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ABUNDANCE ANALYSIS OF GIANT H II REGIONS IN NEARBY SPIRALS

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RESUMEN. Se analizaron datos espectrométricos que cubren un intervalo espectral de λ3600 a 9700 A de las regiones H II gigantes en las galaxies espirales M 101 y M 51 para determinar abundancias químicas y gradientes radiales confiables.

También se exploró el comportamiento del cociente de S/O con la metalicidad. Los datos son consistentes dentro de los errores, con una abundancia constante de S/O.

ABSTRACT. Spectrophotometric data of Giant H II regions covering the spectral range from λ 3600 to 9700 A in the spiral galaxies M 101 and M 51 have been analyzed in order to determine reliable chemical abundances and radial gradients.

The behaviour of the S/O ratio with metallicity is also explored. The data are consistent, within the errors, with a constant S/O abundance although uncertainties are large.

Key words: **ABUNDANCES – GALAXIES-SPIRAL – NEBULAE-H II REGIONS**

I. INTRODUCTION

In 1984 we started an investigation of element abundances in Giant H II regions of nearby spiral galaxies, with the aim of studying in detail their chemical composition and its variation with galactocentric distance. The consistency of abundance determinations by current methods in these outstandingly large H II regions was checked in NGC 604, an easily observable region in M 33 that can be spatially resolved (Díaz *et al.* 1987). NGC 604 is thought to contain a great number of ionizing stars (~ 100) and a mass of ionized hydrogen of about 2×10^6 $M_\odot$ (Israel and van der Kruit 1974). Five different regions of the nebula were individually analysed and, although we found the excitation to vary considerably across the entire H II region, no significant variations in the chemical abundances were found. Also, the line ratio R_{23} = ([O II]+[O III])/Hβ was found to be constant, which allows the use of empirical calibrations of O abundance of the type proposed by Pagel *et al.* (1979) with considerable confidence for other giant H II regions.

Similar analyses were made for other Giant H II regions in M 33 (Vílchez *et al.* 1988). A number of interesting results were found. The O/H abundance gradient appears to be steeper in the inner part of the galaxy; the N/O ratio remains constant over most of the visible disc and the sulphur gradient is slightly flatter than that of oxygen creating a decreasing trend of S/O ratio with oxygen abundance. This latter result was rather unexpected since, being S and O both products of the nuclesynthesis in massive stars, their ratio should, in principle, remain constant.

Different chemical evolution models are able to reproduce variations in the S/O ratio. Some of them are based on variations of the initial mass function (IMF). With simple "closed box" models and an IMF whose upper mass limit decreases with metallicity according to an empirical relation (Campbell 1988), Garnett (1989) obtains a positive gradient of S/O with O/H, contrary to what was found for M 33. In models of the kind proposed by Matteucci and François (1989), however, the negative trend of S/O with abundance arises naturally from the fact that, although S and O both come from massive progenitors, S is produced in stars with masses in a much narrower range than oxygen.

Here we report new results on chemical abundances in Giant H II regions in two galaxies with ver different average metallicity: M 101 and M 51; from those results we investigate the dependence of the S/O ratio wit average metal content.

II. OBSERVATIONS

We have observed three giant H II regions in M 101 (NGC 5471, NGC 5461 and S5) and six in M 5 (72,24,19,71,10 of Carranza *et al.* (1969) and one at 0.5′ from the nucleus, that we denote by X).

The observations were made at the Isaac Newton Telescope (La Palma) and consisted of long sli spectrophotometry of different parts of the nebula using the Intermediate Dispersion Spectrograph and the 235m camera. Two detectors were used: the IPCS for the optical spectral region from λ3600-7500 A and the CCD for th near infrared from λ6200-9700 A. A whole spectrum at a spectral resolution of ≈ 4 A was obtained for each slit position

The reduction of the data was performed as described in Díaz *et al.* 1987. Atmospheric absorption which affects principally the λ 9532 A line (see Díaz *et al.* 1985), was corrected by means of division by the spectrum o a subdwarf star observed the same night as the object.

III. RESULTS

The abundance analysis and ionic abundance determinations in each of the observed regions have bee derived from the measured emission line intensities following the method described in Díaz *et al.* (1987).

Two different regions of NGC 5471, A and B (see Skillman 1985), were analized separately. A full accoun of the line intensity ratios for each observed region can be found in Díaz *et al.* (1990a). In the case of S5 in M 101 onl the red spectra have been analyzed and the data from Torres-Peimbert *et al.* (1989) for the optical region have bee used.

As mentioned above the galaxies chosen for our study, M 101 and M 51, have very different averag metallicities. The effect of this difference can be seen in Figure 1 where the IPCS spectra of NGC 5471 A (M 101) an CCM72 (M 51) are shown in an enlarged scale. The spectrum of NGC 5471 A is that typical of a high excitation H I region with the [O III] lines at λλ4959, 5007 A much stronger than Hβ and the weak temperature sensitive [O II] lin λ4363 A clearly visible. On the other hand, the spectrum of CCM72, typical of a low excitation H II region, shows onl a weak λ5007 A [O III] line.

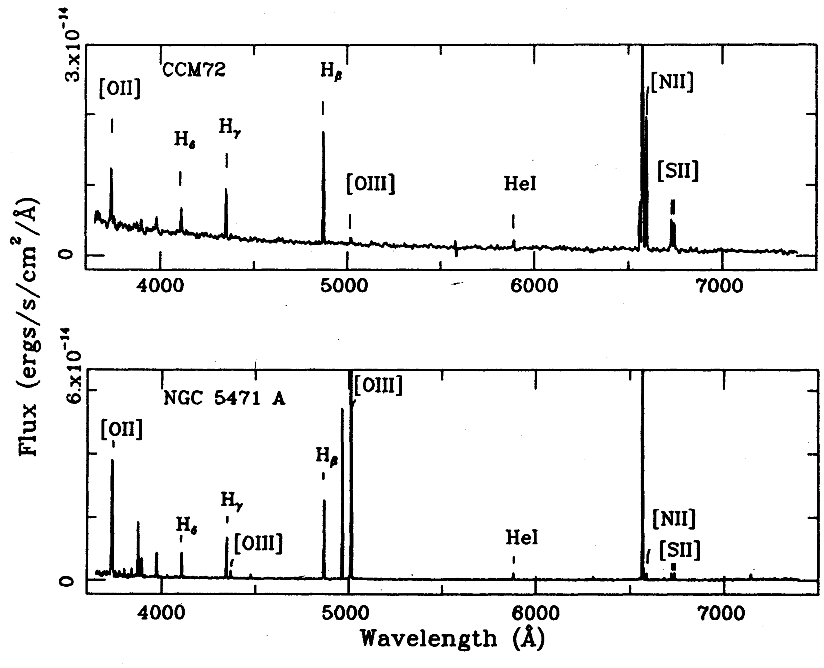

Fig. 1. IPCS spectra of NGC 5471A in M 101 and CCM72 in M 51.

In spite of this difference in metallicity, the [S III] lines at $\lambda\lambda$9069,9532 A are easily detected in both gions as can be seen in their CCD spectra shown in Figure 2. This fact is crucial for the determination of sulphur undances in H II regions, where most of the sulphur appears in the form of S^+ and S^{++}, this later ionization stage nstituting about 60% of the total. Therefore both [S II] and [S III] lines need to be observed. The other available III] line in the optical range, at λ6312 A , is very faint and, when at all observable, is blended with [O I] λ6300 A moderate spectral resolution. The only way of determining reliable S abundances is therefore to observe the [S III] es in the near IR.

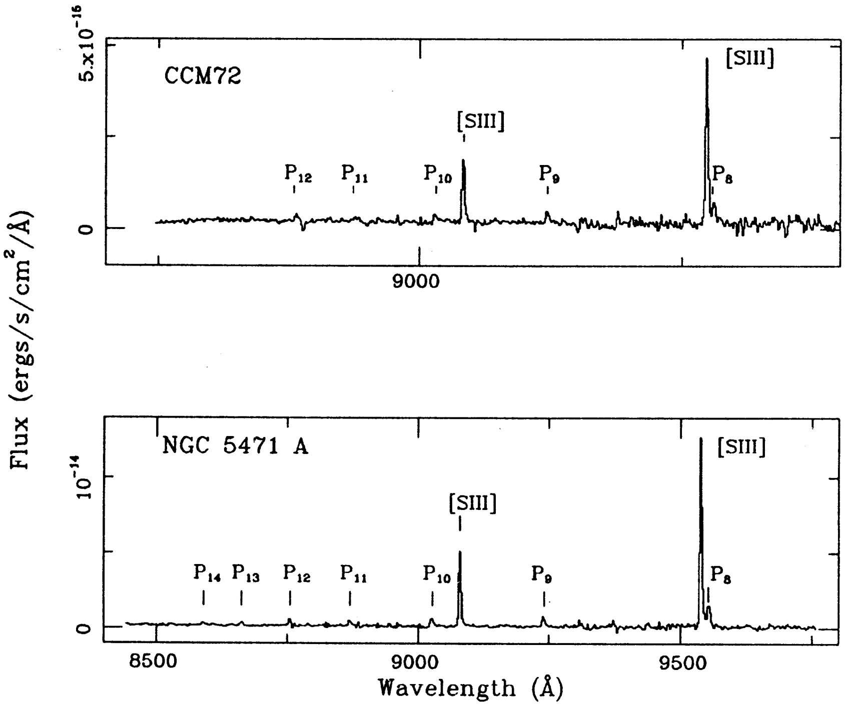

Fig. 2. CCD spectra of NGC 5471A in M 101 and CCM72 in M 51.

Electron temperatures were directly determined for NGC 5471 A and B and NGC 5461. In the case S5 and the H II regions of M 51 the [O III λ4363 A line is not detected and the relation between R_{23} and the verse excitation parameter η (Vílchez and Pagel 1988), as deduced from the photoionization models by Stasińska 980, 1982), has been used to derive the line temperatures necessary to calculate ionic abundances for oxygen and lphur. These temperatures and abundances are given in Table 1. Our results for M 101 are consistent with those Torres-Peimbert *et al.* (1989), which have been derived using the weak λ6312 A [S III] line, and Shields and Searle 978) and Garnett (1989) who use the strong IR [S III] lines. Total O abundances relative to hydrogen were calculated m the ionic O^+, O^{++} and are also listed in Table 1.

ble 1. Line Temperatures and Abundances

Object	10^{-4}			12 +				
	t[OIII	t[OII]	log R_{23}	log O^+/H^+	log O^{++}/H^+	log S^+/H^+	log S^{++}/H^+	log O/H
X	0.45:	0.60	0.16	8.83	8.65:	6.55	6.46:	9.1±0.1
CCM72	0.36:	0.52	-0.17	9.01	8.65:	6.86	7.52	9.2±0.1
CCM24	0.44:	0.58	0.11	8.88	8.64:	6.71	7.08	9.05±0.05
CCM19	0.34:	0.45:	-0.64	8.90:	9.04:	7.18:	6.80:	9.3:
CCM71	0.36:	0.50	-0.30	9.02	<8.84:	6.91	7.42	9.2±0.1
CCM10	0.50	0.64	0.27	8.80	8.26	6.53	6.82	8.90±0.05
S5	0.65		0.38	8.82	7.70	6.72	7.26	8.9±0.15
NGC 5461	0.90	0.92	0.80	7.99	8.28	5.99	6.60	8.46±0.08
NGC 5471A	1.28	1.0:	1.00	7.33	7.91	5.40	5.95	8.01±0.05
NGC 5471B	1.28	1.0:	0.95	7.71	7.71	5.83	5.78	8.01±0.05
IIZw40	1.28		1.01	7.02	8.10	5.23	6.13	8.14±.02

The derivation of the total sulphur abundances requires the estimation of the ionization correction fac (ICF) necessary to account for the presence of S in ionization stages other than S^+ and S^{++}. French (1981) prop an empirical relation to correct for this effect:

$$ICF(S) = \left[1 - \left(\frac{O^{++}}{O}\right)^n\right]^{-1/n}$$

More recently Garnett (1989) has computed photoionization models with the aim of deriving these theoretically. His models use the ratios O^+/O and S^+/S^{++} to estimate the ICF and the T_{eff} of the ionizing stars. have computed ICF for all the observed regions plus those of M33 (Vílchez *et al.* 1988) and the H II galaxy IIZw (Díaz *et al.* 1990b) using both French's relation and Garnett's models. They are listed in Table 2 together with corresponding S/O ratio.

Table 2. ICF and S/O Ratios

Region	$\log(ICF)_F$	$\log(ICF)_G$	$\log(S/O)_F$	$\log(S/O)_G$
CC93	0.00	0.00	-1.79	-1.79
IC142	0.01	0.00	-1.66	-1.67
NGC595	0.04	0.02	-1.55	-1.57
MA2	0.07	0.02	-1.59	-1.64
NGC604	0.13	0.06	-1.43	-1.50
NGC588	0.23	0.00	-1.21	-1.44
X	0.03	0.02	-2.27	-2.28
CCM72	0.02	0.00	-1.58	-1.60
CCM24	0.05	0.00	-1.75	-1.80
CCM19	0.08	0.05	-1.92	-1.95
CCM71	0.05	0.00	-1.65	-1.70
CCM10	0.16	0.00	-1.74	-1.90
NGC 5471A	0.22	0.13	-1.73	-1.82
NGC 5471B	0.06	0.02	-1.84	-1.88
NGC 5461	0.12	0.06	-1.64	-1.70
S5	0.00	0.00	-1.50	-1.50
IIZw40	0.39	0.37	-1.57	-1.59

As can be seen from the table, substantial variations exist between the two sets of ICF which indicate present degree of uncertainty associated with S determinations. Figure 3 shows the possible range of S/O for each of objects in Table 2 indicated by vertical bars. These bars correspond to French's ICF which are systematically larger tl Garnett's and therefore provide a more conservative estimate of the uncertainties. Any trends present are margina

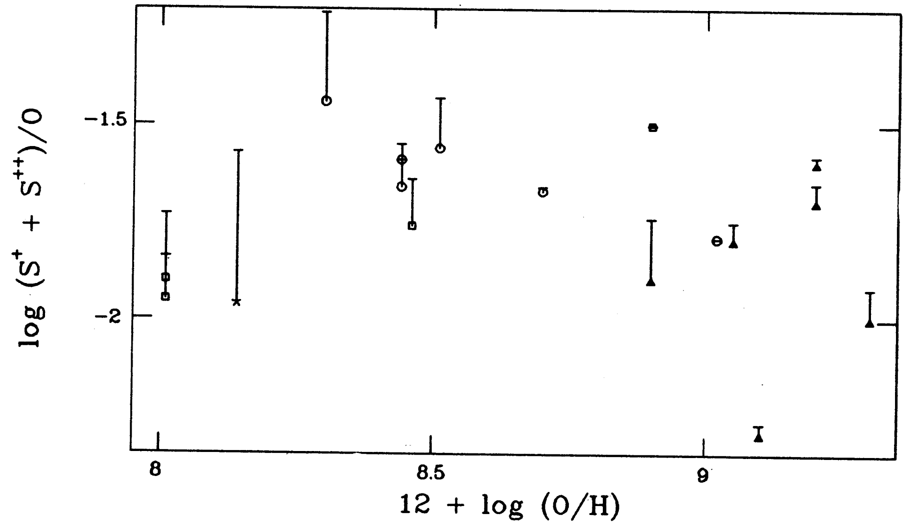

Fig.3. log (S^++S^{++}/O versus 12+log O/H; o: M33, △: M51, □: M101, ★: IIZw 40.

Better observational data of metal rich H II regions and better experimental data for the computation photoionization models are needed in order to settle the question of the existence of a universal dependence of S/O mean abundance. Also, observations of the IR [S IV] line for well observed H II regions would be of great help to eck the model derivations of ICF.

It should be noted that the existence of a radial gradient in S/O in a given galactic disc does not necessarily ply that our assumptions about the nucleosynthesis of sulphur are wrong, since it is rather inprobable that the H II gions on the discs of spiral galaxies evolve as closed systems. Variations in the IMF combined with the stellar lifetimes volved and exchanges of gas, all play an important role in chemical evolution and can lead to the development of fferent gradients of the S/O ratio for different galaxies. That also seems to be the case for N/O (see Díaz 1989).

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EFERENCES

ampbell, A. W. 1988, *Ap.J.*, **335**, 644.

arranza, G., Crillon, R., and Monnet, G. 1969, *Astr. and Ap.*. **1**, 479.

íaz, A.I. 1989, in *Evolutionary Phenomena in Galaxies*, Eds. J.E. Beckman and B.E.J. Pagel (Cambridge: University Press), p377.

íaz, A.I., Terlevich, E., Pagel, B.E.J., Vílchez, J.M., and Edmunds, M.G. 1987, *M.N.R.A.S.*, **226**, 19.

íaz, A.I., Terlevich, E., Pagel, B.E.J., Vílchez, J.M., and Edmunds, M.G. 1990a, in preparation.

íaz, A.I., Terlevich, E., Pagel, B.E.J., Vílchez, J.M. and Edmunds, M.G. 1990b, in *Dynamical and Chemical Evolution of Galaxies*, eds. J.J. Franco, F. Matteucci, F. Ferrini.

vans, I. 1986 *Ap.J.*, **309**, 544.

rench, H.B. 1981, *Ap.J.*, **246**, 434.

arnett, D.R. 1989, *Ap.J.*, **345**, 282.

srael, F.P. and van der Kruit, P.C. 1974, *Astr. and Ap.*, **32**, 363.

atteucci, F. and François, P. 1989, *M.N.R.A.S.*, **239**, 885.

agel, B.E.J., Edmunds, M.G., Blackwell, D.E., Chun, M.S., and Smith, G. 1979, *M.N.R.A.S.*, **189**, 95.

earle, L. 1971, *Ap.J.*, **168**, 327.

hields, G.A. and Searle, L. 1978, *Ap.J.*, **222**, 821.

tasińska, G. 1980, *Astr. and Ap.*, **84**, 320.

tasińska, G. 1982, *Astr. and Ap. Supp.*, **48**, 299.

orres-Peimbert, S., Peimbert, M., and Fierro, J. 1989, *Ap.J.*, **345**, 186.

ílchez, J.M. and Pagel, B.E.J. 1988, *M.N.R.A.S.*, **231**, 257.

ílchez, J.M., Pagel, B.E.J., Díaz , A.I., Terlevich, E., and Edmunds, M.G. 1988, *M.N.R.A.S.*, **235**, 633.

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