RADIO OUTBURSTS FROM CYGNUS X-3

V. A. HUGHES, M. R. VINER, and A. WOODSWORTH
Queen's University, Kingston, Ontario, Canada

Abstract. The variation in flux density obtained at 10522 MHz for Bursts 2, 3, and 4 is compared with that obtained by others at frequencies down to 365 MHz. The bursts appear to have a quasi-periodic modulation with a period of 3–4 h, which is different from the 4.8-h periodicity observed at X-ray and infrared wavelengths. The modulation is attributed to a fluctuation in the size of the expanding cloud of particles produced by either an instability in the atmosphere of Cygnus X-3 or by a built-in instability in the cloud itself.

The first observed giant radio outburst from Cygnus X-3 (Burst 1) occurred on September 2, 1972 (Gregory *et al.*, 1972a). In the period September 20–30, three further outbursts (Bursts 2, 3, 4) were observed by a large number of observatories and provide the most comprehensive frequency coverage yet obtained for any comparable event. The variation in flux density obtained by us at the Algonquin Radio Observatory at 10522 MHz is shown in Figure 1 and is compared with the flux densities as published by others in Figure 2. Since the maximum period for continuous monitoring at any one observatory is typically about 12 h, an attempt has been made to interpolate the values for flux density between observing periods by means of broken lines. Though no great reliance can be placed on detailed values for flux density for these latter periods, they nevertheless show the general features of the bursts. Typical absolute values as shown by the solid lines are better than about 5%, or ± 0.1 Jy, though in most cases relative variations in intensity are far less uncertain.

Burst 1 was originally attributed to the result of an expanding cloud of relativistic particles (Gregory *et al.*, 1972b). On this assumption, when the source was first ob-

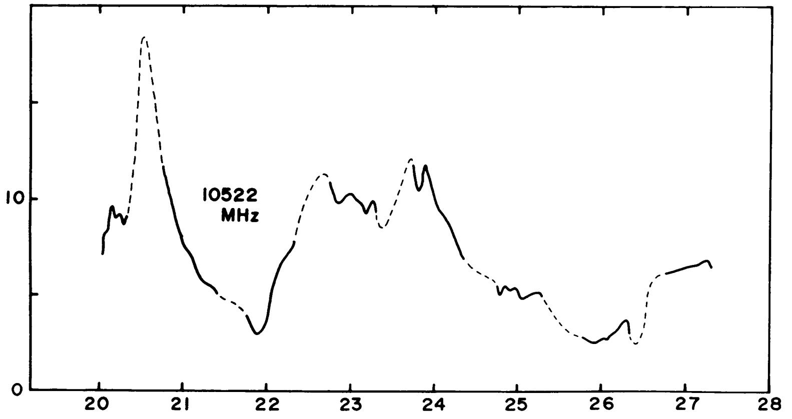

Fig. 1. Flux density from Cygnus X-3 at 10522 MHz for Bursts 2, 3, and 4.

F. J. Kerr and S. C. Simonson, III (eds.), Galactic Radio Astronomy, 401–405.

https://doi.org/10.1017/S0074180900026723 Published online by Cambridge University Press

served at 10522 MHz, its diameter was about 50 AU on the assumption that the magnetic field was about 14 G, though more recent estimates of the magnetic field could reduce this to about 10 AU.

There are a number of differences between the second series of bursts and Burst 1.

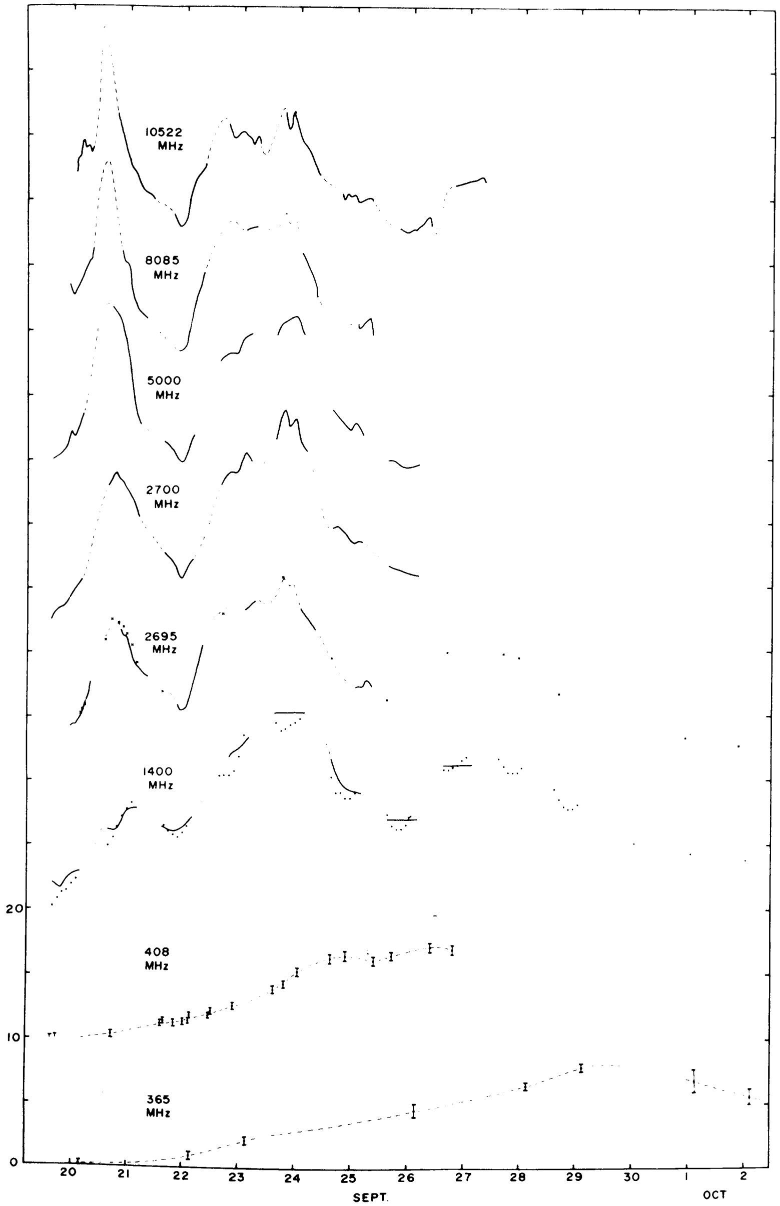

Fig. 2. Variation in flux density from Cygnus X-3 at 10522 MHz compared with that obtained by Hjellming and Balick (1972) at 8085 and 2695 MHz, Bransen *et al.* (1972) at 5000, 2700 and 1400 MHz, Braes *et al.* (1972) at 2695 and 1400 MHz, Anderson *et al.* (1972) at 408 MHz, and Bash and Ghigo (1973) at 365 MHz.

Burst 2 is similar in shape, but its duration is a factor of 2–3 times shorter. Bursts 3 and 4 are more complicated, showing a superimposed modulation. In addition, the rate of drift from high to low frequencies for Bursts 2, 3, and 4 is a factor of about 2 smaller than for Burst 1.

It was suggested by Peterson (1972) that an alternative explanation for Burst 1 was a process of injection of relativistic particles of specific duration such that at no time was the region optically thick to synchrotron radiation. However, attempts to fit this model to Burst 2 using a least squares fit were not satisfactory. It has not been found possible to reproduce the high peak, in particular at 5000 MHz, while still maintaining the observed decay time. The original model of the expanding cloud still seems attractive since it explains both the decay phase of the burst and the change in spectral index for both Bursts 1 and 2, and there is insufficient evidence to show that the later bursts could not be explained in this way. In addition, further confirmation comes from long-baseline observations of the burst on September 24 which show that the source had a size of at least 100 AU, assuming a distance of 10 kpc (Hinteregger *et al.*, 1972).

A further characteristic which was evident in the initial outburst, but which is far more pronounced in the later bursts, is a fluctuation or modulation having a quasi-period of 3–4 h, and which is apparent in Figure 1. The amplitude of the modulation amounts to about three times the uncertainty in the relative value for flux density and, as can be seen in Figure 2, has a counterpart at the lower frequencies. On the assumption that the radiation is produced by a cloud of relativistic particles, such a modulation could be the result of a change in the total number of particles, as would be produced by a series of injections or by an acceleration mechanism acting over the cloud, or of an oscillation in the size of the cloud with corresponding change in magnetic field.

If the fluctuation is the result of a series of injections, then it seems a little strange that, for instance, in Burst 3 the individual injections would just be sufficient to maintain the overall amplitude to within $\pm 10\%$ over a period of about 2 days, when large individual injections such as produce Bursts 1 and 2 are known to exist. It is also difficult to see how an injection mechanism can act almost instantaneously over the whole of the cloud, which must be the case if the estimates of the size of the cloud when seen initially are correct. One possibility is that the expanding cloud is situated in a region of a fluctuating magnetic field, as could be produced by an instability, and that the cloud itself then undergoes oscillation in size. In this case, it is easy to show that under the normal assumptions that the relativistic gas behaves adiabatically, that magnetic flux is conserved and that the cloud has radial oscillations, the flux density, S, will vary with the radius, r, of the cloud as

$$S \alpha r^3, \qquad \tau > 1,$$
$$S \alpha r^{-2\gamma}, \qquad \tau < 1,$$

where it is assumed that the electrons have a power law distribution of energies with an exponent of $-\gamma$. It is also assumed that any acceleration of particles due to the betatron process is negligible. Hence it is expected that at some frequency, namely where $\tau = 1$, the modulation will reverse in phase. There is some evidence that the fluctuations at 1400 MHz are in antiphase with those at higher frequencies, suggesting that at these points τ becomes equal to unity at a frequency of about 2000 MHz. If this is correct, then the radio outburst can be explained in terms of an event which causes to be emitted a comparatively dense cloud of relativistic particles, carrying with it some of the background magnetic field. The cloud moves outwards through a region of instability which takes the form of fluctuations in pressure or magnetic field or both, and which produces a small quasi-periodic modulation in the radius of the cloud, or the cloud itself has its own built-in instability. At the same time, the cloud is expanding such that after a certain time radiation starts to appear, first at the higher frequencies, as in the case of the van der Laan model (van der Laan, 1966), but with superimposed modulation. After a certain distance, the cloud will have moved through the region of instability, or the built-in instability becomes damped out. In either case, the modulation disappears and the cloud continues to expand. It is of interest that the presence of a region of instability suggests that Cygnus X-3 may have a comparatively extensive atmosphere with parameters such that it can sustain oscillations with a period of 3–4 h; more likely the cloud itself has the instability.

Both the X-ray and infrared observations show the presence of a 4.8 h periodicity (Parsignault *et al.*, 1972; Canizares *et al.*, 1973). It is suggested in the two preceding papers that they are both associated with one component of a binary system which consists of a hot plasma of radius about $1 R_{\odot}$ and that the magnetic field associated with the X-ray source is about 5×10^9 G. Attempts have been made to extract a 4.8 h periodicity from the radio modulation, but without success. It appears that the radio emission is not related directly to the X-ray and infrared emissions, though minor variations in the intensity of the latter may indicate that a radio outburst may occur later. The proposed model is consistent with these facts when we also consider the dimensions associated with the different events. The X-rays and infrared appear to originate from a small region with dimensions much less than about 10^{11} cm. The radio emission comes from a cloud of particles which has a size when first seen of at least 10^{14} cm and hence must be at least this distance from the X-ray and infrared source.

Acknowledgements

We thank H. M. Bradford and D. S. Retallack for help in taking the 10522 MHz observations and W.-Y. Chau and R. N. Henriksen for helpful discussions.

This work has been carried out under an Operating Grant from the National Research Council of Canada. The latter also operate the Algonquin Radio Observatory.

References

Anderson, B., Conway, R. G., Davis, R. J., Packham, R. J., Richards, A. C. S., Spencer, R. E., and Wilkinson, P. N.: 1972, *Nature Phys. Sci.* **239**, 117.

Bash, F. N. and Ghigo, F. D.: 1973, *Nature Phys. Sci.* **241**, 93.
Braes, L. L. E., Miley, G. K., Shane, W. W., Baars, J. W. M., and Goss, W. M.: 1973, *Nature Phys. Sci.* **242**, 66.
Bransen, N. J. B. A., Martin, A. H. M., Pooley, G. C., Readhead, A. C. S., Shakeshaft, J. R., Slingo, A., and Warner, P. J.: 1972, *Nature Phys. Sci.* **239**, 133.
Canizares, C. R., McClintock, J. E., Clarke, G. W., Lewin, W. H. G., Schnopper, H. W., and Sprott, G. F.: 1973, *Nature Phys. Sci.* **241**, 28.
Gregory, P. C., Kronberg, P. P., Seaquist, E. R., Hughes, V. A., Woodsworth, A., Viner, M. R., and Retallack, D. S.: 1972a, *Nature* **239**, 440.
Gregory, P. C., Kronberg, P. P., Seaquist, E. R., Hughes, V. A., Woodsworth, A., Viner, M. R., Retallack, D. S., Hjellming, R. M., and Balick, B.: 1972b, *Nature Phys. Sci.* **239**, 114.
Hinteregger, H. F., Catuna, G. W., Counselman, C. C., Ergas, R. A., King, R. W., Knight, C. A., Robertson, D. S., Rogers, A. E. E., Shapiro, I. I., Whitney, A. R., Clark, T. A., Hutton, L. K., Marandino, G. E. Perley, R. A., Resch, G., and Vandenberg, N. R.: 1972, *Nature Phys. Sci.* **240**, 159.
Hjellming, R. M. and Balick, B.: 1972, *Nature Phys. Sci.* **239**, 135.
van der Laan, H.: 1966, *Nature* **211**, 1131.
Parsignault, D. R., Gursky, H., Kellogg, E. M., Malitsky, T., Murray, S., Schreier, E., Tananbaum, H., Giacconi, R., and Brinkman, A. C.: 1972, *Nature Phys. Sci.* **239**, 123.
Peterson, F. W.: 1973, *Nature* **242**. 173.

V. A. Hughes
M. R. Viner
A. Woodsworth
Astronomy Group, Department of Physics and Astronomy,
Queen's University,
Kingston, Ontario, Canada

(Discussion follows the paper by Wynn-Williams, p. 409.)

https://doi.org/10.1017/S0074180900026723 Published online by Cambridge University Press