

# Super-resolving distant galaxies with gravitational telescopes:

## Keck-LGSAO and Hubble imaging of the lens system SDSSJ0737+3216

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with

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and

Raphael Gavazzi, Leon Koopmans, Adam Bolton, Scott Burles, Lexi Moustakas (SLACS)

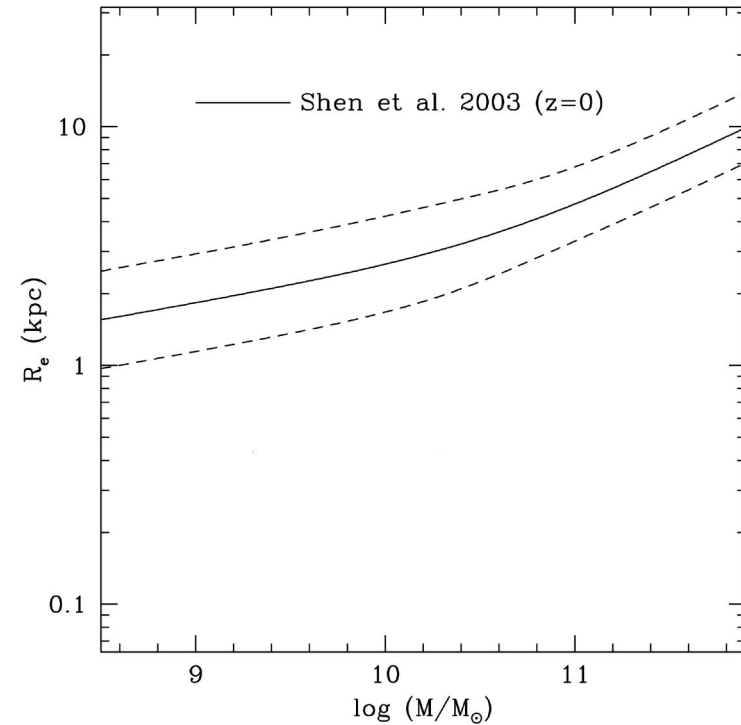
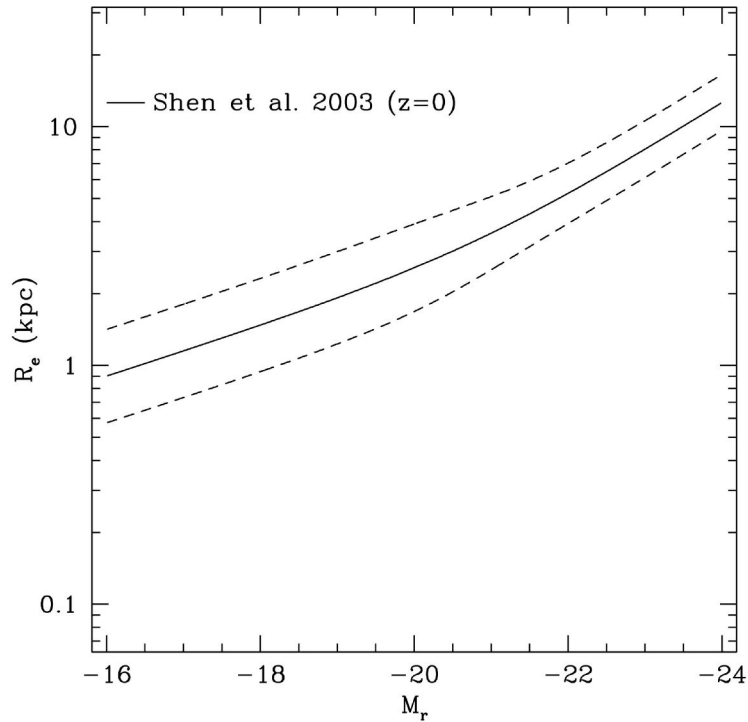
and featuring a stellar mass estimate by Kevin Bundy (Toronto)



March 2007

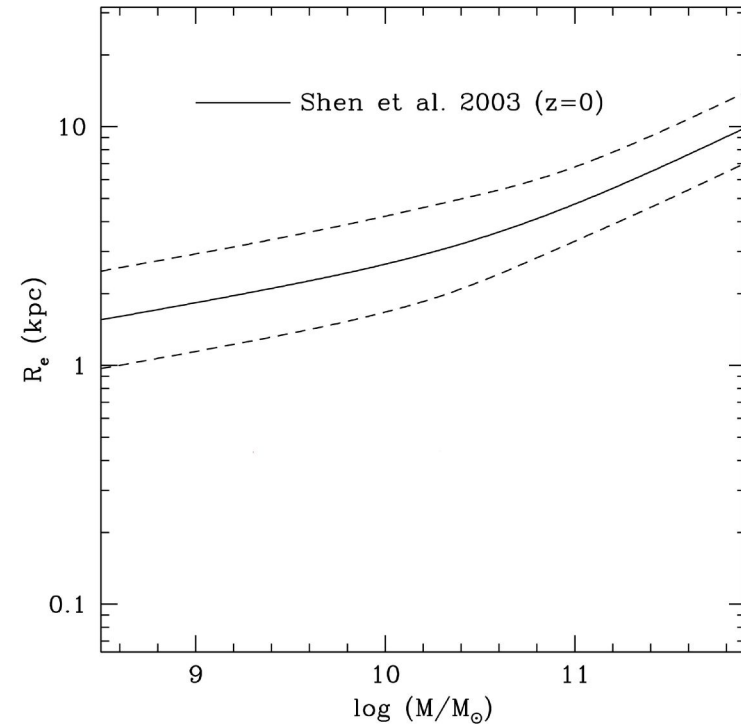
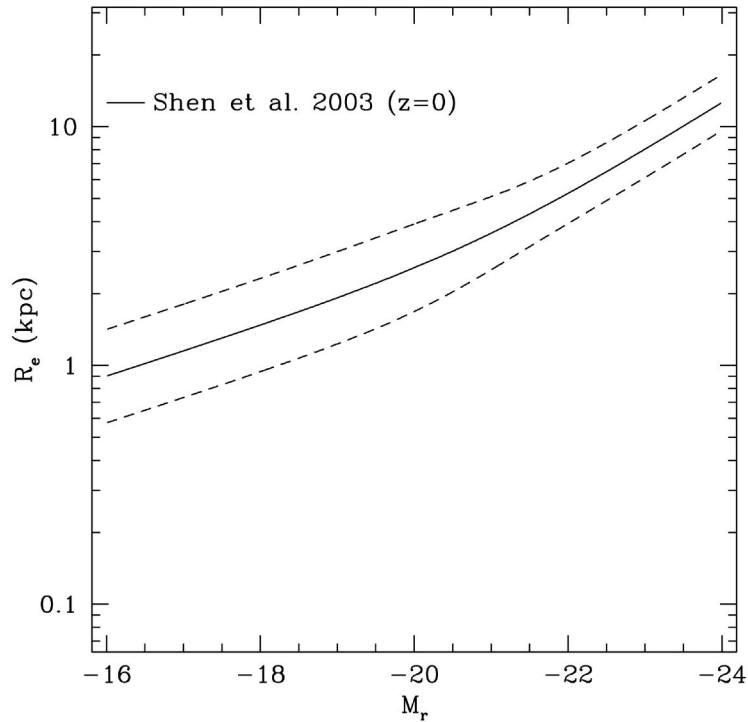


# Galaxy sizes



- Disk galaxies expected to show correlation between size and stellar mass or luminosity, with log-normal scatter
- Slope, shape, and break(!) of these relations provide targets for galaxy formation models
- Luminosity evolution is kept separate in stellar mass analysis

# Galaxy sizes



- Is this break real? Or are we seeing observational difficulties at the small and faint end?
- How did the R-M relation evolve with cosmic time for the smallest, faintest galaxies?
- Can these galaxies be modelled as disks at all?

# Aim

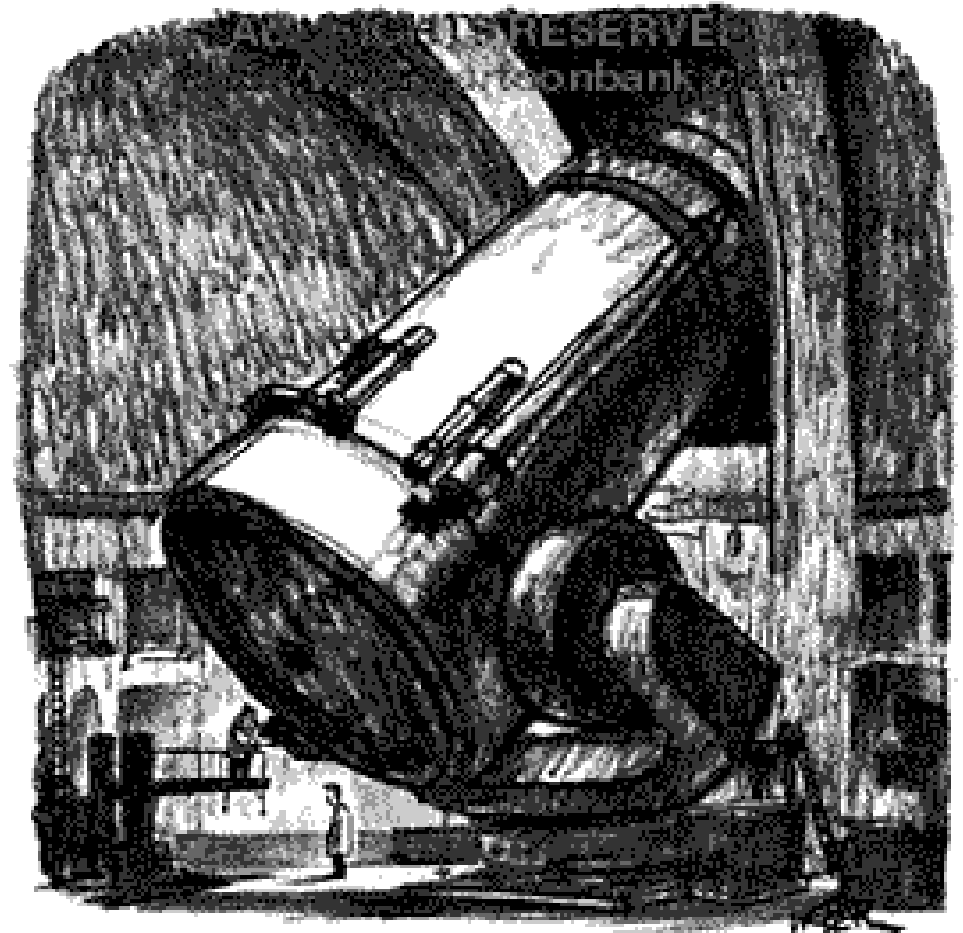
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To probe the R-M relation in disk galaxies to

- an order of magnitude lower mass
  - an order of magnitude smaller size
- and follow its evolution.

We will need:

- near infra-red photometry for the stellar masses
- very high resolution imaging for the small sizes
- *a big telescope*



"See anything?"

# Gravitational lenses: examples

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x 10 resolution  
x 10 magnification



# Gravitational lenses: models

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x 10 resolution  
x 10 magnification



# Gravitational lenses: physics

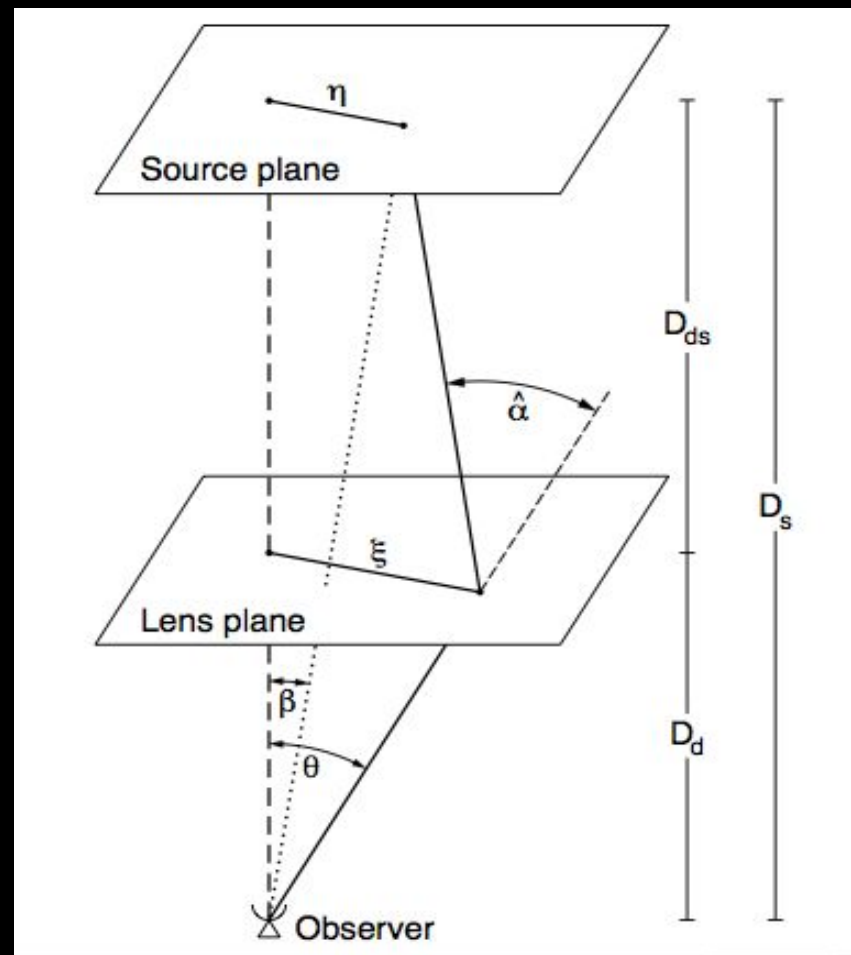
The “lens equation” relates the apparent position  $\theta$  in the image/lens plane to the unlensed source position  $\beta$ :

$$\beta = \theta + \alpha(\theta)$$

$\alpha(\theta)$  is the deflection angle, and is just the gradient of the (projected, rescaled) gravitational potential of the lens galaxy

For a given lens model, we can compute  $\alpha(\theta)$  – and then predict the surface brightness in each image plane pixel given a source intensity model  $I(\beta)$

The predicted and observed images can be compared via an assumed likelihood function, and the source and lens model parameters ( $x$ ) inferred



$$\Pr(x|\text{data}, H) = \frac{\Pr(\text{data}|x, H) \Pr(x, H)}{\Pr(\text{data}, H)}$$

# Case study: SDSSJ0737+3216

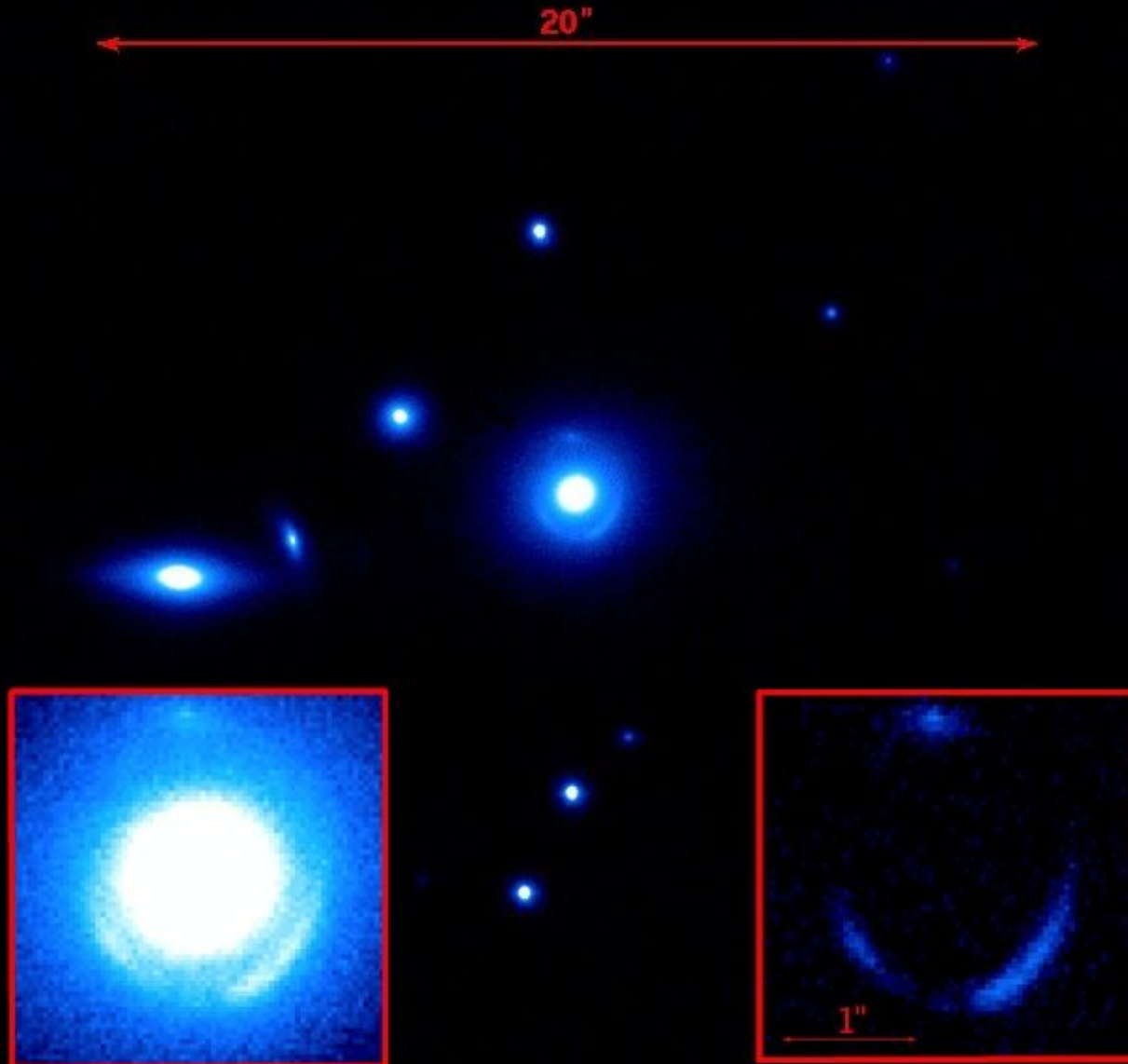
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- Lens galaxy at  $z=0.3223$ , source at  $z=0.5812$
- Discovered in SLACS survey (Bolton et al 2006) – HST follow-up of spectroscopically selected lens candidates
- HST imaging exists in F555W, F814W, F160W filters: v, i and H
- Combine this with Keck NIRC2+LGSAO Kp band to model the lens, and hence infer the source size, SED, and stellar mass

## Quantitative AO science:

- How does the LGSAO image quality compare with that from HST?
- Do we know the PSF well enough to be able to do accurate K band photometry?
- How good is the calibration of the optics of our gravitational telescope?

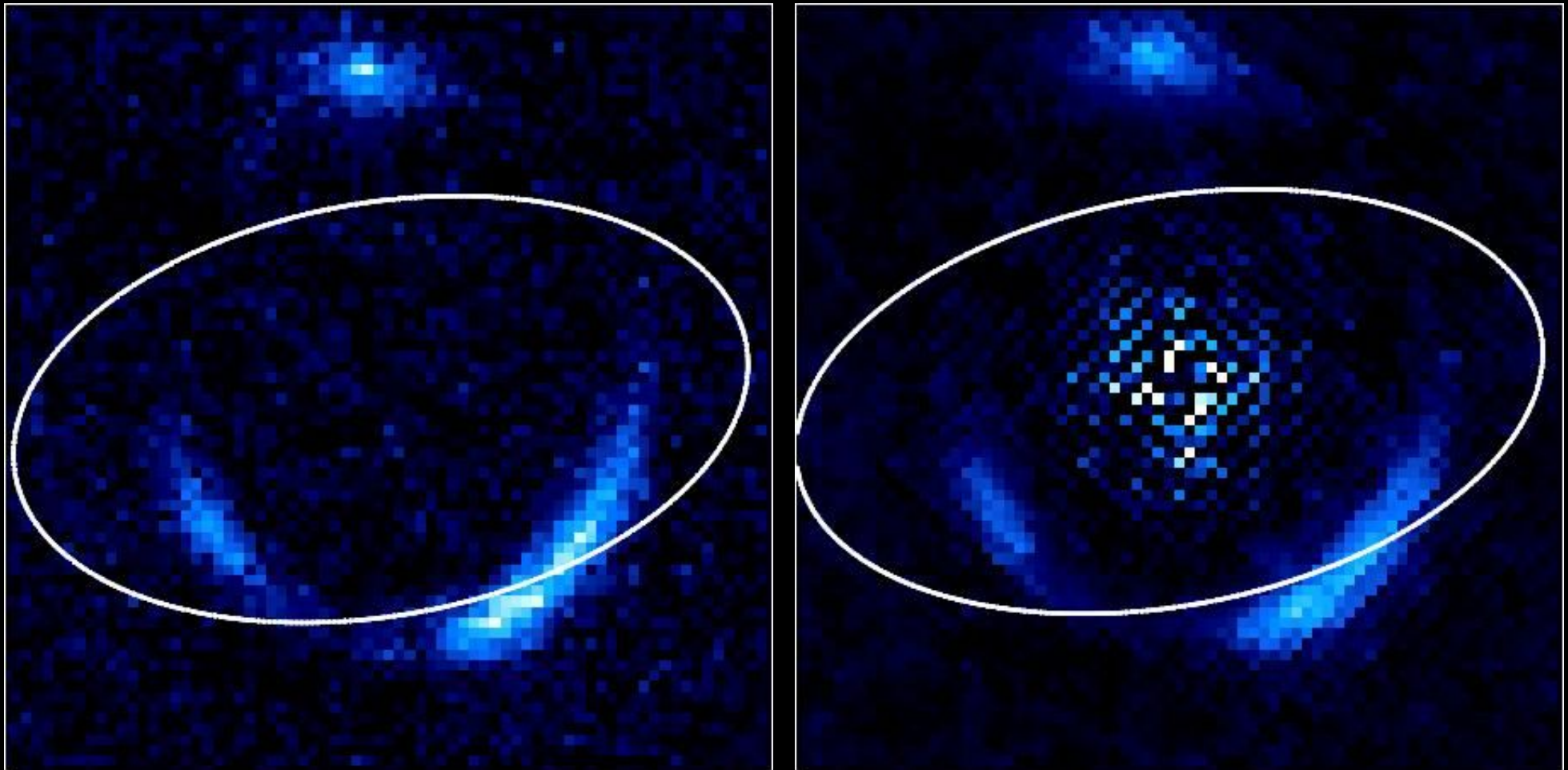
# Keck NIRC2+LGSAO Kp-band image



- 60 minute exposure
- Extracted sub-image of lens
- Extracted sub-images of nearby stars to use as PSF models
- Also took an extra image of a star at the lens position on the detector

# Keck NIRC2+LGSAO vs. HST NICMOS

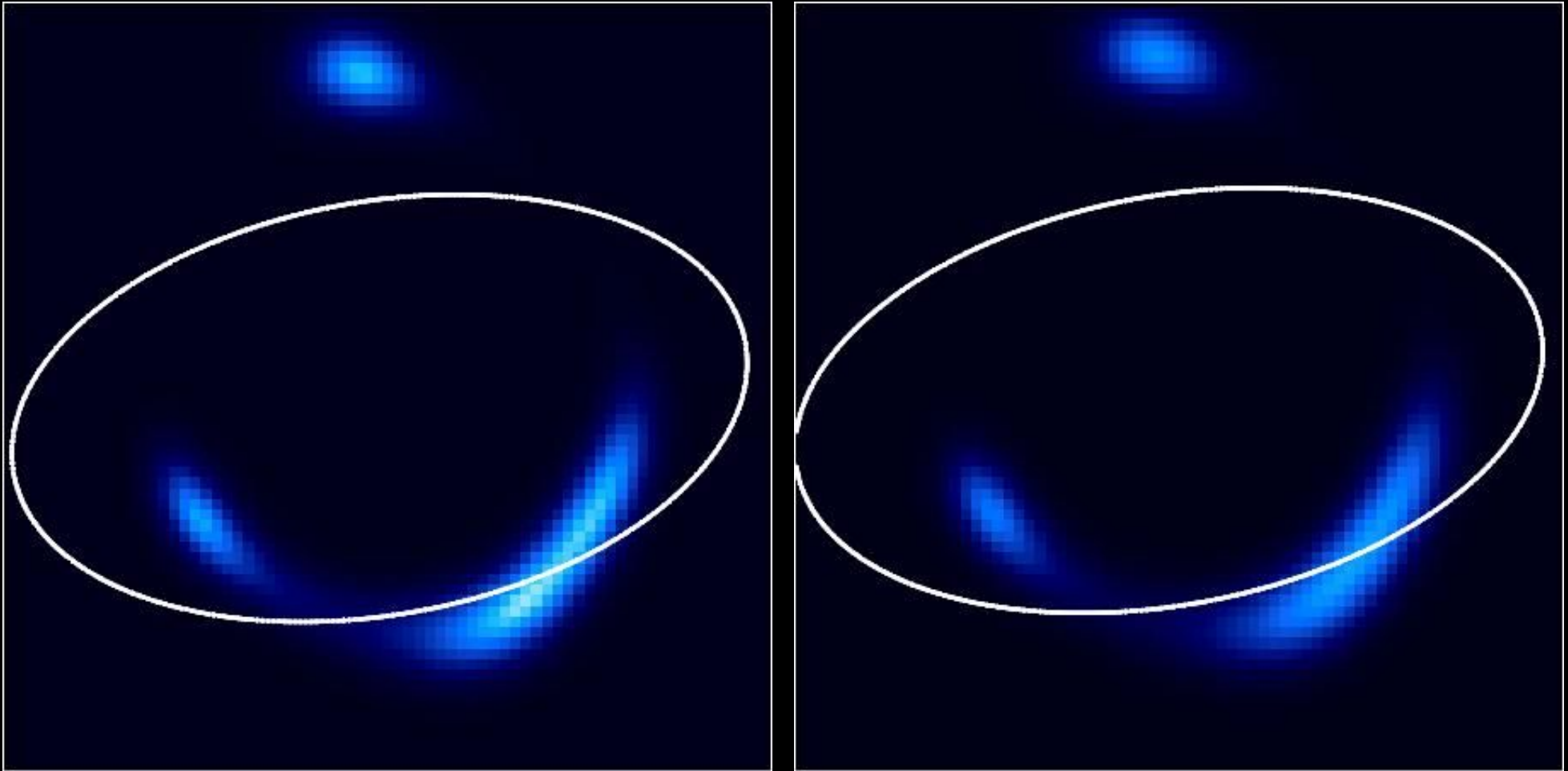
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Lens image after subtraction of a smooth model for the lens galaxy light

# Keck NIRC2+LGSAO vs. HST NICMOS

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Predicted images for best-fit lens and source model parameters

# Keck NIRC2+LGSAO vs. HST NICMOS

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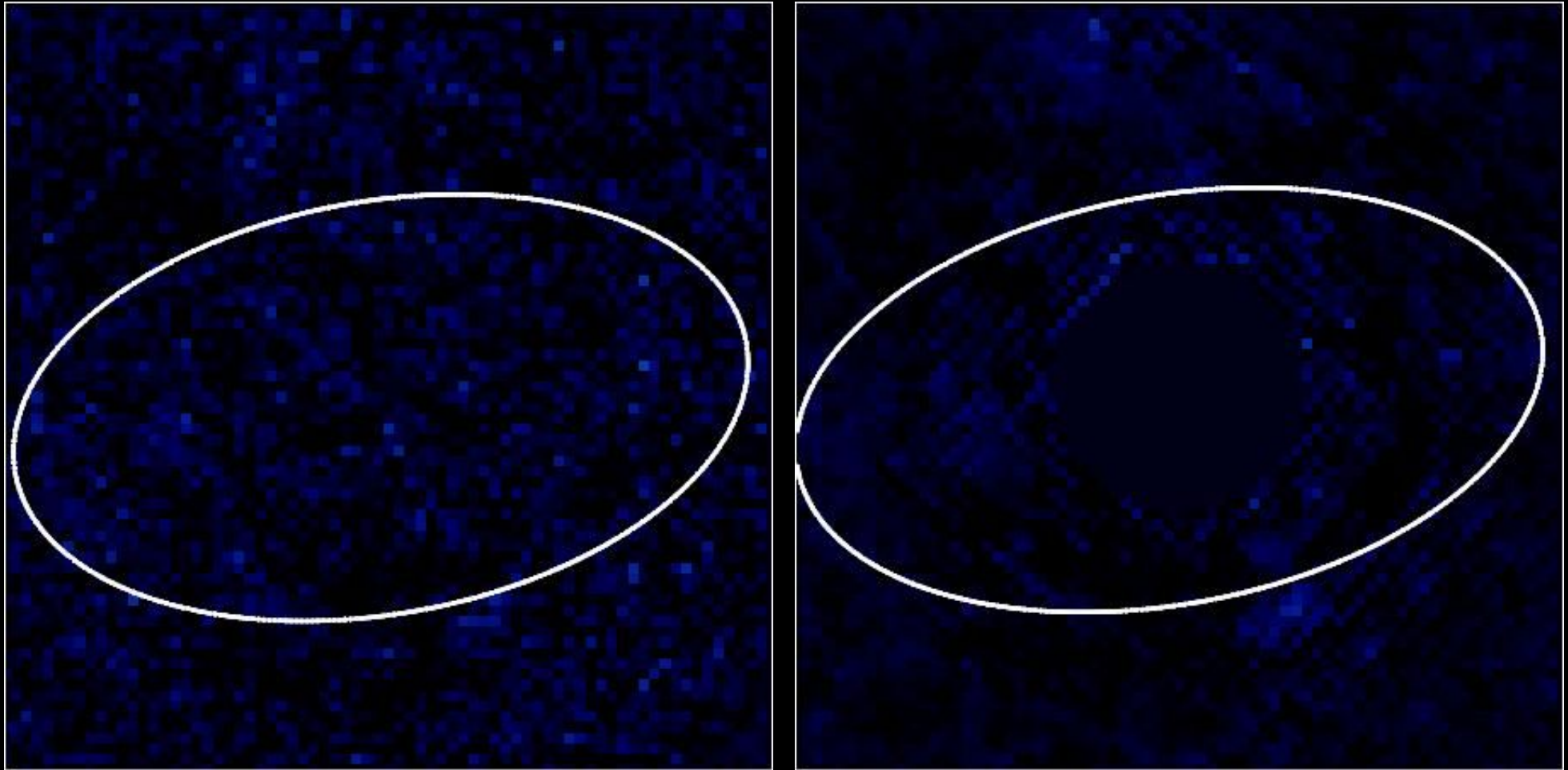
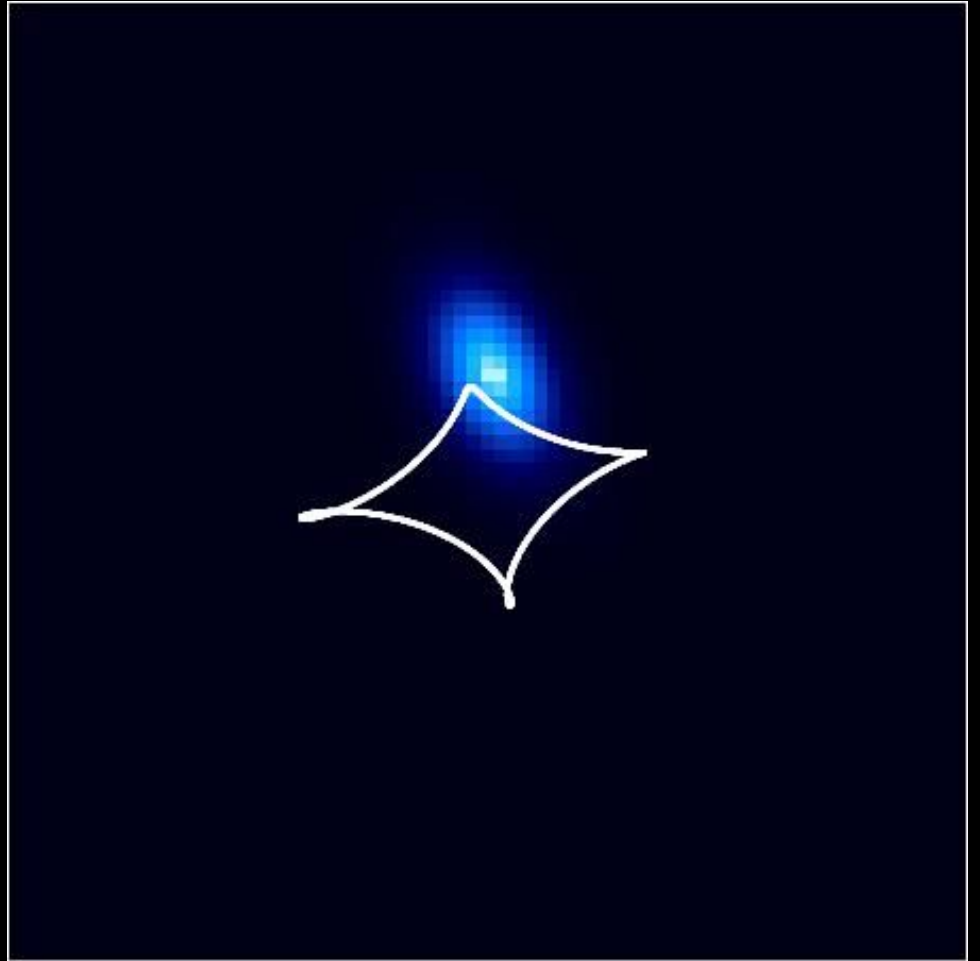
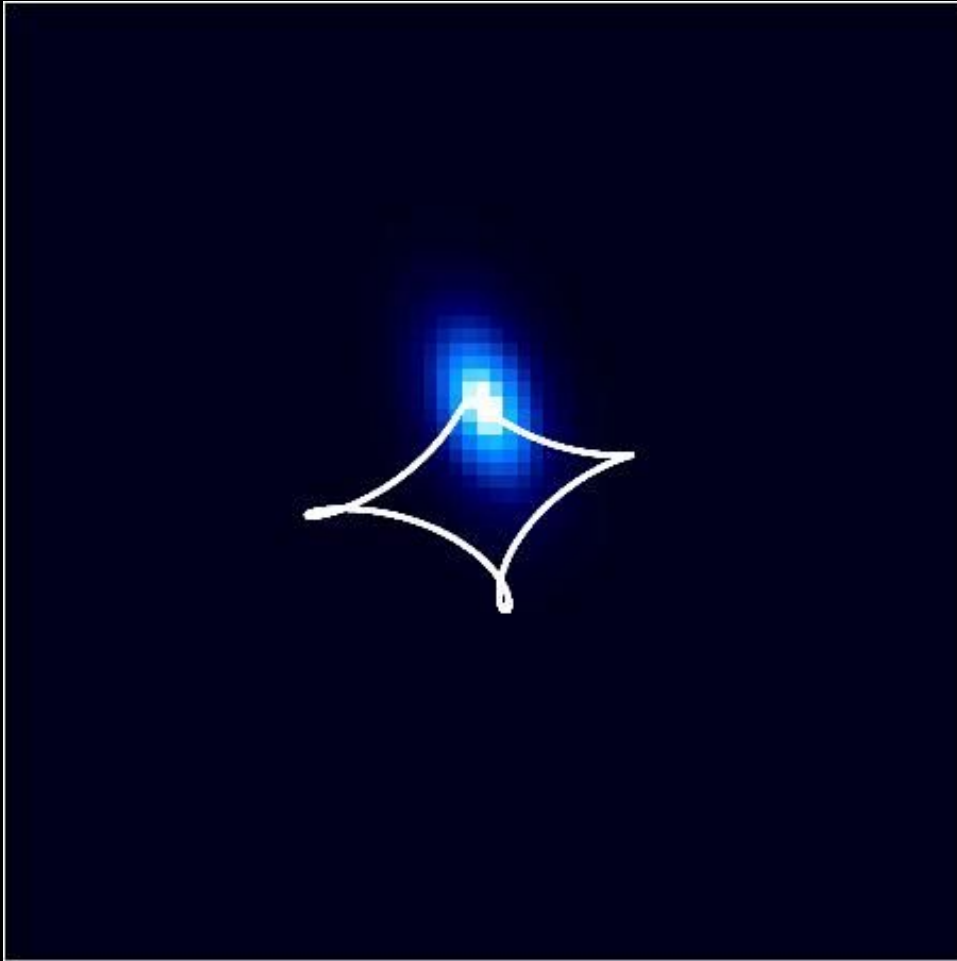


Image residuals – the fit is good

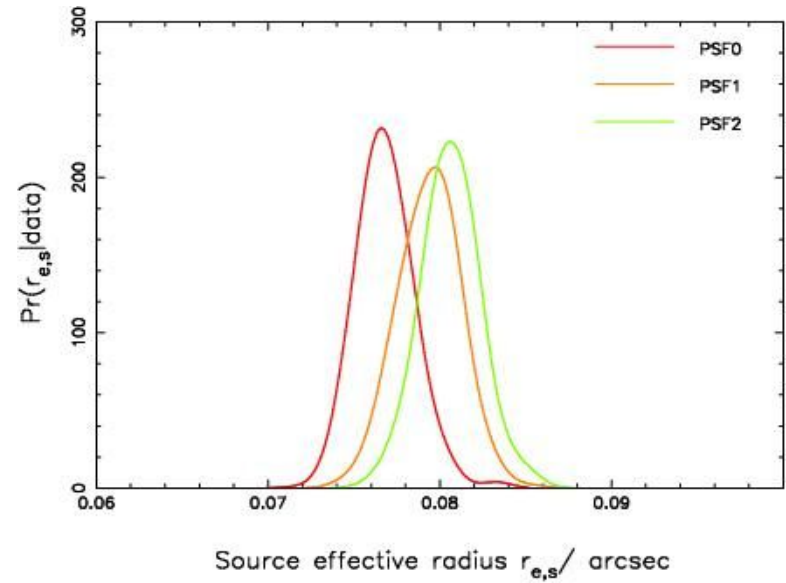
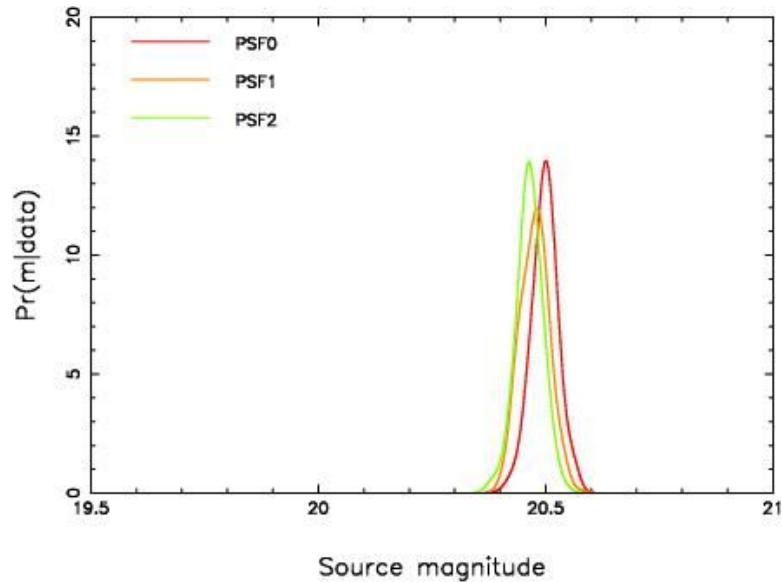
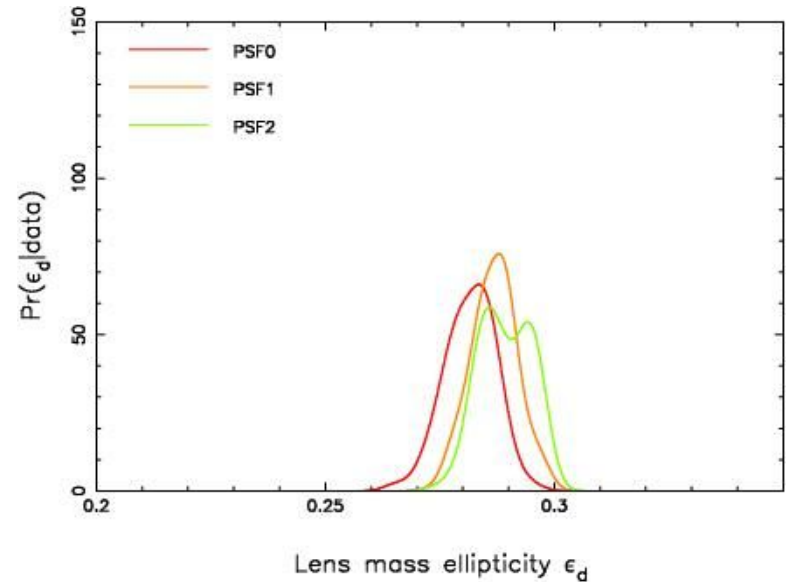
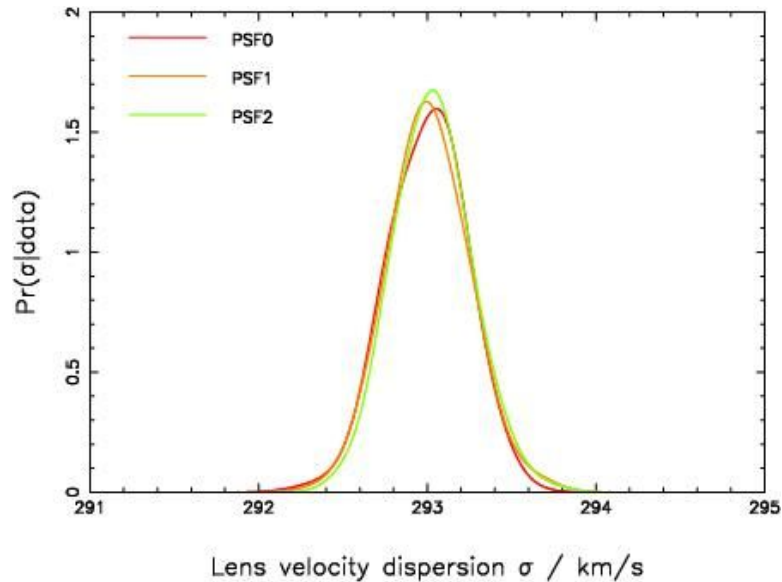
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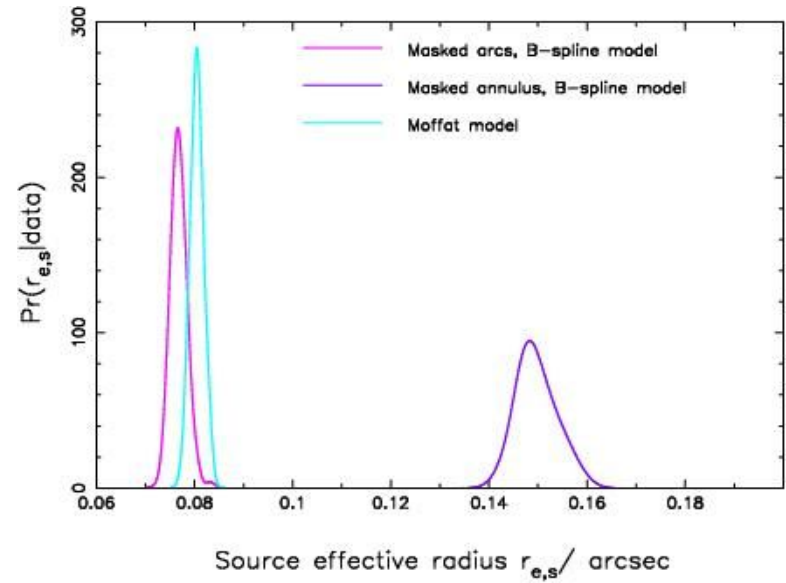
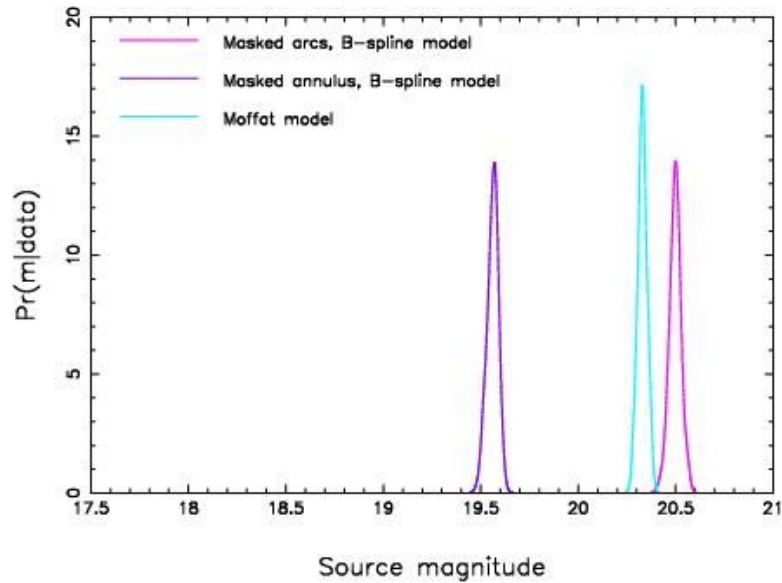
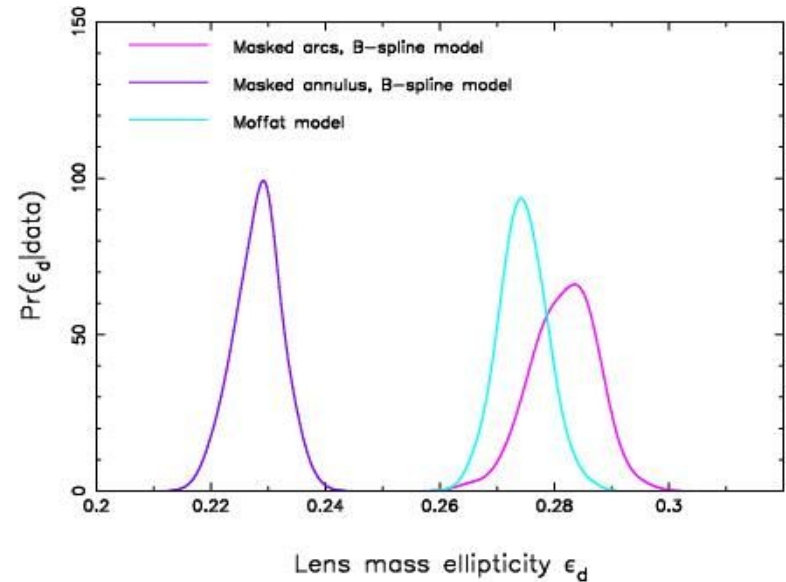
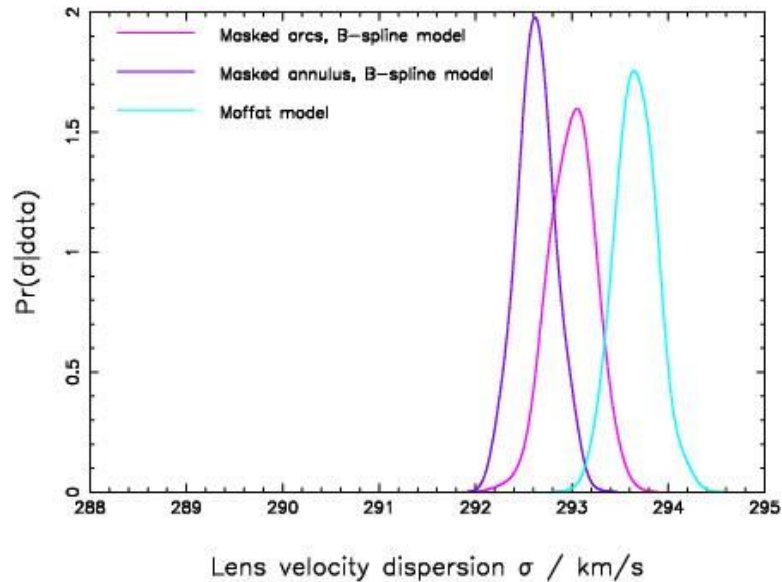
Reconstructed source intensity distribution

# Systematic error no. 1: PSF determination



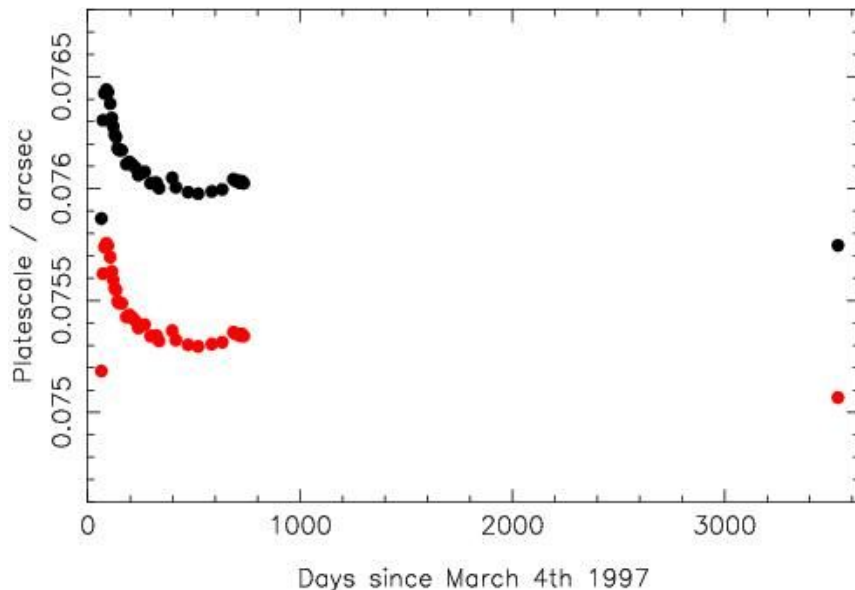
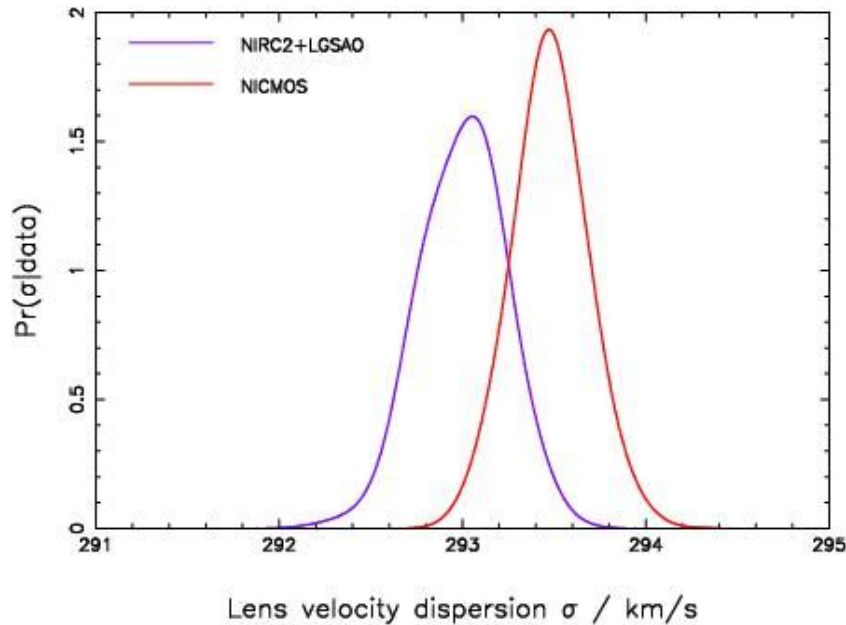
*Photometry not limited by choice of PSF star*

# Systematic error no. 2: Lens galaxy subtraction



*Photometry limited by lens galaxy subtraction*

# Systematic error no. 3: the NICMOS plate scale



For all subtraction schemes, the NICMOS image gives a higher lens mass

- 0.5 km/s in velocity dispersion corresponds to 3.4mas in Einstein radius (an error of 0.3%)

We can use the lens as a “standard rod,” and, with our NIRC2 data, calibrate the (unknown!) NICMOS pixel scale for the first time in 7 years!

- The plate scale is 220 $\mu\text{s}$  smaller than it was in 1999

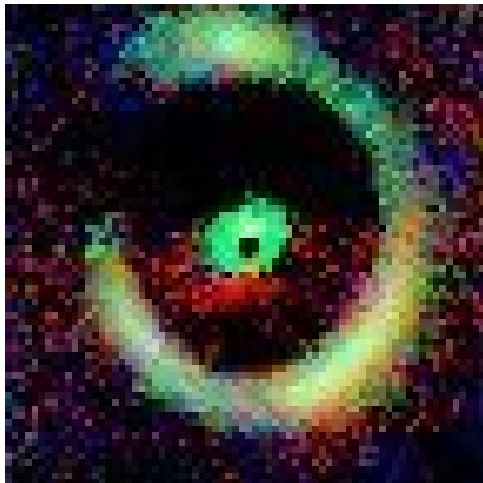
This measurement is also limited by the galaxy subtraction

# SED estimation

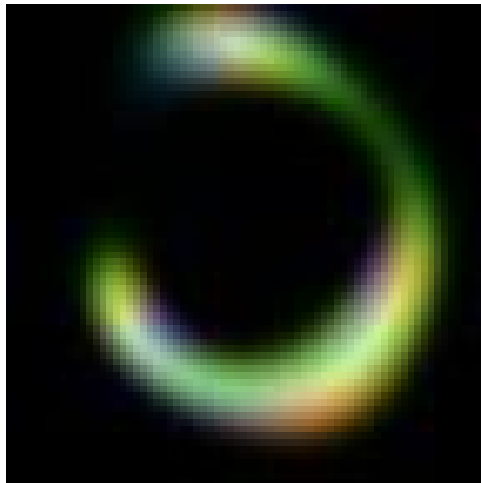
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- Select optimal PSF models in each band according to  $\text{Pr}(\text{data}|\text{H})$
- Assert Moffat profile for lens galaxy and swallow 0.2 mags systematic error
- Infer magnitudes in each band and fit SED

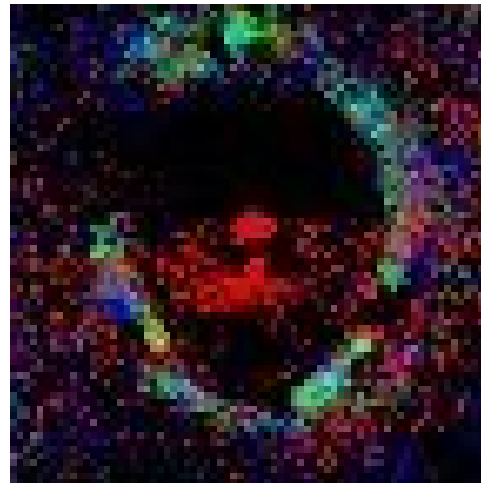
Preliminary results...



Observed image



Predicted image



Fit residuals

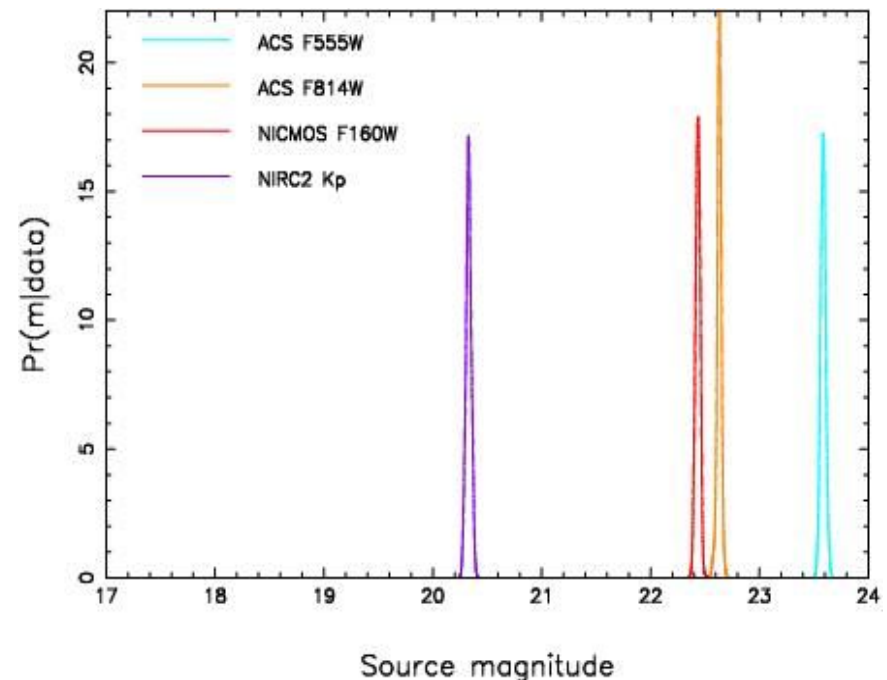
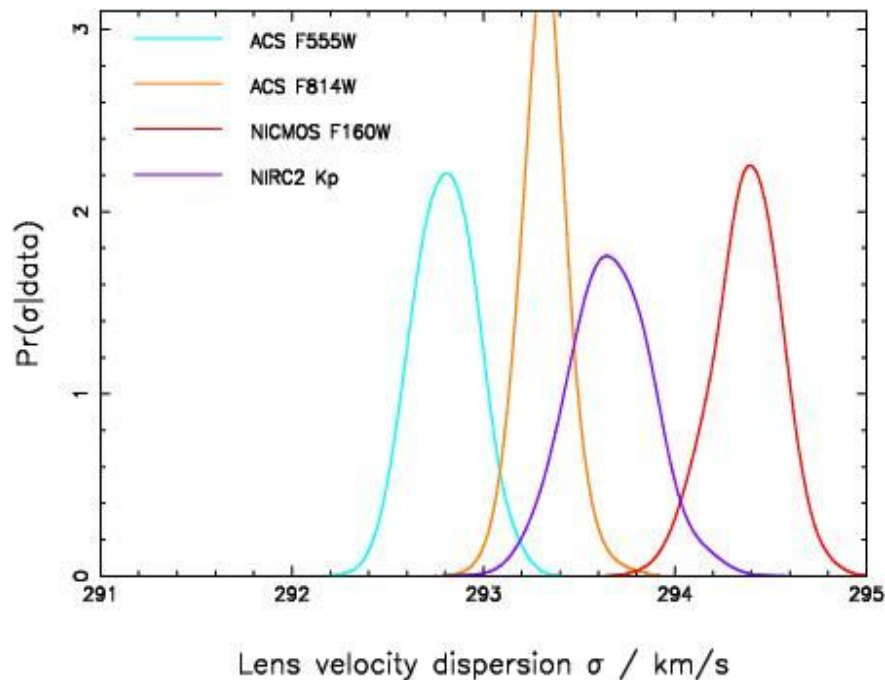


Reconstructed source

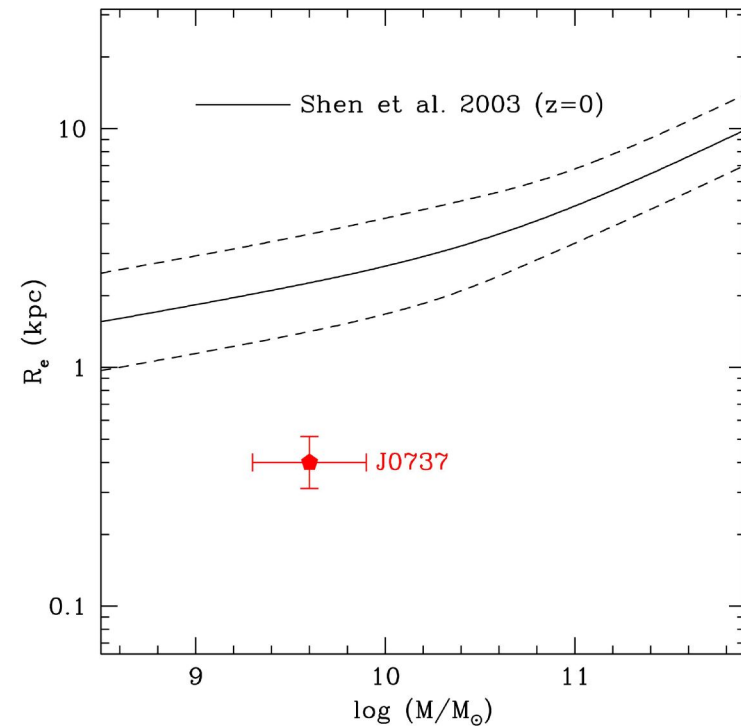
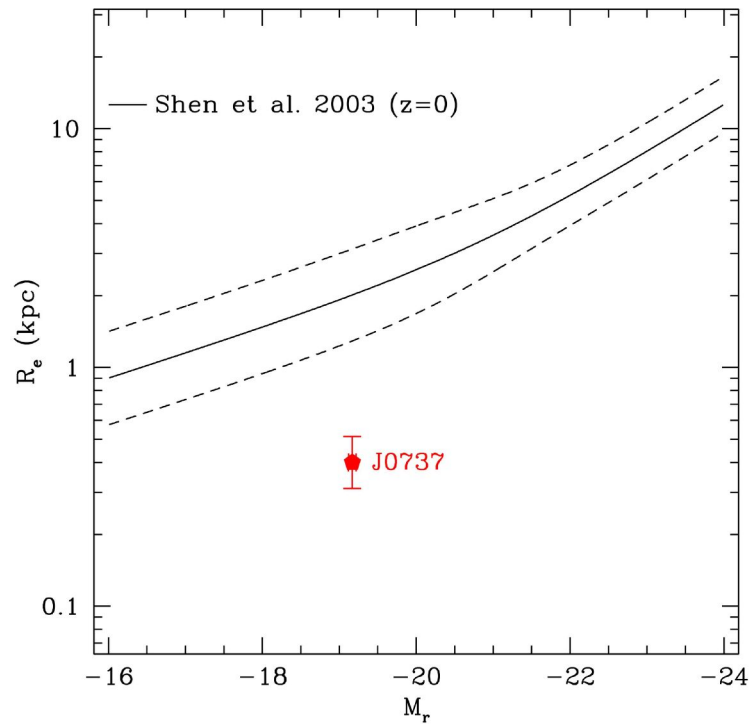
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# Galaxy sizes



- The SDSSJ0737+3216 source appears to be very small (effective radius  $0.08'' = 0.5\text{kpc}$ ) with low stellar mass ( $4 \times 10^9 M_\odot$ ) – we are indeed probing the small, faint end of the population with this lens!

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- The spectroscopic selection means we are probably not biased towards compact sources
- The total magnification due to the lens is  $\sim 10$  – so the angular resolution we have is  $\sim 0.01''$  : our size estimation should be good
- Feasibility shown – now need statistical sample:
- SLACS will provide  $\sim 100$  lensed galaxies at  $z=0.5-0.7$
- SL2S will provide  $\sim 100$  lensed galaxies at  $z > 1.0$

# Slide title: Helvetica 32pt bold

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Some un-bulleted text, Helvetica 24pt

- Bullet point 1
- Bullet point 2