Discussion

Generally, one believes that clusters of galaxies do not rotate. Dressler, for example, found no rotation for the very elongated cluster Abell 2029. This is analogous to the case of the elliptical galaxies which rotate, if at all, only very slowly though they are elongated. The gravitational force of the mass of the member galaxies is balanced by their kinetic energy – the velocity dispersion. The motion of the galaxies is not typically in circular orbits. Nevertheless, the asperical shape can be maintained by an anisotropic distribution of the velocities as has been shown, for instance, by Binney.

One should keep in mind, however, that Gregory and Tifft thought they had detected some rotation for the Coma cluster which is also elongated. But these authors were careful not to exclude an anisotropic expansion.

Generally one can say that there is always a residual angular momentum for any isolated bound object in the universe. Therefore, the elongated shape of the inner part of the cluster may be caused indeed by rotation, the outer isopleths appearing distorted only because of the noise in the galaxy counts. And the dominant galaxy number 18 is not at the dynamical centre but it is roughly where one would expect it to be from the rotation curve. Also the radial velocity of the second most prominent galaxy number 8 is approximately predicted by the rotation curve.

The two massive galaxies number 8 and number 18 are not likely the centres of two clusters being projected onto each other because the line connecting them is far away of being perpendicular to the proposed line separating high velocity galaxies from low velocity ones.

Conclusion

We have probably detected a rotating cluster of galaxies though we cannot exclude that we just observe two clusters partially overlapping. To decide on the correct answer, we have to collect much more information. We should try to determine the luminosity functions of the two possible clusters given by the low and high velocity parts and see if they are shifted, or we should try to look for different contents of types. But this is an ambitious programme.

We (Ulrich Hopp took part in this investigation) would not have been able to pursue this programme without the support by ESO. It is not only the telescope time which counts but also the possibility to reduce observations in Garching or do plate measurements there.

Wolf-Rayet Stars in "Lazy" Galaxies

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We are all very familiar with the concept of "active galaxies" but have you ever heard about "lazy galaxies"? We shall stress that they are the ones which have been recognized as a class by Sargent and Searle (1970: *Astrophysical Journal,* **162,** 455) under the generic name of "extragalactic" H II regions. They are dwarf objects, compact on photographic atlasses such as the Palomar Sky Survey or the ESO Quick Blue Survey. They have low masses but, strikingly, they are blue and their spectra resemble those of Giant H II regions. Therefore, one of us (DK) in his Ph. D., regarding as most probable the current view that these galaxies now experience star formation after a long period of quiescence, suggested they might be regarded as "lazy". Indeed, on average they have not done much: little stellar nucleosynthesis, thus showing marked deficiencies in heavy elements, and containing large quantities of unprocessed neutral hydrogen.

Since their discovery, these unevolved objects have been very much studied. They are especially important for galactic evolution models and in various occasions were chosen for their low metallicities to study the primordial helium abundance. Along these studies—spectroscopic for most of them—a few galaxies have shown the presence of a very large number of Wolf-Rayet stars!

A Huge Number of Wolf-Rayet Stars?

André Maeder has emphasized that WR stars are "much more than a mere curiosity in the zoological garden of spectral peculiarities" (ESO Workshop: The Most Massive Stars, 1981, p. 173) and pointed out a few facts contributing to make their study a fascinating one: they power giant H II regions with large mass losses, may be useful indicators of metallicities in galaxies, contribute to eject processed material into the interstellar medium and are supernova progenitors.

In our Galaxy, WR stars have been discovered individually in young clusters and stellar associations and their number—relative to that of the blue supergiants—is small. Should one not find them in lazy galaxies with active sites of star formation? Of course, one cannot expect to detect individual WR stars in such distant galaxies but one can detect the strongest broad emission lines formed in their atmospheres, for instance the He II 4686 Å emission.

In most of the past spectroscopic observations of giant H II regions and emission line galaxies, WR stars have been overlooked merely because observers have focussed on the intensities of the nebular emission lines for abundance determinations in the gas. As a result, very few cases were found. The broad emission waveband 4600–4700 Å around the He II line remained unnoticed until its first discovery in the emission line galaxy He 2–10 by Allen et al. (1976: *Monthly Notices of the Royal Astronomical Society,* **177,** 91). Since then, spectra of several clusters in H II regions in external galaxies have also been found to exhibit the same WR features (e.g. in NGC 604 and 30 Dor) but only a few lazy galaxies are known to share these properties: Tololo 3, Mkn 750 and other peculiar galaxies such as Mkn 309, NGC 6764 and Tololo 89.

All these observations led to one surprising fact: WR stars largely outnumber the blue supergiants in number in both giant H II regions and lazy galaxies! This can be understood if one picks out objects during a very evolutionary point at which most of the massive stars in the range 25–60 $M_\odot$ have entered a post-red-supergiant stage on which they exhibit WR activity in their He-burning phase. Another way of explaining the data requires that the observed broad-band emission is due to a very small number of WR stars more massive than 60 $M_\odot$

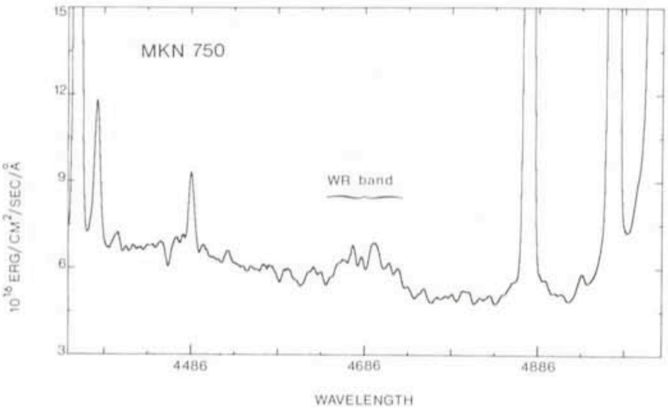

Fig. 1: *Section of the spectrum of Mkn 750 taken with the ESO 3.6 m telescope and showing the WR band.*

losing mass while still on the main sequence. These very massive stars would be largely responsible for the ionization of the nebulae. This shows why giant H II regions and emission line galaxies are ideal sites to test stellar evolution models of massive stars in various conditions of heavy element content and to study the initial mass function in present high rate star formation systems.

Kunth and Sargent (1983: *Ap. J.* **273,** 81) for studying the helium abundance in low heavy element extragalactic systems have been searching for galaxies with hot interstellar gas. During their search, they have accumulated a hundred spectra of these lazy galaxies as well as more luminous and more abundant ones. At this stage we have decided to reanalyse their spectra and see whether any galaxy with milder WR emission had been overlooked. Why do some show these features but not others? Would selection effects be present? In addition to the running observing programme undertaken at La Silla with the 1.5 m and the 3.6 m telescopes equipped with the IDS, we have begun to elaborate a strategy for a deep search of WR emission in relatively distant objects. This study involves a sample with a wider range of metallicity than for H II regions in a single late-type galaxy.

Observations and Analysis

The sample is composed of three sets of independent observations: one is formed by blue compact Zwicky galaxies observed with the SIT spectrograph at the Palomar 200 inch telescope; a second set is composed of lazy galaxies observed with the Varo-Reticon detector at the Cassegrain focus of the Las Campanas 2.5 m telescope, and the third with the IDS on the 1.5 and 3.6 m telescopes at La Silla. Dispersions used were in the range 114 to 240 Å/mm. The reduction procedure is not unusual and is described in our previous papers on similar objects. Since most of the WR lines occur in the He II 4686 Å region, we have measured the WR emission excess WRE above the continuum in the rest wavelength range 4600–4700 Å with allowance for the different instrumental resolutions and assuming a typical WR line of FWHM of 2,000 km/sec. This emission integrated over this wavelength range has been measured above the continuum, together with an estimate of the signal-to-noise ratio of the underlying continuum. About 50 galaxies have been reanalysed so far. As a first guess, we have considered as significant, excesses larger than about 0.8 σ over the adjacent background. This lower limit, although arbitrary at this stage of the discussion, turned to finally provide a workable sample for discussing selection biasses and a strategy for future observations.

Finally, WR stars have been positively detected in 3 galaxies and are suspected in 16 others at 1 σ over the underlying background. A tracing of a typical broad-band WR emission in the spectrum of Mkn 750 is shown in Fig. 1.

What About the Characteristics of Our Sample?

The redshift distributions among the various sets of observations are different, as the Palomar subset picked out fainter and therefore more distant objects than the Las Campanas/La Silla subset. The overall sample covers a range in redshift from z = 0.002 to 0.024 with scarce objects up to z = 0.05. Fig. 2 displays the redshift distribution of our sample of galaxies together with the corresponding histograms of the galaxies in which WR stars are suspected to be present or absent! A statistical test reveals a clear tendency for WR stars to be more easily detectable in nearby galaxies with redshifts not greater

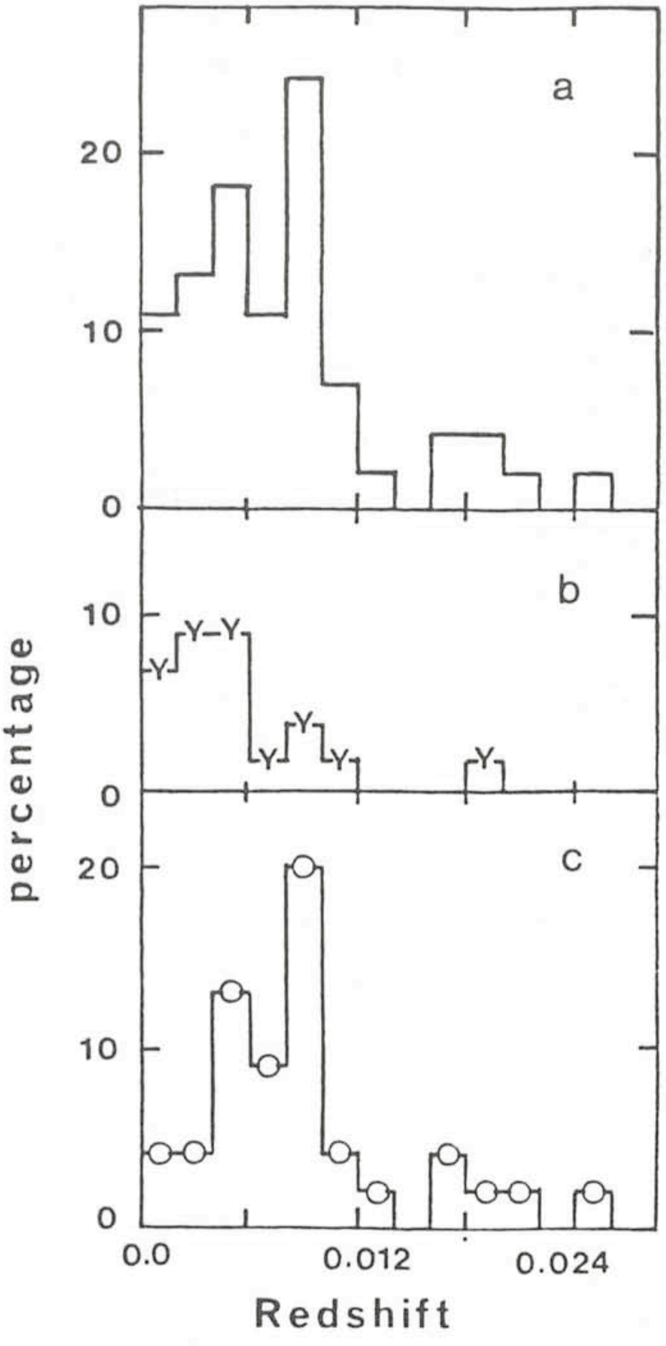

Fig. 2: *a: Redshift distribution histogram of the galaxy sample; b: Histogram of galaxies exhibiting WR emission (Y); c: Histogram of galaxies with no WR emission (O).*

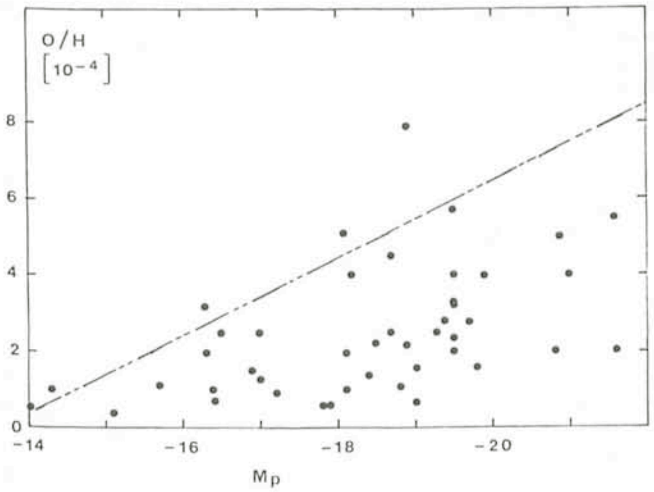

Fig. 3: *Oxygen abundance versus absolute photographic magnitude of the galaxy sample. The dotted line represents the regression fit given in the text using the 12 upper points of the diagram and neglecting the discrepant one at O/H = 8.0 10^{-4}.*

than about 0.02. Clearly beam dilution acts against detection, unless WR are formed in unusually large numbers.

The galaxies largely differ in their metal content, they spread a range from 7.5 to 8.9 in logarithmic scale for the oxygen abundance, hence some exceeding the metallicity in the solar neighbourhood. Their luminosities from Mp = −14 to −21.5 include objects which are not genuinely lazy! Fig. 3 displays the oxygen abundance versus absolute magnitude, it shows that the galaxies evenly populate an area below a line O/H = −1.4 (Mp + 13.6) in surprising agreement with that of Lequeux et al.) 1979: *Astronomy and Astrophysics,* **80,** 155) for a sample of 8 irregular and compact galaxies. This large scatter in the diagram may not be due to observational uncertainties but more likely to dispersion in the properties of this type of galaxies such as galactic winds, infall, and variations in the yield of metals (Matteucci and Chiosi, 1983: *Astronomy and Astrophysics,* **123,** 121).

Where Are Wolf-Rayet Stars Expected to Be?

While the galaxies in our sample are well distributed over 8 magnitudes in luminosity, our study shows no tendency to detect WR stars at any preferred galactic luminosity. Contrary to what had been suspected from both the distribution of galactic WR stars and their number in the Magellanic Clouds, that WR stars would be found in sites of large metallicities, emission was detected in galaxies with no preferential oxygen abundance. But what about their absolute number? In order to estimate the number of WR stars formed in all relevant galaxies we have computed the absolute luminosity of the WR emission per unit area in the galaxy, a quantity independent of the distance. Limitations of this procedure rise from the assumption that WR stars are uniformly distributed and from severe reddening corrections. Fig. 4 displays this quantity as a function of the oxygen abundance and indicates that WR stars seem to be more numerous in sites of higher metallicity.

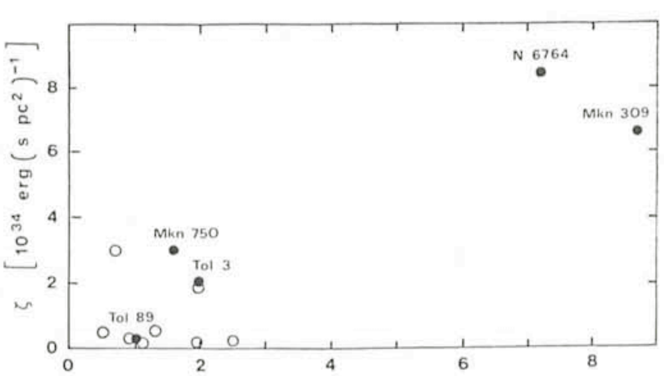

Fig. 4: *Intrinsic luminosity of the WR emission per projected surface in the galaxy as a function of oxygen abundance. Symbols are: Open circles are galaxies with WR excesses larger than the 0.8σ threshold; filled circles are galaxies with WR excesses larger than the 3σ threshold.*

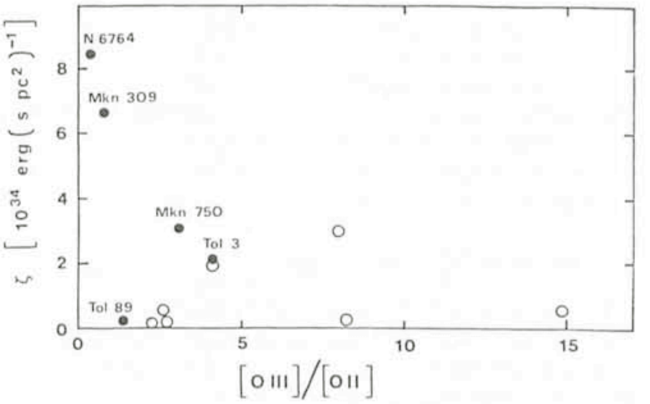

Fig. 5: *Intrinsic luminosity of WR emission per projected surface in the galaxy as a function of the [O III] λ 5007 to [O II] λ 3727 ratio.*

Next we have plotted in Fig. 5 the absolute WR emission per square area as a function of the mean temperature of the ionizing stellar cluster, as guessed from the line ratio [O III] λ 5007/[O II] λ 3727. This says that WR stars are found in larger numbers in regions of low to moderate stellar effective temperature, less than 35,000 K.

About Our Feelings Concerning the Nature of WR Stars in Lazy Galaxies

Let us finally come back to our original question: what kind of WR stars do we see in lazy galaxies? Are they supermassive ones on the main sequence or post-red-supergiant stars in a He-burning phase? Using our 3 best observed cases and the published ones, we are struck by the fact that the equivalent width of the WR feature is in no way related to that of the Hβ emission line. Instead a spread in EW (Hβ) by a factor of more than 20 corresponds to a nearly constant WR emission equivalent width of about 8 Å. The number of WR stars is therefore proportional to the number of stars responsible for the continuum at 4600 Å but not at all to the number of ionizing massive ones. They probably play a minor role in ionizing the gas. This strongly indicates that WR stars in lazy galaxies occur in a population of stars less massive than 60 $M_\odot$ evolving in their He-burning stage. They should be linked to the early evolutionary phase of the burst of star formation.

Galaxies with a continuous range of WR emission may then be found, with 8–10 Å equivalent width being an upper limit. Our observations performed last January at La Silla should answer this question and many others we hope!