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Star Formation Rate estimators: [O II]λ3727 vs. Hα for local star-forming galaxies

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Abstract.
The [O II]λ3727 emission line is frequently used as an indicator of the star formation rate (SFR) despite its complex dependence on metallicity and excitation conditions. We have analysed the properties of the [O II] and Hα emission lines for a complete sample of local Hα-selected galaxies, the Universidad Complutense de Madrid (UCM) survey. We find a large scatter in the [O II]/Hα line ratios, although the scatter in the extinction-corrected $[\mathrm{O\,II}]^0/\mathrm{H}\alpha^0$ ratio is considerably smaller. We also find that the [O II]/Hα ratios are reasonably well correlated with the absolute B- and K-band magnitudes and with EW([O II]). However, the extinction-corrected $[\mathrm{O\,II}]^0/\mathrm{H}\alpha^0$ ratio is largely independent of these quantities, indicating that extinction is the main driver of the correlations. These correlations allow us to statistically predict—with varying degrees of accuracy—the observed and extinction-corrected Hα fluxes from the observed [O II] flux using the information contained in EW([O II]) and/or the absolute magnitudes, but extreme caution is needed to make sure that the sample selection effects are correctly taken into account.

1. Introduction

Measuring the evolution of the SFR density of the universe as a function of look-back time is essential to understand the formation and evolution of galaxies. The Hα luminosity is one of the best optical estimators of the current SFR, modulo the Initial Mass Function (e.g., Kennicutt 1992, 1998). Unfortunately, Hα can only be observed with optical CCDs out to $z \approx 0.4$. At higher redshifts, the [O II]λ3727 line is frequently used as a SFR estimator due to its availability in optical spectroscopic samples. However, the transformation between the number of ionising photons (which is a direct consequence of the current SFR) and the intensity or equivalent width (*EW*) of this line is strongly dependent on the excitation conditions and metallicity. Previous empirical calibrations of the SFR in terms of the [O II] line (e.g., Gallagher, Bushouse, & Hunter 1989; Kennicutt 1992; Guzmán et al. 1997) vary within a factor of a few. Among other problems, these calibrations may suffer from small number statistics, incompleteness in luminosities, starburst ages and/or physical conditions of their samples, and uncertain extinction corrections.

We have analysed the [O II] emission line properties of a local sample of Hα-selected star forming galaxies (the UCM sample) and derived reasonably precise empirical calibrations between the [O II] and Hα luminosities as a function of the galaxy population properties. In a recent paper, Jansen, Franx & Fabricant (2001) carried out a similar study for the Nearby Field Galaxy Survey (NFGS, Jansen et al. 2000a,b) and found, among other things, that the observed [O II]/Hα ratio varies by a factor of 7 at luminosities near M_B^*, and that the [O II]/Hα ratio is inversely correlated with luminosity. Our study is, in many ways, complementary of that of Jansen et al., but we use an Hα-selected (thus SFR-selected) sample of galaxies instead of a *B*-band selected one. We confirm most of the findings of Jansen et al., but we also demonstrate that using an extra piece of information, namely the *EW* of [O II], much of the scatter in the [O II]/Hα ratio can be removed, allowing a much more accurate calibration of [O II] vs. SFR.

Our basic dataset comes from Universidad Complutense de Madrid (UCM) survey of Hα selected galaxies. Optical spectroscopy (Gallego et al. 1996; 1997) and optical and near-infrared photometry (Pérez-González et al. 2000, 2002; Gil de Paz et al. 2000) are available for this sample. Based on their spectroscopic properties, the UCM galaxies have been roughly divided into two main classes: H II-like and disk-like galaxies (see Gil de Paz et al. 2000). We will compare the properties of the UCM galaxies with those of the NFGS galaxies of Jansen et al. A detailed description of our study can be found in Aragón-Salamanca et al. (2002). We assume $H_0 = 50\,\mathrm{km\,s^{-1}\,Mpc^{-1}}$ throughout.

2. Results:

In Figure 1 we plot the [O II]/Hα ratio (both observed and corrected from extinction using the Balmer decrement[1]) for the UCM and NFGS galaxies as a function of absolute *B*- and *K*-band magnitudes and *EW*([O II]). There is a large scatter in the [O II]/Hα and [O II]/Hα^0 ratios for all the galaxies, but the scatter in the extinction-corrected [O II]^0/Hα^0 ratio is considerably smaller, indicating that much of this scatter is due to differences in extinction.

Figure 1 also reveals significant difference in the median [O II]/Hα and [O II]/Hα^0 ratios for the UCM and NFGS galaxies. These ratios are considerably

[1]Throughout this paper [O II]^0 and Hα^0 indicate extinction-corrected emission-line fluxes.

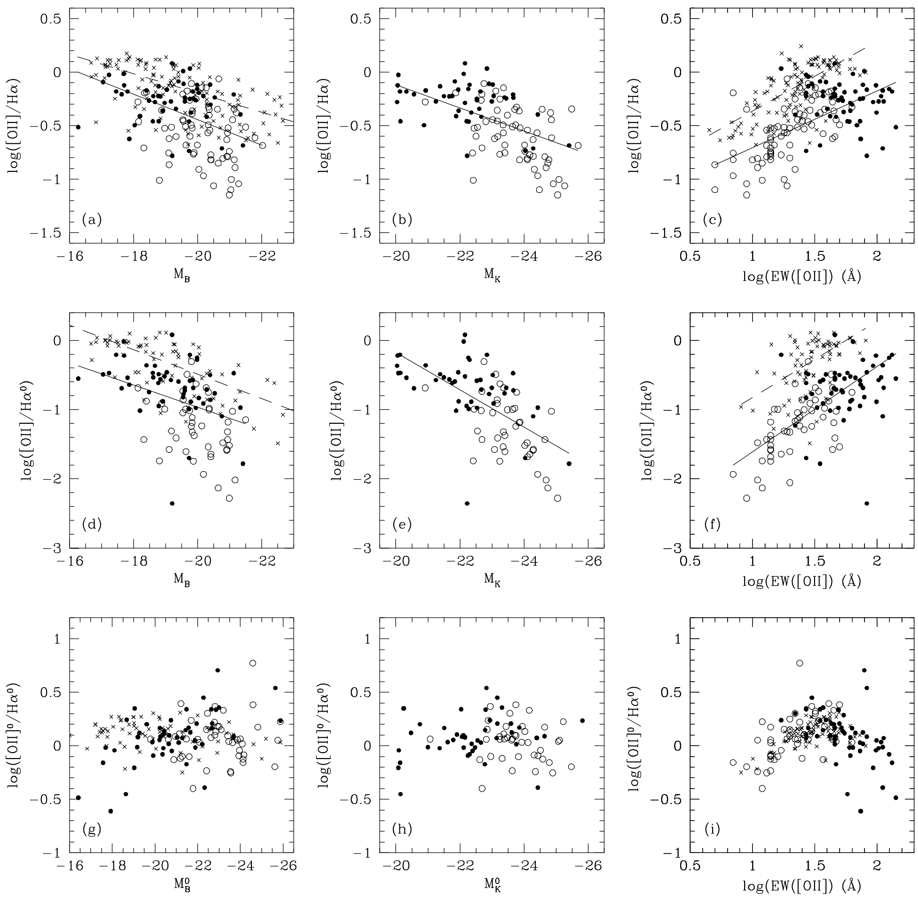

Figure 1. **(a)**, **(b)** and **(c)** The observed log([O II]/Hα) vs. M_B, M_K and $\log EW$([O II]) for the UCM disk galaxies (open circles) and HII galaxies (small filled circles), where [O II] and Hα are the observed emission line fluxes. The solid line is a linear fit to the data. The crosses and the dashed line correspond to the NFGS sample. **(d)**, **(e)** and **(f)** As before, but using the extinction-corrected Hα flux. **(g)**, **(h)** and **(i)** As before, but using extinction-corrected Hα and [O II] fluxes.

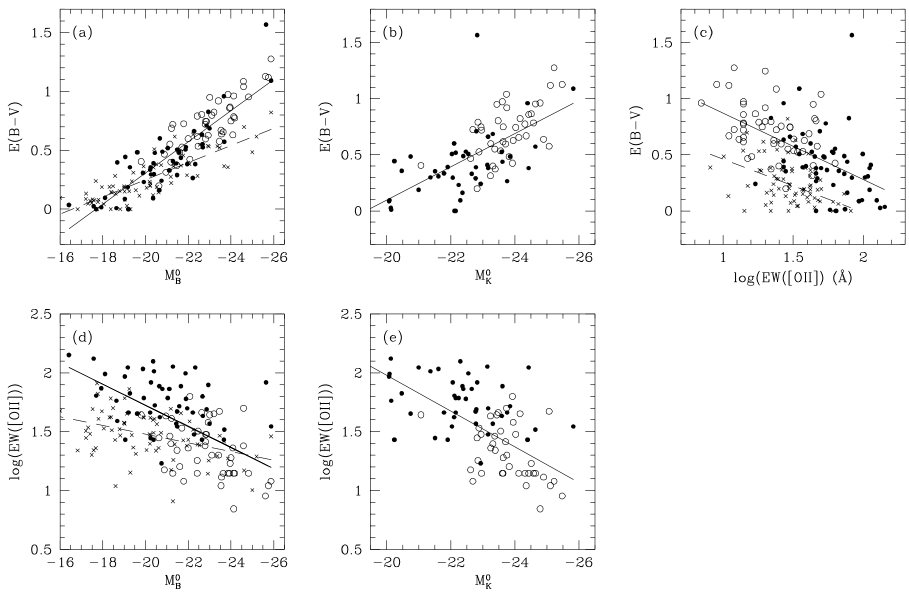

Figure 2. **(a)** The Balmer-decrement derived color excesses vs. the extinction-corrected absolute magnitudes in the B-band for the UCM and NFGS galaxies. Symbols as in Figure 1. **(b)** as (a) but vs. M_K^0. **(c)** The derived colour excesses vs. $\log EW([\text{O II}])$. **(d)** and **(e)** The measured $EW([\text{O II}])$ vs. the absolute magnitudes M_B^0 and M_K^0 respectively. The solid and dashed lines show linear fits to the observed trends for the UCM and NFGS galaxies respectively.

smaller for the UCM galaxies. However, the extinction-corrected $[\text{O II}]^0/\text{H}\alpha^0$ ratios for both samples agree quite well, indicating that the line ratio differences between both samples are mainly due to a difference in the mean extinction. This is readily explained by the fact that the NFGS sample has been selected in the B-band, while the UCM sample was selected in the red (Hα), and thus it is not surprising that galaxies with higher extinction are underrepresented in the blue selected sample. Therefore, differences in sample selection can yield very large differences in the line emission properties.

The third conclusion from these plots is that the $[\text{O II}]/\text{H}\alpha$ and $[\text{O II}]/\text{H}\alpha^0$ ratios for disk-like and H II-like galaxies are very different. However, the average $[\text{O II}]^0/\text{H}\alpha^0$ ratio is the same for both classes of galaxies. Again, the mixture of galaxy types in a given sample can have large effects in the line ratios.

We also find that, although with significant scatter, the $[\text{O II}]/\text{H}\alpha$ and $[\text{O II}]/\text{H}\alpha^0$ ratios are reasonably well correlated with the absolute B- and K-band magnitudes and with $EW([\text{O II}])$. However, the extinction-corrected $[\text{O II}]^0/\text{H}\alpha^0$ ratio is largely independent of these quantities, indicating that extinction is the main driver of these correlations. This is supported by Figure 2, which shows quite reasonable correlations between the extinction and the absolute magnitudes of the galaxies. The extinction is also correlated with EW([O II]). This figure also shows that the typical extinction for the NFGS galaxies is significantly smaller than for the UCM galaxies.

These correlations could allow us to statistically predict—with varying degrees of accuracy—the observed and even extinction-corrected Hα fluxes from the observed [O II] flux using the information contained in the EW([O II]) and/or the absolute magnitudes, provided that the sample selection effects are correctly taken into account. Indeed, it is very important to stress that these correlations apply, strictly speaking, to samples with similar properties to the ones presented here. If the selection of the sample is different, significant systematics could be present, as shown by the differences in behavior between the UCM and the NFGS galaxies. Moreover, there is no guarantee that high redshift galaxy samples would not show significant evolution in their line ratios (e.g., due to chemical evolution) which could, in principle, invalidate any locally-derived calibration.

Any calibration derived from these empirical correlations would have a significant intrinsic scatter, and thus the predictions for individual galaxies will be quite uncertain. However, if one is only interested in statistical properties of large samples (e.g., determining the star-formation rate density of large regions of the Universe), the problem of the large scatter would be alleviated. But it is crucial to take into account the properties of the sample, in particular the selection criteria, luminosity range and mixture of galaxy types, since important systematic effects are also present on top of the large scatter. Obviously, just using large samples would not solve the systematic problems.

Finally, there is another problem we have not discussed and needs to be considered: the effect of galaxies with no [O II] emission on the statistical determination of SFRs and SFR densities. A significant fraction of the UCM galaxies (20%) have Hα emission but no detectable [O II] emission (EW([O II] > -5 Å). This means that by only counting the [O II] emitting UCM galaxies, we would miss $\sim 15\%$ of the extinction-corrected Hα flux, i.e., $\sim 15\%$ of the SFR. This problem becomes negligible for a blue-selected sample such as the NFGS since, due mainly to its lower average extinction, virtually all NFGS galaxies with Hα emission have detectable [O II].

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Discussion

Kennicutt: I was surprised by the large shift in [O II]/Hα ratio between your UCM disk galaxy sample and the NFGS objects because my impression was that the types of galaxies were similar (despite the different selection methods). Could part of the difference arise because your spectra sample only the central parts of the galaxies?

Aragón-Salamanca: I don't think so. The UCM spectra were taken with slit widths that approximately match the size of the galaxies (at the expense of spectral resolution). Thus the spectra used here are close to "global" spectra. Note that the majority of the UCM galaxies are significantly more distant than the NFGS galaxies, and therefore have much smaller angular sizes. Moreover, the fact that the extinction-corrected $[\mathrm{O\,II}]^0/\mathrm{H}\alpha^0$ ratios of the UCM and NFGS galaxies match very well gives us confidence that extinction is the main driver of the observed differences, and that the intrinsic ratios are indeed the same.

R. Terlevich: In a recent analysis I did with Elena Terlevich and Daniel Rosa we found that using the Hα/Hβ ratio without taking into account the the underlying Balmer absorption you tend to overestimate the extinction. Could this be related to the relation found between the EW([O II]) and extinction?

Aragón-Salamanca: It is true that the observed Hα/Hβ ratio can be affected by stellar absorption and thus bias the extinction measurements. But the NFGS Balmer decrement measurements were corrected for stellar absorption, and the trend between EW([O II]) and extinction is similar to the one found for the UCM galaxies (albeit, with higher average extinction, as discussed above; cf. Figure 2c). Moreover, being aware of this problem, we only attempted to determine Balmer-decrement extinctions for UCM galaxies with reasonably strong emission lines ($EW(\mathrm{H}\beta) < -5\,\mathrm{\AA}$), where this effect should be smaller. It is interesting to note that EW([O II]) anti-correlates with extinction *and* luminosity (Figure 2). Because of the luminosity-metallicity relation, it is not unreasonable to expect metal-rich galaxies to have more dust and thus more extinction.