OPTICAL OBSERVATIONS OF M81 GALAXY GROUP IN NARROW BAND [SII] AND Hα FILTERS: HOLMBERG IX

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SUMMARY: We present observations of the nearby tidal dwarf galaxy Holmberg IX in M81 galaxy group in narrow band [SII] and Hα filters, carried out in March and November 2008 with the 2m RCC telescope at NAO Rozhen, Bulgaria. Our search for resident supernova remnants (as identified as sources with enhanced [SII] emission relative to their Hα emission) in this galaxy has yielded no sources of this class, besides M&H 10-11 or HoIX X-1. Nevertheless we found a number of objects with significant Hα emission that probably represent uncatalogued HII regions.

Key words. ISM: supernova remnants – HII regions – Methods: observational – Techniques: photometric – Galaxies: ISM – Galaxies: individual: Holmberg IX

1. INTRODUCTION

M81 galaxy group is the nearest interacting group of galaxies whose main members are M81, M82 and NGC 3077. Yun et al. (1994) found prominent HI structures surrounding these galaxies with large HI complexes and tidal bridges, that are probably a result of the galaxy encounters. It is possible that starburst activity i.e. enhanced star formation of M82 was triggered in a close encounter with M81, which as a consequence have a high supernova rate (see e.g. Arbutina et al. 2007, Huang et al. 1994). The third member in the group, NGC 3077 also shows evidence of enhanced star formation, and consequently a higher supernova rate and presence of SNRs. This was partially confirmed by recent radio observations (see Rosa-Gonzales 2005). There is also a number of optical candidates for supernova remnants (SNRs) detected in M81 (Matonick & Fesen 1997). The SNR candidates in optical are usually identified through enhanced [SII] line emission ([SII]/Hα > 0.4; see e.g. Matonick & Fesen 1997, Blair & Long 2004). The aim of our optical observations was to try to detect new SNR candidates and HII regions in a small "satellite galaxy" of M81 – Holmberg IX (UGC 5336, MCG+12-10-012, LEDA 28757, see Table 1). Holmberg IX and Arp’s loop can be seen as two dark knots in the HI image of the M81 triplet of Yun et al. (1994). Dwarf irregular galaxy Holmberg IX could be the youngest nearby tidal dwarf galaxy, perhaps formed during the last close passage of M82 around M81 (Sabbi et al. 2008).
Fig. 1. The [SII] with continuum image (sky subtracted).

### Table 1. Data for Holmberg IX (MCG+12-10-012) taken from SIMBAD†.

| Right ascension | Declination | Redshift | Velocity | Distance† | Angular size | Magnitude | Morphological type |
|-----------------|-------------|----------|----------|-----------|--------------|-----------|-------------------|
| α J2000         | δ J2000     | z        | v [km s\(^{-1}\)] | d [Mpc] | [']          |           |                   |
| 09 57 32.1      | +69 02 46   | 0.000213 | 64       | 3.7       | 2.6 × 2.2    | 16.5 (B)  | dI                |

†http://simbad.u-strasbg.fr/simbad/ †Karachentsev & Kashibadze (2006)

The adopted distance to Holmberg IX is \(d = 3.7\) Mpc, which is the distance derived from cepheids distance to M81 and known membership in the M81 group (Karachentsev et al. 2004, Karachentsev & Kashibadze 2006). The location of Holmberg IX, its high gas content, and its youthful stellar population, made from this galaxy the primary target of our search.

### Table 2. Characteristics of the narrow band filters.

| Filter | \(\lambda_o\) [Å] | FWHM [Å] | \(\tau_{max}\) [%] |
|--------|------------------|----------|-------------------|
| [SII]  | 6719             | 33       | 83.3              |
| H\(\alpha\) | 6572         | 32       | 86.7              |
| Red cont. | 6416          | 26       | 58.0              |
Fig. 2. The $H\alpha$ with continuum image (sky subtracted).

Table 3. The observations log.

| Object/SS      | Integration time [s] |  |  |  |
|----------------|----------------------|---|---|---|
|                | 2008 March 3         | 2008 November 30 |
|                | Cont. $H\alpha$ [SII] | Cont. $H\alpha$ [SII] | Cont. $H\alpha$ [SII] | Cont. $H\alpha$ [SII] |
| Holmberg IX    | 180 1200 1200        | 1800 1200 1200        | 1800 1200 1200        | 1800 1200 1200        |
|                | 1800 1800 1800        | 1800 1200 1200        | 1800 1200 1200        | 1800 1200 1200        |
|                | 2400 1800 1800        | 1800 1200 1200        | 1800 1200 1200        | 1800 1200 1200        |
| Feige 34       | 180 120 120           | – – –                 | – – –                 | – – –                 |
|                | 240 120 120           | – – –                 | – – –                 | – – –                 |
|                | 180 120 120           | – – –                 | – – –                 | – – –                 |
| G191-B2B       | – – –                 | 300 120 120           | 300 120 120           | 300 120 120           |
|                | – – –                 | 300 120 120           | 300 120 120           | 300 120 120           |
2. OBSERVATIONS AND DATA REDUCTION

The observation were carried out in March and November 2008 with the 2 m Ritchey-Chrétien-Coudé (RCC) telescope at the National Astronomical Observatory (NAO) Rozhen, Bulgaria (ϕ = 41°41′35″, λ = 24°44′30″, h = 1759 m). In the RC focus of the telescope, the equivalent focal length is 16 m and the field-of-view is one square degree with a scale 12″/mm. The telescope is equipped with VersArray: 1300B CCD camera with 1340×1300 px array, with plate scale of 0.′′257732/px (pixel size is 20 µm), giving field of view 5′45″ × 5′35″.

We used the narrow-band filters for [SII], Hα and red continuum. We took sets of three images through each filter, each night, with exposure time ranging from 1200–2400 s. Typical seeing was 1″-3″. Standard stars images (Feige 34 and G191-B2B), bias frames and sky flat-fields were also taken. Filters characteristics and details of the observations are given in Tables 2 and 3. The Hα image (λ6563) is contaminated with some [NII] emission (λ6583), so in principle the "Hα" is actually Hα+[NII] image. The [SII] filter should collect most of the emission from both [SII] λ6716 and λ6731 lines.

Data reduction was performed by using IRIS\(^1\) (an astronomical images processing software developed by Christian Buil). The data were bias subtracted and flat-fielded using the standard methods. Three images in each set are combined using procedures NGAIN3 and COMPOSIT, and then sky-subtracted (SUBSKY). Commands MAX, MIN, EDGE were used for cosmetic corrections (bad pixels, cosmic rays removal). Since the images were taken with different exposures, depending on the filters, we scaled all the images normalizing them to the flux of the stars in the field. Images taken on two nights are then combined to increase the counts, rotated, aligned and distortion corrected by using the procedure COREGISTER. Images obtained after all these corrections, are given in Figs. 1–3.

\(^1\)Available from http://www.astrosurf.com/buil/
The Hα and [SII] images are then continuum-subtracted and final images once again background subtracted to obtain background as flat as possible. The continuum-subtracted Hα image is given in Fig. 4.

Sources in the continuum-subtracted Hα image are extracted by smoothing the image and then drawing 1σ contours from the median value. Relative fluxes (total counts) are then calculated using IRIS photometric tools. Finally, an astrometric reduction of the Hα image was performed by using U.S. Naval Observatory’s USNO-A2.0 astrometric catalogue (Monet et al. 1998).

3. ANALYSIS AND RESULTS

The continuum-subtracted [SII] image did not show any new object with an enhanced [SII] emission, besides M&H 10-11 or HoIX X-1 (Miller & Hodge 1994, Miller 1995, Grisé et al. 2006), a strong optical line source and ultraluminous X-ray source (a possible hypernova remnant or super-shell), and thereby is omitted. As for the continuum-subtracted Hα image, we detected 21 sources – probable HII regions (see Fig. 4; additional dark features are stars not subtracted well).
Fig. 5. Flux – Count \((F − N)\) relation used for absolute calibration. Slope of the relation is calibration coefficient: \(c = (4.97 \pm 0.05) \times 10^{-5}\).

Eleven sources (1–11) were previously identified by Miller & Hodge (1994) and one by Boone et al. (2005) (source 12). Thus, we found nine new sources (13–21).

Table 4. Sources used for absolute calibration.

| Source  | Count \(\times 10^{-15}\) erg cm\(^{-2}\) s\(^{-1}\) |
|---------|-----------------------------------------------|
| M&H 1   | 20721                                         |
| M&H 2   | 12884                                         |
| M&H 3   | 38559                                         |
| M&H 4   | 17229                                         |
| M&H 5   | 83939                                         |
| M&H 6   | 12807                                         |
| M&H 7   | 36059                                         |
| M&H 8   | 57565                                         |
| M&H 9–10| 1282274                                       |
| M&H 11  | 153357                                        |

Table 5. HII regions in Holmberg IX.

| Source  | Right ascension | Declination | \(F_{\text{H}\alpha}\) \(\times 10^{-15}\) erg cm\(^{-2}\) s\(^{-1}\) |
|---------|-----------------|-------------|------------------------------------------------------|
| Aea 1   | 09 57 26.1      | +69 03 09   | 1.03                                                 |
| Aea 2   | 09 57 26.2      | +69 02 47   | 0.64                                                 |
| Aea 3   | 09 57 29.4      | +69 03 24   | 1.92                                                 |
| Aea 4   | 09 57 31.1      | +69 03 24   | 0.86                                                 |
| Aea 5   | 09 57 35.6      | +69 04 01   | 4.17                                                 |
| Aea 6A  | 09 57 49.5      | +69 04 21   | 0.38                                                 |
| Aea 6B  | 09 57 49.8      | +69 04 16   | 0.26                                                 |
| Aea 7A  | 09 57 49.9      | +69 04 55   | 1.03                                                 |
| Aea 7B  | 09 57 49.5      | +69 04 54   | 0.76                                                 |
| Aea 8   | 09 57 50.5      | +69 02 22   | 2.86                                                 |
| Aea 9–10a| 09 57 53.1      | +69 03 49   | 63.71                                                |
| Aea 11  | 09 57 55.2      | +69 03 40   | 7.62                                                 |
| Aea 12  | 09 57 58.5      | +69 03 19   | 0.24                                                 |
| Aea 13  | 09 58 04.7      | +69 01 41   | 0.56                                                 |
| Aea 14  | 09 58 04.4      | +69 01 37   | 0.36                                                 |
| Aea 15  | 09 57 09.0      | +69 04 08   | 0.33                                                 |
| Aea 16  | 09 57 41.0      | +69 05 50   | 0.70                                                 |
| Aea 17  | 09 57 27.4      | +69 03 13   | 0.43                                                 |
| Aea 18  | 09 57 24.6      | +69 02 57   | 0.55                                                 |
| Aea 19  | 09 54 24.6      | +69 02 47   | 1.13                                                 |
| Aea 20  | 09 57 45.0      | +69 02 07   | 0.13                                                 |
| Aea 21  | 09 57 11.8      | +69 01 18   | 0.29                                                 |

\(a\) Possible hypernova remnant or super-shell.

\(^2\)See Aladin Sky Atlas: http://aladin.u-strasbg.fr/.
Additionally, we resolved sources M&H 6 and M&H 7, which we see as two pairs. There are, possibly, two more smaller sources, marked with an asterisk (*) in Fig. 4, at $\alpha_{2000} = 09^h57^m30^s.3$, $\delta_{2000} = +69^\circ 02^\prime 52^\prime\prime$ and $\alpha_{2000} = 09^h58^m04^s.0$, $\delta_{2000} = +69^\circ 03^\prime 16^\prime\prime$, for which we haven’t measured fluxes. Question mark (?) in Fig. 4 marks the position of a source of unknown origin ($\alpha_{2000} = 09^h57^m30^s.9$, $\delta_{2000} = +69^\circ 01^\prime 12^\prime\prime$) which we saw in March 2008 H$\alpha$ images, but not in November 2008.

The absolute flux calibration of the continuum subtracted H$\alpha$ image was performed by using the fluxes of sources identified both by us and Miller & Hodge (1994) (See Fig. 5 and Table 4). The listed fluxes for sources M&H 6 and M&H 7 correspond to the sum of the fluxes for the two sub-regions (A and B). We adopted simple linear relation

$$F = c \cdot N,$$

where $N$ is source’s total count, $F$ the flux in units $10^{-15}$ erg cm$^{-2}$ s$^{-1}$, and $c = (4.97 \pm 0.05) \times 10^{-5}$ is calibration coefficient obtained from the fit.

We define the fractional error

$$f = \frac{F_{\text{MKH}} - F}{F_{\text{MKH}}}$$

where $F_{\text{MKH}}$ is the H$\alpha$ flux from Miller & Hodge (1994), whereas $F$ is our measurement, in order to get an estimate of the accuracy of the obtained values. We find $f_{\text{max}} = 0.50$ i.e., $f = 0.16$.

Estimated fluxes for all sources (HII regions) and approximate positions of source centers are given in Table 5.

4. CONCLUSIONS

We presented observations of Holmberg IX galaxy in narrow band [SII] and H$\alpha$ filters. Our search for objects with an enhanced [SII] emission – possible supernova remnant candidates, has yielded no sources of this class, besides M$\&$H 10-11 or HoIX X-1. Nevertheless we identified 21 objects with significant H$\alpha$ emission. Eleven sources (1-11) were previously identified by Miller & Hodge (1994) and one by Boone et al. (2005) (source 12). Thus, we found nine new sources (13-21) – uncatalogued HII regions. We estimated their H$\alpha$ fluxes and gave their approximate positions.

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REFERENCES

Arbutina, B., Urošević, D. and Vukotić, B.: 2007, IAU Symp., 237, 391.
Blair, W.P. and Long, K.S.: 2004, Astrophys. J. Suppl. Series, 155, 101.
Boone, F., Brouillet, N., Huttemeister, S., Henkel, C., Braine, J., Bomans, D.J., Herpin, F., Ban- hidi, Z. and Allrecht, M.: 2005, Astron. Astrophys., 429, 129.
Grisé, F., Pakull, M. W. and Motch, C.: 2006, IAU Symp., 230, 302.
Huang, Z. P., Thuan, T. X., Chevalier, R. A., Cond- don, J. J. and Yin, Q. F.: 1994, Astrophys. J., 424, 114.
Karachentsev, I. D., Karachentseva, V. E., Huch- meier, W. K., Makarov, D. I.: 2004, Astron. J., 127, 2031.
Karachentsev, I. D. and Kashibadze, O. G.: 2006, Astrophysics, 49, 3.
Matonick, D. M. and Fesen, R. A.: 1997, Astrophysics J. Suppl. Series, 112, 49.
Miller, B.W.: 1995, Astrophys. J., 446, L75.
Miller, B.W. and Hodge, P.: 1994, Astrophys. J., 427, 656.
Monet, D. et al.: 1998, USNO-A2.0 - A catalog of astrometric standards, U.S. Naval Observatory (http://tdc-www.harvard.edu/catalogs/ua2.html).
Sabbà, E., Gallagher, J.S., Smith, J.L., de Mello, D.F. and Mountain, M.: 2008, Astrophys. J., 676, L113.
Rosa-Gonzales, D.: 2005, Mon. Not. R. Astron. Soc., 364, 1304.
Yun, M.S., Ho, P.T.P. and Lo, K.Y.: 1994, Nature, 372, 530.
ОПТИЧКА ПОСМАТРАЊА ГРУПЕ ГАЛАКСИЈА М81 У УСКИМ ФИЛТЕРIMA [SII] И Нα: ХОЛМБЕРГ IX

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Претходно саопштава

У раду су представљена посматрања оближње пагуласти галаксије Холмберг IX у групи галаксија везаних за M81. Посматрања су извршена у марту и септембру 2008. године двометарским RCC телескопом на НАО Рожен, Бугарска, коришћењем уских филтера [SII] и Нα. Потрага за објектима са појачаном емисијом [SII] у односу на Нα емисију – потенцијалним кандидатима за остатке супернових, није резултирала новим објектима, поред МKII 10-11 или HolIX X-1, али је зато детектован један број објеката са значајном Нα емисијом који вероватно представљају до сада непознате III регионе.