VARIABLE HII REGIONS

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Initial CO observations of the Cepheus OB cloud by Sargent (1977), identified the condensation known as Cepheus A. Other observations have shown that it has the normal empirical indications of a star forming region. In the radio continuum, using the WSRT, it consists of two thermal components (Hughes and Wouterloot 1982). The West component is associated with the Herbig-Haro object GGD-37, and will not be considered further here. The East component when observed further with the VLA, is seen to consist of two strings of about 14 compact HII regions, and is the subject of the present paper.

Observations in 1981 with the VLA in the "B" configuration, with angular resolution of 1" and 3" at wavelengths of 6 cm and 21 cm (Hughes, and Wouterloot 1984), showed that though some compact components were resolved, others were not, indicating that some have linear dimensions of less than 700 au. Further observations in 1982 using the "A" configuration with corresponding angular resolution of 0".3 and 1", (linear resolution of 200 and 700 au,) showed that some sources were not resolved at the higher resolutions. Since HII regions with diameters < 200 au were not expected to remain stable, observations were repeated in the "A" configuration in 1986 (Hughes 1988), but this time 2 cm observations were included, where the angular resolution is 0".1, (linear size of 70 au). Not only were some sources still not resolved at this shorter wavelength, but appreciable differences were clearly seen between epochs.

To eliminate artifacts which might be introduced due to procedures used for data reduction, all the data sets have been reprocessed in exactly the same way (Hughes 1988). This applies also to more recent data sets obtained in 1987 and 1988.

The chief features of the area are shown in the 20 cm and 6 cm maps of Figure 1, both from 1986 data sets. They show also the numbering of the components, including the position of the highly variable new components 8, and 9. Spectral indices are difficult to determine accurately unless the components are

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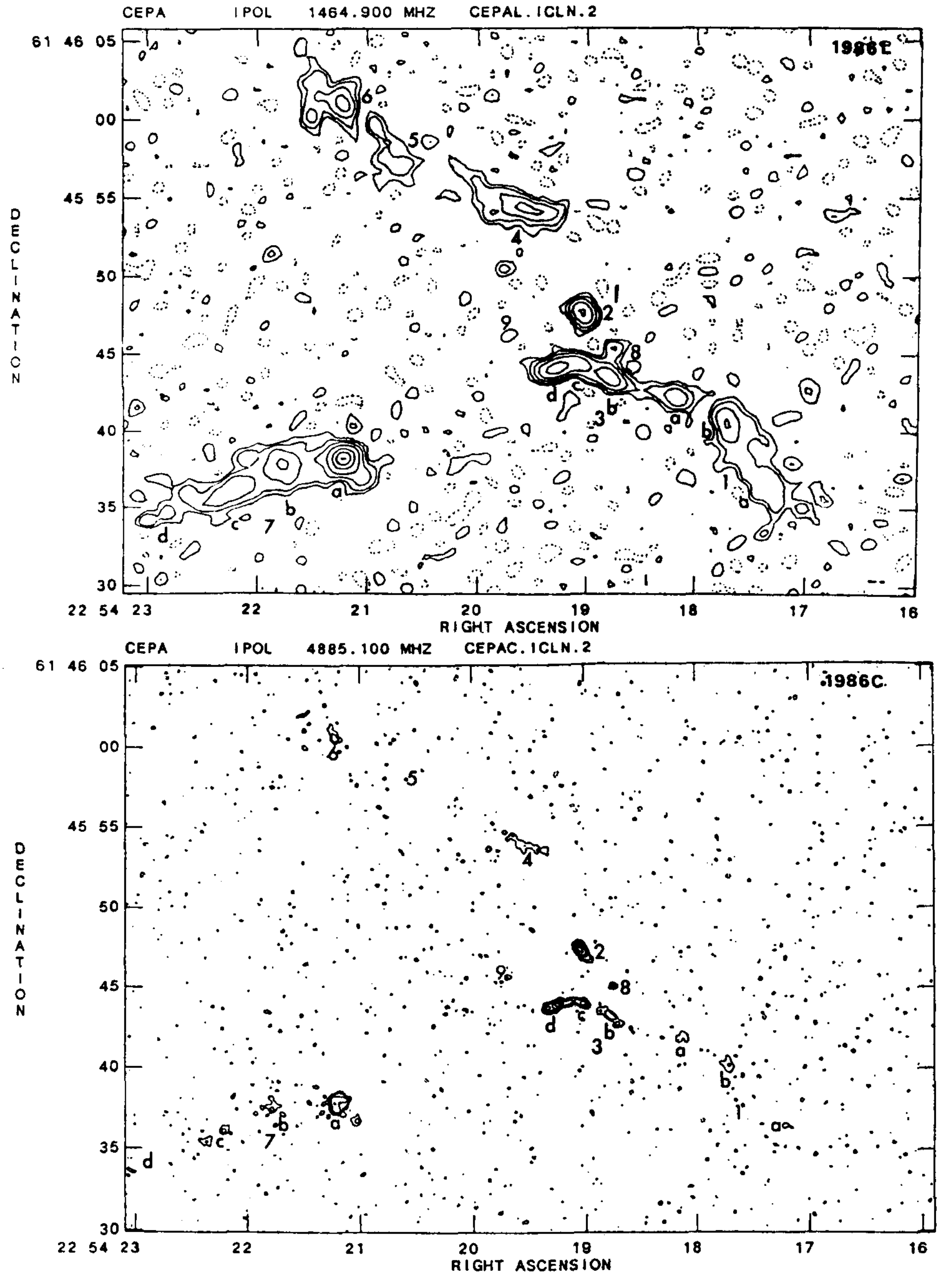

Figure 1, Upper: 20cm map of Cep A, resolution 1", from 1986 data. Contour levels are -0.1, 0.1, 0.2, 0.4, 0.8, 1.6, 2.4, and 3.2 mJy/beam.

Lower: 6 cm map with resolution 0".1 from 1986 data. Contour levels are the same as for the upper figure.

well resolved and observed with the same angular resolution at two frequencies. The early observations at 6 cm in the "B" configuration and 20 cm in the "A" configuration showed spectral indices between 0.4 and 0.6 for components 2, 3d, and 5, and -0.1 ± 0.1 for the other outer components. The latter spectral index is indicative of an optically thin thermal (HII) region, while the former indicates the presence in the region of a part which is optically thick, and is typical of mass loss stars where the electron density varies as r^{-2}; it could equally well apply to stars which are accreting under free-fall conditions. The 2 cm observations showed, in addition, that component 2 was double, consisting of two unresolved sources separated by 70 au, component 3d had two similar sources separated by 200 au, while component 3c was a single unresolved source. Of possible significance is that the orientation of the sources of component 2 is in the direction of Component 8, as is also that of Component 3d.

Associated with the compact components are H_2O and OH masers (Cohen et al 1984). Component 2 has a number of OH masers outside the HII region, as have components 3c and 3d, while component 2, 3a and 3d have H_2O masers at the projected edge of the HII regions.

The most remarkable aspect of the region is the variability of the components. This was suspected in the early observations, but is very pronounced with components 8 and 9. Component 8 was present in 1981, and 1986 with a peak flux density of a few mJy, but below the detection level of 0.1 mJy in 1982, 1987 and 1988. Component 9 was seen as a barely significant source in 1986, was not evident in 1987, but is clearly present in 1988. The spectral indices of both appear to be 0.6. Maps of the region at 6 cm containing these sources for epochs 1986, and 1988, are shown in Figure 2. The variation in flux density of those components which remain well separated from their neighbours is shown in Figure 3. Some characteristics are that the two sources of component 2 appear to vary independantly of each other; component 3 has decreased in time to a level below the noise level at 6 cm, but not at 20 cm, apparently due to an increase in size; component 7 has the appearance of a shell-type object.

The initial interpretation was based on the assumption that the individual HII regions were internally excited, so that, provided they are optically thin, the radio flux density enables the excitation parameter to be determined, and thus the spectral type of the assumed exciting star. This led to an interpretation of the region as consisting of two lines of about 14 B3 stars. However, some reservation was felt about this, since the HII regions must be very young and 14 stars would have to all turn on inside a period of about 1,000 years, and all be in the same stage of evolution.

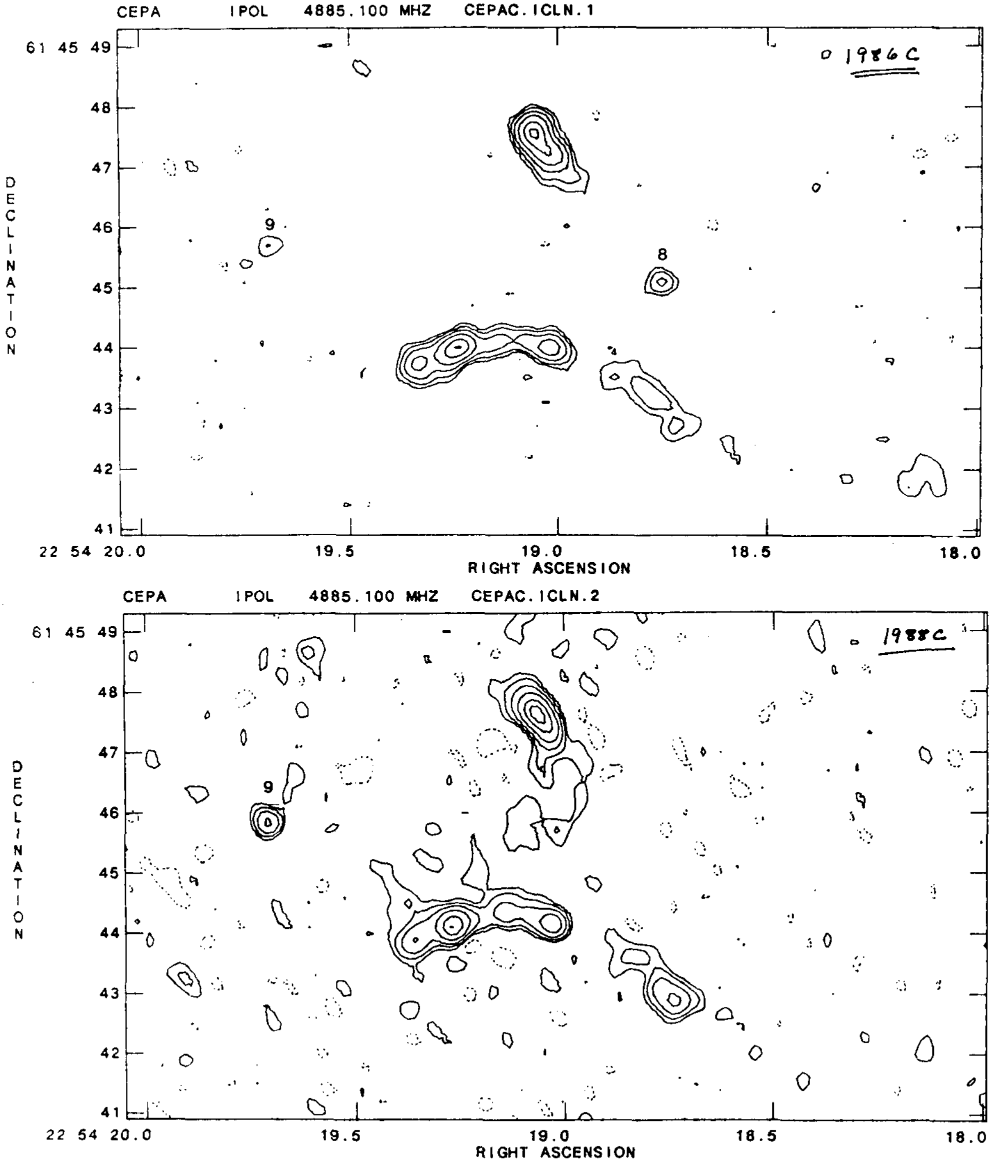

Figure 2. Maps of the central region of Cep A from the 1986 and 1988 data bases; wavelength 6 cm, resolution 0".3. Contour levels are -0.1, 0.1, 0.2, 0.4, 0.8, 1.6, 2.4, and 3.2 mJy/beam. The varibility of components 8 and 9 is clearly seen. The higher noise level in the 1988C map is due to a shorter integration time.

Additional evidence for the presence of stars depended on IR observations, which showed the total 100 μm flux to be that expected from the assumed 14 B3 stars (Evans, et al. 1981). On the other hand, observations at 2 μm by Lenzen

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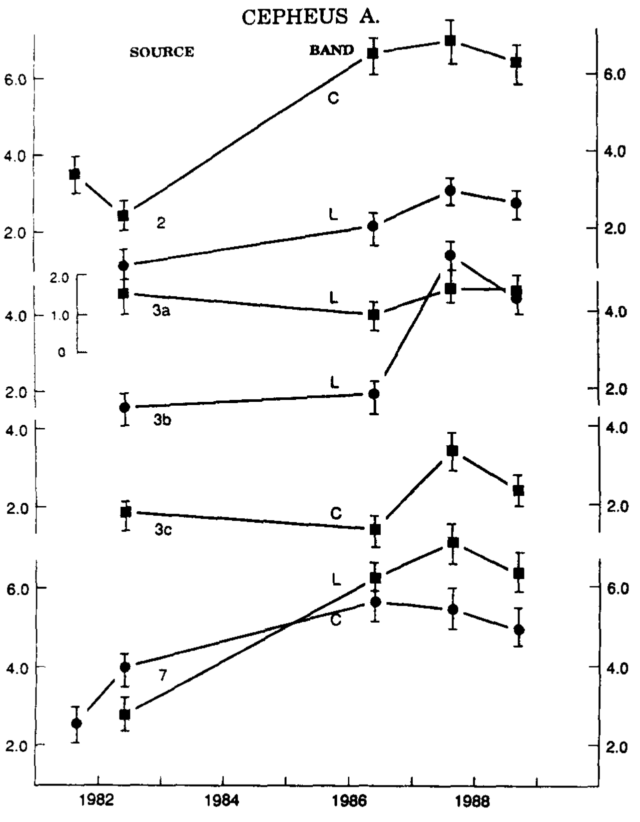

Figure 3. Plot of variation in flux density, in mJy/beam, against time.

(1988) failed to detect emission from any of the sources, except component 3a. Also, scattered polarized IR radiation indicated a source somewhere in the region of component 2. An analysis of IRAS Point Source Catalog by Hughes and MacLeod (1988) indicated extinction of 3-5 mag at 12 μm, suggesting > 100 mag in the visible, and consistent with similar estimates by Lenzen, Hodapp, and Solf (1984).

As would be expected, densities in the region are high, being estimated at 10^3 - 10^4 by Sargent (1977), but more recent observations with Moriarty-Schieven (unpublished) of the CS (7-6) transition gives values > 10^6 cm^{-3}, and possibly as high as 10^7 cm^{-3}. The fact that an HII region can recombine in < 1 year, also requires densities > 10^6 cm^{-3} (Hughes 1988).

One explanation of how stars might produce variable HII regions is suggested from the work by Yorke and Krügel, who simulated a model for stellar accretion. Essentially, if a star of > 5 $M_\odot$ forms, then the core could come onto the main sequence while the outer parts are still accreting. A shock is produced with high IR luminosity, sufficient to slow accretion, which in turn reduces the IR luminosity. Oscillations are produced with periods of between 5 and 1,000 years, depending on the surrounding densities, so that it would appear possible to obtain periods of a few years. The more diffuse HII regions would correspond to the ending of the instability phase and develpment of a stable HII region. In addition, shell sources could be produced as for Source 7 (a), since recombination rates in the denser core would be greater than in the outer parts. Chief objections to the model are that isotropic accretion is unlikely, and in any case, there is no explanation of why stars should form in lines.

An alternative model is one where only a few stars are present, possibly Sources 2, 3c and 3d, which are the source of collimated jets. It is possible that these jets can be focussed along their length, as described in the paper in these proceedings by Cantó. If this is so, then the model will have to explain why two compact (< 70 au) HII regions are in the line of the jets, and form inside a few tens of au from the source. Alternatively, the compact objects could be stars, in which case the jets would have to emanate along the line of the two stars.

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Discussion:

YORKE: In the paper Yorke, Krugel (1977) oscillatory behaviour was found on two time scales, one at about 5 years and another at about 30000 years. Did you look for indications of periodicity in your observations of variability?

HUGHES: Yes, but over the period of 8 years, source 8 is the only one with a clear periodicity. It appears to be a relaxation oscillator, being present in 1981, not in 1982, present in 1986 but not in 1987 or 1988. As far as periodicity, your analysis was dependent on local density, and our density of $\sim 10^6 cm^{-3}$ is far higher than any you considered - one might expect a higher periodicity than 5 years.

SCHWARZ: How sure are you about the reality of these variations? Can these not be due to self-cal in a poor S/N regime?

HUGHES: I am very confident that the major variations that were discussed are real. Each set of observations contained more than 100000 visibilities, there were all reduced using the same self-cal procedures; in no case was the self-cal procedure overdone. As far as S/N ratio is concerned, peak fluxes are 2-3 mJy, but the 3σ noise level was < 0.1 mJy. This did not provide a poor S/N regime.

SARGENT: My first question echoes that of U. Schwarz in that I am also concerned about the effects of "clean" and "self-cal" on the maps. I would also like to know the range of percentage variation in the source fluxes. Are there differences at different wavelengths?

HUGHES: My answer echoes a former answer, in that I see no difficulties in applying the clean procedure, and "self-cal" was not overdone. In some cases, variations in individual sources were difficult to measure due to not being completely resolved; in others, sources may be over-resolved at 6 cm but not at 20 cm, as for Source 3. For those sources for which confident flux densities were determined, the figure in the text shows the variations. Source 8 and the new source (9) were completely resolved, and their flux densities are indicated in the paper.

TERLEVICH, R.: Have you looked for proper motions, and if not detected, can you give an upper limit to the tangential velocity in your objects?

HUGHES: Yes, but the present upper limit is 400 kms^{-1}. We hope in time to lower this value, but one limit is the accurate position of calibrations sources.

HARI OM VATS: How sure are you that variability time scales less than 1 year are not present in HII regions?.

HUGHES: The highly variable sources could have variability of less than 1 year, but at present the minimun interval between observations is about 1.25 years. We have observations taken in 1989 Jan, not yet reduced, wich should show if there is variability over a period of 0.5 years.