Poznań, 23.09.2019

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Review of the doctoral thesis of Marcin Semczuk entitled „Tidally induced morphology of late type galaxies"

Summary of the thesis

Understanding the formation of shapes of galaxies is important in order to have a full picture of galaxy evolution. Marcin Semczuk addresses this issue by analysing what morphological features of galaxies can be formed by interaction with their environment.

In Chapter 2 N-body simulations are used to find that double spiral arms can result from the interaction with the galaxy cluster potential. There are four versions of the orbit of the galaxy in the cluster potential in order to analyse the dependence on the orbit properties.

Chapter 3 describes hydrodynamical simulations used to prove that galaxies M31 and M33 interacted around 2 Gyr ago, which resulted in their increased star formation activity. The simulations of the interaction between these galaxies reproduced the 2-arm shape of M33 and the warp in its gas disk. An isolated case with no interaction with M31 is also run in order to show which features would appear even without interaction (e.g. the bar).

Chapter 4 describes the exploration of the state-of-the-art magnetohydrodynamical simulations IllustrisTNG. First, galaxies with S-shaped warps were identified, and then those having increasing strength of the warp during a pericenter passage with a massive structure were decided to have interaction-driven warps. It has been found that for a third of galaxies with S-shaped warps, the distortion was induced by interaction. Out of those, half of the perturbing galaxies have been accreted by the investigated warped galaxies.

Contribution to the field and the conclusion of this review

Chapter 2 provides an improvement over previous works done 30 years ago on the subject of the arm formation in cluster environments. The conclusion that a 2-arm configuration can form during the interaction with a cluster is not new, but crucial for galaxy evolution, so its confirmation is an important result. The thesis also provides new insights into the details of this process.

Chapter 3 is interesting but it has only indirect impact on the field, as it only concerns one system of two galaxies. However, this can be useful for future studies of this system, which can then draw on the results of these simulations that the spiral arms, warp, stellar stream and increased star formation activity of M33 are caused by the interaction with M31. I also value the comparison of the interaction simulation with an isolated case, which shows that the bar is not a tidal feature, but grows in isolation as well. Hence, more generalised conclusions are also drawn from this work.

Chapter 4 presents the most realistic consideration, as it involves cosmological simulations. The value of this chapter is that it uses the advanced cosmological simulations, so not only it is not just idealised simulations of two mergining galaxies, but also includes gas physics and feedback. This is the first time the formation of warps has been investigated in such simulations. The well-designed method of selecting galaxies with warps induced by interaction makes this study very valuable. It provides novel results on how warps are created.

I conclude that this thesis represent a valuable contribution to the field of galaxy evolution and therefore I recommend granting the doctoral degree to Marcin Semczuk.

Below I point out the weaknesses of this thesis with the aim of helping to improve the future work.

Aims in relation with previous work

The introduction (and to a large extent the rest of the text) is missing a clear description of the aims of this research and of how it adds to previous studies. It should have been clearly explained in what extent the current work differs from previous body of work on simulations aimed at explaining the spiral arms/warp formation. At the moment the introduction leaves the impression that some work on this has been done, and it is not clear what the new contribution is. Indeed, in Chapter 2 (page 25) it is stated that it has been "demonstrated that the cluster's tidal field can induce transient two-armed spiral structure in disky galaxies" (Byrd & Valtonen 1990; Valluri 1993). Then the aim of this chapter is presented as to "focus on the formation and evolution of spiral arms that are tidally excited in a galaxy interacting with the cluster using N-body simulations". I am sure that there are a lot improvements in the current work in comparison with the studies done 30 years ago, but this is not spelled out. It is only on page 50 when it is mentioned that the resolution of these previous simulation is not great, but this is not quantified and no discussion on the limitation of poor resolution on the results is presented.

Similarly, the results on the radial migration of stars (Section 2.4.2, page 44) is proceeded by a statement that "[s]everal authors investigated the influence of the non-axisymmetric structures like spiral arms on the radial migration of the stars", but it is not described what the current work contributes to these previous findings.

To a lesser degree this problem is present in Chapter 3 on the M31-M33 system. The simulations of this system have been done in the past (Bekki 2008; McConnachie et al. 2009). In Section 3.1.2 (page 56) it is mentioned that the simulations of Bekki (2008) had insufficient resolution to study the structure of M33 and in Section 3.4.2 (page 72) it is stated that McConnachie et al. (2009) does not include gas. Obviously then, they were unable to explain the gas distributions presented in this chapter. These factors should have been mentioned at the beginning of this chapter to motivate further simulations.

Simulation setup and statistics

The N-body simulations presented in Chapter 2 do not include gas. Therefore it requires some consideration on whether their applicability is limited. Section 2.5 addresses this question comprehensively from an observational point of view by selecting 2-arm spirals with no obvious interacting companions and showing that simulated galaxies are similar to them. I only miss two points in this consideration. First, a more quantitative comparison of observations and simulations would be necessary than just stating "by-eye" similarities. Second, it would be good to point out the literature work on what the difference is in the properties of galaxies when gas physics is included.

Simulations of the M31-M33 system in Chapter 3 do include a gas component, but only for M33 (which is the main focus of the chapter). The thesis would benefit from the discussion on how the exclusion of a gas disk in M31 could influence the final properties of M33. Moreover, again, Section 3.4 would benefit from a statistical assessment of the correspondence between the observations and the simulation output.

Alternative scenarios

The spiral arms are likely to be formed by perturbations. The thesis explores the idea that this perturbations are caused by external factors, i.e. interactions with other galaxies or a cluster of galaxies. However, it is not demonstrated, or at least discussed, that internal processes (non-uniform distribution of stars and their feedback, bars, jet-like AGN feedback, etc.) are not equally or maybe more important in the formation of arms.

Minor comments

I have several minor comments.

- In the caption of Figure 2.1 (and 4.7) the meaning of the dashed (solid) line is not described.
- In Sections 3.4.3 and 3.4.4 it is stated that the simulated stellar stream and spiral arms resemble those in observations, but Figures 3.10 and 3.11 only show the simulated images. It would be better to reproduce the figures from McConnachie et al. and Corbelli et al., to make this point easier to comprehend.
- On Figure 3.16 the SFH for an isolated simulation should be shown in order to assess which features of the evolution is driven by the interaction. Alternatively a ratio of SFRs during the interaction and in the isolated case could be shown.
- Section 4.1 is the description of the simulations, not an introduction.
- Was the second morphological classification mentioned in Section 4.2.2 (page 100) performed by a different person? That would be more valuable than just repeating the same process by the same person.
- In LaTeX in order for a period after an abbreviation not to be interpreted as the end of the sentence (with a longer space), a tilde symbol should be used, so `e.g.~tidal` instead of `e.g. tidal`.
- In LaTeX the quotation marks should be coded as double apostrophes so ``` `` ``` (resulting in “) and `''` (resulting in ”), not ″ (presumably achieved in the math mode by `$''$`).
- The numbering of sections when mentioned in the text is incorrect, because it does not include the chapter number (inconsistently with the actual section numbers). Hence instead of “Section 3”, it should be “Section 2.3”. I am not sure how to make this mistake in LaTeX, as the default behaviour using the `\label` and `\ref` pair should include the chapter number.

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