DARK ENERGY SPECTROSCOPIC INSTRUMENT

U.S. Department of Energy Office of Science

Spectral Energy Distribution Modeling $\gg 10^7$ DESI Spectra

John Moustakas

Siena College

on behalf of the DESI Collaboration

Pan-Survey SED Fitting Forum

2025 February 10

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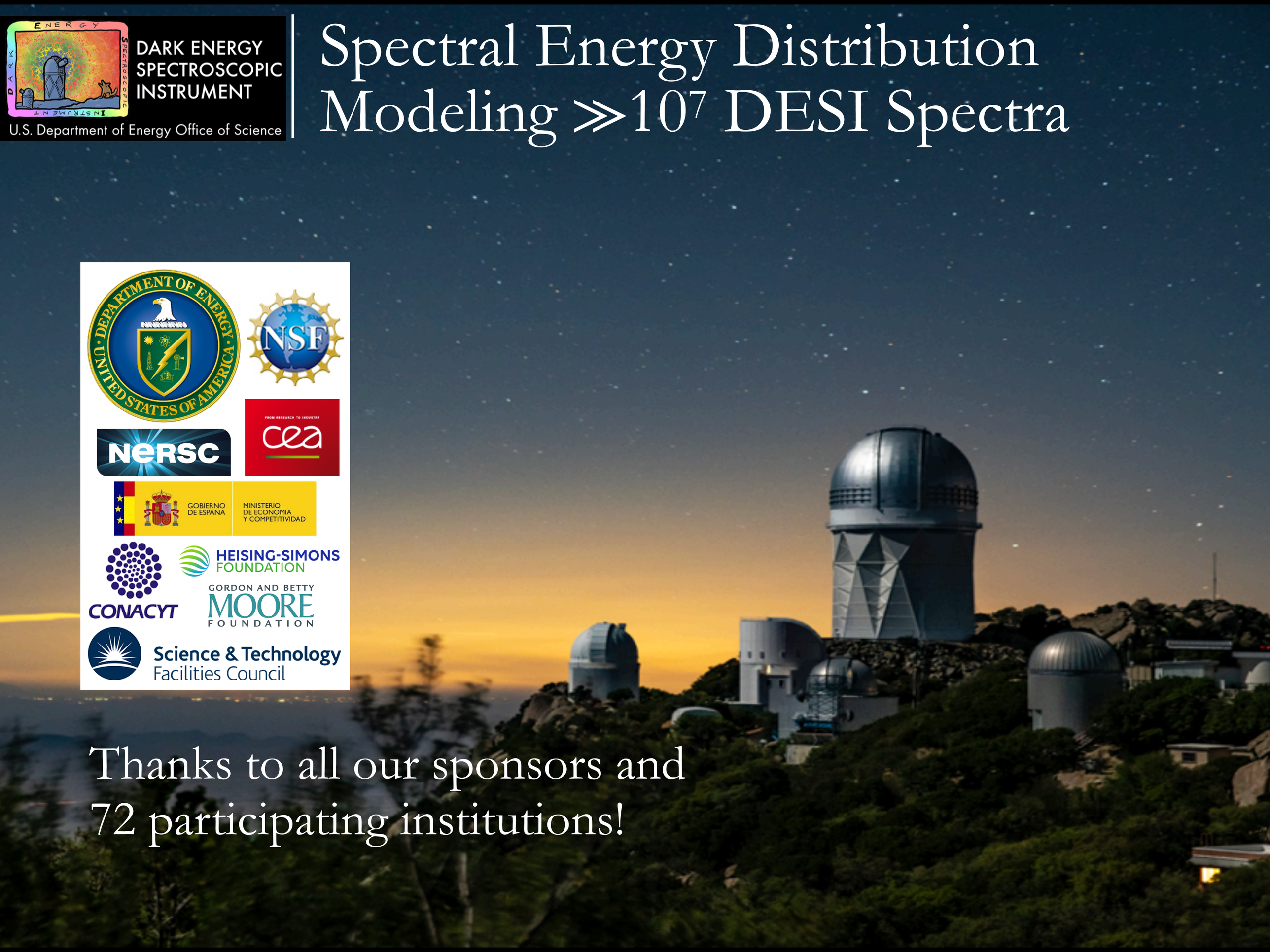

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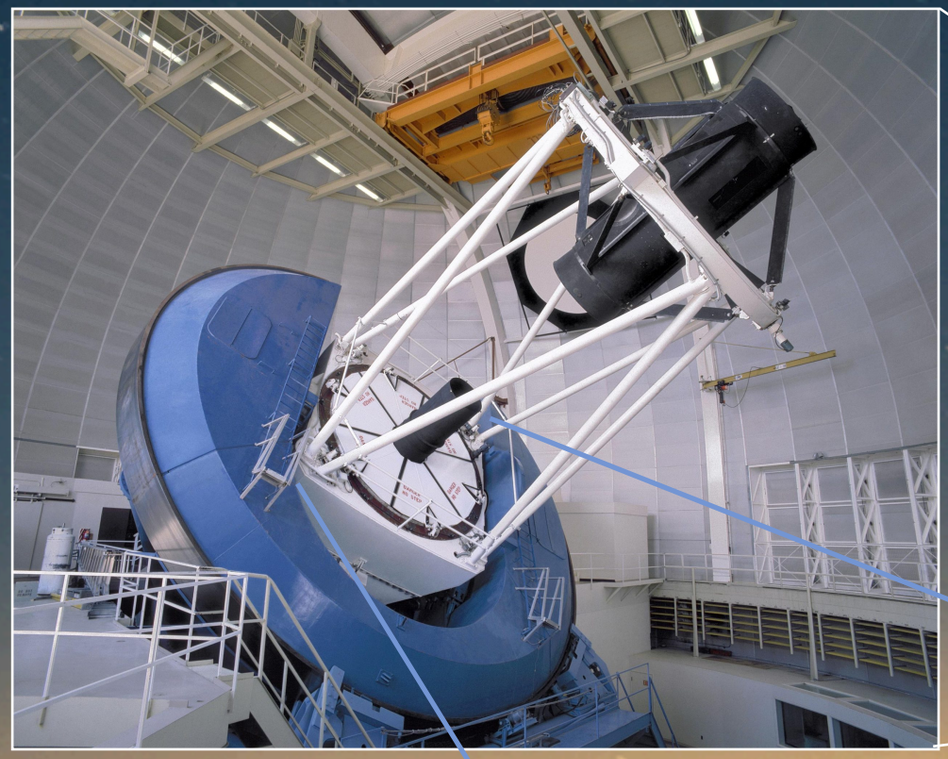
Dark Energy Spectroscopic Instrument (DESI)



DESI is a highly multiplexed optical multi-fiber instrument installed at the 4-meter Mayall telescope at Kitt Peak, AZ.

https://dkirkby.github.io/desipano

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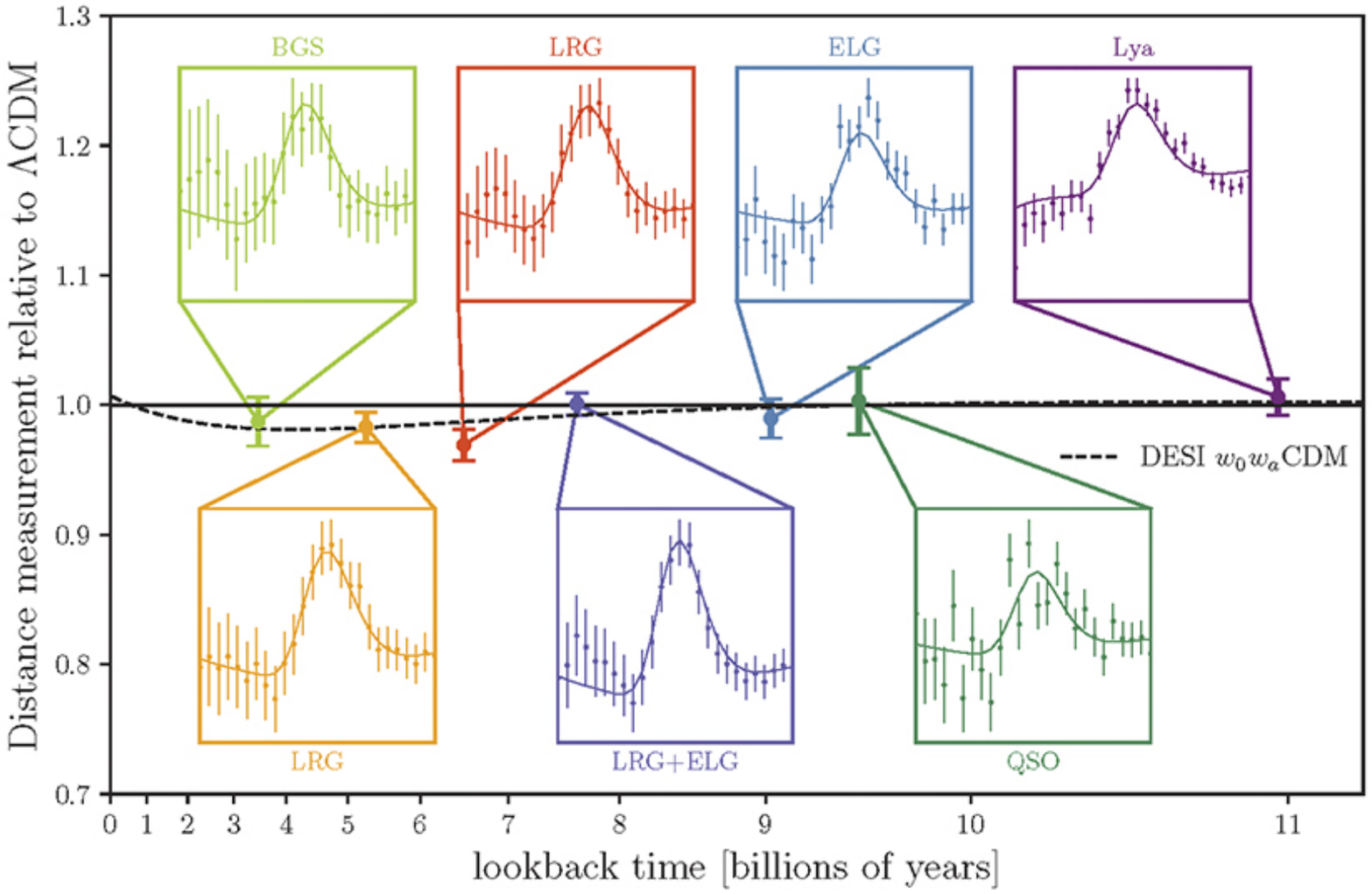
As the first Stage-IV dark-energy experiment, DESI is already delivering transformational precision-cosmological results.



DESI Year-1 data favor (by 2.5-3.9σ) a time-dependent dark-energy equation of state and general relativity for the theory of gravity on cosmological scales.

Stay tuned for Year-3 BAO results on 2025 March 19!

https://www.desi.lbl.gov/2024/04/04/desi-y1-results-april-4-guide

- DESI Collaboration et al., DESI 2024 II: Sample Definitions, Characteristics, and Two-point Clustering Statistics
- DESI Collaboration et al., DESI 2024 III: Baryon Acoustic Oscillations from Galaxies and Quasars
- DESI Collaboration et al., DESI 2024 IV: Baryon Acoustic Oscillations from the Lyman Alpha Forest
- DESI Collaboration et al., DESI 2024 V: Full-Shape Galaxy Clustering from Galaxies and Quasars
- DESI Collaboration et al., DESI 2024 VI: Cosmological Constraints from the Measurements of Baryon Acoustic Oscillations
- DESI Collaboration et al., DESI 2024 VII: Cosmological Constraints from the Full-Shape Modeling of Clustering Measurements

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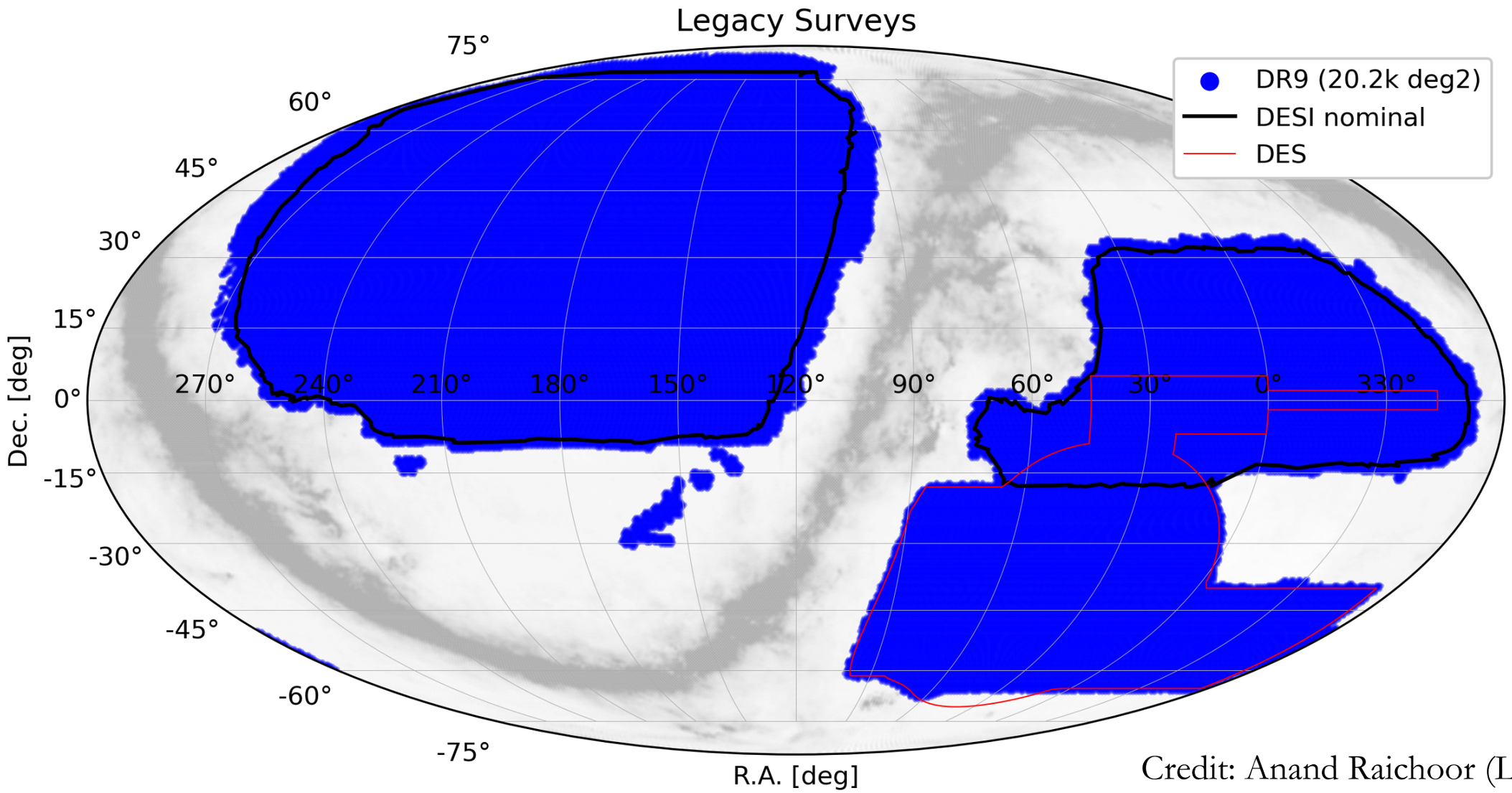
DESI selects targets from ~14,000 deg^2 of the Legacy Imaging Surveys Data Release 9.



Credit: Anand Raichoor (LBNL)

- Data Release 9: https://legacysurvey.org/dr9
  grz + forced unWISE (W1-W4) photometry
- Interactive Sky Viewer: https://legacysurvey.org/viewer
- Siena Galaxy Atlas (SGA-2020): https://sga.legacysurvey.org

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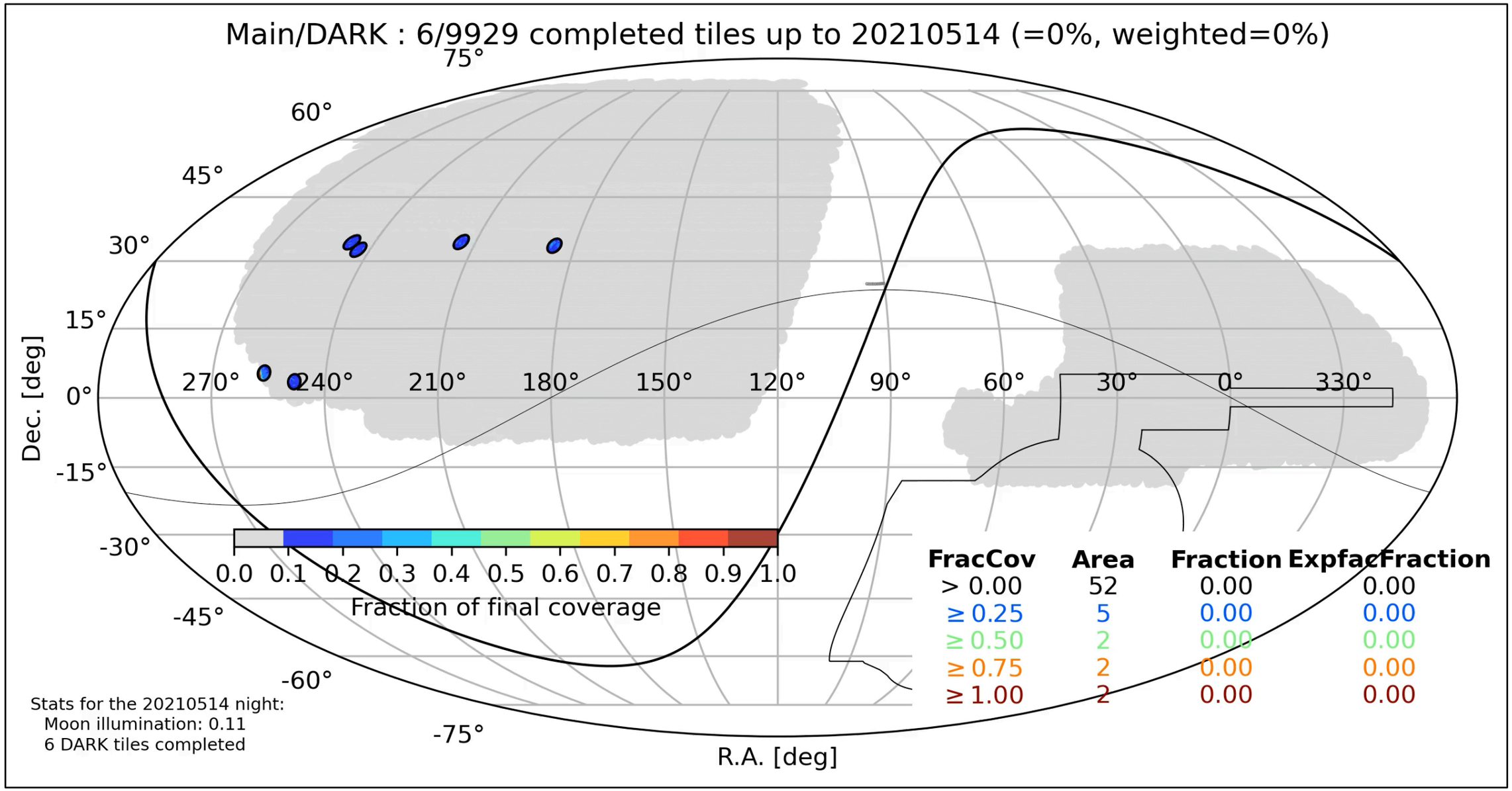
5-year DESI Main Survey began in May 2021 and is currently ~6 months ahead of schedule!



Credit: Anand Raichoor (LBNL)

Dark Program

DARK ENERGY SPECTROSCOPIC INSTRUMENT

U.S. Department of Energy Office of Science

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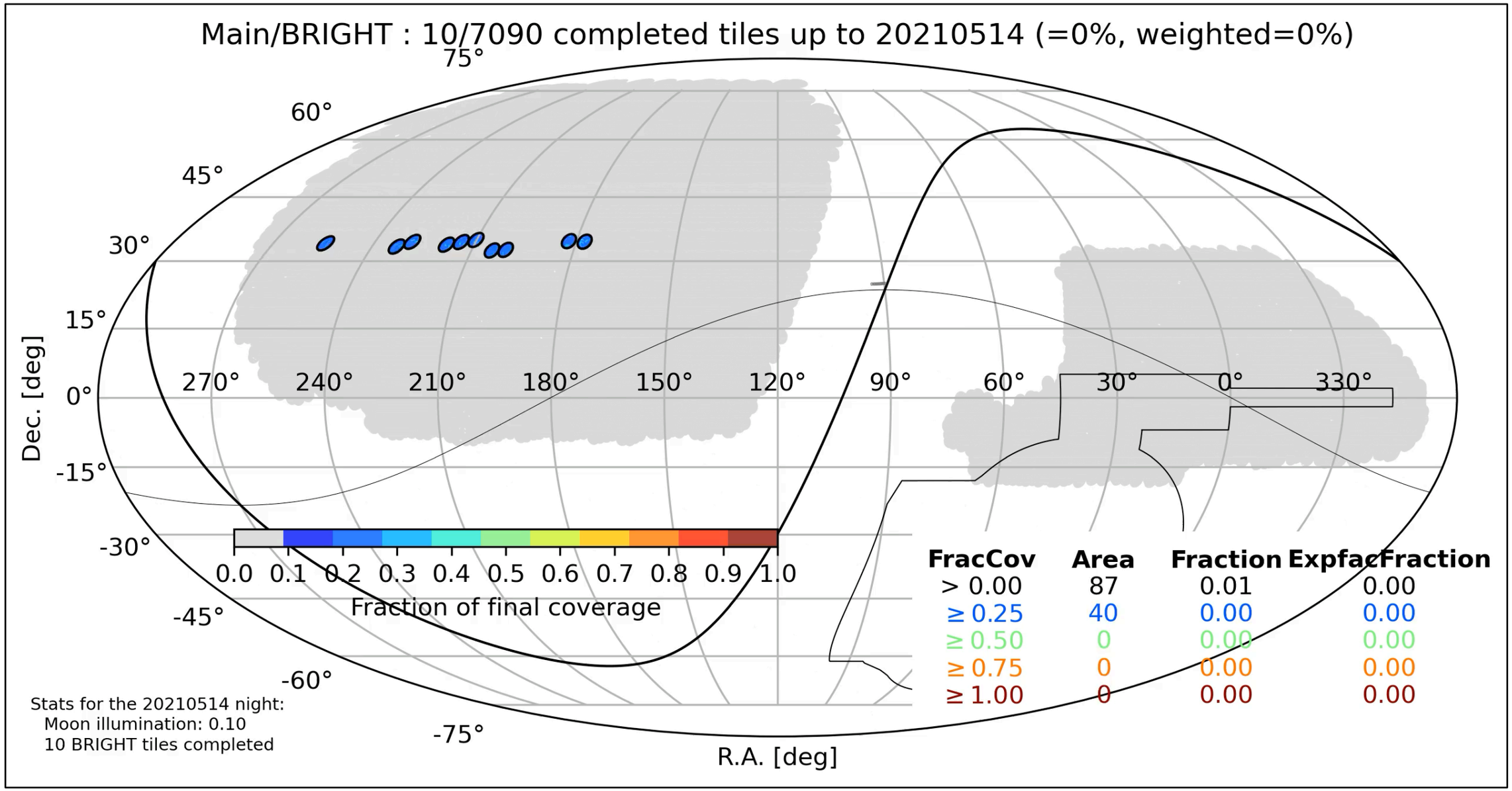

Credit: Anand Raichoor (LBNL)

Bright Program

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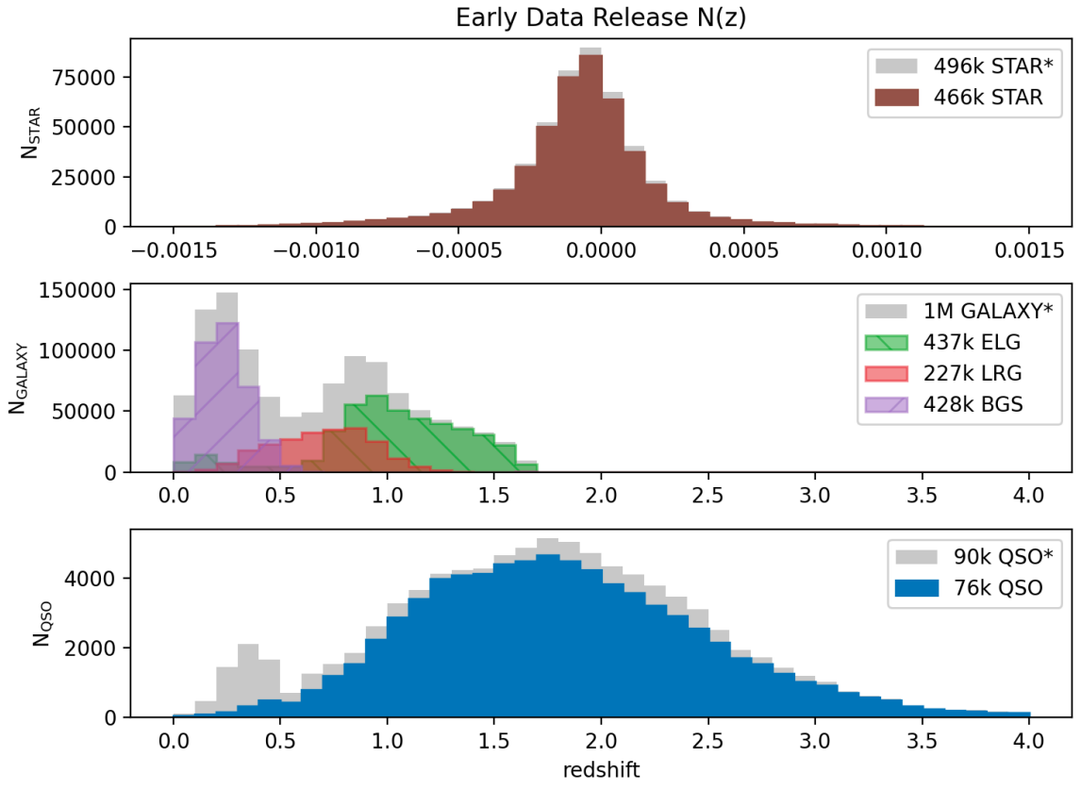
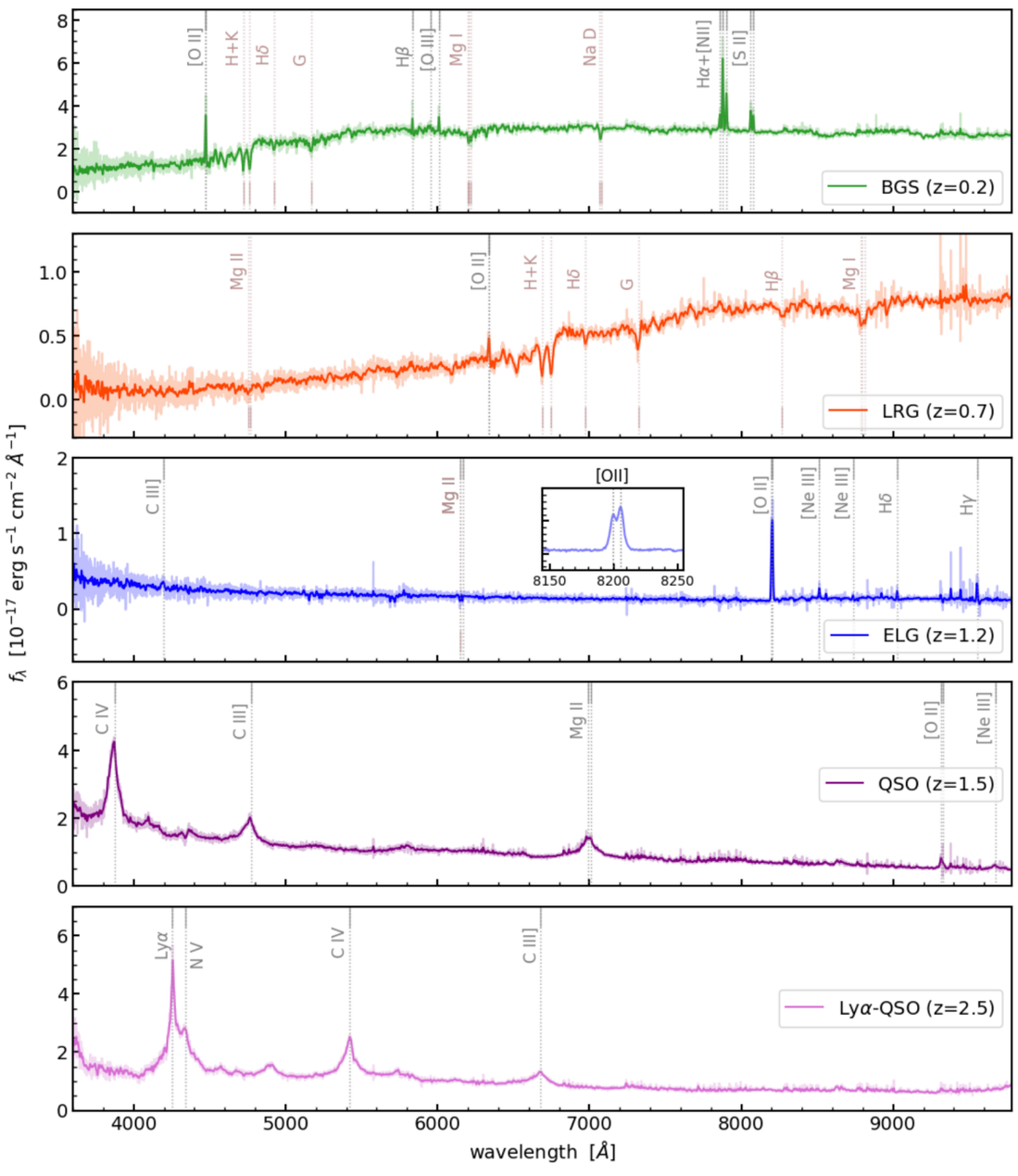
DESI Early Data Release (EDR) has been publicly available since June 2023; roughly 1.5M spectra.



https://data.desi.lbl.gov/doc/releases/edr

Camera	Spectral Range	Resolution
B	3600-5800 A	2000-3500
R	5760-7620 A	3400-4800
Z	7520-9824 A	3800-5200



Credit: Stephanie Juneau (NOIRLab)

- DESI Collaboration et al. 2024a: Validation of the Scientific Program for the Dark Energy Spectroscopic Instrument
- DESI Collaboration et al. 2024b: The Early Data Release of the Dark Energy Spectroscopic Instrument

DARK ENERGY SPECTROSCOPIC INSTRUMENT

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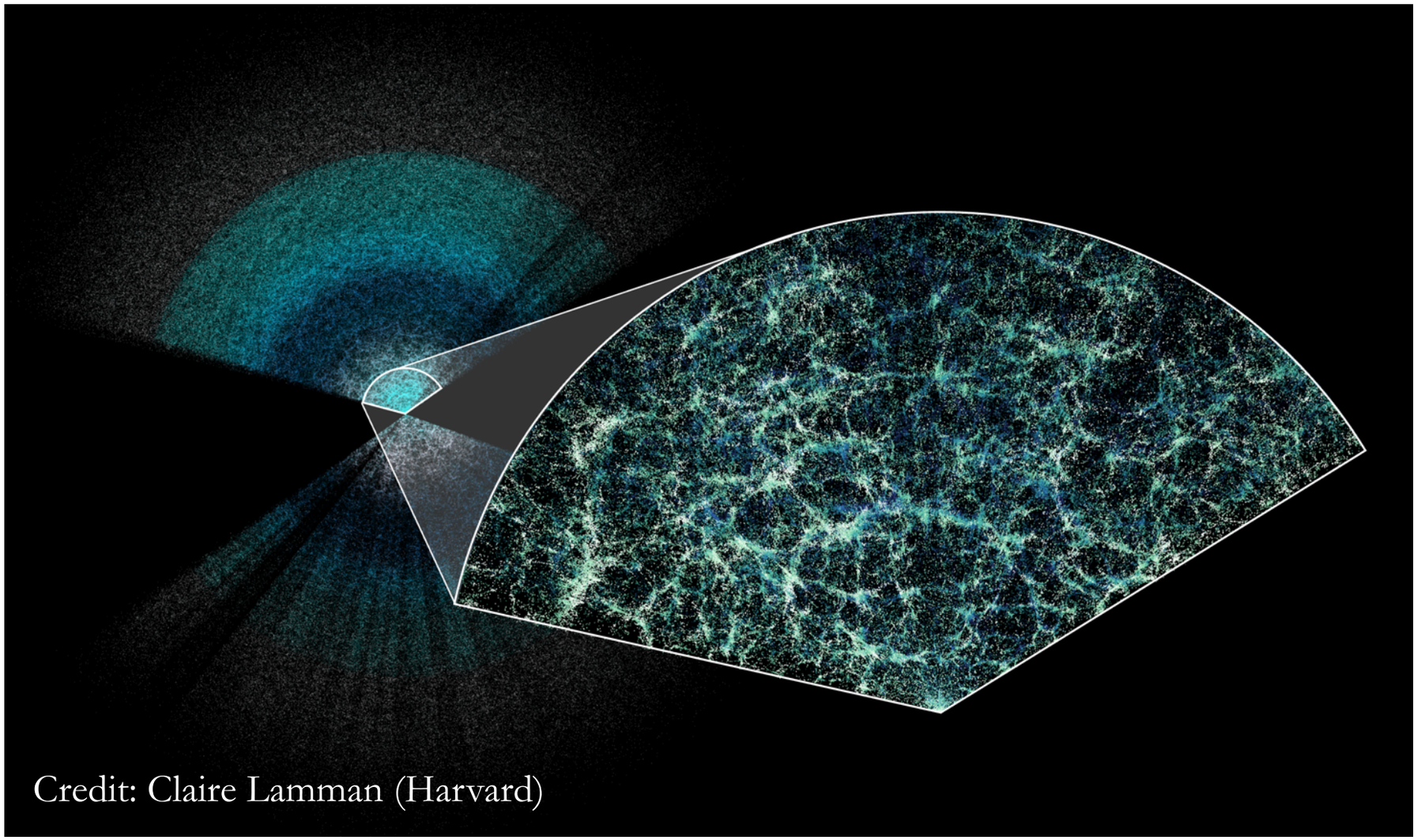
DESI Data Release 1 will become public on 2025 March 19 at the March/April APS meeting.



Credit: Claire Lamman (Harvard)

Sneak-peek: unique, high-confident redshifts for 18.7M objects, including 13.1M galaxies, 1.6M quasars, and 4M stars!

- https://data.desi.lbl.gov/doc/releases/dr1 (private until 2025 March 19).
- DESI Collaboration et al. 2025, Data Release 1 of the Dark Energy Spectroscopic Instrument, in prep.

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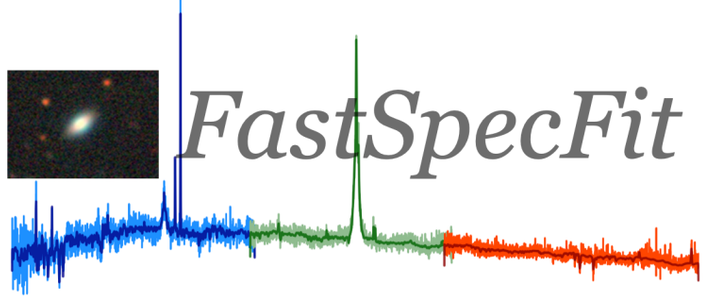
FastSpecFit—fast modeling of DESI spectrophotometry.

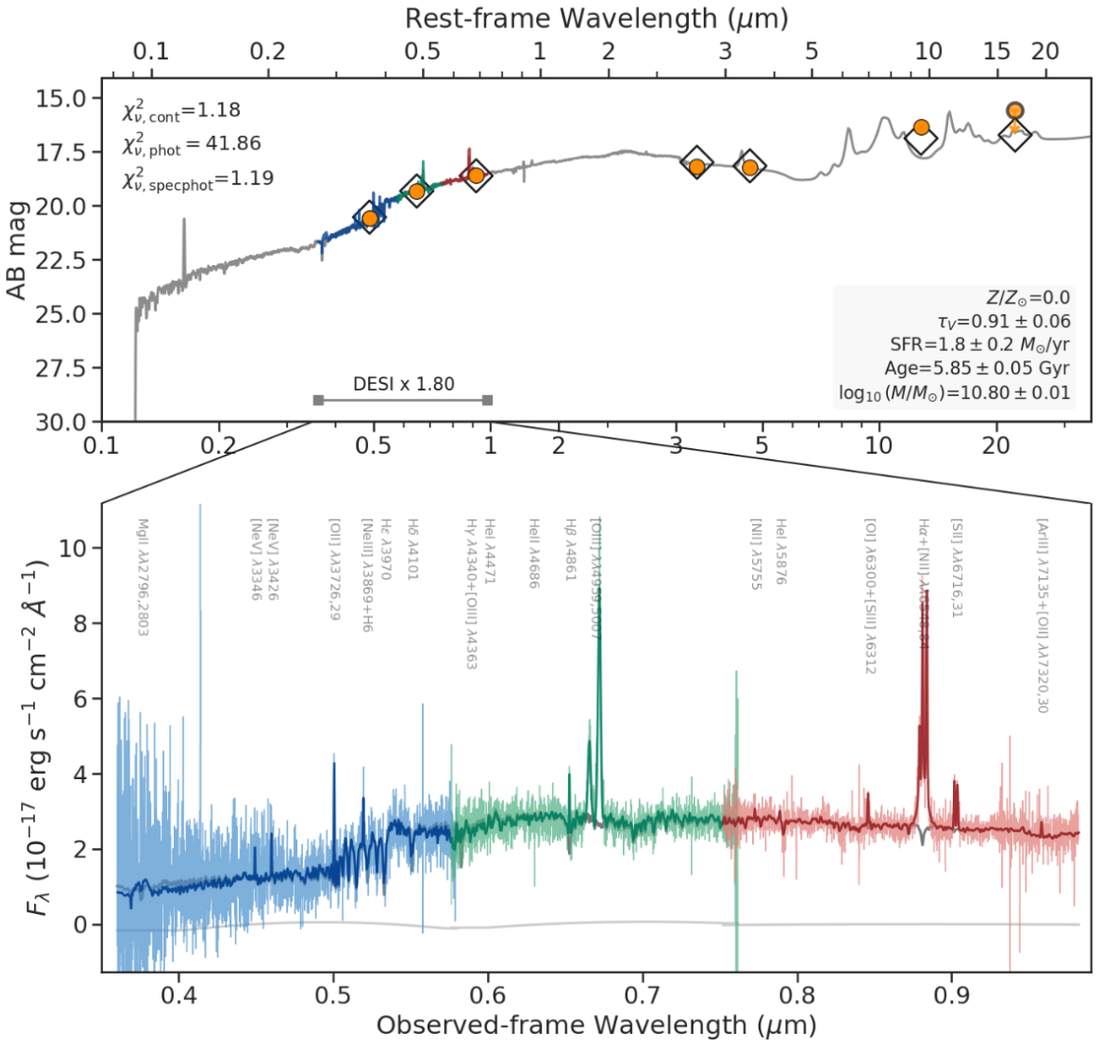


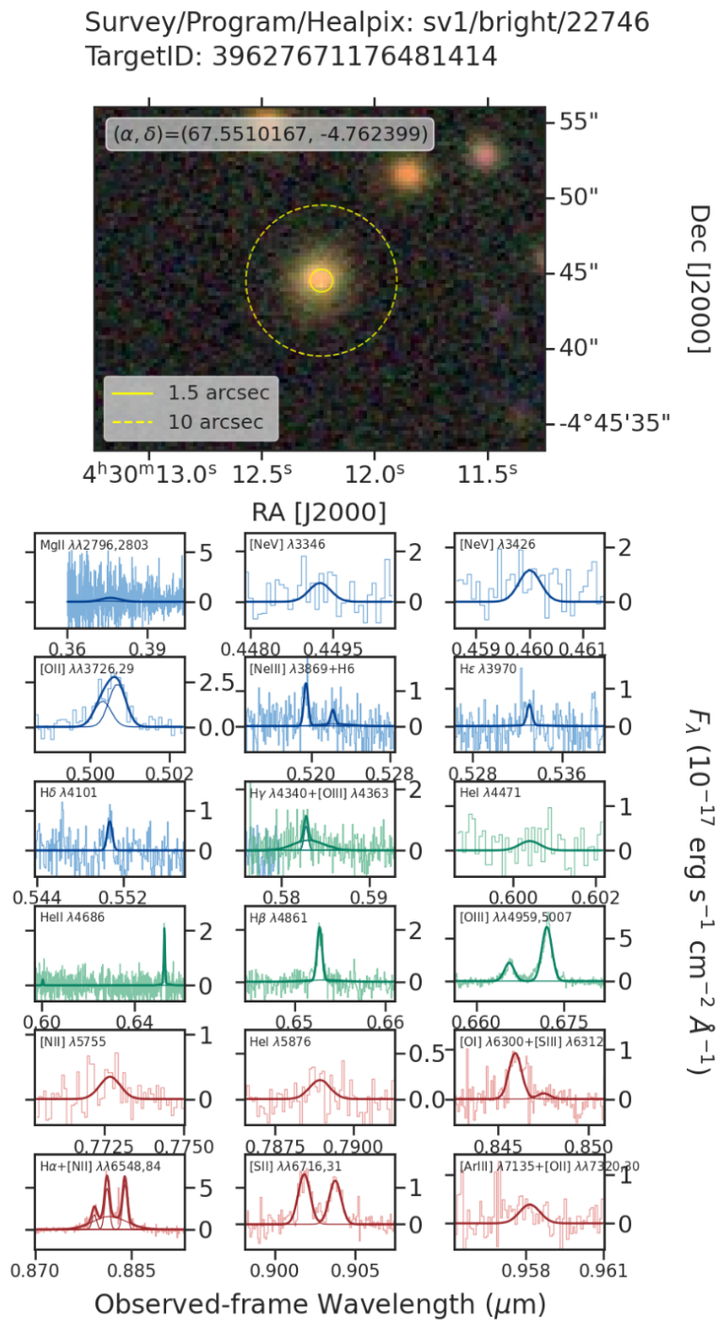
- FastSpecFit is a stellar continuum and emission-line modeling code for DESI which uses physically motivated stellar population synthesis and emission-line templates.
- It simultaneously models the three-camera optical spectrophotometry and the ultraviolet through infrared broadband photometry.
- The code is numba-accelerated and simply maximizes the likelihood given the data (no sampling), using Monte Carlo for simple uncertainty estimates.

Paper, public code, and EDR value-added catalog—

- Moustakas et al., in prep.
- https://fastspecfit.readthedocs.io/en/latest
- https://fastspecfit.readthedocs.io/en/latest/fuji.html

A worked example—Bright Galaxy Survey (BGS) target at $z = 0.342$.





$z = 0.3423384$
$\sigma_{star} = 127 \pm 11$ km/s

$\sigma_{\mathrm{narrow}} = 144 \pm 73$ km/s
$\Delta v_{\mathrm{narrow}} = -2 \pm 31$ km/s
$\sigma_{\mathrm{UV}} = 2877$ km/s
$\Delta v_{\mathrm{UV}} = -65$ km/s
$\sigma_{\mathrm{broad}} = 887$ km/s
$\Delta v_{\mathrm{broad}} = 198$ km/s

$M_{0.1r} = -21.20$
$M_{0.1g} - M_{0.1r} = 0.704$
$M_{0.1r} - M_{0.1z} = 0.624$

$D_n(4000)_{\mathrm{model}} = 1.405$
$D_n(4000)_{\mathrm{data}} = 1.364$

EW([OII]) = 10.3 Å
EW([OIII]) = 35.1 Å
EW(Hα) = 12.8 Å
Hα/Hβ = 3.214
$\log_{10}$([OIII]/Hβ) = 0.987
$\log_{10}$([NII]/Hα) = 0.037
[OII] λ3726/λ3729 = 0.602
[SII] λ6731/λ6716 = 0.871

$\chi^2_{\nu,\mathrm{line}} = 1.19$
$\Delta\chi^2_{\mathrm{nobroad}} = 859$
$\Delta\nu_{\mathrm{nobroad}} = 5$
EW(Hα)$_{\mathrm{broad}}$ = 29.5 Å

EW(MgII) = 24.9 Å
MgII λ2796/λ2803 = 0.168

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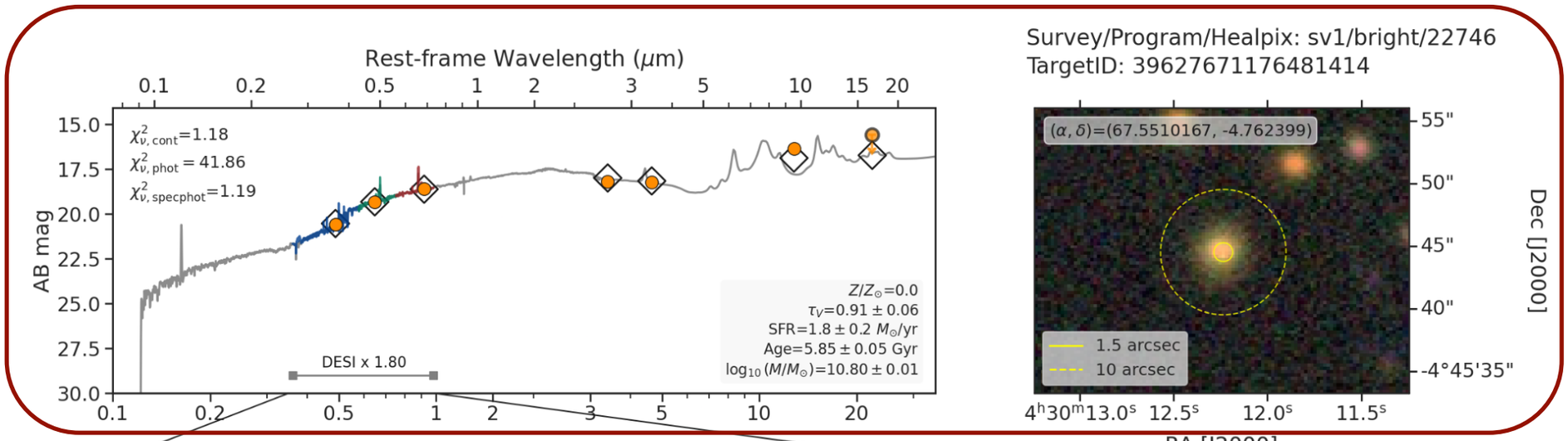

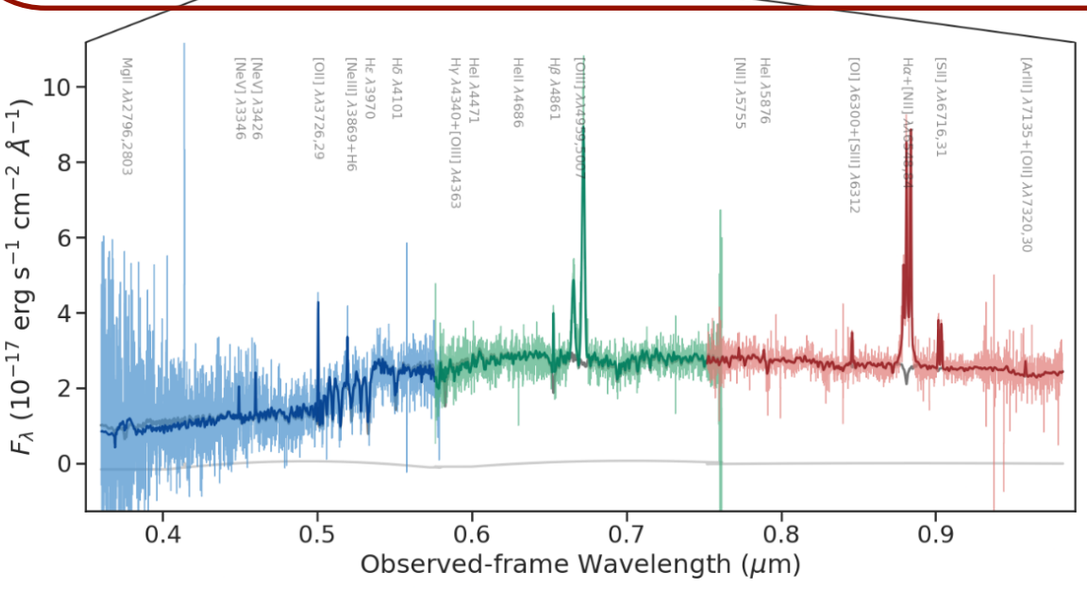

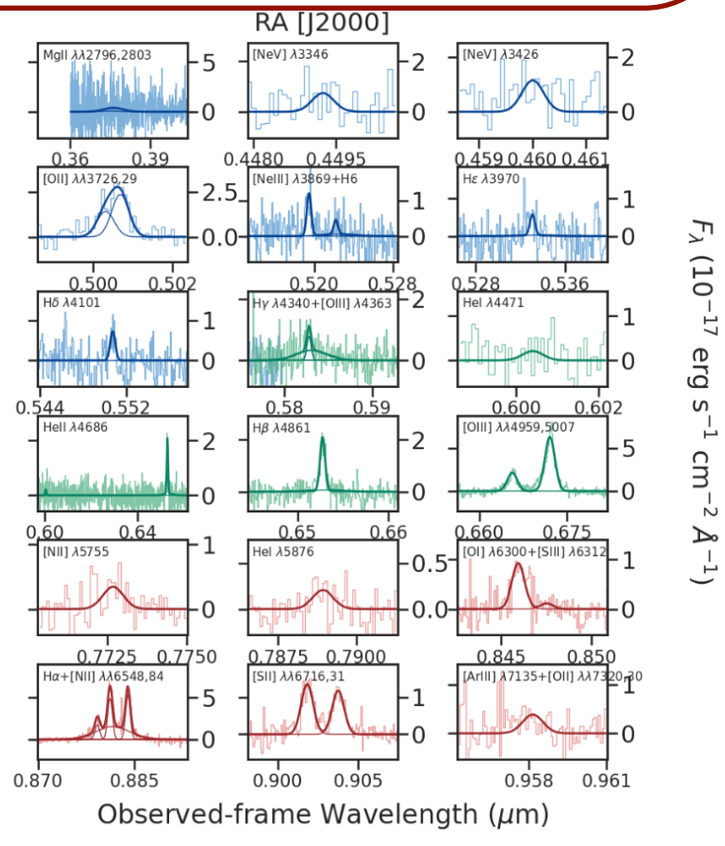

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- The 1.5″ DESI fiber only captures the central light (aka aperture bias) over the observed-frame 0.36-0.98 micron wavelength range.
- Broadband photometry encodes a lot more information about the galaxy.

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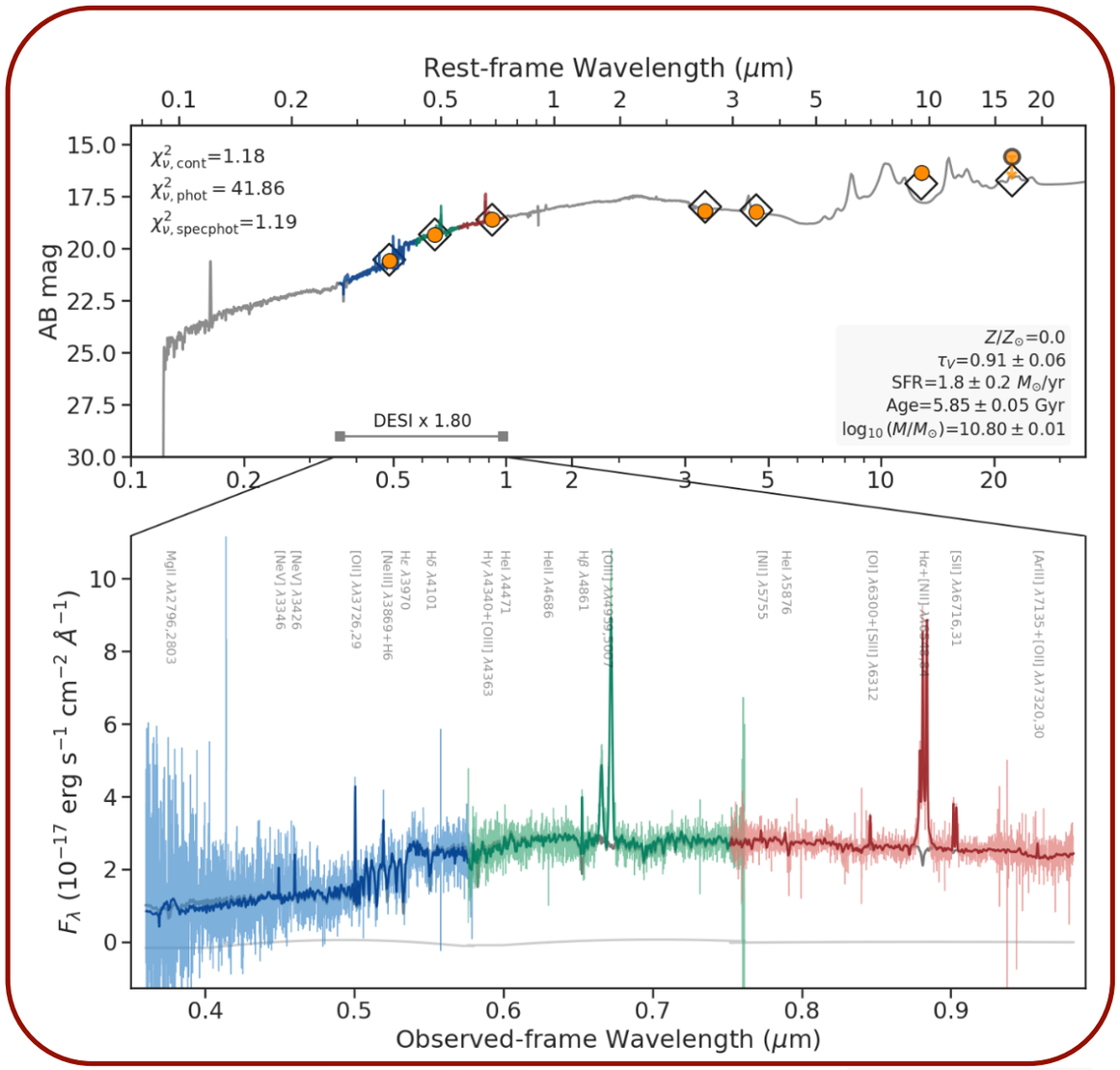

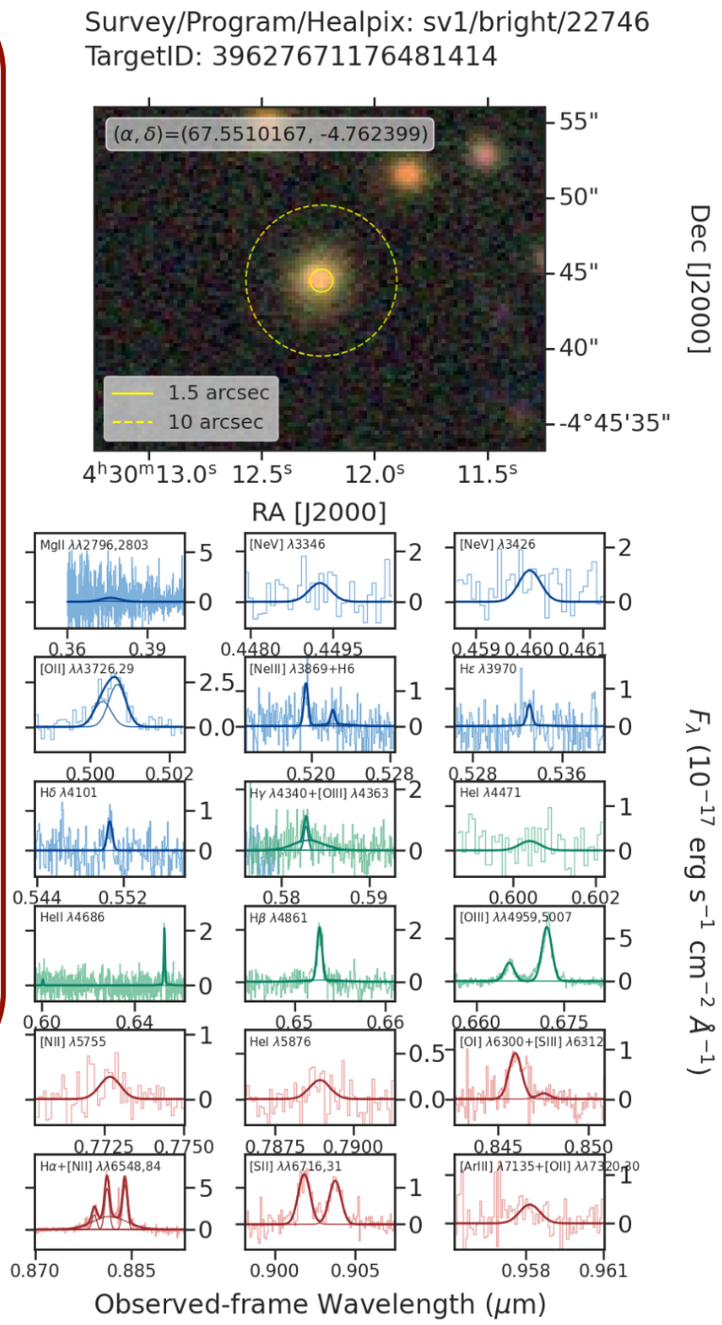

- FastSpecFit simultaneously forward-models the broadband photometry and the three-camera spectrophotometry, making full use of the DESI resolution matrix.
- The continuum model consists of 5 variable-age stellar population synthesis (SPS) models and a simple (power-law) dust model; we compute the IR spectrum on-the-fly.
- An "AGN fitting mode" is in the works.

$z = 0.3423384$
$\sigma_{star} = 127 \pm 11$ km/s

$\sigma_{\rm narrow} = 144 \pm 73$ km/s
$\Delta v_{\rm narrow} = -2 \pm 31$ km/s
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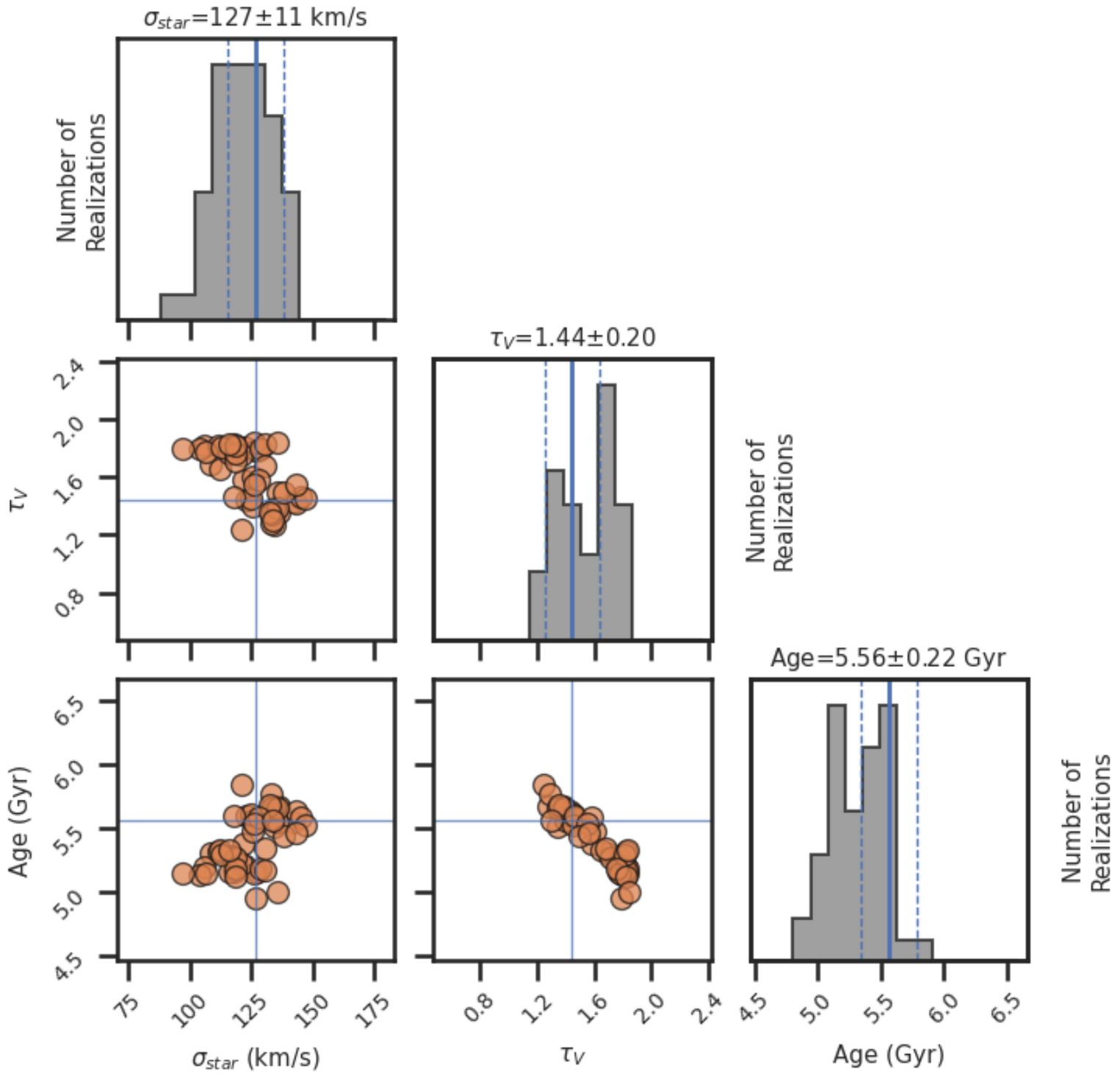

- Where possible, we estimate the velocity dispersion as part of the maximum-likelihood fit.
- We infer the uncertainty in the velocity dispersion using a Monte Carlo approach, marginalizing over the covariance with dust and age.

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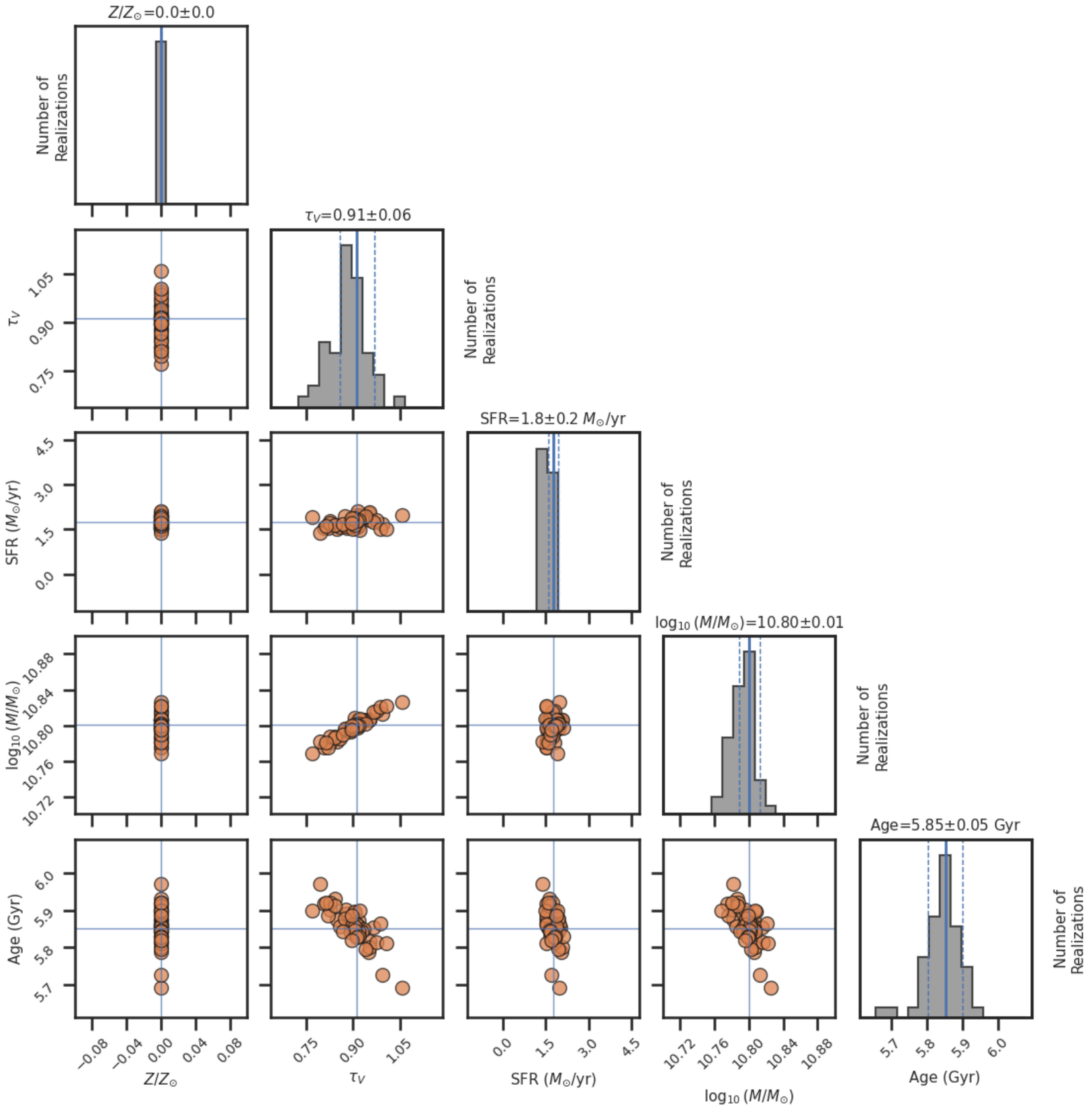

- Monte Carlo fitting also delivers simple estimates of the stellar population synthesis (SPS) model uncertainties.

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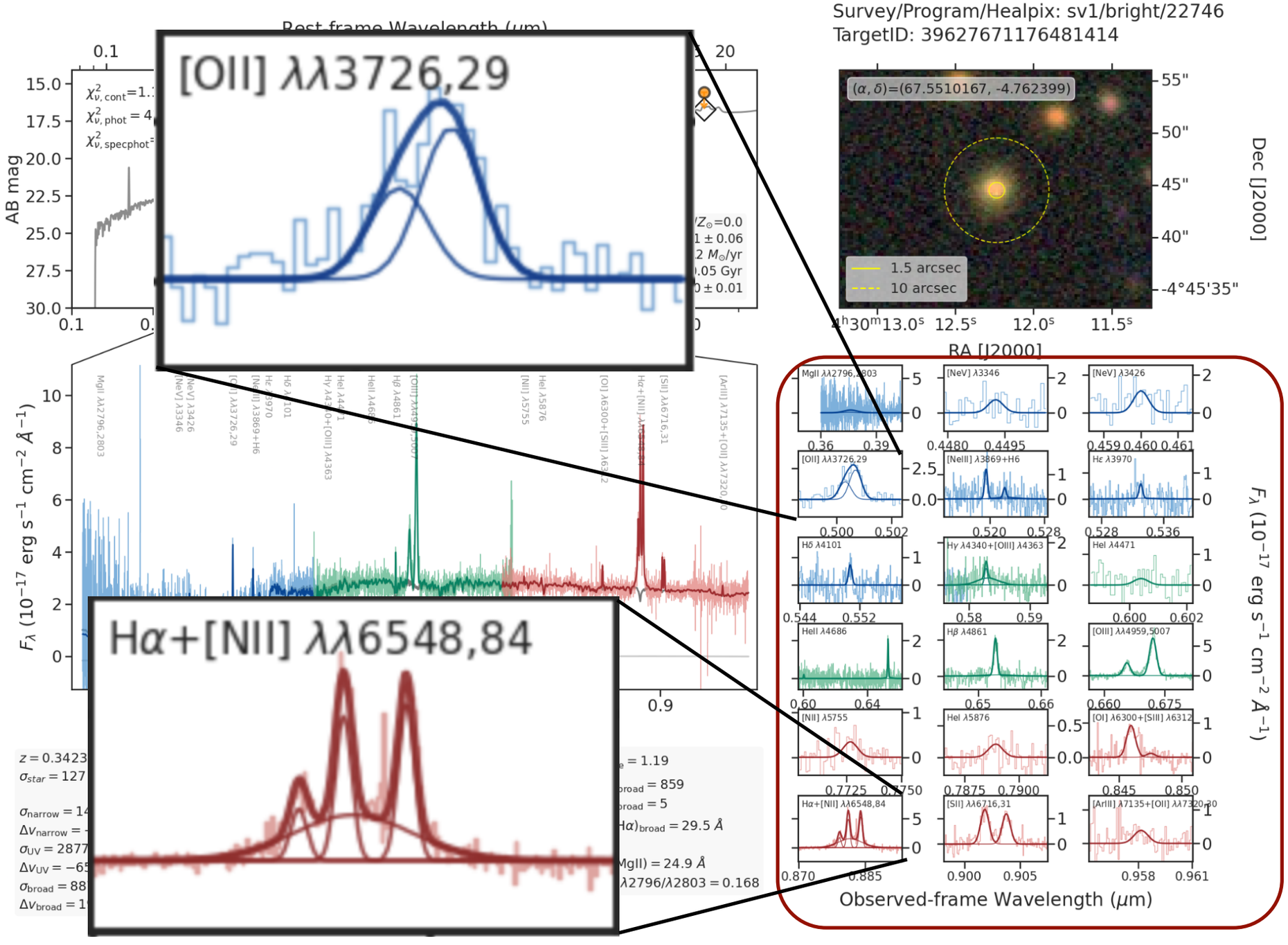
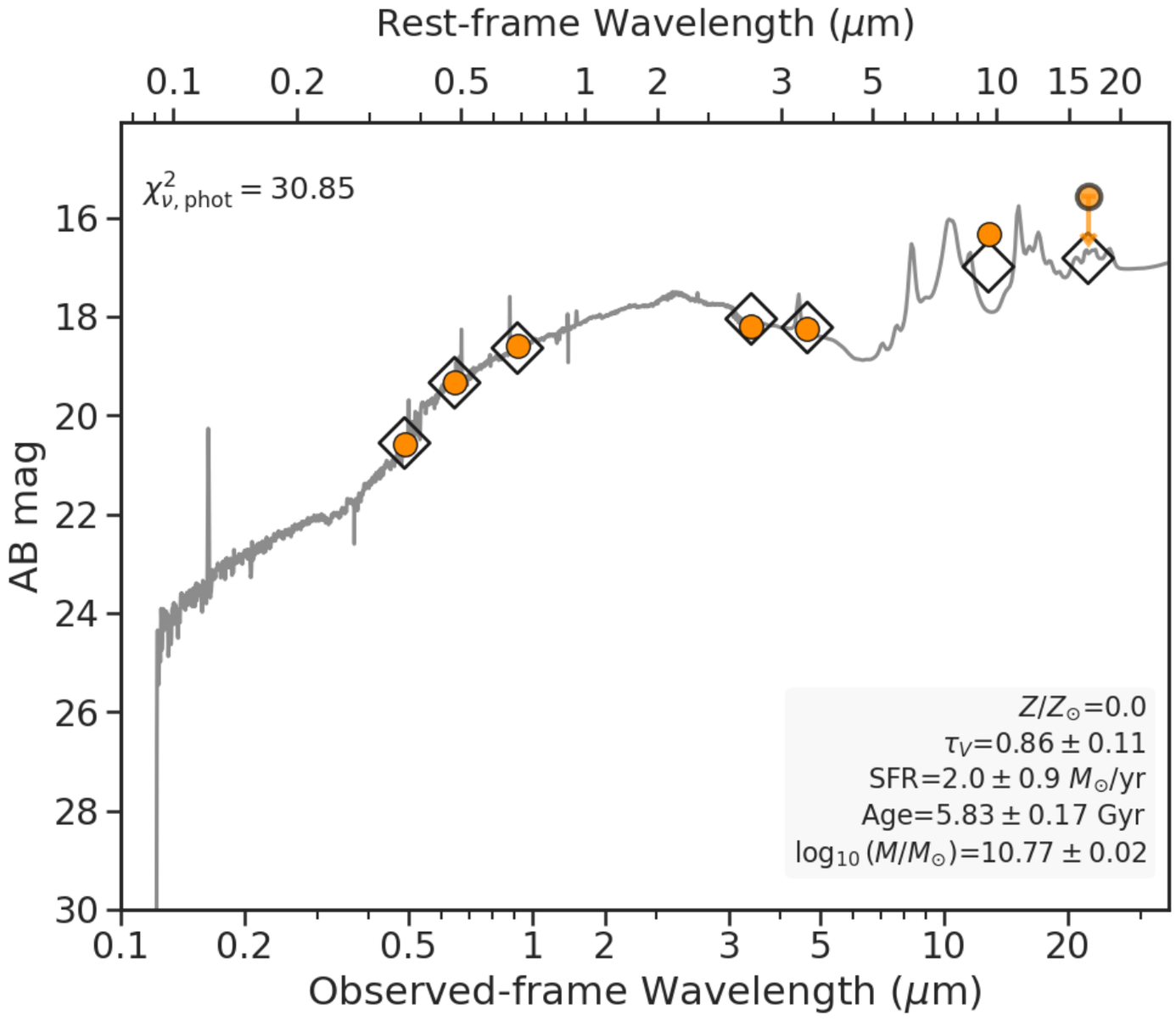
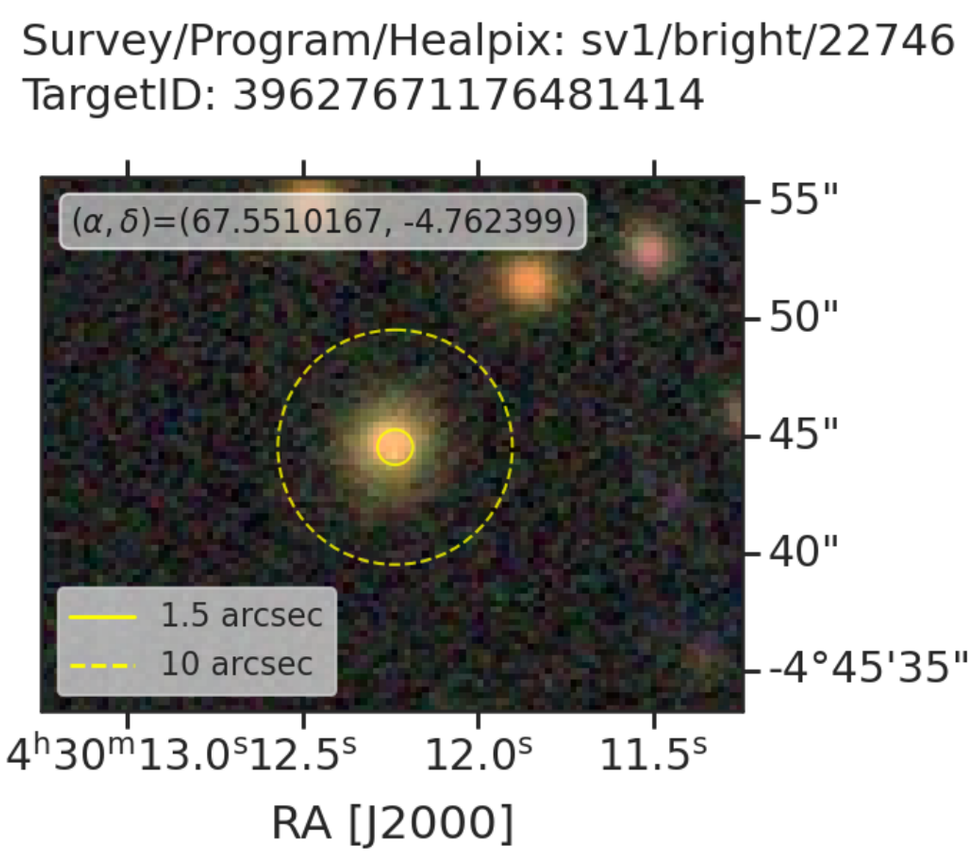


- We robustly fit the amplitudes of doublets like [OII] λλ3726,29 as one amplitude and a physically constrained doublet ratio.
- We attempt to decompose the Balmer lines into broad and narrow components, using a $\Delta\chi^2$ test to choose between the two models.

FastSpecFit also includes a (fast) “photometry-only” fitting mode.





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Summary, performance, and next steps.

- FastSpecFit is a new (public!) spectrophotometric fitting code written from the ground up for DESI.
- A value-added catalog (VAC) of 1.5M objects from the DESI/EDR is already public; the DR1 VAC (18M spectra!) will be released in 2025 March along with DR1.
- Fitting time is 0.5-3 seconds per object depending on the number of Monte Carlo realizations. Numba acceleration and extensive profiling has been used to achieve significant speed-ups (lesson: AstroPy is slow!)
- "Scale" (i.e., fitting of tens of millions of objects in finite time) is achieved using a combination of multiprocessing and MPI parallelization.
- Work in progress:
  - AGN-fitting mode with templates and priors optimized for quasars;
  - SDSS-fitting mode with plans to generate an SDSS VAC.
  - Nascent effort to use JAX/GPUs to achieve the next level of acceleration.

https://fastspecfit.readthedocs.io/en/latest