# Future Prospects for the Integrated Sachs-Wolfe Effect: The Optimistic Case

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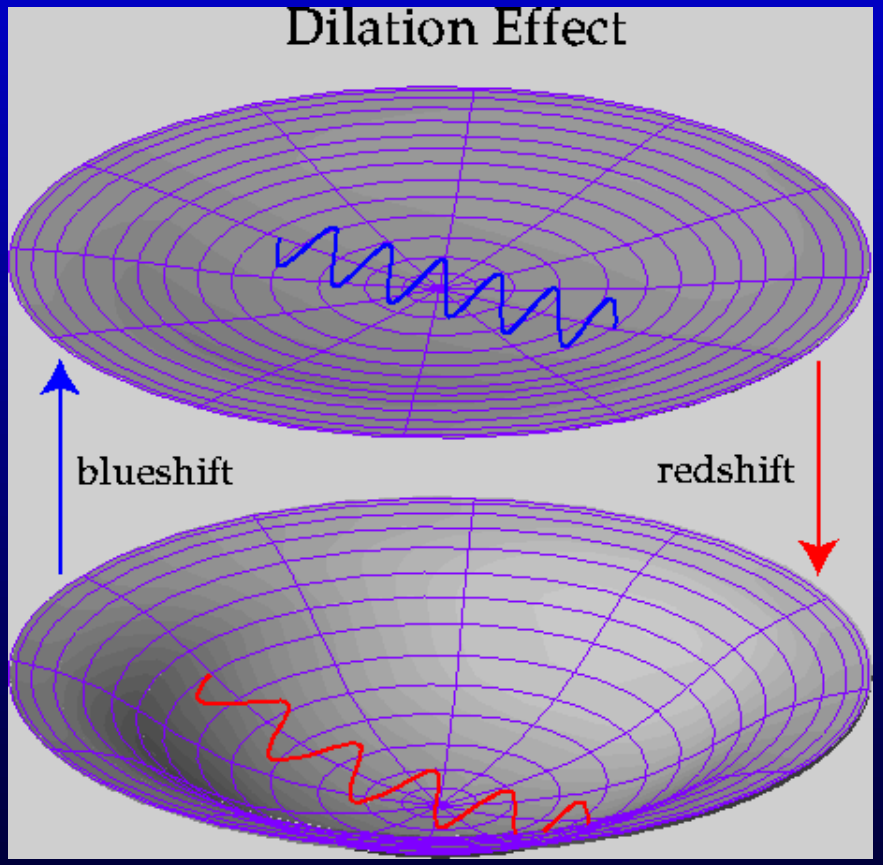
Hu & Scranton, PRD, **70**, 12

# ISW in 1 Minute

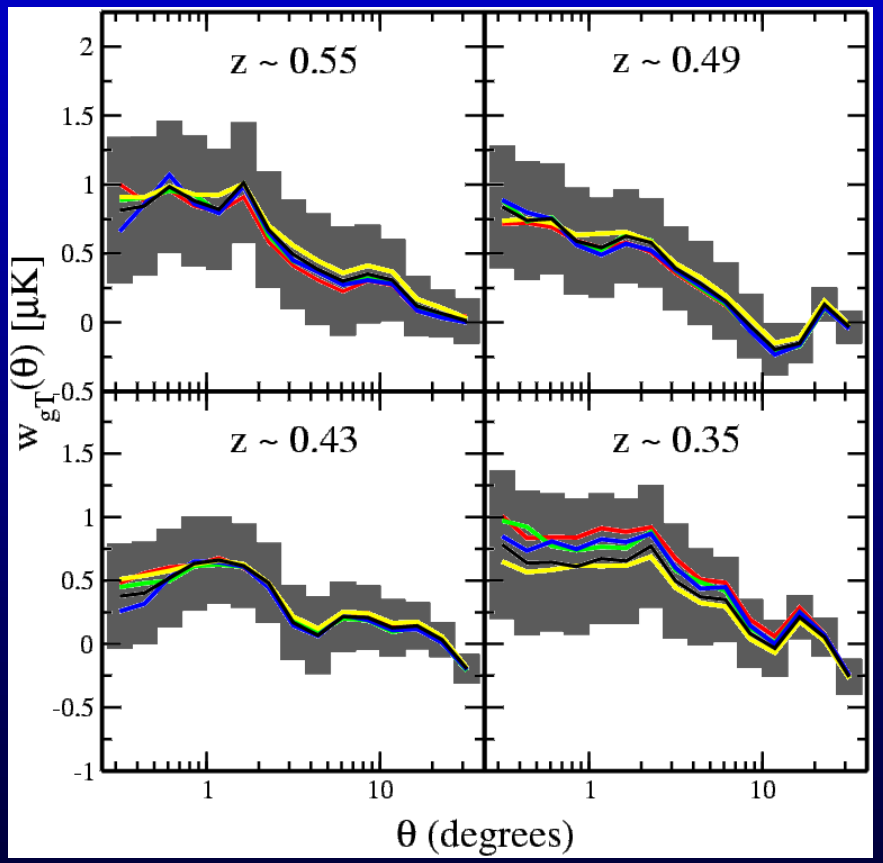
- After matter-radiation equality, dark matter falls into potential wells set up during inflation. For $\Lambda$CDM, universe expands faster than potentials grow
- CMB photons passing through potentials see net blue-shift in energy $\Rightarrow$ **Integrated Sachs-Wolfe Effect**
- Increases CMB autocorrelation at small $l$ and induces positive correlation with galaxies




Wayne Hu, Samuel Laroque

# ISW in 1 Minute

- Cross-correlations detected with optical galaxies (RS et al., Fosalba et al.), radio galaxies (Nolta et al., Boughn & Crittenden) and IR galaxies (Afshordi et al.).
- The detection significance in each case is 2-3$\sigma$ and there are some unexpected secondary results (Padmanabhan et al.), but the general signal seems to be real.



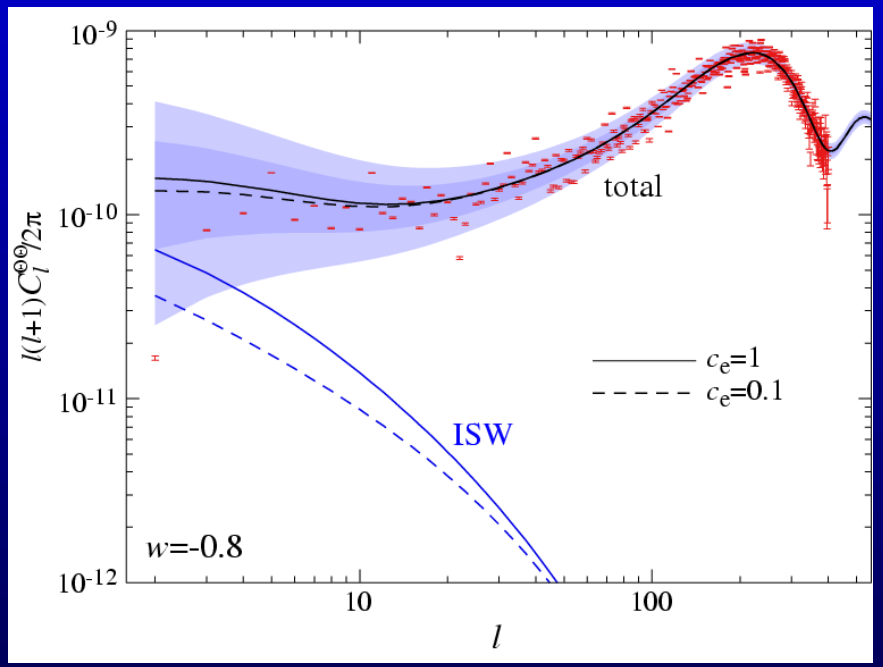

RS et al. (2002)

# Going Beyond Mere Detection

- Classic picture of dark energy:
  - ⋆ Cosmological Constant ($\Lambda$)
  - ⋆ $p/\rho \equiv w = -1$
  - ⋆ $\delta p/\delta\rho \equiv c_e^2 = 1$
- For $w \neq -1$, we have two regimes:
  - ⋆ $c_e \geq 1$: Smooth Dark Energy, clustering only on scales larger than the horizon size, **Quintessence**
  - ⋆ $c_e < 1$: Clustered Dark Energy, $k \sim 1/c_e \Rightarrow$ lower sound speed dark energy enters the horizon at smaller scales, **k-essence**

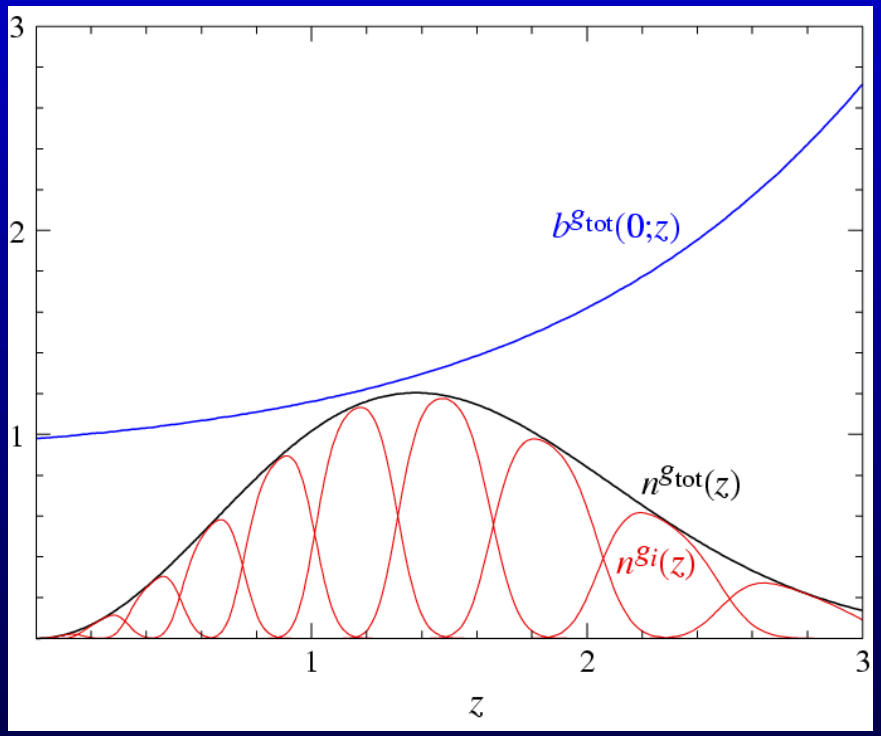
# CMB Only

- Choose $w = -0.8$, modify $h$ and $\Omega_{DE}$ to keep distance to recombination and high-$z$ expansion consistent with WMAP results.
- ISW only dominates at small $l$.
- Cosmic variance makes differences in ISW signature very hard to distinguish.



# ISW Cross-correlation

- Consider full-sky, deep, photometric galaxy survey (LSST++). Select 10 photometric redshift bins based on expected photo-z errors.
- Calculate expected cross-correlation with background CMB for each redshift slice
- Check variations of the ISW signal with respect to $w$ and $c_e$



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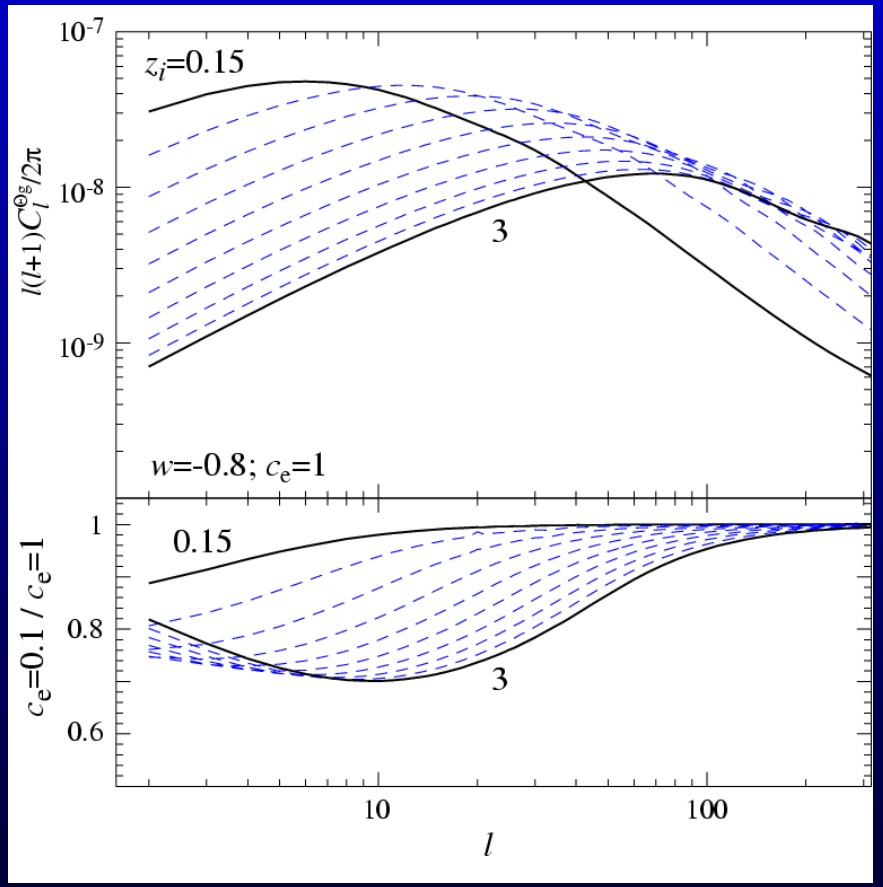

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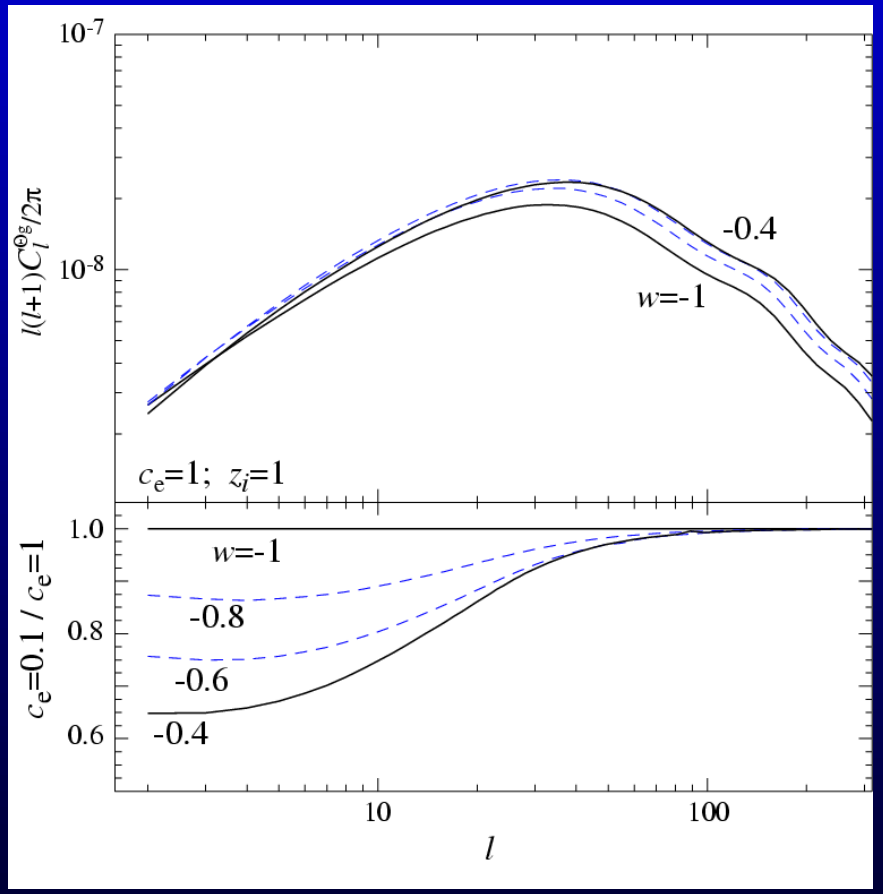
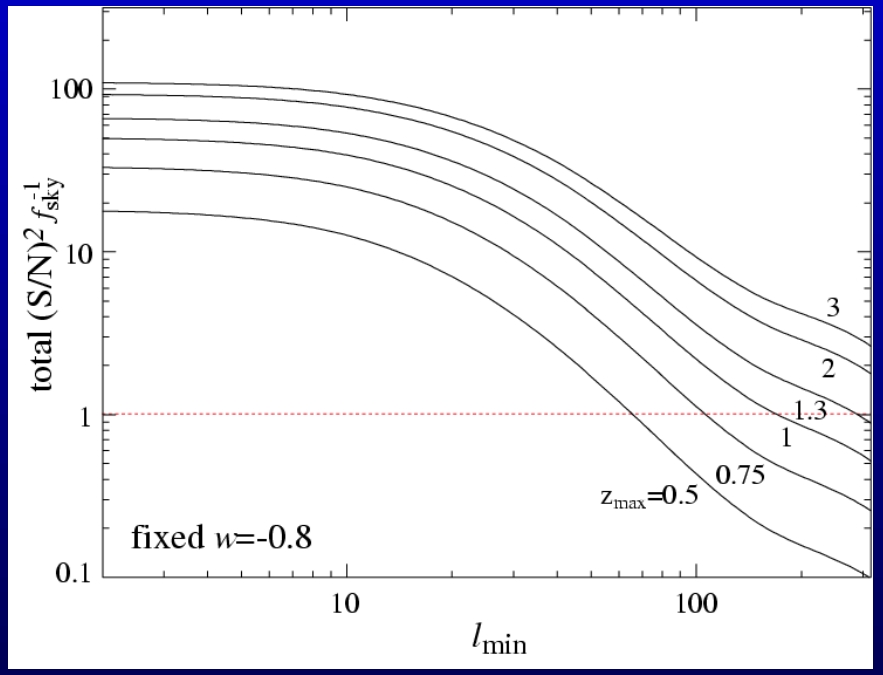


# Our Results

- Expect S/N of about 10 for best case ISW signal. As $w \to 0$, having high redshift information becomes critical. ISW-only constrains $|1+w|$ to 5%.

- Distinguishing between $c_e \sim 0.1$ and $c_e = 1$ can be done at the $2.5\sigma$ level (DE smoothness at 1 Gpc to 3%). Demands high redshift information and most sensitive at $l < 10$.

- Current best shot at quintessence vs. k-essence.



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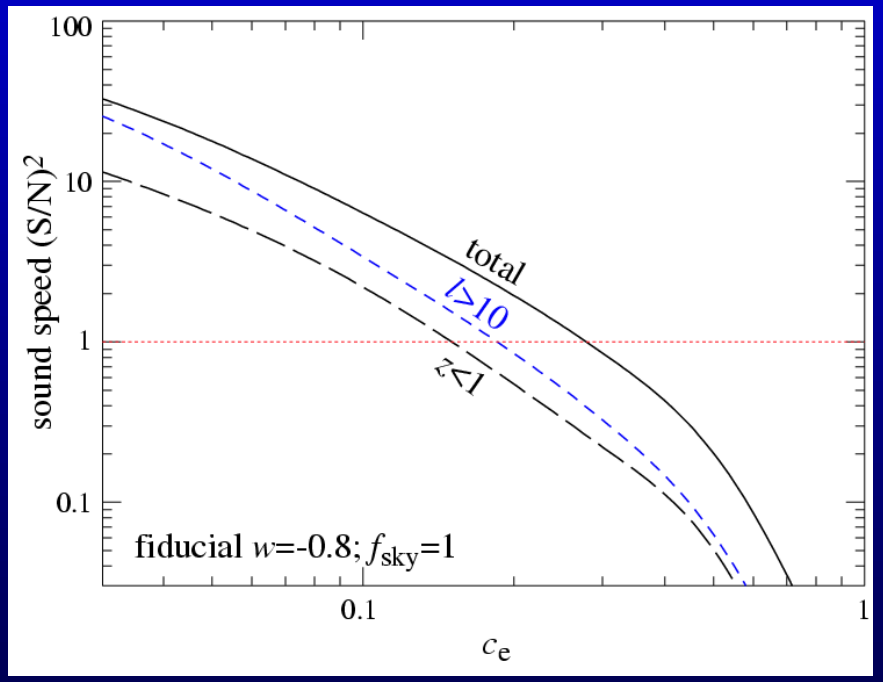

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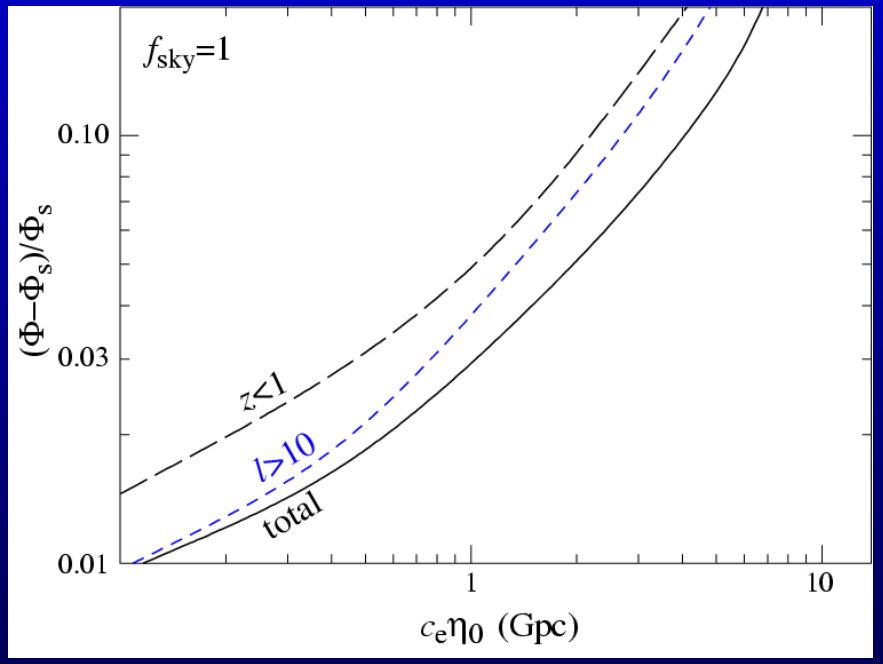

# Summary

- Current ensemble of ISW measurements shows reasonably convincing evidence of detection.
- Moving beyond detection to constraints requires careful modelling and treatment of systematic effects as well as more area and volume.
- Best case ISW can constrain $|1 + w|$ to 5%.
- Eventually, ISW + lensing + auto-correlations can (possibly) constrain the clustering scale for dark energy or at least constrain the smoothness of dark energy for scales $< 5$ Gpc.
- Life would be simpler if dark energy were less like itself.