P5 View of Cosmic Surveys & Computing...

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P5 Panel Report

Since the previous P5 report in 2008, there have been several landmark events in the field. Three Nobel Prizes related to particle physics were awarded: Quark Mixing and Symmetries, the Accelerating Universe & the Higgs Boson, in addition, the θ_{13} neutrino mixing parameter was measured to be relatively large.

These successes demonstrate the deep value of diversity of topic and project scale. New technology, scientific directions and innovative approaches are creating fresh opportunities that promise an even brighter future.

Coupled with budget constraints, choices had to be made. This is where P5 comes in, to “Prioritize” the projects.

Here we take a look at the scientific motivation for the projects in the Cosmic Frontier and their need for computing.

P5 Criteria

- Science: based on the Drivers, assess where we want to go and how to get there, with a portfolio of the most promising approaches.
- International context: pursue the most important opportunities wherever they are, and host world-leading facilities that attract the worldwide scientific community; duplication should only occur when significant value is added or when competition helps propel the field in important directions.
- Sustained productivity: maintain a stream of science results while investing in future capabilities, which implies a balance of project sizes; maintain and develop critical technical and scientific expertise and infrastructure to enable future discoveries.

Multi-disciplinary connections are of great importance to particle physics. For example, the study of the particle physics of dark energy and inflation is performed by historical astrophysical techniques employing the detector technologies and computing techniques of particle physics.

P5 Scientific Drivers for the Cosmic Frontier

Understand cosmic acceleration: dark energy and inflation

An important part of understanding the birth and evolution of the Universe is the existence of two periods during which the expansion of the Universe accelerated.

A primordial epoch of acceleration, called inflation, occurred during the first fraction of a second of existence. The cause of this inflation is unknown but may have involved fundamentally new physics at ultra-high energies. A second distinct epoch of accelerated expansion began more recently and continues today. This expansion is presumed to be driven by some kind of dark energy, which could be related to Einstein's cosmological constant, or driven by a different type of dark energy that evolves with time.

This was the focus for the science drivers in the P5 report on the Cosmic Frontier.

The Cosmic Frontier Projects

Cosmic Surveys: Astronomical observations have provided evidence for dark energy and inflation, physics that powered two epochs of cosmic acceleration. ***DESI***, ***LSST***, and ***CMB-S4*** provide complementary, breakthrough capabilities to survey the sky with the aim of understanding these phenomena and what they say about particle physics. They also provide important probes of neutrino properties.

Recommendation 16 : Build DESI as a major step forward in dark energy science.

Recommendation 17 : Complete LSST as planned.

Recommendation 18 : Support CMB experiments as part of the core particle physics program. The multidisciplinary nature of the science warrants continued multiagency support.

The Cosmic Frontier Goals

Goals and Timeframes:

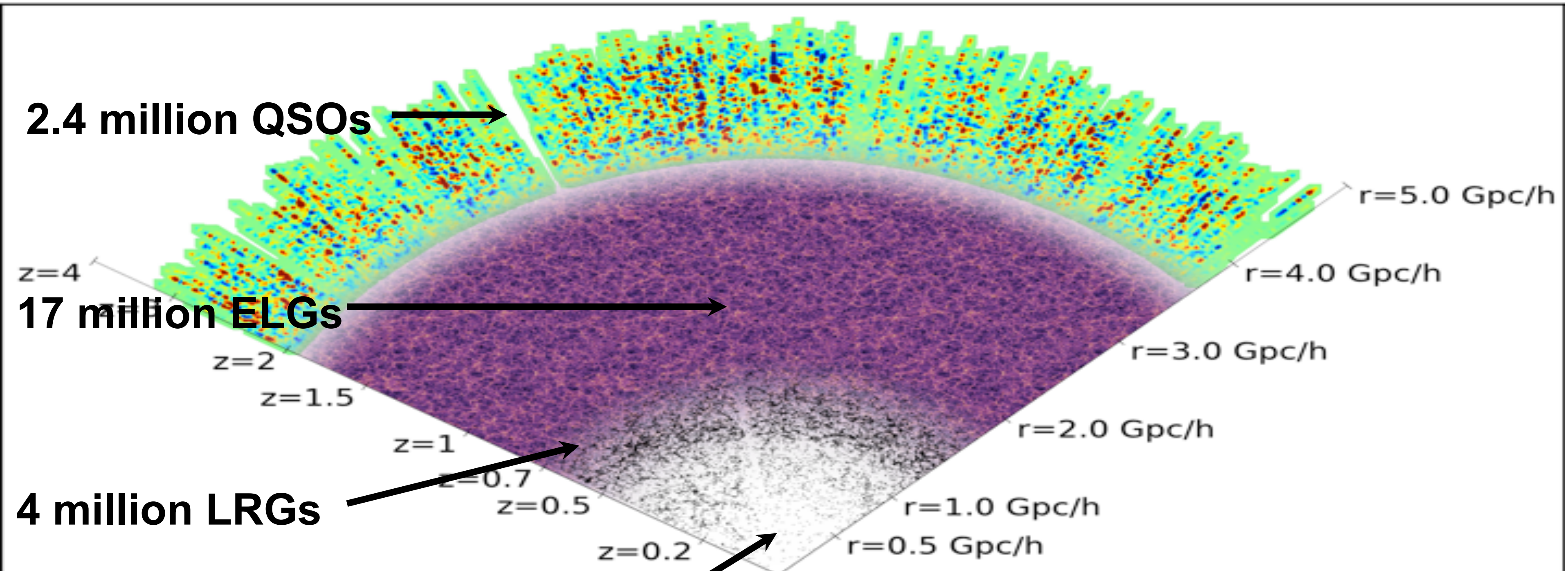
• Measure the parameters that characterize dark energy to 5% precision (2020) and then improve to 1% (2025) over the entire history from the decelerating epoch to accelerating epoch.

• Distinguish dark energy from modified gravity as an explanation of the current epoch of acceleration by measuring structure to 10% (2020), ultimately reaching percent precision over a wide range of distance scales and times (2030)

• Confirm or refute ✔ the BICEP2 detection of primordial gravitational waves from inflation (2015–17). Depending on the outcome, either measure the amplitude of this signal to the percent level or constrain the spectrum to sub-percent accuracy to distinguish between models of inflation (2025).

The largest spectroscopic survey for dark energy

SDSS ~2h^{-3}Gpc^3 BOSS ~6h^{-3}Gpc^3 DESI 50h^{-3}Gpc^3



10 million brightest galaxies

BERKELEY LAB

DESI: Surveys

1. An imaging (targeting) survey over 14,000 deg^2

g-band to 24.0 mag

r-band to 23.6 mag

z-band to 23.0 mag

2. A spectroscopic survey over 14,000 deg^2

10 million Bright Luminous Galaxies

4 million Luminous Red Galaxies

17 million Emission Line Galaxies

1.7 million quasars

0.7 million quasars at $z>2.1$ for Lyman-alpha-forest

DESI: Goals

Distance-redshift relation

- Measure distance scale to <0.3% between $0.0 < z < 1.1$
- Measure distance scale to <0.3% between $1.1 < z < 1.9$
- Measure the Hubble parameter to < 1% in the bin $1.9 < z < 3.7$

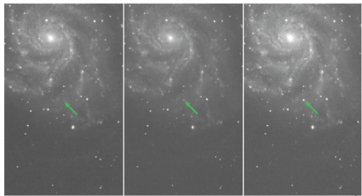
Gravitational growth growth

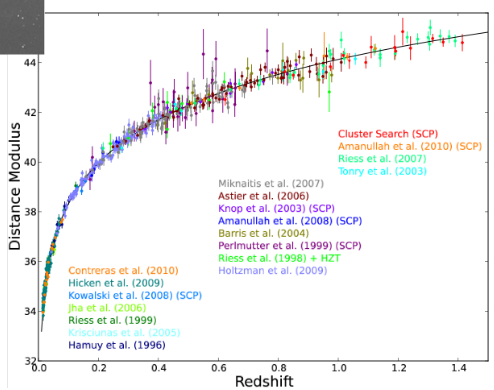
- Constrain the growth factor at ~ a few percent level up to $z=1.5$

Beyond Dark Energy

- Constrain spectral index of primordial perturbations and its running to < 0.4%
- Measure the neutrino masses to < 0.017 eV

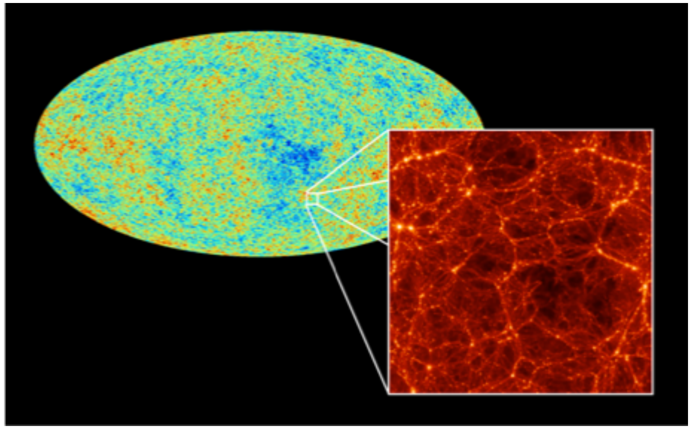
LSST

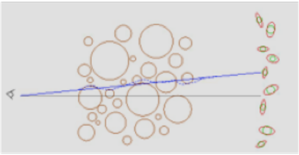


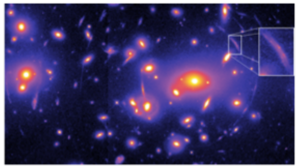


~100k+ SNe Ia

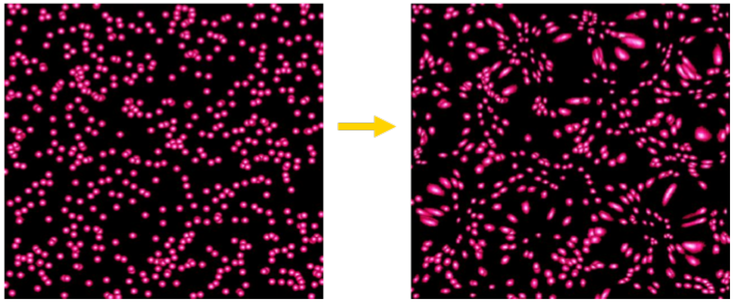
Photometric BAO

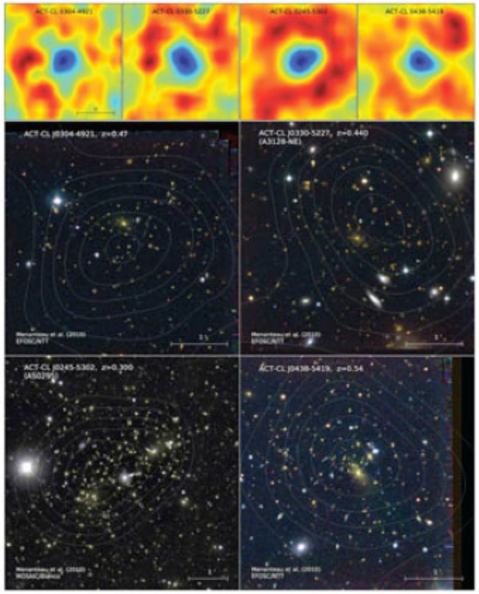






Weak Lensing

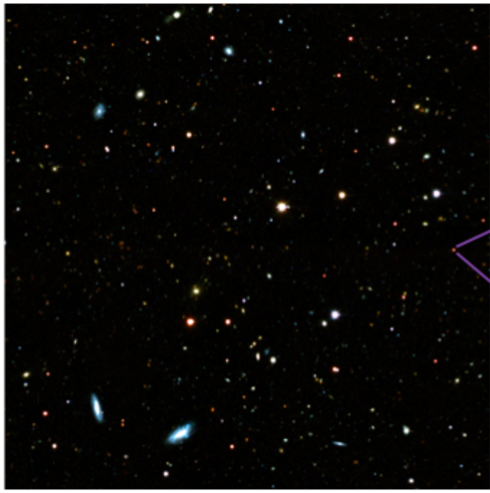


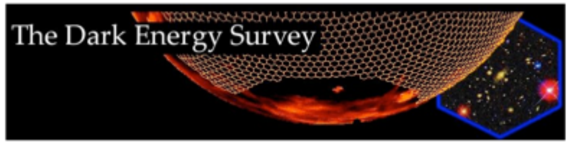


Cluster Counting

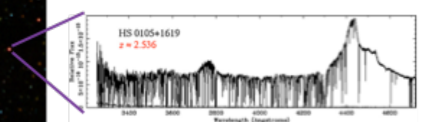
LSST & DESI: Data Processing

Observational Cosmology Data Sets





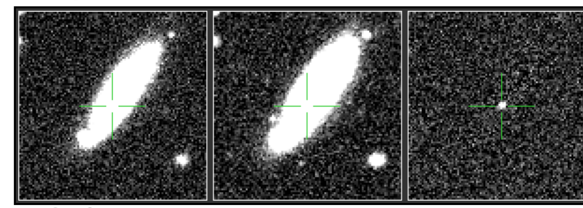
1-2 PB



2-3 PB

LSST
Large Synoptic Survey Telescope

~500 PB

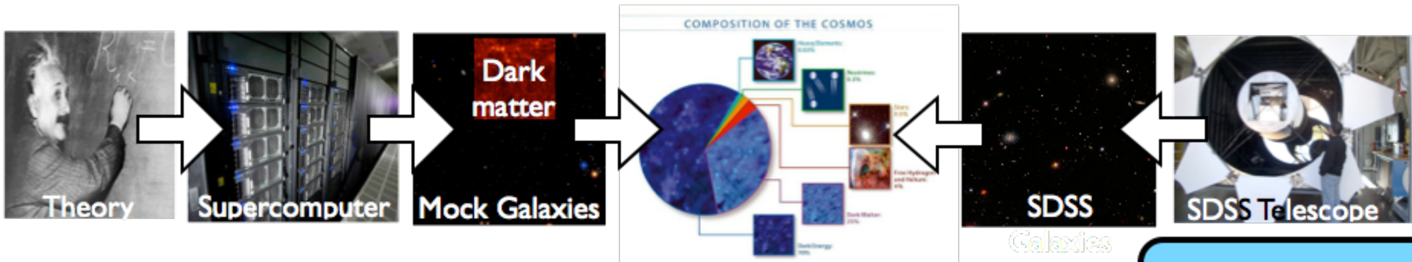


Real-Time SN hunting

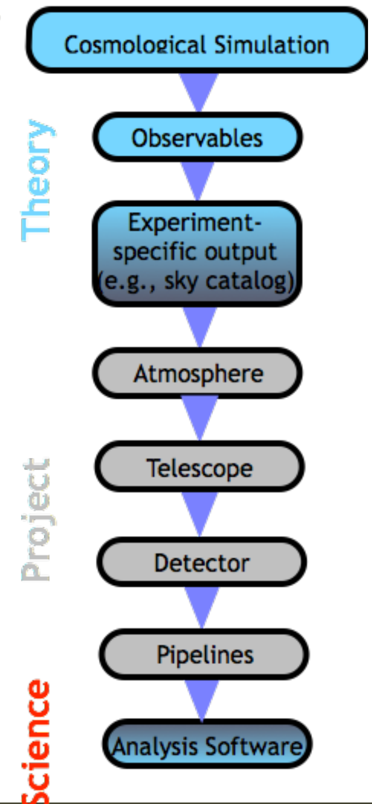
- **Imaging surveys of the sky**
  - Digital images cover a fraction of a square degree (41,000 square degrees on the sky)
  - Typically 2,000 * 4,000 pixels with most detections occupying only 9 pixels
  - 20,000 detections with a signal-to-noise ratio > 5 per image
  - Done in several filter passbands to provide not only shape and brightness, but "color" information on each detection (used to determine its approximate type and distance)
- **Spectroscopic surveys of the sky**
  - For each object, precisely measure the flux as a function of wavelength
  - Use the imaging surveys to provide targets for spectroscopy

LSST & DESI: Simulations

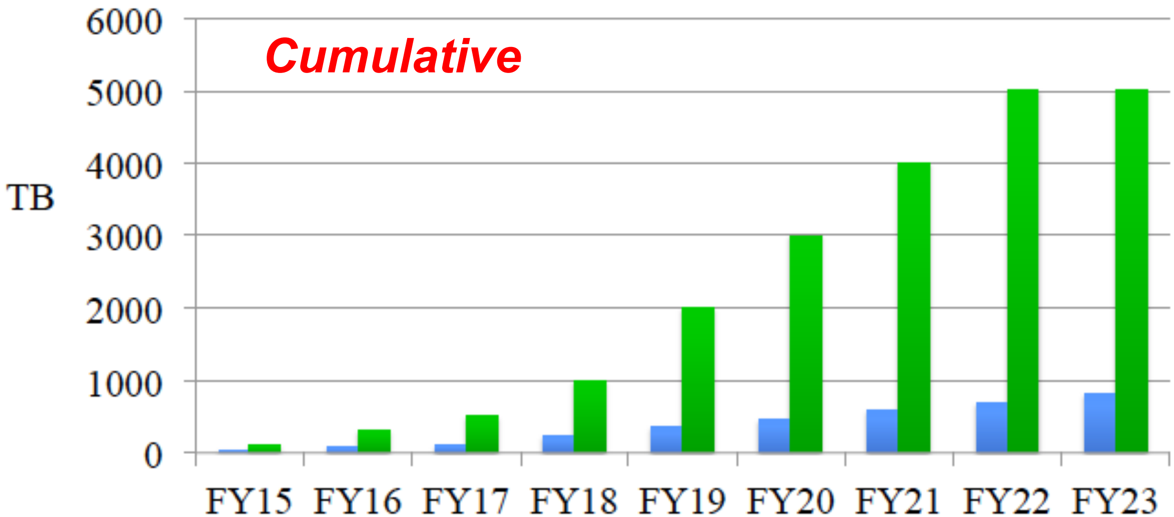
Computational Cosmology: Role of Simulations



- **Three Roles of Cosmological Simulations**
  - Basic theory of cosmological probes
  - Production of high-fidelity ‘mock skies’ for end-to-end tests of the observation/analysis chain
  - Essential component of analysis toolkits: Control systematics
- **Extreme Simulation and Analysis Challenges**
  - Large dynamic range simulations; control of subgrid modeling and feedback mechanisms
  - Design and implementation of complex analyses on large datasets; new fast (approximate) algorithms
  - Solution of large statistical inverse problems of scientific inference (many parameters, ~10-100) at the ~1% level



DESI & LSST Computing

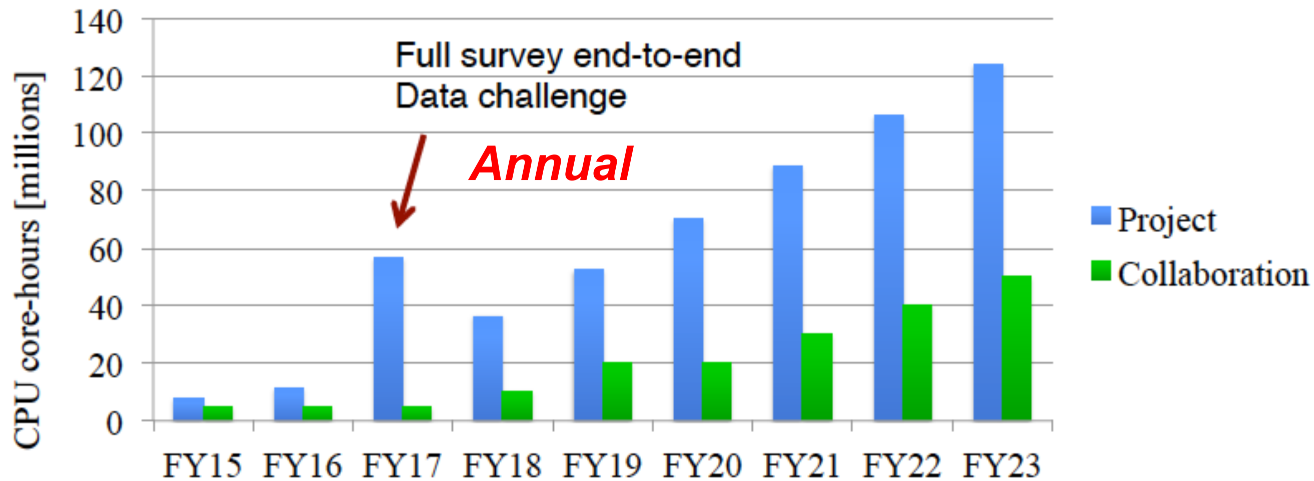


Based on our upcoming CD-2 review – these are minimalist and perhaps not ideal.

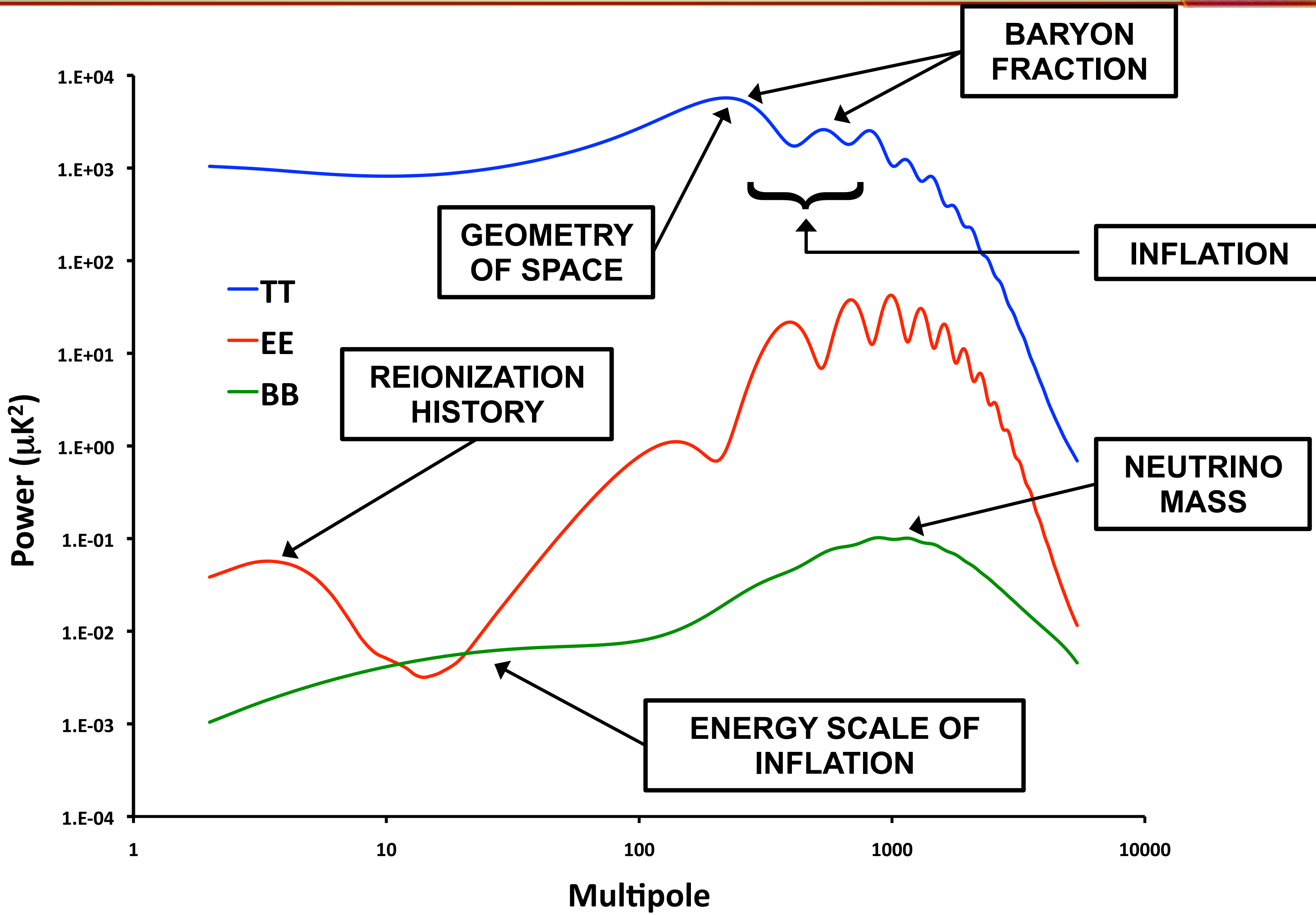
CPU includes simulation analysis, but not the generation of the simulations.

LSST-DESC needs will be far greater than this, but have not fully costed to date.

Also need to figure out the NCSA/Project – DOE/DESC dance...



CMB-S4



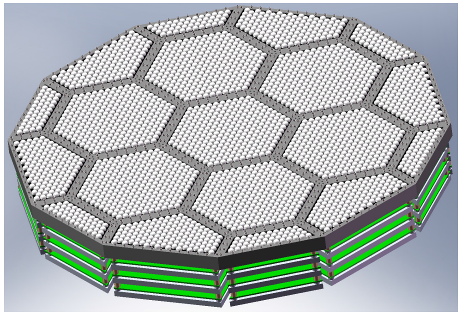
BARYON FRACTION
GEOMETRY OF SPACE
INFLATION
REIONIZATION HISTORY
NEUTRINO MASS
ENERGY SCALE OF INFLATION
TT
EE
BB
1.E+04
1.E+03
1.E+02
1.E+01
1.E+00
1.E-01
1.E-02
1.E-03
1.E-04
1
10
100
1000
10000
Power (μK²)
Multipole

CMB-S4

S4

- **Experimental Configuration:**

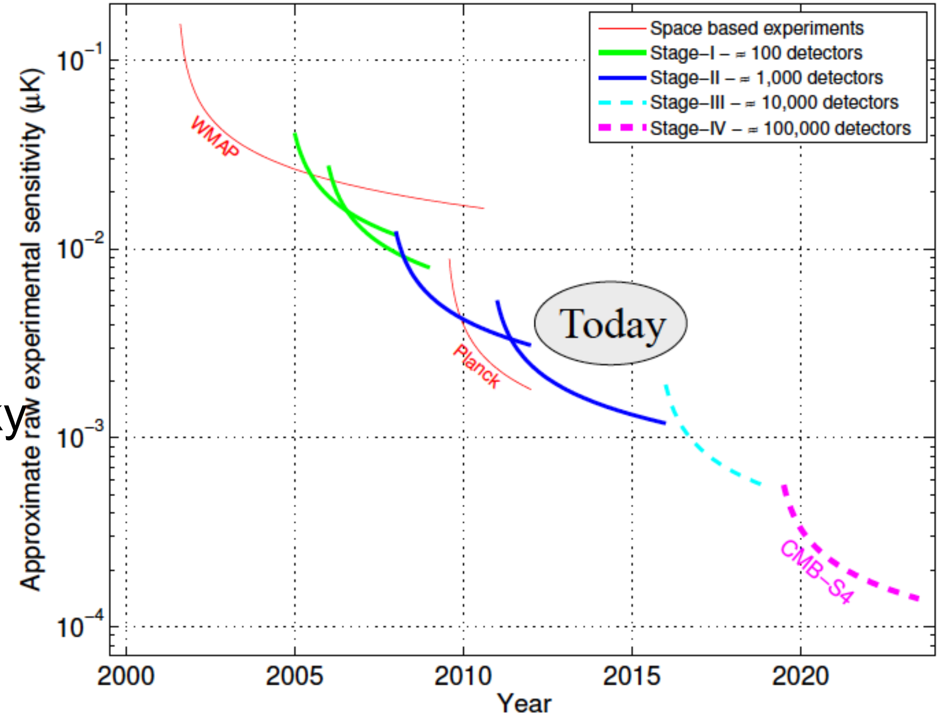
    - 200,000 - 500,000 detectors on multiple platforms
    - Spanning 40 - 240 GHz for foreground removal
    - < 3 arcmin resolution required for CMB lensing, neutrino science



- **Two Nested Surveys:**

    - Inflation survey (~few% of sky)
    - Neutrino survey (~half of sky)

- **Target noise:**
    - ~1 uK-arcmin depth over half the sky



CMB-S4

Need 1%-level statistical uncertainties:

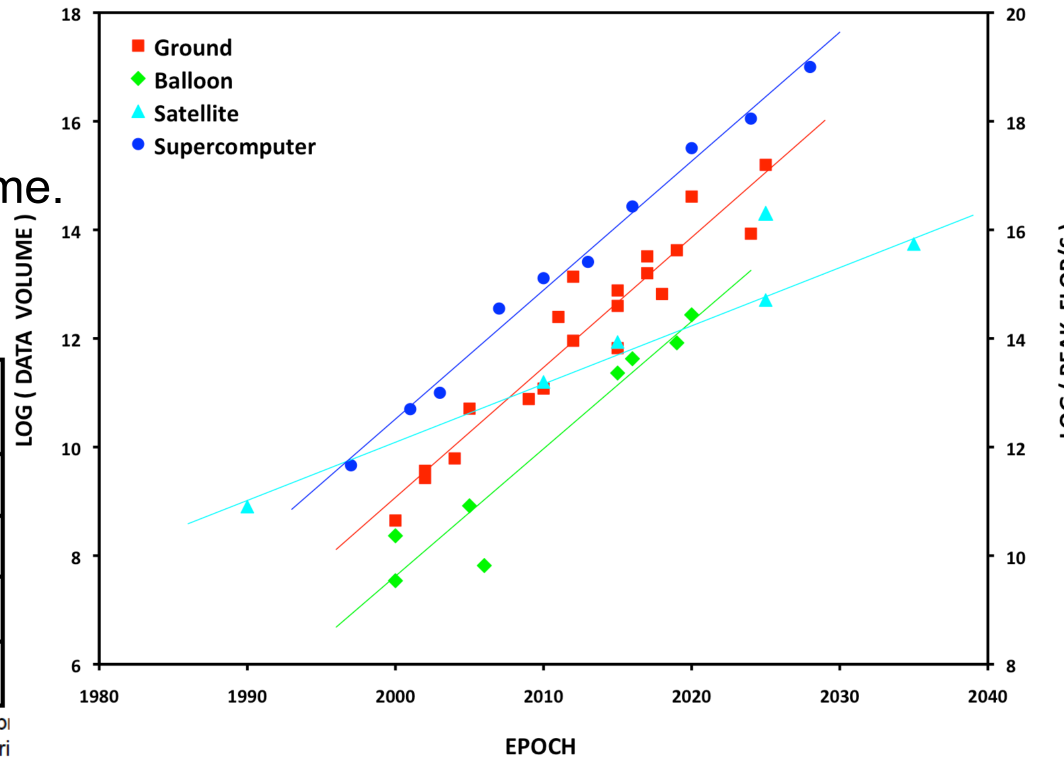
- Simulate 10^4 realizations of the full mission.
- Reduce to $O(10^3)$ maps per realization.

Maintain this capability through:

- thousand-fold increase in data volume.
- several generations of HPC.

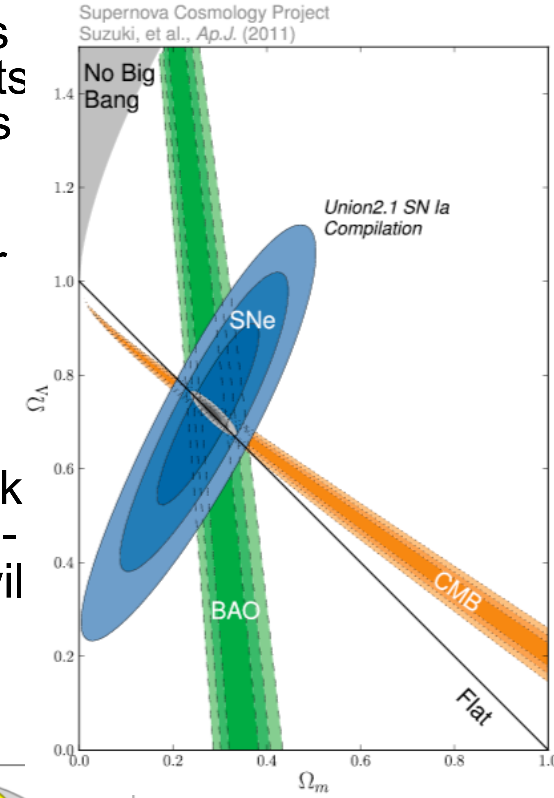
	$\sigma(r)$	$\sigma(N_{\mathrm{eff}})$	$\sigma(\Sigma m_\nu)$
Current CMB	**0.10**	**0.34**	**117 meV**
2016 Stage 2: SPTpol	0.03	0.12	96 meV
2020 Stage 3: SPT-3G	0.01	0.06	61[a] meV
2024 Stage 4: CMB-S4	**0.001**	**0.02**	**16[b] meV**

[a] Includes BOSS pı
[b] Includes DESI pri



Conclusions

The hallmark of our future computational cosmology programs lies in our multi-disciplinary approach spanning the Experiments Physics, Computational Facilities & CS while tackling problems both large: SNe Physics, Hydro & N-body simulations, CMB analysis, and small: providing rapid turn-around on image processing from a remote mountain-top, analysis workflows for scientists, high throughput computing…



Our research programs have rapidly progressed over the past two decades and will continue through the next: COBE - Planck CMB-S4; Supernova Cosmology Project - DES - LSST; SDSS - BOSS - DESI, and our computational efforts have been, and wil be, equally transformative.

Since the future in precision cosmology lies at the intersection of all of these methods *and* the control of systematics, we are well positioned to tackle these challenges given the right resources.