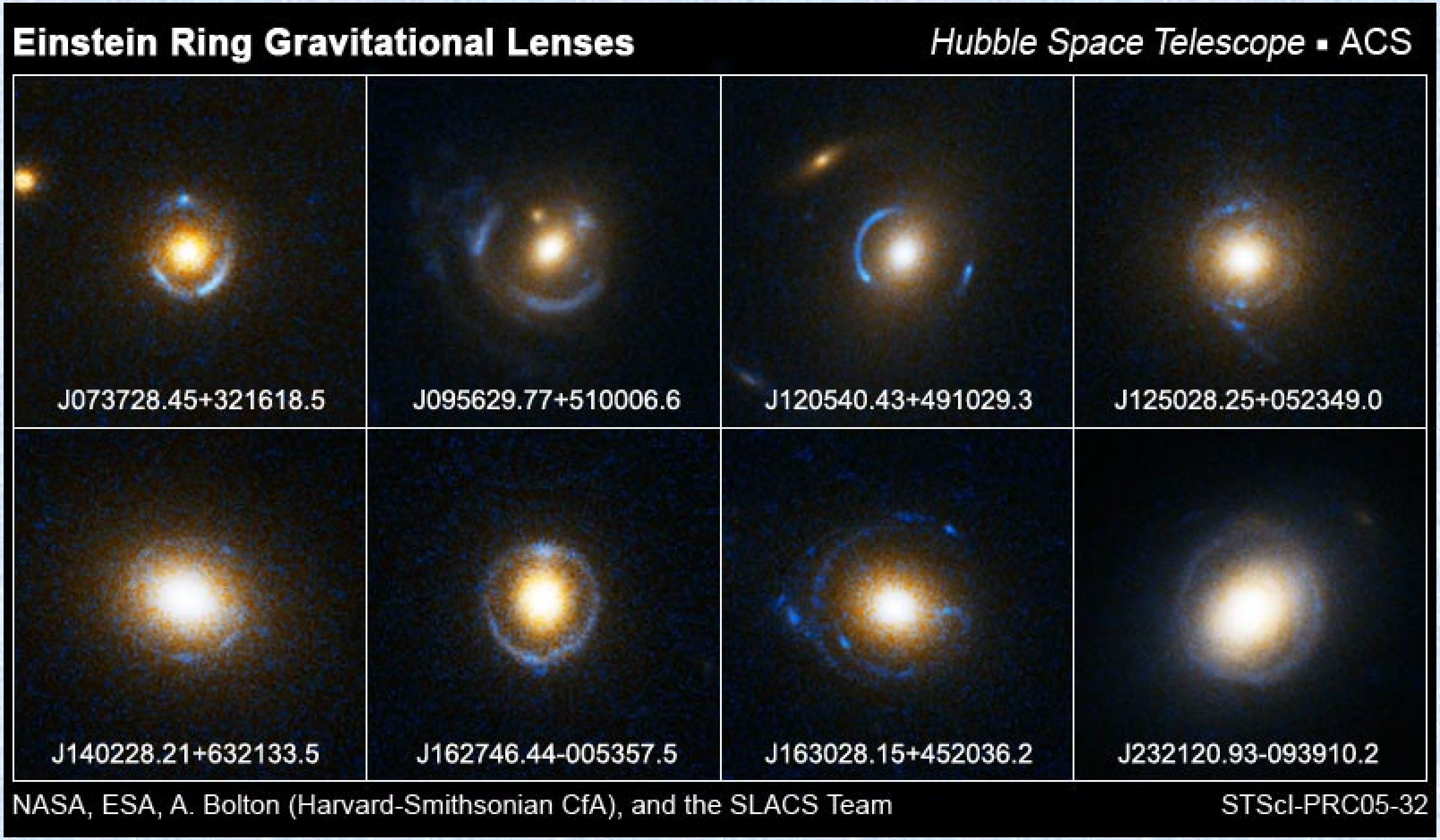
Galaxy scaling laws under the "gravitational microscope"



Tommaso Treu (UCSB)

Collaborators

Leon Koopmans (LSD+SLACS)

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Scott Burles (SLACS)

Leonidas Moustakas (SLACS)

Raphael Gavazzi (SLACS+)

Jason Rhodes (special guest)

Outline

1. The Fundamental Plane as a diagnostic of the internal structure of early-type galaxies
2. The bulge-halo “conspiracy”.
    1. Scaling relations between dynamical, weak and strong lensing properties

The internal structure of spheroids: clues to the formation process

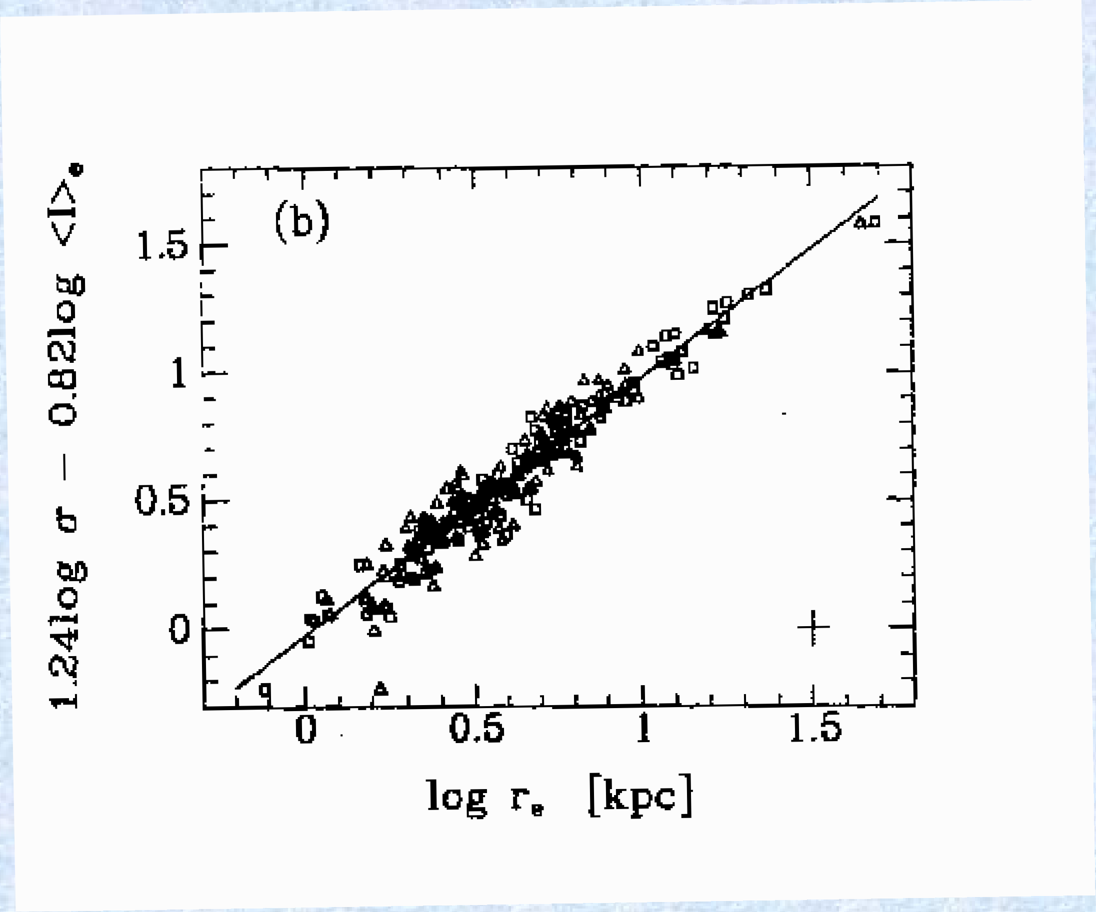
- Dark matter halos detected (sometimes…)
- Most stars are old
- Tight scaling relations between various properties, velocity dispersion, size, luminosity, black hole mass… (e.g. Ma's talk)

The formation of spheroids: questions

- How come the scaling relations, the FP in particular, are so tight?
- Many possible sources of scatter, including:
  - Stellar population effects
  - Distribution function differences
  - Dark matter content
- **Yet somehow, baryons and dark matter "conspire" to produce small scatter**

The Fundamental Plane as a diagnostic of galaxy structure

- Empirical correlation between size, luminosity and velocity dispersion
- Gives "effective M/L" at "effective mass"



Dressler et al. 1987; Djorgovski & Davis 1987;
Bender Burstein & Faber 1992; Jorgensen et al. 1996

The "tilt" of the FP

- In terms of effective mass ($M_*=5\sigma^2 R_e/G$), the FP reads $M_*/L \sim M_*^{0.25}$
- Possible Explanations:
  - Stellar population trends (c.f. 'downsizing' measurements, e.g. Treu et al. 2005)
  - Dynamical Trends. More dark matter, change in distribution function, i.e. virial coefficient ($5 \to K_v$)

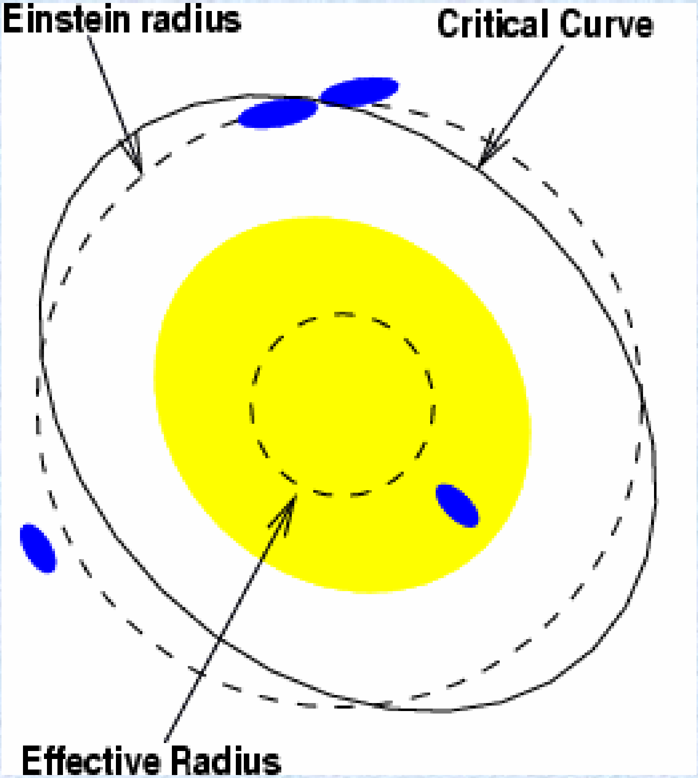
Tilt and tightness. Implications for the formation process

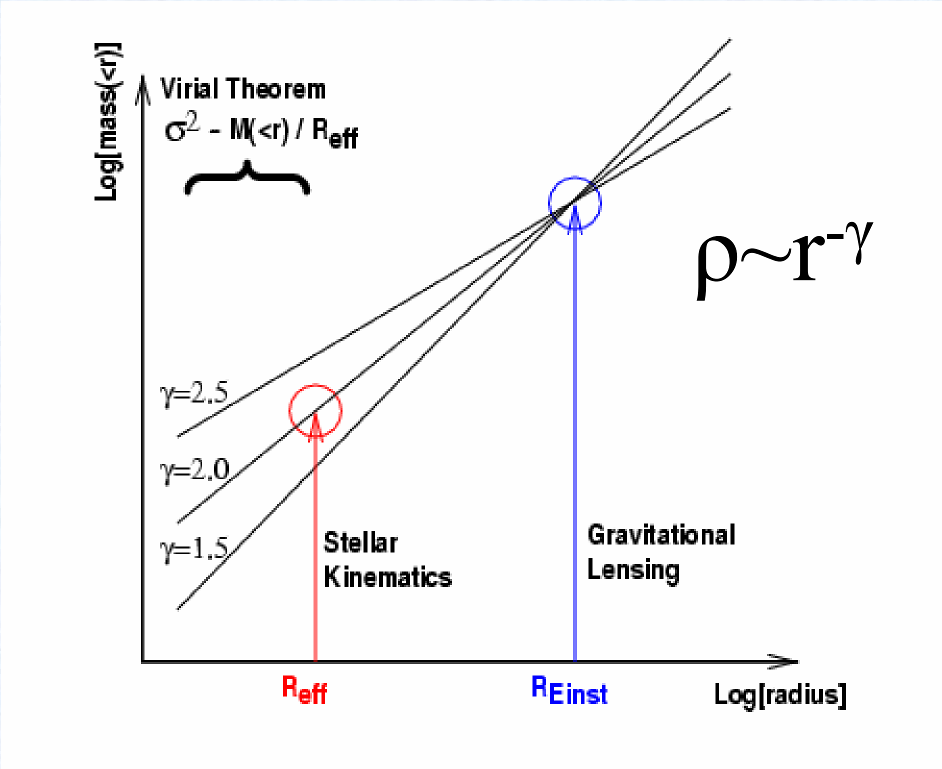
- Formation history, including environmental effects, is not “scale free”: star formation history, halo buildup, depend on final mass
- Yet, at any given mass, star formation history, mass profile, etc are remarkably homogeneous (another “conspiracy”)

What can lensing do for us?

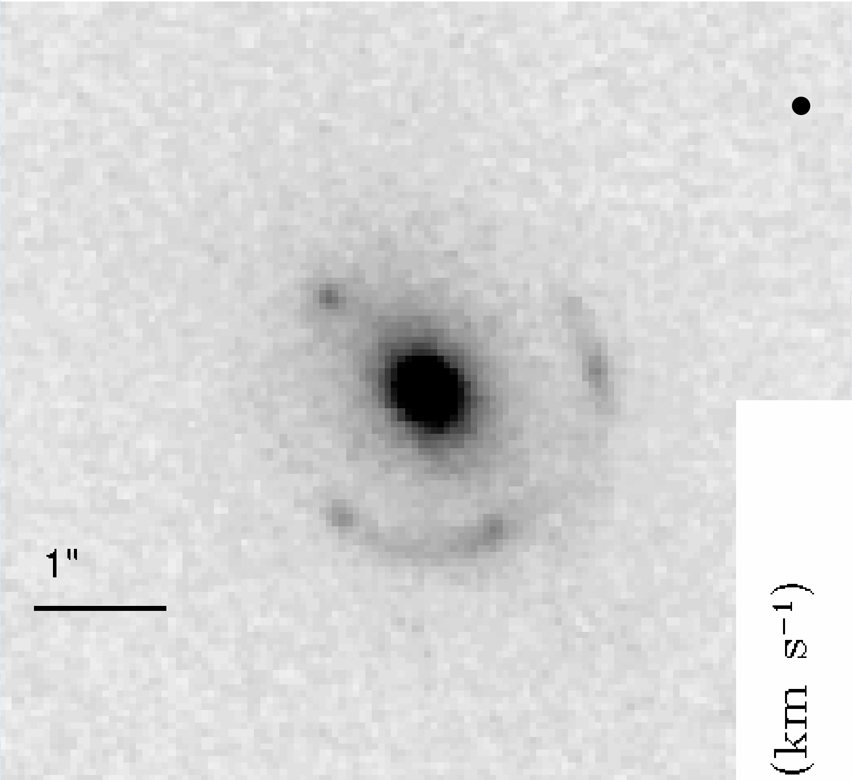
- Most studies of high-z E/S0 measure their star formation history or demographics.
- What about the internal properties?
  - Do high-z E/S0 have dark halos? What do they look like?
  - What is the evolution of the mass structure of E/S0 over cosmic time?
- LENSING ALLOWS US TO “DISSECT” HIGH-Z E/S0s

Z>0: lensing + dynamics

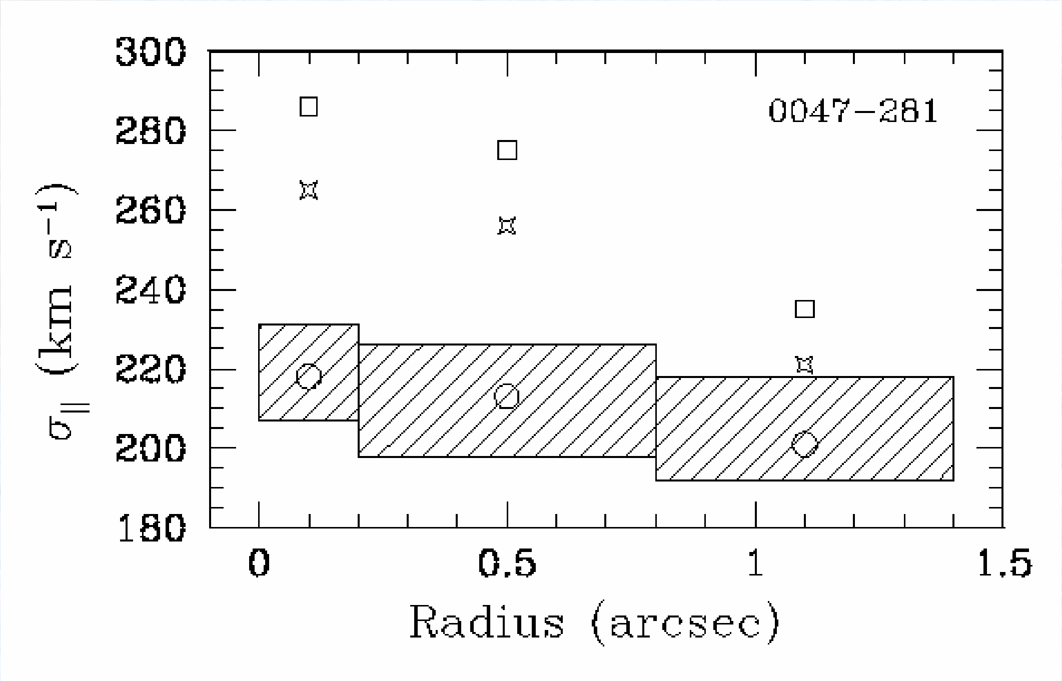




Example of data: 0047 at z=0.485



- 5.75 hrs integration; velocity dispersion profile to ~5 %

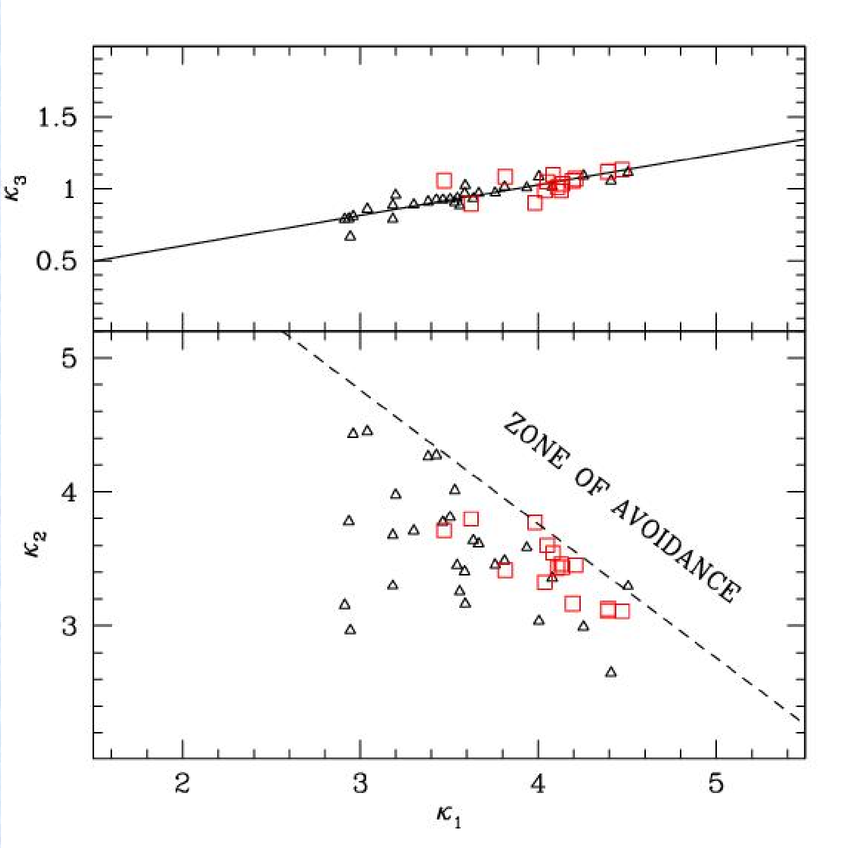


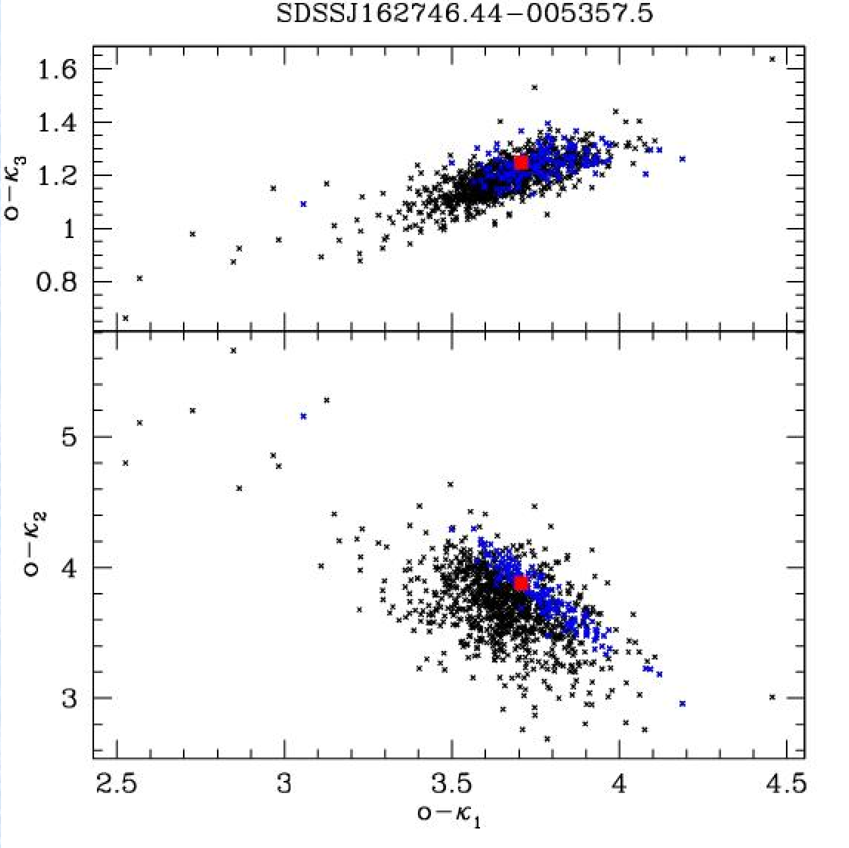
Koopmans & Treu 2003

Samples:

- Lens structure and dynamics survey (LSD): all (10) suitable gravitational lenses known <2002
  - (TT + Koopmans)
- Sloan Lens ACS Survey: ongoing survey. Largest sample of lenses so far (~50! Bolton's talk).
  - (TT + Koopmans, Bolton, Burles & Moustakas)

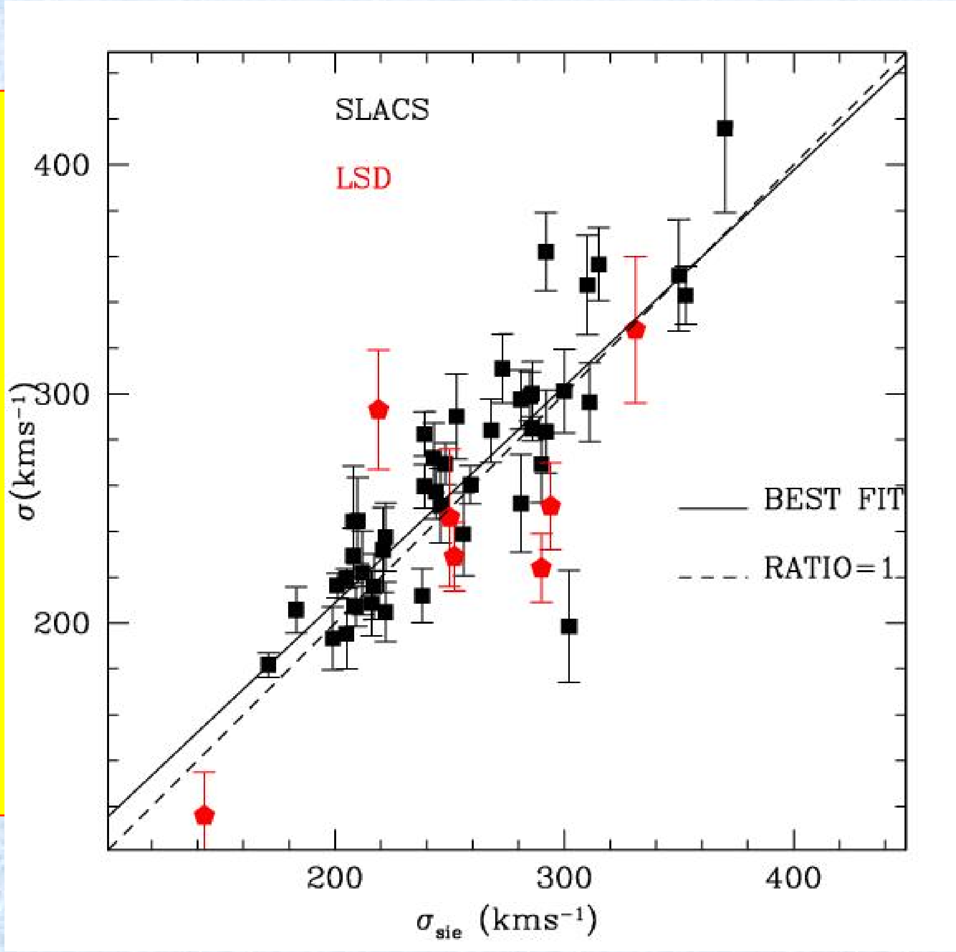
Results: lenses are "normal" spheroids





Lenses live in the same FP as normal spheroids, once selection in σ is taken into account (Treu et al. 2006)

Results: a scaling law measuring mass profiles!

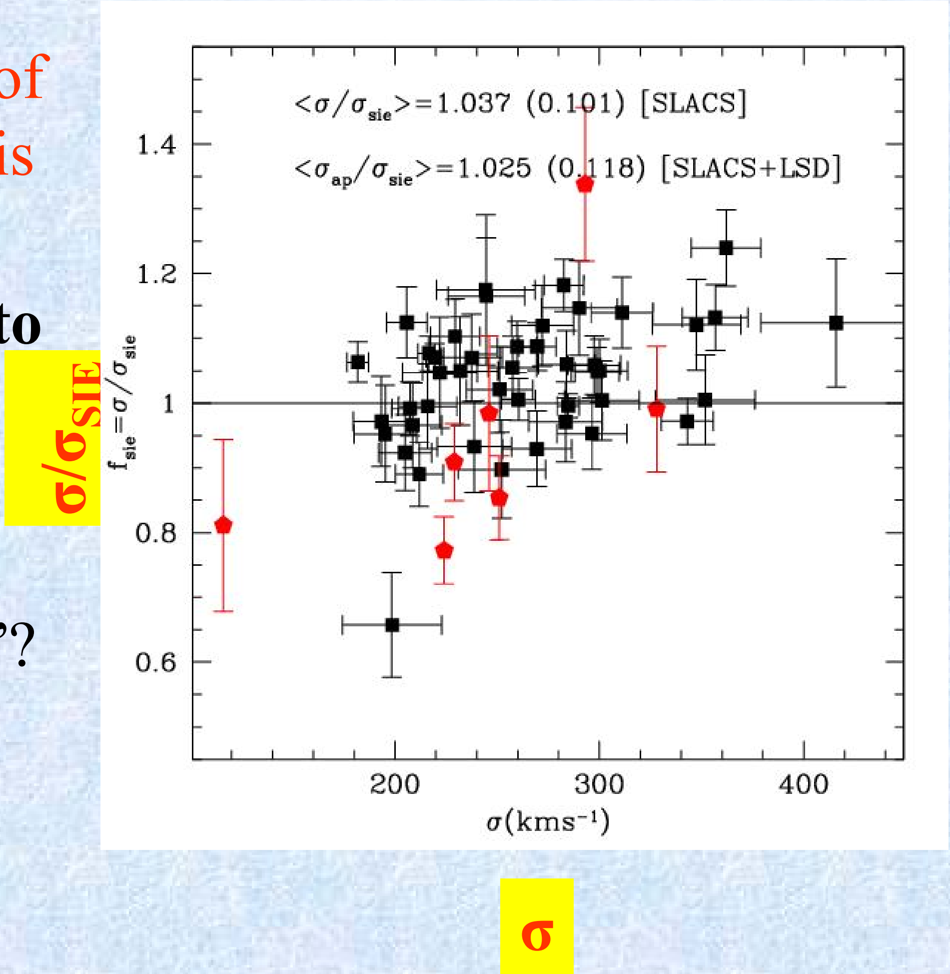


Stellar velocity dispersion

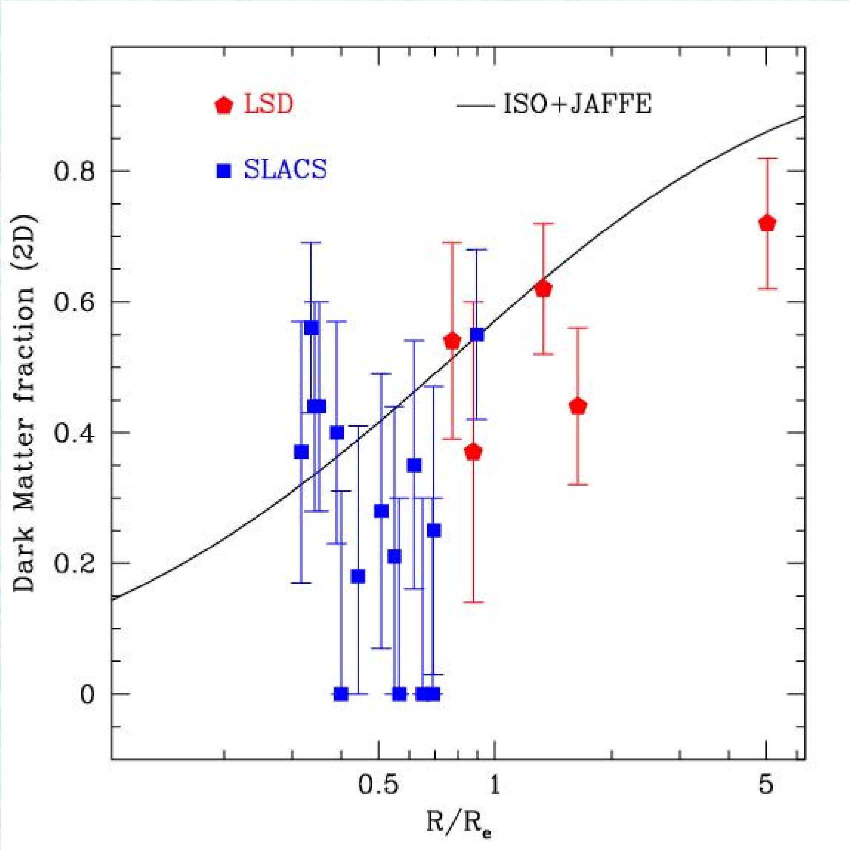
"Lensing" velocity dispersion

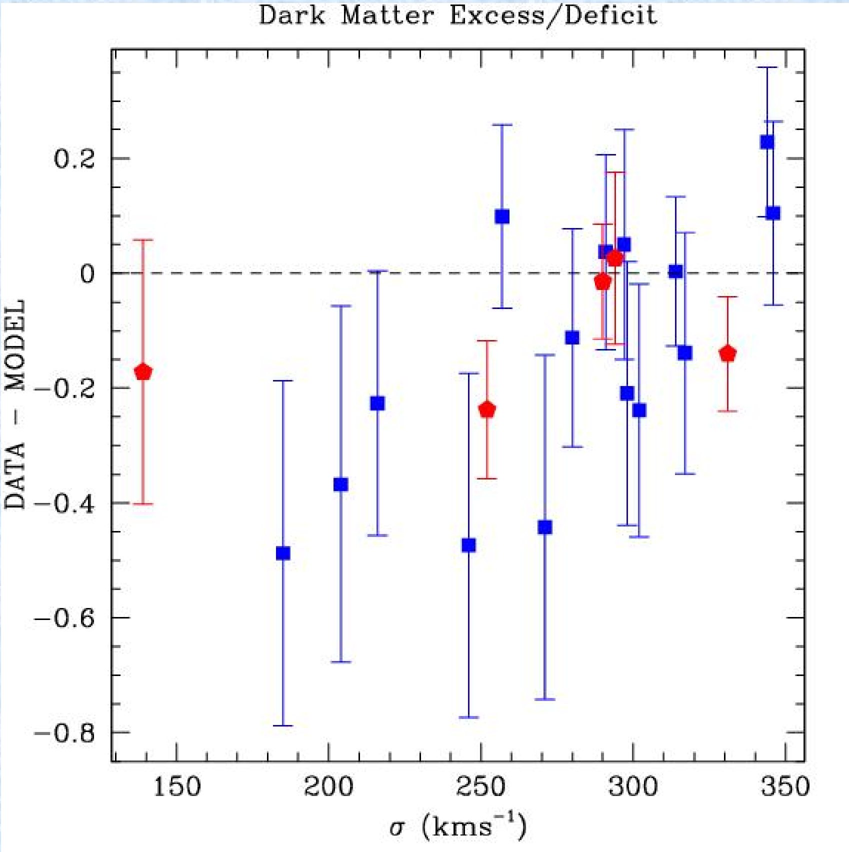
Or in terms of ratio…

- The ratio of the stellar velocity dispersion to that of the best fitting lens model is very close to unity
- **The mass profile is close to isothermal: $\rho \sim r^{-2}$. [Koopmans's talk]**
- How do the stars and dark matter know "where to go"?
- **Dark-luminous mass "conspiracy"**



Are E/S0 exactly isothermal? 1. Velocity dispersion trends





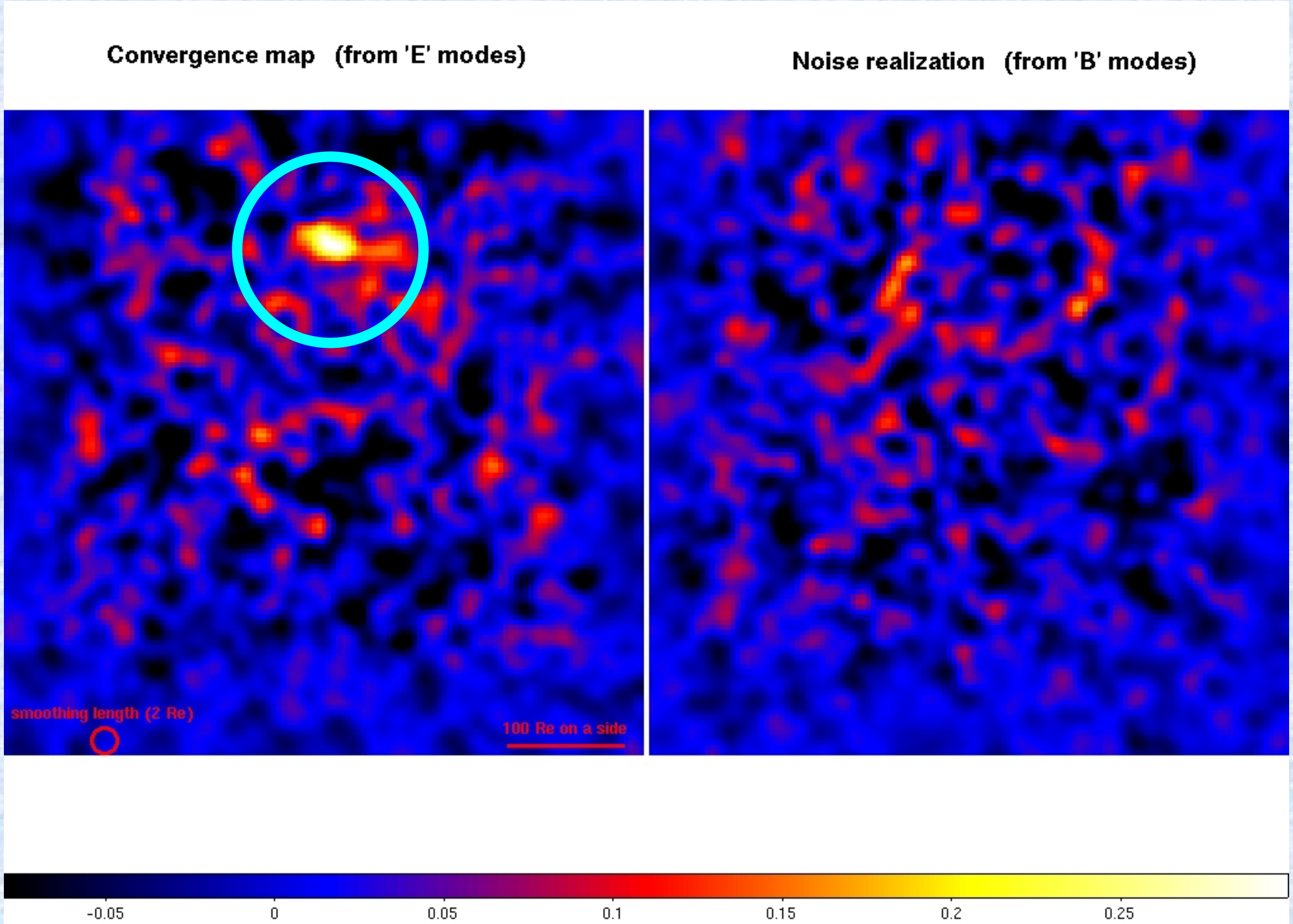
Do more massive galaxies have more dark matter?
Wait for the next SLACS papers….

Are E/S0 exactly isothermal? 2. Enter weak lensing…

- Deeper ACS data (1 orbit F814W) available for 18 SLACS lenses (85 expected by the end of cycle 15).
- Background galaxy density ~80/ square arcmin
- Stacked weak-lensing analysis yields a significant detection of the shear (>8 sigma)
- Analysis exploits the most advanced corrections for ACS-PSF systematics (breathing, CTE…) developed for cosmic shear analysis (Rhodes et al. 2006)

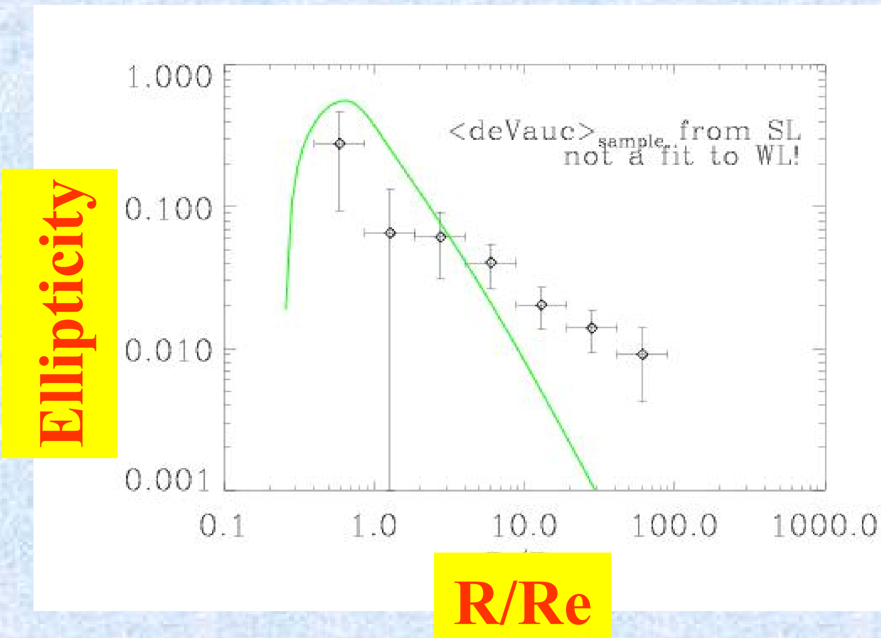
Gavazzi, TT et al. 2006

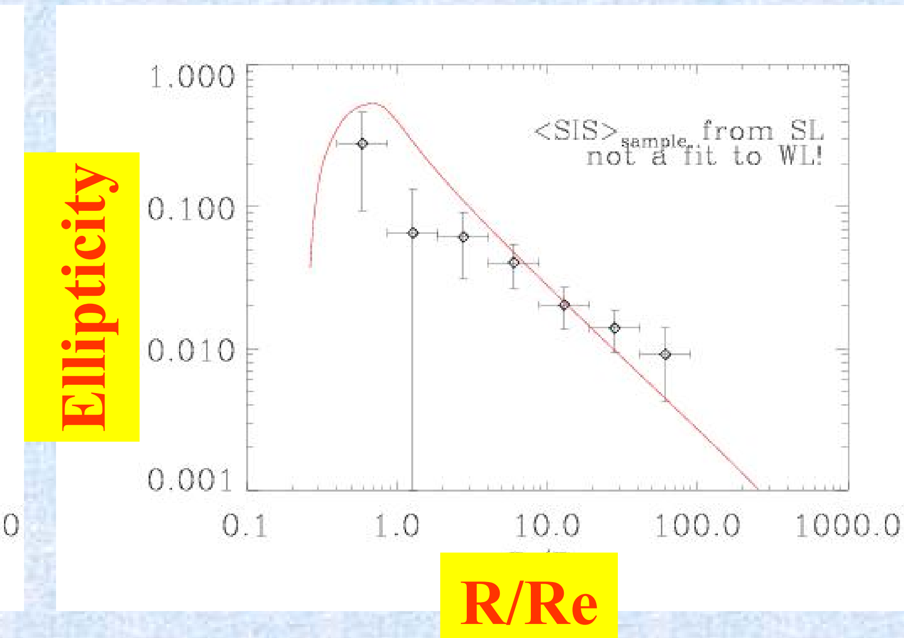
Are E/S0 exactly isothermal? 2. Voila'!



Gavazzi, TT et al. 2006

Are E/S0 exactly isothermal? 2. Behavior at large radii





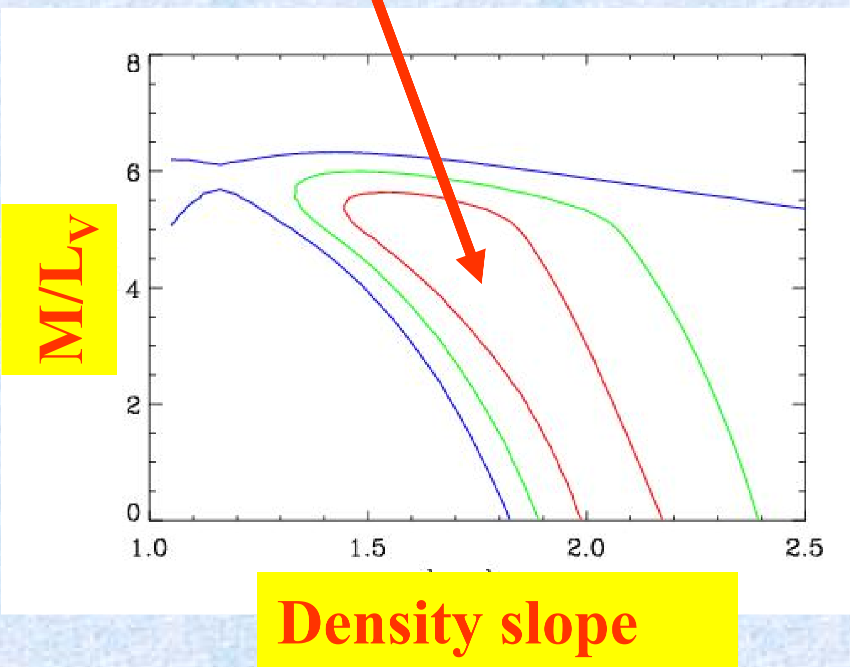
Constant M/L ratio doesn't work

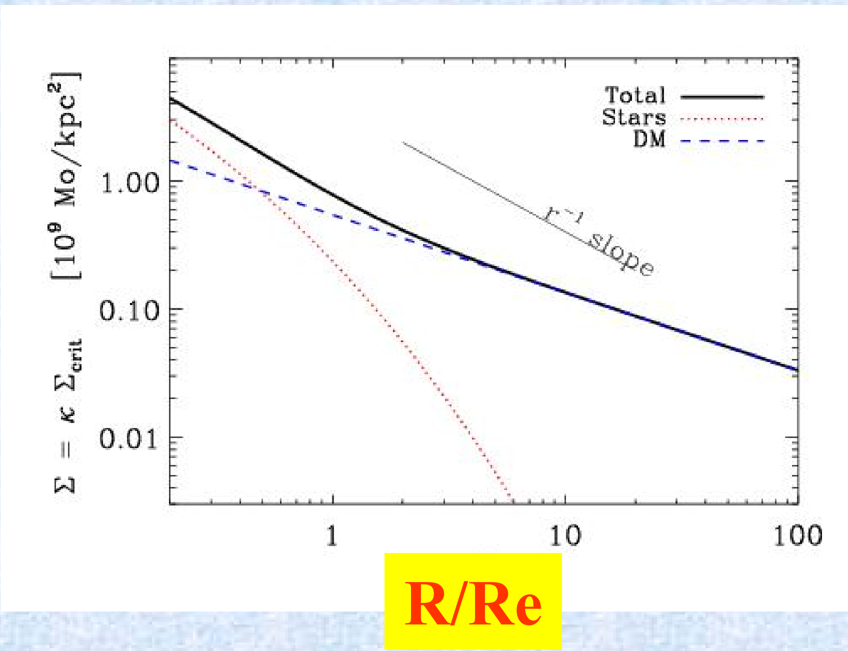
Isothermal works well

Gavazzi, TT et al. 2006

Are E/S0 exactly isothermal? 2. Behavior at large radii

68%

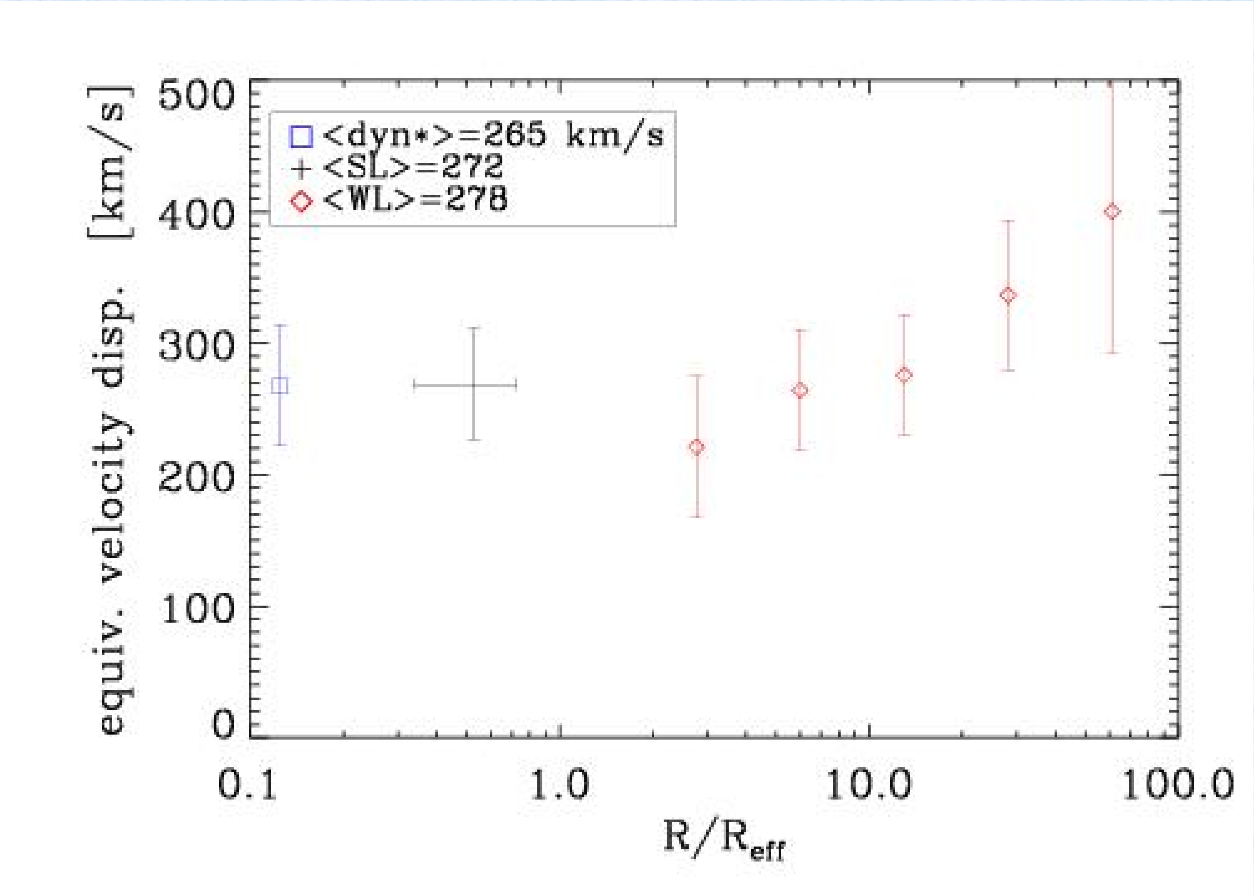


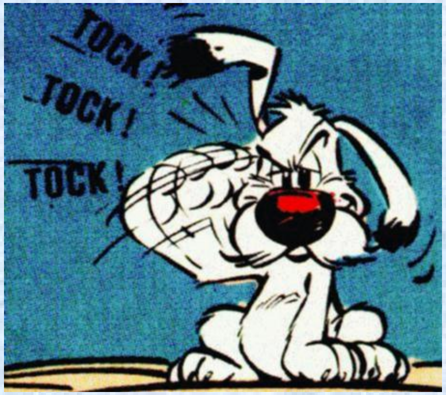


Two component fit. Best slope with M/L=0 is 2.08+-0.08

Gavazzi, TT et al. 2006

Are E/S0 exactly isothermal? 3. "Velocity dispersion" profile





Gavazzi, TT et al. 2006

Conclusions

- The mass density profile of E/S0s can be measured to z~1 by combining lensing and stellar dynamics
- Massive E/S0 lens galaxies are well reproduced by singular isothermal ellipsoids out to z=1:
  - Bulge/Halo conspiracy
  - Jury still out whether the trend extends to smaller masses
- Dark halos can be detected out to ~100 effective radii combining weak-lensing.
  - The total mass profile appears to be close to isothermal all the way out. The plot thickens…

The end