# Probing Dark Energy: Theoretical Uncertainties

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In collaboration with:
Scott Sullivan (UCI/UCLA), Shahab Joudaki (UCI), Alexandre Amblard (UCI),
Daniel Holz (Los Alamos), Asantha Cooray (UCI).

Long Beach, CA 213th AAS Meeting Jan 05, 2009

THE ASTRONOMICAL JOURNAL, 116:1009–1038, 1998 September


# OBSERVATIONAL EVIDENCE FROM SUPERNOVAE FOR AN ACCELERATING UNIVERSE AND A COSMOLOGICAL CONSTANT

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*Received 1998 March 13; revised 1998 May 6*


Illustration: John Kascht

THE ASTROPHYSICAL JOURNAL, 517:565–586, 1999 June 1


# MEASUREMENTS OF Ω AND Λ FROM 42 HIGH-REDSHIFT SUPERNOVAE

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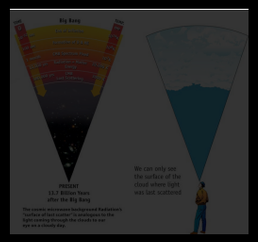
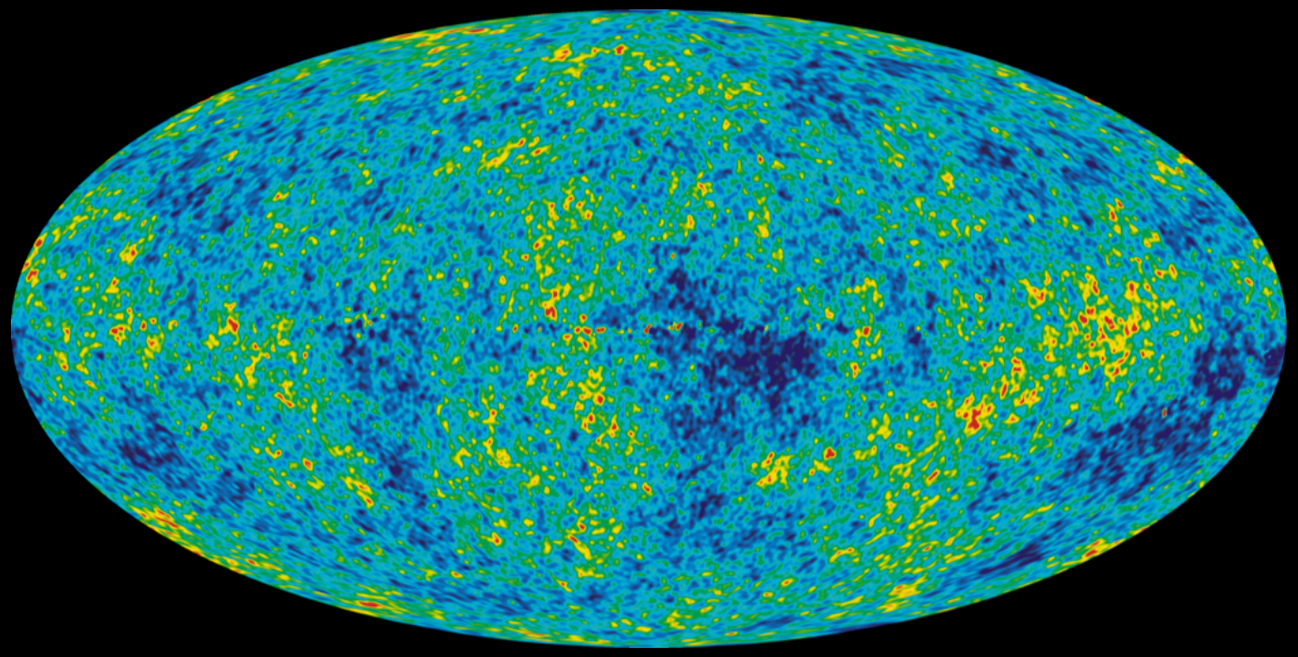
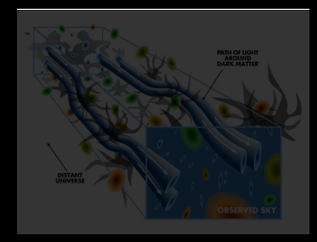
(THE SUPERNOVA COSMOLOGY PROJECT)

*Received 1998 September 8; accepted 1998 December 17*

# Probing Dark Energy





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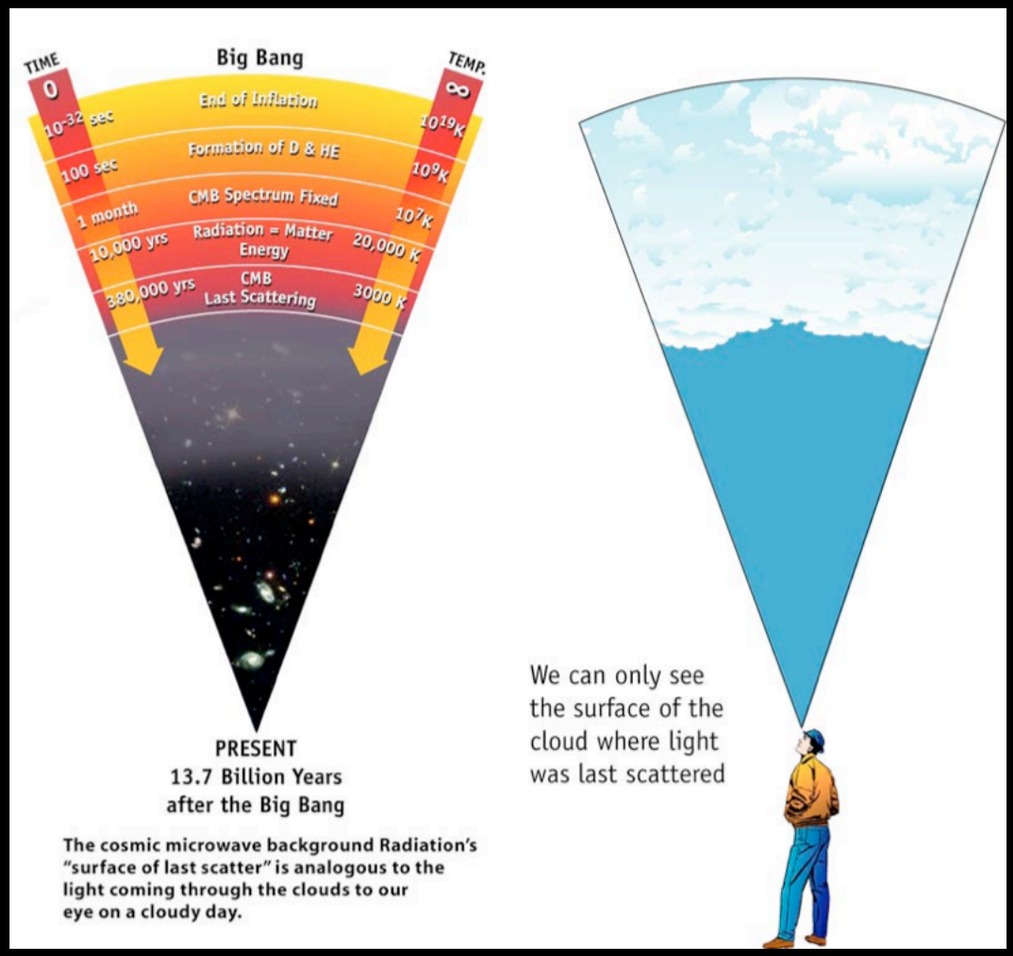
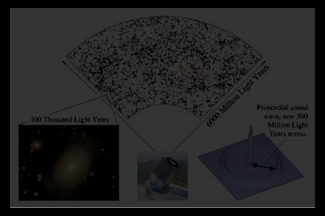
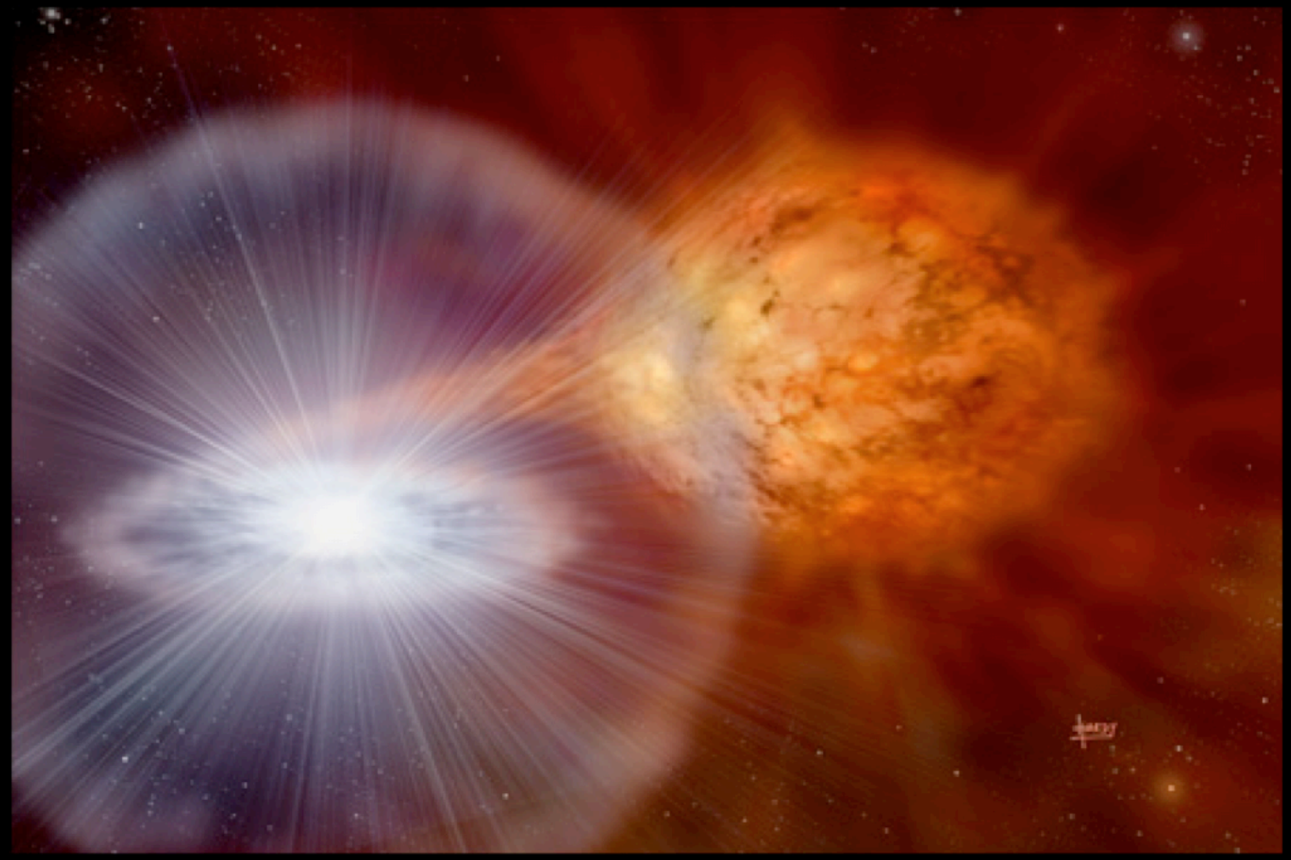
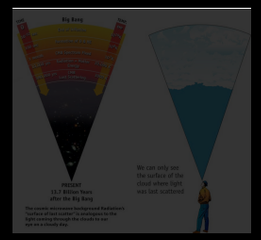



The cosmic microwave background Radiation's "surface of last scatter" is analogous to the light coming through the clouds to our eye on a cloudy day.

# Probing Dark Energy





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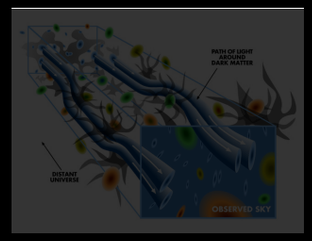


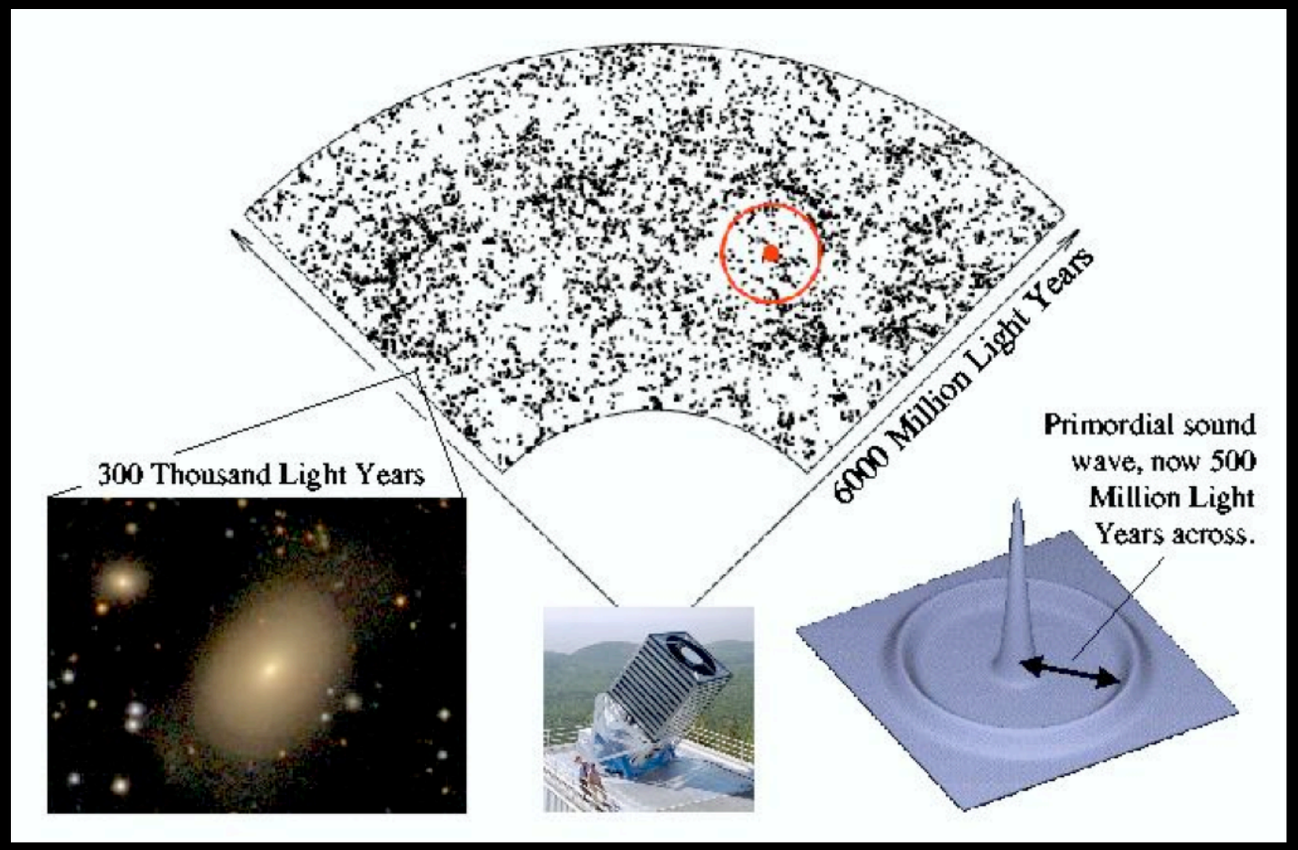


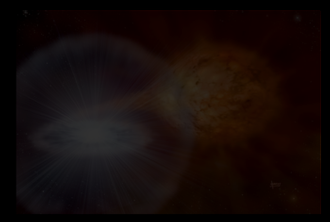

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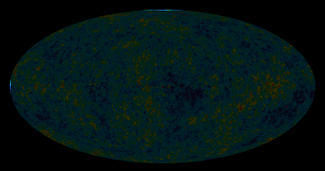
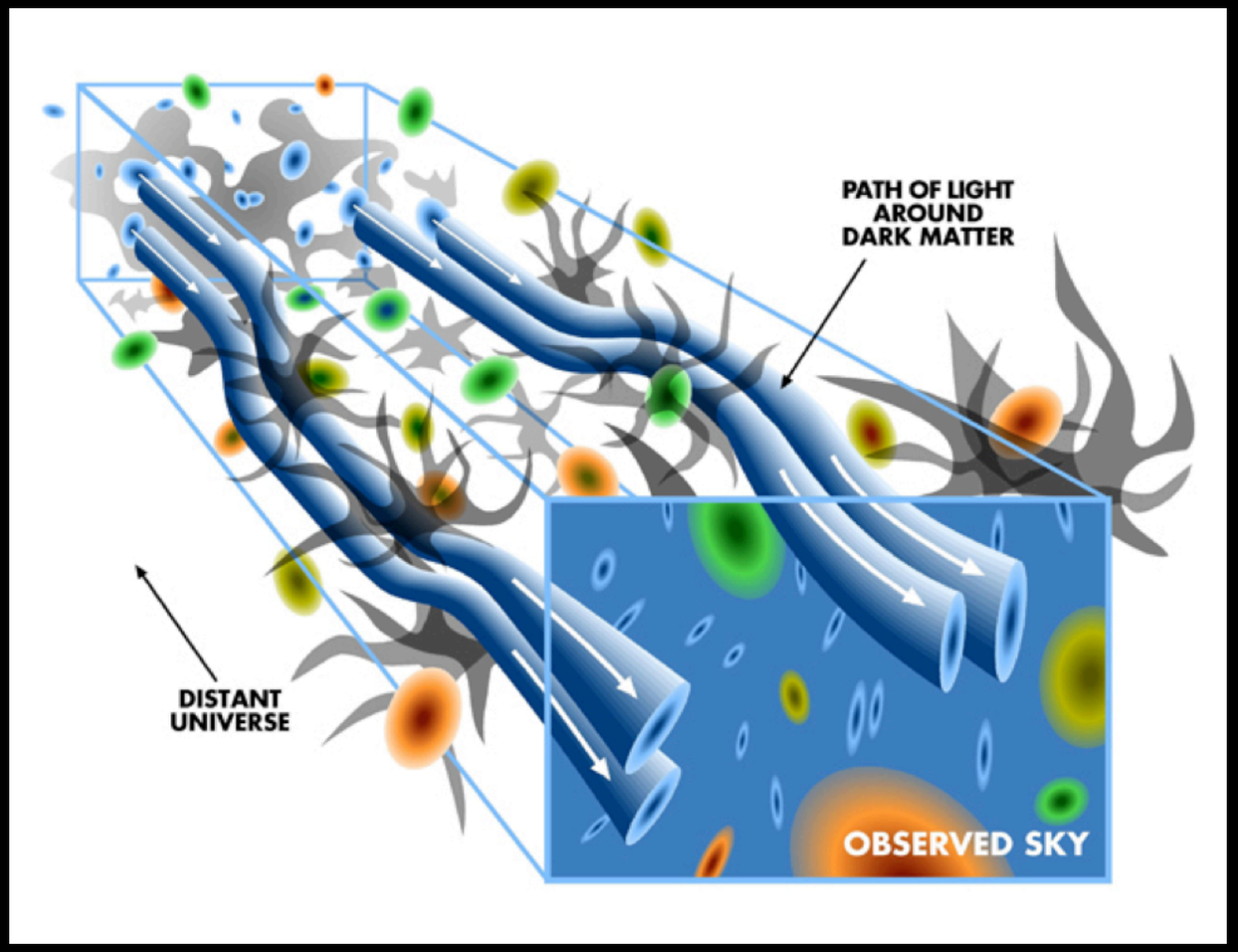
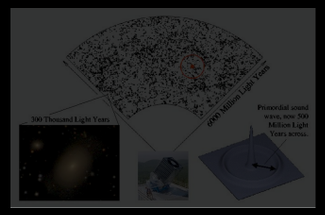
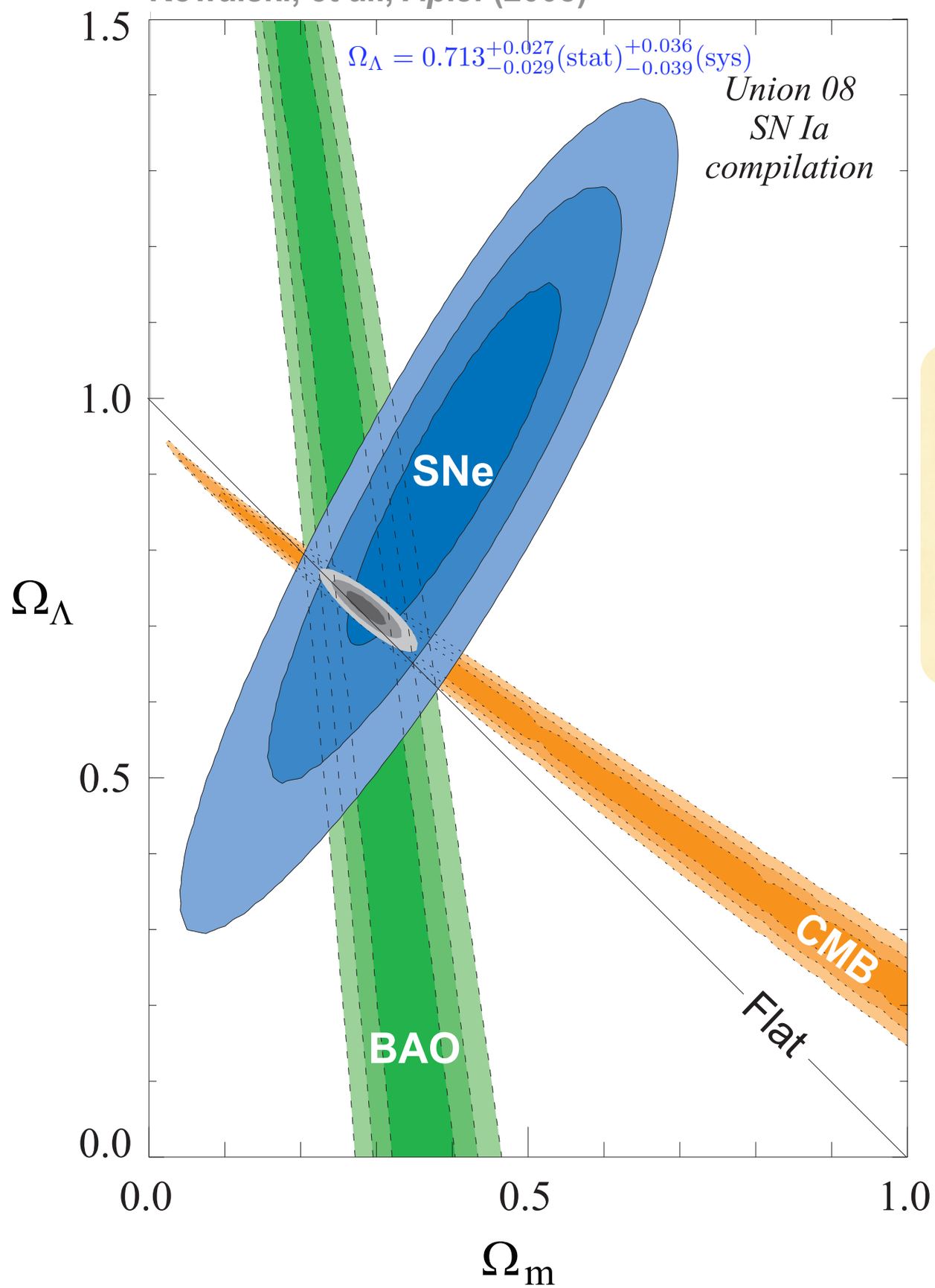
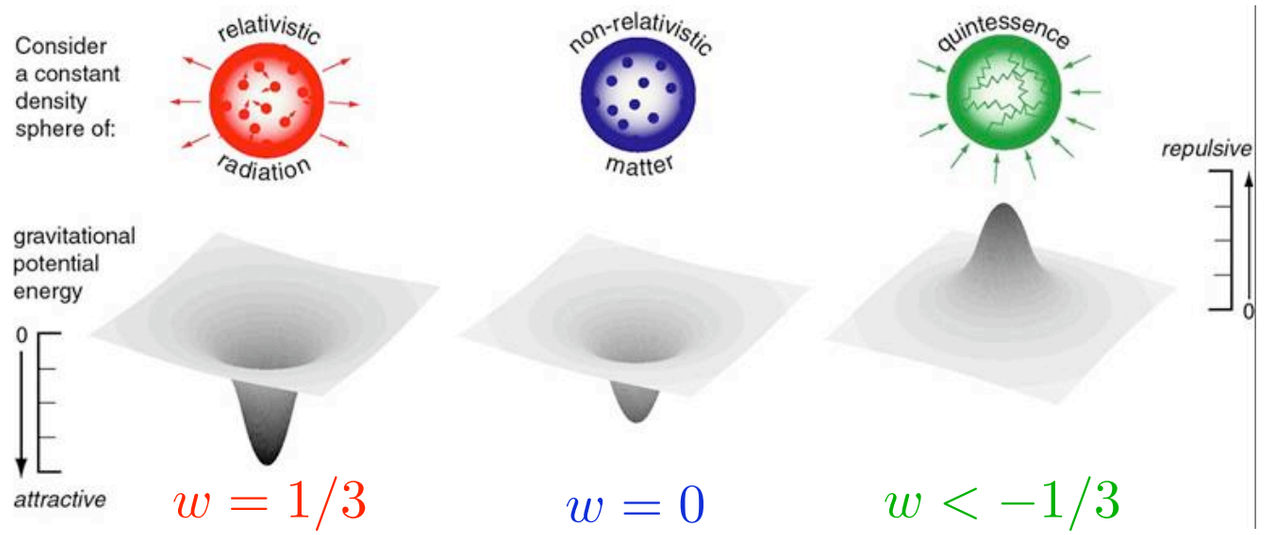




Supernova Cosmology Project
Kowalski, et al., *Ap.J.* (2008)

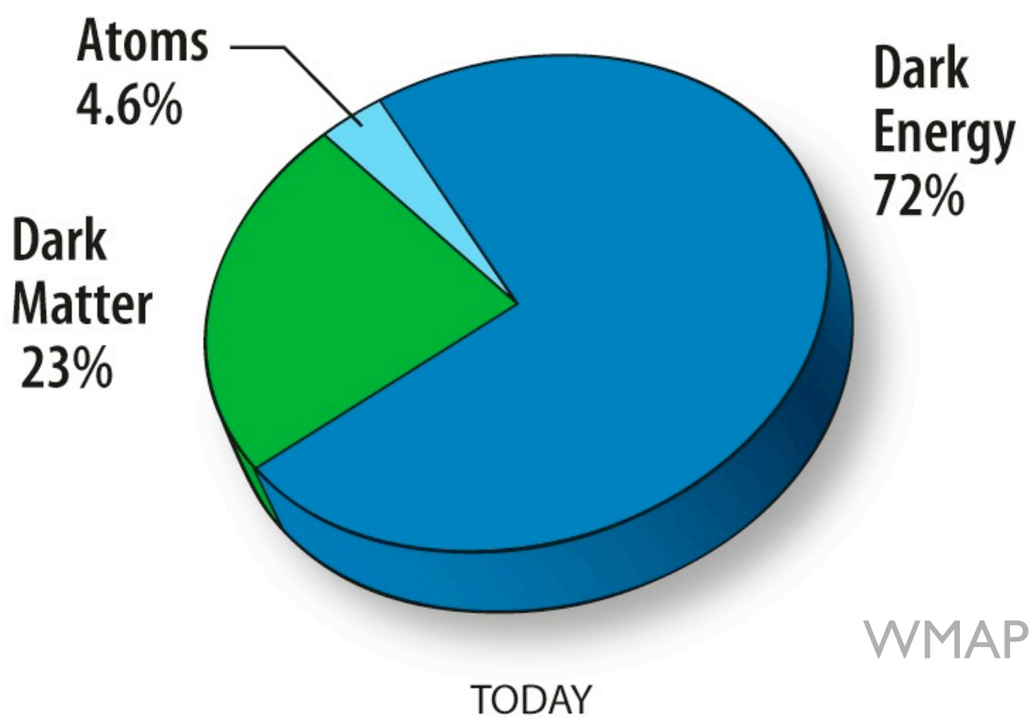



$$w = -0.969^{+0.059}_{-0.063}(\mathrm{stat})^{+0.063}_{-0.066}(\mathrm{sys})\ [\mathrm{Union}]$$

$$w = -\mathrm{x.xxx}^{+0.077}_{-0.077}(\mathrm{stat})^{+0.071}_{-0.071}(\mathrm{sys})\ [\mathrm{SNLS}]$$

(Guy, Conley: Talk at TEXAS 2008 on Dec 09, 2008)



# Running After w(z): The Stumbling Blocks

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# Agenda

## w(z): To Bin or Not To Bin

## Supernovae

### Systematics I

- Lensing of SNe
- P($\mu$)
- Bias on the EOS
- (Not) To Worry About?

### Systematics II

- Two Populations of SN
- Leaking into H.D.
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- Increased Error?

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# Seeking Temporal Evolution of "w"

1. Parametrize w(z) [Adopted by DETF]

$$w(z) = w_0 + w_a z/(1+z)$$

Chevallier and Polarski 2001, Linder 2003

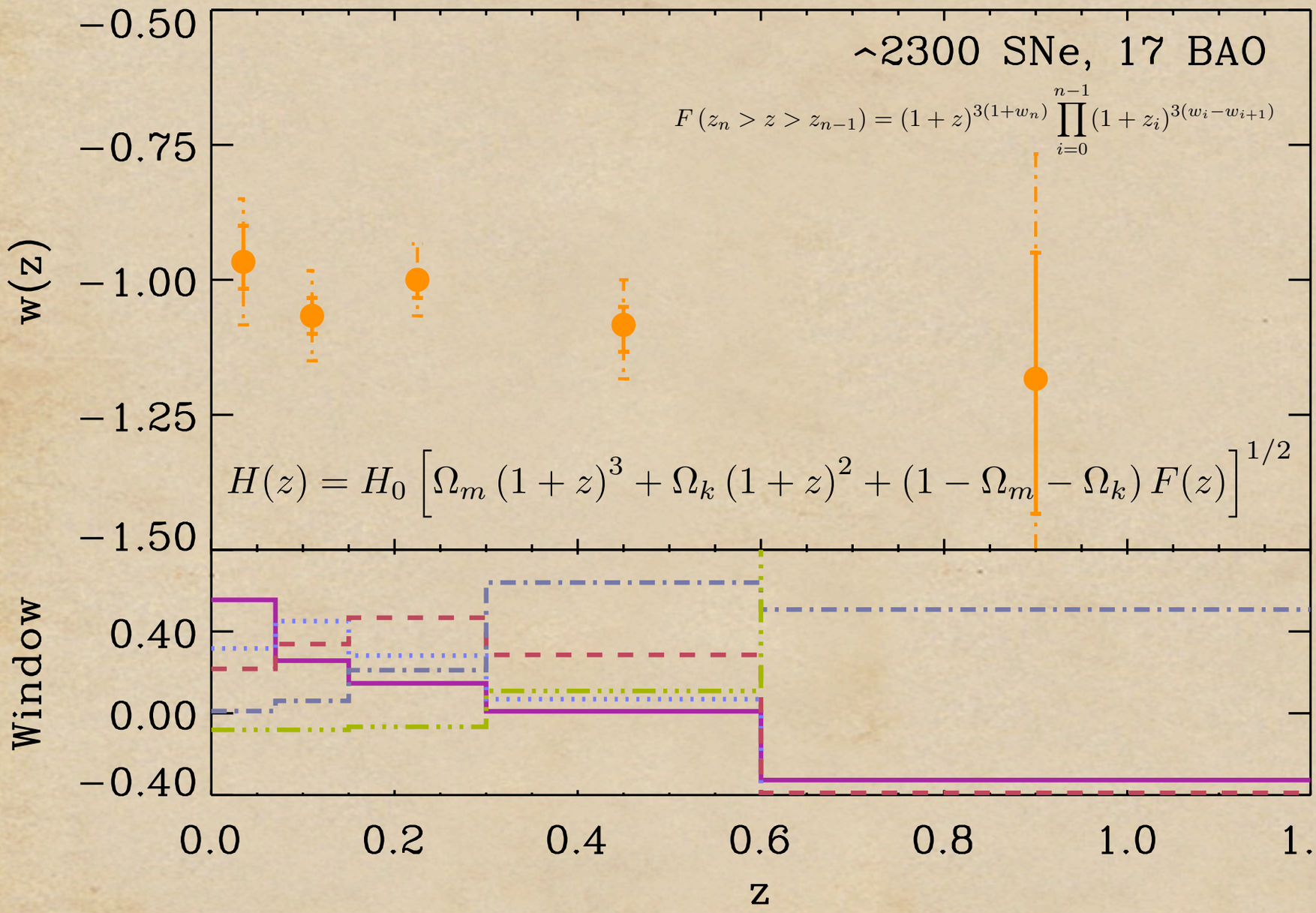
2. Principal Component Analysis

Huterer and Starkman 2003

3. Uncorrelated Estimates of w(z)

Huterer and Cooray 2005

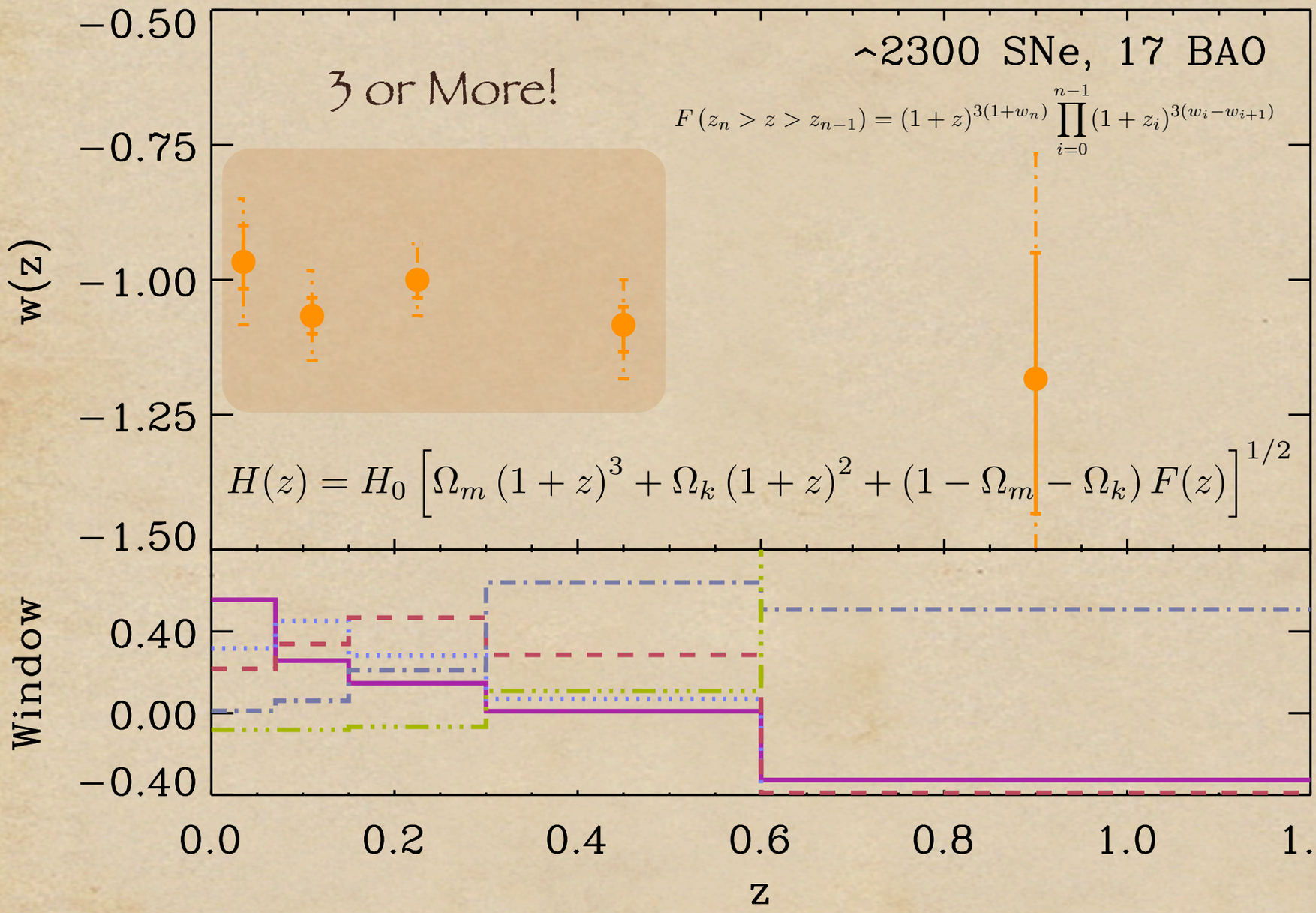
# Going Model-Independent: The Future!




| w | Zup |
|---|---|
| w1 | 0.07 |
| w2 | 0.15 |
| w3 | 0.3 |
| w4 | 0.6 |
| w5 | 1.2 |
| w6 | 1.8 |

D.S., S. Sullivan, S. Joudaki, A. Amblard, D. Holz, and A. Cooray, PRL 100, 241302 (2008)

# Going Model-Independent: The Future!

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# Influence of Gravitational Lensing?

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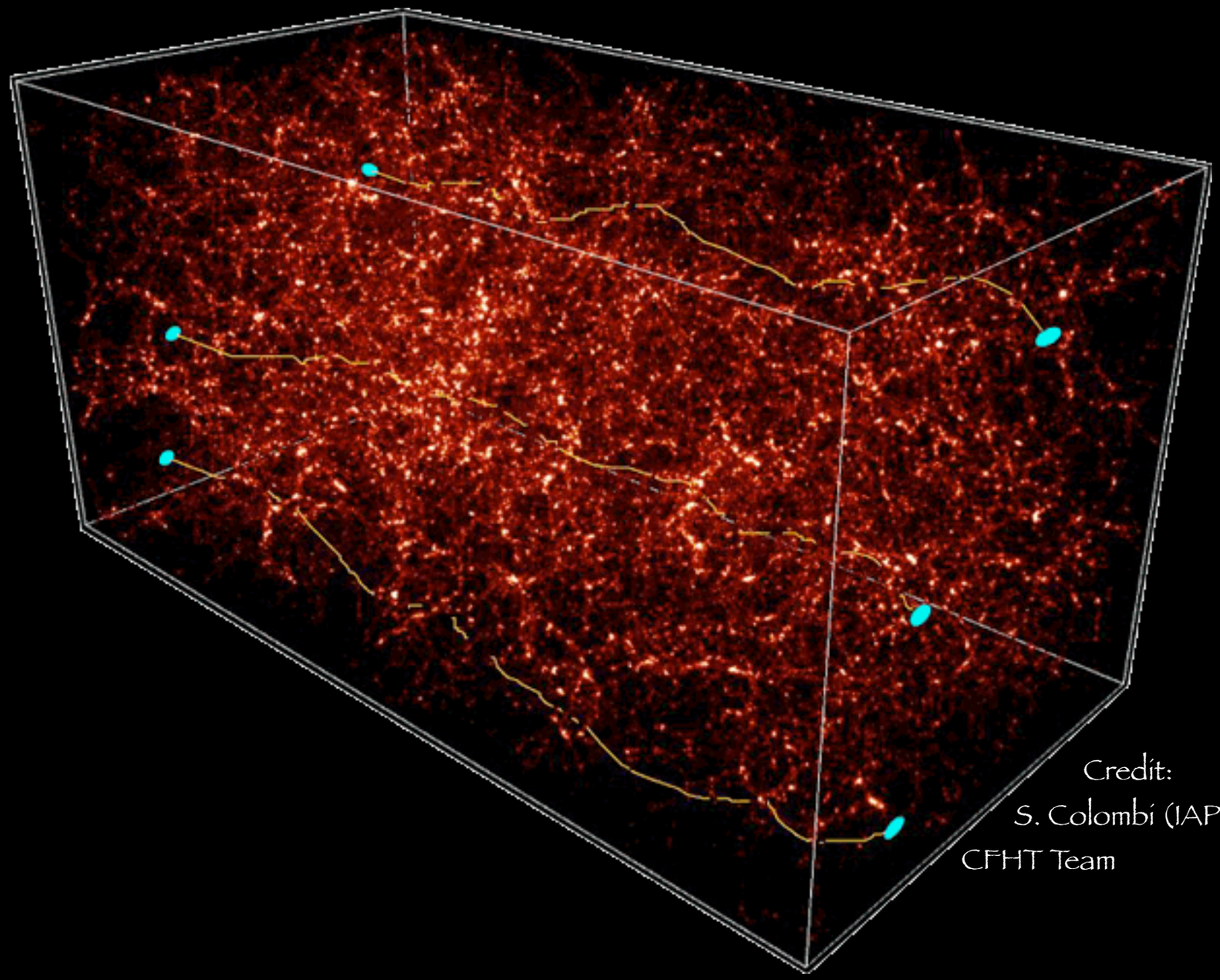
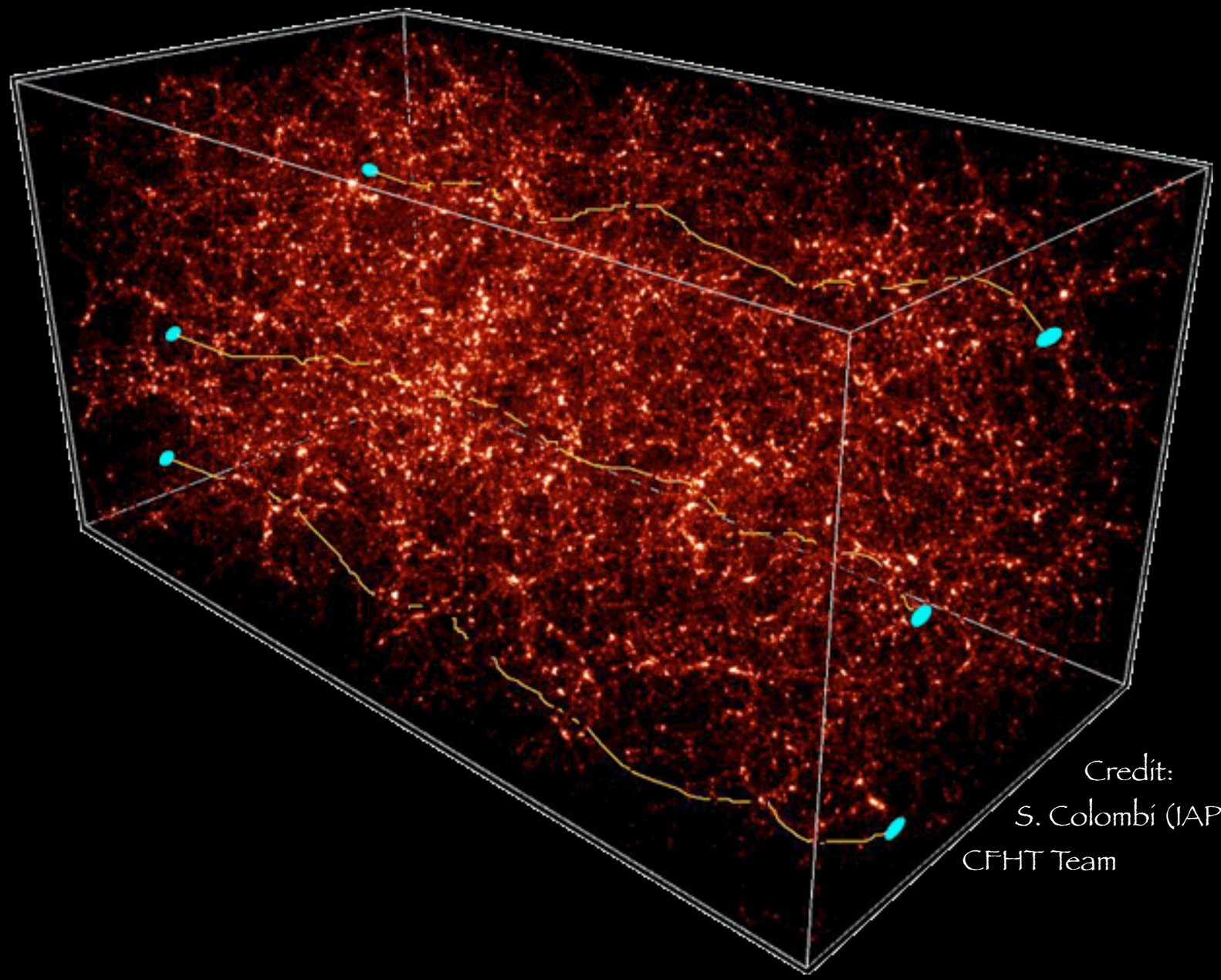


Credit:
S. Colombi (IAP),
CFHT Team

# Influence of Gravitational Lensing?



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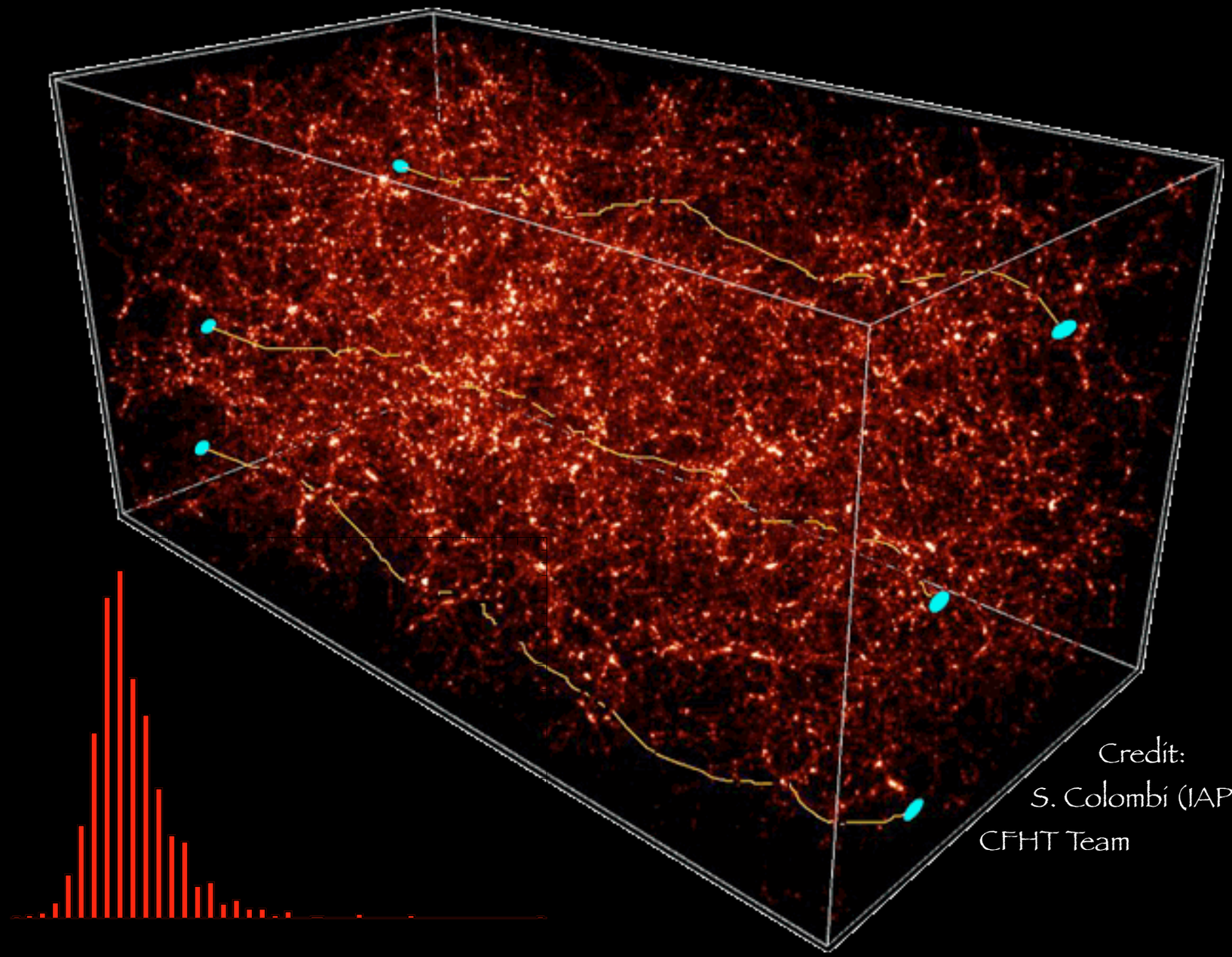
$$\mathcal{F}^{\mathrm{obs,lensed}}(z, \hat{\mathbf{n}}) = \mu(z, \hat{\mathbf{n}}) \mathcal{F}^{\mathrm{obs,true}}(z)$$

# Influence of Gravitational Lensing?



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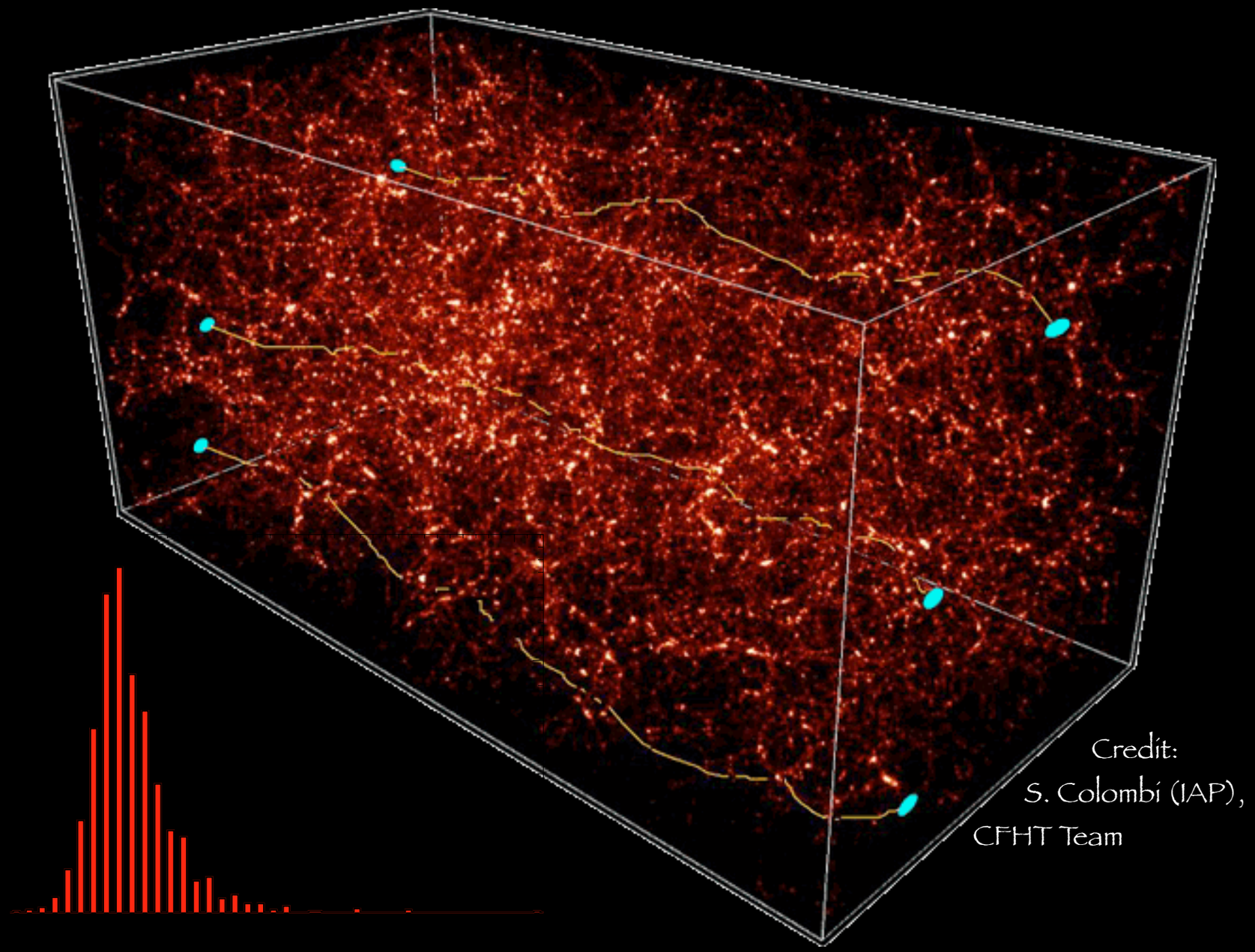
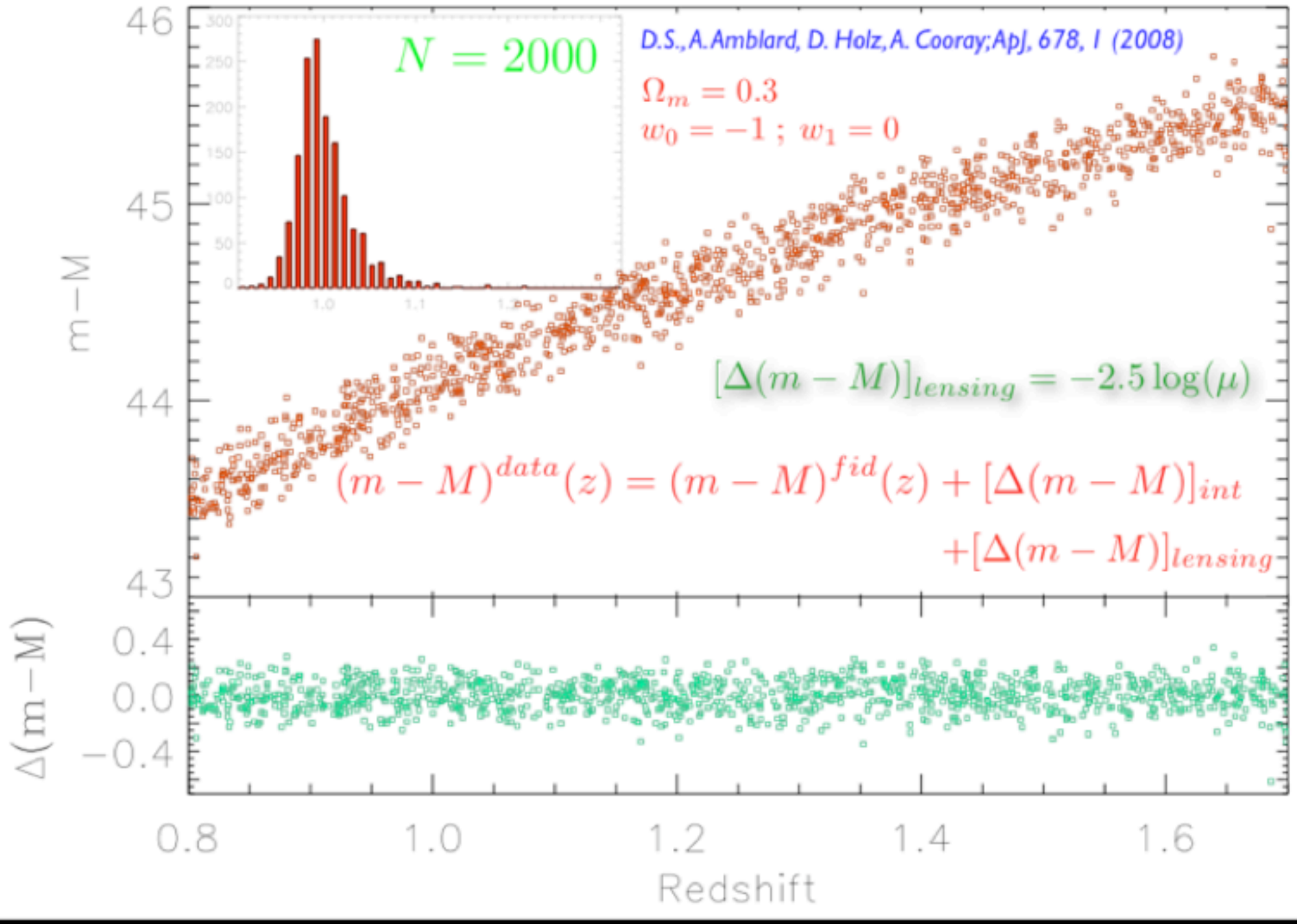


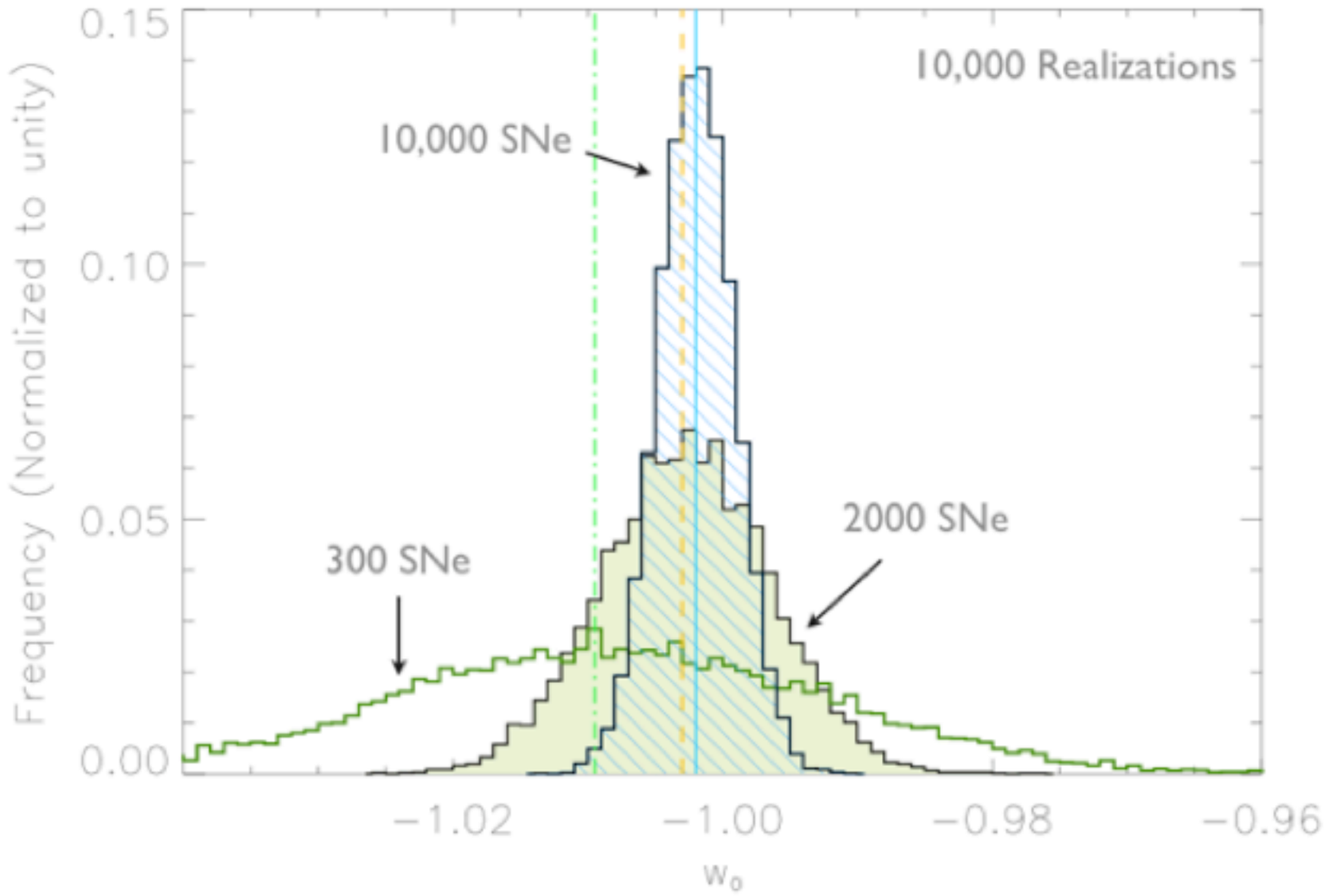

$$\mathcal{F}^{\mathrm{obs,lensed}}(z,\hat{\mathbf{n}}) = \mu(z,\hat{\mathbf{n}})\mathcal{F}^{\mathrm{obs,true}}(z)$$

Weak lensing can modify the SNa flux & bias estimates of w

# Our Analysis with Mock Catalogs

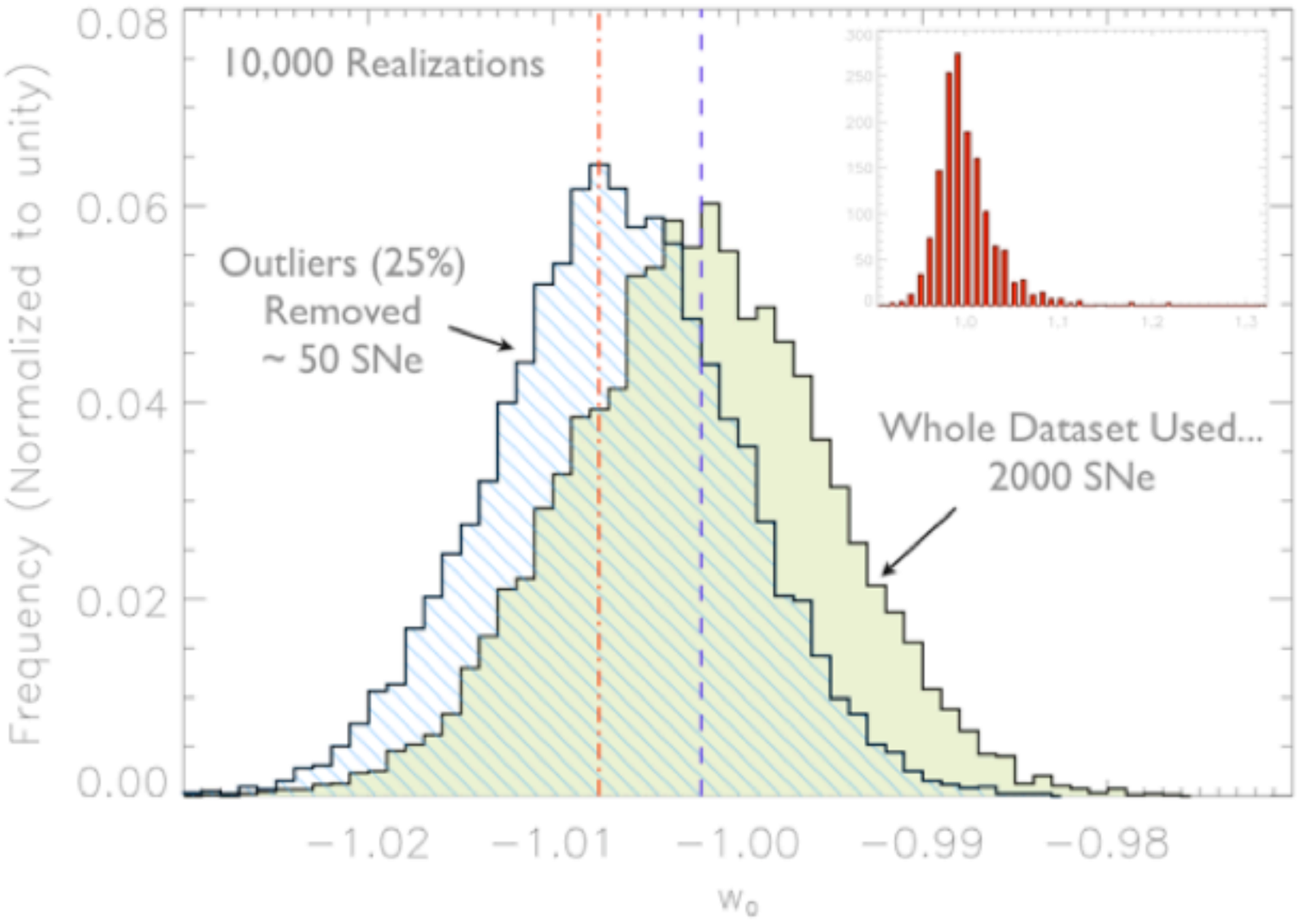


# Effect of Weak Lensing on Estimates of "w"




*D.S., A. Amblard, D. Holz, A. Cooray; ApJ, 678, 1 (2008)*

# Effect of Removing the Outliers

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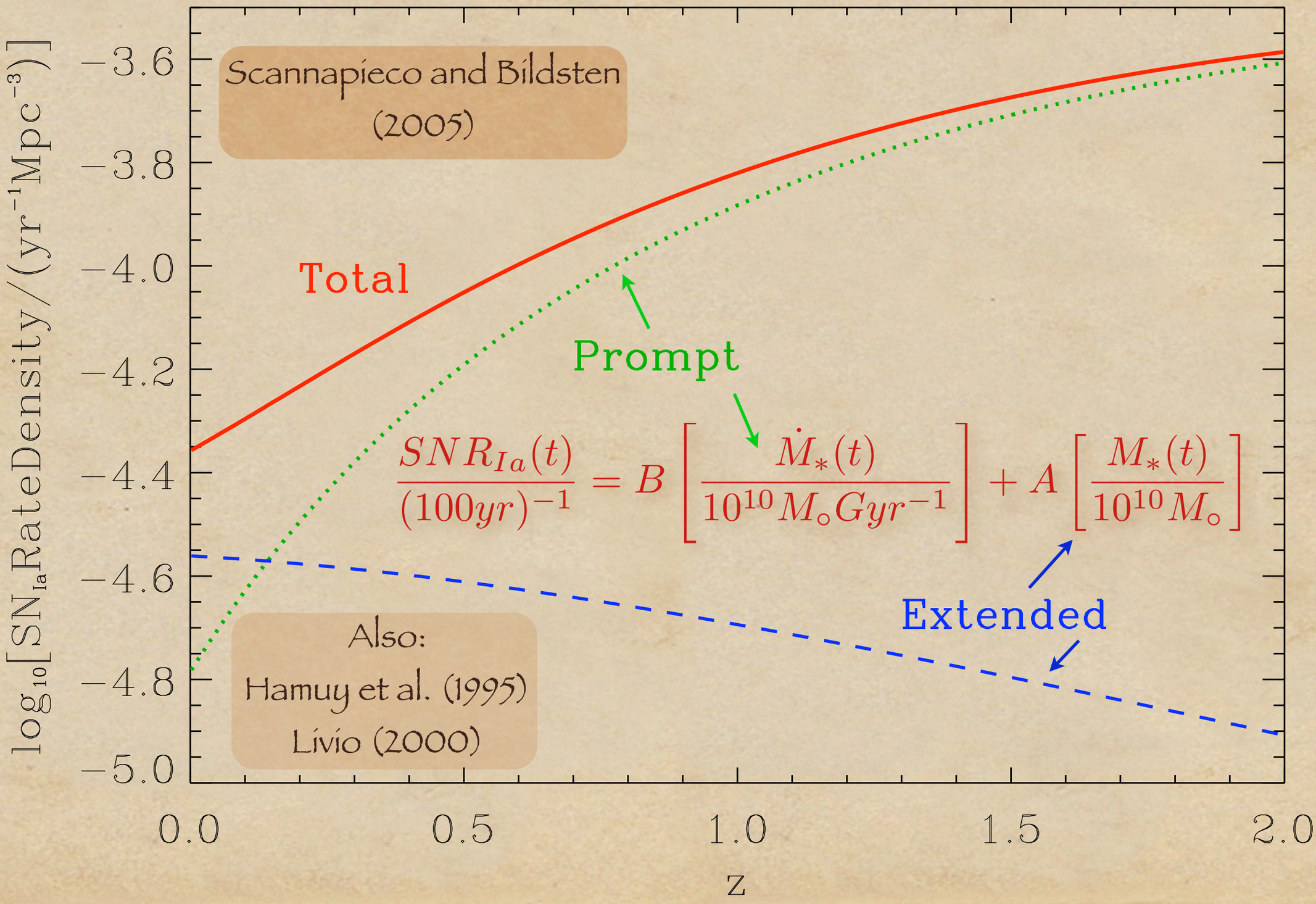
# Two Supernova Populations



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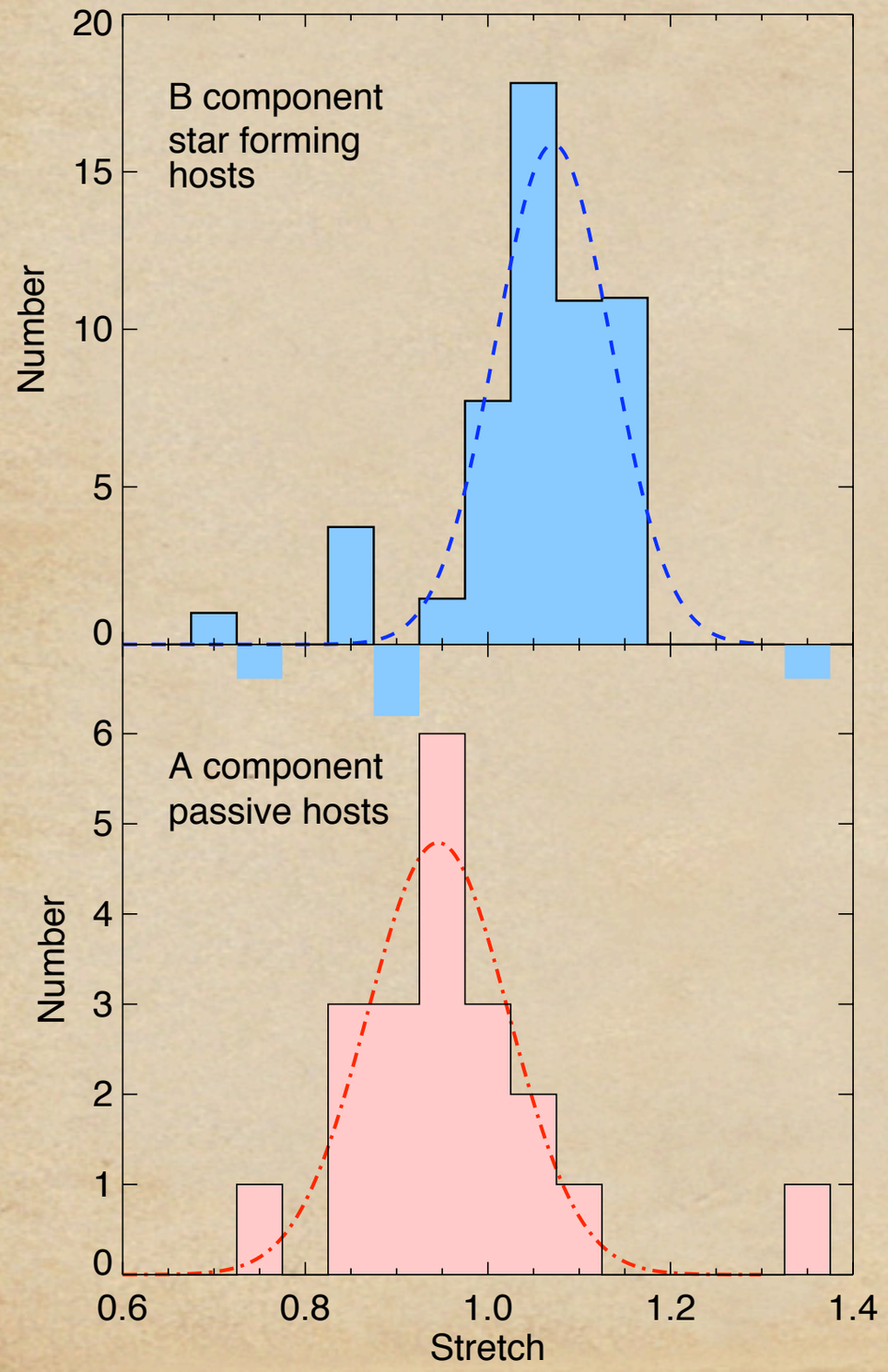


$$\mu_B = m_B^* - M + \alpha(s-1) - \beta c$$

Tripp (1998), Guy et al. (2005)

PROMPT

12% Dfference

in

Intrinsic Luminosity

$$\mathcal{L}_P = \mathcal{L}_E + \Delta\mathcal{L}$$

DELAYED

*Howell et al. 2007*

*Data Source: Sullivan et al. 2006 (SNLS)*

# Is There a Signature in the Hubble Diagram?

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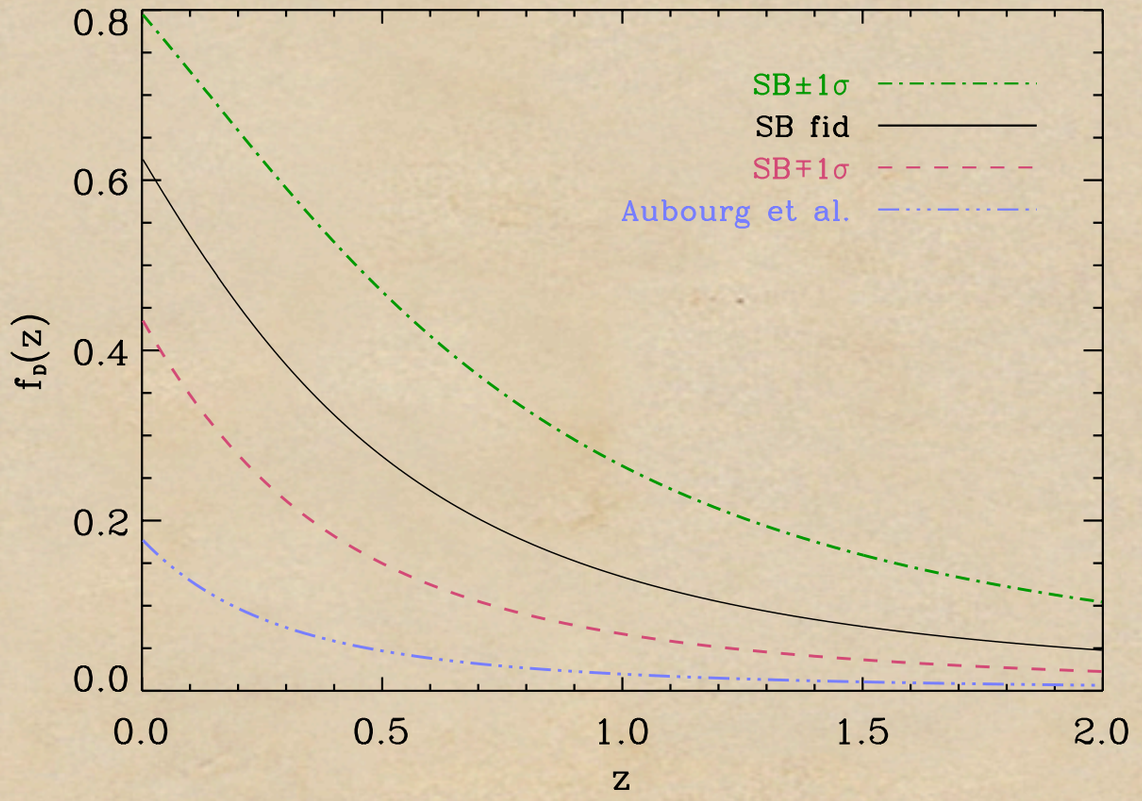
$$m - M = 5 \log \left( \frac{d_L}{\text{Mpc}} \right) + 25 + \mathcal{M}$$

Distance Modulus

# Is There a Signature in the Hubble Diagram?

Propose!

$$m - M = 5 \log \left( \frac{d_L}{\mathrm{Mpc}} \right) + 25 + \mathcal{M} + \delta_D * f_D(z)$$




D.S., A. Amblard, A. Cooray, and D. Holz, ApJL 684, L13 (2008)

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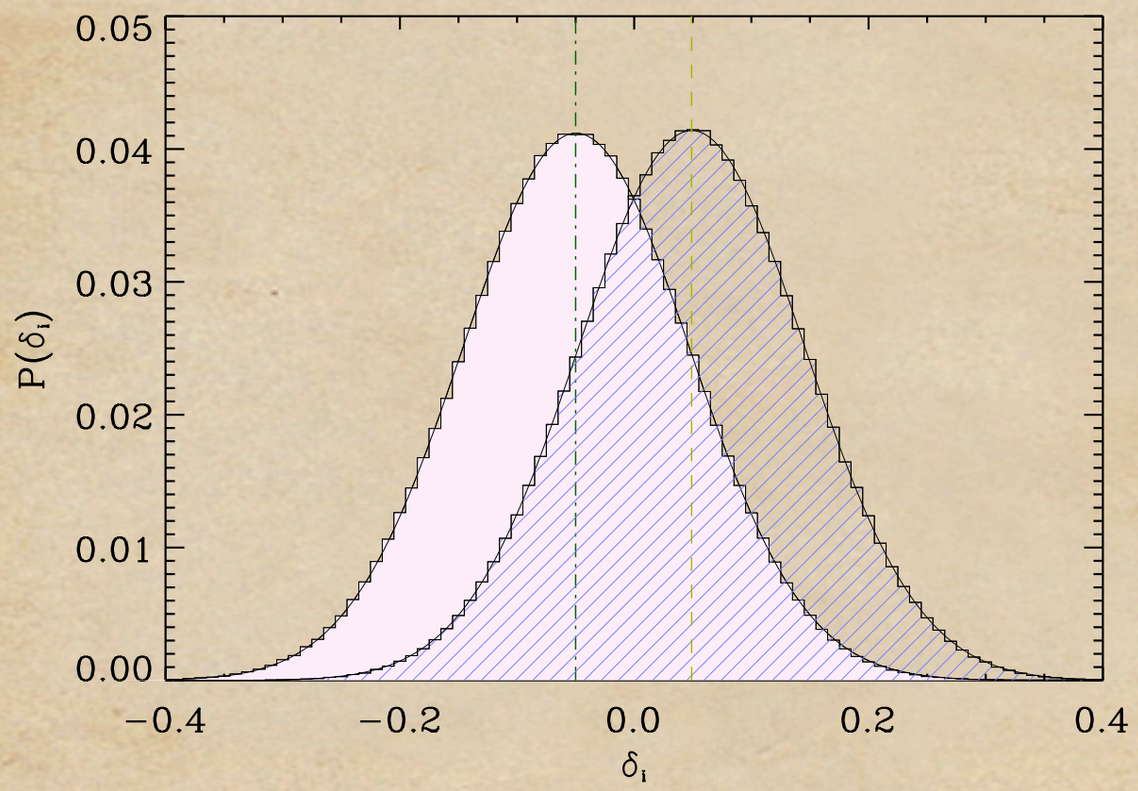


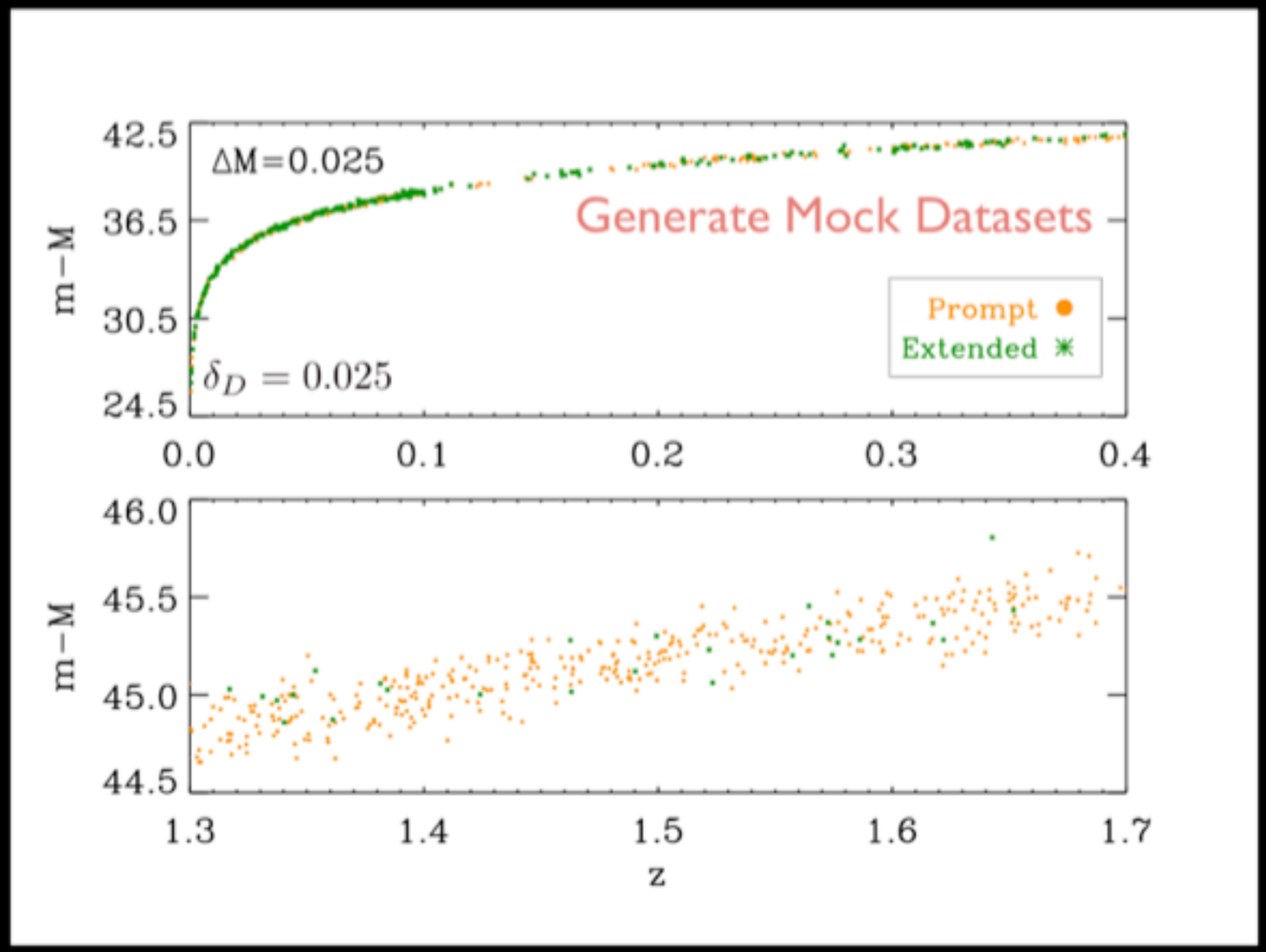

With current data (192 SNe from Davis et al. 2007), the residual is consistent with zero:

$$\delta_D \sim (5 \pm 9)\%$$

With future data, one will be able to constrain the residual much better.

D.S., A. Amblard, A. Cooray, and D. Holz, ApJL 684, L13 (2008)

# Effect on the EOS: Bias in "w"

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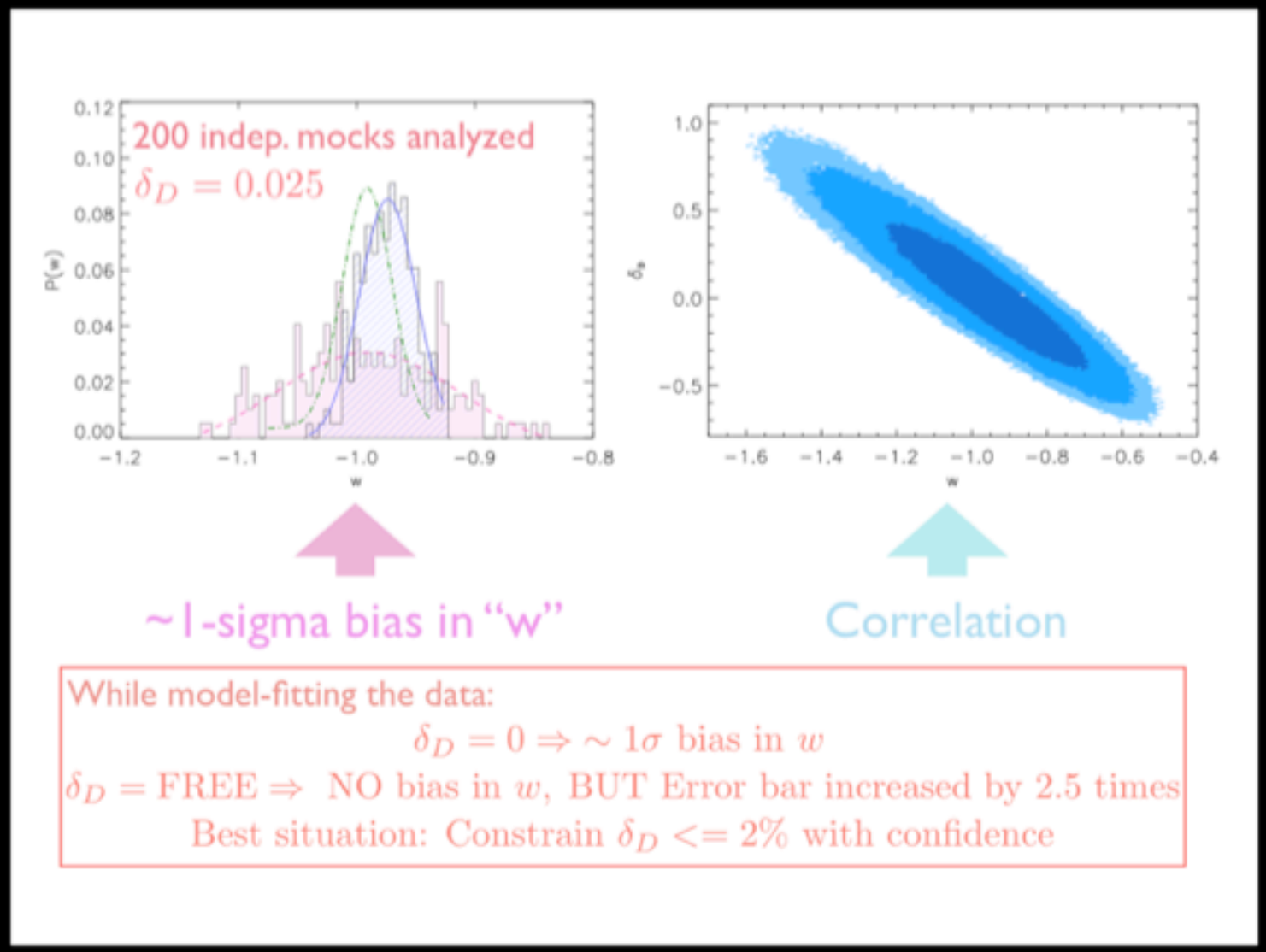


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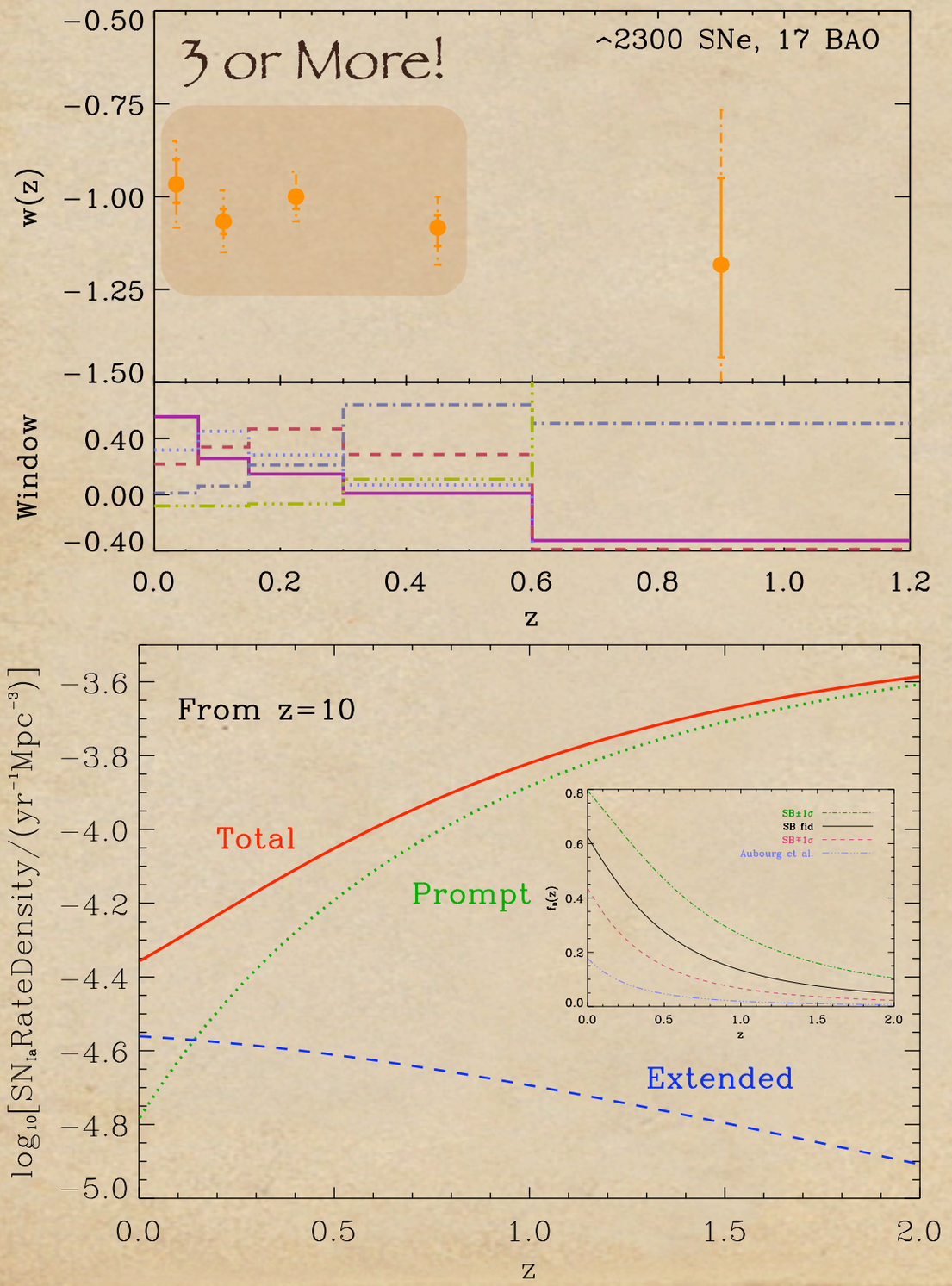
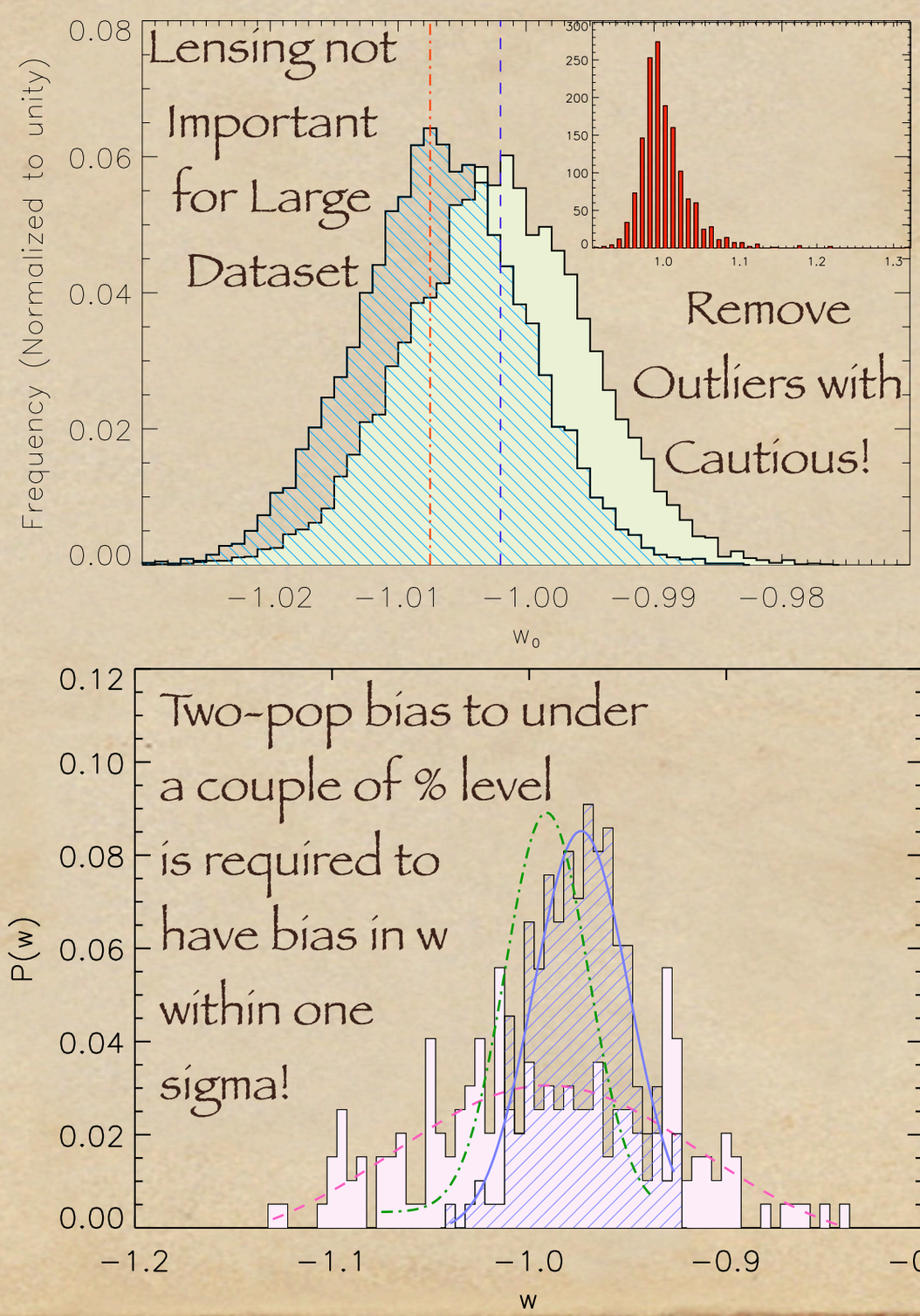
# Summary


3 or More!
~2300 SNe, 17 BAO
w(z)
Window
z
From z=10
Total
Prompt
Extended
$\log_{10}[SN_{Ia}RateDensity/(yr^{-1}Mpc^{-3})]$
z


Lensing not Important for Large Dataset
Remove Outliers with Cautious!
Frequency (Normalized to unity)
$w_0$
Two-pop bias to under a couple of % level is required to have bias in w within one sigma!
P(w)
w

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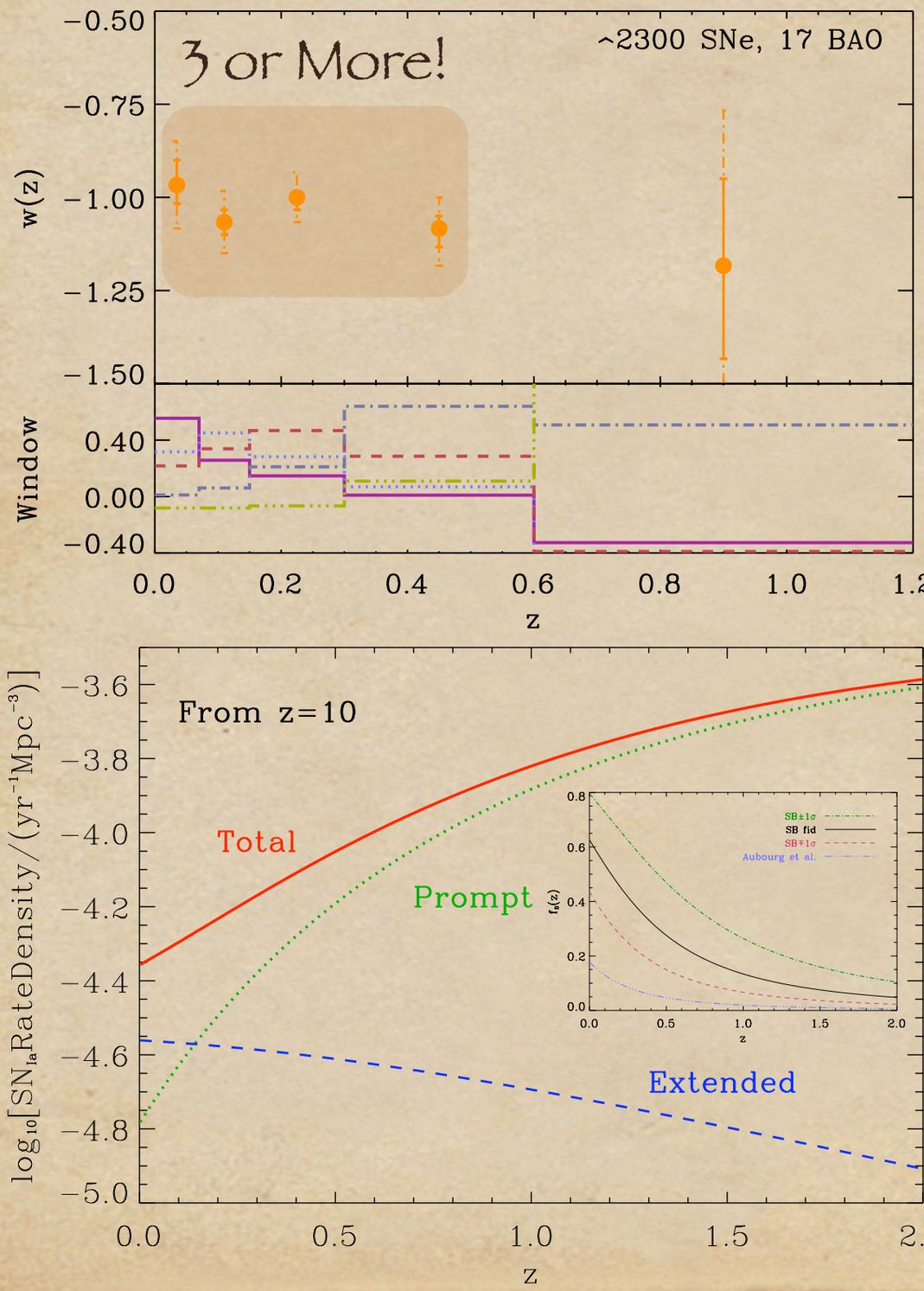
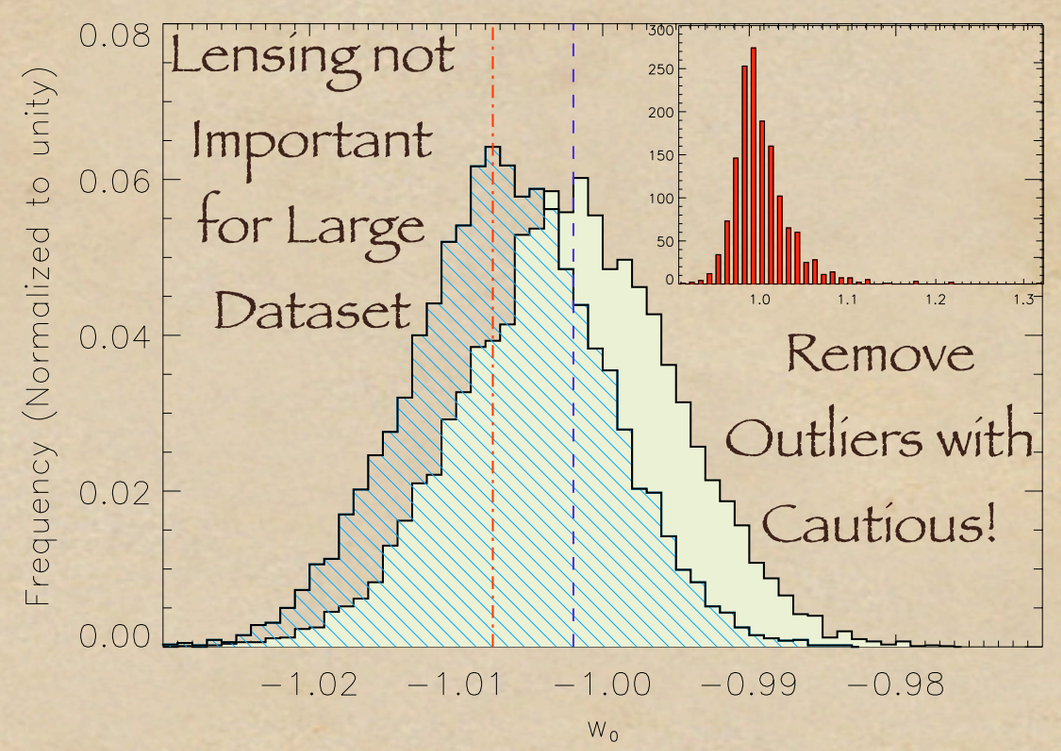
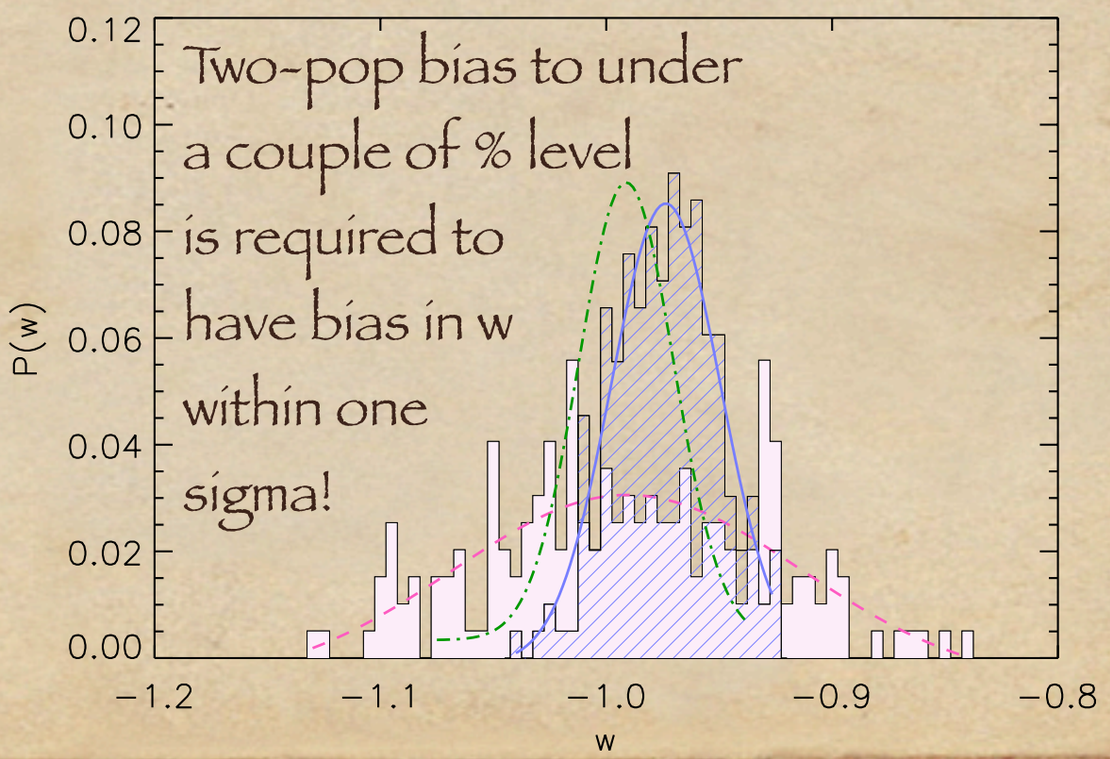


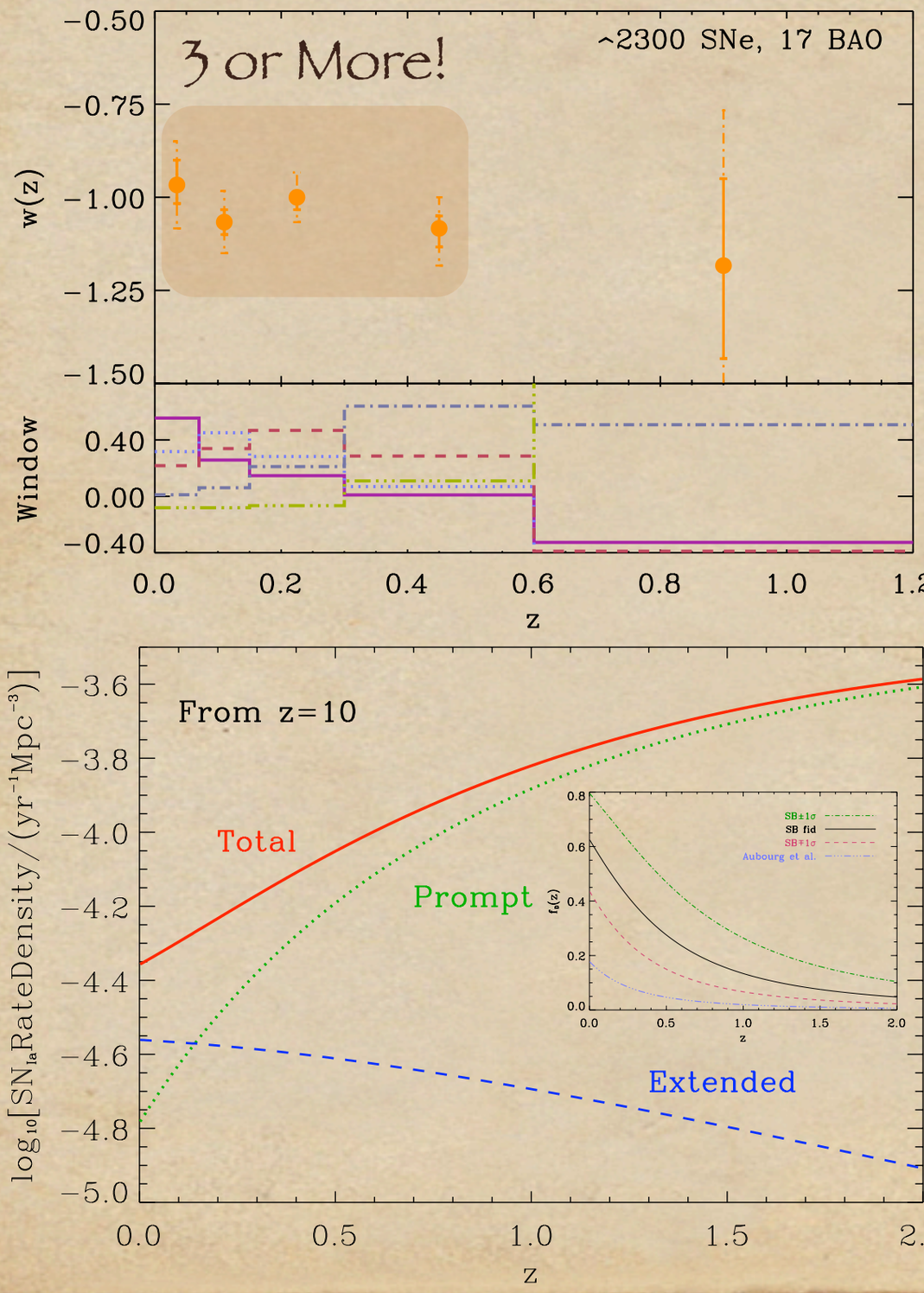


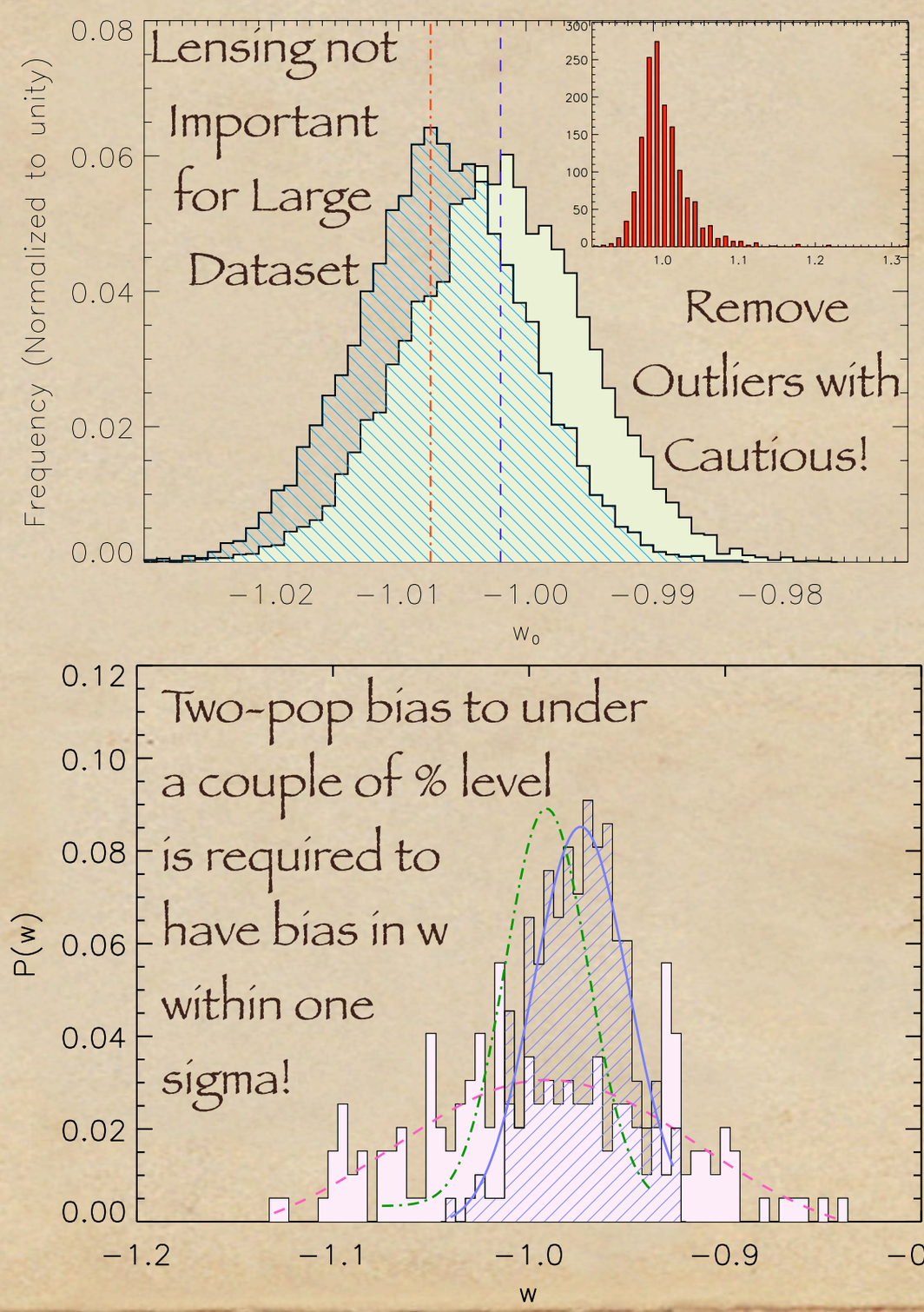





DSARKAR.ORG

# Summary




THANK YOU!