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Wolf-Rayet galaxies and their CCD photometry

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Abstract. Galaxies with Wolf-Rayet star features in their spectra have long been known. They are characterised by a broad emission feature at λ 4686 Å. This is attributed to stellar HeII emission from a large population of WR stars. Broad CIV λ 5808 Å emission has also been detected in about 30 WR galaxies. The WR galaxies are thought to be undergoing present or very recent star formation that produces massive stars evolving to the WR stage. More than 130 WR galaxies are now known and most of them have been studied on the basis of spectroscopic observations. Therefore, a CCD surface photometry programme has been initiated at the U.P. State Observatory, Naini Tal using B V R I and H_α filters. NGC 1741, IIZw40, IRAS01003-2238 have been observed and their morphology is discussed.

Key words : Wolf-Rayet galaxies, surface photometry

1. Introduction

Two French astronomers Wolf and Rayet in 1867 discovered the Wolf-Rayet (WR) phenomena as strong broad emission in stars. The defining characteristics came to us directly from the spectroscopic observations. The characteristics are :

1. Primarily an emission line spectrum superimposed on hot continuous spectrum.

2. The emission lines represent a wide range of excitation and ionization.

3. The emission lines are broad corresponding to widths of hundreds of thousands of kilometers/second. Widths often differ among various ions in the same star.

WR stars in more distant objects are detected indirectly by observing integrated spectra. Strong star formation activity in a galaxy results in a large number of massive stars, the most massive of which evolve through WR phase. Thus at a definite stage of the star burst evolution, many WR stars make their appearance during a short time interval. Despite their small number relative to that of massive stars, especially in low - metallicity galaxies, WR stars are numerous enough for their integrated emission to be detected. The WR features are broad but generally weak, therefore they can be detected only in spectra with high signal to noise in the continuum.

The integrated spectra of WR galaxies show direct signatures from WR stars, most commonly a broad He II λ 4686 Å feature originating in stellar winds of these stars. This feature is seen in moderate and low resolution spectra. Broad CIV at λ 5808 emission has also been detected in a few galaxies.

WR stars have been found in very different extragalactic environments, Giant HII regions, blue compact galaxies, emission line galaxies, IRAS galaxies, seyfert galaxies–, in general always in regions experiencing a strong episode of massive star formation. This fact provided in 1980s a definitive support to the so called 'Conti scenario', according to which W-R stars were the descendents of massive stars, experiencing this short evolutionary phase just before collapsing into a supernova explosion. The Wolf-Rayet phase is characterised by the ejection via strong stellar winds of the outer layers of evolved massive stars. The efficiency in powering these winds is a function of metallicity, so that the lower the metallicity, the higher the initial mass required for a star to become a WR. In general a star will become a WR if its initial mass is above 20 solar mass for solar metallicity and above 80 solar mass at 1/10 of solar metallicity. The evolution of massive stars in binary systems can also lead to the formation of WRs. Therefore, while the standard Conti scenario predicts the presence of WR stars only between 2 and 6 Myr after the onset of the star burst, the binary channel predicts a rather constant amount of WR stars between 5 and around 20-30 Myr.

These are therefore ideal objects for studying the early phases of starbursts, determining burst properties and constraining parameters of high mass end of initial mass function.

Extensive observations in radio, infrared, UV and X-ray regions are providing good data to solve the mystery of evolutionary status of these galaxies (Beck et al. 2000), Murphy et al., 1996, Steven and Strickland, 1998).

WR galaxies have been arranged into three sequences, based upon the appearance of optical emission lines, coming from ions of helium, carbon, nitrogen and oxygen. One in which the helium and nitrogen lines dominate is called WN. In which helium carbon and oxygen ions are found is called WC and in which strong oxygen lines are found is called WO. These sequences can be further subdivided into higher and lower excitation subtypes, depending on the strengths of various ions of helium (HeI, HeII), nitrogen (NIII, IV, V), carbon (CII, CIII CIV) and oxygen (OIII, OIV, OV, OVI). These subtypes range from WN2, WN3,...., WN9 and WC4, WC5,.... WC9. In anology to MK terminology the high excitation and low excitation subtypes are called early or late types respectively. Presumably the ionozation sequence also correspond to run of effective temperature, but it is not yet well determined quantitatively.

WN and WC sequences depict different elemental abundances, the former displaying the properties of core hydrogen burning and later that of the even more highly evolved helium burning material. The absence of hydrogen in WC stars and weak appearance in less than half of WN stars lends additional evidence to the idea that these objects are highly evolved. This one dimensional empirical spectral classification currently in use depends on the properties of the stellar wind. A central question which is yet unresolved is the relationship of this wind classification to the central star.

2. The Spectroscopy survey

Spectroscopic survey of a large sample of Wolf-Rayet galaxies has been done recently by Guseva et al. (2000). High signal to noise spectra of a large sample of WR galaxies in low resolution shows the blue bump at λ 4650 in most of the cases. This unresolved bump is a blend of the NV λ 4605, 4620, NIII λ 4634, 4640, CIII/CIV λ 4650, 4658 and HeII λ 4686 broad WR lines. These are emitted mainly by late WN(WNL) and early WC(WCE) stars. Superposed on the blue bump are much narrower [FeIII] λ 4658, HeII λ 4686, HeI+ [ArIV] λ 4711 and [ArIV] λ 4740 nebular emission lines. The detectability of the weaker red bump emitted mainly by WCE stars is lower. Hence the observed characteristic of WR galaxies are restricted to WNL and WCE. However, in a sample of 37 galaxies 30 galaxies show broad λ 5808 red bump.

The number of WR stars from the luminosity of the blue (λ 4650) and red (λ 5808) bumps can be estimated.

The number of WR stars = (L_{WR}) / (Lo_{WR})

Where L_{WR} is the absolute luminosity of the WR bump corrected for interstellar extinction and Lo_{WR} is the luminosity of WR bump of a single WR star.

Additionally, weaker WR emission lines have also been identified. They are NIII λ 4512 and SiIII λ 4665 lines. These emission features are characteristics of WN7-WN8 and WN9-WN11 stars, respectively.

Guseva et al. (2000) have derived the number of early WC(WCE) and late WN(WNL) stars from the luminosities of the red and blue bumps, and the number of O stars from the luminosity of the H_β emission line. They have also proposed a new technique for deriving the numbers of WNL stars from the NIII λ 4512 and SiIII λ 4565 emission lines. This technique is more precise than the blue bump method because it does not suffer from contamination of WCE and WNE stars and nebular gas emission.

It has been found that the relative number of WR stars N(WR)/N(O+WR) decreases with decreasing metallicity, in agreement with predictions of evolutionary synthesis models. The relative number ratio N(WC)/N(WN) and the equivalent widths of the blue bump and of the red bump derived from observations are also in satisfactory agreement with theoretical predictions.

3. The CCD photometry

Deep optical imaging and spectroscopy of a sample of Wolf-Rayet galaxies have been reported by Mendz and Esteban (2000). Analysis of deep CCD images gives direct evidence for large scale high velocity flows in the ionised gas associated with some Blue Compact Dwarf Galaxies (BCDG). Extensive low intensity filamentary structures have been detected, using H_α images, in more than a dozen of galaxies. These structures dominate the low intensity extended H_α emission. Their morphology is typically filamentary and bipolar, and in most cases aligned with the minor axis of the galaxy.

Deep CCD photometry of 7 WR galaxies reveal that the recent star formation is distributed in different knots. These knots are H II regions ionized by clusters of massive stars. These knots may be analogous to or aggregates of, the so called super star clusters, found in HST images of WR galaxies and interacting galaxies. The star formation processes are very intense, that is to say, the current star formation rate is considerably higher, between 200 (Mrk 750) and 10 (Mrk 33 and Tol 35) times the star formation rate averaged during the last few billion years.

Deep CCD survey has also revealed that many of the irregular WR galaxies that had previously been catalogued as isolated objects have low surface brightness companions that had previously escaped detection. Therefore, the most important consequences of the deep CCD photometry is that the processes that triger the intense star forming bursts in relatively low mass WR galaxies could be due to the interactions not only with luminous galaxies but also with low-mass and low surface brightness companion that had escaped previous detection.

A detailed inspection of the catalogue of WR galaxies by Schaerer et al. (1999) shows that 38 percent of the objects do present clear signs of interaction / or merger processes. Other objects in the catalogue are still awaiting more detailed observations.

The H_α morphology of many of the objects indicate the presence of bubble like and low surface brightness filamentary structures. Spectroscopic observations confirm the presence of high-velocity asymmetric flows that extend upto the external zones. This kind of structure can be associated with the combined action of stellar winds from massive stars and super nova explosionis over the ionized gas surrounding the star forming knots.

4. CCD photometry at State Observatory, Nainital

There are about 30 W-R galaxies, brighter than 15th magnitude, accessible from our 104cm reflector. The telescope is equipped with a 2048 x 2048 CCD camera and a set of B V R I H_α a near H_α continuum filters fitted in a filter wheel at its Cassegrain focus. The plate scale is 15.5 sec. of arc per mm and the CCD covers 12 x 12 arc min of projected sky at this focus. Alongwith the galaxies, standard fields are also be observed for nightly extinction and standardisation. These raw images are cleaned by using standard tasks available in the IRAF. Multiple frames taken in different filters are co-added in order to increase the signal/noise ratio. STSDAS package is used for profile fitting and other analysis. H_α images subracted from the continuum can directly give the different emission zones (knots) and the star forming regions.

The aim of this study is to look for the presence of different star forming regions, dust lanes and its alignment in different colours and the relationship between the irregular W-R galaxies with the low surface brightness compansions. The H_α morphology of some of WR galaxies have shown the presence of bubble like and low surface brightness filamentary structures. This can be confirmed for other WR galaxies.

We have done CCD photometry of three W-R galaxies. The optical images of NGC 1741 show highly disturbed mrophology with two star burst centres, possibly arising from a galaxy merger, most likely as a result of interaction with other member of Hickson compact group 31. Both star burst centres are composed of several intense knots of recent star formation. IIZw40 is a dwarf blue irregular galaxy with a very young starburst in its central region. Visual images of this galaxy are dominated by the bright central core with two faint tails extending out to 30 arc sec. IRAS 01003-2238 is the most distant WR galaxy known (470 Mpc). Dust lanes in the optical V filter image can be seen more clearly in this galaxy.

References

Beck S.C., Turnet J.L., Kovo, Orly, 2000, A J, 120, 244

Guseva N.G., Izotov Y.I., Thuan T.X., 2000, Ap J, 531, 776

Mendez D.I., Esteban C., 2000, A & A, 359, 493

Murphy T.W., Armus Jr. L. Matthews K., Soifer B.T., Mazzarella J.M., Shupe D.L., Strauss M.A., Neugebauer G., 1996, A J., 111, 1025

Schaerer D., Contini T., Pindao M., 1999, A & A, 136, 35

Steven I.R., Strickland D.K., 1998, MNRAS, 301, 215