Theoretical Astrophysics and Dark Energy

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DOE Program Review

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A Brief History

- Touting the virtues of Lambda **Turner**, Steigman, Krauss 1984; **Frieman** 1995; Krauss & **Turner** 1995
- Decaying Lambda Models Adams, Freese, **Frieman**, Mottola 1987
- Loitering Universe models Sahni, Feldman, **Stebbins** 1992
- Scalar Field Models for DE **Frieman**, Hill, **Stebbins, Waga** 1995; **Dodelson,** Kaplinghat, **Stewart** 2000
- Scalar Field DE & LSS Coble, **Dodelson, Frieman** 1997
- Workshop on the Missing Energy in the Universe May 1998
- DE and CMB **Dodelson** and Knox 1999
- DE and neutrino mass **Abazajian** and **Dodelson** 2002
- DE and unimodular gravity Ahmed, **Dodelson, Greene**, Sorkin 2002
- Local cosmic acceleration with inhomogeneities

  Kolb, Matarrese, Riotto, Notari 2004-5

Recent Dark Energy Activities

- Dark Energy models: develop & test
- Dark Energy probes: develop & refine
- Dark Energy experiments/observations:

  SDSS, DES, SNAP

Dark Energy & Fundamental Physics: what is causing cosmic acceleration?

- A new form of stress-energy
- A modification of GR on large scales
- An inhomogeneous universe

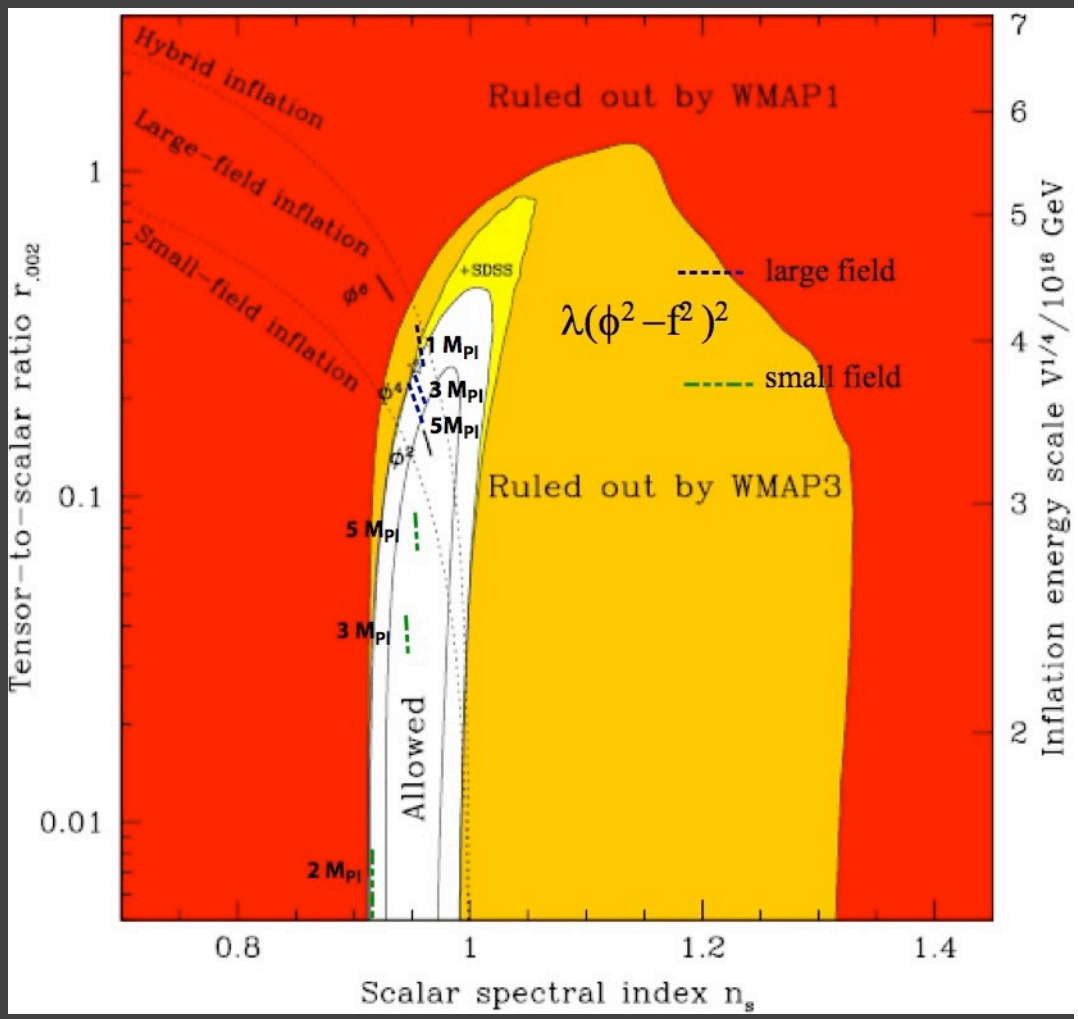
Testing Quintessential Inflation

- Simple model w/ early & late acceleration:

$$V(\Phi) = \lambda\left(\Phi\Phi^* - \frac{f^2}{2}\right)^2 + M^4\left(\cos(Arg(\Phi) - 1\right)$$

$$M^4 \sim 10^{-3} eV, f \sim M_{Pl}$$

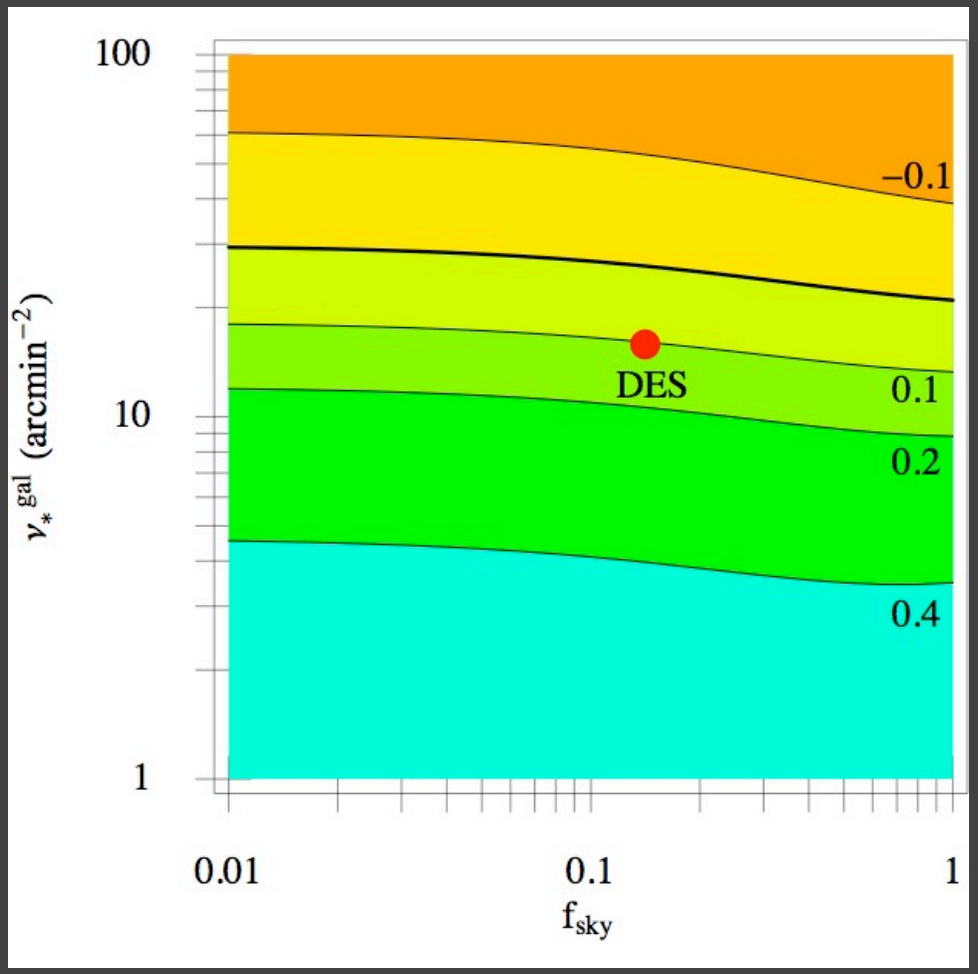
- Hierarchy protected by symmetry



Rosenfeld & **Frieman** 2005, 2007

Probing Dark Energy

- Combine clusters and Weak Lensing cosmic shear, including covariance
- Fractional change in DETF Figure of Merit (+ is good)



Shapiro and **Dodelson** 2007

Primordial Non-Gaussianity & Cluster Counts

Sefusatti, Vale, Kadota, Frieman 2007

- Cluster count prediction assumes Gaussian primordial perturbations:

$$n_{PS}(M)dM = -\frac{2\bar{\rho}}{M^2}\frac{\delta_c}{\sigma_M}\frac{d\ln\sigma_M}{d\ln M}P_G(\delta_c/\sigma_M)dM$$

- Non-Gaussian tails can have large impact on cluster mass function
- Gaussianity predicted by *simplest* inflation models, but direct observational constraints on non-Gaussianity are weak
- Will primordial NG degrade cluster cosmology constraints?
- Adopt a simple class of non-Gaussian models and explore the consequences:

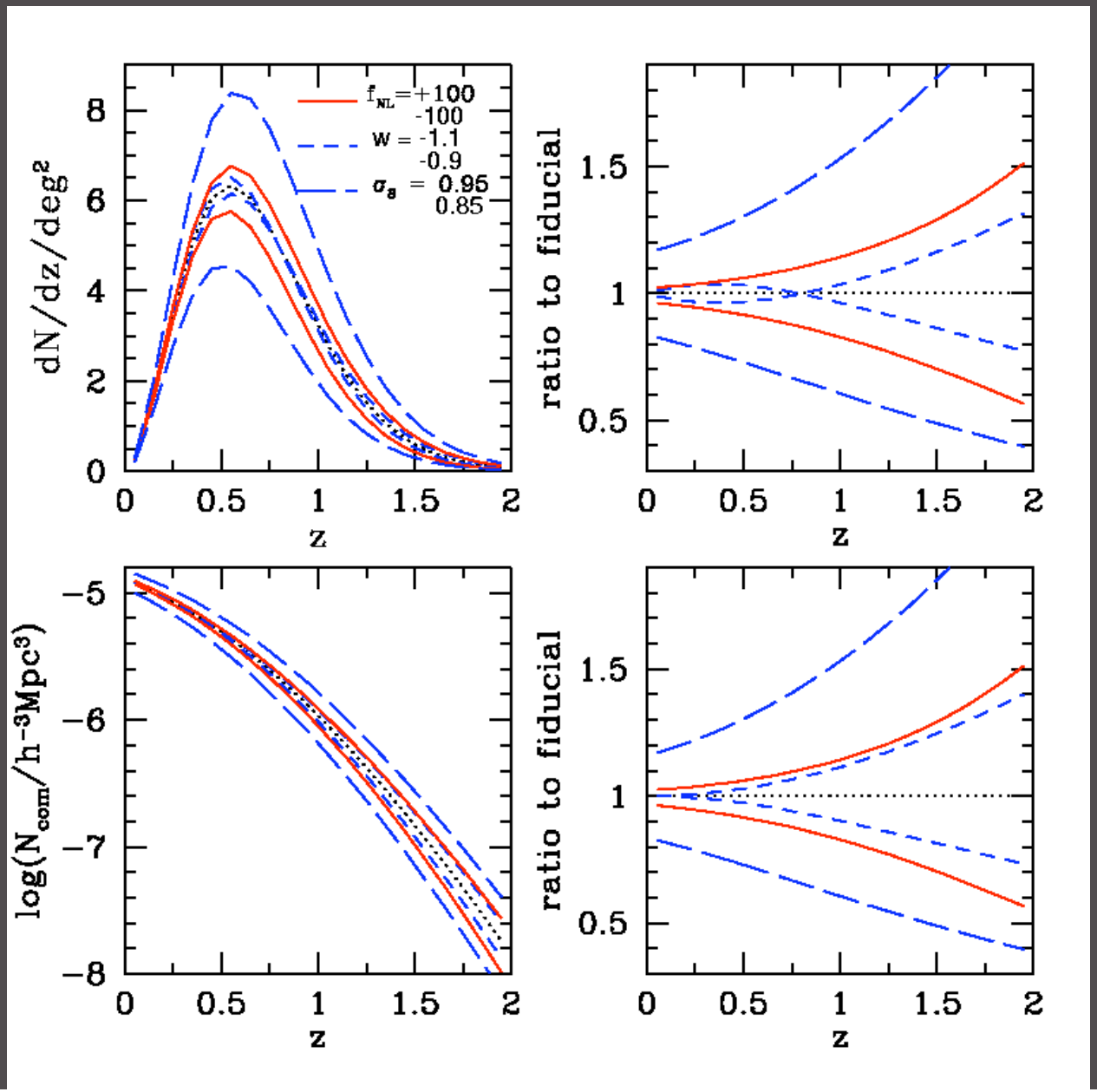
Gravitational potential: $\Phi = \phi + f_{NL}\left(\phi^2 - \left\langle \phi^2 \right\rangle\right)$ Gaussian field

Non-Gaussianity parameter: from WMAP, $-27 < f_{NL} < 121$ at 2σ

Cluster Counts above Mass Threshold

Impact of Non-Gaussianity, Dark Energy, Power spectrum amplitude

on Cluster counts

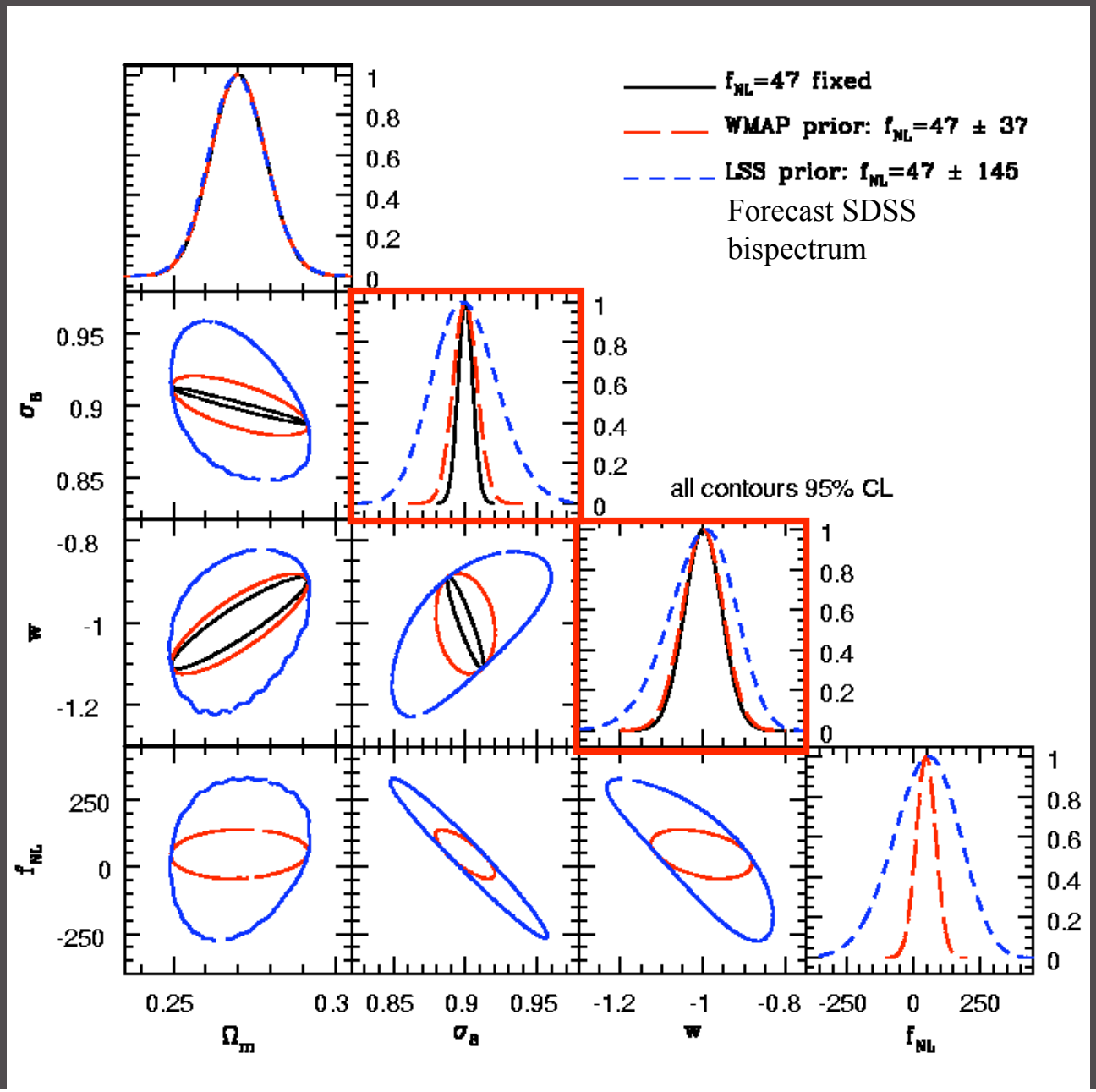


Cosmology Constraints w/ Non-Gaussianity

Idealized DES+SPT Forecast

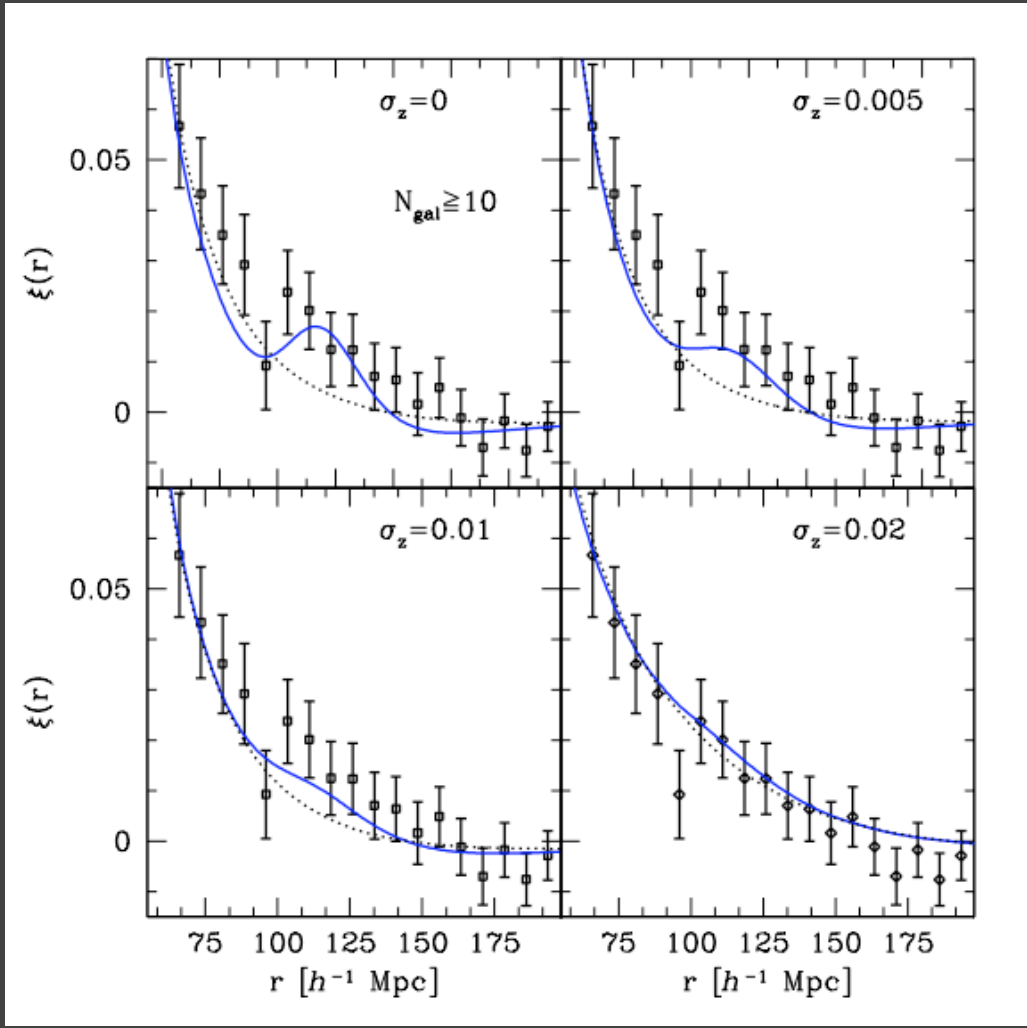
Not using shape of Cluster Mass function

No CMB Priors on Ω_m or σ_8



SDSS Cluster Correlations and BAO

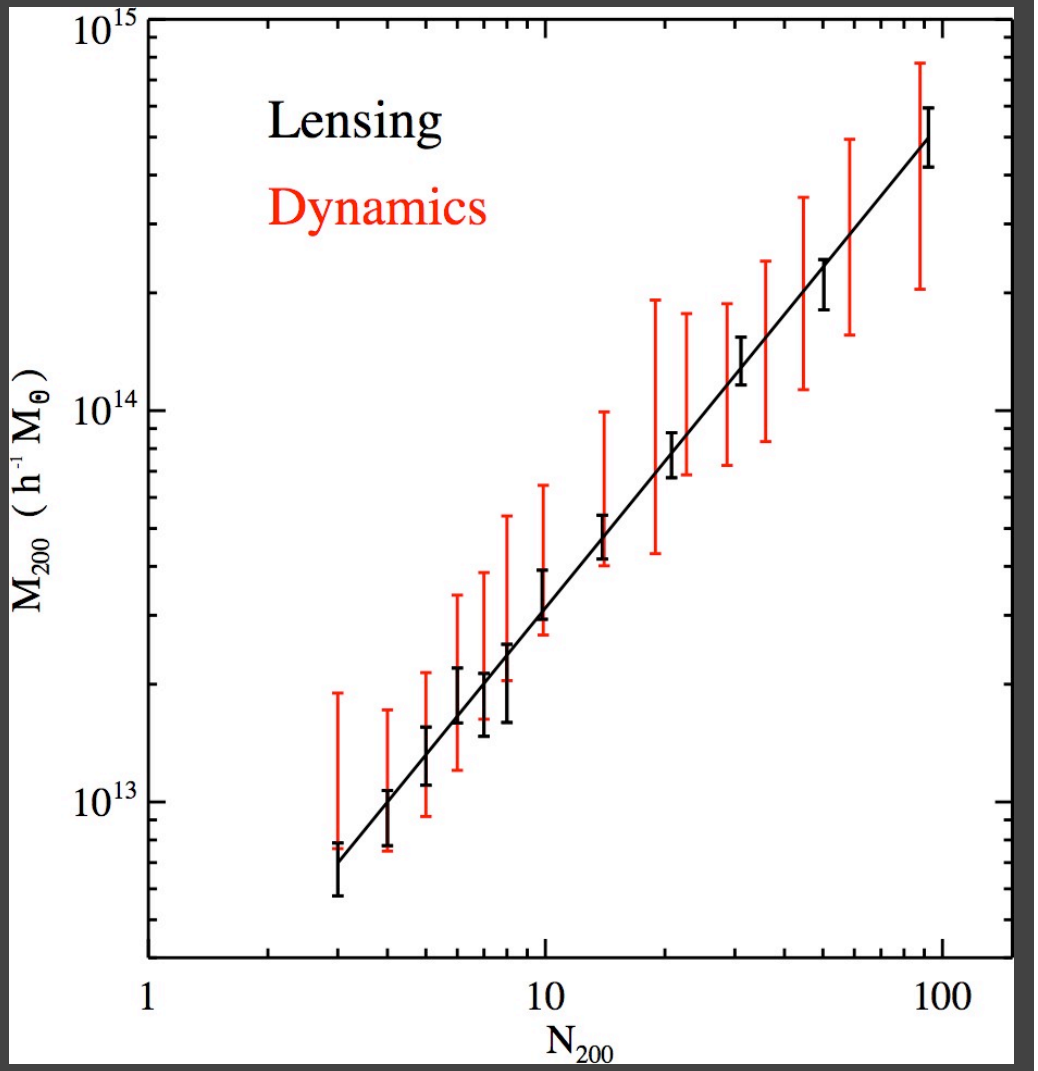
- Two-point correlation function of 12,000 clusters with photometric redshifts
- Predictions sensitive to photo-z errors



Estrada, **Sefusatti**, etal 2007

Cluster Mass-Observable Relation

- SDSS Weak Lensing by stacked Clusters
- insensitive to projection effects
- Calibrate mass-SZ decrement for SPT using DES



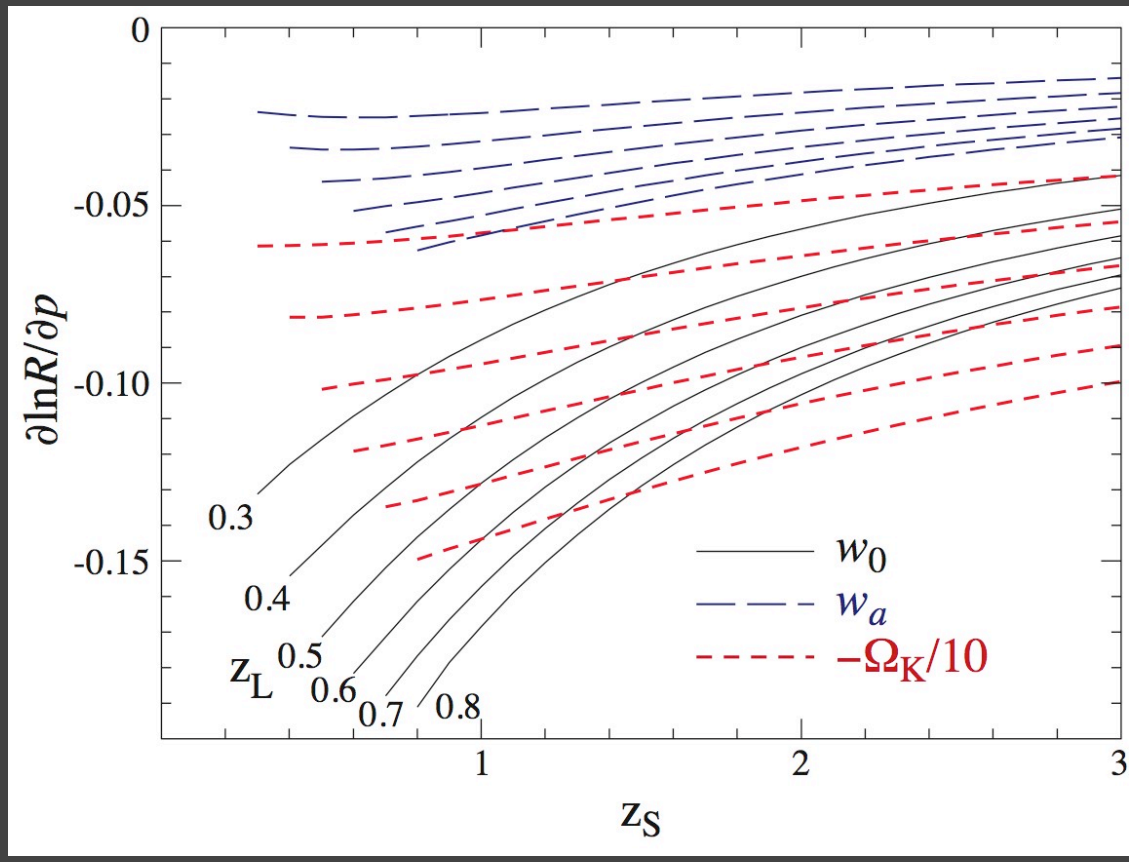
Johnston, Sheldon, Wechsler, Rozo, Koester, **Frieman**, etal 07

CMB Cluster Lensing

- Lensing of galaxies vs. CMB:

$$R(z_L, z_s) = \frac{\kappa(\theta, z_L, z_s)}{\kappa(\theta, z_L, z_*)} = \frac{D_{LS} D_*}{D_{L*} D_S}$$

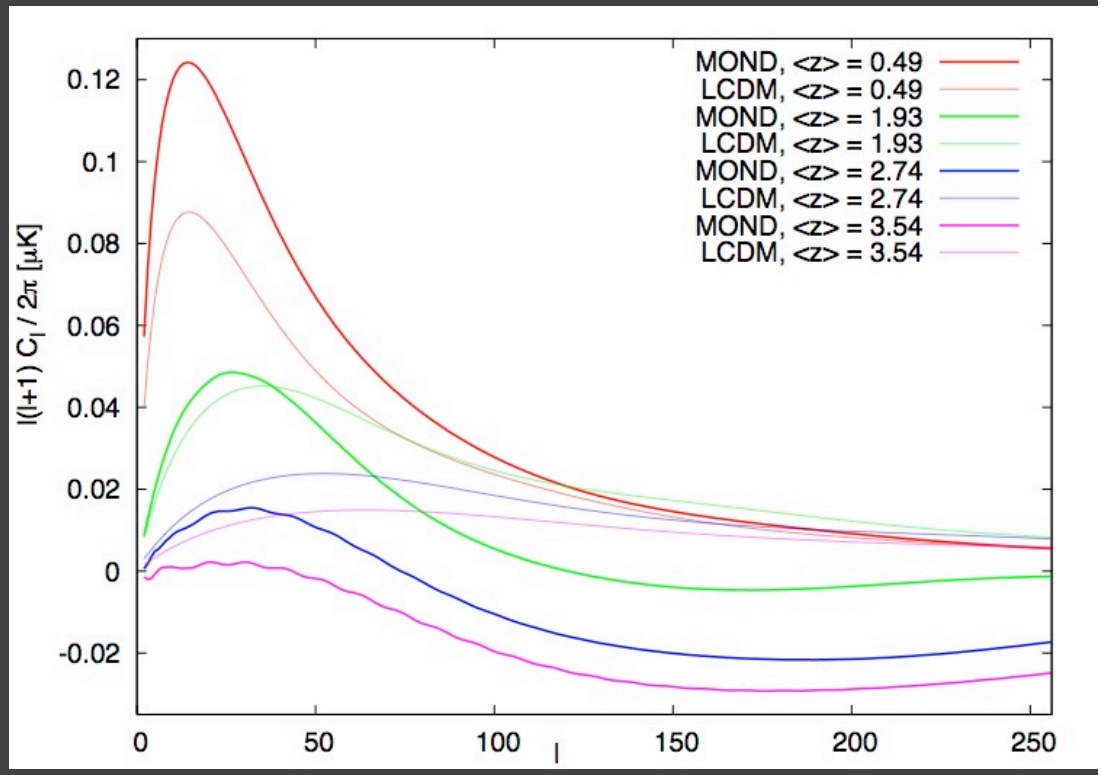
- D_* measured by CMB acoustic peaks
- 1% measurement of R yields 6% measurement of w_0
- DES+SPT



Hu, Holz, **Vale** 2007, Hu, DeDeo, **Vale** 2007

Testing Modified Gravity

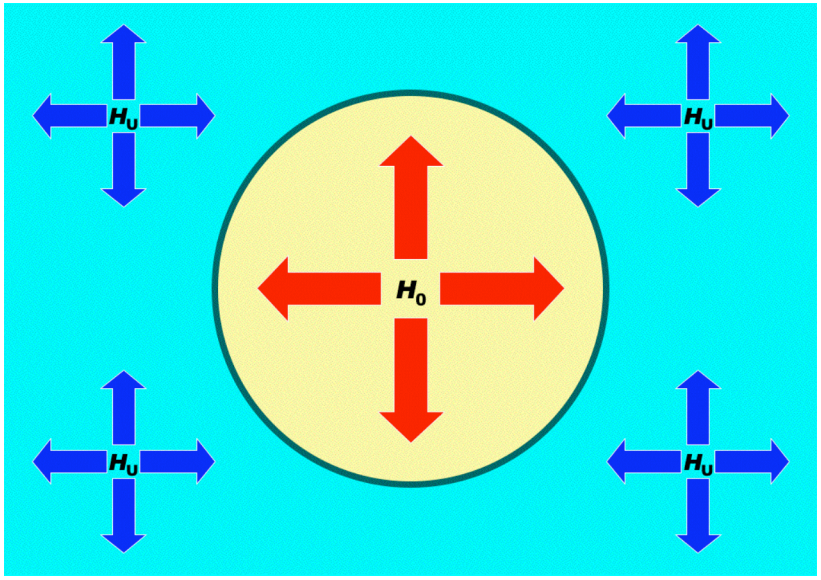
- Galaxy-CMB correlations due to ISW: LCDM vs. TeVeS



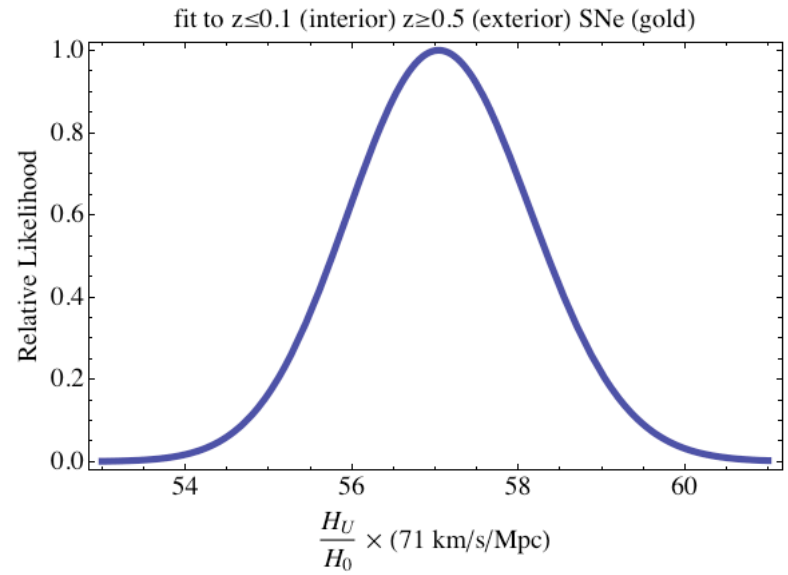
Schmidt, Liguori, **Dodelson** 2007

Could a Very Large Void Be Mimicking Dark Energy?

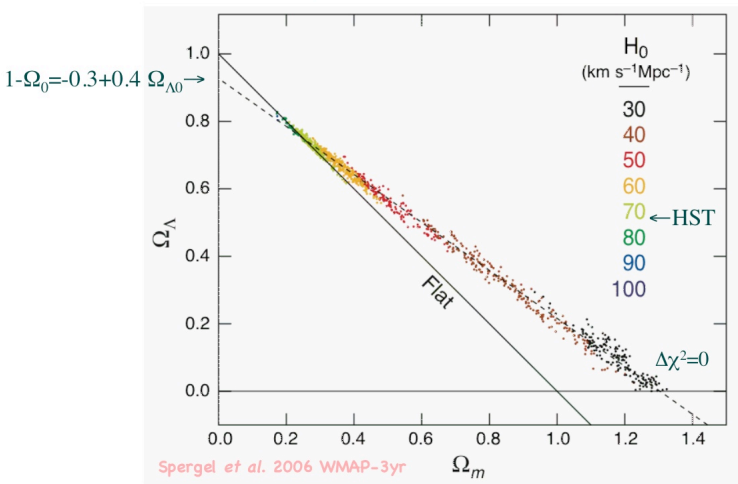
(Hubble parameter smaller at distances > 1 Gpc?)



Can fit SNe-Ia data!

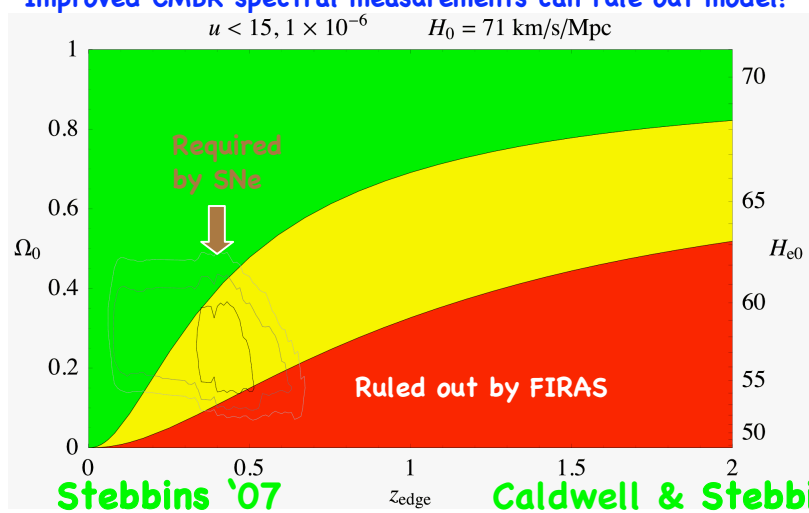


We don't know universal Hubble parameter!



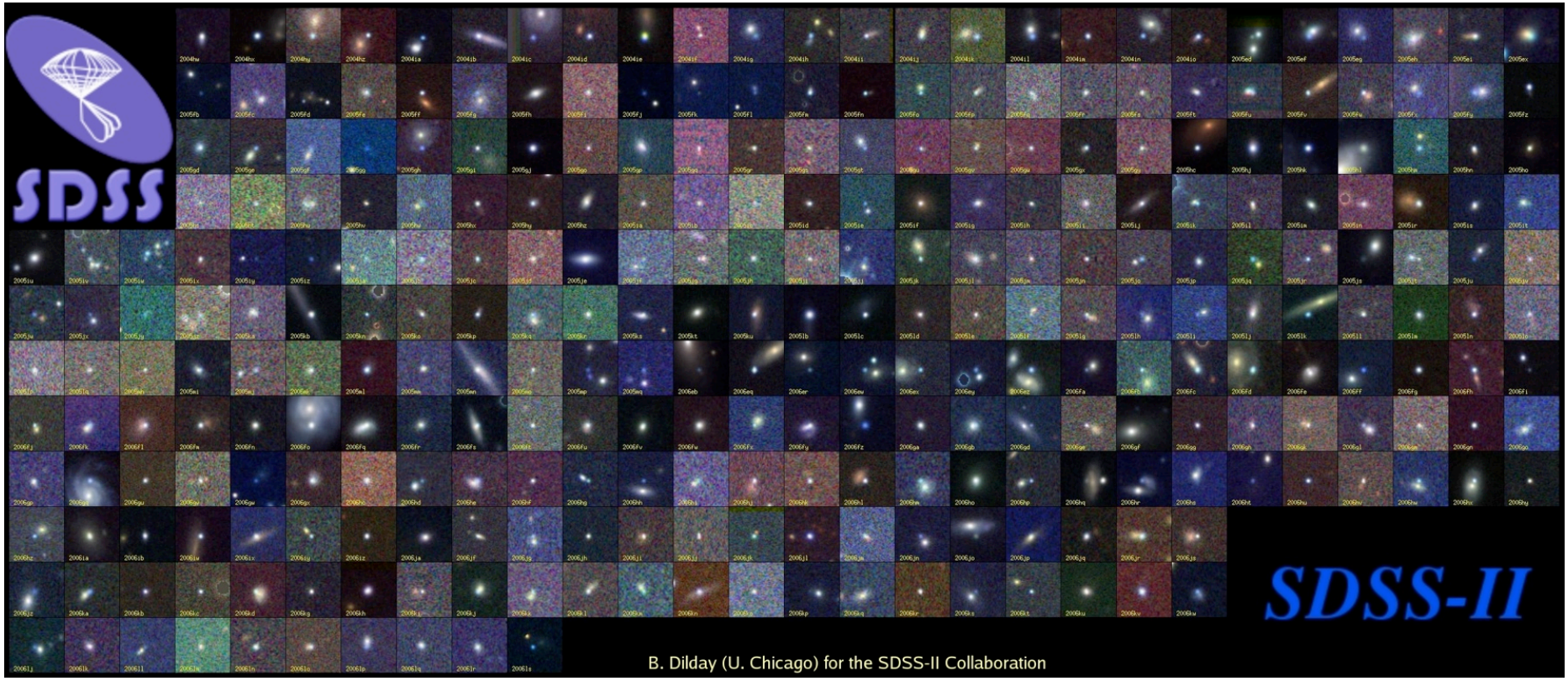
Large structures distort CMBR spectrum.

Improved CMBR spectral measurements can rule out model!



Stebbins '07 **Caldwell & Stebbins '07**

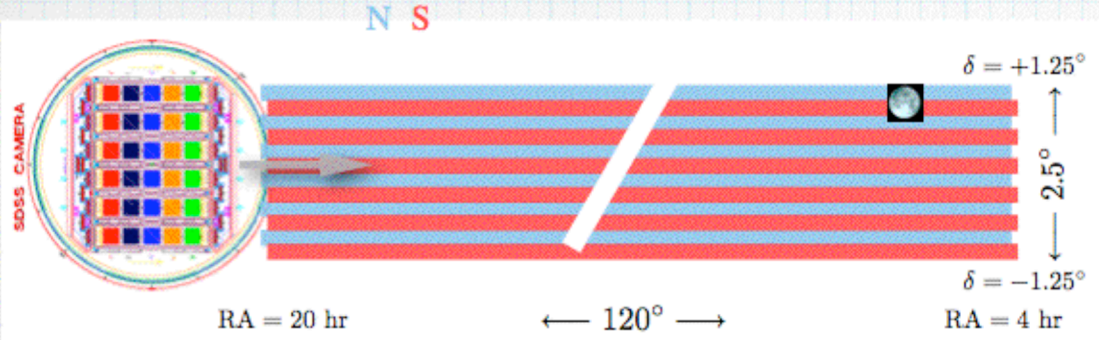
SDSS-II Supernova Survey: The First Two Seasons

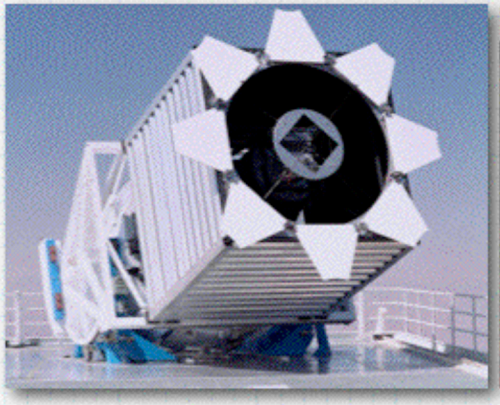


327 spectroscopically confirmed SNe Ia +93 host z, 14 SN Ib/c, 30 SN II

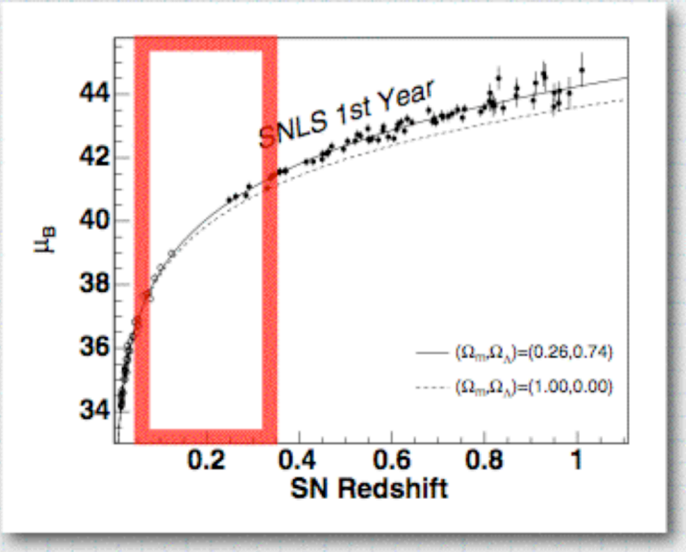
As seen in: National Geographic, 2 Japanese magazines, 1 Chemistry textbook

SDSS-II Survey Strategy





- 280 deg^2 every 2 days during Sept 1 - Nov 30 of 2005/6/7.
- multi-band light curves of SN Ia at $0.05 < z < 0.35$



- On-mountain 24 hr processing
- SN candidates released immediately to public.
- real-time photometric typing.
- spectroscopic follow-up.

http://sdssdp47.fnal.gov/sdsssn/sdsssn.html

SNLS (Astier et al. 2006)

SDSS-II SN Team

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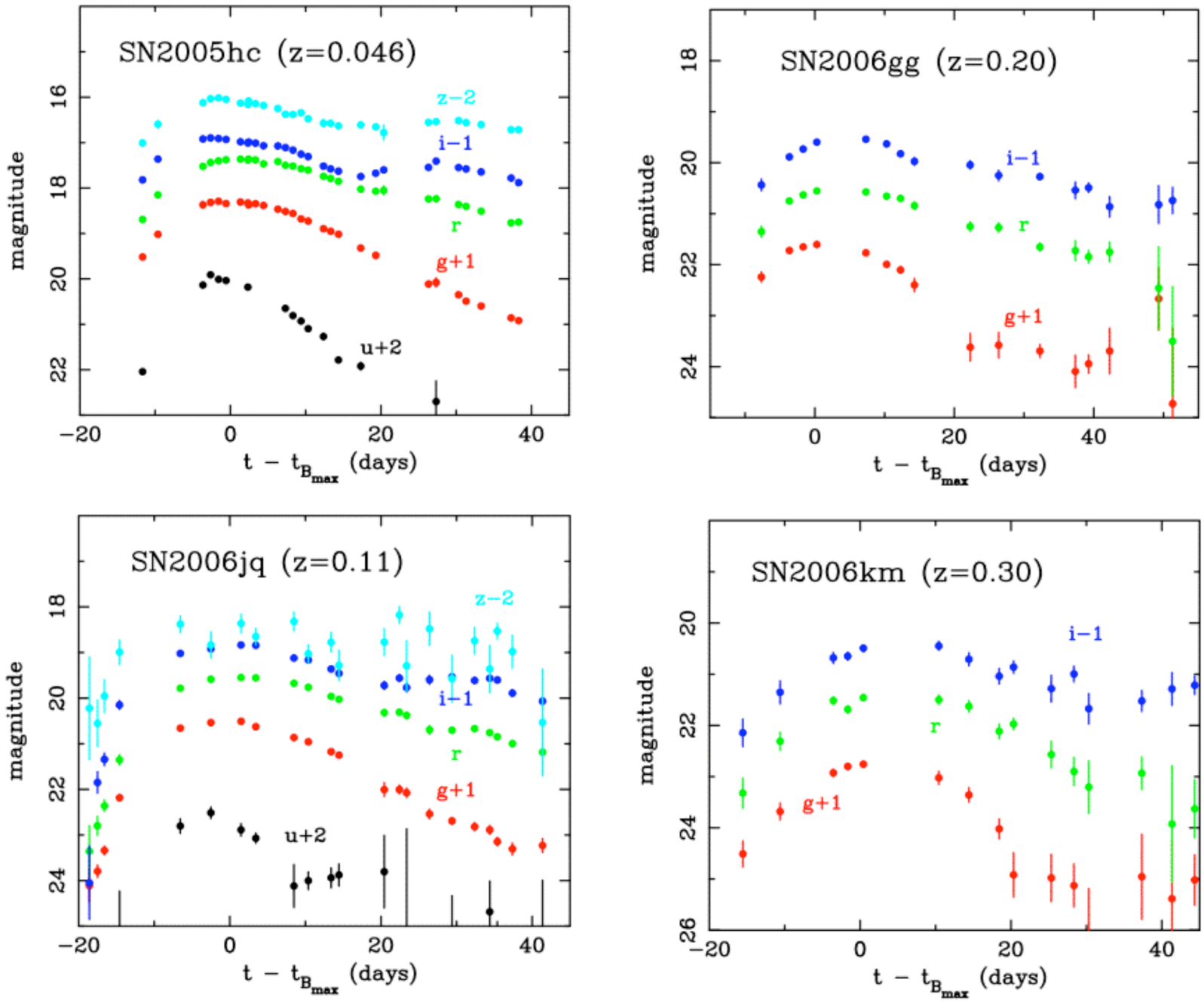
Keck team	R. Foley, A. Filippenko

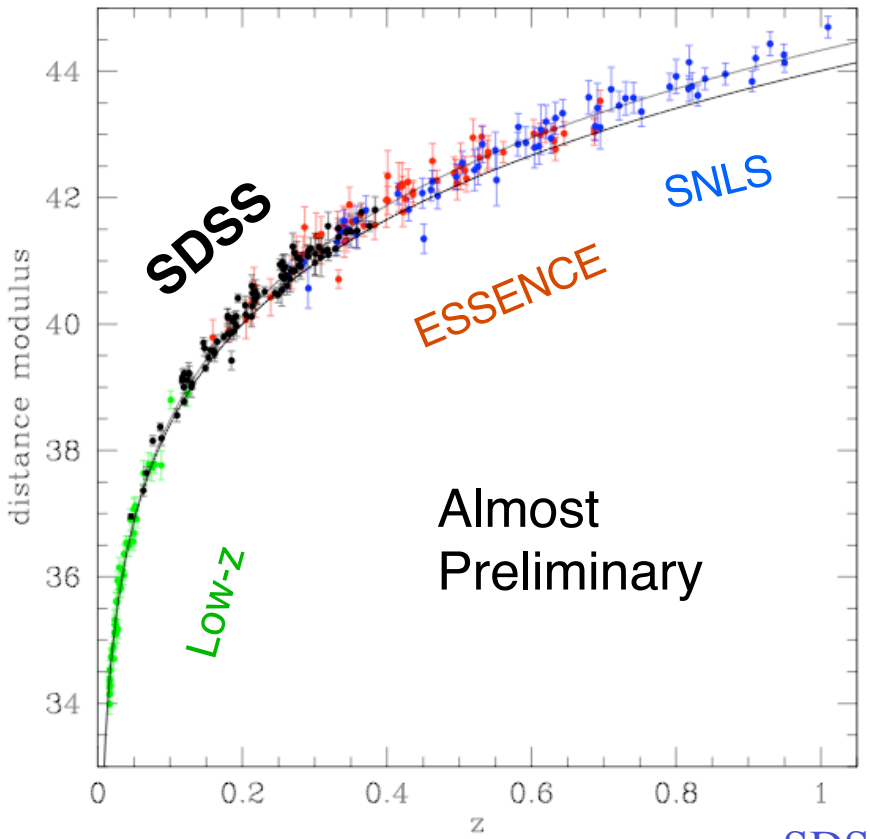
Spectroscopic follow-up telescopes

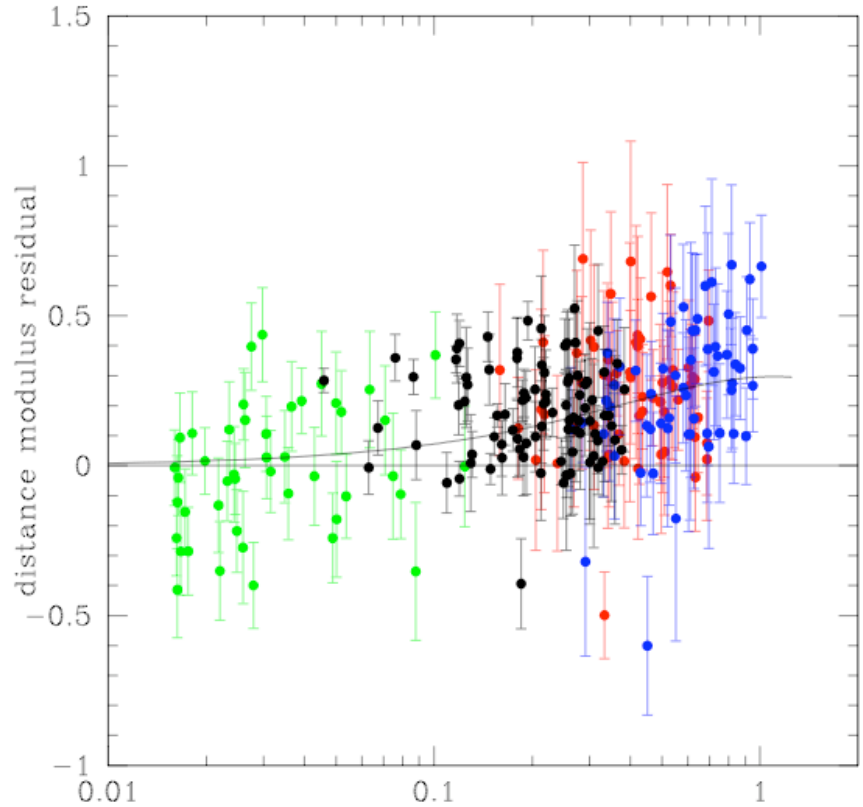
Spectroscopic follow-up



SDSS SN Photometry: Holtzman et al. (2007), to appear

Hubble Diagram





- SDSS 2005 Data
  - 130 SNe Ia
  - ~89 after cuts
  - Kessler, Miknaitis et al (2007) to appear

SN Coherent Peculiar Velocities

Hui & Greene; Caldwell & Cooray

Physically, $$cz_{obs} = cz_{\text{hom}} + \vec{v}_{pec} \bullet \vec{r}$$

Quantitatively, $$\tilde{C}_{ij} \equiv \langle \delta m_i \delta m_j \rangle = \delta_{ij} \frac{(\sigma^{\text{intr.}})^2 + (\sigma_i^{\text{Poiss.}})^2}{N_i} + C_{ij}$$

where

$$C_{ij}^{\text{vel.}} \equiv \left[\frac{5}{\ln 10}\right]^2 \left[1 - \frac{a_i}{a_i' \chi_i}\right] \left[1 - \frac{a_j}{a_j' \chi_j}\right] D_i' D_j' \int \frac{d^3k}{(2\pi)^3} \frac{k_z^2}{k^4} P(k, a=1) W_{ij}^{\text{vel.}}(\mathbf{k})$$

$$W_{ij}^{\text{vel.}}(\mathbf{k}) \equiv \int \frac{d^3x d^3x'}{V_i V_j} e^{-i\mathbf{k}\cdot(\mathbf{x}-\mathbf{x}')}$$

$$= \cos\left[k_z(\chi_i - \chi_j)\right] \left[\frac{2}{k_z \Delta\chi_i} \sin \frac{k_z \Delta\chi_i}{2}\right] \left[\frac{2}{k_z \Delta\chi_j} \sin \frac{k_z \Delta\chi_j}{2}\right] \frac{2J_1(k_\perp \chi_i \theta_i^{\text{max.}})}{k_\perp \chi_i \theta_i^{\text{max.}}} \frac{2J_1(k_\perp \chi_j \theta_j^{\text{max.}})}{k_\perp \chi_j \theta_j^{\text{max.}}}$$

More important for larger data sets

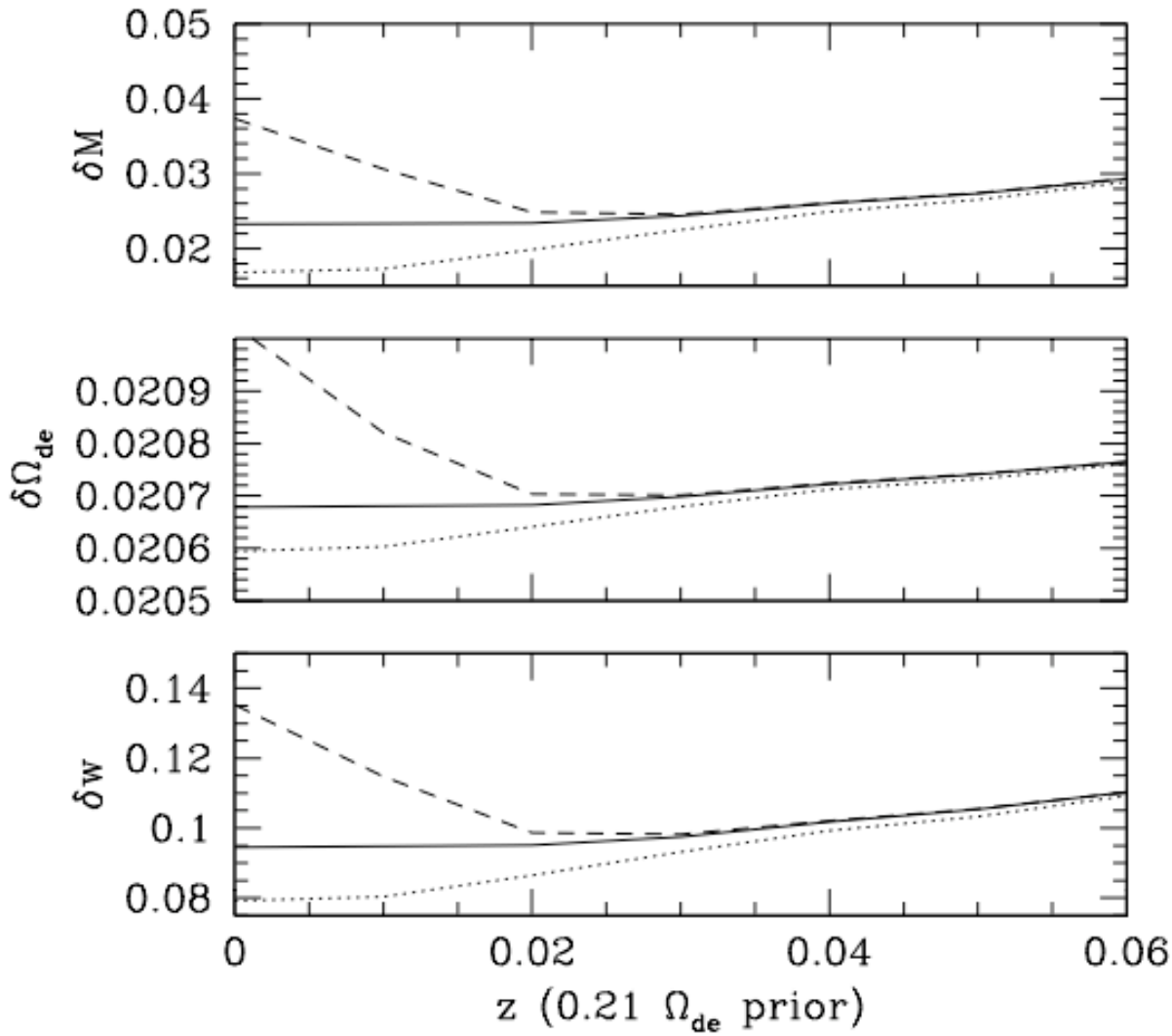
Mass power spectrum

for circular survey

SNe below this *z* are thrown out
(for ESSENCE & SNLS: z_{min}=0.015)

Ignoring coherent flows underestimates statistical errors; implement optimal weighting

Hui & **Frieman** 2008

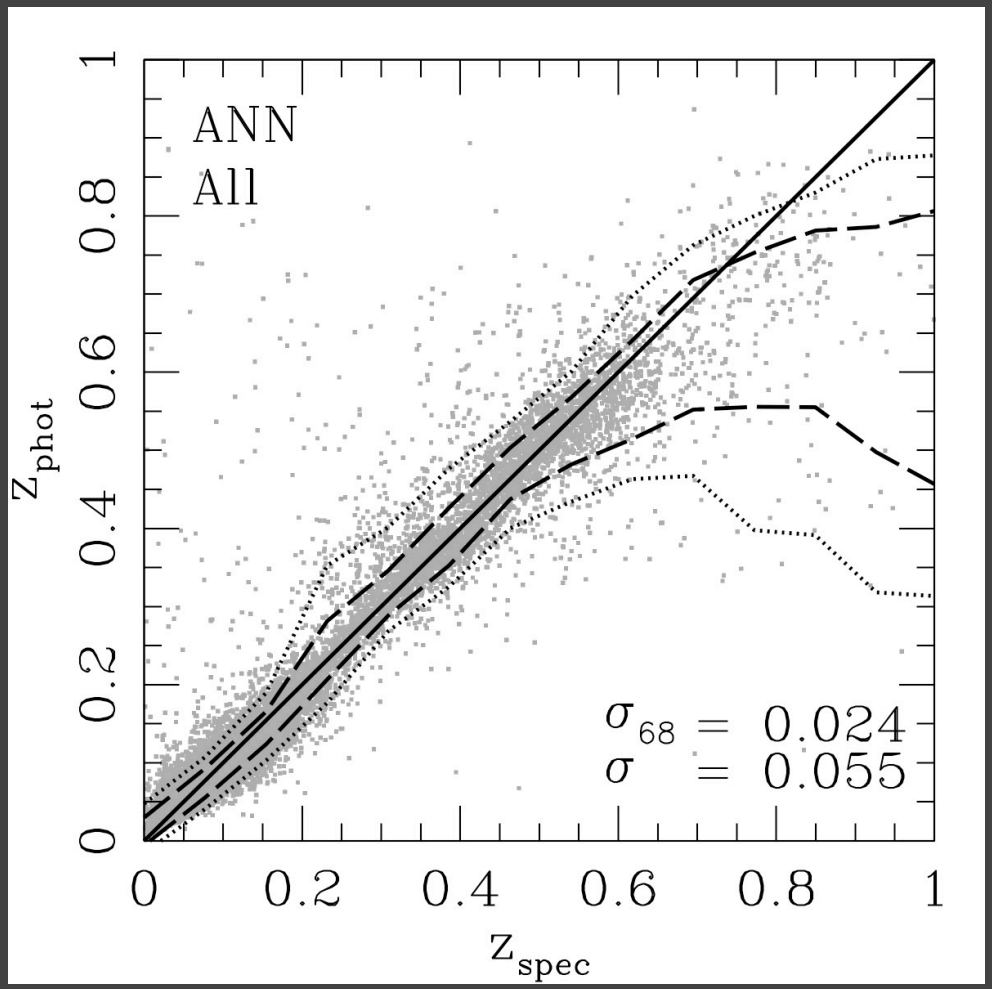


0.021 (BAOish)

Photometric Redshifts for Dark Energy Surveys

- Simulate photo-z's for DES & future surveys
- Optimize photo-z estimates
- Robust photo-z error estimates
- Explore methods that don't rely on individual galaxy photo-z estimates

Oyaizu, Lima, Cunha, Lin, **Frieman**, Sheldon 2007



Neural network photo-z's for SDSS