MegaMapper: Dark Energy and Inflation from spectroscopy at z > 2

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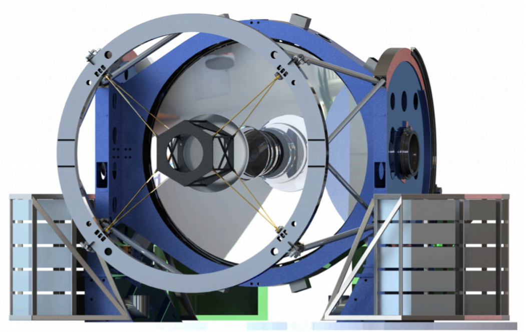


Snowmass CF4 call
September 9, 2020

Reference LOIs

Cosmology science case (Part I):

- Inflation and Dark Energy with the MegaMapper: probing fundamental physics with z >2 spectroscopy [contact: Simone Ferraro] link
- Large-Scale Structure at high redshift: a probe of fundamental physics [contact: Martin White and Simone Ferraro] link

Instrument + telescope (Part II):

- MegaMapper: a Massively-Multiplexed Spectroscopic Instrument for Cosmology [contact: David Schlegel] link

Also:

- MegaMapping Dark Matter [contact: Josh Simon] link
- A number of Astro2020 white papers [in particular link and link]

Part I
Science Drivers for z > 2 spectroscopy

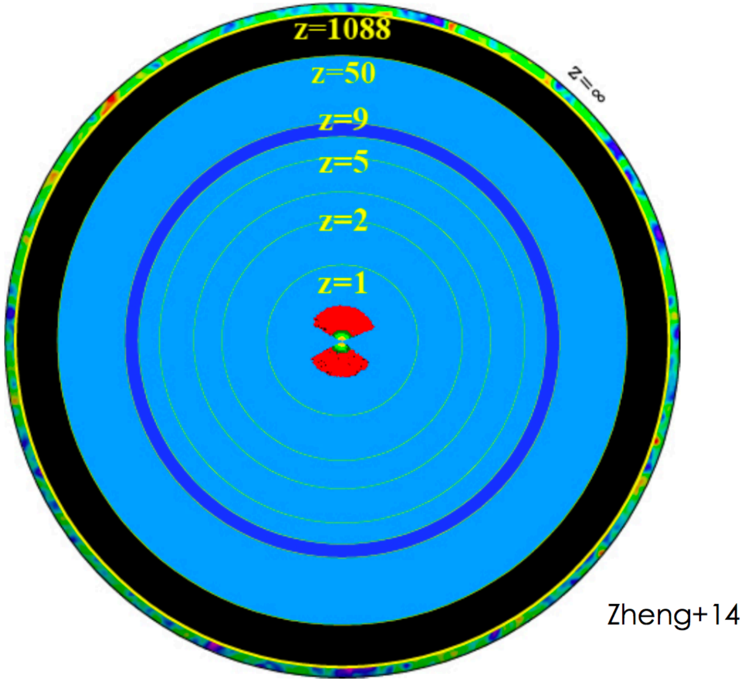
Beyond 6-parameters LCDM

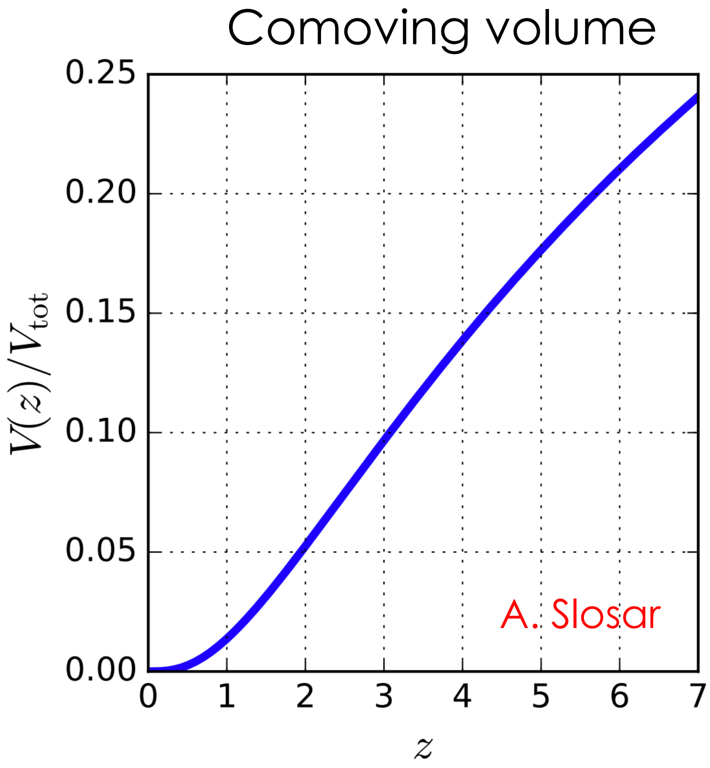
- "Minimal" 6-parameter LCDM is determined to ~percent level. Can (and will) improve a bit, but shouldn't be the primary goal in the 2030s.

- Dark Energy FOM (area of ellipse in the w_0-w_a plane) has been useful for upcoming experiments, but doesn't capture the complexity of general D.E. models.

- Need new ways to compare experiment concepts and judge the improvement over current. Since we lack firm guidance from fundamental physics, optimization of model-independent quantities becomes important (minimize the "noise"!) – See Martin White's talk.

We have observed a very small fraction of the available volume

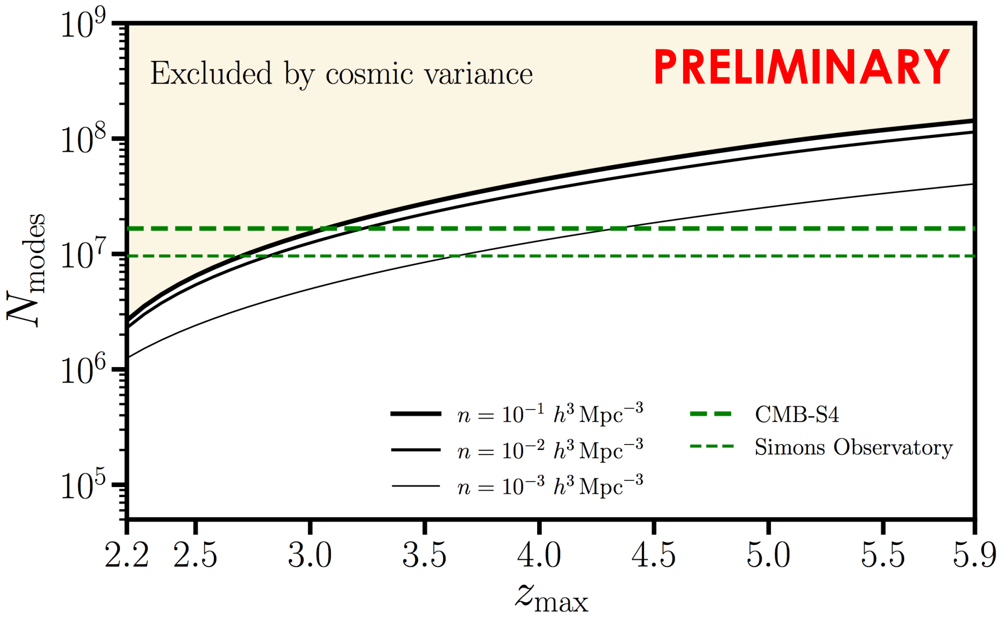




Can <u>quadruple</u> the available volume by observing to z ~ 5.5

Primordial physics: is 3D better than 2D?

Primordial information ~ Number of modes correlated with the initial conditions

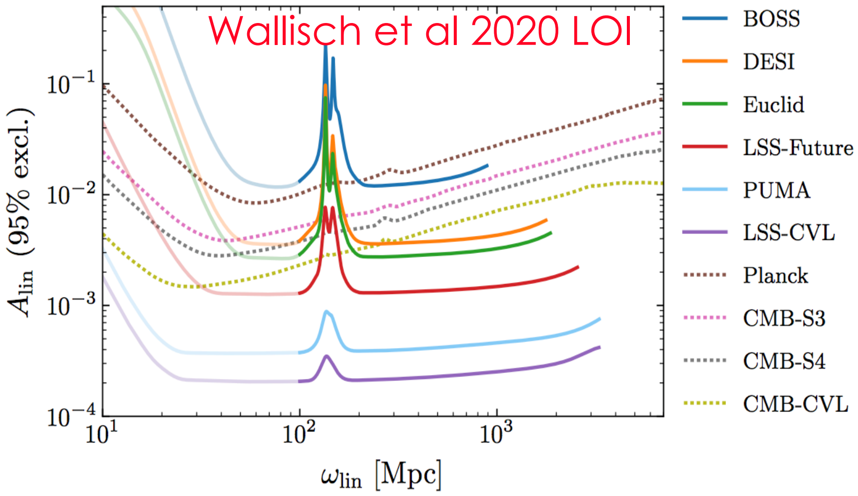


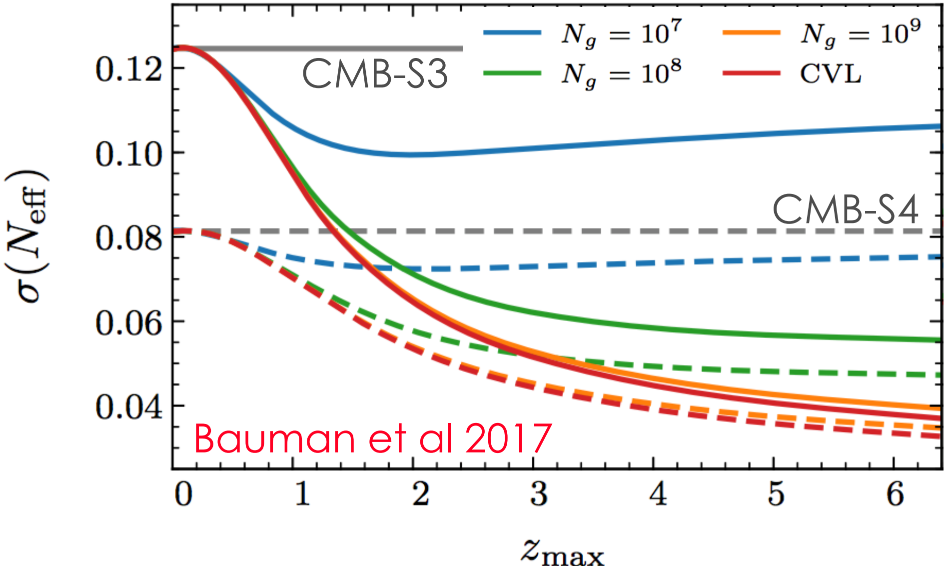
Noah Sailer

Define a "**Primordial Physics FoM**". Equal to N_{modes}? Weigh large scales more? Can further improve with better modeling.

Features in the primordial PS and extra relativistic species

Features or oscillations are a common prediction beyond simplest single-field slow-roll inflation → insight into the highest energies





Search for new light degrees of freedom → N_{eff}

Broad discovery space for new physics in the dark sector!

Primordial non-Gaussianity

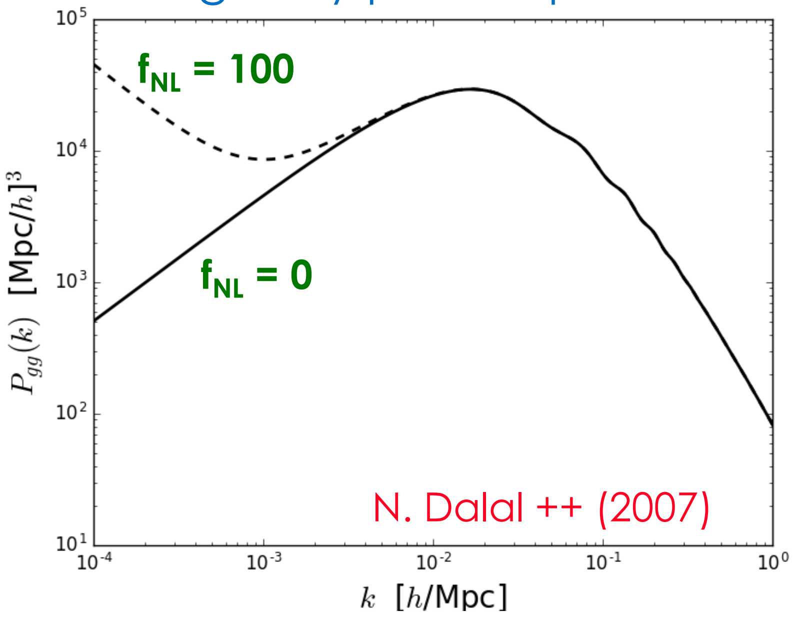
Simplest single-field inflationary models → Gaussian initial conditions
New physics (interactions etc)→ Deviations from Gaussianity

Broadly classified into "shapes":

- Equilateral and Orthogonal probe inflaton self-interaction.
- Local: Interaction with other "light" particles or field during inflation.
- "Threshold" on local $\sigma(f_{NL}) \sim 1$, not reachable with CMB.

- Local leave a characteristic large-scale imprint ($\sim 1/k^2$) on the galaxy bias.
- Equilateral and Orthogonal require measuring the 3-pt function.

Local NG and the galaxy power spectrum



Dark Energy

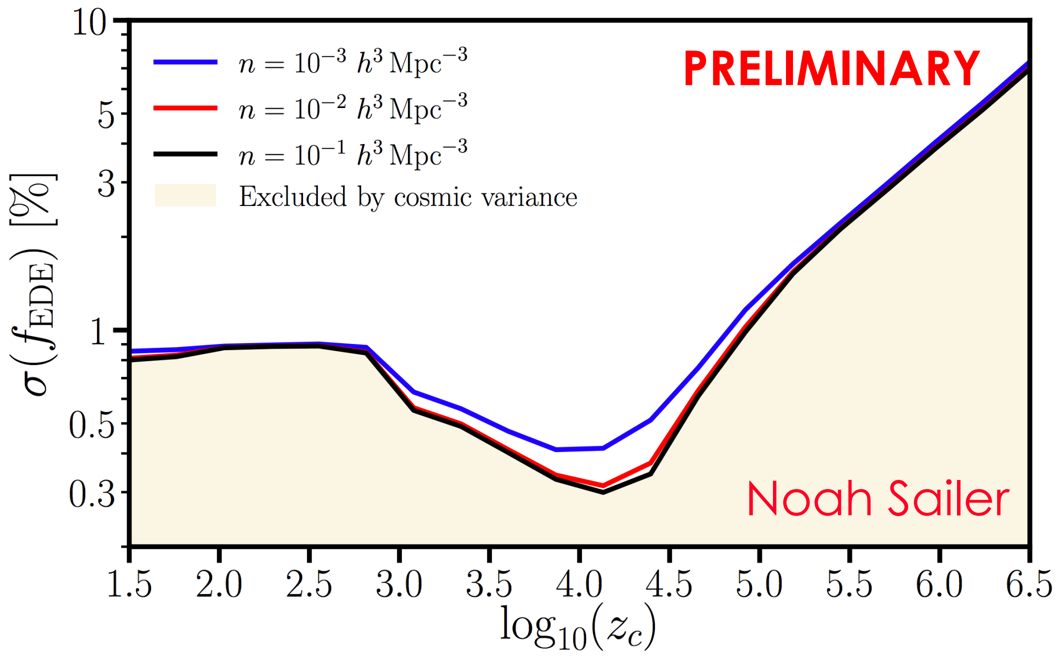
High-z surveys will probe Dark Energy in 3 ways:

1) Direct measurement of DE over the observed redshift range. Broad classes of dynamical DE exhibit "tracking behaviour" with respect to the dominant energy density at a given redshift → *measure DE all the way deep into matter domination*.

2) Degeneracy breaking: parameter sensitivity varies with redshift, breaking degeneracies internally. E.g. dynamical DE vs neutrinos.

3) Indirect measurement of Early DE (EDE): through measurement of the shape of the matter PS (with much reduced cosmic variance) can constrain the fraction of EDE to be below 1% all the way to $z \sim 10^5$ → *precision DE probe throughout most of cosmic history*.

(Early) Dark Energy to z ~ 10^5



Detailed shape of the matter PS → **percent level measurement of expansion history to z ~ 10^5** → tight bounds on EDE and other non-standard components.

The way forward

- Need to refine the "broader" science case and explore different tradeoffs. Include modifications to General Relativity and potential of cross-correlations.

- Often very different forecasted values are due to different forecasting assumptions, rather than experiment capabilities.

- Release a public and documented forecasting code which can provide a comparison between experiments using the same assumptions

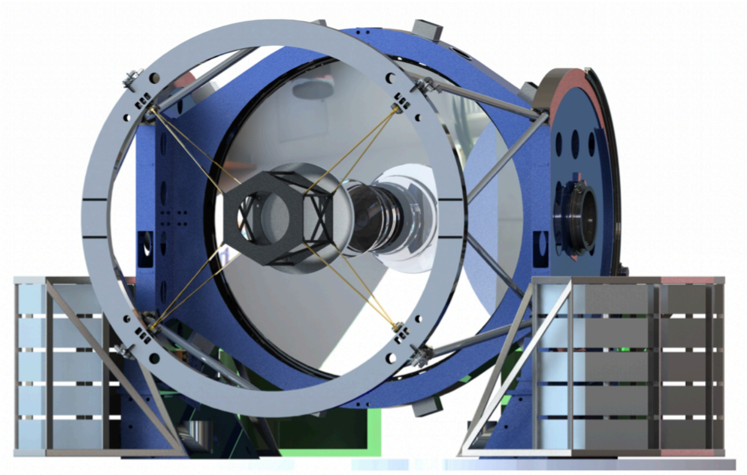
- Compare different probes, such as spectroscopic galaxies, 21cm, other IM.

Part II
MegaMapper: a Massively-Multiplexed Spectroscopic Instrument for Cosmology

WARNING: all the numbers are preliminary and work in progress!

MegaMapper:

Designed to explore the exciting science just discussed, using existing, proven, and cost-effective technologies, reducing the risk and cost of the project

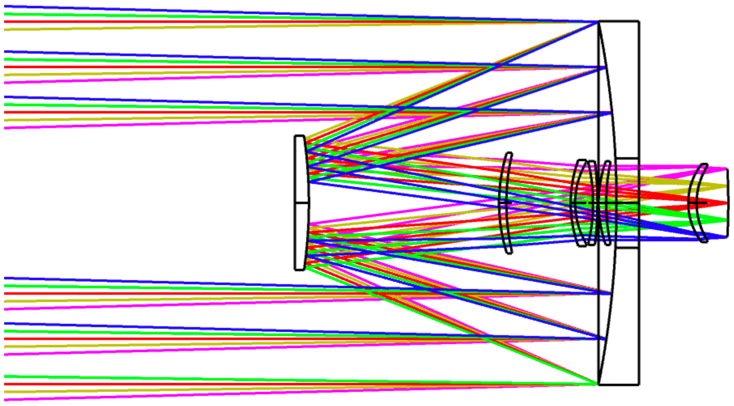


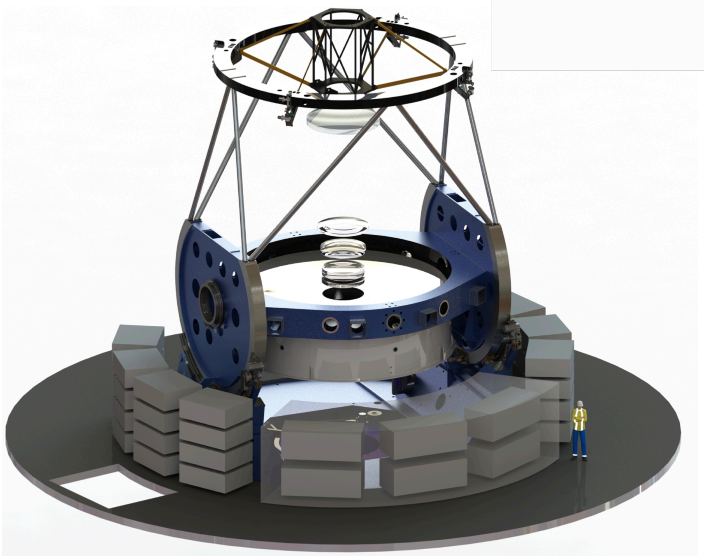
- Magellan-type telescope
- 6.5m primary mirror
- Wide FOV (~7 sq deg)
- Las Campanas Observatory in Chile
- Excellent overlap with Rubin Observatory/LSST for imaging.

Schlegel, Kollmeier et al (2019)

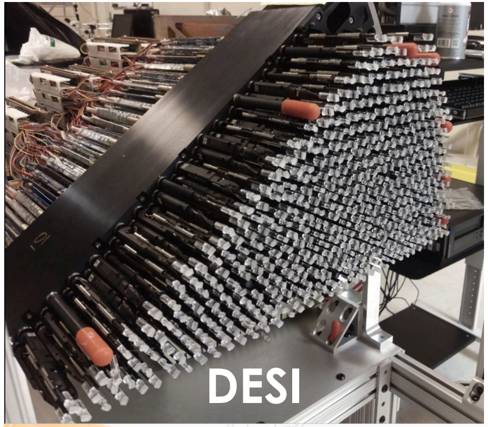
The telescope

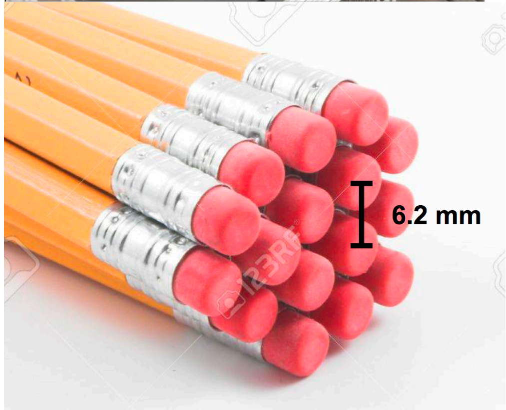
- New optical designs from Steve Shectman (Carnegie Observatories)
- 6.5-m primary mirror, identical to Magellan 1&2 telescopes, except for a larger (~1.2 m) hole in the mirror.
- 2.5 m secondary mirror + 5-lens corrector including ADC
- Same f/3.6 as DESI → can use the same fibers and instrument





Focal plane

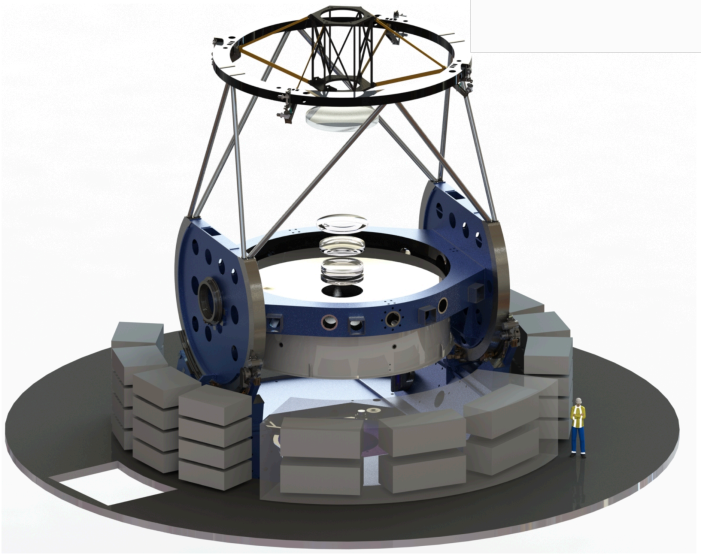


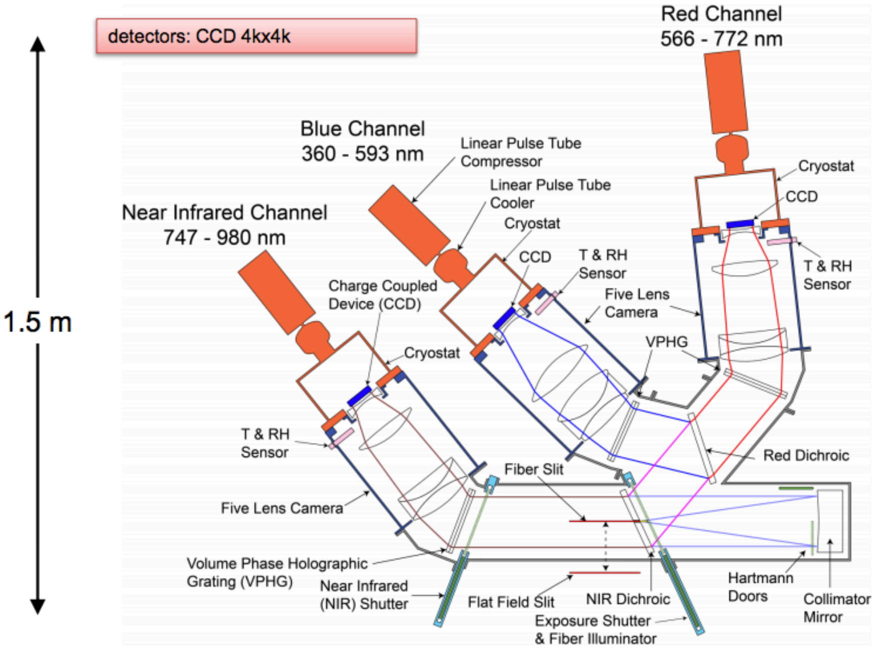


- 1.2 m diameter focal plane with 20,000 fibers with robotic positioners.
- 32 petals, each feeding 625 fibers to a single spectrograph.
- Close-packing at 6.2 mm pitch
- Compare to DESI with 5,000 robots at 10.4 mm pitch.
- Robot R&D underway with DESI partners Berkeley Lab, University of Michigan, EPFL

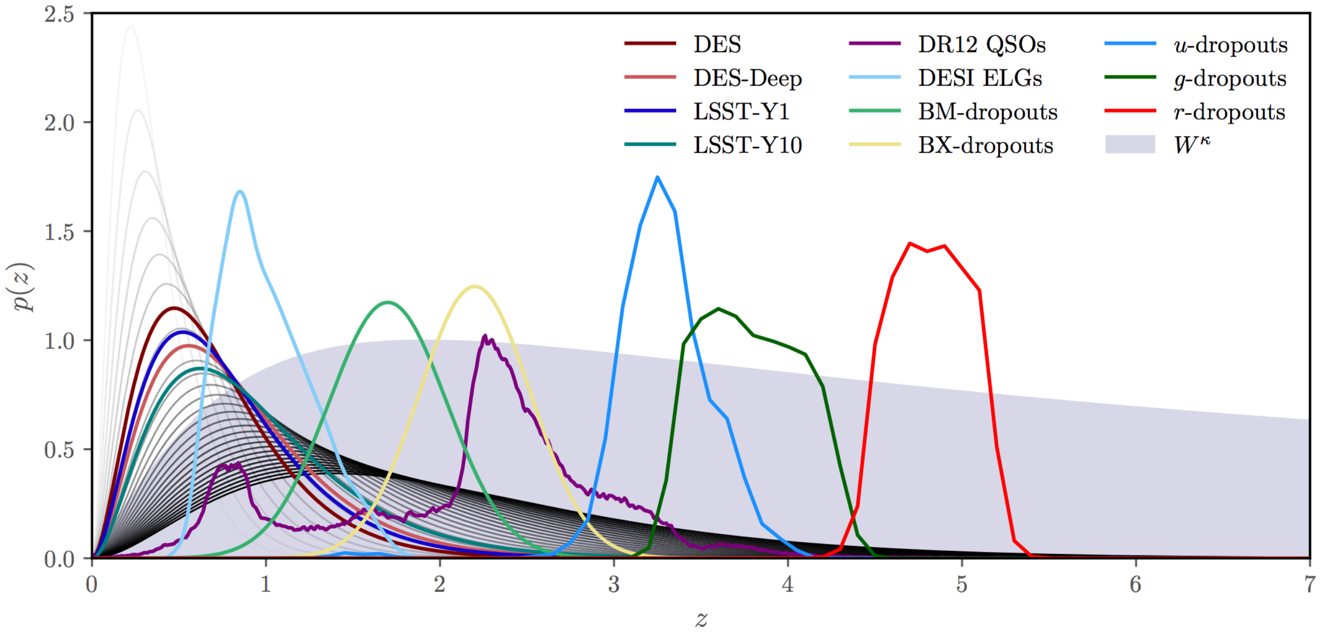
The spectrographs

- 32 DESI-like spectrographs. Range 360 – 980nm, R = 2000 (blue) – 5500 (NIR)
- Option to re-use 10 DESI spectrographs + 6 identical SDSS-V spectrographs
- Spectrographs located near focal plane (less light loss)





Galaxies at high redshift from LSST

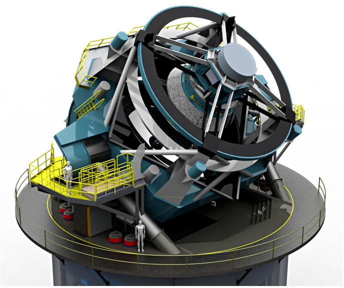


Cosmology with dropout selection: Straw-man surveys & CMB lensing

M. J. Wilson[a,b] and Martin White[a,b,c]

M. J. Wilson & M. White (2019)

Number densities from VRO/LSST imaging



target sample: Dropout selected galaxies from VRO LSST (m_{UV} = 24.5) [“idealized” sample]

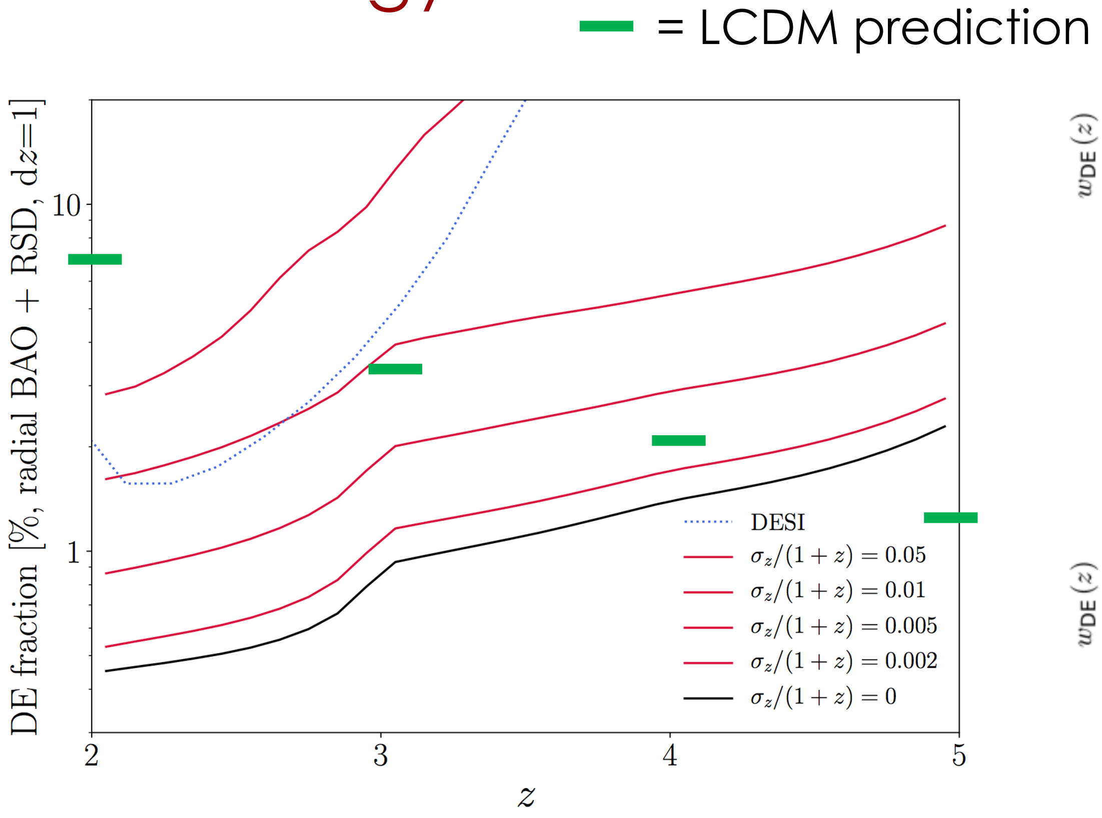
Estimate redshift success with DESI-like spectrograph on a 6.5m telescope [”**fiducial” sample**]:

z	$n(z)$ $[10^{-4}\,h^3\,\mathrm{Mpc}^{-3}]$	$b(z)$		z	$n(z)$ $[10^{-4}\,h^3\,\mathrm{Mpc}^{-3}]$	$b(z)$
2.0	9.8	2.5		4.0	1.0	3.5
3.0	1.2	4.0		5.0	0.4	5.5

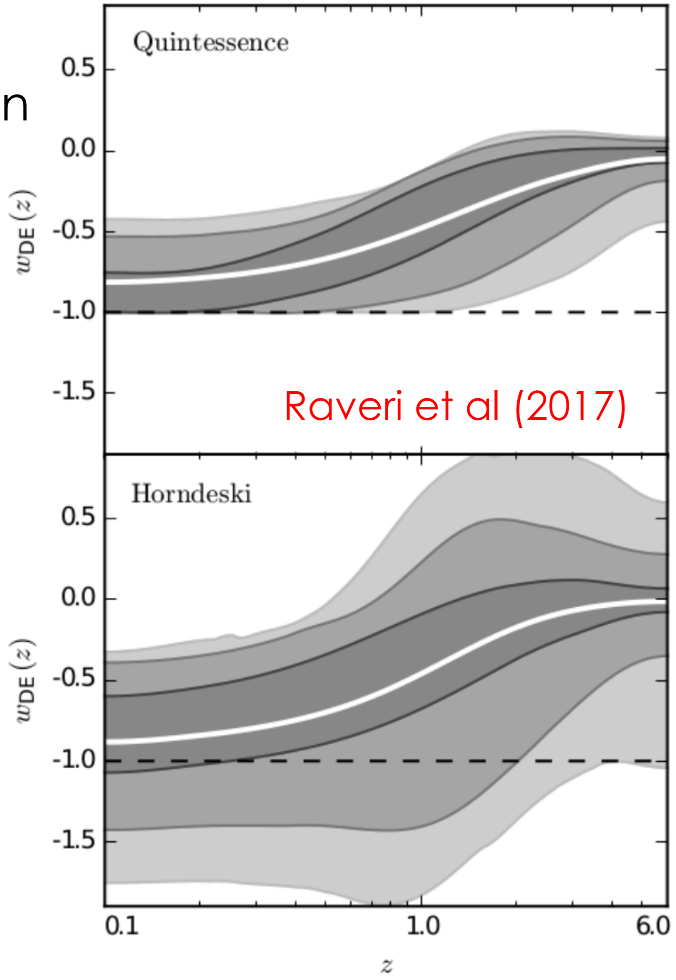
About ~40M galaxies out of ~ 100M targets. Close to “sweet-spot” for BAO of n ~ 10^{-4} $[h/\mathrm{Mpc}]^3$.

S.F., M. J. Wilson et al (2019)
M. J. Wilson & M. White (2019)

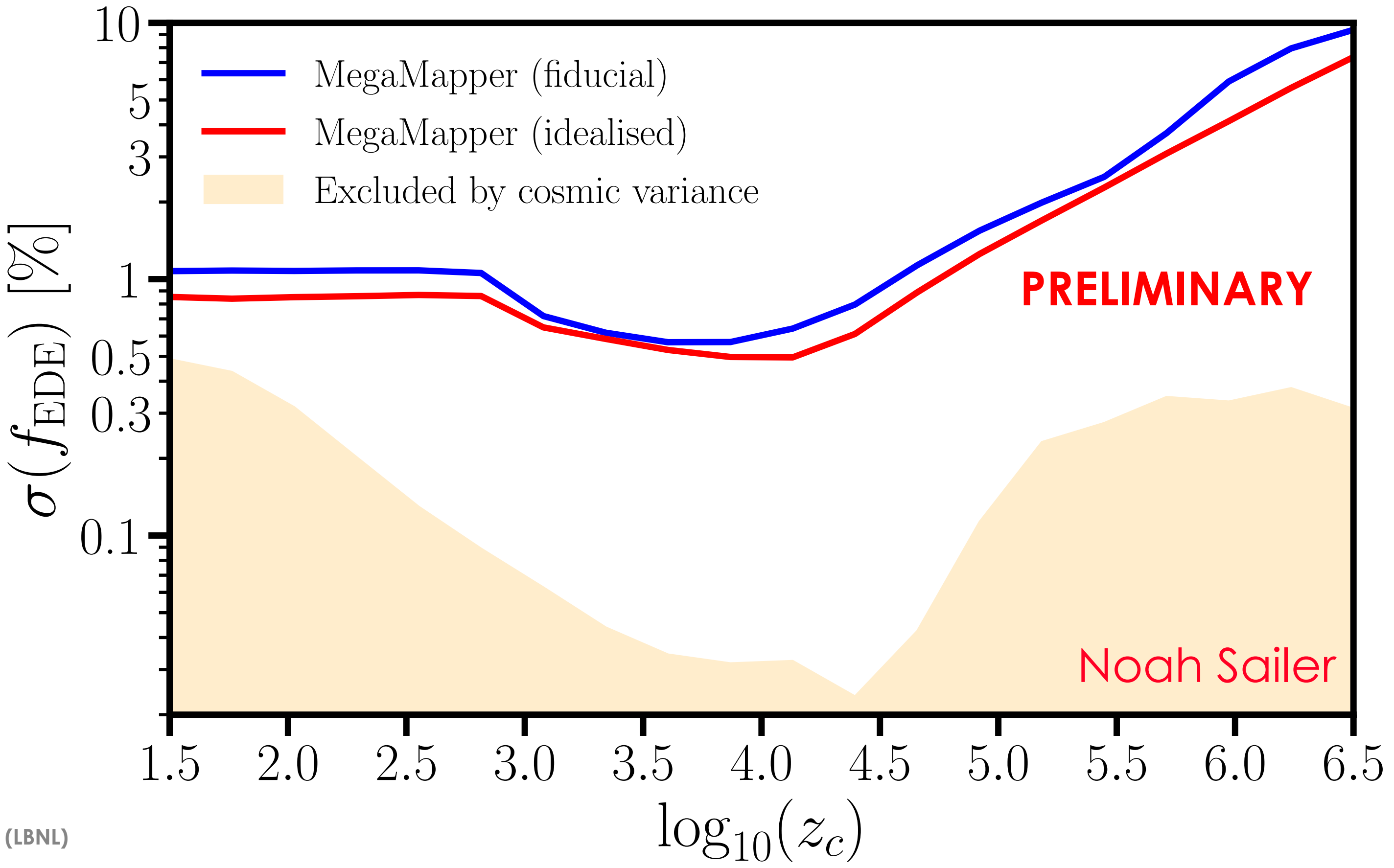
Dark Energy



S.F., Mike Wilson et al (2019). Plot by Pat McDonald



Early Dark Energy: MegaMapper



Primordial non-Gaussianity

local $\sigma(f_{NL}) \propto V^{-2/3}$ from the power spectrum

$\sigma(f_{NL})$ Fiducial / Idealised	P	$+B$	+ External	Current (Planck)	Photo-z degradation
Local	0.75 / 0.63	0.11 / 0.073	0.11 / 0.073	5	$\times 3$
Equilateral	–	43 / 23	23 / 18	43	$\times 4$
Orthogonal	50 / 33	8.8 / 5.0	7.5 / 4.7	21	$\times 3$

Large-scale systematics are challenging (esp. for local), and cross-correlations can help.
Better theoretical modeling can help equilateral and orthogonal.

S.F., Mike Wilson et al (2019)

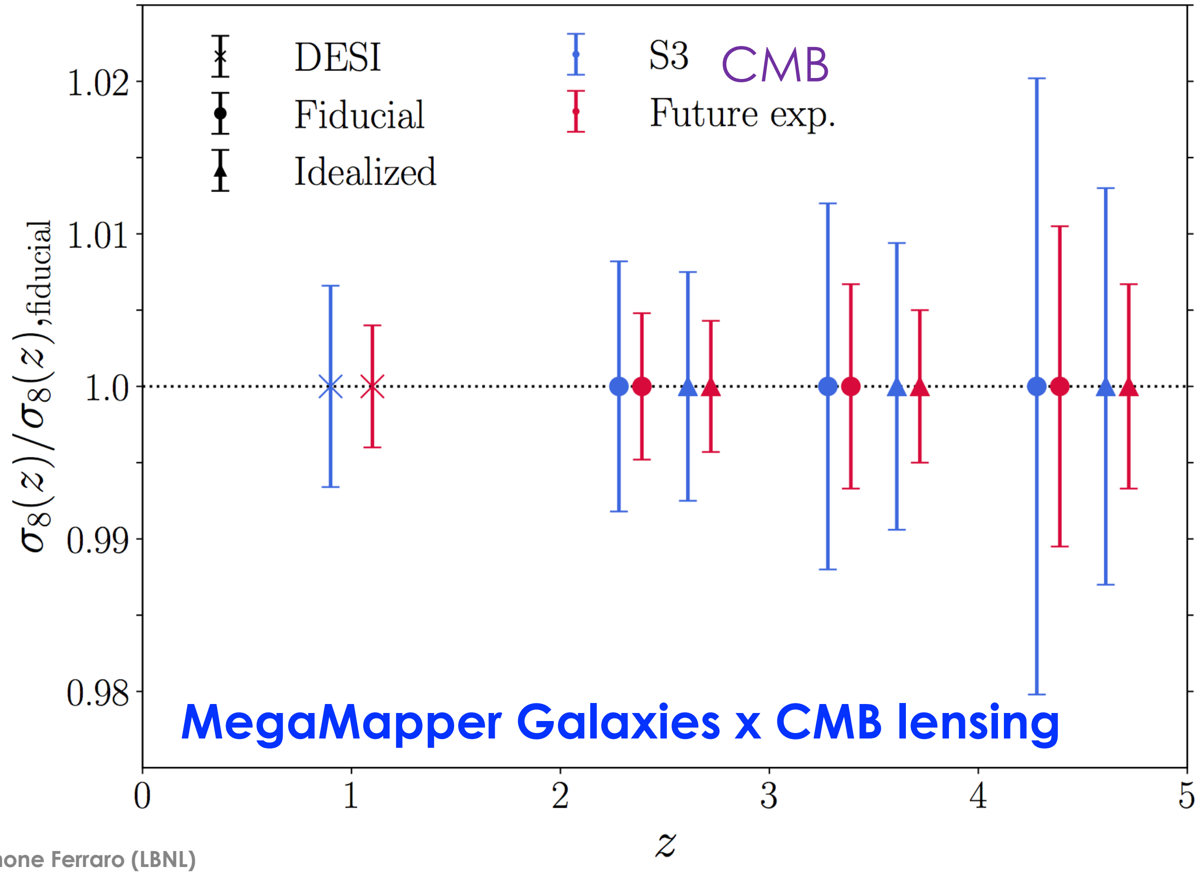
Cosmological parameters

Parameter	σ(parameter) Fid./Ideal.	DESI
Curvature $\Omega_K/10^{-4}$	6.6 / 5.2	12.0
Neutrinos $\sum m_\nu$	0.028 / 0.026	0.032
Spectral index n_s	0.0026 / 0.0026	0.0029
Running α_s	0.003 / 0.003	0.004
Rel. species N_{eff}	0.069 / 0.069	0.078
Gravitational slip	0.008 / 0.008	0.01
D.E. FoM	398 / 441	162

Can relax many restrictive assumptions about the model and initial power spectrum

S.F., Mike Wilson et al (2019)

Mapping the growth of structure



- ~1% constraint on amplitude up to z ~5
- Neutrino mass without CMB optical depth

S.F., Mike Wilson et al (2019)
B. Yu et al (2018)

Conclusions

- Broad portfolio of exciting science at $z > 2$.
- 3D is "better" than 2D, but need to go out to $z > 3$.
- Dropout galaxies from LSST at high-z provide a natural target sample.
- MegaMapper designed with existing technology for cost and risk reduction.
- Many additional science opportunities: MW kinematics for Dark Matter, galaxy formation and evolution, photo-z calibration, SNe follow up etc.
- Further improvements can come from improved theory and modeling. 21st century experiments require 21st century analysis tools to make the most out of them.

Thanks