Abstract

30 Dor is the closest massive star forming region and the best studied template of a starburst. In this conference paper we first summarize the properties of 30 Dor and its stellar core R136. We discuss the effects of insufficient spatial resolution and cluster density profiles on dynamical mass estimates of super star clusters, and show that their masses can be easily overestimated by a factor of ten or more. From a very simple model, with R136-like clusters as representative building blocks, we estimate typical luminosities of the order $10^{11} L_{\odot}$ for starburst galaxies.

Keywords: 30 Dor, Starburst template, Super Star Clusters

1. Overview

At a distance of only about 53 kpc 30 Dor is the closest massive star forming region. To date it has been studied and described in over 3000 papers. In this conference paper we discuss the relevance of 30 Dor as a local template for more luminous starburst systems. The characteristic dimensions for structures related to 30 Dor are given in Tab. 1.

Table 1. Characteristic dimensions, from Walborn (1991)

| Name          | Class         | angular Ø | linear Ø |
|---------------|---------------|-----------|----------|
| LMC           | galaxy        | 5°        | 5000 pc  |
| 30 Dor region | complex       | 1°        | 1000 pc  |
| 30 Dor nebula | HII region    | 15'       | 200 pc   |
| NGC 2070      | stellar cluster | 3'       | 40 pc    |
| R136          | stellar core  | 10''      | 2.5 pc   |

The most relevant properties of its stellar content and instellar medium (ISM) are summarized in Tab. 2. Fig. 1a shows the complex nature of the
ISM in 30 Dor with its interplay between large-scale filaments and wind-blown cavities. According to Walborn & Blades (1997) NGC 2070 consists of several distinct, young stellar generations. The IMF is fully populated up to at least $100 \, M_\odot$ (Massey & Hunter 1998) and there is no evidence for a truncated low-mass IMF, even within R136 (Andersen et al. 2005). The stellar distribution near the center R136 is shown in Fig. 1b.

Table 2. Properties of the stars and the ISM in 30 Dor

| Quantity           | Value         | Reference          |
|--------------------|---------------|--------------------|
| Hα luminosity      | $1.5 \times 10^{40} \text{ erg s}^{-1}$ | Kennicutt (1984)    |
| Ly-cont flux (30Dor)| $1.1 \times 10^{52} \text{ phot s}^{-1}$ | Kennicutt (1984)    |
| Ly-cont flux (NGC 2070) | $4.5 \times 10^{51} \text{ phot s}^{-1}$ | Walborn (1991)      |
| # OB stars (NGC 2070) | 2400          | Parker (1993)      |
| H$_2$ mass         | $7 \times 10^7 \, M_\odot$         | Kennicutt (1984)    |
| HII mass           | $8 \times 10^5 \, M_\odot$         | Kennicutt (1984)    |
| E$_{\text{gas}}$   | $\geq 10^{52} \, \text{erg}$       | Chu & Kennicutt (1994)|
| E$_{\text{kin}}$   |                            |                    |
| LFIR               | $4 \times 10^7 \, L_\odot$         | Werner et al. (1978)|

2. Is R136 a Super Star Cluster (SSC)?

With about 40 stars of spectral type O3 R136 is the densest concentration of very massive stars known (Massey & Hunter 1998). R136 is centrally con-
30 Doradus – a starburst template

densed and displays a remarkably smooth exponential cluster profile (see e.g., Malumuth & Heap (1994), their Fig. 13). The stellar properties of R136 are summarized in Tab. 3.

Table 3. Stellar properties of R136

| Quantity               | Value                      | Reference          |
|------------------------|----------------------------|--------------------|
| age                    | ≈ 2 ± 1 Myr                | a                  |
| central density $\rho_c$ | $5.5 \times 10^4 M_\odot$ pc$^{-3}$ | Hunter et al. (1995) |
| total mass $m_{\text{tot}}$ | $6.3 \times 10^4 M_\odot$ | Hunter et al. (1995) |
| core radius $r_c$      | 0.12 pc (5″)               | Brandl et al. (1996) |
| half-mass radius $r_{hm}$ | 1.2 pc (5″)               | Brandl et al. (1996) |
| tidal radius $r_t$     | 5 pc (21″)                 | Meylan (1993)      |
| IMF slope $\xi$        | 2.2$^c$                   | (Andersen et al. 2005) |

$^a$ the age of the cluster is still subject of controversy  
$^b$ for $m \geq 0.1 M_\odot$  
$^c$ the Salpeter (1955) slope is $\xi = 2.35$ in this notation

However, there are numerous examples of massive young clusters that do not show a density profile like R136. For instance, NGC 604, the most luminous HII region in M33, looks very similar to R136 in H$\alpha$ (Hunter et al. 1996) both in structure and luminosity, but the stellar distribution is completely different, given by numerous smaller clusters — a structure sometimes referred to as a scaled OB association (SOBA) (Maíz-Apellániz et al. 2004).

In recent years, so-called super star clusters, such as in the Antennae galaxies, have received a lot of attention (e.g., Mengel et al. (2002)). The dynamical mass can be estimated via $m_{\text{dyn}} = \eta \frac{\sigma^2 r_{hl}}{G}$, where $\eta \approx 10$. However, this is based on the assumption that the cluster is well resolved, i.e., that $r_{hl}$ can be accurately determined. Fig. 2a shows R136 in the upper left as observed with NICMOS (same as Fig. 1b), and then progressively at $2 \times$ lower resolution. The FWHM derived from the same cluster but at different resolution is plotted as a function of distance in Fig. 2b. Because of spatial undersampling and the light from bright stars near the cluster core, the half-light radius $r_{hl}$ — and thus $m_{\text{dyn}}$ — can easily be overestimated by a factor of ten or more at distances beyond a few Mpc. To complicate matters, the spectroscopically measured velocity dispersion may be significantly affected by the orbital velocities of massive binary stars (Bosch et al. 2001). Furthermore, at distances like the Antennae, a centrally condensed cluster like R136 is indistinguishable from a non-virialized, NGC 604-like SOBA. Given the large uncertainties, it remains to be seen how much more “super” than R136 super star clusters really are.
3. Are luminous starbursts made of 30 Doradus complexes?

30 Dor does not experience a strong gravitational field from its host galaxy, the entire complex can almost freely expand, and its center has no connective supply from a larger gas reservoir. Under different boundary conditions, which may be given in a circum-nuclear starburst, it is conceivable that the densities of gas, dust, and embedded star clusters are much higher — without necessarily requiring different unit cells than R136. Using a very simplified model of identical clusters, spherical geometry, and constant gas density, we can estimate what the total luminosity of such a starburst might be.

Assuming 200 pc for the linear extent of a “typical” extragalactic starburst region, and taking R136’s tidal radius $r_t$ as the (half-)size of a unit cell, there could be the equivalent of as many as 8000 R136-like clusters within the given volume. If only a quarter ($10^7 M_\odot$) of the total 30 Dor far-IR luminosity is being produced within the volume defined by $r_t$, and if $L_{FIR}$ is the sum of the reprocessed UV-radiation and (about the same amount) of shock-heated gas from supernovae, the total far-infrared luminosity is:

$$L_{FIR}^{\text{tot}} = 8000 \times 2 \times 10^7 = 1.6 \times 10^{11} L_\odot$$ (1)

This number is well within the ballpark of luminous starburst galaxies, although it falls short of the luminosity of ultra-luminous infrared galaxies. At any rate, if starbursts have such porous, inhomogenous structures they represent a big challenge for accurate starburst modelling.
References

Andersen, M., Brandl, B.R. & Zinnecker, H. 2005, ApJ, in preparation
Bosch, G. et al. 2001, A & A, 380, 137
Brandl, B.R. et al. 1996, ApJ, 466, 254
Brandl, B.R. et al. 2005, ApJ, in preparation
Chu, Y.-H. & Kennicutt, R.C. 1994, ApJ, 425, 720
Hunter, D. et al. 1995, ApJ, 448, 179
Hunter, D. et al. 1996, ApJ, 456, 174
Kennicutt, R. C. 1984, ApJ, 287, 116
Maíz-Apellániz, J. et al. 2004, AJ, 128, 1196
Malumuth, E.M. & Heap, S.R. 1994, AJ, 107, 1054
Massey & Hunter 1998, ApJ, 493, 180
Mengel, S. et al. 2002, A & A, 383, 137
Meylan 1993, ASP, vol. 48, 588
Moffat 1994, ApJ, 436, 183
Parker, J.W. 1993, AJ, 106, 560
Salpeter, E.E. 1955, ApJ, 123, 666
Walborn, N.R. 1991, IAU S 148, 145
Walborn, N.R. & Blades, J.C. 1997, ApJS, 112, 457
Werner, M.W. et al. 1978, MNRAS, 184, 365