Survey of nearby E/S0s
First Results
Michele Cappellari
Hierarchical galaxy formation

- 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

(see Faber et al. 2007)
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
    - Fast rotating

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

λ_R

Angular momentum per unit mass

“Slow-rotator”

λ_R=0.1

“Fast-rotator”

Emsellem et al. (2007)
Fast/slow rotators on \((V/\sigma, \varepsilon)\) diagram

\[(V / \sigma)^2 \equiv \frac{\langle V^2 \rangle}{\langle \sigma^2 \rangle}\]

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

Anisotropy trend from 25 Models

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

The whole SAURON sample (Cappellari et al. 2007)
\( \lambda_R \) versus Mass

- Competition between
  - Gas-rich mergers or gas accretion: \( \lambda_R \)
  - Dry stellar mergers: \( \lambda_R \)
- 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
  - \(|\delta - 29| < 35^\circ\)
  - \(|b| > 15^\circ\)
  - Atlas\(^3\)D observes all E/S0s
  - “No spiral structure from SDSS/DSS2”

→ 265 galaxies
PIs: Michele Cappellari (Oxford), Eric Emsellem (Lyon), Davor Krajnović (Oxford), Richard McDermid (Gemini)

Cols / Students:
- Roland Bacon, Maxime Bois, Frederic Boursaud, 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 Kleijn
- **CO interferometry** of detections with CARMA
- **Archival** data (Chandra, XMM, GALEX, HST, Spitzer)
Simulating the \((V/\sigma, \epsilon)\) diagram

- SAURON sample relatively small and complex selection
- Is the observed trend due to selection bias?
- \textit{Atlas}^{3D} expected to rule out alternatives

Simulation: 6x more fast rotators

\cite{Cappellari2007}
From simulation to Atlas$^{3D}$

- Predicted trend strongly confirmed
- But Atlas$^{3D}$ uncovers missing population of fast rotators
SAURON survey discovered trends

Atlas\textsuperscript{3D} survey gives true distribution

- SAURON survey discovered trends
- Atlas\textsuperscript{3D} 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 $V/\sigma$
- Deep $\sigma$ depression on major axis at high $V/\sigma$
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

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!

\[
\begin{array}{ccc}
V_{\text{RMS}} < 110 \text{ km/s} & 110 < V_{\text{RMS}} < 210 \text{ km/s} & 210 < V_{\text{RMS}} \text{ km/s}
\end{array}
\]
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!
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?

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