Breaks in the radial oxygen abundance and corotation radius of three spiral galaxies

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ABSTRACT

The correlation between the breaks in the metallicity distribution and the corotation radius of spiral galaxies has been already advocated in the past and is predicted by a chemodynamical model of our Galaxy that effectively introduces the role of spiral arms in the star formation rate. In this work, we present photometric and spectroscopic observations made with the Gemini Telescope for three of the best candidates of spiral galaxies to have the corotation inside the optical disc: IC 0167, NGC 1042 and NGC 6907. We observed the most intense and well-distributed HII regions of these galaxies, deriving reliable galactocentric distances and oxygen abundances by applying different statistical methods. From these results, we confirm the presence of variations in the gradients of metallicity of these galaxies that are possibly correlated with the corotation resonance.

Key words: galaxies: abundances – galaxies: fundamental parameters – galaxies: ISM – galaxies: spiral – galaxies: star formation.

1 INTRODUCTION

The question of what triggers the star formation in discs of galaxies, and in particular the role of the spiral arms, has been the subject of a long debate. Soon after the theory of spiral arms was proposed by Lin, Yuan & Shu (1969), Roberts (1969) showed that shock waves are produced in the passage of the gas across the spiral gravitational perturbation and this could trigger star formation. This was not a surprising result, since the arms are obvious to us, because they are the areas containing bright stars. Oort (1974), analysing the gas distribution in M51, suggested that a constant fraction of the gas per passage through the arms is transformed into stars and consequently that it would be natural to expect the star formation rate to be proportional to $\Omega - \Omega_p$. Jensen, Strom & Strom (1976) tested this expression with a sample of nearby galaxies, by plotting a chemical enrichment indicator ([O III]/Hβ) as a function of $\Omega - \Omega_p$, both quantities being measured at a normalized radius, and concluded that the star formation rate is proportional to $\Omega - \Omega_p$. However, McCall (1986) argued that the correlation found by Jensen et al. could be the result of independent processes having similar dependence on the galactic radius and presented observations of O abundance gradients in two flocculent galaxies, NGC 5055 and 7793, which were found to be very similar to those of grand design spirals. As the flocculent galaxies were supposed to be free of spiral arms, the arms could not be the cause of the observed gradients. This argument was later weakened by the fact that a clear spiral structure was found in NGC 5055, both in the infrared (Thornley 1996) and in molecular gas (Kuno et al. 1997). Thornley found infrared spiral structures in several other flocculent galaxies, which is an indication that it is a normal characteristic of these galaxies. Nevertheless, this does not prove that the spiral arms are responsible for the observed gradients. The nature of the flocculent galaxies is not fully understood and it is not clear if they can be considered (or not) as good examples of galaxies where stochastic self-propagating star formation dominates. As a first step, our effort will be to understand the star formation mechanism in normal spiral galaxies. Zaritsky (1992) investigated the O abundance profile of seven nearby galaxies and found a distinct change in slope for three of them. These changes cannot be associated with calibration problems, since, precisely, the same methods were used in all the cases. Later Zaritsky, Kennicutt & Huchra (1994) extended the study to a larger number of galaxies and found for a few of them not only a change in the slope, but also possible reversals, with metallicity increasing at large radii (see for instance the profiles of NGC 3369). It should be noted that a reversal is easily explained if the star formation rate is considered to be proportional to $|\Omega - \Omega_p|$, which is the same expression as above but takes into account the cases in which corotation is inside the zone being investigated; a minimum of star formation is expected at $\Omega = \Omega_p$. An interesting case is the Milky Way. A simple model of chemical enrichment was proposed by Mishurov, Lépine & Acharova (2002) for our Galaxy, in which the star formation rate is proportional to $\Omega - \Omega_p$. These authors argue that the minimum (or the plateau) in the gradient of metallicity of our Galaxy, observed using different tracers (see Maciel & Queiroz 1999, using planetary nebulae, or Andreiky et al. 2004, using Cepheids), is...
coincident with the corotation radius. The above interpretation for the existence of minima or plateaus in the metallicity gradients is not easy to verify in other galaxies; however, a correlation between radii of minima and/or inflexions in the metallicity distribution and the corotation radius was found by Scarano & Lépine (2010) using published data. One of the difficulties to identify the corotation is that this resonance is not necessarily situated in the optical disc. Nevertheless, Canzian (1998) proposed a test to identify galaxies for which the corotation is favourably placed in the optical disc. This test only requires moderately deep imaging and no spectroscopic observations are needed. In this paper, we present the study of the radial gradients of metallicity in three of the best candidates identified by Canzian’s test (IC 0167, NGC 1042 and NGC 6907) to verify if the connection between metallicity breaks and corotation holds for these galaxies. The observations were performed using the Gemini Multi-Object Spectrograph (GMOS), pointed towards 232 \text{ H II} regions distributed in these galaxies. Different statistical methods were employed to get O abundances from the observed emission lines. A sample of galaxies and \text{ H II} regions are presented in Section 2 of this paper. Observations and data reduction are described in Section 3. The photometric and spectroscopic results are presented in Section 4. Finally, the results are discussed in Section 5, where the corotation radii of these galaxies are estimated.

2 SAMPLE SELECTION

2.1 Galaxies

In order to perform our study, we searched in the literature for galaxies for which the corotation is expected to be favourably placed in the optical disc. This was done by selecting three of the best candidates tested by Canzian (1998) (Table 1) according to the following criteria:

(i) Galaxies should fail in the conservative version of Canzian’s test, evaluated by the ratio of the outer to inner extent of the spiral structure. In principle, this guarantees that the corotation is situated in the optical part of the disc (Canzian 1998).

(ii) Objects with larger values of the ratio mentioned above were preferred in the selection, since larger ratios mean the corotation radius is deeper into the bright part of the galactic disc (Canzian 1998).

Table 1. Parameters of the selected galaxies. ‘RA’ and ‘Dec.’ are the equatorial coordinates, ‘ratio’ is the measured ratio of the outer to inner extent of the spiral structure, \( V_{\text{sys}} \) is the systemic velocity, \( D \) is the Hubble flow distance for \( V_{\text{sys}} \) (\( H_0 = 73 \text{ km s}^{-1} \text{ Mpc}^{-1} \)), \( s \) is the linear scale in the plane of the sky at distance \( D \), and \( a \) and \( b \) are, respectively, the sizes of the major and minor axes, \( m \) is the total magnitude and ‘Type’ is the morphological type.

| Parameter | IC 0167 | NGC 1042 | NGC 6907 |
|-----------|---------|----------|----------|
| RA  \( \text{h}^1 \text{m}^2 \text{s}^{-1} \) | 18:51:08:05 | 20:40:24 | 22:25:00:66 |
| Dec.  \( \text{d}^2 \text{m}^3 \text{s}^{-1} \) | 21° 54′ 46″ | −8° 26′ 03″ | −24° 48′ 34″ |
| Ratio | 2.41 | 2.38/3.31 | 2.85 |
| \( V_{\text{sys}} \) (\text{km s}^{-1}) | 2931\text{b} | 1371\text{b} | 3182\text{c} |
| \( D \) (\text{Mpc}) | 41.6 | 18.6 | 43.6 |
| \( s \) (\text{pc arcsec}^{-1}) | 202 | 90 | 211 |
| \( a \) (arcmin) | 2.9 | 4.7 | 3.3 |
| \( b \) (arcmin) | 1.9 | 3.6 | 2.7 |
| \( m \) | 13.6 | 11.5 | 11.9 |
| Type | SAB(s)c | SAB(r)s|cd | SB(s)bc |

\( \text{a} \) Canzian (1998); \( \text{b} \) NED; and \( \text{c} \) Scarano et al. (2008).

(iii) Only galaxies with angular sizes that fit entirely inside the GMOS field (5.5 \( \times \) 5.5 arcmin\(^2\)) were chosen. The purpose of this was to cover all the extension of the galaxies with maximum spatial resolution.

(iv) Each galaxy should have at least 16 \text{ H II} regions, since this is the minimum number of \text{ H II} regions needed for an ideal sampling to measure the metallicity gradient, according to Dutil & Roy (2001).

(v) The three brightest galaxies among those selected with the previous criteria were chosen for observation.

The fact that the selected galaxies do not have strong bars may simplify the interpretation of the data, since only the secular effect of the spiral arms may be predominant on these galaxies.

2.2 \text{ H II} regions

To perform the spectroscopy, we adopted the following procedures to select the \text{ H II} regions of each galaxy:

(i) Before the GMOS observations, we elaborated a list of \text{ H II} region candidates based on the Second Palomar Sky Survey, photometric calibrated using the second release of the USNO CCD Astrograph Catalog (UCAC). The objects were selected according to their flux profile, brightness and geometry.

(ii) Taking into account that the GMOS supports only one slit per dispersion position and one fixed position angle per observation, we determined instrumental position angles (Table 2) in order to maximize the number of \text{ H II} region candidates to be observed and minimize the number of overlapping spectra in the acquisition process. These position angles were evaluated using the code \text{PAMASKGEM}.\(^1\)

(iii) After the GMOS pre-imaging using the position angle obtained in (ii), we selected the best candidate \text{ H II} regions in each dispersion position. We chose the objects according to their brightness, emission profile (to avoid foreground stars) and colours (as a secondary criterion to exclude foreground stars). Special care was taken to avoid the objects positioned in places where the dispersed spectrum would generate spectral lines away from the GMOS detectors.

3 GEMINI OBSERVATIONS

The observations were conducted at the Gemini-North telescope in the years 2005 and 2006 using the GMOS Multi-Slit Spectrograph in queue mode. All the observations were executed in better conditions than the minimum required (sky background of 50 per cent, cloud cover of 70 per cent and image quality of 70 per cent), ensuring full spectrophotometric conditions of the data.

At first, the pre-images (Figs 1–3) were observed in two filters: \( g' \) and \( r' \). To guarantee a continuous coverage of the GMOS field, we applied different dithering patterns to compose a single frame in each filter. Since these images have better spatial resolution than the public data and they are flux calibrated, we used them to refine the \text{ H II} region selection, as described before. The combination of these results with the morphological data allowed us to design the metallic masks where the slits were placed for the spectroscopic observation. Inclinations and position angles were estimated from the isophotes of the final images of each galaxy. Table 2 summarizes the information related to these observations.

\(^1\) \url{http://www.ctio.noao.edu/ftp/pub/scarano/codes/pamaskgem.pro}
Table 2. Observational parameters for the pre-imaging process of the galaxies IC 0167, NGC 1042 and NGC 6907 in each of the filters $g'$ and $r'$. UT is the universal time when the observation started, $t_{\text{exp}}$ is the exposition time, $n_{\text{exp}}$ is the number of exposures for the dithering pattern, $\text{PA}_{\text{instr}}$ is the instrumental position angle and ‘OIWFS’ is the USNO UCAC2 Catalog index of the star used as the on-instrument wavefront sensor. All the observations were conducted at $2 \times 2$ binned mode.

| Parameter | IC 0167 | NGC 1042 | NGC 6907 |
|-----------|---------|----------|----------|
| UT        | 16/8/2005 | 16/8/2005 | 6/9/2005 | 6/9/2005 | 1/8/2005 | 1/8/2005 |
|           | 14:31:36  | 14:38:57 | 12:58:18 | 13:09:54 | 08:03:12 | 08:09:04 |
| $t_{\text{exp}}$ (s) | 150 | 120 | 240 | 90 | 360 | 120 |
| $n_{\text{exp}}$ | 5 | 4 | 8 | 3 | 12 | 4 |
| $\text{PA}_{\text{instr}}$ (°) | 265 | 265 | 19 | 19 | 243 | 243 |
| Airmass   | 1.001 | 1.001 | 1.179 | 1.163 | 1.691 | 1.66 |
| Seeing (arcsec) | 0.99 | 0.74 | 0.78 | 0.68 | 0.63 | 0.63 |
| OIWFS star | 39427277 | 39427277 | 28845687 | 28845687 | 21894023 | 21894023 |

Figure 1. Slits superimposed on the $r'$ image of the galaxy IC 0167. Only the slits used in the 2006 observations are presented. ‘A’ represents stars used for alignment, ‘F’ represents reference stars for flux calibration and ‘C’ is a slit used for sky sampling. The sky orientation is given by the north-east compass and the spectral dispersion follows the x-direction of the x–y compass. The ellipse represents the projection of a circle in the sky plane, considering the same inclination and position angles as obtained from the spiral arms.

After the mask design, the spectroscopic observations were carried out through individual exposures from 960 to 1200 s using the B600_G5303 grism centred at two different wavelengths to cover the spectral range from 3500 to 7100 Å. With this coverage and considering the systemic velocity of the galaxies, the main spectral lines required for metallicity evaluation could be observed. No spectral dithering was used to cover the GMOS gaps in the final spectra. So, taking this into account, the choice of H$\alpha$ regions only considered the slits in positions that would not generate important spectral lines on the detector gaps. A CuAr arc lamp and a flat-field frame were observed in the sequence of the spectroscopic acquisition, while the telescope was still following the source, to guarantee the quality of the calibrations by avoiding any effect caused by instrumental flexures. The same on-instrument wavefront sensor (OIWFS) stars used in the pre-image process were used for the spectroscopy. Information about the spectroscopic observations can be found in Table 3 and the details of the slits in Tables A1–A6.

4 DATA REDUCTION AND ANALYSIS

Standard procedures for reduction of GMOS imaging and spectroscopy were followed. In both cases, the general Gemini data reduction software was used. The details about this can be found in Scarano et al. (2008) for the specific case of NGC 6907. The same procedures were carried out for IC 0167 and NGC 1042.

For each filter, the multiple dithered frames were mosaicked and co-added. This procedure improved the signal-to-noise ratio of the final images by removing both cosmic rays and the gaps between the GMOS detectors. Since the spectroscopic data correspond to a
Figure 3. Slits and elliptical fitting superimposed on the $r'$ image of the galaxy NGC 6907. The definitions here follow those used in the previous two figures.

single frame, the cosmic-ray events were synthetically removed using the task GSCRED (more details about in the task documentation). In these cases, the GMOS gaps were linearly interpolated. Wavelength calibration was performed using the individual arc lamps observed just after the spectroscopic acquisition. For each individual slit, the spatial distribution was used to improve the spectral calibration. The sky lines and the continuum were removed from the main source by using the contiguous data in the spatial direction of each slit.

4.1 Photometry

The photometric calibration in filters $g'$ and $r'$ was performed using the photometric standard stars supplied by the Gemini baseline, listed in Table 3. Usual procedures applying DAOPHOT IRAF tasks enabled us to recover the zero-point magnitudes, taking into account the effects of the atmospheric extinction and the corrections for the galactic extinction by Schlegel, Finkbeiner & Davis (1998) and Amôres & Lépine (2005). Assuming the limit of detection of the galaxies as the $3 \sigma$ limit of dispersion of the local sky level, elliptical fittings were performed for the estimation of the inclination and position angle of the galaxies. However, as explained in the next section, we did not use the parameters obtained in this way to derive the distances of H\textsc{ii} regions to the galactic centres.

After the conversion of the $g'$ and $r'$ images to the $B$ and $V$ bands, using the expressions by Fukugita et al. (1996) and Hook et al. (2004), we obtained surface brightness profiles similar to those presented by Canzian (1998). However, the inclination and position angles that we derive do not match with previous works, like Canzian (1998) and de Vaucouleurs et al. (1992), even when we apply corrections, such as masking the data from the contribution of stellar fields, the interarm regions and the disturbed parts of the galaxies. However, this is only part of reasons for giving preference to other methods to determine inclinations and position angles. The method of fitting ellipses to the isophotes, although commonly adopted, is based on the questionable hypothesis that the spiral galaxy isophotes are approximately circular when seen face-on. This is particularly incorrect in the case of two-armed spirals with large pitch angles, for which the light distribution is naturally elongated in the direction of the extremities of the arms, the so-called Stocks effect (Stock 1955). The other methods available are the kinematic method, which consists in finding the axes of the spider diagrams or isovelocity contours in H\textsc{i} maps, and spiral-arm fitting, which is based on the assumption that large parts of the arms are logarithmic spirals. Our group performed H\textsc{i} observations, with the Giant Meterwave Radio Telescope (GMRT), of the three galaxies, but for the moment, the results are published only for NGC 6907 (Scarano et al. 2008), where a detailed discussion of its inclination can be found. While the other results are not published, the contradiction between photometric and kinematic results can be seen from the orientation of the velocity fields presented for NGC 1042 by Kornreich et al. (2000) and for IC 0167 by van Moorsel (1988). On the other hand, Ma (2001) proposed a method that uses the spiral arm fitting and applied it to several galaxies, including IC 0167 and NGC 6907. Applying his method to both arms of NGC 1042, we got consistent values for inclination at a given position angle. We found that the kinematic and spiral-arm-fitting methods give similar results, which differ from the isophotal ellipse fitting. We conclude

| Parameter      | IC 0167  | NGC 1042 | NGC 6907 |
|----------------|----------|----------|----------|
| UT             | 6/9/2005 | 23/8/2006| 5/11/2005| 24/8/2006 | 2/9/2005 | 22/8/2006 |
| $t_{\text{exp}}$ (s) | 960      | 1200     | 1200     | 1200     | 960      | 1200      |
| $\lambda_c$ (Å) | 5000     | 5900     | 5000     | 5850     | 5000     | 5950      |
| Band (Å)       | 3500–6300| 4400–7200| 3500–6300| 4350–7150| 3500–6300| 4450–7250 |
| $n_{\text{slit}}$ | 34       | 52       | 35       | 68       | 36       | 57        |
| Airmass        | 1.06     | 1.018    | 1.154    | 1.137    | 1.618    | 1.453     |
| Calibration star | G191B2B | Feige34  | G191B2B  | Feige34  | G191B2B  | Feige34   |

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that the spiral-arm-fitting method is reliable in the present cases and adopted its results in the following analysis (Table 4).

The radial surface brightness profiles (Fig. 4) were obtained by performing the integration of the flux on elliptical rings with the same thickness of the seeing and following the parameters of projection imposed by the spiral arms (Table 4). Since there is an interaction between NGC 6907 and 6908, confirmed by Scarano (2004), the \([\text{Ar}^+]/\text{O}^+\) method of Pettini & Pagel (2004) and Stasińska (2006), the \([\text{N}^+]/\text{O}^+\) method of Pettini & Pagel (2004), the \([\text{Ar}^+]/\text{O}^+\) method of Stasińska (2006) and the \(p\)-method of Pilyugin (2000) and Pilyugin (2001).

4.2 Spectroscopy

With the spectrophotometric calibration stars supplied by the Gemini baseline (Table 3), we determined the sensitivity function and then each spectrum could be flux calibrated.

Considering that all spectral lines have their wavelength systematically changed by the systemic velocity of the galaxies, and locally changed by the projection of the rotation curves on the line of sight, we used the IRAF package \textsc{rvsaO} (Kurtz & Mink 1998) to determine radial velocities and identify the typical spectral lines observed in \(\text{H}^\text{II}\) regions by cross-correlating a template spectrum to the observed spectra. The measured velocities and their errors are given in Tables A1–A8. We then integrated the flux of lines by performing the following steps:

(i) According to the galactic coordinates of each slit, the related spectrum was corrected by the galactic extinction using the reddening calculated by the code \textsc{extint} written by Amôres & Lépine (2005) and an IDL adaptation of the code \textsc{fmcurve} by Fitzpatrick (1999) called \textsc{fm_unred}.

(ii) Using the expected ratios between Balmer lines (Osterbrock 1989), we measured the flux of the hydrogen lines and estimated the intrinsic reddenings of each spectrum employing the relations written by Fitzpatrick (1999), which were introduced in the \textsc{fm_unred} code to correct the spectra by intrinsic reddening.

(iii) Taking into account the wavelengths determined for all recognized spectral lines, we performed the integration of the flux of them by considering the robust mean of the area under the line profile evaluated by the following procedures: (a) Gaussian fitting; (b) Lorentzian fitting; (c) numerical integration; and (d) double gaussian fitting.

(iv) With the fluxes and uncertainties evaluated in the previous step, the metallicities were calculated using statistical methods to determine O abundances. The methods applied were the R23 method of Pagel et al. (1979) with the considerations of McGaugh (1994), the \([\text{O}^+]/[\text{N}^+]\) method of Pettini & Pagel (2004) and Stasińska (2006), the \([\text{N}^+]/\text{H}^\alpha\) method of Pettini & Pagel (2004), the \([\text{Ar}^+]/[\text{O}^+]\) method of Stasińska (2006) and the \(p\)-method of Pilyugin (2000) and Pilyugin (2001).

We next present more details on the steps described above. Since the interstellar medium affects differentially the flux of the spectral

| Parameter | IC 0167 | NGC 1042 | NGC 6907 |
|-----------|---------|----------|----------|
| \(m_0,0\) | 31.49 ± 0.15 | 31.47 ± 0.16 | 31.4 ± 0.15 |
| \(m_0,r\) | 31.79 ± 0.17 | 31.77 ± 0.21 | 31.72 ± 0.14 |
| \(m_t\) | 11.11 ± 0.29 | 9.84 ± 0.20 | 10.45 ± 0.04 |
| \(\Sigma_{\text{lim}}\) | 10.26 ± 0.27 | 9.16 ± 0.19 | 8.90 ± 0.03 |
| \(\Sigma_{r0}\) | 21.95 ± 0.57 | 21.80 ± 0.44 | 21.3 ± 0.08 |
| \(\Sigma_{r}\) | 21.17 ± 0.56 | 20.95 ± 0.44 | 19.7 ± 0.07 |
| \(M_B\) | −21.07 ± 0.47 | −20.63 ± 0.41 | −21.70 ± 0.35 |
| \(L_B\) | 3.9 ± 1.7 | 2.6 ± 1.0 | 7.0 ± 2.2 |
| \(\Sigma_{\text{lim}}\) | 26.26 ± 0.57 | 26.33 ± 0.44 | 25.74 ± 0.08 |
| \(\Sigma_{r0}\) | 25.44 ± 0.56 | 25.4 ± 0.44 | 24.86 ± 0.07 |
| \(\text{RA}_0\) | 27.785629 | 40.099802 | 306.277600 |
| \(\text{Dec}_0\) | 21.912776 | −8.433441 | −24.890200 |
| \(a_{\text{isoph}}\) | 1.82 ± 0.04 | 2.49 ± 0.15 | 1.47 ± 0.02 |
| \(b_{\text{isoph}}\) | 2.15 ± 0.03 | 2.01 ± 0.21 | 1.29 ± 0.02 |
| \(i_{\text{isoph}}\) | 51.5 ± 3.0 | 36.3 ± 3.1 | 29.1 ± 3.0 |
| \(\Phi_{\text{lim}}\) | 73.1 ± 15.8 | 12.5 ± 8.5 | 254.1 ± 3.3 |
| \(\Phi_{\text{iso}}\) | 38.0 ± 3.0* | 29.0 ± 2.9 | 49.5 ± 3.0* |
| \(\alpha\) | 134.0 ± 3.0* | 277.4 ± 5.1 | 239.9 ± 3.0* |
| \(\sigma\) | 26.6 ± 1.9* | 13.3 ± 2.5 | 23.5 ± 5.0* |

\(\Sigma_{\text{lim}}\) and \(\Sigma_{r0}\) are the major and minor semiaxes of the ellipse, respectively, in arcmin.

\(\text{RA}_0\) and \(\text{Dec}_0\) are the equatorial coordinates of the spiral arm centre (which coincide with the H\text{II} velocity centre as mentioned in the text), \(\alpha\) is the pitch angle of the spiral arms, in degrees, and finally \(\sigma\) and \(\beta\) are the major and minor semiaxes of the ellipse, respectively, in arcmin.

**Figure 4.** \(g^\prime\) and \(r^\prime\) radial surface brightness (top panel) and colour profiles (bottom panel). Note that, in both, the order of the filters and the scale is not conventional.

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lines, the correction of the spectra by the extinction is fundamental to estimate metallicities. To do this, we need to distinguish two contributions: one from our Galaxy (the Galactic extinction) and the other internal to the observed galaxies (the intrinsic extinction). A model for the Galactic extinction is well established by Amôres & Lépine (2005) and we applied their model to correct all spectra by the Galactic flux losses. Supposing that the remaining differences in the ratio of the Balmer lines are a consequence of the intrinsic extinction in the observed galaxies and that their extinction laws are similar to the Galaxy extinction law, each spectrum was corrected again by determining the reddening from the Balmer line ratios and using it in the Fitzpatrick (1999) code. In spite of the evidence from the Magellanic Clouds that extragalactic reddening laws may not be rigorously the same as we observe for our Galaxy, the comparison between the results of Gordon et al. (2003) for the Magellanic Clouds and the Fitzpatrick (1999) extinction law reveals that at least in the optical part of the spectrum, where the O abundances are calculated, this hypothesis may be assumed. This was already done in the past (e.g. Misselt, Clayton & Gordon 1999, working with 11 spiral galaxies) and it has the advantage of correcting the rising of the extinction as a function of the galactic inclination (Unterborn & Ryden 2008). Tables B1–B6 contain the values we got for intrinsic extinctions. Typical spectra of each of the observed galaxies corrected for both extinctions can be seen in Fig. 5. Ultimately, the results would be the same if we ignored the extinction components and only the total reddening correction using the Balmer lines was considered.

The option of measuring the fluxes using four procedures was a way to automatically register the differences between the spectral line profiles in each spectrum. The robust mean of these fluxes is equivalent to the mean of the two best-fitting procedures, since in this method the ‘discrepant’ values are discarded. In our case, the best-fitting procedures were the Gaussian fits and the numerical integration. But the mean between these two procedures is exactly the method adopted by Zaritsky et al. (1994) to measure the line fluxes of his sample. The advantage of our method is that it allowed us to automatically compare and identify profiles affected by cosmic-ray remnants, bad sky line subtraction, lines with unusual profiles and blended lines. We adopted uncertainties associated to the robust standard deviation of the measured fluxes in such a way that larger uncertainties are a consequence of less-defined profiles and lines with lower signal-to-noise ratio. These results were verified by computing the Poissonian errors directly from the number of photon counts in the lines and the results are in perfect agreement with our method. Typically, these values are smaller than 10 per cent but considering differential effects, each spectral line has its own typical value (see Tables C1–C3).

One of these effects is the differential atmospheric refraction. Depending on the airmass, seeing, slit width and slit orientation relative to the parallactic angle, the observations may be more or less affected by this kind of refraction. According to our specifications, observations were conducted in seeing conditions better than 0.7 arcsec, while the standard slit width of 1 arcsec was adopted for all objects. Since for the MOS observations the position angles of the slits are fixed and our observations were carried out in queue mode, we were not able to tune the slit position angles to the parallactic angles. Nevertheless, except for the observation of NGC 6907 in 2005, all observations were performed with position angles of the slit differing less than 15° from the parallactic angle. Unfortunately, NGC 6907 is always observed in large airmasses at Mauna Kea and this affected both observations of this galaxy.

Considering only the differential wavelength effect of the airmass on the atmospheric refraction, we verified that the [O ii] spectral line was severely affected in the observations of NGC 6907 in 2005. For these observations, the centres of the H II regions were deviated by at least 0.5 arcsec outside the slit width; this means that the observed [O ii] lines come predominantly from the borders of the H II regions. Moreover, the slit orientation relative to the parallactic angle in 2005 was almost 80°, which means that more than 85 per cent of the [O ii] emission line was not detected.

Fortunately, the situation was different for all the other observations. Taking into account the redshifts of the galaxies, the worst airmasses and the largest deviation of the slit orientation relative to the parallactic angle, the [O ii] flux losses represent less than
5 per cent of the total \[\text{[O II]}\] emission. This is the particular situation of NGC 1042 observed in 2005. Since IC 0167 was observed almost in the parallactic angle and airmass 1, there was no effect of atmospheric refraction. Furthermore, for the 2006 observations, we only used spectral lines above \(\text{H} \gamma\), for which the atmospheric refraction effects are negligible, given our slit widths.

Another thing that must be considered is the underlying Balmer absorption. The corrections are usually done by measuring the equivalent widths of the Balmer lines and applying the procedures by McCall, Rybksi & Shields (1985) and Oey & Kennicutt (1993). According to Zaritsky et al. (1994), such correction amounts to less than 10 per cent for 75 per cent of the regions he studied. Given that for most of the spectra we observed, there is no evident absorption profiles in \(\text{H} \alpha, \text{H} \beta\) or \(\text{H} \gamma\) (used to correct the spectra for reddening and as references for abundance determinations), we opted to eliminate from our analysis the objects for which the \(1\sigma\) level of the background affected by the Balmer absorption represents more than 10 per cent of the peak emission. It represents less than 20 per cent of the observed regions in 2005 and about 10 per cent of our sample observed in 2006. Given the proportions presented by Zaritsky, we believe that the worst effect of the Balmer absorption was eliminated from our sample.

5 RESULTS AND DISCUSSION

The first step to determine O gradients is to evaluate the O abundances and the radial distances inside the galactic planes. Following the procedures mentioned in the previous section, the flux of each spectral line needed to calculate the O abundances, using the statistical methods, was determined and registered in Tables C1–C3. Some individual lines may present underestimated uncertainties; nevertheless, the errors on the abundances, derived by propagating the flux uncertainties of all spectral lines involved, are around 0.2 dex, coherent with those mentioned in the literature (see Pilyugin, Vilchez & Contini 2004 and references therein). Using the inclinations, position angles and the galactic centre coordinates determined using the spiral arms (Table 4), the distances to the \(\text{H} \text{II}\) regions sampled by the slits (Tables A1–A8) were calculated with the expressions given by Scarano et al. (2008). These expressions introduce important corrections to the more traditional ones (e.g. Begeman 1987). For the galaxies studied here, these corrections reach up 20 per cent of the distances calculated with the previous procedures. Since the deviations on the corotation radius range between 2 and 3 kpc, the corrections are needed to avoid too large smoothing of the radial distribution of metallicity.

For each galaxy, the systemic velocities were obtained by taking into account the radial velocities measured from all the observed spectra and calculating the weighted mean of their distribution. Such a procedure is a raw measurement, which assumes that the receding and approaching sides of the galaxies were evenly sampled. In spite of that, the results are in agreement with those found in the literature (Table 1). A few objects were found to be background galaxies or isolated objects, instead of \(\text{H} \text{II}\) regions belonging to the galaxies we study here; these objects were eliminated from the sample based on their velocities. The velocity distribution of the \(\text{H} \text{II}\) regions of each galaxy is approximately Gaussian and we discarded the objects more than 3 HWHM (half width at half-maximum) off from the centre of the distribution.

Remembering that each observational run was optimized for a given spectral range, we present in Fig. 6 the best O abundances.
calculated for each galaxy using the spectral lines available in that run. Since in 2005 observations the [O \text{II}] line was present and H\alpha was not, we applied the R23-based methods to determine O abundances, represented here by the p-method (Pilyugin 2000; Pilyugin 2001). On the other hand, for the 2006 observations, the [O \text{II}] line was out of the range and only the methods that use the H\alpha and H\beta lines could be applied, in particular [O \text{III}] / [N \text{II}] methods, represented here by the Stasińska (2006) method. The advantage of the p-method is that it can provide O abundances with precision comparable with the direct methods, based on the temperature-sensitive line ratios; however, it is double valued at low abundances. Note that the 2005 observations could only be corrected for extinction by measuring the H\beta-to-H\gamma ratio, since H\alpha was not available. This provides a poorer correction than the H\alpha-to-H\beta ratio. In contrast to the p-method, the [O \text{III}] / [N \text{II}] Stasiska method is single valued, with the advantage that it is relatively independent of the reddening (Stasińska 2006).

A constant gradient has been the most commonly adopted law in the study of metallicity of galaxies. This is the first approximation, not a choice dictated by theory. For instance, most chemical abundance models adopt star formation rates proportional to some power of the gas density and most often the gas density presents a peak at several kpc from the centre. The stellar density in the disc of our Galaxy is better described by Kormendy’s function than by an exponential law (see Lépine & Leroy 2000). We make here the choice of fitting the data with fourth-order polynomials. This does not correspond to a theoretical model of galactic structure; the polynomial fitting is only adopted as a smoothing method instead of other methods, like splines or Gaussian filtering, which could be used alternatively. One advantage of the polynomial method is that it gives the positions of minima and inflections in an easy way. The choice of the fourth-order polynomial corresponds to the amount of details that we are willing to reveal. For instance, in our Galaxy, the observations of Cepheids (Andrievsky et al. 2004) show that there is a strong metallicity gradient in the inner regions, followed by a plateau and then followed again by another strong gradient. Such a behaviour, that we expect to observe in other galaxies as well, can be approximated by a fourth-order polynomial.

It is known that the different statistical methods used to calculate the O abundances can result in different values for the same observation and they can produce different dispersion of the data with respect to an average abundance profile and also small differences in the gradients, especially for those methods which do not depend directly on the O ionic abundances. In our observations, the largest differences occurred between the p-method and all the other mentioned methods. This seems to be a consequence of the strong dependence of the p-method on the [O \text{II}] emission line, which is observed at the limit of the instrumental sensitivity and it is strongly affected by the reddening and parallactic angle misalignments.

For IC 0167, most of the methods applied here point towards the existence of a very smooth minimum in the O abundance profile, which is shallower than the one of our Galaxy, according to Mishurov et al. (2002). In particular, the distribution produced by the p-method is more dispersed than the results for the [O \text{II}] / [N \text{II}] method; however, the minima in the O abundance obtained with the two methods almost coincide. The median of the minima and inflections found using all the methods applied to this galaxy is 14.7 ± 2.6 kpc. Obviously, it is necessary to be cautious in the interpretation of the fitted curves. The trend could be fitted by a straight line and the evidence for an inflection is not very strong in this case.

On the other hand, for NGC 1042, the abundance dispersion is less pronounced and a plateau is present in the O abundance profiles of this galaxy obtained by means of the [O \text{III}] / [N \text{II}] and R23-based methods. This plateau could possibly be interpreted as being a consequence of the corotation as well, but in this case, the minimum is too shallow to contrast with the dispersion of the data. The dispersion resulting from the two calibrations of the [N \text{II}] / H\alpha method of Pettini & Pagel (2004) and [Ar \text{II}] / O\alpha is so high that no consistent information can be extracted. Since the point of inflection is a point which is close to being a minimum (see the lower curves in Fig. 6 for NGC 1042), we could speculate that it is also an indicator of the corotation. The median of the inflexions of the abundance curves for NGC 1042 is 8.2 ± 2.8 kpc. Interestingly, at the same position, a small bump can also be observed in the colour distribution of this galaxy (Fig. 4). This might be connected with corotation as well, since a gap in the density distribution of young stars can be expected at corotation, as it happens in our Galaxy (Amôres, Lépine & Mishurov 2009). The lack of young stars would make this region slightly redder than its neighbourhood.

Finally, a bimodal behaviour in the radial distribution of O is found for NGC 6907 using the [O \text{II}] / [N \text{II}] method. Since the argon line is not detected along all the galaxy, the spatial distribution of metallicity derived from this element is inconclusive. The same happens using the [N \text{II}] / H\alpha method, which results in O abundances with large dispersion at radii beyond 15 kpc. Unfortunately, the observations of 2005 were not performed near the parallactic angle and for this reason the measurements of the [O \text{II}] lines are not reliable, causing a huge dispersion of the O abundances derived by the R23 and p-method. Since the nucleosynthetic origin of nitrogen may shift from the secondary to primary in low-abundance H\alpha regions, we need to be more cautious to interpret the inflexions in the NGC 6907 abundance distribution. The median of the radii of the minima found using other statistical methods is 21.1 ± 3.7 kpc. Scarano et al. (2008) have shown that for this galaxy there is a minimum in the H\alpha gas distribution between 20 and 30 kpc, which can be related with the same effect of the corotation found in our Galaxy by Amôres et al. (2009).

The interpretation of the gradient of metallicity for NGC 6907 may seem dangerous, since this galaxy is interacting with NGC 6908 as discussed by Scarano et al. (2008). However, the same authors have shown that the influence of this galaxy on the NGC 6907 gas distribution is restricted to about 20° around NGC 6908, in azimuthal angles measured in the NGC 6907 galactic plane. Except for the spectra sampled by slit 25 in the 2006 run, all the other slits associated to radii greater than 15 kpc are situated on the side opposite to the one where the interaction with NGC 6908 takes place. Similarly to what happens with the rotation curve, which is not perturbed on that side (Scarano et al. 2008), we expect that the metallicities of the H\alpha regions presented here are not affected by the interaction.

Are the polynomial fits really better than the traditional straight-line fits? It should be remembered that we do not consider that the fourth-order polynomials are models, but only a technique used for locating changes in the slope. If the changes in slopes and plateaux are real, then, in principle, the polynomial fit should be better. But of course, a fourth-order polynomial always produces a better fit than straight line, as long as the rms deviations of the data with respect to the fitted curve are taken as the measure of the quality of the fit. To determine if a polynomial fit is effectively a meaningful choice, one must compare chi-square divided by the degree of freedom N − k − 1, where N is the number of data points and k the order of the polynomial (see the discussion in chapter 15 of Press et al. 1992).
We performed these tests and the results can be summarized as follows: after correction for the degree of freedom, the adjustments by fourth-order polynomials are slightly better (chi-square obtained with straight lines is larger by a factor of which ranges from 2 to only a few per cent). In other words, the straight lines are not the best choice, but they cannot be excluded on statistical grounds. Testing different orders of polynomials from 2 to 6, in all cases, the fourth order is slightly better than all the others, except for NGC 1042 for which the third-order polynomial gives a slightly smaller (3 per cent) normalized chi-square. This last result still suggests that an inflection point is present.

Pilyugin (2003) argued that the bends in the slopes of radial abundance gradients in the discs of spiral galaxies are a consequence of a systematic error involving the excitation parameter $P$, which would produce realistic O abundance in high-excitation H II regions, but would overestimate this abundance in low-excitation H II regions. For a measured value of R23, there are two possible solutions for the O abundance. For instance, according to Pilyugin, the positive slope of the observed O abundance by Roy & Walsh (1997) in the external regions of the galaxy NGC 1365 would be changed into a negative slope and the break would disappear, if the lower branch of the graph of O abundance versus R23 were used for these regions. The question then is when one should move from one branch to the other to correctly use the method. According to Pilyugin’s calibrations (Pilyugin 2003), the upper branch corresponds to $12 + \log(O/H) > 8.15$. As can be seen in Fig. 6, the slope breaks are situated above this abundance threshold for two of the galaxies studied here (NGC 1042 and 6907), so they cannot be explained by a change in the O abundance versus R23 law. One argument given by Pilyugin to justify the existence of bends above the previous limit is that the less the value of the excitation parameter $P$ is, the more the oxygen abundance obtained with the R23 method is overestimated (Pilyugin 2003). However, even with an increasing behaviour of the excitation parameter at radii larger than the radius identified as the corotation radius for NGC 1042, the overall decreasing behaviour of the radial metallicity distribution is not flattened by the almost linear radial increase in the excitation parameter $P$. It only presents a small step in the region where the corotation seems to occur. Another important point to be considered is that, in contrast to the R23 or the p-method, the [O II]/[N II] method is single valued and for the galaxies observed here, we verified minima and inflexions independently of the R23-based methods. One might worry that [O II]/[N II] could depend upon a second parameter near corotation and the behaviour of the excitation parameter might even suggest a correlation with the corotation radius, but such a hypothesis would have to be investigated in a large sample of galaxies and for the moment, it is not supported by any theoretical prediction.

This is not the first time that breaks in the radial distribution of metallicity are associated to the corotation radius. The break observed by Roy & Walsh in NGC 1365 is real, as it has been observed using different calibrations, not only R23, and, in addition, the break appears at $12 + \log(O/H) = 8.7$, well in the upper branch defined by Pilyugin. Roy & Walsh (1997) verified that the position of the metallicity break that they found in NGC 1365 is beyond the corotation radius found by Jorsater & van Moorsel (1995). Remembering that Mishurov’s model for our Galaxy, as well as the more recent one by Acharova et al. (2010), claims that the chemical evolution of a galaxy depends not only on the difference between the spiral pattern speed and the angular velocity of the rotation curve, but also on the surface density of the gas, a small displacement of the metallicity break with respect to the corotation radius can be understood. In NGC 1365, there is an intense star formation activity in the bar, at a radius slightly smaller than the corotation radius, in a region where the gas density is higher than average. Slightly beyond the corotation radius, there is steep decline in the gas density (Jorsater & van Moorsel 1995). The presence of a strong gas density gradient across the corotation radius displaces the metallicity minimum, simply because the star formation rate depends strongly on that density (see the details of Mishurov’s model).

6 CONCLUSIONS

The analysis of the gradient of metallicity of our Galaxy by Mishurov et al. (2002) leads us to infer that in other galaxies as well, we should expect that minima or inflexions in the radial gradient of metallicity could be correlated with the corotation radius. One indication that the same process also happens to other galaxies was obtained with the correlation found between the minima and inflexions in the metallicity distribution, using published data and the procedures presented here, and the corotation radius from different references available from the literature (Scarano & Lépine 2010). In order to test this prediction, we performed photometric and spectroscopic observations of three of the best candidates pointed by Canzian (1998) to have the corotation inside the optical disc, IC 0167, NGC 1042 and NGC 6907.

Using images obtained with the Gemini Telescope, we conducted a careful procedure to select H II regions to be observed with the GMOS. To avoid the problems with the isophotal elliptical fittings found for these galaxies, caused by their prominent spiral structure, we adopted the procedure recommended by Ma (2001) to determine the inclination and the position angles. This allowed us to calculate more reliable distances in the galactic plane, since for these galaxies, the spiral arms provide results which are coherent with the velocity fields found by Scarano et al. (2008), Kornreich et al. (2000) and van Moorsel (1988).

The first spectroscopic run was optimized for the blue part of the spectra for which the R23-based methods could be applied, in particular the p-method, while the second run was optimized to the red part of the spectra and the [N II]-based methods could be employed. The number of observed and effectively used spectra in this project changed according to the run, but with the observations of 2006, we overcome the minimum data sample advocated by Dutil & Roy (2001) for an ideal measurement of the metallicity gradient. All data were corrected for Galactic and intrinsic extinctions, and the data affected by the underlying Balmer absorption were removed from the analysis. By fitting polynomials of different orders to the radial metallicity distribution of the three galaxies, we found that the fourth-order polynomials produce better fits than first order (straight lines) in all the cases, even when correcting chi-square for the larger number of degrees of freedom of the fourth-order polynomial. The radii of the minima or points of inflection derived from the statistical methods of determining the abundances adopted here are in relatively good agreement. We recognize, however, that since the gradients and their variations have small amplitudes, we cannot totally exclude the possibility of an interpretation of the data in terms of straight lines. Furthermore, since Canzian’s method only gives us the best candidates of galaxies that have the corotation radii inside the optical disc, it is not possible for the moment to clearly associate the changes in gradient slopes with corotation. If we assume that the minima and inflections are situated at the corotation radius, for IC 0167, NGC 1042 and NGC 6907, then the corotation is at $14.7 \pm 2.6, 8.2 \pm 2.8$ and $21.1 \pm 3.7$ kpc, respectively. Further studies have to be conducted to verify if these estimates of the corotation radius are confirmed by other methods.
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APPENDIX A: POSITIONS, DISTANCES AND VELOCITIES ASSOCIATED WITH THE SLITS

In this appendix, we compile the information about the sky coordinates of the slits and their height [RA (J2000), Dec. (J2000), Δy], the corresponding face-on polar coordinates measured from the kinematic centre of the galaxies (r, θ), the cross-correlated velocities evaluated from the observed spectra (vobs), the velocity dispersion (σvobs), the number of lines detected (nlin), and that effectively used in the calculations (nls).

Table A1. Information about the spectra observed for IC 0167 in 2005. The complete version of this table is found in the electronic version of the article (see Supporting Information).

| ID | RA (°) | Dec. (°) | Δy (arcsec) | r (arcsec) | θ (°) | vobs (km/s) | σvobs (km/s) | nlin | nls |
|----|-------|---------|------------|----------|------|------------|-----------|-----|-----|
| 1  | 27.81954 | 21.94981 | 5          | 222      | -88  | 1620       | 160       | 5   | 8   |
| 2  | 27.82779 | 21.92064 | 5          | 171      | -52  | 74130      | 46        | 9   | 11  |
| 4  | 27.81574 | 21.94136 | 5          | 183      | -84  | -          | -         | -   | -   |
Table A2. Information about the spectra observed for IC 0167 in 2006. The complete version of this table is found in the electronic version of the article (see Supporting Information).

| ID | RA (°) | Dec. (°) | Δy (arcsec) | r (arcsec) | θ (°) | \( v_{\text{obs}} \) (km s\(^{-1}\)) | \( \sigma_{v_{\text{obs}}} \) (km s\(^{-1}\)) | \( n_{\text{us}} \) | \( n_{\text{lin}} \) |
|----|--------|----------|-------------|------------|--------|-------------------------------|----------------|-----------|-----------|
| 1  | 27.76827 | 21.92110 | 3           | 67         | 167    | 2832                          | 36             | 17        | 18        |
| 2  | 27.76503 | 21.91920 | 3           | 77         | 158    | 2749                          | 54             | 8         | 14        |
| 3  | 27.77588 | 21.92118 | 3           | 44         | −177   | 2839                          | 28             | 15        | 16        |

Table A3. Correspondences between the slits observed in 2006 (ID06) and the slits observed in 2005 (ID05) for the galaxy IC 0167. The complete version of this table is found in the electronic version of the article (see Supporting Information).

| ID06 | IC 0167 – correspondences 2006/2005 |
|------|-----------------------------------|
| 1    | 24  | 15  | 6  | 24  | 9  |
| 2    | 25  | 16  | 10 | 25  | 8  |
| 3    | 21  | 17  | 13 | 26  | 44 |

Table A4. Information about the spectra observed for NGC 1042 in 2005. The complete version of this table is found in the electronic version of the article (see Supporting Information).

| ID | RA (°) | Dec. (°) | Δy (arcsec) | r (arcsec) | θ (°) | \( v_{\text{obs}} \) (km s\(^{-1}\)) | \( \sigma_{v_{\text{obs}}} \) (km s\(^{-1}\)) | \( n_{\text{us}} \) | \( n_{\text{lin}} \) |
|----|--------|----------|-------------|------------|--------|-------------------------------|----------------|-----------|-----------|
| 1  | 40.08535 | −8.47102 | 5           | 165        | −84    | 1334                          | 17             | 13        | 14        |
| 2  | 40.09769 | −8.47767 | 5           | 181        | −101   | 1400                          | 100            | 8         | 12        |
| 3  | 40.09000 | −8.46668 | 5           | 143        | −89    | 1350                          | 46             | 14        | 16        |

Table A5. Information about the spectra observed for NGC 1042 in 2006. The complete version of this table is found in the electronic version of the article (see Supporting Information).

| ID | RA (°) | Dec. (°) | Δy (arcsec) | r (arcsec) | θ (°) | \( v_{\text{obs}} \) (km s\(^{-1}\)) | \( \sigma_{v_{\text{obs}}} \) (km s\(^{-1}\)) | \( n_{\text{us}} \) | \( n_{\text{lin}} \) |
|----|--------|----------|-------------|------------|--------|-------------------------------|----------------|-----------|-----------|
| 1  | 40.07691 | −8.39319 | 4           | 179        | 50     | 18917                         | 93             | 7         | 13        |
| 2  | 40.11228 | −8.41074 | 5           | 106        | 103    | 1320                          | 23             | 9         | 12        |
| 3  | 40.11674 | −8.40818 | 3           | 123        | 107    | 31230                         | 120            | 5         | 7         |

Table A6. Correspondences between the slits observed in 2006 (ID06) and the slits observed in 2005 (ID05) for the galaxy NGC 1042. The complete version of this table is found in the electronic version of the article (see Supporting Information).

| ID06 | NGC 1042 – correspondences 2006/2005 |
|------|-----------------------------------|
| 2    | 29  | 15  | 19 | 27  | 3  |
| 3    | 31  | 16  | 15 | 29  | 5 (middle) |
| 4    | 30  | 17  | 20 | 30  | 9  |
Table A7. Information about the spectra observed for NGC 6907 in 2005. The complete version of this table is found in the electronic version of the article (see Supporting Information).

| ID | RA (°) | Dec. (°) | Δy (arcsec) | r (arcsec) | θ (°) | v_{obs} (km s^{-1}) | σ_{v_{obs}} (km s^{-1}) | n_{us} | n_{lin} |
|----|--------|---------|-------------|-----------|-------|-----------------|-----------------|-------|-------|
| 1  | 306.30016 | −24.76257 | 5            | 223       | 137   | 6280            | 180             | 4     | 9     |
| 3  | 306.30690 | −24.78402 | 5            | 137       | −176  | 29817           | 97              | 2     | 3     |
| 4  | 306.30758 | −24.78843 | 5            | 125       | −163  | 3490            | 140             | 5     | 10    |

Table A8. Information about the spectra observed for NGC 6907 in 2006. The complete version of this table is found in the electronic version of the article (see Supporting Information).

| ID | RA (°) | Dec. (°) | Δy (arcsec) | r (arcsec) | θ (°) | v_{obs} (km s^{-1}) | σ_{v_{obs}} (km s^{-1}) | n_{us} | n_{lin} |
|----|--------|---------|-------------|-----------|-------|-----------------|-----------------|-------|-------|
| 1  | 306.24745 | −24.81042 | 3            | 112       | 61    | 3261            | 46              | 12    | 16    |
| 2  | 306.26098 | −24.81597 | 5            | 60        | 40    | 3374            | 42              | 16    | 17    |
| 3  | 306.24993 | −24.80975 | 4            | 104       | 62    | 3318            | 41              | 15    | 17    |

Table A9. Correspondences between the slits observed in 2006 (ID06) and the slits observed in 2005 (ID05) for the galaxy NGC 6907.

| ID06 | ID05 | ID06 | ID05 | ID06 | ID05 |
|------|------|------|------|------|------|
| 1    | 34   | 15   | 27   | 26   | 8    |
| 2    | 28   | 16   | 16   | 27   | 10   |
| 5    | 29   | 17   | 22   | 29   | 12   |

**APPENDIX B: INTRINSIC EXTINCTIONS**

The following tables in this appendix contain the intrinsic extinctions calculated using the Balmer lines observed in the spectrum associated with each slit. They were evaluated using the \( \text{H} \gamma / \text{H} \beta \) ratio for the 2005 observations and the \( \text{H} \alpha / \text{H} \beta \) ratio for the 2006 observations. ID is the identification number of the slit and \( E(B - V) \) is the intrinsic extinction.

Table B1. Intrinsic extinctions for the regions observed in 2005 for IC 0167. The complete version of this table is found in the electronic version of the article (see Supporting Information).

| ID  | \( E(B - V) \) | ID  | \( E(B - V) \) | ID  | \( E(B - V) \) | ID  | \( E(B - V) \) |
|-----|----------------|-----|----------------|-----|----------------|-----|----------------|
| 2   | 0.16           | 11  | 0.02           | 17  | 0.09           | 26  | 0.09           |
| 5   | 0.02           | 12  | 0.05           | 18  | 0.07           | 28  | 0.09           |
| 8   | 0.15           | 13  | 0.10           | 19  | 0.09           | 43  | 0.11           |

Table B2. Intrinsic extinctions for the regions observed in 2006 for IC 0167. The complete version of this table is found in the electronic version of the article (see Supporting Information).

| ID  | \( E(B - V) \) | ID  | \( E(B - V) \) | ID  | \( E(B - V) \) | ID  | \( E(B - V) \) |
|-----|----------------|-----|----------------|-----|----------------|-----|----------------|
| 1   | 0.02           | 15  | 0.04           | 24  | 0.01           | 46  | 0.13           |
| 3   | 0.16           | 16  | 0.01           | 25  | 0.20           | 50  | 0.04           |
| 7   | 0.16           | 18  | 0.07           | 27  | 0.09           | 51  | 0.14           |
### Table B3. Intrinsic extinctions for the regions observed in 2005 for NGC 1042. The complete version of this table is found in the electronic version of the article (see Supporting Information).

| ID  | \( E(B - V) \) | ID  | \( E(B - V) \) | ID  | \( E(B - V) \) | ID  | \( E(B - V) \) |
|-----|---------------|-----|---------------|-----|---------------|-----|---------------|
| 1   | 0.21          | 10  | 0.18          | 20  | 0.16          | 28  | 0.16          |
| 3   | 0.11          | 12  | 0.09          | 21  | 0.10          | 30  | 0.14          |
| 7   | 0.16          | 16  | 0.16          | 22  | 0.18          | 35  | 0.19          |

### Table B4. Intrinsic extinctions for the regions observed in 2006 for NGC 1042. The complete version of this table is found in the electronic version of the article (see Supporting Information).

| ID  | \( E(B - V) \) | ID  | \( E(B - V) \) | ID  | \( E(B - V) \) | ID  | \( E(B - V) \) |
|-----|---------------|-----|---------------|-----|---------------|-----|---------------|
| 2   | 0.10          | 17  | 0.13          | 34  | 0.08          | 56  | 0.16          |
| 4   | 0.10          | 18  | 0.23          | 43  | 0.13          | 57  | 0.13          |
| 5   | 0.21          | 19  | 0.08          | 45  | 0.09          | 59  | 0.06          |

### Table B5. Intrinsic extinctions for the regions observed in 2005 for NGC 6907. The complete version of this table is found in the electronic version of the article (see Supporting Information).

| ID  | \( E(B - V) \) | ID  | \( E(B - V) \) | ID  | \( E(B - V) \) | ID  | \( E(B - V) \) |
|-----|---------------|-----|---------------|-----|---------------|-----|---------------|
| 8   | 0.50          | 17  | 0.47          | 24  | 0.51          | 33  | 0.48          |
| 10  | 0.38          | 18  | 0.60          | 25  | 0.49          | 34  | 0.36          |
| 11  | 0.42          | 19  | 0.56          | 26  | 0.39          | 35  | 0.48          |

### Table B6. Intrinsic extinctions for the regions observed in 2006 for NGC 6907. The complete version of this table is found in the electronic version of the article (see Supporting Information).

| ID  | \( E(B - V) \) | ID  | \( E(B - V) \) | ID  | \( E(B - V) \) | ID  | \( E(B - V) \) |
|-----|---------------|-----|---------------|-----|---------------|-----|---------------|
| 1   | 0.33          | 15  | 0.25          | 27  | 0.54          | 50  | 0.55          |
| 2   | 0.34          | 16  | 0.47          | 28  | 0.27          | 51  | 0.43          |
| 3   | 0.48          | 17  | 0.52          | 29  | 0.52          | 53  | 0.55          |

### APPENDIX C: SPECTRAL LINE FLUXES

The tables in this appendix show the mean flux measured for each spectral line used to evaluate the metallicities, according to the different procedures mentioned in this paper. Slits flagged with a ‘†’ were removed from our analysis due to the underlying Balmer absorption.

### Table C1. Fluxes of the spectral lines observed in IC 0167 using the slit identified by the year of observation and its ID. Slits flagged with a ‘†’ were removed from our analysis due to the underlying Balmer absorption. The complete version of this table is found in the electronic version of the article (see Supporting Information).

| Slit | \([\text{O} \text{II}]\) | \([\text{H}\beta]\) | \([\text{[O} \text{III}]\)] | \([\text{[O} \text{III}]\)] | \([\text{[N} \text{II}]\)] | \([\text{H}\alpha]\) | \([\text{[N} \text{II}]\)] | \([\text{[Ar} \text{III}]\)] |
|------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| 05_15 | 3430 ± 420      | 1380 ± 14       | 621.3 ± 7.1     | 1830 ± 26       | –               | –               | –               | –               |
| 05_17 | 250 ± 130       | 68.50 ± 0.37    | 25.63 ± 0.17    | 80.26 ± 0.87    | –               | –               | –               | –               |
| 06_08 | –               | 16.09 ± 0.80    | 8.47 ± 0.51     | 30.81 ± 0.79    | 0.86 ± 0.27     | 40.80 ± 0.03    | 4.5 ± 2.3       | –               |
Table C2. Fluxes of the spectral lines observed in NGC 1042 using the slit identified by the year of observation and its ID. Slits flagged with a † were removed from our analysis due to the underlying Balmer absorption. The complete version of this table is found in the electronic version of the article (see Supporting Information).

| Slit Year_ID | [O II] (3727 Å) | Hβ (4861 Å) | [O III] (4959 Å) | [O III] (5007 Å) | [N II] (6548 Å) | Hα (6563 Å) | [N II] (6584 Å) | [Ar III] (7136 Å) |
|-------------|----------------|-------------|------------------|------------------|----------------|-------------|----------------|------------------|
| 05_01       | 339 ± 70       | 92.14 ± 0.67| 124 ± 1.6        | 349.9 ± 8.3      | –              | –           | –              | –                |
| 06_09       | –              | 121.10 ± 0.57| 21.8 ± 1.8       | 70.89 ± 0.23     | 31.10 ± 0.01   | 338.4 ± 4.5 | 90.42 ± 0.91  | –                |
| 06_14†      | –              | 27.6 ± 2.8  | –                | 13.5 ± 2.9       | 6.58 ± 0.61    | 65.4 ± 1.9  | 17.66 ± 0.49  | –                |

Table C3. Fluxes of the spectral lines observed in NGC 6907 using the slit identified by the year of observation and its ID. Slits flagged with a † were removed from our analysis due to the underlying Balmer absorption. The complete version of this table is found in the electronic version of the article (see Supporting Information).

| Slit Year_ID | [O II] (3727 Å) | Hβ (4861 Å) | [O III] (4959 Å) | [O III] (5007 Å) | [N II] (6548 Å) | Hα (6563 Å) | [N II] (6584 Å) | [Ar III] (7136 Å) |
|-------------|----------------|-------------|------------------|------------------|----------------|-------------|----------------|------------------|
| 05_15†      | –              | 1335 ± 2.5  | 52.1 ± 14.5      | 332.3 ± 3.4      | –              | –           | –              | –                |
| 06_08       | –              | 2017 ± 45   | 253.30 ± 0.30    | 785 ± 19         | 426.7 ± 9.3    | 4000 ± 120  | 1325 ± 40     | 34.3 ± 5.0       |
| 06_09       | –              | 53.9 ± 4.1  | 12.6 ± 4.2       | 39.5 ± 4.9       | 35.3 ± 3.6     | 285.5 ± 2.4 | 97.8 ± 2.2    | –                |

SUPPORTING INFORMATION

Additional Supporting Information may be found in the online version of this article:

Appendix A. Positions, distances and velocities associated with the slits.
Appendix B. Intrinsic extinctions.
Appendix C. Spectral line fluxes.

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