Flat Rotation Curves of $z \sim 1$ Star-Forming Galaxies and Evidence of Disk-Scale Length Evolution

Gauri Sharma,1,2,3,5* Paolo Salucci,1,2,3 C. M. Harrison,4 Glenn van de Ven,5 Andrea Lapi1,3

1SISSA International School for Advanced Studies, Via Bonomea 265, I-34136 Trieste, Italy
2QGSKY, INFN-Sezione di Trieste, via Valerio 2, I-34127 Trieste, Italy
3IFPU Institute for Fundamental Physics of the Universe, Via Beirut, 2, 34151 Trieste, Italy
4School of Mathematics, Statistics and Physics, Newcastle University, Newcastle upon Tyne, NE1 7RU, UK
5Department of Astrophysics, University of Vienna, Türkenschanzstrasse 17, 1180 Wien, Austria

ABSTRACT
We investigate the shape of the Rotation Curves (RCs) of $z \sim 1$ star-forming galaxies and compare them with the local star-forming galaxies. For this purpose, we have used 409 galaxies from the K-band Multi-Object Spectrograph (KMOS) for Redshift One Spectroscopic Survey (KROSS). This sample covers the redshift range $0.57 \leq z \leq 1.04$, effective radii $0.69 \leq R_e [kpc] \leq 7.73$, absolute H-band magnitude $-24.46 \leq M_H \leq -18.85$ with median stellar mass $log (M_\star [M_\odot]) = 9.95$ and median total star-formation rate $log (SFR_{tot} [M_\odot yr^{-1}]) = 1.49$. Using 3D BAROLO (Barolo), we extract $H\alpha$ kinematic maps and corresponding Rotation Curves (RCs). The main advantage of Barolo is that it incorporates the beam smearing in the 3D observational space, which provide us with the intrinsic rotation velocity even in the low spatial resolution data. Using Asymmetric Drift Correction (ADC), we have corrected the RCs for the pressure gradient effect, which seems to be a more dominant effect than beam smearing in high-$z$ galaxies. Nearly all objects ($0.1 < v/\sigma < 15$) are affected by the pressure gradient, and we noticed that ADC improves the rotation velocity of these systems by $\sim 10 - 87\%$. Only a combination of the three techniques (3D-kinematic modelling + 3D-Beamsmearing correction + ADC ) yields the intrinsic RC of an individual galaxy. Further, we present the co-added RCs constructed out of 237 high-quality objects to obtain intrinsic RC shapes out to $6.4 \times$ disk scale length. We do not see any change in the shape of RCs with respect to the local star-forming disk-type galaxies. In contrast, we do find a significant evolution in the stellar-disk length ($R_\psi$) of the galaxies. Therefore, we conclude stellar disk evolves over cosmic time while total mass distribution stays constant.

Key words: galaxies: kinematics and dynamics;— galaxies: disk-type and rotation dominated; — galaxies: evolution; — galaxies: Dark Matter halo

1 INTRODUCTION
In the late 1980s Rubin et al. (1980) and Bosma (1981) has published the most explicit observational evidence of non-Keplerian Rotation Curves (RCs) of spiral galaxies. These findings have revolutionized the field of Astronomy & Astrophysics as well as Cosmology, by involving the existence of a dark particle (Dark Matter) necessarily beyond the standard model of elementary particles. Since then, DM became the building block of the current cosmological model so as the formation and evolution of all the structures in the Universe (Padmanabhan 1993; Springel et al. 2005). It keeps the $\approx 24\%$ energy budget of the Universe (Freedman & Turner 2003), despite the facts of "no success" in the discovery of its particle.

In the local Universe, using the shape of RCs we have a fair understanding on the nature of Dark Matter (DM) and its contribution to the Galaxy Formation and Evolution (e.g., Rubin et al. 1980; Persic & Salucci 1990; Persic et al. 1996; Salucci & Burkert 2000; Salucci et al. 2007; Reyes et al. 2011; Read et al. 2016; Karukes & Salucci 2017; Lapi et al. 2018b). Whereas at high-redshift (high-$z$) a few novel work Lang et al. (2017); Genzel et al. (2017) was claiming the 'declining RCs' and 'low DM fraction in the central region of galaxies’ respective to the locals. These results are very significant for Galaxy formation and Evolution theory, as well as strongly questioning the role of DM in the galaxy evolution. However, later several studies came in contrast with this claim, (e.g., Drew et al. 2018; ÅdJbler et al. 2019; Tiley et al. 2019) explaining such an outcome is due to particular normalization scale of RCs or due to ‘Beamsmearing effect’. Some studies also suggest
that declining RCs could be a consequence of perturbed or turbulent Inter-Stellar Medium (ISM) conditions at high-z (Burkert et al. 2016; Belli et al. 2016). Therefore, at high-z, the understanding of Dark Matter and its interplay in the Galaxy Formation & Evolution is still under progress and remain controversial due to observational uncertainties (e.g., low resolution, small angular size lead to the beam smearing) and the underlying physical effects, e.g., turbulent pressure gradient (Valenzuela et al. 2007; Weijmans et al. 2008; Read et al. 2016; Wellons et al. 2019). In this article, we intend to reproduce the intrinsic shape of RC of high-z galaxies by disentangling the observational uncertainties in 3D-space as well as accounting the physical effects in the analysis of RCs. For the same purpose, we have taken the data of K-band Multi-Object Spectrograph (KMOS), which is a new generation instrument mounted with Integrated Field Spectrograph (IFS). An IFS is equipped with an Integrated Field Unit (IFU), which is capable of imaging as well as spectroscopy with spatially resolved spectra. In the last decade, advance use of IFS has opened the several possibilities of studying the spatially resolved kinematics and dynamics of galaxies. Nowadays, several surveys have used the IFS mounted with new generation IFUs such as surveys with Multi-Unit Spectroscopic Explorer (MUSE: Bacon et al. 2010), K-band Multi-Object Spectrograph (KMOS: Sharples 2014), the Spectrograph for Integral Field Observations in the Near Infrared (SINFONI: Eisenhauer et al. 2003), KMOS Redshift One Spectroscopic Survey (KROSS: Stott et al. 2016, survey data used in this work), KMOS3D (Wisnioski et al. 2015).

Although, IFUs have shown the remarkable progress in the field; however, due to the small angular size of high-z galaxies, IFUs are constrained to attain required spatial resolution. Without Adaptive Optics (AO), an IFU can achieve only $0.5 - 1.0′$ spatial resolution, whereas, a galaxy from $z \sim 1$ has a typical angular size of $2′′ - 3′′$. In this situation, the Point Spread Function (PSF) which determines the spatial resolution is highly uncertain within $\sim 1′′$ (i.e. $\sim 8$ kpc at $z \sim 1$). In other words, the finite beam size causes the line emission to smeared on the adjacent pixels. As a consequence, the gradient in the velocity fields tend to become flattened, and line emission began to broaden, which creates a degeneracy in the calculation of rotation velocity and velocity dispersion. This effect in observations referred to “Beam Smearing”, which affects the kinematic properties of the galaxies, i.e., underestimated rotation velocity and overestimated velocity dispersion. The same scenario has been seen in HI observations (Bosma & Van der Kruit 1979; Begeman 1989) of local spiral galaxies. In this work, beam smearing problem has treated using the $3D$BAROLO code (Teodoro & Fraternali 2015), which allows $3D$fitting of datacubes and incorporates the beam smearing correction in $3D$ observational space ($x,y,\lambda$), where ($x,y$) representing spatial axis and $\lambda$ is spectral axis coordinate. The details of the kinematic modelling with $3D$BAROLO is explained in Section 3.

On the other hand, in the high-z galaxies, Inter-Stellar Medium (ISM) is highly turbulent (Burkert et al. 2010; Wellons et al. 2019), this turbulence in the ISM induces a force against gravity in galactic disk via radial gradient which suppresses the rotation velocity of gas and stars. This effect is generally referred as ‘Asymmetric Drift’ or ‘turbulent pressure gradient’. Which is generally negligible in rotation dominated galaxies (late-type galaxies) but significantly observed in the local dwarfs and early-type galaxies (e.g., Valenzuela et al. (2007); Read et al. (2016); Weijmans et al. (2008)). Therefore, highly turbulent ISM conditions at high-z make it prominent to disentangle, specifically, in the case of dynamical mass modelling and DM studies. Otherwise, one may lead to the declining rotation curves (as shown in: Lang et al. 2017; Genzel et al. 2017). In our work, we are dealing with Asymmetric Drift Correction (ADC) using the approach published in Weijmans et al. (2008), and it is explained in Section 3.2.

Our work is essential because, in the previous studies, authors have not paid attention to beam smearing correction and ADC (Lang et al. 2017; Genzel et al. 2017). In particular, Tiley et al. (2019) presented a sharp contradiction with Lang et al. (2017); Genzel et al. (2017) work with a more substantial amount of data set and by including beam smearing in the outer region of RCs. However, firstly the Tiley et al. (2019) has used a 2D approach of beam smearing correction, which claimed not be effective while dealing with 3D-data (Di Teodoro et al. 2016). Second, they have not corrected the RCs for Asymmetric Drift (AD) which is more dominant in high-z than the beam smearing effect (see section 3.2). Therefore, it is difficult to compare their $z \sim 1$ RCs with local RCs as well as the conclusion on the dark and luminous matter will not be one-to-one since environmental conditions are not on the same plane (due to no AD correction). However, in this work we have rigorously taken into account: 1) 3D-approach for beam smearing correction since we are dealing with 3D-data; 2) Asymmetric Drift Correction, to achieve the similar environmental conditions for $z \sim 1$ galaxies as $z \approx 0$. Such a combined methodology is allowing us an unbiased study of the dark and luminous matter in high-z systems, which is most likely giving us a piece of viable information on the nature of DM and its relationship with galaxy evolution (discussed in Section 4).

To conclude, our work is mainly focused on obtaining the true shape of RCs of high-z galaxies by rectifying the beam smearing as well as turbulent pressure gradient. The article organized as follows: In Section 2, we describe the sample used in this work; Section 3, contains a brief discussion on the kinematic modelling using $3D$BAROLO code and Asymmetric Drift Corrections; In the Section 4, we have discussed the main results, shown the shape of RCs, and their comparison with locals RCs; Section 5 contains a summary of the work. In this work, we have assumed a flat ΛCDM cosmology with $\Omega_m = 0.27$, $\Omega_\Lambda = 0.73$ and $H_0 = 70$ km s$^{-1}$.

2 DATA

We have studied the publicly available KMOS-Redshift One Spectroscopic Survey (KROSS) data to understand the Dark Matter scenario in high-z rotation dominated star-forming galaxies (most likely disk-type galaxies). KROSS is mainly aimed to study the $z \sim 1$ Star-Forming Galaxies (SFGs). The details of the observations can be found in the first and foremost papers of KMOS (e.g., Stott et al. 2016; Harrison et al. 2017; Tiley et al. 2019). However, we have given a short overview in the following subsections.

2.1 KROSS

KROSS is an Integrated Field Spectroscopic (IFS) survey using the KMOS instrument on ESO/VLT. KMOS consists of 24 Integrated Field Units (IFUs); those can be placed within 7.2 arc-minutes diameter field. Each IFU covers the $2.8′′ \times 2.8′′$ in size with 0.2′′ pixels. The targets for the survey are selected from extragalactic deep field covered by multi-wavelength photometric and spectroscopic data: 1) Extended Chandra Deep Field Survey (E-CDFS; Giacconi et al. 2001; Lehmer et al. 2005), 2) Cosmic Evolution Survey (COSMOS: Scoville et al. 2007), 3) Ultra-Deep Survey (UKIDSS: Lawrence et al. 2007), 4) SA22 field Steidel et al. (1998). Some of
the targets were selected from CF-HiZELS survey (Sobral et al. 2015). The targets were selected such that the Hα emission is shifted into J-band. The median redshift of parent sample (KROSS full data) is \(z = 0.85^{+0.11}_{-0.04}\). The median J-band seeing of observations was 0.79″ with 92 percent of the objects were observed during seeing < 1″. Individual frames have exposure times of 600 sec and a chop to sky was performed every two science frames. The data were reduced using ESOREX/SPARK pipeline (Davies et al. 2013) and flux calibration is performed using standard stars which has been observed during same night as science data. The end product of the process is 3D datacube consists of two spatial axis and one spectral axis of 2048 channels (e.g., 3D datacube = \(x, y, \lambda\)). These datacubes are capable of producing spectrum, the line and continuum images and the moment maps (see: Stott et al. 2016). Since mid-2019, this data is publicly available at KROSS-website\(^1\).

2.2 Sample Selection

We are mainly focusing on the 586 KROSS sample studied by Harrison et al. (2017, hereafter H17). We have selected 409 out of 586 objects on the bases of integrated H\(\alpha\) flux cut (\(F_{H\alpha} > 1.5 \times 10^{-17}\ erg\ s^{-1} cm^{-2}\)) to keep the high signal-to-noise (S/N) and confident detection of H\(\alpha\)-emission line in our sample. The characteristic of analysed sample is the following (with respect to TableA1 of H17): 1)AGN-flag is zero i.e., no evidence for an AGN contribution to the H\(\alpha\) emission-line profile ; 2)H17 Quality-flag 1, 2, and 3, i.e., only H\(\alpha\)-emission line detected objects; 3)We are adopting the values of effective radii (\(R_e\)), photometric position angle (PA), photometric inclination angle (\(\theta_i\)), absolute H-band magnitude (\(M_H\)), K-band AB magnitude (\(K_{AB}\)), z-band AB magnitude (\(z_{AB}\)), H\(\alpha\) luminosity (\(L_{H\alpha}\)), H\(\alpha\) flux (\(F_{H\alpha}\)), and redshift (\(z\)). In the work of Harrison et al. (2017), position angle (PA) and inclination angle (\(\theta_{in}\)) estimated by fitting the two-dimensional Gaussian model to the broad-band images. They compared their PA and \(\theta_{in}\) with van der Wel et al. (2012) which fits Sérsic models to the H\(\alpha\) near-infrared images using GALFIT that incorporates PSF modelling. Their calculations were in agreement with the GALFIT results and those derived using two-dimensional Gaussian fitting method. Moreover, PA and \(\theta_{in}\) for COSMOS targets with I-band images were cross-checked with Tasca, L. A. M. et al. (2009) who derived the PA and \(\theta_{in}\) using the axis ratios. The effective radii (\(R_e\)) is measured form the broad-band images by deconvolving the PSF and semi-major axis of the aperture which contains half of the total flux. Since the broad-band images are observed in I, \(I^\prime\), \(H\) and \(K\) bands (depends on the surveys goal and instrument facility) therefore, the targets where the images are in I and \(I^\prime\) band, a systematic correction factor of 1.1 is applied in \(R_e\) to account the colour gradient (for details see Harrison et al. 2017). The crude approach of colour correction applied because HST images were not available for all the targets. The \(R_e\) and \(z\) distribution of final sample is shown in Figure 1. This sample have median redshift \(z = 0.85^{+0.13}_{-0.04}\) median observed H\(\alpha\) luminosity \(\log (L_{H\alpha} [\ erg\ s^{-1}]) = 41.47 \pm 0.32\) and median effective radii \(\log (R_e [\ kpc]) = 0.45^{+0.42}_{-0.34}\).

3 METHODS

As we mentioned earlier in the introduction, previous KMOS work with large samples looking at rotation curve shapes did not do full 3D-modelling of the datacubes. Instead, they extracted the one-dimensional velocity profiles \(V(R)\) along the major kinematic axes of 2D velocity maps. Even the beam smearing corrections were applied with simple systematic corrections using the technique discussed in Johnson et al. (2018). In our work, we followed the rigorous approach for kinematic modelling as well as full 3D beam smearing corrections on individual galaxy using 3DBAROLO tool. In the section below, we are briefly explaining the 3DBAROLO, which is used in kinematic modelling, extracting velocity profile (so-called rotation curves) as well as rectifying the beam smearing from the datacubes. We have also discussed the Asymmetric Drift Correction (ADC) technique used in disentangling the turbulent pressure gradient from Barolo generated RCs.

\(^1\) http://astro.dur.ac.uk/KROSS/data.html
any functional evolution of kinematic quantities (e.g., Barolo is based on “tilted ring model,” i.e., the motion of the gas dominated in the inner region of the galaxies and relatively in the outskirts. We specifically see this effect in the high-z galaxies due to their small angular size. Therefore, we are following the 3D approach.

3.1 KINEMATIC MODELLING WITH 3D-BAROLO

We have modelled the kinematics of our samples using 3D-Barolo code (Teodoro & Fraternali 2015). The main advantage of modelling the datacube with 3D-BAROLO is that it incorporates the instrumental and atmospheric effects (i.e., the point spread function (PSF) which determines the spatial resolution and line spread function (LSF) which corresponds to spatial broadening). Then compare the data and model in 3D observational space (for details see: Teodoro & Fraternali 2015; Di Teodoro et al. 2016). While, It is not possible in 2D kinematic modelling of the datacubes and hence the resultant Rotation Curves (RCs) are strongly beam smearing dominated in the inner region of the galaxies and relatively in the outskirts. We specifically see this effect in the high-z galaxies due to their small angular size. Therefore, we are following the 3D approach to determine the kinematics of 3D-data using 3D-BAROLO (hereafter Barolo). In the section below, we have discussed the Barolo’s underlying assumptions, its initial requirements for performing the kinematic modelling, and the very first results on a large dataset.

3.1.1 Basic assumption under 3D-BAROLO

Barolo is based on “tilted ring model,” i.e., the motion of the gas and stars is assumed to be in circular orbits. It does not assume any functional evolution of kinematic quantities (e.g., $v_{rot}(R) \propto \arctan(R)$). Therefore, free parameters in Barolo are not forced to follow any parametric form, rather estimated in the annuli of increasing distance from the galaxy centre without making any assumption on their evolution with radius. Moreover, Barolo uses the radial binning for the velocity measurement, which is certainly necessary for high-z observations where current instrument response is moderate for S/N. The number of pixels used per bin depends on the choice of NRADII and RADSEP in the fitting. Therefore, each position velocity diagrams have nearly 3-6 rotation velocity measurements only (similarly for velocity dispersion). The non-parametric approach makes Barolo robust and reliable to use, and this is one of the reasons we are using Barolo for kinematic modelling. There are other high-z 3D kinematic modelling code, e.g., 1) GalPak 3D (Bouchê et al. 2015), which is successfully tested on $z \sim 0.5$ galaxies observed from Multi-Unit Spectroscopic Explorer (MUSE) but it follows the parametric approach. 2) BLoBBY3D (Varidel et al. 2019), which is tested on 20 local star-forming galaxies from SAMI Galaxy Survey. It is a useful tool to study the gas dynamics of high-z low-resolution data. However, it comes with a long list of free parameters, which one may not know in prior without detailed study of system.

3.1.2 Initial requirements of 3D-BAROLO

The modelling of Barolo requires three geometrical parameters, i.e. co-ordinate of galactic centre in datacube $(x_c, y_c)$, inclination angle $(i)$, position angle (PA) and three kinematic parameters i.e., redshift $(z)$, rotation velocity $(v_c)$ and velocity dispersion of ionized gas $(\sigma_{HI})$. In our modelling, we fix the geometrical parameters and redshift (with an exception on PA, discussed below) and free the two kinematic parameters $(v_c$ and $\sigma_{HI})$. The $x_c$ and $y_c$ are the photometric galactic centre positions adopted from H17. Barolo comes with several useful task particularly required/useful for high-z low S/N data (see Barolo documentation2). We are using 3DFIT task of Barolo for performing the kinematic modelling. First, Barolo produced the mock observations on the bases of given initial conditions in 3D observational space $(x,y,\lambda)$. Where $(x,y)$ stands for spatial axis and $\lambda$ is spectral axis coordinate. These models then fitted to the observed datacube in the same 3D-space accounting the beam smearing simultaneously. A successful run of Barolo delivers the beam smearing corrected moment maps, stellar surface brightness profile, rotation curve (RC), dispersion curve (DC) along with the kinematic models. Barolo is well tested on local systems (Teodoro & Fraternali 2015) as well as on the high-z galaxies including the data from K MOS (see: Di Teodoro et al. 2016).

The position angle (PA) is usually fixed to photometric PA ($PA_{phot}$) adopted from H17 catalog, but for nearly 37% objects, $PA_{phot}$ doesn’t allow to extract position-velocity (PV) diagram (example shown in Appendix A2). We know that $PA_{phot}$ and $PA_{kin}$ are not necessarily the same. That is why for these objects, PA is set to free and estimated from Barolo kinematic modelling. In our work, PA calculated form kinematic modelling referred to as kinematic position angle ($PA_{kin}$).

2 Number of rings used in fitting the galaxy
3 Separation between rings in arcsec
4 https://barolo.readthedocs.io/en/latest/
The analysed sample was selected on the basis of the Hα flux and residuals. Moreover, in total, we have 97 Quality-1, 149 Quality-2 and 163 Quality-3 objects. The Quality-3 galaxies are discarded from the analysis of rotation curves.

In Figure 5, we have shown a few examples of the BAROLO outputs. From left to right, broad-band high-resolution image, Hα-image, first-moment map (rotation velocity map), second-moment map (dispersion velocity map), rotation curve, and dispersion curve. In detail, COL 1: Broad-band image is constructed from ground and space-based photometric observational data (discussed in Section 2.1). The central photometric coordinate (galactic centre: $x_0^p, y_0^p$) of the object is shown by a black cross, which is calculated by fitting the 2D Gaussian to the 2D distribution of the data. The size of each image can be inferred in terms of $10 \times 10$ pixel size converted to arcsec (displayed on the bottom left of the image). The size of broad-band images varies from image-to-image due to multi-wavelength data and different photometric surveys. COL 2: Integrated Hα-image constructed from KMOS 3D datacube. The size of the image is displayed in arcsec by drawing the horizontal and vertical black line. The name of the galaxy is displayed on the upper-left corner, and the quality is displayed on the lower-left corner of the image. COL 3.4: Moment-1 map and Moment-2 map, these moment maps are the output of Barolo kinematic modelling. The position angle of the image is shown by the black-grey dashed line. The black cross represents the galactic centre positions adopted from the work of Harrison et al. (2017). COL 5.6: Rotation curve (RC) & Dispersion curve (DC), constructed after a comparison of data and model in 3D-space (output from Barolo). In the Rotation curve, the red contour is the model and the black shaded area with and blue contour represents the data. The orange squares with error bars are best-fit to the rotation velocity and velocity dispersion. The yellow, blue and red vertical dashed lines are representing the effective radius ($R_e$), optical radius ($R_{opt} = 1.89 R_e$), twice optical radius ($R_{2opt} = 3.78 R_e$) respectively. The size $Hα$-image is always $2.8'' \times 2.8''$, so the spatial length of the moment maps, rotation and dispersion curve. In some cases, even though $R_e$ is $1.6 \text{kpc}$ (i.e., $0.2 \text{arcsec}$) but RCs are extended more than $16 \text{kpc}$ (i.e., $2.0 \text{arcsec}$), it is due to $Hα$-image can trace the light up-to large radii in comparison to broad-band filters. A full version of Figure 5 is attached in the external appendix.

### Results from 3D BAROLO

The analysed sample was selected on the basis of $Hα$ flux cut ($F_{Hα} > 1.5 \times 10^{-17} \text{erg} \text{s}^{-1} \text{cm}^{-2}$) to keep the High S/N. Now the quality of 3D-BAROLO output is defined qualitatively on the bases of visual inspection of each object. The reason of qualitative assessment are many, but here we are giving a few: 1) galaxy with high flux/luminosity might be affected by atmospheric conditions which sometimes create problems in masking data, in some cases, high $Hα$ flux data is lost due to skylines. 2) Even if the flux is low but having perfect sky conditions may allow collecting good data. 3) RMS error does not depend on the S/N only, but its a combination of S/N, position angle, comparison plane of data-to-model etcetera. That is why, so far, we did not find any quantitative way of assigning the quality of this data. An example of a qualitative assessment of objects shown in Figure 2. The galaxies with good moment map plus good RC is specified to Quality-1 shown in the first row of the figure; the galaxies with reasonably good RC and moment map are given Quality-2 shown in the middle row; galaxies with Quality-3 has bad moments maps and RCs, shown in the lower row. Furthermore, in Figure 3 we have shown the distribution of Quality-1, 2, & 3 objects in the Mean Square Error (RMSE) and $Hα$ luminosity plane (upper & lower panel respectively). The RMSE shown here is calculated from the modelled and observed PV-diagrams but we have also done the same practice on modelled and observed velocity maps. It is clear from the distribution that it is not possible to separate the qualities on the bases of $Hα$ flux and residuals. Moreover, in total, we have 97 Quality-1, 149 Quality-2 and 163 Quality-3 objects. The Quality-3 galaxies are discarded from the analysis of rotation curves.

#### Asymmetric Drift Correction

A significant amount of Barolo generated RCs are showing a strong asymmetry and rapid fall in the outskirts of galaxies. Which may not be an observational uncertainty because we are rectifying all the possible systematics. Therefore, we thought such a rise and fall could be due to physical effect such as low Dark Matter fraction (Genzel et al. 2017) or could be an impact of turbulent pressure gradient (Wellons et al. 2019). Current studies are in contrast with low Dark Matter fraction scenario (e.g., Burkert et al. 2016; Belli et al. 2016; ÅtJbler et al. 2019; Tiley et al. 2019) for $z \sim 1$ galaxies. However, the pressure gradient is a more convincing phenomenon as it is observed in the local dwarf and early-type galaxies (e.g., Valenzuela et al. 2007; Read et al. 2016; Weijmans et al. 2008), which suppresses the rotation velocity of the gas.

If the ISM is highly turbulent (which is the case for high-z galaxies Burkert et al. 2010), then the turbulence induces a force against gravity in galactic disk via radial gradient, which is generally referred to as 'Asymmetric Drift (AD)' or 'turbulent pressure gradient'. This effect is negligible in rotation dominated galax-
ies (late-type galaxies) unless the HI rotation curves of the dwarf galaxies. However, in the case of dynamical mass modelling and the Dark Matter (DM) studies of high-z galaxies, it is crucial to account AD. For the same purpose, we applied the Asymmetric Drift Correction (ADC) on entire set of RCs (Analysed sample of 409 objects), using the same technique as studied by Weijmans et al. (2008). For spherical symmetric potential, under the assumptions of Weijmans et al. (2008) asymmetric drift corrected circular velocity \( V_c^{ADC} \) can be defined as:

\[
V_c^{ADC} = \sqrt{V_k^2 - \sigma_R^2 \left[ \frac{\partial \ln \Sigma}{\partial \ln R} + \frac{\partial \sigma_v}{\partial \ln R} + \frac{1}{2} \left( 1 - \alpha_R \right) \right]} \quad \text{km s}^{-1}
\]

where \( V_k \) is observed line-of-sight (LOS) velocity, \( \sigma_R \) is observed velocity dispersion, \( \Sigma \) is surface brightness profile, and \( \alpha_R = \frac{\partial \ln v}{\partial \ln R} \) is the slope of velocity profile. In Figure B1, B2 & B3, we have shown a few examples of ADC on rising and falling RCs. A detailed discussion, mass modelling, and the importance of AD corrected RCs will be shown in follow-up paper G. Sharma et al. (in preparation).

4 RESULTS & DISCUSSION

To resume, we have 409 beam smearing corrected rotation curve, dispersion curve, and corresponding moment maps. Out of 409 samples, we have analysed only 246 Quality-1 & 2 objects; this sample is referred to as Q12 sample in the analysis. In this sample, we have 237 rotation dominated \((v/\sigma > 1)\) systems and 9 dispersion dominated \((v/\sigma \leq 1)\) systems, and we have calculated after ADC. A distribution of re-sampled data is shown in Figure 4. This sample keeps the objects with redshift range \(0.77 \leq z \leq 1.04\), effective radii \(-0.16 \leq \log (R_e [kpc]) \leq 0.86\), rotation velocity \(1.47 \leq \log [V_{out} [\text{km s}^{-1}]] \leq 2.84\), stellar mass \(8.3 \leq \log (M_* [M_\odot]) \leq 11.61\), and star formation rate \(0.66 \leq \log (SFR_{Halpha+NIR} [M_\odot \text{ yr}^{-1}]) \leq 2.42\).

4.1 Characteristic Velocity

For an exponential thin disk, the rotation curve of stellar component of a galaxy follows surface density: \( \Sigma_D (R) = \frac{M_D}{2\pi R_D^2} \exp \left( -R/R_D \right) \) (Freeman 1970), where \( M_D \) is disk mass and \( R_D \) is disk radii. Under this assumption, one can relate the scale length \((R_e)\) determined from light profile of the galaxy to compute the characteristic radii such as, disk length \((R_D = 0.39 \ R_e)\). In our work, we preferred to calculate velocities at three different characteristic radii: 1)Optical radius \((R_{opt} = 3.2 \ R_e)\); 2)\(R_{out}\) is twice \(R_{opt}\) (6.4 \(R_D\)) and 3)\(R_{80}\) i.e., radius where RC is presumably flat. The \(R_{opt}\) and \(R_{out}\) are the photometric measurements (derived from effective radii: \(R_e\)), whereas, \(R_{80}\) is the kinematic measurement. Referring the definitions of radii \(R_{opt}\), \(R_{out}\) and \(R_{80}\) corresponding velocities are \(V_{opt}\), \(V_{out}\) and \(V_{80}\). Since observed dispersion curves (of ionized gas) is mostly flat, so we have calculated the overall dispersion velocity \((\sigma)\) of the galaxy via weighted mean statistics (see: Equation 2). Note, the characteristic velocity measured from a AD corrected RCs are referred as \(V^{ADC}_{opt}\), \(V^{ADC}_{out}\) and \(V^{ADC}_{80}\). In Figure 6, we have shown a comparison of ADC and non-ADC rotation velocities computed at \(R_{out}\) \(V^{ADC}_{out}\) and \(V_{out}\) respectively. We have noticed that the without ADC some of the velocities are \(< 30 \text{ km s}^{-1}\) which is not physical, while after ADC these velocities are pushed-up towards higher values. We can see that if the system does not have sufficient rotation \((V_{out} < 100 \text{ km s}^{-1})\) then pressure gradient is a dominant effect, nevertheless effectively accounted by ADC technique. Moreover, if the system is rotation dominated, then ADC does not force to increase the rotation velocity. This is why we can see the strong correlation between \(V^{ADC}_{out}\) and \(V_{out}\) above 100 km s\(^{-1}\). In the Figure 7, we have shown the percentage of ADC correction calculated at optical radii \((q_{opt} = (V^{ADC}_{opt} - V_{opt})/V_{opt} \times 100)\) in the plane of velocity dispersion and \(v/\sigma\). We have noticed the percentage of correction is high for \(1 < v/\sigma < 15\) nearly 10-85%, while it is just

\( R_{80} \) is the characteristic radii which covers 80% of rotation velocity

---

\( \alpha_R = \frac{\partial \ln v}{\partial \ln R} \) ---

\( V_{out} \) ---

\( SFR_{Halpha+NIR} \) ---

\( M_\odot \) ---

\( M_* \) ---

\( \Sigma_D \) ---

\( \Sigma \) ---

\( \partial \ln \Sigma / \partial \ln R \) ---

\( \partial \sigma_v / \partial \ln R \) ---

\( \alpha_R \) ---

\( \sigma_R \) ---

\( V_k \) ---

\( V_c^{ADC} \) ---

\( V^{ADC}_{opt} \) ---

\( V^{ADC}_{out} \) ---

\( V^{ADC}_{80} \) ---

\( V_{opt} \) ---

\( V_{out} \) ---

\( V_{80} \) ---

\( R_{opt} \) ---

\( R_{out} \) ---

\( R_{80} \) ---

\( \Sigma_D (R) = \frac{M_D}{2\pi R_D^2} \exp \left( -R/R_D \right) \) (Freeman 1970) ---

\( \log (M_* [M_\odot]) \leq 11.61 \) ---

\( \log (SFR_{Halpha+NIR} [M_\odot \text{ yr}^{-1}]) \leq 2.42 \) ---

\( 0.77 \leq z \leq 1.04 \) ---

\( -0.16 \leq \log (R_e [kpc]) \leq 0.86 \) ---

\( 1.47 \leq \log [V_{out} [\text{km s}^{-1}]] \leq 2.84 \) ---

\( 8.3 \leq \log (M_* [M_\odot]) \leq 11.61 \) ---

\( 0.66 \leq \log (SFR_{Halpha+NIR} [M_\odot \text{ yr}^{-1}]) \leq 2.42 \) ---

\( R_{opt} = 3.2 \ R_e \) ---

\( R_{out} \) is twice \( R_{opt} \) (6.4 \( R_D\)) and 3)\( R_{80}\) ---

\( R_{80} \) is the kinematic measurement.
Figure 5. Figure Shows a few outputs of kinematic modelling using 3D BAROLO. COL 1: Broad-band image, where black cross shows the central coordinates of the photometric image. The horizontal and vertical white lines in the lower-left corner are showing the $10 \times 10$ pixel size in arcsec (an estimator of image-size). COL 2: Integrated H$\alpha$-image from datacube, the size of the image is shown by black horizontal and vertical lines. The name of the galaxy is shown in the upper left corner and quality is mentioned in the lower left corner. COL 3-4: First and second-moment map, black-grey dashed line is showing position angle, and the black cross represents the galactic centre. COL 5: Rotation curve, the black shaded area with blue contour represents the data while the red contour referring to model and orange squares with error bars are best-fit velocity measurements. COL 6: Best-fit velocity dispersion. The yellow, blue and red vertical dashed lines are representing the effective radius ($R_e$), optical radius ($R_{opt} = 1.89 R_e$), twice optical radius ($R_{out} = R_{2opt} = 3.78 R_e$) respectively.
velocity by tentatively saying, beam smearing has increased the median rotation dominant effect in the high-\(z\) system than beam smearing. Quantitatively, we found the median rotation velocity by our ADC correction is higher than its initial value by more than the 50\% from its initial value. Scatter in the plot could be due to the particular intrinsic properties of individual galaxies. However, detailed aspects of ADC will be discussed in the follow-up paper.

\[ X = \frac{\sum x_i w_i}{\sum w_i} \times w_j \]

where, \(x_i = \text{data}; \quad w_i = \text{error}; \quad X = \text{binned data} \]

\(5 - 10\%\) for \(v/\sigma > 15\). Which clearly shows that the AD is more dominant effect in the high-\(z\) system than beam smearing. Quantitatively speaking, beam smearing has increased the median rotation velocity by \(10 - 12\ km\ s^{-1}\) (similarly observed by Johnson et al. 2018), whereas ADC has increased the median rotation velocity more than the 50\% from its initial value. Scatter in the plot could be due to the particular intrinsic properties of individual galaxies. However, detailed aspects of ADC will be discussed in the follow-up paper.

4.2 Co-added Rotation Curves

Here, we have presented the four co-added and binned RCs constructed from 237 individual RCs. We have performed the co-addition on ADC and non-ADC RCs. The technique of co-adding and binning is the following: first, we batch the RCs according to their dynamical velocity corresponding to \(R_{out}\), where Dark Matter is expected to be dominating. Then we treat each batch of the RCs as a single co-added RC. Second, we bin the galaxies radially at each 2.5 \(kpc\) correspond to the binning scale of Barolo. For the binning, we have used standard weighted mean statistic (using equation 2), and errors are standard Root Mean Square Error (RMSE). We are using such a statistical approach because it has plausible advantages on the RC studies, such as a) It gives us a smooth distribution of RC without accounting the random fluctuations arises by bad data points, i.e. virtually enhances the S/N in data; b) It allows mass decomposition of similar velocities but having different spatial sampling. This kind of approach in RC studies has been used from decades, pioneered by Persic & Salucci (1991) later developed in several other works (Persic et al. 1996; Salucci & Burkert 2000; Salucci et al. 2007; Catinella et al. 2006; Yegorova et al. 2011; Karukes & Salucci 2017; Lapi et al. 2018b). In detail, we have constructed the co-added binned RCs for four-velocity bins defined as following:

(i) bin\(_{50-100}\): \(V_{out}\) lies between 50 to 100 \(km\ s^{-1}\), contains 42 RCs, total 197 data-points (dps).
(ii) bin\(_{100-150}\): \(V_{out}\) lies between 100 to 150 \(km\ s^{-1}\), contains 52 RCs, total 245 dps.
(iii) bin\(_{150-200}\): \(V_{out}\) lies between 150 to 200 \(km\ s^{-1}\), contains 59 RCs, total 303 dps.
(iv) bin\(_{200-250}\): \(V_{out}\) lies between 200 to 250 \(km\ s^{-1}\), contains 15 RCs, total 70 dps.

In the Figure 8, we have shown the co-added rotation curve before and after Asymmetric Drift Correction (ADC). The Upper Row shows the RCs before ADC and Lower Row shows the after ADC on RCs. From Left to Right, bin\(_{50-100}\): orange colour, bin\(_{100-150}\): khaki, bin\(_{150-200}\): blue, and bin\(_{200-250}\): pink (colour codes are same always for each bin). The statistical test shows that the scatter in the circular velocities \((V(R))\) in AD corrected RCs reduced with a factor of 1.5 respective to non-ADC RCs. From representation, ADC and non-ADC RCs appeared the same, but statistical results (variance and standard deviation) of AD corrected RCs wins over non-ADC RCs (shown by \(\delta\) in the legend of each bin). We can see that the final AD corrected RCs are not falling in the outskirts, neither they have strange wiggles in the inner regions of RC (detailed discussion will be shown in G. Sharma et al. 2020 in prep.).

Next, we have compared the co-added and binned RCs (ADC applied) of \(z \sim 1\) with local \((z \approx 0)\) RCs of same velocity bins derived from the Universal Rotation Curves (URC: studied by Persic et al. 1996; Salucci et al. 2007), shown in Figure 9. Form the figure; It is clear that the \(z \sim 1\) and \(z \approx 0\) RCs are similar, they are overlaying on each-other (despite the small deviation in low-velocity bin). Therefore, we can say that the total potential \((\phi(R))\) or total mass is same in \(z \sim 1\) and \(z \approx 0\) star-forming galaxies and it does not evolve over past 10 Gyr. Note, we are not sensitive within 5 \(kpc\) due to low spatial resolution. However, this does not stop us to conclude about the presence of dark matter, which dominates in the outskirts of galaxies (well known from local studies) and flatten the RCs. Figure 9 is an explicit representation of \(z \sim 1\) flat RCs, where RCs are flattening from optical radii out to the last point of observations. Thus we conclude that the DM plays a significant & similar role
Moreover, we want to emphasize that the high rotation dominated explore in the follow-up paper (G. Sharma et al. 2020 in prep.) how on such a representation of high-z galaxies will be discussed ∼today's Universe) with a time scale of stars and establishing the disk-like structures (those we observe in dominated systems, those evolved inside-out transforming gas into is dominating; a) Presumably, star-forming galaxies at a) Most of the baryons are still in the form of gas, i.e. gaseous-disk component has not yet begun to evolve as a function of total mass or total potential of the halo. It could be a consequence of underlying 'complex' astrophysics of galaxy evolution. For example, a) Most of the baryons are still in the form of gas, i.e. gaseous-disk is dominating; b) Presumably, star-forming galaxies at z ∼ 1 are gas dominated systems, those evolved inside-out transforming gas into stars and establishing the disk-like structures (those we observe in today’s Universe) with a time scale of ∼ 10 Gyr. More why and how on such a representation of high-z galaxies will be discussed & explored in the follow-up paper (G. Sharma et al. 2020 in prep.). Moreover, we want to emphasize that the high rotation dominated (V_c > 150 km s^{-1}) system at z ∼ 1 evolves over cosmic time, while the slow rotators (V_c < 150 km s^{-1}) remains the same as the locals (see Figure 10). Therefore, we conclude that rotation plays an important role in galaxy evolution.

We suspect that a consequence size evolution (i.e. constant disk size at z ∼ 1) has reflected in the previous studies of normalized rotation curves (Lang et al. 2017; Genzel et al. 2017; Tiley et al. 2019). Generally, we normalize RCs such that the normalization scale covers most of the total baryons. For local Spirals this normalization is performed at the dynamical radius (R_{opt}) corresponding velocities (V_{opt}) to infer the Dark Matter presence (see: Persic et al. 1996; Lapi et al. 2018b). One can also choose another normalization scale according to the goal of the study, e.g., to infer the DM in the inner region (e.g., at R_e) of galaxies, one can normalize the RCs at inner radii. However, such normalization cannot not be trusted because most galaxies are baryon dominated from R_e to twice R_e. Although, in the case of high-z galaxies, we do not even have precise information about the distribution of baryons due to low spatial resolution. Therefore, normalization in the inner radii may lead to biased results of DM inference. For example, Lang et al. (2017); Genzel et al. (2017) has normalized the RCs at turnover radii to infer the DM in the inner region of galaxies and found declining RCs. We must also remind, their RCs were neither corrected for beam smearing nor AD. Therefore choosing the turnover radii as normalization parameter is risky. Whereas Tiley et al. (2019) has normalized the RCs at 3R_e and shown the flat RCs. In our work, we are not following the normalization approach at all. However, in Figure A1, we have shown a comparison of our normalized RC with Lang et al. (2017); Tiley et al. (2019). We have constructed the normalized RC by normalizing the individual RCs by the effective radius (R_e) of galaxies, one can derive the dynamical radius from the effective radius (R_e) as a rough estimate of the dynamical radius in z ∼ 1 galaxies.

Figure 8. Shows a comparison of non-ADC and ADC applied RCs, Upper and Lower row respectively. From Left to Right, bin_50-100: orange colour, bin_100-150: khaki colour, bin_150-200: blue colour, and bin_200-250: pink colour. The curves/lines are individual rotation curves, whereas binned rotation curves shown with hexagons connected with black lines in the same colour code. The median disk radii (V_c in km s^{-1}) is displayed in the title of each bin. The scatter in each co-added RC is shown by δ value in the upper left corner of each sub-plot. The digits in the bracket of the legend represent the number of RCs co-added in each bin, e.g., RCs(42), i.e. 42 individual RCs were co-added.
Figure 9. Shows a comparison of $z \sim 1$ RCs for four-velocity bins (dashed line connected hexagons) and $z \approx 0$ RCs of same velocity bins derived from the URC (solid line curves: Persic et al. 1996; Salucci et al. 2007). The colour code of each velocity bin is the same for $z \sim 1$ and $z \approx 0$ and given in the legend of the figure. The digits in the bracket of the legend represent the number of RCs co-added in each bin. Dotted and solid vertical lines are showing the $R_{\text{out}}$ and $R_{\text{opt}}$ resp. for each RC (colour coded same as velocity bins).

Figure 10. shows the disk radii of each velocity bin as a function of AD corrected $V_{\text{out}}$, the velocity bins are colour coded similarly as Figure 9. The hexagons with error bars represents the $z \sim 1$ galaxies and diamonds are showing the local galaxies relation.
at $3R_D$ (similarly as Tiley et al. 2019) and co-adding all the velocity bins. Our results are in fair agreement with the Tiley et al. 2019 work, specifically in the outer region ($3.5R_{opt}$-to-$6R_{opt}$), the inner region has shown discrepancy probably due to beam smearing and AD corrections. Whereas, Lang et al. (2017) RC stays apart and shows a different scenario, most probably due to different normalization scale (which we can not apply on our data because we are not sensitive within $5$ kpc) and AD. We emphasize that the stellar disk is not yet formed in $z \sim 1$ galaxies; therefore, the outer region of galaxies might be containing undetected baryons, those are in the gaseous form. That is why, the traditional approach of normalization is not applicable to infer the DM in $z \sim 1$ RCs. However, it gives us a piece of viable information about the ‘disk size evolution’ over cosmic time and a hint that ‘most likely gaseous disk is dominating in high-$z$-systems’. Moreover, comparing our co-added normalized RCs with previous studies validates that our method is pertinent in producing the shape of RCs.

5 CONCLUSION

In this work, we have analysed the KROSS parent sample (Stott et al. 2016; Harrison et al. 2017). These are IFU based (i.e., 3D data) $H_α$ detected star-forming galaxies of redshift range $0.57 \leq z \leq 1.04$. On the bases of $H_α$ flux cut $F_{H_α} > 1.5 \times 10^{-17}$ erg $s^{-1}$ cm$^{-2}$ ($F_{H_α}$ adopted from Harrison et al. (2017) catalogue), we have selected 409 galaxies for analysis. We have used the 3D BAROLO (Barolo) for kinematic modelling of these galaxies, which is also flexible in producing Rotation Curves. The main advantage of this tool is that incorporate the beam smearing corrections simultaneously with kinematic modelling in 3D-space. Thus allows us to determine the unbiased rotation velocity and intrinsic velocity dispersion even at low spatial resolution. Further, we have corrected the RCs for turbulent pressure gradient applying Asymmetric Drift Correction (ADC) (Weijmans et al. 2008). Beam smearing corrections using Barolo along with ADC allows us to reproduce the true shape of rotation curves. Furthermore, we have qualitatively selected the 246 galaxies (see: Section 3.1.3), out of which 237 galaxies are rotation dominated. In our work we are using these 237 rotation dominated galaxies. This sub-sample covers the redshift range $0.77 \leq z \leq 1.04$, absolute H-band magnitude $-24.46 \leq M_H \leq -19.01$, effective radii $0.16 \leq \log (R_e [kpc]) \leq 0.86$, and rotation velocity $1.47 \leq \log (V_{rot} [km s^{-1}]) \leq 2.84$. Using the technique of Persic et al. (1996), we have constructed the co-added RCs of four velocity bins out of 237 individual RCs and compared them with the RCs of local star-forming disk-type galaxies of same velocity bins (see: Section 4.2 and Figure 8 & 9). The main finding of this work is as following:

- A statistically robust approach of co-adding and binning RCs shows that the high-$z$ RCs are identical to the local RCs of star-forming galaxies (see Figure 9).
- We have noticed a significant evolution in the disk scale length with respect to locals (see Figure 10). Therefore we can say, at $z \sim 1$, the stellar disk of star-forming galaxies has not yet begun to evolve as a function of total mass or total potential of the halo.
- Asymmetric Drift is more dominant effect in high-$z$ galaxies as seen in local star-forming disk-type galaxies. Therefore, there is no room for ‘Low Dark Matter problem’ in high-$z$-star-forming systems. Due to low resolution in the inner region ($R < 5$ kpc) of RCs, the technique of mass modelling became cumbersome than the traditional approach (used in: Salucci et al. 2007; Lapi et al. 2018b).
- The dark matter core and cusp issue will be presented in the follow up paper.

Acknowledgements

G.S. thanks Enrico M. Di Teodoro and Luigi Danese for their fruitful discussion and immense support in the entire period of this work. GvdV acknowledges funding from the European Research Council (ERC) under the European Union’s Horizon 2020 research and innovation programme under grant agreement No 724857 (Consolidator Grant ArcheoDyn).

REFERENCES

Bacon R., et al., 2010, The MUSE second-generation VLT instrument. Society of Photo-Optical Instrumentation Engineers (SPIE) Conference Series, p. 773508, doi:10.1117/12.856027, https://ui.adsabs.harvard.edu/abs/2010SPIE.7735E..08B

Begeman K., 1989, Astronomy and Astrophysics, 223, 47

Belli S., Newman A. B., Ellis R. S., 2016, The Astrophysical Journal, 834, 18

Bosma A., 1981, The Astronomical Journal, 86, 1791

Bosma A., Van der Kruit P. 1979, Astronomy and Astrophysics, 79, 281

Bouché N., Carfantan H., Schroetter I., Michel-Dansac L., Contini T., 2015, The Astronomical Journal, 150, 92

Burkert A., et al., 2010, The Astrophysical Journal, 725, 2324

Burkert A., et al., 2016, The Astrophysical Journal, 826, 214

Catinella B., Giovannelli R., Haynes M. P., 2006, The Astrophysical Journal, 640, 751

Davies R., et al., 2013, Astronomy & Astrophysics, 558, A56

Di Teodoro E., Fraternali F., Miller S., 2016, Astronomy & Astrophysics, 594, A77

Drew P. M., Casey C. M., Burnham A. D., Hung C.-L., Kassin S. A., Simons R. C., Zavala J. A., 2018, The Astrophysical Journal, 869, 58

Eisenhauer F., et al., 2003, Proc. SPIE Int. Soc. Opt. Eng., 4841, 1548

Freedman W. L., Turner M. S., 2003, Rev. Mod. Phys., 75, 1433

Freeman K., 1970, The Astrophysical Journal, 160, 811

Genzel R., et al., 2017, Nature, 543, 397

Giovanelli R., et al., 2001, The Astrophysical Journal, 551, 624

Harrison C., et al., 2017, Monthly Notices of the Royal Astronomical Society, 467, 1965

Johnson H. L., et al., 2018, Monthly Notices of the Royal Astronomical Society, 474, 5076

Karukes E. V., Salucci P., 2017, Monthly Notices of the Royal Astronomical Society, 465, 4703

Lang P., et al., 2017, The Astrophysical Journal, 840, 92

Lapi A., et al., 2018a, The Astrophysical Journal, 857, 22

Lapi A., Salucci P., Danese L., 2018b, The Astrophysical Journal, 859, 2

Lawrence A., et al., 2007, Monthly Notices of the Royal Astronomical Society, 379, 1599

Lehner B. D., et al., 2005, The Astrophysical Journal Supplement Series, 161, 21
APPENDIX A: KINEMATIC AND PHOTOMETRIC POSITION ANGLES

If the position angle is correct, then kinematic modelling allows to extract PV-diagram symmetric on the x and y-axis, but if PA is wrong, then an asymmetry can be seen in PV-diagram. For nearly 37% objects \( \text{PA}_{\text{phot}} \) were having the wrong estimate. Therefore we decided to free the PA parameter in Barolo run particularly for these objects. The Barolo estimated PA are referred as \( \text{PA}_{\text{kin}} \) in the analysis. An example of kinematic modelling using \( \text{PA}_{\text{phot}} \) (when it is wrong) and \( \text{PA}_{\text{kin}} \) is shown in Figure A2. Upper panel shows the kinematics and rotation curve derived using \( \text{PA}_{\text{kin}} \), whereas Lower panel shows the kinematics and rotation curve derived from fixed \( \text{PA}_{\text{phot}} \). We can see that PV-diagrams drove from fixed \( \text{PA}_{\text{phot}} \) is asymmetric around x and y-axis, while this problem resolved if PA is free in the Barolo run. We are not keeping PA free to all objects because Brolo documentation suggests- ‘keep the number of free parameter low, specifically in low-resolution data’.

APPENDIX B: ADC EXAMPLES

Some Example of Asymmetric Drift Corrections (ADC) on the Barolo generated rotation curves.

This paper has been typeset from a TeX/LaTeX file prepared by the author.
Figure A2. Upper Panel: Kinematic modelling using $PA_{\text{kin}}$. Lower Panel: Kinematic modelling performed using $PA_{\text{phot}}$. COL 1: Integrated $H\alpha$-image from 3D datacube; COL 2: Rotation velocity map, where $PA_{\text{kin}}$ is shown by dotted dashed black-grey line, and $PA_{\text{phot}}$ is shown by solid grey line; COL 3: LOS rotation velocity curve; COL 4: Tangential velocity profile. In the PV-diagrams, the black shaded area with blue contour represents the data, the red contour is model, and orange squares with error bars are best-fit velocity measurements.

Figure B1. Figure Shows an example of ADC. Upper panel: left-to-right, first second and third-moment maps and corresponding broad-band image. Lower panel: left-to-right surface density, rotation velocity, dispersion velocity-profile and the enclosed mass profile. In moment1 map grey line is photometric position angle and black cross are galactic centre kinematic position $(x_p, y_p)$. The back cross in broad-band image is central photometric coordinate $(x_p, y_p)$. In the light profile and P-V diagram, orange squares with error bars are best fit data. In Rotation curve profile, brown squares connected with the black line is ADC corrected rotation velocity profile. In mass profile, blue squares connected via black line is the minimum mass derived from $V_{\text{rot}}$, while red squares connected with the black line is the dynamical mass profile calculated from $V_{\text{ADC}}$. 

MNRAS 000, 1–12 (2020)
Figure B2. ADC examples continue..
Figure B3. ADC examples continue.