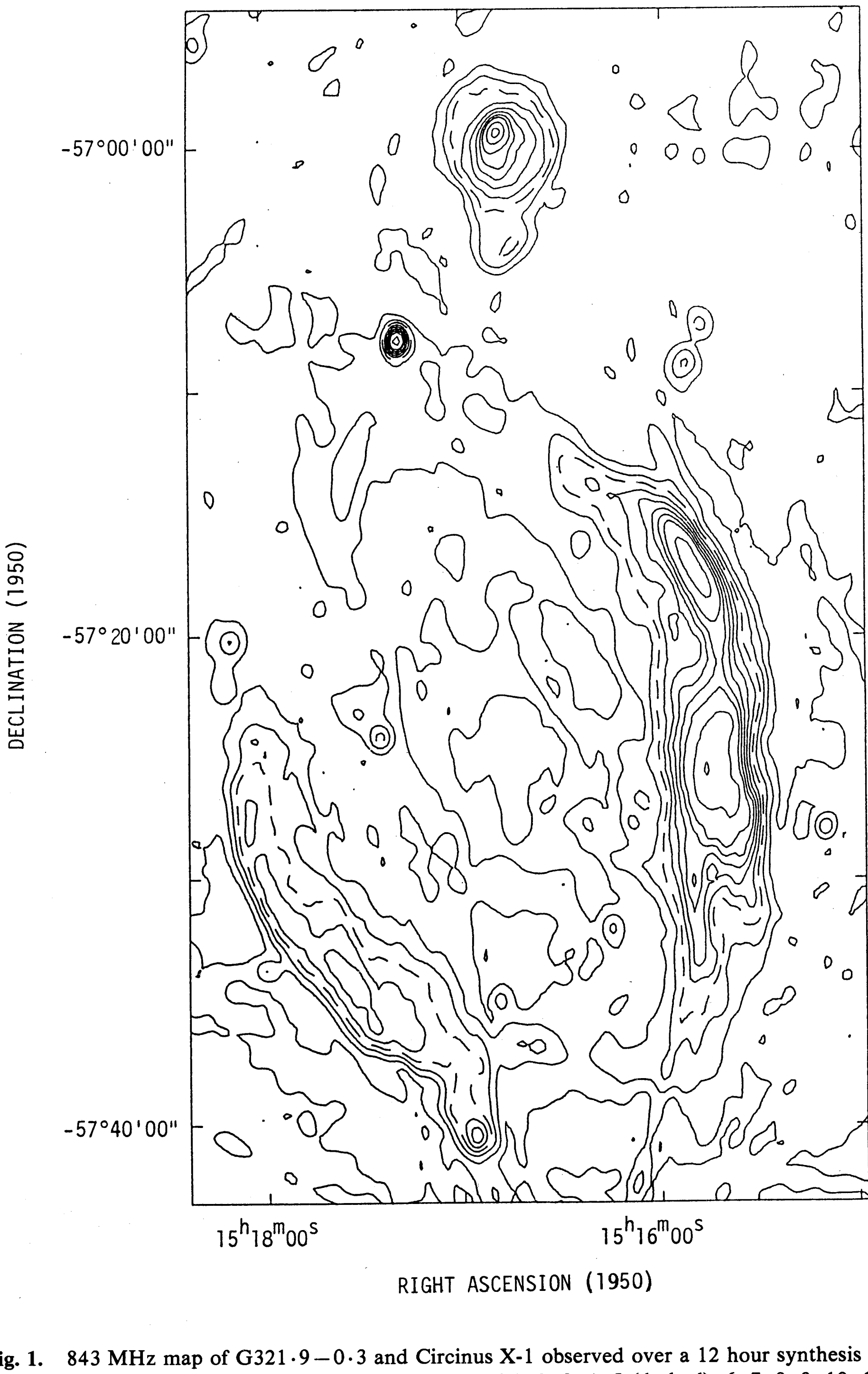

Fig. 1. 843 MHz map of G321·9 − 0·3 and Circinus X-1 observed over a 12 hour synthesis on 1983 October 5. Contours are shown at increments of 1, 2, 3, 4, 5 (dashed), 6, 7, 8, 9, 10, 12, 14 and 16 units, where one contour unit is equivalent to 4·46 mJy per beam area.

Observatory Synthesis Telescope (MOST). At a declination of $-57°$ the MOST has a theoretical beam size of 43″ arc (EW)×54″ arc (NS) (Mills 1981).

SNR G321·9—0·3 Map (Fig. 1)

Fig. 1 shows a combined map at 843 MHz of Cir X-1 and G321·9—0·3 observed over a 12 hour synthesis on 1983 October 5. After cleaning, the r.m.s. noise in the map is ~1·8 mJy per beam area. Synthesis telescopes like the MOST fail to detect low spatial frequencies (Mills 1981) and this leads to larger objects like SNRs appearing to have regions of low emissivity in their centres. We have attempted to

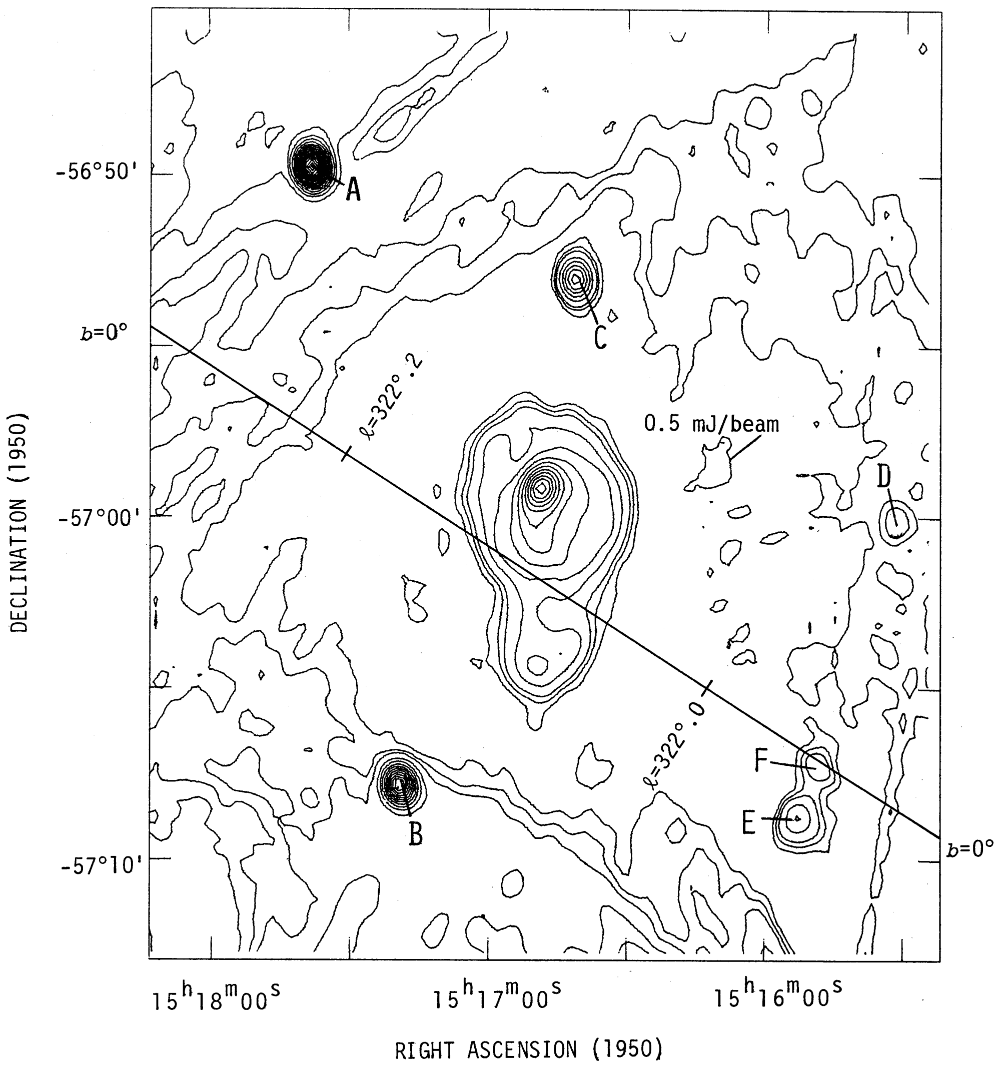

Fig. 2. 843 MHz map of Circinus X-1 obtained by integrating observations made over seven different dates as shown in Table 1. Contours are shown at levels of 1, 3, 5 (dashed), 10, 15, 20, 25, 30, 35, 40, 45, 50, 55, 60, 65, 70, 75, 80, 85 and 90 mJy per beam area.

overcome this effect for G321·9−0·3 by adding low-frequency information using techniques discussed by Roger *et al.* (1984).

Note that the periphery of the supernova shell has a much better defined outer edge in all directions than on the early maps of Clark *et al.* (1975*b*). The western and eastern sides of the shell, particularly south of the centre, show this well, and blending of the remnant into the background appears to be minimal.

At least one point source lies within the boundary of the SNR. The source near R.A. (1950) 15^h17^m, Dec. (1950) −57°07′, is a point-like object within the northern limit of the shell. A much weaker source, which may be a point source, lies near to R.A. 15^h17^m, Dec. −57°40′; this lies close to the shell boundary, or perhaps is even outside it. Both of these sources, although roughly in the direction of the shell, show no morphological relationship to structures in the shell. They are thus probably background objects.

From Fig. 1 we see that G321·9−0·3 has a well-defined axis of mirror symmetry. Models to explain such symmetry of radio supernova shells are developing (see e.g. Roger *et al.* 1987; Manchester 1987; and also Kesteven 1987, present issue p. 815).

The north-eastern limit of the emission along this axis lies close to the position R.A. $15^h17^m22^s$, Dec. −57°07′·5. If we take the southerly limit to be near R.A. $15^h16^m14^s$, Dec. −57°40′ it follows that the geometrical centre of the shell is then close to R.A. $15^h16^m49^s$, Dec. −57°24′; the axis of symmetry lies at a position angle of ~19°. The geometrical centre coincides with a hole in the observed emissivity from the shell.

Table 1. Cir X-1 observations made at the Molonglo Observatory Synthesis Telescope

Observation date	Field size (′ arc)	Orbital phase[A] (day)
1982 Apr. 18	44×83	0·2
1982 Apr. 25	44×83	7·2
1982 Apr. 26	44×83	8·2
1983 Mar. 24	66×124	9·8
1983 Apr. 12	22×42	1·7
1983 Oct. 05	66×124	9·0
1985 Jun. 30	22×42	0·2

[A] Based on the primary 16·6-day period.

Cir X-1 Map (Fig. 2)

Fig. 2 shows a deep map of just the Cir X-1 region obtained by integrating the seven maps summarised in Table 1 to form a final map. The r.m.s. noise on this field is 0·8 mJy per beam area.

The Cir X-1 complex extends over a right ascension range of $15^h16^m28^s$ to $15^h17^m08^s$ and a declination range of −56°56′·3 to −57°06′·3. We have discussed this morphology in detail elsewhere (Haynes *et al.* 1986) but it is important to this review to mention the data here as they relate to the morphology of the SNR G321·9−0·3.

The emission in the Cir X-1 complex may be interpreted as coming from four regions:

(i) The plateau—exemplified by a rather smooth, extended distribution of emission ~ 10 mJy per beam area in intensity.

(ii) An additional emitting region with peak intensity ~ 8 to 10 mJy per beam area superimposed on this plateau near to R.A. $15^h 16^m 49^s$, Dec. $-57°04'\cdot 5$.

(iii) The radio-variable point source which in Fig. 2 is coincident with Cir X-1 and has a flux of ~ 50 mJy per beam area. (Note that the flux of this component in the map of Fig. 2 is determined by the activity of Cir X-1 on the days on which the seven different maps were made.)

(iv) A feature $\sim 1'\cdot 5$ arc south of Cir X-1 provides ~ 25 mJy per beam area of flux to the map.

A VLBI measured position of Cir X-1 placed the flaring component of Cir X-1 at R.A. $15^h 16^m 48^s\cdot 37 \pm 0^s\cdot 04$, Dec. $-56°59'11''\cdot 61 \pm 0''\cdot 3$ (Preston *et al.* 1983) and this coincides, within the positional uncertainties of the MOST map, with the peak of emission we observe.

There is a tantalising alignment in the positions of the source components in the Cir X-1 complex and the centre of the SNR centre. The position of Cir X-1 itself, the direction of the extension in the emission towards G321·9−0·3 and the geometrical centre of the G321·9−0·3 shell all lie on the same line. It seems that this alignment has not occurred by chance and must now be considered important to any model attempting to explain the formation of Cir X-1.

If the extension in the plateau towards G321·9−0·3 is a 'fossil' wake of emission as Cir X-1 moved north away from the SNR, as first suggested by Haynes *et al.* (1978), then Fig. 1 provides circumstantial evidence that Cir X-1 could have originated from near the centre of the supernova explosion which created G321·9−0·3.

The point source already noted near R.A. $15^h 17^m$, Dec. $-57°40'$ also lies very close to the same line connecting Cir X-1 to the geometrical centre of the shell. It is tempting to speculate that this source may have a direct relationship to Cir X-1.

There is some indiction (see Fig. 2) of a 'jet-like' ridge structure extending from the compact centre of the Cir X-1 complex towards G321·9−0·3. This structure has the same morphological shape as that defined by the outer envelope of the Cir X-1 complex already discussed. The resolution of the current observations is probably not good enough to warrant assigning a common cause to these two features. Nevertheless, the similarity in shape between the inner extension or jet-like feature and the outer boundary of the complex seems important to the processes occurring either internally within the complex or, because of the relationship between Cir X-1 and G321·9−0·3, to processes that have occurred in G321·9−0·3 in the past.

When the Australia Telescope (Frater 1984) is complete (in about 1989) we propose to investigate this jet-like feature near to R.A. $15^h 16^m 48^s$, Dec. $-57°01'$ with higher angular resolution, since it has some similarities to jet structures seen in SS 433 (Margon 1982). At this time the feature can only be interpreted as being a result either of a jet of emission out of Cir X-1 or of the presence of another and weaker point-like source situated $\sim 1'\cdot 5$ arc to the south of Cir X-1.

The MOST results indicate that the variable radio source in the complex is a point source. This agrees with earlier VLBI results of Preston *et al.* (1983), which showed a point-like, variable radio source embedded in an unchanging region of emission.

We have compared the maps of Cir X-1 listed in Table 1 using the map made on 1985 June 30 as a reference. The 1985 June 30 map was subtracted from each of the other six maps made between 1982 April 18 and 1983 October 5. Only one major feature in the vicinity of the Cir X-1 complex remained. It is a point source centred on the position of Cir X-1 itself. There is no sign of variability in any other regions of the Cir X-1 complex.

Table 2. Sources in the immediate neighbourhood of Cir X-1 (see Fig. 2)

Source no.	Position (1950) R.A. h m s	Dec. ° ′ ″	Intensity (mJy per beam)	Extension (″ arc)
A	15 17 38·0	−56 49 45·7	87·9	44×57
B	15 17 18·9	−57 07 52·4	58·6	44×54
C	15 16 41·2	−56 53 03·3	34·4	43×58
D	15 15 31·7	−57 00 06·4	6·6	45×54
E	15 15 52·2	−57 08 49·0	16·7	61×79[A]
F	15 15 49	−57 07 18	~6	44×54

[A] Source is extended. The telescope beam is 43′×54′ arc.

Six sources other than those in the Cir X-1 complex are present in Fig. 2. Position and flux information for these sources are shown in Table 2. Note that the sources labelled E and F in Table 2 together morphologically resemble a classical double radio source. This may well be a background galaxy being seen through the Milky Way and as such may warrant further study.

4. New Data and the MH Model

The MH model for Cir X-1 provides a basis from which to discuss the new results of this paper and other, particularly X-ray, data obtained since 1978. Many of the basic ideas behind the MH model, particularly about how radio emission is generated and varies with time, remain unchanged as a result of the last decade of data acquisition.

The MH model postulated a binary star system in which a compact, probably neutron, star (radius $\sim 10^4$ m), revolves about a more massive primary (radius $\sim 10^{10}$ m) in an eccentric orbit. Mass transfer at a rate of $\sim 10^{-6}$ to $-10^{-5} M_\odot\ \mathrm{yr}^{-1}$ over a period of three days near periastron passage time is sufficient to power variable emission processes. It is the mass transfer which generates variable radio, X-ray, optical and IR emission (see Fig. 3).

The only other comprehensive model proposed for Cir X-1 is that by Fransson and Fabian (1980). They suggested that a stellar wind from the supergiant primary star is strongly affected by the luminous Cir X-1 X-ray source. They assumed a complex structure for the stellar wind to account for the abrupt X-ray transition, the residual X-ray flux, the IR and the radio flaring as the X rays cut-off. However, strong support for that model has not been forthcoming, and Nicolson *et al.* (1980) and Robinson-Saba (1983) instead preferred the MH model with modifications to explain their data.

A new analysis of the OSO-8, HEAO-1 and HEAO-2 (Einstein Observatory) X-ray data of Cir X-1 (Robinson-Saba 1983) concluded that the cold plasma absorption mechanism of the MH model was inadequate alone to explain all types of X-ray events seen. The rate of change of photoelectric absorption in the stellar wind is probably too gradual to account for fast X-ray phenomena observed in the 3 to 6 keV energy range. A highly variable, mass transfer rate from the primary to secondary

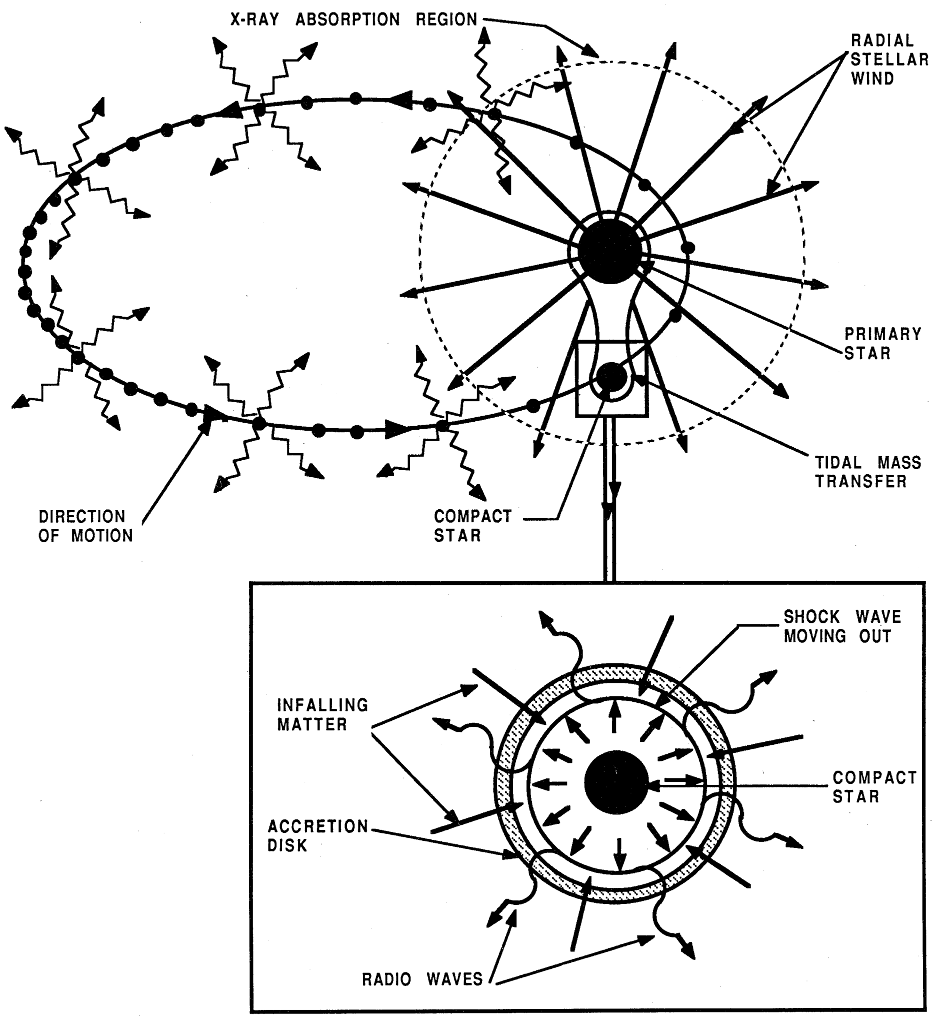

Fig. 3. Pictorial view of the proposed binary star model of Circinus X-1.

star in a 1000 $\mathrm{km\,s^{-1}}$ stellar wind near periastron passage time is, however, still appropriate. A better model must also include the effects of ionisation of the stellar wind material by the X-ray source itself, combined with a changing energy spectrum of the X-ray emission.

Quasi-periodic X-ray emission behaviour on time scales of parts of a second to seconds (Hasinger 1985; Stella 1985; Lamb *et al.* 1986) are taken to be related to transient events in the outer parts of the thick accretion disk and to inhomogeneities in the accretion flow, giving rise to time-variable, but erratic X-ray emission. Nevertheless, high column densities giving absorption of the soft X-ray flux do seem to be present at times. Thus, the photoelectric absorption MH model still has some validity in explaining the X-ray emission, but intrinsic X-ray source changes could dominate any absorption effects that may be present in the medium surrounding the compact star, and Compton scattering of either the radio or infrared flux might also make an important contribution to the quiescent X-ray flux.

Chaotic intensity and spectral fluctuations similar to those seen in black hole candidates such as Cyg X-1 or GX339−4 are definitely also seen on very short time scales in Cir X-1 (Robinson-Saba 1983); this may argue for the compact star to be a black hole instead of a neutron star.

Radio observations of flares from Cir X-1 have been difficult to obtain since 1979. The highly variable radio emitter which frequently flared each 16·6 days from near 50 mJy to ~1 Jy between 1977 and 1979 has been rather less active in recent years. The 5 GHz emission from Cir X-1 has been monitored since 1977 but over these nine years the source has undergone only two extended flaring periods. G. Nicolson (personal communication), using a 26-m telescope in South Africa, has obtained 2·3 and 5 GHz measurements through the most active of these radio emission cycles since 1978. There is some evidence from this to indicate a possible change in the binary period of the star system—a phenomenon predicted by Haynes *et al.* (1978). The best estimate of the ephemeris for 5 GHz flaring is now set as

$$E = \text{JD}\ 2444618 \cdot 23 + (16 \cdot 5696 - 0 \cdot 0000489 N) N,$$

where N is the cycle number since 1981 January 14. This ephemeris is based on data over 88 flare cycles up until 1985 January 17.

The best estimate leads to a change in the period of ~0·1 h over a four-year period. Is this evidence for circularisation of the orbit as predicted by the MH model? That is not yet clear, so more observations must be made in the next few years.

VLBI measurements of Cir X-1 at 2·3 GHz are available (Preston *et al.* 1983). A flaring source of angular size between 0″·0015 and 0″·015 arc was found (equivalent to between 15 and 150 AU at 10 kpc). In the same region as the flaring point source an unvarying source with a scale size of 0″·2 arc was found (equivalent to >2000 AU)—a value greater than 3×10^{14} m and one much larger than that proposed in the original MH model for the size of the semi-major axis ($\sim 7 \times 10^{10}$ m) of the orbit. The MH model proposal that the quiescent radio emission from Cir X-1 came only from the accretion disk region around the compact star is thus wrong.

The MH model was invoked to explain only the variable emissions assumed to arise from a binary star system. The discovery that Cir X-1 is embedded in a non-varying, complex region of emission is new. Exactly how this relates to the MH model for the variable source is not yet clear.

The jet-like feature seen in Fig. 2 south of Cir X-1 and the shape of the outer envelope of the Cir X-1 complex seem unrelated to the MH model. This does not, however, contradict the binary star hypothesis or the emission-generation mechanisms proposed in the model, since structures directly related to the MH model at a distance of 10 kpc will be too small to be resolved using single instruments; only radio VLBI techniques may provide the necessary resolution for this.

5. An Updated Model

The idea of a binary star system generating X-rays, radio and optical emission remains intact with recent data. The eccentricity of the orbit of the compact star about the primary star $e = 0 \cdot 7$ still seems valid on the basis of the X-ray and radio bursts showing the ~16·6-day periodicity.

A new optical candidate was proposed for Cir X-1 by Argue and Sullivan (1982)—a star $\sim 1''$ arc south of the original candidate (star L of Whelan *et al.* 1977) which appeared to coincide better with the flaring radio source detected with radio VLBI methods (Preston *et al.* 1983). Thus the original proposition that the primary star is a $20 M_{\odot}$ early-type supergiant seems inappropriate, and the most likely candidate for the primary star is now a B-type main-sequence star or a later-type more evolved star. Robinson-Saba (1983) suggested a mass ratio of the primary star (M_p) to the compact star (M_c) of ~ 5.

There is 'seconds of time' flickering in the X-ray emissions, which seem to indicate an effective emitting region ~ 40 km in size (Robinson-Saba 1983). Since this size is somewhat larger than that expected for a neutron star of diameter $\leqslant 10$ km, it is suggested that the compact object may be a black hole surrounded by an accretion disk. In that case the emission comes from the accretion disk region and not the surface of the compact star.

No radio or optical data exist yet to test this hypothesis. However, the neutron star or black hole hypotheses do not affect the basic MH binary star idea.

Mass transfer in the model was assumed to occur though Roche lobe overflow and accretion out of the stellar wind from the primary star. This model seems equally applicable today, but the results of X-ray observations seem to indicate a preference for Roche lobe overflow as the transfer mechanism in order to explain the short time variability seen.

Some photoelectric absorption effects, as postulated in the MH model, are still supported, but the X-rays generated probably ionise the stellar wind of the primary star and thus affect the absorption process. The multi-component X-ray spectrum observed to vary on time scales as short as fractions of a second demand a model in which the accretion disk around a $3 M_{\odot}$ compact star becomes a prime requirement of the model. Here X rays and possibly also optical and infrared emissions are generated. X-ray flares coming from regions with scale sizes of $\leqslant 10^{13}$ cm are seen, and absorption effects cannot, by themselves, explain this or the complex spectral/temporal evolution seen in the X-ray emissions (Robinson-Saba 1983).

The new radio maps of Cir X-1 in this paper showing a complex region of emission around Cir X-1 cannot yet be adequately explained in terms of the MH model, or a modified form of it, but the runaway binary idea seems still the most likely model relating Cir X-1 to G321·9−0·3. The extended plateau of emission around Cir X-1 would then be interpreted as the result of the fossil wake of emission as the binary star moved north away from the SNR.

The extension to the south of Cir X-1 found by Haynes *et al.* (1978), and now confirmed by the MOST results, suggests a fossil wake as the runaway binary moved north out of the SNR. On the basis of the masses of the two stars in the MH model, Haynes *et al.* (1978) rejected the runaway binary hypothesis on energetics arguments since a $20 M_{\odot}$ star ejected out of the SNR at the required velocity of $\sim 1300\ \mathrm{km\,s^{-1}}$ would require significantly more energy than the $\sim 10^{50}$ erg of a typical supernova. The new evidence of a lower mass for the primary star (Argue and Sullivan 1982) increases the possibility that Clark *et al.* (1975*b*) were correct in suggesting a runaway binary hypothesis, but the evidence is not yet compelling.

Argue and Sullivan (1982) found an Hα emission line velocity in their optical counterpart for Cir X-1 with velocities as large as 200–300 $\mathrm{km\,s^{-1}}$. This lends support to the runaway binary idea, but this velocity is considerably lower than the

1300 km s^{-1} needed on the basis of the age determined from the diameter of the SNR G321·9−0·3 shell remnant (Haynes *et al.* 1978). Nevertheless, the measured radial velocities from Argue and Sullivan may only be a small fraction of the transverse velocity of the object.

The complex surrounding Cir X-1 is a strange new piece of the jigsaw puzzle which we have discussed in detail recently (Haynes *et al.* 1986), but data on this appear to add little to the model for Cir X-1 itself and the MH model for the generation of radio emission is still applicable.

6. Conclusions

In this paper we have reviewed current models for Cir X-1 and looked at the relationship between Cir X-1 and the SNR G321·9−0·3. New 843 MHz surveys of the region near Cir X-1 have been presented and we find that Cir X-1 lies in an extended complex of size 10′ arc, 25′ arc to the north of G321·9−0·3. These data, together with recent optical, infrared, and X-ray data, are compared and proposals for a current model for Cir X-1 presented.

It is clear that the relationship between Cir X-1 and the SNR G321·9−0·3 remains an important area for study. The objects are important not only to the models for binary star systems, accretion disks around compact objects, and evolutionary models of supernovae, but also to the fundamental physics of creating X-rays, optical emission and radio emission.

In the next few years there remain a number of observational tests of the model for Cir X-1 that need to be done:

(i) If Cir X-1 is a young object ($\leqslant$1000 yr) then its ~16·6-day emission period will change as the orbit of the compact star circularises over a time of 500 yr. The ephemeris of its X-ray and radio bursts should continue to be monitored.

(ii) The line of apsides of the elliptical orbit will precess with a period of roughly 5–50 yr, giving rise to long-period emissivity changes and the binary light curve should evolve on a time scale of years (precession in the system may be as much as $-10°$ yr^{-1}).

(iii) Periastron passage distance will move out only by a few times 10^{10} m before the mass transfer rate will change dramatically in a time scale of ~250 yr. Radio flaring will diminish and lower frequency radio emission will become more easily detectable as the optical depth of the region falls.

(iv) Long-baseline-interferometry measurements should be used to check for proper motion of Cir X-1 relative to G321·9−0·3. This experiment will test the runaway binary hypothesis and perhaps settle the debate on the origin of Cir X-1.

The MOST results of this paper are, if anything, broadening the scope of future measurements that should be made of the Cir X-1 complex. For example, sensitive maps are now required to determine the radio spectrum of the plateau region and the other features of the complex. Radio recombination line measurements over the complex are also needed to test for the presence of ionised hydrogen in the neighbourhood of Cir X-1.

The optical object currently associated with the X-ray star system also needs further investigation.

Acknowledgments

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