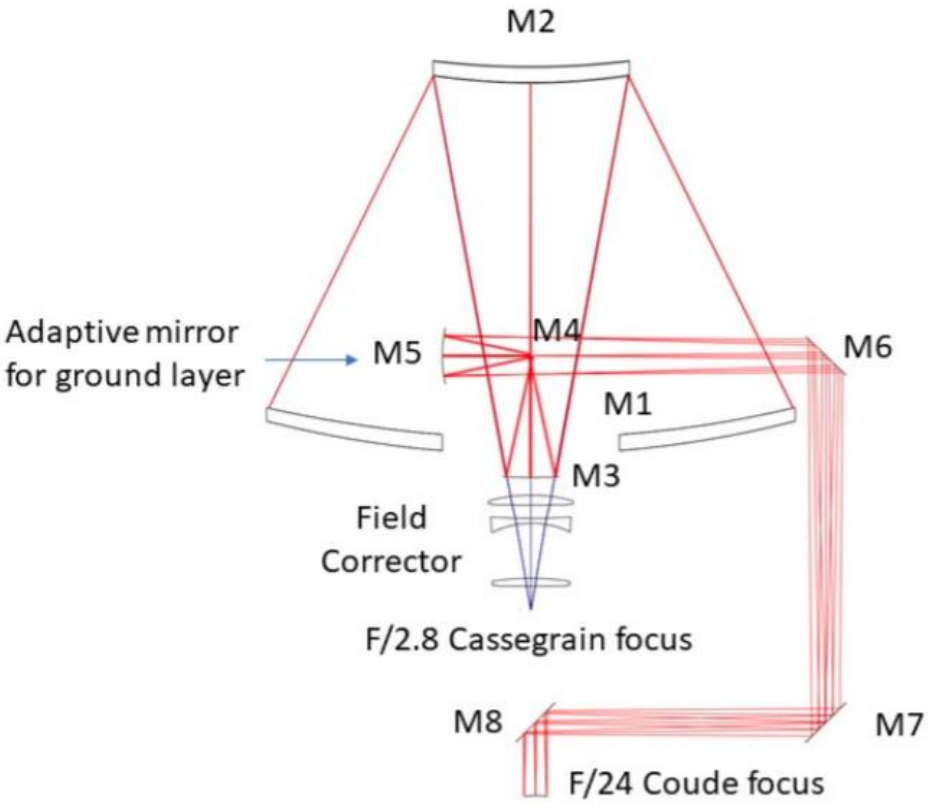
SpecTel: A 10-12 meter Telescope Optimized for Multiplexed Spectroscopy



Kyle Dawson (University of Utah)

Snowmass Workshop

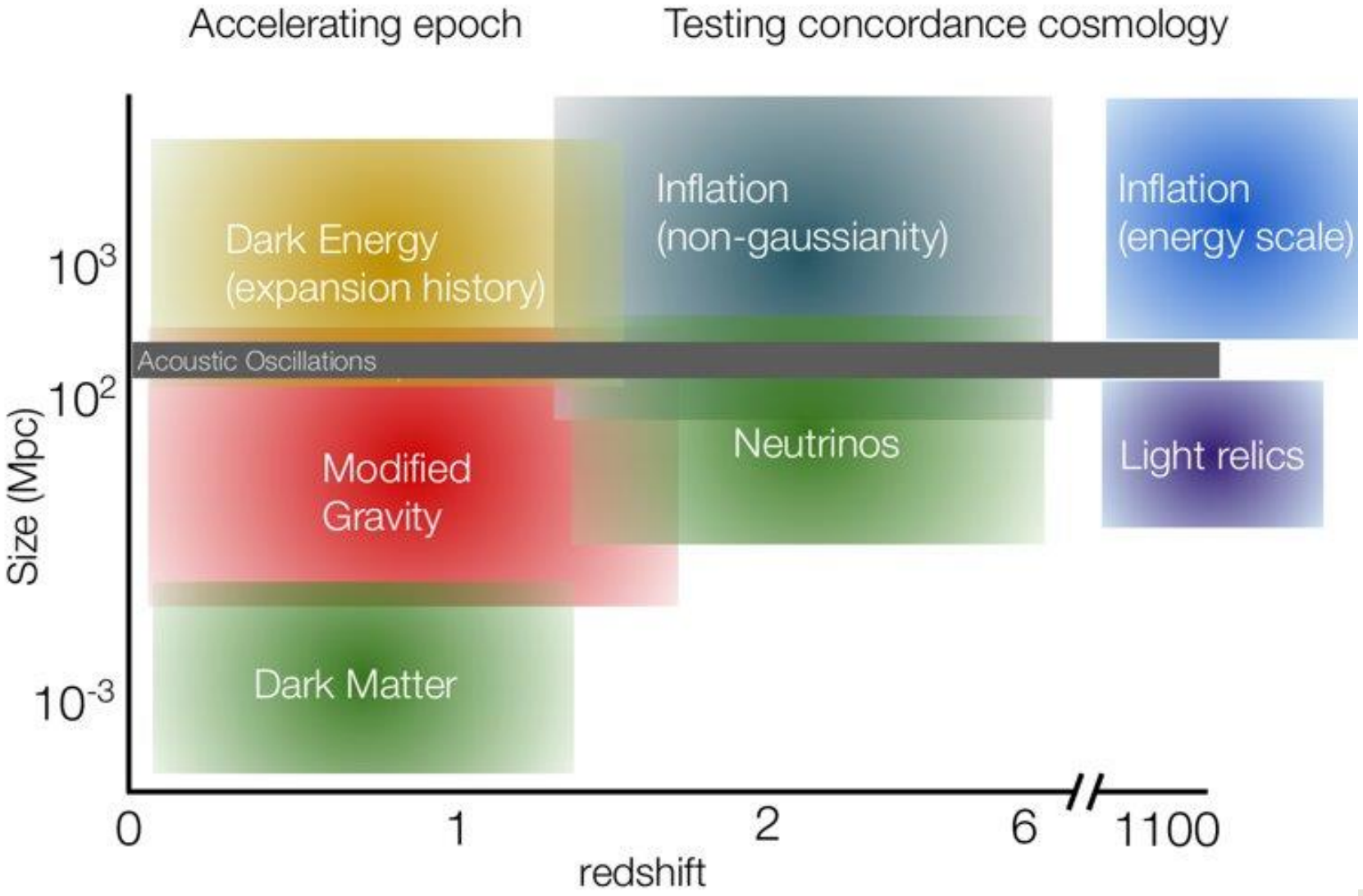
July 15, 2020

Overview

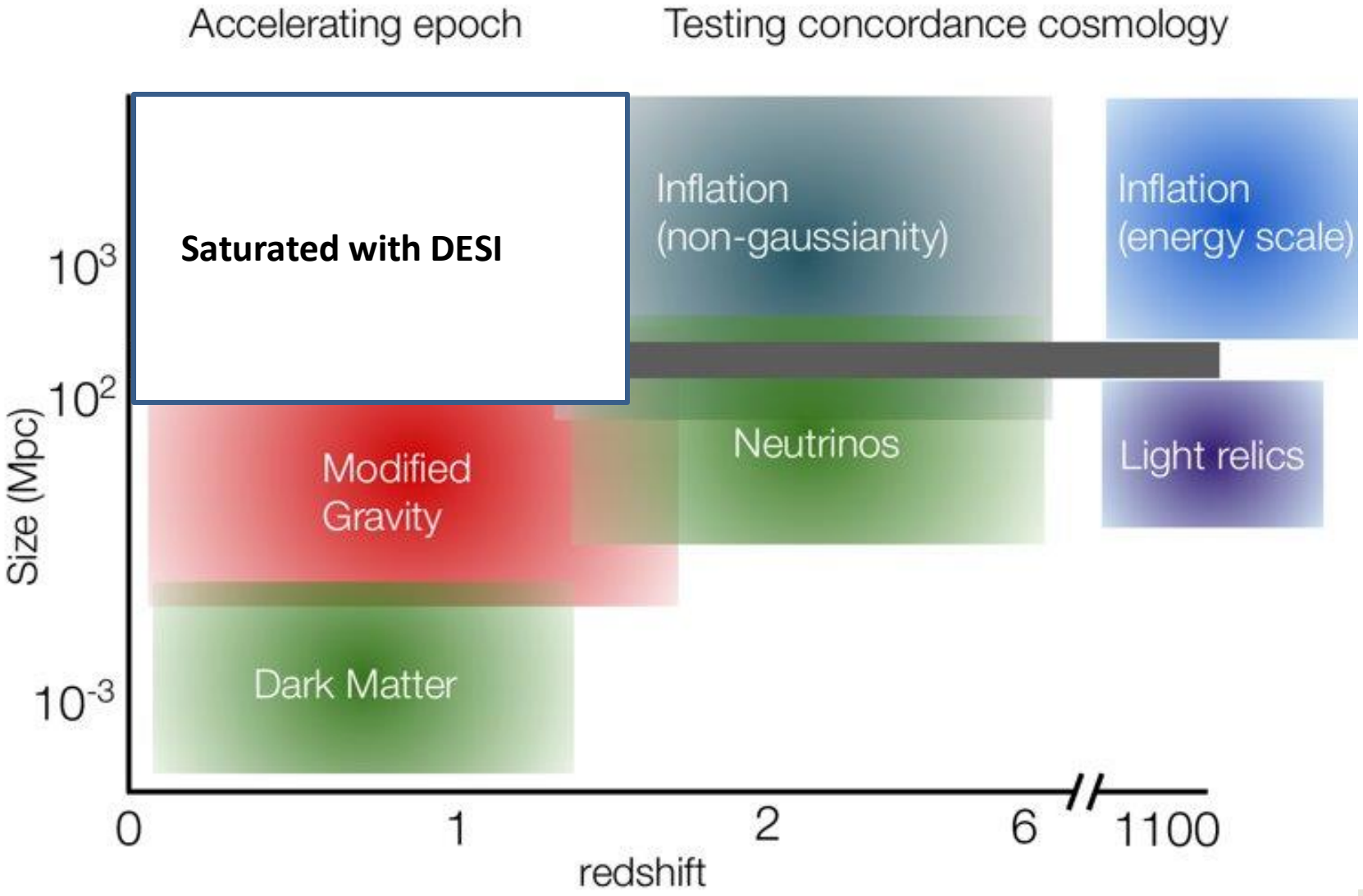
- **Questions for Stage-V Spectroscopy: seeding discussion for the next year**
  - Low redshift: growth into the non-linear regime
  - High redshift: non-Gaussianity, expansion history, growth

- **Scientific potential from the ESO SpecTel design**

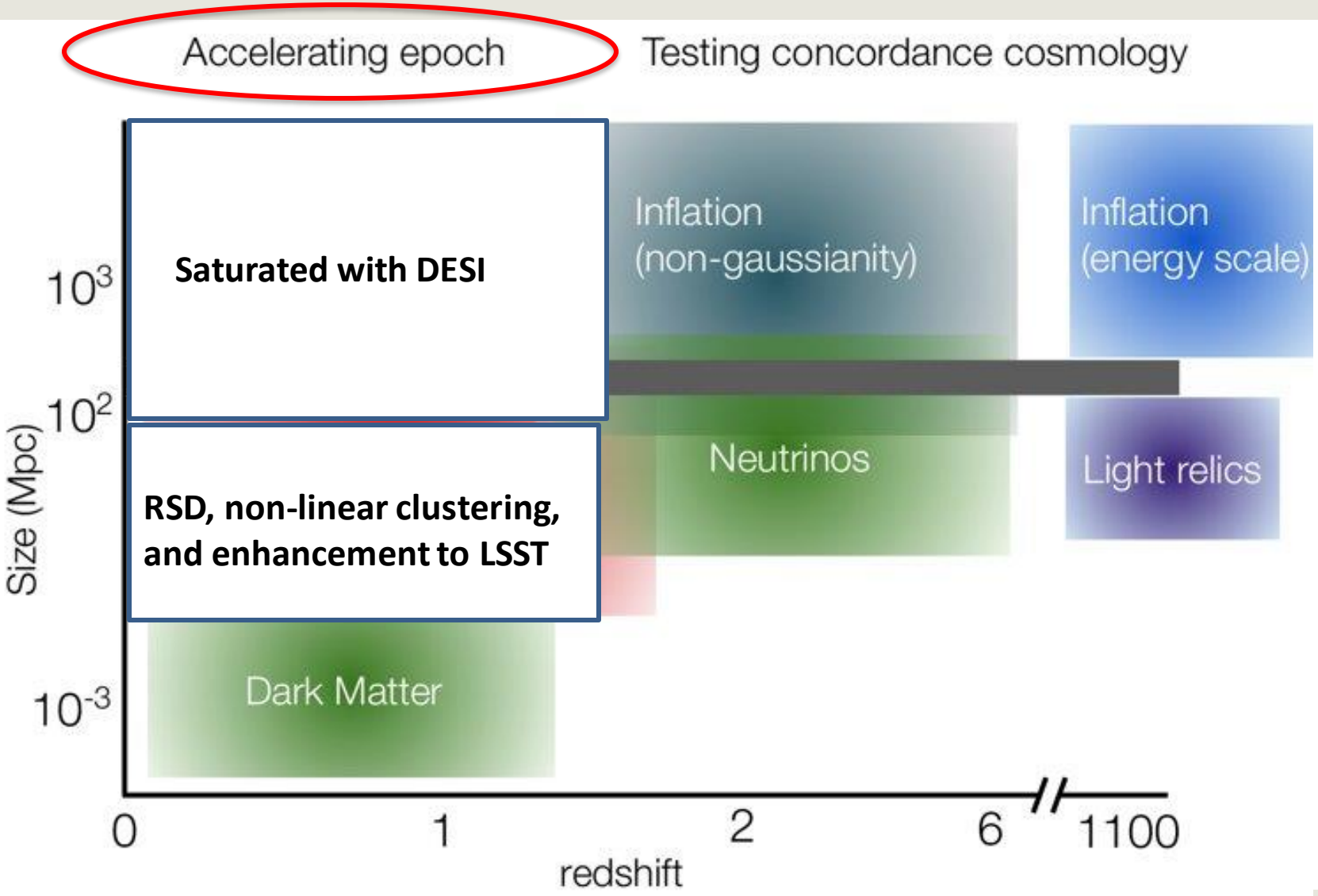
Discovery Space



Discovery Space After DESI



Dark Energy after DESI



Clustering at z<1.5: Upsides and Downsides

- Upsides
  - Numerous bright targets remain after DESI (20k per sqdeg at r<22.5)
  - Spans transition from matter-dominated to DE dominated: best opportunity to explore physics of dark energy and modified gravity
  - Highly-complete spectroscopic sample to complement LSST
  - New physics?

- Downsides
  - Low-hanging fruit already taken (DESI BAO and LSST WL)
  - Further advances require sophisticated modeling
  - Projections for dark energy models difficult (impossible?)

Clustering at z<1.5: Choices for Stage-V

- Do nothing
  - Stage-V program dedicated to high-z Universe
  - Dark energy program saturates with conclusion of LSST
- Subsample z<1.5 density field
  - Pencil beam survey to calibrate LSST?
  - Targeted observations (clusters, voids, filaments, etc.)
  - Photo-z calibration samples
  - **Would not require major facility**
- Independent dark energy program
  - Fully sample density field
  - Three-point statistics
  - Forward model density field
  - Redshift-resolved weak lensing using spectro-z's for lens galaxies
  - Complete samples of galaxy clusters
  - Non-linear clustering
  - **Requires significant dedicated facility**

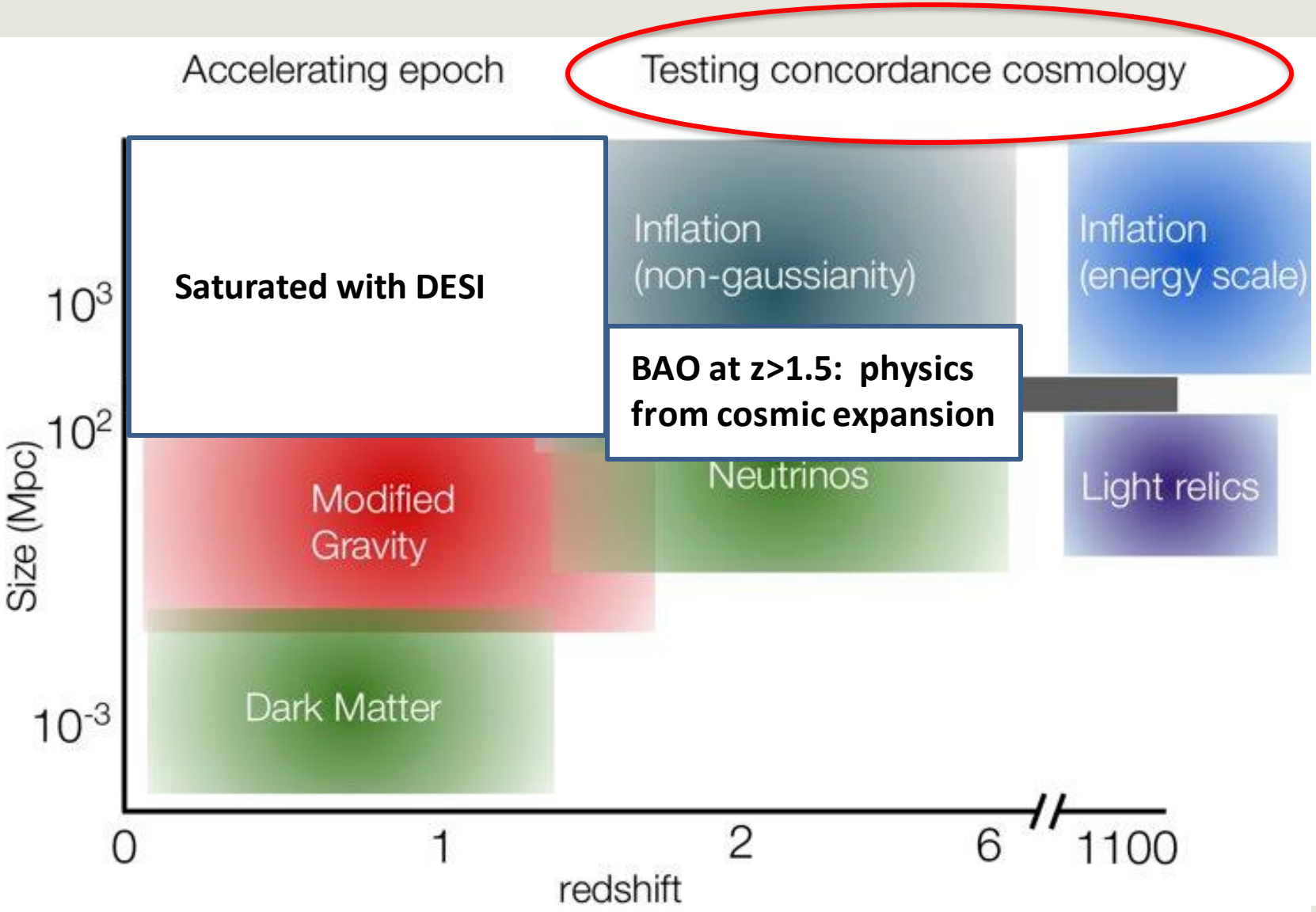
Summary of z<1.5 Spectroscopy

- Mixed target classes available
  - 20,000 per sqdeg at r<22.5
  - Color-selected samples possible for constant comoving densities
  - What number density is required for **compelling** Stage-V measurements?
  - What is target cosmology constraint?

- Ambitious facility requirements
  - 1000-s on DESI for z<1.5 galaxy samples
  - 10-12-meter telescope to observe one magnitude deeper at fixed exposure time
  - DESI: ~2000 z<1.5 galaxies per square degree
  - 10-12M telescope requires 10X multiplex over DESI to 20,000 per sqdeg
  - Comparable duration to DESI (5 years) for 14,000 square degrees
  - 280M total redshifts

  - **10X DESI sample --> ~100X DESI survey power**

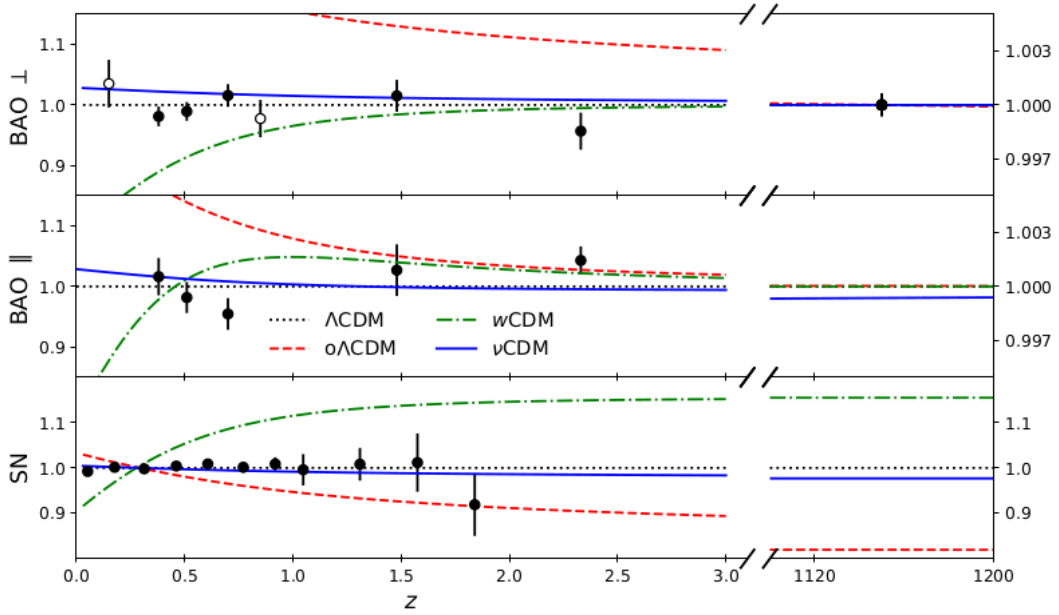
Discovery Space at High Redshift



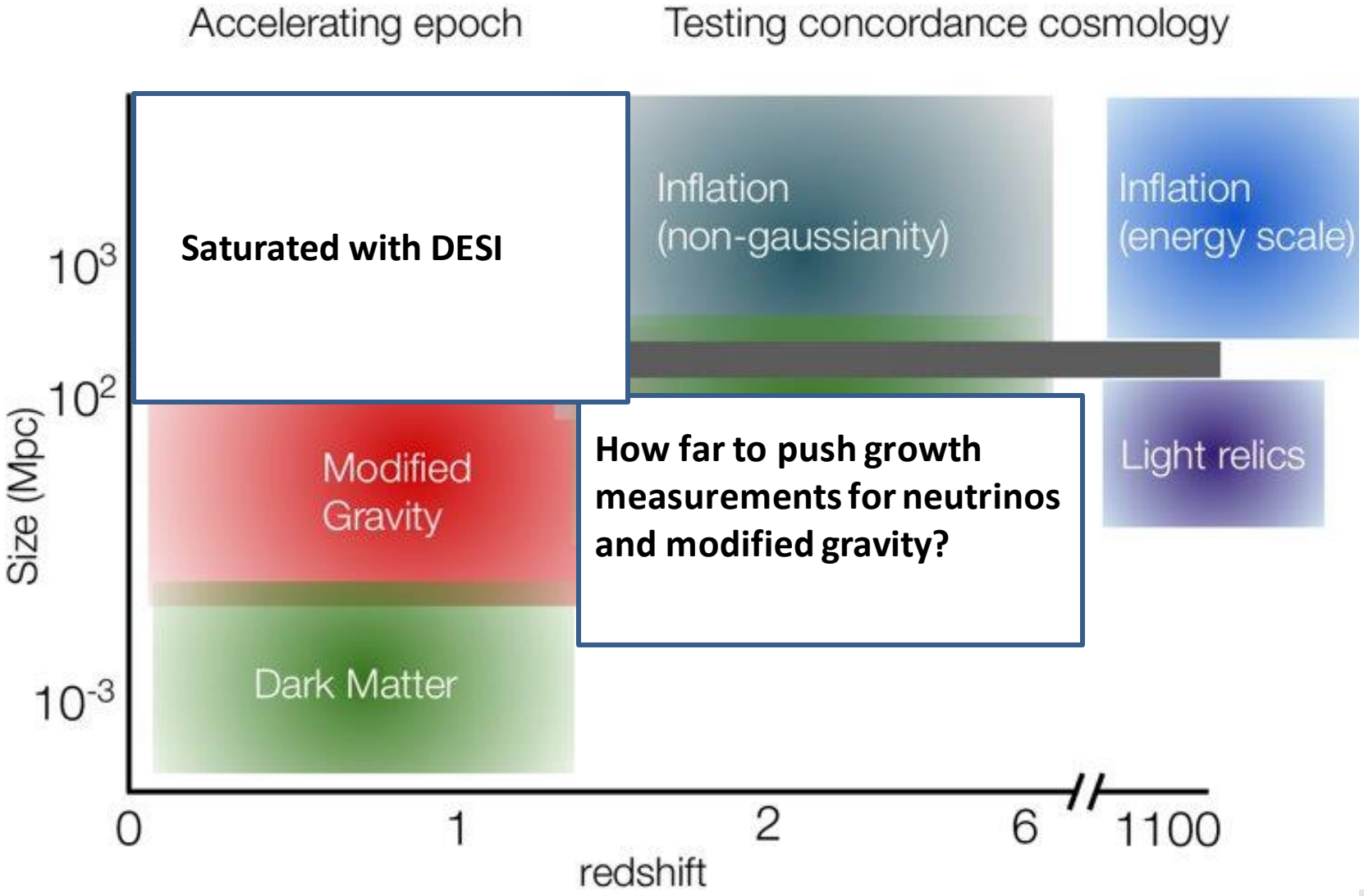
BAO at z>1.5: Upsides and Downsides

- Upsides
  - Obvious potential for massive improvement over current surveys
  - Signal intrinsically robust against spectroscopic completeness/purity

- Downsides
  - Expansion history in only matter-dominated era
  - Poor sensitivity to dynamics due to dark energy equation of state
  - Degeneracy breaking or niche dark energy, but sufficient motivation?



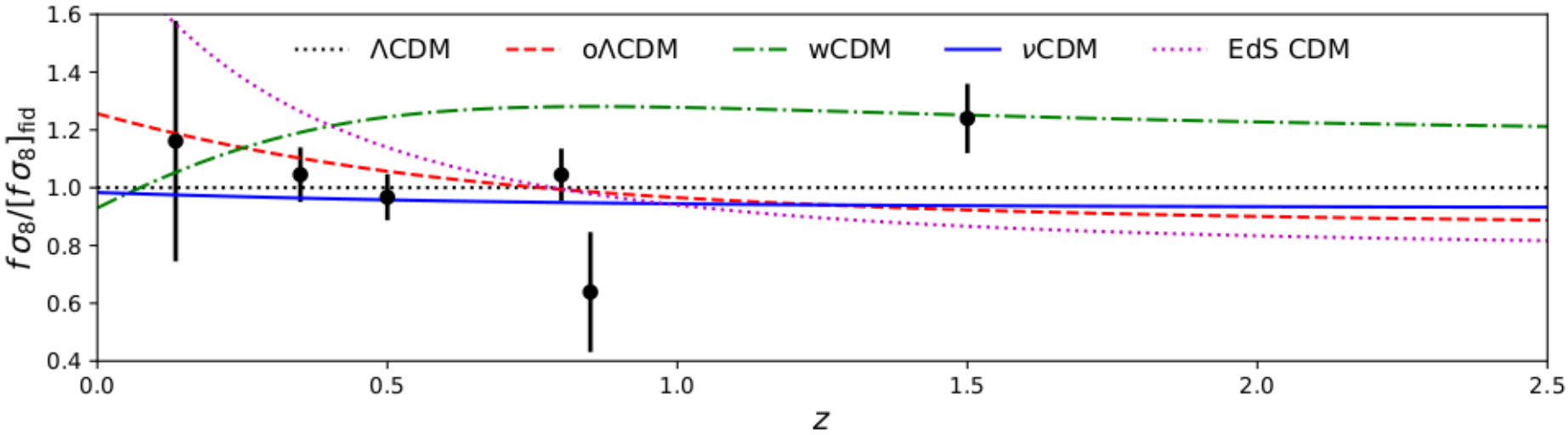
Discovery Space at High Redshift



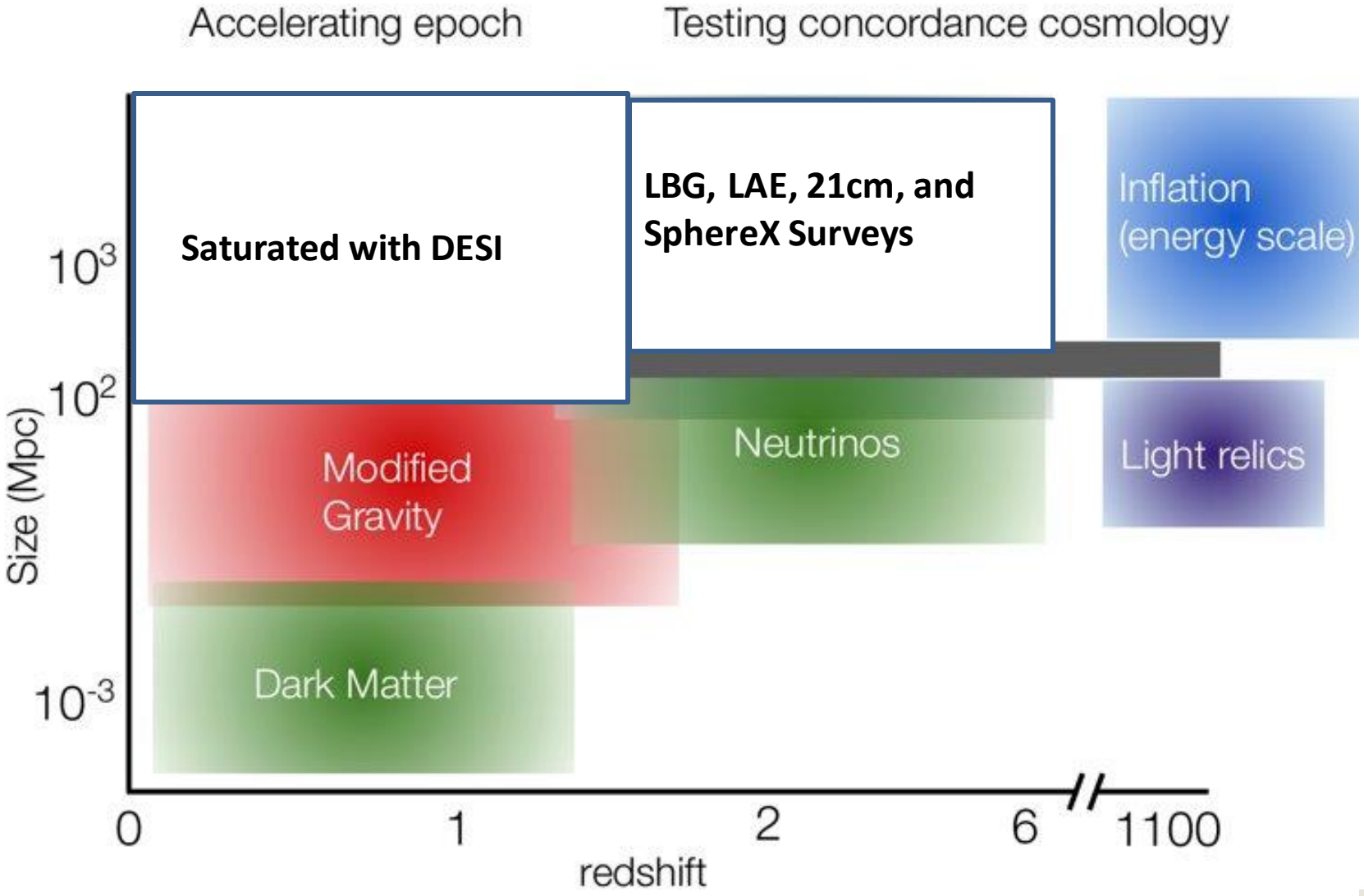
Neutrinos at z>1.5: Upsides and Downsides

- Upsides
  - Obvious potential for massive improvement over current surveys
  - Separate path independent of CMB optical depth

- Downsides
  - Asymptotes toward minimum mass scenario
  - Likely requires high number densities
  - Modified gravity at high redshift? Possibly only anchor for interpreting low-z regime



Discovery Space at High Redshift



Non-Gaussianity: Upsides and Downsides

- Upsides
  - Obvious potential for massive improvement over current surveys (see Christophe's talk)
  - Clear projections for compelling constraints on non-Gaussianity

- Downsides
  - Broadband, weak signal that is not guaranteed
  - Faint targets susceptible to incompleteness/contamination in redshift estimates
  - Will anyone believe a non-zero detection with marginal redshifts?

- What is required to guarantee robustness?
  - Consistency in samples split by redshift?
  - Consistency in samples split by target class?
  - Consistency with varying redshift quality cuts?
  - Three-point statistics?
  - Multi-tracer techniques to alleviate cosmic variance?

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- **Editorial:** non-Gaussianity offers most clearly-defined path toward future survey
  - Effort is needed to contrast Fisher forecasts and robustness of measurement
  - Likely to require substantial improvement over SphereX to be compelling

Summary of z>1.5 Target Classes

- LBG and LAE target classes
  - ~1,000 per sqdeg at r<23.5 --> 14M over 14k sqdeg footprint
  - ~10,000 per sqdeg at r<24.5 --> 140M over 14k sqdeg footprint
  - Dominated by LBG population: redshifts determined by absorption
  - Some fraction identifiable by Lyman-alpha emission

- Cosmology projections
  - Christophe's talk 10M redshifts: --> P(k) sigma(fnl) ~ 1
  - 140M redshifts --> bispectrum sigma(fnl) ~ 0.1 (https://arxiv.org/pdf/1903.09208.pdf)
  - What is proper goal in light of SphereX?
  - What LBG+LAE sample is required for **robust** Stage-V measurements?

Ferraro, Wilson, et al. (2019)
~140M redshifts

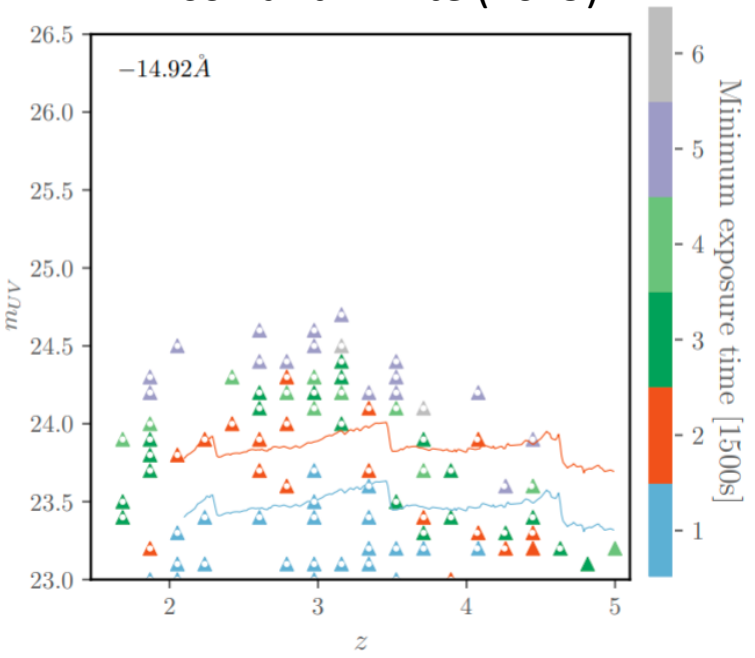
Parameter	σ(parameter) Fid./Ideal.	DESI
Curvature $\Omega_K/10^{-4}$	6.6 / 5.2	12.0
Neutrinos $\sum m_\nu$	0.028 / 0.026	0.032
Spectral index n_s	0.0026 / 0.0026	0.0029
Running α_s	0.003 / 0.003	0.004
Rel. species N_{eff}	0.069 / 0.069	0.078
Gravitational slip	0.008 / 0.008	0.01
D.E. FoM	398 / 441	162

Summary of z>1.5 Spectroscopy

- R<23.5 LBG selection
  - 14M redshifts
  - Simulations indicate 1500-s exposures on 6.5-meter for good redshift efficiency
  - DESI Scaling --> five years, 6.5-meters, 5000 fibers, 50% margin for exposure times
  - MSE --> 5 years with shared instrument
  - Could chase LAE galaxies with larger fiber budget
    - Can we really do fnl at low redshift efficiency/high contamination?

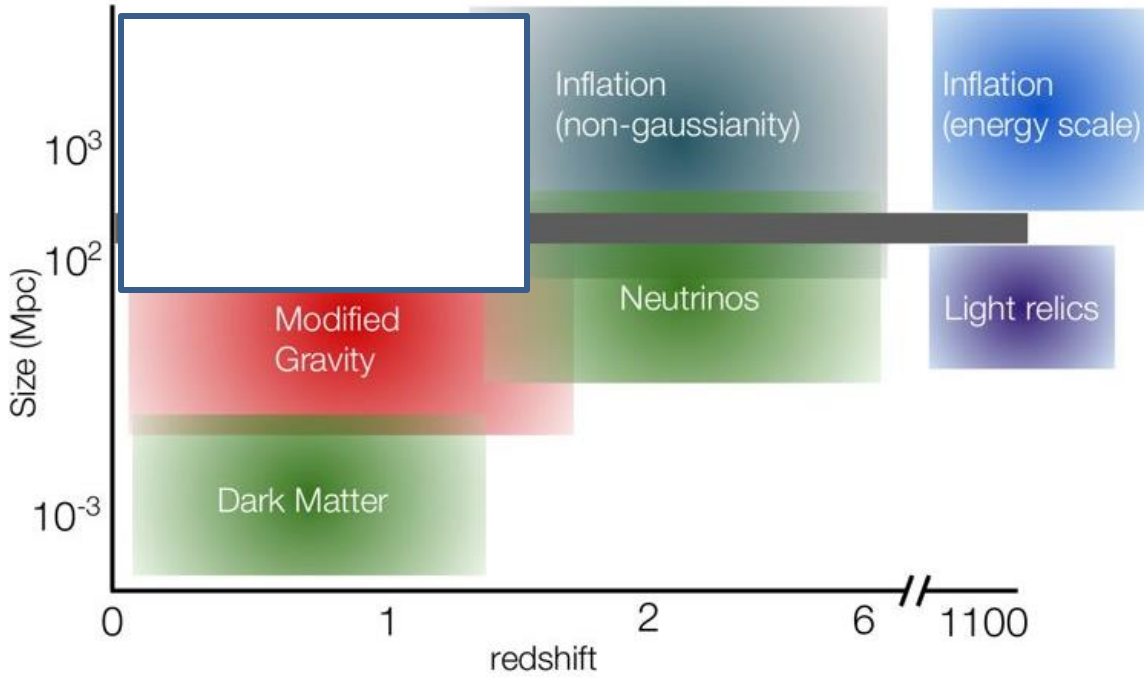
- R<24.5 LBG selection
  - 140M redshifts
  - Simulations --> 1hr exposures, 10-12 meters
  - 140M fiber hours required
  - DESI: 14M fiber hours in 5 years
  - 10-12M telescope requires 10X multiplex over DESI

Wilson and White (2019)



Discovery Space Summary

- Compelling science over 0<z<4 remaining after DESI/LSST
  - Upsides and downsides to each science driver
  - Focus on one case until 2040?
  - Easiest case: but how far to push fnl?
  - Stage-V program to realize all upsides and guard against the downsides?



Comparison of Proposed Facilities

- New proposed facilities easily meet 14M galaxy threshold, and further

Instrument	Primary Mirror Area	# fibers	Relative Survey Speed
SDSS (1999-2008)	3.68 m^2	640	1
BOSS/eBOSS (2009-2019)	3.68 m^2	1000	1.56
DESI (2020-)	9.5 m^2	5000	22.4
PFS (2021-)	50 m^2	2400	56.6
Mauna Kea Spectroscopic Explorer (MSE)	78 m^2	3249	119
MegaMapper (6.5 mm positioners)	28 m^2	20,000	238
SpecTel (DESI positioners)	88 m^2	15,000	560
SpecTel (5 mm positioners)	88 m^2	60,000	1800

Survey speeds for multi-fiber spectrographs as measured by the product of the telescope clear aperture, number of fibers, and losses from mirror reflections. This speed assumes a dedicated program, which would not be possible in all cases. MSE, SpecTel, and MegaMapper are proposed experiments under consideration in the NAS decadal survey.(Table 1 of https://arxiv.org/abs/1907.11171)

140M galaxy case

- Only SpecTel facility with advanced fiber positioners meets survey speed and S/N requirements

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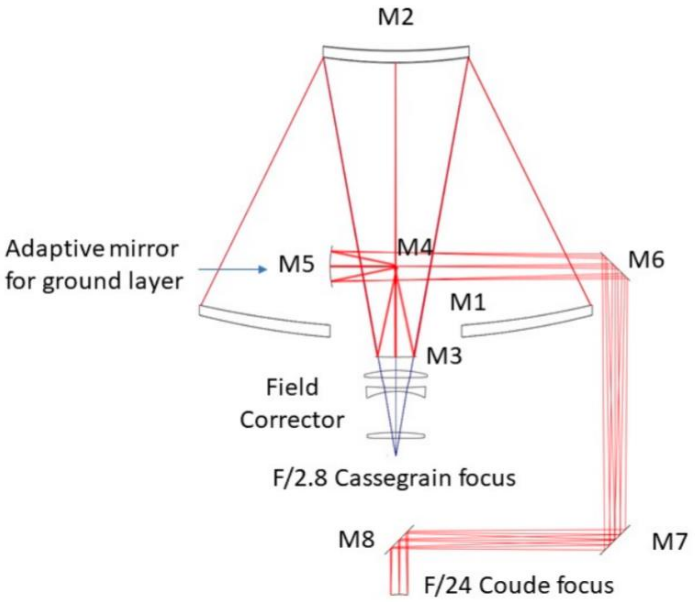
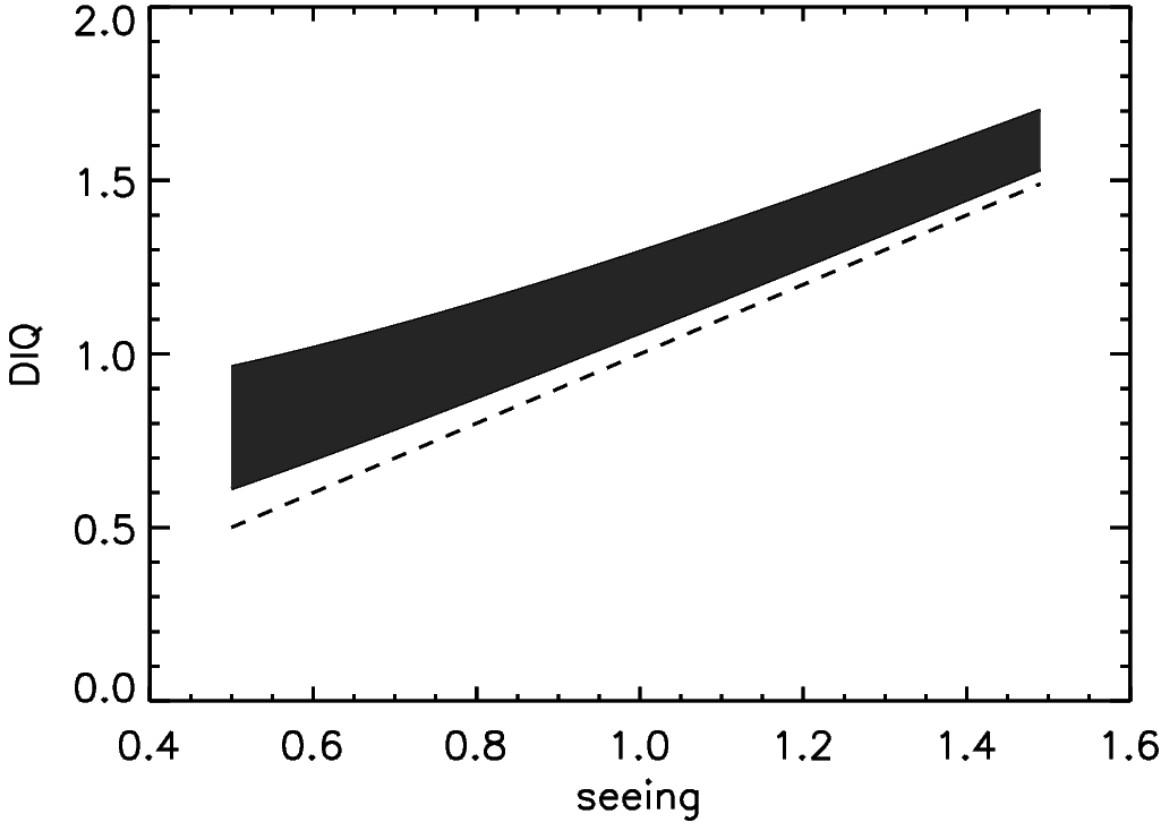
Comprehensive Stage-V Facility

- SpecTel concept from ESO study (Ellis, Dawson, et al. 2019)
  - 11.4-meter telescope
  - Largest possible focal plane; plate scale and input beam well-suited for fibers
  - 15,000 fibers possible with DESI design
  - 60,000 fiber system with ½ spacing of DESI
  - Fiber positioner R&D to meet goals of z<1.5 and z>1.5 Stage-V program
  - Complete spectroscopy on 10% of LSST Gold sample in ten years



SpecTel: Focal Plane Area vs Image Quality

- Spot Diagrams indicate 0.15-0.35 arcsec RMS
- Consequences depend on target morphology, seeing, fiber design
- e.g. 1 arcsecond seeing with 1 arcsecond diameter fiber
  - 8%-32% flux loss relative to perfect optics



Summary

- Now is time to set stage until ~2040 for ground-based cosmology program
- z<1.5 has ample targets for spectroscopy, but needs quantifiable science case
- z>1.5 inflation milestones are easily quantified
  - Automatically includes BAO, structure growth, neutrinos
- z>1.5 spectroscopic facility requirements for five-year survey?
  - ~10's millions galaxy redshifts easily met with MSE and/or MegaMapper
  - 140M galaxies only possible with advanced SpecTel (5mm positioners)
  - What are requirements in sample size to supercede SphereX?
  - What are requirements on completeness/purity in spectroscopy?
- Trades need to be assessed in next year: Fisher Forecasts not sufficient!