Strong Lensing with SNAP

Phil Marshall

with Roger Blandford, Masao Sako and Ted Baltz (KIPAC)

plus Charles Baltay (Yale) and Dragan Huterer (CWRU)

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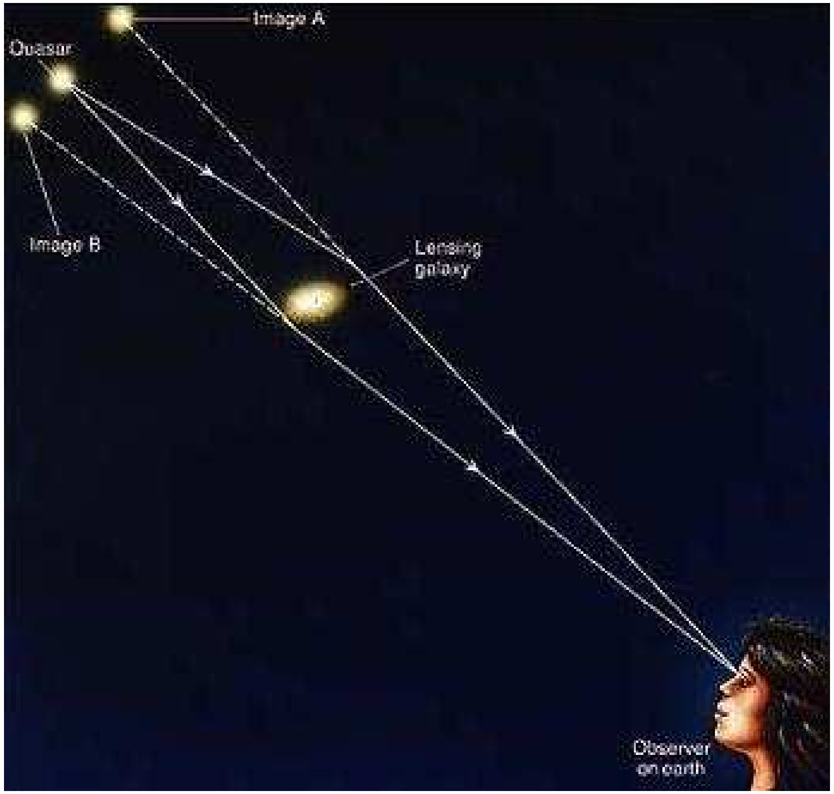
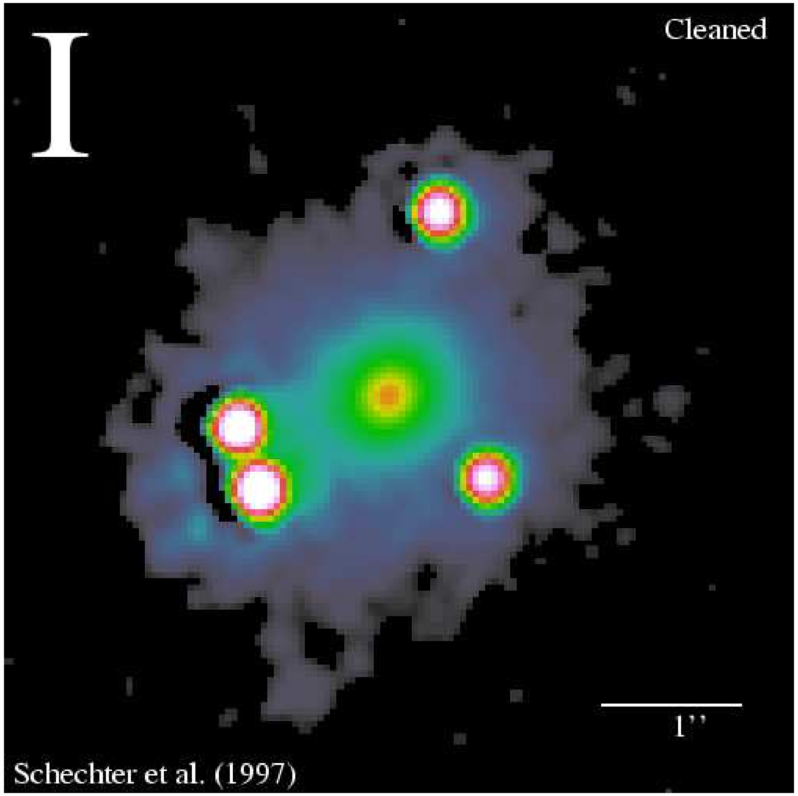
Plan

- Strong lensing overview: prospects with SNAP
- Progress to date: elliptical galaxy lenses
- Cosmography with multiple image separations?
- Future work: image processing, other lenses, applications

Multiple images





PG1115 from CASTLES project `http://cfa-www.harvard.edu/castles/`

Observing with SNAP

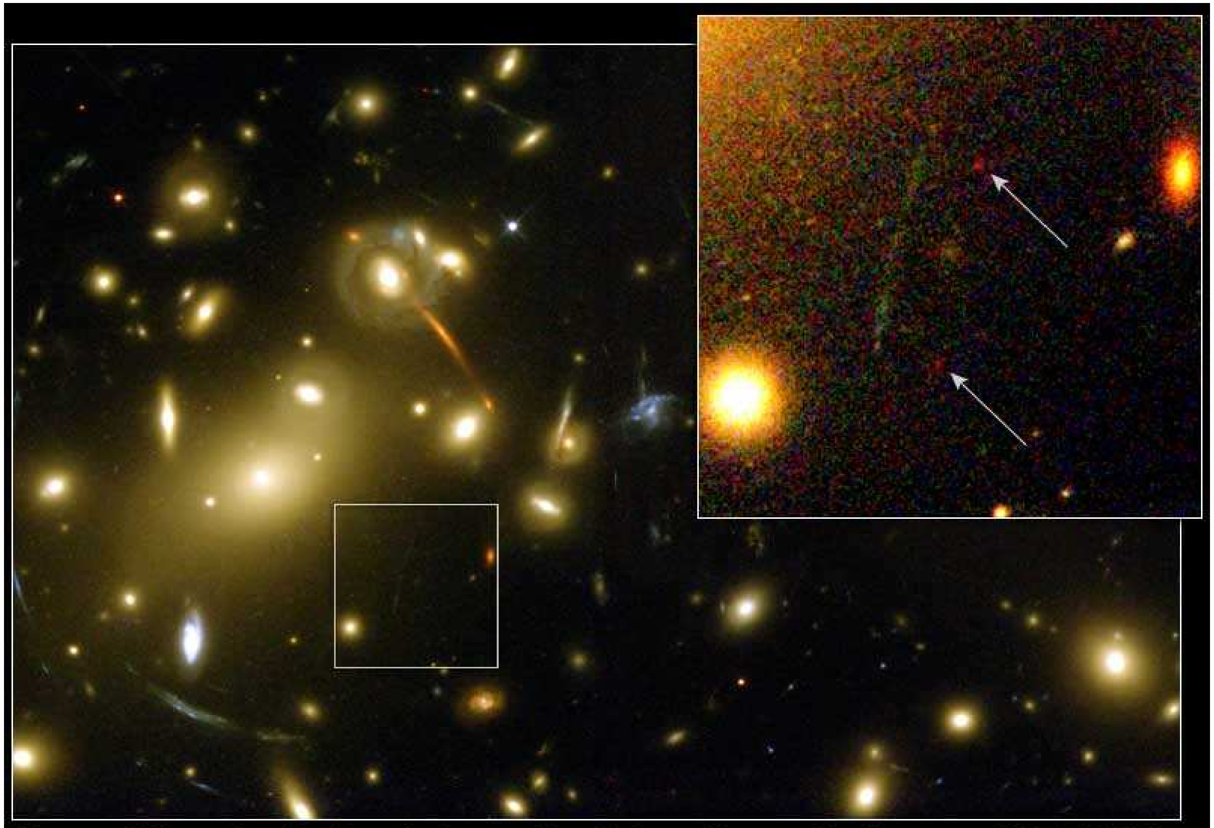
- 2 surveys planned:
  - Wide weak lensing survey: at least 300 sq. degrees, $\mathrm{mag}_{\mathrm{lim}} \approx 28$
  - Deep SN1A survey: 15 sq. degrees, $\mathrm{mag}_{\mathrm{lim}} \approx 30$
  - cf. HDF and UDF
- Small (≈ 0.14 arcsec FWHM) psf, sampled by ≈ 0.04 arcsec (drizzled) pixels: weak lensing requirements are stringent
- Deep survey has 4 day cadence

Strong lensing science

Wide fields, depth and excellent image quality allow statistics–sized samples to be built up

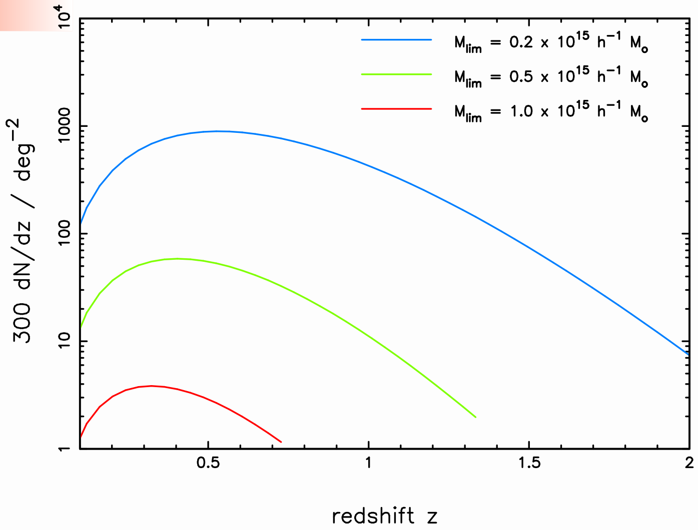
- Cluster arc systems: detailed modelling of many clusters, dark matter profiles, mass calibration, high magnification of very faint protogalaxies, rare events
- "Beasties" – rare (3D) alignments can give exotic image configurations and very high magnifications
- Lensed quasars: large sample with variability information (from SN field or from ground-based follow-up with LSST or SKA) gives H_0, σ_{H_0}
- Galaxy-galaxy lenses: most of cross-section is in ellipticals at $z \lesssim 1$, most sources are faint blue galaxies: lens models, source redshifts, cosmography?

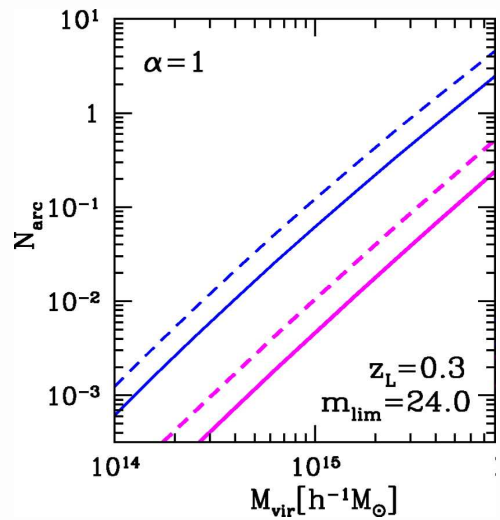
Clusters

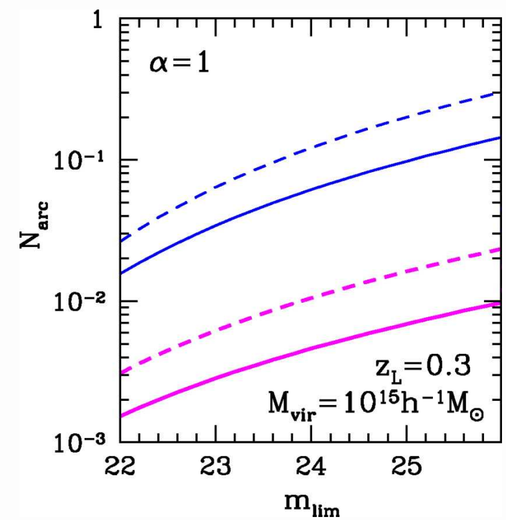

Distant Object Gravitationally Lensed by Galaxy Cluster Abell 2218 HST • WFPC2
NASA, ESA, R. Ellis (Caltech) and J.-P. Kneib (Observatoire Midi-Pyrenees) • STScI-PRC01-32

- Cluster arc systems: detailed modelling of many clusters, dark matter profiles, mass calibration, high magnification of very faint protogalaxies, rare events

Arc numbers

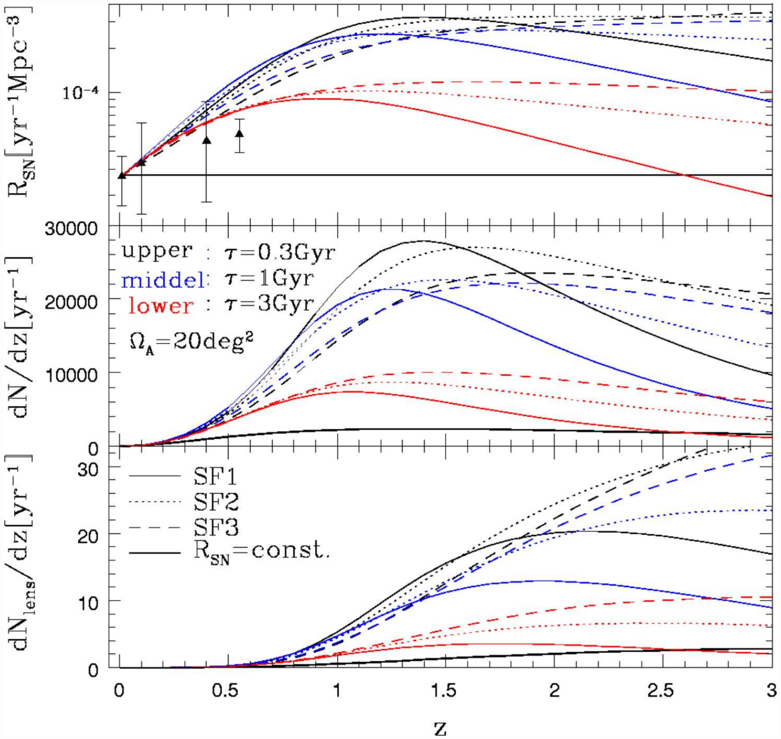






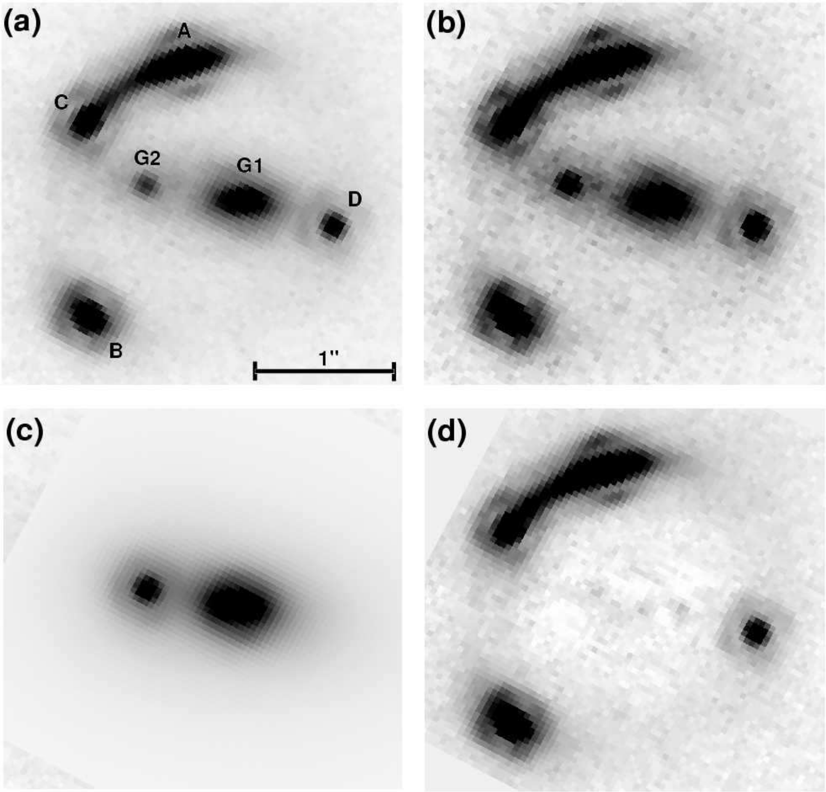
- Arc statistics, and individual lens models, are sensitive to CDM profile (e.g. Oguri et al 2003)
- Significant fraction of clusters in survey will have measurable arcs – quantification in progress. . .
- SLAC experience with higher-order shape distortions (Irwin et al 2003)

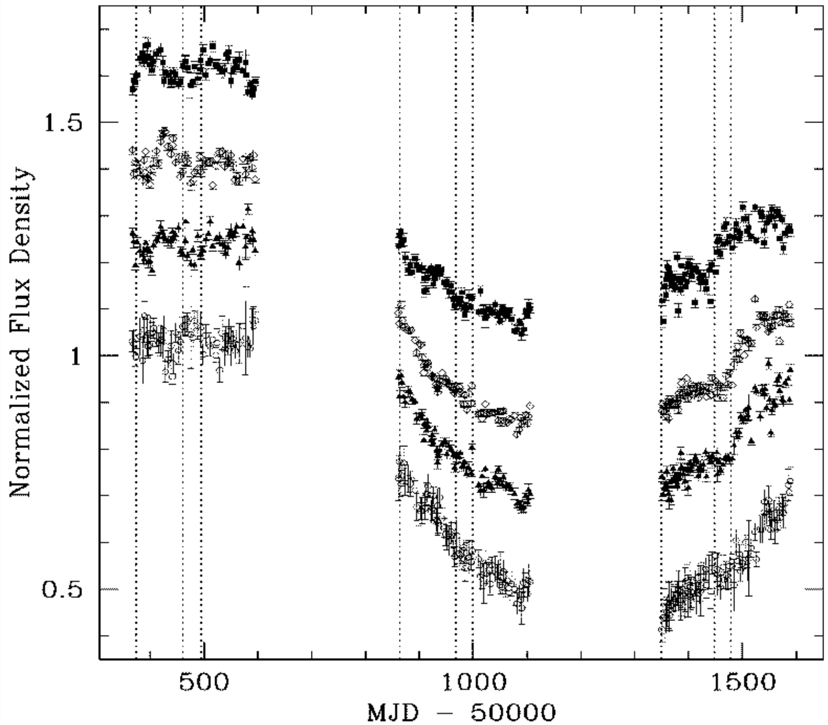
Rare events



- Rare events: expect ~ 20 lensed SNIa per year (Oguri et al 2003) $\longrightarrow$ high redshifts, good lens model constraints, explosion anticipation

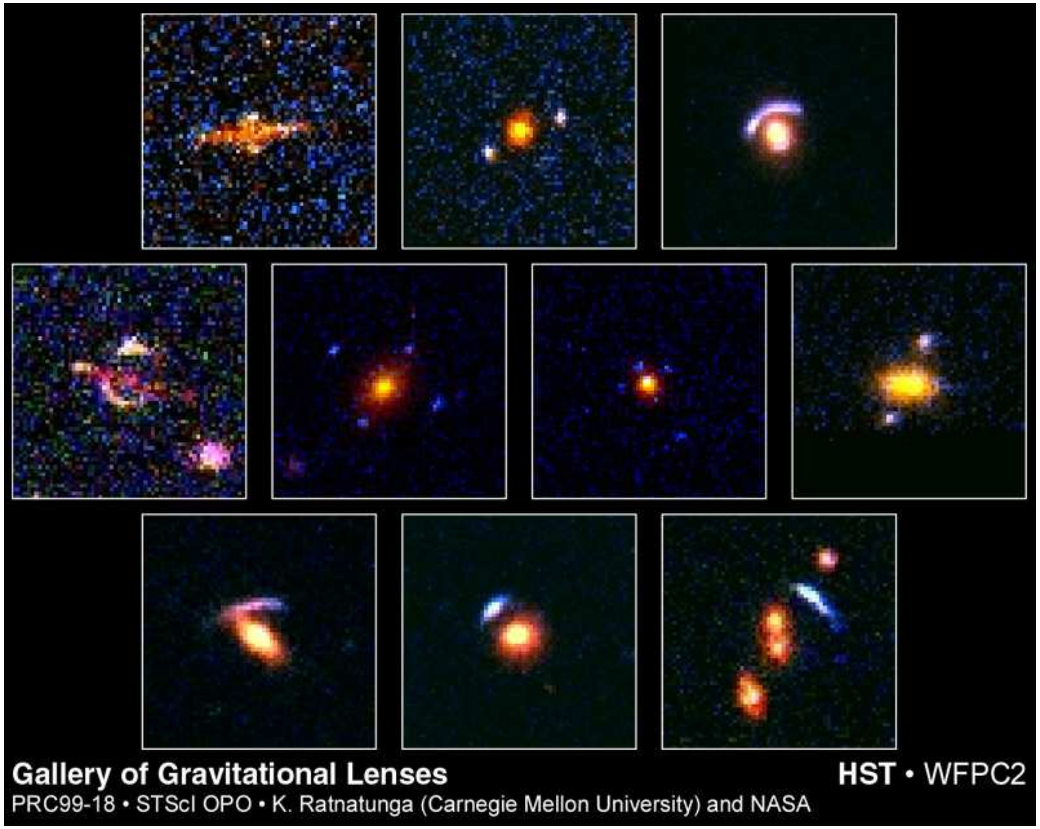
Lensed quasars





- Lensed quasars: large sample with variability information (from SN field or from ground-based follow-up with LSST or SKA) gives H_0, σ_{H_0}
- B1608: HST imaging + VLA time delay (weeks $\pm$ days), lens model dominates uncertainty in this system. . .

Galaxy-galaxy strong lenses



- Galaxy-galaxy strong lenses: most of cross-section is in ellipticals at $z \lesssim 1$, most sources are faint blue galaxies: lens models, source redshifts, cosmography?
- Familiar pattern: bright yellow elliptical galaxy with faint blue smudges around it
- Targeted search: what fraction of elliptical galaxies have multiple-image systems?

Predicting lens numbers

$$N_{\rm lens} = \int X \cdot \frac{d^2 N_d}{dz_d d\sigma_d} \cdot \frac{d^2 N_s}{dz_s dm_s} \; dz_d \, d\sigma_d \, dz_s \, dm_s$$

$$X(z_d, \sigma_d, z_s, m_s) = \int^{\beta_{\rm crit}} 2\pi S(\beta, ...) \; d\beta$$

Model:

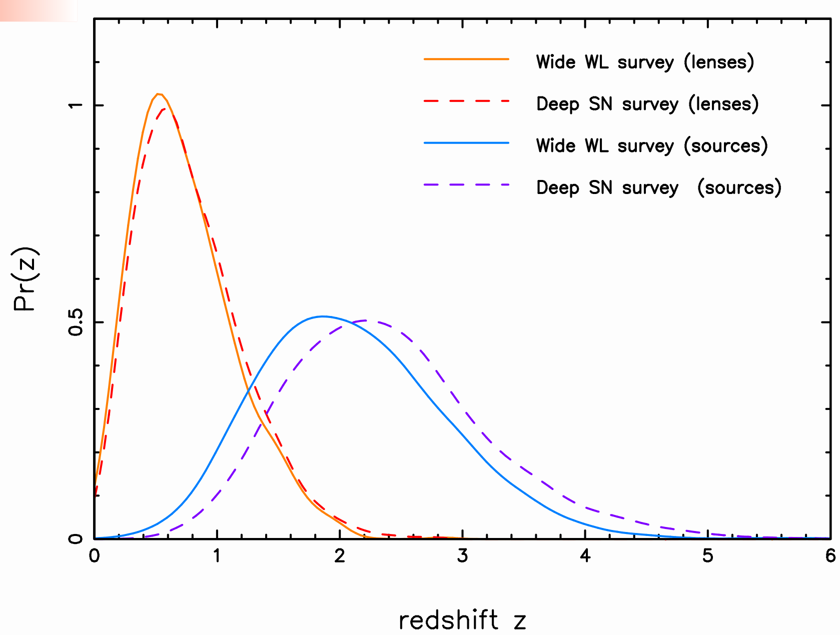
- SIS lenses (Koopmans and Treu)
- SDSS velocity function (Bernardi et al 2003)
- 2DF quasar luminosity function (Croom et al 2004)
- HDF faint galaxy counts (Casertano et al 2000) + model redshift distribution (Massey et al 2003)
- Selection function S includes magnification bias: compact sources preferred. Cross-section by Monte Carlo integration

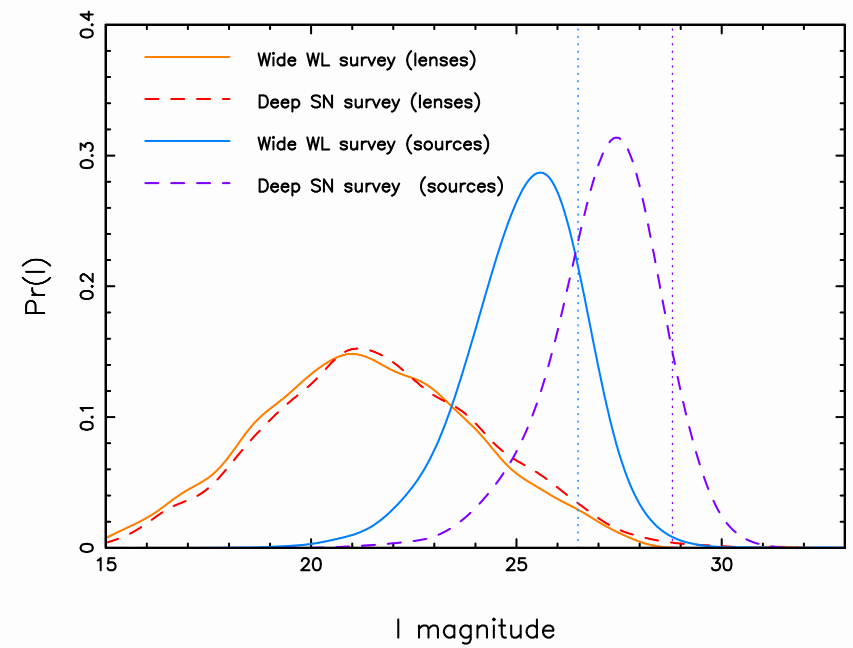
Elliptical galaxy lens counts

	Quasars:		Galaxies	
	$N_{\rm lens}$ deg^{-2}	$N_{\rm lens}$ total	$N_{\rm lens}$ deg^{-2}	$N_{\rm lens}$ total
Wide	0.14	42	50	15000
Deep	0.25	4	325	4900

- Realistic input populations, approximate selection function
- Quasars are rare but easy to see: need to include other types of lens galaxies, and boosting by groups and clusters to get more realistic (larger, $\times 10$?) numbers
- Potentially large numbers of elliptical galaxies with multiple image systems. . .

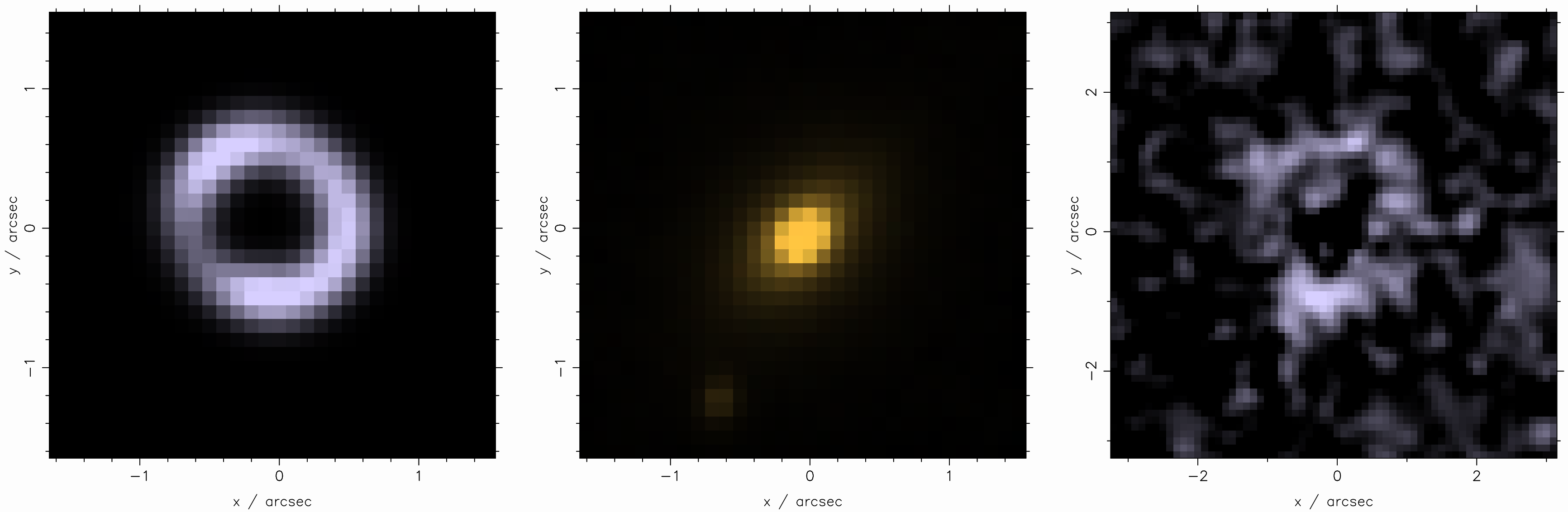
Lens distributions





- Elliptical lenses probe very faint galaxy sources at $z \sim 2$
- Typical system: $z_d = 0.7$, $\sigma = 200\ \mathrm{km\ s^{-1}}$, $z_s = 2.3$, $m_s = 28$
- Assumed transparent lens – but only single colour image data

Extracting Einstein rings



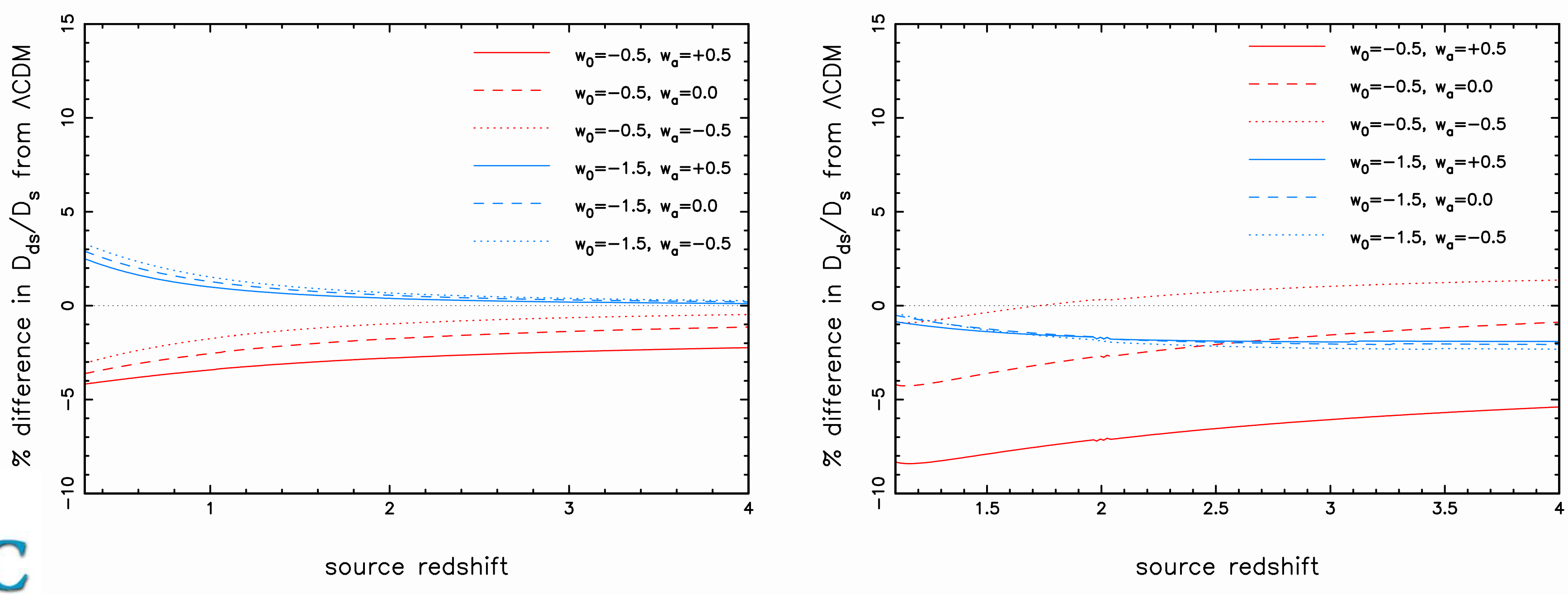
- Knowledge of source and lens spectra allows optimal combination of 9 filters' images to reveal the Einstein ring
- How bad does this become with unknown SEDs (more parameters), morphology changing with wavelength (serious problem), colour gradients, dust. . . ?

Cosmography

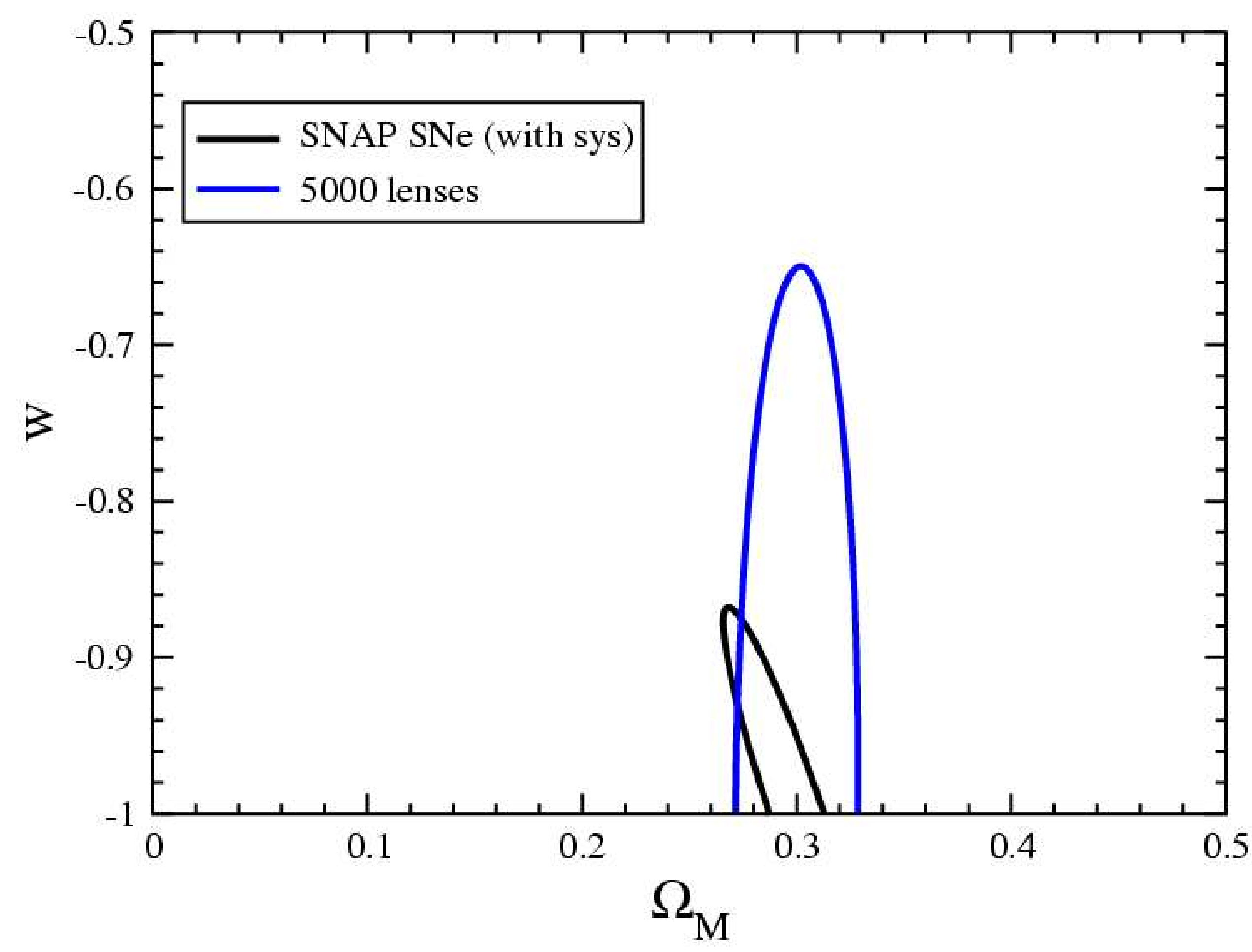
- Einstein radius of an SIS lens:

$$\theta_E = 4\pi \left(\frac{\sigma}{c}\right)^2 \frac{D_{ds}}{D_s}$$

$$\frac{D_{ds}}{D_s} = 1 - \int_{z_d}^{z_s} H(z)^{-1} dz \Big/ \int_0^{z_s} H(z)^{-1} dz$$



Tantalising result



5000 lenses, $\sigma_\sigma = 50\ \mathrm{km\ s}^{-1}$, $\sigma_{z_d} = 0.02$, $\sigma_{z_s} = 0.2$

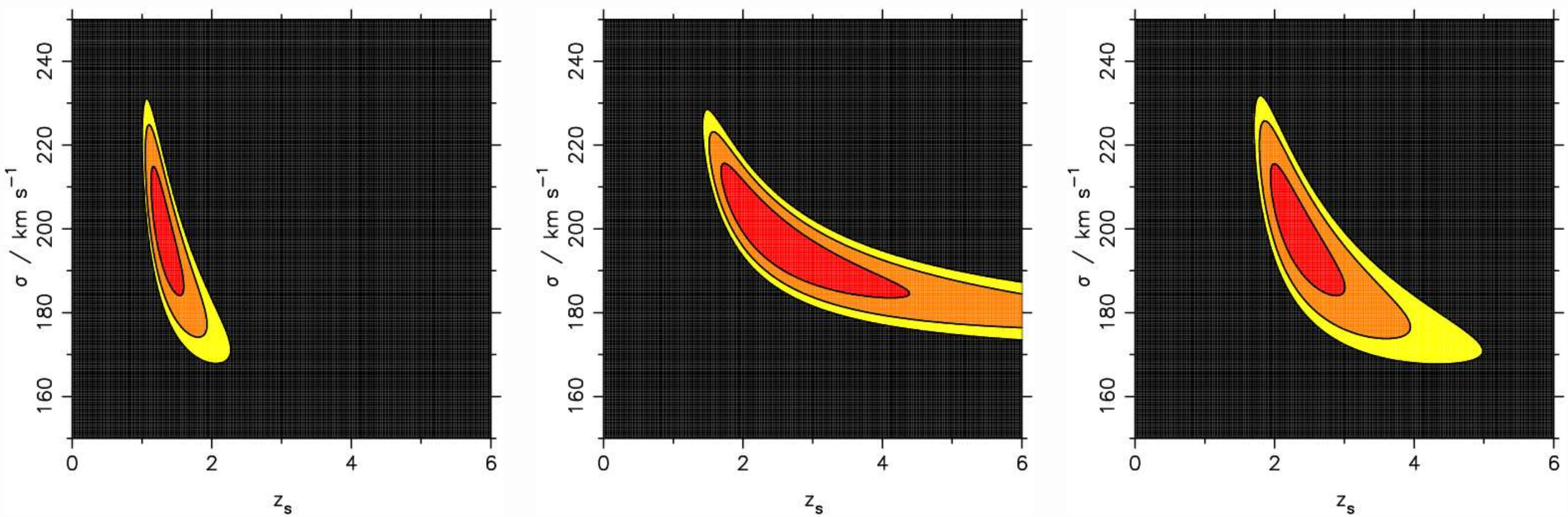
Gritty realism

Assumed 5000 lenses, $\sigma_\sigma = 50 \text{ km s}^{-1}$, $\sigma_{z_s} = 0.2$

- Lens extraction difficulties: is 5000 feasible?
- Fundamental plane scatter is $\sim 50 \text{ km s}^{-1}$: spectroscopic follow up? Is plane thinner with 9 filters?
- Can lens modelling errors be treated statistically? (cf H_0 history…) How does this degrade the cosmology?
- Source redshifts: how realistic is $\sigma_{z_s} = 0.2$ for a 28th magnitude proto-galaxy?
- Marginalisation over astrophysics is not an easy prediction to make – attempts so far suggest we will learn more about the lens and source populations than dark energy
- This conclusion may well change!

Measuring source redshifts

$z_d = 0.7$ $z_s = 1.3$ | $z_d = 0.7$ $z_s = 2.3$ | $z_d = 1.1$ $z_s = 2.3$



- Good lens model: velocity dispersion to ± 10 km s^{-1}, well-measured Einstein radius and lens redshift
- Lensing provides vital additional redshift information for galaxies too faint for spectroscopy

The immediate future

- UDF as a provider of priors (numbers, photo-z, sizes, morphologies); sideline – lenses in HST image data (GOODS, COSMOS), automated searching
- Joint lens/source analysis development:
  - Targeted search of image
  - Lens light constrains mass which predicts images in 9 filters
  - Photo-z models help parameterisation
  - Need good lens and source light models
  - Include PSF deconvolution
- Other lenses:
  - Halo model for cluster and group arcs
  - Crossover with weak lensing cluster counts
  - Effects of larger halos on galaxy lenses (boosting)
  - Quasar lens counts