Cosmology Theory: Implications for Fundamental Physics..

ACP Winter Meeting
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C E R C A

THE 3 FUNDAMENTAL QUESTIONS

1. WHAT IS CURVATURE? FLUCTUATION SPECTRUM?
   - INITIAL CONDITIONS..
2. WHAT IS THE NATURE AND ORIGIN OF DARK MATTER?
   - PARTICLE MODELS
3. WHAT IS THE NATURE, ORIGIN, AND EVOLUTION OF DARK ENERGY?
   - VACUUM ENERGY.

Summary

- Observational Cosmology in the 21st century is the experimental particle physics of the last 2 decades:
  - GOOD NEWS: Lots of new data
  - BAD NEWS: observations will continue to confirm same parameters, without pointing where new physics is....
  - NEED THEORY!

CONCLUSIONS

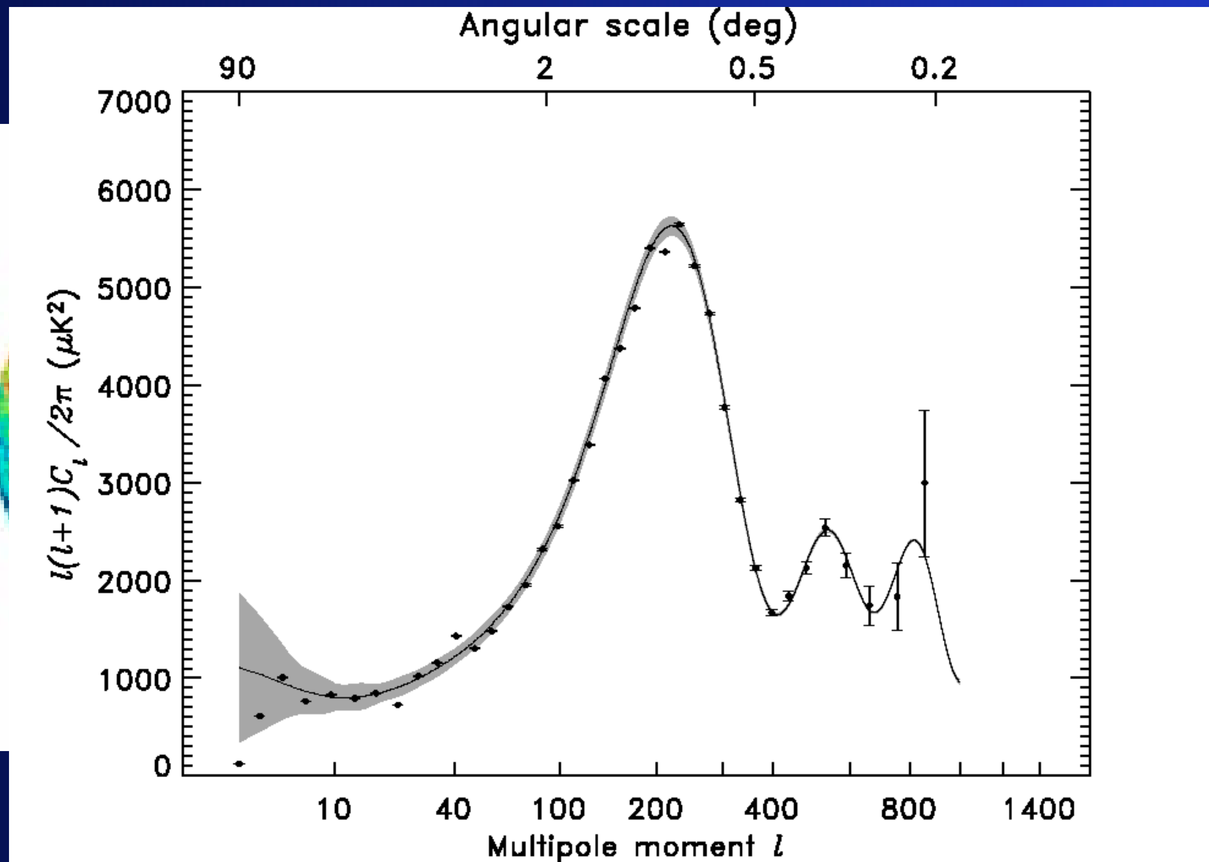
NEED ACCELERATORS AND PARTICLE THEORY:

COSMOLOGY GREAT FOR DISCOVERY,

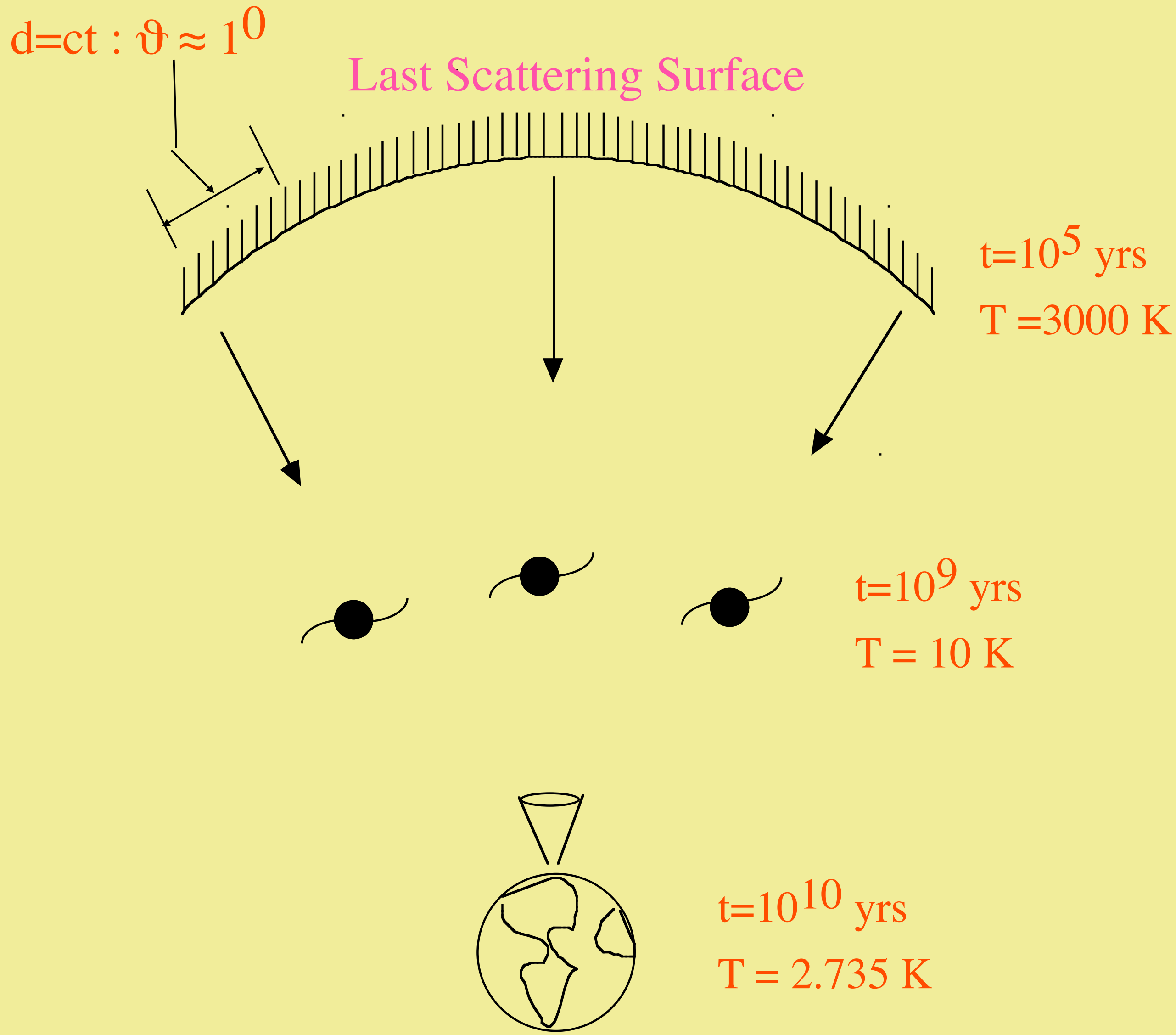
...But not for much more?

DISCOVERIES ALREADY MADE?

Cosmology: Current Status: CMB+LSS

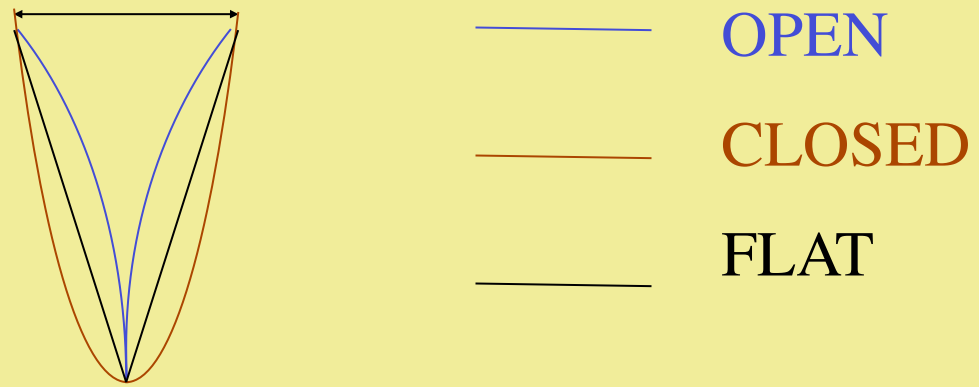


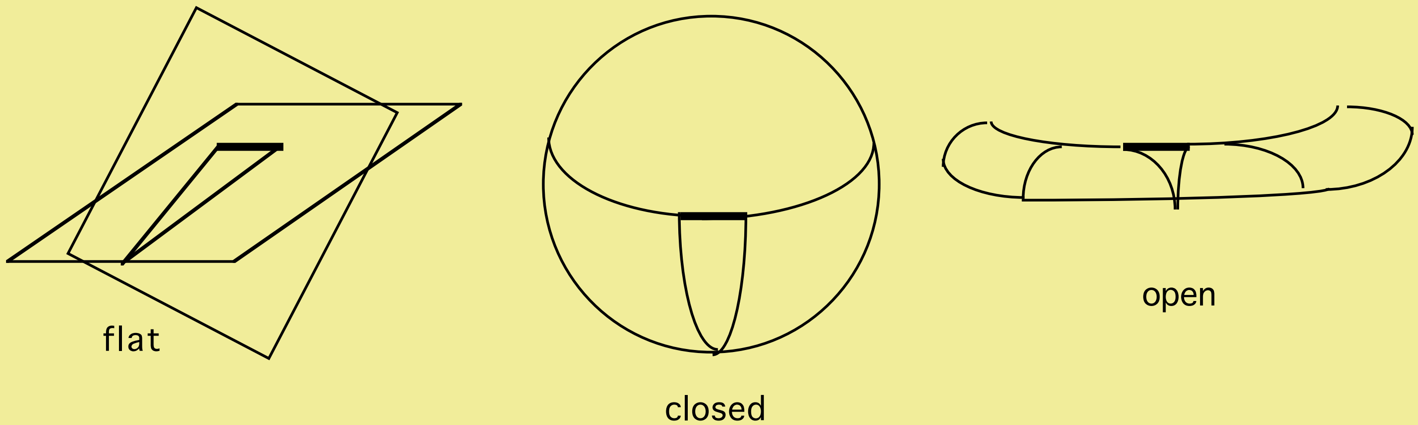
Cosmology: Current Status: CMB +LSS



Cosmology: Current Status: CMB +LSS

First Scale to Collapse after Recombination (≈distance spanned by light ray =horizon size)

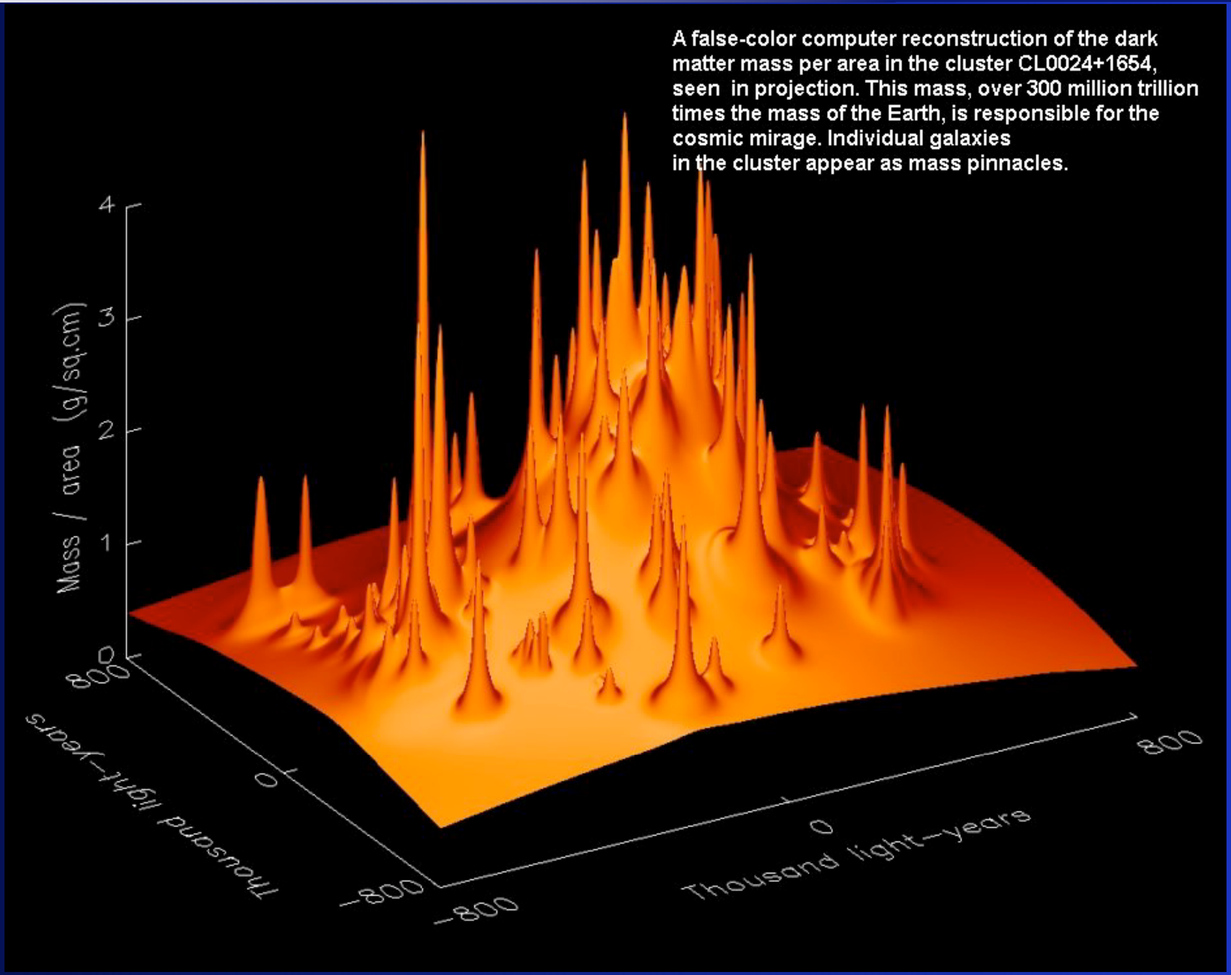




Cosmology: Current Status: CMB +LSS

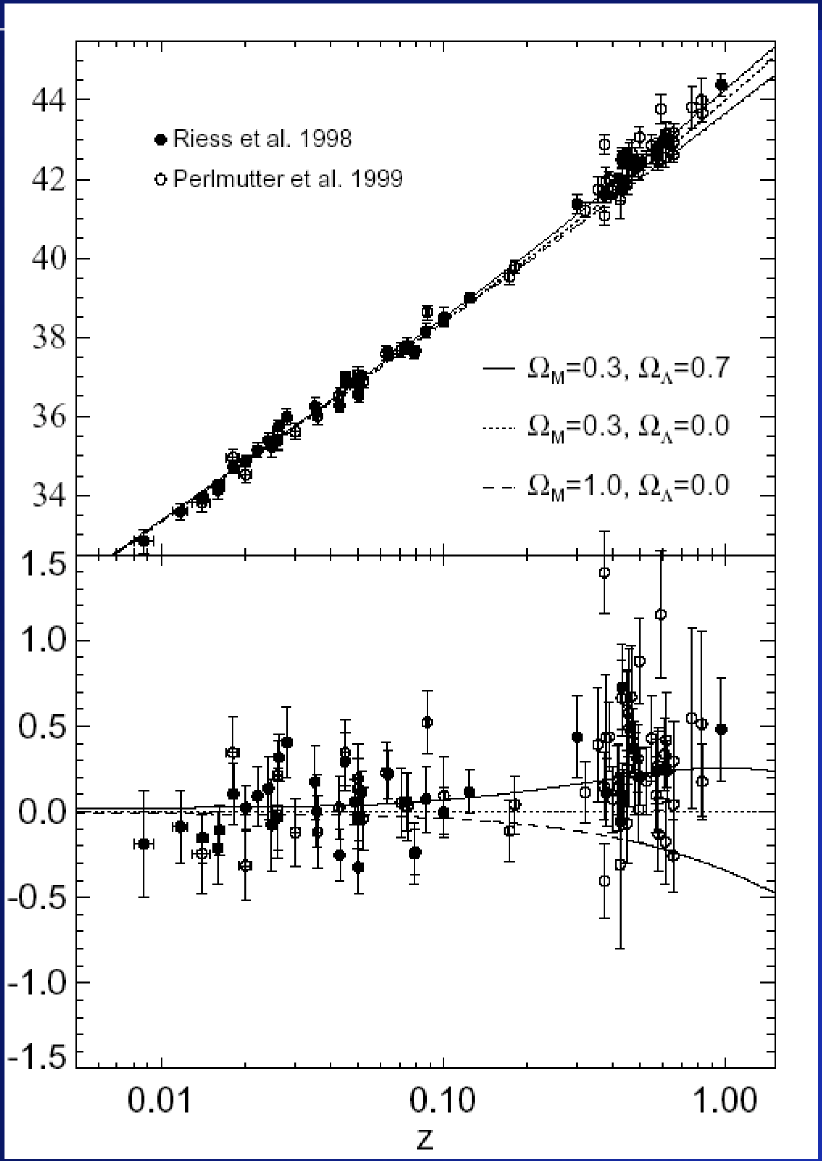
- ‘adiabatic fluctuations’, $n \approx 1$
- possible measure of gravity waves from inflation?
- weinberg: most any mechanism adiabatic $n \approx 1$
- predictions.. small.. unambiguous?

DARK MATTER



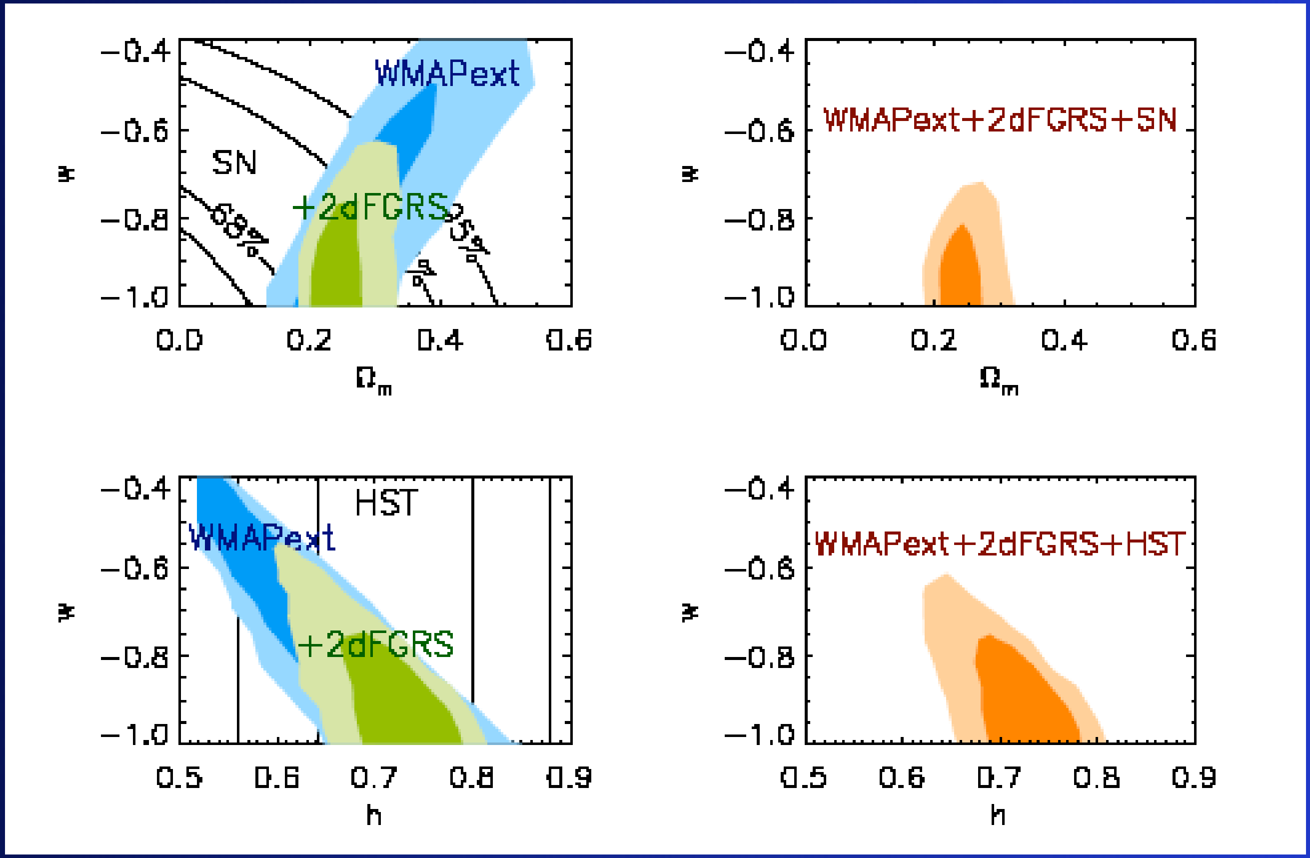
$\Omega_m = 0.30 \pm 0.1$ (95%)

DARK ENERGY



Riess et al. 1998
Perlmutter et al. 1999
Ω_M=0.3, Ω_Λ=0.7
Ω_M=0.3, Ω_Λ=0.0
Ω_M=1.0, Ω_Λ=0.0
44
42
40
38
36
34
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
0.01
0.10
1.00
z

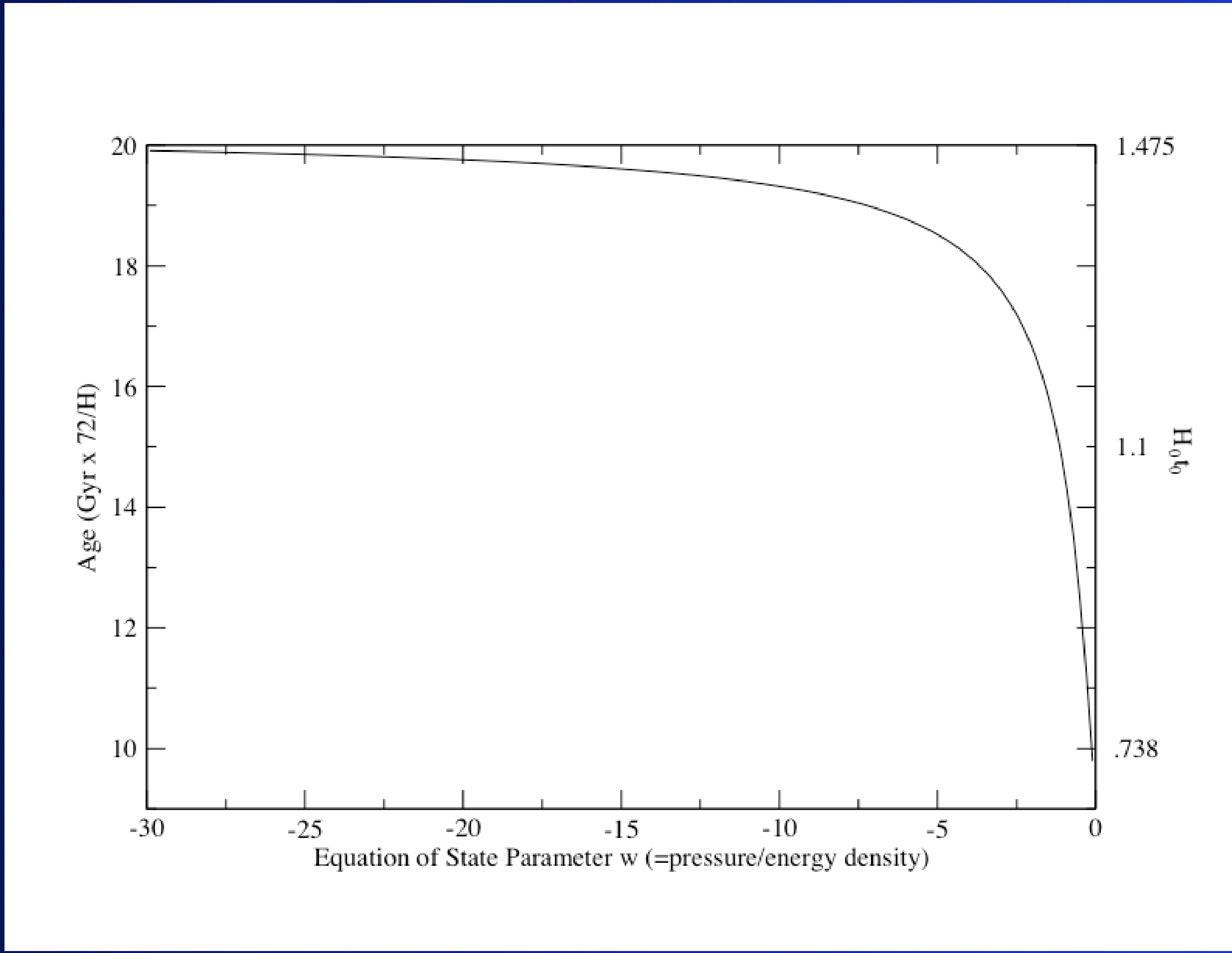
Combined Limits on w..



- w < -0.8

Combined Limits on w.. lower bound... age

LMK, APJ, 03



- w> -1.2

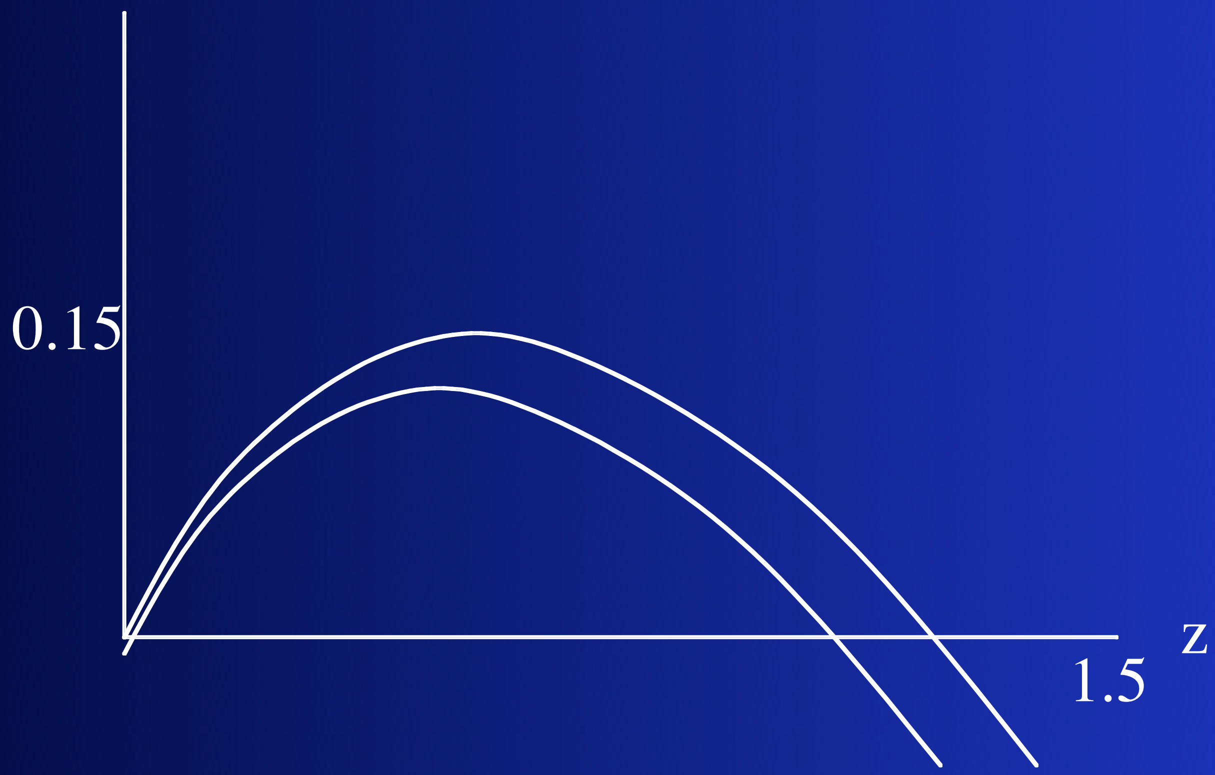
Outline

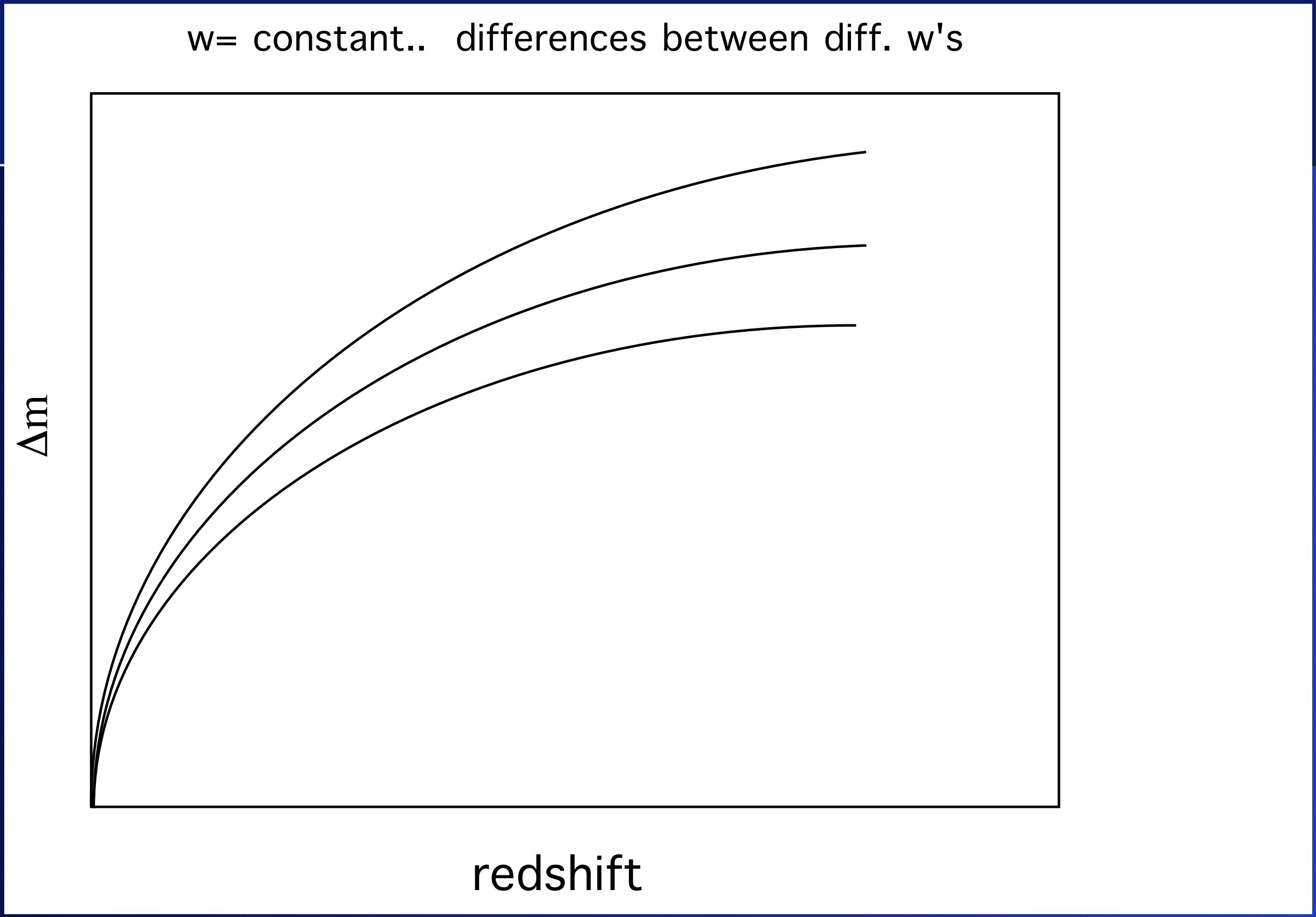
- Dark Energy
- Dark Matter
- Future Predictions

DARK ENERGY:The Problem

- The only truly fundamental question in cosmology at this point is: Is $w \neq -1$?
- The most reasonable theoretical prediction is $w=-1$, via a cosmological constant.
- The most sensible alternatives predict $w \approx -1$
- Observations suggest $w \approx -1$
- Measuring $w \approx -1$ therefore tells us nothing.
- Incorporating realistic uncertainties does not leave much room for optimism. (i.e. supernovae)

Magnitude-redshift relation for various eq. of state (subtracting off empty universe prediction)





UNCERTAINTIES:... MAG.

Canonical m uncertainty assumed 0.15/sn..

Uncertainties:

Observable for SN:

$$m(z_n) = 5\log(H_0 d_L(z_n, \Omega_m, \Omega_\Lambda)) + \mathcal{M} + \varepsilon_n$$

where

$$\mathcal{M} = \mathrm{M} - 5\log\mathrm{H}_0 + 25$$

we model

$w(z) = w_0 = \text{constant}$ $\quad$ Ω_m , w_0 ,and $\mathcal{M}$

$w(z) = w_0(1+z)^b$ $\quad$ Ω_m , w_0 ,and $\mathcal{M}$ $\quad$ b

Uncertainties:

$$F_{ij} = -\left\langle \frac{\partial^2 \ln L}{\partial \theta_i \partial \theta_j} \right\rangle_y$$

$$F_{ij} = \sum_{k=1}^{N} \frac{1}{\sigma_O(z_k)^2} \frac{\partial O(z_k)}{\partial \theta_i} \frac{\partial O(z_k)}{\partial \theta_j}$$

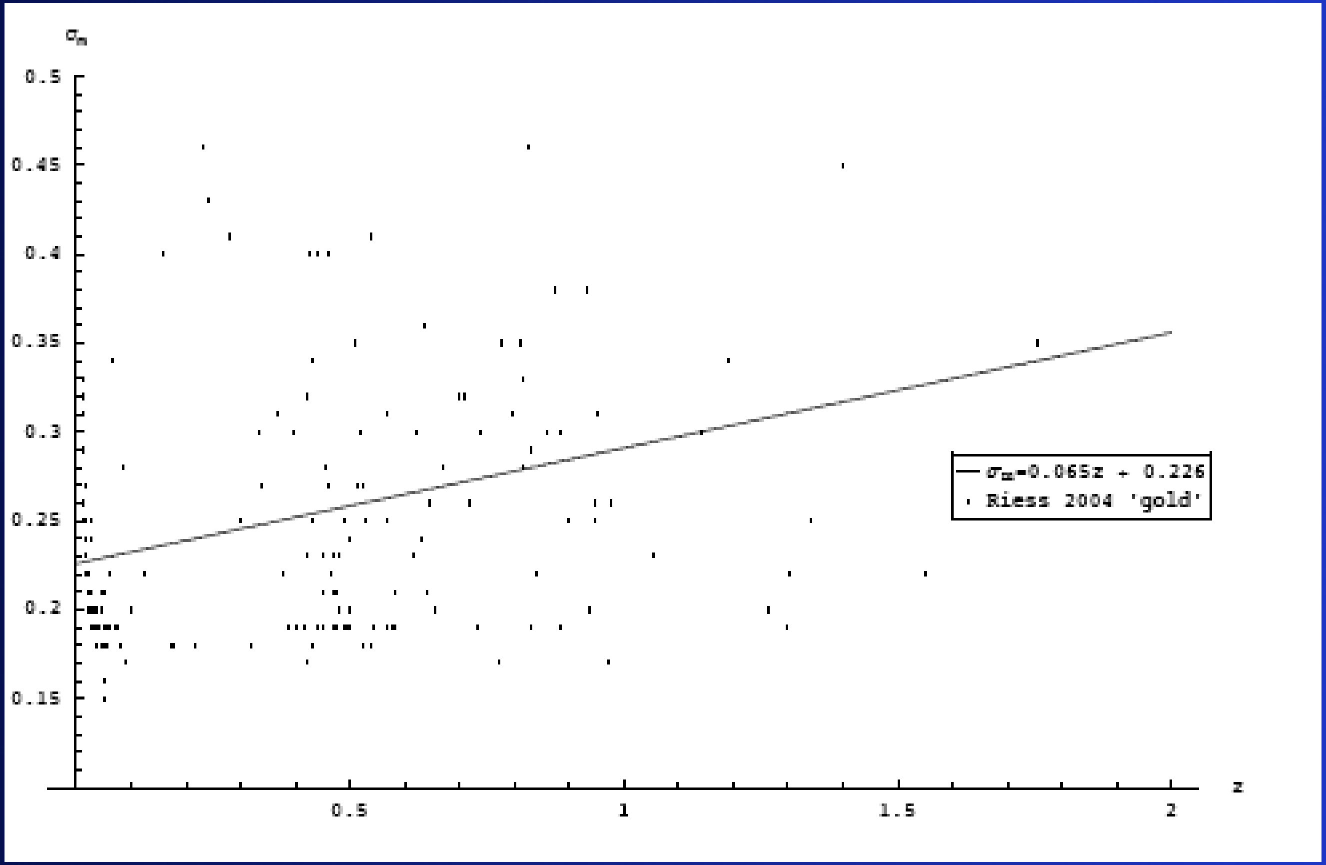
$$\Delta \theta_i \geq \sqrt{F_{ii}^{-1}}$$

Limits on w for sigma_m =0.15

- statistical uncertainty in w approx .04-.09 for 300-3000 SN!
- Is this good enough?
- too good to be true?

Actual Ground-based uncertainties!

LMK, D. Huterer, K. Smith



Actual Ground-based uncertainties!

- 300 Supernovae.. 100 from z=0.03 to .08

z range	$\sigma_m = 0.15$
0.1 - 0.5	0.105
0.5 - 1	0.1015
1 - 2	0.12
0 - 1	0.1011
0 - 2	0.1011

N =300, w(z)=constant

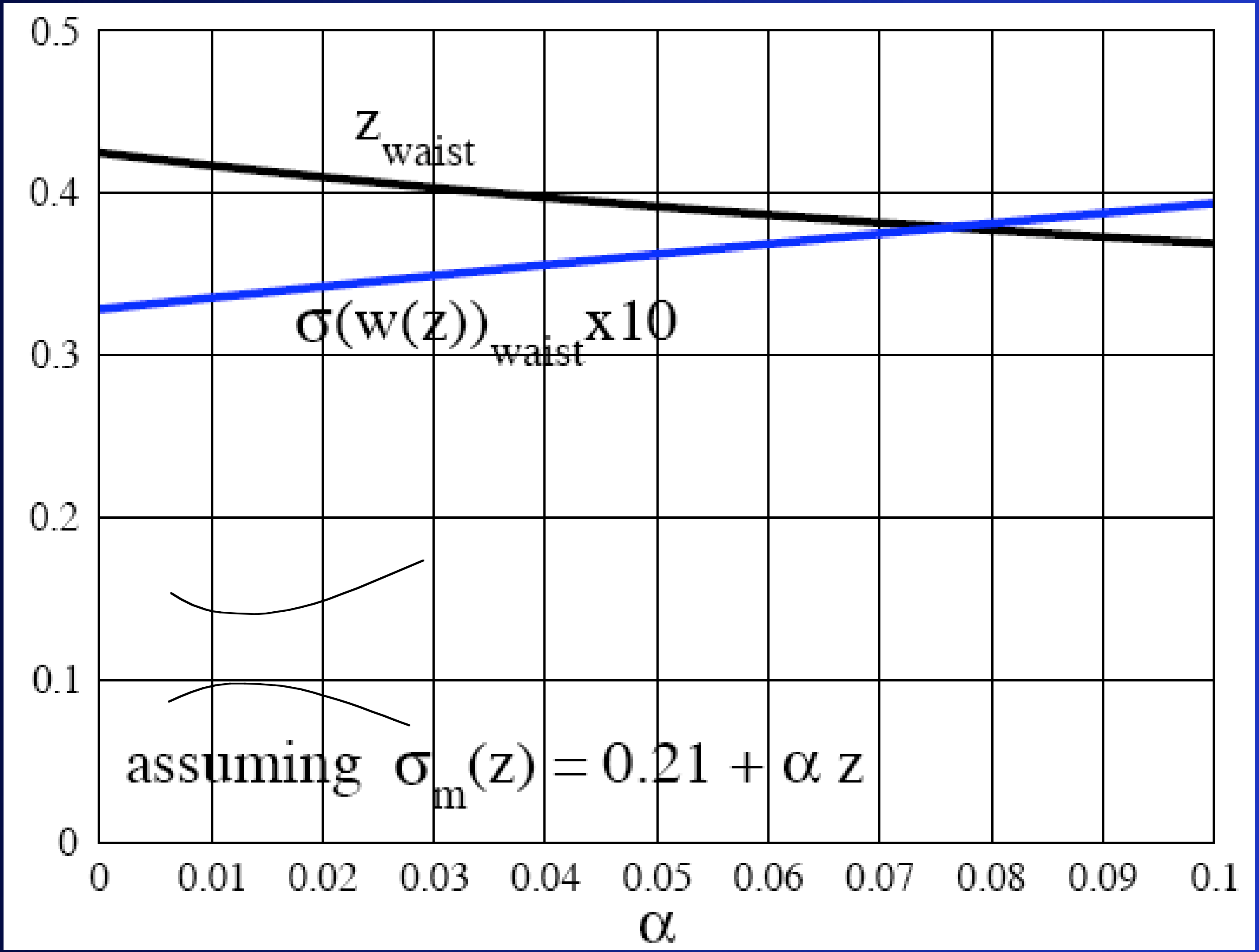
Actual Ground-based uncertainties!

- SNAP: 3000 Supernovae.. 100 from z=0.03 to .08

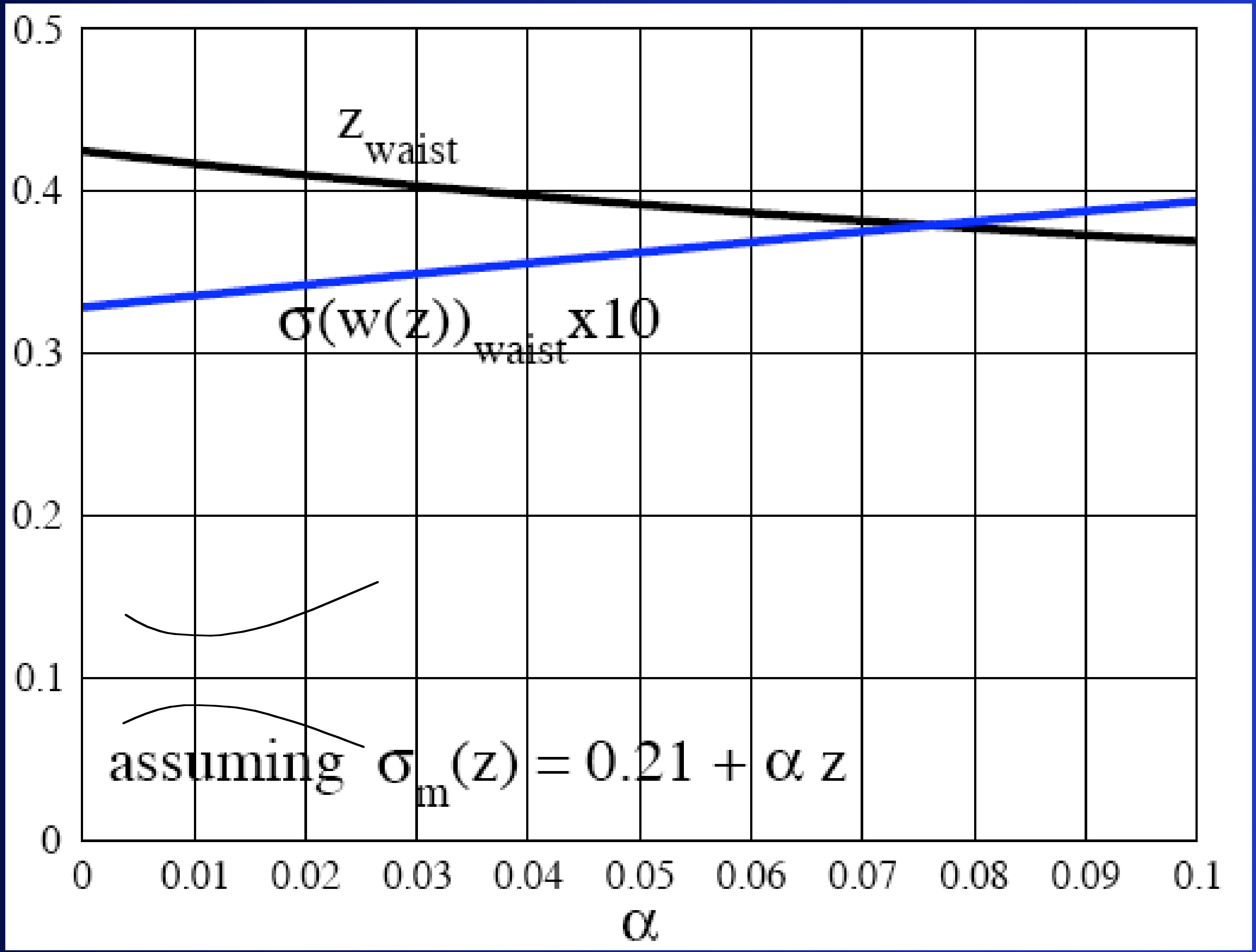
z range	$\sigma_m = 0.15$
0.1 - 0.5	0.085
0.5 - 1	0.088
1 - 2	0.07
0 - 1	0.082
0 - 2	0.057

N=3000 w(z)=

Watching your waist: Looking for dark matter.. no prior



Watching your waist: Looking for dark matter..



But it is worse!...

Actual Ground-based uncertainties!

- We do not know z dependence of w... therefore uncertainty larger..., and parameter dependent!

z range	σ_m=0.226+0.065z
0.1 - 0.5	.529, 3.49
0.5 - 1	.465, 2.09
1 - 2	.568, 1.88
0 - 1	.318, 1.43
0 - 2	.248, .924

$N = 300$, $w(z)= w_0\ (1+z)^b$

z range	σ_m=0.226+0.065z
0.1 - 0.5	.295, 1.6
0.5 - 1	.184, .765
1 - 2	.199, .807
0 - 1	.159. .638
0 - 2	.115, .499

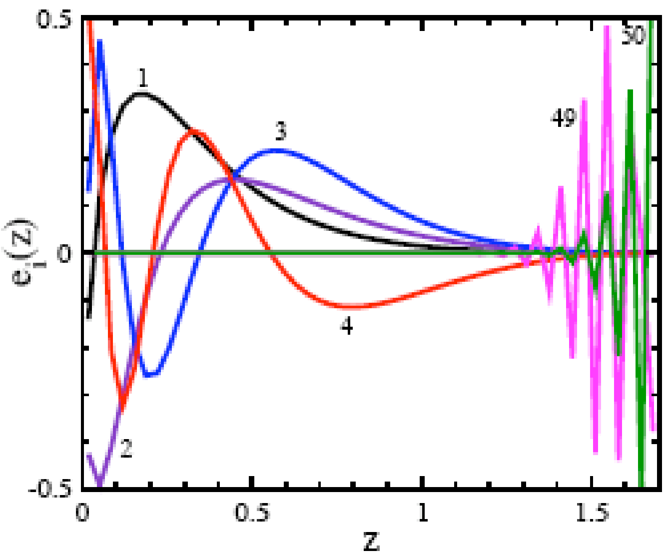
$N = 3000$, $w(z)= w_0\ (1+z)^b$

Ruling out a Cosmological Constant?

- Principle Component Test:

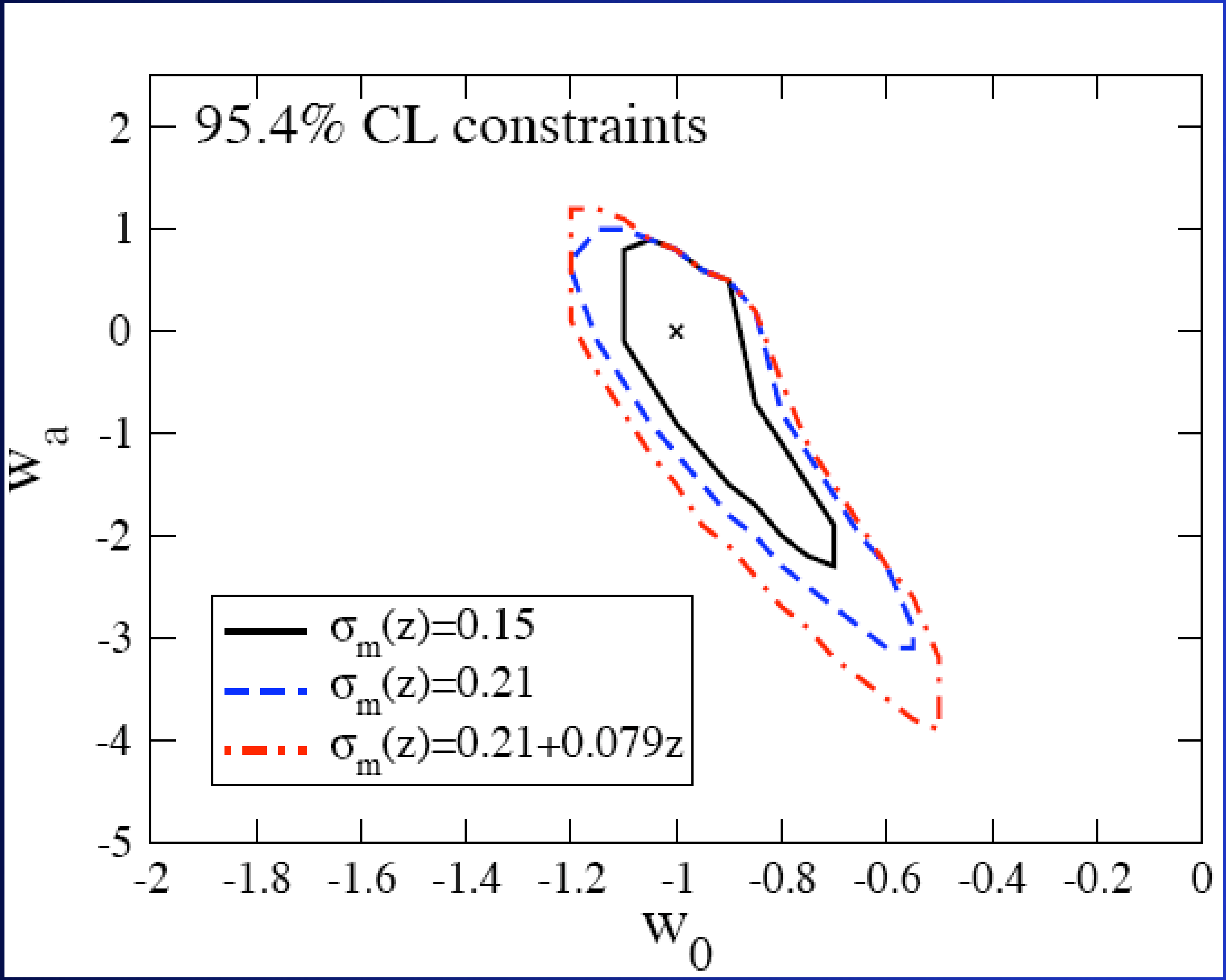
Consider a general description of w (say, w_i in 50 redshift bins at $z \in [0, 1.7]$)

- Compute the covariance matrix for w_i (assuming some SN survey)
- Diagonalize the covariance matrix. Get best, worst measured linear combinations of w_i's.
- $w(z) = \sum_{i=1}^{50} \alpha_i e_i(z)$



Huterer & Starkman 2003

Ruling out a cosmological constant..

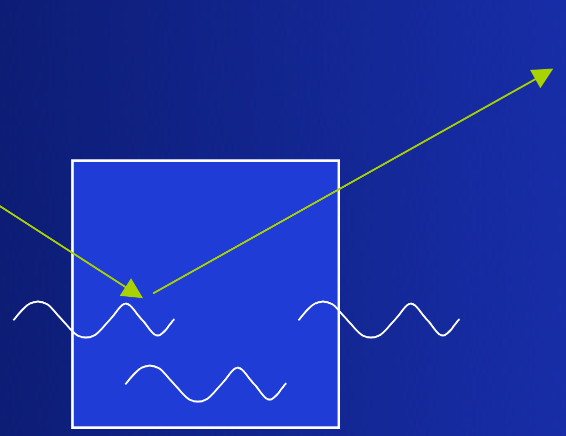


Dark Energy Summary

- w ≈-1
- cosmology of no help
- need theory...

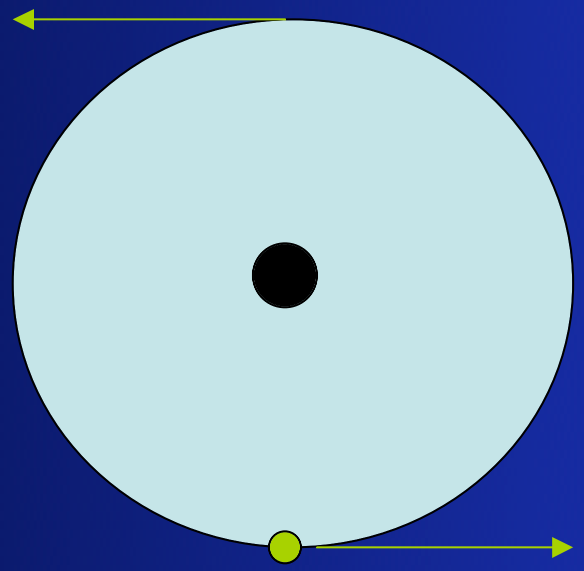
2. Dark Matter:
What is the Signal for WIMPS

- excess noise in a detector (CDMS)



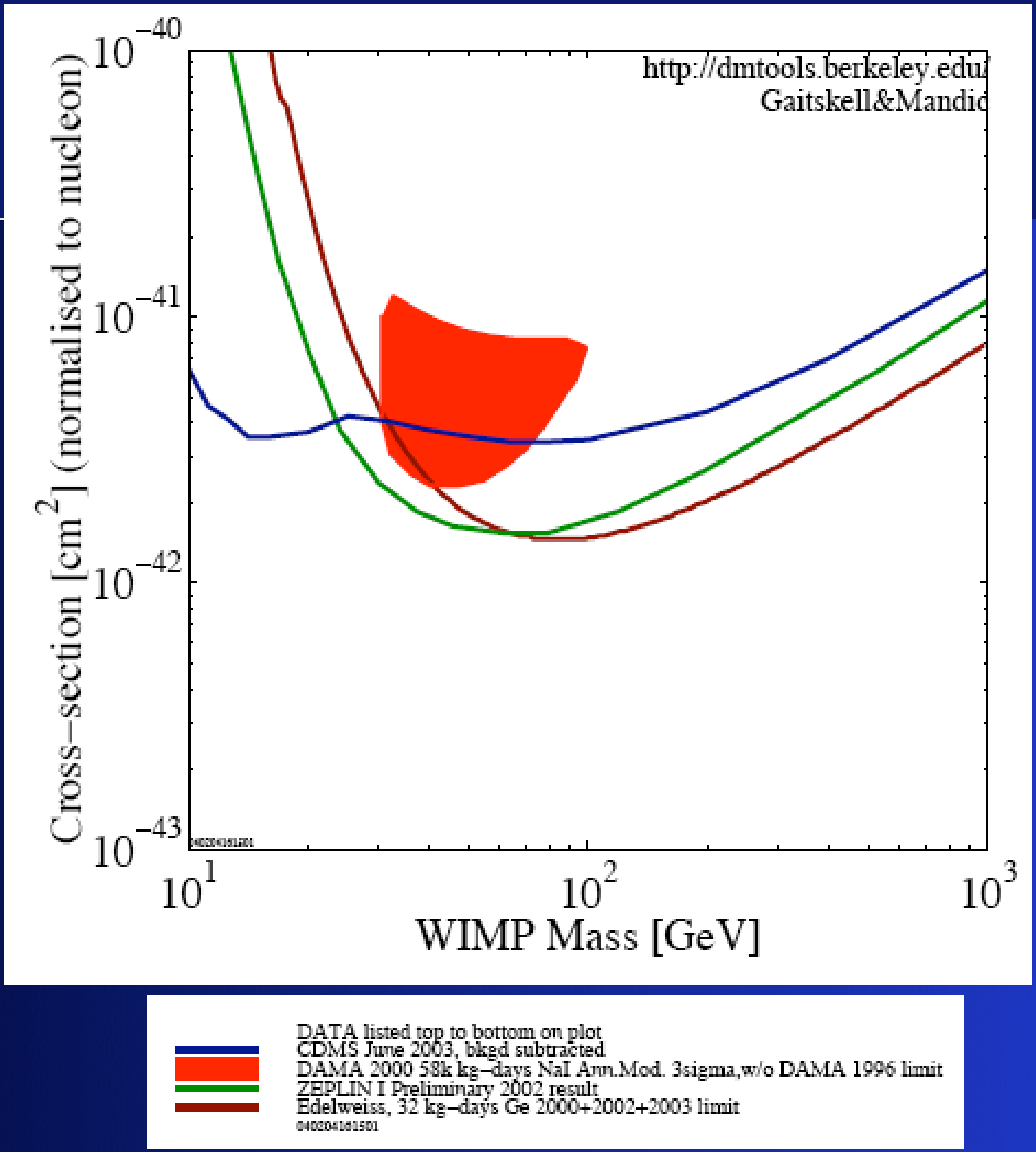
What is the Signal for WIMPS

- (Small) Annual Modulation (DAMA)



What is the Signal for WIMPS

- (Small) Annual Modulation (DAMA)
  - flux change
  - threshold effect.. $R \approx \exp(-v_{min}^2)$....
  - net effect of order 1-2% (<v> =220 km/s)


http://dmtools.berkeley.edu/
Gaitskell&Mandic
Cross-section [cm^2] (normalised to nucleon)
10^-40
10^-41
10^-42
10^-43
10^1
10^2
10^3
WIMP Mass [GeV]
DATA listed top to bottom on plot
CDMS June 2003, bkgd subtracted
DAMA 2000 58k kg-days NaI Ann.Mod. 3sigma,w/o DAMA 1996 limit
ZEPLIN I Preliminary 2002 result
Edelweiss, 32 kg-days Ge 2000+2002+2003 limit
040204161501

IS IT A SIGNAL?

- Uncertainties:
  - halo
  - particle physics
- Can one do better?

That Damn Halo

ISOTHERMAL

$$f(\mathbf{v}) = \frac{1}{\pi^{3/2} v_0^3} e^{-|\mathbf{v}|^2/v_0^2}.$$

TRIAXIAL

$$f(\mathbf{v}) = \frac{1}{\pi^{3/2}\sigma_x\sigma_y\sigma_z} \exp\left[-\frac{v_x^2}{\sigma_x^2} - \frac{v_y^2}{\sigma_y^2} - \frac{v_z^2}{\sigma_z^2}\right].$$

EVANS

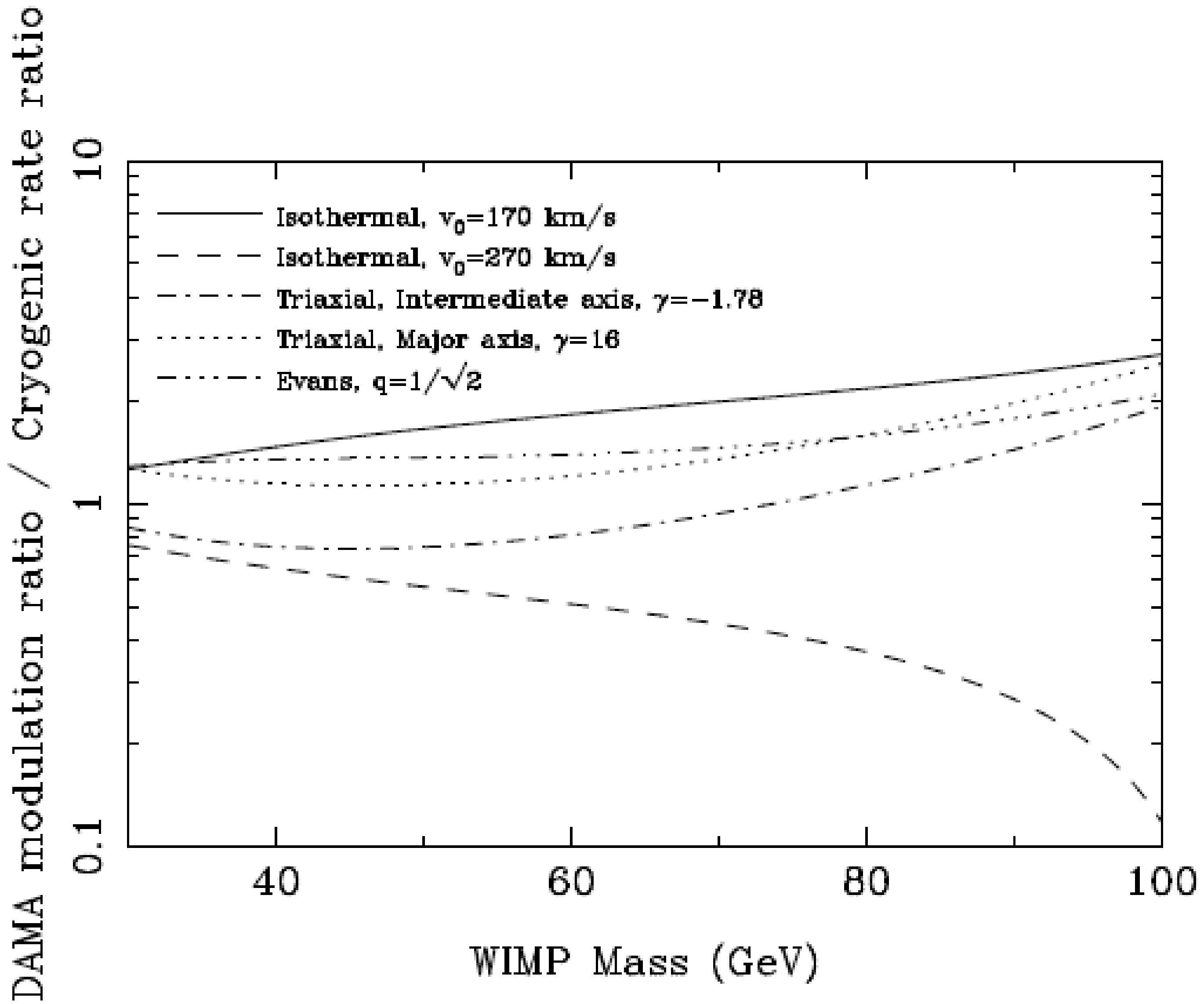
$$f(\mathbf{v}) = \frac{1}{D^2}\left[AR_0\left(v\cos\alpha - v_{\oplus,x}\right)^2 + B\right] e^{-2(v-\Psi)^2/v_0^2}\, e^{-2v_\oplus^2 - \Psi^2/v_0^2} + \frac{C}{D} e^{-(v-\Psi)^2/v_0^2}\, e^{-v_\oplus^2 - \Psi^2/v_0^2},$$

where

$$A = \left(\frac{2}{\pi}\right)^{5/2} \frac{1-q^2}{Gq^2 v_0^3}, \qquad B = \sqrt{\frac{2}{\pi^5}}\frac{R_c^2}{Gq^2 v_0}, \qquad C = \frac{2q^2-1}{4\pi G q^2 v_0},$$

$$D = R_c^2 + R_0^2, \qquad \Psi = v_{\oplus,x}\cos\alpha + v_{\oplus,y}\sin\alpha\cos\beta + v_{\oplus,z}\sin\alpha\sin\beta,$$

q=flattening $q = 1$ to $q = 1/\sqrt{2}.$


Isothermal, v_0=170 km/s
Isothermal, v_0=270 km/s
Triaxial, Intermediate axis, γ=−1.78
Triaxial, Major axis, γ=16
Evans, q=1/$\sqrt{2}$
DAMA modulation ratio / Cryogenic rate ratio
0.1
1
10
40
60
80
100
WIMP Mass (GeV)

Doing Better?: Full Angular Resolution

cjc, lmk, in prep

CJC and L. Krauss, *Phys. Rev. D*, **63** 043507 (2001).

We consider a range of detector taking into account some of the technical challenges being faced.

- 3D: Full three dimensional.
- 3D w/o FB: Three dimensional detector without the ability to determine the track direction (no Forward/Backward discrimination).
- 2D: A two dimensional detector fixed to the surface of the Earth. Recoil tracks are projected onto the plane of the detector.

A consistent set of parameters applied to all the detectors.

- Nuclear target: Xenon ($M_{\rm nuc} = 131$ GeV)
- Spin independent WIMP-Nucleon interaction.
- Isothermal halo models with $v_0 = 170$ km/s, 220 km/s, and 270 km/s.
- Detector threshold: 10 keV (no quenching).
- WIMP mass: $M_W = 100$ GeV ($M_W \approx M_{\rm nuc}$) and $M_W = 1000$ GeV ($M_W \gg M_{\rm nuc}$)

The best you can do?

Angular Results: Preliminary

Detector Type	v_0 (km/s) 170		220		270	
3D	6	14	11	27	18	51
3D w/o FB	176	152	1795	217	$>$35,000	371
2D: best	19	51	34	97	61	175
worst	45	129	75	217	123	368

Number of events required for isothermal models.

$M_W = 100$ GeV (1000 GeV).

Finally: An Uncertain Future...

- Ultimate purpose of particle-astrophysics... to determine future of the universe...
- a red herring..

(2) An Uncertain Future:

We will never know if we live in the worst possible universe!

⟺ GEOMETRY ≠ DESTINY

Vacuum Energy* violates the SEC (w=-1)!

$$\left(\frac{\dot{R}}{R}\right)^2 = \frac{8\pi G}{3}\rho_M - \frac{k}{R^2} \quad \Rightarrow \quad \left(\frac{\dot{R}}{R}\right)^2 = \frac{8\pi G}{3}(\rho_M + \rho_\Lambda) - \frac{k}{R^2}$$

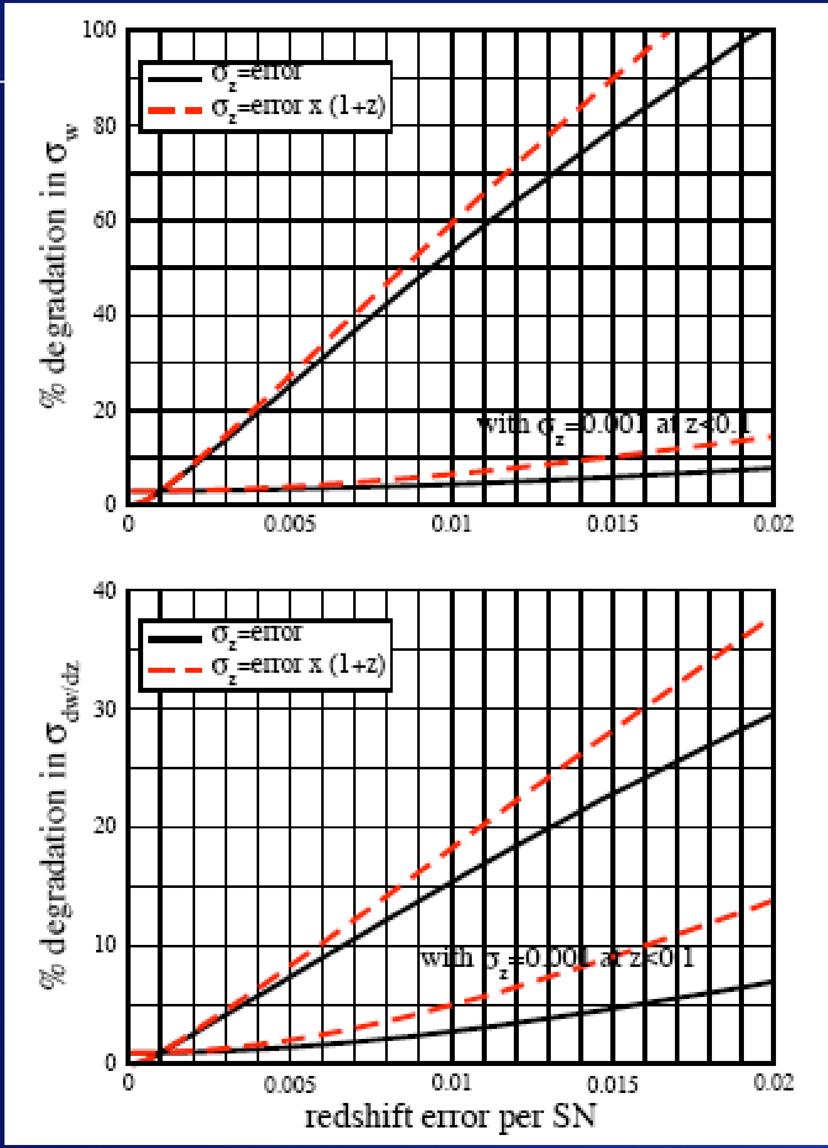
$$* \; T_{\mu\nu} = \Lambda g_{\mu\nu}$$

By Lorentz invariance

An Uncertain Future

- New Rules = No Rules.
- LMK MST..no finite set of observations good enough
- The Future of Particle Physics: Theory and Accel
- The Future of Cosmology is Particle Theory...

Redshift uncertainties: SN



Redshift uncertainties: SN

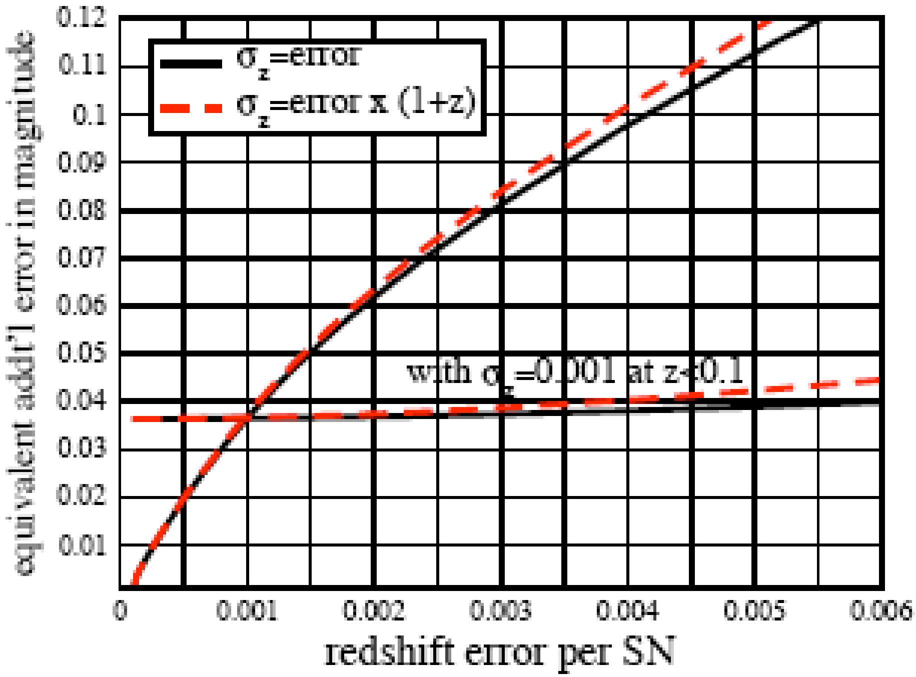


FIG. 3.— Redshift error increases the degradation in σ_w as some equivalent *additional* magnitude error, which is shown on the ordinate. The solid line shows the case when the redshift error is constant for all SNe, while the dashed line shows the case when the error (plotted on the abscissa) is multiplied by $(1+z)$. As in Fig. 2, the flatter pair of curves corresponds to the case when $z < 0.1$ SNe were assumed to have a fixed redshift error of 0.001 per SN.

Redshift uncertainties: Number counts

$$\sigma_{\mathrm{z,bin}} = \sqrt{\frac{\sigma^2_{\mathrm{clus}}}{N(z,\Delta z)} + \sigma^2_{\mathrm{sys}}}, \qquad (6)$$

that is, the redshift error is the sum of the purely statistical (random Gaussian) error per cluster σ_{clus} and an irreducible, systematic error σ_{sys}. The source of the irreducible error could be, for example, a systematic offset in the photometric error determination which affects all clusters in that bin equally. We assume that the irreducible error is uncorrelated between bins. The Fisher matrix is constructed as in Eq. (1), with $O(z) \equiv N(z, \Delta z)$.

Redshift uncertainties: Number counts

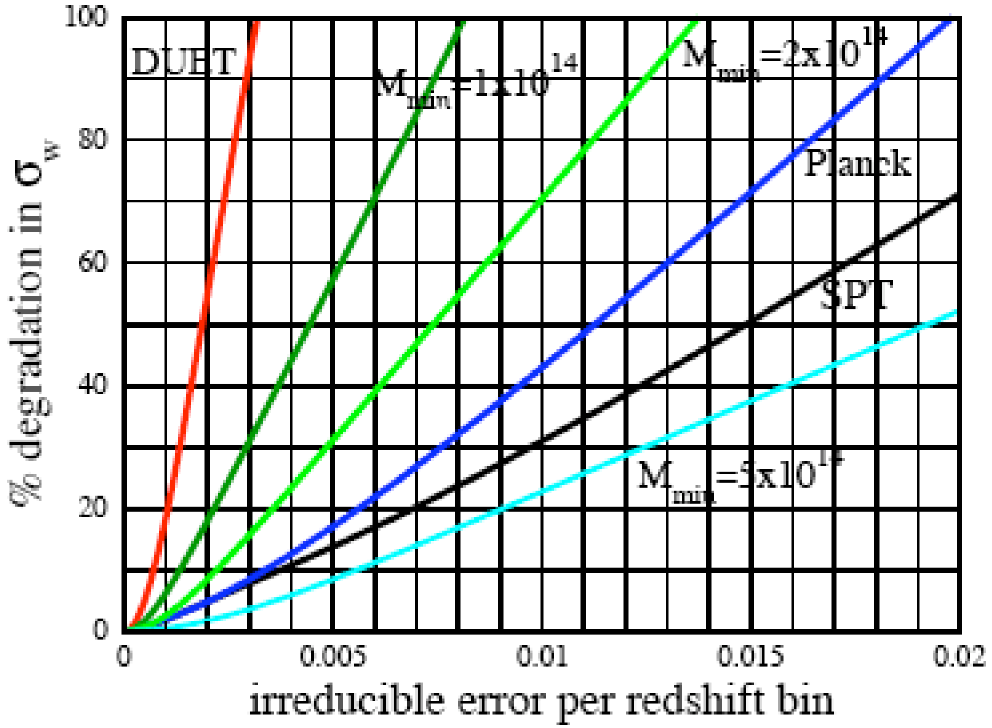


FIG. 4.— Degradation in the measurement accuracy of the equation of state as a function of the *irreducible* redshift error per bin. SPT and Planck curves use the mass-SZ flux relation to compute M_{min}, while the DUET curve uses the mass-Xray flux relation. The three other curves show the SPT survey with fixed M_{min} in units of $h^{-1}M_{\odot}$.

Redshift uncertainties: Number counts

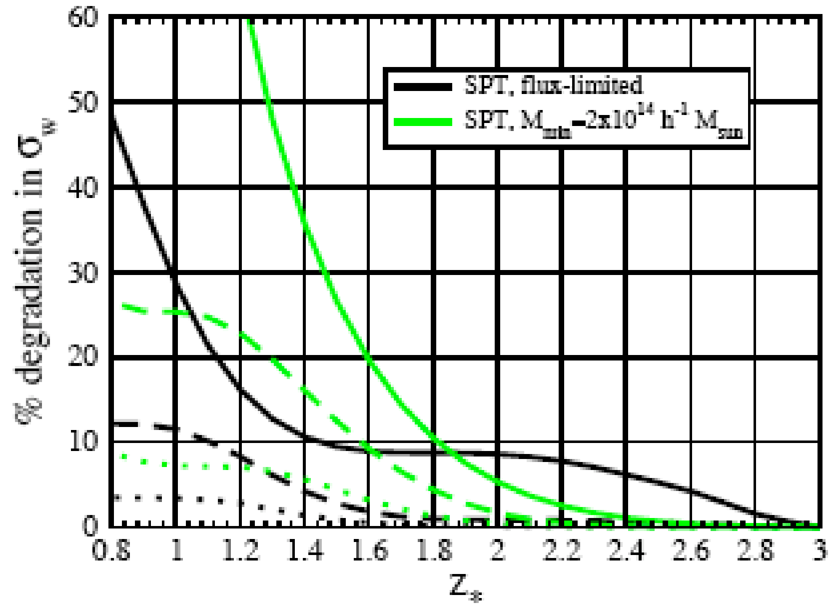


FIG. 5.— Degradation in the measurement accuracy of the equation of state as a function of the redshift z_* beyond which photometric redshift information is poor or nonexistent. Redshift information is assumed to be perfect at $z < z_*$, while at $z > z_*$ we alternatively assume: no redshift information (solid lines), irreducible errors of 0.05 per redshift bin width of $\Delta z = 0.1$ (dashed lines) and 0.02 per redshift bin (dotted lines). We show cases for the flux-limited SPT and for SPT with fixed $M_{\rm min}$. Note that an X-ray survey would show no degradation in σ_w at all, since essentially all of its clusters are at redshifts $\lesssim 1$.