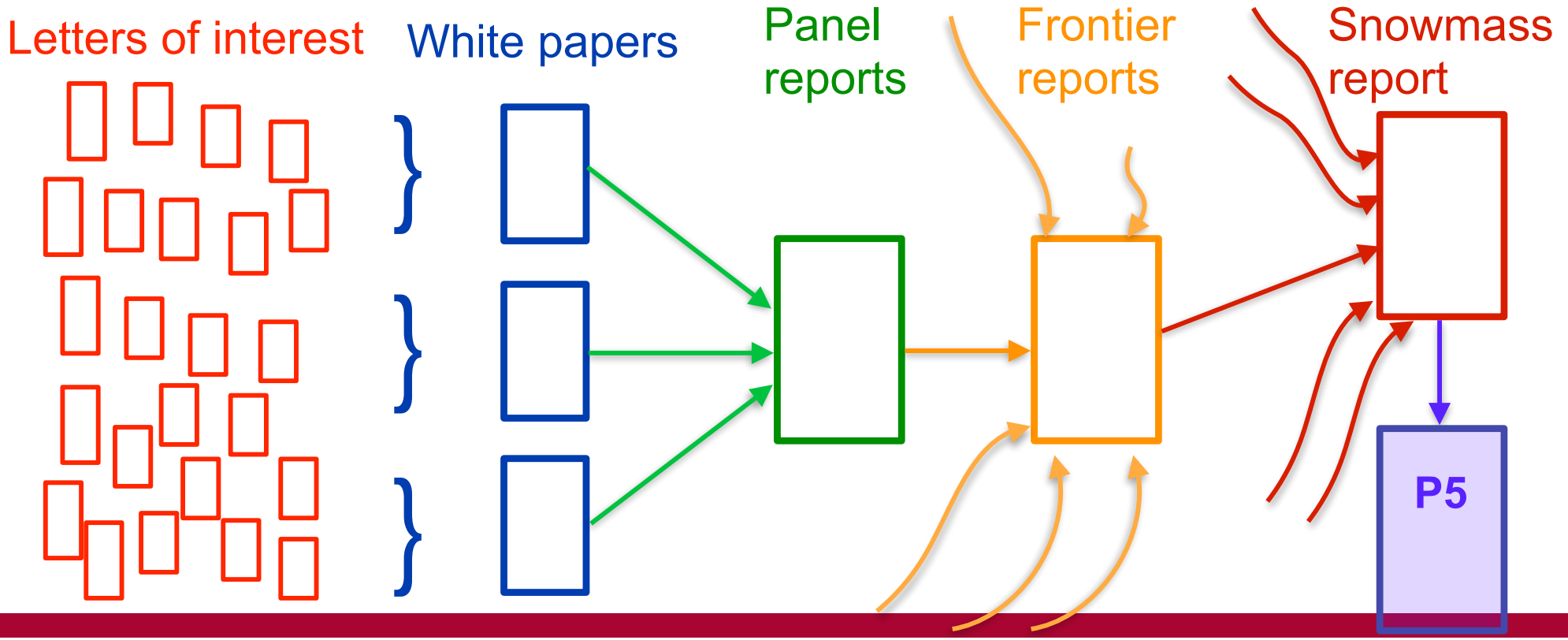
Spec-S5 for Cosmic Acceleration and Beyond: A Perspective from Snowmass

Jeff Newman (with lots of contributions from people who worked on the Cosmic Frontier Snowmass efforts!)

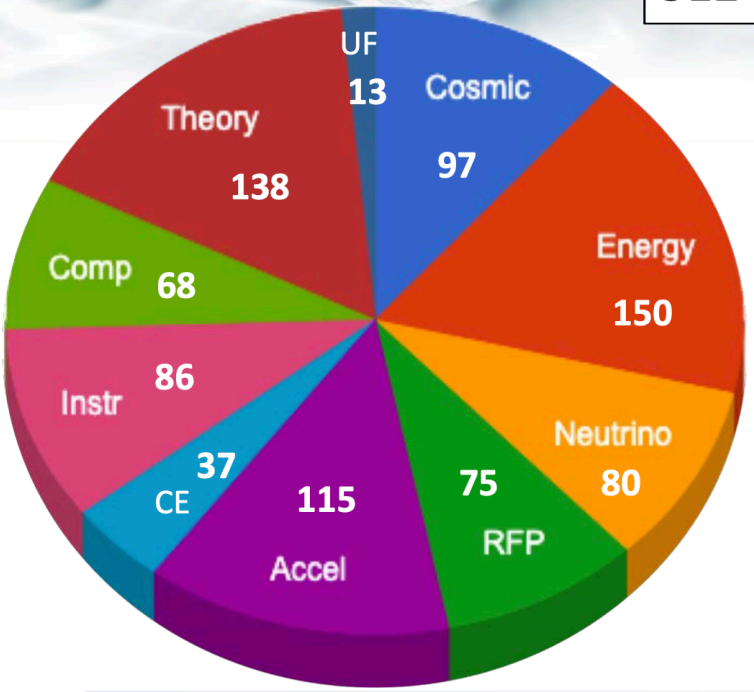
Overview

- The goal of the Snowmass process completed in 2022 was to "identify the most important questions in High Energy Physics and the tools and infrastructure required to address them"
- This process is driven by community input, synthesized at a variety of levels
- The Particle Physics Project Prioritization Panel (P5) takes the input from Snowmass and develops that into a set of recommendations

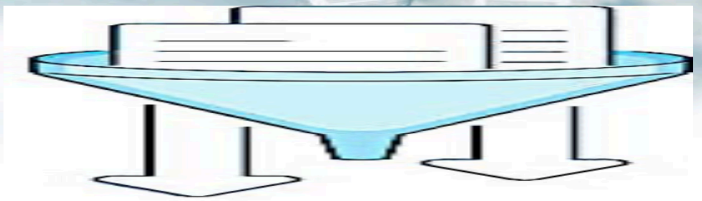


Visual summary of the input (from Prisca Cushman)...

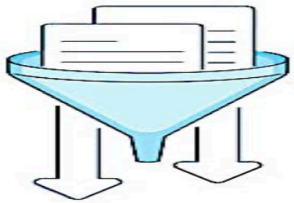
Getting there…



512 White Papers



79 topical group reports



10 Frontier Summaries

And lots of meetings and presentations and plots along the way

Executive Summary by October

Of 7 Cosmic Frontier frontier panels, 4 discussed Spec-S5 science... particularly CF4

- Overall Cosmic Frontier summary report: Chou et al.
- Builds on seven panel reports:
  - CF1. Dark Matter: Particle-like
  - CF2. Dark Matter: Wave-like
  - CF3. Dark Matter: Cosmic Probes
  - **CF4. Dark Energy and Cosmic Acceleration: The Modern Universe**
  - CF5. Dark Energy and Cosmic Acceleration: Cosmic Dawn and Before
  - CF6. Dark Energy and Cosmic Acceleration: Complementary Probes and New Facilities
  - CF7. Cosmic Probes of Fundamental Physics
- The CF4 panel was led by Jim Annis, Anze Slosar and myself (with contributions from Masao Saki in early years)

Spec-S5 plays a key role in a wide variety of Snowmass CF science

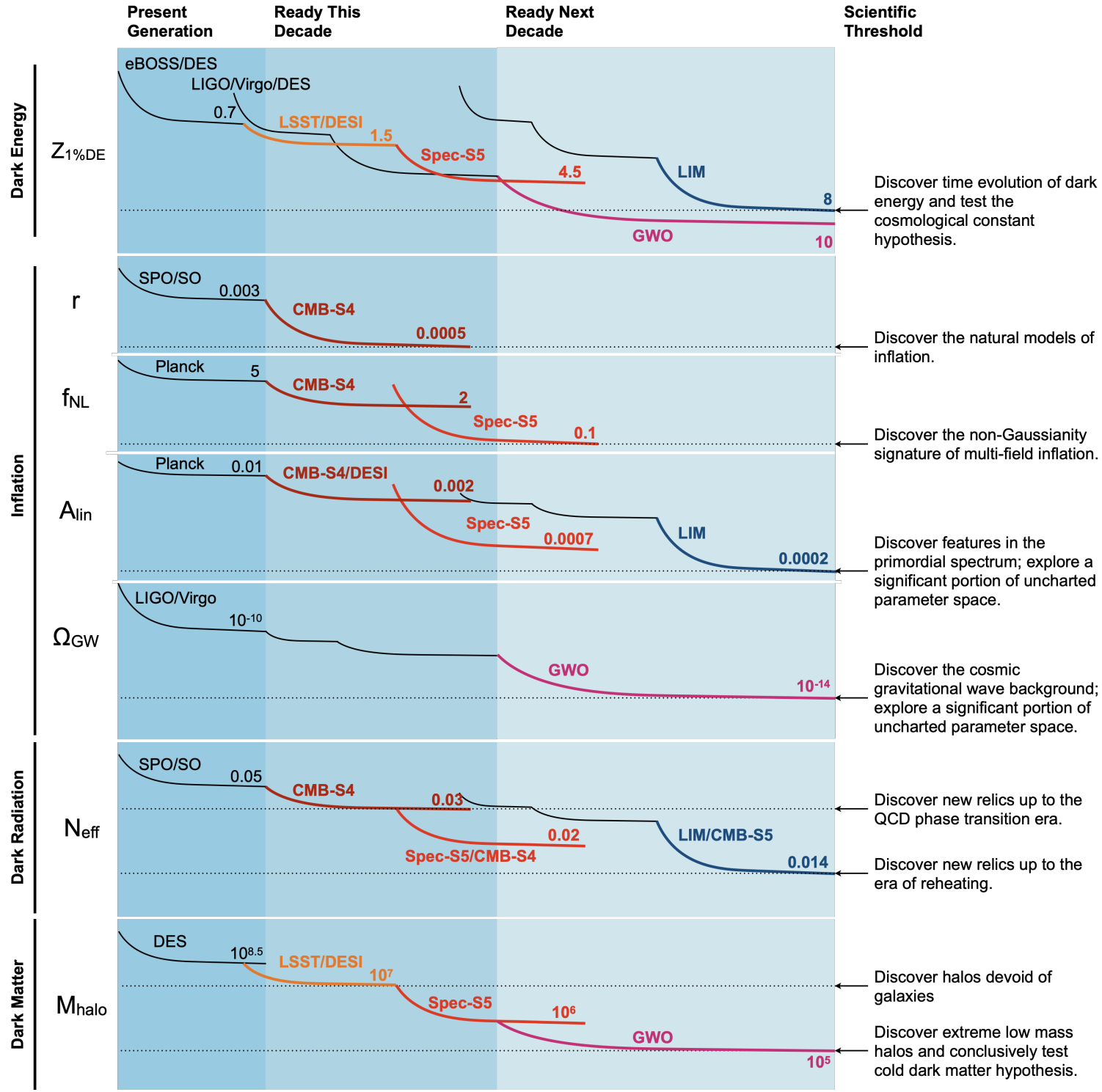
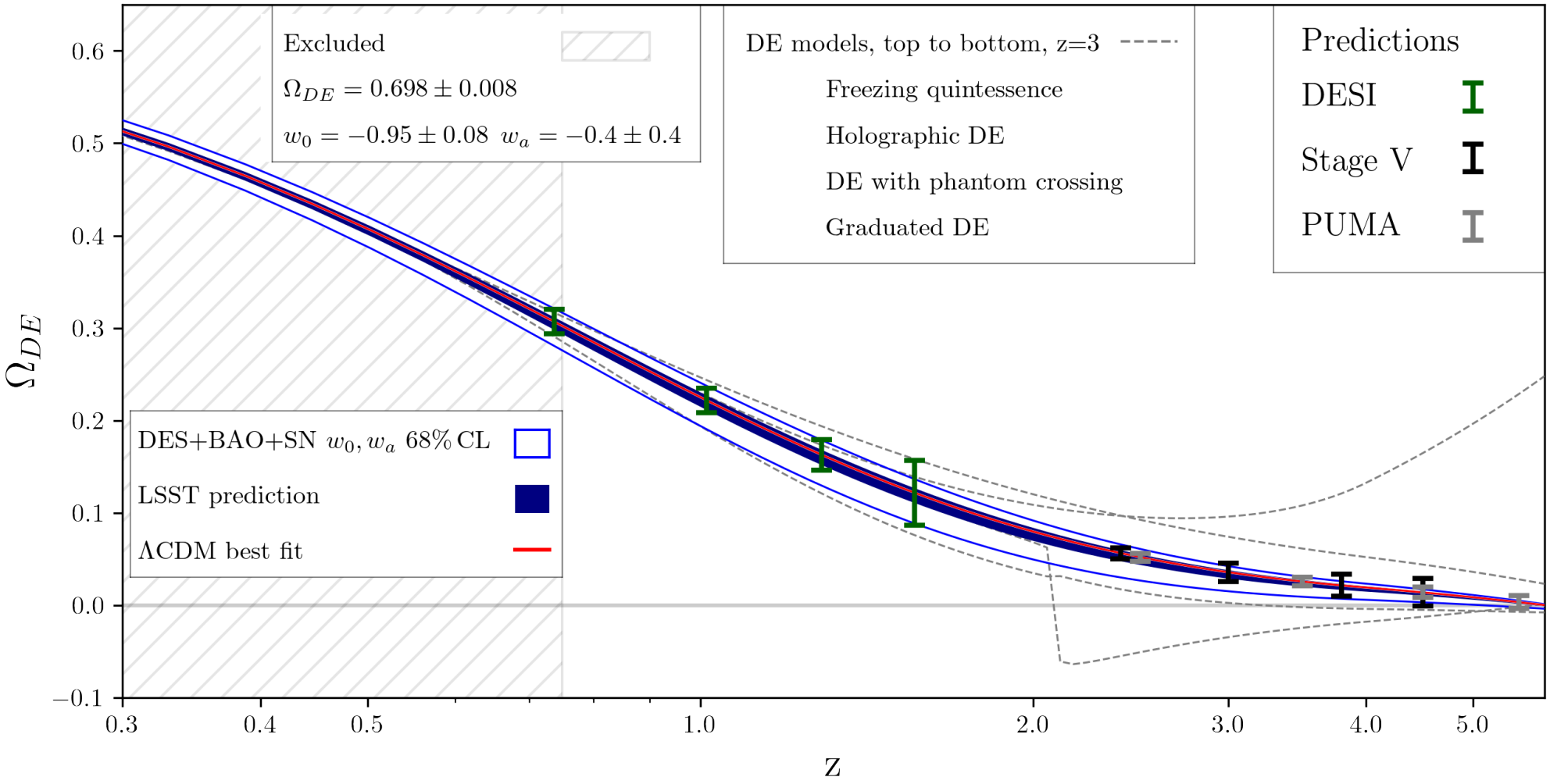


Image: Snowmass Cosmic Frontier report, Chou et al. 2022

Most of the CF4 white papers focused on science that could best be done with a Stage 5 Spectroscopic Facility

- ***Enabling Flagship Dark Energy Experiments to Reach their Full Potential***: Blazek et al.
- *Real-time Cosmology with High Precision Spectroscopy and Astrometry*: Chakrabarti et al.
- ***High Density Galaxy Clustering in the Regime of Cosmic Acceleration***: Dawson et al.
- ***Cosmology and Fundamental Physics from the three-dimensional Large Scale Structure***: Ferraro et al.
- **Rubin Observatory after LSST*: Blum et al.
- ***The MegaMapper: A Stage-5 Spectroscopic Instrument Concept for the Study of Inflation and Dark Energy***: Schlegel et al.
- Additional relevant white papers were submitted to other panels:
  - CF3 (Dark Matter): *Observational Facilities to Study Dark Matter:* Chakrabarti et al.; *Dark Matter Physics from Halo Measurements*: Bechtol et al.
  - CF6 (Facilities and Combined Probes): *A Spectroscopic Road Map for Cosmic Frontier: DESI, DESI-II, Stage-5*: Schlegel et al.

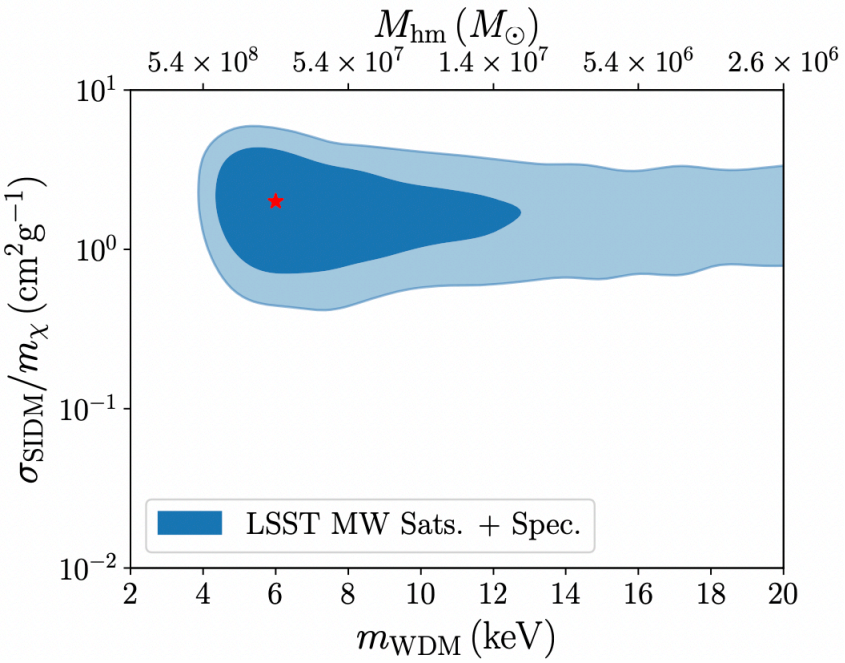
This science includes studies of cosmic acceleration



but goes well beyond...

Examples from the Snowmass reports:

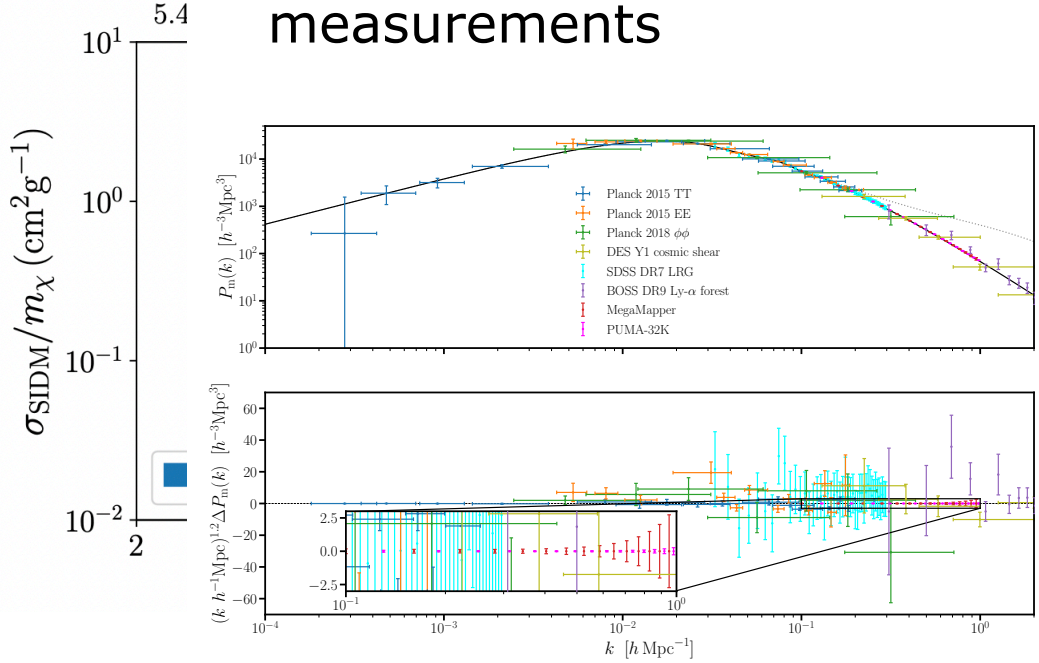
CF3:DM from spectroscopy of dwarf galaxies



Examples from the Snowmass reports:

CF3:DM from spectroscopy of dwarf galaxies

CF4:power spectrum measurements

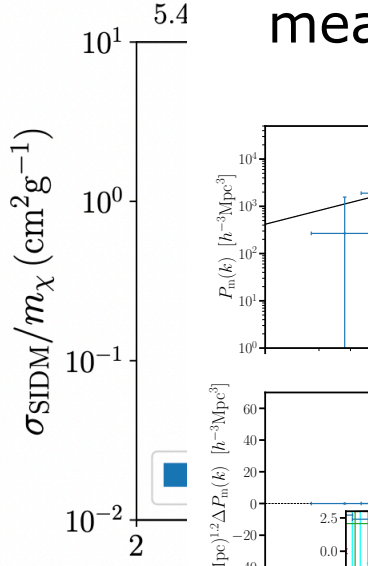


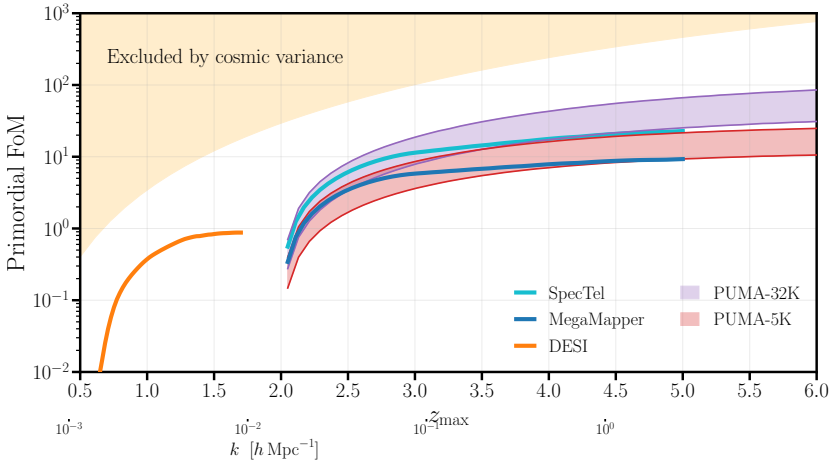
Examples from the Snowmass reports:

CF3:DM from spectroscopy of dwarf galaxies

CF4:power spectrum mea

CF4:primordial figure of merit





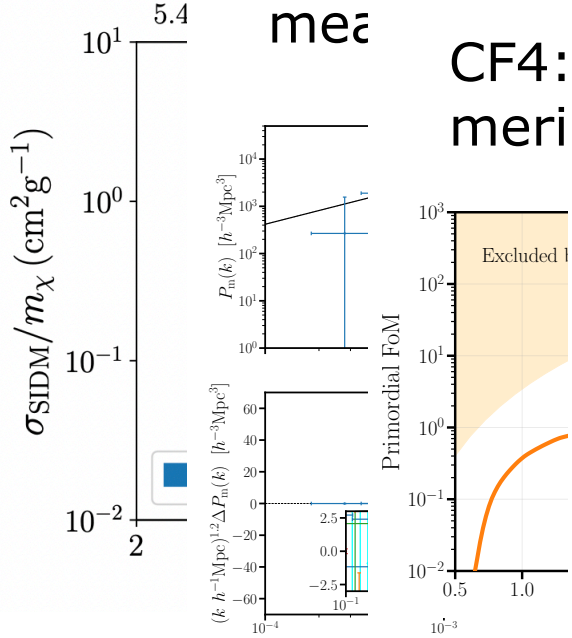
Examples from the Snowmass reports:

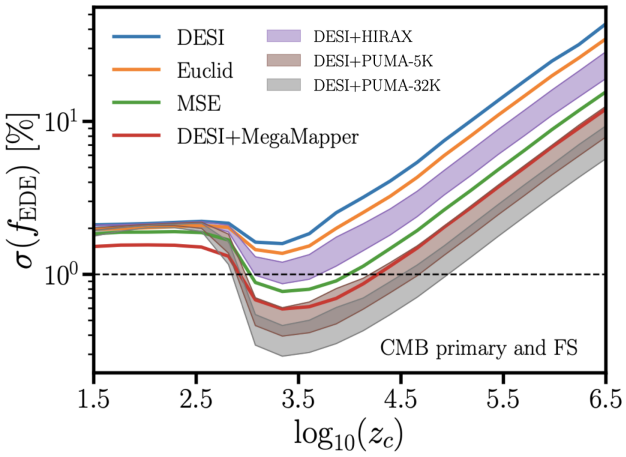
CF3:DM from spectroscopy of dwarf galaxies

CF4:power spectrum mea

CF4:primordial figure of meri

CF4:sensitivity to early dark energy





Examples from the Snowmass reports:

CF3:DM from spectroscopy of dwarf galaxies

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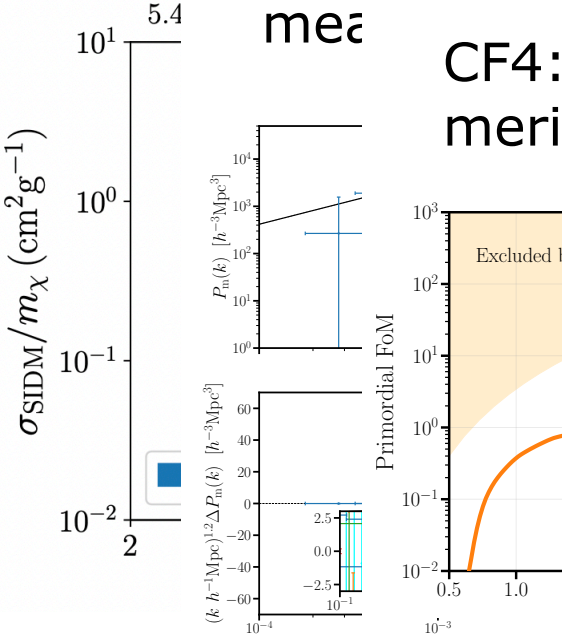
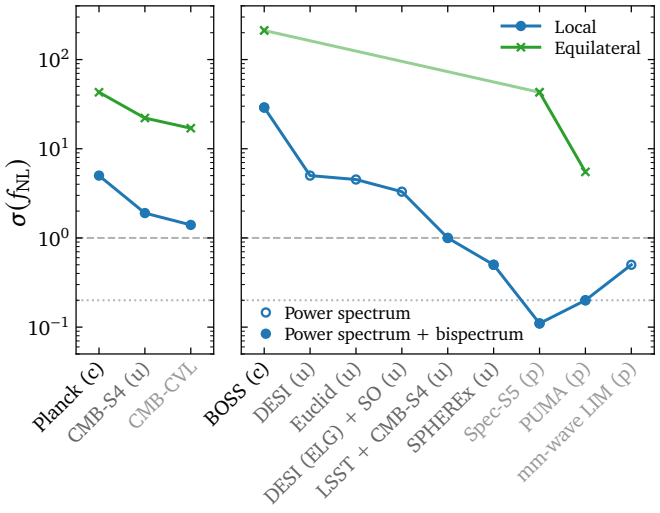
CF4:sensitivity to early dark energ

CF4:testing for primordial non-Gaussianity





Examples from the Snowmass reports:

CF3:DM from spectroscopy of dwarf galaxies

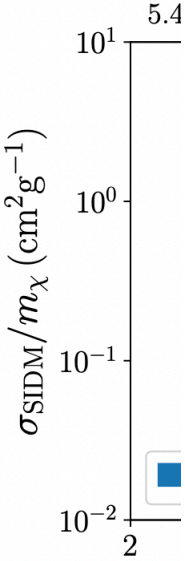
CF4:power spectrum mea

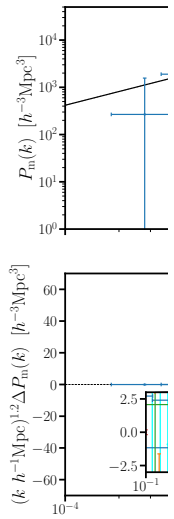
CF4:primordial figure of meri

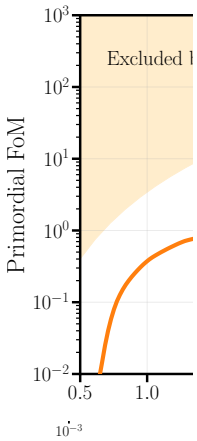
CF4:sensitivity to early dark energ

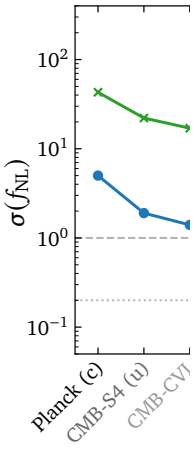
CF4:testing for primordial non-Gaussianity

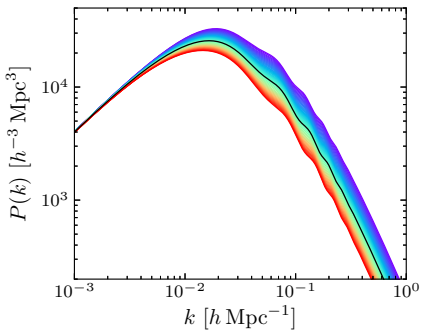
CF4: constraining the effective number of light species

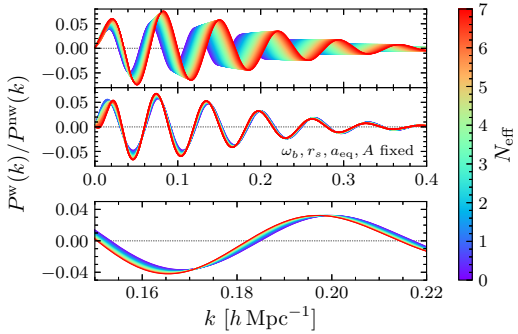












Science goals for Spec-S5 from CF4

- **Key quantitative targets:**
  - Measure dark energy out to z = 5 where ΛCDM becomes negligible
  - Test signatures of non-Gaussianity well enough to exclude $f_{\rm nl}^{\rm loc} \sim 1$
  - Constrain the effective number of light species at $\sigma(N_{\rm eff}) \sim 0.02$ level
- **Opening up new discovery space**:
  - Search for primordial features in the inflationary power spectrum
  - Constrain modified gravity models via redshift-space distortions
  - Measure the sum of the neutrino masses
  - Address tensions in measurements of the Hubble Constant and the power spectrum amplitude σ_8
    - Can incorporate multiple tracers of both galaxy density and matter density to enable many cross-checks
- **Enhance LSST and CMB-S4 via spectroscopy**:
  - Improve photometric redshifts from the Vera C. Rubin Observatory
  - Unlock additional information via cross-correlations with CMB observables (lensing, *x*SZ, etc.)

Spec-S5 could greatly enhance the constraining power of the Rubin Observatory LSST

- Larger samples of secure redshift measurements for faint objects (to i~25) would reduce errors in photometric redshifts from LSST via improved training of algorithms and constraints on possible SEDs
- Particularly enhances LSS and cluster probes of cosmology (we heard yesterday about complementarity of halo mass function to Spec-S5 measurements...)
- A Spec-S5 would be nearly optimal for obtaining such samples
- Simultaneously can obtain the spectra needed to constrain models of intrinsic alignments: retire a major systematic in weak lensing studies

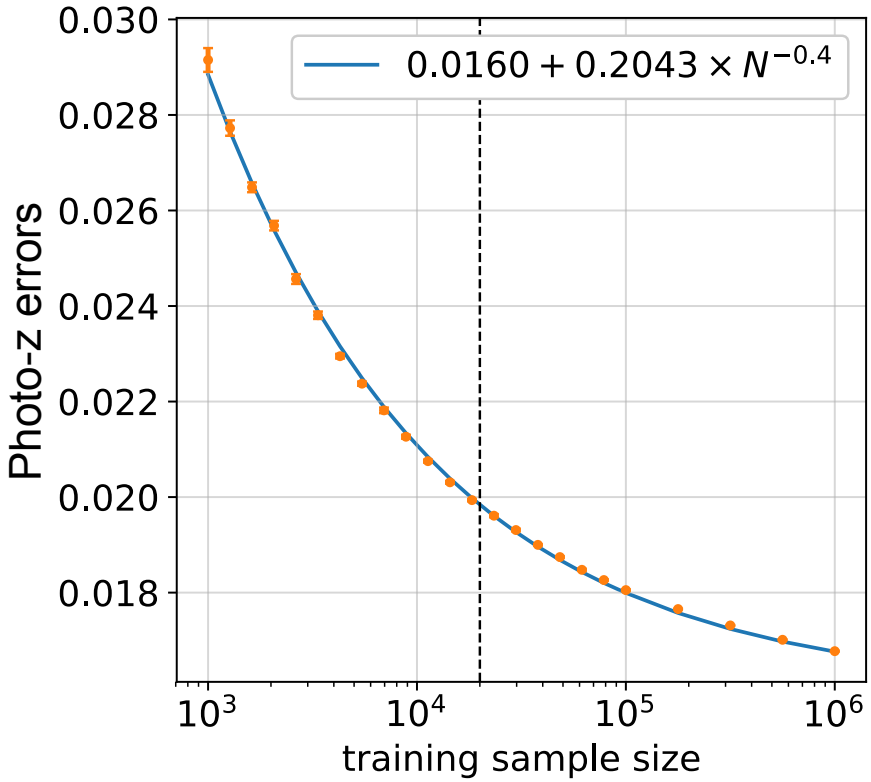


Image: Rongpu Zhou, CF4 report

What did "Stage 5" mean to Snowmass?

- For the Snowmass Cosmic Frontier (see section 5.3.2 of Chou et al.), Spec-S5 was defined by its ability to pursue all this science, along with dark matter studies, at the same time!

A Spec-S5 can simultaneously provide a dense sample of galaxies at lower redshifts to provide robust measurements of the growth of structure at small scales, as well as a sample at redshifts $2 < z < 5$ to measure cosmic structure at the largest scales, spanning a sufficient volume to probe primordial non-Gaussianity from inflation and to search for features in the inflationary power spectrum on a broad range of scales, while also testing dark energy models in poorly-explored regimes, determining the total neutrino mass, and strongly constraining the effective number of light relics. A Spec-S5 would also be able to probe the nature of dark matter using the kinematics of stars in the Milky Way halo and measurements of the matter power spectrum at small scales...

Because of the repeated summarization involved, it is helpful to refer back to Snowmass papers to figure out what P5 was actually talking about...

- P5 report:

The proposed next-generation spectroscopic survey, Spec-S5, holds great promise to advance our understanding and reach key theoretical benchmarks in several areas: inflationary physics via the statistical properties of primordial fluctuations, late-time cosmic acceleration, light relics, neutrino masses, and dark matter. The balance between these scientific goals, which affects survey design, should be refined in light of early DESI and Rubin Observatory LSST results.

- Snowmass summary:

The program includes a powerful new Stage V spectroscopic facility (also referred to here as Spec-S5) that would pursue larger and deeper surveys enabling transformational advances in our understanding of both eras of accelerated expansion in the history of the universe – the early inflationary epoch and the late dark energy-driven one... using precise redshift determinations to map the matter distribution in all 3 dimensions instead of being constrained to a single 2-dimensional slice at the surface of the last scattering... will also extend access to rich dark matter particle physics.

Conclusions

- Snowmass process laid out a variety of science areas a Spec-S5 could address, which led to P5 recommendation
  - Dark matter cases discussed in CF3 report
  - Inflation, dark energy, light relics, etc. cases discussed in CF4, and to lesser degrees CF5 and CF6, reports
- P5 suggested Spec-S5 science goals should be refined in light of early DESI and Rubin LSST results: important to make sure the design has the flexibility to adapt
- These reports were made possible by the efforts of many people across the community - thanks to everyone who contributed!