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Constraints on the secular decrease in the flux density of Cas A at 13.5, 15.5 and 16.5 GHz

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ABSTRACT

Observations of the flux density ratio of Cas A to Cyg A at 13.5, 15.5 and 16.5 GHz made in 1994 and 1995 with the Cosmic Anisotropy Telescope are presented. These observations are compared with the predictions of Baars et al. and lower frequency observations, in order to understand better the frequency dependence of the secular decrease in the flux density of Cas A. When compared with measurements at other frequencies, these observations imply that there is a frequency dependence to the secular decrease in the flux density of Cas A, but that it is not as strongly frequency dependent as was thought by Baars et al. when they constructed their absolute flux density spectrum of Cas A.

Key words: ISM: individual: Cas A – radio continuum: general.

1 INTRODUCTION

The determination of an accurate flux scale which is reliable over a wide range of radio frequencies and epochs is of fundamental importance for radio astronomy. The most commonly used flux density scale is that of Baars et al. (1977), which is primarily based on absolute flux density measurements of Cassiopeia A (Cas A), which is one of the highest flux density sources in the sky at many radio frequencies. However, Cas A is the remnant of a relatively recent supernova (which was probably seen in 1670, see Ashworth 1980). As the remnant expands, its flux density decreases appreciably over periods of only a few years, which complicates its use as a primary flux density calibrator. Baars et al. adjusted the available absolute flux density measurements of Cas A to a standard epoch using the frequency-dependent flux density decrease that was thought appropriate at that time. However, there is growing evidence (e.g. Rees 1990; Hook, Duffett-Smith & Shakeshaft 1992) that the secular decrease of Cas A does not show the frequency dependence as used by Baars et al. to construct their flux density scale. Consequently, observations of the flux density of Cas A, or its ratio to another source such as Cyg A which has a constant flux density, are useful for investigating the true secular decrease of Cas A. Here we present such observations made with the Cambridge Cosmic Anisotropy Telescope at 13.5, 15.5 and 16.5 GHz between 1994 and 1995.

2 BACKGROUND

The flux density scale of Baars et al. (1977) is based on absolute flux density measurements of Cas A made between 1963.0 and 1973.1. These data were brought to a standard epoch (1965.0) using the empirically determined frequency-dependent decrease in flux density of Cas A (as first suggested by Baars & Hartsuijker 1972). The form of the secular decrease used was

$$\frac{1}{S}\frac{\mathrm{d}S}{\mathrm{d}t} = \left[0.97(\pm 0.04) - 0.30(\pm 0.04)\log\left(\frac{\nu}{1\ \mathrm{GHz}}\right)\right]\ \text{per cent yr}^{-1}, \tag{1}$$

where S is the flux density and ν the observing frequency.

However, as noted by Rees (1990), the frequency dependence of the secular decrease rests heavily on one available low-frequency result of Scott, Shakeshaft & Smith (1969) at 81.5 MHz. This indicated a faster decline in the flux density (1.29 ± 0.08 per cent yr^{-1}) than the decline of $\sim$0.8 per cent yr^{-1} reported by the eight other available observations at higher frequencies (0.95–9.4 GHz). Rees also noted that it was not possible to reconcile his observations at 38 MHz with the flux density scale of Baars et al., but that they were consistent with a secular decrease at 38 MHz comparable to that seen at 0.95–9.4 GHz. Subsequently Hook et al. (1992) provided direct evidence that the 81.5-MHz decrease of Cas A was not as fast as reported by Scott et al. (1969). By combining their recent observations with those made earlier, Hook et al. derived a rate of decrease of 0.92 ± 0.16 per cent yr^{-1} for the flux density of Cas A at 81.5 MHz from 1949 to 1990, not significantly different from the ratio of decline of $\sim$0.8 per cent yr^{-1} at GHz frequencies. Similarly, Agafonov (1994) reported a decline of $\sim$0.8 per cent yr^{-1} at 102.5 MHz, suggesting that the secular decrease of the flux density of Cas A is frequency independent.

In order to determine the frequency dependence of the secular decrease of the flux density of Cas A, observations at high frequencies are also useful. Here we present such observations of the flux density ratio of Cas A compared with Cyg A.

3 OBSERVATIONS

The observations presented here were carried out using the Cosmic Anisotropy Telescope (CAT), which is described in detail by Robson et al. (1994). Briefly, the CAT is a three-element interferometer designed especially to detect primordial anisotropies in the cosmic microwave background radiation (CMBR) on scales of $\sim$1/2° (see O'Sullivan et al. 1995; Scott et al. 1996).

The CAT operates at frequencies between 13 and 17 GHz, with an observing bandwidth of 500 MHz. The system temperature, which is continuously monitored using a modulated 1-K noise signal injected into each of the antennas, is typically *c.* 50 K. The baselines are variable from 1 to 5 m. For the observations reported here, the baselines were scaled to give the same synthesized beam (27×23 arcmin^2) at each observing frequency, so both Cas A and Cyg A are unresolved by these observations. The primary beam of the instrument has a FWHM of 2°.2 at 15 GHz. The CAT simultaneously records data from orthogonal linear polarizations. Because the CAT is alt–az mounted, the plane of polarization of a single polarization channel rotates on the sky as the telescope tracks a given source. The telescope is situated within a 5-m high aluminium-lined bank to reduce the effects of ground emission. This shielding limits the elevations down to which observations can be made. None of the observations presented in this paper was made below an elevation of 40°, which is well above that of the screen.

3.1 Observing strategy

The CMBR observing programme required observations of a single field, spanning approximately six weeks at each frequency. At least two calibrator observations per night were used for gain and phase calibration. The calibrator, usually Cas A, was observed at the telescope pointing centre. Where it did not interfere with the CMBR programme, additional calibrators (principally Cyg A) were observed for the purpose of flux density comparison. Each calibrator was observed for a period of one hour, generally at the beginning and end of the night's observing run. The additional observations were often scheduled so that the source was observed when it was at the same elevation as one or other of the Cas A observations. Observations were carried out at 13.5 and 16.5 GHz from 1993 December to 1994 February, at 15.5 GHz during 1994 June and again at 16.5 GHz during 1995 March.

3.2 Data selection criteria

Correlated emission from the atmosphere could have a significant effect on the measured flux density ratios, and so data taken during bad weather were eliminated. A modulated 1-K noise signal was injected into each antenna, and this is measured using phase-sensitive detection after the automatic gain control (AGC) stage of the telescope. This modulated signal is termed the *noise calibration* value, and its relative contribution to the total power provides a measure of the telescope system temperature. There is no simple conversion between the two quantities, but a high noise calibration value corresponds to a low system temperature. The noise calibration values were used to eliminate data taken in poor weather conditions. Fig. 1 shows the noise calibration values for the observations of Cas A and Cyg A at 13.5 GHz. The average values measured during Cyg A observations are systematically higher than those of Cas A as a result of the higher elevation (and consequently larger atmospheric path length) of that source during these particular observations. Most of the values fall within a narrow range but there is a tail towards lower values because of bad weather during some of the nights. Cut-offs at 58 and 62 were adopted for the Cas A and Cyg A values, respectively. Only observations from days where both the Cas A and Cyg A noise calibration values satisfied the above criteria were used in the subsequent derivation of flux density ratios. A similar process was adopted for the 15.5- and 16.5-GHz data. The noise calibration values corresponding to all the remaining observations lay within 3σ of the mean. In total, this resulted in the loss of *c.* 15 per cent of the observations. The power spectrum of the remaining days' correlator data was computed for each of the three CAT baselines. Atmospheric emission shows up as excess power at low frequencies and is particularly strong on the short baselines. We found no evidence for significant atmospheric contamination once the noise calibration cut described above had been applied.

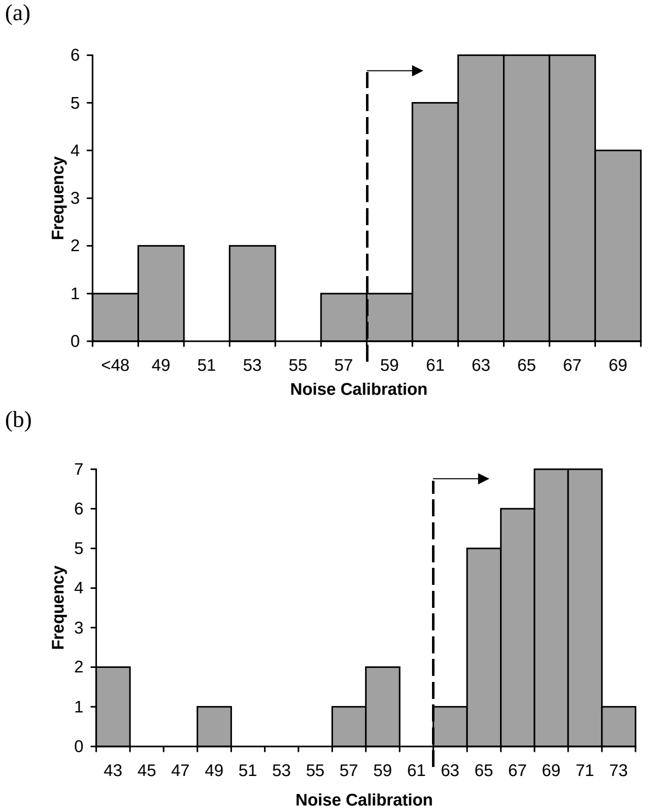

Figure 1. Histogram of noise calibration values for 34 13.5-GHz observations of (a) Cas A and (b) Cyg A taken in 1994 January.

3.3 Elevation correction

Observations of the calibrators at constant elevation show that the gain of the CAT varies by *c.* 5 per cent from night to night, and that this variation is random. Measurements of flux density ratios over several nights should be sufficient to reduce this error. Of more concern is the systematic error arising from differences in the elevation of the two calibrators when they are observed. The atmosphere has two effects on the data. It attenuates the signal from the source and also contributes to the system temperature of the telescope thereby reducing the overall gain (controlled by the AGC). The magnitude of the effect is obviously dependent on the path length of the signal through the atmosphere, and therefore on the source elevation. Our noise calibration signal gives us a measure of these atmospheric effects and our noise calibration procedure, for

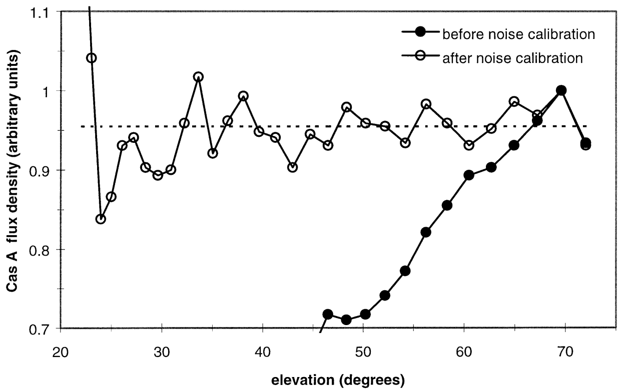

Figure 2. Measured 13.5-GHz flux density of Cas A as a function of elevation before (filled circles) and after (open circles) noise calibration to remove the effect of the atmosphere. The data were taken on a single baseline for a single polarization and each point represents the average of 1000 integrations, each of 0.22 s. Below an elevation of *c*. 25° the source has set below the radiation screen.

reducing them, is described in more detail elsewhere (Robson et al. 1994; Robson 1994). An example of the source flux density before and after this correction is shown in Fig. 2, which shows that the elevation dependence has been successfully removed.

To reduce further any possibility of systematic error, we only include observations where the sources had elevations within 5° of one another in our flux density ratio calculations.

3.4 Results

After initial reduction, the observations of Cyg A and Cas A were averaged over 40 integrations, each of 0.22 s. The ratio of the source flux densities was then calculated for each baseline and polarization, and the average taken.

The results are presented in Table 1. The statistical errors quoted in Table 1 were obtained from the spread in the individual measurements at each frequency and epoch. The average was taken over all three baselines and polarizations (six measurements).

4 DISCUSSION AND CONCLUSION

We compare our results at 13.5, 15.5 and 16.5 GHz with the predictions of Baars et al., as there are no earlier directly comparable observations at these frequencies. Also, our results provide reference ratios for $S_{\mathrm{Cas\ A}}/S_{\mathrm{Cyg\ A}}$ for comparison with future observations at these frequencies.

Table 2 gives the flux densities of Cas A and Cyg A as expected from Baars et al., at the frequencies of our observations. For Cas A the flux density predicted by Baars et al. for epoch 1965 was calculated, and this was then scaled to the appropriate epoch of our observations assuming either (a) a *frequency-dependent* secular flux density decrease from equation (1) (which predicts 0.63, 0.61 and 0.60 per cent yr^{-1} at 13.5, 15.5 and 16.5 GHz respectively), or (b) a *frequency-independent* flux density decrease of 0.8 per cent yr^{-1}.

Table 1. Observed Cas A/Cyg A flux density ratio measurements.

Frequency	Epoch	Number of observations	Average ratio $S_{\mathrm{Cas\ A}}/S_{\mathrm{Cyg\ A}}$
13.5	1994.1	8	3.25 ± 0.09
15.5	1994.5	8	3.47 ± 0.10
16.5	1994.0	4	3.53 ± 0.13
16.5	1995.3	7	3.65 ± 0.07

Table 2. Predicted Cas A/Cyg A flux density ratio measurements, based on the Cas A (epoch 1965.0) and Cyg A spectra of Baars et al. (1977) assuming either: (a) frequency-dependent fading of Cas A, according to equation (1), or (b) frequency-independent fading (at 0.8 per cent yr^{-1}).

(a) Frequency dependent fading of Cas A

Frequency	Epoch	$S_{\mathrm{Cas\ A}}$ /Jy	$S_{\mathrm{Cyg\ A}}$ /Jy	$S_{\mathrm{Cas\ A}}/S_{\mathrm{Cyg\ A}}$ ratio
13.5	1994.1	338.0	105.4	3.21
15.5	1994.5	304.0	888.8	3.42
16.5	1994.0	291.0	882.1	3.54
16.5	1995.3	288.8	882.1	3.52

(b) Frequency independent fading of Cas A

Frequency	Epoch	$S_{\mathrm{Cas\ A}}$ /Jy	$S_{\mathrm{Cyg\ A}}$ /Jy	$S_{\mathrm{Cas\ A}}/S_{\mathrm{Cyg\ A}}$ ratio
13.5	1994.1	321.6	105.4	3.05
15.5	1994.5	287.3	888.8	3.24
16.5	1994.0	275.5	882.1	3.34
16.5	1995.3	271.7	882.1	3.31

Comparison of the results in Table 1 with the predictions in Table 2 shows that the observed flux density ratios $S_{\mathrm{Cas\ A}}/S_{\mathrm{Cyg\ A}}$ are generally consistent with those predicted by Baars et al. That is, they are consistent with a flux density decrease of ~0.6 per cent yr^{-1} at frequencies around 15 GHz, rather than with a frequency-independent flux density decrease of ~0.8 per cent yr^{-1} at all frequencies. Given the results at lower frequencies, this suggests that there is a frequency dependence to the secular decrease in the flux density of Cas A, but that it is not as strongly dependent on frequency as thought by Baars et al. when they constructed their flux density scale.

This conclusion is based on the predictions of how the fitted 1965.0 epoch Cas A spectrum evolves with time, rather than from direct observations at different epochs. As noted above, there are no earlier observations of the ratio of the flux densities of Cas A/Cyg A to make direct comparison with our observations, nor can we directly constrain any changes in rate of flux density decrease. However, the rate of around 0.60 per cent yr^{-1} is in reasonable agreement with the higher frequency (7.8 and 9.4 GHz) flux density decrease rates of Cas A available to Baars et al. (1997). Clearly, further observations are required to measure directly the flux density decrease of Cas A at high frequencies – for which the present observations provide a useful first reference point – in order to understand the flux density scale properly.

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