Welcome to Berkeley Lab!
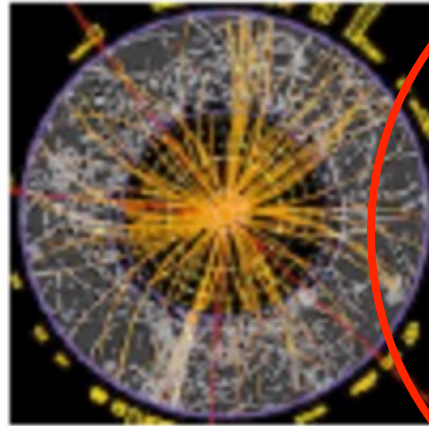
Nathalie Palanque-Delabrouille (LBNL)

Future spectroscopic surveys workshop
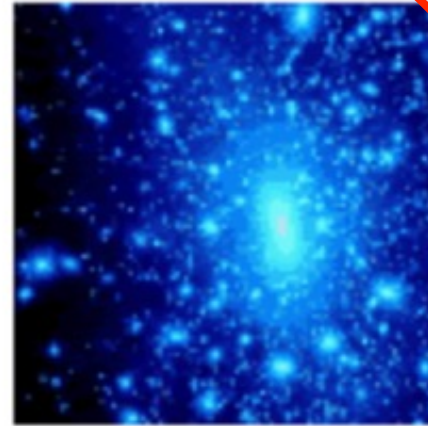May 6-8, 2024

Berkeley Lab (LBNL)

DOE-sponsored National Lab

Research: Physics, Biology, Energy …
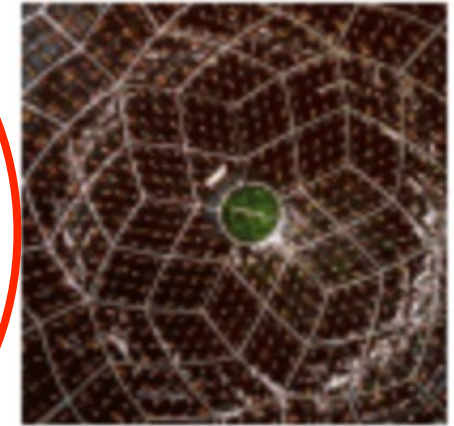400-person engineering division
User facilities: ALS, JGI, NERSC

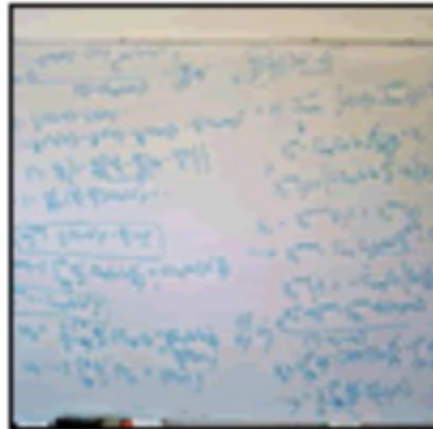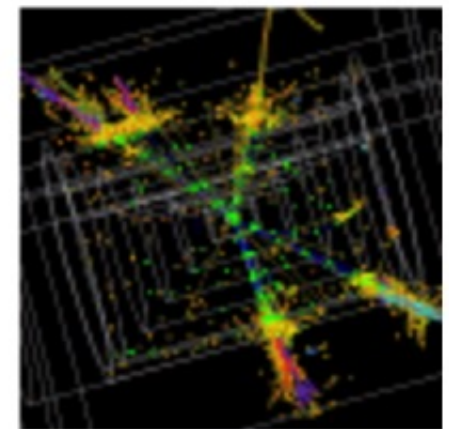**Physics Division Research**

Energy Frontier

Cosmic Frontier

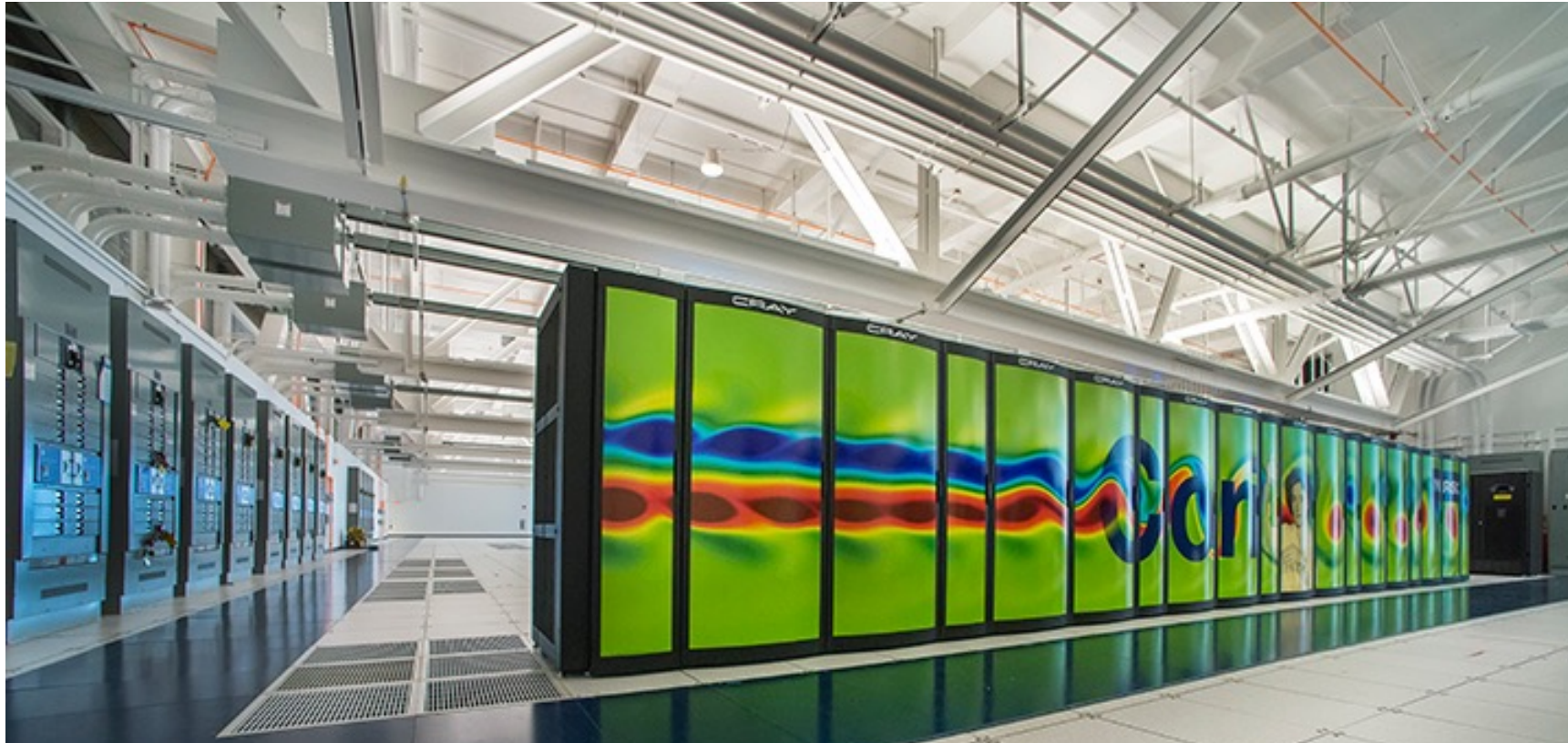Intensity Frontier Physics

Theoretical Physics

Particle Data Group

Detector R&D

Berkeley Lab facilities — NERSC computing

Safety at LBNL

US DOE Facility

- Obey all posted signs

Pedestrian Safety

- Use sidewalk and crosswalks

- Watch your step!

- Do not interact with wild animals

Traffic Safety

- Speed limit is 15 mph on most of site due to construction

- Follow traffic, parking and pedestrian signs and markings

Smoking

- In designated areas only

Nathalie Palanque-Delabrouille

Earthquake Response

Drop down on the floor

Cover under a sturdy desk, table or other furniture

Hold onto it and be prepared to move with the furniture

Evacuate to assembly area (usually in parking lot). Take personal items.

Follow Directions from the Building Emergency Team

5

Nathalie Palanque-Delabrouille

Reporting Emergencies

−**Dial 911 for life threatening emergencies**

−**Dial 6999 for non-life threatening events**
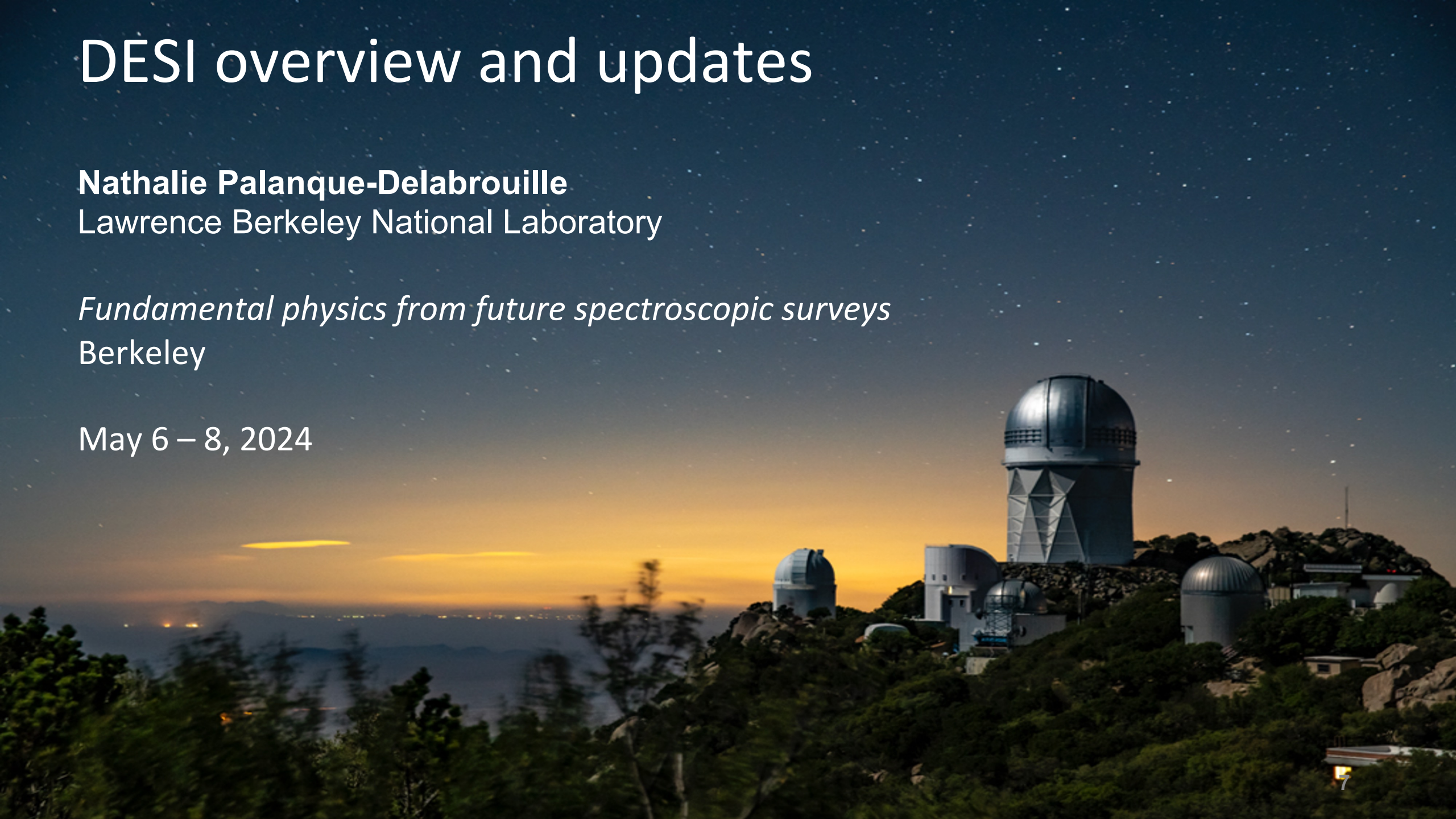
DESI overview and updates

Nathalie Palanque-Delabrouille
Lawrence Berkeley National Laboratory

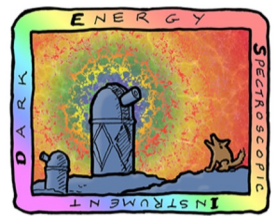*Fundamental physics from future spectroscopic surveys*
Berkeley

May 6 – 8, 2024

DESI overview and updates
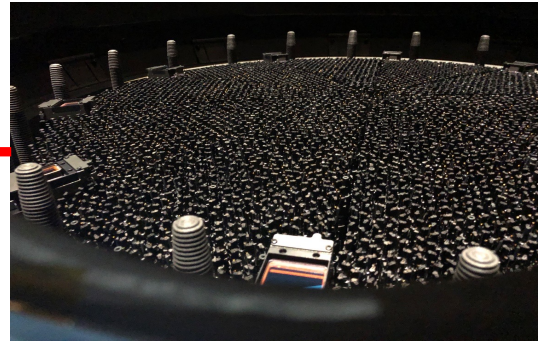
DESI year 1 BAO results

DESI – more coming up!

Beyond DESI

Nathalie Palanque-Delabrouille

DESI fiber-fed multi-object spectrograph

DARK ENERGY SPECTROSCOPIC INSTRUMENT

U.S. Department of Energy Office of Science

Focal plane
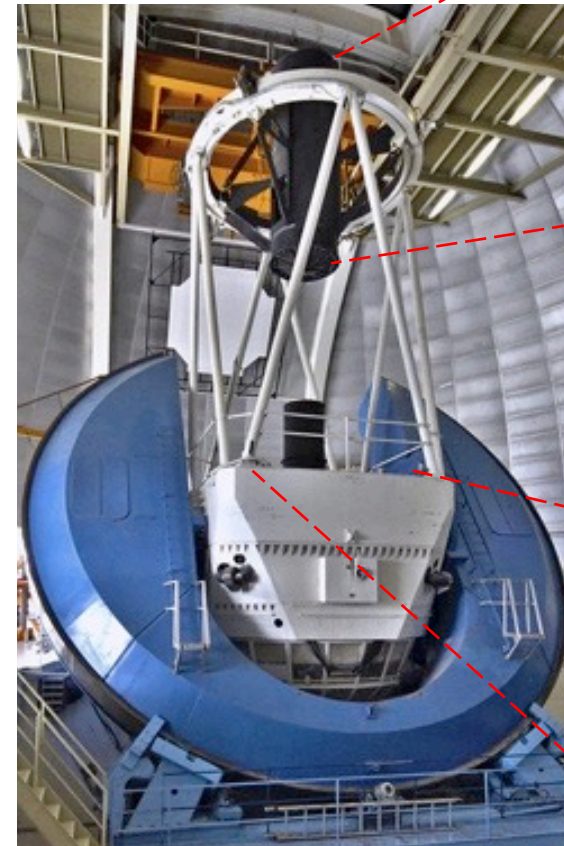**5000 fiber positioners**

6-lens wide-field
corrector (8 deg² FOV)

40m-long optical fibers
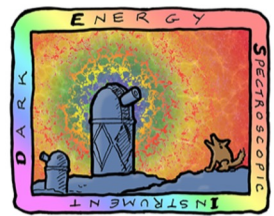
10 3-band spectrographs
(360nm – 980nm)

Lyα λ121.6 nm
down to z = 2.0

[OII] λ373 nm
up to z = 1.6

4m mirror
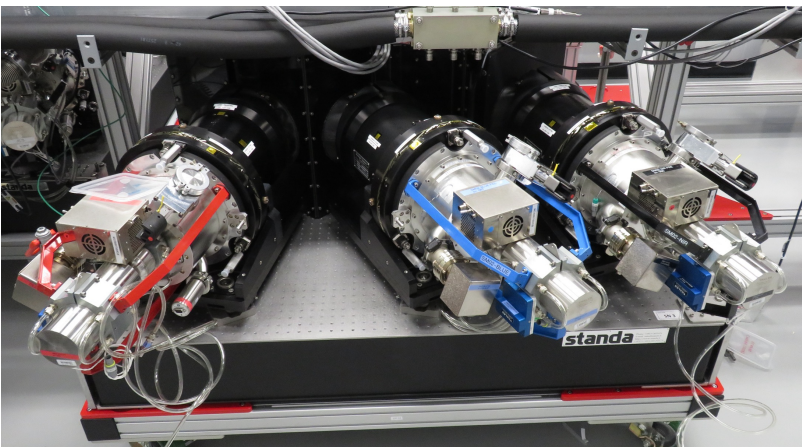
Nathalie Palanque-Delabrouille

9

40 million galaxies and quasars at 0 < z < 4

3 million QSOs
1.0 < z < 4.0

16 million ELGs
0.6 < z < 1.6

8 million LRGs
0.4 < z < 1.0

13 million Bright galaxies
0.0 < z < 0.4

4   12 Gyr
2   10 Gyr
Redshift
1   8 Gyr
0.7
Lookback time
0.2   2 Gyr

BAO precision goal

- 0.28% at z<1.1
- 0.39% at 1.1<z<1.9
- <1% at z>1.9

RSD precision goal

21 independent measurements to z<2.1 with median 5.2% precision
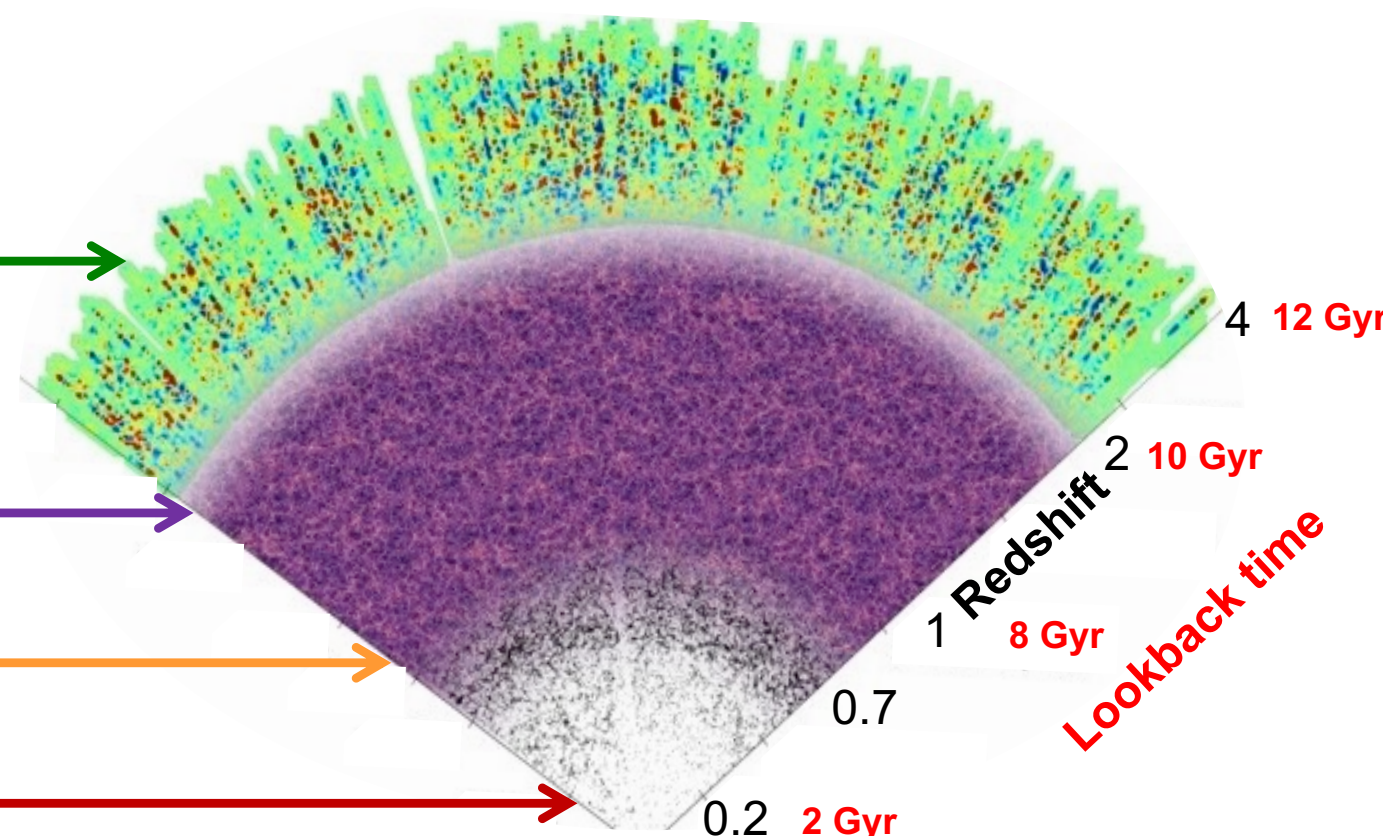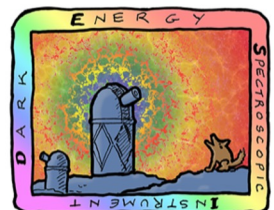
+10 million Milky Way stars

DESI

Year 1 sample

- 6M+ galaxies, quasars & Lyα forest data

- Blinded analysis
  - Catalog-level for tracers
  - Cosmology-level for Lyα

- Systematics uncertainty
  - 0.25% on α_{iso} and 0.3% on α_{AP} for tracers
  - 0.5% on α_{par} and α_{perp} for Lyα
  - Less than 5% increase of statistical uncertainty

Main/DARK : 2744/9929 completed tiles up to 20220611 (=28%, weighted=29%)

Dec. [deg]

Fraction of final coverage

Stats for the 20220611 night:
Moon illumination: 0.94
1 DARK tiles completed

R.A. [deg]

FracCov	Area	Fraction	ExpfacFraction
> 0.00	9721	0.65	0.66
≥ 0.25	6143	0.41	0.43
≥ 0.50	3424	0.23	0.24
≥ 0.75	1985	0.13	0.14
≥ 1.00	1522	0.10	0.11

Year-1 sample is
25% (ELGs) to 45% (QSOs)
of completed survey
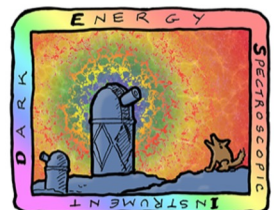
Lyman-alpha forest

Lyβ   **Lyα**

Neutral H absorption
along line of sight to distant
quasars
tracers of matter density

Q1422+2309 $z=3.62$
Lyα forest

Lya auto-correlation
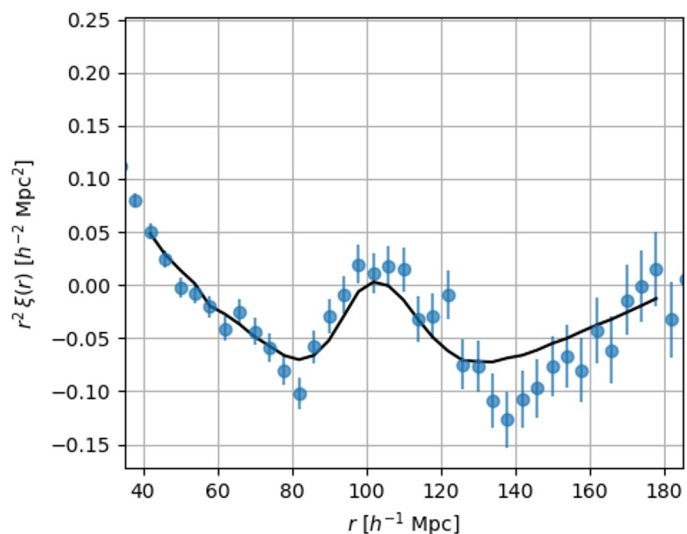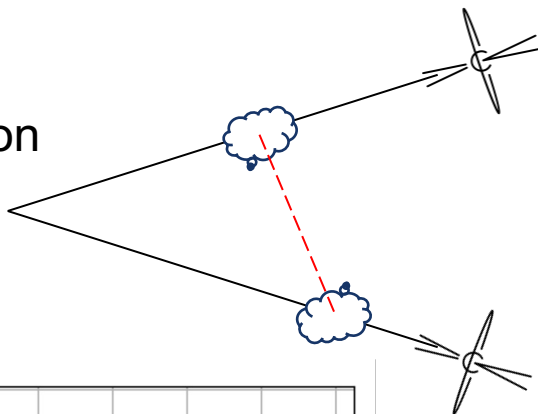
Lya-quasar cross-correlation
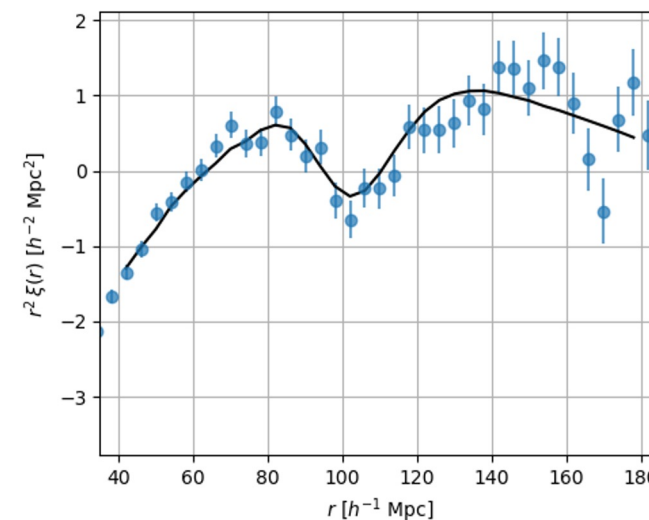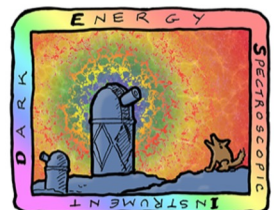
DESI DR1 BAO results at $z_{\rm eff} = 2.33$
- Lyα × Lyα
- Lyα × QSO
- Combined

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12

DARK ENERGY
SPECTROSCOPIC
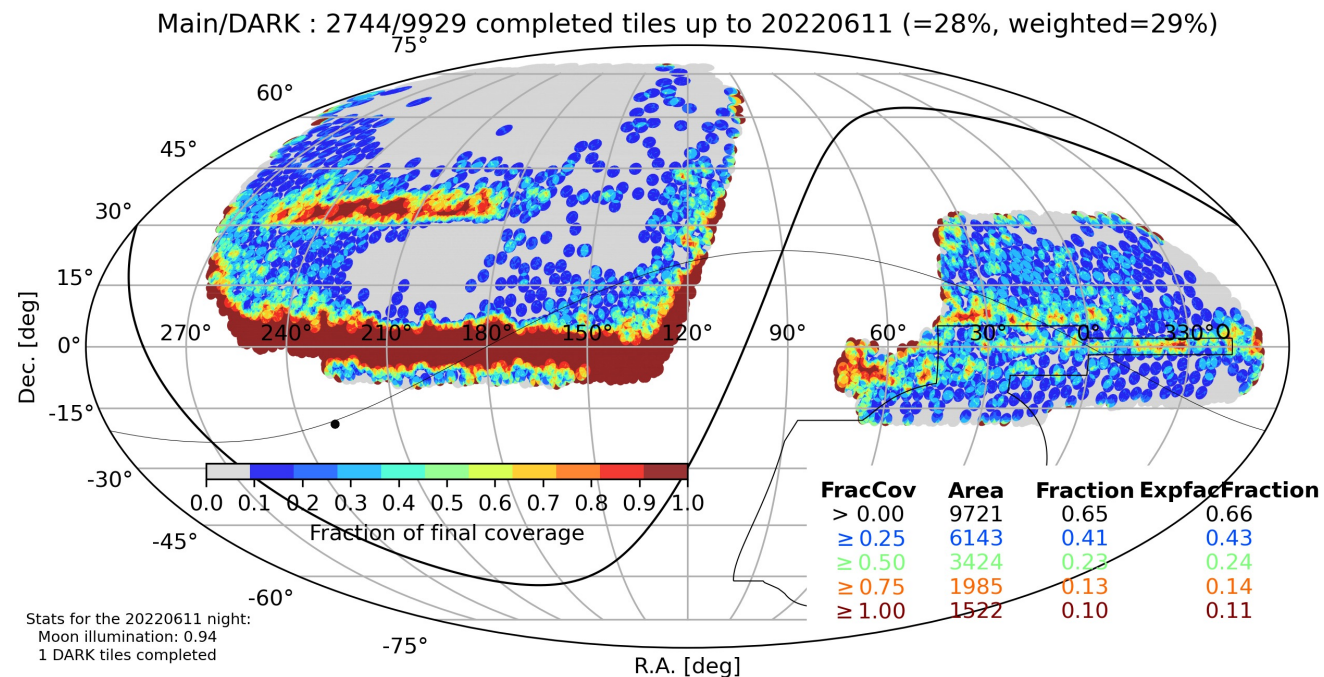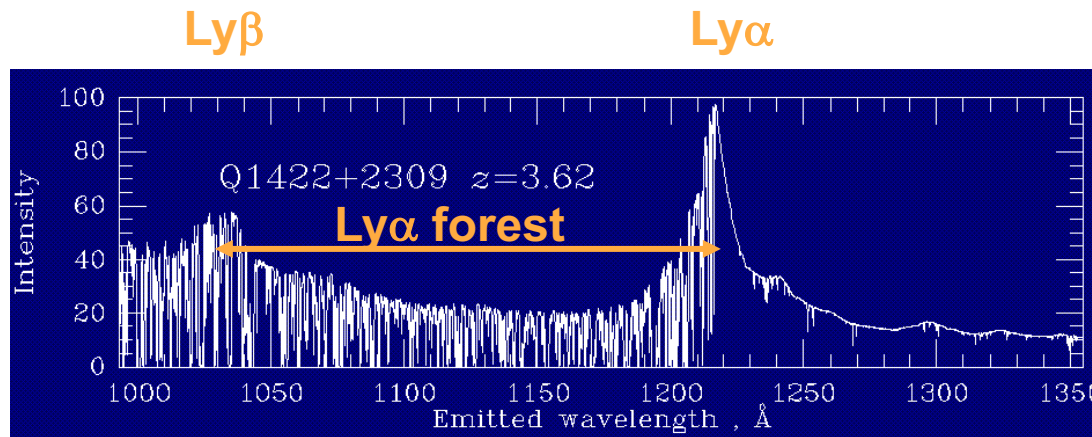INSTRUMENT
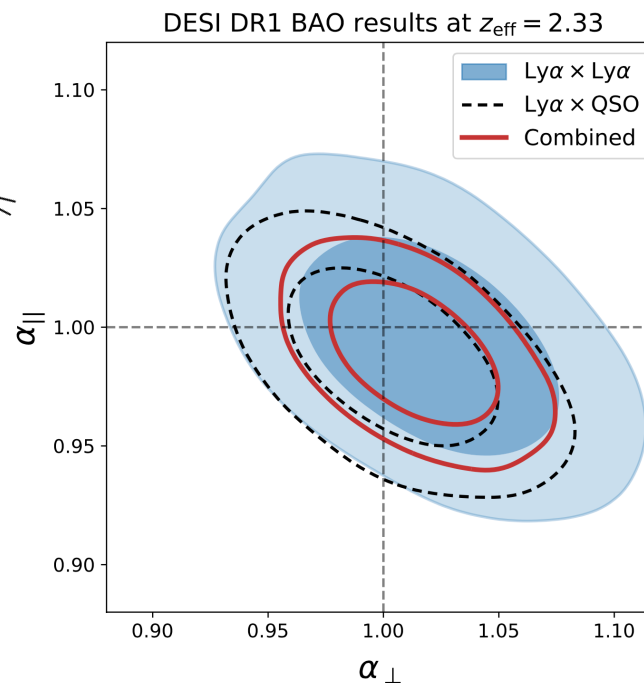
U.S. Department of Energy Office of Science

BAO data $\Delta\theta$ and $\Delta z \rightarrow D_M / r_d$ and D_H / r_d $\Rightarrow$ Ω_M and $H_0 r_d$

$$D_V = \left(z D_M(z)^2 D_H(z)\right)^{1/3}$$
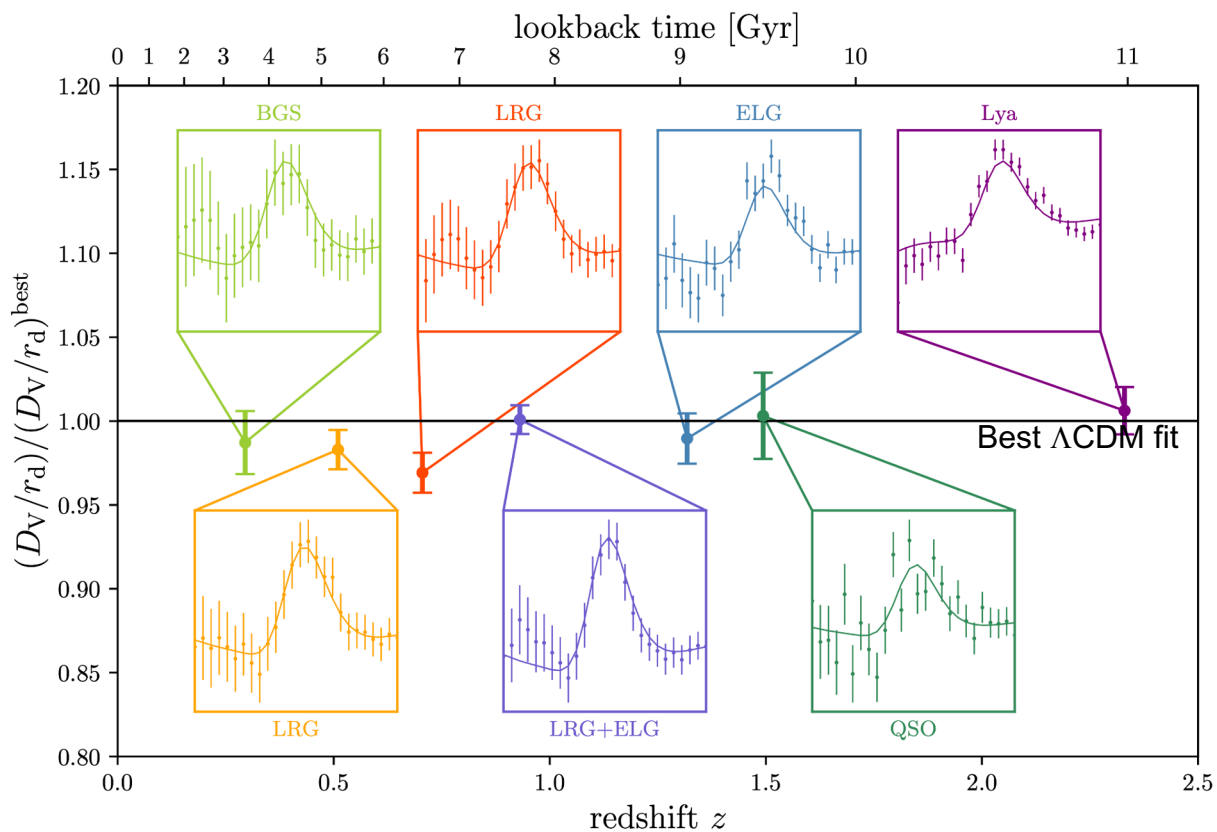
Excellent compatibility between tracers

Aggregated precision
on BAO distance scale $D_V / r_d = 0.5\%$
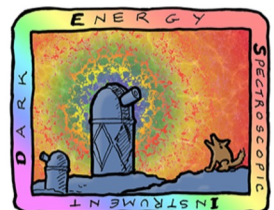
DARK ENERGY SPECTROSCOPIC INSTRUMENT

U.S. Department of Energy Office of Science

BAO data $\Delta\theta$ and $\Delta z \rightarrow D_M / r_d$ and D_H / r_d ➡️ Ω_M and $H_0 r_d$

Need r_d from other probe

$H_0 = (68.53 \pm 0.80)$ km s^{-1} Mpc^{-1} → **1.2%**

DESI + BBN ($\Omega_b \rightarrow r_d$)

$H_0 = (68.52 \pm 0.62)$ km s^{-1} Mpc^{-1} → **0.9%**

DESI + BBN + θ⋆ (Planck angular acoustic scale)

- Consistent with SDSS
- In agreement with CMB
- In **3.7σ** tension with SH0ES

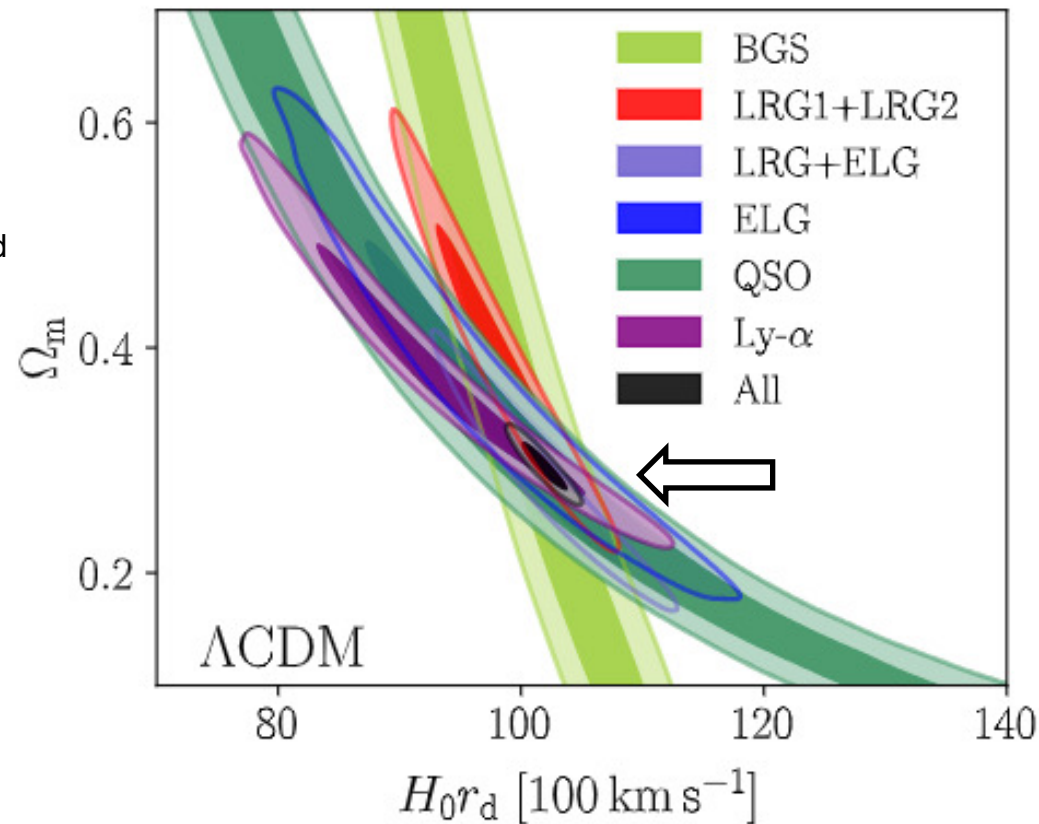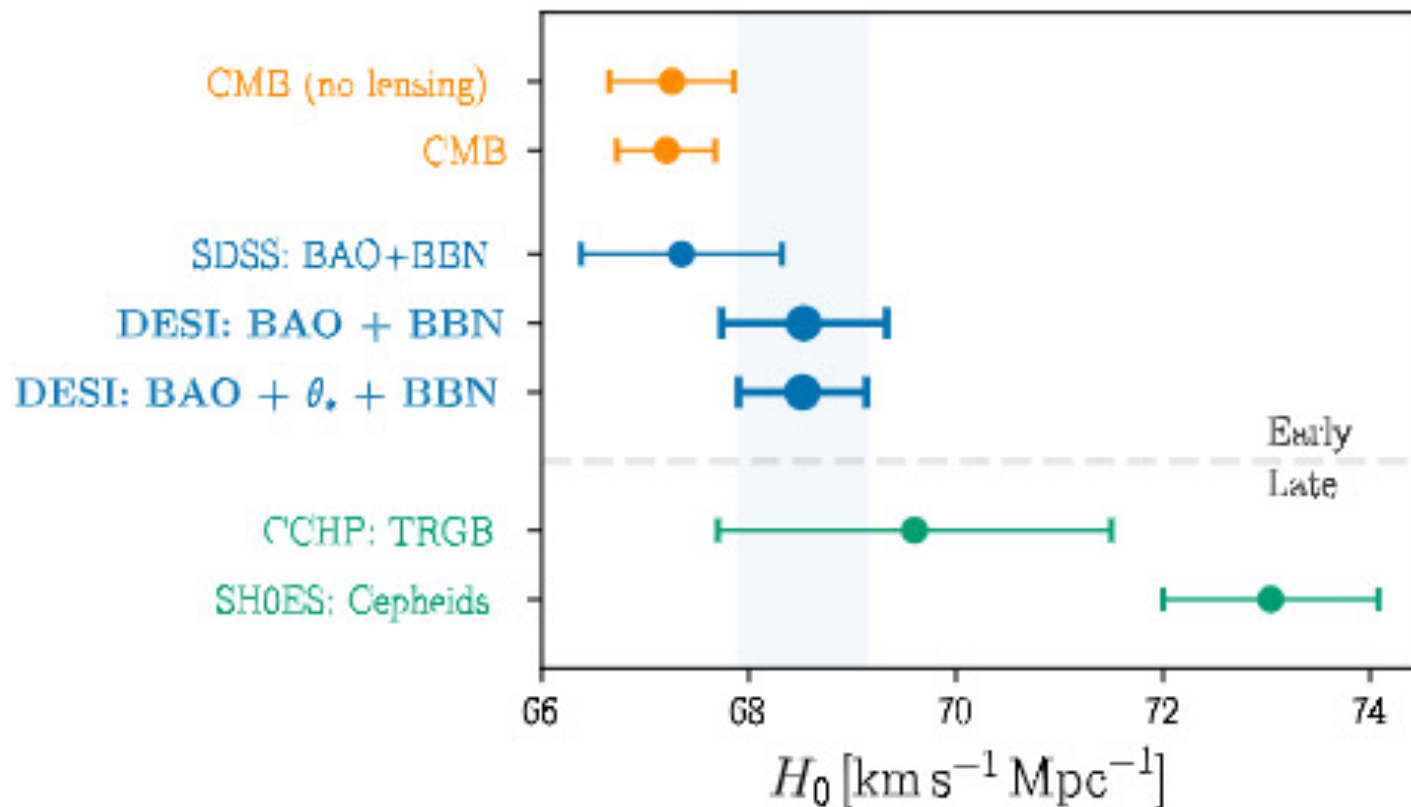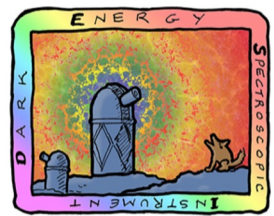**DARK ENERGY SPECTROSCOPIC INSTRUMENT**

U.S. Department of Energy Office of Science

DESI only:

$\Omega_m = 0.293 \pm 0.015$ (**5.1%**)
$w = -0.99 \pm 0.15$ (**15.2%**)

DESI+CMB+SN (e.g. PantheonPlus):

$\Omega_m = 0.3095 \pm 0.0065$ (**2.1%**)
$w = -0.997 \pm 0.025$ (**2.5%**)

Assuming a **constant** EOS, DESI BAO compatible with a cosmological constant but …
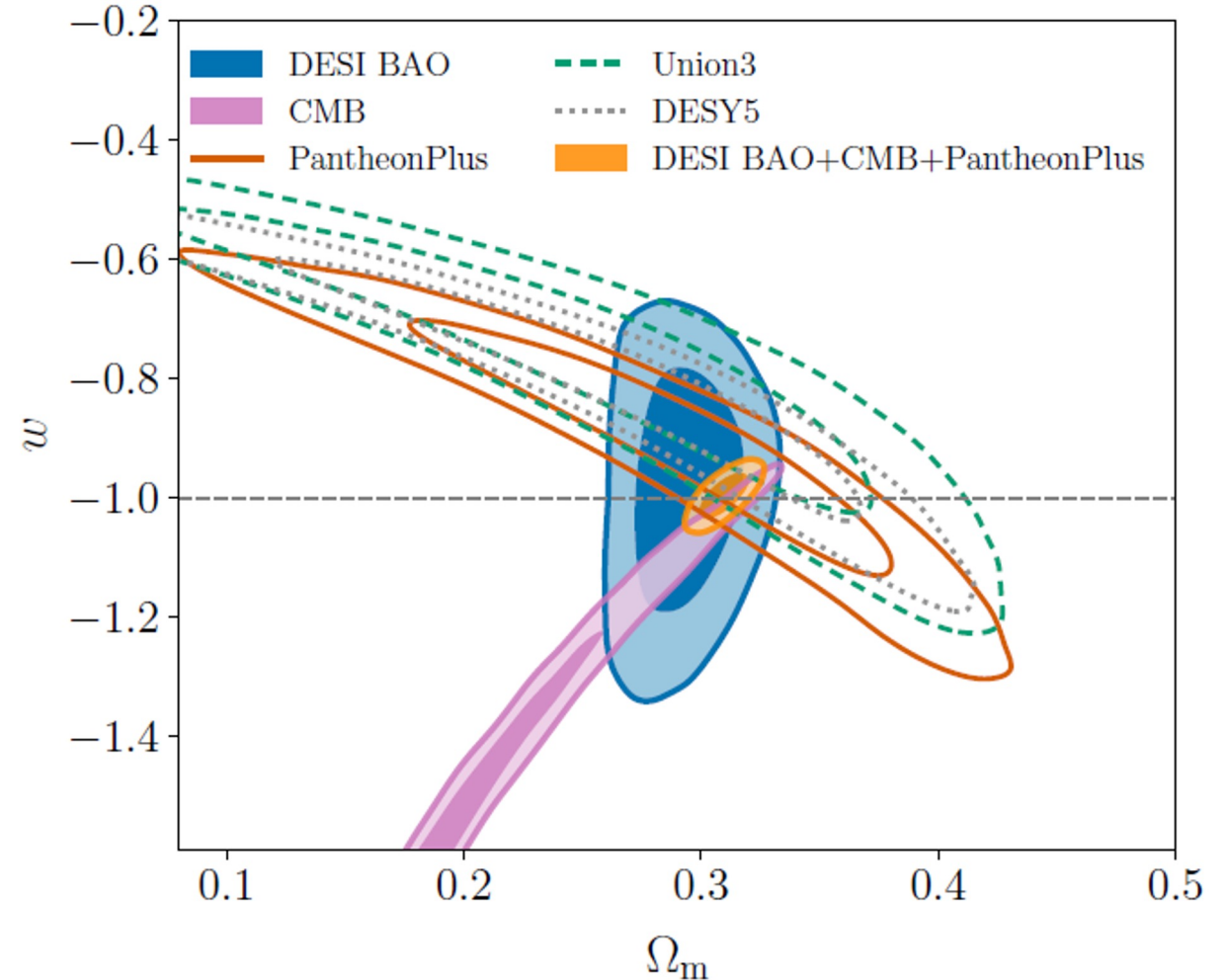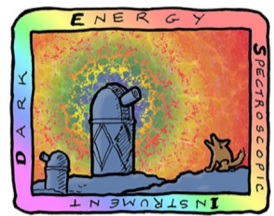
CMB =
Planck (Temp. & Polar.)
& Planck + ACT DR6 lensing
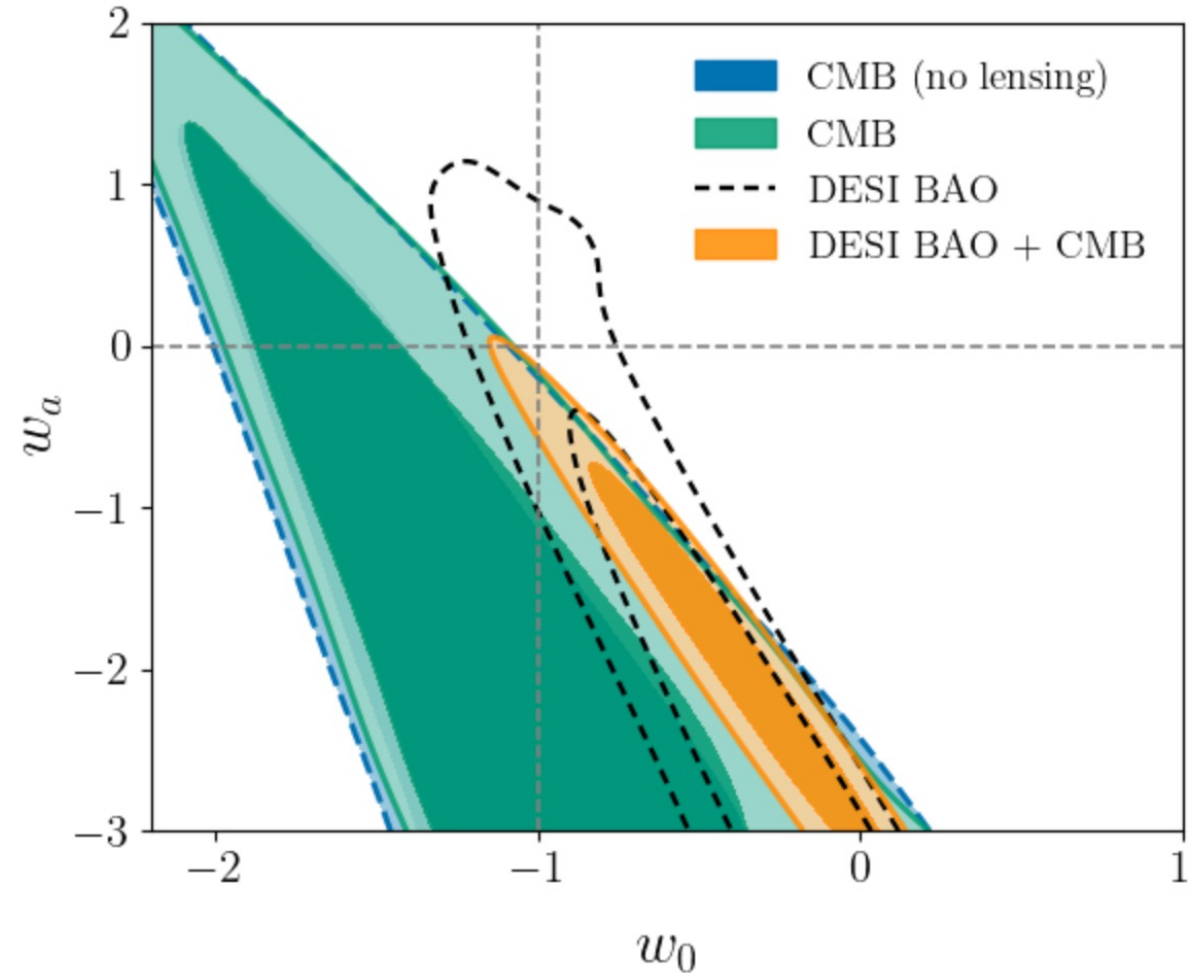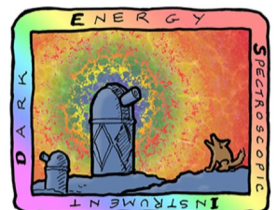
Varying EoS (CPL) $w(a) = w_0 + (1-a)w_a$

$$w_0 = -0.45^{+0.34}_{-0.21} \qquad w_a = -1.79^{+0.48}_{-1.00}$$

DESI + CMB $\Longrightarrow$ 2.6σ

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Dark Energy – w_0 w
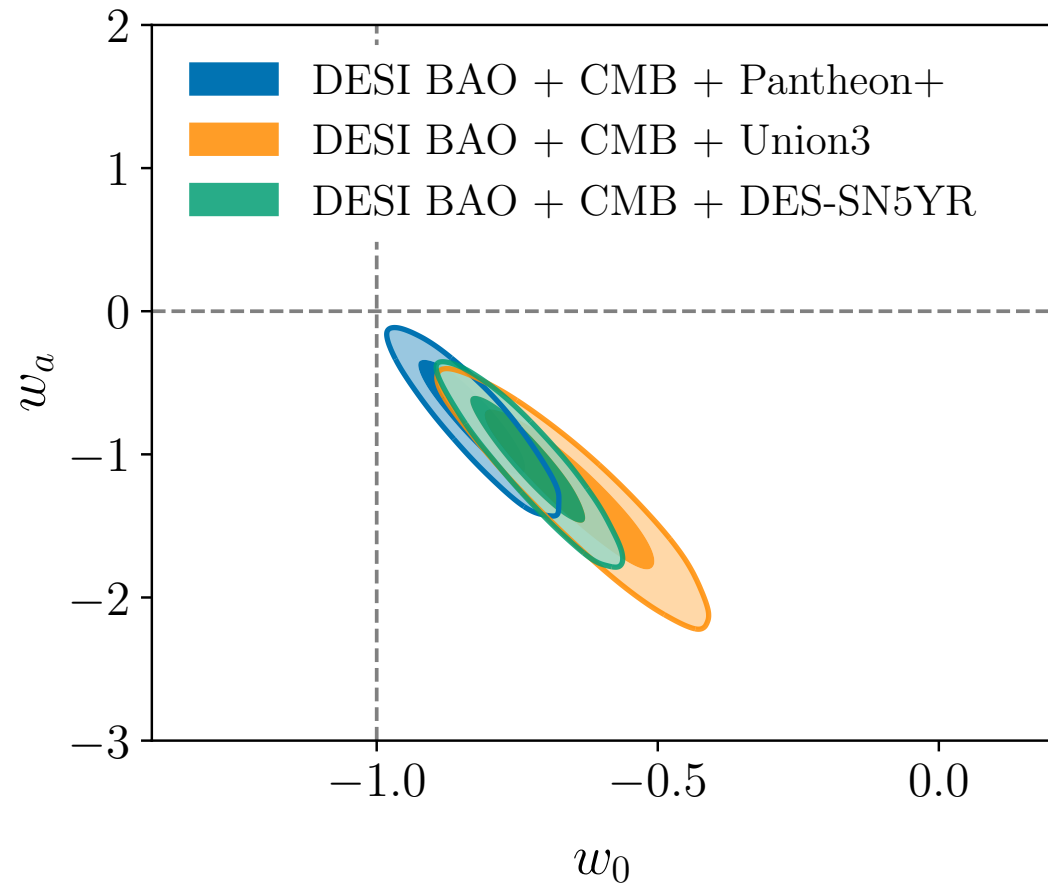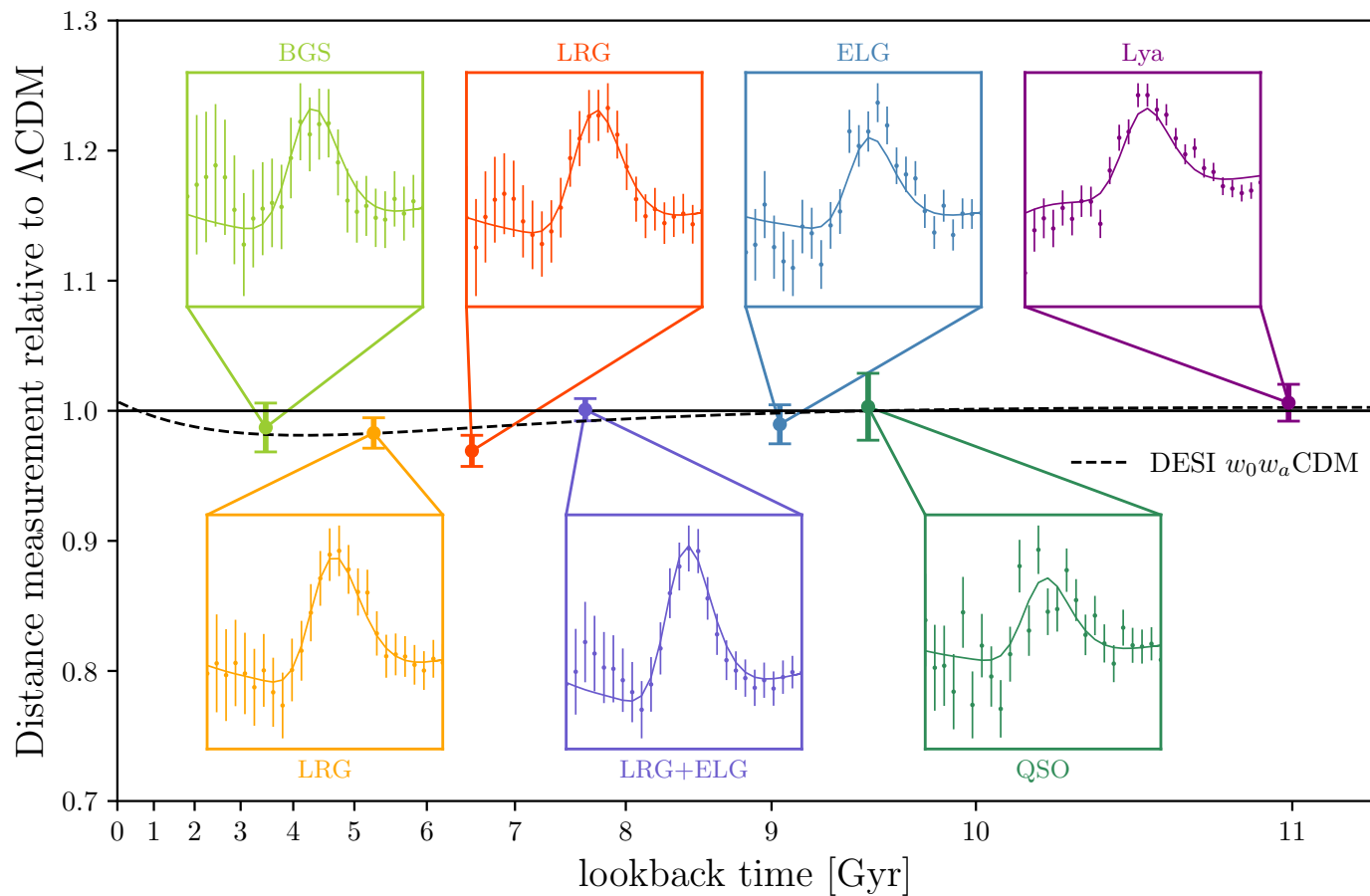
Pantheon+: 2.5σ

Union3: 3.5σ

DES-SN5Yr: 3.9σ

DESI overview and updates

DESI year 1 BAO results

DESI – more coming up!

Beyond DESI

Additional results from DESI year 1 coming up

- **RSD analysis (full shape clustering)**
  - $f\sigma_8(z)$

    Modified gravity
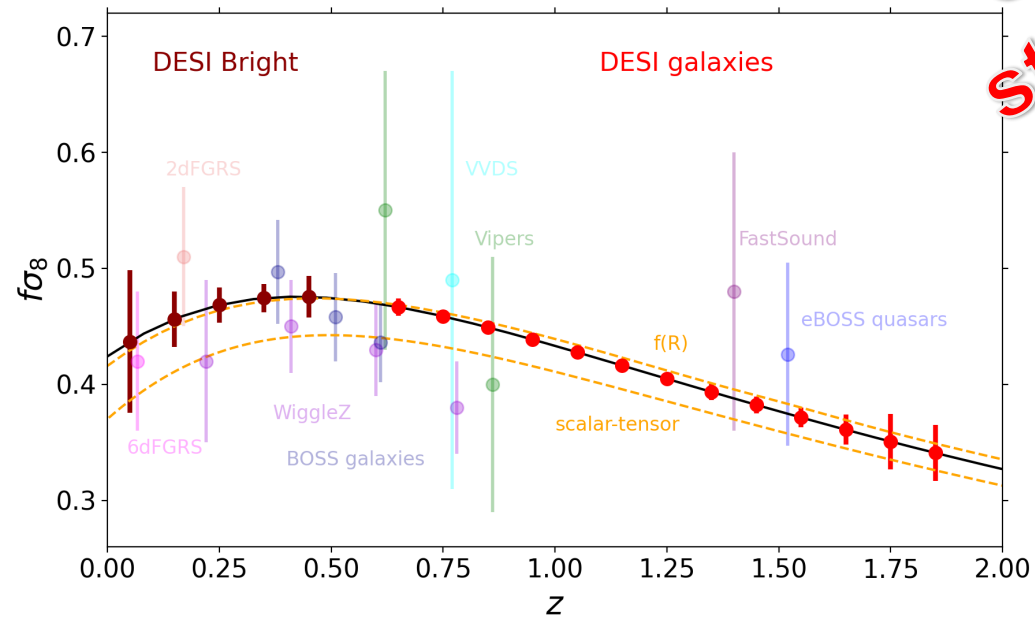
- **Full shape measurement on large scales**
  - Non-Gaussianity f_{NL}

    Inflation

Currently still blinded

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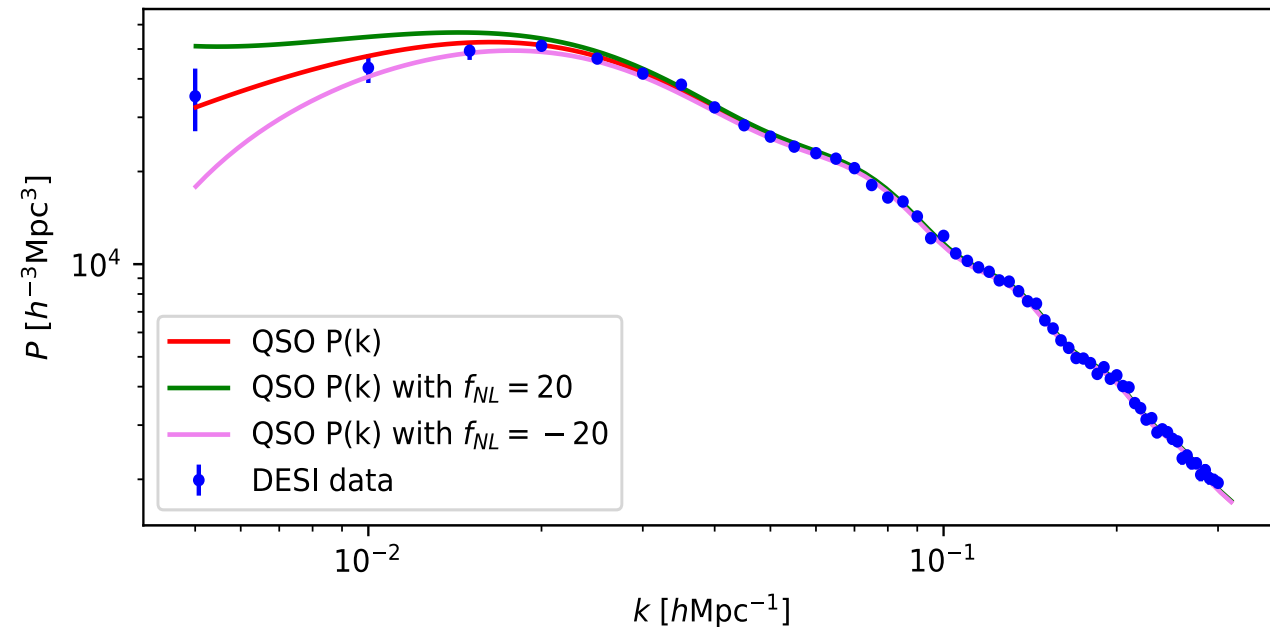
DESI year 3 – data sample

Year 1 – until July 2022 (Contreras fire)

Year 3 – until April 9, 2024 (fiber rack failure)

31M galaxies & quasars
11M stars

Survey about 70% complete
(5 months ahead of schedule)

Main/DARK : 6671/9929 completed tiles up to 20240409 (=67%, weighted=68%)

Stats for the 20240409 night:
Moon illumination: 0.04
28 DARK tiles completed

Npass	Area	Fraction	ExpfacFraction
≥ 1	13262	0.89	0.88
≥ 2	11608	0.79	0.79
≥ 3	9922	0.69	0.70
≥ 4	8526	0.61	0.63
≥ 5	7282	0.55	0.57
≥ 6	5355	0.51	0.53
≥ 7	2135	0.46	0.48

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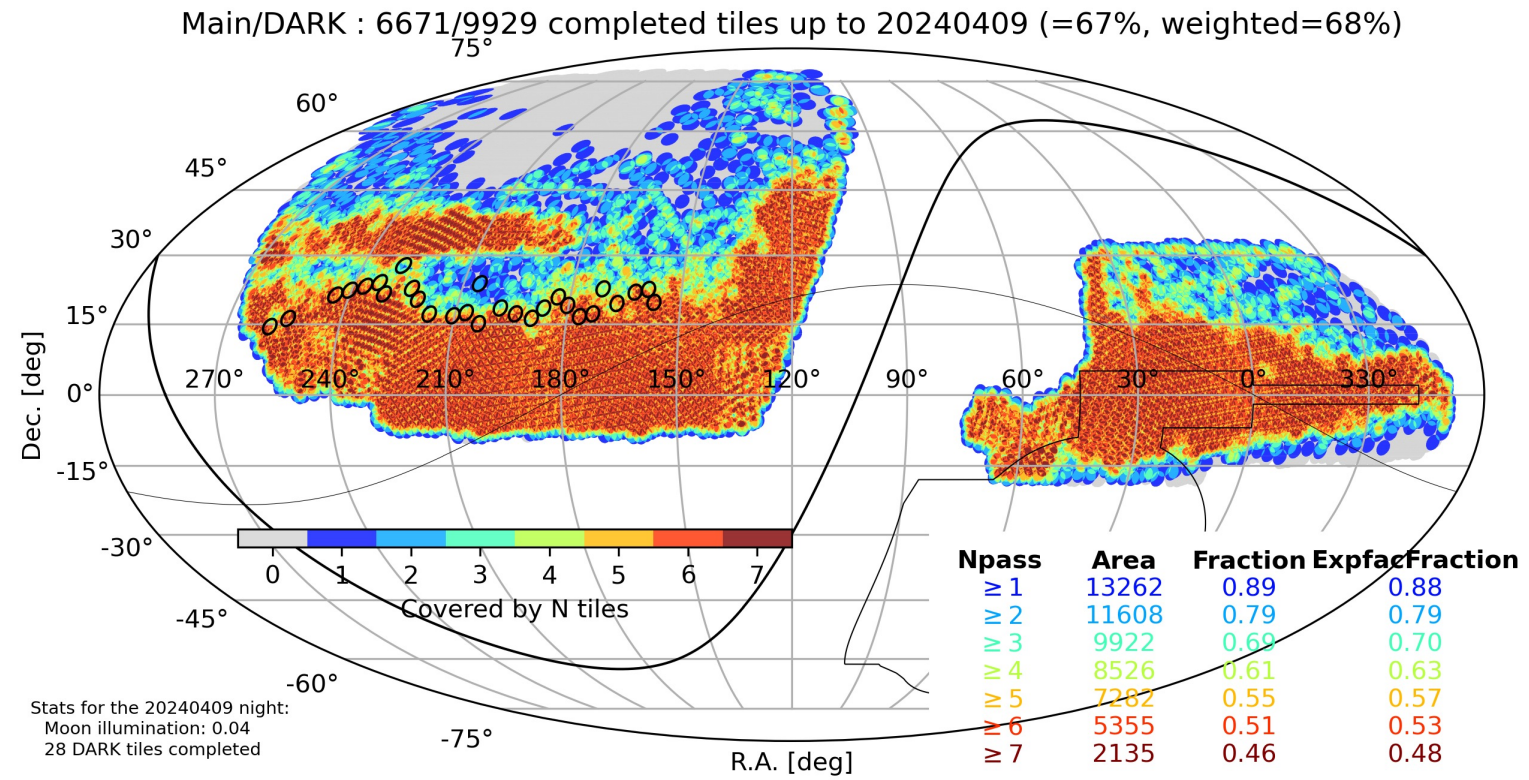
DESI year 3 – beyond BAO and RSD

Enhanced scope compared to year 1

- **Improved precision and robustness of clustering**
  - Higher-order statistics in galaxy and quasar clustering
  - Alcock-Paczynski effect in Lyα forest studies
  - Systematic characterization of the galaxy and quasars for understanding and robustness of tracer properties

- **New techniques and data sets for structure growth**
  - Cross-correlations with galaxy lensing to constrain RSD nuisance terms
  - Cross-correlation with CMB lensing to measure sigma8(z)
  - Use of peculiar velocities for z<0.1 where survey volume limits RSD precision

- **Stellar spectra + Gaia for mass distribution of Milky Way**
  - Local mass density (cross-section constraints in direct detection DM experiments)
  - Constrain on DM models from DESI stellar data

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DESI overview and updates

DESI year 1 BAO results

DESI – coming up!

Beyond DESI

Timeline: DESI / DESI-2 / Spec-S5

- DESI extended to Dec. 2028 (nominal 5 years +2.5 year extension)

- DESI-2:   6-year survey starting Jan 2029

- Spec-S5:   DOE-supported R&D starting 2026

  Survey starting when 10-year LSST imaging available

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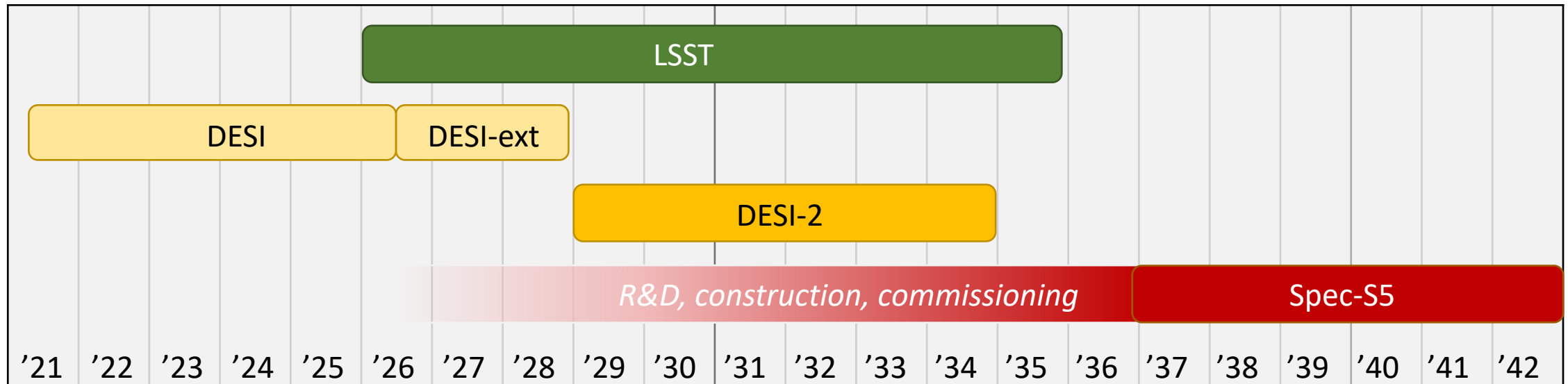
DESI extended (→ end 2028)

Two options (or both!)

- Extend footprint to dec = -30° (14k deg^2 → 17k deg^2)

  → improve precision

  → increase overlap with Southern observatories
  CMB (ACT, SO) and optical (DES, LSST)

- Increase number of passe: denser
  mapping of BGS, ELG, (LRG?)

  → improve completeness
  (+2 additional layers)

  → improve systematic uncertainties

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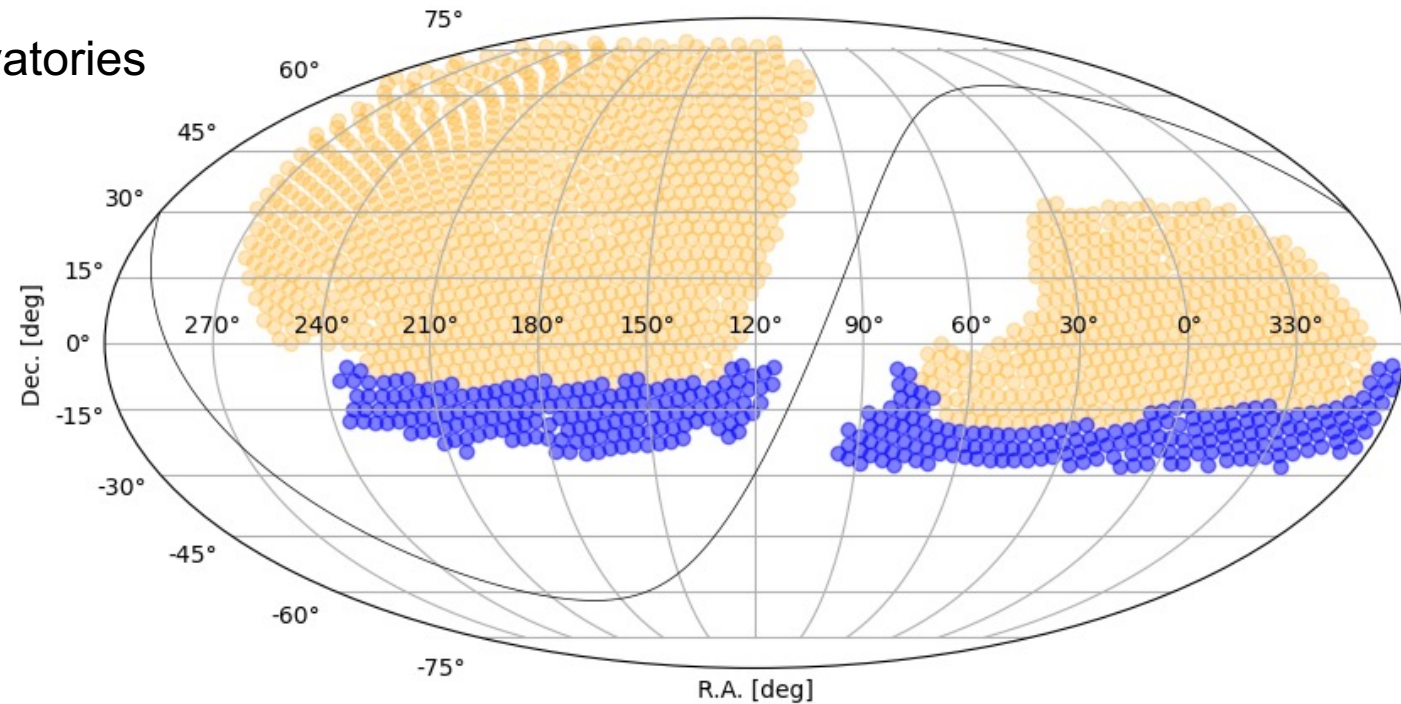
Beyond DESI

Current focus

Accelerating epoch

Testing concordance cosmology

Dark energy (expansion history)

Inflation (non-gaussianity)
Inflation (primordial features)
Indirect expansion

Inflation (energy scale)

Acoustic Oscillations

Modified gravity

Light relics
Neutrinos

Light relics
Neutrinos

Astro. probes of dark matter

Spatial scale (Mpc)

10^3

10^2

10^{-3}

redshift

0

1

2

6

1100

Nathalie Palanque-Delabrouille

From Kyle Dawson

Beyond DESI

Nathalie Palanque-Delabrouille

From Kyle Dawson

DESI-2

(cf. Christophe Yèche & Martin White)

Two-pronged program

- **High-density survey at low z (z<1)**
  - Density splits → sample variance reduction → beating cosmic variance
  - Complete selection of low-z galaxies – (LSST) SNIa hosts and faint galaxies for photo-z calibration
  - z<1 galaxies for Galaxy – Galaxy lensing and CMB cross-correlation
  - Dwarf galaxies & stellar spectroscopy for Dark Matter science

> Simple target selection
>
> Increased density of current targets (optimization in progress)

- **High-z survey (z>2)**
  - Primordial physics (more linear modes, well correlated with initial conditions)

> Challenging target select.
>
> Pilot surveys confirmed LBG and LAE selection (new imaging for LAE in progress)

Nathalie Palanque-Delabrouille

US HEP roadmap on future spectroscopic projects

P5: particle physics roadmap for next decade

P5 report: Strong endorsement for Spec-S5

Spec-S5 holds great promise to advance our understanding and reach key theoretical benchmarks in several areas: inflationary physics …, late-time cosmic acceleration, light relics, neutrino masses, and dark matter.

cf. Kyle Dawson's and David Schlegel's talks

Nathalie Palanque-Delabrouille

Conclusions

- Intriguing results from first-year DESI BAO

    Varying dark-energy?

- A lot more to expect from DESI

    Full-shape information $\rightarrow$ Modified gravity, Inflation

    Improved precision with more data (statistics-limited results) $\rightarrow$ dark energy, neutrino mass

A healthy future for future spectroscopic surveys

Nathalie Palanque-Delabrouille