Opportunities for US-Japan Collaboration: A Personal View

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With thanks to Josh Frieman, Roger Blandford, Angela Olinto and Scott Dodelson

IPMU Opening Symposium 12-March-08

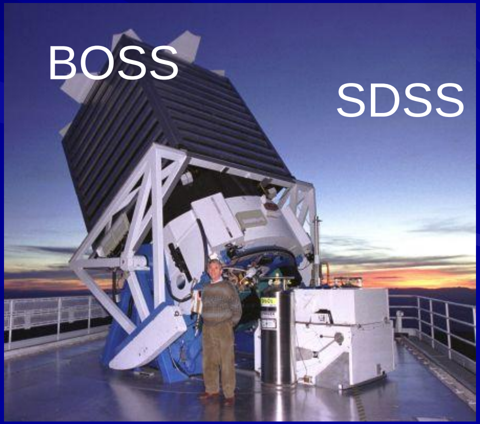
Building International Collaborations

- There are 3 major components to the US program in High Energy Physics with potential for collaboration
  - Accelerator-based particle physics at the energy frontier
  - Accelerator and reactor-based neutrino experiments
  - Astrophysics and Cosmology

Accelerator-based physics already has strong collaborations; astrophysics and cosmology are rich opportunities

Particle Astrophysics and Cosmology: A "grassroots" effort supported by labs

- Numerous efforts initiated by university and lab groups:
  - SCP, GLAST, SDSS, SDSSII
  - DES, BOSS, SNAP, LSST
- DOE-supported discovery of dark energy is among the major achievements of our field.
- Dark energy is the *biggest* challenge in fundamental physics.



Outline

- Cosmology
- Deep Underground Science and Engineering Lab (DUSEL)
- High Energy Astrophysics
- Many experiments I will mention have foreign participation…I'll indicate the thrust areas of interest to the US community

To begin Cosmology, we look at Dark Energy and Cosmic Acceleration

What is causing cosmic acceleration?

Dark Energy:

$$G_{\mu\nu} = 8\pi G[T_{\mu\nu}(\text{matter}) + T_{\mu\nu}(\text{dark energy})]$$

$$\text{DE equation of state :} \qquad w = T_i^i / T_0^0 < -1/3$$

Gravity:

$$G_{\mu\nu} + f(g_{\mu\nu}) = 8\pi G T_{\mu\nu}(\text{matter})$$

Key Experimental Questions:

1. Is DE observationally distinguishable from a cosmological constant, for which w =—1?
2. Can we distinguish between gravity and dark energy?
   Combine distance with structure-growth probes
3. Does dark energy evolve: w=w(z) ?

The nature of Dark Energy?

- Probe dark energy through the history of the expansion rate:

$$\frac{H^2(z)}{H_0^2} = \Omega_m (1+z)^3 + \Omega_{DE} \exp\left[3\int (1+w(z))\, d\ln(1+z)\right] + (1-\Omega_m - \Omega_{DE})(1+z)^2$$

- and the growth of large-scale structure: $\frac{\delta\rho(a)}{\rho}$

$$r(z) = F\left[\int \frac{dz}{H(z)}\right]$$

$$\frac{dV}{dz\,d\Omega} = \frac{r^2(z)}{H(z)}$$

Four Primary Probes (DETF):

- Weak Lensing cosmic shear — Distance *r(z)* + growth
- Supernovae — Distance
- Baryon Acoustic Oscillations — Distance+*H(z)*
- Cluster counting — Distance + growth

Dark Energy Task Force Report

- Defined Figure of Merit to compare experiments and methods

$$FoM \propto \frac{1}{\sigma(w_0)\sigma(w_a)}$$

- Highlighted 4 probes: SN, WL, BAO, CL
- Envisioned staged program of experiments:

  Stage II: on-going or funded as of 2006

  Stage III: intermediate in scale + time

  Stage IV: longer-term, larger scale

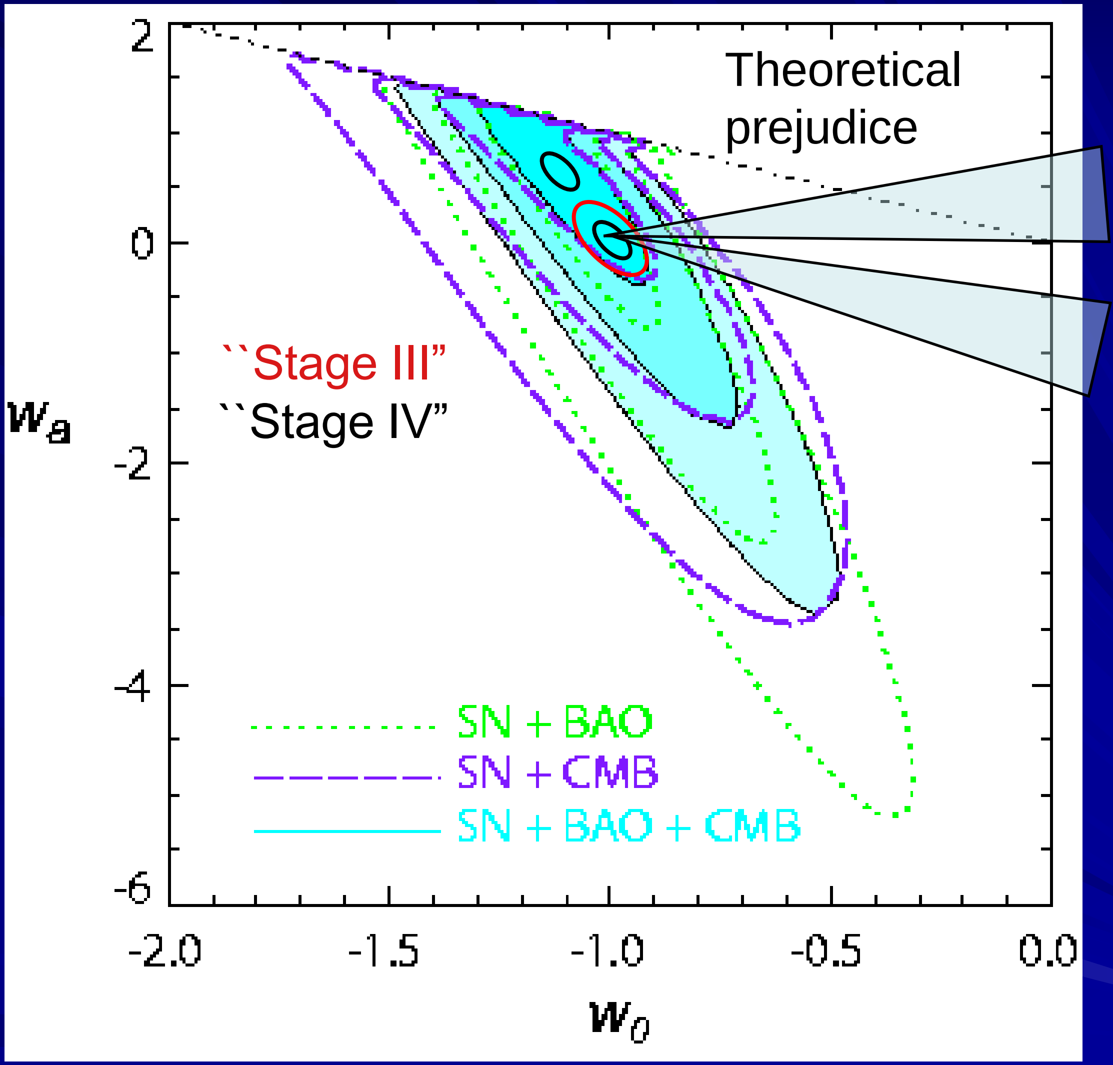
  LSST, JDEM

Much weaker current constraints on Time-varying Dark Energy

3-parameter model

$$w(z) = w_0 + w_a(1-a)$$

marginalized over Ω_m



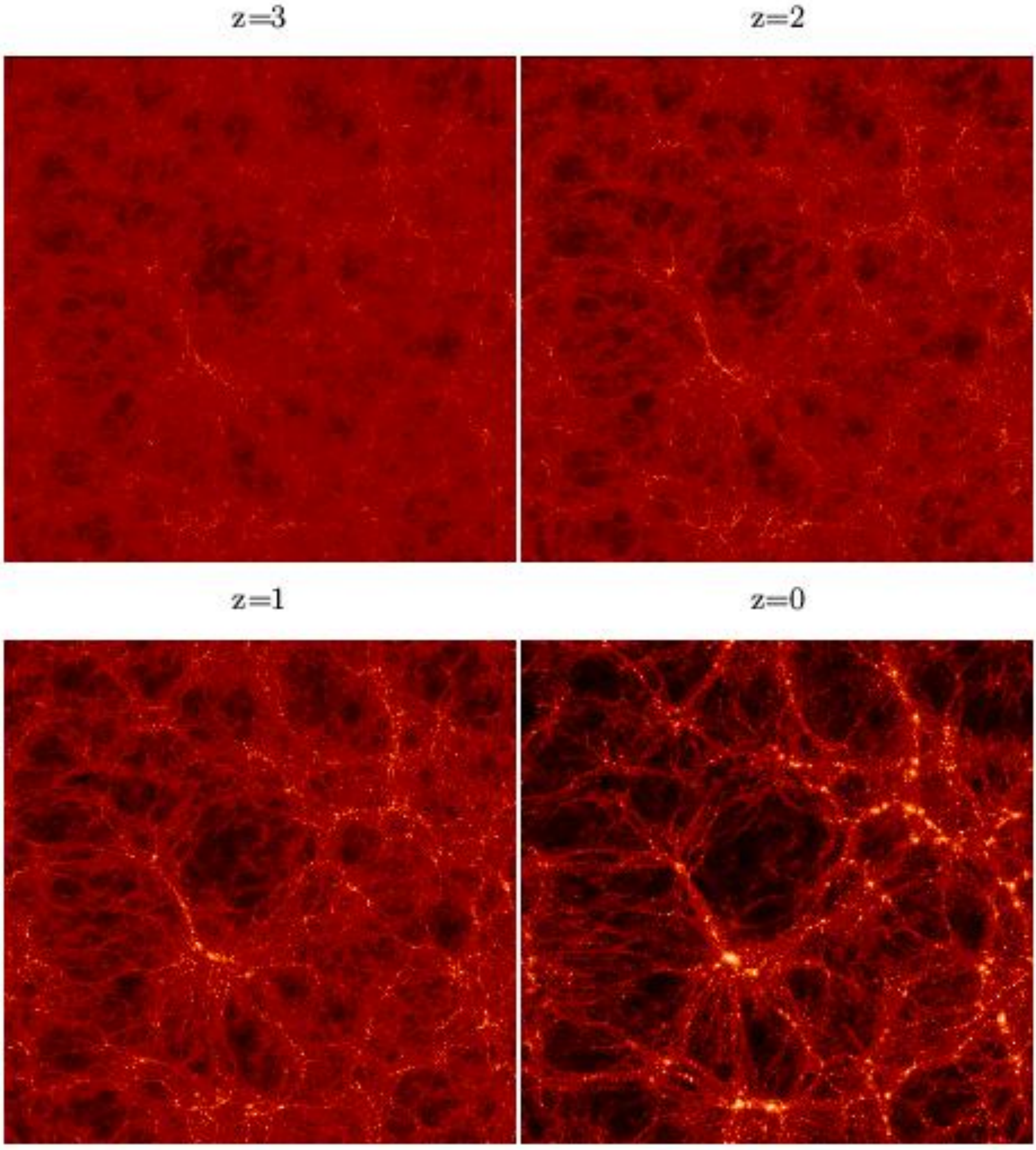
Kowalski et al 08

Growth of Large-scale Structure

Robustness of the paradigm recommends its use as a Dark Energy probe

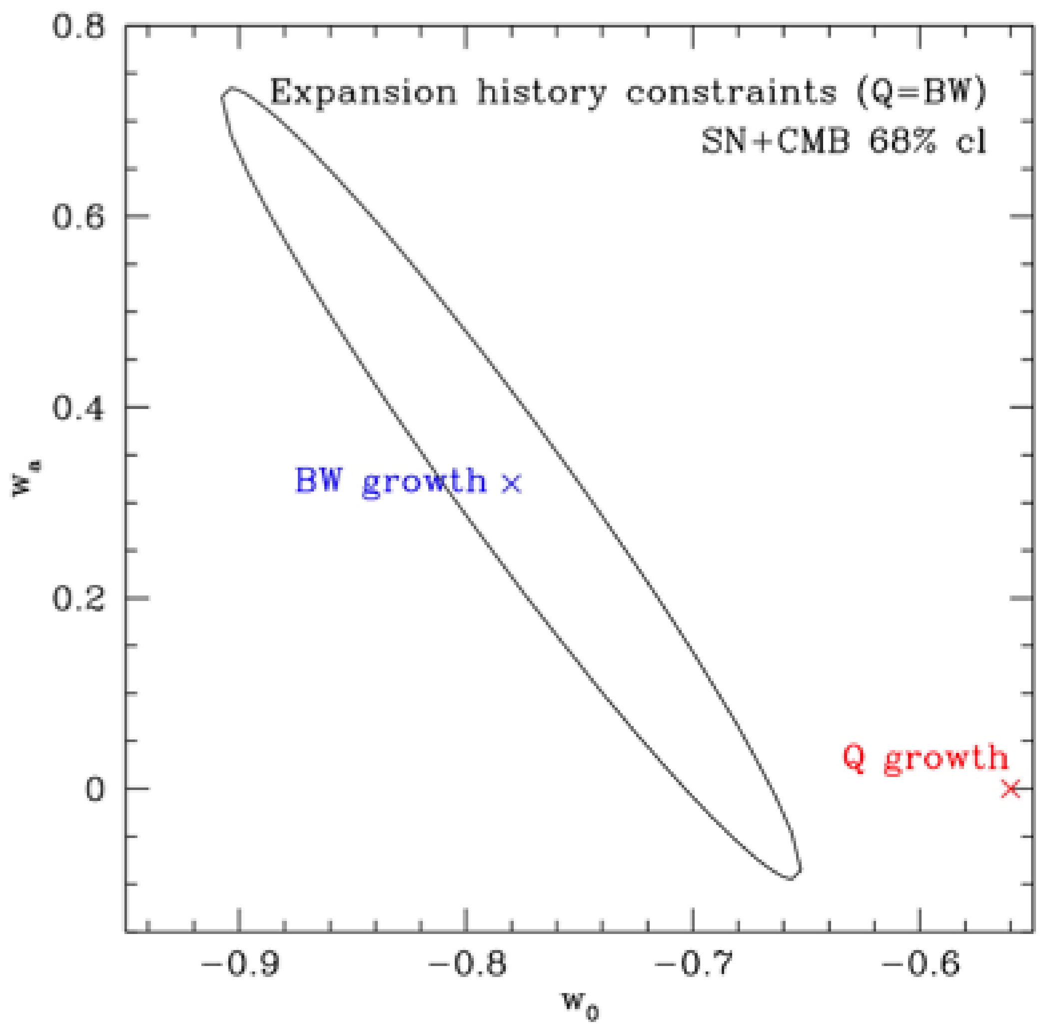
Price: additional cosmological and structure formation parameters

Bonus: additional structure formation parameters



Expansion History vs. Perturbation Growth

Growth of Perturbations probes *H(z)* and gravity modifications



Linder

$$g'' + [5 + \tfrac{1}{2}\frac{d\ln H^2}{d\ln a}]g'a^{-1} + [3 + \tfrac{1}{2}\frac{d\ln H^2}{d\ln a} - \tfrac{3}{2}G\,\Omega_m(a)]\,ga^{-2} = S(a)$$

Caveat: Representative list, not guaranteed to be complete or accurate

Table 3: Dark energy projects proposed or under construction. Stage refers to the DETF time-scale classification.

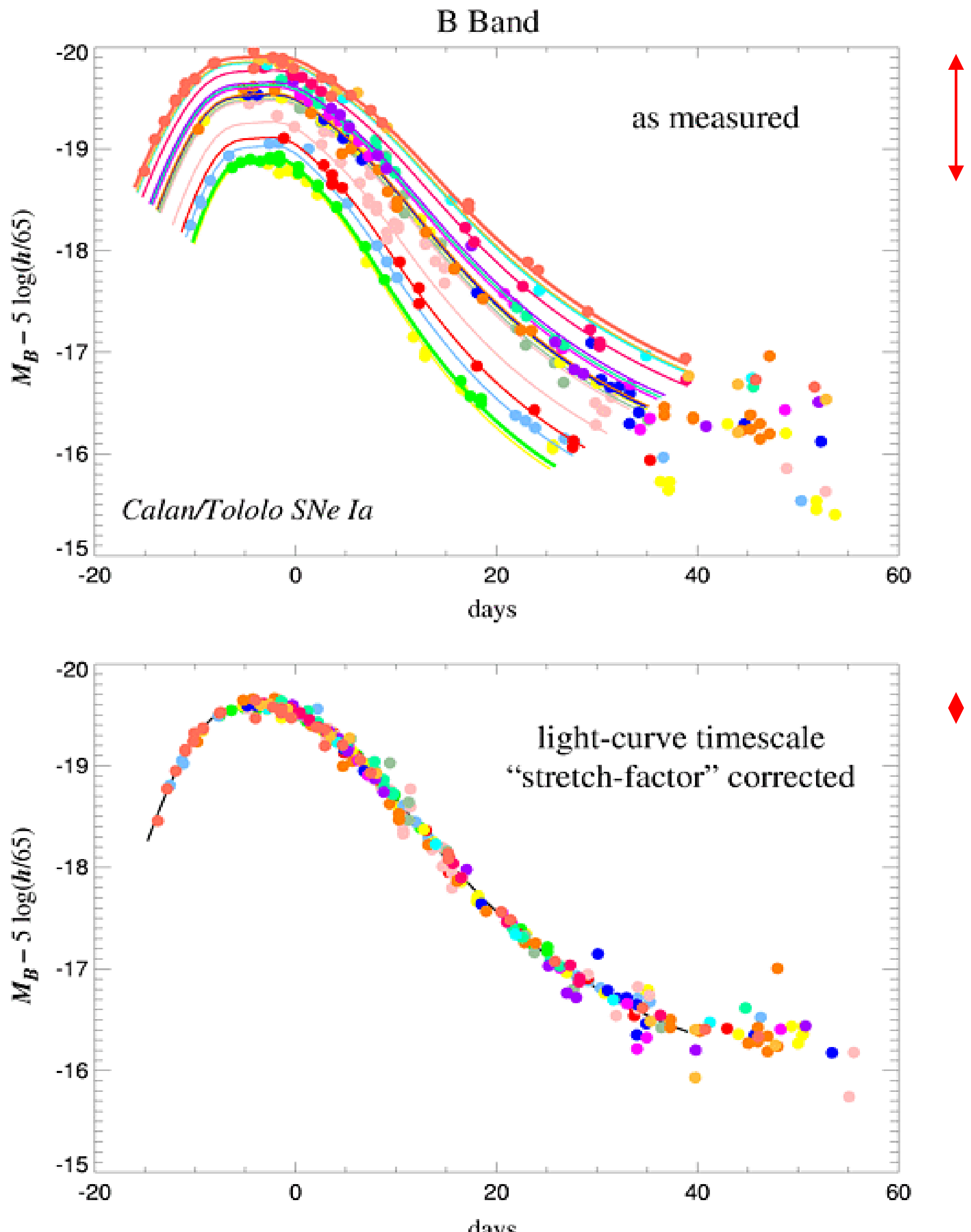
Survey	Description	Probes	Stage
Ground-based:			
ACT	SZ, 6-m	CL	II
APEX	SZ, 12-m	CL	II
SPT	SZ, 10-m	CL	II
VST	Optical imaging, 2.6-m	BAO,CL,WL	II
Pan-STARRS 1(4)	Optical imaging, 1.8-m(×4)	All	II(III)
DES	Optical imaging, 4-m	All	III
Hyper Suprime-Cam	Optical imaging, 8-m	WL,CL,BAO	III
ALPACA	Optical imaging, 8-m	SN, BAO, CL	III
LSST	Optical imaging, 6.8-m	All	IV
AAT WiggleZ	Spectroscopy, 4-m	BAO	II
HETDEX	Spectroscopy, 9.2-m	BAO	III
PAU	Multi-filter imaging, 2-3-m	BAO	III
SDSS BOSS	Spectroscopy, 2.5-m	BAO	III
WFMOS	Spectroscopy, 8-m	BAO	III
SKA	km^2 radio telescope	BAO, WL	IV
Space-based:			
JDEM Candidates			
ADEPT	Spectroscopy	BAO, SN	IV
DESTINY	Grism spectrophotometry	SN	IV
SNAP	Optical+NIR+spectro	SN, WL	IV
Proposed ESA Missions			
DUNE	Optical imaging	WL	
SPACE	Spectroscopy	BAO	
eROSITA	X-ray	CL	
CMB Space Probe			
Planck	SZ	CL	
Beyond Einstein Probe			
Constellation-X	X-ray	CL	IV

Type Ia SN Peak Brightness as calibrated Standard Candle

Peak brightness correlates with decline rate

Variety of algorithms for modeling these correlations

After correction,
σ~ 0.15 mag
(~7% distance error)

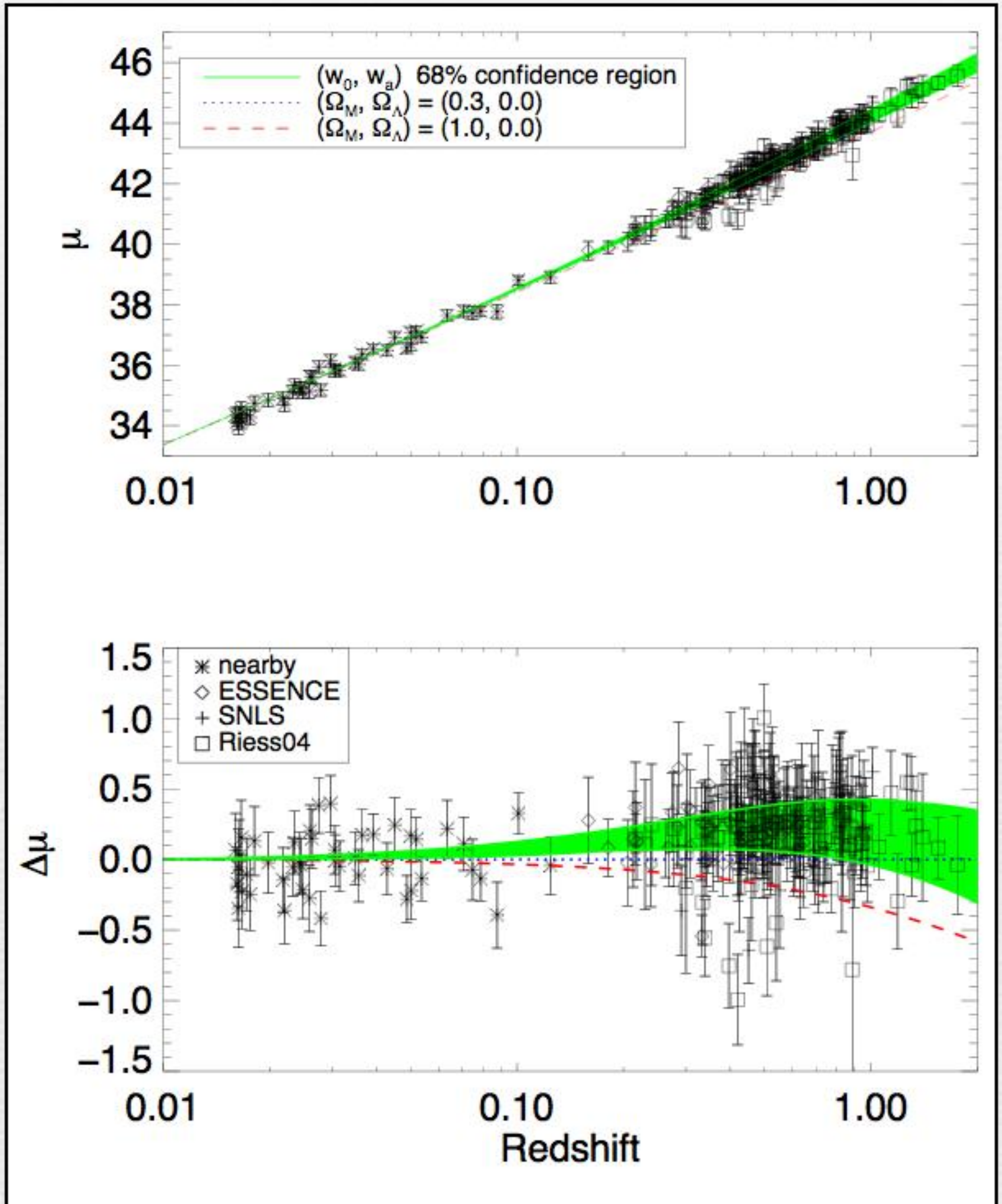


Kim, *et al.* (1997)

Global SNIa Hubble Diagram 2007

Hamuy 1996a,b
Riess 1998
Perlmutter 1999
Riess 1999
Riess 2001
Tonry 2003
Knop 2003
Barris 2004
Riess 2004
Clochiatti 2005
Astier 2006
Jha 2006

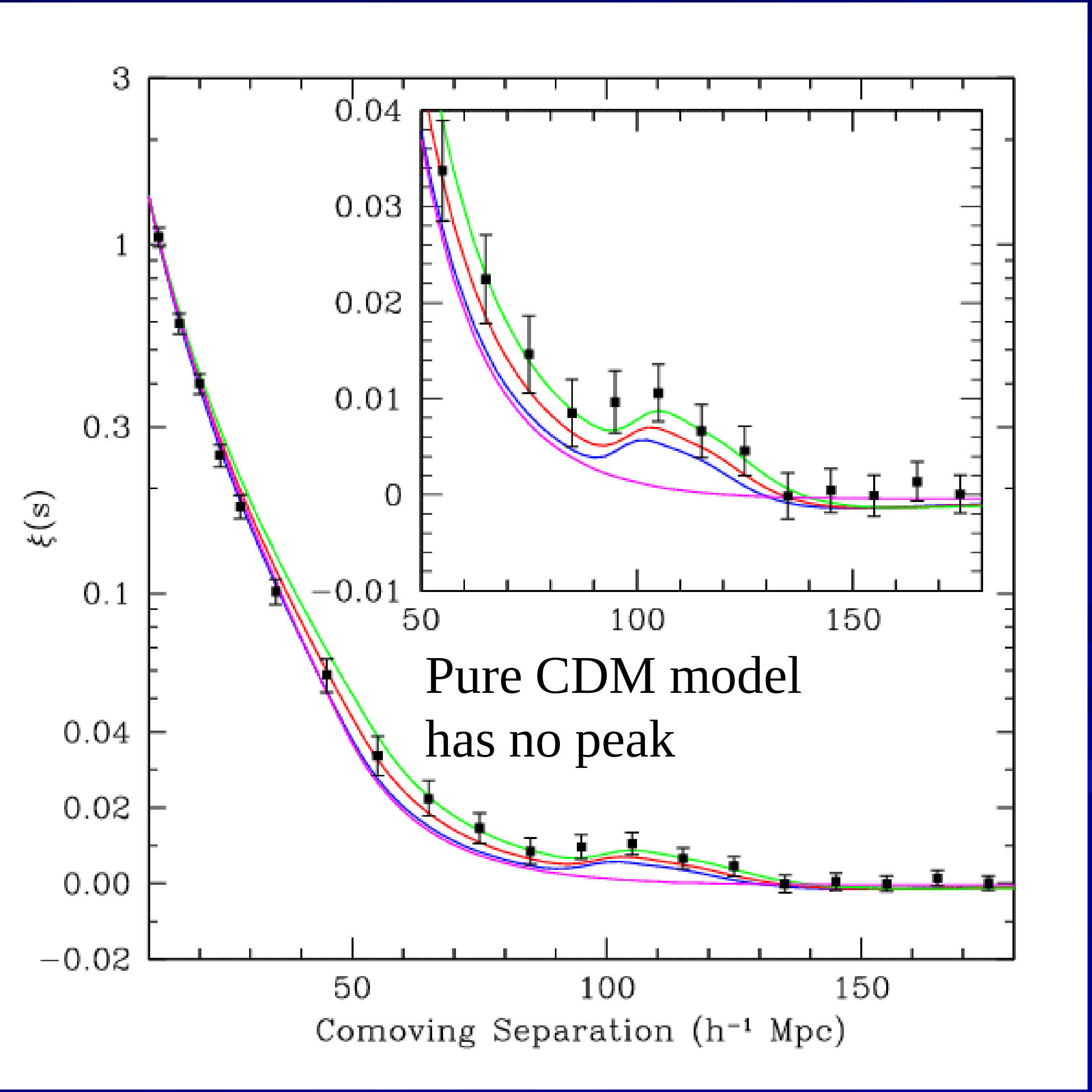
Wood-Vasey etal 07



Large-scale Correlations of SDSS Luminous Red Galaxies

Redshift-space Correlation Function

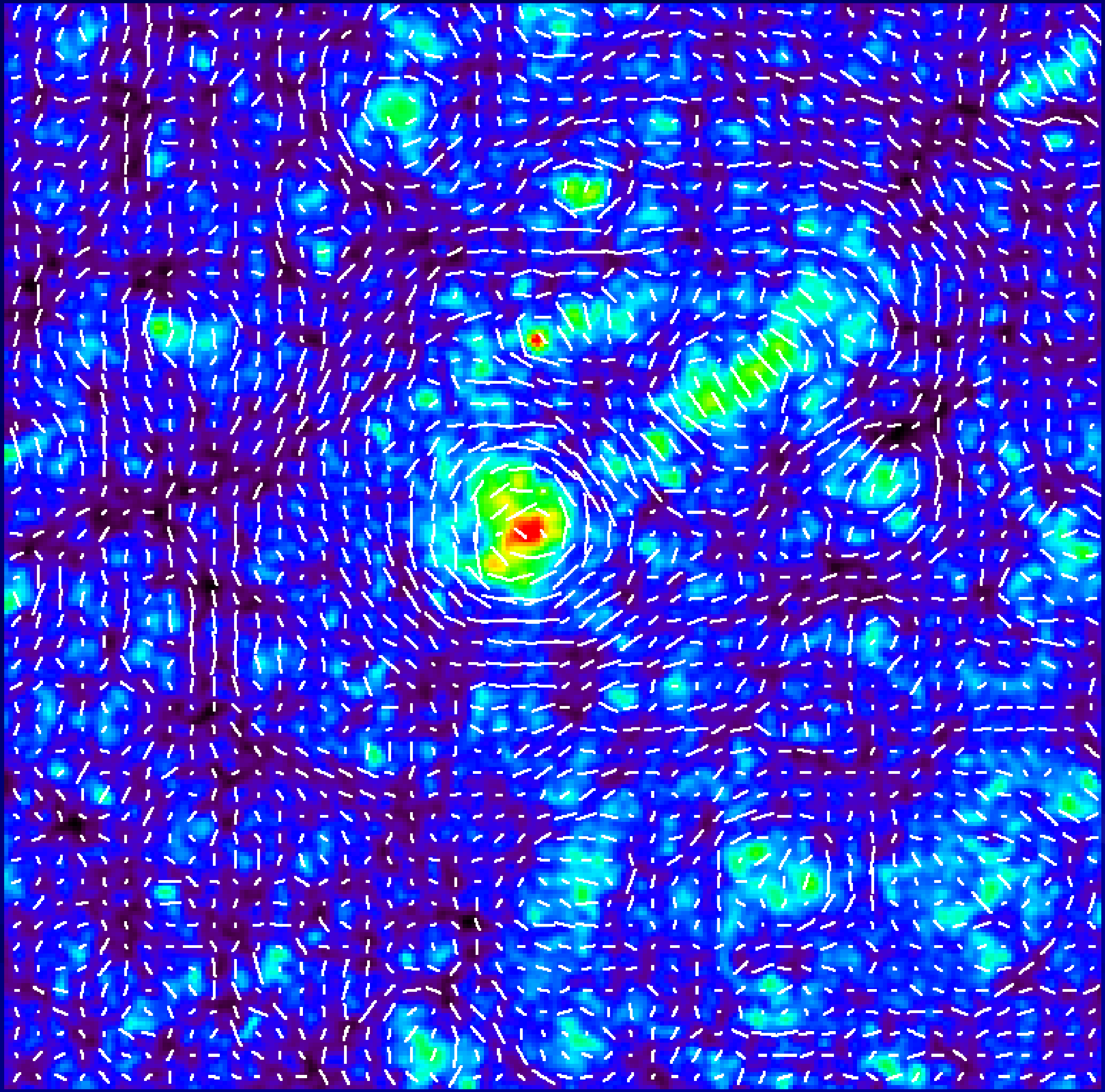
$$\xi(r) = \langle \delta(\vec{x})\delta(\vec{x}+\vec{r}) \rangle$$



Baryon Acoustic Oscillations seen in Large-scale Structure

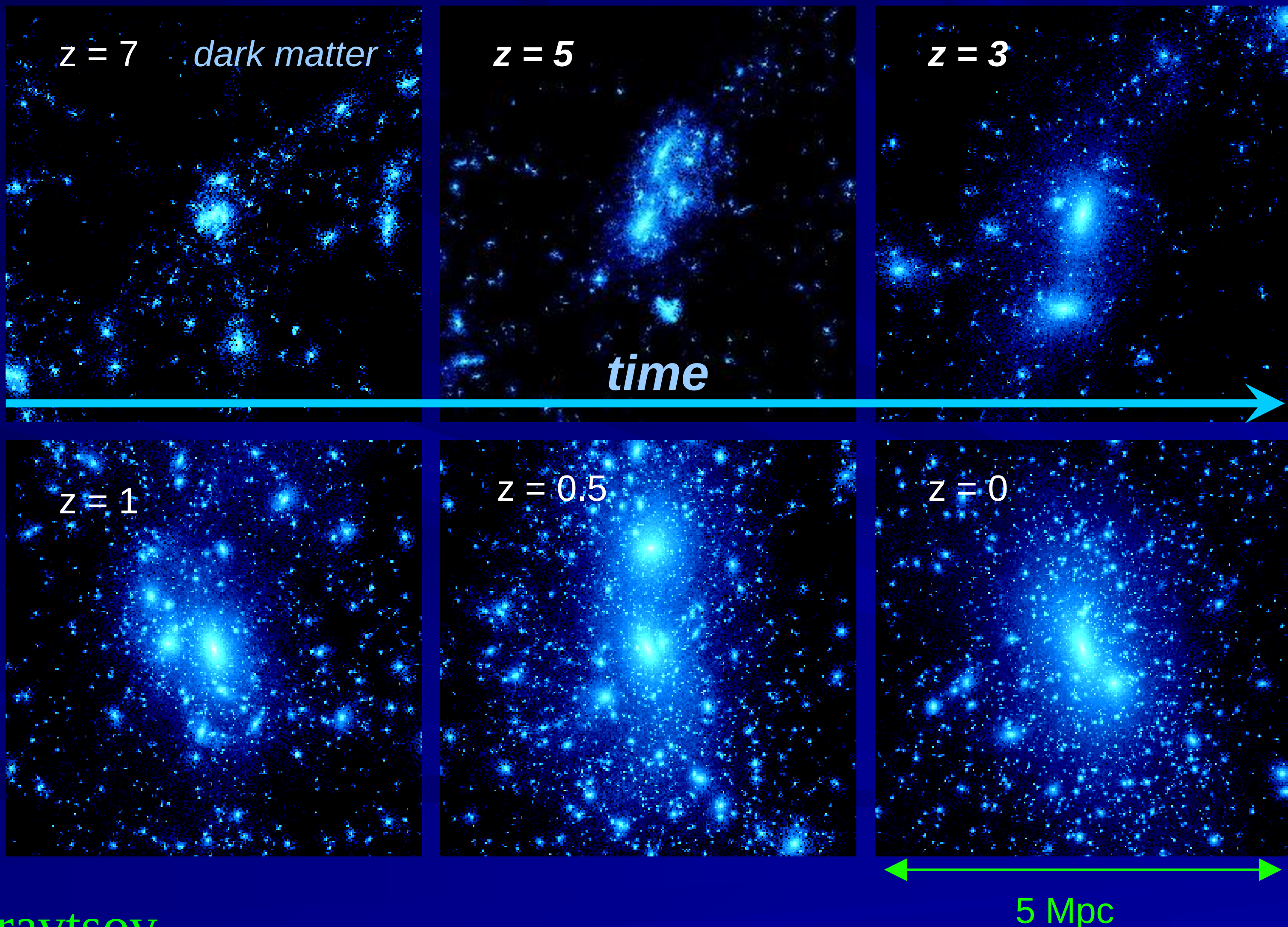
Eisenstein, et al. 05

Weak lensing: shear and mass



Jain

Clusters form hierarchically



Kravtsov

Clusters and Dark Energy

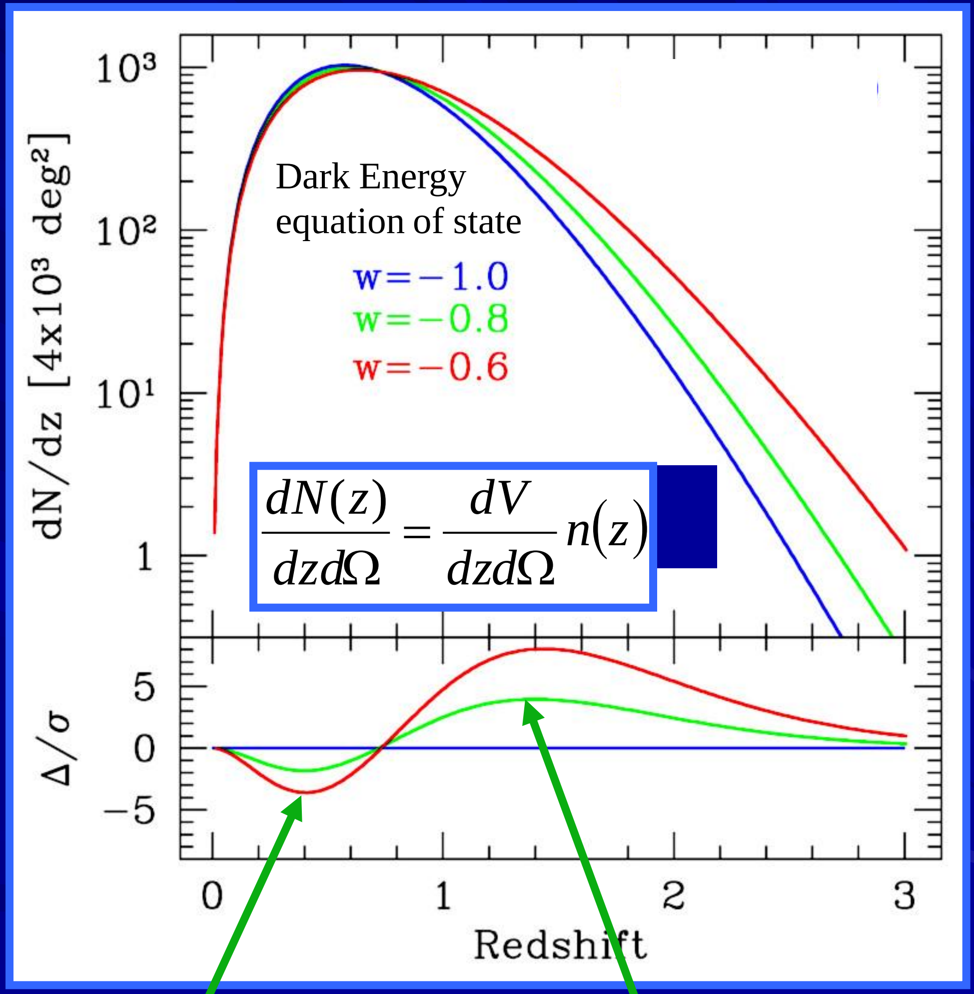
- Requirements
  1. Understand formation of dark matter halos
  2. Cleanly select massive dark matter halos (galaxy clusters) over a range of redshifts
  3. Redshift estimates for each cluster
  4. Observable proxy *O* that can be used as cluster mass estimate:

     p(O|M,z)

Primary systematic:

Uncertainty in bias & scatter of mass-observable relation

Number of clusters above observable mass threshold



Volume (geometry)

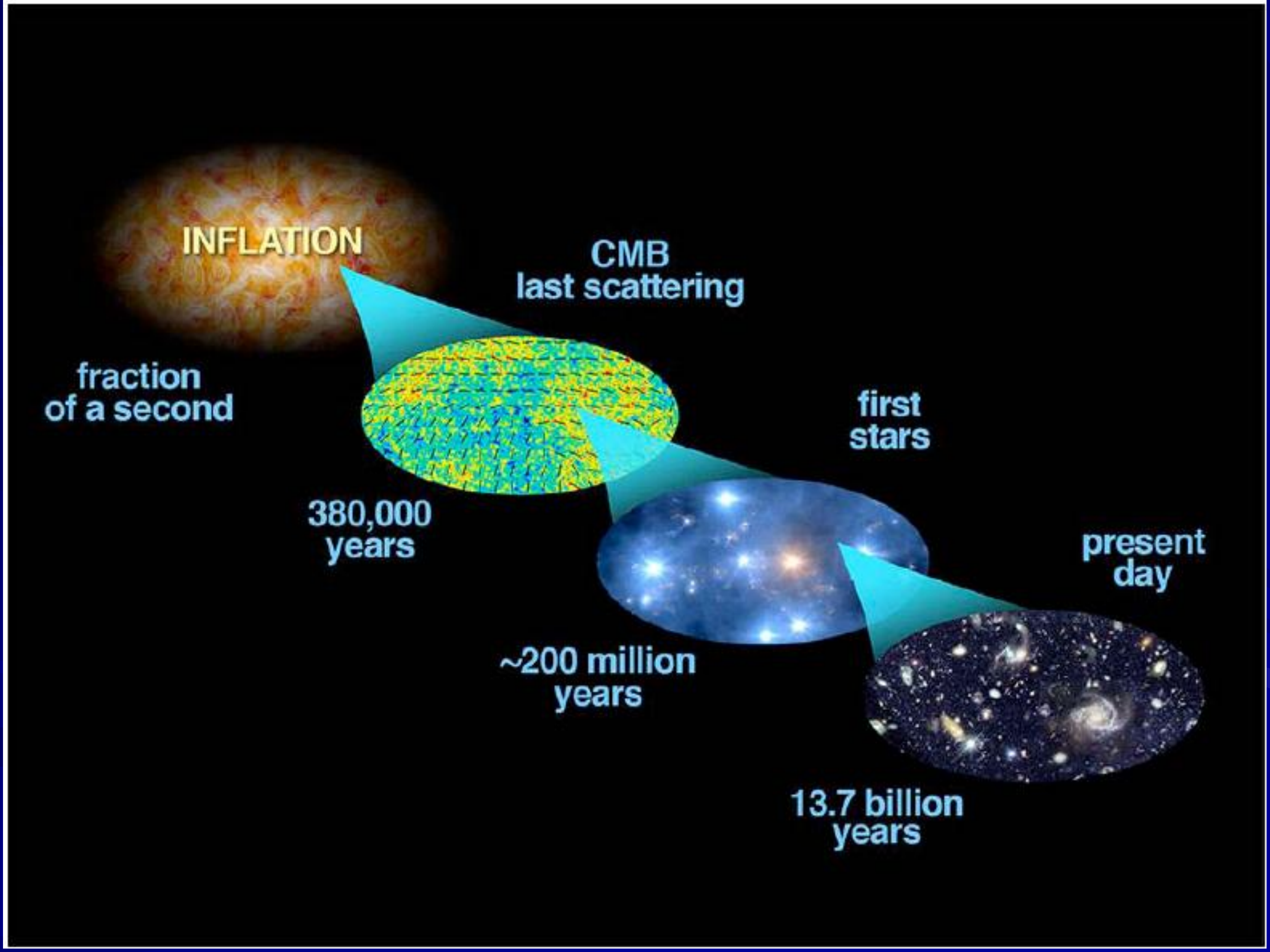
Growth

Mohr

Systematic Errors

- Supernovae: uncertainties in dust and SN colors; selection biases; ``hidden” luminosity evolution; limited low-z sample for training & anchoring
- BAO: redshift distortions; galaxy bias; non-linearities; selection biases
- Weak Lensing: additive and multiplicative shear errors; photo-z systematics; small-scale non-linearity & baryonic effects
- Clusters: scatter & bias in mass-observable relation; uncertainty in observable selection function; small-scale non-linearity & baryonic effects

Observations of CMB temperature anisotropies are the basis of modern cosmology



Cosmic Microwave Background: Evidence for Inflation

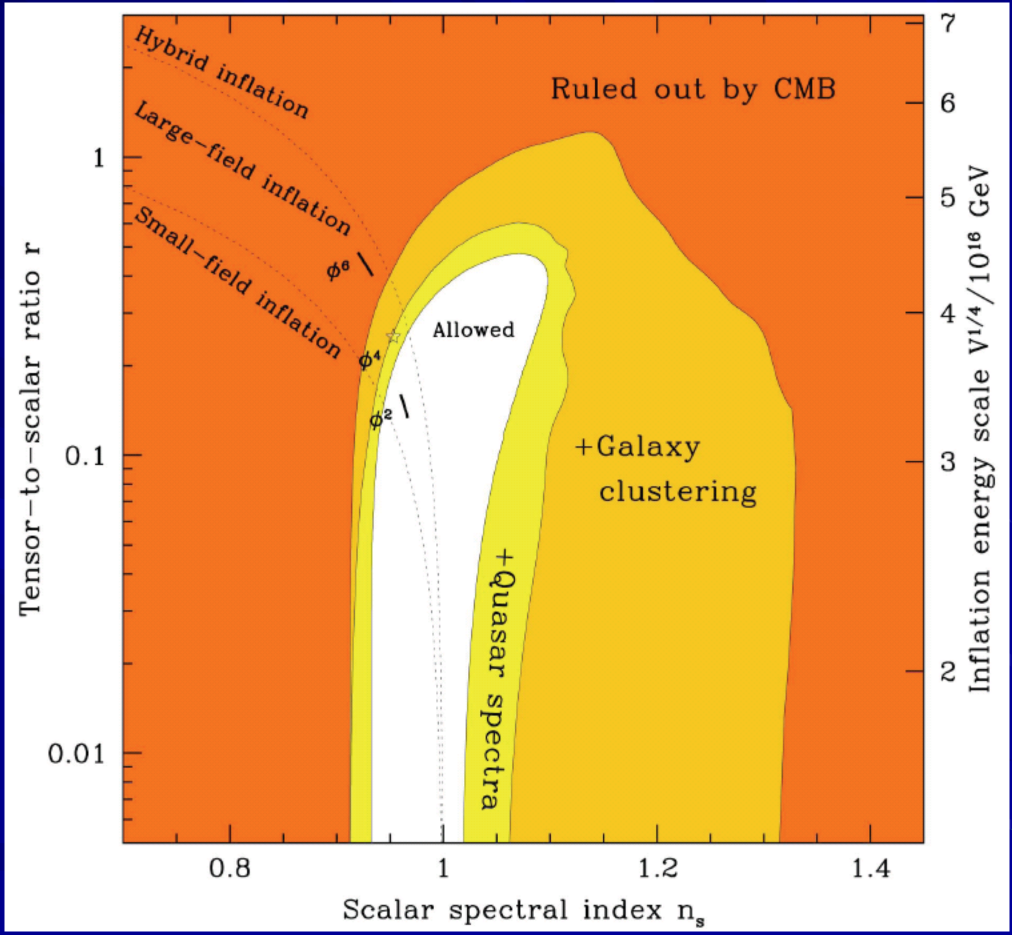
CMB polarization sensitive to gravity waves produced during inflation.

CMB Polarization experiments probe physics at the GUT-scale.

Amplitude of B-mode signal tied to physics of inflation

Tensor/scalar ratio teaches us about the GUT scale physics driving inflation.

$$r = 0.1\left(\frac{V^{1/4}}{3\times10^{16}\,GeV}\right)^4$$

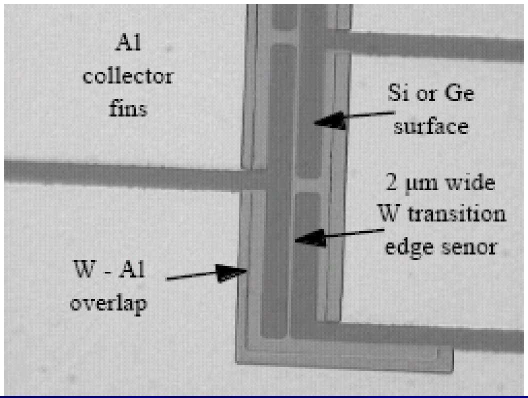


US-Funded CMB Experiments

Experiment	Funding Estimate ($M/yr)	Comments
BICEP	NSF 0.5	40' @ 100,150 GHz; Observing for 2 yrs; 3rd season upcoming; 100 detectors; will get to r=0.1. Plans for detector upgrades
PolarBear	**NSF 1.5**	**4' @ 90,150,200 GHz; NSF Funded for 5 yrs, to start in 2009**
EBEX	NASA 1	8' @ 90,150,200 GHz; Balloon Funded by NASA; test flight this summer; science flight 2010
SPIDER	NASA 1	20-70' @ 90,150,220 GHz; Balloon funded by NASA; test flight 2010; science flight 2011
ACT	NSF 1.5	Planning upgrade to do polarization
SPT	NSF 3	Planning upgrade to do polarization
R&D	NASA 4 NSF 1	Technology development, theory, data analysis
QUIET	NSF 1	12' @ 44,90 GHz; NSF funded first phase + Now applying for 2nd phase
WMAP	NASA 3	Funding continues through at least 2010
Planck	**NASA 8**	**Launch this year**
Other	All 1-2	COFE, BLAST, NERSC, …
Total	**27**	

DOE Technology

SiDet (FNAL)



TES detectors for CDMS

Figure 2 An FPGA motherboard is shown with one of its two analog converter mezzanine boards attached.

Backend Electronics designed at LBNL

CMB Data Analysis at NERSC

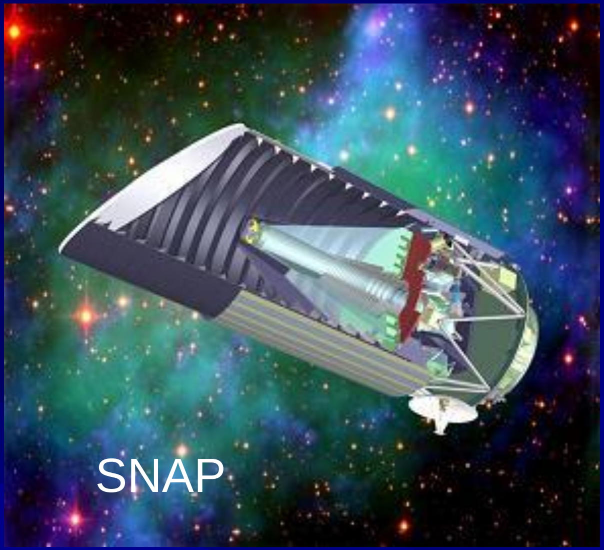
DOE institutions have contributed significant technological resources to this field

Center for Nanoscale Materials (Argonne)

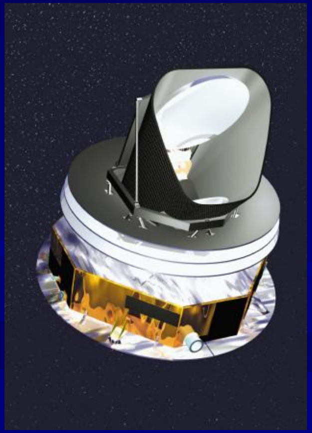
Key Role of CMB

- CMB is the cornerstone of modern cosmology
- CMB polarization studies may provide evidence for inflation, non-zero neutrino mass, and the end of the Dark Ages.
- DOE plays a significant role, leveraging existing facilities/talents.
- The future is promising: many upcoming polarization projects; plans for satellite mission; 21 cm surveys may point to new directions

LBNL Cosmology Program



Nearby Supernova Factory



Planck: next step in CMB after WMAP

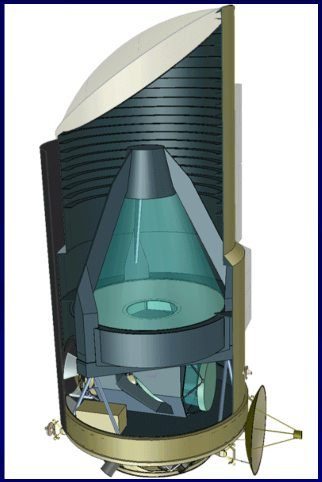
Dark Energy Survey

BOSS: next step in BAO after SDSSII.

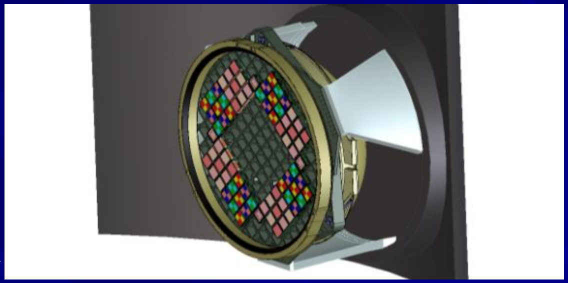
SNAP: measure expansion history and growth of large-scale structure.

- Must measure both to distinguish dark energy from failure of General Relativity.
- Space mission required to reduce systematics.
- SNAP builds on our pioneering program on supernova (SNe Ia) cosmology.
- A weak-lensing survey complements the SNe Ia to optimize program as shown by DETF.
- Anticipated DOE – NASA competition for which SNAP will compete for construction.

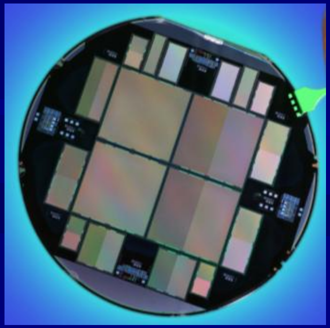
SNAP R&D Achievements



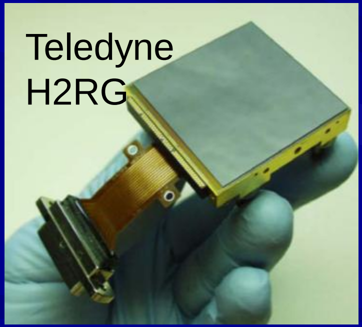
New compact telescope optics concept proved exceptional performance in a rocket-borne experiment (key to JDEM). Founded on LBNL and UCB strong optics heritage from Keck



LBNL HEP IC group developed readout of high channel-count cryogenic pixel plane.



12M-pixel LBNL CCD with high QE out to 1.0 μ and low diffusion is radiation resistant. Same technology is baseline for LSST detectors.



Powerful collaboration of universities and labs with industry resulted in high QE out to 1.7 μ in 4M pixel format. Now detector of choice for other JDEM proposals.

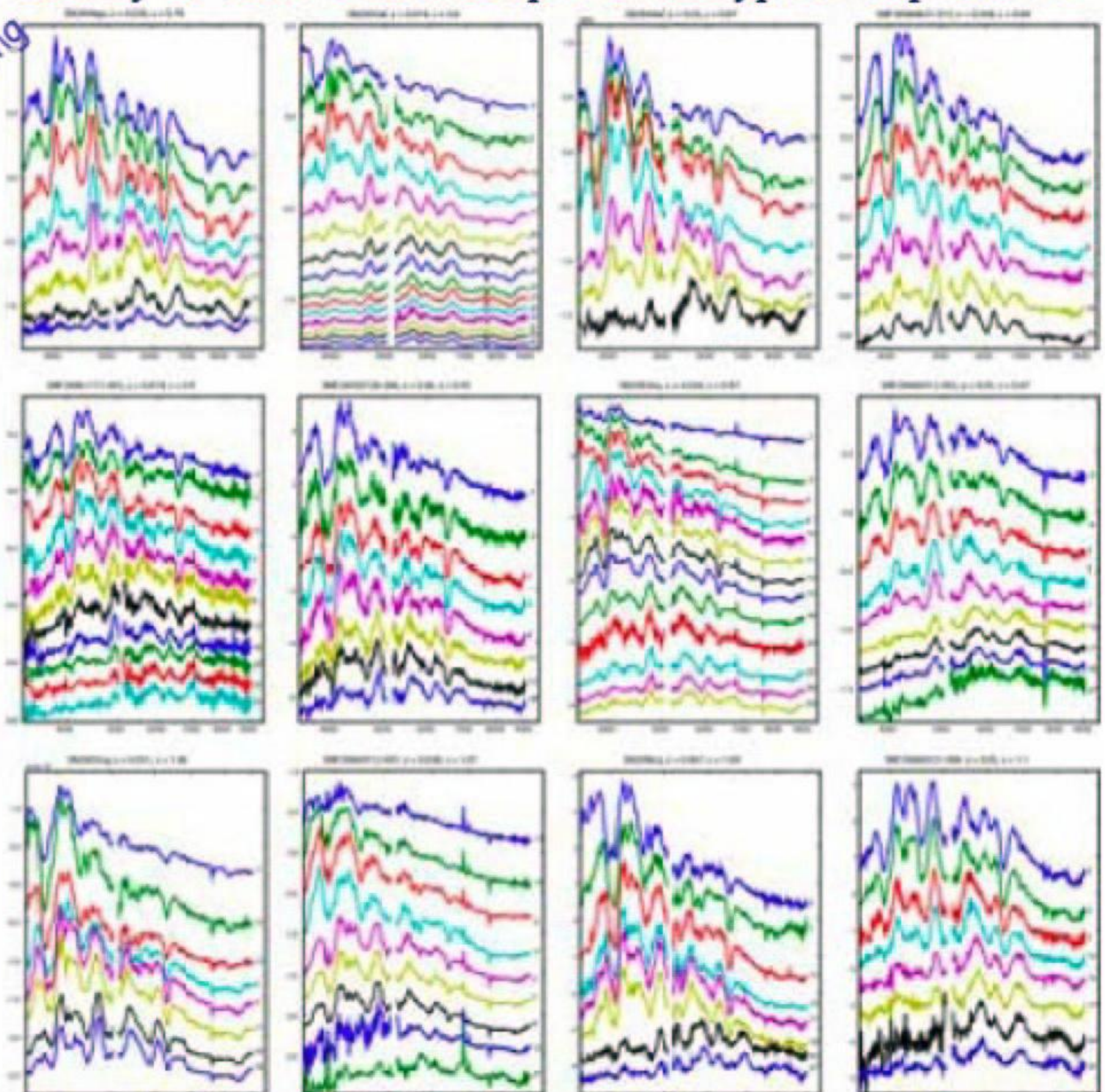
Nearby Supernova Studies

- Nearby Supernovae are critical to anchor the Hubble Diagram for SNAP or other experiments using SNe as distance markers
- LBNL Supernova Factory is the first large scale nearby search and spectroscopic follow-up
- SN discoveries and spectrometer also used by others including Keiichi Maeda of IPMU (current focus on very late times)

Nearby Supernova Factory

Goal: Library of Time Series of Spectra of Type Ia Supernovae

SN Factory now producing



s = 0.90

s = 1.00

s = 1.10

SN Factory discovered 270 SN Ia, z=0.03-0.08

2000 spectra of SN Ia

Future Nearby Studies

- New program led by Charlie Baltay (Yale) will upgrade camera now used at Palomar and install in Chile
- Search operations will continue at Palomar with a new camera.
- Follow-up possibilities in Chile, Greece as well as the UH 2.2m now used in Hawaii
- We are investigating how to best balance photometry and spectroscopy in the new program

Baryon Oscillation Spectroscopic Survey (BOSS) and Dark Energy Survey (DES)

Part of SDSS-III, BOSS uses redshifts of 1.6M galaxies (z˜0.5) and Lyman-α forest of 0.16 M quasars (z~2.5) to determine cosmological parameters.

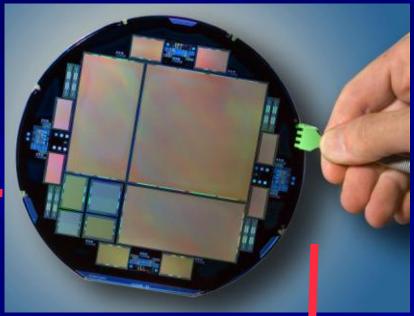
LBNL Leadership roles in BOSS:

PI: *David Schlegel*

Instrument Scientist: *Natalie Roe*

Survey Scientist: *Martin White*

SDSS telescope at Apache Point



Replace red CCDs on SDSS camera with w/red-sensitive LBNL/SNAP CCDs, making it possible to go to higher-z

DES: LBNL furnishes CCDs to upgrade the camera at CTIO for DES. LBNL science role: SNe and WL. Detectors for DES now in production at LBNL Microsystems Lab.

Sloan Foundation agreed to support SDSS-III. Proposals pending at DOE and NSF. MOUs signed or in negotiations with many institutions:

Arizona	LBNL
Brazilian group	LANL
UC Irvine	MPA Garsching
UCSC	MSU
Cambridge	New Mexico State
Case Western	NYU
FNAL	OSU
Florida	Penn State
French group	Portsmouth
Heidelberg	Astrn. Inst. Princeton
Japanese group	Princeton
Johns Hopkins	Virginia
Korean Inst. Adv. Study	Wasington

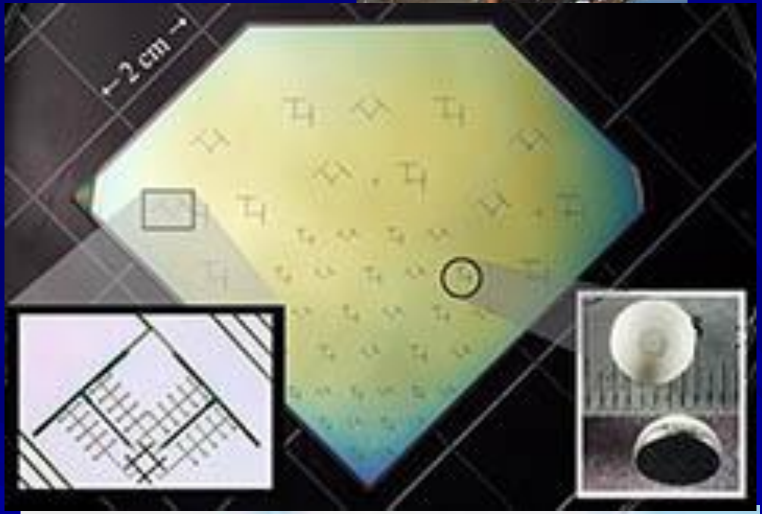
DES Objectives (Fermilab-Led)

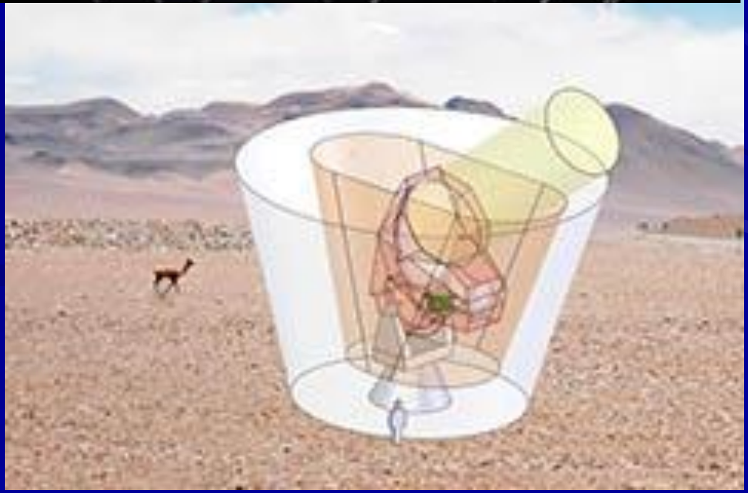
The Dark Energy Survey aims to extract cosmological information on dark energy from

1. cluster counting and spatial distribution of clusters at $0.1 < z < 1.3$,
2. the shifting of the galaxy spatial angular power spectra with redshift,
3. weak lensing measurements on several redshift shells to $z \sim 1$, and 4) 2000 supernovae at $0.3 < z < 0.8$.

PolarBeaR

- Led by Adrian Lee, UC Berkeley and LBNL
- Major sensor development at LBNL
- Will be deployed in Chile after testing in California



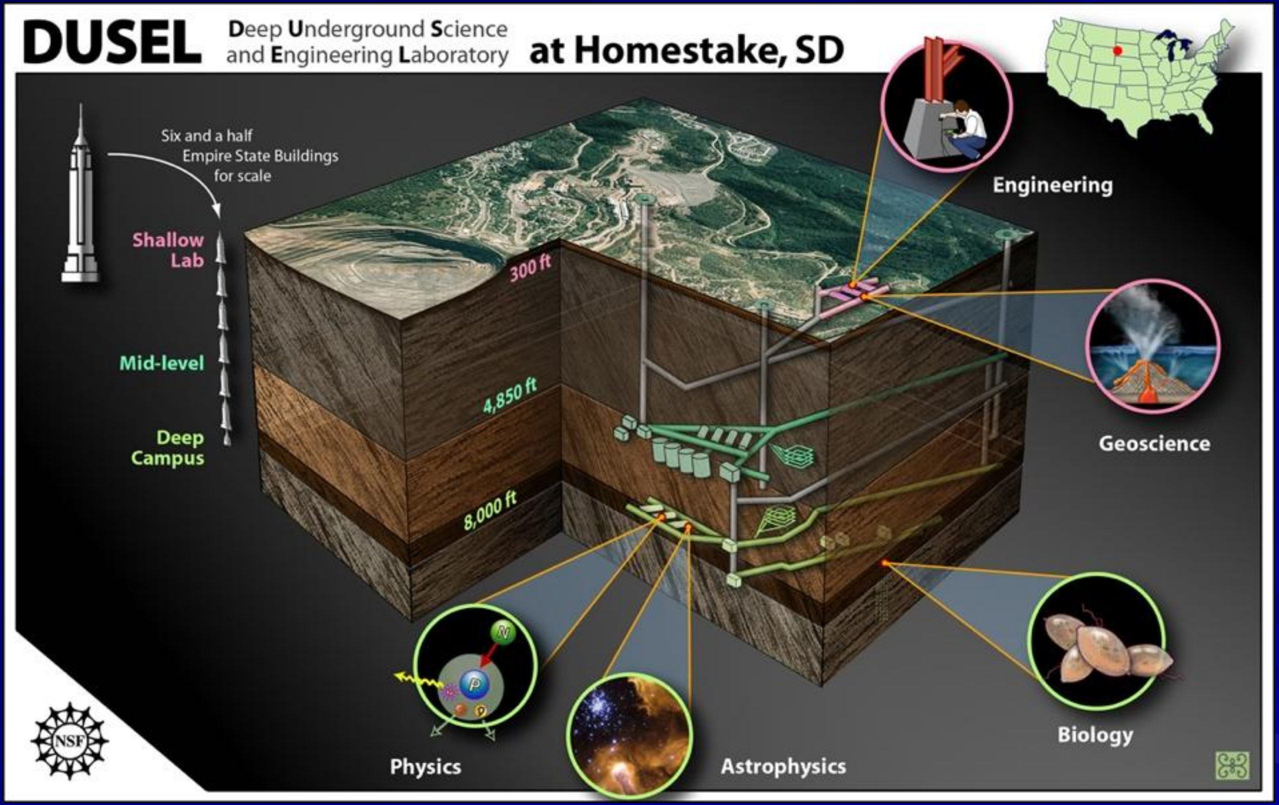


Cosmology Conclusions

Excellent prospects for increasing the precision on Dark Energy parameters from a sequence of increasingly complex and ambitious experiments over the next 5-15 years

Exploiting multiple probes will be key: we don’t know what the ultimate systematic error floors for each method will be. Combine geometric with structure-growth probes to help distinguish modified gravity from dark energy.

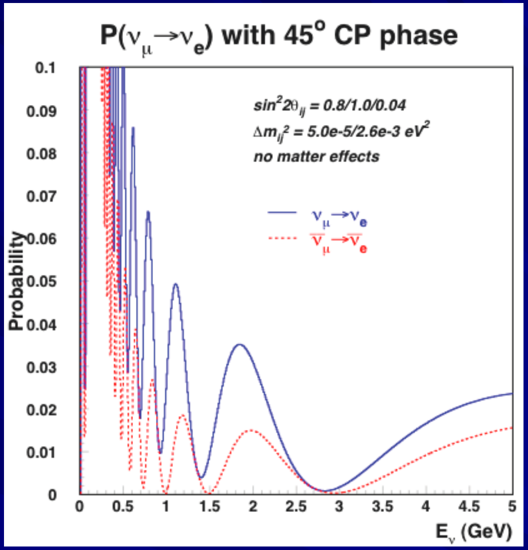
The Deep Underground Science and Engineering Laboratory at Homestake



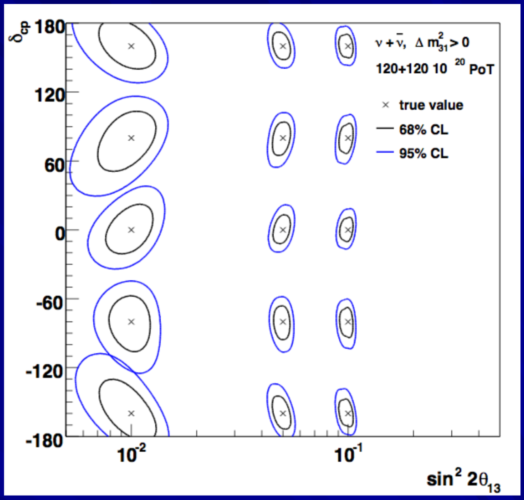
Kevin T. Lesko, LBNL-NSD, DUSEL PI

Long Baseline neutrino, Nucleon Decay, and Ancillary Programs

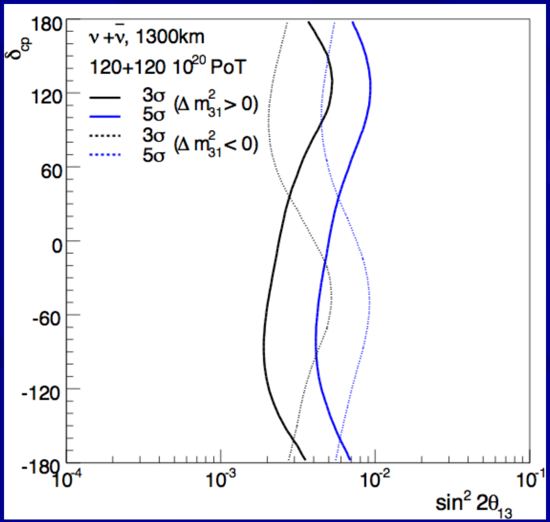
- Long Baseline Neutrinos and Nucleon Decay
  - Same detectors
- Discovery
  - Neutrino mass hierarchy
  - θ_{13}
  - CP violation
  - Nucleon decay
- Diverse Program
  - Full MNSP matrix
  - Atmospheric and solar neutrinos
  - Supernovae neutrinos
- World-class Program



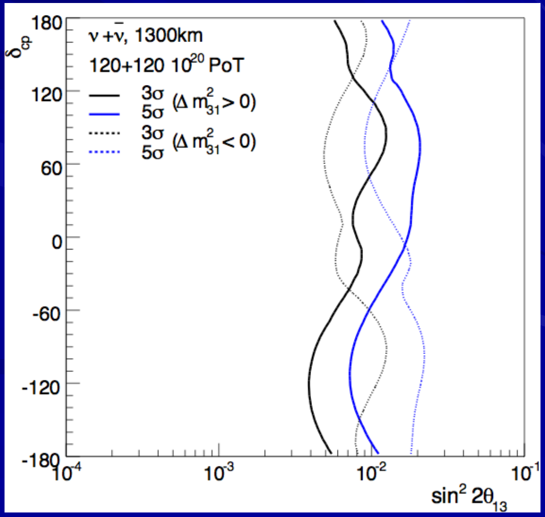
CP Violation



Reach in θ_{13}



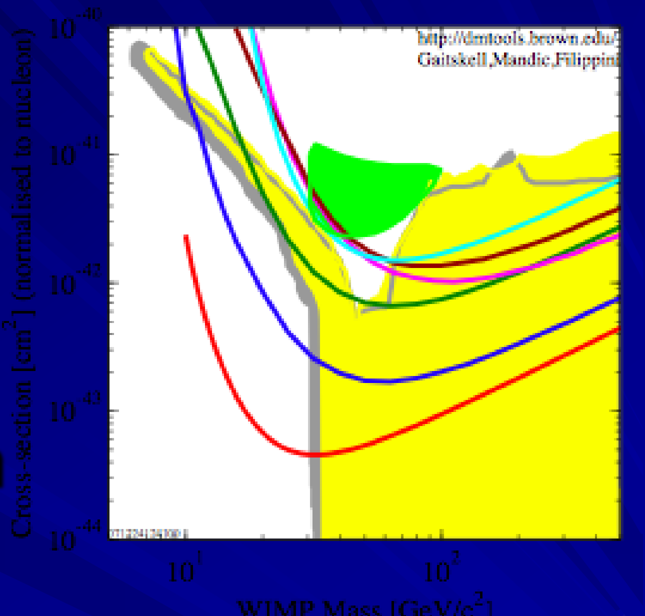
Reach in Mass Hierarchy

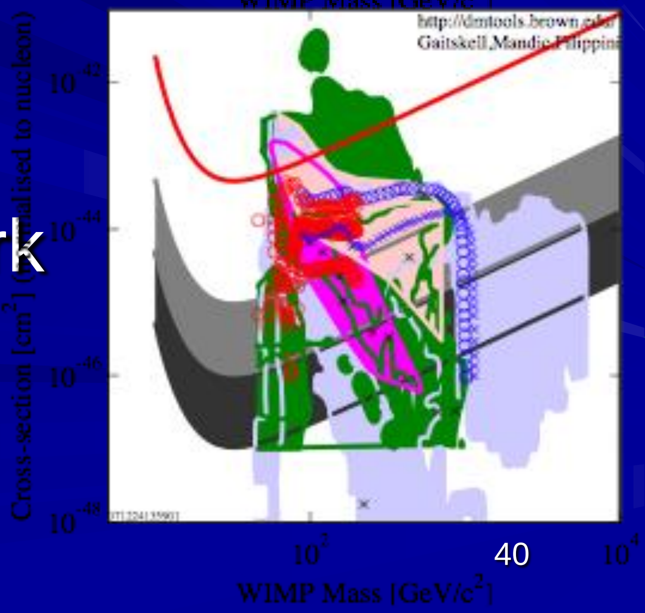


- Homestake anticipates beginning with a ~150-kt Detector (cavity + instrumentation) in Initial Suite of Experiments:
  - Water Cherenkov Detector ≈ 4 to 5 SuperKs
  - Using existing intensity or near-term upgrades
  - Build towards ~ 500-kt or more in modules and enhanced beams ~ 2 MW BP
  - Parallel LAr efforts, including deployments of prototype detectors in the near term
- R&D to begin in Sanford Lab
  - Geotechnical assessment and excavation plans
  - EA and waste rock disposal
  - Access/support improvements and customization

Direct Searches for Dark Matter

- Strong science motivation for discovery
  - Convergence of particle and astrophysics theory/experiment
- Significant recent advancements in sensitivity
  - US is current world leader in field
- Direct searches testing physics complementarity to accelerator work
  - Also indirect/astro signal searches
- Flagship science at DUSEL



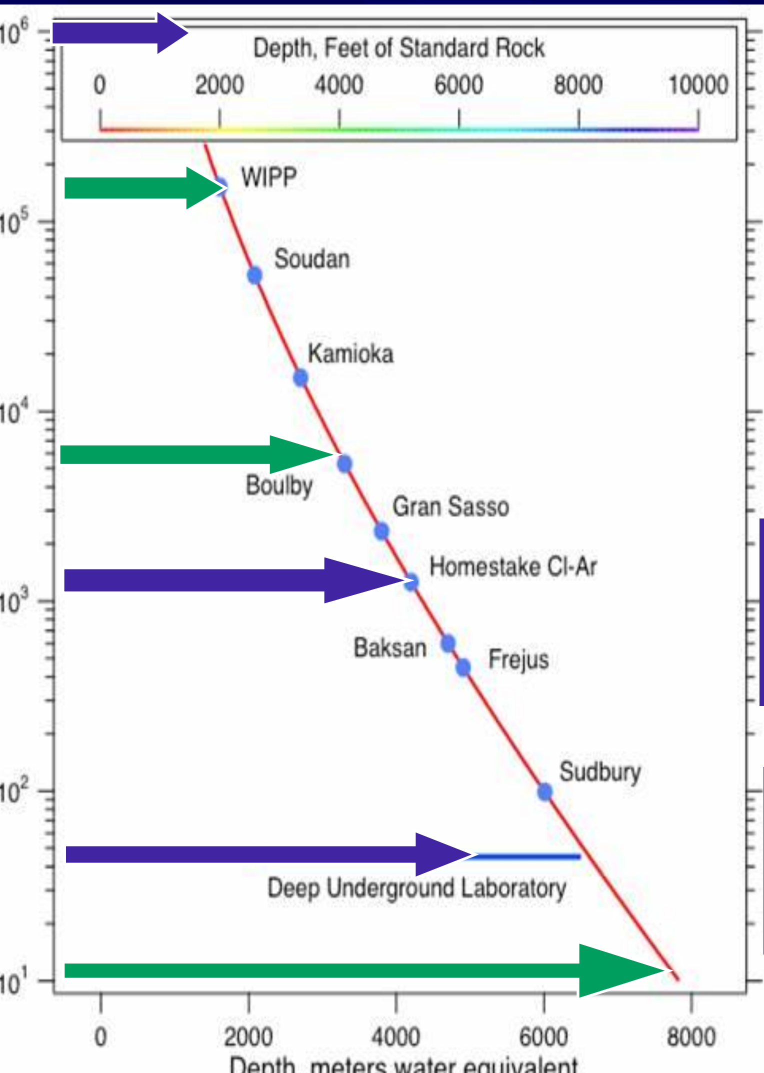


There is a World-wide Need for Space Underground

Assessment and vetting by Homestake Team, S-1 Panel, Town Meeting Group leaders, and community spokespeople

Site	Location	Depth (kmwe)	Total Space for Research (m^2)	Total Available Space (m^2)
Europe				
Baksan Neutrino Observatory (BNO)	Russia	0.9	600	0
		4.7	600	0
Boulby	UK	2.8	1,500	0
Center for Underground Physics at Pyhasalmi	Finland	4.0	2,050	2,050
Gran Sasso (LGNS)	Italy	3.2	17,300	0
Canfranc	Spain	2.4	1,000	1,000
Laboratoire Subterrain de Modane	France	4.7	400	0
Solotwina Underground Laboratory (SUL)	Ukraine	1.1	700	500
Total Europe			***24,150***	***3,550***
Total Europe below 4.0 kmwe			***1,050***	***50***
Asia				
Kamioka	Japan	2.1	10,000	0
OTO-Cosmo Observatory	Japan	1.4	80	0
Y2L	Korea	2.0	100	0
INO	India	3.0	0	0
Total Asia			***10,180***	***0***
Total Asia below 4.0 kmwe			***0***	***0***
Americas				
SNOLab	Canada	6.0	3,055	500
Soudan Underground Laboratory (SUL)	US	2.0	2,300	0
Waste Isolation Pilot Plant (WIPP)	US	1.6	920	400
Total Americas			***6,275***	***900***
Total Americas below 4.0 kmwe			***3,055***	***500***
WORLD TOTAL			***40,605***	***4,450***
WORLD TOTAL BELOW 4.0 KMWE			***4,105***	***550***
DUSEL	***US***	*0.3*	*640*	*640*
		1.7	*20,000*	*20,000*
		3.2	*1,010*	*1,010*
		4.1	*7,200*	*7,200*
		6.4	***4,500***	***4,500***
		7.0	***100***	***100***
Space required for Initial Suite of Experiments		***0.3***	***2,350***	
		1.7	***20,000***	
		3.2	***1,010***	
		4.1	***12,300***	
		6.4	***7,900***	
		7.0	***350***	

Campus Footprints



300L R&D, E&O 10k ft^2

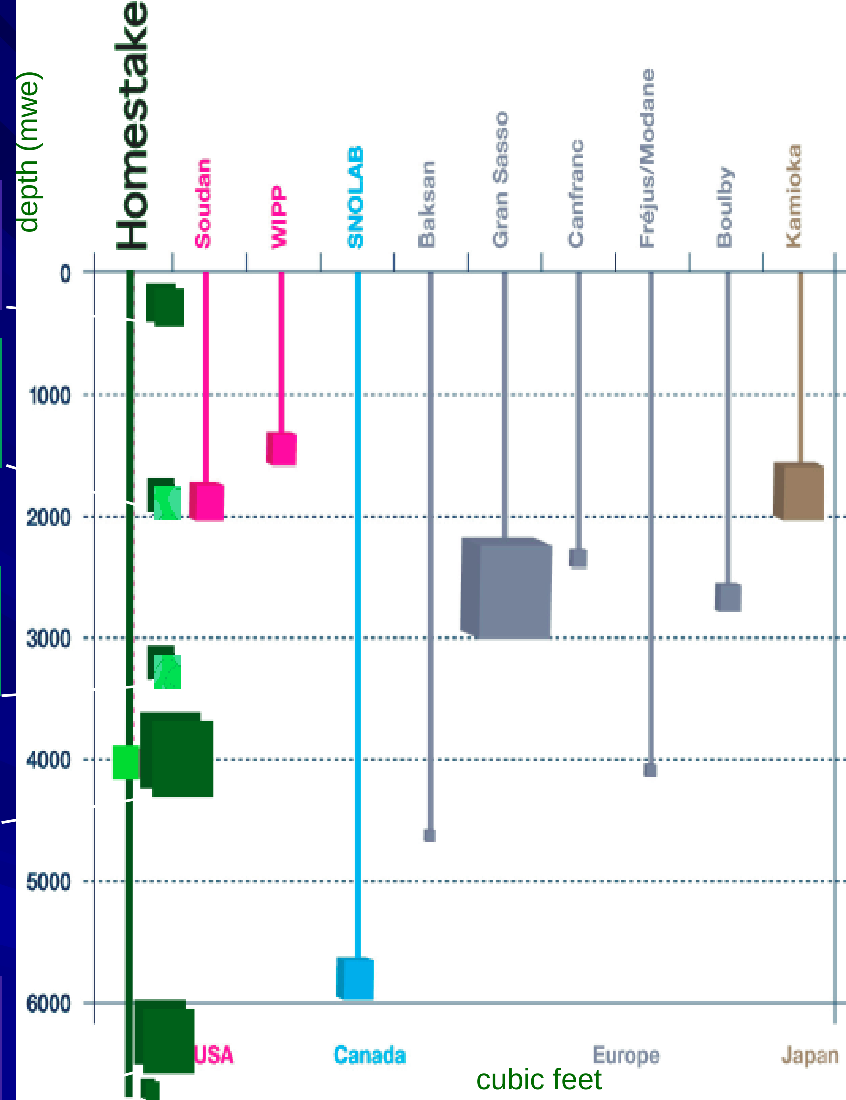
2000L Geo Level

3800L Geo Level

4850L Major Campus 100k ft^2

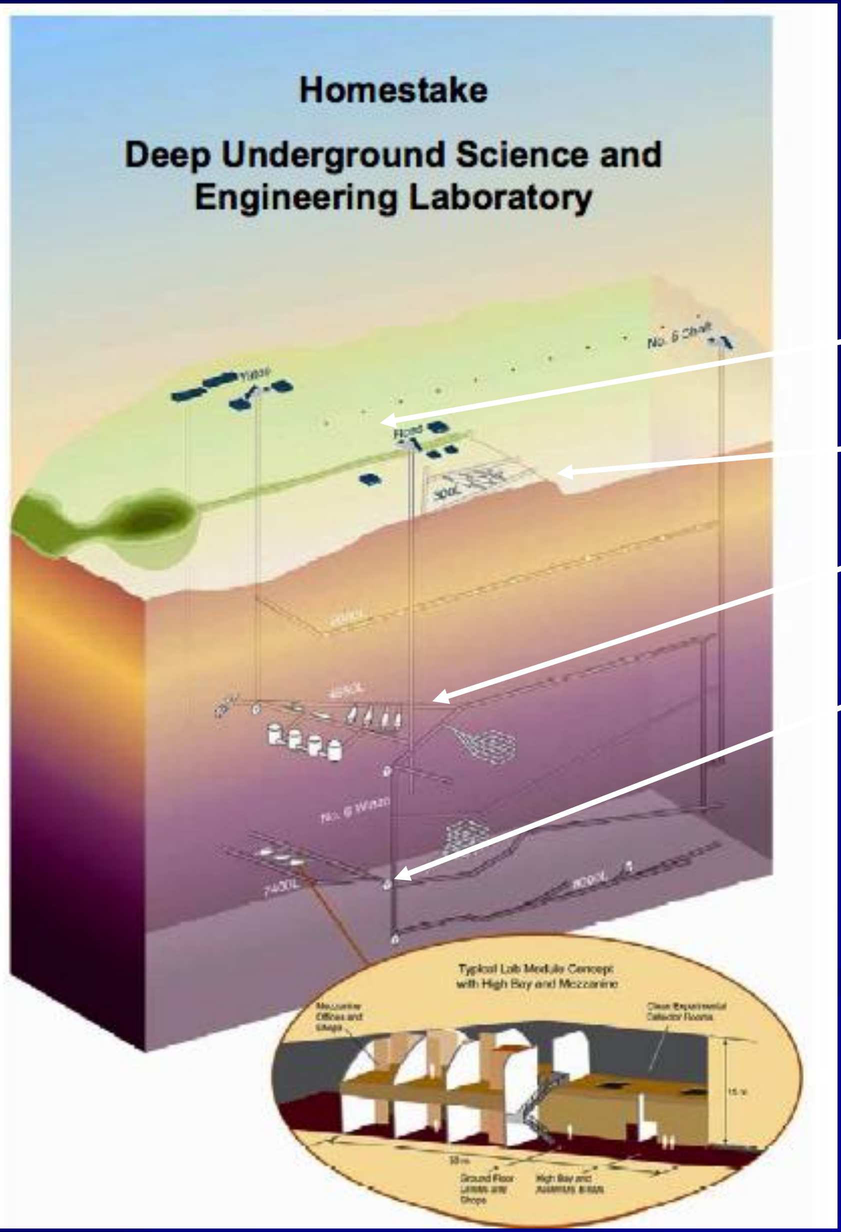
7400L Major Campus 65k ft^2

8000L Geo Lab



Estimates do not include MegaTon Detectors

Campus Concepts



Planning to develop four primary campus locations for research:

1. Surface campus at Yates Complex
2. Near-surface campus at 300 Level
3. Mid-level campus at 4850 Level
4. Deep-level campus at 7400 Level

Infrastructure will be maintained for access to additional, selected levels for bio- and geo- sciences and for unique experiments that require specific or isolated sites.

DUSEL Summary

- World-class Physics Programs
- Unique capabilities in the world
  - 3 or 4 flag-ship experiments identified
- Efforts underway at Sanford Lab to prepare the site ($126M) independent of and parallel to the DUSEL efforts, with $60M in hand FY08
  - phased program for experiments
- Long-term site
  - tailored access
  - 30 + year horizon
  - no competition

LBNL Detector R&D

- Dave Nygren is pursuing detector concepts that might significantly strengthen the underground physics program
- A high pressure Xe TPC could enhance searches for WIMPs and for 0-ν double beta decay

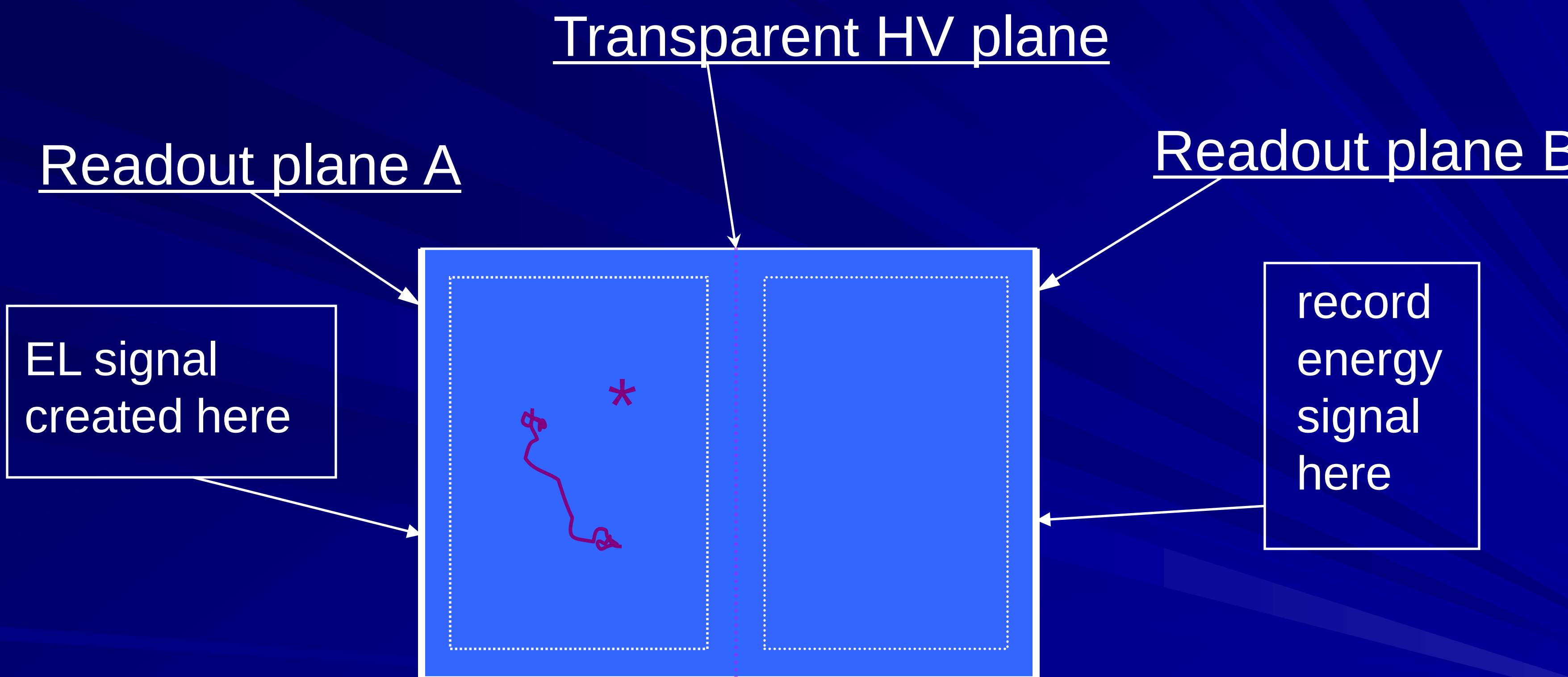
Combined search for WIMPs and 0-ν double beta decay

- High-pressure **xenon gas TPC** can provide:
  - superb energy resolution for 0-ν search $\delta E/E < 4 \times 10^{-3}$ FWHM (at 2.5 MeV)
  - Seamless fully-active fiducial surface for 100% rejection of charged backgrounds from surfaces
  - Much better S_2 / S_1 resolution than LXe for rejection of electron recoils in WIMP search
  - No compromises for either search, and scales well up to 1000 kg.

How is this possible?

- **Electroluminescent** TPC readout planes
  - Convert ionization signal to light signal
  - Most precise amplification mechanism
  - Single electron sensitivity for WIMP search
  - “Count” electrons, match Fano factor (F =.15)
  - Very high statistical precision possible
  - Dynamic range problem avoided by measuring total light signal on opposite readout plane.

TPC Signal



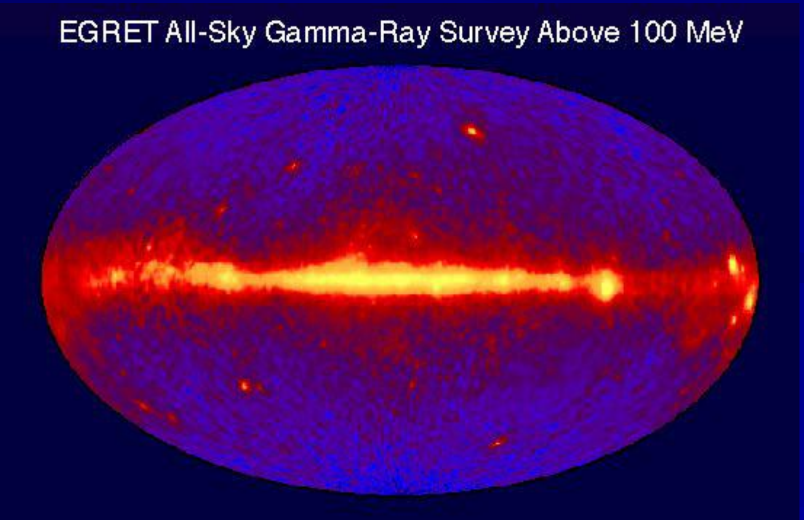
Signal: ββ event or WIMP

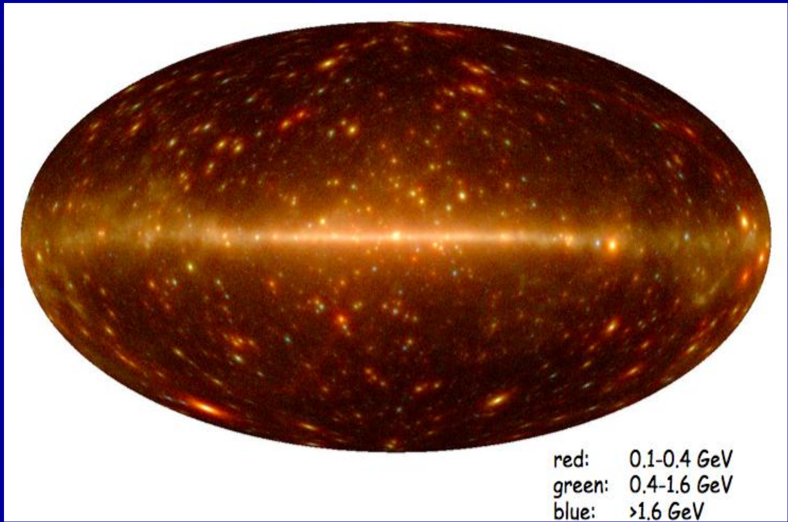
High Energy Astrophysics

A look at the highest energy particles

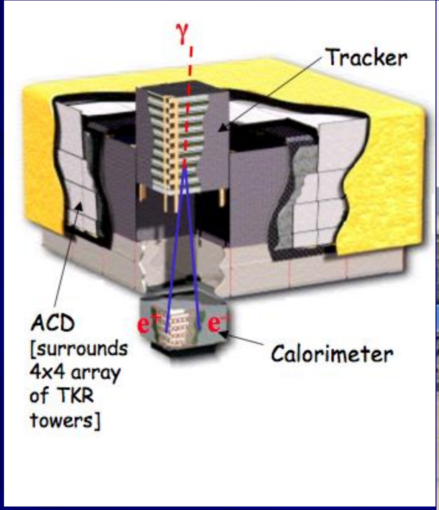
GLAST

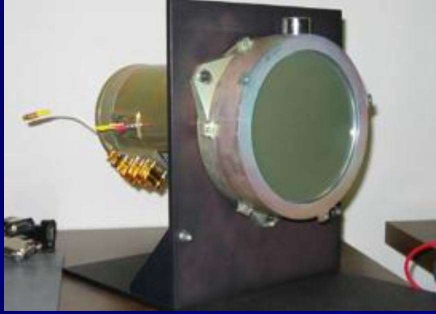
- Joint NASA-DOE-Italy- France-Japan-Sweden, Germany… mission
- Launch May 16 2008
  - Cape Canaveral
- Success of GLAST is top priority
- 50-100 x EGRET; high energy extension
  - Future program likely ground-based for a while





GLAST





LAT

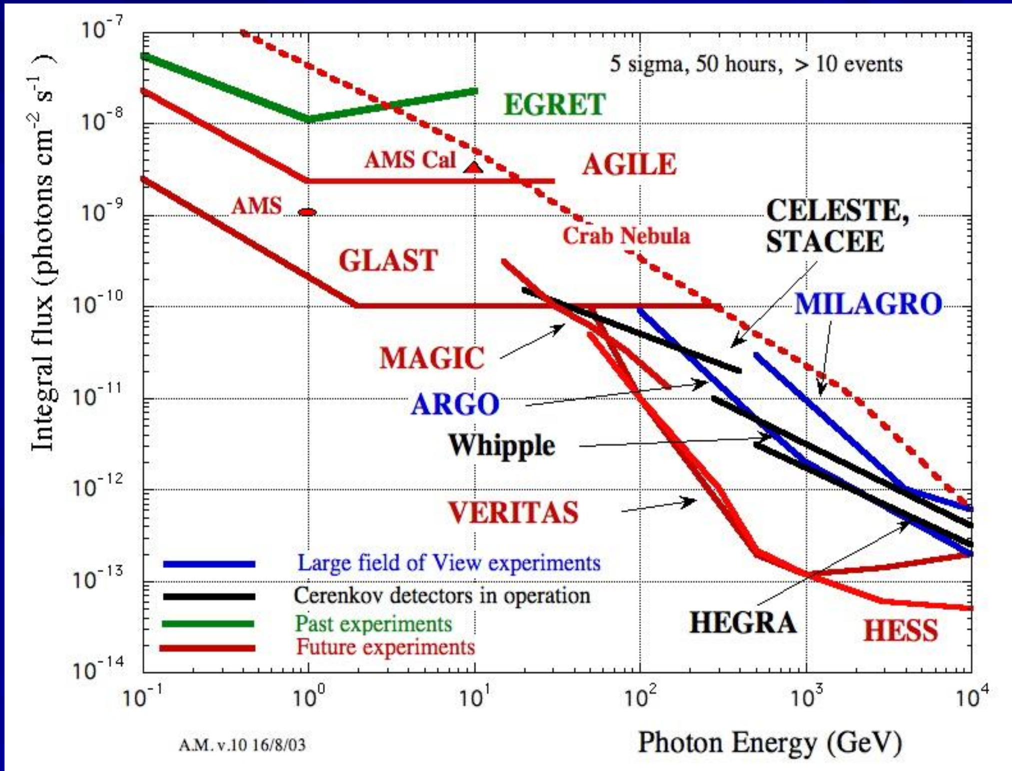
0.02 - 300 GeV
2.5 sr, 0.3 - 0.9m^2
5^o - 5'resolution
Δln E ~ 0.1
3 x 10^{-9} cm^{-2} s^{-1} (>0.1 GeV, point source)
10^9 photons (3Hz)
All sky every 3hr

GBM

- 0.01-30 MeV
- 9sr, 100 cm^2.
- 1^o resolution
- Δln E ~ 0.1
- Combine with Swift

Sources after a decade?

10,000 Active Galactic Nuclei
1000 Gamma Ray Bursts
100 Pulsars
100 Supernova Remnants
10 Galaxies
10 Clusters of Galaxies
10 X-Ray Binaries
? Unidentified Sources



GLAST Objectives

- To understand the mechanisms of particle acceleration in AGNs, pulsars, and SNRs.
- Resolve the gamma-ray sky: unidentified sources and diffuse emission.
- Determine the high-energy behavior of gamma-ray bursts and transients.
- Probe dark matter and early Universe.

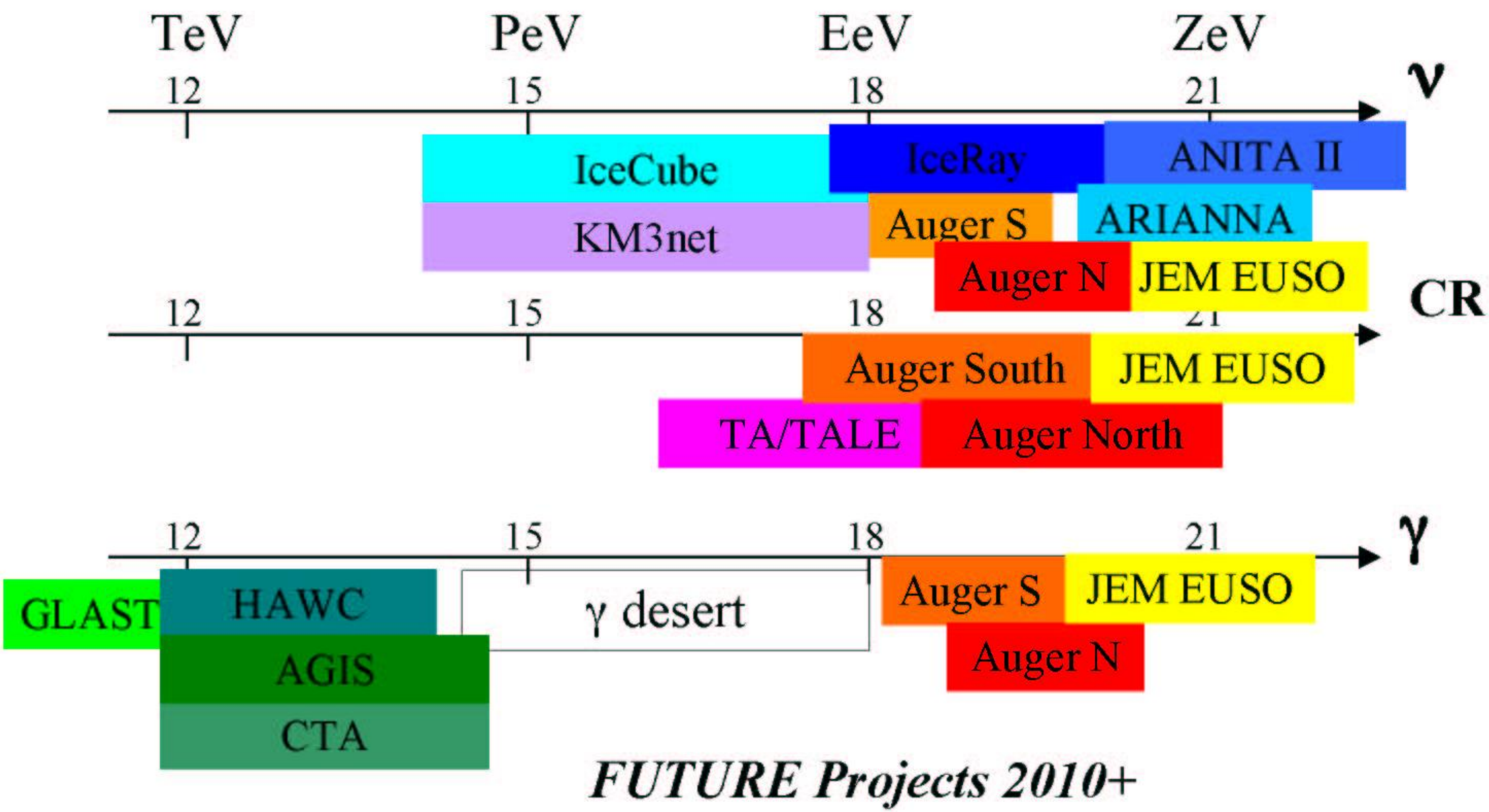
Exploring the Terascale

~1-10 TeV

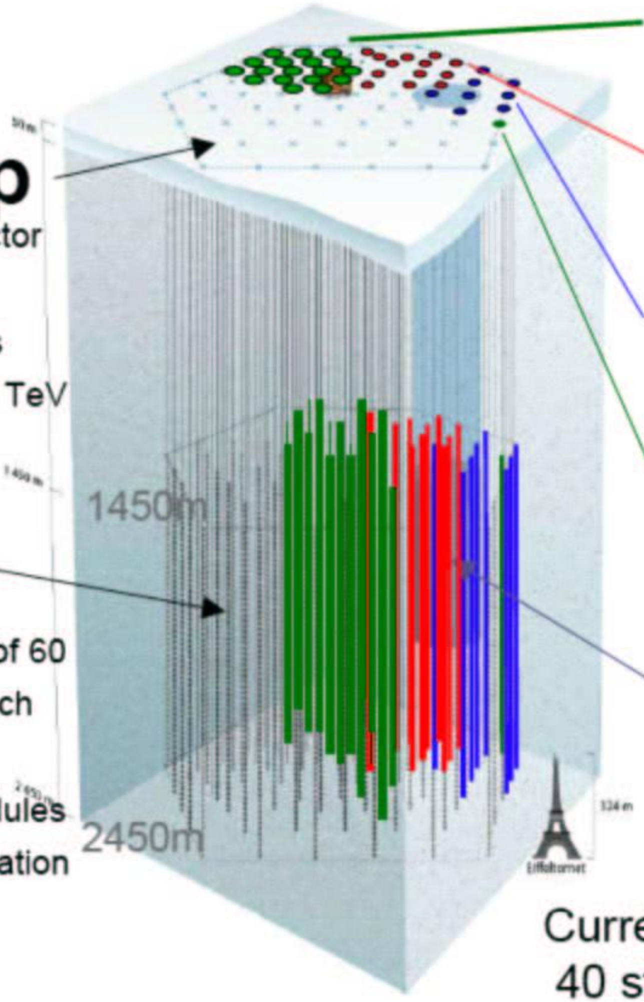
- ~10 ns flash
- ~1º @ 10 km->10^4 m^2
- Stereo imaging
- ~ 0.1-100TeV
- ~5º field of view
- ~5' PSF per photon
- ~100 sources

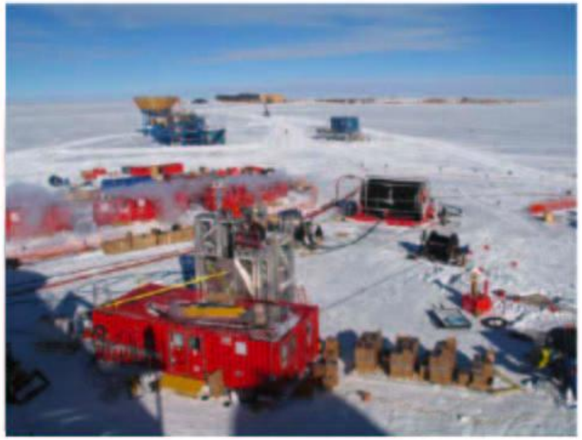
Particle Astrophysics at Ultra High Energies

The Energy Frontier



IceCube





IceTop

Air shower detector
80 pairs of ice
Cherenkov tanks
Threshold ~ 300 TeV

In Ice

Goal of 80 strings of 60
optical modules each

17 m between modules
125 m string separation

2007-2008 :
18 strings

2006-2007:
13 strings

2005-2006:
8 strings

2004-2005 : 1 string

AMANDA-II
19 strings
677 modules

Funded:
NSF MREFC
FY07 \$24.4M
FY08 \$25.9M
FY09 \$11.3M
FY10 \$0.95M

Current configuration:
40 strings,
40 IceTop stations
plus AMANDA

2008/09: add 18 strings and tank stations

Completion by 2011.

The Pierre Auger Observatory

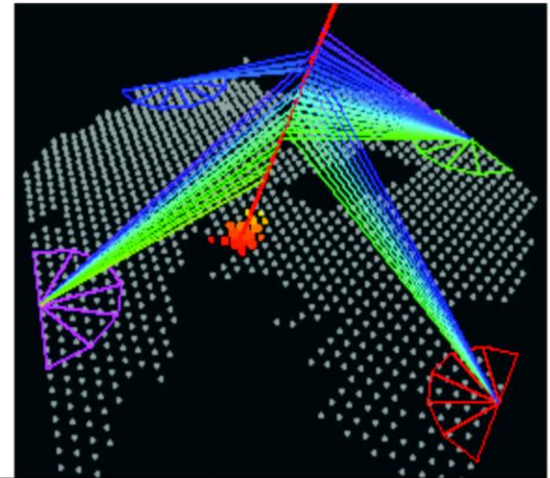
3000 km^2 area observatory in Mendonza, Argentina

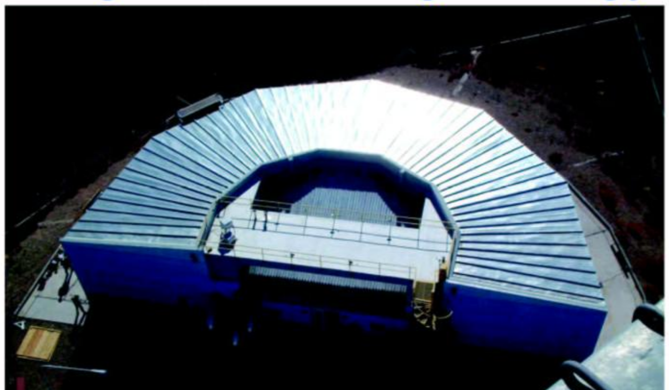
1600 water Cherenkhov detectors - 1.5 km surface array

4 fluorescence sites overlooking the array

Built by 17 countries to discover the

Origin of Ultra-High Energy Cosmic Rays



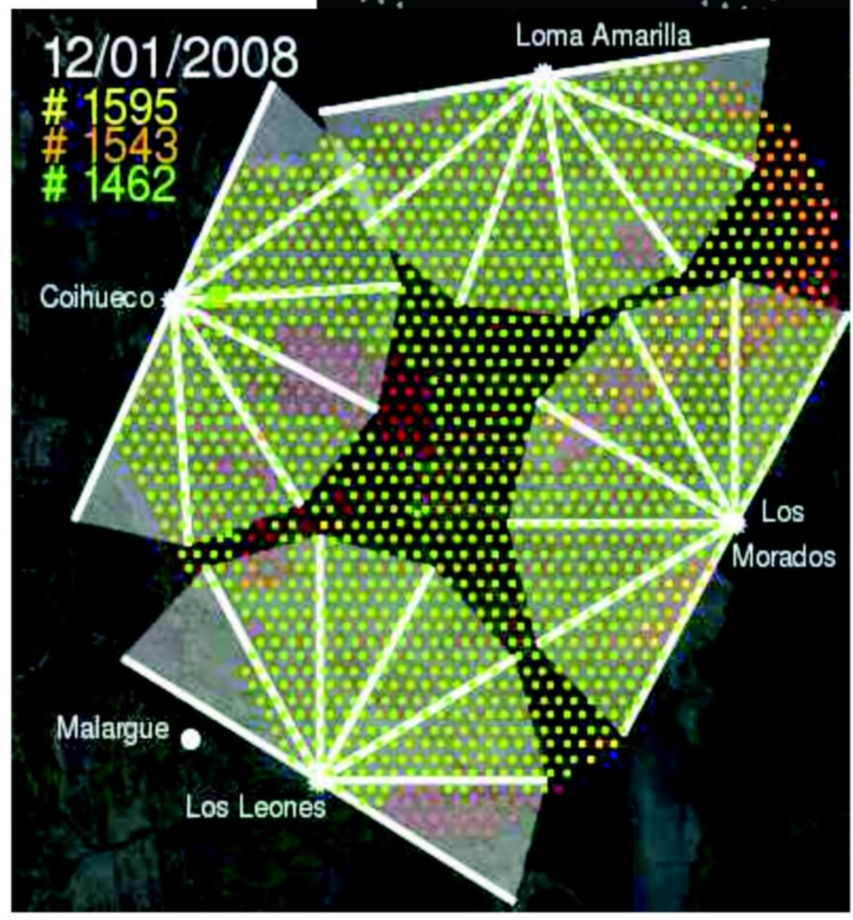


Cost: $53M (under budget)

US funding: DOE/NSF 50/50

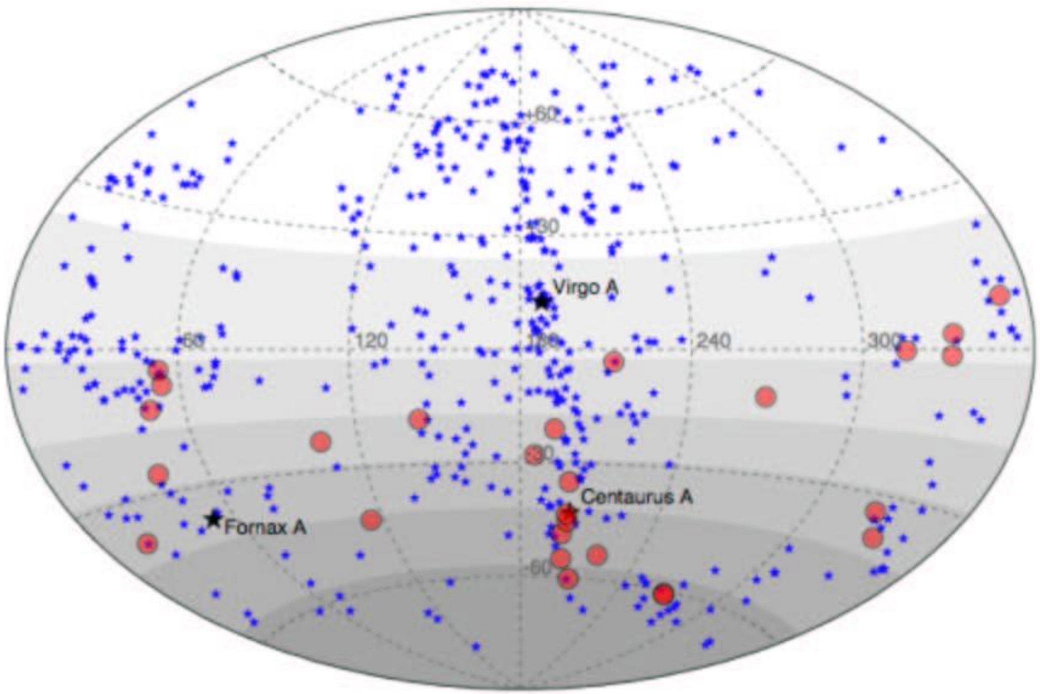
US 27.5% Construction

Operations = 2.4% Capital Costs

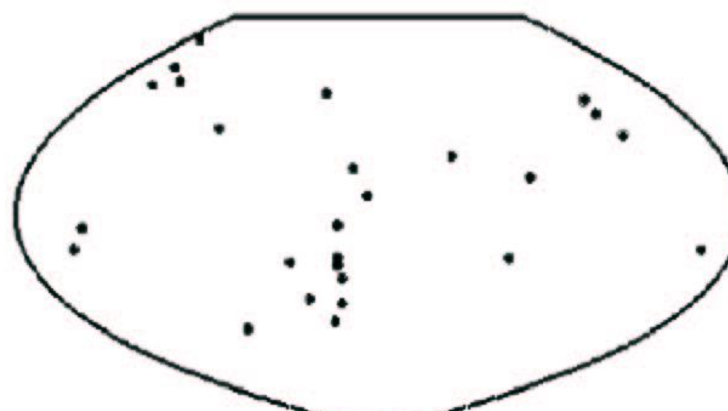


Auger South 2007

began the New Era of Particle Astronomy
by observing a correlation between 27 events
above ~ 6×10^{19} eV and position of
Active Galactic Nuclei within 75 Mpc.



GZK effect confirmed
Sources are extragalactic
Primaries are most likely protons

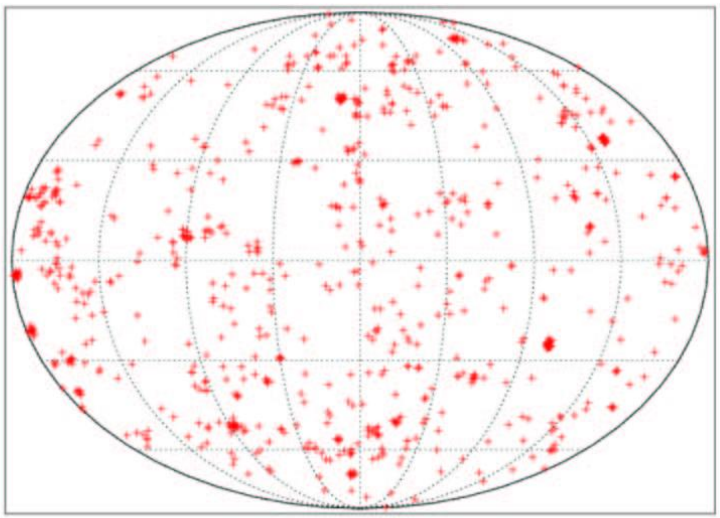


The Pierre Auger Observatory

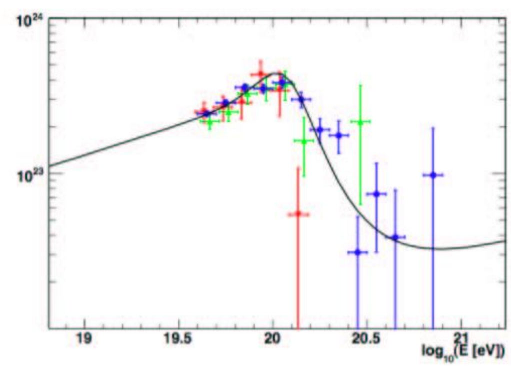
Auger North:

very **High Statistics** > 10^{19} eV & Full Sky Coverage to

1. discover all sources within GZK sphere



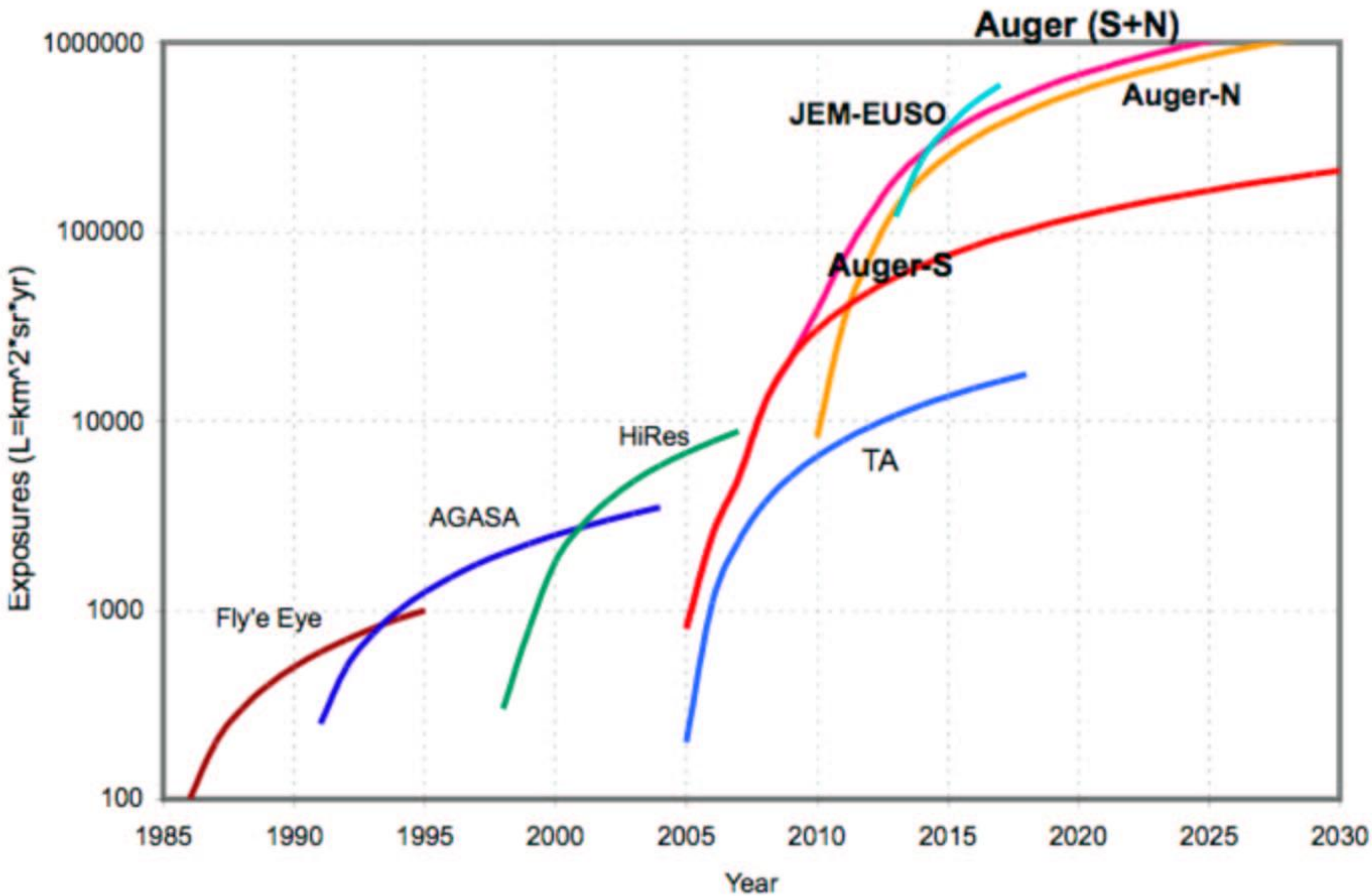
2. measure spectra of Brightest Sources



***3.** study **Hadronic Interactions above** **300 TeV** center of mass*

4. detect GZK (Cosmogenic) Photons and Neutrinos

Exposures


Auger (S+N)
JEM-EUSO
Auger-N
Auger-S
HiRes
TA
AGASA
Fly'e Eye
1000000
100000
10000
1000
100
Exposures (L=km^2*sr*yr)
1985
1990
1995
2000
2005
2010
2015
2020
2025
2030
Year

Overall Conclusions

- There is a rich program of Cosmology and Astrophysics
- Many opportunities for building or strengthening collaborations between US and Japan