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THE INTERACTING WOLF-RAYET GALAXY HARO 15

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RESUMEN

Actualmente se conocen algo menos de 150 galaxias Wolf-Rayet. Muchas de ellas son enanas o irregulares, y algunas muestran objetos compañeros cercanos. En muchos casos aparecen morfologías peculiares como fusiones o colas de marea conectadas a pequeños agregados estelares. De esta forma, pensamos que las interacciones podrían ser un mecanismo importante que dispare la formación estelar en las galaxias Wolf-Rayet, sobre todo en las enanas. Hemos usado imágenes profundas CCD en óptico e infrarrojo cercano para analizar algunas galaxias Wolf-Rayet y objetos circundantes con el objetivo de estudiar su interrelación. Presentamos algunas de nuestras conclusiones sobre la morfología, cinemática, colores y composición química del gas ionizado de Haro 15, así como el análisis de las edades de los brotes observados usando modelos teóricos de síntesis espectral.

ABSTRACT

Only less than 150 Wolf-Rayet galaxies are actually known. Many of them are dwarf or irregular galaxies, and some show close companion objects. Peculiar morphological features, like mergers or tidal tails connecting small stellar aggregates, are found in many cases. Therefore, we think that interaction could be an important mechanism that triggers star formation in Wolf-Rayet galaxies, interestingly in dwarf ones. We have used deep optical and near-infrared CCD imagery and intermediate resolution optical spectroscopy to analyse some Wolf-Rayet galaxies and surrounding objects in order to study their inter-relation. Some of the conclusions about the morphology, kinematics, colors and the chemical composition of the ionized gas of Haro 15 are shown. We have also analysed the ages of the observed bursts making use of spectral synthesis models.

Key Words: **GALAXIES : ABUNDANCES — GALAXIES : INTERACTIONS — GALAXIES : KINEMATICS AND DYNAMICS — STARS : WOLF-RAYET**

1. OUR OBSERVATIONS

We have carried out intermediate resolution long slit spectroscopy and CCD optical and near-infrared imagery of the Wolf-Rayet galaxy Haro 15. The optical CCD images in the B, V and I bands were extracted from de 1.5m JKT archive. All the near-infrared CCD images in J, H and Ks bands were taken with 1.5m CST (CAIN). We used 2.5 m INT (IDS) to obtain the spectra. The V image of Haro 15 is shown in Figure 1. We also plot the slit positions used to obtain the spectra of the analyzed knots. The spectra are shown in Figure 2.

2. DESCRIPTION OF THE GALAXY

Haro 15 (Mrk 960) lies at 85 Mpc. Mazzarella, Bothun & Boronson (1991) described it as two separated galaxies highly perturbed that can be an advanced merger. Schaerer et al. (1999) classified Haro 15 as a Wolf-Rayet galaxy due to the detection of a broad He II 4686 Å emission line (Kovo & Contini 1998). We can distinguish two bright zones in the inner part of the object, a nucleus and an east-southeast (ESE) knot. Other knot is located in the northeast (NE) of the galaxy, which is a dwarf galaxy ($M_B \sim -15.9$). It has an elliptical shape and reveals

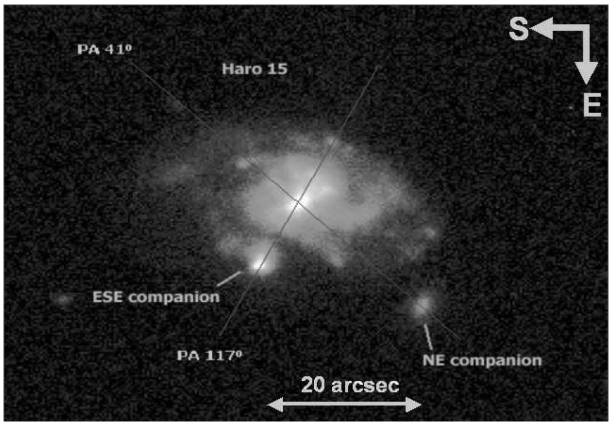

Fig. 1. Deep CCD image in the V band of the Wolf-Rayet galaxy Haro 15 (Mrk 960) and its surroundings. We plot in it the slit position used to obtain the spectra.

TABLE 1

MAGNITUDES, RADIAL VELOCITIES, ABUNDANCES RATIOS & COLORS OF KNOTS IN HARO 15

Object	M_B	Δv_r[a]	O/H[b]	[NII]/Hα	m_V	m_J	(U−B)[b]	(B−V)[c]	(V−J)	(J−H)	(H−Ks)
Center	−19.1	0	8.50	0.20	13.75	13.58	−0.41	0.31	0.17	0.58	0.32
ESE	−18.2	−17	8.17	0.03	14.53	14.33	−0.73	0.34	0.20	0.24	0.18
NE	−15.8	+89	8.30	0.10	16.88	16.31	−0.36	0.38	0.57	···	···

[a]Radial velocity (in km s^{-1}) with respect to the main body of Haro 15

[b]O/H ratio: 12+log(O/H)

[c]Data taken from Cairós et al (2001)

nebular emission. It has a radial velocity of +89 km s^{-1} with respect the center part of Haro 15. In this way, it is located at 9 kpc of the center of the system. The ESE knot lies only at 4 kpc of the ce nter. It has an absolute magnitude of $M_B \sim -18.3$.

All the three zones show nebular emission (Figure 2). The [OIII] 4363 Å emission line was only detected in the ESE knot, and we can be able to calculate the ionic abundances in a direct way for this object, which is consistent with that obtained by the empirical calibrations of Pilyugin (2000) and Denicoló et al. (2002). We have noted a significant difference in the O/H ratio between the nucleus (12+log(O/H)=8.50) and the ESE companion (8.10). This difference is also observed in the [NIII]/Hα ratio. Both ratios suggest that the objects have had a different evolution and, perhaps, they are different galaxies in a process of merging. This result is also in agreement with the position-velociy diagram for AP=117°. The NE dwarf object shows an intermediate O/H ratio (8.30). The position-velocity diagram for AP=41° also reflects its interaction with Haro 15.

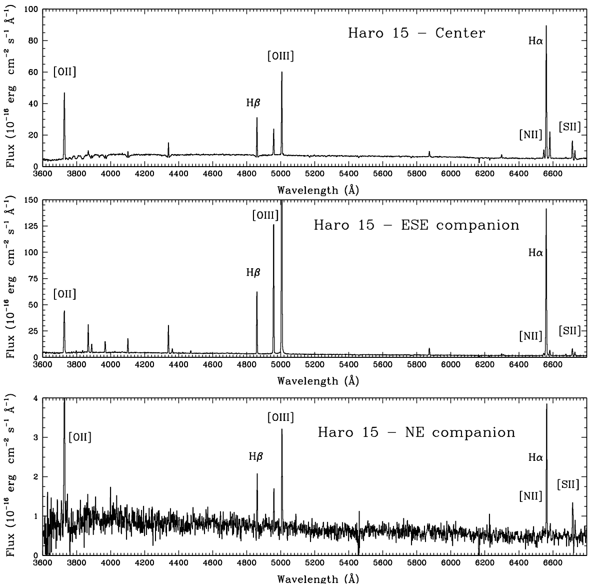

Fig. 2. Optical spectra of the studied bursts in Haro 15.

3. STARBURST STELLAR COLORS

We show our optical and near-infrared photometrical data and the colors derived for each knot in Table 1. They have been corrected by Galactic reddening, but not by internal dust reddening or nebular contribution. U and B magnitudes of Haro 15 are taken from Cairós et al (2001). We can observe the central object and the ESE knot in all the images, but it is difficult to detect the NE companion in Ks near-infrared band. In the J image we can distinguish that the three objects are embedded in the same diffuse emission. Another faint knot can be observed at 50 kpc to the NE of Haro 15 main body.

4. THE AGES OF THE BURSTS

We have used spectral synthesis models to estimate the age of the bursts. In particular, we have chosen STARBURST99 models (Leitherer et al. 1999) to compare the colors, and Wolf-Rayet starburst models by Schaerer & Vacca (1998) to analyse spectral characteristics. We have distinguished between models with $Z/Z_\odot$=1 and 0.4. Both of them are for an instantaneous burst with a Salpeter IMF, a total mass of 10^6 $M_\odot$ and a 100 $M_\odot$ upper mass. We must remember than Haro 15 has a $Z/Z_\odot$=0.37, so the best fit for it should be the $Z/Z_\odot$=0.4 model.

We plot EW(Hβ) vs. time compared with Wolf-Rayet galaxy models in Figure 3. We find a first estimation of the age of the bursts, that we collect in Table 2. We have also used the models of Stansińska & Leitherer (1996); their estimated values using the [OIII] 5007 Å emission line flux are also shown.

We plot the observed near-infrared colors values of (J−H) us (H−K) compared with the STARBURST99 theoretical models in Figure 4. We have not corrected the data for the continuum and emission of the gas, but we have estimated an average

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TABLE 2

AGE ESTIMATIONS (IN MYR) OF THE OBSERVED BURSTS IN HARO 15

Age Indicator	Center	ESE	NE	Models
EW(Hβ)	6	5 - 6	5 - 6	Schaerer & Vacca (1998)
[OIII]/Hβ	5 - 6	6 - 7	5 - 6	Stansińska & Leitherer (1996)
(U−B) vs. (B−V)	6 - 7	8 - 9	7 - 8	Leitherer et al. (1998) STARBURST 99
(J−H) vs. (H−K)	10 - 12[a]	7 - 8	...	Leitherer et al. (1998) STARBURST 99
(V−J)	6 - 7	6 - 7	7	Leitherer et al. (1998) STARBURST 99

[a]Maybe contaminated by underlying old population

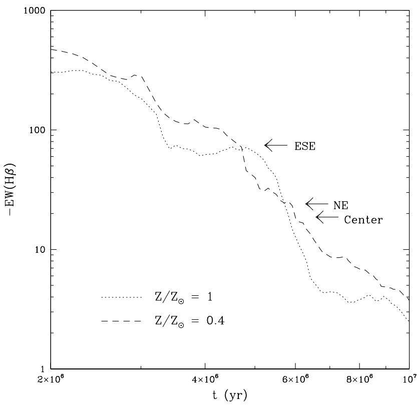

Fig. 3. Age estimations using the Wolf-Rayet starburst models of Schaerer & Vacca (1998)

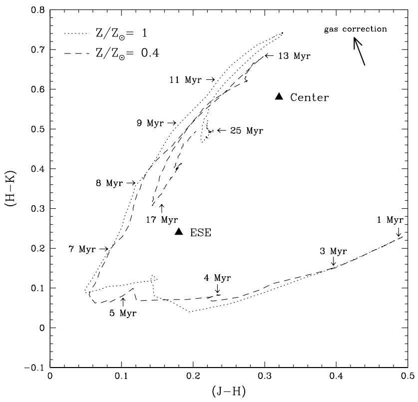

Fig. 4. Age estimations using the near-infrared colors in STARBURST 99 (Leitherer et al. 1999) models. The labeled ages are from $Z/Z_{\odot}$=0.4 model

value of these contributions using the analysis of 24 starbursts by Calzetti (1997). We plot it with the *gas correction* arrow. If we take this displacement into account, the observational data are in quite agreement with the models. Others age estimations can be also found using colors extracted from optical and near-infrared photometry. In particular, we have

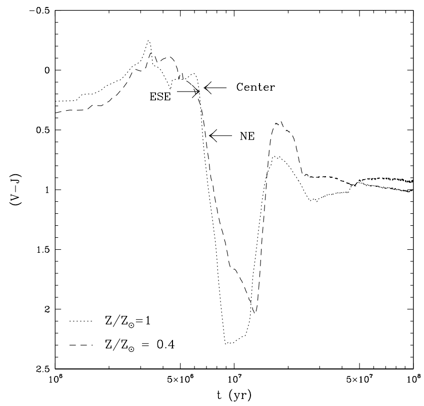

Fig. 5. Age estimations using optical and near-infrared colors in STARBURST 99 (Leitherer et al. 1999) models

plot (V−J) color vs. time in Figure 5. Finally, we can observe a good agreement in all the age estimations showed in Table 2.

5. CONCLUSIONS

We have used deep CCD optical and near infrared imagery and intermediate resolution optical spectroscopy to analyse the Wolf-Rayet galaxy Haro 15 as well as it surrounding objects. We have estimated the ages of the observed bursts using theoretical spectral synthesis models of starbursts. The results about the morphology, the kinematics, the chemical abundances and the ages reinforce the conclusions of Méndez & Esteban (2000) that interactions with or between dwarf objects could be a paramount mechanism in the star formation triggering in Wolf-Rayet galaxies.

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