The SNAP Strong Lens Survey

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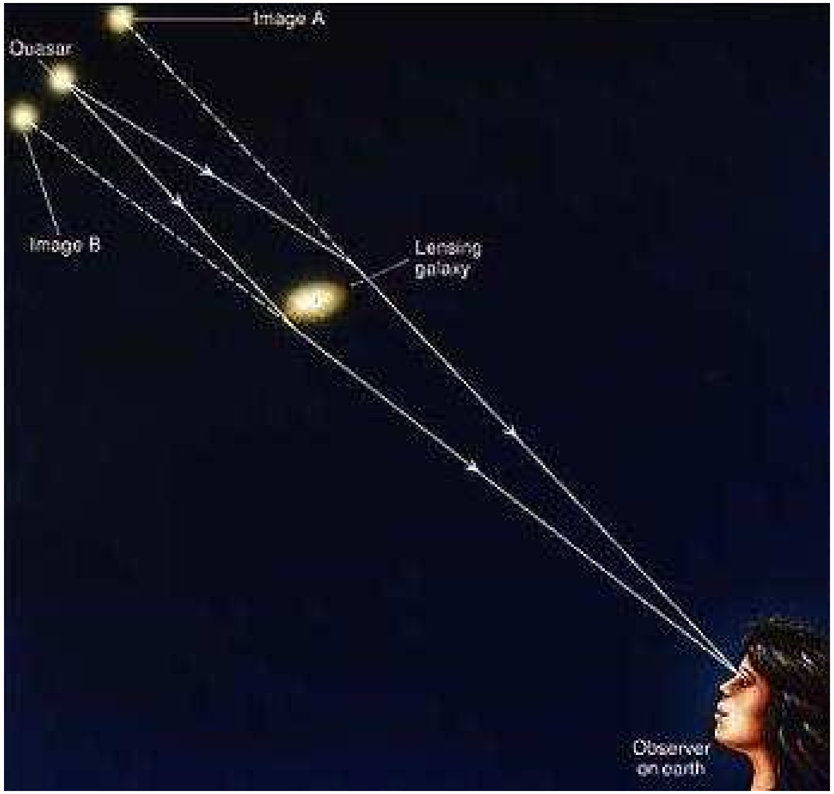
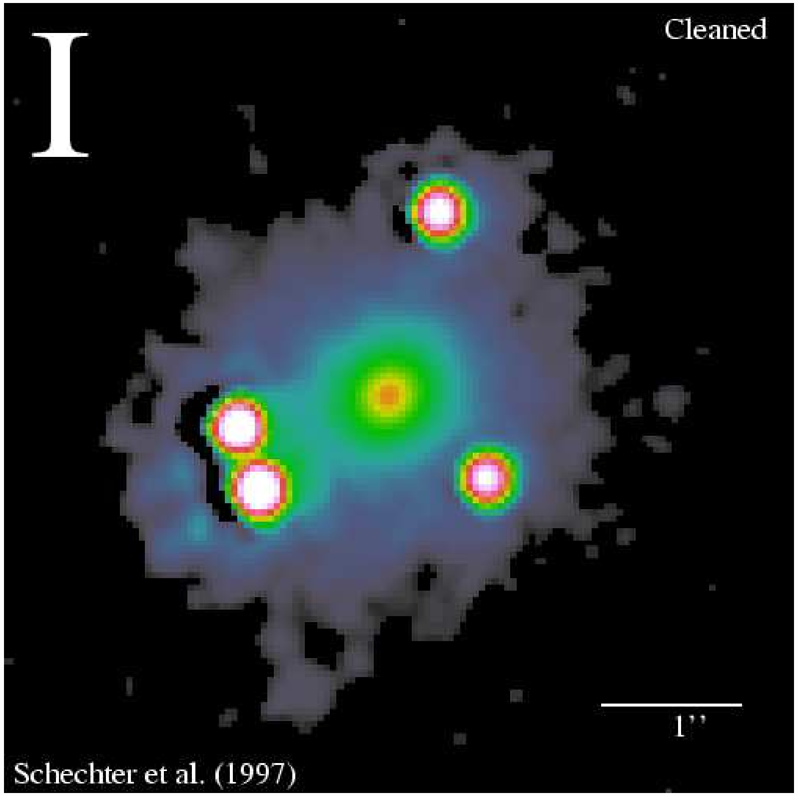
May 2004

Overview

- Strong gravitational lensing: multiple image systems
- SNAP has excellent imaging capability and wide sky coverage – is a survey for strong lenses feasible?
- Strategy:
  - Recognise similarities between WL and SL requirements – "piggy back"
  - Focus on massive elliptical galaxies as "cosmic telescopes" whose optics is relatively clean
  - Calculate how many elliptical galaxy lens systems are detectable with SNAP
  - Applications and difficulties

Multiple images





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

Observing with SNAP

- 2 surveys planned:
  - Wide weak lensing survey: 300 sq. degrees, $\text{mag}_{\text{lim}} \approx 28$
  - Deep SN1A survey: 15 sq. degrees, $\text{mag}_{\text{lim}} \approx 30$
  - 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: good for time delays

Predicting lens numbers

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

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

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

Results

	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

- Quasars are rare but easy to see: important to include other lens galaxies, and also boosting by groups and clusters to get more realistic (larger) numbers
- Even with no such boosting, get large numbers of galaxies multiply-imaged by elliptical lenses
- More details of the galaxy calculation to follow. . .

(A Selection of) Science Goals

. . . But first, some thoughts on what one could do with a large sample of strong gravitational lenses:

- The lens galaxy population: galaxy substructure out to $r \sim 10$ kpc
- The source population: measure redshifts, luminosities, star formation rates etc. of the faintest galaxies
- Cosmography: distance ratios, Hubble's constant, counting lenses. . .
- ?

The SNAP Selection Function

$$S = H(m_d - m_{\rm lim}) \cdot H(\Delta\theta - 2\mathrm{FWHM}_{\rm psf}) \cdot H(I_{\rm trough} - 2I_{\rm lim})$$

- Lens galaxy must be visible
- Images must be measurably separated
- Surface brightness detection criterion – magnification bias is replaced by size/ellipticity bias
- Assume faint galaxies are fairly compact – using exponential disks reduces numbers by 1/2

Lens distributions

- Probability density $\propto$ Number density
- Re-write lens number equation:

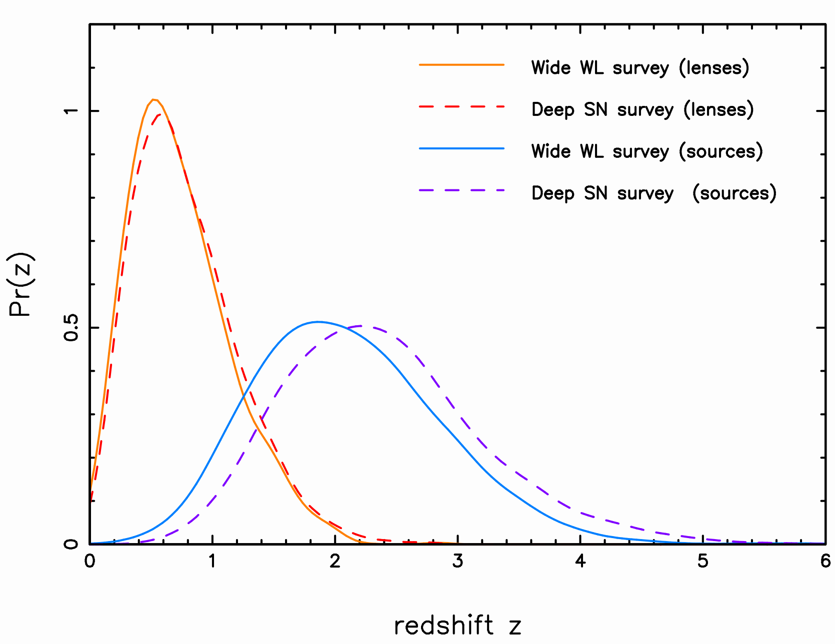
$$\frac{d^4 N_{\rm lens}}{dz_d\, d\sigma_d\, dz_s\, dm_s} = X \cdot \frac{d^2 N_d}{dz_d\, d\sigma_d} \cdot \frac{d^2 N_s}{dz_s\, dm_s}$$

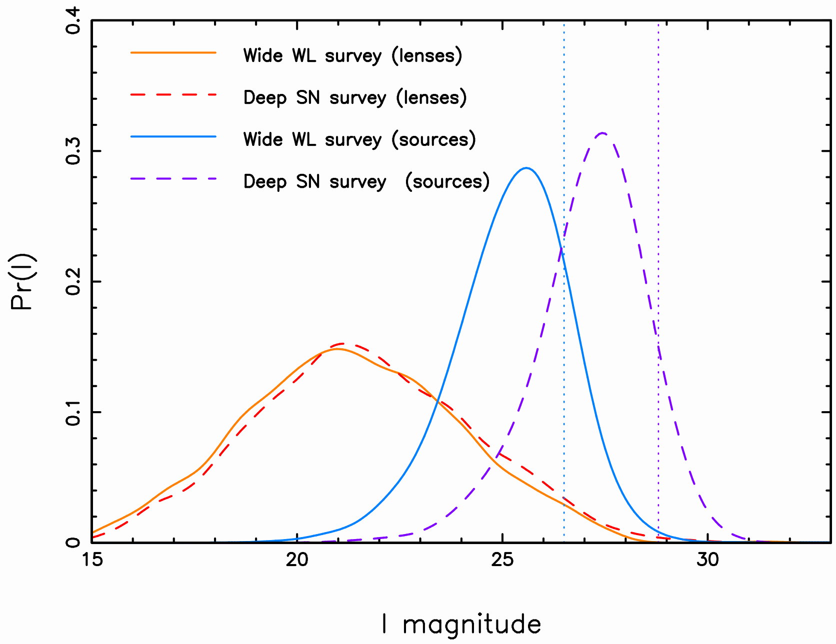
$$\mathrm{Pr}(z_d, \sigma_d, z_s, m_s|\mathrm{lens}) \propto \bar{\mathrm{Pr}}(\mathrm{lens}|z_d, \sigma_d, z_s, m_s) \cdot \bar{\mathrm{Pr}}(z_d, \sigma_d) \cdot \bar{\mathrm{Pr}}(z_s, m_s)$$

- ie. X is a likelihood and can be sampled with MCMC – samples make transforming distributions trivial, and MCMC is efficient compared to grid calculations or straight Monte-Carlo

Do the cross-section integral over the source plane by MC integration: include distribution of source sizes and ellipticities as well

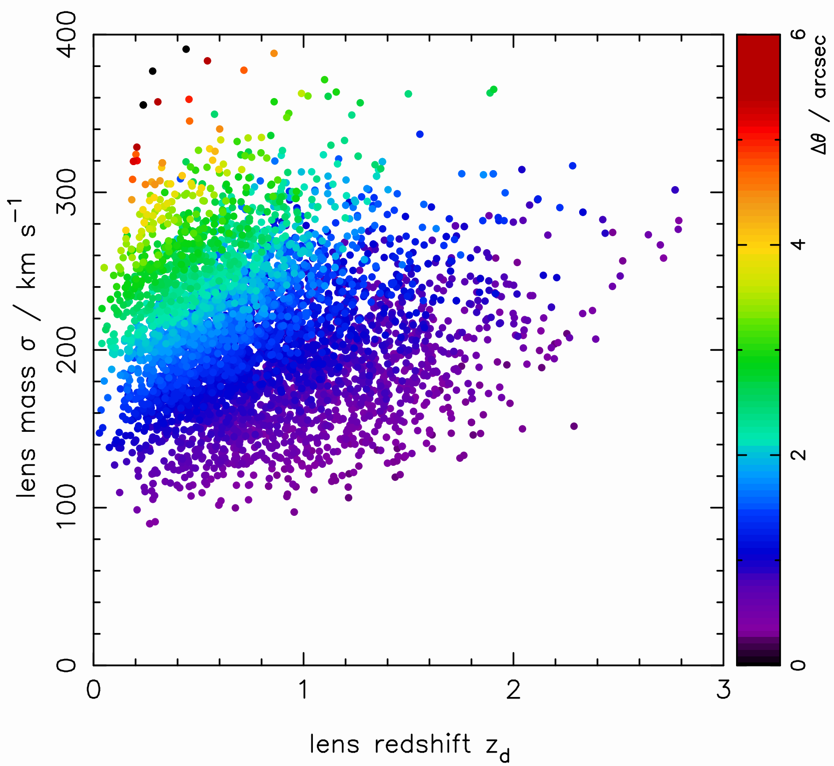
Lens distributions (2)

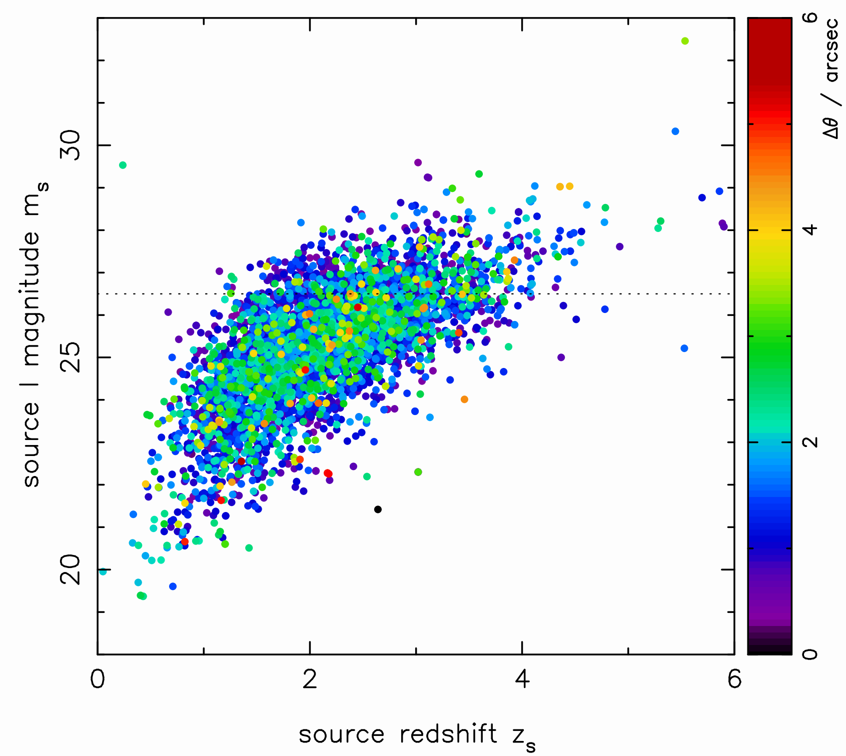




- 2 surveys probe different source magnitudes but similar source redshifts

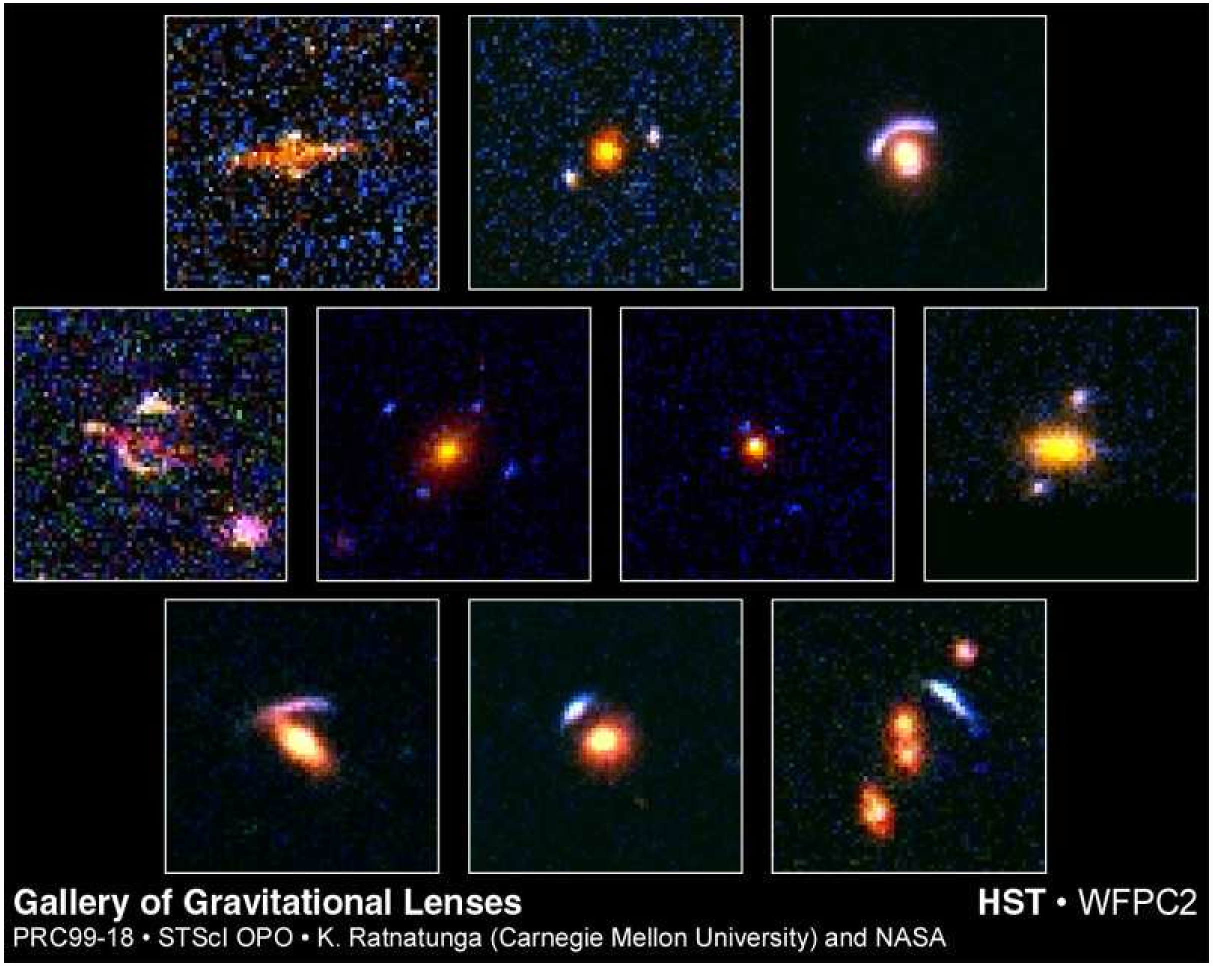
Lens distributions (3)





- Faber-Jackson cuts off lens population – see where the easy lenses are
- Wide survey source sample – a few sources from beyond the magnitude limit, easy lenses are distributed through redshift and magnitude

Easy lenses (!)



Visible by eye in 4-colour HST data: images are small, separations are large

Issues

- Prediction for HDF depth are ~ 0.1 elliptical galaxy lens per field
- UDF should contain ~ 2 elliptical galaxy lenses. . .
- Faint galaxy counts and redshifts are highly uncertain: the UDF can help here
- Gunn, Ostriker & Turner, CLASS result: one in 500 high redshift objects are lensed $\longrightarrow$ should be ~ 2000 lenses per sq. degree. It's not just ellipticals!
- 20000 lenses from SNAP would be a good sized sample: can they be extracted from the images? $1-2$ percent of ellipticals have a multiple image system
- So far have assumed lens galaxy is transparent. . .

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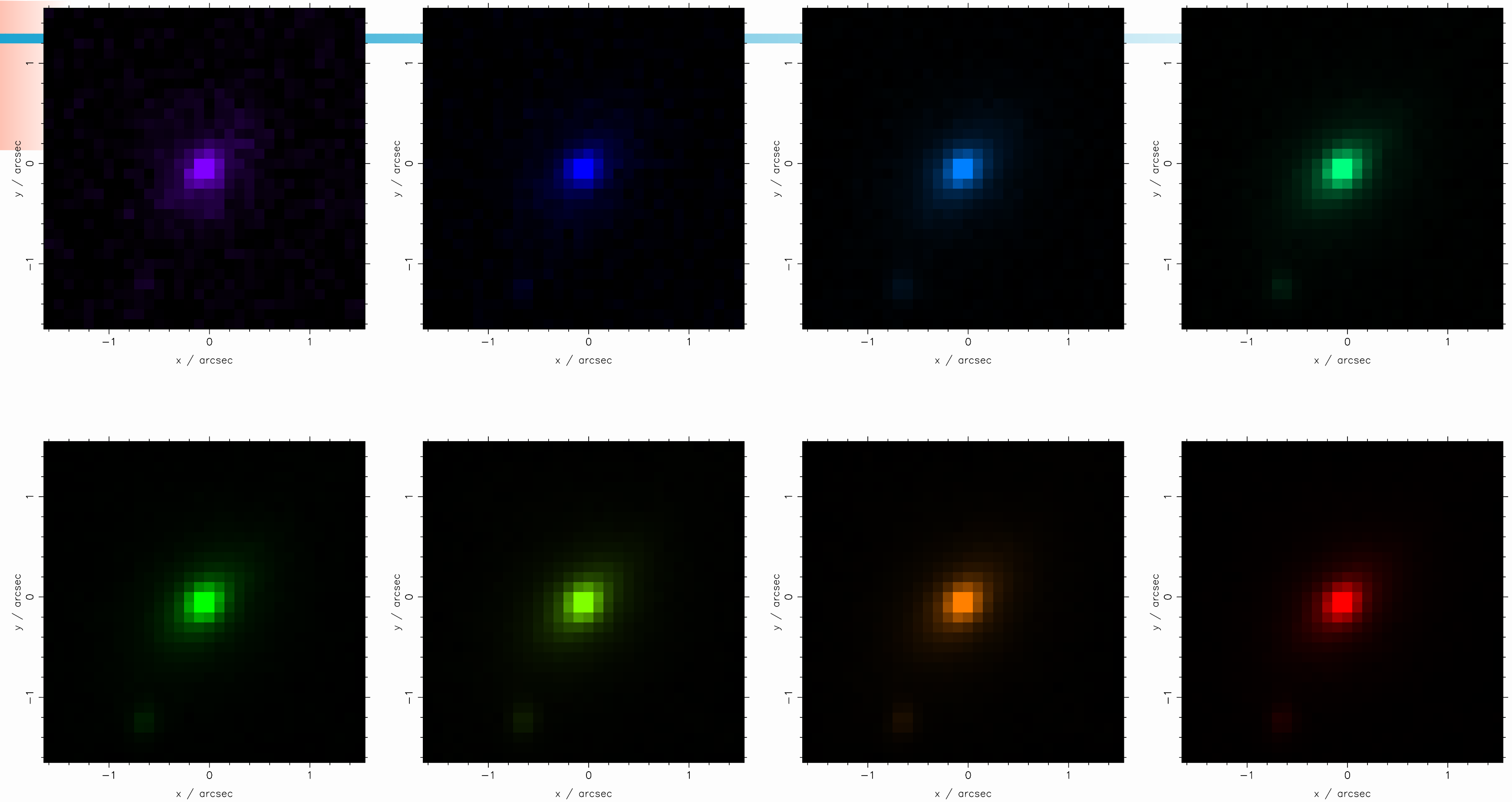
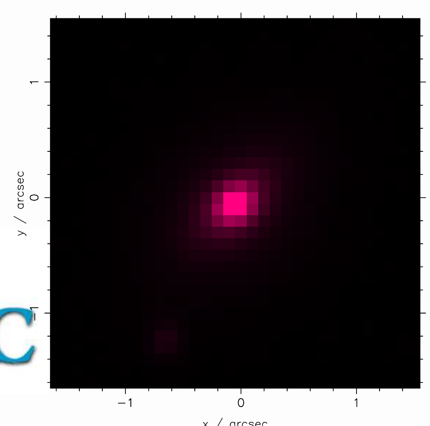
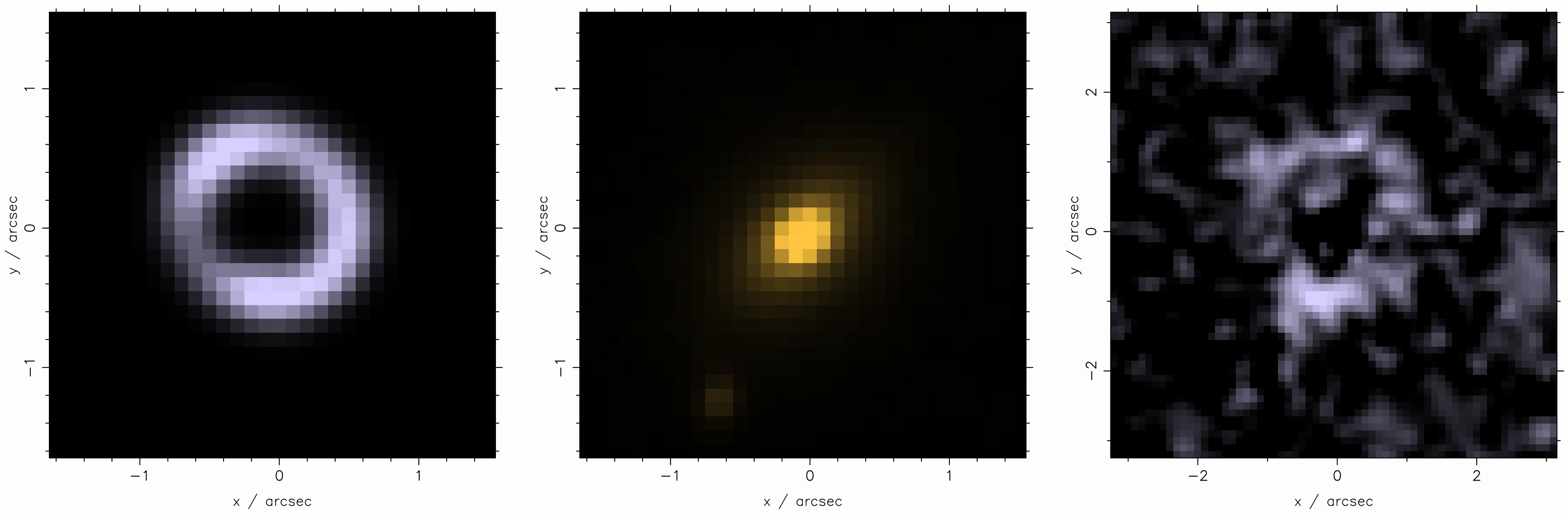
Grounds for optimism. . .





. . . but only ONE filter was assumed in the lens counts calculation

Extracting Einstein rings



- Typical survey lens
  $(z_d = 0.7, \sigma_d = 200 \text{ km s}^{-1}, z_s = 2.3, m_s = 28)$
- Optimal weighting of nine filters' images $\longrightarrow$ Einstein ring appears
- Assumed perfect knowledge of lens galaxy SED (well, ok) and source galaxy SED (ahem), and that morphology is unchanging with frequency (ahem ahem ahem)

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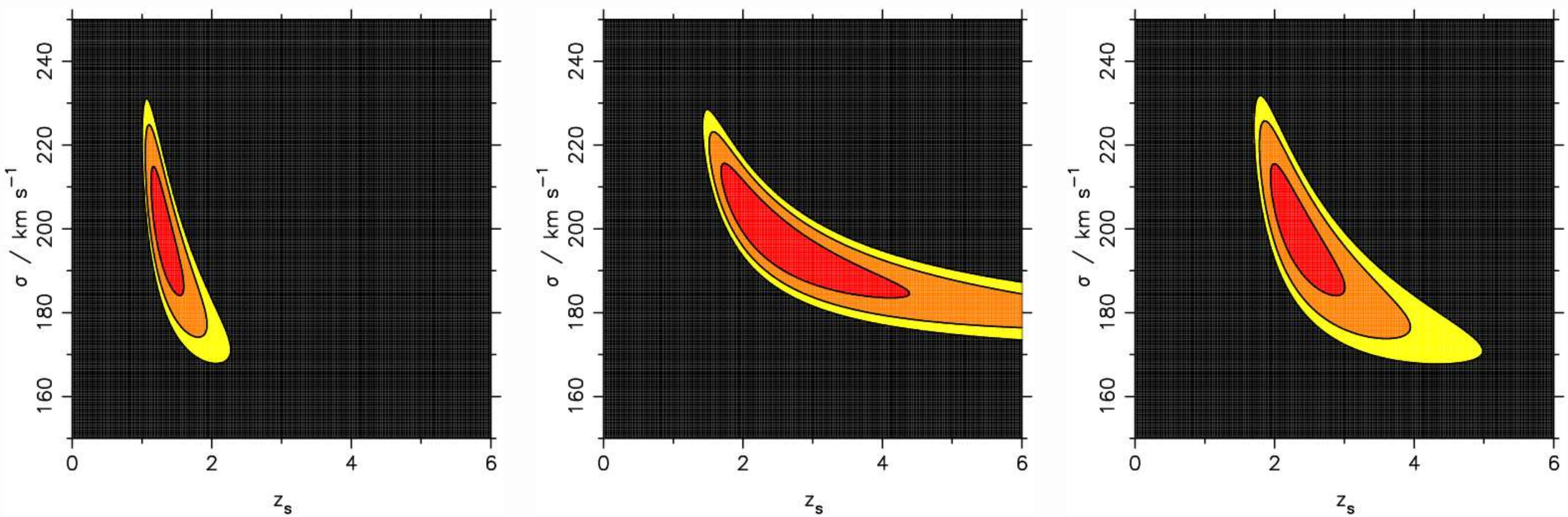
Measuring source redshifts

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



- Einstein radius to $\pm 1/4$ pixel
- Lens galaxy photo-z to ± 0.02
- Lens galaxy velocity dispersion to ± 10 km s^{-1}
- Lensing provides vital additional source redshift information

Cosmography

- Einstein radius porportional to ratio of angular diameter distances $D_{ds}(z_d, z_s)/D_s(z_s)$
- Measure enough Einstein radii, with redshifts: can constrain Ω_m, w, w' etc. etc.
- How good are photo-z's beyond $z = 1$?
- Can we estimate the parameters of the redshift distribution and the cosmological parameters at the same time?
- Will strong lensing ever be competitive with its weaker cousin?

Conclusions

- SNAP's 9 filters, small psf and low background make it a promising instrument for searching for strong gravitational lens systems
- Focussing on elliptical galaxy lenses simplifies both the analysis and its interpretation
- ~ 20000 such multiple image systems would be detected by SNAP if the lenses were transparent
- Optimally combining the multi-band imaging data seems promising, but there is much to be done in making the extraction of large numbers of lensed sources a realistic prospect
- This is work in progress!