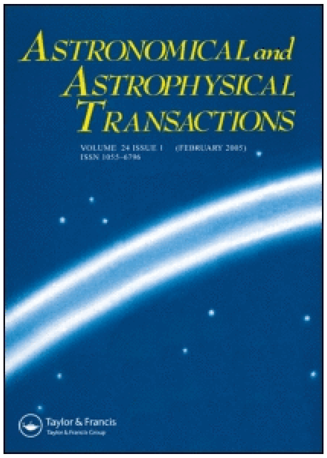

Astronomical & Astrophysical Transactions
The Journal of the Eurasian Astronomical Society
Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t713453505

THE RELATIONSHIP BETWEEN GAS, STARS AND STAR FORMATION: GIANT COMPLEXES OF MULTIPLE HI AND HII SHELLS IN THE IRR GALAXY IC 1613

T. A. Lozinskaya [a]
[a] Sternberg Astronomical Institute, Universitetskij pr. 13, Moscow, 119899 Russia.

Online Publication Date: 01 January 2002
To cite this Article: Lozinskaya, T. A. (2002) 'THE RELATIONSHIP BETWEEN GAS, STARS AND STAR FORMATION: GIANT COMPLEXES OF MULTIPLE HI AND HII SHELLS IN THE IRR GALAXY IC 1613', Astronomical & Astrophysical Transactions, 21:4, 223 - 229
To link to this article: DOI: 10.1080/10556790215592
URL: http://dx.doi.org/10.1080/10556790215592

Astronomical and Astrophysical Transactions, 2002, Vol. 21(4–6), pp. 223–229

THE RELATIONSHIP BETWEEN GAS, STARS AND STAR FORMATION: GIANT COMPLEXES OF MULTIPLE HI AND HII SHELLS IN THE IRR GALAXY IC 1613

T. A. LOZINSKAYA

Sternberg Astronomical Institute, Universitetskij pr. 13, Moscow, 119899 Russia

(Received 15 February 2002)

We use our H-α and 21-cm observations of the dwarf Irr galaxy IC 1613 to analyze the relationship between stars and the ISM in the area of a recent burst of star formation in the galaxy. We trace several possible loci of favorable conditions for star formation triggered by collisions of shells and supershells.

Keywords: ISM, star: formation, stellar wind, supershell

1 INTRODUCTION

Dwarf Irr galaxies open up the best opportunity to learn about the large-scale and long-term interrelation between stars, gas, and triggered star formation. Huge multi-shell complexes are more likely to form in Irrs, because the latter lack spiral density waves, and because of the slow (and usually rigid) rotation of dwarf galaxies. The formation of huge multi-shell complexes is also favored by weaker gravity fields, larger disk scale heights, and lower number densities in dwarf Irrs compared to spirals. These factors favor the growth of supershells and multi-shell complexes produced by stellar winds and SNe of OB associations. These complexes are long-lived objects capable of causing triggered star formation.

Therefore, Irrs provide the best laboratory to study large-scale complexes of ongoing violent star formation. I am using the IC 1613 laboratory to discuss some aspects of interaction between stars and the ISM, and star formation triggered by this interaction.

Our observations of the galaxy include VLA observations made in radio continuum and at the 21-cm line, optical observations with a Fabry-Perot interferometer and with the Multi-Pupil Fieber Spectrograph at the 6-m telescope, deep images taken with the 4-m telescope and X-ray observations with HRI ROSAT (Goss and Lozinskaya, 1995; Lozinskaya *et al.*, 1998; Afanasiev *et al.*, 2000; Lozinskaya *et al.*, 2001; Lozinskaya *et al.*, 2002).

ISSN 1055-6796 print; ISSN 1476-3540 online
DOI: 10.1080/1055679021000017349

2 THE ONLY COMPLEX OF VIOLENT STAR FORMATION IN 1C 1613

The early HI map of the whole galaxy by Lake and Skillman (1989) showed two most prominent features: a "superhole" and a very bright HI "spot", both of about 1–1.5 kpc across. Today it appears that these two features represent two giant star-forming complexes at different stages of their evolution.

Figure 1 shows a high-resolution VLA HI map of a large sector of the galaxy superimposed on the deep Hα image. VLA observations at 21 cm were proposed by E. Wilcots and published by Lozinskaya *et al.* (2001). Both the bright "spot" and the "superhole" surrounding a large fraction of the stellar population of the galaxy can be seen clearly on this figure.

The bright "spot" represents the only recent star-forming region known in the galaxy. Figure 1 clearly demonstrates the huge complex of ionized shells and the neutral shells that surround them. Most of bright HII regions and the only SNR known in 1C 1613 belong to the complex. The complex includes about 20 OB associations and open clusters with ages ranging from 5 to 20 mln yrs according to Georgiev *et al.*, 1999. Shells in the complex have sizes ranging from 100 to 300 pc; the expansion velocities of ionized shells are about

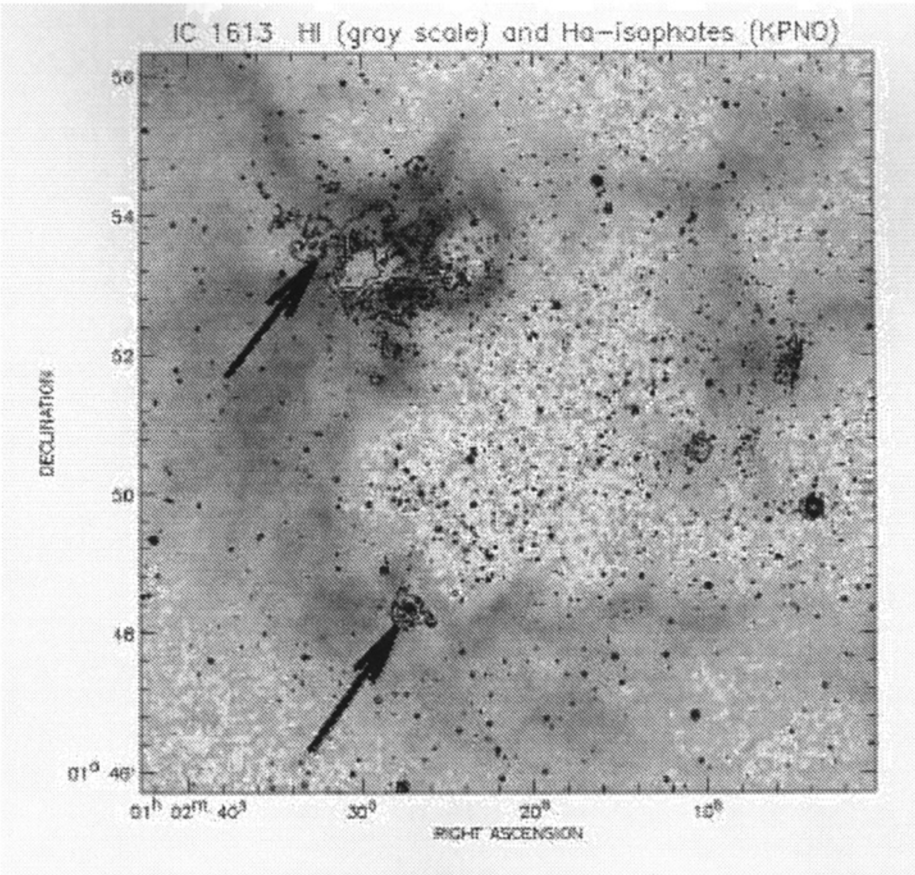

FIGURE 1 The HI map of the large sector of the galaxy IC 1613 (shown in shades tones) superimposed on the deep Hα image (shown by isophotes). The arrow at NE indicates location of the chain of compact objects; the arrow at SE indicates on the WO star and its nebula.

TABLE I Stars in the Fields I, II and III of the Star Formation Complex.

Star No	*V*	*B-V*	*E(B–V)*	M^v	*sp*
I.1	17.94	+0.02	0.33	−7.4	O I
I.2	19.18	−0.10	0.18	−5.7	O III
I.3	19.32	+0.37	0.18	−5.5	A7 III
I.4	19.80	+0.10	0.18	−5.0	B8 II
I.5	19.80	−0.05	0.29	−5.4	O8 III or O4 V
II.1	18.94	+1.33	0.08	−5.6	G8 – K0 II
II.2	20.04	+1.53	0.18	−4.8	K0–K2 II–I
III.1	19.40	+0.01	(0.3)	(−5.8)	O III
III.2	19.62	+0.07	0.3	−5.6	O–B
III.3	20.17	−0.06	0.3	−5.0	Of ?
III.4	19.69	+0.14	(0.4)	−5.8	O III

30–50 km/s (Meaburn *et al.*, 1988; Valdes-Guttieres *et al.*, 2001) and those of HI shells, about 15–20 km/s (Lozinskaya *et al.*, 2003). Therefore what we see here is actually a set of expanding ionized and neutral shells in contact. This leads us to the subject of triggered star formation. According to modern understanding the gravitational instability in a massive expanding shell may be triggered by an external push, like a shell–cloud collision or shell–shell collision (Chernin *et al.*, 1995; Ehlerova and Palous, 2002; and references herein).

Star formation is still going on in the multishell complex. We identified on a deep Hα image what seemed to be a signature of star-formation triggered by a shell–shell collision. A remarkable chain of compact emission objects is located at the edge of the ionized shell at the curved interface between the ionized and neutral shells, exactly where two HI shells may have been colliding. (Its position is indicated by the arrow on Fig. 1.)

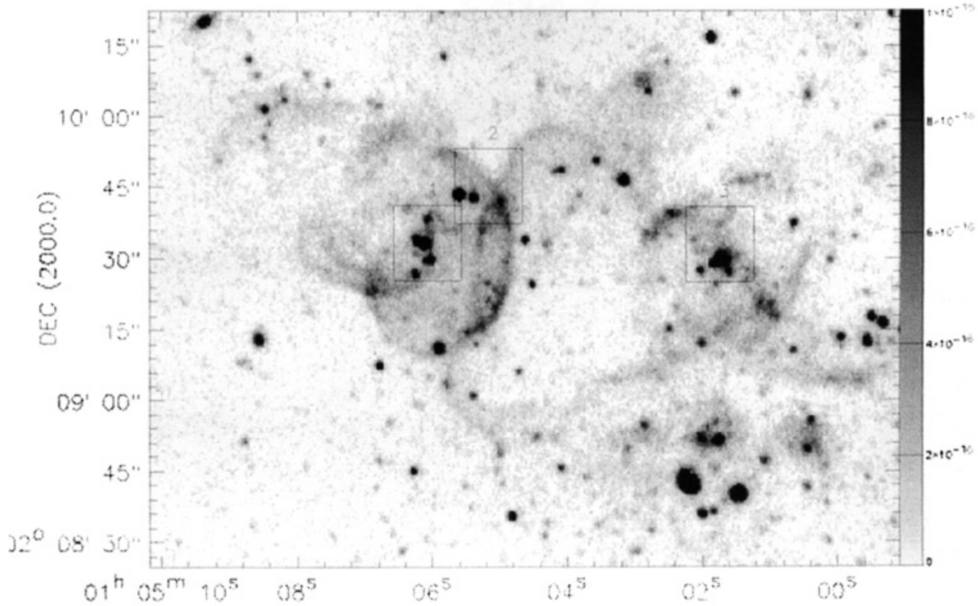

FIGURE 2 Image of the star formation complex taken with 1-m telescope using wide filter centered on $\lambda = 6620$ Å, FWHM = 190 Å coadding emission in the Hα and [NII] lines and the continuum. The rectangles indicated three fields observed with the Multi-Pupil Fieber Spectrograph at the 6-m telescope SAO, corresponding to the Table.

One could expect compact objects like these to represent either bright dense shocked fragments of the shell, recently formed stars still partially embedded, or OB stars already evolved.

Our spectroscopic observations made with the 6-m telescope SAO RAS showed that objects are OB giants and supergiants (luminosity classes I–III) (Lozinskaya *et al.*, 2002). Table I represents our results for three fields of the multishell complex. The chain shown by an arrow at the Figure 1 corresponds to the Field I at the Figure 2.

The ionized shell with the chain of stars appears to be the most dynamically active one in the complex, with velocities of its inner motions as high as $\simeq 100\,\mathrm{km/s}$. The optical spectra of the shell are typical for cooling gas behind a shock front. We therefore see here what might be a fine example of star formation triggered by a shell–shell collision. Better understanding requires the knowledge of detailed high-resolution kinematics of both ionized and neutral gas at the interface of the two shells.

3 THE SUPERCAVITY

The supercavity of about 1–1.5 kpc across appears to be surrounded by a neutral ring with the width of about 200–350 pc. The giant HI ring could be the projection of a torus because the size of the ring is larger than the scale-height of the disk of the galaxy leading to the break-out of the wind-blown supercavity.

This large-scale structure has apparently formed as a result of a burst of star formation in the region.

Several richest and largest OB-associations from the list by Hodge (1978) are located within the supercavity; Borissova and collaborators (see Rosado *et al.*, 2001) have outlined the new boundaries of the OB associations. There are no problems with the energy and ages of agents responsible for producing the supercavity and the surrounding HI supershell.

The neutral ring displays a remarkable system of arclike filaments with sizes of about 200–300 pc that might have been shaped by the collective stellar winds (and SNe?) of OB associations located inside the supercavity. This filamentary pattern is indicative of dynamically active processes and suggest a star formation triggered another way. The gravitational instability of a massive expanding shell may be triggered not only by a collision from outside but else by a push from inside (Chernin, Lozinskaya, 2002). Our observations of the velocity fields of the ISM around OB associations in the Milky Way Galaxy indicate that a rich association produces a massive slowly-expanding supershell and fast inner shells that expand rapidly and can impact the slow one (Lozinskaya, 1998; 1999). A slow massive shell may undergo multiple collisions with fast shells. Dynamical structures of this type provide very favorable conditions for triggering star formation. The process is regulated by a combined action of gravitational fragmentation in the slow shell and shock compression of the fragments by the fast shells. The way in which it develops depends on the ambient density: fragmentation of the slow shell occurs before (or after) its termination, before (or after) WR stars appear if the density is relatively high (low). In all cases the typical ambient density in the large area should be $n_o \geq 1$–$10\,\mathrm{cm}^{-3}$ to induce the fast inner shocks colliding a slow shell. Therefore the process seems to be essential for rich OB associations or stellar grouping located in a rather dense ISM.

It seems that we do already see fingerprints of star-formation within the HI ring triggered by collisions from inside. There is a star of a very rare class WO in the wall of the supercavity. We have shown that the WO star in IC 1613 is associated with a large nebula of unique structure: two lobes on both sides of the previously known bright elongated core (Lozinskaya, 1997; Afanasiev *et al.*, 2000; Lozinskaya *et al.*, 2001).

Only six WO stars have been identified in the Local Group galaxies so far (compared to about 600–700 WRs). WO stars occur within a very short final stage of the evolution of massive stars – that of a nearly naked CO core – immediately preceding the SN explosion. Progenitors of WO stars are very massive objects, $M_{init} \geq 40$–$50\,M_{\odot}$. Such a massive star cannot live for more than 10^7 yrs, which appears to be shorter than the lifetime of the HI ring.

Therefore the WO star in IC 1613, being among the most massive and short-lived stars, might present a case of star-formation triggered by collisions of the dense ring with fast inner shocks. There is a source of energy capable of initiating fast shocks to push the HI ring: the association No 9 from the list by Hodge (1978), which is adjacent to and inside the supercavity. This association is the largest one and the richest in the galaxy.

4 LARGE-SCALE AND LONG-TERM EVOLUTION

What fate awaits the violent star-forming complex? One can expect to find here in about 10^8 yrs a supercavity surrounded by a dense neutral shell, just like the one nearby. Therefore the two most conspicuous HI features in IC 1613: the giant complex of star formation and the supecavity surrounded by HI ring represent two stages of evolution of a giant molecular complex.

The properties of the only large region of ongoing violent star formation in IC 1613 seem to be similar to those of a superassociation according to the terminology introduced by Baade in 1963. A superassociation is a complex of stars that has a burst of simultaneous violent star formation over the whole area up to 1 kpc across and with a typical total mass as high as about $10^6\,M\odot$ (Efremov, 1994).

The region of violent star formation in IC 1613 has the size of about 1 kpc; it includes about 20 young stellar associations and open clusters (Hodge, 1978; Georgiev *et al.*, 1999); Goss and Lozinskaya (1995) give the mass of gas in the complex $M \simeq 1.5 \times 10^5\,M\odot$ from its IR luminosity.

Superassociations are very rare objects. Only three such objects have been identified in the Local Group galaxies so far: (30 Dor in LMC; NGC 206 in M31, and NGC604 in M33, see references in Efremov, 1994; Chernin *et al.*, 1995). Here we apparently see one more superassociation, the small one and a very young one.

A superassociation may be induced by shell–shell collisions as considered by Chernin *et al.* (1995). From our recent HI observations of the galaxy it appears that the star-forming complex in IC 1613 might have been produced by a very large-scale shell–shell collision in the region (Lozinskaya *et al.*, 2003). (However, not exactly as described in the theoretical model proposed.) The HI distribution in the whole galaxy shown at the Figure 3 demonstrates that the only region of star-formation is located at the interface between two giant HI rings: the one we are discussing here and the other north of it. An encounter of the two expanding HI supershells may well have produced this dense HI supercloud and triggered star formation in it.

Supershells are well known to sweep-up very large mass of gas, and merge, perhaps triggering collapse of HI and molecular complex.

And this supershell–supershell collision might probably trigger the formation of the complex of violent star formation, maybe even a superassociation.

Our study of large-scale kinematics of HI in the galaxy did not found an expansion of the superrings. No wonder, since both are at the late stage of supershells' evolution that is near termination with the expansion velocity about the isothermal sound speed.

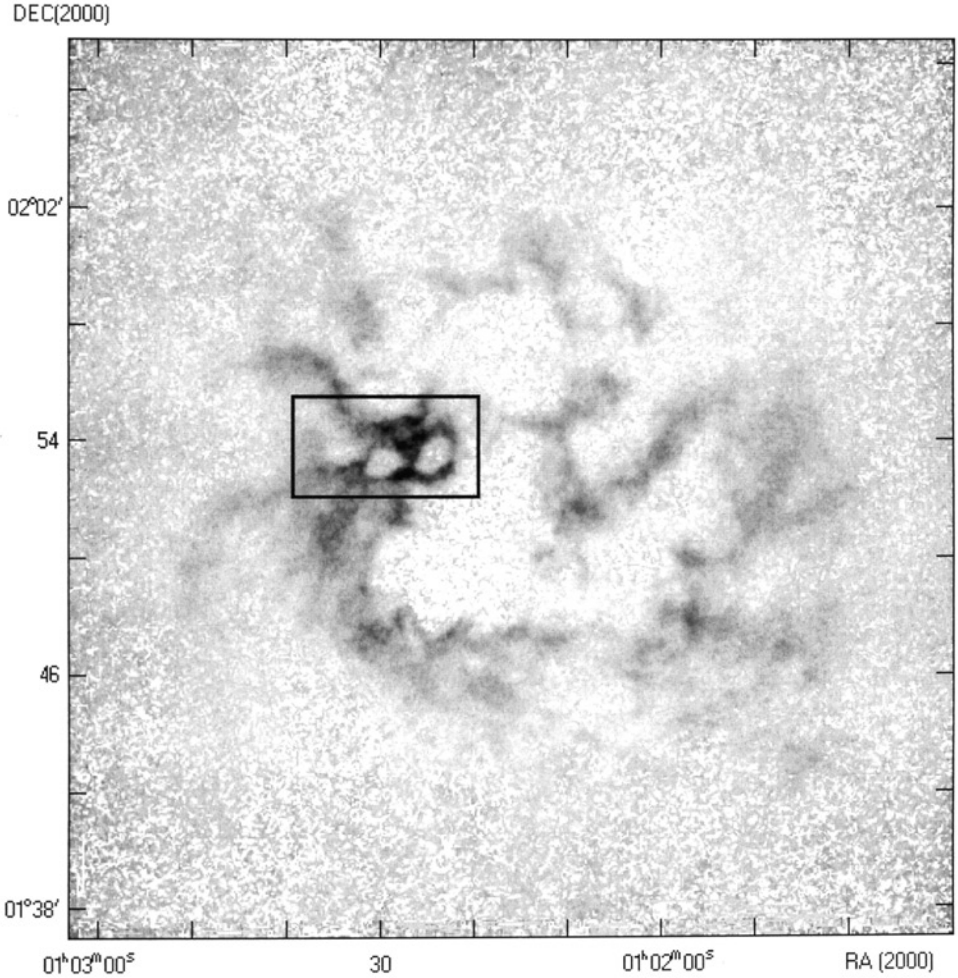

FIGURE 3 The total HI map of galaxy IC 1613; the brightest area corresponds to the star formation complex.

This work was supported by the Russian Foundation for Basic Research (project codes 98-02-16032, 01-02-16118) and the Astronomy State Science and Technology Program (project no. 1.3.1.2). The National Radio Astronomy Observatory is a facility of the National Science Foundation operated under cooperative agreement with Associated Universities, Inc.

References

Afanasiev, V. L., Lozinskaya, T. A., Moiseev, A. V. and Blanton, E. (2000). *Astronomy Letters*, **26**(3), 153 (Translated from *Pis'ma Astron. Zh.*, **26**(3), 190) (ASTRO-PH-0011385).

Baade, W. (1963). *Evolution of Stars and Galaxies.* Harvard University Press, Cambridge, Massachusetts.

Chernin, A. D., Efremov, Yu. N. and Voinovich, P. A. (1995). *Mon. Not. R. Astron. Soc.*, **275**, 313.

Chernin, A. D. and Lozinskaya, T. A. (2002). *Astron. Astroph. Transactions*, **21**, 231–243.

Efremov, Yu. N. (1994). In: Tenorio-Tagle, (Ed.), *Violent Star Formation: From 30 Doradus to QSSOs.* Cambridge Univ. Press, 61 p.

Ehlerova, S. and Palous, J. (2002). *Mon. Not. R. Astron. Soc.*, (ASTRO-PH-0111495), **330**, 1022.

Georgiev, L., Borissova, J., Rosado, M., Kurtev, R., Ivanov, G. and Koenigsberger, G. (1999). *Astron. Astrophys. Suppl.*, **134**, 21.

Goss, W. M. and Lozinskaya, T. A. (1995). *Astrophys. J.*, **439**, 637.

Hodge, P. W. (1978). *Astrophys. J. Suppl.*, **37**, 145.
Lake, G. and Skillman, E. D. (1989). *Astron. J.*, **98**, 1274.
Lozinskaya, T. A. (1977). *Astrophys. Space Sci.*, **252**(1/2), 199.
Lozinskaya, T. A. (1998). *Astronomy Letters*, **24**(2), 237 (Translated from *Pis'ma Astron. Zh.*, **24**(3–4), 285).
Lozinskaya, T. A. (1999). New perspectives on the interstellar medium. In: Taylor, A. R., Landecker, T. L. and Joncas, G. (Eds.), *ASP Conf. Proc.*, pp. 427–436.
Lozinskaya, T. A., Silchenko, O. K., Helfland, D. J. and Goss, M. W. (1998). *Astron. J.*, **116**, 2328.
Lozinskaya, T. A., Moiseev, E. V., Afanasiev, V. L., Wilcots, E. and Goss, W. M. (2001). *Astronomy Reports*, **45**(6), 417. (Translated from *Astron. Zh.*, **78**(6), 485.) (ASTRO-PH-0103312).
Lozinskaya, T. A., Arkhipova, V. P., Moiseev, A. V. and Afanasiev, V. L. (2002). *Astronomy Reports*, **46**(1) (Translated from *Astron. Zh.*, **79**(1)).
Lozinskaya, T. A., Moiseev, A. V. and Podorvanyuk, N. Yu. (2003). *Astronomy Letters* (in press).
Meaburn, J., Clayton, C. A. and Whitehead, M. J. (1988). *Mon. Not. R. Astron. Soc.*, **235**, 479.
Rosado, M., Valdes-Gutierrez, M., Georgiev, L., Arias, L., Borissova, J. and Kurtev, R. (2001). *Astron. J.*, **122**, 194.
Valdes-Guttieres, M., Rosado, M., Georgiev, L., Borissova, J. and Kurtev, R. (2001). *Astron. Astrophys.*, **366**, 35.