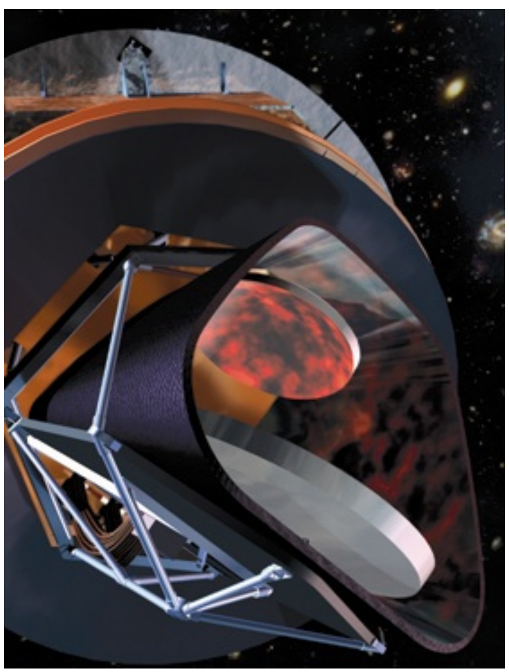
Testing Cosmic Gravity
Now and Then

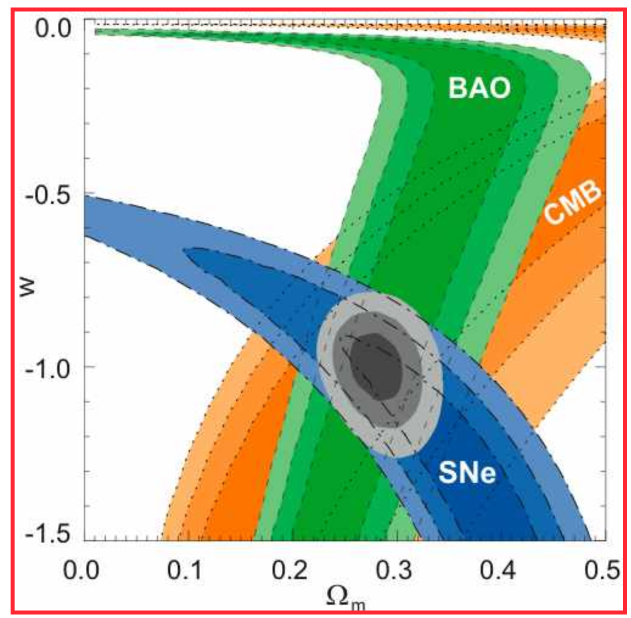


Eric Linder

3 August 2010

Institute for the Early Universe
Ewha University, Korea

UC Berkeley & Berkeley Lab



Outline

1. Testing GR with Current Data
2. Testing GR with Future Data – Galaxy Surveys
3. Did Radiation/Matter Always Dominate?

Parametrizing Gravity

"To summarize the theory of general relativity in one sentence, it is that spacetime tells matter how to move and matter tells spacetime how to curve." I.e. *metric* → velocity, density → metric.

But is metric = *metric*?

$$\nabla^2(\phi+\psi) = 8\pi G\, a^2\, \delta\rho \times \mathcal{G}$$

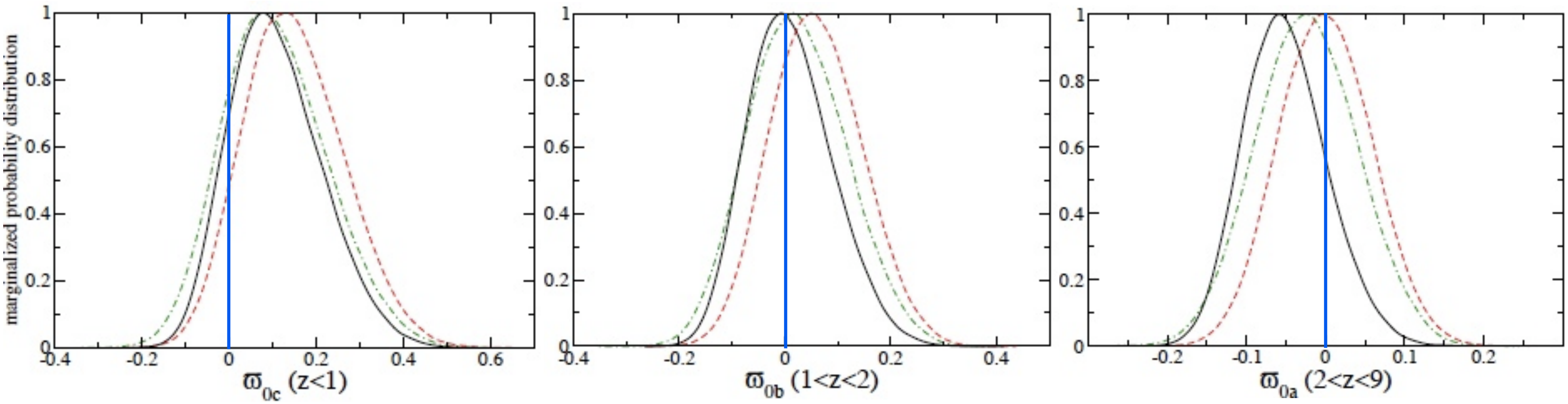
$$-\vec{\nabla}\psi = \ddot{x}$$

Are ϕ and ψ the same? (yes, in GR)

Gravitational Slip

Are ϕ and ψ the same?

Daniel et al 1002.1962

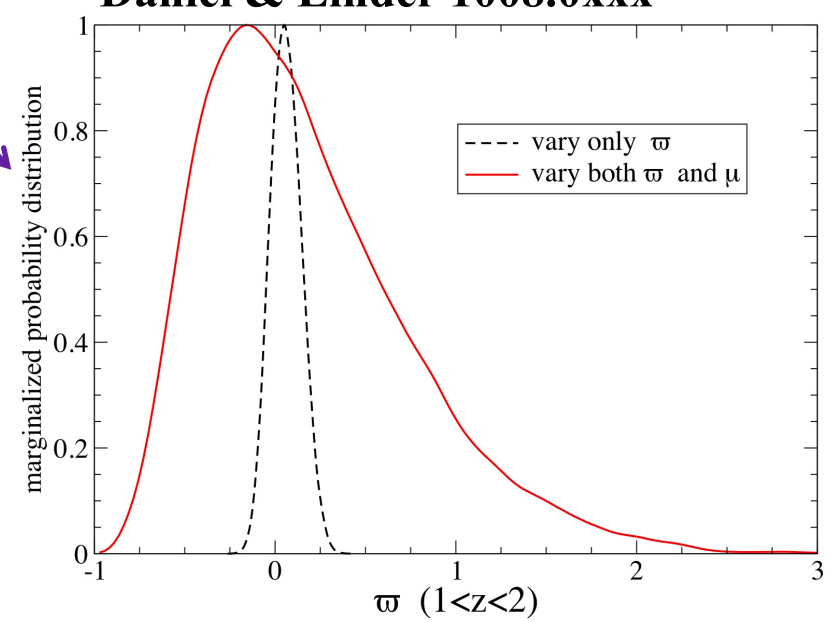


CMB+SN

CMB+SN+WL/COSMOS

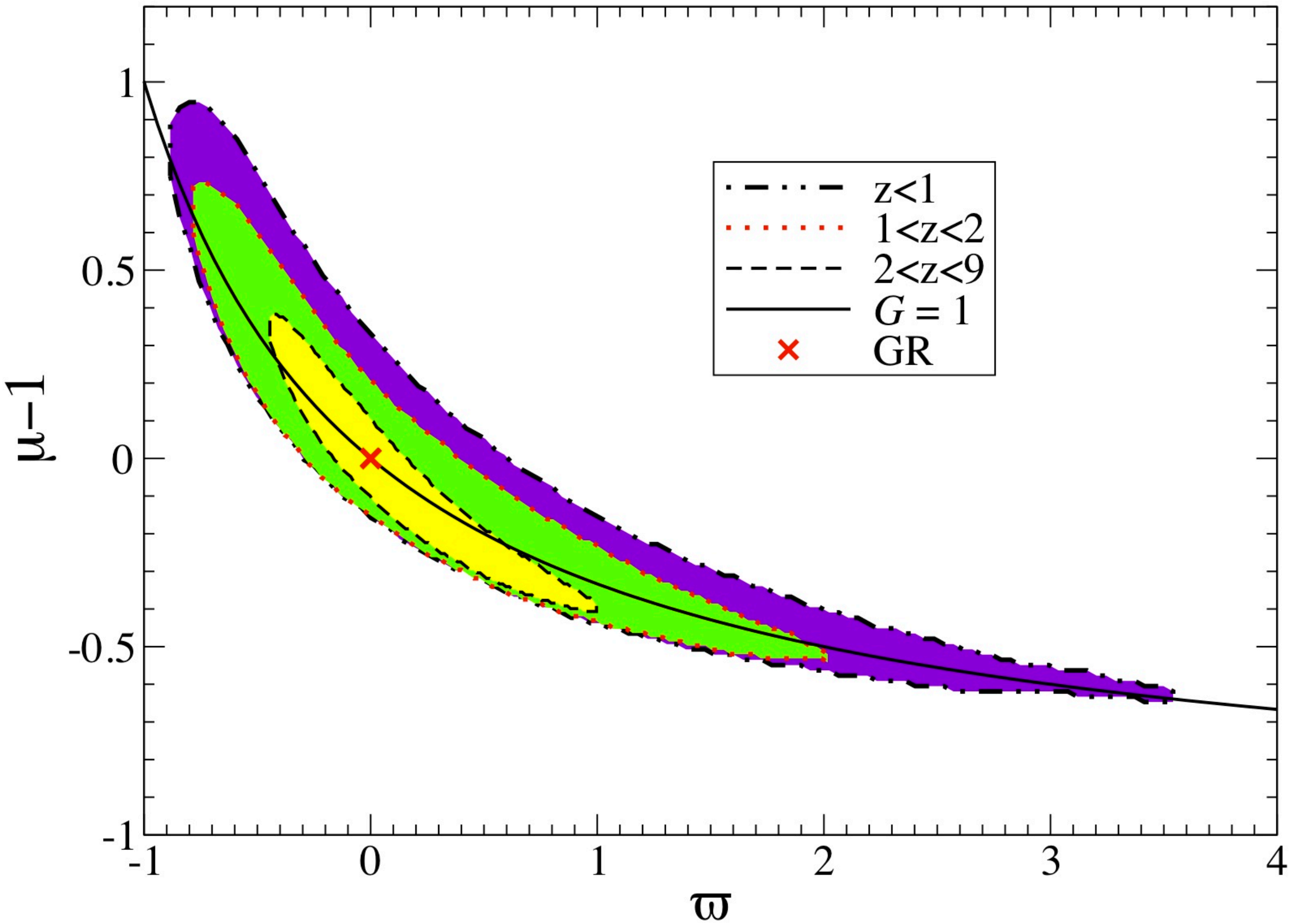
CMB+SN+WL/COSMOS,CFHTLS

Daniel & Linder 1008.0xxx



Gravity beyond Einstein is generally described by two functions, scale- and time-dependent.

Gravity Parameters



μ and ϖ are correlated and give banana-shaped contours. Since ISW and lensing care about φ+ψ (note degeneracy direction above), we change parameters to decorrelate.

Testing Gravity

Look for time variation between bins of redshift z.
Look for space variation between bins of wavemode k.
No model assumed – model independent approach.

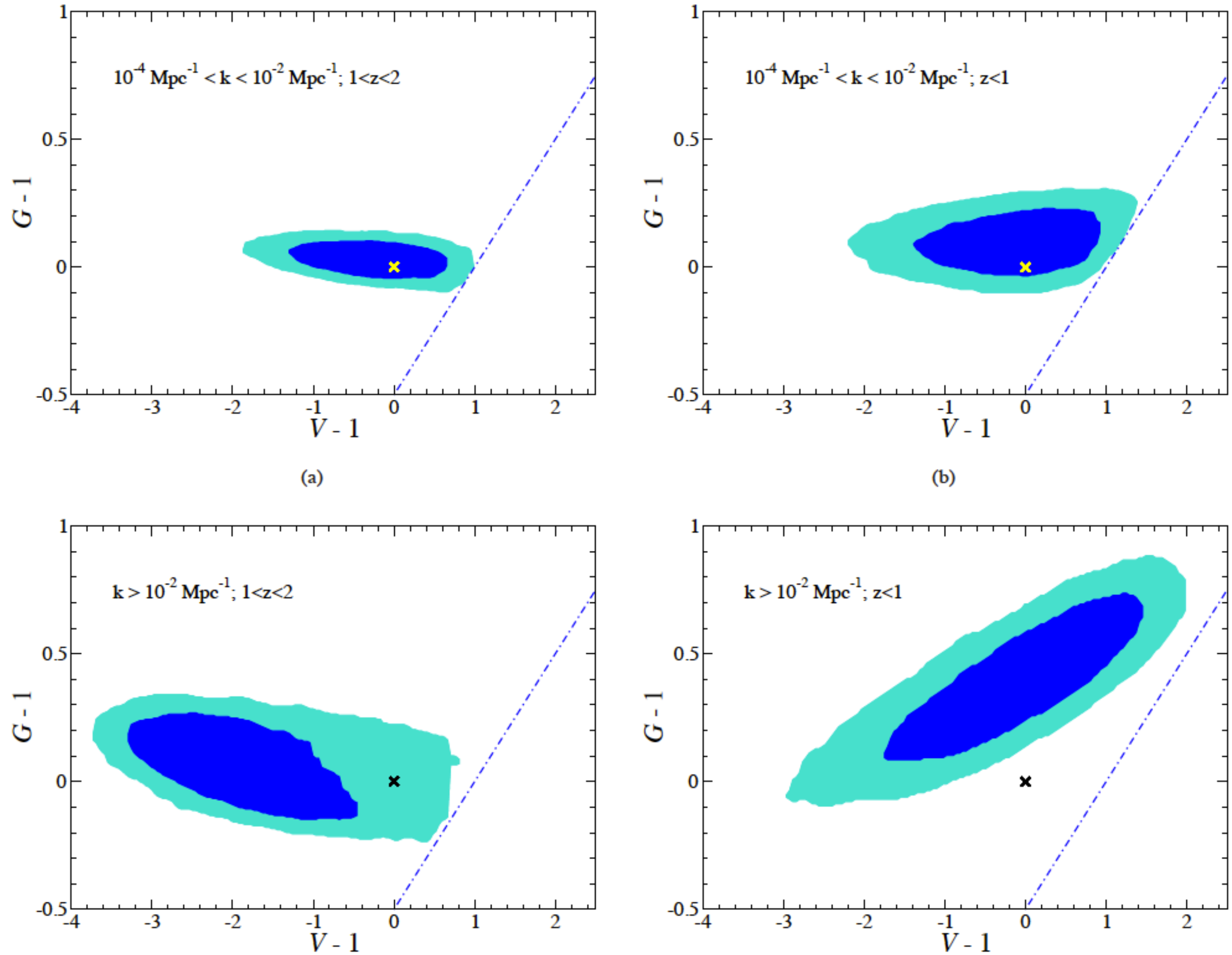
Use gravity-density and gravity-velocity parameters:

$$\nabla^2(\phi+\psi) = 8\pi G\, a^2\, \delta\rho \times \mathcal{G}$$
$$\nabla^2\psi = 4\pi G\, a^2\, \delta\rho \times \mathcal{V}$$

"Potential" probes (ISW, weak lensing) mostly sensitive to $\mathcal{G}$.
Growth probes (galaxies) mostly sensitive to $\mathcal{V}$.
Complementarity also exists between large scale (low k) / small scale (high k), and early (high z) / late (low z) probes.

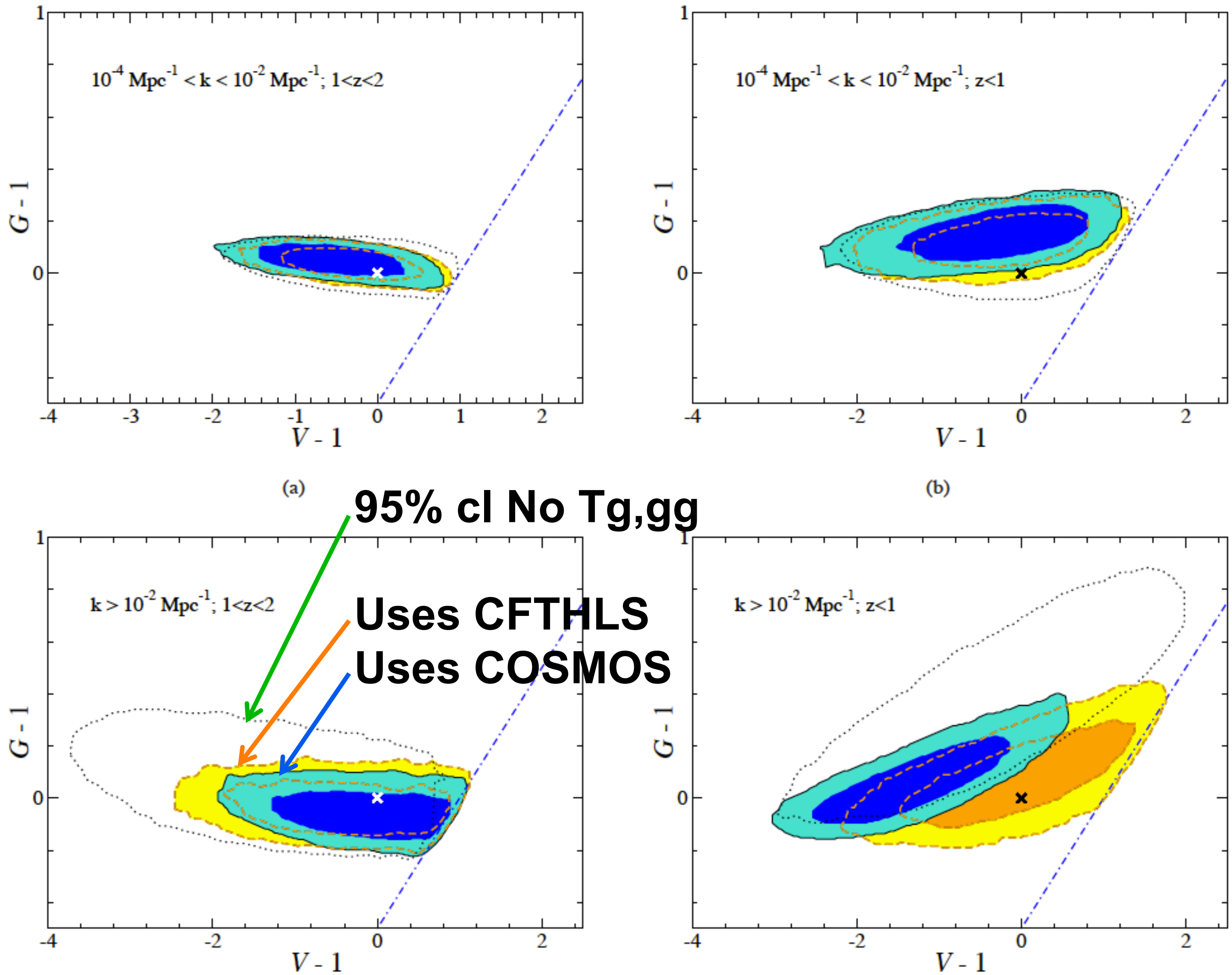
Test with Current Data 1

CMB (WMAP7), Supernovae distances (Union2), Weak gravitational lensing (CFHTLS) constrain 2×2×2 gravity.



Test with Current Data 2

Good constraints on potential ($\mathcal{G}$), poor on growth ($\mathcal{V}$). Add temperature-galaxy (Tg), galaxy-galaxy (gg) correlations.



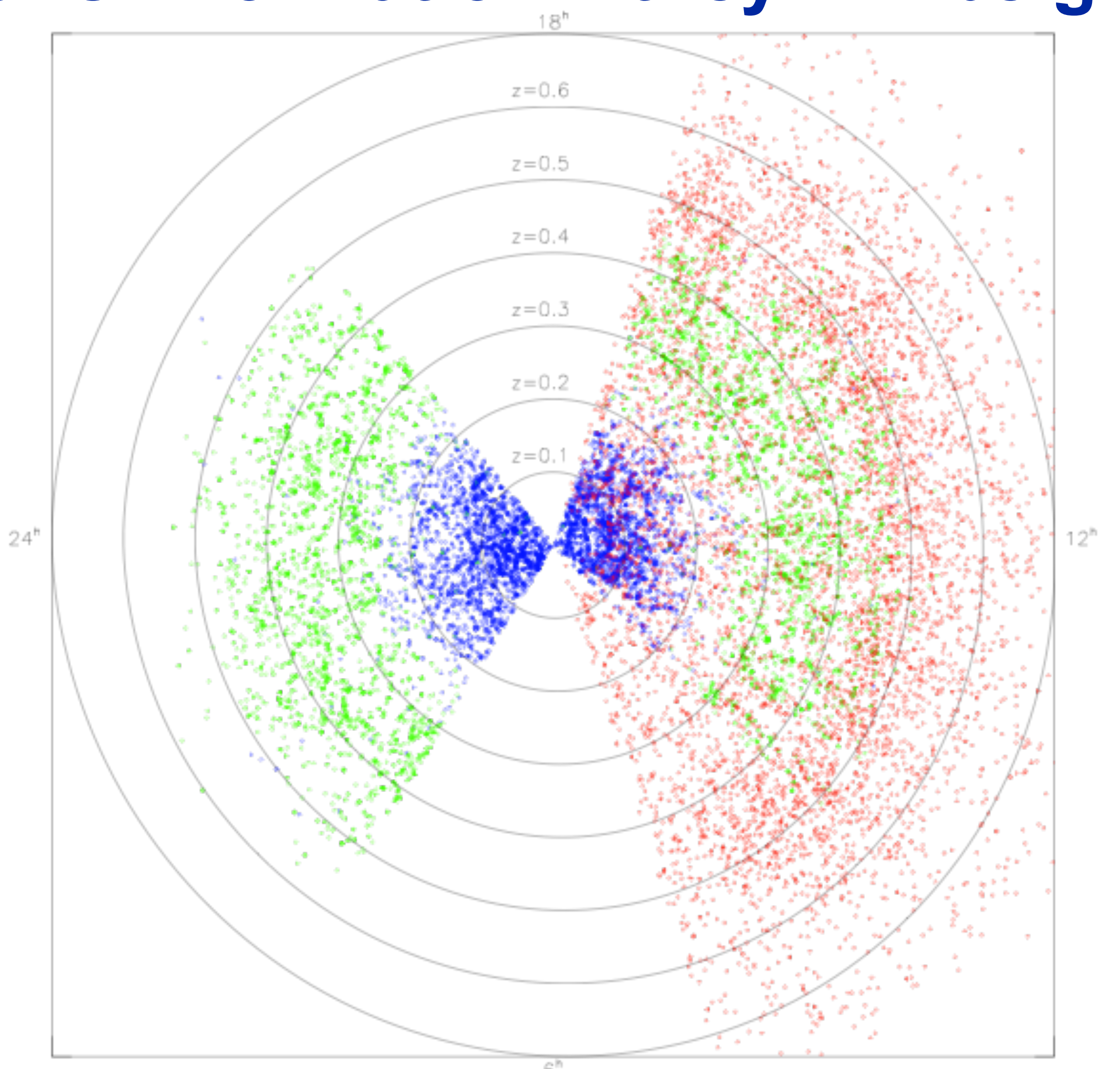
Constraints at high k improve.

$\mathcal{V}$ still poorly constrained.

CFHTLS systematic.

Test with Future Data

We need much better galaxy data to test growth/ velocity. Future large scale redshift surveys can give this information – they will be gravity machines!



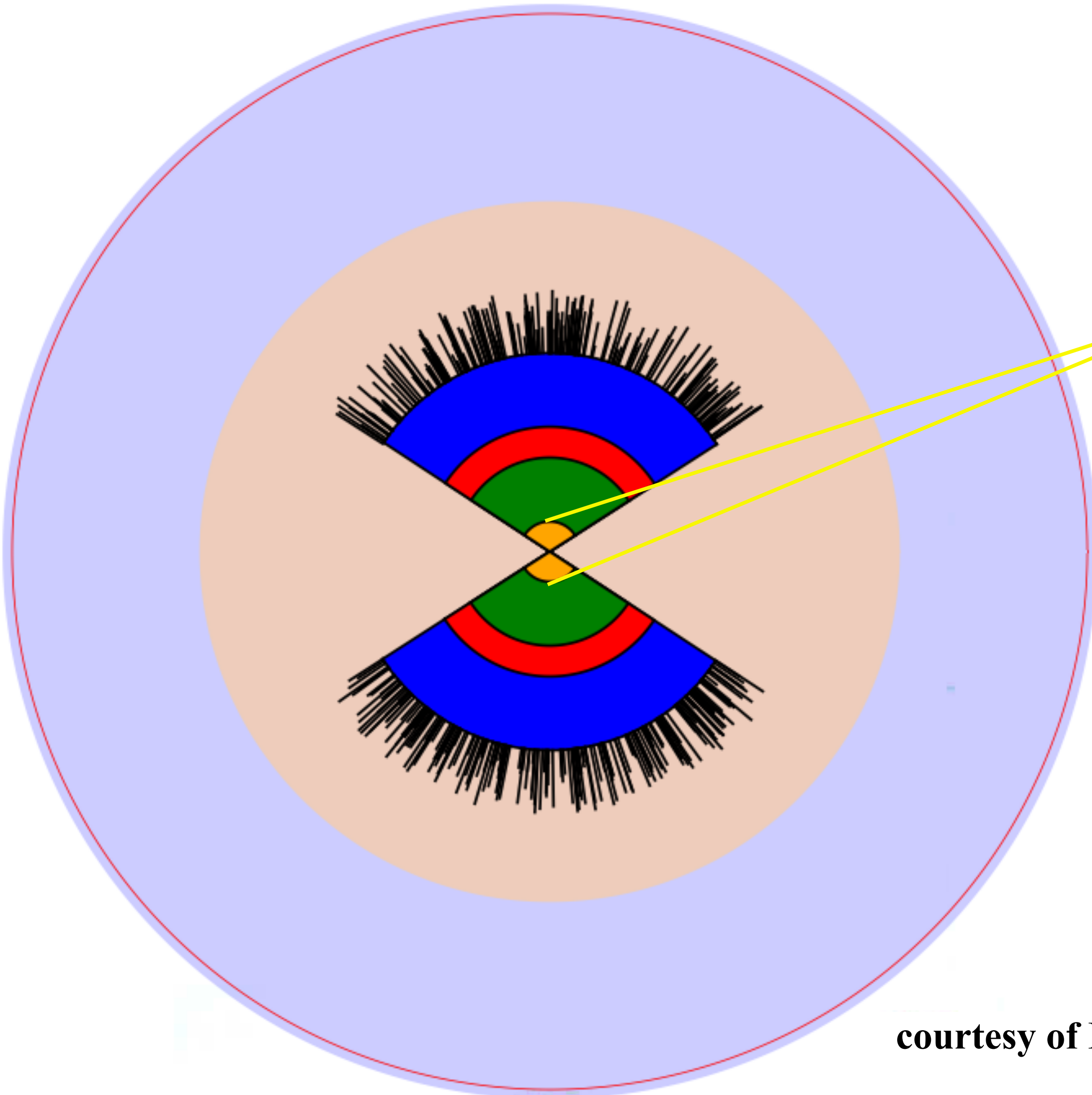
SDSS main galaxy survey
~650,000 galaxies

SDSS luminous red galaxies
~100,000 galaxies

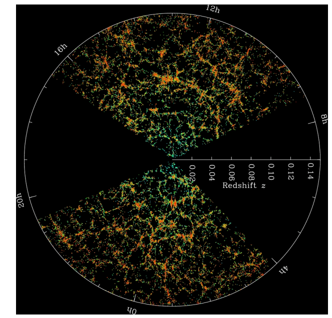
BOSS red galaxies [now]
1.5 million galaxies

courtesy of David Schlegel

Mapping Structure in 3D



2dF
SDSS I, II

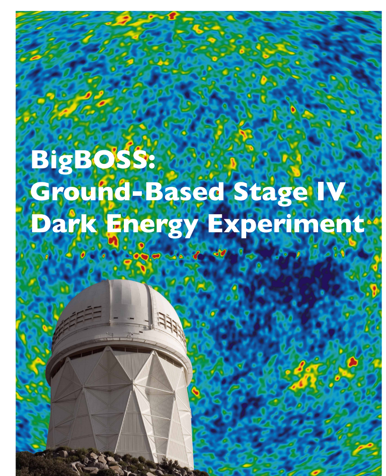


BOSS (SDSS III)

BigBOSS
50 million galaxies
z=0.2-2

1 million QSOs
z=1.8-3

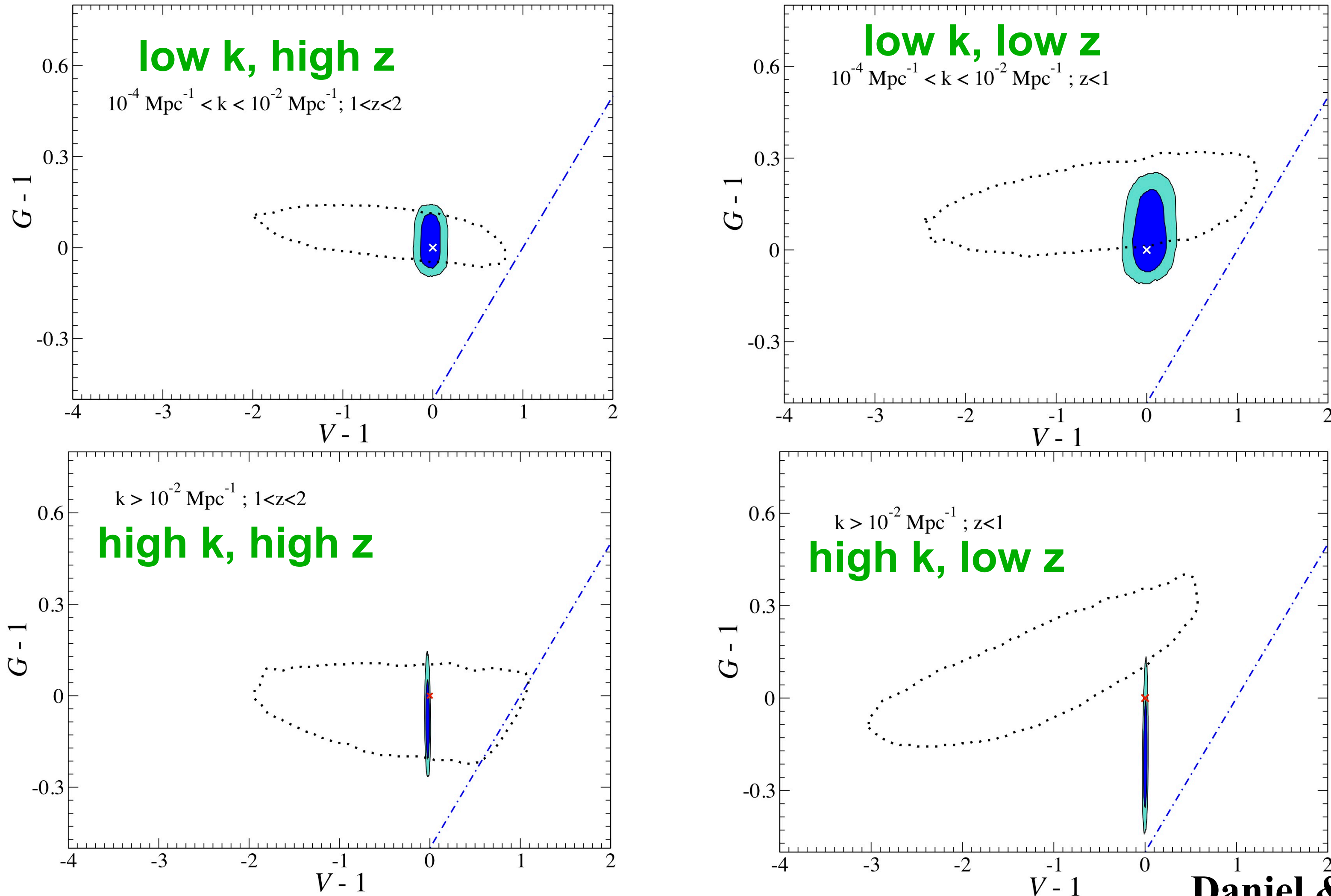
courtesy of David Schlegel



Conformal diagram of Universe

Future Data Leverage

BigBOSS (gg) + Planck CMB + JDEM SN



Daniel & Linder 2010

Factor of 10-100 improvement;

5-10% test of model-independent gravity.

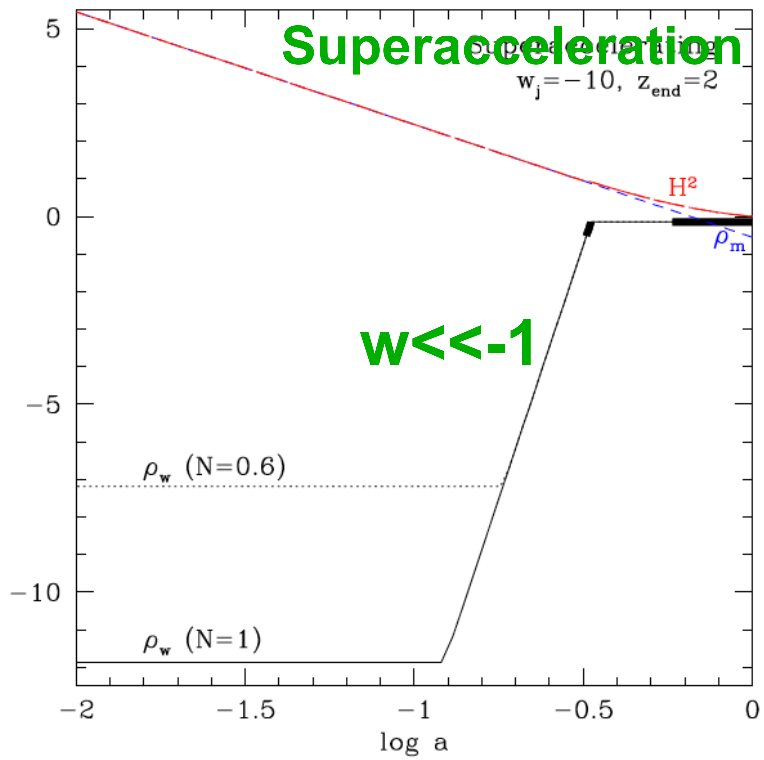
Testing Expansion History

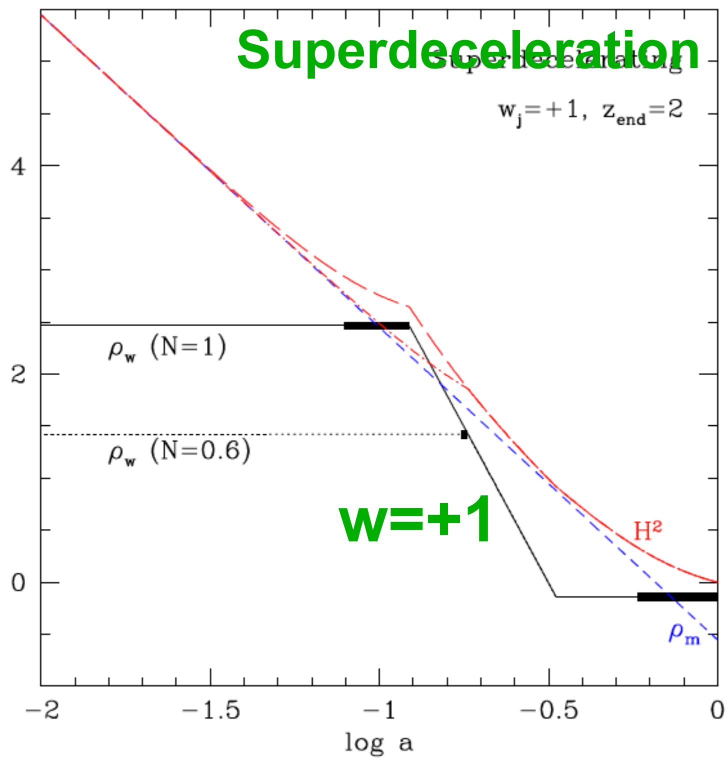
How well do we really know the standard picture of radiation domination → matter domination → dark energy domination?

Not well at all in detail. Although we know the *magnitude* of H, we don't know its *slope*. Even during BBN, w=[0,1].

Carroll & Kaplinghat 2002

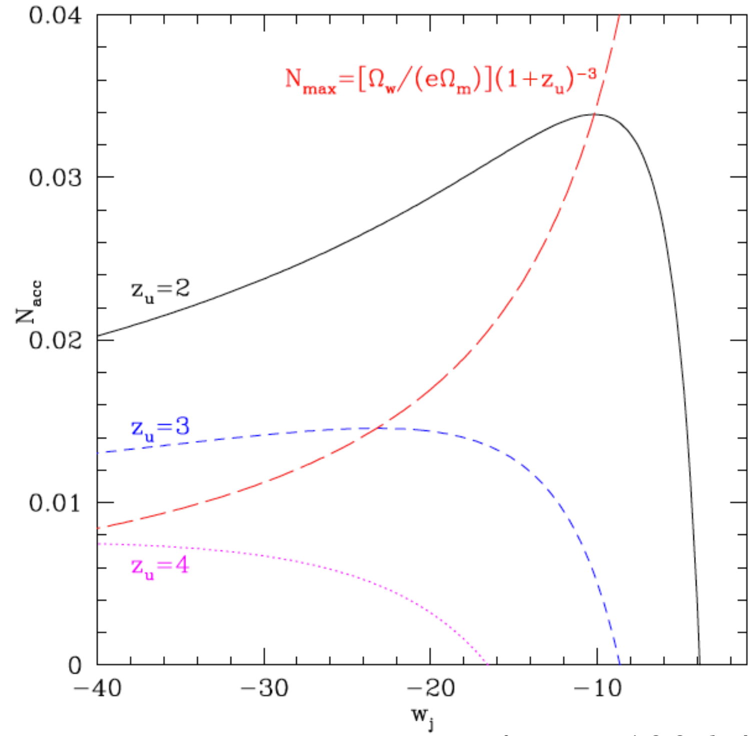
Maybe acceleration is occasional; two ways to get early acceleration:



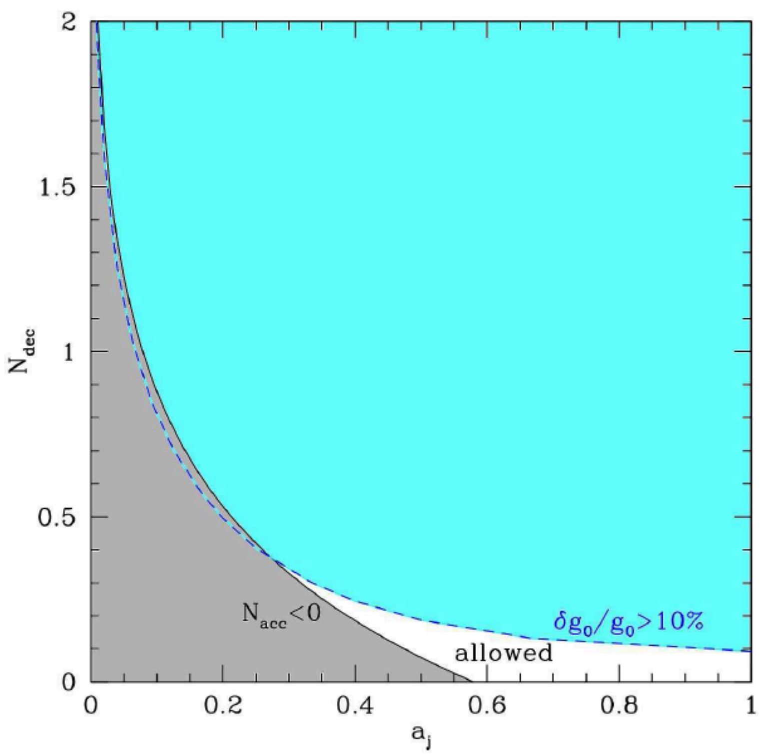


Early Acceleration

Superacceleration: Less than 0.035 e-folds allowed by dynamics (if w too negative, Ω_w driven too small to allow $w_{tot}<-1/3$).



Linder 1006.4632

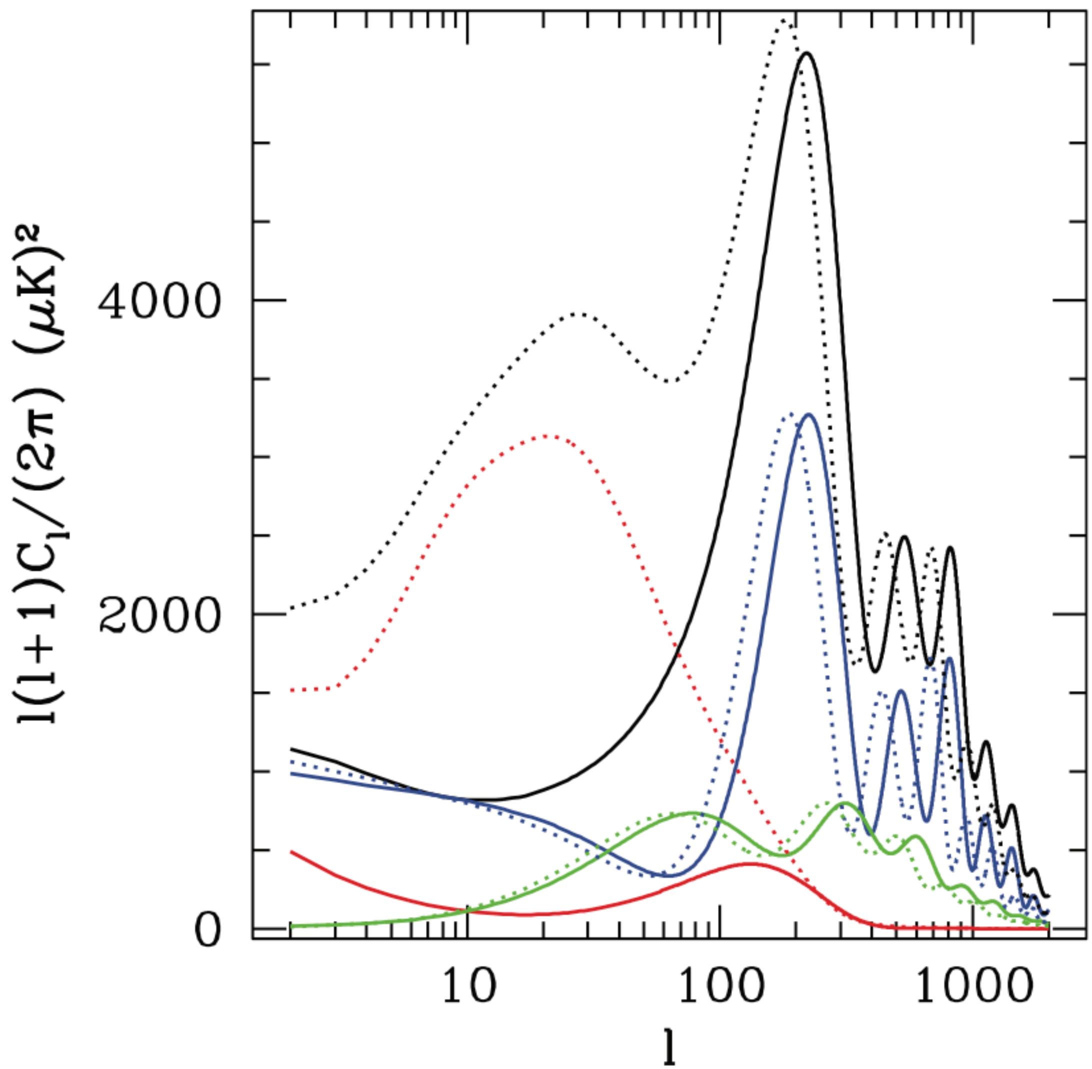


Superdeceleration: Less than 0.05 e-folds allowed by dynamics (lower limit) + matter growth (upper limit) – and can't be early!

CMB and Expansion History

Further tight constraints from CMB.

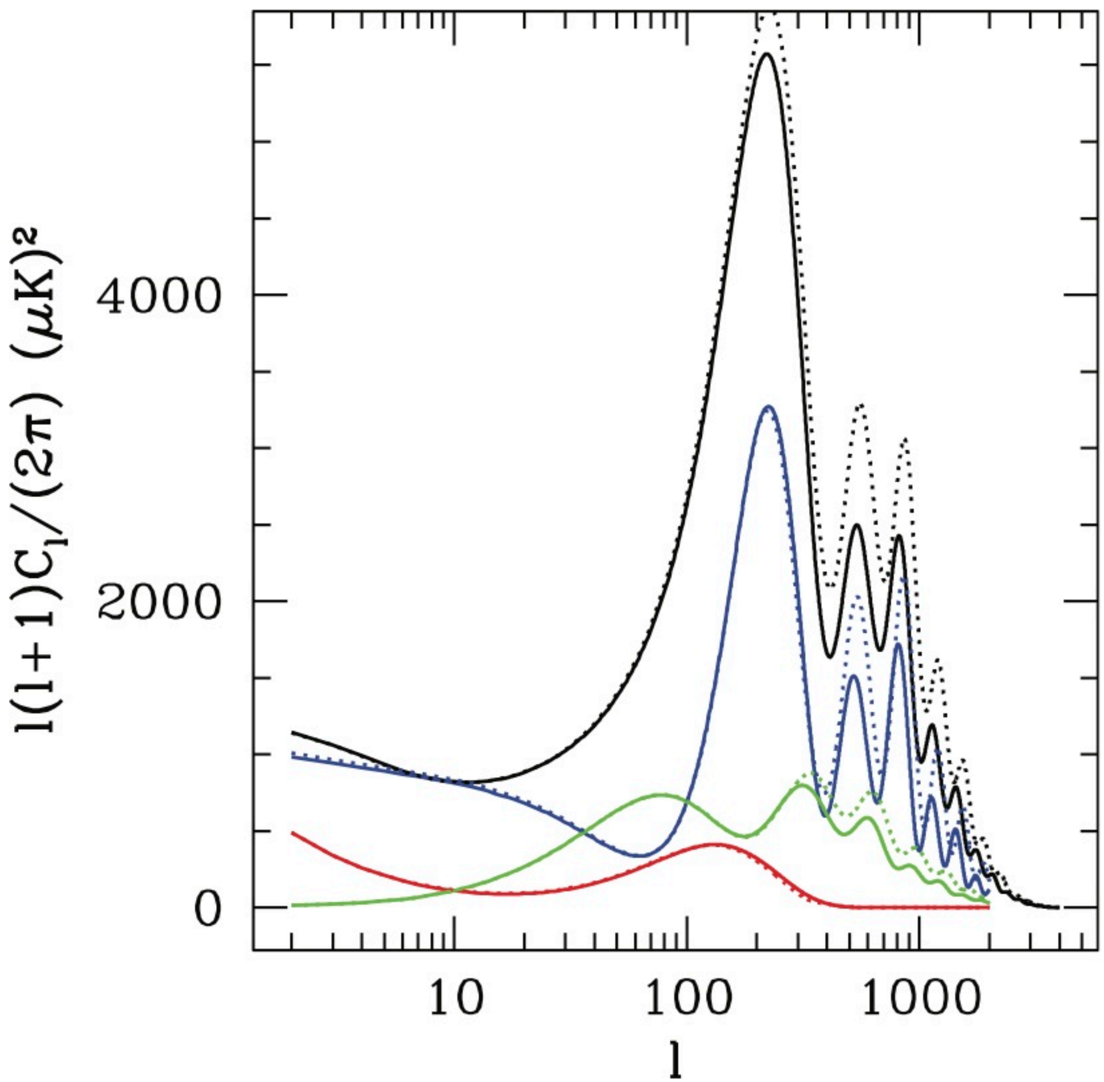
Post-recombination acceleration leads to ISW and shift in d_{lss}.



Linder & Smith 2010

CMB and Expansion History

Pre-recombination acceleration leads to shift in time of recombination and changes photon damping.



Linder & Smith 2010

Summary

General Relativity can be tested on cosmic scales. It is consistent with current data (but systematics must be watched).

Future galaxy redshift surveys will be powerful for testing the dark/gravity sector. BigBOSS will be up to 100 times more constraining than current data.

Expansion history (Λ/Coincidence problem/Early Acceleration) can be tested at all redshifts. Current acceleration appears rather unique (<0.05 e-folds z>2).

Institute for the Early Universe

"World Class University" program in Seoul, Korea.
8 postdocs hired, 6 more open, 2 new faculty open.