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The Interplay between Galactic Angular Momentum and Morphology

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Abstract. In both observed galaxies and in galaxy formation simulations, the degree of rotation vs. dispersion support declines with increasing mass, at least up to $L \sim L_\star$. While most isolated Milky-Way mass galaxies have thin, centrifugally supported gas disks, many lower-mass galaxies are puffy and irregular, supported by a mix of thermal pressure and feedback-driven turbulence. Cosmological simulations show that many of the halos whose galaxies fail to form disks harbor high angular momentum gas in their circumgalactic medium. The ratio of the specific angular momentum of gas in the central galaxy to that of the dark-matter halo increases significantly with galaxy mass, from $j_{\rm galaxy}/j_{\rm halo} \sim 0.1$ at $M_{\rm star} = 10^{6-7}{\rm M}_\odot$ to $j_{\rm galaxy}/j_{\rm halo} \sim 2$ at $M_{\rm star} = 10^{10-11}\,M_\odot$. Such a decrease in the angular momentum retention factor is also required to reproduce the observed $j_{\rm galaxy} - M_{\rm vir}$ relation at low masses. In simulations, the reduced rotational support in the lowest-mass galaxies is a result of (a) stellar feedback and the UV background suppressing the accretion of high-angular momentum gas at late times, and (b) stellar feedback driving large non-circular gas motions.

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1. Overview

Cosmological simulations of galaxy formation have only recently become capable of producing galaxies with structural parameters in broad agreement with observations. While many aspects of the galaxy formation process remain imperfectly understood, high-resolution zoom-in simulations make it possible to begin to resolve galaxies' multiphase ISM, star formation in dense gas, and the effects of feedback in driving galactic outflows.

In simulated galaxies from the FIRE project, the degree of rotational support decreases strongly below $M_{\rm star} \sim 10^9 M_\odot$ (El-Badry et al. 2018). Gas in most dwarf galaxies in the simulations is supported primarily by pressure, not rotation, and the galaxies do not form thin disks. In mock-IFU observations of the simulations, it is clear that the gas is in a state of disequilibrium, perpetually perturbed and disrupted by stellar feedback. Below $M_{\rm star} \sim 10^9 M_\odot$, galaxies also have lower specific angular momentum than naively expected from the Fall (1983) relation. As a consequence, the ratio between the specific angular momentum of the galaxy and that of the dark matter halo, $f_j \equiv j_{\rm galaxy}/j_{\rm halo}$, must decrease by more than an order of magnitude from MW-mass galaxies to the dwarf scale. Recently, it has been pointed out by Posti et al. (2018) that given the shape of the $M_{\rm star}/M_{\rm halo}$ relation, a decrease in f_j at low masses is inevitable if the $j_{\rm galaxy} - M_{\rm vir}$ relation remains a constant power law.

While this decrease in f_j is also found in simulations, there it is possible to assess its origin more physically. The specific angular momentum of MW-mass galaxies increases steadily with cosmic time, such that gas accreted at $z = 0$ has an order of magnitude higher specific angular momentum than gas accreted at $z = 2$. Low-mass galaxies accrete almost all of their baryons before $z = 2$; at later times, the combination of heating from the UV background and stellar feedback-driven outflows that entrain gas in the CGM prevents new baryons from being accreted. Thus most of the baryons that end up in low-mass galaxies at late times were accreted at early times, before high-angular momentum gas was available. In the FIRE simulations, this leads directly to reduced rotational support and more irregular morphology (El-Badry et al. 2018b). Angular momentum content is also connected to the "burstiness" of galaxies' star formation histories: coherent bursts of star formation occur when large amounts of gas fall into the galactic center and accumulate at high density, and this cannot occur if gas is angular-momentum supported and settles into a disk.

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