The Stellar Content of Giant HII Regions in NGC 2403

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Abstract. We present some results of a study on the stellar population of two giant H II regions in the nearby galaxy NGC 2403, based on Hubble Space Telescope images. The emphasis is put on the distribution of the Wolf-Rayet and red supergiant stars and the information they provide about the star-forming history of these large complexes. We also discuss the presence of a luminous, compact stellar cluster at the core of both regions, and the overall morphology of the star-forming regions.

1. The stellar content of nearby giant HII regions

The study of individual stars and stellar populations in nearby giant HII regions is a pre-requisite to understand the starburst phenomenon, and to interpret the observations of distant starburst galaxies, for which only integrated properties can be gathered. In particular, many questions related to the star formation history and the property of the initial mass function in distant starbursts remain without satisfying answers. Do all stars form instantaneously, or rather in a continuous process? Is the IMF skewed towards massive stars?

In this context, the Hubble Space Telescope has been of great help over the past six years by providing us with high-resolution images of numerous, previously poorly resolved starburts (Hunter et al. 1995a, 1995b; Walborn et al., these proceedings), as well as optical and UV spectra of individual massive stars in the nearest H II complexes (Heap et al. 1994, Drissen et al. 1995).

We present in this paper the results of our study on the stellar populations of two giant H II regions in the nearby spiral galaxy NGC 2403. These results are based on WFPC2 images obtained with the following purposes in mind: (a) to determine the star-formation history of the regions by studying the distribution of the Wolf-Rayet and red supergiant stars; (b) to study the morphology of the ionizing clusters of the large H II complexes.

2. Observations of NGC 2403

NGC 2403 is an ScIII galaxy, member of the M81 group ($D = 3.5$ Mpc). Among its numerous H II regions, two are exceptionally bright, with $L(H\alpha) \sim 1.0 - 1.5 \times 10^{40}$ erg/s, comparable to the most massive starburst region in the Local Group, the 30 Doradus complex. Unlike 30 Dor however, both regions in NGC 2403 are relatively metal-rich, with $12 + O/H \sim 8.75$ (Fierro et al. 1986). We
call them N2403-A (also known as VS44; 07h37m07s, +65°36'39" [J2000]) and
N2403-B (07h36m46s, +65°36'59" [J2000]).

WFPC2 images of these two giant H II regions were obtained with broad-
band B (F439W) and V (F547M) filters, as well as with two narrowband filters:
F502N ([O III]), to study the distribution of the ionized gas and F469N (He II
λ4686) to detect Wolf-Rayet stars. In addition, spectra and Hα images of the
same regions were secured with the Canada-France-Hawaii telescope.

3. Stellar Populations

It is obvious from a B-band image (Figure 1) that massive star formation did
not occur as a single event in N2403-A: three major sub-clusters (with diameters
ranging from 35 to 80 pc) and a few smaller stellar aggregates are seen amongst
a non-uniform background of luminous stars throughout the region, spanning
∼ 400 pc. By comparison, the ionizing cluster of N2403-B (not shown here) is
much more compact: most of its stars are confined within a region of radius
r ∼ 45 pc. In both cases, the gaseous halo of the surrounding H II region has a
diameter of ∼ 500 – 600 parsecs.

The color-magnitude diagram of N2403-A based on HST images is shown
in Figure 2. More than 1400 stars are detected in B and V; among them, 800
are bright and blue enough to be O stars. In N2403-B, the numbers are 850 and
397, respectively. Incompleteness becomes important at V \geq 24.5 (M_V \geq -4),
but stars as faint as V = 26 (M_V \sim -2.7) are detected; this limit corresponds to
stars with a main sequence mass of \sim 15M_\odot. The vast majority of bright stars
are well represented by young isochrones, suggesting an age of \sim 3 \sim 4 Myrs
for the dominant population, but a small population of older (\sim 8 Myrs) stars
is also present (at 22 \leq V \leq 23, 1.5 \leq B - V \leq 2.5). Both regions harbor a
luminous, compact cluster which presumably contains a few dozens unresolved
massive stars (see below).

Wolf-Rayet and red supergiant stars are good indicators of the age of their
parent population and can be used to study the star-formation history of giant
star clusters. Since most Wolf-Rayet stars are the descendants of very massive
(M_i \geq 40M_\odot) O stars (Massey et al. 1995), they are associated with a young (2-6
Myrs) population. Red supergiants are expected to be seen in older (\geq 7 Myrs)
populations, since their progenitors are less massive (15M_\odot \leq M_i \leq 40M_\odot).
These two types of stars are therefore not expected to cohabit in an exactly
coeval population of stars formed during a very short burst.

What is the distribution of Wolf-Rayet and red supergiant stars in NGC
2403-A and B? Ground-based longslit spectra centered on the brightest knot
of each region already indicated the presence of many Wolf-Rayet stars (Figure
2). The association of broad WR features (4670 Å and 5810 Å) and narrow
nebular lines is typical of young massive star-forming regions (D’Odorico et al.
1983), and is found in an increasing number of starburst galaxies (Vaccarini
1992). Comparison between the continuum B and He II 4686 images reveals 23
individual WR stars in N2403-A and a dozen in N2403-B, exclusive of the bright,
unresolved clusters. These numbers are lower limits, since some WR stars fainter
than M_V = -5.0 may have remained undetected in the most crowded regions.
Figure 1. WFPC2 B-band image of N2403-A. Wolf-Rayet stars are surrounded by squares and red supergiants by circles. The image is $18'' \times 21''$ (300 $\times$ 350 parsecs), with a resolution of $0.046''$/pixel.
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Let us now focus on N2403-A (Figure 1). In this region, Wolf-Rayet stars are seen everywhere, but show a strong preference for the richest sub-clusters. This implies a short (Δt ≤ 3 – 4 Myrs) delay between the formation of these individual sub-clusters. A few older (∼ 8 Myrs) red supergiants are also seen. They are distributed over the whole region, but, contrary to the Wolf-Rayet stars, they tend to avoid the richest sub-clusters. In particular, we note that red supergiants are totally absent from an area of radius r ≈ 35 pc centered on the brightest, central cluster, where almost half of the Wolf-Rayet stars of the entire complex are located (see Figure 1). It is interesting to note that the maximum of the nebular emission in the whole H II region coincides with the center of this cluster. The situation is similar in the sub-cluster at the lower left of Figure 1: it contains two WR stars, and the only red supergiant in its vicinity is 35 pc away from its center.

It therefore appears that star formation was already going on some 10 Myrs ago in N2403-A (as evidenced by the distribution of red supergiants), but the dominant stellar population was created as a result of a few recent (2-5 Myrs old), independent bursts. The co-existence of massive stars of different ages is also observed in Galactic OB associations (Massey et al. 1995).

4. The compact cores

Meurer et al. (1995) showed that starburst galaxies of all types often form luminous compact star clusters. The nearest examples of compact, young massive star clusters in giant H II regions are HD 97950, the ionizing core of NGC 3603 in the Milky Way and R136 in 30 Doradus, and the super star clusters in NGC 1569 (O'Connell et al. 1994).
At the core of both giant H II regions in NGC 2403 also lie a dense luminous cluster. With $M_B = -10.7$ and a half-light radius $R_{0.5} = 3$ pc, the core of N2403-A is slightly less luminous and dense than R136. N2403-B's core rivals the luminosity, density and surface brightness of the super star clusters in NGC 1569, with $M_B = -12.5$ and $R_{0.5} = 2$ pc. Both clusters in NGC 2403 show an excess of light in the F469N filter, indicating the presence of WR stars.

5. The overall morphology

The stellar complexes of N2403-A and B have about equal total luminosities, but their sizes are quite different, with N2403-B being much more compact than N2403-A. The isophotal radius (radius including half the total light of the cluster) is about 45 pc for region B and 100 pc for A.

The length and mass scales of gravitational instabilities depend primarily on the balance between the self-gravitational force density and the pressure gradient. Assuming gravitational coalescence of several small clouds, the characteristic wavelength of the fastest growing mode for a two dimensional distribution of gas leads to a primary object of approximate size $\lambda = 2\sigma^2/(G\mu)$, and characteristic mass of $M = \sigma^2(\lambda/2)^2 \sim 4\sigma^4/(G^2\mu)$ (Elmegreen et al 1993); $\sigma$ is the velocity dispersion and $\mu$ is the gas surface density. High velocity dispersions and low column densities result in more massive collapsing clouds. Thus at equal surfacic densities (and same age and total mass), resulting stellar clusters have sizes inversely proportional to the $\sigma^2$ of their initial clouds. The relative compactness of N2403-B with respect to that of N2403-A could be the result of its original cloud having a higher velocity dispersion than that of N2403-A.

Heating by a stellar association formed many million years before the present episode could have increased the velocity dispersion of the protocloud which led to N2403-B.

References