U.S. DEPARTMENT OF ENERGY | Office of Science

The Next 20 Years of Cosmic Observations

Kyle Dawson
University of Utah

Snowmass at Seattle

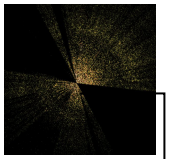
Stage-IV and Beyond

- Well-defined measurement goals
  - Dark Energy
  - Inflation
  - New physics from early Universe messengers

- Optical/IR spectroscopy, imaging, and Cosmic Microwave Background
  - Baryonic matter, dark matter, gravitational waves
  - Galaxy cluster to horizon scales
  - Current epoch to inflationary epoch

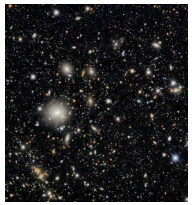
- Discovery potential
  - New techniques in development
  - High precision measurements across multiple probes
  - Consistency and tests for new physics

Cosmic Discovery Space

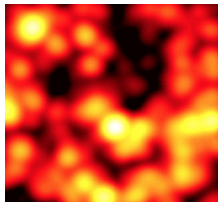


BAO scale and larger

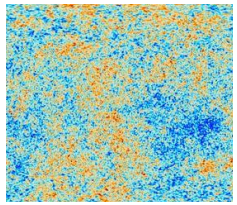
Size of a galaxy cluster



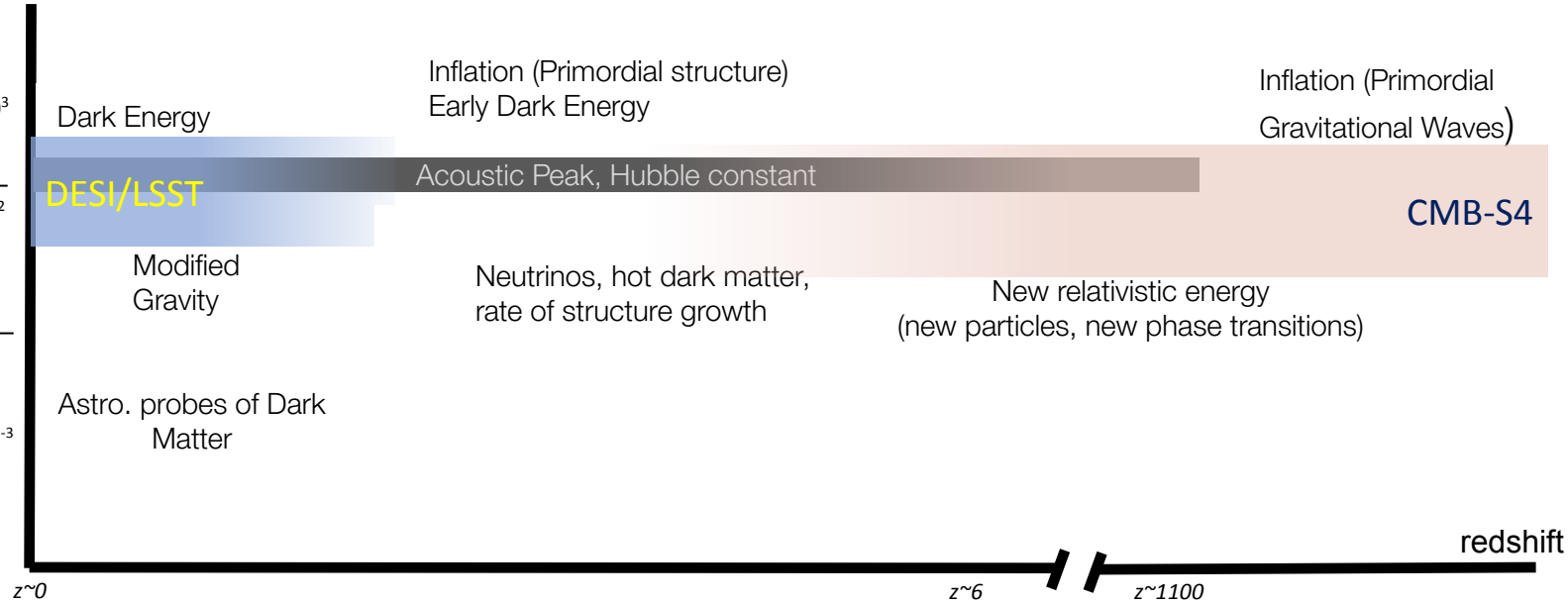
Galaxies emitting in optical wavelengths and spatially resolved.



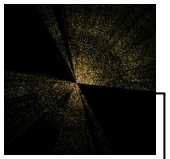
Galaxies and gas emission at redder wavelengths and spatially dense.



Hot dense state. Detectable relics include CMB, gravitational waves and neutrinos.



Cosmic Discovery Space: Stage-IV



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Size (Mpc)

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10^{-3}

Dark Energy

DESI/LSST

Modified Gravity

Astro. probes of Dark Matter

Inflation (Primordial structure)
Early Dark Energy

Acoustic Peak, Hubble constant

Neutrinos, hot dark matter, rate of structure growth

Inflation (Primordial Gravitational Waves)

CMB-S4

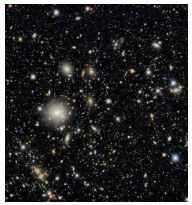
New relativistic energy (new particles, new phase transitions)

redshift

z~0

z~6

z~1100



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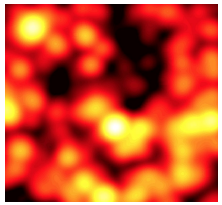

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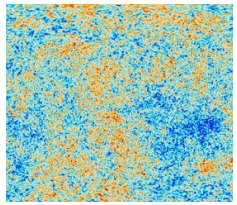

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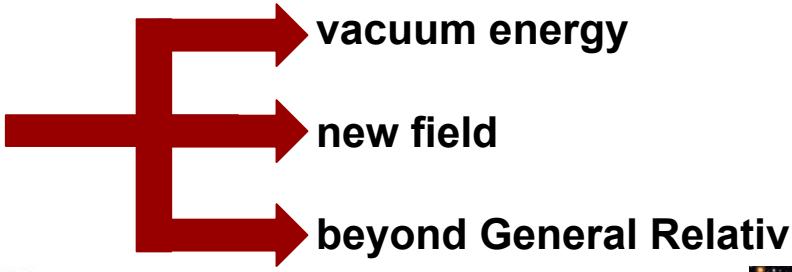
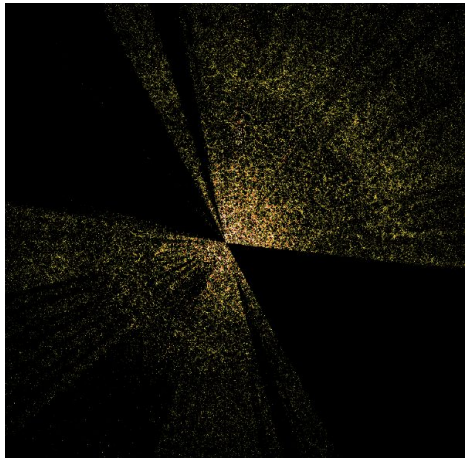
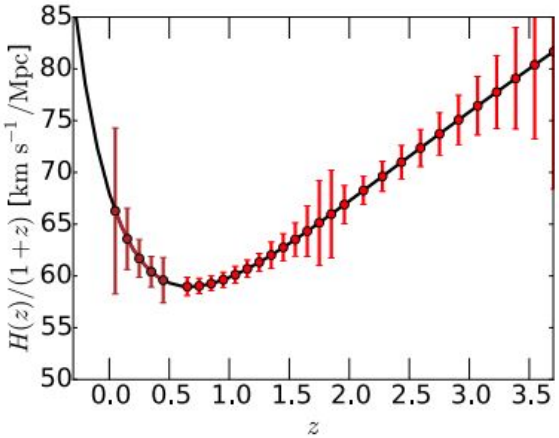
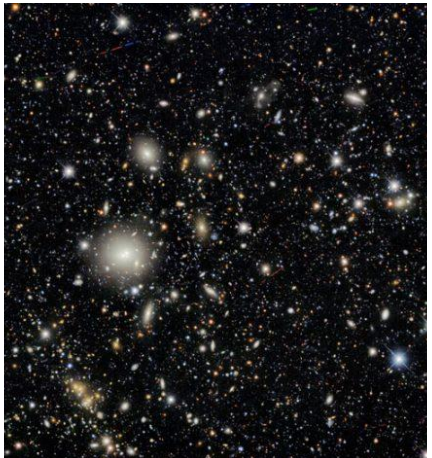
Dark Energy

- Figure of Merit for Stage-IV dark energy surveys: From discovery to precision
  - Expansion history
  - Growth of structure



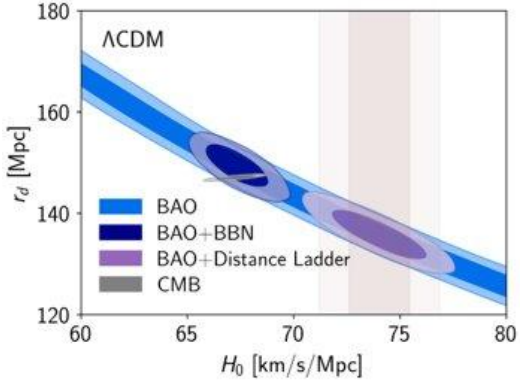






New Physics

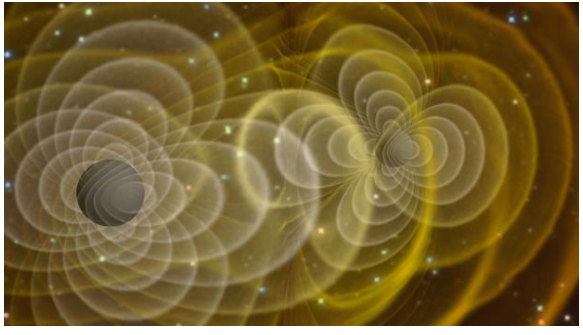
- Early Universe versus late Universe: over-constrain direct H_0 measures to the percent level



neutrino couplings

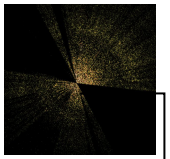
new particle or field

alternate model for dark energy



Credit: Henze/NASA

Cosmic Discovery Space: CMB-S4



BAO scale and larger

Size of a galaxy cluster

Size (Mpc)

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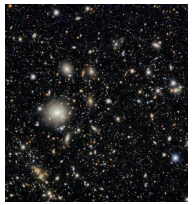

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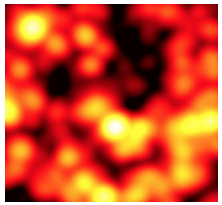

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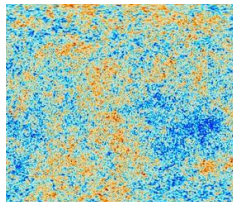
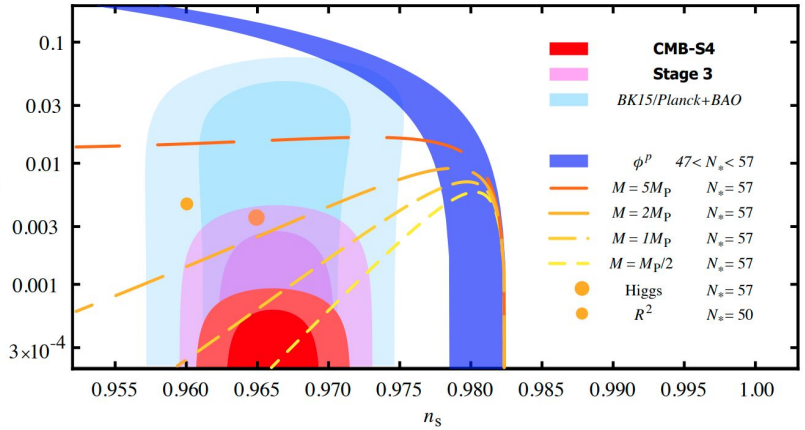


Hot dense state. Detectable relics include CMB, gravitational waves and neutrinos.

Inflation

- Determine tensor-to-scalar ratio at threshold r=0.001: the energy scale of inflation



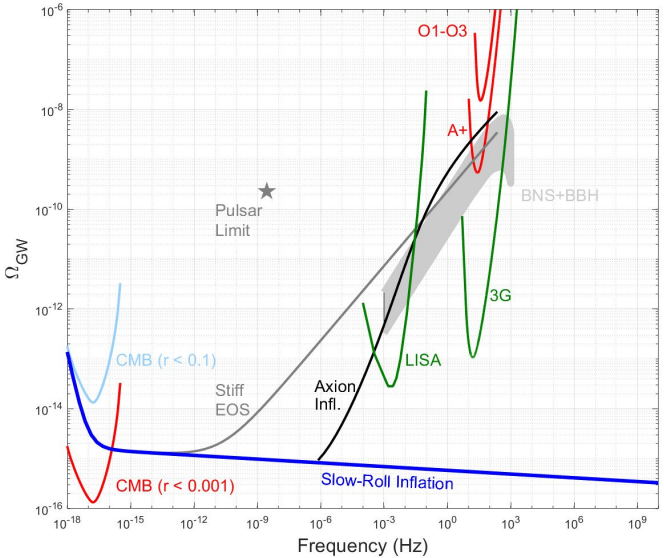
r>0.003: Super-Planckian field excursion, shift symmetry in quantum gravity

r>0.001: simplest models of inflation with characteristic scale > M_Planck.

r<0.001: Small field inflation with spontaneous symmetry breaking

Inflation

- Direct detection of gravitational waves: Synergy with gravitational wave observatories

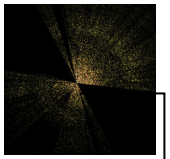


inflaton coupling to a gauge field

new pre-radiation dominated epoch

alternatives to inflation

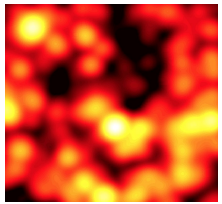
Cosmic Discovery Space: Stage-V



BAO scale and larger

Size of a galaxy cluster

Galaxies emitting in optical wavelengths and spatially resolved.



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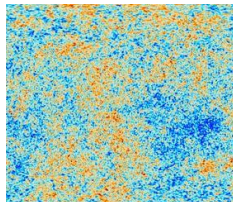

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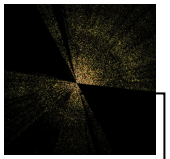
Stage-V Spectroscopic Survey

- Massively multiplexed spectrograph on large aperture telescope
  - 10X++ improvement in survey speed over current facilities
  - 10X++ increase in z>2 sample size
  - Samples at z<1.5 near sample-variance limit to single halo scales

- DESI → Stage-V roadmap
  - Establish and characterize z>2 samples
  - High precision BAO and RSD at z>2
  - Development of structure growth measurements in limit of high density clustering at z<1

- Imaging and CMB
  - Weak lensing, galaxy-galaxy lensing, target selection, galaxy clusters from Rubin
  - Lensing, Sunyaez-Zel'dovich, amplitude of clustering, optical depth from CMB
  - **Full constraints only possible with full suite of measurements**

Cosmic Discovery Space: non-Gaussianity



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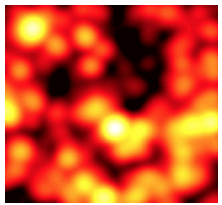

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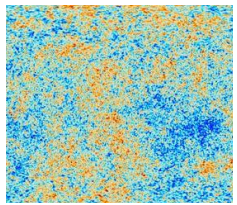

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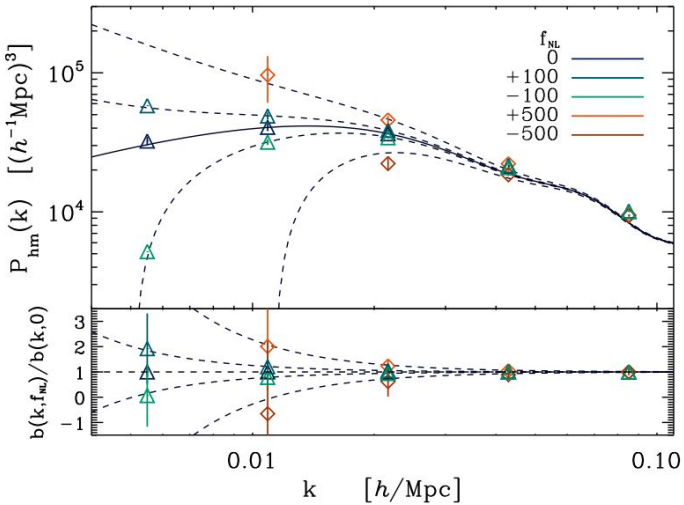
Inflation

- Measure fNL local to 0.2 precision: dynamics of inflation



Local: single or multi-field inflation

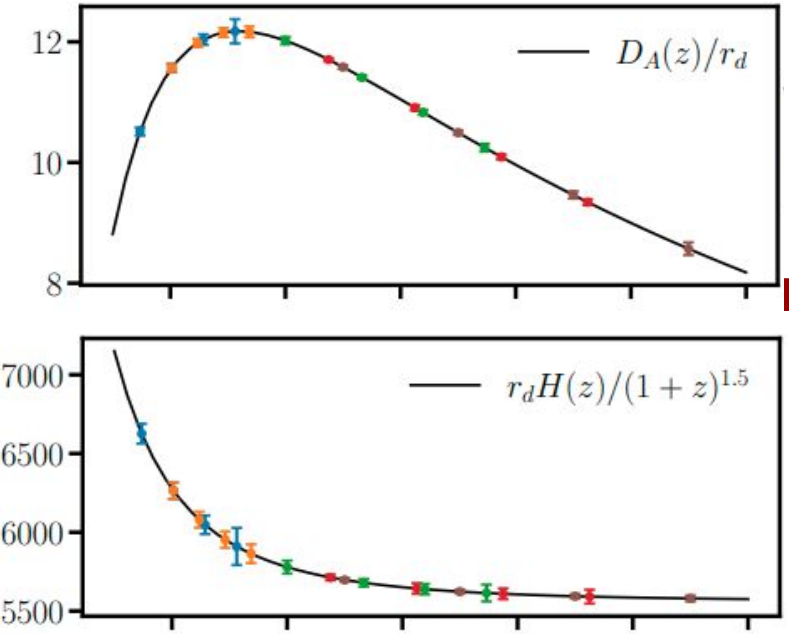
Orthogonal: excited states

Equilateral: inflaton/particle interactions

Dalal et al., 2008

Dark Energy

- Baryon acoustic oscillations and the redshift/distance relation at z>2

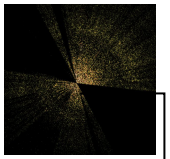


early dark energy

non-zero global curvature

tension in concordance model

Cosmic Discovery Space: CMB & Stage-V



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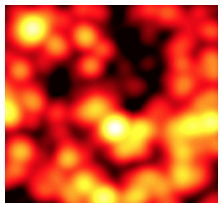

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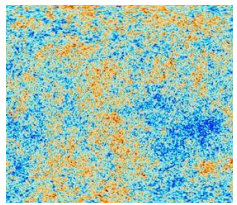

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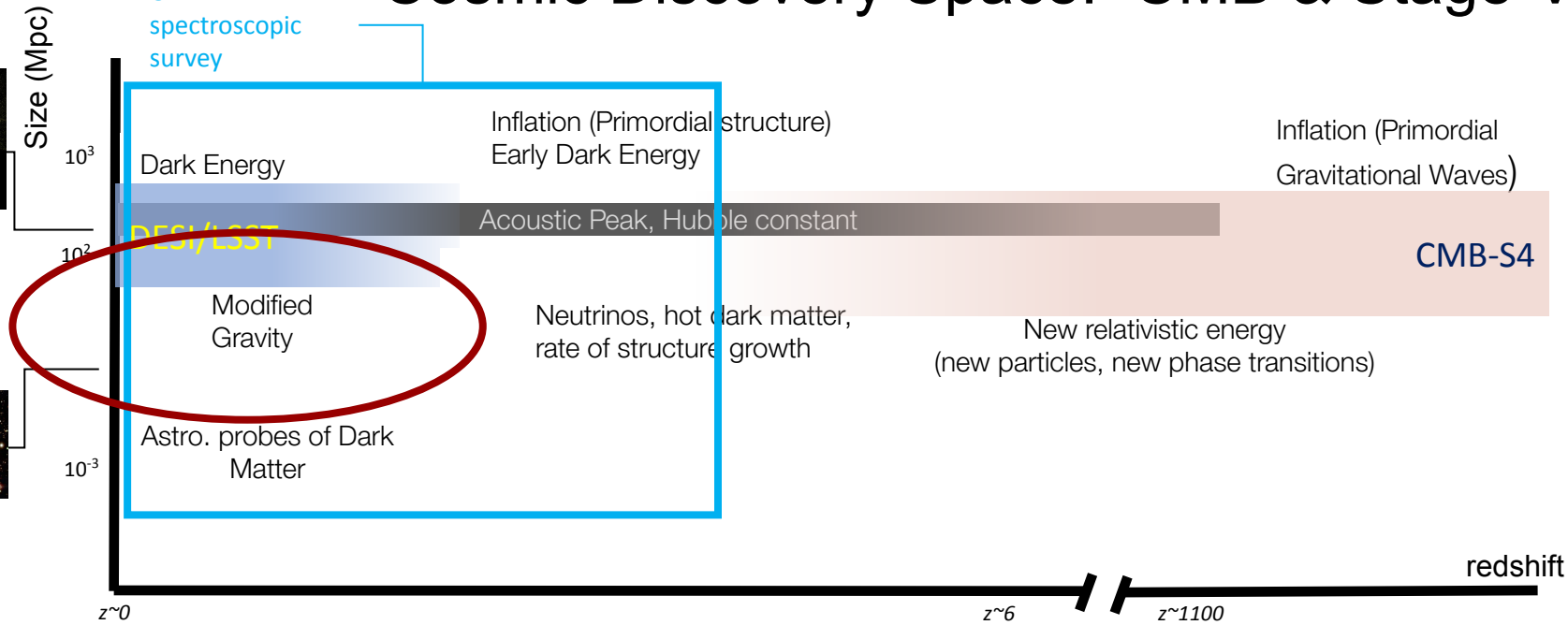
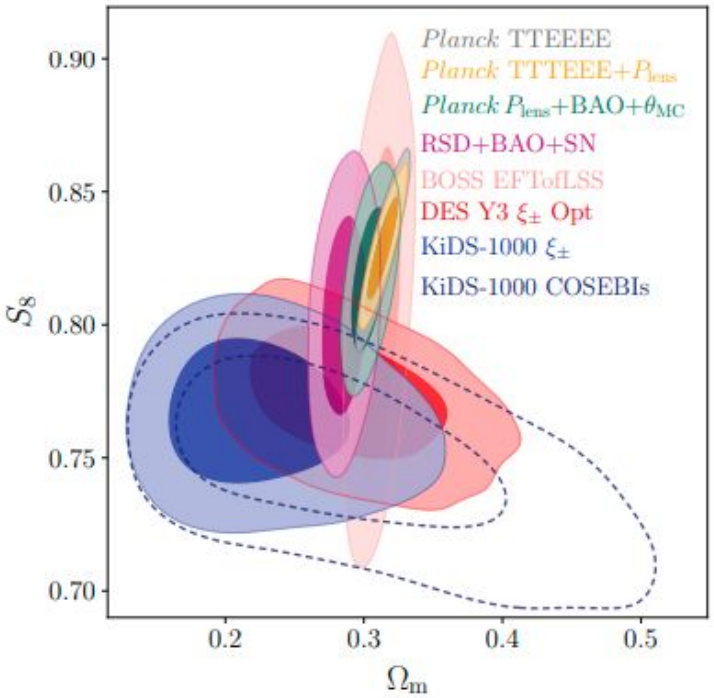


Dark Energy

- Decadal Survey: Measure sigma8 (growth of structure) to 0.2% precision



new properties of dark matter

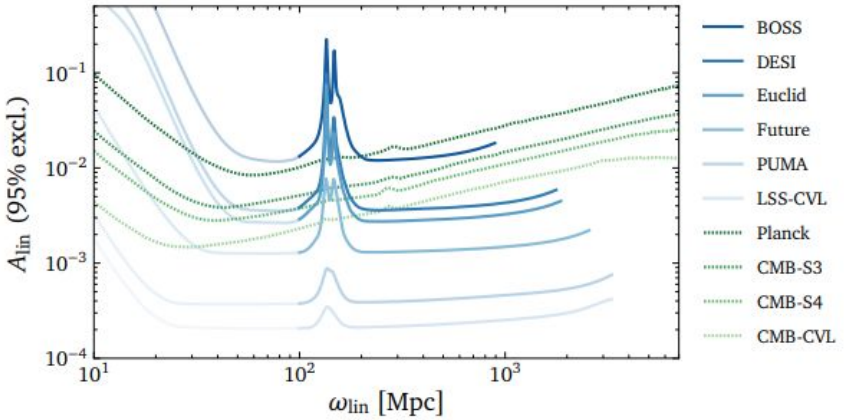
new fields or interactions

modifications to General Relativity

Amon and Efstathiou, 2022

Inflation and New Physics

- High precision power spectrum measurements: 1-2 order of magnitude improvement in search for departures from scale invariance in the inflationary field

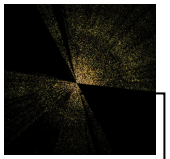


10^{-22} eV axion-like particles

early universe particle production

periodic corrections to potential

Cosmic Discovery Space: CMB & Stage-V



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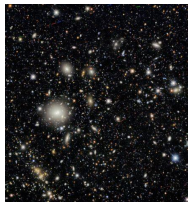

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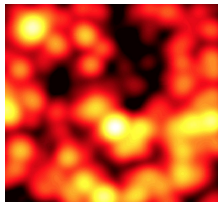

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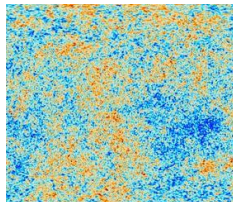

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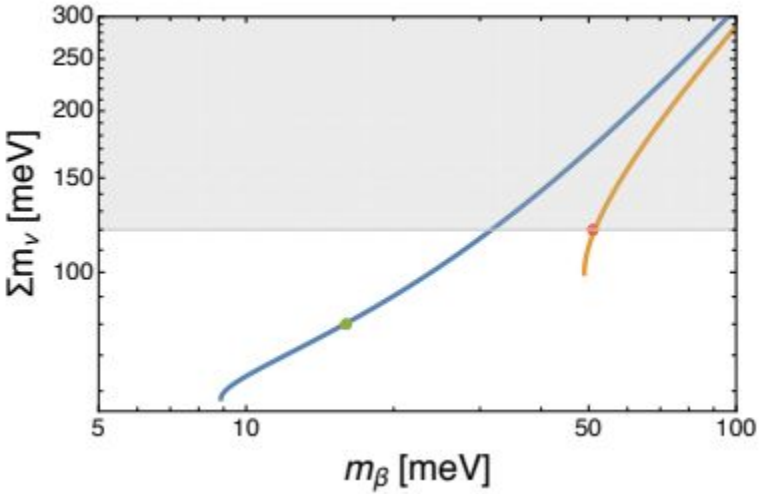
New Physics

- Snowmass 2013: Measure sum of neutrino masses to 15 meV precision



absolute neutrino mass

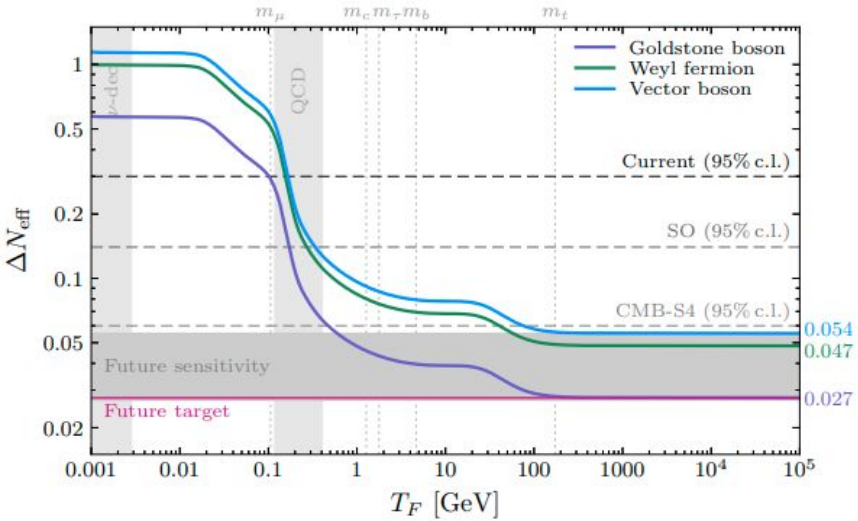
inverted or normal hierarchy

new massive particles or dark sector interactions

Snowmass neutrino white paper, 2022

New Physics

- Early radiation content to precision sigma(Neff)=0.027 → tests beyond standard model



particle contents since inflation

axion and axion-like particles

thermalized dark sector with more than 5 degree of freedom

Cosmological Observations: the next 20 years

- Vast discovery space available
  - Dark Energy across cosmic time
  - Multi-dimensional tests of inflation
  - Neutrino masses, new particles, and new interactions

CF4 - CF7 roadmap to these discoveries