E6: Astro/Cosmo/Particle Experiments

Snowmass Closing Plenary

July 19, 2001

Tim McKay

University of Michigan

Conveners:

- Suzanne Staggs: Princeton
- Harry Nelson: UCSB
- Kevin Lesko: LBL
- Tim McKay: Michigan

The place of “ACP” in fundamental physics

ACP was there at the birth of fundamental physics

- Relativity from Michelson-Morley
- Discovery of the proton, electron and neutron with natural radioactivity
- Discovery of the muon, positron, and other particles with CR beams

The universe: a well equipped lab

ACP plays a key role now

Watershed discoveries:

- Expanding universe (1920's)
- Dark matter (1930's)
- Black holes (1970's)
- Neutrino oscillations (1990's)
- Dark energy (3 years ago…)

Explosive advance in cosmology

A goal: take fundamental physics beyond the standard model

The requirement: pursue every promising approach

<u>Busy, diverse, *highly incomplete* schedule</u>

E6.1 CMBR experimentation: Staggs
- 7/6: Next Generation CMB Experiments: Polarization
- 7/7: Next Generation CMB Experiments: Sunyaev-Zeldovitch

E6.2 Dark matter detection: Nelson
- 7/7: Existing Dark Matter Experiments
- 7/9: Future Dark Matter Experiments

E6.3 The history of expansion/dark energy detection: McKay
- 7/11: Current Status of Dark Energy Experiments
- 7/14: Future of Dark Energy Experiments

E6.4 Underground experiments: Lesko
- 7/11: Double Beta Decay
- 7/13: Next Generation Solar and Supernova Neutrino Experiments
- 7/17: Proton Decay Experiments
- 7/16: A National Underground Laboratory

E6.5 High energy astrophysics/cosmic rays: McKay
- 7/10: Large Astrophysical Neutrino Detectors (w/Barwick)
- 7/17: Future Cosmic Ray Experiments (w/Thompson)
- 7/13: Future Gamma-Ray Astrophysics Experiments (w/Buckley)

E6.6 Tests of gravity/gravity waves: Nelson
- 7/4: Future Tests of Gravity and General Relativity

Very selective “Snowmass” sample of activity

The "particle" part of E6

Particle experiments

– Sometimes astrophysical beams

Dark matter direct detection

– Emphasis on WIMPs and Axions

Underground experiments

– Solar neutrino experiments
– Double beta decay
– Proton decay

Gravity

– Extra dimensions

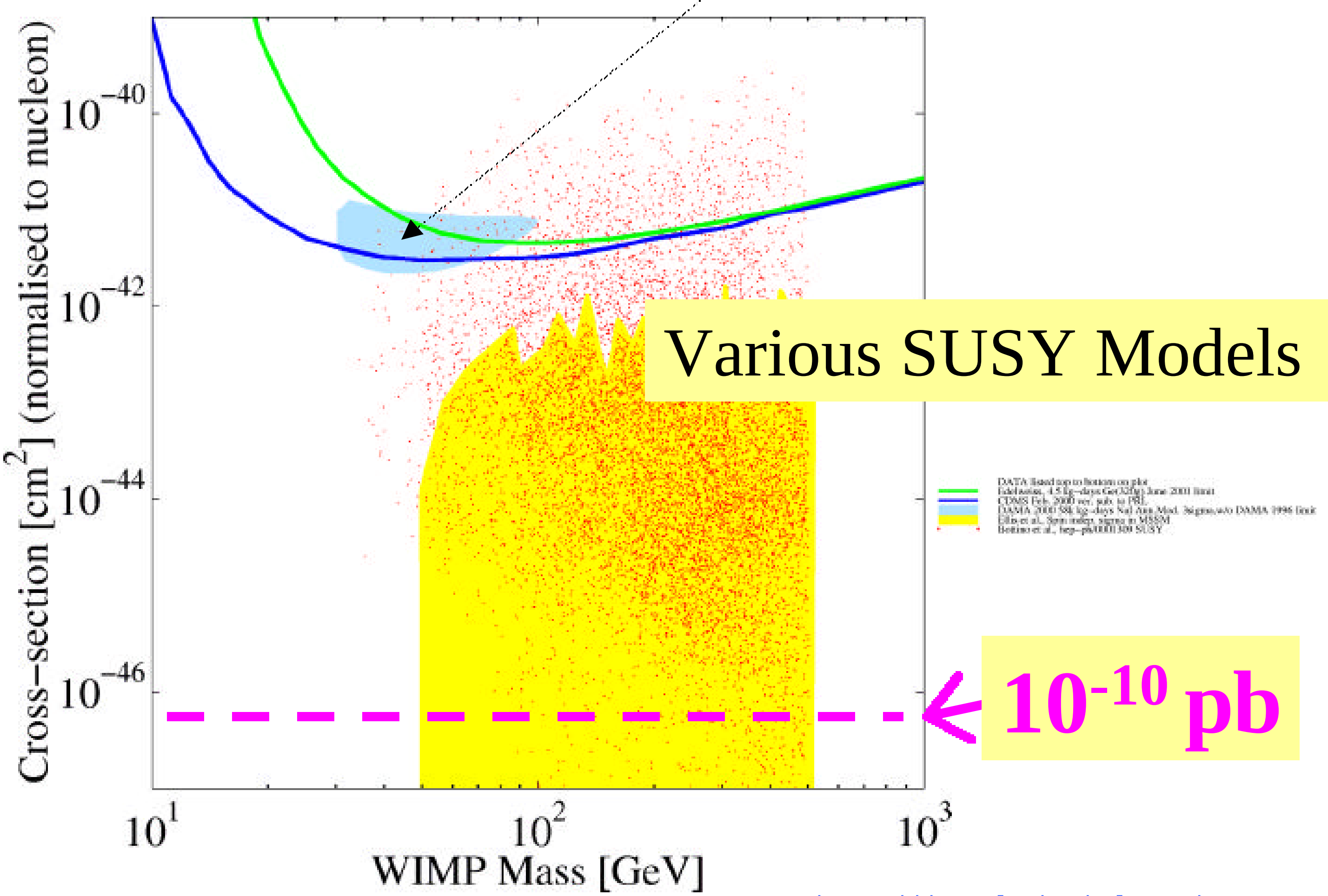
E6.2: Dark matter detection

- WIMP - massive Dark Matter particle, weak interaction cross section ó
  - ó enables dark/luminous matter balance
  - SUSY broken at weak scale provides attractive candidate - LSP (Neutralino, χ)
  - SUSY discovery at accelerators would be ideal!
- Favored SUSY models have no definitive floor on χ-nucleon scattering cross section ó
  - ó $\approx 10^{-46}$ cm^2 (=10^{-10} picobarn) significant
  - tiny ó » strong amplitudes cancel » when does that ever happen?

Harry Nelson: UCSB

Current Status of DM detection

Experiment (CDMS, DAMA, Edelweiss)



http://dmtools.berkeley.edu
(Gaitskell/Mandic)

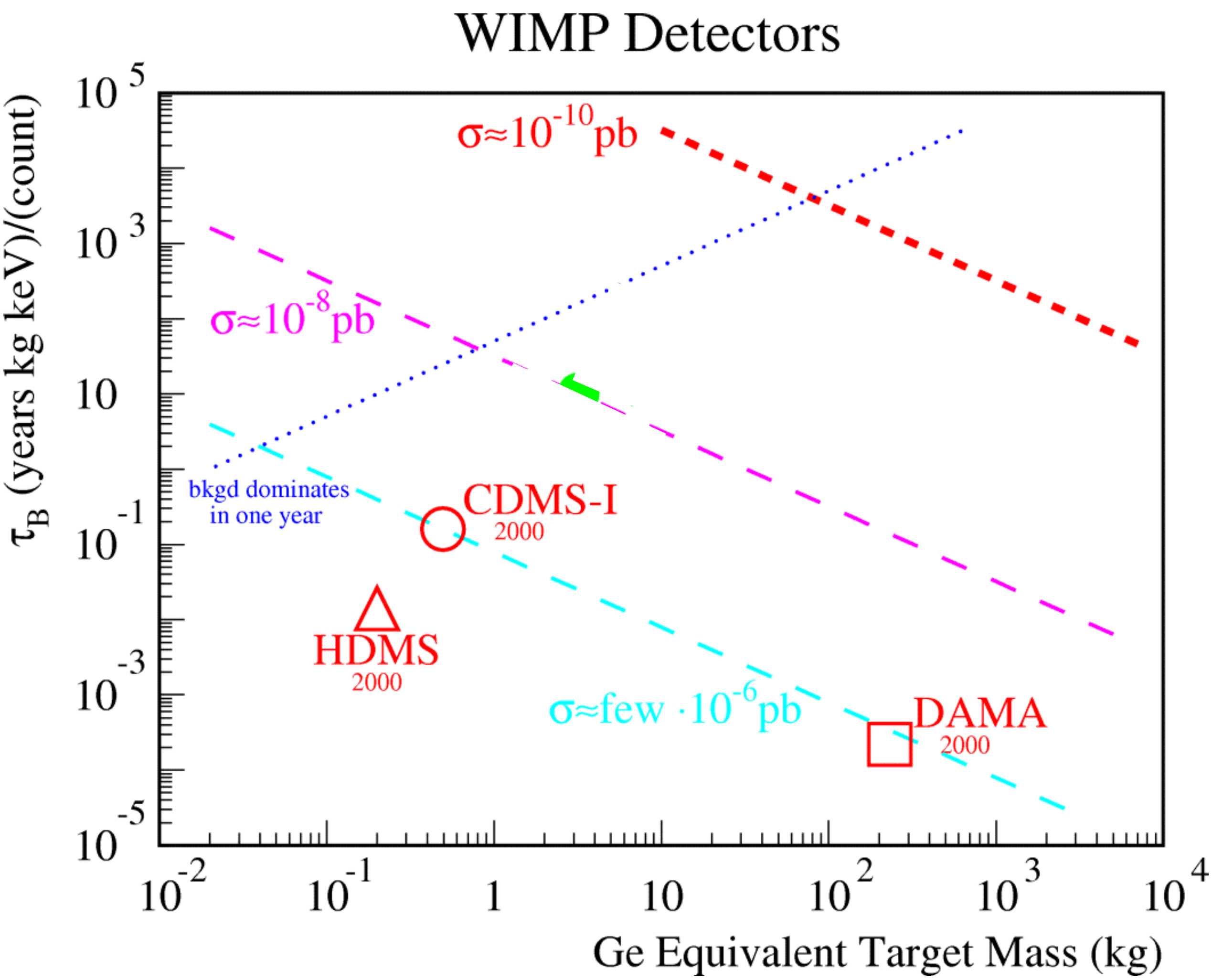
Some Key Variables

- Mass - converted to kg Germanium, assuming coherence

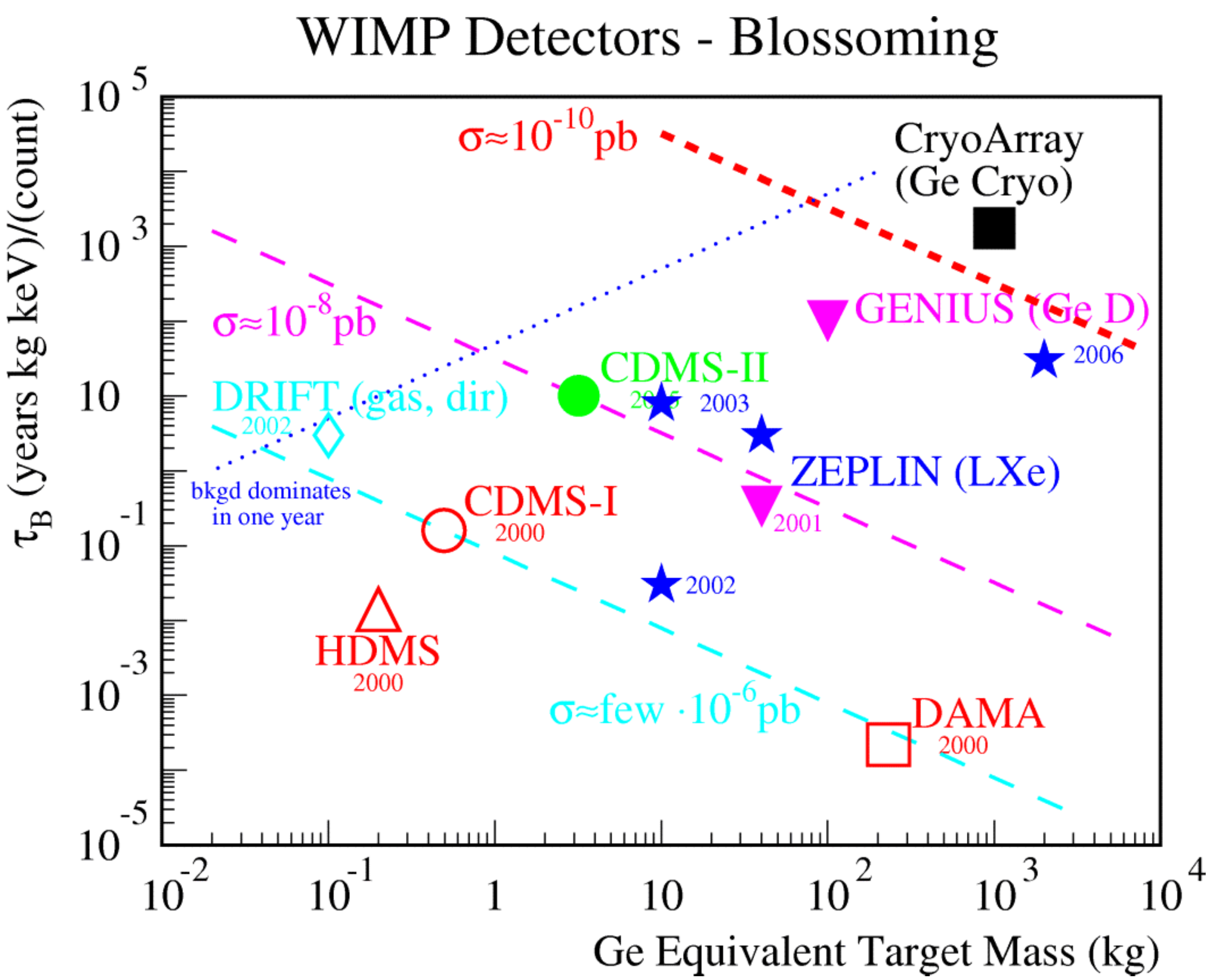
- Time τ_B between background events in years, for 1 kg and for a bin width in energy deposition of 1 keV.
  - Experiments usually run until background limited… region shown on the plot...

- Plot τ_B v. Mass to see progression from 10^{-6} pb sensitivity (now) to **10^{-10} pb**

Current comparison space



Future comparison space



E6-4

Solar Neutrino Experiments

Double Beta Decay

Proton Decay

Underground Science Lab

Kevin T. Lesko
lear and Particle
erkeley National

Solar Neutrino Experiments

- SNO confirms solar model!
- Sun is ν source calibrated to 1%: the best low energy ν source!
- Next generation experiments will be proposed in < 5 years
  - H_2O Cerenkov, Superfluid He, TPC, Doped liquid scint., Mo foils + scint., 76Ge….
- Much more in neutrino sessions…

Backgrounds are **the** major issue
=> deep underground site?

Double-Beta Decay

- Observing a factor of 2 increase in $t_{1/2}$ each year
- 2-ν decay may be a major background for 0-ν experiments
- Only experimental approach to Dirac/Majorana nature of neutrinos
- May be the only direct approach to neutrino masses
- Next Generation Experiment Proposals ready within 1 to 2 years
- Significant overlap with Low Energy Solar Neutrinos and Dark Matter: again, background is a limiting factor

A low background underground Lab

Dark Matter Searches
Double Beta Decay
Low Energy Solar Neutrinos

Require great depth for next generation experiments, at least 4500 and realistically >6000 mwe

World's deepest Multipurpose Lab

- **Double beta decay**
- **Low energy solar neutrinos**
- **Supernovae searches**
- **Dark matter searches**
- **Proton decay**
- **Long baseline**

Extensive Nuclear Physics Discussion

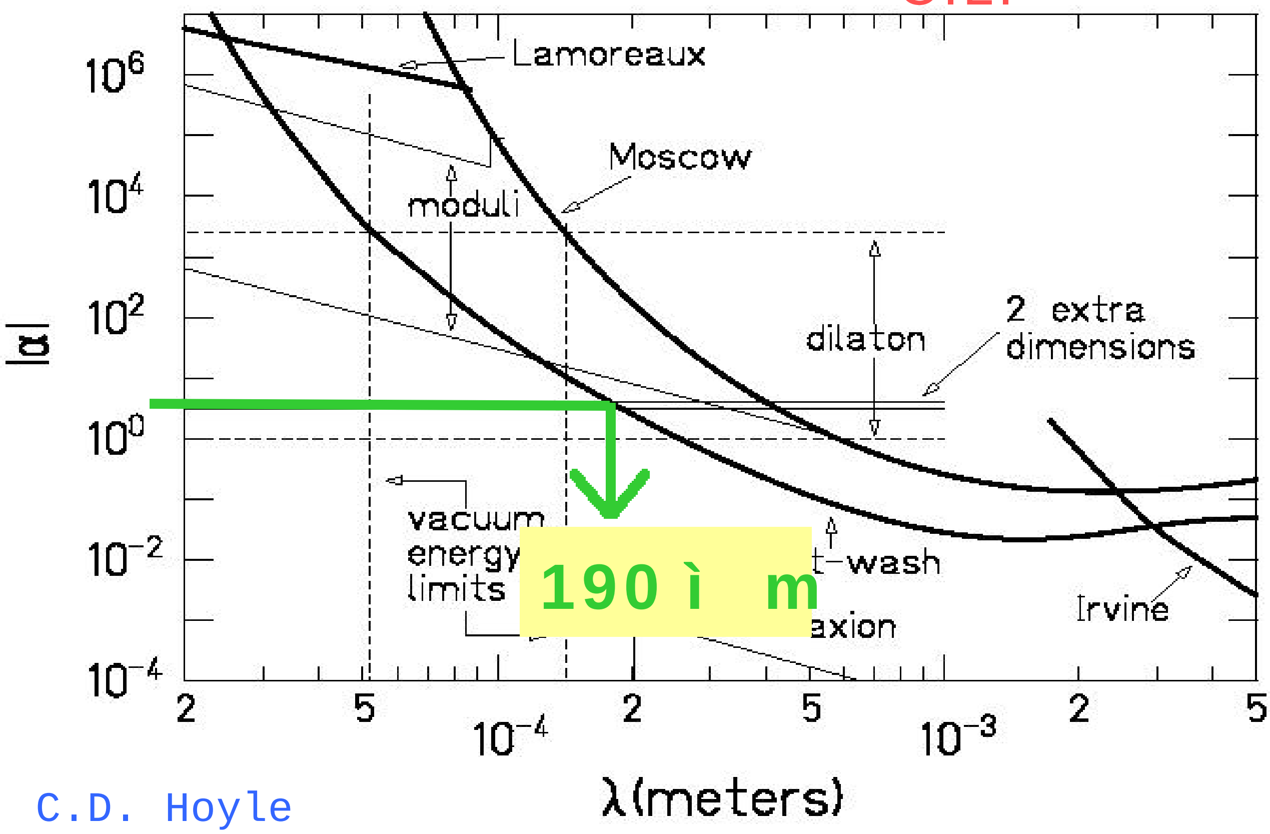
Independent Multidisciplinary Committee Examination

NSF Proposal
- **Usual peer review**

A new national lab?

E6.6: Gravity

UW Torsion Balance: $V = V_N\,(1+\alpha\, e^{-r/\lambda})$ 95% C.L.



C.D. Hoyle

20ì m foreseen: Large extra dimensions start to look small…

The "astro" part of E6

Experiments *primarily* directed at understanding astrophysical phenomena: *can often challenge fundamental physics!*

Use HEP technologies/approaches

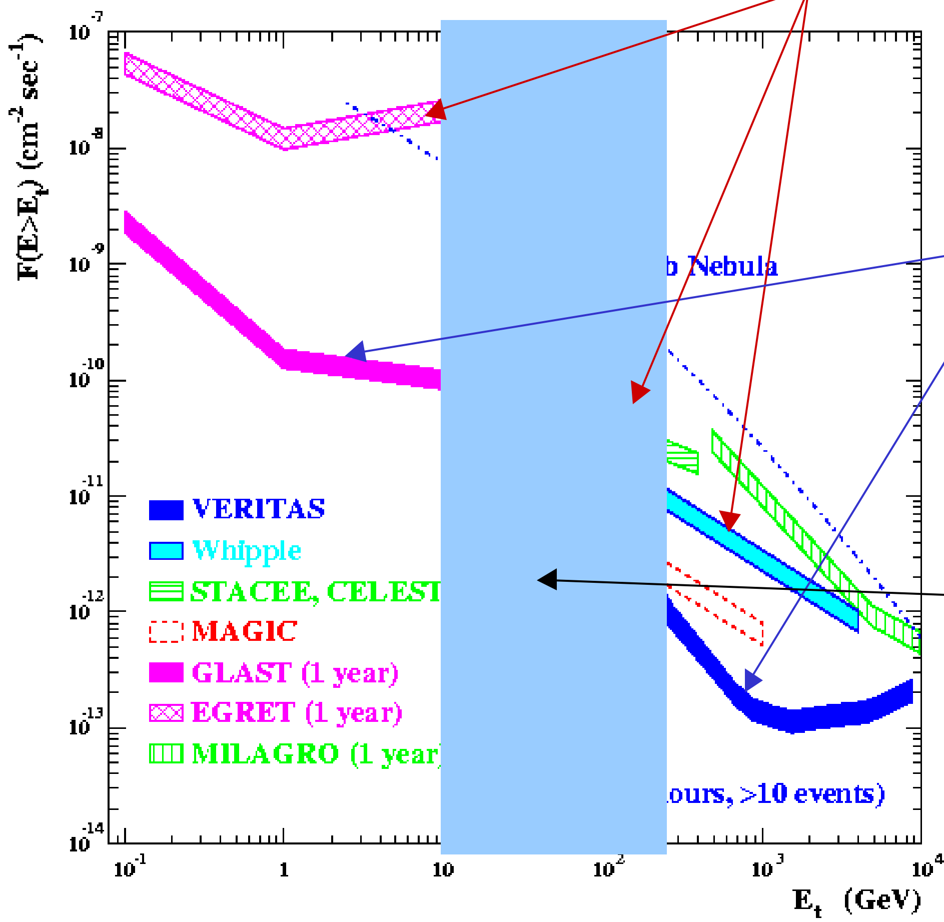
E6.5:

- Large astrophysical ν detectors (w/Barwick)
- Future gamma-ray astronomy (w/P4 and Buckley)
- Future cosmic ray experiments (w/Thompson)

E6.5: ν’s, γ’s and CR’s

- Km^3 ν detectors are on the horizon.
- γ-ray astronomy closing the space/ground gapi
  - Down from above: ACT’s
  - Up from below: GLAST: 2005
- CMBR π photo-production cut-off and the IR background

Current sensitivity



5-10 years

Old energy gap

E6.5: ν's, γ's and CR's

- Cosmic Rays: a primary goal is understanding acceleration
- Very large detectors needed for highest energies
  - High-Resolution Fly's eye and AGASA
  - Auger: 5000 km^2 air shower array in construction in Argentina
  - Telescope array
- At lower energies: composition
  - Balloons: HEAT, etc.
  - Space: AMS on the space station

The “cosmo” side of E6

Contents and evolution of the universe provide a direct constraint on fundamental physics

- Probes unique conditions (early universe)
- Probes unique timescales
- Only way to watch space-time evolve

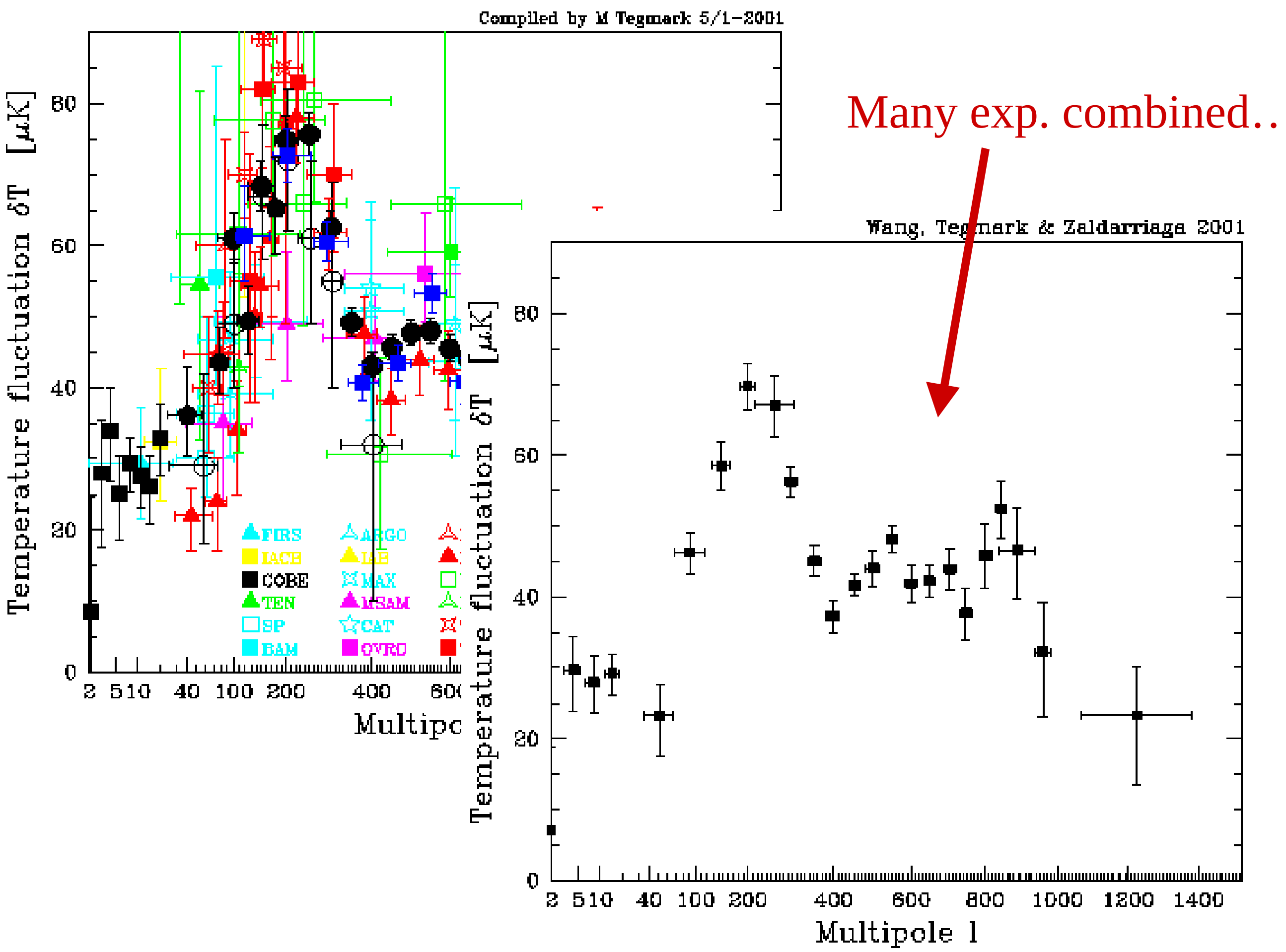
E6.1 and E6.3

- Cosmic microwave background exp.
- Dark energy detection

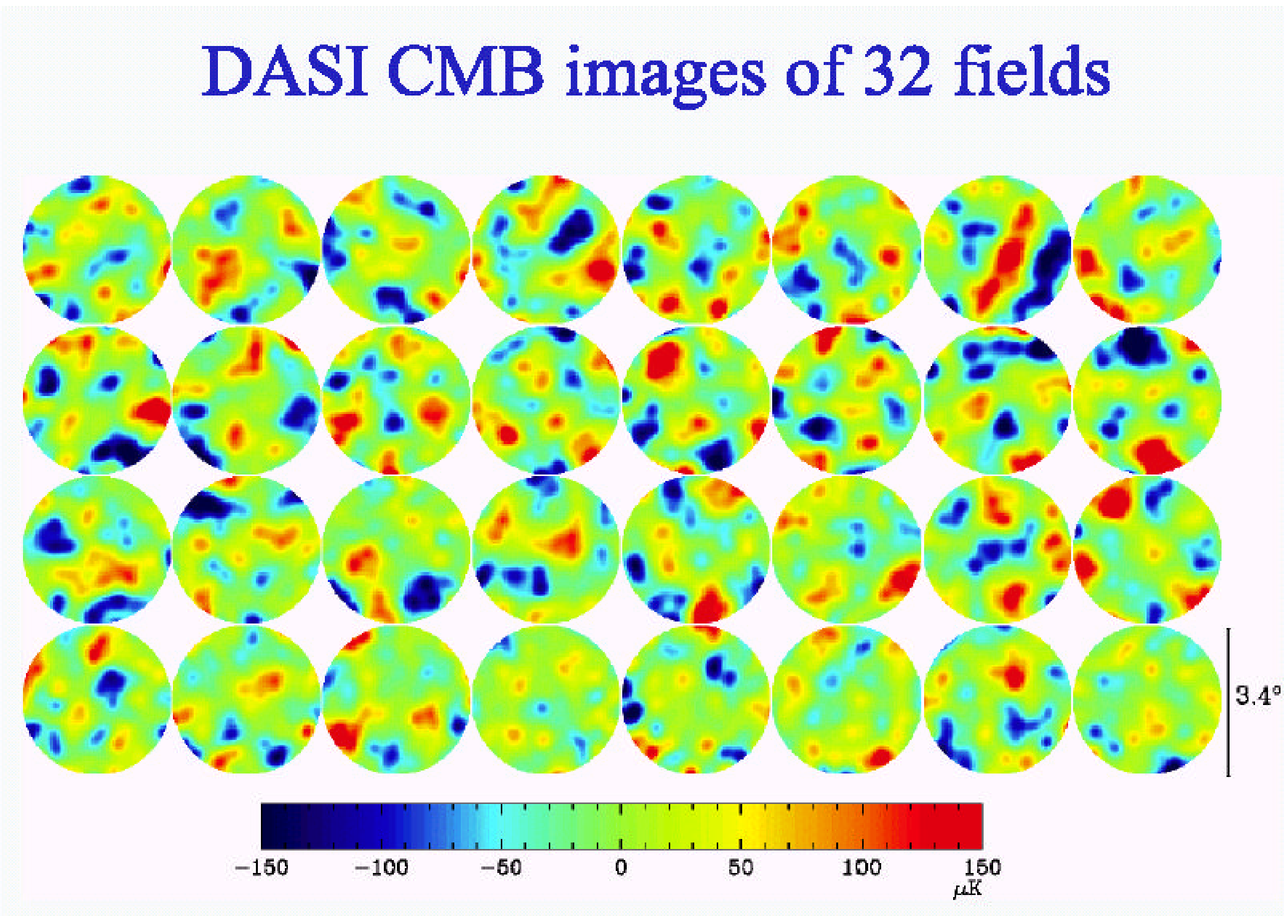
E6.1: CMBR experiments

CMBR is advancing to few % science.

Anisotropy accessible to many exp.



Big step: single exp. detections



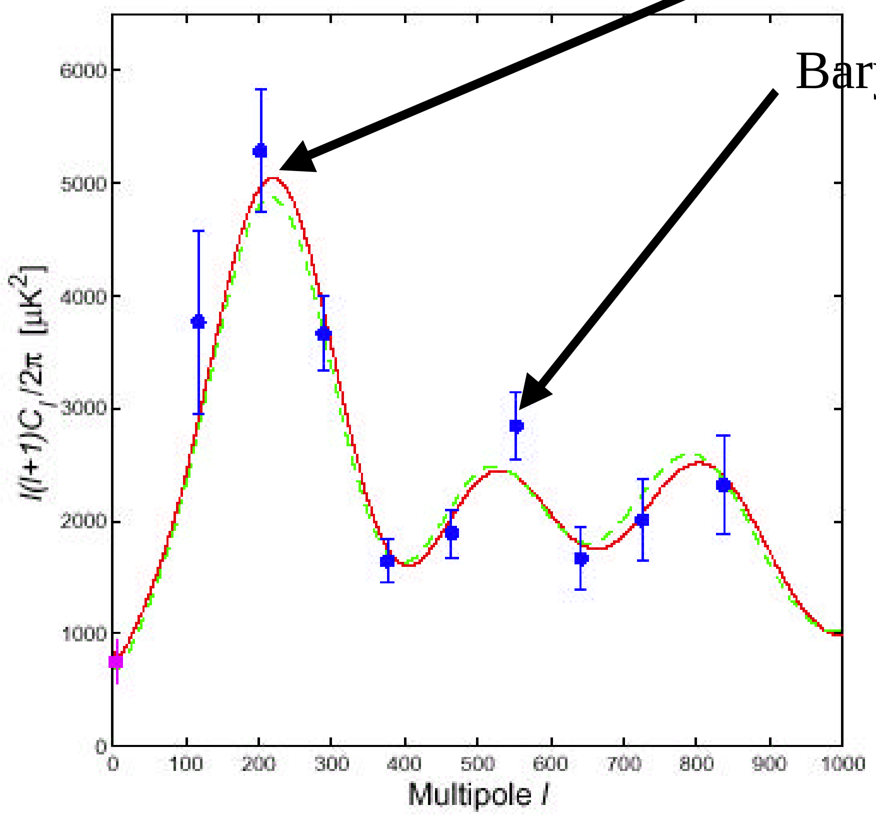
Carlstrom et al., Chicago and MSFC

Big step: single exp. detections

Ω_{total}=1.04+/-0.06

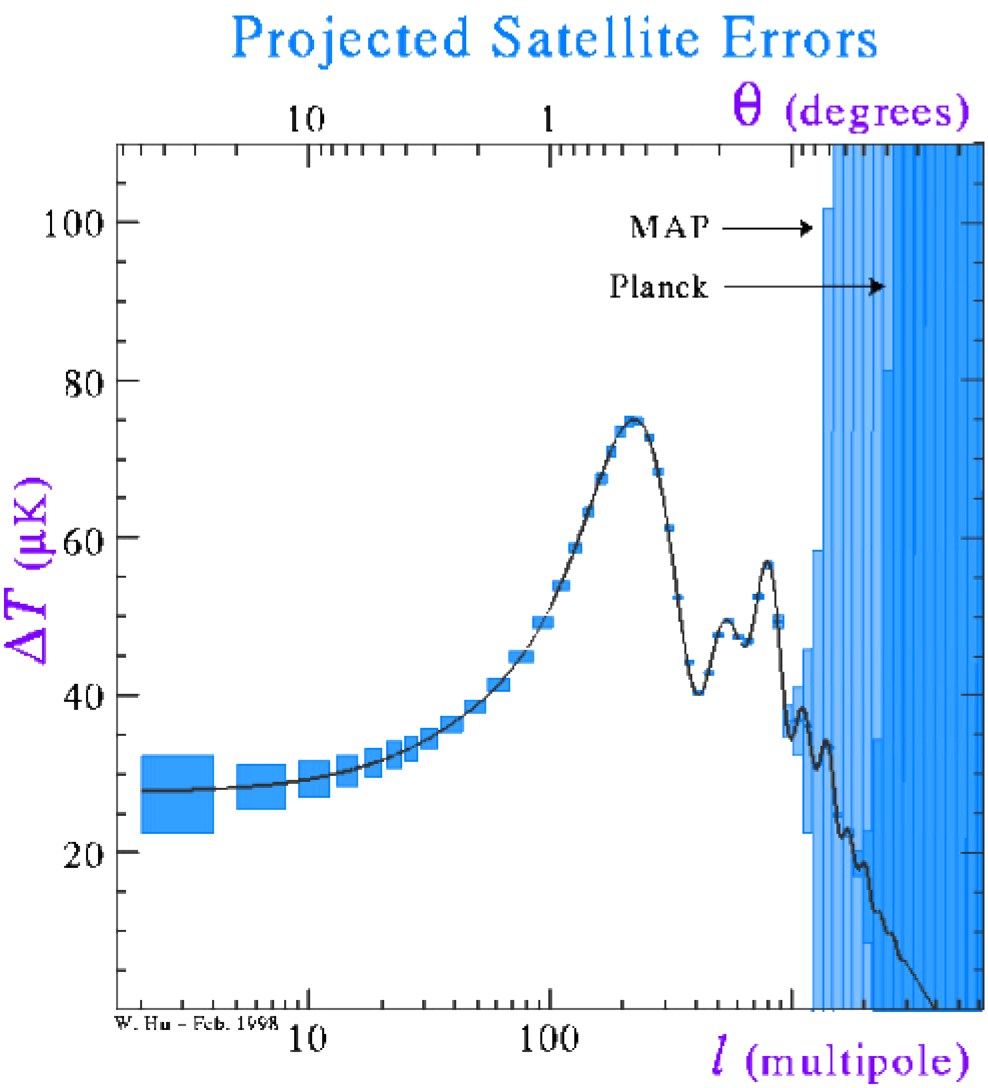
Flat universe

Baryon density



DASI example: Pryke et al. astro-ph/0104490

The future of CMB anisotropy: MAP + Planck



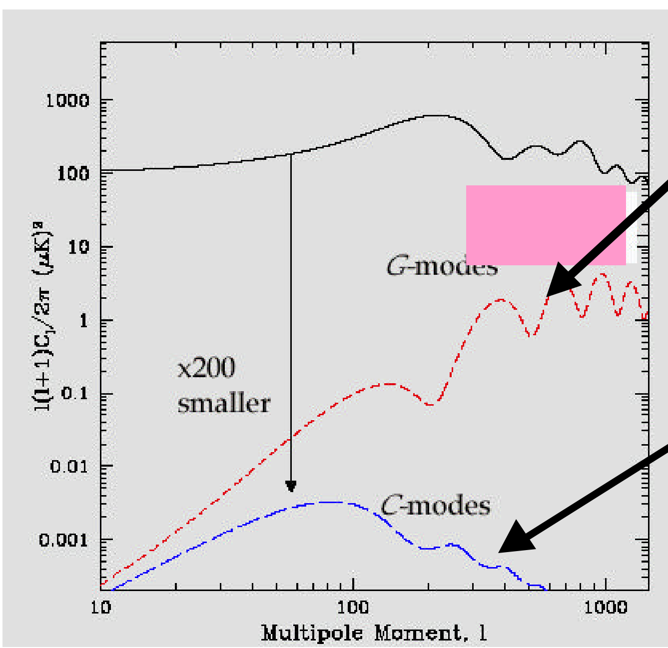
Wayne Hu: Chicago

CMB Polarization

Polarization imprinted before decoupling and during reionization

- Hints of the inflaton potential

This is the new frontier for CMB



Sarah Church: Stanford

E modes: density fluctuations and reionization

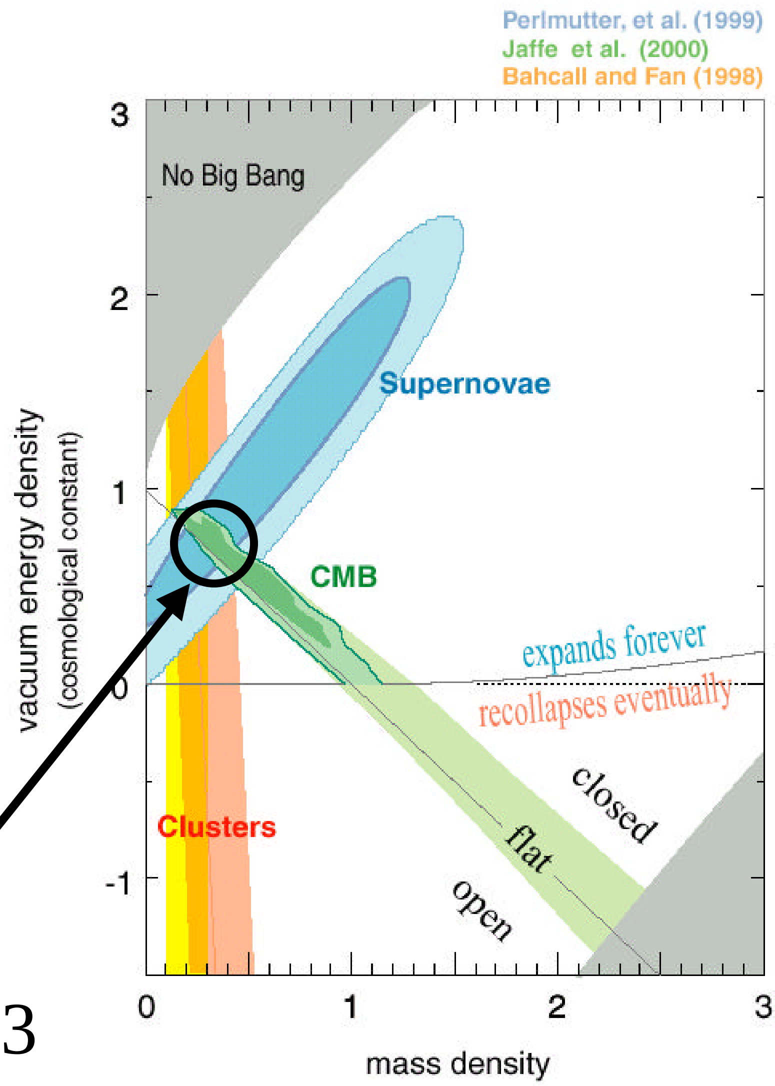
B modes: **inflaton potential**

E6.3: Dark energy detection

Biggest surprise since Snowmass ‘96

Is it real?

Combination of SNe, matter density, and CMBR makes dark energy inescapable



You are here:

$\Omega_\Lambda \approx 0.7 \quad \Omega_m \approx 0.3$

Why is it important?

Because it isn't zero….Comments on dark energy

J. Harvey: "Basically, people don't have a clue as to how to solve this problem"

S. Weinberg: "Right now, not only for cosmology but for elementary particle physics, this is the bone in our throat"

E. Witten: "…would be number one on my list of things to figure out"

From Science Times, 30 Nov. 1999, J. Glanz

Dark energy experiments

Fundamental cosmology: must observe the expansion history of the universe

Inaccessible to accelerators

Many approaches: SNe standard candles, cluster counting, lensing, Lyman-α forest…

CMBR is *not* sensitive to this

Different sensitivities and systematics: all must be pursued

Only the SNe approach has detected dark energy and faced its systematic errors: it will play a crucial role in the decade to come

Nature provides a SNe ‘beam’ to allow us to view the evolution of the expansion rate.

Already systematics limited!

Score Card of *Current* Uncertainties

on $(\Omega_{M,}^{flat}\ \Omega_{\Lambda}^{flat}) = (0.28, 0.72)$

Statistical

☑ high-redshift SNe	0.05
☑ low-redshift SNe	0.065
Total	***0.085***

Systematic

☑ dust that reddens $R_B(z=0.5) < 2\ R_B(\text{today})$	< 0.03
evolving grey dust	
? clumpy	
? same for each SN	
☑ Malmquist bias difference	< 0.04
? SN Ia evolution shifting distribution of prog mass/metallicity/C-O/..	
☑ K-correction uncertainty including zero-points	< 0.025
Total identified entities/processes	***0.05***

Late 1998….

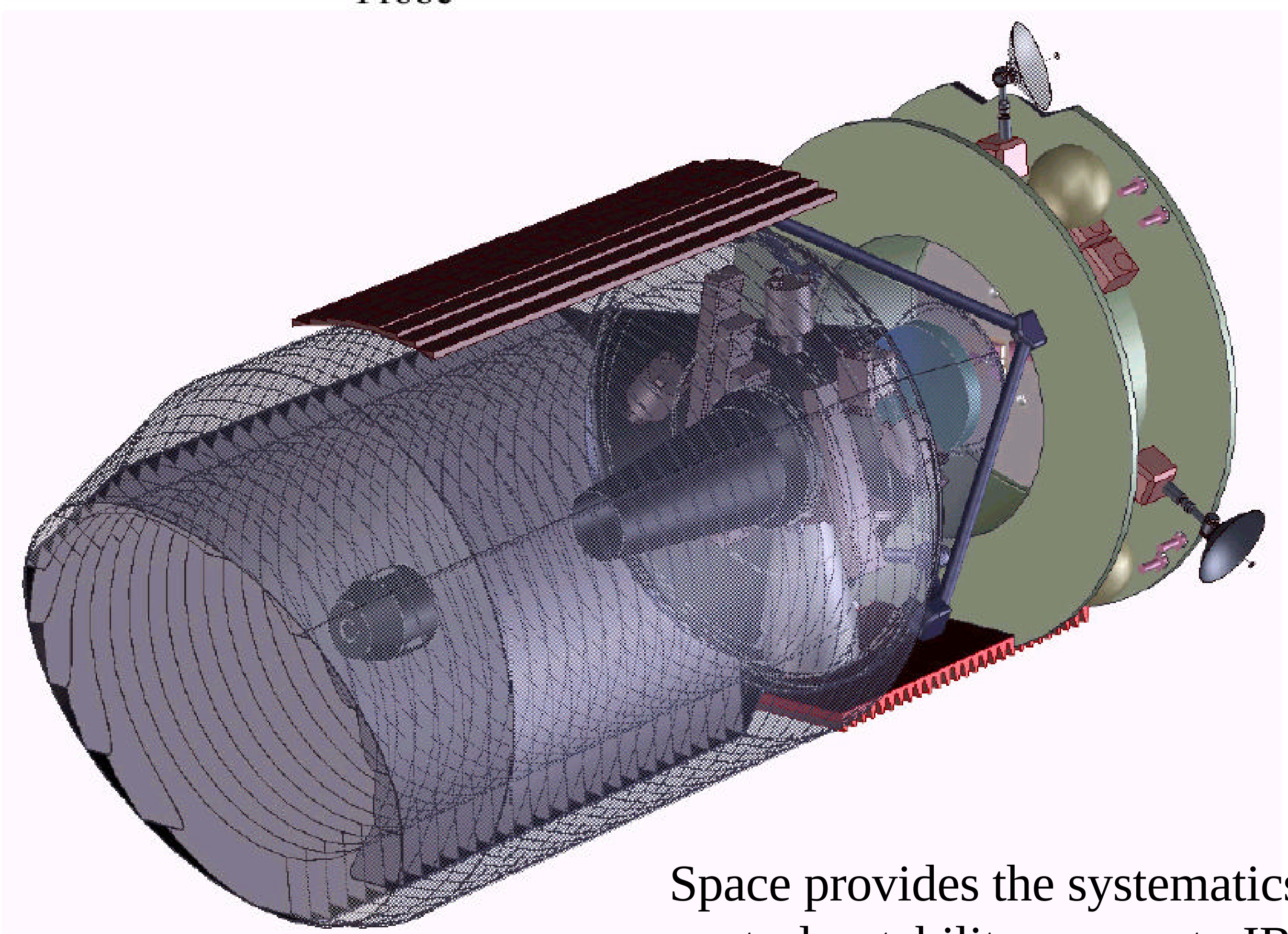
Cross-Checks of sensitivity to

☑ Width-Luminosity Relation	< 0.03
☑ Non-SN Ia contamination	< 0.05
☑ Galactic Extinction Model	< 0.04
☑ Gravitational Lensing by clumped mass	< 0.06

Perlmutter *et al.* (1998)
astro-ph/9812133

Taking advantage of the SNe beam

SNAP SuperNova Acceleration Probe

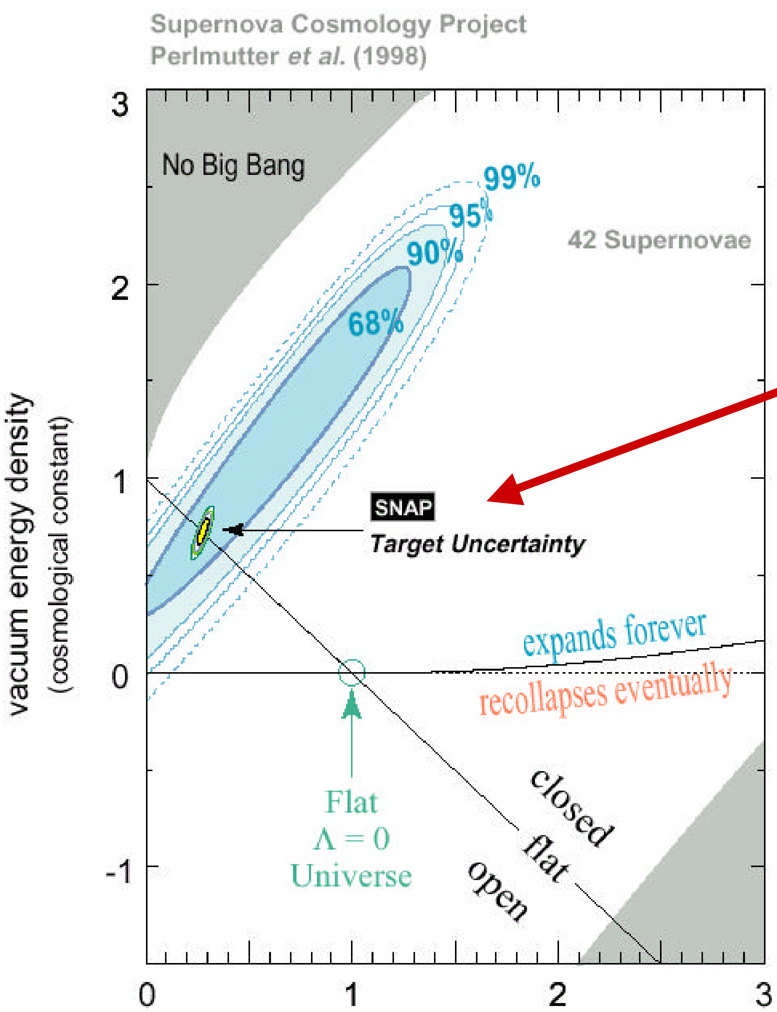


Space provides the systematics controls: stability, access to IR observations, high-z

Why space? Systematic error control

Score Card of Current Uncertainties on $(\Omega_{M,}^{flat}\ \Omega_{\Lambda}^{flat}) = (0.28, 0.72)$		SNAP Requirement to satisfy $\delta M(peak) < 0.02$
Statistical		
✓ high-redshift SNe	0.05	Discover and follow 2000+ SN Ia per year
✓ low-redshift SNe	0.065	
Total	***0.085***	
Systematic		
✓ dust that reddens $R_B(z=0.5) < 2\ R_B(\text{today})$	< 0.03	Optical & NIR calibrated spectra to observe wavelength dependent absorption
evolving grey dust		
? clumpy		NIR spectra, go to high redshift
? same for each SN		
✓ Malmquist bias difference	< 0.04	Detection of every SN 2.5 mag below peak for z = 0 to 1.7
? SN Ia evolution shifting distribution of prog mass/metallicity/C-O/..		Spectral features and lightcurve features. Go to high redshift.
✓ K-correction uncertainty including zero-points	< 0.025	Restframe B matched filters, spectral time series, cross wavelength relative flux calibration,
Total identified entities/processes	***0.05***	
Cross-Checks of sensitivity to		
✓ Width-Luminosity Relation	< 0.03	
✓ Non-SN Ia contamination	< 0.05	Restframe SiII.
✓ Galactic Extinction Model	< 0.04	SDSS+SIRTF & SNAP WD spectra
✓ Gravitational Lensing by clumped mass	< 0.06	~75 SN per redshift bin.SNAP microlensing experiments

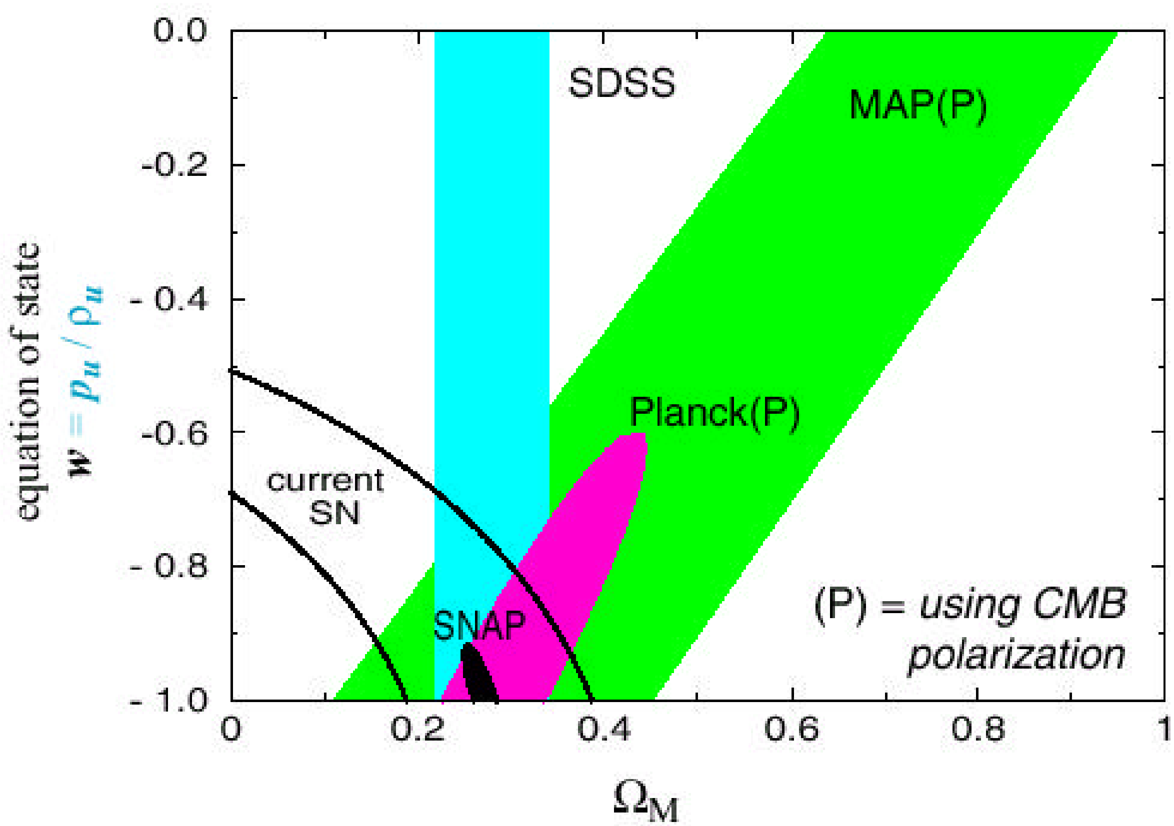
Where will we get?



Includes systematic errors

What will we learn?

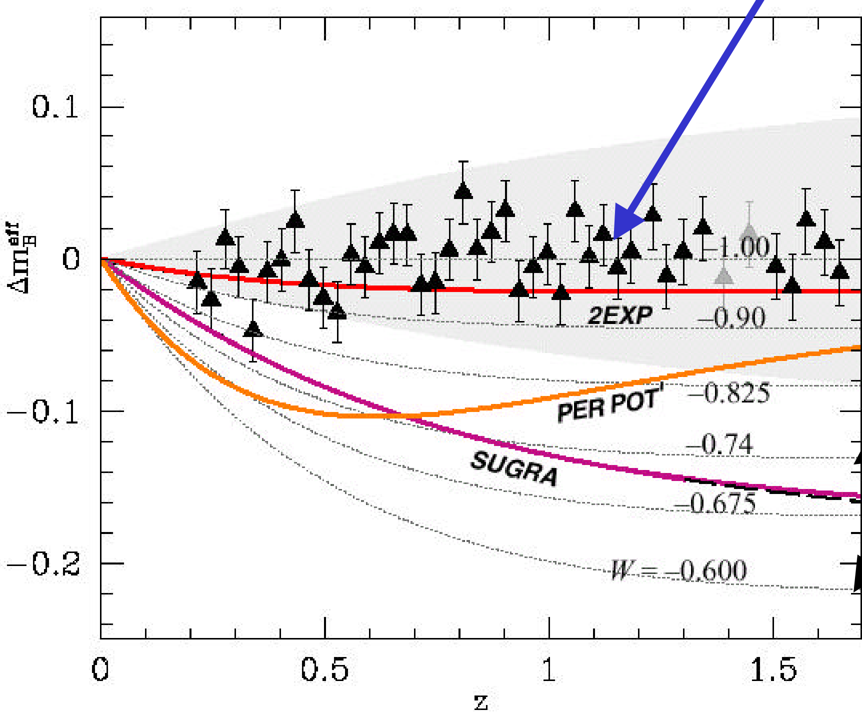
- Basic nature of dark energy
  - Equation of state: $w = p/\rho$
- Good constraints on *evolution* of dark energy: w'



Variations of w

SNAP simulated data

Binned simulated SNAP data
compared with Dark Energy models.



Constant w models

based on
Weller & Albrecht (2000)

How will it affect fundamental physics?

"It is difficult for physicists to attack this problem without knowing just what it is that needs to be explained; a cosmological constant or a dark energy that changes with time as the universe evolves, and for this they must rely on new observations by astronomers. Until it is solved, the problem of the dark energy will be a roadblock on our path to a comprehensive fundamental physical theory."

Steven Weinberg, 2001

Some E6 Conclusions

The universe *is* our laboratory. It provides:

- A bath of DM particles
- Beams of neutrinos
- Spacetime singularities
- A big-bang
- A chance to watch the evolution of a space-time

Fundamental physics, esp. the unification of gravity with other forces, will not be understood without appeal to astro/cosmo/particle experiments