Revista Mexicana de Astronomía y Astrofísica, **27**, 29-31 (1993)

HIGH METALLICITY GIANT HII REGIONS

Elena Terlevich

Royal Greenwich Observatory, U. K.

RESUMEN

Se discuten las dificultades para derivar abundancias en regiones de HII de alta metalicidad (baja excitación) debido a que en ellas, la linea de [OIII] en λ4363 Å que es sensible a la temperatura, o es muy débil o no está presente. Usando líneas de emisión intensas sobre un amplio rango espectral (de λ3700 a λ9600 Å) se pueden determinar abundancias en dichas regiones gracias a métodos empíricos combinados con modelos de fotoionización.

ABSTRACT

Abundances of high metallicity (low excitation) HII regions are difficult to derive, as the temperature sensitive λ 4363 Å line is very weak or absent in these objects. Empirical methods using strong emission lines covering a wide spectral range (λ 3700 to λ 9600 Å) combined with photoionization models provide reliable abundances for these objects.

Key words: **GALAXIES: ABUNDANCES — GALAXIES: ISM — H II REGIONS**

1. INTRODUCTION

Giant HII regions, which are easily seen on the discs of nearly face-on spiral galaxies, are commonly used for deriving information about the chemical composition of the interstellar medium in external galaxies. Chemical evolution models are constrained by abundance variations of different elements, and the detailed study of element ratios provides tests of nucleosynthesis and stellar evolution theories.

Giant extragalactic HII regions (GEHR) differ from Galactic ones in that they are outstandingly large and ionized by a large cluster of stars. In order to determine if standard photoionization models are adequate, we studied in detail the spatially resolved GEHR NGC 604 in M 33 (Díaz *et al.* 1987) and found that, although the excitation and measured electron temperatures vary across the nebula, neither the abundances of O, N, Ne, S, nor the empirical abundance indicators that use the intensity ratios of strong emission lines, do. These abundance indicators can therefore be used for unresolved more distant GEHR; similar results have been obtained for 30 Dor in LMC (Mathis, Chu & Peterson 1985) and NGC 5471 in M 101 (Skillman 1985).

It is known that HII regions of low excitation (as measured by the ratio [OIII]$\lambda\lambda$ 4959,5007/H_β) have relatively high metal abundance. In these regions, the temperature sensitive lines required for reliable abundance determination ([OIII] λ 4363 Å, [NII] λ 5755 Å) are either very weak or absent. Sample spectra of a high excitation - low metallicity and a low excitation - high metallicity GEHR can be seen in Figure 1 of Terlevich, Terlevich & Franco, this volume.

Abundances of metal rich HII regions are therefore much more difficult to study. Empirical calibration of strong emission line intensity ratios with electron temperatures and abundances can be used (R_{23}=([OII]+[OIII])/H_β from Pagel *et al.* 1979; Alloin *et al.* 1979); the high metallicity end – where T_e is very low, elements other than O contribute to the cooling, and IR lines become important – might need to be calibrated using theoretical models (Edmunds & Pagel 1984; McCall *et al.* 1985; Dopita & Evans 1986; McGaugh 1991).

Vílchez & Pagel (1988) have developed an improved method that requires an extensive spectral coverage (λ 3727-9532 Å) and uses simultaneous fitting of the empirical abundance parameter R_{23} and a parameter characterising the hardness of the ionizing spectrum, $\eta = (O+/O{+}{+})/(S+/S{+}{+})$, to an appropriate grid of theoretical models (e.g., Stasińska 1982). η has the atractive properties of being almost insensitive to the ionizing parameter (u), inversely proportional to the effective temperature T_{eff}, almost independent of reddening, almost independent of electron temperature T_e, and linear with $\eta\prime$=([OII]/[OIII])/([SII]/[SIII]), the observed line ratios. This method has been successfully applied to determine the physical parameters of HII regions in M 33 (Díaz *et al.* 1987; Vílchez *et al.* 1988).

The results of extending this study to low excitation regions in M 51 (Díaz *et al.* 1991) using long slit spectroscopy and photoionization models are summarised in what follows.

2. OBSERVATIONS AND RESULTS

Long slit spectrophotometry of six GEHR in M 51 was performed at the 2.5m INT in La Palma using an Intermediate Dispersion Spectograph with an IPCS detector covering the range λ3600-7500 Å and a CCD detector to cover λ 6200-7500 Å and 8500-9800 Å giving spectral resolutions of 4.7 Å and 5.2 Å and spatial resolutions 0.82 and 0.7 arcsec respectively. [OII], [OIII] and [NII] situate all observed regions of M 51 at the low T_e end of the empirical calibration.

A second indicator related to the ionizing spectrum ($\eta\prime$) was used in conjunction with R_{23} to select an appropriate photoionization model from a grid. GEHR emission line spectra are basically controlled by the shape of the ionizing radiation, u – the density of ionizing photons divided by particle density – and the chemical composition of the gas. In order to determine the effect of these parameters on R_{23} and $\eta\prime$, photoionization models were computed with the 1990 version of Ferland's code CLOUDY. This code, appropriate for studying HII regions of high metallicity, assumes spherical symmetry and uniform density and chemical composition for the nebula. It does not include dust. The code has the advantage though, of allowing the use of relevant values of u; it also includes reasonable estimates of dielectronic recombination coefficients for sulphur, allowing S^{++}/S^{+} to be calculated to accuracies comparable to observational ones.

The empirical callibrator R_{23} depends mainly on the chemical composition of the gas and the T_{eff} of the ionizing stars, being almost independent of u. $\eta\prime$ reflects the shape of the ionizing continuum; it depends strongly on T_{eff}, slightly on u but is independent of Z. So in the plane R_{23}–$\eta\prime$, once u has been determined, one can derive T_{eff} and global metallicity values for the observed regions. u can be determined from S^{+}/S^{++} (Mathis 1985) but equally well from the observed line ratios [SII]λλ6717,6731/[SIII]λλ9069,9532 (Díaz *et al.* 1991). Individual photoionization model fitting for each region provides line ratios, abundances, and temperatures. After this iterative process, we end up knowing T_{eff}, log u and Z and are ready to infer the physical properties of the nebula and its ionizing cluster. Recent evolutionary models for high metallicity giant extragalactic HII regions (García Vargas & Díaz 1993) can now be used in conjunction with the R_{23}–$\eta\prime$ method.

The agreement between our determination of H_α fluxes and those from surface photometry studies (van der Hulst *et al.* 1988) indicates that our spectra are representative of the whole regions and the spectrophotometry can therefore be used to derive the number of photons required to ionize them (NLy). The observed H_β fluxes combined with the low u found and the sizes of the regions, provide particle densities, filling factors and masses of ionized hydrogen. NLy values point to large clusters ionizing the HII regions, and therefore T_{eff} is taken to be the effective temperature of the stars that dominate the ionization. Assuming a particular IMF, one can also estimate lower limits for the mass of the ionizing clusters.

In summary, for the studied regions in M 51, we were able to determine the ionization parameter, the effective temperature of the cluster stars dominating the ionization, and the metallicity. All metallicities found are higher than solar and both ionization parameter and effective temperature are low, extending previously found trends between metallicity and ionization parameter and radiation hardness. The HII regions in M 51 are large (R∼250pc), diffuse ($n_H < 100 cm^{-3}$) and have small filling factors. The estimated mass of ionized hydrogen is around $10^6\,M_\odot$ and the minimum mass of the ionizing star clusters is of the order of $10^4\,M_\odot$. The small equivalent widths of H_β observed suggest contribution from older clusters.

S/O ratios are lower than solar in all the studied regions. If this effect is real and not a model artifact, it implies that the S/O ratio is lower in regions of high metallicity, which should be explained by stellar nucleosynthesis theory and chemical evolution models. N/O ratios are also different from solar in all but one of the regions, increasing with metal content, as expected if part of the nitrogen is of secondary origin.

The combination of spectrophotometric observations over a wide spectral range including the nebular [SIII] lines with adequate photoionization models, proves to be a very powerful tool for determining reliable abundances and physical conditions in low excitation regions.

These results could be improved even further by including nebular density and temperature inhomogeneities as well as dust in the photoionization models.

Acknowledgements: I would like to acknowledge the British and Spanish committees for allocation of telescope time (PATT and CAT) and my colleagues Angeles Díaz, Bernard Pagel, Pepe Vílchez and Mike Edmunds with whom this work has been done. It is also a pleasure to thank the organizers of this meeting and NATO for financial support.

REFERENCES

Alloin, D., Collin-Souffrin, S., Joly, M., & Vigroux, R. 1979, A&A, 78, 200
Díaz , A.I., Terlevich, E., Pagel, B., Vílchez, J.M., & Edmunds, M.G. 1987, MNRAS, 226, 19
Díaz , A.I., Terlevich, E., Pagel, B., Vílchez, J.M., & Edmunds, M.G. 1990, RMAA, 21, 223
Díaz , A.I., Terlevich, E., Vílchez, J. M., Pagel, B., & Edmunds, M.G. 1991, MNRAS, 253, 245
Dopita, M.A., & Evans, I.N. 1986, ApJ, 307, 431
Edmunds, M.G., & Pagel, B. 1984, MNRAS, 211, 107
García Vargas, M.L. & Díaz, A.I. 1993, ApJ, submitted
Mathis, J.S. 1985, ApJ, 291, 247
McCall, M.L., Rybski, P.M., & Shields, G.A. 1985, ApJS, 57, 1
McGaugh, S.S. 1991, ApJ, 380, 140
Pagel, B., Edmunds, M.G., Blackwell, D.E., Chun, M.S., & Smith, G. 1979, MNRAS, 189, 95
Stasińska, G. 1982, A&A, 48, 299
van der Hulst, J.M., Kennicutt, R.C., Crane, P.C., & Rots, A.H. 1988, A&A, 195, 38
Vílchez, J.M. & Pagel, B. 1988, MNRAS, 231, 257
Vílchez, J.M., Pagel, B., Díaz, A.I., Terlevich, E., & Edmunds, M.G. 1988, MNRAS, 235, 633

Elena Terlevich: Royal Greenwich Observatory, Madingley Road, Cambridge CB3 0EZ, U.K.