H\textsubscript{\alpha} Luminosity and Star Formation of Galaxies in HCGs

Paola Severgnini
(paola@ifctr.mi.cnr.it, paolas@arcetri.astro.it)
IFC-CNR ‘G. Occhialini’, via Bassini 15, 20133 Milano, Italy
Univ. Studi di Firenze, Dip. Astronomico di Arcetri, Firenze, Italy

Paolo Saracco (saracco@merate.mi.astro.it)
Osservatorio Astronomico di Brera, via E. Bianchi 46, 22055 Merate, Italy

Abstract.
We have obtained H\textsubscript{\alpha} fluxes and luminosities for a sample of 95 accordant galaxies from observations of 31 Hickson Compact Groups (HCGs) in the North hemisphere. This sample is the largest H\textsubscript{\alpha} selected catalogue of galaxies having H\textsubscript{\alpha} calibrated fluxes so far. The results obtained from a preliminary analysis of a subsample of 66 galaxies show that the H\textsubscript{\alpha} luminosity of galaxies is correlated with velocity dispersion and compactness of groups. Such correlations would point toward a scenario in which H\textsubscript{\alpha} brightest galaxies reside in compact groups having higher probability of galaxy interaction i.e. lower values of velocity dispersion. Moreover such relations seem to depend on the environment in which HCGs themselves are embedded.

1. Introduction

Hickson Compact Groups (hereafter HCGs; Hickson 1982) are small systems of several galaxies (four or more) in an apparent close proximity in the sky. Their dynamical state has been the subject of a controversial debate. Comparison of the observational data with model calculations led Mamon (1986, 1987) to conclude that less than a half of HCGs could be considered bounded dense systems. However accumulated statistical evidences (Hickson & Rood 1988; Hickson 1992) together with observational evidences, also coming from X-ray observations (Saracco & Ciliegi 1995; Ponman et al. 1996; Pildis et al. 1995), clearly favor the view that the majority of HCGs are physical systems and not chance projections or transient systems.

One of the expected consequences of the gravitational interactions between galaxies is the enhancement of the star formation rate (SFR) in the interacting systems (Joseph & Wright 1985; Bushouse 1987; Laurikainen & Moles 1989). The photometric and spectroscopic studies carried out so far (Rubin et al. 1991 & Mendes de Oliveira et al. 1997; Moles et al. 1994 & Mendes de Oliveira et al. 1994; Vilchez & Iglesias
Paramo 1998; Plana et al. 1998, Iglesias Paramo & Vilchez 1999), aiming at establishing the fraction of interacting galaxies in HCGs, have often given contradictory results. Actually a possibility exists that only a fraction of the HCGs are bound systems and that bound HCGs evolve in different ways. Different evolutions could be due to both the different dynamical properties of HCGs and to their different 'birthplace', i.e. the environment in which they are embedded.

Powerful signs of star formation activity are the ionization lines emitted by the heated gas surrounding the regions of star formation. Unlike the color indexes in the \( U, B, V \) filters, that give indications about the past star formation (> 10\(^8\) years), the H\(_\alpha\) emission line at 6563 Å can be used as a quantitative and spatial tracer of the rate of massive (\( \geq 10 \, M_\odot \)) and therefore recent (\( \leq 10^7 \) years) star formation (Kennicutt 1983; Ryder & Dopita 1994). Therefore, knowing the H\(_\alpha\) emission of the HCG galaxies, it is possible in principle to carry out important knowledges about the present merger and interaction events in these systems. Up to now the only H\(_\alpha\) images regarding HCG galaxies have been collected by Rubin et al. (1991) and more recently by Vilchez & Iglesias Paramo (1998). They carried out H\(_\alpha\) emission-line images respectively for 14 and 16 HCGs. While Vilchez & Iglesias Paramo estimate the H\(_\alpha\) flux for each of the 63 galaxies of their sample (Iglesias Paramo & Vilchez 1999), Rubin et al. do not use flux calibrated and they take into account a sample constituted by disk galaxies only. We have recently obtained H\(_\alpha\) fluxes and luminosities for a sample of 95 galaxies from calibrated observations of 31 HCGs (Severgnini et al. 1999). Here we present the preliminary results of the analysis performed on a subsample of 66 galaxies.

2. Observations

Observations have been carried out at the 2.1 meter telescope (design Ritchey-Chretien) at the National Observatory of Mexico in S. Pedro Martir during three different observing runs (November 1995, April 1996 and February 1997). The telescope was equipped with a Tektronix CCD of 1024x1024 pixels, each 24\(\mu\)m x 24\(\mu\)m. The telescope scale (13 arcsec/mm) and the pixel dimensions provide a pixel size of 0.3 arcsec/pix with a resulting field of view of 5.12' x 5.12'. During these three runs we observed 31 HCGs in H\(_\alpha\) filters. The remaining 61 HCGs were not in ours sample because the adequate H\(_\alpha\) interferometric filters were not available. This is the only criterion used to select the observed groups.
In order to calibrate our data, we have observed some spectrophotometric stars, equally spaced in time during each night, taken from the list of Massey & Strobel (1988). The standards were observed in all the $H_\alpha$ narrow-band filters used to observe HCGs.

During the observations the seeing was in the range of 2 to 2.6 arcsec and the photometry was within 0.05 mag in all but one (worse) night. The mean limiting flux of the observations, at one sigma from the background and within the mean seeing disk (2.3 arcsec), is $9.22 \times 10^{-17}$ erg cm$^{-2}$ s$^{-1}$. We estimated the $H_\alpha$ flux and luminosity for 66 galaxies, 12 out of which are upper limits. We adopt $H_0=100$ km/(s Mpc) and $q_0=0.5$.

In Figure 1 the distribution of $H_\alpha$ luminosity ($L_{H_\alpha}$) of the 54 detected galaxies is shown. $L_{H_\alpha}$ for each galaxy has been derived from using a $H_\alpha$ isophotal flux computed within the region defined by a detection threshold of one sigma above the background. A detailed description of the data reduction, the photometric calibration, the flux estimate and the luminosity derivation is given in Severgnini et al. (1999).

3. Results

We have investigated about the dependency of the $H_\alpha$ luminosity of galaxies on the dynamical properties of HCGs and on the environment in which groups are embedded. The statistical analysis we have performed has made use of the survival analysis (Isobe, Feigelson & Nelson...
Figure 2. $H_\alpha$ luminosity of the 66 galaxies of our sample vs velocity dispersion of the groups. There is a clear correlation (the probability of the two not being correlated is $P=0.001$) which suggests an increasing of $H_\alpha$ luminosity of galaxies with decreasing of velocity dispersion of groups.

Figure 3. $H_\alpha$ luminosity of galaxies vs velocity dispersion of the isolated HCGs (upper panel) and of the HCGs embedded in loose groups (lower panel). The velocity dispersion of HCG$_L$ is correlated to $H_\alpha$ luminosity of their galaxies (the probability of the two not being correlated is $P=0.03$), while the same correlation is absent for HCG$_I$ ($P=0.60$). In both the Figures 2 and 3, galaxies are binned in dynamical properties. The dots represent the mean luminosity and the error bars are the standard deviations of the values. The down arrows refer to upper limits inside of the bin. In Figure 2 the width of the bins is also shown.
1986) since some of the observed galaxies have not been detected in our observations.

In an undisrupted galaxy it is expected that actual SFR ($<10^{6-7}$ years) is correlated to the quantity of young stellar population (O,B stars). To test if this correlation is present also for HCG galaxies we searched for a correlation between the $H\alpha$ luminosity of galaxies and their $B$ absolute magnitude ($M_B$ ("Atlas of Compact Groups of Galaxies", Hickson 1993)), good tracer of young stars. We found a significant correlation between these two quantities in the sense that:

- galaxy having higher (lower) $H\alpha$ luminosity have higher (lower) $B$ luminosity.

We have then searched for correlations between the dynamical parameters of HCGs (velocity dispersion, mass density, surface brightness and crossing time, as from Hickson et al. 1992) and the $H\alpha$ luminosity of the member galaxies. Our analysis shows the presence of correlations between each of these parameters and the $H\alpha$ luminosity of the galaxies. In particular we found that the $H\alpha$ emission is correlated to crossing time and it is anti-correlated to velocity dispersion, mass density and surface brightness in the sense that:

- HCGs having higher (lower) densities have higher (lower) velocity dispersions and the galaxies inside them have lower (higher) $H\alpha$ luminosities.

In Figure 2 the relation between $H\alpha$ luminosity of galaxies and the velocity dispersion of the groups is shown (the probability of the two not being correlated is 0.001). Such correlations would seem to point toward a dependence of the $H\alpha$ luminosity of galaxies, and hence of their SFR, on the dynamical properties of HCGs.

To test if different environments, where HCGs are actually found, affect the $H\alpha$ of galaxies inside them we have divided our sample in two subsamples, following the Rood and Struble’s (1994) classification: the first composed by the isolate compact groups (HCG$_I$) and the second one consisting of those compact groups embedded in loose groups (HCG$_L$). Through a statistical comparison we found that there aren’t significant differences between $H\alpha$ luminosity distributions of galaxies inside HCG$_I$ and HCG$_L$. The same result is found if we compare the dynamical parameters of isolate HCGs to those of HCGs in loose groups. Nevertheless, from our data we found that the velocity dispersion (Figure 3) and crossing time of HCG$_L$ are correlated to the $H\alpha$ luminosity of their galaxies and that these correlations are absent for HCG$_I$. We thus can assert that inside HCG$_L$ there are correlations between two dynamical parameters and $H\alpha$ emission that are not present inside
HCG\textsubscript{I}. These results suggest that, although the surrounding environment of HCGs does not directly influence the SFR of galaxies and the dynamical properties of groups, it modifies the relation between dynamical properties of groups and SFR of their galaxies. Moreover we have tested that the correlation found between \( H_\alpha \) and \( B \) luminosity is present only for galaxies inside HCG\textsubscript{L} (Figure 4). This result suggests that the different HCG environments affect also the ratio between the population of young stars and actual star formation of galaxies.

Thus we assert that the surrounding environment of HCGs affects the evolution of the HCG galaxies.

Finally, we also investigated if the morphology of galaxies is influenced by different environments and if a particular HCG surrounding environment can favor the formation and evolution of a particular morphology. We divide all the galaxies of Hickson’s sample in Ellipticals + Lenticulars (E/S0) and Spirals + Irregulars (S/I) finding the same fraction of E/SO and S/I inside HCG\textsubscript{I} and HCG\textsubscript{L} respectively. Thus we conclude that the environment in which HCGs are embedded does not influence the morphology of their member galaxies.
4. Discussion and Conclusions

We have studied $H_\alpha$ calibrated fluxes for a sample of 66 galaxies in 31 HCGs. 12 galaxies of our sample have not been detected in our images and this implies that they have a $H_\alpha$ emission lower than $f_{\text{lim}} = 9.22 \cdot 10^{-17} \text{ erg s}^{-1} \text{ cm}^{-2}$, being $f_{\text{lim}}$ the $1\sigma$ limiting flux integrated within one seeing disk reached in our observations.

From the analysis presented above, we could conclude that the $H_\alpha$ luminosity of galaxies is affected by the dynamical properties of compact groups. The correlations found would point towards a merger scenario in which $H_\alpha$ brightest galaxies are inside groups with higher probability of interaction i.e. lower values of velocity dispersion and mass density. It is worth noting however that $H_\alpha$ luminosity could be matched by mass of galaxies, that is the SFR could be higher (lower) because of the higher (lower) quantity of the available gas and not because of a real higher efficiency or fraction. In principle such degeneracy could be avoided normalizing the $H_\alpha$ luminosity by a mass tracer of galaxies which is very well represented by the luminosity in the near IR band (H or K band), as shown by Gavazzi et al. (1996). Nevertheless some authors (e.g. Iglesias Paramo et al. 1999) make use of the absolute B magnitude under the implicit assumption that $M \propto L_B$. On the other hand, since a correlation between $H_\alpha$ and B luminosities is expected under robust assumptions (and we found it) the use of $L_B$ to remove the degeneracy could lead to misleading results. Thus, even if we find correlations between $H_\alpha$ luminosity and dynamical parameters of the groups, further investigations are required in order to establish if the dynamics of HCGs affects the evolution of their member galaxies.

Moreover the relations we find seem to depend on the environment in which HCGs are embedded, as confirmed by the correlations found only in the case of HCG_L sample. Since the $H_\alpha$ luminosity is a good star formation tracer, this result suggests that also the environments surrounding HCGs could influence the evolution of galaxies into HCGs.

The SFR for objects can be directly inferred by $H_\alpha$ luminosity using the result of Kennicutt (1983), which relates the SFR to $H_\alpha$ luminosity through the relation

$$\text{SFR} (\text{total}) = \frac{L(H_\alpha)}{1.12 \cdot 10^{41} \text{ erg s}^{-1} M_\odot \text{ yr}^{-1}}$$

where a Salpeter initial mass function with an upper mass cutoff of 100 $M_\odot$ have been assumed. From the luminosities we infer a star formation rate for our detected galaxies in the range 0.01-2.88 $M_\odot \text{ yr}^{-1}$ in absence of internal extinction.
References

Bushouse H. A., 1987, ApJ 320, 49
Gavazzi G., Pierini D., Boselli A. 1996, A&A, 312, 397
Hickson P. 1982, ApJ 255,382
Hickson P. 1993, ApJL V.29:1-3, P.1 "Atlas of Compact Groups of Galaxies"
Hickson P., Mendes de Oliveira C., Huchra J. P., Palumbo G. G. C., 1992, ApJ 399, 353
Hickson P., Rood H. J., 1988, ApJ 331, L67
Iglesias Paramo J. & Vilchez J.M. 1999, astroph/9902336
Isobe T., Feigelson E.D. & Nelson P.I. 1986, ApJ 306, 490
Joseph R. D., Wright G. S. 1985, MNRAS, 214, 87
Kennicutt R. C., 1983, ApJ, 272, 54
Laurikainen E., Moles M., 1989, ApJ, 345, 176
Mamon G.A. 1986, ApJ 307, 426
Mamon G.A. 1987, ApJ 321, 622
Massey P., Strobel K., Barnes J.V. e Anderson E. 1988, ApJ 328, 315
Mendes de Oliveira C.M., Amaram P., Balkowski C. & Boulesteix J. 1997, ASP Conf. Ser., Vol. 117, 156
Mendes de Oliveira C.M. & Hickson P. 1994, ApJ 427, 684
Moles M., del Olmo A., Perea J., Masegosa J., Marquez I. & Costa V. 1994, A&A 285, 404
Pildis R.A., Bregman J.N. & Evrard A.E. 1995, ApJ 443, 514
Pildis R.A., Bregman J.N. & Schombert J.M. 1995, AJ 110, 1498P
Plana H., De OliveiraC., Ambram P. & Boulesteix J. 1998, AJ 116, 2123P
Ponman T. J., Bourner P. D. J., Ebeling H., Bohringer H., 1996, MNRAS, 283, 690
Rood H.J.e Struble M.F. 1994, P.A.S.P. 106, 413
Rubin V.C., Hunter D.A. & Ford W.K.1991, ApJS 76, 153
Ryder S. D., Dopita M. A., 1994, ApJ, 430, 142
Saracco P., Ciliegi P., 1995, A&A, 301, 348
Severgnini P., Garilli B., Saracco P.& Chincarini G., 1999, A&A, in press.
Vilchez J.M. & Iglesias Paramo J. 1998, ApJS 117, 1

Address for Offprints: Paola Severgnini
IFC 'G. Occhialini', via Bassini 15
20133 Milano, Italy
e-mail: paola@ifctr.mi.cnr.it