CASPEN Exit Report:
Structure and equilibrium of simulated dwarf galaxies

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Objectives

The proposed activities for this exchange consisted of an exploratory collaborative investigation of connections between stellar and gas morphology and kinematics in simulated dwarf galaxies from the TNG50 cosmological hydrodynamical simulations [1]. The questions guiding the exploration were: (i) are there hints that similarities between the stars and gas in dwarf galaxies, such as a common angular momentum axis, correlate with a galaxy being closer to equilibrium within its gravitational potential, e.g. as reflected by having a gas rotation curve close to the circular velocity curve of the galaxy? (ii) can any of the above be linked to key evolutionary events, such as mergers or bursts of star formation?

Outcomes

Note A technical issue out of our control hindered our progress. The Max Planck Computing and Data Facility (MPCDF) suffered a multiple disk failure on March 24 affecting the filesystem hosting the TNG50 simulation data. This made essentially all snapshot files from the highest-resolution TNG50-1 simulation unreadable. Tape backups exist but recovery will likely take some weeks. Some files from the lower-resolution TNG50-2 simulation survived intact, enough for about half of the galaxies in this simulation to be used, so we decided to use these as preliminary data. We carried out some initial analysis, including tabulating and saving some derived data, before the MPCDF decided to unmount the filesystem hosting the TNG50 data for maintenance/repair from March 31 to beyond the end of the exchange. From this point all analysis had to derive from what we had tabulated so far, significantly limiting our options.

The total mass enclosed within a given radius $M(<r)$ in a galaxy corresponds to a characteristic orbital velocity $V_{\rm circ}$ at that radius r through the relation $V_{\rm circ}^2 = GM(<r)/r$. We calculated this circular velocity curve for the few hundred available simulated gas-rich dwarf galaxies in the TNG50-2 simulation, and also calculated separately the median orbital speeds of stars and atomic gas in the same galaxies.

In an ideal scenario the orbital speeds of both of these kinematic tracers agree with the circular velocity curve, but galaxies are subject to many processes which can perturb them away from this ‘equilibrium’ situation. Since stars and atomic gas are affected by different physical processes, their corresponding rotation curves do not always agree with the circular velocity curve, or which each other. We show one example in the top panel of Fig. 1. In this case the asymmetric drift-corrected [2] stellar rotation curve (solid red line) and pressure support-corrected [3] atomic hydrogen (H I) rotation curve agree reasonably well across the radial range where both tracers are present, but both provide a rather poor estimate of the circular velocity (grey line) at small radii.

In order to compress the available information, we express the degree to which two curves agree (in the radial range where both are defined) with a single number which we will term the ‘mean absolute deviation’ (MAD) $\langle |V_a(r)/V_b(r)-1|\rangle$, where V_a and V_b may be substituted for the atomic hydrogen rotation curve $V_{\rm HI}$, the stellar rotation curve $V_\star$, or the circular velocity curve $V_{\rm circ}$. The MAD for $V_{\rm HI}/V_{\rm circ}$ and $V_\star/V_{\rm circ}$ are shown by the horizontal dotted lines in the lower two panels of Fig. 1. We proceeded to search for correlations between these two MAD parameters and other galaxy properties for a sample of gas-rich dwarf galaxies with $50 < V_{\rm max}/{\rm km\,s^{-1}} < 100$, ${\rm SFR} > 0.1\,{\rm M_\odot\,yr^{-1}}$, and that are centrals (i.e. not satellites). We looked particularly for hints that agreement between the observable stellar and atomic gas rotation curves might signal agreement with the (unobservable) circular velocity curve, possibly restricted to cases where some additional criterion is met. For instance, perhaps when the two curves agree they tend to trace the circular velocity, but only if the star formation rate is relatively low. This turns out not to be the case, as illustrated in Fig. 2: galaxies where both the H I rotation curve traces the circular velocity ($\langle|V_{\rm HI}/V_{\rm circ}-1|\rangle\sim0$), and the stellar rotation curve does as well ($\langle|V_\star/V_{\rm circ}-1|\rangle\sim0$) do not have obviously lower ${\rm SSFR}={\rm SFR}/M_\star$ (bluer colour of points), although there is a hint that dwarfs with higher SSFR may avoid the lower-left corner of the figure.

We investigated several other possible trends between the rotation curves, circular velocity curves and other galaxy properties and have not yet identified any strong trends of the kind that would obviously motivate further study. However, it will be interesting to revisit many of these with both the fiducial resolution TNG50-1 simulation and some adjustments to the calculations that were impossible after the disks hosting the data were unmounted for maintenance.

Other activities

During the exchange, Kyle presented his work on applications of the H I velocity width function in cosmology [4] at the UCL Cosmology/Extragalactic Astrophysics seminar on March 30, participated in the Extragalactic Journal Club and met with members of research groups with interests overlapping his own (Saintonge; Pontzen).

References

[1] A. Pillepich et al. "First results from the TNG50 simulation: the evolution of stellar and gaseous discs across cosmic time". In: MNRAS 490.3 (Dec. 2019), pp. 3196–3233. DOI: `10.1093/mnras/stz2338`. arXiv: `1902.05553 [astro-ph.GA]`.

[2] E. Noordermeer, M. R. Merrifield, and A. Aragón-Salamanca. "Exploring disc galaxy dynamics using integral field unit data". In: MNRAS 388.3 (Aug. 2008), pp. 1381–1393. DOI: `10.1111/j.1365-2966.2008.13487.x`. arXiv: `0805.3230 [astro-ph]`.

[3] O. Valenzuela et al. "Is There Evidence for Flat Cores in the Halos of Dwarf Galaxies? The Case of NGC 3109 and NGC 6822". In: ApJ 657.2 (Mar. 2007), pp. 773–789. DOI: `10.1086/508674`. arXiv: `astro-ph/0509644 [astro-ph]`.

[4] K. A. Oman. "The ALFALFA H I velocity width function". In: MNRAS 509.3 (Jan. 2022), pp. 3268–3284. DOI: `10.1093/mnras/stab3164`. arXiv: `2108.08856 [astro-ph.GA]`.

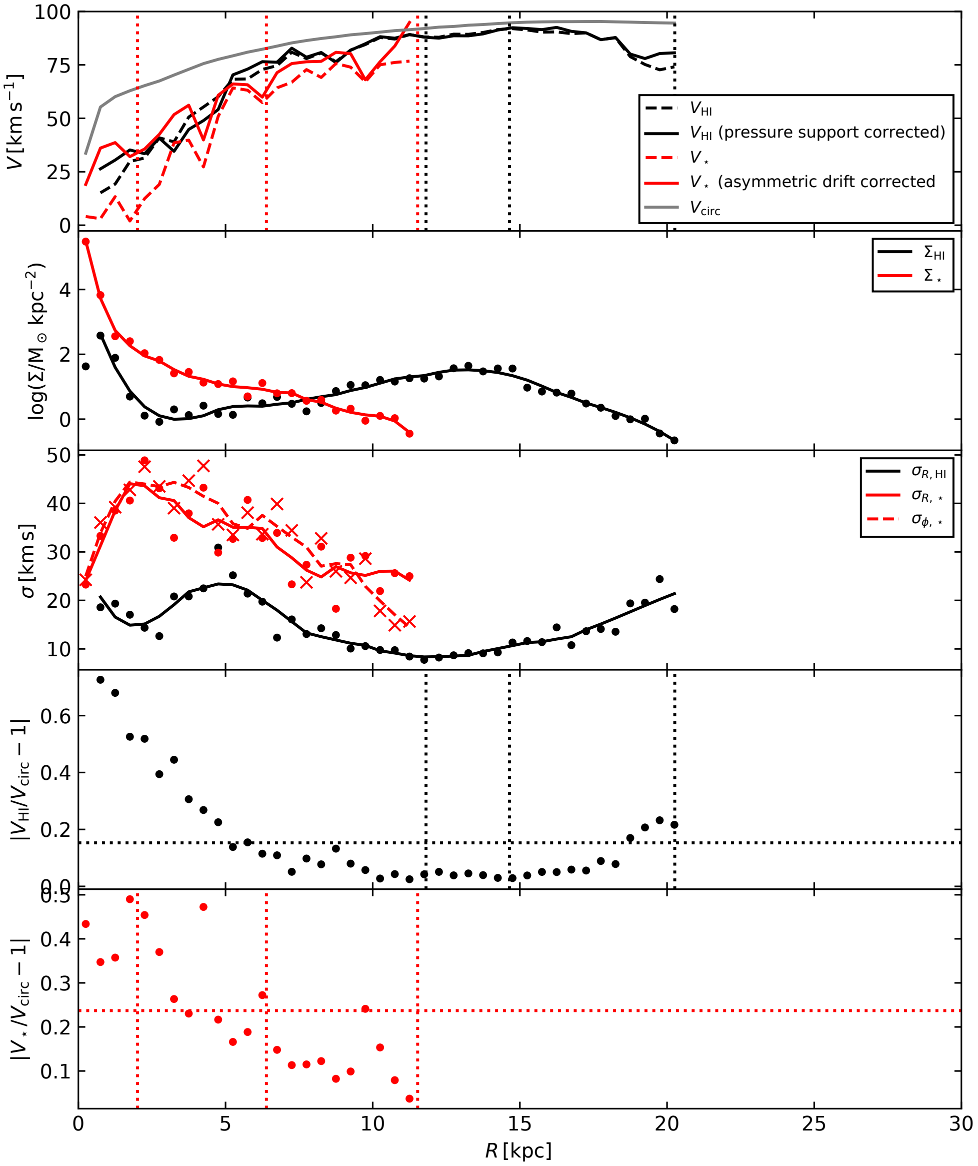

Figure 1: Radial profiles of an example galaxy from the TNG50-2 simulation. *Panel 1:* The circular velocity curve (grey) is set by the gravitational potential of the galaxy – ideally, stars and gas should orbit at this speed as a function of radius. The actual rotation curves of the stars and atomic gas are shown with the dashed lines, but these are corrected for asymmetric drift (for stars; red) and pressure support (for gas; black; corrected curves shown with solid lines) before comparing with the circular velocity. *Panels 2 & 3:* Surface density and velocity dispersion profiles (points) and smoothed versions (lines) involved in the asymmetric drift and pressure support corrections. *Panels 4 & 5:* Absolute deviation from the circular velocity curve for the atomic gas and stellar rotation curves, respectively. The mean absolute deviations are shown with the horizontal dashed lines.

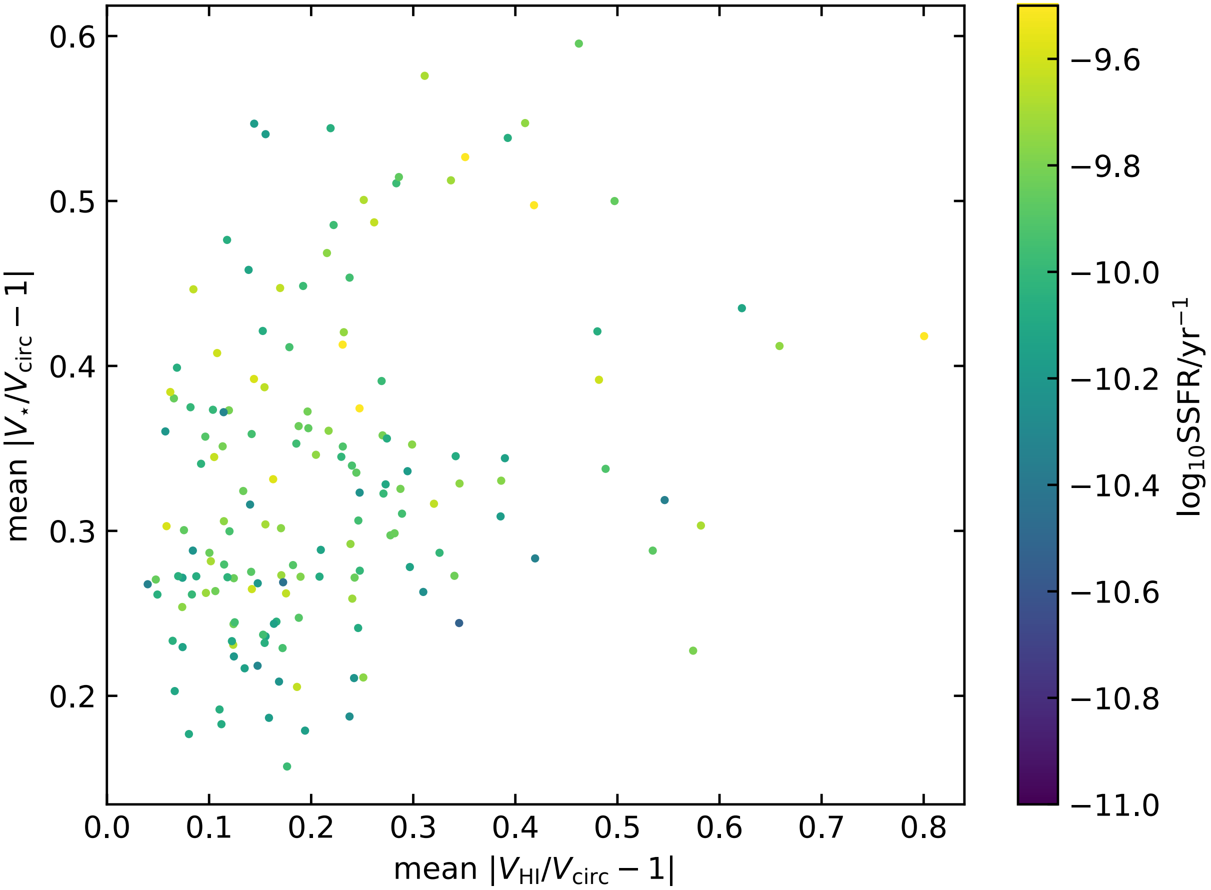

Figure 2: Stellar rotation curve MAD from the circular velocity curve as a function of H I rotation curve MAD from the circular velocity curve. Points are coloured according to the specific star formation rates of the galaxies, SSFR = SFR/$M_\star$. Although there is a hint that galaxies with low MADs for both rotation curves (lower left corner) do not have the highest SFRs in the sample, any trend is very weak.