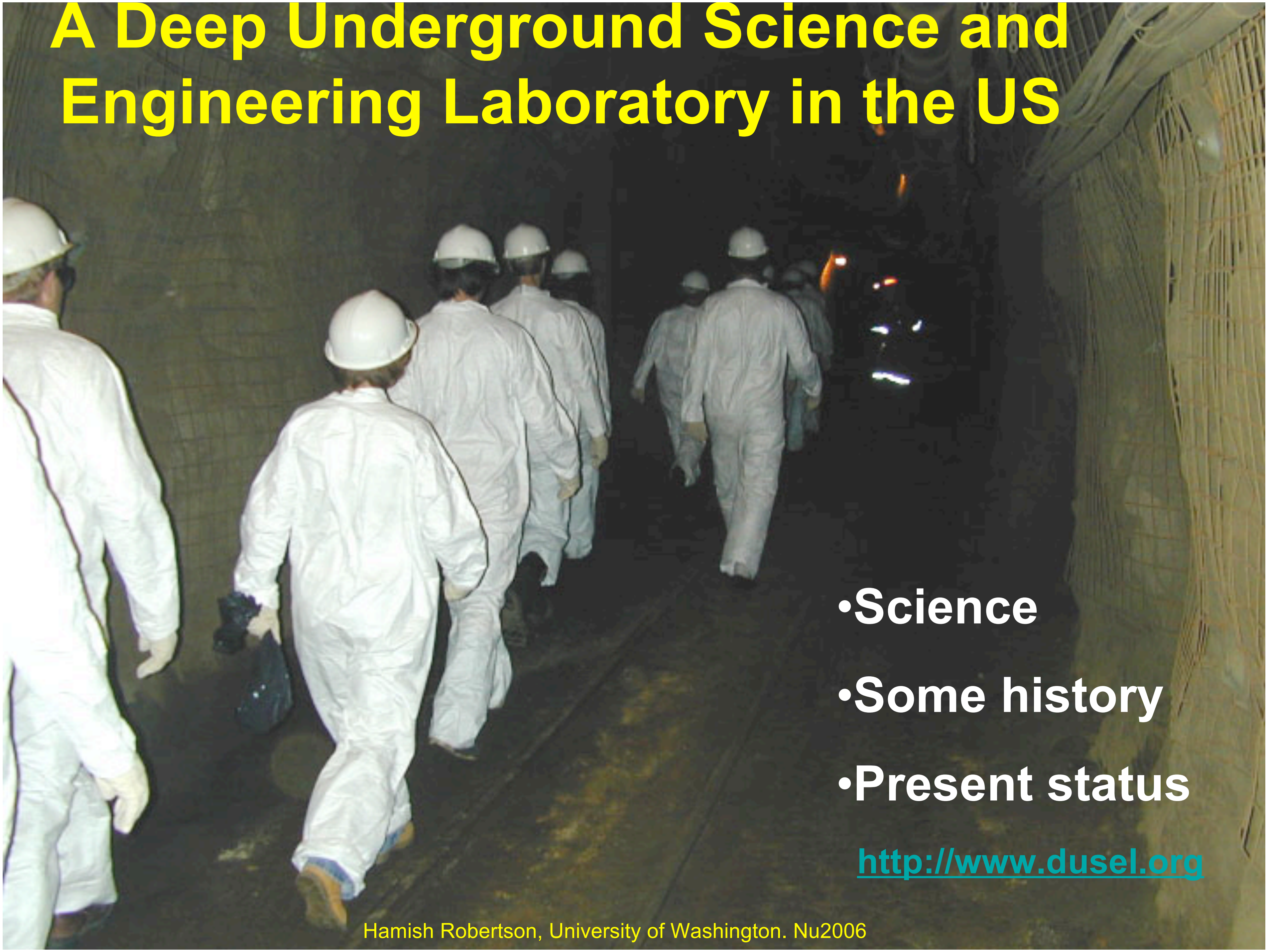
A Deep Underground Science and Engineering Laboratory in the US



- Science
- Some history
- Present status

http://www.dusel.org

Hamish Robertson, University of Washington. Nu2006

Brief History of Deep Underground Lab in US

- 1980 – attempt to start a multi-disciplinary laboratory in Yucca Mountain or San Jacinto.

- Homestake, Soudan, WIPP, host physics.

  WIPP is supporting the identification of viable 250-Ma-old bacteria, their DNA and viable phage within intact cells found in included water in salt beds.

- 2000 – New attempt to start lab motivated by imminent closing of Homestake mine

- 2004 – NSF restarts the process with a planned series of three solicitations

The NSF solicitations

Four NSF directorates – MPS, GEO, ENG, BIO

S1 – Research definition and associated infrastructure requirements.

S2 – Site development and conceptual design.

8 proposals “down-selected” to 2 sites, now 3.

S3 – Site specific, detailed infrastructure plan for science and engineering for a single site.

Earliest MRE funding available – beginning FY 2009

~ a few X 10^8 $ for lab plus experiments.

Look beyond the next generation of experiments

Three Major Research Areas

Physics

Geosciences & Engineering

Geomicrobiology

Physics: the Big Questions

- **What is the dark matter?**
- **What is the nature of the dark energy?**
- **How did the universe begin?**
- **Did Einstein have the last word on gravity?**
- **What are the masses of the neutrinos, and how have they shaped the evolution of the universe?**
- **How do cosmic accelerators work and what are they accelerating?**
- **Are protons unstable?**
- **Are there new states of matter at exceedingly high density and temperature?**
- **Are there additional spacetime dimensions?**
- **How were the elements from iron to uranium made?**
- **Is a new theory of matter and light needed at the highest energies?**

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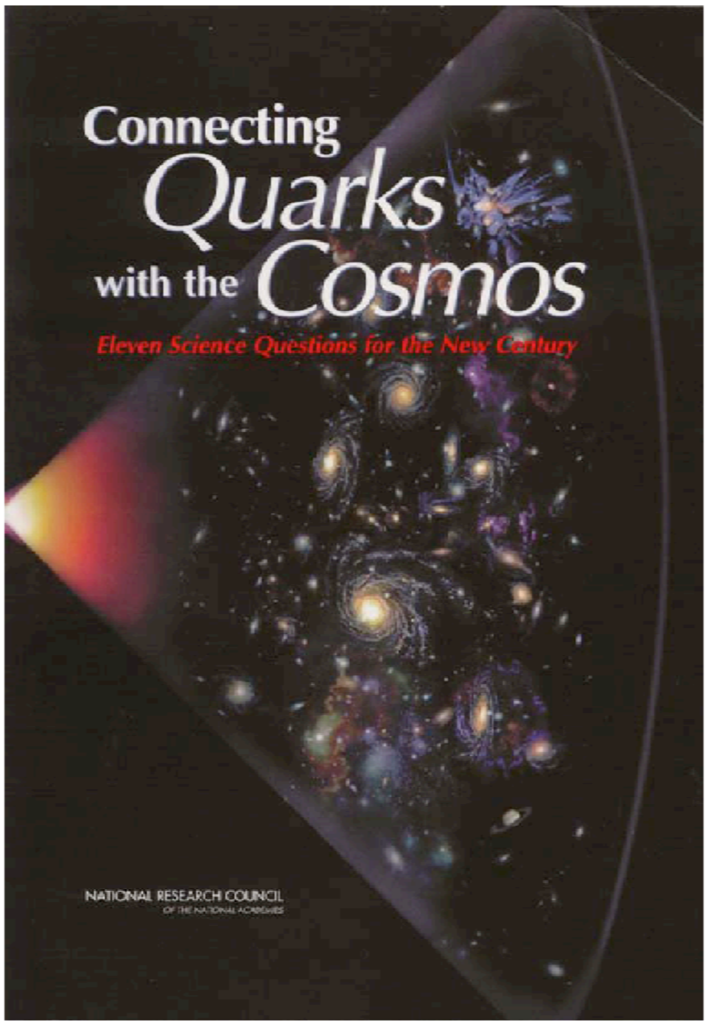
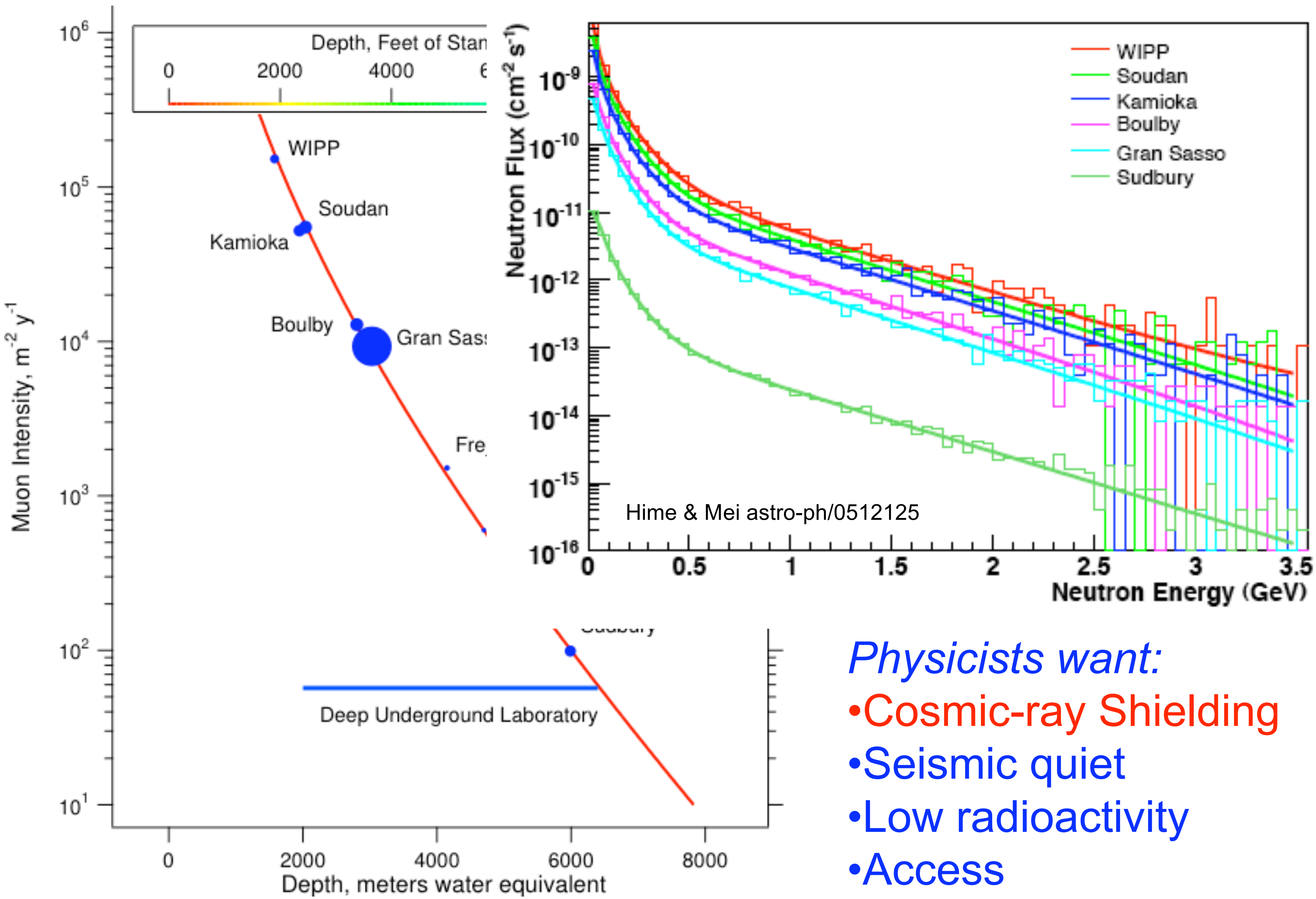
Scientific case has been established and validated by two National Academy Studies, two long-range plans and several community workshops



Determine the neutrino masses, the constituents of the dark matter and the lifetime of the proton. The Committee recommends that DOE and NSF work together to plan for and to fund a new generation of experiments to achieve these goals. We further recommend that an underground laboratory with sufficient infrastructure and depth be built to house and operate the needed experiments.

(3rd Turner Committee Recommendation, 2002)



Physicists want:

- Cosmic-ray Shielding
- Seismic quiet
- Low radioactivity
- Access

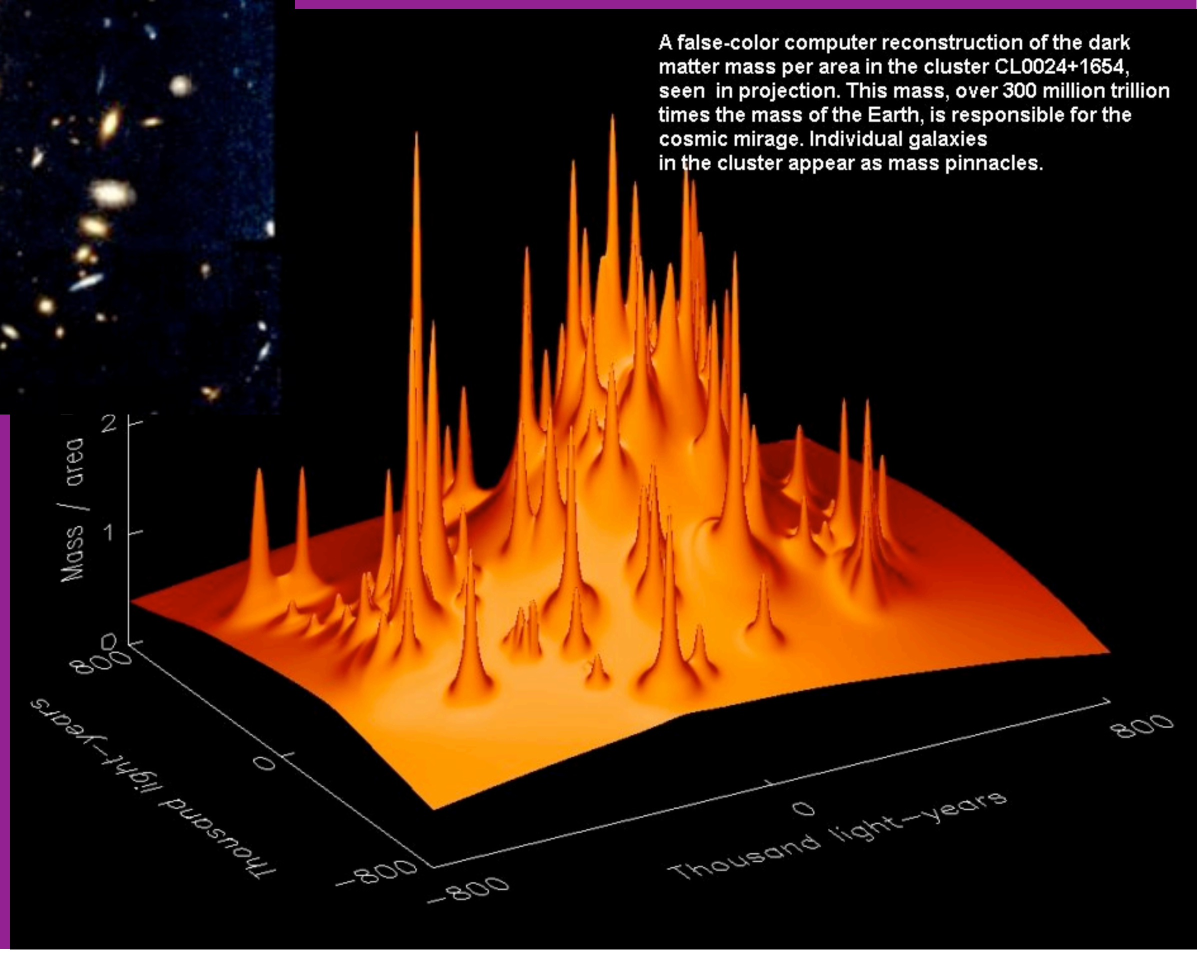
Data: Hime & Mei, astro-ph/0512125
Curve: Miyake, N.Cim. 32, 1505 (1964)

DARK MATTER:

Gravitational Lensing reveals distribution of dark matter in CL0024+1654

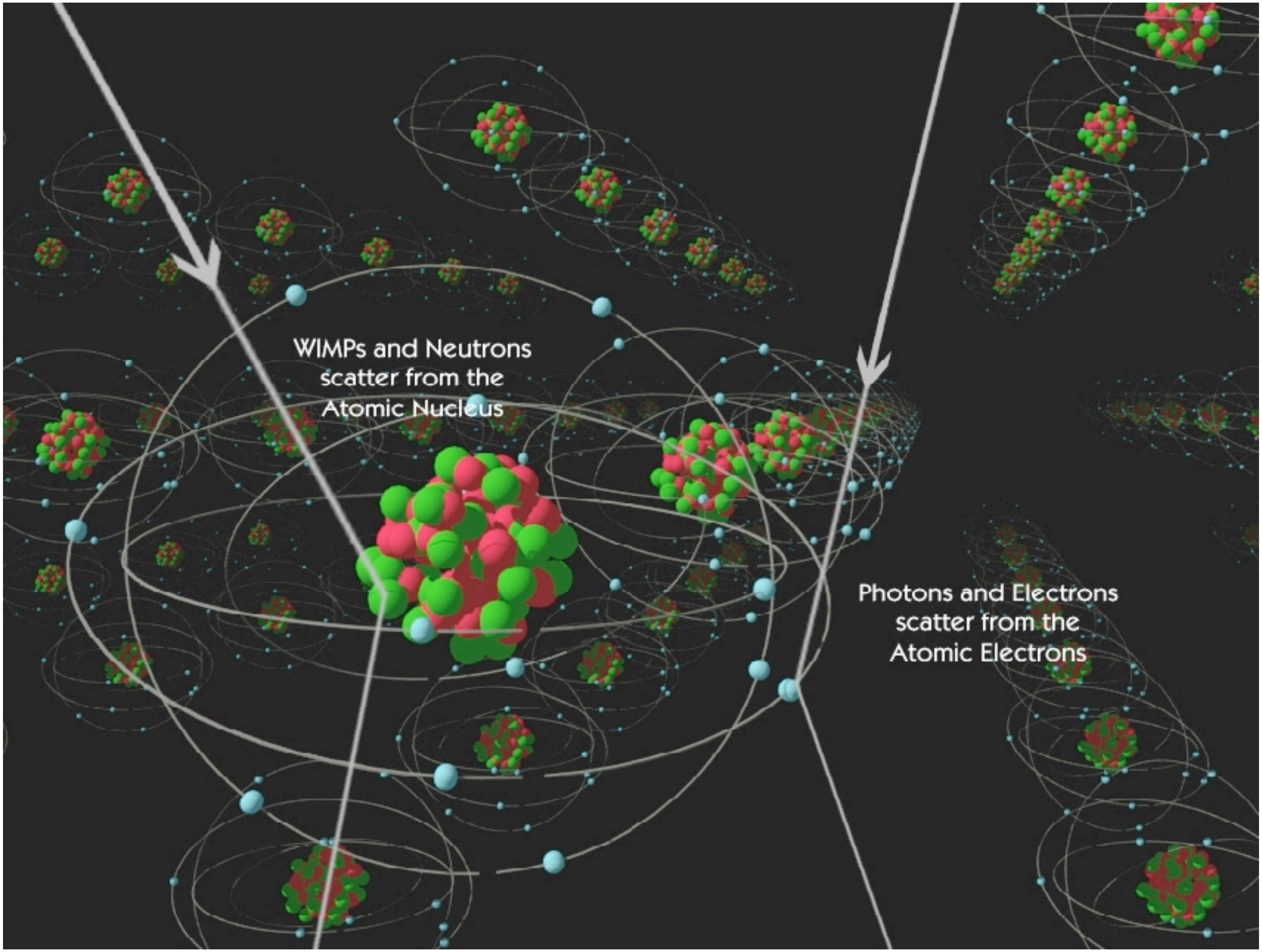
(Tyson et al. astro-ph/9801193)

HST0024



Cosmological data indicate 23% of universe's density is CDM. But what IS it?

Example: CDMS WIMP search



WIMP searches need depth

- Raw neutron rates with μ veto, passive shield
- Shallow + active veto?
  - 90% efficiency at Soudan OK for 25 kg SCDMS

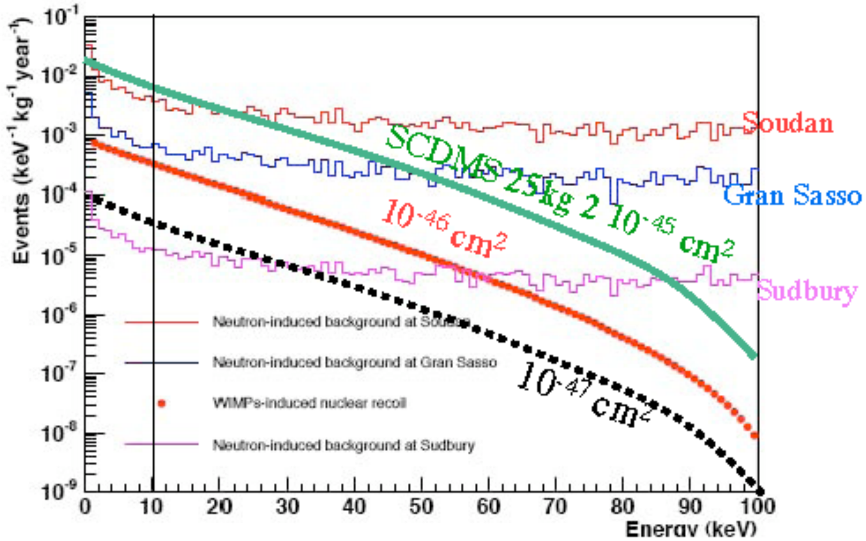
But:

Risky – shielding difficult

No safety margin

No path to future

Fast neutron recoil spectrum



Mei, Hime astro-ph0512125

M_{WIMP}=100GeV/c^2

Low background is easier than rejecting background

Physics Program

- Dark matter
- Neutrinoless Double Beta Decay:
  - Lepton number violation, matter-antimatter transition in early universe
  - Mass of the neutrino
- Low-energy neutrinos
  - Solar neutrino spectrum, CNO
  - Sterile neutrinos
  - Luminosity of future sun
  - Geoneutrinos
  - Supernova neutrinos
- Low-cross-section accelerator facility (in addition to LUNA)
- Low background counting
  - Physics
  - National security
- CP Violation, Hierarchy, Nucleon Decay: Mega-detector

Geoscience: the Big Questions

Draft* from NRC Committee on “Grand Questions in the Solid Earth Sciences"

- How did the Earth and planets form?
- What happened during Earth's dark age (the half billion years before the oldest known rock formed)?
- How did life begin on Earth?
- Why plate tectonics?
- How has Earth's interior evolved, and how has it affected the surface?
- Why does Earth have a magnetic field?
- How do life and Earth coevolve?
- How has Earth's climate changed, and why?
- Can we understand and predict catastrophic natural events?
- How do material properties control planetary processes?
- How do air, water, land, and life processes interact to shape our environment?

*http://dels.nas.edu/besr/grq_input.php

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Failure of Malpasset Dam, 1958

Remains of the Malpasset Dam;
Reproduced courtesy of Structurae;
photographer Jean-François Perréard

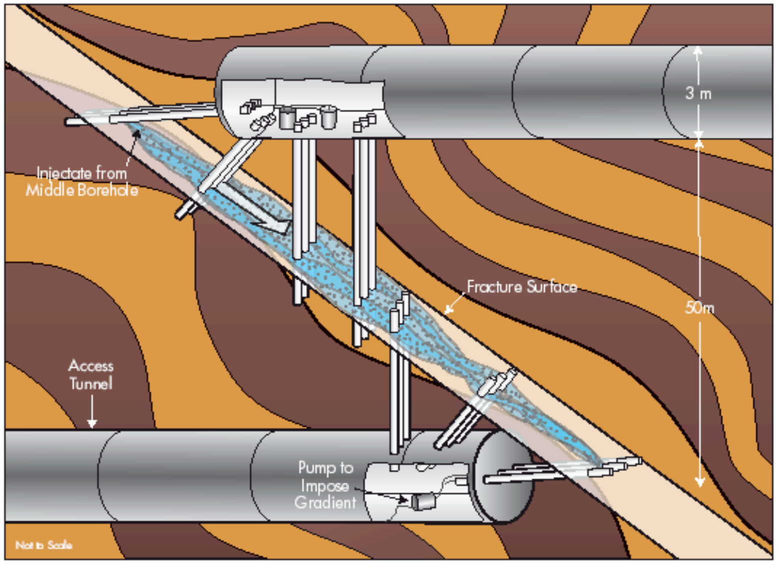
Malpasset Dam Remains.
Reproduced courtesy of Structurae;
photographer Alain Pasquet

The tragedy killed 424 people and led to the realization that geoscience and engineering required new directions.

Complex Coupled Processes – HTMCB
(Hydro-Thermal-Mechanical-Chemical-Biological)

- How do coupled **HTMCB** processes in rock vary with depth and over a decadal time scale?

- How do local coupled **HTMCB** processes scale up to ~100 m's and what characterization data are required to accurately predict behavior at this scale?



http://www.earthlab.org/

Big questions – Geomicrobiology

- **How deeply does life extend into the Earth?**
- **What fuels the deep biosphere?**
- **How does the interplay between biology and geology shape the subsurface?**
- **What are subsurface genomes telling us?**
- **Did life on the earth's surface originate underground?**
- **Is there life in the subsurface as we don't know it?**

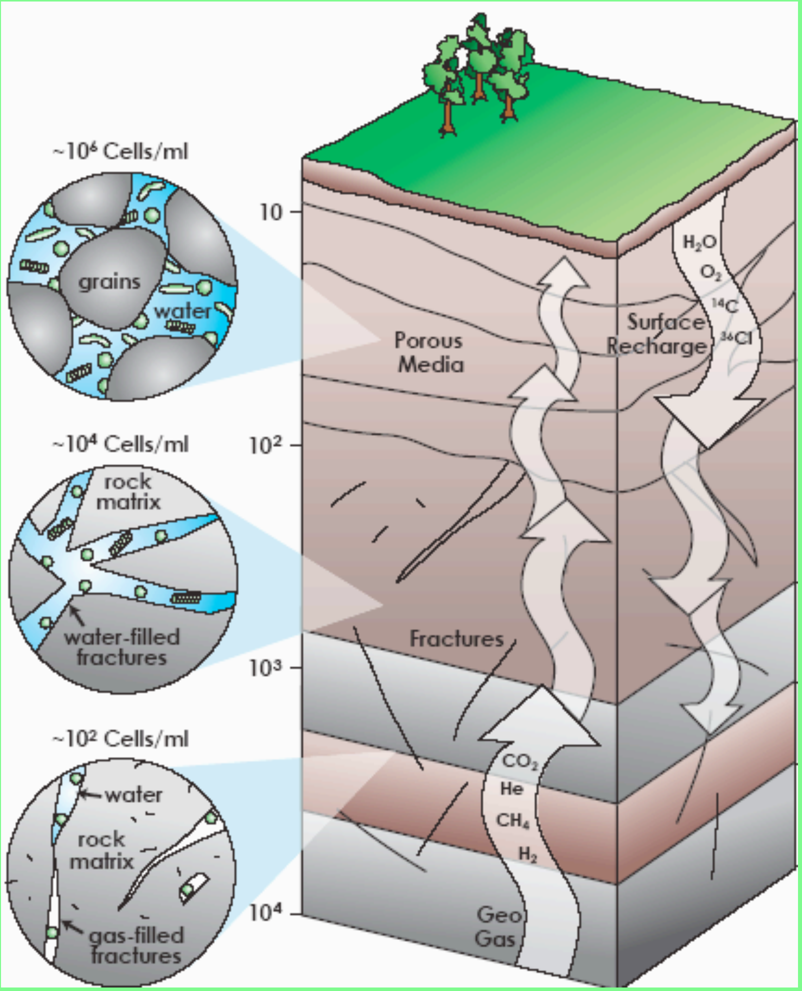
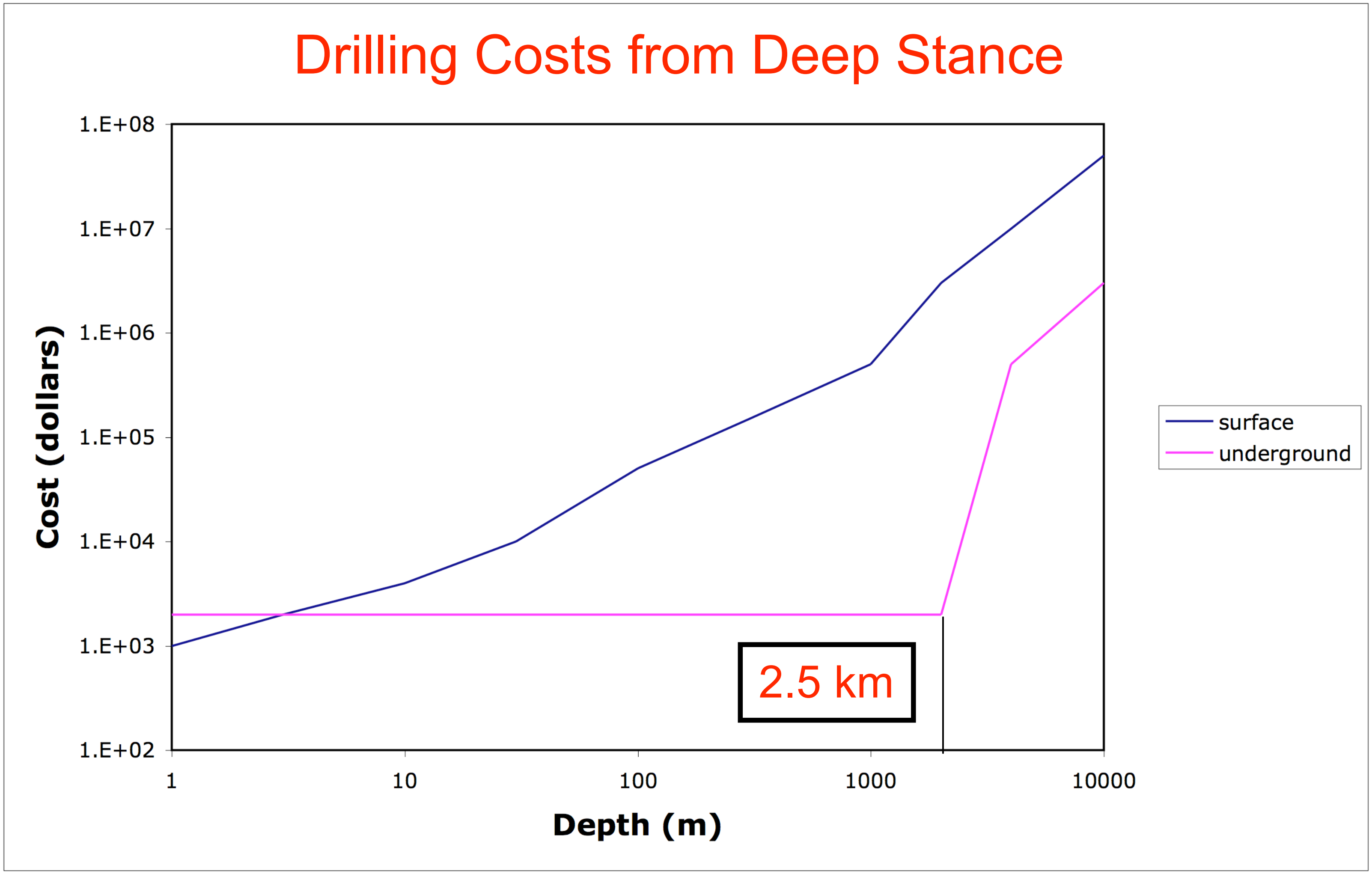


Figure 2 - Earthlab Report
(Thanks to Tommy Phelps – ORNL)



Objectives:

Prevent sample contamination
Study microbes in situ (microbial activity at low respiration rate)
Deep platform to drill deeper – 12,000 ft (120^0 C – find limit of life)

S1 activities and status

6 Principal Investigators:

- Bernard Sadoulet -- U.C. Berkeley, Physics (Astro) - Director
- Eugene Beier -- U. Pennsylvania, Physics (Particle)
- Charles Fairhurst -- U. Minnesota, Civil Eng/Rock Mechanics
- T.C. Onstott -- Princeton U., Geosciences/Geomicrobiology
- Hamish Robertson -- U. Washington, Physics (Nuclear)
- James Tiedje -- Michigan State U., Microbiology

2 Consulting Groups:

Site consultation group – Channel for S2 site proponents to communicate

Initiative coordination group – Allows other stakeholders (e.g. labs) to communicate

14 Technical Working Groups…

S1 Working Groups – Physics
Determine the scientific reach of DUSEL

Dark Matter
- Dan Akerib (Case Western Reserve U.)
- Elena Aprile (Columbia U.)

Low-Energy Neutrinos
- Tom Bowles (LANL)
- Bruce Vogelaar (Virginia Tech)

Long Baseline Neutrino Experiments
- Milind Diwan (BNL)
- Gina Rameika (Fermilab)

Neutrinoless Double-Beta Decay
- Steve Elliott (LANL)
- Charles Prescott (SLAC)

Nuclear Astrophysics and Underground Accelerators
- Joachim Goerres (U. Notre Dame)
- Michael Wiescher (U. Notre Dame)

Nucleon Decay/Atmospheric Neutrinos
- Chang Kee Jung (SUNY Stony Brook)
- Hank Sobel (UC Irvine)

Low-Background Counting Facilities and Prototyping
- Harry Miley (PNNL)
- Prisca Cushman (U. Minnesota)

Other S1 Working Groups
Determine the scientific reach of DUSEL

Rock Mechanics/Seismology
- Larry Costin (SNL)
- Paul Young (U. Toronto)

Applications
- Francois Heuzé (LLNL)
- Jean-Claude Roegiers (U. Oklahoma)

Coupled Processes
- Brian McPherson (New Mexico Tech)
- Eric Sonnenthal (LBNL)

Geomicrobiology
- Tommy Phelps (ORNL)
- Tom Kieft (New Mexico Tech)

Microbial Biology and Evolution
- Jim Fredrickson (PNNL)
- Nancy Moran (U. Arizona)

Infrastructure Requirements and Management
- Lee Petersen (CNA Engineers)
- Derek Ellsworth (Penn State U.)
- David Berley (U. Maryland)

Education and Outreach
- Willi Chinowski (LBNL)
- Susan Pfiffner (U. of Tennessee)

S1 Workshops – Identifying the user community

- UC Berkeley Workshop
  Berkeley, CA, August 11–14, 2004
- Biosciences, Geosciences, and Engineering Workshop
  Blacksburg, VA, November 12–14, 2004
- University of Colorado Workshop
  Boulder, CO, January 4–7, 2005
- University of Minnesota Workshop
  Minneapolis, MN, July 22–24, 2005

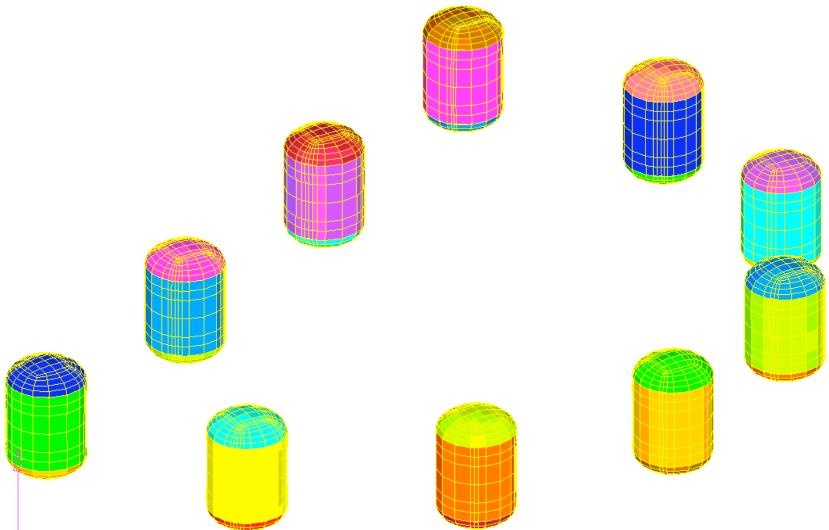
Deliverables

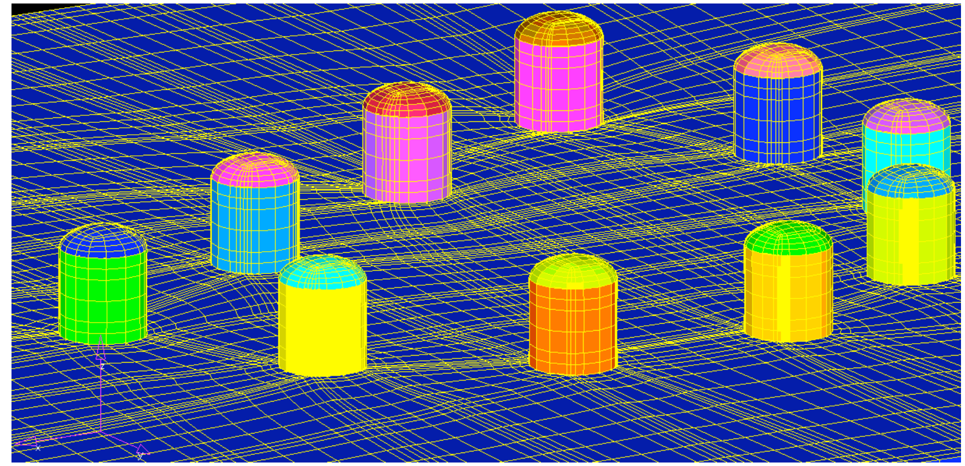
Printed report directed at generalists
for Agencies, OMB/OSTP/Congress (cf. Quantum Universe)

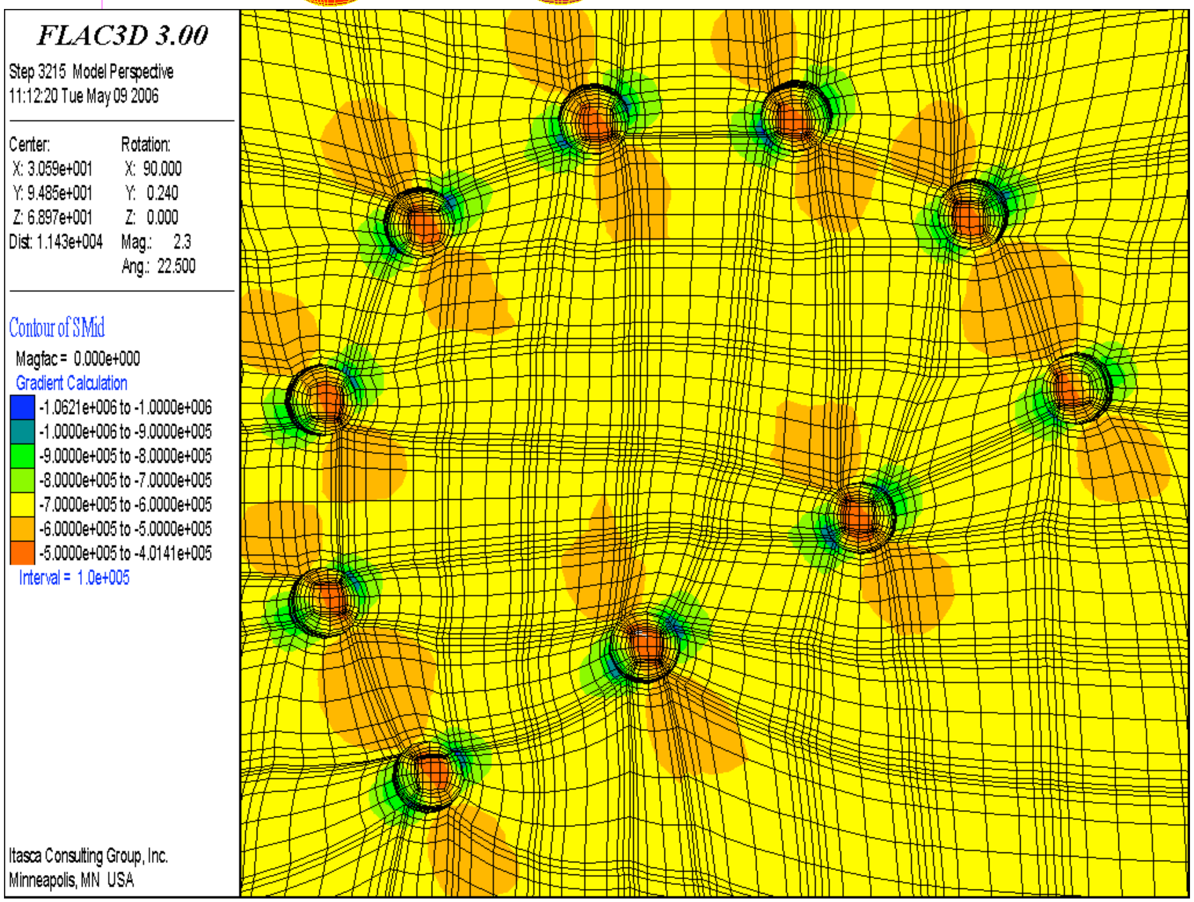
Web based reports with technical information
for scientists and program monitors

Is there a need for US national facility?

- Fundamental questions in science and engineering need to be addressed.
- International demand for UG lab space is high.
  - e.g. 85 letters of intent submitted to Homestake
    - 60% earth sciences, 25% physics, 5% bio, 5% education…
- Multi-disciplinary lab is unique in world.
  - Interesting synergies: Instrumentation, low background, education…
- A "National Lab" Home for some very important science. (e.g. neutrino physics presently 2% of DOE NP budget).







Geotechnical stresses for 10-cavity megadetector array

(courtesy C. Fairhurst)

S1 Recommendations (Preliminary)

1. **A new initiative in deep underground science**.
   - Importance of deep underground science, high potential for revolutionary discoveries, likely transformative impact --> we recommend U.S. agencies collaborate on a new initiative in deep underground science. Long-term, multidisciplinary program supporting both deep underground researchers at individual institutions and the national facilities needed.
2. **Implementation of funding, advising and coordination mechanisms**.
   - Coordination between the agencies and between disciplines within the agencies.
   - Prioritization of deep underground science with respect to other major research programs.
   - Prioritization within underground science.
   - Optimal use of national assets and international collaborative opportunities.
   - Maximization of societal benefits, through the involvement of other sectors and a powerful program in education and outreach.

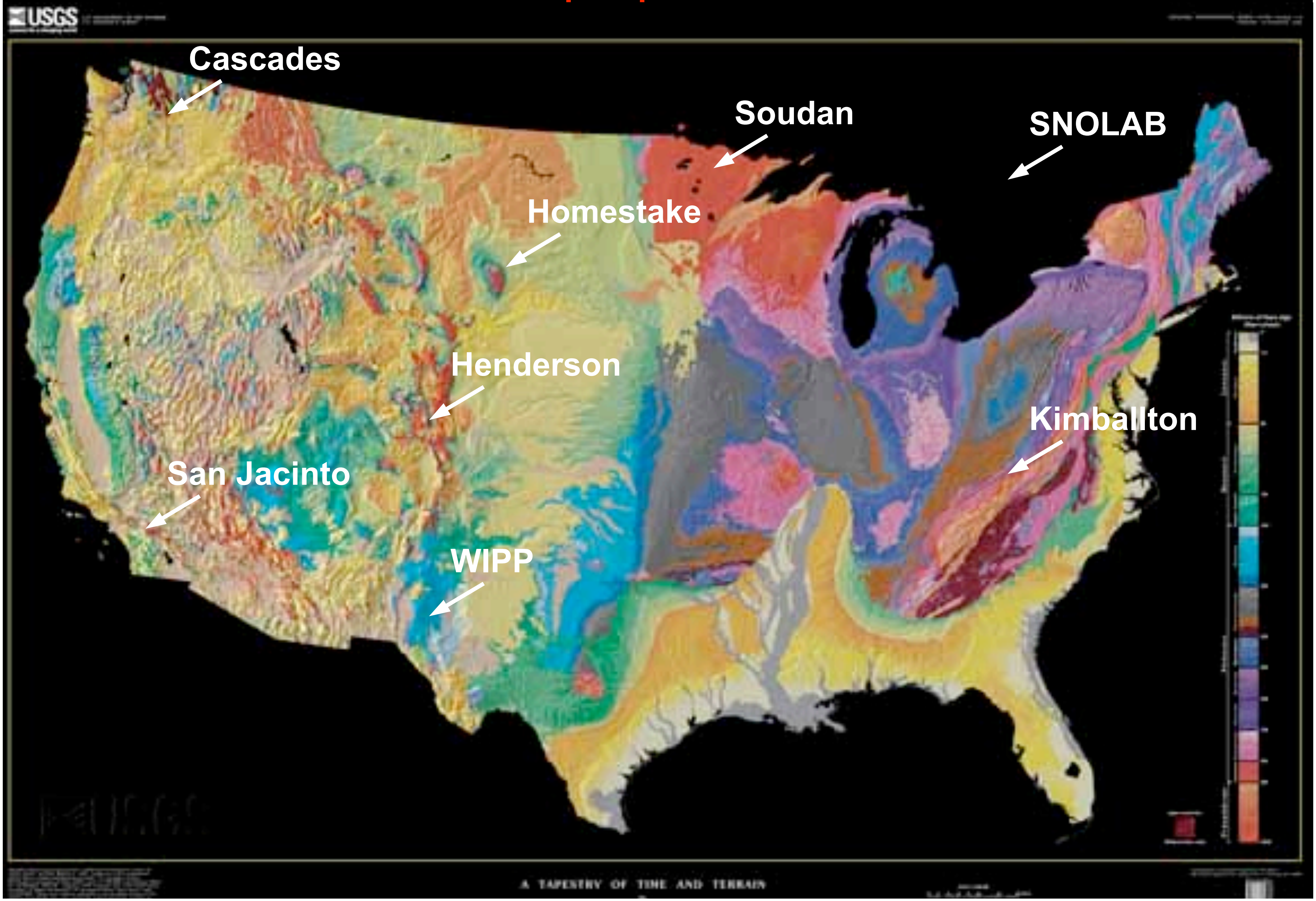
S1 Recommendations (Preliminary)

3. **A Deep Underground Science and Engineering Laboratory**. The U.S. should fix a major deficiency in its assets for frontier underground science, and construct a deep underground laboratory (~ 6000 m.w.e), which will naturally include facilities at intermediate depth. Such a Deep Underground Science and Engineering Laboratory (DUSEL) should offer premier characteristics in terms of access, environment control, safety, and evolutionary capabilities. It would have maximum impact if the first round of facilities were available within five years. The lifetime of the laboratory is estimated to be 30 to 50 years. The project should be structured to allow full use of the scientific and engineering opportunities arising during the site exploration and construction.

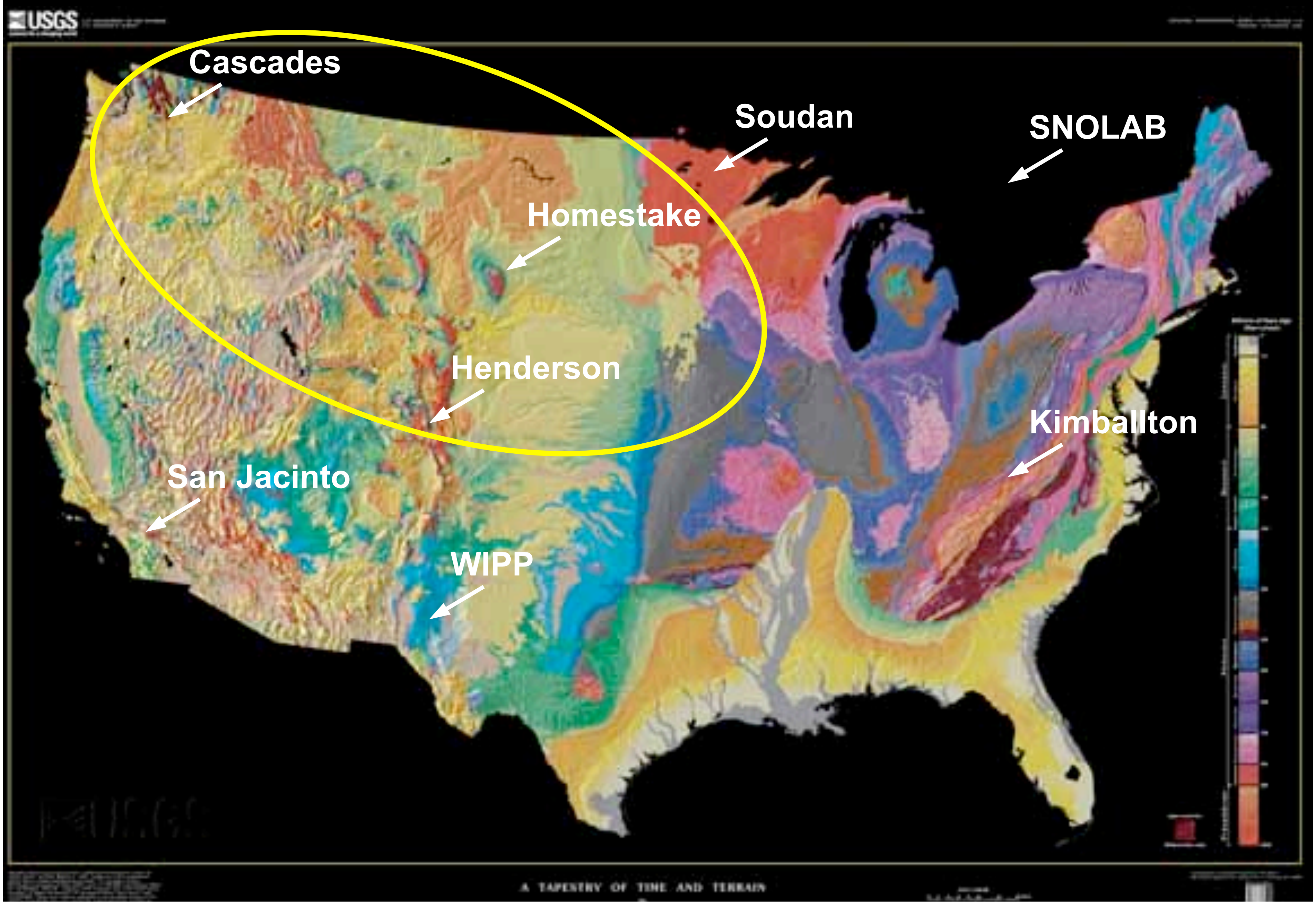
   The Laboratory will naturally fulfill some of the program management functions outlined in recommendation 2.

4. **Extension possibility to complementary sites**. Although financial constraints are likely to limit DUSEL initially to a single site, the U.S. should keep open the possibility of establishing a complementary site for biology, earth science and engineering studies that strongly benefit from a different rock type.

DUSEL S2 proposed sites



DUSEL S2 selected sites



Time Line

July 20, 2005: S2 Downselection announced by NSF

June 12, 2006: Reviews of Technical Reports due -- most received, a few will be delayed.

June 18: Draft Reports to S2 for info.

June 23: Henderson, Homestake S2 CDRs due at NSF (?).

June 26: Overview Report draft ready.

~May, 2007: Cascades S2 CDR due at NSF (?)

~late 2007: S3 selection (?)

~2008: S3 proposal submitted.

~2008-9: NSF and NSB submit MRE request

~2011-12: DUSEL construction starts.