Survey of nearby E/S0s
First Results

Michele Cappellari

# Hierarchical galaxy formation

Millennium (Springel et al. 2005)
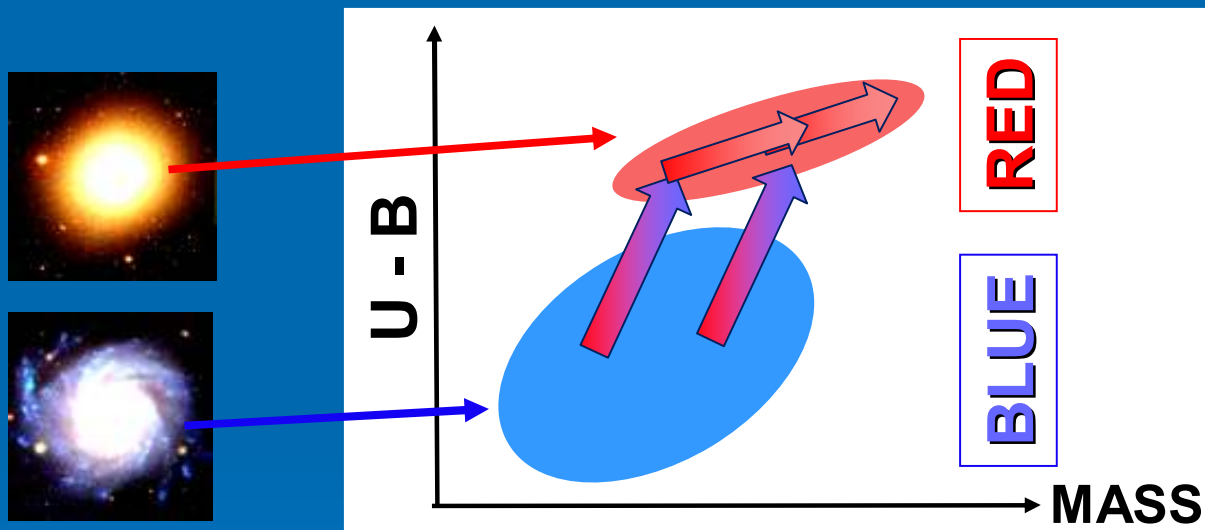
(see Faber et al. 2007)

- Bimodal galaxy colour distribution
- Mergers of blue galaxies → Red galaxies
- Feedback required for quick transition: Blue → Red
- Merger of red galaxies required to reach highest masses

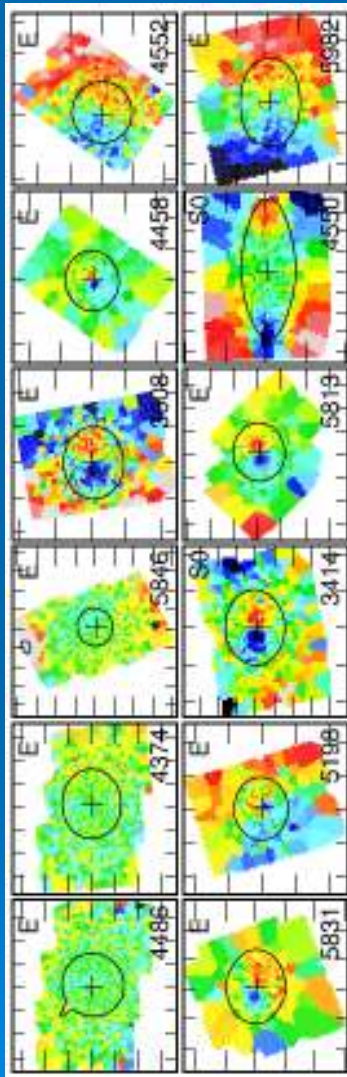# Expected relics on red sequence

- Disk-like galaxies at low mass end
  - Faded spirals (+ minor mergers + slow gas accretion)?
  - Gas rich mergers?
  - AGN feedback likely not important
  - → <u>Fast rotating</u>

- **<u>True</u>** ellipticals at high mass end
  - Major mergers
  - Collisionless?
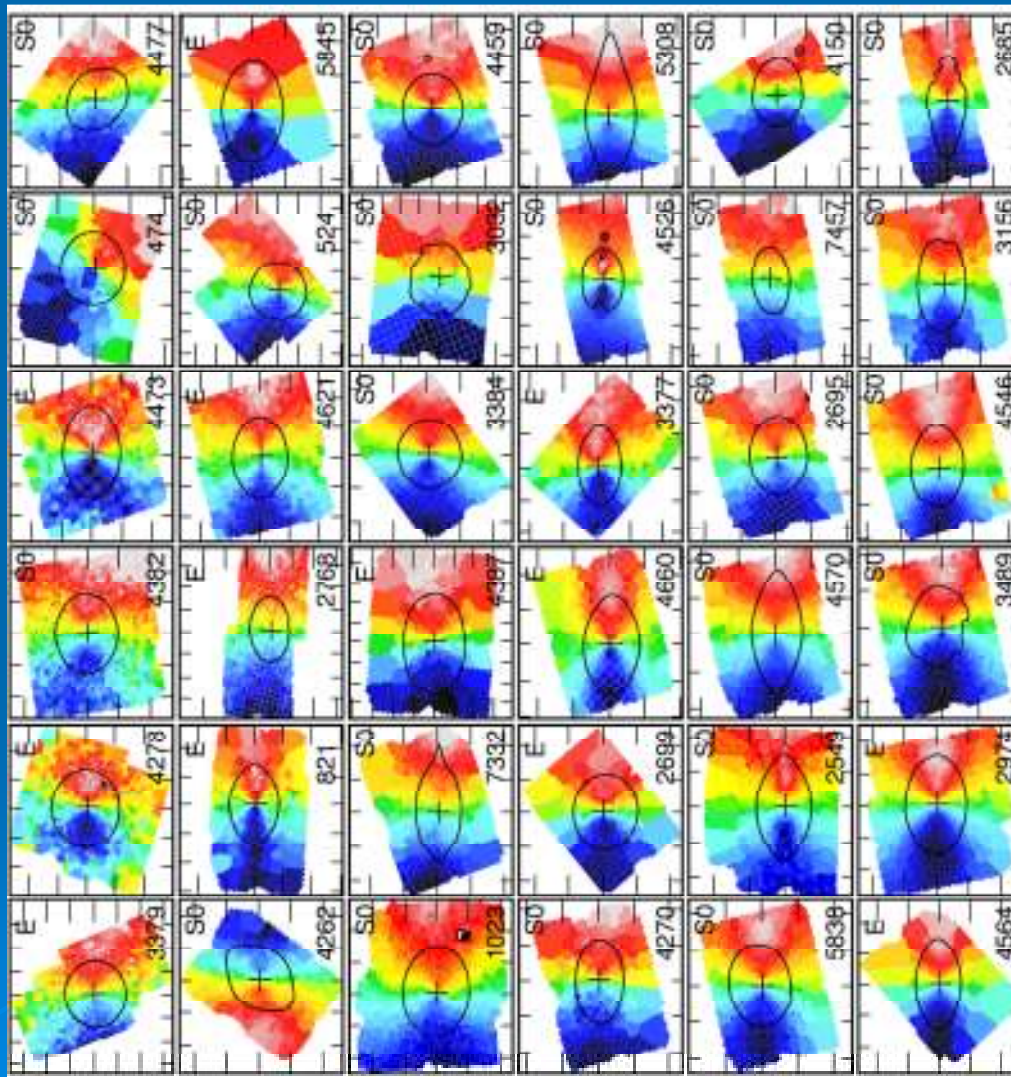 - Gas rich mergers?
  - AGN feedback?
  - → <u>Slowly rotating</u>
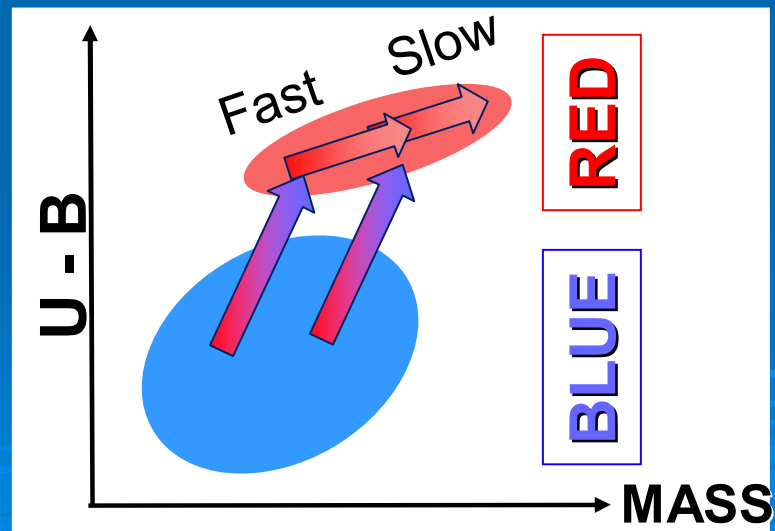
Two classes of early-type galaxies

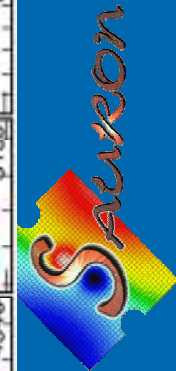λ_R $\longrightarrow$ Angular momentum per unit mass
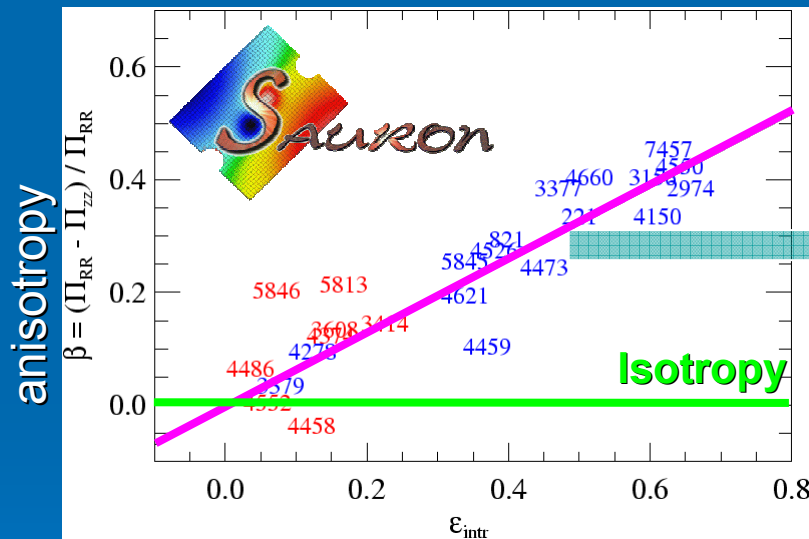

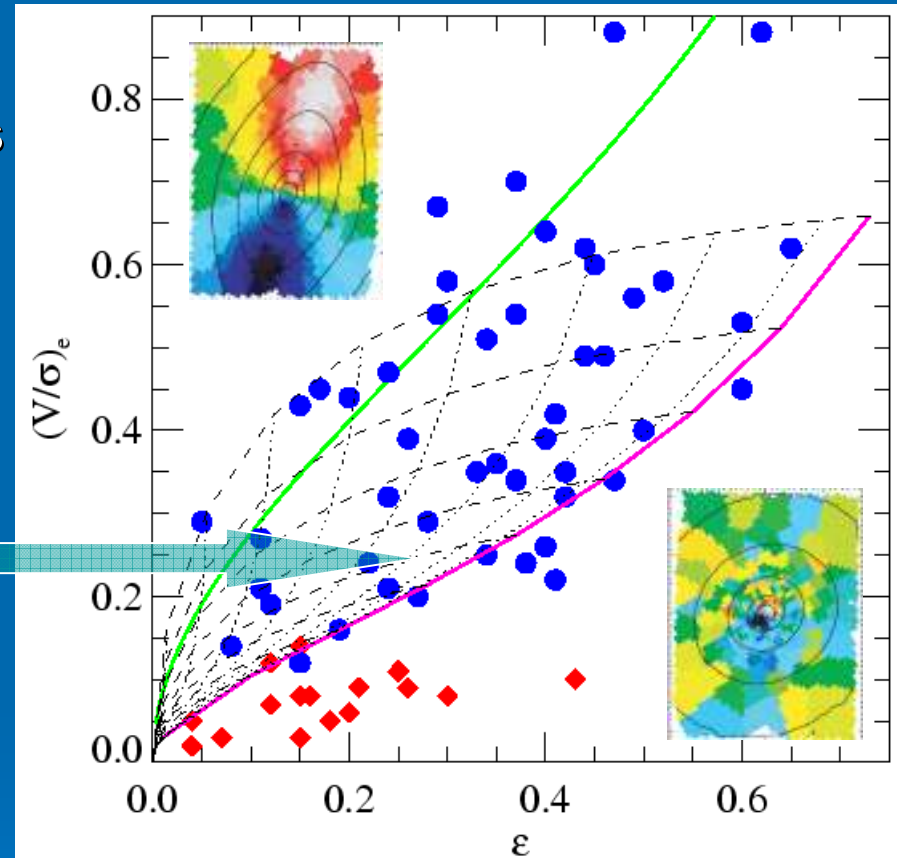**"Slow-rotator"** | $\lambda_R = 0.1$ | **"Fast-rotator"**

Emsellem et al. (2007)

Fast/slow rotators on (V/σ,ε) diagram

$$(V/\sigma)_e^2 \equiv \frac{\langle V^2 \rangle}{\langle \sigma^2 \rangle}$$

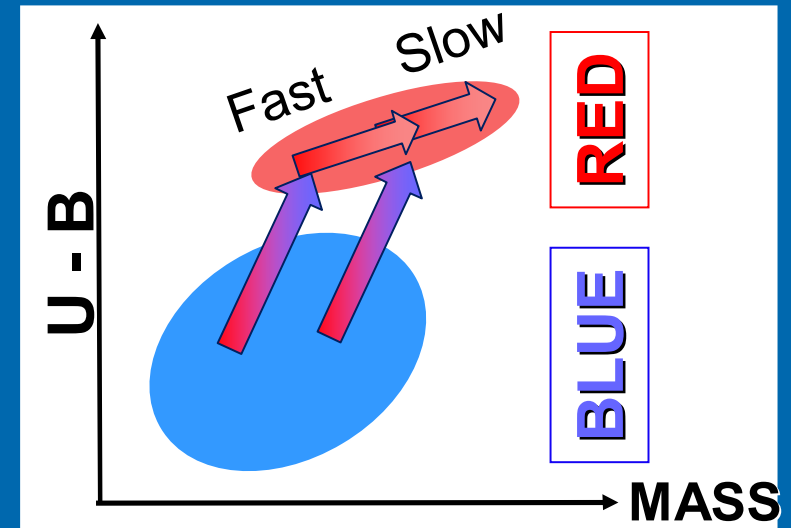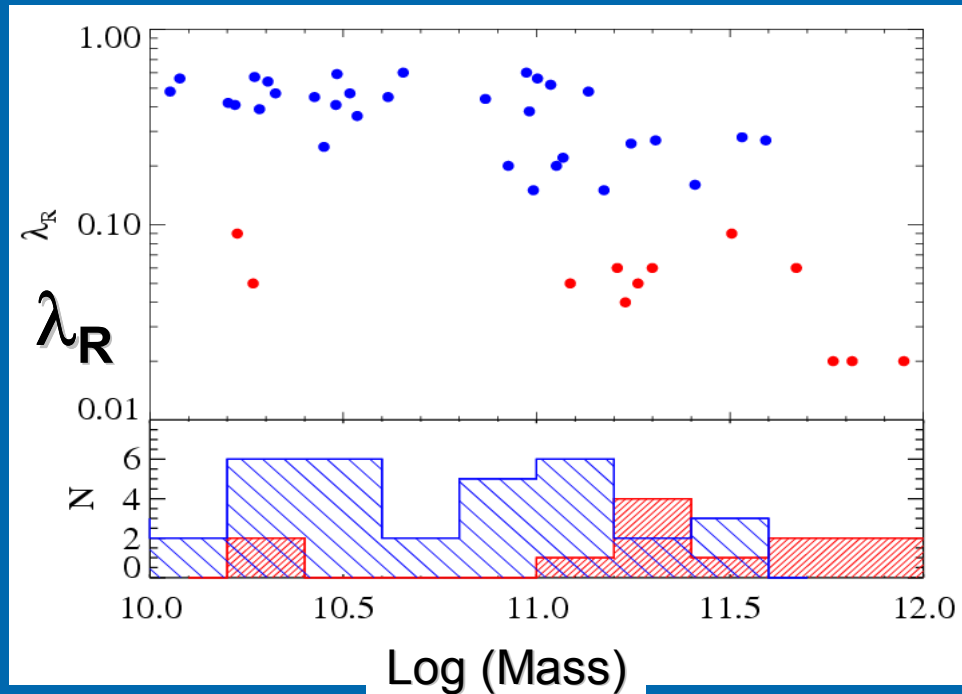Use new formalism for integral-field kinematics (Binney 2005)

Anisotropy trend from 25 Models

The whole SAURON sample
(Cappellari et al. 2007)

- **Fast-rotators:** oblate systems (+ bars)
- **Slow-rotators:** distinct - likely triaxial

λ_R versus Mass

- Competition between
  - Gas-rich mergers or gas accretion: λ_R ↗
  - Dry stellar mergers: λ_R ↘
- Baryonic angular momentum
  - expelled outwards in slow rotators (Emsellem et al. 2007)

Next step → Complete survey

- **Need volume-limited sample**
  - To understand distribution of **Fast** & **Slow** Rotators
  - To determine the relative fraction of **wet / dry mergers**
  - To provide strong low-z constraints on simulations
  - To understand the role of SF and feedback
- **Sample selection**
  - $M_K < -21.5$ (from 2MASS)
  - $D < 41$ Mpc
  - $|\delta - 29| < 35°$
  - $|b| > 15°$
  - Atlas[3D] observes **all E/S0s**
 - "No spiral structure from SDSS/DSS2"

→ **265 galaxies**
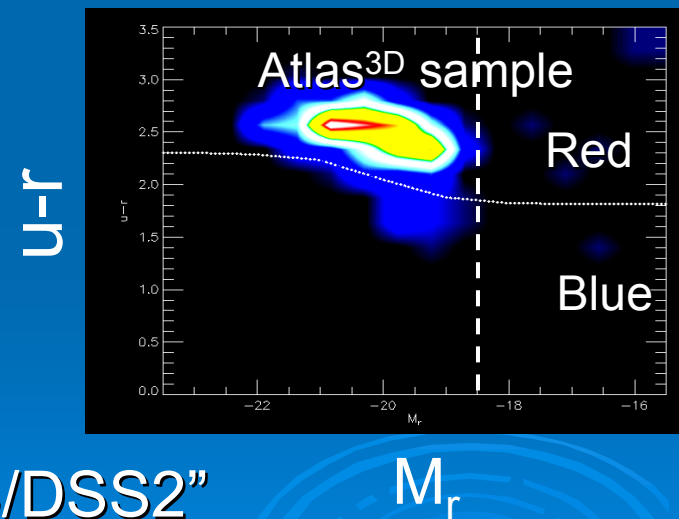
The Team

PIs: Michele Cappellari (Oxford), Eric Emsellem (Lyon),
Davor Krajnović (Oxford), Richard McDermid (Gemini)

CoIs / Students:

Roland Bacon, 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
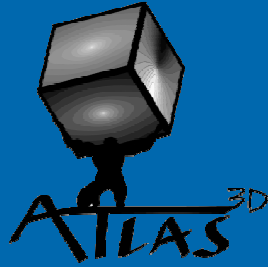
Multi-λ approach

- **_Optical integral-field:_** Large Program with **SAURON@WHT**
  - 38 nights over 3 semesters (4 runs): **DONE !!!**

- **_Single-dish CO:_** survey of full sample (**IRAM 30m**)
  - Martin Bureau (see talk) and Lisa Young

- **_HI survey:_** ~150 northern galaxies with **WSRT** (excl. Virgo)
  - Raffaella Morganti, Tom Oosterloo, Paolo Serra (see talk)

- **_Photometry:_** multi-bands (**INT**, 2MASS, SDSS) Gijs verdoes Klejin

- **_CO interferometry_** of detections with **CARMA**

- **_Archival_** data (Chandra, XMM, GALEX, HST, Spitzer)

Simulating the (V/σ,ε) diagram
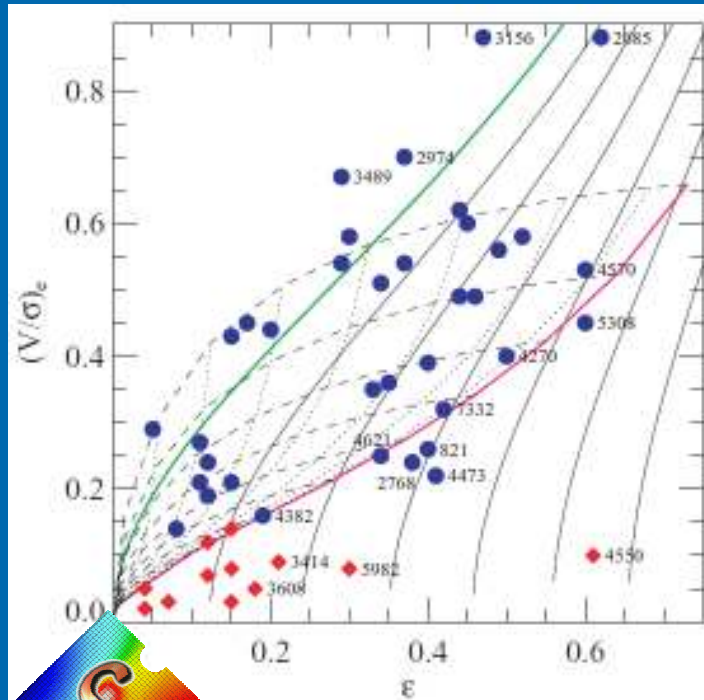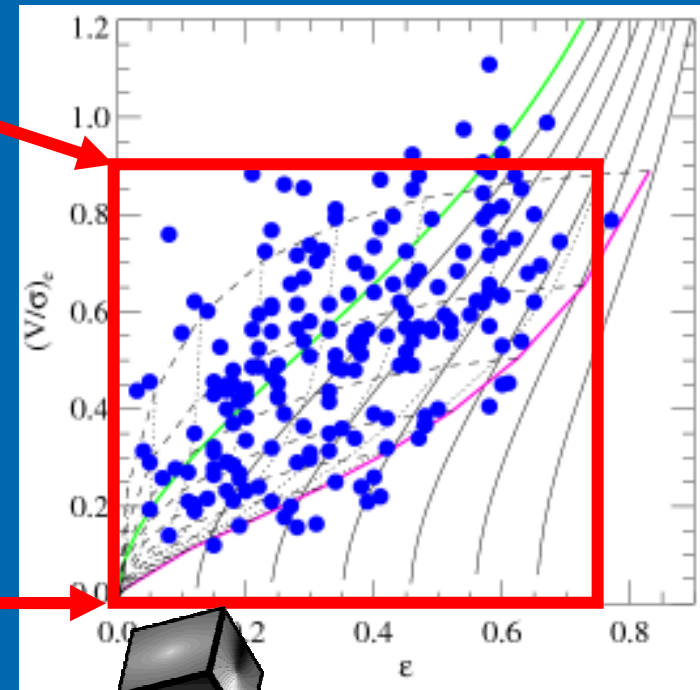

SAURON sample
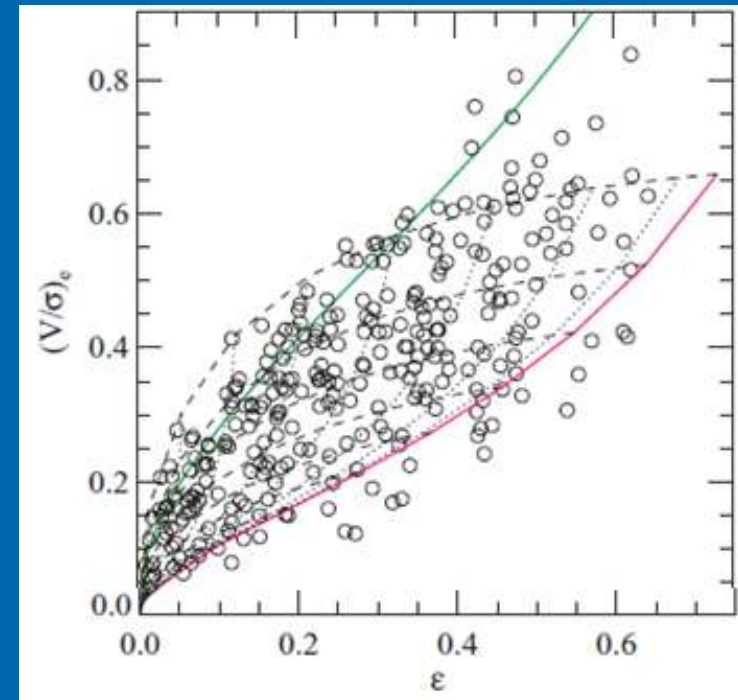
Simulation: 6x more fast rotators
(Cappellari et al. 2007)

- SAURON sample relatively small and complex selection
- Is the observed trend due to selection bias?
- Atlas^{3D} expected to rule out alternatives
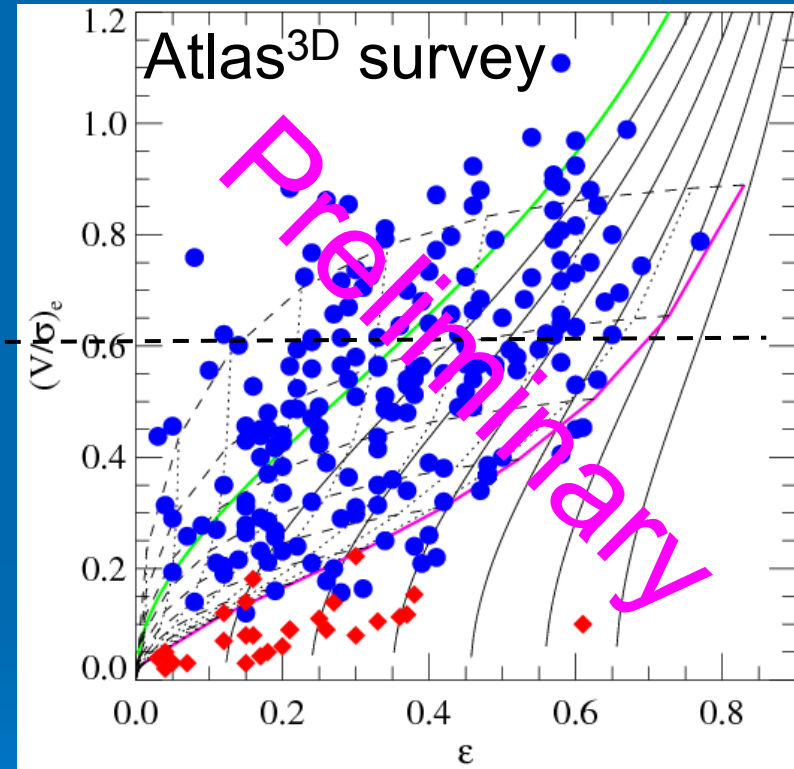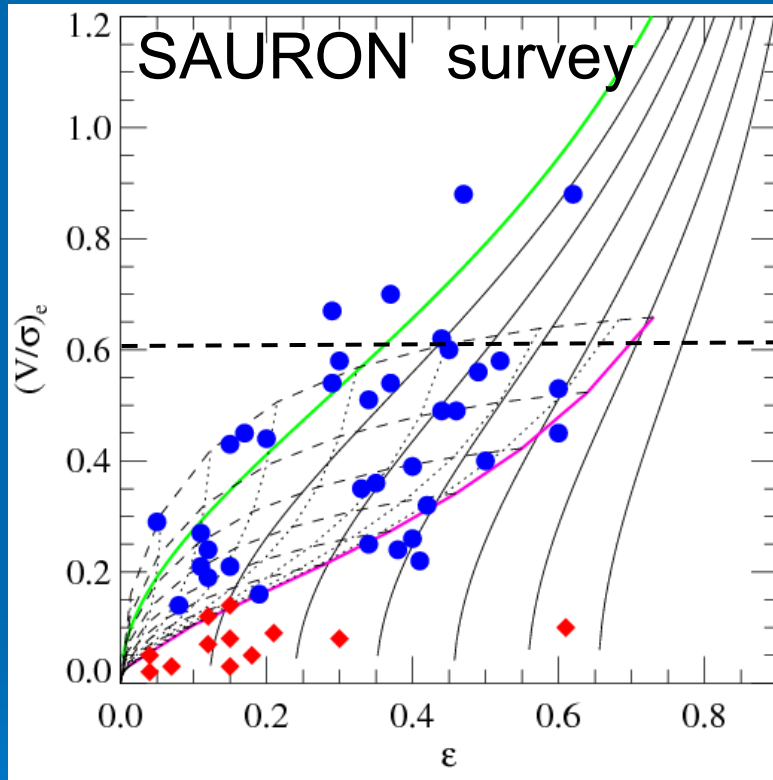
From simulation to Atlas³D
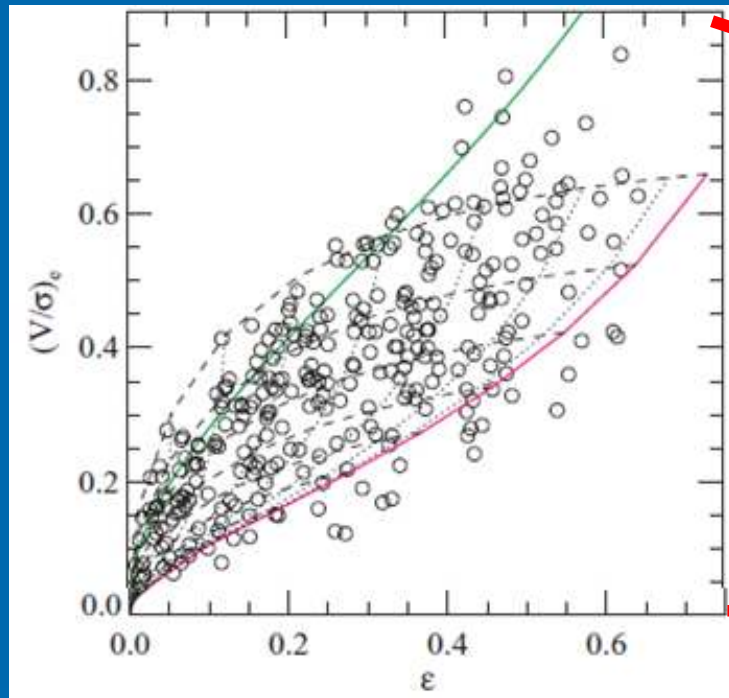
Simulation   observations

- Predicted trend strongly confirmed
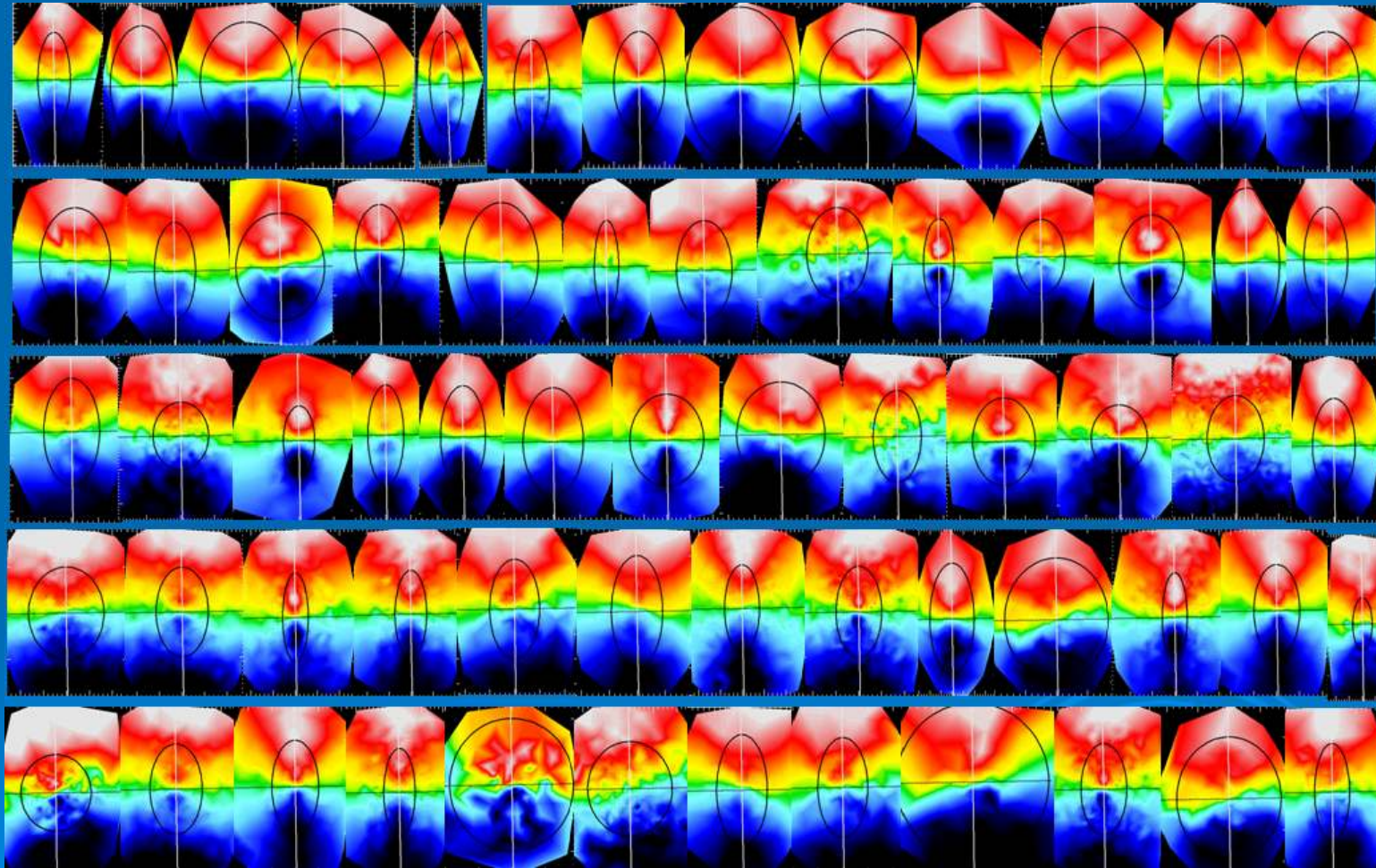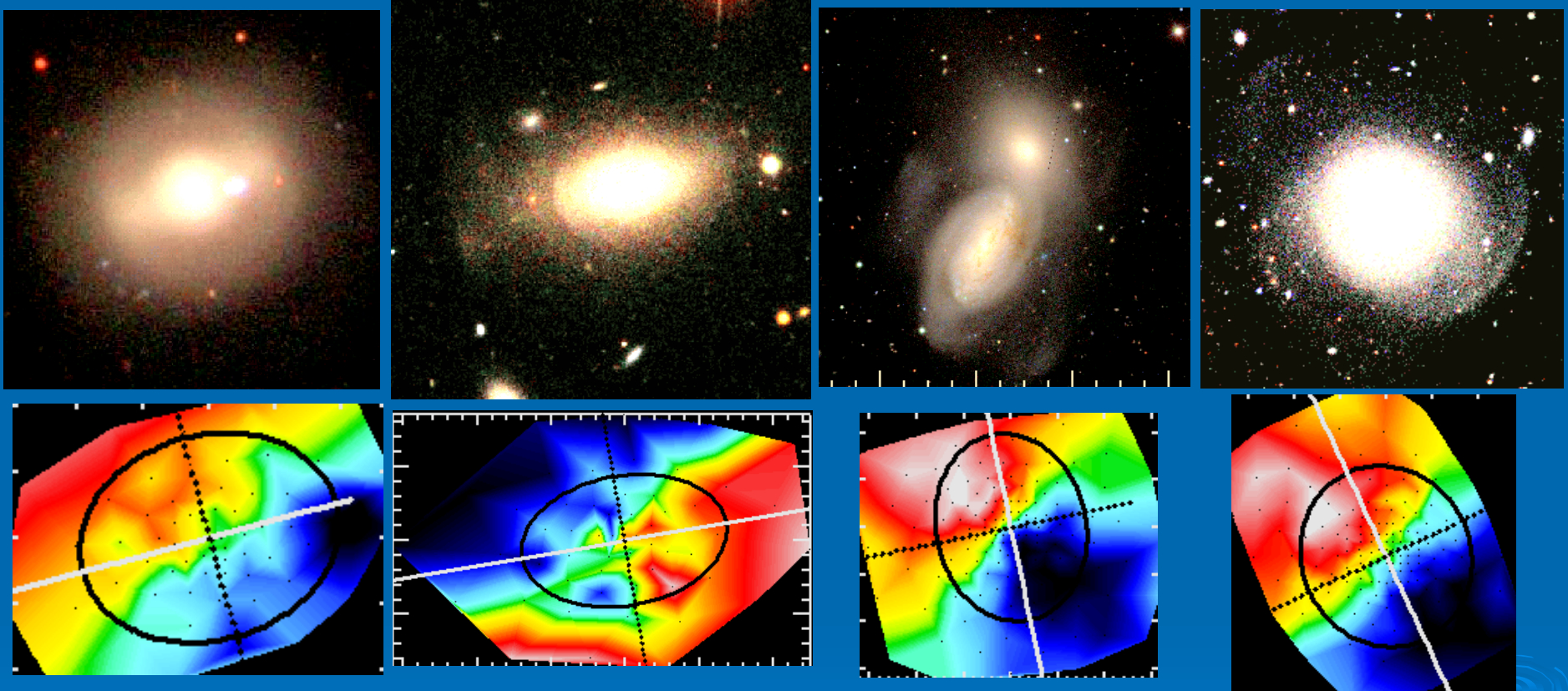- But Atlas³D uncovers missing population of fast rotators

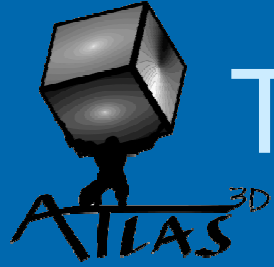# From ~~SAURON~~ to ~~Atlas³ᴰ~~

- SAURON survey discovered trends
- Atlas³ᴰ survey gives true distribution

Fast rotators are axisymmetric

Exceptions: bars and mergers

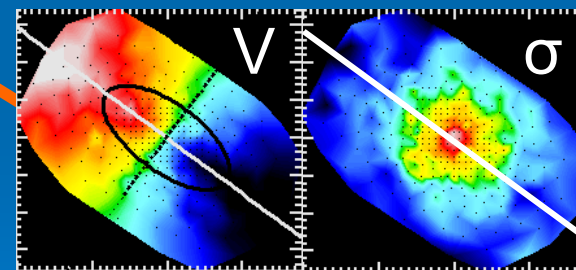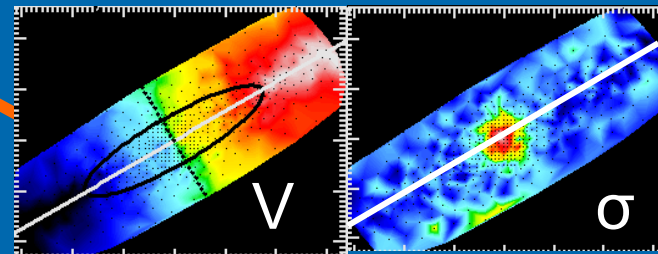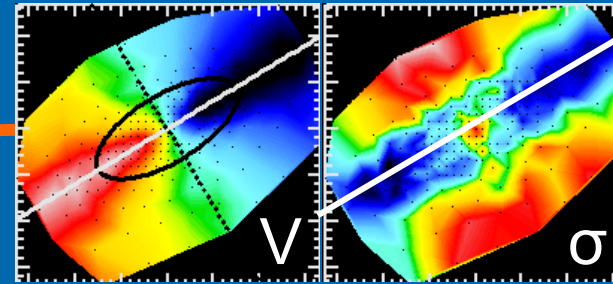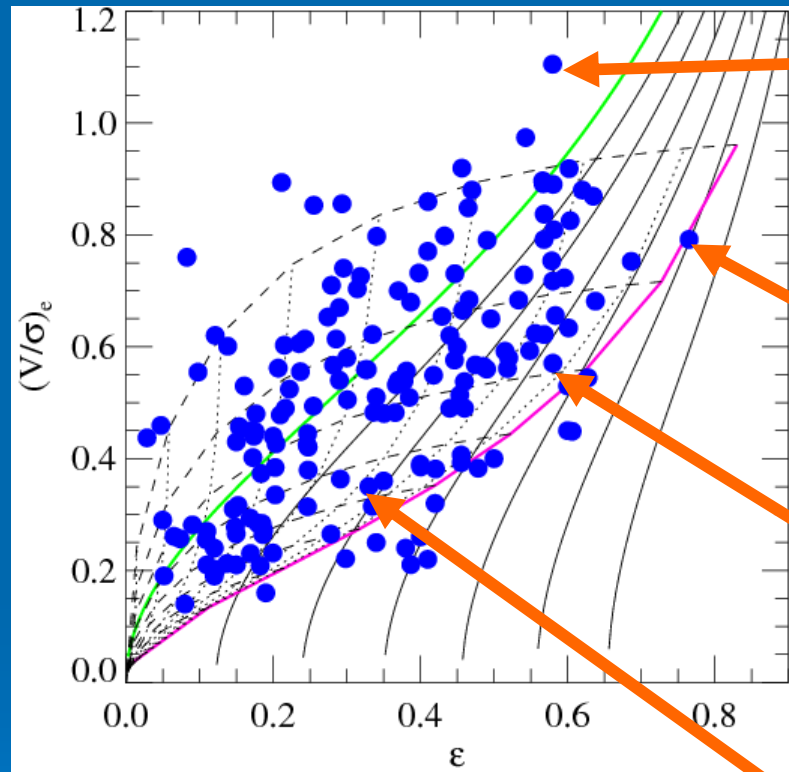- Misalignments in fast-rotators due to
  - Ongoing interaction
  - Recent mergers
  - Bars

Trend of disk/bulge ratio?
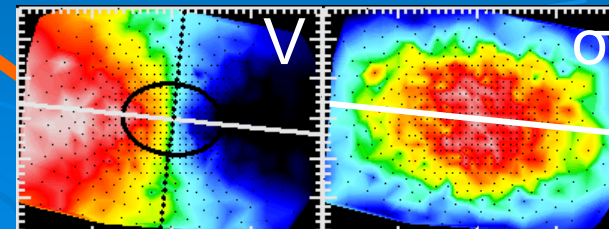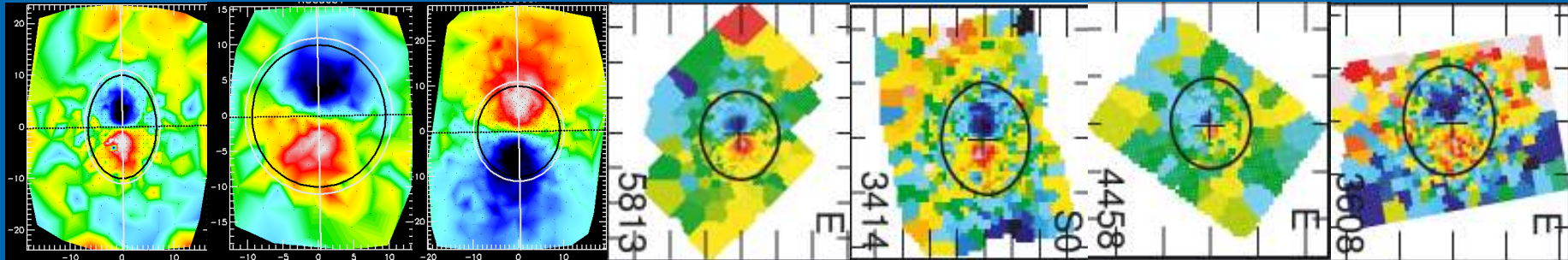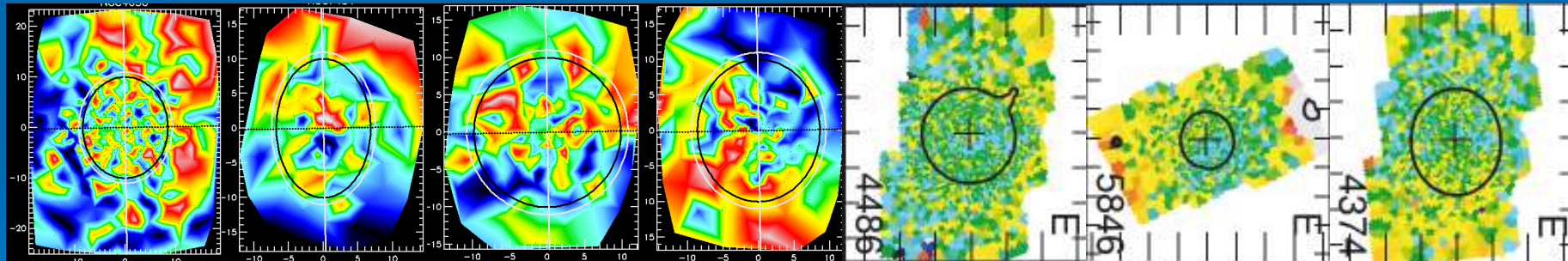

- Roundish sigma field at low V/σ

- Deep σ depression on major axis at high V/σ
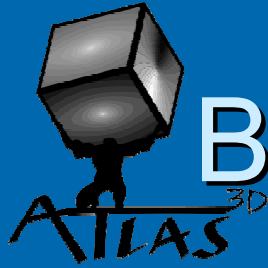
More disk dominated
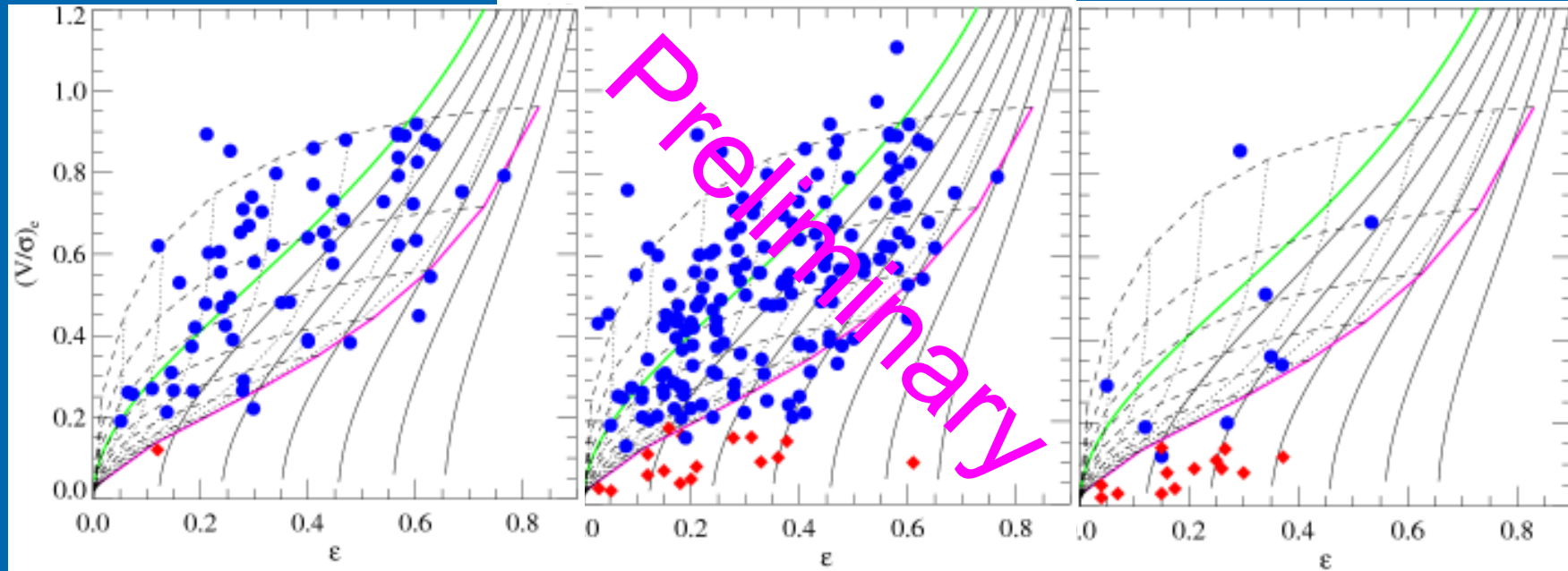
Two types of slow rotators?

- Kinematically decoupled components
- Generally aligned with photometry

- `Non rotators'
- Rotation at the limit of measurement errors
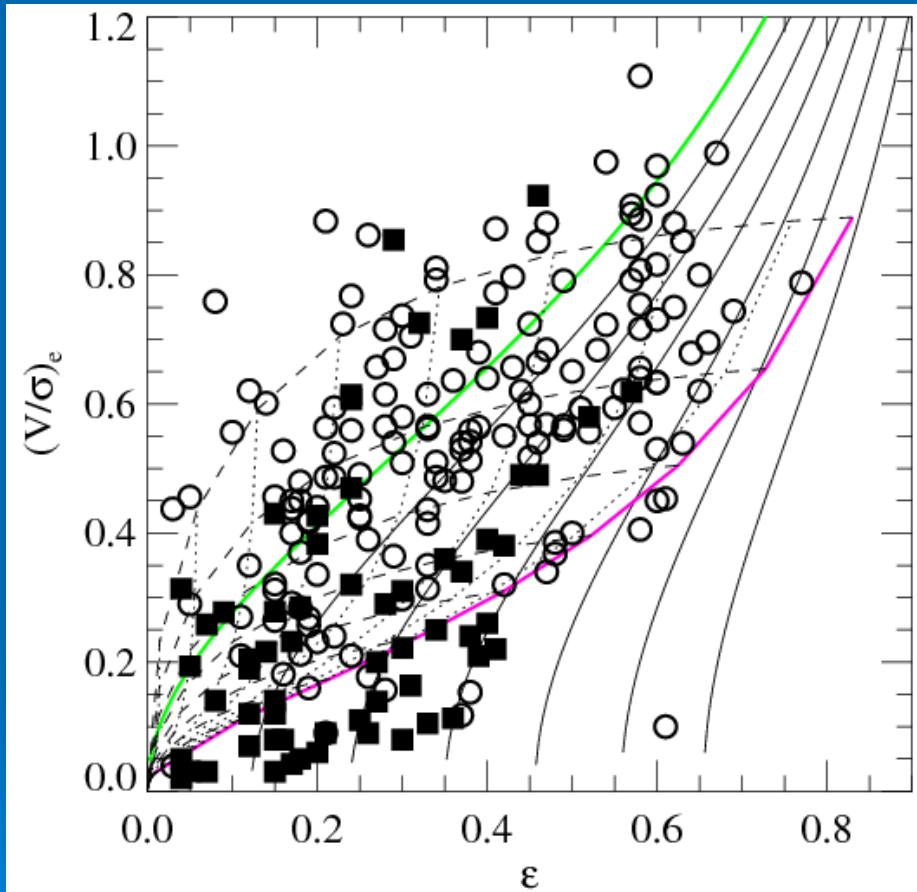
Build up of red sequence

$V_{RMS} < 110$ km/s $110 < V_{RMS} < 210$ km/s $210 < V_{RMS}$ km/s

- At low masses only fast rotators
- Almost only slow rotators at high mass end
- Slow rotators are only 10% of early-types population
- New paradigm for early-type galaxies!

Kinematics and morphology

- Most fast-rotators are lenticulars (OK)

- Most slow-rotators are ellipticals (OK)

- **Many** fast-rotators classified E at low inclination

- Little physical information in E/S0 classification
  (see Kormendy & Bender 1996)

- **E/S0 classification destined to extinction!**

■ = Elliptical (E)
O = Lenticular (S0)

Some implications for galaxy formation

- ETG are end result of galaxy formation
- 90% are nearly axisymmetric fast rotators
→ Limits on dark matter content
    - Dark matter is collisionless → Triaxial
    - Orbit in triaxial potential are misaligned
→ Limits on dry mergers
    - Dry mergers are collisionless → Triaxial
    - Significant dry mergers destroy alignment
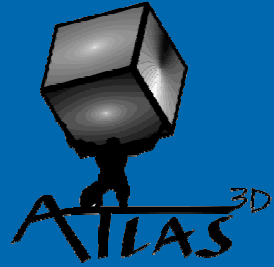
Fast-rotators are faded spirals?


Gas starvation + Fading

Spirals
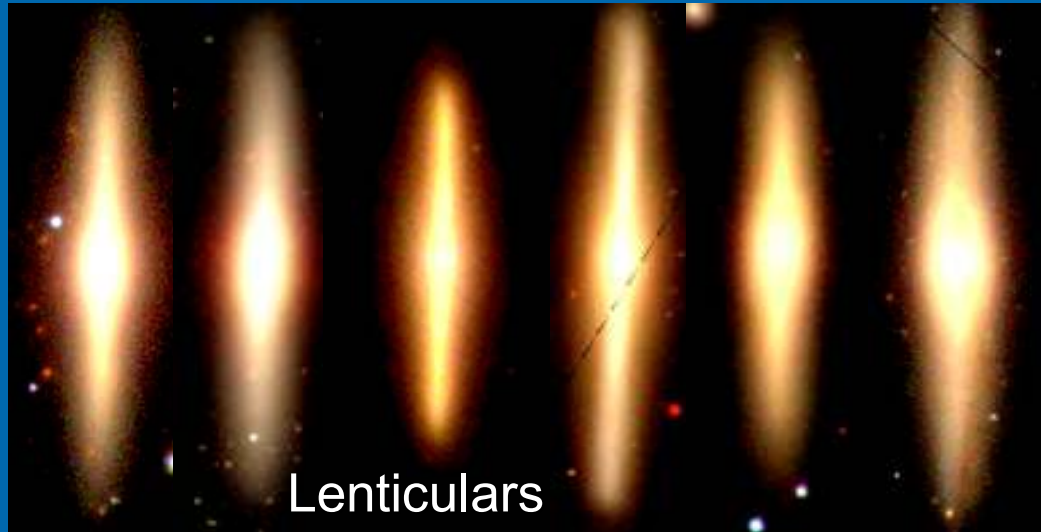
Lenticulars

- Many thin lenticulars
- Morphology consistent with faded spirals
- Mass & population consistent with fading (Bedregal et al. 2006)
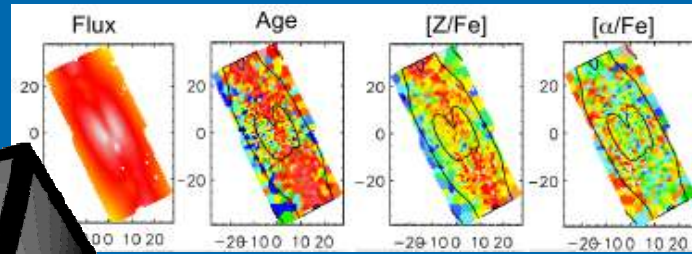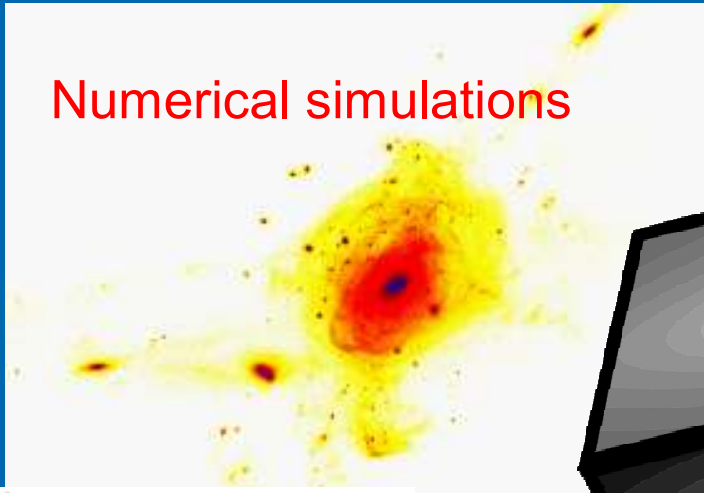- Only minor merging
- No BH feedback

Spiral

Lenticular

Simulation approach

- **Simulations are integral part of the survey**
  - **Binary mergers**

    Lead by Frederic Bournaud & Maxime Bois (talk today)

  - **Simulations in cosmological context**

    Lead by Thorsten Naab (talk today)

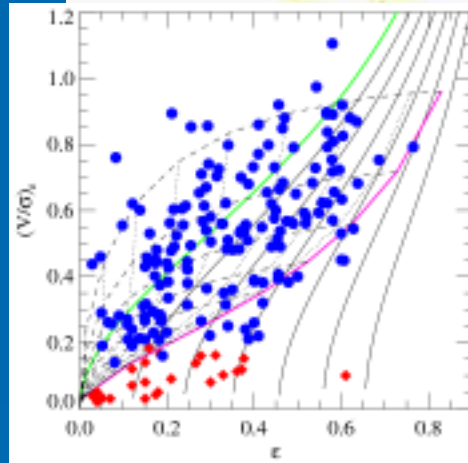 - **Semi-Analytical Modelling**

    Lead by Sadegh Kochfar
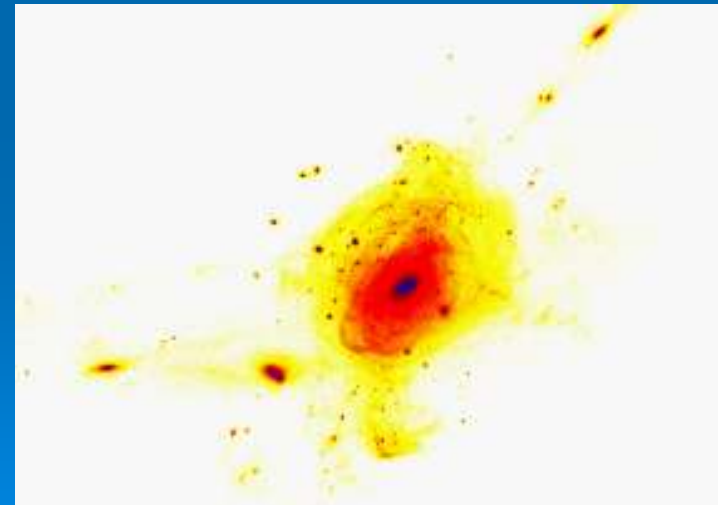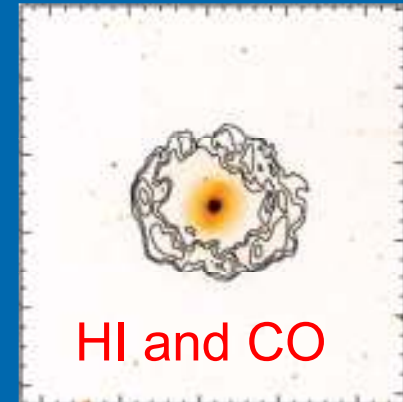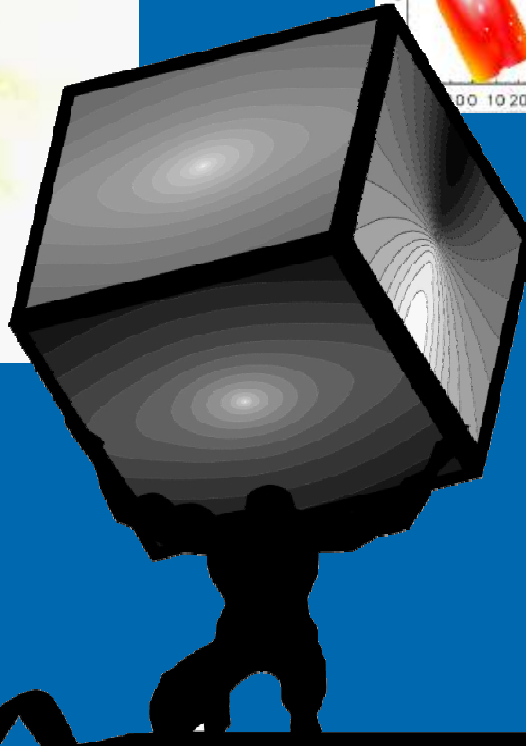

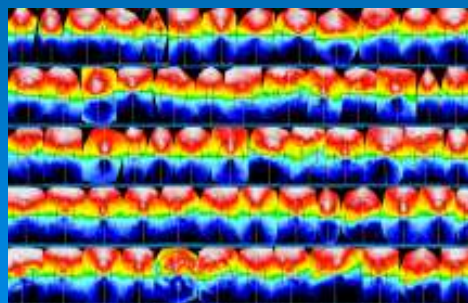(Bournaud et al. 2008 astro-ph)
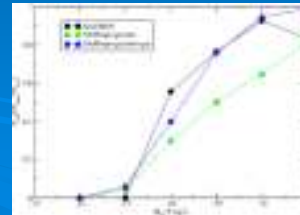
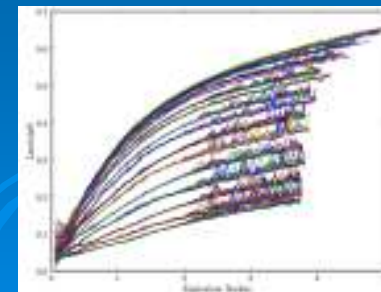Numerical simulations

Stellar population

Dynamical models

HI and CO

Stellar kinematics

Semi-analytic models

Binary mergers

ATLAS 3D