RevMexAA (Serie de Conferencias), **22**, 73–76 (2004)

YOUNG AND VERY YOUNG STARS IN NGC 3372, THE CARINA NEBULA

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RESUMEN

Se presentan los resultados de un estudio fotométrico de la población estelar en el norte de NGC 3372 en un intervalo espectral que cubre 0.33 a 2.5 μm. Las observaciones se llevaron a cabo en el Observatorio de Las Campanas. Se determinaron los tamaños de los tres cúmulos, Tr 14, Tr 15 and Tr 16, por medio de conteo de estrellas. Diagramas color-color y color-magnitud sugieren edades entre 3 y 60 millones de años para Tr 15 y entre menos de 1 y 6 millones de años para Tr 14 y Tr 16. Los tres cúmulos se encuentran a la misma distancia: $< d >= 2.7$ kpc aunque con gran dispersión real en A_V y en d. Tr 14 es un cúmulo que se encuentra parcialmente inmerso en una nube molecular densa que se extiende hacia el sureste, teniendo su máxima densidad a unos tres minutos de arco del núcleo del cúmulo. Casi todo el gas de la región HII es ionizado por las estrellas de Tr 14. Sin embargo, imágenes en JHK profundas revelan la presencia de una joven población de estrellas O y B inmersas en la nube, en donde se encuentra también una región HII ultracompacta.

ABSTRACT

Results are presented of a large-scale imaging photometric study of the stellar population in the northern part of NGC 3372 with a wavelength coverage from 0.33 to 2.5 μm. All observations were made at Las Campanas Observatory. The sizes of the three stellar clusters, Tr 14, Tr 15 and Tr 16, were determined by means of star counts. Two-colour and colour-magnitude diagrams are presented and analyzed for each individual cluster. The three clusters were found to be at a similar distance from the Sun, $< d >= 2.7$ kpc, but with very large scatter in both A_V and d. suggesting drastic variations in intracluster dust density. Dust particle size distribution variations are evident resulting in wide variations in extinction law. We determined ages between 3 and 60 million years for Tr 15 and between less than 1 and 6 million years for Tr 14 and Tr 16. The Tr 14 cluster is partially embedded in a dense molecular cloud that extends towards the southwest reaching its highest density some three arcmin from the cluster nucleus. The rich UV field created by the Tr14 stars ionizes most of the visible HII region in its vicinity and most of the radio HII region Car I. Deep JHK images of the Car I region reveal the presence of a young, embedded stellar population that includes several O9–B0 stars and an ultracompact HII region.

Key Words: **GALAXY: OPEN CLUSTERS AND ASSOCIATIONS: GENERAL — H II REGIONS — ISM: INDIVIDUAL: NGC 3372 — STARS: FORMATION**

1. INTRODUCTION

The Great Carina Nebula is not only one of the greatest celestial spectacles of the Southern skies but also a very important natural laboratory for studying the birth and evolution of the brightest and most massive stars in the Galaxy. In this huge HII region, dozens of O–B0 type stars produce a large UV radiation field which, together with strong stellar winds, interact heavily with the material in its parental giant molecular cloud. The stars are members of four distinct open clusters, TR 15 to the farthest north, Tr 14 and Tr 16 in the northern half of the nebula, and Cr 228, widely scattered in the southern region, covering most of that huge area. The whole nebula extends more than four square degrees on the sky and, as a result of the evidently complex mass motions, it presents peculiar morphologies at all scales. These include clumps, filaments, arcs, and all sorts of chemical, kinematical and density inhomogeneities.

There is mounting observational evidence that the process of massive star formation has been active for several million years and has not ceased. Recent radio CO-line observations together with mid-IR maps of the nebula indicate that massive stars are being born in several regions within molecular condensations, located mainly to the SE and NW of the cluster Trumpler 16 (Tr 16), whose most famous member is η Carinae. It is becoming evident that the new generations of stars now being born in several parts of the complex are the result of the mo-

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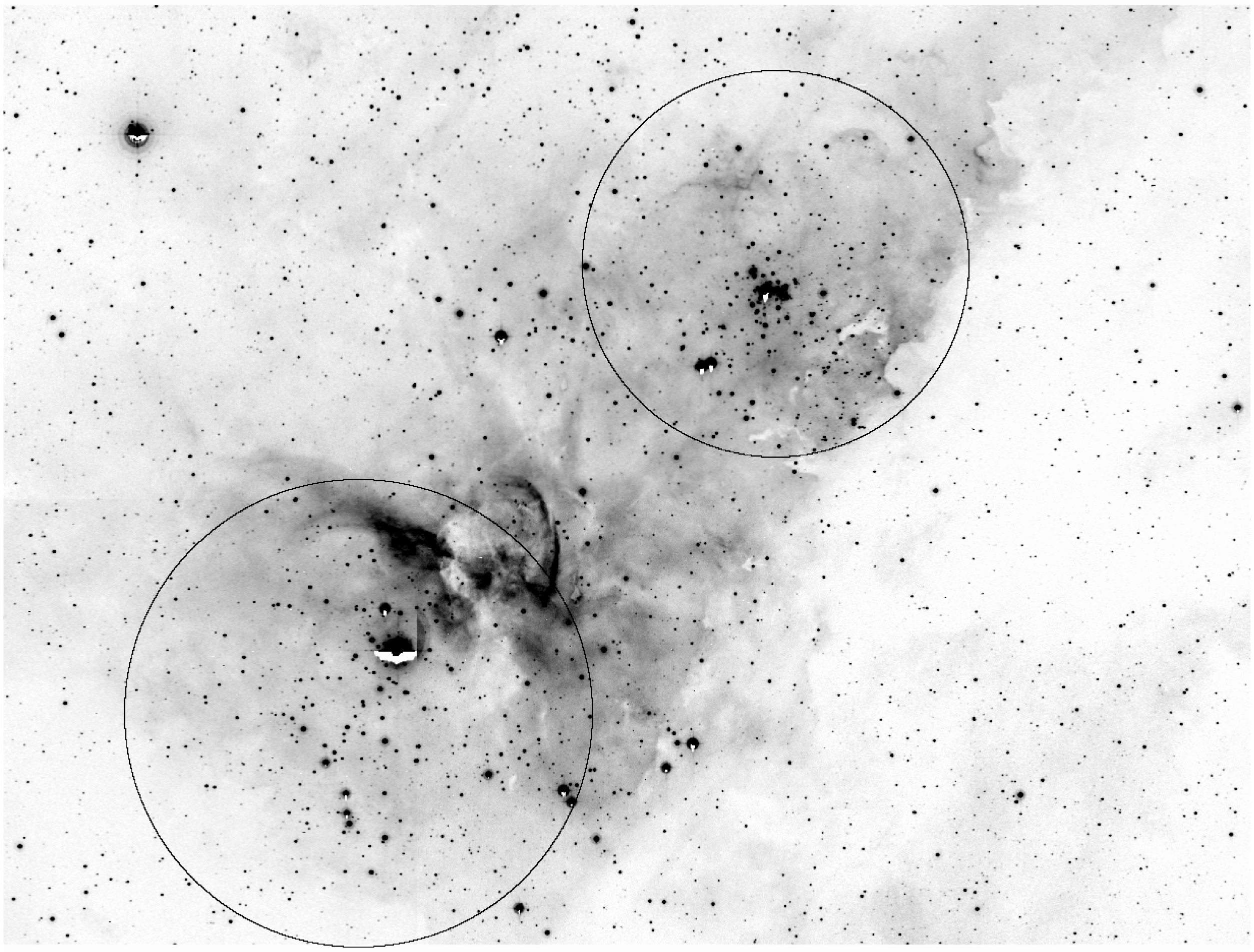

Fig. 1. R-band short-exposure mosaic of the northern Carina nebula region containing the clusters Tr 14 and Tr 16. The area covered is 31.6×22.0 arcmin^2 centred at $\alpha = 10^{\rm h}\ 44^{\rm m}\ 25.6^{\rm s}$; $\delta = -59^o\ 36'\ 35''$ (J2000). North is to the top, east to the left. The circles mark the location and extension of the clusters Tr 14 and Tr 16 as derived from star counts.

mentum inserted into the medium by the large-scale winds and UV radiation from the "older" generations of stars.

The present work presents a comprehensive photometric study of the northenr clusters, Tr 15, Tr 14 and Tr 16, covering a wavelength range 0.33 to 2.2 μm. The survey is supplemented with deep near-infrared images of the Car I region, which includes the densest region of the molecular cloud.

All observations were carried out at Las Campanas Observatory in Chile using the 1.0 m ($UBVRI$ and JHK), 2.5 m DuPont (JHK) and 6.5 m Clay/Magellan (deep JHK) telescopes. The details of this work, except the more recent Magellan observations, can be found in Tapia et al. (2003).

2. RESULTS

$UBVRI$ photometry of more than 4000 stars is reported to a limiting magnitude of around 20 in all photometric bands in an area covering 850 arcmin^2, implying that the present survey of Tr 14, Tr 15 and Tr 16 is the deepest and most complete to date. Assuming the clusters to be spherical, their centres and radii were determined by means of star counts. The results are shown in Table 1. The areas occupied by Tr 14 and Tr 16 are marked in Fig. 1. It is interesting to note that the boundaries determined by direct counts, regardless of the star brightness, are quite different from those defined by a number of bright stars, even to the extreme that Cr 232, sometime thought to be a separate open cluster defined by HD 93250, HD 93268 and HDE 303311 and other bright stars, is found void of a faint stellar popula-

TABLE 1

CENTRES AND RADII OF CLUSTERS IN THE V BAND.

Cluster	Central R.A. h m s (J2000)	Central Decl. ° ′ ″	Radius arcsec.
Tr 14	10 43 55.4	-59 32 16	264
Tr 15	10 44 40.8	-59 22 10	320
Tr 16	10 45 10.6	-59 42 28	320

tion and thus cannot be considered a real cluster. The reason for this is unclear at present.

It is well established (cf. Tapia et al 1988) that the dust extinction towards the stars in the Carina nebula is extremely variable, both in terms of variations of optical depth (measured by A_V) and, most

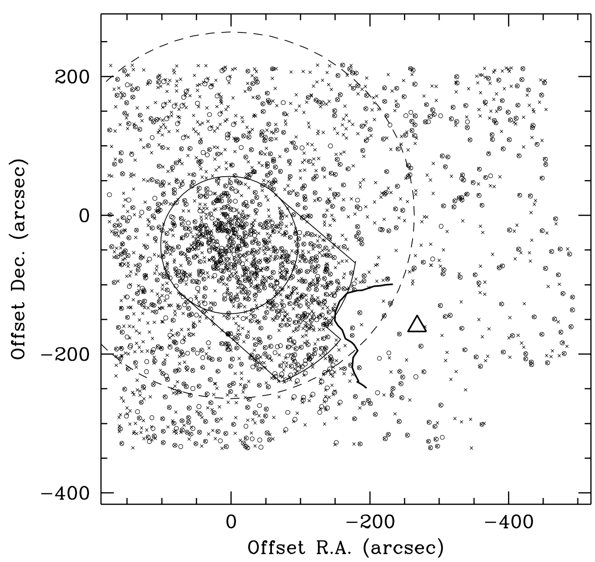

Fig. 2. Position diagram of the stars detected in the K (circles) and H (crosses) bands in Tr 14 and adjacent area to the west. The broken-line circle marks the boundaries of the optical cluster as given in Table 1. Note that the absence of stars near (+20,-35) is caused by saturation of several bright stars in the optical core. The thin continuous lines show the core and SW extension of the cluster as determined in the near-IR. The thick continuous line delineates the sharp semicircular bright-rimmed feature clearly seen on all optical and near-infrared images. The triangle marks the location of the Car I CO emission peak. The origin is at $\alpha = 10^{\rm h}\ 43^{\rm m}\ 55.4^{\rm s}$, $\delta = -59°\ 32'\ 16''$ (J2000).

TABLE 2

MEAN REDDENINGS $A_V = 1.39\mathrm{E}(V-J)$ AND SPECTROSCOPIC DISTANCES.

Cluster	No.	D.M.	$\sigma_{\rm DM}$	A_V	σ_{A_V}
Tr 14	17	12.23*	0.67*	2.52	0.44
Tr 15	17	12.34*	0.81*	1.64†	0.43†
Tr 16	32	12.02	0.57	2.06†	0.60†
All	65	12.14*	0.67*	2.08†	0.56†

*Excluding Tr14-15 and Tr15-21;
†Excluding Tr15-18 and Tr16-149

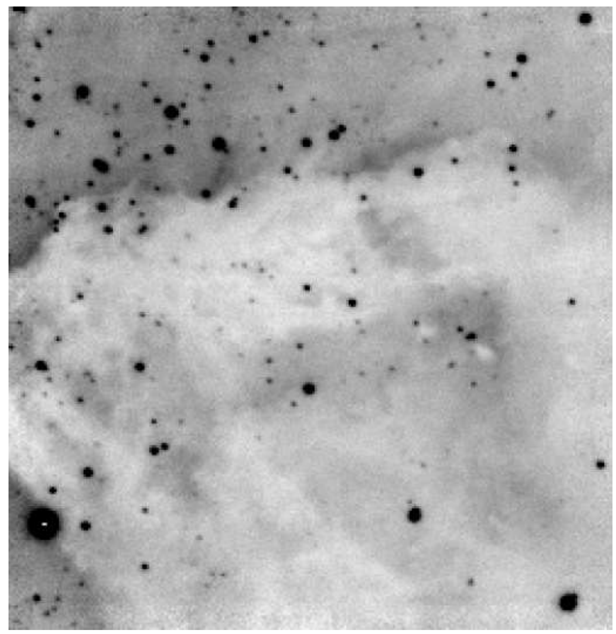

Fig. 3. K-band image of the Car I region taken with the 6.5 Clay/Magellan telescope. The area covered is 126×130 arcsec^2 centred at $\alpha = 10^{\rm h}\ 43^{\rm m}\ 26.2^{\rm s}$; $\delta = -59°\ 34'\ 29''$ (J2000). North is to the top, east to the left.

conspicuously, of variations of shape in the extinction law (measured by $R_V = A_V/\mathrm{E}(B-V)$). This is evidence of a very inhomogeneous intracluster dusty medium and of great diversity in dust particle size distributions across the nebula. The small scale variations suggest a local origin for the dust processing.

Individual distance and extinction determinations were obtained to derive mean distances and reddening for the clusters. The results are presented in Table 2. Note the large dispersion in both $< d >$ and $< A_V >$ which are not caused by observational uncertainties. The data is compatible with the three clusters being a the same distance from the Sun,

d = 2.7 kpc. Analyses of the calibrated colour-magnitude diagrams indicate that the stars in the dust-free cluster Tr 15 have ages between 3 and 40 million years while Tr 14 and Tr 16 are considerably younger, with the older stars with ages around 6 million years and with new stars that are still being formed.

The case of Tr 14 and its neighbouring radio HII region, Car I, at the position of the CO peak is noteworthy. Near-infrared images reveal that the centrally condensed cluster is partially embedded in a dense cloud that lies behind the visible cluster. This cloud extends to the southwest, where star formation is still active, "wraping" the visible nebula and ionizing stars. Fig. 3 shows the distribution of the stars in Tr 14 as seen in H and K. Note the sudden decrease in star density occuring at the position of an ionization front expanding towards the densest part of the molecular cloud where, naturally, the extinction increases drastically.

Extended radio emission from an HII region in the densest zones of the cloud suggest the presence of an embedded population of massive stars. This was searched for by means of deep near-infrared imaging with the 6.5 m Clay/Magellan telescope. The 2.2 μm image of this region, centred close to the Co peak is shown in Fig. 3, confirming the presence of such stars deep in the cloud. As expected, a fraction of those, including a point source at the position of an ultracompact HII region, show significant IR excesses.

We thank the staff of Las Campanas Observatory for their support. Part of this work was financialy supported by DGAPA–UNAM grant No. IN-102803 (MT).

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