A new look at galaxy scaling relations

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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) <u>masses</u>
- Only comparable effort with lensing (SLACS)
  - Smaller sample + complex selection (Bolton+06,08)
  - Lower quality stellar kinematics and population
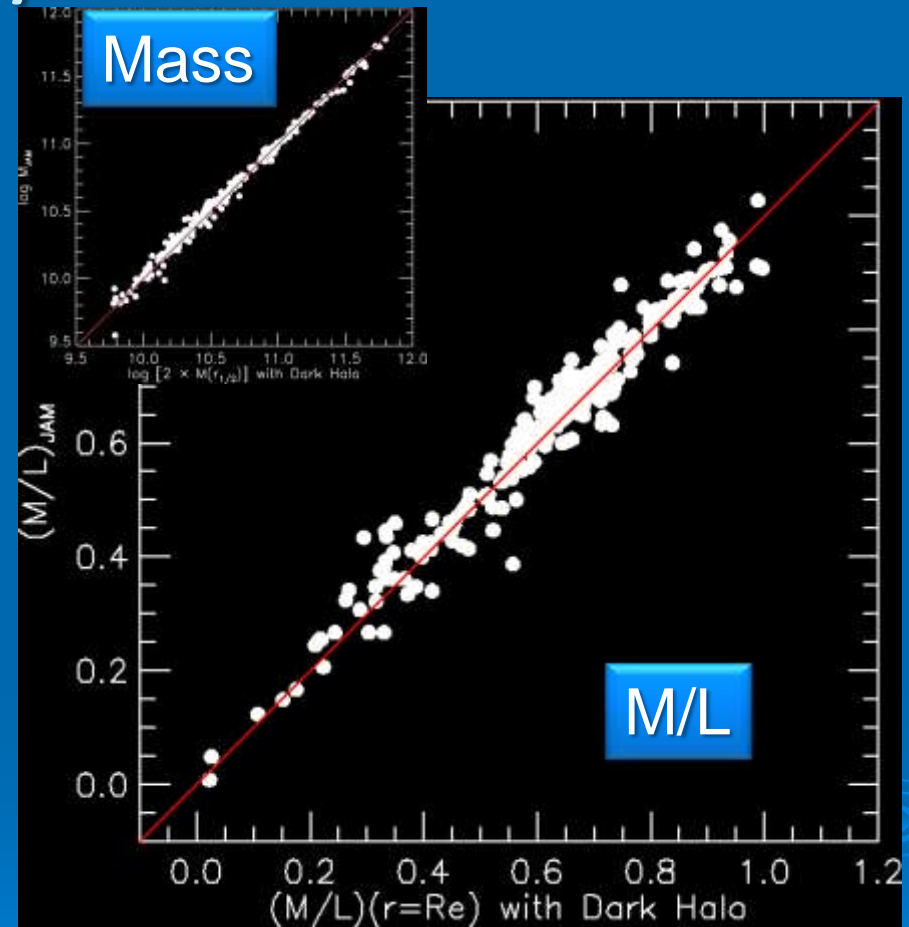
10% of our models: $\sqrt{V^2 + \sigma^2}$
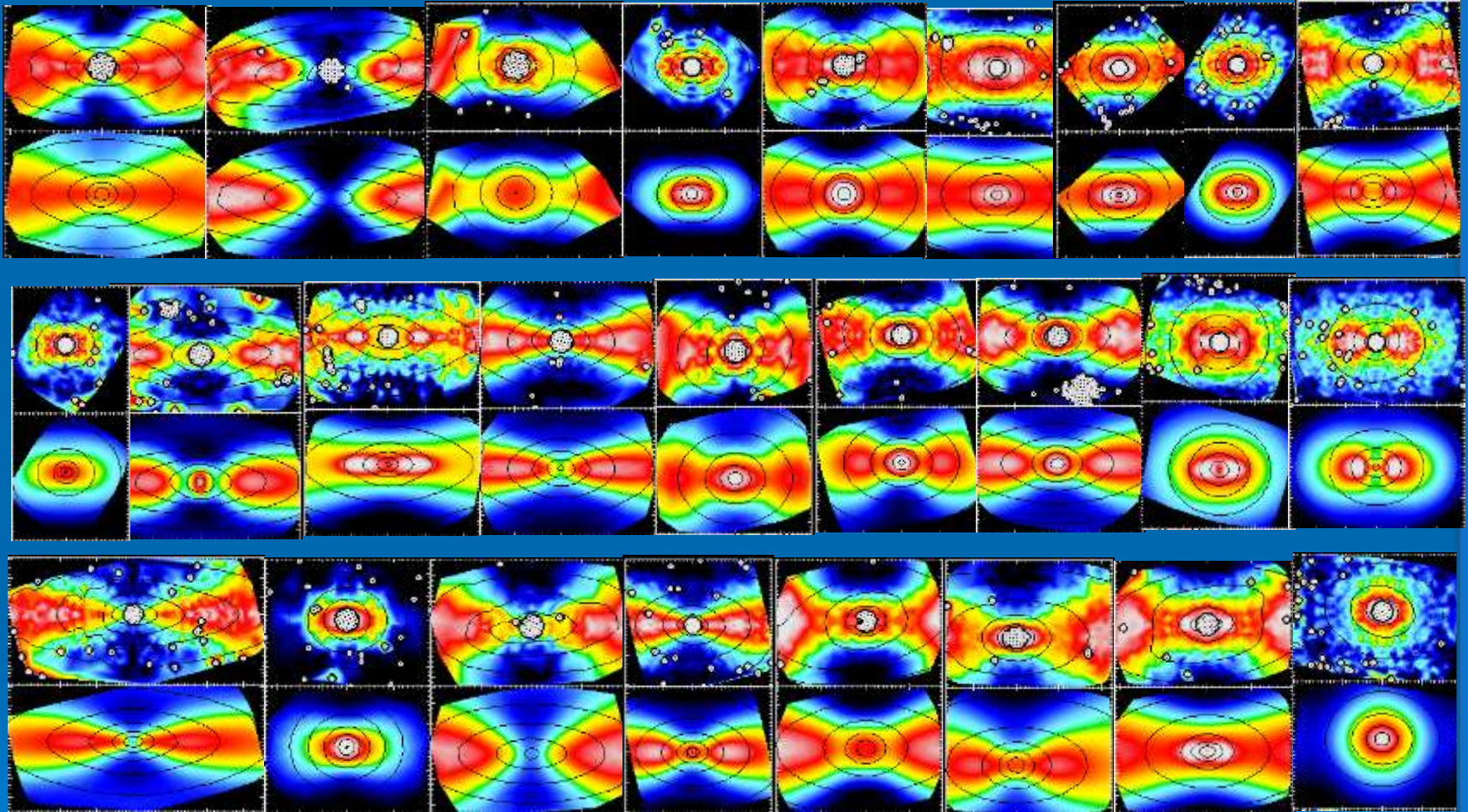
Data Model Data Model Data Model Data Model

- Use Multi-Gaussian Expansion (Emsellem+94)
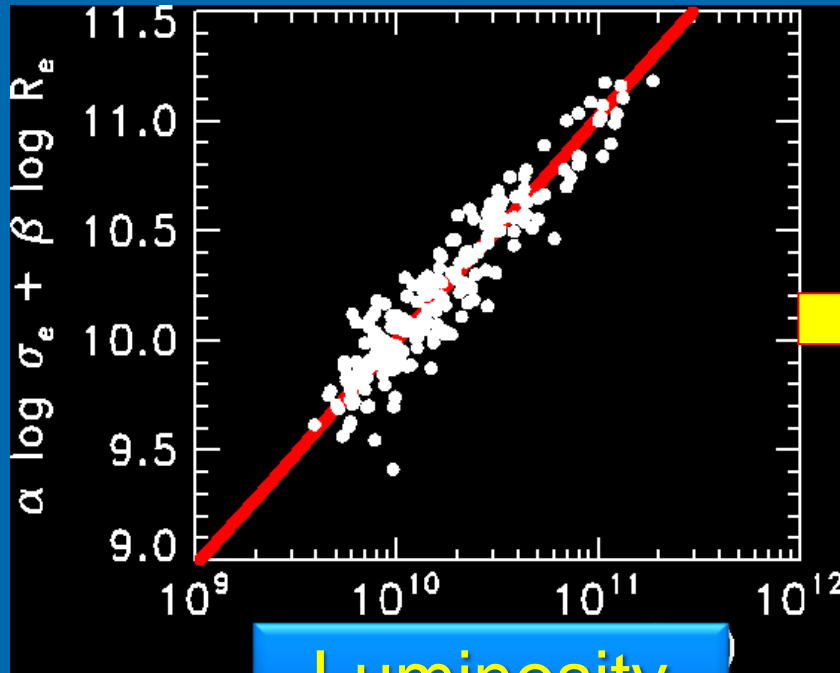- Jeans Anisotropic MGE solution (Cappellari+08)

Robustness of M/L determination

- M/L robust to assumed DM profile

- No bias in M/L with/without DM (see also Williams+10)

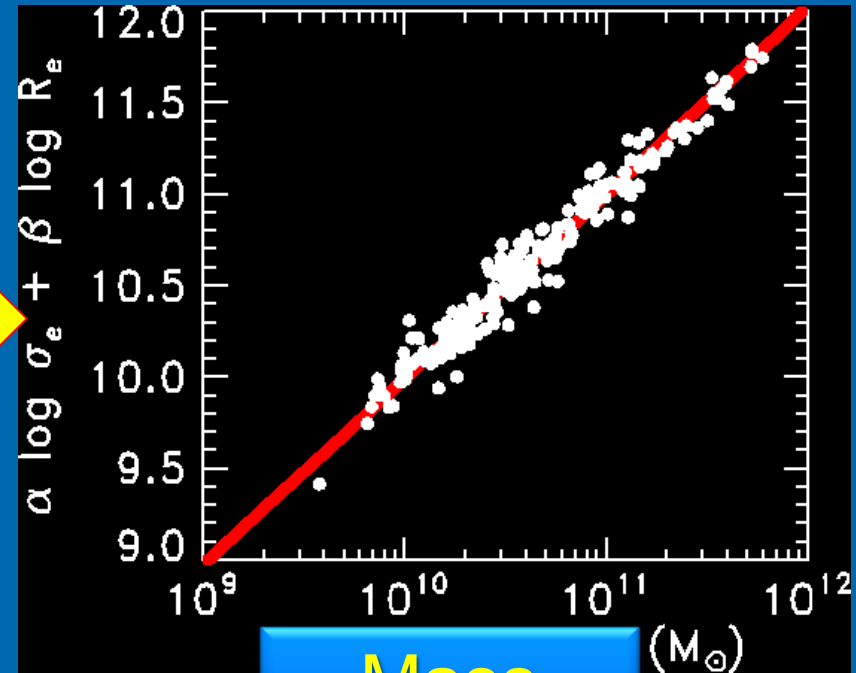- Implied errors 7% Lablanche+ test with N-body simulations

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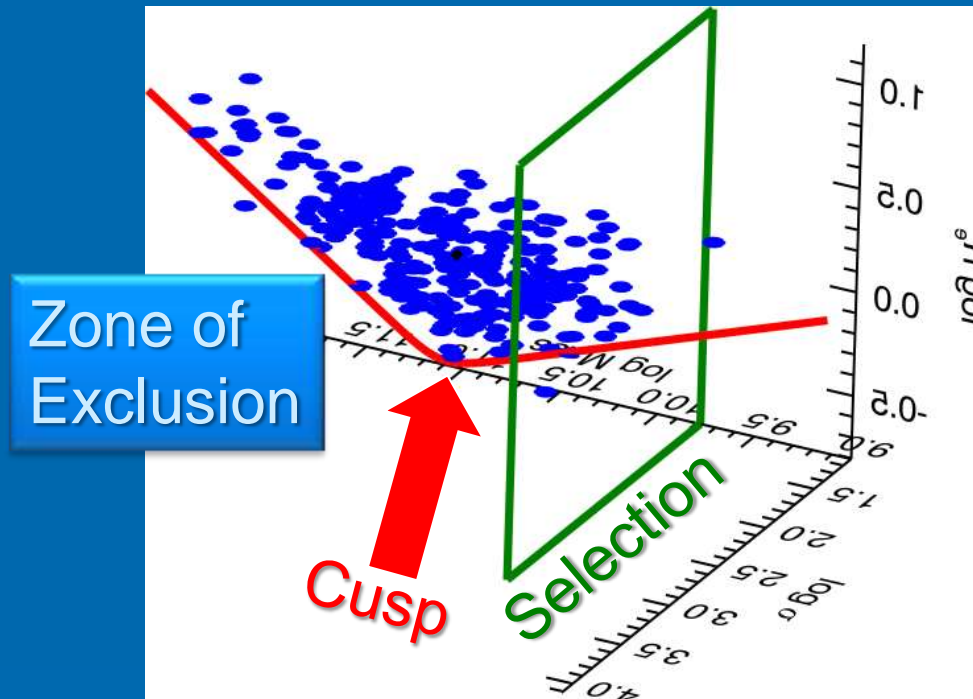
From FP to Mass Plane

Luminosity

Mass

- 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

Face-on view of Mass Plane

- Galaxies occupy limited area of plane (Bender+92; Burstein+97)
- Sharp double power-law boundary
- Cusp @characteristic mass M≈3×10^{10} M$_\odot$ (cfr. Kauffmann+03)
- Minimum radius and maximum density for ETGs
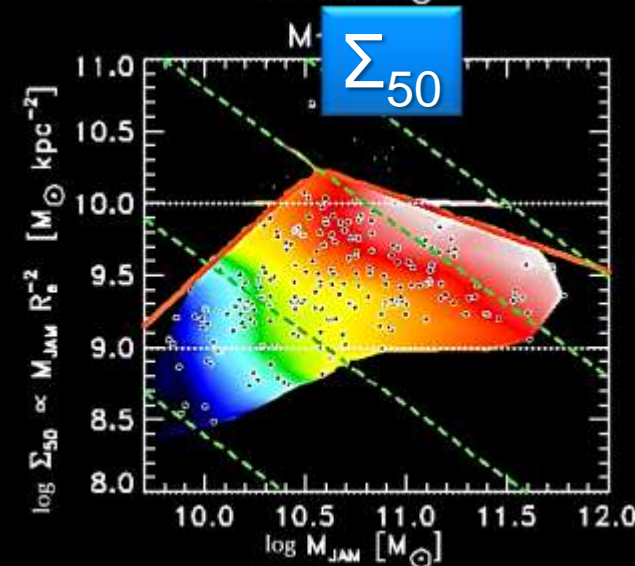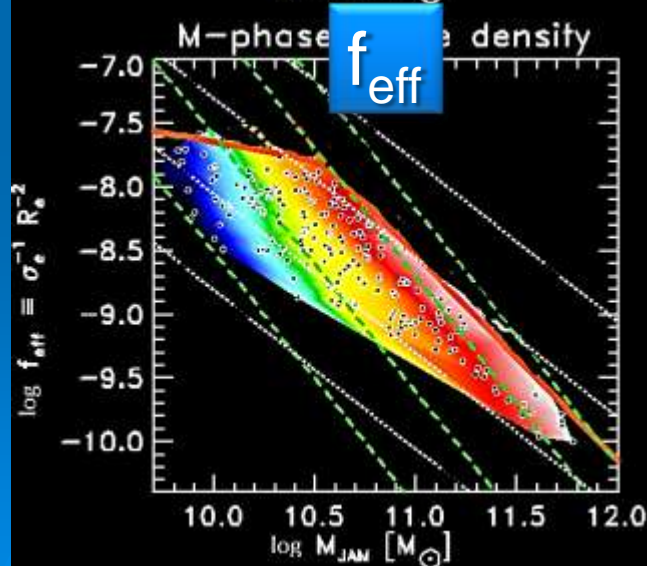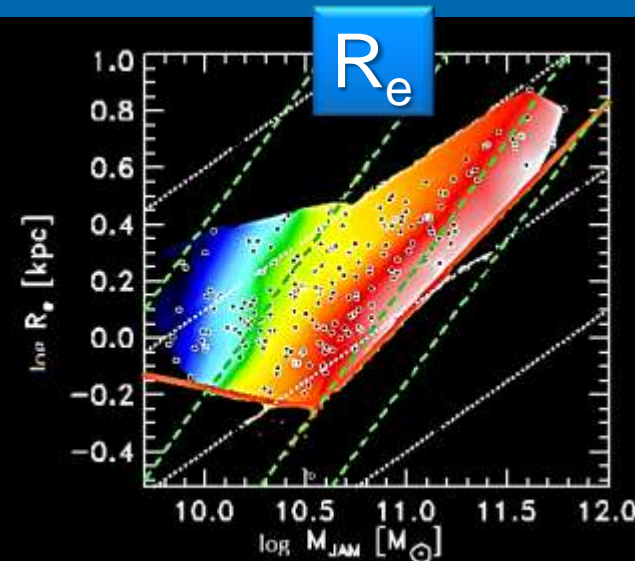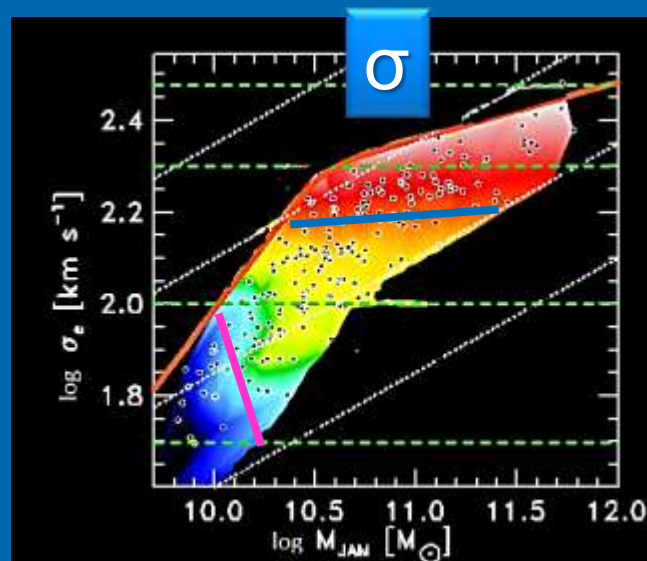
Mass Plane projections

- All projections are equivalent
- Unique mapping of (M,σ,R$_e$)
- Both M-R$_e$ and M-σ (mass FJ) "relations" are cusped
- Just envelopes of distribution
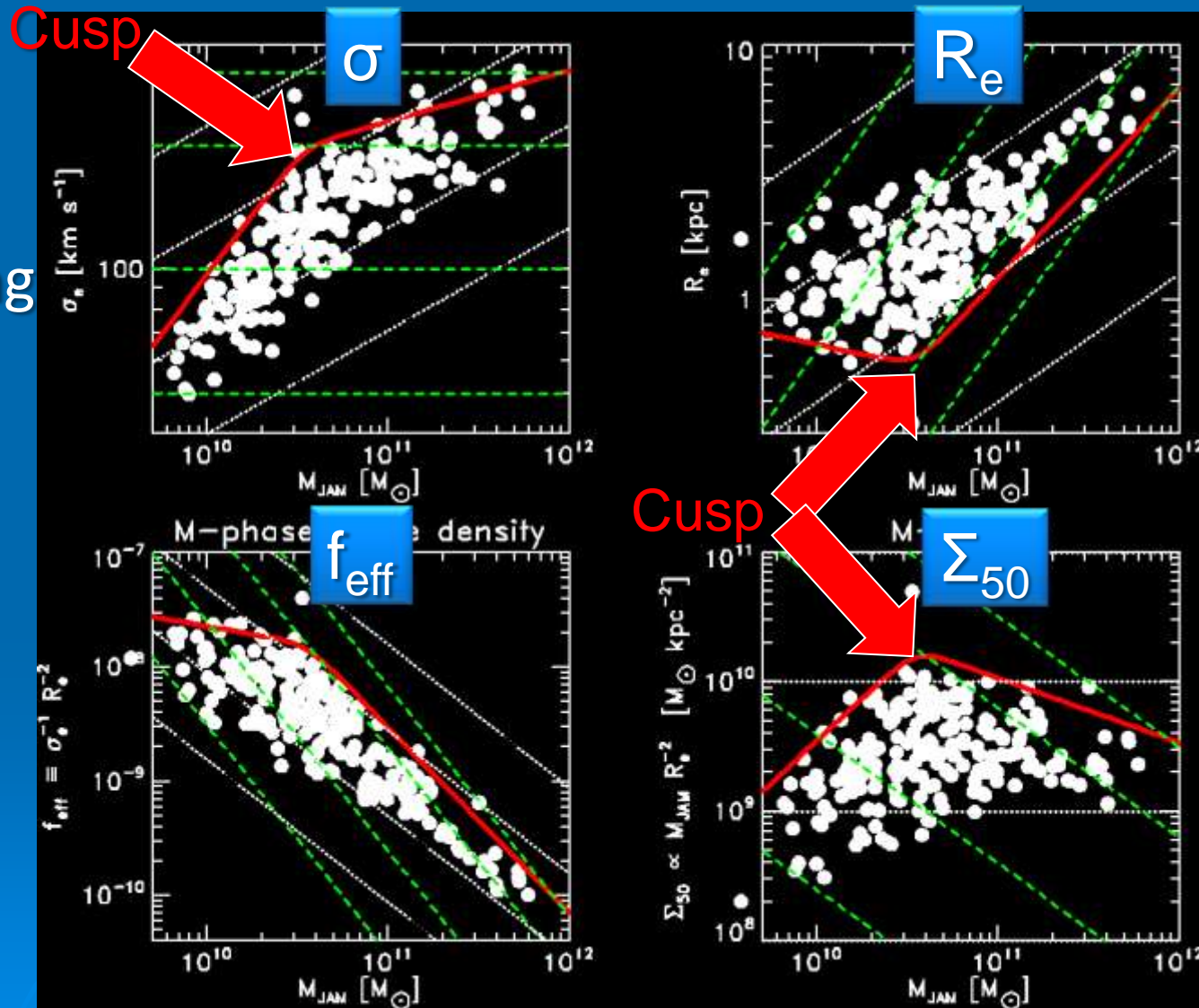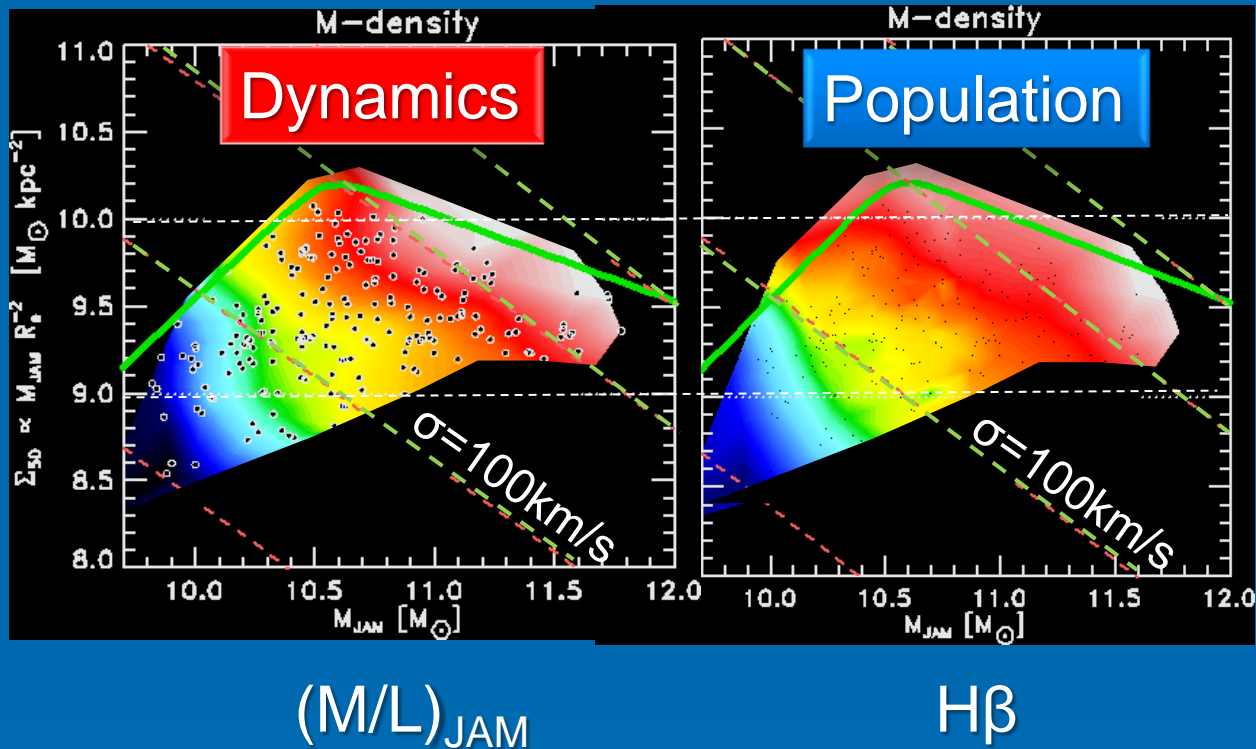

Some meaningful projections of the MP

Fundamental "Plane" not a plane!

- $\dfrac{M}{L} \parallel \sigma$ if
  $\sigma \gtrsim 120$ km/s

- $\dfrac{M}{L} \perp \sigma$ if
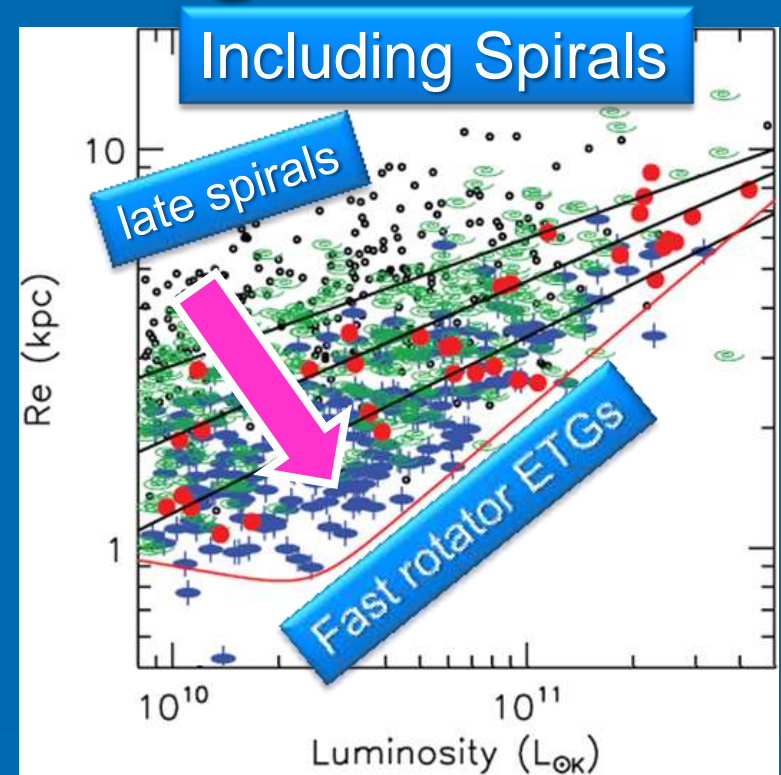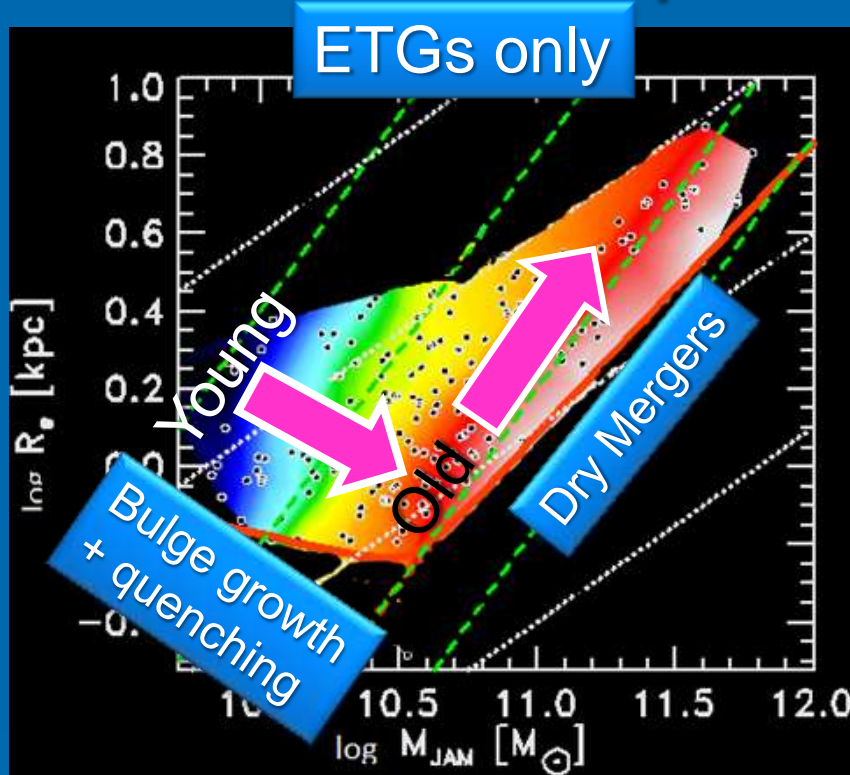 $\sigma \lesssim 120$ km/s

Dynamical M/L on the Mass Plane

Dynamical M/L traces population

(M/L)$_{JAM}$ Hβ

- Dynamical M/L follows estimator of (M/L)$_{pop}$
- σ (not Σ or M) is best predictor of galaxy prop.
- Main effect is an age variation (McDermid+)

The build-up of scaling relations

ETGs only

Including Spirals

late spirals

Young

Old

Bulge growth + quenching

Dry Mergers

Fast rotator ETGs

Cappellari+11a (P1)

- Continuity spirals–ETGs (Cappellari+11b, P7)
- Spirals essential to understand picture
- Bulge growth + quenching

  (cfr. VanderWel+09, Shankar+Bernardi09, Valentinuzzi+10)

Conclusions

- Light → Mass = Mass Plane

- Due to virial equilibrium

- Galaxy formation encoded in face-on view

- Sharp cusped boundary

- M/L and population trends

- Explain σ best predictor

- Imply bulge growth + quench

  - Distinct route for high-z ETGs?

  - Or high-z disks (vanderWel+11) evolve into fast rotator ETGs?

Low M/L & Young

High M/L & Old
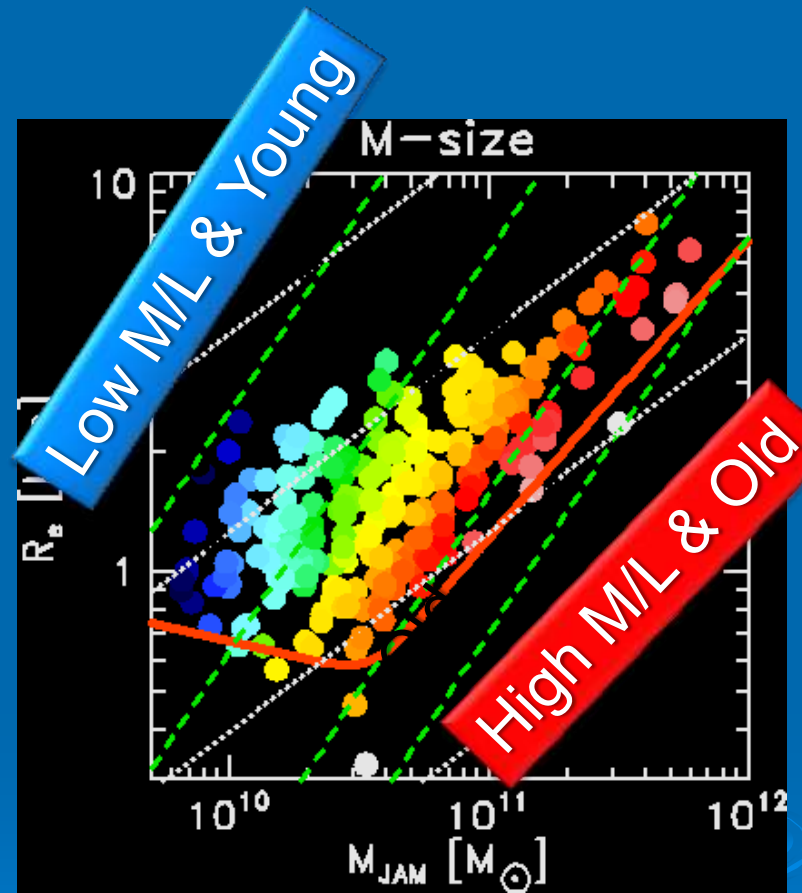
Projection of Mass Plane

(Cappellari+ TBS)