A new look at galaxy scaling relations

Michele Cappellari
Why one more study?

- Galaxy luminosity, size and velocity are related
  - FJ ($L - \sigma$): Faber+Jackson76 (for ellipticals)
  - TF ($L - V_c$): Tully+Fisher77 (for spirals)
  - KR ($L - R_e$): Kormendy77
  - FP: Djorgovski+Davis87; Dressler+87; Faber+87
- Samples of $10^4$ galaxies (Bernardi+03, Springob+)
- Our novelty are 260 accurate (enclosed) masses
- Only comparable effort with lensing (SLACS)
  - Smaller sample + complex selection (Bolton+06,08)
  - Lower quality stellar kinematics and population
10% of our models: $\sqrt{V^2 + \sigma^2}$

- Use Multi-Gaussian Expansion (Emsellem+94)
- Jeans Anisotropic MGE solution (Cappellari+08)
Robustness of M/L determination

- M/L robust to assumed DM profile
- No bias in M/L with/without DM (see also Williams+10)
- Implied errors 7%
  Lablanche+ test with N-body simulations

\[
(M / L) (R_e) = \frac{L(R_e) \times (M/L)_\star + M_{DM}(R_e)}{L(R_e)}
\]
From FP to Mass Plane

- Use mass instead of light
  - Much decreased scatter
  - Plane close to virial prediction (as Cappellari+06, Bolton+08)
- Edge-on view becomes not interesting
- Galaxy formation encoded in face-on view
Galaxies occupy limited area of plane \((\text{Bender+92; Burstein+97})\)

- Sharp double power-law boundary
- Cusp @characteristic mass \(M \approx 3 \times 10^{10} \, M_\odot\) \((\text{cfr. Kauffmann+03})\)
- Minimum radius and maximum density for ETGs
Mass Plane projections

- All projections are equivalent
- Unique mapping of \((M, \sigma, R_e)\)
- Both \(M-R_e\) and \(M-\sigma\) (mass FJ) “relations” are cusped
- Just envelopes of distribution

Some meaningful projections of the MP
Fundamental “Plane” not a plane!

- \( \frac{M}{L} \parallel \sigma \) if \( \sigma \gtrsim 120 \) km/s
- \( \frac{M}{L} \perp \sigma \) if \( \sigma \lesssim 120 \) km/s

Dynamical M/L on the Mass Plane
Dynamical M/L traces population

- Dynamical M/L follows estimator of \((M/L)_{\text{pop}}\)
- \(\sigma\) (not \(\Sigma\) or \(M\)) is best predictor of galaxy prop.
- Main effect is an age variation (McDermid+)
The build-up of scaling relations

- Continuity spirals–ETGs (Cappellari+11b, P7)
- Spirals essential to understand picture
- Bulge growth + quenching
  (cfr. VanderWel+09, Shankar+Bernardi09, Valentinuzzi+10)
Conclusions

- Light $\rightarrow$ Mass = Mass Plane
- Due to virial equilibrium
- Galaxy formation encoded in face-on view
- Sharp cusped boundary
- M/L and population trends
- Explain $\sigma$ best predictor
- Imply bulge growth + quench
  - Distinct route for high-z ETGs?
  - Or high-z disks (vanderWel+11) evolve into fast rotator ETGs?

Projection of Mass Plane
(Cappellari+ TBS)