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Thick discs in galaxies were most likely not accreted.

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Abstract

The origin of thick discs in galaxies remains shrouded in mystery. A variety of formation scenarios has been proposed. Here we aim to test one such scenario where the thick disc stars are proposed to be accreted from satellite galaxies. In this scenario, in at least some galaxies a fraction of thick disc stars would rotate in a retrograde way, which would cause a large thick disc velocity lag. Here, we compare the rotation curves of the thin and the thick discs of eight edge-on galaxies observed with MUSE at the VLT. We find that the velocity lags of the thick discs are compatible with those expected from asymmetric drift. If we consider the galaxies with thick disc rotation curves in the literature, only one in about fifteen shows clear signs of an accreted thick disc. Based on simulations in the literature we estimate that if thick discs were accreted, at least one in six would show clear signs of retrograde material. Thus, there is a growing tension between the observations and the hypothesis that thick discs are made of accreted stars.

1 Introduction

The formation and early evolution epoch of galaxies is hard to study due to observational issues such as cosmological dimming and the lack of means to properly resolve objects at large angular diametre distance. An alternative approach to unveil how galaxies evolved is to study with an exquisite level of detail the oldest stars in local objects and deduce their origin (this approach is called galactic archæology). The oldest stars of a galaxy are typically found in the halo and in the thick disc. In this paper we will focus on the thick discs to advance in our understanding of galaxy evolution.

In edge-on galaxies thick discs are seen as roughly exponential excesses of light that become apparent a few thin disc scale-heights above the mid-plane. They contain a significant fraction of the baryons in a galaxy and, in low-mass galaxies, can be as massive as the thin discs[30, 6, 7, 10].

The origin of thick discs has been a source of debate. Some authors have argued for an internal origin of the thick disc stars. Either a pre-existing thin disc would have been thickened by dynamical heating[28, 23, 24, 19], or the thick disc would have been born thick in an early phase of the galaxy evolution when the interstellar medium was very turbulent and the specific star formation rate was much larger than it is nowadays[12, 2, 8]. Alternatively, the thick discs could have been accreted through minor mergers[1].

The stars of the Milky Way thick disc are now known to be mostly of internal origin[22, 18, 15]. However, it is known that at least one external thick disc – that in FGC 227 – has stellar rotation velocities close to zero[29], which implies that about half of the light is emitted by retrograde stars. This strongly suggests an external origin for a large fraction of its thick disc stars. Unfortunately, the number of thick disc rotation curves in the literature is small – about ten[29, 30, 9, 11, 14, 16] –, so it is not possible to say whether the case of FGC 227 is unique or not.

Here we aim to obtain additional thick disc rotation curves to determine whether accretion is a plausible origin for the majority of stars in thick discs.

2 Sample, observations, and data processing

We observed eight nearby edge-on galaxies with MUSE at the VLT. MUSE is an integral field unit with a $1' \times 1'$ field of view and a simultaneous wavelength coverage between 4750 Å and 9300 Å. All the observed galaxies had previously been observed within the *Spitzer* Survey of Stellar Structure in Galaxies ($\mathrm{S^4G}$)[25] and have photometric decompositions available in 3.6μm[10]. The selected galaxies are relatively small with circular velocities below $180\,\mathrm{km\,s^{-1}}$. All but one are bulgeless.

The galaxies were exposed for almost three hours. They were reduced using the standard ESO pipelines. We used `ZAP`[26] to remove the sky residuals. The datacubes where Voronoi-binned[3] to a signal-to-noise ratio of $S/N \sim 25$ in the wavelength range between 5490 Å and 5510 Å. Then `PPXF`[4] was applied to the spectra obtained for each Voronoi bin. `PPXF` fits the spectra with a linear combination of spectral energy distribution templates and obtains the line of sight velocity distribution. We used the templates from the MIUSCAT library[27]. The templates and the spectra where Gauss-convolved to match their spectral full width at half maximum at every wavelength.

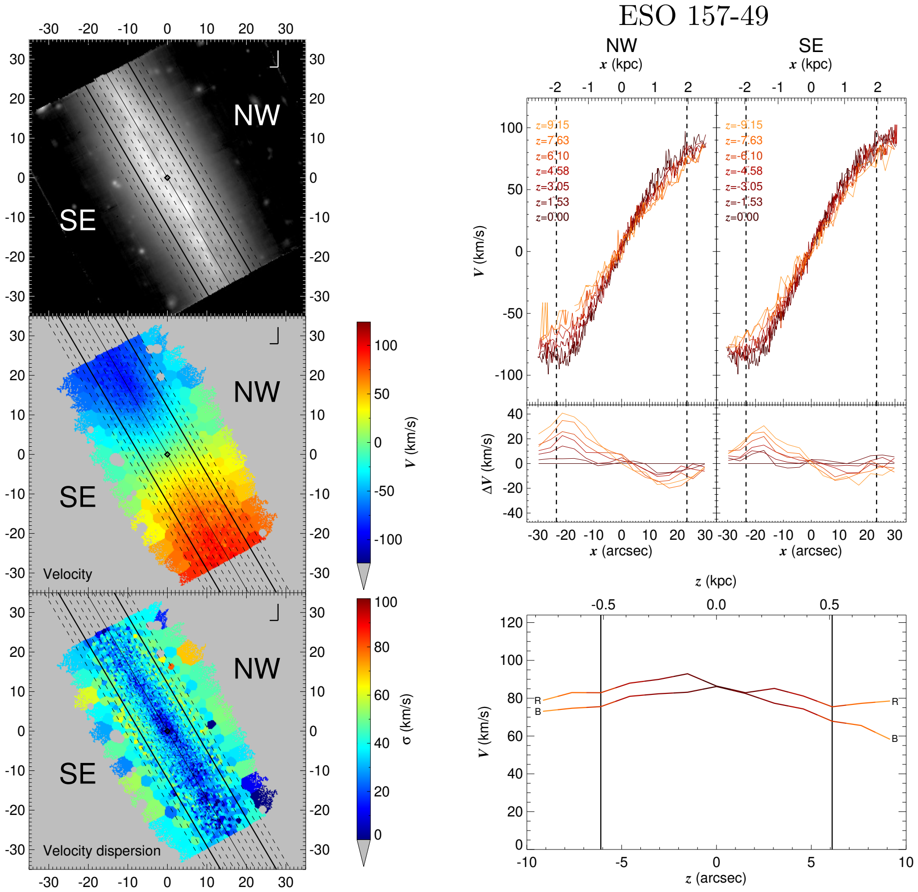

Figure 1: *Top-left:* Image of ESO 157-49. *Middle-left:* Velocity map of ESO 157-49. *Bottom-left:* Velocity dispersion map of ESO 157-49. The values in the axes are in arcseconds. North is up and East is left (shown by the reverse-L symbol). The lines parallel to the mid-plane denote the heights for which the rotation curves (*top-right* panels) were computed. The thin continuous line indicates the mid-plane and the thick continuous lines indicate the height where the thick disc starts to dominate the surface brightness[10]. The *middle-right* panels show the difference between the velocity at a given height and that at the mid-plane. The dashed vertical lines indicate where the rotation curve becomes flat. The *bottom-right* panel shows the velocity as a function of height for the flat part of the rotation curve for the blue-shifted and red-shifted sides of the galaxy (indicated by "B" and "R", respectively). The vertical lines indicate the height above which the thick disc dominates the surface brightness.

3 Results

We produced velocity and velocity dispersion maps for the eight galaxies in our sample. We used the velocity maps to compute rotation curves at different heights above and below the mid-planes. In Fig. 1 we show the maps and the rotation curves extracted for ESO 157-49.

In Fig. 2 we show, for the eight galaxies in our sample, the circular velocity as a function of height for the regions where the rotation curve of the galaxies is flat. We find

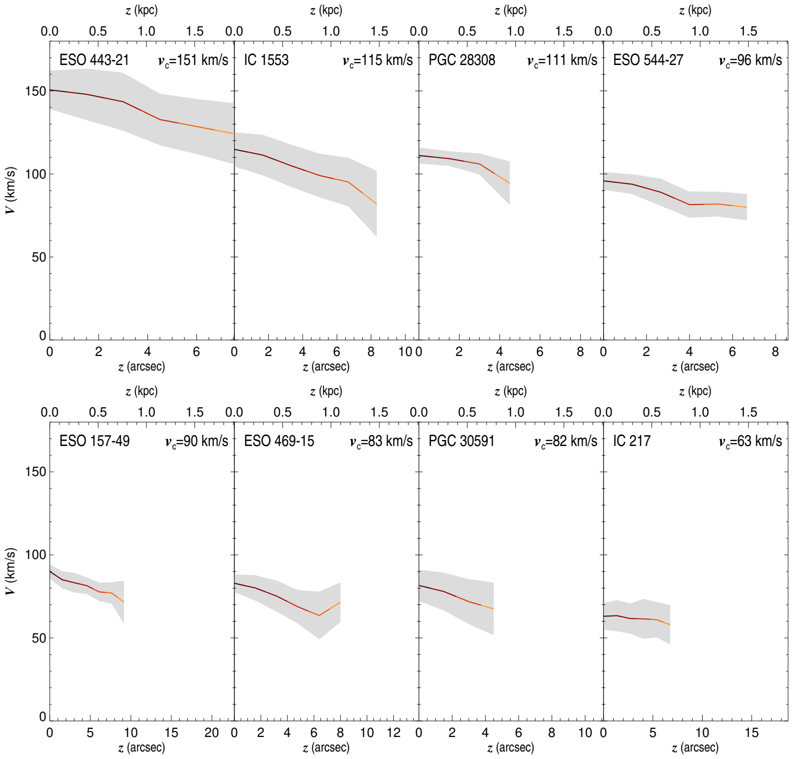

Figure 2: Velocity as a function of height for the flat part of the rotation curve for the galaxies in our sample. The horizontal axes are scaled so all the plots cover the same height range. The grey bands indicate the dispersion in the velocity for the Voronoi bins used to compute each data point. The maximum velocity at the mid-plane is denoted by $v_{\rm c}$.

that the maximum velocity is lower at increasing distances from the mid-plane, with a lag at large heights of a few tens of kilometres per second for all the galaxies in the sample. This is compatible with the combined effects of asymmetric drift and a not perfectly edge-on orientation. Indeed, in the past we have shown that retrograde thick disc fractions larger than $10-20\%$ would result in lags larger than those that we detect[9]. Also, large retrograde material fractions would result in a velocity dispersion comparable to the circular velocity of the galaxy, $v_{\rm c}$. Therefore, our data indicate a very small fraction – compatible with zero – of retrograde stars in the thick discs. We shall however note that only five out of our eight galaxies have massive thick discs that dominate the luminosity at some of the observed height range[10].

4 Discussion and conclusions

Our observations increase the number of available thick disc rotation curves to about fifteen. Only one of them (FGC 227[29]) shows clear evidence for retrograde stars. One may thus naively conclude that accreted thick discs are rare. This is, however, not necessarily true because accretion is more efficient for prograde encounters than it is for retrograde ones. The reason for that is how dynamical friction works. Dynamical friction in its linear regime acts over an infalling satellite as described by the Chandrasekhar formula[5]

$$F \propto \mathcal{M}^2 \rho / V^2, \tag{1}$$

where $\mathcal{M}$ is the mass of the satellite, ρ the density of the main galaxy, and V the relative velocity between the satellite and the particles of the main galaxy. When the satellite is far away from the disc of the main galaxy, V does not depend on whether the merger is prograde or retrograde because the dark matter halo is pressure-supported and, hence, has a mean velocity of zero. However, as the satellite falls and becomes influenced by the disc, prograde objects feel a larger force than retrograde ones. The detailed calculation on the decay times of satellites requires numerical simulations, and it can be estimated that a retrograde satellite takes at most two times longer than a prograde one to be accreted[20]. Given a halo merger rate proportional to $\propto (1+z)^2$[13], isotropic accretion, and a galaxy age of 10 Gyr, we obtain that about a third of the satellites accreted by now had retrograde orbits.

Another effect to be taken into account is in-plane dragging. Prograde satellites with orbital inclinations smaller than $i = 20^{\mathrm{o}}$ are dragged into the plane of the main galaxy by dynamical friction and dissolve into the thick disc[21]. Satellites with larger incoming inclinations dissolve into the inner halo. The effect of in-plane dragging is diminished for retrograde satellites and we estimate that only those with inclinations smaller than $i = 10^{\mathrm{o}}$ are accreted into the thick disc. Hence, an accreted retrograde satellite is two times less likely to end in a thick disc than a prograde satellite.

In summary: 1) one third of the satellites accreted by now by disc galaxies were retrograde and 2) a retrograde merger is two times less likely to contribute to a thick disc than a prograde one. This implies that in the limit where all thick discs have been created in single merger events, we expect $\sim 1/6$ of the thick discs to be retrograde. However, the observed figure is $\sim 1/15$. Hence, our results point to a tension between the observations and the hypothesis of accreted thick discs. If thick discs were created in a small number of mergers (two or three), the tension would worsen. We can therefore conclude that an accretion origin for thick discs is not favoured by the observations.

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