The $[\text{OII}]\lambda3727$ Luminosity Function of the Local Universe$^1$

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ABSTRACT

The measurement of the Star Formation Rate density of the Universe is of prime importance in understanding the formation and evolution of galaxies. The $[\text{OII}]\lambda3727$ emission line flux, easy to measure up to $z \approx 1.4$ within deep redshift surveys in the optical and up to $z \approx 5.4$ in the near infrared, offers a reliable means of characterizing the star formation properties of high-$z$ objects. In order to provide the high-$z$ studies with a local reference, we have measured total $[\text{OII}]\lambda3727$ fluxes for the well analyzed local sample of star-forming galaxies from the Universidad Complutense de Madrid Survey. This data is used to derive the $[\text{OII}]\lambda3727$ luminosity function for local star-forming galaxies. When compared with similar luminosity densities published for redshift up to $z \approx 1$, the overall evolution already observed in the star formation activity of the Universe is confirmed.

Subject headings: Galaxies: luminosity function, fundamental parameters, evolution

1. Introduction

The measurement of the Star Formation Rate (SFR) density of the Universe as a function of look-back time is a fundamental parameter in order to understand the formation and evolution of galaxies. The current picture, outlined in the last years, is that the global SFR density has been declining from a peak at redshift of $z \approx 1.5$ to the present day value (see Hogg 2002, and references therein). Despite one of the best direct measurements in the optical of current SFR is the nebular $\text{H}\alpha$ luminosity (Kennicutt 1998; Charlot & Longhetti 2001), this emission line is only detectable with CCDs out to $z \approx 0.4$. $\text{H}\alpha$ luminosities have been used to trace the SFR density in this redshift range (Gallego et al. 1995; Tresse & Maddox 1998; Jones & Bland-Hawthorn 2001; Pascual et al. 2001).

The alternative indicators used in the optical for estimating the SFR at high-$z$ have been mainly two: UV continuum luminosities (Lilly et al. 1996; Madau et al. 1996; Madau 1997; Connolly et al. 1997); and $[\text{OII}]\lambda3727$ luminosities (Hammer et al. 1997; Hogg et al. 1998). UV fluxes are easy to obtain from broadband photometry and, when combined with photometric redshifts, are useful to analyze large samples. The $[\text{OII}]$ flux is easy to measure when in emission and is available in the optical until $z \approx 1.5$.

In this paper we use $[\text{OII}]\lambda3727$ fluxes for the Universidad Complutense de Madrid local sample to derive the local $[\text{OII}]\lambda3727$ luminosity function. In §2 we discuss the sample and the new data. In §3, the local $[\text{OII}]$ luminosity function is obtained. Finally, in §4 we compare the local luminosity density with estimations already available for higher redshifts. A Friedman cosmology with $H_0 = 100$ km s$^{-1}$ Mpc$^{-1}$ and $q_0 = 0.5$ has been used.
2. The UCM survey of Local Star-forming Galaxies: [OII]λ3727 data

The Universidad Complutense de Madrid (hereafter UCM) objective-prism survey (List I&II, Zamorano et al. 1994, 1996) provides an ideal tool for studying the population and properties of star-forming galaxies at low redshift. The sample consists of 191 galaxies in 471.4 deg² with z≤0.045 and equivalent width EW(Hα+[NII])≥20Å. Objects were selected according to their Hα+[NII] + continuum fluxes and therefore they constitute a representative sample of current star-forming galaxies. Accurate spectrophotometry (Gallego et al. 1996, 1997) and broad-band photometry in the optical (Vitores et al. 1996a,b; Pérez-González et al. 2000; Pérez-González et al. 2001) have already been published.

In September 1996 a new spectroscopic run was carried out to obtain high quality data in the [OII]λ3727 region. In this run a total of 108 (56%) UCM galaxies were observed again. The telescope used was the 2.5-m Isaac Newton Telescope (INT) at La Palma (Spain). The wavelength range covered was 3640Å-6180Å with a dispersion of 2.5Å/pixel. The slit width was 2 arcsec (spectral resolution of ~7Å) except for 13 galaxies that, given their large size, were observed with a 4 arcsec slit. The reduction was made following the standard procedure using both IRAF and the Reduce software package (Cardiel 1999).

When joining the new results to the Gallego et al. (1996) data, a final 92% (176 out of 191) of the UCM objects had the [OII]λ3727 region well covered. In 145 of these 191 objects (76%), we have measured [OII] in emission with EW≥5Å. A total fraction of 24% of objects show no line. Most of them are starburst nuclei-like objects, with a contribution to the global SFR (as measured from Hα) that is ~25% of the total amount. The quality of the new spectra revealed the existence of underlying absorptions in the Hβ emission line. However, we could not estimate Balmer decrements because the Hα region was not covered. Color excesses were re-calculated using the observed Hα/Hβ from Gallego et al. (1996) but assuming equivalent widths of the Balmer lines in absorption equal to 3Å (González Delgado et al. 1999). The new values, 0.2 in average smaller than previous ones, were used to correct for reddening.

The Hγ line, when observed, provided a consistency check. We were not able to estimate extinction for five galaxies.

Based on the emission line diagnostic diagrams and morphological properties, Gallego et al. (1996) classified spectroscopically each of the UCM galaxies. We decided to remove all UCM galaxies under the Seyfert type. Independently of its spectroscopic class, each nucleated galaxy could harbor a dwarf seyfert nucleus. Ho et al. (1997) estimated that 43% of galaxies had such a nucleus with Hα luminosity 1/100th of the typical Hα luminosity of a Seyfert galaxy. This amount turns out to be about one hundredth of the L* measured by Gallego et al. (1995) We decided not to include any correction relative to this effect. Once the AGNs and objects with no emission were removed, the final sample consisted of 134 and 129 galaxies with observed and extinction corrected luminosity.

3. The Local [OII]λ3727 luminosity function

Direct information on the amount and nature of the present-day SFR in the local Universe can be obtained by constructing the [OII]λ3727 luminosity function for galaxies with current star formation activity. To correct for the signal not covered by the slit, the total [OII]λ3727 luminosity line for each galaxy was computed from the [OII] equivalent width and its continuum as obtained from the Johnson B band magnitude. Given that the [OII]λ3727 line is not included into the B band for the UCM galaxies, we analyzed the ratio of the actual continuum adjacent to the [OII]λ3727 line, and the average continuum within the B band, as measured in our spectra. The average $k = F_B / F_{[OII]}$ ratios for each spectroscopic type (0.94, 1.15 and 1.43 for Blue Compact Dwarfs, HII-like and disk-like objects respectively) were applied. The observed total [OII] line luminosity $L_{[OII]}^{obs}$ was computed as

$$L_{[OII]}^{obs} = EW_{[OII]}^{obs} L_{[OII]}^{c, obs}$$

and the adjacent continuum $L_{[OII]}^{c, obs}$ as the scaled B continuum $L_{[OII]}^{c,B}$ without the line contamination

$$L_{[OII]}^{c,B} = L_{[OII]}^{c,B} / (k + EW_{[OII]}^{obs} Q(3727) / \Delta \lambda(B))$$
\[ L_{\text{obs}}^{z,B} = P_0^B \ 10^{-0.4 \ m_B} \ D(z) \]  

where \( m_B \) is the Johnson B apparent magnitude, \( P_0^B \) the corresponding photometric zero point and \( D(z) \) is the luminosity distance. It is worth noting that the B band magnitudes were not corrected for galactic extinction in order to compare with those observed \([\text{OII}]\) luminosities measured from not extinction-corrected spectroscopy. The mean galactic extinction in the B band for the UCM sample is 0.23±0.21 if Schlegel et al. (1998) is considered or 0.12±0.10 if Burstein & Heiles (1982) is considered.

In a sample such as the UCM survey, the completeness is determined by the Hα+[NII] line+continuum flux. This is a pseudo apparent magnitude proportional to the current star-forming activity of the source. Gallego et al. (1995) used the V/Vmax test to obtain a complete sample of 176 galaxies within the UCM survey. These objects were selected with line+continuum flux larger than 1.9 \times 10^{-14} \text{ erg cm}^{-2} \text{ s}^{-1}. They used that sample to determine the Hα and SFR density luminosity functions for the local Universe. We proceeded here in a similar manner to estimate the \([\text{OII}]\lambda3727\) luminosity function. Instead of adding artificial galaxies, we chose a final limiting flux slightly fainter than the one provided by the V/Vmax method and then we included all galaxies having non-zero flux in \([\text{OII}]\lambda3727\. With the goal of quantifying the goodness of V/Vmax results, we compared with the maximum-likelihood parametric fit (STY, Yahil et al. 1991) and the nonparametric step-wise maximum-likelihood (SWML, Efstathiou et al. 1988) methods.

The resulting Schechter best fitting parameters as provided by the STY method for a limiting flux of \(4.0 \times 10^{-14} \text{ erg cm}^{-2} \text{ s}^{-1}\) are: \( \alpha = -1.17\pm0.08 \), \( \phi^* = 10^{-3.71\pm0.16} \text{ Mpc}^{-3} \), and \( L^* = 10^{42.66\pm0.17} \text{ erg s}^{-1} \). Densities are in Table 1 (again V/Vmax and SWML results are similar).

Sullivan et al. (2000) published the luminosity function for a sample of 273 galaxies in the range \(z = 0.01 - 0.3\) selected by their emission in the ultraviolet. Their \([\text{OII}]\lambda3727\) luminosities were obtained from follow-up spectroscopy and were extinction-corrected. A Schechter fit provides the following parameters: \( \alpha = -1.59\pm0.12 \), \( \phi^* = 10^{-2.82\pm0.19} \text{ Mpc}^{-3} \), and \( L^* = 10^{41.96\pm0.09} \text{ erg s}^{-1} \). The differences have to be understood as coming different galaxy populations, with more abundant but less luminous galaxies in the UV-selected sample.

4. The evolution of the \([\text{OII}]\lambda3727\) luminosity density

One of the major uncertainties when analyzing SFR densities at different redshifts arises when results obtained with several tracers have to be compared. This is why it is so important to obtain the evolution of the luminosity densities for each SFR tracer. Our local \([\text{OII}]\lambda3727\) luminosity density, when combined with similar results from deep samples up to \(z \sim 1.5\), allow us to sketch the evolution of the SFR density as traced by the observed \([\text{OII}]\) luminosity. Given that the luminosity function is well fitted as a Schechter function, and
\[ \alpha \leq -2, \phi(L) \] can be integrated for the whole range of luminosities:

\[ L_{\text{tot}} = \int_0^{\infty} L \phi(L) dL = \phi^* L^* \Gamma(2 + \alpha) \quad (4) \]

For the observed luminosities, the total \([\text{OII}]\) luminosity density is \(10^{38.01 \pm 0.15} \text{erg s}^{-1} \text{Mpc}^{-3}\) in the Local Universe (\(z \lesssim 0.045\)) for star-forming galaxies with \(\text{EW}(\text{H}_{\alpha} + \text{[NII]}) \gtrsim 20\text{Å}\). When the effect of the extinction is considered, the total \([\text{OII}]\) extinction-corrected luminosity per unit volume corresponds to \(10^{39.00 \pm 0.11} \text{erg s}^{-1} \text{Mpc}^{-3}\).

The extinction correction amounts for a total of one dex. This luminosity density is similar to the one we could estimate from the B band luminosity function published by cite1997ApJ...475..502G for the UCM sample. It is also comparable to the luminosity density we would obtain if we apply an average \([\text{OII}]\lambda3727/\text{H}_{\alpha}\) factor to the extinction-corrected \(\text{H}_{\alpha}\) luminosity density measured by Gallego et al. (1995).

In Figure 2 we have plotted all the \([\text{OII}]\) luminosity densities published in the literature. The CFGRS sample already revealed a strong evolution from \(z=1\) to the low redshift universe. This evolution is in agreement with the Canada-France Redshift Survey results (Hammer et al. 1997). Unfortunately, these surveys only provide with observed luminosities. We have also plotted both the observed and the extinction-corrected value for the Sullivan et al. (2000) sample.

The right axis of Figure 2 shows how the \(L([\text{OII}])\) scale transforms into a SFR density scale using the nominal transformation provided by Kennicutt (1998):

\[ \frac{\text{SFR}}{M_\odot \text{yr}^{-1}} = 1.4 \times 10^{-41} L_{\text{[OII]}} \quad (\text{erg s}^{-1}) \]

Our total extinction-corrected \([\text{OII}]\) luminosity density translates into a SFR density of \(0.014 \pm 0.003 M_\odot \text{yr}^{-1} \text{Mpc}^{-3}\).

Assuming that the SFRD evolves with redshift as \((1 + z)^n\), the combination of the UCM local value with the CFGRS data implies a \(n \approx 4\). Such strong evolution is similar to the one obtained using \(\text{H}_{\alpha}\) as SFR tracer for the same redshift range. However, we want to stress that the selection effects and calibrations for each sample were different and some caution is necessary when interpreting these quantitative results.

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| log L([OII]3727) [erg s⁻¹] | Observed LF | Corrected LF | |
|---------------------------|------------|--------------|
| log(Φ) [Mpc⁻³ per logL interval] | Number of galaxies | log(Φ) [Mpc⁻³ per logL interval] | Number of galaxies |
| 39.0 | ... | 0 | ... | 0 |
| 39.4 | -2.63 ± 0.22 | 4 | -2.48 ± 0.43 | 1 |
| 39.8 | -2.82 ± 0.14 | 10 | ... | 0 |
| 40.2 | -2.89 ± 0.08 | 33 | -3.06 ± 0.14 | 9 |
| 40.6 | -3.08 ± 0.06 | 60 | -3.30 ± 0.10 | 18 |
| 41.0 | -3.61 ± 0.09 | 22 | -3.58 ± 0.09 | 23 |
| 41.4 | -4.25 ± 0.19 | 5 | -3.47 ± 0.08 | 33 |
| 41.8 | ... | 0 | -3.59 ± 0.09 | 25 |
| 42.2 | ... | 0 | -3.88 ± 0.12 | 13 |
| 42.6 | ... | 0 | -4.69 ± 0.31 | 2 |
| 43.0 | ... | 0 | -4.51 ± 0.25 | 3 |
Fig. 1.— Observed [OII]λ3727 luminosity functions for both the UCM (filled triangles) and the CFGRS (filled circles) samples.
Fig. 2.— The evolution of the [OII]λ3727 luminosity density of the Universe. Both the observed and extinction-corrected values for the UCM sample are represented as filled and open triangles. Filled circles correspond to Hogg et al. (1998), filled stars are for the (Hammer et al. 1997) values, and the filled and open squares are for the observed and extinction corrected Sullivan et al. (2000) values.