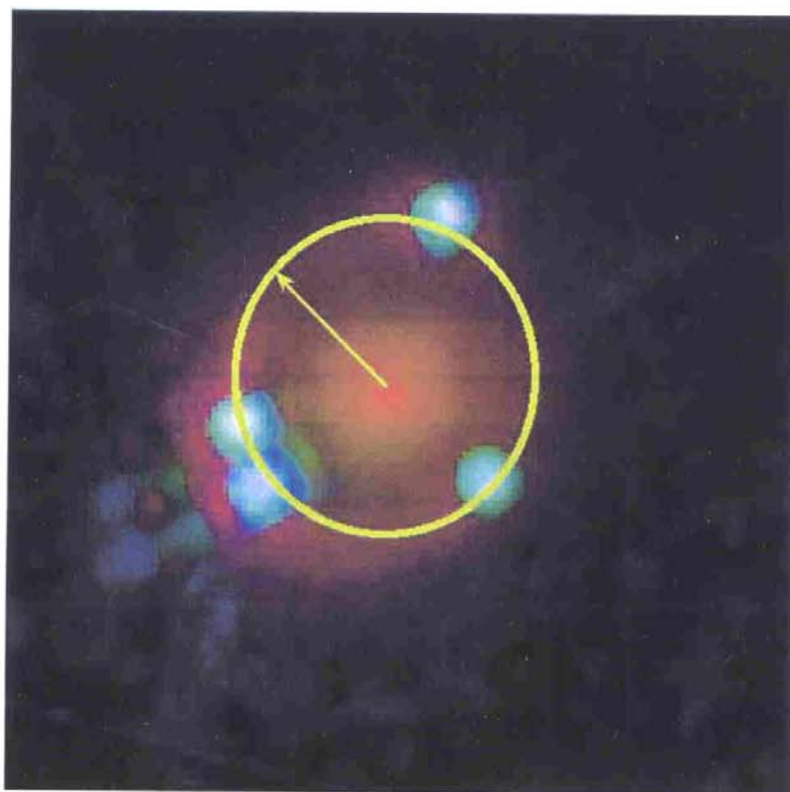


# Galaxy Masses with Strong Lensing

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PG 1115+080



# Principles of Lens Modeling

(CRK & Zabludoff in prep.; also see Saha & Williams astro-ph/0303261)

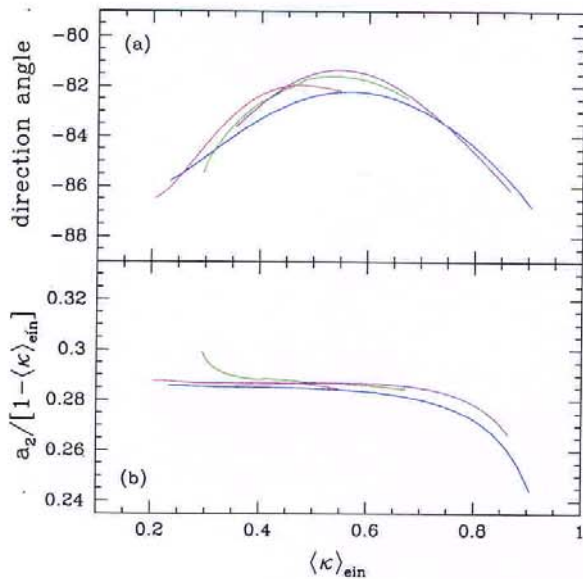
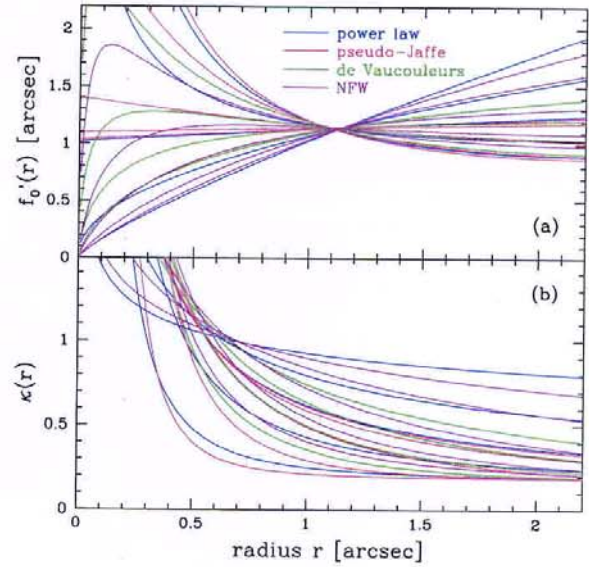
## Monopole

Do measure:

- Einstein radius  $R_{\text{ein}}$
- Aperture mass  $M(R_{\text{ein}})$

Do NOT measure:

- Density profile
- $\kappa_{\text{ein}} \equiv \Sigma(R_{\text{ein}})/\Sigma_{\text{crit}}$

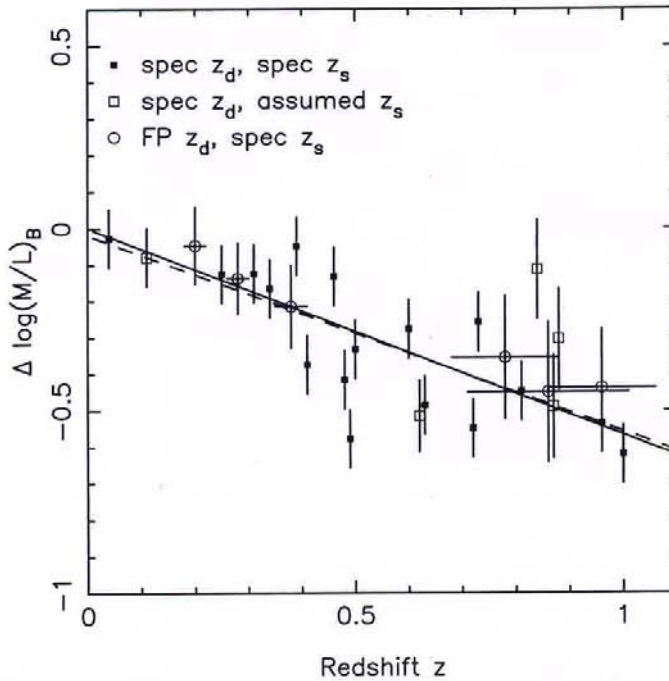


## Quadrupole

- Direction
- Amplitude  $a_2/(1 - \kappa_{\text{ein}})$

# The Evolution of Early-Type Galaxies

(Rusin et al. 2003 ApJ 587:143)

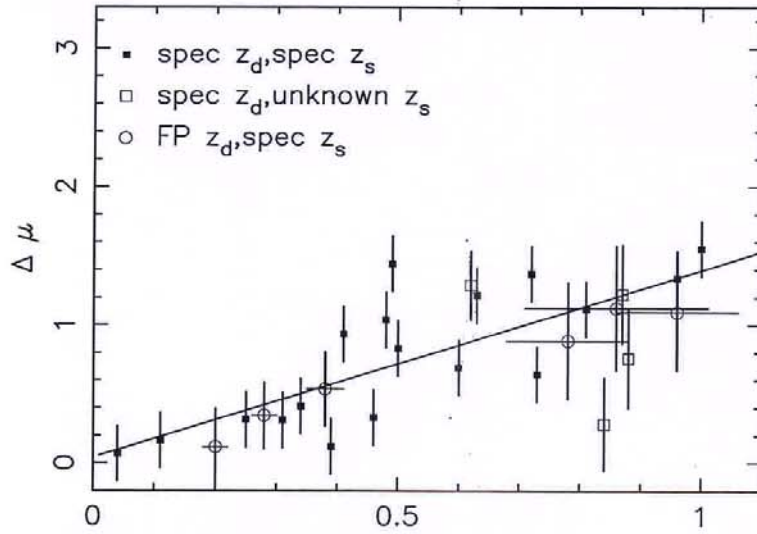


Early-type lens galaxies have old stars ( $z_{\text{form}} > 1.8$ ).

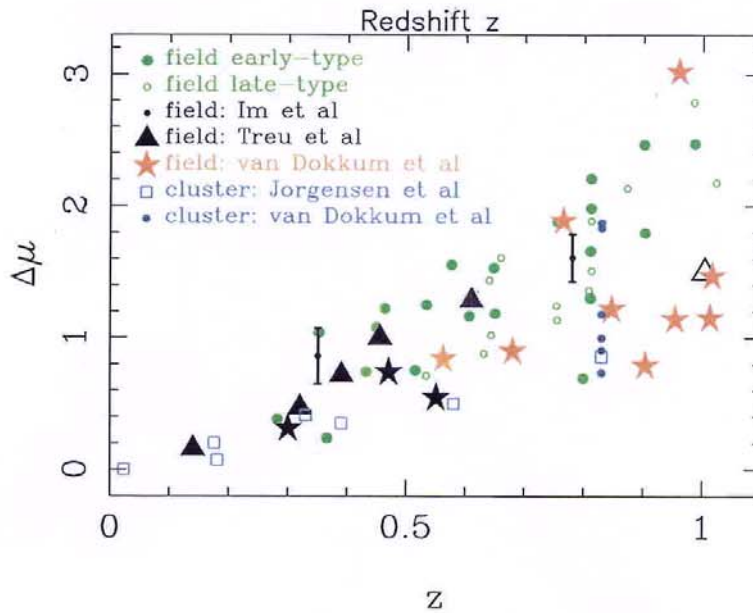
$d \log(M/L)/dz$	environment	sample
$-0.56 \pm 0.04$	low-density	Rusin et al. (lenses)
$-0.72^{+0.11}_{-0.16}$	field	Treu et al. (2002)
$-0.59 \pm 0.15$	field	van Dokkum et al. (2001)
$-0.49 \pm 0.05$	cluster	van Dokkum et al. (1998)

Other samples: *Jørgensen et al. (1999)*, *van Dokkum & Ellis (astro-ph/0306474)*, *Gebhardt et al. (astro-ph/0307242)*

# The Evolution of Early-Type Galaxies



Lens galaxies  
(Rusin et al. 2003  
*ApJ* 587:143)



Non-lens galaxies  
(Gebhardt et al.  
*astro-ph/0307242*)

## The Profile Degeneracy

Problems for:

- Baryon/DM decompositions
- CDM cusps
- Hubble constant,  $H_0 \propto (1 - \kappa_{\text{ein}})$
- Substructure lensing

Breaking the degeneracy:

- Special lenses *(Cohn et al. 2001; also poster by C. Trott)*
- Lens ensembles *(Rusin et al. astro-ph/0306096)*
- Lensing + dynamics *(T. Treu & L. Koopmans)*

All evidence points to isothermal profiles ( $\rho \propto r^{-2}$ ) with small but significant amounts of dark matter.

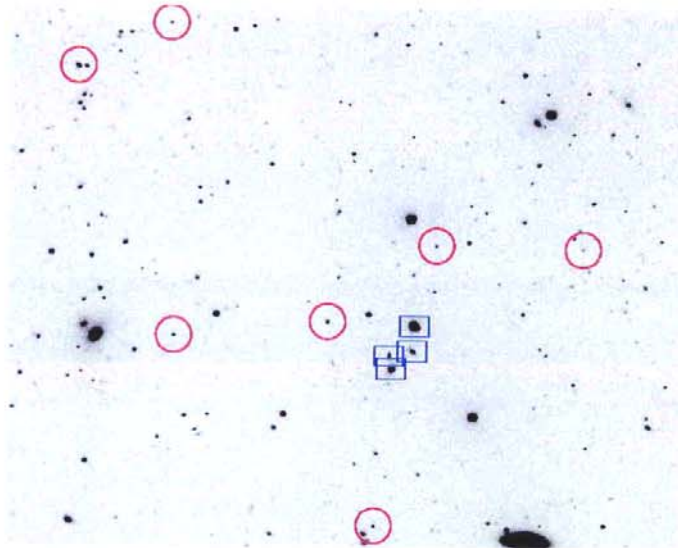
DM fraction	Radius	Method	Reference
10–40%	$< R_{\text{eff}}$	dynamics	Gerhard et al. (2001)
$\sim 25\%$	$< R_{\text{eff}}$	tightness of FP	Borriello et al. (2003)
$< 40\%$	$< 2R_{\text{eff}}$	lens statistics	CRK (2001)
12–32%	$< 2R_{\text{eff}}$	lens $M(R_{\text{ein}})$	Rusin et al. (2003)

# The Importance of Lens Galaxy Environments

(with A. Zabludoff, K. Williams, I. Momcheva)

- Lens models measure scaled quadrupole  $a_2/(1 - \kappa_{\text{ein}})$ .
  - If we can measure  $a_2$  ...
- ⇒ Get  $\kappa_{\text{ein}}$ !

How to measure  $a_2$ ? Tidal shear from group environments!



- Break model degeneracies, finally get sophisticated lens models for studying galaxy halo shapes,  $H_0$ , lens statistics, ...
- New way to discover  $\gtrsim 20$  groups at  $z = 0.2-1$ .

*See poster by K. Williams.*

## Summary

### *Monopole.*

- Precise aperture mass  $M(R_{\text{ein}})$ .
- $M/L$  and evolution: lens galaxies are old ( $z_{\text{form}} > 1.8$ ).
- But density profile is often degenerate.

### *Quadrupole.*

- Can study galaxy halo shapes  $\Leftrightarrow$  baryon/DM interactions.  
(poster by R. Wayth)
- But: intimate connection between lens galaxy and environment.
- Need to study the galaxy groups around lenses.  
(poster by K. Williams)