HIGH-RESOLUTION RADIO OBSERVATIONS OF A GIANT H II REGION IN CYGNUS

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Abstract. Westerbork observations of several large H II regions in the Cygnus-X region are described. IC 1318 appears to be a giant H II region, and two nearby sources may be genetically related to it.

I. Introduction

The highest angular resolution for observations of H II regions with a single antenna was obtained a few years ago by Schraml and Mezger (1969). They used the NRAO 43-m telescope at 2-cm wavelength, which resulted in a half-power-width of the main beam of about 2′. The results, particularly those on the nebula W49 (Mezger *et al.*, 1967), indicated that, given a sufficiently narrow antenna beam, many interesting details would be seen in H II regions of small overall angular size.

Consequently such observations have been undertaken with interferometers, e.g., the Cambridge 'One-Mile-Telescope'. (Wynn-Williams, 1971) and the NRAO three-element interferometer (Webster *et al.*, 1971). These two aperture-synthesis instruments are either extremely slow or incapable of covering the aperture plane completely. Therefore the observations have been restricted mainly to bright regions of small angular size (in most cases significantly smaller than the beam of the antenna pattern of the interferometer elements).

These observations have shown the existence of compact condensations ('bright knots'). They are thought to be excited from a star within and are considered as very young H II regions. In almost all cases the total flux density in the interferometer map is less than the total flux density measured with a single antenna. This indicates that the source contains angular structure on a scale large enough to be resolved by the shortest interferometer spacing.

The Synthesis Radio Telescope (SRT) at Westerbork, The Netherlands, delivers a completely sampled aperture plane from 36 m to 1458 m with 18-m intervals in 4 half-days of observing time. This enables the study of sources of relatively large angular size with a very good resolution.

We therefore used this instrument for observations of several large H II regions in the Cygnus-X region. One aim was to study the hierarchy of sub-structures in these presumably old sources. The choice of the general region of the sky was influenced by the availability of plates in the Hα line, enabling the study of the relation between radio and optical structures and the absorption across the nebulae.

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II. The Radio Observations

Figure 1 shows part of the Cygnus-X region as observed by Wendker (1970) at 11-cm wavelength with an angular resolution of 11′. The SRT observations have been done in the region of IC 1318b and c, the companion sources north (G79.3 + 1.3) and south (G78.1 + 0.6) of these, the so-called γ-Cygni source, and the area around G78.2 − 0.4 and G78.0 + 0.0. Note that the northern and southern companions are much smaller and appear more symmetrical than the regions IC 1318b and c. Figure 2 is a copy of the Hα plate of the region; IC 1318b and c are separated by a large lane of dust, while the northern and southern sources are highly obscured. We adopt a distance of 1.5 kpc to all the sources (Dickel *et al.*, 1969).

We turn now to the Westerbork observations of IC 1318b, at 21 cm with a synthesized beam of 30″ × 45″. Figure 3 shows the resulting contour map. Integration of the map indicates that only 15% of the flux density measured with a single antenna is present. The map appears to be a blend of about 10 substructures of the size of a few

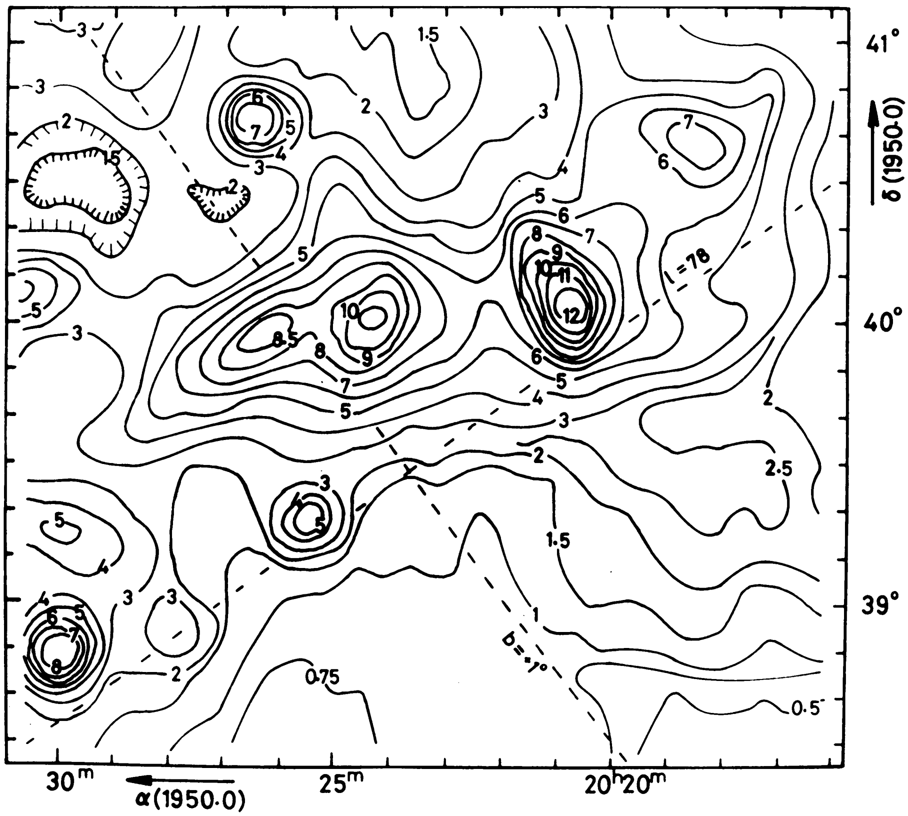

Fig. 1. Part of 11-cm map of Cygnus-X region obtained by Wendker at $\lambda = 11$ cm with a resolution of 11′. The brightest source is the γ-Cygni source; to the east of it are IC 1318b and c with their northern and southern companions.

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Fig. 2. A photograph in Hα of IC 1318b and c. Note the conspicuous dust lane crossing the region. Photograph by H. R. Dickel and H. J. Wendker. Courtesy of Hale Observatories.

arcmin. The half-power angular width of the source, as deduced from the single-antenna observations is $20' \times 30'$, beyond the region where the SRT sees significant radiation. An obvious conclusion is that the greater part of the source's flux density comes from a large, smooth component which is at best only partially seen by the smallest interferometer spacing of 36 m.

To check this quantitatively we have used the source parameters from the 11-cm map as starting parameters. Since the sources are known to be optically thin at 21 and 11 cm no serious error can arise in doing this. By an iterative least-squares fit to the complex visibilities we found the parameters of those sources which dominate the 36-m and 54-m spacings of the SRT observations. In comparing the final fit with the single dish data we find that the SRT sources fit only the upper part of the single antenna scans. This suggests that a component exists with size $> 1°$ which is thus completely absent in the 36-m spacing but contributes heavily to the single-antenna

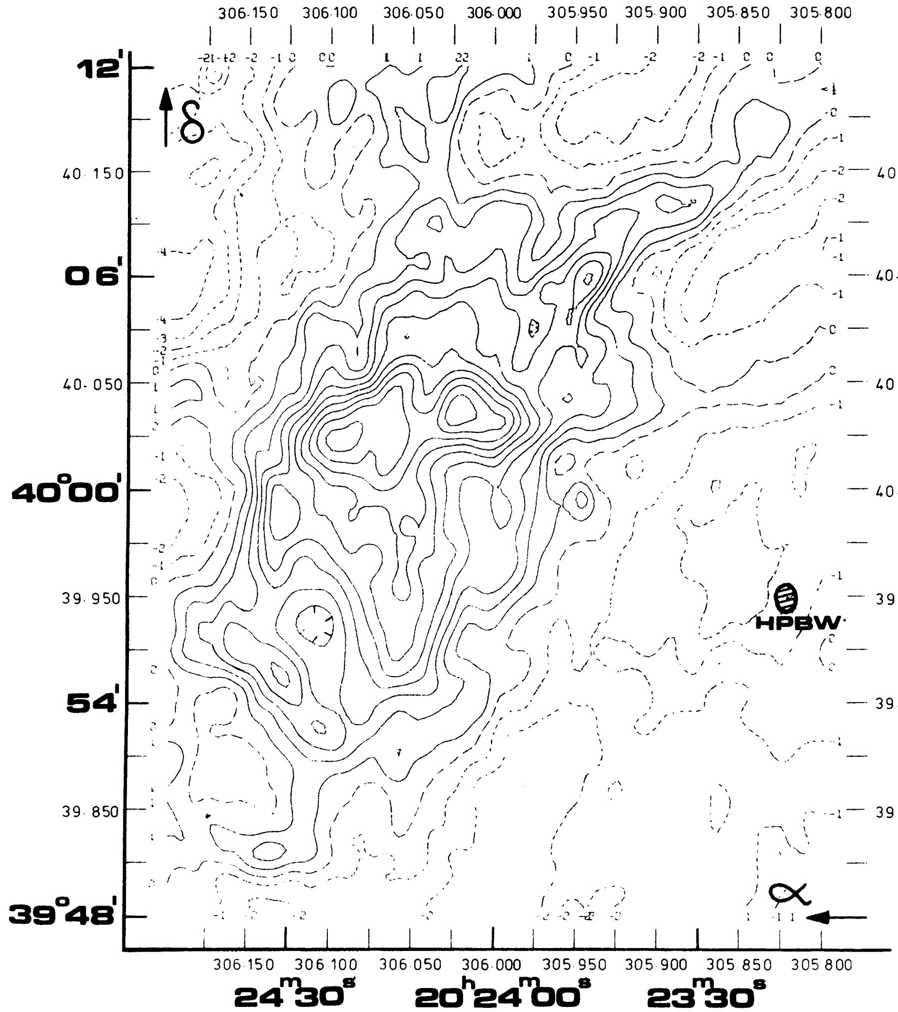


Fig. 3. IC 1318b as observed with the SRT at $\lambda = 21$ cm with a synthesized beam of $30'' \times 45''$. The full contours are 1 (1) 10 K in brightness temperature, the dashed contours are negative responses. The observed size of the source is much too small, because of the loss of information on the large-scale structure in the interferometer output.

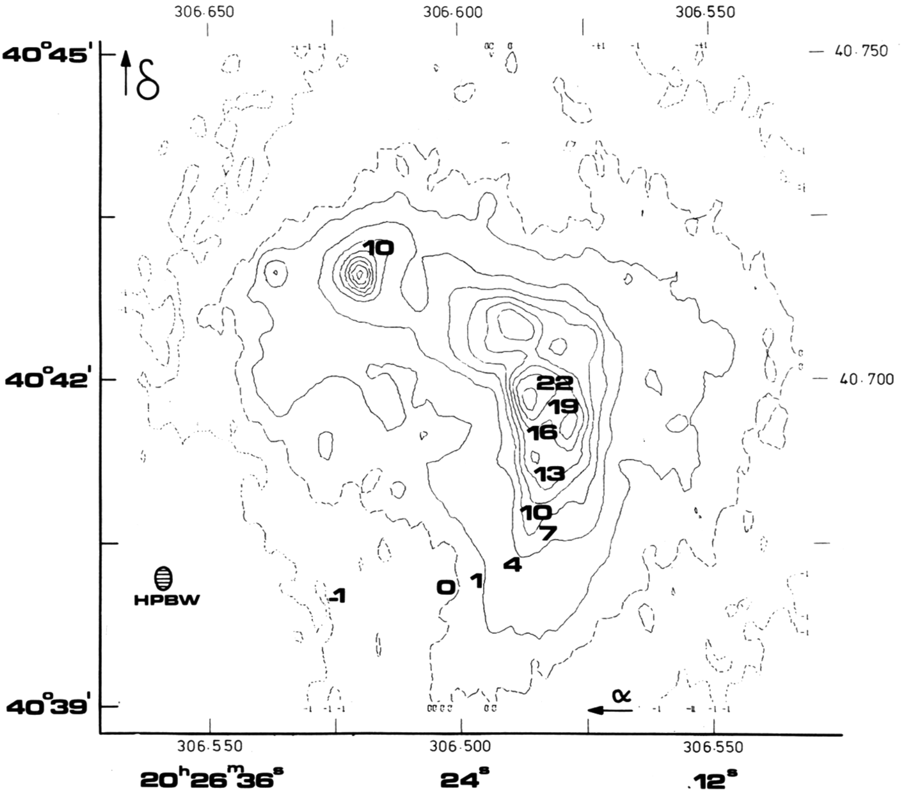
flux density. Introducing such a component in the single-dish data together with the components found from the two smallest spacings of the interferometer we obtained a reasonable fit to the single-dish data. We find a half-width of 75′ and a flux density of about 300 Jy for this large extended component. Almost all of this component was considered to belong to the unresolved background contained in the 11-cm data by Wendker (1970).

We conclude that we see the following hierarchy of angular structures in IC 1318b:

(i) an extended envelope of size 75′;

(ii) the intermediate sources, dominating the 11-cm data, of size 15′–30′;
(iii) the finer scale substructure, seen only with the SRT, of size less than 5′.
The ratios of flux densities are about: (i):(ii):(iii) = 10:3:10^{-2}.

Quite a different picture emerges in the case of the source G79.3 + 1.3, the northern companion of IC 1318b. SRT maps at 6 cm and 21 cm are available for this source. Figure 4 shows the 6-cm map. Here small-scale components stand out clearly. They



Figs. 4a–b. Contour map of G79.3 + 1.3, observed at $\lambda = 6$ cm with a resolution of 6″ × 10″. Contour values are approximately in kelvins in equivalent brightness temperature. There are at least seven small-scale components.

are rather symmetrical in appearance and of small angular size. A comparison with the single-antenna flux density shows that by far the largest percentage of the flux density is contained in the condensations. This is very different from IC 1318. However, an analysis similar to that described above shows that at 21 cm there is a weak extended component which is smooth and covers the total source area. This component is lost at 6 cm, but the 6-cm data do show a smooth component underlying the condensations which is of intermediate size.

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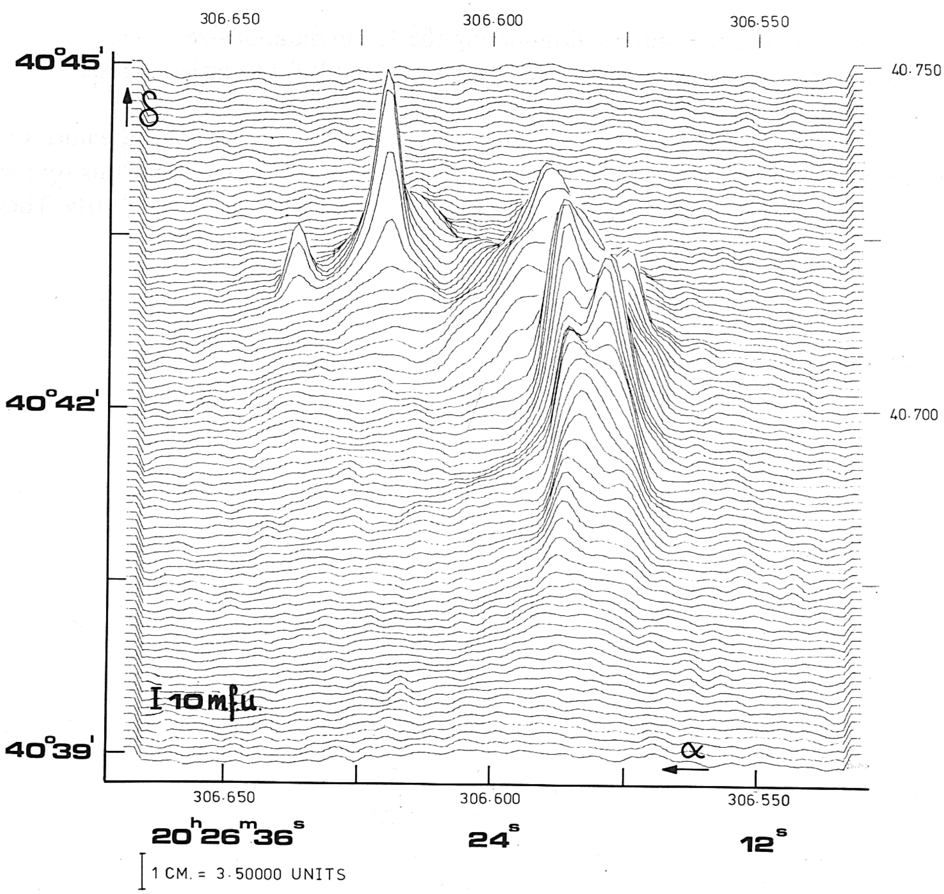

Fig. 4b. The same observation represented in a profile map.

III. Discussion

Results similar to IC 1318b have been obtained for IC 1318c and in a preliminary form also for G78.2−0.4. In the same sense the southern companion and G78.0+0.0 resemble the northern companion of IC 1318b. Therefore the appearance of the two sources discussed above is not unique.

A main point from the above analysis is that the extended component of size 75′ covers both sources IC 1318b and c. This leads us to suggest that both nebulae IC 1318b and c are in fact one H II region. This source then belongs to the class of giant H II regions, as defined by Mezger (1970). If this suggestion is accepted it is probably of interest to point out that IC 1318 is then the giant H II region closest to the Sun. Although it is intrinsically weaker than W49, the prototype of a giant H II region, it contains all the hierarchy of substructures found in W49.

Physical parameters for the components, derived under the usual assumptions for H II regions, are listed in Table I.

TABLE I

Physical parameters of IC 1318b and c components

Parameter	Envelope	Intermediate component	Small component	Total source
T_b(K) at 11 cm	4	8	1	12
Size (arcmin)	75	25	3	75
Size in pc	32	11	1.3	32
E (pc cm^{-6})	8400	17000	2100	25200
n_e (cm^{-3})	16	40	40	28
U (pc cm^{-2})	100	65	8	150
Type of exciting star	O6/7	O8 V	B0.5–1 V	O4–O5

If the total source has one excitation center, a star of type O5 would be required for a smooth distribution of the gas. Since the observations clearly show this not to be the case, a somewhat hotter star, O4, is needed. There are no O4 stars observed as yet. The intermediate components in IC 1318b and c can be excited by an O8 V star alone. The small scale components are quite different from the compact H II regions studied, e.g., by Webster *et al.* (1971) or Habing *et al.* (1972). Their bright 'knots' require an O star as excitation center, while for our small components an early B star would suffice. In the present case however, we feel that the small-scale structure should be considered as an inherent part of the intermediate component, its appearance resulting from density gradients in the gas.

Now we discuss the sources of smaller angular size. As a prototype we take G79.3+ +1.3, the northern companion of IC 1318b. The physical parameters of the components mentioned above are summarized in Table II.

TABLE II

Physical parameters of G79.3+1.3 components

Parameter	Envelope	Intermediate component	Condensation (average)	Total source
T_b(K) at 11 cm	5	17	50	50
Size (arcmin)	5	1.8	0.3	1.8
Size in pc	2.2	0.77	0.13	0.77
E (pc cm^{-6})	10300	35700	105000	105000
n_e (cm^{-3})	70	215	900	370
U (pc cm^{-2})	38	14	6	20
Type of exciting star	O9	B0.5 V	B1 V	O9

It is seen that the condensations dominate the source G79.3+1.3. Certainly an O9 star could excite the total H II region. However, it is hard to see how sharp small scale structure could develop in such a case.

We suggest on the basis of the morphology, as described in the previous section (see also Figure 4) that the condensations each have their own excitation center. This is contrary to our suggestion for IC 1318b and c. A typical condensation here can be excited by a B1 V star. Thus this H II region could represent a very young association of B stars, so young that the stars have not yet lost their surrounding ionized shells. The situation is analogous to the young O-star association thought to be responsible for the appearance of W49.

At this point it is tempting also to suggest that there is a genetic relationship between the giant H II region IC 1318b and c and their northern and southern companions. In projection both companions are contained in the very extended envelope discussed in connection with IC 1318b and c. The whole complex would then be the first stage of the generation of an OB-star association, where the H II components of different size and density represent the formation of different members at different ages. A similar relationship is suggested by Israel *et al.* (1973) for a group of H II regions around $l = 111°$. A similar group may be represented by the H II regions G81.6+0.0 and G81.7+0.5 also situated in the Cygnus-X region (see Wendker, 1970).

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DISCUSSION

Terzian: What distance did you adopt for the source? Does it correspond well with the kinematic distance from recombination lines?

Baars: We adopted 1.5 kpc; I think it agrees.