The Zeldovich Universe:
Genesis and Growth of the Cosmic Web
Proceedings IAU Symposium No. 308, 2014
R. van de Weygaert, S. Shandarin, E. Saar & J. Einasto, eds.

doi:10.1017/S1743921316010668

Observations of dwarfs in nearby voids: implications for galaxy formation and evolution

Simon A. Pustilnik

Special Astrophysical Observatory of Russian Academy of Sciences,
369167, Nizhnij Arkhyz, Russia
email: sap@sao.ru

Abstract. The intermediate results of the ongoing study of deep samples of ∼200 galaxies residing in nearby voids, are presented. Their properties are probed via optical spectroscopy, *ugri* surface photometry, and HI 21-cm line measurements, with emphasis on their evolutionary status. We derive directly the hydrogen mass M(HI), the ratio $M(\mathrm{HI})/L_{\mathrm{B}}$ and the evolutionary parameter gas-phase O/H. Their luminosities and integrated colours are used to derive stellar mass M_* and the second evolutionary parameter – gas mass-fraction (f_{g}). The colours of the outer parts, typically representative of the galaxy oldest stellar population, are used to estimate the upper limits on time since the beginning of the main SF episode. We compare properties of void galaxies with those of the similar late-type galaxies in denser environments. Most of void galaxies show smaller O/H for their luminosity, in average by ∼30%, indicating slower evolution. Besides, the fraction of ∼10% of the whole void sample or ∼30% of the least luminous void LSB dwarfs show the oxygen deficiency by a factor of 2–5. The majority of this group appear very gas-rich, with f_{g} ∼(95–99)%, while their outer parts appear rather blue, indicating the time of onset of the main star-formation episode of less than 1–4 Gyr. Such unevolved LSBD galaxies appear not rare among the smallest void objects, but turned out practically missed to date due to the strong observational selection effects. Our results evidense for unusual evolutionary properties of the sizable fraction of void galaxies, and thus, pose the task of better modelling of dwarf galaxy formation and evolution in voids.

Keywords. galaxies: evolution, galaxies: formation, galaxies: dwarf, galaxies: abundances, galaxies: photometry, galaxies: statistics, large-scale structure of universe, radio lines: galaxies

1. Introduction and Overview

Studies of galaxies in low-density environments were tempting in the hope to probe the basics of galaxy evolution in isolation. The modern concepts suggest however that even the most isolated objects are related to and influenced by the baryon flows of adjacent filaments. Observational studies of galaxy samples in voids, based on large deep surveys (SDSS, 2dRGS), were mostly limited by large distant voids ($D \sim$ 100–200 Mpc). As a consequence, they probed only the upper part of void galaxy luminosity function ($M_{\mathrm{r}} < -16$). Only subtle or at most moderate differences with wall galaxies were found on their SFR and colours.

The complementary approach to study tens-hundred less luminous galaxies in nearby voids was suggested in Pustilnik & Tepliakova (2011). The first void intrinisically faint galaxy sample (down to $M_{\mathrm{B}} = -11$) was drawn up in the nearby Lynx-Cancer void ($D_{\mathrm{centre}} = 18$ Mpc), currently including over 100 objects. Several interesting findings on void galaxy evolution (see below) evidense for importance of this direction and emphasize the need of larger statistics and detailed studies of the least luminous void galaxies.

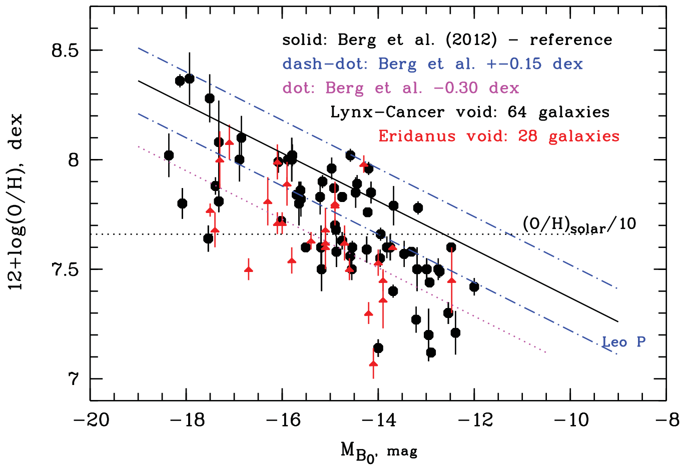

Figure 1. O/H (with error bars) vs $M_{\rm B}$ relation for 92 galaxies in the Lynx-Cancer (filled octogons) and Eridanus (filled triangles) voids in respect of similar galaxies in denser environment (Berg *et al.* 2012, "reference"). The significant systematic O/H drop in void galaxies is evident as well as the sizable fraction of strong outliers (deficiency of O/H by factor of 2–5) (Pustilnik *et al.* 2011, 2014; Kniazev *et al.* 2014, in prep.)

2. Ongoing project and intermediate results

To significantly encrease the number of faint void galaxies and conduct more reliable statistical study of their properties, we work on the revision of the sample of nearby voids and the sample of galaxies residing in them. In particular, galaxies residing in Monoceros and Cetus voids and in the equatorial part of Eridanus void (Fairall, 1998) are added to the current sample of the Lynx-Cancer void. Some of the important results on the evolutionary status of void galaxies are illustrated below.

In Fig. 1 we summarise determinations of gas-phase O/H in 92 galaxies residing in the Lynx-Cancer (filled octogons) and Eridanus (filled triangles) voids (Pustilnik, Tepliakova & Kniazev, 2011, Pustilnik *et al.* in prep., Kniazev *et al.* in prep.). In the large fraction of studied spectra no [OIII]λ4363 line was detected, and hence semi-empirical method by Izotov & Thuan (2007) was used to determine O/H. These O/H are shown vs absolute blue magnitudes $M_{\rm B}$. For comparison we use the sample of similar galaxies from the Local Volume for which the confident O/H, distances and $M_{\rm B}$ are known (Berg *et al.*, 2012). Their linear regression of 12+log(O/H) and $M_{\rm B}$ is shown by solid line, while $\pm 1\sigma$ rms scatter in O/H (0.15 dex) are shown by dash-dotted lines. The substantial shift of the whole void O/H data below the 'reference' Berg *et al.* relation is well seen. Moreover, the sizable fraction of void galaxies shows the O/H deficiency of more than by factor of two (up to five).

Another important result comes from mass photometric study of Lynx-Cancer void galaxies based on the SDSS database (Abazajian *et al.* 2009). In particular, we determined *ugri* colours of outer parts for 85 void galaxies and compared them with PEGASE2 (Fioc & Rocca-Volmerange, 1999)) evolutionary tracks for two extreme SF laws: instantaneous and continuous with constant SFR (Fig. 2). While the great majority of void galaxies started their main star formation 7-14 Gyr ago, for about 15% of the sample we have clear indication of the retarded main star formation, commenced 1–5 Gyr ago.

The third direction in study of void galaxies is related to their HI content and structure. Integrated HI data on 96 Lynx-Cancer void galaxies (Pustilnik, Martin, in prep.) indicate that void objects are in average gas-rich, with median M(HI)/$L_{\rm B}$=1.2, ∼40% higher than

https://doi.org/10.1017/S1743921316010668 Published online by Cambridge University Press

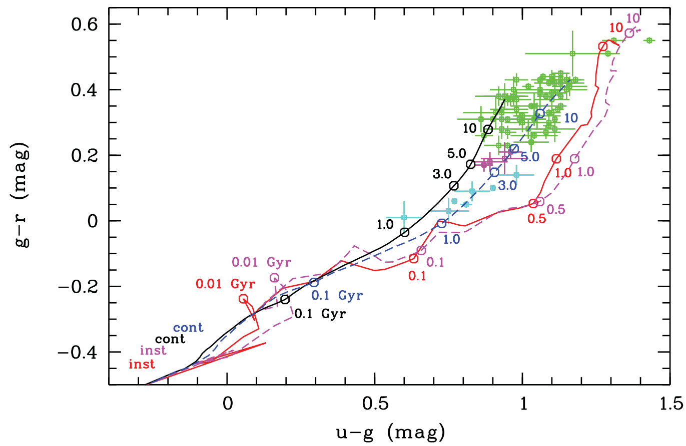

Figure 2. Age indicators: *ugr* colours of outer parts of 85 Lynx-Cancer void galaxies superimposed on PEGASE2 evolutionary tracks. ∼15% show retarded main Star Formation, started only 1–5 Gyr ago (see Perepelitsyna *et al.*, 2014)). Solid lines correspond to Salpeter IMF, while dashed lines - to Kroupa *et al.* IMF.

for the sample of similar galaxies in denser environment. Mapping of their HI with Giant Meterwave Radio Telescope leads to discovery of extremely gas-rich LSB dwarfs with $M(\mathrm{HI})/L_{\mathrm{B}}$=10 and 25, and $M_{\mathrm{gas}}/M_{\mathrm{bary}}$ >0.99 (Chengalur & Pustilnik, 2013; see Fig. 3, left). Such 'unevolved' galaxies are found mostly among the least luminous void galaxies. They can be not rare among void objects with $M_{\mathrm{B}} \gtrsim -11$, but due to severe observational selection effects they escape appearance in common wide-angle spectral surveys. Another interesting result of HI-mapping of three the most isolated void LSBD galaxies shows their disturbed morphology (Fig. 3, right). Probably here we see the most clear cases of cold accretion along void filaments (Chengalur *et al.* in prep.).

3. Implications

Summarising all above and some published findings on properties of galaxies residing in nearby voids, we notice the following implications:

• void galaxies in average show slower chemical evolution, having O/H in average 30%–40% lower than similar galaxies in denser environment; ∼10% of void galaxies have O/H lower by 2–5 times, indicating their unusual evolutinory status.

• *ugri* colours of outer parts for ∼15% void galaxies indicate the main SF episode started ∼1–5 Gyr ago.

• More than a half of void galaxies are gas-rich, with $M(\mathrm{HI})/L_{\mathrm{B}}$ >1. Extremely gas-rich dwarfs, with $M(\mathrm{HI})/L_{\mathrm{B}} = 4 - 25$ already found in voids can be not rare among the least luminous dwarfs ($M_{\mathrm{B}} > -11$).

• All together these results imply that evolution of void galaxies in average goes substantially more slowly. In addition, there are indications on that ∼10% void galaxies formed with significant delay. This fraction reaches ∼30% if we consider the least luminous void LSB dwarfs.

Acknowledgements. SAP is grateful to A. Kniazev, J.-M. Martin, J. Chengalur, A. Tepliakova, Y. Perepelitsyna and E. Safonova for fruitful collaboration and their contribution to the discussed topics. The author acknowledges the partial support of this work through RFBR grant 14-02-00520 and IAU travel grant.

https://doi.org/10.1017/S1743921316010668 Published online by Cambridge University Press

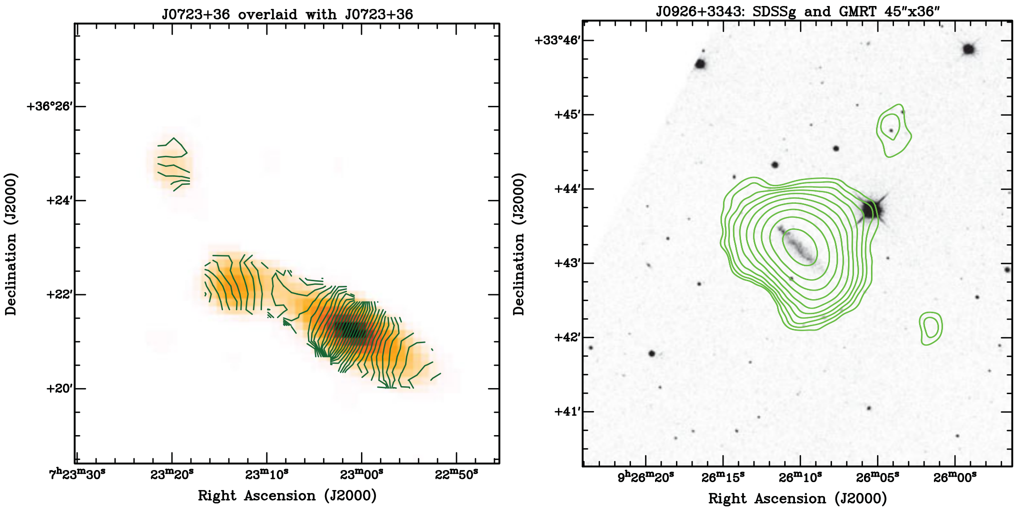

Figure 3. Left panel: Extremely gas-rich dwarf triplet J0723+36 near the centre of Lynx–Cancer void, at D =16 Mpc, with $M(\mathrm{HI})/L_{\mathrm{B}}$ of ∼3, 10 and 25. The two more massive members appear to experience a minor merger, while the least massive and most gas-rich dwarf at the NE is still well separated. HI column density is shown in grey scale, while contures show isovelocity lines with step of 6 km s^{-1}. This finding can be a hint to possible hidden void population of very gas-rich low mass galaxies (Chengalur & Pustilnik, 2013). **Right panel:** Disturbed HI morphology in isolated void LSBD galaxies: the 2-nd most metal-poor LSBD J0926+3343 (Chengalur *et al.*, in prep.). HI column density (in contures) is superimposed on g-band SDSS image. Evidence for cold accretion?

References

Abazajian K. N., Adelman-McCarthy J. K., Agüeros M. A. *et al.*, 2009, *ApJS*, 182, 543

Berg D. A., Skillman E. D., Marble A. R., *et al.* 2012, *ApJ*, 754, 98

Chengalur J. N. & Pustilnik S. A. 2013, *MNRAS* 428, 1579

Fairall A., 1998, *Large-Scale Structures in the Universe, Wiley-Praxis, 196 pp.*

Fioc M. & Rocca-Volmerange B. 1999, *arXiv:astro-ph/9912179*

Izotov Y. I. & Thuan T. X. 2007, *ApJ* 665, 1115

Kreckel K., Platen E., Aragon-Calvo M. A., *et al.* 2012, *AJ* 144, 16

Perepelitsyna Y. A., Pustilnik S. A., & Kniazev A. Y. 2014, *Astroph. Bull.* 69, 247 (arXiv:1408.0613)

Pustilnik S. A. & Tepliakova A. L. 2011, *MNRAS* 415, 1188

Pustilnik S. A., Tepliakova A. L., Kniazev A. Y., *et al.* 2010, *MNRAS* 401, 333

Pustilnik S. A., Tepliakova A. L., & Kniazev A. Y. 2011, *Astroph. Bull.* 66, 255 (arXiv:1108.4850)

Pustilnik S. A., Tepliakova A. L., & Kniazev A. Y. 2011, *MNRAS* 417, 1335

Pustilnik S. A., Martin J.-M., Lyamina Y. A., & Kniazev A. Y. 2013, *MNRAS* 428, 1579