UV OBSERVATIONS OF GIANT EXTRAGALACTIC H II REGIONS

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UV observations of extragalactic H II regions were pioniered by the ANS Satellite which collected spectra of 30 Dor in the LMC (Koorneef 1977, 1978, Israel & Koorneef 1979), of NGC 604 in M 33 (Israel et al. 1982) and of the brightest regions in M 101 (Blitz et al. 1981). It was however the International Ultraviolet Explorer, IUE, which allowed to extend the UV spectroscopic observations to a larger number of giant H II complexes with a combination of spectral and spatial resolution and sensitivity not available before. It should be noted that IUE, together with the data on the extragalactic H II regions, has provided a wealth of UV spectra of all class of astrophysical objects. These archive data are easily accessible and being all processed and calibrated in the same way, represent a unique tool for the interpretation of a composite spectrum such as the one obtained from extragalactic H II regions. For this reason the present review mainly deals with new IUE data.

Before attempting any interpretation of the UV (IUE) spectra of giant H II complexes it is important to establish how much the different sources of light (stars, scattered starlight, nebular emission) contribute to the total observed spectrum, and how this contribution can change with the distance of the object. We note, as a term of reference, that the dimensions of the IUE large slit, 10x20 arcsec, correspond to 2.5x5 pc at the distance of the LMC, 35x70 pc at M 33, 350x700 pc at M 101 and 2.4x4.8 Kpc at the distance of the clumpy irregular galaxy Markarian 325. A proper match with the dimensions of a giant H II region is therefore obtained for distances between 5 and 10 Mpc. For closer objects the IUE observations usually refer to the brightest part of the region, where there is the highest concentration of stars. Hence it may be expected that the ratio between starlight and scattered/nebular light varies with the distance.

Koorneef and Mathis (1981) observed 30 Dor at 11 adjacent positions centered around the object R136. They note that the certainly stellar emission of He II at 1640 Å, characteristic of WR stars, is strong in the central spectrum but very weak or absent in the next two positions, where R136 is not within the slit. They also compared the spectra of R136

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obtained through the small and large slit of IUE, finding the expected ratio for a point-like source and no significant spectral variations. The authors conclude that scattered light is unimportant in their observations. Lequeux et al. (1981), using the results of Perinotto & Patriarchi (1980) on the Orion nebula, obtained an upper limit for the total scattered light contribution as 18% of the exciting stellar radiation. The authors preferred however not to apply this result to their UV observations of extragalactic H II regions. We can conclude that a precise evaluation of the scattered light is still a serious difficulty because of geometrical and internal absorption effects. An improvement of the situation will be provided by extrapolating the detailed studies on the dust scattering properties in the UV range which are now becoming available for galactic objects (see e.g. Mathis et al. 1981).

The continuum nebular contribution is more easily evaluated: in the short wavelength IUE range (1200-2000 Å) it is essentially due to the Hydrogen two photon emission which has been detected in the spectrum of SNRs (Benvenuti et al. 1980), of planetary nebulae (e.g. Benvenuti and Perinotto 1980) and recently in the spectra of Type II SNe (Benvenuti et al. 1982). In all cases the signature of the two photon spectral distribution is present, while it is not detected in any of the H II regions short wavelength spectra. In the same spectral range Perinotto & Patriarchi (1980) show that the nebular emission in Orion is negligible with respect to the scattered light: using this result, Lequeux et al. (1981) computed an upper limit of 4% of the far UV flux from atomic emission in the region CM 39 in NGC 4449. The nebular emission becomes more important at long wavelength: Rosa (1980) estimates a maximum contribution of 50% at 3200 Å for NGC 5471 in M 101 and only 10% for NGC 604 in M 33 due to geometrical reasons. Line emission, usually limited to CIII] 1909 Å, is present in some objects, e.g. NGC 5471. Geometrical effects, as well as dust scattering, can again play a role in the line strength. From the above discussion we can assume, as a working hypothesis, that the observed spectrum is mainly that of the ionizing star cluster.

The determination of the extinction affecting the spectrum of extragalactic H II regions is of paramount importance in the UV range because the steepness of the reddening curve can heavily modify the slope of the stellar continuum leading to large errors in its interpretation. The extinction in the UV has been recently analysed by Israel and Koorneef (1979) in the case of 30 Dor and by Lequeux et al (1981) who presented a detailed discussion of the problem. Briefly summarizing the situation we recall that the observable quantities we can use to determine the extiction are: i) The Balmer decrement: the extinction coefficient $C_B(H_\beta)$ is obtained by comparison of the observed Balmer decrement with the theoretical value. ii) The radio flux: if it is purely thermal, a relation exists between optical (H_α or H_β) and the radio fluxes (see e.g. Lequeux 1980), and an extinction coefficient $C_R(H_\beta)$ can be obtained. A well known problem is that for most of the extragalactic H II regions $C_R > C_B$. A plausible explanation is that the optical emission arises preferently at low optical depths, therefore can easily underestimate the total internal extinction. The extinction affecting the extragalactic H II regions can be schematically divided into: i) extinction in our Galaxy: in principle it can be evaluated from galactic observations towards the same direction. ii) Extinction in the parent galaxy, external to the region: this can be highly non uniform, e.g. due to the presence of molecular clouds; moreover the appropriate reddening law is not known 'a priori'. iii) Internal extinction: it is the most difficult to evaluate since it depends both on the dust albedo and on the geometrical and physical distribution of stars, gas and dust within the region.

A glance through the IUE observation Log shows that a large fraction of the extragalactic H II regions which are bright enough to be accessible in less than 8 hours exposure have already been observed (about 40 objects for a total of ~ 150 spectra). In spite of this large amount of data only few papers have been published. The core of 30 Dor was observed, as already mentioned, by Koorneef and Mathis (1981): in all the spectra they analysed,the source of radiation is direct starlight, heavily reddened with A(1550) ~ 3 mag. They derive a reddening curve which lays between the galactic and the LMC law. Rosa (1980) discussed the spectra of NGC 604 and NGC 5471 showing that the continuum distribution and the absorption features are characteristic of luminous early type stars. He also discuss the extinction and the composition of the ionizing cluster. An extensive discussion of NGC 604, including observational data over six decades in frequency is presented by Israel et al. (1982). In this case the UV data come from the ANS satellite. The largest H II regions in M 101 were discussed by Blitz et al. (1981) using millimeter, IR and UV data, the latter from ANS. They note that the 2200 Å feature is generally attenuated in these objects. Meier & Terlevich (1981) observed three galaxies rich in H II regions and with a redshift high enough to separate the intrinsic Ly$_\alpha$ emission from the geocoronal one. They discuss the observed weakness or absence of the Ly$_\alpha$ emission suggesting an inverse correlation of UV features with the metal abundance. Lequeux et al. (1981) discuss the UV observations of a number of extragalactic H II regions, comparing them to the prediction of an evolutionary model of the ionizing cluster. Their main conclusions are: the massive star formation proceeds as large, very short bursts, on which assumption the age of the cluster can be estimated from the Lyman continuum and far UV flux (typical ages are 1-5 $*10^6$ y). The IMF is poorly determined. The slope of the far UV is heavily affected by the extinction with a reddening law which is varying from object to object. Benvenuti et al. (1979,1982) presented observations of four clumpy irregular Markarian galaxies. These objects are characterised by the presence of large, bright H II complexes. Their UV spectra show a continuum amd spectral features of luminous early type stars. The UV luminosity of a typical clump is estimated about 100 times that of 30 Dor although its dimensions are not much larger.

The main characteristics of the observed spectra may be summarised as follows:

1) All spectra show stellar continua and spectral features typical of luminous early type stars.
2) The nebular emission, practically limited to CIII] is detected only in few objects and its intensity agrees with the H$_\beta$ flux.

3) The slope of the continuum is heavily affected by the interstellar absorption with a wavelength dependance which seems to vary from object to object and may be correlated with the chemical abundance.
4) Some objects, in particular the supergiant H II regions of the clumpy Markarian galaxies, show an extremely high UV luminosity concentrated in a limited space, indicating the presence of an exceptional star burst.
5) Many spectra, if not all, show the characteristic signature of the the WR stars.

In order to verify part of the above conclusions I tried to fit an IUE spectrum of an H II region with a synthetic spectrum, mixing spectra of standard stars retrieved from the IUE Archive. A similar exercise was already attempted for Markarian 325 with promising results: in this case I selected NGC 604 because its spectrum has the best S/N among the observed objects. The result of the fit, see Fig. 1, shows that not only the continuum can be satisfactorily fitted but also the stellar absorption features, both the strong and faint ones, can be reproduced.

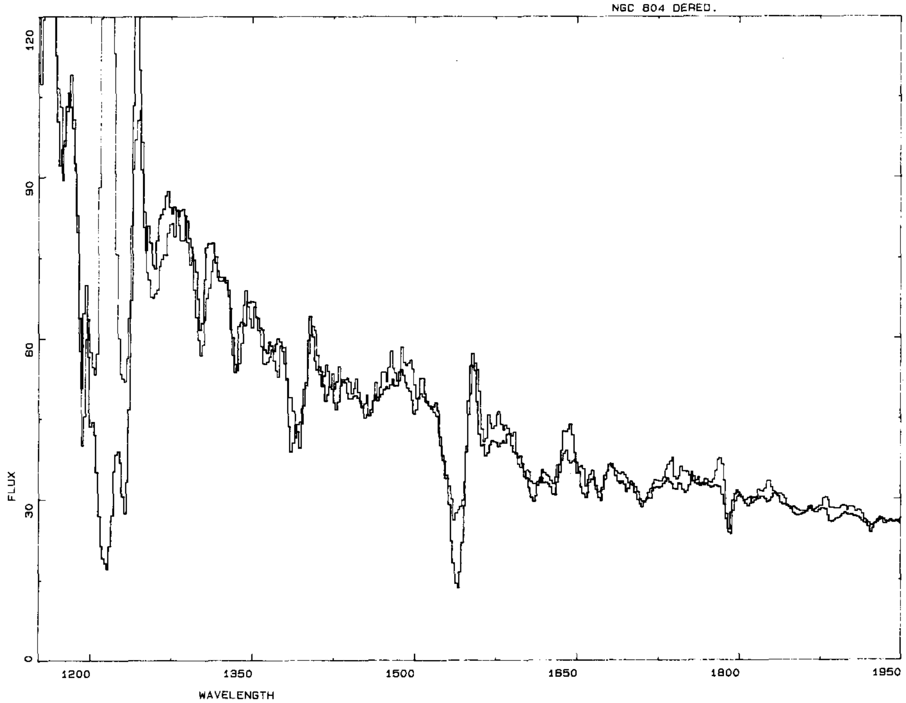

Fig. 1 - A synthetic fit of NGC 604

The fit is particularly good in the case of P-Cygni profiles of NV, SiIV and CIV, although in the latter the bottom of the absorption seems filled. Also the He II 1640 Å emission, typical of WR stars is reproduced, although overestimated. Prior to the fit,the spectrum was dereddened for galactic extinction (E(B-V)=0.03). It was found that, when the matching of the stellar absorption features was satisfactory, the far UV continuum was overestimated by the fit. Interpreting this as due to extinction in M 33, the shape of the relevant reddening law can be derived. The curve appeared to lay, in the far UV, between the galactic and the LMC curves, in agreement with the indipendent result of Lequeux et al. (1981). After a further dereddening for the external extinction with a color excess E(B-V)=0.06, the fit provided the number and type of stars as follows: 3 WN4, 16 O6V, 22 O8V, 15 O9.5V, 12 B5Ia (spectral types were mainly selected on the basis of the availability of good IUE spectra). The number of ionizing photons coming from this mixture is consistent, once geometrical factors are taken into account, with previous estimates (e.g. Israel et al. 1975). When a UV stellar classification will be established on the basis of the IUE Archive, the above method could provide useful information on the IMF of the observed star clusters.

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