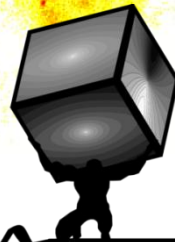


The stellar angular momentum of Early-type galaxies:

A paradigm shift

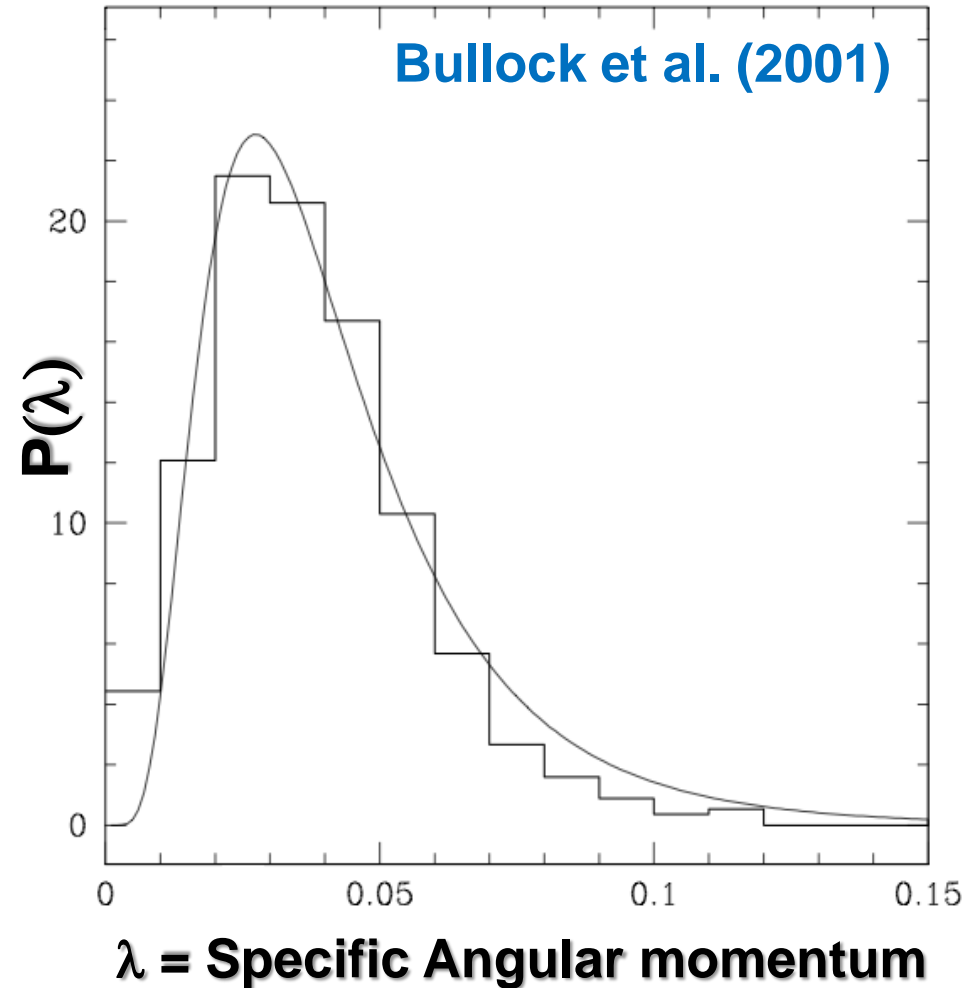
Eric Emsellem



and the ATLAS^{3D} team

From DM halos to galaxies

- ❖ Mergers
- ❖ Interactions, harassment...
- ❖ Secular evolution, bars, ...
- ❖ Disk instabilities and clumps
- ❖ Cold accretion (at high z)
- ❖ Star formation, feedback
- ❖ Cooling and shocks
- ❖ 2D/3D Turbulence
- ❖ Small scales physics



Mare Nostrum = Teyssier et al.

The Team



PIs: Michele Cappellari, Eric Emsellem,
Davor Krajnović, Richard McDermid

Cols :

Katey Alatalo, Leo Blitz, Maxime Bois, Frederic Bournaud,
Martin Bureau, Roger Davies, Tim Davis, Tim de Zeeuw,
Pierre-Alain Duc, Sadegh Khochfar, Harald Kuntschner, Pierre-
Yves Lablanche, Raffaella Morganti, Thorsten Naab, Tom
Oosterloo, Marc Sarzi, Nicholas Scott, Paolo Serra, Lisa
Young, Anne-Marie Weijmans

Associates: Estelle Bayet, Alison Crocker, Jesus Falcon-
Barroso, Gijs Verdoes-Kleijn, Marie Martig, Leo Michel-Dansac,
Kristina Nyland, Krysten Shapiro, Remco van der Bosch,
Glenn van de Ven

Atlas^{3D}: the sample

→ Observe a complete volume-limited sample of ETGs

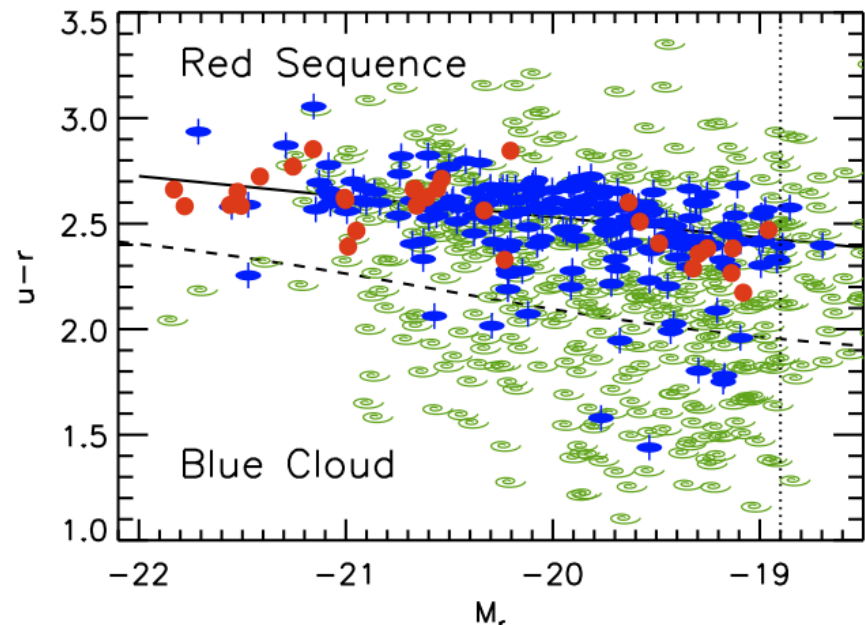
$$M_K < -21.5, D < 42 \text{ Mpc}$$

$$|\delta - 29| < 35^\circ, |b| > 15^\circ$$

→ Parent sample: 871 nearby galaxies

“No spiral structure” (SDSS/DSS2/INT)

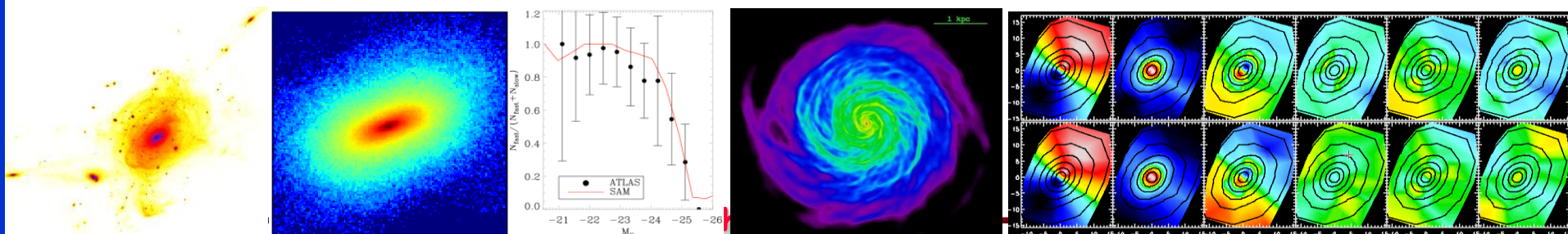
→ 260 galaxies





- ❖ **2D-spectroscopy (SAURON-WHT)**
- ❖ **Single-dish + interferometric CO (IRAM 30m, CARMA PdB)**
- ❖ **HI survey (WRST, excl. Virgo)**
- ❖ **Multi-band and deep Photometry (INT, 2MASS, SDSS, MegaCam)**

- ❖ **Stellar populations & Dynamical modelling (JAM)**
- ❖ **Suite of high-res numerical simulations of mergers**
- ❖ **Simulations in a cosmological context**
- ❖ **Semi Analytic Modeling (SAM)**

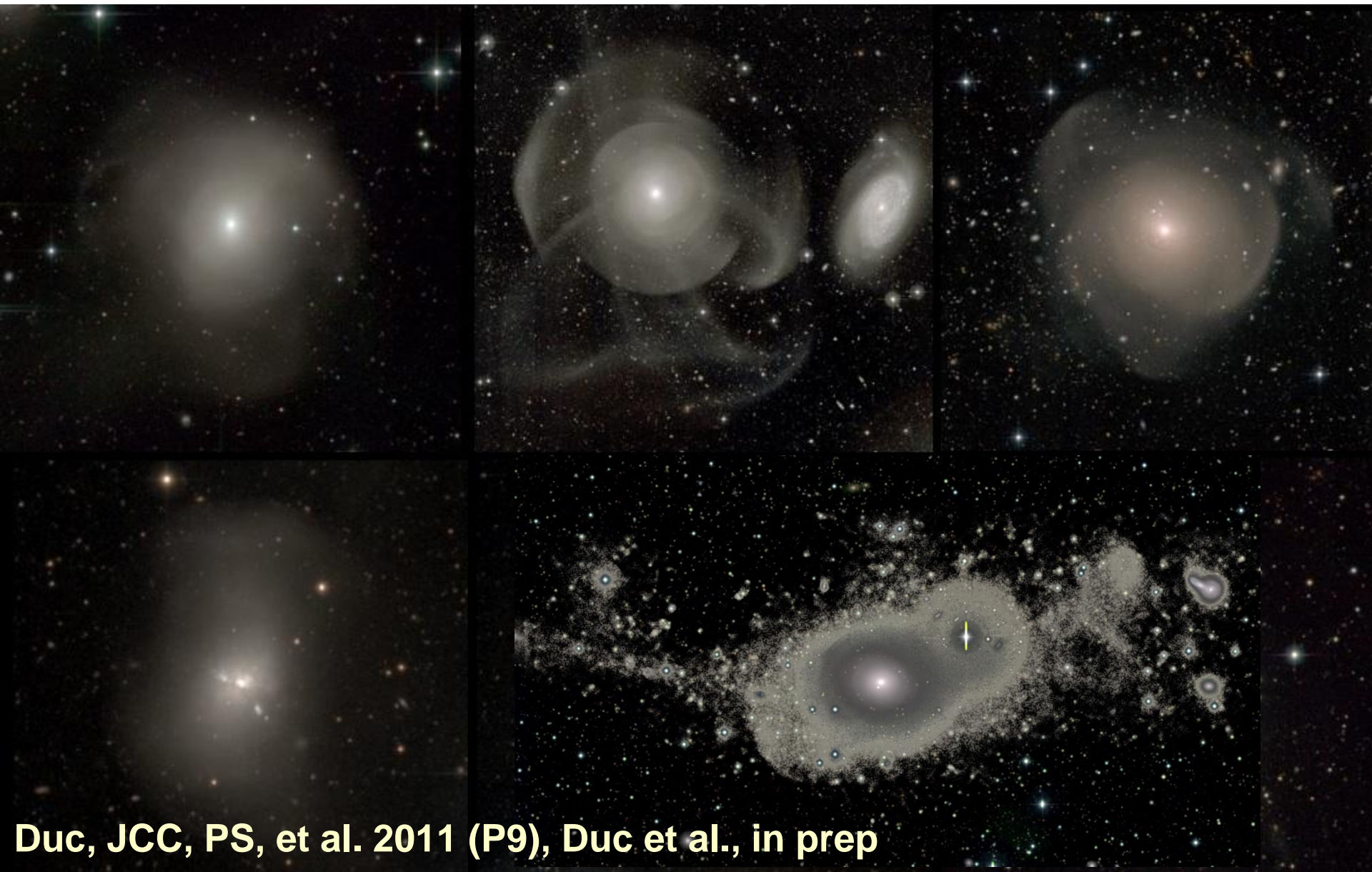


Atlas^{3D} Project : First results

- I. Cappellari , Emsellem, Krajnović, McDermid et al. 2011 (Sample)
- II. Krajnović, Emsellem, Cappellari et al. 2011 (Kinematic properties)
- III. Emsellem, Cappellari, Krajnović et al. 2011 (Angular momentum)
- IV. Young, Bureau, Davis et al. 2011 (CO Singe dish)
- V. Davis, Bureau, Young et al. 2011 (CO Tully–Fisher relation)
- VI. Bois, Emsellem, Bournaud et al. 2011 (Binary disk mergers)
- VII. Cappellari , Emsellem, Krajnović, McDermid et al. 2011 (Environment)
- VIII. Khochfar, Emsellem, Serra, et al. 2011 (SAM)
- IX. Duc, Cuillandre, Serra, et al. 2011 (Deep Imaging)
- X. Davis, Alatalo, Sarzi, et al. 2011 (Origin of ionised/molecular gas)

- XI. Serra, Oosterloo, Morganti et al., 2011 (HI content)
- XII. Lablanche, Cappellari, Emsellem et al. 2011 (M/L recovery)

- + Bois, Bournaud, Emsellem et al. 2010 (Numerical resolution)
- + Alatalo, Blitz, Young et al. 2011 (Large-scale AGN outflow in NGC1266)

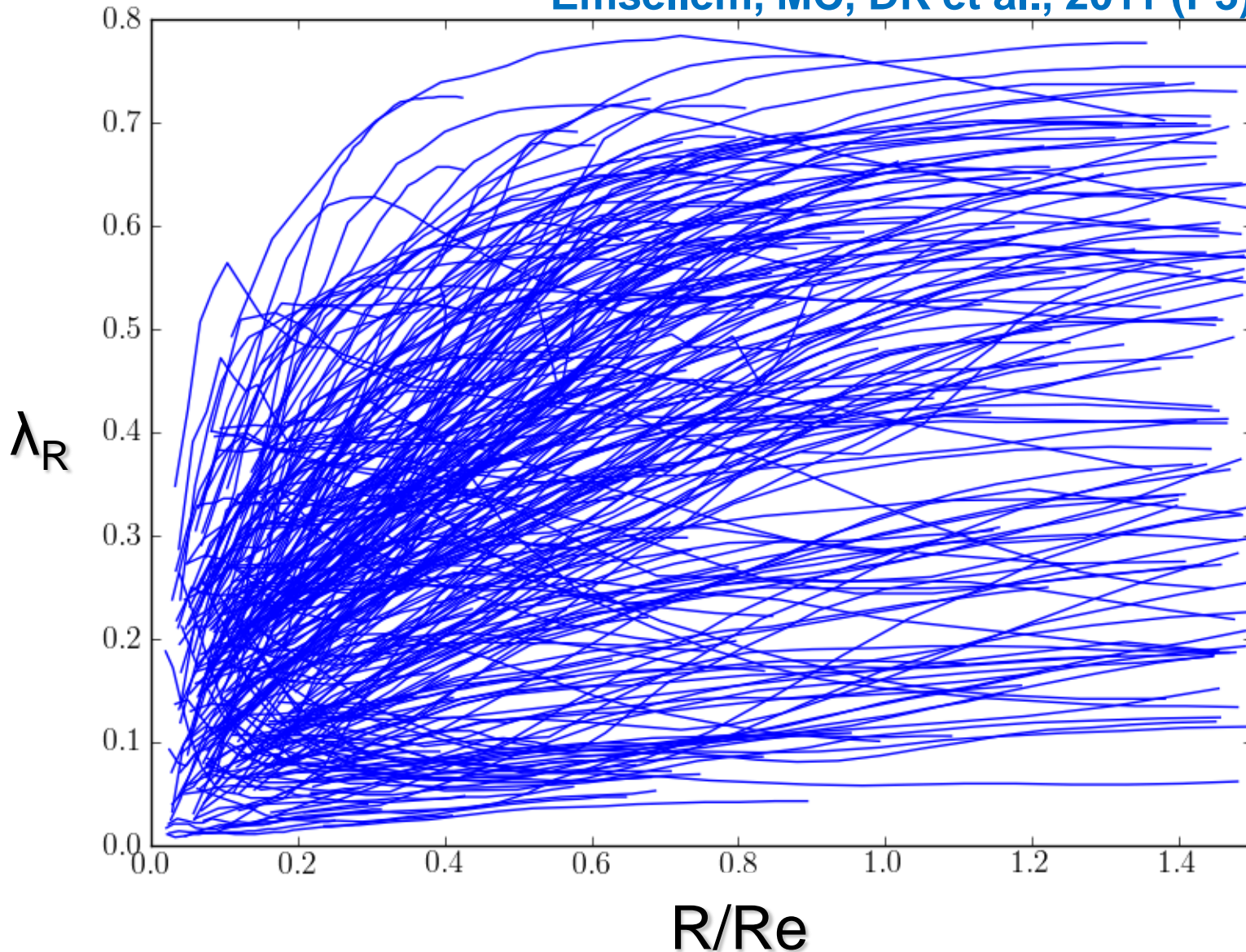


Duc, JCC, PS, et al. 2011 (P9), Duc et al., in prep

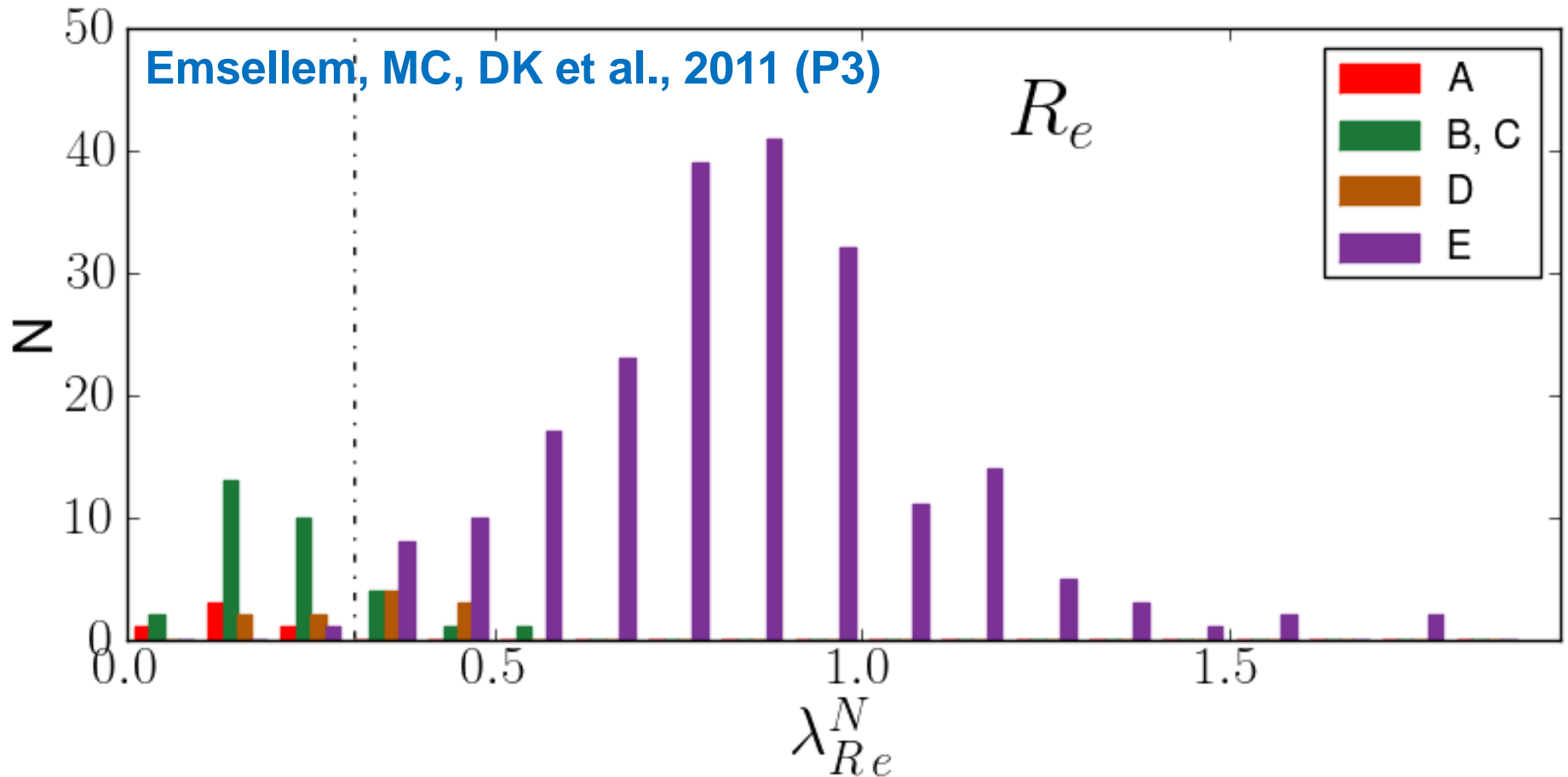


IFU → Stellar angular momentum

Emsellem, MC, DK et al., 2011 (P3)



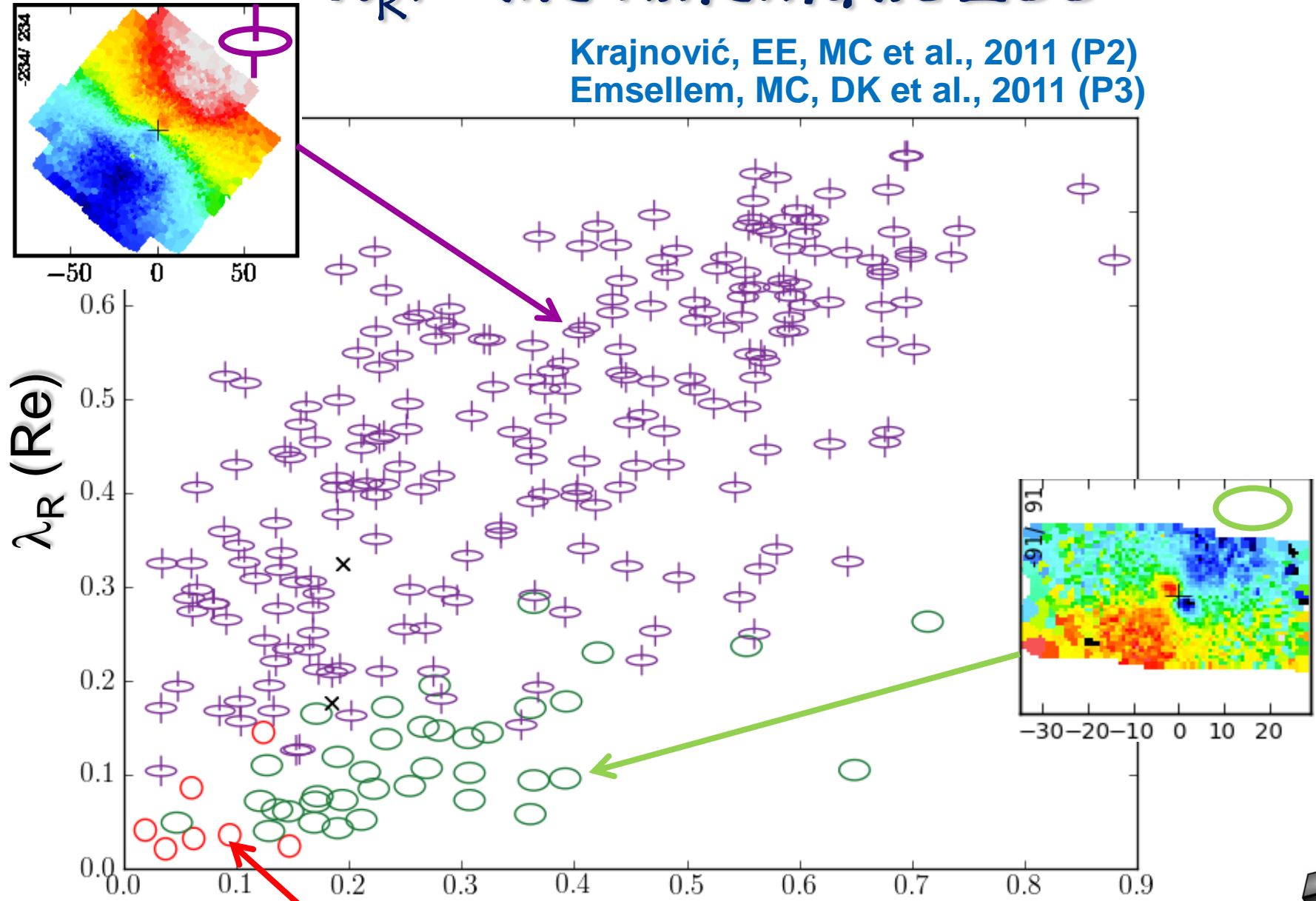
λ_R : Stellar angular momentum



- ❖ Dark Matter Halos → slow rotating
- ❖ Early-Type Galaxies → mostly fast rotators!
(with a mass dependence)

λ_R : the kinematic Zoo

Krajnović, EE, MC et al., 2011 (P2)
Emsellem, MC, DK et al., 2011 (P3)



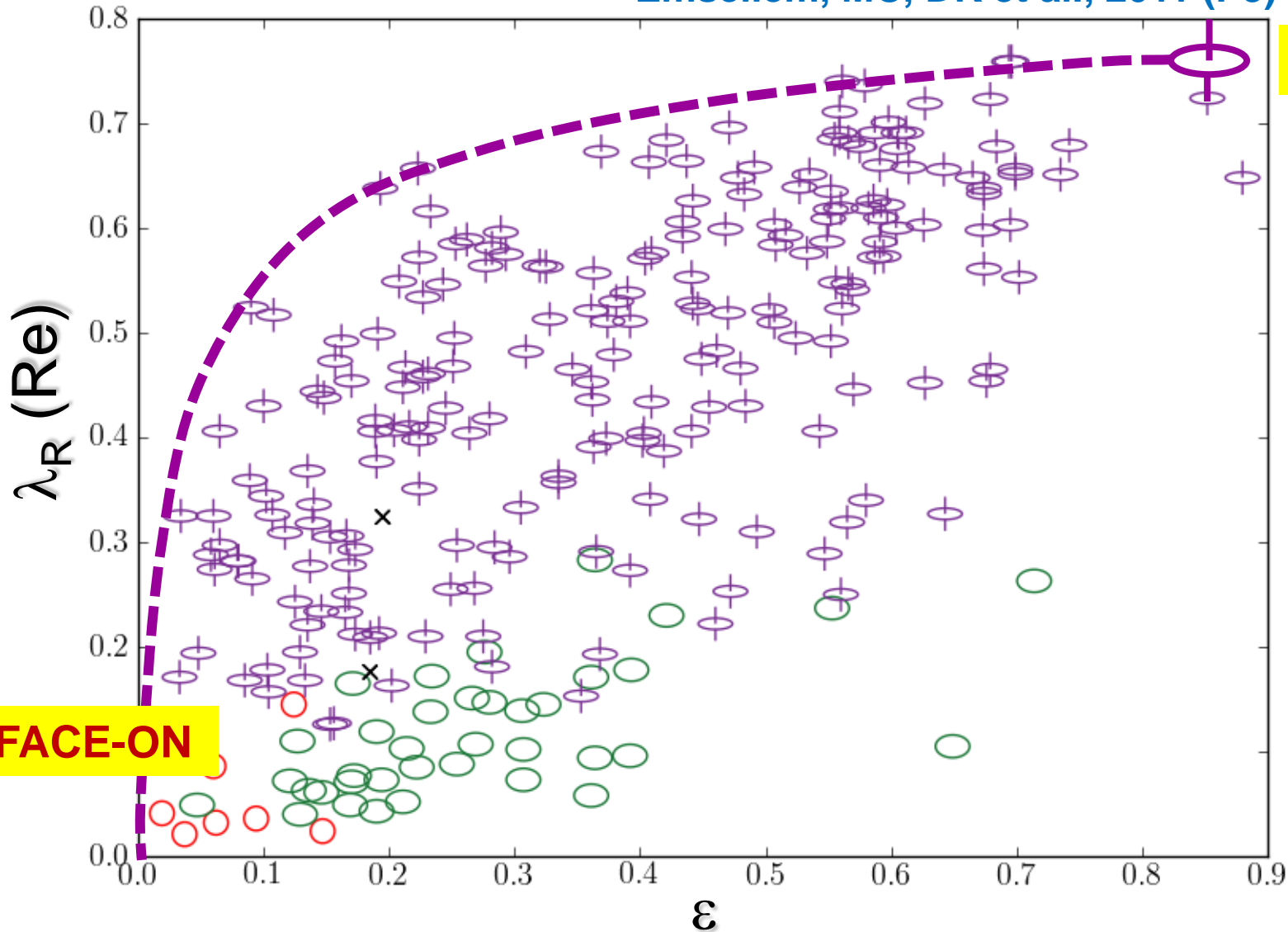
Non-Rotators

Durham 2011



λ_R : Inclination effects

Emsellem, MC, DK et al., 2011 (P3)



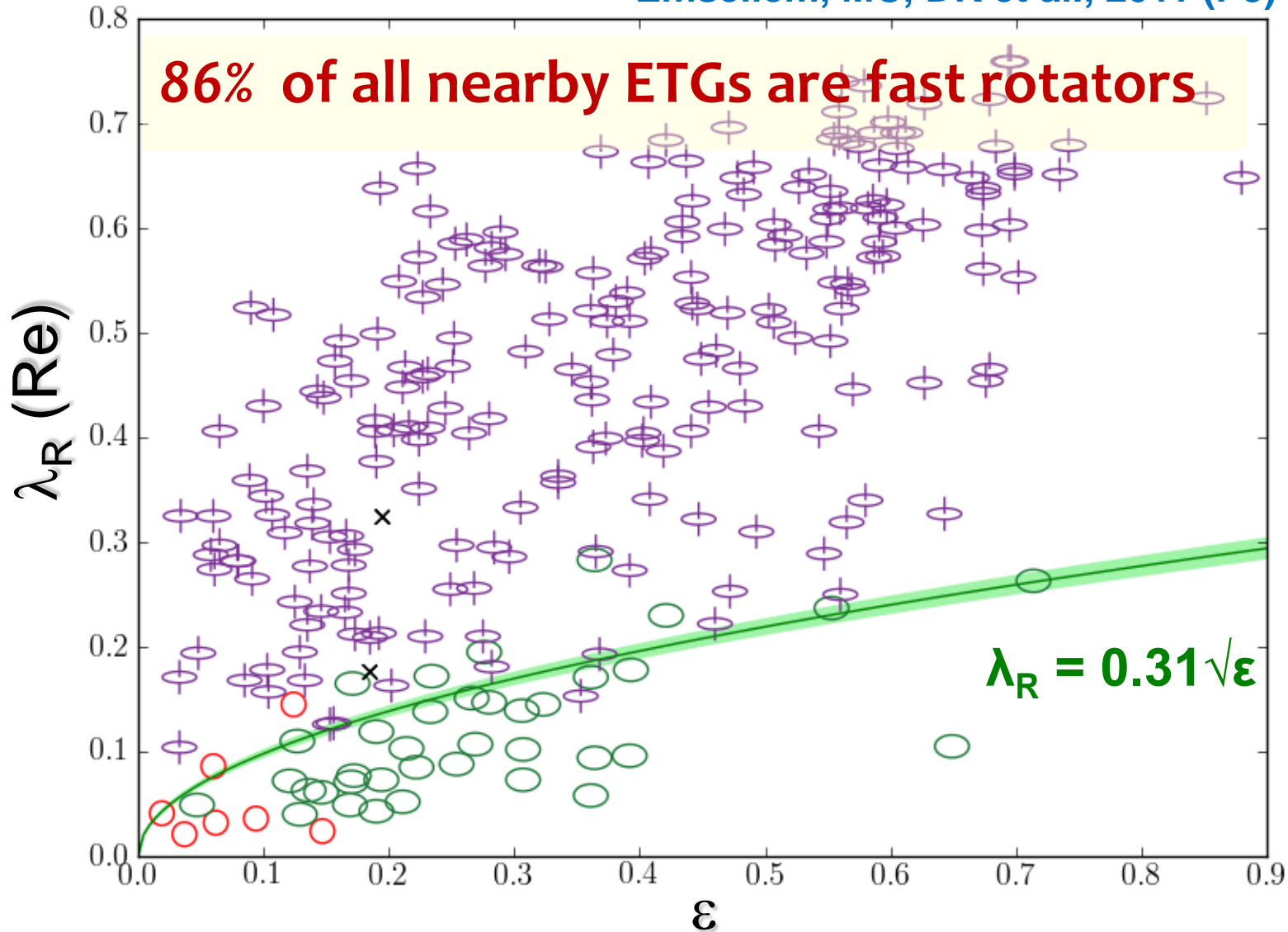
EDGE-ON

FACE-ON

λ_R : Fast versus Slow rotators

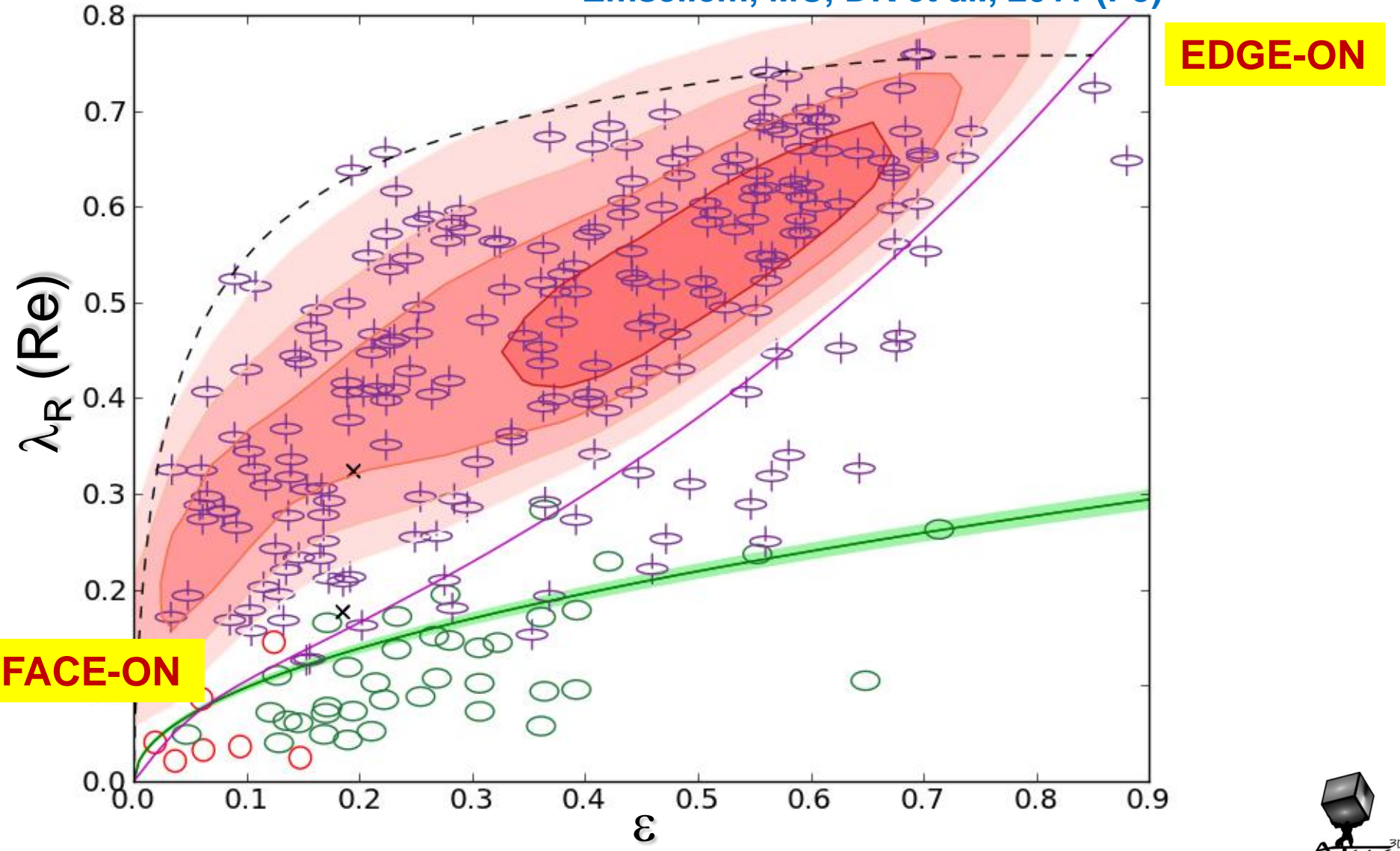
Emsellem, MC, DK et al., 2011 (P3)

86% of all nearby ETGs are fast rotators



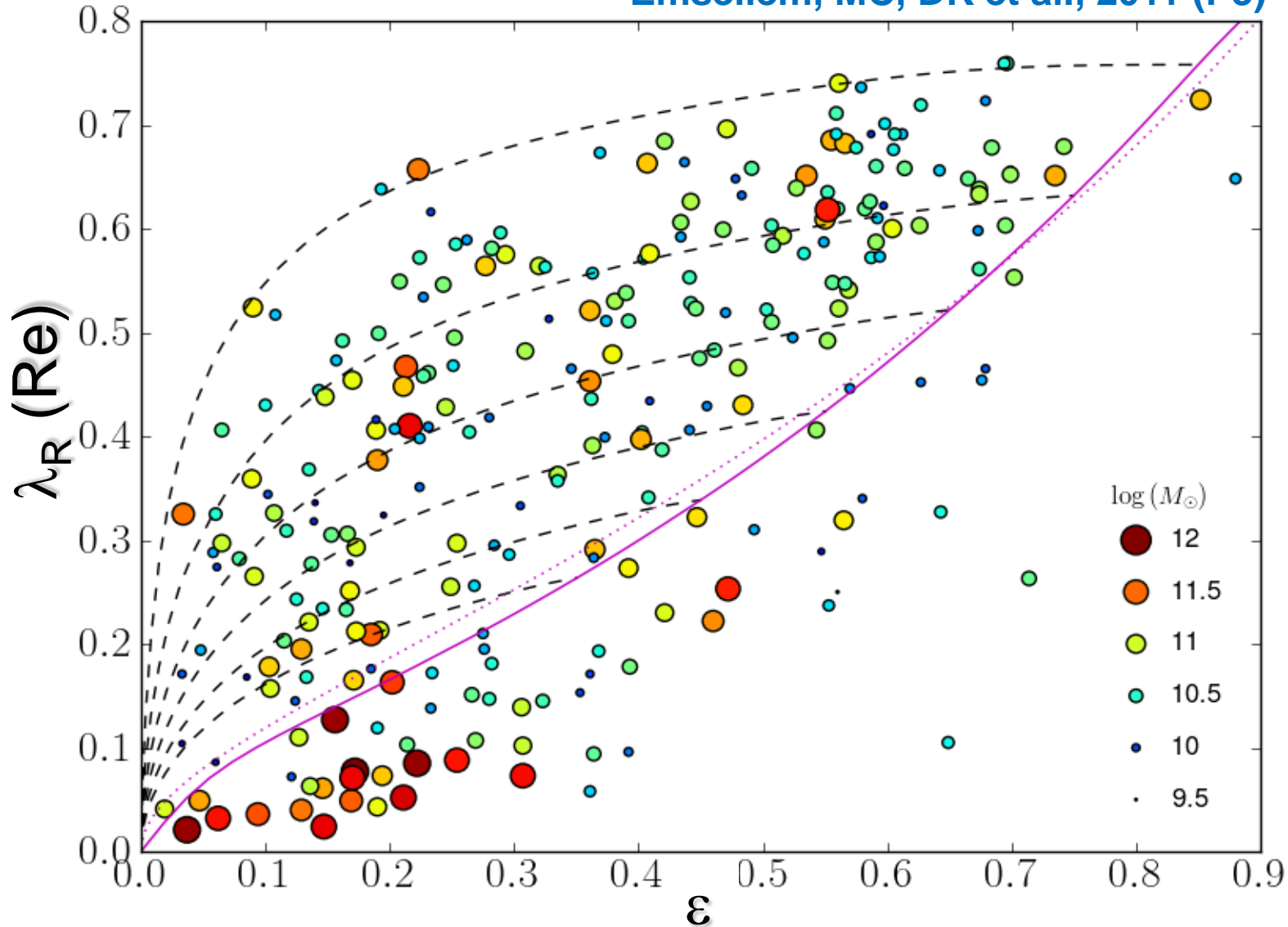
Fast Rotators → Family of oblate rotators

Emsellem, MC, DK et al., 2011 (P3)



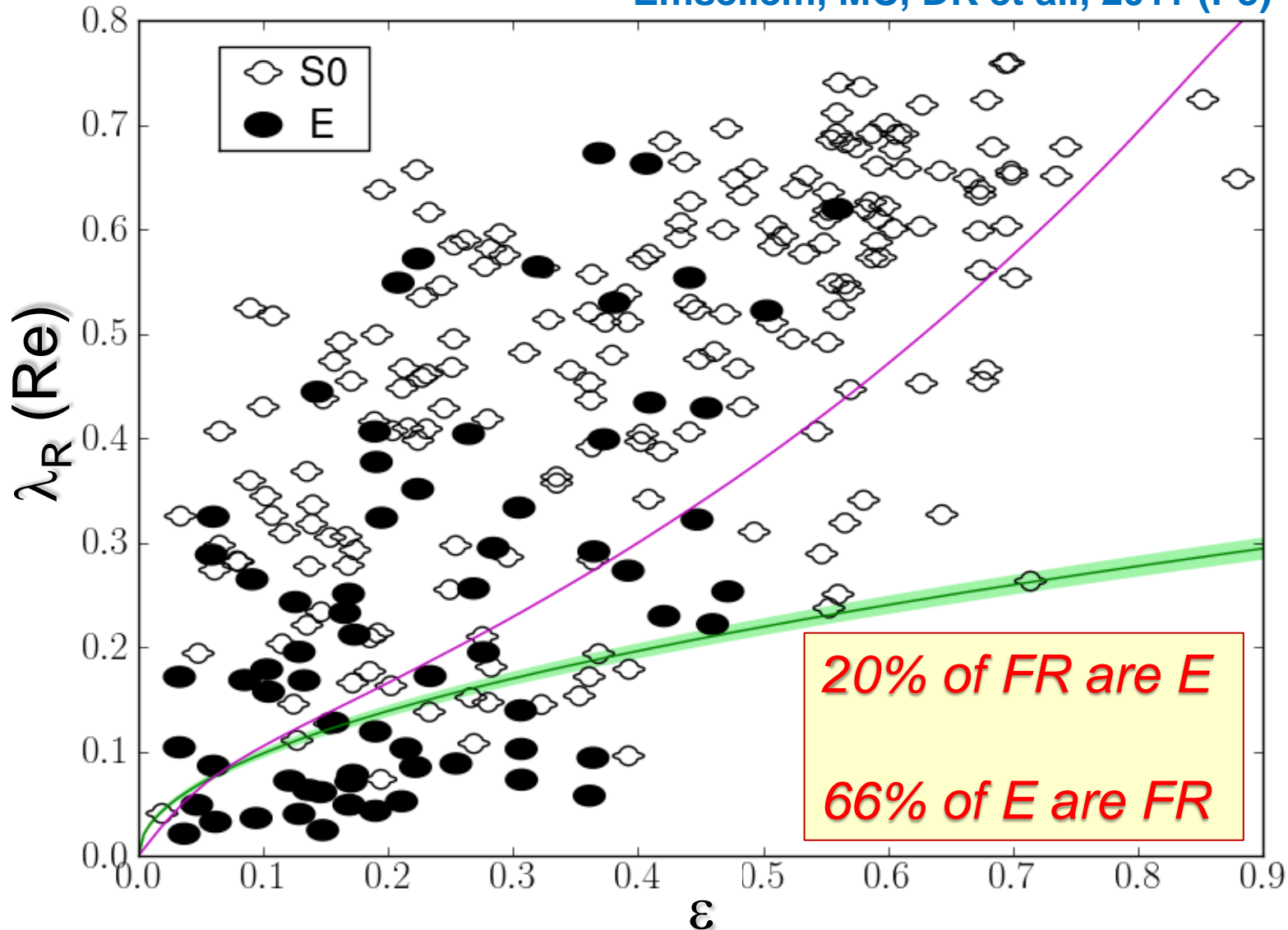
Trend with Mass

Emsellem, MC, DK et al., 2011 (P3)



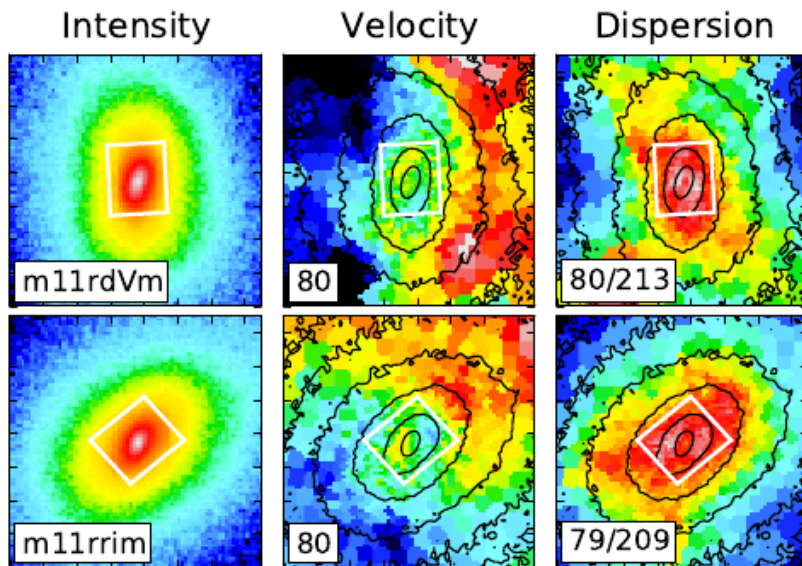
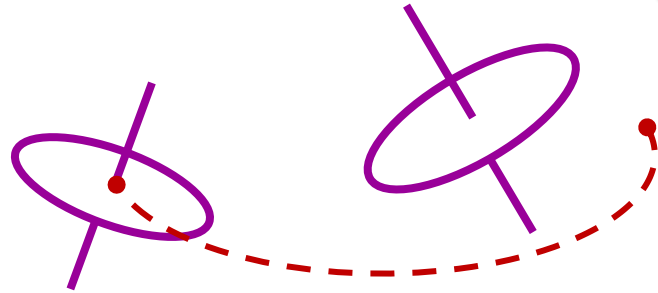
What about E's and SO's ?

Emsellem, MC, DK et al., 2011 (P3)

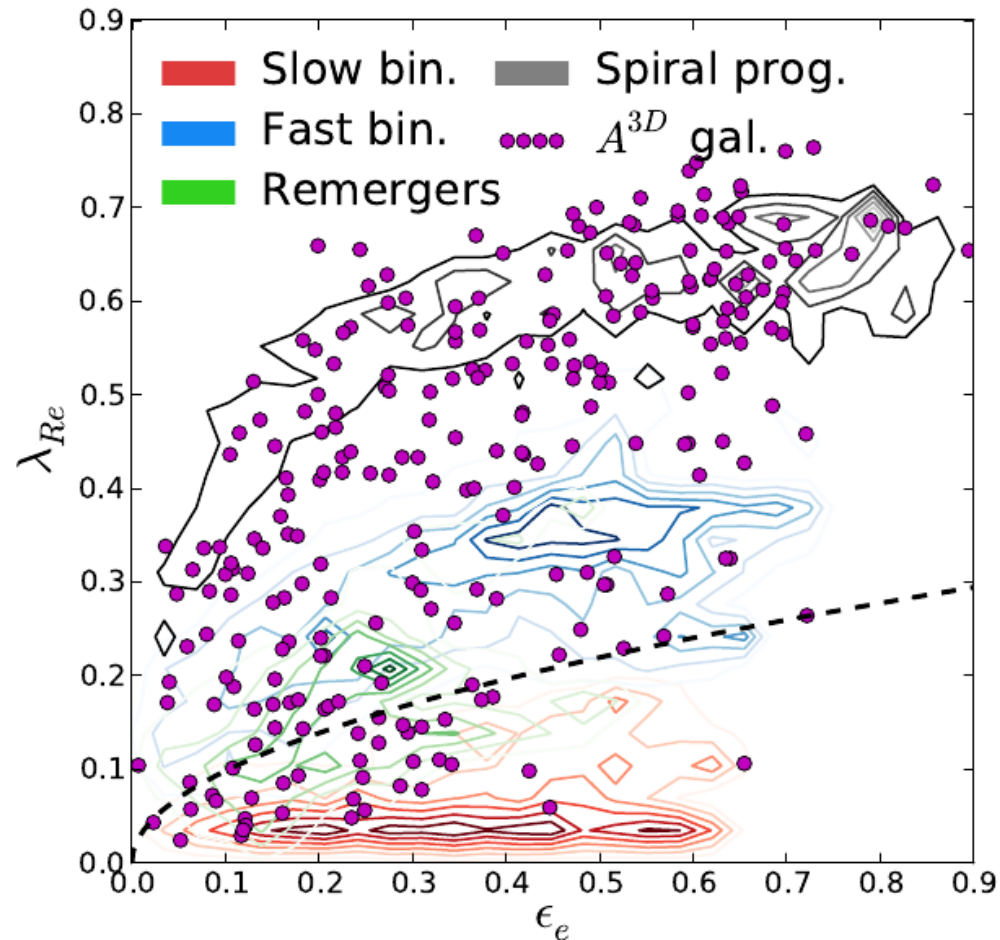


20% of FR are E
66% of E are FR

Generic Simulations: Binary mergers

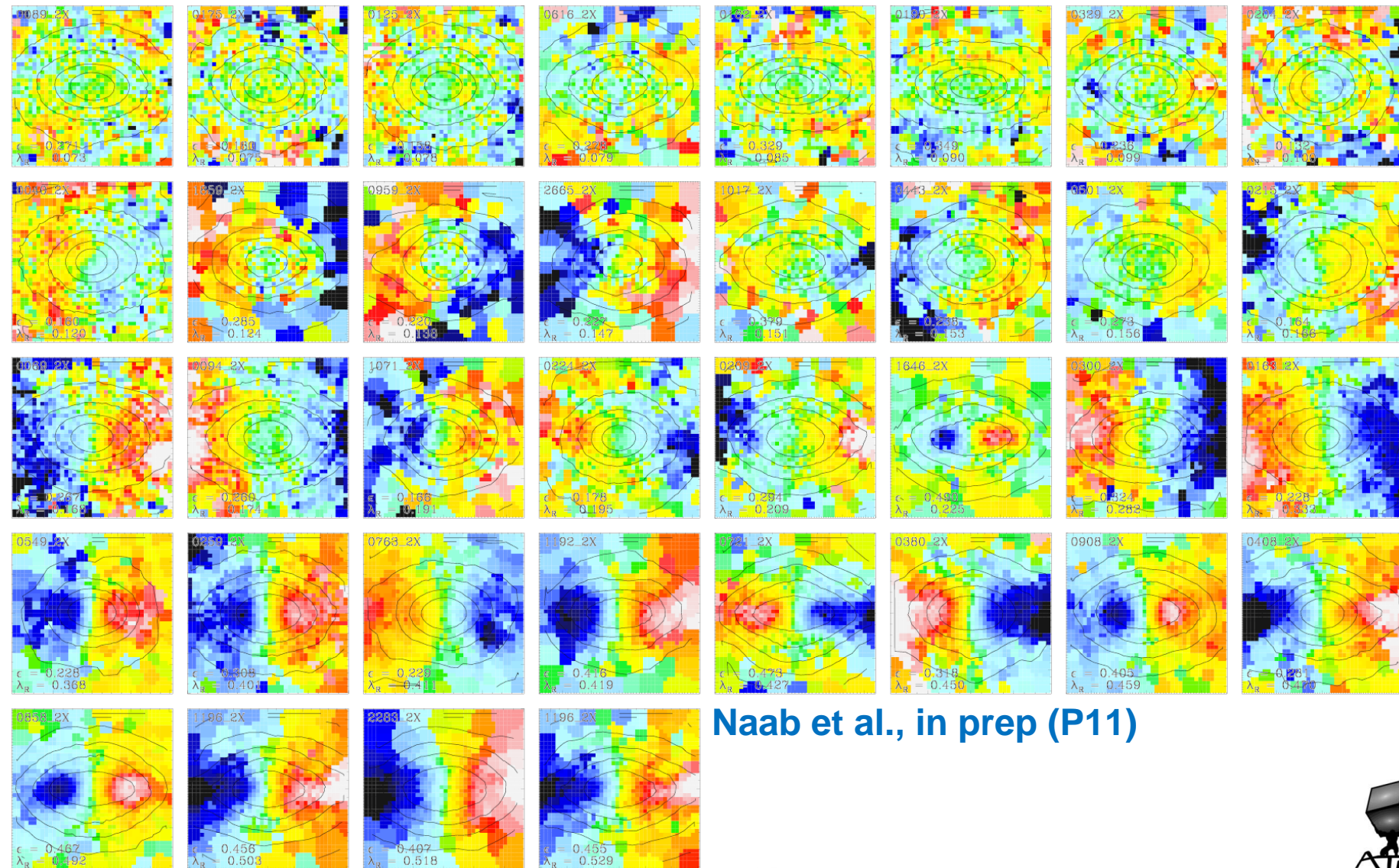


Bois, EE, FB et al. 2011 (P6)



- ❖ Fastest ETGs are as spirals (λ_R)
- ❖ Most binary mergers \rightarrow Fast Rotators
- ❖ Slow rotators have KDCs, but are **TOO flat**

Kinematical analysis of cosmological simulations

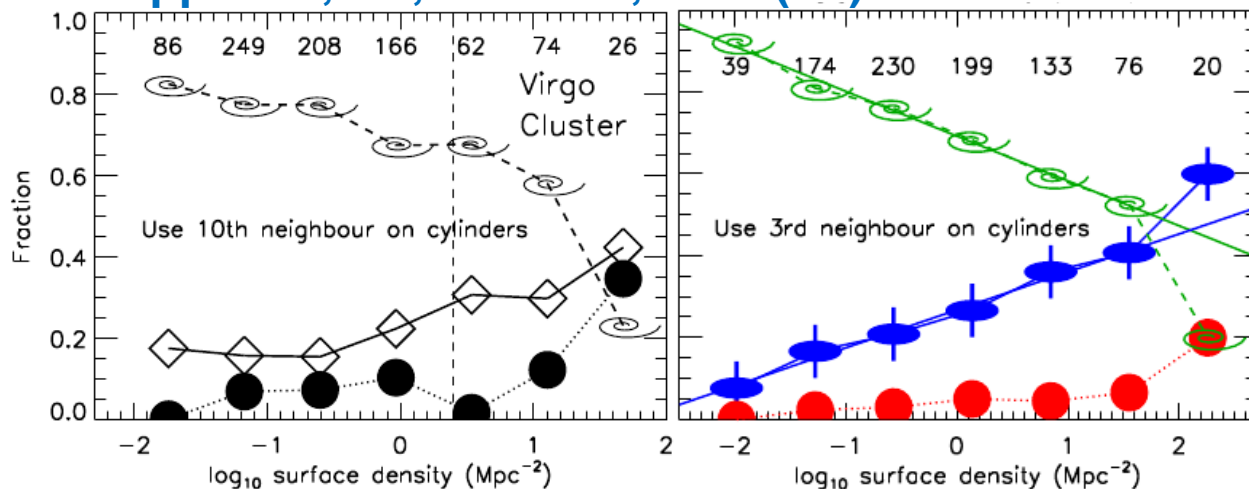


Naab et al., in prep (P11)



Forming Slow Rotators

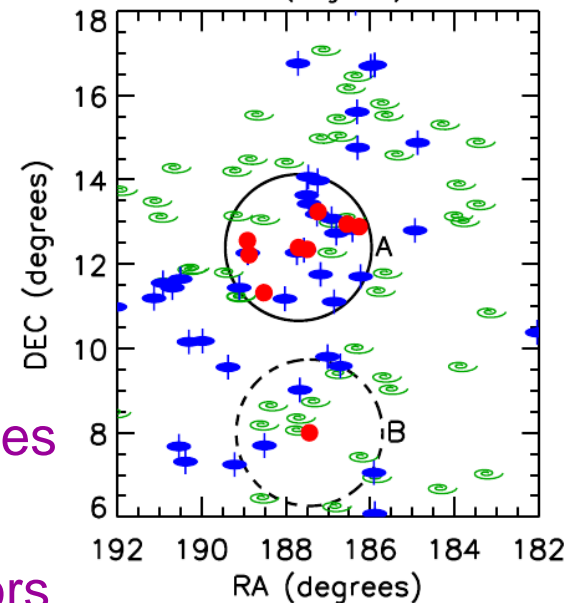
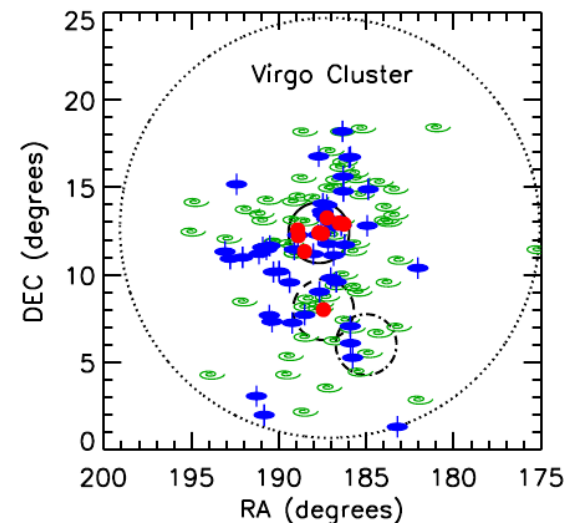
Cappellari, EE, DK et al., 2011 (P7)



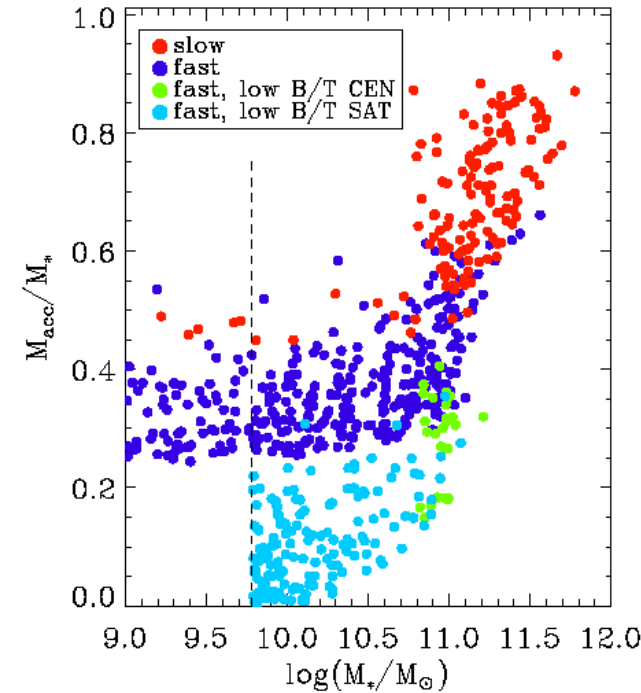
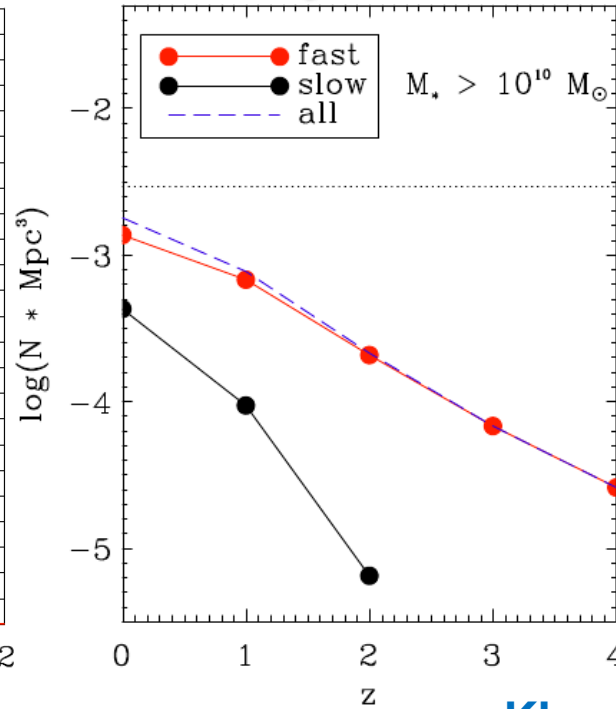
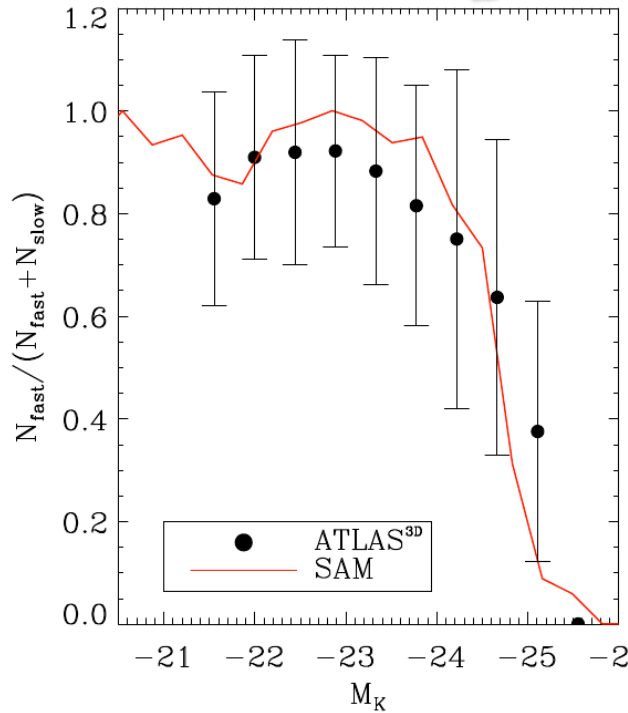
FR  SR 

*Only 1/3 of systems classified as E's are SR
~4% of the parent sample are Slow Rotators*

- ❖ **Slow rotators** : efficient formation only at high densities
- ❖ Monotonic trends from low to high densities
- ❖ Excludes cluster processes for the onset of fast rotators
- ❖ Processes at the small-groups scale in low density environments



Probing Growth processes via SAM



Khochfar, EE, PS, et al. 2011 (P8)

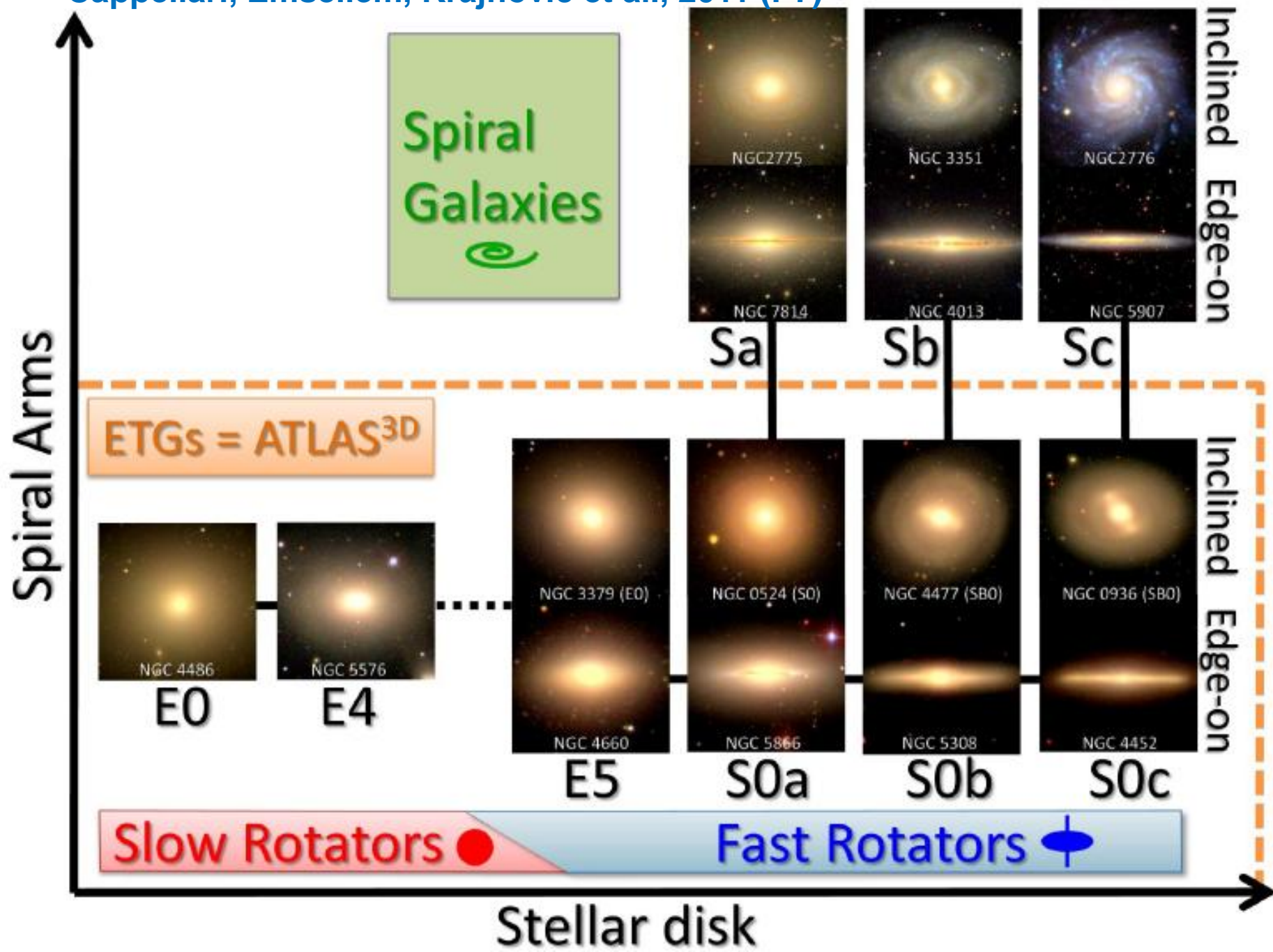
Growing in size and mass: SF versus Assembly

❖ Slow rotators

- ⊙ Accrete more material (50-90%), more major mergers (~3), KDCs
- ⊙ Very few at $z > 2$: progenitors should have been fast
- ⊙ Complete shut-down of gas cooling

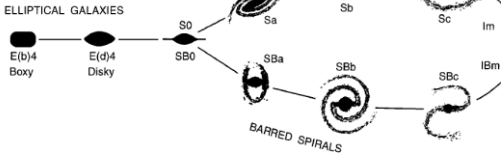
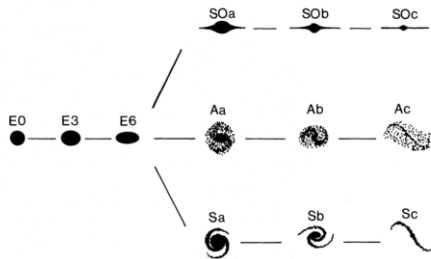
⊙ Fast rotators:

- ⊙ 2/3 have large B/T, 1/3 have low B/T (e.g., stripped in clusters)



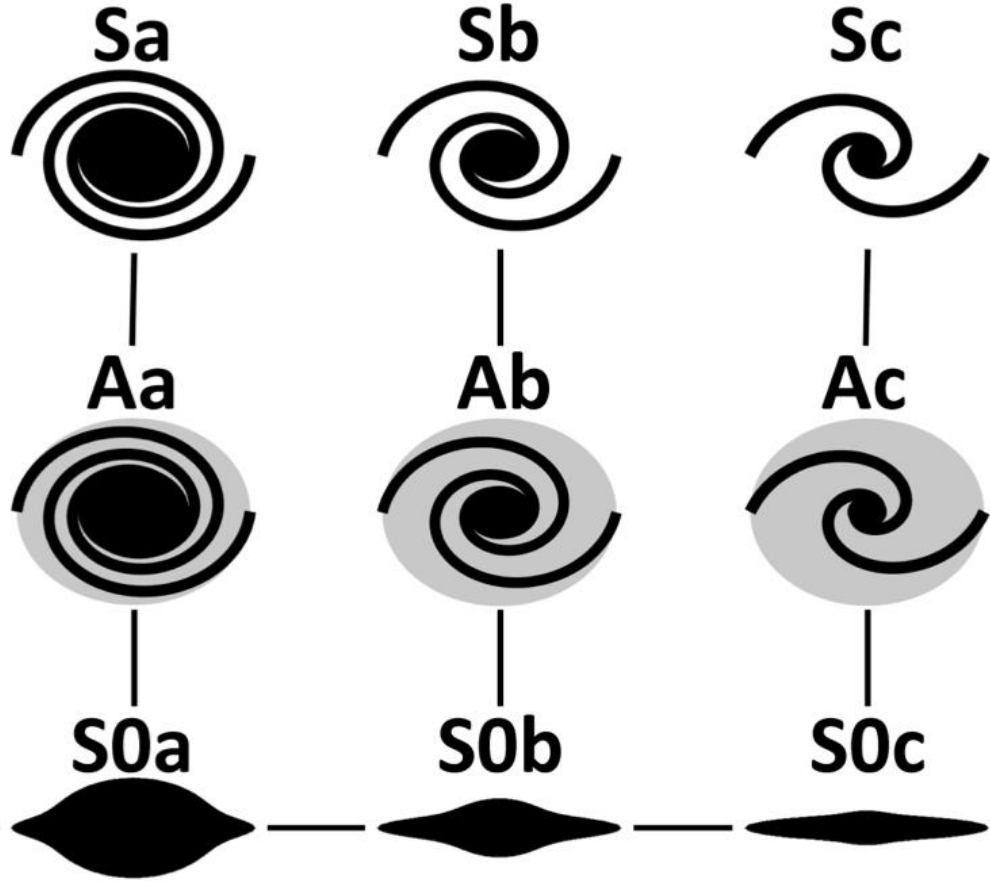
"ATLAS^{3D} comb"

van den Bergh 1976



Kormendy & Bender 1996

Spiral Galaxies



E0
E4
E5
Slow Rotators

S0a
S0b
S0c
Fast Rotators

Cappellari, Emsellem, Krajnović et al., 2011 (P7)

A paradigm shift for ETGs

- ❖ ***E/S0 separation should be abandoned:***
 - ⊙ results based on this separation → consider with scepticism
- ❖ **Continuity from spirals:** fastest rotators → stripped spirals
- ❖ **> 86% of ETGs are disk-like**
 - ⊙ S0, anaemic spiral & regular, each can be **barred**.
 - ⊙ Fewer major mergers, lower stellar mass accretion
- ❖ **<14% of ETGs have low angular momentum :**
 - ⊙ mostly massive, quiescent, mildly triaxial & rounder than E4
 - ⊙ more (gas-rich) major mergers (mostly high z)
+ minor mergers (at low z)
- ➔ **Only 4% (9% in mass) of local galaxies are “ellipticals”**
- ❖ **Environment & local (groups) effects are important**
 - ⊙ Slow rotators in cores of clusters/groups
 - ⊙ Mass dependent growth process: SF vs Assembly

