Study of Galaxies in Voids

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Abstract. We firstly summarize previous observational studies of void galaxies. They used the SDSS spectral and photometric data dealing with galaxies in the distant voids. We then summarize the results of our study of galaxies residing in the nearby Lynx-Cancer void. Finally, we present results of the on-going project to search for and study unusual galaxies in voids. Among the least luminous dwarfs of the nearby voids, ten unusual objects are found with metallicity Z(gas) $\lesssim Z_\odot/30$ (eXtremely Metal Poor, XMP), partly resembling the prototype galaxy IZw18 with Z(gas)=$Z_\odot/30$ and several other void dwarfs. Their baryonic matter is highly dominated by gas while the colours of their main stellar population are consistent with non-cosmological ages. The majority of them are LSB dwarfs and their SF efficiencies are orders of magnitude lower than that of IZw18. These unusual galaxies appear the best candidates to Very Young Galaxies in the nearby Universe.

Keywords: galaxies: evolution; galaxies: dwarf; large-scale structure of the Universe

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1 Introduction. Previous Work on Galaxies in Voids

Four types of Large-scale Structure elements in the Universe are identified, in the order of decreasing density: nodes, filaments, walls, voids. Voids occupy 3/4 of the Universe volume and contain ∼15% of its mass (Cautun et al. 2014). Due to the specific environmental conditions, void galaxies are expected to show some differences relative to those residing in the denser regions (Einasto et al. 2011; Aragon-Calvo & Szalay 2013). Predicted to possess unusual properties, the void main (dwarf) galaxy population, however, remains largely unexplored.

Previous mass studies of void galaxies have dealt with large distant voids (distances of ∼100–200 Mpc), based on the Sloan Digital Sky Survey (SDSS) galaxy samples. Accounting for the limiting apparent magnitude of the main spectral data base for SDSS galaxies, at these distances, they probe only the top of the void Luminosity Function ($-20 \lesssim \mathrm{M_{B,r}} \lesssim -17$). Despite some differences of properties for void and wall galaxies are found, for the brighter void galaxies they are small. They appear somewhat more gas-rich, higher SFR, e.g. Rojas et al. (2004, 2005). These results are consistent with the general idea that properties of more massive galaxies are weakly sensitive to their environment.

2 Galaxy Study in the Nearby Lynx-Cancer Void

Models and N-body simulations predict that small-mass dwarfs are the most sensitive to effect of environment. There were also a few observational indications on the preferable occurrence of very low metallicity actively star-forming dwarfs in voids.

To conduct the unbiased study of the least massive void late-type galaxies, one needs a large galaxy sample in the nearest voids. 15 years ago it was a problem, since the only large nearby void known was the Local (Tully) Void. Unfortunately, the major part of this void is obscured by the Milky Way dust, and only about a dozen galaxies were known to reside within the void.

We were lucky to identify a nearby void Lynx-Cancer (at D∼18 Mpc). Its important advantage is the good coverage of this sky region by the ongoing large and sensitive surveys - of optical redshifts with SDSS and the blind HI 21-cm line survey ALFALFA (Abolfathi et al. 2018; Haynes et al. 2018). This allowed us to increase the void galaxy sample from the initial 40 to the final 108 objects (Pustilnik & Tepliakova 2011; Pustilnik et al. 2016).

The main results of the unbiased study of a hundred galaxies in the Lynx-Cancer void are summarized as follows. In comparison to the late-type galaxies from the Local Volume sample by Berg et al. (2012), consisting mostly of galaxies in typical groups, a) void galaxies are in average more metal-poor by ∼1.4 times; b) void galaxies, in average are more gas-rich by a factor of ∼1.4. c) there is a small group of unusual dwarfs with very low gas metallicity, reduced by a factor of 2–5 relative to the expected for their luminosity. They appear extremely gas-rich ($\mathrm{M_{gas}/M_{bary}}$ ∼0.97–0.99). Besides, for majority of them, the blue colours of their outer parts indicate non-cosmological ages of their oldest stellar population.

They appear exclusively low-luminosity dwarfs, comprising ∼30% among the void LSB dwarfs with $M_B \gtrsim -13.5$.

3 Development of Nearby Void Galaxy Studies. The On-Going Project Results

The results on study of galaxies in the Lynx-Cancer void were exciting and promising. However, the statistics of small void galaxies was rather poor. There was a clear need in the extension of this study to a much larger sample. As a further step in this direction, we defined 25 voids within the volume with R $<$ 25 Mpc from the Local Group and formed the 'Nearby Void Galaxy' (NVG) sample of ∼1350 galaxies residing inside these voids. See more details in Pustilnik et al. (2019).

3.1 Least Luminous Dwarfs in NVG Sample

The least luminous dwarfs in NVG sample are good objects to explore the effect of void environment and to search for unusual (XMP, gas-rich) dwarfs. Based on the original NVG sample of 1350 galaxies, we selected a subsample of 378 void dwarfs with $-8.0 \geq M_B \geq -14.2$. This subsample is further studied as a first step to compare properties of void galaxies with those in the denser environments. In particular, we used this subsample to search for new very low-metallicity gas-rich dwarfs - analogs of the unusual dwarf group in the Lynx-Cancer void.

3.2 Extremely Metal-Poor (XMP) Galaxies in Voids

Prototype XMP dwarfs are blue compact galaxies (BCGs) IZw18 (with $Z \sim Z_\odot/30$) and SBS 0335–052E. They were found thanks to their current starbursts and related strong UV and emission lines. They enter to interacting pairs with young dIrr IZw18C and XMP dIrr SBS0335–052W. These XMP dwarfs and a few of their local analogs attract attention as the best nearby proxies of the high-redshift young galaxies, which are still barely available for detailed studies. XMP galaxies (here with $Z(gas) \lesssim Z_\odot/30$) are extremely rare. Of many thousands of Emission-Line Galaxies in the SDSS survey with known Z(gas), only about ten were identified as XMPs (Izotov et al. 2019). A few XMP dwarfs were found with other methods. Based on the finding of XMP dwarfs in the Lynx-Cancer void and a conclusion on that the void environment is a conducive for XMP objects, the search for such unusual dwarfs in voids looks promising.

3.3 XMP Candidate Selection and Follow-Up Spectroscopy

To conduct a more efficient follow-up spectroscopy with a reasonable detection rate of the sought-for XMP dwarfs, it is crucial to perform a careful selection of candidates for the respective observational program. For this end, we used the known properties of 8 prototype XMP gas-rich void dwarfs to separate among ∼380 low-luminosity NVG dwarfs those with relatively large ratios of $M(HI)/L_B$ and blue colours. We also used the available spectral data for a part of preselected candidates to estimate the possible range of their gas metallicity. This selection procedure resulted in a list of 60 candidates (Pustilnik et al. 2020a). Spectra of 90% of them were obtained at 11-m Southern African telescope SALT and 6-m Russian telescope BTA. The results for ∼3/4 of the list are presented in Pustilnik et al. (2020c,b).

3.4 Results and Preliminary Conclusions

Of 46 observed galaxies residing in the nearby voids, presented in Pustilnik et al. (2020c,b), we found 10 new XMP dwarfs with the range of 12+log(O/H) = 6.95 – 7.20 (or Z(gas) $\sim Z_\odot/50 - Z_\odot/30$). The majority of them are Low Surface Brightness dwarfs with a low star formation rate. According to their very high gas mass-fraction and blue colours, the majority of them can be good proxies of the predicted local 'Very Young Galaxies' (VYGs) (Tweed et al. 2018). In addition to this group, we found 14 more void dwarfs with somewhat higher O/H, of 12+log(O/H) = 7.21 – 7.31. Galaxies with such low O/H are still very rare, especially within the studied volume. Besides, some of them also resemble VYGs on their properties.

For a dozen of new XMP and similar void dwarfs, we conducted with the Giant Meterwave Radio Telescope (GMRT, India) the HI 21-cm line mapping, to address properties of their dominant baryonic component. Our preliminary analysis shows that they invariably display the disturbed gas morphology and kinematics which evidence for their non-equilibrium state. While for a part of them, this picture is due to interaction with another void galaxies, for the remaining XMP objects the reason is unclear.

Summarizing the above results, we draw the following conclusions:

1. Voids present a unique environment, conducive for survival of the least evolved dwarfs. Their observed properties combine the lowest gas metallicity, the extremely large gas mass fraction and a dominant stellar population with ages of one to a few Gyr.

2. Despite that such galaxies are uncommon even in voids, their search and study remain a key direction due to several important implications related to cosmology. Their existence itself is a challenge for models and simulations of galaxy formation since up to now the group of such dwarfs is not predicted. The so-called local Very Young Galaxies are defined only via the age of their main stellar population and, in principle, can have rather diverse properties.

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