ANALYSIS OF THE INTERACTION EFFECTS IN THE SOUTHERN GALAXY PAIR Tol 1238–364 AND ESO 381-G009

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ABSTRACT

In the context of the connection among galaxy-galaxy interaction, starbursts, and nuclear activity, we present and discuss a quantitative morphological analysis based on BVR images and a detailed spectroscopic investigation of two interacting galaxies, the Seyfert 2 Tol 1238–364 (IC 3639) and its companion ESO 381-G006. Broadband optical photometry is complemented by Hα imaging, which provides information about the distribution of star-forming regions across the galaxies. Long-slit spectroscopic data obtained at different position angles of the slit are employed to determine the physical conditions of circumnuclear and extranuclear regions. A mixture of thermal and nonthermal ionizing radiation is found in the surroundings of the nucleus of Tol 1238–364, and the energy budget supports the presence of a circumnuclear starburst. Several regions in both the galaxies show anomalous line ratios: additional ionization by shock heating and low ionization of some extranuclear H II regions are suggested as possible explanations. An analysis of the emission-line profiles reveals the presence of a broad Hα component in the nuclear region of Tol 1238–364. Independent estimates of the star formation rates (SFRs) were obtained through flux-calibrated Hα images and far-infrared (FIR) emission in the four IRAS bands. Overall, SFR densities have been compared with the SFR densities derived from Hα emission in the individual regions of the galaxies sampled by long-slit spectra. In both the galaxies an enhancement of the star formation activity with respect to isolated galaxies is revealed. The prevalence of starburst or nuclear activity has been examined through FIR color indices. The interaction scenario is discussed on the basis of the observed galaxy properties.

Subject headings: galaxies: individual (Tol 1238–364, ESO 381-G009) — galaxies: interactions — galaxies: Seyfert — galaxies: starburst

1. INTRODUCTION

The importance of the role played by interaction in triggering nuclear bursts of star formation and activity in galaxies has been clearly pointed out in the last decades. N-body simulations have shown that interactions drive large gas flows toward the center of galaxies (e.g., Barnes & Hernquist 1991). Disk instabilities in colliding galaxies lead rapidly to the formation of strong bars and to gas inflows fueling early starbursts and/or active galactic nucleus (AGN) activity before the galaxy merging (Mihos & Hernquist 1996; Barnes & Hernquist 1996; Mihos 1999). The role of the orbital geometry in triggering inflow and activity has been considered: prograde encounters favor bar instabilities (Barnes & Hernquist 1996). Other clues to the connection between interaction and starburst and AGN activity come from several statistical studies: an excess of both starburst and Seyfert galaxies among galaxy pairs and an excess of physical companions in samples of starburst galaxies (SBGs) and Seyfert galaxies have been observed (e.g., Keel & Van Soest 1992; Rafanelli, Violato, & Baruffolo 1995; Rafanelli, Temporin, & Baruffolo 1997).

Detailed studies of interacting systems can provide a mean to evaluate the validity of this scenario (e.g., Rifatto et al. 2001). In this context we performed a photometric and spectroscopic analysis of the Seyfert 2 Tol 1238–364 and of its companion ESO 381-G009, as well as an evaluation of interactions...
far-infrared (FIR) emission of each galaxy of the pair in order to determine the physical properties of circumnuclear and extranuclear regions and to obtain independent estimates of the star formation rates (SFRs).

Tol 1238–364 is a Seyfert 2 galaxy morphologically classified as SB(rs)bc; its near-infrared bar is aligned at P.A. = 150° (Mulchaey, Regan, & Kundu 1997; González Delgado et al. 1998). After the recent detection of a broad Hα component in polarized light (Heisler, Lumsden, & Bailey 1997), the galaxy is listed among the Seyfert 2 galaxies hosting a hidden broad-line region (BLR). The column density, as measured by means of the photoelectric absorption cutoff in the hard X-ray spectrum, assumes values larger than 10^{25} \text{cm}^{-2} (Risaliti, Maiolino, & Salvati 1999). It is also classified as a luminous infrared galaxy \(L_{\text{FIR}} = 4.36 \times 10^{10} L_\odot\) (Lutz 1992) and is located in the “radio-bright” side of the FIR/radio correlation (Helou, Soifer, & Rowan-Robinson 1985), as shown by Bransford et al. (1998). It forms a triple system along with the almost face-on SB(r) ESO 381-G009, located at 1.8 northeast, and an edge-on galaxy 2.6 to northwest (e.g., Karachentseva & Karachentsev 2000). Even if the optical images do not reveal strongly distorted morphologies, traces of plumes and bridges of neutral gas have been detected in the H ι 21 cm line (Babic, Price, & Jones 2000; Barnes & Webster 2001).

The Seyfert 2 and its northeast companion are characterized by strongly enhanced star formation also in the nuclear region. The starburst nature of Tol 1238–364 is pointed out by UV (González Delgado et al. 1998; González Delgado & Heckman 1999), FIR (Lutz 1992), and radio (Bransford et al. 1998) observations. ROSAT HRI data show soft X-ray emission extended up to a radius of 6.8 kpc best fitted with a two-component model of a power law and thermal emission (Levenson, Weaver, & Heckman 2001). ESO 381-G009 presents enhanced FIR emission, even if its FIR luminosity is not sufficient to classify it as an infrared luminous galaxy \(L_{\text{FIR}} = 7.42 \times 10^{9} L_\odot\) (Lutz 1992).

The present paper is organized as follows: Observations and data reduction are described in § 2. The main properties of the galaxies are derived through the analysis of the photometric and spectroscopic data and the comparison with photoionization models in § 3. Comments on the FIR emission of each of the two galaxies, obtained applying maximum entropy procedures to the IRAS data, are given in § 4. The results are summarized and extensively discussed in § 5, where considerations on the environment of the galaxies and the evolutionary history of the triplet are expressed as well.

## 2. OBSERVATIONS AND DATA REDUCTION

Our data were obtained under good seeing conditions \((\lesssim 1^\prime\prime)\) during an observing run in 1995 April at the ESO-MPIA 2.2 m telescope in La Silla, equipped with the Faint Object Spectrograph and Camera EFOSC2. The detector was a 1k × 1k CCD with a pixel size of 19 μm and a scale of 0.336 pixel⁻¹. Two images were taken during the same nights in redshifted, narrowband Hα \((\lambda_c = 6651.7 \, \AA, \text{FWHM} = 61.3 \, \AA)\) and continuum \((\lambda_c = 6521.2 \, \AA, \text{FWHM} = 74.3 \, \AA)\) filters. The spectrophotometric standard star Kopff 27 was also observed with the same filters. Additionally, broadband BVR images of both galaxies, together with standard-star fields, were taken. Observation details concerning both imaging and spectroscopy, including exposure times, slit position angles (P.A.), and limit surface brightnesses and magnitudes, are summarized in Table 2.

Hα images were reduced in a standard way: they were bias-subtracted, flat-fielded, cleaned from cosmic rays, and background-subtracted. The tabulated spectrum of Kopff 27 was convoluted with the system (filter + CCD + telescope) transmission curve and normalized to the bandwidth of the Hα filter. From the comparison with the counts measured on the images, corrected for atmospheric extinction, we computed the zero points to be applied for flux calibration.

The flux-calibrated images were corrected for atmospheric extinction. The continuum image was aligned to the Hα image using field stars close to the galaxy and then subtracted from it; a check that the scaling factor derived from the photometric calibration was correct was given by the disappearance of nonsaturated stars in the continuum-subtracted image. A further check consisted in comparing the Hα fluxes of the nucleus and the extranuclear regions extracted from the spectra (see below) with those of the relevant regions in the calibrated image. The fluxes were found in good agreement (they differ by less than 20%, which is within the errors of measurement).

After the subtraction of the Hα continuum component, the images were processed by means of an adaptive smooth filtering procedure developed at the Astrophysikalisches Institut Potsdam (Richter et al. 1991; Lorenz et al. 1993) in order to reduce the noise and enhance faint details of the internal structure of the galaxies (Fig. 1). BVR images were also reduced in a standard way and registered. The nonsaturated foreground stars were subtracted by fitting them with a model of the point-spread function (PSF) obtained with IRAF²/DAOPHOT routines. Saturated stars were masked with the task IMEDIT. The photometric calibration constants have been derived by use of the package PHOTCAL.

### 1. Galaxy Properties

| Object        | α (J2000.0) | δ (J2000.0) | Radial Velocitya (km s⁻¹) | MBb |
|---------------|-------------|-------------|---------------------------|-----|
| Tol 1238–364  | 12 40 52.9  | −36 45 22   | 3282                      | −20.2 |
| ESO 381-G009  | 12 40 58.4  | −36 43 55   | 3288                      | −19.3 |
| ESO 381-G006  | 12 40 40.8  | −36 44 20   | 3101                      | −17.2 |

Note. — Units of right ascension are hours, minutes, and seconds, and units of declination are degrees, arcminutes, and arcseconds.

² IRAF is distributed by the National Optical Astronomy Observatories, which are operated by the Association of Universities for Research in Astronomy, Inc., under cooperative agreement with the National Science Foundation.
applied to the standard stars, with the usual transformation equations. A $B-R$ color map (Fig. 2) was obtained to analyze the color gradient across the galaxies and to have an insight into the spatial distribution of young and old stellar populations.

A 2'' wide slit was used to obtain long-slit spectra covering the spectral ranges 3200–6030 Å (grism 3) and 3850–7950 Å (grism 6) with dispersions 1.9 and 2.6 Å pixel$^{-1}$, respectively. The resulting spectral resolution estimated from the FWHM of faint comparison lines is of the order of ~10 Å, while the scale along the slit is 0.336 pixel$^{-1}$.

Tol 1238–364 was observed at three different slit position angles: P.A. = 90°, 146°, and 150°. The spectra at P.A. = 150° and 146° were taken across the center of the galaxy (the first one along the galaxy’s bar and centered on the nucleus), while the spectrum at P.A. = 90° covers the

**TABLE 2**

**Observation Summary**

| Object              | Date         | UT (hh:mm) | Exposure Time (s) | P.A. (deg) | Spectral Range (Å) | Filter | $\rho_{\text{lim}}^a$ (mag arcsec$^{-2}$) | $m_{\text{limb}}^b$ (mag) |
|---------------------|--------------|------------|-------------------|------------|--------------------|--------|------------------------------------------|--------------------------|
| **Spectroscopy**    |              |            |                   |            |                    |        |                                          |                          |
| Tol 1238–364        | 1995 Apr 1   | 09:23      | 900               | 150        | 3850–7950          | ...    | ...                                      | ...                      |
|                     | 1995 Apr 1   | 09:47      | 1200              | 150        | 3200–6030          | ...    | ...                                      | ...                      |
|                     | 1995 Apr 3   | 05:55      | 900               | 90         | 3850–7950          | ...    | ...                                      | ...                      |
|                     | 1995 Apr 3   | 06:47      | 900               | 90         | 3200–6030          | ...    | ...                                      | ...                      |
|                     | 1995 Apr 4   | 06:28      | 1800              | 146        | 3850–7950          | ...    | ...                                      | ...                      |
|                     | 1995 Apr 4   | 07:04      | 2400              | 146        | 3200–6030          | ...    | ...                                      | ...                      |
| ESO 381-G009        | 1995 Apr 3   | 06:23      | 900               | 90         | 3850–7950          | ...    | ...                                      | ...                      |
|                     | 1995 Apr 3   | 07:59      | 900               | 125        | 3850–7950          | ...    | ...                                      | ...                      |
|                     | 1995 Apr 3   | 08:16      | 900               | 125        | 3200–6030          | ...    | ...                                      | ...                      |
| **Imaging**         |              |            |                   |            |                    |        |                                          |                          |
| Tol 1238–364, ESO 381-G009 | 1995 Apr 1   | 07:49      | 600               | ...        | ...                | $B$    | 23.79                                    | 22.79                    |
|                     | 1995 Apr 1   | 08:02      | 300               | ...        | ...                | $V$    | 23.96                                    | 23.13                    |
|                     | 1995 Apr 1   | 08:10      | 300               | ...        | ...                | $R$    | 24.11                                    | 23.12                    |
|                     | 1995 Apr 1   | 07:05      | 900               | ...        | ...                | H$\alpha^b$ | $3.56 \times 10^{-16}$ | $8.47 \times 10^{-16}$ |
|                     | 1995 Apr 1   | 07:23      | 900               | ...        | ...                | H$\alpha$ continuum | ...                                      |

$^a$ Limit surface brightnesses are evaluated at a 3 $\sigma$ level above the background, and the limit magnitudes are evaluated assuming a 3 $\sigma$ signal within the PSF radius corresponding to 80% of the total flux.

$^b$ For the H$\alpha$ image we give the brightness and flux limit in units of ergs cm$^{-2}$ s$^{-1}$.

![Fig. 1.—H$\alpha$ images of ESO 381-G009 (left) and Tol 1238–364 (right), after application of an adaptive smooth filter](image-url)
region ~3'' south of the nucleus, where many knots of emission are visible in the Hα image (Fig. 3, top panels). The spectra of ESO 381-G009 were taken at P.A. = 90° and 125° through the nucleus (Fig. 3, bottom panels). This last orientation of the slit allowed us to observe both the nucleus and the emission knot on its northwest side (see Fig. 3, bottom panels). Spectra of the standard stars Kopff 27 and Feige 56 were taken immediately before or after the spectra of the galaxies, to allow their flux calibration.

The two-dimensional spectra were reduced with standard IRAF packages: after bias subtraction, flat-fielding, and a careful subtraction of cosmic rays, they were wavelength-calibrated. The IRAF tasks IDENTIFY, REIDENTIFY, FITCOORDS, and TRANSFORM were used in sequence to determine the dispersion solution and linearize the two-dimensional spectra. An estimate of the wavelength calibration error was obtained by evaluating the rms of the mean difference between measured and predicted sky-line wavelengths. This rms value is ~1.3 Å, equivalent to 80 km s$^{-1}$ at λ = 5000 Å. The spectra were corrected for atmospheric extinction and calibrated (CALIBRATE) to a flux scale using sensitivity functions obtained with the tasks STANDARD and SENSFUNC applied to the observed spectro-photometric standard stars. Finally, the sky background was fitted by using two column samples at both sides of the galaxy spectrum and subtracted with the task BACKGROUND.

Fig. 2.—B−R image of ESO 381-G009 (upper left) and Tol 1238−364 (lower right). Darker regions are bluer.

Fig. 3.—Contour maps of the Hα adaptive-smoothed images of Tol 1238−364 (top) and ESO 381-G009 (bottom) with the traces of the slit positions superimposed and the regions extracted from the spectra. Regions are labeled according to the explanations in the text.
Contour maps of the extended H\textalpha + [N ii] λ6548,6583 emission lines and continuum-subtracted H\textalpha profiles along the slit were used to identify and extract the spectra of the nucleus and of several extranuclear emitting regions. Such regions are labeled on the slit images overlaid to the contour maps of the galaxies in Figure 3: labels without prime symbols are used for regions at P.A. = 150° in Tol 1238–364 and P.A. = 90° in ESO 381-G009, a prime symbol indicates the regions at P.A. = 146° in Tol 1238–364 and P.A. = 125° in ESO 381-G009, while a double prime symbol indicates the regions at P.A. = 90° of Tol 1238–364.

A comparison with the H\textalpha images revealed a clear one-to-one correspondence among the so-selected emitting regions and the emission knots enhanced by the adaptive smooth filter (see Fig. 3). One-dimensional spectra of these regions (Figs. 4 and 5) were extracted and the corresponding blue and red parts were combined together. The central regions N and N' of Tol 1238–364 were further divided into ≳ 70 wide subregions (n1, n2, n3, n4, n5, n1', n2', n3', n4', n5') in order to analyze the circumnuclear region in more detail. Their spectra are shown in Figure 6. Regions n3 and n3' are centered on the H\textalpha emission peaks along the slit. The signal-to-noise ratio (S/N) of the spectra ranges from 5 to 15 in the blue (λ ≈ 4000 Å) and from 35 to 55 in the red (λ ≈ 6500 Å) in the central regions of Tol 1238–364 (n1, . . ., n5, n1', . . ., n5', C'). In the outermost regions the S/N in the continuum is significantly lower, although it is still sufficiently good in the prominent emission lines. The regions with the lowest values are the outermost ones at P.A. = 150° and have S/N of ~2 in the blue, around λ ≈ 4000 Å, ~5 around λ ≈ 5000 Å, and ~15 in the red.

For ESO 381-G009 the S/N in the center is ~8 in the blue and ~40 in the red, while in the outer regions the S/N is ~2 in the blue and ~8 in the red.

A correction for Galactic extinction (A_V = 0.17 mag, as derived from the A_V value given by Burstein & Heiles 1982 following Cardelli, Clayton, & Mathis 1989 and assuming a visual selective extinction RV = 3.1) was applied.³ Before measuring the emission-line fluxes, a template spectrum, conveniently diluted to match the absorption features following the method outlined by Ho, Filippenko, & Sargent (1993), was used to correct the spectra for the effects of the underlying stellar population, particularly affecting H\beta. The H\beta absorption was detected in all but one of the

³ The use of the Galactic extinction value derived from the maps of Schlegel, Finkbeiner, & Davis (1998), A_V = 0.229 mag, would imply a 5% difference in the measured fluxes.

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Fig. 4.—Nuclear and extranuclear spectra of Tol 1238–364, labeled according to Fig. 3
extracted one-dimensional spectra of Tol 1238–3634 and in the central regions of ESO 381-G009.

A careful deblending of Hα and the [N II] satellite lines was performed using a multi-Gaussian fit procedure. In the nuclear region of the Seyfert galaxy a better fit of the blend was obtained assuming the presence of a broad Hα component (Fig. 7), possibly indicating that this galaxy is a Seyfert of type 1.9. The mean FWHM of the broad component found in the nuclear regions at P.A. = 150° and 146° is 1735 ± 60 km s⁻¹, in agreement with the FWHM ~ 1860 km s⁻¹ found in polarized light by Heisler et al. (1997). The mean FWHM of the narrow line is ~300 km s⁻¹.

Measured fluxes of the narrow lines were corrected for internal extinction assuming as intrinsic value of the Balmer decrement Hα/Hβ = 2.85 (Osterbrock 1989). The Galactic interstellar reddening curve parameterized by Miller & Mathews (1972) has been used. Hereafter we indicate with the term “intensities” these extinction-corrected fluxes. The internal extinction derived in the above way can be considered an upper limit in the case of the nucleus of the Seyfert galaxy, since the intrinsic ratio Hα/Hβ = 3.1 might be more appropriate according to some authors (e.g., Veilleux & Osterbrock 1987). The observed emission-line fluxes and intensities relative to Hβ, the absolute fluxes of Hα and Hβ, and the values of internal extinction for the individual regions are listed in the Appendix. The distances of the extremes of every region to the intensity peak along the slit, expressed in arcseconds, are indicated as well.

3. MORPHOLOGICAL, PHOTOMETRIC, AND SPECTROSCOPIC PROPERTIES

3.1. Morphology

The morphology of the two galaxies was investigated through the analysis of the broadband optical images. In order to study the radial trend of the ellipticity (e = 1 − b/a, with a and b semi-axes of the ellipse) and the P.A., their isophotes were fitted with ellipses with fixed center. In the outermost isophotes of Tol 1238–364 the P.A. had to be fixed as well. The e and P.A. versus a plots in Figure 8 reveal in Tol 1238–364 the existence of a bar extended until a ~ 5" with e ~ 0.5 and P.A. ~ 145°, spiral arms mostly visible in B and extended until a ~ 16", and a clear twist of the isophotes (P.A. ~ 80°), which become nearly circular beyond a ~ 30". Also in ESO 381-G009 (Fig. 9) we observe a twist of the isophotes, whose P.A. changes from ~120° to ~30° and whose ellipticity increases beyond a ~ 30", giving the impression that they are stretching toward Tol 1238–364. A strongly elliptical bar (e ~ 0.8) is located at P.A. ~ 125° and seems to extend its isophotes up to a ~ 20", after which we
observe a sudden transition to the spiral arms arranged into a ringlike shape.

We repeated the isophote fitting with free ellipses in order to investigate the change in the position of the isophote center. We estimated a decentering degree, as defined by Márquez & Moles (1999), of 7.5% for Tol 1238/C0 and 3.4% for ESO 381-G009. This parameter gives an indication of the degree of asymmetry of the galaxy disks.

A bulge-disk decomposition of the surface brightness profiles of both galaxies in the three passbands was performed without a PSF deconvolution, assuming an exponential law for the two components (Andredakis 1998; Andredakis & Sanders 1994):

\[
\Sigma_{\text{bulge}}(r) = 5.36B_e \exp\left(-1.68 \frac{r}{r_e}\right),
\]

\[
\Sigma_{\text{disk}}(r) = D_0 \exp\left(\frac{r}{h_D}\right),
\]

where \(\Sigma_{\text{bulge}}(r)\) and \(\Sigma_{\text{disk}}(r)\) are the surface intensities of the bulge and disk components (in mag arcsec\(^{-2}\)) at a radius \(r\), \(B_e\) is the surface intensity at the effective radius \(r_e\) (i.e., the radius containing half of the bulge light), \(D_0\) is the central surface intensity of the disk, and \(h_D\) is the disk scale length.

Fig. 6.—Spectra of the nuclear and circumnuclear regions extracted from the central portions N and N' of Tol 1238–364. The regions are labeled with increasing numbers from northwest to southeast.

Fig. 7.—Multi-Gaussian fit of the blend H\(\alpha + [\text{N II}] \lambda\lambda 6548, 6563\) for the nuclear region of Tol 1238–364. Fluxes (in ergs cm\(^{-2}\) s\(^{-1}\) Å\(^{-1}\)) are plotted vs. the wavelength (in Å). The fit of the blend is drawn with a dotted line, while the individual fit components are drawn with dashed lines. A broad H\(\alpha\) component was required to match the observed profile.
The structural parameters averaged on the three passbands, the bulge-to-total light ratios $B/T$, and the total magnitudes integrated to infinity are listed in Table 3. Magnitudes corrected for Galactic extinction are reported as well. The $B$ and $V$ magnitudes measured for Tol 1238–364 are in agreement with Hunt et al. (1999). The $B/T$ ratios are typical of disk-dominated galaxies. Let us note that the existence of a real bulge in ESO 381-G009 is uncertain. Actually, the central part of the galaxy consists of a structure composed by two knots, the brightest of which was chosen as the nucleus, although it is not located in the geometrical center and we lack information about the kinematics of the system. In order to investigate the color gradient $B/R$, we built a new $B$ surface brightness profile by applying the same ellipses fitted to the $R$-band isophotes. The $B/R$ profile of Tol 1238–364 (Fig. 10) shows a red color for the bar, which is probably dominated by an old stellar population and blue spiral arms and becomes red again in the outermost part of the galaxy, where the disk might be affected by dust extinction. In ESO 381-G009, instead, the inner part of the bar exhibits a blue color (Fig. 11), probably as an effect of the presence of central star-forming regions in agreement with the bright knots visible in the H$\alpha$ image. The profile reddens in the outer part of the bar and becomes blue again in correspondence with the spiral arms.

The continuum-subtracted H$\alpha$ image shows the presence of bright emitting regions distributed all over Tol 1238–364, but more concentrated toward its nucleus and in the northeastern spiral arm facing the companion galaxy (Figs. 1 and 3), and confirms the structures already revealed by the analysis of the broadband images for ESO 381-G009. Additionally, a sort of plume departing from the northern side of ESO 381-G009 is visible in all images, as well as an extension of star-forming regions (better visible in the H$\alpha$ image) on the south, outside the “ring,” especially in the direction of the companion galaxy. All the above features are also emphasized as blue regions in the $B/R$ image (Fig. 2).

### Table 3

| Object              | $B$ (mag) | $V$ (mag) | $R$ (mag) | $\langle r_e \rangle$ (arcsec) | $\langle h_D \rangle$ (arcsec) | $B/T$ |
|---------------------|-----------|-----------|-----------|-------------------------------|-------------------------------|-------|
| Tol 1238–364        | 12.92     | 12.45     | 11.98     | 2.2                           | 7.5                           | 0.2   |
|                     | 12.69     | 12.28     | 11.84     | ...                           | ...                           | ...   |
| ESO 381-G009        | 13.71     | 13.22     | 12.74     | 3.0                           | 12.5                          | 0.12  |
|                     | 13.48     | 13.05     | 12.60     | ...                           | ...                           | ...   |

**Notes.**—For each galaxy, observed magnitudes are listed on the first row and magnitudes corrected for Galactic extinction on the second row. Extinction values in $V$ and $R$ were derived from $A_V$ (Burstein & Heiles 1982) following Cardelli et al. 1989 and assuming a visual selective extinction $R_V = 3.1$. 

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**Fig. 8.**—Trend of the isophotal ellipticity (top) and P.A. (bottom) with increasing radius for Tol 1238–364 in $B$ (filled circles), $V$ (stars), and $R$ (squares).

**Fig. 9.**—Trend of the isophotal ellipticity (top) and P.A. (bottom) with increasing radius for ESO 381-G009 in $B$ (filled circles), $V$ (stars), and $R$ (squares).
3.2. Spectroscopic Classification of the Emission-Line Regions

We analyze in this section the spectroscopic characteristics of the two galaxies separately.

*Tol 1238–364.*—The trend of the ionization degree along the direction of the slits is shown in Figure 12, where the emission-line ratios [O iii] λ5007/Hβ and [N ii] λ6583/Hα are plotted against the radial distance to the nucleus for the regions identified as explained in § 2. All the diagrams show a peak in correspondence with the nucleus, as expected in the case of photoionization by a source with a power-law spectrum, and a decreasing ionization degree moving away from it. Nevertheless, the outermost regions exhibit an increasing trend of the [O iii]/Hβ ratio and an exactly opposite trend of the [N ii]/Hα ratio. This symmetric behavior is typical of H ii–like regions; however, we stress that this trend is observed in only two bins per slit position. The rise of the ionization degree is more evident at P.A. = 90° for the regions at the east side of the nucleus and could be partly caused by an underestimate of Hβ, difficult to measure in spectra with relatively low S/N, and partly an effect of the presence of a hot interstellar medium.

In order to investigate the nature of the emission-line regions and of their ionizing sources, we used the intensities listed in the Appendix in order to build the classic diagnostic diagrams (Figs. 13 and 14) [O iii] λ5007/Hβ versus [O i] λ6300/Hα, [N ii] λ6583/Hα, [S ii] λλ(6716 + 6731)/Hα (Veilleux & Osterbrock 1987; VO diagrams), and [O i] λ6300/Hα, [O i] λ6300/[O iii] λ5007, [N ii] λ6583/Hα, [O iii] λ5007/Hβ versus [O ii] λ3727/[O iii] λ5007 (Baldwin, Phillips, & Terlevich 1981; Shields & Filippenko 1990; Halpern & Steiner 1983).

A careful examination of the diagnostic diagrams allowed us to investigate in some detail the nature of the circumnuclear and extranuclear regions (throughout this paper we call “circumnuclear regions” the regions within 1 kpc from the nucleus, assuming H0 = 75 km s⁻¹ Mpc⁻¹). The nuclear and circumnuclear regions n2, n3, n4, n2’, n3’, and n4’ extracted from the central portions of the bidimensional spectra have line ratios characteristic of Seyfert galaxies, while the adjacent regions n1, n5, n1’, and n5’, as well as region C0’ at P.A. = 90°, gradually move toward the LINER area of the diagrams, probably indicating a transition from a dominating nonthermal photoionizing source to a dominating thermal source.

Along P.A. = 150° a progressive transition from Seyfert-like to H ii–like properties is evident when going out from the nucleus. The region A1 on the west side of the nucleus shows typical H ii–like features, while B1 on the opposite side has transition properties between LINERs and H ii regions. At P.A. = 146° the extranuclear regions all fall in the H ii–like area of the diagrams, although A2’ approaches the LINER region in the [O i]/Hα diagram and enters it in the [S ii]/Hα one. A similar behavior is observed in the regions B2’ and A3’ at P.A. = 90°; the region B3’ has an anomalously high [O iii]/Hβ ratio, which locates it at the border between Seyfert galaxies and LINERs. However, this could be a consequence of an underestimate of Hβ, and the region is most likely to be classified as LINER type. In contrast with Bransford et al. (1998), we do not observe any marked east/west asymmetry in the distribution of the emission-line ratios. The discrepancy among different diagnostic diagrams could be caused by an enhancement of [O i] and [S ii] lines consequent to ionization by starburst-driven shocks, as suggested by Bransford et al. (1998). However, some of the anomalous regions are not well centered on any knot of emission in the Hα image (Fig. 3) and have low

4 The correction for underlying stellar absorption was particularly difficult for this spectrum; therefore, the measured Hβ flux is uncertain.
density of SFR (see last column of Table 4; details on the content of the table are given in §3.4). This could indicate that these regions are weakly ionized by a low number of young stars. Actually, “faint emission” regions are found to have relatively high values of $\langle S/\text{H}\rangle$ ($\sim 0.3–0.5$) and $\langle \text{O}/\text{H}\rangle$ ($\sim 0.04–0.1$) because of their low ionization degree (Smith et al. 1993).

A qualitative examination of the spectra of the individual extranuclear and circumnuclear regions (Figs. 4 and 6) gives further insights into their nature. In particular, we notice that the spectra of the outermost regions tend to be dominated by young (or sometimes very young) stellar populations, as suggested by the weakness of metal absorption lines, the strength of Balmer absorption lines, the high strength of the CaH + He doublet (2.3 \(\lesssim\) EW \(\lesssim\) 9.5 \(\AA\)) relative to the CaK absorption line (0.5 \(\lesssim\) EW \(\lesssim\) 5.2 \(\AA\)), and the blue continuum usually peaked around 4000 \(\AA\) (e.g., region A2' in Fig. 15). These spectra appear to be dominated by a population of A-type (or F-type) stars. Toward inner radii, the extranuclear regions show a slightly redder continuum, peaked around 4500 \(\AA\), progressively deeper metal absorption lines, but still very strong Balmer absorption lines indicating important contributions to the spectrum from both a relatively young and an old (G- to K-type) stellar population (e.g., region B1 in Fig. 15). The most important contribution from old stellar populations is found in the circumnuclear regions, which exhibit a red continuum, strong metal lines, and comparably strong Balmer absorption lines (see, e.g., regions n5 and n2' in Fig. 15). The CaK (3.5 \(\lesssim\) EW \(\lesssim\) 7.7 \(\AA\)) absorption line becomes stronger than the CaH + He doublet (1.6 \(\lesssim\) EW \(\lesssim\) 4.5 \(\AA\)), as is typical of G-type or later stellar populations (e.g., Rose 1984; Leonardi \& Rose 1996), but not in all the regions within the central kiloparsec. In particular, this is not the case for regions n1', C'', and especially the nucleus n3 [EW(CaK) \sim 3 \(\AA\), EW(CaH + He) \sim 5 \(\AA\)], where an A-type population probably gives a nonnegligible contribution to the spectrum, and region n2, where a red continuum is overlapped with a component rising toward blue wavelengths (Fig. 15). These last spectra give evidence of the presence of (relatively) recent nuclear and circumnuclear starbursts. The general trend described above, with old population contributions becoming progressively more important with decreasing radius and young populations dominating the outermost regions (at radii of about 3–5 kpc), is in agreement with the stellar population gradients observed by Raimann et al. (2003). However, these authors (their Fig. 3) find that in the nucleus the CaK absorption line has equivalent width significantly larger than CaH + He. This discrepancy with our results could be a consequence of a different spatial sampling and size of the extracted regions. While the spatial scale of their spectra is 0.7 pixel\(^{-1}\) and they extracted one-dimensional spectra in windows of 2 pixel in the nuclear regions, our spatial scale is 0.336 pixel\(^{-1}\) and the good seeing conditions allowed us to extract nuclear regions \sim 1 pixel in size along the slit. Rebinning our spectra to match the spatial sampling of Raimann et al. (2003) and extracting regions of similar size, we verified that a 1 pixel off-center (i.e., 0.7 pixel) is sufficient to obtain a spectrum of the nucleus dominated by an old stellar population and thus reproduce the findings of Raimann et al. (2003). Indeed, the distribution of stellar populations in the
circumnuclear regions appears very inhomogeneous with strong variations within a few arcseconds, which makes the analysis very sensitive to the extraction method.

Since in H II regions the equivalent widths of Balmer emission lines are proportional to the ratio of ionizing photons to visible continuum photons from the embedded stars (Kennicutt, Keel, & Blaha 1989b), we can obtain additional information on the population of the H II regions from the observed values of EW(Hα) listed in Table 4. The Hα EWs of the extranuclear regions are at (or even below) the lower limit of the distribution found by Kennicutt et al. (1989b) for disk H II regions (defined as the regions located at a distance greater than 1 kpc from the nucleus) of spiral and irregular galaxies. These low emission-line equivalent widths could indicate that the contribution of the young stellar associations to the optical continuum is rather small and might suggest a significant contribution to the continuum by older stellar populations or a prolonged period of star formation over the disk.

**ESO 381-G009.**—The ionization-sensitive line ratios at several positions along the slits (Fig. 16) and the diagnostic diagrams (Figs. 17 and 18) have been plotted for the companion of Tol 1238–364 as well (emission-line fluxes are given in Tables 7 and 8 in the Appendix). As
expected, the [O ii]/Hβ and [N ii]/Hα ratios (Fig. 16) have symmetric trends typical of H ii–like regions, except for the regions A3', A4', and A5', which exhibit the same trend in both the line ratios. Actually, also for this galaxy not all the line ratios can be explained by pure photoionization from thermal radiation: the shift of several points toward the LINER area in the [S ii]/Hα diagnostic diagram (Fig. 17) could be caused in some cases by the faintness of the emission regions (A2, B1), but in other cases (A1, A1', A2', A3') they are probably an indication of shock heating as an additional ionization mechanism (Dopita & Sutherland 1995).

The spectra of all the regions show typical properties of young stellar populations with a blue continuum. Metal absorption lines are detectable only in the nucleus (N and N'), together with deep Balmer absorptions. However, the Hα equivalent widths measured in the spectra are rather low (see Table 5), ranging from ~15 to ~83 Å.

![Fig. 14. —[O ii] λ3727–based diagnostic diagrams for all the regions of Tol 1238–364. Symbols and S, L, and H are as in Fig. 13; the corresponding areas of the diagrams are separated by dashed lines.](image-url)
### TABLE 4

| ID  | $R^0$ (kpc) | $L(H_\alpha)$ $(\times 10^{40}\text{ ergs s}^{-1})$ | $Q_{\text{ion}}$ (photons s$^{-1}$) | $Q_{\text{esc}}$ (photons s$^{-1}$) | EW($H_\alpha$) (Å) | SFR $(M_\odot\text{yr}^{-1})$ | SFR/pc$^2$ $(M_\odot\text{yr}^{-1}\text{pc}^{-2})$ |
|-----|-------------|---------------------------------|---------------------------------|---------------------------------|-----------------|-----------------------------|---------------------------------|
| A2  | -3.90       | 1.57                            | 1.15E+52                        | 2.20E+51                        | 94.93           | 0.111                      | 7.47E-8                        |
| A1  | -1.60       | 2.31                            | 1.69E+52                        | 5.74E+51                        | 31.31           | 0.164                      | 2.50E-7                        |
| n1  | -0.70       | 0.68                            | 4.98E+51                        | 8.28E+51                        | 9.39            | 0.048                      | 2.65E-7                        |
| n2  | -0.30       | 21.21                           | 1.55E+53                        | 4.53E+52                        | 53.96           | ...                        | ...                             |
| n3  | 0.0         | 19.45                           | 1.42E+53                        | 2.82E+53*                       | 106.62          | ...                        | ...                             |
| n4  | 0.26        | 0.89                            | 6.49E+51                        | 3.61E+52                        | 50.57           | ...                        | ...                             |
| n5  | 0.51        | 0.22                            | 1.59E+51                        | 1.22E+51                        | 12.77           | 0.015                      | 1.06E-7                        |
| B1  | 0.93        | 1.39                            | 1.01E+52                        | 6.59E+51                        | 16.70           | 0.098                      | 3.86E-7                        |
| B2  | 1.83        | 1.45                            | 1.06E+52                        | 3.91E+51                        | 46.95           | 0.103                      | 1.77E-7                        |
| B3  | 3.43        | 1.14                            | 8.32E+51                        | 1.75E+51                        | 87.16           | 0.081                      | 8.87E-8                        |
| P.A. = 150° |
| A2'    | -3.71       | 0.92                            | 6.73E+51                        | 2.48E+51                        | 36.28           | 0.065                      | 4.27E-8                        |
| A1'    | -1.53       | 1.35                            | 9.85E+51                        | 4.84E+51                        | 43.68           | 0.095                      | 1.88E-7                        |
| n1'    | -0.81       | 0.97                            | 7.06E+51                        | 7.40E+51                        | 9.42            | 0.068                      | 3.13E-7                        |
| n2'    | -0.39       | 2.43                            | 1.77E+52                        | 2.68E+52                        | 25.38           | ...                        | ...                             |
| n3'    | 0.26        | 2.69                            | 1.96E+52                        | 3.61E+52                        | 49.09           | ...                        | ...                             |
| n4'    | 0.37        | 0.64                            | 4.69E+52                        | 2.36E+52                        | 17.83           | ...                        | ...                             |
| n5'    | 0.67        | 0.77                            | 5.61E+51                        | 9.04E+51                        | 9.86            | 0.054                      | 2.99E-7                        |
| B1'    | 1.74        | 2.05                            | 1.50E+52                        | 6.19E+51                        | 35.73           | 0.145                      | 1.73E-7                        |
| B2'    | 4.13        | 0.86                            | 6.27E+51                        | 1.86E+51                        | 98.28           | 0.061                      | 4.29E-8                        |
| P.A. = 146° |
| A3'    | -5.10       | 0.38                            | 2.76E+51                        | 1.07E+51                        | 64.92           | 0.027                      | 2.16E-8                        |
| A2'    | -2.95       | 1.61                            | 1.17E+52                        | 2.06E+51                        | 94.16           | 0.114                      | 1.42E-7                        |
| A1'    | -1.37       | 2.19                            | 1.60E+52                        | 9.12E+51                        | 57.72           | 0.155                      | 2.03E-7                        |
| C'     | 0.66        | 0.83                            | 6.05E+51                        | 1.88E+52                        | 11.71           | 0.059                      | 1.61E-7                        |
| B1'    | 0.97        | 2.15                            | 1.57E+52                        | 7.80E+51                        | 24.21           | 0.152                      | 4.65E-7                        |
| B2'    | 1.83        | 0.76                            | 5.58E+51                        | 3.88E+52                        | 27.01           | 0.054                      | 9.30E-8                        |
| B3'    | 3.90        | 1.07                            | 7.80E+51                        | 2.11E+51                        | 28.00           | 0.076                      | 5.33E-8                        |
| P.A. = 90° |

**Notes.**—$Q_{\text{ion}}$ values are calculated taking as reference the value with an asterisk in correspondence with the central region n3 and obtained as explained in the text. SFR and SFRD values marked with a colon are upper limits.

* Distance to the center of the galaxy. Negative distances indicate regions west of the nucleus.

#### 3.3. Photoionization Models

The code CLOUDY 90 (Ferland et al. 1998) has been used to calculate photoionization models, which have been compared to observational emission-line flux ratios, in order to evaluate the physical parameters of extranuclear and circumnuclear regions. CLOUDY is designed to simulate emission-line regions ranging from intergalactic

### TABLE 5

| ESO 381-G009: Ionizing Photons and SFR |
|--------------------------------------|
| ID  | $R^0$ (kpc) | $L(H_\alpha)$ $(\times 10^{40}\text{ ergs s}^{-1})$ | $Q_{\text{ion}}$ (photons s$^{-1}$) | $N(\text{O}_5)$ | EW($H_\alpha$) (Å) | SFR $(M_\odot\text{yr}^{-1})$ | SFR/pc$^2$ $(M_\odot\text{yr}^{-1}\text{pc}^{-2})$ |
|-----|-------------|---------------------------------|---------------------------------|-----------------|-----------------|-----------------------------|---------------------------------|
| A2  | -3.10       | 0.23                            | 1.65E+51                        | 33              | 28.41           | 0.016                      | 9.36E-9                        |
| A1  | -1.94       | 1.43                            | 1.04E+52                        | 208             | 15.47           | 0.101                      | 1.01E-7                        |
| N   | 0.0         | 5.52                            | 4.03E+52                        | 805             | 76.07           | 0.390                      | 4.49E-7                        |
| B1  | 1.74        | 0.37                            | 2.72E+51                        | 54              | 32.60           | 0.026                      | 1.76E-8                        |
| P.A. = 90° |
| A2'    | -5.93       | 0.44                            | 3.24E+51                        | 65              | 82.61           | 0.031                      | 2.77E-8                        |
| A1'    | -3.40       | 0.40                            | 2.91E+51                        | 58              | 45.92           | 0.028                      | 3.60E-8                        |
| N'     | -1.39       | 1.28                            | 9.35E+51                        | 187             | 58.24           | 0.091                      | 1.09E-7                        |
| B1'    | 19.35       | 0.09                            | 6.80E+50                        | 14              | 16.83           | 0.007                      | 2.59E-9                        |
| P.A. = 125° |

* Distance to the center of the galaxy. Negative distances indicate regions west of the nucleus.
medium to the BLR of quasars. Assuming diluted gas, heated and ionized by the radiation field of a central object, and simultaneously solving the equations of statistical and thermal equilibrium, CLOUDY can predict the physical conditions of the gas and its resulting emission-line spectrum.

Simple models can be obtained by specifying as input parameters the continuum emitted by the source, a set of assumed chemical abundances, the total hydrogen density $N_{\text{H}}$, and the ionization parameter $U = Q_{\text{H}}/(4\pi r^2 N_{\text{H}} c)$, where $Q_{\text{H}}$ is the number of ionizing photons and $r$ is the distance between the source and the inner side of the gas cloud assumed to have a plane-parallel geometry.

We derived a first estimate of the physical parameters and abundances of the ionized gas in the extranuclear regions by comparison with empirical diagrams (McGaugh 1991; Denicolo, Terlevich, & Terlevich 2002). In particular, the $R_{23}$ ratio, defined as

$$\log\left(\frac{[\text{O} \text{II}] \lambda 3727 + [\text{O} \text{III}] \lambda \lambda 4959, 5007}{\text{H}\beta}\right),$$

was compared with the model grid in the plane $[\text{O} \text{III}]/[\text{O} \text{II}]$ versus $R_{23}$ in Figure 10 of McGaugh (1991). From this comparison the ionization parameter was found in the range $-3.5 \leq \log U \leq -3.0$. The metal abundances were derived by means of the $N_{2} = [\text{N} \text{II}] \lambda 6584/\text{H}\alpha$ calibrator (Denicolo et al. 2002, their Fig. 1) by referring to the model track for $\log U = -3$. They were found in the ranges $5 \leq 8$ for Tol 1238–364 and ESO 381-G009, respectively. The choice not to directly calculate the abundances was motivated by the fact that the metallicity is very sensitive to the gas temperature, whose determination requires the measurement of the $[\text{O} \text{III}] \lambda 4363$ line. Some authors (Raimann et al. 2000) found a ratio $[\text{O} \text{III}] \lambda 4363/\text{H}\beta \leq 0.02$ in H II and starburst galaxies, which implies electronic temperatures lower than $10^{4}$ K. Unfortunately, the low S/N of our spectra in the blue range prevented the detection of this line at $5 \leq 8$. 

Fig. 15.—Enlargement of the blue range of a few circumnuclear regions and two extranuclear regions of Tol 1238–364 showing different behaviors of metal and Balmer absorption lines, which suggest different underlying stellar populations (see text for details).
In the case of the circumnuclear regions of Tol 1238–364, which are dominated by the nonthermal ionization (§ 3.2), the models were calculated by assuming as continuum a power law with spectral index \( \alpha = -1.8 \) (\( F_\nu \propto \nu^\alpha \)), \( N_H = 10^3 \text{ cm}^{-3} \) (as derived from the [S ii] \( \lambda 6716/\lambda 6731 \) ratios), and \(-3 < \log U < -2\). Models with different power-law index (\( -1.5 \) and \(-2.0\)) have also been attempted, but they significantly deviate from the observed values. In these regions the electronic temperature of the gas can be estimated since [O iii] \( \lambda 4363 \) is sufficiently strong to be measured. Nevertheless, the usual formulae (e.g., Pagel et al. 1992; Izotov, Thuan, & Lipovetsky 1994) for the direct calculation of metal abundances are calibrated with typical H ii regions and not with active nuclei; therefore, they cannot be applied in this case. Trying to model the N2 calibrator as a function of metallicity and ionization parameter for a power-law ionizing continuum with index \(-1.5\), we have obtained theoretical tracks, which are far below the observed [N ii]/H\( \alpha \) ratios. This is an indication that there is a significant overabundance of nitrogen. Indeed, theoretical tracks obtained assuming a triple nitrogen abundance approach much more the data in the range of the expected ionization parameter for an AGN. For the above reason we constructed a grid of models with metallicities \( Z = 0.5, 1.0, \) and \( 1.5 \, Z_\odot \) and nitrogen abundances higher by a factor of 3. The models with \(-2.75 < \log U < -2.50 \) and solar or even supersolar metallicity (Fig. 19; dot-dashed lines) reproduce in a reasonable way the nuclear and circumnuclear regions within a radius of \( \approx 0.5 \) kpc from the nucleus. The comparison of these models with the observed [S ii] emission line fluxes reveals also a possible overabundance (by a factor of \( \approx 2\)) of sulfur in the circumnuclear regions of Tol 1238–364. Similar cases of nitrogen and sulfur overabundances have been frequently observed in Seyfert 2 galaxies (Storchi-Bergmann & Pastoriza 1990) and are probably a consequence of circumnuclear starburst activity. However, our observed flux ratios show also a good agreement with the two-component models by Moy & Rocca-Volmerange (2002), which combine the effects of shocks with AGN photoionization. In particular, the strong [O iii] \( \lambda 4363 \) and [O i] \( \lambda 6300 \) measured in the circumnuclear regions of Tol 1238–364 are well reproduced by these models, whereas pure photoionization models predict too low values for these emission lines. Therefore, we cannot exclude as an
alternative explanation to our flux ratios the presence of shocks as an additional source of ionization.

Regions n1, n5, n1', n5', and C' are not reproduced by any of the above models. As we have already pointed out in § 3.2, these regions are located in a transition area of the diagnostic diagrams. Their properties can be explained with hybrid models involving different proportions of mixed thermal and nonthermal ionization, as explained in Radovich, Hasinger, & Rafanelli (1998).

3.4. Star Formation and Energy Budget

The Hα line intensities of all emitting regions extracted from the spectra of Tol 1238–364 and ESO 381-G009 were converted into luminosities (Tables 4 and 5) using the distances 47.9 and 44.3 Mpc, respectively, derived from the mean redshift values measured along the slits for each of the two galaxies. These luminosities were used to calculate the corresponding SFRs (except for the pure Seyfert-like regions) adopting the relation of Hunter & Gallagher (1986):

$$\text{SFR} = 7.07 \times 10^{-42} L_{\text{H}\alpha} \ M_\odot \text{yr}^{-1}.$$  

The values shown in Tables 4 and 5 for Tol 1238–364 and ESO 381-G009 range from about 0.001 to 0.15 M_\odot \text{yr}^{-1}, but much more significant are the SFR densities, which are 10–100 times higher than in normal spiral galaxies (Elmegreen 1998). The mean value of the SFR density derived considering all H II–like regions identified along the slits up to a distance of 28" from the nucleus is $1.60 \times 10^{-7} \ M_\odot \text{yr}^{-1} \text{pc}^{-2}$ in Tol 1238–364.

The total flux measured on the calibrated Hα image within a radius of 37" is $F(\text{H}\alpha + [\text{N}\ II]) = 3.83 \times 10^{-12} \text{ergs s}^{-1} \text{cm}^{-2}$. The percentage of [N II] emission detected by the Hα interference filter has been evaluated taking the average of the [N II]/Hα ratios measured in the extranuclear spectra ($\langle [\text{N}\ II]/\text{H}\alpha \rangle = 0.48$), although in the central kiloparsec the [N II] lines contribute to the flux in the Hα image by a higher percentage. Galactic and internal extinction corrections were applied. For the last, the mean extinction value derived from the spectra, $E(B-V) = 0.4$, was used. No attempt was made to correct for the contribution from the active nucleus. The resulting corrected Hα luminosity is $L_{\text{H}\alpha} = 1.44 \times 10^{42} \text{ergs s}^{-1}$, which yields a total SFR = $10.22 \ M_\odot \text{yr}^{-1}$ and an SFR density of $4.41 \times 10^{-8} \ M_\odot \text{yr}^{-1} \text{pc}^{-2}$.

In a similar way, mean SFR densities of $1.1 \times 10^{-7}$ and $1.62 \times 10^{-8} \ M_\odot \text{yr}^{-1} \text{pc}^{-2}$ were obtained from the spectra and the Hα image of ESO 381-G009. The total luminosity and SFR evaluated from the image within a radius of 41" are $5.58 \times 10^{41} \text{ergs s}^{-1}$ and $3.95 \ M_\odot \text{yr}^{-1}$, respectively. In this case the average observed ratio $[\text{N}\ II]/\alpha = 0.33$ and the mean internal extinction value $E(B-V) = 0.59$ were used to correct the flux $F(\text{H}\alpha + [\text{N}\ II]) = 1.0 \times 10^{-12} \text{ergs s}^{-1} \text{cm}^{-2}$ measured in the image. In both cases the SFR densities derived from the

![Fig. 18.—Same as Fig. 14, but for ESO 381-G009 at P.A. = 125°](image)
spectra are considerably larger than the corresponding value derived from the Hα images. This apparent discrepancy is a natural consequence of the orientation of the slit, preferentially located along alignments of knotty structures on the galaxies. A comparison with the work of Bushouse (1987) shows that both galaxies have SFR densities approaching the upper value found for a sample of interacting spiral galaxies

\[
(6.1 \times 10^{-11} \, M_\odot \, \text{yr}^{-1} \, \text{pc}^{-2} \leq \text{SFRD}) \\
\leq (7.6 \times 10^{-8} \, M_\odot \, \text{yr}^{-1} \, \text{pc}^{-2})
\]

and clearly higher than values found in a sample of isolated spirals

\[
(2 \times 10^{-10} \, M_\odot \, \text{yr}^{-1} \, \text{pc}^{-2} \leq \text{SFRD}) \\
\leq 2 \times 10^{-8} \, M_\odot \, \text{yr}^{-1} \, \text{pc}^{-2})
\]

Low values of H i depletion timescales, \(M_{\text{H}i}/\text{SFR} = 8.5\text{–}9\) yr, are also observed. This is expected in the case of interacting systems, according to the distribution shown in Figure 11 of Bushouse (1987).

As already noticed in § 3.1, the Hα-emitting regions of Tol 1238–364 appear more concentrated in the spiral arm facing the companion galaxy. Also in ESO 381-G009 a concentration of H ii regions seems to be present in the direction of Tol 1238–364 (Fig. 2). In order to better investigate the distribution of the emitting regions in the two galaxies, we measured the Hα fluxes in 18 circular sectors with aperture 20° and radii 2, 4, and \(\sim 10\) kpc, excluding the nuclei. In each galaxy, the fluxes were normalized to the total galaxy flux (excluding the nucleus). The angular distribution of the normalized fluxes is represented with bar histograms in Figure 20. Bars with horizontal dashes indicate fluxes within 2 kpc, bars with inclined dashes indicate fluxes between 2 and 4 kpc, and empty bars indicate fluxes at radii greater than 4 kpc. The range of angles in which each galaxy faces the companion is marked with horizontal bars. The enhancement of Hα flux at these positions is evident, especially at the outer radii for ESO 381-G009 and at both intermediate and outer radii for the Seyfert galaxy. A second peak in the angular flux distribution of ESO 381-G009 is found around P.A. = 30° in correspondence with the northwest end of its bar.

SFRs in the active galaxy have been calculated for all the extranuclear regions and those circumnuclear regions whose diagnostic emission-line ratios suggest a mixture of thermal and nonthermal ionizing radiation. In the latter case the SFR values quoted in Table 4 are upper limits (marked with a colon), since the fractional contribution of the active nucleus to the Hα luminosity is unknown.

However, some simple energy budget considerations could be done in order to verify the capability of the Seyfert's nonthermal source to ionize the regions outside the nucleus. The number of ionizing photons necessary to produce the observed Hα luminosity,

\[
Q_{\text{ion}} = 7.3 \times 10^{11} L_{\text{H}α} \, \text{photons s}^{-1}
\]

(Kennicutt 1998), was evaluated in every region and compared (Table 4) with the number of nuclear ionizing photons that, in principle, could reach the considered region \(Q_{\text{nuc}}\).

\(Q_{\text{nuc}}\) is actually a fraction of the total number of ionizing photons produced per second by the central source \(Q_{\text{nuc}}\). In fact, it is diluted by the covering factor \(\Omega/4\pi\), which depends on the size and distance of each region to the
nucleus ($\Omega$ is the solid angle under which the considered region is seen from the nucleus). Obviously, a precise measure of this factor cannot be achieved, since we see only the projected sizes and distances of the regions.

The value of $Q_{\text{nuc}}$ is given by

$$Q'_{\text{nuc}} = Q_{\text{nuc}} \frac{\Omega}{4\pi}. \quad (5)$$

Because of the impossibility to estimate the covering factor of the very central region n3, the value of $Q_{\text{nuc}}$ has been evaluated in an indirect way by selecting among all the circumnuclear regions those exhibiting a clear Seyfert nature and similar line ratios according to the diagnostic diagrams, namely, n2, n4, n2', n3', and n4'. The $Q_{\text{nuc}}$ of such regions was multiplied by $4\pi/\Omega$, and the average of the resulting values was assumed to be the actual number of nuclear ionizing photons

$$Q_{\text{nuc}} = \left\langle Q_{\text{ion}} \frac{4\pi}{\Omega} \right\rangle, \quad (6)$$

included in Table 4 in correspondence with the central sub-region n3. This $Q_{\text{nuc}}$ was then diluted to obtain $Q_{\text{nuc}}$ of every region.

In the region-by-region comparison of $Q_{\text{ion}}$ and $Q'_{\text{nuc}}$ there was no need to take into account the filling factor, that is, the fraction of the total volume occupied by the gas. This factor is believed to be very low, typically a few times $10^{-2}$ (Durrett 1990), and is generally assumed to affect in the same measure both the narrow-line region and the extranuclear regions.

This comparison revealed that $Q_{\text{ion}} > Q'_{\text{nuc}}$ for all the regions located at distances $R \geq 1$ kpc from n3, indicating that their ionization is not dominated by the active nucleus. This result is in agreement with the diagnostic diagrams, which show a clear thermal nature of the ionizing source in these regions. Within the central kiloparsec $Q_{\text{ion}} \approx Q_{\text{nuc}}$, except for the region n2. In fact, the nuclear ionization is clearly dominating in the regions n4, n2', n3', and n4', which lie inside the Seyfert area of the diagnostic diagrams. Instead, it is likely mixed in different percentages to the ionization from thermal sources in the regions n5, n5', and C'', which lie in the Seyfert area, but slightly displaced toward the LINERs, and in the regions n1' and n1, which occupy the Seyfert-LINER transition region and the LINER area, respectively. According to the diagnostic diagrams (Fig. 13), also the circumnuclear region n2 is dominated by the nuclear nonthermal radiation; however, it exhibits an opposite behavior ($Q_{\text{ion}} > Q_{\text{nuc}}$) with respect to the other circumnuclear regions. In particular, its high observed $Q_{\text{ion}}$ would require a number of nuclear ionizing photons a factor of 3.4 higher than the estimated one. One could argue that $Q_{\text{nuc}}$ as determined above, is still underestimated as a result of dust absorption and that only in the direction of n2 the real amount of nuclear ionizing radiation can be estimated. In such a circumstance we expect to observe a similarly high $Q_{\text{nuc}}$ also in the immediately adjacent n1 region. Since this is not the case, we rule out this hypothesis and confirm instead the presence of a circumnuclear starburst inside n2 as already suggested in § 3.2 on the basis of the analysis of its spectral properties. This idea is also supported by the estimated value of internal extinction in n2, $A_V \approx 3.3$ mag, much higher than in the surrounding zones.

The number of ionizing photons produced in every region was calculated also for ESO 381-G009 (Table 5) and expressed in equivalent number of O5 stars, $N(05)$, assuming that each O5 star emits $\sim 5 \times 10^{49}$ ionizing photons s$^{-1}$ (Osterbrock 1989). The obtained values range from the upper limit for normal H ii regions ionized by clusters or associations of OB stars to values found for "giant" and

![Angular and radial distribution of H$\alpha$ fluxes normalized to the total H$\alpha$ flux (excluding the nucleus) of Tol 1238–364 (left) and ESO 381-G009 (right). Fluxes are summed within circular sectors with aperture 20°. Horizontal dashed bars indicate fluxes within a radius of 2 kpc, inclined dashed bars indicate fluxes between 2 and 4 kpc, and empty bars indicate fluxes at radii greater than 4 kpc. The horizontal bars indicate the range of angles in which each galaxy faces the companion.](https://example.com/image1.png)
“supergiant” H II regions (Kennicutt, Edgar, & Hodge 1989a). The starbursts with the highest values of SFR are located in the nucleus of the galaxy.

4. FIR EMISSION

The connection between the enhanced far-infrared emission and galaxy interactions has been established in many works (e.g., Telesco, Wolstencroft, & Done 1988; Borne et al. 2000). In order to study the infrared activity of each member of the pair, position and flux-calibrated raw IRAS data were extracted from the IRAS database server of the Space Research Organization Netherlands (SRON). The program GIPSY (Groningen Image Processing System; Assendorp et al. 1995) was used to create low-resolution co-added maps at 12, 25, 60, and 100 μm centered on Tol 1238–364.

The overlap of these maps on the corresponding Digitized Sky Survey optical image allowed us to show the fainter emission of ESO 381-G009 at 12 and 25 μm, compared with the active galaxy. At 60 and 100 μm both galaxies seemed to be embedded in the same emission because of the larger size of the detectors at those wavelengths (Assendorp et al. 1995). To remove the “confusion” and evaluate the contributions of the two objects, a higher resolution (by a factor of ~5) was achieved (Fig. 21) by applying the program HIRAS, which drives the MEMSYS5 maximum entropy imaging algorithm (Bontekoe, Koper, & Kester 1994).

The result showed ESO 381-G009 as an emitting source clearly separated from Tol 1238–364 in all the four bands. The sum of the flux densities of the two galaxies, measured by means of the GIPSY task FLUX (Table 6), was compared with previously published values, for which only a unique emitting source was considered. In particular, our results are in good agreement with both the Point Source Catalog, apart from a slightly higher emission at 100 μm in our measurement, and the values of Rush, Malkan, & Spinoglio (1993) obtained using the ADDSCAN procedure of the Infrared Processing and Analysis Center (IPAC).

Our flux ratios were compared with the infrared color-color diagrams log(F25/F12) versus log(F60/F25) and log(F100/F25) versus log(F60/F12), which can indicate whether the FIR emission is dominated by a dust-extinguished active nucleus, a pure starburst, or a mixture of these two components (Dopita et al. 1998). We found that the FIR emission of Tol 1238–364 is dominated by a moderately obscured AGN, while ESO 381-G009 has an expected “warm” starburst nature (Fig. 22). Further

![Fig. 21.—IRAS co-added contour maps of the galaxy pair at 60 and 100 μm (top) and the corresponding high-resolution HIRAS contour maps (bottom), overimposed to the Digitized Sky Survey optical image; 1 and 2 σ (dashed lines) and 3, 4, 6, 10, 30, 50, 100, and 200 σ (solid lines) contour levels are drawn. Right ascension and declination (B1950.0) are displayed along x- and y-axes.](image-url)
confirmations came from the analysis of the spectral indices \(\alpha_{100,60}\) and \(\alpha_{60,25}\) and mostly of the 60 \(\mu\)m curvature \((\alpha_{60,25} - \alpha_{100,60})\), whose values \(-0.425\) and \(-1.545\) are typical of a Seyfert 2 and an H II galaxy, respectively (Miley, Neugebauer, & Soifer 1985).

The total fluxes between 42.5 and 122.5 \(\mu\)m have been calculated following Helou et al. (1985),

\[
FIR = 1.26 \times 10^{-11} (2.58 F_{60} + F_{100}) \text{ ergs cm}^{-2} \text{ s}^{-1},
\]

and converted into luminosities, using the distances given in \(\S\) 3.4. The resulting values (Table 6) indicate that Tol 1238–364 is \(\sim 10\) times brighter than ESO 381-G009, a clear effect of the presence of an active nucleus. In fact, the dusty torus is expected to contribute notably to the far-IR luminosity (Storchi-Bergmann, Mulchaey, & Wilson 1992; Genzel et al. 1998; Lutz et al. 1998), which is generally produced by interstellar dust heated by the UV radiation field of young and hot stars. Considering a single-temperature component and a \(\lambda^{-1}\) emissivity law (Young et al. 1989), a major content of warm dust was revealed in Tol 1238–364 (Table 6), likely concentrated into the bar and in correspondence with the giant H II regions populating its spiral arms. However, the SFR, derived from the FIR luminosities following the relation given by Hunter et al. (1986), is high in both galaxies as expected to occur in an interacting system. The overall SFR estimated from \(L_{\text{FIR}}\) \((\text{SFR}_{\text{LIR}} \sim 15.9 M_\odot \text{ yr}^{-1})\) appears somewhat higher than that estimated from \(L_{\text{H} \alpha}\) \((\text{SFR}_{\text{H} \alpha} \sim 10.2 M_\odot \text{ yr}^{-1})\). In fact, the far-infrared luminosity generally includes the contribution of the cirrus component, diffuse dust heated by the starlight radiation field, whose effect is to give an overestimate of the SFR, up to a factor of 2 (Elmegreen 1998). Furthermore, in the case of the Seyfert galaxy the dust heated by the nuclear nonthermal radiation contributes to the total FIR emission in a percentage that cannot be determined. On the opposite, for ESO 381-G009, \(\text{SFR}_{\text{LIR}}\) is a factor of \(\sim 2\) lower than \(\text{SFR}_{\text{H} \alpha}\). A possible reason could be the error related to the “deblending” of the two \(\text{IRAS}\) sources.

5. DISCUSSION AND CONCLUSIONS

We have analyzed the physical properties of the galaxy pair Tol 1238–364 and ESO 381-G009, which belongs to a triple system together with ESO 381-G006, on the basis of optical imaging and long-slit spectroscopy in order to point out possible effects of interaction.

The triple system was analyzed by Barnes & Webster (2001) as well, who suggested that also a fourth galaxy, ESO 381-G014, might belong to this small galaxy group, as a result of its detection in radio observations at a radial velocity of 3304 km s\(^{-1}\). For the supposed four-member group they reported a median radial velocity of 3285 km s\(^{-1}\), a median projected velocity dispersion of 11 km s\(^{-1}\), a median projected galaxy-galaxy separation of 110 kpc, and a median crossing time of order 10 Gyr. Since they did not detect strong signs of galaxy interactions, like a common envelope of neutral gas or prominent tidal tails, they speculated that the triple system might be much looser than the projected density implies. ESO 381-G014 has been indicated as a member of the group also in the catalog of groups of

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**Table 6**

| Quantity             | Tol 1238–364 | ESO 381-G009 |
|----------------------|-------------|-------------|
| \(F_{12}(\text{Jy})\) | 0.580 ± 0.065 | 0.125 ± 0.035 |
| \(F_{32}(\text{Jy})\) | 2.198 ± 0.140 | 0.204 ± 0.085 |
| \(F_{60}(\text{Jy})\) | 7.942 ± 0.130 | 1.122 ± 0.102 |
| \(F_{100}(\text{Jy})\) | 13.591 ± 0.431 | 1.378 ± 0.296 |
| \(\log(F_{25}/F_{12})\) | 0.578 ± 0.076 | 0.212 ± 0.302 |
| \(\log(F_{60}/F_{25})\) | 0.558 ± 0.034 | 0.740 ± 0.220 |
| \(\log(F_{100}/F_{25})\) | 0.791 ± 0.041 | 0.829 ± 0.274 |
| \(\log(F_{100}/F_{60})\) | 1.136 ± 0.055 | 0.953 ± 0.161 |
| \(\alpha_{60,25}\) | -1.476 ± 0.090 | -1.947 ± 0.580 |
| \(\alpha_{100,60}\) | -1.051 ± 0.094 | -0.402 ± 0.598 |
| \(T_{\text{dust}}(\text{K})\) | 39.5 | 45.1 |
| \(M_{\text{dust}}(M_\odot)\) | 5.5 \times 10^6 | 3.0 \times 10^5 |
| \(L_{\text{FIR}}(L_\odot)\) | 3.04 \times 10^{10} | 3.24 \times 10^9 |
| \(\text{SFR}(M_\odot \text{ yr}^{-1})\) | 15.86 | 1.69 |

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**Fig. 22.**—Infrared color-color diagrams, similar to the ones in Dopita et al. (1998), but with the two galaxies represented as distinct sources: ESO 381-G009 (square) clearly appears as a “warm” starburst, while Tol 1238–364 (star) is dominated by a moderately obscured AGN.
nearby optical galaxies (NOGG) compiled by Giuricin et al. (2000). However, its projected separation from the triplet (we assume as average coordinates of the triplet \( \alpha = 12^h40^m50^s, \delta = -36^\circ44'32'' \) [J2000.0]) is \( \sim 42'' \), corresponding to \( \sim 0.5 \text{ Mpc} \), assuming \( H_0 = 75 \text{ km s}^{-1} \text{ Mpc}^{-1} \), i.e., \( \sim 33 \) times the diameter of Tol 1238–364 as estimated at the 25 mag arcsec\(^{-2} \) B isophote. Instead, the centers of the galaxies in the triplet are all encompassed by a minimum circle of radius 1.87 (25 kpc) and have a median projected separation of 2.63 (i.e., \( \sim 35 \) kpc). While we have no pieces of evidence other than the concordant radial velocity to support the membership of ESO 381-G014 in the group, we consider it unlikely for this galaxy to have a strong gravitational influence on the members of the triplet.

The radial velocity of the galaxies poses them at the same distance of the Centaurus Cluster (A3526, \( \alpha = 12^h48^m48^s, \delta = -41^\circ18'44'' \) [J2200.0]). However, they are at a projected distance of \( \sim 3.5 \text{ Mpc} \) from the cluster center and well separated from the main cluster galaxy concentration; therefore, it is unclear whether they can be considered cluster members. In any case, at such a separation the influence of the Centaurus Cluster on the triplet, if any, is most likely negligible with respect to the mutual influence of the galaxies within the triplet itself, provided that this is really a tight system. We have actually observed properties in Tol 1238–364 and ESO 381-G009 (the tightest pair within the triplet system, at least in projection on the sky) that are consistent with an interaction scenario, as we discuss in the following.

Both galaxies show a prominent bar, and ESO 381-G009 also shows a ring of \( \text{H} \beta \) regions. Theoretical N-body simulations show that close encounters between galaxies can lead to bar formation (e.g., Noguchi 1987; Gerin, Combes, & Athanassoula 1990), although bars can form in isolated galaxies as well, as a consequence of disk instabilities. Indeed, studies of the relative frequency of bars among various Hubble types and in different environments have demonstrated that galaxies in close binary systems and some groups have a greater occurrence of bars than field galaxies (Elmegreen, Elmegreen, & Bellin 1990). This result is somewhat controversial; in fact, it was recently found (van den Bergh 2002) that the bar frequency does not appear to depend on the galaxy environment. Nevertheless, we think that the presence of a bar in at least two out of three members of a galaxy system, like in our case (since ESO 381-G006 is edge-on, we cannot establish whether it is barred or not), strongly favors the hypothesis that the mutual interaction has played a role in the bar formation. Further support to this hypothesis is given by the detection of star formation along the bars, which indicates that the bars are still relatively young and actively funneling gas toward the center of the galaxies.

The two galaxies show evidence of only slight morphological distortions (see § 3.1). Specifically, we observe a twist of the inner isophotes, most likely caused by the bars, and an elongation and change of the P.A. of the outermost isophotes of both galaxies toward one another. Additionally, the decentering degree of the most external isophotes with respect to the luminosity center of Tol 1238–364 is higher than the maximum value (5%) found by Márquez & Moles (1999) for isolated galaxies, indicating a significant asymmetry of the outskirts of the disk likely caused by interaction processes. On the contrary, ESO 381-G009 does not exhibit such an asymmetry of the outermost isophotes, but its H\( \alpha \) image shows an extension of \( \text{H} \beta \) regions, also detectable in the broadband images, on the southern side of the disk, outside the ringlike structure, facing the Seyfert galaxy. Additionally, the optical images show a plume on its northern side. This plume appears more extended in the contour maps of the \( \text{H} \beta \) 21 cm line (Babic et al. 2000; Barnes & Webster 2001). No other tidal features are visible in the optical images, but there are signs of an \( \text{H} \beta \) bridge between Tol 1238–364 and ESO 381-G006 (Babic et al. 2000). However, since the detection of this bridge is limited to one velocity channel, the possibility that this is a spurious feature cannot be excluded. Most of the neutral hydrogen remains located in the discs of the galaxies.

We note that the formation of prominent tidal tails is not ubiquitous in interacting galaxies but depends on the geometry of the encounters, being particularly favored in prograde interactions, as shown by numerical simulations (see, e.g., the seminal work of Toomre & Toomre 1972). In a recent work, Barton Gillespie, Geller, & Kenyon (2003) identified within a sample of close galaxy pairs a number of galaxies exhibiting triggered star formation but not long tidal tails. The color profiles of these galaxies show blue dips in their centers, in analogy with the \( B-R \) profile we obtained for the nonactive galaxy ESO 381-G009.

In fact, we could not identify a real bulge structure in this galaxy, but two knots with high SFR, the brightest of which we adopted as the nucleus. This kind of structure appears in agreement with the gas infall and centrally concentrated star formation predicted by the numerical simulations of Mihos & Hernquist (1996) for bulgeless galaxies in the early stages of interactions.

Tol 1238–364 hosts a typical Seyfert 2 nucleus, with a hidden BLR. The nonthermal ionization produced by the central power-law source is confined within the first kiloparsec, and no evidence of ionization cones is found along the three studied directions. Considerations on the energy budget (§ 3.4) reveal the presence of at least one circumnuclear starburst, a hypothesis that finds support in the observed spectral features. Besides the central starbursts, a large number of \( \text{H} \beta \) regions are found in both galaxies with a major concentration in the zone of their minimal mutual distance, further supporting the interaction scenario. In ESO 381-G009 the \( \text{H} \beta \) regions are mainly located along the bar and in the ring, while in Tol 1238–364 they are diffused all over the disk. The SFR and the density of SFR are strongly enhanced with respect to normal and/or isolated spirals and higher in Tol 1238–364 than in its companion (see § 3.4). This enhancement could be a combined effect of the mutual interactions of the galaxies, as shown by the comparison between the star formation properties of interacting and isolated galaxies (see, e.g., Bushouse 1987; Kennicutt et al. 1987; Keel & Van Soest 1992) and of the perturbation of the whole galactic disk by the stellar bar (Aguerri 1999), although the relation between the global star formation and the presence of a bar in a galaxy is still debated. In addition, numerical simulations demonstrated that both galaxy interactions (e.g., Barnes & Hernquist 1991, 1996; Mihos & Hernquist 1996) and bars or, in

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\footnote{In the NOGG catalog, which contains only galaxies brighter than \( B = 14 \text{ mag} \), the group is erroneously indicated as a quartet, because the galaxy ESO 381-G009 is counted twice, with the alternative names PGC 042519 and PGC 097487.}
general, nonaxisymmetric features (as summarized, e.g., in Combes 2001, p. 223) can produce torques and gas radial inflows toward the center, inducing nuclear starbursts and/or fueling a central AGN.

The H\textsc{ii} regions of both galaxies, whose excitation is in general the effect of photoionization from hot, young stars (although in some cases the contribution of starburst-driven shocks cannot be excluded), exhibit subsolar metallicities. However, the Seyfert nucleus shows higher (solar or even supersolar) metallicity, with traces of overabundance of nitrogen and sulphur, which could be related to the presence of a circumnuclear starburst.

The IRAS infrared colors confirmed the dual starburst-AGN nature of Tol 1238–364 and the simple starburst nature of ESO 381-G009, but the infrared emission of the Seyfert appears dominated by the active nucleus and shows higher FIR luminosity and dust content.

Based on the results of their analysis, Barton Gillespie et al. (2003) suggested that blue central colors, moderate EW(H\textalpha), and small velocity separations in galaxy pairs are indicative of galaxies that have undergone a close pass and that moved apart, while their triggered burst of star formation ages. Accordingly, numerical simulations by Mihos & Hernquist (1994) showed that two interacting disk/halo galaxies remain relatively unperturbed and show no increase of star-forming activity until they reach the perigalacticon. Furthermore, an enhanced star formation activity is also induced in the disks of the galaxies before they reach the widest separation after their first encounter. The observational properties we have outlined in the present work suggest that this stage of the evolution, i.e., the phase subsequent to a first close passage, might be the case for the galaxy pair under study. The lack of really prominent morphological distortions might indicate that the galaxy separation is actually larger than appearing in projection on the sky.

In conclusion, although some of the observed properties, taken individually, can be found also in isolated galaxies, when considered all together they provide, in our opinion, a significant indication of an undergoing interaction between two gas-rich galaxies. From our data we cannot establish which role is played by ESO 381-G006 in the interaction. On the basis of a comparison with the findings in other interacting pairs (e.g., Barton Gillespie et al. 2003) and the results of galaxy encounter simulations (Mihos & Hernquist 1994, 1996), we suggest that the galaxy pair has already undergone a first close passage, which determined the onset of bursts of star formation in both the disks and the central regions and caused moderate morphological distortions and, possibly, disk instabilities leading to bar formation. Nevertheless, a clear connection of the Seyfert activity with the interaction cannot be demonstrated and remains at a speculative level.

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APPENDIX

MEASURED EMISSION-LINE FLUXES OF Tol 1238–364 AND ESO 381-G009

We list in Tables 7–12 the observed emission-line fluxes and intensities relative to H\textbeta, determined as explained in § 2, the absolute fluxes of H\alpha and H\beta, and the values of internal extinction for the individual regions identified in the spectra of Tol 1238–364 and ESO 381-G009.
| Line | A1 | A2 | N | B1 | B2 | B3 |
|------|----|----|---|----|----|----|
| [O iii] λ3727 | 3.05 ± 0.98 | ... | 0.55 ± 0.10 | 2.35 ± 0.96 | 2.00 ± 0.70 | 4.14 ± 1.12 |
| [Ne iii] λ3869 | ... | 4.86 | ... | 0.84 | 4.50 | 2.69 | 5.22 |
| Hγ λ4340 | ... | ... | 0.39 ± 0.14 | 2.16 ± 1.36 | ... | ... |
| [O ii] λ4363 | ... | ... | 0.12 ± 0.02 | ... | ... | ... |
| He ii λ4686 | ... | ... | 0.14 | ... | ... | ... |
| [O iii] λ4959 | ... | 0.24 ± 0.06 | 2.41 ± 0.07 | 0.39 ± 0.23 | 0.22 ± 0.09 | 0.38 ± 0.11 |
| [O iii] λ5007 | 0.71 ± 0.20 | 0.81 ± 0.11 | 7.38 ± 0.15 | 1.55 ± 0.45 | 0.51 ± 0.12 | 0.95 ± 0.15 |
| [Fe v] λ5158 | ... | ... | 0.08 ± 0.03 | ... | ... | ... |
| [Fe v] λ5177 | ... | ... | 0.07 | ... | ... | ... |
| [N ii] λ5199 | ... | ... | 0.10 | ... | ... | ... |
| [Ca v] λ5309 | ... | ... | 0.16 | ... | ... | ... |
| He i λ5876 | 0.16 ± 0.07 | 0.16 ± 0.04 | 0.18 ± 0.02 | 0.37 ± 0.16 | 0.09 ± 0.04 | 0.38 ± 0.08 |
| [O i] λ6300 | 0.17 ± 0.06 | ... | 0.81 ± 0.03 | ... | 0.12 ± 0.07 | ... |
| [O i] λ6364 | ... | 0.10 | ... | 0.52 | ... | 0.09 | ... |
| [N ii] λ6548 | 0.32 ± 0.20 | ... | 0.27 ± 0.05 | 1.27 ± 0.04 | 1.43 ± 0.29 | 0.30 ± 0.06 | 0.30 ± 0.07 |
| Hα λ6563 | 4.97 ± 0.70 | 2.85 | 3.89 ± 0.27 | 2.85 | 4.72 ± 0.09 | 6.20 ± 0.93 | 4.06 ± 0.37 | 3.76 ± 0.34 |
| [N ii] λ6583 | 1.90 ± 0.30 | 1.08 | 1.14 ± 0.10 | 2.50 | 4.16 ± 0.08 | 2.85 ± 0.51 | 1.45 ± 0.15 | 1.18 ± 0.14 |
| [S ii] λ6717 | 1.06 ± 0.19 | 0.59 | 0.61 ± 0.07 | 0.68 | 1.17 ± 0.04 | 1.36 | 1.57 ± 0.36 | 0.85 ± 0.10 | 0.67 ± 0.10 |
| [S ii] λ6724 | 1.73 ± 0.33 | 0.95 | 1.01 ± 0.12 | 0.72 | 2.48 ± 0.07 | 2.61 ± 0.63 | 1.42 ± 0.18 | 1.01 ± 0.16 |
| [S ii] λ6731 | 0.67 ± 0.14 | 0.37 | 0.40 ± 0.06 | 0.29 | 1.31 ± 0.04 | 1.45 | 1.04 ± 0.28 | 0.57 ± 0.08 | 0.35 ± 0.06 |
| Hβ λ4861 = 1.00: | 0.09 | ... | 0.03 | ... | 0.23 | ... | 0.26 | ... |
| F(Hα) (×10^{−15} erg s^{-1} cm^{-2}) | 27.2 ± 0.3 | 84.0 | 30.4 ± 0.3 | 57.2 | 238.8 ± 0.0 | 664.8 | 10.4 ± 0.1 | 50.4 | 25.7 ± 0.3 | 52.8 | 23.6 ± 0.2 | 41.4 |
| F(Hβ) (×10^{−15} ergs cm^{-2}) | 5.5 ± 0.7 | 29.5 | 7.8 ± 0.5 | 20.1 | 50.6 ± 1.0 | 233.2 | 1.7 ± 0.2 | 17.7 | 6.3 ± 0.5 | 18.5 | 6.3 ± 0.5 | 14.5 |
| c_{B−V} | 0.03 | 0.51 | 0.41 | 0.28 | 0.66 | 0.46 | 1.02 | 0.71 | 0.47 | 0.32 | 0.25 | ... |

**Notes.**—In this and the following tables, for each listed emission line, measured flux ratios or absolute fluxes are reported in the first row, while flux ratios or absolute fluxes corrected for internal extinction (i.e., intensities) are reported in the second row. Below the label of each region, the distances in arcsec of the region’s extremes to the intensity peak along the slit are indicated; positive distances are in the east direction.

* Extinction coefficient.
| Line          | $A_1'$ | $A_2'$ | $N'$  | $B_1'$ | $B_2'$ |
|---------------|--------|--------|-------|--------|--------|
| [O ii] $\lambda$3727 | 3.74 ± 0.30 | 4.14 ± 0.87 | 1.61 ± 0.16 | 2.74 ± 0.36 | 3.62 ± 0.40 |
| [Ne iii] $\lambda$3869 | 4.89 | 5.92 | 2.58 | 3.75 | 4.03 |
| H$\gamma$ $\lambda$4340 | ... | ... | 0.82 ± 0.26 | ... | ... |
| [O iii] $\lambda$4363 | ... | 1.24 | ... | ... | 0.48 ± 0.09 |
| He ii $\lambda$4686 | ... | ... | 0.17 ± 0.07 | ... | ... |
| [O ii] $\lambda$4959 | 0.22 ± 0.04 | 0.37 ± 0.12 | 2.27 ± 0.14 | 0.23 ± 0.06 | 0.30 ± 0.04 |
| [O iii] $\lambda$5007 | 0.91 ± 0.06 | 1.10 ± 0.19 | 7.19 ± 0.36 | 0.64 ± 0.08 | 0.87 ± 0.06 |
| [N ii] $\lambda$5199 | 0.67 | 1.06 | 6.81 | 0.62 | 0.86 |
| He i $\lambda$5876 | 0.16 ± 0.03 | ... | 0.25 ± 0.04 | 0.15 ± 0.03 | 0.12 ± 0.03 |
| [O i] $\lambda$6300 | 0.10 ± 0.03 | 0.21 ± 0.06 | 0.88 ± 0.07 | 0.18 ± 0.04 | 0.13 ± 0.04 |
| [O i] $\lambda$6364 | 0.08 | 0.14 | 0.54 | 0.13 | 0.12 |
| [N ii] $\lambda$6548 | 0.48 ± 0.04 | 0.40 ± 0.10 | 1.51 ± 0.09 | 0.53 ± 0.06 | 0.37 ± 0.04 |
| H$\alpha$ $\lambda$6563 | 3.93 ± 0.16 | 4.37 ± 0.44 | 5.00 ± 0.25 | 4.15 ± 0.25 | 3.24 ± 0.13 |
| [N ii] $\lambda$6583 | 1.43 ± 0.07 | 1.60 ± 0.19 | 4.52 ± 0.23 | 1.51 ± 0.11 | 0.95 ± 0.05 |
| [S ii] $\lambda$6717 | 0.56 ± 0.05 | 1.09 ± 0.13 | 1.48 ± 0.09 | 0.85 ± 0.07 | 0.61 ± 0.05 |
| [S ii] $\lambda$6724 | 1.05 ± 0.09 | 1.76 ± 0.23 | 2.97 ± 0.18 | 1.41 ± 0.11 | 0.97 ± 0.09 |
| [S ii] $\lambda$6731 | 0.74 | 1.11 | 1.63 | 0.94 | 0.85 |
| H$\beta$ $\lambda$4861 | 0.49 ± 0.05 | 0.68 ± 0.10 | 1.49 ± 0.09 | 0.56 ± 0.05 | 0.37 ± 0.04 |
| $F(H\alpha)$ ($\times 10^{-13}$ ergs s$^{-1}$ cm$^{-2}$) | 25.5 ± 0.3 | 14.1 ± 0.3 | 89.9 ± 0.9 | 34.7 ± 0.3 | 24.1 ± 0.2 |
| $F(H\beta)$ ($\times 10^{-13}$ ergs s$^{-1}$ cm$^{-2}$) | 6.5 ± 0.2 | 3.2 ± 0.3 | 18.0 ± 0.7 | 8.4 ± 0.4 | 7.4 ± 0.2 |
| $c^a$ | 0.42 | 0.56 | 0.74 | 0.49 | 0.17 |
| $E(B-V)$ | 0.29 | 0.39 | 0.51 | 0.34 | 0.12 |

$^a$ Extinction coefficient.
TABLE 9
Tol 1238–364 (P.A. = 90°): Flux Ratios

| Line          | A1* | A2* | A3* | C*  | B1* | B2* | B3* |
|---------------|-----|-----|-----|-----|-----|-----|-----|
| [O ii] λ3727  |    |     |     |     |     |     |     |
|               | 2.15 ± 0.34 | 3.01 ± 0.57 | 3.08 ± 1.48 | 4.05 ± 1.34 | 1.73 ± 0.54 | 1.30 ± 0.92 | 9.37 ± 4.69 |
| [O iii] λ5007 |    |     |     |     |     |     |     |
|               | 0.24 | 0.33 | 0.34 | 0.34 | 0.24 | 0.46 | 0.13 |
| [Ne iii] λ4686 |    |     |     |     |     |     |     |
| [He i] λ5876  |    |     |     |     |     |     |     |
|               | 0.14 ± 0.04 | 0.15 ± 0.05 | 0.40 ± 0.24 | 0.22 ± 0.05 |     |     |     |
| [O i] λ6300   |    |     |     |     |     |     |     |
|               | 0.09 ± 0.02 | 0.17 ± 0.04 | 0.46 ± 0.20 | 0.21 ± 0.08 | 0.48 ± 0.24 |     |     |
| [O i] λ6364   |    |     |     |     |     |     |     |
|               | 0.06 | 0.11 | 0.29 |     |     |     |     |
| [N ii] λ5007  |    |     |     |     |     |     |     |
|               | 0.34 ± 0.04 | 0.37 ± 0.04 | 0.30 ± 0.09 | 0.57 ± 0.09 | 0.32 ± 0.10 | 0.33 ± 0.19 |     |
| [Hα] λ6563    |    |     |     |     |     |     |     |
|               | 4.34 ± 0.22 | 4.52 ± 0.23 | 3.31 ± 0.46 | 4.73 ± 0.90 | 5.25 ± 0.42 | 4.22 ± 0.51 | 6.06 ± 1.70 |
| [N II] λ6583  |    |     |     |     |     |     |     |
|               | 1.58 ± 0.09 | 1.38 ± 0.08 | 0.99 ± 0.18 | 3.85 ± 0.77 | 2.41 ± 0.22 | 1.73 ± 0.24 | 2.33 ± 0.77 |
| [S II] λ6717  |    |     |     |     |     |     |     |
|               | 0.79 ± 0.06 | 0.74 ± 0.06 | 0.77 ± 0.17 | 1.33 ± 0.33 | 0.98 ± 0.12 | 0.94 ± 0.18 | 1.79 ± 0.63 |
| [S II] λ6724  |    |     |     |     |     |     |     |
|               | 1.29 ± 0.12 | 1.30 ± 0.10 | 1.31 ± 0.30 | 2.58 ± 0.65 | 1.70 ± 0.22 | 1.60 ± 0.34 | 3.05 ± 1.13 |
| [S II] λ6731  |    |     |     |     |     |     |     |
|               | 0.50 ± 0.06 | 0.56 ± 0.05 | 0.54 ± 0.14 | 1.25 ± 0.31 | 0.72 ± 0.10 | 0.66 ± 0.15 | 1.26 ± 0.49 |
| Hβ λ4861 = 1.00: |     |     |     |     |     |     |     |
| F(Hα) (×10^{-15} erg s^{-1} cm^{-2}) | 79.5 | 58.4 | 13.7 | 30.1 | 78.2 | 27.8 | 38.8 |
| F(Hβ) (×10^{-15} erg s^{-1} cm^{-2}) | 27.9 | 20.5 | 4.8 | 10.6 | 27.5 | 9.8 | 13.6 |
| c | 0.55 | 0.61 | 0.20 | 0.67 | 0.80 | 0.52 | 0.99 |
| E(B−V) | 0.39 | 0.42 | 0.14 | 0.46 | 0.56 | 0.36 | 0.69 |

a The emission-line ratios for region B3 are somewhat uncertain because of difficulties in appropriately correcting Hβ for the underlying stellar absorption. This additional source of uncertainty is not contained in the errors quoted in the table.

b Extinction coefficient.
| Line                          | n1  | n2  | n3  | n4  | n5  | P.A. = 150° | P.A. = 146° |
|------------------------------|-----|-----|-----|-----|-----|-------------|-------------|
| [O\textsc{i}] 3727           |     |     |     |     |     | 4.00 ± 3.56 | 6.14 ± 2.27 |
|                             | 6.87|     |     |     |     | 13.20       | 2.15 ± 0.32 |
| [Ne\textsc{iii}] 3869        |     |     |     |     |     | 0.15 ± 0.15 | 0.74 ± 0.19 |
|                             |     |     |     |     |     | 0.51 ± 0.11 | 1.18 ± 0.18 |
| [H\textsc{ii}] λ4340         |     |     |     |     |     | 1.39         | 0.06 ± 0.01 |
|                             |     |     |     |     |     | 0.62         | 0.19 ± 0.04 |
| [O\textsc{iii}] λ4363        |     |     |     |     |     | 0.11 ± 0.03 | 0.21 ± 0.03 |
|                             |     |     |     |     |     | 0.19 ± 0.05 | 0.12 ± 0.04 |
| [He\textsc{ii}] λ4686        |     |     |     |     |     | 0.12 ± 0.03 | 0.72 ± 0.03 |
|                             |     |     |     |     |     | 0.12 ± 0.04 | 0.15 ± 0.01 |
| [O\textsc{iii}] λ4959        | 1.07|     |     |     |     | 1.96 ± 0.05 | 2.30 ± 0.16 |
|                             | 1.03| 2.57|     |     |     | 1.96 ± 0.14 | 3.27 ± 0.03 |
| [O\textsc{ii}] λ5007         | 2.69| 8.38|     |     |     | 1.96 ± 0.14 | 2.39 ± 0.07 |
|                             | 2.53| 7.50|     |     |     | 1.96 ± 0.14 | 2.06 ± 0.16 |
| [F\textsc{ii}] λ5158         |     |     |     |     |     | 1.81 ± 0.03 | 1.19 ± 0.45 |
|                             |     |     |     |     |     | 1.81 ± 0.03 | 1.19 ± 0.45 |
| [F\textsc{ii}] λ5177         |     |     |     |     |     | 1.81 ± 0.03 | 1.19 ± 0.45 |
|                             |     |     |     |     |     | 1.81 ± 0.03 | 1.19 ± 0.45 |
| [N\textsc{ii}] λ5199         |     |     |     |     |     | 0.15 ± 0.04 | 0.16 ± 0.02 |
|                             |     |     |     |     |     | 0.15 ± 0.04 | 0.16 ± 0.02 |
| [Ca\textsc{ii}] λ5309        |     |     |     |     |     | 0.15 ± 0.04 | 0.16 ± 0.02 |
|                             |     |     |     |     |     | 0.15 ± 0.04 | 0.16 ± 0.02 |
| [N\textsc{ii}] λ5755         |     |     |     |     |     | 0.15 ± 0.04 | 0.16 ± 0.02 |
|                             |     |     |     |     |     | 0.15 ± 0.04 | 0.16 ± 0.02 |
| [He\textsc{i}] λ5876         |     |     |     |     |     | 0.15 ± 0.04 | 0.16 ± 0.02 |
|                             |     |     |     |     |     | 0.15 ± 0.04 | 0.16 ± 0.02 |
| [F\textsc{ii}] λ6086         |     |     |     |     |     | 0.15 ± 0.04 | 0.16 ± 0.02 |
|                             |     |     |     |     |     | 0.15 ± 0.04 | 0.16 ± 0.02 |
| [O\textsc{ii}] λ6300         | 0.77| 1.15|     |     |     | 0.37 ± 0.03 | 0.33 ± 0.12 |
|                             | 0.44| 0.42| 0.52| 0.37| 0.32| 0.22 ± 0.04 | 0.88 ± 0.04 |
| [O\textsc{ii}] λ6364         |     | 0.40| 0.20| 0.19| 0.15| 0.22 ± 0.04 | 0.88 ± 0.04 |
|                             |     | 0.40| 0.10| 0.37| 0.15| 0.22 ± 0.04 | 0.88 ± 0.04 |
| [N\textsc{ii}] λ6548         | 1.06| 2.53|     |     |     | 0.31 ± 0.06 | 0.25 ± 0.07 |
|                             | 0.56| 0.81| 0.81| 0.51| 0.79| 0.31 ± 0.06 | 0.25 ± 0.07 |
| [He\textsc{i}] λ6653         | 5.44| 2.85| 2.72| 2.03| 2.34| 1.36 ± 0.50 | 0.94 ± 0.36 |
|                             | 2.85| 2.85| 2.85| 2.85| 2.85| 1.36 ± 0.50 | 0.94 ± 0.36 |
| [N\textsc{ii}] λ6853         | 3.10| 2.06| 2.06| 1.84| 2.03| 1.36 ± 0.50 | 0.94 ± 0.36 |
|                             | 1.61| 2.06| 2.06| 1.84| 2.03| 1.36 ± 0.50 | 0.94 ± 0.36 |
| LINE              | n1        | n2        | n3        | n4        | n5        | n1'       | n2'       | n3'       | n4'       | n5'       |
|-------------------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|
|                   | −3.7 to −2.0 | −2.0 to −0.3 | −0.3 to 0.7 | 0.7−1.7 | 1.7–3.0 | −4.0 to −2.0 | −2.0 to −0.3 | −0.3 to 0.7 | 0.7–2.0 | 2.0–3.7 |
| [S ii] λ6717      | 1.34 ± 0.48 | 1.92 ± 0.17 | 1.27 ± 0.03 | 0.47 ± 0.03 | 0.92 ± 0.17 | 1.91 ± 0.63 | 1.55 ± 0.11 | 1.30 ± 0.04 | 1.35 ± 0.11 | 1.66 ± 0.46 |
|                   | 0.67      | 0.56      | 0.57      | 0.47      | 0.89      | 0.72      | 0.78      | 0.83      | 1.00      | 0.71      |
| [S ii] λ6724      | 2.49 ± 0.92 | 4.04 ± 0.36 | 2.77 ± 0.06 | 0.95 ± 0.07 | 1.66 ± 0.33 | 3.40 ± 1.16 | 3.05 ± 0.21 | 2.70 ± 0.08 | 2.67 ± 0.21 | 2.81 ± 0.84 |
|                   | 1.25      | 1.18      | 1.24      | 0.95      | 1.61      | 1.28      | 1.54      | 1.73      | 1.99      | 1.19      |
| [S ii] λ6731      | 1.15 ± 0.44 | 2.12 ± 0.19 | 1.49 ± 0.03 | 0.48 ± 0.03 | 0.75 ± 0.16 | 1.49 ± 0.54 | 1.51 ± 0.11 | 1.40 ± 0.04 | 1.32 ± 0.11 | 1.14 ± 0.36 |
|                   | 0.57      | 0.62      | 0.66      | 0.48      | 0.73      | 0.56      | 0.76      | 0.90      | 0.98      | 0.48      |

Hβ λ4861 = 1.00:

|                   | n1        | n2        | n3        | n4        | n5        | n1'       | n2'       | n3'       | n4'       | n5'       |
|-------------------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|
|                   | −3.7 to −2.0 | −2.0 to −0.3 | −0.3 to 0.7 | 0.7−1.7 | 1.7–3.0 | −4.0 to −2.0 | −2.0 to −0.3 | −0.3 to 0.7 | 0.7–2.0 | 2.0–3.7 |
| F(Hα)(×10^{-16} ergs s^{-1} cm^{-2}) | 66.6 ± 2.0 | 746.5 ± 0.0 | 1528.0 ± 0.0 | 322.7 ± 3.2 | 74.7 ± 2.2 | 54.7 ± 1.6 | 240.9 ± 2.4 | 419.5 ± 0.0 | 132.9 ± 1.3 | 55.1 ± 1.7 |
|                   | 247.5     | 7702.0    | 7065.0    | 322.7    | 79.0     | 351.0     | 881.4    | 975.8    | 233.2    | 279.1    |
| F(Hβ)(×10^{-16} ergs s^{-1} cm^{-2}) | 12.3 ± 2.7 | 83.0 ± 5.8 | 252.2 ± 2.5 | 176.8 ± 7.1 | 25.5 ± 2.5 | 7.7 ± 1.6 | 44.6 ± 2.2 | 97.2 ± 1.9 | 35.3 ± 1.8 | 8.7 ± 1.6 |
|                   | 86.9      | 2703.0    | 2479.0    | 176.8    | 27.7     | 123.1     | 309.3    | 342.6    | 342.6    | 97.9     |
| e*                | 0.85      | 1.51      | 0.99      | 0.00     | 0.04     | 1.20      | 0.84     | 0.55     | 0.36     | 1.05     |
| E(B−V')           | 0.59      | 1.05      | 0.69      | 0.00     | 0.03     | 0.84      | 0.59     | 0.38     | 0.25     | 0.73     |

* Extinction coefficient.
| Line              | A1          | A2          | N           | B1          |
|------------------|-------------|-------------|-------------|-------------|
|                  | −14.4 to −3.6 | −32.9 to −14.4 | −3.6 to 5.8 | 5.8–21.8    |
| [O III] λ4959    | ...         | ...         | 0.31 ± 0.06 | ...         |
| [O III] λ5007    | 1.07 ± 0.66 | 0.94 ± 0.64 | 1.06 ± 0.08 | 1.72 ± 0.71 |
| [N ii] λ5199     | 0.96        | 0.89        | 1.00        | 1.59        |
| He i λ5876       | ...         | ...         | 0.20 ± 0.04 | ...         |
| [O III] λ6300    | ...         | ...         | 0.14        | ...         |
| [O III] λ6364    | ...         | ...         | ...         | ...         |
| [N ii] λ6548     | 0.81 ± 1.44 | ...         | 0.44 ± 0.04 | ...         |
| [O III] λ6563    | 8.78 ± 3.86 | 4.75 ± 2.00 | 5.01 ± 0.20 | 6.59 ± 1.58 |
| [N ii] λ6583     | 2.23 ± 1.36 | 1.11 ± 0.79 | 1.13 ± 0.07 | 1.96 ± 0.76 |
| [S ii] λ6717     | 2.23 ± 1.56 | 1.08 ± 0.79 | 0.61 ± 0.05 | 1.09 ± 0.51 |
| [S ii] λ6724     | 4.57 ± 3.15 | 2.36 ± 1.63 | 1.10 ± 0.10 | 2.27 ± 1.04 |
| [S ii] λ6731     | 2.35 ± 1.60 | 1.28 ± 0.84 | 0.49 ± 0.05 | 1.17 ± 0.53 |
| Hβ λ4861 = 1.00: |             |             |             |             |
| F(Hα) (×10⁻¹⁶ ergs s⁻¹ cm⁻²) | 61.8 ± 7.4  | 34.1 ± 3.1  | 745.5 ± 0.0 | 28.8 ± 1.7  |
| F(Hβ) (×10⁻¹⁶ ergs s⁻¹ cm⁻²) | 606.0       | 96.2        | 2343.0      | 158.1       |
| $c^*$            | 7.0 ± 2.3   | 7.2 ± 2.4   | 148.8 ± 6.0 | 4.4 ± 0.8   |
| $E(B−V)$         | 212.7       | 33.8        | 821.9       | 55.5        |

* Extinction coefficient.
| Line     | \( A_1' \) | \( A_2' \) | \( A_3' \) | \( N' \) |
|----------|-----------|-----------|-----------|--------|
| \([\text{O} \text{~i}]\) \( \lambda 3727 \) | 2.80 ± 0.53 | 5.58 ± 2.96 | 6.08 ± 3.47 | 2.27 ± 0.30 |
| \([\text{Ne} \text{~i}]\) \( \lambda 3869 \) | 3.73 | 8.82 | 8.42 | 3.20 |
| \( \text{H} \gamma \) \( \lambda 4340 \) | 1.14 | | | 1.09 |
| \([\text{O} \text{~i}]\) \( \lambda 4363 \) | | | | |
| \( \text{He} \alpha \) \( \lambda 4686 \) | | | | |
| \([\text{O} \text{~i}]\) \( \lambda 4959 \) | 0.26 ± 0.06 | 0.75 ± 0.40 | 0.47 ± 0.30 | 0.27 ± 0.03 |
| \([\text{O} \text{~i}]\) \( \lambda 5007 \) | 0.63 ± 0.07 | 1.70 ± 0.48 | 1.41 ± 0.49 | 0.87 ± 0.05 |
| \([\text{N} \text{~i}]\) \( \lambda 5199 \) | 0.61 | 1.61 | 1.36 | 0.84 |
| \( \text{He} \beta \) \( \lambda 5876 \) | 0.14 ± 0.03 | 0.23 ± 0.15 | 0.20 ± 0.02 | 0.15 |
| \([\text{O} \text{~i}]\) \( \lambda 6300 \) | 0.14 ± 0.04 | 0.18 | 0.15 | |
| \([\text{O} \text{~i}]\) \( \lambda 6364 \) | 0.10 | | | 0.04 |
| \([\text{N} \text{~ii}]\) \( \lambda 6548 \) | | | | 0.23 ± 0.19 |
| \([\text{H} \alpha] \) \( \lambda 6563 \) | 4.01 ± 0.20 | 4.93 ± 1.04 | 4.21 ± 1.26 | 4.30 ± 0.17 |
| \([\text{N} \text{~ii}]\) \( \lambda 6583 \) | 2.85 | 2.85 | 2.85 | |
| \([\text{S} \text{~ii}]\) \( \lambda 6717 \) | 0.12 ± 0.09 | 1.16 ± 0.36 | 0.78 ± 0.53 | 1.08 ± 0.05 |
| \([\text{S} \text{~ii}]\) \( \lambda 6724 \) | 0.63 | 0.67 | 0.53 | 0.71 |
| \([\text{S} \text{~ii}]\) \( \lambda 6731 \) | 0.14 ± 0.04 | 0.18 | 0.15 | |
| \( \text{H} \beta \) \( \lambda 4861 \) | 0.10 | 0.15 | 0.06 ± 0.03 | |

| \( f(H\alpha)(\times 10^{-15} \text{ erg s}^{-1} \text{ cm}^{-2}) \) | 27.2 ± 0.3 | 5.6 ± 0.2 | 8.5 ± 0.8 | 65.1 ± 0.7 |
| \( f(H\beta)(\times 10^{-15} \text{ erg s}^{-1} \text{ cm}^{-2}) \) | 54.4 | 17.0 | 18.8 | 150.1 |
| \( \epsilon(E-B-F) \) | 19.1 | 5.9 | 6.6 | 52.6 |

a Extinction coefficient.

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INTERACTION EFFECTS IN Tol 1238–364 AND ESO 381-G009

![Table 12](image-url)
