On the nature of dwarf galaxies in the interacting group HCG 31

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ABSTRACT

We present our results about the interacting compact group **HCG 31**. We have carried out intermediate long slit spectroscopy and CCD optical and near-infrared imagery to study the different objects belonging to HCG 31. We have analysed the morphology, kinematics, colors and the chemical composition of the ionized gas in order to get **a global view on the origin and evolution of the system** and, specially, the **dwarf galaxies** present in it.

INTRODUCTION

The **compact group HCG 31** is at a distance of around 54 Mpc. Members A and C are clearly interacting, forming **NGC 1747**, that was described by Conti (1991) as one of the most luminous Wolf-Rayet galaxies known. UV studies performed by Conti, Leitherer & Vacca (1996) revealed that its centre is dominated by two main starbursts of **recent star formation**. Johnson et al. (1999) obtained HST images and detected several hundreds of super star clusters in them. E, F, and the close galaxy Mrk 1090 (G) were included as new members of HCG 31 by Rubin et al (1990). The H I map of the group (Williams 1991) shows that all **the galaxies**, (except D, that is a background galaxy), **are embedded in the same cloud**. Maximum of H I column density are coincident with the galaxies, indicating that they are **gas-rich** objects.

OBSERVATIONS

Optical **U**, **B** and **V** images of HCG 31 were carried out at *2.56m Nordic Optical Telescope (NOT)* at Observatorio del Roque de los Muchachos (La Palma) with the ALFOSC camera. We used the *1.55m Carlos Sánchez Telescope (CST)* at Observatorio de Izaña (Tenerife) to obtain near-infrared images in **J, H** and **Ks** broad-band filters. **Intermediate-resolution spectroscopy** were carried out at *4.2m William Herschel Telescope (WHT)* with the ISIS spectrograph at the Observatorio del Roque de los Muchachos (La Palma). Three different slit positions were observed in order to study all the members of HCG 31. We plot them over a colour image of HCG 31 in FIGURE 1, as well as the eight regions analysed.

TABLE 1: General properties of bursts in HCG 31

	A1	B	C	E	F1	F2	G	H
M_B	-18.36	-18.71	-19.43	-15.76	-15.76	-14.34	-18.88	< -13.1
C(Hβ)	0.16	0.28	0.09	0.11	0.32	0.14	0.09	0.15
T_e [OIII] (K)	8250[1]	11500	9740	11120	12630	12290	11580	9000[1]
N_e (cm^{-3})	< 100	< 100	210	< 100	< 100	< 100	< 100	< 100
W(Hβ)	27.0	12.9	91.1	21.1	218	256	37.0	117
O/H	8.45[1]	8.14	8.22	8.13	8.07	8.03	8.15	8.37[1]
- log (N^+/O^+)	1.21	1.39	1.12	1.26	1.27	1.43	1.31	1.33
Age[2]	6 - 8	5 - 8	4 - 6	5 - 6	2 - 3	2 - 3	5 - 7	3 - 5
Z/Z_o[3]	0.58[1]	0.28	0.34	0.28	0.24	0.22	0.29	0.48[1]

[1] Calculated by empirical calibrations.
[2] Estimated age for each burst.
[3] Metallicity respect the solar value, Z_o= 8.69 (Allende Prieto, Lambert & Asplund, 2001).

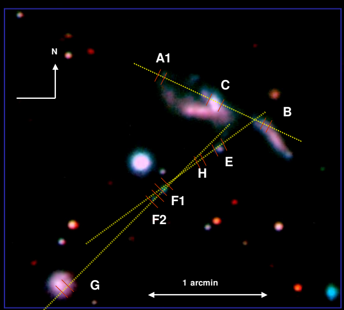

FIGURE 1: Deep B (blue), V (green) and J (red) HCG 31 image, showing the different members of the system and the three slit positions for spectroscopy.

KINEMATICS

We have studied the **kinematics of the ionized gas** using the bright emission line along each slit position (see FIGURE 1). We show the **position-velocity diagrams** obtained for them in FIGURE 3a, b and c . Our main conclusions are:

- **C** shows a **sinusoidal pattern** in its center of the object (figure 3a), indicating that a **merging process** is ongoing in the central zone of A+C complex.
- **B** shows a **solid-body rotation** pattern (figure 3a) that could be affected by a possible **tidal streaming motion** between it and the A+C complex.
- **G** also shows **solid-body rotation** (figure 3b)
- **E** shows a very different behavior between **P.A. 133º** (figure 3b) and **P.A. 128º** (figure 3c). We consider that we are seeing two different kinematical objects that coexists in apparent close proximity:
  - ✓ **E member** (P.A. 128º, figure 3c) and
  - ✓ **an optical tidal tail** that seems to be extending from the south of A+C complex towards the faint H member (P.A. 133º, figure 3b), showing an **streaming motion** with increasing radial velocities as it extends.
- **F1 and F2** seem clearly to be **kinematically different** of this optical tidal tail.

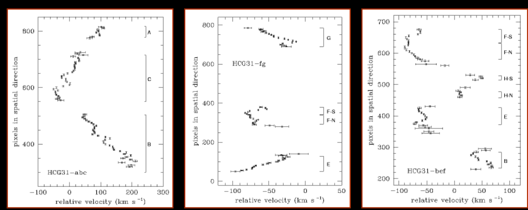

FIGURE 3: Position-velocity diagrams for PA 61º (3a, left, members A, C and B), PA 133º (3b, center, E zone and members G and Fs) and PA 128º (3c, right, members E, H and Fs).

FIGURE 5: Deep U (blue) B (green) and V (red) HCG 31 image. We have included the H I map (grey-black contours, Williams et al. 1991) and the optical tidal tail (blue-violet contour, Iglesias-Páramo & Vílchez 2001) extending from A+C complex to H member. E, F1 and F2 are coincident with H I maxima, and show similar radial velocities.

CHEMICAL ABUNDANCES

We easily observe the **[OIII] 4363 Å** emission line in all the members (except A1 and faint H), so we have direct determination of **electron temperature**. All the members show the **[OII] and [SII] doublets**, so we have derived the **electron density** of the ionized gas. Electron temperature was also estimated making use of empirical methods (Pylyugin 2000, Denicoló et al. 2002). The **O/H ratios** obtained from direct determination (the first reported for E, F2 and G) are rather similar for all the objects and range between 8.0 and 8.2 [in units of 12+log (O/H)], and consistent with other previous from the literature. We collect these data in TABLE 1.

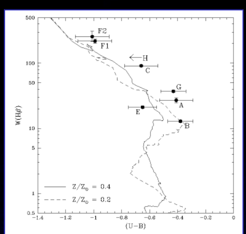

FIGURE 2: W(Hβ) vs. (U – B) color for HCG 31 observed bursts compared with STARBURST 99 models for Z/Z⊙ =0.4 and 0.2 and instantaneous burst with a Salpeter IMF, a total mass of 10^6 M⊙ and a 100 M⊙ upper mass.

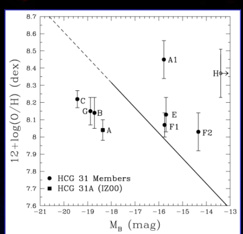

FIGURE 4: Luminosity-metallicity diagram for bursts in HCG 31. The solid line is the Richer & McCall (1995) relation for dwarf irregular galaxies. It is extrapolated towards no-dwarf galaxies (doted line). The metallicity of member A has been taken from Izotov & Thuan (1998).

METALLICITY-LUMINOSITY RELATION

The oxygen abundances of the galaxies are unusual taking into account the **luminosity-metallicity relation** of Richer & McCall (1995) (FIGURE 4). The four brightest members of HCG 31 (A, B, C and G) show rather similar O/H, about a factor of 2 (0.3 dex) lower than the value expected from this relation. E and F show the same oxygen abundances as the brightest galaxies, despite the interval of about 5 magnitudes between them.

We consider that the metallicity-luminosity relation of dwarf irregular galaxies is **not appropriate for interpreting the properties of starburst galaxies** because the B-luminosity is dominated by a transient young starburst. The actual position of E and F near the metallicity-luminosity relation could be incidental because the relative contribution of the young population to the total emission of the object could be even more important than in the brightest galaxies of the group due to their small sizes, as it would be expected following population synthesis models. The future photometric evolution of the starbursts could move their positions toward lower luminosity, moving away of the relation. This fact seems to favor their nature as **tidal dwarf galaxies** (TDGs).

AGES OF THE BURSTS

We have combined our optical and near-infrared photometric values with **STARBURST 99** models (Leitherer et al. 1999) to estimate the age of the bursts. All the color-color diagrams studied give consistently **similar ages** for each object. We have also compared our spectroscopic data with Stasinska & Leitherer (1996) and Schaerer & Vacca (1998) theoretical models. We have found that F1 and F2 are the youngest members, with an age between 2 and 3 Myr. We show all the age estimations in TABLE 1.

We have obtained **surface brightness profiles** in C, E, F1, F2 and G to study a possible low surface brightness underlying component, that was only clearly detected in C. In FIGURE 2 we plot the Hβ equivalent width versus (U-B) color for Z/Z⊙ = 0.4 and 0.2 STARBURST 99 models (Leitherer et al. 1999). We found a very good agreement between our observational data and the theoretical predictions. Both studies and the excellent agreement in the ages obtained from different methods suggest that the **old population seems not to be important** in the bursts of HCG 31, specially in **E, F1** and **F2** members.

WHERE TIDAL DWARF GALAXIES CAME FROM ?

The mean velocities of **F1 and F2** are similar to that of **E and G**, which coincides with the radial velocity of the HI cloud in this zone of HCG 31. This fact suggests that perhaps **these objects are related to the arm-like HI structure** that extends to the southeast of A+C complex (see FIGURE 5). The velocity pattern and the morphology of the system are compatible with the presence of two spatially coincident kinematical structures:

1. the **arm-like HI structure** that extends from A+C in direction to member G, from which **objects E and F may be formed** (*yellow-pale* in FIGURE 5), and
2. the **optical tidal tail that emerges from the southwest of the A+C complex**, which consist of a curved string of faint star-forming regions that ends at the position of object H (blue and violet in FIGURE 5).

The H I extension has a rather constant radial velocity but the optical tidal tail shows a clear streaming motion. **We propose that E, F1, and F2 are TDG candidates made by material from the southern arm-like HI extension, which was stripped from the parent galaxy** (probably the A+C complex) **due to a fly-by encounter between it and G**. This hypothesis is both supported by their ***kinematic*** patterns and because their relatively ***high chemical abundances***, very similar to those of the brightest galaxies of the group. The apparent absence of old stellar population in E, F1 and F2 indicates that they are basically made of gaseous material. In fact, a local maximum in the distribution of HI emission coincides with the position of member F.

CONCLUSIONS

We have analyzed the bursts of HCG 31 making use optical and near-infrared photometry and intermediate-resolution spectroscopy. Our data suggest that **is necessary a strong interaction among, at least, three galaxies in order to explain all the observed features in HCG 31**. This behavior could be an interesting prototype of interaction between several galaxies, probably very common in high density systems and at high redshift.

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Dawn at Observatorio de Izaña (Tenerife). The Moon, Venus and the dome of Carlos Sánchez Telescope can be observed in this picture (Ángel R. López-Sánchez).