The Fundamental Plane of Galaxy Group Mergers

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Abstract

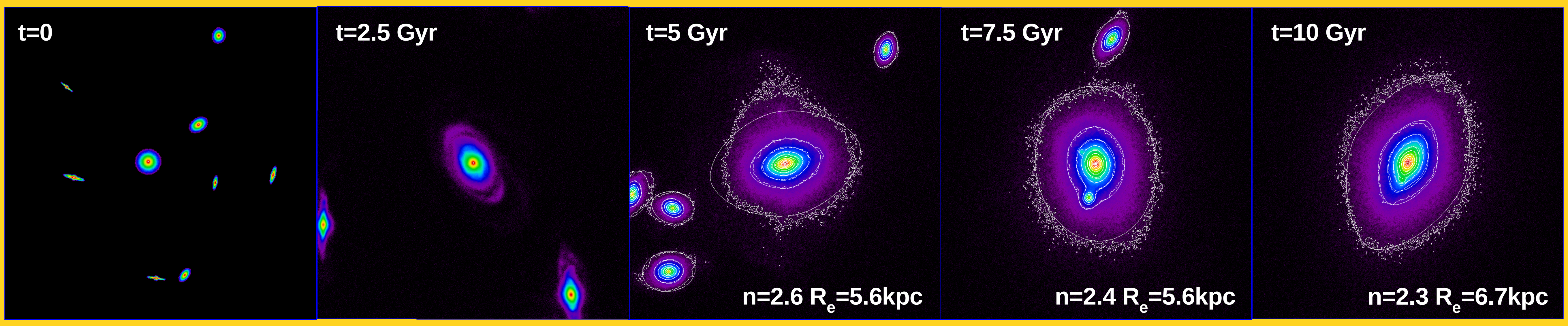
We present a large sample of high resolution simulations of galaxy group mergers. These simulations are intended to test the hypothesis that elliptical galaxies can form through dry mergers of galaxy groups, a formation scenario supported by CDM predictions of hierarchical growth and observations of the decline of the red fraction of group galaxies at high redshifts. Analyses of the central galaxies in our simulations show that these simulations are able to reproduce a tilted fundamental plane (FP) relation of R_e, σ and μ_e from stellar dynamical (not dissipational) processes. However, the kinematic and morphological properties of the merger remnants do not fully match observations, indicating that the merging galaxies may require massive, steep classical (de Vaucouleurs) bulges and/or some gas content in the disk.

Simulations

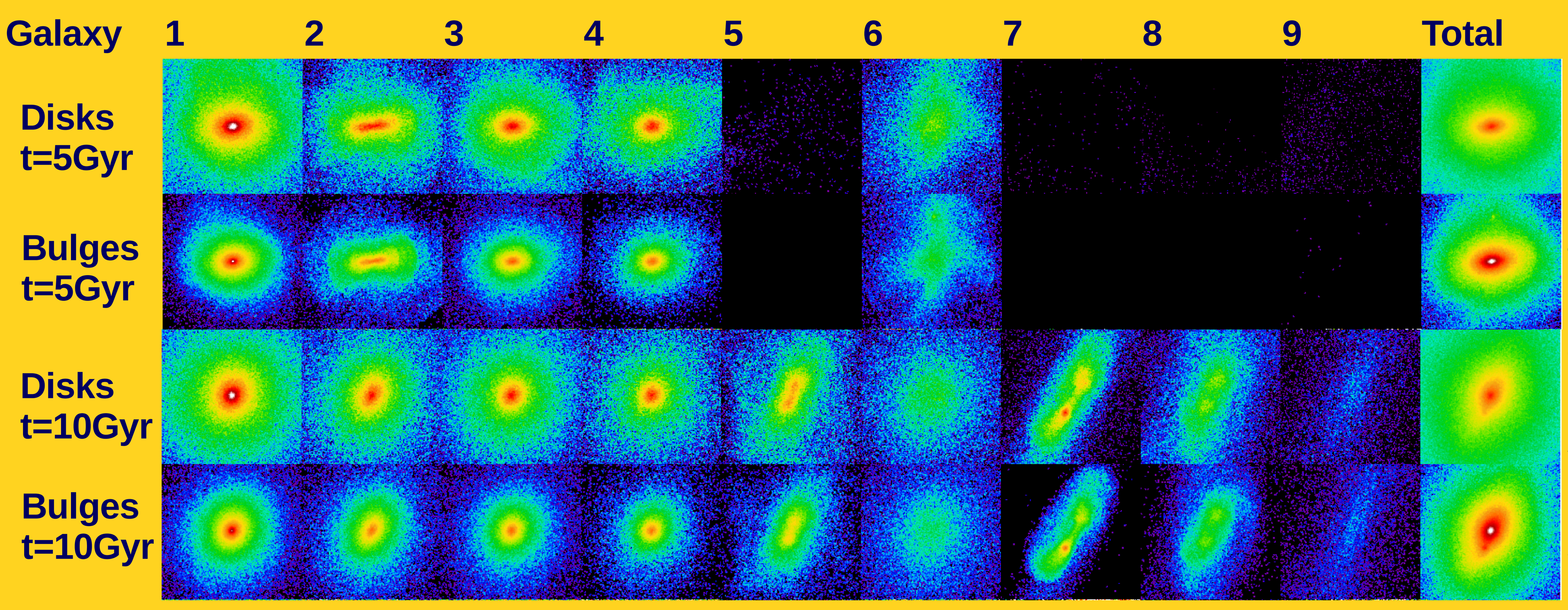
We mock up ~100 galaxy groups to closely resemble collapsing structures at the turnaround radius. Galaxies are placed to produce an r^{-1} density profile within the group and given preferentially inward and radial orbits. Galaxies are M31 models (Widrow, Pym & Dubinski 2006) rescaled by the Tully-Fisher relation $V \propto L^{0.29}$, with luminosities selected from an observed luminosity function. Groups range in mass from ~10^{10}-10^{12} $M_\odot$ (stellar) and 10^{11}-10^{13} $M_\odot$ (total) in 3-25 galaxies (depending on group mass). We use a standard n-body tree code (Dubinski 1996). Groups contain 0.5-5 million stellar and 1.5-15 million dark particles, depending on the total mass, and simulations run for 10 Gyr at a physical resolution of 100 pc (softening length).

Anatomy of a Merger

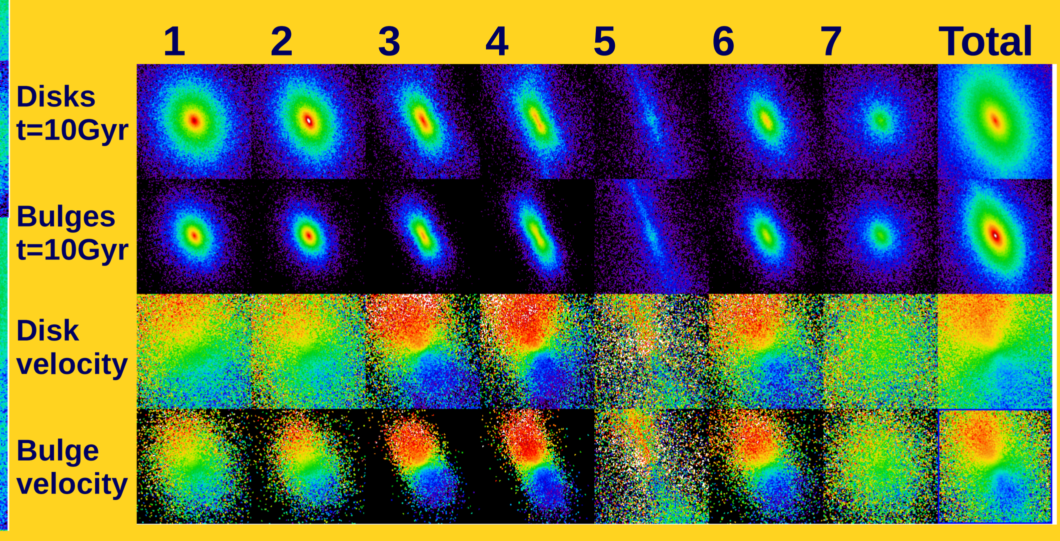
Surface brightness maps of a 2L* group merger are shown to the right, starting from initial conditions. Mock SDSS photometry (at a very nearby observed redshift of z=0.01) is shown for each time step using the medial axis projection. Raw photometric and GALFIT model isophotal contours are overlaid for merged remnants.



The images can be further decomposed into contributions from the bulges & disks of the nine original spirals, ordered by mass. These images show that the bulges remain compact, while the disk stars are scattered to large distances from the center of the remnant. Recently merged satellites show as clearly disturbed systems in these plots, although the effects on the galaxy as a whole are less extreme. More massive galaxies merge earlier and are rounded by later mergers.



Velocity maps of progenitors of a 0.5L* fast rotator (v/σ~0.35) below show that both disks and bulges can contribute to rotation.



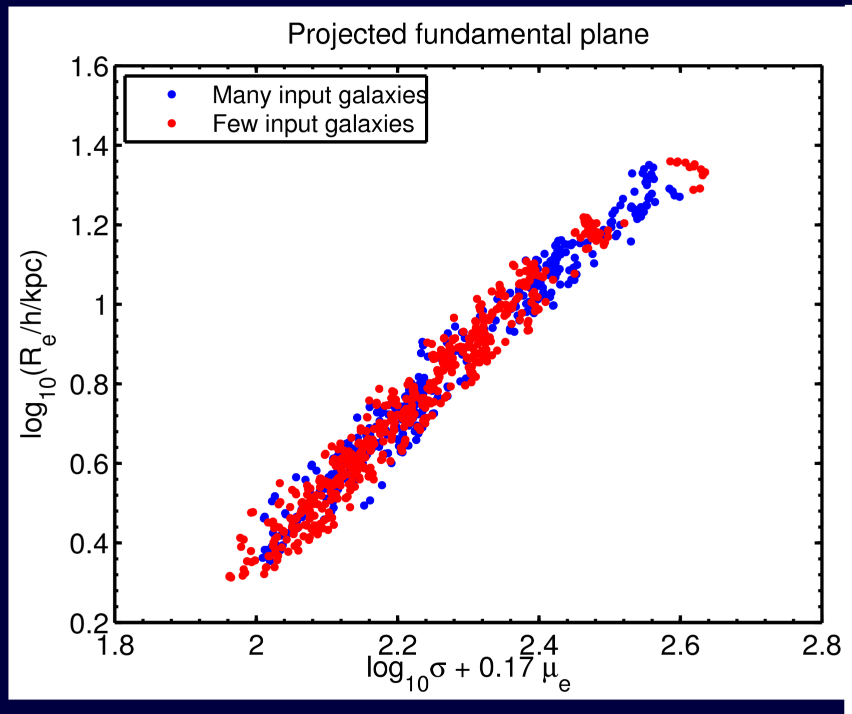
Analysis

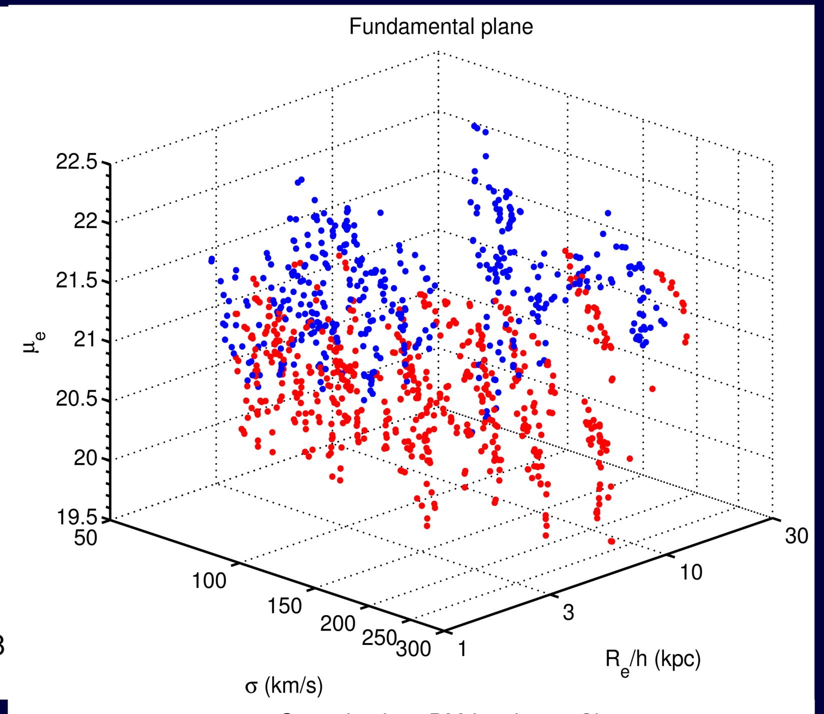
We analyze merger remnants using both traditional n-body techniques and by creating mock observations. The analysis pipeline is used to create SDSS-like r-band observations of groups at observed redshifts of 0.01, 0.025 and 0.1. GALFIT (Peng et al. 2010) is used to simultaneously fit a single Sersic profile to each galaxy in the image. 10 equally spaced, randomly oriented projections are used, as well as each of the principal (major, medial and minor) axes.

The Fundamental Plane: $\log(R_e) = a\log(\sigma) + b\mu_e + c$

The best-fit coefficients to our main sample are not virial but 'tilted'. The tilt is less than in SDSS observations (Hyde & Bernardi 2009) but closer to their stellar mass relation, which excludes tilt from stellar populations (as in our simulations). Groups take ~5 Gyr to establish a tilt, but those with many galaxies take ~7-8 Gyr to relax from mergers, requiring collapse at z~1 where the dry merging assumption is not completely safe. Mergers of many identical galaxies produce a similar tilt to the luminosity-function sampled groups. However, mergers of a few identical galaxies produce a nearly virial FP, similar to results of dry mergers of pairs of galaxies (Robertson et al. 2006). Many mergers are required to create a tilt.

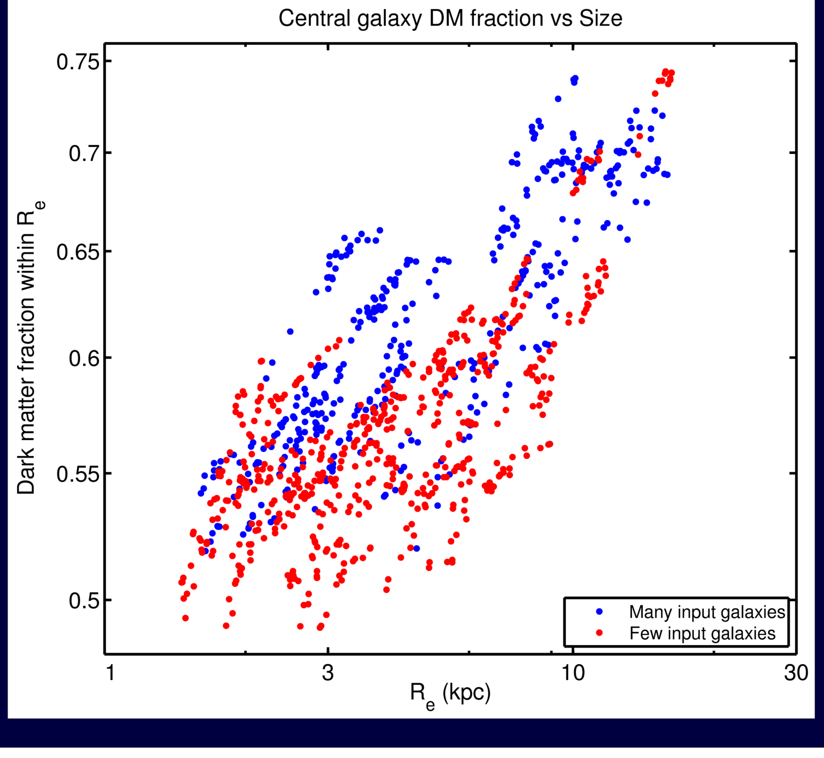
Sample	a	b	Scatter
Virial	2	0.4	0
5 Gyr	1.79	0.29	0.083
5G-few	1.88	0.39	0.046
5G-many	1.84	0.22	0.115
10 Gyr	1.72	0.31	0.048
10G-few	1.81	0.35	0.044
10G-many	1.69	0.29	0.044
10G-few-equal	1.96	0.45	0.042
10G-many-equal	1.65	0.34	0.057
SDSS:			
HB'09	1.43	0.32	0.058
HB'09 - $M_{stellar}$	1.63	0.34	0.049





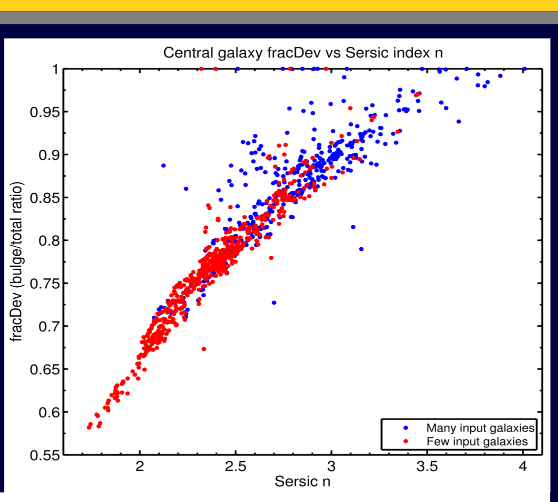
The source of the tilt is variation in the dark matter fraction within the effective radius, shown to the right. Remnants formed from more mergers have relatively larger effective radii containing more of the remnants' dark halo mass. $M_{dark}(R<R_e)$ > 50% is consistent with models of ellipticals (Weijmans et al 2007). The conversion from stellar to total mass (M_*/M_{total}) creates the FP tilt.

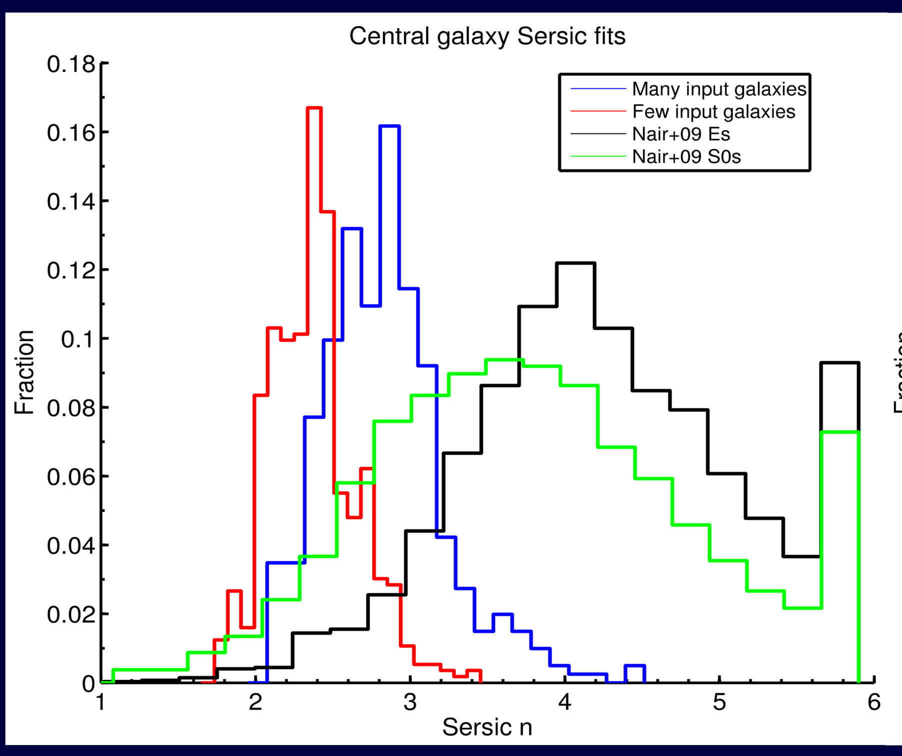
In the face-on view, groups with many galaxies occupy different locii on the FP than those with few but both subsamples have small enough scatter to combine to fit a single plane also with similar scatter.

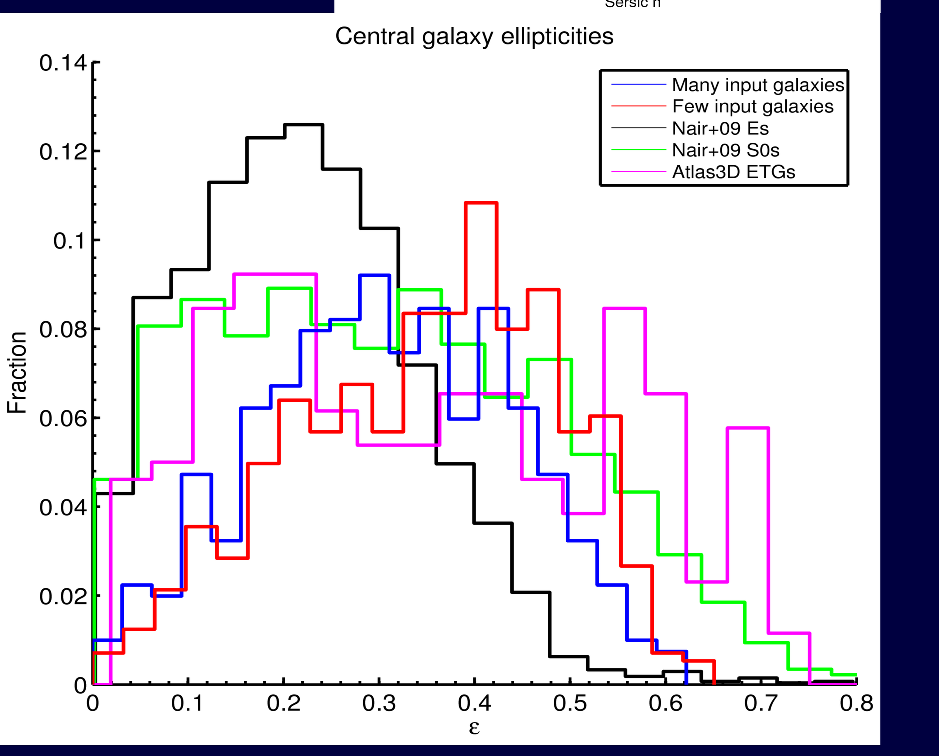


Morphology

We use the SDSS fracDev (fraction de Vaucouleurs) as a measure of bulge/total ratio, combining separate Sersic index n_s=1 and n_s=4 fits. The remnants are bulge-dominated. The correlation between Sersic index and fracDev suggests that multi-component fits are not necessary at this resolution.







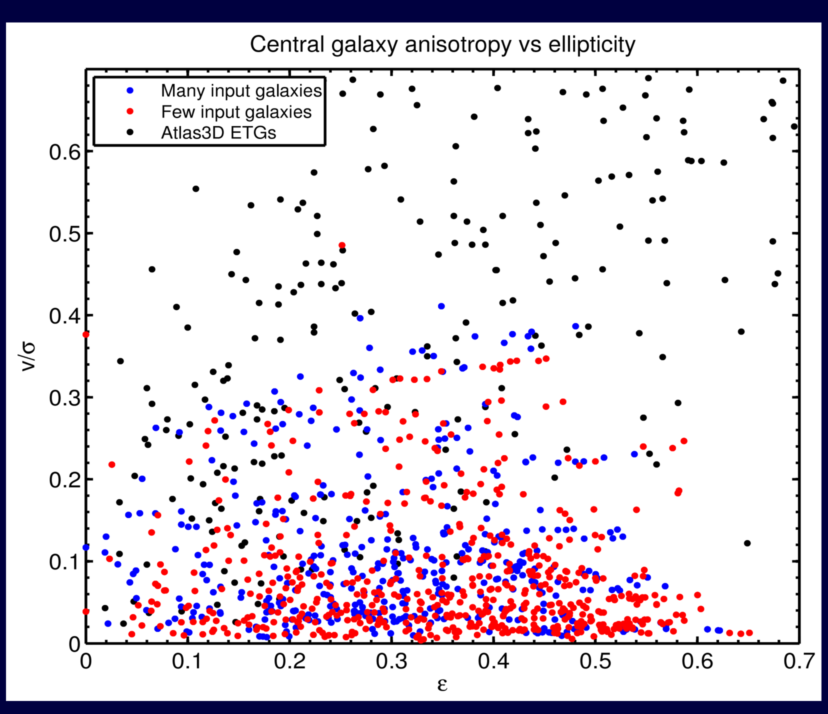
Remnants have lower n_s (between 2-3) than observations (4, Nair & Abraham 2010). Many-galaxy mergers have larger n_s due to the scattering of stars to large radii by violent relaxation. This produces a weak correlation with luminosity if luminous ellipticals form from more mergers than faint ones. Ellipticity distributions show a bias towards flatter remnants than in SDSS samples but are not inconsistent with early-type galaxies from Atlas3D (Emsellem et al. 2011).

The M31 model used has an n_s=1 bulge; a model with a steeper, n_s=4 classical bulge could produce remnants with higher n_s. The inclusion of bulges in spiral progenitors is known to affect properties of both pair and group mergers (Weil & Hernquist 1996). A central starburst from gas disks might also suffice (Cox et al. 2006). Future simulations will include a range of galaxy models as well as gas dynamics and star formation.

Kinematics

Kinematical maps are generated using the same pixel size as SDSS imaging. We measure central velocity dispersions and spatially averaged rotation measures (v/σ) within Re, as in the Atlas3D sample of ~300 local early type galaxies (Emsellem et al. 2011).

Although most of the merger remnants are slow rotators (v/σ < 0.1), some fast rotators are formed from residual group angular momentum. Dry pair mergers do not produce this result (Cox et al. 2006), while group mergers were noted to do so by Weil & Hernquist (1996).



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