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A MODEL OF THE QUASI-STELLAR RADIO VARIABLE CTA 102

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According to Sholomitsky [1] the quasi-stellar [2] radio source CTA 102 [3] has a variable flux density at 32.5 cm, the period being about 100 days. Sholomitsky takes this to mean that the source cannot be larger than ~ 0.1 pc, which is the distance light travels in one period. Since its angular diameter is not less than about 0.01", [4,5] he concludes that it must be closer than 2 Mpc, and is possibly inside our own Galaxy. However Schmidt [6] has recently announced that the optical object identified with CTA 102 has a red shift $z = \frac{\delta\lambda}{\lambda}$ of 1.037, and so is probably at a distance comparable with the radius of the universe ($\sim 3{,}000$ Mpc).

Although it is by no means certain that the observed variations originate in the source itself, we wish to propose a model which assumes this, and is consistent with the red shift observations.

The model is illustrated in fig. 1. The radio emission is produced in a spheroidal shell whose axis of symmetry is approximately along the line of sight. (Shell models for radio sources have been discussed by several authors,[7] and spheroidal shells in particular by Layzer [8]). The main part of the emission comes from the region ADB, and its spectrum is taken to have a peak at about 300 Mc/s (see fig. 2). The variable part is assumed to come from the disc-like region ACB, which is pulsating (perhaps as a result of an explosion occurring at O, whose effect may reach all parts of the disc at about the same time). When this region is compressed, the magnetic field strength will rise, the individual electrons will be accelerated by the betatron mechanism, and the radiated power will be greatly enhanced. When radiating at its maximum, it is required to emit ~ 25 per cent of the total flux observed at 1,000 Mc/s in order to account for the observed variations (i.e. its flux density must be $\sim 2.10^{-26}$ W/m²/(c/s)). Its spectrum is taken to be as shown in fig. 2. The total spectrum then agrees with the observed spectrum of CTA 102 [9].

The disc will have its minimum size consistent with the required flux if it is opaque at (proper) frequencies up to $\sim$ 1,000 (1+z)Mc/s when compressed. Furthermore if its emission is to vary with a(proper) period of 100/(1+z) days, its thickness cannot exceed $3.10^{17}/(1+z)$ cms. The electrons which radiate at frequencies around 1,000 (1+z) Mc/s have energies of $\sim 2.10^{-5}(1+z)^{\frac{1}{2}}H^{-\frac{1}{2}}$ ergs, each electron producing $\sim 2.16.10^{-22}H$ ergs/sec/(c/s) (where H is in gauss). If synchrotron self-absorption is occurring, the power radiated from the surface of the disc at this frequency is $\sim 3.10^{-8}(1+z)^{\frac{5}{2}}\ H^{-\frac{1}{2}}$ergs/sec/(c/s)/cm². The number density of these electrons is therefore $\sim 5.10^{-4}\ (1+z)^{\frac{7}{2}}\ H^{-\frac{3}{2}}$ per c.c., and their energy density $\sim 10^{-8}(1+z)^4H^{-2}$ ergs/cc. Allowing for the fact that they only contribute a few percent of the particle energy density, and assuming that the total particle energy is comparable with the magnetic energy, we conclude that the magnetic field when the disc is compressed is $\sim 5.10^{-2}(1+z)$ gauss. A threefold increase in the field strength will probably be sufficient to produce the required increase of about 20 in luminosity at 1,000 (1+z) Mc/s (though the exact factor depends on the energy spectrum of the electrons). The pulsations will be sufficiently rapid if the Alfven speed $\sim c$, and this will be true if the particle density of the ambient gas does not exceed ~ 1 per cc.

The angular diameter of the disc when the magnetic field has the above value is [4,5] $\sim 3.10^{-3}\,(1+z)^{\frac{1}{2}}$ seconds [10]. It follows that $r \simeq 22.5 \left(\frac{z}{(1+z)}\right)^{\frac{1}{2}}$ pc in the steady state cosmology. (In the Einstein-de Sitter model this value must be decreased by a factor ~ 2 if $z \sim 1$). Estimating the average magnetic field over the whole shell as $10^{-2}\,(1+z)$ gauss, we deduce from the occurence of self-absorption below 300 Mc/s that, in the steady state model, $R \simeq 225 \left(\frac{z}{(1+z)}\right)^{\frac{1}{2}}$ pc. The probability that the shell should be oriented so that the disc points towards us is then about $\frac{1}{300}$, which is reasonable in view of the likely number of quasi-stellar objects as bright as CTA 102 at 178 Mc/s. Our estimate of R also enables the parameter η to be determined, for since the disc must not deviate from the tangent plane at C by more than $\sim 0.1/(1+z)$ pc, it follows from the geometry that $R \simeq 2500\, z^2/\eta$ and so $\eta \simeq 11z(1+z)^{\frac{1}{2}}$.

If $z \sim 1$ the dimensions are: $R \sim 160$ pc, $r \sim 16$ pc, and $\eta \sim 15$. The lifetime of the electrons is 50 - 100 years in the fluctuating region, and rather longer in the rest of the source. The total energy of the source is at least $\sim 10^{57}$ ergs, of which $\sim 10^{54}$ ergs is in the disc.

Our model makes the following predictions:

(i) The amplitude of the variations depends on the frequency ν of observation as follows:

$$\begin{array}{ll} \sim 0 & 0 < \nu < 300, \\ \sim 0.013\left\{\left(\frac{\nu}{300}\right)^{2.5} - 1\right\} & 300 < \nu < 1000, \\ \sim 0.25 & \nu > 1000, \end{array}$$

where ν is in megacycles. Thus the observations of Caswell and Wills [11], who found no variations at 178 Mc/s, are not necessarily inconsistent with Sholomitsky's observations.

(ii) For $300 < \nu < 1{,}000$ the intensity reaches a maximum in a time t (ν) days, say, ($t < 50$), and then remains constant for a time (100-2t) days (that is, while the disc is opaque to frequencies between ν and 1,000 Mc/s). The rise-time t (ν) is an increasing function of ν , as illustrated in fig. 3.

(iii) The times at which the intensity is a minimum should be the same at all frequencies $\nu > 300$ Mc/s, unless there is appreciable dispersion.

However, as regards (iii), even if there is negligible dispersion in the source, there may be appreciable dispersion produced by ionised intergalactic gas [12]. At 400 Mc/s, for instance, the resulting delay may be as large as 2 hours. At this frequency our model predicts an increase in flux of over one percent in about 10 days following minimum, so that an intergalactic delay might be detectable. Moreover there may be, superposed on the main variation, an additional small amplitude variation of much shorter time-scale than 50 days, which might then be detectable when the main variation is at a minimum. It would therefore appear to be worthwhile to develop the sophisticated techniques necessary to detect the possible dispersion, and so to test the hypothesis that there is a significant ionised gas in intergalactic space, and perhaps even to determine the scale-factor of the universe if other radio variables are discovered [12].

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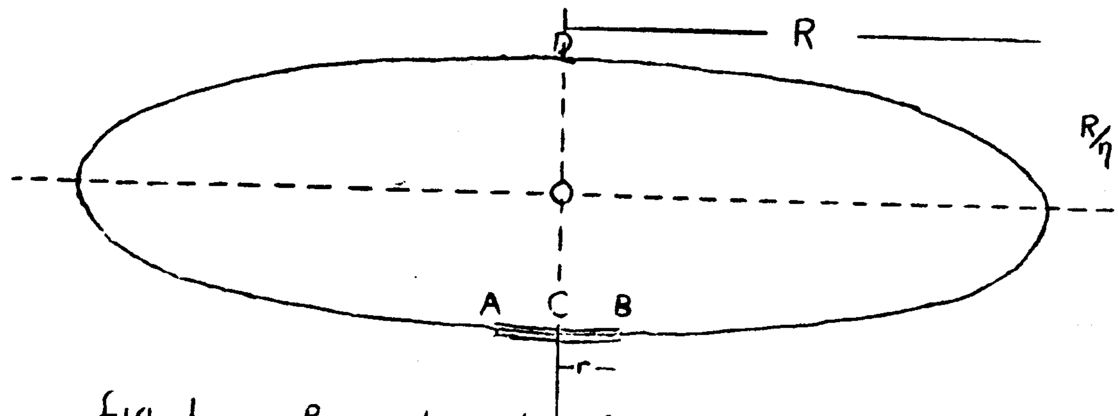

Fig. 1 Proposed model of CTA 102

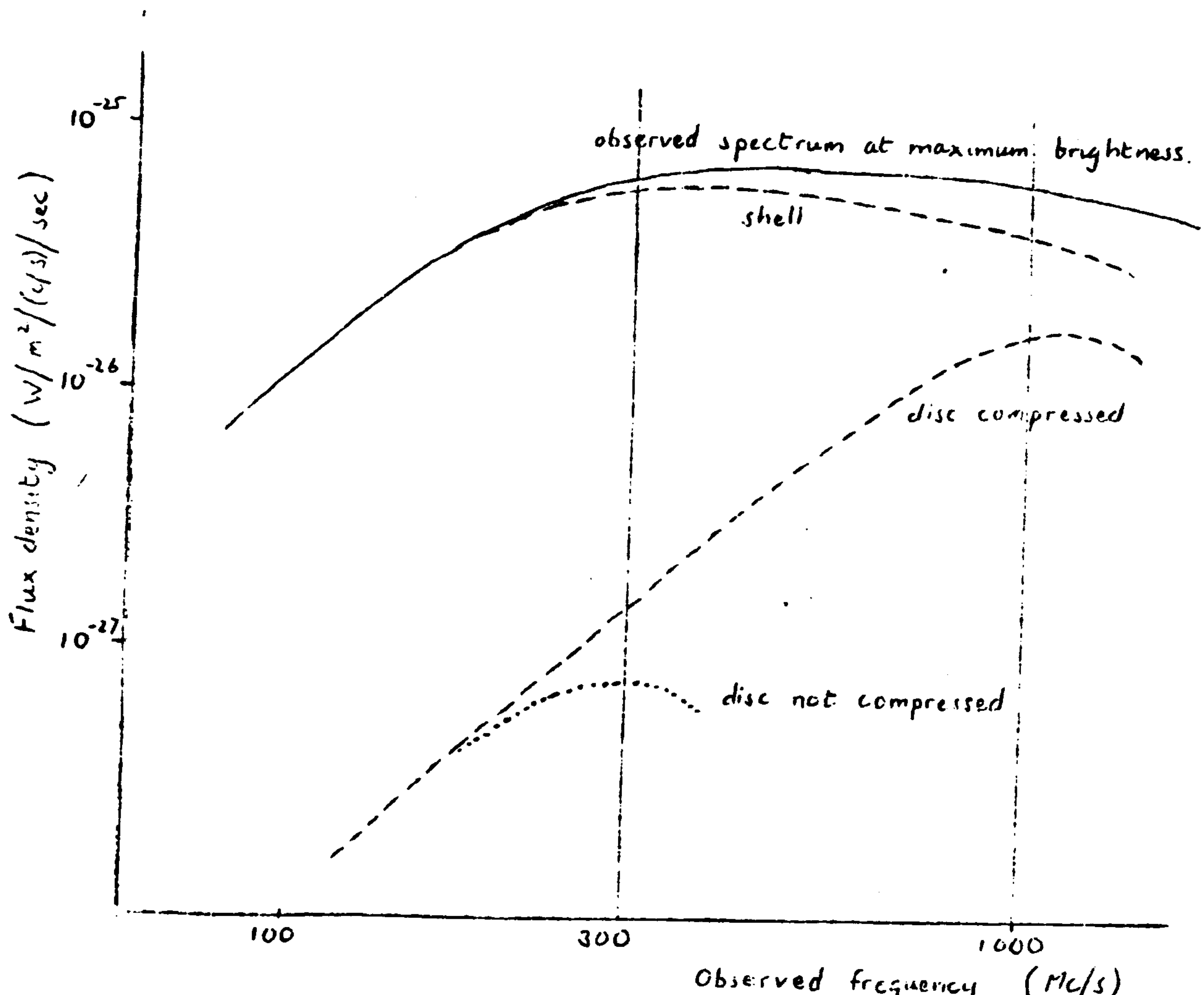

fig 2

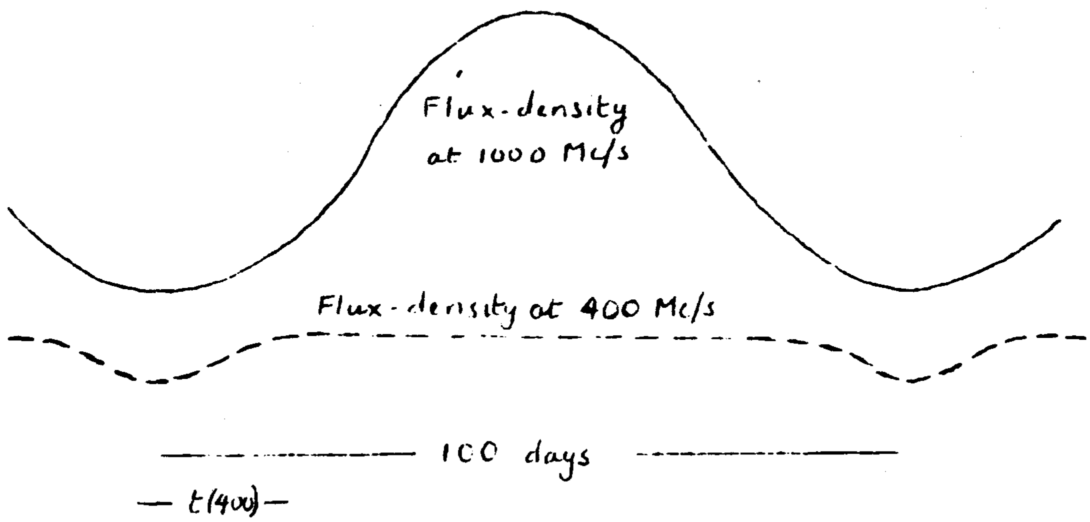

fig. 3 Time variation of flux-density

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10. This assumes that the electrons are radiating incoherently. If they were coherent the angular diameter of the source could be much smaller, which might permit its linear diameter to be ~ 0.1 pc, consistently with a large red shift.

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