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Integrated photometry of galactic H II regions

M.V.F. Copetti

Laboratório de Análise Numérica e Astrofísica, Departamento de Matemática, Universidade Federal de Santa Maria, 97119-900 Santa Maria, RS, Brazil

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Abstract. Integrated photoelectric measurements of the equivalent width $W_{\mathrm{H}\beta}$, the [O III]/Hβ ratio and the Hβ emission line flux are presented for 31 southern hemisphere galactic H II regions. The Lyman continuum photon fluxes are obtained for some of these objects. The integrated [O III]/Hβ ratios have not shown any statistically significant deviation from non-integrated measurements found in the literature.

Key words: H II regions — ISM: general

1. Introduction

Most of the model results for line intensities of H II regions refer to the emission of the whole nebula. However, most of the observational determinations of optical emission line fluxes of galactic H II regions are based on spectroscopic data taken from special and small areas (usually the brightest ones) of the objects. Integrated absolute fluxes in optical emission lines are very scarce in the literature. A recent exception is the abundance study by Deharveng et al. (2000) based on the integrated line fluxes of Caplan et al. (2000). In the present paper, we present integrated photoelectric measurements of the flux and equivalent width of the Hβ emission line, denoted by $F(\mathrm{H}\beta)$ and $W_{\mathrm{H}\beta}$ respectively, and of the [O III]/Hβ ratio, defined as the intensity relative to Hβ of the doublet [O III]$\lambda\lambda$4959, 5007 for a sample of 31 southern hemisphere galactic H II regions. For most of these objects, optical absolute fluxes have never been obtained before. Three of them, RCW 87, RCW 88 and RCW 99, are misclassified planetary nebulae (Acker et al. 1987) and other three are Wolf-Rayet nebulae (Chu 1981). The [O III]/Hβ ratio is the simplest parameter used to characterise the level of excitation of H II regions, whereas the Hβ flux combined with distance and the amount of extinction estimates give us the total number of ionising photons emitted by the stars per unit time. Copetti et al. (1986) have shown that the age of the ionising cluster of an H II region may be estimated from the equivalent width $W_{\mathrm{H}\beta}$.

Send offprint requests to: e-mail: mvfc@lana.ccne.ufsm.br

2. Observations

The observations were made in 17 photometric nights between 1984 and 1985 with a photoelectric photometer attached to the 0.61 m Lowell telescope of the Cerro Tololo Interamerican Observatory, using a CO_2 cooled ITT FW130 S20 photomultiplier and a photometric system composed of three interference filters: an Hβ narrow, an Hβ wide and an [O III] filter centred at 5000 Å, with passbands of 30, 150 and 70 Å, respectively. In the first run, two additional filters, centred at 4517 and 5320 Å with bassbands of 75 and 100 Å respectively, were used in order to evaluate the continuum emission independently of the Hβ filters. Later on, in view of the compatibility within few percents of the results obtained with and without these two filters we dropped them. The basic observational routine was composed of four exposures of 10 s in each filter, alternating the filters in the sequence 1–2–3–3–2–1. The total exposure time of this routine for the pair object and sky was 480 s (800 s for the first observations with the five filters system). For each object, we have repeated this routine at least twice, taking different positions for the sky subtraction. Each night two or three of the spectrophotometric standard stars ξ Cet, θ Crt, η Hya and θ Vir were observed for the absolute flux calibration. Due to the presence of strong Balmer absorption lines on the spectra of the standard stars, the absolute fluxes were obtained by comparison between the counts of the H II regions and the standard stars in the [O III] filter. Stellar fluxes published by Kohoutek & Martin (1981) were used. The reduction procedure was the same as described in details in Copetti & Dottori (1989) for an analogous programme. A sample of planetary nebulae was also observed in order to check the quality of the observations and reduction procedure.

Table 1. Photometry of 31 galactic H II regions

Object	Other names	α (2000)	δ (2000)	aperture	N	$W_{H\beta}$ (Å)	[O III]/Hβ	log $F(H\beta)^*$
NGC 2467	Gum 9, RCW 16, S 311	$07^h52^m22.1^s$	−26°26′30″	3′20″	2	368 ± 131	2.7 ± 01	−9.87 ± 0.02
		07 52 22.1	−26 26 30	6′40″	2	177 ± 23	2.8 ± 0.1	−9.55 ± 0.01
RCW 19	Gum 10	08 15 55.7	−35 34 17	6′40″	2	30 ± 12	1.0 ± 0.3	−10.84 ± 0.11
NGC 2579	Gum 11	08 20 54.8	−36 13 00	3′20″	6	53 ± 9	5.5 ± 0.4	−10.72 ± 0.04
RCW 29	Part of Gum 13	08 21 38.8	−42 39 43	2′30″	2	67 ± 20	2.0 ± 0.4	−12.05 ± 0.15
RCW 31		08 23 59.4	−43 01 53	2′30″	6	123 ± 45	1.0 ± 0.2	−12.19 ± 0.05
RCW 34	Gum 19	08 56 28.2	−43 05 57	1′40″	4	45 ± 12	1.8 ± 0.6	−11.45 ± 0.17
RCW 36	Gum 20	08 59 44.9	−43 43 56	2′30″	2	207 ± 103	0.1 ± 0.1	−11.76 ± 0.08
		08 59 39.2	−43 47 00	3′20″	2		0.6 ± 0.2	−11.88 ± 0.11
		08 59 23.5	−43 45 47	2′30″	2	260 ± 140	0.6 ± 0.1	−11.91 ± 0.05
		08 59 23.1	−43 43 37	2′30″	2	135 ± 56	0.3 ± 0.1	−11.80 ± 0.07
Gum 22	Part of RCW 38	08 59 01.0	−47 30 34	3′20″	3		8.2 ± 1.0	−11.47 ± 0.06
RCW 39		09 03 21.7	−48 25 49	3′20″	6		1.0 ± 0.1	−11.63 ± 0.09
RCW 40	Gum 25	09 02 21.0	−48 42 29	3′20″	2	92 ± 21	0.9 ± 0.1	−10.60 ± 0.05
		09 02 26.5	−48 39 48	3′20″	2	108 ± 90	0.7 ± 0.3	−10.82 ± 0.16
		09 02 34.5	−48 37 52	3′20″	2	54 ± 17	0.6 ± 0.1	−11.11 ± 0.06
		09 02 26.0	−48 41 22	6′40″	2	55 ± 6	0.7 ± 0.1	−10.35 ± 0.05
RCW 42	Gum 26	09 24 34.6	−52 00 59	1′40″	2	84 ± 30	5.5 ± 1.7	−11.96 ± 0.10
		09 24 20.1	−51 59 19	1′40″	2		5.4 ± 0.6	−11.61 ± 0.12
		09 24 28.9	−51 57 50	1′40″	2	28 ± 10	5.4 ± 0.6	−11.90 ± 0.09
NGC 3199	Gum 28, RCW 48	10 16 27.8	−57 56 02	6′40″	2	86 ± 42	11.2 ± 1.4	−10.23 ± 0.06
		10 16 43.3	−57 50 41	6′40″	2	80 ± 16	10.9 ± 1.0	−10.54 ± 0.05
		10 16 58.3	−57 58 25	2′30″	2	250 ± 71	8.9 ± 0.4	−10.89 ± 0.03
		10 16 36.8	−57 57 05	3′20″	2		9.5 ± 0.5	−10.55 ± 0.03
		10 16 35.6	−57 52 28	6′40″	2	191 ± 74	10.1 ± 0.8	−10.23 ± 0.04
RCW 49	Gum 29	10 24 09.0	−57 47 23	3′20″	2		6.6 ± 1.0	−10.98 ± 0.04
		10 24 15.2	−57 47 27	6′40″	2		8.9 ± 2.1	−10.61 ± 0.13
RCW 52	Gum 32	10 46 11.4	−58 39 15	6′40″	2	32 ± 18	0.7 ± 0.3	−10.69 ± 0.17
RCW 55		10 56 32.3	−63 00 47	1′40″	3	5 ± 1	0.8 ± 0.2	−11.95 ± 0.10
NGC 3503	Gum 11	11 01 19.0	−59 50 57	3′20″	2	32 ± 6	4.1 ± 0.3	−11.42 ± 0.05
RCW 54		11 02 37.4	−59 53 35	2′30″	2	17 ± 4	0.9 ± 0.1	−11.20 ± 0.06
NGC 3603	Gum 38b, part of RCW 57	11 15 06.0	−61 16 07	3′20″	2	10 ± 3	14.3 ± 1.5	−10.89 ± 0.06
		11 15 06.0	−61 16 07	6′40″	2	17 ± 3	9.2 ± 0.9	−10.50 ± 0.03
RCW 69	Gum 45	12 44 27.0	−62 31 03	2′30″	2		8.6 ± 2.9	−12.04 ± 0.12
RCW 87	PK 320+00 1	15 05 20.1	−57 31 01	3′20″	6	88 ± 20	1.9 ± 0.3	−11.81 ± 0.09
RCW 88	PK 320+00 2	15 07 05.3	−57 47 16	3′20″	4	85 ± 46	0.5 ± 0.3	−11.59 ± 0.10
RCW 99	Gum 50, PK 328-00 1	15 59 36.8	−53 45 27	2′30″	4	63 ± 11	1.8 ± 0.2	−11.22 ± 0.04
RCW 104		16 24 07.9	−51 32 07	3′20″	4	31 ± 6	1.8 ± 0.4	−11.47 ± 0.05
RCW 105	Gum 51	16 10 39.5	−49 06 20	2′30″	4	61 ± 16	1.2 ± 0.2	−11.67 ± 0.08
		16 10 32.1	−49 08 26	2′30″	2	56 ± 21	1.6 ± 0.4	−11.83 ± 0.10
RCW 110	Part of Gum 54	16 54 22.1	−45 13 27	3′20″	4	71 ± 40	0.5 ± 0.2	−11.12 ± 0.08
		16 53 54.9	−45 09 48	3′20″	4	29 ± 8	1.3 ± 0.3	−11.53 ± 0.12
RCW 111	Part of Gum 54	16 55 07.2	−45 07 15	3′20″	4	51 ± 8	0.8 ± 0.1	−11.45 ± 0.05
RCW 120	Gum 58, S 3	17 12 27.4	−38 29 53	3′20″	2	21 ± 6	2.3 ± 0.3	−11.31 ± 0.06
Gum 64a	Part of RCW 127, NGC 6334, S 8	17 20 03.3	−35 58 25	2′30″	4	273 ± 62	0.6 ± 0.1	−11.38 ± 0.03
Gum 64c	Part of RCW 127, NGC 6334, S 8	17 20 30.6	−35 46 01	2′30″	4	121 ± 10	0.3 ± 0.1	−11.07 ± 0.02
NGC 6357	Gum 66, RCW 131, S 11	17 24 47.8	−34 10 16	3′20″	4		4.8 ± 0.4	−10.80 ± 0.03
M 20	Trifid Nebula, NGC 6514	18 02 23.1	−23 01 59	3′20″	2	26 ± 3	2.2 ± 0.1	−9.79 ± 0.02
		18 02 23.1	−23 01 59	6′40″	2	148 ± 10	1.2 ± 0.1	−9.12 ± 0.02

Catalogues: Gum = Gum (1955); PK = Perek & Kohouteck (1967); RCW = Rodgers et al. (1960); S = Sharpless (1959).
* in erg s^{-1} cm^{-2}.

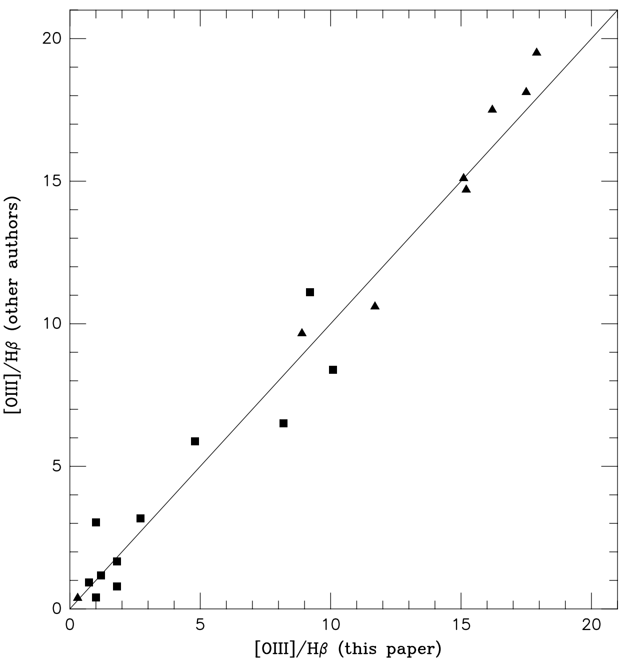

Fig. 1. Comparison of the [O III]/Hβ measurements with mean values from the literature. The squares correspond to the H II regions (Danziger 1974; Esteban et al. 1992; Girardi et al. 1997; Hawley 1978; Heydari-Malayeri 1988; Kwitter 1984; Lortet et al. 1984; Peimbert et al. 1978; Shaver et al. 1983) and the triangles refer to the planetary nebulae of the controlling sample (Acker et al. 1989; Backer 1985; Danziger et al. 1973; Freitas Pacheco et al. 1991; Kaler 1976, 1983; Kohoutek & Martin 1981 Oliver & Aller 1969; Peimbert & Torres-Peimbert 1978; Shaw & Kaler 1989; Webster 1969, 1983). Also shown the identity line

The results obtained for this control sample, which have been published elsewhere (Copetti 1990), agreed very well with data taken from the literature with a mean difference of 6% for the [O III]/Hβ ratios and 0.03 dex for the logarithmic Hβ fluxes. No evidence of systematic deviations was found.

3. Results

The results of our observations are shown in Table 1, which lists some designations of the studied H II regions, the equatorial coordinates of the centres of the observed areas, the diameter of the circular diaphragm used, the number N of repetition of the basic observing routine (or the integration time per filter in units of 160 s), the equivalent width $W_{\mathrm{H}\beta}$, the [O III]/Hβ line ratio and the logarithmic Hβ flux in units of erg s^{-1} cm^{-2}. The error estimates of these properties correspond to the propagation of the (1σ) statistical errors of the counts in each filter. The sky

Table 2. Lyman continuum photon fluxes

Object	D (kpc)		C(Hβ)		log N_{c} (s^{-1})
NGC 2467	4.5	[1]	0.7	[6,14,15]	48.9
RCW 19	3.0	[1,2,3]	1.3	[3,6]	47.8
NGC 2579	3.3	[2,3,4]	1.1	[3]	47.8
RCW 34	2.9	[5]	1.9	[5,6]	47.8
Gum 22	1.7	[2]	3.0	[6,16]	48.4
RCW 39	3.0	[6]	3.2	[6]	48.9
RCW 40	1.7	[1,2]	1.4	[6]	48.2
NGC 3199	3.5	[2,7]	1.3	[17,18]	48.9
NGC 3503	2.8	[8]	0.7	[8]	46.6
NGC 3603	7.7	[2]	3.6	[19]	51.3
RCW 104	3.7	[2]	1.8	[17]	47.9
Gum 64a	2.0	[2,9,10]	1.7	[9,10]	47.3
Gum 64c	2.0	[2,9,10]	1.7	[9,10]	47.6
NGC 6357	1.7	[2,10]	2.5	[16]	48.6
M 20	1.8	[11,12,13]	0.9	[15,20]	48.7

References: [1] Brand & Blitz (1993); [2] Avedisova & Palous (1989); [3] Moffat et al. (1979); [4] Neckel & Staude (1995); [5] Heydari-Malayeri (1988); [6] Shaver et al. (1983); [7] Hidayet et al. (1982); [8] Herbst (1975); [9] Walborn (1982); [10] Neckel (1978); [11] Buscomb (1963); [12] Lada & Wooden (1979); [13] Walborn (1973); [14] Peimbert et al. (1978); [15] Hawley (1978); [16] Danziger (1974); [17] Esteban et al. (1992); [18] Kwitter (1984); [19] Girardi et al. (1997); [20] Lynds et al. (1985); *Note:* $E(B-V)$ converted to C(Hβ) by C(Hβ) = 1.5 $E(B-V)$.

subtraction is the most important source of uncertainty, specially for the equivalent width $W_{\mathrm{H}\beta}$, due to the inevitable inclusion in the large apertures used of relatively bright field stars. In order to minimise this problem we have taken different sky positions around each nebula. In some cases the measurements of $W_{\mathrm{H}\beta}$ were ruin by severe brightness fluctuations of the background.

Table 2 presents our estimates for the Lyman continuum photon fluxes N_{c} calculated from our Hβ line fluxes for those objects with the additional data required available in the literature, namely the heliocentric distance, D, and the logarithmic extinction in the Hβ emission line, C(Hβ). We must stress that all these objects show extended emission outside the observed area. So, our values should be more properly considered as lower limits for N_{c}. Nearly five orders of magnitude separate the ionising powers of NGC 3503 and NGC 3603, one of the most luminous H II region in the Galaxy excited by more than 50 O stars. The objects in the sample have also shown varied degrees of excitation even at similar galactocentric distances, with [O III]/Hβ ranging from 0.3 to 10. The large majority has shown $W_{\mathrm{H}\beta} \leq 100$ Å, which according to the models of Copetti et al. (1986) with a normal IMF slope indicates that they are evolved objects with ages around or larger than 4 10^6 years.

In Fig. 1 we have shown that our [O III]/Hβ measurements for both the programme H II regions and the planetary nebulae of the controlling sample are very well correlated with the mean spectroscopic values found in the literature with a correlation coefficient $R = 0.99$. Moreover, the regression line, [O III]/Hβ (other authors) = $(0.03 \pm 0.41) + (1.02 \pm 0.04)$ [O III]/Hβ (this paper), is statistically indistinguishable from the identity line, which justifies the usual procedure of adopting for the whole nebula data collected from a small region. Of course, every line measurement is a weighted integration along the line of sight. In particular, the similarity between the integrated and non-integrated [O III]/Hβ ratios may in great part be attributed to the fact that in normal H II regions the O^{++} zones usually occupy large fractions of the total nebular volumes. We would expect to find more discrepant comparison of this sort among measurements of emission lines produced by more localised ions (e.g., [O I] and [O IV] lines).

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List of objects