Cosmic Visions Dark Energy Report

Small Projects Portfolio (arXiv:1802.07216)

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HEPAP Spring Meeting 2018

Components of the Cosmic Visions Program

- DOE HEP Cosmic Frontier program managers assembled three groups to look into future directions of the field
- Groups report regularly to program managers and organize community input

CMB

Delivered CMB-S4 Science Book, now preparing for the Decadal Survey

arXiv:1610.02743

Dark Matter

Delivered comprehensive White Paper on direct detection experiments small-scale portfolio

arXiv:1707.04591

Dark Energy

Delivered two White Papers on Science and Technology in 2016, third on small-scale portfolio

arXiv:1802.07216

The Charge

- Possible projects beyond LSST and DESI to further our understanding of “dark energy”, *out to 2030+*
- What can be done to enhance the science outcome from DESI and LSST and prepare for the next projects *now*?
- Develop near-term small scale project portfolio (~$10M)
- Gather input from the community

The Process

Planning

Group of Eight

Identify five broad topics to help structure community workshop

Call for abstracts from the community

Organized abstracts into five categories

Workshop

Community

Two topic leaders per category organized sessions including talks and discussions

Slack channels and google docs used to capture information

White Paper

Group of Eight with Community Feedback

After workshop, f2f of group of eight to plan White Paper

First draft was distributed in January for feedback

Final White Paper published in February

The Roadmap Concepts (2 of 5 categories)

- 21 cm
  - Many opportunities to further P5 science: Dark energy, neutrinos, early Universe physics …
  - Small-scale opportunities that can be realized now: Build (or join) a small instrument that will enhance LSST/DESI science
  - Technology developments that pave the road to an ambitious experiment to follow LSST/DESI
  - Develop plan for large instrument/survey in 2025+
- “Southern” Spectroscopic Roadmap
  - Opportunities while LSST is on the sky: Spectroscopic follow-up
  - DESI-2 opportunities
  - Technology developments that pave the road to an ambitious experiment to follow LSST/DESI
  - Develop plan for large instrument/survey in 2030+

Small-scale Ideas (3 of 5 Categories)

- New Technology Developments for the Future
  - Research on technologies for the next big project is essential!
  - New technology developments (e.g., innovative fiber positioners, new sensors) might open up new opportunities that would have been deemed impossible earlier
- New Observational Windows to Enhance LSST and DESI
  - Are there additional observations that will enhance the science return of Stage IV missions?
  - What would it take to make this happen (e.g., build a small new instrument, carry out follow-up observations with existing facilities)?
- Theory, Analysis, and Computing
  - Develop new ideas to push beyond LCDM
  - Cross-correlations of data in different wavebands, requires cross-project work
  - Simulations play an ever more important role in cosmology …

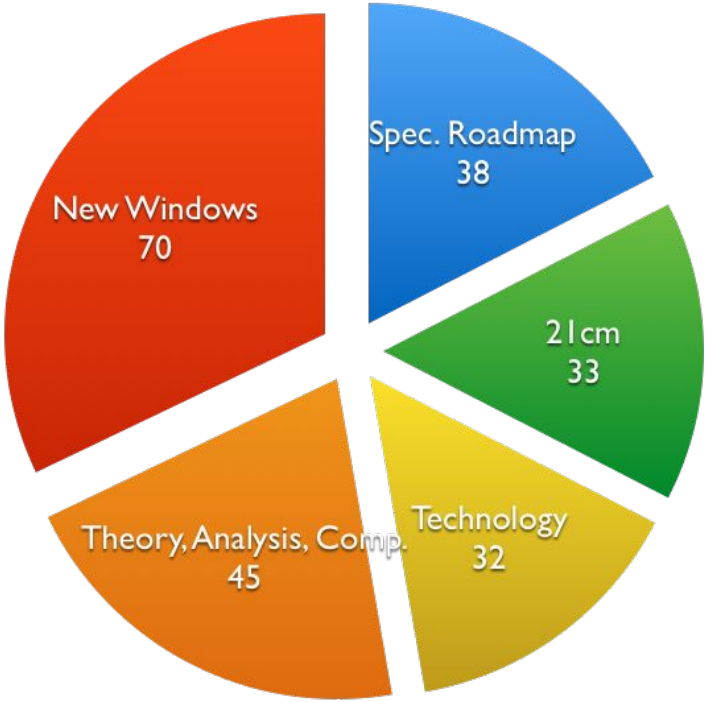
Based on these three areas we have developed a timely, strong Small Projects Portfolio to enhance Stage IV experiments and prepare us for the next large survey!

The Workshop

LBNL, November 14-15, 2017, Webpage: cvde2017.lbl.gov

Workshop Overview

- Two-day workshop at LBNL in November ‘17
- More than 100 participants
- Participants were requested to note down their interests regarding the 5 topics (allowed to choose up to 5)
- Plenary sessions introducing topics at the start and summarizing outcome of discussions at the end
- Parallel sessions for roadmap and small-scale ideas with lots of time for discussions



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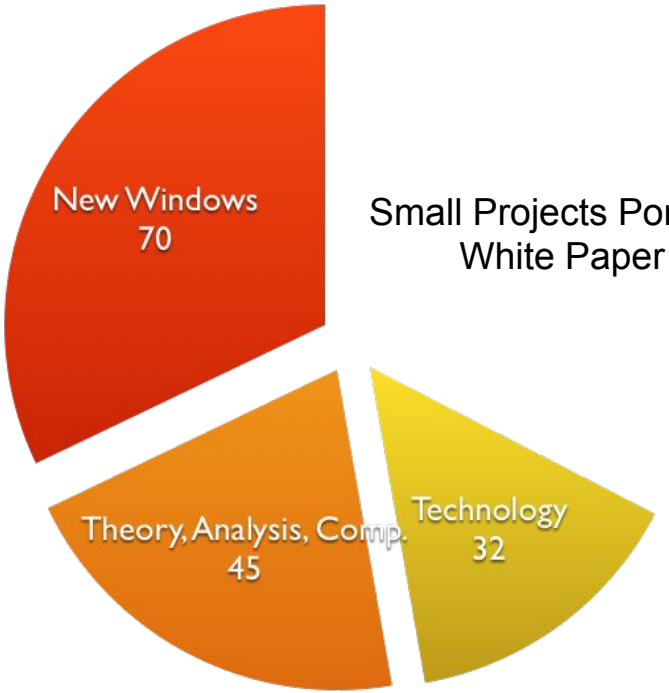

21-cm Roadmap

- A novel way of mapping the universe using 21-cm transition in neutral hydrogen
- Combines the advantages of optical spectroscopic and photometric surveys with very different systematics
- A working group with ~20 active members is preparing the roadmap **White Paper**:
  - Building the science case
  - Forecasting strawman experiment
  - Preparation for decadal submission
- 3-day community workshop ***Tremendous Radio Arrays 2018*** at BNL 7/30-8/1

Cosmic Visions Dark Energy: 21-cm Roadmap

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CONTENTS

Spectroscopic Roadmap

- Spectroscopic follow-up while LSST is on the sky is extremely desirable
- Science drivers for a Wide-field Spectroscopic Survey
  - Cosmic acceleration
  - What is dark matter?
  - Origin of the elements in the periodic table
- Several options from smaller to very large facilities at different time scales
- Community White Paper for the Decadal Survey is in preparation, following a SnowPAC meeting earlier this year

I. Introduction
   A. Context in the 2020s and 2030s
   B. XYZ
II. Science drivers for future spectroscopy
   A. Photometric redshift training (J. Newman)
   A. Cosmology from nonlinear modes (Andrew Hearin, Zheng Zheng)
   B. Constraining the galaxy-halo connection
   C. SN hosts (Dan S, Bob K, Alex K), Gravitational wave source hosts (Marcelle, Jim A), dark matter in dwarfs (Keith B), …
   D. IGM (KG)
   E. Voids, higher-order correlations & primordial NG (Elisabeth, Zach)
   F. Connections to astrophysics science cases?
III. Example surveys and forecasts
   A. ABC (Jeff, Kyle, Elisabeth)
   B. XYZ
IV. Potential hardware for these surveys
   A. DESI-2
   B. DESI-South or other 4m wide field spectrograph in south
   C. LASSI
   D. BOA
   E. Options with external projects: Subaru/PFS, MSE, TMT, GMT, …
   F. Technology R&D needs: GLAO (Aaron R), fiber pitch (Tom D), NIR/Ge detectors (Steve H, David S)
   G. Cost estimates (Pat H)
V. An integrated roadmap / Timeline

The White Paper

Motivation

- P5 Report identified understanding of cosmic acceleration as one of the key science drivers for high-energy physics in the next decade
- Currently, Stage III dark energy experiments are ongoing and generating excellent science results and some small hints of possible tensions (e.g. H_0)
- LSST and DESI will begin operations soon, promising an order of magnitude improvement in constraining the physics of the accelerating Universe
- This is the ideal time for a matching Small Projects Portfolio that can
  - Greatly enhance the science reach of these flagship projects
  - Have immediate scientific impact
  - Lay the groundwork for the next stages of the Cosmic Frontier Dark Energy program
- We outline here a balanced portfolio that combines observational, experimental and theory and simulation efforts

Science Drivers for Small-Scale Portfolio

- Reduction of statistical and systematic uncertainties for LSST and DESI beyond the current baseline to enhance cosmological constraints on dark energy, inflation, and neutrinos
  - Since the inception of LSST and DESI, most important sources of systematic uncertainties have been better characterized given Stage III experience
  - Small-scale investments in calibration efforts and efforts to lower the systematics floor through targeted observations could have a large payoff, now is the time!
- Exploration of new probes and reduction of systematic uncertainties via cross-correlations
  - No new data needs to be acquired
  - Rather, investment in efforts to develop methodologies to bring together data from different sources; this can include survey strategies and analysis efforts

Science Drivers for Small-Scale Portfolio

- Exploration of small scales beyond the current DESI and LSST baseline
  - Extending large-scale structure probes well into the nonlinear regime can significantly improve dark energy constraints
  - Requires comprehensive modeling and simulation effort and therefore investment in personnel at the theory-simulation interface would result in large impact
- Investigation of novel probes
  - Going beyond two-point correlations and to even smaller scales by investigating, e.g., galaxy cluster profiles
  - Requires development of methodical data analysis plan and new efforts at the theory-simulation-observation interface
- Preparing for next-generation experiments
  - LSST and DESI will tell us where to go next! Preparation for Stage V experiments
  - Requires advances in hardware technology and theory (origin of the cosmological constant, compelling alternatives, new probes)

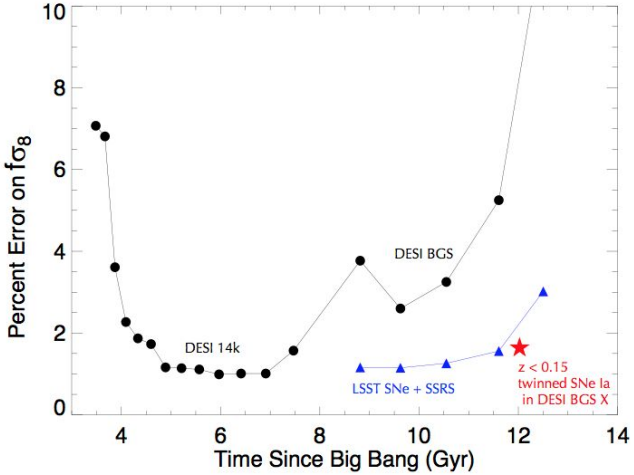
Executive Summary

- Given the motivation and science drivers, we have identified three areas of great promise to enhance DESI and LSST and prepare us for the next generation of experiments:
  - Enhancing LSST and DESI with complementary data
  - New technology advances
  - Theory and simulation advances
- Small-scale investments in all three areas would greatly enhance the Stage IV program; each would require similar amounts of support to succeed (overall a $10-15M program)
- These investments are very timely — to impact DESI and LSST, most of the recommended efforts must begin in the next 1-2 years

Disclaimer: In the following we will provide several ideas that emerged from the workshop. The list is intended to provide powerful representative examples (rather than a complete list) of small, targeted programs.

Enhancing LSST and DESI with Complementary Data — Complementary Measurement Efforts

- Photometric Calibration
  - Type Ia supernovae will play a key role in LSST cosmology constraints (expansion history)
  - Accurate flux calibration (<1%) is crucial and can be obtained via a program referencing standard stars to NIST-traceable light sources at very modest cost
  - Such a program will also be crucial to fully exploit the synergy of LSST and WFIRST
- Peculiar Velocity Studies
  - Peculiar velocities probe structure growth
  - Supernova distances can map out peculiar velocity fields
  - At lower redshift, DESI will be dominated by cosmic variance; a low-z peculiar velocity program can greatly enhance the power of DESI
  - Several thousand SNe over the DESI footprint could be obtained with modest investment in operating costs of *existing facilities*.



Enhancing LSST and DESI with Complementary Data — Complementary Measurement Efforts

- Offset Broad-band Imaging
  - Well-calibrated photometric redshift estimates are *critical* for LSST dark energy science
  - Offset broad-band imaging over a small portion of the LSST footprint could provide a cost-effective approach to significantly improve photometric redshift estimation
  - Support for efforts to design, e.g., a DECam-based approach and to cover the cost of the filters could significantly reduce this major source of systematic uncertainty for LSST
- Ground-based Spectroscopy
  - Ground-based spectroscopic facilities could complement LSST and DESI in many ways
  - Many opportunities, from buying to “trading” data or contributions to new instruments
  - More detailed studies would be required to establish the most impactful program and would become part of the Spectroscopic Roadmap development

Enhancing LSST and DESI with Complementary Data — Bridging Surveys

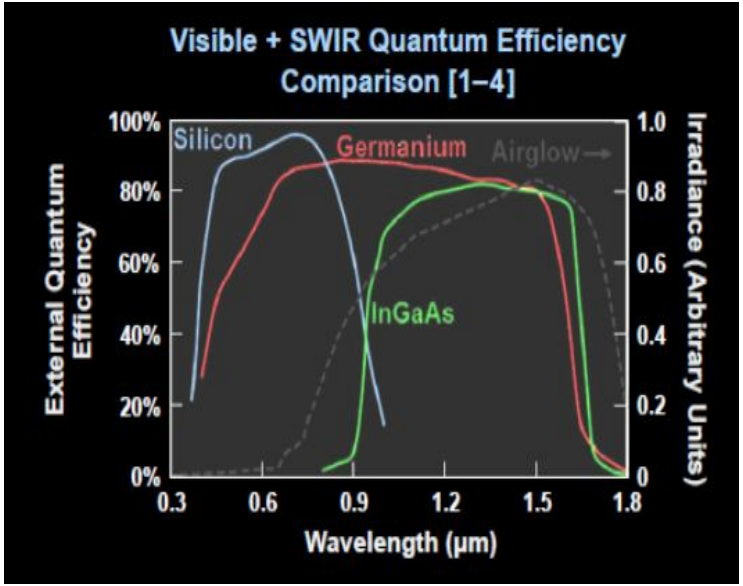
- WFIRST and LSST
  - Several interesting science opportunities can be explored between the two surveys, e.g.,
    - Supernova imaging and spectroscopy
    - Spectroscopy for photometric redshift training and/or calibration
  - However, significant preparatory development and testing of robust pipelines has to be carried out in advance due to the space-based effort involved and therefore resources to work on their design are needed well in advance of the launch of WFIRST
- LSST and DESI + CMB-S4
  - Many scientific opportunities by combining CMB-S4 with LSST and/or DESI:
    - CMB lensing cross-correlation with LSST
    - Kinematic and thermal Sunyaev-Zel'dovich effect
  - No new data needed, but resources to enable cross-survey preparatory work are required

New Technology Developments
— Ground Layer Adaptive Optics (GLAO)

- Turbulence in ground layer and upper layers of atmosphere degrade resolution of ground-based imaging and spectroscopic surveys
- By correcting for turbulences in real time, adaptive optics can yield improved angular resolution and improvement of signal-to-noise ratio
- GLAO uses bright guide stars as reference and has been tested on 2.2-meter telescope on Mauna Kea
- Potential to improve current or future facilities; for LSST: GLAO on secondary mirror; for DESI: GLAO on primary mirror
- R&D toward larger mirrors, larger field of view, and site characteristics required

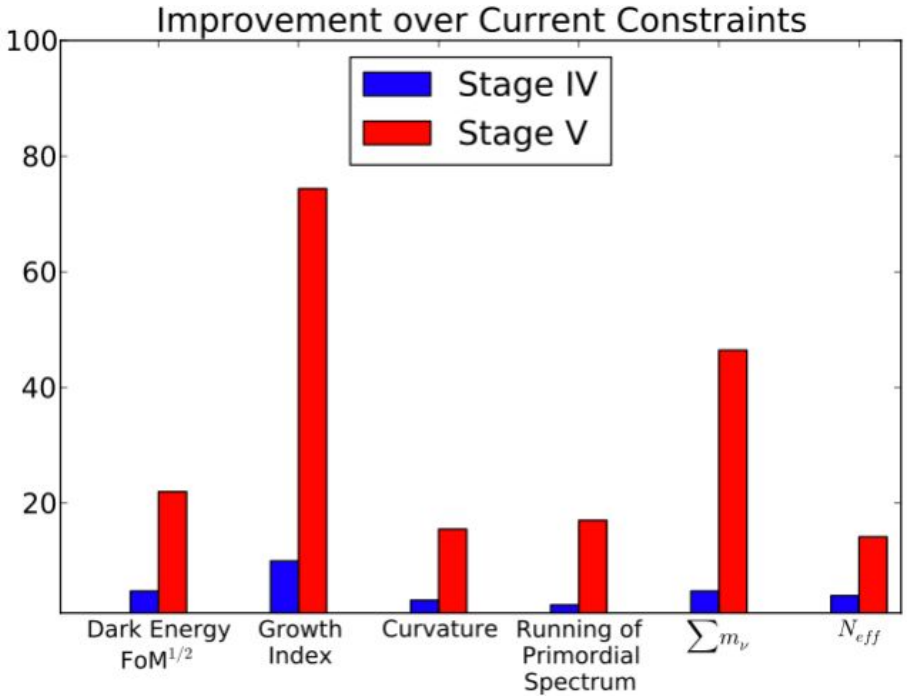
New Technology Developments
— Germanium CCDs

- Silicon CCDs have restrict access to galaxies below redshift z<1.6
- Enormous volumes will still be unexplored at higher redshifts even after DESI is completed that provide information about many physical models
- Germanium CCDs provide promising alternative but still face several challenges
- A five-year effort is required to develop a manufacturing pipeline



New Technology Developments
— Fiber Positioner Systems

- After DESI and LSST, a massive spectroscopic program has great potential to advance cosmology
- With spectroscopy of 40,000 galaxies per square degree we could obtain clustering sample out to z < 3.25
- A new design for fiber positioners would be crucial to enable such an effort



Theory and Simulation Advances
— Unlocking Small Scales

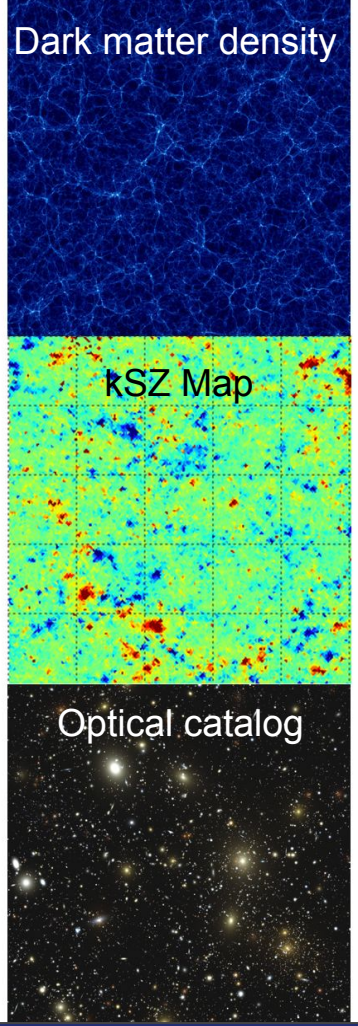
- From Tegmark 1997: *“The nonlinear domain appears to be a gold mine of cosmological information, but one whose riches may prove extremely difficult to extract”*
- Krause & Eifler, 2017: Figure of Merit gains of factor 2-4 by extending LSST galaxy clustering and lensing analysis into the highly nonlinear regime
- Simulations and modeling efforts now have matured to help unlock access to the information on nonlinear scales
- A dedicated program in simulations and modeling, including major calibration and validation efforts, has the potential to have a major impact on ongoing and upcoming surveys

Theory and Simulation Advances
— Going Beyond wCDM

- Going beyond two-point correlation functions and to even smaller scales holds great promise for new insights into the cause of the accelerated expansion of the Universe
- Exploration of physics beyond wCDM, such as self-interacting dark matter models or modified gravity, requires careful simulations and modeling
- At the same time, the theories have to be rigorously confronted with observation data
- A targeted effort is needed that brings together theorists, simulators, modelers and observers to build a program

Theory and Simulation Advances
— A Multi-wavelength Virtual Observatory

- Cross-correlations of different data sets hold a wealth of information and constraining power
- A major analysis, modeling, and simulation effort has to accompany the observational campaigns to take full advantage of this opportunity
- Effort would provide “same sky mocks” for different wavelengths
- Biggest obstacle: Funding resources to be provided to allow work *across* surveys



Theory and Simulation Advances
— Enabling Community Science

- Many tools and simulations developed in the dark energy community can be applied across different surveys
- Given the limited resources currently available and the cost associated with the simulations, developing an infrastructure that allows for easy access and sharing of tools and simulations seems most natural
- Resource requirements for building such an infrastructure depend on its sophistication (*easiest:* provide access to simulations, *more difficult:* provide access to analysis capabilities, *even more work:* provide a range of tools)
- Community could contribute to this; opportunities to closely collaborate across agencies and DOE Offices

Project Matrix

Readiness	Total Cost	
	<$1M	$1M - $3M
<2020	*Extending DESI/LSST**: - Photometric calibration instrumentation - Narrow-band or offset broad-band imaging - WFIRST + LSST synergies	*Theoretical and Simulation Advances*: - Modeling & simulations for small scale clustering - Modeling & simulations beyond ΛCDM - Multiwavelength Virtual Observatory - Enabling Community Science
2020-23	*Extending DESI/LSST**: - Personnel costs for ground-based spectroscopy - Peculiar velocity studies - LSST and DESI + CMB S4 synergies	*New Technology Developments*: - Ground layer adaptive optics over 10 deg^2 field of view - Germanium CCDs manufactured at scale - Fiber Positioner Systems at 5 mm pitch

⋆ Less prescriptive category with more scope for new options and ideas.

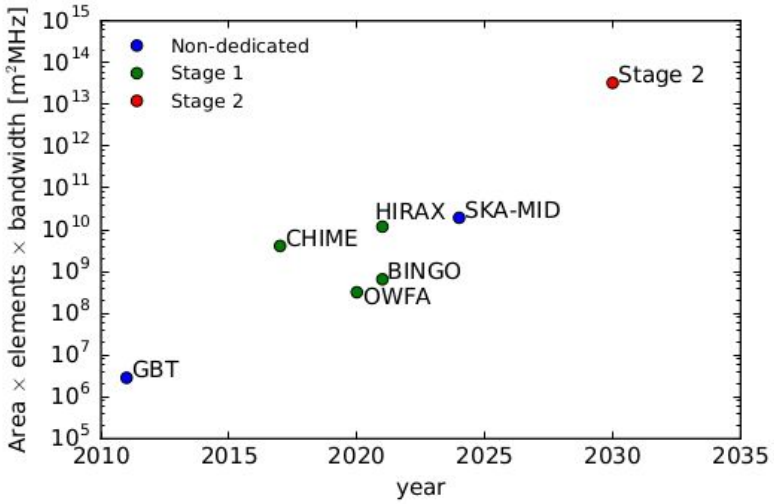
Summary

- A community-driven Small Projects Portfolio with three key components has been presented:
  - Enhancing LSST and DESI with complementary data
  - New technology advances
  - Theory and simulation advances
- We strongly believe that support of these areas will have a very strong impact on dark energy science in the next decade and beyond
- The efforts are extremely timely with LSST and DESI starting soon

Back-up Slides

21-cm Roadmap

- Main proposal is for a US-led **Stage 2** experiment following current crop of Stage 1 experiments
- Main Science Drives:
  - **Expansion history to z=6**: extends the range to pre-acceleration era
  - **Search for inflationary relics** in primordial power spectrum: order of magnitude improvements wrt to DESI/LSST
  - **Search for primordial non-Gaussianity**: order of magnitude improvements in equilateral/orthogonal bispectra wrt to Planck/DESI/LSST
- White Paper (to be completed by fall) argues for **vigorous R&D program** to:
  - **Research** to better define science case for Stage 2 experiment
  - **Data analysis** of Stage 1 and testbed experiments in preparation for Stage 2
  - **Technology** to develop new hardware and calibration methods



- Bonus Science Drives:
  - **Quadruple** the observed cosmic volume
  - Provide **~10 new and high SNR weak-lensing screens** for cross-correlation studies (with CMB-S4, with LSST)
  - Improve **cosmological parameters**
  - **Directly measure expansion** of the universe (possible at z=1, further optimization req'd)
  - Explore **modified gravity using pulsars**
  - Explore physics of **Fast Radio Bursts**