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On the role of non-circular motions in MaNGA galaxies I: global properties

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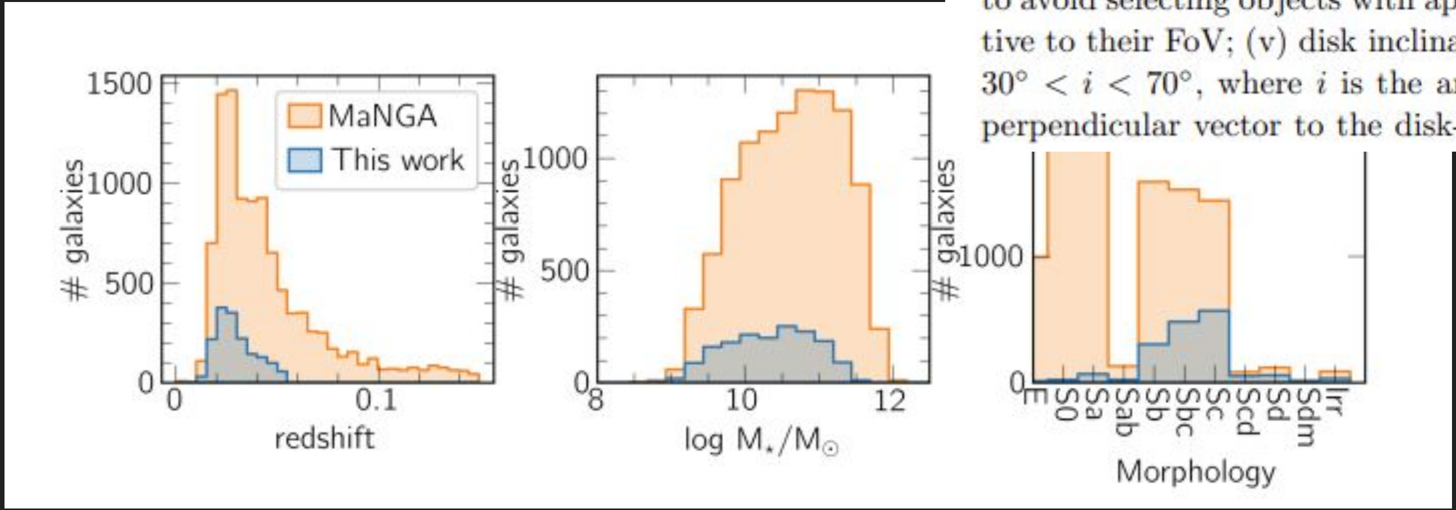
ABSTRACT

Non-circular (NC) motions represent the imprints of non-axisymmetric structures in galaxies, providing opportunities to study the physical properties of gas departing from circular rotation. In this work we have conducted a systematic study of the non-circular motions in a sample of 1624 gas-rich disk galaxies from the MaNGA MPL-11. By using the Hα velocity as a tracer of the disk rotation, we find indications that the amplitude of the non-circular motions is related to the stellar mass, with the low mass and late-type galaxies the most affected. In our sample, we find ratios of non-circular to circular rotation ranging from 5% to 20%. By implementing harmonic models to include NC motions associated with spiral arms and stellar bars, we find that the rotational curves traced with Hα are barely affected by the NC induced by these structures. Consequently, in our sample, we do not find evidence that NC motions contribute to the scatter of the stellar Tully-Fisher relation. Our results suggest that non-circular motions might have a more localized effect in galaxies rather than a global one.

Sample: 1624 MANGA candidate galaxies

Then, from these filtered galaxies we select those with the major coverage of their optical extension, following the criteria below. (i) galaxy redshifts must lie between $0.005 < z < 0.055$, this ensures maximum spatial scales of 1 kpc/″; (ii) objects should be observed by more than 91-fiber integral field units (IFU) to maximize the number of independent pixels within the FoV (field-of-view), which is important for the rotation curve estimation; (iii) the effective radius (r_e) should be larger than the FWHM resolution; (iv) the ratio between the cube FoV diagonal radius and r_e should be less than or equal to 3 to avoid selecting objects with apparent small sizes relative to their FoV; (v) disk inclinations should lie within $30° < i < 70°$, where i is the angle formed between a perpendicular vector to the disk-plane and the LoS di-

Вопрос: некруговые движения (NC) - они вообще какие? Ответ часто зависит от предположений анализа. Драйверы NC - спиральные рукава, бары, балджи (?), галактический ветер



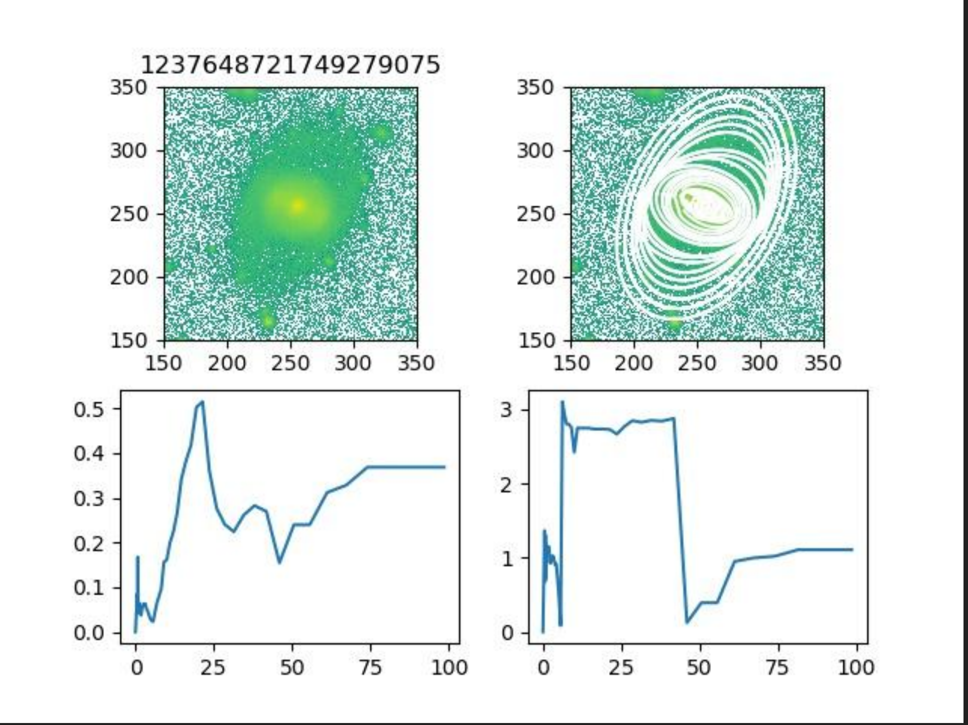
Method: XookSuut (XS, L´opez-Coba´ et al. 2024), Halpha две модели - круговая и harmonic.

*This code creates an interpolated model over concentric rings adopting the flat disk approximation, that is, the ellipticity and the position angle are **assumed constant** throughout the galaxy. The latter criterion will be crucial for our analysis since, as we will see later, it favors the appearance of non-circular motions induced by non-axisymmetric structures, instead of vanishing them if variations in the position angle or inclination were allowed in the model.*

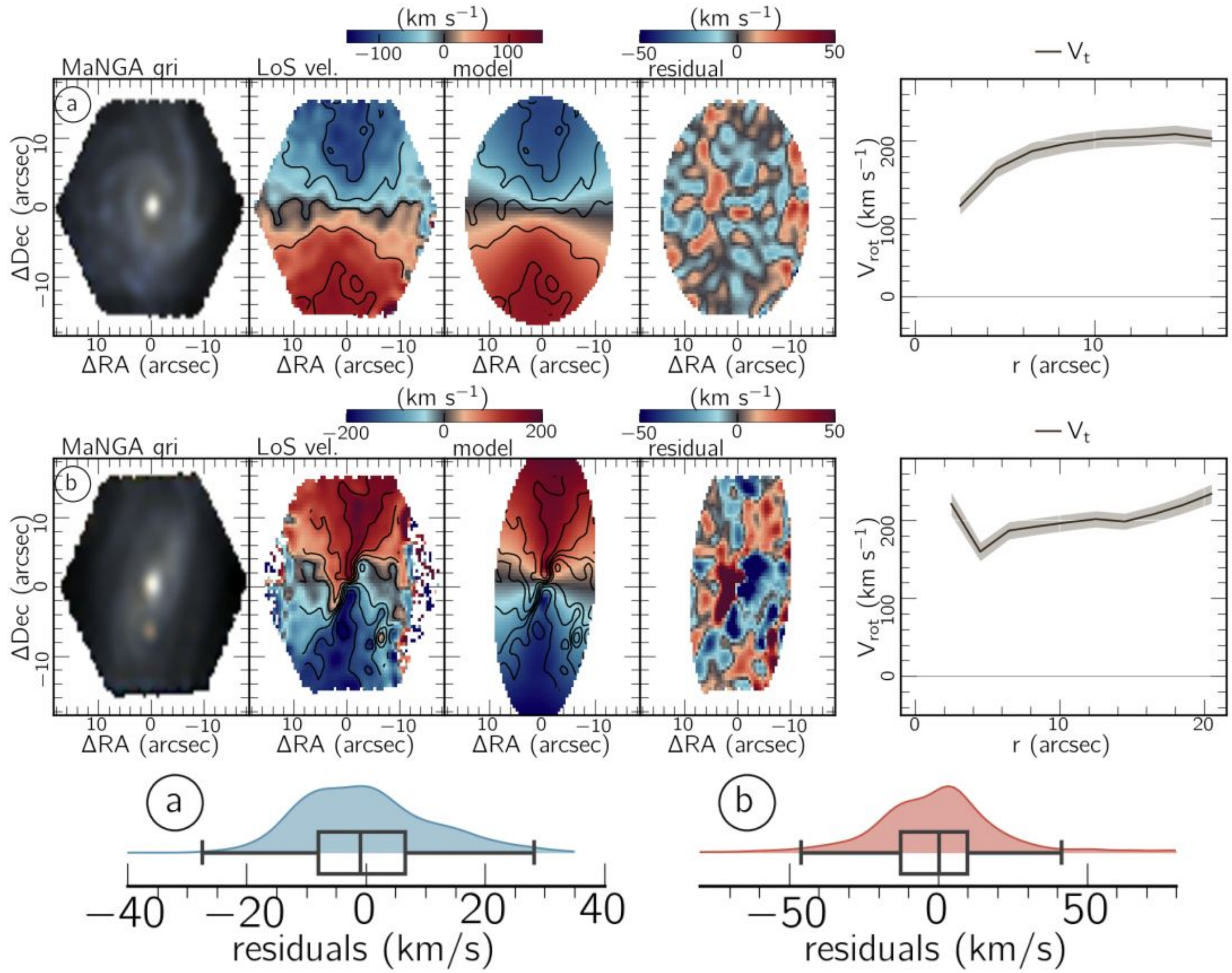
$$V_{\mathrm{circ}}(r,\theta) = V_{\mathrm{sys}} + \sin i \; V_t(r)\cos\theta, \qquad (1)$$

$$V_{\mathrm{los}} = c_0 + \sin i\left[c_1(r)\cos\theta + c_3(r)\cos 3\theta + s_1(r)\sin\theta + s_3(r)\sin 3\theta\right], \qquad (2)$$

model that accounts for perturbations induced by two-armed spiral arms and stellar bars as in Schoenmakers et al. (1997)+ assumption that NC motions can be described as slight perturbations of circular orbits, transforming them into slightly elliptical closed orbits



While variations in the position angle and inclination can produce this pattern in the velocity field, it is not as frequent to observe warps within the optical extent of galaxies as is observed in H I disks (e.g., Kamphuis et al. 2015). Thus, the presence of streaming flows in the Hα disks is a more likely interpretation. Moreover, our kinematic analysis favors per ce the appearance of non-circular motions due to non-axisymmetric structures, and random motions, rather than those due to projection effects



(km s^{-1})
−100 0 100
(km s^{-1})
−50 0 50
MaNGA gri
LoS vel.
model
residual
a
ΔDec (arcsec)
ΔRA (arcsec)
— V_t
V_{rot} (km s^{-1})
r (arcsec)
(km s^{-1})
−200 0 200
(km s^{-1})
−50 0 50
MaNGA gri
LoS vel.
model
residual
b
ΔDec (arcsec)
ΔRA (arcsec)
— V_t
V_{rot} (km s^{-1})
r (arcsec)
a
−40 −20 0 20 40
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b
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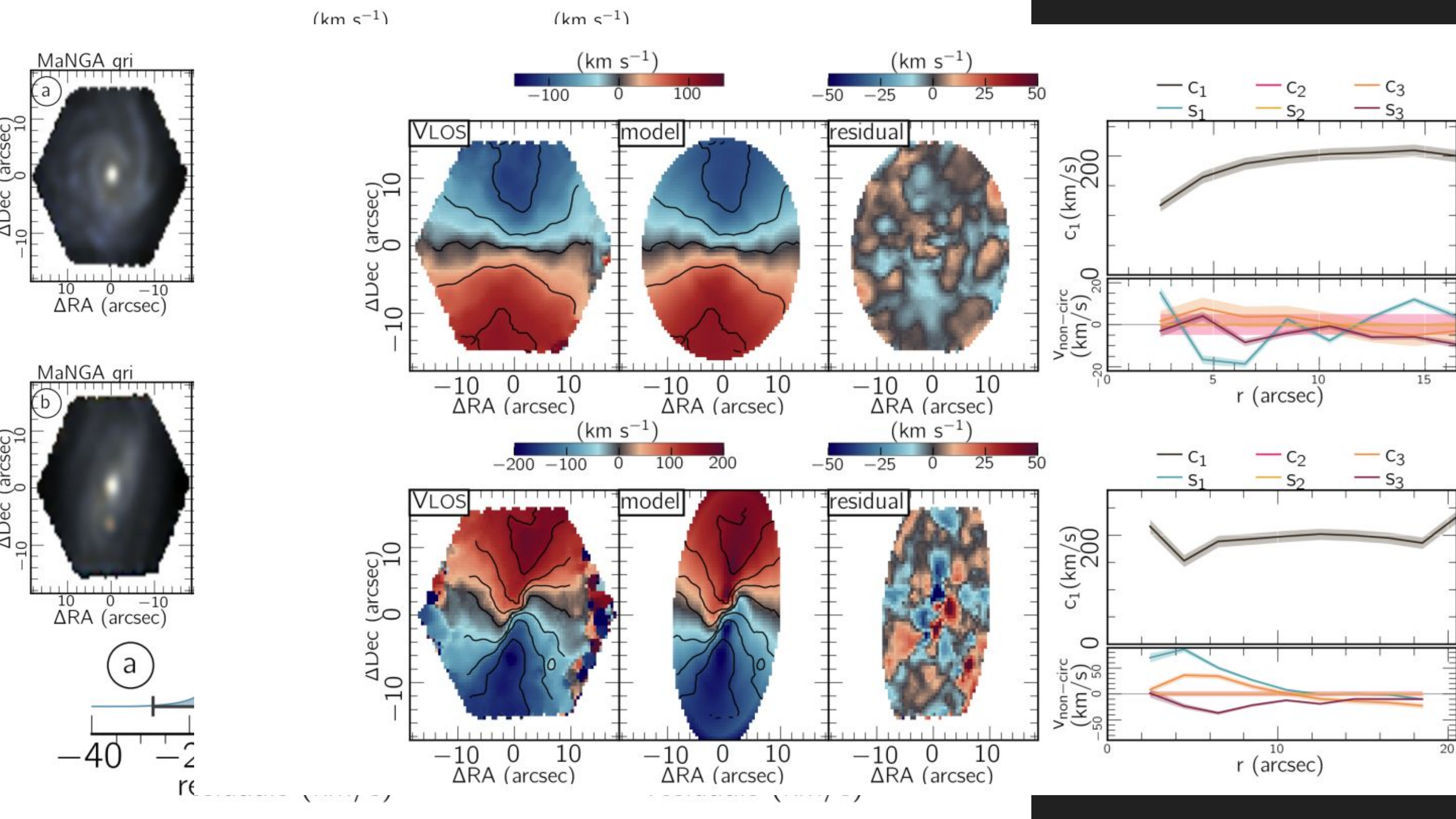
residuals (km/s)



MaNGA gri
a
b
ΔDec (arcsec)
ΔRA (arcsec)
(km s−1)
VLOS
model
residual
c1
c2
c3
s1
s2
s3
c1 (km/s)
vnon−circ (km/s)
r (arcsec)

This figure reveals that circular rotation motions dominate in the majority of spaxels in our objects.

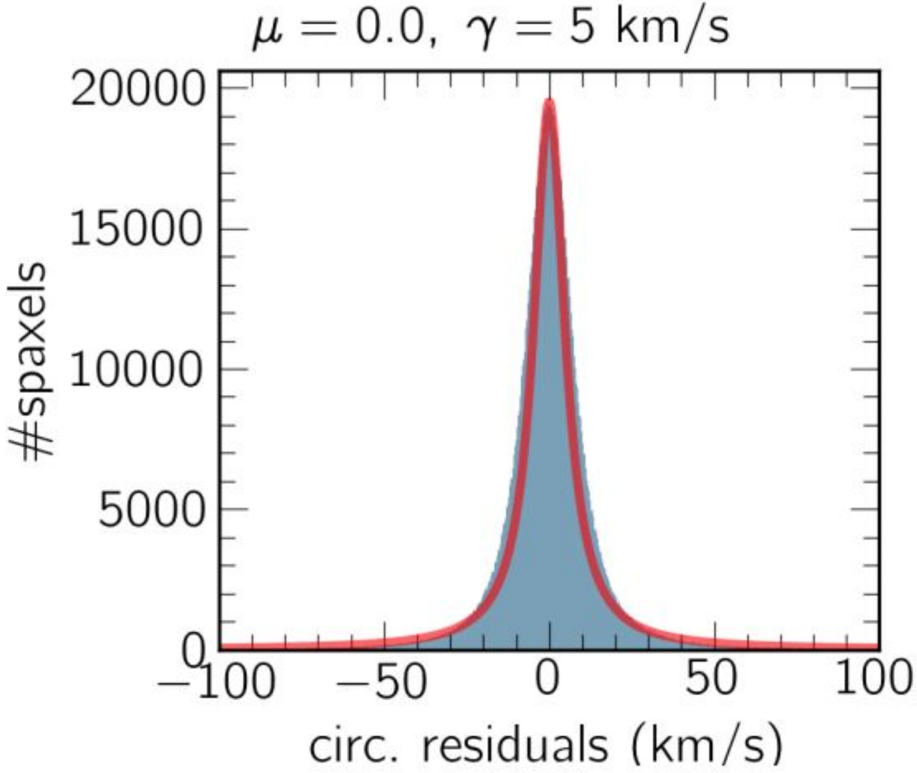


Figure 4. Distribution of circular rotation residual velocities in our kinematic sample. The distribution is characterized by a Cauchy distribution, shown in red, centered in 0 with a 5 $\mathrm{km\,s^{-1}}$ scale.

Vmax & T - F relation

We parameterize the rotation curves $V_t(r)$ and $c_1(r)$ adopting the following expression (e.g., Courteau 1997):

$$V_{\rm rot}(x) = V_0 \frac{(1+x)^\beta}{(1+x^\gamma)^{(1/\gamma)}} \quad \text{with } x = r/r_t, \qquad (3)$$

where V_0 is the asympthotic velocity, r_t is the transition radius from rising to flat rotation and β and γ define the shape of the rotation curve; we assumed for all cases $\beta = 0$.

For each object in our kinematic sample, we estimate the maximum rotational velocity ($V_{\rm max}$) at $r_{\rm max} = 2.15h$ with h being the disk scale. It has been observed

Overall, we do not find significant differences when considering non-circular motions in computing Vmax. However, this does not mean that locally they are not important, as observed previously. Globally, noncircular motions do not appear to notably affect the characteristic rotation of galaxies, at least not in the optical rotation curves addressed here. This is somewhat expected for galaxies hosting bars, where most non-circular motions are confined to the bar region, while Vmax typically occurs at larger radii, a few times the effective radius.

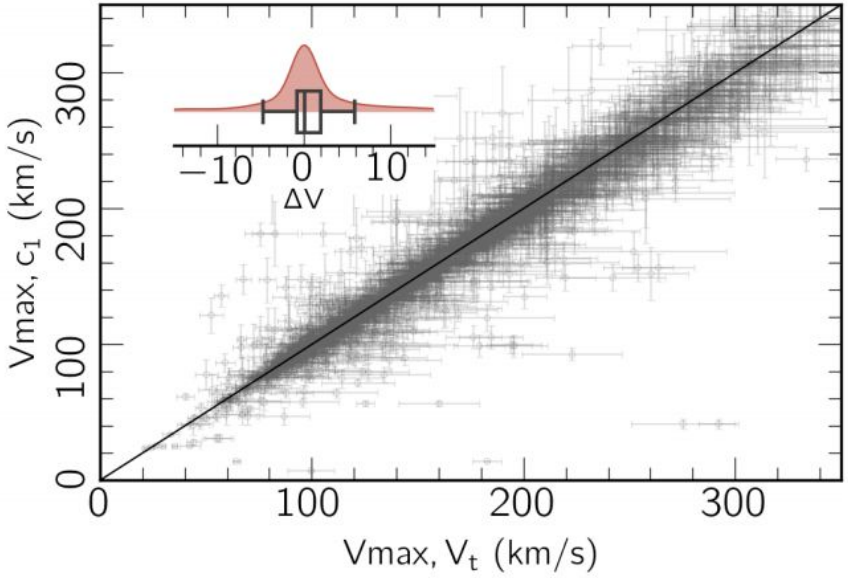
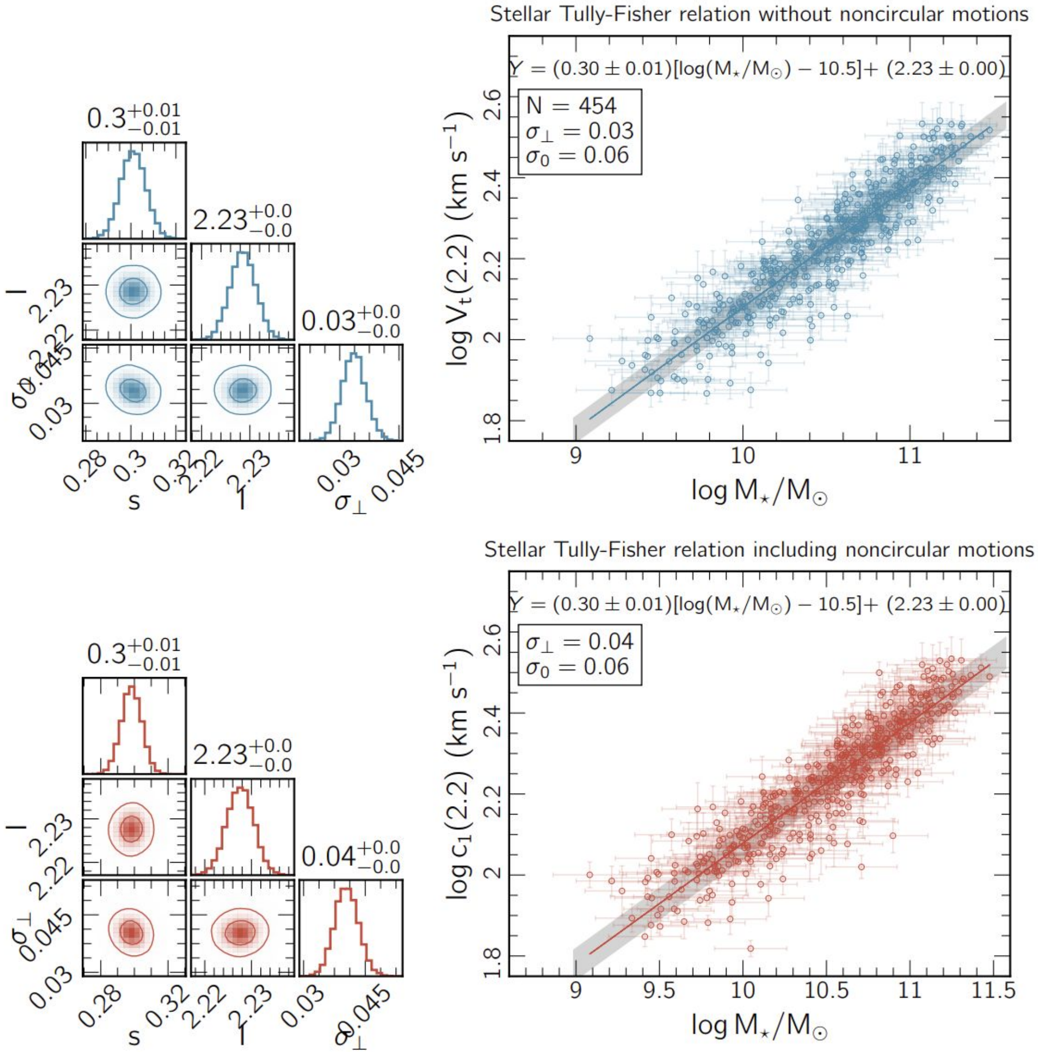


Figure 5. Comparison between maximum rotational velocities estimated from the circular rotation velocities $V_t(r)$, and the $c_1(r)$ velocities from the harmonic model. Every point here represents one individual object. The black straight line represents the 1-to-1 line. The inset panel shows a violin plot of the difference between both velocities, *i.e.*, $\Delta V = V_{max,c1} - V_{max,t}$. The dispersion of the difference is 5 $\rm km\,s^{-1}$.

Vmax & T - F relation

To minimize the scatter in the TFR due to rising, falling, or wiggling rotation curves, we choose to include only flat rotational curves where we are confident in measuring the maximum rotation speed. We achieve this by following the automated algorithm from Lelli et al. (2016). Following this procedure, 454 objects were found to exhibit bonafide flat rotational curves. We then estimate Vmax at 2.15h thorough linear interpolation of these rotational curves.

These results may suggest that non-circular motions are not responsible of the observed scatter in the TFR, or at least this is not observed in optical rotational curves.



With the aim of performing a homogeneous study of the non-circular motions in our sample, we adopt the width of the residual distribution that contains 80% of the non-circular velocities. That is, $V_{80} = (V_{90} - V_{10})/\sin i$, where V_{90} and V_{10} represent the velocity at the 90th and 10th percentile of the cumulative distribution of the residual map (namely, observed-model), and i is the disk inclination. We note that similar definitions have been adopted in the literature to characterize non-circular motions (e.g., Erroz-Ferrer et al. 2015). We correct V_{80} by inclination, as other sources of non-circular motions, such as spiral arms or oval-distortions, lie on the disk plane. Since V_{80} is estimated from the tails of the residual distribution, it tends to quantify the largest amplitudes from all different sources of non-circular motions. For an axisymmetric velocity field, the distribution of residuals should be characterized by a Gaussian function centered around zero, with $V_{80} = 2.56\,\sigma \sim$ FWHM (see appendix A).

$$\eta = \log(V_{80}/V_{\max}). \qquad (4)$$

In this way, η represents a characteristic strength of the non-circular motions in a galaxy, and simultaneously provides a systematic method for measuring non-circular motions in our sample.

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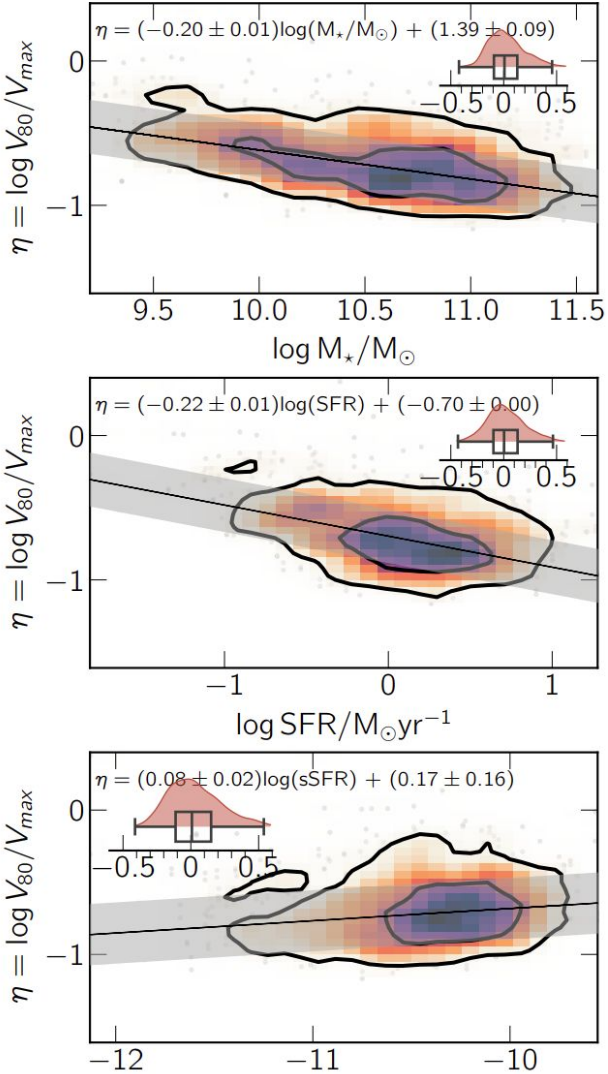

sSFR

Вариация NC по диску:

-from this figure, we observe that the amplitude of the non-circular motions in massive galaxies can be as large as 5% of the local circular rotation, while this ratio of non-circular to circular amplitudes can reach up to 20% in less massive galaxies.

-latest type spirals have larger amplitudes of NC motions

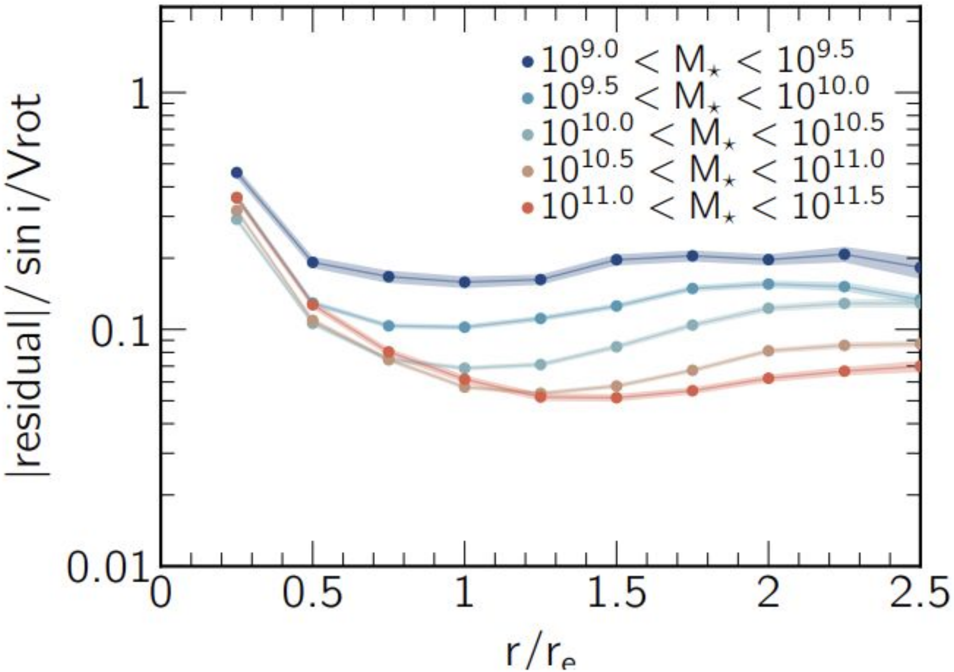

Figure 7. Radial distribution of the circular model residuals (in absolute value) normalized by the rotational curve $V_t(r)$ for the 1624 objects in our kinematic sample. Each dot represents the median value of the residuals in $0.25r_e$ bins. Galaxies are segregated into 5 different mass bins represented by different colors.

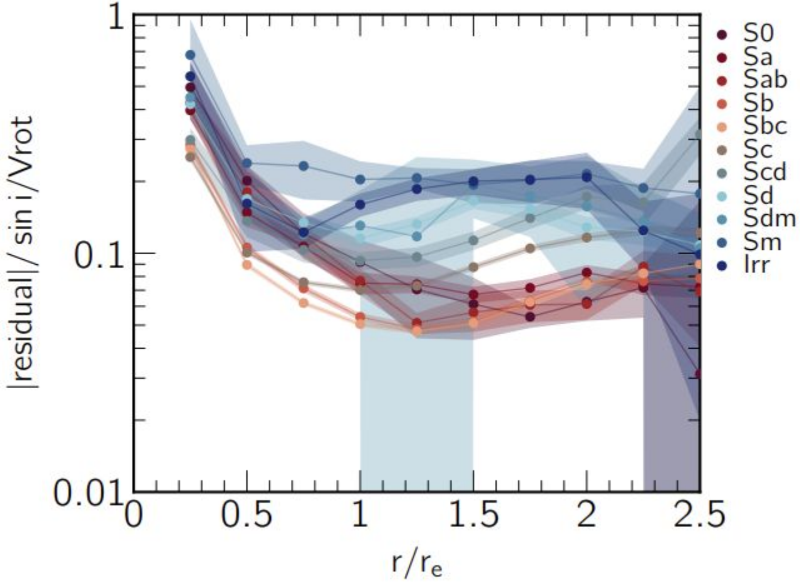

Figure 8. Similar figure as fig. 7, but this time galaxies have been segregated by morphological types from S0 to Irregulars.

Заключение:

Residual velocity maps, while useful for for characterizing the local and global strength of non-circular motions in galaxies, however the choice of the best normalization method for describing these motions remains unclear. Interestingly, both local and global measurements of NC motions reveal a correlation between the average amplitudes of NC motions and the stellar mass.

We found that the rotational curve traced with circular (V_t) and non-circular rotation models (c_1) show minimal differences, even though the harmonic model captures underlying non-axisymmetric motions. Consequently, the maximum rotational velocity V_{max} remains unaffected when considering non-circular motions. This study, therefore, indicates that non-circular rotation has minimal influence on the estimation of the rotation speed of galaxies. Scaling relations involving V_{max}, such as the barionic Tully-Fisher relation, show no changes in the slope, zero point, or scatter when non-circular motions are considered. However, this conclusion may be influenced by the assumed non-circular rotation model, which is intended to account for small perturbations. If confirmed with larger samples and kinematic models that account for arbitrary amplitudes of NC motions, this would suggest that non-circular motions do not contribute to the intrinsic scatter in the TFR.