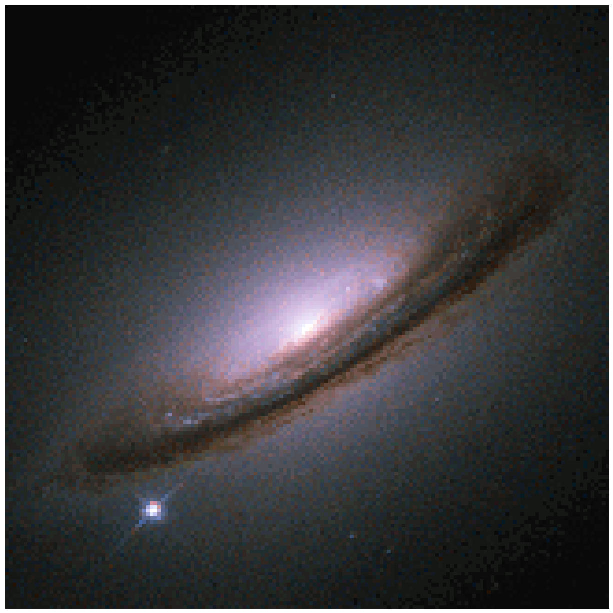
Gravitational lensing of standard candles



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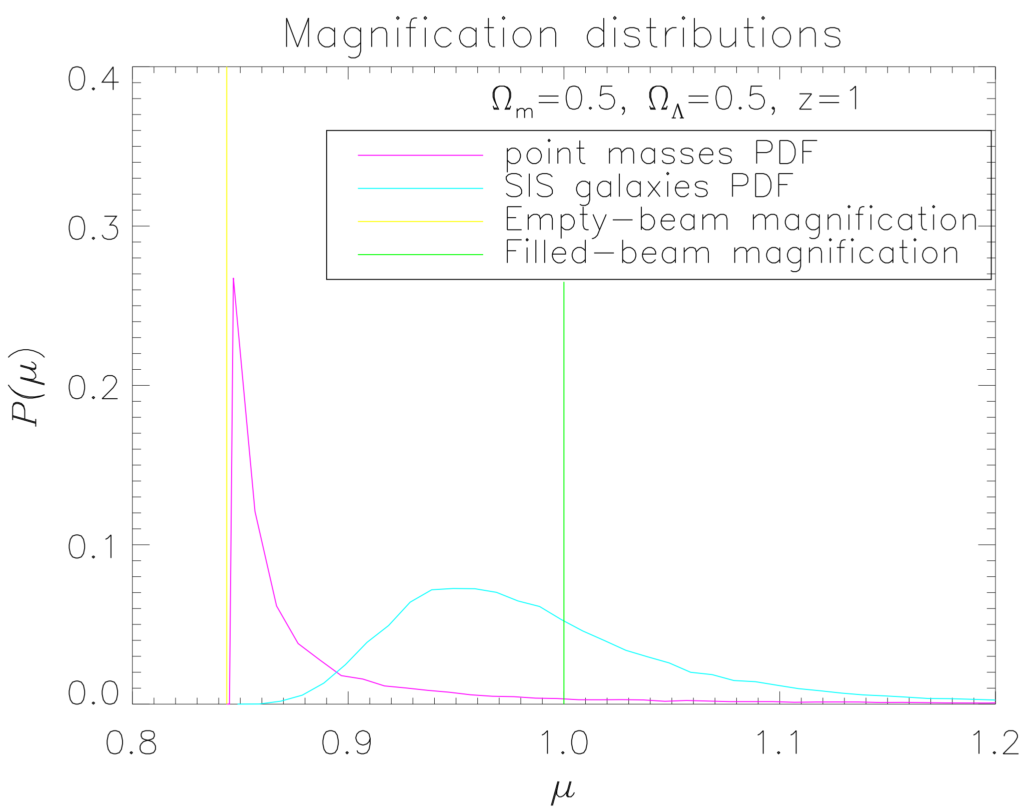
Magnification Distribution

Probability distribution, $P(\mu)$, of image magnification, μ, at high redshift



- The average magnification is given by the Robertson-Walker filled-beam value (normalized to 1).
- The minimum magnification, $\mu_{\rm min}$, is given by the empty-beam value.
- The distributions are peaked at $\mu < 1$, and have tails to high magnification.

  $\Rightarrow$ The distributions are non-Gaussian.

In a realistic Universe, the majority of high redshift sources are dimmer than would have been expected in a perfectly smooth Universe

Universal Magnification PDF

Wang, Y., DH, & Munshi, D. 2002, ApJL 572, 15

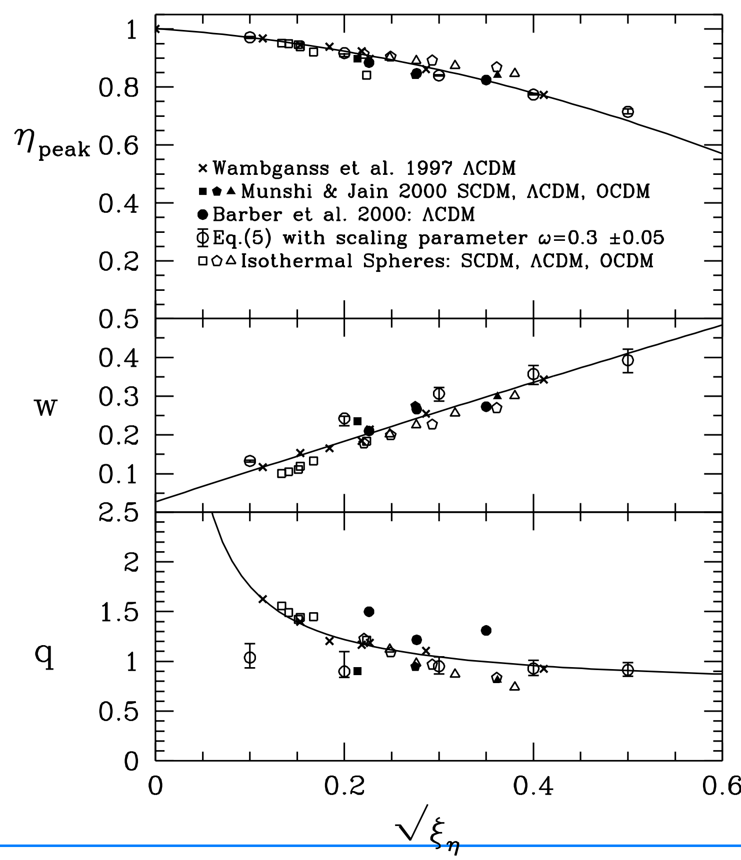
Define the reduced convergence:

$$\eta \equiv \frac{\mu - \mu_{\rm min}}{1 - \mu_{\rm min}}$$

Then all reduced convergence lensing distributions can be well-approximated (in the weak lensing regime) by:

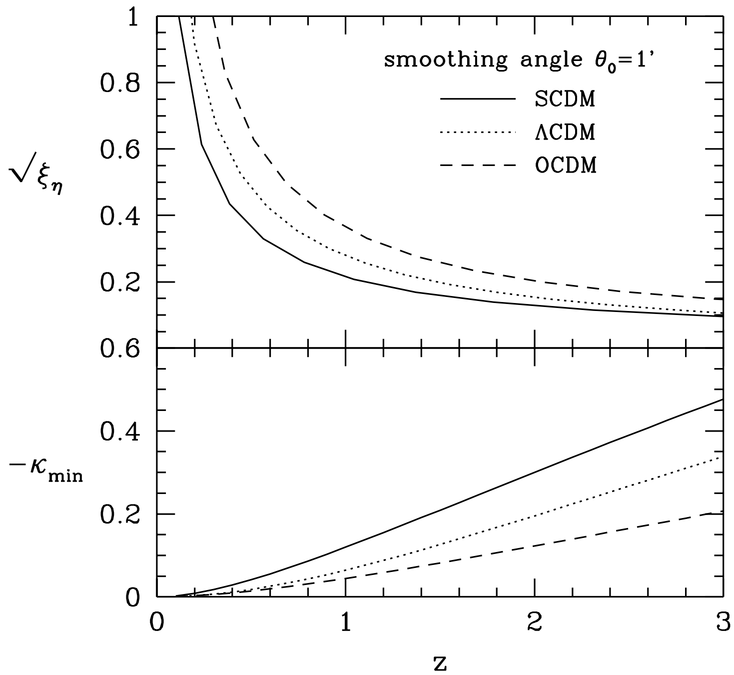
$$P(\eta;\xi_\eta) = C \exp\left[-\left(\frac{\eta - \eta_{\rm peak}}{w\eta^q}\right)^2\right]$$

$\eta_{\rm peak}$, w, and q depending solely on the variance of η, denoted by ξ_η.

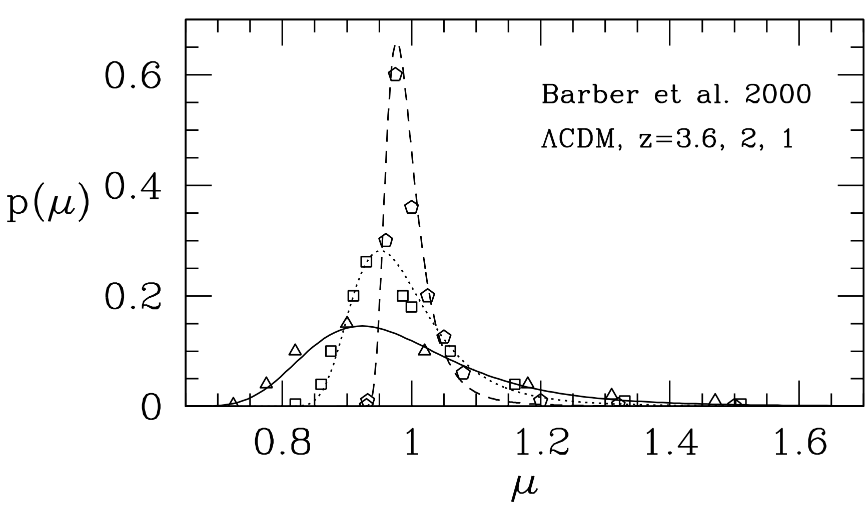


Fitting for Universal PDF

A single function, $\xi_\eta(z)$, describes the weak lensing amplification effects in a given cosmology:



Some sample UPDFs, for different redshifts:

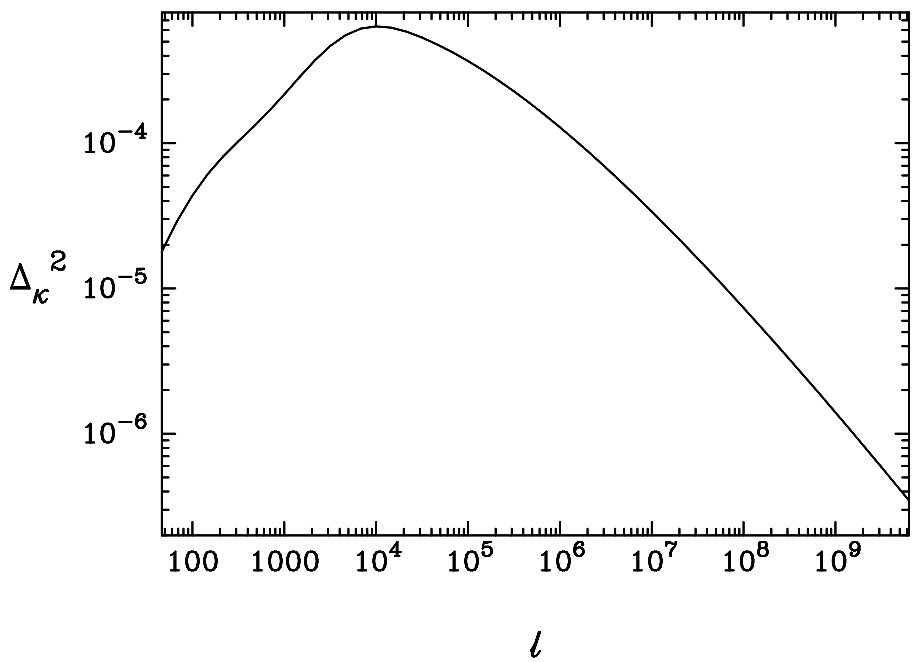


"Fixing" standard candles?

Dalal, N., DH, Chen, X., & Frieman, J.A. 2002, astro-ph/0206339

- Lensing amplification affects all high-redshift sources.
- Is there any way to correct for the lensing effects?
- Use a weak lensing shear map:
  - Take a deep image of the surrounding field.
  - Measure shear lensing effects on background galaxies.
  - Use the shear mass map to estimate lensing amplification effects.

The convergence power spectrum (at $z = 2$, for ΛCDM):



The variance of the effective convergence is given by:

$$\left\langle \kappa^2 \right\rangle = \frac{1}{2\pi}\int_0^\infty d\ell\,\ell\,\mathrm{P}_\kappa(\ell)$$

$$= \frac{9\pi}{4}\left(\frac{\Omega_m H_0^2}{c^2}\right)^2 \int_0^{R_S} \mathrm{dR}\left(\frac{\mathrm{R}(1-\mathrm{R}/\mathrm{R_S})}{\mathrm{a(R)}}\right)^2 \int_0^\infty \frac{\mathrm{dk}}{\mathrm{k}^2}\,\Delta^2_{\mathrm{mass}}(\mathrm{k},\mathrm{a(R)})$$

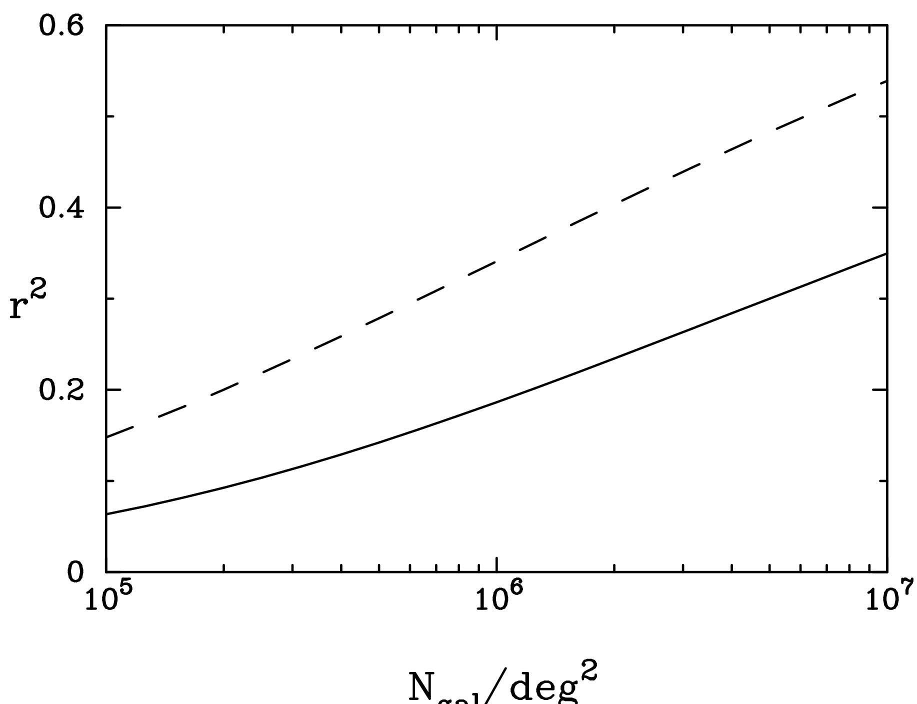
Lensing can't be undone

The reduction of the lensing error due to inclusion of weak lensing shear measurements is given by:

$$\begin{aligned} \langle \kappa^2 \rangle_\gamma &= (1 - r^2) \langle \kappa^2 \rangle \\ &= \left(1 - \frac{\langle \kappa \kappa_\theta \rangle^2}{\langle \kappa^2 \rangle \left(\langle {\kappa_\theta}^2 \rangle + \gamma^2 / N \right)} \right) \langle \kappa^2 \rangle \end{aligned}$$

θ is the shear lensing smoothing angle
γ is the intrinsic galaxy ellipticity
N is the number of source galaxies within θ

For $\gamma = 0.4$, ΛCDM, at $z = 2$:

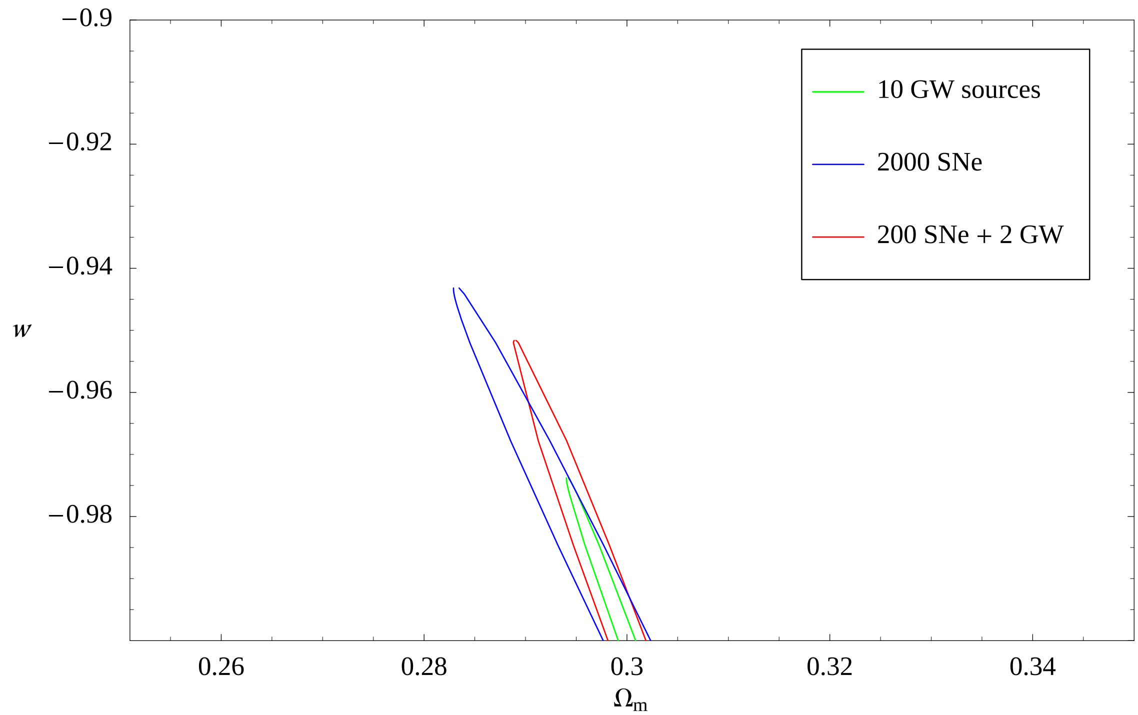


⇒ Shear maps cannot be used to correct for lensing amplification.

Near-perfect standard candles

work in progress, with Scott Hughes

Imagine having a standard candle that has an intrinsic dispersion of better than 1%, out to redshift 5. How well could you measure cosmological parameters?



Gravitational lensing of standard candles

Gravitational lensing affects the apparent brightness of all sources at high redshift.

Even perfect standard candles only do marginally better than type Ia supernovae as distance measures.

Cosmological parameter estimation, with the inclusion of lensing: