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Research Note

An H II Region Near NML Cygnus

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Summary. Using the Westerbork Synthesis Radio Telescope (WSRT), an extended continuum radio source near NML Cygnus has been detected at 21 cm. The source has a thermal spectrum between 2.8 and 21 cm and is associated with a faint H II region 35″ to the west of NML Cygnus. We argue that the H II region probably is physically associated with NML Cygnus. The H II region may have resulted from mass lost previously by the M supergiant and now ionized by a nearby B 1–B 2 star.

Key words: supergiants – OH-sources – masers – mass loss – variable stars

Introduction

Using the 100-m telescope, Goss et al. (1974) detected a weak continuum radio source near NML Cygnus at 2.8 cm. This result was not expected (in spite of the predictions by Davies et al., 1972) since this star is an M supergiant with associated OH, SiO, and H_2O maser sources. Gregory and Seaquist (1976) extended these continuum observations and suggested that the emission arises from a faint optical H II region of ~2′ in size close to NML Cygnus. Earlier Rubin et al. (1967) had observed Hα emission from this nebula.

Since these early detections of NML Cygnus were made with on-off observing techniques with beams of 1′.3 and 2′.8, it was desirable to map the source with higher angular resolution. The field has been observed with the Westerbork Synthesis Radio Telescope (WSRT) at 21 cm with two main goals: (1) to confirm the thermal radio spectrum and (2) to determine the shape and precise position of the radio continuum in order to study the association of NML Cygnus and the Hα nebulosity.

Observations

The field of NML Cygnus ($l = 80\overset{\circ}{.}80$, $b = -1\overset{\circ}{.}92$) was observed for 12^h with the WSRT in August, 1978. The digital line backend (Bos et al., 1981) was used with a 10-MHz bandwidth. The WSRT was used in the "high density" array with the movable telescopes (*A*, *B*, *C*, and *D*) spaced by 36 m. The range of 40 interferometer spacings is 36, 72, 108, ... 1440 m. The grating rings appear at radii of 20′ × 31′ ($\alpha \times \delta$); the half-power beamwidth is 36′ and a field of $1\overset{\circ}{.}3$ was mapped. The rms noise is 0.4 mJy/beam (1 mJy/beam is 0.6 K in beam brightness) with a synthesized beam of 25″ × 39″ ($\alpha \times \delta$).

The data were analysed using the Groningen Interactive Picture Processing System (GIPSY). A total of 22 background sources were detected. The 33 W list (thirty-third Westerbork list) of background sources is given in Table 1. Most of the sources are unresolved; to improve the sensitivity of the map these were subtracted from the field. The size and size limits are listed in column 5 (e.g. *L* is less than). The sources with no entry are less than 15″ in size. The source 33 W 17 is within 38″ of a point source (8 mJy at 11 cm) described by Gregory and Seaquist (1976). The source 33 W 15 is within two arcmin from NML Cyg, and is at the edge of our extended radio source. Cross cuts through the source showed it to be a point source, whose subtraction from the background was easy. A referee asked whether the source could be physically associated with the nebula. We cannot exclude this association definitely, but we think it to be improbable for the following reasons:

1. At 2.8 cm Gregory and Seaquist (1976) have measured the total flux of 33 W 15 and of our nebulosity; they find 27 ± 4 mJy. This is exactly the total flux at 21 cm that we find in this paper from the nebulosity itself; we conclude that at 2.8 cm 33 W 15 has a flux density of < 5 mJy. Since the flux density at 21 cm is 10 mJy the source has a non-thermal spectrum.
2. In a field of 1° × 1° we expect 15 background non-thermal sources with $S > 10$ mJy (Oosterbaan, 1978). We detect 16 or 17. The hypothesis that 33 W 15 is a background source is therefore completely acceptable. On the other hand, if it were associated with the NML Cyg nebula it would be quite a unique object. We prefer the simpler hypothesis that it is not.

Results

The WSRT contour map at 21 cm is shown in Fig. 1, superimposed on a copy of the Palomar Sky Survey red print. The positional accuracy of the superposition is ~1″. The central cross is the position of NML Cygnus and the cross to the south-west is the position where a 10.5 mJy point source (33 W 15) has been subtracted. The total flux density of the extended source at 21 cm is 28 ± 3 mJy. At 2.8 cm the flux density is 27 ± 4 mJy (Gregory and Seaquist, 1976). Thus the source has a flat spectrum in the cm range, characteristic of an optically thin H II region.

The radio source shows remarkable agreement in size (~100″ × 50″) and shape with the red image which presumably arises from

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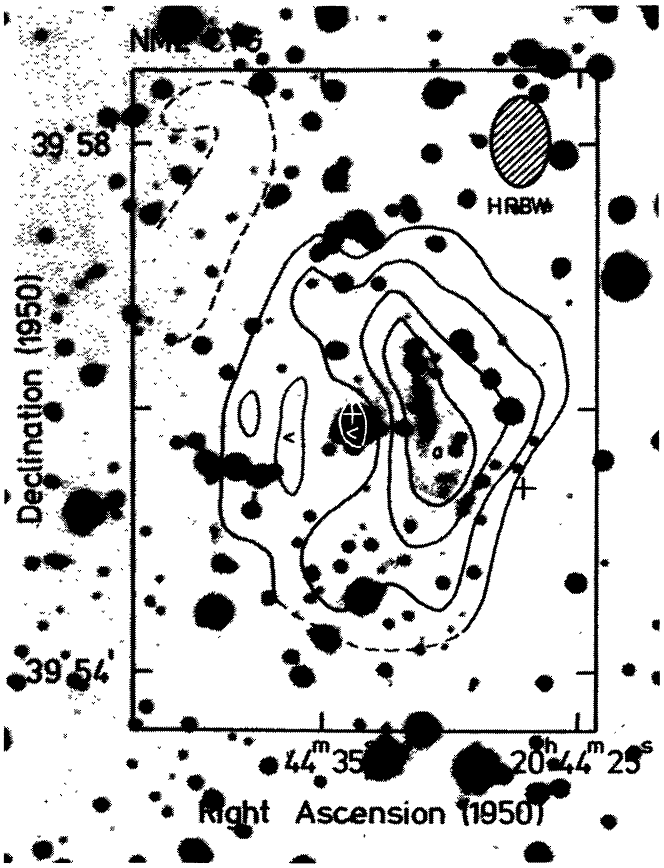

Fig. 1. 21 cm continuum map near NML Cygnus obtained with the WSRT superimposed on the Palomar Sky Atlas *E* plate. The contour units are −0.5, 0.5, 1, 2, 3, 4 mJy/beam where 1 mJy/beam is 0.6 K in beam brightness. The half-power beam of 25″ × 39″ is indicated. The rms noise is 0.4 mJy/beam. The central cross is the position of NML Cygnus at $\alpha(1950) = 20^h44^m33\overset{s}{.}9 \pm 0\overset{s}{.}1$ $\delta(1950) = +39°55'57\overset{''}{.}2 \pm 2$ (Hyland et al., 1972). The south-west cross indicates the position where the source 33 W 15 (Table 1) (10.5 mJy) has been subtracted

Table 1. Background sources near NML Cygnus

Name (33W)	α(1950)	δ(1950)	S mJy	size "arc
1	$20^h42^m19\overset{s}{.}80 \pm \overset{s}{.}08$	30°54'40"±1"	56 ±3	
2	20 42 42.39±.15	39 59 02 ±2.2	12 ±3.6	L20
3	20 43 20.07±.18	40 04 10 ±2.7	6.2±1.0	L20
4	20 43 20.40±.14	39 42 05 ±2	10.8±1.3	
5*	20 43 29.10±.08	39 47 20 ±1	31.0±0.6	
6	20 43 29.42±.08	39 45 58 ±1	20.3±0.9	
7	20 43 32.37±.10	39 50 32 ±1.2	14.8±0.8	
8	20 43 44.66±.12	40 18 45 ±1.6	20.8±2.5	
9	20 43 52.84±.08	39 54 36 ±1	23.2±0.7	
10	20 43 53.65±.16	40 00 40 ±2.2	5.5±0.8	
11	20 43 55.36±.11	40 07 30 ±1.5	12.9±0.9	
12	20 44 10.57±.16	39 57 50 ±2	4.8±0.7	
13	20 44 13.61±.22	39 50 10 ±3.5	2.7±0.7	L20
14	20 44 13.88±.08	39 55 35 ±1	19.1±0.7	
15**	20 44 27.32±.10	39 55 20.5±1.5	10.5±1.5	L20
16	20 44 31.19±.10	39 37 46 ±1.3	21.1±1.2	∿25
17	20 44 35.86±.08	39 52 17 ±1	21.0±1.0	
18	20 45 06.44±.12	40 13 03 ±2	9.6±1.2	
19	20 45 33.92±.15	40 03 19 ±2	6.7±0.9	
20	20 45 37.83±.08	40 19 54 ±1	174 ±5	∿15
21	20 46 21.72±.15	40 00 22 ±2	36.1±1.2	34×12
22	20 47 08.75±.10	39 59 53 ±1.2	59 ±4	

* 5 and 6 are apparent double.

** 15 near NML Cygnus. See Fig. 1

Hα. There is thus little doubt that this nebula is a low-luminosity H II region with an emission measure of 1.5 10^3 pc cm^{-6}. If the distance to NML Cygnus is 500 F pc (F is uncertainty factor) (Hyland et al., 1972) the size of the H II region is $\sim 0.2\,F$ pc, the r.m.s. electron density is $80\,F^{-0.5}$ cm^{-3}, the excitation parameter is $2.6\,F^{0.67}$ cm^{-2} pc and the ionized mass content is $2.3\;10^{-2}F^{2.5}M_\odot$. The implied A_V may be derived from a comparison of our 21-cm observations and the brightness in Hα. H. R. Dickel (private communication) has estimated that the Hα brightness is $3 \pm 2\;10^{-5}$ erg cm^{-2} s^{-1} sterad^{-1}. The implied A_V is then $2\overset{m}{.}2^{+1.5}_{-0.7}$.

Discussion

The first question to be asked is whether the positional coincidence between the H II region and NML Cyg is causal or accidental. Three arguments are in favour of a causal, non-accidental coincidence. (i) We have inspected the Palomar Observatory Sky Survey red plate over an area about 15 times the diameter of the faint, but well-visible nebulosity. No other similar object was found. [The general nebulosity of the Cyg X area lies much farther away on the POSS plate (~2°).] The nebulosity appears to be rather unique. Coincidence of this unique object with an even more unique object such as NML Cyg is thus unlikely to be an accident. (ii) NML Cyg coincides with a very clear minimum in the radio continuum source; it clearly is at a special position. (iii) The radial velocity of the nebulosity (+2 km s^{-1} with respect to LSR) as measured in Hα by Rubin et al. (1967) agrees with the systemic velocity of NML Cyg for which we take the velocity of the SiO maser line (+4 km s^{-1}) measured by Spencer et al. (1981).

At the position of NML Cyg some ^{12}CO emission has been detected by Hong-ih Cong (1978). The integrated line flux density, estimated from his Fig. 8, is approximately 13 K km s^{-1}. The CO is detected in the velocity range $V_{\text{LSR}} = +5$ to $+25$ km s^{-1}. More details are not given. CO observations with higher angular resolution are required to investigate the relation of the molecules to NML Cyg. CO emission from the immediate surroundings of NML Cyg has also been detected by Zuckerman et al. (1977) and Zuckerman et al. (1978); however, they conclude only "that the nature of the CO distribution is complicated".

The interesting fact that NML Cyg is in a "bay" of emission nebulosity suggests that NML Cyg may have pushed the ionized gas aside. To estimate the effect semi-quantitatively, assume that NML Cyg has a mass-loss rate $\dot{M}$, at a constant outflow velocity V. Then, the ram pressure ϱV^2 of this outflowing gas at a distance r is given by,

$$1.1\;10^{-5} \cdot \left(\frac{\dot{M}}{10^{-4}\,M_\odot\;\text{yr}^{-1}}\right) \cdot \left(\frac{V}{20\;\text{km s}^{-1}}\right) \cdot \left(10^{16}r\right)^2 \text{erg cm}^{-3}.$$

For the outflowing gas to push aside the H II region, assume that the ram pressure exceeds the thermal pressure in the gas, nkT, $\approx 1.4\ 10^{-10}$ erg cm^{-3}. Taking for the outflow velocity $V=20$ km s^{-1}, we find $\dot{M}r^{-2}>1.3\ 10^{-41}$. To push a hole of 10^{17} cm a mass loss rate of $\dot{M}>10^{-7}\,M_\odot\cdot\mathrm{yr}^{-1}$ is required. This should be compared with estimated values of the mass loss rate which are in the range 10^{-5}–$10^{-3}\,M_\odot$ yr^{-1} (Gehrz and Woolf, 1971; Davies et al., 1972).

The ionization of the nebula is most easily accomplished if an early type star is in the neighbourhood. This is quite probable. This general area of Cygnus contains several OB associations and, if NML Cyg is a massive star, it could be a member of one of these associations. If the nebula is at 500 pc, a fully embedded B 1–B 2 star emits enough ionizing photons; if the nebula is at 1500 pc, a fully embedded B 0.5 star is required; if the star is outside the nebula a still earlier spectral type is required (Panagia, 1973). Other explanations for the ionization appear quite unrealistic. NML Cyg is an M 6 III star (Herbig and Zappala, 1970) and unlikely to provide the ionizing flux. Since it is a unique object, it might have unique UV properties, but it is unlikely that this UV radiation could pass through the circumstellar dust shell and ionize the gas outside. Collisional ionization is also unlikely; the nebulosity is rather thick and the cooling time and recombination time in the nebula are probably too short to leave sufficient gas ionized to be observed.

The origin of the ionized gas is another question. Could it have been emitted by NML Cyg, or is it connected with the CO cloud? The ionized gas has a very low mass, and for that reason it is conceivable that it has been expelled by NML Cyg: a period of 10^4 yr, a mass loss rate of $10^{-6}\,M_\odot$ yr, and an outflow velocity of 20 km s^{-1} are sufficient to fill the volume of the H II region. Another possibility is that the ionized gas is connected with the CO cloud, evaporating from the cloud because of ionization by the (hypothetical) early type star. The situation then becomes reminiscent to that of VY CMa. This object is associated with a CO cloud, an H II region and a young cluster (Lada and Reid, 1978). As an OH/IR star VY CMa is in the same (limited) class of supergiants as NML Cyg and they both might be equally young.

We recommend NML Cyg for further observational study: more extensive CO observations may elucidate the relation between the star and the molecular cloud, discovered by Zuckerman et al. (1978) and by Hong-ih Cong (1978). A search for B stars or OB associations near NML Cyg might show up these (hypothetical) companions of NML Cyg. If detected, these stars would provide a direct means to determine the distance to NML Cyg. Since NML Cyg is probably one of the nearest OH/IR supergiant stars, and since these very rare stars are probably in a unique phase of their evolution, a better distance determination is of great importance.

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