Handbook of Star Forming Regions Vol. II
Astronomical Society of the Pacific, © *2008*
Bo Reipurth, ed.

Young Stars and Molecular Clouds in the IC 2944/2948 Complex

Bo Reipurth

Institute for Astronomy, University of Hawaii
640 N. Aohoku Place, Hilo, HI 96720, USA

Abstract. One of the fine clusters of the southern sky is found within the extended HII region IC 2944/2948. The cluster, which appears to be only a few million years old, contains a dozen O stars, many of which are binaries, and is surrounded by a shell of remnant molecular clouds containing embedded IRAS sources. At a distance of about 2 kpc, only a few of the faint cluster members have been identified so far. The region contains a remarkable group of small globules silhouetted against the luminous gas around the OB stars and known as Thackeray's globules.

1. IC 2944 and IC 2948

IC 2944 and IC 2948 form a large HII region in the constellation Centaurus, approximately 7 degrees west of the Coalsack. There is considerable confusion in the literature about what exactly IC 2944 and IC 2948 refer to. The two objects were among many new nebulae discovered by Royal H. Frost, who between 1902 and 1905 worked as an observing assistant at the Harvard College Observatory's station in Arequipa, Peru, using the 24 inch f/5.6 Bruce telescope. IC 2944 and 2948 were found by Frost on Plate 6715, a 4 hour exposure obtained on May 5, 1904. They are listed as H.N. 789 and 790 in Table VII of Pickering (1908), with the 1900-coordinates $11^h31.1$, $-62^o28'$ and $11^h34.1$, $-62^o58'$, respectively. Frost provided the following comments for H.N. 789, now known as IC 2944: *Neb. around A.G.C. 15848* (now known as λ Cen), *ext. from* 11^h30^m *to* $11^h\ 31^m$ *and from* $-62^o\ 14'$ *to* $-62^o\ 40'$, and for H.N. 790, now known as IC 2948: *Neb. patch ext. from* $11^h30.6^m$ *to* $11^h\ 38.1^m$, *and from* $-62^o\ 28'$ *to* $-63^o\ 14'$. Figure 1 shows a modern widefield image, and using the original coordinates and descriptions of Frost it is evident that IC 2944 refers to the almost vertical bright rim just west of the bright star λ Cen, whereas IC 2948 is the much larger and brighter HII region that dominates the lower central part of the figure. This is the nomenclature that will be used in the following, even though many researchers (including the present author) have erroneously used IC 2944 to describe the main IC 2948 region. As will become clear in the following, IC 2944 and IC 2948 represent different parts of the same, large complex of clouds surrounding a cluster of OB stars. This grouping is sometimes also known as the Centaurus OB2 association (Alter, Balazs, & Ruprecht 1970).

Figure 1 also shows three smaller HII regions, Gum 39, 40, and 41. The northernmost, Gum 39, is illuminated by the O6 star HD 99897, the central one, Gum 40, by the eclipsing binary O9V star HD 99898, and the southernmost one, Gum 41 or RCW 61, by the O9III star HD 100099. Almost nothing is known about these three regions, and it is not even clear if they are associated with the IC 2944/48 complex.

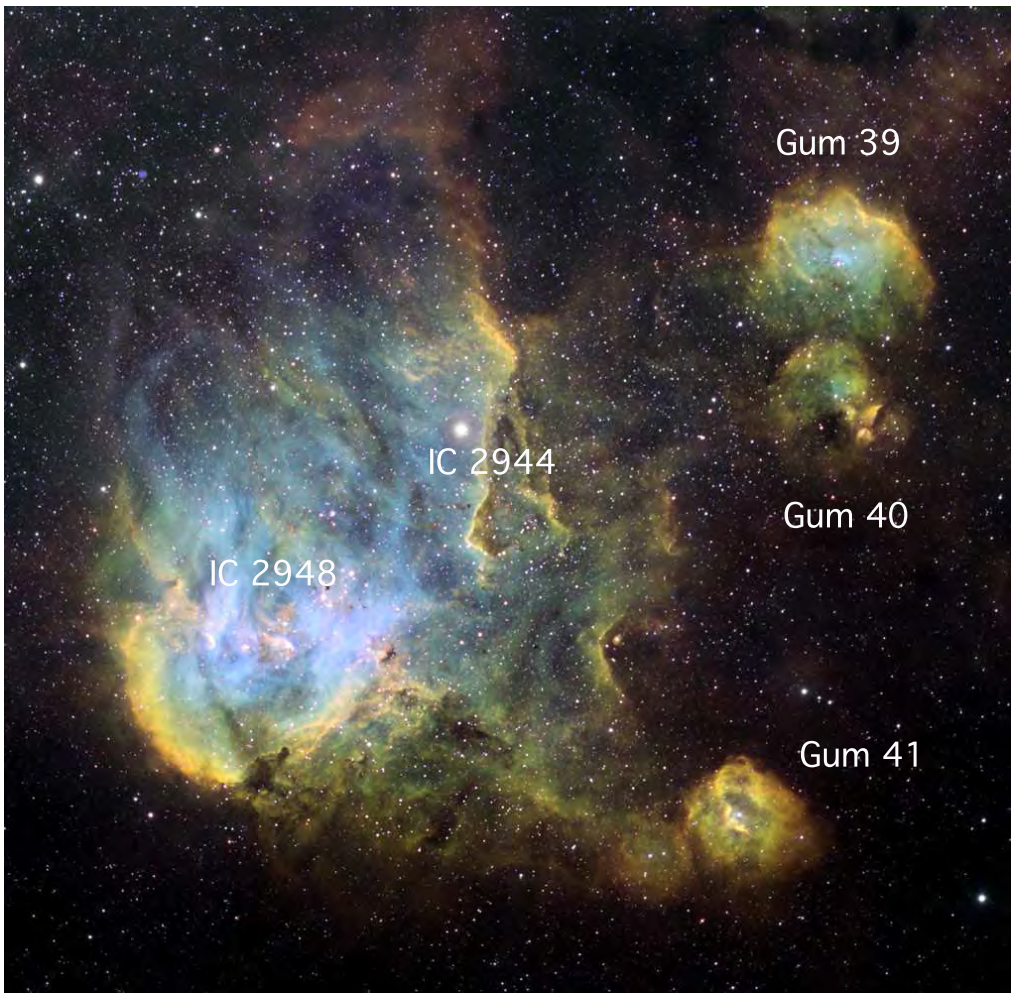

Figure 1. The IC 2944/2948 region as seen in a color composite from Hα, [SII], and [OIII] images. IC 2944 is the bright rim in the middle of the image, to the right (west) of the bright star λ Cen and including the bright rim around the prominent cometary cloud. IC 2948 is the large bright HII region in the lower central part of the image. Three smaller HII regions are labeled. The field is approximately $2^\circ \times 2^\circ$. North is up and east is left. Image courtesy John Ebersole.

2. The Massive Young Stars

Gould (1897) drew attention to a concentration of bright stars in the region of λ Cen. Collinder (1931) included the cluster (Cr 249) in his list of clusters and labeled it IC 2944, although it is actually located within IC 2948 (Figure 2). Hoffleit (1956) pointed out that the high-luminosity stars in this direction of the Galactic plane stretches for many kiloparsec along the line of sight. The first detailed study of the concentrated group of O and B stars within the IC2944/2948 region was performed by Thackeray & Wesselink (1965), who presented photoelectric photometry, MK spectral classifications, and radial velocities, and concluded that the cluster is extremely young, with

half or more of its massive members being binaries. They suggested a distance of 2.0 kpc. A major photometric and spectroscopic study of the stellar aggregate surrounding HD 101205, the brightest O-star within the IC2944/2948 complex, was carried out by Ardeberg & Maurice (1977a,b), who concluded that the OB stars are located at a distance of 2.5 kpc. In a follow-up study, Ardeberg & Maurice (1980,1981) suggested that the OB stars are strung out into separate stellar groups at various distances, with the OB stars ionizing the IC 2944/2948 complex located at a kinematically determined distance of 1750 pc. In a subsequent study, Perry & Landolt (1986) took this idea one step further, and concluded that the HD 101205 aggregate forms only an apparent stellar concentration due to the superposition of isolated early-type stars along our line of sight. However, Walborn (1987) emphasized that, although we do look down along the inner Carina spiral arm in this direction, the cluster of OB stars within IC 2944/2948 is a real, and indeed a significant physical cluster, which is responsible for the excitation of the gas in this region. Using Walraven WBLUW photometry, Brand & Wouterloot (1988) found a distance of 2.1 kpc to the cluster. Tovmassian et al. (1998) used observations at 1640 Å from the UV space telescope Glazar to derive a distance of 2.2 kpc. Reviewing the various distance estimates, it seems reasonable at present to adopt a value of 2.0 kpc, the same as the original value by Thackeray & Wesselink (1965), but noting that it is likely to be uncertain by several hundred parsec.

Several of the OB stars in IC 2944/2948 have been studied in greater detail, and we here just mention two of the brightest stars, both close binaries:

HD 101205 is the brightest (V$\sim$6.5) massive star in the IC 2944/2948 region, and is classified as O7 IIIn(f) by Walborn (1973,1987). Balona (1992) discovered that it is a low-amplitude eclipsing binary (although he labeled it HD 101191, another nearby O-star), with a short period of 2.08 days. Further eclipse timings are given by Mayer, Lorenz, & Drechsel (1992), but a full study of this system is still waiting to be done.

HD 101131 is also very bright (V$\sim$8.5), and is classified as O6 V(f) by Walborn (1973,1987). It is a double-lined spectroscopic binary with a period of 9.65 days, no eclipses, and unevolved components with an age of about 2 million years (Gies et al. 2002).

Several other eclipsing binaries are part of the young cluster, the best studied is BH Cen = HD 308826, which is a B1.5 V type system with double lines and a period of only 0.79 days, leading to speculations that the components may be in contact (Leung et al. 1984 and Qian, Liu & Kreiner 2006 and references therein).

Table 1. Hα Emission Stars in IC 2944/2948 (from Reipurth et al. 1997)

Star	α_{2000}	δ_{2000}	EW[a]	2MASS[b]	J	H	K
ESO Hα 301	11:35:45.3	–63:08:08	100	11354531-6308080	10.32	9.37	8.35
ESO Hα 302	11:35:46.1	–63:14:31	98	11354610-6314309	9.84	8.71	7.71
ESO Hα 303	11:36:19.5	–63:15:06	18	11361961-6315063	12.22	11.50	10.72
ESO Hα 304	11:37:47.0	–63:42:56	116	11374699-6342562	11.23	10.51	9.84
ESO Hα 305	11:39:42.7	–63:21:27	34	11394271-6321273	12.25	11.27	10.40
ESO Hα 306	11:39:56.7	–63:29:27	31	11395678-6329266	12.57	11.84	11.07
ESO Hα 307	11:40:58.8	–63:28:07	14	11405885-6328069	11.87	11.73	11.60

a: Equivalent width of Hα emission

b: All 2MASS sources are closer than 1 arcsec to the position of the Hα emission star

Figure 2. The small group of Thackeray's Globules is seen silhouetted against the cluster of OB stars and the central part of IC 2948. The field is approximately 17 × 20 arcmin. North is up and east is left. Courtesy Martin Pugh.

3. The Young Low-Mass Population and Ongoing Star Formation

Very little is known about the young low-mass stars in the IC 2944/2948 region. If the age for HD 101131 of about two million years mentioned above is characteristic for the whole stellar cluster, then the aggregate should contain large numbers of T Tauri stars. Identifying the fainter cluster members is made difficult because of the richness of the background star fields in this region. Thackeray & Wesselink (1965) noted as strong evidence for the presence of some faint members the subclustering of faint stars surrounding the star CPD -62^o2167 (=V870 Cen). Ardeberg & Maurice (1980) mentioned that they found a few fainter stars that could be either binary stars or pre-main sequence stars, several of them showing emission lines. Reipurth et al. (1997) attempted to find the T Tauri population with photographic objective prism spectra, but detected only 7 Hα emitters, see Table 1. One of the brighter of these, ESO Hα 302, is located right in front of the main cometary cloud in IC 2944 (seen in Figure 3), and shows a rich emission line spectrum without a discernible stellar spectrum (Figure 4), most likely it is a highly veiled Herbig Ae/Be star. Both ESO Hα 301 and 302 are bright MSX sources at 8.3 μm. Sugitani & Ogura (1994) identified several IRAS sources embedded

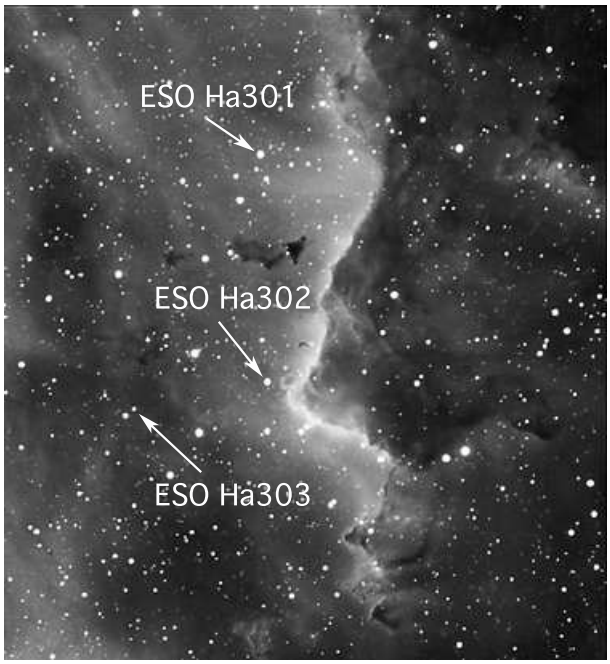

Figure 3. The principal bright rim of IC 2944 and several Hα emission stars. Courtesy Daniel Verschatse.

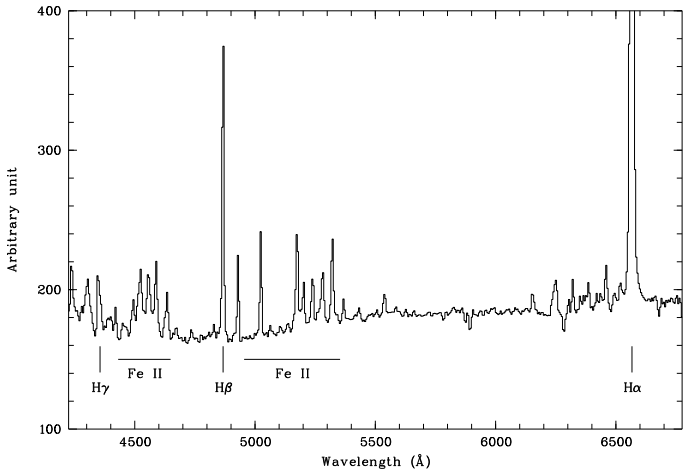

Figure 4. The rich emission line star ESO Hα 302 shows numerous FeII lines in addition to Balmer emission. From Reipurth et al. (1997).

in bright-rimmed clouds in the IC 2944/2948 region. In a study of the molecular clouds in this area (see the next section), Yamaguchi et al. (1999) found 17 IRAS sources located towards the clouds, most of which they estimate are physically associated with the clouds. If so, some of these IRAS sources would be evidence for on-going star formation in the complex. One of these sources, IRAS 11332-6258 is located within

the main cometary cloud mentioned above and seen in Figure 3. It contains a Class I source with a luminosity of several thousand $L_{\odot}$. The source is associated with an H_2O maser and a methanol maser (e.g., Braz et al. 1989, MacLeod & Gaylard 1992, Walsh et al. 1998). Zinchenko, Mattila, & Toriseva (1995) detected a several hundred $M_{\odot}$ cloud core in CS around the IRAS source. It is likely that the source is a relatively massive star that has recently been born in the dense cometary cloud.

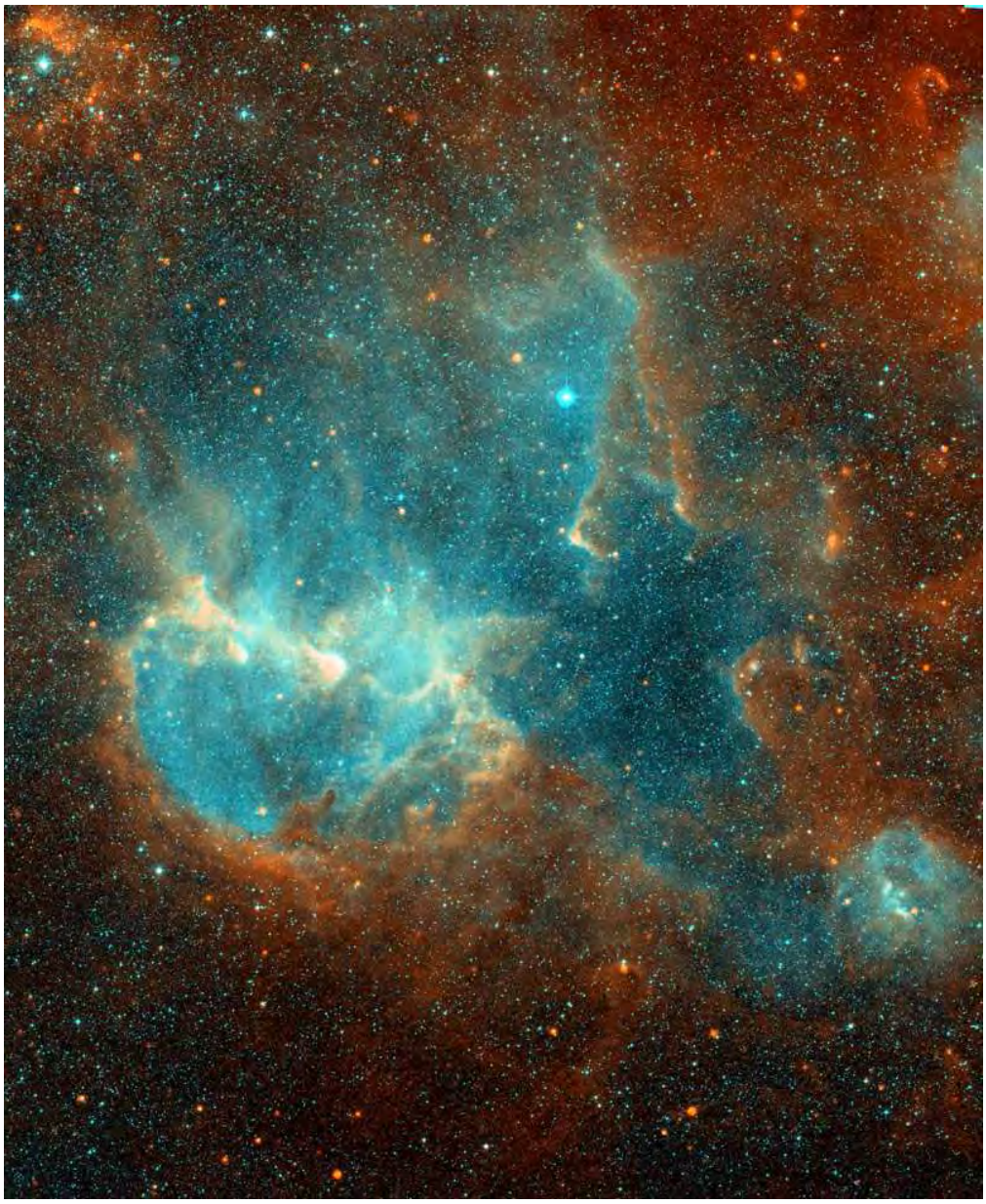

Figure 5. The IC 2944/2948 complex as seen in a composite of the red DSS2 survey and the MSX band A emission at 8.3 μm. Hα emission is blue, and orange is PAH emission from warm dust. Courtesy Lise Deharveng.

4. The Gas, the Molecular Clouds, and the Globules

In addition to the names IC 2944 and IC 2948, the ionized gas in this region is also known as Gum 42 (Gum 1955), as RCW 62 (Rodgers, Campbell, & Whiteoak 1960), and G294.8-1.8 (Georgelin et al. 2000). The region is highly complex, as can be ascertained in the composite optical/infrared map of the region seen in Figure 5. The figure indicates that the HII region IC 2948 is density limited towards the south, whereas ionized gas escapes to the north. Georgelin et al. (2000) used a widefield Fabry-Perot interferometer to map the structure and kinematics of a large area of the Galactic plane between l = 289^o and 295^o, which just barely includes the IC 2944/2948 region (l = 294.8). They find that the ionized gas divides into two subgroups, with velocities between -18 and -21 km/sec and between -24 and -27 km/sec, and argue that only the former gas is associated with the OB stars in the young cluster. The prominent bright rim associated with IC 2944 was studied spectroscopically by Danks & Manfroid (1976), who listed intensities for a large number of emission lines. Manfroid (1976) modeled the bright rim to find the abundances and excitation conditions corresponding to the observations.

Grabelsky et al. (1987) presented the results from the Columbia CO (J=1-0) Galactic plane survey through the Vela-Carina-Centaurus region and showed how the Carina arm is the dominant feature in the data, showing the characteristic loop in an (l,v) diagram. The map shows a major cloud complex from l = 293^o to 296^o and from b = -3^o to -0.5^o. This complex is labeled TGU 1802 in the extinction atlas of Dobashi et al. (2005). In a subsequent study, Grabelsky et al. (1988) attempted to associate the various clouds with HII regions and stars in the region, and suggested that the just mentioned cloud (their cloud 20) is linked to the IC 2944/2948 complex. Later, Yamaguchi et al. (1999) have presented NANTEN ^{13}CO (J=1-0) maps that include this cloud complex (their region 13). Pirogov et al. (2003) detected a massive core in the IC 2944/2948 region in their N_2H^+(1-0) survey.

Vega, Orsatti, & Marraco (1994) obtained polarimetry of 30 stars belonging to the IC 2944/2948 complex in order to study the distribution and characteristics of the dust associated with the aggregate.

By far the most striking and unusual objects in the IC 2944/2948 region is a complex of small globules sharply silhouetted against the HII region and stretching across about 4 pc; they can be seen in the center of Figure 2. The globules were discovered by Thackeray (1950), who noted that the largest globule shows a bright lane crossing the dark area, and concluded that the globules are thus enmeshed in the HII region rather than being foreground objects. Thackeray (1955) noted a faint star at the edge of the largest globule which between 1950 and 1954 had faded by about 2.5 magnitudes. In a study of this region, Reipurth et al. (1997) presented CO observations of the larger globules, and found that the larger globule consists of two components with distinct velocities and masses of 11 and 4 $M_\odot$. Surprisingly, the globules in the complex have velocities ranging from -8 to -29 km/sec, suggesting that after the globules have been exposed from a previously existing molecular cloud by the strong UV radiation, they are now shaped by violent and highly dynamic processes. In an attempt to understand these processes better, Reipurth, Raga, & Heathcote (2003) obtained HST images of the largest globule (see Figure 6), which clearly shows that it consists of two components. A large complex of tiny splinters, among the smallest entities observed in the interstellar medium, surround the main globule. Such tiny globules should have a very short lifetime because of their large surface-to-mass ratio, indicating that they are probably

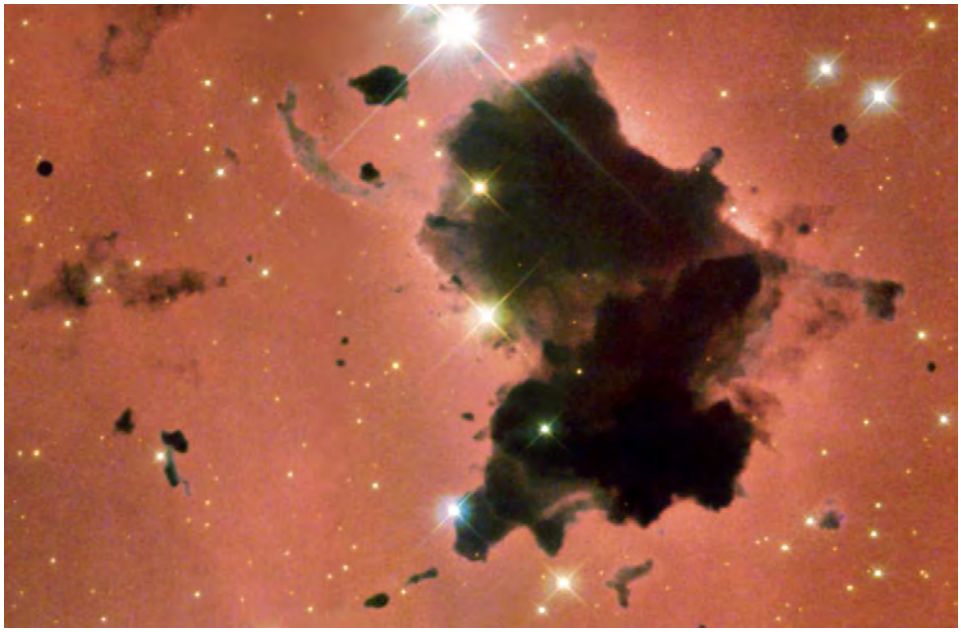

Figure 6. The main globule, Thackeray 1, in IC 2948 as seen in Hα with WFPC2 on HST. From Reipurth, Raga, & Heathcote (2003).

continously formed and destroyed. The precise details of the physical processes that lead to this fragmentation are not yet fully understood, although numerical simulations of radiation-driven implosion of molecular cloud cores (e.g. Kessel-Deynet & Burkert 2003) show remarkably similar structures and fragments.

Acknowledgements. I am thankful to the referee Lise Deharveng for valuable comments and for permission to use Figure 5, and to John Ebersole, Martin Pugh and Daniel Verschatse for permission to use Figures 1, 2 and 3, respectively. This research has made use of NASA's Astrophysics Data System, of the SIMBAD database operated at CDS, Strasbourg, France, of the Digitized Sky Survey, and of the 2MASS database. BR was supported in part by the NASA Astrobiology Institute under Cooperative Agreement No. NNA04CC08A and by the NSF through grants AST-0507784 and AST-0407005.

References

Ardeberg A. & Maurice E., 1977a, A&A, 54, 233,
Ardeberg A. & Maurice E., 1977b, A&AS, 28, 153
Ardeberg A. & Maurice E., 1980, A&AS, 39, 325
Ardeberg A. & Maurice E., 1981, A&A, 98, 9
Balona, L.A. 1992, MNRAS, 254, 404
Brand, J. & Wouterloot, J.G.A. 1988, A&AS, 75, 117
Braz, M.A., Scalise, E., Gregorio Hetem, J.C., Monteiro do Vale, J.L., & Gaylard, M. 1989, A&A Suppl., 77, 465
Collinder, P. 1931, Ann. Obs. Lund, 2, 1

Danks, A.C. & Manfroid, J. 1976, A&A, 48, 213
Dobashi, K., Uehara, H., Kandori, R., Sakurai, T., Kaiden, M., Umemoto, T., & Sato, F. 2005, PASJ, 57, S1
Georgelin, Y.M., Russeil, D., Amram, P., Georgelin, Y.P., Marcelin, M., Parker, Q.A., & Viale, A. 2000, A&A, 357, 308
Gies, D.R., Penny, L.R., Mayer, P., Drechsel, H., & Lorenz, R. 2002, ApJ, 574, 957
Gould, B.A. 1897, *Fotografias Cordobesas: Observaciones de Cumulos de Estrellas* ..., Resultados de Observatorio Nacional Argentino en Cordoba, vol.19.
Grabelsky, D.A., Cohen, R.S., Bronfman, L., & Thaddeus, P. 1987, ApJ, 315, 122
Grabelsky, D.A., Cohen, R.S., Bronfman, L., & Thaddeus, P. 1988, ApJ, 331, 181
Gum, C.S. 1955, Mem. Roy. Astron. Soc., 67, 155
Kessel-Deynet, O. & Burkert, A. 2003, MNRAS, 338, 545
Leung, K.-C., Sistero, R.F., Zhai, D.-S., Grieco, A., & Candellero, B. 1984, AJ, 89, 872
MacLeod, G.C. & Gaylard, M.J. 1992, MNRAS, 256, 519
Manfroid, J. 1976, A&A, 51, 235
Mayer, P., Lorenz, R., & Drechsel, H. 1992, IBVS, No. 3765
Moneti A., 1991, in *Astrophysics with Infrared Arrays*, ed. R. Elston, Astron. Soc. Pacific Conf. Ser. vol. 14, p. 261
Perry C.L. & Landolt, A.U., 1986, AJ, 92, 844
Pickering, E.C. 1908, Annals of Harvard College Observatory, 60, 147
Pirogov, L., Zinchenko, I., Caselli, P., Johansson, L.E.B., & Myers, P.C. 2003, A&A, 405, 639
Qian, S.-B., Liu, L., & Kreiner, J.M. 2006, New Astr., 12, 117
Reipurth, B., Corporon, P., Olberg, M., & Tenorio-Tagle, G. A&A, 327, 1185
Reipurth, B., Raga, A.C., & Heathcote, S. 2003, AJ, 126, 1925
Rodgers, A.W., Campbell, C.T., & Whiteoak, J.B. 1960, MNRAS, 121, 103
Sugitani, K. & Ogura, K. 1994, ApJS, 92, 163
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
Tovmassian, H.M., Epremian, R.A., HovHannessian, R.Kh., Cruz-Gonzalez, G., & Navarro, S.G. 1998, AJ, 115, 1083
Vega, E.I., Orsatti, A.M., & Marraco, H.G. 1994, AJ, 108, 1834
Walborn N.R., 1973, AJ, 78, 1067
Walborn N.R., 1987, AJ, 93, 868
Walsh, A.J., Burton, M.G., Hyland, A.R., & Robinson, G. 1998, MNRAS, 301, 640
Yamaguchi, R., Saito, H., Mizuno, N., Mine, Y., Mizuno, A., Ogawa, H., & Fukui, Y. 1999, PASJ, 51, 791
Zinchenko, I., Mattila, K., & Toriseva, M. 1995, A&A Suppl., 111, 95