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FLUX DENSITIES OF CASSIOPEIA A AND CYGNUS A AT 10·05 MHz

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Absolute measurements of the flux densities of the radio sources Cassiopeia A and Cygnus A have been made at a frequency of 10·05 MHz at the Dominion Radio Astrophysical Observatory, Penticton, Canada.

The observations were made using a 180°-switched interferometer in which the gains of the two antennae could be calculated from theory. Each antenna consisted of two parallel half wave dipoles $\lambda/2$ apart fed in phase. The dipoles were at a height of 0·125 λ above a horizontal reflecting screen 1 λ by 0·75 λ in extent. The two antennae were 30 λ apart along an East-West line and were joined by equal coaxial cables to a receiver in a laboratory mid-way between them. Typical drift records taken for 24 hours with the system showed interference fringes from Cygnus A and Cassiopeia A, intense noise outbursts from the planet Jupiter, and strong broadcast transmissions which were especially predominant during the hours of daylight, and which necessitated restriction of the reception bandwidth to 8 kHz. An output time constant of 40 seconds was employed. The fringes from Cygnus A and Cassiopeia A were frequently marred by severe ionospheric scintillations or by interference, but twelve unspoiled transits of Cassiopeia A with peak signal-to-noise of 10 to 1, and four of Cygnus A with peak signal-to-noise of 5 to 1 were recorded during November and early December of 1965.

The sensitivity of the receiver was calibrated before and after each pair of transits of the sources by replacing the signals from the antennae with noise signals produced by splitting the output of a diode noise generator, and recording the receiver output for several different anode currents drawn by the diode. Automatic gain control was not applied in the receiver so that its sensitivity was not modulated by the galactic background radiation. The variation in sensitivity between calibrations was normally less than 0·5 per cent. The records were corrected for ionospheric absorption by making simultaneous observations on the site with a 10·04 MHz riometer[1]. The absorption correction, which was typically 0·20 dB for transits of Cassiopeia A and 0·60 dB for transits of Cygnus A, is thought to be accurate to about $\pm$0·20 dB. Allowance was also made for confusion of the fringes from the two sources using their known positions.

The equivalent noise temperature of the output of the diode noise generator (Aerospace Corporation Type NS-B) was known in absolute units to within 0·1 dB from the manufacturer's calibration. Its output was compared with that of a diode noise generator calibrated in a series of absolute noise temperature measurements made by Purton[2], and the temperature scale adopted here was thereby shown to be consistent with Purton's within the experimental errors. Losses in the antenna feeders, which were of order 10 dB, were measured with an accuracy of $\pm$0·1 dB. Losses in the reflecting screens, which consisted of parallel wires spaced 0·02 λ apart, were calculated to be 0·05 dB.

The absolute gains of the antennae were computed from theory assuming that the dipole elements, which were similar to those described by Galt *et al.*[3], behaved as ideal half-wave dipoles, and that the ground screen was effectively infinite. The mutual impedances between the dipoles, which were found experimentally to be less than 5 per cent of their self-impedance, were neglected. Their effect on the antenna gain should be very small as the dipoles were fed in phase. The computation of the gain consisted of the numerical integration of the theoretical polar diagram over a hemisphere, and was carried out on the computer of the Department of Mines and Technical Surveys, Ottawa, using a programme kindly supplied by Dr. C. H. Costain.

The flux densities for Cassiopeia A and Cygnus A derived by averaging the values obtained from individual transits are:

$$S_{CAS} = 28{,}000 \pm 2{,}800 \times 10^{-26}\ \mathrm{w\ m^{-2}\ Hz^{-1}}$$
$$S_{CYG} = 13{,}500 \pm 3{,}500 \times 10^{-26}\ \mathrm{w\ m^{-2}\ Hz^{-1}}.$$

The ratio of S_{CAS} to S_{CYG} from these observations is $(2{\cdot}2 \pm 0{\cdot}5)$ to 1, in good agreement with the relative flux density measurements of Clark[4] and of Lovell and Wells[5], which give $S_{CAS} / S_{CYG} = 2{\cdot}4 \pm 0{\cdot}8$ at 10 MHz, and $1{\cdot}9 \pm 0{\cdot}2$ at 16 MHz respectively.

Fig. 1 shows the 10·05 MHz flux densities plotted together with other measurements of these sources at higher frequencies, taken from Kellerman[6] and Purton[7]. The 10·05 MHz flux density for Cassiopeia A shown in the figure has been corrected to 1961·0, the epoch selected by Kellerman for his tabulation, assuming that the secular decrease in intensity of 1·06 per cent per year measured at 81·5 MHz by Högbom and Shakeshaft[8] also occurs at this frequency. This will be true if the electron energy spectrum in the source follows a simple power law.

The decrease in flux density of both sources with decreasing frequency below about 20 MHz is the salient feature of the spectra; it has previously been noticed by Bazelyan *et al.*[9]

Mechanisms which might account for the decreasing intensities of these sources at low frequencies are (i) cut-offs in the electron energy spectra in the sources, (ii) synchrotron self-absorption, (iii) the Tsytovich-Razin effect, (iv) absorption in interstellar ionized hydrogen, and (v) free-free absorption in ionized hydrogen in the sources themselves.

The sharpest possible electron energy cut-off, with no electrons having energies below the cut-off energy, gives rise to a $S \propto \nu^{1/3}$ spectrum below the corresponding cut-off frequency. The flux densities of both sources decrease more rapidly than permitted by this law below 20 MHz, so we may conclude that mechanism (i) is inadequate to explain the observed effect in either source.

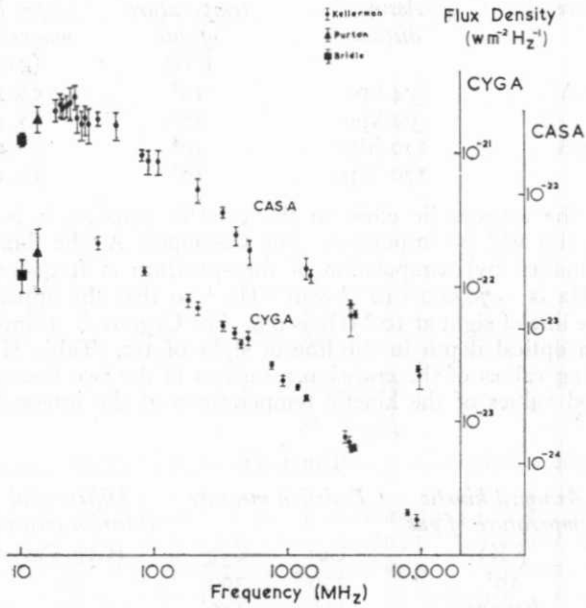

FIG. 1
Radio frequency spectra of Cassiopeia A (epoch 1961·0) and Cygnus A.

For an assumed magnetic field of 10^{-4} gauss in the emitting regions of the sources, synchrotron self-absorption would not be observed at 20 MHz in either of them unless an appreciable fraction of the emitted radiation originates in regions of smaller angular extent than presently suggested. The recent high-resolution observations of Cassiopeia A at 21 cm[10] and of Cygnus A at 10 cm wavelength[11] have, however, indicated that some of the emission in both sources originates from regions of small angular size. Further observations of structure in Cassiopeia A of 10″ arc scale, and in Cygnus A of 5″ arc scale will be necessary before the importance of mechanism (ii) can be fully assessed.

The Tsytovich-Razin effect occurs in a medium containing ionized hydrogen and a weak magnetic field. However, mechanism (v) will become important below 20 MHz if the emission measure of the ionized hydrogen in the source exceeds 100. By assuming values for the distances to the sources, and for the kinetic temperature of ionized hydrogen in them, we may derive an upper limit on the magnetic field in the source for the Tsytovich-Razin effect to predominate over free-free absorption. Table I shows the results of such an analysis. For Cassiopeia A, the upper limit to the field is not unreasonable, and so the Tsytovich-Razin effect might be partly responsible for the decrease observed. It is unlikely that the magnetic field in so powerful a source as Cygnus A could be as low as 10^{-7} gauss and we conclude that the Tsytovich-Razin effect is unlikely to be of importance.

TABLE I

Source	*Assumed distance*	*Assumed kinetic temperature of gas* (°K)	*Upper limit on magnetic field* (gauss)
Cas A	3·4 kpc	10^4	5×10^{-6}
	3·4 kpc	10^5	3×10^{-5}
Cyg A	170 Mpc	10^4	5×10^{-8}
	170 Mpc	10^5	3×10^{-7}

As both the sources lie close to the galactic equator, it is likely that mechanism (iv) will be important. For Cassiopeia A, the flux density at 10 MHz obtained by extrapolation of the spectrum at frequencies greater than 20 MHz is $\sim 70{,}000 \times 10^{-26}$ w m^{-2} Hz^{-1} so that the apparent optical depth in the line of sight at 10 MHz is 0·9. For Cygnus A, a similar analysis indicates an optical depth in the line of sight of 1·2. Table II shows the corresponding values of the emission measures in the two lines of sight for two assumed values of the kinetic temperatures of the interstellar ionized hydrogen.

TABLE II

Assumed kinetic temperature of gas (°K)	*Emission measure* Cas	Cyg	*Differential emission measure* (Cyg-Cas)
10^4	230	300	70
6×10^3	110	140	30

Free-free absorption within the sources themselves cannot be distinguished from absorption in interstellar ionized hydrogen until the precise shape of the spectrum below the frequency of maximum flux density is determined for each source.

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