INTEGRATED Hα PROFILES OF GIANT EXTRAGALACTIC H II REGIONS

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ABSTRACT

Integrated Hα profiles of 47 giant extragalactic H II regions in 26 nearby galaxies were obtained with a large-aperture Fabry-Perot spectrometer. It is found that 66% of the profiles are symmetrical and best fitted with a single Doppler component; the remaining profiles show asymmetries and are best fitted with two or three spectral components. More than half of the single-component Hα profiles are better characterized with a de Voigt profile than with a Gaussian profile. The H II regions with complex integrated profiles tend to have larger total widths than the H II regions with symmetrical profiles. In two-component line profiles, the weaker component is seen to be more often redshifted with respect to the main component. The heliocentric radial velocities are given with other profile parameters, and the individual profiles are presented. The Hα profiles of five isolated extragalactic H II regions and of three galaxy nuclei are also shown and briefly discussed.

I. INTRODUCTION

Giant extragalactic H II regions (GEHR) are gigantic volumes of ionized gas found in the disk of late-type spirals and in dwarf irregulars of Magellanic type or isolated objects in the intergalactic space (H II galaxies). A "giant extragalactic H II region" is any extragalactic H II region ionized by an aggregate of early-type stars. Compared with most local H II regions, a typical object is larger (> 100 pc), less dense (10–100 cm–3), has faster gas flows, and is ionized by more stars (tens to hundreds). GEHRs are or have been very active star-forming complexes of stars. The luminous flux of these giant nebulae indicates that they harbor massive stars which inject enormous quantities of energy into the interstellar medium via radiation, stellar winds, and finally as supernova events. Studies of GEHRs can help us to establish the large-scale physical conditions in the interstellar medium and to understand the triggering of star formation in galaxies.

Despite their great sizes (100–1000 pc), GEHRs have angular sizes less than 30 arcsec except for the few nearby objects such as NGC 3603 in the Galaxy, 30 Dor in the Large Magellanic Cloud, and NGC 604 in M33. Consequently, most investigations have explored integrated properties of these objects. Despite greatly differing structural properties, such as luminosities, masses, and densities (Kennicutt 1984), GEHRs have in common the property of large supersonic internal motions first established by Smith and Weedman (1970), Melnick (1977) and Terlevich and Melnick (1981) later found a correlation between the velocity widths (in excess of thermal width) of integrated Hα line profiles and the linear diameters and luminosities of GEHRs. Melnick (1978) and de Vaucouleurs (1979b) showed that the mean velocity widths of the largest H II regions also correlate with the absolute blue magnitudes of the parent galaxy. However, doubts were raised about the above relations were raised by Gallagher and Hunter (1983), who failed to confirm the relation between diameters and velocity widths in GEHRs smaller than 500 pc. However, in a recent Fabry-Perot interferometric study of the integrated Hα profiles of 47 GEHRs, we confirmed the basic trends found by Melnick (Roy, Arsenault, and Joncas 1986, hereafter referred to as Paper I; Roy and Arsenault 1986). Because of the small angular sizes of GEHRs, it is difficult to obtain data with spatial resolution. Nonetheless, there have been several spectroscopic investigations using echelle spectroscopy (Rosa and Solf 1984 of NGC 604; Skillman and Balick 1984 for several GEHRs; Meaburn 1977 of 30 Dor) and Fabry-Perot interferometry (e.g., Smith and Weedman 1972 of 30 Dor; Lasker 1980 of N51D). Melnick (1980) and Hippelein and Fried (1984) obtained interferometric data allowing a spatially resolved study of the kinematics of NGC 604.

Integrated Hα profiles of GEHRs are generally well adjusted with a single Gaussian profile (Melnick 1977; Skillman and Balick 1984; Paper I). On the other hand, profiles obtained in [O iii] 5007 Å, and several instances of high-signal-to-noise Hα profiles, show asymmetries (Skillman and Balick 1984). Data with spatial resolution reveal that line profiles of GEHRs are not well represented by single Gaussians, and that asymmetrical profiles appear to be spatially limited to inner regions of small extent (Skillman and Balick 1984).

This paper presents high-signal-to-noise integrated Hα profiles of GEHRs. Attention is paid to the shapes of these profiles, which are used to draw conclusions about the internal kinematics of giant H II regions. Positions, radial velocities, and other profile characteristics of GEHRs are also given. In addition, Hα profiles of five isolated extragalactic H II regions and of three nuclei of galaxies are also presented.

II. OBSERVATIONS

The integrated Hα profiles of the giant H II regions were obtained with a large-aperture Fabry-Perot spectrometer; the servo-controlled piezoelectrically scanned etalon has a FWHM of about 20 km/s, and a free spectral range of 283 km/s at Hα. Various interference filters were used to match the right interference order of the etalon with the redshifted Hα profiles of the different galaxies. The instrument is described in Arsenault and Roy (1984) and in Paper I. The observations were obtained with the 1.6 m telescope of the Observatoire Astronomique du Mont Mégantic, and with the Canada-France-Hawaii 3.6 m telescope. The entrance diaphragm of the spectrometer isolates the observed H II region from the surrounding area of the sky; it corresponds to...
48" on the 1.6 m telescope and to 21" on the 3.6 m telescope. The galaxies in which GEHRs were observed are listed in Table I, with their positions, morphological types, luminosity classes, and distance moduli. The distance moduli come from the work of Richter and Huchtmeier (1984); these distances are slightly different but consistent with those of the Revised Shapley-Ames Catalog of Bright Galaxies (Sandage and Tammann 1981). This set of distances was chosen for reasons of methodology discussed in Paper I; the reader should refer to Table II, where the heliocentric radial velocities of the parent galaxies are given in the RSA for this first-order approximation. Heliocentric radial velocities deduced from the Ha profiles of the individual H II regions are listed in Table II; the radial velocity corresponds to the centroid wavelength of the best-fitted Gaussian profile adjusted to the observed points of the profiles. As we will see later, this adjusted Gaussian is not always the best function to use in fitting the observations. The uncertainty of the radial velocities depends on the uncertainty of the centroid wavelengths of the observed and the calibration profiles.

The internal velocity dispersion of GEHR is measured by the velocity width W corresponding to the e-folding width of the Gaussian which, convolved with the thermal broadening and with the instrumental function, reproduces the observed profile. Temperatures of GEHRs were taken from different sources when available, or were assumed to be 10 000 K. Details are given in Paper I. For each H II region, the instrumental profile was taken as the Lorentzian profile of the neon line at 6595 Å given by the spectrometer, using an entrance diaphragm of a size corresponding to the angular diameter of the H II regions. Paper I gives the sources of angular diameters used for deriving the linear diameters of GEHRs. A majority of GEHRs have isophotal diameters taken from Kennicutt (1978).

The observed profiles and the fitted profiles are shown in Fig. 1. The cross symbols are the observed points; the full line is the best-fitted function. When more than one component is present, they are shown as broken-line profiles. The straight line at zero count is the reference line for the residuals. The wavelength scale (in nanometers) is relative; the straight line at zero count is the reference line for the residuals.

TABLE I. Observed galaxies.

<table>
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a) Richter and Huchtmeier (1984)
b) Sandage and Tammann (1981)
c) Kraan-Korteweg and Tammann (1979)
The reduced \( \chi^2 \) of a one-component Doppler Gaussian fit was larger than 2, we tried fits with one de Voigt profile, or with two or three Gaussians, wherever the FWHM of each component was large enough to have reasonable meaning. We found that the most complicated profiles (e.g., NGC 4631 cm 67, NGC 4321 nuc, etc.) were well adjusted with three components. The presence of these multiple components in several profiles does not necessarily mean that they originate from separate physical components or clouds in the complex. The multicomponent fit is merely a mathematical way of describing the obvious asymmetry of the profiles.

Nine GEHRs were observed both at Mont Mégantic (1.6 m telescope) and with the CFHT telescope (3.6 m). We find a slight but systematic difference of 2.2 km/s between those velocity widths, with the Mont Mégantic values being larger; the angular size of the entrance diaphragm on the sky was larger on the smaller telescope. A larger projected diaphragm accepts more light from the surrounding gas; this may change the width of the integrated profile. On the other hand, the CFH profiles had a higher signal-to-noise ratio; part of the excess width of the Mont Mégantic profiles could be due to noise.

Table III lists each GEHR according to the shape of its best-fitted profiles (one Gaussian, one de Voigt, double or triple Gaussian). No particular trend of shape or number of components is observed as a function of galaxy type. Very broad components are sometimes present (as in NGC 592, NGC 2403, and NGC 5194I). This broad component is weak and reveals the presence of very extended wings in these profiles; they are seldom centered at the position of the main component. In the two-component profiles, the weaker component is redshifted with respect to the main component for seven out of ten H II regions with double components. Six GEHRs show three-component profiles. The most conspicuous of these profiles is that of NGC 4631 cm 67, which is very broad and displays some of the features found in nuclei of galaxies.

Twenty (43%) GEHRs have profiles characterized by a de Voigt profile; 11 (23%) other GEHRs have profiles that are better fitted with a single Gaussian; ten (21%) GEHRs have profiles adjusted with two Gaussians, and six (13%) with three Gaussians. The complexity of the profiles is somewhat related with the signal-to-noise ratio. Indeed, the mean S/N is 14.1 for the single Gaussian profiles, 18.4 for the de Voigt profiles, 19.1 for the two Gaussian profiles, and 21.0 for the triple Gaussians. Obviously profiles with better S/N reveal more fine structure. Nevertheless, some high S/N profiles are clearly symmetrical and single-component profiles.

The total velocity widths of the profiles increase significantly when going from single-component to triple-component profiles. This progression in the velocity widths is illustrated in Fig. 2. The histogram including all the velocity widths shows a depression at the center of the distribution. However, because of the small size of the sample, the number of GEHRs per bin is not high enough to draw a conclusion about the reality of this lack of velocity widths at around 25 km/s. Following the relation between the absolute magnitude of the parent galaxies and the mean velocity widths of their largest giant H II regions (Roy and Arsenault 1986), a value of \( W = 25 \) km/s corresponds to galaxies with \( M_p \).
Fig. 1. Integrated Hα profiles of giant extragalactic H II regions obtained with a large-aperture Fabry-Perot spectrometer. The crosses (+) are the observed points; the full lines are the fitted profiles. The horizontal line at zero level is the reference line for the residuals. When a multicomponent fit is better, the separate components are shown as broken-line profiles. Several profiles of isolated extragalactic H II regions and three profiles of galaxy nuclei are also presented. The wavelength range scaled in nanometers is relative (0.1 nm = 46 km/s); refer to Table I for the values of the radial velocities deduced from the centroids of single Gaussians adjusted to the observed points.
Fig. 1. (continued)
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Fig. 1. (continued)
### Table III. Line profiles of giant H II regions.

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\[ \approx 18, \text{ a range of magnitudes that is well represented in our sample. This apparent discrepancy may support a bimodal distribution of velocity widths. If real, this type of distribution would mean the existence of two classes of GEHRs, or at least two mechanisms acting as energy sources for internal motions in GEHRs.} \]

**IV. DISCUSSION**

**a) Normal Giant H II Regions**

Normal giant H II regions refer here to objects found in the disks of late-type galaxies and in irregulars. The observed trend is for GEHRs with large diameters to have large velocity widths (Melnick 1977; Paper I). The observation of a large H II region means a larger probability of observing a volume of ionized gas having several exciting sources (Kennicutt 1984). Several high-intensity knots with slightly different radial velocities may contribute to the integrated Hα profile, where each intensity knot corresponds to one profile component. There is an increase in total velocity width as one considers more complicated profiles [Fig. 2(b)].

The common occurrence of de Voigt profiles leads to the conclusion that there are, at least, two empirical types of line profiles for giant H II regions: Gaussian and de Voigt. It is not clear whether one should associate the broad wings of profiles of H II regions characterized by de Voigt profiles with the motions of gas belonging to halos of giant H II regions, or with small cores having high velocity dispersion but contributing little to the total intensity. For example, Melnick (1980) and Hippelein and Fried (1984) have observed larger velocity dispersions in the "core" of NGC 604 than in

![Fig. 2. Histograms of the velocity widths of giant extragalactic H II regions. The profiles of galaxy nuclei have been excluded. (a) Velocity width (assuming a one-component fit) distribution for all giant extragalactic H II regions. The binning of the velocity widths has been chosen to emphasize a possible bimodal distribution (lower panel). (b) Velocity width (assuming a one-component fit) distribution for giant H II regions fitted with one (top panel), two (middle panel), and three (lower panel) component profiles.](https://example.com/f2.png)
its envelope. On the other hand, echelle spectroscopy of several GEHRs by Skillman and Balick (1984) did not reveal a decrease of the FWHM of the profiles as a function of distance from the centers of the GEHRs; the FWHMs that they measure show local variations but no systematic trend.

If Gaussian profiles are the reflection of random velocities of gas cells, de Voigt profiles indicate a different distribution of velocities. The latter profiles would be related to GEHRs having more gas cells departing from the bulk radial velocity. These could come from the dimmer parts of the H II complex and the furthest away from the exciting sources and be associated with the largest spatial structures. On the other hand, these broad components could as well be due to small cores contributing little to the total line intensity; these regions of small extension would correspond, for example, to recent supernova activity in the giant H II complexes. Echelle and low-dispersion spectroscopy of giant H II regions should allow comparative studies of various line ratios and spatial connection with the right velocity features. Follow-up spectroscopy is certainly needed.

Several integrated profiles show asymmetries suggesting a fit with more than one spectral component. The entrance aperture used is generally larger than the H II region, and there could be confusion with other distinct H II regions. Therefore gas from neighboring regions could be responsible for the asymmetry. In addition to this factor, different mechanisms could give rise to asymmetries. For example, the weaker second component of the two-component profiles is generally redshifted with respect to the main component (NGC 592, NGC 24031, NGC 42361, etc.). We could be observing some kind of expanding shell. The receding part of the shell would appear weaker because of absorption by internal dust in the GEHRs. However, this second component is also of different spectral width, an unlikely behavior for an expanding shell. An alternative explanation is the weaker redshifted component resulting from infalling gas onto the H II region. This component could be due to ionized gas from the galactic fountain, or returning gas ejected away from the galactic plane by supernova events, stellar winds, or “champagne flows.” Finally, the two-component profiles could correspond to two volumes of gas belonging to H II regions located at different heights above the galactic plane; the cloud of gas giving the redshifted component would have sunk closer to the plane, and would be moving faster; its Hα profile would be weaker because of extinction. Unfortunately, our observations do not allow determination of the relative importance of all these various effects; high-dispersion imaging spectroscopy is necessary.

The picture for objects with three-component profiles is even more difficult to disentangle. The overall characteristic velocity widths of these profiles are large, and the third component has about twice the e-folding width of the main component. We may be detecting the diffuse component of the Hα emission associated with the disk of the galaxies, or we may be seeing a small core characterized by high velocities (recent supernovae?). It is interesting to note that all multiple-component objects belong to spiral galaxies, except for one case in NGC 4656 (1m).

b) Isolated Extragalactic H II Regions

These objects have spectra characteristic of H II regions; they are also called blue compact galaxies or H II galaxies, and several have a “Markarian” number. The sizes of the emitting regions are of the order of 0.2 kpc; their $(B - V)$ and $(U - B)$ colors are in the range of 0.4 to 0.0 and — 0.4 to — 0.7, which lead to very blue integrated spectra. Their most conspicuous feature is their low metallicities (Alloin, Bergeron, and Pelat 1978; Lequeux 1979; French 1980; Kunth and Sargent 1983). These objects seem to extend the GEHRs' properties to larger volumes, luminosities, and velocity widths. As opposed to most GEHRs located in the disks of galaxies, gravitation may well play an important role in their dynamics, since their mass is typically of the order of $10^9 M_\odot$, with a gas-to-total-mass ratio of 0.2–0.4 (Alloin, Bergeron, and Pelat 1978).

We measure large velocity widths in Mk 35 ($W = 53$ km/s), Mk 108 ($W = 32$ km/s), and Mk 116 ($W = 33$ km/s), a moderate velocity width in Mk 36 (25 km/s) and a small velocity width in Mk 178 (19 km/s). Mk 36 is the only H II galaxy to display a well-defined second spectral component (blueshifted by — 19 km/s). Because the radial velocities of the observed isolated H II regions are small, distances computed from their systematic velocities can be grossly in error. Our present sample of integrated profiles for this category of H II complexes is too small to draw any conclusion.

c) Galaxy Nuclei

The velocity widths of galaxy nuclei are very large; the large amplitudes of the observed motions come from the superposition of several velocity components, mainly galaxian rotation, activity in the nucleus (ejection or accretion), and random motions. If we compare the rotational velocities measured over the field corresponding to the Fabry-Perot spectrometer diaphragm, the rotation of the galaxy cannot always explain the total Doppler width of the nuclear Hα profiles. For example, the rotation curve of NGC 2903 (Marcelin, Boulesteix, and Georgelin 1983) can account for only about 45 km/s of the observed width (70.9 km/s) of the Hα profile of its nucleus. Something more is at work, but it is impossible from our data to differentiate between mass motions resulting from ejection from those due to accretion or other types of motions. There is a controversy about the systematic radial velocity of NGC 2903. Values ranging from 473 to 590 km/s have been quoted (Simkin 1975). We measure 508 km/s, while Marcelin, Boulesteix, and Georgelin (1983) obtain 560 km/s for the dynamical center of the galaxy. Our Fabry-Perot spectrometer measurements correspond to the bulk radial velocity of several hotspots; hotspot “a” is the brightest at Hα and is located north of the dynamical center (toward lower radial velocities). Our value is therefore in agreement with the measurement of Marcelin et al. The nucleus of NGC 5236 (M83) has a smaller velocity width (54.4 km/s) and two spectral components. Again, the normal rotation of the galaxy (de Vaucouleurs, Pence, and Davoust 1983) cannot account for the total linewidth. The second component is 20% as intense as the main component and has a redshift of 88 km/s relative to the nuclear component. There appear to be two spectral components within the 1 kpc diameter central region. A plausible explanation of the redshifted component is infalling material. Ejected material is unlikely to lead to this spectral component, since it would suffer from extinction (cf. Ulrich 1978: discussion on NGC 253). The nuclear Hα line profile of NGC 4321 is the most complex with three components; the two weaker of which are blueshifted by — 39 and — 99 km/s with respect to the main component. The velocity differences between the components are large. Several H II regions are known to be present very near the nucleus of NGC 4321 (Anderson, Hodge,
and Kennicutt 1983). NGC 4321 is a massive galaxy, and the observed H components reflect motions that are comparatively small with respect to rotation at such linear scales. The profile of NGC 4321 can therefore be produced by randomly moving ionized clouds (as suggested by Rubin, Ford, and Thonnard 1980). Finally, and most important, we cannot rule out structures with velocity greater than the free spectral range (283 km/s) of the F-P étalon used in our spectrometer; velocities up to 1000 km/s are known to be present in the nuclei of some galaxies (see Goad and Gallagher 1985, for example).

The Hα line profile of NGC 4631 cm 67, a giant H II region observed in an edge-on Sc spiral, displays a very large velocity width characteristic of galaxy nuclei. It is unlikely that one is observing far into the galaxy disk. A redshifted component (68 km/s) and a blueshifted component (— 46 km/s) are observed in addition to the main component. The Hα map by Crillon and Monnet (1969) shows three conspicuous H II regions inside the diameter encompassed by our spectrometer, each of which may contribute to one spectral component. This is the most obvious object where the morphology of the H II complex appears closely linked with the integrated Hα profile of the region.

V. SUMMARY

As many as 53 Hα integrated line profiles of GEHRs were obtained with a large-aperture Fabry-Perot spectrometer. This sample includes some galaxy nuclei and isolated extra-galactic H II regions. The profiles of GEHRs show the following characteristics:

1) About two-thirds of the profiles of GEHRs are symmetrical, and about one-third (34%) are better fitted with two or three Gaussians.
2) More than half of the single-component Hα profiles are better characterized with a de Voigt profile than with a Gaussian; this emphasizes the existence of extended spectral wings revealing high-velocity gas.
3) The full velocity width of multicomponent line profiles is larger than for one-component profiles.
4) The second component of two-component-profile H II regions is generally redshifted with respect to the main profile. Infalling gas or differentially moving clouds could be responsible for this component.
5) The Hα line profiles of three galaxy nuclei show large motions, some well in excess of those expected from the rotation of the galaxy (NGC 2903 and NGC 5226), evidence of active phenomena in these nuclei. The giant H II region cm 67 in the edge-on spiral NGC 4631 displays features characteristic of galaxy nuclei.

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