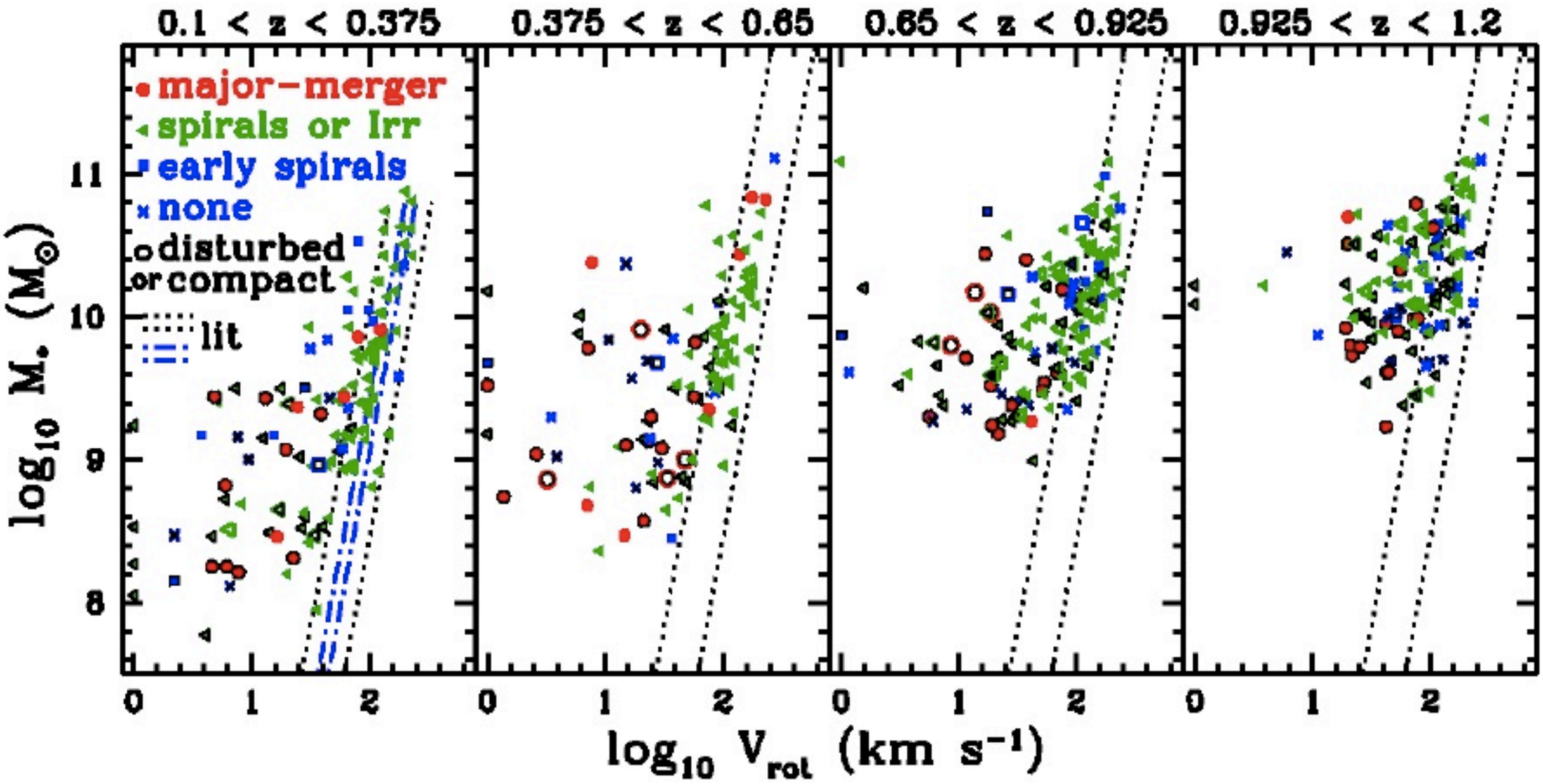
Stellar Mass Tully-Fisher Relation Evolution in Disk Galaxy Merger Simulations

Matthew D. Covington, Susan A. Kassin, Aaron A. Dutton, Benjamin J. Weiner, Thomas J. Cox, Patrik Jonsson, Joel R. Primack, Sandra M. Faber, & David C. Koo

The standard paradigm for forming spheroidals is through mergers of disk galaxies, in which case the FJ law descended from the TF law, as modified by mergers. Kassin et al. 2007 showed that morphologically normal disk galaxies lie close to the TF law, whereas disturbed/merging galaxies rotate too slowly for their mass. However, all galaxies lie on a TF-like law, if their random internal motions as well as V_{rot} are included, using $\mathbf{S_{0.5} = (\sigma^2 + 0.5V_{rot}^2)^{1/2}}$.
Here we analyse a suite of merger simulations of disk galaxies initially set up to obey the TF law. The relation between $S_{0.5}$ and stellar mass holds not only for progenitor disks but also for spheroidal remnants and intermediate disturbed/merging stages. The $S_{0.5}$-stellar mass relation is thus a link between the TF and FJ laws. We also find that the $S_{0.5}$ parameter tracks the mass, including both baryonic and dark matter components, of all types of galaxies.

THE STELLAR MASS TULLY-FISHER RELATION TO Z = 1.2 FROM AEGIS

Susan Kassin et al., ApJ Letters, 2007



M* TF relations { z ~ 0, Bell & de Jong 2001; z ~ 1, Conselice et al. 2005

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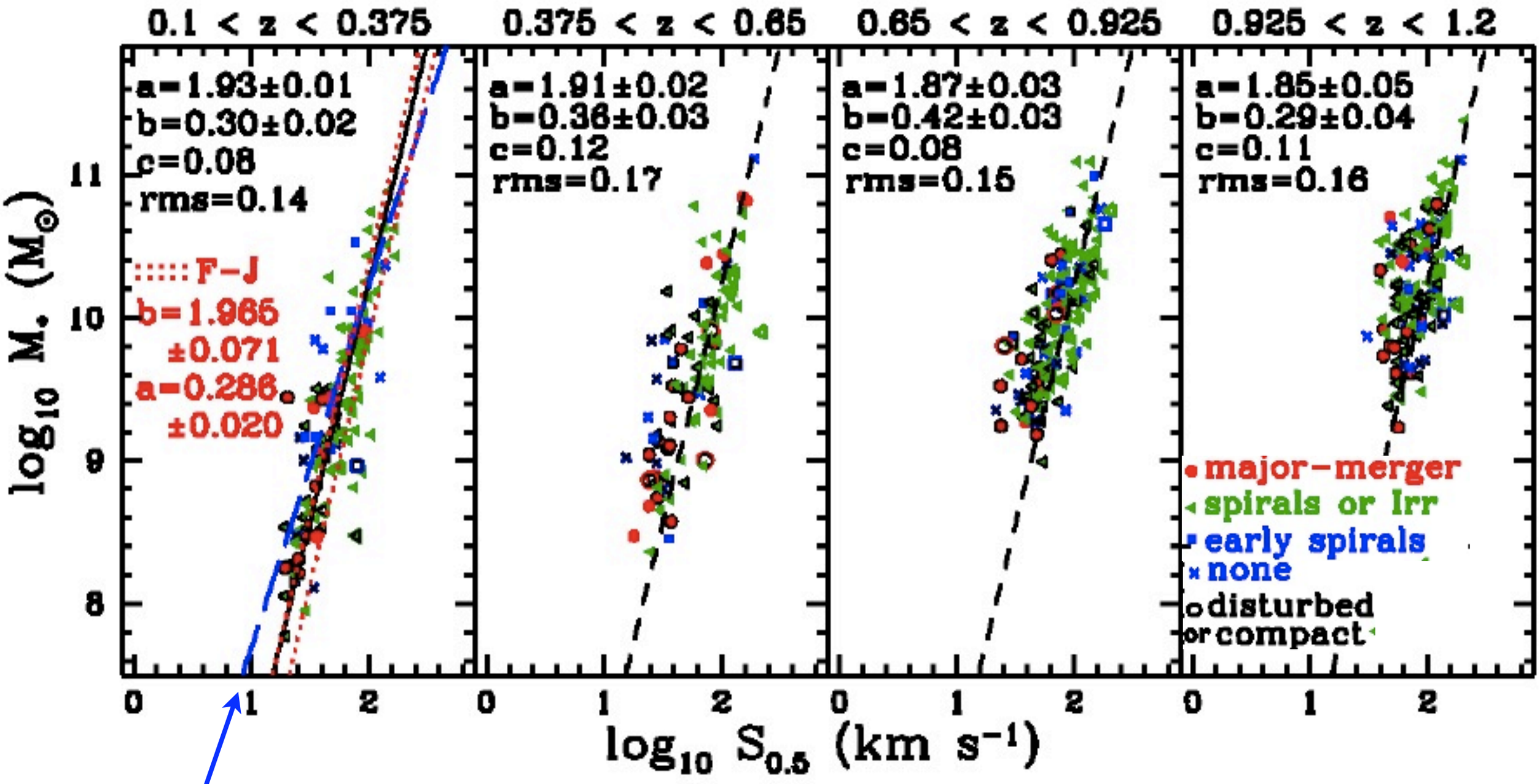

local $S_{0.5}$-M* relation

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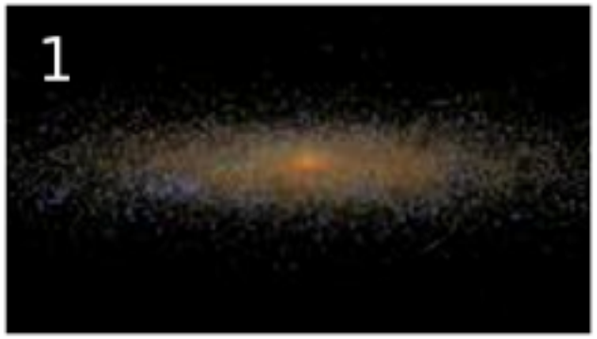
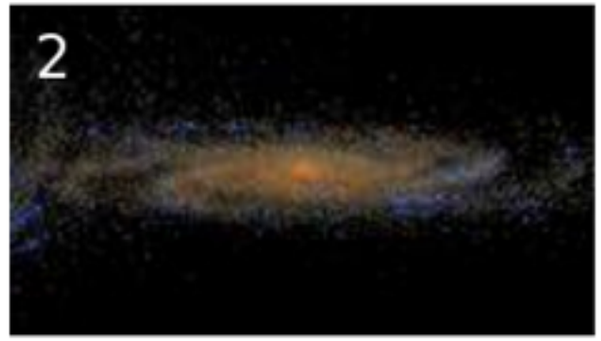
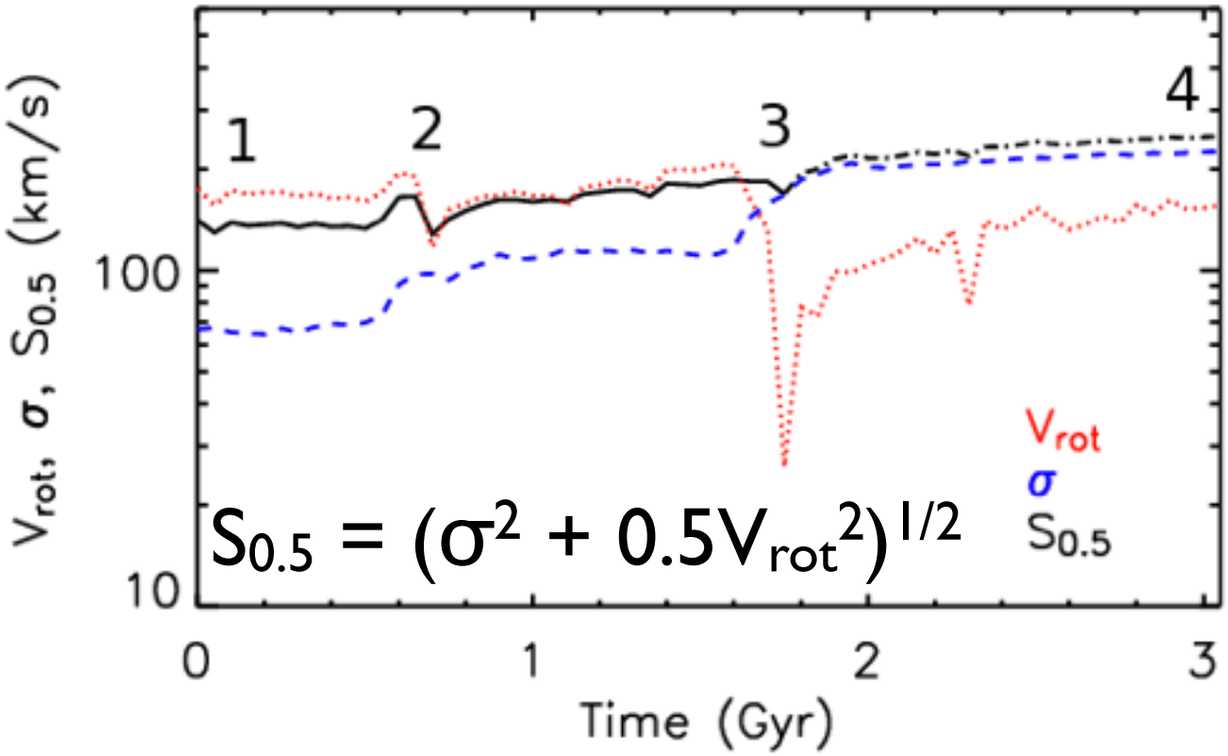


Before any encounters

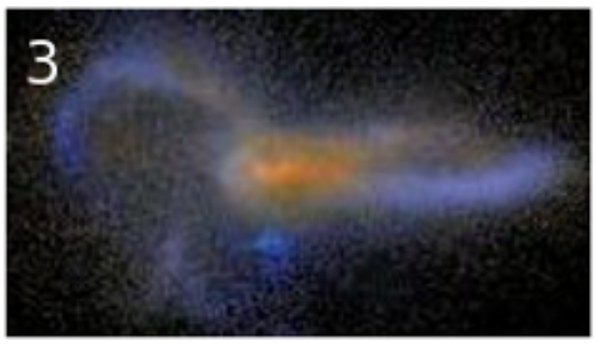


Shortly after the initial encounter

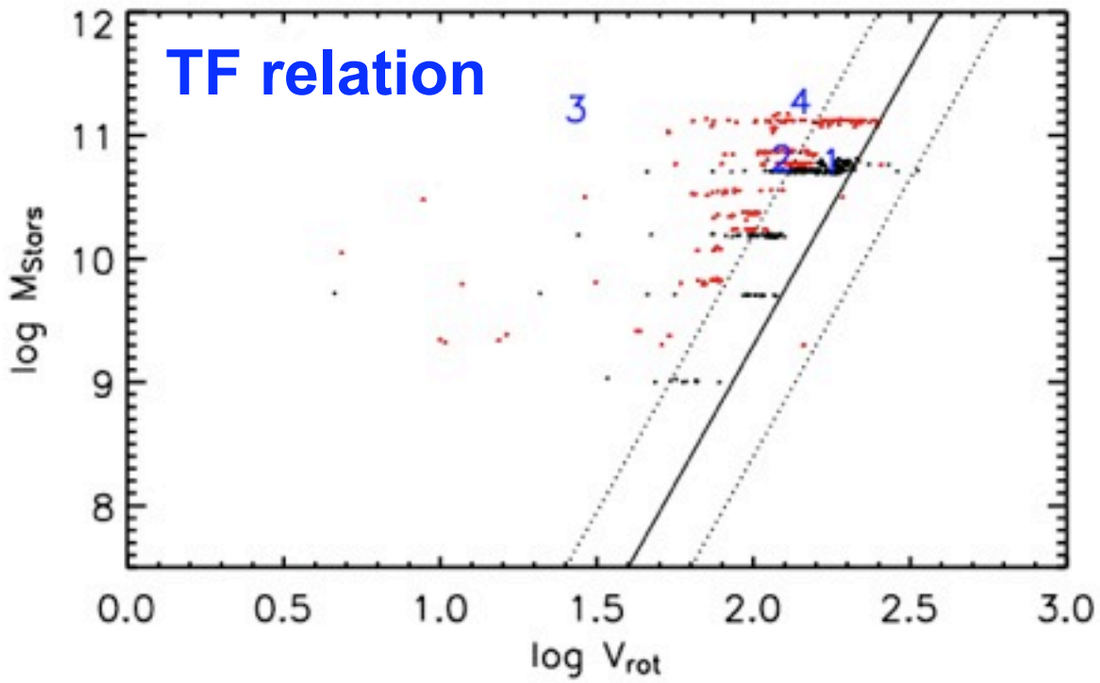
Time evolution of rotation velocity (red dotted line), velocity dispersion (blue dashed line), and $S_{0.5}$ (solid and dash-dot black lines) during a single merger simulation of two Sbc galaxies with stellar masses of ~5x10^{10} solar masses initially on a parabolic orbit. Care is taken to "observe" the simulations just as in the actual observations. The solid portion of the $S_{0.5}$ line denotes the snapshots where only a single progenitor is ``observed," in the slit and the dash-dot portion denotes snapshots where both progenitors are "observed" in the slit.

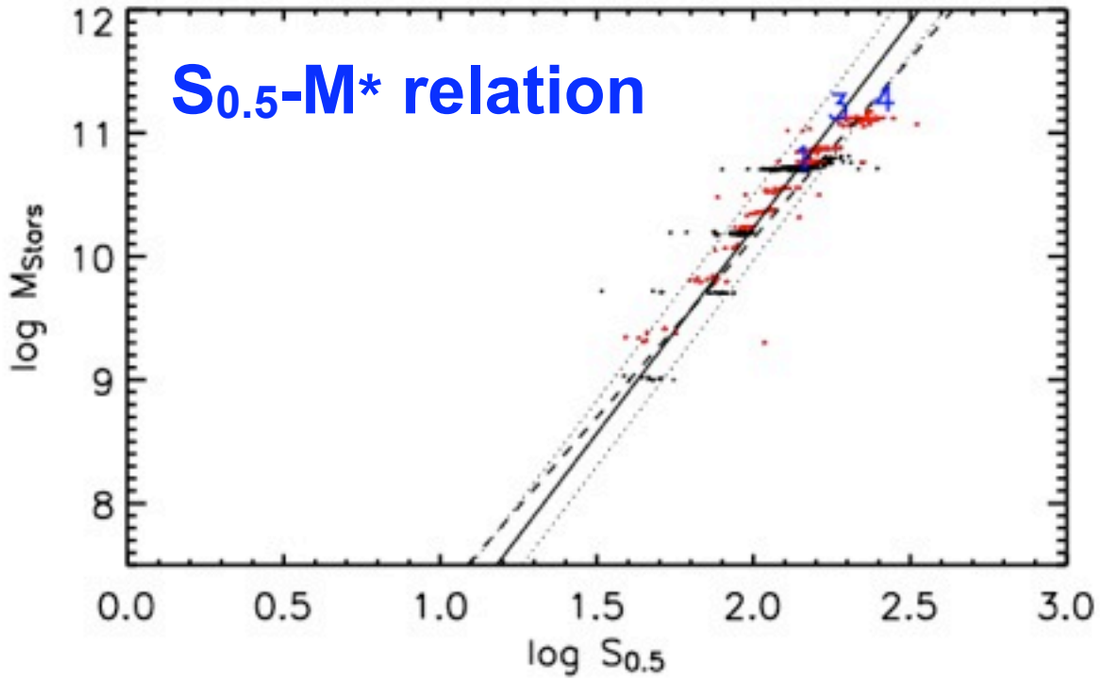


At the final coalescence



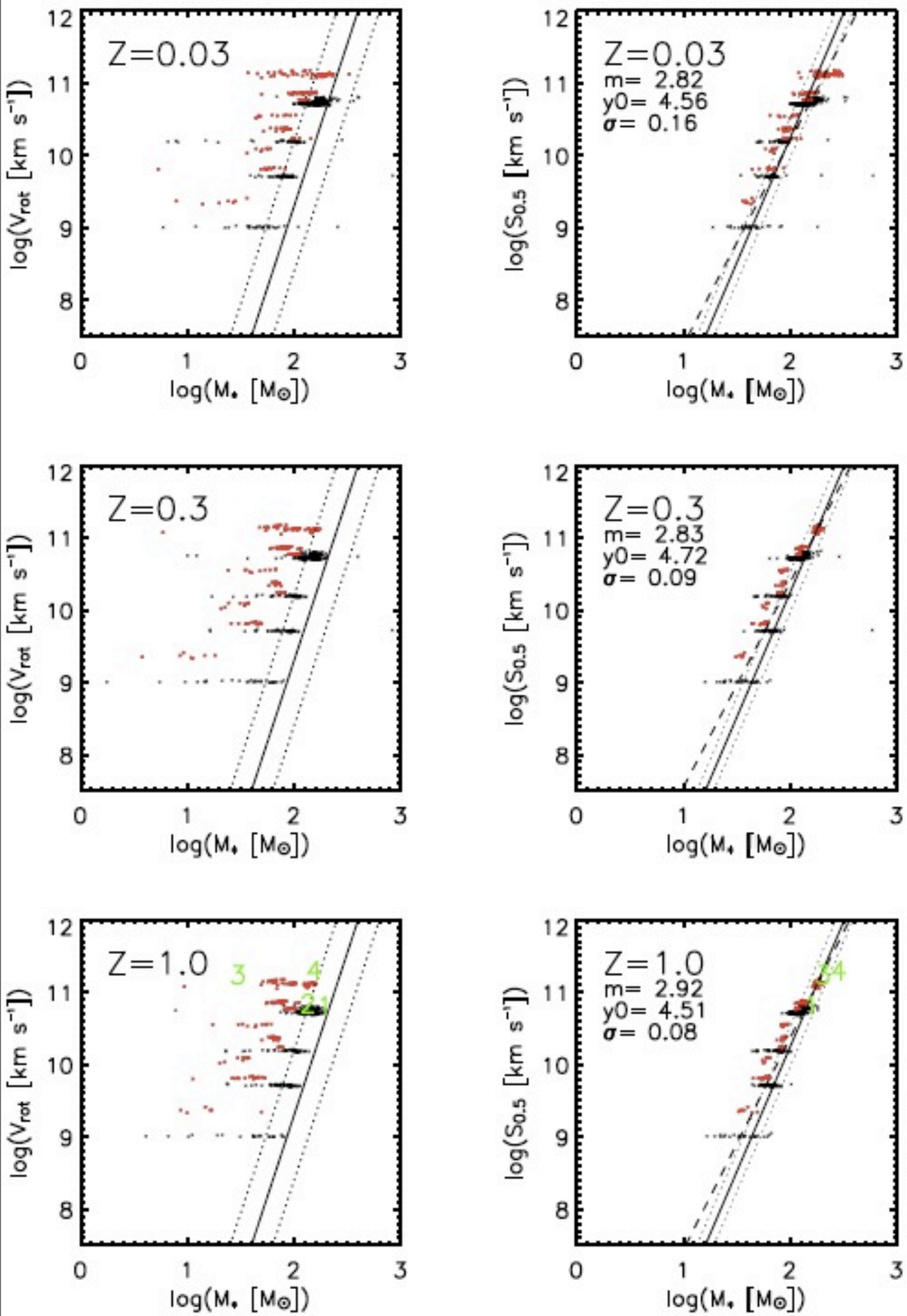
Remnant after coalescence





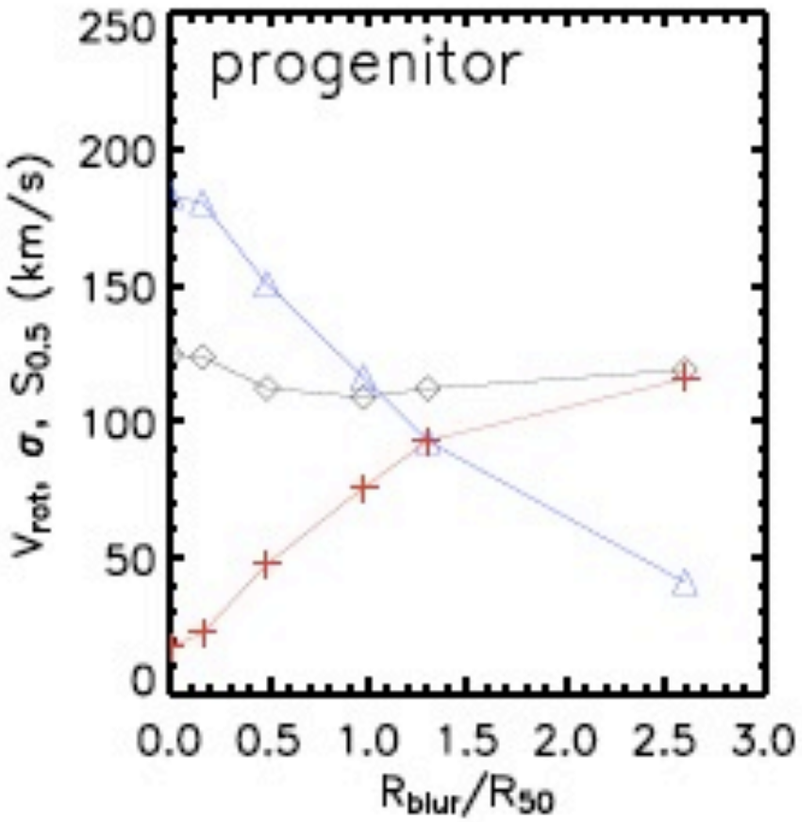
Numbers on the plots show the location of the numbered merger stages. In the bottom panel, 2 overlaps 1.

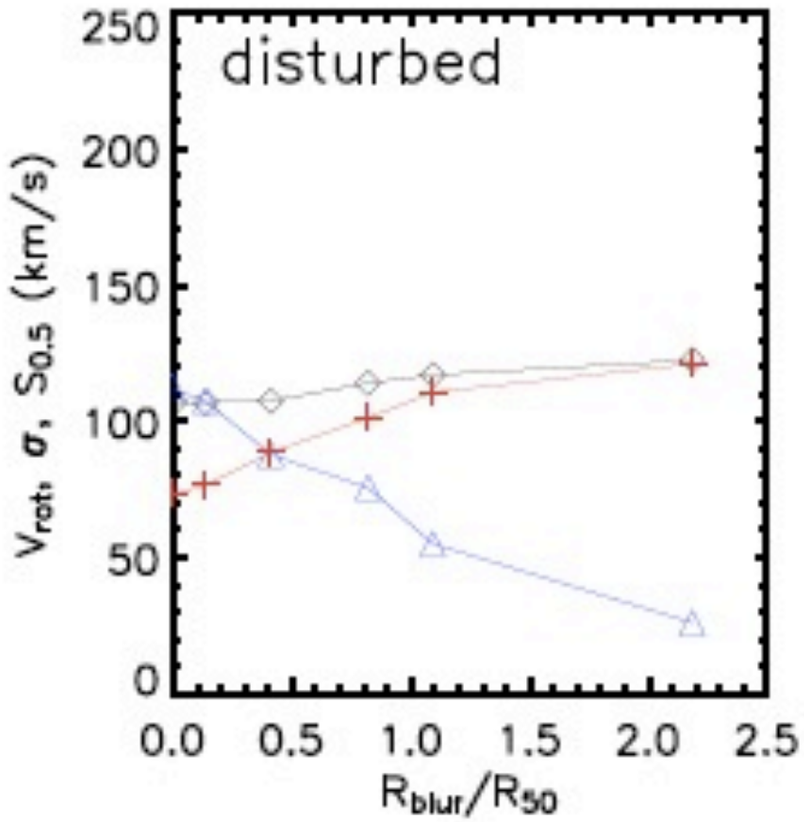
The TF relation (top) and $S_{0.5}$-stellar mass relation (bottom) for mock observations of simulated merging galaxies. Each dot represents a mock observation of a single snapshot viewed from a single angle. In order to compare with the observational results from Kassin et al. 2007, 500 such images were chosen from the simulation set at random. Red points are mock observations where both galaxies are present in the slit (i.e. close encounters and the merger remnant), and black points are mock observations of single simulated galaxies. The solid line is the high-redshift TF ridgeline, with the dotted lines representing the scatter. As in Kassin et al. a significant number of the simulated galaxies scatter to low V_{rot}. In the Kassin et al. observations, these galaxies have disordered or compact morphologies, and in the simulations the majority of these are cases that either are undergoing or have recently undergone an encounter. In the bottom panel, the solid line is a fit to the observations of Kassin et al., and the dotted lines depict scatter in the relation. The dashed line is the best fit to the simulations. Including velocity dispersion greatly reduces the scatter and brings the progenitors, disturbed galaxies, merging galaxies, and merger remnants onto a single kinematic relation. The relation and scatter found for the simulated galaxies is comparable to the observed relation.

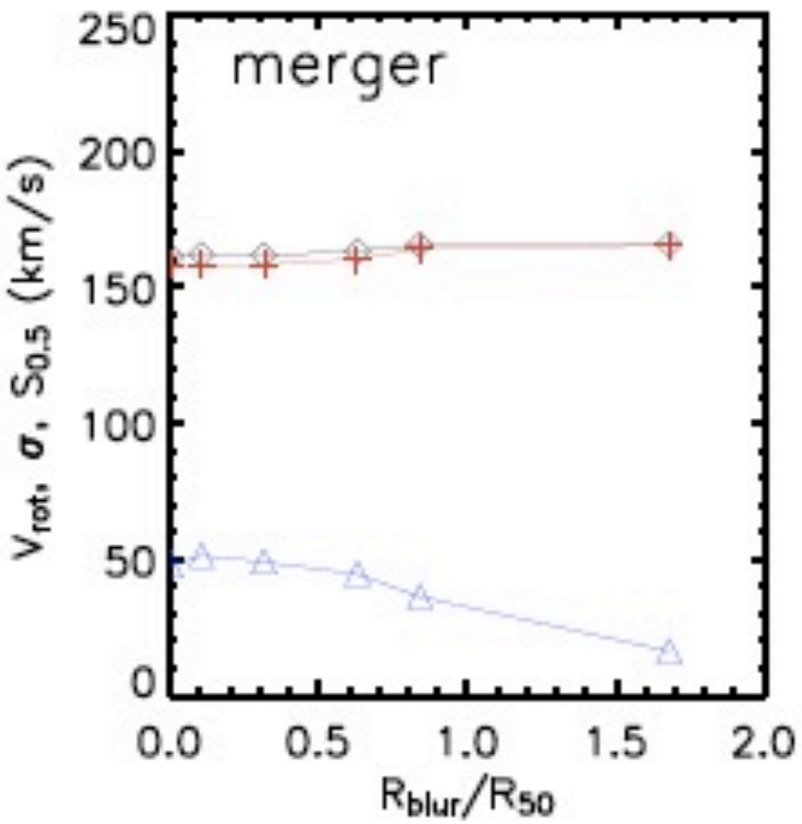


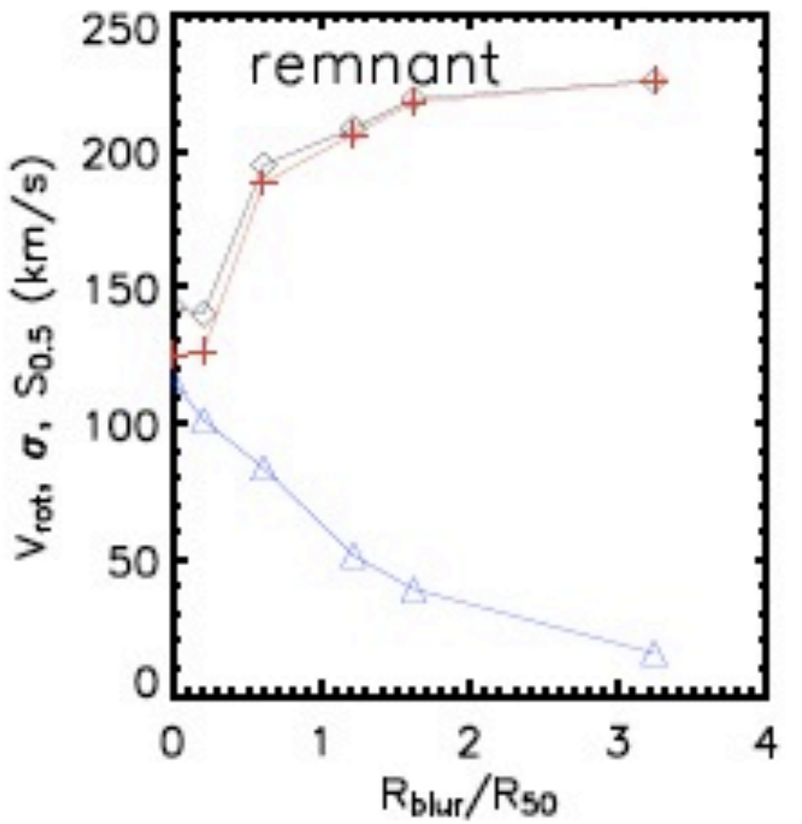
The TF relation (left) and S0.5-stellar mass relation (right) for mock observations of simulated merging galaxies. Each dot represents a mock observation of a single snapshot viewed from a single angle. In order to compare with the observational results from Kassin et al. (2007), 500 such images were chosen from the simulation set at random. Red points are mock observations where both galaxies are present in the slit (i.e. close encounters and the merger remnant), and black points are mock observations of single simulated galaxies. In the TF plots, the solid line is the high-redshift TF ridge line from Conselice et al. (2005), with the dotted lines representing the scatter. As in Kassin et al. (2007), a significant number of the simulated galaxies scatter to low V_{rot}. In the observations, these galaxies have disordered or compact morphologies. Similarly, in the simulations, the majority of the cases scattered to low V_{rot} are either undergoing or have recently undergone an encounter. In the $S_{0.5}$ plots, the solid line is the fit to the observed $S_{0.5}$ relation at $z=1.0$, and the dotted lines depict scatter in the relation. The dashed line is the best fit to the simulations. Slopes (m), zero points (y_0), and scatters (σ) for each fit are listed ($y = y_0 + mx$). Including velocity dispersion greatly reduces the scatter and brings the progenitors, disturbed galaxies, merging galaxies, and merger remnants onto a single kinematic relation. The relation and scatter found for the simulated galaxies are comparable to the observed relation. Numbers on the plots show the location of the various numbered merger stages from Figure 3.1. The bottom panel has no '2' because it overlaps '1'.

Fig. 3





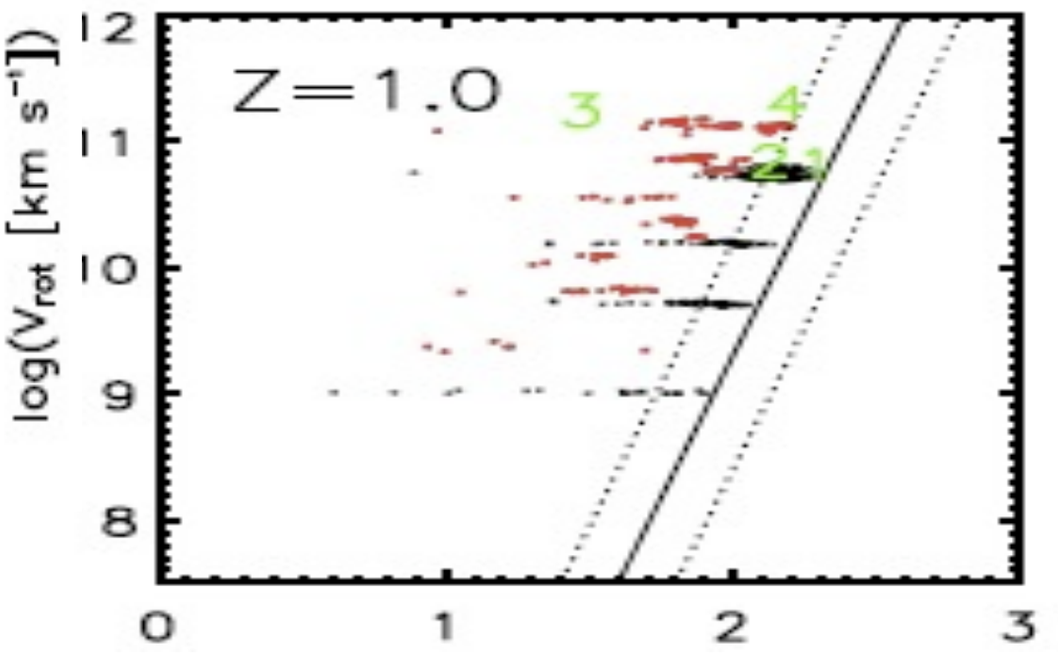




Effect of blurring on kinematics. We take the four snapshots from our fiducial Sbc merger and analyze the kinematics after blurring the particle positions by gaussians with σ's of 0.0", 0.1", 0.3", 0.6", 0.8", and 1.6". Blurring is normalized using the (unblurred) radius that contains 50% of the stellar mass (R_{50}). Lines and symbols are rotation velocity (blue triangles), (red crosses), and $S_{0.5}$ (black diamonds). Since the physical radii are different for each stage, and the blurring is held constant, each plot shows a different range of R_{50}/R_{blur}.

From Fig. 2

Using All Star Particles



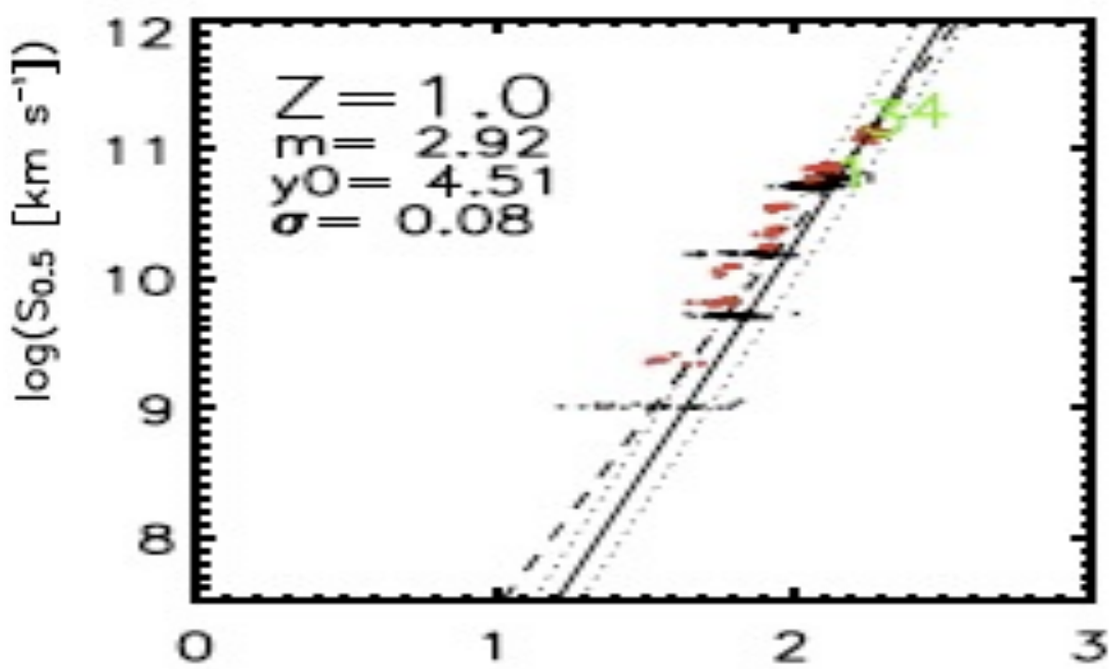
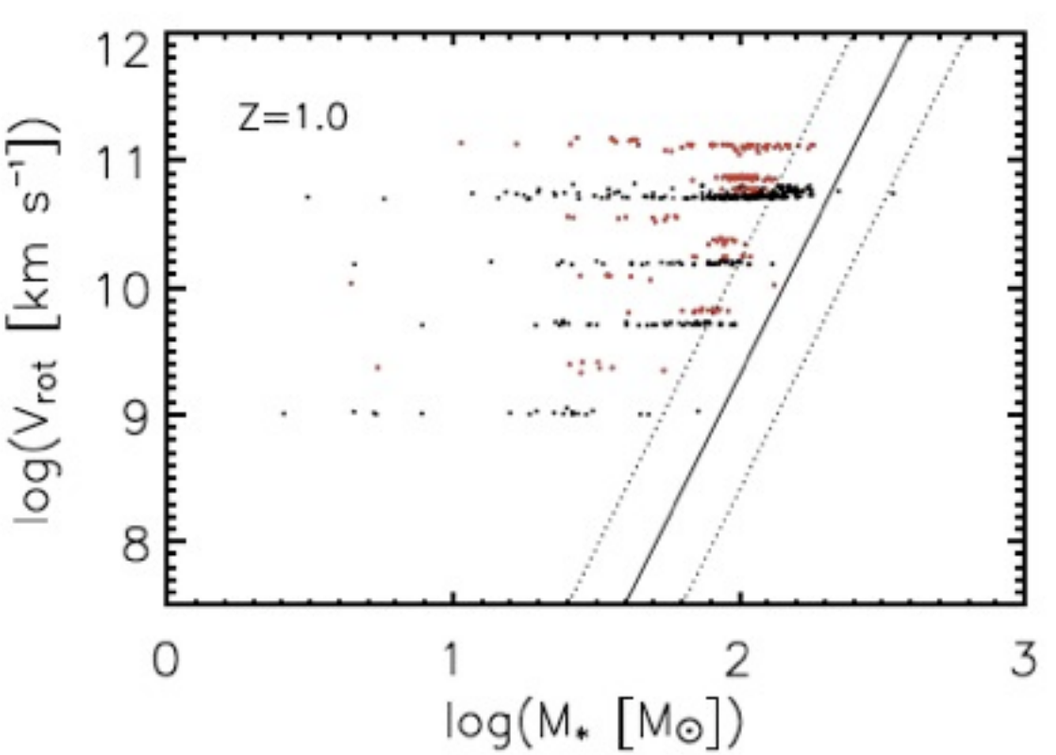


Fig. 4

Using Only New Star Particles



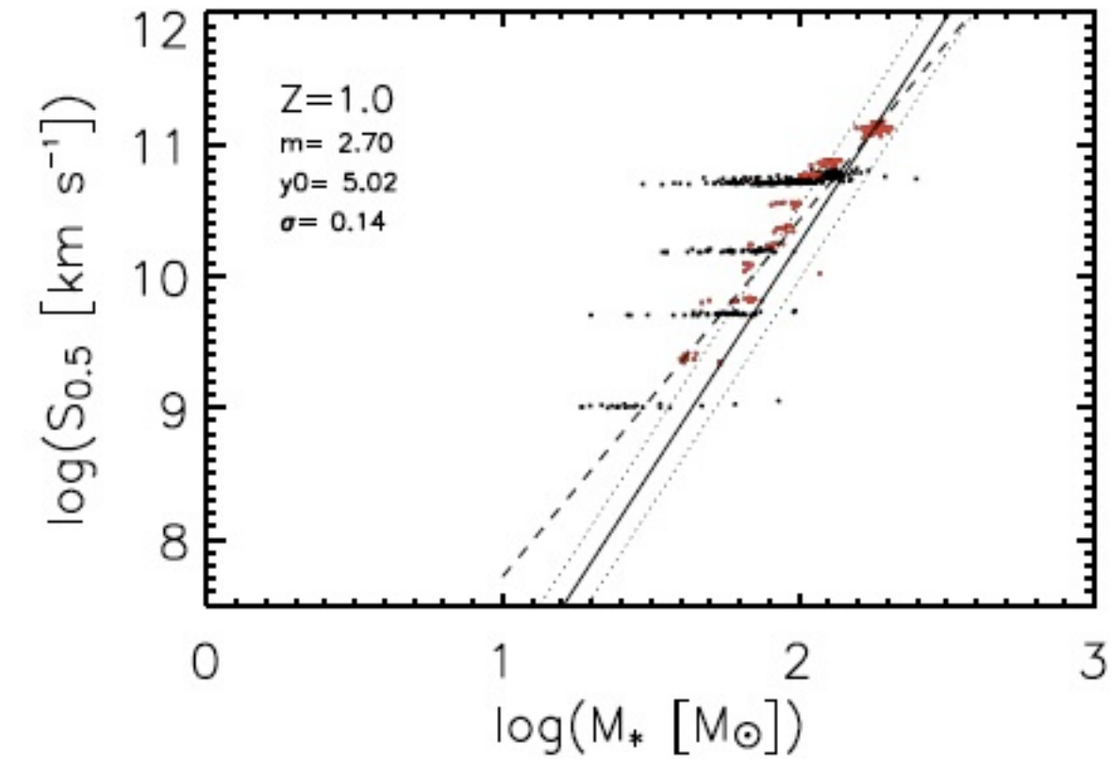
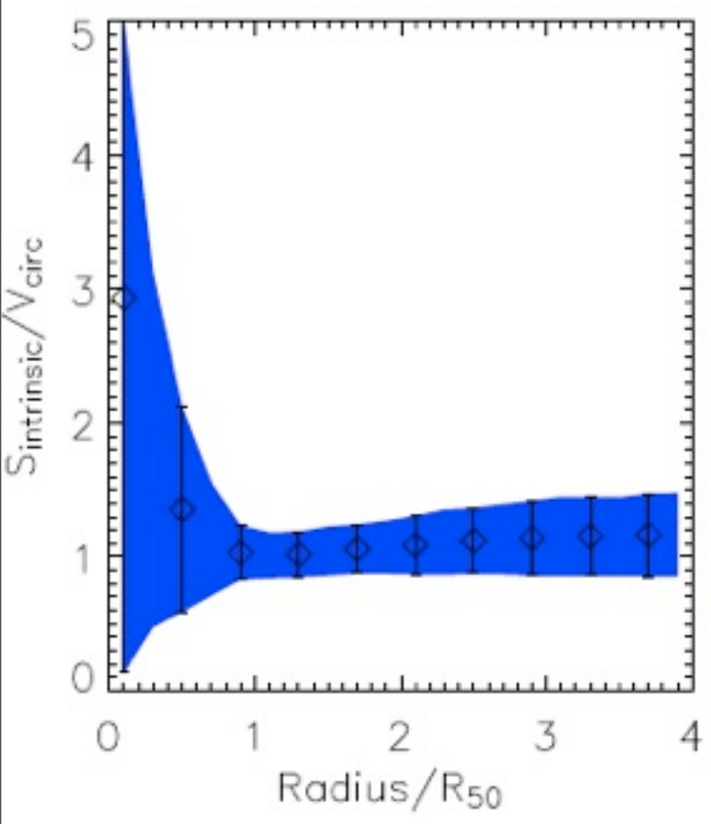
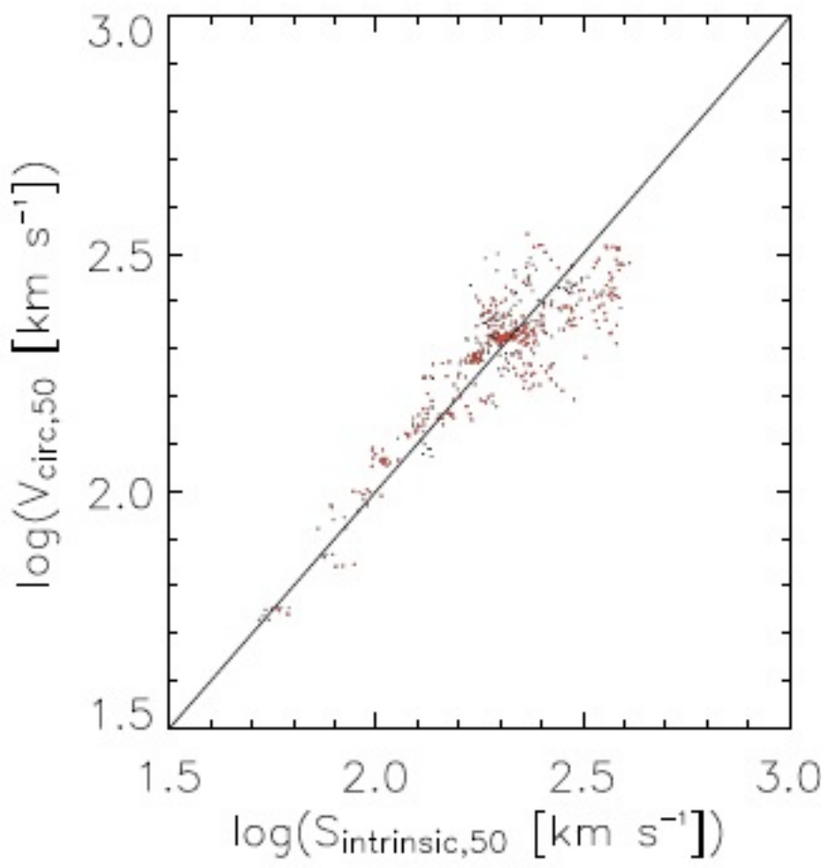


Fig. 5



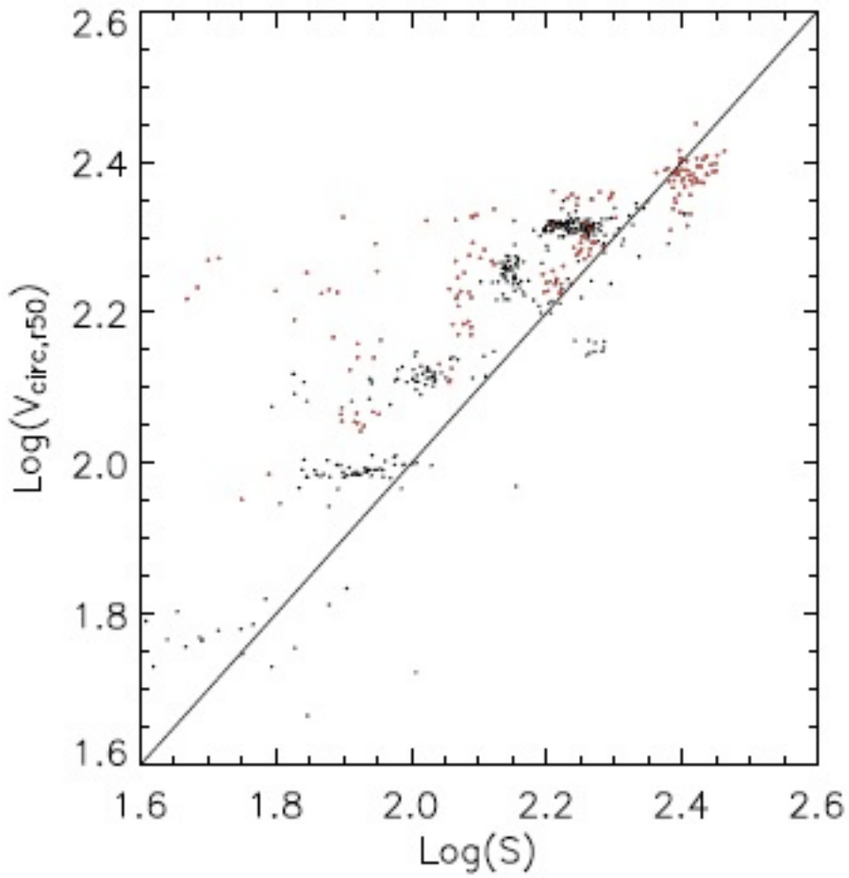
Ratio of $S_{intrinsic}$ and V_{circ} as a function of radius averaged over all simulation snapshots and normalized to R50. Blue range shows the 1σ scatter in the profiles. At radii larger than ~ R50, $S_{intrinsic}$ is a good estimator of total enclosed mass.

Fig. 6



Relation between intrinsic $S_{intrinsic}$ and V_{circ} at R50 as observed in the galaxy merger simulations. Red points are cases for which both galaxies were analyzed together, most of which are remnants. The x = y line shows the rough equivalence of $S_{intrinsic}$ and V_{circ}.

Fig. 7



Relation between $S_{observed}$ and V_{circ} as measured at R50. Red points are cases for which both galaxies are analyzed together. The line plotted is the x=y line, demonstrating the correspondence between the two values.

Future work:

Include dust attenuation in kinematics

Use kinematic signatures (e.g., V_{rot}/σ) to help determine merger stage, along with morphologies and colors

Make mock 2D kinematic observations for comparison with IFU observations of merging galaxies