3D structure of H\textsc{ii} region Sh2-235 from tunable filter optical observations

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ABSTRACT
We present observations of the H\textalpha, H\beta, [S\textsc{ii}] \textlambda6716,6731 and [N\textsc{ii}] \textlambda6583 emission lines in the galactic H\textsc{ii} region Sh2-235 with the Mapper of Narrow Galaxy Lines (MaNGaL), a tunable filter at the 1-m telescope of Special Astrophysical Observatory of the Russian Academy of Sciences. We show that the H\textsc{ii} region is obscured by neutral material with $A_V \approx 2-4$ mag. The area with the highest $A_V$ is situated to the south-west from the ionizing star and coincides with a maximum detected electron density of $\gtrsim 150$ cm$^{-3}$. The combination of these results with archive AKARI far-infrared data allows us to estimate the contribution of the front and rear walls to the total column density of neutral material in S235, and explain the three-dimensional structure of the region. The H\textsc{ii} region consist of a denser, more compact portion deeply embedded in the neutral medium and the less dense and obscured gas. The front and rear walls of the H\textsc{ii} region are inhomogeneous, with the material in the rear wall having a higher column density. We find a two-sided photodissociation region in the dense clump S235 East 1, illuminated by a UV field with $G_0 = 50 - 70$ and 200 in the western and eastern parts, respectively.

Key words: ISM: HII regions — ISM: dust, extinction — ISM: photodissociation region (PDR) — stars: massive — techniques: imaging spectroscopy

1 INTRODUCTION

The H\textsc{ii} region Sh2-235 (S235 hereafter, Sharpless 1959) is the brightest H\textsc{ii} region among four close emission nebulae (the others being Sh2-231, Sh2-232 and Sh2-233) located in the giant molecular cloud G174+2.5 (Ladeyschikov et al. 2016) in the direction of the Aur OB1 association (Straizys et al. 2010) in the Perseus Spiral Arm. S235 and its surroundings are a region of active star formation (see e.g. recent studies by Chavarria et al. 2014; Bieging et al. 2016).

It contains at least five young stellar clusters projected on the border of the H\textsc{ii} region, as was initially shown by Kirsanova et al. (2008), and later studied by Camargo et al. (2011); Dewangan & Anandarao (2011); Kirsanova et al. (2014). The surroundings of S235, namely the photodissociation region (PDR), molecular envelope, and young stellar objects embedded in the envelope, has been extensively observed at infrared (Allen et al. 2005; Klein et al. 2005; Anderson et al. 2019) and radio wavelengths (Israel & Felli 1978; Silverglate & Terzian 1978; Evans & Blair 1981; Lafon et al. 1983; Heyer et al. 1996; Kirsanova et al. 2014; Bieging et al. 2016; Ladeyschikov et al. 2016; Burns et al. 2019), although the H\textsc{ii} region itself has not been extensively studied.

Using radio recombination line (RRL) emission, Quireza et al. (2006a,b) determined that S235 (their source G173.60+2.80) has a nearly circular shape with an angular diameter of about 5′, an electron density of $n_e=81.6$ cm$^{-3}$ and an electron temperature of $T_e = 8940 \pm 170$ K. Anderson et al. (2019), using a combination of carbon and hydrogen RRLs, [C\textsc{ii}] emission at 158 \textmu m and CO emission determined that the H\textsc{ii} region lies on the near side of the associated molecular cloud and is expanding in the direction of the observer. The distance to the central star of S235, BD+35°1201, is $1.65 \pm 0.1$ kpc, based on the Gaia DR2 parallax measurements (Gaia Collaboration et al. 2016, 2018) and the distance calibration of Baier-Jones et al. (2018). The H\textsc{ii} region is excited by a late O- (Georgelin et al. 1973) or early B-type (Hunter & Massey 1990) star. Lafon et al. (1983) inspected an H\alpha image of the nebula, and found that it consists of a bright northern, and more dif-
fuse southern parts. They also reported a north–south radial velocity gradient of the ionized gas, although this was not confirmed by recent observations of RRLs by Anderson et al. (2019). Straižys et al. (2010) determined the interstellar extinction towards the ionizing star to be $A_V = 3.7$ mag. Esteban & García-Rojas (2018) measured the physical parameters of the nebula with optical slit spectroscopy, and found $n_e = 120$ cm$^{-3}$ from the $[\text{S} \text{ii}] \lambda 6716, 6731$ lines and $T_e$ in the range from 7100 to 11900 K, depending on the line ratio used ($[\text{N} \text{ii}], [\text{S} \text{ii}], [\text{O} \text{ii}]$ or $[\text{O} \text{ii}]$ lines). These optical observations were confined to a single slit position with a length of 30″, and therefore do not give a full overview of the properties of the ionized gas in this extended H II region.

The aim of the present work is to study the properties and spatial distribution of the ionized gas in S235 using narrow-band images in optical forbidden and Balmer emission lines, obtained with a new tunable filter photometer at the 1-m Zeiss-1000 telescope of the Special Astrophysical Observatory of the Russian Academy of Sciences (SAO RAS), supplemented by additional imaging and spectroscopic data from space- and ground-based telescopes ($\text{AKARI}$ infrared imaging satellite, SAO RAS 6-m telescope, and previously published CO maps).

2 OBSERVATIONS AND DATA REDUCTION

2.1 MaNGaL imaging

We performed observations using the Zeiss-1000 telescope of SAO RAS with the Mapper of Narrow Galaxy Lines (MaNGaL). MaNGaL is a new tunable filter photometer developed at SAO RAS, based on a piezoelectric scanning Fabry-Perot interferometer (FPI) with low interference order ($n \approx 7$) at SAO RAS, based on a piezoelectric scanning Fabry-Perot interferometer (FPI) with low interference order ($n \approx 20$ in the Hz line). The device is described by Moiseev & Perepelitsyn (2019) and at the SAO RAS web-page\(^1\). First results using the instrument were presented by Keel et al. (2019). The width of the instrumental profile in the spectral range used was $FWHM = 14 \pm 1$ Å, and the central wavelength (CWL) of the peak of FPI transmission was precisely tuned to the desired wavelength (better than 0.5 Å) at the centre of the field of view. For the observations in January 2018 we used an Andor iKON-M 934 CCD Camera, which provides a field of view of 8.7′ and a plate scale 0.51″/px.

Unlike the ‘classical’ optical layout having a tunable filter in the collimated beam (e.g. Jones et al. 2002), MaNGaL is an afocal reducer with the FPI in the convergent beam (Courtes 1960). This arrangement provides a significantly larger field for the central monochromatic region (‘Jacquinit spot’), which is crucial for studying extended targets. In our case, CWL varies with a range smaller than the filter $\pm 0.5FWMH$ across the whole field of view. As a result, variations of the FPI transmission of the nebular emission lines in S235 should be negligible, because their line-of-sight velocity variations are smaller than 100 km s$^{-1}$ (Sec. 2.2). Nevertheless, we applied a correction for the effects of CWL variations (see below).

We show the observation log of the MaNGaL observations in Table 1, where the seeing is given for the resulting combination of all frames. The most deep and detailed data in the Hz and $[\text{S} \text{ii}]$ lines were obtained in January, 2018, in the ‘single images FPI mode’, where the CWL is tuned first to the emission line (taking into account the systemic velocity of the target and heliocentric correction), and then to the neighbouring continuum (shifted by 30–50 Å). This cycle was repeated, which averages the contribution of atmospheric seeing and variations in atmospheric transparency. The FPI transmission peaks from neighbouring interference orders were fully blocked using medium-width filters with a bandwidth of $\approx 250$ Å. Different blocking filters were used for Hz and $[\text{S} \text{ii}]$ spectral ranges. In the case of the $[\text{S} \text{ii}]$ doublet, the continuum was observed both redward and blueward of the emission lines; for Hz, the continuum was observed only on the blue side.

In order to understand how these single images were affected by the mismatch between the FPI peak CWL and the emission line centre, immediately after taking deep images we performed observations in the ‘scanning FPI mode’; i.e. we quickly scanned the wavelength regions around the Hz+$[\text{N} \text{ii}]$ and $[\text{S} \text{ii}]$ emission lines: 12 subsequent frames with CWL increments of 7.5 Å were obtained for each spectral interval with relatively short (60 s) exposures, to minimize the effects of atmospheric variations. The CCD was operated with $4 \times 4$ binning in order to obtain a signal-to-noise (S/N) ratio comparable to that of the single images.

In September 2018, we used an Andor Neo 5.5 sCMOS camera, because the primary CCD detector was under repair. With $2 \times 2$ binning the Neo sCMOS provides the same sampling (0.5″/px) and field of view, but with lower quantum efficiency and significantly higher noise compared to the iKON CCD. For these observations MaNGaL was operated in the ‘direct images mode’ like a standard photometer, without the FPI. Images were exposed in medium-band filters with $FWHM \approx 100$ Å centred on the Hβ emission line (filter CWL =4880 Å) and continuum near (CWL =5150 Å).

The data reduction was performed using a custom software package running in the IDL environment\(^2\), which includes bias (for CCD) and dark current (for sCMOS) subtraction, flat-field correction, and cosmic ray removal by combining individual short exposures at the same wavelength. Continuum emission was removed from the images in the lines, by normalising the continuum to minimise the flux residuals in the background and foreground stars. The quality of the continuum subtraction in the single images obtained with the FPI mode was significantly better than in those obtained in the ‘classical’ filter direct images in Hβ, due to the fact that the continuum was observed at very close wavelengths and with a much narrower filter width.

In order to calibrate the images to the absolute intensity scale, each night we observed spectrophotometric standard stars in the corresponding observing mode immediately before or after S235, and at a similar airmass. The astrometric calibration was performed using the astrometry.net web interface\(^3\) (Lang et al. 2010).

For the wavelength calibration and analysis of the images obtained in the scanning mode, we modified the IDL-

\(^1\) https://www.sao.ru/Doc-en/Events/2017/Moiseev/moiseev_eng.html

\(^2\) https://www.harrisgeospatial.com/Software-Technology/IDL

\(^3\) http://nova.astrometry.net/
based software for scanning FPI data reduction of Moiseev & Egorov (2008). The images were merged into data cubes containing a 12-channel spectrum at each pixel. These low-resolution spectra were fitted at each position in the field by a combination of Gaussians, corresponding to the Hα, [N ii]λ6548,6583 and [S ii]λ6717,6731 emission lines. The wavelength difference between lines, \(FWHM\) and [N ii] doublet ratio (1:3) were fixed, while the radial velocity and line amplitudes were left as free parameters. After this procedure we have two types of 4×4 binning maps in the Hα and [S ii] lines: (1) the fitting results (\(F_\text{fit}\)), free from CWL-emission peak mismatch; (2) the data cube channels (\(F_\text{image}\)) observed with the same parameters of the FPI as the corresponding ‘single images’. The ratio of \(F_\text{fit}/F_\text{image}\) after smoothing and interpolation was used to correct the emission line images in the original 1×1 binning resolution. In most areas of the field the correction is negligible (\(F_\text{fit}/F_\text{image} = 0.95\sim 1.1\)), and it exceeded a factor of 1.2 only in the northwest edge of the field, where a small emission filament is located. This type of correction only affects the absolute flux distribution and Hβ/Hα ratio, and does not affect the line ratio maps taken in the ‘single images’ mode: [S ii]/Hα, [S ii]λ6717/[S ii]λ6731. As a side result, the data cube fitting also provided an emission map of the [N ii]λ6583 line.

### 2.2 SCORPIO-2 spectroscopy

In order to check the calibration of the line flux ratios measured by MaNGaL, we used two medium-resolution (\(FWHM \sim 4.5\) Å) slit spectra presented by Boley et al. (in preparation), obtained with the SCORPIO-2 instrument (Afanasiev & Moiseev 2011) on the 6-m BTA telescope of SAO RAS in February, 2019. The spectra cover two portions of the S235 nebula along the 6′ slit, illustrated in Fig. 1, and the Hα, Hβ, [S ii]λ6716, 6731 Å lines are spectrally resolved. We refer to the work of Boley et al. for a full description of these observations and their reduction.

For each wavelength observed with MaNGaL, we matched the spatial resolution of the images (2.1′′) to that of the SCORPIO-2 spectra (2.6′′) by simple Gaussian convolution. Next, we created spatial profiles of the emission in each line from the MaNGaL observations by integrating along the width of the slit (1′′) at each position along the length of the SCORPIO-2 slit. Finally, because of the lower SNR in the slit spectra of the fainter regions of the nebula, we applied 9-pixel (3.1′′) boxcar smoothing to the spatial profiles (from both MaNGaL and SCORPIO-2).

### 3 METHODS

#### 3.1 Properties of the ionized gas

Electron density \(n_e\) was determined from the ratio of [S ii] lines \(λ6716/λ6731\). Because the wavelength difference between the doublet lines is comparable to the MaNGaL FPI instrumental profile, a correction must be applied. For a Lorentzian profile, which is a good approximation of FPI instrumental contour (Moiseev & Egorov 2008, and references therein), the real ratio \(r_\text{real}\) of two lines separated by \(\Delta\lambda\) is related to the observed ratio \(r_\text{obs}\) by the relation

\[
r_\text{real} = \frac{1 - C \cdot r_\text{obs}}{r_\text{obs} - C},
\]

where \(C = 1 + \left(\frac{2\Delta\lambda}{FWHM}\right)^2\) characterises the Lorentzian profile.

The observed MaNGaL map of [S ii]λ6716/λ6731 was corrected according to Eq. (1). Finally, we compared the spatial profiles of the [S ii] line ratio along the SCORPIO-2 slit with the same locations in the MaNGaL data using the procedure described in Sec. 2.2. We found that the [S ii]λ6716/λ6731 and Hα/Hβ values measured by MaNGaL must be further multiplied by a constant factor of 1.186 and 0.798 respectively to bring them in line with the flux-calibrated slit spectra. This secondary correction may be due to the deviations of the real instrumental profile wings from purely Lorentzian. The value of \(n_e\) was then calculated at each pixel with S/N level > 3 from the corrected ratio of the [S ii] lines using Eqs. (3) and (4) of Proxaux et al. (2014), for an electron temperature \(T_e = 7280\) K (Boley et al., in prep).

We determined the interstellar extinction \(A_V\) using the observed Hα/Hβ intensity ratio and the intrinsic ratio for Case B conditions and the reddening law of Cardelli et al. (1989). By interpolating the values from Table 4.2 of Osterbrock & Ferland (2006) in log-log space for \(T_e = 7280\) K, we find an intrinsic intensity ratio of \(R_{H\alpha}/R_{H\beta} = 2.95\). For the ratio of total to selective extinction, we adopted a value of \(R_V = 3.0\) (Boley et al., in preparation).

To study geometry of the H II region, we estimate its extent along the line of sight (S) for each pixel using equation:

\[
S = \frac{4\pi n_{H\alpha}}{\hbar c n_e} \frac{1}{\alpha_2} \text{cm},
\]

where \(\alpha_2 = 3.94 \times 10^{-14} \text{ cm}^3 \text{ s}^{-1}\) is the Case B hydrogen recombination coefficient, interpolated for an electron temperature of \(T_e = 7280\) K (Table 4.2 Osterbrock & Ferland 2006), \(n_{H\alpha}\) is from original calibrated MaNGaL files in ergs cm\(^{-2}\)sec\(^{-1}\)arcsec\(^{-2}\) transferred to ergs cm\(^{-2}\)sec\(^{-1}\)sr\(^{-1}\). We assume that the physical conditions do not vary over...
the line of sight and ignore ionization of all atoms except of hydrogen: \( n_e = n_{\text{H}^+} \), in \( \text{cm}^{-3} \).

3.2 Dust temperature and column density

In order to estimate dust temperature and column density, we used far-infrared emission maps at 90, 140, and 160 \( \mu \text{m} \) (WIDE-S, WIDE-L and N160 bands, respectively, Kawada et al. 2007), collected by Far-Infrared Surveyor (FIS) instrument on the AKARI satellite (Murakami et al. 2007; Kameda et al. 2007) during the AKARI Far-infrared All-Sky Survey (Doi et al. 2013; Takita et al. 2015). The spatial resolution of the instrument at each IR band is 39, 58, and 61\( '' \), respectively. The data were downloaded from the IRSA archive\(^4\) and regridded to the astrometric grid of the 90 \( \mu \text{m} \) image with a pixel size of 15\( '' \). As the spatial resolutions of the maps at the used wavelengths are not very much different, we have not attempted to convolve them to the same resolution. Dust temperatures and column densities were computed with the modified black body approach, adopting \( \beta = 2 \) and an opacity at 350 \( \mu \text{m} \) of 3.6 \( \text{cm}^2 \text{g}^{-1} \) (Ossenkopf & Henning 1994).

To estimate the radiation field in units of the Habing field, we use equation (5.44) from Tielens (2005) for a grain radius of 0.1 \( \mu \text{m} \):

\[
T_d \approx 33.5 \left( \frac{1 \mu \text{m}}{a} \right)^{0.2} \left( \frac{G_0}{10^4} \right)^{0.2}. \quad (3)
\]

4 RESULTS OF THE OBSERVATIONS WITH MANGAL

Images of the emission in the H\( \alpha \), H\( \beta \), [S\( ii \)], and [N\( ii \)] lines are shown in Fig. 1. Only pixels with \( S/N \) higher than 3 are shown. The images of H\( \alpha \) and H\( \beta \) show a bright central part (‘main’ part) around the ionizing star, with a sharp edge to the north and west, and diffuse emission to the south. The peak of the H\( \alpha \) and H\( \beta \) emission are about 60\( '' \) to the north-east of the ionizing star (0.5 pc in the plane of the sky). The area of the brightest H\( \alpha \) and H\( \beta \) emission is marginally coincident with the 1.4 GHz radio emission peak. The radio continuum emission is also present in the diffuse, southern part of the optical nebula.

In contrast to the bright H\( \alpha \) emission, [S\( ii \)] lines were only detected in the main part of the nebula with S/N > 3. The peak of the [S\( ii \)] emission is coincident with the peak of H\( \alpha \) and H\( \beta \) emission. Several arc-like filaments are visible in the [S\( ii \)] maps to the north-east from the ionizing star. There is also a bright, separated filamentary structure in the north-west part of the main nebula detected in all five lines. In Fig. 2, we show the spatial distribution of \( n_e \) throughout the nebula. We find a density gradient from the north-east to the south-west part of the nebula, from \( \sim 20–30 \text{ cm}^{-3} \) to more than 200 \( \text{ cm}^{-3} \), with a median value of 96 \( \text{ cm}^{-3} \). The ionizing star is projected on a region with \( n_e > 150 \text{ cm}^{-3} \). Due to the faintness of the [S\( ii \)] lines in the diffuse part of the nebula to the south, the value of \( n_e \) cannot be determined there from our observations. The bright north-west filament visible in Fig. 1 is not distinguishable on the \( n_e \) map.

The right panel of Fig. 2 shows the spatial distribution of the optical extinction value \( A_V \). There is a gradient from \( A_V = 1.5–2 \text{ mag} \) in the north-east part of the nebula to \( A_V > 4 \text{ mag} \) in the south-west part. The \( A_V \) value in the direction of the ionizing star is \( \sim 4 \text{ mag} \), consistent with the value found by Straizys et al. (2010). The typical uncertainty of the \( A_V \) value is about 0.2 mag, which is less than 6% of the minimum \( A_V \) value found in the north-west part of the nebula. Comparing the \( n_e \) and \( A_V \) maps, we find that the direction of the gradients is approximately the same, with higher \( n_e \) corresponding to higher \( A_V \). So, the ionizing star is projected on the transitional region between the dense part of the H\( ii \) region more deeply embedded in the surrounding neutral material and the more rarefied part.

We evaluated the extent of the H\( ii \) region along the line of sight using Eq. (2) and obtained \( S \approx 8–10 \text{ pc} \) in S235. The linear size of the nebula in the plane of the sky, corresponding to \( \theta' \) at 1.6 kpc, is 2.4 pc. Thus, according to the optical data, the nebula is more extended along the line of sight. If we use the emission measure from the radio recombination lines of \( E.M \approx 3 \times 10^6 \text{ pc cm}^{-6} \) (Silverplate & Terzian 1976) with the same median value of \( n_e \), we obtain 4.0 pc; i.e. our estimate of the extent from the optical recombination lines is in agreement with the radio-based value within a factor of 2.

We performed a visual comparison of the \( n_e \) map from Fig. 2 with the spatial distribution of hydrogen and carbon radio recombination lines (RRLs and CRRLs, respectively) given by Anderson et al. (2019), shown in their Fig. 7. Due to the square-root dependence on density, the RRLs are the best tracers of \( n_e \) in the H\( ii \) region, but CRRLs trace \( n_e \) in the surrounding PDR. We see that the peak of the RRL emission corresponds to the direction of the ionizing star, but the peak of the CRRL emission is shifted to the south-west of the star and coincides with the region of the maximum \( A_V \) found with MaNGaL. Hence, the densest part of the H\( ii \) region is adjacent to the densest part of the PDR around S235.

The dereddened H\( \alpha \) image is shown in Fig. 3. After accounting for the foreground reddening, it can be seen that maximum of the H\( \alpha \) emission coincides with the maximum of the 1.4 GHz NVSS image. The uncertainty of the dereddened H\( \alpha \) flux reaches 50% in the south-west part of the nebula, where the \( A_V \) value is highest, but not more than 10-20% in other parts of the nebula.

According to the radiative shock model library from Allen et al. (2008), the ratio of [S\( ii \)](6716,6731) to H\( \alpha \) lines can be used as a shock indicator. We show this ratio in Fig. 4 and find the similar filamentary structure seen on the images of the line emission in Fig. 1. Perforated semi-arcs surround the ionizing star. We find that for \( 30 < n_e < 200 \text{ cm}^{-3} \) the ratio [S\( ii \)](6716,6731) / H\( \alpha \) > 0.4 corresponds to the region affected by a shock. In our object the shock-induced regions are situated on the northern border of the H\( ii \) region. An even higher ratio is observed for ratio of the [N\( ii \)](6583) to H\( \alpha \) lines (not shown) in the same region, which confirms the contribution of the shock to the line excitation.

\(^4\) https://irsa.ipac.caltech.edu
Figure 1. MaNGaL images of S235. Only pixels with S/N ratio > 3 are shown here. NVSS 1.4 GHz image of S235 (Condon et al. 1998) is superimposed on the Hα image with white contours which are evenly spaced from 2.25 mJy/beam (5σ level) to 123 mJy/beam. Location of the ionizing star is shown by the red star.

Figure 2. Electron density (left) and $A_V$ (right) maps after correction of the MaNGaL images with SCORPIO-2 spectra. Only pixels with S/N ratio > 3σ are shown.
find that the dust-based column \( A_V^{\text{IR}} \) is about twice as high as \( A_V \) in the direction of BD+35°1201. There is a dense region with an embedded young stellar cluster (S235 Central; Kirsanova et al. 2008) to the south of the ionizing star, where \( A_V^{\text{IR}} \) is significantly higher than the \( A_V \) value, implying that the cluster is situated in the rear wall of the H\(_\text{II} \) region. This conclusion is in agreement with findings by Anderson et al. (2019), who compared the radial velocities of carbon and hydrogen RRLs with the velocities of molecular gas in that region. They found that the ionized gas flows in the direction of the observer, and that the neutral material forms a semi-envelope around the H\(_\text{II} \) region from the rear and two sides. In the present study, we show that the H\(_\text{II} \) region has an inhomogeneous front wall, with a smaller column of neutral material than the rear wall.

The dust temperature determined by the SEDs represents the average value of \( T_{\text{dust}} \) along the line of sight. \( T_{\text{dust}} \) varies from 18 to 30 K across the area of the H\(_\text{II} \) region and surrounding PDR, with a minor peak to the south-east of the ionizing star. Comparison of the CO(2 – 1) emission with the spatial distribution of the \( T_{\text{dust}} \) values shows that the peaks of the CO(2 – 1) in direction of the stellar clusters S235 East 1 and East 2 (Kirsanova et al. 2008) to the east of the H\(_\text{II} \) region coincide with the regions with \( T_{\text{dust}} \) < 20 K. We do not find decreasing \( T_{\text{dust}} \) in the direction of S235 Central, probably due to the projection effect of the warm foreground dust heated by the BD+35°1201 star.

The typical value of FUV radiation field is \( G_0 \approx 200 \) in Habing units in the direction of the H\(_\text{II} \) region. The maximum value of \( G_0 \) does not correspond to the position of the ionizing star or to the bright infrared sources IRS 1 or IRS 2 found by Evans & Blair (1981), but rather with the local lows of the dust column density map to the north of the ionizing star, where the FUV emission is not absorbed by the dense neutral medium. The minimum FUV field in the direction of the S235 East 1 and East 2 clusters can be explained by the high gas density in the molecular clumps. The projected distance from the ionizing star to the western border of the dense gas ridges in the direction of the East 1 and East 2 clusters is \( \approx 6' \), which corresponds to 2.8 pc. The value of \( G_0 \) is \( \approx 50 – 70 \) in the direction of the western border of East 1 from the side of the ionizing star (S235 East 1 W below). The value of \( G_0 \) here is comparable with the Horsehead PDR, where \( G_0 \approx 100 \) (Zhou et al. 1993). The projected distance between the ionizing star and S235 East 1 W is smaller than the distance between \( \sigma \) Ori and the Horsehead PDR (3.5 pc), but the \( G_0 \) value is higher in the latter region. This might be related with the projection effect, where real distance between the BD+35°1201 star and S235 East 1 W is higher, but also could be related with attenuation of the FUV emission by dust. We find \( G_0 \approx 200 \), or 3-5 times higher, on the eastern border of East 1 (which we call S235 East 1 E below). The dense clump with the embedded cluster East 1 is probably irradiated from the east by another stellar source, visible, for example, on WISE or Spitzer images of the region at \( \alpha(J2000.0)=05^h41^m35.2^s, \delta(J2000.0)=35^\circ48'27.5'' \) (the source is shown in the bottom panel of Fig. 5). The gas number density in the S235 East 1 dense clump reaches up to \( 2 \times 10^4 \) cm\(^{-3} \) based on measurements of NH\(_3 \) lines by Kirsanova et al. (2014). Thus, the dense clump S235 East 1 is a two-sided dense PDR with different \( G_0 \) values at each region.
side, making this region an interesting target for studies of PDR chemistry.

6 CONCLUSIONS

We present the first observations of a galactic H ii region with the optical tunable filter photometer MaNGaL at the Zeiss-1000 telescope of SAO RAS. The observations were done in Hα, Hβ, two [SII] lines at $6716, 6731$ Å and the [NiII] line at 6583 Å. The distribution of absorbing material (in terms of $A_V$) was obtained using the Hα and Hβ images. The [SII] lines were used to obtain the value of $n_e$, while the ratio of [SII] to Hα and [NiII] to Hα allowed us to find regions where shocks contribute to the line excitation.

We conclude that optical emission of the H ii region is attenuated by neutral material with $A_V \approx 2 – 4$ mag and a peak to the south-east from the ionizing star. The direction to the highest $A_V$ coincides with the maximum detected electron density (up to $n_e > 150$ cm$^{-3}$), with a median value 96 cm$^{-3}$.

The combination of the results of the optical observations with archive FIR data from the AKARI satellite allowed us to describe the 3D structure of the H ii region: we obtain a contribution of the front and rear walls to the total column density of neutral material. We find that the rear wall of the H ii region contains higher column of material than the front wall. This result agrees with recent study by Anderson et al. (2019), who found that the ionized gas of the H ii region expands in the direction of the observer. The thick rear wall does not allow to the ionized gas to expand to the direction from the observer. The extent of the H ii region along the line of sight is $8 – 10$ pc.

We also estimated $T_{dust}$ and the mean FUV field in terms of $G_0$ in S235 and the surrounding PDR, and found an interesting two-sided PDR in the dense clump S235 East 1, where $G_0 = 50 – 70$ and 200 in the western and eastern parts, respectively. This region is attractive for studies of dense PDR chemistry.

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Figure 5. Top: dust column density in terms of extinction, middle: dust temperature, bottom: UV field in Habing units. NVSS radio continuum emission (Condon et al. 1998) is shown by white contours. The ionizing star is shown by the red star symbol. Infrared sources IRS 1 and IRS 2 (Evans & Blair 1981) are shown by black diamonds. The map of the CO(2–1) line emission from Biegling et al. (2016) is shown by grey contours where dense clumps with embedded young stellar clusters from Kirsanova et al. (2008) are designated. Another black diamond shown on the bottom panel is possible illuminating source for S235 East 1 E PDR, see text.
