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A KINEMATICAL STUDY OF THE GIANT H II REGIONS IN NGC 4449

Oriol Fuentes–Masip,[1] Casiana Muñoz–Tuñon,[1] Héctor O. Castañeda[2] and Guillermo Tenorio–Tagle[3]

RESUMEN

Presentamos los resultados de un estudio cinemático de las regiones H II en la zona central de la galaxia irregular gigante NGC 4449. Se define un nuevo método para determinar el tamaño de las regiones. Luego de obtener los parámetros integrados de las regiones H II (radio, luminosidad, velocidad radial y dispersión de velocidades), definimos correlaciones empíricas entre el tamaño y la luminosidad con la dispersión de velocidades de las regiones gigantes. Demostramos que las correlaciones son válidas únicamente para nebulosas con brillo superficial mayor que 2×10^{35} erg s^{-1} pc^{-2} en Hα y con líneas de emisión de ancho supersónico y con una única componente de perfil gausiano. El exponente de los ajustes de las correlaciones es consistente con mecanismos de virial.

ABSTRACT

We present the results of a kinematical study of the H II regions in the central area of the giant irregular galaxy NGC 4449. A new method is defined to determine the sizes of the regions. We obtained the integrated parameters of the H II regions: radius, luminosity, radial velocity and velocity dispersion. We define the size and luminosity vs. velocity dispersion empirical correlations for the giant H II regions in the galaxy, and show that the correlations only hold for nebulae with surface brightness higher than 2×10^{35} erg s^{-1} pc^{-2} in Hα and with a supersonic single line Gaussian profile. The exponent of the fits are consistent with virial mechanisms.

Key Words: **GALAXIES: IRREGULARS — HYDRODYNAMICS — ISM: H II REGIONS — ISM: KINEMATICS AND DYNAMICS**

1. INTRODUCTION

Giant H II regions (GHRs) are areas of active star formation, ubiquous in spiral and high luminosity irregular galaxies (Kennicutt 1984). The objects provide important clues to the problems of massive star formation, the chemical evolution of galaxies, and are very useful as secondary distance indicators, due to their large size and luminosity.

Since the work of Smith & Weedman (1970) it became clear that an important intrinsic characteristic of these regions was the fact that they present a supersonic velocity dispersion. This has become a central issue in interstellar medium studies. First, because it has been shown that the velocity dispersion (σ) correlates with both the size and luminosity of the regions, facts that have allowed for their use as a distance indicator. Also, because it has led to searches of the physical source required to sustain the supersonic motions, which should lead to the formation of strong radiative shocks and thus are expected to decay rapidly.

Melnick (1977) and Terlevich and Melnick (1981) found that both the size and luminosity of giant H II regions correlate with the velocity dispersion of the nebulae. The correlations between size and sigma (R $\sim \sigma^2$, and luminosity and sigma (L $\sim \sigma^4$) were also noted to be similar to the relations that hold in virialized stellar systems, such as globular clusters, spiral bulges and the nuclei of elliptical galaxies. These facts allowed them to postulate that the observed σ values reflect the total mass of the systems. Whereas the correlation seems to

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be well established (Melnick et al. 1987), different groups (see, for example, Hippelein 1986; Roy et al. 1986; Arsenault & Roy 1988) reports slopes slightly different to the ones found by Terlevich and Melnick (1981).

The value of the slope is closely dependent of the mechanism that explains the origin of the supersonic line–widths. Those mechanisms split into two main groups. In the gravitational models, the detected Gaussian line profiles are believed to be related to virialized motions within the H II regions, predicting $\sigma \sim (GM/R^2)^{0.5}$, as in the most recent cometary stirring model (CSM) of Tenorio–Tagle, Muñoz–Tuñon & Cox (1993). A completely different broadening mechanism involves the combine action of several unresolved stellar wind–driven expanding shells and filaments (Dyson 1979; Chu & Kennicutt 1994). The understanding of this effect is very important, since the line width of a region is easier to measure precisely and objectively than the luminosity and the diameter. However, establishing and using these correlations still requires a precise determination of sizes and luminosity, what requires a sample of GHRs as homogeneous as possible.

With this aim, we have started a long term program for the study of GHRs in irregular galaxies. Here we present the results obtained for the Giant H II regions of the irregular galaxy NGC 4449. This is the first time that an irregular galaxy is selected for this kind of study.

2. OBSERVATIONS

TAURUS–II Fabry–Pérot imaging spectroscopy was carried out on NGC 4449. The observations were taken at the 4.2 m William Herschel Telescope at the Observatorio del Roque de los Muchachos at La Palma, in the Canary Islands. Four data cubes were obtained for the galaxy, two in Hα and two in [O III]λ5007. The observed area contains the largest and most luminous H II regions of the galaxy. The Free Spectral Range of the intrument was 13.4 Å, or 610 km s^{-1} in Hα, and 7.78 Å (466 km s^{-1}) in [O III]λ5007. Spectral scanning was 0.29 Å per step in Hα, 0.13 Å per step in [O III]. The spatial scale was 0.26 arcsec pixel (6.30 pc at the distance of NGC 4449). Exposure time for each cube was one our. We use the Image Photon Counting System (IPCS) as detector, scanning 100 planes continuously with 10 millisecond exposures to average effects of atmospheric transmission variation during the one–hour exposure time. A phase corrected and wavelength calibrated TAURUS data cube was produced using the specific software MATADOR (Muñoz–Tuñon, Gavryusev & Castañeda 1995).

3. DATA ANALYSIS

The high density of nebulae per unit area, together with the important diffuse luminosity engulfing the H II made it particularly difficult to catalogue and determine the integrated parameters of all the objects. We modeled and subtracted the diffuse luminosity of the galaxy. To get rid of effects of subjectivity in size determination we used FOCAS (Faint Objects Classification and Analysis System, developed within the IRAF environment). The program analyzed the continuum free flux maps, finding the relative maxima of emission, their position, average level of the corresponding lower isophote (defined from a threshold of 3 times the local background) and the area and flux enclosed. Finally, we extrapolate their luminosity profiles to get estimations of their sizes, assuming that the original profile is gaussian.

Two typical sizes were defined for a region: $\mathbf{R}$ (defined at a count level 3 times higher than the standard deviation of the local background), and $\mathbf{R}_F$ (corresponding to the full width at half maximun of the real luminosity profile). The luminosity $\mathbf{L}$ of each H II region was defined as the total volume enclosed by the bidimensional gaussian that represents the luminosity profile. To obtain the kinematical parameters of the nebulae, we restricted the spectra extraction to areas detected by FOCAS (this is, the highest part of each luminosity profile, presumably not affected by neighbouring H II regions). Spectra with low S/N ratios were eliminated from the analysis. Also, on those nebulae showing asymmetric or split profiles, the σ value, measured by the fitting of one single Gaussian, is clearly badly defined (for example, an asymmetric or split profile may be the result of several H II regions overlapped along a line of sight), and were eliminated for the study of correlations. This analysis was carried out independently for both Hα and [O III], and the resulting sub–sample of H II regions that fulfilled the criteria of line quality was used for the analysis (see Fuentes–Masip, Castañeda & Muñoz–Tuñon 2000 for a detailed discussion). In this paper we will only present the Hα results.

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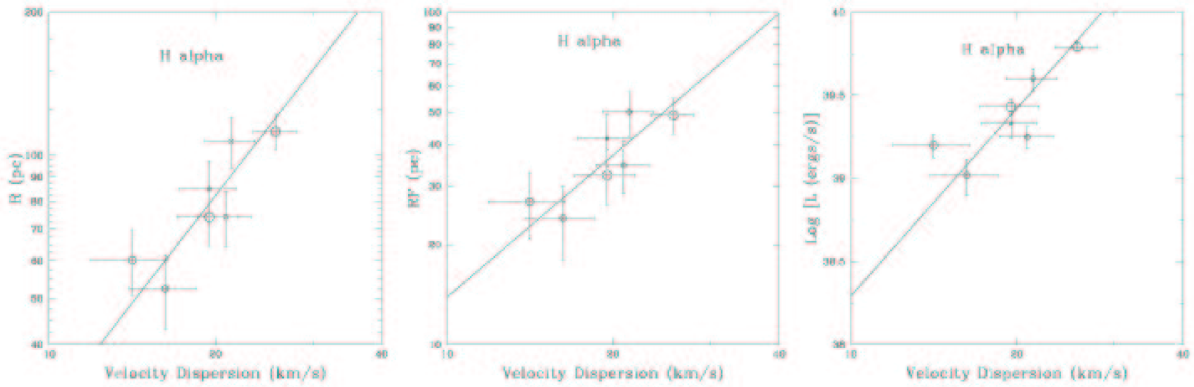

Fig. 1. The size and luminosity vs. σ correlations in NGC 4449, from the Hα data. We present the correlations between log R vs. log σ (left), log R$_F$ vs. log σ (center) and log L vs. log σ (right) for the regions of highest surface brightness, with symmetric spectral profiles and good S/N. Symbols are scaled to the surface brightness of the regions (From Fuentes–Masip et al. 2000). (Due to the poor reproduction of the original figure, the scales are: a) left figure: **R** scale: 40-200 pc – σ scale: 10-40 km s^{-1}; b) center figure: **R**$_F$ scale: 10-100 pc – σ scale: 10-40 km s^{-1}; c) right figure: **L** scale 38-40 – σ scale: 10-40 km s^{-1}).

4. DISCUSSION

The most important result that follows from our study is that only those regions with high surface brightness present a significant correlation among the varius parameters. The range of surface brightness for the nebulae that display correlations between their integrated parameters amoung those already classified by having a good line profile was derived from a trial and error procedure searching for the best fit in the log L - log σ representation. The surface brightness (ν) threshold was set at log $\nu_{H\alpha}$ (erg s^{-1} pc^{-2} $\geq$ 35.3).

The resulting set of points has been fitted using a standard regression procedure, accounting for the errors associated to every single point. The parameters resulting from the regression, the errors and the correlation coefficients for the Hα data are:

$\log(\mathbf{R}\ [pc]) = (1.50 \pm 0.53)\ \log\ (\sigma[km\ s^{-1}]) - (0.03 \pm 0.76)$; r = 0.866,

$\log(\mathbf{R_F}\ [pc]) = (1.42 \pm 0.60)\ \log\ (\sigma[km\ s^{-1}]) - (0.28 \pm 2.42)$; r = 0.845,

$\log(\mathbf{L}\ [ergs^{-1}]) = (3.75 \pm 1.17)\ \log\ (\sigma[km\ s^{-1}]) + (34.54 \pm 1.74)$; r = 0.825.

Similar parameters for the fits were obtained for the [O III] data (Fuentes–Masip et al. 2000). The parameters derived for the correlation between size and σ and luminosity and σ are not in disagreement with the values derived by other groups, particularly if one considers the errors in the determination of all physical variables and the scatter around the regression curves.

A similar result has been found in studies of the spiral galaxy NGC 4321 (Arsenault, Roy & Boulesteix 1990; Rozas et al. 1998) in which, only after restricting the sample to nebulae with the highest surface brightness, the **L**-σ correlation became evident. Nevertheless, in both studies the slope of the correlation was lower ($\sim$ 2.6) than our results. Rozas et al. (1998) explain the lower slope of their fit (when compared with the expected value for virialized motions) in terms of density bounding for the regions of highest luminosity.

5. CONCLUDING REMARKS

From our two dimensional spectroscopic data of the giant irregular galaxy NGC 4449 we have catalogued 44 H II regions from their Hα emission lines and 24 from their [O III] counterparts. For all the detected regiones we have obtained their diameter, luminosity, surface brightness as well as their radial velocity and velocity dispersions.

The statistical analysis of the giant H II regions in our sample has shown that the correlation between size and σ and luminosity and σ only become apparent for nebulae with a high surface brightness that show also single Gaussian supersonic emission lines. The need of a high surface brightness sample is an effect hardly noticed in previous studies due to their bias towards first ranked giant H II regions.

Our results show that the regression curves, within the errors, are consistent with all former works supporting virialized systems as the ultimate origin of the supersonic motions. This holds despite the fact that only a small number of H II regions, among all those catalogued in NGC 4449, define the log-log relationship between their structural and intrinsic parameters. We have noticed that all these regions surpass a surface brightness threshold, and thus the existence of the correlations may also involve the age, evolution, disruption and expansion of the considered nebulae.

Regarding sizes, we conclude that our results hold for both $\mathbf{R}$ and $\mathbf{R}_F$, implying that any of them can be used in future work. Regarding luminosity, as stated previously, the more luminous the region is, the better that it fits the correlation. Note however that the more luminous regions may be affected by the structure of the host galaxy and the distribution of the ISM. Indeed, larger and brighter H II regions may rapidly evolve into density bounded nebulae. In such cases, the number of detected recombinations would not balance all photons emitted by the exciting stars and thus the true luminosity will be ill determined.

On the other hand, an ionization bounded H II region may simply reflect the fact that no all massive stars have formed. In this case although σ may already fully established as in the cometary stirring model, and well determined by accurate observations of single gaussians, the line and luminosity of the region would be underestimated.

The fact that the most luminous regions are the ones that best follow the defined relationships, points towards a physical mechanim which should involve the whole mass of the cloud. This, together with the exponents found, favour the virial as the physical scenario behind them.

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