



# MCMC ANALYSIS OF BIASES IN THE INTERPRETATION OF DISK GALAXY KINEMATICS.

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## ABSTRACT

The new generation of galaxy surveys like SAMI, CALIFA and MaNGA opens up the possibility of studying simultaneously properties of galaxies such as spiral arms, bars, disk geometry and orientation, stellar and gas mass distribution, 2D kinematics, etc. The previous task involves exploring a complicated multi-dimensional parameter space. Puglielli et al. (2010) introduced Bayesian statistics and MCMC (Monte Carlo Markov Chain) techniques to construct dynamical models of spiral galaxies. In our study we used synthetic velocity fields that include non-circular motions and assume different disk orientations in order to produce mock observations. We apply popular reconstruction techniques in order to estimate the geometrical disk parameters, systemic velocities, rotation curve shape and maximum circular velocity which are crucial to construct the scaling relations. We conclude that a detailed analysis of kinematics in galaxies using MCMC technique will be reflected in accurate estimations of galaxy properties and more robust scalings relations, otherwise physical conclusions may be importantly biased.

## INTRODUCTION

The most robust predictions of the cosmological model LCDM is the “Halo mass function” (Warren et al. 2006) which can be translated to maximum circular velocity function for halos and sub-halos (Klypin et al. 2011). To understand more about dark matter halos we have the scaling relations as Tully-Fisher (TFR) (Tully & Fisher 1977) and Faber-Jackson (FJR) relations (Faber & Jackson 1976) which connects dark matter halos properties with galaxy observables. For example, TFR connect the halo maximum circular velocity with the integrated star formation history, i.e., luminosity and this relation also offers some insights into the physics of disk galaxy formation and evolution.

Verheijen (2001) studied the TFR in four bands B, R, I and K for three different estimations of rotational velocity. He found that scatter and slope depend on the technique used to estimate the rotational velocity. We using a subsample of CALIFA galaxies did a comparison between the TFR with the  $V_{rot}$  estimated with the width of velocity histogram and modeling the velocity field. In Figure 1 show the results where scatter and slope decrease with  $V_{rot}$  estimated modeling the velocity maps in agreement with Verheijen (2001).

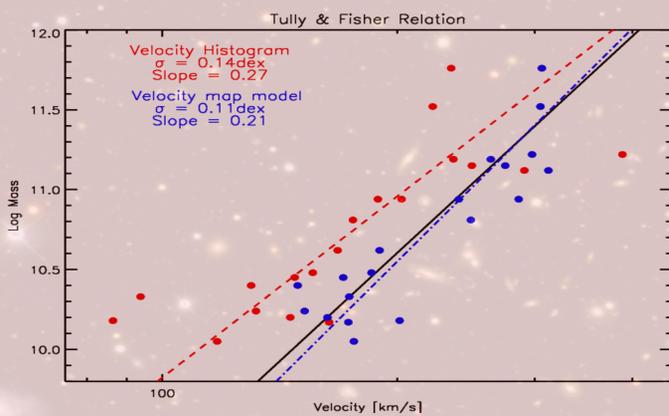


Figure 1.- Comparison between the Tully-Fisher relation with  $V_{rot}$  estimated with the velocity histogram and  $V_{max}$  estimated modeling the velocity map. Black dots represent a  $V_{rot}$  with the histogram and blue  $V_{max}$  modeling kinematic maps.

Disk asymmetries, star formation, nuclear activity, inflows, outflows can produce non-circular motions introduce bias in the  $V_{max}$  estimations. The Fig. 1 show the importance of detail kinematic analysis in galaxies.

## SYNTHETIC VELOCITY MAPS

In order to study the non-circular motions effect in the  $V_{max}$  estimations in galaxies we construct a great variety of synthetic velocity maps including a bi-symmetric distortion as a bar-like using the next equation:

$$V_{model} = V_{sys} + \sin i [\bar{V}_t \cos \theta - V_{2,t} \cos(2\theta_b) \cos \theta - V_{2,r} \sin(2\theta_b) \sin \theta]. \quad (1)$$

Where  $V_{sys}$  is the systemic velocity,  $i$  the inclination,  $\bar{V}_t$  tangential velocity component,  $\theta$  is the azimuthal angle from the major axis in the plane of the disk,  $\theta_b$  the angles relative to the bar axis,  $V_{2,t}$  and  $V_{2,r}$  are the amplitudes of the tangential and radial components of the non-circular flow, respectively.

In Figure 2 we show three synthetic velocity maps for different geometrical configurations, i.e., with different inclination and position angle, as well as different bar orientations.

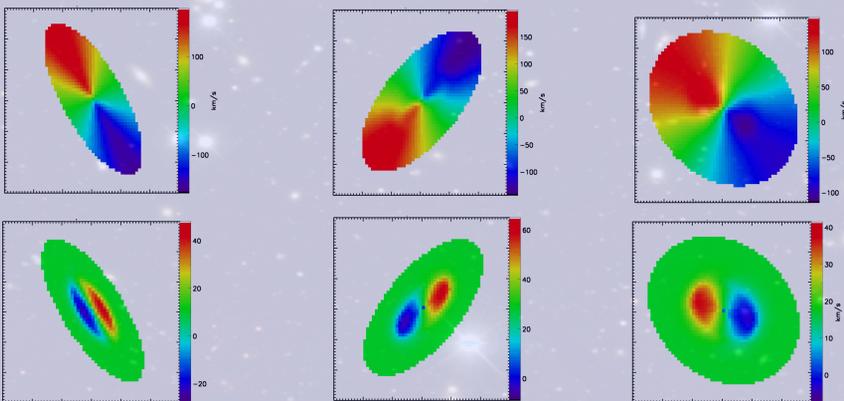


Figure 2.- Top: Synthetic velocity maps and Bottom panels the non-circular motions as a bar, respectively. Left:  $i = 68^\circ$ ,  $PA = 33^\circ$  and  $\phi = 19^\circ$ . Middle:  $i = 62^\circ$ ,  $PA = 139^\circ$  and  $\phi = 48^\circ$ . Right:  $i = 36^\circ$ ,  $PA = 49^\circ$  and  $\phi = 62^\circ$ .

In the next sections we modeled the synthetic velocity maps to explore if we can recover geometric parameters, maximum circular velocity and the rotation curve shape.

## KINEMATIC ANALYSIS

To carry out our kinematic modelling of velocity maps we use the publicly available Velfit code developed by Spekkens and Sellwood (2007). This code allow us three types of kinematic models. The simplest model includes rotation only, the second model includes disk asymmetries as a lopsided galaxy and finally bisymmetric model introduces non-circular flows produced by a bar-like. Assuming a flat disk and using a Fourier modes decomposition around concentric rings velfit returns systemic velocity, kinematic center ( $x_c, y_c$ ), inclination, disk PA and rotational velocity, moreover for bi-symmetric distortion we also need determine the bar position angle respect to galaxy major axis as well as radial and tangential non-circular motions components.

Velfit use a Levenberg–Marquardt (LM) algorithm as a minimization technique. The LM algorithm uses a maximum likelihood approach to answer the question: How likely is the data set given a set of geometric parameters?. This routine minimizes the  $\chi^2$  maximum likelihood estimator by using a gradient search through parameter space. The concern with least-squared approaches is that for data sets with less than optimal sampling, corresponding to many local minima in  $\chi^2$ -space, the LM routine is sensitive to initial guesses and is easily trapped.

To solve this problem we implement a Bayesian technique and a Markov-chain Monte Carlo (MCMC) that provides a method of surveying the parameter space that rapidly converges to the posterior probability distribution of the input parameters using the Metropolis–Hastings algorithm. (e.g. Puglielli et al. (2009)).

## RESULTS

The ergodic theorem tell us that if we consider a larger number of iterations we ensure that we are covering the entire space of parameters. The following figures show the results of the detailed kinematic analysis for three synthetic velocity maps with different geometry.

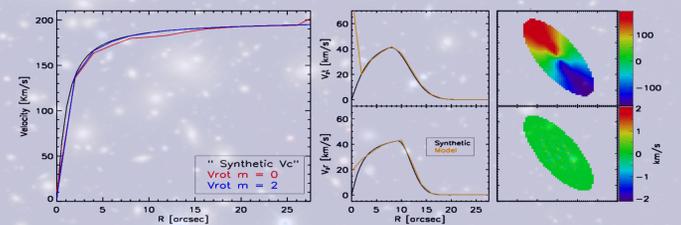


Figure 3.- a) Velocity map with  $i = 68^\circ$ ,  $PA = 33^\circ$  including a bi-symmetric distortion as a bar-like with  $\phi = 19^\circ$ . In this case the rotation curve including only rotational velocity (red curve) is very similar to the rotation curve used to construct the synthetic maps (Black curve). When we modeled including a bi-symmetric distortion we can see that the rotation curve (Blue curve) is in agreement with the synthetic.

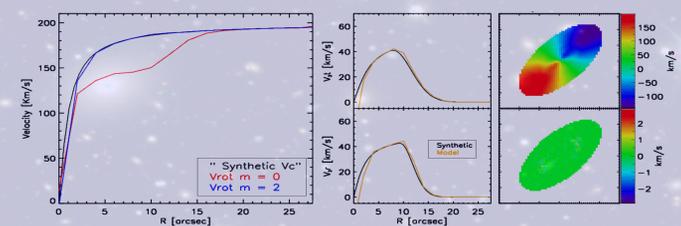


Figure 4.- a) Velocity map with  $i = 62^\circ$ ,  $PA = 139^\circ$  including a bi-symmetric distortion as a bar-like with  $\phi = 48^\circ$ . In this case the rotation curve including only rotational velocity (red curve) is underestimating the rotation curve used to construct the synthetic maps (Black curve). When we modeled including a bi-symmetric distortion we can see that the rotation curve (Blue curve) is in agreement with the synthetic.

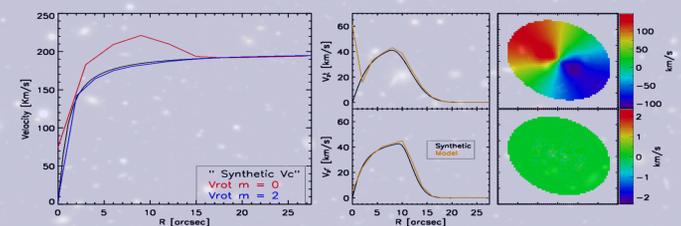


Figure 5.- a) Velocity map with  $i = 36^\circ$ ,  $PA = 49^\circ$  including a bi-symmetric distortion as a bar-like with  $\phi = 62^\circ$ . In this case the rotation curve including only rotational velocity (red curve) is overestimating the rotation curve used to construct the synthetic maps (Black curve). When we modeled including a bi-symmetric distortion we can see that the rotation curve (Blue curve) is in agreement with the synthetic.

## DISCUSSION AND CONCLUSIONS

In this poster we show three important examples in order to show that for the model including only rotational velocities the rotation curve shape is affected in the region where we have non-circular motions (See Fig. 3, 4 and 5) can be similar, underestimated or overestimated introducing bias in mass distribution and maximum velocity in this radius. After modeling only rotational velocity, we modeled with our MCMC technique simultaneously using the bi-symmetric model the rotational curve and the non-circular motions and we can see that recover the rotation curve shape, the geometric parameters and maximum circular velocity.

We conclude that a detailed analysis of kinematics in galaxies using MCMC technique will be reflected in accurate estimations of galaxy properties and more robust scalings relations, otherwise physical conclusions may be importantly biased.