Local Volume dwarf KK242: radial velocity, SF region, and metallicity

S.A. Pustilnik, A.L. Tepliakova, Y.A. Perepelitsyna, A.Y. Kniazev, L.N. Makarova, A.N. Burenkov, S.S. Kotov, E.A. Malygin

1 Special Astrophysical Observatory of RAS, Nizhnij Arkhyz, Karachai-Circassia 369167, Russia
2 South African Astronomical Observatory, PO Box 9, 7935 Observatory, Cape Town, South Africa
3 Southern African Large Telescope Foundation, PO Box 9, 7935 Observatory, Cape Town, South Africa
4 Sternberg Astronomical Institute, Lomonosov Moscow State University, Universitetskij Pr. 13, Moscow 119992, Russia

Accepted 2022 September 9. Received 2022 September 5; in original form 2022 June 21

ABSTRACT

KK242 is a LV dwarf of transition type residing in the void environment. Koda et al. present clear indications on its connection with Scd galaxy NGC6503. This implies the distance to KK242 of \( \sim 6.3 \) Mpc and its \( M_B = -10.5 \) mag. Its radial velocity, known from the Effelsberg radio telescope \( \text{H} \) observations, reveals, however, the difference with that of NGC6503, \( \Delta V \sim 400 \text{ km s}^{-1} \). If real, this fact implies the substantial constraints on its origin. To clear-up the issue of KK242 radial velocity, we obtained with the SAO 6-m telescope spectra of its faint star-forming (SF) complex. \( \text{H} \alpha \) and \( \text{H} \beta \) emission is detected in two adjacent compact regions, the southern and northern, separated by \( \sim 2 \text{ arcsec} \) (\( \sim 60 \text{ pc} \)). Their mean radial velocity is \( V_{\text{hel}} \sim -66 \text{ km s}^{-1} \), \( \sim 100 \text{ km s}^{-1} \) lower than that of NGC6503. We use the HST Legacy Archive images and photometry of individual stars from the Extragalactic Distance Database, available for KK242, to identify in the SF complex the exciting hot stars, the probable BHeB and RHeB stars and a supernova remnant. We address, based on the possible range of its gas metallicity, the probable evolutionary paths of KK242. Using package Cloudy and parameters of the exciting B0V stars, we conclude that the observed flux ratio of [S\( \text{II} \)] doublet to \( \text{H}\alpha \) is consistent with the value of \( 12 + \log(O/H) \sim 7.35 \pm 0.18 \) dex, expected for a stripped void dIrr galaxy.

Key words: galaxies: abundances – galaxies: dwarf – galaxies: evolution – galaxies: photometry – cosmology: large-scale structure of Universe

1 INTRODUCTION

A low surface brightness (LSB) dwarf galaxy of ‘transition type’ (dTr) KK242 was first discovered by Karachentseva & Karachentsev (1998) as a potential companion of Scd galaxy NGC6503. Huchtmeier et al. (2000) observed KK242 in the 21-cm \( \text{H} \)-line with the Effelsberg 100-m radio telescope and found an emission line at the radial velocity of 426 km s\(^{-1}\). The latter differs from the radial velocity of NGC6503 by \( \sim 400 \text{ km s}^{-1} \) that looks quite unusual. Later, Koda et al. (2015) rediscovered this galaxy in the deep images of their survey for LSB dwarfs around spiral galaxies. They presented images of KK242 (their name NGC6503-d1) in various filters, including H\( \alpha \). Besides, they resolved in the broad-band images about three hundred the brightest stars of KK242. From the analysis of the colour-magnitude diagram (CMD), they derived the TRGB-based (Tip of Red Giant Branch) distance estimate consistent with that known for NGC6503.

Both galaxies fall to the region of a nearby void occupying a part of the Local Volume (hereafter LV, see for more detail Section 4.2). In the framework of the ongoing project aimed in studying various subsamples of void galaxies in the Nearby Void Galaxy (NVG) catalog (see Pustilnik et al. 2019, 2020, 2021), we conduct, in particular, their spectral observations to derive their gas metallicities and/or improve the accuracy of radial velocities. As said above, Koda et al. (2015) show that there is a compelling evidence of KK242 to be a companion of NGC6503. However, its known estimate of the radial velocity, based on a single \( \text{H} \) observation with the Effelsberg 100-m radio telescope, is too much deviating from that of the host Scd galaxy. This may ‘provoke’ various ‘exotic’ scenarios of the origin of this pair. This was the primary motivation to clear-up the issue of KK242 radial velocity.

For this end, we obtained the spectrum of the only...
known faint complex of Hα emission in KK242 detected in papers of Koda et al. (2015) and Kaisin & Karachentsev (2019). The derived here radial velocity of −66 km s$^{-1}$ differs drastically from that measured via the single dish 21-cm Hı line emission. Recently Karachentsev et al. (2022) used our Hα radial velocity to search for the possible Hı 21-cm line emission based on the VLA D-configuration data cube for KK242. They detected the very faint Hı line at the position of KK242 with the radial velocity of V(Hı) = −80 km s$^{-1}$, which is consistent within uncertainties with V(Hα) obtained in this work.

The estimate of the radial velocity of KK242 via its Hα line was our primary task. Fortunately, thanks to the appropriate seeing during these observations and a suitable position angle of the long slit, we also got the interesting by-product results related to the substructure of this emission region and its individual components. Coupled with the Hubble Space Telescope (HST) Advanced Camera for Surveys (ACS) images from the Hubble Legacy Archive (HLA) and with the photometry of individual stars available in the Extragalactic Distance Database (EDD) (Anand et al. 2021, and references therein), this enables us to discuss this star-forming complex in a more detail.

The galaxy KK242 is also interesting for a deeper insight as one of a few known dTr objects in the void environment. The great majority of the 30 known dTrs within the distances of 5 Mpc (Karachentsev et al. 2014) are related to a more typical environment like the Local Group and similar nearby groups. Such a connection can be related to the origin of this type dwarfs. Only two of these 30 dTrs, UGC1703 and KK258 reside within the nearby voids described in Pustilnik et al. (2019). Two more dTrs, Kks03 and DDO210, are well isolated, despite the latter is situated close to the border of the Local Group.

In this context, KK242 as a representative of the small minority of the void galaxy population, might display various deviations from other known dwarfs of this rare type. Besides, it is interesting to study the evolutionary path of such an unusual dwarf in the void-type global environment. The gas metallicity, if it could be estimated, is one of the important parameters used for the comparison of the observed properties of KK242 with those expected in the variety of possible evolutionary scenarios. Moreover, the issue of the massive star formation in such an atypically low-gas-density dwarf is crucial to address since this case represents even more extreme gas environment than in the late-type gas-dwarf is crucial to address since this case represents even more extreme gas environment than in the late-type gas-

### Table 1. Journal of BTA observations of KK242

| Date     | Grism       | Expos. time, s | β arcsec | Air mass |
|----------|-------------|----------------|----------|----------|
| 2020.11.11 | VPHG1200R  | 3×900          | 1.3      | 1.30     |
| 2021.11.05 | VPHG12000540 | 4×1200        | 1.1      | 1.34     |
| 2022.07.29 | VPHG1200R  | 8×900          | 1.3      | 1.25     |

2 OBSERVATIONS AND DATA PROCESSING

We obtained three optical spectra of KK242. The first spectrum of KK242 was obtained with the BTA multimode instrument SCORPIO-1 (Afanasiev & Moiseev 2005) during the night 2020 November 11, under photometric conditions (see Table 1). The long slit with the width of 1.2 arcsec and the scale along the slit of 0.36 arcsec pixel$^{-1}$ (after binning by 2) was positioned on the brightest band source along the elongation of Hα emission, corresponding to PA = −15° (see the left-hand panel of Fig. 1). For a more detailed description of the slit position relative to the emission-line regions, see Sect. 1. The grism VPHG1200R with the 2K×2K CCD detector E2V 42-40 (13.5×13.5 μm pixel) provided the spectrum coverage of 5700–7500 Å with the FWHM ∼5.0 Å.

The second spectrum of KK242 was obtained with the next observation BTA multimode instrument SCORPIO-2 (Afanasiev & Moiseev 2011) during the night 2021 November 5, under photometric conditions (see Table 1). We aimed to pick up in this spectrum all the light collected in the first observation. Therefore, accounting for the smaller seeing on this night (∼1.1 versus 1.3 arcsec), we select of the two possible slit width options, 1.0 and 1.5 arcsec, the wider one. This should allow us to directly compare the results for both spectra. The long slit with the width of 1.5 arcsec and the scale along the slit of 0.40 arcsec pixel$^{-1}$ (after binning by 2) was positioned similar to that in the first observations with PA = −15°. The grism VPHG12000540 with the 4K×2K CCD detector E2V 261-84 (15×15 μm pixel) provided the spectrum coverage of 3650–7250 Å with the FWHM ∼6.0 Å.

The third spectrum of KK242 was obtained with SCORPIO-1 and grism VPHG1200R during the night 2022 July 29, with the similar set-up as for the first observation. The long slit for this observation was positioned exactly as for the first time. Since the seeing also was close to that of the first observation, the main difference was the total integration time: 7200 sec in July 2022 versus 2700 sec in November 2020. The main goal of the latter observation was to improve the S-to-N ratio for [Sı]λλ6716,6731 doublet in the resulting average spectrum, since from the previous data its uncertainty was too high to come to more or less confident conclusion on the KK242 gas metallicity.

The main procedures of data reduction are described in Pustilnik et al. (2016). Here we briefly outline them. Our
Figure 1. Slit positions (PA = –15°) overlaid on the BTA R-band (left panel) and the HST F606W filter (ProjID 15922) (right panel) images. N is up, E is to the left. Thin lines show SCORPIO-1 slit (width = 1.2 arcsec), thick lines - SCORPIO-2 slit (width = 1.54 arcsec). A ‘nebula’ in the HST image, with the apparent diameter of ∼0.5 arcsec, is at ∼ 3.3 arcsec to the South from the brightest star of the frame (No. 1). Both objects are visible on the BTA 2d spectrum in Fig. 2 (top panel). Arrows show the brightest stars within the BTA slit. Their parameters are given in Table 3. The scales, 30 and 1 arcsec, respectively, are shown by horizontal bars. Circle in the HST image shows the FWHM = 1.3 arcsec seeing for the SCORPIO-1 spectrum.

standard pipeline with the use of IRAF$^1$ and MIDAS$^2$ was applied for the reduction of long-slit spectra. It includes the following steps: removal of cosmic ray hits, bias subtraction, flat-field correction, wavelength calibration, night-sky background subtraction. Spectrophotometric standard stars observed during these nights, were used to obtain spectra in the absolute flux scale.

In the resulting 2d spectra of all observations of KK242, two distinct Hα knots are seen with centres separated along the slit by ∼2 arcsec. In Fig. 3 (top panel), we show a part of the 2d spectrum for the first night. The Southern knot is about twice brighter in Hα, and has a much weaker underlying continuum in comparison to that of the N knot. The 1d spectra for the S and N knots were extracted, summing up 5 or 6 (for different detectors) and respectively 6 or 7 pixels along the slit (∼ 2.1 and 2.5 arcsec, respectively), without weights, centred on each of two maxima of the Hα line signal. We have no opportunity to compare directly our observed Hα knots with those separated by Koda et al. (2015) on their Subaru telescope Hα image of KK242 with the seeing of 0.8 arcsec. However, their small angular size on the 2d spectrum indicates that their observed extent is mainly due to the seeing.

Deep images of KK242 obtained with the HST/ACS in 2019 in the framework of the SNAP program ‘Every Known Nearby Galaxy’ (Prop. 15922, PI R.B. Tully) are available in the HLA$^3$. Stellar photometry of the resolved stars at the KK242 ACS images is available at the Extragalactic Distance Database (EDD; Anand et al. 2021). They provide us with the suitable data to get a deeper insight in the star-forming complex covered by the BTA long slit.

We used both F606W and F814W HST/ACS images of this program to identify objects related to the Hα emission in our spectrum and to estimate their available physical parameters such as luminosity, size, colour. Close in the position to the S knot, in both HST images there is a well resolved almost round nebulosity with the diameter of ∼

---

1 IRAF: the Image Reduction and Analysis Facility is distributed by the National Optical Astronomy Observatory, which is operated by the Association of Universities for Research in Astronomy, Inc. (AURA) under cooperative agreement with the National Science Foundation (NSF).

2 MIDAS is an acronym for the European Southern Observatory package – Munich Image Data Analysis System.

3 https://archive.stsci.edu
Table 2. Average (top) and separate nights (bottom) parameters of S and N knots in KK242. Line fluxes in $10^{-17}$ erg cm$^{-2}$ s$^{-1}$; FWHM in Å.

| $\lambda_0$(Å) | Ion       | F(λ)       | FWHM†       | F(λ)       | FWHM†       |
|---------------|-----------|-------------|-------------|-------------|-------------|
| 6563 Hα       | S knot    | 2.98±0.05   | 5.8±0.1     | 1.63±0.07   | 5.1±0.1     |
| 6717 [S ii]   | S knot    | 0.44±0.11   | 7.9±0.7     | 0.11±0.15   | 5.1         |
| 6731 [S ii]   | S knot    | 0.23±0.09   | 6.0±1.0     | 0.07±0.13   | 5.1         |
| EW(Hα) Å      |           | 333±7.0     |             | 55±0.3      |             |
| 4861 Hβ       | S knot    | 1.47±0.22   | 6.5±0.9     | 0.44±0.11   | 8.3±1.9     |
| 5007 [O iii]  |           | <0.30 (2σ)  | ...         | <0.20 (2σ)  | ...         |
| 6563 Hα       | N knot    | 3.62±0.15   | 5.9±0.1     | 1.74±0.11   | 6.2±0.2     |
| Rad. vel.     |           | -65±10 km s$^{-1}$ | -44±14 km s$^{-1}$ |
| 2021.11.05    | S knot    | N knot      |             |             |             |
| Rad. vel.     |           | -80±10 km s$^{-1}$ | -59±14 km s$^{-1}$ |
| 2022.07.29    | S knot    | N knot      |             |             |             |
| Rad. vel.     |           | -87±10 km s$^{-1}$ | -61±14 km s$^{-1}$ |

Notes. * For S knot, the average FWHMs for all three lines are taken on two observations with SCORPIO-1 as having the better spectral resolution. For N knot, the similar average only for the Hα line is adopted. For the low-signal [S ii] lines, the two-gauss fitting was performed with the FWHM equal to that of Hα.

0.5 arcsec (or ~15 pc). No any reliable star-like counterpart is visible within the nebulosity extent. On the other hand, a more careful analysis (see Section 3.2) of this HST image reveals a blue star at ~0.7 arcsec to the North (No. 5 in Fig. 1, right), which could ionize the surrounding gas and, thus, to also contribute to the Hα emission in this region.

For the Northern Hα knot, the situation also appears to be complicated. We discuss this issue in Section 3.2. The resulting 1d spectra are shown in the middle and bottom panels of Fig. 2.

3 RESULTS

3.1 Emission line parameters of KK242

The results of emission line measurements and analysis for the average spectra of all three nights are presented in Table 2. For the S and N emission-line 'knots', we present the absolute fluxes (in units of $10^{-17}$ erg cm$^{-2}$ s$^{-1}$) for Hα and [S ii] doublet and their widths (FWHM), as well as the equivalent widths of Hα and the measured heliocentric radial velocities with their uncertainties.

We notice that the measured line widths in the spectra of the S knot are somewhat broaden relative to the instrumental FWHM ~ 5.1 Å, as measured for the Hα line in the N knot. While for the lines of the [S ii] doublet, the S-to-N is lower, there is also a hint on their broadening in the S knot. The spectral resolution for the spectrum on 2021 November...
The radial velocities measured on Hα for the S and N knots, averaged on the three independent datasets, are respectively, $-77 \pm 10$ km s$^{-1}$ and $-55 \pm 10$ km s$^{-1}$. The radial velocities for the both knots seem to show the systematic difference of $\sim 20$ km s$^{-1}$ in all three spectra. We have no at the moment additional arguments to treat one of them to be a more representative of the galaxy radial velocity. Therefore, we adopt their average of $-66 \pm 10$ km s$^{-1}$ as the robust estimate of KK242 radial velocity in the line Hα.

The line [NII]λ6584 is not detected. The upper limit on its flux F(λ) in the S knot, adopted as 3σ(noise) in the adjacent continuum multiplied by the instrumental FWHM = $5.0 \, \text{Å}$, is $0.2 \times 10^{-17}$ erg cm$^{-2}$ s$^{-1}$. This is a factor of three smaller than the flux of the [SII] doublet.

The relative flux of [SII] doublet to that of Hα is a sensitive parameter for checking the possible range of gas metallicity in KK242. For the S knot, the contribution of the emission from the nebula, a probable SN remnant, can substantially exceed the expected contribution from an HII region excited by a nearby hot mass star (see discussion in Sect. 4.4). For the N region, we have an unambiguous case, in which only the nearby hot stars provide the ionizing radiation, so that [SII] lines should reflect the abundance and physical conditions characteristic of normal HII regions.

The comparison of the three individual spectra of the N knot indicates that the strength of the [SII] doublet relative to that of Hα varies by a factor of 2–3. This means that these faint lines are in fact at the level of about one σ of the noise or so. Therefore, discussion of [SII] doublet in the individual spectra is irrelevant. To derive a more reliable estimates of the strength of the [SII] doublet, we obtained the weighted mean of all three individual spectra with the weights adopted as $1/\sigma^2_{\text{noise}}$. Here the noise was estimated on the wavelength range between Hα and [SII] doublet. As one can see in Figure 2 (middle) and Figure 3 (left), the signal in the individual lines of the doublet in the N knot is comparable to the noise spikes.

We employ the next approach to get the best approximation of the real line fluxes. We use all a priori information on the line positions and widths based on the measured parameters of the Hα line. We also adopt the low-density case and the related flux ratio $I(H6716)/I(H6731) = 1.4$. With these parameters fixed, we vary the amplitude of the main peak to get the lowest value of the residuals. The resulting line fluxes are shown in the top part of Table 2. For further discussion, we use for the N knot the parameter of flux ratio $[\text{SII}]/H\alpha = 0.18/1.63 = 0.11$, with the conditional uncertainty of 50%, that is $0.11 \pm 0.055$. For the S knot, the respective value of $[\text{SII}]/H\alpha$ is $0.67/2.98 = 0.225 \pm 0.073$. We use this parameter in Section 4.3.

In Fig. 4, we present a wider range spectra of both the N and S knots of KK242. They show the absence of the [OIII]λ5007 that is consistent with the very low excitation in the discussed HII regions.

For discussion of the possible interpretation of the visible nebular emission, it is useful to examine the Hα flux distribution along the slit relative to the northern peak of continuum related to the brightest red star at the HST im-

---

**Figure 3.** Two-gauss fitting of the region of [SII]λ6716.6731 doublet in KK242. Dotted lines show the observed signal. Solid lines show the fitting. See comments on the gauss fitting in the text. **Left-hand panel:** The N knot. **Right-hand panel:** The S knot.

**Figure 4.** BTA spectra of 2021.11.05 of KK242 for the N and S knots in the range from Hβ to Hα and [SII]λ6716.6731. **Top panel:** The N knot including part of continuum of star No. 1 (the extracted range along the slit of $\Delta X = [-0.3, -1.5]$ arcsec) in Fig. 6. **Bottom panel:** The S region including continuum of the nebula (the extracted range of $\Delta X = [-1.5, -3.5]$ arcsec) in Fig. 6.
Figure 5. Hα line and the adjacent continuum emission distribution along the slit in KK242 spectrum on 2021.11.05. The position of the brightest continuum peak (X = 0) corresponds to position of Star No.1 at the HST image in Fig. 1 (right panel). Top panel: Net Hα (red), sum of the adjacent continuum and Hα (black), the adjacent continuum (green). The secondary ‘peak’ of continuum is at ~3 arcsec to the South, is close to the positions of the Nebula and star No. 5 and looks to be extended further to the South. Bottom panel: Same for the region of Hβ emission.

age, star No. 1 (see the right-hand panel of Fig. 1). In the top panel of Fig. 5, we show the flux distribution along the slit for Hα-line emission (red), for the adjacent continuum (green) and for their sum (black). To tie the relative positions of the line emission to the position of the ‘bright’ red star No. 1 in Fig. 1, we count X-axis coordinate in Fig. 5 from the position of the highest peak of continuum which corresponds to this star. Negative values of X-axis correspond to the direction approximately to the south.

One can see that Hα emission has a two-peak distribution, both shifted to the S relative to star No. 1. A two-Gaussian fit to the flux distribution allows us to get their positions as X(S) = −2.5 arcsec and X(N) = −0.7 arcsec.

Finally, the total flux of Hα is adopted as a sum of the nominal fluxes in S and N knots according to the data on 2021.11.05 as obtained with the better seeing and a wider slit (bottom of Table 2), namely F(Hα) = (5.36 ± 0.18) × 10^{-17} erg cm^{-2} s^{-1}. We expect that due to the loss of a fraction of Hα emission falling outside the slit, the real flux in this region can be a factor of 1.5–2 larger. We address the comparison of this parameter with earlier data in Section 4.3.

3.2 HST objects in the SF region

In Table 3 we present positions and parameters of the brightest 8 stars and of one nebula which fall within the central area of the BTA long slit. They all can contribute to the visible continuum and the line emission. All these objects are marked in Fig. 1 (right). This should help to identify them in the course of the further discussion. Their HST/ACS pixel coordinates and visible V and I magnitudes are taken from the table KK242.phot.WEB at the EDD site where parameters of all measured in KK242 636 stars are presented.

Their world coordinates are taken from the available HST fits images of this region. For the nebula, we obtained our own aperture photometry with the radius of 0.25 arcsec, which encompasses the whole object’s light. We linked its instrumental magnitudes with those derived for star No. 1. From their difference, we derived the V and I magnitudes of the nebula, presented in Table 3. We further discuss objects identified at the HST images in Sect. 4.1.

4 DISCUSSION

4.1 Morphology of the SF region and related issues

The long-slit position for spectroscopy of the HII region in KK242 was determined based on the published Hα images available at that time (Koda et al. 2015). The slit PA = −15° was also chosen to put the slit closer to the visible elongation of the HII region in order to increase the chances to catch a knot with a higher excitation. As the analysis of the HST image in Fig. 1 (right) reveals, the slit properly covers all hot stars except the bluest one, no. 6. For this object, accounting for the seeing of 1.1–1.3 arcsec, we probably lose up to a half of the star and the related HII region flux relative to the other discussed stars.

Besides, as described at the end of Sect. 3.1 the nominal measured flux of Hα in this region is ~ (0.54 ± 0.02) × 10^{-16} erg cm^{-2} s^{-1}, with the possible upwards correction by a factor of 1.5–2 due to the loss on the slit. There are two independent estimates of this parameter (obtained from Hα imaging, in units of 10^{-16} erg cm^{-2} s^{-1}) in papers by Koda et al. (2015) (2.3 with the uncertainty of factor of two) and Karachentsev et al. (2022) (4.7 ± 2.5). Taking into account their large uncertainties and our upward correction of the nominal flux of Hα, we suggest that the real flux of Hα in this region is of ~10^{-16} erg cm^{-2} s^{-1}.

Our task is to connect the visible Hα emission on the BTA long-slit spectra with the exciting hot stars visible in this region at the HST image. This allows us to better understand probable parameters of the SF episode in this region. Besides, this information will be helpful in the attempt of modelling the observed nebular emission (e.g. with CLOUDY package, see the Appendix).

4 https://edd.ifa.hawaii.edu/get_cmd.php?pgc=4689184
As the derived (V–I)_0 colours of stars in Table 3 indicate, the two brightest stars, no.1 and no.2 are not hot and therefore have no relation to the observed nebular emission. No.1 is likely a Red Helium Burning (RHeB), while no.2 and 7 with the colour (V–I)_0 ~ 0.0 mag are likely Blue Helium Burning (BHeB) stars (McQuinn et al. 2011, 2012). Both types are products of the late evolution with the He-core burning of stars with the intermediate masses of 2–15 M⊙. The measured absolute magnitudes of M_V = −7.0 mag for star no. 1 and −4.3 and −4.4 mag for no.2 and 7, evidence to the extended episode of SF in this region, with the duration of at least of 100 Myr (McQuinn et al. 2011).

Stars no.3, 4, 5 and 6 all are rather blue and luminous, seemingly representing the main-sequence late O-type and/or early B-type stars. We use the sample of O and B stars from the Wing of the Small Magellanic Cloud (SMC) of Ramachandran et al. (2019) for which these authors present the observed and model physical parameters. Since this large sample of OB stars have the nearest metallicity and thus are the best proxies to KK242 massive stars, we use their M_V as a comparison for our blue luminous stars. As one can see, the SMC OB stars show the substantial scatter in their M_V. Accounting for this information, the blue stars found in the KK242 SF complex can be assigned to the range of 0.9V to B1V. The bluest (hottest) star No. 6 is probably an O9V, while the remaining, a bit redder stars, are probably of B0V–B1V type.

The positions of blue stars no. 3, 4 and 6 are close to the position of the brightness peak of the Northern Hα knot. Respectively, the position of the brightness peak of the Southern Hα emission is close to the position of the blue star no. 5. On the other hand, it is also rather close to the position of the adjacent red nebula, so that it can contribute to the observed nebular emission of the S region as well.

Since the projected distances between the hot stars no. 3, 4 and 6 are of ~20–30 pc, for the gas density N ≲ 10 cm⁻³, their Strömgren radii should be smaller than their mutual distances, so it is unlikely that they form a common HII region. However, the separate HII regions around these stars can contribute to the total observed nebular emission in the northern Hα knot due to the insufficient angular resolution along the slit. A similar situation takes place for the southern Hα emission. Here, the hot star no. 5 is a clear candidate for the line emission from the related HII region. However, the adjacent nebula, a probable SN remnant, can make a major contribution.

Indeed, as one can see from Table 2 the Hα line flux is a factor of two larger in the southern knot relative to that in the northern knot. Taking into account that in the N region, we have three hot massive stars (no. 3, 4, 6) with parameters close to those of star no.5 in the S knot, it is reasonable to assume that the Hα luminosity of HII region excited by star no.5 is lower (about factor of 2–3) than the respective luminosity for the three HII regions comprising the N knot. From this consideration it follows that the main contribution to the line and continuum emission of the S knot comes from the nebula, a candidate SN remnant.

This coarse analysis shows that the observed spectra of this SF complex, with the limited angular resolution typical of the ground-based observations, represent rather complicated combination. So that their interpretation, even for a higher S-to-N case, can be not that straightforward. They can hope that for the exceptional ground-based observational conditions, with a seeing of ≤0.5 arcsec and with the appropriate slit width oriented at a proper direction, one can disentangle the contribution of various HII regions and en...
able obtaining of the strong-line fluxes and the subsequent estimates of the gas metallicity. More chances for the detection of the strong oxygen lines are expected for the H ii region around star no. 6, the hottest of all massive stars in KK242, judging on its V–I colour. Also, the projected distance of ∼0.7 arcsec between star no. 5 and the centre of the nebula should be sufficient to disentangle emission lines of the two objects.

4.2 Environment

The dwarf galaxy KK242, as well as its host spiral galaxy NGC6503, resides within a nearby void, No. 22 (also named Dra-Cep) in the list of Pustilnik et al. (2019). Their distance to the nearest luminous galaxy NGC6946 is $D_{NN} = 2.25$ Mpc. The void is a bit flattened spheroid with the large diameter of 21 Mpc. The centre of the void is at the distance of 13.9 Mpc from the Local Group, in the direction of RA = 20.4 h, Dec. = +71°. The Dra-Cep void is situated above the supergalactic plane $SGZ=0$, being adjacent at SGX ∼ +10 to +20 Mpc to the largest nearby void Oph-Sgr-Cap which includes the well known Local (Tully) Void (see illustration in fig. A5 of [Pustilnik et al. 2019]). Fifty galaxies reside within the void boundaries (Pustilnik et al. 2019). Of them, 44 are classified as the ‘inner’ void galaxies, defined as those with the distance to their nearest luminous neighbour $D_{NN} \geq 2.0$ Mpc. Both KK242 and NGC6503 are assigned to the ‘inner’ void galaxies.

4.3 Evolutionary scenarios and gas metallicity

4.3.1 KK242 as a void dwarf of transition type

The phenomenon of dTr is not well understood. The assignment of a dwarf to the transition type is a purely phenomenological. While these dwarfs have in general the substantial amount of gas, comparable with that in dIrrs, their current star formation as traced by the H ii emission of the related Hii regions, is (almost) quenched. Five the nearest and seemingly the best studied examples of dTrs (or dIrr/dSph) are found within the Local Group and reviewed by [Mateo 1988], [Skillman et al. 2003] added to them three similar dwarfs in the Sculptor group and via the analysis of the HST CMDs addressed the nature of "transition" dwarfs. They conclude that the examined dTrs are similar on the gas content to dIrr and are "found preferentially among the lowest luminosities and nearer to spiral galaxies. Their appearance thus is caused by the temporary interrupted star formation. However, the tidal effects of massive hosts also may play a role'.

Later [Weisz et al. 2011], with deep HST data, studied SF histories (SFHs) of 60 dwarfs within 4 Mpc. Of them, 12 are classified as dTrs. One of their conclusions is that despite the large diversity, the mean SFHs of dIrrs, dTrs and dSphs are similar over most of cosmic time, with the clearest difference between the three only during the most recent 1 Gyr. They also conclude: ‘In terms of their environment, SFHs and gas fractions, the majority of the dTrs appear to be low-mass dIs that simply lack Hα emission, similar to the LG dTr DDO210. However, a handful of dTrs have remarkably low (but detectable) gas fractions, suggesting that they nearly exhausted their gas supply, analogous to the LG dTrs such as Phoenix and LG83.’

As mentioned in Section Introduction, to date, the great majority of the known dTrs are found in groups and near massive hosts [Karachentsev et al. 2014]. This can be, at least partly, due to the observational selection effects, since for the faint isolated dwarfs of this type, the determination of their radial velocity, similar to the case of dEs, is a difficult task.

One can think on the different origin and evolutionary scenarios of dTr objects, that can be related, in particular, to their global environment. For the majority of the currently known dTrs, the simplest scenario assumes their relation to ‘normal’ dIrrs with the lowest baryonic mass, in which the intermittent SF occurs with the duty cycle larger than (a few) tens Myr. For the alternative scenarios, in particular, for gas-poor dTrs, there are various options. For example, a normal dIrr progenitor could lose the major part of its gas due to the close passage near a more massive host (e.g., Di Cintio et al. 2021). Another option is a long-ago formed dSph/dE which was recently rejuvenated due to the gas accretion. As far as we aware, the variant of the metal-enriched gas accretion from the outer parts of a massive host to a dwarf companion is not yet modelled. That is one can not describe, at which circumstances this will occur, if at all. On the other hand, in voids, where gas velocities in filaments are low [Aragon-Calvo & Szalay 2013], the unprocessed gas accretion from filaments to small dwarfs can probably work.

Coming back to the properties of KK242, we notice, that on the low gas content it resembles the minority of dTrs, which ‘nearly exhausted their gas supply’, in difference to the main group of dTrs. Due to the similar SFHs of dIs and dTrs, with except of the last 1 Gyr [Weisz et al. 2011], one of the evolutionary scenarios for dTr objects involves the late gas removal and the related star formation quenching. Therefore, one can expect that the progenitors of gas-poor dTr objects have been evolving most of their lifetime similar to dIrrs with the same mass. Then, if the metallicity of the removed gas was typical of the gas in the whole galaxy, the remaining gas should be representative of the previous secular evolution. In this scenario, it is probable that the gas metallicity in dTrs is similar to that in dIs with the same stellar mass and luminosity.

4.3.2 Gas metallicity as expected from the global parameters

The gas metallicity of late-type galaxies in the LV follows the trend described by the relation of O/H versus $M_B$ from Berg et al. (2012). The respective linear regression reads as $12+\log(O/H) = 6.272 - 0.107 \times M_B$, with the rms scatter of $\log(O/H)$ of 0.15 dex. It extends over the range of $M_B = [-9.0, -19.0]$. The great majority of this LV reference sample belongs to typical groups and their close environs. As shown in [Pustilnik et al. 2016, 2021], the late-type dwarfs in the nearby voids have, on average, the reduced values of $\log(O/H)$ by 0.14 dex (or by ∼30 percent, with the rms scatter of 0.18 dex) relative to this reference relation. This finding was interpreted as an evidence of the slower galaxy evolution in voids. Consistently with this idea, void galaxies have also the elevated H i content, on average by 40 percent [Pustilnik, Martin 2016].
Since KK242 is not a typical late-type dwarf, the above statistical relations between O/H and blue luminosity or stellar mass, derived in Berg et al. (2012), may be not directly applicable to it. Those relations are assumed to reflect the specifics of the secular evolution of disc galaxies in the wide range of baryonic mass.

It is interesting to compare its gas metallicity with the other dwarfs of the same blue luminosity. We first derive the expected gas O/H in KK242 if its H ii region(s) metallicity obeys the above reference relation for the Local Volume late-type galaxies from Berg et al. (2012). For M_B(KK242) = −10.5 mag, its expected T2+log(O/H) = 7.40 ± 0.15 dex.

Koda et al. (2015) present the estimate of the total stellar mass for KK242 for their adopted distance of 5.27 Mpc. Accounting for the scaling due to the increased distance by a factor of 1.2, we adopt it as log(M_∗) = 6.78 dex.

We can use this log(M_∗) for an alternative estimate of the gas O/H, based on the similar relation from Berg et al. (2012), namely: 12+log(O/H) = 5.61 ±0.29 × log(M_∗), with the rms scatter of α = 0.15 dex. This gives the value 12+log(O/H) = 7.58±0.15 dex. Taking the average of the two independent estimates (7.40 and 7.58), we adopt the expected value of gas O/H for a typical dIrr with those M_B and stellar mass, as 12+log(O/H) = 7.49±0.10 dex.

If we take into account that the secular evolution of KK242 took place within a void, then, as mentioned in the beginning of this section, the expected value of O/H is lower, on average by 0.14 dex, that is, of 12+log(O/H) = 7.35 ± 0.18 dex.

4.3.3 Use of [Sii] doublet to constrain gas O/H

With a lack of information on the strong oxygen lines, our spectral data, on the first glimpse, cannot be used to derive more or less reliable empirical estimate of O/H. The only means to probe gas metallicity in KK242 and to check, whether this is consistent with the above estimate of the expected O/H, is the relative strength of [Sii] doublet. Its statistical relation with the parameter 12+log(O/H) can provide us, in principle, with the possible range of the gas metallicity of KK242 and help in the comparison with the gas metallicity expected within a particular scenario in the previous section.

In the following discussion of the N knot, we adopt the flux ratio of the [Sii] doublet and Hα as a weighted mean of the three independent measurements, as shown in the top of Table 2, namely 0.110±0.055. We adopt conditionally, for illustration, the error at the level of 50%. From the formal estimates, it’s probably twice larger. In the further comparison of the strength of [Sii] doublet to galaxies with known O/H, we need its ratio to the flux of Hβ. We adopt it from the typical flux ratio of Hα and Hβ for the Case B recombination, of ∼2.8. The latter is consistent with the flux ratio of the N component as visible in the intensity cuts along the slit in Fig. 5 (top and bottom). Then, the respective parameter, called S2 (a ratio of [Sii] doublet flux to that of Hβ), is adopted for further to be equal to 0.31±0.155. That is the most probable range of S2 is [0.155,0.465]. The respective value of lg(S2) = −0.509, with the most probable range of [−0.810,−0.333].

The parameter log(S2) can be used in principle for comparison with the statistical data compiled by Pilyugin et al. (2012) for various H ii regions in galaxies with the wide range of O/H. In Fig. 6, we plot the relation between the parameter log(S2) and 12+log(O/H) for a subsample of 161 data points from the compilation by Pilyugin et al. (2012) for all H ii regions with 12+log(O/H) (the direct method) in the range of ∼7.1 − 8.0 dex. The vertical solid black and blue dashed lines mark the expected value of gas O/H for the absolute blue magnitude and stellar mass of KK242 and its ±1 rms corridor for the case when the gas metallicity (O/H) of KK242 obeys the reference relation for late-type galaxies from Berg et al. (2012).

As discussed above, for the S region, the Hα emission appears to be the sum of two components. The first is an H ii region excited by the star no. 5, a probable B0V-B1V, and the second is the emission from a round red nebula without a detectable exciting central star. As we argued above, the main contribution to the emission of this region is due to radiation from the nebula. The profile of Hα line in this region looks broadened by the amount corresponding to the intrinsic FWHM ∼ 128 km s⁻¹. The latter corresponds to a shell expansion with the characteristic velocity of ∼64 km s⁻¹. Therefore, it is very likely that the round nebula is a supernova remnant (SNR) with an age of less than 1 Myr.

It is well known that the ratio of [Sii]λ6716,6731 flux to that of Hα (hereafter, [Sii]/Hα) is enhanced in the optical spectra of SNR due to the shock excitation. The often used empirical criterion to assign the observed emission to the shock-excited is [Sii]/Hα > 0.4. However, Kopsacheili, Zezas & Leonidaki (2020) from the analysis of the shock-excitation models based on the package MAPPINGS III (Allen et al. 2008) show that this parameter can be substantially smaller for the subsonar gas metallicities and for the shock velocities less than 200 km s⁻¹. Therefore, the observed in the Southern knot ratio [Sii]/Hα ∼ 0.225, accounting for a low gas metallicity and a ‘small’ shock velocity, is consistent with the expected in the models. Therefore, for the S region, we can not use this ratio for comparison with the statistical data for normal H ii regions.

For the N region, we adopt that the nebular emission, visible on the slit, is the sum of emission of three normal H ii regions excited by the hot stars no. 3, 4 and 6. In Fig. 6, the nominal value of log(S2)(KK242) = −0.509 for the N knot is shown by the red horizontal line, while the lines, corresponding to +1σ (−0.333) and −1σ (−0.81) are shown by the dashed blue lines.

As well seen in Fig. 6, the nominal value of log(S2)(KK242), being directly compared to the data points from Pilyugin et al. (2012), corresponds to rather wide range of 12+log(O/H) ∼ 7.8 ± 0.2 dex. The latter is significantly larger than the O/H expected for its very low M_B and M*.

This apparent inconsistency needs explanations and a discussion.

Since the used data from Pilyugin et al. (2012) is based on H ii regions with the directly measured O/H, they all have the well detected line [Oiii]λ4363. According to the CLOUDY models discussed in the Appendix, this case corresponds to H ii regions with the sufficiently large value of the ionization parameter, namely to log(U) ≥ −3.0. According to the same model grids, for a given gas metallicity, the parameter S2 can vary substantially for the range of T eff of the exciting stars of [25, 50] kK and the range of log(U) = [−4.0,−1.0].
Figure 6. Plot of parameter log(S2) versus 12+log(O/H) for observed and model H\textsc{ii} regions. Black octagons show points for 161 H\textsc{ii} regions with 12+log(O/H)(T_{e\text{ff}}) < 8.0. They are drawn from the compilation of the literature data in Pilyugin et al. (2012). Vertical solid black and blue dashed lines show the expected value of 12+log(O/H) and its probable variance (7.49±0.10 dex), corresponding to M_B and stellar mass of KK242, in the case if its O/H follows the reference relation 'O/H versus M_B' for the LV sample of Berg et al. (2012). Green solid and dashed vertical lines show the probable O/H for similar galaxies residing in voids (7.35 dex) and its ±1σ value (7.53 dex) (Pustilnik et al. 2021). The horizontal solid red and two blue dashed lines show the nominal value of log(S2) for KK242 Northern knot and its ±1σ range. We also draw the linear regression of log(S2) on log(O/H) for the above sample of 161 points (solid black) and its upper envelope (dotted black). Red and green diamonds correspond to the maximal values of S2 for a given value of O/H, which occur for models with the values of the ionisation parameter of lg(U) = –4.0 and –3.0, respectively. They occur for the lowest considered T_{e\text{ff}} of the exciting stars, of 25–30 kK, as illustrated in Fig. A1 of Appendix A. The red dotted line shows the linear approximation of positions of the red diamonds. We also add 9 points with the direct values of 12+log(O/H) ≲ 7.32 dex (blue squares), published after 2012 (see references in the text), to illustrate the large scatter of the parameter S2 for the low values of O/H in comparison to the limited data from Pilyugin et al. (2012). See text for details and discussion of this figure.

To discuss more general cases, we draw in Fig. 6, in addition to the observed H\textsc{ii} regions with the direct O/H from Pilyugin et al. (2012), the model-predicted values of S2 for a wider range of log(U) and T_{e\text{ff}}, derived with the Cloudy package in Appendix. Here, green and red diamonds show the maximal values of log(S2) for nine values of 12+log(O/H) between 7.00 to 8.04 dex for log(U) = –3.0 and –4.0, respectively. These maximal values of S2 correspond to the minimal values of T_{e\text{ff}} from the grid with T_{e\text{ff}} = 25–50 kK with the step of 5 kK.

Coming back to the N region of KK242, we notice that its nominal value of log(S2)=-0.51 corresponds to 12+log(O/H)=7.44 dex in the case of this region is ionized by the lowest T_{e\text{ff}} (25–30 kK) and the lowest log(U) source (~–4). This is well consistent with the expected void dwarfs metallicity mentioned above of 12+log(O/H) = 7.35 ± 0.18 dex.

It is worth to noting that the sample of the reference H\textsc{ii} regions from Pilyugin et al. (2012) does not cover completely the real parametric space in the plane 12+log(O/H), log(S2) for regions with the directly derived O/H, at least for the lowest gas metallicities. We added in Fig. 6 ten data points with the direct 12+log(O/H) ≲ 7.3 dex (blue squares), appeared in the literature after 2011 in papers by Izotov, Thuan & Guseva (2012), Izotov et al. (2018), Izotov, Thuan & Guseva (2019), Skillman et al. (2013), Hirschauer et al. (2016), Hsyu et al. (2017), Pustilnik et al. (2021). Seven of them fit well the region defined by the data from Pilyugin et al. (2012) and its extension to the lower O/H. However, the parameter log(S2) for 'Little Cub' and regions UGC772-N2 and N3 falls significantly higher than for the
remaining majority. In particular, the region UGC772-N2 has the S2 parameter close to that of the N knot in KK242 and very low 12+log(O/H) ~ 7.3 dex.

4.3.4 Probable parameters of exciting stars in KK242.
Similar case of Pegasus DIG

To complete the discussion on the consistency of the observed parameter S2 in the Northern Hα knot in KK242 with the expected low gas metallicity, of 12+log(O/H) ≲ 7.40 ± 0.10 dex, we examine the range of possible parameters of the hot massive stars illuminating this Hα region. We are interested whether their effective temperatures and the ionising photon fluxes are consistent with the CLOUDY package parameters resulting in the largest values of S2 for that low gas metallicity (red and green diamonds in Fig. 6).

The observed parameters of the related stars nos. 3, 4 and 6 are summarized in Table 3 and discussed in Section 4.4. We use the results of modelling of a large sample of massive OB stars in SMC presented in Ramachandran et al. (2019). The metallicity of this sample is the closest to that expected for gas and young stars in KK242. Thanks to the good statistics and the large set of modelled physical parameters, this allows one to use the average parameters for a star of the given spectral class as well as to understand the real range of their scatter.

The rough estimate of the expected parameter log(U) in the considered region can be derived taking the typical flux of the ionising photons of B0V stars in the SMC, pre-

As the examination of the CLOUDY grids in Appendix shows, for 12+log(O/H) = 7.35, the largest value of parameter S2 occurs at log(U) = -4.0, and for the lowest T$_{\text{eff}}$ = 25–30 kK, reaching the value of 0.26. Similarly, for grid with 12+log(O/H) = 7.53, the largest value of parameter S2 occurs at log(U) = -4.0, reaching the value of 0.37. The nominal value of the observed parameter S2 = 0.31, midway between the values of S2 for the latter the lowest log(U) models, implies that the respective value of its 12+log(O/H) falls midway between 7.35 and 7.53 dex, that is ~7.44 dex. For this combination, the expected ratio of F(3727)/F(Hβ) = 1.2 – 1.4, F(5007)/F(Hβ) ≲ 0.02. It is worth to noting that despite the current data on the value of parameter S2 allows us to safely assign the N region to the very low metallicity regime, the higher S-to-N fluxes for the [SII] doublet are required to increase the accuracy of the derived O/H.

4.3.5 Alternative value of KK242 gas metallicity and a possible related scenario

In the previous sections we presented the arguments that in the N knot of KK242, the measured parameter S2 is well consistent with the value of the gas O/H, expected from Berg et al. (2012) reference relations for log(O/H) versus M_B and versus M_eff, and also with the reduced gas metallicity as expected for a void galaxy. With this low gas metallicity one could think on the typical late-type galaxy secular evolution and the ‘recent’ loss of the main gas mass and the related drop of the ‘normal’ star formation.

Since the real uncertainty of the nominal value of S2 is ~100%, we should check the variant of interpretation of a twice larger value of S2, that is 0.62, or log(S2) = -0.21. As one can see in Fig. 6, this value of log(S2) is close to the CLOUDY model points for log(U) = -4.0 (red dotted line) at 12+log(O/H) ~ 7.8 dex that is too high for void dIrrs with the luminosity and mass similar to that of KK242.

What kind of scenario could result at that elevated gas metallicity for the very low stellar mass and luminosity of KK242? One of the possible variants is related to the gas in-flow to KK242 from the outer parts of the disc of NGC6503 in course of their pericenter passage. We did not find in the literature the published estimates of the gas metallicity in NGC6503 despite its 2D spectra in the range 3600–6800 Å were obtained with the integral field unit VIRUS-P (Blanc et al. 2013). Therefore, we adopt for NGC6503 the expected gas metallicity, that follows from the relation in Berg et al. (2012) for the Local Volume late-type galaxies. For its absolute magnitude of M_B = -19.1 mag (HyperLEDA, averaged on several sources), the expected value of 12+log(O/H) is ~8.37 ± 0.15 dex. For disc galaxies with the visible metallicity gradients, this parameter is usually adopted at the radial distance of r_eff/2. Thus, taking into account rather small metallicity gradients in the subluminous galaxies like NGC6503 (~0.02–0.03 dex r_eff), we expect the gas metallicity in the outer disc of NGC6503 at the level of 12+log(O/H) ≥ 8.1–8.2 dex.

Therefore, if we accept the hypothesis of gas inflow from NGC6503 to the extremely gas-poor precursor of dTr...
KK242, with the subsequent triggered episode of star formation, we should expect the metallicity of gas in the N knot, corresponding to 12+log(O/H) \gtrsim 8.1 \pm 0.15 dex. In Fig. 6, the 12+log(O/H) = 8.1 dex for Cloudy models with log(U) = -4.0 (red diamonds) corresponds to the value of S2 \sim 1.0 (log(S2) = 0), that is more than 2\sigma larger than the nominal value S2 = 0.31.

These estimates adopt the gas metallicity of NGC6503 based on the relation established by [Berg et al. 2012] on the subsample of the late-type galaxies within the Local Volume, and hence, should be nicely applicable to NGC6503. However, as discussed in our papers [Pustilnik et al. 2016, 2020, 2021], this sample is mostly related to the typical groups and their environs. For galaxies with the same M_B residing in the nearby voids, the gas metallicity (or log(O/H)) is in average lower by 0.14 dex. For ‘luminous’ galaxies similar to NGC6503, this effect is smaller, \sim 0.1 dex (Pustilnik et al. 2021, Fig. 1). Since NGC6503, as described in Section 4.2, resides in the void Dra–Cep, we expect that the above estimates of 12+log(O/H) should be reduced. That is the expected value of gas O/H in the N knot, in the framework of the hypothesis with the gas inflow from the outer disc of NGC6503, is 12+log(O/H) \gtrsim 8.0 dex.

We summarize this attempt to relate the highest possible value of S2 (about two S2 nominal) and the respective value of 12+log(O/H) \sim 7.8 dex for the KK242 N knot with the ‘metal-rich’ gas from the outer parts of NGC6503 (12+log(O/H) \gtrsim 8.0 dex), as follows. The gap between the two extreme possible values for the gas metallicity in KK242 and NGC6503 remains too large. So that it is hard to reconcile this hypothesis with the available data.

4.4 Fading stages of faint SF episodes and the problem of gas metallicity estimate

In the light of the discussed above dwarf galaxies with only the weak tracers of the recent SF episode, we would like to emphasize that this type of objects should be numerous and widely spread among the low mass dwarfs. Due to their low masses, their gas metallicity is expected to be in the low-Z regime.

Indeed, in a sizeable fraction of low mass late-type LSB galaxies, the observed SFR is subtle. See, e.g., [Kaisin & Karachentsev 2019] for dwarfs in the Local Volume and [Hau & et al. 2013] for small gas-rich dwarfs selected from the ALFALFA survey [Haynes et al. 2018] and [Izotov et al. 2001]. The observed H\alpha luminosities per individual H\alpha region indicate a small number of the hot massive stars in such dwarfs. The LV dwarfs with the lowest observed luminosities of L(H\alpha) of the order of \sim 10^{36} \text{erg s}^{-1} correspond to the ionising photon fluxes Q_0 of stars O9V and later. Several XMP galaxies from our recent papers [Pustilnik et al. 2020, 2021] fall to this regime as well. In addition, the new current and upcoming deep sky surveys will drastically increase the number of such galaxies.

For an instantaneous SF episode, the probability to catch it in the early phases (say, younger than \sim 8–10 Myr) when sufficiently hot stars (conditionally, O5V–O8V) are still alive\(^6\) and provide a high enough log(U) and T_{\text{eff}}, is lower than to catch a region with the exciting stars of O9V–B0V, with the lower fluxes of the ionising photons and T_{\text{eff}}. In such cases, if we wish to obtain the estimates of gas metallicity, we need some alternative means.

For that low excitation conditions and the related very low fluxes of [O\text{iii}] lines, the possibility to use the ‘strong-line’ empirical methods to estimate their gas metallicity is hampered. Due to various observational selection effects, such objects remain largely underexplored, in particular, in the context of their gas metallicity.

We suggest to use for such low excitation H\alpha regions with the Hydrogen Balmer series lines and only a few heavy element lines detected – [O\text{ii}]\lambda 3727, [Si\text{ii}]\lambda 6716, 6731 doublets and probably [N\text{ii}]\lambda 6584, the grid of Cloudy model packages with the low log(U) and low T_{\text{eff}} as typical for H\alpha regions ionized by the early B-type and late O-type stars.

The examples of such analysis for KK242 and DDO216 presented above, show that this is feasible. The main prerequisite of the successful application of such models is a sufficiently good S-to-N ratio for the used heavy element line fluxes.

The used here the Cloudy grids are based on the models of the central star with T_{\text{eff}}. The more advanced grids, with the modern stellar atmosphere models and the stellar metallicity included, can give us an advanced mean to treat spectra and derive a more reliable estimates of the gas metallicity in the low excitation H\alpha regions in a large number of dwarf galaxies within the Local Volume and its environs. This, in turn, should allow one to address the issue of chemical evolution on a wider range of galaxy parameters.

The output of such model grids in the form of the relative line fluxes can be used similar to the ‘Counterpart’ method of [Pilyugin et al. 2012] which seeks in the reference database of the observed H\alpha regions with known direct O/H for a combination of the relative line fluxes which is the closest to that in the studied H\alpha region without detected [O\text{iii}]\lambda 4363 line.

4.5 Physical parameters and star formation

The dTr galaxy KK242 is very interesting in the context of its current and recent star formation. Its gas mass is several times smaller than the typical of the comparable stellar mass and luminosity late-type LSB dwarfs. Therefore, if its H\alpha gas distribution is not strongly clumped, this suggests the reduced column density. Indeed, as the VLA map in the H\alpha line reveals [Karachentsev et al. 2022], the peak H\alpha column density in this galaxy reaches only \sim 3 \times 10^{19} \text{atom cm}^{-2}. This is to compare with the typical threshold gas column density for the onset of star formation in dwarf irregulars, blue compact and LSB galaxies defined at the level of \sim 1.0 \times 10^{21} \text{atom cm}^{-2} for the linear scales of \sim 0.5 kpc [Skillman 1987; Taylor et al. 1994; Begum et al. 2008; Eleta et al. 2008]. This can be partly explained by the large effective beam-size of \sim 60 \times 40 arcsec\(^2\) (or 1.85 \times 1.24 kpc), which smears the higher density features at smaller linear scales. However, the significant column gas underdensity of the KK242 SF region attracts the special attention to this point.

The issue of the threshold column density for the onset of SF is not settled, however (see, e.g., discussion in [Eleta et al. 2008]). The model calculations (e.g. [Schaye 2004]) predict a range for this parameter which depends on gas mass frac-

---

\(^6\) if they were really formed in the modest total mass involved.
tion, pressure, its metallicity, ionising flux radiation. Therefore, it will take much effort to understand whether the formation of the studied complex of several massive hot stars in KK242 took place in a low density gas under the special conditions.

The important factor of the SF episode onset is the proximity of KK242 to its host NGC6503. As many N-body simulations indicate (e.g., Di Matteo et al. 2007), the peak of the tidally induced SF episode occurs in a few hundred Myr after the first pericenter passage. We can roughly estimate the time since the passage of KK242 near the host. Taking the relative tangential component of velocity ($\delta V_{\text{tang}}$) approximately equal to the relative radial velocity $\delta V_{\text{rad}} \sim 100$ km s$^{-1}$, and the mutual projected distance of $\delta r \sim 31$ kpc, we estimate the respective time $t_{\text{passage}} \sim 300$ Myr. Therefore, the presence in the discussed SF region of RHeB and BHeB stars, with ages of $\sim 100$ Myr, does not contradict to the assumption that the long-lasting very localised SF episode was triggered by the strong tidal interaction with the massive host. To get a deeper insight into gas properties involved in the SF episode at such atypical conditions, it seems, one needs to wait for the ngVLA, which will allow one to obtain H$\alpha$ data simultaneously with the high sensitivity and suitable angular resolution.

### 5 SUMMARY AND CONCLUSIONS

In this study we primarily interested in the determination of the radial velocity of the ionised gas in KK242 in order to get its value independent on the previous H$\alpha$ observation. Thanks to the proper observational conditions, we spatially resolved two faint emission regions (the N and S knots) within the studied SF complex. Their appearance is rather different that pushed us to analyze them individually. Thanks to the publicly available F606W and F814W HST images of KK242, as well as of the photometry of its individual stars, we were able to disentangle the exciting stars of the observed nebular emission. In the S knot we also identify a nebula, a likely SN remnant.

Due to rather low S-to-N of the available spectra of this SF complex and comparatively low effective temperatures of the ionising massive stars, the only heavy element lines detected so far is the [SII] $\lambda$6716,6731 doublet. Its flux ratio to that of H$\beta$ (parameter S2) can be used as a rough empirical indicator of the gas metallicity. However, the S2 in our data has the large uncertainty that allows rather wide range of O/H. If we compare the observed S2 in the N knot of KK242 with the data for the sample of H$\alpha$ regions with the directly derived O/H (that is with the medium or high excitation), it corresponds to values of $12+\log(O/H)$ between 7.6 and 8.0 dex.

However, the examination of our CLOUDY package grids with the wide range of $\log(U)$ and $T_{\text{eff}}$ of ionising stars, reveals the elevated values of S2 for the 'extremely' low values of $\log(U) \sim -4.0$ and $T_{\text{eff}} \sim 25-30$ kK. These elevated values of S2 are consistent with the observed one for $12+\log(O/H)$ as low as $\sim 7.45$ dex. Meanwhile, the mentioned above 'extremely' low $\log(U)$ and $T_{\text{eff}}$ are consistent with those expected for B0V stars directly observed in this region at the HST images. The possibility of that 'low' value of O/H is important, since this is expected for KK242 luminosity and stellar mass from the reference relations for the LV late-type galaxies in [Berg et al. 2012]. The gas metallicity is a crucial parameter for the choice between possible evolutionary scenarios. The currently available estimate of O/H is consistent with the case of the typical secular chemical evolution of late-type dwarfs as possible predecessors of the dTr KK242. This conclusion remains valid if we take into account that the evolution of KK242 took place in a void, and therefore one expects it to be reduced.

We also examine an alternative scenario involving the higher metallicity gas inflow from the outer disc of NGC6503 to the 'gas-free' dE predecessor of KK242 after its pericenter passage. From the estimates of the possible metallicity of the in-flowed gas, this variant seems to be improbable due to the substantial gap between the upper limit of the gas metallicity in KK242 and the lower limit of that in the outer part of NGC6503.

Therefore, the most likely scenario of the origin of KK242 as a void dTr, combines its secular evolution as a void low-mass dIr and the 'recent' rapprochement and interaction with the much more massive host NGC6503. The pericenter passage of KK22 several hundred Myr ago resulted in the tidal stripping of its gas and triggered the episode of SF (e.g., Di Cintio et al. 2021). The traces of this 'recent' star formation are seen in the GALEX UV images as light of stars with the ages of less than a few hundred Myr (Koda et al. 2015) as well as BHeB stars in the studied here region with the faint H$\alpha$ emission.

Summarising all available data and the above analysis and discussion, we arrive at the following conclusions.

(i) KK242 is a transition type dwarf residing in a nearby void. We report its BTA spectroscopy and the new value of its radial velocity, $V_{\text{rad}} = -66 \pm 10$ km s$^{-1}$, based on the observed H$\alpha$ line in two adjacent regions of the star-forming complex identified by [Koda et al. 2015]. This value is consistent with that of the recently found faint H$\alpha$ emission from KK242 (Karachentsev et al. 2022) and is lower than the radial velocity of its host spiral NGC6503 by $\sim 100$ km s$^{-1}$.

(ii) The appearance of these two regions in the BTA 2d spectra of KK242 looks very different due to the bright light of the 'unrelated' Red Supergiant at the projected angular distance of $\sim 0.7$ arcsec from the H$\alpha$ intensity peak of the Northern H$\alpha$ knot. On the HST images of KK242, we identify the sources responsible for the visible H$\alpha$ emission within the BTA long slit. The Northern region is a superposition of three H$\alpha$ regions exciting by the late O-type and early B-type stars at the mutual projected distances of $\sim 0.7-1.0$ arcsec (20–30 pc). The H$\alpha$ emission of the Southern region is a superposition of an H$\alpha$ region excited by an early B-star and of a probable supernova remnant at a projected distance of $\sim 0.7$ arcsec.

(iii) Besides the early-type blue stars, we identify within the boundaries of this SF complex three additional luminous stars. They are tentatively classified as one RHeB star (the mentioned above Red Supergiant) and two BHeB stars. Their colours and absolute magnitudes imply their ages of $\lesssim 100$ Myr. This suggests that the recent SF episode as traced by several massive young main-sequence stars (O9-B1) in fact lasts in this location at least of $\sim 0.1$ Gyr or so.

(iv) Due to rather low S-to-N ratio spectrum of the
Northern H\textsc{ii} region and its low excitation, the only detectable metal lines appear those of the [S\textsc{ii}] doublet. We use the parameter S2 (the flux ratio of [S\textsc{ii}] to that of H\beta) to constrain the gas metallicity in this region. The direct comparison of the nominal value of S2(KK242,N) = 0.31 with the H\textsc{ii} regions from the compilation of Pilyugin et al. (2012), allows the wide range of 12+log(O/H) = 7.6–8.0 dex. This range, however, is poorly consistent with the low 12+log(O/H) ~7.4±0.1 dex, expected for KK242 low stellar mass and luminosity in the case it is treated as a dIrr which lost most of its gas.

(v) For the Southern H\alpha knot, the higher S-to-N value of flux of the [S\textsc{ii}] doublet indicates its elevated ratio relative to the flux of H\alpha. We argue that since the main contribution to the emission of this knot comes from the nearby nebula, a likely SN remnant, this elevated [S\textsc{ii}] emission is related to the shock excitation in the SNR shell.

(vii) We pay attention to the generalisation of the problem of gas metallicity determination in common low-excitation low-metallicity H\textsc{ii} regions of LSB dwarfs. In such regions, only a few heavy element emission lines are typically observed and the use of the popular strong-line empirical estimators can be impossible. We suggest to develop a grid of \textsc{Cloudy} package models representing the observed line ratios for the wide range of gas and young star metallicity when only a population with the ages of more than 10–15 Myr excites their related H\textsc{ii} regions (late O and early B-type). This will give one a new advanced mean to address the gas low metallicity in the dwarfs of the Local Universe with the low/subtle current SF.

ACKNOWLEDGEMENTS

The work was supported by the Russian Scientific Fund (RScF) grant No. 22-22-00654. The authors thank I.D. Karachentsev for sharing some results on KK242 before publication. We also thank D.I. Makarov for the help with the use of the publicly available HST data. We acknowledge the constructive suggestions of the anonymous referee which helped us to improve and clear up the paper contents. The authors acknowledge the allocation of the SAO DDT time at BTA in November 2021. Observations with the SAO RAS telescopes are supported by the Ministry of Science and Higher Education of the Russian Federation. The renovation of telescope equipment is currently provided within the national project "Science and Universities". This research is partly based on observations made with the NASA/ESA Hubble Space Telescope obtained from the Space Telescope Science Institute, which is operated by the Association of Universities for Research in Astronomy, Inc., under NASA contract NAS 5-26555. These observations are associated with program SNAP-15922. We acknowledge the use of the \textsc{Cloudy} photoionisation code to model the intensities of the common emission lines in H\textsc{ii} regions of the low excitation. We acknowledge the use for this work of the database HyperLEDA. This research has made use of the NASA/IPAC Extragalactic Database (NED) which is operated by the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration.

DATA AVAILABILITY

The data underlying this article are available in the The Extragalactic Distance Database (EDD) The HST/ACS data used in this article are available in the STScI data archive.

REFERENCES

Afanasiev V.L., Moiseev A.V., 2005, Astron. Lett., 31, 193
Afanasiev V.L., Moiseev A.V., 2011, BaltA, 20, 363
Allen M.G., Groves B.A., Dopita M.A., Sutherland R.S., Kewley L.J., 2008, ApJS, 178, 20
Anand G.S., Rizzi L., Tully R.B. et al. 2021, AJ, 162, 80
Aragon-Calvo M.A., & Szalay A.S., 2013, MNRAS, 428, 3409
Asplund M., Grevesse N., Sauval A.J. Scott P., 2009, Ann.Rev.Astron.Astrophys., 47, 481
Bagum A., Chengalur J.N., Karachentsev I.D., Shangina E.M., Kaisin S.S., 2008, MNRAS, 386, 1667
Blanc G.A., Weinzirl T., Song M. et al., 2013, AJ, 145, 138
Berg D.A., Skillman E., Marble A. et al. 2012, ApJ, 754, 98
Di Cintio A., Mostoghiu R., Knebe A., Navarro J.F., 2021, MNRAS, 506, 531
Di Matteo P., Combes F., Melchior A.-L., Semelin B., 2007, A&A, 468, 61
Ekta, Chengalur J.N., Pustilnik S.A., 2008, MNRAS, 391, 881
Ferland G.J., Chatzikos M., Guzmán F. et al. (2017) Revista Mexicana de Astronomia y Astrofisica, 53, 385-438
Filippenko A.V., 1982, PASP, 94, 715
Hauberg N.C., Salzer J.J., Cannon J.M., Marshall M.V., 2015, ApJ, 800, 121
Haynes M.P. et al., 2018, ApJ, 861, 49
Hirschauer A.S. et al., 2016, ApJ, 822, 108
Hsyu T., Cooke R.J., Prochaska J.X., Bolte M., 2017, ApJ Lett., 845, L22
Huchtmeier W., Karachentsev I.D., Karachentseva V.E., Ehl M., 2000, A&A Suppl., 141, 469
Izotov Y.I., Thuan T.X., 1999, ApJ, 639
Izotov Y.I., Chaffee F.H., Holtz C.B., Thuan T.X., Green R.F., Papaderos P., Fricke K.J., Guseva N.G., 2001, ApJ, 560, 222

7 http://leda.univ-lyon1.fr
8 http://edd.ifa.hawaii.edu/
Weisz D.R., Dalcanton J.J., Williams B.F., et al. 2011,
Taylor C.L., Brinks E., Pogge R.W., Skillman E.D., 1994,
Skillman E.D., Salzer J.J., Berg D.A. et al., 2013, AJ, 146,
Skillman E.D., Côte S., Miller B.W., 2003, AJ, 125, 593
Skillman E.D., Salzer J.J., Berg D.A. et al., 2013, AJ, 146, 3
Taylor C.L., Brinks E., Pogge R.W., Skillman E.D., 1994, AJ, 107, 971
Weisz D.R., Dalcanton J.J., Williams B.F., et al. 2011, ApJ, 739, 5

This paper has been typeset from a TeX/ LATEX file prepared by the author.

APPENDIX A: [SII]λλ6716,6731 DOUBLET: THE RANGE OF ITS STRENGTH VIA CLOUDY

In this Appendix we use the CLOUDY.17 version of the CLOUDY radiative transfer code, as described by Ferland et al. [2017], to perform calculations of the possible range for the value of parameter S2 (flux ratio of the doublet [SII]λλ6716,6731 to that of Hβ) for a range of H ii region gas metallicities. We took Oxygen abundances of 12+log(O/H) = 7.00, 7.17, 7.35, 7.53, 7.70, 7.90 and 8.04 dex.

The relative abundances C/O, N/O, Ne/O, Si/O, S/O, Ar/O, Fe/O are adopted as the averages found in the systematic study of 54 supergiant H ii regions with the range of 12+log(O/H) = 7.1 – 8.2 dex in the paper by Izotov & Thuan (1999). Since the abundance of O/H is set in the units of the Solar one, we adopt 12+log(O/H)$_\odot$= 8.69 dex according to Asplund et al. [2009].

We construct a grid of models with the range of the ionisation parameter U (log(U) from -4.0 to -1.0, with the step of 0.5, and the effective temperature of the central star (black-body) $T_{\text{eff}}$ from 25 to 50 kK, with the step of 5 kK. We then apply these results to the observational data for the Northern knot in KK242 (Fig. 6 and Section 4.3.3) and attempt to constrain its metallicity from the observed parameter S2.

We run CLOUDY in the mode ”sphere” with the adopted input parameters of the inner radius of $R_0 = 10 ^ {17}$ cm and the number density of the hydrogen nuclei of $n(H) = 10^{-3}$ cm$^{-3}$. CLOUDY then computes the structure of the photoionised region by requiring that the density be constant. The outer radius is assumed to be the one where the gas temperature falls to 4 kK since the colder gas practically does not produce optical emission lines. The resulting geometry of all models was closed, that is, the gas covers most of the central ionising source. The iterations were carried out until the optical depth of the line and continuum became stable. For the gas element abundances, we do not take into account a presumably small fraction of material which is possibly locked into grains. We remark for clarity, that the ionisation parameter $U$ shown on the X-axes of Figs. A1 and A2, is obtained as a result of a model and relates to the Strömgren radius, in a,: "sphere" model and relates to the Strömgren radius, in a ratio of

\[ \frac{U}{S_2} \approx \frac{U}{S_0} \]

according to Asplund et al. (2009).

In this Appendix we use the CLOUDY radiative transfer code, as described by Ferland et al. [2017], to perform calculations of the possible range for the value of parameter S2 (flux ratio of the doublet [SII]λλ6716,6731 to that of Hβ) for a range of H ii region gas metallicities. We took Oxygen abundances of 12+log(O/H) = 7.00, 7.17, 7.35, 7.53, 7.70, 7.90 and 8.04 dex.

The relative abundances C/O, N/O, Ne/O, Si/O, S/O, Ar/O, Fe/O are adopted as the averages found in the systematic study of 54 supergiant H ii regions with the range of 12+log(O/H) = 7.1 – 8.2 dex in the paper by Izotov & Thuan (1999). Since the abundance of O/H is set in the units of the Solar one, we adopt 12+log(O/H)$_\odot$ = 8.69 dex according to Asplund et al. [2009].

We construct a grid of models with the range of the ionisation parameter U (log(U) from -4.0 to -1.0, with the step of 0.5, and the effective temperature of the central star (black-body) $T_{\text{eff}}$ from 25 to 50 kK, with the step of 5 kK. We then apply these results to the observational data for the Northern knot in KK242 (Fig. 6 and Section 4.3.3) and attempt to constrain its metallicity from the observed parameter S2.

We run CLOUDY in the mode ”sphere” with the adopted input parameters of the inner radius of $R_0 = 10 ^ {17}$ cm and the number density of the hydrogen nuclei of $n(H) = 10^{-3}$ cm$^{-3}$. CLOUDY then computes the structure of the photoionised region by requiring that the density be constant. The outer radius is assumed to be the one where the gas temperature falls to 4 kK since the colder gas practically does not produce optical emission lines. The resulting geometry of all models was closed, that is, the gas covers most of the central ionising source. The iterations were carried out until the optical depth of the line and continuum became stable. For the gas element abundances, we do not take into account a presumably small fraction of material which is possibly locked into grains. We remark for clarity, that the ionisation parameter $U$ shown on the X-axes of Figs. A1 and A2, is obtained as a result of a model and relates to the Strömgren radius, in a ratio of

\[ \frac{U}{S_2} \approx \frac{U}{S_0} \]

according to Asplund et al. (2009).

In this Appendix we use the CLOUDY radiative transfer code, as described by Ferland et al. [2017], to perform calculations of the possible range for the value of parameter S2 (flux ratio of the doublet [SII]λλ6716,6731 to that of Hβ) for a range of H ii region gas metallicities. We took Oxygen abundances of 12+log(O/H) = 7.00, 7.17, 7.35, 7.53, 7.70, 7.90 and 8.04 dex.

The relative abundances C/O, N/O, Ne/O, Si/O, S/O, Ar/O, Fe/O are adopted as the averages found in the systematic study of 54 supergiant H ii regions with the range of 12+log(O/H) = 7.1 – 8.2 dex in the paper by Izotov & Thuan (1999). Since the abundance of O/H is set in the units of the Solar one, we adopt 12+log(O/H)$_\odot$ = 8.69 dex according to Asplund et al. [2009].

We construct a grid of models with the range of the ionisation parameter U (log(U) from -4.0 to -1.0, with the step of 0.5, and the effective temperature of the central star (black-body) $T_{\text{eff}}$ from 25 to 50 kK, with the step of 5 kK. We then apply these results to the observational data for the Northern knot in KK242 (Fig. 6 and Section 4.3.3) and attempt to constrain its metallicity from the observed parameter S2.

We run CLOUDY in the mode ”sphere” with the adopted input parameters of the inner radius of $R_0 = 10 ^ {17}$ cm and the number density of the hydrogen nuclei of $n(H) = 10^{-3}$ cm$^{-3}$. CLOUDY then computes the structure of the photoionised region by requiring that the density be constant. The outer radius is assumed to be the one where the gas temperature falls to 4 kK since the colder gas practically does not produce optical emission lines. The resulting geometry of all models was closed, that is, the gas covers most of the central ionising source. The iterations were carried out until the optical depth of the line and continuum became stable. For the gas element abundances, we do not take into account a presumably small fraction of material which is possibly locked into grains. We remark for clarity, that the ionisation parameter $U$ shown on the X-axes of Figs. A1 and A2, is obtained as a result of a model and relates to the Strömgren radius, in a ratio of

\[ \frac{U}{S_2} \approx \frac{U}{S_0} \]

according to Asplund et al. (2009).
Figure A1. Plots showing variation of parameter S2 in an H\textsc{ii} region as a function of the ionisation parameter log(U) for ionising central stars with the range of T\textsubscript{eff} from 25 to 50 kK for three values of gas O/H, 12+log(O/H) = 7.35, 7.53 and 7.70, from top to bottom, respectively, as obtained with the package Cloudy. For the fixed O/H, the S2 parameter appears a factor of 2 or so larger at log(U) $\sim$ -4.0 than for H\textsc{ii} regions with log(U) $\gtrsim$ -2.5, typical of the observed for O/H (dir) (see Fig. A2).

Figure A2. Similar plots as in Fig. A1 showing variation of the line flux ratio [O\textsc{iii}]$\lambda$4363 to H$\beta$. For T\textsubscript{eff} $\lesssim$ 35 kK, this ratio exceeds the conditional level of 0.01 (for H\textsc{ii} regions with the direct O/H determination) only for models with the ionisation parameter log(U) $\gtrsim$ -3.0.