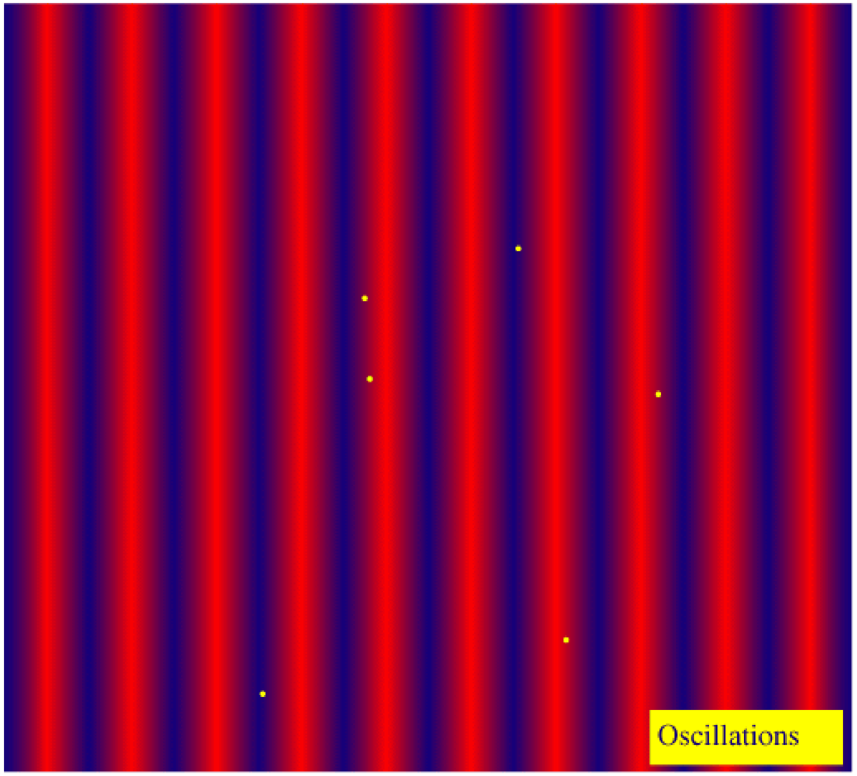
Fundamental physics with 21st Century Facilities

Comoving scale
~ (1+1000) c_S t ~
100 Mpc

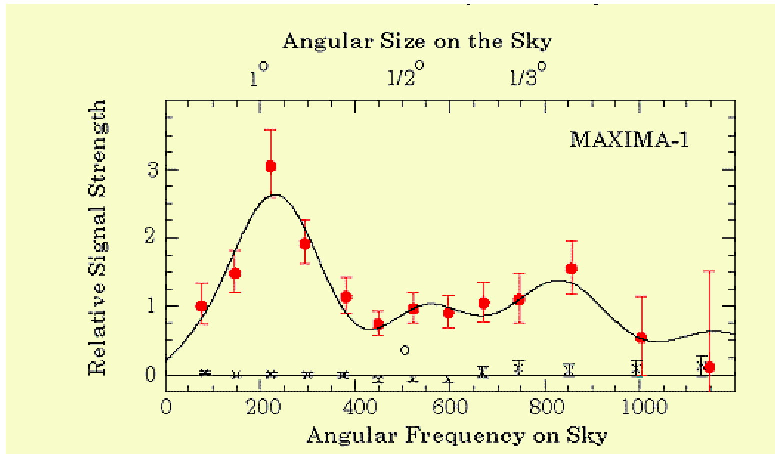


from

Wayne Hu's superb web page

Steve Rawlings, Filipe Abdalla (Oxford), Chris Blake (UNSW), Sarah Bridle (Cambridge)

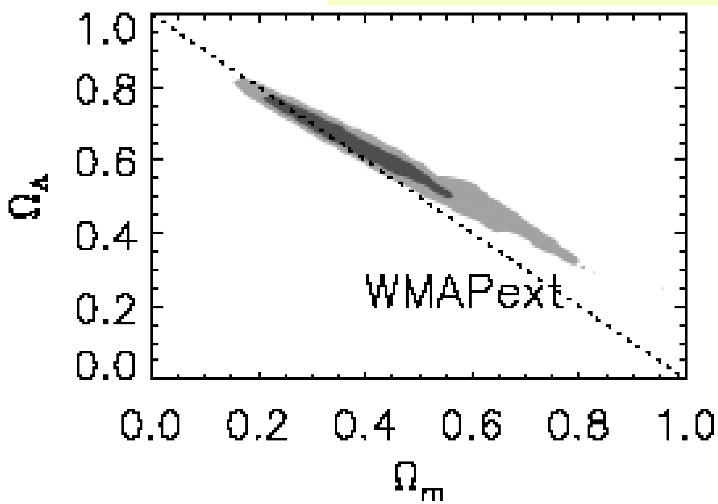
Universe is flat(ish), dark energy exists

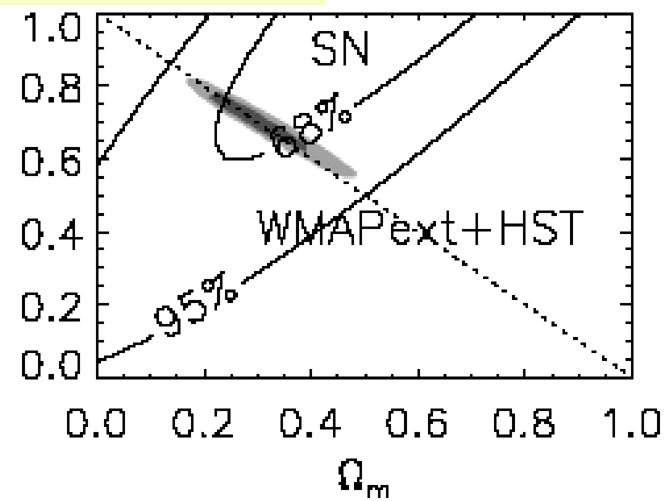


Empty D_A~10 kpc/arcsec

Flat D_A~0.05 kpc/arcsec

Angle $\theta = s / D_A$





Note h prior, `orthogonal' (SN) constraints and theoretical prejudice (that the Universe IS spatially flat). Also note dark energy can't cluster with the galaxies.

See Peebles & Ratra (2003)

Dark Energy exists

GR + CMB Wiggles tell us $\Omega_{\text{baryon}} + \Omega_{\text{CDM}} + \Omega_{\text{rel}} + \Omega_{\text{DE}} = 1$

$0.05 \quad 0.25 \quad \sim 0 \quad 0.7$

Dark energy now dominates the Universe

GR + hi-z SN tells us Universe is now accelerating, so

$p_{DE} = w\, \rho_{DE}$ $w < -1/3$ "antigravity"

INFLATION → RADIATION → MATTER → DARK-ENERGY

See Peebles & Ratra (2003)

...BUT what is it?

Vacuum energy (cosmological constant) with $w=-1$?

....but 'natural' vacuum energy density $\sim 10^{120}$ larger!!

So DYNAMIC alternatives, naturally with $w= w(t)$, preferred

Quintessence (Ω_{DE} rolling to zero) with $-1/3 > w > -1$?

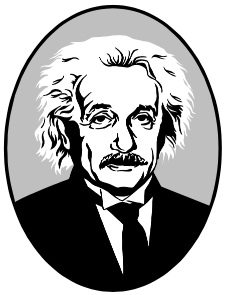
Phantom (Ω_{DE} rolling to infinity) with $w < -1$?

(...or Chaplygin gas, or ....).

Or, in a nutshell, Physics beyond GR!

Progress needs MEASUREMENTS of w and its time evolution.
The Dark Energy Measuring machine will yield Nobel Prizes!

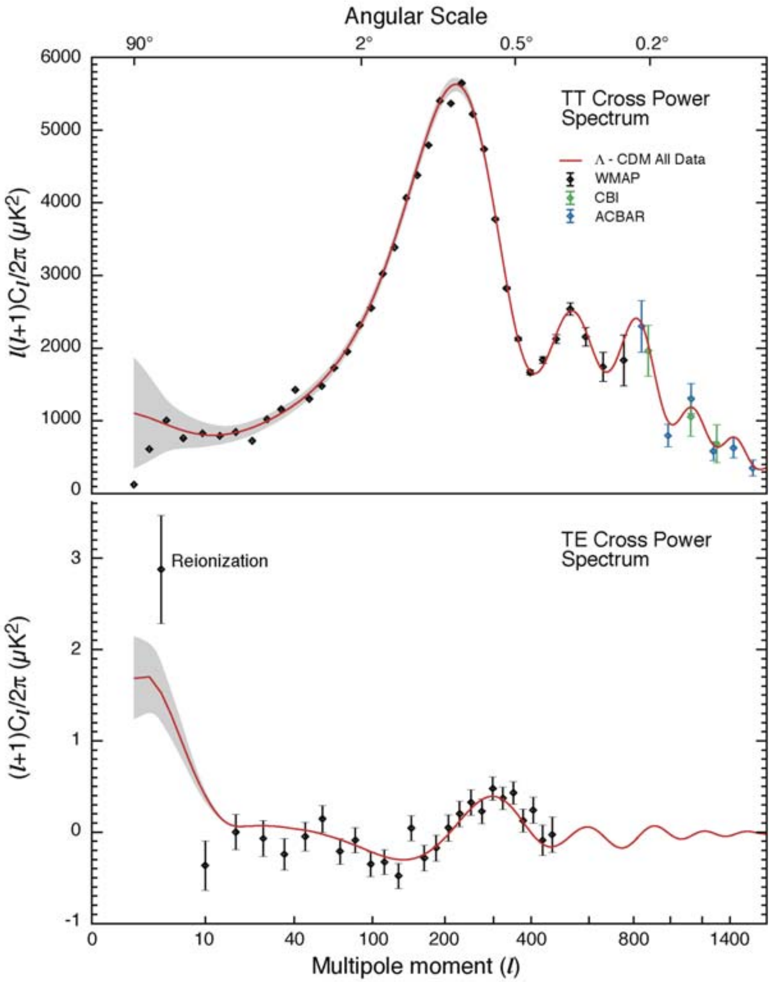
Was Einstein right part II?



- Cosmological constant
- new type of particle?
- leakage from other dimensions?

Only SKA can provide the answer to this question.
The most important currently in physics?

WMAP - Precision Cosmology



1st/plateau	$\Omega_m h^2 = 0.14$
2nd/1st	$\Omega_b h^2 = 0.024$
Flat assumption	$h = 0.7$
Norm+Pol	$\sigma_8 = 0.9$, $\tau = 0.17$
3rd/1st	$n_{scalar} = 1$

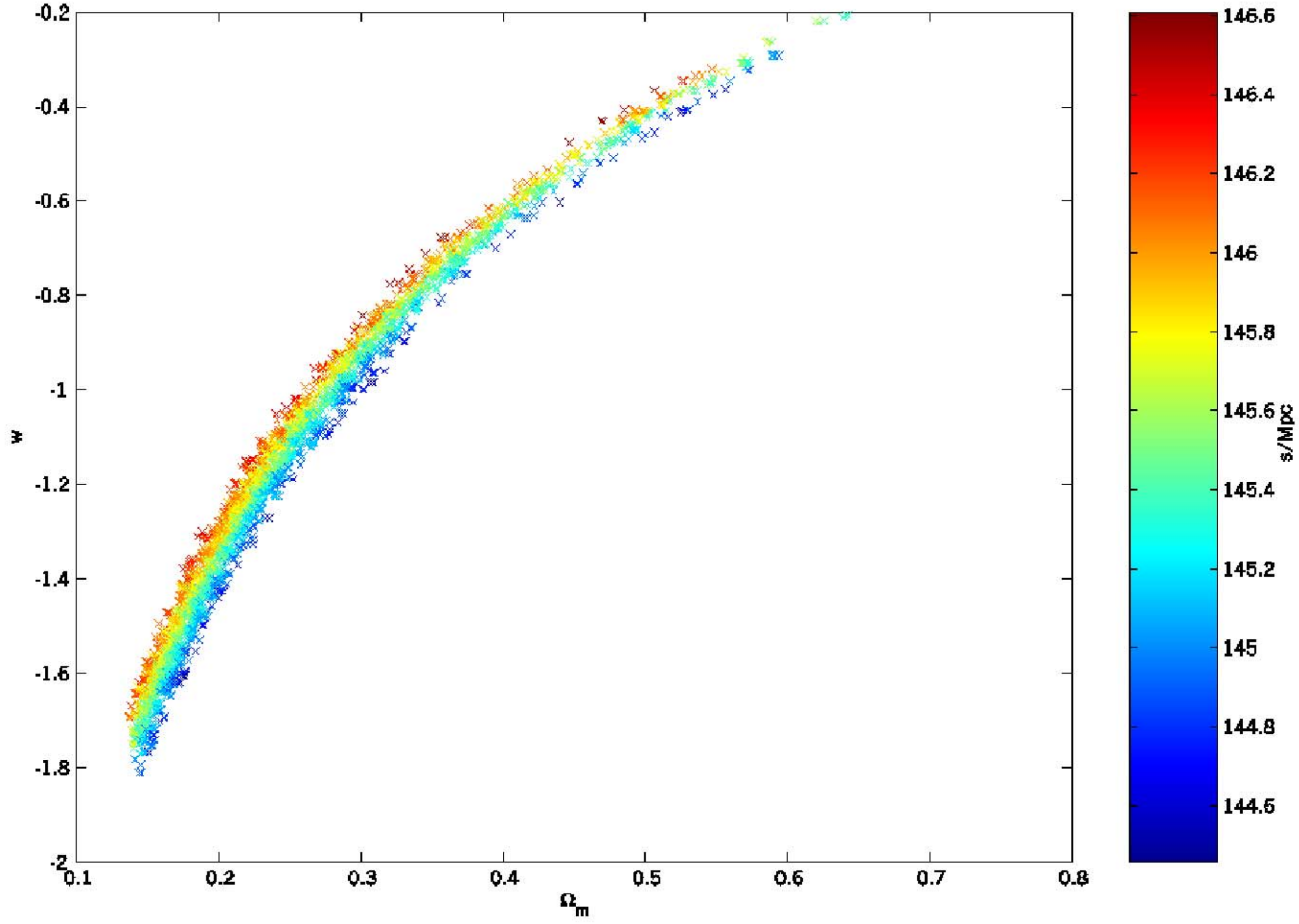
SIX numbers to 5-10% accuracy

Great agreement with independent methods (Cepheids/SN/clusters) showing systematics not yet dominating these.

Sample Variance $= (2l + 1) f_{sky}$

Improvements with Planck important but not transformational.

Planck – NOT the dark energy machine

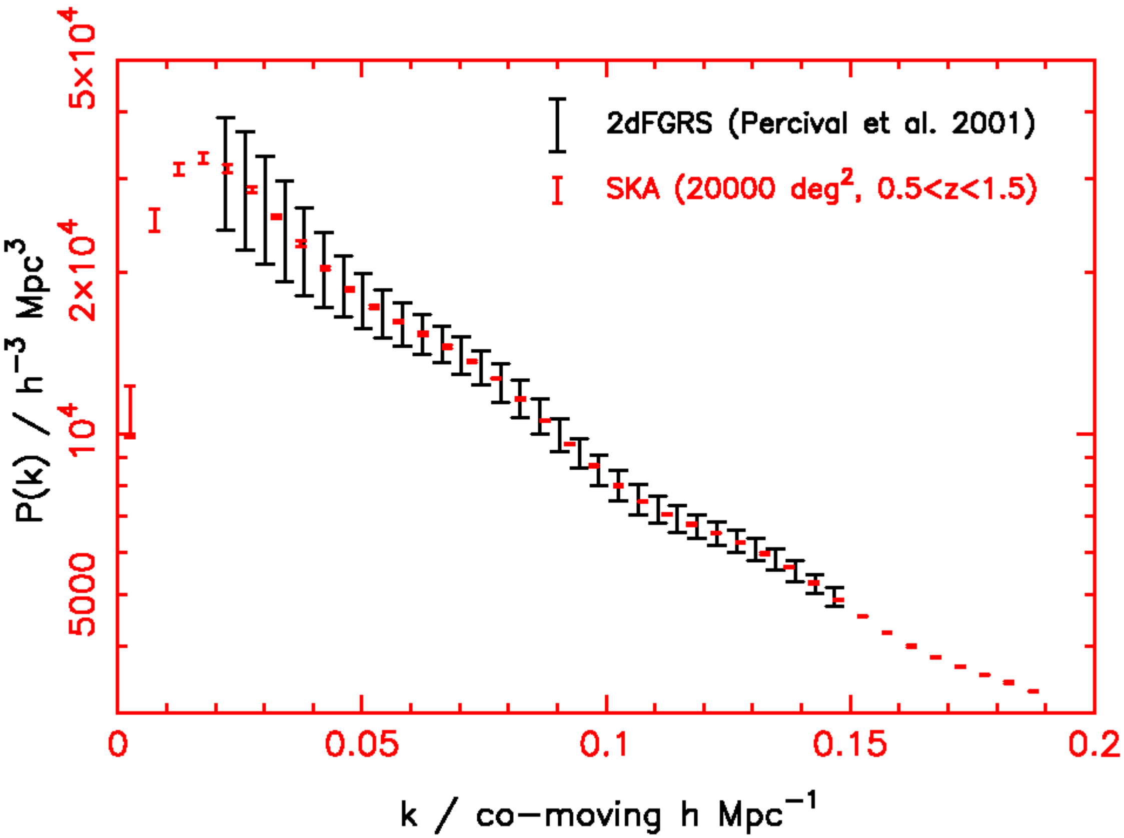


$\Omega_m h^2$ to 1%

BUT

Even assuming flatness, uncertainties in our sound horizon size (sensitive to mix of baryons/CDM/HDM) makes our cosmic ruler squashable (at the 2% level) - and w can't be measured.

Very high precision P(k)



Galaxy redshifts over ~1000-times volume V of 2dF/SDSS by measuring redshifts for all galaxies out to z~2.

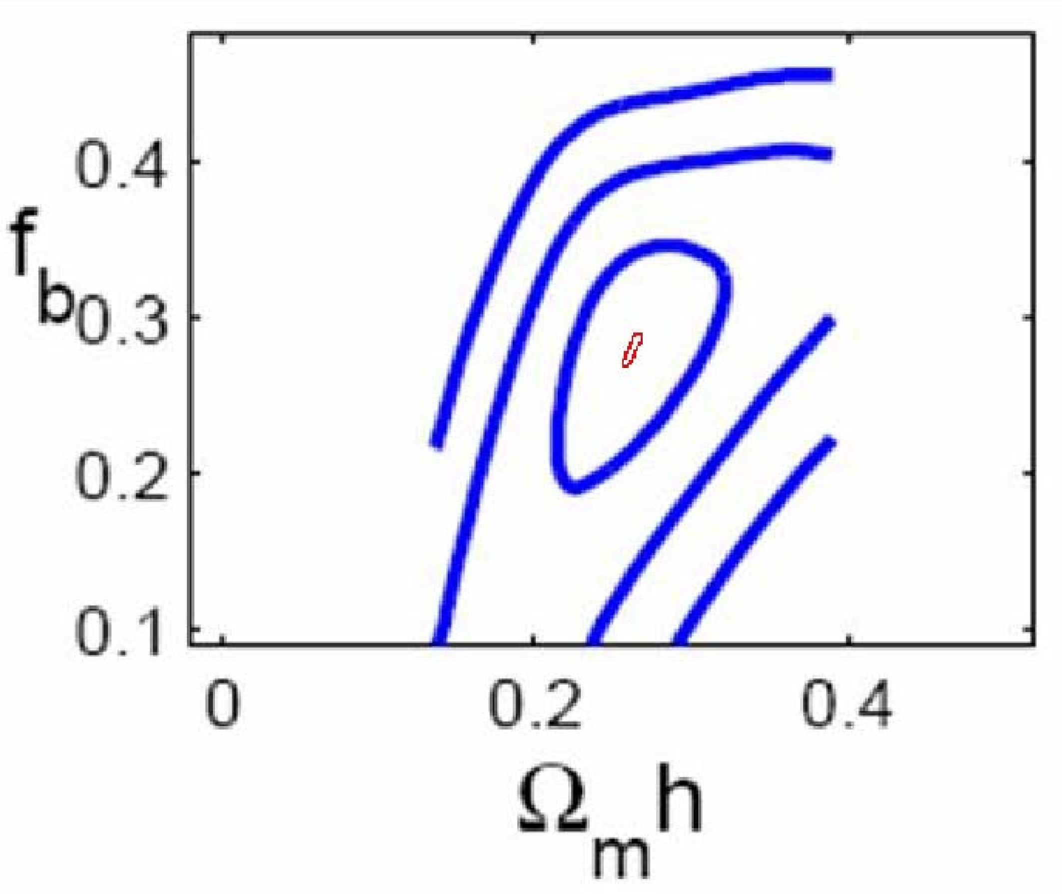
Errors (due to cosmic variance) scale as sqrt(V)

And errors much less correlated if the window function is sharp in k space.

Will find wiggles in the baryons (traced by galaxies) and the `turnover'.

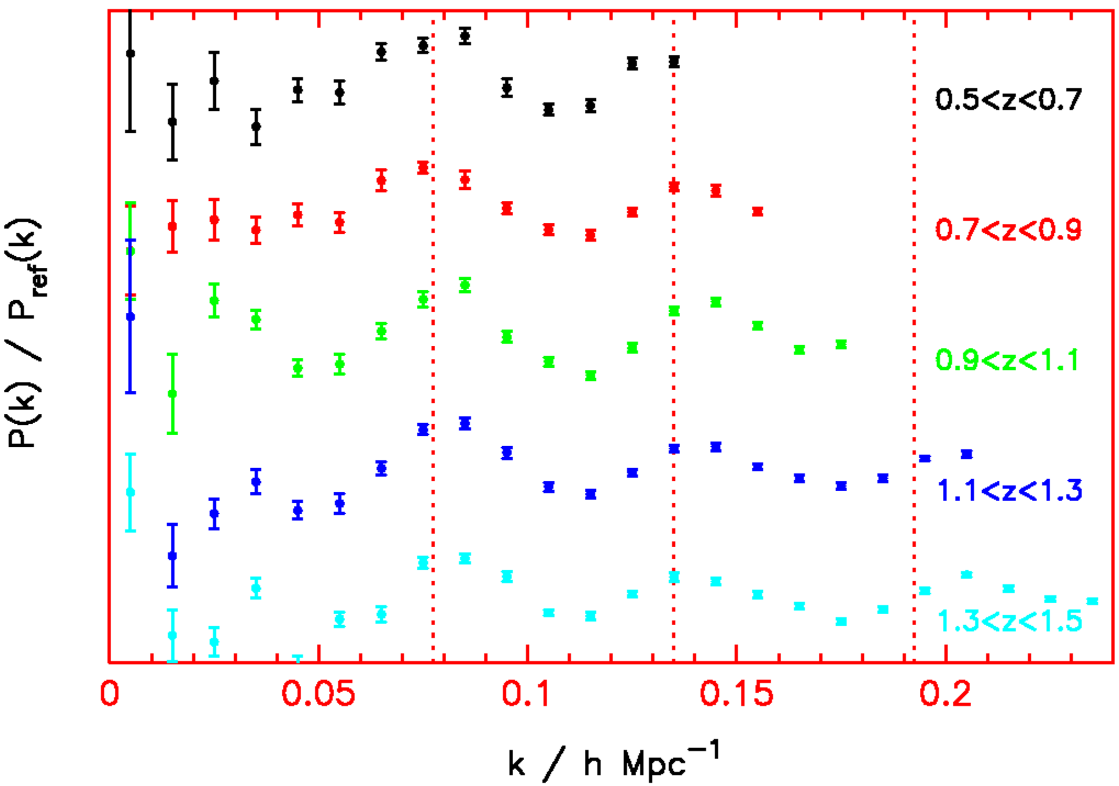
But 'bias' is likely to be stochastic, scale-dependent, non-local & non-linear, CARE!

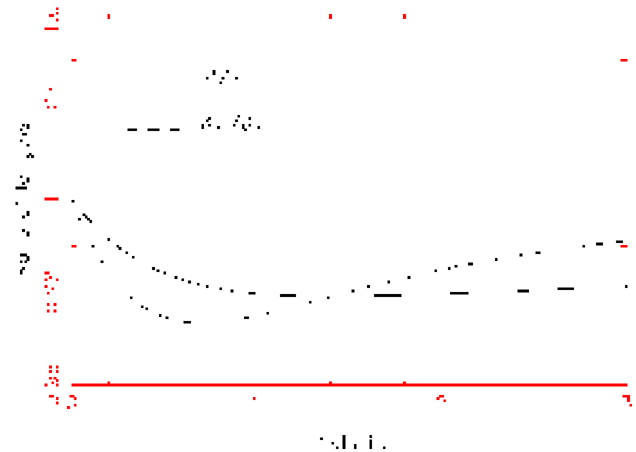
But precision is not all!



Worries about systematics, so that targeted experiments should certainly be cleaner.

Experiment I: `wiggles'



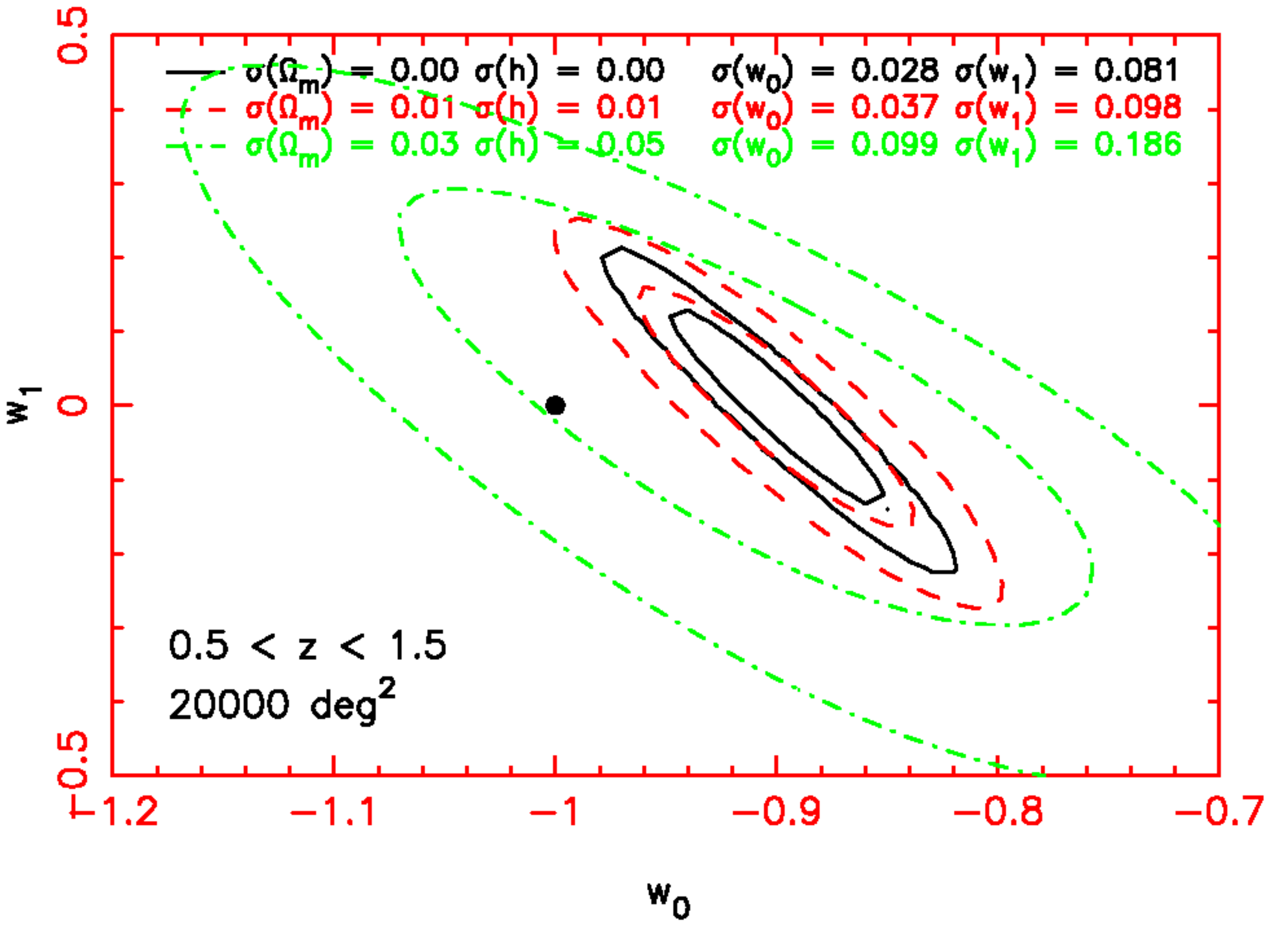


Tangential rods: can cancel s, so that $D_A(z=z_{eff}) / D_A(z=1000) = \theta_{CMB} / \theta_{wiggles}$

Radial rods: extra information from isotropy (c.f. AP test), and z<2 key regime.

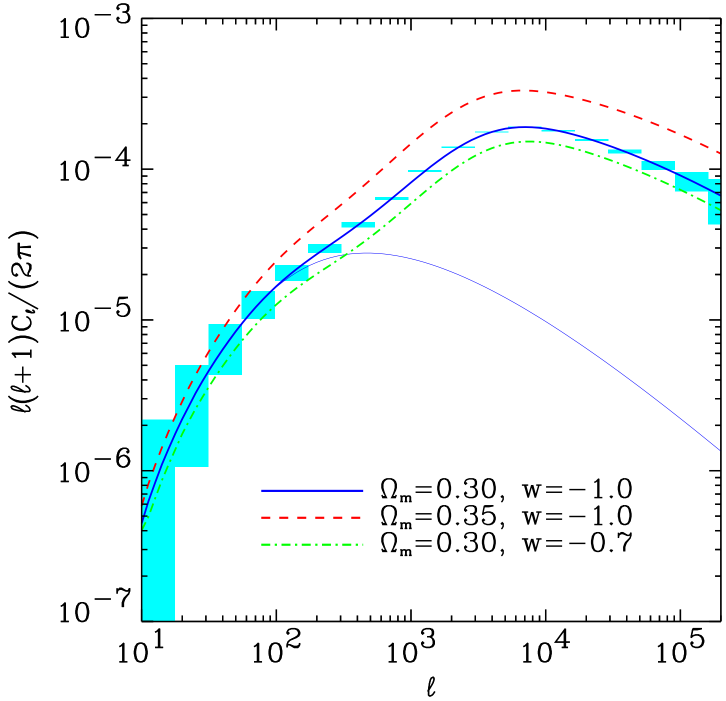
As s now measured (independent of baryons etc), finally have a standard rod.

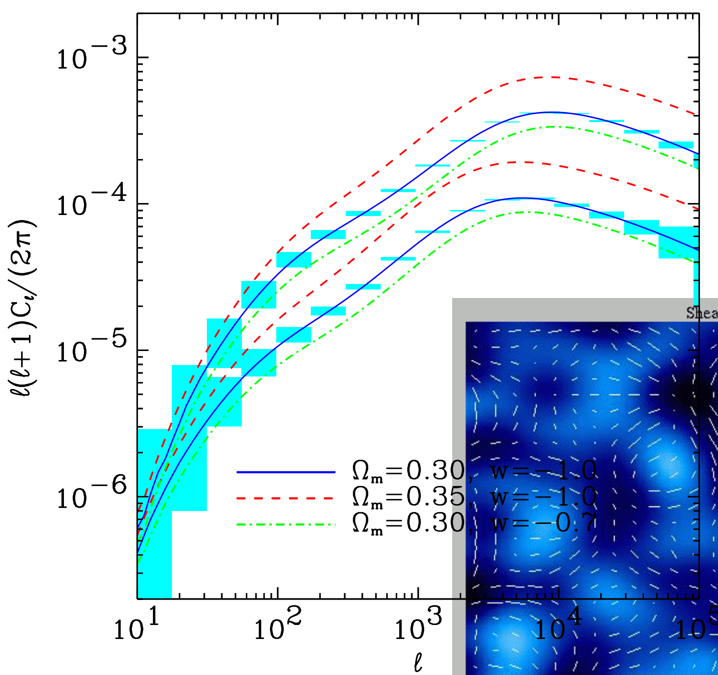
Testing Einstein with wiggles

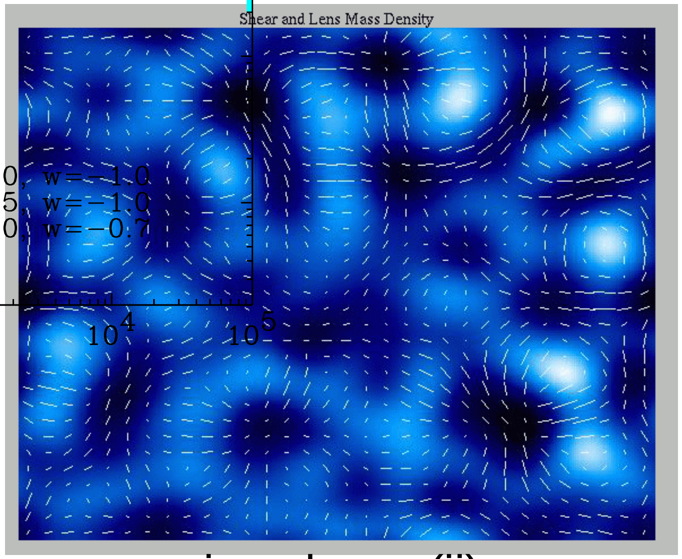


Note, still needs \`priors' on Ω_m h^2 and h (with Planck and/or, e.g., SKA masers)

Experiment II: Weak lensing







SNAP 300 deg^2 survey from Refregier et al.

Requires: (i) good image quality and low systematics for measuring shear; (ii) source density >100 arcmin^{-2} to beat down noise; (iii) wide-field to beat down cosmic variance (particularly away from strongly non-linear scales); (iv) lensing tomography.

Requirements for Experiments

Experiment I: Machine delivering redshifts for all ~10^9 galaxies out to redshift ~2 in `whole' sky ($f_{sky}$ << 1 does not produce transformational science). Then get immense cosmic volume, access to large scales (where nuisances like bias and non-linear growth are minimised), narrow `k-space' window functions, and different degeneracies from CMB.

Experiment II: Machine delivering good quality (0.1 arcsec, low systematic, stable psf) imaging of >10^{10} galaxies in at least two redshift bins (say at ~1 and ~2) across 'whole' sky (again f_{sky} << 1 limits critically), different degeneracies from CMB and Experiment I.

Meaning what for this meeting:

Planck clearly essential.

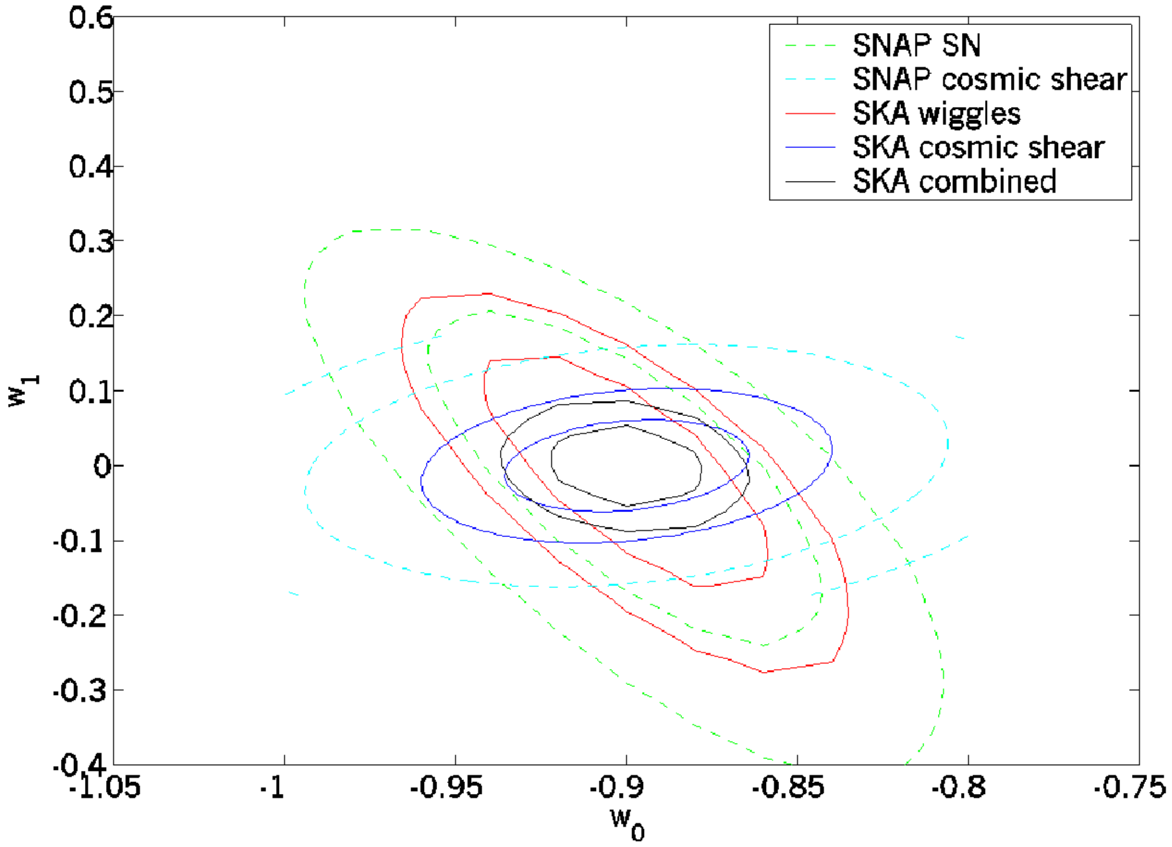
ALMA,OWL,JWST,XEUS,Constellation-X insufficient FOV to map `whole of sky'

Traditionally lead by optical surveys: SNAP (in space), FMOS/KAOS (from ground) may take next steps (but note HIFAR poster), but all limited by ~1 degree FOV, so will have f_{sky} << 1.

A strong argument for a new approach

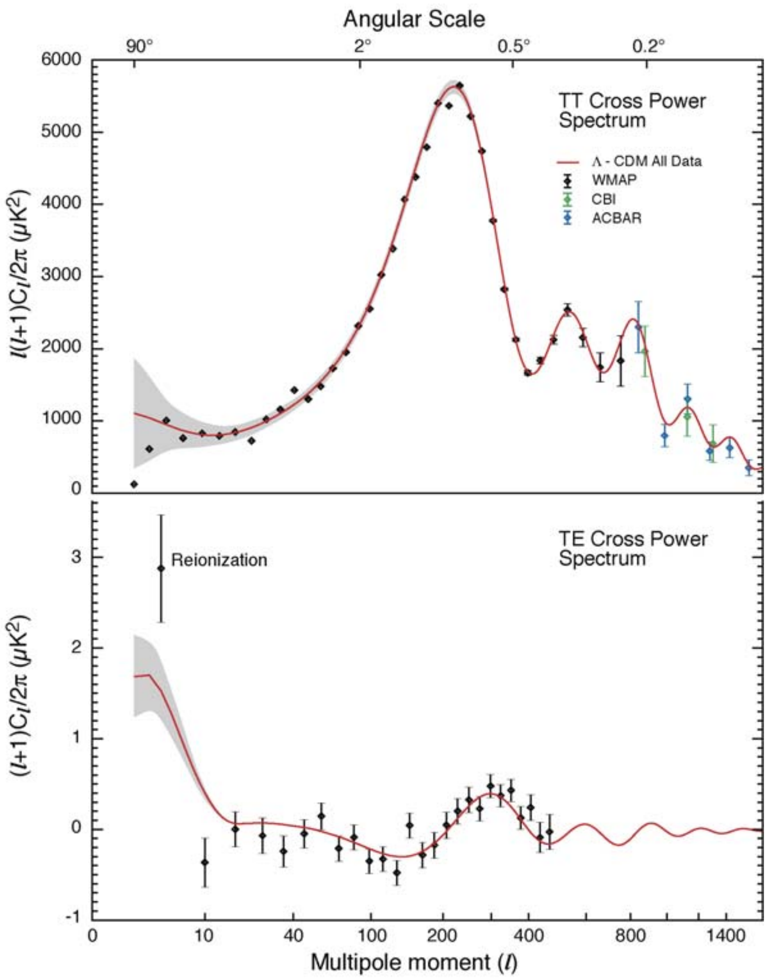
Detect fields not photons. Ideally make FOV limited by cost not physics.
Practicalities key but strive for upgradability (ie as computing resources improve)

Prospects look excellent



Different degeneracies because shear depends on growth of mass fluctuations as well as D_A.

….and not just dark energy!



- Measurements of inflation via running spectral index (rather than n_{scalar}) and isolation of tensor (gravitational wave) modes.
- Clustering of dark energy through Integrated Sachs Wolfe effect.
- Gaussianity of fluctuations via statistics of rare objects.
- Sharp features in P(k) – transPlankian physics!
- Small Universes – direct detection of ghost Milky Ways/Andromedas!