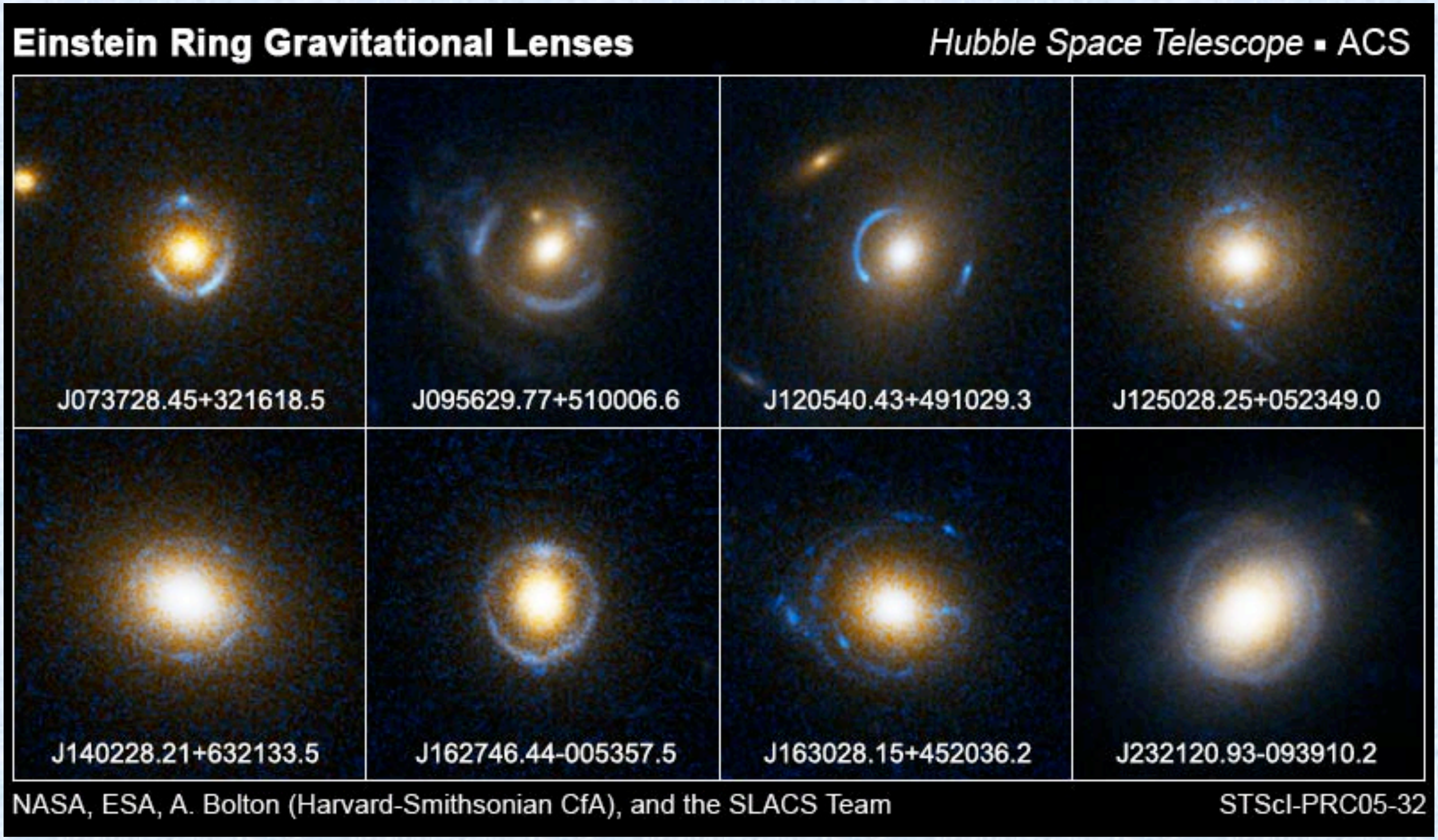
The SLACS survey: overview and highlights



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SLACerS and friends:

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- **Raphael Gavazzi (UCSB)**
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- **Leon Koopmans (Kapteyn)**
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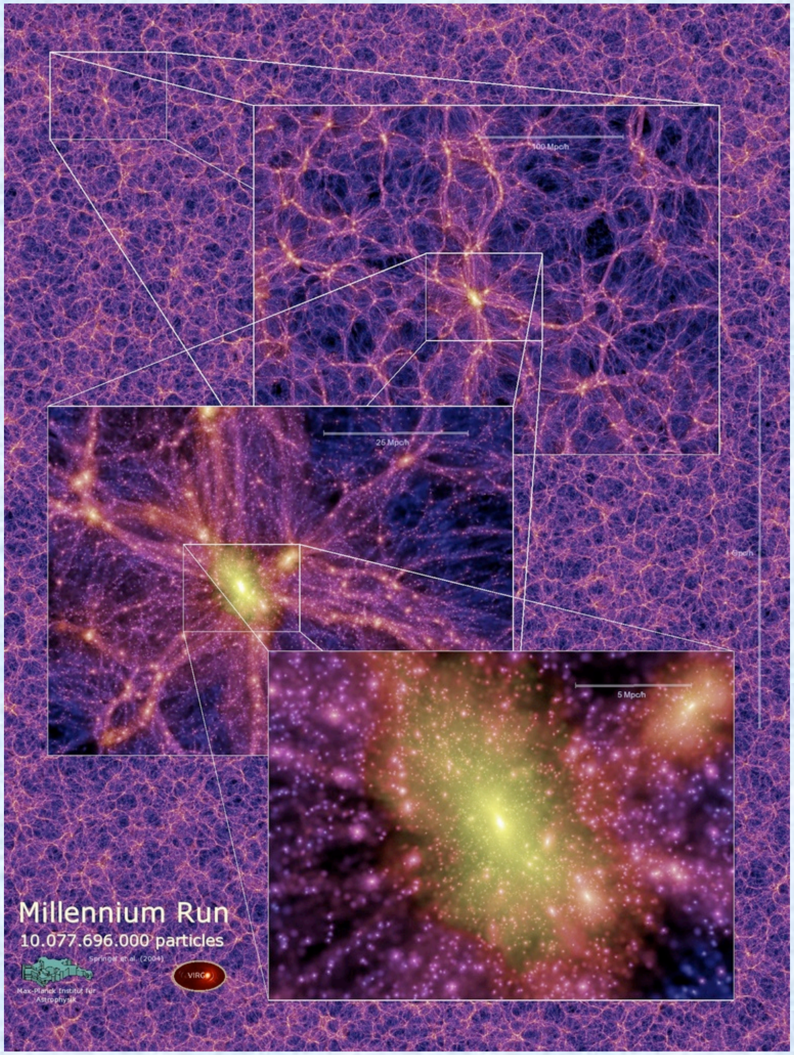
- **Leonidas Moustakas (JPL)**
- Simona Vegetti (Kapteyn)

Outline

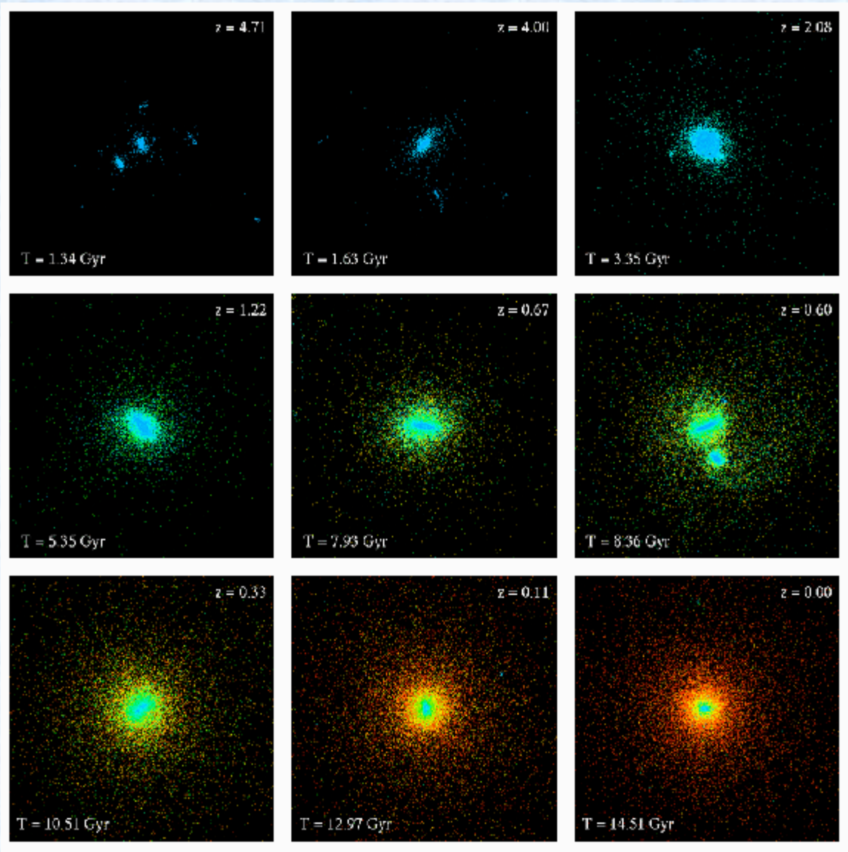
- Introduction:
  - Luminous and dark matter in early-type galaxies. The power of gravitational lensing
  - Does mass follow light?
- The SLACS Survey
  1. Overview, strategy and numbers
  2. Are Lenses normal early-type galaxies?
  3. The bulge halo conspiracy. Lensing and dynamics
  4. A more Fundamental Plane?
  5. Weak lensing: mass density profiles to 100 effective radii
  6. SLACS lenses as cosmic telescopes: FBCNELLGs

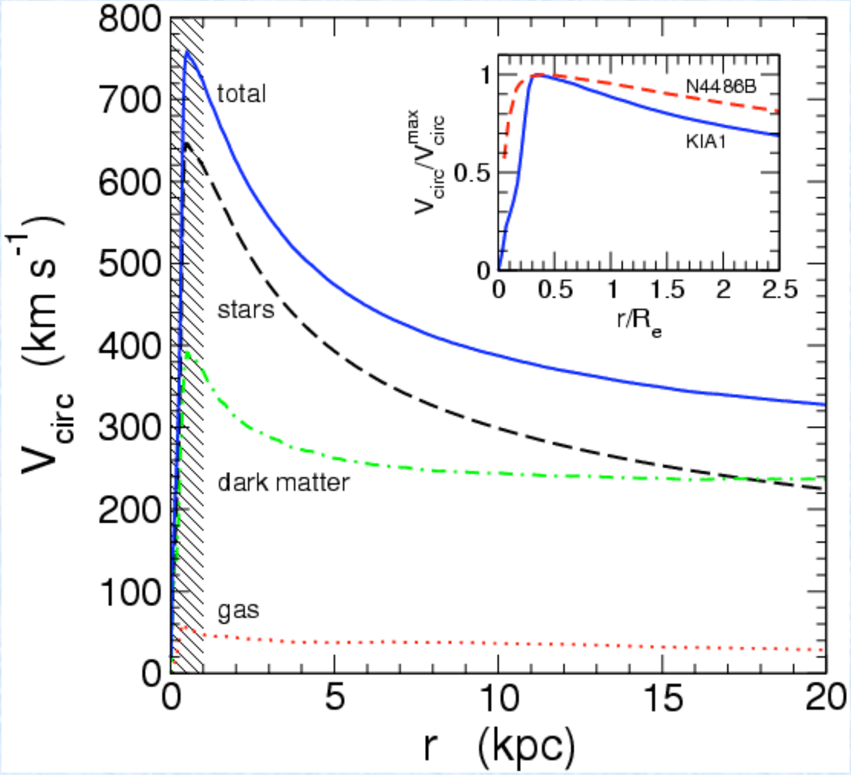
Hierarchical formation



- Disks form in dark matter halos
- Spheroids form by mergers of disks
- Halos (and the galaxies inside) grow hierarchically over time

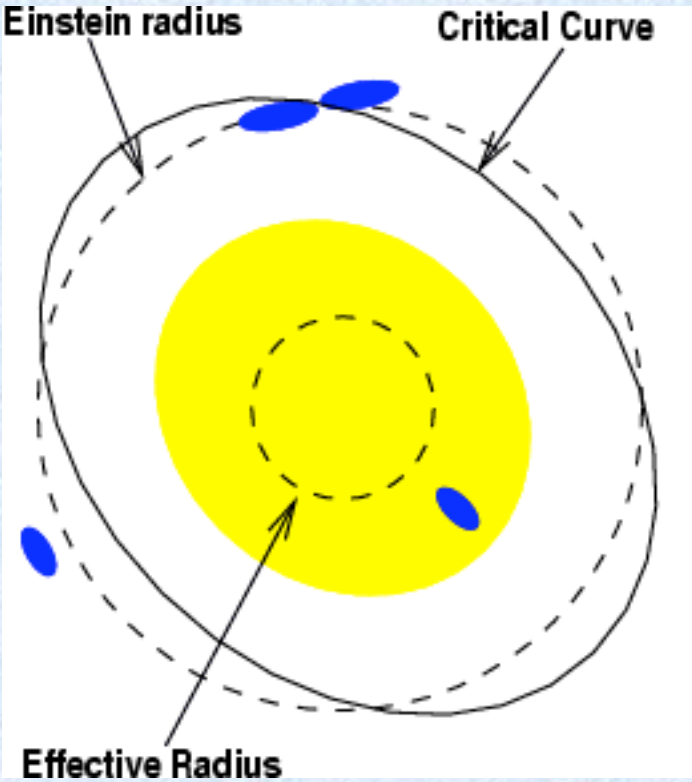
But there are stars and gas…

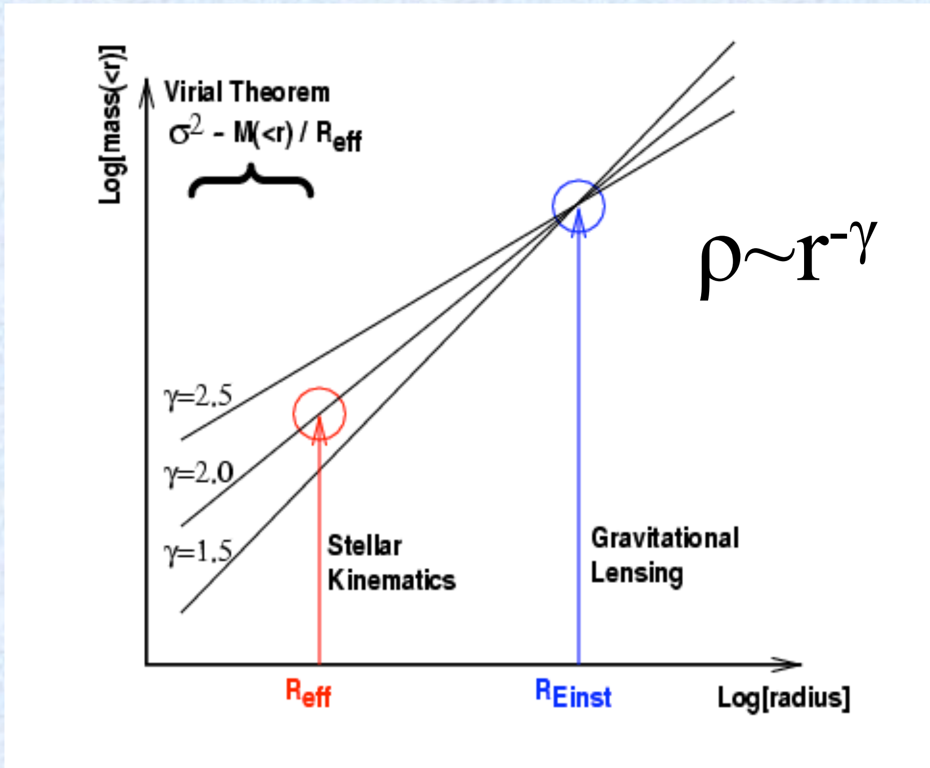




Meza et al. 2003; see also, e.g., Nagamine et al. 2005, Robertson et al. 2006

Z>0: lensing + dynamics



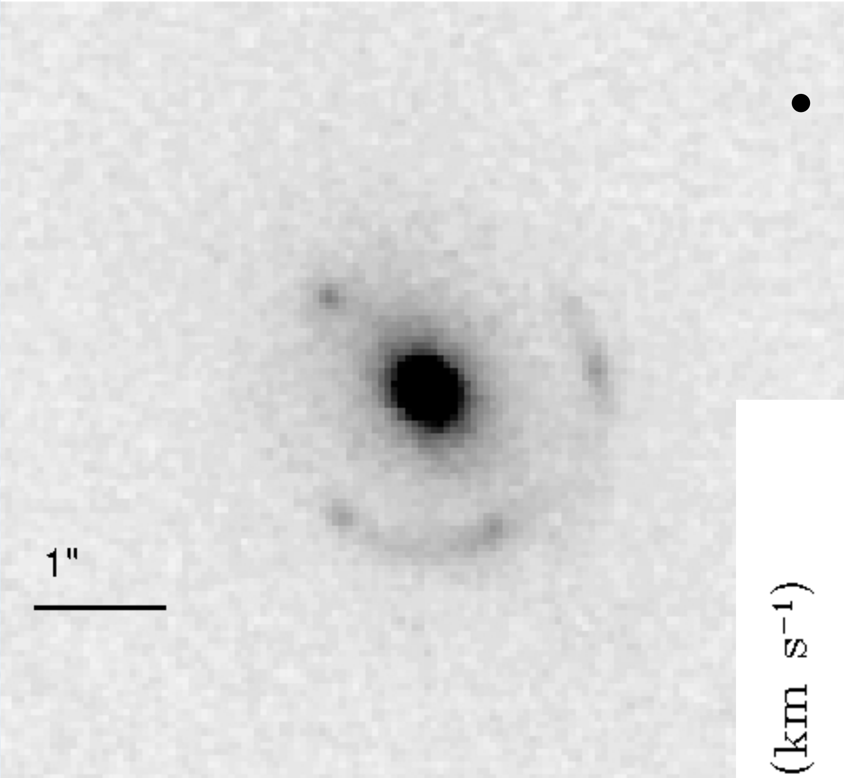


The Lensing Structure and Dynamics (LSD) Survey:

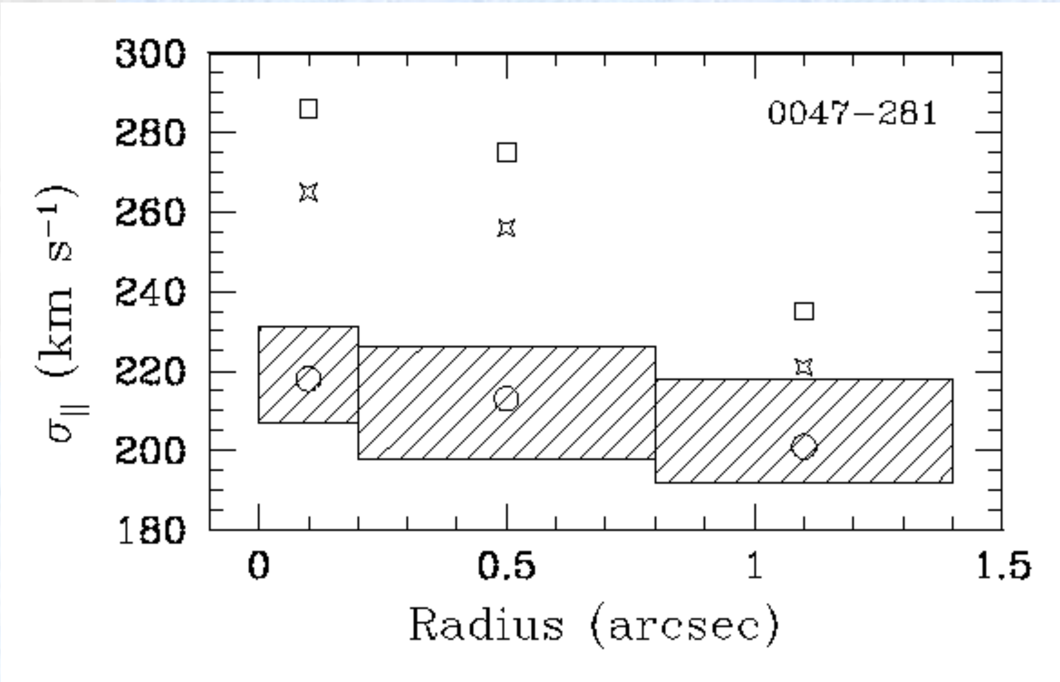
- Sample: all 11 suitable gravitational lenses known at the time
- Aim: Spatially resolved kinematics profiles
- Status: COMPLETED DECEMBER 2002
  - 8 nights on ESI/Keck-II
  - extended kinematic profiles for 10 lenses and 1 central velocity dispersion out to z=1

Treu & Koopmans 2002a, 2003,2004; Koopmans & Treu 2002, 2003

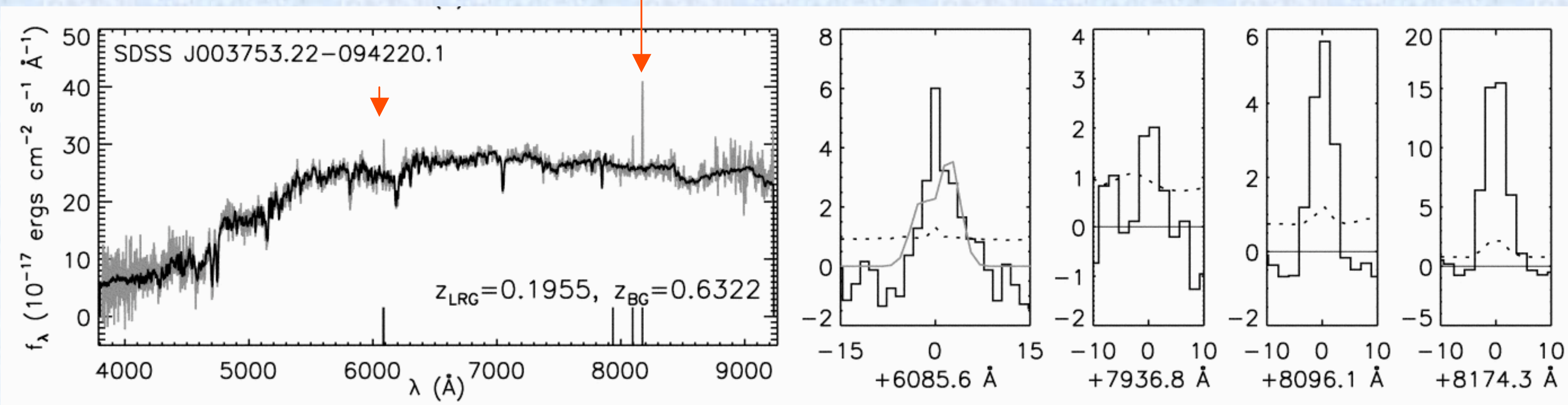
Mass does not follow light: E.g. 0047-281 at z=0.485



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



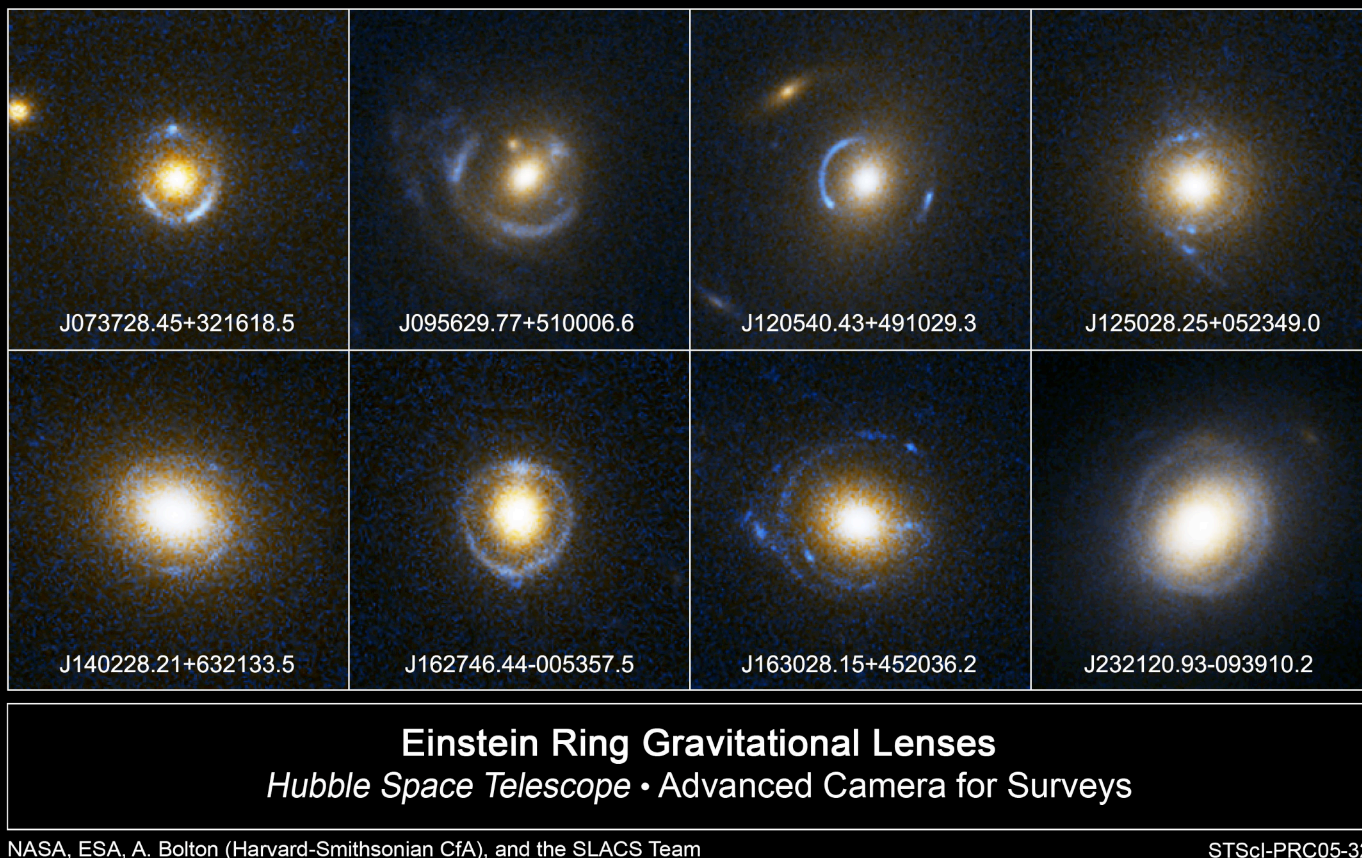
SLACS: the strong lens factory (www.slacs.org)



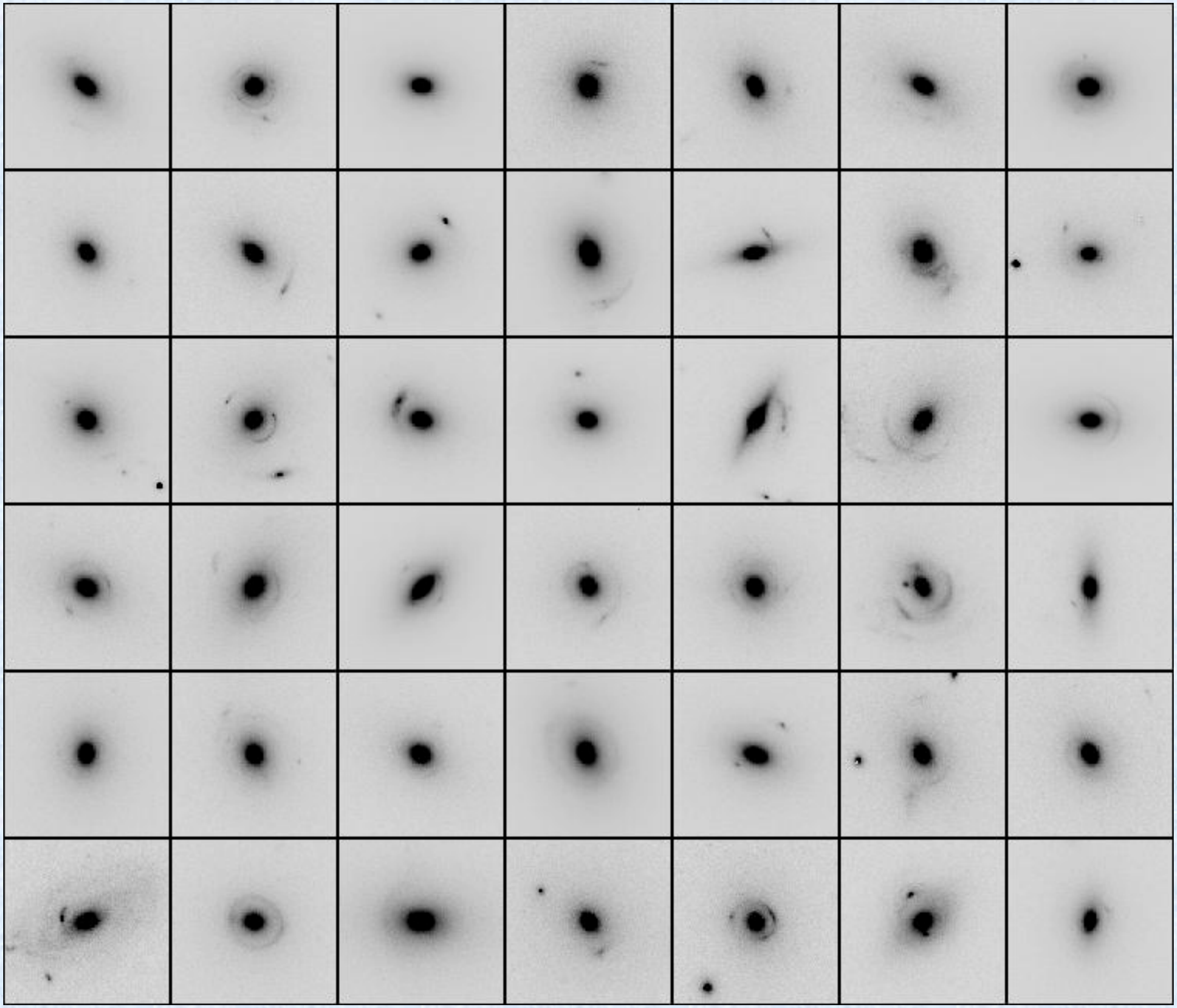
- Candidate lenses selected from SDSS as red galaxies with “spurious” emission lines (Bolton et al. 2004,2005,2006,2007)
- 167 snapshot targets approved for HST imaging in Cycles 13-14
- 155 GO orbits approved in Cycle 14-15
- 159 GO orbits approved in Cycle 16 (full three-color followup of 87 lenses)
- **SDSS velocity dispersion can be used to pre-select masses**

SLACS: the largest search for lenses..

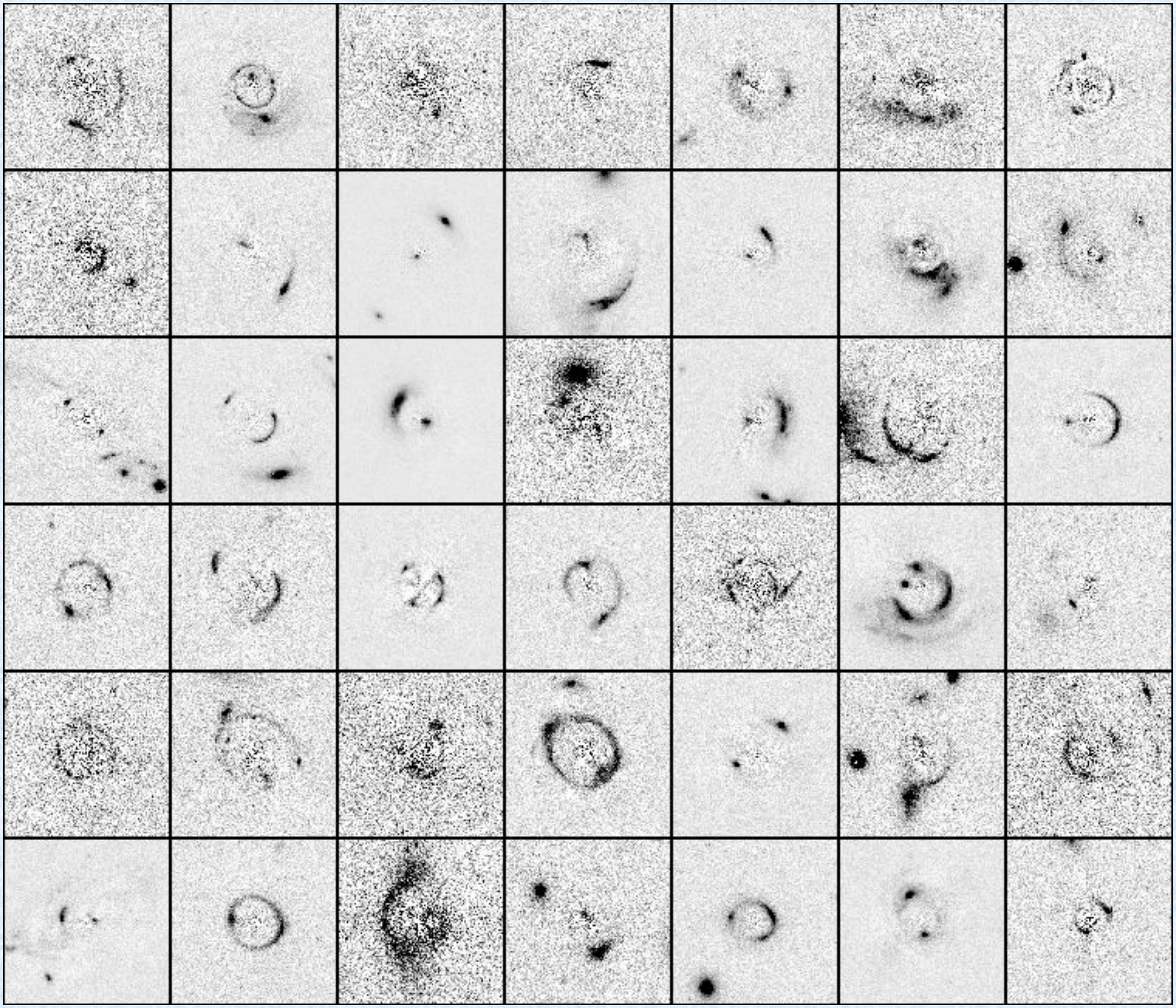
See www.slacs.org and Bolton et al. 2006, 2007



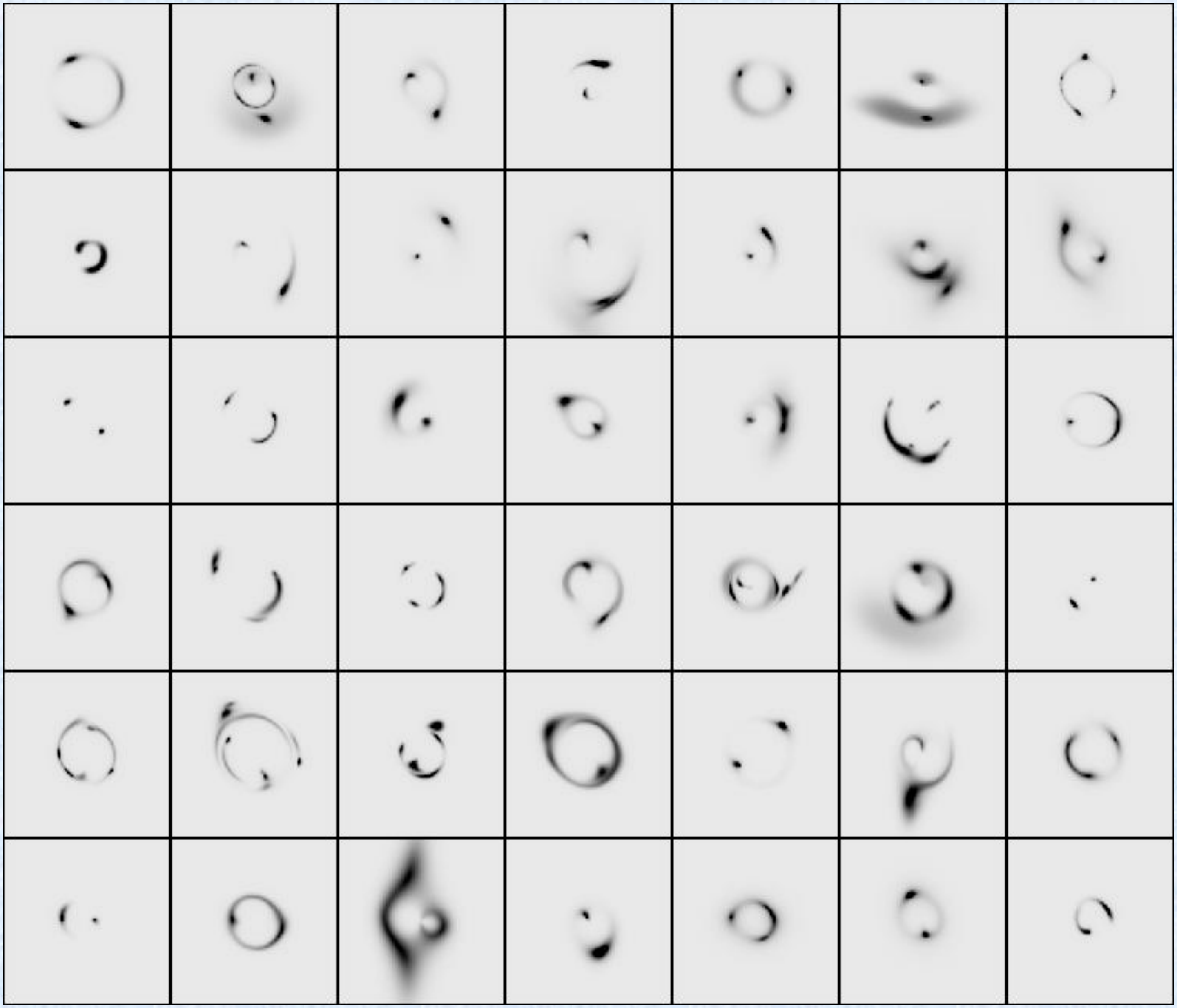
97 confirmed lenses so far! With WFPC2 we hope to reach 100 lenses by the end of Cycle 15



Bolton et al. 2007

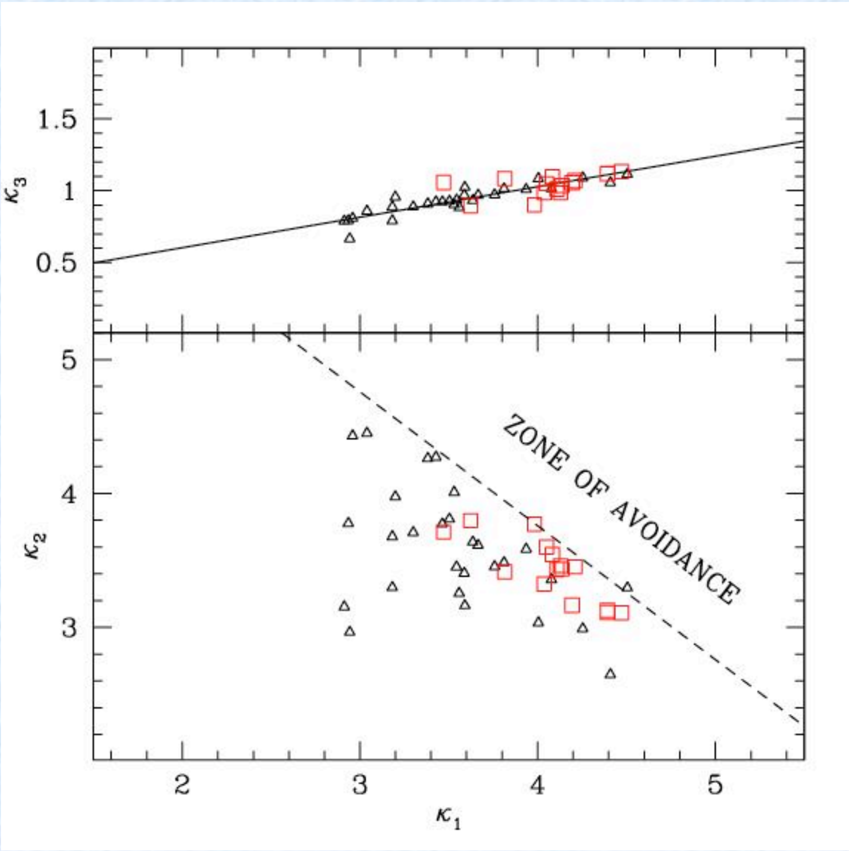


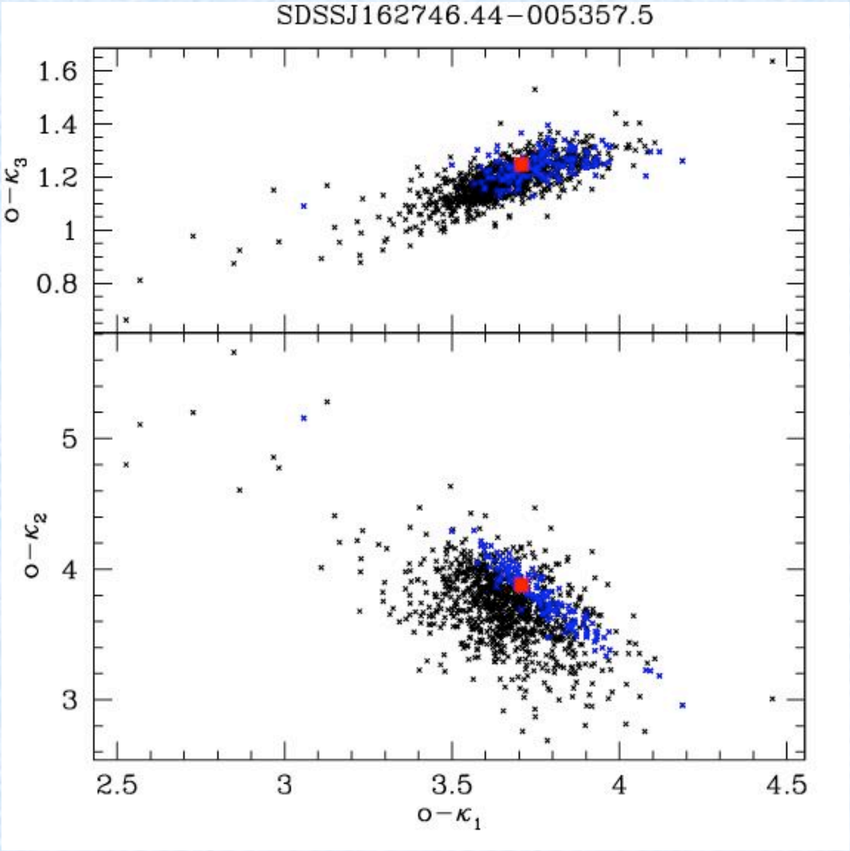
Bolton et al. 2007



Bolton et al. 2007

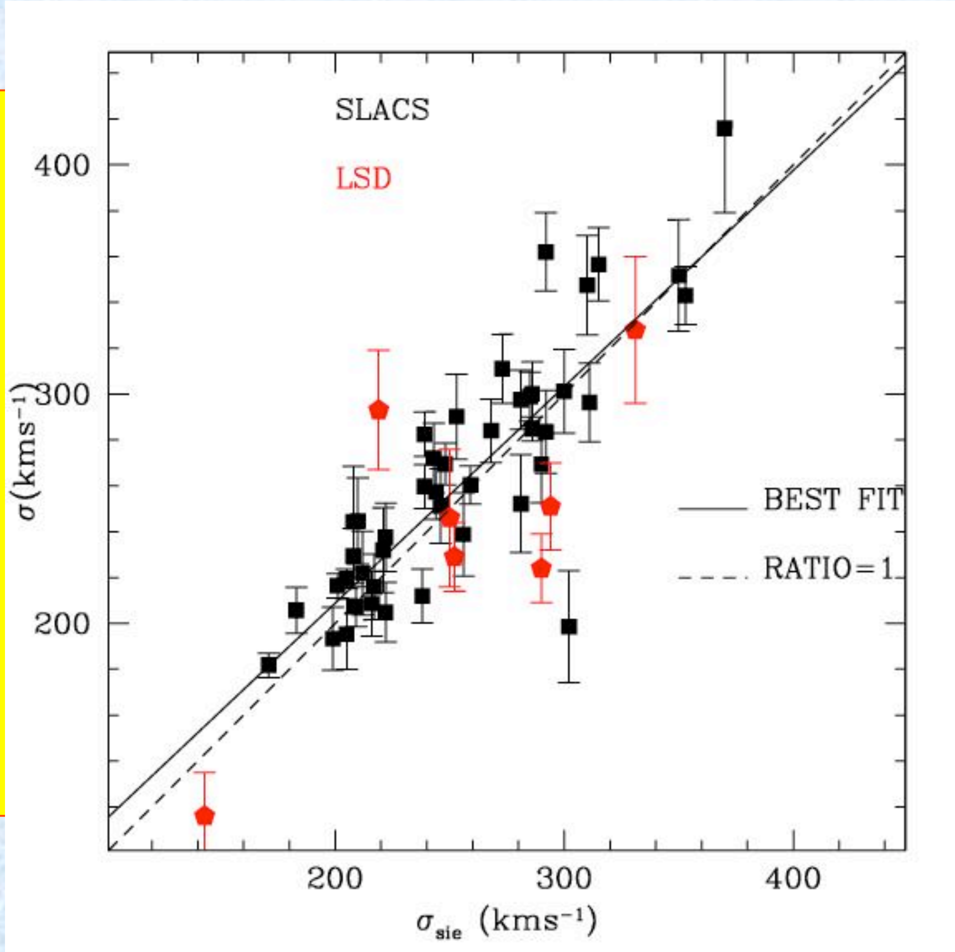
Lenses are "normal" spheroids





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

Bulge-halo conspiracy. I

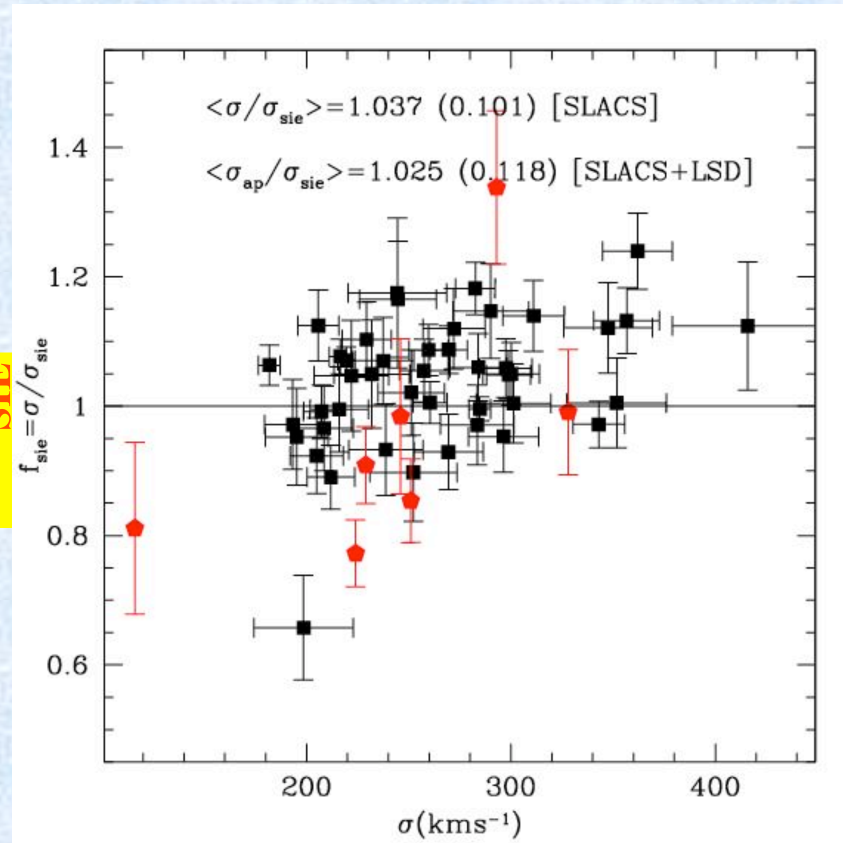


Stellar velocity dispersion

"Lensing" velocity dispersion

Bulge-halo conspiracy. II

- 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: $\rho \sim r^{-2}$.**
- How do the stars and dark matter know "where to go"?
- **Dark-luminous mass "conspiracy"**



σ/σ_{SIE}

σ

Bulge halo conspiracy.
III: dynamical models

Two spherical components

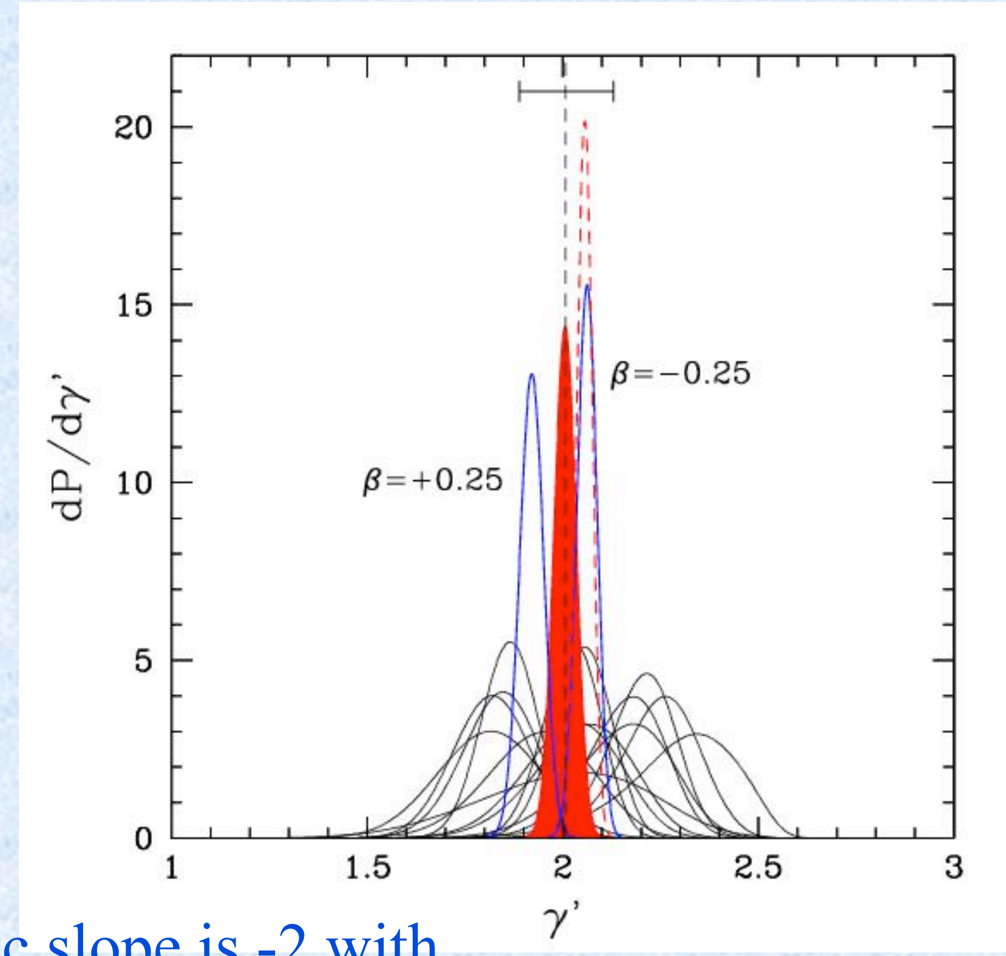
- **Luminous component: Hernquist/Jaffe mass distribution**
- **Dark matter profile: generalized NFW profile, with inner slope -γ , outer slope -3, break radius R_b**
- **Osipkov-Merritt or constant anisotropy.**

Spherical Jeans equation

$$\frac{d\rho_*(r)\sigma_r^2(r)}{dr} + \frac{2\beta(r)\rho_*(r)\sigma_r^2(r)}{r} = -\frac{GM(r)\rho_*(r)}{r^2}$$

$$\beta(r) = \begin{cases} 1 - \frac{\sigma_\theta^2}{\sigma_r^2} = \frac{r^2}{r^2+r_i^2} & r_i^2 \geq 0 \\ b_{\rm iso} \in [-1,+1] \end{cases}$$

Bulge-halo conspiracy. IV: total mass density profile

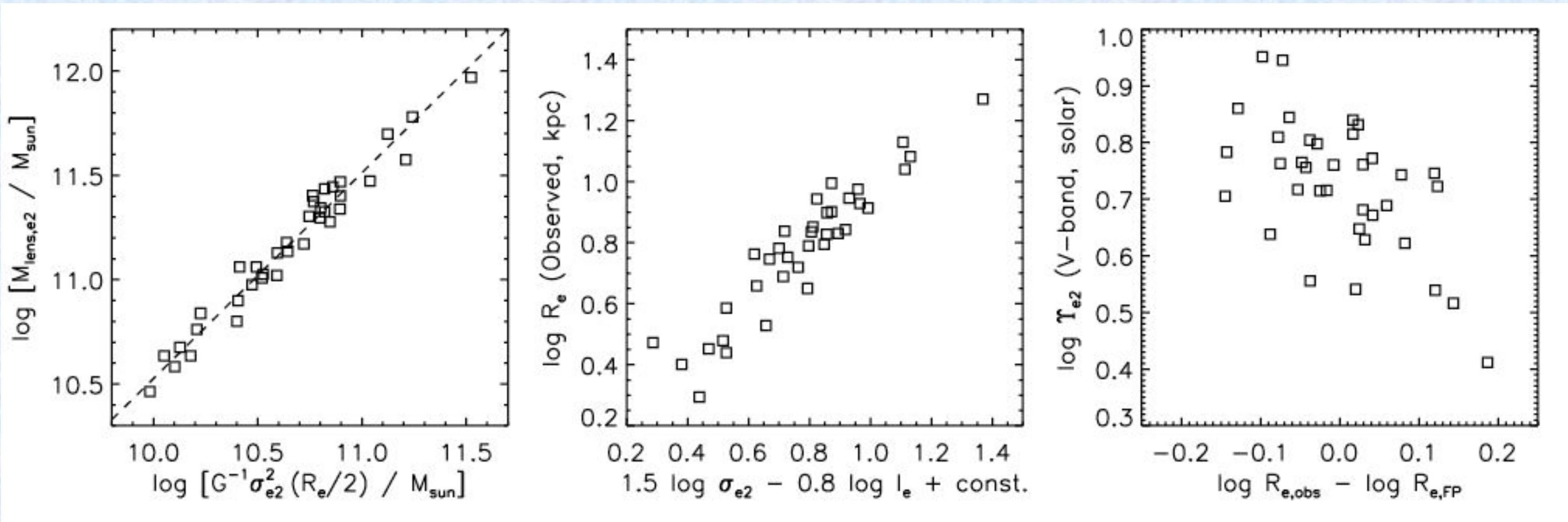


The logarithmic slope is -2 with very little scatter (6%)

Koopmans, Treu et al. 2006

A more Fundamental Plane

$$\log R_{\rm e} = a \log \sigma + b \log \Sigma_{\rm lens} + d$$



- Intrinsic scatter of MFP is half that of the classic FP
- MFP has no "tilt", i.e. $M_{\rm tot} \propto \sigma^2 R_{\rm e}/G$
- Tilt of the classic FP $L \propto \left(\sigma^2 R_{\rm e}/G\right)^{0.8}$ due to varying dark matter content?

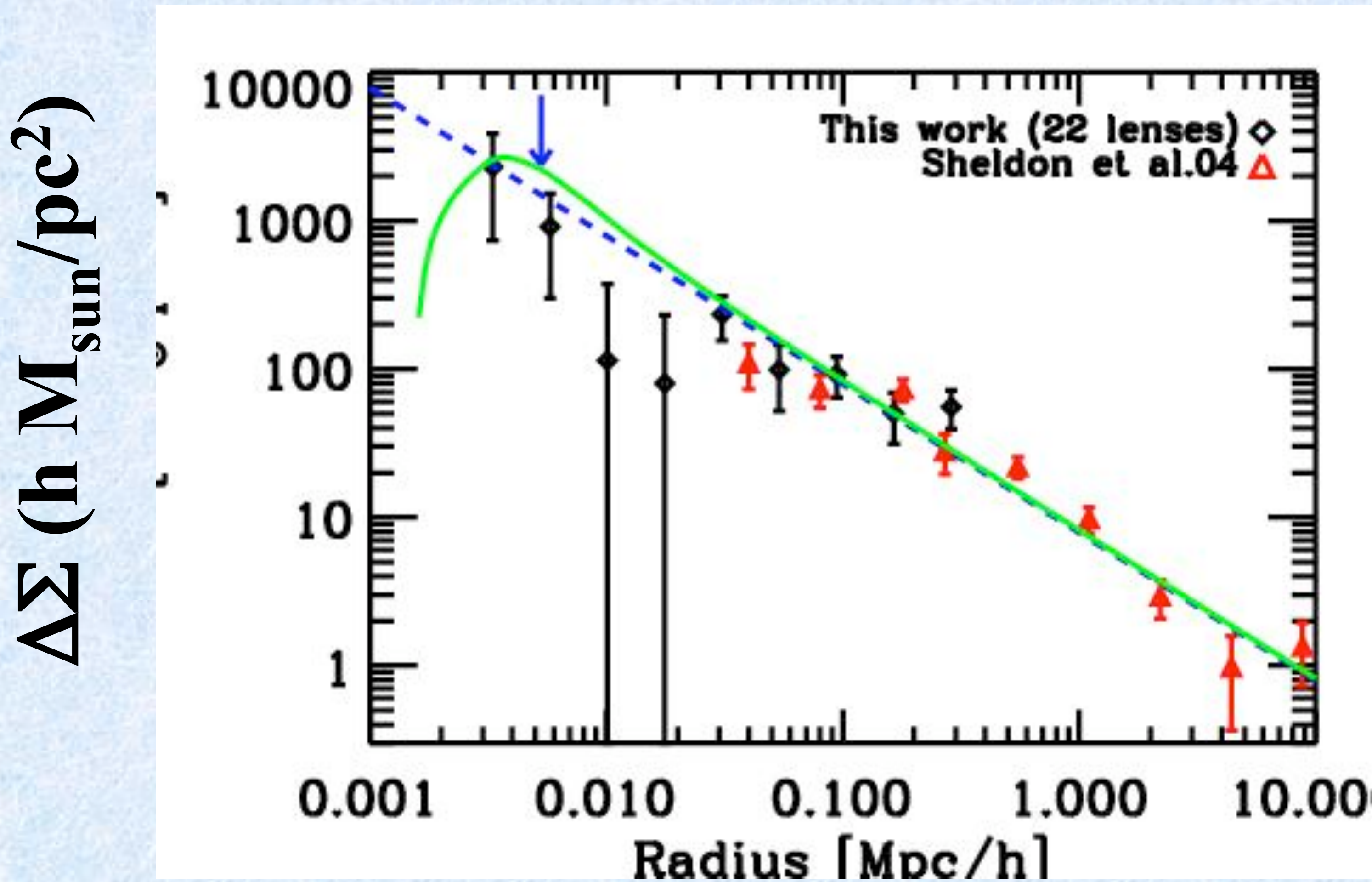
Bolton et al. 2007

What about at larger radii? Enter weak lensing…

- Deeper ACS data (1 orbit F814W) available for a subsample of 54 lenses...
- Background galaxy density ~80/ square arcmin
- Stacked weak-lensing analysis for the first 22 fields (as of October 2006): shear is detected
- Analysis exploits corrections for ACS-PSF systematics (breathing, CTE…) developed for cosmic shear analysis (Rhodes et al. 2006)

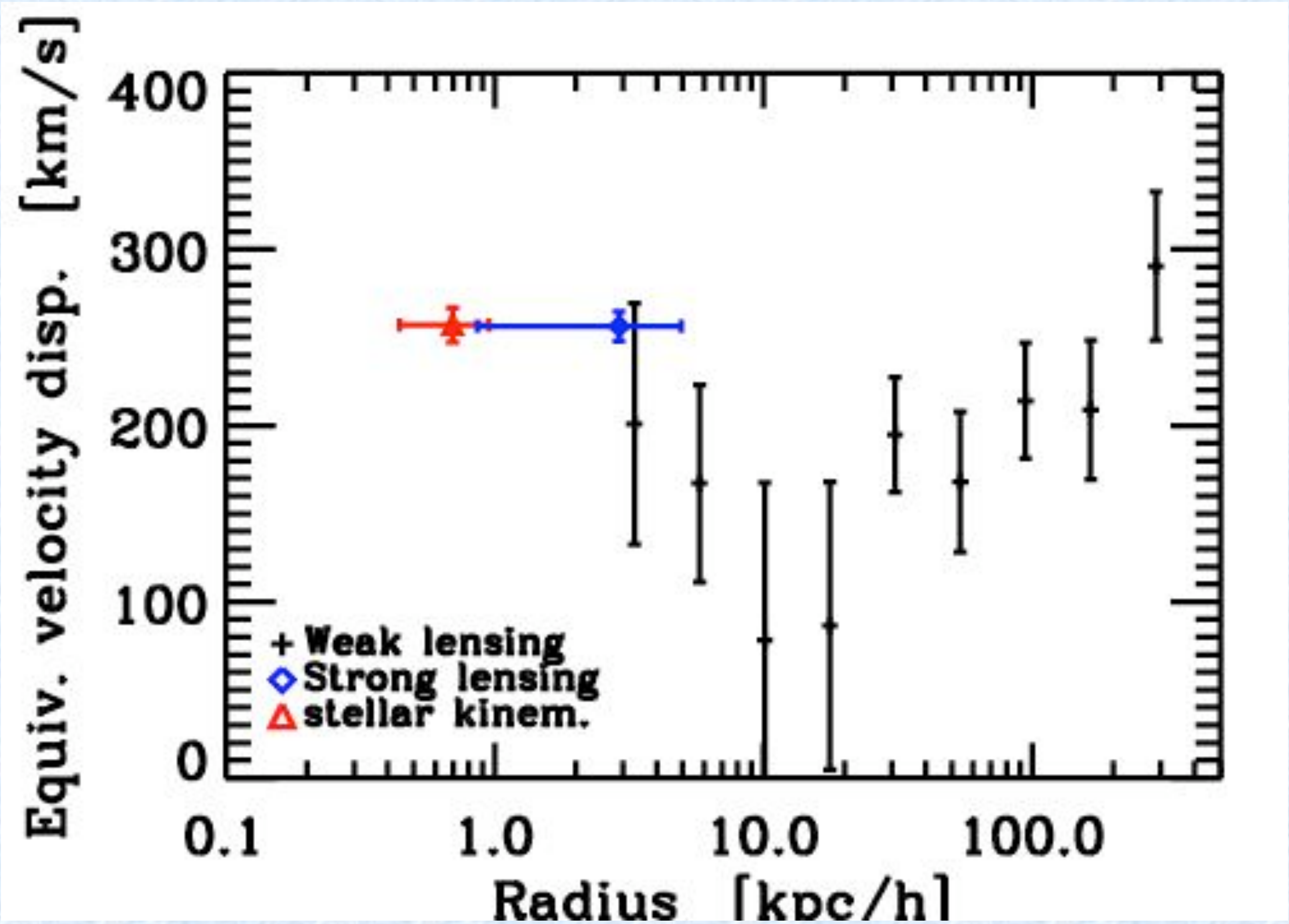
Gavazzi, TT et al. 2007

Shear profile



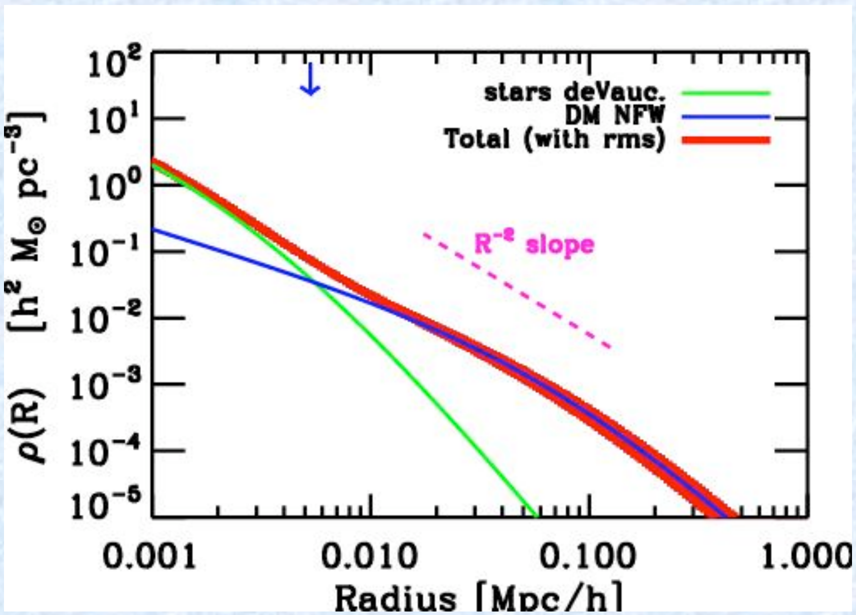
Gavazzi, TT et al. 2007

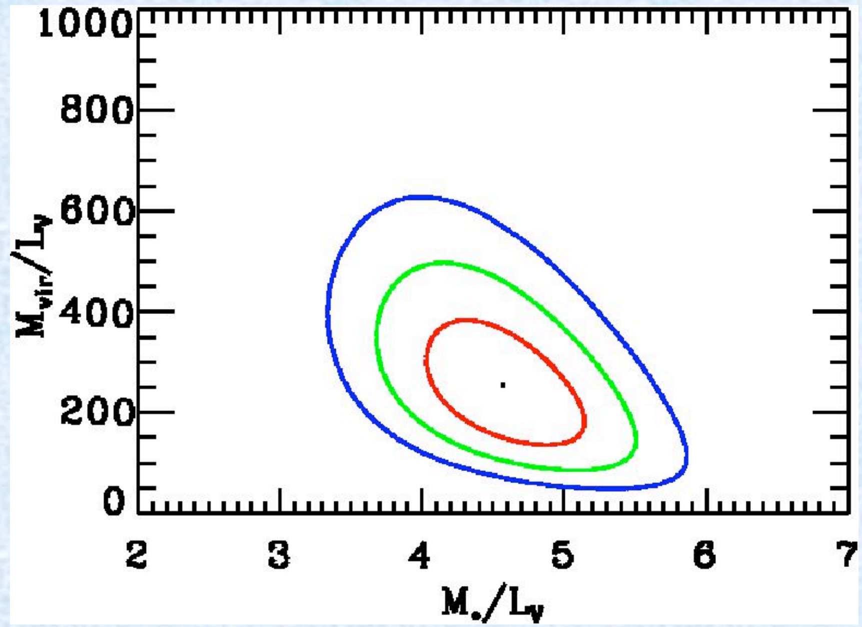
“Velocity dispersion” profile



Gavazzi, TT et al. 2007

A two component model.
Strong and weak lensing analysis



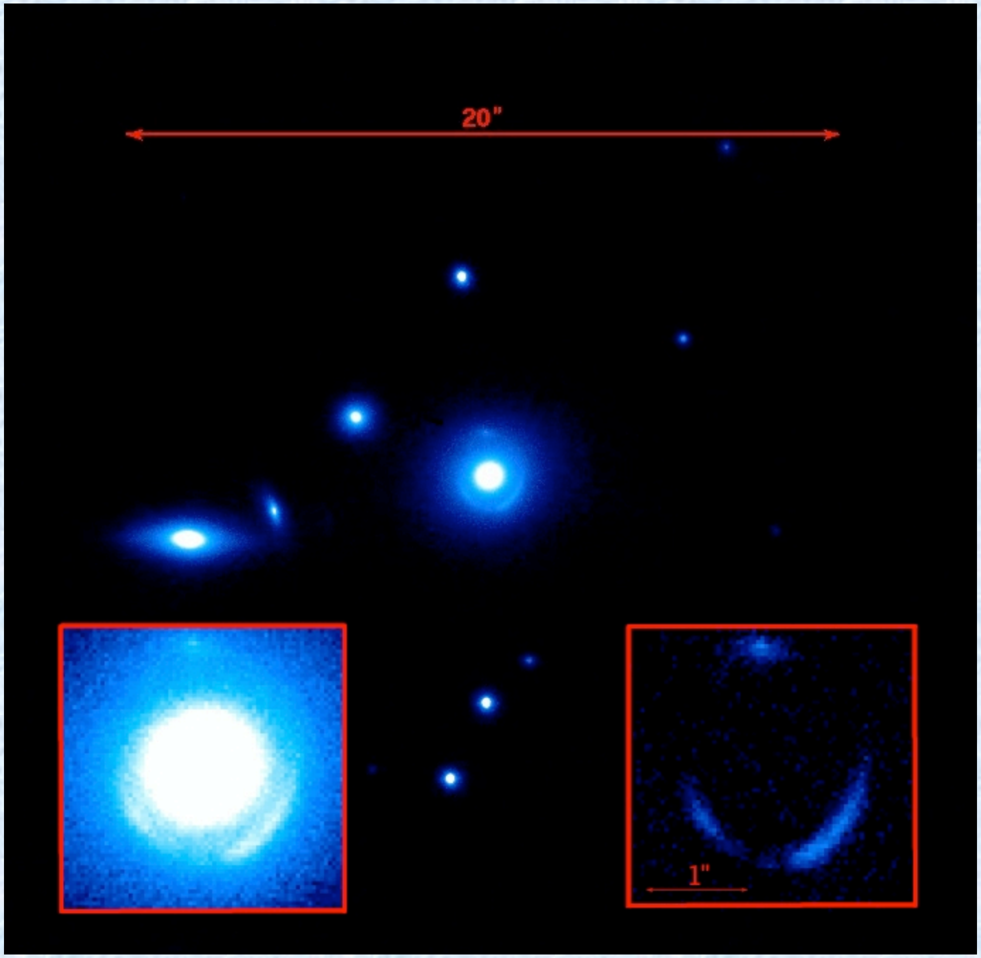


Constant M/L ratio doesn't work
Need an extended halo

Gavazzi, TT et al. 2007

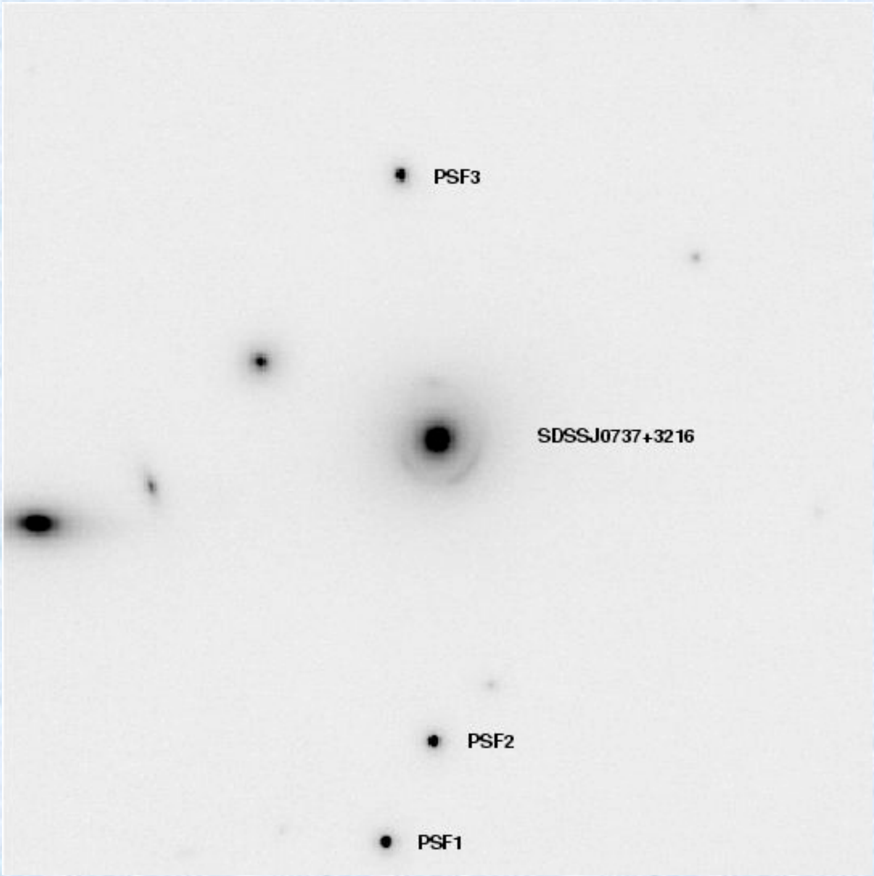
SLACS lenses as gravitational telescopes. Enter LGS-AO

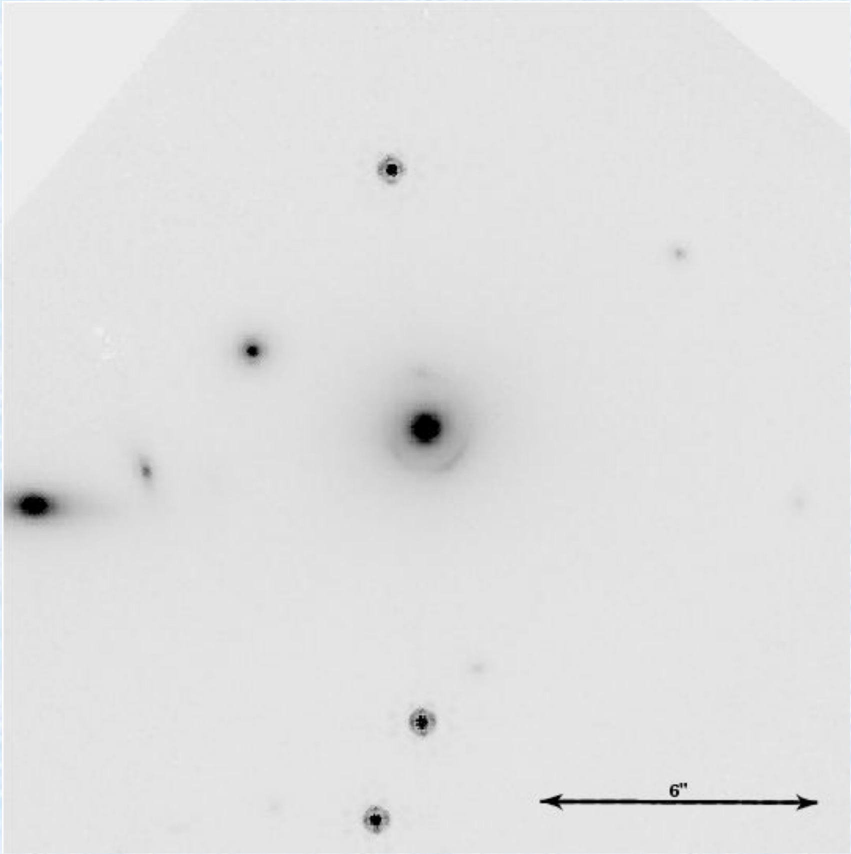
Strong Lensing with LGS-AO?



Marshall, TT, et al. 2007

NICMOS and NIRC2

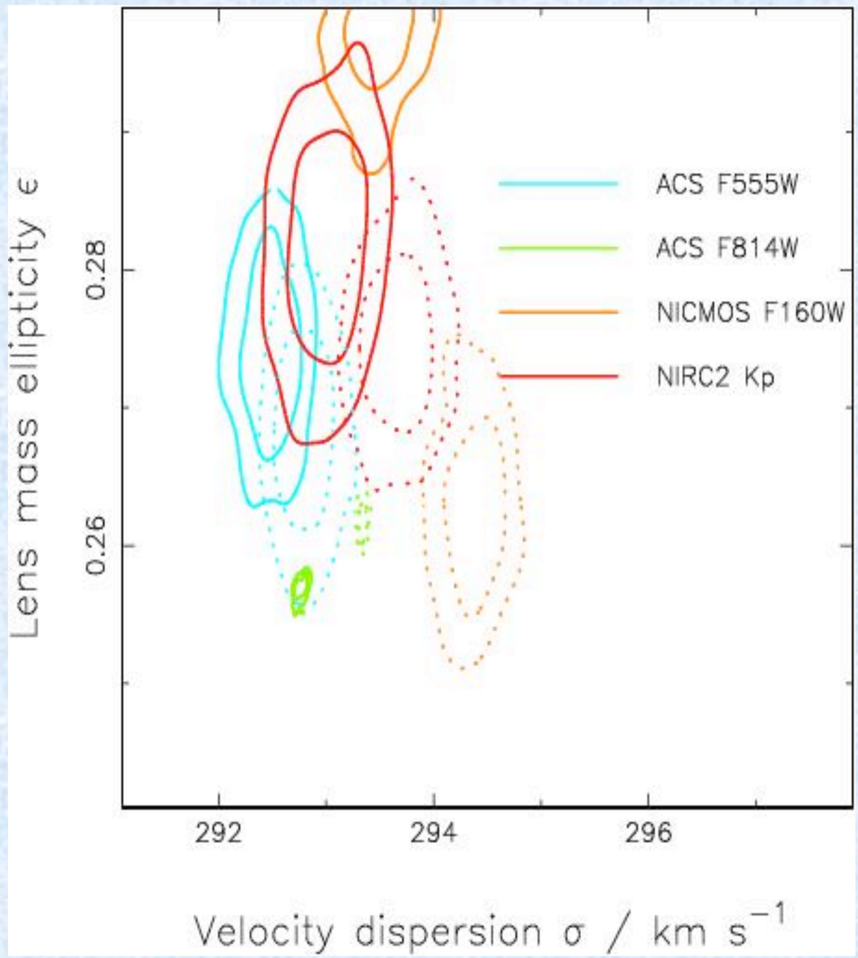




Marshall, TT et al. 2007

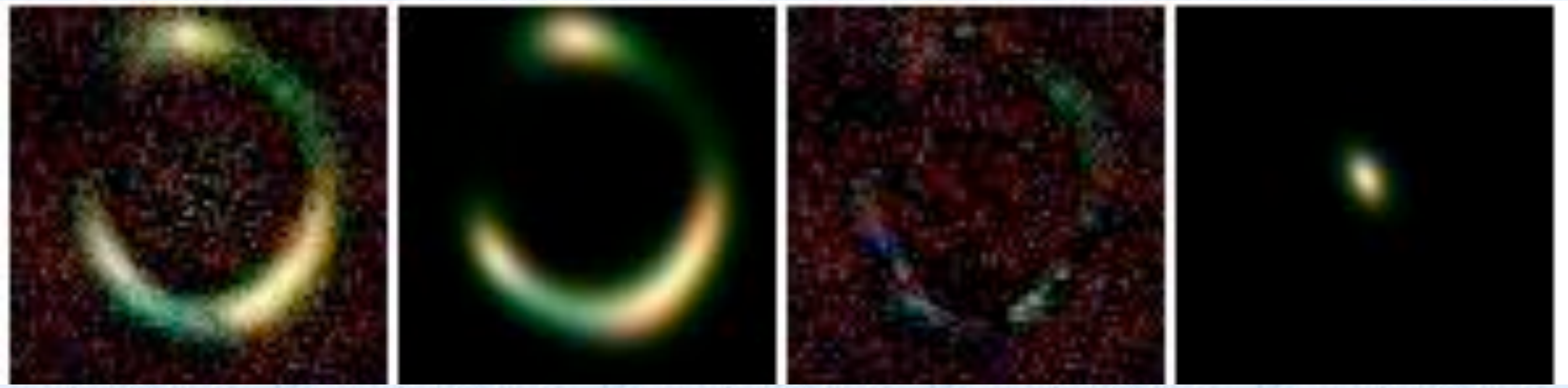
NICMOS + NIRC2 +ACS

- Tested 4 psfs
- Tested 2 different subtraction schemes
- Best fit parameters are very well constrained and stable:
  - Einstein Radius the same within 0.3%



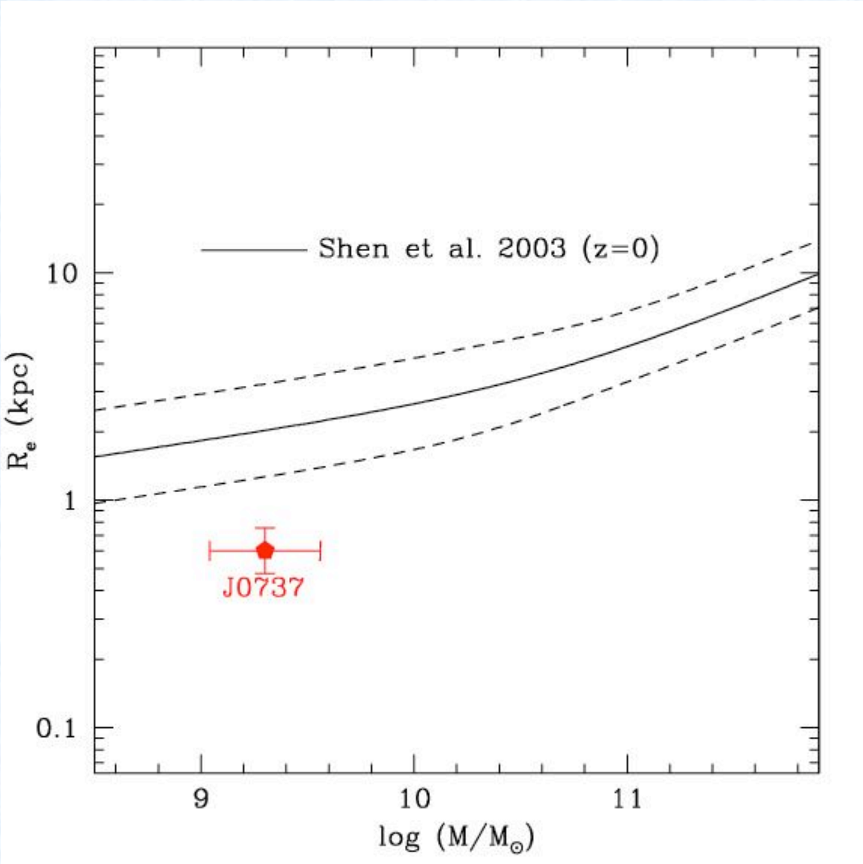
Marshall, TT et al. 2007

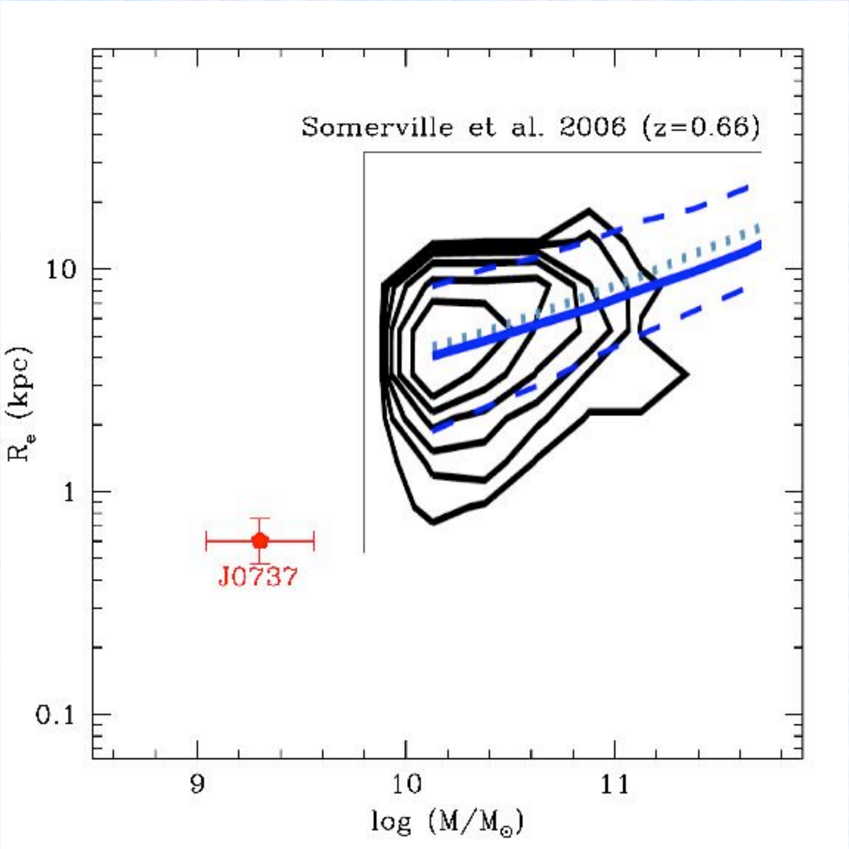
Faint Blue Compact Narrow Emission Line Lensed Galaxies (FBCNELLGs)



- The source at z=0.5882 has extreme properties:
  - Sersic index: 1.0 (disk)
  - Size: 0.6 kpc
  - Mass: 2 billion solar masses
- Building block of modern galaxies? Progenitor of local dwarfs?
- Effective resolution 0.01”, like galaxies in Virgo in 1” seeing

Extending the mass-size relation





With SLACS and other lens surveys we can study the structure of a new population of galaxies missed by surveys at HST resolution

Summary. SLACS Highlights:

- Discovered 97 strong gravitational lenses
- SLACS lenses are normal early-type galaxies
- Mass does NOT follow light
- At scales of ~10 kpc luminous and dark matter conspire to form an isothermal profile
- A more Fundamental Plane is found by replacing surface brightness with surface mass density
  - The scatter is halved and the “tilt” disappears
  - Evidence for conspiracy and increasing dark matter with mass
- Mass profiles can be extended to 100 effective radii with weak lensing
  - Strong and weak lensing well fit by light+NFW profile
- SLAC lenses are excellent cosmic telescopes:
  - FBCNELLGs can be studied with exquisite detail
- Under good conditions strong lensing with AO works!

PhD and Postdoc positions open Fall 2007; e-mail me if interested!