The importance of morphology for understanding galaxy evolution

Roger Davies, 23rd Sept 2013

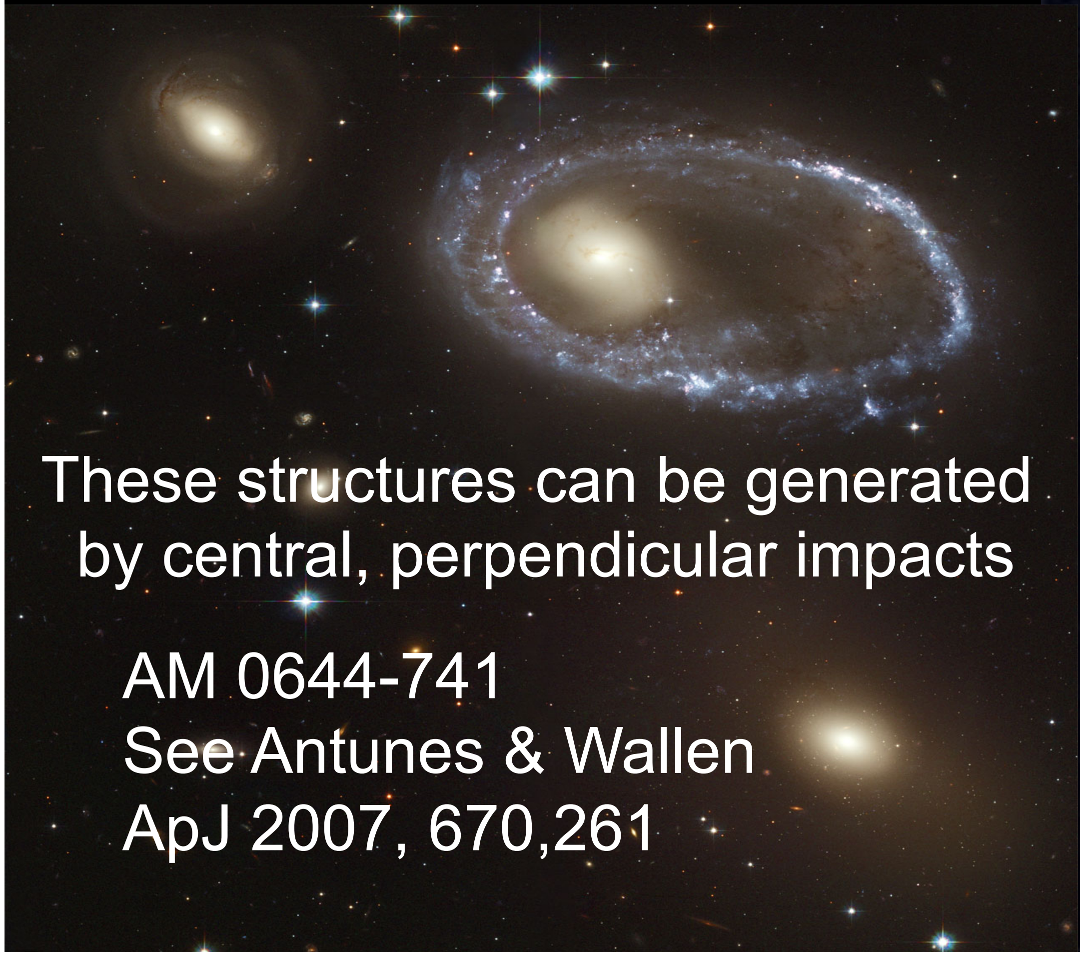
Arp 147 see Fogarty et al 2011, 417,835

Evolutionary Paths in Galaxy Morphology, Powerhouse Museum, Sydney

Outline

- Ring galaxies – a clear case?
- What can we hope to learn from morphology?
- Disk galaxies
- Early-type galaxies
- Conclusions

Sometimes it's obvious........ ring galaxies

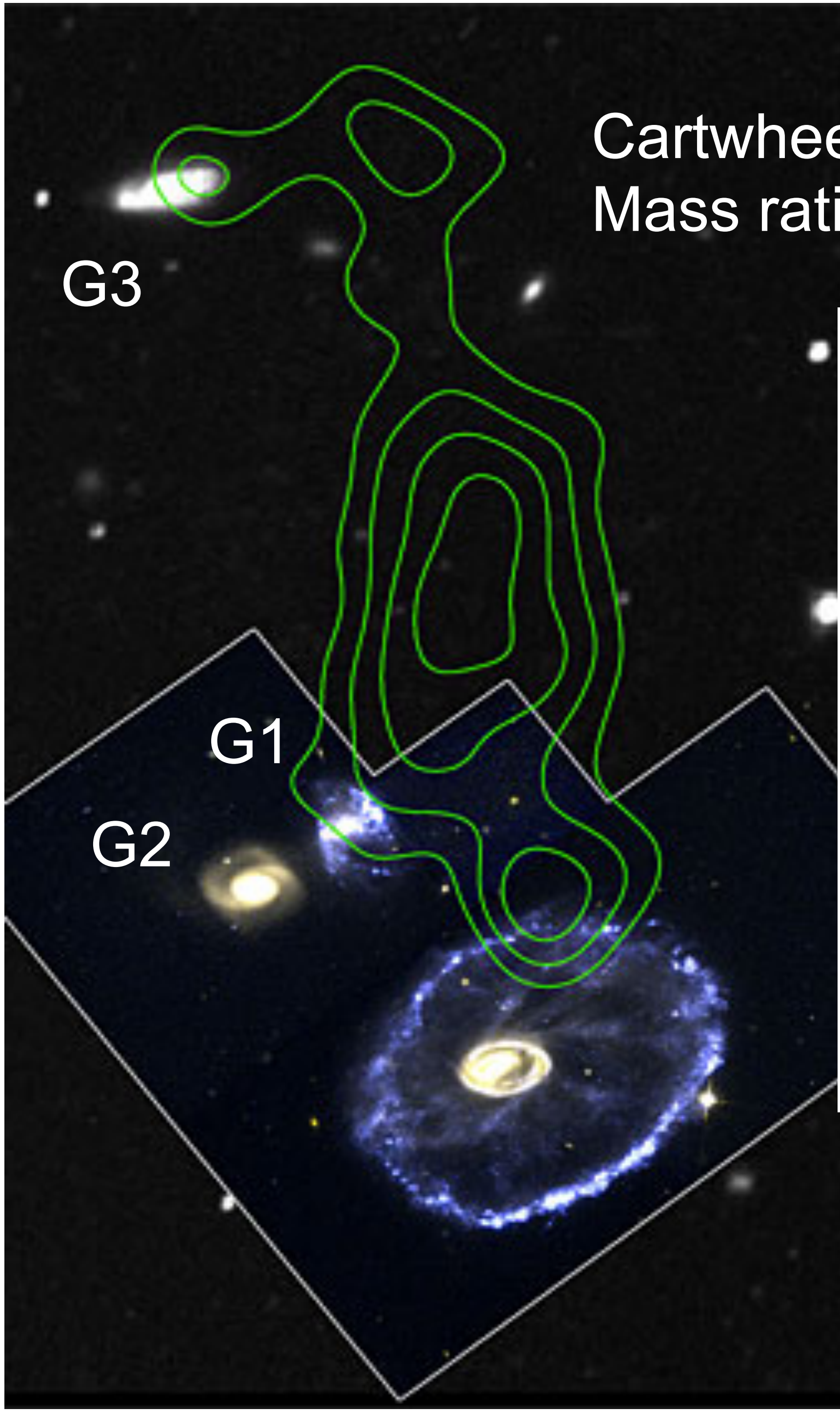


These structures can be generated by central, perpendicular impacts

AM 0644-741
See Antunes & Wallen
ApJ 2007, 670,261

The Cartwheel

Cartwheel : Hernquist and Weil 1993
Mass ratio 4:1 to 1:1.



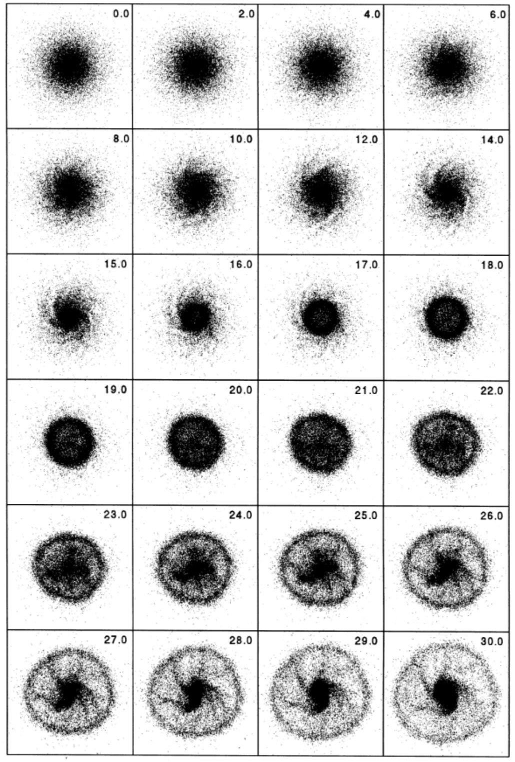


Figure 3. Time evolution of the stellar component of the primary in the fiducial model, seen face-on to the disc plane.

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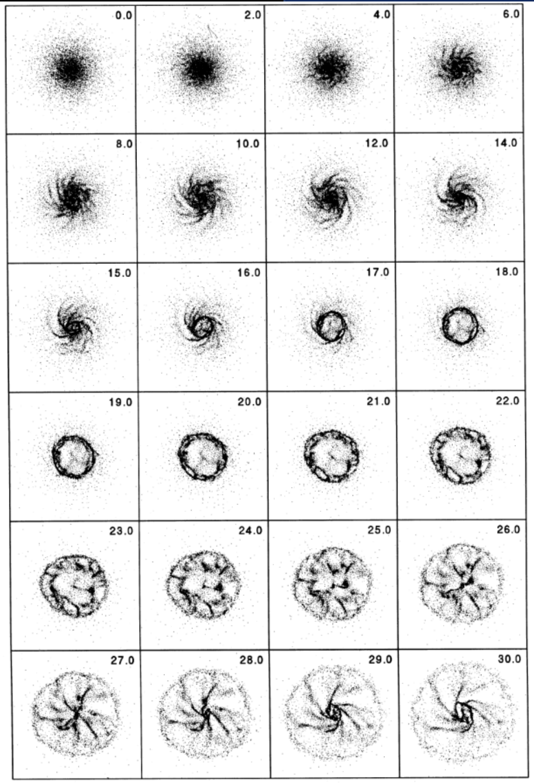
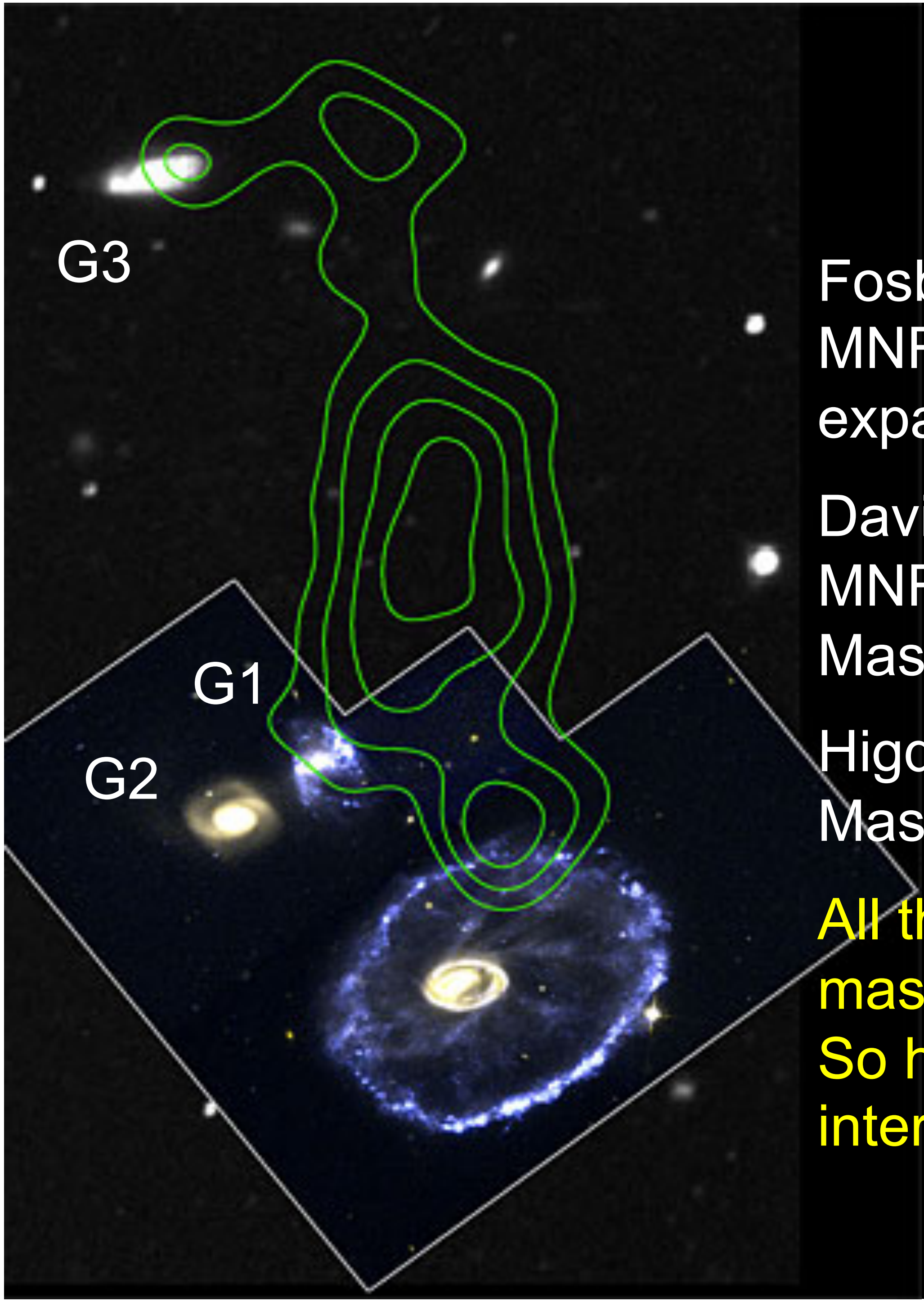


Figure 4. Time evolution of the gas component of the primary in the fiducial model, seen face-on to the disc plane.

Stars

Gas



Fosbury & Hawarden 1977
MNRAS 178, 473
expansion time for ring ~ 300 Myrs

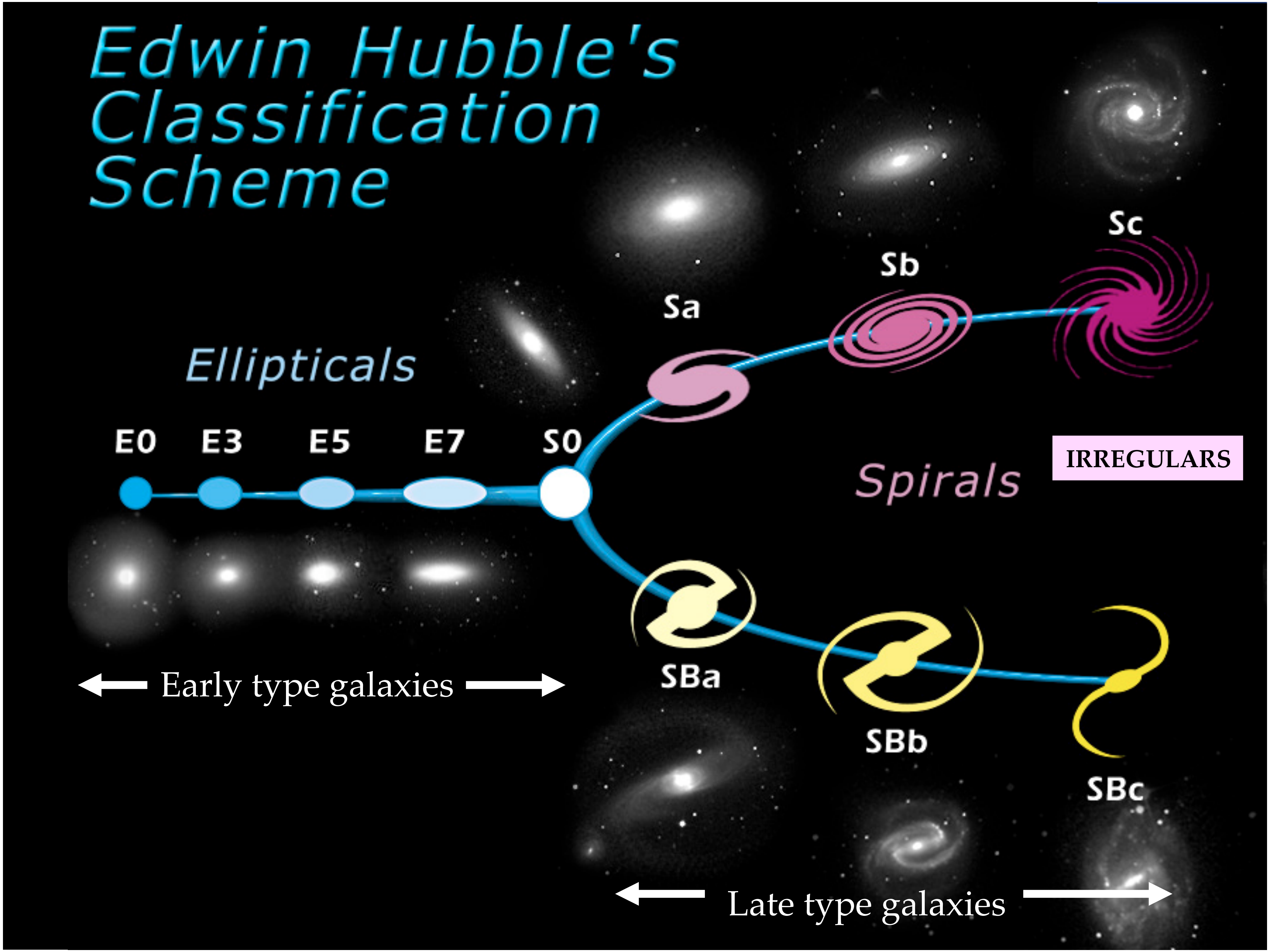
Davies & Morton, 1982
MNRAS 201, 69
Mass of G2 ~ 5-10%

Higdon 1996 ApJ. 467, 241
Mass of G1 & G3 ~ 6%

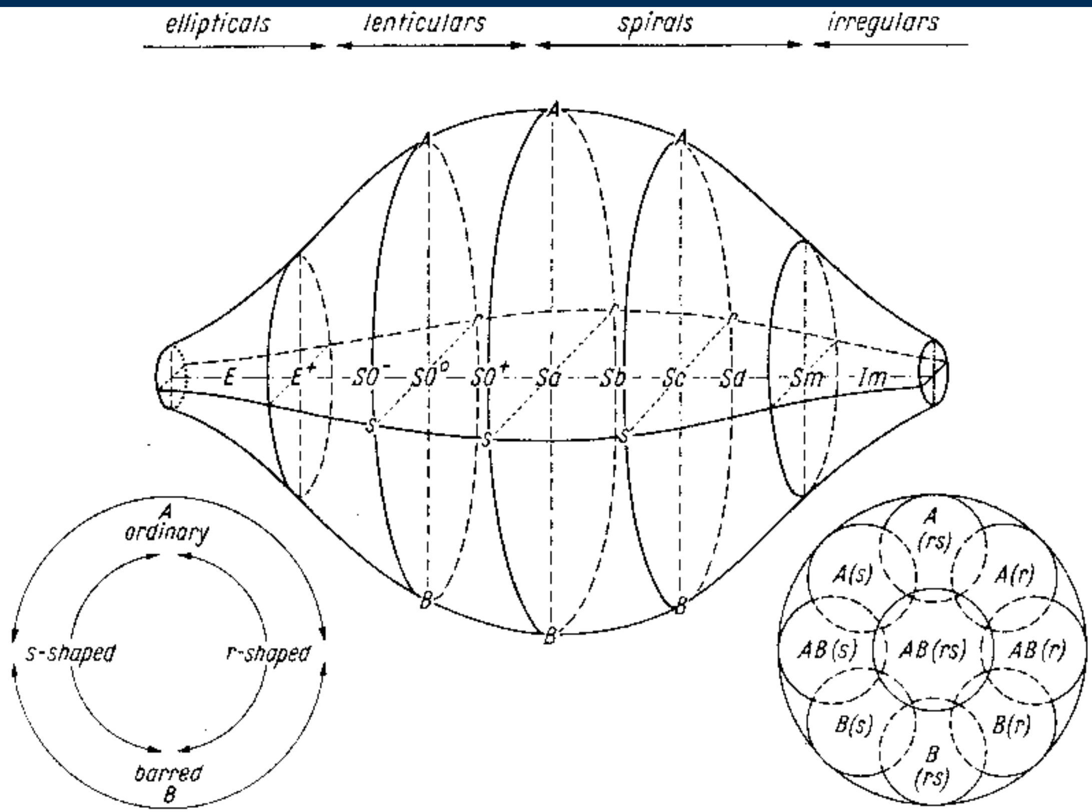
All the models have interloper masses ¼-½ the disk mass. So how does a 5-10% mass interloper make the ring?

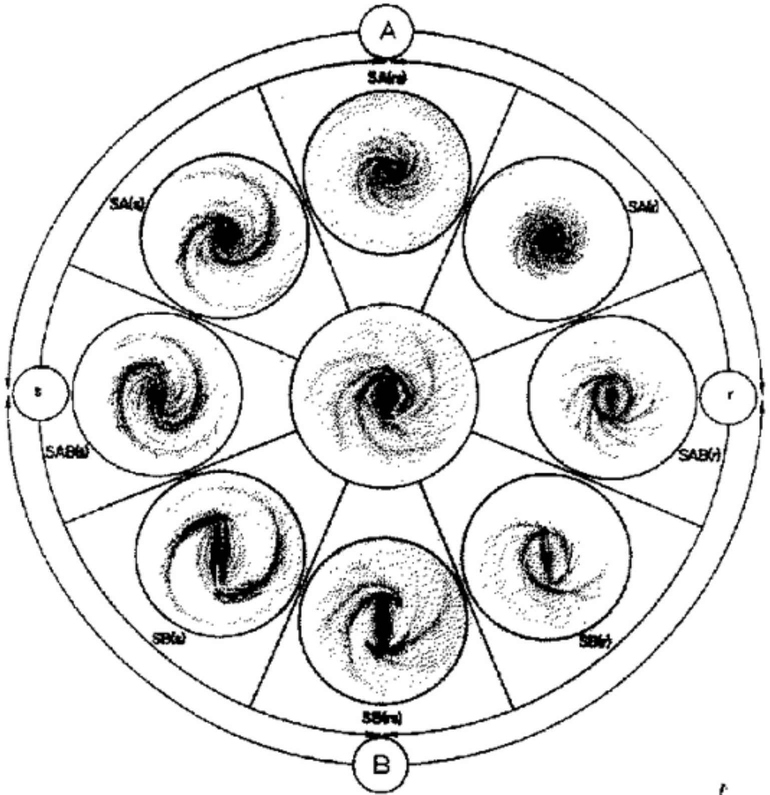
What can we hope to learn?

- Morphology is determined by the orbital structure of galaxies. The shape of galaxy potentials determine which orbital families are present.
- Stars moving on the allowed orbits occupy specific parts of phase space generating morphological features – bars, rings, peanut bulges, pseudo-bulges etc.
- Gas piles up close to orbital resonances producing regions of star formation e.g. rings at the end of bars. By looking at morphology as f(λ) we can learn about the star formation history & secular evolution of galaxies.
- The stability (or otherwise) of such features tells us about the distribution of mass (both luminous & dark).


Edwin Hubble's Classification Scheme
Ellipticals
E0
E3
E5
E7
S0
Sa
Sb
Sc
Spirals
IRREGULARS
SBa
SBb
SBc
Early type galaxies
Late type galaxies

but don’t forget de Vaucouleurs…

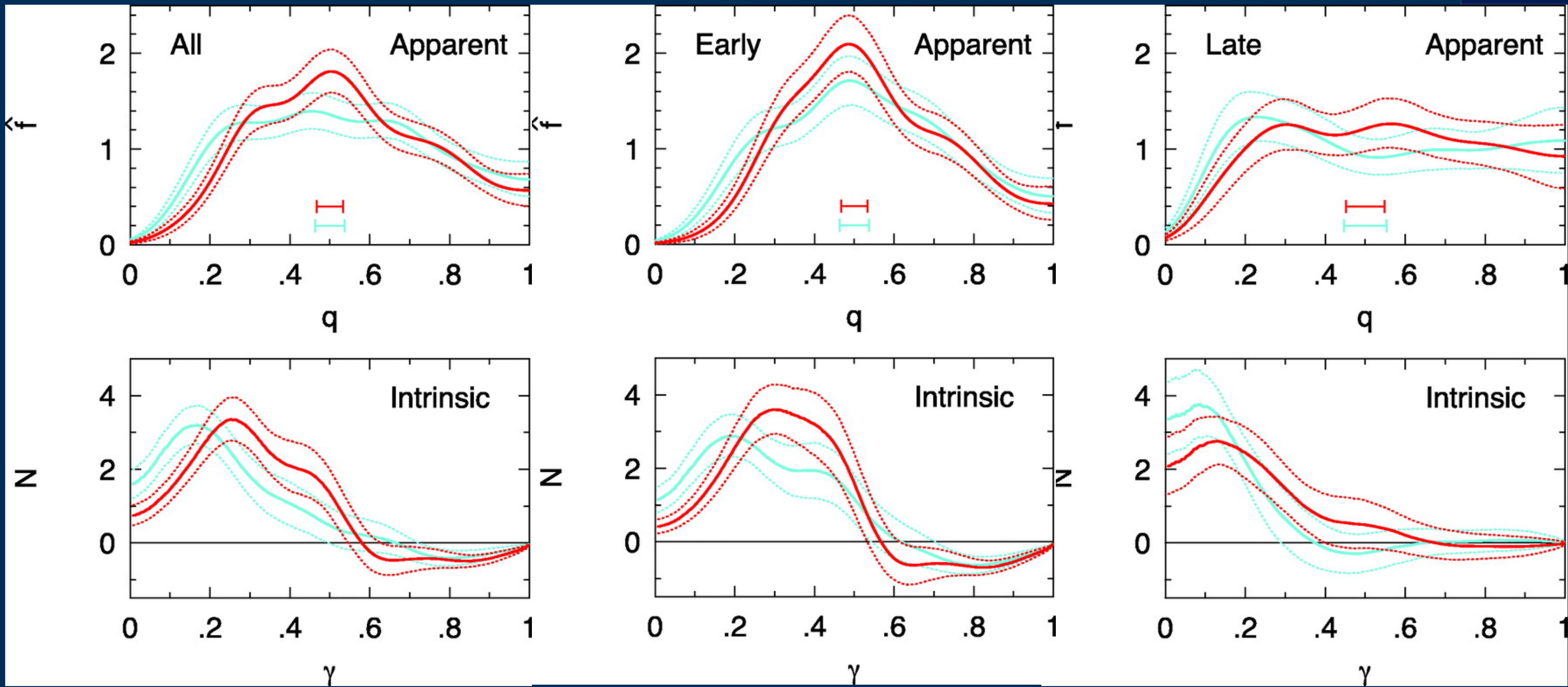




Disk galaxies

Intrinsic shape distribution

Ryden 2006 ApJ. 641 773



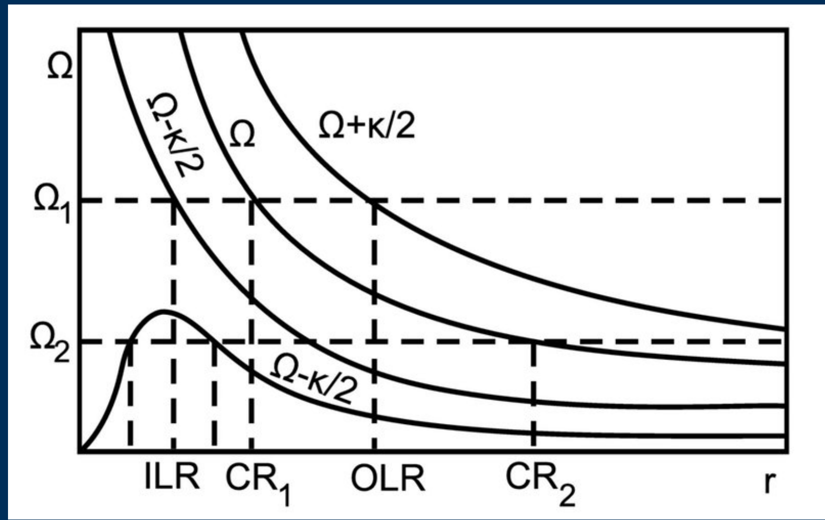
2Mass spirals: showing apparent and intrinsic axial ratios.
Red curve K-band , blue curve B-band
Late type spirals (130) <γ> = 0.12 (B) 0.19 (K) are consistent axi-symmetry => **we know the intrinsic shape & inclination**

Structures in disk galaxies

- Optical morphology is determined by orbits.
- In disk potentials orbital resonances occur where:

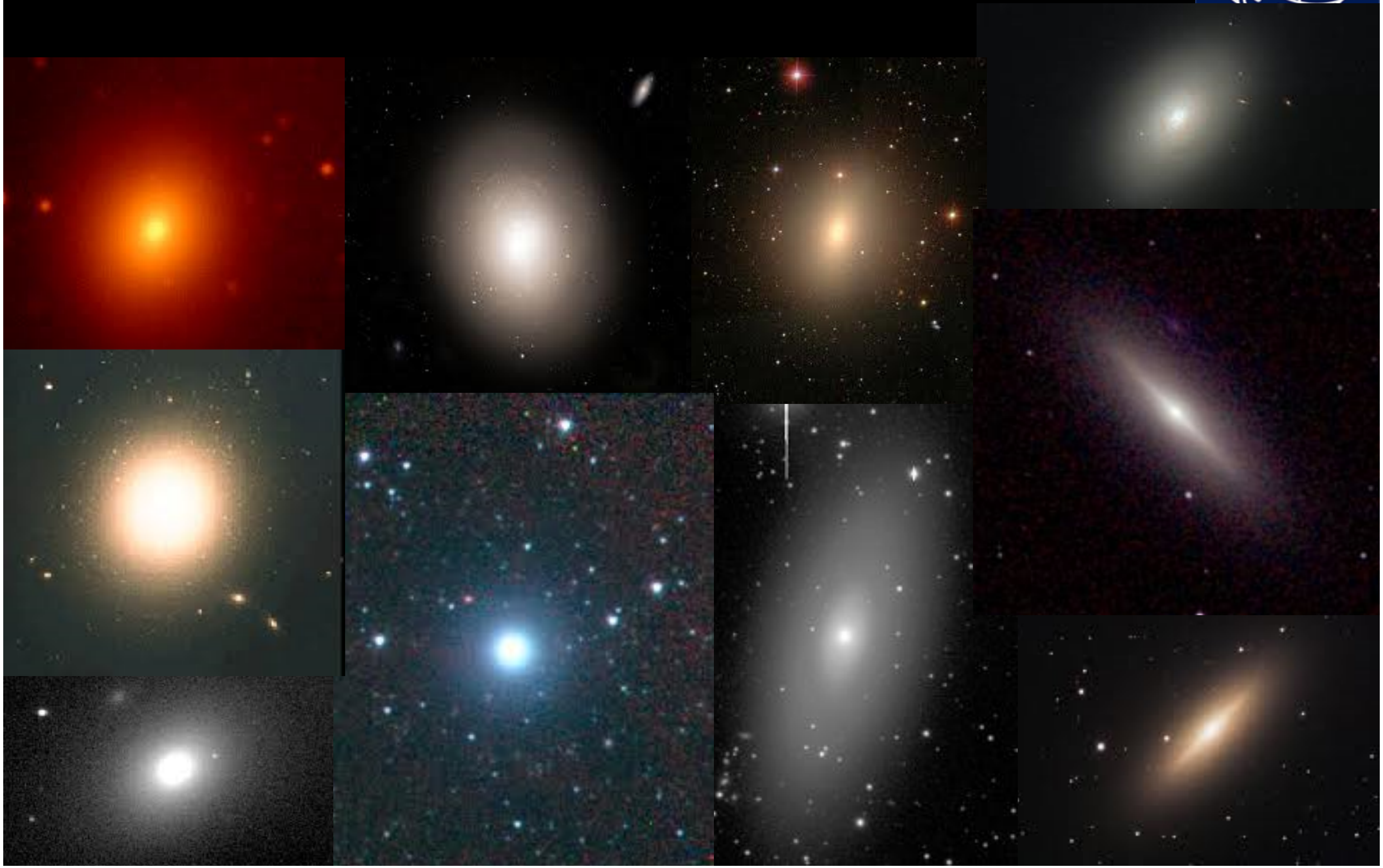
$$\Omega_p = \Omega \pm \kappa/m$$

where Ω_p is the pattern speed, κ the radial epicyclic frequency and m an integer



- Bars & rings trace these resonances
- gas settles in rings → star formation
- For cold disk galaxies morphology → orbits → star formation history.
- Morphology → secular evolution

Early-type galaxies

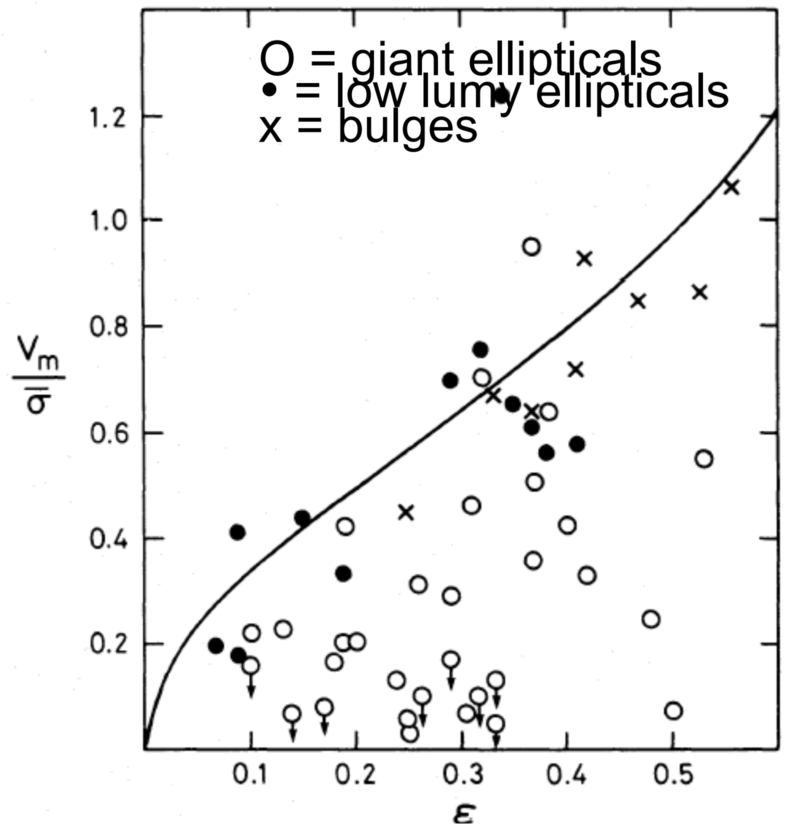


What do we mean by morphology for ETGs?

- classification in a catalogue depending in appearance.
- shape, concentration, luminosity profile (Sersic-n?)
- at its best it should give us some physical insight e.g. is there a disk? a core?

Orbits in triaxial potentials

- The slow rotation of Es (Bertola & Capacioli 1975; Ilingworth,1977, Binney 1977) implies they can have oblate, prolate or triaxial shapes with anisotopic velocity tensors ⟶ range of allowed orbit families expanded.
- Unknown intrinsic figure means we cannot invert apparent distribution of axial ratios to give true distribution.
- **Intrinsic shape & inclination for individual galaxies are unknown.**



Davies et al. 1983

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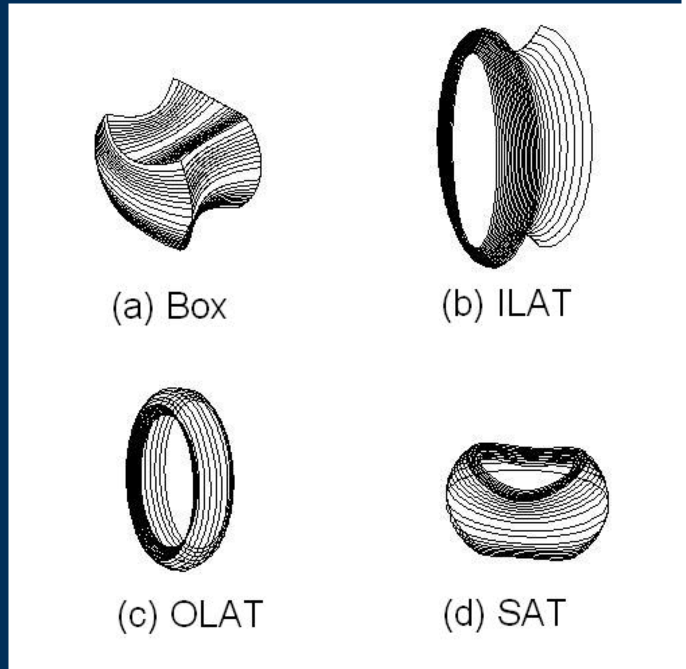


Boxy and Disky

see Carter 1978 MNRAS 182, 797

FIGURE 3. — Distribution of the ellipticity classes for all observed elliptical galaxies.

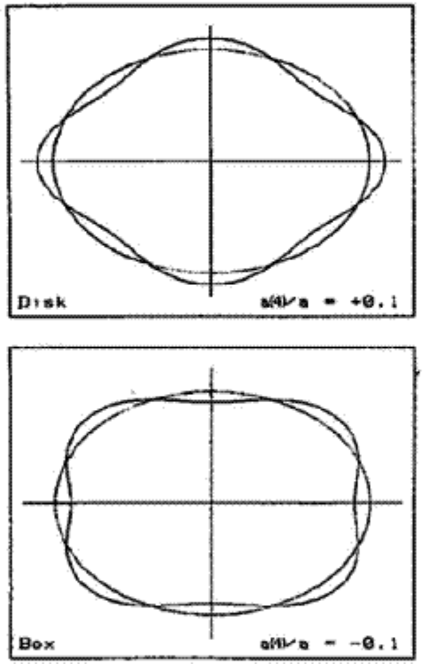


FIGURE 5. — Schematic drawing illustrating isophotes with $a(4)/a = +0.1$ and $a(4)/a = -0.1$.

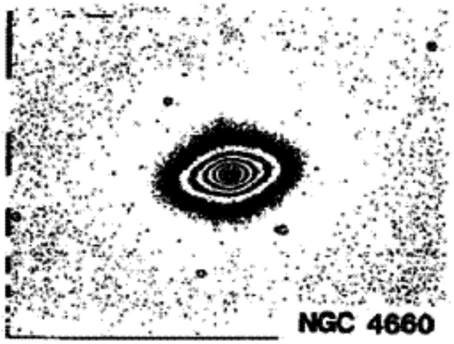


FIGURE 6. — R-image of NGC 4660, an elliptical galaxy with a disk-component in the isophotes ($a(4)/a \sim +0.03$).

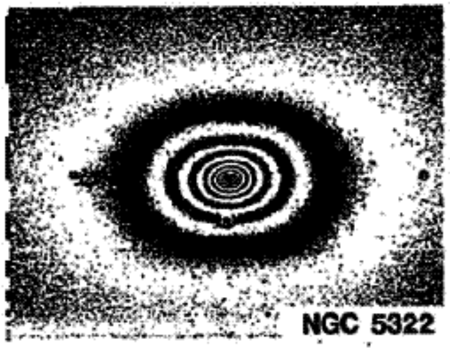
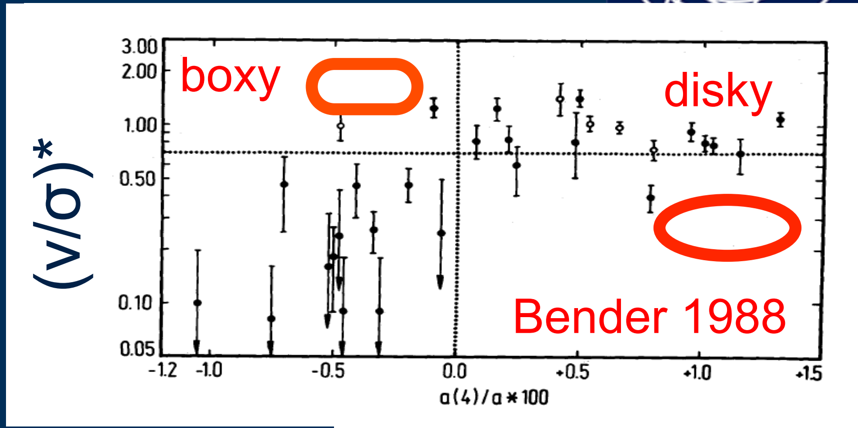


FIGURE 7. — R-image of NGC 5322, an elliptical galaxy with box-shaped isophotes ($a(4)/a \sim -0.01$).

Examples for boxy and disky isophotes from Bender et al. (1988)

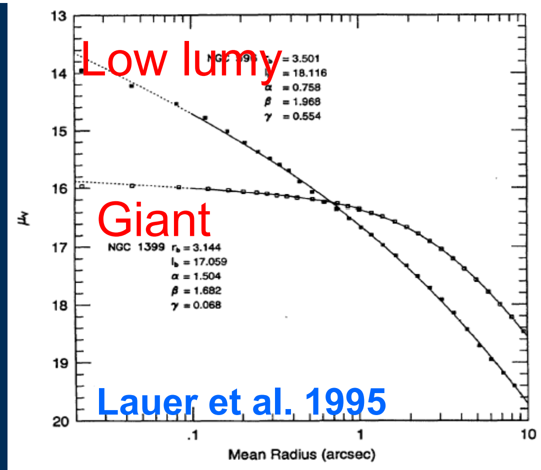
`Dichotomy' of ellipticals

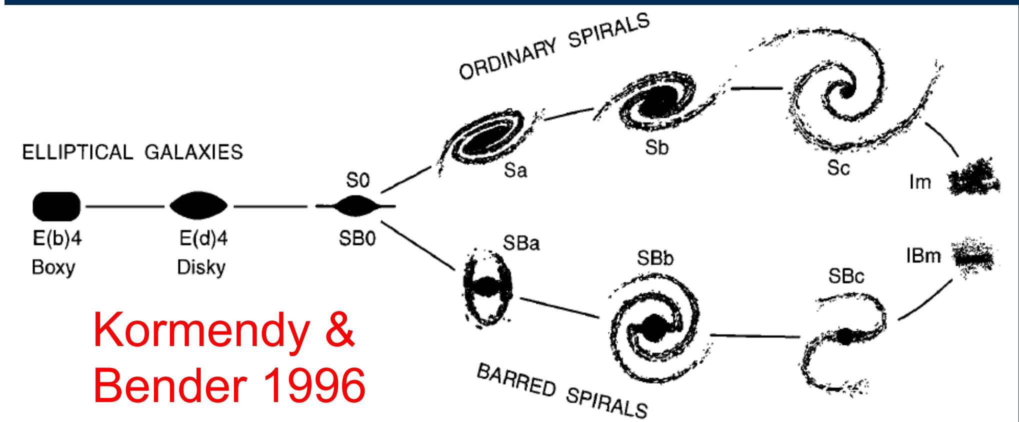
Bender 1988 & B et al 1989:
Boxy: triaxal, anisotropic, radio loud, X-ray halos, high M/L
Disky: oblate, isotropic



Rix & White 1990 : almost all `radio-weak' ellipticals could have disks containing ~ 20% of the light

Lauer et al 1995 + Faber et al. 1997 (using HST):
Giant Es have core profile & low lum'y ellipticals have cusps





Kormendy & Bender 1996 : disky ellipticals are intermediate between big ellipticals and lenticulars

Physical distinctions between classes of ETGs

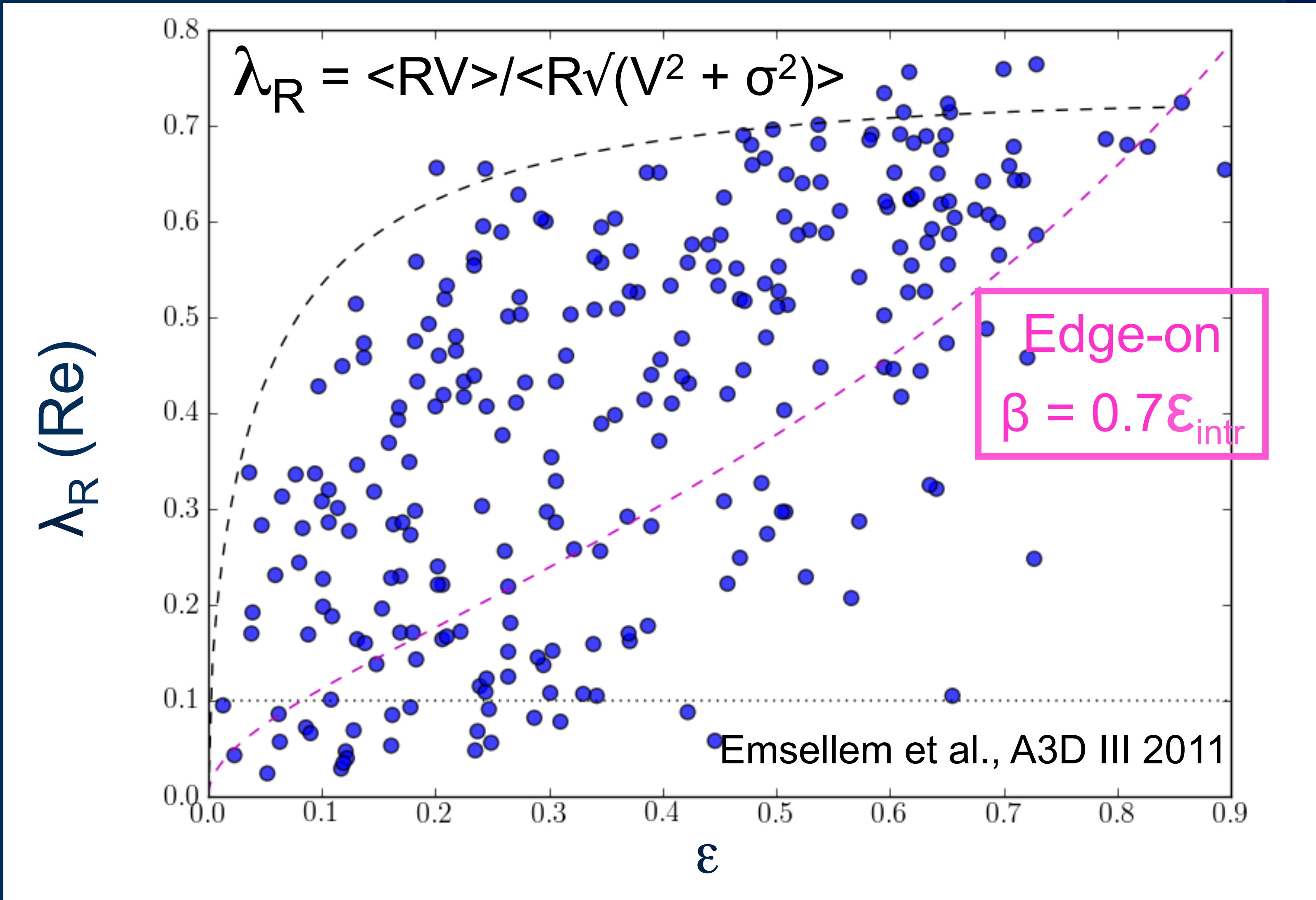
With acknowledgement to the SAURON & ATLAS^{3D} teams

ATLAS ^{3D}

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

Team: Kathey Alatalo, Roland Bacon, Leo Blitz, Maxime Bois, Frederic Bournaud, Martin Bureau, Roger Davies, Tim de Zeeuw, Jesus Falcon-Barroso, Sadegh Khochfar, Harald Kuntschner, Raffaella Morganti, Thorsten Naab, Tom Oosterloo, Marc Sarzi, Nicholas Scott, Paolo Serra, Remco van den Bosch, Glenn van de Ven, Gijs Verdoes-Kleijn, Lisa Young, Anne-Marie Weijmans

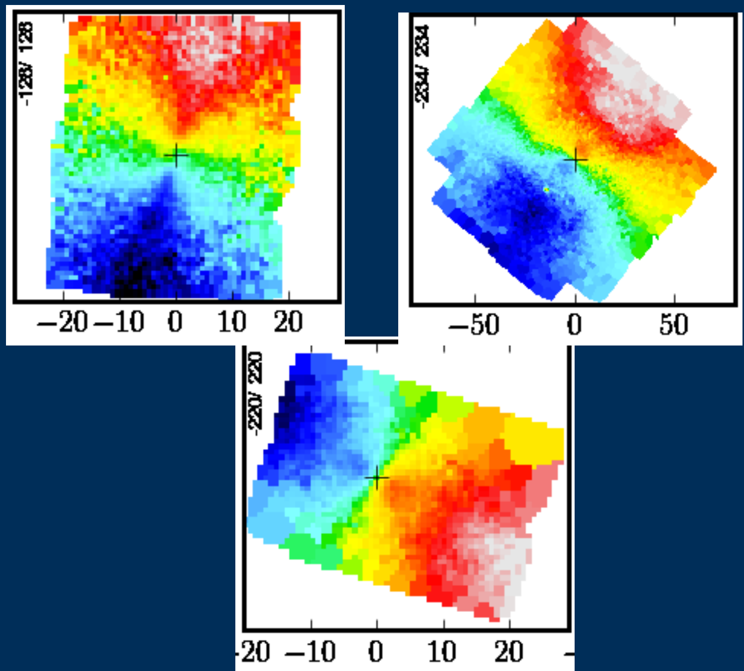
λ_R vs ε



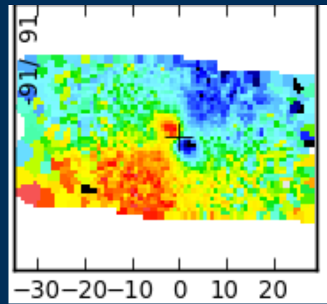
$\lambda_R = \langle RV \rangle / \langle R\sqrt{(V^2 + \sigma^2)} \rangle$
Edge-on
$\beta = 0.7\varepsilon_{intr}$
Emsellem et al., A3D III 2011
λ_R (Re)
ε
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9

Rotation fields

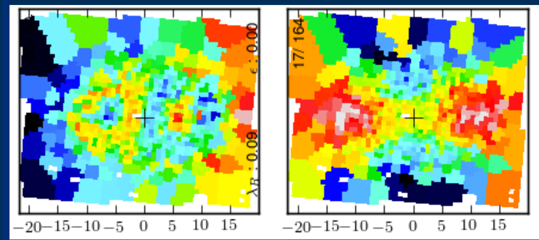
Disk-like Rotators



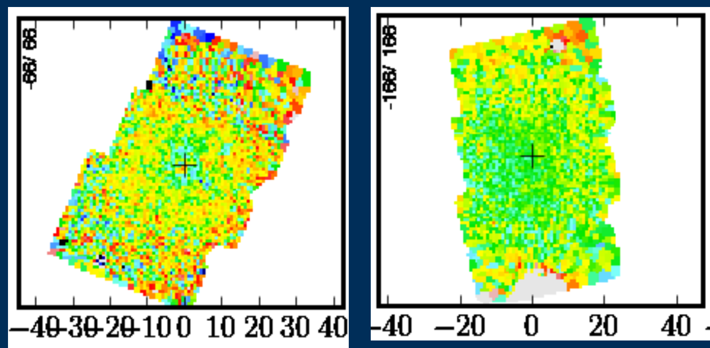
KDCs



2-σ

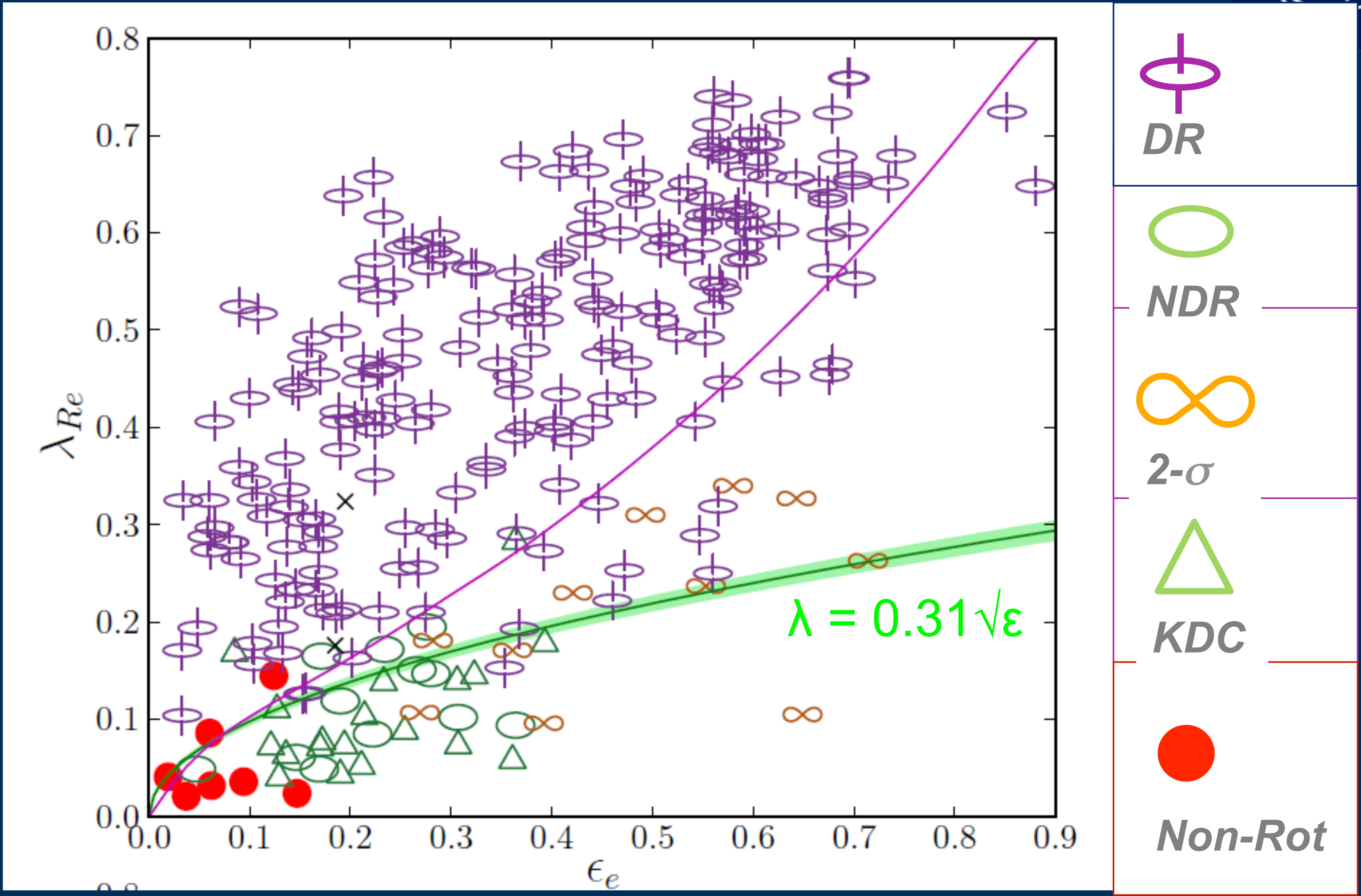


Krajnović et al., A3D II 2011
Emsellem et al., A3D III 2011

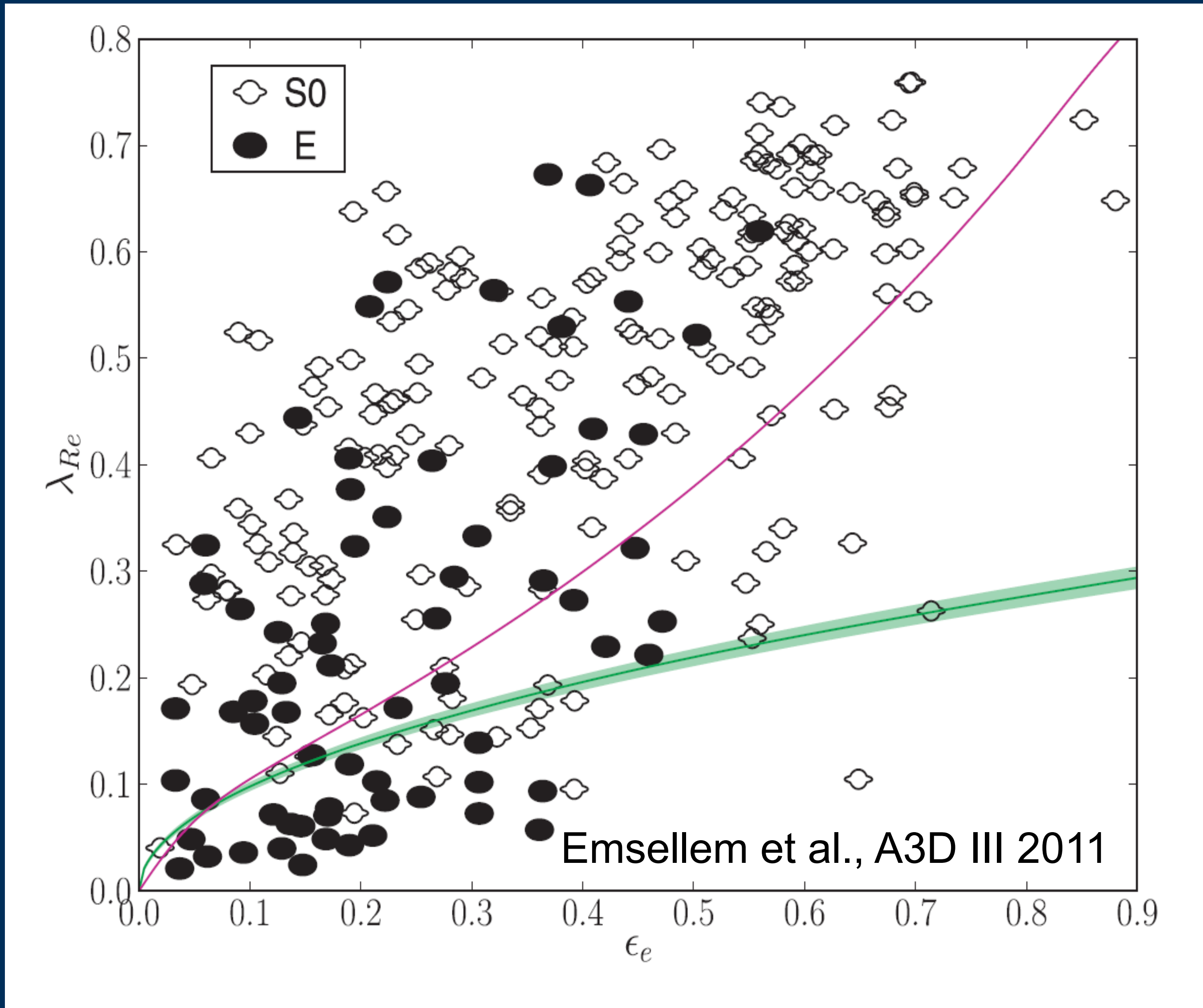


Non-rotators

Key with rotation field morphology

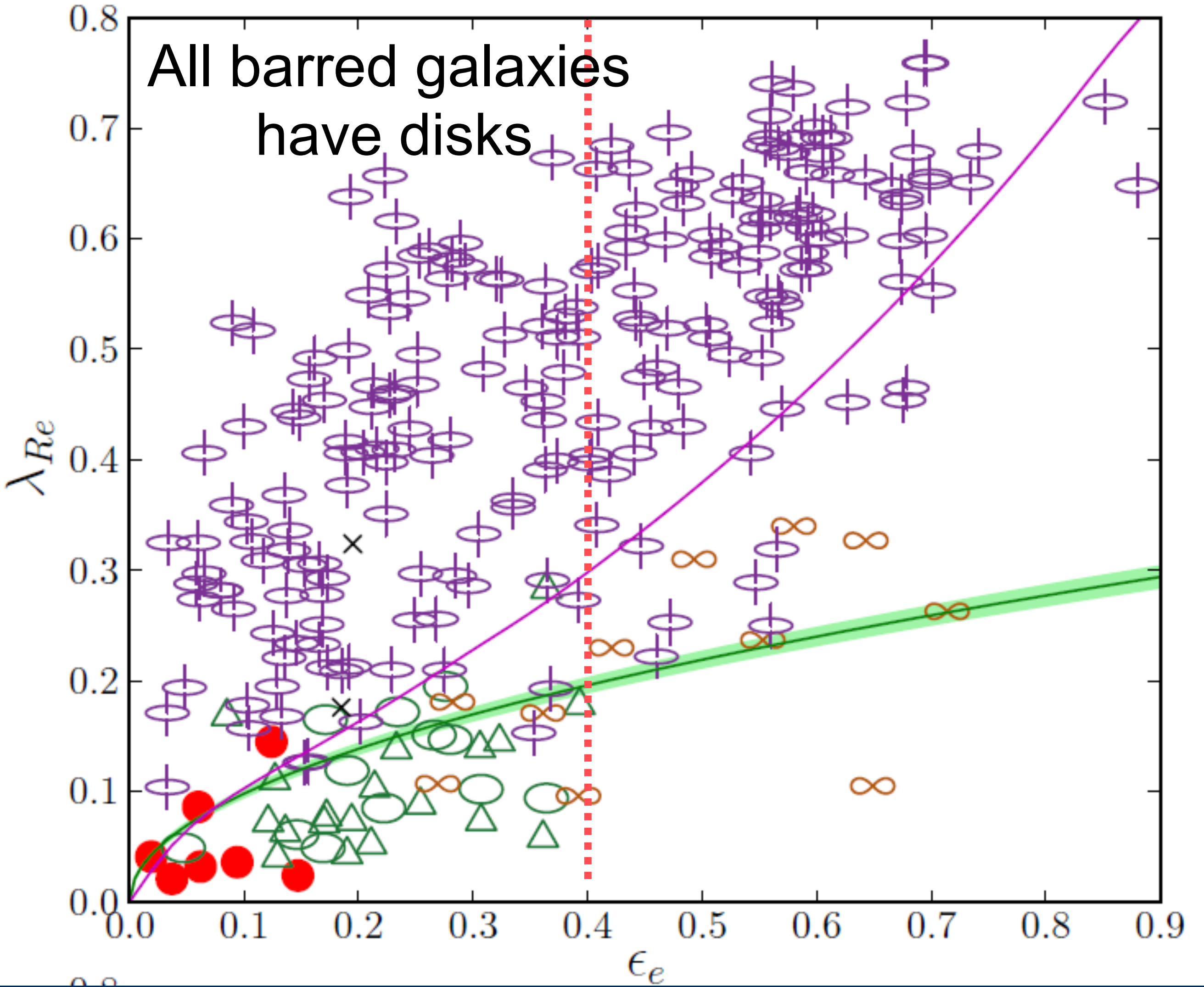


and by Hubble type

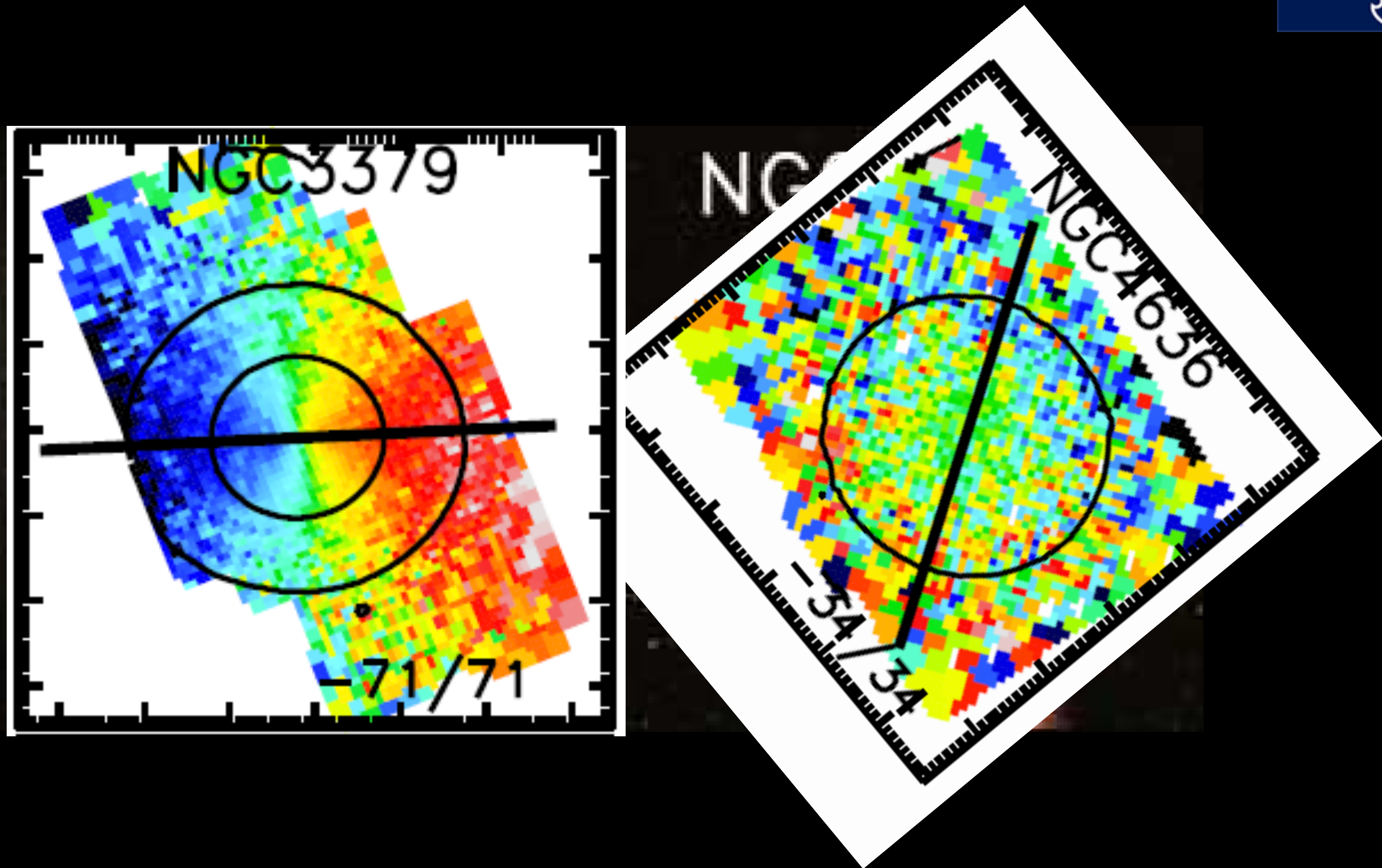


Key with rotation field morphology

NB. All galaxies flatter than E4 are fast rotators



Which one rotates fast?



Census of ATLAS^{3D}

871 galaxies in the parent sample of which:
611 are spirals &
260 are ETGs (68 Es & 192 S0s) of which
224 are fast rotators – oblate

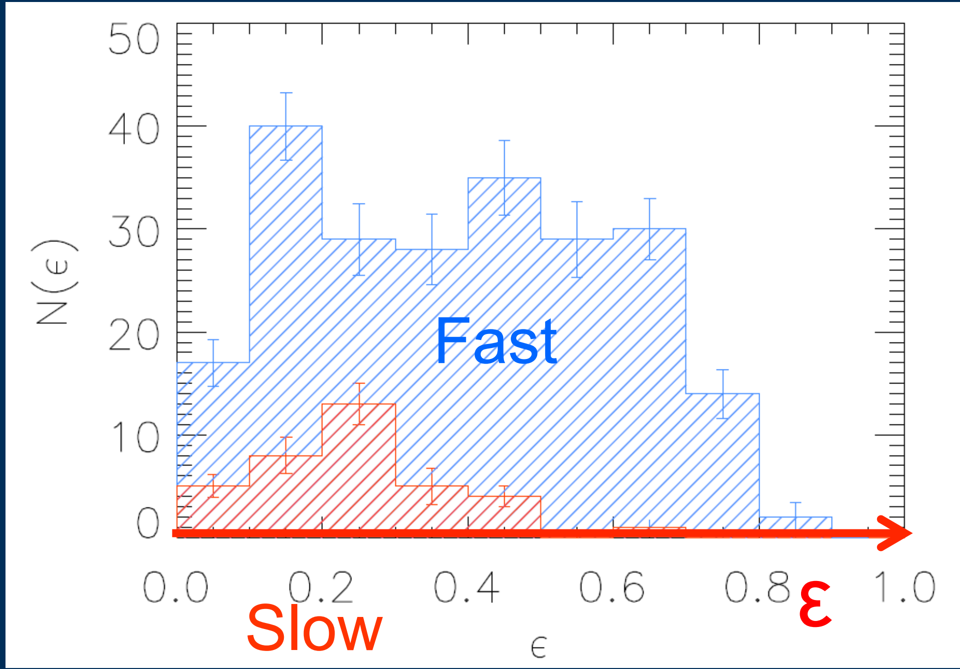
of the 36 slow rotators 4 have counter-rotating disks
leaving 32 true slowly rotating `ellipticals'
ie. <4% of the parent (volume limited) population

Intrinsic shapes

Selection:
All fast rotators with ε from large radius (~ 3Re) to avoid the influence of bars.
Slow rotators do not include co-extensive, counter-rotating disks. ε at 1Re.

Method : Invert observed distribution assuming oblate figures & using Lucy iteration.

Weijmans et al 2013



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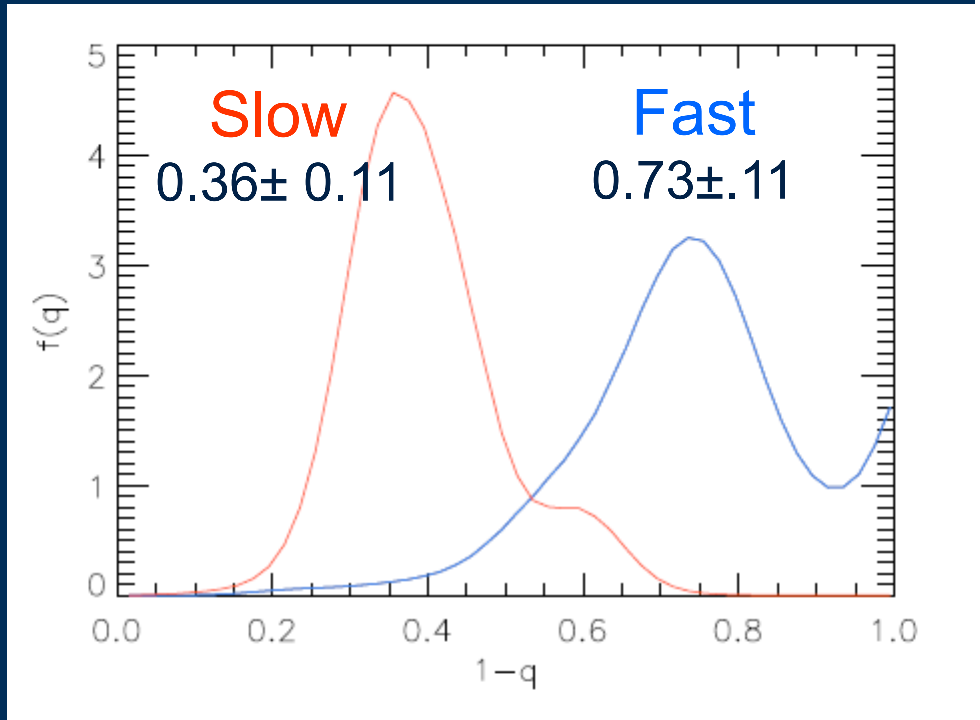
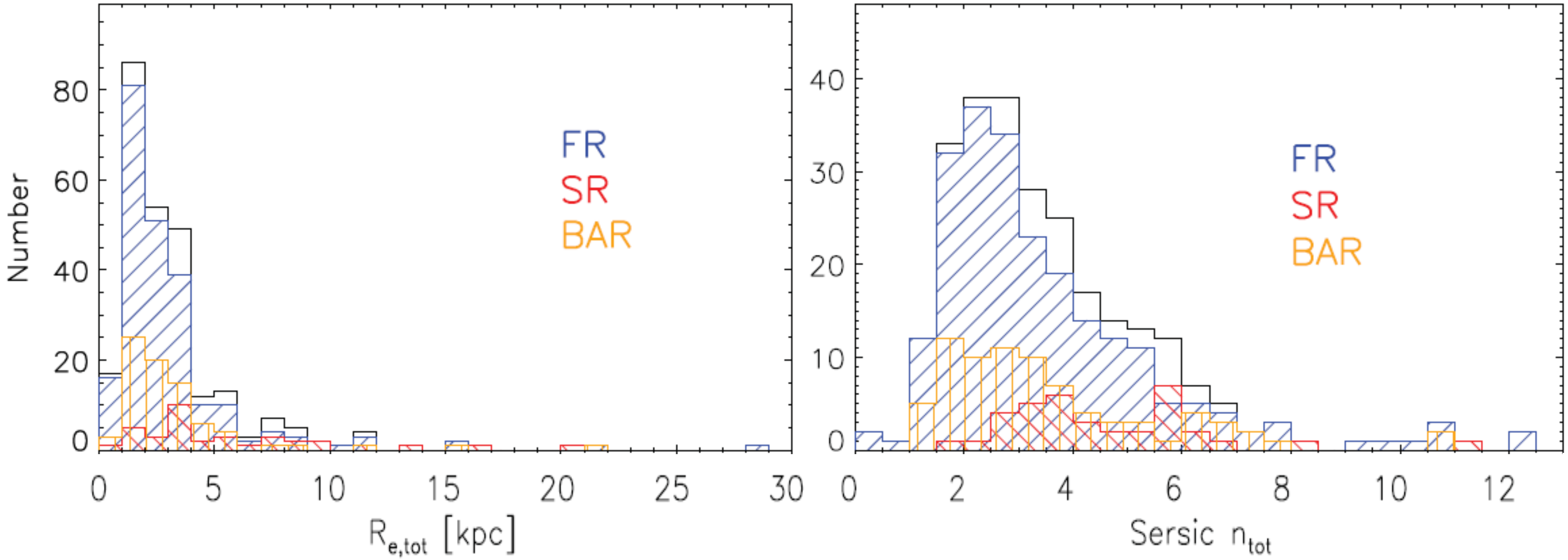


Fast & Slow rotators have distinct distributions of intrinsic shapes

How can we find disks in ETGs?

Krajnović et al A3D XVII 2012 arXiv:1210.8167
doi:10.1093/mnras/sts315

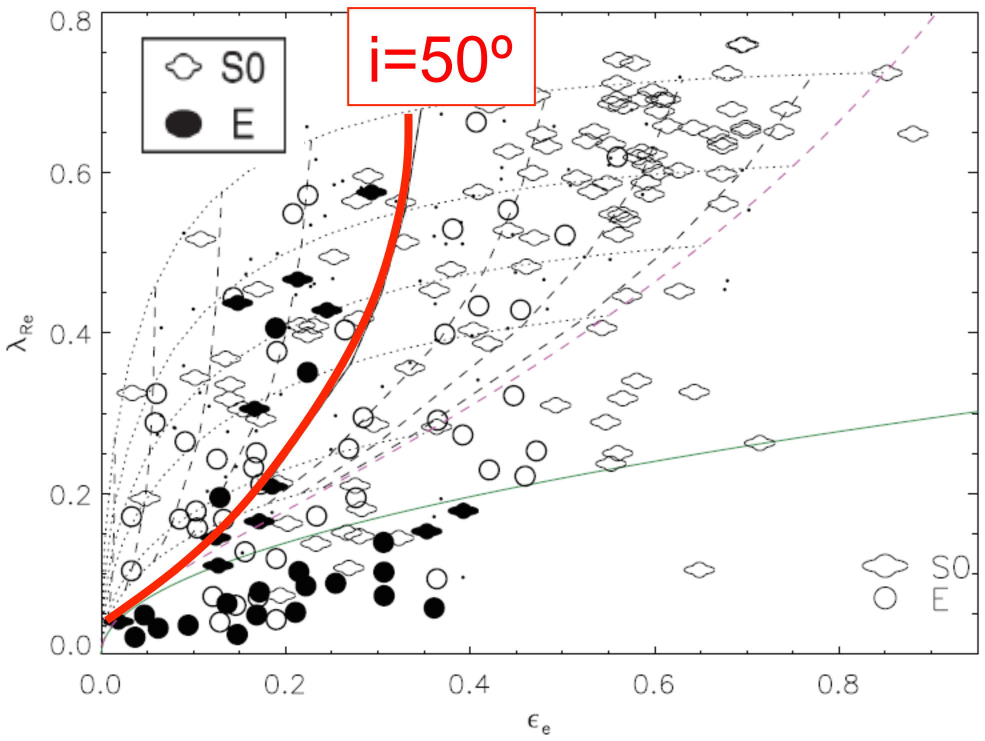
Single Sersić law => R_e and n (all 260 objects)



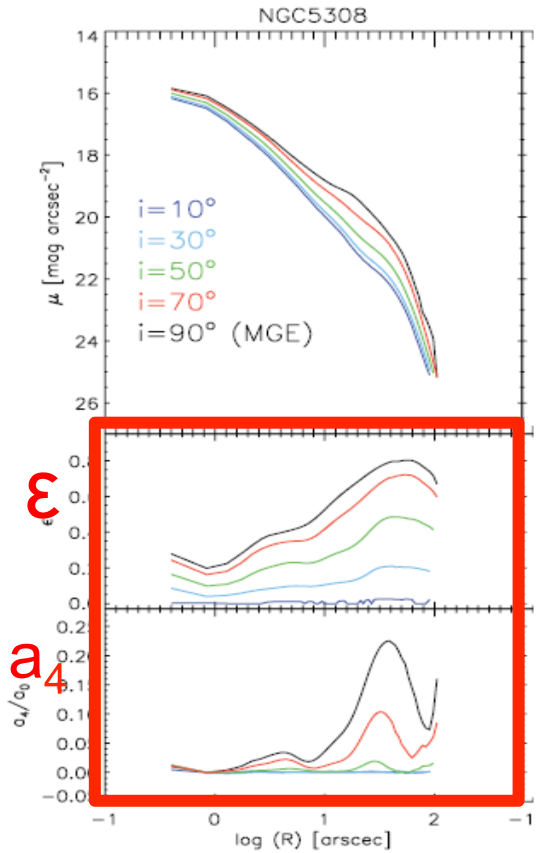
Slow rotators tend to be bigger and on average have higher n but neither size, nor n reliably identify FR & SR.
(if n>3 is used to select SRs => 22% chance of success!)

Morphological structure hidden from view when i<50º

Krajnović et al A3D XVII 2012 building on :
Rix & White 1990, Gerhard & Binney 1996



Solid symbols – single component

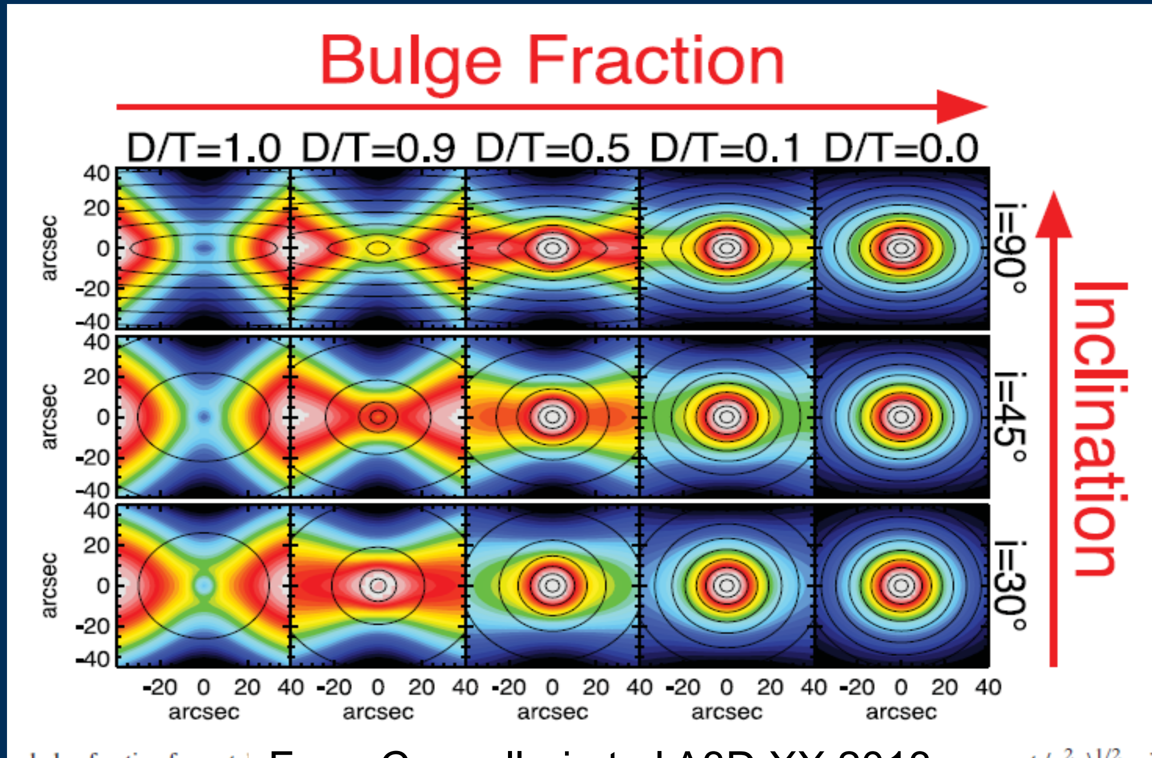


i=10°
i=30°
i=50°
i=70°
i=90°

V_{rms} reveals disks when D/T = 0.1 and at i=30º

Models with:
R_e(disk)/(bulge) = 5.2
Sersic n = 1.7
q(disk) = 0.2
q(bulge) = 0.7

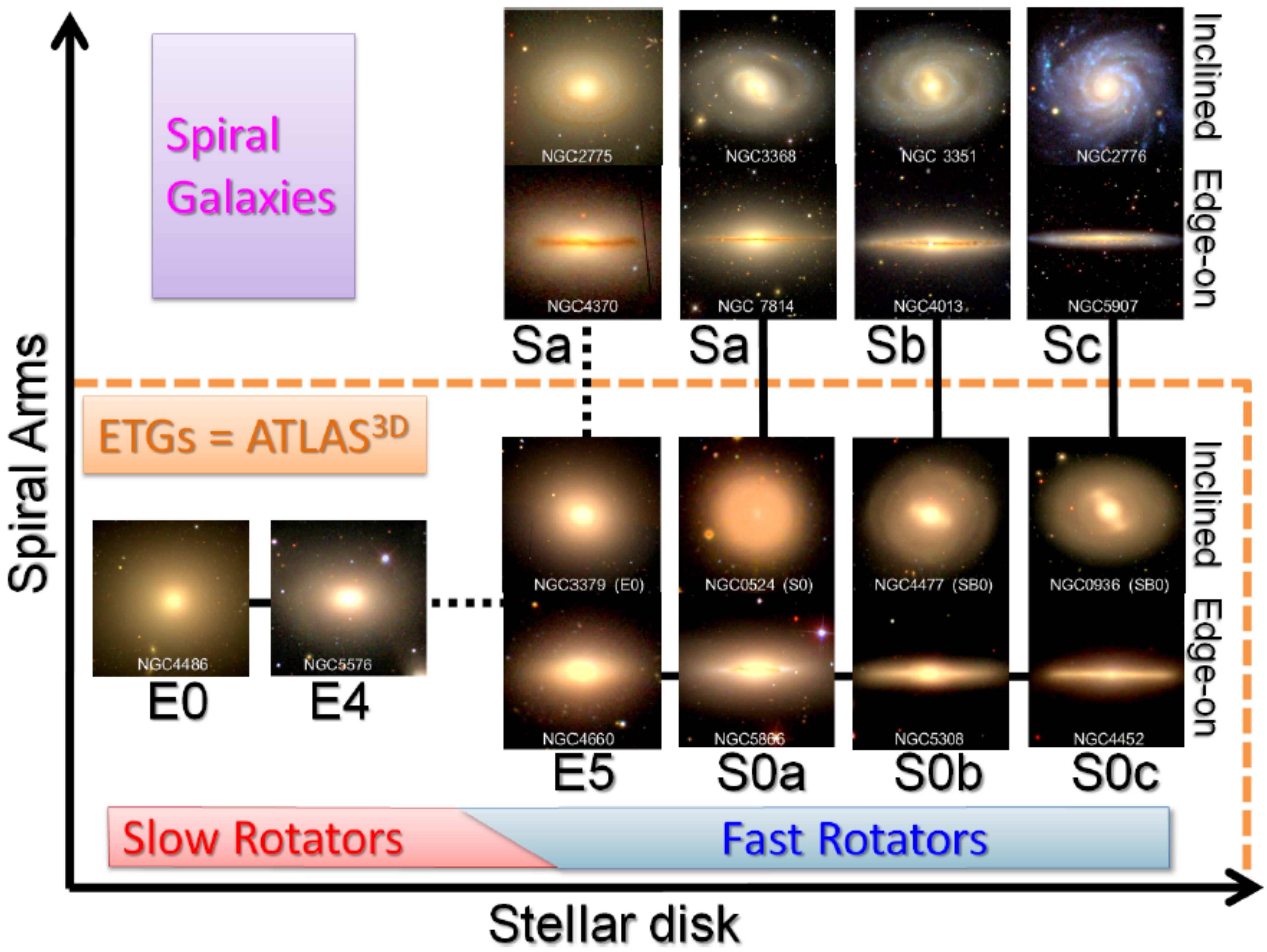
Flattening of the contours of V_{rms} compared to isohotes reveal the presence of low mass disk at low i.



From Cappellari et al A3D XX 2013

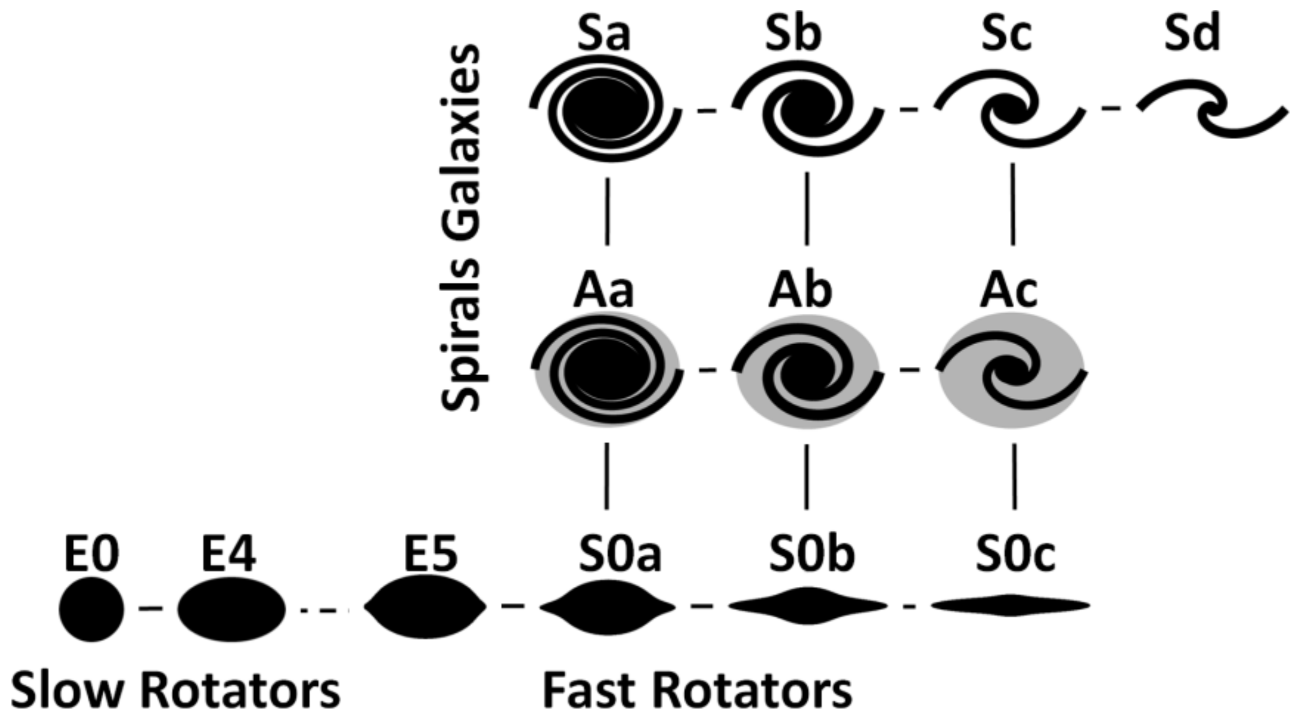
Above M=2×10^{11} $M_{\odot}$
all galaxies have D/T <0.2

A physically based classification system



Spiral Galaxies
ETGs = ATLAS3D
Spiral Arms
Stellar disk
Inclined
Edge-on
NGC2775
NGC3368
NGC 3351
NGC2776
NGC4370
NGC 7814
NGC4013
NGC5907
Sa
Sa
Sb
Sc
NGC3379 (E0)
NGC0524 (S0)
NGC4477 (SB0)
NGC0936 (SB0)
NGC4486
NGC5576
NGC4660
NGC5866
NGC5308
NGC4452
E0
E4
E5
S0a
S0b
S0c
Slow Rotators
Fast Rotators

Recall : van den Bergh 1976, ApJ, 206, 883



Morphology-density relation re-visited ....

........kinematic morphology density relation

See Nic Scott’s talk this afternoon!

Conclusions

- Some dramatic morphologies reveal the incidence of specific events e.g. ring galaxies. Can we model these systems accurately? Can we use them to determine the merger rate more generally?
- Using our knowledge of their intrinsic shapes the detailed morphology reveals the mass distribution and star formation history of spiral disks.
- Morphology of ETGs does not reveal their physical nature, largely because of lack of knowledge of the inclination of individual galaxies.
- The presence of exponential components or disky isophotes is not sufficient to indicate that rotation is important dynamically.
- Kinematic maps provide a physical classification sequence based on angular momentum rather than appearance.