Hi observations of IC 10 with the DRAO synthesis telescope

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ABSTRACT

Hi observations of the nearby blue compact dwarf galaxy IC 10 obtained with the Dominion Radio Astrophysical Observatory synthesis telescope (DRAO), for a total integration of ∼ 1000 hours, are presented. We confirm the NW faint 21 cm Hi emission feature discovered in GBT observations. The Hi feature has an Hi mass of 4.7 × 10^5 M_☉, which is only ∼ 0.6% of the total Hi mass of the galaxy (7.8 × 10^7 M_☉). In the inner disk, the rotation curve of IC 10 rises steeply, then flattens until the last point where it rises again, with a maximum velocity of 30 km s^{-1}. Based on our mass models, the kinematics of the inner disk of IC 10 can be described without the need of a dark matter halo. However, this does not exclude the possible presence of dark matter on a larger scale. It is unlikely that the disturbed features seen in the outer Hi disk of IC 10 are caused by an interaction with M 31. Features seen from our simulations are larger and at lower surface density than can be reached by current observations. The higher velocity dispersions seen in regions where several distinct Hi features meet with the main core of IC 10 suggests that there is ongoing accretion.

Key words: techniques: interferometric; ISM: kinematics and dynamics; galaxies: dwarf; galaxies: Local Group; galaxies: individual: IC 10; dark matter

1 INTRODUCTION

Dwarf galaxies are fundamental laboratories used to constrain the impact that structural and intrinsic properties have on the evolution of galaxies. Investigating the physical processes occurring in dwarf galaxies is therefore crucial for understanding a wide range of astrophysical phenomena, from star formation mechanisms to the way galaxies are connected to their environment. Among the different dwarf galaxies, blue compact dwarf galaxies (BCDs) are the most fascinating and puzzling objects. While star forming dwarf galaxies, blue compact dwarf galaxies (BCDs) are the most efficient at transforming their gas into stars (Leroy et al. 2008), a different case is observed for BCDs. BCDs are known to be undergoing violent bursts of star formation (Sargent & Searle 1970; Meurer et al. 1994; Gil de Paz et al. 2003; Lee et al. 2004; Wu et al. 2006). However it remains unclear what mechanisms are responsible for the ignition of the star bursts in these systems.

Whilst studies have shown that gravitational interaction, mergers, or accretion can explain the burst of star formation in certain BCDs (Wilcots & Miller 1998; Noeske et al. 2001; Bekki 2008; Nidever et al. 2013; Cloet-Osselaer et al. 2014), the absence of nearby companions around most BCDs suggests that mergers or interactions are unlikely starburst triggers. This, however, does not completely rule out possible interactions with companions or Hi clouds that may be too faint to be detected and may have been missed in earlier studies of BCDs.

The neutral hydrogen atomic (Hi) gas has been known to be an ideal tracer for the starburst triggers in galaxies Taylor et al. (1993, 1995, 1996a,b). This is because external disturbances are detected easily in Hi 21 cm-line images in comparison to the optical images. From the Hi morphology, signatures of interactions and mergers can easily be seen in the form of bridges or tidal tails (Nidever et al. 2013). Bridges are often associated with early stages of mergers or on-going interactions while tidal tails are often linked to past close encounter events with other galaxies. In addition to this, progressive stages of interactions can be traced from Hi kinematical disturbances.

IC 10 (UGC 192) located at a distance of 0.7 Mpc (Hunter et al. 2012) is the only known BCD galaxy in the Local Group. Its proximity makes it an excellent candidate for exploring starburst triggers in BCD galaxies. IC 10 is located at low galactic latitude (l=118°.95, b=-3°.33) where the foreground reddening is expected to be large. In addi-
tion, the internal reddening of IC 10 may vary spatially due to its strong star-forming activity. Therefore, it is difficult to determine reliably the reddening and distance of IC 10 (Kim et al. 2000). The presence of so many WR stars (Mateo 1998) and high Hα luminosity suggest that the starburst in IC 10 must have occurred ∼ 10 Myrs ago (Richer et al. 2001). The basic parameters of IC 10 are given in Table 1. The first HI observations of IC 10 with the single dish 100 m Effelsberg telescope revealed HI extending 50′ in diameter (Huchtmeier 1979). Early interferometric HI observations showed that the outer regions of IC 10 were rotating counter-clockwise with respect to a regularly inner rotating disk (Shostak & Skillman 1989; Wilcots & Miller 1998). Manthey & Oosterloo (2008) obtained a deep HI mosaic of IC 10 using the Westerbork interferometer and found a complex and disturbed HI distribution covering almost 1 deg². HI observations with the Green Bank Telescope revealed a new extended faint feature stretching 1.3 degrees north-west of IC 10 (Nidever et al. 2013). Detailed analysis of these observations combined with high spatial resolution VLA data (LITTLE THINGS) showed that the HI disk of IC 10 is much more extended than previously reported (Ashley et al. 2014) if the faint features seen with the GBT are real (see Section 3.4).

Different mechanisms have been proposed to explain starburst triggers and the observed disturbed morphology and kinematics in IC 10. Shostak & Skillman (1989) suggested that the observed complex morphology of IC 10 could be the result of IC 10 colliding with the intergalactic medium. They, however, highlighted that given the similarity of IC 10 with other dwarf galaxies, it is likely that the HI observed in this galaxy is primordial gas which is still in a collapse phase. Wilcots & Miller (1998) analyzed high-resolution HI data of IC 10 and concluded that the observed extended and counter-rotating distribution of gas in IC 10 was due to accretion. They explained that the features seen in IC 10 correspond to what would be seen for a galaxy experiencing later stages of formation via the ongoing infall of primordial material. Recent HI studies of IC 10 suggest that an interaction or merger with another unknown low surface density dwarf galaxy is the most probable explanation for the observed morphology of this galaxy (Nidever et al. 2013; Ashley et al. 2014). However, Gerbrandy et al. (2015) argued that the lack of streams or shells, or any disturbances in the stellar component of IC 10 strongly indicates that it is unlikely that IC 10 has undergone an interaction with an unknown companion. Nidever et al. (2013) used a Gravitylab N-body integrator code to perform orbit calculations to determine if the origin of the new HI feature near IC 10 was due to an IC 10 – M 31 interaction. Their results show that the HI extension is inconsistent with the trailing portion of the orbit, making it unlikely that an M 31 – IC 10 tidal interaction can explain the origin of this feature. We will explore this further in Section 5.

The majority of published HI synthesis observations on IC 10 discuss the disturbed morphology and kinematics of this galaxy based on observations only. The orbital simulations done by Nidever et al. (2013) focused on the origin of the new HI feature and not on the entire disturbed morphology of IC 10. To advance our understanding on possible mechanisms responsible for the observed HI structure of IC 10, we have combined new DRAO HI observations with simulations. The DRAO observations allow us to study the extended HI morphology and kinematics while the simulations provide detailed investigation of possible interactions between IC 10 and M 31. The outline of this paper is as follows. In Section 2 we discuss the observations and data reduction. In Section 3 we present the results of the HI distribution of IC 10. In Section 4 we discuss the tilted ring and mass model results of the main disk of IC 10. Then in Section 5 we provide simulations to see if M 31 could be responsible of the outer HI structure of IC 10. The summary and conclusions of this work are given in Section 6.

### Table 1. Basic parameters of IC 10

| Parameter | Value |
|-----------|-------|
| Morphology | BCD³ |
| Right ascension (J2000) | 00:20:24.6α |
| Declination (J2000) | +59:17:30.0α |
| Distance (kpc) | 6.7μ |
| MHI (Mag) | −16.3μ |
| α (kpc) | 0.40 ± 0.03d |
| VHEL (km s⁻¹) | −348.0μ |
| Optical PA (°) | -38.0μ |
| Optical inclination (°) | 41.0μ |
| Total HI mass (M⊙) | 8.0 × 10⁶μ |
| Av (mag) | 4.3μ |
| Galactic latitude (°) | 118.95μ |
| Galactic longitude (°) | -3.33μ |
| proper motion (RA (km s²)) | -122 ± 31μ |
| proper motion (DEC (km s²)) | -57 ± 27μ |

**Notes.** Ref (a) de Vaucouleurs et al. (1991a); (b) Richer et al. (2001); (c) Ashley et al. (2014); (d) Hunter & Elmegreen (2006); (e) Hunter et al. (2012); (f) Schlegel et al. (1998); (g) Kim et al. (2009)

### Table 2. DRAO Synthesis Telescope observational set-up

| Obs. field data | Field center coordinates (J2000) | Beam parameter (arcsec) | 1σ Noise at field center (mJy/beam) |
|-----------------|---------------------------------|-------------------------|-------------------------------------|
| 20 Feb., 1997   | 0:20:23.1, +59:19:08.4          | 6.78 ± 58.98            | 13.2                                |
| 9 Sept., 2017   | 0:20:17.3, +59:22:14.0          | 67.63 ± 59.13           | 11.5                                |
| 9 Sept., 2017   | 0:20:17.3, +59:22:14.0          | 68.18 ± 59.98           | 11.1                                |
| 1 Oct., 2018    | 0:22:28.0, +60:25:09.0          | 66.19 ± 59.11           | 11.1                                |
| 5 Apr., 2019    | 0:16:12.8, +60:05:29.8          | 66.40 ± 58.97           | 11.2                                |
| 5 Apr., 2019    | 0:17:32.8, +59:49:35.6          | 68.69 ± 58.95           | 10.9                                |
| 5 Apr., 2019    | 0:14:49.1, +60:21:18.3          | 69.31 ± 59.39           | 11.0                                |

### Table 3. Observational parameters for the full resolution DRAO Synthesis Telescope mosaic

| Parameter | Value |
|-----------|-------|
| Total length of observation | 864 hrs (6 fields) |
| Integration length of archived data | 144 hrs (1 fields) |
| Frequency center of band | 1422.0643 MHz |
| Number of velocity channels | 256 |
| synthesized beam | 59'' x 68'' |
| Velocity resolution | 2.64 km s⁻¹ |
| Number of spatial pixels | 1024 |
| Pixel angular size | 18'' |
| 1σ RMS noise (single channel) | 0.8 Kelvin (5.3 mJy/beam) |
| Measured 3σ column density over 16 km s⁻¹ | 3.1 × 10¹³ cm⁻² |

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2 DRAO OBSERVATIONS AND DATA REDUCTION

The primary observations for this study were made in the 21 cm line of neutral hydrogen with the Synthesis Telescope at the DRAO. This telescope is an East-West interferometer consisting of seven 9 m diameter dishes spaced variously across a maximum baseline of 617.2 m. This longest baseline achieves a synthesized half-power beamwidth of $49\arcsec$ (EW) $\times 49\arcsec$/sin $\delta$ (NS) with uniform weighting, although in the HI line we chose natural weighting (a Gaussian taper in the $u, v$ plane) to increase the sensitivity at the slight expense of resolution ($58\arcsec \times 58\arcsec$/sin $\delta$). Further specifications and capabilities of the DRAO can be found in Landecker et al. (2000) and Kothes et al. (2010). Other observing frequencies of IC 10 were in a 30 MHz continuum band centered at 1420 MHz ($\lambda = 21$ cm), and a 2 MHz band at 408 MHz ($\lambda = 74$ cm). The telescope also produces fully calibrated and instrumentally-corrected Stokes U,Q,V polarization maps, observed in four 7.5 MHz-wide sub-bands centred at 1420 MHz; however the radio polarization and continuum data for IC 10 are not presented here.

Six full synthesis fields were observed on and immediately around IC 10, each 12 hours (per set of spacings) times 12 days. The spectrometer was set to a 2 MHz-wide band in the line with 256 channels spaced by $\Delta v = 1.65$ km s$^{-1}$ per channel. The band was centered on a heliocentric velocity of $v_{\text{hel}} = -350$ km s$^{-1}$. The synthesized beam of these observations is $59\arcsec \times 68\arcsec$, and the velocity resolution is 2.64 km s$^{-1}$. The bandwidth and these resolution parameters produce a 1$\sigma$-RMS noise in each (empty) channel of 1.5-1.7 K. To increase sensitivity to the extended HI disk of IC 10, another full-synthesis field with the same pointing centre and observing parameters was obtained from the DRAO archive (observed in 1997). Table 2 lists the field centers, synthesized beamwidths and typical RMS noise for the seven total individual fields (noise figures quoted are measured after continuum subtraction).

Prior to mosaicking the seven fields together, we perform standard data processing steps on each developed for the Canadian Galactic Plane Survey (described in Taylor et al. 2003). Channels that are free of line-emission are averaged at both the low and high velocity ends of the band to produce continuum-only maps, and a map that is linearly-interpolated at frequencies between these two is subtracted from each channel in the data cube. To calibrate the flux scale of each continuum-subtracted cube, we compare point sources in the mean of both continuum end-channel maps to those in the 30 MHz continuum map of each field (these maps are first CLEANed around the stronger sources). The observed 30 MHz wide continuum maps are flux calibrated against several strong sources observed by the ST (e.g. 3C 48, 3C 286; see Table 1 of Taylor et al. 2003, for sources and fluxes). An error-weighted mean of the flux ratio $S_{\text{120cont}}/S_{\text{Hi cont}}$ for all point-sources above a cut-off level (20 mJy beam$^{-1}$) is obtained; this sample is further trimmed by rejecting sources $\pm 2\sigma$ away from the mean. Typically, 20-30 sources remained in the sample for each field. The uncertainty introduced to the flux by this step is $\sim 5\%$.

Each synthesis field is trimmed to the half-power width of the primary-beam of the individual antennae ($107\arcsec \times 107\arcsec$), and corrected from the primary beam pattern prior to mosaicking. The seven fields were mosaicked together with each weighted proportionally to the inverse of their relative RMS noise, and points across the field are assigned a weight proportional to the primary-beam pattern squared. The final step was to recover missing spatial structures (aka “short-spacings”) that the DRAO ST is not sensitive to (larger than about 45$\arcsec$). We use the Effelsberg Hi Survey Winkel et al. (2016), a single-dish survey with a beam of 10.82 arcminutes and a noise per 1.29 km s$^{-1}$-wide channel of $\Delta T_B = 0.09$ K. Using this survey gives excellent spatial-frequency overlap with the DRAO ST; providing a smooth transition between structures imaged by the interferometer and the 100-m Effelsberg dish. We add these data together in the map-plane, first by smoothing ST maps to the Effelsberg beam, and then adding the difference between the corresponding EBHIS map and this smoothed ST map back to the high-resolution ST-only data. The resulting short-spacings-added map contains no negative “bowls” around any extended emission strong or weak down to the level of the noise, giving confidence not only in our simple map-plane approach to adding in structures but in our flux calibration as well. Once stacked the measured 1$\sigma$ noise at the centre of the final 7-field short-spacings-added mosaic is 5.3 mJy/beam, or $\pm 0.8$ K per (empty) channel for the full resolution of $59\arcsec \times 68\arcsec$. Table 3 shows the parameters for the final mosaic cube of IC 10.

3 HI DISTRIBUTION AND KINEMATICS OF IC 10

The HI maps of IC 10 were created using the HI source finding algorithm, SoFiA (Serra et al. 2015). The ability of SoFiA to search for emission on multiple scales while taking into account artifacts and variations in noise allow us to deal with the complex HI structure of IC 10 with much ease. The smooth + clip source detection algorithm was used to search for emission by setting a detection limit of 2$\sigma$ which corresponds to a column density limit of $10^{19}$ cm$^{-2}$. A detailed description of this software and how it is used is given in Serra et al. (2015).

3.1 The HI global profile

The HI global profile, derived from a primary beam corrected data cube is presented in Figure 1. We compare the DRAO global profile to the GBT (Nidever et al. 2013) and VLA LITTLE THINGS (Hunter et al. 2012) global profiles. The resulting profile is asymmetric with more HI around the southern extension ($\sim 300$ km s$^{-1}$ to $\sim 250$ km s$^{-1}$) where the HI is on scales $> 15'$ not seen by the VLA. From the profile, a mid-point velocity of $-339 \pm 6$ km s$^{-1}$ at 50% level is found, which is a better representation of the systemic velocity than the intensity weighted mean because of the asymmetry of the profile. This value is comparable to the value of $-338$ km s$^{-1}$ found by Nidever et al. (2013). The profile widths calculated at the 20 and 50 per cent levels of the peak flux density are $\Delta V_{20} = 96 \pm 3$ km s$^{-1}$ and $\Delta V_{50} = 61 \pm 3$ km s$^{-1}$. A total flux of 675 $\pm 6$ Jy km s$^{-1}$ is estimated from the global profile. The total HI mass is
calculated as
\[ M_{\text{HI}} = 2.36 \times 10^5 \left( \frac{D}{\text{Mpc}} \right)^2 \int FdV \]

where \( FdV \) is the source total flux in units of Jy km s\(^{-1}\) and \( D \) is the distance in Mpc. Adopting a distance of 0.7 Mpc (Hunter et al. 2012), a total HI mass of \((7.8 \pm 0.07) \times 10^7\) M\(_{\odot}\) is calculated. This mass is larger by \(\sim 36\%\) than the value of \((5.0 \pm 0.046) \times 10^7\) M\(_{\odot}\) measured from the VLA data (Ashley et al. 2014) and is smaller by \(\sim 1\%\) than the value of \((7.9 \pm 0.08) \times 10^7\) M\(_{\odot}\) measured from the GBT data (Nidever et al. 2013). All masses are calculated using our adopted distance. This result shows that no flux has been missed by the DRAO observations. This is because the compact configuration of DRAO is sensitive to extended HI emission that is missed by the VLA and detected with the single dish GBT.

3.2 HI distribution

The HI intensity map extracted from the natural weighted HI data cube is shown in Figure 2(a). As has been seen in previous HI interferometric observations (Shostak & Skillman 1989; Wilcots & Miller 1998; Ashley et al. 2014), the HI distribution of IC 10 is characterized by several distinct HI features. These features include a southern plume, a rotating arm, and spurs north-west and north-east of IC 10. It is important to note that although all these features were previously reported, the DRAO observations are sensitive to large scale structures and detect these features out to a much larger extent. For instance, the last VLA HI observations of IC 10 measure the southern plume out to 17\(\prime\) (Hunter et al. 2012) while our DRAO observations measure this feature out to 32\(\prime\). Figure 3 shows the total column density map of the central parts of IC 10 superposed on a WISE 3.4 \(\mu\)m band map, which is sensitive to light from the old stellar populations. The brightest HI peak coincides with the stars.

3.3 HI kinematics

The velocity field and dispersion maps of IC 10 are shown in Figure 2(b) and 2(c) respectively. As noted in previous HI observations, IC 10 is characterized by a distorted velocity field. The southern plume is seen to have velocities different from the rest of the galaxy. A closer look at the central region of the velocity field map shows that the central disk of IC 10 behaves like a rotating disk (see below, Figure 7(a)). On the other hand, the spurs and the southern plume are counter-rotating with respect to the central disk. The velocity dispersion of IC 10 varies from \(\sim 10\) km s\(^{-1}\) to \(\sim 35\) km s\(^{-1}\). High velocity dispersion is seen in regions where different velocity structures meet with each other (Figure 2(b)). This indicates that the southern plume, the west and east extensions are probably accreting on the main body of IC 10 as suggested by Wilcots & Miller (1998), and this could explain the recent starburst that occurred \(\sim 10\) Myr ago (Richer et al. 2001).

3.4 GBT new HI feature of IC 10

One of the aims of this study was to verify the existence of the NW faint 21 cm HI feature discovered in the GBT observations and detected at a column density \(N_{\text{HI}} \sim 7 \times 10^{17}\) cm\(^{-2}\) (Nidever et al. 2013). Verifying whether this feature is real or not is crucial for our interpretation of the HI data of IC 10. If this feature is an HI cloud it could explain the very disturbed and highly extended HI disk of IC 10 (through possible interaction, including tidal stripping and merging). If it is a new satellite galaxy of IC 10, the intermediate spatial resolution of DRAO will allow us to explore its kinematics and distribution, and look for more such clouds around IC 10.

Our DRAO observations are able to confirm the NW faint 21 cm HI emission feature discovered in the GBT observations. However, in order to be sure that the HI feature is real, our data had to be smoothed both in spatial and velocity resolution to increase the column density sensitivity. Figure 4a shows the integrated column density map of IC 10 at 3\(\prime\) spatial resolution and 10.35 km s\(^{-1}\) velocity resolution. The map was created by selecting the velocity range from -412 km s\(^{-1}\) to -388 km s\(^{-1}\). The 3\(\sigma\) column density limit at 3\(\prime\) resolution is \(4 \times 10^{18}\) cm\(^{-2}\). At this column density limit, we clearly resolve the Northern HI cloud seen in the GBT observations. Figure 4b and 4c shows the integrated column density and velocity field maps of the faint HI feature. The maps were created by selecting the region around the HI feature.

In order to examine our data at column densities comparable to the GBT limit, the DRAO data was smoothed to the GBT spatial resolution of 9\(\prime\). This allowed us to reach a 3\(\sigma\) column density limit of \(8 \times 10^{17}\) cm\(^{-2}\) thus revealing the northern extension (bridge between the new HI cloud and IC 10, see Figure 4d and 4e) that was not visible at 3\(\prime\) resolution. The length and width of the HI feature is found to be 0.9\(\prime\) and 0.3\(\prime\) respectively. Adopting a distance of 0.7 Mpc, an HI mass of \(4.7 \times 10^8\) M\(_{\odot}\) is measured.

As discussed in (Nidever et al. 2013), possible origins of the northern extension might include tidal or ram pressure, cold accretion, or stellar feedback to mention just a few. Looking at our data, the northern extension could either be
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Figure 2. Moment maps of IC 10 created using the SoFiA software. Figure 2(a) shows the intensity map, Figure 2(b), the velocity field map, Figure 2(c) is the dispersion map, and Figure 2(d) is the position-velocity diagram of IC 10 along the major axis. The contours are at 1, 2, 4, 8, 16 × 3σ, where 1σ = 0.0053 Jy/beam.

4 CENTRAL HI DISK OF IC 10

From the velocity field map in Figure 7(a), it is clear that the central region of IC 10 is a regularly rotating disk. In that sense, the rotation velocities of this region can be determined. To separate the main disk from the rest of the galaxy, we first created regions in each channel around emission perceived to be associated with the disk (based on morphology and velocity). From this, a new cube consisting of only the selected emission was created. The MOMNT task in AIPS was used to derive the moment maps of the central part of IC 10. A second check in determining the extent of the central region was done using the dispersion map. For a regularly rotating disk, we expect the dispersion velocities to be high at the center and decrease uniformly with increasing radius. Using this approach, a mask was created around the velocity dispersion map excluding outer regions showing non-uniform dispersion values. This region was then applied to the intensity and velocity field maps. The final intensity, velocity field, and dispersion map of the central disk of IC 10 are shown in Figure 7(d), 7(a) and 7(e). A total flux of
The synthesized beam is shown in the bottom left corner. Density contours are at 1, 2, 3, 4, 5, 6, 7, and 8 × 10²⁰ cm⁻². The synthesized beam is shown in the bottom left corner. Density contours are at 1, 2, 3, 4, 5, 6, 7, and 8 × 10²⁰ cm⁻².

196.2 ± 2.3 Jy km s⁻¹ is measured from the intensity map, corresponding to an Hα mass of (2.300 ± 0.026) × 10⁷ M⊙ adopting a distance of 0.7 Mpc. This corresponds to ∼ 33% of the total Hα mass of the complex. The dispersion velocities of the central region vary from ∼ 30 km s⁻¹ in the inner regions to ∼ 10 km s⁻¹ in the outer regions.

4.1 Tilted-ring modeling

We modeled the kinematics of the central part of IC 10 using the velocity field map shown in Figure 7(a). The rotation curve was derived by means of a tilted-ring model. The tilted ring model assumes that the gas rotates as a set of concentric rings, and that each ring can be described by the following dependent quantities: rotation velocity (Vrot), the systemic velocity (Vsys), the central position of the ring (x, y), the inclination (i), and the position angle (PA). The line of sight velocity at any position V(x, y) on a ring can be expressed as

\[ V(x, y) = V_{sys} + V_{rot}\sin(i)\cos(\theta) \]  

where \( \theta \) is an angle from the major axis of the galaxy plane and is related to the PA by the following relation:

\[ \cos(\theta) = \frac{-(x - x_0)\sin(PA) + (y - y_0)\cos(PA)}{r} \]  

\[ \sin(\theta) = \frac{-(x - x_0\cos(PA)) - (y - y_0\sin(PA))}{r\cos(i)} \]  

where \( r \) is the radius of the ring in the galaxy plane. The GIPSY task ROTCUR (Begeman 1989) was used to fit tilted ring models to the Hα velocity field along rings that are spaced by half the spatial resolution, i.e., 32″ in this case. A [cos\( \theta \)] weighting function and an exclusion angle of ± 10° about the minor axis were applied to the data points to give less weight to pixels close to the minor axis. First, we carried out ROTCUR with all initial parameters kept free (PA, i, x, y, Vsys, and Vrot). Assuming that the kinematical center and Vsys do not vary from ring to ring, their mean values were determined from the first model and kept fixed throughout the fitting process. Different iterations were made either keeping PA or inclination or both fixed to determine the best fit model. After obtaining a satisfactory model for both sides, we made ROTCUR models of the approaching and receding sides separately.

4.2 Results of the tilted ring fit

The results of the tilted ring model to the velocity field are shown in Figure 6 and 7. The resulting kinematical parameters are presented in Table 4. The Hα rotation curve of the central disk of IC 10 is measured out to 0.81 kpc. The rotation curve of IC 10 is similar in form to those of other dwarf galaxies (Namumba et al. 2017, 2018) having a linearly rising (solid body) inner portion and then turning over to become approximately flat. On the other hand, the slope of the inner part of IC 10 is ∼ 3 times steeper (65 km s⁻¹/kpc) than what has been derived for most dwarf galaxies. Namumba et al. (2017, 2018) calculates the inner slopes of 21, 21, and 13 km s⁻¹/kpc for NGC 6822, Sextans A and B while Meurer et al. (1996) and Meurer et al. (1998) derive the inner slopes of 25 km s⁻¹/kpc and 22 km s⁻¹/kpc for BCD galaxies NGC 2915 and NGC 1705. We find the kinematical Vsys = -351 ± 1.8 km s⁻¹, this value is different from the Vsys of -339 ± 6 km s⁻¹ derived from the global profile due to the asymmetry. A mean PA = 65° ± 4° and i = 47° ± 6° are found. These values are in agreement with the results of Oh et al. (2015) who measured Vsys = -348 km s⁻¹, PA ~ 60°, and i ~ 48°. Shostak & Skillman (1989) measured a Vsys = -352 km s⁻¹ and slightly lower values of i = 40° and PA = 50°. Figure 9 compares the IC 10 DRAO rotation curve with the rotation curve derived by Oh et al. (2015) from high resolution VLA LITTLE THINGS data. The two curves agree well within the errors.

To check the reliability of our derived kinematical parameters, we built a model velocity field (7(b)) using the best-fitting values and compared this to the observed velocity field (Figure 7(a)). The two maps agree well with small deviations. The residual map (Figure 7(c)), which is the difference between the observed and model velocity field does not show any large scale deviations which implies that the derived velocity field model is in good agreement with the observed velocity field. The mean value of the residual map is 1.0 km s⁻¹ with a rms spread of 6.2 km s⁻¹. The residual velocity field shows some large scale structure in the sense that the south-east part shows negative residuals and the north and west parts predominantly positive residuals which are consistent with the velocity field in Figure 7. This indicates that the inner disk could be associated with non circular motions. Figure 8 shows the rotation curve overlaid on a position-velocity (PV) diagram obtained along the major axis.

The errors on the final rotation curve are calculated as the quadratic sum of the dispersion in each ring and half the

Figure 3. Integrated Hα column density contours of IC 10 from the DRAO data overlaid on a WISE 3.4 μm map. The Hα column density contours are at 1, 2, 3, 4, 5, 6, 7, and 8 × 10²⁰ cm⁻².
Figure 4. (a) Integrated column density map of the H\textsubscript{i} feature at 3′ resolution for the velocity range $-412$ km s$^{-1} \leq -388$ km s$^{-1}$. The $3\sigma$ column density limit at 3 arcmin is $4 \times 10^{18}$ cm$^{-2}$. At this column density, the H\textsubscript{i} cloud is clearly detected. (b) and (c) integrated column density and velocity field maps of the H\textsubscript{i} feature ($-2.65 \leq$ Galactic Latitude $\leq -2.3$, $118.3 \leq$ Galactic Longitude $\leq 118.7$). The contours in (b) are $4, 6, 7 \times 10^{18}$ cm$^{-2}$. (d) and (e) integrated column density and velocity field maps of the H\textsubscript{i} feature at the GBT spatial resolution (9′). The $3\sigma$ column density limit at 9′ is $8 \times 10^{17}$ cm$^{-2}$. The H\textsubscript{i} column density contours in (d) are at $8.2, 16.4, 32.8$ and $65.6 \times 10^{17}$ cm$^{-2}$. A “bridge-companion” structure between the H\textsubscript{i} cloud and IC 10 is visible at column densities $\sim 8 \times 10^{17}$ cm$^{-2}$. 

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5. Comparison of the H\textsubscript{i} global profile of IC 10 central region (solid line) and the outer region of IC 10 (dash-dotted line).

\begin{equation}
\Delta V = \sqrt{\sigma^2 + \left(\frac{|V_{\text{app}} - V_{\text{rec}}|}{2}\right)^2}
\end{equation}

The rotation velocities were corrected for the asymmetric drift. Following the procedure used by Côté et al. (2000), the corrected rotation velocities are given by:

\begin{equation}
V_{c}^2 = V_{\text{rot}}^2 - 2\sigma^2 \frac{\delta \sigma}{\delta \ln R} - \sigma^2 \frac{\delta \ln \Sigma}{\delta \ln R}
\end{equation}

Table 4. Radial H\textsubscript{i} distribution and kinematical parameters of IC 10.

\begin{tabular}{cccccccc}
Radius [arcsec] & $\Sigma_g$ [M$_\odot$ pc$^{-2}$] & $\sigma$ [km s$^{-1}$] & $V_{\text{rot}}$ [km s$^{-1}$] & $\Delta V$ [km s$^{-1}$] & $V_{\text{corr}}$ [km s$^{-1}$] & $V_c$ [km s$^{-1}$] \\
\hline
0.0 & 9.4 & 13.7 & 0.0 & 0.0 & 0.0 & 0.0 \\
16 & 9.1 & 13.2 & 3.0 & 0.7 & 1.8 & 4.9 \\
48 & 9.3 & 12.8 & 14.2 & 3.2 & 0.6 & 14.8 \\
80 & 9.9 & 12.4 & 22.5 & 3.2 & 0.3 & 22.8 \\
112 & 9.7 & 12.5 & 25.6 & 4.8 & 0.8 & 26.4 \\
144 & 9.0 & 12.7 & 27.4 & 5.3 & 0.7 & 28.1 \\
176 & 8.8 & 12.4 & 27.6 & 3.9 & 2.1 & 29.7 \\
208 & 9.7 & 13.3 & 29.7 & 4.5 & 3.8 & 33.5 \\
240 & 10.6 & 13.2 & 31.1 & 4.8 & 2.3 & 33.4 \\
\end{tabular}

Notes. Column (1) gives the radius, column (2) the surface densities, column (3) the velocity dispersion, column (4) the observed rotation velocities, column (5) the errors of those velocities, column (6) correction from asymmetric drift, and column (7) the corrected velocities used for the mass models.

4.3 Mass modeling

The rotation velocity is a direct reflection of the gravitational potential of the galaxy, and can therefore be used to derive the total distribution of matter. The gravitational potential is the sum of the individual mass components in each galaxy. Expressed in velocities, this sum becomes:

\begin{equation}
V_{\text{rot}}^2 = V_g^2 + V_d^2 + V_h^2
\end{equation}

with $V_{\text{rot}}$ being the observed total rotation velocity, $V_g$ the contribution of the gas disk to the total rotation curve, $V_d$ the contribution of the stellar disk and $V_h$ the contribution of the dark matter halo component.

4.3.1 Stellar and gas component

The contribution of the gaseous disk was computed using the H\textsubscript{i} surface density profile shown in Figure 10. The profile was derived from the H\textsubscript{i} column density map using the GIPSY task ELLINT and applying the kinematical parameters derived from the tilted ring fit. The H\textsubscript{i} surface dis-
DRAO observations of IC 10

Figure 7. Maps of the central disk of IC 10: Observed velocity field 7(a), model velocity field map 7(b), residual map 7(c), intensity map 7(d), and velocity dispersion map 7(e). The observed and model velocity field contours run from -370 to -330 km s$^{-1}$ in steps of 5 km s$^{-1}$. The white star in Figure 7(a) represents the position of the kinematical center.

distribution was then multiplied by a factor of 1.4 to account for helium and other metals. The gas surface density profile were then converted to the corresponding gas rotation velocities assuming the gas component is mainly distributed in a thin disk. This was done using the gipsy task ROT-MOD. We used the WISE 3.4µm surface brightness profile to characterize the stellar distribution in IC 10. The 3.4µm WISE band traces light from the old stellar population and therefore is an effective measure of stellar mass. The surface brightness profile in mag arcsec$^{-2}$ was converted into luminosity density profile in units of L$_{\odot}$ pc$^{-2}$ and then to mass density using the expression

$$\Sigma[M_\odot pc^{-2}] = (M/L)_{3.4} \times 10^{0.4 \times (\mu_{3.4} - C_{3.4})}$$

where $\mu_{3.4}$ is the stellar brightness profile, $(M/L)_{3.4}$ is the mass to light ratio in the 3.4µm WISE band, and $C_{3.4}$ is the...
4.3.2 Dark matter models

We have considered two different models to study the properties of dark matter in IC 10: the Navarro Frenk and White (NFW) (Navarro et al. 1997) (NFW) and the pseudo-isothermal (Begeman et al. 1991) (ISO) models. The NFW profile is derived from the results of dark matter only cosmological simulations performed within the frame of the ΛCDM theory. The density $\rho_{\text{NFW}}$ is given by

$$\rho_{\text{NFW}}(r) = \frac{\rho_s}{\left(\frac{r}{r_s}\right)^2 \left(1 + \frac{r}{r_s}\right)^2},$$

(10)

where $\rho_s$ and $r_s$ are the characteristic density and scale radius of the NFW halo. The NFW halo rotation curve is given by

$$V(r) = V_{200} \left[\log(1+cx) - cx/(1+cx) \right]^{1/2},$$

(11)

where $c = r_{200}/r_s$ is the concentration parameter, $x = r/r_{200}$, and $V_{200}$ is the characteristic velocity. The radius $r_{200}$ is the radius where the density contrast with respect to the critical density of the universe exceeds 200, roughly the virial radius.

The ISO model results from the shape of the observed rotation curves, and models the halo as a central constant-density core. The form of this core-like halo is given by:

$$\rho_{\text{ISO}}(r) = \frac{\rho_0}{1 + \left(\frac{r}{r_e}\right)^2},$$

(12)

where $\rho_0$ is the central density and $r_e$ is the scaling radius. The corresponding halo rotation curve is given by

$$V(r) = 4\pi G \rho_0 r_e^2 \left[1 - \frac{r_e}{r} \arctan\left(\frac{r}{r_e}\right)\right].$$

(13)

4.3.3 Mass modeling results

The results of the mass modeling of IC 10 are summarized in Figure 11 and Table 5. The GIPSY task ROTMAS was used to decompose the observed rotation curve into luminous and dark matter components. The inverse squared weighting of the rotation curve data points with their uncertainties were used during the fitting. The $M/L$ value of 0.6 derived from Equation 9 was too large to fit the stellar component of IC 10, therefore we used the best fitting model by letting $M/L$ freely vary. It can be seen from Figure 11 that the ISO model reproduces better the observed rotation curve of the inner disk of IC 10 with a reduced $\chi^2$ value of 1.0. However, a $M/L$ of 0.04 ($\sim 15$ times smaller than predicted from the WISE infrared color) derived from this fit is too small to make physical sense. On the other hand, the NFW

Figure 8. Position velocity diagram of IC 10 central regions with the projected rotation curve over plotted. The dotted grey lines represent the centre of the galaxy and the systemic velocity. Superimposed is the rotation curve derived from the tilted ring model, corrected for the inclination of a slice along the galaxy major axis.

Figure 9. Comparison of the IC 10 DRAO rotation curve (red circles) with the analysis by Oh et al. (2015) (green circles). The black arrow indicates the region used in the Oh et al. (2015) analysis.

Figure 10. HI surface density profile of IC 10 derived from GIPSY task ELLINT.
Table 5. Results for the Mass Models of IC 10. The densities have the units of $10^{-3}\,M_\odot\,pc^{-3}$ and the radii are in units of kpc.

| Model   | $\chi^2_{\text{red}}$ | $\rho_0$ | $r_c$ | $\chi^2_{\text{red}}$ | $V_{\text{rot}}$ (km s$^{-1}$) |
|---------|---------------------|----------|-------|---------------------|-------------------------------|
| ISO     | 1.00                | 476.33   | 0.21  | 0.04 $\pm$ 0.04     | 0.04 $\pm$ 0.04              |
| NFW     | 1.60                | 852.42   | 0.03  | 0.11 $\pm$ 0.02     | 0.23 $\pm$ 0.07              |
| no-DM   | 2.2                 | 0.60     | 0.07  | 0.17 $\pm$ 0.08     | 0.21 $\pm$ 0.07              |

The difference between the two models is seen in the inner most part where the ISO model fits better than the NFW model. The large errors derived for the NFW fitted parameters (see Table 5) suggest that this model does not produce a good fit to the observed rotation curve. Moreover, the value of the concentration parameter $c$ found is unphysical: $c = 1$ means no collapse and $c < 1$ is impossible in the $\Lambda$CDM context (de Blok et al. 2008). The bottom panel of Figure 11 shows the results of the mass model fit without a dark matter component. Although a larger $\chi^2$ value of 2.2 is derived, it is clear that the kinematics of the inner disk of IC 10 can be reproduced without the need of a dark matter halo.

In this case, a M/L of 0.17 $\pm$ 0.08 is obtained. This value is closer to a M/L of 0.2 expected at the lower end for most dwarf galaxies as derived by Lelli et al. (2016). It is important to note that this result does not exclude the possibility that dark matter may be present on larger scales in IC 10. Oh et al. (2015) derived their mass model fit of IC 10 using high resolution VLA data. By fitting the inner disk out to $\lesssim 0.57$ kpc (see black arrow in Figure 9), they derived lower $\chi^2$ values of 0.23 and 0.07 for the NFW and ISO respectively with the stellar component dominating the gravitational potential at most radii. Comparing with the results of other BCDs from the literature, Lelli et al. (2012a) and Lelli et al. (2012b) showed that baryons may dominate the gravitational potential in the inner regions of UGC 4483 and I Zw 18, with the stellar component contributing $\sim 50\%$ of the observed rotation curve of UGC 4483. This could suggest, as from our result of IC 10, that the kinematics of the inner disks of most BCDs can be described without a dark matter halo.

5 NUMERICAL SIMULATIONS

The origin of the stream-like features seen in IC 10 has been widely discussed (see Nidever et al. (2013); Ashley et al. (2014) and references therein). In general, these discussions focus on whether they are caused by an interaction with M 31 or whether they arise from dwarf-dwarf interactions or some other trigger. In particular Nidever et al. (2013) compared the Northern Extension to 1000 possible orbits and concluded that the origin of that feature is not due to an interaction with M 31. However, streams do not quite follow the orbits of their progenitors (Sanders & Binney 2013). Thus, it is possible that the separation of the Northern Extension from the possible orbits of IC 10 in Fig. 2 of Nidever et al. (2013) may be due to the tidal evolution. To test this possibility for both the Southern Plume and the Northern Extension, we have run a suite of simulations of possible IC 10 – M 31 interactions.

The parameter space of the IC 10 – M 31 system is quite large. It includes the individual galaxy properties as well as the relative geometry between the two systems. While the system has been studied in detail, the uncertainties in these parameters allow for quite different orbital histories. In this work we have focused on the effects of uncertainties in IC 10’s proper motions. For simplicity, we run nine simulations, where the only difference is the proper motion vector. While these are representative of the orbits allowed by IC 10’s tangential motion, it is important to be cautious when interpreting the results of these simulations.

We have generated the initial conditions (ICs) for each galaxy using the GALACTICS code (Kuijken & Dubinski 1995; Widrow et al. 2008; Deg et al. 2018). The version of the code given in Deg et al. (2018) can generate equilibrium models with a bulge, two stellar disks, a gas disk, and a dark halo. Once the ICs for M 31 and IC 10 are determined, the combined system is evolved using the GADGET-2 smoothed particle hydrodynamics code (Springel 2005).
The GALACTICS code generates equilibrium models using a Sersic bulge, two exponential stellar disks, an exponential gaseous disk, and a double power law halo. Prugniel & Simien (1997) found that the density that gives rise to a gaseous disk, and a double power law halo. Prugniel & Simien (1997) found that the density that gives rise to a Sersic profile is

$$\rho_b(r) = \rho_{b,0} \left( \frac{r}{R_d} \right)^{-\frac{n}{n+4}} \exp \left( -\frac{(r/a)^{1/n}}{\bar{R}_d} \right),$$

(14)

where \( r \) is the spherical radius and \( p = 1 - 0.6097/n + 0.05563/n^2 \). However, GALACTICS parameterizes the bulge with a scale velocity, \( \sigma_b \), given by

$$\sigma_b = [4\pi m_0^{(n-2)}(n(2-p))^{3/2} \rho_{b,0}]^{1/2}.$$

(15)

The exponential stellar disks have a density of

$$\rho_{d}(R,z) = \frac{M_d}{4\pi R_d^2} e^{-\left(\frac{R}{R_d}\right)\sech^2 \left(\frac{z}{z_d}\right)} C(R; R_d, \delta R_d),$$

(16)

in cylindrical coordinates where \( M_d \) is the disc mass, \( R_d \) is the disc scale length, \( z_d \) is the disc scale height, and \( C(R; R_d, \delta R_d) \) is a truncation factor given by

$$C(R; R_d, \delta R_d) = \frac{1}{2} \text{erfc} \left( \frac{R - R_d}{\sqrt{2} \delta R_d} \right).$$

(17)

The double-power-law halo density is

$$\rho(R) = \frac{2^{2-\alpha} - \sigma_b^2}{4\pi R^2} u^\alpha (1 + u)^{3-\alpha} C(r; r_1, \delta r_1),$$

(18)

where \( \sigma_b \) is a scale velocity, \( u = r/r_h \), \( r_h \) is a scale radius, \( \alpha \) and \( \beta \) are the inner and outer slopes respectively, \( C(r; r_1, \delta r_1) \) is another truncation factor.

M 31 is the most well studied galaxy after the MW. As such, it has been constrained quite well by a variety of observations. We have chosen to use the isothermal model found by Chemin et al. (2009) to build the M 31 ICs. The specific parameters of this model are listed in Table 6. For IC 10, we modified the NFW mass model to a GALACTICS analogue with the same general rotation curve, gas mass, and scale lengths. The parameters for this model are also listed in Table 6.

### 5.2 Geometry

M 31 is located at \((783 \text{ kpc}, 121.2^\circ, -21.6^\circ)\) with a radial velocity of \( v_r = -300 \text{ km s}^{-1} \) (de Vaucouleurs et al. 1991b). van der Marel et al. (2012) utilized HIST observations to determine that the proper motions of M 31 are \((-76.3, 45.1) \text{ km s}^{-1}\) in RA and Dec. IC 10 is located at \((794 \text{ kpc}, 119^\circ, -3.3^\circ) \) (Hunter et al. 2012) with a radial velocity of \( v_r = -348 \text{ km s}^{-1} \) (Ashley et al. 2014). Unlike many dwarf galaxies, there are measurements of IC 10’s proper motions. Brunthaler et al. (2007) used the Very Large Baseline Array to see the movement of the galaxy relative to background masers. They found IC 10’s proper motions to be \((-122 \pm 31, 97 \pm 27) \text{ km s}^{-1}\) in RA and Dec.

### 5.3 Simulations

Determining the initial relative phase-space coordinates for simulation of an IC 10 - M 31 system that will end up with IC 10 at the current position and velocity relative to M 31 is not a trivial task. Our solution is to essentially run each simulation twice. First, M 31 is placed at the origin and the model IC 10 system is placed at the current phase-space coordinates. With IC 10 orbiting around M 31, the system is then evolved backwards for 6 Gyr. The center-of-mass and velocity of IC 10 in the final snapshot of this first simulation is used as the initial phase-space coordinates for the forwards simulation. The IC 10 system in the final snapshot of the forwards simulation is used for our analysis. This results in a system that is close to the observed phase-space coordinates of IC 10, with some small differences caused by dynamical friction and the disruption of the IC 10 model.

Given the relatively large uncertainty in the proper motions of IC 10, we ran a set of nine simulations exploring the range of possible tangential velocity vectors. Each simulation has \(1.6 \times 10^6\) M 31 particles broken up into \(2 \times 10^5\) gas particles, \(3 \times 10^5\) disk particles, \(10^6\) bulge particles, and \(10^6\) halo particles, and \(3 \times 10^5\) IC 10 particles, with \(5 \times 10^4\) disk particles, \(2 \times 10^5\) IC 10 particles. Each simulation was evolved for 6 Gyr using the Gadget 2 code with a softening length of 0.05 kpc. The evolution time was chosen to give IC 10 enough time to complete at least one orbit.

Figure 12 shows mock observations of the IC 10 gas disk at the final time step of each simulation. These observations are made using 120 arcsec pixels with a 300 arcsec beam. Most of the systems do not show clear tidal features other than a cloud of disrupted particles around the central regions. However, the simulation with \((\mu_{\alpha} + \Delta_{\alpha}, \mu_{\delta} + \Delta_{\delta})\) shows a clear tidal stream. Therefore, there are at least some possible orbits for IC 10 that can produce tidal features.

The tidal feature seen in \((\mu_{\alpha} + \Delta_{\alpha}, \mu_{\delta} + \Delta_{\delta})\) (top right of Fig. 4.12) is quite interesting. It is much larger than the stream-like feature in the HI disk of IC 10. Moreover, it is a very low surface-density feature. To investigate this in greater detail, Figure 13 is a mock image with the same pixel scale and column density as the DRAO observations. To be clear, the image is limited to a column density of \(6.9 \times 10^{18} \text{ cm}^{-2}\), corresponding to a surface density of \(0.055 \text{ M}_{\odot}\text{pc}^{-2}\). Any pixel values lower than this limit are artificially set to zero. With these limits and at this scale, the image does not show strong evidence of a tidal feature as the extended tidal tails lies below the detection limit.

These results suggest that it is possible that IC 10 is on an orbit that allows for a disruption by M 31. However, the features from such a disruption are more extended than those observed. Moreover they are at a lower surface density than can be reached by current observations. Thus, it is unlikely that the actual features seen in the HI disk of IC 10 are caused by the interaction with M 31 as suggested by Nidever et al. (2013).

It is important to note that these conclusions have been reached using a limited number of simulations. While these are representative of possible orbital histories for IC 10, there is a large area of parameter space that we have yet to explore. We have not included the potential of M33, which may affect IC 10’s orbital history. Nor have we varied the M 31 or IC 10 models, or explored the effects of uncertainties in distance or radial velocities.

Nonetheless, the results are quite interesting and suggest that further observations that reach to lower column densities be carried out. While the currently observed fea-
Table 6. Summary of the model parameters.

| Parameter                      | Units | M 31 | IC 10 |
|--------------------------------|-------|------|-------|
| Halo scale velocity: \( \sigma_h \) | km s\(^{-1}\) | 390  | 31    |
| Halo scale radius: \( R_h \)    | kpc   | 5.1  | 2     |
| Inner slope: \( \alpha \)       |       | 0    | 1     |
| Outer slope: \( \beta \)       |       | 3    | 3     |
| Halo Truncation: \( r_t \)     | kpc   | 100  | 8     |
| Halo Truncation Length: \( \delta r_t \) | kpc | 2    | 3     |
| Disk mass: \( M_d \)           | \( 10^9 M_\odot \) | 59.  | 0.12  |
| Disk scale length: \( R_d \)    | kpc   | 5.6  | 0.3   |
| Disk truncation: \( R_t \)      | kpc   | 25   | 1.1   |
| Disk truncation length: \( \delta R_t \) | kpc | 3    | 0.1   |
| Gas mass: \( M_g \)            | \( 10^9 M_\odot \) | 10.  | 0.12  |
| Gas scale length: \( R_g \)     | kpc   | 8.5  | 0.9   |
| Gas Temperature: \( T \)        | K     | \( 10^4 \) | \( 10^4 \) |
| Gas truncation: \( R_{g,t} \)   | kpc   | 40   | 4     |
| Gas truncation length: \( \delta R_{g,t} \) | kpc | 2    | 0.9   |
| Bulge Sérsic index: \( n \)    |       | 1.1  | -     |
| Characteristic bulge velocity: \( \sigma_b \) | km s\(^{-1}\) | 250  | -     |
| Bulge scale length: \( R_b \)   | kpc   | 1.3  | -     |

Figure 12. Mock images of the final state of the IC 10 gas disk in the nine simulations. The labels indicate the proper motions used to determine the initial conditions. The maps use a logarithmic surface density. The axes are in units of degrees.

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is important to use the stream simulations rather than the impressive suite of orbits used in Nidever et al. (2013) due to the difference between streams and orbits.

6 SUMMARY

We have analyzed \(\sim1000\) hours of DRAO H\textsc{i} observations of the blue compact dwarf galaxy IC 10 combined with simulations to study the H\textsc{i} morphology and kinematics, and investigate if an interaction of IC 10 with M 31 can reproduce the observed H\textsc{i} features we see in the outer regions of IC 10. The main outcome of this study are:

(i) We are able to verify the faint H\textsc{i} feature previously reported from GBT observations at a column density limit \(\sim 8 \times 10^{17}\) cm\(^{-2}\). In order to further carry out detailed kinematical analysis on the H\textsc{i} feature, there is a need for high sensitivity high resolution H\textsc{i} observations.

(ii) The compact configuration of the DRAO has allowed us to detect the extended H\textsc{i} disk of IC 10 further than previous H\textsc{i} interferometric studies. The H\textsc{i} mass of \(7.8 \times 10^7\) M\(_\odot\) derived from our DRAO data is comparable to the H\textsc{i} mass derived from the single dish GBT data. We detect \(\sim 33\%\) more H\textsc{i} mass than the VLA LITTLE THINGS data.

(iii) The rotation curve of IC 10 is similar in form to those of other dwarf galaxies (Namumba et al. 2017), having a linearly rising (solid body) inner portion and then turning over to become approximately flat. On the other hand, the slope of the inner part of IC 10 is \(\sim 3\) times steeper (65 km s\(^{-1}\)/kpc) than what has been derived for most dwarf galaxies. Namumba et al. (2017, 2018) calculates the inner slopes of 21, 21, and 13 km s\(^{-1}\)/kpc for NGC 6822, Sextans A and B while Meurer et al. (1996) and Meurer et al. (1998) derive the inner slopes of 25 km s\(^{-1}\)/kpc and 22 km s\(^{-1}\)/kpc for BCD galaxies NGC 2915 and NGC 1705. We derive a mean \(V_{sys} = -351 \pm 1.8\) km s\(^{-1}\), PA = 65\(\pm\)4\(^\circ\), and \(i = 47 \pm 6\(^\circ\), these values are consistent with the literature.

(iv) We ran mass models with a dark matter halo component. A M/L of 0.04 derived from the ISO fit is too small and does not make physical sense. On the other hand, the large errors derived for the NFW fitted parameters and the nonphysical small value of the concentration parameter c suggest that this model is not suitable to explain the mass distribution of the inner disk of IC 10. Although a no dark matter model has a slightly higher reduced \(\chi^2\), we find that we can represent the kinematics of the inner disk of IC 10 without the need of a dark matter halo, which does not exclude that dark matter may exist on a larger scale in this galaxy.

(v) It is unlikely that the H\textsc{i} features observed in IC 10 are caused by an interaction with M 31. The disruptions seen in our simulations are at lower densities and larger than those observed. We think that, as suggested by Wilcots & Miller (1998), the H\textsc{i} extensions with different kinematics seen south, east and west of the main core of IC 10 may be the result of accretion, as suggested by their counter-rotation and by the increase in velocity dispersion observed at the point of contact of those regions with the inner regular disk. The accreted material might be coming from the low column density H\textsc{i} gas that is not visible to the sensitivity of our existing telescopes.

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