Cosmic Visions: Dark Energy

Introduction
Cosmic Surveys
Status and Report
Next Steps

Klaus Honscheid
Ohio State University
HEPAP, Dec 2, 2016

Cosmic Visions –Dark Energy

Cosmic Visions Dark Energy group:

Established by DOE OHEP 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.

What will complement, build on, and extend beyond the currently planned HEP Dark Energy experiments.

2 other CV groups (CMB and Dark Matter) coordinate with DOE

CMB is in a different phase

The CMB-S4 community-based collaboration release a first version of their Science Book

We are now starting along the same process: building broad community support and developing strong science case)

1-2 years away from a DE++ Science Book (good timing for next Snowmass/P5 and Decadal Survey)

Future Cosmic Surveys Studies

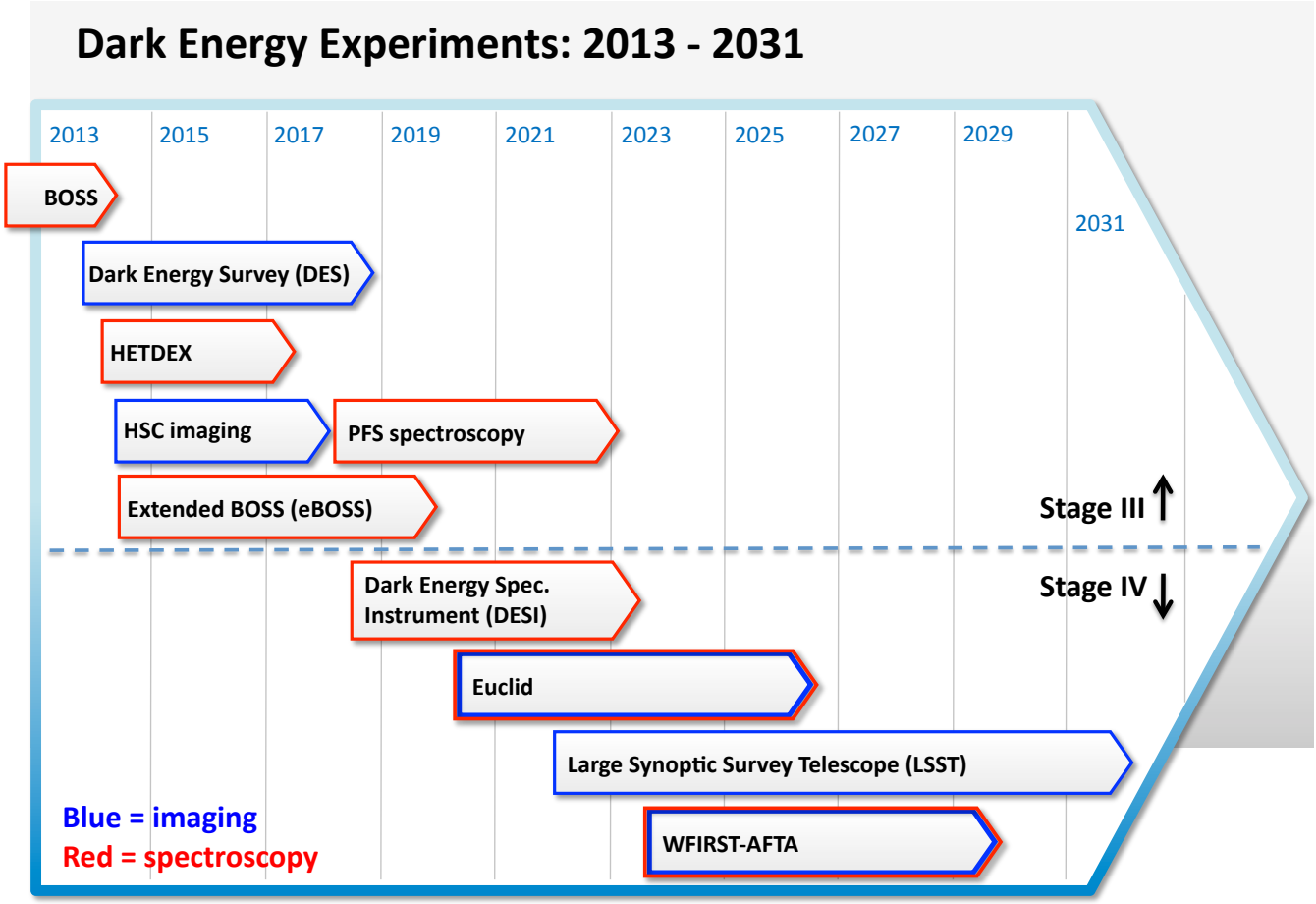
NAS's "A Strategy to Optimize the U.S. Optical and Infrared System in the Era of LSST" (Elmegreen report)

Report on Kavli Futures Symposium (NOAO,LSST): "Maximizing Science in the Era of LSST: A community Based Study of Needed U.S. OIR Capabilities"

Process

- Weekly telecons between August 2015 and January 2016
- Attended DESI and LSST DESC Collaboration Meetings
- Organized 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
- Face-to-Face meeting at Fermilab in January 2016
  - Three whitepapers submitted to DOE
  - Two papers were submitted to the arXiv: 1604.07626 and 1604.07821

Findings

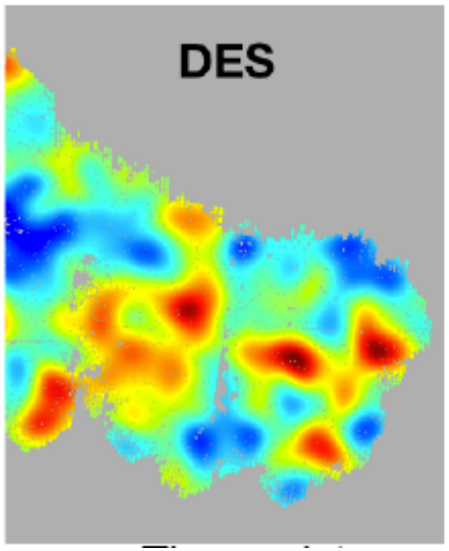


(A) The roadmap for cosmic surveys is well defined.
Since Snowmass: LSST, DESI, WFIRST approved*

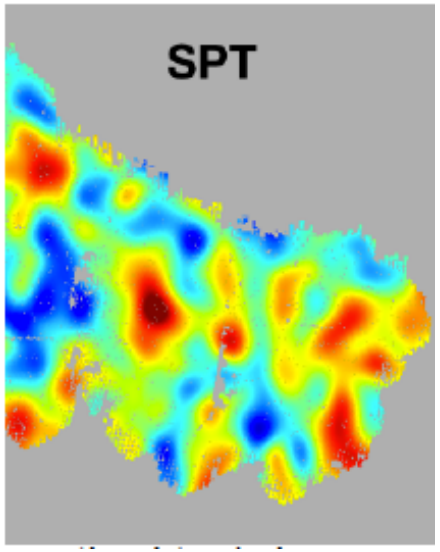
A new project cannot be incremental

Great Synergies

Galaxy Surveys and CMB

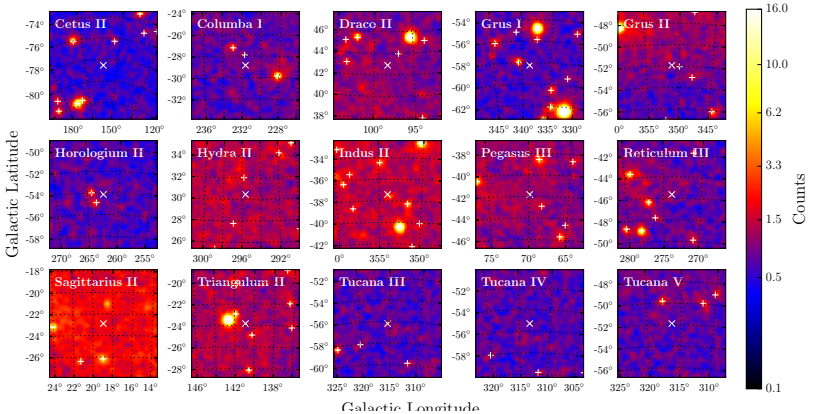


DES WL mass map

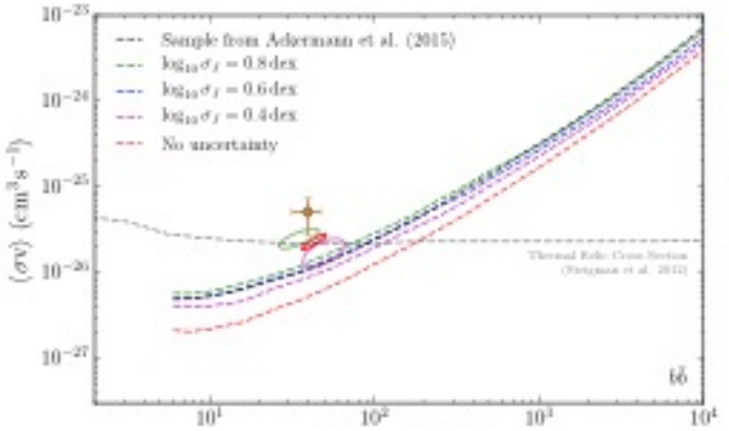


Mass map (κ) inferred from distortions in CMB

Galaxy Surveys and Gamma Rays



Gamma Rays from DES Dwarf Galaxies



Dark Matter Mass [GeV]

Analogy with Particle Physics

Particle Physics

New physics discovery relies on:

- increasing energy of collisions,
  - Allows access to new events that don't appear at lower E.
- increasing accelerator luminosity
  - e.g. produce more Higgs, and measure decay modes more accurately.
  - Can allow very rare decays to be discovered at statistically significant level.

Survey Cosmology

New physics discovery relies on:

- increasing redshift of detection,
  - Allows access to new events and objects absent at lower z.
- increasing number of objects
  - detecting more objects, allows more precise measurements of inhomogeneities.
  - Can allow different signatures in shape of power spectrum to be discovered at statistically significant level.

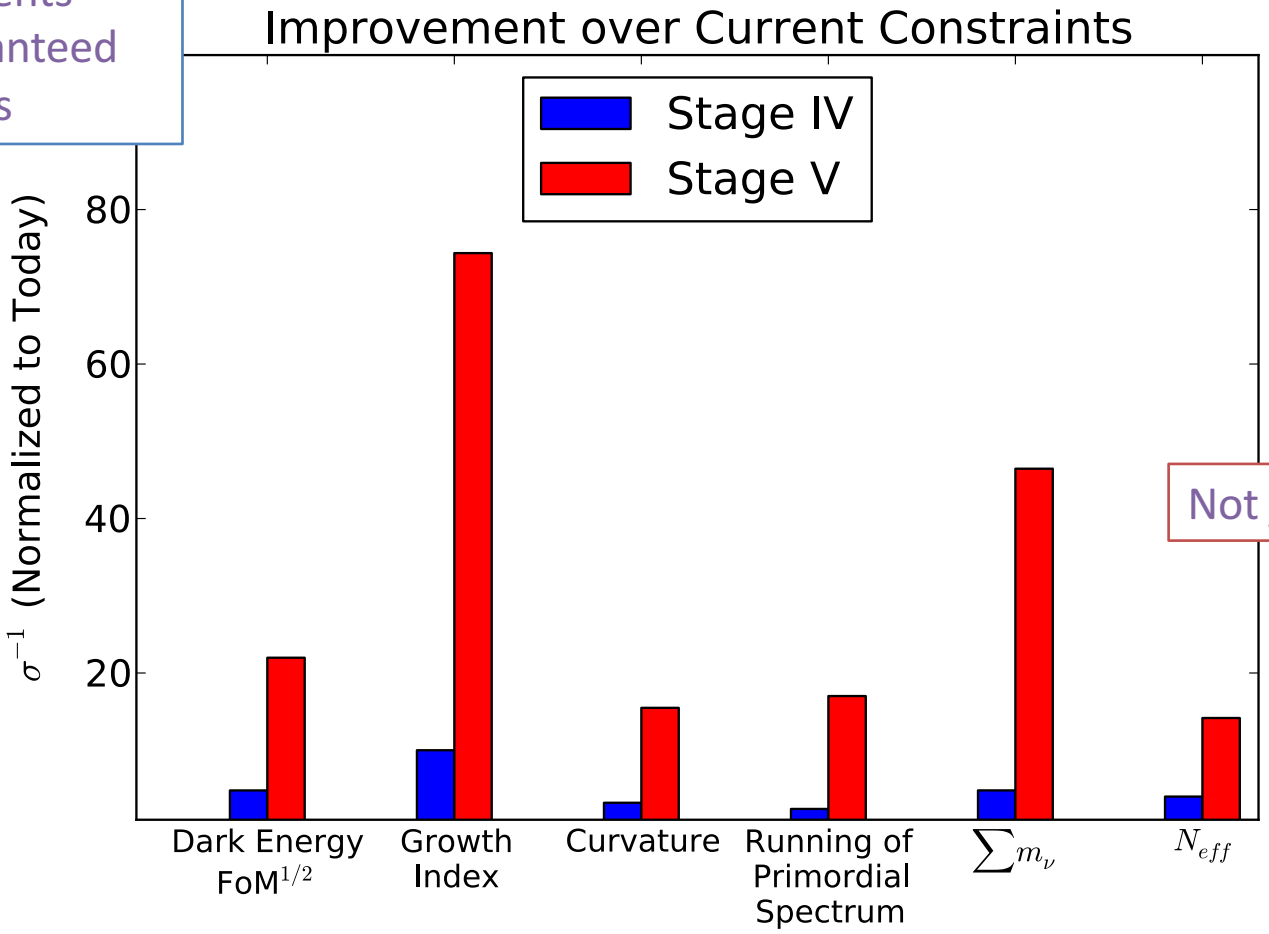
All allow access to **a lot of** new physics!

Slide by
Mark Trodden

Findings

1604.07626

Broad range of improvements from guaranteed to searches

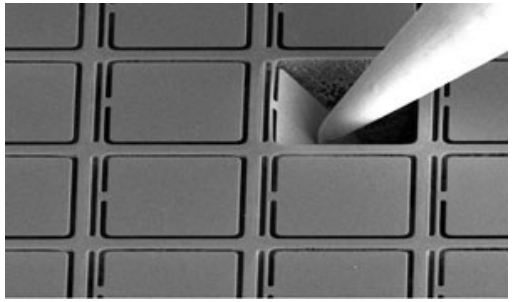


Not just Dark Energy

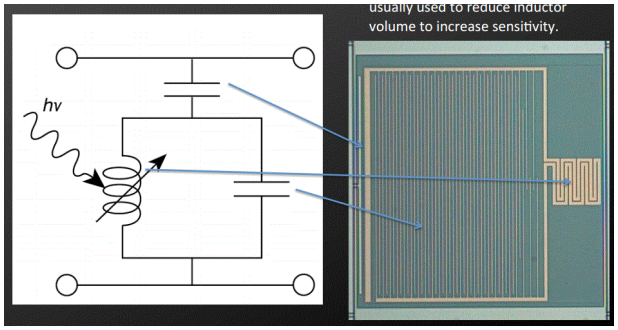
(B) Even after DESI and LSST, there will be a lot of information left in the sky

Findings

Micro Shutter Arrays developed for JWST

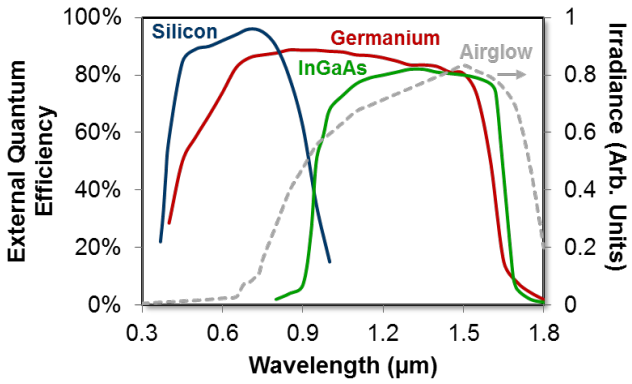


MKIDS Detector Arrays



CV Whitepaper on arXiv 1604.07821

Ge CCDs (MIT LL, LBNL)



C. Leitz

Cosmic Visions Dark Energy: Technology

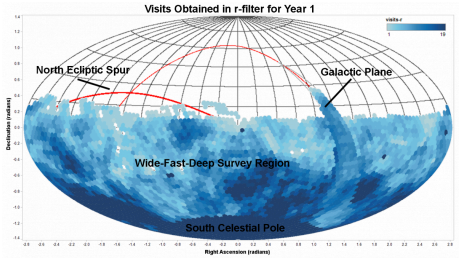
Scott Dodelson, Katrin Heitmann, Chris Hirata, Klaus Honscheid, Aaron Roodman, Uroš Seljak, Anže Slosar, Mark Trodden

Executive Summary

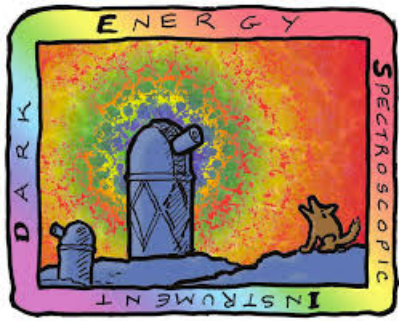
A strong instrumentation and detector R&D program has enabled the current generation of cosmic frontier surveys. A small investment in R&D will continue to pay dividends and enable new probes to investigate the accelerated expansion of the universe. Instrumentation and detector R&D provide critical training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

(C) Instrumentation R&D and new technologies will be key for many (all) future cosmic surveys

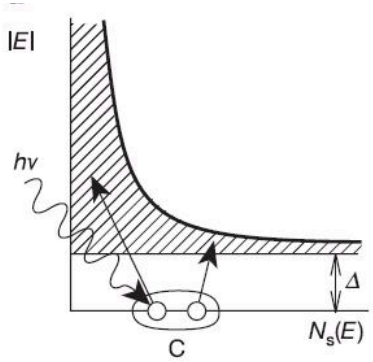
Findings



Southern Spectroscopic Survey Initiative (SSSI)

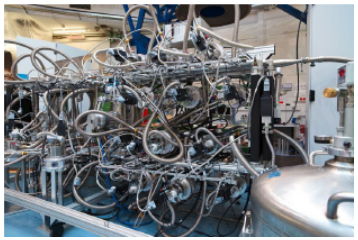


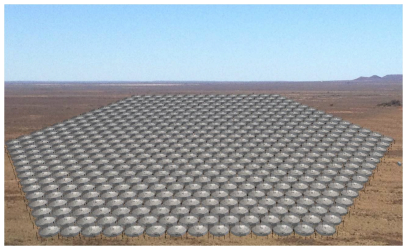
DESI-2



Low Resolution Spectroscopy
aka Hi-Res Photometry

Billion Object Apparatus



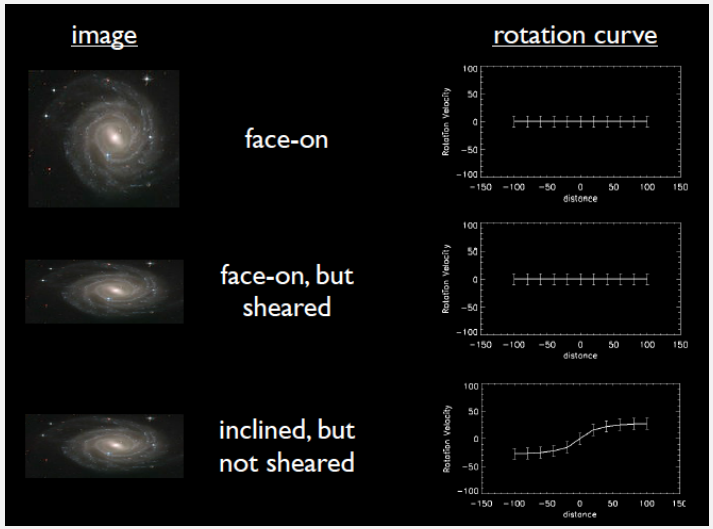


21 cm

(D) There are multiple ideas for future projects that can mine that information

Many additional ideas, variations and more

Kinematic WL (E. Huff): Get shape priors by measuring rotation curves



Novel Probes (Study Modified Gravity)

Compare the behavior of gravity in screened and unscreened regions (e.g. infall velocities of nearby galaxies)

Pixel Level Comparison

Combine data samples at the pixel level across projects, funding agencies and continents.

Theory, Synthetic Sky Maps & Simulations

Reliable predictions of observables on small Scales; viable fundamental physics models, modeling efforts to match the expected statistical power of LSST and DESI; End-to-end simulations and synthetic catalogs for validation of pipelines and systematics

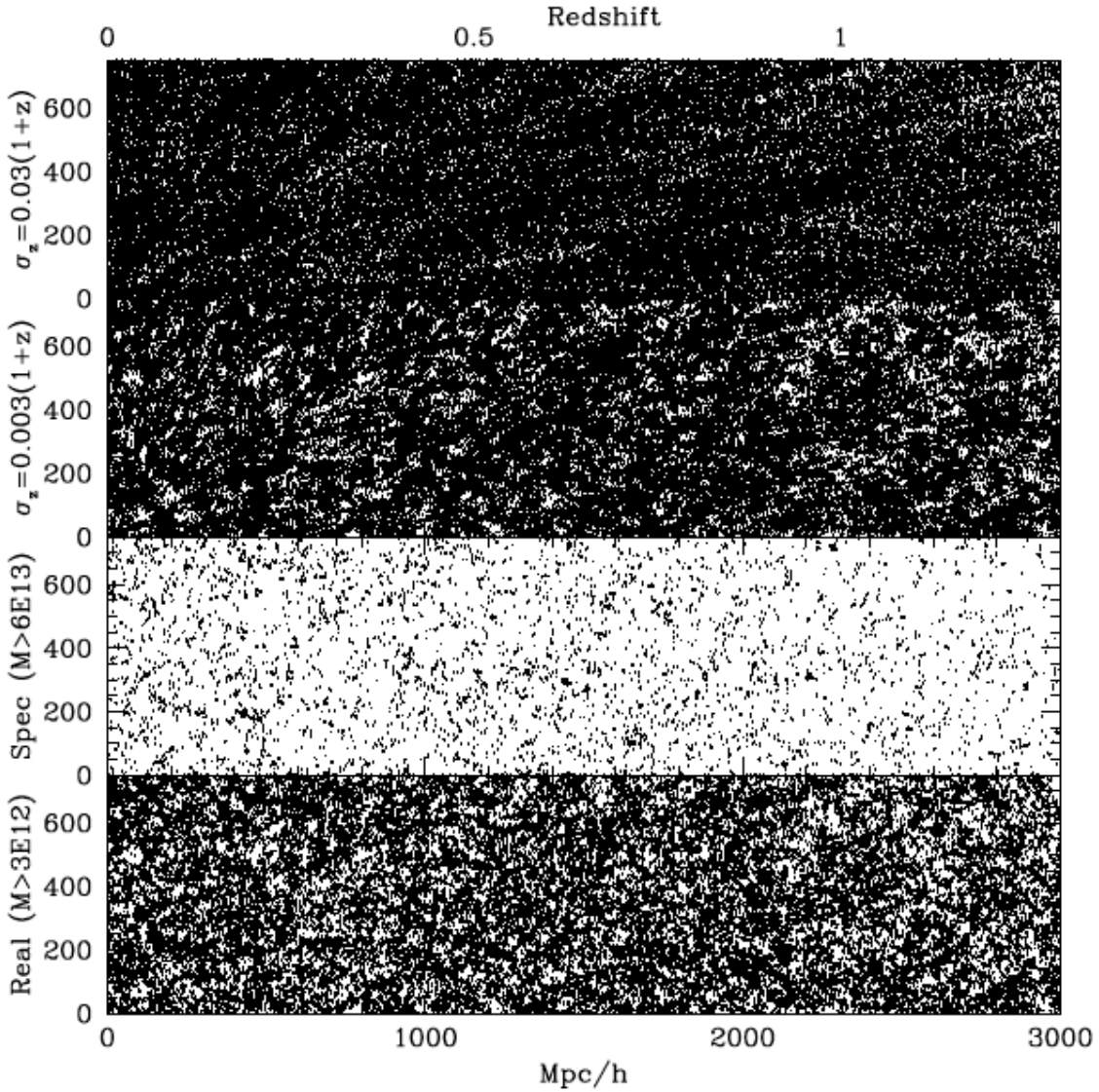
Recent Activity

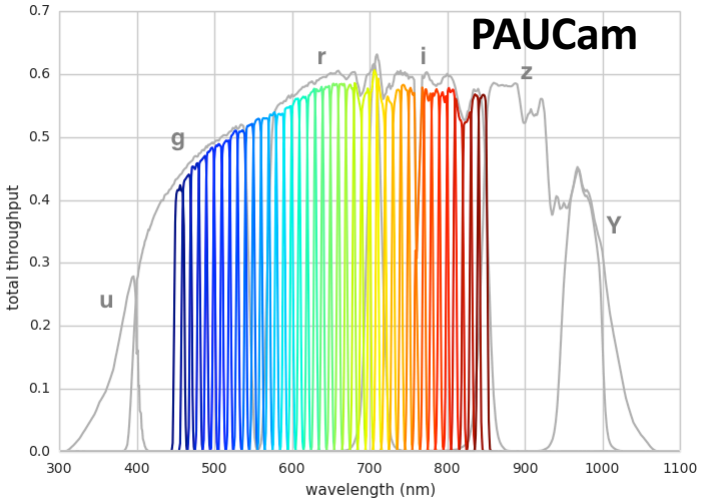
- **Cosmology using Low-Resolution Spectroscopy**
  https://kicp-workshops.uchicago.edu/LowResCosmology2020/overview.php
  (35 participants)
- **SSSI**
  https://indico.hep.anl.gov/indico/conferenceDisplay.py?ovw=True&confId=1035
  (40 participants)
- **Future Cosmic Surveys**
  https://kicpworkshops.uchicago.edu/FutureSurveys/index.php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

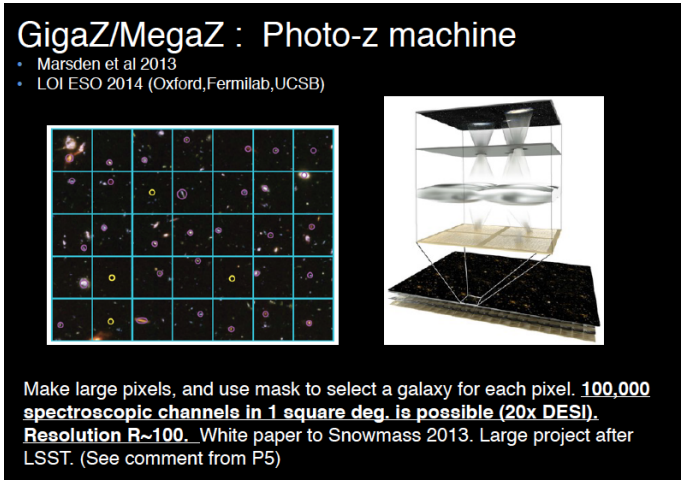
DESI-2

- **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



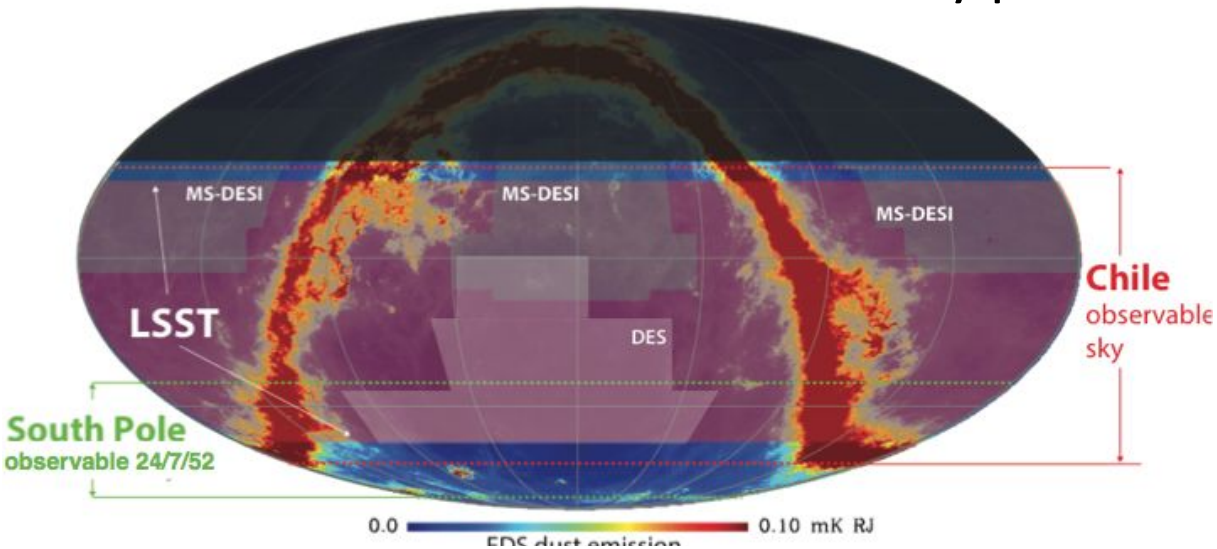




MKIDS (energy sensitive)
R ~ 100 achievable?

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

Possible Road Map for Spectroscopy

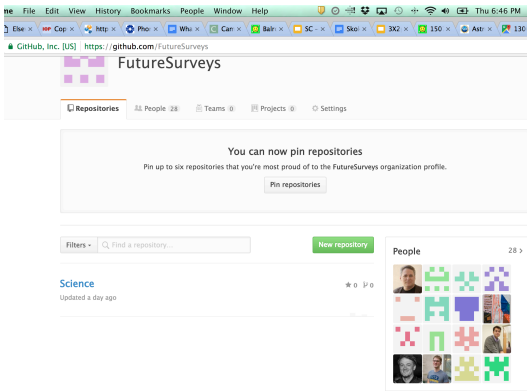
- The proposed spectroscopic surveys build on each other directly
- DESI-2 would be relatively low in cost and could follow DESI immediately in 2024
  - Spectrograph upgrades to add IR arm would enhance capabilities at higher redshifts
  - Moving to Blanco is an option, increasing LSST overlap
- SSSI 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"

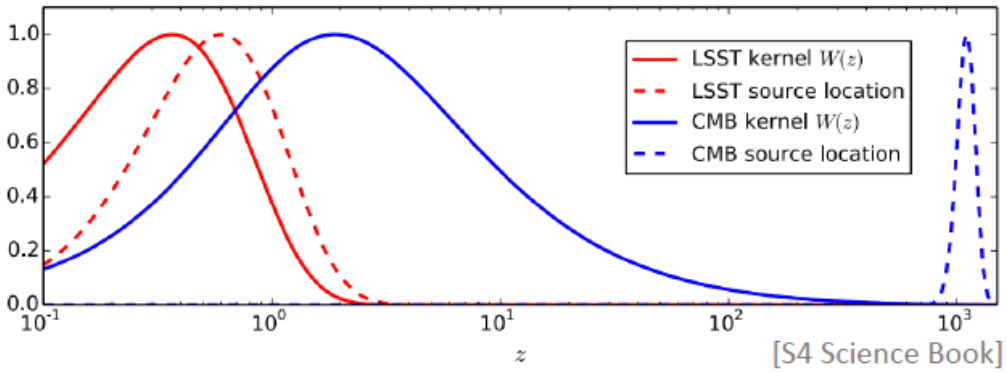
Our Next Steps

- Interest groups formed at the Cosmic Surveys Workshop
- Proceed together generating projections over the next 6 months-one year, with telecons once every 3 months
- CVDE Group provides coordination
  - git Organization for code sharing, prediction comparisons, writing, issues, …
  - Follow-up workshop in one year with the goal of starting the Science Book by then
- Toward Snowmass 202x, P5 and the next Decadal Survey



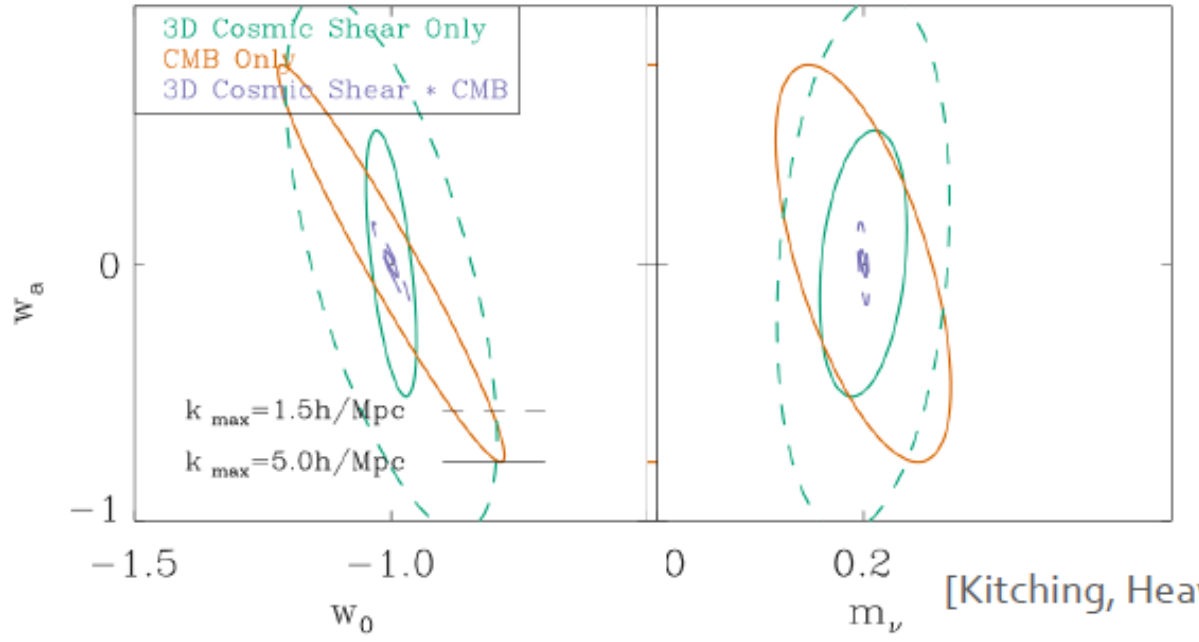
Backup

Overlap with CMB: Lensing



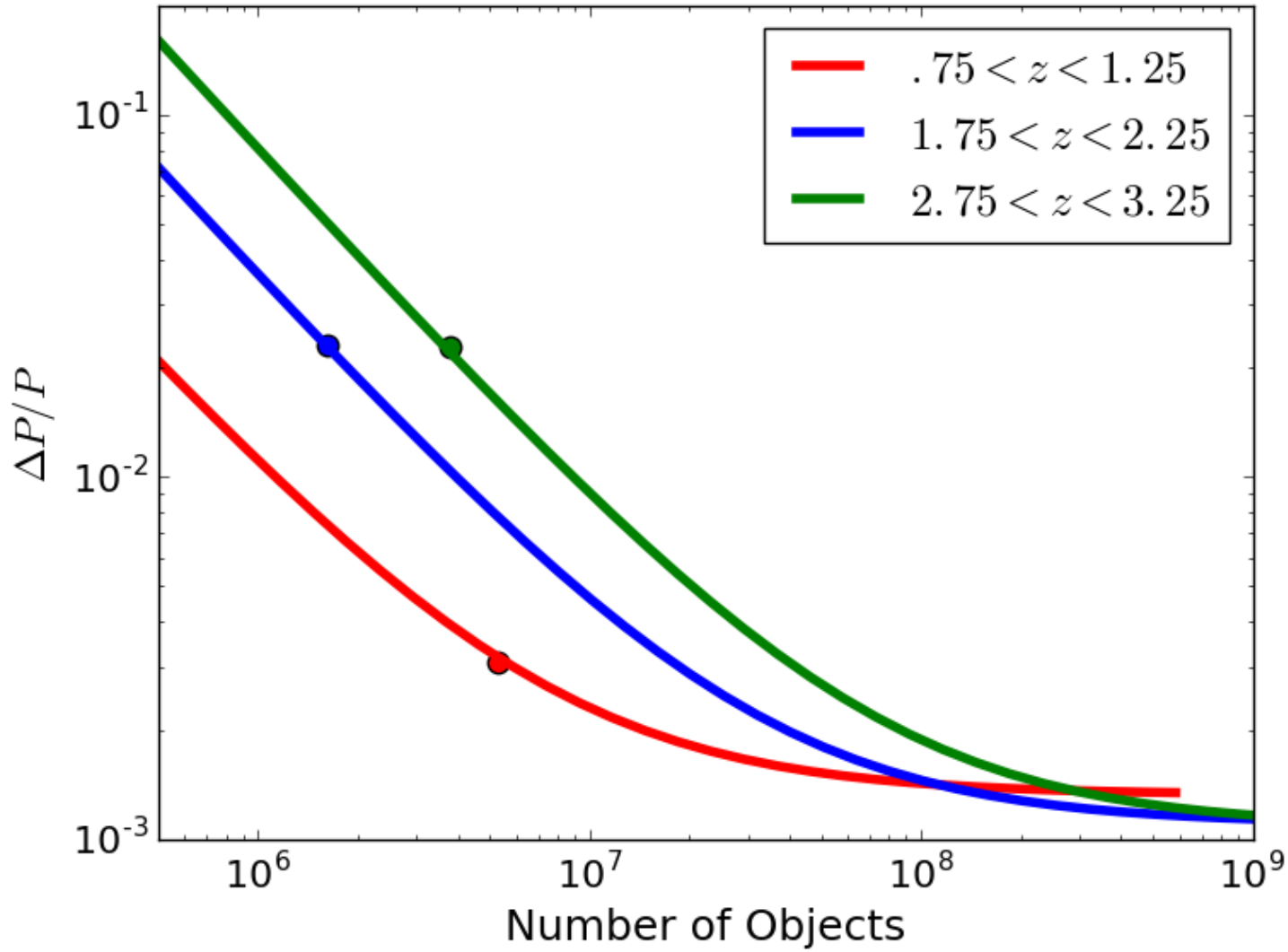
[S4 Science Book]

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