Astron. Astrophys. 327, 1185–1193 (1997)

ASTRONOMY AND ASTROPHYSICS

Thackeray's globules in IC 2944*

Bo Reipurth[1], **Patrice Corporon**[1,2], **Michael Olberg**[3], **and Guillermo Tenorio-Tagle**[4,5]

[1] European Southern Observatory, Casilla 19001, Santiago 19, Chile
[2] Laboratoire d'Astrophysique – Observatoire de Grenoble, BP 53X F-38041 Grenoble Cédex 9, France
[3] Onsala Space Observatory, S-439 92 Onsala, Sweden
[4] Institute of Astronomy, University of Cambridge, Madingley Road, Cambridge CB3, UK
[5] Royal Greenwich Observatory, Madingley Road, Cambridge CB3 OEZ, UK

Received 10 January 1997 / Accepted 5 May 1997

Abstract. We have studied the complex of small globules discovered by A.D. Thackeray in the southern HII region IC 2944. They are located precisely on the line-of-sight to the luminous OB stars in the region, and thus appear as shadows against the bright HII region. Thanks to this geometry, exceptionally fine details can be discerned on CCD images, which show that the globules are generally sharp-edged and highly structured, and that the complex contains a multitude of fragments in all sizes down to the resolution element of about one arcsec (1800 AU). CO millimeter observations reveal that the largest globule consists of two kinematically separate entities, with masses of about 11 and 4 $M_{\odot}$. Very large velocity differences exist between the various globules, suggesting that the globules comprise a highly dynamic system perhaps one million years old. We believe that the globules are the remnants of an elephant-trunk observed from behind, originating as a Rayleigh-Taylor instability in an expanding neutral shell powered by the hot HII region. The globule complex is now in an advanced stage of disintegration. We have found no evidence for star formation in any of the globules.

Key words: stars: formation – stars: pre-main sequence – ISM: individual objects: IC 2944 – ISM: clouds – radio lines: ISM

1. Introduction

Fifty years ago, Bok & Reilly (1947) drew attention to two classes of small dark clouds, the large and the small globules. The large globules, or Bok globules as they are known today, are now well studied at optical, infrared and mm-wavelengths. Such studies have borne out Bok's conjecture that the large globules can be intimately related to the process of star formation (e.g. Bok 1977, Reipurth 1983, Keene 1983, Yun & Clemens 1990).

The small globules, on the other hand have been largely overlooked. Bok noted the fact that small globules are found always in association with HII regions and luminous OB stars. Indeed, wide field CCD images of HII regions almost invariably show the presence of these tiny globules.

The Rosette Nebula is a large, relatively nearby HII region, which is particularly abundant in small globules. Herbig (1974) discussed these globules, and suggested that they are pinched-off blobs from elephant trunks, produced as an HII region expands into surrounding molecular clouds.

A remarkable and beautiful set of small globules was discovered by Thackeray (1950) in the large southern HII region IC 2944. Fig. 1 shows IC 2944 from a red ESO Schmidt plate and the location of Thackeray's small globules.

In this note, we present detailed CCD images of these globules, and, based on the images and an objective prism Hα emission star survey, conclude that star formation has not taken place in the globules.

2. Observations

CCD images of Thackeray's globules were obtained at the ESO 3.6m telescope on 03 march 1988 employing EFOSC with a RCA 620 x 1024 pixels CCD, giving a scale of 0.38 arcsec per pixel. An Hα filter centered on 6546 Å and a FWHM of 81 Å was used. The region was observed at two different telescope positions and the resulting images combined to form a mosaic. Due to the presence of very bright stars in the field, different exposures time were used: for the upper part of the mosaic, 8 frames of 45 seconds each have been averaged, while for the lower part, 5 frames of 1 minute plus 1 frame of 5 minutes have been averaged.

Two CCD images of globules in NGC 6611 were taken with 90 seconds exposure time at the ESO NTT through an R-band filter. An objective prism plate was taken at the ESO 1m Schmidt telescope on 28 Feb 1982, employing a 4 degree

Send offprint requests to: B. Reipurth

* Based on observations collected at the European Southern Observatory, La Silla, Chile

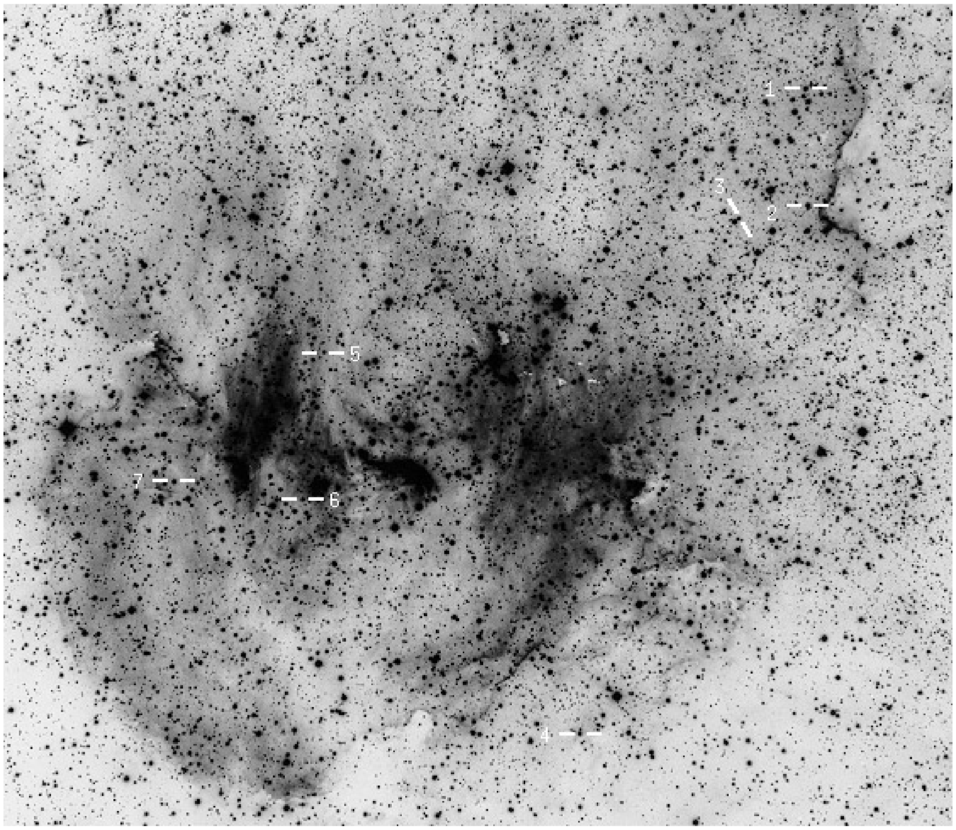

Fig. 1. The HII region IC 2944 as seen on a red ESO Schmidt plate. The small globules discovered by A.D. Thackeray are in the middle of the figure. Seven Hα emission line stars, ESO Hα 301–307, are marked as 1–7. The image is approximately 53 x 46 arcmin. North is up and east is left

prism. A baked 098-04 plate was used with RG 630 filter and an exposure time of 30 min. Another objective prism plate was taken at the Curtis Schmidt of the Cerro Tololo Interamerican Observatory on 11 March 1983, employing a 6 degree prism. The exposure time was 68 min on a baked IIIaF plate through a RG 630 filter. A direct plate of the IC 2944 region was taken at the ESO Schmidt telescope on 29 April 1987 on a baked IIIaF plate and an exposure of 45 min. Spectra were taken of the emission line stars found on the objective prism plates using the ESO 2.2m telescope and a Boller & Schivens spectrograph on 21 May 1988. Astrometry was made at the Optronics machine at ESO/Garching, using a direct Schmidt atlas plate.

The millimetre data were taken with the 15m Swedish ESO Submillimetre telescope (SEST) at ESO La Silla during May and November 1988, as well as January 1989. The main beam efficiency of the SEST changed from 0.66 to 0.74 at 112 GHz in November 1988 due to a subreflector adjustment; this has been taken into account by the data reduction which we applied.

3. The globules and the HII region

IC 2944 and the adjacent IC 2948 comprise a bright and very extensive HII region (Fig. 1). Within its boundaries there are numerous OB stars located, the brightest being HD 101205, a sixth magnitude O7 III star (Walborn 1973). Thackeray & Wesselink (1965) studied these stars and suggested a distance of 2 kpc. However, Ardeberg & Maurice (1977, 1980, 1981) suggested that the concentration of OB stars is a line-of-sight effect, in fact consisting of 5 different sub-groups at different distances. This interpretation has been supported by Perry & Landolt (1986). More recently, Walborn (1987) has argued that at least the O-type stars in the region constitute a significant physical cluster, which is responsible for the IC 2944 HII region. The present paper cannot resolve these differing views, but we note that the HII region is likely to be associated with the most luminous and the earliest of the O-stars, HD 101205, and that the globules certainly are associated with the HII region. As discussed by Ardeberg & Maurice (1980), the nebular kinematic distance is about 1800 pc, a distance we adopt in the following for the globules.

The large-scale plate in Fig. 1 demonstrates that the globules are very isolated in the HII region, situated away from the receding walls of neutral material, where the HII region is ionization-bounded. This is a situation different from the Rosette Nebula, where the small globules are closely associated with the dense shell surrounding the HII region.

Fig. 2a shows the region of Thackeray's globules on our CCD images obtained through an Hα filter. The major ones are identified in Fig. 2b, and the positions of the principal ones are listed in Table 1. The angular scale is related to a physical length assuming a distance of 1.8 kpc. Within the very localized region of the globules, about 50 globules, or fragments or splinters of globules are visible. At an assumed distance of 1.8 kpc, one arcsecond corresponds to about 0.01 pc. The projected separation of the eastern- and western-most globules is 7.5 arcminutes, corresponding to 3.9 pc.

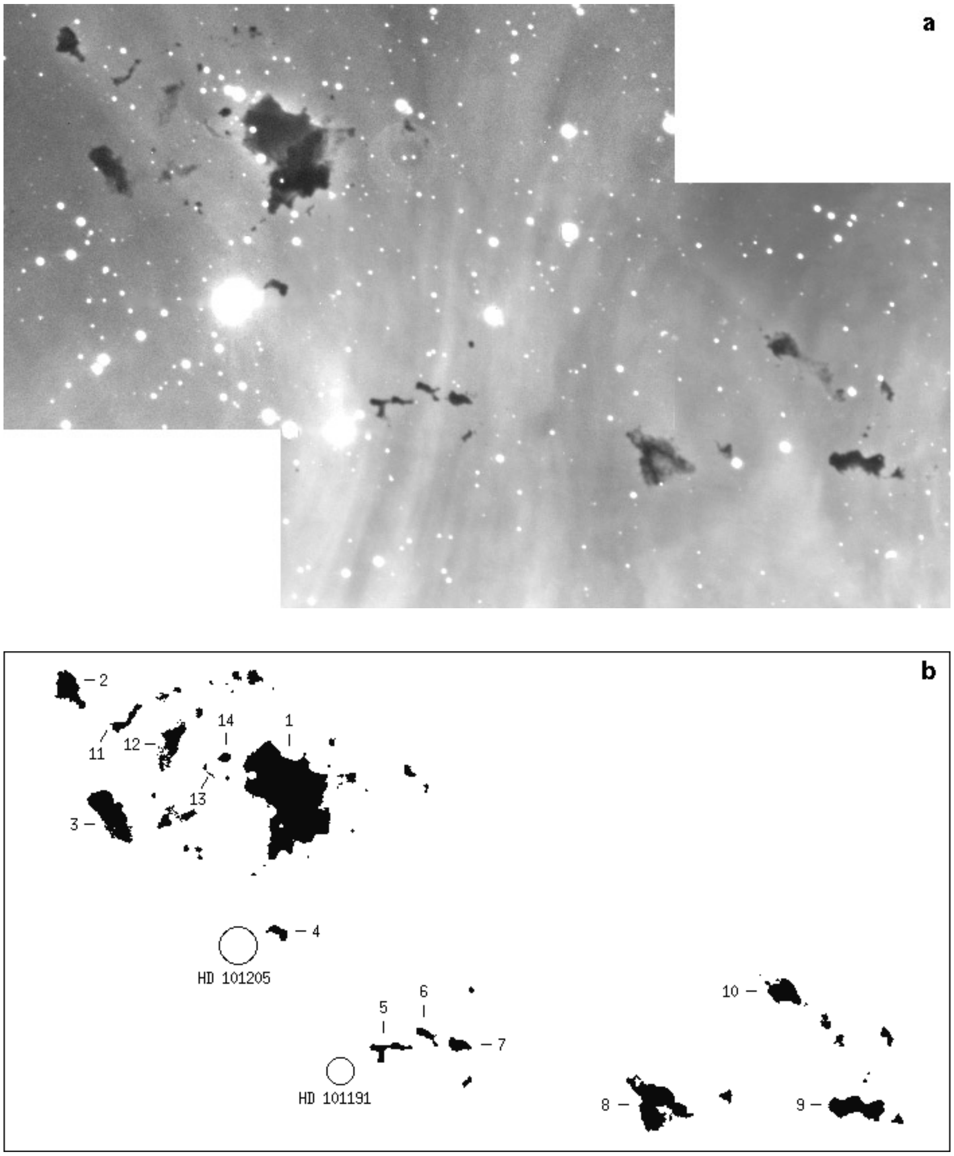

Fig. 2a and b. Thackeray's globules in IC 2944. **a** Thackeray's globules as seen in a composite of CCD images obtained at the ESO 3.6m telescope through an Hα filter. **b** Identification of selected globules as well as the two O-stars in the field, HD 101205 (O7 III) and HD 101191 (O8 V). The width of the images is 8.9 arcmin and its height is 5.7 arcmin, which at 1800 pc corresponds to 4.7 pc and 3.0 pc respectively. North is up and east is left

Table 1. Positions of selected globules

Object	Alpha (1950) h m s	Delta (1950) ° ′ ″
Thackeray 1	11 35 55.8	−63 04 24
2	11 36 09.2	−63 04 34
3	11 36 12.1	−63 03 22
5	11 35 47.1	−63 06 33
6	11 35 45.7	−63 06 27
7	11 35 43.3	−63 06 32
8	11 35 28.9	−63 07 03
9	11 35 19.3	−63 06 04
10	11 35 13.8	−63 07 03

There are three basic features to be noted in the deep Hα CCD image. First, the largest globule is clearly surrounded by bright rims. Second, the edges of all globules are generally extremely sharp and highly structured. Third, well-defined fragments of globules are visible in all sizes down to the resolution limit.

A large number of theoretical studies of isolated dense globules immersed in HII regions around O stars have been performed, among the pioneering studies are Kahn (1969), Dyson (1973) and Tenorio-Tagle (1977). They found that at the interface between neutral and ionized material an ionization-shock front is set up, from which ionized gas streams away supersonically. Because of recombination in the downflow region the neutral globule is largely shielded from the incident uv radiation, and the front moves only slowly into the globule, which can then survive for a considerable time.

If a globule is situated towards the edge of an HII region, it takes a cometary shape, with a rather smooth front facing the ionizing source(s), and a tail streaming in the opposite direction (e.g. Reipurth 1983). But such a morphology is not seen for Thackeray's globules.

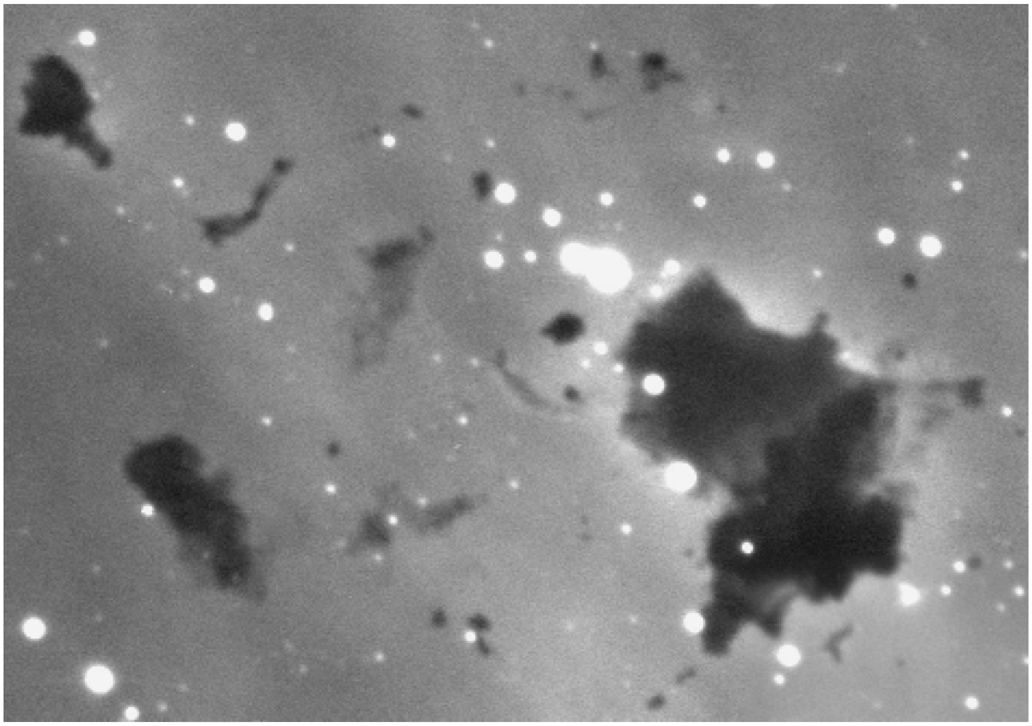

Fig. 3. A detailed view of Thackeray 1 and surrounding globules. Note the bright rims of Thackeray 1, and how the globule appears to consist of two nearly overlapping components, to the N–E and to the S–W. The field is 2.1 x 3.0 arcmin, which at 1800 pc corresponds to 1.1 x 1.6 pc. North is up and east is left

What is the origin of these globules? In principle, there are two possibilities. Firstly, the globules could be cloud cores originally located inside a larger more tenuous cloud, which has by now been evaporated, thus exposing its skeleton of dense structures at their original locations. The dimensions of the largest globule, 0.3 x 0.5 pc, is typical of dense cloud cores (Myers et al. 1991). The remarkably sharp edges displayed by most of the globules is unlikely to have existed prior to exposure, and would in this picture be a result of subsequent erosion by ionization-shock fronts driven into the cores. The large number of very small globules down to the resolution limit (2 pxl = 0.007 pc) may not have pre-existed inside the larger cloud, but could be products of a fragmentation process or an instability in the ionization-shock front.

Another, and as we shall argue, more likely possibility is that the globules are remnants of an elephant trunk, similar to the well known "Pillars" in M16 (e.g. Hester et al. 1996), which formed as the HII region interacted with the walls of the neutral material out of which the O-star cluster was born. This scenario finds support in our CO data.

4. Masses and kinematics of the globules

We have made a ^{13}CO J=1-0 map with a FWHM beam of 44 arcsec towards the largest globule Thackeray 1 centered at α_{1950} 11:35:55.8, $\delta_{1950} = -63$:04:24, and at a number of positions find a double lined profile, with v_{lsr} of -20 and -25 km s^{-1} . Fig. 6a shows the map of these two lines, and it is evident that we see two globules superposed, not a single large one. In the following we refer to Thackeray 1A for the larger globule at v_{lsr} of -20 km s^{-1} , and Thackeray 1B for the smaller globule located towards south west at v_{lsr} of -25 km s^{-1} . It is interesting to note that closer inspection of the optical image of Thackeray 1 in Fig. 3 indeed reveals what appears as two large globules superposed along the line-of-sight. The averaged ^{13}CO line profile from the central 9 pointings is shown in Fig. 6b, and it is evident that Thackeray 1A has a much larger velocity dispersion than Thackeray 1B.

We have also observed Thackeray 1 in the ^{12}CO J=1-0 transition and the lowest spectrum in Fig. 6c shows the profile towards the center of the globule at (0,0). Again we see the same double lined profile. The peak antenna temperature of the CO emission is 5.2 K, which corresponds to an excitation temperature of 11 K, assuming the transition is optically thick and the globule fills the main beam.

Applying the same excitation temperature T_{ex} for the ^{13}CO emission, we can convert the integrated intensities into estimates of total ^{13}CO column densities according to

$$N(^{13}\mathrm{CO}) = 2.42 \cdot 10^{14} \frac{(T_{ex} + 0.88)}{(1 - exp(-\frac{h\nu}{kT_{ex}}))} \frac{\int T_A^* dv/\eta_{mb}}{(J(T_{ex}) - J(T_{bg}))}$$

where T_{bg} is the temperature of the cosmic microwave background, $J(T)$ is the Planck function and η_{mb} is the main beam efficiency given in Sect. 2 to convert from the antenna temperature scale T_A^* to main beam brightness temperatures.

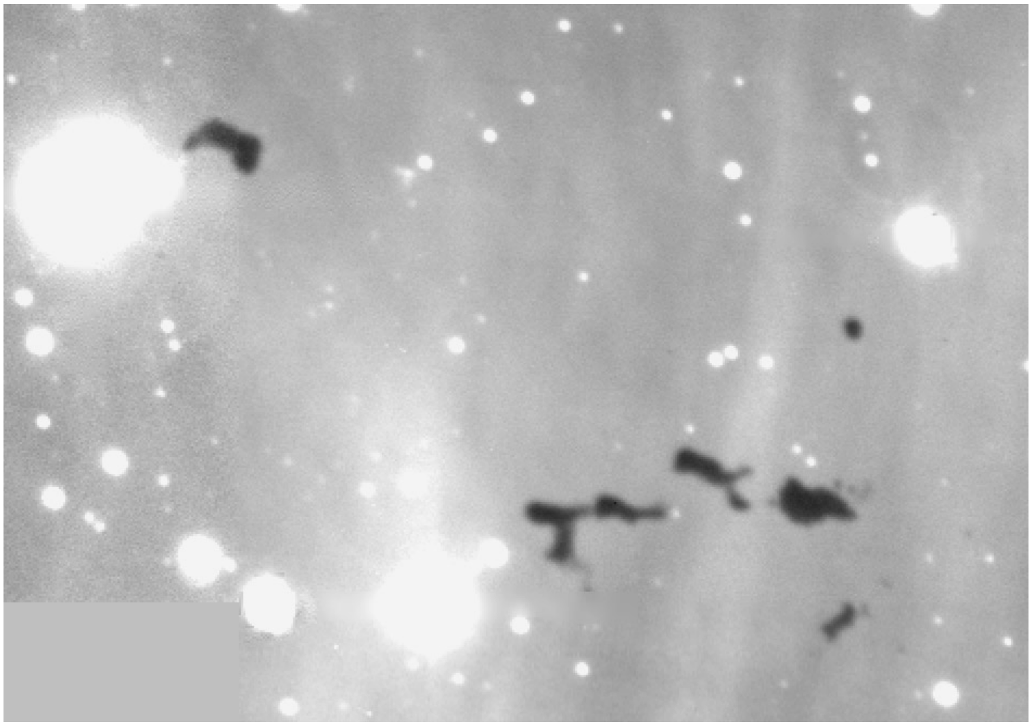

Fig. 4. A detailed view of the smaller globules Thackeray 4, 5, 6 and 7. The field is 2.1 x 3.0 arcmin, which at 1800 pc corresponds to 1.1 x 1.6 pc. North is up and east is left

Summed over the whole map as shown in Fig. 6 the integrated antenna temperatures are 36 K km s^{-1} and 13 K km s^{-1} for the line components at -20 km s^{-1} and -25 km s^{-1}, respectively. For a distance of 1800 pc to the globule and an assumed [^{13}CO]/[H_2] abundance ratio of $2.5 \cdot 10^{-6}$ the resulting column densities correspond to total molecular masses of 11 $M_\odot$ and 4 $M_\odot$, for Thackeray 1A and 1B, respectively.

We have also obtained ^{12}CO spectra towards six other globules, as shown in Fig. 6c and at the positions listed in Table 1. All spectra show a faint emission at $v_{lsr} = -16$ km s^{-1}, which is not detected in the ^{13}CO spectra towards Thackeray 1, and we assume it is from a low density fore- or background region unrelated to the globules. The surprising result is that the globules show a wide range in velocity, from -8 km s^{-1} to -29 km s^{-1}. This strongly suggests that the globules are not high-density condensations that originally existed inside a more tenuous cloud and is now exposed by the strong *uv* radiation field. Rather, the chaotic distribution of globules suggests that violent and highly dynamic processes are at play, and this is borne out by the kinematics of the complex.

If we make the assumption that, to first order, the 3.9 pc extent of the globule field is also representative of the depth of the complex, then the maximum radial velocity difference of 21 km s^{-1} between the globules suggests a dynamic timescale of 180000 yr. Since the *uv* radiation and the expansion of the HII region, which are the main forces on the globules, is along the line-of-sight, the complex may actually stretch out so that it is deeper than it is wide. Also, most velocity differences are smaller than the observed maximum of 21 km s^{-1}, plus these velocities were presumably much smaller earlier. Altogether, we are probably dealing with a timescale closer to 1 million years. This is comparable or slightly less than the age of the most massive stars in the newborn OB association, and thus suggests that the formation of the massive stars heralded the beginning of the demise of the globules.

The only mechanism that could realistically be invoked to create the observed large velocity differences is a Rayleigh-Taylor instability in an expanding dense shell pushed by the hot HII region. Seen in the restframe of the accelerating shell, the whole body of a Rayleigh-Taylor instability is in free fall towards the OB cluster, with a velocity gradient along the body and the tip having the largest velocity. Seen from the OB stars the tip of the elephant trunk is at rest or slowly moving away, while more distant parts of the trunk move away with gradually higher velocities (e.g. Spitzer 1954).

We have evidence that just such a kinematic behaviour is present in another elephant trunk like structure in IC 2944. To the northwest of the OB stars, at a projected distance of roughly 10 pc, there is a large dense region, seen in the upper right corner of Fig. 1. We have mapped this structure in ^{13}CO, and the resulting map is shown in Fig. 7. We additionally show the accumulated radial velocity differences for each map point relative to the front of the globule. We have chosen to display this radial velocity map with vectors pointing away from HD 101205. It is evident that we are seeing precisely the kinematic behavior expected for a Rayleigh-Taylor unstable cloud, and we believe that, given enough time, the dense structure will develop into a fullfledged elephant trunk, before eventually disintegrating. An

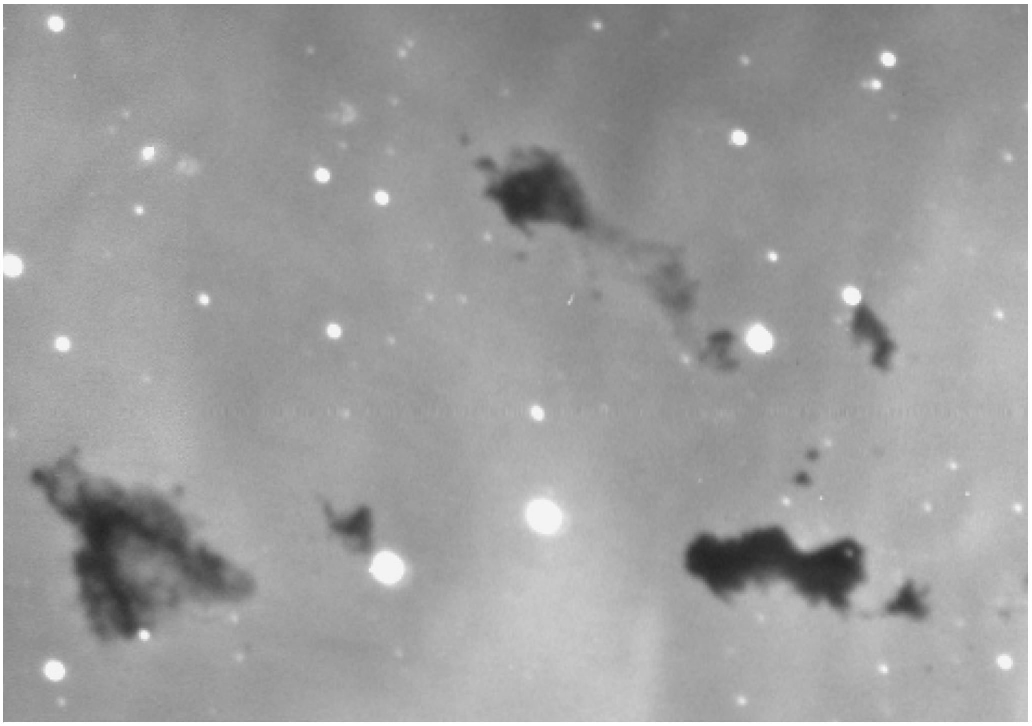

Fig. 5. A detailed view of the globules Thackeray 8, 9 and 10. The field is 2.1 x 3.0 arcmin, which at 1800 pc corresponds to 1.1 x 1.6 pc. North is up and east is left

observer behind the remnants of this future globule complex should see a structure very similar to the Thackeray's globules of today.

5. A search for young stars

Because of the obvious influence on the globules of the ambient medium, it is possible that the formation of stars has taken place in the globules or in the lower-density molecular cloud material, which once enveloped them. However, our objective prism plates show no Hα emission stars in direct association with the globules. This is perhaps not surprising, since the ability of objective prism plates to pick up Hα emission decreases with distance, and at 1.8 kpc only very intense Hα can be expected to be recognized. Seven Hα emission stars were found in the HII region, and they are identified in Fig. 1, and their positions are listed in Table 2.

The identification of ESO Hα 301 on the direct plate was difficult, and is not completely certain. Most, if not all, of the emission line stars are physically associated with the HII region, because in a search of random areas of the same size on the same plates one finds between 0 and 1 emission line stars. The seven stars all show strong Hα emission. The majority of these stars are probably young pre-main sequence stars of intermediate mass, presumably similar to Herbig Ae-Be stars. There is no Hα emission star associated with or even near the globule complex. It should be noted that the survey for emission line stars around the globules was hampered by the glare of HD 101205, and cannot be considered complete. Slit spectra in the spectral range 4200 Å to 6750 Å were obtained of the Hα emission stars, and in Table 2 we list the Hα equivalent width. Only one star, ESO Hα 302, shows a rich emission line spectrum, with numerous FeII lines in emission in addition to the Balmer lines (see Fig. 8). This star is located just outside a large windswept cloud structure at the western edge of the HII region, and was probably born as a result of the compression of the neutral material by the advance of the ionization-shock front.

Table 2. Emission line stars in IC 2944

Stars	Alpha (1950) h m s	Delta (1950) ° ′ ″	$W_{H\alpha}$ (Å)
ESO Hα 301	11 33 26.0	−62 51 32	100.6
ESO Hα 302	11 33 26.9	−62 57 55	98.4
ESO Hα 303	11 34 00.0	−62 58 30	18.5
ESO Hα 304	11 35 26.9	−63 26 19	116.2
ESO Hα 305	11 37 21.3	−63 04 49	33.8
ESO Hα 306	11 37 35.3	−63 12 49	30.9
ESO Hα 307	11 38 36.8	−63 11 29	14.4

Three stars are visible within the outline of Thackeray 1. The deep Hα CCD images show no reflection nebulosity around the stars, and they are presumably line-of-sight associations. Moneti (1991) searched the globule for embedded infrared sources, but found that all sources within the outline of the globule are consistent with highly reddened background late-type stars.

Thackeray (1955) drew attention to a star which between 1950 and 1954 had faded from about 15.5 mag to about 18

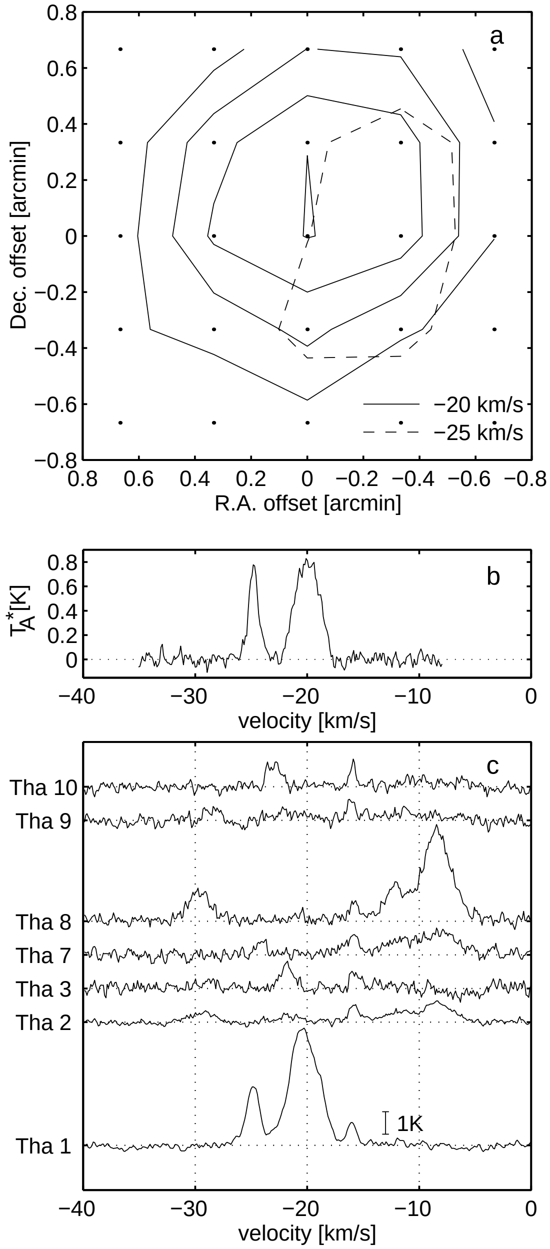

Fig. 6. a A ^{13}CO map of Thackeray 1. The fully drawn contours are from the $-20\,\mathrm{km\,s^{-1}}$ line and the dotted line is emission at $-25\,\mathrm{km\,s^{-1}}$. Levels start at $1\,\mathrm{K\,km\,s^{-1}}$ in steps of $1\,\mathrm{K\,km\,s^{-1}}$ of integrated antenna temperature. The dots mark observed positions. **b** The average ^{13}CO antenna temperature line profile averaged from the central 9 points of the map. **c** ^{12}CO line profiles towards seven globules. The scale in units of antenna temperature is indicated.

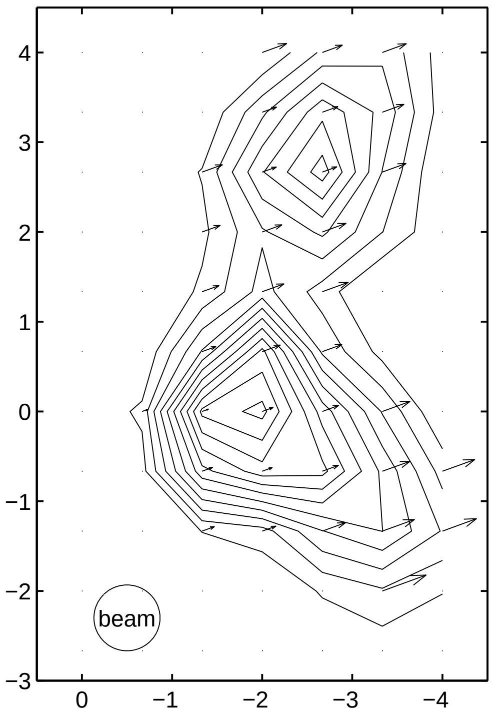

Fig. 7. A ^{13}CO map of the cometary structure seen on Fig. 1 just west of ESO Hα 302, which is marked "2" in the figure. Tickmarks are in arcminutes. Levels start at $2\,\mathrm{K\,km\,s^{-1}}$ in steps of $2\,\mathrm{K\,km\,s^{-1}}$ of integrated antenna temperature. There is a clear increase in radial velocity as one moves in the direction away from the O star HD 101205

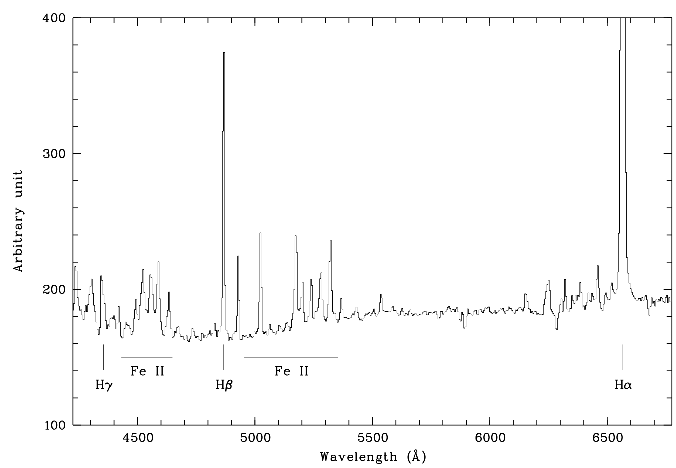

Fig. 8. A spectrum of the rich emission line star ESO Hα 302. Besides the Balmer lines, numerous FeII lines are prominent

mag (photo-visual magnitudes). An intermediate plate taken in 1951 showed it at about 17 mag. Because of its location at the sharp eastern edge of the larger globule, Thackeray considered it possible that he witnessed the actual obscuration of the star behind the cloud-edge, due to relative motion of star and globule. The star has been identified on the present images and on this higher resolution material it is clear that the star is several arcseconds from the sharp globule edge. The star is seen in Fig. 3 at the same declination and immediately to the left of the sharp northern peak of Thackeray 1. The red filter/plate combination used by Thackeray is not quite the same as used for Fig. 2a, but, for what it is worth, comparison between the variable star and neighbouring stars shows it at about the same relative magnitude as in 1954.

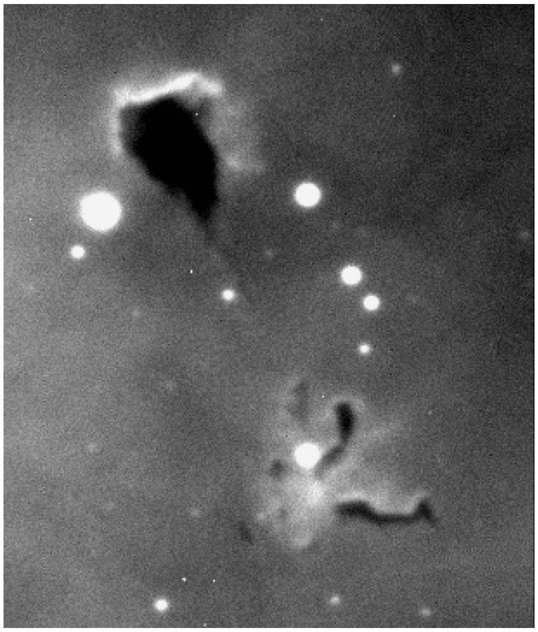

Fig. 9. A group of globules in NGC 6611. The image was taken through an R-band filter. The field is 3.6 x 4.3 arcmin, which at 2000 pc corresponds to 2.1 x 2.5 pc. North is up and east is left

Fig. 10. Another globule region in NGC 6611. Same scale and orientation as Fig. 9

6. Comparison with globules in NGC 6611

NGC 6611 is a bright HII region excited by a group of OB stars at a distance of about 2 kpc (e.g. Goudis 1976), and also associated with a number of young intermediate mass stars (e.g. Hillenbrand et al. 1993). The region is famous for its large complex of "elephant trunks", recently imaged with HST by Hester et al. (1996), and likely caused by Rayleigh-Taylor instabilities (Frieman 1954).

Small globules are also found in NGC 6611. Fig. 9 shows an R-band CCD image of a small group of globules. The exciting stars are located towards the upper left corner, and it appears that we see the globules more or less sideways. The southern complex shows the same splintering of globules as seen in IC 2944. The northern globule, on the other hand, is a single unfragmented mass and it has a long tail pointing away from the OB stars. This last feature perhaps indicates that the globule is the remnant of a small elephant trunk, which has been mostly destroyed by the uv radiation. In Fig. 10 another little globule in NGC 6611 is seen. In this image the O stars are towards the top of the figure. The long axis of the little globule is parallel to the large elephant trunks in the region (for a wide field view of the surroundings of Fig. 10, see Spitzer 1954). Part of the base of the elephant trunks is seen in the lower left corner of Fig. 10. This location supports the view that the little globule is the remnant of an elephant trunk.

7. The detectability of globules in HII regions

In an idealized situation, the perfect balance established between the number of recombinations and the stellar uv output that causes an HII region implies that high density condensations, or globules, able to trap the ionization front are not always detectable if placed at particular locations with respect to an observer.

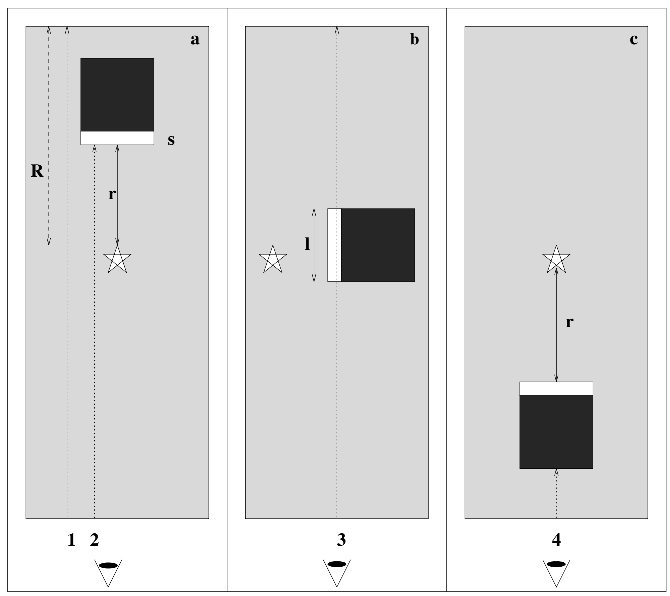

Fig. 11. A schematic representation of a globule seen in three different locations within an HII region. The globule is black in each panel, and its bright rim is white, with a depth s and a width l. The observer is towards the bottom, and four different lines-of-sight are considered

We refer to Fig. 11, where a globule is seen in three different locations within an HII region. In case a, we look into an HII region with radius R, excited by a central OB star. We consider two adjacent lines-of-sight, where line 1 passes through the entire HII region, and line 2 is intercepted by a neutral globule located behind the OB star at a distance r from the star. The uv radiation penetrates a distance s into the globule. We assume that the ambient gas and the globule are homogeneous, with densities of n_o and n_g. Along line 1 the number of recombinations is proportional to $2Rn_o^2$. Along line 2 the number of recombinations is proportional to $(R+r)n_o^2 + sn_g^2$. In the particular geometry where the globule is right behind the star, the radiation available at the globule surface equals the recombinations that would have occurred behind the globule $(R-r)n_o^2$, that is sn_g^2 equals $(R-r)n_o^2$. The emission measure along line 1 is $E_1 = 2R\beta n_o^2$, and along line 2 it is

$$E_2 = (R+r)\beta n_o^2 + s\beta n_g^2 = (R+r)\beta n_o^2 + (R-r)\beta n_o^2 = 2R\beta n_o^2$$

in other words the emission measures of the two adjacent lines-of-sight are identical, and the globule is invisible! From the above equality, and defining the density contrast $a = n_g/n_o$, it follows that

$$s = (R-r)/a^2,$$

that is, for globules closer to the star the penetration into the globule will be deeper. At the same time, denser globules will allow a uv penetration distance inversely proportional to the square of the density contrast. Scattering by dust particles around the borders of a globule will enhance its possible detection although only a small contrast is expected from lines of sight traversing the whole HII region.

The chances of detection increase if the ionized jacket around the globule is seen tangentially rather than face on. In this case, globules would appear as sharp luminous edges or bright rims, against the emission of the HII region (see Fig. 11, line 3). Here the emission measure is increased over adjacent lines-of-sight by $l\beta(n_g^2 - n_o^2)$.

Finally, if globules are placed between the observer and the ionizing source (Fig 11, line 4), they will be apparent as dark patches against the luminous background, because they block the HII region emission $(R+r)\beta n_o^2$, as well as the bright rim contribution $s\beta n_g^2$.

In a more realistic situation, detection strongly depends on the shape of the high density condensations, which could go from small round globules to elongated elephant trunks. It depends also on the number and location of the massive stars causing the ionization. The first issue defines the shape of the observed bright rims around condensations as well as the shape of the detected dark patches seen against the luminous background. The number of stars and their location strongly define the general orientation of bright rims in an HII region. Detection of bright rims is also enhanced by the gas dynamical evolution of the ionized globule material which enhances the surrounding gas density as it streams away from the condensation in a localized champagne flow (Bedijn & Tenorio-Tagle 1984). This flow leads to a fuzzy but broader rim around high density condensations, perhaps better seen around condensations sitting between the observer and the ionizing sources. This is very noticeable in the case of Thackeray 1. The broad rim effect is enhanced if the streaming of matter away from the ionization front is forced to converge. As the flow of ionized gas follows pressure gradients, and these are inevitably perpendicular to the border around dense condensations, the flow resultant from an ionized concave dense edge would lead to convergency of the ionized flow. The opposite is to be expected from the ionization of convex cloud surfaces, since then the pressure gradient would cause the flow to diverge, making the broad bright rim effect less evident. The enhanced rim luminosity due to a converging flow is quite clear in the concave borders of Thackeray 1 and 9. On the other hand, round and convex edges leading to a diverging flow present a much less brightened edge, as in some edge sectors of Thackeray 1 and 9 as well as in 5, 6 and 7 etc.

Acknowledgements. We are grateful to Willem Wamsteker for taking an early photographic plate at the ESO 3.6m telescope for this project. Also, thanks are due to G. Pizarro and O. Pizarro for taking the ESO Schmidt plates. GTT gratefully acknowledges the BBV foundation for the visiting professorship at the University of Cambridge.

References

Ardeberg A., Maurice E., 1977, A&AS 28, 153
Ardeberg A., Maurice E., 1980, A&AS 39, 325
Ardeberg A., Maurice E., 1981, A&A 98, 9
Bedijn P.J., Tenorio-Tagle G., 1984, A&A 135, 81
Bok B.J., 1977, PASP 89, 597
Bok B.J., Reilly E.F., 1947, ApJ 105, 225
Dyson J.E., 1973, A&A 27, 459
Frieman E.A., 1954, ApJ 120, 18
Goudis C.,1976, Ap&SS 41, 105
Herbig G.H., 1974, PASP 86, 604
Hester J.J., 1996, AJ 111, 2349
Hillenbrand L.A., Massey P., Strom S.E., Merril K.M., 1993, AJ 106, 1906
Kahn F.D., 1969, Physica 41, 172
Keene J., 1983, ApJ 274, L43
Moneti A., 1991, in *Astrophysics with infrared arrays*, ed. R. Elston, Astron. Soc. Pacific Conf. Ser. vol. 14, p. 261
Myers P.C., Fuller G.A., Goodman A.A. and Benson P.J., 1991, ApJ 376, 561
Perry C.L., Landolt, A.U., 1986, AJ 92, 844
Reipurth B., 1983, A&A 117, 183
Spitzer L., 1954, ApJ 120, 1
Tenorio-Tagle G., 1977, A&A 54, 517
Thackeray A.D., 1950, MNRAS 110, 529
Thackeray A.D., 1955, Mem. Soc. Roy. Sci. Liege, Ser. 4 vol. 15, p. 437
Thackeray A.D., Wesselink, AJ, 1965, MNRAS 131, 121
Walborn N.R., 1973, AJ 78, 1067
Walborn N.R., 1987, AJ 93, 868
Yun J.L., Clemens D.P., 1990, ApJ 365, L73

This article was processed by the author using Springer-Verlag LaTeX A&A style file *L-AA* version 3.