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XMP gas-rich dwarfs in Nearby Voids: results of BTA spectroscopy

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ABSTRACT

We present the second part of results of the on-going project of searching for and studying eXtremely Metal-Poor (XMP, adopted as those with $Z(\text{gas}) \lesssim Z_{\odot}/30$, or with $12+\log(\text{O}/\text{H}) \lesssim 7.2$) very gas-rich blue dwarfs in voids. They were first identified in course of the ‘unbiased’ study of galaxy population in the nearby Lynx-Cancer void. These very rare and unusual galaxies seem to be the best proxies of so-called Very Young Galaxies (VYGs) defined recently in model simulations by Tweed et al. To date, for 16 preselected void XMP candidates, we obtained with the SAO 6-m telescope (BTA) spectra suitable for determination of O/H. For majority of the observed galaxies, the principal line $[\text{OIII}]\lambda 4363 \text{ \AA}$ used for the direct classical T_e method of O/H determination, is undetected. Therefore, to estimate O/H, we use the semi-empirical method by Izotov & Thuan, and when suitable, a new ‘Strong-lines’ method by Izotov et al. The latter is the most accurate empirical O/H estimator for the range of $12+\log(\text{O}/\text{H}) \lesssim 7.4$. Six of those 16 candidates are found to be the confident XMP dwarfs. In addition, eight studied galaxies are somewhat less metal-poor, with $12+\log(\text{O}/\text{H})=7.21\text{--}7.31$. They also can fall into the category of VYG candidates. With account of the recently published by us and previously known (9 prototype galaxies) XMP gas-rich void objects, the new findings increase the number of this type galaxies to the total of 19.

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

1 INTRODUCTION

This paper is the third in the series devoted to searching and studying the most metal-poor dwarfs in the nearby voids. In the introductions to the two preceding papers (Pustilnik et al. 2020a,b) we described in detail the previous work and motivation for the on-going project. Therefore, here we only briefly outline the main points of the earlier searches for the most metal-poor galaxies and the results obtained so far.

The prototype galaxy with the extremely low gas metallicity $[Z(\text{gas}) \sim Z_{\odot}/30]$ ¹ was discovered about a half century ago (Searle & Sargent 1972). This was a famous Blue Compact Dwarf Galaxy IZw18 (=MRK 116). Being a remarkable

on its intense star-formation burst, IZw18 remained during the long time in the focus of studies in many wavelengths, including the HST study of its resolved stellar population. The early ideas on IZw18 suggested it to be a very young galaxy formed the first stars several hundred thousand years ago. When its Red Giant Branch (RGB) stars were detected with the help of HST, its age was increased to at least $\sim 1\text{--}2$ Gyr. Meanwhile, all the accumulated observational data were reconsidered carefully by Papaderos & Östlin (2012), who accounted for a large contribution of the overall nebular emission to various photometric parameters. They concluded that despite the older stellar population may present, the major part of the stellar mass in IZw18 have formed during the last $\lesssim 1$ Gyr. For its companion IZw18C, the respective age estimate is $\lesssim 0.2$ Gyr.

The search for IZw18 analogs continued during all past

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¹ The solar value of $12+\log(\text{O}/\text{H})=8.69$ dex is adopted according to Asplund et al. (2009)

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years, mostly among the star-forming emission-line galaxies. The important step in this long-lasting process was the discovery of SBS0335–052E and its companion SBS0335–052W with the similar and a lower gas metallicity (Izotov et al. 1990; Pustilnik et al. 1997; Izotov et al. 2009).

The substantial advancement in the discovery of XMP galaxies was achieved thanks to the results of the massive spectroscopy surveys of faint galaxies, mostly of the Sloan Digital Sky Survey (SDSS Abazajian et al. 2009; Abolfathi et al. 2018). Several groups used the SDSS to search for very metal-poor candidates and to check them with the high-quality follow-up spectroscopy (e.g. Izotov, Thuan, Guseva 2012; Izotov et al. 2016; Guseva et al. 2017; Sanchez Almeida et al. 2016). In particular, about three hundred galaxies were found with the gas metallicity of $Z \lesssim Z_{\odot}/10$ (or $12+\log(\text{O}/\text{H}) \lesssim 7.7$ dex) (Izotov et al. 2016). However, the number of this way found galaxies with $Z_{\text{gas}} \lesssim Z_{\odot}/30$, to date does not exceed ~ 10 objects.

Several alternative methods based on colour and morphology selection of XMP candidates from the SDSS image data base resulted in only singular detections (e.g., Hsyu et al. 2017, 2018).

One of perspective methods for XMP dwarf search was suggested in Pustilnik & Tepliakova (2011); Pustilnik et al. (2016). It is based on the discovery of the metallicity deficiency (in average, by a factor of ~ 1.5) of galaxies in voids in comparison to similar objects in the Local Volume (LV) typical groups. It was also found that $\sim 1/3$ of the faintest void late-type dwarfs show the strongly reduced gas metallicity. Namely, their values of O/H are lower by a factor of 2–5 relative to those in galaxies of the same luminosity residing in typical groups of the Local Volume (hereafter, the reference sample from Berg et al. (2012)).

Several dwarfs with the extremely low gas O/H [$12+\log(\text{O}/\text{H}) \lesssim 7.0\text{--}7.2$], and the low or modest SFR were found in the nearby Lynx-Cancer void at the distances of 10–25 Mpc (Pustilnik et al. 2010, 2011, 2016; Hirschauer et al. 2016). The majority of them also show blue colours of the outer parts, consistent with the time since the onset of the main SF episode of $\lesssim 1\text{--}3$ Gyr, and the extreme gas-mass fractions $M_{\text{gas}}/M_{\text{bary}} \sim 0.98\text{--}0.99$. However, since they have low luminosities, mostly rather low surface brightness and faint emission lines, the discovery of such galaxies in typical redshift surveys is limited due to the severe observational selection effects.

The above discovery of the unusual void dwarfs revealed that they are almost exclusively the least luminous blue LSB galaxies in the Lynx-Cancer void. This fact suggests to look for similar objects in the other nearby voids. Thanks to the recently published ‘Nearby Void Galaxies’ (NVG) sample by Pustilnik et al. (2019, hereafter PTM19), this became real. This sample was used to separate a group of sixty NVG low-luminosity late-type dwarfs, resembling on their properties the prototype gas-rich XMP galaxies (Pustilnik et al. 2020a). For these 60 selected void dwarfs, we perform the long-slit spectroscopy to determine their gas O/H. The first part of spectroscopic results obtained with the Southern African Large Telescope (SALT) was presented in Pustilnik et al. (2020b). Here we present the second part of this study, based on spectroscopy with the Big Telescope Azimuthal (BTA), 6-m telescope of the Special Astrophysical Observatory of Russian Academy of Sciences (SAO RAS).

The rest of this paper is arranged as follows. In Section 2, we describe observations and data processing. The results of spectral observations of 20 galaxies are presented in Section 3. In Section 4, we discuss the obtained results along with other available information. Finally, in Section 5, we present our conclusions. In Appendix A, tables with line intensities, derived physical parameters and Oxygen abundances are presented.

2 OBSERVATIONS AND DATA REDUCTION

The spectral observations of mainly the Northern part of the XMP candidate sample were conducted with the SAO 6-m telescope BTA and the multi-mode focal reducer SCORPIO (Afanasiev & Moiseev 2005) in the telescope prime focus. In the period from September 2017 to January 2019 (5 nights), we used SCORPIO in the original version in the long-slit mode (width of $1.0''$, length of $\sim 6'$). In the period from October 2019 to August 2020 we observed during 7 more nights with the upgraded version of SCORPIO. This upgraded instrument allows, in particular, to change without the time loss the pre-installed grisms during observations of the same target. In this period we used the long-slit mode with the slit width of $1.2''$.

The details of observations for individual galaxies are presented in Table 1, in which we give galaxy names, the dates of observations, used grisms, exposure times (in seconds), position angles of the long slit (PA, in degrees), J2000 coordinates of the target galaxies, seeings θ (in arcseconds), and airmass.

For the main program, during the dark time, when conditions allowed, we used grism VPHG1200B with the full range of 3650 to 5450 Å and the FWHM=5.5 Å. The CCD $2K \times 2K$ detector was EEV-42-40 with the pixel size of 13.5μ , corresponding to $0.18''$ on the detector. We used the binning factor of 2 along the slit. Since our main goal was to obtain the gas metallicity in the observed galaxies, the long slit was oriented close to the current parallactic angle, in order to minimize the effect of atmospheric dispersion (Filippenko 1982). The emission lines of these spectra were used to derive the electron temperature T_e and the oxygen abundance O/H. When it was suitable, during the period since October 2019, we used along with grism VPHG1200B also grism VPHG1200R. This was done to acquire spectrum of a studied galaxy in the red (full range 5680–7430 Å, FWHM=5.5 Å) at exactly the same slit position as for grism VPHG1200B.

For the back-up program (for cases of ‘poor’ seeing and/or Moon time), we used grism VPHG1800R with the range of ~ 6100 to 7100 Å and the spectral resolution of FWHM ~ 3.5 Å. Since October 2019, grism VPHG1800R was unavailable, so we used for such cases grism VPHG1200R. These spectra allowed us to check the coincidence of optical radial velocity with that derived from H I data for those H I sources which were identified only due to the close radio and optical positions for ALFALFA blind H I survey (Haynes et al. 2018).

Besides, these spectra were used for estimates of the strength of lines $[\text{NII}]\lambda 6584$ and doublet $[\text{SII}]\lambda 6716, 6730$ relative to that of $\text{H}\alpha$. This information was subsequently used to rank the observed galaxies as more or less confident XMP candidates for the follow-up observations with

Table 1. Journal of BTA spectral observations

	Name (1)	Date (2)	Grating (3)	Exp.time (4)	PA (5)	Galaxy coord. (6)	θ'' (7)	Airmass (8)
1	AGC102728	2019.10.22	1200B	4×1200	99.0	J000021.4+310119	1.5	1.05
	—#—	2019.10.22	1200R	2×900	99.0	—#—	1.1	1.06
2	PGC000083	2019.10.22	1200B	4×900	131.0	J000106.5+322241	1.3	1.04
	—#—	2019.10.28	1200B	2×600	41.5	—#—	1.5	1.03
	—#—	2020.01.20	1200B	2×900	59.0	—#—	1.4	1.37
	—#—	2020.01.20	1200R	2×900	59.0	—#—	1.4	1.84
3	PISCESA	2017.11.16	1200B	2×1200	35.5	J001446.0+104847	1.3	1.52
4	AGC411446	2017.09.13	1800R	4×900	98.0	J011003.7-000036	1.7	1.39
	—#—	2017.11.16	1200B	3×1200	177.0	—#—	1.2	1.39
5	PISCESB	2017.11.16	1200B	2×1200	35.9	J011911.7+110718	1.0	1.44
6	AGC122400	2019.10.22	1200R	2×600	20.0	J023122.1+254245	1.2	1.19
	—#—	2020.01.20	1200B	2×900	53.0	—#—	1.5	1.31
	—#—	2020.08.19	1200B	3×900	140.0	—#—	1.2	1.13
7	AGC124609	2019.10.26	1200B	2×900	60.0	J024928.4+344429	1.1	1.10
8	KKH18	2018.01.14	1800R	3×900	235.0	J030305.9+334139	1.9	1.19
9	AGC189201	2019.01.01	1800R	2×900	42.0	J082325.6+175457	3.0	1.33
	—#—	2019.10.26	1200B	2×900	137.0	—#—	1.3	1.27
	—#—	2019.10.26	1200R	1×900	137.0	—#—	1.3	1.25
	—#—	2020.01.19	1200B	3×900	173.6	—#—	1.2	1.33
	—#—	2020.01.19	1200R	1×600	173.6	—#—	1.0	1.33
10	J0823+1758	2020.01.19	1200R	1×600	163.0	J082335.0+175813	1.0	1.11
	—#—	2020.01.20	1200B	3×900	163.0	—#—	1.5	1.12
	—#—	2020.01.20	1200R	2×900	163.0	—#—	1.5	1.33
11	J1012+3946	2018.04.15	1800R	1×900	70.0	J101259.9+394617	1.8	1.11
12	AGC208397	2018.04.15	1800R	3×900	10.0	J103858.1+035227	3.0	1.31
13	AGC239144	2018.04.15	1200B	4×900	109.0	J134908.2+354434	1.2	1.19
	—#—	2019.01.01	1800R	2×900	120.5	—#—	3.3	1.07
	—#—	2020.01.19	1200B	4×900	118.2	—#—	1.7	1.14
	—#—	2020.01.19	1200R	2×900	118.2	—#—	1.7	1.08
14	J1440+3416	2020.01.20	1200B	1×900	119.0	J144431.6+341601	1.1	1.25
	—#—	2020.05.14	1200B	2×1200	125.6	—#—	2.6	1.02
	—#—	2020.05.14	1200R	1×600	125.6	—#—	2.6	1.02
15	J1444+4242	2017.04.17	1200B	3×1200	41.0	J144449.8+424254	2.4	1.12
16	PGC2081790	2018.04.15	1200B	4×900	11.3	J144744.6+363017	1.3	1.01
17	J1522+4201	2017.09.13	1200B	2×900	62.0	J152255.5+420158	1.4	1.57
18	J2103-0049	2017.09.13	1200B	5×900	05.0	J210347.2-004950	1.7	1.44
19	AGC321307	2017.09.13	1800R	2×900	48.5	J221404.7+254052	1.6	1.14
	—#—	2017.11.16	1200B	1×1200	23.6	—#—	1.7	1.07
20	AGC334513	2019.10.28	1200B	2×900	96.0	J234850.4+233527	1.5	1.07
	—#—	2019.10.28	1200R	2×600	96.0	—#—	1.5	1.07
	—#—	2020.01.19	1200B	4×900	49.2	—#—	1.2	1.47
	—#—	2020.01.19	1200R	2×900	49.2	—#—	1.3	1.74
21	J0823+1748	2020.01.19	1200R	1×600	163.0	J082310.6+174826	1.0	1.11
22	AGC322279	2017.09.13	1800R	2×900	167.0	J220316.8+174744	1.4	1.14
23	AGC332939	2017.09.13	1800R	2×900	56.0	J230816.7+315406	1.7	1.11
	—#—	2017.11.16	1200B	3×1200	25.0	—#—	1.7	1.03

grism VPH1200B. A couple of galaxies (No.22 and 23 in Tables 1, 2) were observed at the time when the selection of the void XMP candidates was not finalized. They were identified later as residing outside the Nearby Voids from PTM19.

emission line fluxes with the use of both *IRAF*² and *MIDAS*³ we described in detail in Pustilnik et al. (2016). Below we draw the main steps of all used procedures. The standard

² 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).

³ MIDAS is an acronym for the European Southern Observatory package – Munich Image Data Analysis System

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pipeline included removal of cosmic ray hits, bias subtraction, flat-field correction, wavelength calibration and night-sky background subtraction. With the use of observed at the same nights data of spectrophotometric standards, all spectra were transformed to absolute fluxes. The individual 1D spectra of the studied HII regions were then extracted by summing-up without weighting of several rows along the slit. Typically we extracted 6–12 binned pixels ($\sim 2''$ – $4''$).

We note that after the continuum in 1D spectra was drawn and the line fluxes are measured as described in Pustilnik et al. (2016), we used the iteration procedure from (Izotov et al. 1994) which simultaneously determines the extinction coefficient $C(H\beta)$ and the equivalent width of Balmer absorption EW(abs) in the underlying stellar continuum. See also Sect. 3 for use of the model continuum for several spectra of E+A type.

The plots of obtained 1D spectra are presented in Figures 4, 5. The measured relative fluxes for presented spectra are available in the 'On-line data' section in the electronic version of the paper (in Tables A1 - A7).

As in our previous paper PKPE20, the majority of the observed candidate XMP dwarfs are very faint and/or of low surface brightness. Thus, to obtain their independent spectra and to point slit to the right HII-region can be a challenge. To ease an opportunity for independent checks of our data, we provide in Figures 1-2 the slit positions for each of our program galaxy overlaid on the galaxy images taken either from DECaLS (Dey et al. 2019), or PanSTARRS PS1 (Flewelling et al. 2016), or SDSS (Abazajian et al. 2009; Abolfathi et al. 2018) databases. In Figure 3 we also show the slit positions for three additional observed galaxies which are not in the XMP void candidate list.

3 RESULTS OF SPECTRAL OBSERVATIONS AND O/H ESTIMATES

Tables with measured line intensities, derived electron temperatures and Oxygen abundances are presented in Appendix A of the online version (Tables A1 - A7).

Due to very low fluxes of emission lines in the observed HII-regions and due to their low metallicities, the principal faint auroral line $[OIII]\lambda 4363$ used for the determination of the electron temperature, was not detected in the majority of our targets, as it was expected. Indeed, even for the highest values of the observed $T_e \gtrsim 20000$ K, the flux ratio of $[OIII]\lambda 5007$ and $[OIII]\lambda 4363$ is expected to be $\gtrsim 25$. To detect $[OIII]\lambda 4363$ line at S-to-N level of ~ 3 , we need to acquire the flux of $[OIII]\lambda 5007$ line with S-to-N level at least of $\gtrsim 80$. Most of our observed HII regions are too faint. So that for a reasonable exposure time per galaxy used for the search program (~ 1 – 2 hour), we usually could get the flux of $[OIII]\lambda 5007$ line at the S-to-N level of $\lesssim 20$ – 50 .

The line $[OIII]\lambda 4363$ Å was reliably detected only in the spectra of three galaxies. For them, O/H was estimated via the direct method and was marked as $12+\log(O/H)(T_e)$. The respective formulae with the most updated atomic data are given in Izotov et al. (2006a). All calculations for the direct method O/H estimate are made similar to those in Kniazev et al. (2008); Pustilnik et al. (2016).

For the remaining objects, we used two methods described below. The first one, a so-called semi-empirical 'se'

method by Izotov & Thuan (2007), is based on a correlation between T_e and parameter R_{23} . The functional relation between the two variables was fitted based on calculations for the grid of HII region models in paper by Stasinska & Izotov (2003). Parameter R_{23} is the ratio of the sum of fluxes of the strong oxygen lines $[OII]\lambda 3727$ Å, $[OIII]\lambda 4959$ Å, $[OIII]\lambda 5007$ Å to the flux of $H\beta$. Thus, it first calculates the empirical estimate of T_e from the measured R_{23} and then uses this T_e similar to the classical direct method. This method was carefully checked and calibrated by Izotov & Thuan (2007), Pustilnik et al. (2016) and other authors. Its internal scatter is ~ 0.07 – 0.08 dex. The method is applicable for $12+\log(O/H) \lesssim 7.9$.

As shown in Izotov et al. (2019b), when used for values of $12+\log(O/H) \lesssim 7.40$, this method gives the systematical shift of 0.08 dex relative to the values of O/H derived via the direct method. Therefore, to put values of $12+\log(O/H)$ derived via the 'se' method to the scale of T_e method, we apply to $12+\log(O/H)$ (se) a correction -0.08 dex, and call this $12+\log(O/H)$ (se,c).

Besides, for objects with the lowest O/H, we employed also the new empirical method of Izotov et al. (2019b), based also on the relative fluxes of the strong Oxygen lines. The respective relation reads as follows:

$$12 + \log(O/H) = 0.950 \times \log(R_{23} - 0.08 \times O_{32}) + 6.805$$

In this formulae, O_{32} is the flux ratio of the line $[OIII]\lambda 5007$ Å to that of $[OII]\lambda 3727$ Å. This 'Strong-lines' method is suitable only for the lowest metallicities, namely, for the range of $12+\log(O/H) \lesssim 7.40$. However, for this range, it provides a very good internal scatter of 0.05 dex. The above relation empirically accounts for the large scatter in the ionization parameter U in various HII-regions. This allows to reduce the relatively large internal scatter inherent to the other methods based on the strong Oxygen lines.

For some of the observed galaxies, Balmer absorption lines were clearly visible in the blue-UV range. We modelled their underlying continuum with the ULYSS package (<http://ulyss.univ-lyon1.fr>, Koleva et al. 2009). This model continuum fitted Balmer absorption lines, and thus corrected to a first approximation the flux of $H\beta$ emission. For these objects, the EW(abs) derived in the next step via iterations, as described above with the procedure from Izotov et al. (1994), relates in fact to the residual EW(abs), which is already mainly accounted for by the ULYSS fitting (e.g., in galaxies J2103–0049 and J2214+2540).

As the 'se' method, this method also gives a small systematical shift of ~ 0.04 dex in $12+\log(O/H)$ relative to that of the T_e method. Therefore, to have $12+\log(O/H)$ estimated by this method, in the same scale as derived by the direct method, we apply a correction -0.04 dex and call these corrected values $12+\log(O/H)$ (s,c).

In Table 2 we present the following parameters. In columns 1 and 2 – name and J2000 RA and Declination of the galaxy. In column 3 we give the heliocentric velocities as adopted from HyperLEDA database. For J0823+1758 and J0823+1748, we present the radial velocity which was at first time measured by us (see subsection 4.1 for details). The distances in Mpc (column 4) derived from the HST data via the Tip of RGB for 4 galaxies are taken from HyperLEDA. For the remaining 16, they are taken from our Nearby Void Galaxy catalog (PTM19) based on the velocity field model

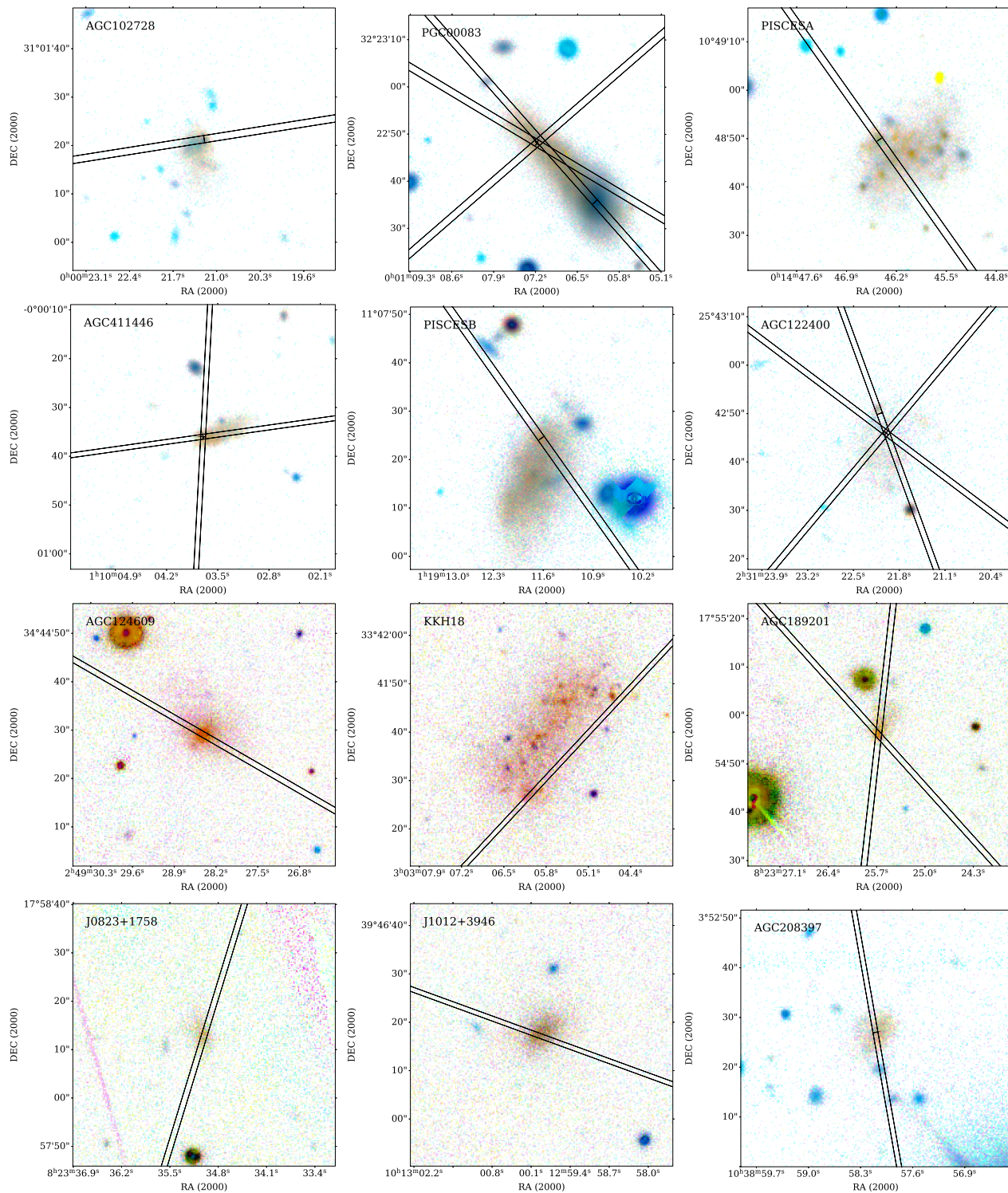


Figure 1. Finding charts of void XMP candidates from BTA program with slit positions superimposed. Inverted colours are used to underline the LSB features of dwarf morphology. North is up, East is to the left. **Top row, from left to right:** AGC102728 = J0000+3101, PGC00083 = J0001+3222; PISCESA = J0014+1048. **Second row, from left to right:** AGC411446 = J0110-0000; PISCESB = J0119+1107; AGC122400 = J0231+2542; **Third row, from left to right:** AGC124609=J0249+3444; KKH18=J0303+3341; AGC189201=J0823+1754, **Bottom row, from left to right:** J0823+1758; J1012++3946; AGC208397 = J1038+0352

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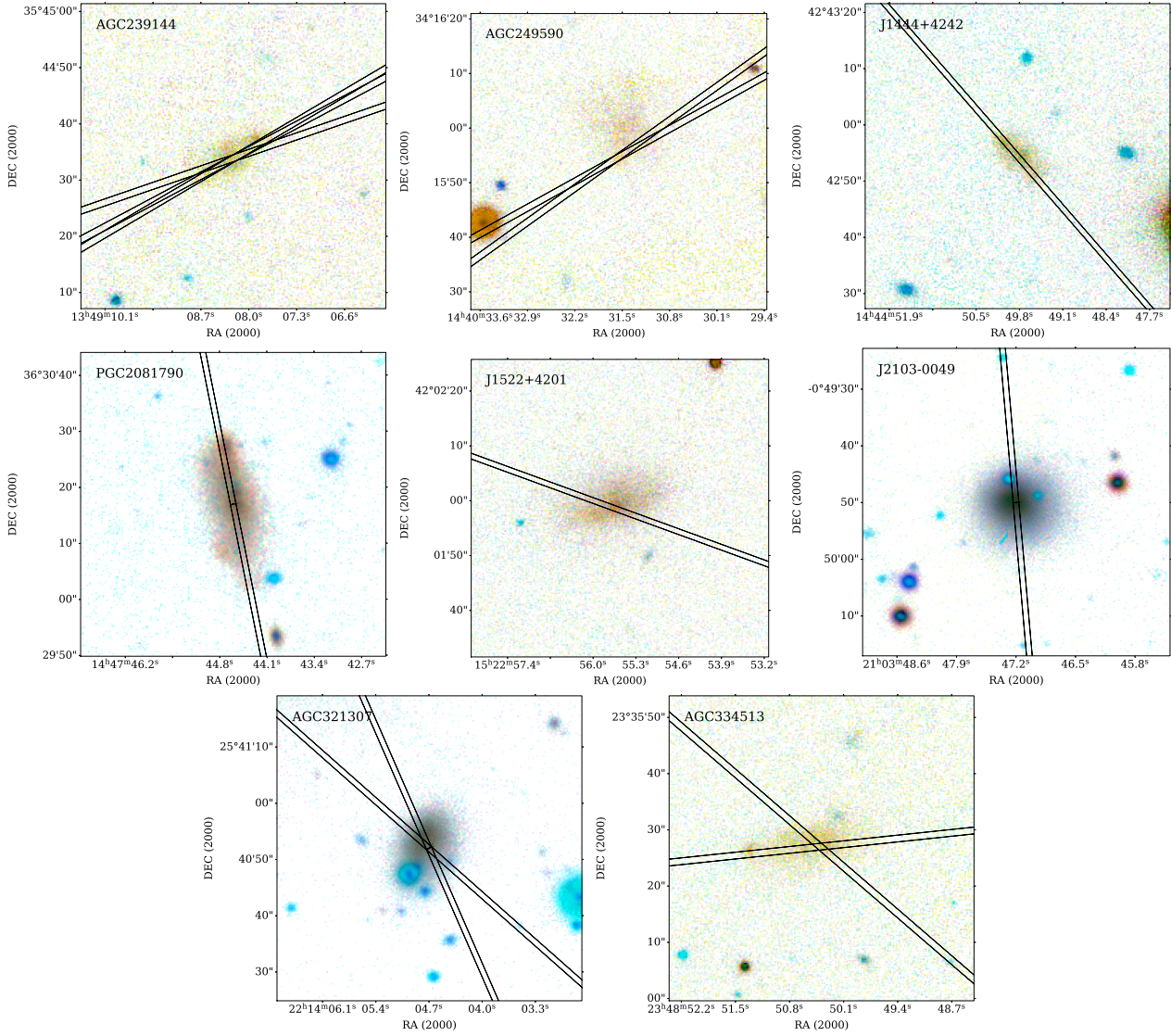


Figure 2. Finding charts of void XMP candidates from BTA program with slit positions superimposed. Inverted colours are used to underline the LSB features of dwarf morphology. North is up, East is to the left. **Top row, from left to right:** AGC239144=J1349+3544; AGC249590=J1440+3416; J1444+4242; **Second row, from left to right:** PGC2081790 = J1447+3630, J1522+4201; J2103-0049; **Bottom row, from left to right:** AGC321307=J2214+2540; AGC334513=J2348+2335.

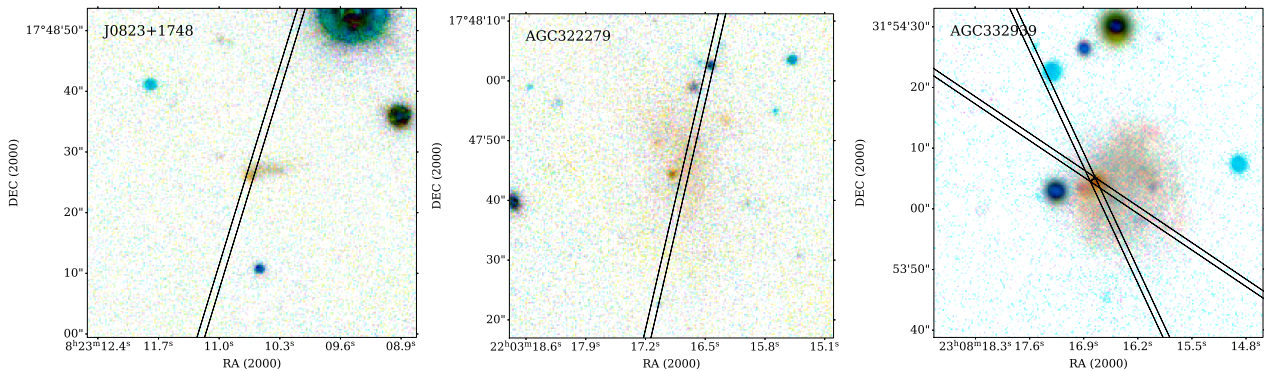


Figure 3. Finding charts of the three not-NVG sample galaxies observed at BTA, with slit positions superimposed. Inverted colours are used to underline the LSB features. North is up, East is to the left. **From left to right:** J0823+1748 – a distant SF galaxy in the field of AGC189201; AGC322279=J2203+1747 – non-void galaxy; AGC332939 = J2308+3154 – non-void galaxy.

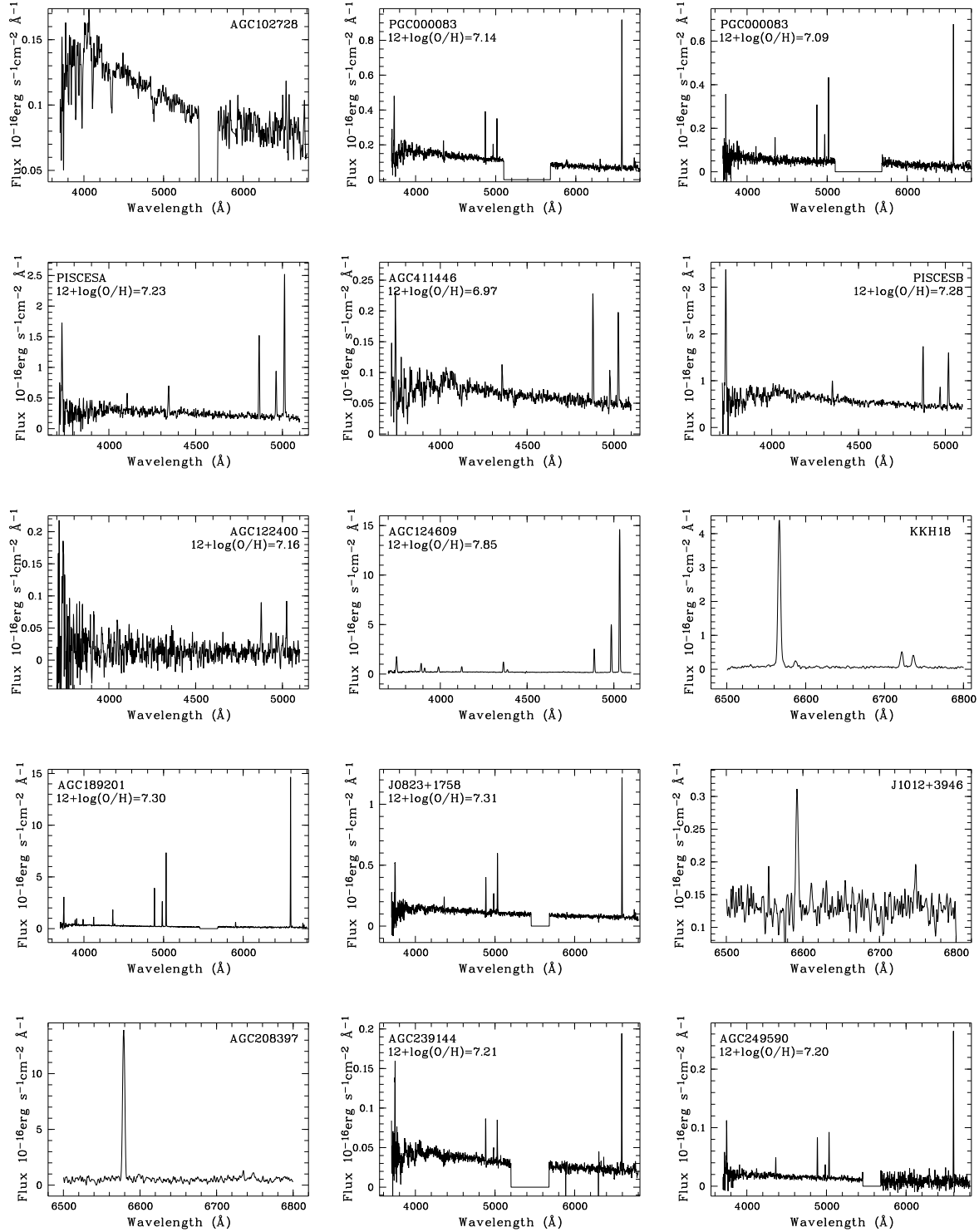


Figure 4. 1D spectra of void XMP candidates obtained with BTA. The wavelengths on the X axis are observed, not in the rest-frame. The flux densities on the Y axis are shown in units of 10^{-16} ergs $s^{-1} cm^{-2} \text{Å}^{-1}$. The galaxy name and derived value of $12+\log(O/H)$ are shown at the top of each box. **Top panel, from left to right:** AGC102728=J0000+3101. Only very faint emission $H\alpha$ is detected besides Balmer absorptions. PGC000083=J0001+3222. Spectra of two knots are shown with somewhat different $O/H=7.14$ for "a" and 7.09 for "b". **Second panel, from left to right:** PiscesA=J0014+1048, $O/H=7.23$; AGC411446=J011003-000036, $O/H=6.97$; PiscesB=J0119+1107, $O/H=7.28$; **Third panel, left to right:** AGC122400=J0231+3542, $O/H=7.16$; red spectrum of AGC122400; AGC124609=J0249+3444, $O/H=7.89$; **Fourth panel, from left to right:** KKH18=J0303+3341, red spectrum. AGC189201=J0823+1754, $O/H=7.31$; J0823+1758, $O/H=7.89$; **Bottom panel, from left to right:** J1012+3946, red spectrum, $[NII]/H\alpha$ inconclusive due to large noise near $[NII]\lambda 6584 \text{Å}$; back-up time red spectrum of AGC208397=J1038+0352; AGC239144=J1349+3544, $O/H=7.21$; AGC249590=J1440+3416, $O/H=7.20$.

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Table 2. Candidate XMP dwarfs observed at BTA and new O/H data

Name	Galaxy coord.	V_h km s ⁻¹	D Mpc	B_{tot} mag	M_B mag	$M(\text{H I})/L_B$	12+log(O/H)	Notes
1	2	3	4	5	6	7	8	9
1 AGC102728	J000021.4+310119	566	8.8	19.40	-10.53	2.44	...	very faint H α
2 PGC000083	J000106.5+322241	542	9.1	17.14	-12.89	3.13	7.12 $\pm$ 0.06 (s,c)	average of 2 knots
3 PiscesA	J001446.0+104847	235	5.6	17.98	-11.31	2.22	7.23 $\pm$ 0.05 (s,c)	
4 AGC411446	J011003.7-000036	1137	15.9	19.58	-11.54	4.80	6.97 $\pm$ 0.06 (s,c)	
5 PiscesB	J011911.7+110718	616	8.9	17.63	-12.23	2.80	7.28 $\pm$ 0.06 (s,c)	
6 AGC122400	J023122.1+254245	938	15.5	18.48	-12.97	2.27	7.16 $\pm$ 0.08 (s,c)	
7 AGC124609	J024928.4+344429	1588	25.0	18.20	-14.10	1.51	7.89 $\pm$ 0.02 (Te)	
8 KKH18	J030305.9+334139	210	4.8	16.70	-12.56	0.98	...	I(NII)/I(H α)=0.03
9 AGC189201	J082325.6+175457	1475	23.4	19.24	-12.76	3.94	7.31 $\pm$ 0.04 (Te)	
10 J0823+1758	J082335.0+175813	1509	23.8	19.49	-12.54	...	7.31 $\pm$ 0.06 (s,c)	
11 J1012+3946	J101259.9+394617	1340	21.9	18.32	-12.43	3.80	...	I(NII)/I(H α) uncertain
12 AGC208397	J103858.1+035227	763	11.9	19.95	-10.59	5.60	...	I(NII)/I(H α)=0.03
13 AGC239144	J134908.2+354434	1366	20.4	19.06	-12.54	3.17	7.21 $\pm$ 0.07 (s,c)	average of 2 knots
14 AGC249590	J144031.6+341601	1489	21.7	18.45	-13.28	2.67	7.20 $\pm$ 0.06 (s,c)	
15 J1444+4242	J144449.8+424254	634	10.9	19.69	-10.54	1.30	7.14 $\pm$ 0.04 (s,c)	average of 2 knots
16 PGC2081790	J144744.6+363017	1226	18.1	18.04	-13.29	2.11	7.29 $\pm$ 0.05 (s,c)	
17 J1522+4201	J152255.5+420158	608	9.8	17.74	-12.31	0.43	7.27 $\pm$ 0.06 (s,c)	
18 J2103-0049	J210347.2-004950	1411	17.4	17.44	-14.07	1.30	7.19 $\pm$ 0.05 (s,c)	
19 AGC321307	J221404.7+254052	1152	16.2	18.15	-13.27	2.37	7.76 $\pm$ 0.08 (se)	
20 AGC334513	J234850.4+233527	1662	23.8	18.89	-13.25	3.49	7.21 $\pm$ 0.06 (s,c)	
21 J0823+1748	J082310.6+174826	27600	376.4	20.15	-17.86	...	...	distant I(NII)/I(H α) $\sim$ 0.01
22 AGC322279	J220316.8+174744	1272	17.2	18.39	-12.98	2.37	...	non-void I(NII)/I(H α)=0.19
23 AGC332939	J230816.7+315406	692	10.7	17.18	-13.22	1.61	7.69 $\pm$ 0.06 (Te)	non-void

Parameter $M(\text{H I})/L_B$ is in solar units.

by Tully et al. (2008). In columns 5 and 6 we give the total apparent and respective absolute blue magnitudes. The latter are calculated from the apparent magnitudes and the adopted distances, with account for the Galaxy extinction from Schlafly & Finkbeiner (2011). The apparent blue magnitudes B_{tot} were estimated by us via measurements of their g, r magnitudes if their images were available in the mentioned above public data bases. Then these g, r magnitudes were transformed to B band via the relation of Lupton et al. (2005). In the rest cases we took B_{tot} from HyperLEDA. In column 7 we also give the ratio of hydrogen mass to blue luminosity $M(\text{H I})/L_B$, in the solar units. In column 8 the adopted value of 12+log(O/H) is presented as derived in this paper. In column 9 we give some notes.

Tables with measured line intensities, derived electron temperatures and Oxygen abundances are presented in Appendix A. For O/H in Table 2 in the range of 12+log(O/H) $\lesssim 7.4$, when the 'Strong-lines' method is applicable, we adopted the value of 12+log(O/H) (s,c) since it has a smaller errors relative to that of 12+log(O/H) (se,c). Moreover, as one can see in Tables A1 - A7, both estimates are well consistent within their cited uncertainties.

4 DISCUSSION

4.1 Notes on individual galaxies

For some of our observed XMP dwarf candidates it is worth giving the additional information or comments.

AGC102728 = J0000+3101. Only a faint H α line was seen in one of positions along the long slit. This galaxy is resolved into individual stars at the HST images, and its

'Tip of RGB' derived distance 8.84 $\pm$ 0.68 Mpc is published by Tikhonov & Galazutdinova (2019). In the colour HST image, several faint red galaxies are seen in the close surroundings of this galaxy, which can be representatives of a distant group or a cluster. One of these red galaxies is projected on the body of AGC102728. Our slit position crossed this faint galaxy. A clear emission line was detected in its red part of spectrum at $\lambda 6863 \text{ \AA}$, corresponding to H α -line shifted with $z=0.04571$.

PiscesA=J0014+1048. This galaxy was included among others in the list of about 80 candidate low-metallicity dwarfs selected on their morphological and colour properties by James et al. (2017). However, for two different positions of the long slit, these authors did not detect emission lines in their spectra. As our results show, the reason is that PiscesA seems has only one substantially bright HII-region. We identified it in the BTA acquisition images with the medium-width SED665 filter (see Fig 1, top row).

AGC124609 = J0249+3444. This void galaxy has rather bright high excitation HII-region with more or less normal metallicity for its luminosity. Its spectrum displays rather strong line of HeII 4686 $\text{\AA}$. Besides, its high ratio $O_{32}=8.3$, along with $R_{23}=8.7$, is indicative of an HII-region with possibly leaking Lyman continuum (e.g. Izotov et al. 2018b, 2020). As such this galaxy appears one of the nearest and least massive known Ly-c leaker candidates and deserves further the high S-to-N spectroscopy. This can be important in the context of study the diversity of Ly-c leaker properties and the possibility to study this phenomenon with the high spatial resolution.

J0823+1758 and J0823+1748. These galaxies were neither in our list of the preselected XMP candidates

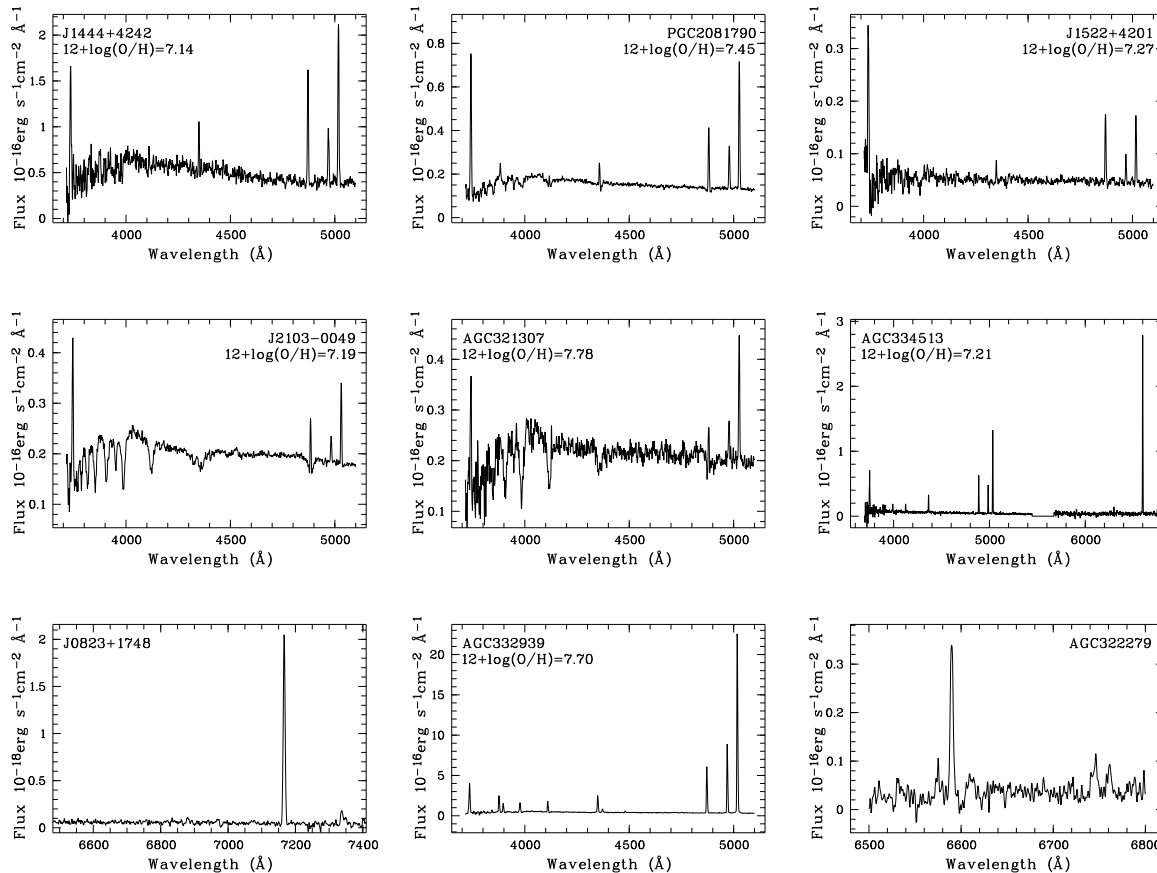


Figure 5. 1D spectra of void XMP candidates obtained with BTA. The galaxy name and derived value of $12+\log(\text{O}/\text{H})$ are shown at the top of each box. **Top panel, from left to right:** J1444+4242, $\text{O}/\text{H}=7.14$ (average on 2 knots); PGC2081790 = J1447+3630, $\text{O}/\text{H}=7.45$; J1522+4201, $\text{O}/\text{H}=7.27$; **Second panel, left to right:** J2103-0049, $\text{O}/\text{H}=7.19$; AGC321307=J2214+2540, $\text{O}/\text{H}=7.78$; AGC334513 = J2348+2335, $\text{O}/\text{H}=7.21$. **Bottom panel, from left to right: Non-void galaxies:** red spectrum of J0823+1748 with $z=0.092$, AGC332939=J2308+3154, $\text{O}/\text{H}=7.70$; red spectrum of AGC322279=J2203+1747.

(PEPK20), nor in any data base as objects with known radial velocity. They were noticed as possible counterparts of a void galaxy AGC189201 (J0823+1754) in course of the visual inspection of its surroundings. The main reason to check their radial velocity was their relative angular proximity and their blue colours and morphology. Both galaxies were first observed in red during the Moon time. This allowed to classify the first one as a real counterpart and a new void object (with $\delta V=+34 \text{ km s}^{-1}$ relative to that of AGC189201), while the second one appeared a distant object at the redshift of $z \sim 0.092$.

It was not a surprise that a new void galaxy J0823+1758, with $M_B \sim -12.5$, in the vicinity of another very metal-poor dwarf AGC189201, may have $Z(\text{gas})$ of $\sim Z_{\odot}/25$. As for the distant galaxy J0823+1748 with $M_B \sim -17.9$, this, to our surprise, also shows the spectral signatures of a very low metallicity. Namely, its flux ratio of $[\text{NII}]\lambda 6584$ and $\text{H}\alpha$ is $\sim 0.01 \pm 0.01$ and that of $[\text{SiI}]\lambda 6716/6730$ to $\text{H}\alpha$ is $\lesssim 0.10$. Both these low line flux ratios are characteristic of very low-metallicity HII-regions. We did not observe its blue part of spectrum due to lack of observational time. However, it certainly deserves the follow-up spectroscopy since it can appear one of the most luminous very metal-poor objects. According to the reference relation of Berg et al. (2012, see

Figure 6), a galaxy with $M_B \sim -17.9$, residing in the typical LV groups, is expected to have $12+\log(\text{O}/\text{H}) \sim 8.2 \pm 0.15$ dex. At the same time, the mentioned above line flux ratios are similar to those of very metal-poor galaxies from this work, e.g., to AGC334513 (J2348+2335) with $12+\log(\text{O}/\text{H})(\text{s},\text{c})=7.21$ (Table A6).

J1522+4201. For this object, we have no the red part of spectrum. To estimate its $\text{C}(\text{H}\beta)$ and O/H , we adopted the flux of $\text{H}\alpha$ line, based on the Balmer ratio $\text{I}(\text{H}\alpha)/\text{I}(\text{H}\beta)=3.0$ from its SDSS spectrum (SpecObjID = 1889302432475801600), acquired on the same region within the round aperture with diameter of $3''$. This galaxy appeared also as a very metal-poor candidate among 66 other objects separated in SDSS DR14 by Izotov et al. (2019b). To estimate its O/H , they adopted the flux of $[\text{OII}]\lambda 3727 \text{ \AA}$ line relative to that of $\text{H}\beta$ to be ~ 2.6 . It was derived from the empirical relation between the flux of $[\text{OII}]\lambda 3727$ and that of the line $[\text{NII}]\lambda 6584 \text{ \AA}$. Our independent BTA spectrum reveals a somewhat lower value of its relative flux, ~ 2.2 . The both values are consistent within uncertainties, however.

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4.2 New the lowest metallicity void dwarfs

Among the twenty observed at BTA nearby void candidate very metal-poor galaxies, we found six galaxies with $Z_{\text{gas}} \lesssim Z_{\odot}/30$ (or $12+\log(\text{O}/\text{H}) \lesssim 7.2$). They deserve further discussion since the search for such objects and their study is the main goal of our observational program.

PGC00083 = J0001+3222. For this galaxy, we obtained good quality spectra for two knots 'a' and 'b', with $12+\log(\text{O}/\text{H}) = 7.14 \pm 0.06$ and 7.09 ± 0.06 , both derived via the 'Strong-lines' method (Izotov et al. 2019b). Their separation along the slit is $\sim 6.5''$ or ~ 240 pc. This object is one of the nearest XMP objects known. According to the velocity field model of Tully et al. (2008) adopted for galaxy distances in the Nearby Voids (PTM19), its distance is of 9.1 Mpc. That is this galaxy resides in the Local Volume. Indeed, it enters to the Updated Nearby Galaxy Catalog (UNGC) by Karachentsev et al. (2013, and the most updated version in <http://www.sao.ru/lv/lvgdb/>), with the adopted distance of 9.4 Mpc (derived via the baryonic Tully-Fisher relation). Thus, both distance estimates are well consistent. According to PTM19, this galaxy resides in void No. 25 and its distance to a luminous nearest neighbour is $D_{\text{NN}} \sim 4.1$ Mpc.

The apparent tadpole morphology of this galaxy (see Figure 1) with a 'head' on the SW edge is due to the chance projection of a distant reddish galaxy to the edge of the void disc-like dwarf. The slit position with $\text{PA} = 41.5^\circ$ with grism VPH1200B, crosses the center of the 'head'. Two clear emission lines are visible in its well registered spectrum: $[\text{OII}]\lambda 3727 \text{ \AA}$ and $\text{H}\beta$ that allows to determine its redshift of $z = 0.0872$. The line $[\text{OIII}]\lambda 5007 \text{ \AA}$ appears just outside the range, while $[\text{OIII}]\lambda 4959 \text{ \AA}$ is not detected. We also obtained spectra with $\text{PA} = 59^\circ$ with grisms VPH1200B and VPH1200R. For them, the slit crosses the edge of this distant galaxy. Here we clearly identify $[\text{OII}]\lambda 3727 \text{ \AA}$ in blue and $\text{H}\alpha$ in red, with the same redshift.

It is worth mentioning that there is another candidate XMP galaxy in our program, AGC102728=J0000+3101, situated in the close surroundings. In its spectra we detected only a faint $\text{H}\alpha$ emission. Its angular distance to J0001+3222 is $\sim 45'$. It has the radial velocity differing from that of PGC00083 only by $\delta V = +24 \text{ km s}^{-1}$. Its distance estimated in the frame of the same velocity field model is $D = 9.4$ Mpc. Its recent velocity-independent distance estimate is $D(\text{TRGB}) \sim 8.8$ Mpc (adopted in Table 2). It is derived from the available HST data by Tikhonov & Galazutdinova (2019) based on the 'Tip of RGB' method. Both distance estimates are consistent each to other within their cited uncertainties. The projected distance between these void galaxies of ~ 120 kpc is probably too large to treat that low-mass objects to be gravitationally bound. If they are not bound, they may belong to the same structure element like a void filament.

AGC411446 = J0110-0000. This dwarf, with $12+\log(\text{O}/\text{H}) = 6.97 \pm 0.06$ derived via the 'Strong-lines' method of Izotov et al. (2019b), is the second most metal-poor galaxy found so far in our search program. Its extremely low O/H was at first time discovered with the presented here BTA spectrum. To improve the spectra quality and the accuracy of O/H determination, we made the follow-up SALT observations (PKPE20). We derived its $12+\log(\text{O}/\text{H}) = 7.04 \pm 0.05$. This is corrected down by

0.01 dex from that in PKPE20 for consistency with the adopted here correction for the 'Strong-lines' method. This value is fully consistent with our BTA determination. In fact, since both estimates are obtained with the 'Strong-lines' method and have the similar uncertainties, the most robust estimate would be their weighted mean (~ 7.01). However, we prefer to keep in Table 3 a more conservative estimate.

According to PTM19, the galaxy is situated in a large void No. 3 (Cet-Scu-Psc), probably at the periphery of a small void group with the central spiral galaxy NGC428 ($M_B = -19.2$). Its $D_{\text{NN}} \sim 6.0$ Mpc. We do not extend much its description in this paper since we present properties of this remarkable XMP dwarf based on its complex study in the separate publication (Pustilnik et al. 2020, in preparation).

AGC122400 = J0231+2542. This new void XMP object at $D = 15.5$ Mpc, with $12+\log(\text{O}/\text{H}) = 7.16 \pm 0.08$, has somewhat larger O/H uncertainty due to rather noisy signal for $[\text{OII}]\lambda 3727 \text{ \AA}$ doublet. The galaxy also falls in void No. 3 of PTM19. Its distance to the nearest luminous neighbour is of $D_{\text{NN}} \sim 3.6$ Mpc.

AGC249590 = J1440+3416. This new void XMP dwarf at $D = 21.7$ Mpc, with $12+\log(\text{O}/\text{H}) = 7.20 \pm 0.06$ resides in void No. 16 from PTM19, with $D_{\text{NN}} \sim 2.5$ Mpc. This XMP dwarf is probably a companion of the void SAB galaxy NGC5727 ($M_B = -17.1$) at $\sim 17'$ (or ~ 107 kpc in projection) with $\delta V = 9 \text{ km s}^{-1}$. There is one more companion of NGC5727, PGC2043836 with $M_B = -15.3$.

J1444+4242 This new void XMP dwarf with $12+\log(\text{O}/\text{H}) = 7.14 \pm 0.04$, resides in the Local Volume at $D = 10.9$ Mpc. It is a faint companion (4.5 magnitudes fainter) of a larger host, a disk metal-poor dwarf UGC9497, at the angular separation of $\sim 8.5'$ (~ 27 kpc). It was discovered in course of H I mapping of the host UGC9497 (Chengalur et al., in preparation). For the BTA slit position, approximately along the major axis of the blue elongated LSB body, we detected two emission-line knots separated by $\sim 3''$, or 150 pc, with the similar values of $12+\log(\text{O}/\text{H})(\text{s,c}) = 7.17 \pm 0.05$ and 7.10 ± 0.06 , for knots "a" and "b", respectively.

It is of interest that besides the more massive host UGC9497 with the wide range of estimates of $12+\log(\text{O}/\text{H}) = 7.27-7.63$ (Guseva et al. 2003; Izotov et al. 2019b), there exists in the same space cell (at $D \sim 1$ Mpc) one more very metal-poor dwarf J1522+4201, with $12+\log(\text{O}/\text{H})(\text{s,c}) = 7.27 \pm 0.06$ (see Table 2 and Section 4.1). No one of the discussed three void galaxies is included yet into UNGC.

J2103-0049. This new void XMP dwarf resides in void No. 25, at the distance of 17.4 Mpc. Again, as the two other new void XMP dwarfs, J0001+3222 and J1444+4242, this object is situated rather close to the known XMP dwarf J2104-0035 (discovered by Izotov et al. (2006b)) at $D \sim 17.2$ Mpc. Their mutual angular distance of $\sim 22'$ corresponds to the projected distance of ~ 110 kpc, while the radial distances differ by ~ 200 kpc. They probably belong, as several other cases, to the same element of void substructure, likely a void filament. It is worth to noting that J2104-0035 itself bears the traces of the recent interaction or probable merging as its unusual H I morphology evidence (revealed by GMRT mapping in Ekta et al. (2008)).

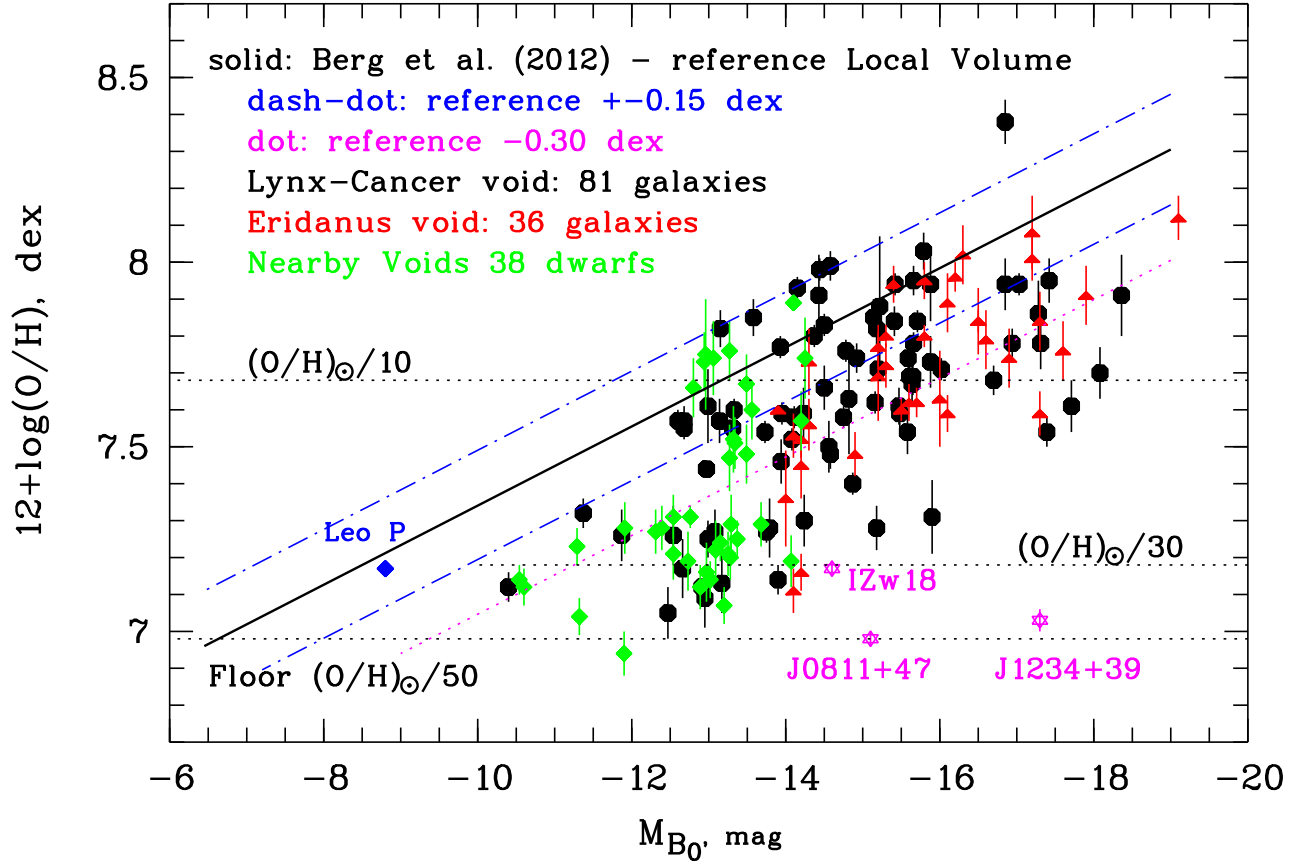


Figure 6. Positions of all 37 studied NVG XMP candidates plus one known from the literature (J2104–0035) in diagram $\log(\text{O}/\text{H})$ versus absolute blue magnitude M_B (green rhombs) along with similar data for voids Lynx-Cancer (black octagons, Pustilnik et al. (2016)) and Eridanus (red triangles, Kniazev et al. (2018)). The diagram is substantially updated relative to the similar plot in Pustilnik et al. (2020b) (see text). The solid line shows the relation between $\log(\text{O}/\text{H})$ and M_B for the reference sample of the Local Volume late type galaxies from Berg et al. (2012) (extrapolated for $M_B > -10.5^m$). Two distant record-low XMP BCGs J0811+4730 and J1234+3901 from papers by Izotov et al. (2018a, 2019) as well as the prototype BCG IZw18, are shown by purple stars for comparison.

4.3 Intermediate summary of new void XMP galaxies

In course of our on-going project described in Introduction, as a result of both, SALT and BTA spectroscopy programs, we found 10 new XMP dwarfs. Since the follow-up spectroscopy of the preselected ~ 60 candidates is completed only by $\sim 75\%$, we expect to present in the forthcoming paper(s) several more such and similar objects. Besides, in parallel, for a major part of the new void XMP dwarfs, we are preparing the results of the GMRT H I mapping and of their multi-band photometric study performed on the available public data base images. Therefore, we postpone a more advanced analysis of new and prototype XMP dwarfs till the completion of these parts.

However, the current sample of 10 void XMP dwarfs is already sufficiently large, so that it is worth to summarizing preliminary some of their properties. In Table 3 we

collect their main observational parameters, partly from the literature and partly from our data, published or prepared for submission. Below we briefly discuss some of the related issues.

The content of the columns is explained in the bottom of Table 3. For XMP galaxies from our SALT program results (PKPE20), we change their $12+\log(\text{O}/\text{H})$ (s,c) in that paper down by 0.01 dex, in order to match the same scale of O/H as adopted in this paper (see comments in Appendix A).

In the process of XMP dwarf candidate selection in PEK20, we initially imposed several limitations on their observational parameters, based on the observed properties of the prototype XMP dwarfs. Furthermore, we intensively have widen the boundaries to outside of the parameter ranges found in the prototype group. This is considered as an attempt to probe the occurrence of XMP dwarfs in the regions of the parametric space not covered by the proto-

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type objects. We can summarize the current status of the new void XMP dwarfs as follows.

The absolute blue magnitudes of 10 new void XMP galaxies, M_B vary between -10.5 and -14.07 mag, with the median value of -12.6 mag. That is, the blue luminosity of this group varies by a factor of ~ 25 . The total M_B range matches well that of 8 XMP prototype dwarfs with known O/H from table 1 of PEPK20.

Mass of H I $M(\text{H I})$ also varies in the large range, from 0.34 to $\sim 8 \times 10^7 M_\odot$ (or $\log M(\text{H I})$ in the range 6.53 to 7.90), that is by a factor of 27. The median $M(\text{H I}) = 3.8 \times 10^7 M_\odot$. As for comparison of this parameter to the prototype group, for new XMP dwarfs, $M(\text{H I})$ appears substantially lower. Its both the upper and the lower boundaries have $\log M(\text{H I})$ by about 0.6 dex (or by a factor of 4) lower than those for prototype objects. The median $M(\text{H I})$ of the prototype group is $\sim 4 \times 10^8 M_\odot$, that is an order of magnitude larger than for the newly found void XMP dwarfs.

The similar difference is visible for parameter $M(\text{H I})/L_B$. Even if we exclude the extreme value of 17.1 for the prototype dwarf J0706+3020, 3 new XMP dwarfs have $M(\text{H I})/L_B = 1.3$ – 1.7 , well below the lower boundary of 2.4 for the prototype group.

The integrated colours $g - r$ of new XMP dwarfs vary from very blue -0.03 to quite reddish ~ 0.4 , with the median value of ~ 0.11 . This is to compare with the $g - r$ range of -0.08 to $+0.19$ for the prototype group. Again, we see that 3 new XMP dwarfs with $g - r = 0.25$ – 0.4 are redder than the prototype XMP dwarfs.

Thus, we indeed see rather large scatter and a shift of parameters of new XMP dwarfs (colours $g - r$, $M(\text{H I})/L_B$) relative to those of the prototype group. This might indicate to the diversity of the origin and/or evolutionary status of some void XMP dwarfs. Further more sensitive and more accurate measurements of the most outlying XMP dwarf representatives should help to elucidate this issue.

Of 10 new XMP void dwarfs, 8 are the typical late-type LSB galaxies with the range of central surface brightness $\mu_{B,0,c}$ between 23.4 and ~ 25 (in mag/ $\square''$). The two remaining XMP dwarfs with the absent $\mu_{B,0,c}$, appear somewhat brighter, seemingly due to the enhanced overall star formation during the recent epoch. On this parameter, they match well the prototype group in which at least a half of objects have $\mu_{B,0,c}$ in the range of 24.1 to 25.4 mag/ $\square''$, while the remaining XMP dwarfs, with the clear traces of the recent disturbance, are somewhat brighter.

The majority of new O/H values from this work and PKPE20 well match in the plot $12 + \log(\text{O}/\text{H})$ versus M_B (see Fig. 6) the distribution of the low luminosity galaxies from the Lynx-Cancer void. The lowest O/H dwarfs also fill the region of parameters occupied by the earlier known XMP gas-rich objects. This diagram in Fig. 6 is similar to that shown in PKPE20, but with three important modifications. First, 7 new dwarfs from this paper are added. Second, several of the preliminary O/H estimates from the BTA list are significantly changed in the final version. Third, all previous estimates with $12 + \log(\text{O}/\text{H}) \lesssim 7.4$ for objects from Pustilnik et al. (2016); Kniazev et al. (2018); Pustilnik et al. (2020b), based on the 'Strong-lines' method (Izotov et al. 2019b), are corrected downwards by 0.04 dex from the O/H derived with their original formula, as explained earlier on its application in our work.

The issue of 'clustering' or the 'local' environment of void XMP dwarfs is difficult to describe in terms of a simple numerical parameter. We illustrate this property qualitatively, going from the strong and the evident interaction indicating an advanced merger to the opposite case of the confident isolation and the absence of visible disturbing agent.

In the prototype XMP group we have 4 members of the certain or probable mergers, one object - a member of an interacting pair and three more galaxies - fairly well isolated dwarfs. Among the newly found XMP dwarfs, only two galaxies belong to a triplet (J1440+3416) or a pair (J1444+4242). Two more objects are probable members of the distant periphery of a void group. The remaining six dwarfs are well isolated, despite two of them have rather distant neighbours marking probable elongated void structures. That is, in total, about a half or more XMP void dwarfs do not show presence of evident disturbing neighbours.

4.4 Relation of void XMP dwarfs to VYGs

One of the goals of this project is the search for new unusual void dwarfs resembling Very Young Galaxies (VYGs) predicted by Tweed et al. (2018). They are defined as objects formed more than a half their stellar mass during the last 1 Gyr.

Two record-low XMPs galaxies ($12 + \log(\text{O}/\text{H}) = 6.98$ and 7.02) found by Izotov et al. (2018a, 2019a) show no tracers of the old stellar population. This fact is consistent with their extremely low metallicity if one suggests that both properties are related to the short time elapsed since the beginning of the main SF episode.

We arrived at the similar conclusion on the probable existence of young dwarfs in voids in our work devoted to the study the galaxy population of the Lynx-Cancer void (Perepelitsyna et al. 2014; Pustilnik et al. 2016). Probably it is not by chance that one of the most studied void XMP dwarfs assigned to VYG type and the first prototype XMP dwarf is a blue compact galaxy IZw18=MRK 116 (Papaderos & Östlin 2012). Such actively star-forming blue and UV-excess objects have attracted attention in course of the pioneer surveys of the sky. However, such outstanding star-forming (candidate) VYGs are very rare. This follows from only a few findings of XMP objects from over the whole emission-line galaxy sample in the SDSS DR14 (Izotov et al. 2019b).

On the results of our search program, we find that in the volume limited by the Nearby Voids (described in PTM19), the majority of the XMP dwarfs resembling the predicted VYGs, are mostly the blue LSB galaxies with a much lower star-formation efficiency than that in actively star-forming galaxies. Therefore, in the context of the search for VYGs, obtaining their census in the local Universe and comparison with model simulations, our project looks rather perspective and deserves further development.

5 CONCLUSIONS

The NVG sample provides us with a new opportunity to search for the unusual XMP gas-rich dwarfs in voids. We performed the selection with the use of publicly available galaxy properties, based on their similarity to the properties

Table 3. Parameters of new Nearby Void XMP dwarfs found at BTA and SALT

IAU name	O/H	$\frac{M(HI)}{L_B}$	$\mu_{B,0,c}$	M_B	$(g-r)_0$	V_h	D	logMHI	logM _*	B_{tot}	Notes
1	2	3	4	5	6	7	8	9	10	11	12
J0001+3222	7.12±.06†	3.1	23.5:	-12.86	0.13	542	9.1	7.48	6.19	17.14	AGC103567,PGC00083
J0110-0000	7.04±.05‡	4.8	23.4	-11.54	0.07	1137	15.9	7.53	5.66	19.58	AGC411446, near group NGC428
J0112+0152	7.14±.05†	1.7	...	-13.09	0.04	1089	15.4	7.62	6.02	18.08	AGC114584, near group NGC428
J0231+2542	7.16±.08†	2.3	25:	-12.45	0.17	938	15.5	7.73	...	18.92	AGC122400
J0256+0248	6.94±.06†	3.6	24:	-11.58	0.10	794	12.4	7.22	5.88	19.46	AGC124629
J1038+0352	7.12±.05†	5.6	24:	-10.59	-0.03	763	11.9	7.18	5.60	19.95	AGC208397
J1259-1924	7.19±.08†	3.1	25:	-12.73	0.4:	827	7.3	7.77	6.87	17.00	PGC044681
J1440+3416	7.20±.06†	2.7	24:	-13.28	0.10	1489	21.7	7.90	...	18.45	AGC249590, in triplet
J1444+4242	7.14±.04†	1.3	24:	-10.54	0.25	634	10.9	6.53	5.71	19.69	Pair with UGC9497
J2103-0049	7.19±.05†	1.3	...	-14.07	0.38	1411	17.4	7.83	...	17.44	PGC1133627

The meaning of Table columns. Col. 1: Short IAU-type name; Col. 2: gas O/H in units $12+\log(O/H)$ and its 1σ error; Col. 3: $M(HI)/L_B$ in solar units; Col. 4: corrected for MW extinction and inclination, the central surface brightness $\mu_{B,0,c}$ in mag/□''; Col. 5: Absolute B -band magnitude; Col. 6: corrected for MW extinction total $g-r$ colour; Col. 7: heliocentric radial velocity in km s⁻¹; Col. 8: adopted distance in Mpc; Col. 9: log of galaxy HI-mass in $M_\odot$; Col. 10: log of stellar mass in $M_\odot$; Col. 11: total B -band magnitude; Col. 12: Notes and common names (see sect. 4.3 for detail). Low accuracy data are marked with (:).

† O/H derived via the 'Strong-lines' method by Izotov et al. (2019b), minus 0.04 dex, to match its offset from $(O/H)_{Te}$.

‡ this O/H value is adopted from the higher S-to-N SALT spectra of J0110-0000 in PKPE20.

of the known small XMP dwarf group. As a result, we formed a list of ~ 60 void XMP candidates with the M_B range of $[-10, -14.3]$ for their follow-up more careful study. For 26 of them, on the southern sky and near the celestial equator, we conducted spectroscopy with SALT which resulted in the discovery of 5 new XMP dwarfs with $12+\log(O/H) \lesssim 7.2$. In this paper we present 5 more new XMP void dwarfs observed at BTA. That is, to date we discovered 10 new void XMP dwarfs. In addition, at both telescopes, we found 14 very metal-poor void dwarfs with $7.21 \lesssim 12+\log(O/H) \lesssim 7.31$.

Summarizing the presented results and the related discussion, we draw the following conclusions:

(i) In the frame of the on-going project to search for new unusual void dwarfs among the preselected 60 XMP candidates residing in nearby voids, we perform with BTA the long-slit spectroscopy of 20 candidates in addition to 26 galaxies already observed at SALT. Two of these 20 objects are common with those observed at SALT. They were at first time observed at BTA.

(ii) For 16 of 20 galaxies observed at BTA, we derive estimates of their gas O/H. Only two of them have a 'normal' for their luminosity $12+\log(O/H)$ of 7.76 and 7.89 dex. The remaining 14 of our void galaxies, with $12+\log(O/H) \leq 7.31$, appear very metal-poor. Six of them, with $12+\log(O/H) = 6.97 - 7.20$, fall to the category of XMP galaxies, defined as objects with $Z(gas) \lesssim Z(IZw18)$. Of them, J0110-0000, already presented in our previous paper PKPE20, was initially found at BTA.

(iii) The O/H values of XMP dwarfs are reduced by a factor of 2.5–4 relative to those of the reference sample of similar galaxies in the Local Volume from Berg et al. (2012). Their colours show a significant scatter. However, for half of

them, we find blue colours of outer parts and extremely large gas-mass fraction (0.97–0.99). These properties are similar to those of the prototype XMP group, including those from the Lynx-Cancer void. This finding extends the group of the **nearby** candidates to Very Young Galaxies to a dozen and allows us to better study their statistical properties, including their similarity and diversity.

(iv) The remaining 8 new void dwarfs with the measured values of O/H, fall in the adjacent range of $12+\log(O/H)=7.21-7.31$ dex. Such low metallicity dwarfs are still very rare, especially in the Local Volume and the adjacent space. The division to XMP objects as those with $Z \lesssim Z_\odot/30$ is somewhat conditional. It was suggested in order to separate the most remarkable void dwarfs. It will not be surprising if similar objects will be identified in the group of a bit less metal-poor galaxies. More detailed studies of this group will give insights on their evolutionary state and possible relation to the most extreme XMP representatives.

(v) In Table 3 we summarize some of the known parameters of all found to date at SALT and BTA ten nearby void XMP dwarfs. The comprehensive multi-wavelength study of already found XMP void dwarfs will advance our understanding in galaxy formation and evolution and the specifics of star formation in so atypical conditions. This also will give chances to confirm the discovery of the predicted rare Very Young Galaxies.

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DATA AVAILABILITY

The data underlying this article are available in Appendix A

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⁴ <http://leda.univ-lyon1.fr>

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APPENDIX A: TABLES WITH LINE FLUXES AND DERIVED PARAMETERS

The tables in this Appendix include the measured line fluxes $F(\lambda)$ (relative to the flux of $H\beta$) and the line fluxes $I(\lambda)$, corrected for extinction and the underlying stellar Balmer absorption, with their errors. The error for $F(H\beta)$ reflects its measurement uncertainty. The tables also include the measured EW of $H\beta$ emission line and the derived parameters: the extinction coefficient $C(H\beta)$, the equivalent width of the underlying stellar Balmer absorptions $EW(abs)$, the electron temperatures $T_e(OIII)$ and $T_e(OII)$ in two zones of Oxygen ionization. We also present the derived Oxygen abundances in two stages of ionization and the total value of O/H , including its value in units of $12+\log(O/H)$. Electron densities n_e in HII-regions could not be estimated when the doublet $[SiII]\lambda\lambda 6716, 6730 \text{ \AA}$ was outside the observed wavelength range. In this case we adopted n_e to be 10 per cm^3 , typical of HII-regions in dIrr galaxies.

When the faint auroral line $[OIII]\lambda 4363 \text{ \AA}$ was found in the spectra, O/H was estimated via the direct method and marked as $12+\log(O/H)(T_e)$. Otherwise we used two methods described in Sec. 3. O/H values derived via the semi-empirical (se) method of Izotov & Thuan (2007) are marked as (se,c), which means the small correction to the original value of O/H derived with the method. The correction of -0.08 dex was adopted according to Izotov et al. (2019b) for values of $12+\log(O/H) \lesssim 7.40$ to put estimates of $O/H(se)$ to the scale of the direct method.

For objects with the lowest O/H , we employed also the new empirical method by Izotov et al. (2019b) based on the relative fluxes of the strong Oxygen lines. The values of

O/H estimated by this method are marked (s,c). The letter (c) for these estimates also means a small correction (-0.04 dex). It was applied to the original method value $O/H(s)$, which according to Izotov et al. (2019b) should eliminate the difference with O/H derived via the direct method.

For the lowest metallicity objects, we also present the estimates of O/H via the empirical estimator of Yin et al. (2007), also based on the relative fluxes of the strong Oxygen lines. According to Izotov et al. (2019b) and Pustilnik et al. (2016), it appeared rather robust method for the lowest metallicities, albeit with a larger internal scatter. As our analysis in Pustilnik et al. (2016) have shown, this method also leads to the systematical shift of O/H relative to that derived via the direct method. So, to put their derived O/H estimates to the scale of $O/H(T_e)$, we add to its original numbers 0.05 dex. We call this $O/H(Y07,c)$ in Tables A1 - A7.

When the respective corrections are applied for all three methods, they give well consistent values of O/H (see the results in Tables below).

We do not include the following objects from Table 2 into Tables A1 - A7: AGC102728 (J0000+3101), KKH18 (J0303+3341), J1012+3946, and J1038+0352. They either show only faint $H\alpha$ emission in the spectra (AGC102728), or we obtained for them only the red parts of spectra. The same relates to two non-void galaxies at the bottom part of Table 2: J0823+1748 and AGC322279 (J2203+1747).

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Table A1. Measured and corrected line intensities, and derived Oxygen abundances

	PGC000083a=J0001+3222a		PGC000083b=J0001+3222b		PiscesA=J0014+1048	
$\lambda_0(\text{\AA})$ Ion	F(λ)/F(H β)	I(λ)/I(H β)	F(λ)/F(H β)	I(λ)/I(H β)	F(λ)/F(H β)	I(λ)/I(H β)
3727 [O II]	1.768 $\pm$ 0.137	1.530 $\pm$ 0.143	0.612 $\pm$ 0.105	0.631 $\pm$ 0.115	1.196 $\pm$ 0.096	1.187 $\pm$ 0.107
4101 H δ	—	—	0.190 $\pm$ 0.028	0.294 $\pm$ 0.057	0.161 $\pm$ 0.019	0.296 $\pm$ 0.044
4340 H γ	0.352 $\pm$ 0.022	0.475 $\pm$ 0.042	0.402 $\pm$ 0.027	0.476 $\pm$ 0.042	0.359 $\pm$ 0.025	0.457 $\pm$ 0.039
4861 H β	1.000 $\pm$ 0.049	1.000 $\pm$ 0.060	1.000 $\pm$ 0.049	1.000 $\pm$ 0.053	1.000 $\pm$ 0.040	1.000 $\pm$ 0.045
4959 [O III]	0.264 $\pm$ 0.020	0.222 $\pm$ 0.020	0.498 $\pm$ 0.027	0.471 $\pm$ 0.027	0.551 $\pm$ 0.020	0.498 $\pm$ 0.020
5007 [O III]	0.880 $\pm$ 0.034	0.741 $\pm$ 0.034	1.360 $\pm$ 0.055	1.283 $\pm$ 0.054	1.689 $\pm$ 0.056	1.520 $\pm$ 0.056
6563 H α	3.196 $\pm$ 0.114	2.725 $\pm$ 0.125	—	—	3.264 $\pm$ 0.098	2.744 $\pm$ 0.098
6717 [S II]	0.281 $\pm$ 0.022	0.230 $\pm$ 0.022	—	—	—	—
6731 [S II]	0.179 $\pm$ 0.020	0.147 $\pm$ 0.019	—	—	—	—
C(H β) dex	0.04 $\pm$ 0.05		0.12 $\pm$ 0.06		0.12 $\pm$ 0.04	
EW(abs) $\text{\AA}$	3.10 $\pm$ 0.26		2.75 $\pm$ 0.75		3.80 $\pm$ 0.37	
F(H β) ^a	1.68 $\pm$ 0.06		1.40 $\pm$ 0.04		7.76 $\pm$ 0.21	
EW(H β) $\text{\AA}$	17 $\pm$ 1		54 $\pm$ 2		38 $\pm$ 1	
$T_e(\text{OIII})(\text{K})$	20,827 $\pm$ 1104		21,090 $\pm$ 1113		19,334 $\pm$ 1056	
$T_e(\text{OII})(\text{K})$	14,794 $\pm$ 224		15,986 $\pm$ 283		14,961 $\pm$ 22	
$N_e(\text{SII})(\text{cm}^{-3})$	10 $\pm$ 10		10 $\pm$ 10		10 $\pm$ 10	
$\text{O}^+/\text{H}^+(\times 10^5)$	1.448 $\pm$ 0.151		0.472 $\pm$ 0.089		1.085 $\pm$ 0.098	
$\text{O}^{++}/\text{H}^+(\times 10^5)$	0.380 $\pm$ 0.043		0.675 $\pm$ 0.074		0.928 $\pm$ 0.110	
$\text{O}/\text{H}(\times 10^5)$	1.828 $\pm$ 0.158		1.148 $\pm$ 0.116		2.013 $\pm$ 0.147	
12+log(O/H)(se,c)	7.18 $\pm$ 0.08		6.98 $\pm$ 0.08		7.22 $\pm$ 0.08	
12+log(O/H)(s,c)	7.14 $\pm$ 0.06		7.09 $\pm$ 0.06		7.23 $\pm$ 0.05	
12+log(O/H)(Y07,c)	7.10 $\pm$ 0.10		7.05 $\pm$ 0.10		7.25 $\pm$ 0.09	

Table A2. Measured and corrected line intensities, and derived Oxygen abundances

	AGC411446=J0110-00000		PiscesB=J0119+1107		AGC122400=J0231+3542	
$\lambda_0(\text{\AA})$ Ion	F(λ)/F(H β)	I(λ)/I(H β)	F(λ)/F(H β)	I(λ)/I(H β)	F(λ)/F(H β)	I(λ)/I(H β)
3727 [O II]	0.918 $\pm$ 0.108	0.774 $\pm$ 0.109	2.551 $\pm$ 0.147	2.331 $\pm$ 0.168	1.600 $\pm$ 0.750	1.192 $\pm$ 0.849
4340 H γ	0.227 $\pm$ 0.024	0.388 $\pm$ 0.059	0.300 $\pm$ 0.062	0.446 $\pm$ 0.143	0.114 $\pm$ 0.059	0.448 $\pm$ 0.464
4861 H β	1.000 $\pm$ 0.044	1.000 $\pm$ 0.055	1.000 $\pm$ 0.055	1.000 $\pm$ 0.091	1.000 $\pm$ 0.202	1.000 $\pm$ 0.340
4959 [O III]	0.282 $\pm$ 0.033	0.238 $\pm$ 0.033	0.300 $\pm$ 0.024	0.258 $\pm$ 0.024	0.543 $\pm$ 0.138	0.361 $\pm$ 0.137
5007 [O III]	0.848 $\pm$ 0.044	0.715 $\pm$ 0.044	1.006 $\pm$ 0.051	0.861 $\pm$ 0.050	1.657 $\pm$ 0.263	1.097 $\pm$ 0.261
6548 [N II]	0.033 $\pm$ 0.065	0.028 $\pm$ 0.065	—	—	—	—
6563 H α	3.111 $\pm$ 0.141	2.706 $\pm$ 0.159	—	—	—	—
6584 [N II]	0.102 $\pm$ 0.079	0.086 $\pm$ 0.079	—	—	—	—
6717 [S II]	0.171 $\pm$ 0.087	0.144 $\pm$ 0.087	—	—	—	—
6731 [S II]	0.080 $\pm$ 0.078	0.068 $\pm$ 0.078	—	—	—	—
C(H β) dex	0.00 $\pm$ 0.06		0.08 $\pm$ 0.04		0.15 $\pm$ 0.04	
EW(abs) $\text{\AA}$	3.70 $\pm$ 0.34		2.50 $\pm$ 1.00		4.50 $\pm$ 1.25	
F(H β) ^a	1.09 $\pm$ 0.03		7.19 $\pm$ 0.27		0.46 $\pm$ 0.04	
EW(H β) $\text{\AA}$	20 $\pm$ 1		16 $\pm$ 1		9 $\pm$ 1	
$T_e(\text{OIII})(\text{K})$	23,009 $\pm$ 1188		18,898 $\pm$ 1083		20,468 $\pm$ 2972	
$T_e(\text{OII})(\text{K})$	16,406 $\pm$ 218		14,958 $\pm$ 35		15,633 $\pm$ 78	
$N_e(\text{SII})(\text{cm}^{-3})$	10 $\pm$ 10		10 $\pm$ 10		10 $\pm$ 10	
$\text{O}^+/\text{H}^+(\times 10^5)$	0.537 $\pm$ 0.079		2.131 $\pm$ 0.154		0.952 $\pm$ 0.679	
$\text{O}^{++}/\text{H}^+(\times 10^5)$	0.310 $\pm$ 0.035		0.540 $\pm$ 0.071		0.596 $\pm$ 0.212	
$\text{O}/\text{H}(\times 10^5)$	0.847 $\pm$ 0.086		2.671 $\pm$ 0.170		1.548 $\pm$ 0.711	
12+log(O/H)(se,c)	6.85 $\pm$ 0.08		7.35 $\pm$ 0.08		7.11 $\pm$ 0.20	
12+log(O/H)(s,c)	6.97 $\pm$ 0.06		7.28 $\pm$ 0.06		7.16 $\pm$ 0.08	
12+log(O/H)(Y07,c)	6.90 $\pm$ 0.10		7.30 $\pm$ 0.10		7.13 $\pm$ 0.25	

^a in units of 10^{-16} ergs s $^{-1}$ cm $^{-2}$.

Table A3. Measured and corrected line intensities, and derived Oxygen abundances

	J0823+1758		AGC239144=J1349+3544		AGC249590=J1440+3416	
$\lambda_0(\text{\AA})$ Ion	F(λ)/F(H β)	I(λ)/I(H β)	F(λ)/F(H β)	I(λ)/I(H β)	F(λ)/F(H β)	I(λ)/I(H β)
3727 [O II]	1.807 $\pm$ 0.148	1.936 $\pm$ 0.173	2.575 $\pm$ 0.384	2.131 $\pm$ 0.396	1.471 $\pm$ 0.134	1.462 $\pm$ 0.147
4101 H δ	—	—	—	—	0.143 $\pm$ 0.020	0.252 $\pm$ 0.044
4340 H γ	0.381 $\pm$ 0.025	0.472 $\pm$ 0.040	0.181 $\pm$ 0.038	0.351 $\pm$ 0.108	0.397 $\pm$ 0.025	0.486 $\pm$ 0.037
4861 H β	1.000 $\pm$ 0.039	1.000 $\pm$ 0.045	1.000 $\pm$ 0.066	1.000 $\pm$ 0.084	1.000 $\pm$ 0.036	1.000 $\pm$ 0.041
4959 [O III]	0.454 $\pm$ 0.026	0.418 $\pm$ 0.026	0.323 $\pm$ 0.044	0.267 $\pm$ 0.044	0.357 $\pm$ 0.020	0.326 $\pm$ 0.020
5007 [O III]	1.514 $\pm$ 0.051	1.386 $\pm$ 0.051	0.857 $\pm$ 0.062	0.710 $\pm$ 0.062	1.178 $\pm$ 0.036	1.070 $\pm$ 0.035
6548 [N II]	—	—	0.084 $\pm$ 0.205	0.069 $\pm$ 0.205	—	—
6563 H α	3.387 $\pm$ 0.097	2.755 $\pm$ 0.093	3.177 $\pm$ 0.294	2.739 $\pm$ 0.333	3.201 $\pm$ 0.106	2.737 $\pm$ 0.108
6584 [N II]	—	—	0.253 $\pm$ 0.217	0.209 $\pm$ 0.217	—	—
6717 [S II]	0.208 $\pm$ 0.020	0.164 $\pm$ 0.017	—	—	—	—
6731 [S II]	0.154 $\pm$ 0.022	0.122 $\pm$ 0.019	—	—	—	—
C(H β) dex	0.20 $\pm$ 0.04		0.00 $\pm$ 0.12		0.12 $\pm$ 0.04	
EW(abs) $\text{\AA}$	1.80 $\pm$ 0.38		2.30 $\pm$ 0.28		3.05 $\pm$ 0.34	
F(H β) ^a	2.40 $\pm$ 0.10		0.34 $\pm$ 0.02		0.46 $\pm$ 0.01	
EW(H β) $\text{\AA}$	24 $\pm$ 1		11 $\pm$ 1		33 $\pm$ 1	
$T_e(\text{OIII})(\text{K})$	18,418 $\pm$ 1076		19,520 $\pm$ 1387		20,017 $\pm$ 1085	
$T_e(\text{OII})(\text{K})$	14,929 $\pm$ 98		14,955 $\pm$ 60		14,918 $\pm$ 113	
$N_e(\text{SII})(\text{cm}^{-3})$	56 $\pm$ 218		10 $\pm$ 10		10 $\pm$ 10	
O ⁺ /H ⁺ ($\times 10^5$)	1.790 $\pm$ 0.169		1.949 $\pm$ 0.363		1.348 $\pm$ 0.140	
O ⁺⁺ /H ⁺ ($\times 10^5$)	0.920 $\pm$ 0.120		0.440 $\pm$ 0.074		0.597 $\pm$ 0.069	
O/H($\times 10^5$)	2.710 $\pm$ 0.208		2.389 $\pm$ 0.370		1.945 $\pm$ 0.156	
12+log(O/H)(se,c)	7.35 $\pm$ 0.08		7.30 $\pm$ 0.12		7.21 $\pm$ 0.08	
12+log(O/H)(s,c)	7.31 $\pm$ 0.07		7.22 $\pm$ 0.07		7.20 $\pm$ 0.06	
12+log(O/H)(Y07,c)	7.35 $\pm$ 0.10		7.22 $\pm$ 0.13		7.18 $\pm$ 0.10	

^a in units of 10^{-16} ergs s⁻¹cm⁻².

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Table A4. Measured and corrected line intensities, and derived Oxygen and Neon abundances

	J1444+4242a		J1444+4242b		PGC2081790=J1447+3630	
$\lambda_0(\text{\AA})$ Ion	F(λ)/F(H β)	I(λ)/I(H β)	F(λ)/F(H β)	I(λ)/I(H β)	F(λ)/F(H β)	I(λ)/I(H β)
3727 [O II]	1.162±0.088	1.070±0.092	1.233±0.115	1.161±0.120	1.868±0.061	1.698±0.063
3967 [Ne III] + H7	—	—	—	—	0.109±0.017	0.234±0.049
4101 H δ	0.132±0.017	0.273±0.048	0.110±0.016	0.212±0.043	0.195±0.018	0.306±0.035
4340 H γ	0.317±0.025	0.441±0.045	0.416±0.024	0.477±0.035	0.338±0.018	0.435±0.029
4861 H β	1.000±0.032	1.000±0.038	1.000±0.035	1.000±0.042	1.000±0.024	1.000±0.028
4959 [O III]	0.471±0.023	0.419±0.023	0.278±0.026	0.253±0.026	0.530±0.013	0.482±0.013
5007 [O III]	1.403±0.043	1.248±0.043	0.877±0.036	0.797±0.036	1.616±0.036	1.469±0.036
6563 H α	—	—	—	—	2.865±0.057	2.749±0.067
C(H β) dex	0.04±0.04		0.04±0.05		0.00±0.03	
EW(abs) $\text{\AA}$	2.50±0.25		1.25±0.22		5.05±0.41	
F(H β) ^a	0.77±0.02		0.56±0.02		1.78±0.03	
EW(H β) $\text{\AA}$	21±0.5		13±0.3		50±1	
$T_e(\text{OIII})(\text{K})$	20,274±1057		21,545±1113		18,565±1016	
$T_e(\text{OII})(\text{K})$	15,626±48		16,098±264		14,941±74	
$N_e(\text{SII})(\text{cm}^{-3})$	10±10		10±10		10±10	
$\text{O}^+/\text{H}^+(\times 10^5)$	0.857±0.074		0.851±0.097		1.558±0.062	
$\text{O}^{++}/\text{H}^+(\times 10^5)$	0.695±0.076		0.387±0.042		0.978±0.117	
$\text{O}/\text{H}(\times 10^5)$	1.551±0.107		1.238±0.106		2.536±0.133	
12+log(O/H)(se,c)	7.11±0.08		7.01±0.08		7.33±0.07	
12+log(O/H)(s,c)	7.17±0.05		7.10±0.06		7.29±0.05	
12+log(O/H)(Y07,c)	7.15±0.10		7.02±0.10		7.33±0.09	
$\text{Ne}^{++}/\text{H}^+(\times 10^5)$	—		—		0.268±0.050	
ICF(Ne)	—		—		1.280	
$\text{Ne}/\text{H}(\times 10^5)$	—		—		0.34±0.06	
12+log(Ne/H)	—		—		6.54±0.08	
log(Ne/O)	—		—		-0.87±0.08	

Table A5. Measured and corrected line intensities, and derived Oxygen abundances

	J1522+4201		J2103-0049		AGC321307=J2214+2540	
$\lambda_0(\text{\AA})$ Ion	F(λ)/F(H β)	I(λ)/I(H β)	F(λ)/F(H β)	I(λ)/I(H β)	F(λ)/F(H β)	I(λ)/I(H β)
3727 [O II]	2.481±0.169	2.202±0.171	1.621±0.084	1.639±0.086	2.764±0.384	2.823±0.403
4340 H γ	0.208±0.026	0.310±0.064	—	—	—	—
4861 H β	1.000±0.037	1.000±0.057	1.000±0.028	1.000±0.038	1.000±0.103	1.000±0.224
4959 [O III]	0.390±0.028	0.346±0.028	0.311±0.011	0.310±0.011	0.764±0.091	0.762±0.091
5007 [O III]	1.026±0.037	0.911±0.037	0.913±0.026	0.912±0.026	2.800±0.223	2.793±0.223
6563 H α	3.000±0.087	2.746±0.102	2.767±0.066	2.735±0.071	2.854±0.227	2.790±0.330
C(H β) dex	0.00±0.04		0.01±0.03		0.03±0.10	
EW(abs) $\text{\AA}$	2.20±0.68		0.00±0.05		0.00±0.61	
F(H β) ^a	0.77±0.02		0.50±0.01		0.55±0.04	
EW(H β) $\text{\AA}$	17.4±0.55		2.04±0.04		3.09±0.25	
$T_e(\text{OIII})(\text{K})$	18,882±1079		20,011±1033		15,244±1203	
$T_e(\text{OII})(\text{K})$	14,958±37		14,919±107		14,026±575	
$N_e(\text{SII})(\text{cm}^{-3})$	10±10		10±10		10±10	
$\text{O}^+/\text{H}^+(\times 10^5)$	2.014±0.157		1.511±0.086		3.168±0.620	
$\text{O}^{++}/\text{H}^+(\times 10^5)$	0.608±0.078		0.523±0.057		2.815±0.585	
$\text{O}/\text{H}(\times 10^5)$	2.621±0.175		2.034±0.103		5.983±0.852	
12+log(O/H)(se,c)	7.34±0.08		7.23±0.07		7.76±0.06	
12+log(O/H)(s,c)	7.27±0.06		7.19±0.05		—	
12+log(O/H)(Y07,c)	7.29±0.10		7.18±0.09		7.73±0.10	

^a in units of 10^{-16} ergs s $^{-1}$ cm $^{-2}$.

Table A6. Measured and corrected line intensities, and derived Oxygen and Neon abundances

	AGC332939=J2203+1747		AGC334513=J2348+2335	
$\lambda_0(\text{\AA})$ Ion	F(λ)/F(H β)	I(λ)/I(H β)	F(λ)/F(H β)	I(λ)/I(H β)
3727 [O II]	0.720 $\pm$ 0.024	0.714 $\pm$ 0.026	1.784 $\pm$ 0.143	1.750 $\pm$ 0.165
3967 [Ne III] + H7	0.213 $\pm$ 0.007	0.222 $\pm$ 0.012	—	—
4101 H δ	0.190 $\pm$ 0.011	0.200 $\pm$ 0.015	—	—
4340 H γ	0.363 $\pm$ 0.015	0.369 $\pm$ 0.017	0.324 $\pm$ 0.028	0.471 $\pm$ 0.105
4363 [O III]	0.076 $\pm$ 0.010	0.076 $\pm$ 0.010	—	—
4471 He I	0.033 $\pm$ 0.003	0.033 $\pm$ 0.003	—	—
4861 H β	1.000 $\pm$ 0.031	1.000 $\pm$ 0.032	1.000 $\pm$ 0.038	1.000 $\pm$ 0.078
4959 [O III]	1.414 $\pm$ 0.049	1.402 $\pm$ 0.049	0.351 $\pm$ 0.029	0.306 $\pm$ 0.029
5007 [O III]	3.727 $\pm$ 0.114	3.695 $\pm$ 0.115	1.081 $\pm$ 0.040	0.939 $\pm$ 0.040
6548 [N II]	0.017 $\pm$ 0.014	0.016 $\pm$ 0.014	0.000 $\pm$ 0.054	0.000 $\pm$ 0.054
6563 H α	2.811 $\pm$ 0.086	2.791 $\pm$ 0.094	3.405 $\pm$ 0.164	2.740 $\pm$ 0.168
6584 [N II]	0.021 $\pm$ 0.021	0.021 $\pm$ 0.021	0.081 $\pm$ 0.081	0.063 $\pm$ 0.072
6717 [S II]	0.093 $\pm$ 0.018	0.093 $\pm$ 0.018	0.243 $\pm$ 0.028	0.188 $\pm$ 0.025
6731 [S II]	0.069 $\pm$ 0.018	0.068 $\pm$ 0.018	0.108 $\pm$ 0.027	0.084 $\pm$ 0.024
C(H β) dex	0.00 $\pm$ 0.04		0.15 $\pm$ 0.06	
EW(abs) $\text{\AA}$	0.75 $\pm$ 0.62		2.55 $\pm$ 1.19	
F(H β) ^a	32.07 $\pm$ 0.62		3.72 $\pm$ 0.06	
EW(H β) $\text{\AA}$	89 $\pm$ 2		19 $\pm$ 1	
$T_e(\text{OIII})(\text{K})$	15,172 $\pm$ 977		19,736 $\pm$ 1102	
$T_e(\text{OII})(\text{K})$	13,990 $\pm$ 476		14,943 $\pm$ 77	
$N_e(\text{SII})(\text{cm}^{-3})$	45 $\pm$ 455		10 $\pm$ 10	
$\text{O}^+/\text{H}^+(\times 10^5)$	0.811 $\pm$ 0.104		1.606 $\pm$ 0.154	
$\text{O}^{++}/\text{H}^+(\times 10^5)$	4.084 $\pm$ 0.665		0.548 $\pm$ 0.067	
$\text{O}/\text{H}(\times 10^5)$	4.895 $\pm$ 0.673		2.154 $\pm$ 0.168	
12+log(O/H)(T _e)	7.69 $\pm$ 0.06		—	
12+log(O/H)(se,c)	—		7.25 $\pm$ 0.08	
12+log(O/H)(s,c)	—		7.21 $\pm$ 0.06	
12+log(O/H)(Y07,c)	—		7.21 $\pm$ 0.10	
$\text{Ne}^{++}/\text{H}^+(\times 10^5)$	0.876 $\pm$ 0.169		—	
ICF(Ne)	1.069		—	
$\text{Ne}/\text{H}(\times 10^5)$	0.94 $\pm$ 0.18		—	
12+log(Ne/H)	6.97 $\pm$ 0.08		—	
log(Ne/O)	-0.72 $\pm$ 0.10		—	

^a in units of $10^{-16} \text{ ergs s}^{-1} \text{ cm}^{-2}$.

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Table A7. Measured and corrected line intensities, and derived Oxygen and Neon abundances

$\lambda_0(\text{\AA})$ Ion	AGC124609=J0249+3444		AGC189201=J0823+1754	
	F(λ)/F(H β)	I(λ)/I(H β)	F(λ)/F(H β)	I(λ)/I(H β)
3727 [O II]	0.733 $\pm$ 0.031	0.720 $\pm$ 0.032	0.760 $\pm$ 0.046	0.880 $\pm$ 0.056
3835 H9	0.046 $\pm$ 0.018	0.068 $\pm$ 0.029	—	—
3967 [Ne III] + H7	0.266 $\pm$ 0.008	0.284 $\pm$ 0.011	0.178 $\pm$ 0.009	0.251 $\pm$ 0.015
4101 H δ	0.237 $\pm$ 0.007	0.256 $\pm$ 0.010	0.223 $\pm$ 0.006	0.290 $\pm$ 0.011
4340 H γ	0.463 $\pm$ 0.012	0.476 $\pm$ 0.014	0.404 $\pm$ 0.010	0.466 $\pm$ 0.013
4363 [O III]	0.120 $\pm$ 0.005	0.118 $\pm$ 0.005	0.051 $\pm$ 0.006	0.053 $\pm$ 0.006
4388 He I	—	—	0.009 $\pm$ 0.003	0.009 $\pm$ 0.003
4438 He I	—	—	0.009 $\pm$ 0.003	0.009 $\pm$ 0.003
4471 He I	—	—	0.023 $\pm$ 0.006	0.023 $\pm$ 0.006
4686 He II	0.040 $\pm$ 0.006	0.039 $\pm$ 0.006	—	—
4712 [Ar IV] + He I	0.021 $\pm$ 0.004	0.021 $\pm$ 0.004	—	—
4861 H β	1.000 $\pm$ 0.023	1.000 $\pm$ 0.024	1.000 $\pm$ 0.020	1.000 $\pm$ 0.021
4959 [O III]	2.034 $\pm$ 0.046	1.998 $\pm$ 0.046	0.630 $\pm$ 0.012	0.603 $\pm$ 0.012
5007 [O III]	6.056 $\pm$ 0.124	5.951 $\pm$ 0.124	1.901 $\pm$ 0.032	1.808 $\pm$ 0.031
5869 He II	—	—	0.127 $\pm$ 0.006	0.109 $\pm$ 0.005
6548 [N II]	—	—	0.006 $\pm$ 0.011	0.004 $\pm$ 0.009
6563 H α	—	—	3.424 $\pm$ 0.055	2.756 $\pm$ 0.049
6584 [N II]	—	—	0.025 $\pm$ 0.014	0.020 $\pm$ 0.012
6678 He I	—	—	0.037 $\pm$ 0.006	0.029 $\pm$ 0.005
6717 [S II]	—	—	0.096 $\pm$ 0.003	0.076 $\pm$ 0.003
6731 [S II]	—	—	0.079 $\pm$ 0.006	0.062 $\pm$ 0.005
C(H β) dex	0.00 $\pm$ 0.03		0.25 $\pm$ 0.02	
EW(abs) $\text{\AA}$	1.50 $\pm$ 0.42		3.15 $\pm$ 0.35	
F(H β) ^a	14.77 $\pm$ 0.19		3.53 $\pm$ 0.04	
EW(H β) $\text{\AA}$	89 $\pm$ 1.5		101 $\pm$ 1	
$T_e(\text{OIII})(\text{K})$	15,146 $\pm$ 341		18,464 $\pm$ 1209	
$T_e(\text{OII})(\text{K})$	13,978 $\pm$ 167		14,933 $\pm$ 103	
$N_e(\text{SII})(\text{cm}^{-3})$	10 $\pm$ 10		235 $\pm$ 161	
$\text{O}^+/\text{H}^+(\times 10^5)$	0.820 $\pm$ 0.048		0.829 $\pm$ 0.057	
$\text{O}^{++}/\text{H}^+(\times 10^5)$	6.415 $\pm$ 0.378		1.223 $\pm$ 0.175	
$\text{O}^{+++}/\text{H}^+(\times 10^5)$	0.542 $\pm$ 0.154		—	
$\text{O}/\text{H}(\times 10^5)$	7.778 $\pm$ 0.374		2.052 $\pm$ 0.184	
12+log(O/H)(T_e)	7.89 $\pm$ 0.02		7.31 $\pm$ 0.04	
12+log(O/H)(se,c)	—		7.22 $\pm$ 0.07	
12+log(O/H)(s,c)	—		7.26 $\pm$ 0.05	
12+log(O/H)(Y07,c)	—		7.28 $\pm$ 0.09	
$\text{Ne}^{++}/\text{H}^+(\times 10^5)$	1.032 $\pm$ 0.074		0.235 $\pm$ 0.041	
ICF(Ne)	1.073		1.176	
$\text{Ne}/\text{H}(\times 10^5)$	1.11 $\pm$ 0.08		0.28 $\pm$ 0.05	
12+log(Ne/H)	7.04 $\pm$ 0.03		6.44 $\pm$ 0.08	
log(Ne/O)	-0.85 $\pm$ 0.04		-0.87 $\pm$ 0.09	

^a in units of $10^{-16} \text{ ergs s}^{-1} \text{cm}^{-2}$.