Kinematic properties of early-type galaxies across environments

Davor Krajnović

Introduction

- E/S0 distinction not physical
  - Viewing angle dependant!
- Use kinematics to classify galaxies
  - ATLAS^{3D} survey
- Kinematic classification
  - Krajnović, Cappellari, Emsellem et al. (2011, arXiv: 1102.3801)
  - Emsellem, Cappellari, Krajnović et al. (2011, arXiv: 1102.4444)
- Kinematic morphology-density relation
  - Cappellari, Emsellem, Krajnović et al. (2011, arXiv: 1104.3545)

The ATLAS3D team

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(33 researchers in ~16 institutes)

Comprehensive approach

OBSERVATIONS					
Optical Spectra	Optical imaging	Radio	mm	NIR spectra	Archive
SAURON IFU	MegaCam, INT	WRST, EVLA	IRAM 30m, Carma	NIFS, SINFONI	2MASS, SDSS, HST, Spitzer, Chandra, Galex

MODELLING AND SIMULATIONS					
Dynamics	Stellar populations	High-res sim. binary mergers	High-res sim. of gas in ETGs	Cosmological simulations	Semi-Analytic Models

Sample

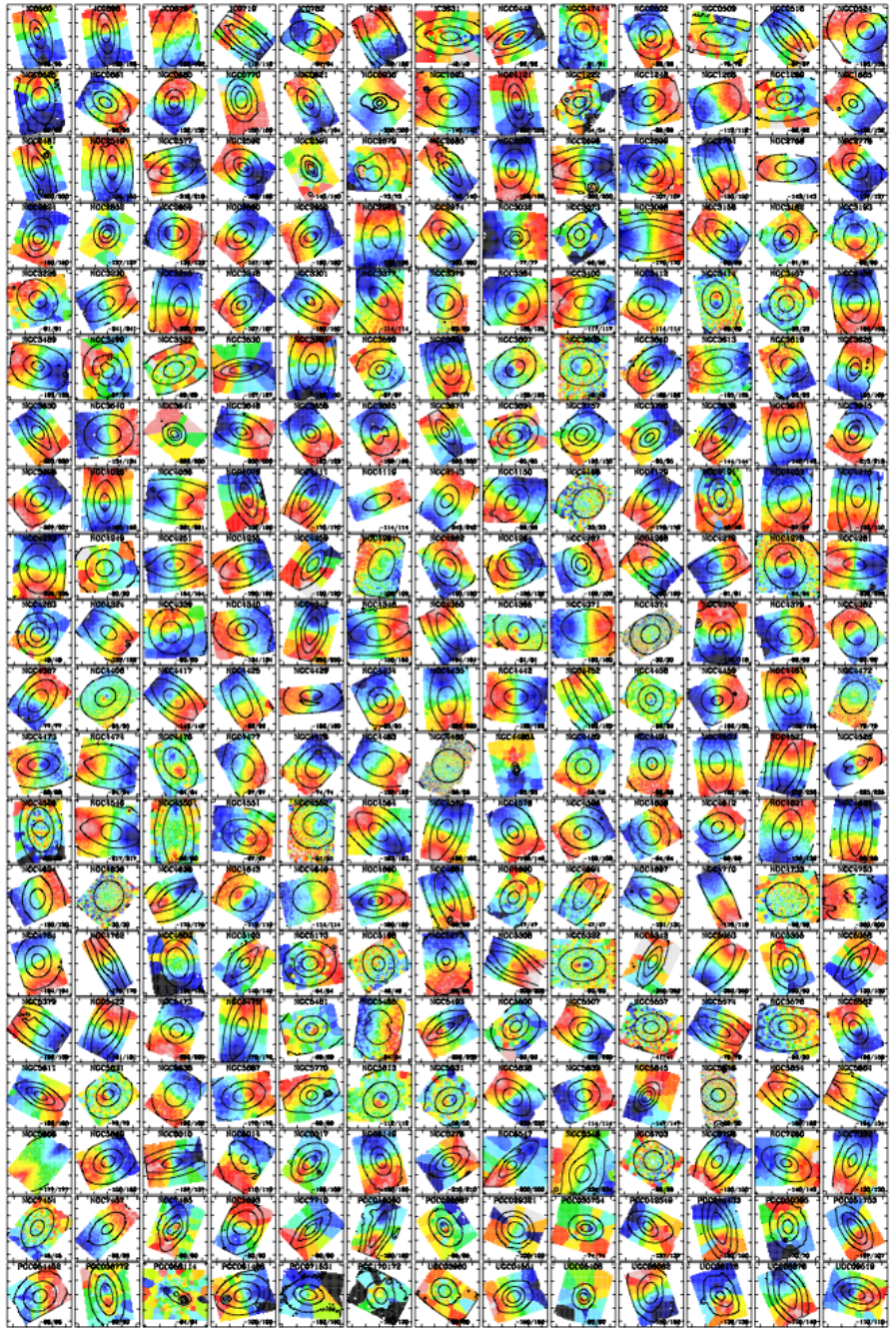
$M_K < -21.5$
$D < 42$ Mpc
$|\delta - 29| < 35°$
$|b| > 15°$

- Parent sample: 871 nearby galaxies
- Morphological selection: No spiral arms (DSS/SDSS)
- No colour cut
- Observe a complete volume limited sample of ETGs: 260

Cappellari et al. (2011)

Kinematics

- Observation of large variety of kinematics
- Classification of velocity structures
- Measurement of stellar angular momentum

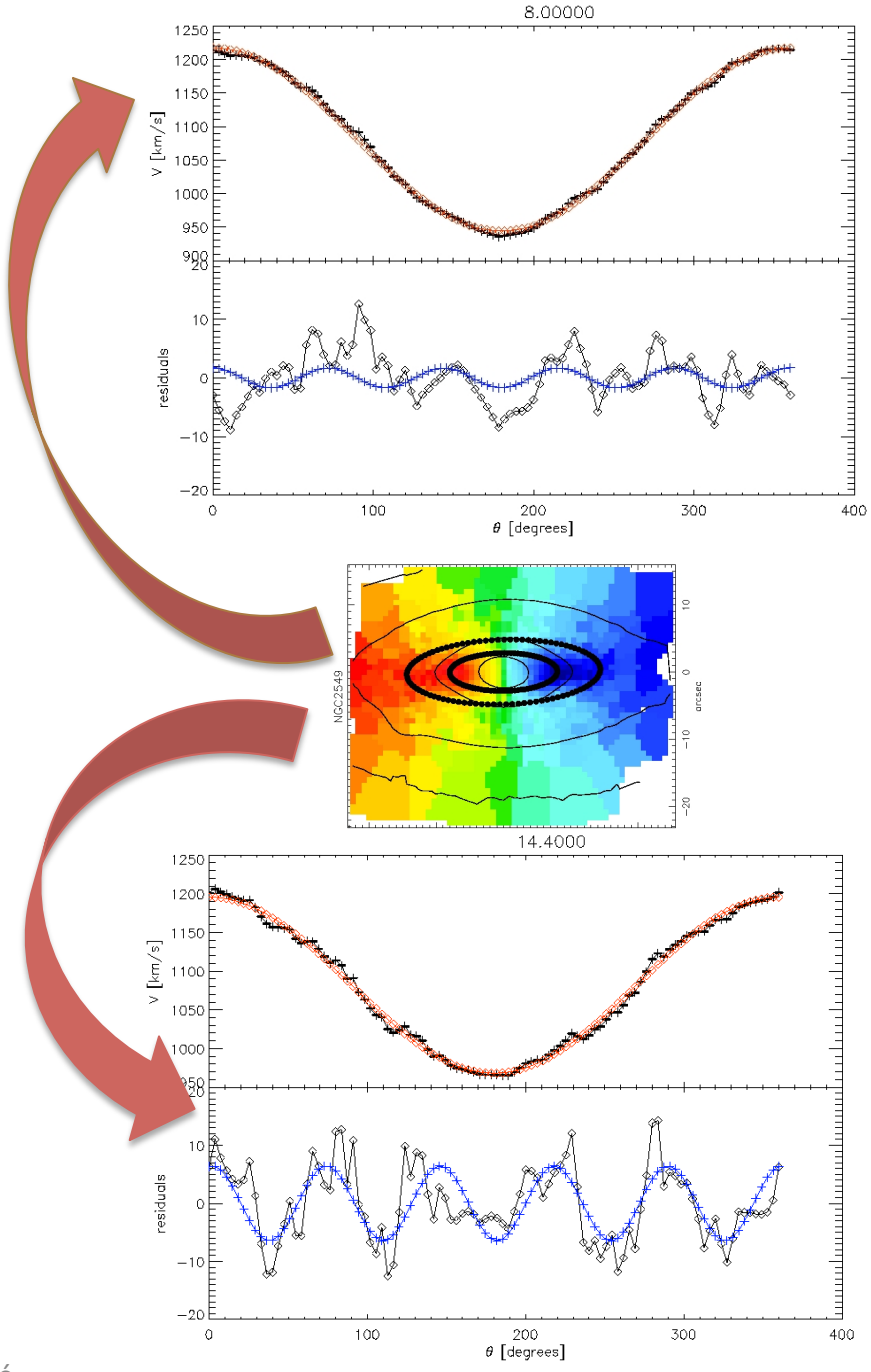


Krajnović et al. (2011)

Kinemetry

- Generalisation of surface photometry (e.g. Jedrezejewski 1987) to higher-order moments of the LOSVD; www.eso.org/~dkrajnov/idl
- Best fitting ellipse by minimising higher-order harmonic terms
- Applicable for both photometry (images) and kinematics (IFU maps: V, σ, h_3, h_4 …)
- Images: even terms (up to the second harmonics)
- Velocity maps: odd terms (up to the third except cos(θ)

$$V = V_0 + V_R \cos(\theta)$$



Krajnović et al. (2006)

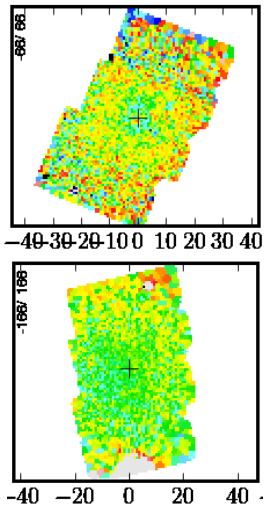
Kinematic richness: classification

Non-Regular Rotators
Large residuals

Regular Rotators
Small residuals

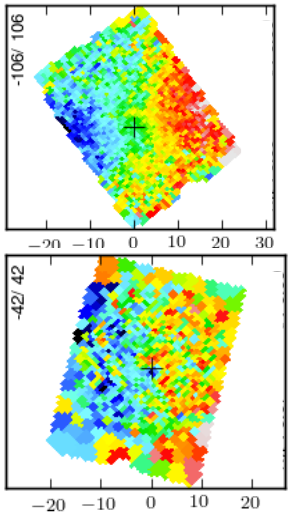
Group a
(Low Velocity - LV)

3%



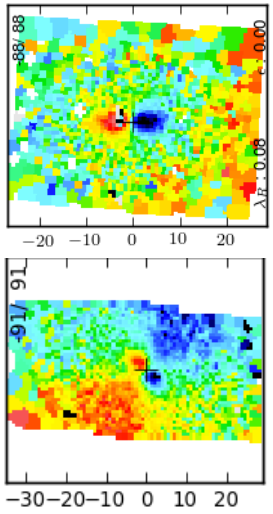
Group b
(No Feature - NRRNF)

5%



Group c
(Kinematically distinct cores- KDC)

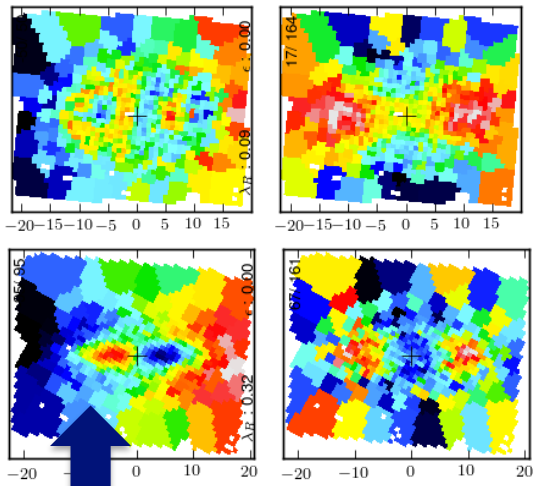
7%



Group d
(Double σ - 2σ)

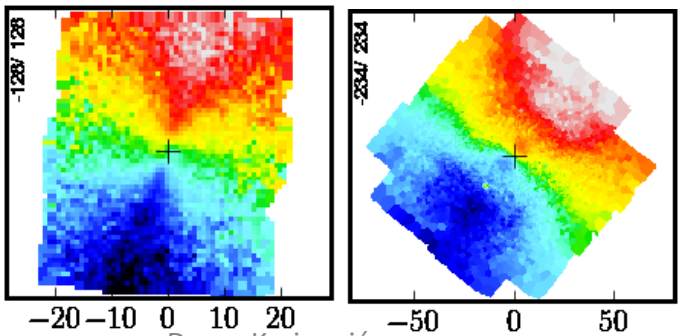
4%

V map | σ map



Group e
(No Feature - RRNF)

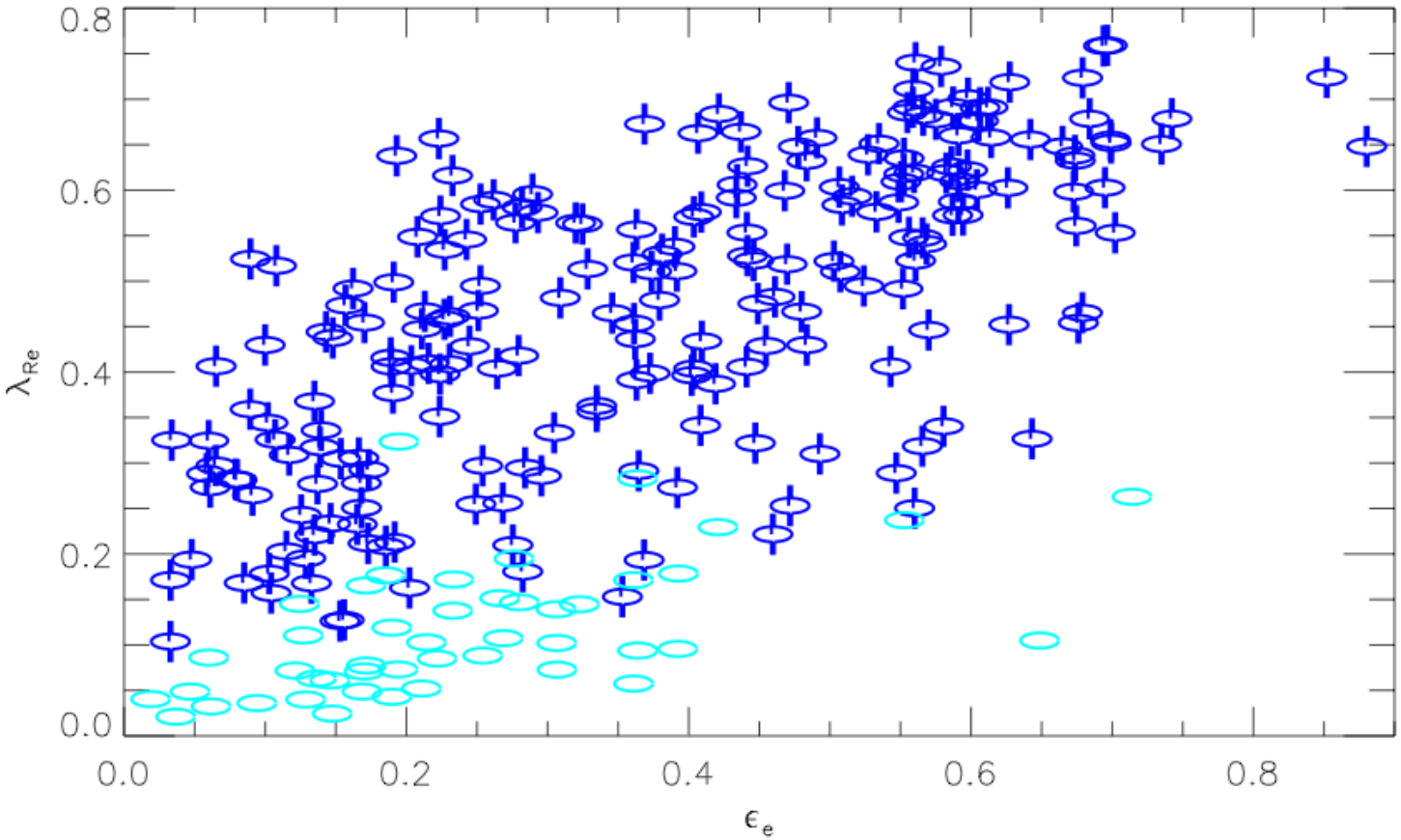
80%

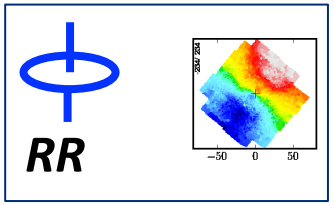


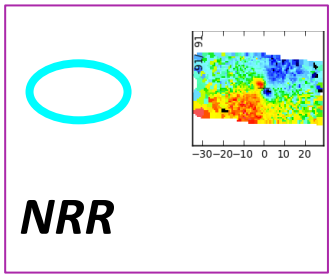
Fraction of counter-rotation

Krajnović et al. (2011)

Calibrating λ_R





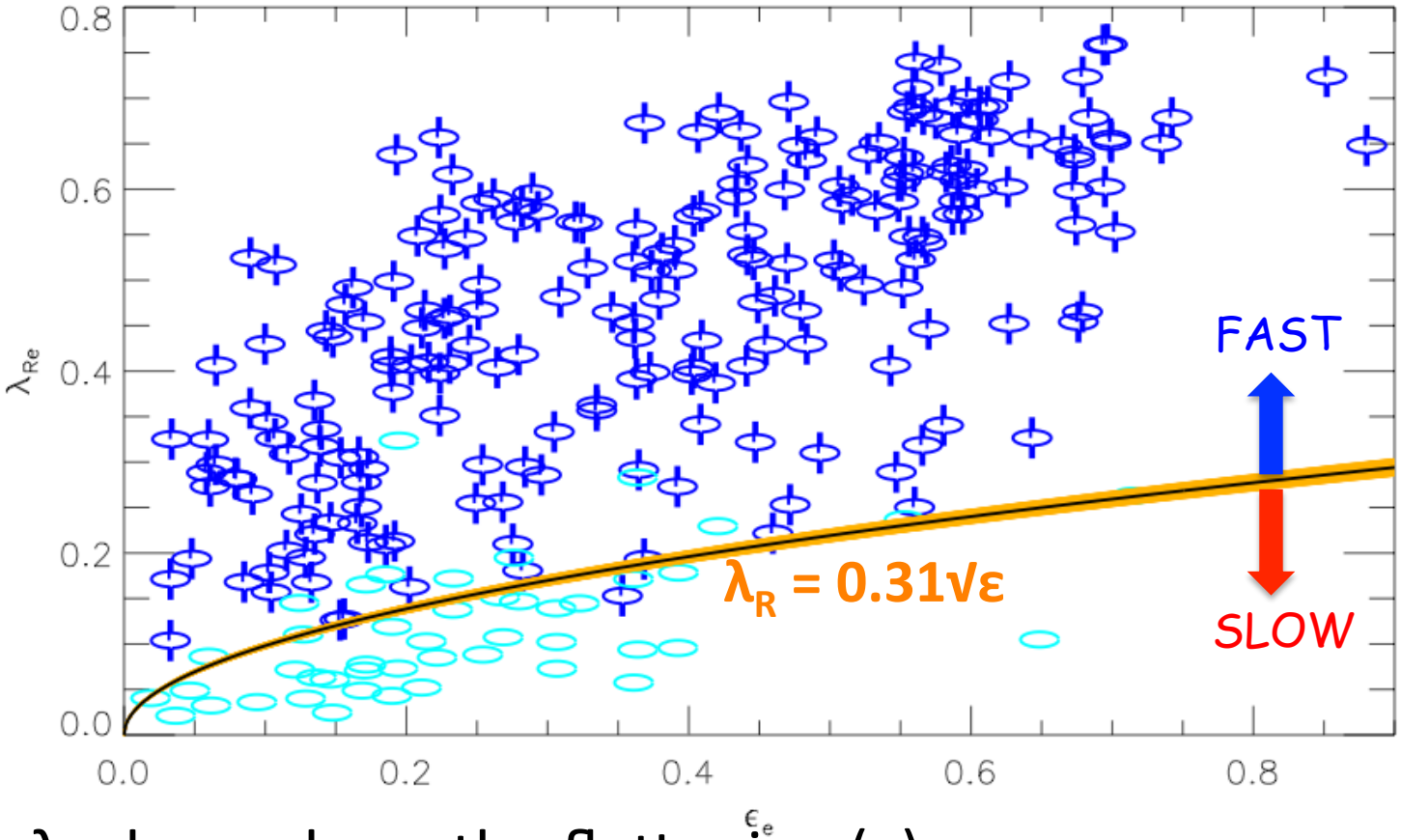


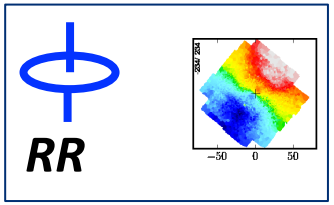
$$\lambda_R \equiv \frac{\langle R \cdot |V| \rangle}{\langle R\sqrt{V^2+\sigma^2} \rangle}$$

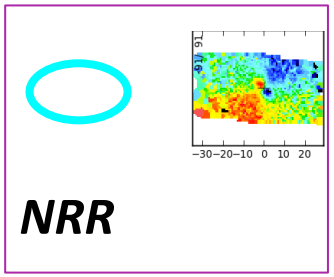
- Specific stellar angular momentum
- Using kinemetry classification to distinguish between Fast and Slow rotators

Emsellem et al. (2011)

Calibrating λ_R



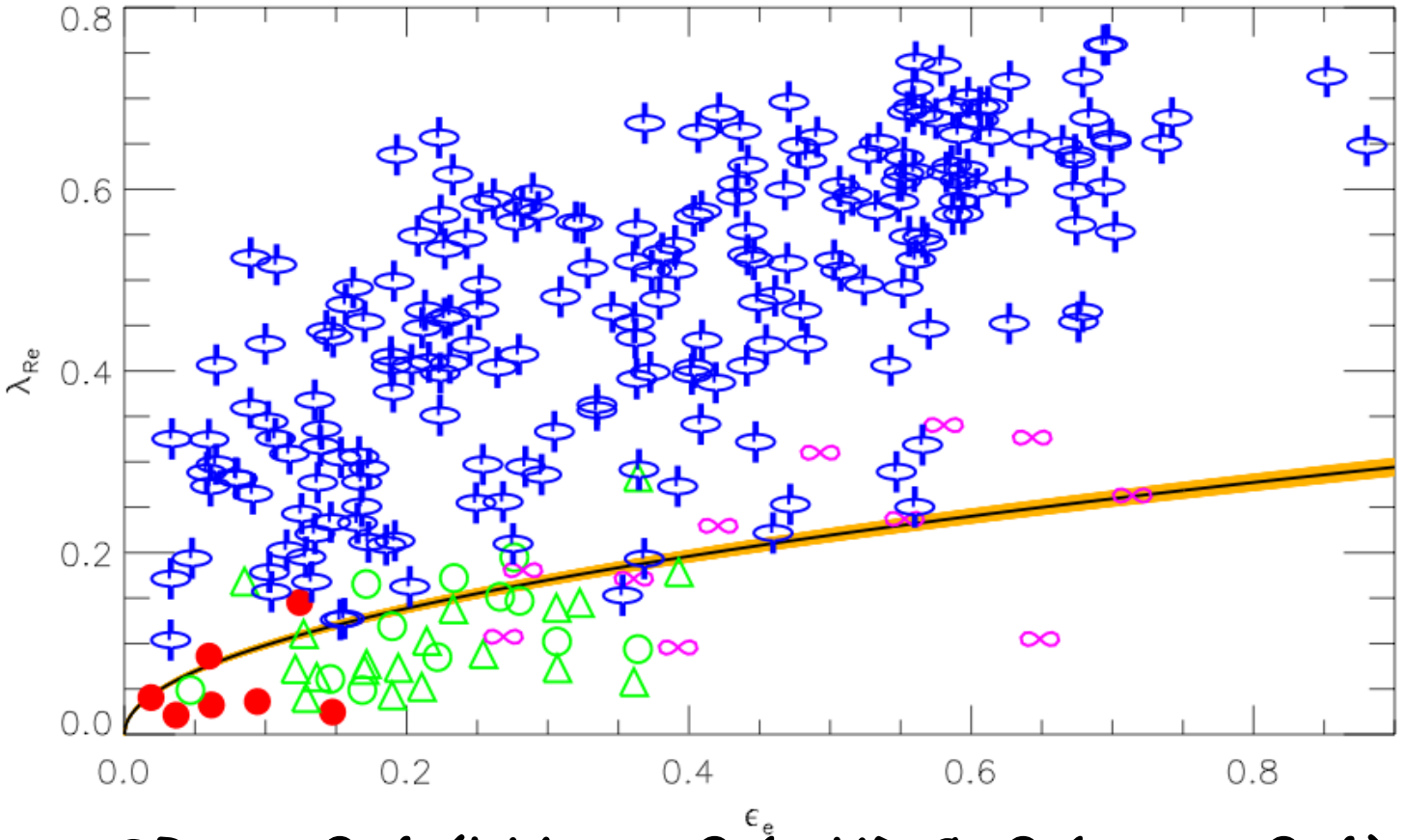


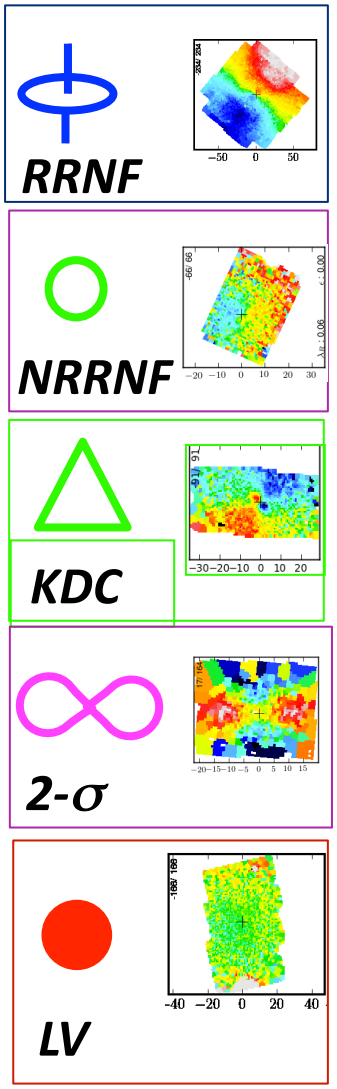


- λ_R depends on the flattening (ϵ)
- ***85%* of all nearby ETGs are fast rotators**
- ETGs generally not spheroidal, but disk-like

Emsellem et al. (2011)

λ_R vs kinematic structure



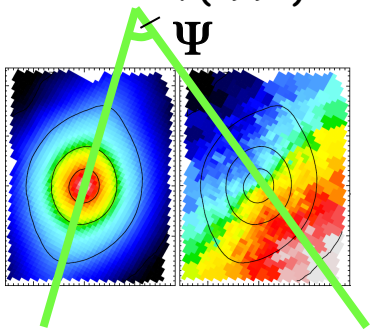


- SR ε < 0.4 (LV: ε < 0.1; KDC: 0.1 < ε < 0.4)
- 2-σ: ε > 0.25

Emsellem et al. (2011)

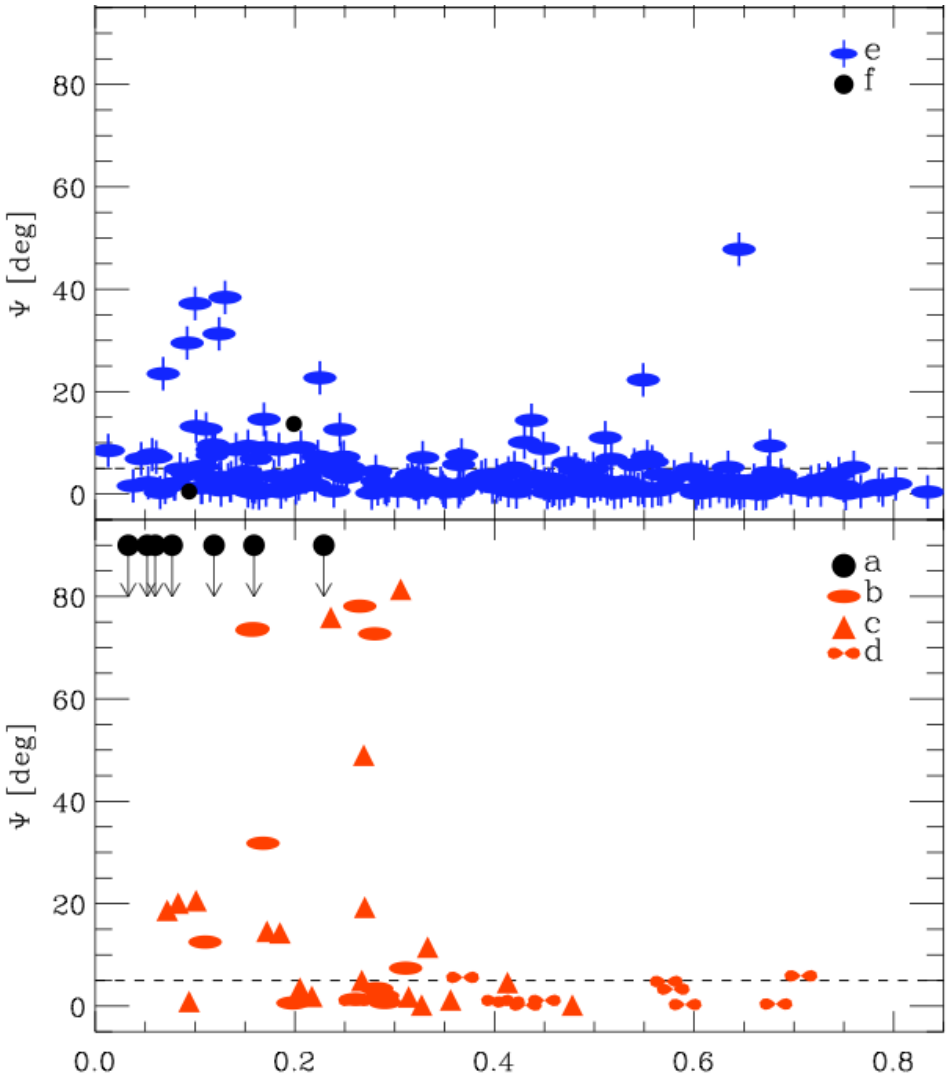
Kinematic misalignment

$\sin(\Psi) = \sin(|Pa_{phot} - Pa_{kin}|)$
Franx et al. (1991)



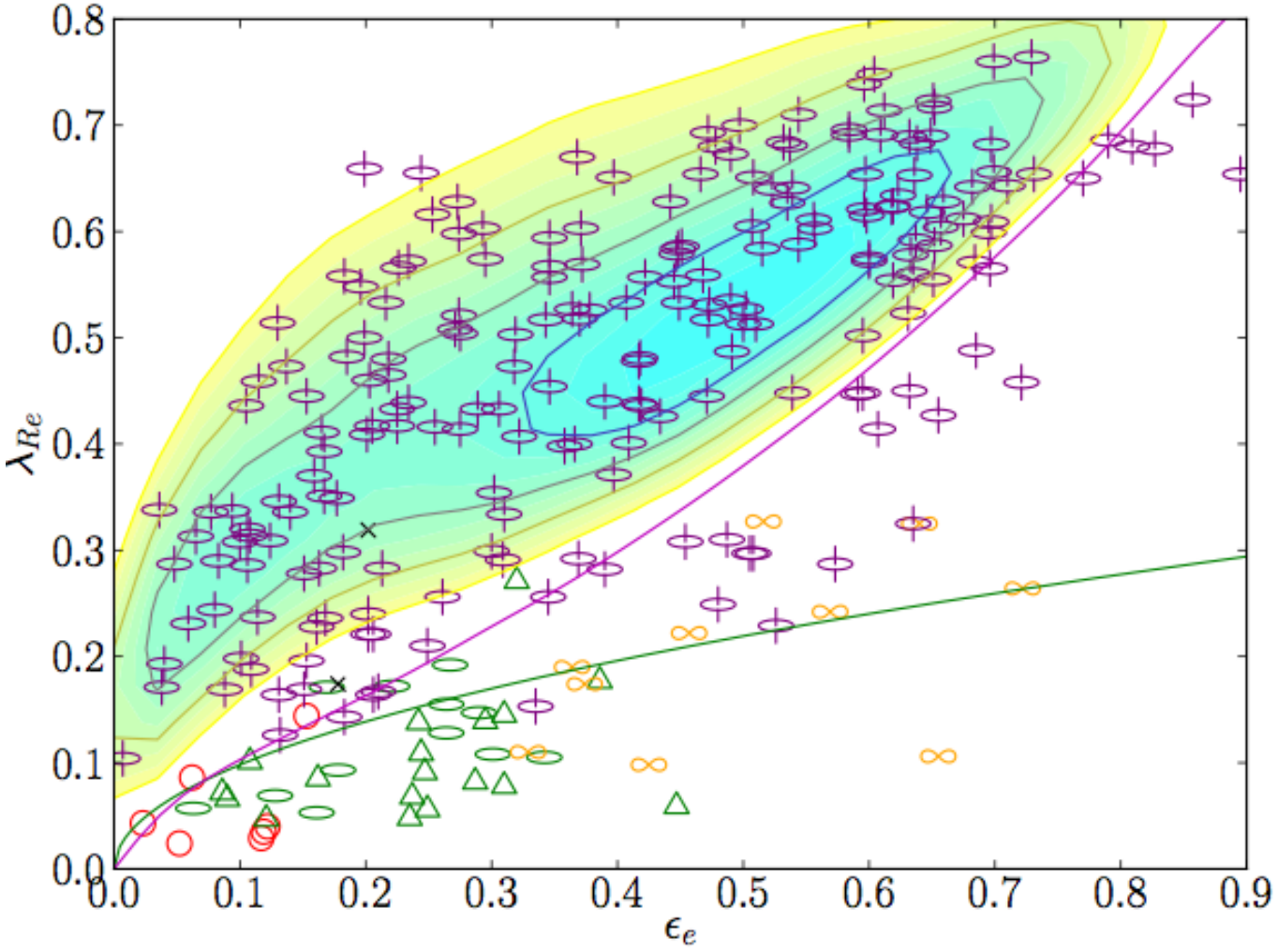
Aligned:
Ψ < 5° 71%
Ψ < 10° 84%
Ψ < 15° 90%

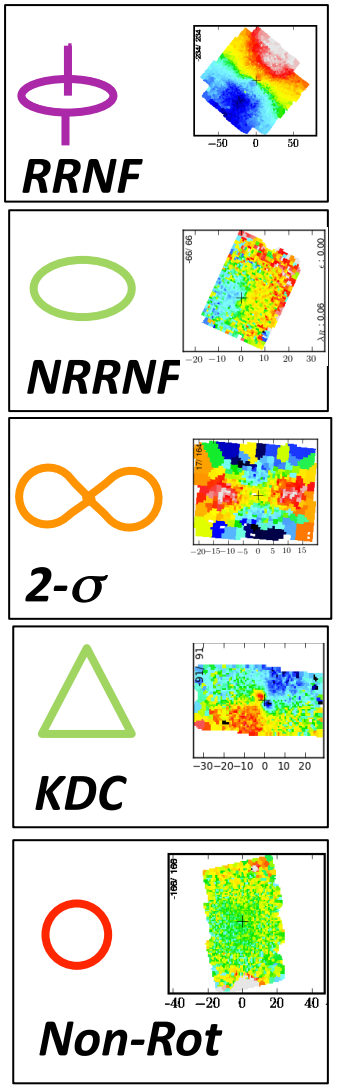
- FR: aligned → nearly axisymmetric systems (+ bars!)
- SR: (also) misaligned → triaxial systems



Krajnović et al. (2011)

Families of the nearby ETG?

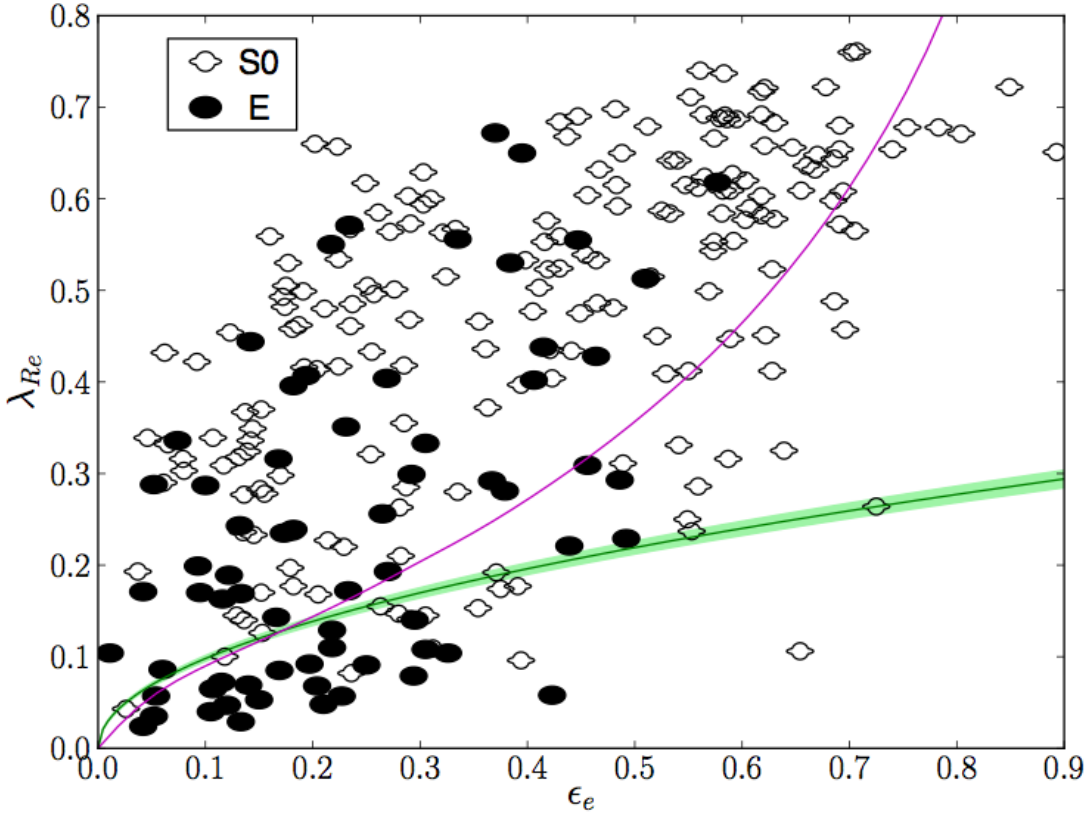




- Fast Rotators: A family of oblate objects: $\varepsilon_{int} = 0.7 \pm 0.2$

Emsellem et al. (2011)

λ_R vs Hubble classes

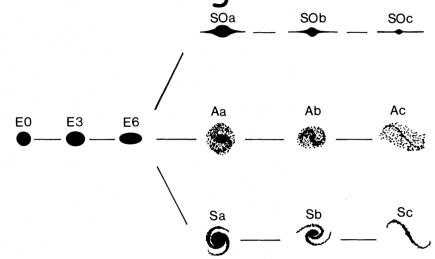


- **66% of E are FR**
- 20% of FR are E
- FR ≈ S0 + E(d)
- SR = true ellipticals

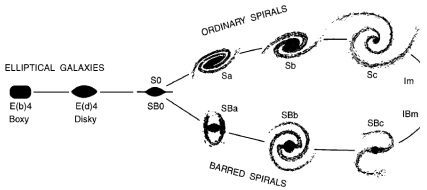
Emsellem et al. (2011)

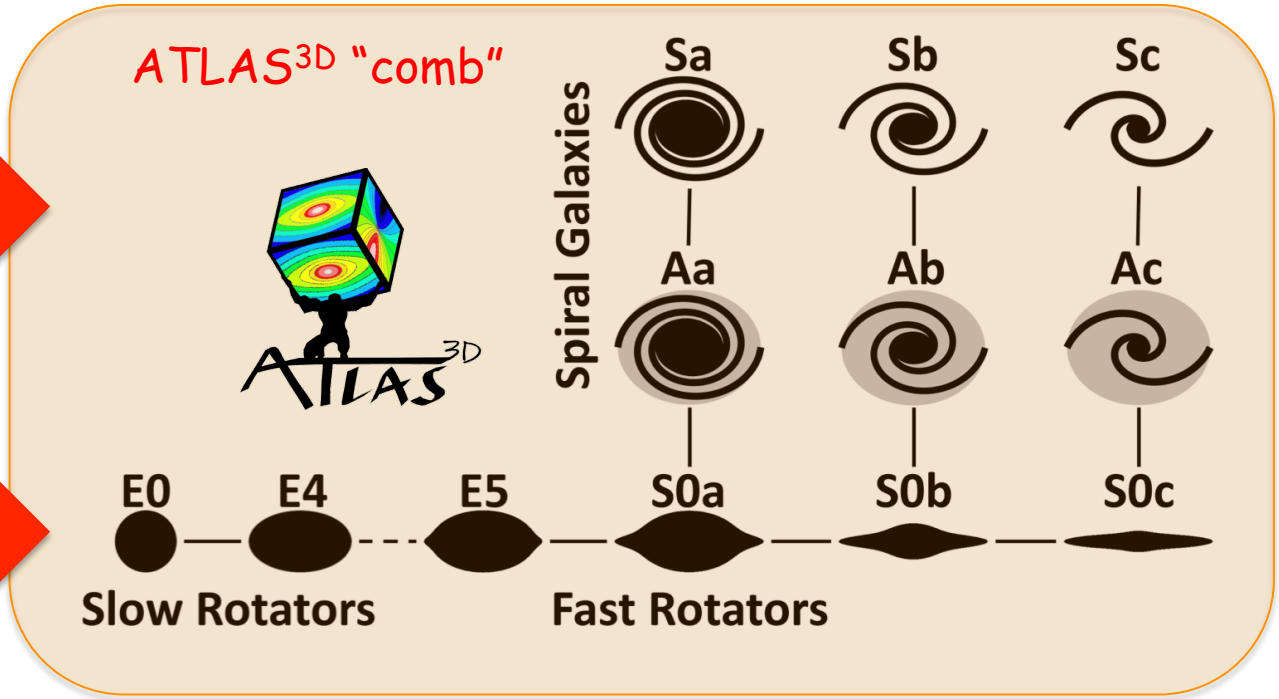
Galaxy Classification (z=0)

van den Bergh 1976



Kormendy & Bender 1996





- Tune Hubble diagram to describe ETGs
- **E/S0 -> SR/FR**
- Building on previous modifications - disks in spheroids (Kormendy & Bender 1996)
- Fast Rotators – parallel sequence to spirals (see Spitzer & Baade 1951; van den Bergh 1976)

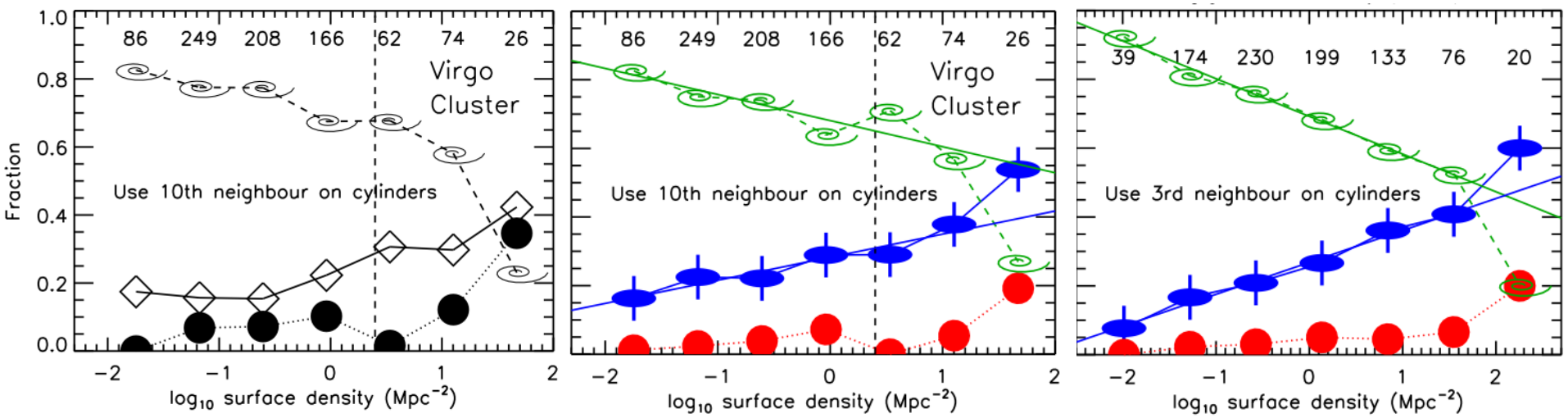
- Kinematics
- Intrinsic shapes
- Varying S0 bluge ratios
- Similarity of S0 and spiral bulges (e.g. Laurikainen et al. 2010)

Cappellari et al. (2011b)

Kinematic morphology-density relation

following Dressler (1980)

Cappellari et al. (2011b)



- E / S0 → FR / SR
- Local density measure (3rd neighbour)
- FR converted into spirals even at lowest densities
- Excludes cluster environment mechanisms
- Small group processes (e.g. harassment, gravitational heating)
- SR don't participate except at high densities

Cappellari et al. (2011b)

Census of ATLAS^{3D}

ALL	SPIRALS	ETG
871	611	260

Fast Rotators	
224 (45 Es, 179 S0s)	
number	mass
26%	25%

Slow Rotators	
36 (21 Es, 15 S0s)	
number	mass
4%	9%

Conclusions

- λ_R not cheap, but clean proxy for classification
- SR/FR separation captures physical processes among ETGs better than E/S0 classification
- 86% of ETGs have "disk-like" kinematics and high angular momentum
  - one family of flattened nearly axisymmetric objects ($\varepsilon_{int} \sim 0.7$)
  - kinematically and morphologically similar to (anaemic & regular) spirals
- 14% of ETGs have complex kinematics (e.g. no rotation, KDC…) and low angular momentum
  - typically (but not exclusively) most massive objects
  - large misalignments, $\varepsilon < 0.4$, triaxial
  - the "handle" of the "Hubble comb" (i.e true ellipticals)
- Environment dependence:
  - Smooth kinematic morphology – density relation over 4 orders of magnitude in surface density (from $\Sigma_3 \approx 0.01$ to 100 Mpc^{-2})
  - Decline in # of spirals linked to rise in # of FR
  - SR only found in the densest regions (core of clusters or groups)
  - Transformations driven by local effects at small group scales