The ionized gas in and around the Wolf-Rayet galaxy NGC 1741

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ABSTRACT

Interaction can be the main mechanism that triggers star formation in Wolf-Rayet galaxies. The compact group **HCG 31** has one of this objects, **NGC 1741**, and presents important interacting processes. We present deep optical intermediate-resolution spectroscopy of the different individual galaxies of HCG 31. We analyse the physical conditions and chemical composition of the ionized gas in order to get a more complete view on the origin and evolution of the system.

INTRODUCTION

NGC 1741 is included in the first catalogue of Wolf Rayet galaxies (Conti 1991). It is one of the members of the **Hickson Compact Group 31 (HCG 31)**, and it lies at 51 Mpc (Vacca 1992). In *Figure 1* we show the members of this system. Hickson (1982) identified the galaxies A, B, C and D. Rubin et al. (1990) appointed the members E, F and G. Galaxies A and C form the galaxy NGC 1741. In fact, both objects are in interaction (Johnson et al, 1999), and they host a burst of star formation of around 5 Myr (Johnson & Conti 2000). They form one of most luminous Wolf-Rayet galaxies known (M_B = -20.3, Conti 1991). Member D is a background galaxy (Rubin et al. 1990). E and F may be Tidal Dwarf Galaxies (TDGs), and F shows a starburst of around 4 Myr, although it can be younger (Johnson & Conti 2000). It does not posses an old population. We have distinguished the F1 and F2 zones inside F. We have also found another member between F1 and E, that we have named as H.

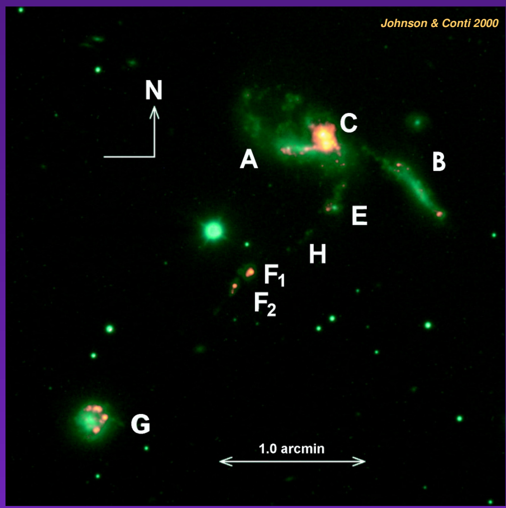


Figure 1: Color image of the members of HCG31 using the narrowband Hα and continuum images. Members A and C form the Wolf-Rayet galaxy NGC 1741. Johnson & Conti 2000.

TABLE 1: General properties of HCG 31

	A	B	C	E	F1	F2	G	H
m_B	15.62	15.21	13.30	-	-	-	15.00	-
C(Hβ)	0.16	0.04	0.09	0.10	0.32	0.14	0.06	0.15
T_e (K)	10450[(1)]	11700	9740	11120	12630	12290	11530	10950[(1)]
N_e (cm^{-3})	< 100	< 100	210	< 100	< 100	< 100	< 100	< 100
Δv_r(km/s)[(2)]	+105	+132	0	-39	-66	-62	-2	+28
-EW(Hβ)	28.8	13.6	84.6	24.6	308	277	46.7	55.5
-EW(He II)[(3)]	1.30	0.52	1.89	-	2.73	2.51	-	-

(1) Calculated by empirical calibrations.
(2) Radial velocity with respect member C.
(3) Equivalent width of the WR Bump main emission line, He II 4868 Å.

OUR OBSERVATIONS

Intermediate-resolution spectroscopy were taken on 1999 December at the Observatorio del Roque de los Muchachos (La Palma), using the 4.2 m William Herschel Telescope (WHT) with the ISIS spectrograph. Three different slit positions were taken. In *Figure 2* we show the calibrate spectra of members C, F1, F2 and G. Note strong [OIII] 4959 and 5007 Å lines relative to Hβ, indicative of a high-excitation, low metallicity galaxy. We can also observe the [OIII] 4363 Å emission line. C is the most luminous galaxy, and it has the highest S/N ratio. B and G show underlying stellar absorption, specially intense in B. Galaxy H is the faintest object.

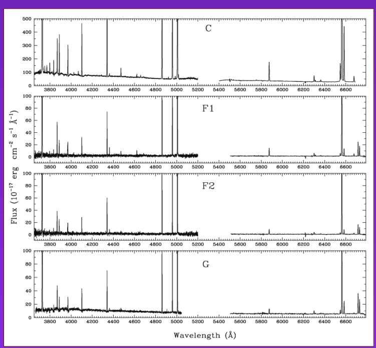


Figure 2: WHT spectra of members C, F1, F2 and G of HCG31.

IONIC ABUNDANCES

We have determined **O^+, O^{++} and N^+ abundances**, as well the **O/H ratio**. We checked the obtained results with empirical calibrations. Specifically, we made use of the **R_{23} parameter** (Pilyugin 2000) and the **[NII] 6584 Å / Hα ratio** (Denicoló et al. 2002). In fact, we derived the ionic abundances for members A and H in this way. Our determinations agree with the ones using the empirical calibrations. We used the [NII] 6583, 6548 Å emission lines to obtain the ionic N^+ abundances. Our results are shown in *Table 2*.

TABLE 2: Abundance ratios

	A	B	C	E	F1	F2	G	H
12+log(O/H)	8.45[(1)]	8.31	8.55	8.29	8.06	8.05	8.26	8.40[(1)]
Log (O^+/N^+)	-1.29	-1.45	-1.62	-1.36	-1.27	-1.46	-1.38	-1.36

(1) Calculated by empirical calibrations.

According to the **O / H ratio** of each object, we can see that there are important differences. Member C shows the highest abundance (8.55) and F1 and F2, the youngest bursts (see below), show the lowest values (8.06 and 8.05). This difference makes difficult that F can be considered as a TDG produced from material stripped from C or A. In fact, the O/H ratio of F is more similar to that of G, or even B. In any case, the remarkable low O/H value of F merits further investigation. Another interesting result is the detection of **C II 4267 Å** in the spectrum of C (see *Figure 3*). This is the first time this recombination line is reported in an H II galaxy and opens new possibilities for the chemical abundance studies to be done in the future with large aperture telescopes.

TEMPERATURES, DENSITIES AND VELOCITIES

We easily observe the **[OIII] 4363 Å** emission line in the systems C, F1, F2 and G (see *Figure 3*), but we can also detect it in B and E. Therefore, we have been able to do determinate electron temperature estimations using the [OIII] 4959+5007/[OIII] 4363 ratio. All the members of HCG31 show the **[OII] 3726,3729 Å** and **[SII] 6716, 6731 Å doublets**. Therefore, we have been able to derive the electron density of the ionized gas. Electron densities are always below the low density limit (<100 cm^{-3}), except in member C. For the regions A and H we have estimated the electron temperature and density making use of empirical methods (see below). Our results are compiled in *Table 1*.

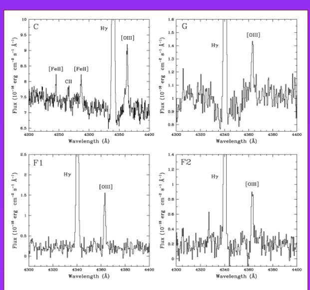


Figure 3: Detail of the spectra of members C, F1, F2 and G showing the [OIII] 4363 Å emission line. Member C also shows the C II 4267 Å and [FeII] 4244, 4287 Å emission lines.

We have determined the radial **velocity** of each member of HCG 31 from Hβ and [OIII] 5007 Å emission lines. We have taken the most luminous member (C) as reference. The results are also shown in *Table 1*. We can observe than E, F1, F2 and G objects have negative values of the velocity. The new object, H, belongs to the compact group because it has a radial velocity similar to the system.

THE AGES OF THE BURSTS

We have used the models of **Stasinska and Leitherer (1996)** to estimate the age of the bursts. We have chosen four different models: those with metallicity Z/Z⊙=1 and 0.25, and with a total mass of M/M⊙= 10^3 and 10^6. In *Figure 4* we plot our observational values of EW(Hβ) and the [OIII] 5007 Å emission line flux (see *Table 1*) compared with the theoretical models. F1 and F2 show a somewhat different behaviour than the rest of the members. They fit well with a **Z/Z⊙ ~0.25 and M/M⊙ ~1000 burst.** The rest of the members fit well to the four models (except perhaps B due to the important underlying old population), although ones with Z/Z⊙ ~0.25 seem to fit better.

We can obtain a good estimation of the age of the bursts plotting the observed EW(Hβ) (see *Figure 5*). In this case, models with same metallicity give equal results. We can observe that **F1 and F2 are the youngest members**, and we find that they have an age between **2 and 3 Myr.** The rest of the burst are more evolved, and they have an age between 4 and 8 Myr. Similar ages are obtained from the observed EW([OIII]). We have also used the **Schaerer and Vacca (1998)** models to make age estimations, and they provided similar results to the ones of Stasinska and Leitherer (1996). We show these results in *Table 3*, as well as other estimations of the age of the burst in HCG 31 in the literature. Our results agree very well with previous studies, put perhaps ours are more precise.

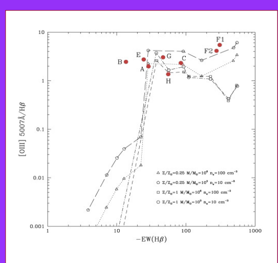
TABLE 3: Age estimations

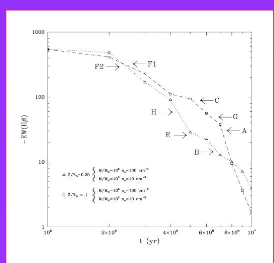
Method	A	B	C	E	F1	F2	G	H	Ref.
EW(Hβ) SL96	4 - 8	6 - 8	4 - 6	6 - 8	2 - 3	2 - 3	4 - 7	4 - 6	This Work
EW([OIII]) SL96	5 - 8	5 - 8	3 - 5	5 - 8	2 - 3	2- 3	3 - 7	3 - 7	This Work
EW(Hβ) CV98	5 - 6	5.5 - 7	3 - 4.5	5 - 6	2 - 3	2- 3	4.5 - 6	4 - 5	This Work
Hα vs. U	3 - 10	~ 10	3 - 10	~ 10	3 - 10		~ 5	-	IV97
VST-IST W(Hα)	~ 5	5 - 10	~ 5	1 - 3	< 4		~ 5	-	JC00

All the ages are in Myr.

Figure 4 (left): F([OIII] 5007 Å) vs. EW (Hβ). Models by Stasinska & Leitherer (1996).

Figure 5 (right): EW(Hβ) vs. age of the bursts. Models by Stasinska & Leitherer (1996).





THE WR BUMP

We can observe clearly the **WR Bump** between **4650 and 4698 Å** in member C. Furthermore, we detect the nebula He II 4686 Å emission in F1. Galaxies A and C could also show a faint WR Bump (see *Figure 6*). In addiction, faint He II 4686 Å emission could be present in F2. We have used the evolutionary synthesis models for O and Wolf-Rayet populations in young starburst of Schaerer and Vacca (1998) to compare our observations. We have assumed our WR Bump He II 4686 Å emission line detections as upper limits (see *Table 1*). We can derivate upper limits to the number of O stars, the WR/O ratio and the number of Wolf-Rayet stars. We have found that the galaxy C has the highest number of Wolf Rayet star (around 0.67%). However, these results are still preliminary.

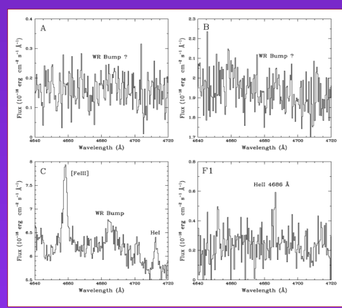


Figure 6: Detail of the spectra of members A, B, C and F1 showing the WR Bump or the He II 4686 Å emission.

CONCLUSIONS

Deep intermediate-resolution spectra of the different members of HCG 31 show that there are important differences in their chemical content. Member C show the highest O/H ratio and the youngest burst (F, between 2 and 3 Myr) shows the lowest one. This suggests that F is not a tidal dwarf galaxy (TDG) produced from material from C, instead it can be originated from material stripped from G or B. We have detected He II 4686 Å emission in F, indicating the presence of Wolf-Rayet stars in this interesting object.

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