Lensing with KIDS

studying dark matter and dark energy with light rays

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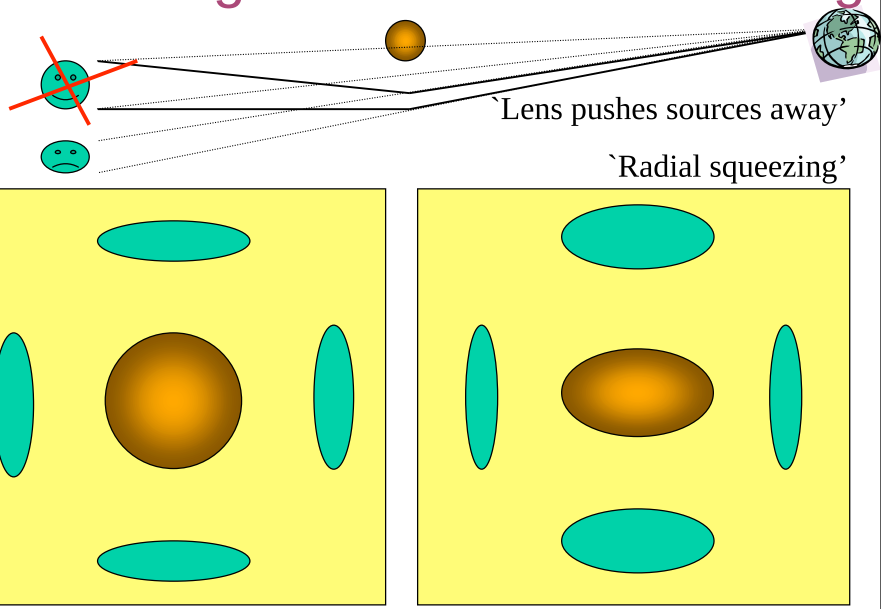
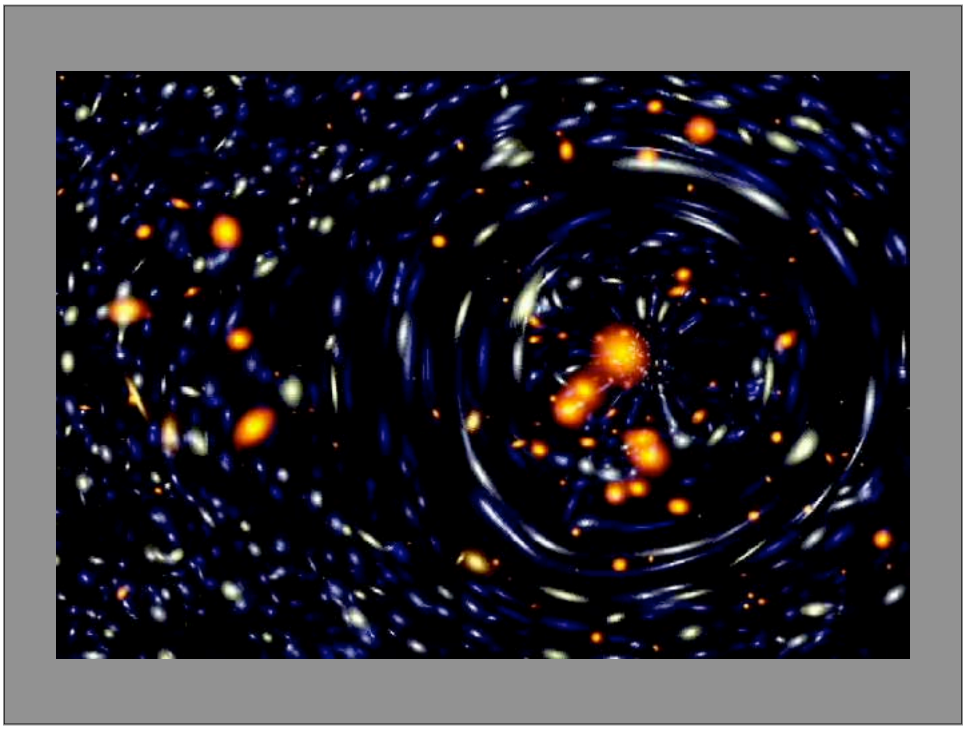
Outline:

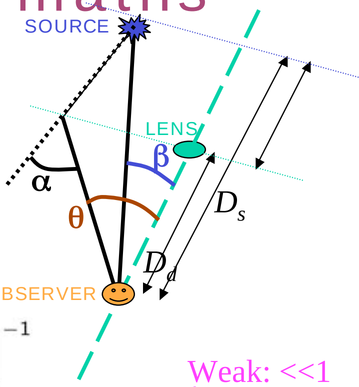
1. Weak lensing introduction
2. The KIDS survey
3. Galaxy-galaxy lensing (halos)
4. Cosmic shear (large scale structure)

1. Weak gravitational lensing





Weak lensing maths



Lensing potential $\Psi(x,y) = \int \psi dz$

Deflection $\alpha = \frac{2}{c}\int \nabla\psi \frac{dz}{c} \equiv \frac{2}{c^2}\nabla\Psi$

Image shift $\theta - \beta = \frac{D_{ls}}{D_s}\alpha = \frac{2}{c^2}\frac{D_{ls}}{D_s}\nabla\Psi(D_l\theta)$

Distortion $A \equiv \left[\frac{\partial\beta}{\partial\theta}\right]^{-1} = \left[\delta_{ij} - \frac{2}{c^2}\frac{D_{ls}D_l}{D_s}\Psi_{ij}\right]^{-1}$

Weak: <<1

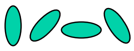
$$A^{-1} = \begin{pmatrix} 1-\kappa-\gamma_1 & -\gamma_2 \\ -\gamma_2 & 1-\kappa+\gamma_1 \end{pmatrix} \equiv (1-\kappa)\begin{pmatrix} 1-g_1 & -g_2 \\ -g_2 & 1+g_1 \end{pmatrix}$$

$$\begin{aligned} \kappa &= \Sigma/\Sigma_{\text{crit}} \\ \gamma_1 &= 4\pi G(\Psi_{11}-\Psi_{12})/\Sigma_{\text{crit}} \quad \text{for } \Sigma_{\text{crit}} = \frac{4\pi G c^2 D_s}{D_{ls}D_l} \\ \gamma_2 &= 4\pi G(2\Psi_{12})/\Sigma_{\text{crit}} \end{aligned}$$

Key to weak lensing

Galaxies have all kinds of shapes

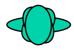
But orientations are random



So *average* galaxy is round

Sheared population:

average galaxy is elliptical



Weak lensing pro/con

- Study projected mass distribution directly
  - Independent of whether dark or light
- Technical difficulties:
  - Projection along very long sightline
  - Noisy: each background galaxy is estimator of shear with $\sigma \sim$ 10% (cf. <1% signal)
  - Very accurate shape measurements require control of systematic distortions in camera, atmosphere, etc.
  - Need source & lens distances (Σ_{crit})

Weak lensing from space

- Control systematics:
  - Brighter galaxies better resolved than from ground
  - PSF more stable
- Increase redshift range:
  - Can detect fainter galaxies (but then PSF more important again), including high-z
- Increase number density of galaxies on sky
  - Hence reduce noise
- BUT hard to cover as much sky as from ground

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2. The KIDS survey

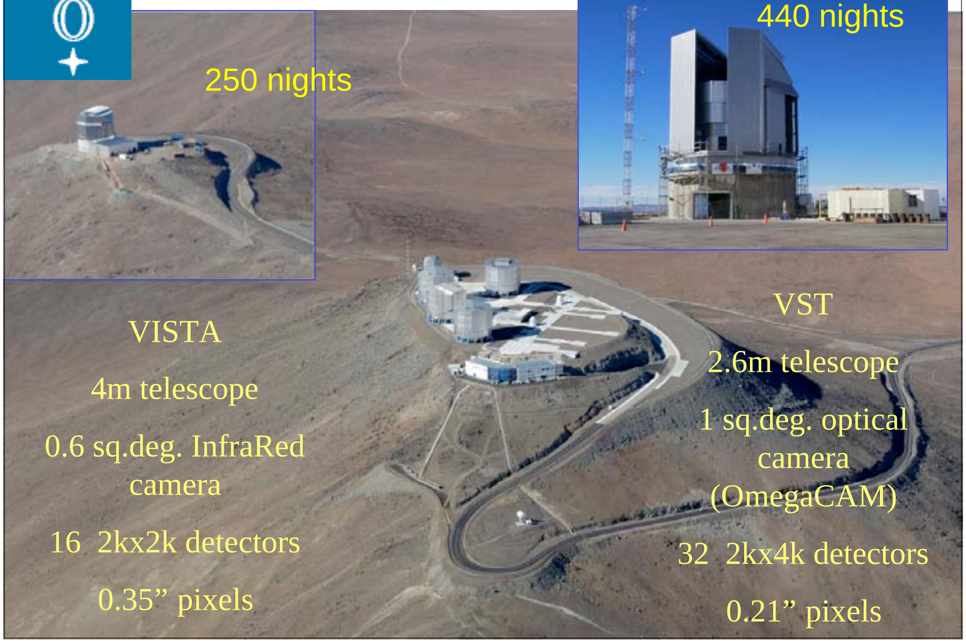
KIDS: a 1500-square degree cosmological survey with VST/OmegaCAM

PI: Konrad KUIJKEN, Leiden Observatory, The Netherlands
Ralf Bender, Hans Böhringer, Massimo Capaccioli, Thomas Erben, Ulrich Hopp, Yannick Mellier, Mark Neeser, John Peacock, Mario Radovich, Roberto Saglia, Peter Schneider, Peter Schuecker, Stella Seitz, Roberto Silvotti, Will Sutherland, Andy Taylor, Edwin Valentijn, Steve Warren

The VISTA Kilo-degree Infrared Galaxy survey (VIKING)

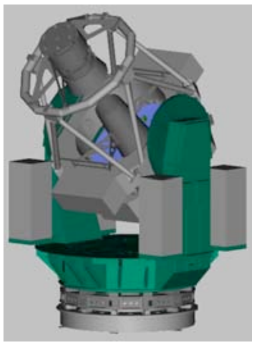
PI: Will Sutherland, Institute of Astronomy, Cambridge, UK
Ralf Bender, Hans Böhringer, Malcolm Bremer, Massimo Capaccioli, Lee Clewley, Gavin Dalton, Simon Driver, Alastair Edge, Jim Emerson, Thomas Erben, Philippe Heraudeau, Ulrich Hopp, Matt Jarvis, Konrad Kuijken, Jochen Liske, Richard McMahon, Yannick Mellier, Mark Neeser, John Peacock, Chris Pearson, Steve Phillipps, Mario Radovich, Kathy Romer, Roberto Saglia, Peter Schneider, Peter Schuecker, Stella Seitz, Roberto Silvotti, Andy Taylor, Edwin Valentijn, Bram Venemans.

PARANAL OBSERVATORY



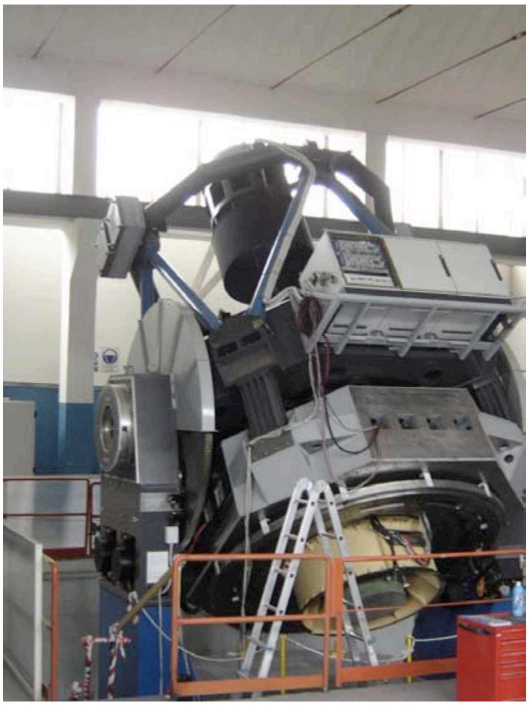
The VST

(Naples obs.)



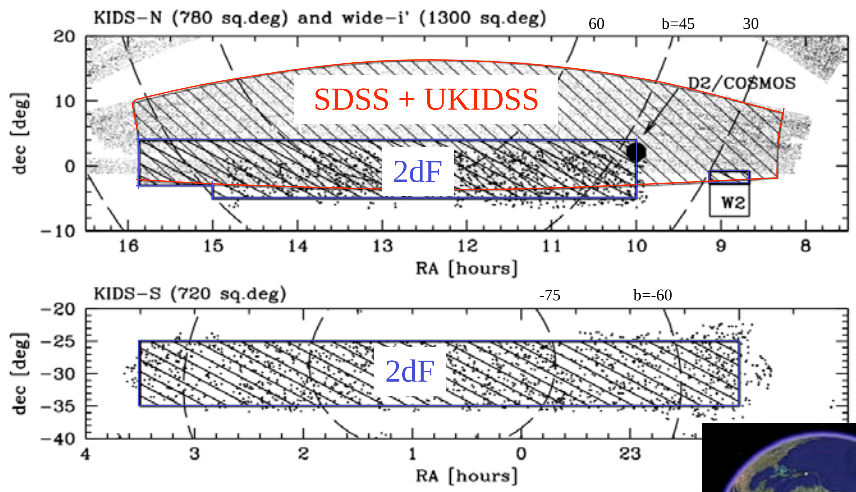
- VST: 2.6m f/5.5, 1.4 deg Φ field, active primary mirror
- Only one instrument: OmegaCAM = 16k x 16k CCD camera

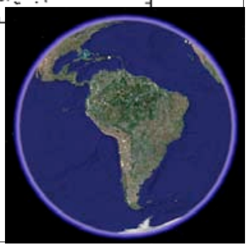
- Operational in 2008
- ~300 nights/year, 30 square deg/night
  =10,000 square deg / year!
  =10 TByte of pixel data / year!



OmegaCAM

300 million pixels, 36 CCDs





1500 sq.deg. in ugriZYJHK

+2000 sq.deg. in i (+UKIDSS YJHK)

KIDS + VIKING

- VST/OmegaCAM: 1 sq deg, 2.6m telescope
- VISTA/VISTACAM: 0.6 sqdeg, 4m telescope
- 1500 sq.deg. of ugri (~400n VST)
  + ZYJHK (~200n VISTA)
- Deeper in r, with good seeing
- VST 2m deeper than SDSS
  (1m shallower than CFHTLS)
- VISTA 1.5m deeper than UKIDSS

filter	Exp (s)	5-σ 2" AB	cf. UKIDSS
Z	500	23.1	-
Y	400	22.4	+1.6
J	400	22.2	+1.8
H	300	21.6	+1.6
K	500	21.3	+1.3

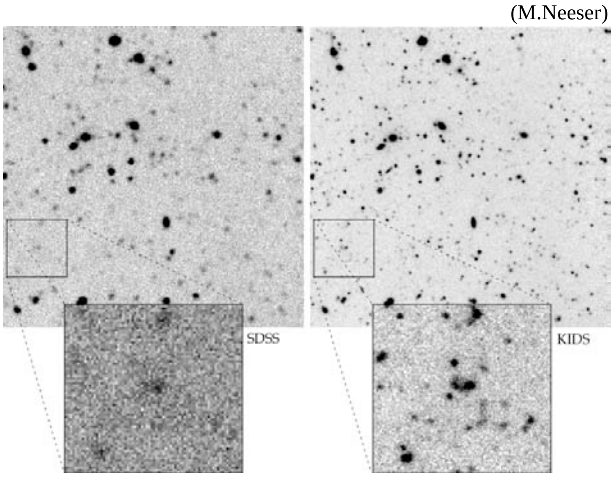
	<0.7" (40%)	0.7-0.85" (20%)	0.85-1.1" (20%)
Dark (50%)	r'	g'	u'
Grey (15%)	-	-	-
Bright (35%)	i'	i'	i'

filter	Exp time (s)	Medn seeing (")	5-σ 2" AB
u'	900	1.0	24.8
g'	900	0.75	25.4
r'	1800	0.6	25.2
i'	1080	0.75	24.2

KIDS vs. SDSS, CFHTLS

SDSS	CFHTLS
6 x area	1/9th area
2 mag shallower	1 mag deeper
2x worse seeing	~same

(M.Neeser)

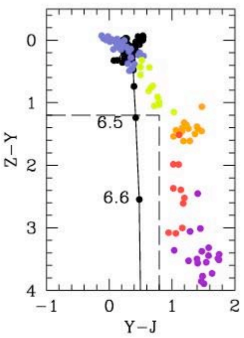


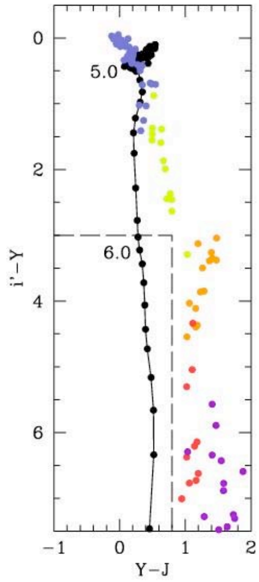
KIDS: Kilo-Degree Survey

- ESO Public Survey
- Goals:
  - – Halo structure (weak lensing)
  - – Dark energy (*w* via ang. power spec; wk lensing)
  - – Galaxy evolution vs. environment
  - – Cluster searches
  - – Higher-redshift quasars than SDSS
  - – White dwarf searches (2nd pass for `movers & shakers')
  - – …

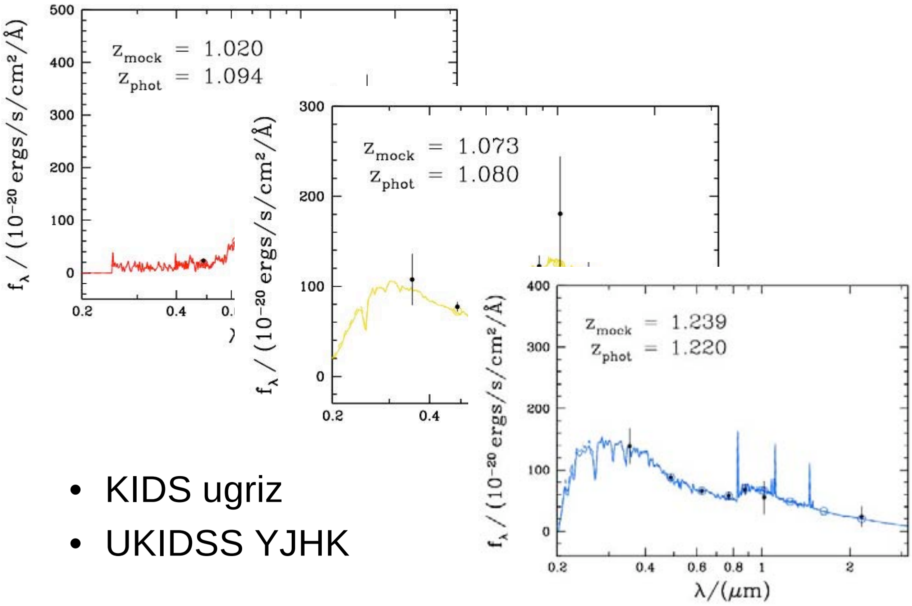
z>6.4 QSOs

- Combine with IR (UKIDSS, VISTA)
- Look for IR objects faint in i or z
- Find brown dwarfs and high-z QSOs
- Expect ~7 @ z>6.4
- Many fainter z~5-6





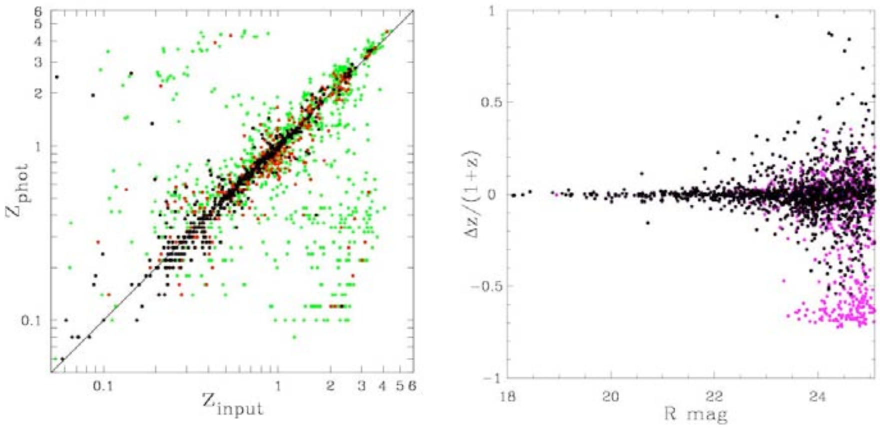
Typical SED's (r~24, redshift~1)



- KIDS ugriz
- UKIDSS YJHK

Photo-z from KIDS/UKIDSS

(Saglia)



r<23.5 **r<24** **r<25** **0<z<6** **0<z<1.5**

Scatter further reduced with deeper IR data

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3. Galaxy-galaxy lensing: halo parameters

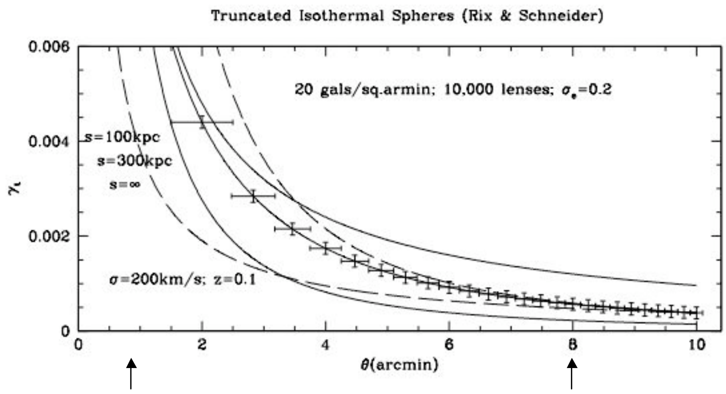
- Clear predictions on 100kpc-1Mpc scales on dark matter distribution
  - Dark matter dominates the potential
  - Gravity dominates the physics
  - Star formation/feedback etc confined to inner <100kpc
- Barely tested!
  - Rotation curves, satellite dynamics << 50kpc
  - Large-scale structure >>1Mpc

Galaxy-galaxy lensing

- Some crucial tests of galaxy formation:
  - Total baryon / dark matter mass in galaxies
  - Radial profile of dark matter distribution
  - Shape of dark halos
  - …
  - All best probed at several 100kpc scale where dark halo dominates clearly
- Halo ***shapes*** are fundamental test for alternative gravity theories as well

In practice

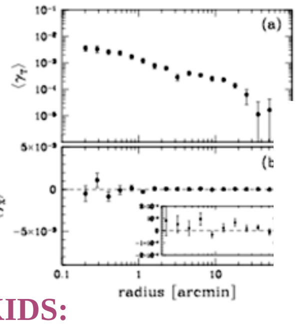
- Average 10,000 foreground galaxies
  - (1/20th of KIDS foreground galaxies)
- Measure truncation radius



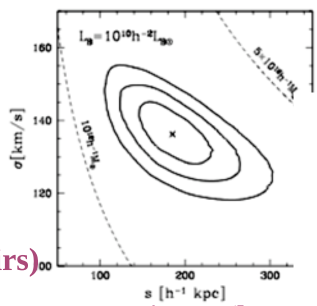
100kpc 1Mpc

Galaxy-galaxy lensing

45 sq. deg from RCS survey (Hoekstra, Yee, Gladders 2004)

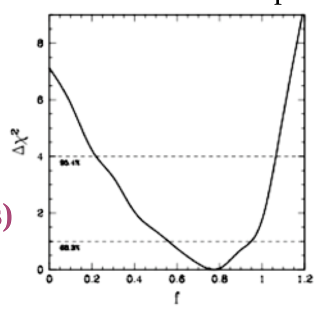


Galaxy-mass correlation



Halo radii

Halo shapes



KIDS:

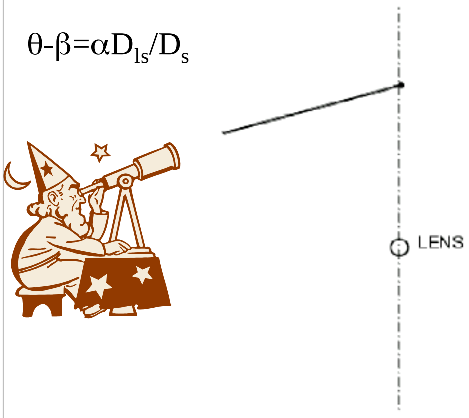
6x smaller errors (#pairs)

Good photo-z's (b/g), spectroscopic z's (lenses)

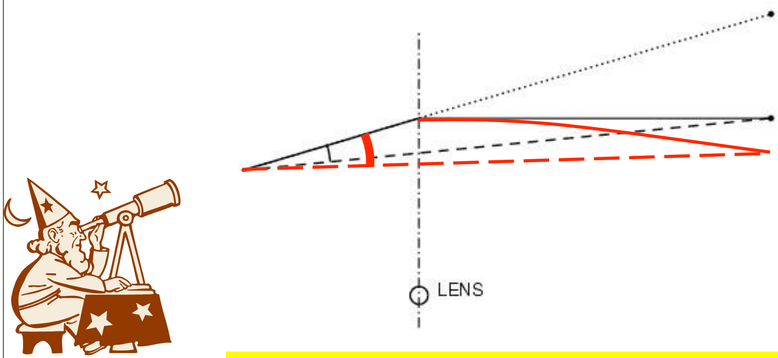
Study effect by galaxy type, scaling relations

LENS EFFECT DEPENDS ON DISTANCE TO THE SOURCE

$\theta-\beta=\alpha D_{ls}/D_s$



Light bending in an expanding universe



Redshift dependence of bending angle depends on expansion history:

Geometric way to deduce expansion history

Learn about evolution of dark energy

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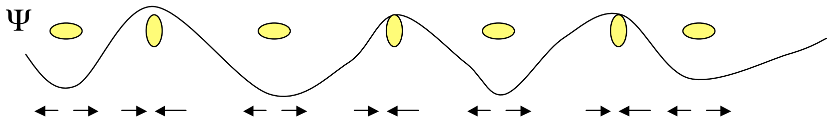
4. Cosmic shear



- ‘Direct’ measure of matter power spectrum
- Evolution of power spectrum amplitude fundamental test of gravitational instability picture
- Detailed growth rate constrains cosmological parameters (Ω, Λ) as well as `w’.

Cosmic shear maths

- Evolution of scale factor a(t) = $(1+z)^{-1}$:

$$\left(\frac{\dot{a}}{a}\right)^2 = H_0^2\,(\Omega_m + \Omega_\Lambda + \Omega_k)$$

$$\Omega_m \propto (1+z)^3$$

$$\Omega_\Lambda \propto (1+z)^{3(w+1)}$$

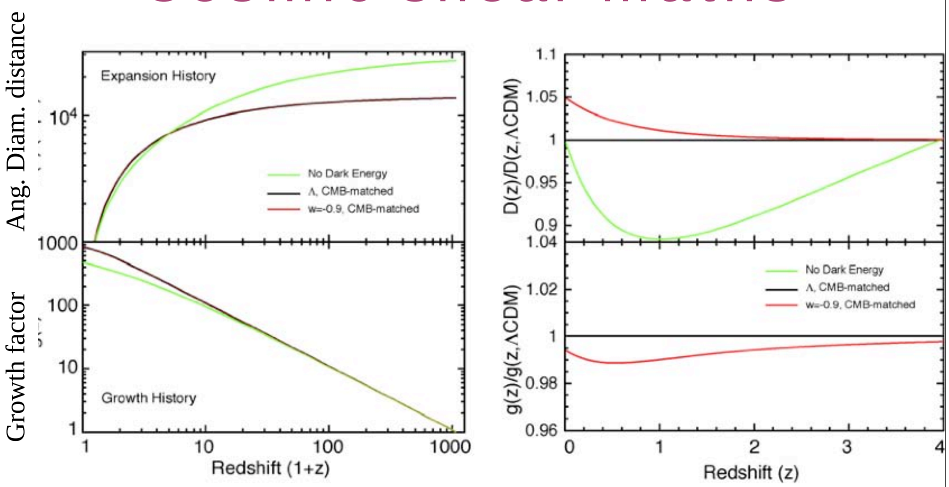
$$\Omega_k \propto (1+z)^2$$

- Growth of structure in expanding universe

$$\ddot{g} + 2\dot{a}\dot{g}/a = 4\pi G\rho g = 3\Omega_m H_0^2 g/2a^3$$

+ non-linear effects on small scales…

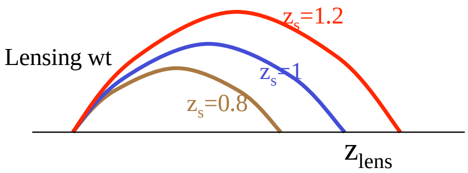
Cosmic shear maths



(From ‘Dark Energy Task Force’ report)

Cosmic shear

- Systematic correlations of galaxy ellipticities
  ⇐ gravitational shear effect
  ⇐ power spectrum of the mass distribution ~ halfway between lens and source
- Many source redshifts ⇒ tomography

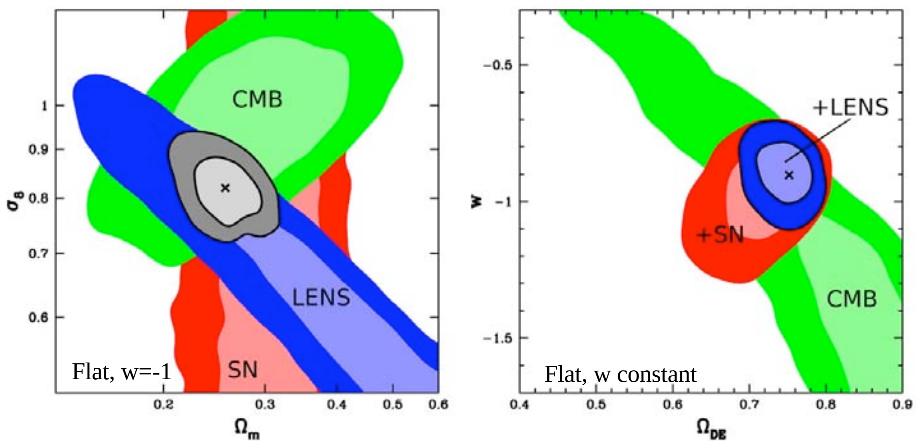


Measure correlation between lensing patterns to different source redshifts

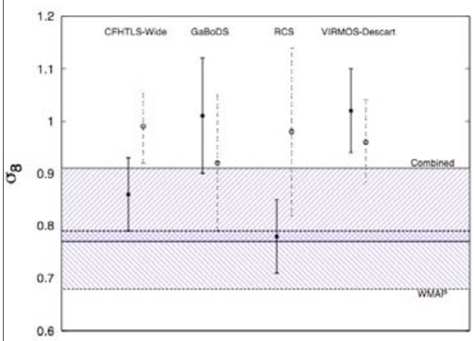
CTIO survey (75sq.deg.)

(Jarvis et al 2006)

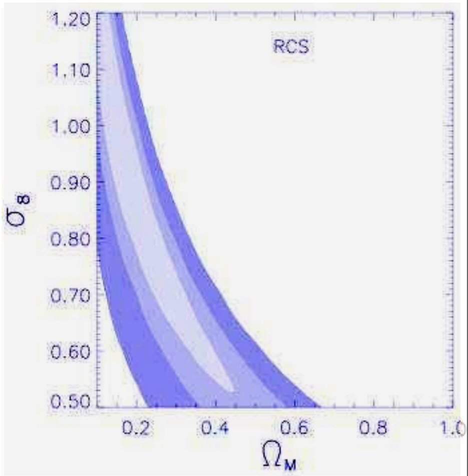
- Wk lensing: complimentary info to SNe, CMB
- Constraints on dark energy



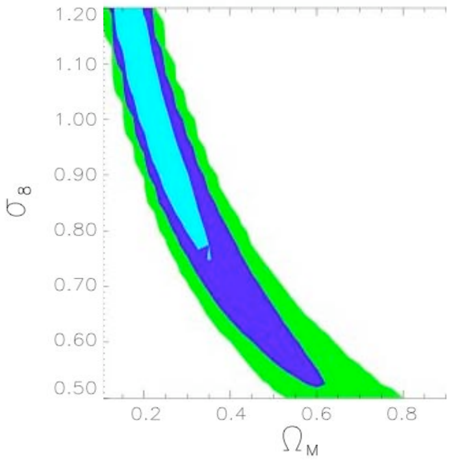
100 sq.deg. Survey
(Benjamin et al 2007)

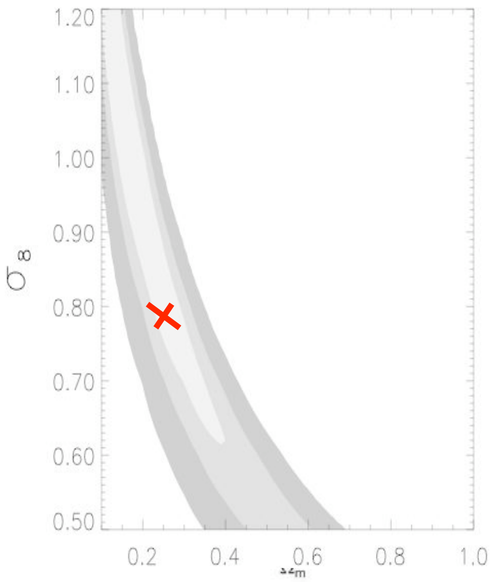


$\chi^2 \sim 5.5$ (3d.o.f.)



CFHTLS vs. WMAP-3yr





Cosmic shear & w

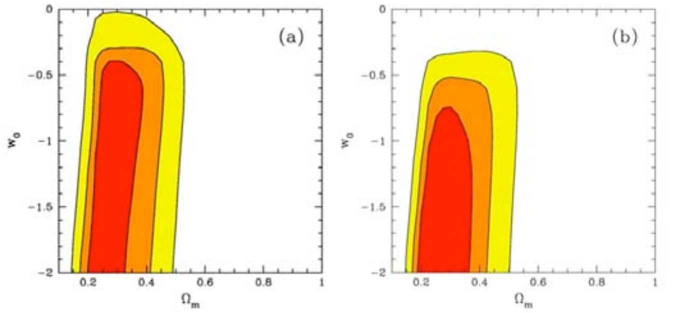
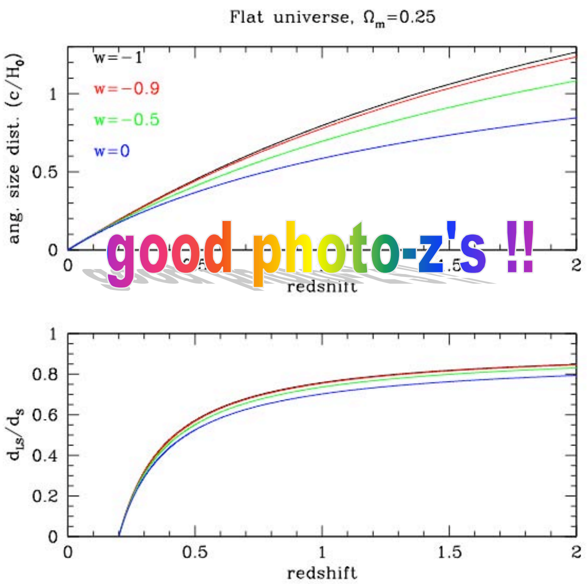


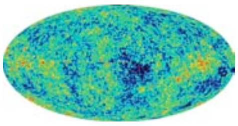
FIG. 12.— *panel a:* Dark energy constraints using the measurements from the W1 and W3 fields. The contours indicate the 68.3%, 95.4%, and 99.7% confidence limits on two paramaters jointly. We marginalised over $\sigma_8 \in [0.7, 1.0]$, $h \in [0.6, 0.8]$ and the source redshift distribution as described in the text. *panel b* Results when the measurements from the Deep component (Semboloni et al. 2005) are included. We used the Peacock & Dodds (1996) prescription for the non-linear power spectrum.

Constraints on w from CFHT wide, wide+deep

3 handles on w from KIDS

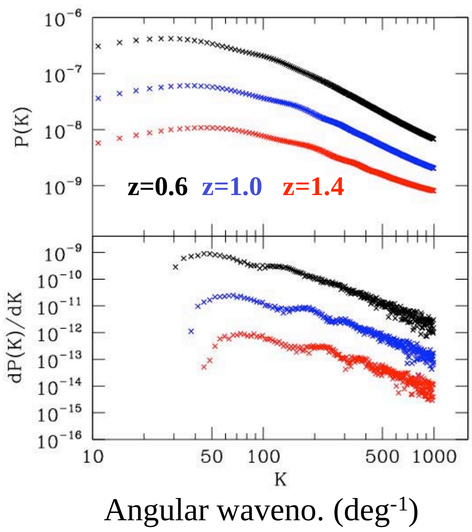
- Cosmic shear:
  growth of structure
- Baryon oscillation bumps in angular corr. fn.
  (angular diameter-redshift relation)
- Galaxy-galaxy lensing: shear dependence on source redshift (angular diameter-redshift relation





‘w’ (wiggles)

(P. Schuecker)



- Use scale of power spectrum wiggles as standard length
- Spec redshift surveys: need few 100,000 gals for detection
  - Photometric redshift surveys: wash out z information, but many more galaxies!
    - KIDS: 67,000,000 gals with $r<23.5$ (20-σ fluxes)
    - Photo-z accurate to 0.03(1+z) (ugrizYJHK)
  - w(z=0) to <15% from KIDS
  - w(z=1) to better accuracy

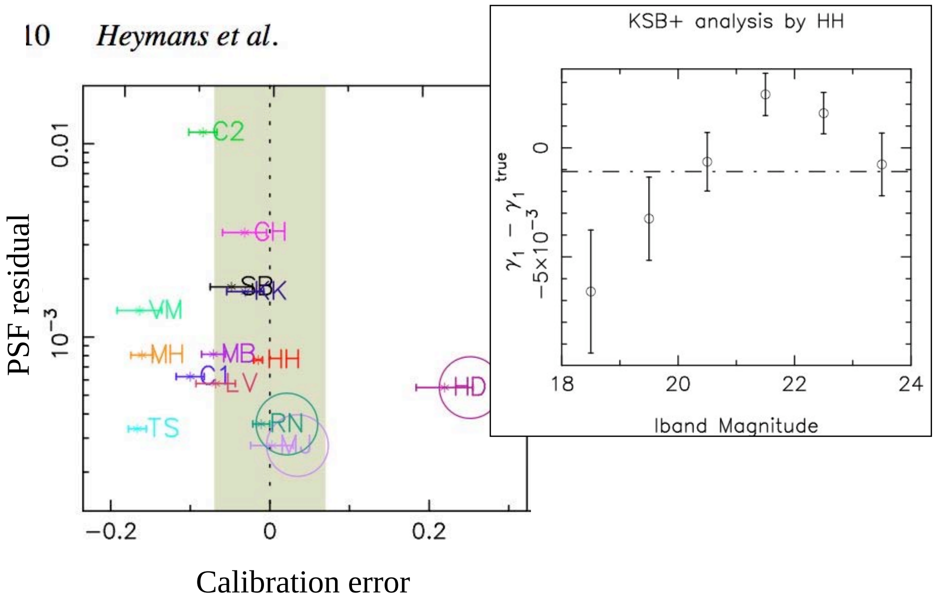
STEP: shear testing prog.

(Heymans + al. 2005, Massey et al. 2006)

- Trick: extract intrinsic ellipticity in spite of blurring by PSF, pixels

- Blind experiments on simulated sheared images
- Compare methods: (KSB’s, shapelets, ellipto, im2shape, …)
- First round: agreement at ~ 5-10% level
  - (idealized galaxies, realistic CFHT PSFs)
- Second round: few percent accuracy
  - (more realistic galaxies and PSFs)
- Space-STEP: ongoing
  - Realistic faint galaxies + SNAP-like PSFs
- Improving further will be hard work!

STEP1 results



KiDS

LEIDEN GRONINGEN MUNCHEN PARIS NAPLES BONN EDINBURGH CAMBRIDGE IMPERIAL

- Big astronomical survey, starts in 2007;
  - 1500 square degrees map (= area of South America on Earth globe)
  - Many applications incl. studying dark matter and dark energy
- Will use millions of ordinary galaxies as `lenses'
  - Average signal → high accuracy
  - Determine redshifts from colours measured with 9 filters
- Measure ripples from galaxy distribution on sky
- Cf. Sloan Survey:
  - Images 2 x sharper (equiv to map of Earth at 6m resolution!)
  - Will include sources 6 x fainter
- Data volume: 15 terabyte pixel data, +++
  - Astro-WISE data archiving / processing system (with EU funding)
  - Large team!

Future:

- Studies of dark matter:
  - Find the ^#%$*^ particle!
  - (even) better models of predicted growth of structure power spectrum P(k,z)
- Studies of dark energy:
  - Get some real theories to test!
  - DES@CTIO, PANSTARSS, Baryon oscillations
  - LSST / space satellite TBD will improve accuracies dramatically
    - Detect whether w(z)≡ -1 consistent
    - Look for evidence of varying w(z)
  - Weak lensing/photo-z is very (most?) promising technique
- KIDS:
  - Expand survey area?
  - Supplement with spectra, Spitzer post-cryo,… ?

w: the sky is the limit

- Most ambitious astronomical surveys
  - Wk lensing + supernovae + BAO's