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STAR FORMING KNOTS EMBEDDED IN THE NGC 3603 H II REGION

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RESUMEN

Condensaciones de gran brillo superficial con emisión en Hα, pertenecientes a la región H II gigante NGC 3603, fueron halladas utilizando imágenes obtenidas con filtros R y Hα. Se presentan aquí imágenes y espectroscopía detallada de dos de ellas (C 13 y C 16), localizadas a 1 pc del sistema tipo trapecio HD 97950. Los tamaños de las condensaciones son 2.″3 y 3.″9 y tienen un decremento de Balmer extremadamente alto (Hα/Hβ ≈ 20). La relación [N II]/Hα es de 0.2 y 1.5, respectivamente. Parte de la estructura gaseosa de C 16 pertenece a la eyección bipolar de la supergigante B Sher 25, lo cual explica su enriquecimiento en nitrógeno. La fuente estelar en C 16, detectada en K, es probablemente una gigante o supergigante roja muy oscurecida del fondo y vista en proyección. La relación [S II] 671.7 nm/[S II] 673.2 nm indica para C 13 una alta densidad electrónica, $N_e \approx 10^5\,\mathrm{cm}^{-3}$. Este nudo también muestra emisión de [O I] 630.0 nm. Imágenes del infrarrojo cercano revelan un objeto de tipo estelar dentro de C 13, con un anillo que la rodea de 11″ × 17″. La intensidad de las líneas de Balmer es consistente con la ionización producida por el cúmulo central de NGC 3603. La condensación estelar en C 13 puede ser un capullo en cuyo interior se encuentre una estrella de pre-secuencia de masa intermedia, indicando que algunas condensaciones podrían sobrevivir por varios millones de años en condiciones extremadamente adversas dentro del campo de radiación del gran cúmulo ionizante.

ABSTRACT

Narrowband Hα and broadband R imaging has been used to find high surface brightness, Hα emitting condensations within the giant H II region NGC 3603. We present here detailed imaging and spectroscopy of two of them (C 13 and C 16) located at about 1 pc from the trapezium-like system HD 97950. The size of the condensations is 2.″3 and 3.″9. They have an extremely high Balmer decrement (Hα/Hβ ≈20). The ratio [N II]/Hα is 0.2 and 1.5, respectively. Most of the gaseous part of C 16 belongs to the bipolar ejecta of the B supergiant Sher 25, which explains its N enrichment. The star-like source in C 16 detected in K is most likely a heavily obscured background red giant or supergiant seen in projection. The line ratio [S II] 671.7 nm/[S II] 673.2 nm indicates high $N_e \approx 10^5\,\mathrm{cm}^{-3}$ for C 13. This knot also shows [O I] 630.0 nm emission. Near-infrared imaging reveals a star-like object within C 13. A ring of 11″ × 17″ surrounds C 13. The Balmer line intensity is consistent with ionization produced by the central cluster of NGC 3603's. The stellar condensation in C 13 may be a cocoon containing an intermediate-mass pre-main-sequence star, indicating that some condensations might survive for several Myr the extremely adverse conditions within the radiation field of a big ionizing cluster.

Key words: **(ISM:) H II REGIONS: INDIVIDUAL (NGC 3603) — STARS: FORMATION**

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1. INTRODUCTION

The giant H II region NGC 3603 is located in the Carina spiral arm at a distance of 7 kpc (Moffat 1983; Clayton 1986). Star formation in this region seems to have extended over a long period of time (Moffat 1983; Melnick, Tapia & Terlevich 1989; Brandner et al. 1997a). The stellar density in the core of the central ionizing cluster of NGC 3603 is comparable to that of R136a (Moffat, Drissen, & Shara 1994; Drissen et al. 1995; Hofmann, Seggewiss, & Weigelt 1995). Because of its proximity, the giant H II region NGC 3603 provides a unique opportunity to study star formation processes in great detail.

Our original goal was to identify Hα emitting pre-main-sequence stars (Brandner et al. 1999). At an age of approximately 2–3 Myr (Drissen et al. 1995; Maeder & Meynet 1994) all stars less massive than 3 $M_\odot$ should still be in their pre-main-sequence evolutionary phase (Palla & Stahler 1993). By comparing deep Hα narrowband and R images we noticed extended emission-line condensations with typical sizes between 1″ and 4″ (scale 0.033 pc/″ at 7 kpc). Twenty times larger emitting knots (1–2.5 pc), excited by embedded massive stars, have been identified in the LMC (Heydari-Malayeri & Testor 1985, 1986; Testor & Lortet 1987). On a much smaller scale (0.005–0.01 pc) partially ionized globules externally excited by the Trapezium stars have been identified in the Orion nebulae (Dyson 1968; Laques & Vidal 1979; O'Dell 1993). In the present work, we study the nature of two condensations (C 13 and C 16, Brandner et al. 1999) inside the Hα region NGC 3603, with imaging and spectroscopy.

2. OBSERVATIONS AND DATA REDUCTION

Hα images were obtained in March 1995 under subarcsec seeing conditions with the CCD camera at the Danish 1.54-m telescope at ESO/La Silla, Chile. K-band high spatial resolution imaging ($0\farcs30 \times 0\farcs45$) of C 16 was obtained on 1994 April 1 with the adaptive optics system COME-ON PLUS (CO+) at the ESO 3.6-m telescope with a total exposure time of 1200 s. In 1993 December 27, we used the ESO 1.5-m and the Boller & Chivens spectrograph (B&C) to obtain long-slit spectra of C 16. The B&C spectrograph was equipped with a 2k×2k CCD and grating 23, giving a wavelength coverage from 400 nm to 780 nm and a resolution of 0.19 nm per pixel. The exposure time was 1800 s, the slit width was $1\farcs8$, and the orientation of the slit north-south. In February 1997, we observed C 13 with the EFOSC2, attached to the ESO MPI 2.2-m telescope with grisms 3 and 5 to obtain spectra in the range 340–606 nm and 516–928 nm, respectively. In both cases, spectrophotometric standards were observed for flux calibration. The reduction was carried out with standard IRAF and IDL procedures.

3. THE MORPHOLOGY

In Fig. 1 we show the Hα image of NGC 3603 with a zoom of C 13 and C 16. The condensations are located at a projected distance of about 1 pc from the central ionizing cluster. In both cases, it is possible to distinguish a diffuse spherical body, of $2\farcs3$ and $3\farcs9$ (0.076 pc and 0.13 pc), respectively. C 13 is surrounded by a faint, $11'' \times 17''$ ring-like structure, which might result from outflow of matter or wind originating from the central object, suggesting that it has suffered in the past a process of mass ejection. Adopting an expansion velocity of 100 km s^{-1} for the phenomenon, as found frequently in outbursts of young stars (Hamann 1994), it should have occurred ≈ 3200 yrs ago. The knot C 16 shows a high surface brightness, bow-like structure extending from the main body, which is part of the ejecta of the B1.5 supergiant Sher 25 near the central ionizing cluster (Brandner et al. 1997b). C 13 contains a centered star-like source. In the C 16 12″ field there are several star-like sources visible in the K-band image. One of the sources is centered on the knot (see Fig. 2).

4. SPECTRAL DATA

We present in Fig. 3 and Fig. 4 the spectra of C 13 and C 16. In Table 1 we list the observed line fluxes. Important properties to emphasize are:

a) The line ratio Hα/Hβ is around 20 for C 13 and C 16;

b) The ratio [S II] 671.7 nm/[S II] 673.2 nm indicates high density, especially in knot C 13;

c) In C 16 [N II] 658.4 nm/H$\alpha \geq 1$, which is much higher than in C 13 and in the surrounding ionized gas;

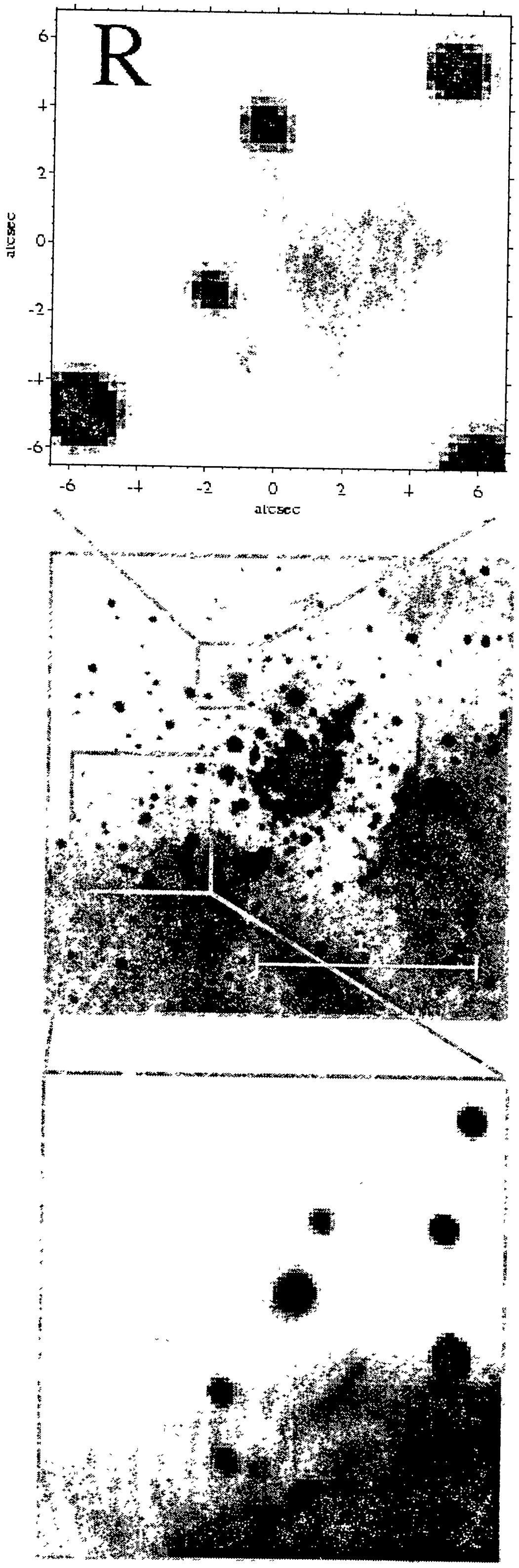

Fig. 1. NGC 3603 Hα image with enlargements of the condensations C 13 (bottom) and C 16 (R image, top).

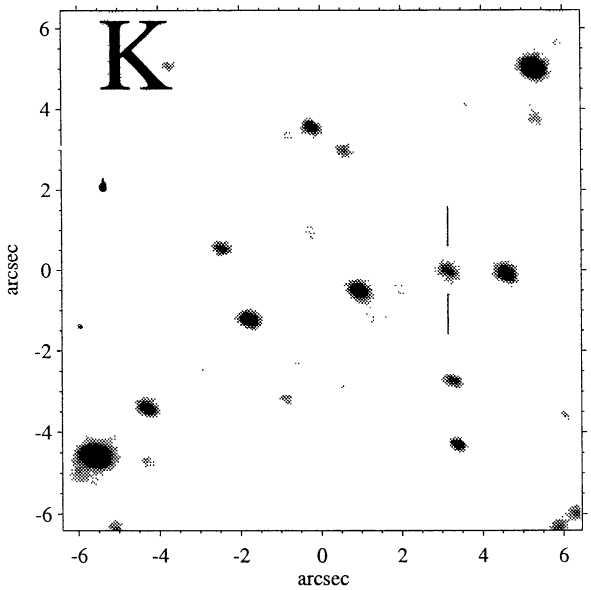

Fig. 2. Adaptive optics (CO^+) K image of C 16. Stars are elongated due to anisoplanatism, as Sher 25, used for wavefront sensing, is at $\approx 30''$ from C 16.

d) The ratio [S II] 671.7+673.2 nm/Hα within the knots is not enhanced compared to the surrounding Hα region, suggesting that shocks are not the major ionization mechanism (Bally, Levine, & Sutherland 1995);

e) The relative intensity of the He I 667.8 nm, [S II] 671.7+673.2 nm, He I 706.5 nm, [Ar III] 713.4 nm and [O II] 732.0+733.0 nm lines is higher in C 13 than in C 16;

f) The low ionization line [O I] 630.0 nm is present in knot C 13.

As can be seen in Fig. 3, the continuum blow-up of C 13 shows a strong IR contribution. This is a clear signature of an embedded IR source. No such IR continuum enhancement is seen in the spectra of C 16.

As shown by Brandner et al.'s (1997a) study of the velocity structure around Sher 25, we see two different objects in superposition in C 16. However, Brandner et al. (1997a) also point out that the northeastern lobe contains portions with a velocity component very similar to the surrounding giant H II region. The available data do not allow us to determine which portion of the gas (if any) is related to the infrared (IR) stellar knots in C 16.

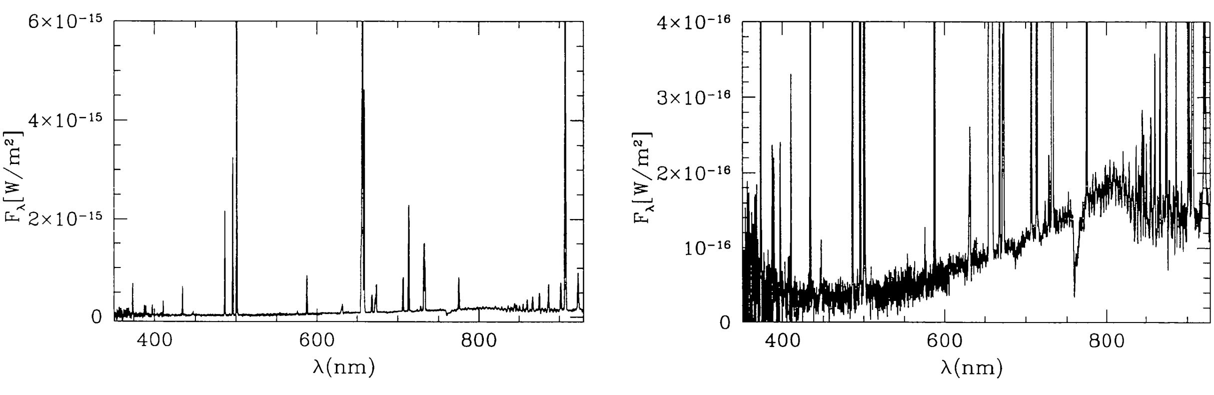

Fig. 3. Flux-calibrated spectrum of knot C 13. The enlargement shows the infrared continuum contribution of the central source.

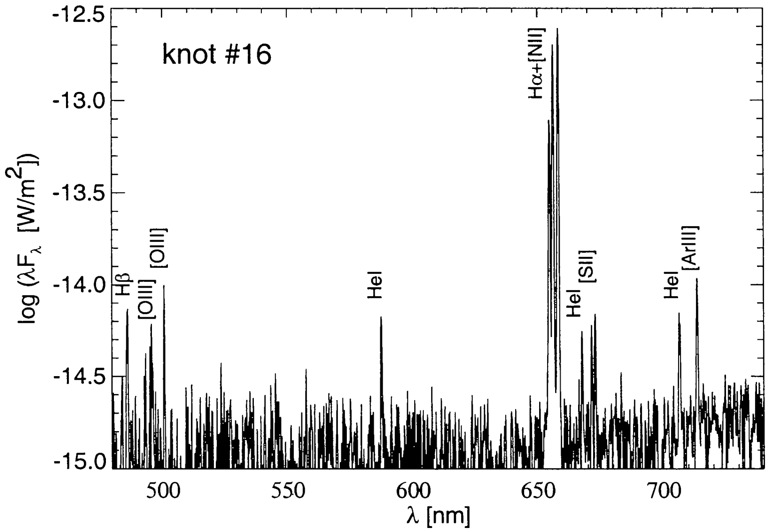

Fig. 4. Flux-calibrated spectrum of knot C 16 obtained with the ESO 1.5-m and the B&C spectrograph. The most prominent emission lines are marked.

5. PHYSICAL PROPERTIES

In Table 1 we present the physical properties of C 13 and C 16. By rows we quote: 1) knot diameter; 2) projected distance from the ionizing cluster HD 97950; 3) Hα emission line intensity; 4) Hα emission line luminosity; 5) number of ionizing photons necessary to produce the observed Hα intensity; 6) number of ionizing photons reaching the knot with origin in the central source; 7) electron density, as obtained from the [S II] 671.7+673.2 nm lines; 8) electron density, as obtained from the total emission, supposing that the whole knot is ionized; 9) filling factor; 10) mass of ionized gas; and 11) emission measure.

TABLE 1

CONDENSATION PARAMETERS

Property	C 13	C 16
diameter ($''$)	2.3	3.9
distance ($''$)	40	30
$F_{\mathrm{H}\alpha}$ [10^{18} W m^{-2}]	326	254
$L_{\mathrm{H}\alpha}$ [10^{-23} W]	1.2	1.0
$q(H^0)$ [10^{46} s^{-1}]	8.9	6.9
$Q'(H^0)$ [10^{46} s^{-1}]	22	120
N_e[S II] [10^4 cm^{-3}]	$\leq$ 10	0.5
N_e(rms) [10^4 cm^{-3}]	$\geq$ 0.6	$\approx$ 0.2
ff	$\geq$ 0.06	$\geq$ 0.4
Ionized mass [$M_\odot$]	0.27	0.11
EM [10^6 pc cm^{-6}]	22	5

6. CONCLUSIONS

We have detected high surface brightness Hα emitting condensations in the field of the H II region NGC 3603. In the present study we analyzed 2 of them (C 13 and C 16). Their diameter are 0.076 pc and 0.13 pc, respectively. Most of the gaseous part of C 16 is part of the northwestern lobe of the bipolar nebula of Sher 25 (Brandner et al.

1997a). The enrichment of the gas is due to its origin in the evolved supergiant. A portion of the northeastern lobe is not moving with the ejecta (Brandner et al. 1997a). There is no velocity information for the star-like objects seen in the IR in C 16 but it would seem unlikely that they are moving along with the ejecta. The bipolar outflows from Sher 25 could not have caused subsequent star formation after hitting a dense pocket of gas. Not only are the derived masses too low, but the dynamical age of the nebula of only $\approx$ 6600 years (Brandner et al. 1997a) excludes this interpretation. It is more likely that the red objects seen in C 16 are projected heavily extincted background stars (possibly red supergiants).

In contrast, the underlying IR continuum emission of C 13 (lacking in C 16) indicates the presence of an embedded young stellar object that might currently be in the process of dissolving its surrounding shell. The derived masses for C 13 are consistent with hosting an intermediate-mass pre-main-sequence star.

Both condensations contain a high amount of dust, selectively distributed at the periphery. The knots' emission spectrum can be explained by external photoionization produced by the central ionizing cluster in NGC 3603. The condensations are partially ionized. C 13 is surrounded by a ring-like structure, indicating a past mass ejection phase. Other objects similar to C 13 have been detected inside the NGC 3603 H II region and are being presently studied. The presence of the apparent pre-main-sequence late B or early A star in C 13 shows that ambient star formation around the central ionizing cluster is still continuing.

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