Oxygen abundance distributions in six late-type galaxies based on SALT spectra of H II regions*

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ABSTRACT

Spectra of 34 H II regions in the late-type galaxies NGC 1087, NGC 2967, NGC 3023, NGC 4030, NGC 4123, and NGC 4517A were observed with the South African Large Telescope (SALT). In all 34 H II regions, oxygen abundances were determined through the “counterpart” method (C method). Additionally, in two H II regions in which we detected auroral lines, we measured oxygen abundances with the classic Te method. We also estimated the abundances in our H II regions using the O3N2 and N2 calibrations and compared those with the C-based abundances. With these data, we examined the radial abundance distributions in the disks of our target galaxies. We derived surface-brightness profiles and other characteristics of the disks (the surface brightness at the disk center and the disk scale length) in three photometric bands for each galaxy using publicly available photometric imaging data. The radial distributions of the oxygen abundances predicted by the relation between abundance and disk surface brightness in the W1 band obtained for spiral galaxies in our previous study are close to the radial distributions of the oxygen abundances determined from the analysis of the emission line spectra for four galaxies where this relation is applicable. Hence, when the surface-brightness profile of a late-type galaxy is known, this parametric relation can be used to estimate the likely present-day oxygen abundance in the disk of the galaxy.

Key words. galaxies: abundances – HII regions – galaxies: general

1. Introduction

Metallicities play a key role in studies of galaxies. The present-day abundance distributions across a galaxy provide important information about the evolutionary status of that galaxy and form the basis for the construction of models of the chemical evolution of galaxies.

Oxygen abundances and their gradients in the disks of late-type galaxies are typically based on emission-line spectra of individual H II regions. When the auroral line [OIII]λ4363 is detected in the spectrum of an H II region, the Te-based oxygen (O/H)Te abundance can be derived using the standard equations of the Te-method. In our current study, we do not always have this information and use alternative methods where the auroral line is not detected. In those cases, we estimate the oxygen abundances from strong emission lines using a recently suggested method (called the “C method”) for abundance determinations of Pilyugin et al. (2012) and Pilyugin et al. (2014a). When the strong lines R1, N2, and S2 are measured in the spectrum of an H II region, the oxygen (O/H)C method abundance can be determined. When the strong lines R3, R4, and N2 are measured in the spectrum, we can measure the oxygen (O/H)C method abundance.

It should be emphasized that the C method produces abundances on the same metallicity scale as the Te-method. In contrast, metallicities derived using one of the many calibrations based on photoionization models tend to show large discrepancies (of up to ∼0.6 dex) with respect to Te-based abundances (see the reviews by Kewley & Ellison 2008; López-Sánchez & Esteban 2010; López-Sánchez et al. 2012). Coupling our emission-line measurements with available line measurements from the literature or public databases, we measured the radial distributions of the oxygen abundances across the disks of six galaxies.

The study of the correlations between the oxygen abundance and other properties of spiral and irregular galaxies is important for understanding the formation and evolution of galaxies. The correlation between the local oxygen abundance and the stellar surface brightness (the OH – SB relation) or surface mass density has been a subject of discussion for a long time (Webster & Smith 1983; Edmunds & Pagel 1984; Vila-Costas & Edmunds 1992; Ryder 1995; Moran et al. 2012; Rosales-Ortega et al. 2012; Sánchez et al. 2014). We examined the relations between the oxygen abundance and the disk surface brightness in the infrared W1 band of the Wide-field Infrared Survey Explorer (WISE; Wright et al. 2010) at different fractions of the optical isophotal radius R25 in our previous paper (Pilyugin et al. 2014b). We found evidence that the OH – SB relation depends on the galactocentric distance taken as a fraction of the optical

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radius $R_{25}$ and on other properties of a galaxy, namely its disk scale length and the morphological $T$-type. In that study, we suggested a parametric OH – $S_B$ relation for spiral galaxies.

In our current paper, we present results from observations of emission-line spectra of H II regions in six spiral galaxies. These observations were obtained with the South African Large Telescope as a part of our investigation of the abundance properties of nearby late-type galaxies (Pilyugin et al. 2014a,b).

We constructed radial surface-brightness profiles of our galaxies in the infrared $W_1$ band using the photometric maps obtained by the WISE satellite (Wright et al. 2010). The characteristics of the disk for each galaxy were obtained through bulge-disk decomposition. The radial distributions of the oxygen abundances predicted by the parametric OH – $S_B$ relation are compared to the radial distributions of the oxygen abundances determined from the analysis of the emission-line spectra of the H II regions in our target galaxies.

The paper is organized as follows. Our sample of galaxies is presented in Sect. 2. The spectroscopic observations and data reduction are described in Sect. 3. The photometric properties of our galaxies are discussed in Sect. 4. The oxygen abundances are presented in Sect. 5. Section 6 contains a discussion and a brief summary of the main results.

Throughout the paper, we use the following standard notations for the line intensities $I$:

$$R = \frac{I_{[OIII] \lambda 4363}}{I_{H\beta}},$$

$$R_2 = \frac{I_{[OII] \lambda 3727 + \lambda 3729}}{I_{H\beta}},$$

$$N_2 = \frac{I_{[NII] \lambda 6584}}{I_{H\beta}},$$

$$S_2 = \frac{I_{[SII] \lambda 6717 + \lambda 6731}}{I_{H\beta}},$$

$$R_3 = \frac{I_{[OIII] \lambda 4959 + \lambda 5007}}{I_{H\beta}}.$$

2. Our galaxy sample

Our original sample of spiral galaxies for follow-up observations with the Southern African Large Telescope (SALT; Buckley et al. 2006; O’Donoghue et al. 2006) was devised based on Sloan Digital Sky Survey (SDSS) images and the fact that SALT can observe targets with a declination $\delta < 10$ degrees and has a field of view of 8 arcmin. Each selected spiral galaxy contains a sufficiently large number of bright H II regions distributed across the whole galaxy disk and fitting SALT’s field of view. The total sample consists of ~30 nearby galaxies that are located in the equatorial sky region.

Out of this sample of 58 galaxies, we have obtained spectra of H II regions in six galaxies (NGC 1087, NGC 2967, NGC 3023, NGC 4030, NGC 4123, NGC 4517A) thus far. In Fig. 1 we present the images and slit positions for those galaxies. For a detailed description of the observations, we refer to Sect. 3.

Table 1 lists the general characteristics of each galaxy. We listed the most widely used identifications for our target galaxies, i.e., the designations in the New General Catalogue (NGC) and in the Uppsala General Catalog of Galaxies (UGC). The morphological type of the galaxy and morphological type code $T$ were adopted from LEDA (Lyon-Meudon Extragalactic Database; Paturel et al. 1989, 2003). The right ascension and declination were taken from the NASA/IPAC Extragalactic Database (NED)\(^1\). The inclination of each galaxy, the position angle of the major axis, and the isophotal radius $R_{25}$ in arcmin

\(^1\) The NASA/IPAC Extragalactic Database (NED) is operated by the Jet Populsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration. http://ned.ipac.caltech.edu/
of each galaxy were determined in our current study. The distances were taken from NED. These distances include flow corrections for the Virgo cluster, the Great Attractor, and Shapley Supercluster infall. The isophotal radius in kpc was estimated from the isophotal radius \( R_{25} \) in arcmin and the distance listed above. The characteristics of the disks (the surface brightness at the disk center in the \( W_1 \) band and the disk scale length) were determined through the bulge-disk decomposition carried out in our current paper. The surface brightness at the disk center was reduced to a face-on galaxy orientation and is given in terms of \( L_0 \) pc\(^{-2}\).

Three galaxies of our sample are members of pairs of galaxies and are included in the "Catalogue of Isolated Pairs of Galaxies in the Northern Hemisphere" (Karachentsev 1972): NGC 3023, NGC 4030, and NGC 4123. NGC 3023 is a low surface brightness galaxy (Romanishin et al. 1983).

### 3. Spectroscopic observations and reduction

#### 3.1. Observing procedures

The spectroscopic observations of our selected galaxies were obtained with the multioject spectroscopic mode (MOS) of the Robert Stobie Spectrograph (RSS; Burgh et al. 2003; Kobulnicky et al. 2003) installed at SALT. For each galaxy from our sample, we constructed a MOS mask, where the slit positions were selected using \( R_{25} \) in arcmin and the distance listed above. The characteristics of the disks (the surface brightness at the disk center in the \( W_1 \) band and the disk scale length) were determined through the bulge-disk decomposition carried out in our current paper. The surface brightness at the disk center was reduced to a face-on galaxy orientation and is given in terms of \( L_0 \) pc\(^{-2}\).

Three galaxies of our sample are members of pairs of galaxies and are included in the "Catalogue of Isolated Pairs of Galaxies in the Northern Hemisphere" (Karachentsev 1972): NGC 3023, NGC 4030, and NGC 4123. The galaxy NGC 4517A is a low surface brightness galaxy.

### 3.2. Data reduction and line flux measurements

Cosmic ray rejection was done using the IRAF\(^2\) task \texttt{lacose/spec} (van Dokkum 2001). The wavelength calibration was accomplished using the IRAF tasks \texttt{identify}, \texttt{reidentify}, \texttt{fitcoord}, and \texttt{transform}. The spectral data were divided by the illumination-corrected flat field to correct for pixel-to-pixel sensitivity variations of the detector. After that, the bias- and gain-corrected and mosaiced MOS data were reduced in the way described below.

\(^{2}\) IRAF is distributed by the National Optical Astronomical Observatories, which are operated by the Association of Universities for Research in Astronomy, Inc., under cooperative agreement with the National Science Foundation.
two-dimensional spectra were extracted from the MOS images for each slit. The background subtraction was done using the IRAF task background. Since we used a multislit mask, the slits for the individual objects have a length of ~5–20 arcsec and the background was fitted by a low-order polynomial function along the spatial slit coordinate at each wavelength. This allows us to extract the flux from the H\textsc{ii} regions only, without galactic stellar background. The spectra were corrected for sensitivity effects using the Sutherland extinction curve and a sensitivity curve obtained from observed standard star spectra. Finally, all two-dimensional spectra of a slit position obtained with the same observational setup were averaged.

From each two-dimensional spectrum of the blue and red setups, one-dimensional spectra were extracted in spatial direction for each pixel along the slit. We refer to these spectra as "one-pixel-wide". The line fluxes ([O\textsc{ii}], λλ3727,3729, [O\textsc{iii}], λ6563, H\textbeta, [O\textsc{iii}], λ4959, [O\textsc{iii}], λ5007, [N\textsc{ii}], λ6548, H\alpha, [N\textsc{ii}], λ6584, [S\textsc{ii}], λλ6717, and [S\textsc{ii}], λ6731) were then measured with IRAF or by fitting the lines with Gaussians following Pilyugin & Thuan (2007) and Pilyugin et al. (2010a).

We first consider the distribution of the emission-line fluxes along the slit. The measured fluxes in the H\textbeta and R3 emission lines in the blue and red one-pixel-wide spectra for slit 8 in NGC 3023 as a function of the pixel number along the slit are shown in Fig. 2. Examination of Fig. 2 shows that the position of the peak in the H\textbeta (and R3) emission line in the red spectrum is shifted as compared to that in the blue spectrum by approximately three pixels. This shows that the position of the slit of the red spectrum does not coincide with the position of the slit for the blue spectrum. Instead they are shifted in the direction along the slit by approximately three pixels with respect to each other. Inspection of Fig. 2 also shows that the form of the distribution of the H\textbeta (and R3) emission-line flux per pixel in the red spectrum differs from that in the blue spectrum. This demonstrates that the position of the slit for the red spectrum is also shifted in the direction perpendicular to the slit or that the position angles of the red and blue spectrum are different. This prevents us from considering the lines of the blue and red spectra together. Therefore we derived the abundances using the lines from the blue (or red) spectrum individually.

The full set of lines [O\textsc{ii}], λλ3727,3729, H\textbeta, [O\textsc{iii}], λ5007, H\alpha, and [N\textsc{ii}], λ6548 or H\textbeta, [O\textsc{iii}], λ5007, H\alpha, [N\textsc{ii}], λ6584, and [S\textsc{ii}], λλ6717,6731 is needed to correct for interstellar reddening and to determine the oxygen abundances. For this reason, only slits that provide at least one of these line sets in either the blue or red setup are chosen for further study. As the actual spectral coverage for each of our slits varies slightly depending on the position of a given slit on the mask, in some cases the H\textbeta+[O\textsc{iii}], λ5007 lines of the red spectra and the H\alpha+[N\textsc{ii}], λ6548 lines of the blue spectra are shifted beyond the actual spectral coverage of the slit. This is the reason why

Table 2. Journal of the observations.

| Galaxy  | Date for blue setup | Date for red setup | Exposure time for blue setup | Exposure time for red setup | Seeing for blue setup | Seeing for red setup |
|---------|---------------------|--------------------|-----------------------------|-----------------------------|---------------------|---------------------|
| NGC 1087| ...                 | 2012.12.20         | ...                        | ...                        | 1.4                 | ...                 |
| NGC 2967| 2013.02.02          | 2013.02.02         | 2 × 1000                   | 2 × 1000                   | 1.5                 | 1.2                 |
| NGC 3023| 2013.01.05          | 2013.01.06         | 2 × 1000                   | 2 × 1000                   | 2.5                 | 2.3                 |
| NGC 4030| 2013.03.20          | ...                | 2 × 1000                   | ...                        | 1.0                 | ...                 |
| NGC 4123| 2013.04.29          | 2013.03.03         | 2 × 1000                   | 2 × 910                    | 1.7                 | 2.2                 |
| NGC 4517A| 2012.06.16         | ...                | 1 × 900 + 2 × 725         | ...                        | 1.7                 | ...                 |

Fig. 2. Fluxes in the H\textbeta (upper panel) and R3 (lower panel) emission lines in the blue (solid lines) and red (dashed lines) spectra as a function of the pixel number along the slit for slit 8 in NGC 3023. The fluxes are in arbitrary units.

the number of the presented observations of H\textsc{ii} regions varies from one in NGC 4030 to up to nine in NGC 1087.

We constructed the aperture for the blue and red spectra by averaging the seven one-pixel-wide spectra near the flux maximum. As mentioned before, the emission from the underlying stellar population of the galactic disk was subtracted during the background correction, i.e., we removed the stellar continuum averaged along the spatial slit coordinates near the H\textsc{ii} region. Since the continuum in the spectra of our H\textsc{ii} regions is sufficiently weak or undetectable, we neglected possible stellar absorption by the stellar populations of the H\textsc{ii} regions. The measured emission fluxes were corrected for interstellar reddening. We obtained the extinction coefficient C(H\textbeta) using the theoretical H\alpha-to-H\textbeta ratio (=2.878) and the analytical approximation to the Whitford interstellar reddening law of Izotov et al. (1994).

The dereddened emission-line fluxes in the averaged spectra of the target H\textsc{ii} regions are listed in Table 3 for the blue spectra and in Table 4 for the red spectra. The theoretical ratio
### Table 3. Dereddened emission line fluxes in units of the Hβ line flux and the extinction coefficient C(Hβ) in the blue spectra of a sample of the target [H II] regions in NGC 3023.

| Slit | RA° | Dec° | [O III]15007 | [N II]6584 | [S II]6717 | [S II]6731 | C(Hβ) |
|------|-----|------|-------------|-----------|-----------|-----------|-------|
| 17   | 145.503249 | 0.340438 | 2.712 ± 0.164 | 0.371 ± 0.033 | 0.772 ± 0.044 | 0.579 |
| 18   | 147.476616 | 0.616676 | 1.627 ± 0.051 | 0.072 ± 0.003 | 0.617 ± 0.200 | 0.297 |
| 19   | 147.474086 | 0.615905 | 2.600 ± 0.084 | 0.030 ± 0.003 | 3.280 ± 0.109 | 0.317 |
| 20   | 147.468182 | 0.619303 | 3.662 ± 0.120 | 1.654 ± 0.057 | 0.474 ± 0.021 | 0.345 |
| 21   | 180.111544 | −1.074890 | 2.340 ± 0.104 | 0.820 ± 0.034 | 0.849 ± 0.038 | 0.524 |
| 22   | 182.032991 | 2.88044 | 2.281 ± 0.131 | 0.457 ± 0.031 | 0.858 ± 0.036 | 0.535 |
| 23   | 182.030381 | 2.882922 | 2.324 ± 0.139 | 0.896 ± 0.045 | 0.817 ± 0.039 | 0.403 |
| 24   | 182.031526 | 2.888546 | 2.322 ± 0.146 | 0.473 ± 0.036 | 0.903 ± 0.040 | 0.689 |
| 25   | 182.024433 | 2.889972 | 2.925 ± 0.166 | 0.781 ± 0.051 | 0.694 ± 0.032 | 0.483 ± 0.026 | 0.331 ± 0.017 | 0.485 |
| 26   | 182.022560 | 2.908112 | 1.771 ± 0.088 | 3.457 ± 0.142 | 0.217 ± 0.014 | 0.113 |
| 27   | 188.108016 | 0.381737 | 4.566 ± 0.224 | 0.936 ± 0.050 | 0.269 ± 0.020 | 0.402 |
| 28   | 188.116422 | 0.390758 | 2.310 ± 0.084 | 2.109 ± 0.096 | 0.305 ± 0.021 | 0.194 |

### Notes. (a) In degrees (J2000).

### Table 4. Dereddened emission line fluxes in units of the Hβ line flux and the extinction coefficient C(Hβ) in the red spectra of a sample of the target [H II] regions in our galaxy sample.

| Slit | RA° | Dec° | [O III]15007 | [N II]6584 | [S II]6717 | [S II]6731 | C(Hβ) |
|------|-----|------|-------------|-----------|-----------|-----------|-------|
| 15   | 41.605348 | −0.482317 | 0.794 ± 0.034 | 0.633 ± 0.030 | 0.410 ± 0.018 | 0.292 ± 0.013 | 0.353 |
| 16   | 41.609253 | −0.490142 | 0.494 ± 0.020 | 0.750 ± 0.029 | 0.479 ± 0.017 | 0.336 ± 0.013 | 0.282 |
| 17   | 41.607925 | −0.493503 | 0.400 ± 0.031 | 0.664 ± 0.026 | 0.377 ± 0.018 | 0.259 ± 0.014 | 0.306 |
| 18   | 41.604852 | −0.497109 | 0.211 ± 0.011 | 0.935 ± 0.043 | 0.373 ± 0.017 | 0.278 ± 0.012 | 0.380 |
| 19   | 41.610902 | −0.500035 | 0.429 ± 0.033 | 0.754 ± 0.026 | 0.443 ± 0.020 | 0.334 ± 0.015 | 0.252 |
| 20   | 41.610902 | −0.486017 | 0.427 ± 0.017 | 0.696 ± 0.033 | 0.320 ± 0.016 | 0.225 ± 0.010 | 0.340 |
| 21   | 41.603902 | −0.504827 | 0.449 ± 0.014 | 0.764 ± 0.027 | 0.275 ± 0.009 | 0.206 ± 0.007 | 0.443 |
| 22   | 41.604192 | −0.512645 | 0.932 ± 0.036 | 0.615 ± 0.031 | 0.464 ± 0.027 | 0.322 ± 0.023 | 0.417 |
| 23   | 41.609197 | −0.515824 | 0.406 ± 0.021 | 0.589 ± 0.025 | 0.402 ± 0.016 | 0.280 ± 0.016 | 0.251 |
| 24   | 145.509118 | 0.341424 | 0.129 ± 0.013 | 0.840 ± 0.031 | 0.309 ± 0.013 | 0.226 ± 0.009 | 0.900 |
| 25   | 145.522704 | 0.332752 | 0.195 ± 0.060 | 0.820 ± 0.046 | 0.395 ± 0.024 | 0.270 ± 0.019 | 1.040 |
| 26   | 145.521731 | 0.326422 | 0.930 ± 0.048 | 0.613 ± 0.045 | 0.328 ± 0.031 | 0.216 ± 0.019 | 0.970 |
| 27   | 145.509866 | 0.328543 | 0.294 ± 0.070 | 0.676 ± 0.031 | 0.350 ± 0.029 | 0.252 ± 0.035 | 0.734 |
| 28   | 145.502932 | 0.349615 | 0.738 ± 0.126 | 0.689 ± 0.061 | 0.608 ± 0.049 | 0.295 ± 0.050 | 0.902 |
| 29   | 145.507574 | 0.355989 | 1.596 ± 0.199 | 0.530 ± 0.059 | 0.451 ± 0.064 | 0.229 ± 0.025 | 0.644 |

### Notes. (a) In degrees (J2000).

of [N II]6584/[N III]6548 is constant and close to 3 (Storey & Zeippen 2000) since those lines originate from transitions from the same energy level. Since the [N II]6584 line measurements are more reliable than the [N II]6548 line measurements, the value of N2 is estimated as N2 = 1.33× [N II]6584 unless indicated otherwise. Similarly, the value of R3 can be estimated as R3 = 1.33× [O III]15007 since the [O III]15007 and [O III]λ4959 lines also originate from transitions from the same energy level and their flux ratio is very close to 3 (Storey & Zeippen 2000; Kniazev et al. 2004). Therefore, the [N II]6548 and λ4959 lines are not included in Tables 3 and 4.

The uncertainty of the emission-line flux Fλmin is estimated taking the uncertainty of the continuum level, errors in the line flux, and the uncertainty in the sensitivity curve into account (see Kniazev et al. 2004, for details). The uncertainty of the continuum, econt, is determined in the region near the emission

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line where the continuum is approximated by a linear fit. The line-flux uncertainty, $\epsilon_{\text{line}}$, is estimated as the deviation from a Gaussian profile. The uncertainty in the sensitivity curve, $\epsilon_{\text{sc}}$, is less than 2–3% in all considered wavelength ranges (see, e.g., Kniazev 2012). We adopt the maximum value of the relative uncertainty as $\epsilon_{\text{sc}} = 0.03$.

### 4. Photometry

To estimate the deprojected galactocentric distance (normalized to the optical isophotal radius $R_{25}$) of the H II region from its coordinates on the celestial sphere, one needs to know the values of the inclination, $i$, the position angle of the major axis, PA, and the isophotal radius of a galaxy, $R_{25}$. It is common practice to take those values from de Vaucouleurs et al. (1991, thereafter RC3) or from the LEDA database. However, some values from those sources show a significant difference for galaxies from our list. For example, the isophotal radius of NGC 4517A in the RC3 is larger by a factor of two than that given in the LEDA database. Therefore we obtained our own estimates of the values of $i$, PA, and $R_{25}$ for our target galaxies.

We analyzed the publicly available photometric maps in the infrared W1 band with an isophotal wavelength of 3.4 $\mu$m obtained by the (WISE; Wright et al. 2010) and in the $g$ and $r$ bands obtained by the SDSS data release (DR) 9 (Ahn et al. 2012). We derived the surface-brightness profile and disk orientation parameters in three photometric bands for each galaxy. The determinations of the surface-brightness profile, position angle, and ellipticity were performed for each band separately in the way described in Pilyugin et al. (2014b). For NGC 3023, however, we were not able to estimate reliable values of the position angle and ellipticity for the $g$ and $r$ bands. Therefore, for this galaxy, we take the values of the position angle and ellipticity obtained for the W1 band were used for the construction of the surface-brightness profiles in all three filters.

It should be noted that the WISE and SDSS surveys are sufficiently deep for our surface-brightness profiles to extend beyond the optical isophotal radii $R_{25}$. The obtained surface-brightness profiles are shown in Fig. 3. The adopted inclinations and position angles are given in Table 1.

The value of the isophotal radius is derived from the obtained surface-brightness profiles in the $g$ and $r$ bands. Surface-brightness measurements were corrected for foreground Galactic extinction using the $A_V$ values from the recalibration by Schlafly & Finkbeiner (2011) of the extinction maps of Schlegel et al. (1998) and the extinction curve of Cardelli et al. (1989), assuming a ratio of total to selective extinction of $R_V = A_V/E_{B-V} = 3.1$. We adopted the $A_V$ values given in the NASA Extragalactic Database NED. Afterward, we corrected the surface-brightness measurements for the inclination. The measurements in the SDSS filters $g$ and $r$ were converted to $B$-band magnitudes, and the $B$ magnitudes were reduced to the Vega photometric system using the conversion relations and solar magnitudes of Blanton & Roweis (2007). First, we obtained the $B$-band magnitudes from the $g$ and $r$ magnitudes

$$B_{\text{AB}} = g + 0.2354 + 0.3915 \left[(g - r) - 0.6102\right],$$

where the $B_{\text{AB}}$, $g$, and $r$ magnitudes in Eq. (1) are in the AB photometric system. Then, the $AB$ magnitudes were reduced to the Vega photometric system

$$B_{\text{Vega}} = B_{\text{AB}} + 0.09.$$

The obtained isophotal radii are given in Table 1.

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**Fig. 3.** Observed surface-brightness profiles of our galaxies in the $g$ and $r$ bands of the SDSS photometric system and in the W1 band of the WISE photometric system. The X-axis shows the galactocentric radius in arcmin, and the Y-axis the surface brightness in mag arcsec$^{-2}$. The optical isophotal radius $R_{25}$ is marked with an arrow.

**Fig. 4.** Comparison between the measured surface-brightness profiles of NGC 4123 in the $B$ band reported by Weiner et al. (2001; solid line), by Micheva et al. (2013; long dashed line), and obtained here (short dashed line). The X-axis shows the galactocentric radius in arcmin, and the Y-axis the surface brightness in mag arcsec$^{-2}$. The arrow indicates the optical isophotal radius $R_{25}$.

Surface brightness profiles of the galaxy NGC 4123 in the $B$ band were published by Weiner et al. (2001) and Micheva et al. (2013). Figure 4 shows the comparison between their profiles with that derived here from the photometric imaging data in the SDSS $g$ and $r$ bands.

We performed a bulge-disk decomposition of the observed surface-brightness profiles using a purely exponential disk (PED) approximation in the same way as in Pilyugin et al. (2014b). Exponential profiles were used to fit the observed disk surface-brightness profiles, and the bulge profiles were fitted with a general Sérsic profile. The observed surface-brightness profiles of five galaxies from our sample are fitted satisfactorily well. The upper panel of Fig. 5 shows the bulge-disk decomposition of the galaxy NGC 1087 as an example. The measured surface profile is marked by circles. The fit to the bulge contribution is shown with a dotted line, the fit to the disk with a dashed line, and the total (bulge + disk) fitting with a solid line.
Fig. 5. Patterns resulting from the bulge-disk decomposition of our target galaxies (X-axis: galactocentric radius in kpc, Y-axis: logarithm of the central surface brightness for a face-on galaxy orientation in solar luminosities per pc²). Each panel shows the decomposition assuming a purely exponential profile for the disk. The measured surface profile is plotted using gray (blue) circles. The bulge contribution is shown with a dotted line, the disk contribution with a dashed line, and the total (bulge + disk) fit with a solid line.

Table 1 lists the parameters of the disk surface-brightness profiles of those galaxies in the W1 band: the logarithm of the central surface brightness of the disk in the W1 band reduced to a face-on galaxy orientation in terms of \( L_0 \) pc⁻² and the disk scale length in the W1 band, \( h_{W1} \), in kpc. Those values are parameters of the exponential disk approximation, described in detail in Pilyugin et al. (2014b).

For the galaxy NGC 3023, we could not determine a reliable disk scale length, \( h_{W1} \), and central surface brightness of the disk, \( \Sigma_{L_{W1}} \). The lower panel of Fig. 5 shows the surface-brightness-profile fit for this galaxy. The disk contribution to the surface brightness is close to the observed surface-brightness profile over a small interval of radial distances only (in fact, this is a bulge-dominated galaxy). Therefore, the values of the disk scale length and central surface brightness of the disk are questionable.

5. Abundances

5.1. Abundance determination

Baldwin et al. (1981) proposed the [OIII]λ5007/Hβ vs. [NII]λ6584/Hα diagram (the so-called BPT classification diagram), which is often used to distinguish between star-forming regions and active galactic nuclei (AGNs). The exact location of the dividing line between star-forming regions and AGNs is still controversial (see, e.g., Kewley et al. 2001; Kauffmann et al. 2003). Figure 6 shows the positions of our targets (open circles) in the BPT classification diagram. The solid line is the dividing line between star-forming regions and AGNs according to Kauffmann et al. (2003), while the dashed line is the same line according to Kewley et al. (2001). Regardless of which line is adopted, Fig. 6 shows that all our objects are H II regions and their oxygen abundances can be estimated using standard techniques.

The \( T_e \)-based oxygen (O/H)\(_e\) abundances of the H II regions with the detected auroral line [O III]λ4363 were determined using the equations for the \( T_e \)-method from Pilyugin et al. (2010b, 2012).

A new method (called the “C method”) for oxygen and nitrogen abundance determinations from strong emission lines was recently suggested (Pilyugin et al. 2012, 2014a). In our red spectra, we measured the strong lines \( R_1 \), \( N_2 \), and \( S_2 \), which allowed us to determine the oxygen (O/H)\(_C\) abundances using those strong lines. In some of our blue spectra, the strong lines \( R_2 \), \( R_3 \), and \( N_2 \) were measured and applied to determine the oxygen (O/H)\(_C\) abundances.

5.2. The robustness and precision of the abundance determination

The emission-line fluxes measured in the one-pixel-wide spectra represent the radiation of a small part of the H II region. One would expect that the \( T_e \)-based abundances in a given H II region derived from the spectra of different areas on the H II region image should be the same or at least should be close to each other. Is this the case for the abundances estimated from the counterpart method? To clarify this matter we have estimated the oxygen abundances from the individual one-pixel-wide spectra and considered the variations in those abundances.

Figure 7 shows the distribution of the oxygen abundances along the slit for the bright, extend H II region (#8) in NGC 3023, i.e., the abundance estimated from the individual one-pixel-wide
Our current sample of reference H II regions (our standard reference sample from 2013) contains 250 H II regions for which the absolute differences in the oxygen abundances \((O/\text{H})_{\text{C}_1} - (O/\text{H})_{\text{M}}\) and \((O/\text{H})_{\text{C}_2} - (O/\text{H})_{\text{T}_1}\), and in the nitrogen abundances \((N/\text{H})_{\text{C}_1} - (N/\text{H})_{\text{M}}\) and \((N/\text{H})_{\text{C}_2} - (N/\text{H})_{\text{T}_1}\), are less than 0.1 dex (Pilyugin et al. 2014a). Thus the true uncertainty in the C-based oxygen abundance may be up to around 0.1 dex even if the formal error due to the uncertainties in the strong line measurement is small. Therefore we assume that the uncertainties in the obtained oxygen abundances in our investigated H II regions in the current paper can exceed 0.1 dex, although the formal error caused by the uncertainty in the line fluxes measurement is lower.

5.3. Radial gradients

The radial distribution of the oxygen abundances across the disk within the isophotal radius in each of our target galaxies was fitted with the following equation:

\[
12 + \log(\text{O/H}) = 12 + \log(\text{O/H})_{0} + C_{\text{O/H}} \times (R/R_{25}),
\]

where \(12 + \log(\text{O/H})_{0}\) is the oxygen abundance at \(R_{0} = 0\), i.e., the extrapolated central oxygen abundance, \(C_{\text{O/H}}\), is the slope of the oxygen abundance gradient expressed in terms of dex \(R_{25}^{-1}\) and \(R/\text{R}_{25}\) is the fractional radius, i.e., the galactocentric distance normalized to the disk’s isophotal radius \(R_{25}\).

NGC 1087. The strong lines H\(\beta\), [O III]\(\lambda\lambda 4959,5007\), H\(\alpha\), [N II]\(\lambda\lambda 6548,6584\), and [S II]\(\lambda\lambda 6717,6731\) were measured in nine red spectra. In those H II regions, we derived the oxygen abundance \((O/\text{H})_{\text{C}_1}\). The resulting oxygen abundances are listed in Table 5. Those abundances are shown by the filled circles in panel a of Fig. 8.

There are three SDSS spectra of H II regions in the galaxy NGC 1087 in data release 7 (DR7, Abazajian et al. 2009), namely Sp 409-51871-237, Sp 1069-52590-193, and Sp 1511-52946-192. (The SDSS spectrum number consists of the SDSS plate number, the modified Julian date of the observation, and the number of the fiber on the plate.) Since SDSS data release 10 (DR10, Ahn et al. 2014) reported line measurements in only one spectrum, we used the SDSS spectra from DR7. The oxygen \((O/\text{H})_{\text{C}_2}\) abundances inferred using the SDSS spectra are shown with open (blue) circles in panel a of Fig. 8.

The best linear fit to all the data points (12 points) with galactocentric distances smaller than the isophotal radius \(R_{25}\) radius is

\[
12 + \log(\text{O/H}) = 8.61 \pm 0.02 - 0.285 \pm 0.056 \times (R/R_{25}),
\]

with a mean deviation of 0.034 dex around the relationship. The obtained relation is shown by a solid line in panel a of Fig. 8.

NGC 2967. The strong lines H\(\beta\), [O III]\(\lambda\lambda 4959,5007\), H\(\alpha\), [N II]\(\lambda\lambda 6548,6584\) and [S II]\(\lambda\lambda 6717,6731\) were measured in six red spectra. Oxygen \((O/\text{H})_{\text{C}_1}\) abundances were then inferred for those H II regions. Those abundances are shown with filled circles in panel b) of Fig. 8. The scatter in individual (12 points) with galactocentric distances smaller than the isophotal radius \(R_{25}\) radius is

\[
12 + \log(\text{O/H}) = 8.61 \pm 0.02 - 0.285 \pm 0.056 \times (R/R_{25}),
\]

with a mean deviation of 0.034 dex around the relationship. The obtained relation is shown by a solid line in panel a of Fig. 8.

There are three SDSS spectra (Sp 476-52314-622, Sp 266-51630-387, and 266-51602-394) of H II regions in the galaxy NGC 2967 in DR7. The oxygen \((O/\text{H})_{\text{C}_2}\) abundances derived using the SDSS spectra are shown with gray (blue) open circles in panel b) of Fig. 8.
Table 5. Oxygen abundances in the H II regions in the disks of our sample of galaxies.

| Slit | R/R25 | 12+log(O/H) | Method | Spectrum |
|------|-------|-------------|--------|----------|
|      |       |             |        |          | NGC 1087 |
| 15   | 0.527 | 8.44        | C_{NS} red |          |
| 16   | 0.359 | 8.48        | C_{NS} red |          |
| 17   | 0.232 | 8.50        | C_{NS} red |          |
| 23   | 0.050 | 8.61        | C_{NS} red |          |
| 28   | 0.327 | 8.50        | C_{NS} red |          |
| 30   | 0.506 | 8.52        | C_{NS} red |          |
| 31   | 0.231 | 8.55        | C_{NS} red |          |
| 32   | 0.444 | 8.42        | C_{NS} red |          |
| 36   | 0.603 | 8.48        | C_{NS} red |          |
|      |       |             |        |          | NGC 2967 |
| 14   | 0.232 | 8.66        | C_{NS} red |          |
| 17   | 0.554 | 8.53        | C_{ON} blue |        |
| 23   | 0.454 | 8.60        | C_{NS} red |          |
| 28   | 0.575 | 8.45        | C_{NS} red |          |
| 29   | 0.494 | 8.55        | C_{NS} red |          |
| 33   | 0.936 | 8.35        | C_{ON} blue |        |
| 37   | 0.785 | 8.44        | C_{NS} red |          |
| 39   | 0.949 | 8.36        | C_{NS} red |          |
|      |       |             |        |          | NGC 3023 |
| 08   | 0.449 | 8.16        | T_{\beta} blue |     |
| 12   | 0.336 | 8.16        | T_{\beta} red |         |
| 14   | 0.110 | 8.34        | C_{ON} blue |          |
| 18   | 0.665 | 8.09        | C_{NS} red |          |
| 19   | 0.575 | 8.22        | C_{NS} red |          |
| 21   | 0.826 | 8.09        | C_{NS} red |          |
| 22   | 1.117 | 7.99        | C_{NS} red |          |
|      |       |             |        |          | NGC 4030 |
| 46   | 0.910 | 8.52        | C_{ON} blue |          |
|      |       |             |        |          | NGC 4123 |
| 6    | 0.001 | 8.60        | C_{NS} red |          |
| 14   | 0.528 | 8.54        | C_{ON} blue |          |
| 18   | 0.711 | 8.47        | C_{NS} red |          |
| 20   | 0.629 | 8.51        | C_{NS} red |          |
| 21   | 0.646 | 8.54        | C_{NS} blue |         |
| 22   | 0.889 | 8.44        | C_{NS} blue |         |
| 26   | 1.399 | 8.26        | C_{ON} blue |          |
|      |       |             |        |          | NGC 4517A |
| 44   | 0.603 | 7.95        | C_{ON} blue |          |
| 56   | 0.082 | 8.32        | C_{ON} blue |          |

Notes. Standard error for the C-based methods is around 0.1 dex. See Sect. 5.1 for more details.

The best linear fit to all the data points (11 points) with galactocentric distances smaller than the isophotal R_{25} radius is

\[ 12 + \log(O/H) = 8.75 \pm 0.02 - 0.414 \pm 0.030 \times (R/R_{25}), \]

with a mean deviation of 0.026 dex around the relationship. The resulting relation is represented with a solid line in panel b) of Fig. 8.

**NGC 3023.** The auroral line R = [OIII]4363 was detected in two blue spectra of H II regions in the disk of NGC 3023. The oxygen abundances in those H II regions were determined through the direct T_{\beta} method. Those abundances are shown with plus signs in panel c) of Fig. 8. The strong lines [OII]\lambda 3727, 3729, H\beta, [OIII]4959,5007, H\alpha, and [NII]6548 were measured in one blue spectrum.

We derived the oxygen (O/H)_{CNS} abundance, finding the total nitrogen flux N_{2} to be 4 [NII]6548. This abundance is shown with the black filled square in panel c of Fig. 8. The strong lines H\beta, [OIII]\lambda 4959,5007, H\alpha, [NII]\lambda 6548,6584, and [SII]\lambda 6717,6731 were measured in seven red spectra and used to infer the oxygen (O/H)_{CNS} abundance for those H II regions. The total nitrogen fluxes were determined to be N_{2} = 1.33[NII]6584. Those abundances are shown with black filled circles in panel c) of Fig. 8.

There are four SDSS spectra (Sp 480-51989-056, Sp 481-51908-289, Sp 267-51608-384, and Sp 267-51608-389) of H II regions in the galaxy NGC 3023. Since there is a large discrepancy between the line fluxes reported in DR7 and DR10, these SDSS spectra were not used.

The best linear fit to the data points (nine points) with galactocentric distances smaller than the isophotal R_{25} radius is

\[ 12 + \log(O/H) = 8.32 \pm 0.04 - 0.315 \pm 0.078 \times (R/R_{25}), \]

with a mean deviation of 0.047 dex around the relationship. The obtained relation is plotted with a solid line in panel c) of Fig. 8.

**NGC 4030.** Unfortunately, the spectral setup used for this galaxy only covers the wavelengths of the H\alpha and [NII]6584 lines for one of the slits. Therefore, the strong lines [OII]\lambda 3727,3729, H\beta, [OIII]\lambda 4959,5007, H\alpha, and [NII]6584 were measured in only one blue spectrum of an H II region in the galaxy NGC 4030. The oxygen (O/H)_{CNS} abundance was estimated using the measured strong lines. The inferred abundance is shown with black filled squares in panel d) of Fig. 8. There are six SDSS spectra (Sp 285-51930-042, Sp 285-51663-044, Sp 285-51930-049, Sp 285-51663-058, Sp 331-52368-405, and Sp 2892-54552-293) of H II regions in the galaxy NGC 4030 in DR7. The oxygen (O/H)_{CNS} abundances based on the SDSS spectra are shown with gray (blue) open circles in panel d of Fig. 8.

The best linear fit to all the data points (seven points) with galactocentric distances smaller the isophotal R_{25} radius is

\[ 12 + \log(O/H) = 7.88 \pm 0.01 - 0.286 \pm 0.017 \times (R/R_{25}), \]

with a mean deviation of 0.009 dex from the relationship. The relation is shown with a solid line in panel d) of Fig. 8.

**NGC 4123.** The strong lines [OII]16717,6731 were also measured in the blue spectrum of one H II region in the galaxy NGC 4123. This allowed us to obtain the oxygen (O/H)_{CNS} abundance for this particular H II region. The strong lines H\beta, [OIII]\lambda 4959,5007, H\alpha, [NII]6548,6584, and [SII]\lambda 6717,6731 were measured in two red spectra. The inferred oxygen (O/H)_{CNS} abundances are shown with black filled squares in panel e) of Fig. 8. It should be noted that the H II region at the center of NGC 4123 (Slit 06) is located close to the line dividing AGNs and star-forming regions in the BPT classification diagram.

Spectra of the region near the center of the NGC 4123 were observed by Kehrig et al. (2004) and by SDSS (Sp 517-52024-504). We obtained abundances of 12+log(O/H)_{CNS} = 8.56 and 12+log(O/H)_{CNS} = 8.63 using the spectral measurements of Kehrig et al. (2004). Moreover, we measured an abundance of 12+log(O/H)_{CNS} = 8.63 using the D10 line fluxes.

The best linear fit to all the data points (ten points) with galactocentric distances smaller than the isophotal R_{25} radius is

\[ 12 + \log(O/H) = 8.61 \pm 0.01 - 0.164 \pm 0.025 \times (R/R_{25}). \]
Fig. 8. Radial distributions of oxygen abundances in the disks of our target galaxies. The plus signs are abundances derived through the $T_e$ method, the circles are abundances obtained through the $C_{SN}$ method, and the squares are those inferred through the $C_{ON}$ method. The filled symbols show abundances based on our SALT spectra, the open (blue) symbols are abundances based on spectra from the literature (see text). The solid line in each panel is the best linear fit to the data points with galactocentric distances less than the isophotal $R_{25}$ radius. (A color version of this figure is available in the online version.)

with a mean deviation of 0.025 dex. This relation is represented with a solid line in panel e) of Fig. 8.

**NGC 4517A.** The strong lines $[O\text{II}]\lambda\lambda 3727,3729$, H$\beta$, $[O\text{III}]\lambda 4959, 5007$, H$\alpha$, and $[N\text{II}]\lambda 6584$ were measured in the blue spectrum of an H II region in the galaxy NGC 4517A. In another spectrum, the line $[N\text{II}]\lambda 6584$ is out of our spectral range, but the line $[N\text{II}]\lambda 6548$ is included. We derived the oxygen ($O/H)_{C\text{SN}}$ and nitrogen ($N/H)_{C\text{SN}}$ abundances in these spectra. The total nitrogen flux $N_2$ was determined to be $N_2 = 1.33[N\text{II}]\lambda 6584$ in the former case and to be $N_2 = 4[N\text{II}]\lambda 6548$ in the latter case. These abundances are shown with black filled squares in panel f) of Fig. 8.

Romanishin et al. (1983) reported emission-line ratios $[S\text{II}]\lambda \lambda 6717 + 6731)/H\alpha$, $H\alpha/[N\text{II}]\lambda 6548 + 6584$, and $[O\text{III}]\lambda \lambda 4959 + 5007)/H\beta$ obtained from photographic spectra of four H II regions in NGC 4517A. We estimated the oxygen ($O/H)_{C\text{SN}}$ and nitrogen ($N/H)_{C\text{SN}}$ abundances from those strong lines. Romanishin et al. (1983) did not provide the positions of the observed H II regions, but listed the deprojected radii instead.

We corrected these galactocentric distances for the galaxy distance adopted here and used the resulting values. Furthermore, there are two SDSS spectra (Sp 289-51990-627 and Sp 290-51941-350) of H II regions in NGC 4517A. The abundances based on the SDSS and Romanishin et al.’s data are shown with gray (blue) open circles in panel f) of Fig. 8.

The best linear fit to all the data points (eight points) with galactocentric distances smaller than the isophotal $R_{25}$ radius is

$$12 + \log(O/H) = 8.35 \pm 0.01 - 0.663 \pm 0.033 \times (R/R_{25}), \quad (9)$$

with a mean deviation of 0.023 dex. This relation is indicated by a solid line in panel f) of Fig. 8.

5.4. Comparison between the distributions of the abundances determined through the C method and via the O3N2 and N2 calibrations

Many calibrations based on photoionization models and/or H II regions with abundances determined through the direct
Fig. 9. Comparison of the radial distributions of oxygen abundances in the disks of our target galaxies determined through the C method (filled dark [black] circles), via the O3N2 calibration (open gray [red] circles), and through the N2 calibration (plus signs). The solid line in each panel is the best linear fit to the (O/H)$_C$ abundances (the same as in Fig. 8). (A color version of this figure is available in the online version.)
the O3N2 calibration (upper panel) and through the N2 calibration (lower panel). The solid line indicates a one-to-one correspondence. The dashed lines are shifted by ±0.1 dex. Figure 10 shows the comparison of the oxygen abundances in the individual H II regions of our sample determined through the C method with the oxygen abundances obtained through the O3N2 calibration (upper panel) and through the N2 calibration (lower panel).

Figures 9 and 10 demonstrate that the (O/H)O3N2 abundances are in satisfactory agreement (within 0.1 dex) with the (O/H)C abundances for H II regions with metallicities 12+log(O/H) ≥ 8.1. However, a small systematic difference, around 0.05 dex, between (O/H)O3N2 and (O/H)C abundances seems to exist; in the sense that the (O/H)O3N2 abundances are slightly lower than the (O/H)C abundances. A large disagreement between (O/H)O3N2 and (O/H)C abundances for H II regions with metallicities 12+log(O/H) ≤ 8.1 is not surprising since the O3N2 calibration of Marino et al. (2013) is constructed for H II regions with metallicities 12+log(O/H) ≥ 8.1 and does not work at low metallicities. The differences between the (O/H)O3N2 and (O/H)C abundances exceed 0.1 dex for some H II regions with metallicities 12+log(O/H) ≥ 8.1. This may suggest that the O3N2 calibration of Marino et al. (2013) provides more reliable abundances than their N2 calibration.

In summary, the comparison between C-, O3N2-, and N2-based abundances in our target H II regions allows us to suggest that the uncertainties in the obtained (O/H)C abundances are within ±0.1 dex. This supports our estimation of the uncertainties in the abundances discussed in Sect. 5.2.

6. Discussion

The radial distributions of the oxygen abundances across the disks of all the galaxies of our sample are well fitted by linear relationships within the isophotal radius (with the abundances on the logarithmic scale). The mean deviation from the relationship is less than 0.05 dex for each galaxy. The values of the radial abundance gradient vary by a factor of ~4 among the galaxies of our sample; from ~0.16 dex R−25 for NGC 4123 to ~0.66 dex R−1 for NGC 4517A.

The correlation between the local oxygen abundance and the stellar surface brightness (OH – SB relation) or surface mass density has been discussed in many studies (Webster & Smith 1983; Edmunds & Pagel 1984; Vila-Costas & Edmunds 1992; Ryder 1995; Moran et al. 2012; Rosales-Ortega et al. 2012; Sánchez et al. 2014). In our previous paper (Pilyugin et al. 2014b), we examined the relations between the oxygen abundance and the disk surface brightness in the infrared W1 band of WISE at different fractions of the optical isophotal radius R25. We found evidence that the OH – SB relation varies with galactocentric distance and depends on the disk scale length and the morphological T-type of a galaxy. We derived a general parametric relation between abundance and surface brightness in the W1 band, O/H = f(SB) for spiral galaxies of type Sa – Sd,

\[
12 + \log(O/H) = 7.732 + 0.303 x + 0.290 x^2 + (0.288 + 0.120) x - 0.139 \times 10^{-2} \log(SB) - 0.0418 - 0.0022 x^2 \quad (12)
\]

where \(x = r/R_{25}\) is the fractional radius expressed in terms of the isophotal radius of a galaxy (\(R_{25}\)), \((SB)\) is the disk surface brightness, \(h_{W1}\) the radial disk scale length, and \(T\) the morphological T-type. It is interesting to compare the radial distributions of oxygen abundances predicted by this relationship to the radial abundance trends traced by the oxygen abundances in the H II regions in the disks of our sample of galaxies.

Figure 11 shows the comparison between the radial distributions of the oxygen abundances predicted by the O/H = f(SB) relation, Eq. (12), and the abundances obtained from the analysis of the emission-line spectra of H II regions for four of our galaxies, NGC 1087, NGC 2967, NGC 4030, and NGC 4123. The O/H = f(SB) relation cannot be applied to the other two galaxies of our sample. It was noted above that we could not determine a reliable disk scale length \(h_{W1}\) and surface brightness at the center of the disk of the galaxy NGC 3023 since the disk contribution to the surface brightness is close to the observed surface-brightness profile over a small range of radial distances only (see lower panel of Fig. 5). NGC 4517A is a Sdm galaxy (with morphological type \(T = 8\)), whereas the O/H = f(SB) relation was derived for spiral galaxies of the types Sa – Sc (i.e., for a range of morphological types from \(T = 1\) to \(T = 7\)).

Inspection of Fig. 11 shows that the oxygen abundances predicted by the parametric O/H = f(SB) relation are rather close to the abundances obtained from the analysis of the emission-line spectra of H II regions of the galaxies of the present sample where the OH – SB relation is applicable. The discrepancy usually does not exceed 0.1 dex. Thus, the parametric O/H = f(SB)
relation can be used for a rough estimation of the oxygen abundances in the disks of spiral galaxies.

Summary

Spectra of HII regions in six late-type galaxies were observed with the South African Large Telescope (SALT). The auroral line [OIII]λ4363 was detected in two spectra. The T_C-based oxygen (O/H)_T_C abundances in these two HII regions were derived using the equations of the standard T_C-method. The oxygen abundances of the other HII regions were estimated from strong emission lines through the recently suggested “counterpart” method (C method). When the strong lines R3, N2, and S2 were measured in our spectra, oxygen (O/H)_Cox abundances could be obtained. When, on the other hand, the strong lines R2, R1, and N2 were available, then oxygen (O/H)_COX abundances were determined. Moreover, we also inferred oxygen abundances of the HII regions in our target galaxies with available spectral measurements from the literature or from the SDSS spectroscopic data base through the C method.

We derived oxygen abundances from the individual one-pixel-wide spectra and considered the variations in those abundances. The abundances determined with the C method from the individual one-pixel-wide spectra are close to each other and are close to the abundances obtained from the integrated seven-pixel-wide spectrum. This can be considered as supporting evidence for the robustness and precision of the C-based abundances, which are independent of the area in the HII region image that is measured. In other words, the C method produces a reliable oxygen abundance even if a spectrum of only a part of an HII region is used.

We also determined the (O/H)O3N2 and (O/H)N2 abundances in our target HII regions using the O3N2 and N2 calibrations of Marino et al. (2013). The (O/H)O3N2 abundances are in satisfactory agreement (within 0.1 dex) with the (O/H)C abundances for HII regions with metallicities 12+log(O/H) $\geq$ 8.1. However, a small systematic difference, around 0.05 dex, between (O/H)O3N2 and (O/H)C abundances seems to exist in the sense that the (O/H)O3N2 abundances are slightly lower than the (O/H)C abundances. The differences between the (O/H)N2 and (O/H)C abundances are larger than 0.1 dex for some HII regions. This may suggest that the O3N2 calibration of Marino et al. (2013) provides more reliable abundances than their N2 calibration.

We determined the abundance gradients in the disks of our six late-type target galaxies. The radial distributions of the oxygen abundances across the disks of all the galaxies of our sample are well fitted by linear relationships within the isophotal radius (with abundances on a logarithmic scale). The mean deviation from the relationship is less than 0.05 dex for each galaxy. The values of the radial abundance gradient vary by a factor of $\sim$4 among the galaxies of our sample, i.e., from $-0.164$ dex $R_{25}^{-1}$ for NGC 4123 to $-0.663$ dex $R_{25}^{-1}$ for NGC 4517A.

We derived surface-brightness profiles in three photometric bands (the W1 band of WISE and the g and r bands of the SDSS) for each galaxy using publicly available photometric imaging data. The characteristics of the disks (the surface brightness at the disk center and the disk scale length) were found through bulge-disk decomposition. Using the photometric parameters of the disks, the oxygen abundance distributions were estimated from the relation between abundance and surface brightness of the disk in the W1 band, O/H = S/B, which had been obtained for spiral galaxies in our previous study. The oxygen abundances predicted by the O/H = S/B relation are rather close to the abundances determined from the analysis of the emission-line spectra of the HII regions in the galaxies of the present sample where
the OH – S B relation is applicable. The discrepancy is usually not larger than 0.1 dex. Thus, the parametric O/H = f(S B) relation can be used for a rough estimation of the oxygen abundances in the disks of spiral galaxies.

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