THE EXPANSION OF CASSIOPEIA A

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INTRODUCTION

This paper describes a detailed comparison of radio maps of Cas A obtained with the Cambridge 5 km Radio Telescope in 1974 and 1978. Accurate proper motions and brightness changes are presented for 342 distinct radio peaks, ranging in angular size from 1 arc minute for fragments of the intense ring to less than the resolution limit of 2.0×2.3 arc seconds for the compact radio knots.

OBSERVATIONS

Cas A was observed at 5 GHz with the Cambridge 5 km Telescope (Ryle 1972) during September - December 1974 and October - December 1978. Identical interferometer baselines were used for both epochs. The spacing increment is 35.74 m, providing a grating ring radius (5.8 arcmin in RA) which exceeds the maximum angular size of Cas A (5.4 arcmin). No polarisation data was taken in 1974 so that the present work is restricted to a comparison of maps of I-Q. This is not a serious limitation since the percentage polarisation at 5 GHz mapped across Cas A with the full resolution of the instrument never rises above $\sim$5 percent.

Amplitude and phase corrections were applied to each spacing according to the procedure outlined by Ryle & Elsmore (1973). Astrometric uncertainties in proper motions (due principally to tropospheric phase fluctuations and short term temperature dependent variations in telescope geometry) are smaller than 0.02 arcsec yr^{-1}. A greyscale representation of the 1978 observations is presented in fig. 3.

PROPER MOTIONS

The change in position of each peak was measured using a computer program which shifted one map with respect to the other until the square of the difference in each pixel summed over a region containing the peak had been minimised. Proper motions of all 342 radio features are displayed in fig.1 as arrows with length proportional to the protected velocity.

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Figure 1. Proper motions of 342 radio features in Cas A.

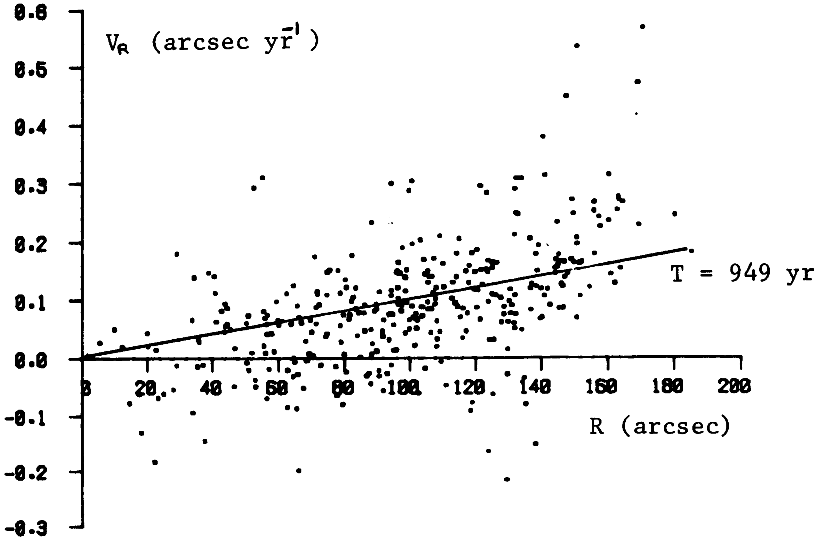

Figure 2. Radial component of projected velocity vs distance from the optical expansion centre.

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There is an unmistakable expansion of the remnant. Outwards motion is shown both by broad scale structure such as the intense ring and by compact structure such as the bright knots. The expansion timescale is independent of radio morphology. The centre of expansion of the radio features is at $\alpha = 23^h21^m10\overset{s}{.}2$ ($\pm 0\overset{s}{.}7$), $\delta = 58°32'19.7''$ ($\pm 4.4''$), offset by 1.8″ N and 13.8″ W from the optical expansion centre (OEC) for the system of fast filaments (Kamper & van den Bergh 1976).

The variation in projected velocity outwards from the OEC with projected radius from the OEC is shown in fig. 2. A best straight line fit to fig. 2 constrained to pass through the OEC has an expansion timescale of 949 yr with upper and lower one sigma limits (determined by the intrinsic spread in the data) of 993 and 908 yr. This radio expansion age is some three times that of the undecelerated optical filaments (Kamper & van den Bergh 1976) and is in good agreement with Bell's earlier comparison of observations made in 1969 and 1974 (Bell 1977). It differs however from the measurements of Dickel & Greisen (1979) who, using the NRAO interferometer at 2.7 GHz, failed to detect any systematic outwards motion of radio features over a 9 yr interval. It is not clear whether the results obtained with the NRAO interferometer are inconsistent with the present work since this instrument did not have sufficient coverage of the aperture plane to oversample the visibility function of Cas A and the effect of such an undersampling on the proper motions is difficult to predict. In the present work the proximity of the radio expansion centre to the centre of the intense radio ring and its 25 arcsec offset from the map centre suggests that the expansion is real and not due to some unforseen scaling error in one or other of the maps about the map centre.

Seemingly random motions are superimposed on the general expansion. Most peaks have substantial tangential components of projected velocity and several peaks, including the brightest, have components of proper motion directed towards the OEC. Furthermore there are regions of the remnant (particularly in the Eastern plateau) in which proper motions appear to be mutually aligned. These random motions are not accounted for by measurement errors (due mainly to random brightness variations in fore and background sources in the remnant) but it is not yet clear whether shape changes within the peaks are wholly responsible since the changes in position are still smaller than the beam. Random motions are generally independent of the size, shape, flux and change in intensity of the radio features. The rms values for random motions in radial and tangential directions to the OEC (with measurement errors subtracted) are 0.085 arcsec yr^{-1} and 0.053 arcsec yr^{-1} respectively.

Bell's peak 38, which is almost certainly associated with a quasi-stationary flocculus (Chevalier & Kirshner 1979) has proper motions in right ascension and declination of 0.01 ± 0.01 arcsec yr^{-1} and -0.11 ± 0.01 arcsec yr^{-1} respectively. The intensity of this unresolved radio peak has increased from 174 mJy in 1974 to 218 mJy in 1978.

It should be emphasised that it is by no means clear how the radio expansion of Cas A may be related to a physically meaningful parameter such as an outer shock velocity. In contrast to the highly limb-brightened remnant of Tycho's supernova, whose radio luminosity must have a substantial contribution from emission associated with the outer shock, the plateau and compact features in Cas A are distributed over a large range of deprojected radii so that only a small proportion of the radio emission may be directly associated with an outer shock. The overall expansion of the remnant nevertheless suggests that the velocity of the radio features deep inside Cas A is related in some way to the velocity of the outflowing matter between back and front shocks. One dimensional hydrodynamical simulations of young supernova remnants evolving away from the free expansion phase (eg Gull 1973) predict a steep internal velocity profile behind the outer shock front. If such simple models may legitimately be applied to a source as complex as Cas A the average of 949 yr will be an overestimate of the deprojected expansion age of the radio emission at the periphery of the remnant. Some evidence for this is provided by the fact that features in the plateau have an average expansion age of only 750 ± 50 yr.

BRIGHTNESS CHANGES

A subtraction of the 1974 map from the 1978 map (fig. 4 - hereafter called the difference map) shows the supernova remnant to be divided into regions of either predominantly increasing or decreasing brightness. A large area of increasing brightness extends from the NW into the plateau in the SW and contains the majority of the brightest compact peaks. The main broken ring of radio emission is decreasing in brightness at 1.32 percent yr^{-1} and accounts for half the secular decrease in flux of Cas A at 5 GHz (Baars et al 1977). The remainder of the secular decay is due to the plateau and its extensions across the face of the remnant.

The difference map shows that broad regions of increasing flux include most of the brightening compact radio peaks and similarly decreasing broad scale radio brightness is associated with mainly fading compact features. This gives credibility to the extended emission on the difference map and suggests that the broad scale structure in Cas A may in fact consist of an aggregation of compact features of similar nature to the conspicuous bright compact knots but of much lower power.

Proper motions of many of the compact features and of parts of the intense ring are prominent on the difference map as adjacent patches of positive and negative, separated by the angular size of the feature in the direction of its motion. Twice as many compact peaks are decaying as are brightening but although most are resolved there is no evidence that the decaying features are increasing in size- The average decay rate for all compact features is 1.57 percent yr^{-1} but the total integrated power of a complete sample of compact features with peak fluxes greater than the average surface brightness of the remnant is insufficient for these features to make a significant contribution to the overall secular decay of Cas A.

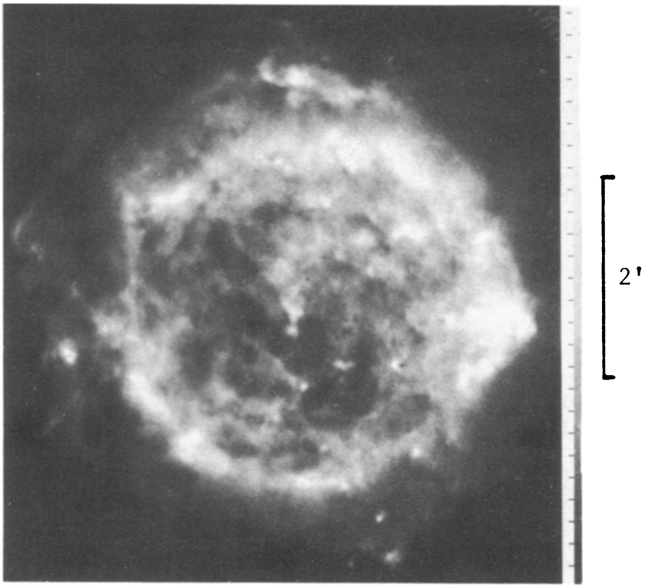

Figure 3. Cas A at 5 GHz in 1978.
Range (black to white) is 0 to 150 mJy beam^{-1}.

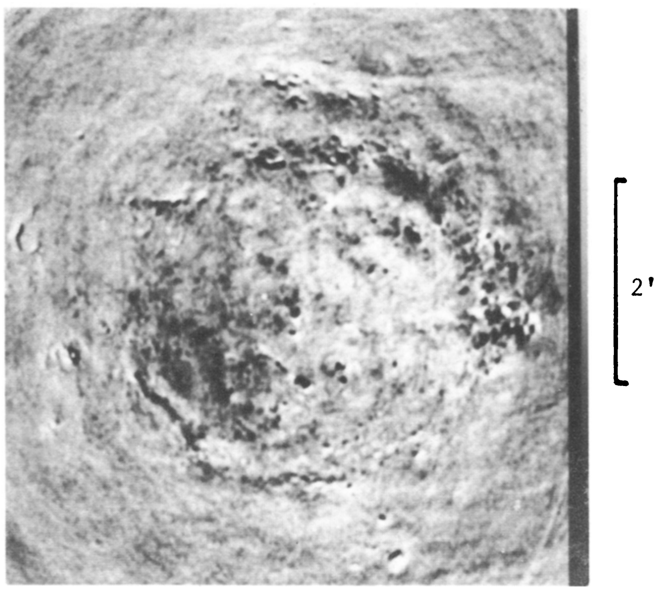

Figure 4. Secular changes within Cas A at 5 GHz.
Range (black to white) is −6 to +6 mJy yr^{-1} beam^{-1}.

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