HI observations of Sextans A and B with the SKA pathfinder KAT-7

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ABSTRACT

HI observations of the Local Group dwarf irregular galaxies Sextans A and B, obtained with the Karoo Array Telescope (KAT-7) are presented. The KAT-7 wide field of view and excellent surface brightness sensitivity allows us to verify the true HI extent of the galaxies. We derive HI extents of 30′ and 20′ and total HI fluxes of 181 ± 2.0 Jy km s−1 and 105 ± 1.4 Jy km s−1 for Sextans A and B respectively. This result shows clearly the overestimate of the HI extent and total flux of 54′ and 264 Jy km s−1 reported for Sextans A using the Effelsberg observations. Tilted ring models allow us to derive the rotation curves (RCs) of Sextans A and B out to 550″ (∼3.5 kpc) and 650″ (∼4 kpc) respectively. The RCs of the two galaxies are seen to decline in the outer parts. The dark matter distribution in Sextans A is better described by the pseudo-isothermal halo model when a M/L ratio of 0.2 is used. For Sextans B, the mass model fits are not as good but again an isothermal sphere with a M/L of 0.2 represents best the data. Using the MOdified Newtonian Dynamics (MOND), better fits are obtained when the constant a0 is allowed to vary. The critical densities for gravitational instabilities are calculated using the Toomre-Q and cloud-growth based on shear criterion. We find that in regions of star formation, the cloud growth criterion based on shear explains better the star formation in both Sextans A and B.

Key words: techniques: interferometric; ISM: kinematics and dynamics; galaxies: dwarf; galaxies: Local Group; galaxies: individual: Sextans A & B; dark matter

1 INTRODUCTION

The neutral hydrogen (HI) component of the interstellar medium (ISM) is an ideal tracer of the kinematics of disk galaxies. The ISM in nearby dwarf galaxies are the closest analog to conditions which prevailed in the early universe due to their low metallicity and high gas content. Numerous previous observations of dIrrs showed extremely large HI envelopes several times larger than their optical cores (e.g., Huchtmeier et al. 1981; Meurer et al. 1996; Wilcots & Miller 1998; Gentile et al. 2007; Kreckel et al. 2011; Schmidt et al. 2011; Schmidt et al. 2014; Namumba et al. 2017). Such extended HI envelopes allow us to probe very far out into the dark halo potential and derive the large-scale kinematics of these galaxies (e.g., Carignan & Purton 1998).

Most interferometric studies of HI gas in dwarf galaxies lack the required sensitivity to detect large scale extended HI emission (e.g., Skillman & Bothun (1986); Côté et al. (2000); de Blok & Walter (2000); Kreckel et al. (2011); Hunter et al. (2012)). We would ideally probe the extended HI gas using single dish telescopes as these instruments do not filter out any emission (Pisano 2014). However, single dish telescopes do not have the required spatial resolution to derive the kinematics of the gas. Our best alternative is to use an interferometer with short baselines that has better spatial resolution and is sensitive to large scale structures.

As we prepare for the Square Kilometer Array (SKA) in the near future, SKA pathfinders are being built for engineering tests and early science. Among the telescopes being built for the SKA early science is MeerKAT. One of the main aim of MeerKAT is to detect low column density gas in nearby galaxies using high resolution and achieving column density sensitivity of < 1018 cm−2. As MeerKAT is still being built, the KAT-7, initially built as an engineering test-bed for MeerKAT has been able to produce new exciting early SKA science. The KAT-7 compact configuration of
its seven 12m dishes, combined with the low $T_{\text{sys}} \sim 26$ K have been able to detect, when present, low column density gas in many nearby galaxies that could not be detected by other synthesis arrays such as the VLA or ATCA.

KAT-7 observations of the Magellanic-type spiral NGC 3109 (Carignan et al. 2013) detected 40% more Hi mass than what was detected with the VLA observations. This allowed the measurement of the RC of NGC 3109 out to 32′, doubling the angular extent of existing measurements. Lucero et al. (2015) detected 33% more flux for NGC 253 than what was previously detected with the VLA, giving new results on the kinematics of the low column density gas in NGC 253. KAT-7 polarized radio continuum and spectral line observations of M83 revealed massive Hi gas distribution that appears to be tightly coupled with interaction of the galaxy and the environment (Heald et al. 2016). These observations detected more flux than the VLA observations and allowed the rotation curve to be measured out to 50 kpc. The recently published KAT-7 observations of the nearby dwarf irregular galaxy NGC 6822 (Namumba et al. 2017) revealed 23% more Hi mass than the previous ATCA observations.

The discrepancy between the single dish (Effelsberg and Green Bank Telescope (GBT)) data on the true Hi extent of Sextans A (Huchtmeier et al. 1981; Hunter et al. 2011) and the interferometric data from the Very Large Array (VLA) (Skillman et al. 1988; Wilcots & Hunter 2002) has motivated us to map Sextans A and B in Hi using the KAT-7. KAT-7 is ideally suited for this project due to its short baselines and low receiver temperature which makes it sensitive to large scale, low surface brightness emission.

The structure of the paper is as follows. Brief descriptions of Sextans A and B are given in Section 2, followed by the observations and data reduction in Section 3. In Section 4, we present the results on the Hi distribution. The rotation curve results derived from the tilted ring fit are presented in Section 5, and the dark matter mass models of the galaxies are explained in Section 6. In section 7, we explore instability models for the onset of star formation in Sextans A and B and in Section 8 we summarize our work.

2 Sextans A and Sextan B

Sextans A (DDO 75, UGC 205) is a dIrr galaxy at a distance of 1.3 Mpc (de Vaucouleurs et al. 1991), which places it in the Local Group of galaxies, lying between Sextans B and NGC 3109. Sextans A is classified as an Ib m galaxy (de Vaucouleurs et al. 1991), having an absolute magnitude of $M_V = -14$ (Kniazev et al. 2005). The stellar distribution in Sextans A has been observed to have a square-like distribution (Hunter & Plummer 1996). Its optical angular diameter is $D_0 = 4.8$′ (de Vaucouleurs et al. 1991).

Huchtmeier et al. (1981) first mapped the Hi distribution around Sextans A using the Effelsberg 100m single dish telescope. Their results yielded a large Hi extent of 54′, which is 5.8 times the galaxy optically-defined Holmberg diameter, and a total Hi mass of $1.6 \times 10^7$ $M_\odot$. The first interferometric observations of Sextans A were done by Skillman et al. (1988) using the VLA. They were able to detect only about 50% of the total Hi flux reported by Huchtmeier et al. (1981) and measured an Hi extent of 9.4′. Skillman et al. (1988) suggested that the 50% missing gas could exist in large scale low column density gas unable to be detected by the VLA due to the lack of short baselines and limited field of view. Wilcots & Hunter (2002) mapped Sextans A using a VLA mosaic that allowed them to sample a much larger field of view than Skillman et al. (1988). They were able to recover only 62% of the flux reported by Huchtmeier et al. (1981) with an Hi extent of 18′. Comparing their VLA Hi maps from the peaks in the profiles at each position with data from the Hi Parkes All-Sky Survey (HIPASS) observations confirmed the fact that there was a good deal of Hi gas missing from the VLA mosaic due to the short spacings problem.

To verify the existence of the gas at the outer edges of Sextans A and explore how far it extends, Hunter et al. (2011) observed Sextans A with the Green Bank 100m single dish telescope (GBT). Their observations detected 25% more flux compared to Wilcots & Hunter (2002), but only 78% of the flux detected by (Huchtmeier et al. 1981). They measured an Hi extent of 22.1′. They outlined significant differences between the GBT and the Effelsberg observations that may contribute to the difference in the observed Hi extent. One difference was that the signal to noise of the GBT observations was higher, and the extended features in the Huchtmeier et al. (1981) occurred at low signal to noise. The other difference was that the GBT has a clear point spread function out to several degrees from the main beam while the Effelsberg telescope has significant sidelobes. This lead them to believe that the Effelsberg map had galaxy emission entering from the sidelobes, which resulted in an overestimate of both the extent and the total flux.

Sextans B (DDO 70, UGC 5374) is classified as an Ib m galaxy at a distance of 1.3 Mpc (de Vaucouleurs et al. 1991). It is a faint galaxy with an absolute magnitude of $M_V \sim -14$ (Kniazev et al. 2005). As far as global properties are concerned, Sextans B is considered to be a twin of Sextans A, except for the profile width, due to different inclinations. Huchtmeier et al. (1981) first mapped the Hi of Sextans B using the Effelsberg single dish telescope. They were able to derive an Hi extent of 13′, which is 1.7 times the Holmberg diameter, and a total Hi mass of $1.3 \times 10^7 M_\odot$. VLA study of the neutral hydrogen in Sextans B (Worth & Wilcots 2009) showed that the Hi kinematics of this galaxy are similar to those of other dwarfs. They found that the rotation curve of Sextans B was flat out to a radius of 250′ , which is about 1.6 kpc. Several distinct Hi holes have also been identified in Sextans B. Oh et al. (2015) derived the rotation curve of Sextans B out to a radius of ~3 kpc using the VLA Local Irregulars That Trace Luminosity Extremes, The Hi Nearby Galaxy Survey (LITTLE THINGS) (Hunter et al. 2012).

3 KAT-7 Observations and Data Reduction

The observations were obtained with the compact, seven-dish KAT-7 telescope (Foley et al. 2016), located close to the South African SKA core site in the Northern Cape Karoo desert region. The parameters of the KAT-7 observations are given in Table 2.

The data were collected between 2014 December and 2015 July. Sextans A was observed over 19 observing sessions for a total of 60 hours on source while Sextans B was
The individual calibrated data sets were then combined to-gether using the CASA task 

The time-varying visibilities satisfying the condition

The central frequencies of our observations were 1418.9 MHz for Sextans A and 1419.0 MHz for Sextans B. All the data were hanning smoothed to 1.28 km.s\(^{-1}\) before calibration. The observations were done using a 5, 6 or 7 antenna configuration depending on the availability of the antennas.

All the data were reduced using the standard calibration tasks in the Common Astronomy Software Application CASA 3.4.0 package (McMullin et al. 2007). Calibration was performed separately for each observing session. Flagging of bad data due to radio frequency interferences (RFI) and antenna malfunctions were done using the CASA task FLAGDATA. The corrections for the flux/bandpass shape were determined using the correlator 0407+658. The time-varying phases and antenna gains were calibrated based on observations of the phase calibrator 0942+080. The calibration solutions were applied to the targets and the target sources were then split from the calibration solutions using the task SPLIT.

The calibrated data sets were then combined together using the CASA task CONCAT. The combined data were continuum subtracted by using the first order polynomial in the task UVCOUNTS. Doppler corrections were performed on the data to ensure that proper velocity coordinates were used (Carignan et al. 2013). At this point, visibilities satisfying the condition |u| ≤ 10\(\lambda\) were removed from the data set to avoid the low level RFI that are correlated when the fringe rate is equal to zero (Lucero et al. 2015; Hess et al. 2017).

The data were Fourier transformed using the CASA task CLEAN. Firstly, dirty cubes were imaged and the rms noise in line free channels was measured. For both Sextans A and B, the noise level in line free channels was found to be \(\sim 1.5\) times the theoretical noise, see Table 2. Using a flux threshold of 1 times the typical r.m.s. of the flux in a line free channel, the data were cleaned in a non-interactive mode using a clearly defined mask. For each galaxy, two cubes were produced by applying the natural (na) and robust 0 weighting to the uv data. Taking into account the spatial resolution of KAT-7, we have decided to use the robust 0 cubes for our analysis.

| Parameter                  | Sextans A | Sextans B |
|----------------------------|-----------|-----------|
| Morphology                 | HII \(^{a}\) | HII \(^{a}\) |
| Right ascension (J2000)    | 10:11:01.3\(^{a}\) | 05:19:57\(^{a}\) |
| Declination (J2000)        | -04:42:48.0\(^{a}\) | 05:19:57\(^{a}\) |
| Distance (Mpc)             | 3.3\(^{a}\) | 1.3\(^{a}\) |
| \(M_g\) (Mag)              | -13.9\(^{a}\) | -13.9\(^{a}\) |
| \(v_{helio}\) (km.s\(^{-1}\)) | 324\(^{a}\) | 301\(^{a}\) |
| P.A.\(^{opt\,(c)}\) (\(^{\circ}\)) | 41.0\(^{a}\) | 88.0\(^{a}\) |
| Inclination\(^{opt\,(c)}\) (\(^{\circ}\)) | 33.5\(^{a}\) | 57.8\(^{a}\) |
| Total HI mass (M\(_{\odot}\)) | (7.3 ± 0.07) \times 10\(^{7}\) | (4.2 ± 0.06) \times 10\(^{7}\) |

Notes. Ref (a) de Vaucouleurs et al. (1991); (b) Dolphin et al. (2003); (c) Karachentsev et al. (2002); (d) Kniazev et al. (2005); (e) Hunter et al. (2012)

3.1 Deriving HI Maps

For each galaxy, the data cube was smoothed to 2 times the original spatial resolution. Noise pixels were removed from the smoothed cubes by excluding pixels < 2\(\sigma\), where \(\sigma\) is the noise in line free channels. The remaining noise pixels were removed by creating masks around the galaxy emission in each channel. The final mask from the smoothed cube was then applied to the full resolutions cubes. The integrated HI maps were created by adding together all clipped channels with emission using a primary beam corrected cubes. The maps were converted to column density by using the following formula:

\[
\frac{H_1 (\text{cm}^{-2})}{\text{IWM}} = \frac{1.835 \times 10^{18} \times dv \times 6.07 \times 10^5}{\theta_{\text{major}} \times \theta_{\text{minor}}}
\]

where \(dv\) is the velocity resolution, \(\theta_{\text{major}}\) is the major axis and \(\theta_{\text{minor}}\) is the minor axis of the beam. The values of these parameters are given in Table 2.

To construct the velocity field maps, two methods were considered. The most popular one being the intensity weighted mean (IWM). However, this method is known to produce uncertainties in deriving velocities when the S/N is low (de Blok et al. 2008) as in our case for Sextans A. An alternative, in this case, was to construct the velocity field maps by fitting Gaussians to each profile. This method has already been implemented successfully by various authors (see e.g. Carignan et al. 1990) and has proven to give a better result compared to the IWM.

We fitted a first order Gaussian to each HI cube line profile to generate the velocity field maps. This was done using the GIPSY task xGAUFIT. We used the data sets without primary beam correction in order to retain the original properties of the data when performing profile fitting. To ensure high quality velocity field maps, three filters were used: 1) only profiles with fitted fluxes maxima higher than 3\(\sigma\) were retained, 2) profiles with a fitted line width less than the velocity resolution of the data were excluded, and 3) fitted profiles had to be within the velocity range of the data. The dispersion maps were produced using the AIPS task MOMNT. The final velocity field and dispersion maps were masked using the amplitude map from xGAUFIT. The final velocity field and dispersion maps are shown Figure 8(a,b) and 11(a,b) for Sextans A and B respectively.

4 HI DISTRIBUTION

4.1 Sextans A

The global HI profile of Sextans A is given in Figure 1. Plotted for comparison is the HI global profile from the VLA LITTLE THINGS data (Hunter et al. 2012). The mid-point velocity at the 50% level is 324 ± 2 km.s\(^{-1}\) identical to the previous measurements Huchtmeier et al. (1981); Wilcots & Hunter (2002); Barnes & de Blok (2004); Hunter et al. (2011). The 50% line width is \(\Delta V = 45 ± 2\) km.s\(^{-1}\). This is close to the value of \(\Delta V = 46\) km.s\(^{-1}\) derived by Barnes & de Blok (2004) but smaller than the value of \(\Delta V = 55\) km.s\(^{-1}\) derived by Wilcots & Hunter (2002). An integrated flux of 181 ± 2 Jy km.s\(^{-1}\) was measured, yielding a total HI mass of (7.3 ± 0.07) \times 10\(^{7}\) M\(_{\odot}\) at the adopted distance of 1.3 Mpc. This is similar to the Parkes single dish results observed for 17 sessions for a total of 51 hours on source. The HI observations were carried out using the c16n25M4K spectral line mode. This correlator mode gives a total bandwidth of 12.5 MHz and 4096 channels of 0.64 km.s\(^{-1}\) width. The central frequencies of our observations were 1418.9 MHz for Sextans A and 1419.0 MHz for Sextans B. All the data were hanning smoothed to 1.28 km.s\(^{-1}\) before calibration. The observations were done using a 5, 6 or 7 antenna configuration depending on the availability of the antennas.
of Barnes & de Blok (2004) and in agreement within the error to their H\textsubscript{i} mass of 6.7 ± 0.5 × 10\textsuperscript{7} M\textsubscript{☉}. The GBT single dish observations (Hunter et al. 2011) reported an H\textsubscript{i} mass of 8.2 ± 10\textsuperscript{7} M\textsubscript{☉}, which is 11% more compared to our derived H\textsubscript{i} mass. The GBT observations report a ∼ 10% uncertainty on the flux due to calibration. Taking this into account brings the KAT-7 derived mass in agreement with the GBT calculated mass. This implies that KAT-7 does not miss out any galaxy flux. The KAT-7 derived H\textsubscript{i} mass is 5% more than the mass of 6.9 × 10\textsuperscript{7}M\textsubscript{☉} detected by the VLA mosaic observations (Wilcots & Hunter 2002) and in excellent agreement with the H\textsubscript{i} mass of 7.1 × 10\textsuperscript{7} M\textsubscript{☉} (Hunter et al. 2012).

Figure 2 shows the integrated column density map of Sextans A superposed on the DSS image. The Hi distribution is well resolved by the KAT-7 beam. The 3σ column density limit in Figure 2 is 5.8 × 10\textsuperscript{18} cm\textsuperscript{−2}. This is higher than the 3σ limit of 2 × 10\textsuperscript{18} cm\textsuperscript{−2} of Hunter et al. (2011) and lower than the 7.5 × 10\textsuperscript{18} cm\textsuperscript{−2} of Wilcots & Hunter (2002). At the 3σ column density level, we measure an H\textsubscript{i} diameter of 30′. Comparing with the literature, we measure an H\textsubscript{i} diameter of 23′ at 10\textsuperscript{19} cm\textsuperscript{−2} similar to an H\textsubscript{i} diameter of 22′ of Hunter et al. (2011).

Figure 3 shows the azimuthally averaged KAT-7 radial H\textsubscript{i} density profile of Sextans A. Plotted for comparison is the H\textsubscript{i} radial profile from the VLA observations of Hunter et al. (2012). Both profiles were derived using the GIPSY task ELLINT by applying the tilted ring kinematics parameters described in Section 5. It can be seen that the large beam of KAT-7 has averaged out the depression and peak in the center.

### 4.2 Sextans B

The global H\textsubscript{i} spectrum of Sextans B is given in Figure 4. This is compared to the LITTLE THINGS derived global profile. The mid-point velocity at 50% level is 301 ± 1.4 Jy km s\textsuperscript{−1}. The 50% line width is ∆V = 40.8 ± 1.84 km s\textsuperscript{−1}. An integrated flux of 105 ± 1.4 Jy km s\textsuperscript{−1} is measured, giving a total H\textsubscript{i} mass of 4.2 × 10\textsuperscript{7} M\textsubscript{☉}. Using the same distance, the KAT-7 observations measure a ∼ 15% more H\textsubscript{i} mass than the VLA-ANGST (Ott et al. 2012) and is in agreement with the value of 3.9 × 10\textsuperscript{7} M\textsubscript{☉} derived from the VLA LITTLE THINGS (Hunter et al. 2012).

Figure 5 shows the H\textsubscript{i} column density map of Sextans B superposed on a DSS optical image. The H\textsubscript{i} distribution is well resolved by the KAT-7 beam. The lowest contour is 5.4 × 10\textsuperscript{18} cm\textsuperscript{2}, which corresponds to the 3σ limit calculated over 16 km s\textsuperscript{−1}. At the lowest contour, the H\textsubscript{i} diameter is 20′. The azimuthally averaged H\textsubscript{i} densities of Sextans B are shown in Figure 6. This is plotted together with the derived H\textsubscript{i} profile from the LITTLE THINGS data (Hunter et al. 2012). Again the beam smearing in the KAT-7 data has reduced the peak seen at high resolution.
Figure 3. KAT-7 H\textsc{i} radial profile of Sextans A (black solid line) compared to the VLA LITTLE THINGS \citep{Hunter2012}. The dashed line shows the LITTLE THINGS radial profile smoothed to the KAT-7 spatial resolution while the dash-dotted lines shows LITTLE THINGS radial profile at VLA full spatial resolution. The surface densities are multiplied by a factor 1.4 to take into account helium and other metals.

Figure 4. Global H\textsc{i} line profile of Sextans B from the KAT-7 primary beam corrected data cube (black solid line) compared to the VLA LITTLE THINGS H\textsc{i} \citep{Hunter2012} global profile (black dash-dot line). The mid-point velocity of 301 km.s\textsuperscript{−1} is indicated.

Figure 5. Integrated H\textsc{i} column density map of Sextans B superposed on a DSS image. The contours are 5.4, 10.8, 21.6, 43.2, 86.4, 172.8, and 345.6 × 10\textsuperscript{18} cm\textsuperscript{−2}. The synthesized beam is shown in the bottom left corner.

Figure 6. KAT-7 H\textsc{i} radial profile of Sextans B (black solid line) compared to the VLA LITTLE THINGS \citep{Hunter2012}. The dashed line shows the LITTLE THINGS radial profile smoothed to the KAT-7 spatial resolution while the dash-dotted lines shows LITTLE THINGS radial profile at VLA full spatial resolution. The surface densities are multiplied by a factor 1.4 to take into account helium and other metals.

4.3 General remark on the H\textsc{i} distribution

It can be seen in Figure 1 and 4 that KAT-7 recovered a small fraction of flux missing from the VLA observations because of the lack of short spacings. However, the price to pay for having a lower spatial resolution is to wash out the high brightness features in the center, as can be seen in Figure 3 and 6. What is clear however is that the KAT-7 observations dismiss completely the large extents and fluxes derived for Sextans A from the Effelsberg observations. The
The errors on $V_{\text{cur}}$ values of Sextans A and B using a spacing and width of 100″. Following Namumba et al. (2017) we derive the rotation curve.

### 5 HI KINEMATICS

#### 5.1 Tilted ring model

We fit a tilted-ring model to the velocity fields using ROTCUR in GIPSY (Begeman 1989) to derive the parameters that best describe the observed velocity fields.

#### 5.2 Deriving the rotation curve

Following Namumba et al. (2017) we derive the rotation curves of Sextans A and B using a spacing and width of 100″. The errors on $V_{\text{rad}}$ were derived using Equation 2 (Carignan et al. 2013).

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

We correct the rotational velocities for the asymmetric drift as the dynamical support by random motions of the gas disk is significant. Following the method described in Coté et al. (2000), we correct for the asymmetric drift as follows:

$$V_c^2 = V_0^2 - 2\sigma^2 \frac{\delta\sigma}{\delta \ln R} - 2\sigma^2 \frac{\delta \ln \Sigma}{\delta \ln R}$$

where $V_c$ is the corrected velocity, $V_0$ is the observed one, $\sigma$ is the velocity dispersion and $\Sigma$ is the gas density.

#### 5.3 Sextans A rotation curve results

Results of the tilted ring model fitted to the first order gaussian velocity field for Sextans A are presented in Figure 7 and 8. The first and second panel of Figure 7 shows the behavior of the inclination and position angle when the parameters are left free to vary while the green solid lines show the fitted parameters used to derive the final rotation curves for the approaching, receding, and both sides, shown in the third panel of Figure 7. We derive the rotation curve out to 550″, which is ~3.5 kpc. The rotation curve rises as $V(R) \propto R$ out to ~250″. Beyond this radius, the rotation curve is seen to decline down to 550″. This feature in the RC is not peculiar to dwarf galaxies such as Sextans A. The analysis of the rotation curve of GR 8 (Carignan et al. 1990) showed that the RC of the galaxy was declining in the outer regions (see also e.g. the case of the late-type spiral NGC 7793: Dicaire et al. (2008)). A systemic velocity of $V_{\text{sys}} = 23.0$ km.s$^{-1}$ is found, similar to the value obtained from the global profile. A mean $i$ and $P.A.$ of 34° and 86° are measured respectively.

#### 5.4 Sextans B rotation curve results

The results of the tilted ring model fitting for Sextans B are shown in Figure 10 and 11. A constant inclination and a varying P.A. were used to derive the final rotation curve. A constant inclination was chosen as the variation of the inclination with radius was small. We measure the rotation curve out to 650″, which corresponds to ~4 kpc. The rotation curve is seen to be rising out to ~550″, with the last point showing a decline. A declining RC of Sextans B has been reported by Oh et al. (2015). A mean systemic velocity, $V_{\text{sys}}$, of 302 ± 0.9 km.s$^{-1}$ is found, similar to the value derived from the global profile. We find a mean $i$ and P.A. of 49° and 56.6° respectively, values consistent with the literature Oh et al. (2015).

In Figure 11, we compare the observed velocity field (a) to the derived model velocity field (c), while (d) shows the residual map (observed velocity field - model velocity field). (b) shows the velocity dispersion map. Figure 12 shows the comparison between our KAT-7 rotation curve and the VLA LITTLE THINGS curve (full resolution and smoothed to KAT-7 spatial resolution)(Hunter et al. 2012). The rotation curves are in agreement within errors.
Figure 7. Results of the tilted ring fits for Sextans A. The blue and red triangles in the middle and top panels show the behavior of the PA and inclination as free parameters. The black squares show the radial variation of the PA and inclination derived for both sides. The green solid lines show the behavior of the PA and inclination fixed to the model used to derive the final rotation curve. In this case the PA is varying while the inclination is fixed to the mean value. For the bottom panel, the blue triangles represent the curve for the approaching side, the red triangles represent the curve for the receding side, and the black diamonds show the rotation curve derived from both sides.

6 MASS MODELS AND DARK MATTER CONTENT

The rotation curve reflects the dynamics of the disk due to the total mass of the galaxy, luminous and dark matter. Dwarf irregulars, like most low-mass surface density galaxies, are believed to be dominated by dark matter at all radii due to the small contribution of luminous matter (stars and gas) to the total dynamics (Carignan & Beaulieu 1989). The extended HI rotation curves of dwarf irregulars allow us to probe dark matter potentials to much larger radii, making them ideal objects for studying dark matter properties in galaxies. To this end, we decompose the observed rotation curve of Sextans A and B into the luminous and dark matter mass components and verify if dark matter indeed dominates the total dynamics of these systems. The pseudo-isothermal DM halo model (ISO) (Begeman et al. 1991) and the Navarro-Frenk-White DM halo model (NFW) (Navarro et al. 1997) have been used to derive the dark matter components of Sextans A and B. Detailed description of the mass models has been given in Namumba et al. (2017).

6.0.1 Gas and Stellar components

We derive the mass models for the stellar and gas components following the procedure described by Namumba et al. (2017). The Wide Field Infrared Survey Explorer (WISE) surface brightness profiles in the 3.4 µm band were used to account for the stellar contribution. The luminosity profiles are from Jarrett (private communication). At 3.4 µm, WISE probes the emission from the old stellar disk population and is also less affected by dust.
6.1 Fitting ISO and NFW models for Sextans A and B

The GIPSY task ROTMAS was used to construct the mass models of Sextans A and B. We fitted the ISO and NFW models to the rotation curves derived from the tilted ring models, taking into account the mass of the luminous matter (stars and gas). All the data points were weighted according to the errors using the inverse square weighting.

The values of the mass to light ratio, M/L (Υ∗), were determined by scaling the contribution of the stellar rotation curve to the total rotation curve. This was done using two predetermined M/L values: 1), the M/L of 0.2 (Lelli et al. 2016). This value has been derived to be the lower end of the mass to light ratio for dwarf galaxies at mid-infrared band, and 2), the M/L derived using Equation 4 (Cluver et al. 2014). This equation is used to calculate the M/L of star

Table 5. Radial variation of the Hz surface densities Σg, the gas velocity dispersions σ, the observed rotation velocities V0, the errors of the observed velocities ∆V, and the asymmetric drift corrected rotation velocities Vc for the KAT-7 data of Sextans B.

| Radius (arcsec) | Σg (M⊙pc⁻²) | σ (km s⁻¹) | V0 (km s⁻¹) | ∆V (km s⁻¹) | Vc (km s⁻¹) |
|----------------|-------------|------------|-------------|-------------|-------------|
| 0.0            | 3.7         | 13.3       | 0.0         | 0.0         | 0.0         |
| 50             | 3.5         | 13.2       | 6.1         | 0.9         | 6.2         |
| 150            | 2.7         | 12.7       | 14.1        | 1.5         | 16.6        |
| 250            | 1.8         | 12.1       | 24.0        | 1.5         | 28.1        |
| 350            | 0.9         | 11.1       | 32.6        | 1.0         | 37.6        |
| 450            | 0.4         | 9.7        | 37.9        | 1.3         | 43.4        |
| 550            | 0.2         | 8.8        | 38.6        | 1.8         | 44.4        |
| 650            | 0.1         | 6.9        | 37.3        | 6.0         | 41.3        |

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, and column (6) the corrected velocities used for the mass models.

![Figure 8. Maps of Sextans A: Observed velocity field map (a), velocity dispersion map (b), model velocity field (c), and residual map (d). The observed and model velocity field contours run from 310 to 340 km.s⁻¹ in steps of 5 km.s⁻¹.](image)

![Figure 9. Comparison of the KAT-7 and VLA LITTLE THINGS rotation curves of Sextans A. The red square show the KAT-7 rotation curve, the black triangles show the LITTLE THINGS RC smoothed to the KAT-7 spatial resolution, and the green triangles show the full resolution LITTLE THINGS RC.](image)
Figure 10. Results of the tilted ring fits for Sextans B. The blue and red triangles in the middle and top panels show the behavior of the PA and inclination as free parameters. The black squares show the radial variation of the PA and inclination derived for both sides. The green solid lines show the behavior of the PA and inclination fixed to the model used to derive the final rotation curve. In this case the PA is varying while the inclination is fixed to the mean value. For the bottom panel, the blue triangles represent the curve for the approaching side, the red triangles represent the curve for the receding side, and the black diamonds show the rotation curve derived from both sides.

forming low mass galaxies.

$$\log_{10} = M_{\text{stellar}}/L_{W1} = -1.93(W_{3.4 \mu m} - W_{4.6 \mu m}) - 0.04$$  (4)

where $W_{3.4 \mu m} - W_{4.6 \mu m}$ is 0.04 ± 0.02 for Sextans A and 0.01 ± 0.02 for Sextans B. This gives the M/L of 0.9 and 0.8 for Sextans A and B respectively.

### 6.2 Mass model results for Sextans A

The fitted parameters for the mass model results of Sextans A are shown in Figure 13 and Table 6. Figure 13 shows that Sextans A is dark matter dominated at all radii. Regardless of the assumption made for the M/L ratio, the ISO model produces a better fit compared to the NFW at radius $\leq 1.3$ kpc. Beyond that radius, the two models tend to give similar fits to the observed rotation curve. For the ISO halo models, we find the lowest $\chi^2$ of 3.4 when the M/L value of 0.2 (Lelli et al. 2016) is used. It is not surprising that we get a better fit when we use a smaller M/L of 0.2. Literature shows that for most dwarf galaxies the stellar disk does not contribute significantly to the rotation curve (Weldrake et al. 2003; de Blok et al. 2008; Oh et al. 2011). The mass models yield DM halo parameters of $R_0 \sim 0.5$ kpc and $\rho_0 \sim 0.1$ M$_\odot$ pc$^{-3}$.

### 6.3 Mass model results for Sextans B

The dark matter models for Sextans B are shown in Figure 14 and Table 6. Both ISO and NFW models give larger $\chi^2$ values than for the models of Sextans A but again ISO with an M/L of 0.2 (Lelli et al. 2016) gives the best fit to the data but with a small overestimate for $r < 1.3$ kpc. This suggests that M/L should be slightly smaller. Oh et al. (2015) derived a mass model for Sextans B using higher resolution obser-


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Figure 11. Maps of Sextans B: Observed velocity field map (a), velocity dispersion map (b), model velocity field (c), and residual map (d). The observed and model velocity field contours run from 280 to 340 km.s\(^{-1}\) in steps of 10 km.s\(^{-1}\).

Figure 12. Comparison of the KAT-7 and VLA LITTLE THINGS rotation curves of Sextans B. The red square show the KAT-7 rotation curve, the black triangles show the LITTLE THINGS RC smoothed to the KAT-7 spatial resolution, and the green triangles show the full resolution LITTLE THINGS RC.

6.4 MOND Models

The Modified Newtonian Dynamics (MOND) was proposed by (Milgrom 1988) as an alternative to DM. Milgrom pos-
### Table 6. Results for the Mass Models Sextans A and Sextans B.

| Assumption | Sextans A | Sextans B |
|------------|-----------|-----------|
|            | ISO Halo  | NFW Halo  |
|            | (1)       | (6)       |
|            | (2)       | (11)      |
|            | (3)       | (12)      |
|            | (4)       | (13)      |
|            | (5)       | (14)      |
| M/L model  | 0.90      | 0.90      |
| M/L model  | 0.80      | 0.80      |
| M/L model  | 0.20      | 0.20      |
| \(a_0\)    | 0.46 ± 0.11 | 10.61 ± 3.40 |
| \(a_0\)    | 0.40 ± 0.08 | 12.62 ± 3.71 |
| \(a_0\)    | 0.35 ± 0.08 | 10.35 ± 3.90 |
| \(\chi^2_{\text{red}}\) | 3.57 ± 0.98 | 33.84 ± 5.57 |
| \(\chi^2_{\text{red}}\) | 3.57 ± 0.98 | 33.84 ± 5.57 |
| \(\chi^2_{\text{red}}\) | 3.57 ± 0.98 | 33.84 ± 5.57 |

**Notes.** Columns 1, 11 and 16, the stellar \(Y_\star\) assumption. Column 2, 12 and 17, \(Y_\star\) . Column 3, 13, fitted scaling radius of the ISO halo model in kpc. Column 4, 14, fitted central density of the pseudo-isothermal halo model in \(10^{-3} \, M_\odot \, \text{pc}^{-3}\). Column 9, 19 the radius in kpc where the density contrast exceeds 200. Column 8, 18 concentration parameter \(c\) of the NFW halo model. Columns 5, 15 and 10, 20, reduced \(\chi^2\) value. The dotted line (...) are due to unphysical large values of uncertainties.

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**6.6 Comparison with the literature**

There are a lot of studies on the dark matter distribution in dwarf galaxies in the literature, but this Section will focus on the comparison between this work and that of Oh et al. (2011), which looks at the dark matter distribution of the LITTLE THINGS galaxies. A dominant trend in the core-like distribution has been reported by Oh et al. (2011). This is in agreement with our mass model results in which the ISO model produces better fits as compared to the NFW model. The KAT-7 ISO model fits suggest a dark matter core radius of \(R_c = 0.46\) to 2.45 kpc and density \(\rho_0 = 15\) to 125 \(M_\odot\) \(\text{pc}^{-3}\). The values are in the range of Oh et al. (2011). Oh et al. (2011) found the values of \(R_c\) and \(\rho_0\) to be in the range 0.10 to 9.82 kpc and 1.8 to 725 \(M_\odot\) \(\text{pc}^{-3}\) respectively.
For both observations, we see cases were the NFW fit yields unrealistic halo parameters when trying to fit the observed RCs. From our KAT-7 data, we obtained $c$ values $< 0$ for Sextans B while the LITTLE THINGS observations record $c$ values $< 0.1$ for DDO 53 and NGC 2366. As emphasized by de Blok et al. (2008), $c$ represents the collapse factor, and therefore $c$ values $< 1$ make no sense in the CDM context. The estimated concentration parameter for Sextans A is $\sim 11$. The LITTLE THINGS observations record $c$ values ranging from $\sim 4$ to 48. The concentration parameter for Sextans A is within the LITTLE THINGS range and also consistent with $c$ values derived for most dwarf galaxies (de Blok et al. 2008). We obtain $V_{200}$ of 26 km.s$^{-1}$ for Sextans A. This value is in the range of Oh et al. (2011). Oh et al. (2011) record $V_{200}$ values ranging from 3.7 to 58 km.s$^{-1}$.

One thing to note from our KAT-7 mass model fits is that although we do not get perfect fits to our observed RCs, the parameters we derived for Sextans A and B are in agreement and within the ranges found for other dwarf galaxies.

| $a_0$ (cm.s$^{-2}$) | Sextans A | Parameter | Result |
|--------------------|-----------|-----------|--------|
| Fixed (1.2 $\times 10^{-8}$) | (M/L) | 0.006 | $\chi^2_{red}$ | 26.40 |
| Free (6.9 $\times 10^{-9}$) | (M/L) | 0.2 | $\chi^2_{red}$ | 6.40 |

| $a_0$ (cm.s$^{-2}$) | Sextans B | Parameter | Result |
|--------------------|-----------|-----------|--------|
| Fixed (1.2 $\times 10^{-8}$) | (M/L) | 0.005 | $\chi^2_{red}$ | 46.50 |
| Free (1.5 $\times 10^{-8}$) | (M/L) | 0.2 | $\chi^2_{red}$ | 47.44 |

7 STAR FORMATION THRESHOLDS

The mechanisms that assist star formation activities in low surface brightness (LSB) galaxies remain a puzzling question. The low stellar densities in most gas rich LSB galaxies imply that the star formation process has been inefficient in converting the available gas into stars. Several studies (Hunter & Plummer 1996; Hunter et al. 1998; de Blok & Walter 2006) have been able to show that, although being gas rich, the gas densities in most LSB galaxies fall below the threshold needed to support star formation.

Kennicutt (1989) found that a modified Toomre-Q criterion model, could satisfactorily describe the star formation threshold gas densities in active star forming galaxies. In this model, the density above which the gas becomes unstable and form stars is a function of the kinematics of the galaxy. The threshold for star formation depends on the parameter $\alpha_c$, which is defined by (Martin & Kennicutt 2001):

$$\alpha_c = \frac{\Sigma_c}{\Sigma_{HI}}$$

where $\Sigma_{HI}$ is the gas surface density corrected for helium and other metals, and $\Sigma_c$ is the critical density for cloud formation. The critical density is described by (Martin & Kennicutt 2001):

$$\Sigma_c(r) = \alpha \frac{\sigma(r)}{\pi G}$$

where $\sigma_r$ is the gas velocity dispersion, $\alpha$ is a constant close to unity which is included to account for a more realistic disk, and $k(r)$ is the epicyclic frequency given by

$$k^2(r) = 2\frac{V^2}{r^2} + \frac{V^2}{r} \frac{dV}{dr}$$

where $V$ is the rotation velocity in kpc, and $r$ is the radius in km. Kennicutt (1989) found $\alpha_c = 0.63$ at the edge of

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star forming disks and Martin & Kennicutt (2001) found $\alpha_c = 0.69$. If $\Sigma_c(r)$, the surface density of the gas in the disk exceed $\Sigma_c(r)$, then the disk will be unstable to axisymmetric disturbances and large scale star formation can occur.

An alternative to the Toomre-Q criteria is the cloud growth criteria based on shear. This criteria explains the star formation threshold based on the local shear rate (Hunter et al. 1998) and is described by the Oort’s A constant:

$$A = -0.5 \frac{d\Omega}{dr} = 0.5 \left( \frac{V}{r} - \frac{dV}{dr} \right)$$

Then the threshold has the form

$$\Sigma_{c,A}(r) = \frac{\alpha(r) \sigma(r) A}{\pi G}$$

Where $\alpha_{c,A}$ is taken to be 2.5 (Hunter et al. 1998), but the normalization for $\Sigma_{c,A}$ is relatively uncertain. In this case, the threshold parameter $\alpha$ is defined by

$$\alpha_{c,A} = \frac{\Sigma_{HI}}{\Sigma_{c,A}}$$

We have used the KAT-7 observations to examine the star formation threshold throughout Sextans A and B as a function of radius to determine if the subcritical gas density is preventing the galaxies from large scale star formation. To derive the critical densities, a constant gas velocity dispersion $\sigma$ of 9 km.s$^{-1}$ is used. This is derived from the medium value of our azimuthally averaged HI velocity dispersion radial profile. We have assumed $\alpha = 1$ and establish the ratios of the gas densities to the critical densities as a function of radial using the Toomre-Q and cloud-growth based on shear criteria.

7.1 Star formation threshold results for Sextans A and B

Figure 17 (a) and (b) compares the observed HI gas surface densities to the critical densities derived using the Toomre-Q (Kennicutt 1989) and the cloud-growth based on shear (Hunter et al. 1998) criterion for Sextans A and B respectively. The gas surface densities in Sextans A and B are low relative to the Toomre-Q critical densities $\Sigma_c$ necessary for instabilities that lead to cloud formation and later star formation. We find that the critical densities $\Sigma_c$ in Sextans A exceed the gas surface density at all radii. For Sextans B, $\Sigma_c$ is lower than the gas surface density in regions $\leq 2.1$ kpc.

Figure 18 and 19 shows the radial dependance of the ratios $\Sigma_{HI}/\Sigma_c$ and $\Sigma_{HI}/\Sigma_{c,A}$ for Sextans A and B. We see that for both galaxies, the ratios derived from the Toomre-Q critical densities $\Sigma_{HI}/\Sigma_c$ fail to predict the observed star formation in Sextans A and B. At all radii, $\Sigma_{HI}/\Sigma_c$ is below the stability parameter $\alpha = 0.63$, the median value from Kennicutt (1989) above which the gas density is high enough for large scale star formation. We calculate a mean $\alpha_c = 0.25$ and 0.20 for Sextans A and B by finding the ratio $\Sigma_{HI}/\Sigma_c$ from the center to the Holmberg radius. This result suggests that the gas surface density in Sextans A and B is low to effectively form stars if the Toomre-Q stability criterion is used to determine the star formation in these galaxies.

The ratio $\Sigma_{HI}/\Sigma_{c,A}$ seems better suited to explain the star formation in Sextans A and B. In both galaxies, $\Sigma_{HI}/\Sigma_{c,A}$ exceeds the stability parameter $\alpha = 0.63$ in the inner regions. We measure a mean $\alpha_{c,A}$ value of 0.64 and 5 for Sextans A and B respectively. These results suggest that shear may play an important role in facilitating cloud formation and later induce star formation in Sextans A and B.

Many different models have been used to examine the star formation threshold in dwarf galaxies. Hunter et al. (1998) used different models to determine regions of star formation using a sample of spiral and dwarf galaxies. Their results showed that for dwarf galaxies, the Toomre-Q ratio $\alpha_c$ was too low to induce star formation at all radii. Examples of their derived average $\alpha_c$ values include: 0.45 for IC 1613, 0.36 for DDO 154, 0.30 for DDO 155, and 0.26 for Sextans A. These values are in excellent agreement with our calculated $\alpha_c$ values of Sextans A and B using the KAT-7 observations. We reach the same conclusion as Hunter et al. (1998) that the cloud-growth criterion based on shear is well suited to explain star formation in star forming regions of dwarf galaxies. In most cases, Hunter et al. (1998) derived $\alpha_{c,A}$ values close to 1. We see that the high values of $\Sigma_{HI}/\Sigma_{c,A}$ derived for Sextans B are not odd when compared with the literature. Hunter et al. (1998) records high $\Sigma_{HI}/\Sigma_{c,A}$ for IC 1613 and DDO 50, showing the highest peak $\sim 10$.

8 SUMMARY AND CONCLUSION

We have obtained high sensitivity, intermediate resolution HI observations of Sextans A and B and have used them to study the HI distribution, kinematics, and star formation thresholds. At column densities of 5.8 and 5.4 $\times 10^{18}$ cm$^{-2}$ for Sextans A and B, we do not detect new HI emission. In fact, our results, which are close to the GBT and VLA, contradict the large extents and fluxes claimed by Huchtmeier et al. (1981) from the Effelsberg observations.

A tilted ring model is fitted to the HI velocity fields to derive the rotation velocities. We measure the RCs of Sextans A and B out to 3.5 and 4.0 kpc respectively. The RCs of both galaxies are seen to decline at outer radii. For Sextans A, we calculate a mean $V_{sys} = 342 \pm 0.6$ km.s$^{-1}$, P.A. = 34$^\circ$, and inclination = 86$^\circ$ while $V_{sys} = 302 \pm 0.9$ km.s$^{-1}$, P.A. = 57$^\circ$, and inclination = 49$^\circ$ are calculated for Sextans B.

Using the observed RCs as mass model inputs show that the galaxies have a higher fraction of dark matter compared to luminous matter (gas and stars). For Sextans A, the ISO DM model reproduces better the observed RC than the NFW model. In the case of Sextans B both DM models fail to represent properly the data but with a slightly better fit for the ISO model with a M/L of 0.2. Better mass model fittings are obtained when the stellar disk does not contribute significantly to the rotation curve. Fixing the M/L to a predetermined value of 0.2 (Lelli et al. 2016) produces better fits than using high M/L values of 0.9 and 0.8 for Sextans A and B derived in the infrared band using the WISE colors. For both galaxies, the MOND model produces better fit when $a_0$ is allowed to vary. This poses a challenge as $a_0$ should be considered as a universal constant.

Regions of star formation in Sextans A and B are better explained using the cloud-growth criteria based on shear.
Figure 17. Shows the gas surface density, black solid line (corrected for helium), the green dashed line shows the critical density derived using the Kennicutt (1989), and the red dash-dotted line shows the critical density as derived by Hunter et al. (1998).

as compared to the Toomre-Q criterion, as was found previously for NGC 6822 (Namumba et al. 2017)

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Figure 19. The radial variation in the ratios of the observed gas surface density to the critical densities for Sextans B. The top panel shows the ratio $\alpha_c = \Sigma_{HI}/\Sigma_c$ calculated using the Toomre-Q while the bottom panel shows the ratio $\alpha_{c,A} = \Sigma_{HI}/\Sigma_{c,A}$ calculated using cloud-growth criteria based on shear. The red dashed line shows $\alpha_Q = 0.63$, the median value from Kennicutt (1989) above which the gas density is high enough for large scale star formation.

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