Future Cosmic Surveys

- **DOE OHEP Cosmic Visions: Dark Energy**
- NAC's "A Strategy to Optimize the U.S. Optical and Infrared System in the Era of LSST" (Elmegreen report)
- Report on Kavli Futures Symposium (NOAO,LSST): "Maximizing Science in the Era of LSST: A community Based Study of Needed U.S. OIR Capabilities"

Cosmic Visions: Dark Energy

- The Cosmic Visions Dark Energy group was formed by the DOE's Office of High Energy Physics in August 2015 as a 2-way communication group with the HEP community: Scott Dodelson (Chair), Katrin Heitmann, Chris Hirata, Klaus Honscheid, Aaron Roodman, Uros Seljak, Anze Slosar, Mark Trodden.
- Two other CV groups (CMB and Dark Matter) coordinate with DOE.
- CMB is in a different phase: The CMB-S4 community-based collaboration released a first version of their Science Book (1610.02743). The HEP CV-CMB group has people in the collaboration and is concentrating on coordinating the HEP community activities.
- We are now starting along the same process (building broad community and developing strong science case) and are about 1-2 years away from a Science Book (good timing for Decadal Survey)

Process

Between formation and the end of January 2016, the group of eight members held weekly telecons. Representatives of the group met with leaders of DESI at their November collaboration meeting and with leaders of the LSST Dark Energy Science Collaboration at their October collaboration meeting. There were three workshops held to gather input for the three white papers:

- Brookhaven, October 1, 2015. Agenda and slides available at https://indico.bnl.gov/categoryDisplay.py?categId=124
- Fermilab, November 10, 2015. Agenda and slides available at https://indico.fnal.gov/conferenceOtherViews.py?view=standard\&confId=10639
- SLAC, November 13, 2015. Agenda and slides avaiable at https://indico.fnal.gov/conferenceDisplay.py?confId=10842

The group of eight met for a one day face to face meeting on January 14, 2016 at Fermilab.

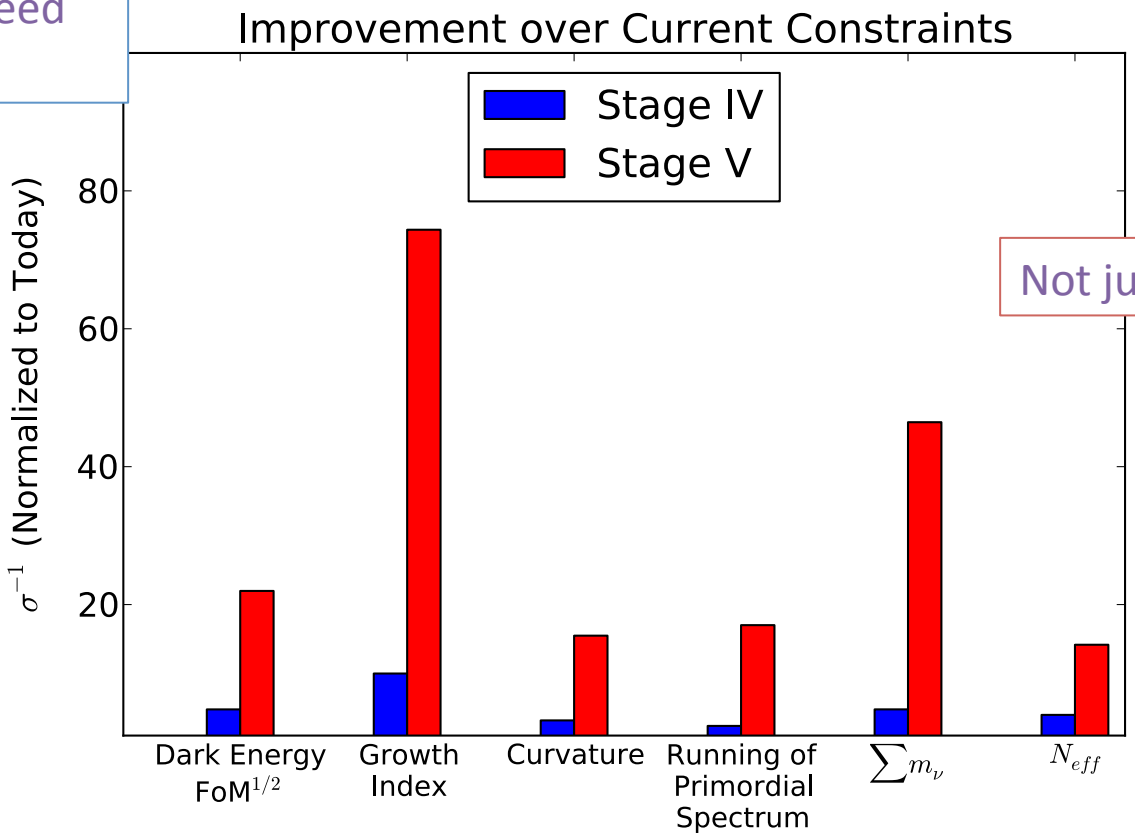
Two papers were submitted to the arXiv:

1604.07626

1604.07821

Findings

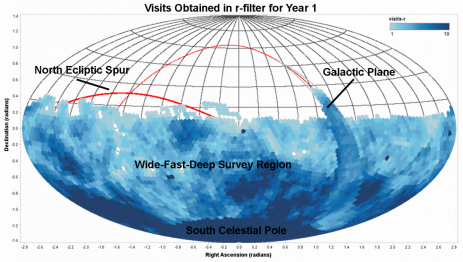
Broad range of improvements from guaranteed to searches



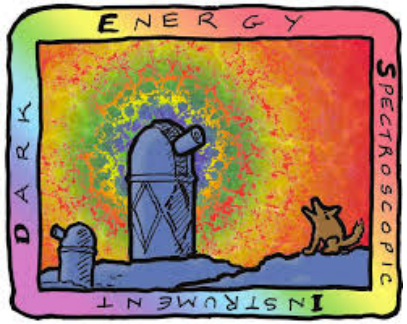
Not just Dark Energy

[1] Even after DESI and LSST, there will be a lot of information left in the sky

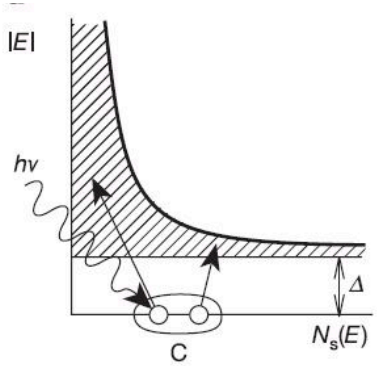
Findings



Southern Spectroscopic Survey Initiative

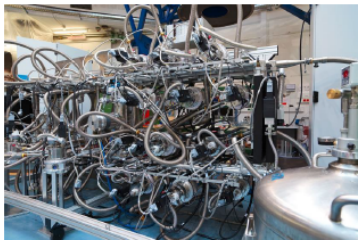


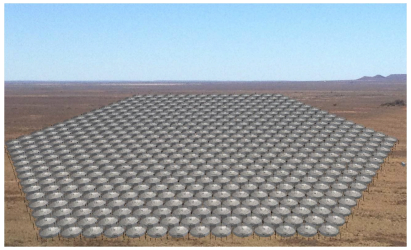
DESI-2



Low Resolution Spectroscopy
aka Hi-Res Photometry

Billion Object Apparatus



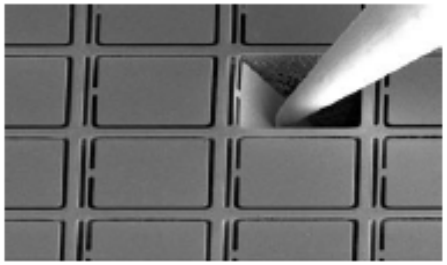


21 cm

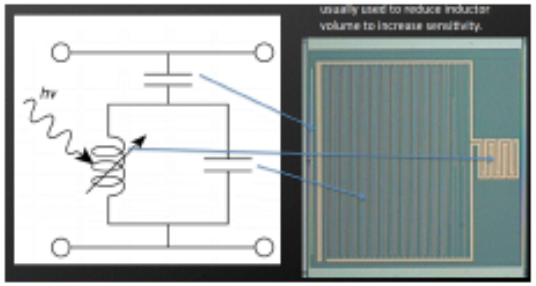
[2] There are multiple ideas for future projects that can mine that information

Findings

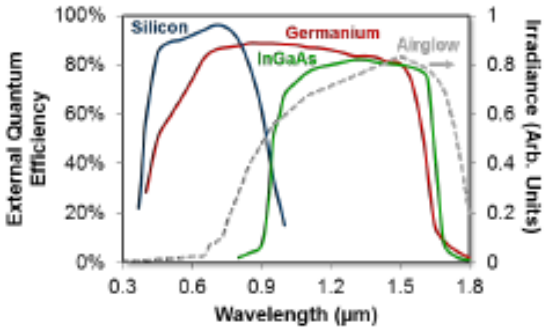
Micro Shutter Arrays developed for JWST



MKIDS Detector Arrays



Ge CCDs (MIT LL, LBNL)



C. Leitz

CV Whitepaper on arXiv 1604.07821

Cosmic Visions Dark Energy: Technology

Scott Dodelson, Katrin Heitmann, Chris Hirata, Kless Honscheid, Aaron Roodman, Uroš Seljak, Anže Slosar, Mark Trodden

Executive Summary

A strong instrumentation and detector R&D program has enabled the current generation of cosmic frontier surveys. A small investment in R&D will continue to pay dividends and enable new probes to investigate the accelerated expansion of the universe. Instrumentation and detector R&D provide critical training opportunities for future generations of experimentalists, skills that are important across the entire DOE HEP program.

[3] Instrumentation R&D and new technologies will be key for most of these ideas

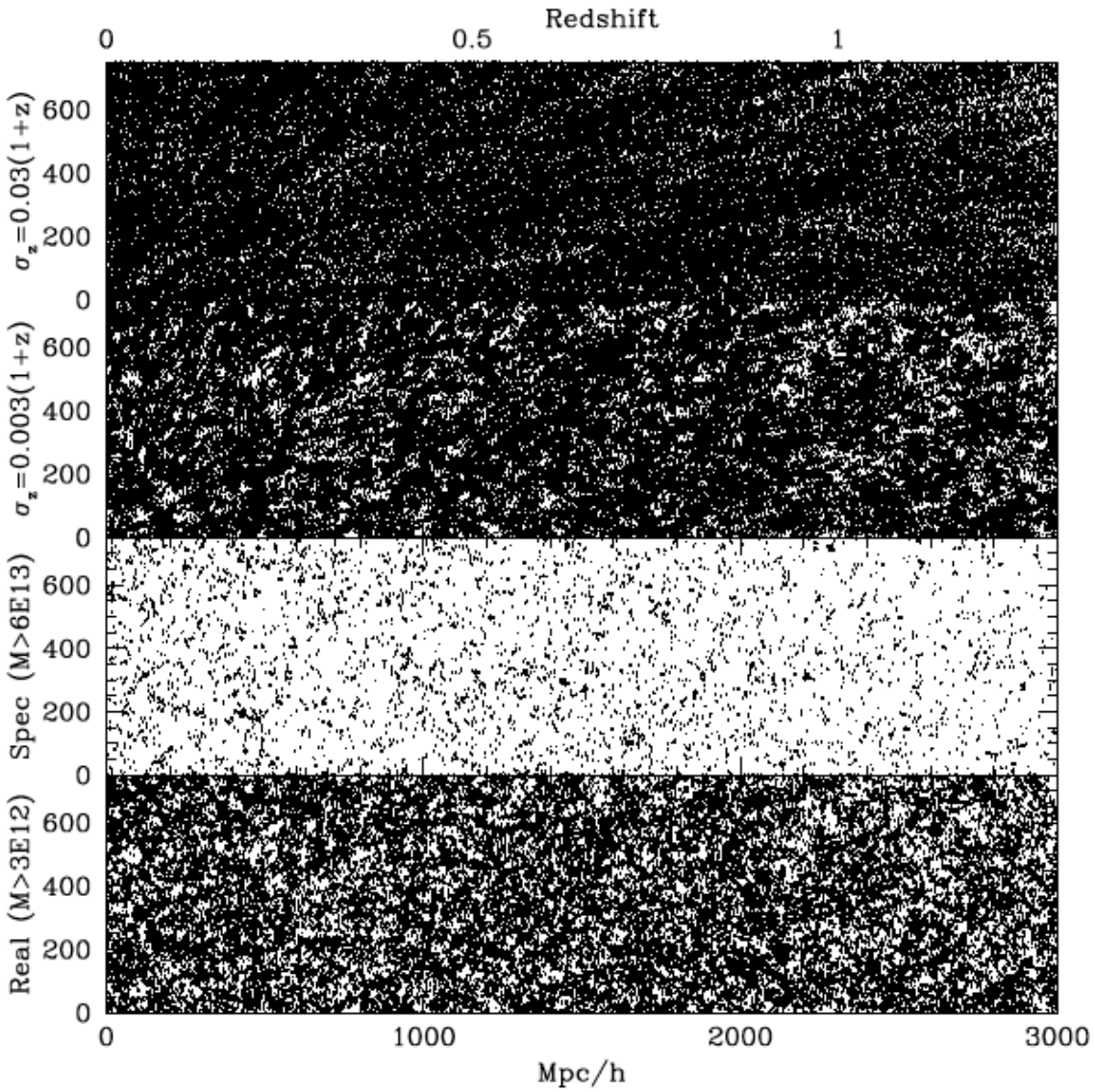
Recent Activity

- Cosmology using Low-Resolution Spectroscopy https://kicp-workshops.uchicago.edu/LowResCosmology2020/overview.php (35 participants)
- SSSI https://indico.hep.anl.gov/indico/conferenceDisplay.py?ovw=True&confId=1035 (40)
- Future Cosmic Surveys https://kicp-workshops.uchicago.edu/FutureSurveys/index.php (145)

DESI-2

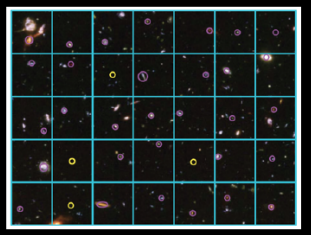
- **DESI** is a 5000-fiber, 8 deg^2 FOV spectroscopic instrument with R=2000 (350nm)-5500 (980 nm), to be installed on the Mayall @ Kitt Peak. Will do a 14sq. deg survey of 35 M galaxies & quasars + 10 M stars from 2019-2024
- **DESI-2**: science with DESI after the planned survey is complete (2025+). Operating costs estimated at 7-8M per year.
  - DESI as is will still be a world leading instrument in 2025, can observe roughly 20M spectra per year.
  - Modest upgrades to DESI could extend the spectrograph in the red and enable an efficient higher redshift survey
- Possible surveys / science drivers:
  - Dense low redshift survey (e.g. magnitude limited to 21.5) allows precise power spectrum, density & velocity field, with broad science applications in galaxy formation and cosmology including tests of modified gravity
  - High redshift survey at $z > 1.5$ would provide new information in the linear regime beyond DESI, could be enabled with modest instrument upgrades or improved selection
  - Significant overlap and cross-correlation science with LSST and CMB-S4
  - Targeted surveys, e.g. gravitational wave follow-up, stellar streams, dense sampling of cluster or lens fields, etc.

High-Res Photometry



GigaZ/MegaZ : Photo-z machine

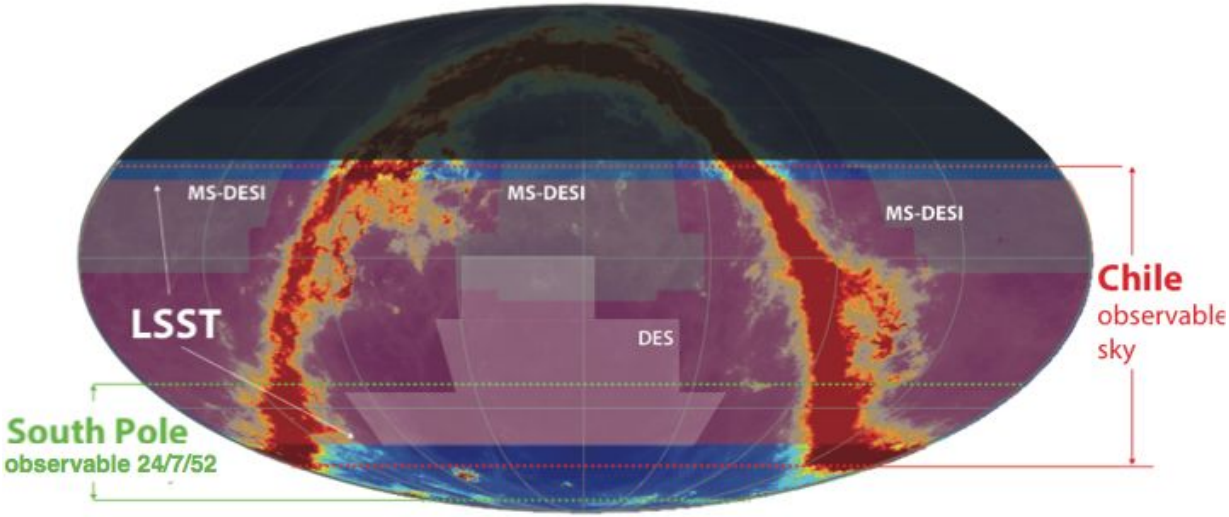
- Marsden et al 2013
- LOI ESO 2014 (Oxford,Fermilab,UCSB)



Make large pixels, and use mask to select a galaxy for each pixel. **100,000 spectroscopic channels in 1 square deg. is possible (20x DESI). Resolution R~100.** White paper to Snowmass 2013. Large project after LSST. (See comment from P5)

Southern Spectroscopic Survey Instrument

- SSSI would be a massively multiplexed (>2500x), wide-field (goal: >1 deg^2) optical/IR spectrograph on a 6.5+m telescope
- SSSI provides spectroscopic capabilities matched to LSST and CMB-S4 survey areas and depths; Southern site preferable
- SSSI takes full advantage of current technologies and DESI legacy
- Wide variety of science cases; e.g.: reduce LSST photo-z errors by a factor of 2 via training spectroscopy
- A top priority from Kavli/NOAO/LSST and international prioritizations as well as Cosmic Visions: many potential partners



Billion Object Apparatus

- **Concept:** optical/IR spectrograph on a 10m telescope
  - massively multiplexed (50k-100k fiber)
  - wide-field (1-5 deg^2)
- **Primary Objective:** complete sampling of linear density field using between 500M and 1B spectroscopic tracers
  - Maximal precision on cosmological constraints with clustering to $z<3.5$
- **Feasibility:** shares instrument design with existing/proposed experiments
  - Design for 10-m class telescope with large FOV (Pasquini et al., 2016)
  - Spectrograph design for DESI adaptable to 4^{th} infrared channel (1-1.4 micron)
  - Tests of target selection and spectroscopic completeness with PFS
- **Programmatics:** Staged development with other spectroscopic surveys
  - Similar spectrograph design to DESI, DESI-II
  - Shared platform with SSSI
- **Partnership with DOE labs:** R&D to meet technical challenges
  - Dense packing of fibers in focal plane
  - Scale spectrograph production to 100,000 fibers
  - Development of Ge CCDs at LBNL

Road Map for Spectroscopy

- The proposed spectroscopic surveys build on each other directly
- DESI-2 would be relatively low in cost and could follow DESI immediately in 2024
  - Spectrograph upgrades to add IR arm would enhance capabilities at higher redshifts
  - Moving to Blanco is an option, increasing LSST overlap
- SSSI could reuse DESI spectrographs to reduce costs
  - Earliest possible deployment c. 2026
  - Most efficient option would be to deploy on 11-12m telescope (e.g. MSE or European wide-field concepts)
- BOA would require both a >10m wide-field telescope and significant hardware R&D
  - Earliest possible deployment early 2030s
  - Could utilize telescope originally developed for SSSI

Radio Cosmology: 21 cm/Intensity Mapping

- **Near term:** Forecasts tailored to v. high radial resolution of radio cosmology; use existing instruments to uncover systematics and try to constrain τ for CMB-S4 neutrinos.
- **Long term:** Pushing the redshift, scale, and sensitivity frontiers with BAO measurements from $2 < z < 6$; matter power spectrum on small scales at $z > 35$.
- **Contrast with the SKA:** Proposed instruments would be targeted cosmology experiments, rather than the SKA's philosophy of a general observatory, allowing fundamental physics to be probed at a fraction of the cost.
- **Partnerships with DOE labs:**
  - High data rates: DOE HEP expertise in high throughput computing.
  - Next-gen correlator tech leveraging DOE radio frequency tech.
  - R&D for real-time ionospheric calibration for highest z.
  - Large scale DOE manufacturing capabilities for ~10^6 element "dream cosmology instruments"

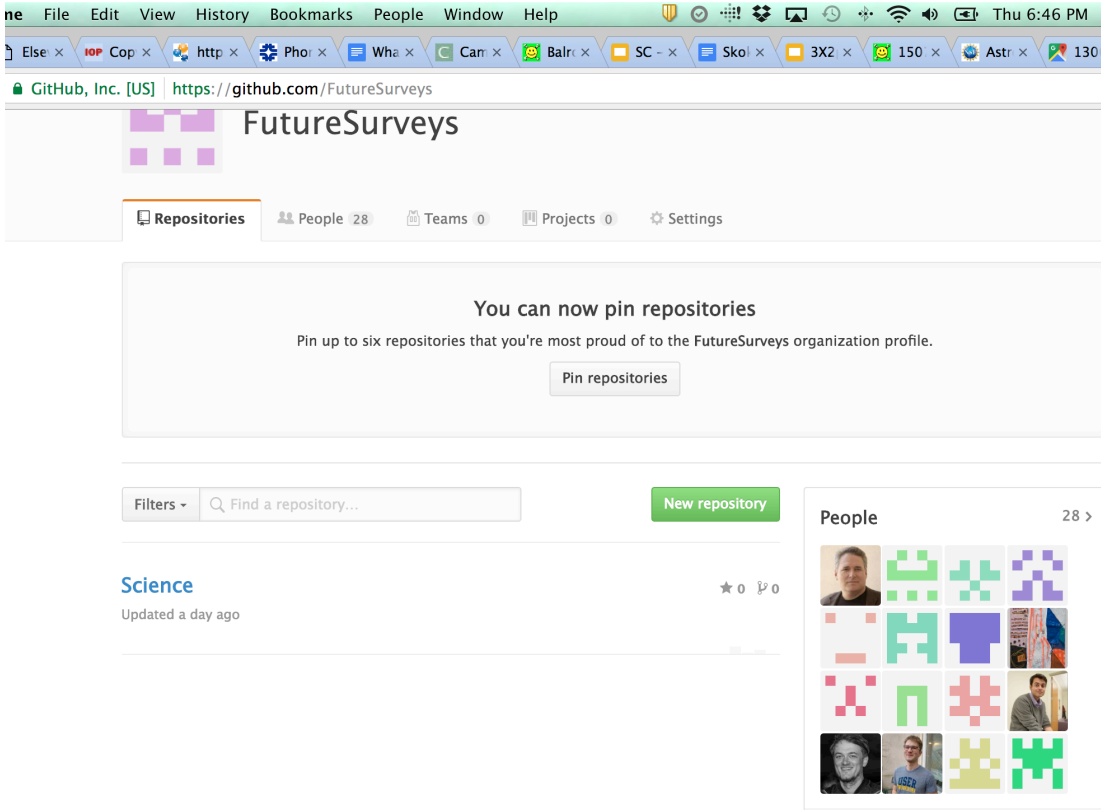
Overlap Day with CMB-S4

KPTC (5720 S. Ellis Avenue, 1st floor)

8:50 AM	Introduction and Goals **Scott Dodelson**
9:00 AM - 9:15 AM	Future Surveys Summary **Klaus Honscheid**
9:15 AM	CMB-S4 Summary **John Carlstrom**
9:30 AM	**Breaking Parameter Degeneracies** • S4+DESI/LSST: mnu, w, nâ€™, N_eff, fnl ; systematic checks/complementarity Joel Meyers • how much more can you do with 21 cm/spectroscopy Anze Slosar
10:15 AM	Break
10:30 AM	**Cross-correlation of Future Surveys with CMB kappa** ***Moderator: Gil Holder*** • Science case for doing CMB lensing + LSS Blake Sherwin • Additional calibration of shear Emanuel Schaan • photo-z calibration Eric Baxter + Pat McDonald • E_G and other cross-signals Anthony Pullen • sampling variance cancellations Marcel Schmittfull
1:00 PM	Lunch (provided) *ERC (5640 S. Ellis Avenue, room 401)*
2:00 PM	**Clusters** ***Moderator: Brad Benson*** • kSZ Simone Ferraro + Kendrick Smith • Cluster counts and mass calibration: photo-z for WL masses; CMB cluster lensing; velocity dispersion Adam Mantz + Jim Bartlett
4:00 PM	Break
4:30 PM	Creative Ideas; Consistency Tests: Challenges beyond getting the same parameters: identifying joint null tests, generalized B-modes, e.g. de-lensing, ISW maps TBD **Erminia Calabrese, Jo Dunkley, Cora Dvorkin, Dragan Huterer**
5:00 PM	Discussion

Our Next Steps

- Proceed together generating projections over the next 6 months-one year, with telecons once every 2 months
- Git Organization: allows for code sharing, prediction comparisons, writing, issues, …
- Another workshop in one year with the goal of starting writing by then



What Would We/I Like from AAAC?

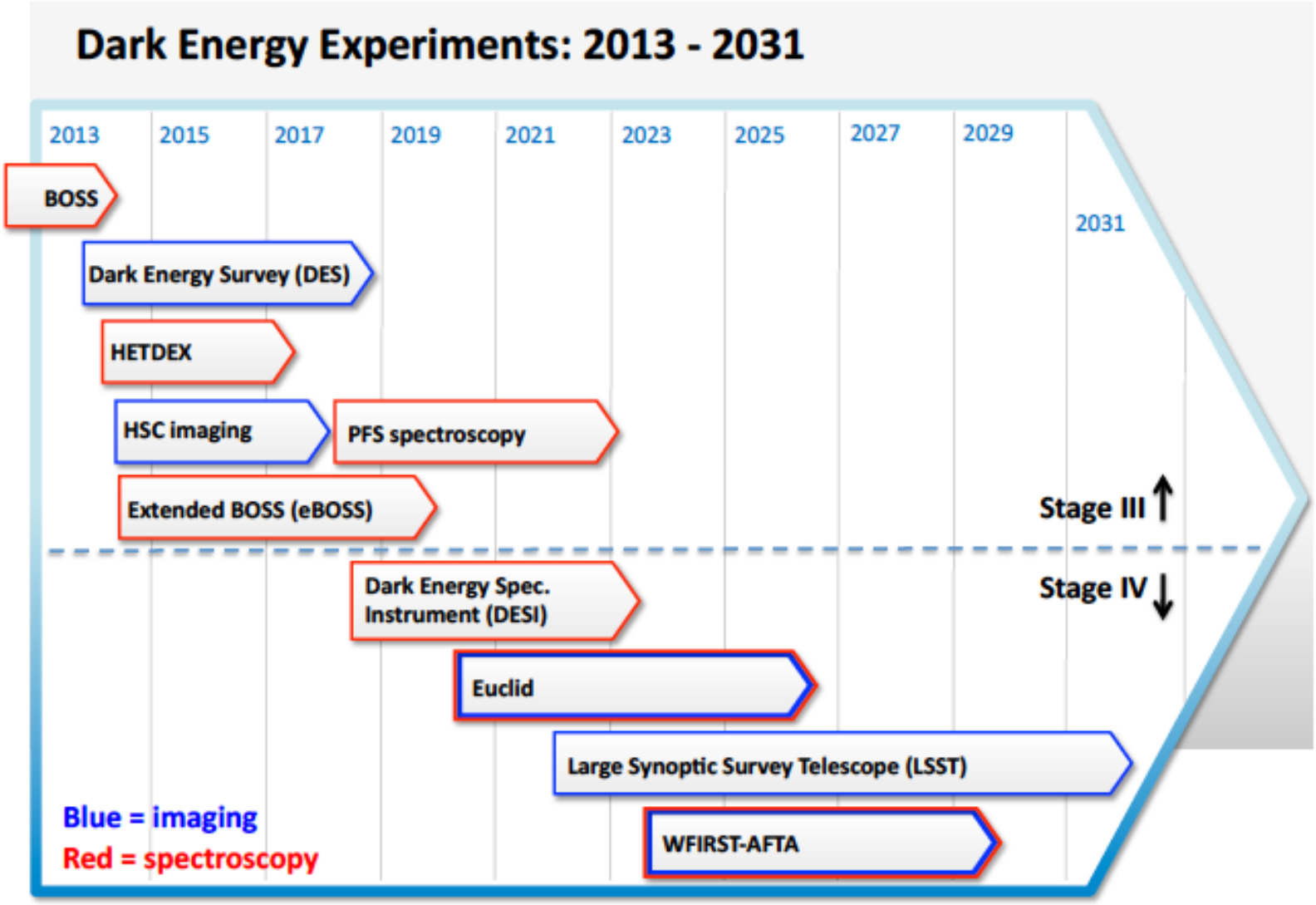
A recommendation like the one in the 2016 report: "We encourage DOE, NSF, and university community to continue working toward a plan for a future (Stage 4) ground-based CMB experiment."

Probably cannot be this definitive without endorsement of Decadal Survey or P5

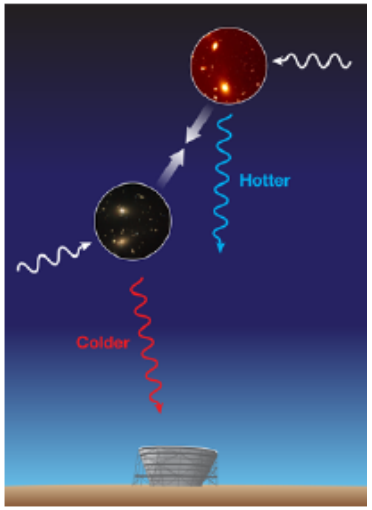
- Acknowledge the studies and the community interest in surveys beyond those in the current program
- Express your support for continuing these studies

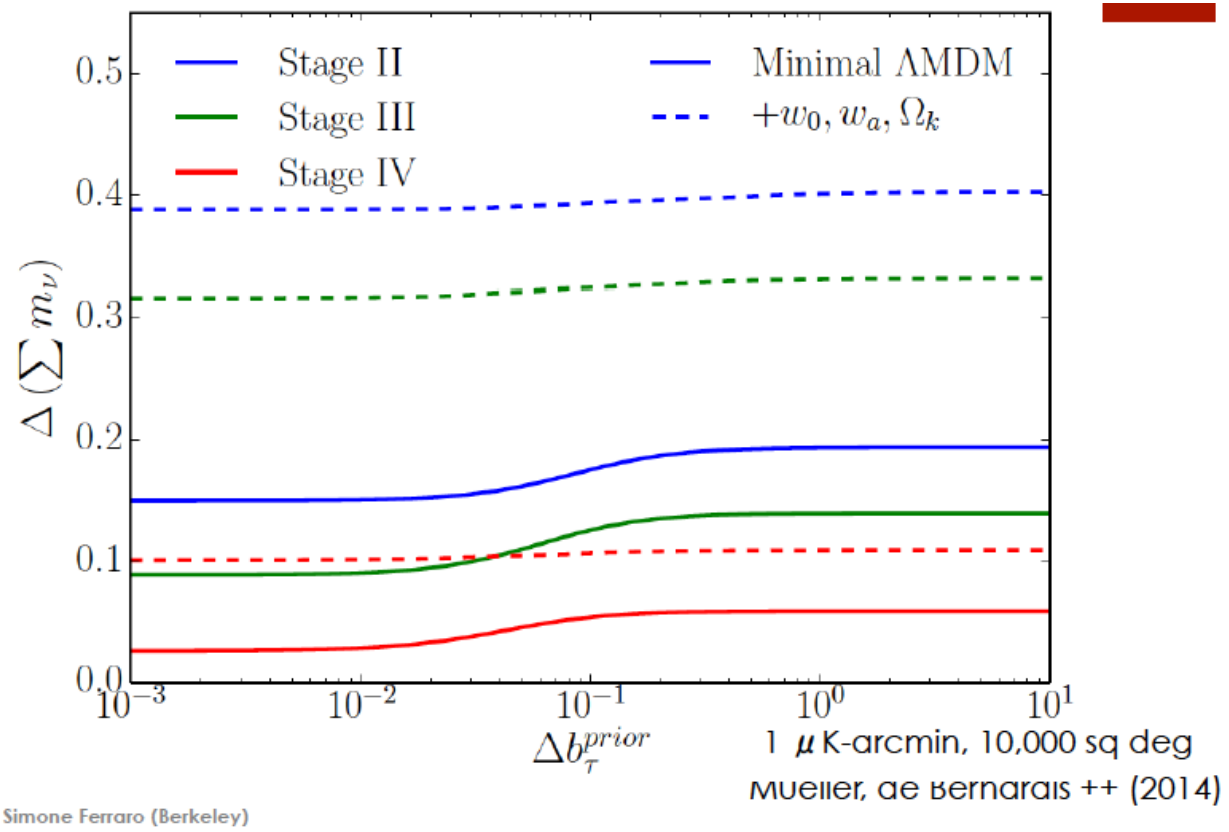
Backup

Context


Dark Energy Experiments: 2013 - 2031
2013
2015
2017
2019
2021
2023
2025
2027
2029
2031
BOSS
Dark Energy Survey (DES)
HETDEX
HSC imaging
PFS spectroscopy
Extended BOSS (eBOSS)
Stage III
Stage IV
Dark Energy Spec. Instrument (DESI)
Euclid
Large Synoptic Survey Telescope (LSST)
WFIRST-AFTA
Blue = imaging
Red = spectroscopy

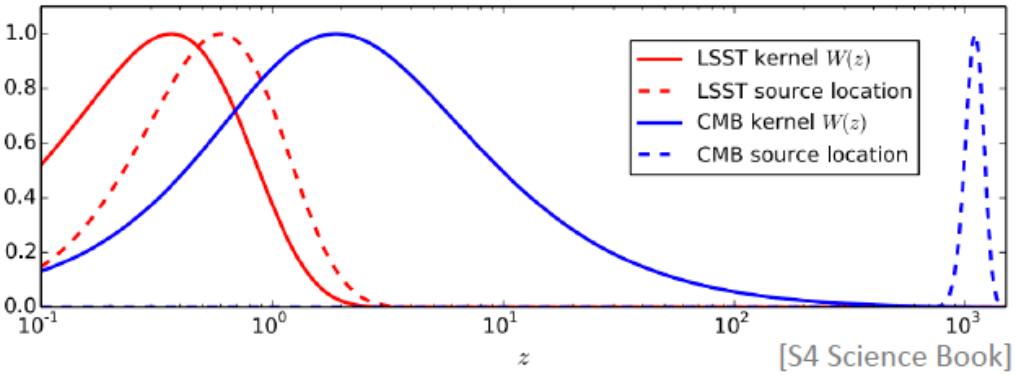
Overlap with CMB: kinetic Sunyaev-Zel'dovich Effect (kSZ)





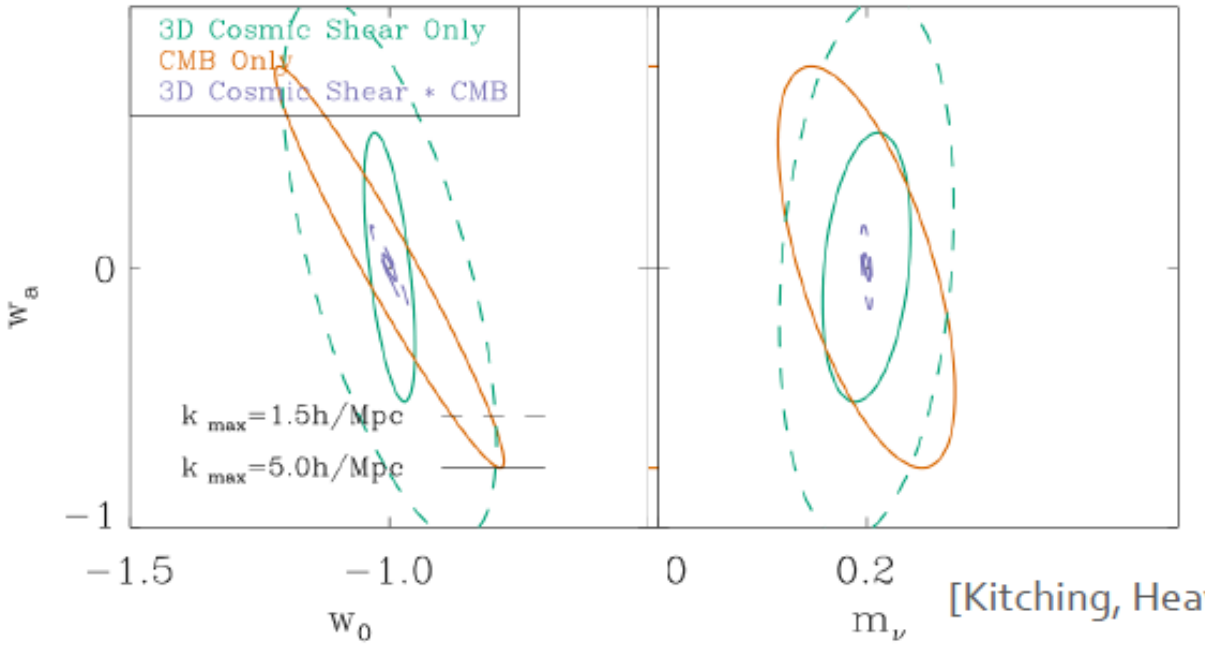
Simone Ferraro (Berkeley)

Overlap with CMB: Lensing



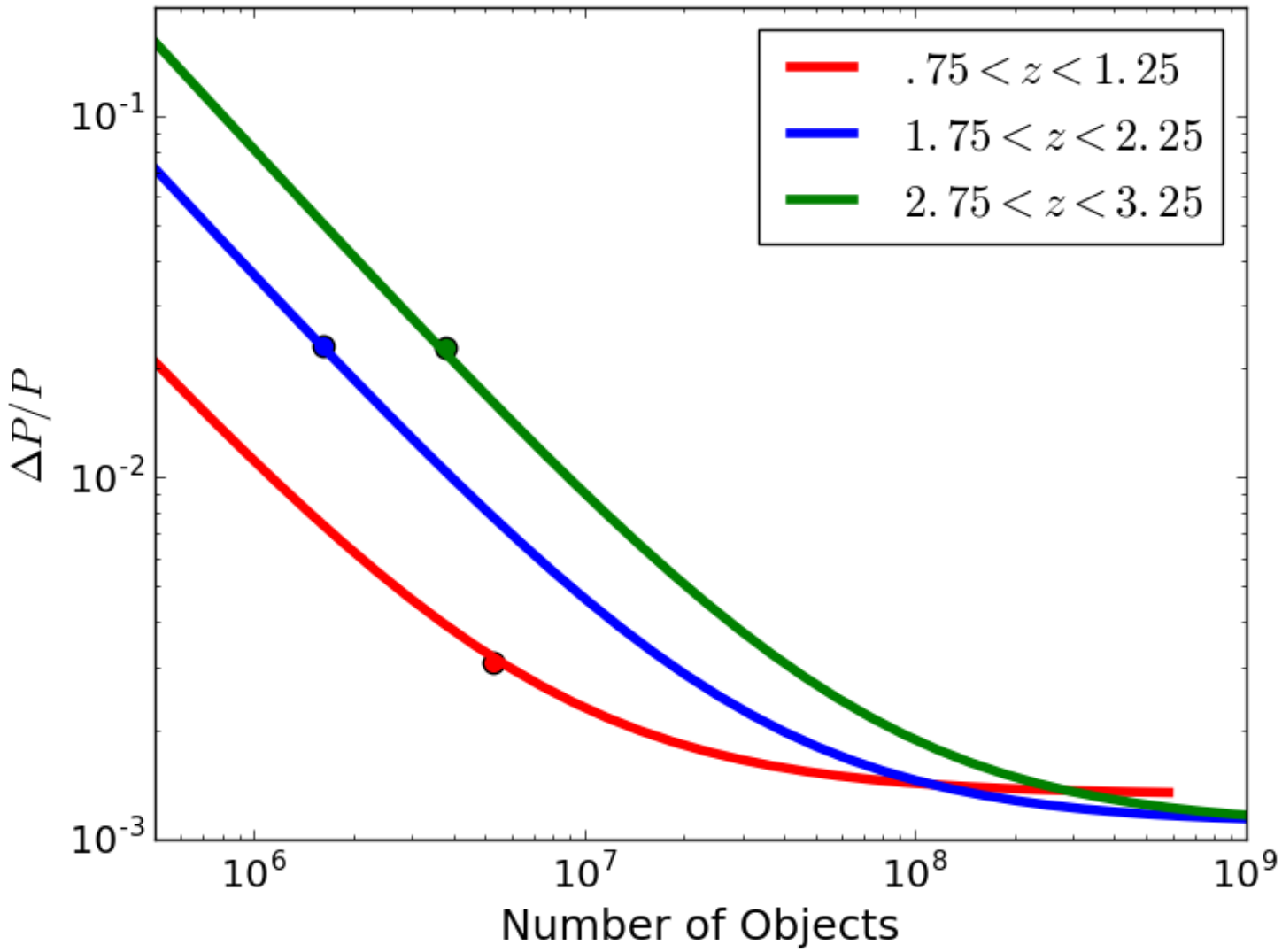
[S4 Science Book]

Core x Euclid Weak Lensing [S4 similar]



Big improvements if minimal datasets, lots of model freedom. Otherwise, moderate improvements or cross-checks.

[Kitching, Heavens, Das 2014]


$.75 < z < 1.25$
$1.75 < z < 2.25$
$2.75 < z < 3.25$
10^{-1}
10^{-2}
10^{-3}
$\Delta P/P$
10^{6}
10^{7}
10^{8}
10^{9}
Number of Objects