The Virial Relation and Shape of Early-Type Galaxies

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The fundamental plane

\[ \log R_e = a + b \log \sigma + c \log \Sigma_e \]

- \( a = 0.193 \pm 0.0074 \)
- \( b = 1.063 \pm 0.041 \)
- \( c = -0.765 \pm 0.023 \)
- \( \varepsilon_z = 0.072 \pm 0.0056 \)
- \( \Delta = 0.091 \text{ (dex)} \)
- \( x_0 = 2.11 \)
- \( y_0 = 8.7 \)

Expected: \( b = 2, c = -1 \)

Observed: \( b \approx 1, c \approx -0.8 \)

\[ \rightarrow \text{Difference due to scaling of } M/L \text{ with velocity dispersion} \]

Dressler+ (1987); Djorgovski & Davis (1987); many others since then
The mass plane

Mass Plane ($M$, $\sigma_e$, $R_e$)

\[ a = 10.597 \pm 0.0041 \]
\[ b = 1.928 \pm 0.026 \]
\[ c = 0.964 \pm 0.018 \]
\[ \varepsilon_z = 0.004 \pm 0.016 \]
\[ \Delta = 0.062 \text{ (dex)} \]
\[ (x_0 = 2.11) \]
\[ (y_0 = 0.301) \]

Cappellari+ (2013)

Virial relation

\[ M = k_e \frac{\sigma^2 R_e}{G} \]

\[ k_e \approx 4 \ldots 5 \]

Theory: $b = 2$, $c = 1$; observations agree? Or not?

The ATLAS$^{3D}$ sample

- 260 elliptical galaxies within 42 Mpc
- Volume-limited sample
- SAURON integral-field spectroscopy
- Masses and effective radii from modeling of surface brightness and velocity dispersion distributions in the sky plane
  - Jeans Anisotropic Multi-Gaussian Expansion (JAM) algorithm
- High-quality results for 101 galaxies
- Formal uncertainties:
  - 0.041 dex for effective radii
  - 0.021 dex for average velocity dispersions
  - 0.049 dex for galaxy masses

Cappellari+ (2011), 30+ more ATLAS$^{3D}$ papers since then
The Saglia+ (2016) sample

- 72 galaxies & bulges within 150 Mpc
- Aimed at black holes – galaxy relations, selected for large range in dispersion
- SINFONI integral-field spectroscopy, various archival data sets
- Masses and radii from photometry, various dynamical models
- Median formal uncertainties:
  - 0.096 dex for effective radii
  - 0.021 dex for average velocity dispersions
  - 0.083 dex for galaxy masses

Saglia+ (2016), obviously
The virial relation with $R_e$

\[ \log \left( \frac{M}{10^{11} M_\odot} \right) = x \log \left( \frac{\sigma^2 R_e / G}{10^{10.5} M_\odot} \right) + y \]
The virial relation with $R_e$

The virial relation of ETGs is tilted

$x = 0.924 \pm 0.016$

$x = 0.923 \pm 0.018$
The virial relation with semimajor axis $a$

$\log \left( \frac{M}{10^{11} M_\odot} \right) = x' \log \left( \frac{\sigma_*^2 a/G}{10^{10.5} M_\odot} \right) + y'$

where the half-light ellipse obeys

$$R_e = \sqrt{ab}$$
$$R_e = a\sqrt{1 - \epsilon}$$

gives a new slope

$x' = 0.976 \pm 0.018 \equiv 1$

Semimajor axis, not effective radius, is the true scale radius of ETGs
Ellipticity scales with mass

\[ M \left[ M_\odot \right] \]

\[ 1 - \epsilon \]

Slope: 0.123 ± 0.041

⇒ Lack of very elliptical high-mass galaxies explains mass plane tilt

cf. van der Wel+ (2009)
There is no mass “plane”

Best-fit virial relations agree with zero intrinsic scatter

¬ 2-parameter virial relation is sufficient (Occam's razor)

¬ 3-parameter mass plane has too many parameters
There is no mass “plane”

Best-fit virial relations agree with zero intrinsic scatter
→ 2-parameter virial relation is sufficient (Occam's razor)
→ 3-parameter mass plane has too many parameters
Local ETGs are axisymmetric and oblate

If not, $a$ were not a characteristic radius
Agrees with dynamical modeling (Weijmans+ 2014)
Summary

➢ 72 & 101 ETGs from 2 recent surveys: ATLAS$^{3D}$, Saglia+ (2016)

➢ Using the virial relation with $R_e$ shows a significant tilt

➢ Tilt disappears when using the semimajor axis $a$ as scale radius

➢ Tilt is caused by a lack of very elliptical high-mass galaxies

➢ Virial relation fully determines ETG dynamics, no mass “plane”

➢ $a$ is scale radius ➔ local ETGs are (mostly) axisymmetric and oblate
