Rapid rotators: Simulated merger remnants vs. the ATLAS3D Survey

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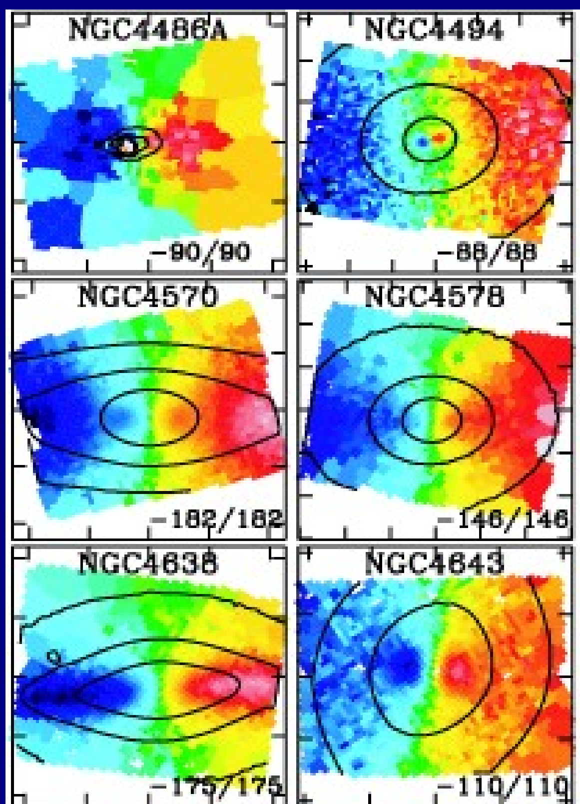
- Predecessor: SAURON survey - High-resolution IFS of ~50 nearby early-type galaxies within ~ 1 effective radius; Revealed a variety of kinematic structures, such as kinematic twists and KDCs
- ATLAS3D: Representative, volume-limited sample of 260 early-type galaxies with D < 42 Mpc, designed to probe the dominant S0 and elliptical formation mechanisms; Parallel simulation effort



(i) How do slow rotators form? What are the physical processes that determine their kinematic and photometric features? What is the role of major and minor mergers in their formation history? This will be reflected in the kinematics, gas content and stellar population.

(ii) Why are most ETGs fast rotators? There seems to be a dominant formation mechanism that delivers galaxies with quite homogenous rotation properties. Can this be merging? Can significant major merging be excluded?

(iii) How is star formation in ETGs quenched? Is it different for fast- and slow-rotators ETGs? How does it depend on environment? Can we infer the quenching mechanism from the amount and distribution of the leftover gas, the presence of active galactic nuclei (AGN) or metallicity gradients? The distribution of stellar population and gas properties constitutes a stringent test for future galaxy formation models.

(iv) Most past studies have focused on single stellar population models of ETGs, but cosmological models predict more complex histories. Can we infer the star formation history in ETGs for detailed comparison with simulations?

(v) How do counter rotating cores in massive and old ETGs form and survive to the present time? Are these relics of the very early Universe?

(vi) Can we link the present day properties of ETGs to results form existing and upcoming surveys at higher redshift with respect to e.g. masses, sizes, stellar populations, gas fractions, star formation? Our study will constitute a $z = 0$ redshift benchmark to trace the time evolution of galaxies.

ATLAS I:
Cappellari et al. 2011

Krajnovic et al. 2011 (ATLAS II):

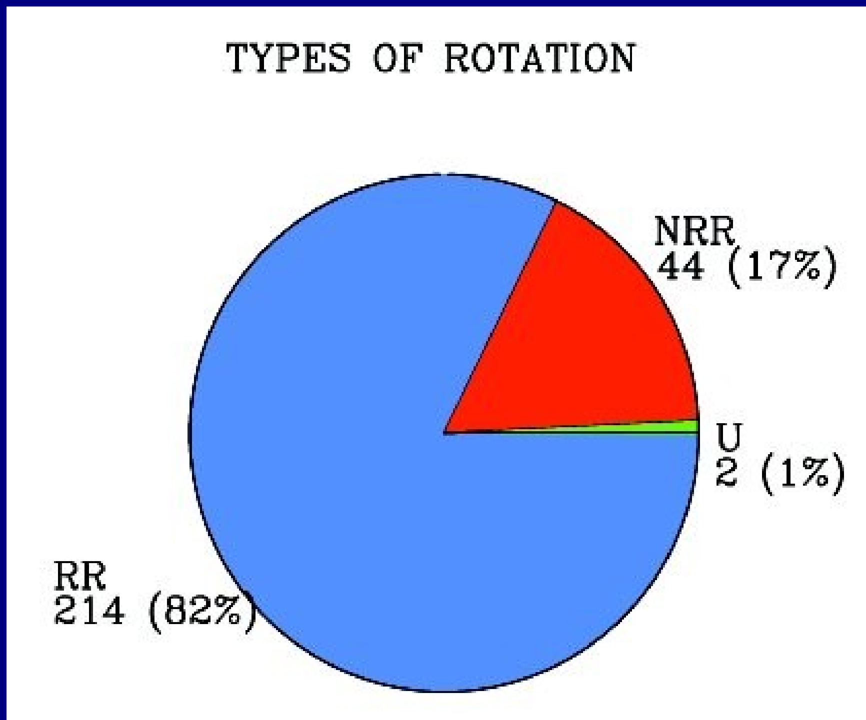
We find that 71 per cent of nearby early-type galaxies are strictly aligned systems (Psi ≤5 degrees), an additional 14 per cent have 5 deg < Psi ≤ 10 deg, and 90 per cent of galaxies have Psi ≤ 15 deg. Taking into account measurement uncertainties, 90 per cent of galaxies can be considered aligned to better than 5 deg, suggesting that only a small fraction of early-type galaxies (~10 per cent) are not consistent with the axisymmetry within the projected half-light radius.

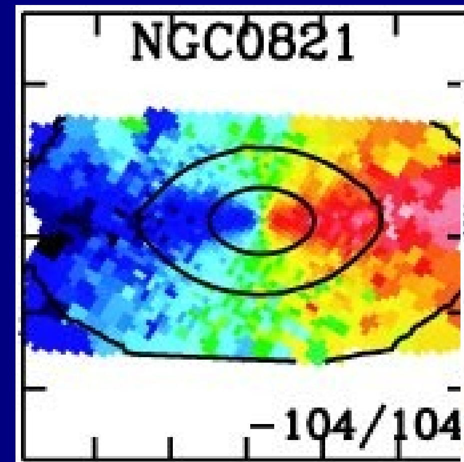
We use KINEMETRY to analyse the mean velocity maps and separate galaxies into two broad types of regular and non-regular rotators. We find 82 per cent of regular rotators and 17 per cent of non-regular rotators ... Taking into account the kinematic alignment and the kinemetric analysis, the majority of early-type galaxies have velocity maps more similar to that of the spiral discs than to that of the remnants of equal-mass mergers. We suggest that the most common formation mechanism for early-type galaxies preserves the axisymmetry of the disc progenitors and their general kinematic properties. Less commonly, the formation process results in a triaxial galaxy with much lower net angular momentum.

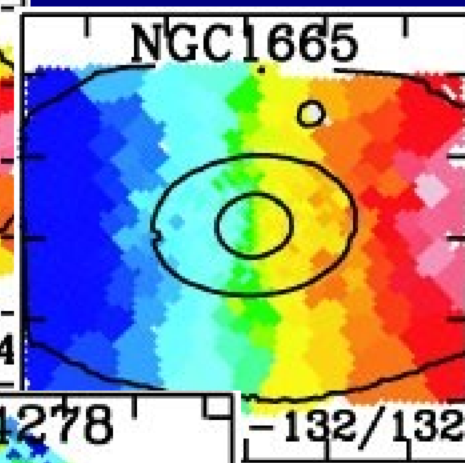
Emsellem et al. 2011 (ATLAS III):

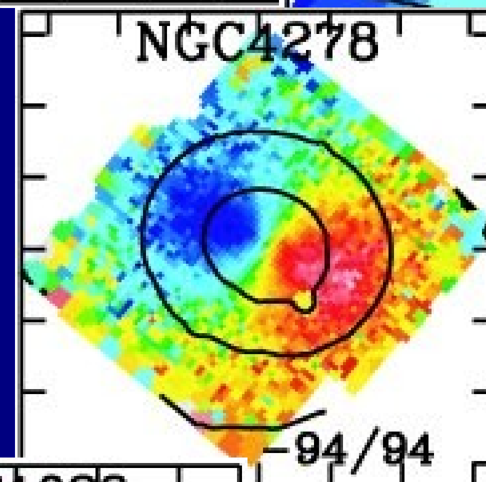
We show that the vast majority of ETGs are fast rotators: these have the regular stellar rotation, with aligned photometric and kinematic axes (Paper II of this series), include discs and often bars and represent 86 ± 2 per cent (224/260) of all ETGs in the volume-limited ATLAS3D sample ... We ... argue for a shift in the paradigm for ETGs, where the vast majority of ETGs are galaxies consistent with nearly oblate systems (with or without bars) and where only a small fraction of them (less than 12 per cent) have central (mildly) triaxial structures.

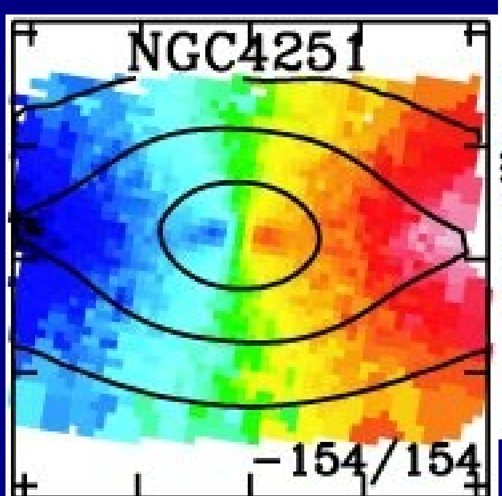
The variety among RRs

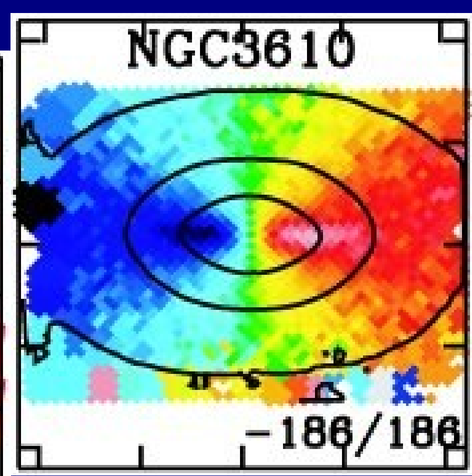


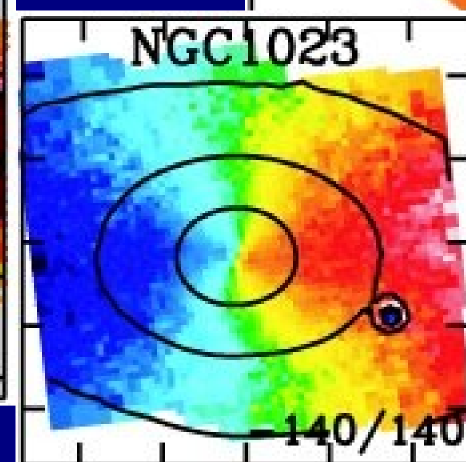


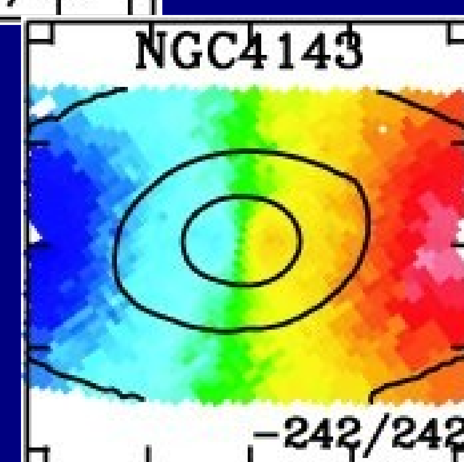








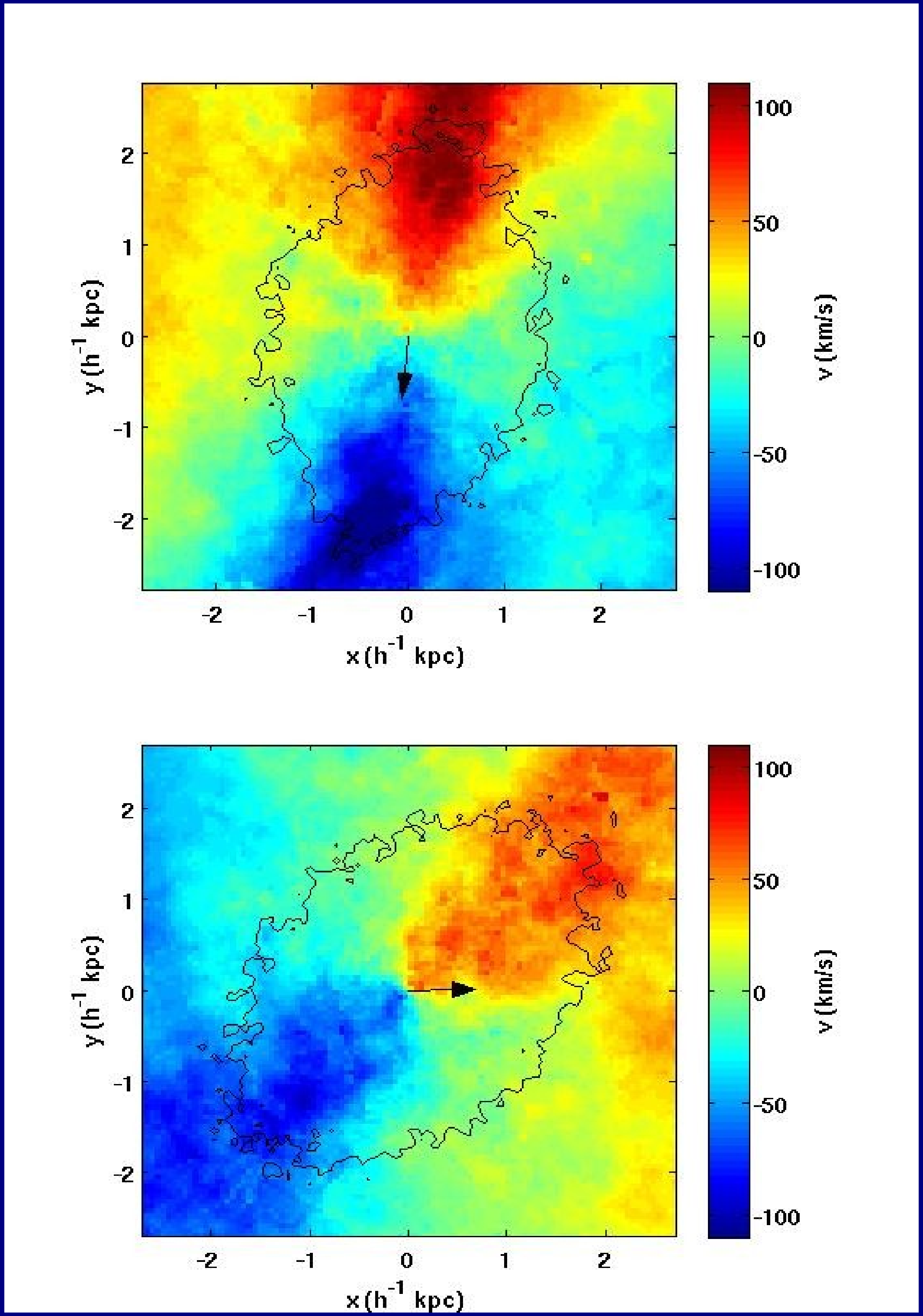


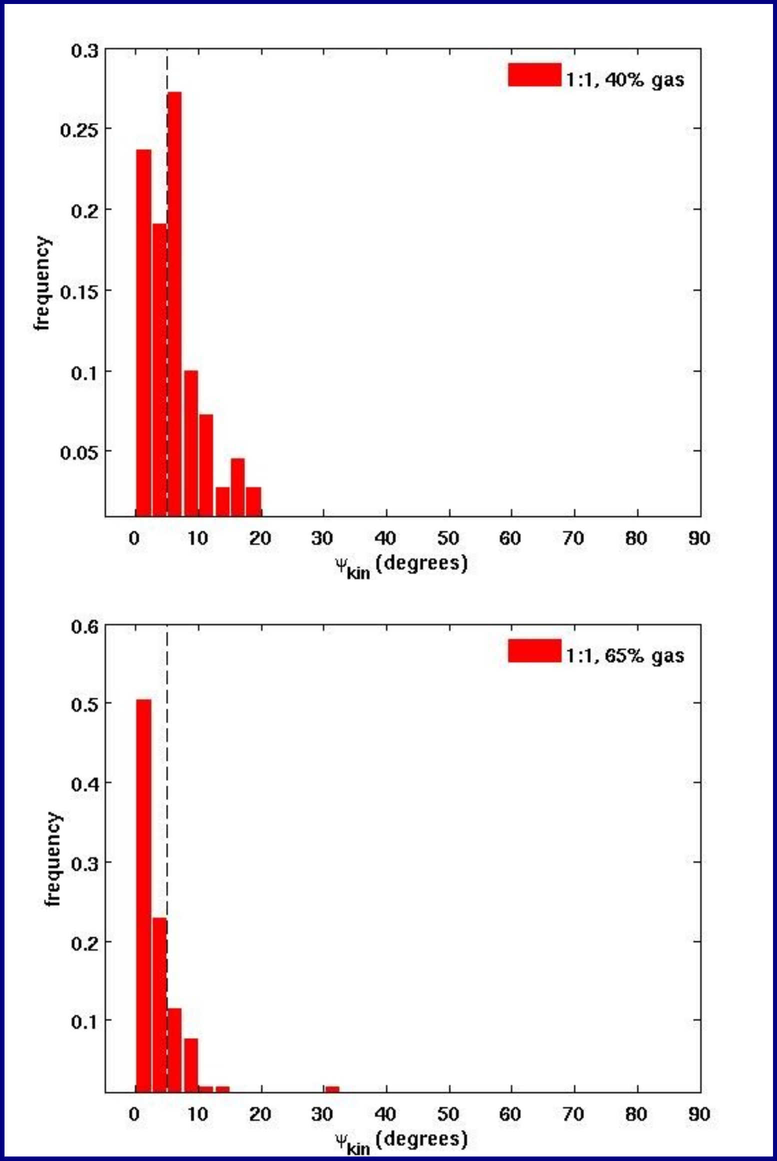


How to make RR's in major mergers?

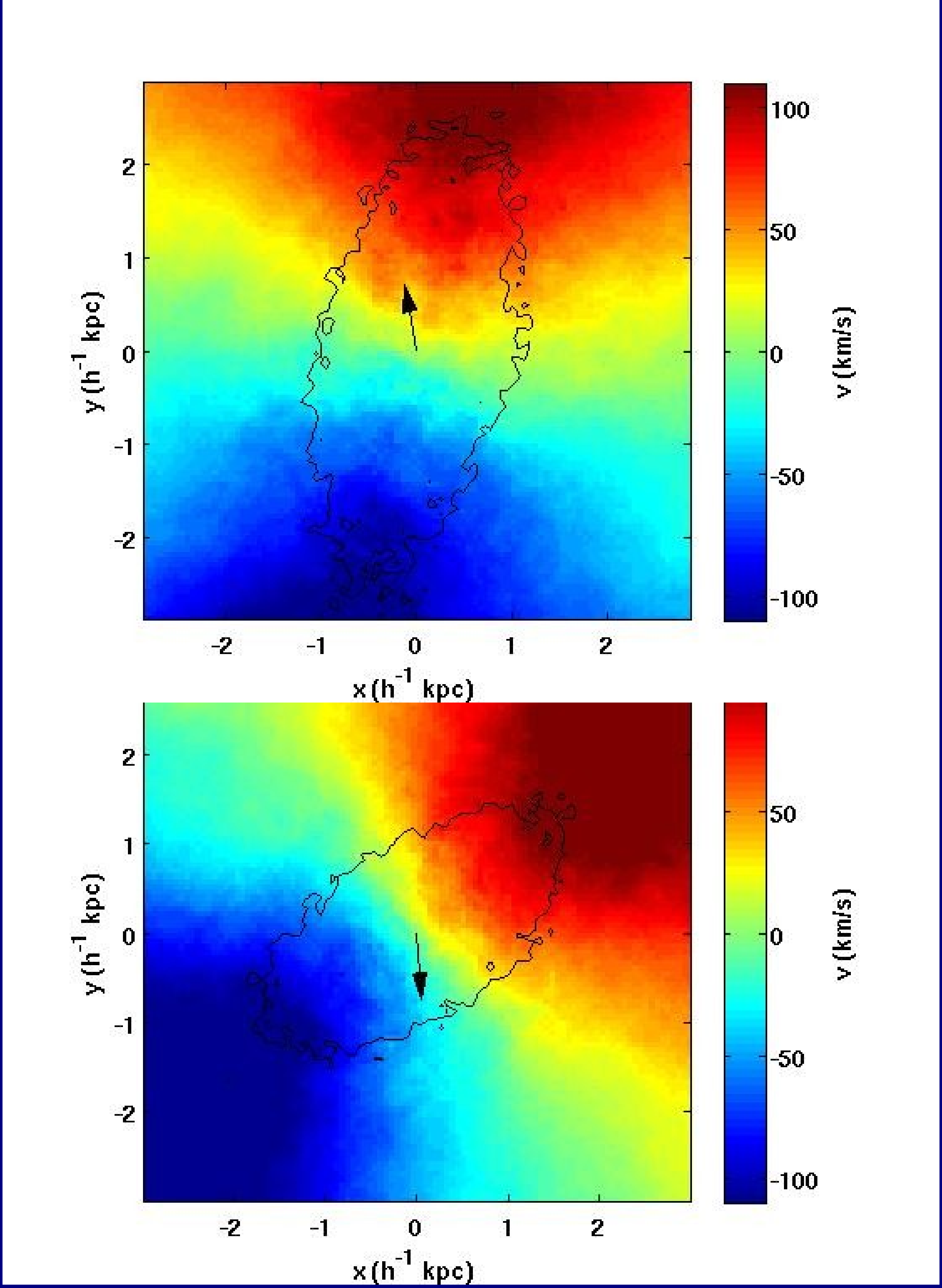
1) *High enough gas fraction*

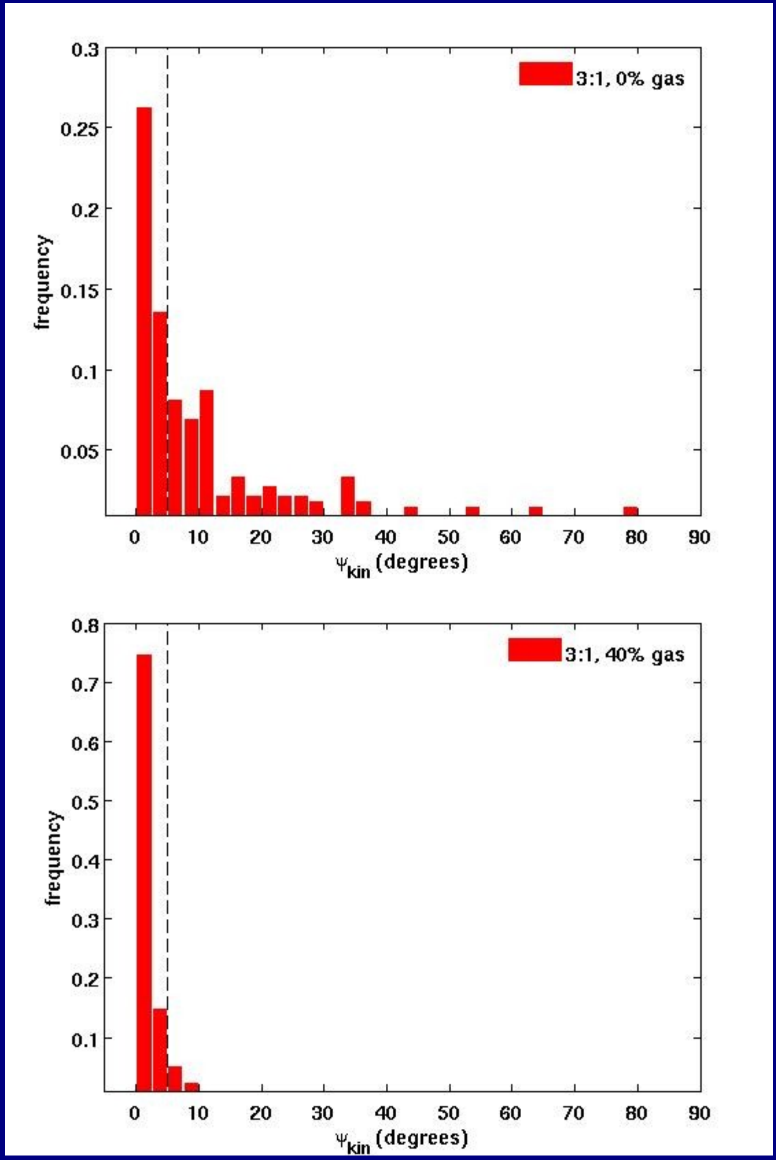
(e.g. Robertson et al. 2006, Hopkins et al. 2009)

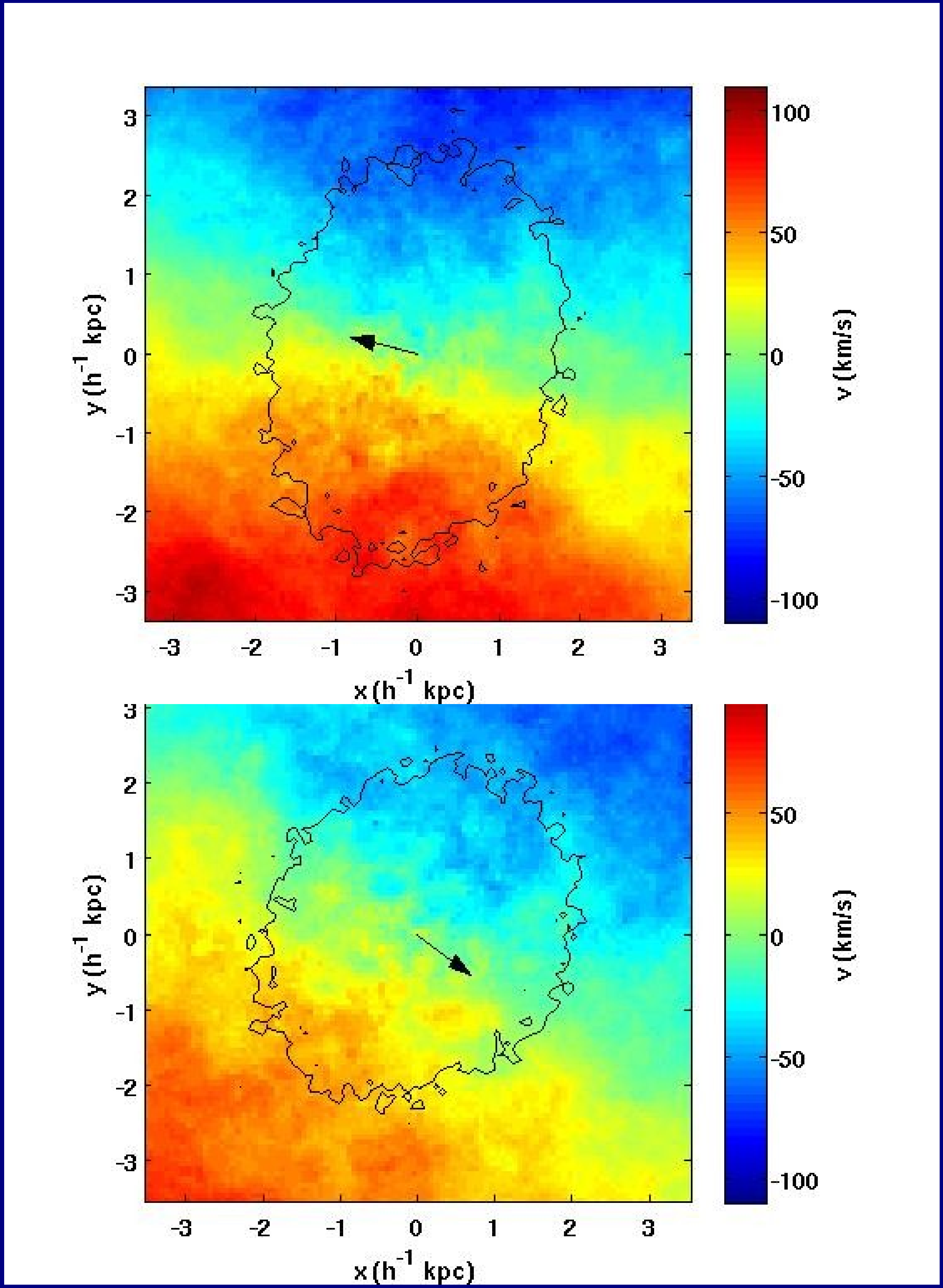




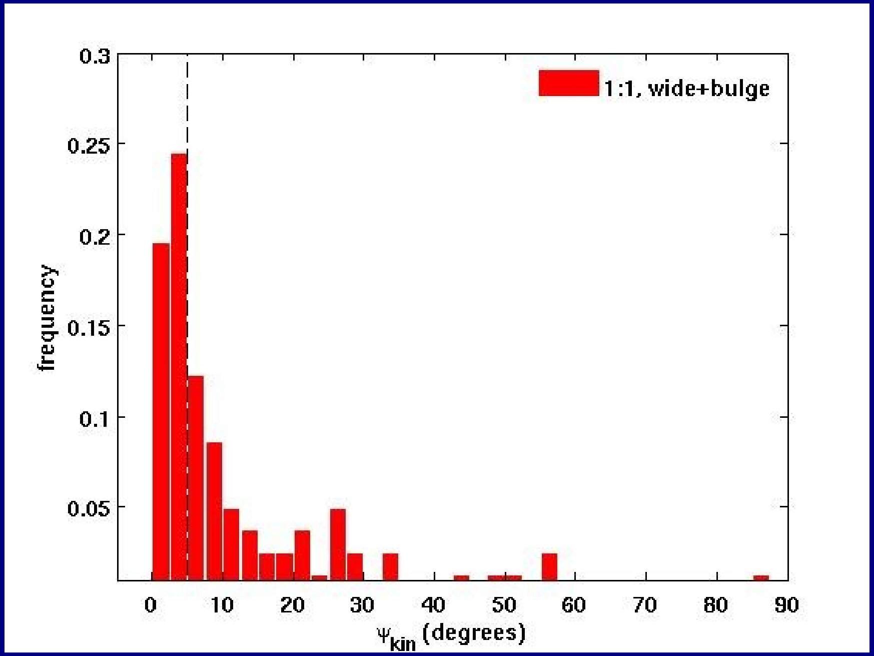
2) *Low enough mass ratios* (e.g. Bournaud et al. 2005, Johansson et al. 2009)



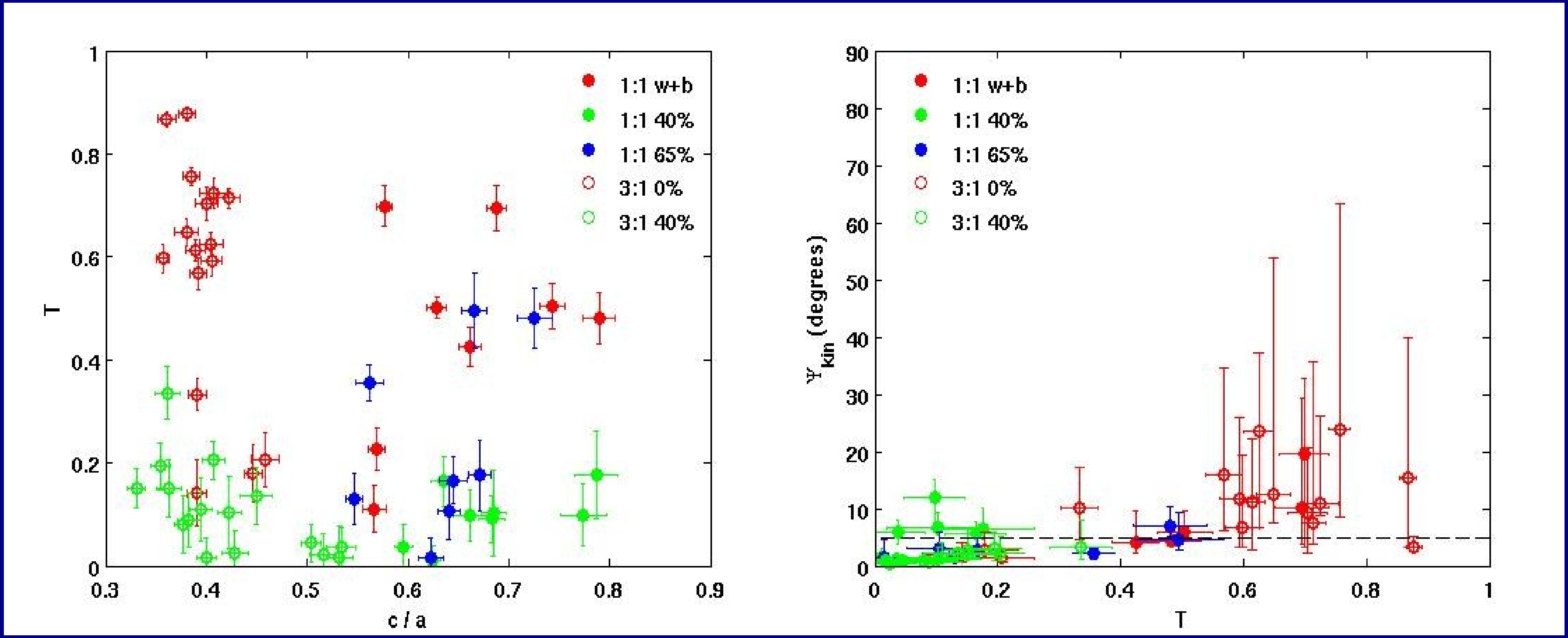




3) *Wide enough orbit, with a massive enough bulge*
(e.g. Barnes 1992, Novak et al. 2006)



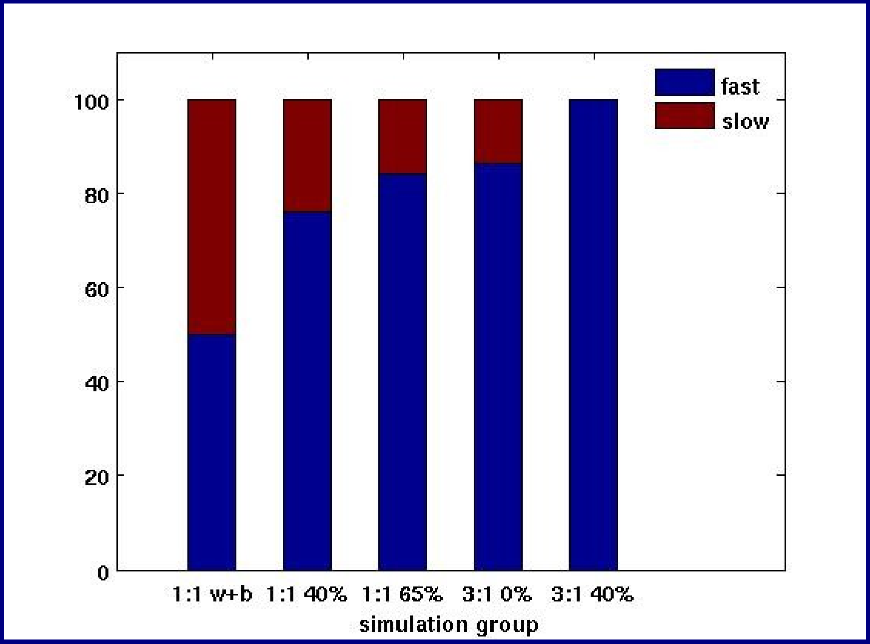
Intrinsic shapes and kinematic misalignments

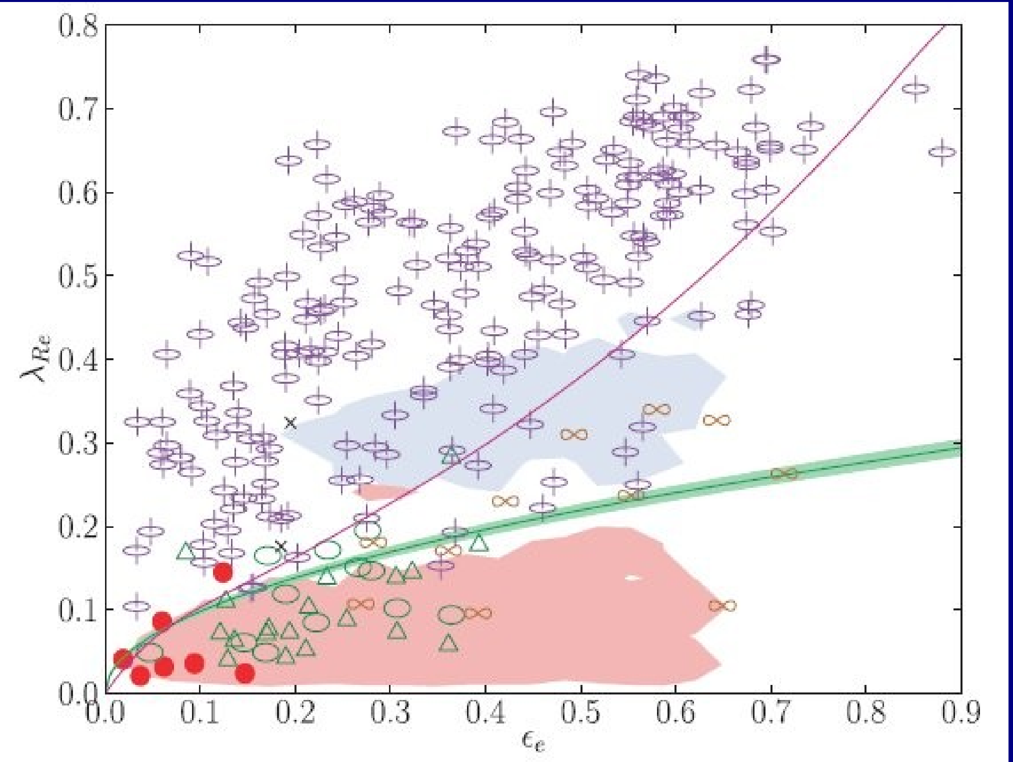


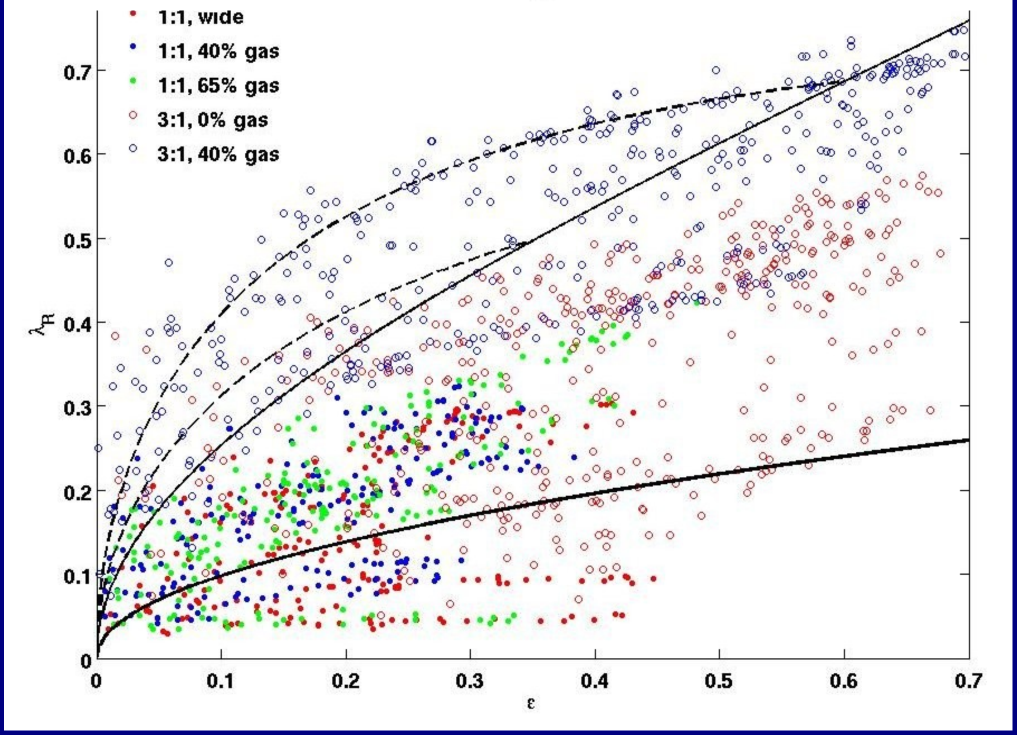
Rapid rotation is the norm, in ATLAS3D and in theoretical modeling

$$\lambda_R \equiv \frac{\langle R\,|V|\rangle}{\langle R\sqrt{V^2+\sigma^2}\rangle}$$

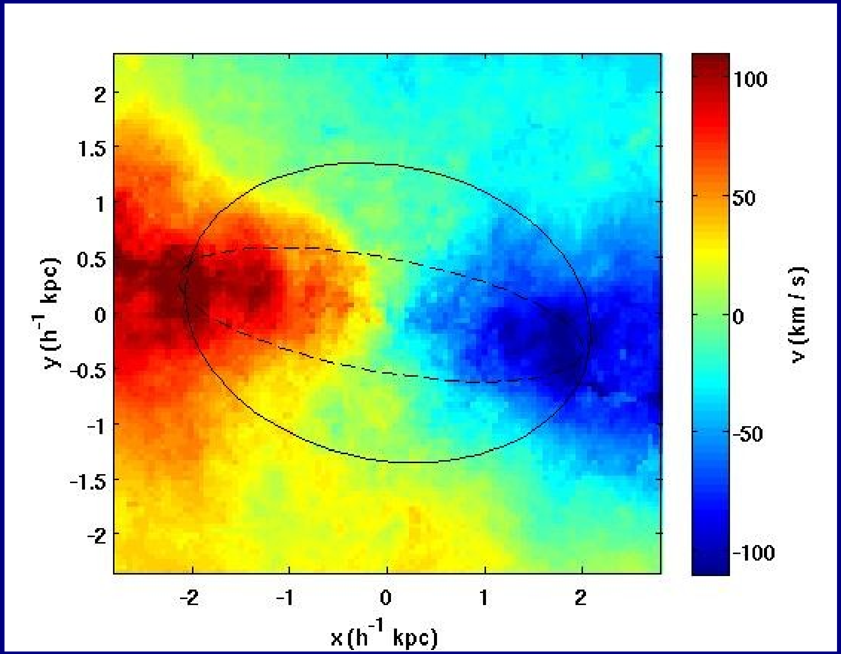
$$\lambda_{Re} = (0.31 \pm 0.01) \times \sqrt{\epsilon_e}$$

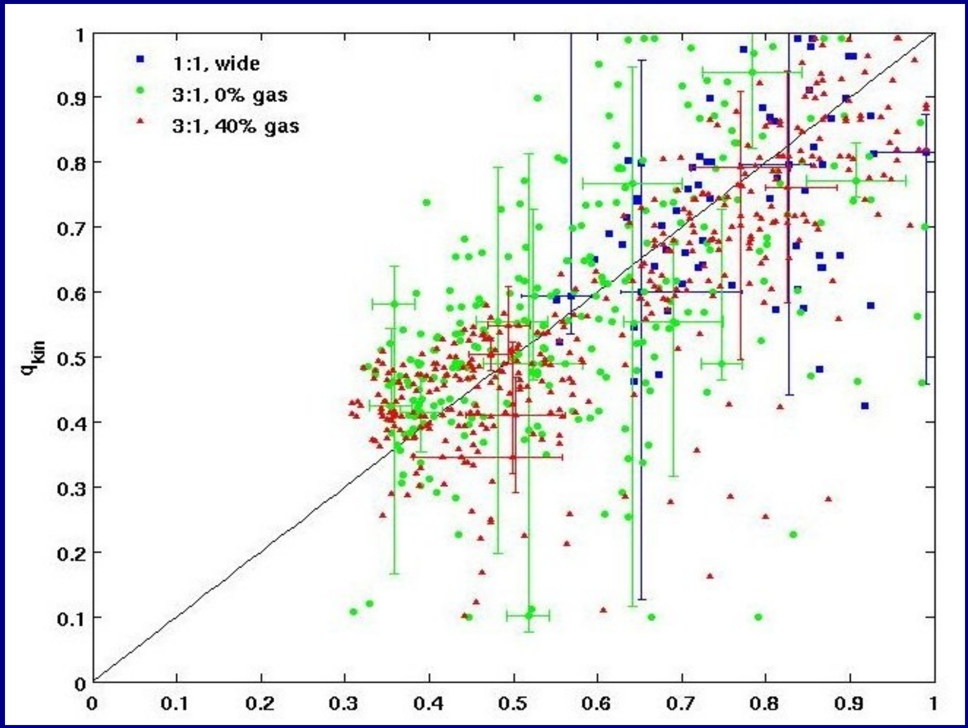


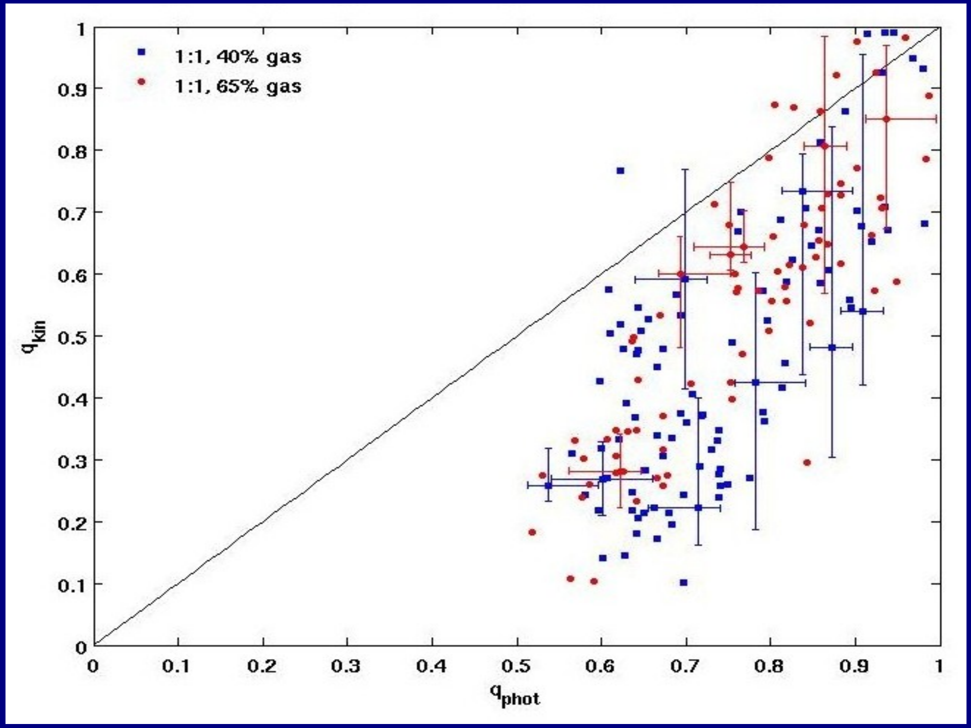




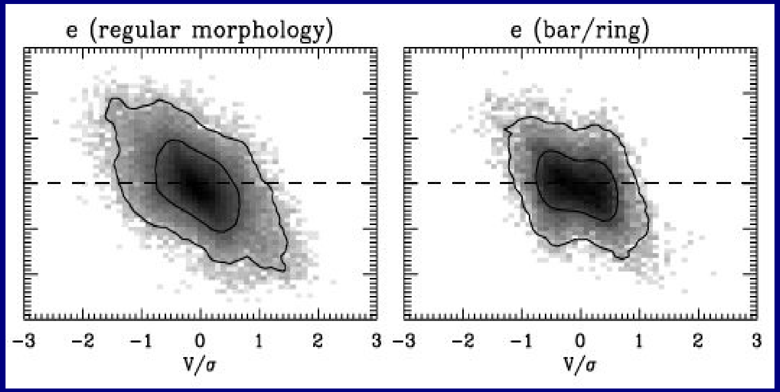
Kinemetric vs. photometric flattening

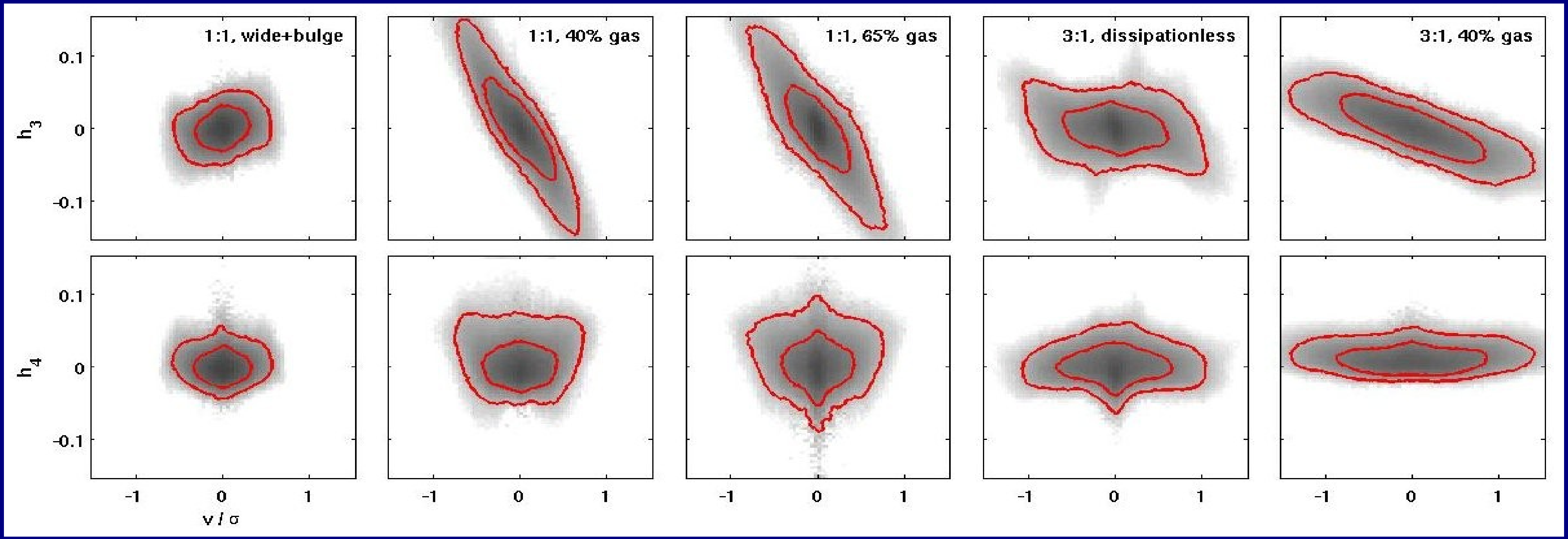




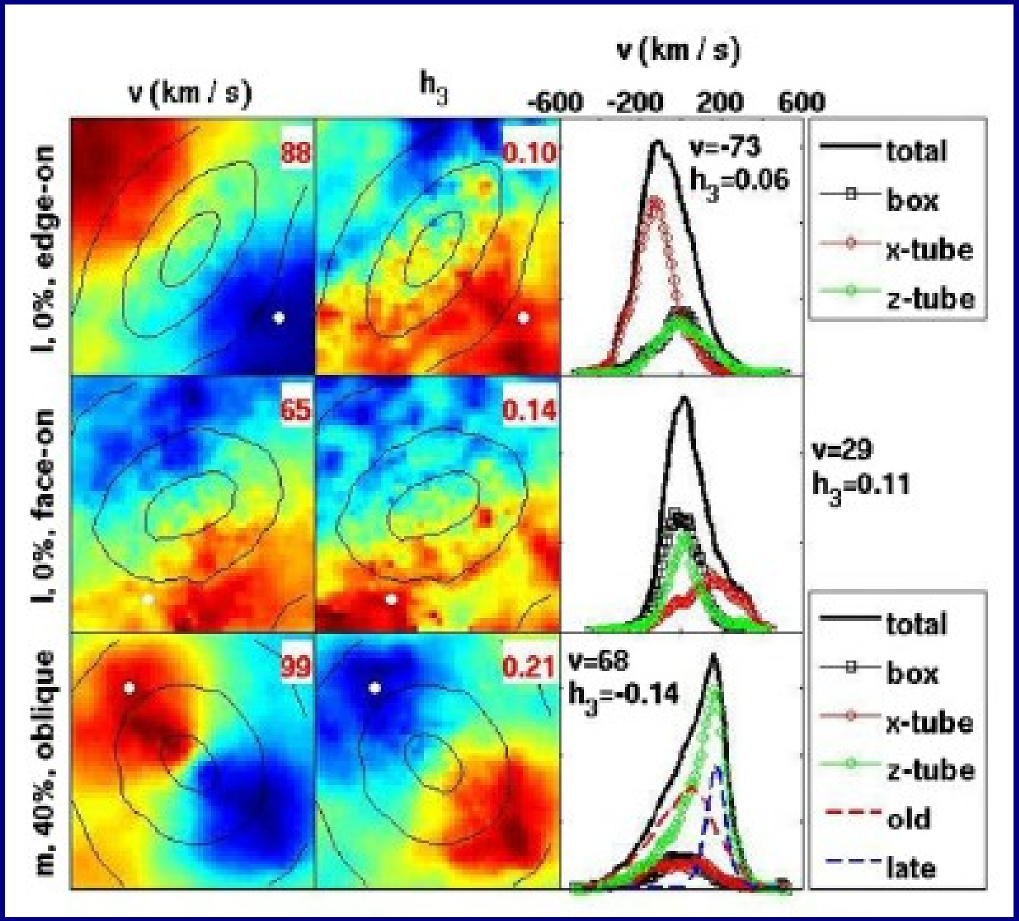


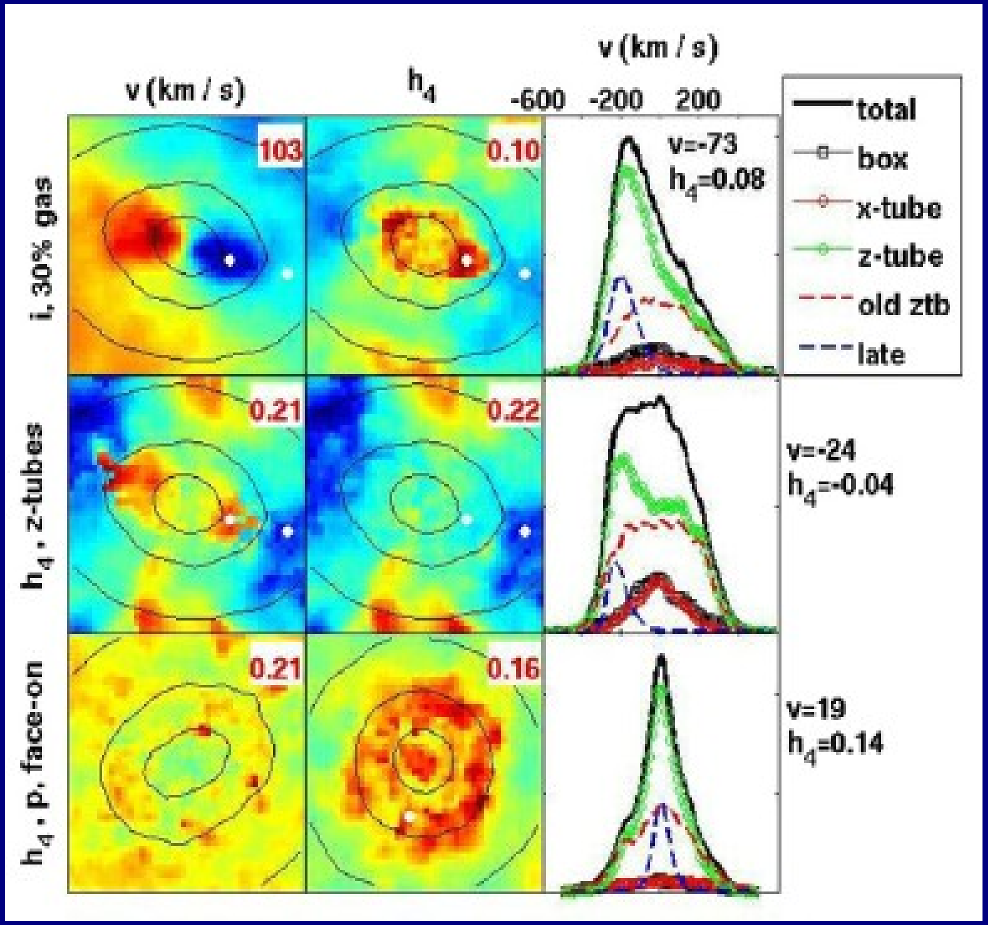
Higher-order moments of the LOSVDs



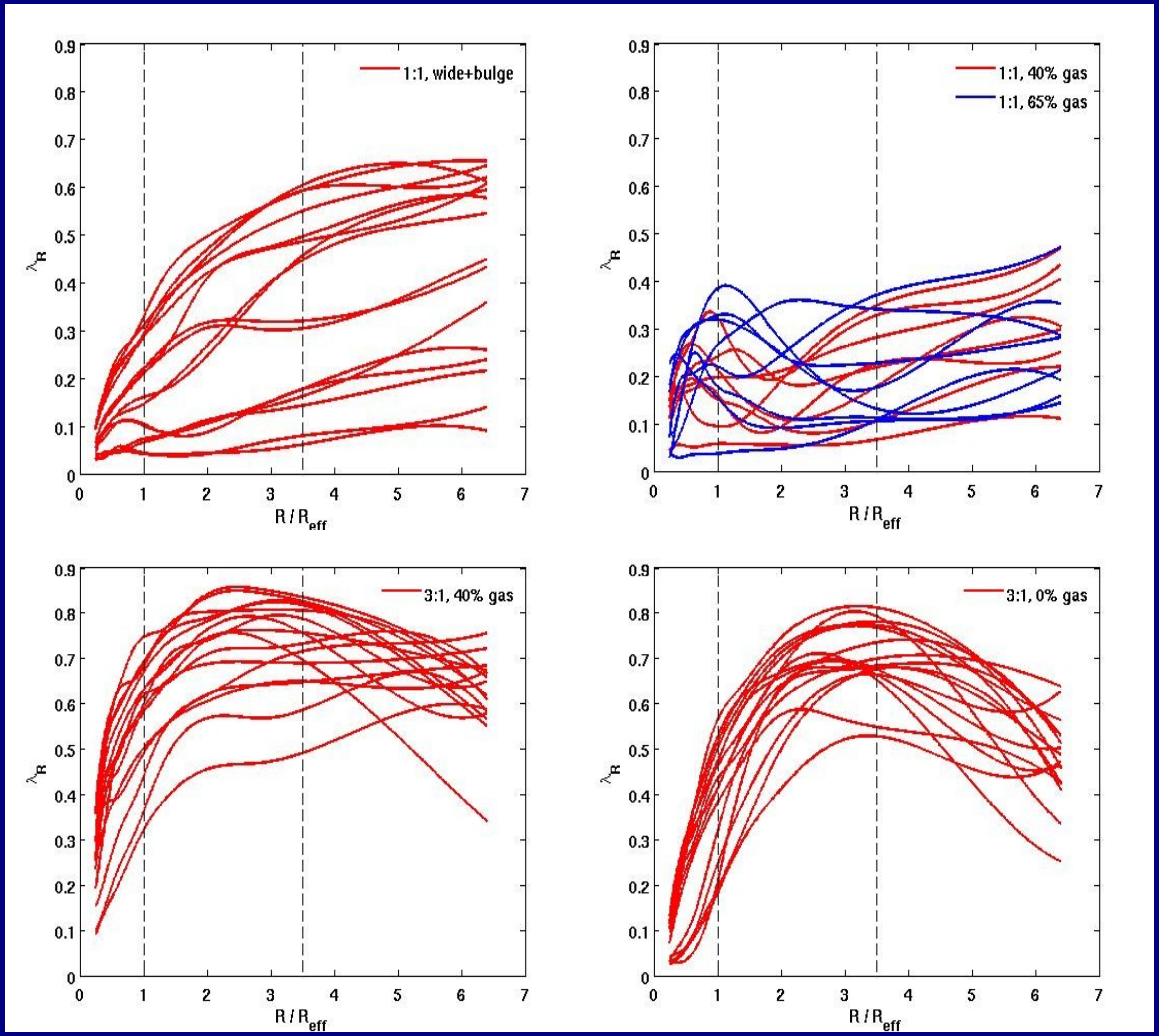


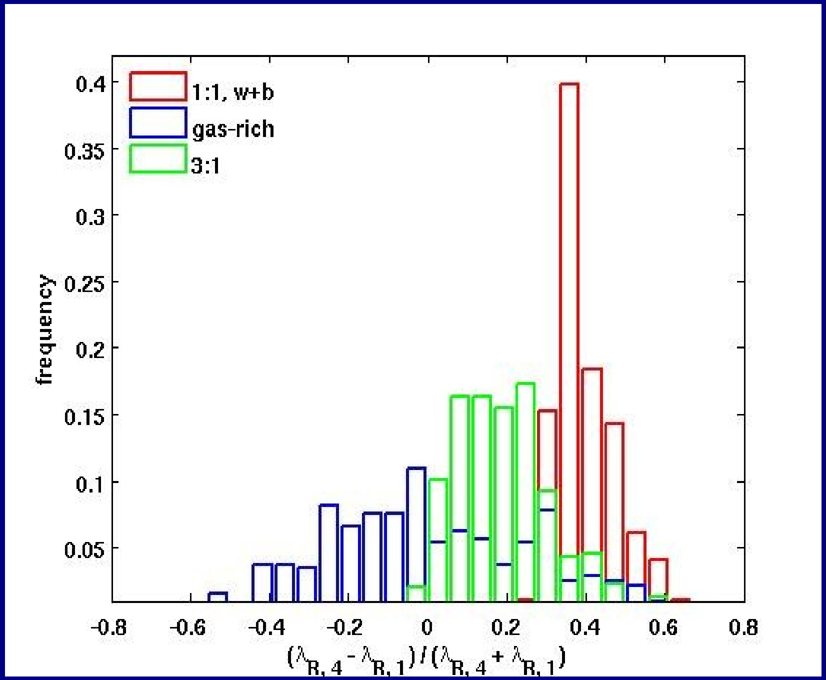
Explanation for the shapes of the h3,4 - v / sigma diagrams

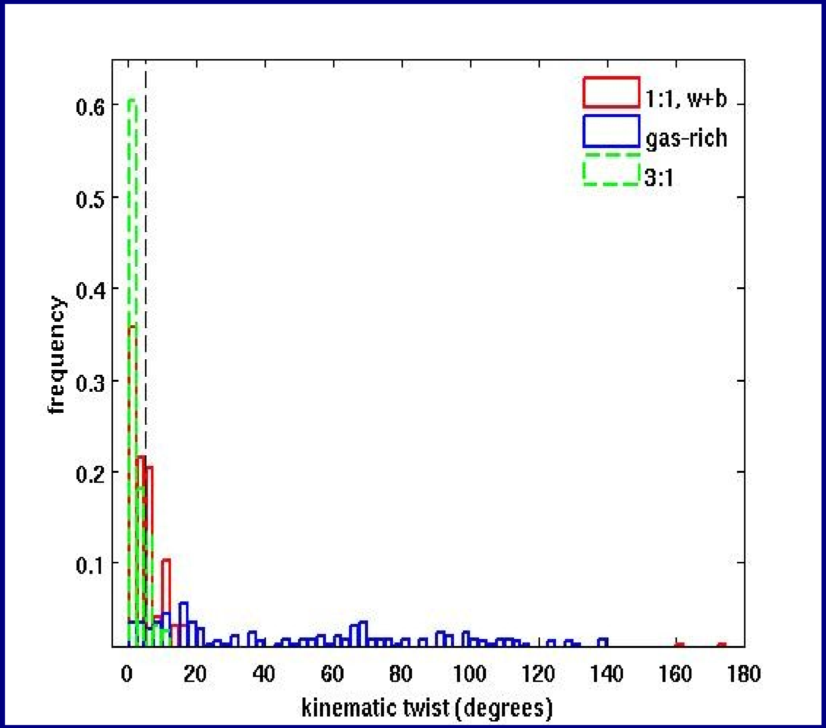




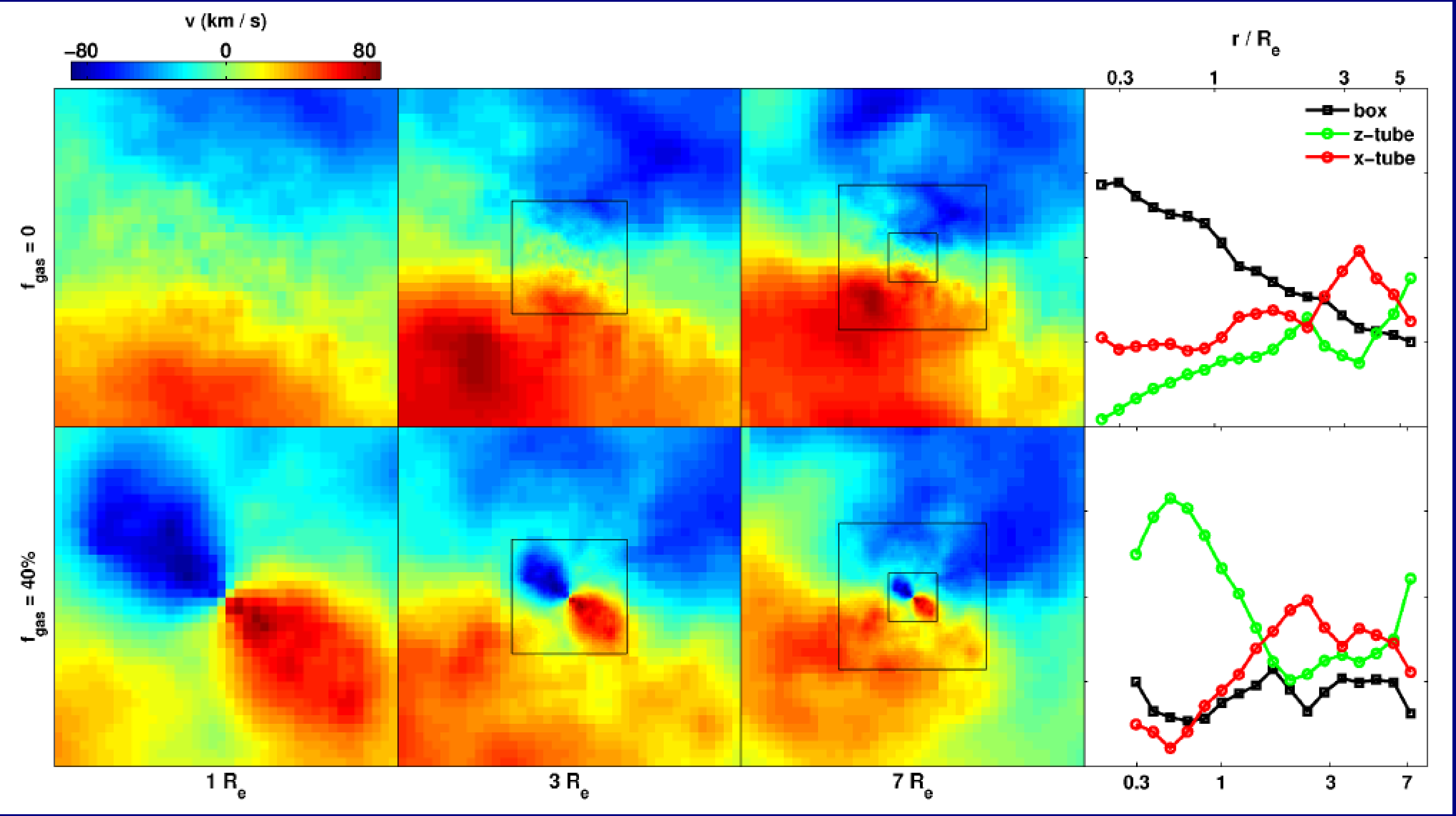
Radial variation of the angular momentum



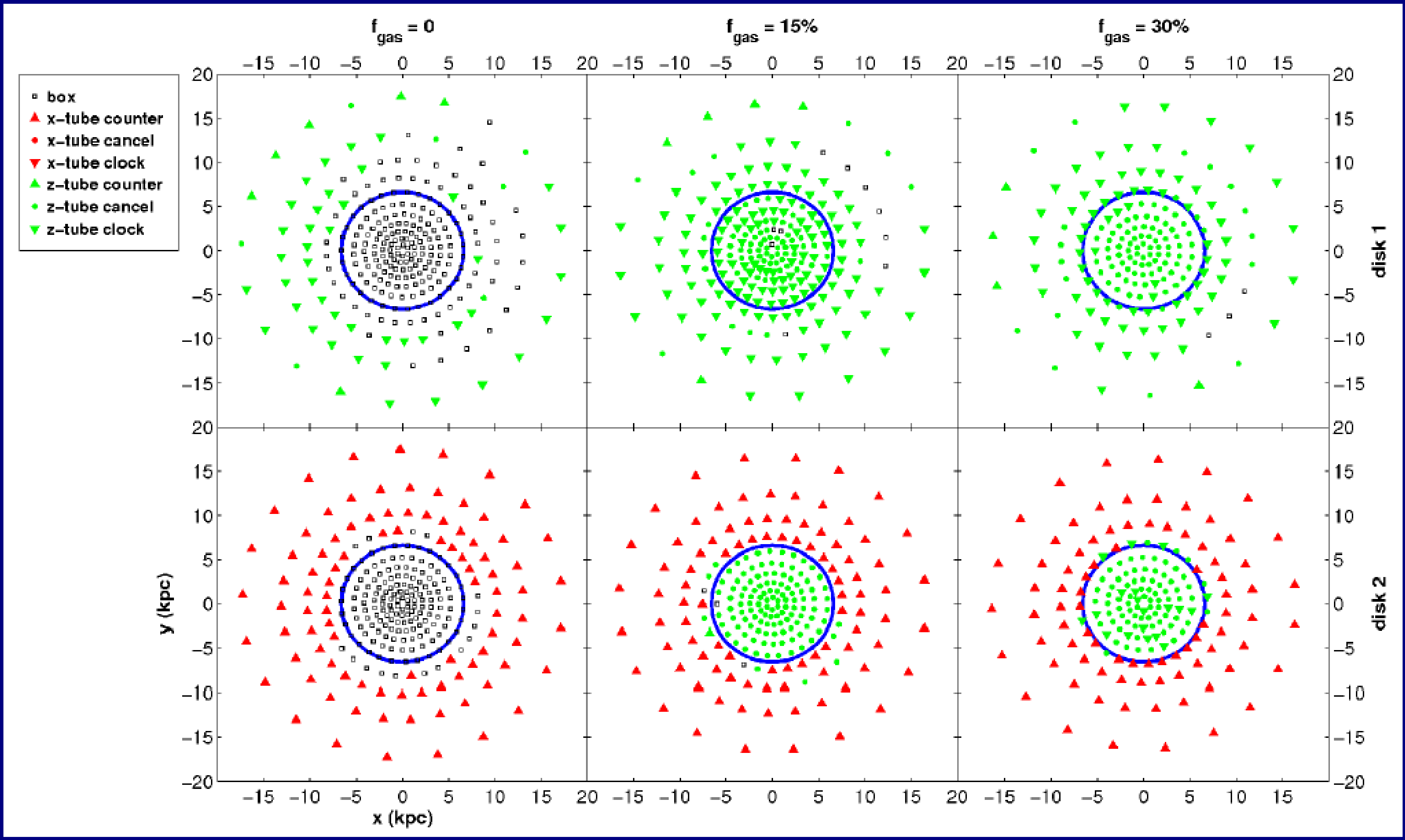




Large kinematic twists in the highly dissipative remnants



Speculation for the next project - phase space signatures of galaxy formation



Conclusions

Broadly speaking, both observations and theory support the aligned, rapid rotator as the generic outcome of early-type galaxy formation.

Using the goldmine of kinematic information available in ATLAS3D and other 2D kinematic surveys (particularly those probing larger radii - talk to e.g. Aaron and Jean) we may soon be able to identify the most common mechanisms of early-type galaxy formation.