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A 31-GHz map of W3 (OH) with a resolution of 0.3 arcsec

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Summary. The compact H II region W3 (OH) has been mapped at 31.4 GHz with 0.3-arcsec resolution. The emission is concentrated in an irregular ring with a low central minimum, and an electron density in the shell of at least $2 \times 10^5\,\mathrm{cm}^{-3}$ is implied. One group of OH maser sources lies near a continuum peak, another is south of the source and the remainder are on the periphery of the ionized gas. No emission is detected in the vicinity of the H_2O masers.

1 Introduction

W3 (OH) has been studied over a wide range of wavelengths although it is completely obscured optically. In addition to the radio and infrared continuum emission, a group of OH masers coincides with the source while a group of H_2O masers lies about 6 arcsec to the east, each group being contained within an area approximately 2 arcsec in extent (Harvey *et al.* 1974. Mader *et al.* 1975). The OH masers reveal Zeeman splitting consistent with a field strength of ~ 5 mG (Moran *et al.* 1978). Previous high-resolution radio continuum observations have been described by Wink, Altenhoff & Webster (1973), Harten (1976) and Harris & Scott (1976); the maximum angular resolution was 0.65 arcsec, sufficient to indicate the overall extent of the source, but not to resolve internal detail. The present paper describes measurements at a frequency of 31.4 GHz with a HPBW of 0.3 arcsec; in addition to providing an improved angular resolution, the higher frequency gives a better indication of electron-density variations by reducing the effects of optical depth.

2 The observations

W3 (OH) has been observed with the Cambridge 5-km telescope (Ryle 1972) at a frequency of 31.4 GHz. At this frequency the 13-m antennae had an efficiency of between 20 and 25 per cent and the use of uncooled mixer receivers gave an overall system noise temperature of ~ 1600 K. The aerial feeds were linearly polarized at pa 0°. The measurements comprised three repeated 12-hr runs, on 1980 January 16, 25 and 26, each with the same 16 interferometer spacings, resulting in a HPBW of 0.32 × 0.36 arcsec with a first grating response at a radius of 6.7 arcsec. Phase calibrations were based on measurements of 3C 345 before and after each observation, and the amplitude scaling on measurements of 3C 84 and 3C 345 for which flux densities of 42 and 7.3 Jy were assumed (C. Henderson, private communication). The latter are uncertain by at least 10 per cent, with corresponding errors in the quoted flux densities and brightness temperatures. The measurements were made at times when tropospheric disturbances were below average and it was not found necessary to employ a 'nodding' technique for calibration as used in previous 15-GHz observations (Riley & Pooley 1978).

The contour map obtained by combining the three sets of data is presented in Fig. 1, the physical scale indicated being based on an assumed distance to W3 (OH) of 3 kpc (Schraml & Mezger 1969). The estimated rms noise level is 20 mJy per beam area (250 K). The integrated flux density is 2.7 ± 0.5 Jy; this is less than expected from extrapolating the spectrum, the difference most probably being attributable to the omission of low-brightness structure (Harten 1976). Comparison of the maps derived from the individual measurements indicates a probable uncertainty (excluding any systematic effects) of less than one contour in the combined map. At this resolution the source is only partially resolved, but nevertheless provides clear evidence for an irregular ring structure. The peak brightness temperature in the northern 'hotspot' is 3100 K and it is probable that some parts of the source remain optically thick.

In addition to the standard Fourier procedure for map reduction, a maximum entropy analysis (Gull & Daniell 1978) has been applied to the data and also used to optimize the relative mean phase and sensitivity of the individual aerials. The values obtained were within 10 to 20 degrees of phase and 4 to 8 per cent in amplitude of those deduced from the calibration sources. The resulting map is shown in Fig. 2. There is not only a marked improvement in the effective signal-to-noise ratio, but also a resolution similar to that given by a uniform aperture grading, without the penalty of negative responses. The source shows a pronounced shell structure, and the central minimum is less than 30 per cent of the mean brightness in the ring. The peak brightness temperature on this map is 5100 K.

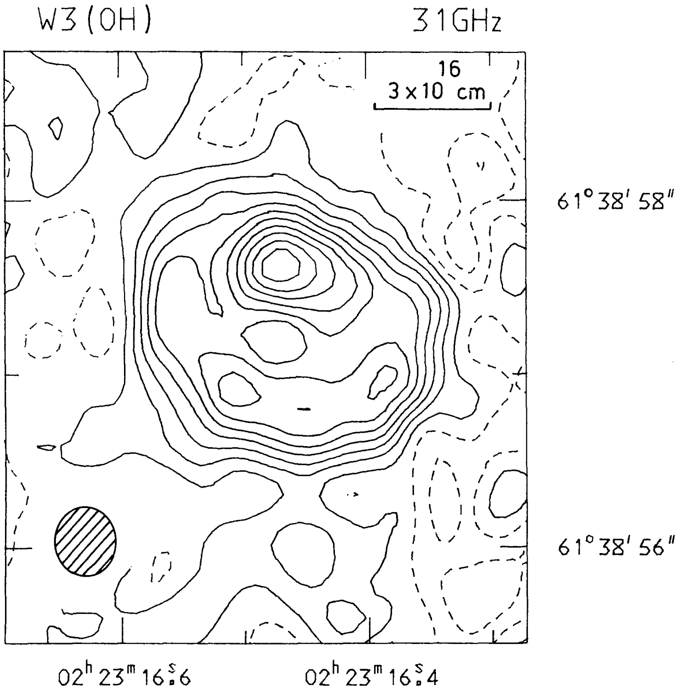

Figure 1. Contour map of W3 (OH) at 31.4 GHz. The contour interval is 300 K and the lowest contour is at 240 K. Negative contours are shown dashed. The shaded ellipse represents the HPBW.

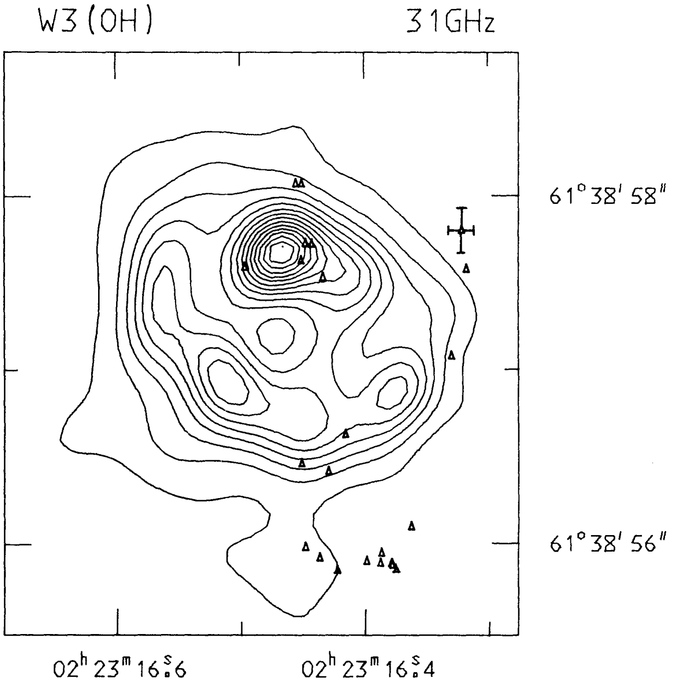

Figure 2. Maximum entropy map of W3 (OH). The lowest contour corresponds to a brightness temperature of 165 K and the contour interval is 330 K. The positions of the OH masers (Harvey *et al.* 1974) are indicated by the open triangles. The uncertainty in the overall positioning of the masers relative to the continuum map is indicated by the error bars on one of the components.

3 The distribution of ionized gas and its relation to the OH masers

The most striking feature of the results is the partial shell structure of the ionized gas. Similar distributions have also been observed in the more evolved members of the main W3 complex, namely components (A) (Krügel & Mezger 1975), (B) (Harris & Wynn-Williams 1976) and (C) (Colley 1980). The broad features of the emission from W3 (OH) can be modelled by a uniform spherical shell having inner and outer radii of 0.5 and 0.8 arcsec, although a better fit to the data could probably be obtained by postulating an electron density which increases towards the outer edge. The model implies an electron density in the shell of $\sim 2 \times 10^5$ cm^{-3} for a source distance of 3 kpc, whereas the density in the central region must be below about $6 \times 10^4\ \mathrm{cm}^{-3}$ to be consistent with the minimum emission observed.

The OH masers associated with W3 (OH) have been mapped by Harvey *et al.* (1974) and Moran *et al.* (1978) amongst others, but generally with positional accuracies inadequate for useful comparisons with the continuum source. Recent measurements by Norris, Booth & Davis (1980), however, have quoted errors of about 0.1 arcsec and these have been used to calibrate the earlier measurements by Harvey *et al.* Within the combined errors the positioning of this recalibrated map then agrees with the absolute determination by Moran *et al.* The positions of the OH masers are shown superposed on the map of Fig. 2, the uncertainty in overall relative positioning being indicated by the error bars on one of the maser components. One group of maser sources coincides with the northern hotspot and another lies close to the faint emission to the south, while the remainder are close to the periphery of the continuum component, as tentatively suggested on the basis of earlier measurements (Baldwin, Harris & Ryle 1973).

As noted earlier, the H_2O masers are clustered some 6 arcsec to the east of the continuum source (Forster, Welch & Wright 1978) and have been mapped by Genzel *et al.* (1978). A

2.5σ upper limit of 40 mJy may be set to the flux density of any compact components in this area, corresponding to an angular size of less than 0.1 arcsec for any optically-thick H II region.

4 Discussion

Dynamical models for the development of massive protostars have been discussed by Yorke & Krügel (1977). As shown earlier by Kahn (1974), for much of its early evolution the protostar is surrounded by an optically-thick cocoon, typically 10^{16} cm in radius, in which the stellar UV is converted to near-IR. Radiation pressure from this IR field leads to the formation of an outer cocoon at a radius of some 10^{17} cm where the mass infall is halted or reversed. At some later stage, the inner cocoon will become transparent to the stellar Lyman continuum and an ionization front will propagate outwards rapidly. The shell structure observed in W3 (OH) would be a natural result of the stellar UV radiation impinging on this outer cocoon. The UV continuum required to explain the radio emission implies an exciting star of O7 or earlier (Panagia 1973); it may be noted that the radiation pressure at the radius of the shell is then several times the estimated pressure in the ionized gas and could contribute to maintaining the shell structure even in the absence of any stellar wind. In view of the likely high density of dust in the outer cocoon, the required Lyman continuum may be considerably higher.

The appearance of a compact group of OH masers near the peak in the radio emission is particularly interesting. Ammonia absorption measurements towards W3 (OH) suggest (Wilson, Bieging & Downes 1978) that part (~ 30 per cent) of the continuum source is covered by a dense neutral globule, optically thick to the NH_3 line. A possible explanation both of the hotspot itself and also of the OH masers would be to postulate the presence of a neutral inclusion, perhaps a fragment of an earlier neutral shell, with the enhanced continuum emission arising from the flow of ionized gas from the interface. A second possibility is that this region is separately excited, as may also be the case for the group of masers to the south, although the velocity patterns of the OH sources provide no positive support for this.

It is clear, both from considerations of the pumping (Forster *et al.* 1978) and from the spatial distribution (Genzel *et al.* 1978), that the H_2O masers have a separate source of excitation. It may also be noted that the total IR luminosity for the region of $\sim 3.2 \times 10^5 L_\odot$ (Furniss, Jennings & Moorwood 1975) is several times the suggested minimum luminosity of W3 (OH) itself. The radio source is probably the most evolved of a compact group of OB protostars, the majority of which are still completely dust-bound.

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References

Baldwin, J. E., Harris, C. S. & Ryle, M., 1973. *Nature*, **241**, 38.
Colley, D., 1980. *Mon. Not. R. astr. Soc.*, **193**, 495.
Forster, J. R., Welch, W. J. & Wright, M. C. H., 1978. *Astrophys. J.*, **215**, L121.
Furniss, I., Jennings, R. E. & Moorwood, A. F. M., 1975. *Astrophys. J.*, **202**, 400.

Genzel, R., Downes, D., Moran, J. M., Johnston, K. J., Spencer, J. H., Walker, R. C., Haschick, A., Matveyenko, L. I., Kogan, L. R., Kostenko, V. I., Rönnäng, B., Rydbeck, O. E. H. & Moiseev, I. G., 1978. *Astr. Astrophys.,* **66**, 13.

Gull, S. F. & Daniell, G. J., 1978. *Nature,* **272**, 686.

Harris, S. & Scott, P. F., 1976. *Mon. Not. R. astr. Soc.,* **175**, 371.

Harris, S. & Wynn-Williams, C. G., 1976. *Mon. Not. astr. Soc.,* **174**, 649.

Harten, R., 1976. *Astr. Astrophys.,* **46**, 109.

Harvey, P. J., Booth, R. S., Davies, R. D., Whittet, D. C. B. & McLaughlin, W., 1974. *Mon. Not. R. astr. Soc.,* **169**, 545.

Kahn, F. D., 1974. *Astr. Astrophys.,* **37**, 149.

Krügel, E. & Mezger, P. G., 1975. *Astr. Astrophys.,* **42**, 441.

Mader, G. L., Johnston, K. J., Moran, J. M., Knowles, S. H., Mango, S. A., Schwartz, P. R. & Waltman, W. B., 1975. *Astrophys. J.,* **200**, L111.

Moran, J. M., Reid, M. J., Lada, C. J., Yen, J. L., Johnston, K. J. & Spencer, J. H., 1978. *Astrophys. J.,* **224**, L67.

Norris, R. P., Booth, R. S. & Davis, R. J., 1980. *Mon. Not. R. astr. Soc.,* **190**, 163.

Panagia, N., 1973. *Astr. J.,* **78**, 929.

Riley, J. M. & Pooley, G. G., 1978. *Mon. Not. R. astr. Soc.,* **184**, 769.

Ryle, M., 1972. *Nature,* **239**, 435.

Schraml, J. & Mezger, P. G., 1969. *Astrophys. J.,* **156**, 269.

Wilson, T. L., Bieging, J. & Downes, D., 1978. *Astr. Astrophys.,* **63**, 1.

Wink, J. E., Altenhoff, W. J. & Webster, W. J., 1973. *Astr. Astrophys.,* **22**, 251.

Yorke, H. W. & Krügel, E., 1977. *Astr. Astrophys.,* **54**, 183.