

We have observed ϵ Cr A at the ESO 1 m telescope during the nights of July 2/3 and 3/4, 1982. The period of the system is $14^h.1942336$ and we have a large part of a complete cycle (a 12 hours run centred on the meridian transit). The In Sb photometer was used with a K-band filter ($2.2 \mu\text{m}$) and γ Cr A was used as a comparison star. The light curve obtained during the first night (of better photometric quality than the second one) is shown in fig. 1, where 140 individual observations are reported. The observed minimum is later than the computed one ($O-C = 0.07$) when Tapia's elements are used. Since his observations, about 9,200 cycles have elapsed. The derived ($O-C$) could also be explained by a slight difference ($0^s.7$) on the period:

$$P = 0^d.5914345 \text{ instead of } 0^d.5914264.$$

A light curve was obtained during the second night but it is very difficult, from two observed minima, to determine a precise value of the period. We don't observe a complete eclipse at the secondary minimum, but this fact could be explained by a sky transparency fluctuation which unfortunately occurred during

the secondary minimum (the expected minimum is shown in figure 1 as a dashed line).

The above results emphasize the need of a more complete and accurate monitoring of this bright and interesting system.

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Search for Wolf-Rayet, Carbon and M Stars in External Galaxies with the GRISM/GRENS Technique

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Introduction

Surveying in extended field objects which are recognizable only by their spectral features would be an almost impossible task without instruments having *simultaneously* a wide field and some spectral discrimination capabilities. Monochromatic imaging with colour or interference filters offers such a means, which has been widely used for searching for HII regions and planetary nebulae in the Galaxy and in external galaxies. An alternative method is to use objective prisms or transmission gratings which supply for each object in the field of the telescope a spectrum, usually recorded on a photographic plate. However, the difficulties involved in manufacturing very large gratings or prisms, limit this method to telescope diameters of about 1 metre, the approximate size of the largest existing Schmidt telescopes. Fortunately, there is a variant of this set-up adapted to larger telescopes, in which a prism, or a grating, or a combination of both is inserted in the converging lightbeam at a short distance of the focal plane. These devices, usually fitted on the prime focus adapter, are called GRISMs or GRENSes. A GRISM combines a transmission grating and a prism with opposed dispersion to compensate the aberrations (coma, astigmatism and field curvature) produced by the grating in the convergent beam, and is associated with a wide-field corrector. A GRENS has a grating grooved on one face of the last lens of a wide field corrector, and also has minimal aberrations. Both are blazed such that most of the light is concentrated in the first order. The GRISM technique has already been widely used to search for quasars through their emission lines, mainly at the Cerro Tololo Inter-American Observatory (Hoag and Smith, 1977, *Astrophysical Journal* **217**, 362; Osmer, 1982, *Astrophys. J.* **253**, 28), and at La Silla for the detection of carbon and M stars in nearby galaxies (Westerlund, *The Messenger* No. 19, December 1979, p. 7).

From a preliminary study of the statistics of Wolf-Rayet (WR) stars, M supergiants and blue massive stars in our Galaxy at different distances from the centre, and in the Magellanic

Clouds where systematic WR surveys have been made most recently by Azzopardi and Breysacher (1979, *Astronomy and Astrophysics*, **75**, 120, 243; 1980, *Astron. Astrophys. Suppl.* **39**, 19), Maeder, Lequeux and Azzopardi (1980, *Astron. Astrophys.* **90**, L 17) concluded that the WR/M number ratio decreases very fast with decreasing heavy element abundance, while the ratio $(WR + M)/(\text{blue massive stars})$ remains roughly constant. This can be explained in the following way: amongst the various scenarios which can lead to the formation of WR stars, one seems dominant for stars of initial masses $20-60 M_{\odot}$ (Maeder, 1982, *Astron. Astrophys.*, **105**, 149). These stars, after having exhausted hydrogen in their cores, move to the right of the Hertzsprung-Russell diagram and become red supergiants. In the absence of mass loss they would stay there until they explode as supernovae. However, mass loss at the different stages of their evolution may be such that the hydrogen envelope disappears completely at some stage, having a star whose surface is mainly composed of helium, with a lot of ^{14}N produced by the previous CNO cycle: the star has become a Wolf-Rayet of the WN type. Further mass loss may peel of the star still deeper until the carbon fabricated by the $3\ ^4\text{He} \rightarrow\ ^{12}\text{C}$ reaction appears at the surface: the star is now a WC. The star may end its life as a supernova at any of these stages (the evolution of the core is independent from what happens to the outer parts of the star). If the mass loss at *any* stage is large, the star has a good chance of reaching the WR stage before exploding and will not stay long as a M supergiant. The most massive stars will even by-pass the M supergiant stage. Since mass loss is likely to increase with metallicity, we expect more WR stars and less M supergiants at high metallicities, just as observed. The ratio $(WR + M)/(\text{blue massive stars})$ is roughly equal to the ratio of the duration of the helium burning phase to that of the hydrogen burning phase and does not depend on mass loss in a first approximation, as observed.

Stimulated by the agreement between theoretical ideas and observations, a collaboration was set up between Marc

Azzopardi (Marseille), André Maeder (Genève), Bengt Westerlund (Uppsala) and us in order to survey other galaxies for WR stars; we use the GRISM/GRENS technique applied to the detection of the WR typical strong emission features from either C III at 4650 Å (WC) or He II at 4686 Å (WN). We soon realized that this spectral range is also very favourable for detecting carbon stars and M stars, and we are also searching for these objects, extending previous searches with the red ESO GRISM.

The GRISM/GRENS Technique

As said above, one could think of two different techniques to search for WR stars. The first one was used with success as early as 1972 for searching for WR stars in the nearby galaxy M 33 (Wray and Corso, 1972, *Astrophys. J.* **172**, 577). It consists in blinking two plates, one taken through an interference filter centred on a relatively line-free region and one taken through a narrow filter whose bandpass includes the strong λ 4686 and λ 4650 emission lines. This technique is presently used by Shara and Moffat (1982, IAU Symp. No. 99, 531) and by Massey and Conti (1983, *Astrophys. J.*, in press). In principle it has the advantage of being less sensitive to crowding, background and seeing than the second method, the GRISM/GRENS method. However, our experience shows that, using a limited spectral range of about 1000 Å, the first two problems are very minor, while the sensitivity of both methods is comparable. As an important bonus the GRISM/GRENS technique allows us to detect other objects than WR stars: carbon and M stars show up via their absorption bands and small H II regions and planetary nebulae are seen through the emission of H β and of [O III] at 4959 and 5007 Å.

At ESO, we have used a blue GRISM mounted on the triplet corrector at the prime focus of the 3.6 m telescope; this set-up has the following characteristics: field of view: 1 degree; blaze wavelength: 4900 Å; dispersion: 2200 Å/mm; grooves: 35/mm; spectral range: 4400–5400 Å, limited by a GG 435 filter and the response of the IIIa-J emulsion.

As shown by fig. 1 the efficiency in the first order is excellent in our wavelength range. On the plates, the zero order image appears as a dot for bright stars only and gives no trouble in practice. The transmission curve for the GRISM was established using the universal spectrophotometer of the optical laboratory at ESO Garching. We also used the green GRENS at the prime focus of the CFH telescope, which has almost identical characteristics. The limiting magnitude for detection of the continuum is about 20 in a 1-hour exposure with average-to-good seeing. Some WR star candidates with a fainter continuum appear as isolated dots if only the line emission is above the plate threshold; they have to be confirmed by further spectroscopic observations.

Wolf-Rayet and Carbon Stars in the Magellanic Clouds

We have obtained GRISM plates of two fields in the LMC and most of the SMC with the 3.6 m ESO telescope, with various exposure times. The aim was to test the method, but also to check to what extent the previous surveys of WR stars made by objective-prism techniques are complete. We have so far not discovered any new WR stars down to magnitudes 19–20, confirming the completeness of these surveys, at least in the regions explored. This is at variance with the suggestion by Massey and Conti (1983, *Astrophys. J.* 264, 126) that in the Magellanic Clouds not all of the WR stars with $M_V > -2$ have been detected (we except from this discussion the much fainter WR “objects” which are nuclei of planetary nebulae). This

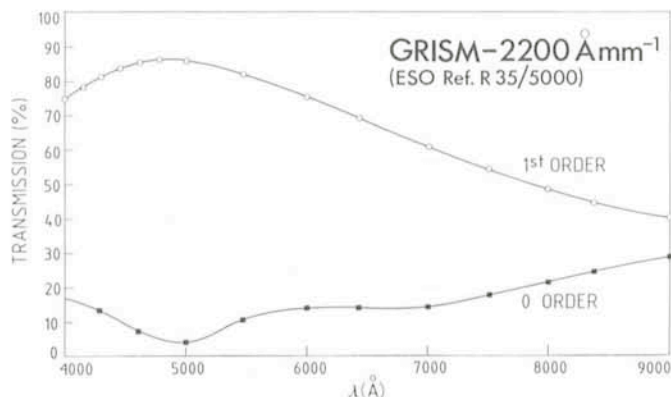


Fig. 1: Curves showing the efficiency as a function of λ of the blue GRISM used with the triplet corrector at the prime focus of the ESO 3.6 m telescope.

makes us confident that we can eventually obtain complete samples of WR stars in more distant galaxies.

As a bonus of the technique, we have detected a large number of planetary nebulae, M stars and carbon stars. Identification of these objects with those catalogued previously is under way, but is time-consuming because of their large number: we estimate that we have something like 200–300 carbon stars per square degree in the central parts of the SMC!

Wolf-Rayet Stars in NGC 6822 and IC 1613

We have now ESO GRISM plates and CFH GRENS plates of several galaxies of the Local Group and of the Sculptor Group. Many emission-line candidates can be seen on those plates, but they can be either WR stars characterized by the λ 4650 C III or the λ 4686 He II emissions, or H II regions (or planetary nebulae) emitting mainly around 5007 Å. It is not possible to distinguish between these objects when the continuum is invisible: further spectroscopy is necessary, in any way also for classifying the WR stars. We obtained time at the ESO 3.6 m telescope with the IDS to carry out spectroscopy of the most promising candidates. Unfortunately the weather was not on our side and only a limited number of observations could be made. The WR nature of one star in the dwarf irregular galaxy NGC 6822 could nevertheless be confirmed (fig. 2). This is a 19.5 mag star in an association and a weak H II region, and it is classified WN3 (Westerlund, Azzopardi, Breysacher and Lequeux, 1983, *Astron. Astrophys.*, in press). Its absolute magnitude is $M_V \sim -4.6$, which agrees well with the values found for WN3 stars in the LMC. There is another promising WR candidate on our GRISM survey plate. From what we know of the stellar content and the metallicity of NGC 6822, we can predict the existence of 1 or 2 WR stars in this galaxy. Therefore, the agreement is satisfactory within the limits of the small-number statistics.

We have also good CFH GRENS plates of the dwarf irregular IC 1613, another nearby member of the Local Group. A cursory examination shows no other candidate than the peculiar WR star of $M_B \geq -5$ (fig. 3) discovered by D’Odorico and Rosa (1982, *Astron. Astrophys.* **105**, 410). This is not unexpected since we predict (statistically) 0.7 WR in this galaxy! However, our plates show the presence of many carbon stars which deserve further study.

Carbon Stars in the Fornax Dwarf Elliptical Galaxy

The presence of carbon stars in this galaxy is well established by a number of recent studies (see Westerlund, *The Messenger* No. 19, December 1979, p. 7; Richer and Wester-

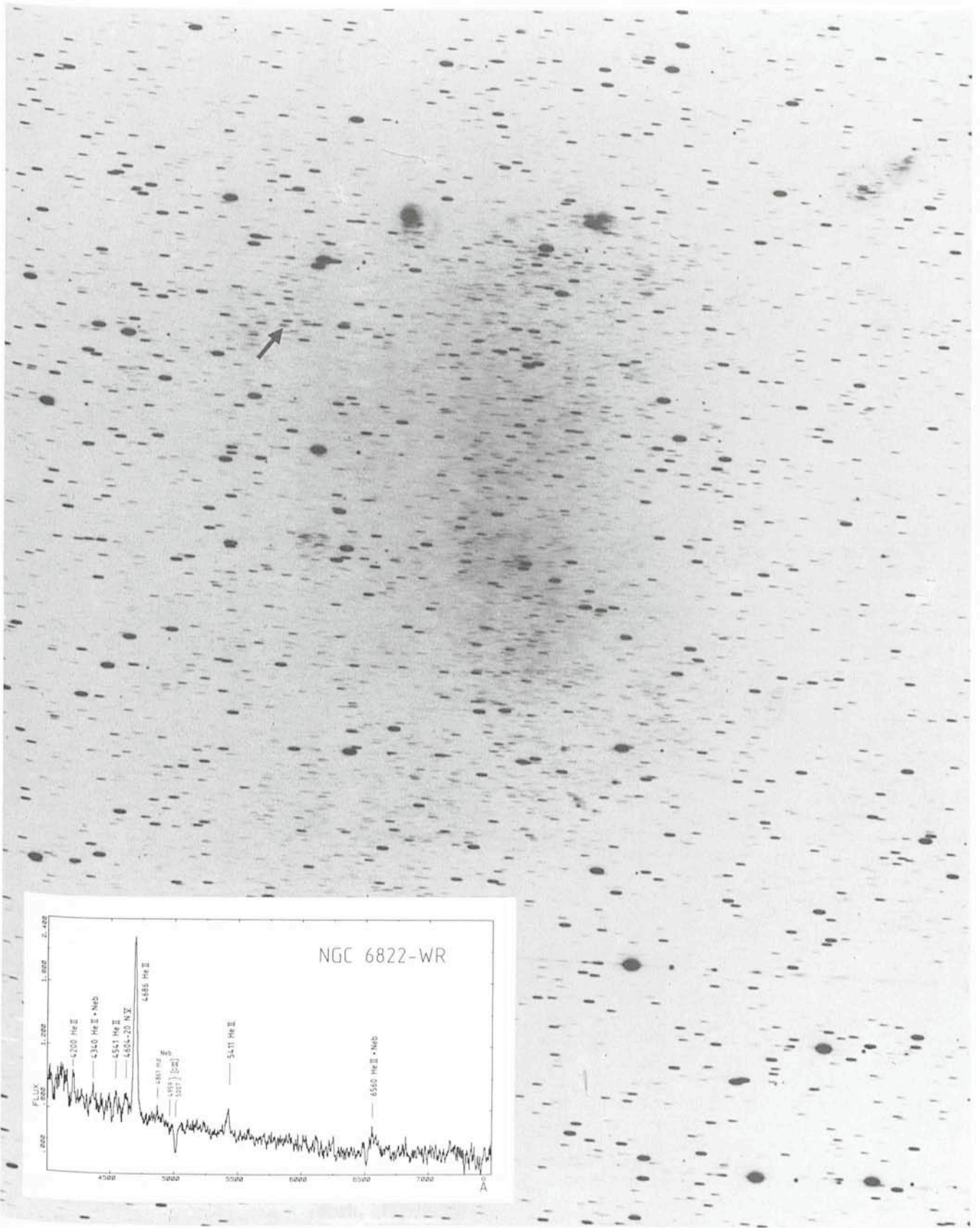


Fig. 2: A 90-min. exposure of the galaxy NGC 6822 obtained with the blue ESO GRISM at the prime focus of the 3.6 m telescope. The first WR star discovered in this galaxy is indicated by an arrow. The spectral type derived from the IDS spectrum is WN3.

lund, 1983, *Astrophys. J.* **264**, 114). The very presence of carbon stars whose progenitors are relatively massive and thus cannot be very old, shows that the Fornax galaxy, in spite of being presently completely deprived of interstellar gas, has

managed to form stars only a few thousand million years ago. Carbon stars appear more readily in galaxies of low metallicity, simply because carbon dredge-up episodes during the evolution on the asymptotic branch raise more easily the C/O ratio

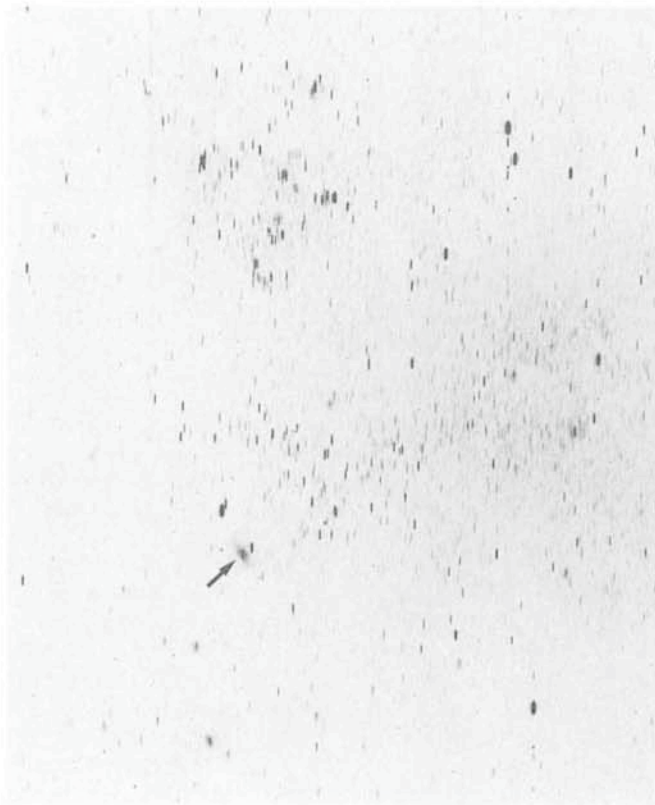


Fig. 3: CFHT green GRENS photograph of the eastern part of IC 1613. The spectrum indicated by an arrow corresponds to the peculiar WR star discovered in this galaxy by D'Odorico and Rosa (1982).

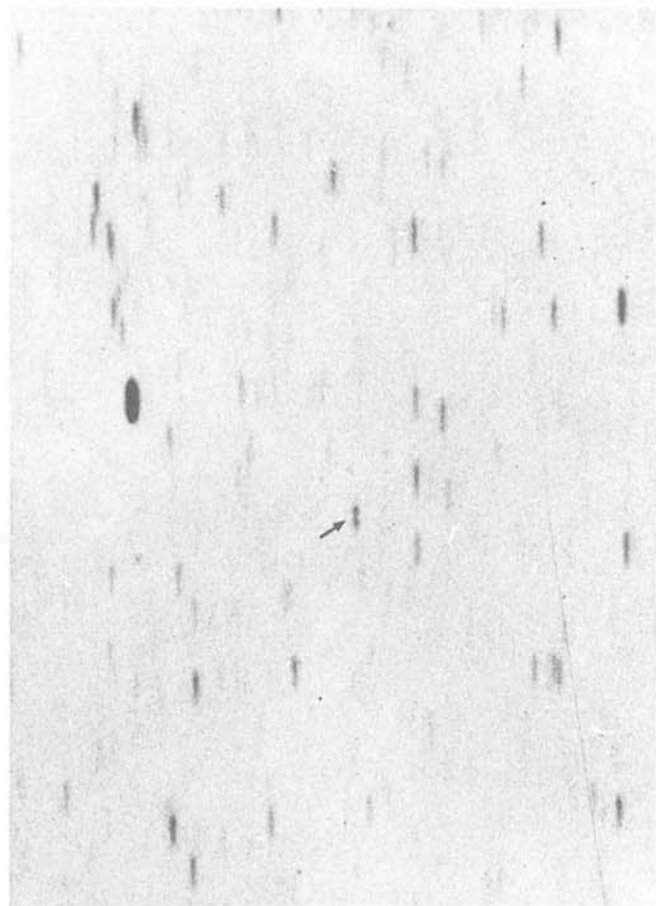


Fig. 4: Part of a CFHT green GRENS plate of the Fornax dwarf elliptical galaxy. The spectrum marked with an arrow corresponds to a newly identified carbon star. Previously known as DK 36 this star has $V = 18.40$ and $B-V = 2.09$ (Demers and Kunkel, 1979, PASP **91**, 761).

above unity (the definition of a carbon star) when the oxygen abundance is low; the large number of carbon stars we find in the Fornax galaxy shows that its metallicity must have been rather low at the time of their formation. As discussed by Iben and Renzini (1983, *Ann. Rev. Astron. Astrophys.*, in press) everything is very far from clear in our detailed understanding of the evolution of carbon stars: this is one further reason to study them in as many galaxies as possible. Using the red ESO GRISM, Richer and Westerlund (1983, *Astrophys. J.* **264**, 114) were able to raise the number of known carbon stars in the Fornax galaxy to 49 and estimate their total number as about 65; they also discovered 1 new carbon star in the Sculptor dwarf elliptical galaxy which is now known to contain 3 such stars. In Fornax, Westerlund also found a rare S star – the intermediate class between M and C stars (Westerlund, 1983, *Astron. Astrophys.* **118**, L5).

We obtained a 1-hour green GRENS plate of the Fornax dwarf elliptical galaxy at the CFH telescope. This plate shows an incredible number of objects with absorption bands, of the order of 300. Most of them appear to be carbon stars (fig. 4), thus the actual number of the latter objects is probably far above the predictions by Richer and Westerlund. It may be that our IIIa-J plates allow the detection of a hotter type of carbon star than identified on the near-infrared plates. This looks very exciting, but must be confirmed by further GRISM/GRENS and spectroscopic observations.

Towards More Distant Galaxies

Finding WR and carbon stars in more distant galaxies becomes increasingly more difficult. Prime targets are M 33 and various galaxies of the Local Group and of the Sculptor Group. We are presently looking hard at those galaxies.

On a 1-hour CFHT plate of M 33 we see about the same number of emission-line objects as described by Massey and Conti (1983, *Astrophys. J.*, in press) who used the filter technique – but not quite the same objects: this illustrates that the two techniques are more complementary than competing. However, both groups are probably still far from having detected the 200 or so WR stars that we predict to exist in M 33. M 31, in which 17 WR stars have been found by Shara and Moffat (1983, *Astrophys. J.*, in press) is even more difficult because this galaxy is seen more edge-on and has more internal extinction than M 33.

The GRISM plates obtained at the ESO 3.6 metre telescope for the galaxies NGC 55 and NGC 300 of the Sculptor Group have revealed 115 emission-line objects for which slit spectroscopy is now under way. Concerning NGC 300, a recent spectroscopic survey of continuum emission from 16 giant HII regions, by D'Odorico, Rosa and Wampler (ESO preprint No. 243, April 1983), resulted in the detection of WR stars in two regions. WR features were also identified in the spectra of 2 HII regions out of the 6 surveyed in NGC 5457.

Complete sampling of WR stars in more distant galaxies would be beyond the possibilities of the techniques we use presently. However, bigger telescopes and/or more sophisticated detectors could enlarge the range of such searches in a not-too-distant future.

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