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Direct measures of chemical abundances from stacked spectra of star-forming galaxies: Implications for the mass–metallicity–star formation rate relation

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Abstract. The stellar mass–star formation rate–metallicity relation provides clues on the chemical evolution of galaxies. We revisit this relation by measuring the gas-phase metallicity using the direct method. For metal-rich galaxies this is not straightforward, because auroral emission lines sensitive the electron temperature are lost in spectral noise. In order to increase the spectral signal-to-noise ratio and detect faint auroral lines, we stack the spectra of similar galaxies. This allows us to use the direct method to obtain consistent metallicity measurements.

Keywords. galaxies: abundances, galaxies: ISM, ISM: HII regions, ISM: abundances

1. Introduction

Chemical abundances are the product of various processes within and interactions outwith galaxies, e.g. stellar activity, infall and outflow of chemically-poor or enriched gas. These processes are interlinked to physical properties of galaxies, such as their stellar mass and star formation rate. Empirical relations between the oxygen abundance and other physical properties of galaxies are thus informative for chemical evolution models.

Oxygen abundance measurements are hard to pin down, especially if using indirect methods based on strong emission lines (e.g. Kewley & Ellison 2008). The golden standard to measure gas-phase abundances is the direct method, which relies on measuring the electron temperature from colisionally-excited lines. In a ionized nebula, free electrons collide with ions and atoms and excite their bound electrons; the latter can de-excite radiatively emitting photons at specific wavelengths. Therefore, the electronic temperature can be measured from line ratios of the same ion with different excitation potentials, for example [O III]λ4363/[O III]λ5007. However, auroral lines such as [O III]λ4363 are very faint, and to detect them we need high signal-to-noise ratio (SNR) spectra.

2. Preliminary results from stacked spectra

To increase the spectral SNR, we stack of galaxies with similar properties. We select $111,253$ star-forming galaxies (below the Kauffmann *et al.* 2003 line on the [N II]λ6584/Hα versus [O III]λ3727/Hβ plane) from the Sloan Digital Sky Survey (SDSS) Data Release 7 (Abazajian *et al.* 2009). Before stacking galaxies we perform the following procedures to individual spectra. **First**, we model and subtract the stellar continuum spectra using STARLIGHT (Cid Fernandes*et al.* 2005). **Second**, we deredden galaxy spectra with a Cardelli *et al.* (1989) dust attenuation law assuming an intrinsic ratio for

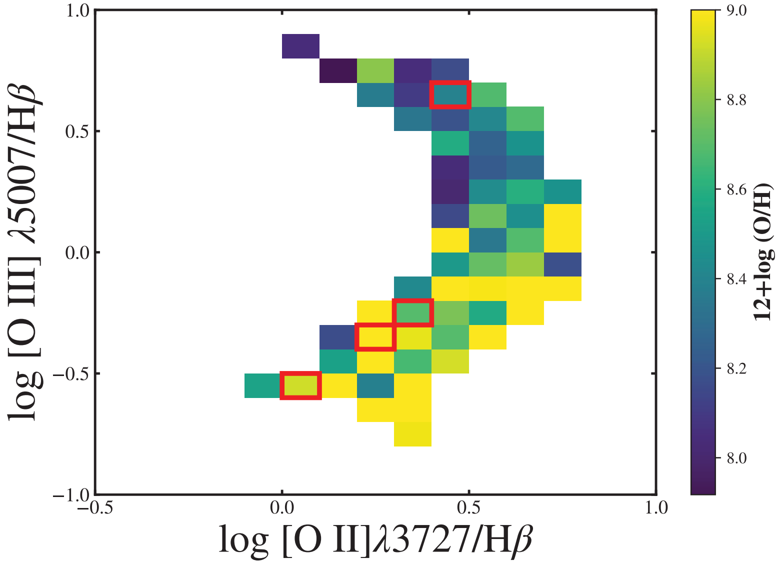

Figure 1. Oxygen abundances measured in SDSS stacked spectra using the direct method. O/H for the bins outlined in red have been calculated as a linear interpolation of the surrounding bins.

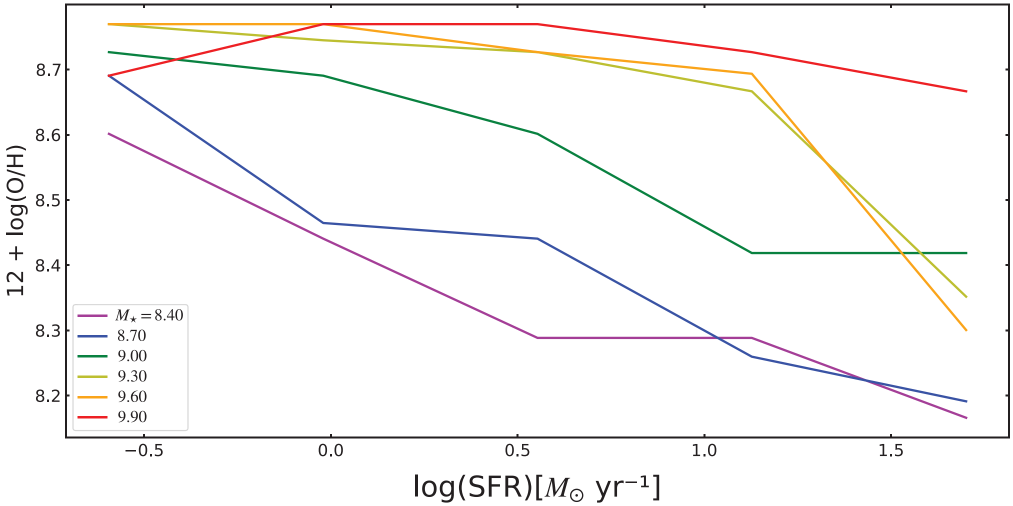

Figure 2. Preliminary results for the mass–metallicity–star formation relation. We show only the results for low-mass galaxies. There is an anti-correlation between O/H and star formation rate within a mass bin.

the Balmer lines Hα/H$\beta = 2.86$ (Case B), and normalise them by the dust-corrected Hβ luminosity. **Third**, we shift the spectra to their rest-frame adopting as a reference the systemic velocity of the [O III]λ5007 emission line. Emission lines are modelled with Gaussian profiles using DOBBY (Florido 2018).

We stack galaxies in 0.1-dex-wide bins in the [O II]λ3727/Hβ versus [O III]λ5007/Hβ plane, following Curti *et al.* (2017). Bins contain 100 to 6442 spectra, and are expected to house galaxies with approximately the same oxygen abundance and ionization parameter. We use PyNeb (Luridiana *et al.* 2015) to measure the nebular electron temperature and ionic oxygen abundances for each bin. The total oxygen abundance is obtained by adding up the abundances of all oxygen ions found in a nebula, i.e. O^+/H^+ and O^{++}/H^+.

Fig. 1 shows our first results for the oxygen abundance from stacked spectra. Four bins had non-physical results, such as too-high temperatures, so we have linearly interpolated measurements of oxygen abundances around them. We can see that the oxygen abundance tends to increase as [O III]λ5007/Hβ decreases.

Fig. 2 shows the mass–metallicity–star formation rate relation with the direct method. In contrast to Curti et al.'s method, galaxies within a bin are assigned its bin's metallicity. The stellar mass is obtained from the STARLIGHT spectral fits and the star formation rate from the Hα luminosity using eq. (9) from Asari *et al.* (2007). We exclude bins where the metallicity measurement is too uncertain, which leaves only galaxies in the low-mass regime. Our results show, within a mass bin, an anti-correlation between metallicity and star formation rate similar to the one found by Mannucci *et al.* (2010).

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