*Dwarf Galaxies: From the Deep Universe to the Present*
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# Influence of the Void Environment on Chemical Abundances in Dwarf Galaxies and Implications for Connecting Star Formation and Halo Mass

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**Abstract.** We study how the void environment affects the chemical evolution of galaxies by comparing the metallicity of dwarf galaxies in voids with dwarf galaxies in denser regions. Using spectroscopic observations from SDSS DR7, we estimate oxygen and nitrogen abundances of 889 void dwarf galaxies and 672 dwarf galaxies in denser regions. A substitute for the [O II] $\lambda$3727 doublet is developed, permitting oxygen abundance estimates of SDSS dwarf galaxies at all redshifts with the direct method. We find that void dwarf galaxies have about the same oxygen abundances and slightly lower N/O ratios than dwarf galaxies in denser environments. The lower N/O ratios seen in void dwarf galaxies may indicate both delayed star formation and a dependence of cosmic downsizing on the large-scale environment. Similar oxygen abundances in the two dwarf galaxy populations might be evidence of larger ratios of dark matter halo mass to stellar mass in voids.

**Keywords.** galaxies: abundances, galaxies: dwarf, galaxies: evolution

## 1. Introduction

Galactic redshift surveys have revealed that the large-scale distribution of galaxies is similar to a three-dimensional cosmic web (Bond *et al.* 1996), with voids (large, underdense regions of space) surrounded by thin filaments of galaxies that connect galaxy clusters. Cosmic voids are an essential component for understanding the role of a galaxy's environment on its formation and evolution (see van de Weygaert & Platen 2011 for a review). Since their discovery, voids have provided the ideal location to study the role of the environment in galaxy formation. Void galaxies have been found to be bluer (Grogin & Geller 1999; Rojas *et al.* 2004; Patiri *et al.* 2006; von Benda-Beckmann & Müller 2008; Hoyle *et al.* 2012), to be of a later morphological type (Grogin & Geller 2000; Rojas *et al.* 2004; Park *et al.* 2007), and to have a higher specific star formation rate (Rojas *et al.* 2005; von Benda-Beckmann & Müller 2008; Moorman *et al.* 2015; Beygu *et al.* 2016). These trends are all attributed to the availability of cool gas in the voids to fuel star formation. It has also been shown that there is a shift toward fainter objects in voids in the galaxy luminosity function (Hoyle *et al.* 2005; Moorman *et al.* 2015), consistent with the predicted shift in the dark matter halo mass function (Goldberg *et al.* 2005).

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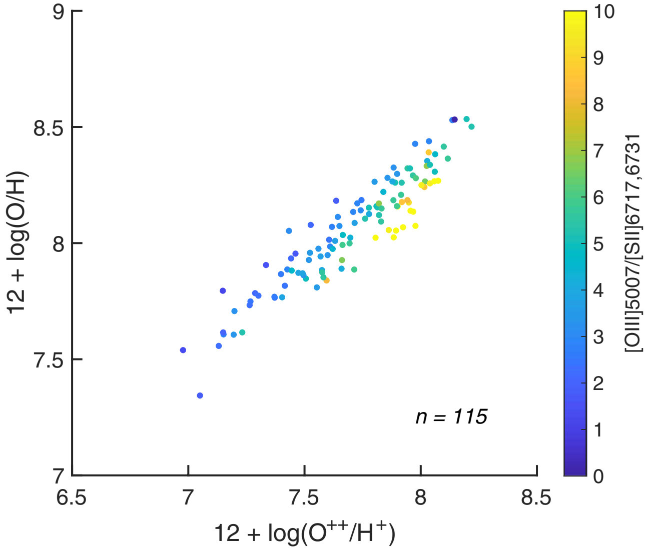

**Figure 1.** Approximation developed to estimate the total oxygen abundance for use when [OII] $\lambda3727$ is unavailable. The ratio of [OIII]/[SII] is used as a proxy for the ionization parameter. (Image courtesy of Douglass *et al.* 2018).

These observations are all consistent with ΛCDM cosmology, where void galaxies have lower masses and are retarded in their star formation when compared to those in denser regions (e.g. Gottlöber *et al.* 2003; Goldberg *et al.* 2005; Cen 2011).

We want to study the environmental effects on the chemical evolution of dwarf galaxies because they are the most sensitive to environmental effects. Due to the lack of available data, no large study of the gas-phase abundances of void dwarf galaxies has yet been completed. Those few void galaxies that been examined indicate that the metallicity of galaxies in voids is less than those in more dense environments for a variety of reasons: more pristine gas surrounding void galaxies, fewer galactic interactions, etc. With the advent of SDSS, we can now begin to probe the variation of dwarf galaxy properties over a wide range of cosmic environments.

## 2. $O^+$ abundance approximation and the Direct $T_e$ method

We use the Direct $T_e$ method outlined in Izotov *et al.* (2006), based on the astrophysics described by Osterbrock (1989), to estimate the gas-phase chemical abundances as defined by the ratio of oxygen or nitrogen to hydrogen. The ratio of the flux of the [OIII] $\lambda4363$ auroral line to the [OIII] $\lambda\lambda4959, 5007$ emission line doublet is sensitive to the electron temperature, and the ratio of [SII] $\lambda6717$ to [SII] $\lambda6731$ is sensitive to the electron number density in an HII region. From the flux of these forbidden emission lines, the electron temperature and number density of an HII region can be found; it is then possible to calculate the abundance ratios for all heavy elements with respect to H. The total abundance of an element is equal to the sum of the abundances of each of its ionized states. For oxygen,

$$\frac{\mathrm{O}}{\mathrm{H}} = \frac{\mathrm{O}^{++}}{\mathrm{H}^{+}} + \frac{\mathrm{O}^{+}}{\mathrm{H}^{+}} \tag{2.1}$$

The [OIII] $\lambda4363, \lambda\lambda4959, 5007$ emission lines are used to calculate the electron temperature and the abundance of doubly-ionized oxygen. Either the [OII] $\lambda3727$ emission

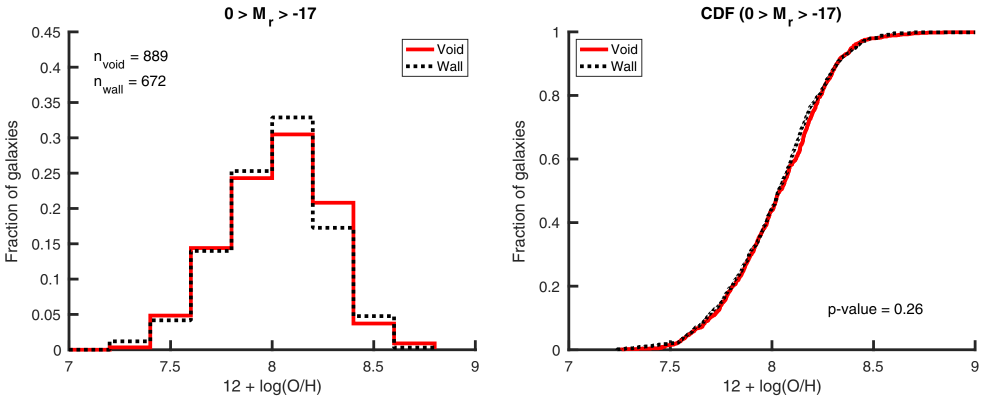

**Figure 2.** Gas-phase metallicity of void dwarf (red solid line) and wall dwarf (black dashed line) galaxies. There is very little difference between the metallicity distributions of the void and wall dwarf galaxy sample populations. (Image courtesy of Douglass *et al.* 2018.)

line (when available) or the relationship shown in Fig. 1 (described in Douglass *et al.* 2018) is used to calculate the abundance of singly-ionized oxygen.

## 3. Large-scale environment

All galaxies are classified as either void or wall based on the void catalog compiled by Pan *et al.* (2012). This catalog is built with the VoidFinder algorithm by Hoyle & Vogeley Hoyle & Vogeley (2002), which locates large ($r > 10\ h^{-1}$Mpc) dynamically distinct voids in the SDSS and is based upon the algorithm described by El-Ad & Piran (1997). Galaxies which fall within the void regions are classified as void galaxies. The remaining galaxies are either considered wall galaxies or edge galaxies (if they are located within 5 $h^{-1}$Mpc of the survey edge).

## 4. Similar metallicities, lower N/O ratios in void dwarf galaxies

The chemical abundances of void dwarf galaxies might be expected to be less than that of dwarf galaxies in denser regions (wall galaxies). Previous studies of select void dwarf galaxies have found them to have low metallicities (Pustilnik *et al.* 2006; Sánchez Almeida *et al.* 2016, for example). However, as the CDF and histogram in Fig. 2 indicate, we do not find a statistically significant difference in the metallicity distributions of void and wall dwarf galaxies.

As described in Douglass *et al.* (2018), both similar distributions or a shift towards higher metallicities in void dwarf galaxies could be due to a larger ratio of dark matter halo mass to stellar mass in voids, as seen in simulations by Jung *et al.* (2014) and Tonnesen & Cen (2015). If the ratio of dark matter halo mass to stellar mass is larger in void galaxies, then their gravitational potential wells are slightly deeper, allowing them to retain more of their heavy metals. This would result in them having higher metallicities than initially expected, causing them to have about the same metallicites as galaxies in denser regions.

We also find a shift towards lower N/O ratios in void dwarf galaxies, as seen in Fig. 3 (Douglass *et al.* 2018) and by Douglass & Vogeley (2017b). Predicted in simulations by Cen (2011), we surmise that this shift indicates that the star formation is retarded in voids and that there is a large-scale environmental influence on cosmic downsizing (Douglass *et al.* 2018). As suggested by van Zee & Haynes (2006), a galaxy with a constant SFR will have a lower N/O ratio than one that has a declining SFR at later

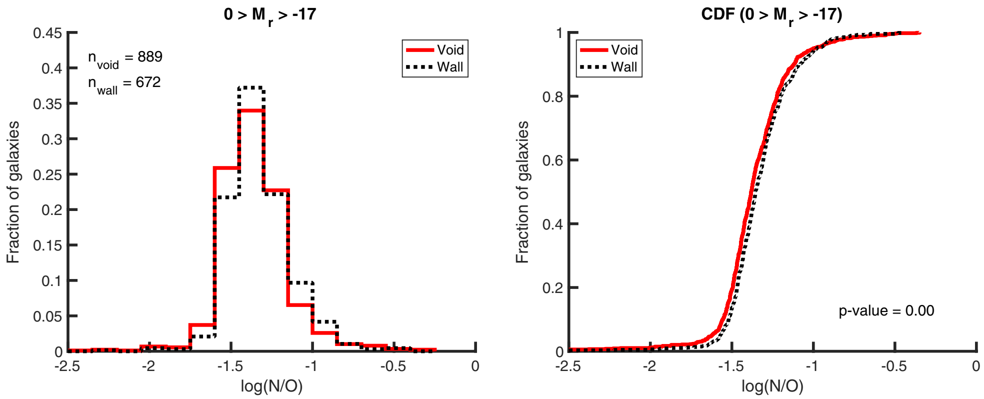

**Figure 3.** Ratio of nitrogen to oxygen of void dwarf (red solid line) and wall dwarf (black dashed line) galaxies. The void galaxies have a lower value of N/O than the wall galaxies. (Image courtesy of Douglass *et al.* 2018.)

times. The ongoing star formation experienced by the void galaxies will release the oxygen produced in massive stars, decreasing their N/O ratios.

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