*RevMexAA (Serie de Conferencias)*, **15**, 284–286 (2003)



# THE IRREGULAR GALAXY IC 1613: DETAILED KINEMATICS OF H I AND H II SHELLS IN THE COMPLEX OF ONGOING STAR FORMATION

T. A. Lozinskaya,[1] A. V. Moiseev,[2] and N. Yu. Podorvanyuk[1]

RESUMEN

Utilizamos nuestras observaciones de la galaxia enana irregular IC 1613 tomadas en la línea de H$\alpha$ con el IFP en el telescopio de 6 m del Observatorio Astronómico Especial RAS y las observaciones a 21 cm del Conjunto Muy Grande (VLA) para obtener datos cinemáticos detallados de las cáscaras múltiples de H I y H II en la única región de formación estelar violenta conocida en esta galaxia. Demostramos que las cáscaras ionizadas más brillantes y sus poblaciones estelares están ubicadas en las bordes de cáscaras gaseosas neutras más grandes y antiguas en un patrón característico de formación estelar no coeval en el complejo.

ABSTRACT

We use our observations of the dwarf irregular galaxy IC 1613 made in the H$\alpha$ line with the IFP at the 6 m telescope of the Special Astronomical Observatory RAS and 21 cm line Very Large Array observations to obtain detailed kinematical data for multiple H I and H II shells in the only region of violent star formation known in the galaxy. The brightest ionized shells and their stellar populations are shown to be located at the edges of older and larger neutral gaseous shells in a pattern characteristic of non-coeval star formation in the complex.

*Key Words:* **GALAXIES: INDIVIDUAL (IC 1613) — GALAXIES: ISM — STARS: FORMATION — STARS: WINDS, OUTFLOWS**

Dwarf Irr galaxies provide the best laboratory to study large-scale complexes of ongoing violent star formation. Here we report our 21 cm line Very Large Array (VLA) of the NRAO[3] observations of the IC 1613 galaxy and Fabry-Perot spectroscopy in the H$\alpha$ line made at the 6 m telescope. We use these data to discuss long-term and large-scale effects of the stellar wind on the interstellar medium (ISM) and to trace the remnants of different episodes of star formation (Lozinskaya, Moiseev, & Podorvanyuk 2003).

Figure 1 shows our H I map of the galaxy superimposed on an H$\alpha$ image (brightest isophotes). The H I map has an angular resolution of $7''$(23 pc), the optical map has a resolution of about 6 pc. The scaled-up image represents the only complex of recent star formation known in the galaxy. We see here a set of ionized and neutral shells in physical contact. The complex accommodates the three brightest and most conspicuous H I shells in the galaxy. The stellar population of the galaxy includes about 20 young OB associations listed by Georgiev et al. (1999). The properties of this region of violent star formation appear to resemble those of a very small and young superassociation (Lozinskaya 2002).

[1]Sternberg Astronomical Institute, Moscow State Lomonosov University, Russia.

[2]Special Astrophysical Observatory, Russia.

[3]NRAO is a facility of the National Science Foundation operated under cooperative agreement by Associated Universities, Inc.

TABLE 1

H I AND H II SHELLS IN THE COMPLEX

| Shell | Size (pc) | $V_{\rm exp}$ (km s$^{-1}$) | $V_{\rm exp}{}^{\rm a}$ (km s$^{-1}$) | Age (Myr) |
|---|---|---|---|---|
| H II shells | | | | |
| R1 | 188×138 | 60 to 75 | 29 | 0.7 |
| R2 | 145×88 | 50 to 60 | 49 | 0.6 |
| R3 | 258×209 | ··· | 30 | 1.9[a] |
| R4 | 234×138 | 40 to 45 | 32 | 2.2 |
| R5 | 113×113 | 30 to 50 | 38 | 0.8 |
| R6 | 226×184 | $\leq 20$ | 25 | 2.0[a] |
| R8 | 217×154 | $\simeq 65$ | 26 | 1.7 |
| H I shells | | | | |
| I | 350 | ··· | ··· | ··· |
| II | 270 | 12 to 17 | ··· | 5.6 |
| III | 300 | 16 to 18 | ··· | 5.3 |

[a]From Valdez-Gutierrez et al. (2001)

The kinematics of ionized gas in the complex was studied by Meaburn, Clayton, & Whitehead (1988) and Valdez-Gutiérrez et al. (2001), whereas that of neutral gas in the region has never been investigated.

We are the first to obtain high-resolution kinematical data for the neutral gas in this star-formation complex. We also report about 30 position/velocity diagrams for the ionized gas covering the entire star-forming region. Several such diagrams

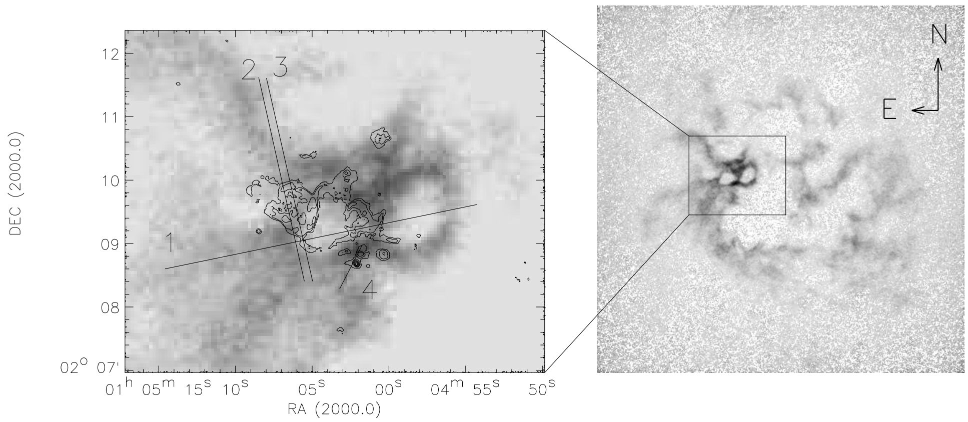


Fig. 1. The H I map of the galaxy superimposed on an H$\alpha$ image (brightest isophotes). The scaled up image shows the complex of recent star formation; lines indicate the locations of the position-velocity diagrams, see Fig. 2.

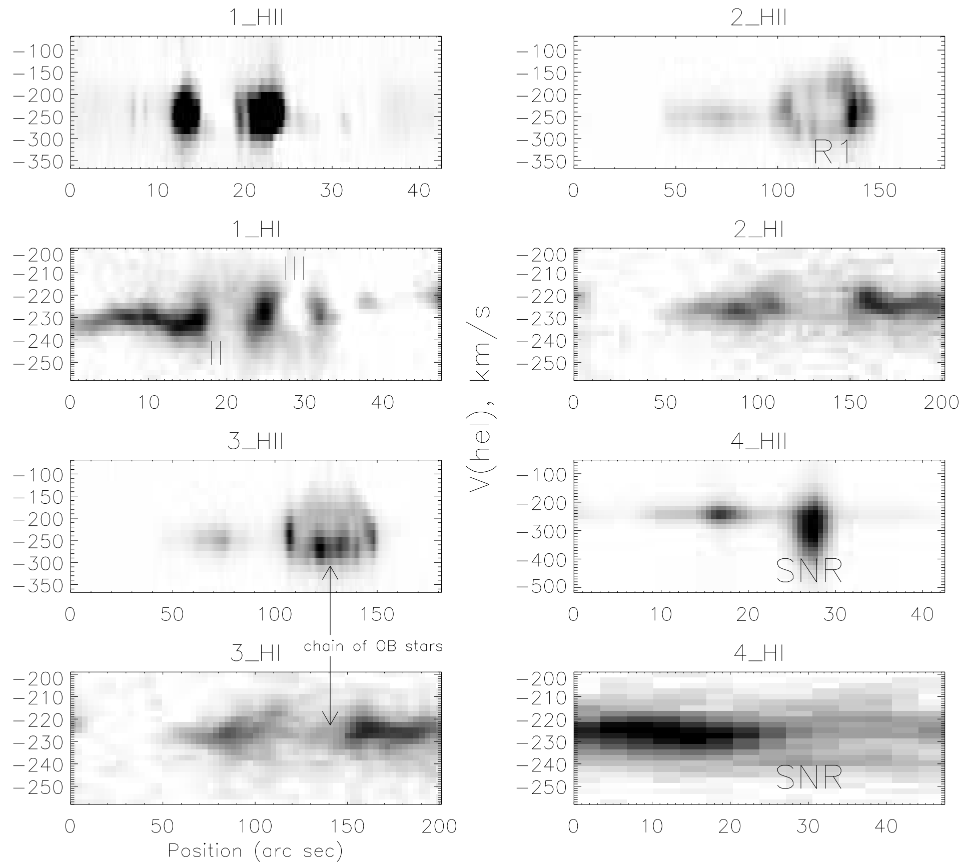


Fig. 2. Position-velocity diagrams for ionized and neutral gas. The locations of the scans are shown in Fig. 1.

are shown in Figure 2 as examples, which clearly demonstrate the characteristic shapes of expanding H I and H II shells. The locations of the scans are shown in Fig. 1.

Table 1 lists the expansion velocities and kinematical ages for the H II and H I shells as inferred from the velocity ellipses on our position/velocity diagrams. We use the identifications of the H II shells given in the list in Valdez-Gutiérrez et al. (2001). The fourth column gives the expansion velocities for the H II shells that the above authors inferred from velocity differences of the integrated-line components.

The H II shells in the complex have kinematical ages ($t = 0.6 \times R/V$) of 0.6 to 2.2 million years, while those of the H I shells have ages of 5.5 million years. The OB associations related to the H II shells have ages 5 to 20 million years (Georgiev et al. 1999). We showed the brightest ionized shells in the complex to be physically related to the larger and older H I shells. Moreover, there is observational evidence for non-coeval star formation in the complex. All but one of the bright and young H II shells are located at the dense edges of the neutral shells and so are young OB associations (see Fig. 1b in Lozinskaya et al. 2003). The only exception is the oldest shell R4 (2.2 million years). Its shape fits well into that of the surrounding H I shell and young OB associations are located at the edges of this ionized + neutral gaseous structure.

We have identified an expanding H I feature around the only SNR known in IC 1613 predicted by Lozinskaya et al. (1998) to explain the unusual coexistence in the SNR of very bright X-ray emission from hot plasma and very bright optical emission from a slow shock.

The chain of young OB stars (luminosity classes I, II, and III) identified by Lozinskaya et al. (2002) is located at the curved interface between the ionized shell R1 and neutral shells where two H I shells may have been colliding. This appears to be the most dynamically active region in the entire complex. Our position/velocity diagrams (Fig. 2) are indicative of high-velocity inner motions of ionized ($V$(hel) = $-130$ to $-340\,\mathrm{km\,s^{-1}}$) and neutral ($V$(hel) = $-210$ to $-250\,\mathrm{km\,s^{-1}}$) gas. Optical spectra of the ionized shell betoken cooling of gas behind a shock front. We possibly have here a fine example of triggered star formation in colliding shells.

Fig. 1 clearly shows a huge supercavity surrounded by a dense H I superring southwest of the star-forming complex. This large-scale structure may be a remnant of a previous burst of star formation in this galaxy. There are several OB associations within the supercavity that are responsible for its formation (Hodge 1978; Borissova et al. 2003). The neutral superring displays a remarkable system of arc-like filaments, which might have been shaped by the stellar winds (and SNe?) of inner OB associations, which provide favorable conditions for the next episode of star formation (Chernin & Lozinskaya 2002). The WO star located in the wall of the superring (Lozinskaya et al. 2001; Rosado et al. 2001), which is one of the most massive and short-lived stars in the galaxy, may represent a case of triggered star formation in the dense H I ring.

One can find in Fig. 1 many other huge arc-like H I structures affected by stellar feedback, which appear to be tracers of previous star-formation episodes in the galaxy. We can speculate that the complex of recent violent star formation formed via an encounter of two expanding H I supershells.

This presentation was supported by the Russian Foundation for Basic Research (projects nos. 98-02-16032, 01-02-16118), Federal Science and Technology Program (contract no. 40.022.1.1.1103), and CONACyT (Mexico, project 36132-E).

## REFERENCES

Borissova, J., Kurtev, R., Georgiev, L., Rosado, M., & Ivanov, G. 2003, A&A, in press

Chernin, A. D., & Lozinskaya, T. A. 2002, AApTr, 21, 231

Georgiev, L., Borissova, J., Rosado, M., Kurtev, R., Ivanov, G., & Koenigsberger, G. 1999, A&AS, 134, 21

Hodge, P. W. 1978, ApJS, 37, 145

Lozinskaya, T. A. 2002, AApTr, 21, 223

Lozinskaya, T. A., Arkhipova, V. P., Moiseev, A. V., & Afanasiev, V. L. 2002, ARep, 46, 16 (astro-ph/0112377)

Lozinskaya, T. A., Moiseev, A. V., Afanasiev, V. L., Wilcots, E., & Goss W. M. 2001, ARep, 45, 417 (astro-ph/0103312)

Lozinskaya, T. A., Moiseev, A. V., & Podorvanyuk, N. Yu. 2003, Astronomy Letters, 29, 77

Lozinskaya, T. A., Silchenko, O. K., Helfand, D. J., & Goss, M. W. 1998, AJ, 116, 2328

Meaburn, J., Clayton, C. A., & Whitehead, M. J. 1988, MNRAS, 235, 479

Rosado, M., Valdez-Gutiérrez, M., Georgiev, L., Arias, L., Borissova, J., & Kurtev R. 2001, A&A, 122, 194

Valdez-Gutiérrez, M., Rosado, M., Georgiev, L., Borissova, J., & Kurtev, R. 2001, A&A, 366, 35

T. A. Lozinskaya: Sternberg Astronomical Institute, Moscow State Lomonosov University, Universitetski pr.13, Moscow V234, 119899, Russia (lozinsk@sai.msu.ru).

A. V. Moiseev: Special Astrophysical Observatory, Nizhnii Arkhyz, Karachaevo-Cherkessia, 369167, Russia (moisav@sao.ru).

N. Yu. Podorvanyuk: Sternberg Astronomical Institute, Moscow State Lomonosov University, Universitetski pr.13, Moscow V234, 119899, Russia (nicola@sai.msu.ru).