Cosmic Frontier Theory Group
Argonne National Laboratory

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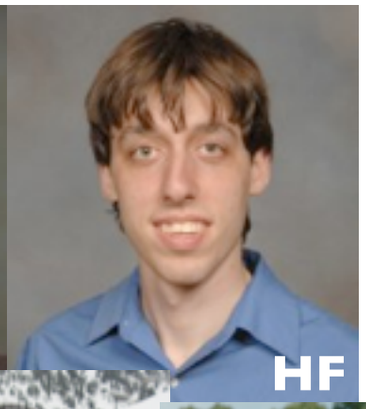
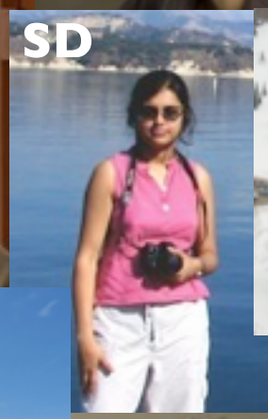
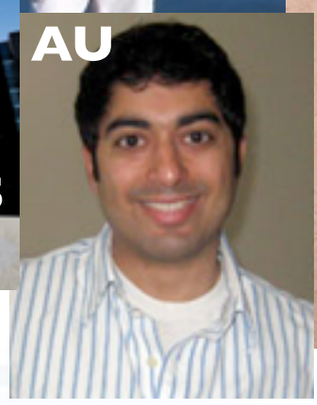
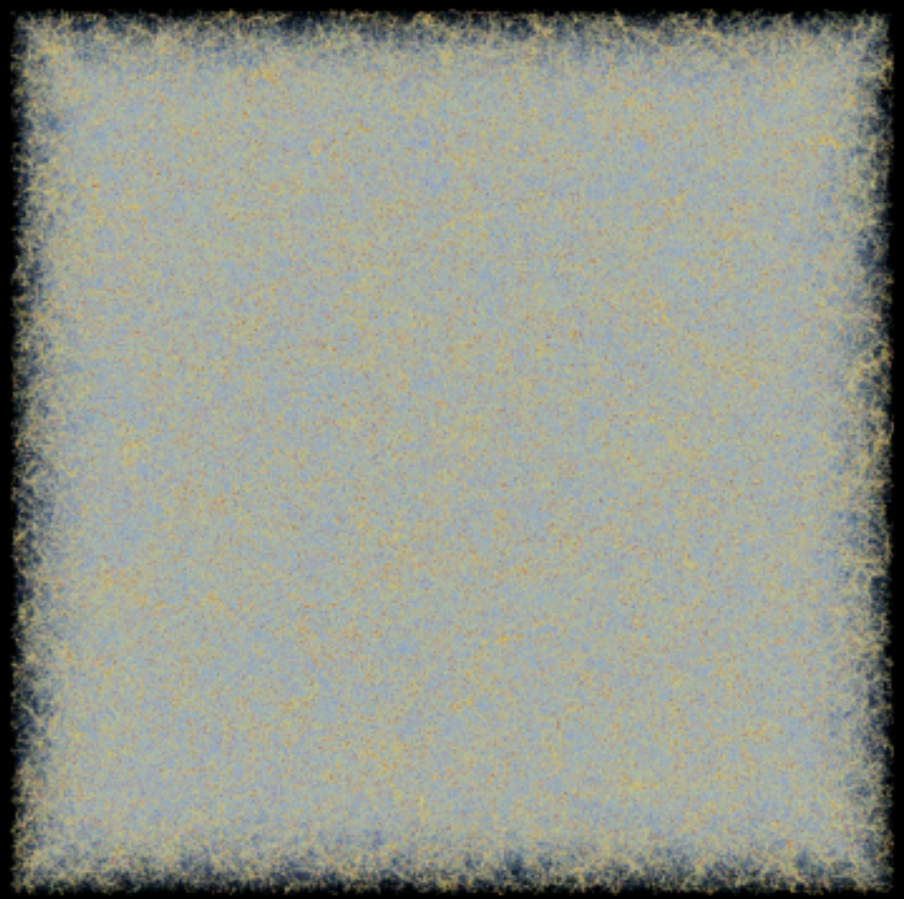








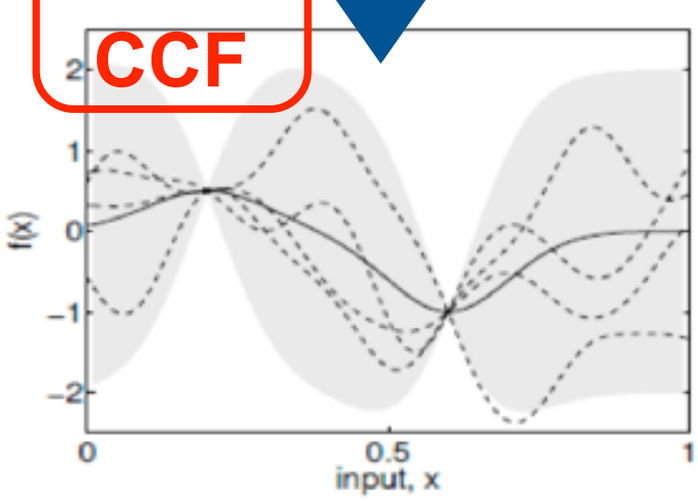
2 Gpc box, 8 billion particle run with HACC

Visualization by J. Insley, ALCF

Precision Cosmology: Calibrating the Universe

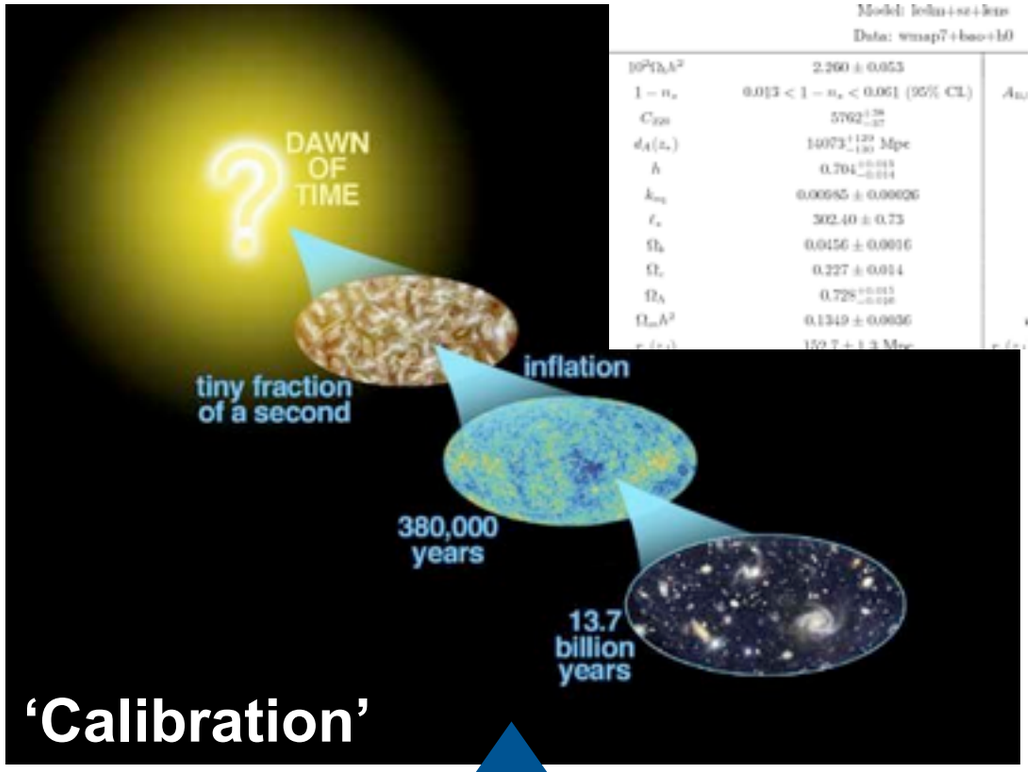
Supercomputer Simulation Campaign

HACC + CCF

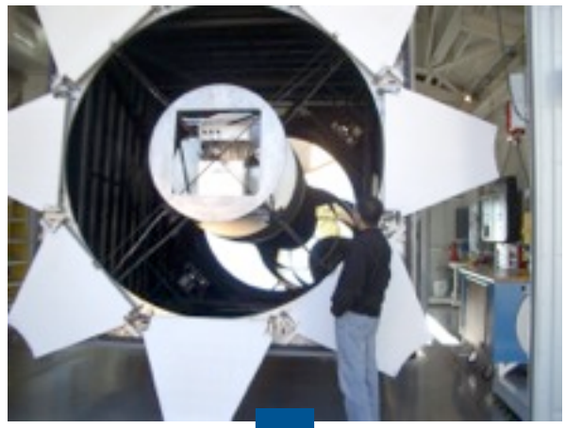


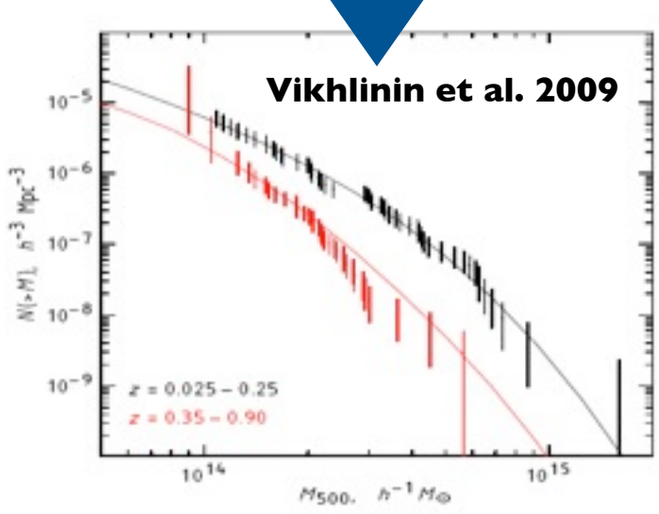
Emulator based on GP Model Interpolation in High-Dimensional Spaces

‘Precision Oracle’



Mapping the Sky with Survey Instruments



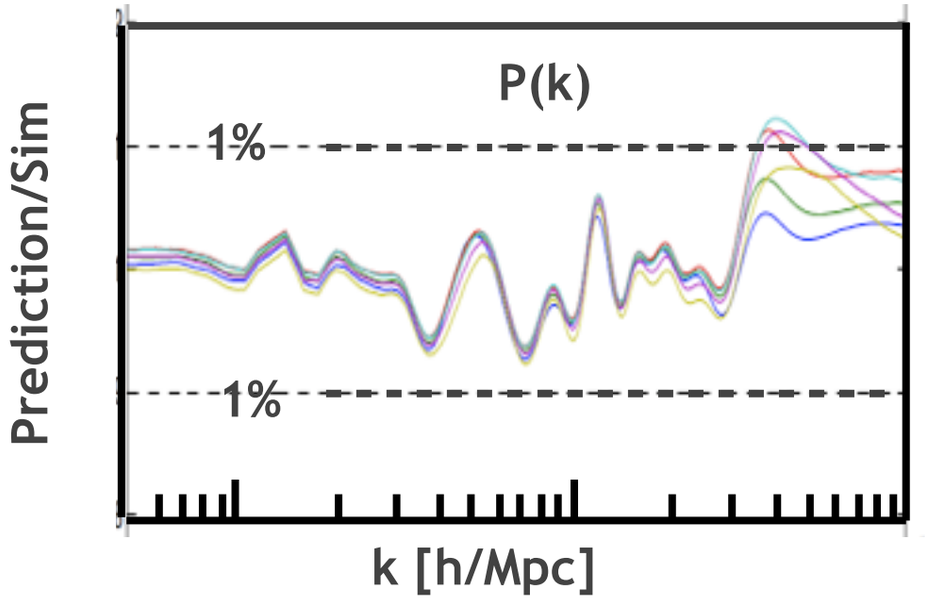


Observations: Statistical error bars will ‘disappear’ soon!

HACC and CCF

- **Architecture Challenge:** HPC is rapidly evolving (clusters/BG/CPU+GPU/MIC --)
- **HACC:** Hybrid/Hardware Accelerated Cosmology Code Framework
- **Code for the Future:** Melds optimized performance, low memory footprint, embedded analysis, and cross-platform scalability
- **CCF:** Cosmic Calibration Framework
- Optimal Sampling
- PCA-compression, adaptive filtering
- Gaussian Process Modeling
- Error validation
- Instantaneous oracle for cosmic MCMC: Statistical inference in hours instead of decades

HACC: Habib et al. 2009, Pope et al. 2010, ---



CCF: Heitmann et al 2006, Habib et al. 2007, Heitmann et al. 2009, 2010, Lawrence et al. 2010, ---

Cosmic Frontier Computing Collaboration: CFCC

- **Cosmic Frontier Computing at NERSC:** CFCC gets major computing allocation at NERSC/LBNL
- **SciDAC Call:** Major proposal submitted in partnership with SciDAC ASCR Institutes
- **Labs as National Hub:** Unique opportunity to build effort to provide simulations and analysis tools to the cosmology community

Cosmic Frontier Computing Collaboration
S. Habib (ANL, Spokesperson), A. Slosar (BNL),
S. Dodelson (Fermilab), P. Nugent (LBNL),
R. Wechsler (SLAC)

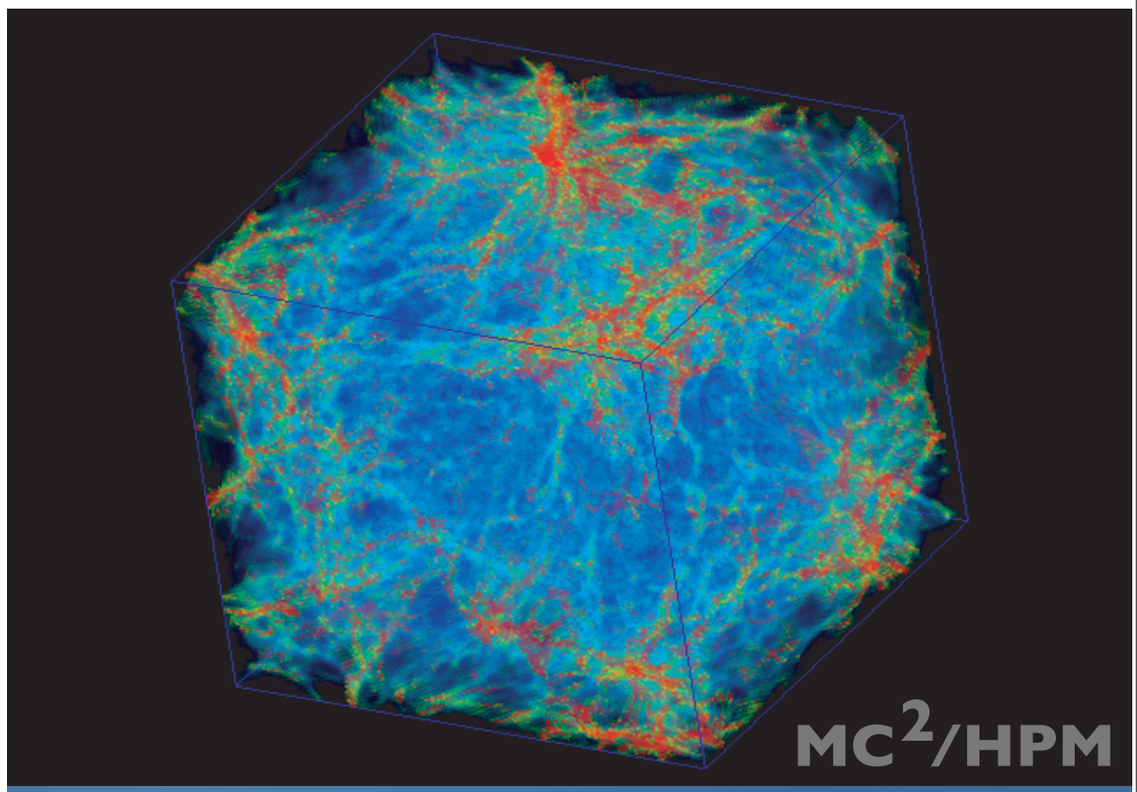
Summary: Latest Developments

- **Architecture Challenge:** New algorithms implemented on IBM BG/P at ALCF, code scales to the full machine (160K cores); first cosmology code to scale on a Blue Gene system
- **ALCF/MCS Collaborations:** Intensive collaborations with CS researchers; I/O, performance, new architectures, visualization, workflows, large data
- **Joining DES:** Weak lensing, clusters, --
- **LSST:** Started membership process with Tony Tyson, members of Science Working Groups
- **ANL LDRD:** Supports interactions across the Lab, HEP with ALCF/MCS (SciDAC is future path for this)
- **Strategic LDRD:** Large data initiative at ANL, another future direction for HEP interaction with ASCR
- **NASA Theory Award:** Supports Post-Doc

Back-Up Slides

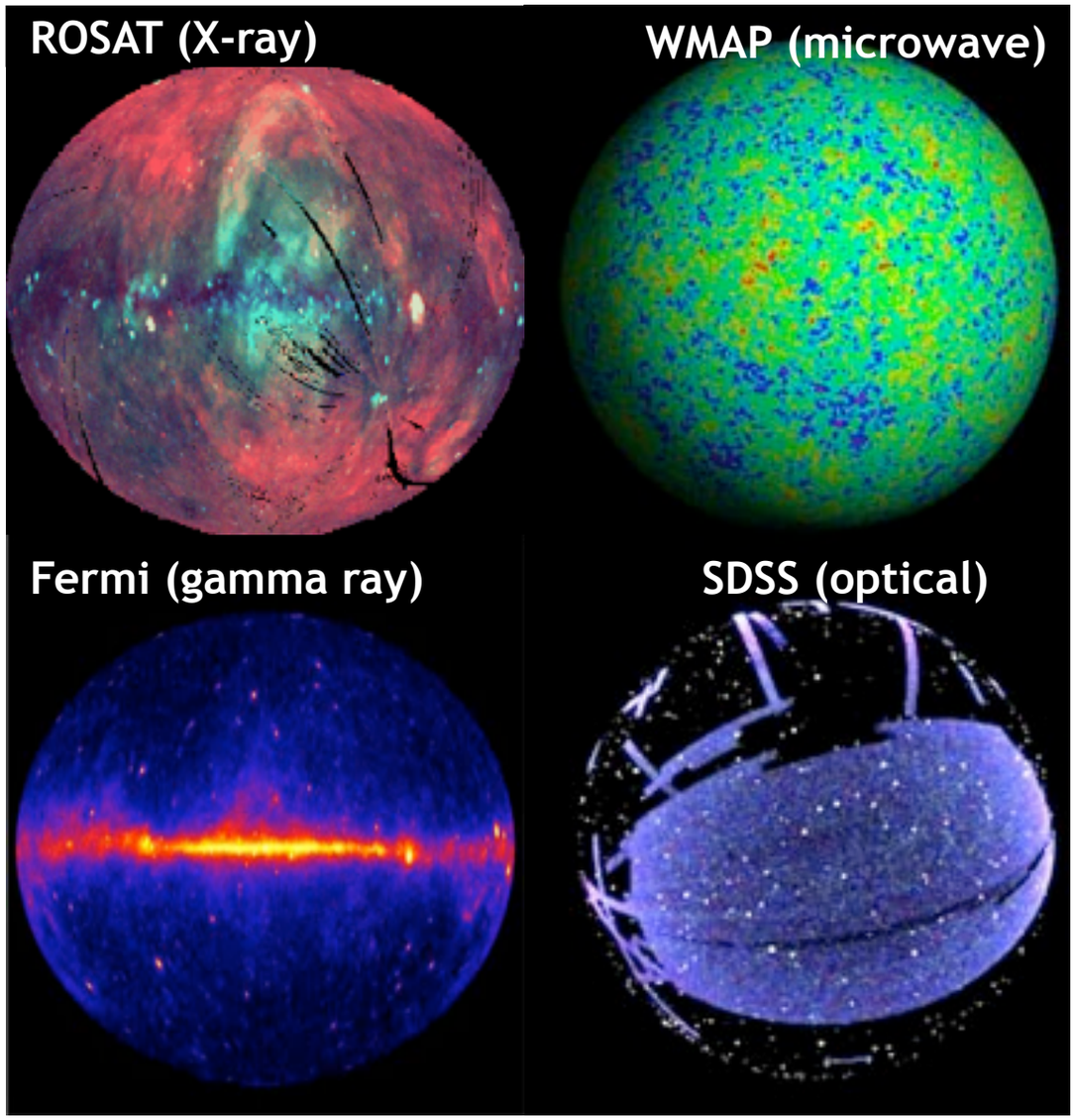
Group Overview

- **Primary Target of Group Research:** Cosmological signatures of physics beyond the Standard Model
- **Structure Formation Probes:** Exploit nonlinear regime of structure formation
  - **Discovery Science:** Derive signatures of new physics, search for new cosmological probes
  - **Precision Predictions:** Aim to produce the best predictions and error estimates/distributions for structure formation probes (rough analogy with lattice QCD)
- **Design and Analysis:** Advance ‘Science of Surveys’; contribute to major ‘Dark Universe’ missions: BOSS, DES, LSST, BigBOSS, DESpec --



Cosmological Probes of Physics Beyond the Standard Model

- **Dark Energy:** Properties of DE equation of state, modifications of GR, other models?
  Sky surveys, terrestrial experiments
- **Dark Matter:** Direct/Indirect searches, clustering properties, constraints on model parameters
  Sky surveys, targeted observations, terrestrial experiments
- **Inflation:** Probing primordial fluctuations, CMB polarization, non-Gaussianity
  Sky surveys
- **Neutrino Sector:** CMB, linear and nonlinear matter clustering
  Sky surveys, terrestrial experiments

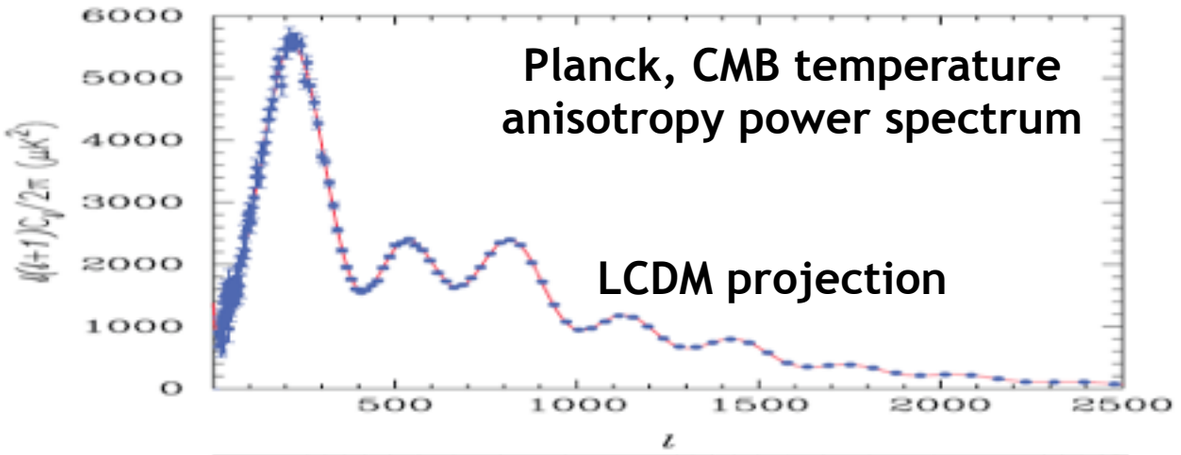


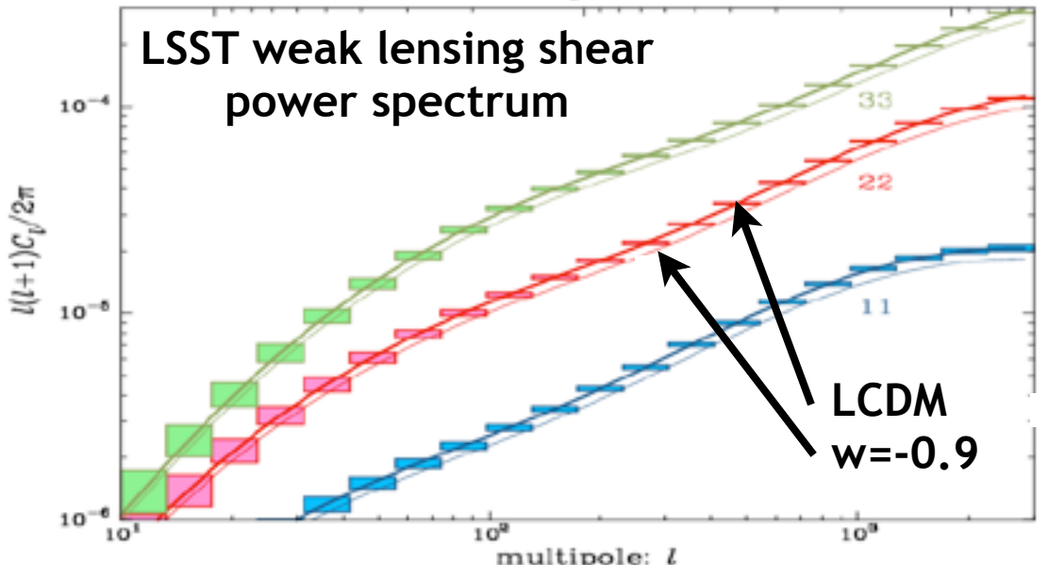
Explosion of information from sky maps: Precision Cosmology

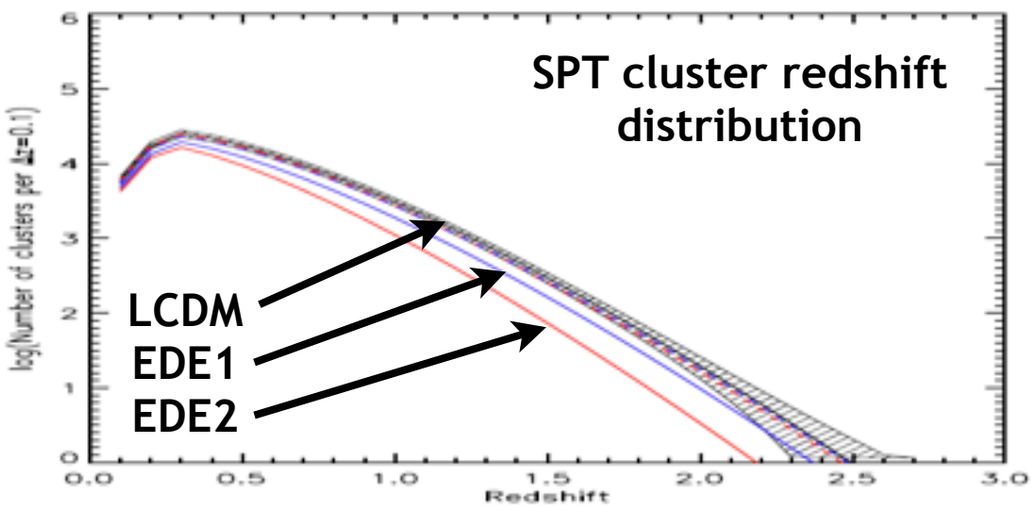
Precision Cosmology: "Inverting" the 3-D Sky

- **Cosmic Inverse Problem:** From sky maps to scientific inference
- **Cosmological Probes:** Measure geometry and presence/growth of structure (linear and nonlinear)
- **Examples:** Baryon acoustic oscillations (BAO), cluster counts, CMB, weak lensing, galaxy clustering, --
- **Cosmological Standard Model:** Verified at 5-10% with multiple observations

- **Future Targets:** Aim to control survey measurements to the ~1% level
- **The Challenge:** Theory and simulation must satisfy stringent criteria for inverse problems and precision cosmology not to be theory-limited!

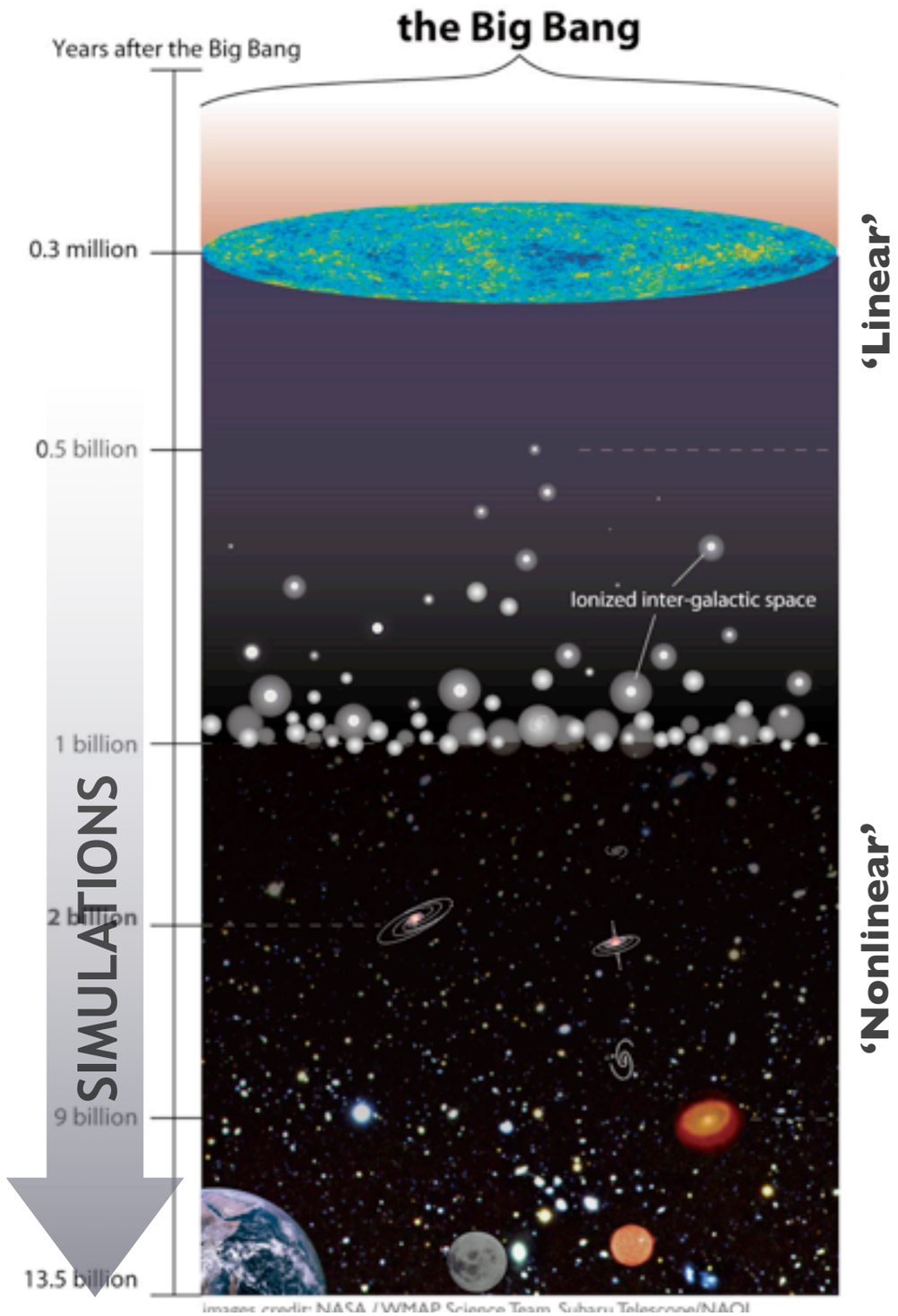






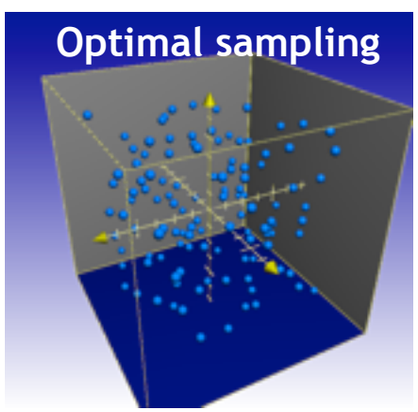
Structure Formation: The Basic Paradigm

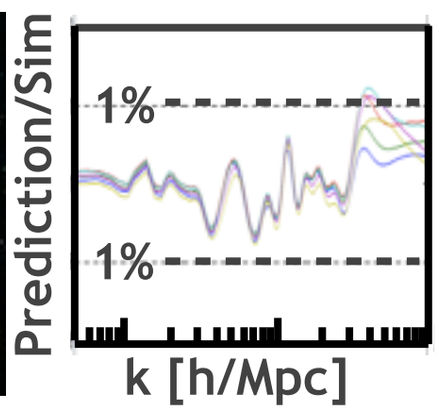
- **Solid understanding of structure formation; success underpins most cosmic discovery**
  - Initial conditions laid down by inflation
  - Initial perturbations amplified by gravitational instability in a dark matter-dominated Universe
    - Relevant theory is gravity, field theory, and atomic physics (‘first principles’)
- **Early Universe:** Linear perturbation theory very successful (CMB)
- **Latter half of the history of the Universe:** Nonlinear domain of structure formation, impossible to treat without large-scale computing



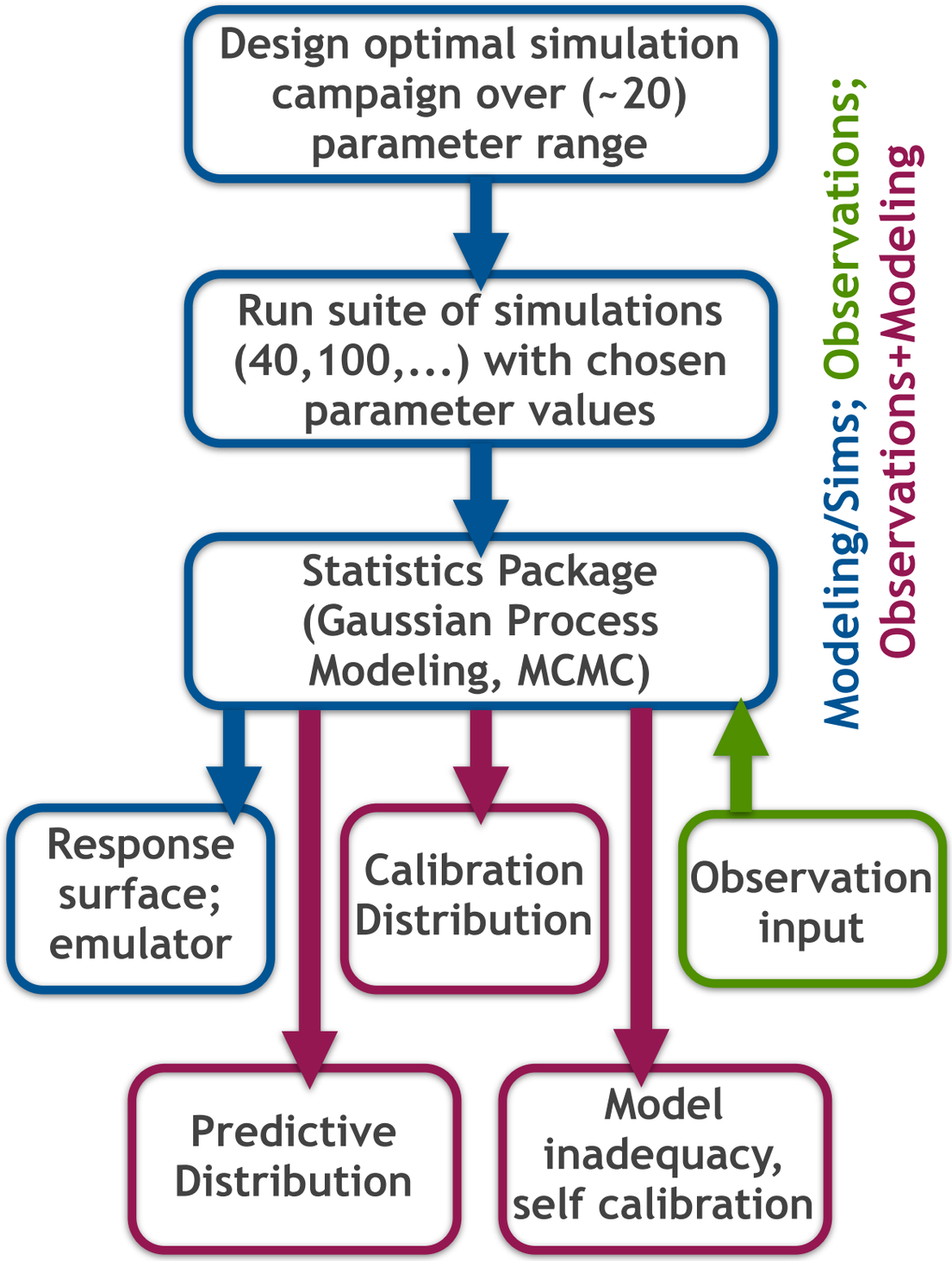
Cosmic Calibration: Solving the Inverse Problem

- **Challenge:** To extract cosmological constraints from observations in the nonlinear regime, need to run Markov Chain Monte Carlo; input: 10,000 - 100,000 different models
- **Brute Force:** Simulations, ~30 years on 2000 processor cluster ---
- **Current Strategy:** Fitting functions, e.g. for P(k), accurate at 10% level, not good enough!
- **Our Solution:** Precision emulators



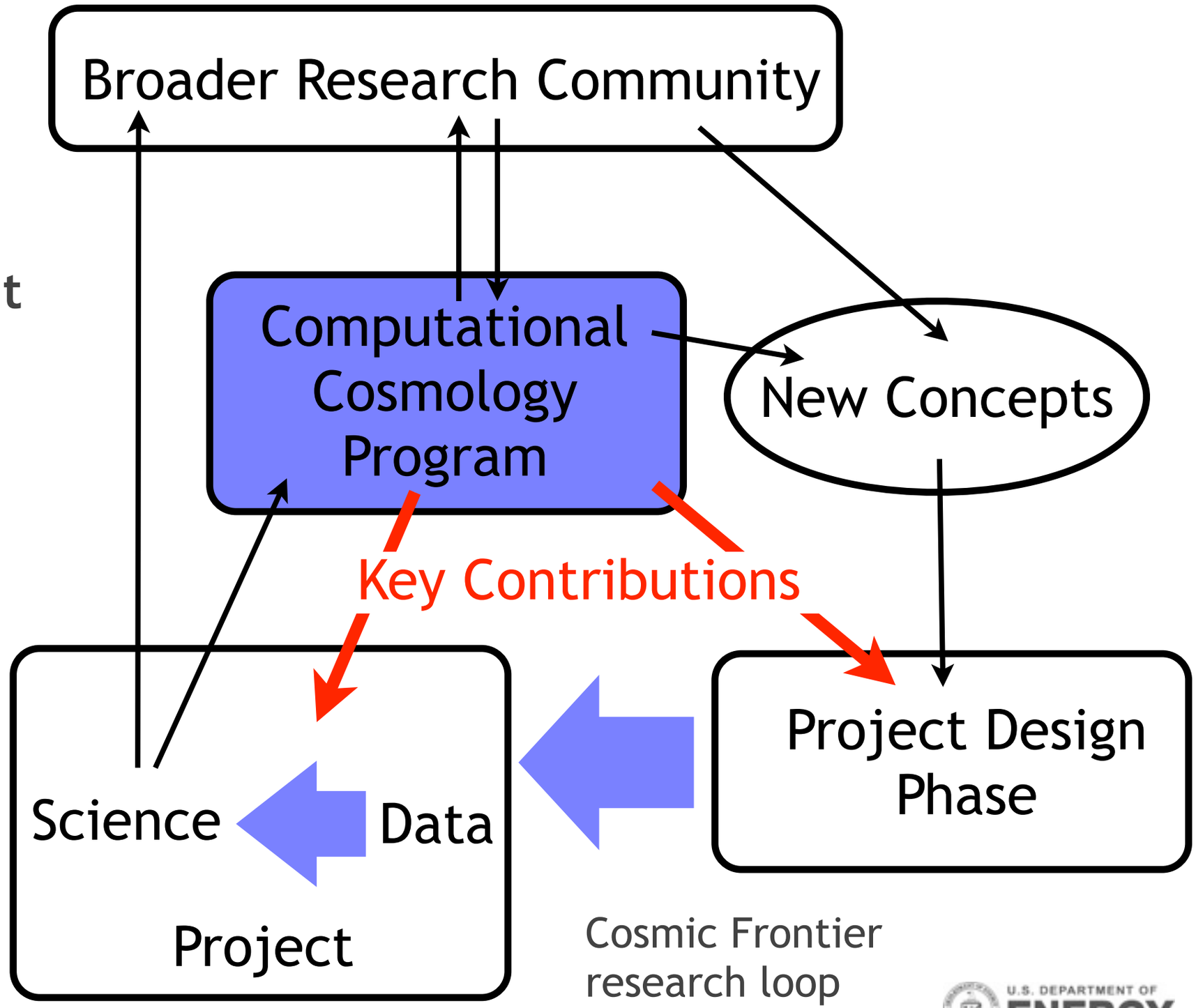


Heitmann et al. 2006, Habib et al. 2007



Locating the DOE HEP Computational Cosmology Program

- Resides as a core capability program within DOE HEP
- Contributes to ‘discovery space’
- Catalyzes development of concepts into projects
- Plays a key role in project optimization
- Is an essential component of the **‘Data to Science’** step for projects
- Functions as a major community resource



DOE HEP Computational Cosmology Program Advantages

- Key Roles
  - One-point contact for scientists, projects, and programs
  - In-house theory, modeling, and simulation capability
  - Connection to HEP computing
  - Efficient collaboration, ability to work to milestones/time tables
  - Repository of ‘Lessons Learnt’ and ‘Best Practices’ (crucial in precision cosmology)
  - Continuous development paths
  - Develop and maintain simplified ‘detector model’ views of project space (hunt for subtle signals)
  - Connections across projects (joint analyses)