Internal Kinematics of UM 461 and CTS 1020

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Accepted XXX. Received YYY; in original form ZZZ

ABSTRACT

We have used integral field spectroscopy to study the internal kinematics of the H II galaxies CTS 1020 and UM 461. We based our analysis on the velocity and velocity dispersion maps, and intensity-velocity dispersion ($I - \sigma$) and velocity-velocity dispersion ($V_r - \sigma$) diagrams. We found that the motion in both star-forming knots of UM 461 has different patterns, suggesting a weak kinematical connection between the knots. The overall kinematics of the galaxy is probably affected by stellar feedback. CTS 1020 has an ordered motion with a gradient compatible with a disc rotating at $\sim 50$ km s$^{-1}$, though the velocity field is disturbed. In both galaxies the highest and lowest $\sigma$ values are distributed in the outer parts and are associated with the diffuse gas that permeates the galaxies. UM 461 has a ring-like structure with small regions of increasing $\sigma$ in the eastern knot, which resemble what we could expect in a collect and collapse scenario of star formation. We found that UM 461 seems to be more susceptible to stellar feedback, whereas in CTS 1020 the gravitational potential dominates.

Key words: H II galaxies: kinematics and dynamics – galaxies: individual (CTS 1020, UM 461)

1 INTRODUCTION

H II galaxies, also known as blue compact dwarf depending on classification criteria (Melnick et al. 1985), are a subclass of dwarf galaxies characterized by its compactness ($\sim 1$ kpc), high star formation rate and a spectrum dominated by intense emission lines superimposed to a weak stellar continuum, which resembles that observed in giant H II regions in spiral galaxies (Sargent et al. 1970). Among the observed emission lines are the hydrogen Balmer series and the forbidden lines of oxygen ([O III] $\lambda\lambda$4959, 5007, 4363, [O II] $\lambda\lambda$3726, 3729), nitrogen ([N II] $\lambda\lambda$6548, 6583), and sulfur ([S II] $\lambda\lambda$6716, 6731).

The fact of being gas-rich and metal-poor objects raised the hypothesis that these galaxies were young systems forming their first stars (Searle & Sargent 1972), but the idea of being old systems with intermittent star formation bursts interleaved by quiescent periods has been supported by observations of an underlying old stellar population (Thuan 1983; Telles & Terlevich 1997; Westera et al. 2004; Corbin et al. 2006).

An important characteristic of these galaxies is the supersonic nature of their emission line profile, which is broader than that observed in typical H II regions (Smith & Weedman 1970, 1971). Terlevich & Melnick (1981) proposed that the gravitational potential is responsible for this supersonic line widths, as they found a correlation between H$\beta$ luminosity and velocity dispersion ($L \sim \sigma^4$) and radius and velocity dispersion ($R \sim \sigma^2$) in giant H II regions. This scenario was further supported by Tenorio-Tagle et al. (1993), who proposed a model to explain and maintain the supersonic motion, which is given by the constant passage of low-mass stars producing bow shocks. Alternatively, the supersonic motions may be maintained by the mechanical energy injected into the interstellar medium from the ongoing star formation activity, stellar winds, radiation pressure and supernovae explosions, all of which contribute to increase the turbulence (Green et al. 2010; Moiseev & Lozinskaya 2012; Moiseev et al. 2015). These scenarios have difficulties to explain the $L \sim \sigma^4$ and $R \sim \sigma^2$ relations.

Which of these mechanisms is dominant remains an open problem. Gallagher & Hunter (1983) suggested that the dominant mechanism depends on the system scale, being the gravitational potential in regions of hundreds of parsecs (supergiant H II regions) and energy from massive young stellar populations in regions of tens of parsecs (giant H II regions). Furthermore, Tenorio-Tagle et al. (1996) demonstrated that the mechanical energy from massive stars is not sufficient to explain the observed line broadening, in agreement with Yang et al. (1996) who found that the stellar winds and su-
pernovae explosions act increasing the dispersion caused by the gravitational potential.

Kinematics and dynamics of H II galaxies have been investigated, early on, by looking at their velocity dispersion. Rapidly a scale relation between emission line and velocity dispersion have been established (Melnick & Terlevich 1985). These scale relations have been used early on as distance indicator. Taking advantage of larger survey and better data, recent studies could minimise errors in these relations (Bordalo & Telles 2011; Chávez et al. 2014). These studies also show that such relations are subject to evolutionary effects, responsible, according to authors, for part of the dispersion of such relations. More recently, high redshift H II galaxies have been used as tools for precise cosmology (Terlevich et al. 2015).

Kinematical studies of H II galaxies with 2D mapping instrumentation were first made by Östlin et al. (1999, 2001) and focused on the analysis of velocity field to determine the mass distribution using rotation curves. The results showed a disturbed velocity field and supersonic velocity dispersion in a small sample of H II galaxies, what pointed out that velocity dispersion dominates the gravitational potential. However, as the morphology of the galaxies suggested interaction or merger, the authors concluded that those galaxies were not systems in equilibrium, but in a merger process (Östlin or merger, the authors concluded that those galaxies were ever, as the morphology of the galaxies suggested interaction.

In order to disentangle the line broadening mechanisms, we used diagnostic diagrams, such as $I-\sigma$, $I-V_r$ and $V_r-\sigma$, that have been revealed to be precious tools to find signatures of peculiar motions, as expanding shells, radial motions (Muñoz-Tuñón et al. 1996; Bordalo et al. 2009; Plana et al. 2017) and of turbulent ISM and H II region (Moiseev & Lozinskaya 2012).

The paper is organized as follows. In Section 2 we present observations and the reduction techniques used. The ionized gas kinematics is presented in § 3, discussion of the diagnostic diagrams of H II complexes is presented in § 4 along with a statistical analysis of specific diagrams in section § 5. The section § 6 is dedicated to a Principal Component Analysis of the data cubes. In § 7 our results are discussed. Finally in § 8, we give the summary and draw general conclusion.

2 SAMPLE, OBSERVATIONS AND DATA REDUCTION

2.1 Sample

2.1.1 UM 461

UM 461 was discovered in objective prism survey from the University of Michigan (MacAlpine & Williams 1981). It has an optical structure formed by two compact star-forming knots, enveloped by a diffuse medium distorted toward the southwest, as seen in Fig. 1. The knots are off-center, the brightest located east of the galaxy. The southwest extension of the nebulosity has been attributed to tidal effect due to an interaction with UM 462 (Lagos et al. 2011; Noeske et al. 2003; Doublier et al. 1999). Taylor et al. (1995) first studied this interpretation as they observed distortions in the isophotes of H I emission of UM 461 towards UM 462, suggesting a binary system in interaction. On the other hand, in H I observations from Van Zee et al. (1998) these two galaxies appear as isolated systems with no clear interaction signs. Although a possible interaction with UM 462 could be responsible for trigger the star formation in UM 461, Olmo-Garcia et al. (2017) show evidence of accretion of metal-poor gas in the latter, producing a difference in metallicity along the galaxy and probably fueling the star formation activity.

Near-infrared observations showed that the western knot can be spatially resolved into several stellar clusters and complexes, whereas the eastern knot is more compact (Noeske et al. 2003; Lagos et al. 2011). These clusters are young ($\sim$ 5 Myr) with diameters smaller than 37 pc and masses of the order of $\sim 10^4 - 10^5 M_\odot$. A stellar population with ages $\gtrsim 10^8$ yr is embedded in the nebular component that envelops the star-forming knots (Lagos et al. 2011). In a recent work, Lagos et al. (2018) report VIMOS-IFU observations of UM 461. They conclude that the ISM is well mixed, at large scale, but their study also reports a low metallicity region close to the brightest H II region. It leads the authors to imagine a scenario where a recent infall of a low mass metal-poor dwarf or H I cloud occurred.

2.1.2 CTS 1020

CTS 1020 was also discovered by objective prism technique in the Calán-Tololo Survey (Maza et al. 1991). It is a roughly spheroidal form and a well defined nucleus (Fig. 1), classified as a H II type II according to Telles et al. (1997). It is a less studied galaxy, but its observational properties are reported in a number of catalogs (Maza et al. 1991; Kilkenney et al. 1997; Stobie et al. 1997; Kehrig et al. 2004; Lagos et al. 2007; Kopparapu et al. 2008; Jones et al. 2009). Analysis of H I equivalent width indicates an intense star formation activity in a region slightly shifted from the center of the galaxy (Lagos et al. 2007).

2.2 Observations and Data Reduction

Observations have been carried out in two runs in February 12th 2008 and in February 18th 2010 as part of the GS-2008-Q32 program with Gemini South 8m telescope in Chile, using the Gemini Multi-Object Spectrograph (GMOS) equipped with an Integral Field Unit (IFU) on single-slit mode(Allington-Smith et al. 2002). Observations have been done under very good seeing conditions. UM 461 has been observed with a seeing between 0.35′′ and 0.45′′ and CTS1020 between 0.35′′ and 0.5′′. Table ?? gives essentials characteristics for both galaxies. This mode uses 750 hexagonal lenses, each associated with a fiber, to sample the focal plane. The fibers are arranged to form single column positioned at the entrance of the slit of the spectrograph. The sky is sampled by 250 lenses at a distance of 1′ from the science
field. As individual IFU provides a field of view of $5'' \times 3.5''$ (in single-slit mode), it was necessary nine and five fields to cover UM 461 and CTS 1020, respectively (see Fig. 1). The time exposure of each field was 600s and the R831/550 grating has been used along with the g filter G5322 (see Table 2 for the journal of observation). The IFU fields positioning are shown in Fig. 1 superimposed to the acquisition image taken with a g filter and time exposure of 30 s.

Data have been reduced using special reduction package given by Gemini Staff using the IRAF reduction package. All raw images have been bias corrected, trimmed and flat fielded. Flatfield images have also been used to locate the positions of the 750 lenses on the frame. Twilight images were used to estimate the grating response. Arcs, from the CuAr lamp, have also been taken for the wavelength calibration. Using the bright OI night sky line at $5577.338\AA$ we have estimated the wavelength accuracy to 0.1 Å. The last step of the reduction was the sky subtraction using the field of $1''$ from the science field. Finally the data cube has been created with the gfcube. We used a spacial resampling of 0.1'' per pixel. The total spectral coverage for both objects is between 4442 Å and 6559 Å. From the arcs spectra, we deduced a spectral sampling of 0.33 Å per spectral pixel.

| Galaxy     | $\alpha$ (J2000) | $\delta$ (J2000) | $v_{sys}$ (km s$^{-1}$) | $D$ (Mpc) |
|------------|------------------|------------------|-------------------------|-----------|
| UM 461     | 11 53 33.1       | -02 22 22        | 1039                    | 19.3      |
| CTS 1020   | 10 47 44.3       | -20 57 49        | 3789                    | 57.4      |

Informations obtained from NED.

Table 1. General parameters of the galaxies.

3 IONIZED GAS MOMENT MAPS

Specific macro using IDL (Image Data Language) have been used to produce the different maps. We perform a linear fit of the continuum and a Gaussian fit of the emission lines, using the GAUSSFIT task in IDL. We have considered signal from the galaxy a profile $3\sigma$ above the sky level. The Gaussian fit gave us directly three maps: monochromatic (area of the profile), radial velocity (central wavelength) and velocity dispersion ($\sigma$). Fig. 2 and Fig. 3 show profiles and the associated fit, estimated in 0.4'' x 0.4'' boxes, in four zones located in different areas for both objects. Location of zones is shown in Fig. 4a and Fig. 4b. The Gaussian fit appears to be very good, even in outskirts zones where the SNR is lower ($\approx 20$). Following the GAUSSFIT routine help, we estimate that the 1-$\sigma$ fit error is between 0.2 to 0.5 km s$^{-1}$ depending on SNR (see Fig. 2 and Fig. 3 captions).

For both galaxies, we were able to derive monochromatic map, velocity and velocity dispersion maps using only [OII]$\lambda$5007 emission line. The velocity dispersion map has been corrected from the instrumental and thermal broadening. The velocity dispersion ($\sigma$) was obtained by correcting the observed one ($\sigma_{obs}$) for both instrumental ($\sigma_{inst}$) and thermal ($\sigma_{th}$) broadening, $\sigma_{obs} = \sqrt{\sigma^2 + \sigma_{th}^2 + \sigma_{inst}^2}$. We have estimated the thermal dispersion to $\sigma_{th} = 3.2$ km s$^{-1}$ for the oxygen (at a temperature of $10^4$K), and $\sigma_{inst} = 27.5 \pm 0.1$ km s$^{-1}$ for both galaxies, from several emission lines in calibration lamp used for the wavelength calibration. To take into account the seeing quality of observations, we performed a Gaussian smoothing of 0.4'' FWHM for the maps. Tests in regions on the outskirts of galaxies, where the SNR is below 20, reveal that sigma estimation from the gaussian fit has an relative error less than 3% when continuum level is estimated till three times the linear fit errors.

3.1 UM 461

3.1.1 Monochromatic map

The [OII]$\lambda$5007 monochromatic emission map is superimposed on both velocity and velocity dispersion maps presented in Fig. 4a and Fig. 4b, respectively. The eastern knot is a factor of 12 brighter compared to the western knot.

3.1.2 Radial Velocity map

The velocity map has been elaborated using a systemic velocity $v_{sys} = 1039$ km s$^{-1}$ from NASA/IPAC Extragalactic Database (NED)\(^3\). The eastern knot shows a velocity gradient of $15$ km s$^{-1}$ from the southeast to the northwest of the knot. The western knot has a different pattern, as does not exhibit a clear gradient and is dominated by velocities between 1048 and 1061 km s$^{-1}$. Despite the low amplitude gradient in the eastern knot, the overall motion of the ionized gas is not ordered. Considering the stellar clusters and complexes spread along the galaxy, as observed in the near-infrared (Lagos et al. 2011; Noeske et al. 2003), the overall kinematics could result from the interaction of these stellar populations with the interstellar medium, as they evolve and inject mechanical energy into the medium through stellar winds and supernova explosions. The eastern knot, despite more compact, has at least three smaller companions around it, which could be responsible for the disturbed velocity field, mainly in the northeastern region. In the western knot, the stellar clusters are more spread out among them, producing a much less ordered motion. In fact, the velocity map of UM 461 suggests a weak kinematical connection between the knots. In agreement with this scenario, Olmo-Garcia et al. (2017) show evidence of stellar feedback in the eastern knot and its coherent motion within the host galaxy. Lagos et al. (2018) velocity field of UM 461 is consistent with ours, showing the same velocity gradient in both knots. Radial velocities show a difference of $\approx 15$ km s$^{-1}$, that can be attributed to the spectral resolution difference.

3.1.3 Velocity dispersion map

The velocity dispersion map in Fig. 4b shows that all velocity dispersions are supersonic, ranging between 15 to 35 km s$^{-1}$ in a few pixels. In the eastern knot, it is noticeable a ring-like structure with $\sigma$ values between 25 and 29 km s$^{-1}$ that envelopes a region of lower dispersion (21-24 km s$^{-1}$).

\(^1\) http://www.gemini.edu/node/10795
\(^2\) Image Reduction and Analysis Facility is a software developed by the National Optical Astronomy Observatory - iraf.noao.edu
\(^3\) http://ned.ipac.caltech.edu/
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**Figure 1.** Acquisition images of UM 461 and CTS 1020 taken with a $g$ filter and time exposure of 30s. Superimposed are the IFU field mosaic. Each IFU has a $3.5'' \times 5''$ field of view.

**Figure 2.** UM 461: Profiles and Gaussian fit in four different zones of $0.4'' \times 0.4''$. Different zones locations are given in Fig. 4b. They represent integrated profiles in areas with very high SNR ($>200$) to area with SNR < 20.

**Figure 3.** CTS 1020: Profiles and Gaussian fit in four different zones of $0.4'' \times 0.4''$. Different zones locations are given in figure Fig. 5b. They represent integrated profiles in areas with very high SNR ($>200$) to area with SNR < 20.

**Table 2.** Journal of Observation

| Galaxy  | Observation Date | Instrument | Exposure Time | Fields Number | Grating Filter   | Resolution |
|---------|------------------|------------|---------------|---------------|------------------|------------|
| UM 461  | Feb. 12$^{th}$ 2008 | GMOS/IFU   | 600s          | 9             | R831 - G5322     | 4396       |
| CTS 1020| Feb. 18$^{th}$ 2010 | GMOS/IFU   | 600s          | 5             | R831 - G5322     | 4396       |

Informations from Gemini website.
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Figure 4. UM 461: a) Radial velocity and b) velocity dispersion maps. The superimposed contours are the flux from [O iii]λ5007 line. Labels refer extracted profiles in Fig. 2 (numbers) and Fig. 14 (letters). c) Velocity dispersion contour map with isocurves varying by 0.1 km s$^{-1}$. In colors we have points in the interval 20–29 km s$^{-1}$ and in gray scale for values out of this interval.

Melnick & Terlevich (1985) and Bordalo & Telles (2011) reported slightly lower velocity dispersion of 14.5 km s$^{-1}$ and 12.6 km s$^{-1}$, respectively. Our lowest $\sigma$ is 15 km s$^{-1}$, but in the center of the brightest knot, where the one fiber measurement certainly has been done, our value is $\approx$ 20 km s$^{-1}$. In the western knot, the velocity dispersion increases toward the southeast, with some small regions of increasing $\sigma$. A few pixels show very high velocity dispersion (especially in the connection between the knots) up to 50 km s$^{-1}$. In Fig. 4c we show a velocity dispersion contour map obtained varying the isocurves by 0.1 km s$^{-1}$. In this map, we wanted to highlight regions in the interval 20 to 29 km s$^{-1}$ (shown in colors), because the contrast with the highest and lowest $\sigma$ values (in gray scale) makes it difficult to see some fine structures within these regions. In fact, we found several regions of increasing $\sigma$ (meaning a local $\sigma$ peak surrounded by decreasing values) along the galaxy. By restricting the $\sigma$ range allowed us to better distinguish the ring-like structure in the eastern knot. This structure resembles the distribution of H$\beta$ equivalent width reported by Lagos et al. (2007), that exhibits $EW(H\beta)$ higher than 300 $\AA$, indicating an intense star formation activity in the eastern knot.

3.2 CTS 1020

3.2.1 Monochromatic map

The [O iii]λ5007 monochromatic emission map is superimposed on both velocity and velocity dispersion maps presented in Fig. 5a and Fig. 5b, respectively. Emission extends across all observed fields (and possibly beyond the observed fields in the northeast and east). It is also noticeable an extension towards the southwest, which probably is a manifestation of a second nucleus, but the lack of spatial resolution prohibits to see it.

3.2.2 Radial Velocity map

We used $v_{\text{sys}} = 3789$ km s$^{-1}$ as systemic velocity from NED. The velocity field of CTS 1020 is very different from UM 461. Here we can clearly see a velocity gradient more consistent with a rotating disk. Across a velocity major axis of 0$''$, radial velocity varies from 3752 km s$^{-1}$ in the south to 3800 km s$^{-1}$ in the north. Southwest from the monochromatic center (at $\sim$ 1$''$), a small region shows radial velocities 10 km s$^{-1}$ higher than immediate surroundings. We speculate that it can be a high velocity cloud. East of the center, on the edge of the field, a region of 2$''$ × 1.5$''$ shows high radial velocities between 3805 and 3818 km s$^{-1}$, the highest of the velocity field. Here too, we can speculate that it is a high velocity cloud, but because our fields did not cover the galaxy entirely, it is difficult to conclude. Despite a clear velocity gradient compatible with a disk pattern, it is almost certain that the kinematics is more complex than it seem.

From the monochromatic map we derived an inclination angle of the disk by doing the ratio of the minor axis to the major axis, we found 30$''$.

3.2.3 Velocity dispersion map

The outskirt of the velocity dispersion map (Fig. 5b) shows velocity dispersion lower than $\sigma = 20$ km s$^{-1}$, where the SNR is close to the limit discussed above and the Gaussian fit profile is not so good. Nevertheless, after an eye check
of these profiles, we are confident that the estimated dispersion is accurate. Beside this region, the velocity dispersion reaches low values ($\sigma < 38$ km s$^{-1}$) in the northern and southern regions, while highest values ($\sigma > 47$ km s$^{-1}$) are concentrated in an arch in the southeastern part of the galaxy. Crossing the center of the galaxy in the east to west direction $\sigma$ assumes values between 38 and 47 km s$^{-1}$. Fig. 5c shows the $\sigma$ contour map restricted to the range 38–47 km s$^{-1}$ (shown in colors). These values are mainly concentrated in the area along the center toward the west of the galaxy. By restraining the $\sigma$ range, we can now distinguish few regions of increasing $\sigma$: in the center, $\sigma$ increases with intensity; in the west coincides with the disturbed region seen in the velocity field; in the southeastern region $\sigma$ reaches values higher than 47 km s$^{-1}$.

4 DIAGNOSTICS DIAGRAMS

4.1 Description

As mentioned before, several studies have shown that H II galaxies have supersonic velocity dispersion and little velocity gradient. In order to study the dynamic of these objects, several studies have suggested over the years, the use of the so-called, diagnostic diagrams such: $I - \sigma$, $I - V_r$ or $V_r - \sigma$. For each galaxy, we are presenting the $I - \sigma$ in Fig. 6a, $I - V_r$ in Fig. 6b and $V_r - \sigma$ in Fig. 6c. Bordalo et al. (2009) summarise the different interpretations of these diagrams. Introduced by Muñoz-Tuñón et al. (1996), the $I - \sigma$ diagram has been used by those authors to identify expanding shells by localizing inclined bands. This interpretation is based on the fact that the velocity dispersion should be higher at the center of the shell and the intensity lower because less material is crossed along the line of sight than at the inner and outer edges of the shell. Large variations of radial velocity with a relatively narrow intensity interval in a $I - V_r$ diagram, could mean an expansion or an inflow of matter. The $V_r - \sigma$ panel looks at the dependence between the two variables. If a significative correlation is found between velocity and dispersion, it could mean the presence of relative motion inside the system. The inclined pattern is the signature of systematic motion, such as Champagne flows such that cloud of gas with high $\sigma$ moves away from us (positive slope) or toward us (negative slope).

4.1.1 UM 461

The top panels of Fig. 6 shows for UM 461. Each knot is represented with two different symbols. The $I - \sigma$ plot shows a similar behaviour for both knots, a trumpet like shape where the low intensity region has a large velocity dispersion range and the high intensity a narrow velocity dispersion interval. The $I - V_r$ panel clearly shows the velocity differences between both knots, with the western knot moving away from the eastern knot. The radial velocity range is larger at very low intensity level, due to the lowest SNR. No vertical bands, characteristic of expansion motion, is visible in either knots. The $V_r - \sigma$ plot shows a clear correlation, but a closer look seems to show sub-structures. We decided to investigate further using robust statistical tools, detailed in Section 5.

4.1.2 CTS 1020

The bottom panels of Fig. 6 show the diagrams for CTS 1020. The $I - \sigma$ diagram exhibits a different behaviour of $\sigma$ compared to UM 461. Here, $\sigma$ increases with intensity until reaches a lane along all intensities with values between 38 and 43 km s$^{-1}$ (highlighted in Fig. 5c), and a mean of 40.3 km s$^{-1}$. Fig. 6b shows the $I - V_r$ corresponding diagram...
for this object. No radial motions (materialised by a vertical band) can be seen. The triangular shape toward the higher intensity, is more characteristic of a rotation pattern, with a maximum velocity amplitude of 80 km s\(^{-1}\). The third plot (Fig. 4c) represents the \(V_r - \sigma\) diagram. It seems that two populations are present, we have performed a deep statistical analysis in the Section 5 in order to extract those two populations.

4.2 \(I - \sigma\) diagram

In Figs. 7 and 8, we further explored the \(I - \sigma\) diagram by looking at different regions and their respective location in the velocity dispersion map. We have divided the \(I - \sigma\) diagram in three intervals of intensity (high – \(\log I > 3.5\); intermediate – \(2.7 < \log I < 3.5\); and low – \(\log I < 2.7\)), and \(\sigma\) intervals according to values in the horizontal lane, in order to distinguish their distribution over the galaxy.

4.2.1 UM 461

Fig. 7 shows the \(I - \sigma\) diagram and the respective velocity dispersion map for UM 461. This galaxy has a simple morphology with intensity decreasing outwards the knots. The high intensity regions (in dark blue) have an almost constant velocity dispersion (\(\langle \sigma \rangle \sim 21.8 \, \text{km s}^{-1}\)), which also comprises an horizontal lane along the intensity range. The regions in \(2.7 < \log I < 3.5\) also exhibit values around \(\langle \sigma \rangle\) (in orange – mainly in the eastern knot) with some regions of higher \(\sigma\) (in yellow), which coincides with the ring-like structure shown in Fig. 4c. The lowest (\(\sigma < 20 \, \text{km s}^{-1}\)) and highest \(\sigma\) values (\(\sigma > 32 \, \text{km s}^{-1}\)) are located in the outermost regions of the galaxy, surrounding both star-forming knots. Only a few pixels reach \(\sigma\) values higher than 32 km s\(^{-1}\). These regions (shown in grey and red) cover the whole \(\sigma\) range and form a triangular pattern, which is related to the turbulent motion in the diffuse gas that permeates the star-forming regions in the galaxy (Moiseev & Lozinskaya 2012; Moiseev et al. 2015). It was not possible to identify signatures of expanding shells, as proposed by Muñoz-Tuñón et al. (1996). The horizontal lane with an almost constant \(\sigma\) is supposed to be a supersonic random motion caused by a constant passage of bow shocks from low-mass stars in the model of Muñoz-Tuñón et al. (1996).

4.2.2 CTS 1020

In CTS 1020, the velocity dispersion distribution (Fig. 8) shows a different pattern from that of UM 461. Although the \(\sigma\) range also decreases with intensity, the regions of high intensity are related to high velocity dispersion. This galaxy also presents a horizontal lane of an almost constant velocity dispersion (\(\langle \sigma \rangle \sim 40.3 \, \text{km s}^{-1}\)), but contrary to UM 461, in CTS 1020 this value is higher than the overall mean (37.1 km s\(^{-1}\)) along the galaxy. The points in this lane (represented in dark blue, dark orange and red) are not widely spread along
Figure 7. $I - \sigma$ diagram and respective velocity dispersion map for UM 461. The black horizontal lines indicate, from top, the velocity dispersion in 24 and 19 km s$^{-1}$. The intensity is given in arbitrary units and is shown as contours in the map.

Figure 8. $I - \sigma$ diagram and respective velocity dispersion map for CTS 1020. The black horizontal lines indicate, from top, the velocity dispersion in 43, 38 and 28 km s$^{-1}$. The intensity is given in arbitrary units and is shown as contours in the map.
the galaxy (see also Fig. 5c), as seems to be the case of UM 461. Instead, the regions represented in light blue, light orange and light grey, seems to cover a large area of the galaxy. The velocity dispersion seems to decrease outwards, but some regions show a velocity dispersion higher than the local average, such as the regions in dark orange. The high intensity region with \( \sigma \) values around \( \langle \sigma \rangle \) (in dark blue) cross the center of the galaxy in the east to west direction (As also seen in Fig. 5c). As observed in UM 461, the lowest \( (\sigma < 28 \text{ km s}^{-1}) \) and highest \( \sigma \) values \( (\sigma > 43 \text{ km s}^{-1}) \) are located in the outer parts of the galaxy, except by a small region with \( \sigma \) higher than \( 43 \text{ km s}^{-1} \) in the southeast (in yellow), which would be an evidence of expanding motion. Despite the different pattern, the main similarity with UM 461 is that the outermost regions (shown in grey and red) cover the whole \( \sigma \) range, and could also be related to the turbulent motion of the diffuse gas.

5 STATISTICAL ANALYSIS

In order to extract information from the \( V_r - \sigma \) diagram, we performed statistical analysis to determine the possibility of having several independent populations. To achieve this goal, we employed the \texttt{R} statistical package (\texttt{R} Development Core Team 2009), largely used in different statistical analysis. We aim at finding how many independent components are present (task \texttt{Mclust}), to locate them in the diagram and in the map (so-called geographic location). \texttt{Mclust} is a \texttt{R} function for model-based clustering, classification, and density estimation based on finite Gaussian mixture modeling. An integrated approach to finite mixture models is provided with routines that combine model-based hierarchical clustering and several tools for model selection (see Frakerly & Raferty 2007).

A central question in finite mixture modelling is how many components should be included in the mixture. In the multivariate setting, the volume, shape, and orientation of the covariances define different models (or parameterisation) with their different geometric characteristics. In \texttt{Mclust}, the number of mixing components and the best covariance parameterisation are selected using the Bayesian Information Criterion (BIC). \texttt{Mclust} also relates each element in the dataset to a particular component in the mixture.

The code uses the Expectation-Maximization (EM) algorithm that maximizes the conditional expected log-likelihood at each M-step of the algorithm.

Below, we are detailing how we applied these different tasks and their results.

5.1 UM 461

In this case, we had to separate knots on the East and West. Fig. 9a, b shows the result of such statistical analysis for the eastern knot and Fig. 9c, d western knot.

In UM 461 eastern knot, we found \( m = 4 \) components. Two of these components did not seem to have physical meaning since they were regrouping dispersed points in the galaxy outskirt and small areas. The two others components correspond to two peaks in a density map of the diagram (not presented here), which gave us more confidence in the statistical decomposition.

Both components are plotted in Fig. 9a, respectively in blue and orange, within a 80% confidence level. We perform a standard Pearson’s product-moment correlation test for the different components, in order to show the existence of systematic motions mentioned before. Subcomponent 1 (in orange) has a correlation of 0.37 and correlation of subcomponent 2 (in blue) is 0.28, both are considered as weak correlation.

In UM 461 western knot, we also found \( m = 4 \) components. As previously, only two seems to show a physical meaning. The relevant components correspond to denser areas of the diagram. The Pearson test, in both components gives respectively 0.33 (orange component) and −0.01 (blue component).

In both, East and West regions, we performed a simple linear regression (showed as solid lines in Fig. 9a, Fig. 9c) for these components when the correlation is relevant. In this context, both subcomponents in the eastern region can be interpreted as complexes with relatively high dispersion, moving away from the observer (positive slope). In the western region only the orange component shows a relevant correlation and the linear regression has a positive slope, corresponding to a complex moving away from the observer.

Fig. 9b, d show the geographic location of the different components and subcomponents for both eastern and western knots.

In both knots, the geographic location is compatible with the velocity field represented in Fig. 4a, with the subcomponent in blue representing the low velocity area and the orange subcomponent representing higher velocities.

5.2 CTS 1020

As for UM 461, before analysis, \( V_r \) and \( \sigma \) were normalized in order to avoid bias due to amplitude differences between \( V_r \) and \( \sigma \).

The \texttt{Mclust} analysis is presented in Fig. 9e, f. It has separated three components in the \( V_r - \sigma \) diagram. All of three components appear to have a physical meaning when we look at the X-Y location map (Fig. 9f). The first two ones (blue and grey) show weak (0.3 for first component) and moderate (0.54 for the second) correlation.

Fig. 9f, representing the X-Y location of these regions, is also compatible with CTS 1020 velocity map (Fig. 5c) where the orange region represents the high radial velocities in the northwest and the blue region represents the lower radial velocities. The third component (grey) seems to correspond to the highest radial velocities but does not show any correlation with the Pearson test. We also perform a simple linear regression for both components (orange and blue, showed as solid lines in Fig. 9e), where the correlation is relevant.

6 PRINCIPAL COMPONENT ANALYSIS OF DATA CUBES

The basic idea of this analysis, used with multidimensional data, consists in apply a linear orthogonal transformation to take the data from their original basis, where they are correlated, to a new basis, where the variables are not. This new orthogonal basis, formed by eigenvectors, is then used to
Figure 9. UM 461 East (a) $V_\text{r} - \sigma$ diagram. Two components, blue and orange, separated using statistical analysis with the task \texttt{Mclust}. (b) Geographic representation of the different components. UM 461 West (c) $V_\text{r} - \sigma$ diagram. \texttt{Mclust} decomposition result, (d) Geographic representation of the different components. CTS 1020 (e) $V_\text{r} - \sigma$ diagram. Five components separated using \texttt{MClust} task. CTS 1020 (f) Geographic representation of the different components. Solid lines represent linear regression of the different components in all plots.
represent the data. Eigenvectors in this new coordinate system are classified by decreasing variance (Stark & Murtagh 2006). A tomogram (or eigenimage) is a 2D representation of the projected data in this new basis. Each tomogram corresponds to an eigenspectrum, which is the representation of the eigenvector components (or weights) versus the wavelength (or radial velocity). Weight values can be positive or negative which is reflected in the respective tomograms (Cerqueira et al. 2015; Steiner et al. 2009).

This variance can be understood as the information quantity contained in each eigenvector. It is possible then to reconstruct the original cube using only the most relevant tomograms (the ones with higher variance), leaving aside the rest (basically noise or instrument fingerprint). The use of PCA with data cube has been explored by several authors during the past decade. Steiner et al. (2009) and Menezes et al. (2014) give details about PCA treatment and data preparation, see also Cerqueira et al. (2015) for more details. In the following, we are presenting the Principal Component Analysis for both galaxies, first analysing the four most relevant eigenspectra and tomograms and then presenting the reconstructed maps. We choose to perform this decomposition using [O\textsc{iii}]λ5007 emission line because it is the brightest line.

### 6.1 Tomograms and Eigenspectra

Fig. 10 and Fig. 11, respectively show the PCA decomposition of UM 461 and CTS 1020. On top, we present the four most relevant tomograms, representing respectively 99.55%, 0.40%, 0.03% and 0.001% of variance for UM 461 and 98.99%, 0.90%, 0.05% and 0.02% of variance for CTS 1020. On top, we present the four eigenspectra and tomograms, we performed some simple toy models to be analysed using PCA and looked at results. Only one phenomenon comes to mind when we think about describing the ionized gas kinematics in a galaxy: a rotating disk. We basically simulate two kinds to rotation in order to be analysed using PCA, we first present a rigid body rotation and then a differential rotating disk. For the latter one, we decide to give three different inclinations. All models have in common an exponential light distribution, a position angle of 45° and a poissonian noise has been added. The light distribution is not important since it always represents the higher variance in the decomposition and the first tomogram represents it.

- **Rigid Body Rotation**
  
  Fig. 12 gives the first four tomograms and eigenvectors for the model. As expected, the first component represents the exponential light distribution. The second tomogram is the velocity field, with the classic straight line isovelocities. The corresponding eigenvector reproduce the 60 km s$^{-1}$ velocity gradient. Third and fourth eigenvectors, show alternately positive and negative coefficients.

- **Rotating Disk**
  
  In this model we simulate a rotating disk, with three different inclinations, $i=20^\circ$, $i=45^\circ$ and $i=60^\circ$ and a maximum rotational velocity of 60 km s$^{-1}$. As mentioned before, we found that the second tomogram represents more or less the velocity field (confirmed by the amplitude found in the second tomogram). Fig. 13 only present the result of the PCA for a disk inclination of $i=45^\circ$. The second tomogram/eigenspectrum shows the velocity field of a rotating disk with a velocity amplitude of 60 km s$^{-1}$ and a plateau after the first few arc seconds. The third and fourth eigenvectors, also show alternate positive and negative coefficients. The last two eigenspectra and tomograms show negative (blue) and positive areas with two positive (red) regions in between.

### 6.2 Toy Models

In order to interpret the physical meaning (if any) of eigenspectra and tomograms, we performed some simple toy models to be analysed using PCA and looked at results. Only one phenomenon comes to mind when we think about describing the ionized gas kinematics in a galaxy: a rotating disk. We basically simulate two kinds of rotation in order to be analysed using PCA, we first present a rigid body rotation and then a differential rotating disk. For the latter one, we decide to give three different inclinations. All models have in common an exponential light distribution, a position angle of 45° and a poissonian noise has been added. The light distribution is not important since it always represents the higher variance in the decomposition and the first tomogram represents it.

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The principal aim of such simple models was to deter-
mine if a PCA decomposition was able to separate some kinematical parameters, such as inclination for instance, and our answer is no. We also simulate rotating disk with two different velocity dispersions, but the different eigenvectors look like the same and no differences can be found. As a result we are fairly confident that, only the two first eigenvectors/tomograms can have a physical interpretation, respectively as the light distribution (always with the highest variance) and the velocity field of some kind showing a velocity gradient. The interpretation of lower variance of eigenvectors will highly speculative.
6.3 Reconstructed Data Cubes

The great strength of the PCA decomposition, regarding data reduction, is the fact that it can eliminate noise in a very clean and efficient way. The reconstructed cube will be done by using the most significant eigenvectors (the one with higher variance), following the description by Steiner et al. (2009); Cerqueira et al. (2015). We have limited the reconstruction to the first three eigenvectors representing 99.98% of the variance in UM 461 case and 99.94% for CTS 1020. In Fig. 14 and Fig. 15, we present four original and reconstructed profiles in regions across UM 461 and CTS 1020. These regions are 0.4′ × 0.4′ and are located in different parts of the galaxies. Zones 1 are located in the bright parts of each galaxy. The other zones are located in low SNR regions in the outskirts of each galaxy. In high SNR areas, there are virtually no differences between the original and the reconstructed profile. In the others zones, we can note that reconstructed profiles are more regular in shape. We can also note that the central velocities are almost identical between the original and reconstructed profiles. The major difference comes from the FWHM (and then the velocity dispersion). In both galaxies, the reconstructed profile appears to be narrower compared to the original profile. We have selected those profiles as examples, where the SNR is low. The differences in velocity dispersion is clearer when looking at the diagnostic diagrams, presented below.

For both galaxies, we built the different maps and diagnostic diagrams and analysed them. Both the eastern and western parts of UM 461 do not show significant differences in the $V_r$ vs $\sigma$, where differences could be seen more easily.
Both regions, East and West, show similar distribution in the \( V_r - \sigma \) plane compared to data without PCA analysis. In CTS 1020 case, the result is different. Fig. 16 presents the diagnostic diagram Velocity Dispersion vs Radial Velocity from both reconstructed profiles and originals. Blue symbols represent original data and black symbols represent data from reconstructed profiles. Fig. 16 shows velocities lower than 3740 km s\(^{-1}\) coming from regions in the South West. Fig. 16 also shows a lower number of pixels with velocity dispersion higher than 45 km s\(^{-1}\) compared to original data. More generally, it is noticeable that the velocity and the velocity dispersion distribution have changed, even if the bulk of points seems to remain the same. The region with high velocity (beyond 3780 km s\(^{-1}\)) and high velocity dispersion (larger than 40 km s\(^{-1}\)) is not present anymore. These points came from the East - South East region in Fig. 5b, where the velocity dispersion is the highest. Profiles from Zones e and f (Fig. 15), clearly show that reconstructed profiles are narrower than original ones.

7 DISCUSSION

In the following we discuss implications, for both galaxies, of our kinematical study.

The motion in both star-forming knots of UM 461 has different patterns, suggesting a weak kinematical connection between the knots. The velocity field is disturbed mainly in the western knot, which is spatially resolved in individual stellar clusters and complexes (Noeske et al. 2003; Lagos et al. 2011). The overall kinematics of the galaxy is probably a result from the interaction with a low mass metal-poor dwarf or \( H_i \) cloud occurred (Lagos et al. 2018).

At first glance, CTS 1020 seems to show a more ordered motion with a gradient of \( \sim 50 \) km s\(^{-1}\) (from velocity field top to bottom). The velocity field can be seen as a rotating disc, even though the velocity field is disturbed in several regions.

The velocity dispersion in the eastern knot of UM 461 form a ring-like structure that resembles what we could expect in a collect and collapse scenario (Elmegreen & Lada 1977) in which the first generation of stars produces an \( H_{\text{II}} \) region that expands and sweep up the interstellar medium creating a shell of material that will collapse and start to form stars within it. In that shell, the newly formed stars also create \( H_{\text{II}} \) regions that expands into the shell ionizing it.

In that way, the velocity dispersion induced to the gas in the most central region increases as the gas encounter an inhomogeneous medium and increases further as the stars within the shell drive \( H_{\text{II}} \) regions. In that context, the regions of increasing \( \sigma \) seen in Fig. 4c could be related to \( H_{\text{II}} \) regions within the ring-like structure. This kind of ring-like structure has been observed in molecular gas that surrounds \( H_{\text{II}} \) regions (Deharveng et al. 2003, 2010), but in an advanced stage the gas will be ionized by the stellar population formed in the shell and this molecular signature disappears. Thus,

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**Figure 14.** UM 461: Reconstructed profiles from the PCA decomposition, in four regions of the galaxy. In blue are represented the reconstructed profile and in black, the original profile.

**Figure 15.** CTS 1020: Reconstructed profiles from the PCA decomposition, in four regions of the galaxy. In blue are represented the reconstructed profile and in black, the original profile.
we could be looking at this advanced stage of a collect and collapse scenario, also favoured by the morphology of the eastern knot. This is in agreement with Olmo-García et al. (2017) that show a global expansion of this knot.

Galaxies also differ in the $I - \sigma$ diagram distribution, but the overall picture still agree with the observed picture for this type of galaxy, in which the $\sigma$ range decreases with increasing intensity. The main difference is that, in UM 461, high intensity regions are related to low velocity dispersion, which is typically observed in H ii galaxies (Moiseev & Lozinskaya 2012; Moiseev et al. 2015), whereas the high intensity regions in CTS 1020 are related to high velocity dispersion. Despite this, the main similarity is that gas with low intensity covers the whole $\sigma$ range and permeates the brightest regions of the galaxies. As proposed by Moiseev & Lozinskaya (2012), this pattern is representative of the turbulent motion in the diffuse gas due to the injected mechanical energy from the stellar population.

On the other hand, in CTS 1020 $\sigma$ decreases along with monochromatic intensity onwards the galaxy, implying that $\sigma$ is driven by virial motion (Moiseev et al. 2015). However, $\sigma$ is also probably affected by the injection of mechanical energy from the stellar population that increases the velocity dispersion in the outermost parts of the galaxy, where it should be lower in the proposed scenario. Signatures of disturbed regions can be observed in the velocity dispersion contour map (Fig. 5c), where the western and southeastern regions exhibit structures of increasing $\sigma$, and the southeastern where it reaches $\sigma$ higher than 47 km s$^{-1}$.

In summary, by using the $I - \sigma$ diagram along with the velocity dispersion contour map restricted to specific intervals it was possible to separate the line broadening mechanisms. The kinematics in both galaxies is affected by stellar feedback, but in CTS 1020 the gravitational potential dominates, whereas UM 461 seems to be more susceptible to the energy injection from the stellar population.

The other diagnostic diagram that we used was the $V_c - \sigma$ diagram, which allows to detect systemic motions away or toward us. In order to find such correlations, we decided to use different statistical tests to separate independent components in this diagram.

The MClust analysis result of the eastern part of UM 461, shows two subcomponents with a weak, but measurable, correlation that points to a motion away from the observer. In the western knot of UM 461, the MClust analysis result also gives two subcomponents, one with weak correlation and the other with no measurable correlation. This analysis points that one region is moving away from us.

The MClust analysis of $V_r - \sigma$ diagram for CTS 1020 also reveals three regions, two having weak and moderate correlations. Those regions appear to reproduce the radial velocity map in Fig. 9f, revealing a weak motion toward us.

In summary, the $V_c - \sigma$ diagram analysis for both galaxies shows a correlation between $V_c$ and $\sigma$ compatible with systemic motions toward and/or away from the observer. The use of reconstructed data cubes, after a PCA decomposition, changes the shape of several previously low SNR profile. These changes are reflected in the $V_r - \sigma$ diagram in Fig. 16c.

Lagos et al. (2018) gave a baryonic mass of $1.76 \times 10^8 M_\odot$ for UM461. The relation between dynamical mass and baryonic mass for starburst galaxie from Bergvall et al. (2016) gives then an estimated dynamical mass of $3.15 \times 10^8 M_\odot$. With UM 461 data: $R=0.4\text{kpc}$ and $\sigma = 25 \text{ km.s}^{-1}$, we found a dynamical mass (using the same aproximation as Bergvall et al. (2016)) of $2.75 \times 10^8 M_\odot$. To reach the predicted dynamical mass, the mean velocity dispersion should be $27 \text{ km.s}^{-1}$.

8 SUMMARY AND CONCLUSIONS

In this work, we have studied the H ii galaxies UM 461 and CTS 1020 based on integral field spectroscopy (Gemini GMOS-IFU). Taking advantage of monochromatic, velocity and velocity dispersion maps, we embarque in a kinematical analysis using different diagnostic diagrams (like $I - \sigma$ and $V_r - \sigma$) to investigate the nature of the internal kinematics for both objects.

As mentioned before, velocity dispersion of ionized gas plays a major role in the H ii galaxies dynamics. The $L$ vs $\sigma$ relation, based on single measurements, is interpreted as gravity being the main mechanism causing the supersonic broadening of emission profiles (Chávez et al. 2014).

The main result of our study is that the kinematics of ionized gas of these two galaxies is different, but it also shows similarities. Differences come from the velocity and velocity dispersion maps themselves: in UM 461 no ordered motion is present, only velocity gradient; in CTS 1020 a disk like rotation pattern can be seen, even if a larger field of view is necessary to confirm it.

Velocity dispersion maps show the same differences: in UM 461 regions of low dispersion correspond to high intensity regions, and CTS 1020 shows high dispersion areas where the intensity is the highest and where intensity is low as well.
I – σ diagrams for both galaxies offer some differences. UM 461 diagram shows, according Moiseev & Lozinskaya (2012), signature of H II regions, constant velocity dispersion and high monochromatic emission, in both knots centers. It also shows the presence of turbulent diffuse gas. On the other hand, despite the fact that, in CTS 1020 case, is still possible to identify the turbulent diffuse gas surrounding the galaxy, high σ is related to high intensity and seems to decrease outwards, suggesting that σ is driven by virial motions.

Applying statistical methods, a closer analysis of the V – σ diagrams, shows that several independent regions with weak and moderate correlation are consistent with systemic motions toward or away the observer. When reported on a geographic map, these regions are consistent with low and high velocities on the velocity maps. In the case of CTS 1020, it might means that the rotating disk can also be interpreted as large regions animated of opposite motions. A large field of view will be needed in order to find out if the velocity field really represents a rotating disk in that case. Finally, we also performed a PCA analysis of the data cube in order to improve the SNR. Our results show that data have been improved where the SNR was low, but also show that PCA seems to have modified the shape of the reconstructed profiles, resulting in more symetrical ones.

ACKNOWLEDGMENTS

This work is Based on observations obtained at the Gemini Observatory, which is operated by the Association of Universities for Research in Astronomy, Inc., under a cooperative agreement with the NSF on behalf of the Gemini partnership: the National Science Foundation (United States), the National Research Council (Canada), CONICYT (Chile), Ministerio de Ciencia, Tecnología e Innovación Productiva (Argentina), and Ministério da Ciência, Tecnologia e Inovação (Brazil). MSC would like to thanks Instituto Nacional de Tecnologia - Astrofísica for its financial support. HP wants to thanks Casadinho CAPES/Cnpq project number 7916/2015. Authors warmly thanks A.L.B. Ribeiro for his help on the statistical analysis and the project number 552236/2011-0 for its financial support. HP ac-
knowledge the usage of the Nasa Extragalactic Database (http://ned.ipac.caltech.edu/) and R free software.

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