The Astrophysical Journal, 570:L1–L4, 2002 May 1

THE [O II] λ3727 LUMINOSITY FUNCTION OF THE LOCAL UNIVERSE[1]

J. Gallego, C. E. García-Dabó, J. Zamorano, A. Aragón-Salamanca,[2] and M. Rego
Departamento de Astrofísica, Universidad Complutense de Madrid, Facultad CC Físicas,
Ciudad Universitaria, E-28040 Madrid, Spain; jgm@astrax.fis.ucm.es
Received 2002 February 2; accepted 2002 March 21; published 2002 April 4

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 [O II] λ3727 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 [O II] λ3727 fluxes for the well-analyzed local sample of star-forming galaxies from the Universidad Complutense de Madrid Survey. These data are used to derive the [O II] λ3727 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: evolution — galaxies: fundamental parameters — galaxies: luminosity function, mass function

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 $z \sim 1.5$ to the present-day value (see Hogg 2002 and references therein). Despite one of the best direct measurements in the optical of the current SFR being the nebular Hα 6563 Å luminosity (Kennicutt 1998; Charlot & Longhetti 2001), this emission line is detectable only with CCDs out to $z \approx 0.4$. Hα 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 [O II] λ3727 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 [O II] flux is easy to measure when in emission and is available in the optical until $z \simeq 1.5$.

In this Letter, we use [O II] λ3727 fluxes for the Universidad Complutense de Madrid (UCM) local sample to derive the local [O II] λ3727 luminosity function. In § 2, we discuss the sample and the new data. In § 3, the local [O II] 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.

[1] Partly based on observations collected at the German-Spanish Astronomical Center, Calar Alto, Spain, operated by the Max-Planck-Institute für Astronomie, Heidelberg, jointly with the Spanish National Commission for Astronomy. Partly based on observations made with the Isaac Newton Telescope operated on the island of La Palma by the Royal Greenwich Observatory in the Spanish Observatorio del Roque de Los Muchachos of the Instituto de Astrofísica de Canarias.

[2] School of Physics and Astronomy, University of Nottingham, Nottingham NG7 2RD, England, UK.

2. THE UCM SURVEY OF LOCAL STAR-FORMING GALAXIES: [O II] λ3727 DATA

The UCM objective prism survey (lists I and 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 deg^2 with $z \lesssim 0.045$ and equivalent width EW(Hα + [N II]) $\gtrsim$ 20 Å. Objects were selected according to their Hα + [N II] + continuum fluxes, and therefore they constitute a representative sample of current star-forming galaxies. Accurate spectrophotometry (Gallego et al. 1996, 1997) and broadband photometry in the optical (Vitores et al. 1996a, 1996b; Pérez-González et al. 2000, 2001) have already been published.

In 1996 September, a new spectroscopic run was carried out to obtain high-quality data in the [O II] 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 at La Palma (Spain). The wavelength range covered was 3640–6180 Å with a dispersion of 2.5 Å pixel^{-1}. The slit width was 2″ (spectral resolution of ∼7 Å) except for 13 galaxies that, given their large size, were observed with a 4″ slit. The reduction was made following the standard procedure using both IRAF and the REDUCEME 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 [O II] λ3727 region well covered. In 145 of these 191 objects (76%), we have measured [O II] in emission with EW $\gtrsim$ 5 Å. 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 recalculated using the observed Hα/Hβ from Gallego et al. (1996) but assuming equivalent widths of the Balmer lines in absorption equal to 3 Å (González Delgado, Leitherer, & Heckman 1999). The new values, 0.2 on 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.

TABLE 1
[O II] λ3727 Luminosity Function for the UCM Survey

log L([O II] λ3727) (ergs s^{-1})	Observed Luminosity Function: log Φ (Mpc^{-3} per log L interval)	Observed Luminosity Function: Number of Galaxies	Corrected Luminosity Function: log Φ (Mpc^{-3} per log L interval)	Corrected Luminosity Function: 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

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, Filippenko, & Sargent (1997) estimated that 43% of galaxies had such a nucleus with Hα luminosity 1/100 of the typical Hα luminosity of a Seyfert galaxy. This amount turns out to be about 1/100 of the L^* measured by Gallego et al. (1995). We decided not to include any correction relative to this effect. Once the active galactic nuclei 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 [O II] 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 [O II] λ3727 luminosity function for galaxies with current star formation activity. To correct for the signal not covered by the slit, the total [O II] λ3727 luminosity line for each galaxy was computed from the [O II] equivalent width and its continuum as obtained from the Johnson B-band magnitude. Given that the [O II] λ3727 line is not included in the B band for the UCM galaxies, we analyzed the ratio of the actual continuum adjacent to the [O II] λ3727 line, and the average continuum within the B band, as measured in our spectra. The average $k = F_B^c/F_{[\mathrm{O\,II}]}^c$ ratios for each spectroscopic type (0.94, 1.15, and 1.43 for blue compact dwarfs, H II–like, and disklike objects, respectively) were applied. The observed total [O II] line luminosity $L_{\mathrm{obs}}^{\mathrm{O\,II}}$ was computed as

$$L_{\mathrm{obs}}^{\mathrm{O\,II}} = \mathrm{EW}_{\mathrm{obs}}^{\mathrm{O\,II}} L_{\mathrm{obs}}^{c,\,\mathrm{O\,II}} \quad (1)$$

and the adjacent continuum $L_{\mathrm{obs}}^{c,\,\mathrm{O\,II}}$ as the scaled B continuum $L_{\mathrm{obs}}^{c,\,B}$ without the line contamination,

$$L_{\mathrm{obs}}^{c,\,\mathrm{O\,II}} = L_{\mathrm{obs}}^{c,\,B} \Big/ \left[k + \mathrm{EW}_{\mathrm{obs}}^{\mathrm{O\,II}} \frac{\mathrm{QE}(3727)}{\Delta\lambda(B)}\right],$$
$$L_{\mathrm{obs}}^{c,\,B} = P_0^B 10^{-0.4 m_B} D(z), \quad (2)$$

where m_B is the Johnson B apparent magnitude, P_0^B is 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 [O II] luminosities measured from spectroscopy not extinction-corrected. The mean Galactic extinction in the B band for the UCM sample is 0.23 ± 0.21 if Schlegel, Finkbeiner, & Davis (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 + [N II] 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/V_{max} test to obtain a complete sample of 176 galaxies within the UCM survey. These objects were selected with line+continuum flux larger than 1.9×10^{-14} ergs cm^{-2} 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 [O II] λ3727 luminosity function. Instead of adding artificial galaxies, we chose a final limiting flux slightly fainter than the one provided by the V/V_{max} method, and then we included all galaxies having nonzero flux in [O II] λ3727. With the goal of quantifying the goodness of V/V_{max} results, we compared with the maximum likelihood parametric fit (of Sandage, Tammann, & Yahil [STY]; see Yahil et al. 1991) and the nonparametric step-wise maximum likelihood (SWML; Efstathiou, Ellis, & Peterson 1988) methods.

The resulting Schechter best-fitting parameters as provided by the STY method for a limiting [O II] flux of 2.2×10^{-14} ergs cm^{-2} s^{-1} are $\alpha = -1.21 \pm 0.21$, $\phi^* = 10^{-2.98 \pm 0.19}$ Mpc^{-3}, and $L^* = 10^{40.92 \pm 0.13}$ ergs s^{-1}.

The number densities for each luminosity interval obtained from the V/V_{max} (both observed and extinction-corrected) are tabulated in Table 1. Both fit and values, within errors, are almost identical to the ones obtained by both the V/V_{max} and SWML methods. The densities were corrected for the 8% of UCM galaxies for which there is no [O II] data available. The luminosity function errors are those obtained considering a Gaussian distribution of σ equal to the square root of the number of galaxies in each log L(O II) bin.

Any comparison with previous [O II] luminosity functions has to be done with caution, given that different measurements come from samples built with very different selection criteria. In Figure 1, we have plotted our [O II] observed luminosity function for the local universe, in comparison with the one by Hogg et al. (1998) for the Caltech Faint Galaxy Redshift Survey (CFGRS), a sample of galaxies at intermediate redshift ($0.35 < z < 1.5$). The [O II] luminosity density of the universe was obviously higher in the past.

Given that we have $E(B-V)$ for every object but seven, we

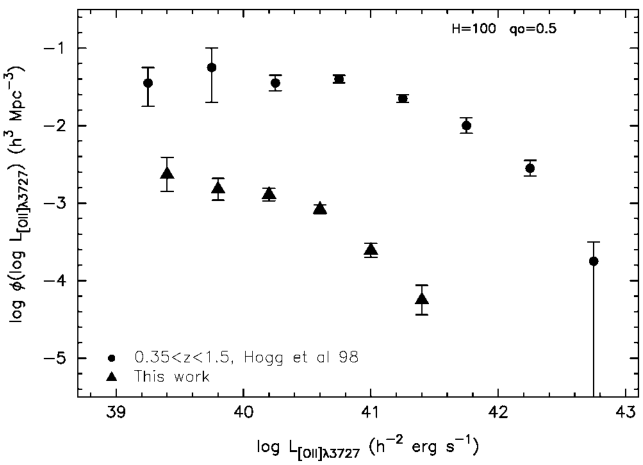

FIG. 1.—Observed [O II] λ3727 luminosity functions for both the UCM (*filled triangles*) and the CFGRS (*filled circles*) samples.

corrected each object luminosity as

$$L_{\rm corr}^{\rm O\,II} = {\rm EW}_{\rm obs}^{\rm O\,II} L_{\rm obs}^{c,\,{\rm O\,II}} 10^{0.4[A_{3727}E_l(B-V)]}, \qquad (3)$$

where $A_{3727} = f(3727)/0.295 = 4.81$ (Osterbrock 1989).

The resulting Schechter best-fitting parameters as provided by the STY method for a limiting flux of 4.0×10^{-14} ergs cm^{-2} s^{-1} are $\alpha = -1.17 \pm 0.08$, $\phi^* = 10^{-3.71\pm0.16}$ Mpc^{-3}, and $L^* = 10^{42.66\pm0.17}$ ergs s^{-1}. Densities are in Table 1 (again the $V/V_{\rm max}$ 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 [O II] λ3727 luminosities were obtained from follow-up spectroscopy and were extinction-corrected. A Schechter fit provides the following parameters: $\alpha = -1.59 \pm 0.12$, $\phi^* = 10^{-2.82\pm0.18}$ Mpc^{-3}, and $L^* = 10^{41.96\pm0.09}$ ergs s^{-1}. The differences have to be understood as coming from different galaxy populations, with more abundant but less luminous galaxies in the UV-selected sample.

4. THE EVOLUTION OF THE [O II] λ3727 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 [O II] λ3727 luminosity density, when combined with similar results from deep samples up to $z \sim 1.5$, allows us to sketch the evolution of the SFR density as traced by the observed [O II] 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:

$$L_{\rm tot} = \int_0^\infty L\phi(L)dL = \phi^* L^* \Gamma(2+\alpha). \qquad (4)$$

For the observed luminosities, the total [O II] luminosity density is $10^{38.01\pm0.15}$ ergs s^{-1} Mpc^{-3} in the local universe ($z \lesssim 0.045$) for star-forming galaxies with EW(Hα + [N II]) $\gtrsim 20$ Å.

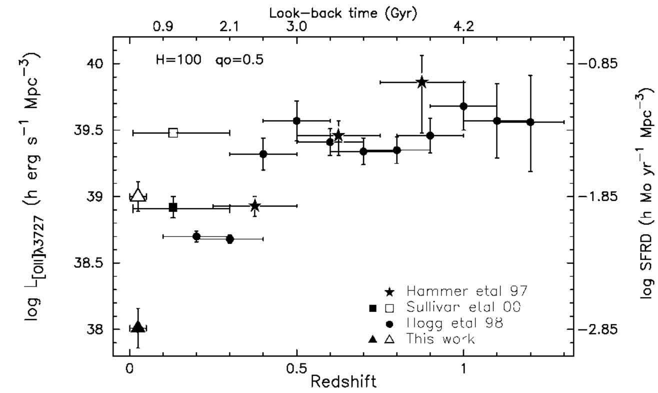

FIG. 2.—Evolution of the [O II] λ3727 luminosity density of the universe. Both the observed and extinction-corrected values for the UCM sample are represented as filled and open triangles. Filled circles correspond to Hogg et al. (1998), filled stars are for the Hammer et al. (1997) values, and the filled and open squares are for the observed and extinction-corrected Sullivan et al. (2000) values.

When the effect of the extinction is considered, the total [O II] extinction-corrected luminosity per unit volume corresponds to $10^{39.00\pm0.11}$ ergs s^{-1} Mpc^{-3}. The extinction correction amounts for a total of 1 dex. This luminosity density is similar to the one we could estimate from the *B*-band luminosity function published by Gallego et al. (1997) for the UCM sample. It is also comparable to the luminosity density we would obtain if we apply an average [O II] λ3727/Hα factor to the extinction-corrected Hα luminosity density measured by Gallego et al. (1995).

In Figure 2, we have plotted all the [O II] 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 provide only observed luminosities. We have also plotted both the observed and the extinction-corrected value for the Sullivan et al. (2000) sample.

The right-hand axis of Figure 2 shows how the L([O II]) scale transforms into an SFR density scale using the nominal transformation provided by Kennicutt (1998): SFR/($M_\odot$ yr^{-1}) = $1.4 \times 10^{-41} L_{\rm [O\,II]}$ (ergs s^{-1}). Our total extinction-corrected [O II] luminosity density translates into an SFR density of 0.014 ± 0.003 $M_\odot$ yr^{-1} Mpc^{-3}.

Assuming that the SFR density evolves with redshift as $(1+z)^n$, the combination of the UCM local value with the CFGRS data implies $n \approx 4$. Such strong evolution is similar to the one obtained using Hα as an 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.

Valuable discussions with A. Alonso-Herrero, P. G. Pérez-González, and S. Pascual are gratefully acknowledged. We would also like to thank the anonymous referee for his/her useful suggestions that improved this Letter. This work was supported in part by the Spanish Plan Nacional de Astronomía y Astrofísica under grant AYA2000-1790.

REFERENCES

Burstein, D., & Heiles, C. 1982, AJ, 87, 1165
Cardiel, N. 1999, Ph.D. thesis, Univ. Complutense Madrid
Charlot, S., & Longhetti, M. 2001, MNRAS, 323, 887
Connolly, A. J., Szalay, A. S., Dickinson, M., Subbarao, M. U., & Brunner, R. J. 1997, ApJ, 486, L11
Efstathiou, G., Ellis, R. S., & Peterson, B. A. 1988, MNRAS, 232, 431
Gallego, J., Zamorano, J., Aragón-Salamanca, A., & Rego, M. 1995, ApJ, 455, L1
Gallego, J., Zamorano, J., Rego, M., Alonso, O., & Vitores, A. G. 1996, A&AS, 120, 323
Gallego, J., Zamorano, J., Rego, M., & Vitores, A. G. 1997, ApJ, 475, 502
González Delgado, R. M., Leitherer, C., & Heckman, T. M. 1999, ApJS, 125, 489
Hammer, F., et al. 1997, ApJ, 481, 49
Ho, L. C., Filippenko, A. V., & Sargent, W. L. W. 1997, ApJ, 487, 568
Hogg, D. W. 2002, ApJL, submitted (astro-ph/0105280)
Hogg, D. W., Cohen, J. G., Blandford, R., & Pahre, M. A. 1998, ApJ, 504, 622
Jones, D. H., & Bland-Hawthorn, J. 2001, ApJ, 550, 593
Kennicutt, R. C., Jr. 1998, ARA&A, 36, 189
Lilly, S. J., Le Fèvre, O., Hammer, F., & Crampton, D. 1996, ApJ, 460, L1
Madau, P. 1997, in AIP Conf. Proc. 393, Star Formation Near and Far, ed. S. S. Holt & L. G. Mundy (Woodbury: AIP), 481
Madau, P., Ferguson, H. C., Dickinson, M. E., Giavalisco, M., Steidel, C. C., & Fruchter, A. 1996, MNRAS, 283, 1388
Osterbrock, D. E. 1989, Astrophysics of Gaseous Nebulae and Active Galactic Nuclei (Mill Valley: University Science Books)
Pascual, S., Gallego, J., Aragón-Salamanca, A., & Zamorano, J. 2001, A&A, 379, 798
Pérez-González, P. G., Gallego, J., Zamorano, J., & Gil de Paz, A. 2001, A&A, 365, 370
Pérez-González, P. G., Zamorano, J., Gallego, J., & Gil de Paz, A. 2000, A&AS, 141, 409
Schlegel, D. J., Finkbeiner, D. P., & Davis, M. 1998, ApJ, 500, 525
Sullivan, M., Treyer, M. A., Ellis, R. S., Bridges, T. J., Milliard, B., & Donas, J. 2000, MNRAS, 312, 442
Tresse, L., & Maddox, S. J. 1998, ApJ, 495, 691
Vitores, A. G., Zamorano, J., Rego, M., Alonso, O., & Gallego, J. 1996a, A&AS, 118, 7
Vitores, A. G., Zamorano, J., Rego, M., Gallego, J., & Alonso, O. 1996b, A&AS, 120, 385
Yahil, A., Strauss, M. A., Davis, M., & Huchra, J. P. 1991, ApJ, 372, 380
Zamorano, J., Gallego, J., Rego, M., Vitores, A. G., & Alonso, O. 1996, ApJS, 105, 343
Zamorano, J., Rego, M., Gallego, J. G., Vitores, A. G., González-Riestra, R., & Rodríguez-Caderot, G. 1994, ApJS, 95, 387