ON THE LOCATION OF RADIO AND X-RAY EMISSION IN THE ALGOL SYSTEM

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The radio behaviour of Algol at centimeter wavelengths has been reviewed by Hjellming (1976, 1977), and by Gibson (1976). The observed radio emission can be roughly divided into two types: a quiescent type and a flare-like or outburst type. The quiescent emission is characterized by a low flux density, usually between 20 - 50 mJy, and a nearly flat spectral index. The latter means that the value of the flux density is nearly independent of wavelength. The variations in flux density, when present, are gradual and have a time scale on the order of days. The flare-like behaviour shows rapid and large changes in flux density. The amplitude of an outburst is wavelength dependent, the shorter wavelengths having larger amplitudes. Woodsworth and Hughes (1976, hereafter WH) attributed the two types of behaviour to two physically distinct sources. The quiescent type of emission is produced by a very large, thermally emitting cloud which surrounds the eclipsing system. The flare-like variations are due to a synchrotron source that is associated with mass loss. Their model is inconsistent with optical and X-ray information concerning the Algol system. However, a model with two radio components can be modified to agree with other types of data.

Guinan _et_ _al_. (1976) detected a disk of material surrounding Algol A. The radius of the disk was estimated to extend to the Roche lobe of Algol A. Material from the disk could be lost from the binary system via the outer Lagrange point, L_3. The amount of material that is ejected from the system is not known. However, it is likely that some material does escape, and could form a cloud of ionized hydrogen that surrounds the binary. WH tried models for this cloud that have density distributions of the form $n_e \propto r^m$. The models were constrained by the condition that the cloud must be optically thin, and that the maximum radius, deduced from the time scale of variability, must be roughly one light-day. Two solutions were found: $m = -1$ with $T_e \geq 10^5$K, and $m = -1.5$ with $T_e > 10^6$K. These solutions were rejected by WH because a stellar wind was considered to be the only possible mode of mass ejection, and a wind would have a $m = 2$ distribution. However, a cloud formed by mass loss from the L_3 point is not required to have this distribution. Thus either of the above solutions is possible. The cooler model of uniform density

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that was adopted by WH is harder to accept. Also, the suggestion that the variations in the free-free emission from the cloud are caused by changes in the ionizing flux from the stars seems very unlikely. No large intrinsic variations in the ultraviolet have been observed by Eaton (1975), or by Chen et al. (1977). A possible mechanism, related to the flare activity, that explains the radio variations and the high temperature of the cloud will be described below.

Pooley and Ryle (1975), and Gibson (1976) found no correlation between the orbital phase and the occurrence of a flare. Gibson (1976) found a correlation between the maximum flux of a flare and the spectral index. Also, he noted that 6 of the 9 strongest flares occurred near secondary eclipse. Assuming that all flares are caused by the same physical mechanism, then differences in flare amplitude would be due to differing numbers of particles involved, and by possible eclipse or other geometrical effects. Bielicki et al. (1974) found for a binary similar to Algol, that the disk material is loosely bound. An increase of about ten percent in the kinetic energy of a particle in the disk will eject the particle. The mass loss rate from Algol B could be irregular. Short term random increases in the mass loss could transfer enough kinetic energy to eject a sizeable fraction of the disk material. The ejected material would hit the inner regions of the cloud, and a compressional shock would form. In the impact region the material becomes optically thick, and some acceleration process supplies energy to the electrons. Gyrosynchrotron emission could occur and form a flare. The turbulence of the material in the impact zone causes the magnetic field to be randomly oriented, and the flare would have no net polarization. This is in agreement with the observations of Gibson et al. (1975). An observer is looking directly at the impact area between phases 0.6 - 0.7. This region is eclipsed by Algol A and B during phases 0.04 - 0.15. The impact area is close to the location calculated by Bielicki et al. (1974). If the flare source expands during an outburst, then the source will have a density gradient. This implies that the size of the source is wavelength dependent. The longer wavelength radiation will be emitted from the less dense, outer layers, and the shorter wavelength radiation will be emitted from the denser, inner layers. An eclipse of the flare source will be deeper at shorter wavelengths because the smaller size implies that a larger percentage of the flux at that wavelength will be blocked from view. This could explain, at least partially, the peak flux density and the spectral index of a flare. An eclipse would explain the very rapid decline and the inverted spectral index of the flare that was observed at phase 0.04 on July 11, 1972 by Pooley and Ryle (1973) and by Hjellming et al. (1972). Also, an eclipse could also explain the large differences in the expansion velocities, obtained by VLBI observations, of two flares (B. Clark et al., 1975; T. Clark et al., 1976). The first flare listed in the table below was observed during an eclipse. In their analysis both groups assumed that changes in the observed visibilities were only caused by changes in the brightness distribution due to expansion. However, this is not true for the first flare because an eclipse also changes the brightness distribution. Thus, for the first flare the value determined for the expansion velocity is spurious.

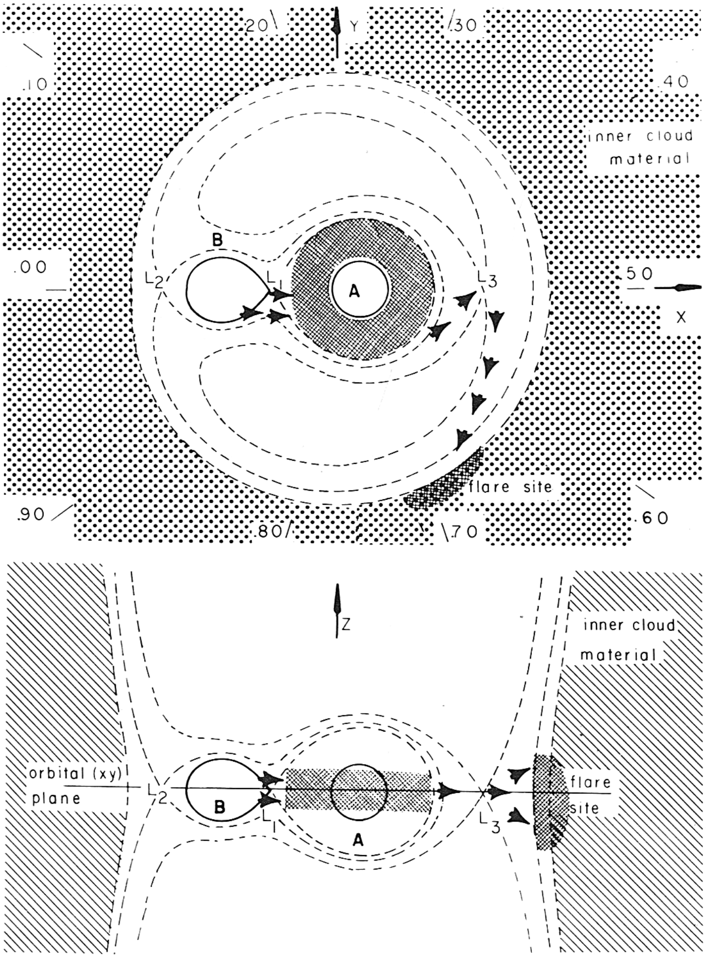

Figure 1. (Top)Orbital plane view of Algol, The indicated flare site is approximate. The enhanced mass flow is shown schematically by arrows. (Bottom) View of Algol perpendicular to the orbital plane. An arbitrary disk thickness is shown.

Table 1
Very Long Baseline Interferometry of Algol at 3.8 cm

Date	Angular dia.* (milli-arc sec)	S_{max} (Jy)	Velocity Expansion (km/sec)	Orbital Phase	Notes
May 4-5, 1974	3.6 - 4.6	0.6	500 - 1000	.02 - .15	1
Jan 15-16, 1975	1.2	1.	<100	.42 - .53	2

Notes: 1. B. Clark _et al_. (1975)
2. T. Clark _et al_. (1976)

*Gaussian brightness distribution assumed.

The decay of a flare could release energetic (faster than thermal) electrons which interact with the cloud material. This would heat the cloud, and produce nonthermal bremstrahlung radiation at radio (the observed quiescent emission) and at X-ray wavelengths. The variability is caused by variations in the numbers of the "fast" electrons released from different flares. The energy distribution of the X-ray emission (Harnden et al. 1977) indicates temperature of (3 - 6) x 10^6 K which is consistent with the values needed for the quiescent emission. Hence, both of them could originate in the cloud. Takakura (1975), for example, discusses physical mechanisms to produce both solar and X-ray flares. Analogous mechanisms, operating over much larger scales, may be at work in the circumstellar material in the Algol system.

More observations are needed to further out understanding of Algol. In particular radio observations should be made to check the various correlations mentioned above. Multi-wavelength observations of eclipses of the flare source would be very valuable. Since the depth of an eclipse depends on wavelength, viewing angle, and the surface brightness of the flare source (the latter two being independent functions of time), and since flares occur randomly, observed eclipses will be rare. The nonspherical expansion of the flare source should be detectable by means of VLBI. Optical observations of dilution sensitive lines should be made. Lines formed in densities $<10^{11}$ cm^{-3}, such as HeI 10830 A, would be produced in the same region as the radio emission. Also, coordinated observations in different spectral regions may reveal new insights.

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