Stellar orbits in cosmological galaxy simulations: the connection to formation history and line-of-sight kinematics

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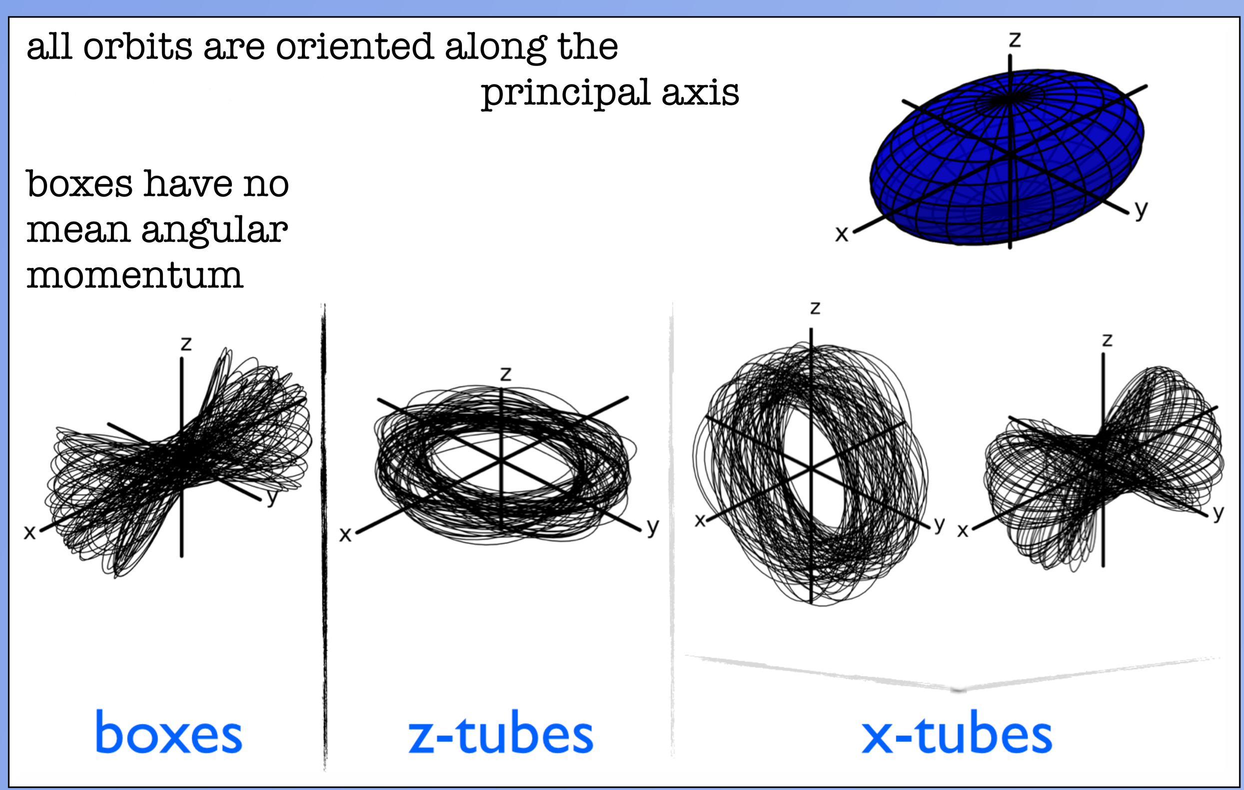
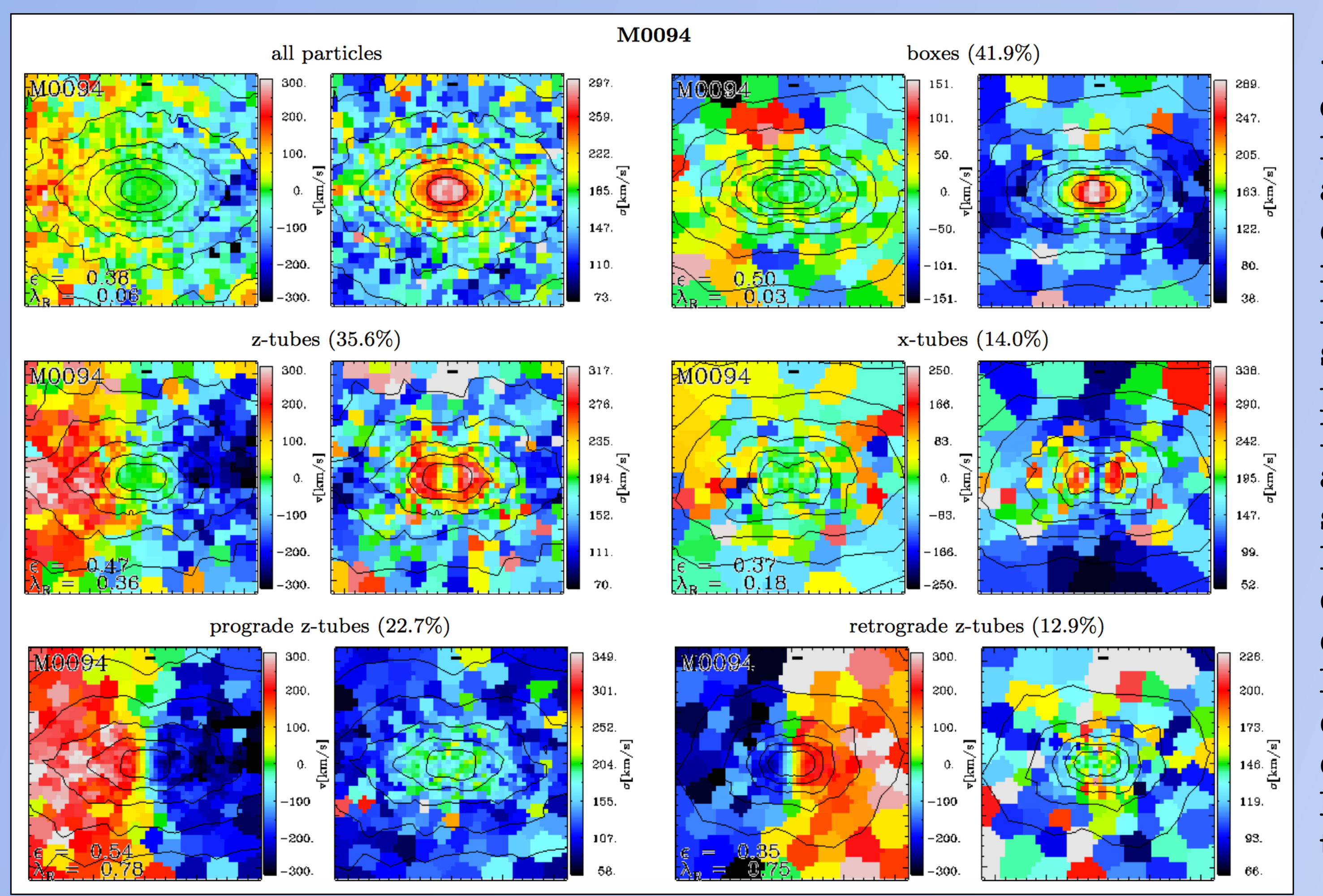
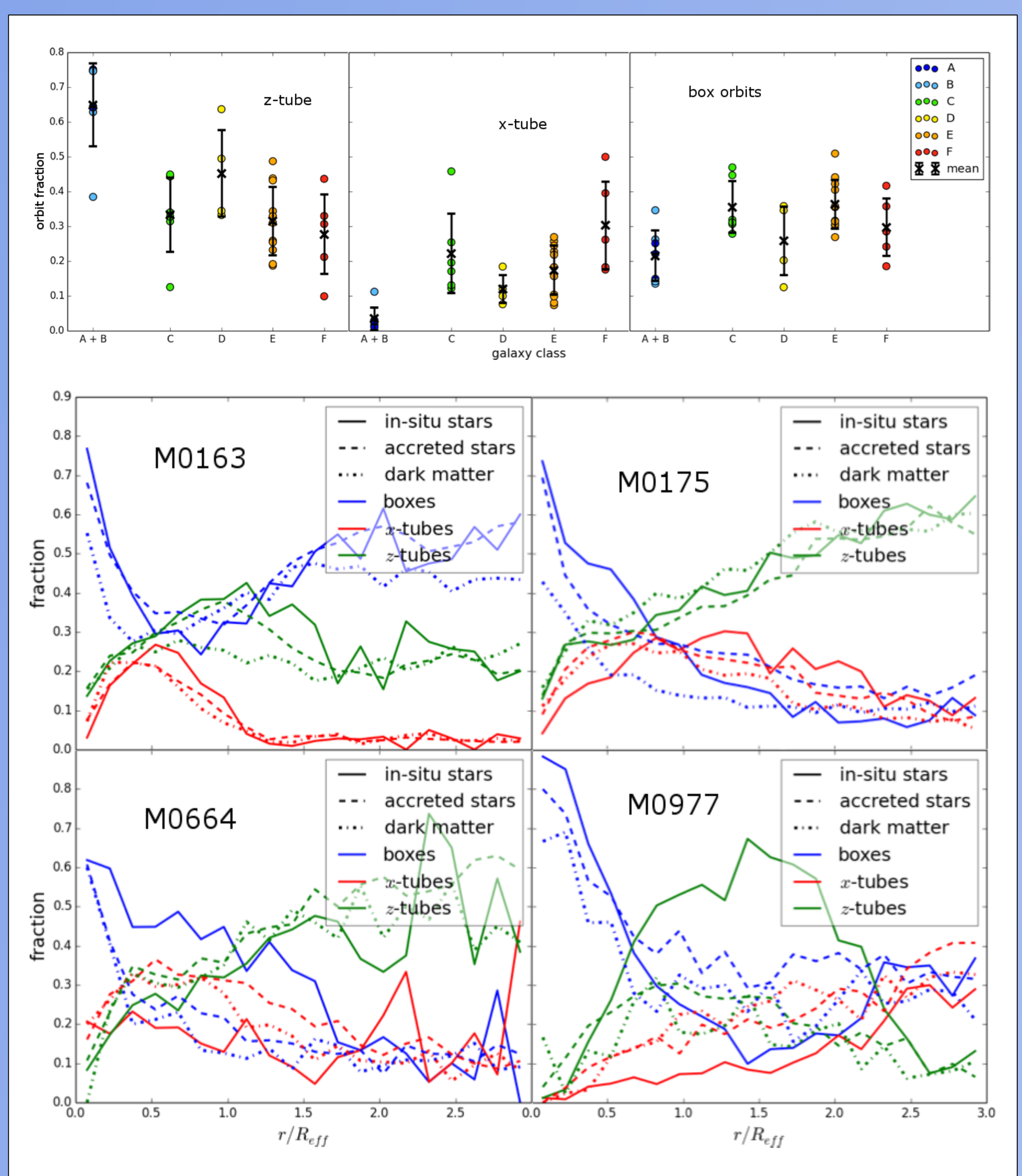
Summary

We analyze orbits of stars and dark matter out to three effective radii for 42 galaxies formed in cosmological zoom simulations. Box orbits always dominate at the centers and z-tubes become important at larger radii. We connect the orbital structure to the formation histories and specific features (e.g. disk, counter-rotating core, minor axis rotation) in two-dimensional kinematic maps. Globally, fast rotating galaxies with significant recent in-situ star formation are dominated by z-tubes. Slow rotators with recent mergers have significant box orbit and x-tube components. Rotation, quantified by the λ_R-parameter often originates from streaming motion of stars on z-tubes but sometimes from figure rotation. The observed anti-correlation of h_3 and V_0/σ in rotating galaxies can be connected to a dissipative formation history leading to high z-tube fractions. For galaxies with recent mergers in-situ formed stars, accreted stars and dark matter particles populate similar orbits. Dark matter particles have isotropic velocity dispersions. Accreted stars are typically radially biased ($\beta \approx 0.2 - 0.4$). In-situ stars become tangentially biased (as low as $\beta \approx -1.0$) if dissipation was relevant during the late assembly of the galaxy.





← Kinematic decomposition of a counter-rotating core: Here we plot the LOS velocity and velocity dispersion maps of one of our simulated galaxies for all stellar particles and also LOS velocity map only from stellar particles on box orbits, prograde or retrograde z-tubes. Box orbits do not have a mean angular momentum and hence show no rotation ($\lambda_R \approx 0$). Rotating (streaming motion) originates from z-tubes and the counter rotating core is not kinematically decoupled, but decomposes into smooth components of prograde (lower left panels) and retrograde z-tubes (lower right panels).

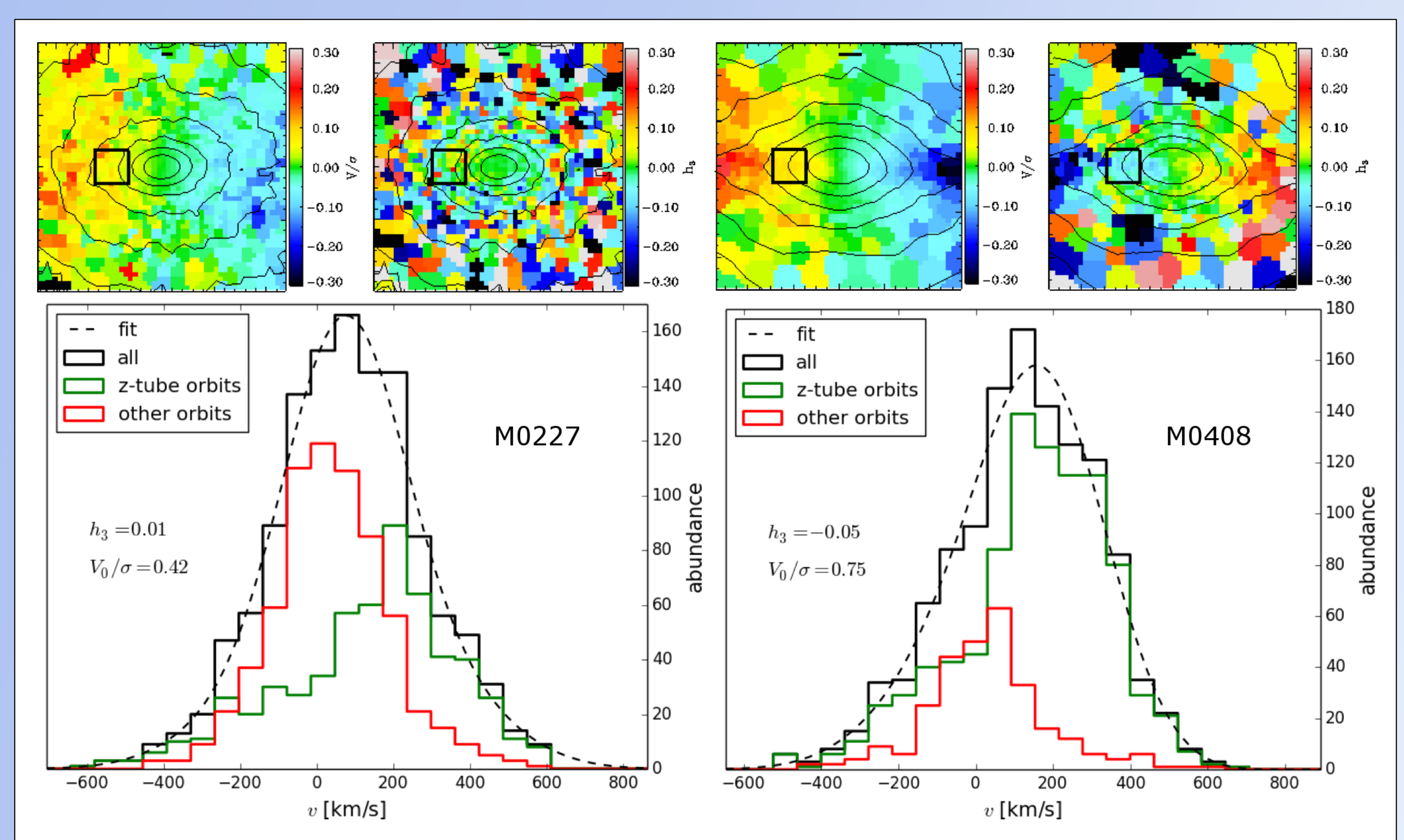


Galaxy Classification (Naab et al., 2013):

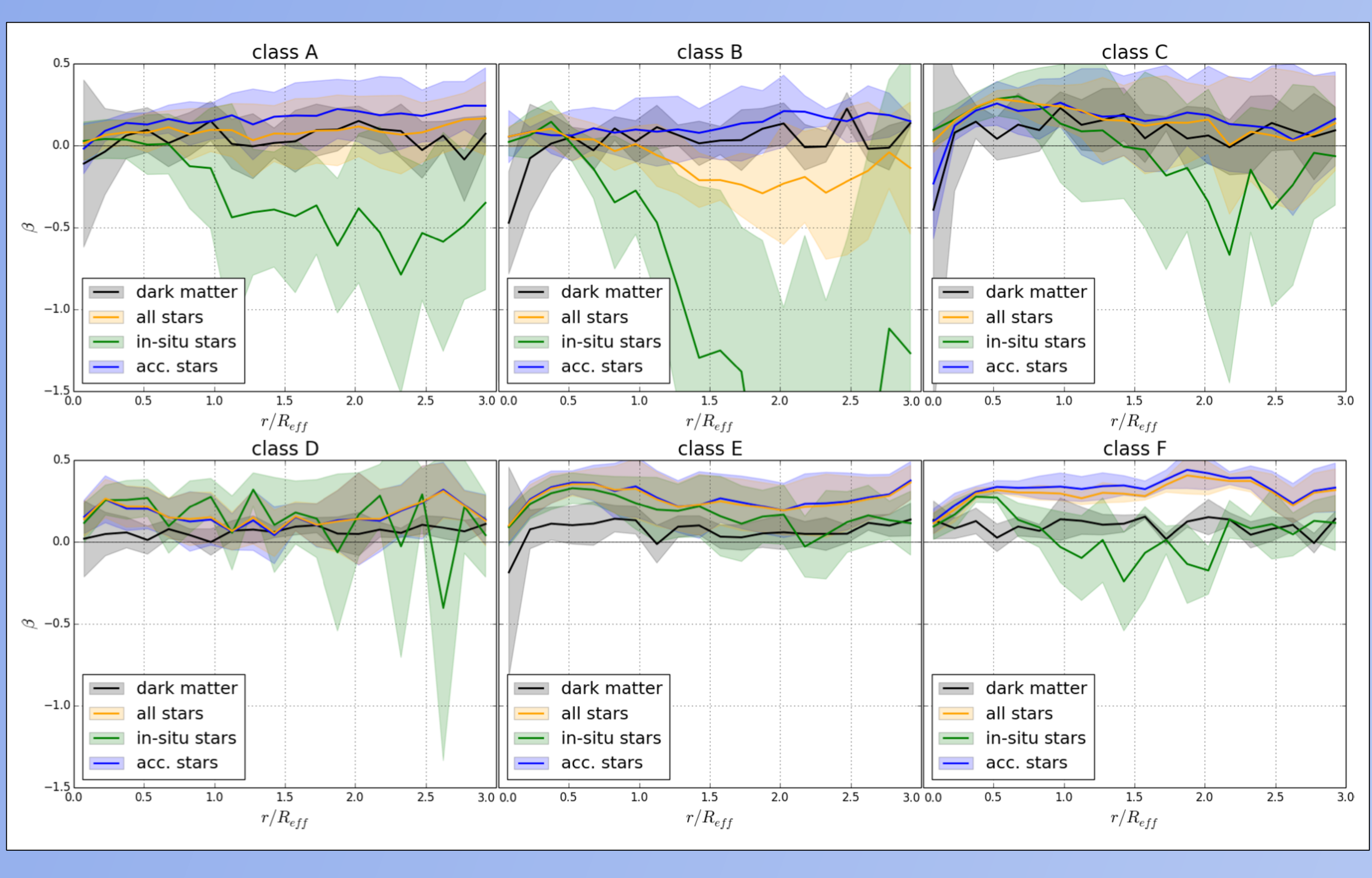
	minor mergers	major mergers
gas-rich	A	B, C
gas-poor	F	D, E

green: fast-rotator
blue: slow-rotator

← Orbits and formation history: Orbit profiles of different galaxy components are very similar (probably due to violent relaxation during mergers). Even the dark matter particles' orbit profiles are similar to the stars' orbit profiles. Only two of our 42 galaxies (M0664 and M0977) show large differences between the orbit profiles of the in-situ formed stars and accreted stars.
However, there are trends of the overall orbit fractions with the formation history (galaxy classes A though F, see table).

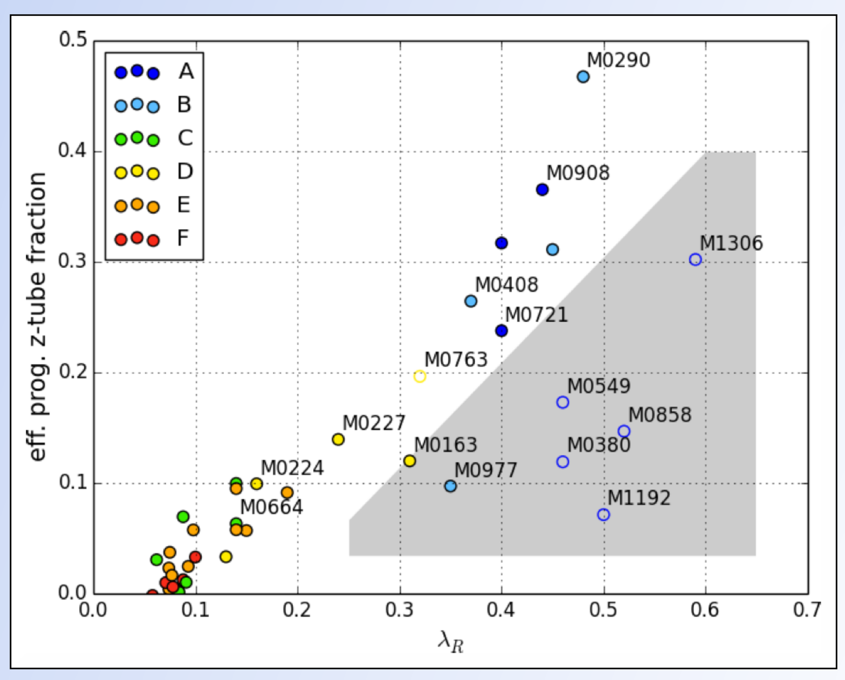


↑ The origin of the h_3-V_0/σ correlation: In a rotating galaxy there are more prograde than retrograde z-tubes. Hence, the LOSVD of the z-tubes alone has a steep leading wing (correlated h_3 and V_0/σ). If they dominate, the overall distributions also have a correlated h_3 and V_0/σ (see M0408). If, however, the other orbits, having a symmetric LOSVD centered at V_0=0, dominate, the overall distributions no longer have correlated h_3 and V_0/σ.



← Formation history and anisotropy parameter β: The anisotropy profiles of our galaxies depend on the galaxy formation history (galaxy classes A though F, see table). Accreted stars are always radially biased and in-situ formed stars always have smaller β than the accreted stars. For fast rotators with gas-rich merger histories (classes A & B), they are even strongly tangentially biased.
We find dark matter particles to be always isotropic (β ≈ 0).

Z-tubes and galaxy rotation: → Rotation—quantified with the λ_R-parameter—is mostly due to streaming motion, some galaxies, however, show signs for figure rotation (open circles). Streaming motion primarily comes from z-tubes. The net-effect is quantified with the 'effective prograde z-tube fraction': (prograde z-tube fraction) minus (retrograde z-tube fraction).



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