Dark Matter, Stars, Black Holes in Massive Ellipticals

Chung-Pei Ma

Mike Boylan-Kolchin

E. Quataert, L. Desroches, A. West

(UC Berkeley)

MS 1054 (z=0.83):

Evidence for red pairs/mergers in clusters

Tran et al. (2005)

Types of Galaxy Merger Simulations

- **Collisionless disk mergers**

  shells; tidal tails

  central phase space density problem

- **Gaseous disk mergers**

  starbursts

  origin of fundamental plane?

- **Spheroid mergers**

  gas-poor merging (but $\Delta E_* \neq 0$)

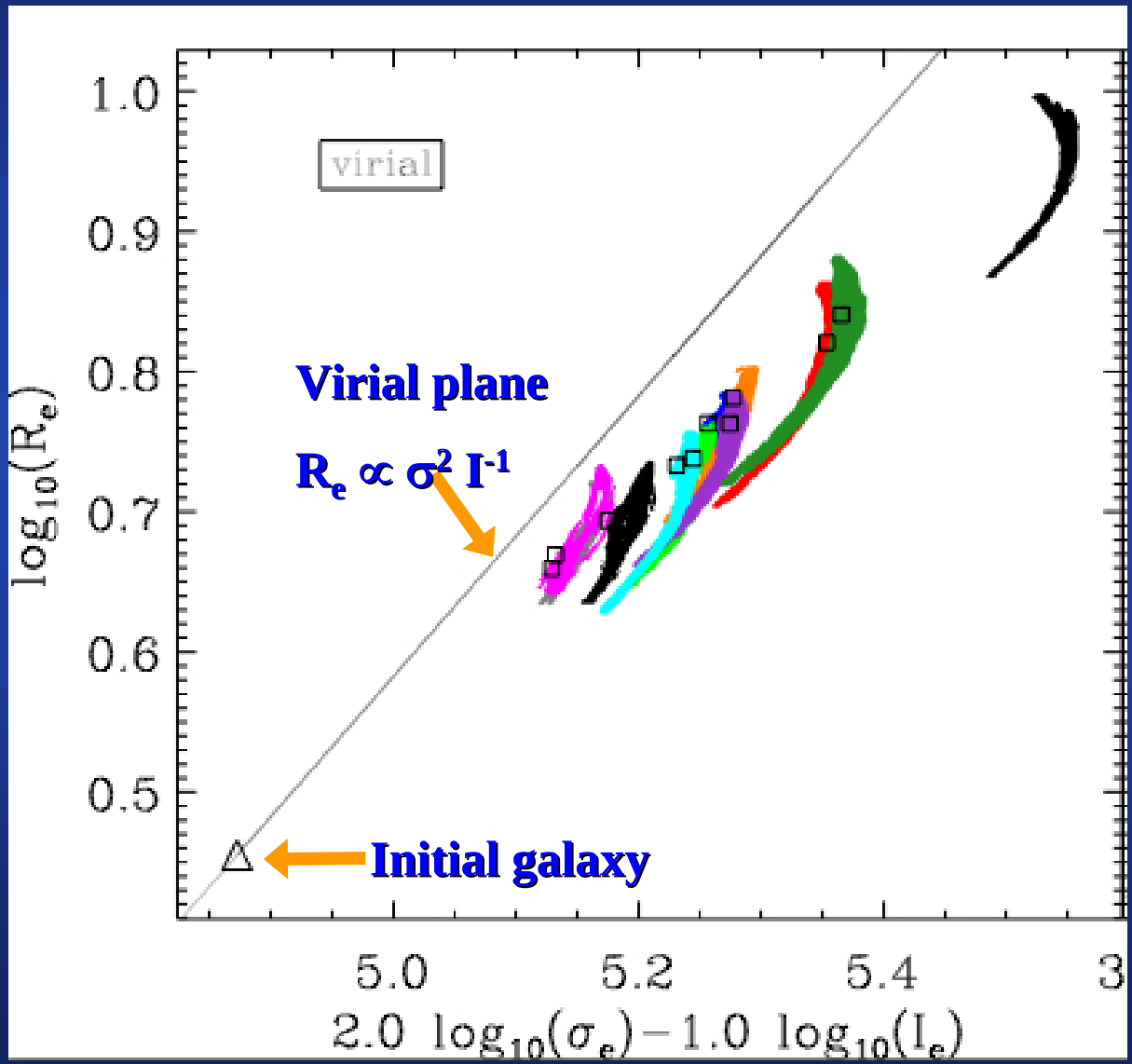
  evolution of massive ellipticals

  major mergers (R_e-L-σ -M_{bh} scaling relations)

  minor mergers (central properties, black holes)

Fundamental Plane

Boylan-Kolchin, Ma, Quataert (05, 06)



Virial Theorem

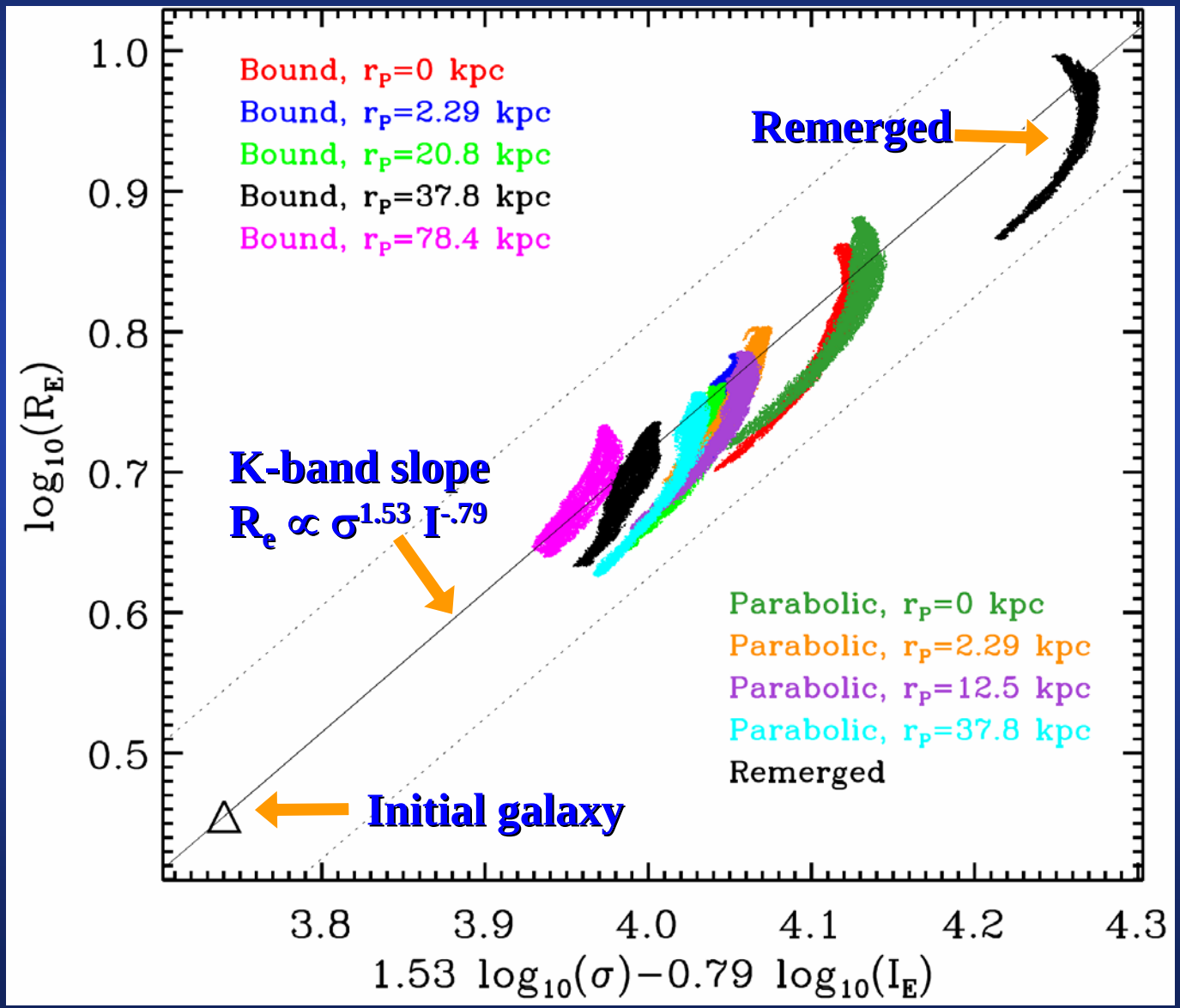
$\sigma^2 \propto M_{dyn}\ R_e^{-1}$

$\propto (M_{dyn}/L)\ I_e\ R_e$

Tilt from virial plane due to increasing (M_{dyn}/M_*) with M

Fundamental Plane

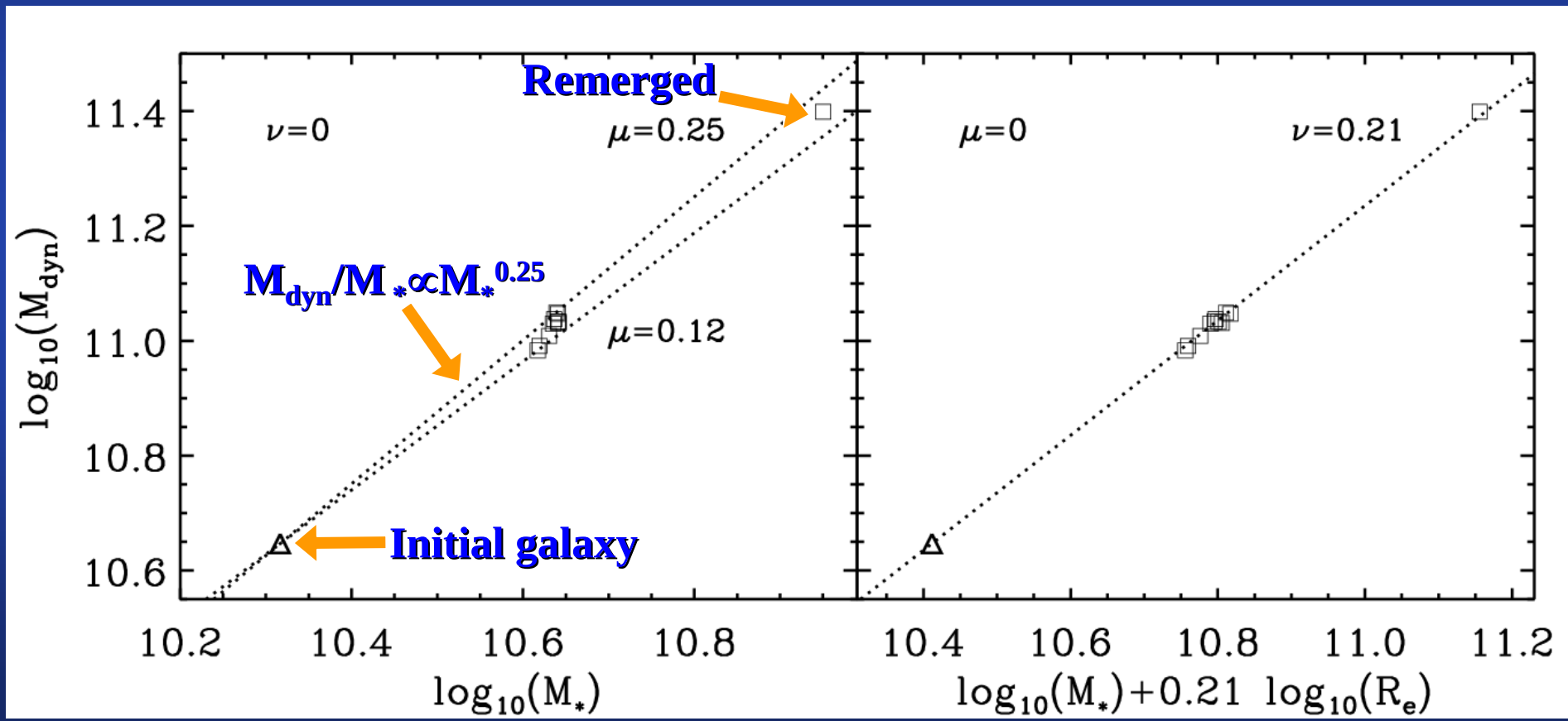
Boylan-Kolchin, Ma, Quataert (05, 06)



Fundamental Plane

Boylan-Kolchin, Ma, Quataert (05, 06)

Tilt from virial plane due to increasing $M_{dyn}/M_*(<R_e)$ with M

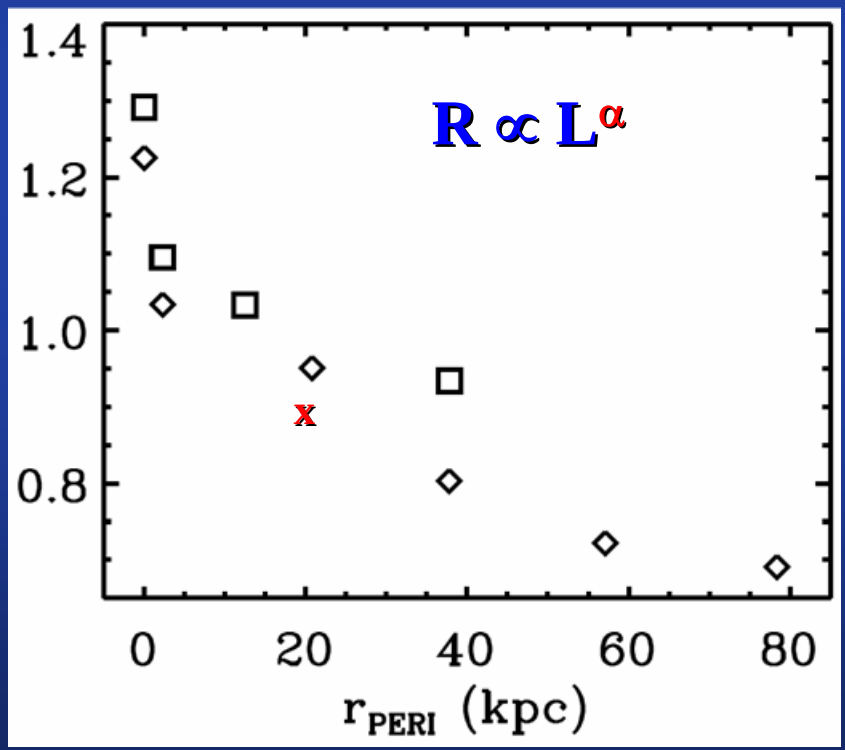


R-L and sigma-L Relations

Boylan-Kolchin et al (06)

⇒Scaling relations are a function of energy and angular momentum of merger orbit.

⇒Bulge loses less energy to dark matter halo on a more radial orbit



Merger Energetics

Energy of a single stellar bulge: $E = -f \frac{GM^2}{R}$

Energy conservation of mergers:

$$f_f \frac{M_f^2}{R_f} = f_1 \frac{M_1^2}{R_1} + f_2 \frac{M_2^2}{R_2} + (f_{orb} + f_t) \frac{M_1 M_2}{R_1 + R_2}$$

For $M_1 = M_2, f_{orb} = f_t = 0$ merger,

$M_f = 2M_1, R_f = 2R_1$

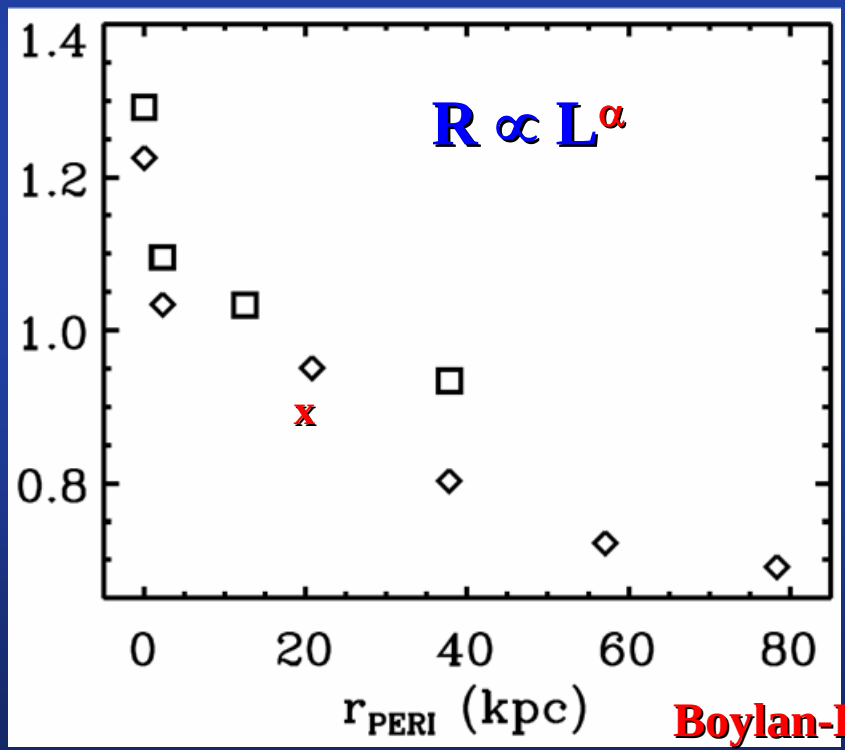
$\Rightarrow R \propto M$

R-L and sigma-L Relations

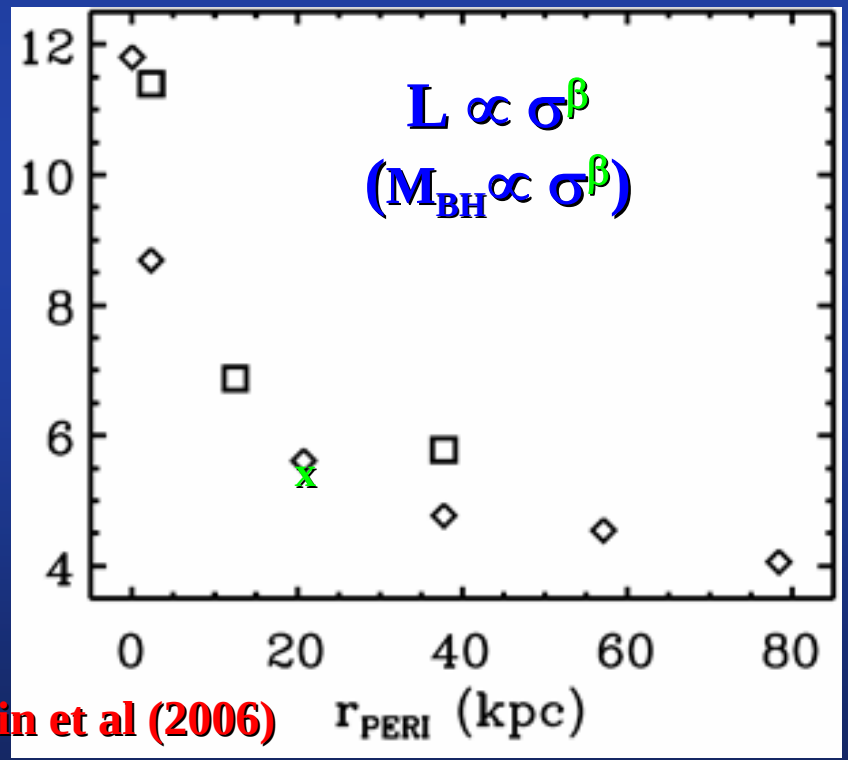
⇒Scaling relations are a function of energy and angular momentum of merger orbit.

⇒Bulge loses less energy to dark matter halo on a more radial orbit

α



β



Boylan-Kolchin et al (2006)

Sloan non-BCGs

Desroches, Quataert, Ma, West
(astro-ph/0608747)

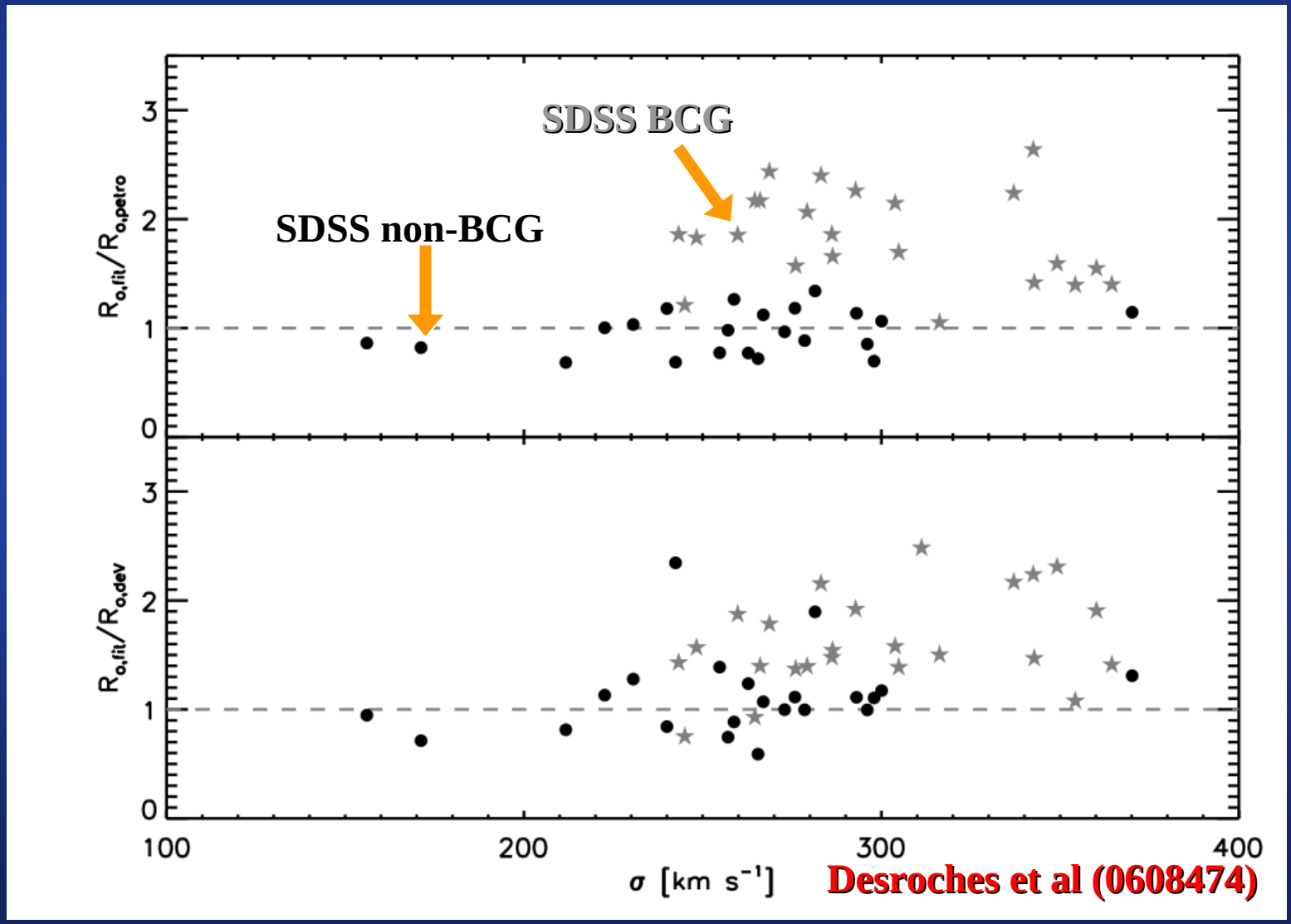
SDSS DR4 + VAGC catalog

Cuts: concentration c > 2.86
Sersic index n > 2.5
color (g-r) > 0.7

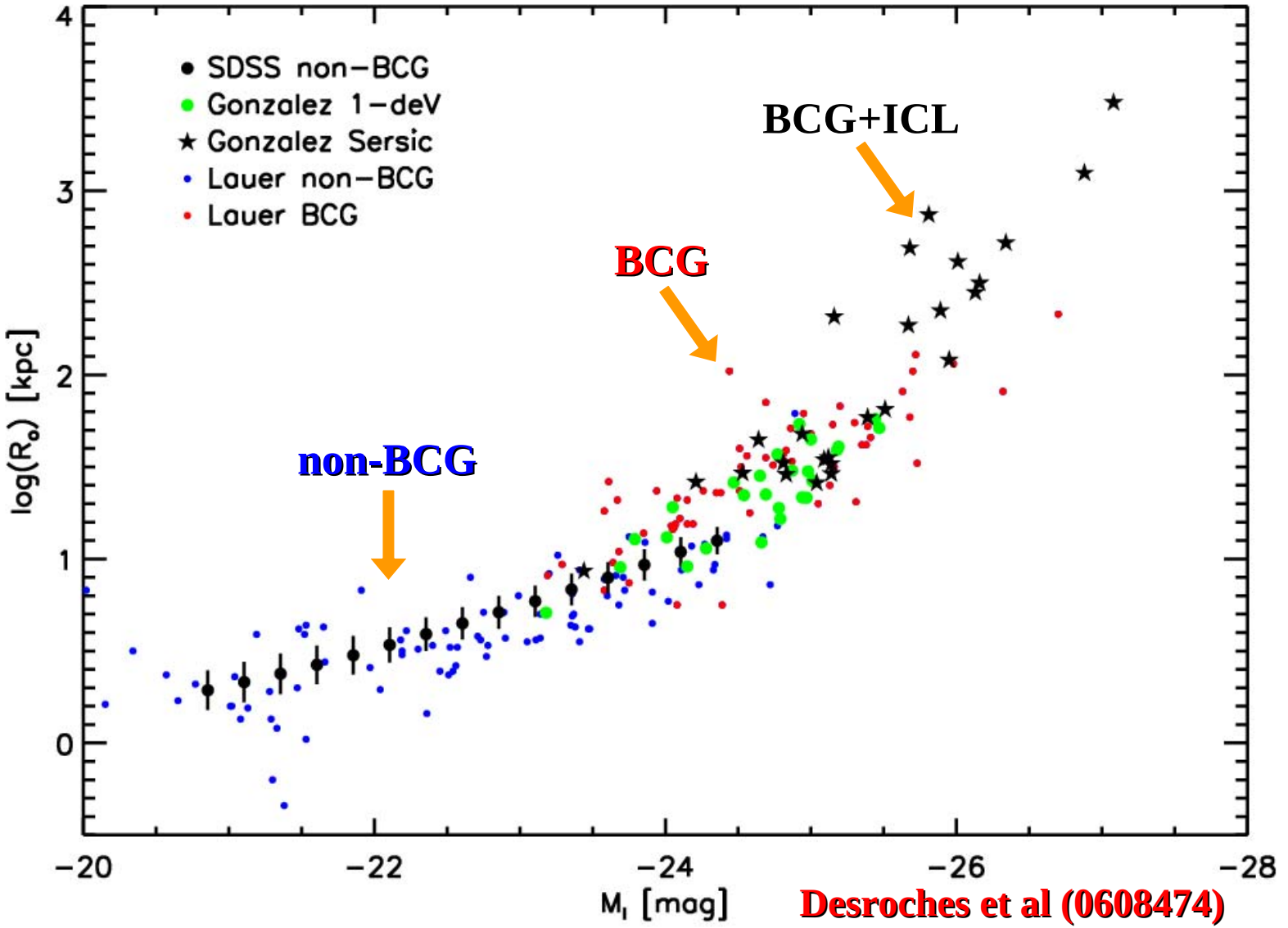
exclude BCGs (C4 catalog) $\Rightarrow$ **79,482** early-type non-BCGs

SDSS: excess sky subtraction issue

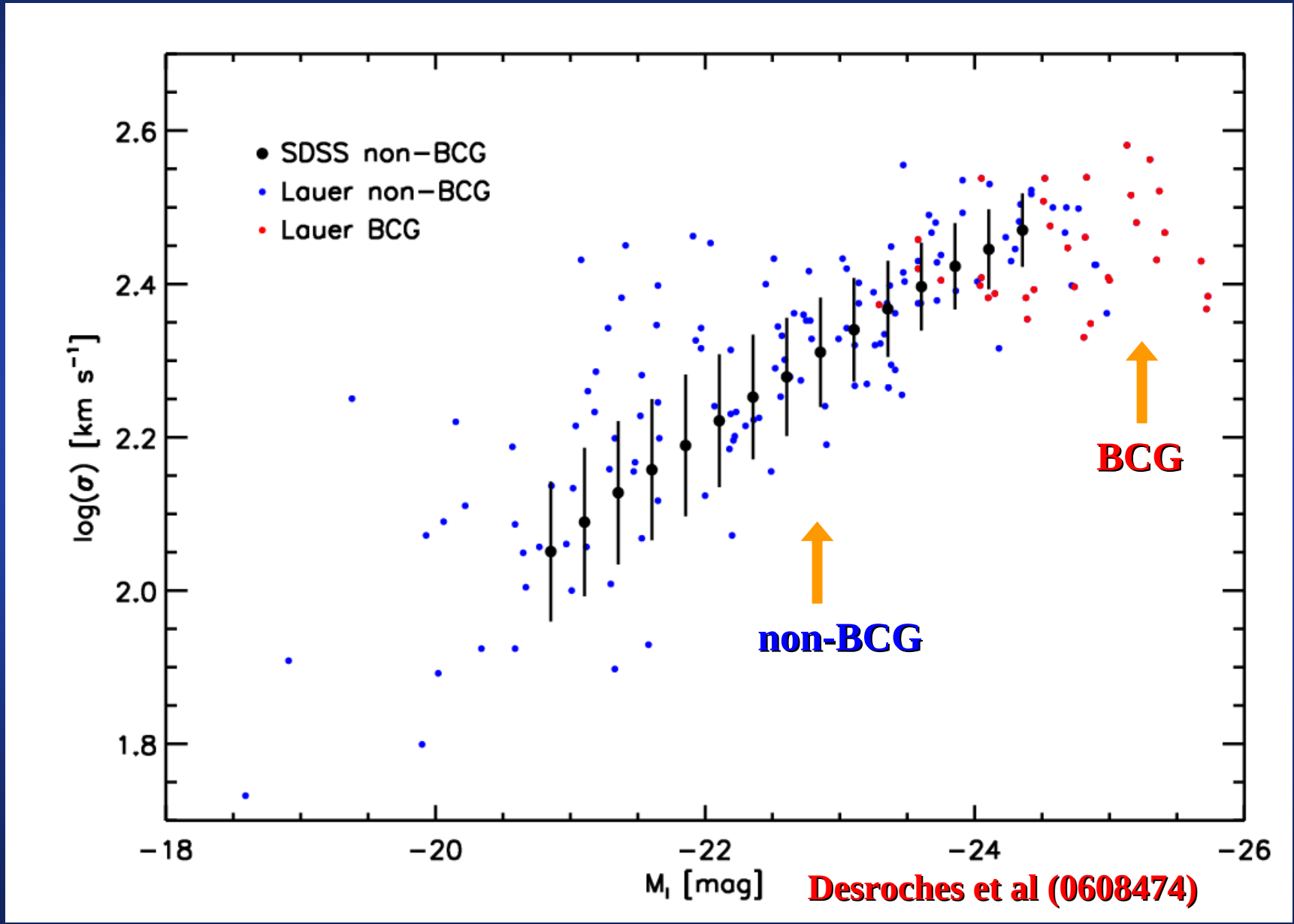
Also see http://sdss.org/dr4/help/known.html
Lauer et al (2006) Bernardi et al (2006)



Radius-Luminosity Relation



Sigma-Luminosity Relation

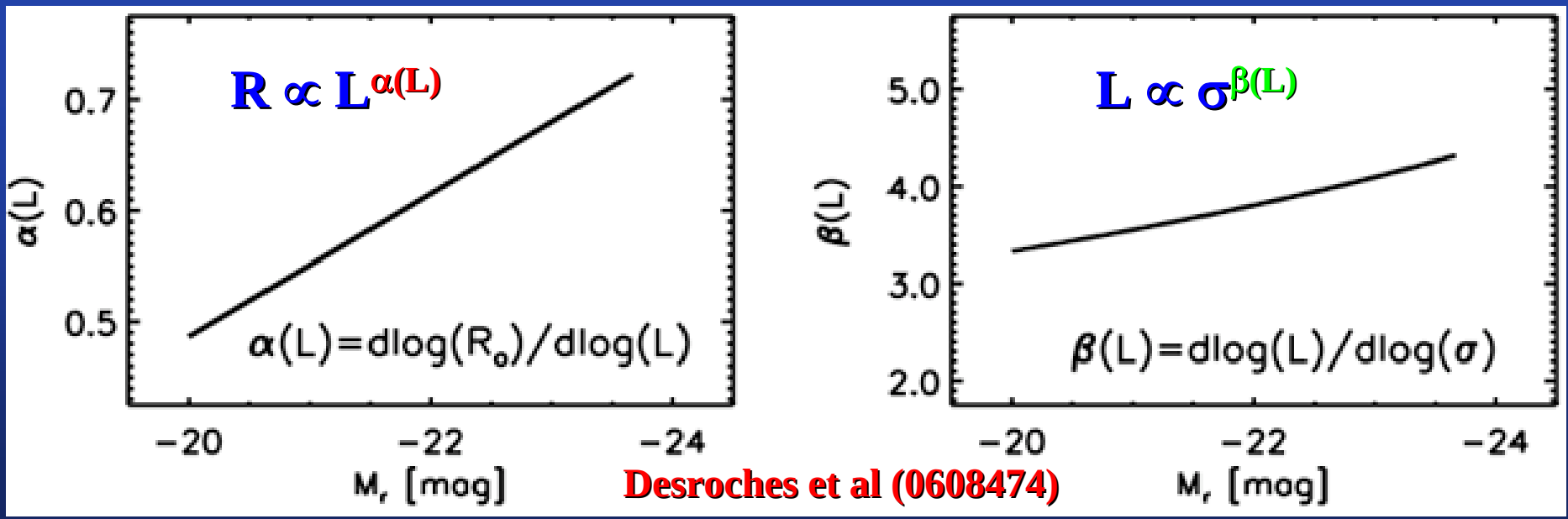


Sloan non-BCGs

SDSS DR4 + VAGC catalog

Cuts: concentration c > 2.86
Sersic index n > 2.5
color (g-r) > 0.7

exclude BCGs (C4 catalog) $\Rightarrow$ **79,482** early-type non-BCGs



Desroches et al (0608474)

Summary

Data

Sloan non-BCG ellipticals (Desroches et al 06)**:**

R_e - L and L - σ relations show systematic steepening with L.

$\Rightarrow$ Steeper M_{bh}- σ relation for massive ellipticals? (see also Wyithe)

BCGs:

Steepening with L continues (Lauer et al 2006, Bernardi et al 2006)

Photometry issues in SDSS. Intra-cluster light.

Need deeper understanding of ICL, BGG, rank 2+ galaxies.

Summary

Simulations

R_e - L, L - σ, M_{bh}- σ relations (Boylan-Kolchin et al 2006)**:**

Steepen for massive ellipticals formed via gas-poor mergers on more radial orbits (e.g. along filaments).

Fundamental plane (Boylan-Kolchin et al 2005)**:**

Preserved by gas-poor mergers of ellipticals.

Increasing dark matter fraction (within R_e) with L gives sufficient tilt from virial plane

Implications

M_{bh} ~10^{10} M_{sun} out there?

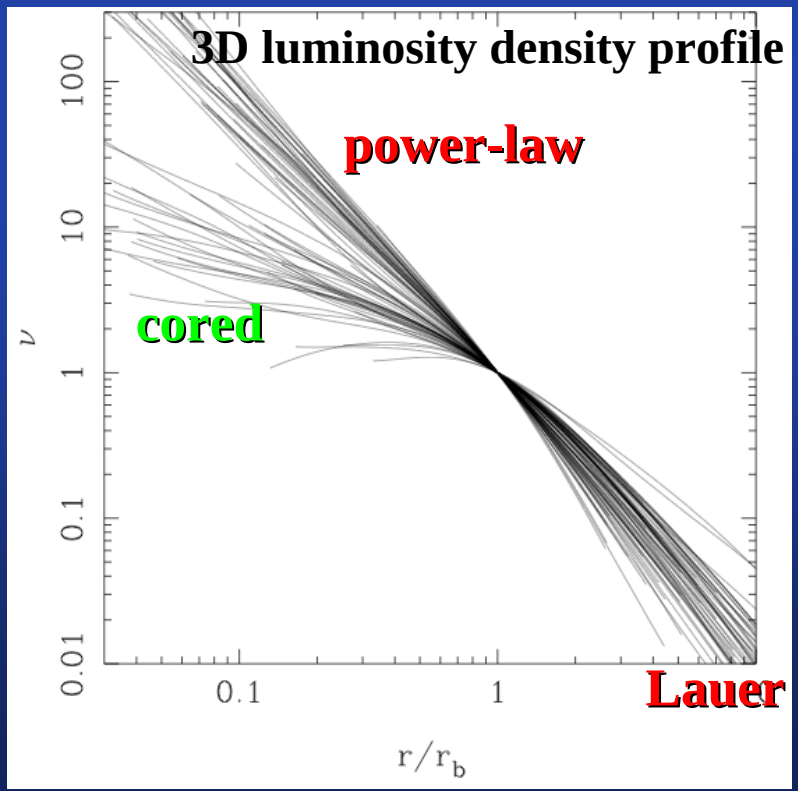
Lensing galaxies' L - σ ?

Ellipticals: cusp vs core

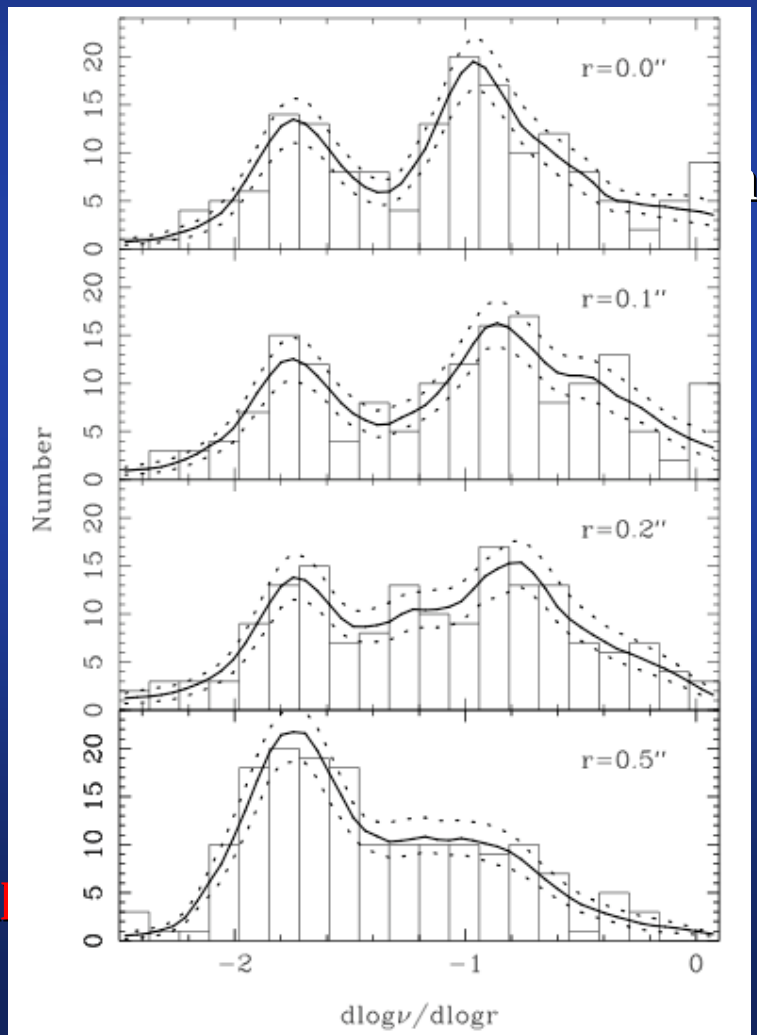
e.g. Bender et al (1992)

"Power-law" Ellipticals (dlog I/dlog r < -0.5):
less luminous, rotation, disky, **gas-rich** merger remnant

"Cored" Ellipticals (dlog I/dlog r >
more luminous, little rotation, nant



Lauer et al



Our Merger Simulations: Initial Galaxy Models

Stellar bulge

$\rho \propto (r/a)^{-1}(1+r/a)^{-3}$ (Hernquist 1990)

$M_{dm} = 20\ M_*$

Dark matter halo

$\rho \propto (r/r_s)^{-1}(1+r/r_s)^{-2}$ (NFW 1996)

$M_{dm} = 10^{12}\ M_{sun}$, $c = r_{vir}/r_s = 10$

adiabatically contracted initially (Blumenthal et al.1986)

Black holes

$M_{bh} = M_* /500$

Our Merger Simulations: Parameters

- **Gadget 2: parallel N-body mode**
- **$N_{DM} = 5\times10^5$, $N_* = 2.5\times10^4$, $\varepsilon = 0.1\ R_e$**
- **For comparison, vary orbital E and L**

  1:1 and 1:3 mergers