ASTRONOMY & ASTROPHYSICS
SUPPLEMENT SERIES

JUNE I **1999**, PAGE 299

Astron. Astrophys. Suppl. Ser. **137**, 299–304 (1999)

The Hamburg/SAO survey for emission–line galaxies

II. The second list of 128 galaxies

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Received December 21, 1998; accepted March 19, 1999

Abstract. We present the second part[1,2] of the Hamburg/SAO Survey for Emission-Line Galaxies (HSS therein, SAO – Special Astrophysical Observatory, Russia) which is based on the digitized objective-prism photoplates database of the Hamburg Quasar Survey (HQS). The main goal of the project is the search for emission-line galaxies (ELG) in order to create a new deep sample of blue compact/HII galaxies (BCG) in a large sky area. Another important goal of this work is to search for new extremely low-metallicity galaxies. In this paper we present new results of spectroscopy obtained with the 6 m Russian telescope. The main ELG candidate selection criteria applied are blue or flat enough continuum (near λ4000 Å) and the presence of strong or moderate [OIII] $\lambda\lambda$4959, 5007 Å emission lines recognized on digitized prism spectra of galaxies with the survey estimated B-magnitudes in the range $16^{\rm m} - 19\overset{\rm m}{.}5$. No other criteria were applied. The spectroscopy resulted in detection and quantitative spectral classification of 134 emission-line objects. For 121 of them the redshifts are determined for the first time. For 13 ELGs known before emission line ratios are presented at first time. 108 of 134 emission-line objects are classified as BCG/HII galaxies and probable BCGs, 6 – as QSOs, 1 – as Seyfert galaxy, 1 – as super-association in a dwarf spiral galaxy, 2 – as probable LINERs, 14 are low excitation objects – either of starburst nuclei (SBN), or dwarf amorphous nuclei starburst galaxy (DANS) type, and 2 – nonclassified. 23 galaxies did not show significant emission lines. The five most metal-deficient BCGs discovered have oxygen abundances log(O/H)+12 in the range 7.4 to 7.7, similar to the most metal-deficient BCGs known before.

Key words: surveys — galaxies: distances and redshifts — galaxies: starburst — galaxies: compact

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[1] Tables 2 to 6 are only available in electronic form at the CDS via anonymous ftp to cdsarc.u-strasbg.fr (130.79.128.5) or via http://cdsweb.u-strasbg.fr/Abstract.html. Figures A1 to A13 will be made available only in the electronic version of the journal.

[2] Appendix A is only available at http://www.edpsciences.com

1. Introduction

The studies of various types of galaxies with strong current star formation (SF) are among the most popular in extragalactic astronomy. For many purposes in this work it is very important to deal with large enough and well selected samples of such objects. In particular, the authors are involved in studies of SF bursts in low-mass galaxies (HII-galaxies, or blue compact galaxies - BCGs), and thus are interested in dealing with large samples of BCGs. There are three such large BCG/HII galaxy samples on the northern sky, each covering about 1000 square degrees. The first one is situated in the zone of the Second Byurakan Survey (Markarian et al. 1983; Stepanian 1994) ($\alpha = 7^{\rm h}40^{\rm m} - 17^{\rm h}20^{\rm m}$, $\delta = +49° - +61°$). It is described partly by Izotov et al. (1993a, 1993b); Thuan et al. (1994) and Pustilnik et al. (1995). The second one is under completion (Salzer et al. 1995; Ugryumov 1997; Ugryumov et al. 1998) and is situated in a region, which is a part of the Case objective prism survey ($\alpha = 8^{\rm h}00^{\rm m} - 16^{\rm h}20^{\rm m}$, $\delta = +29° - +38°$) (Pesch et al. 1995). The third one, the Heidelberg void survey (Popescu et al. 1996, 1998), is located in two separated regions. The new Hamburg/SAO Survey for Emission-Line Galaxies is intended to cover the

Table 1. Journal of observations at the SAO 6 m telescope

Run No (1)	Date (2)			Instrument (3)	Grating [grooves/mm] (4)	Wavelength Range [Å] (5)	Dispersion [Å/pixel] (6)
1	14	Dec.	1995	CCD, SP–124	300	4600−7400	5.2
2	17	Dec.	1995	CCD, SP–124	300	4000−7200	5.2
3	14	Jan.	1996	CCD, SP–124	300	4000−7000	5.2
4	15–17	Jan.	1996	CCD, SP–124	300	3800−7000	5.2
5	19–20	Feb.	1996	CCD, SP–124	300	3800−7000	5.2
6	21–22	Feb.	1996	CCD, SP–124	600	3800−5400	2.7
7	7–8	Oct.	1996	CCD, SP–124	600	3700−6000	2.4
8	12–14	Nov.	1996	CCD, LSS	650	3700−7000	3.1
9	16	Jan.	1997	CCD, LSS	650	3700−5400	3.1
10	1	Dec.	1997	CCD, SP–124	600	3700−6000	2.4
11	3–5	Apr.	1998	CCD, SP–124	600	3700−6000	2.4
12	6	Apr.	1998	CCD, SP–124	300	3700−8000	4.5
13	19	Apr.	1998	CCD, SP–124	600	3700−7500	2.4
14	27	Apr.	1998	CCD, SP–124	300	3700−8000	4.5
15	1–2	May	1998	CCD, SP–124	300	3600−8000	4.5
16	27–30	Jun.	1998	CCD, SP–124	300	3700−8000	4.5

gap between the regions of the SBS and the Case survey and to create a new BCG/HII galaxy sample in that region. It covers the region between $7^{\rm h}20^{\rm m}$ to $17^{\rm h}40^{\rm m}$ in right ascension and between $+35°$ to $+50°$ in declination. This is the second article of the series devoted to follow-up spectroscopy results of preselected ELG Hamburg/SAO candidates. The basic ideas of the Hamburg/SAO survey and the selection methods of ELG candidates are described along with the first results of follow-up spectroscopy in Ugryumov et al. (1999) (Paper I).

This article is organized as follows. In Sect. 2 we give the details of the 6 m telescope spectroscopic observations and of the data reduction. In Sect. 3 the results of the observations are presented in several tables. Along with general parameters for emission-line galaxies and several quasars the parameters of the strongest emission lines are summarized in a separate table. The information on several non emission-line galaxies is presented as well. In Sect. 4 we briefly discuss the new data and summarize the current state of the Hamburg/SAO survey. Throughout this paper a Hubble constant $H_0 = 75$ km s^{-1} Mpc^{-1} is used.

2. Spectral observations and data reduction

All results presented below were obtained by observations with the Russian 6 m telescope, mainly in the snapshot mode during 16 runs between December 1995 and June 1998. The spectrograph SP-124 attached to the Nasmyth-1 focus of the telescope and equipped with a new Photometrix CCD-detector PM1024 (with 24×24 μm pixel size) was used in most of the runs. We used the gratings either with 300 grooves/mm or with 600 grooves/mm (see journal of observations in Table 1). Due to an experimental set-up of the CCD detector, it was not properly optimized, and significant vignetting prevented us in several runs in 1995 and early 1996 to get spectra in the UV ($\lambda \leq 4000$ Å). Various spectral set-ups were used with dispersions from 2.4 to 5.5 Å/pixel. The long slit with a length of 40″ was used. The slit width was 2″ in almost all observations. The scale along the slit was 0.4″ or 0.5″/pixel. Normally, short exposures were used (2 − 5 min) in order to detect strong emission lines, to measure redshifts and make some crude classification. Several spectra were taken with the Long Slit spectrograph (LSS in Table 1) (Afanasiev et al. 1995) at the 6 m telescope prime focus equipped with a CCD-detector on base of an ISD015A chip (530 × 580 pixels, with rectangular pixel size 18 × 24 μm), produced at SAO RAS. Long slit spectra (2″ × 180″) were obtained with the grating having 650 grooves/mm and a dispersion 3.1 Å/pixel, and a scale along the slit of 0.41″/pixel. Reference spectra of an Ar–Ne–He lamp were recorded before or after each observation to provide a wavelength calibration. The spectrophotometric standard stars from Massey et al. (1988) were observed for flux calibration at least twice a night.

All observations and data acquisition with the spectrograph SP-124 have been conducted under software package `NICE` in MIDAS, described by Kniazev & Shergin (1995).

2.1. Data reduction

The data reduction was done at SAO with the MIDAS software package. The context LONG was adapted to the SAO data formats to perform an automatic reduction.

The reduction of the originally two-dimensional CCD data included standard steps such as: bias and dark subtraction, flat-fielding, cosmic-ray removal. After wavelength mapping the subsequent night sky background subtraction was performed. 1-D spectra were extracted by adding $6 - 10$ (depending on seeing and galaxy size) consecutive CCD rows centered on the object intensity peak along the slit. Then the corrections for atmospheric extinction and flux calibration were applied. For the flux calibration we used the mean response curve obtained from the observations of standard stars, mainly Feige 34 and HZ 44.

In the final spectra showing emission lines, redshifts and line fluxes are measured applying Gaussian fitting. To determine redshifts for individual galaxies averages are taken over prominent individual emission lines (mostly Hβ, Hα, [OIII] λ4959, 5007 Å). The line [OII] λ3727 Å is not used for redshift determination since for most of the objects its observed wavelength is determined with significantly larger uncertainties due to the extrapolation of the linear scale below the first line of HeI λ3889 Å in the reference spectrum.

The emission line fluxes are computed by summing up the pixel intensities inside the line region by using standard MIDAS program tools. For all spectra, the individual emission line fluxes of the Hα, [NII] $\lambda\lambda$6548, 6583 Å and [SII] $\lambda\lambda$6716, 6731 Å line blends are obtained by summing up of pixel intensities over the total blend and then modelling the individual line fluxes using Gaussian fitting.

3. Results of follow–up spectroscopy

In total 196 new candidates and 13 known ELGs have been observed. Among them 128 are new or confirmed emission line galaxies, 6 are quasars (all with redshifts in the range 2.93 to 3.35) and 23 are galaxies without emission lines (only 5 of them have good enough S/N ratio to identify absorption features and to measure redshifts). The remaining 52 objects appeared to be either stars with characteristic absorption lines or stellar objects with featureless spectra mainly due to insufficient signal-to-noise ratio to identify weak lines.

3.1. Emission-line galaxies

The new emission line galaxies are listed in Table 2 containing the following information:
Column 1: The object's IAU-type name with the prefix HS.
Column 2: Right ascension for epoch B1950.
Column 3: Declination for epoch B1950. The coordinates were measured on direct plates of the HQS and are accurate to $\sim 2''$ (Hagen et al. 1995).
Column 4: Heliocentric velocity and its rms uncertainty in km s^{-1}.
Column 5: Apparent B-magnitude obtained by calibration of digitized photoplates with photometric standard stars (Engels et al. 1994), having an rms accuracy of $\sim 0\overset{m}{.}5$ for objects fainter than $m_B = 16\overset{m}{.}0$ (Popescu et al. 1996). Since the algorithm to calibrate the objective prism spectra is optimized for point sources the brightnesses of extended galaxies are underestimated. We expect that uncertainties of the magnitudes can be up to 2 mag (Popescu et al. 1996).
Column 6: Absolute B-magnitudes calculated from the apparent B-magnitude and heliocentric velocity. No correction for galactic extinction is made because all observed objects are located at high galactic latitudes and because the corrections are significantly smaller than the uncertainties of the magnitudes.
Column 7: Preliminary spectral classification type according to the spectral data presented in this article. BCG means that the galaxy posesses a characteristic HII-region spectrum and low enough luminosity, SBN and DANS are galaxies of lower excitation with a corresponding position in line ratio diagrams, as discussed in Paper I. SBN are the brighter fraction of this type. The Seyfert galaxy shows widened Hα and Hβ and strong and widened HeII λ4686 Å line. SA are probable super-associations in the outskirts of two dwarf spirals. Two objects are difficult to classify. They are coded as NON.
Column 8: One or more alternative names, according to the information from NED[3].

The spectra of all emission-line galaxies are shown in the Appendix A.

The results of line flux measurements are given in Table 4. It contains the following information:
Column 1: The object's IAU-type name with the prefix HS.
Column 2: Observed flux (in $10^{-16}\,\mathrm{erg\,s^{-1}\,cm^{-2}}$) of the H$\beta$ λ4861 Å line. For few objects without Hβ emission line the fluxes are given for Hα marked by an asterisk. For about 10 objects observed during non-photometric conditions this parameter is unreliable and marked by (:)
Columns 3, 4, 5: The observed flux ratios [OII]/Hβ, [OIII]/Hβ and Hα/Hβ.
Columns 6, 7: The observed flux ratios [NII] λ 6583 Å/Hα, and ([SII] λ 6716 Å + [SII] λ 6731 Å)/Hα.
Columns 8, 9, 10: Equivalent widths of the lines [OII] λ 3727 Å, Hβ and [OIII] λ 5007 Å. For few objects without detected Hβ emission line the equivalent widths are given for Hα marked by an asterisk.

Below we give notes on several individual objects in Table 2.

[3] The NASA/IPAC Extragalactic Database (NED) is operated by the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration.

HS0737+4011 This is a comet-like galaxy. The spectrum is shown for its head.
HS0811+4913 This is a probable super-association (SA) at 75″ to NEE from the nucleus of the SA(s)cd galaxy NGC 2541 ($M_B = -17.5$) with a radial velocity 556 km s^{-1}.
HS1035+4758 Nearby BCG with a recent supernovae type IIP (SN1998bv, Kniazev et al. 1998; Merlino et al. 1998; Pustilnik et al. 1999).
HS1057+4632 KUG 1047+465 is at 67″ to NNE.
HS1102+4120 An object resembling on the Digital Sky Survey (DSS) an elliptical galaxy with a size 15″ × 12″ elongated NE–SW. Due to strong [SII] lines the galaxy is classified as LINER in diagnostic diagrams involving this line. But its luminosity is untypically low for a LINER. An alternative classification is therefore an HII galaxy with some enhanced [SII] shock excitation (post-merger starburst?).
HS1457+4458AB Two ELGs with close redshifts at ≈20″ from each other (15 kpc in projection). Interacting pair?
HS1542+4116 Seemingly a dwarf companion of the SB(r)b galaxy NGC 5993, which is at 52″ to the west. This SB galaxy is a component of the pair KPG 471.
HS1604+4127 Seemingly a dwarf companion of a barred dwarf spiral CGCG 1604.0+4127 at 41″ to NE. The latter is a component of the galaxy pair KPG 482.
HS1614+4709 Probable companion of the face-on dwarf spiral UGC 10310≡Arp 2.
HS1643+4015 This is a disturbed galaxy of about 24″ in extent with two knots in the central part. The spectrum is shown for the brighter eastern one.
HS1717+4955 Seemingly a dwarf companion of the SB(s)dm galaxy UGC 10806 ($M_B = -17.8$) with a radial velocity of ∼ 927 km s^{-1} (see for details Kniazev et al. 1999).

Several new BCGs from this paper were reobserved with higher S/N ratio in order to measure the flux of the [OIII] λ 4363 line, necessary to determine unambiguously the electron temperature T_e([OIII]) of the HII-region and the oxygen abundance. A preliminary determination according to the procedure decribed by Izotov et al. (1997) shows a log(O/H)+12 for the five most metal-deficient BCGs HS 0822+3542, HS 0837+4717, HS 1013+3809, HS 1033+4757 and HS 1442+4250 to be 7.4, 7.68, 7.63, 7.7 and 7.7, respectively. A more detailed presentation of their spectroscopy will appear in forthcoming publications.

3.2. Quasars

In the course of our follow-up spectroscopy six QSOs were discovered with a strong emission line in the wavelength region between 5000 Å and the sensitivity break of the Kodak IIIa-J photoemulsion near 5400 Å. For all of them it was Lyα λ 1216 redshifted to $z \sim 3$. This strong line produces an easily visible emission peak in the digitized prism spectra even for very faint objects ($B \sim 19\overset{m}{.}0 - 20\overset{m}{.}0$) which is hard to distinguish from low-redshifted [OIII] features. In other cases QSOs normally were not selected as candidates for follow-up spectroscopy.

The data for these six new high-redshift quasars are presented in Table 3. Their finding charts and plots of spectra can be found on www-site of the Hamburg Quasar Survey (http://www.hs.uni-hamburg.de/hqs.html).

3.3. Non emission-line objects

In total for 75 candidates no (trustworthy) emission lines are detected. We divided them into three categories.

3.3.1. Absorption line galaxies

For five bright non-ELG galaxies the signal-to-noise ratio of our spectra was sufficient to detect absorption lines, allowing the determination of redshifts. The data are presented in Table 5.

3.3.2. Stellar objects

To separate the stellar objects among all objects without emission lines we used a list of the most common stellar features as a template, and cross-correlated this list with observed the spectra. As a result we found 31 objects with definite stellar spectra and redshifts close to zero. Three of them are obvious M-stars. The rest were classified roughly in categories from definite A-stars to definite G-stars, with most of them G-type, and intermediate between F and G. The data for these stars are presented in Table 6.

3.3.3. Non-classified objects

39 non emission-line objects are hard to classify. Their continuum have too low signal-to-noise ratio to detect trustworthy absorption features, or small EW emission lines. 18 of them are certainly non-stellar on DSS images. For half of these galaxies we have spectra only in the range ≈ 4000 to ≈ 5400 Å, and they could have emission in Hα. For the other half we have spectra in the range ≈ 4000 to ≈ 7000 Å, and we can exclude the presence of strong Hα. The remaining 21 objects are indistinguishable from stellar ones, and we suggest that most of them are galactic stars.

4. Discussion

Altogether we have observed 209 objects preselected as ELG candidates on HQS objective prism plates, of which 196 had no previous spectroscopic information. 134 (64%) are found to be either ELGs, or quasars. Of 128 detected ELGs 108 were classified on the character of their spectra and their absolute magnitudes as BCGs or probable BCGs. One galaxy showing broad Hα ($FWHM$ = 1800 km s^{-1}) and Hβ ($FWHM$ = 1400 km s^{-1}) and wide and strong HeII λ 4686 (I(HeII)/I(Hβ) $\sim$ 0.7) is a Seyfert galaxy (HS 1057+4632). One very faint object (HS 0811+4913) of absolute magnitude $M_B = -11.4$ is probably a super-association in the dwarf spiral NGC 2541. Two galaxies show emission line ratios characteristic for LINERs. Two are difficult to classify. The remaining 14 ELGs are objects of lower excitation: either Starburst Nuclei galaxies (SBN) or their lower mass analogs Dwarf Amorphous Nuclear Starburst galaxies (DANS) (Salzer et al. 1989). Since the main goal of the HSS is an efficient search for new BCGs, the fraction of this type among all new detected ELGs – 84%, or 80% among all emission-line objects, is very encouraging.

It is worth to note that after the analysis of the results of pilot part of the HSS (see Paper I), the selection algorithm was improved in order to clean the candidate lists for follow-up spectroscopy from the majority of stellar-like and second priority objects. The majority of the former have been found as blue stars, and the latter are either low excitation ELG or galaxies without emission lines. The overall detection efficiency of emission-line objects has grown significantly, up to 64% for this second part of the HSS.

The distributions of the new HSS ELGs in the line-ratio diagrams [OIII] λ 5007/Hβ versus [NII] λ 6583/Hα and [OIII] λ 5007/Hβ versus [OII] λ 3727/[OIII] λ 5007 (see Baldwin et al. 1981; Veilleux & Osterbrock 1987, for details) in general are similar to those shown in Paper I. Several new high excitation BCGs are discovered or rediscovered. Follow-up spectroscopy with high signal-to-noise of these prominent galaxies resulted in the discovery of new very metal-poor galaxies. This data will appear in separate papers currently in preparation.

One more immediate conclusion comes from the absolute magnitudes of new the ELGs in Table 2. Even with some reservations concerning the accuracy of the apparent magnitudes, the Hamburg/SAO Survey picks up well objects with $M_B \geq -15$. Thus, with additional photometry to improve the accuracy of B-magnitudes, this sample will serve as an important instrument to study the still poorly known faint end of the ELG luminosity function.

Altogether in Paper I and in the present paper we discovered 176 new emission-line objects (10 of them QSOs), and for 32 more galaxies we got quantitative data for their emission lines. Preliminary classification of the 198 ELGs yields 155 confident or probable blue compact/low-mass HII-galaxies. Thus a large fraction of BCGs relative to all ELGs is found ($\sim$ 78%) demonstrating the high efficiency of this survey to find on the Hamburg Quasar Survey photoplates namely galaxies with HII-type spectra. A statistical analysis of this BCG sample, supplemented with galaxies from the next parts of the survey is underway.

5. Conclusions

We conducted follow-up spectroscopy for the second part of candidates from the Hamburg/SAO Survey for ELGs. Summarizing the results presented, the analysis of the content of various types of objects, and the discussion above, we draw the following conclusions:

- The intended methods to detect ELG candidates on the plates of the Hamburg Quasar Survey give a reasonably high detection rate of emission-line objects ($\sim$ 64%) (134 objects of 209 observed in this second part). Additional selection criteria applied in comparison to the first, pilot part increased the efficiency of follow-up spectroscopy by a factor of about two.
- Besides of ELGs we found also 6 new quasars, all with Lyα in the wavelength region 5000 – 5300 Å (i.e. with $2.9 < z < 3.35$) near the red boundary of the IIIa-J photoplates.
- The high fraction of BCG/HII galaxies among all newly discovered ELGs (about 84%) is in line with our main goal — to pick up a deep BCG sample in the sky region under analysis.

Acknowledgements. This work was supported by the grant of the Deutsche Forschungsgemeinschaft No. 436 RUS 17/77/94. U.A.V is very grateful to the staff of the Hamburg Observatory for their hospitality and kind assistance. SAO authors appreciate the partial financial support from the Russian Foundation for Basic Research grant No. 96-02-16398 and from the Russian Center of Cosmoparticle Physics "Cosmion". Partial support by the INTAS grant No. 96-0500 is acknowledged. We acknowledge also partial support by the Russian Ministry of Science and Technology for the 6 m telescope of SAO RAS (BTA, Reg. number 01-43). The authors thank the referee G.Comte for useful suggestions helping to improve the text. SAO authors are pleased to thank A. Burenkov for the help in observations with the 6 m telescope long-slit prime focus spectrograph. The authors acknowledge the use of the NASA/IPAC Extragalactic Database (NED).

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