A tidally induced global corrugation pattern in an external disc galaxy similar to the Milky Way
Catalina Mora-Urrejola
F. A. Gómez & S. Torres-Flores
cmora@dfuls.cl

Universidad de La Serena

Abstract

We present evidence of a tidally induced global corrugation pattern in an external disc galaxy similar to the Milky Way. Using Hα Fabry-Perot observations we obtain a 2D line-of-sight velocity (V_{los}) field of the low-inclination, late-type galaxy VV304a. The 2D kinematic map reveals a global, coherent and extended perturbation that is likely associated with a recent interaction with the massive companion VV304b. We use multi-band imaging and a suite of test imaging and cosmological simulations to quantify the plausible strength of in-plane flows due to non-axisymmetric perturbations, and show that the observed velocity flows are much too large to be driven either by spiral structure or by a bar. The final V_{los} map suggests the presence of a structure in the VV304a disc similar to the Monoceros ring seen in the Milky Way.

Introduction

Studies show strong evidence of a corrugation pattern in the outskirts of the Milky Way disc (Widrow et al. 2012; Xu et al. 2015). A corrugation pattern can be described as a vertical oscillatory perturbation with an amplitude that grows with galactocentric distance. Recently, thanks to the data from Gaia Data Release 2 (Aleksić et al. 2018) such perturbations have been confirmed. The most likely culprit behind this perturbation is the Sagittarius Dwarf Galaxy (Laporte et al. 2018b). According to cosmological simulations, corrugation patterns are expected to be common (Gómez et al. 2016). However, to date, most observational studies of late-type galaxies have reported the presence of classical S-shaped warps. Due to projection effects, corrugations patterns are harder to detect. One way to detect such pattern is through line-of-sight velocity (V_{los}) fields of very low-inclination galaxies. Due to their oscillatory nature, such patterns are also observable in the mean disc vertical velocity as a function of distance. In this work we present the first full 2D kinematic map of a nearby spiral galaxy, VV304a, which reveals a corrugation pattern similar to the ones observed in our own disc. This pattern is likely the results of the recent interaction with its companion galaxy, VV304b.

Method

VV304a (Fig. 1), located at 54 Mpc, has an optical radius of R_{opt} = 18 kpc, a maximum rotational velocity of V_{max} = 245 km s^{-1}. Its massive companion, VV304b (1:10 fraction mass), shows signatures of previous interaction. VV304a was observed with Fabry-Perot Interferometer in Hα line with high spectral resolution (R ~ 13000) using the Coudé-descent of the GALEXIES (CIGALE) on ESO 3.6 m telescope at La Silla (Chile). The 2D velocity moment maps were obtained using a publicly available package (Daigle et al. 2006; Epinat et al. 2018), which utilizes an adaptive spatial binning based on 2D voronoi tessellations method. This results in 3D data cubes with high spectral resolution in high signal-to-noise regions and large spatial coverage in low signal-to-noise regions.

Results

The left panel of Fig. 2 shows the velocity map and the axisymmetric model of this velocity field. The model indicates a kinematic inclination i = 39°, and position angle PA = 104°. The residual velocity (V_{res}) map is obtained after subtracting the axisymmetric model to data (Right panel, Fig. 2). The V_{res} reveals global and coherent perturbations, consistent with a corrugation pattern. Note the large amplitudes in the V_{res} map of VV304a, reaching values of 40 km s^{-1}.

As the inclination of a galaxy increases, the contribution from in-plane velocity components (radial and rotational) to the V_{los} also increases. Since the inclination of VV304a is non-negligible, we analyzed numerical models of VV304a to characterize the plausible contribution from its spiral structure and weak bar to V_{los}. Fig. 3 shows the resulting V_{los} map for such models considering an inclination of 35°, PA = 105°, and asymmetric perturbations with different strength. We showed that, for the inclination angle of VV304a, not even a 100% spiral overdensity with respect to the background disc can produce velocity flows with the amplitude observed in the data.

Conclusions

We analyzed the 2D V_{los} field of the spiral galaxy VV304a. The V_{los} field shows a strong, global and coherent perturbation which is consistent with a corrugation pattern, similar to the one observed in the Milky Way. The amplitude of the perturbations reaches 40 km s^{-1}. We showed that, given the inclination of VV304a, such strong velocity perturbations cannot be described by flows induced by its spiral structure nor its weak bar. These strong flows are the reflection of a vertically perturbed disc, likely due to the recent interaction of VV304a with its nearest massive companion VV304b.

Incoming

We are extending this analysis to low inclination nearby face-on galaxies. In Mora-Urrejola et al. 2021 in prep. we present the Waves in Nearby Disc galaxies Survey (WINDS), which consists in a sample of 40 low-inclination late-type galaxies observed in Hα using Fabry-Perot Interferometer with high spectral resolution. We have derived 2D line-of-sight velocity and residual velocity maps (Fig. 4) for each object, to search for the possible presence of vertical velocity flows in these external galaxies. Fig. 4 show three examples taken from WINDS. The main goal is to characterize how frequent warps and corrugation patterns, such as those observed in the Milky Way, arise in the Local Universe.

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