# DESI Part 1:
# Overview of the DESI survey


DARK ENERGY SPECTROSCOPIC INSTRUMENT

U.S. Department of Energy Office of Science

**Antoine Rocher**

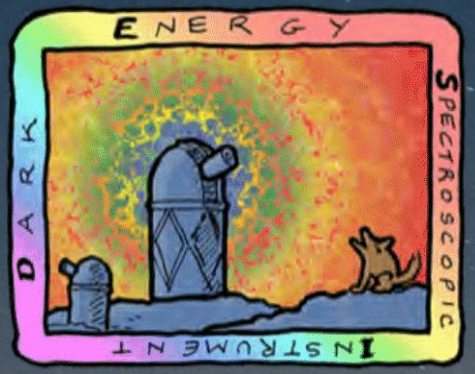
**Postdoc**

*Ecole Polytechnique Fédérale de Lausanne*

**On behalf of the DESI collaboration**

*Credit : DESI collaboration*

***Swiss Cosmo days – 2025 June 5th - Zurich***




# DARK ENERGY SPECTROSCOPIC INSTRUMENT

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# Dark Energy Spectroscopic Instrument

- DESI is a state-of-the-art spectroscopic instrument installed at the **Mayall 4-meter telescope at Kitt Peak National Observatory.**

- First **Stage-4 spectroscopic survey** on sky
  - measures the 3D distributions of galaxies
  - 1/3 sky 14000 deg$^2$

- **40M redshifts at the end of the survey (5 years)**
  x13 previous spectroscopic surveys

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# Dark Energy Spectroscopic Instrument

**Key questions:**

- **Expansion history of the Universe**

  => Constraint Dark Energy with BAO

- **How does the structure form?**

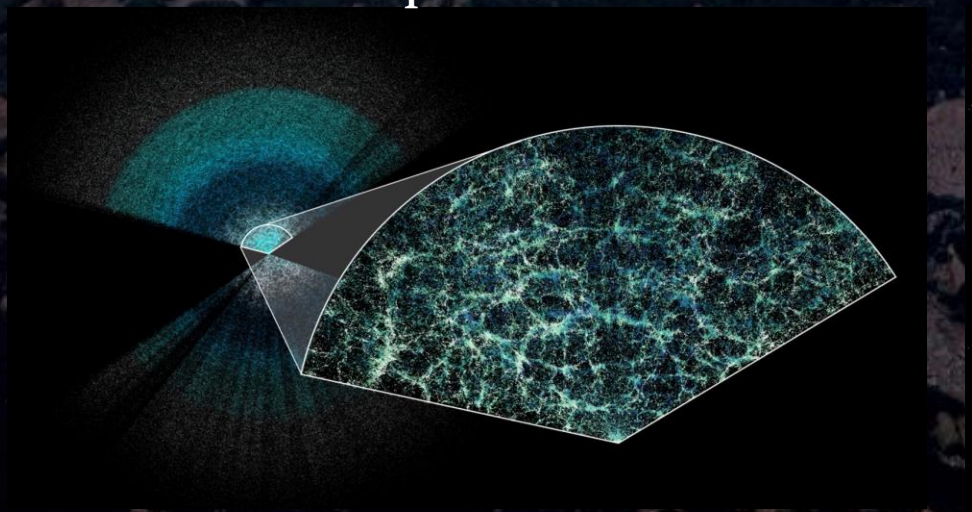
  => Test of gravity (GR)

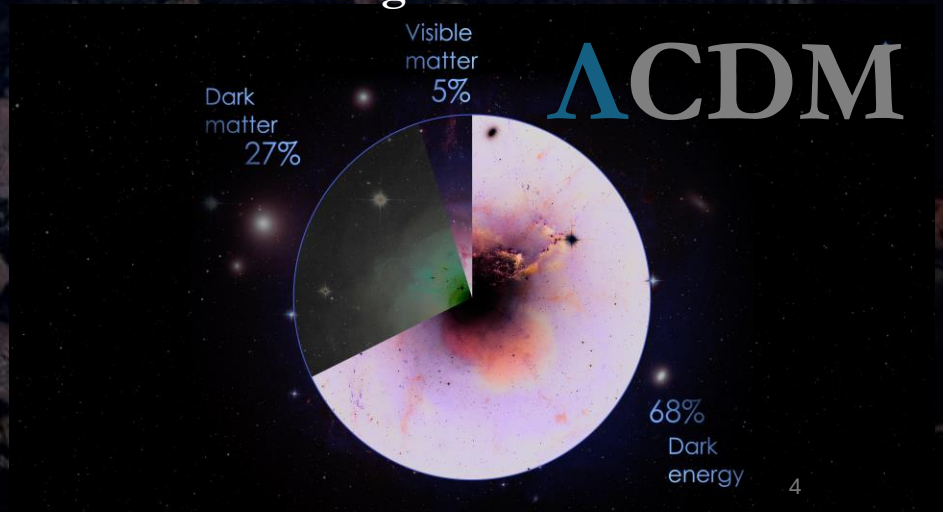
- **Primordial physics, inflation ($f_{nl}$)**

- **Neutrino mass, dark matter models...**

**+ many other science cases**

**Map the Universe in 3D to constrain the cosmological model**






*Credit : DESI collaboration/Claire Lamman*

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**DESI is a state-of-the-art instrument installed at the Mayall 4-meter telescope at Kitt Peak National Observatory.**

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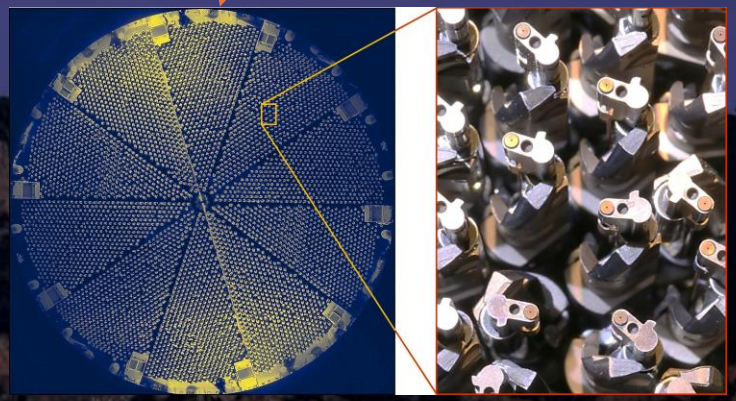
Focal plane is populated with 5000 robotics fibers



**DESI is a state-of-the-art instrument installed at the Mayall 4-meter telescope at Kitt Peak National Observatory.**

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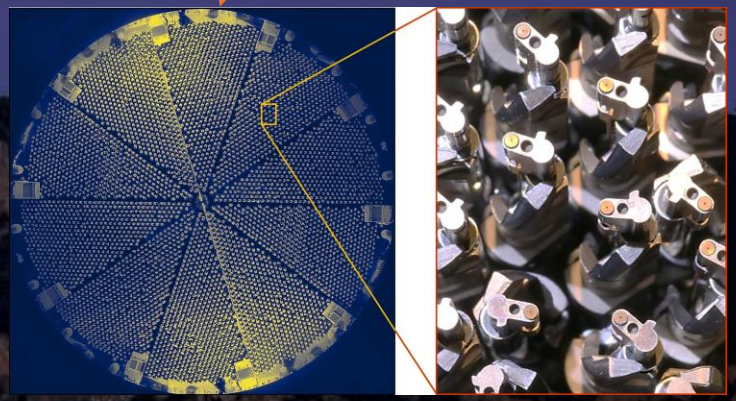
Focal plane is populated with 5000 robotics fibers

That feed 10 spectrographs

$\lambda \sim 360\text{-}980$ nm



**DESI is a state-of-the-art instrument installed at the Mayall 4-meter telescope at Kitt Peak National Observatory.**

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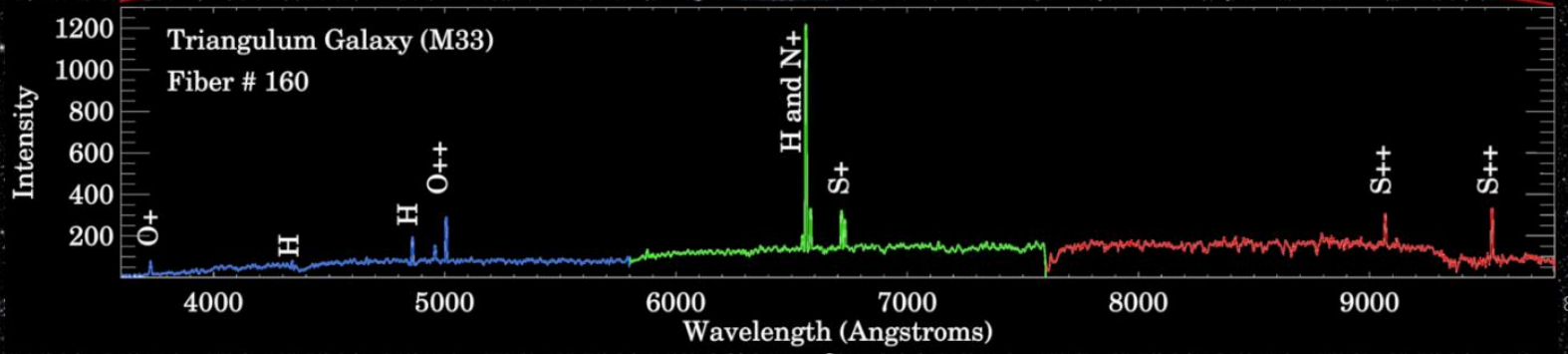
# These fibers allow DESI to map an area of the sky larger than 30 full moons—simultaneously.

Full Moon
(to scale)

3.2 degrees

Credit: Arjun Dey
(NOIRLab)



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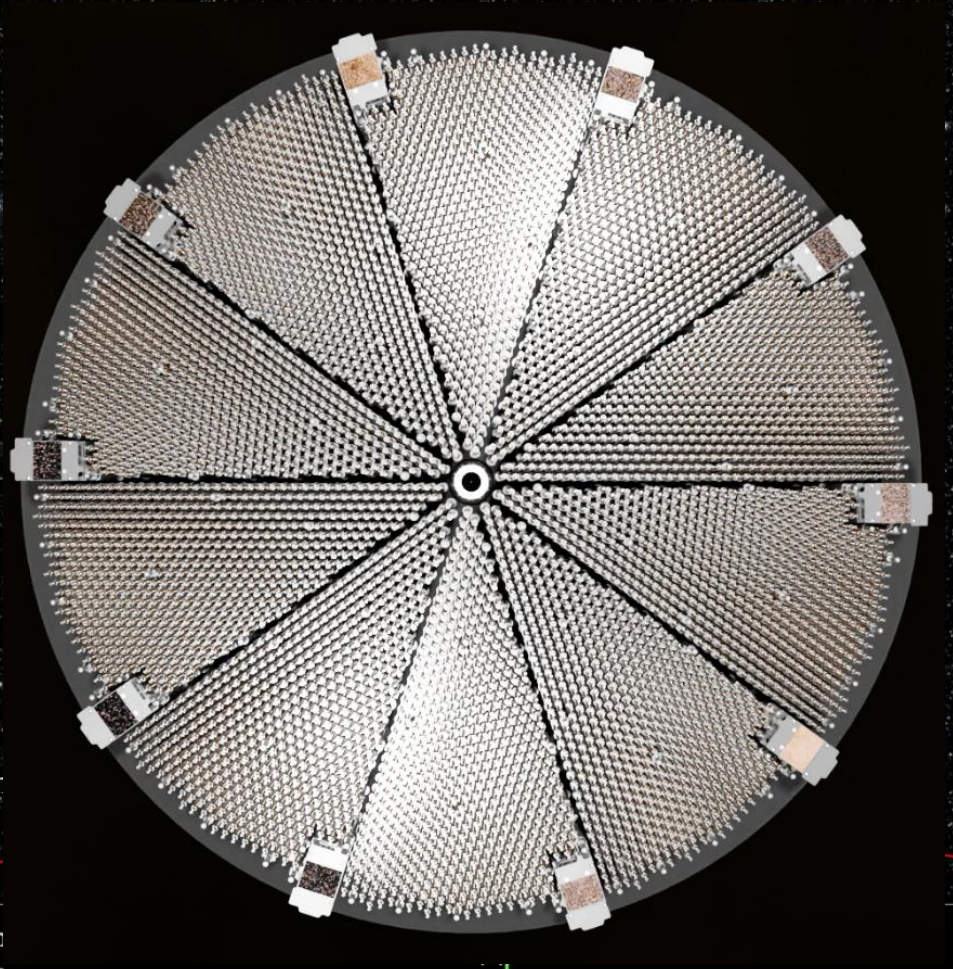

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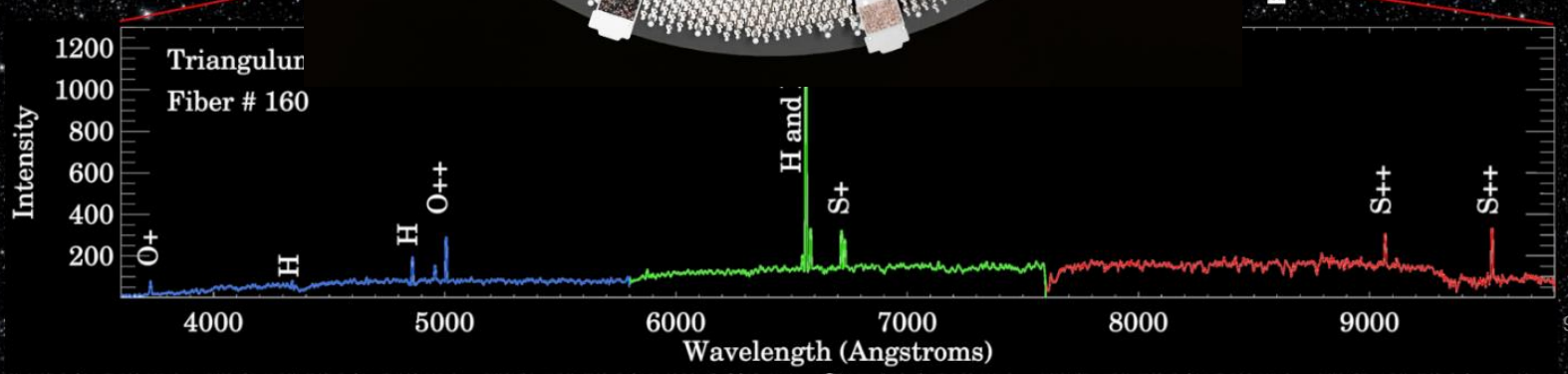

DARK ENERGY SPECTROSCOPIC INSTRUMENT

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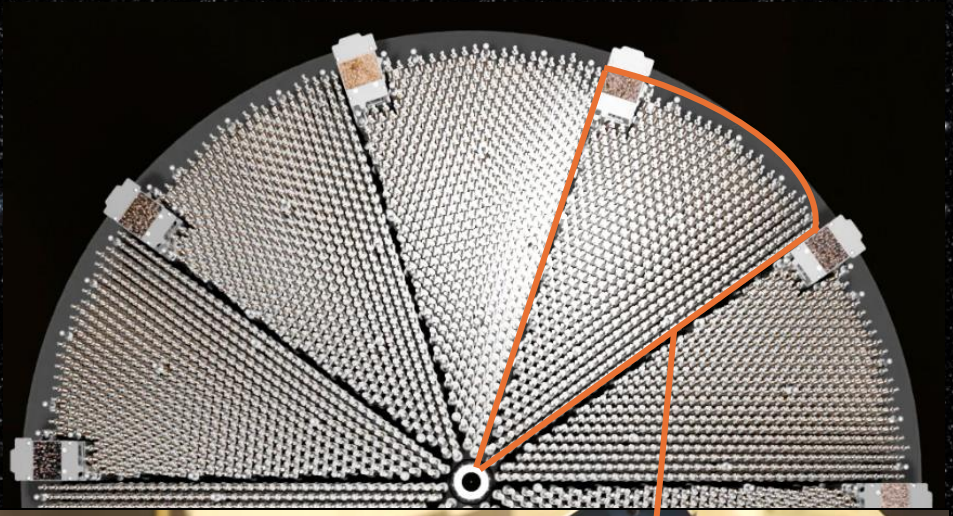
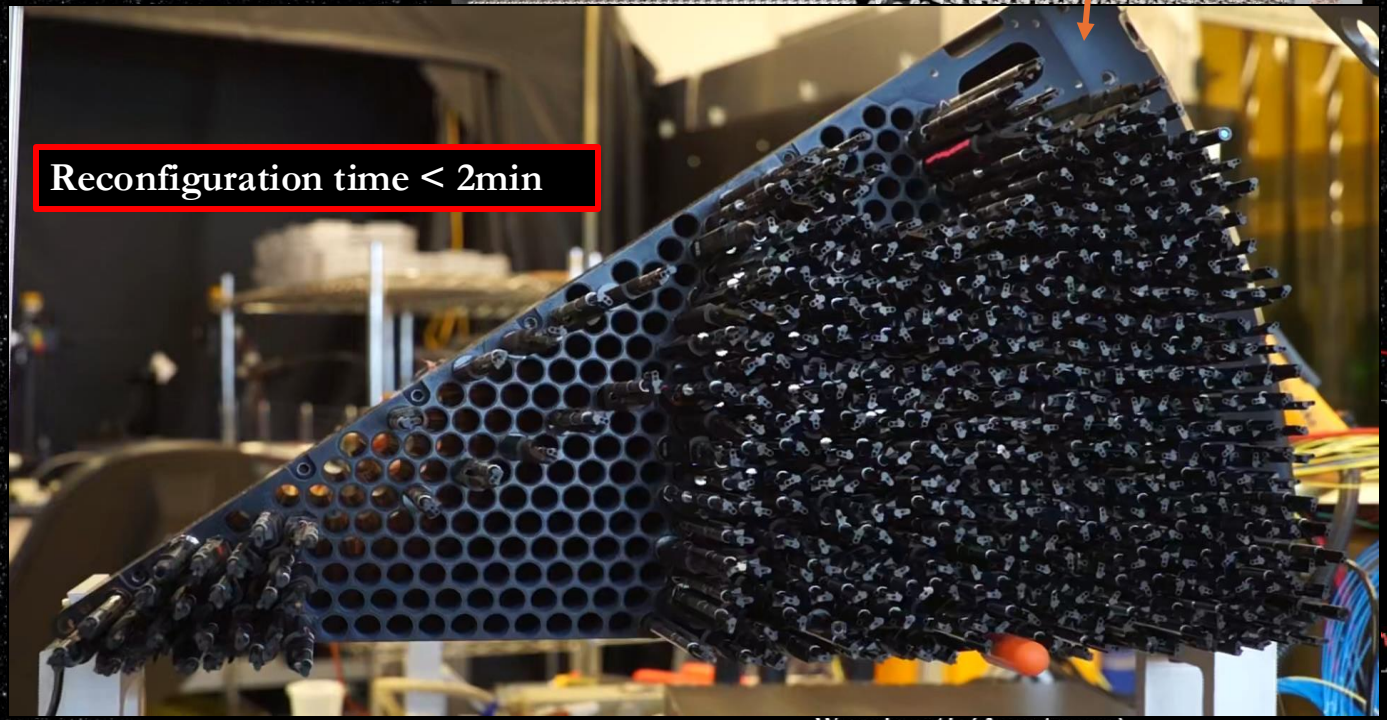
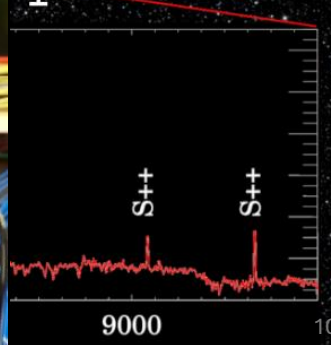


3.2 degrees




Wavelength (Angstroms)

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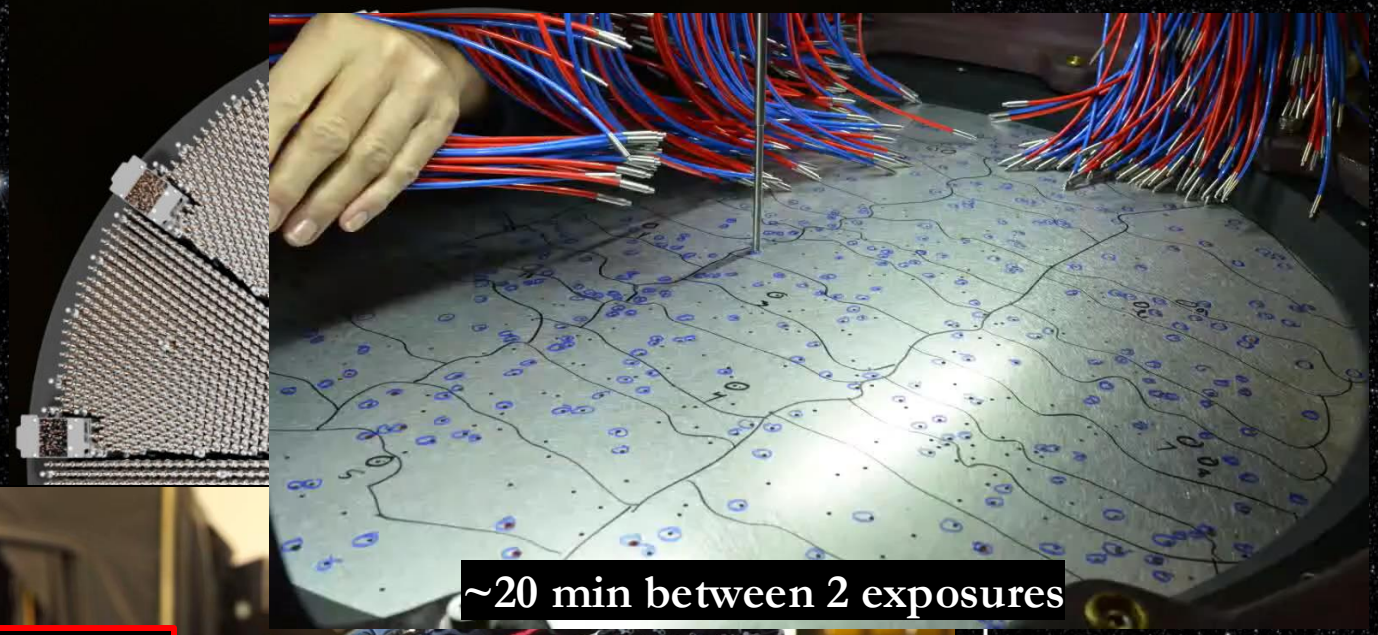
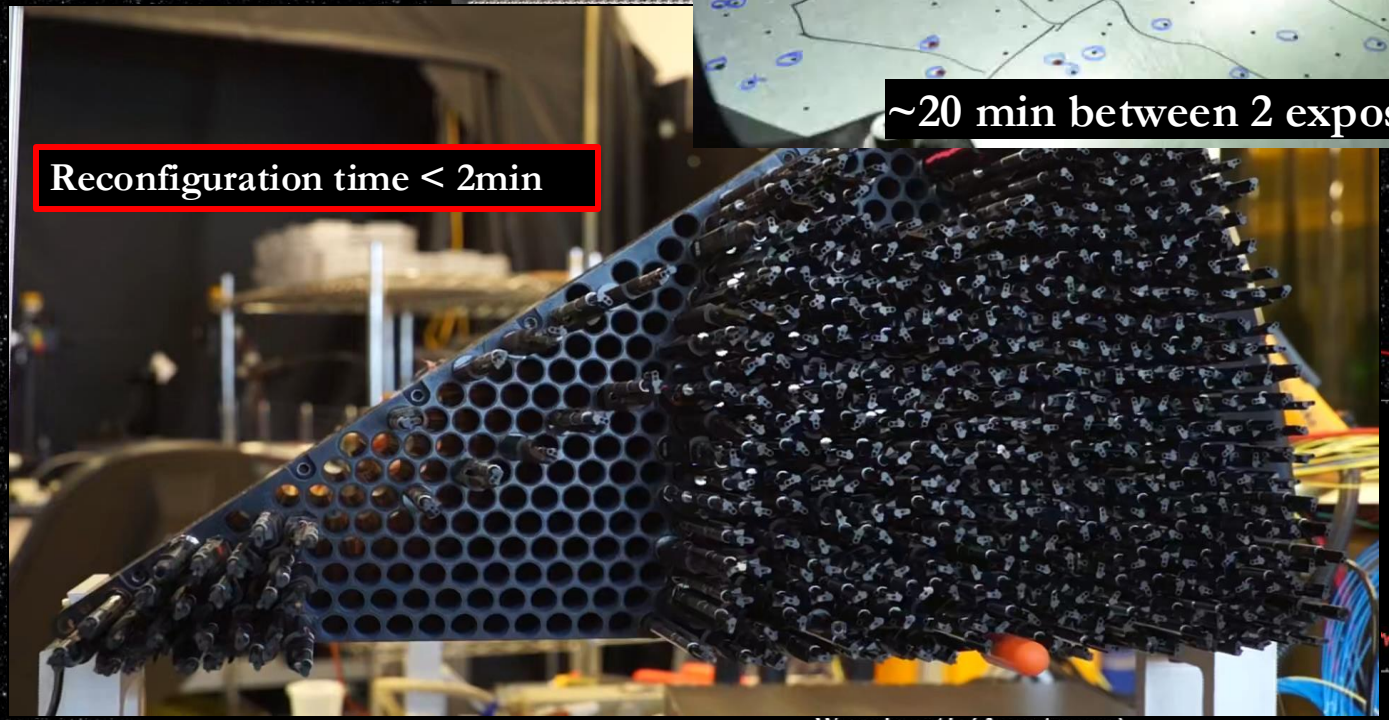
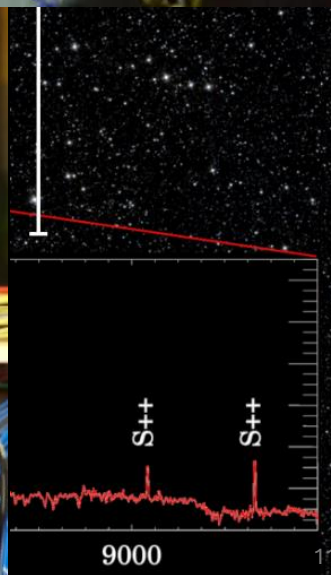
# larger than 30 full moons—simulta

SDSS

Full Moon
(to scale)



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# The DESI main survey

**4 different tracers to probe the Universe z < 3.5**

**3M Quasars (QSOs)**
**0.8<z<2.6**

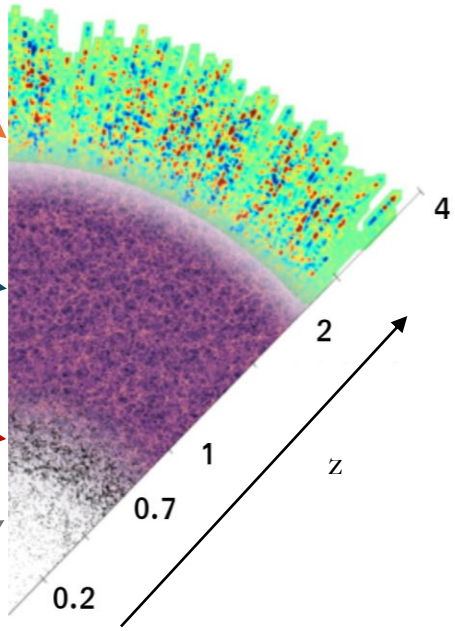
**+ Ly-α** **z > 2.1**

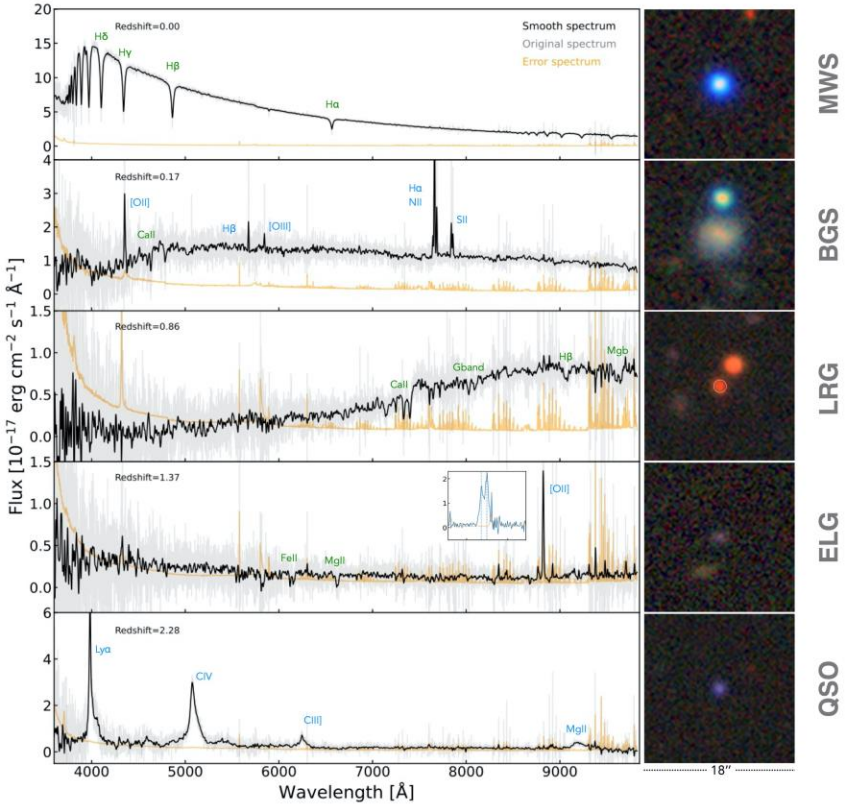
**17M Emission line galaxies (ELGs)**
**0.6<z<1.6**

**8M Luminous red galaxies (LRGs)**
**0.4<z<1.1**

**13.5M Bright galaxies**
**0<z<0.5**

**+ Milky way Stars**



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# The DESI main survey

## 4 different tracers to probe the Universe z < 3.5

**Dark time survey**

**3M Quasars (QSOs)**
0.8<z<2.6

**+ Ly-α** z > 2.1

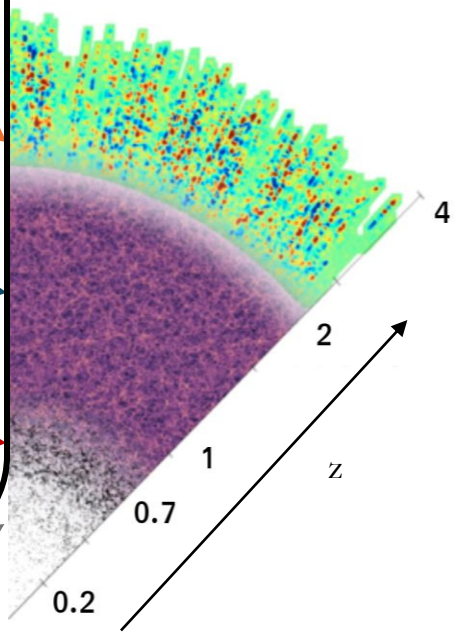
**17M Emission line galaxies (ELGs)**
0.6<z<1.6

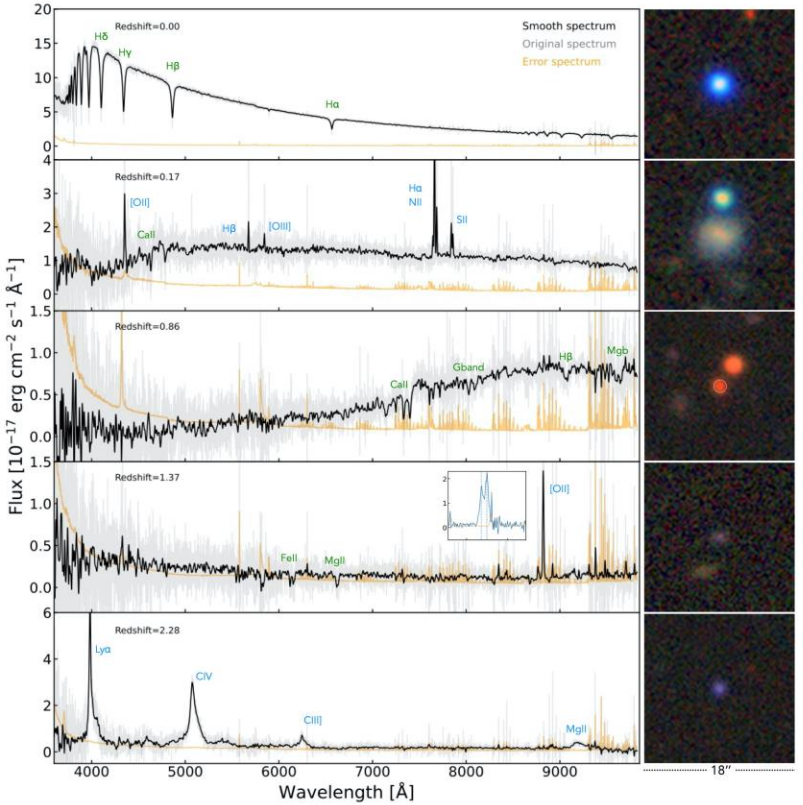
**8M Luminous red galaxies (LRGs)**
0.4<z<1.1

**13.5M Bright galaxies**
0<z<0.5

**+ Milky way Stars**

**Bright time survey**



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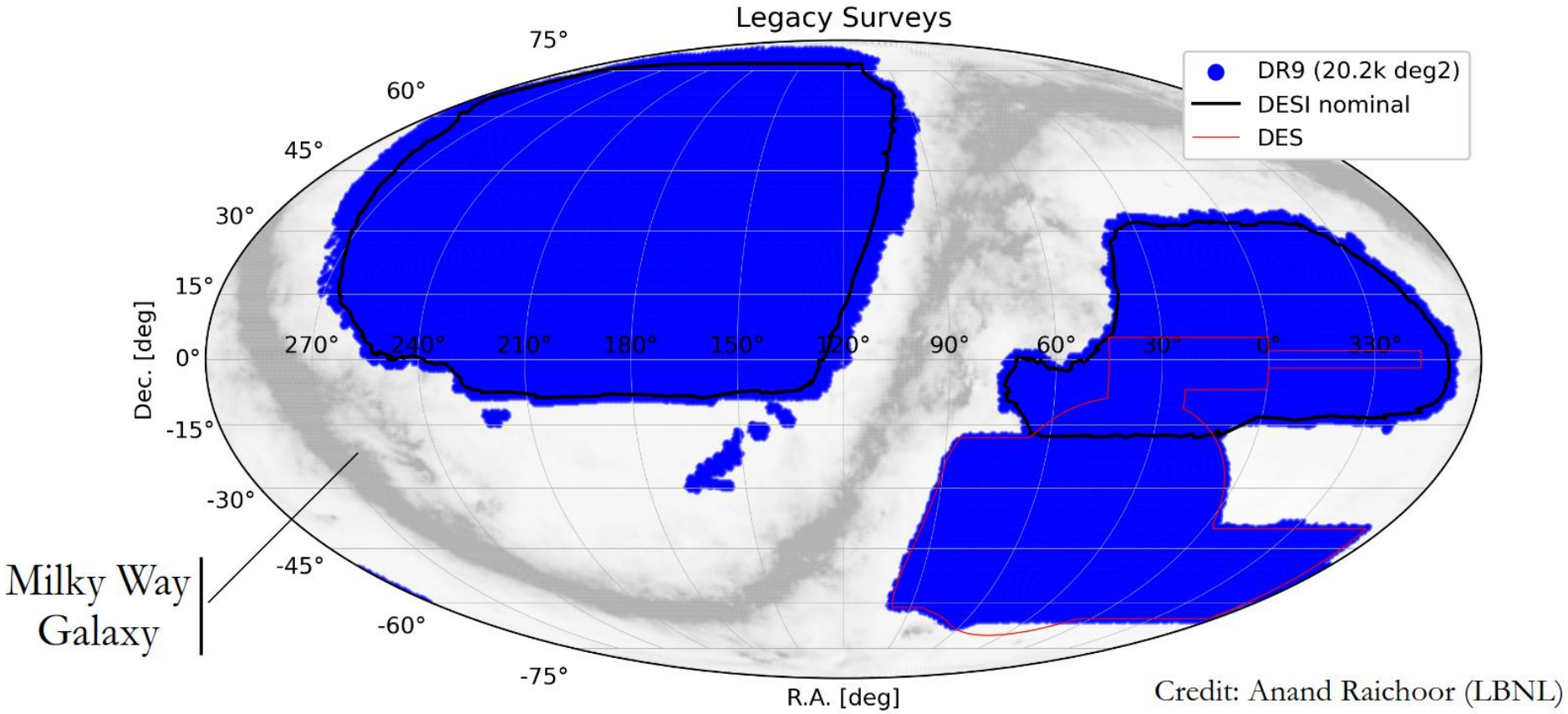
# DESI Legacy photometric surveys




DESI Legacy Imaging Surveys: https://legacysurvey.org/dr9

Interactive Sky Viewer: https://legacysurvey.org/viewer

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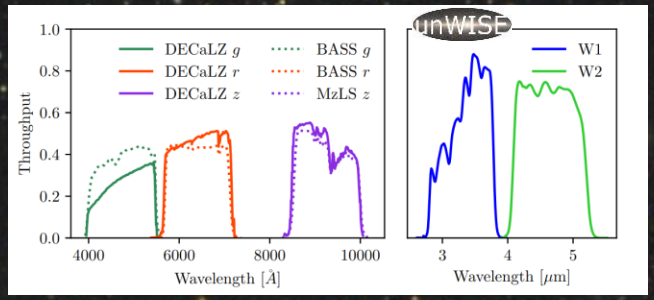
**Legacy surveys grz bands:**

- BASS+MzLS
- DECaLS
- DES

+ W1/W2 infrared bands from unWISE




Interactive Sky Viewer: https://legacysurvey.org/viewer

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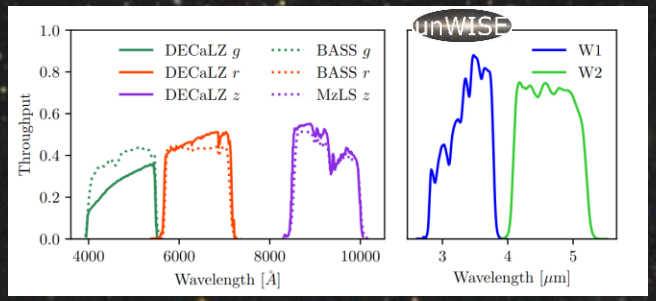
# DESI Target Selection

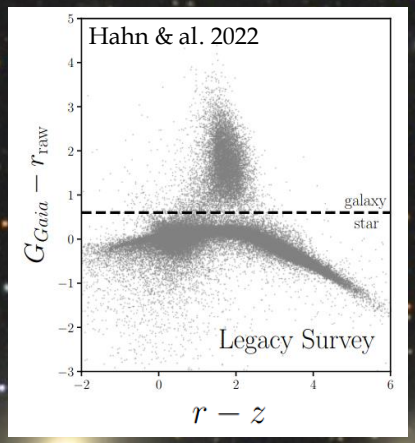
**Legacy surveys grz bands:**

- BASS+MzLS
- DECaLS
- DES

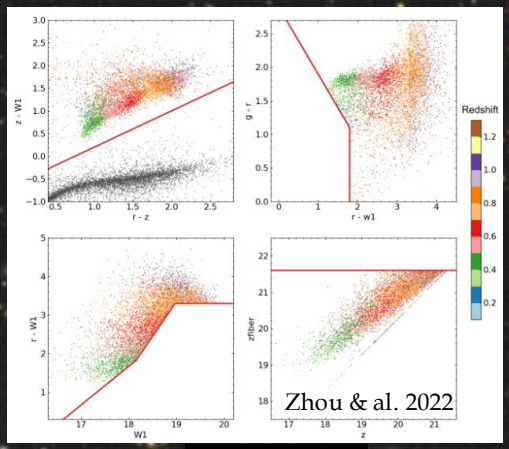
+ W1/W2 infrared bands from unWISE



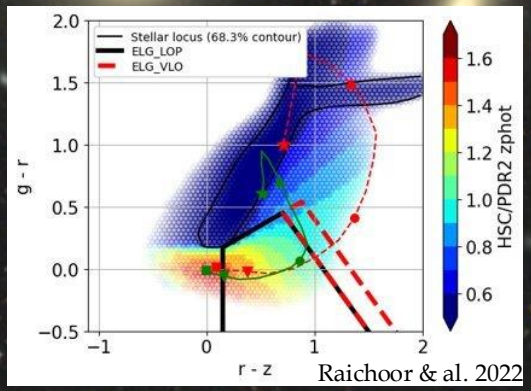

**Bright Galaxy Sample**



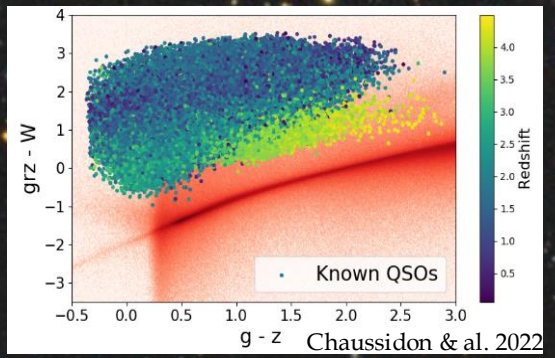

**Luminous Red Galaxies**



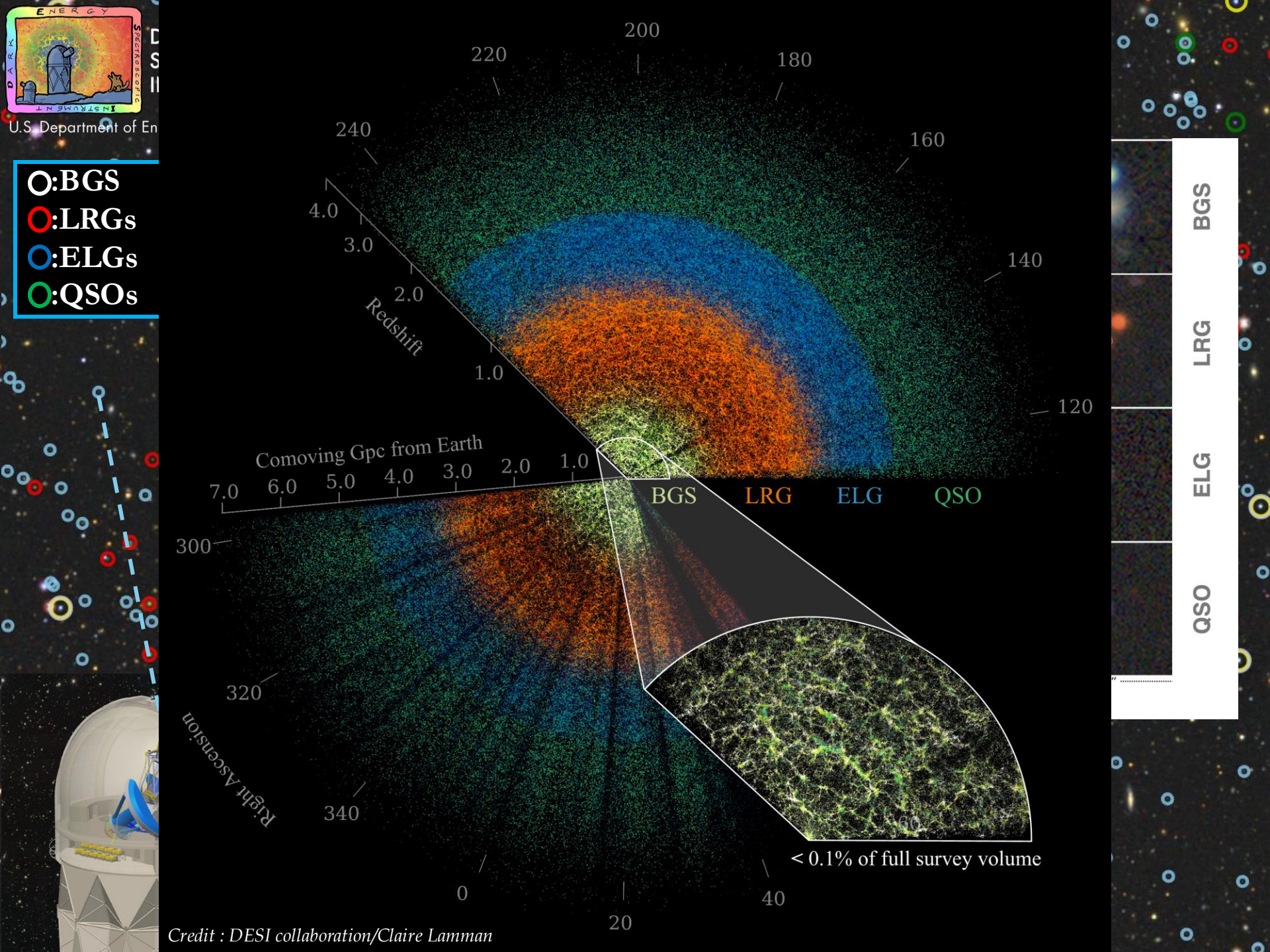

**Emission Line Galaxies**




**DESI Quasar**




Interactive Sky Viewer: https://legacysurvey.org/viewer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:BGS
:LRGs
:ELGs
:QSOs
200
220
180
240
160
4.0
3.0
140
2.0
Redshift
1.0
120
Comoving Gpc from Earth
7.0
6.0
5.0
4.0
3.0
2.0
1.0
BGS
LRG
ELG
QSO
300
320
Right Ascension
340
0
20
40
< 0.1% of full survey volume
BGS
LRG
ELG
QSO
Credit : DESI collaboration/Claire Lamman

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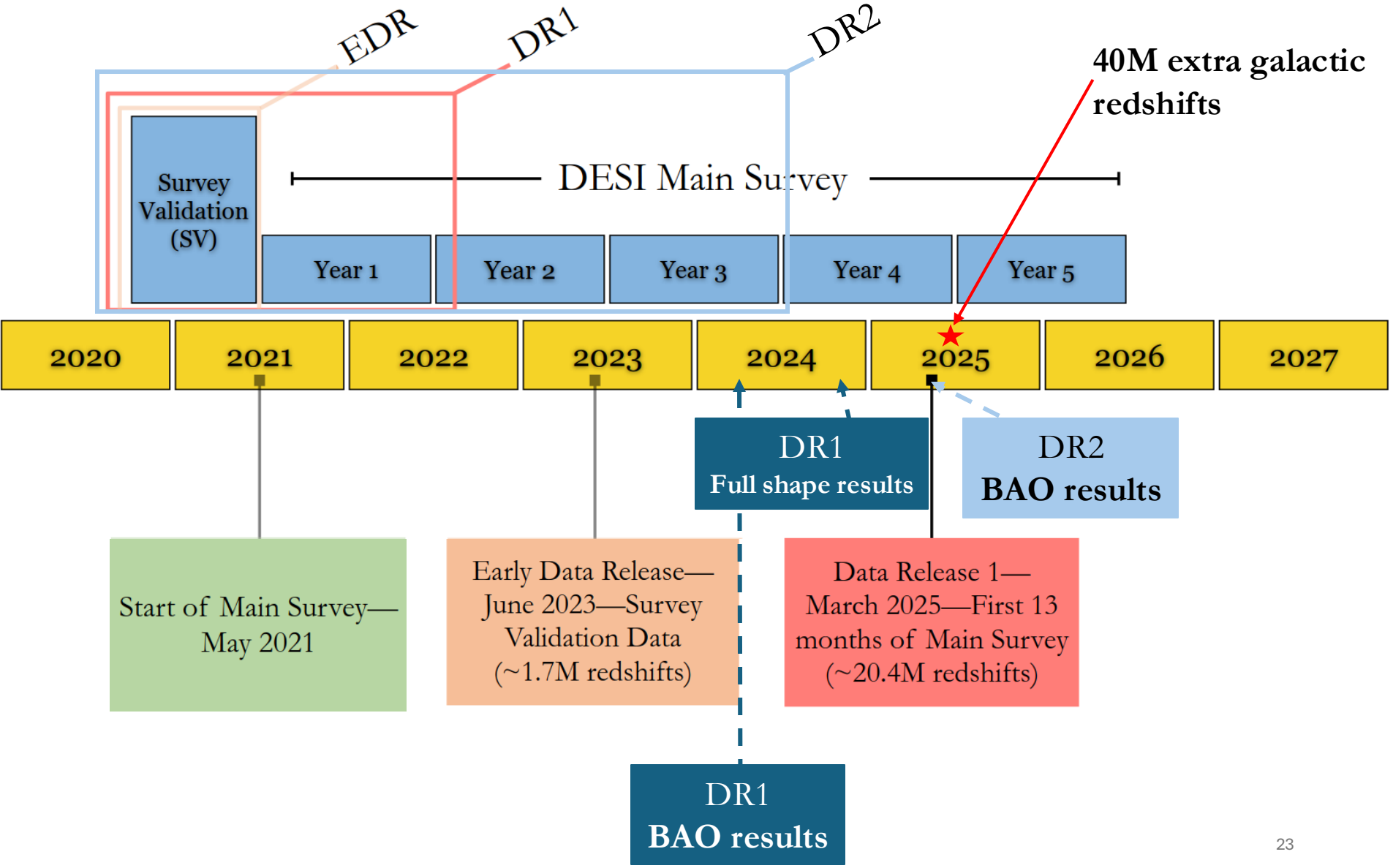
# DESI Timeline



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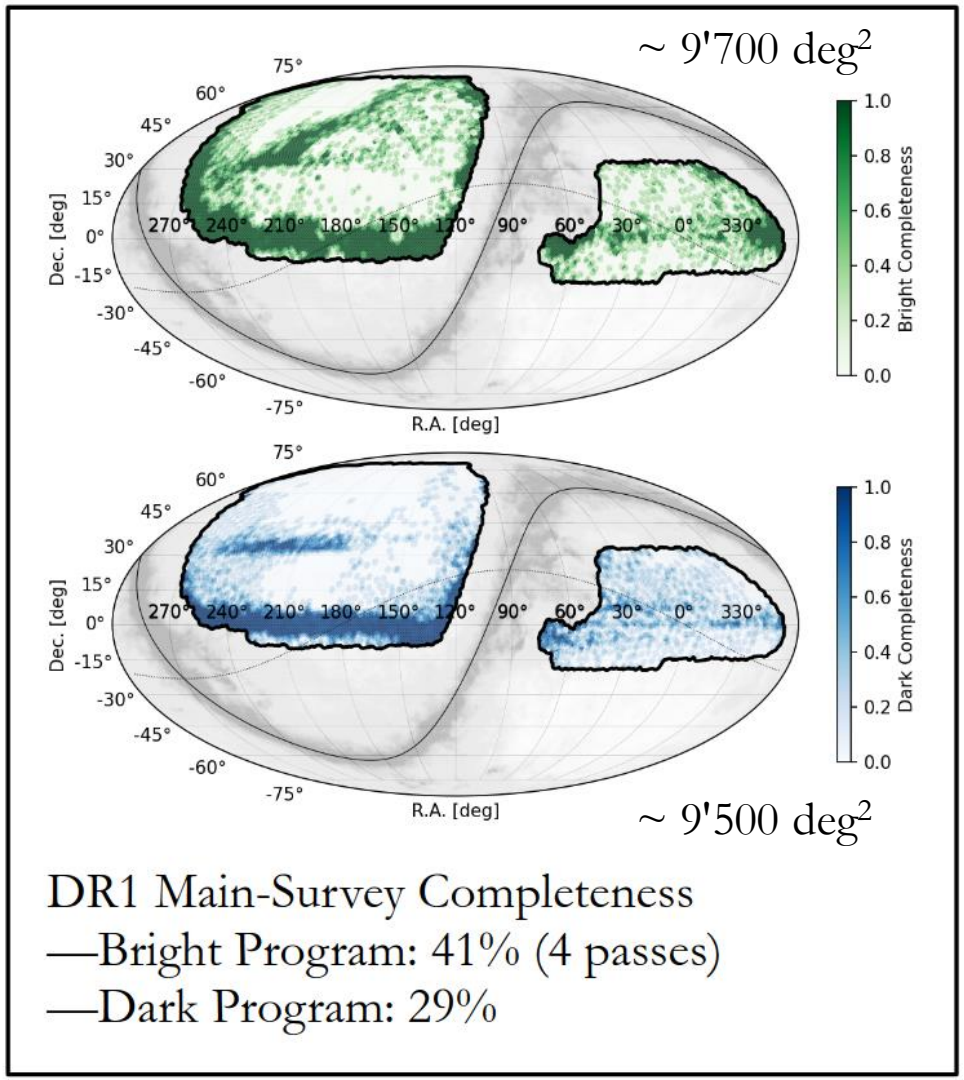
**DESI DR1** contains the **most detailed 3D map of the universe** ever, spanning 12 billion years of cosmic time.




DR1 Main-Survey Completeness
—Bright Program: 41% (4 passes)
—Dark Program: 29%

Main Survey :

- **13.1M galaxies**
- **1.6M quasars**
- **4M stars**

+ Survey Validation (1.7M objects)

**Total: 20.4M redshifts**

**Redshifts for the BAO analysis**

| Tracer | DR1 |
|---|---|
| BGS | 300,043 |
| LRG | 2,138,627 |
| ELG | 2,432,072 |
| QSO | 1,223,391 |
| Total | 6,094,133 |

https://data.desi.lbl.gov/doc/releases/dr1

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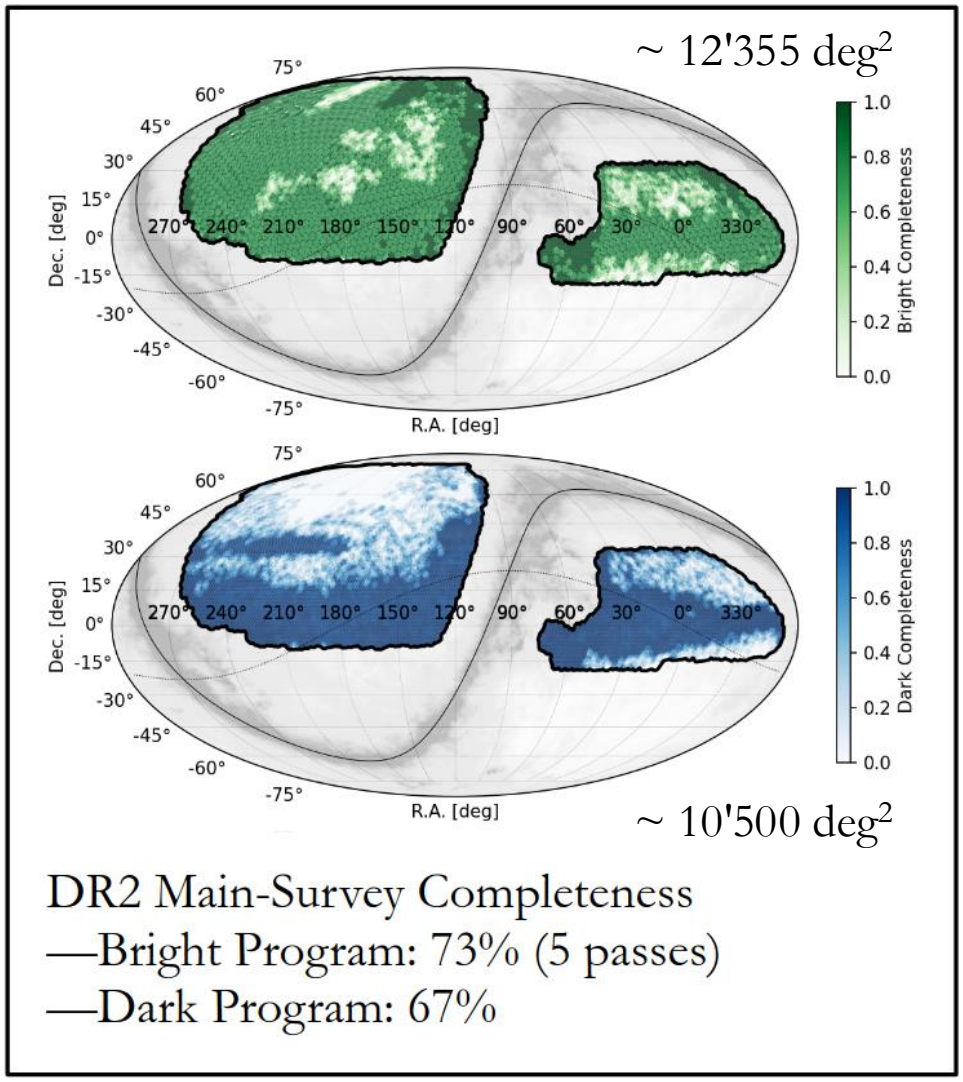
# DESI DR2 will contain two-thirds of the 5-year survey data and ~50M redshifts, two times more than DR1!




DR2 Main-Survey Completeness
—Bright Program: 73% (5 passes)
—Dark Program: 67%

Main Survey (internal release):

- **31M galaxies**
- **2.8M quasars**
- **12.3M stars**

+ Survey Validation (1.7M objects)

**Total: 46.1M redshifts**

**Redshifts for the BAO analysis**

| Tracer | DR1 | **DR2** |
|---|---|---|
| BGS | 300,043 | **1,188,526** |
| LRG | 2,138,627 | **4,468,483** |
| ELG | 2,432,072 | **6,534,844** |
| QSO | 1,223,391 | **2,062,839** |
| Total | 6,094,133 | **14,254,692** |

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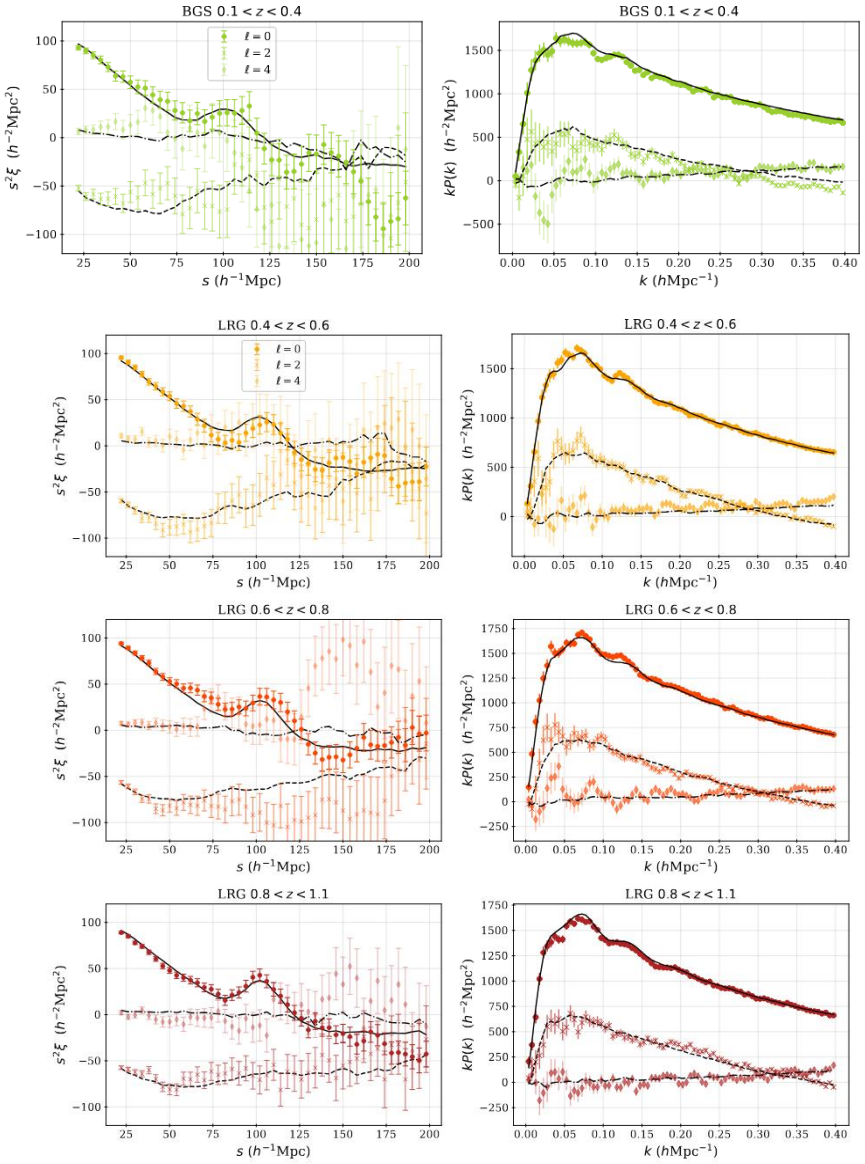
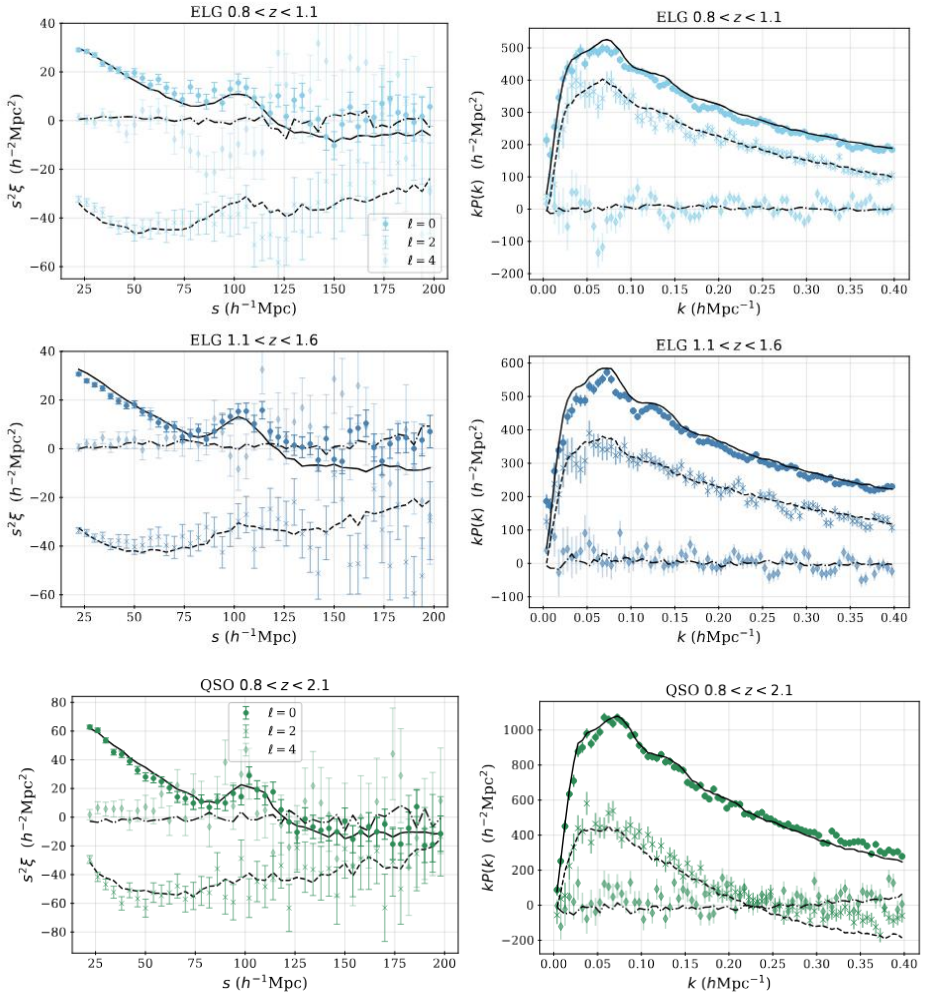
# DESI 2024 II: Sample Definitions, Characteristics, and Two-point Clustering Statistics

arxiv: 2411.12020v1



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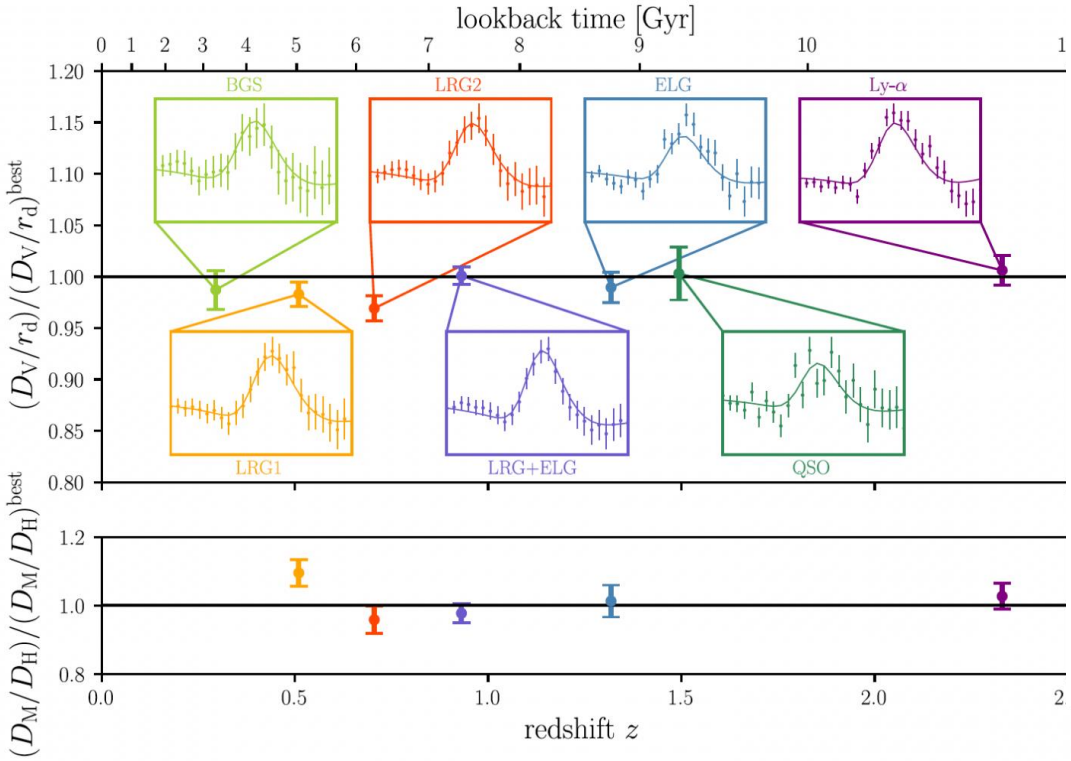
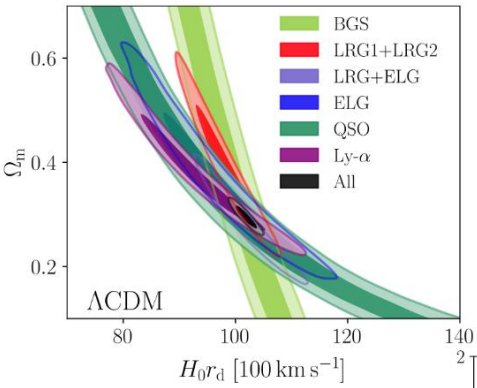
# Flash BAO results from DESI DR1

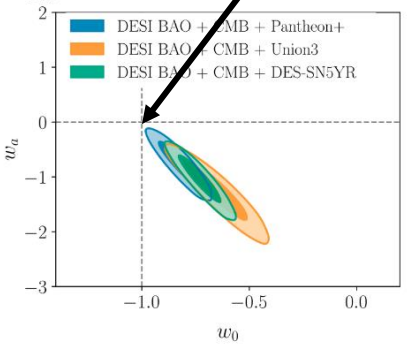



Constraints on $\Omega_m$ and $H_0 r_d$ from BAO under ΛCDM

$$w(a) = w_0 + (1-a)w_a$$

**ΛCDM (w=-1)**




When combined with SNe & CMB showed a preference for $w_0 w_a$CDM

*Credit : DESI collaboration*

**Hint for Time dependent dark energy!**

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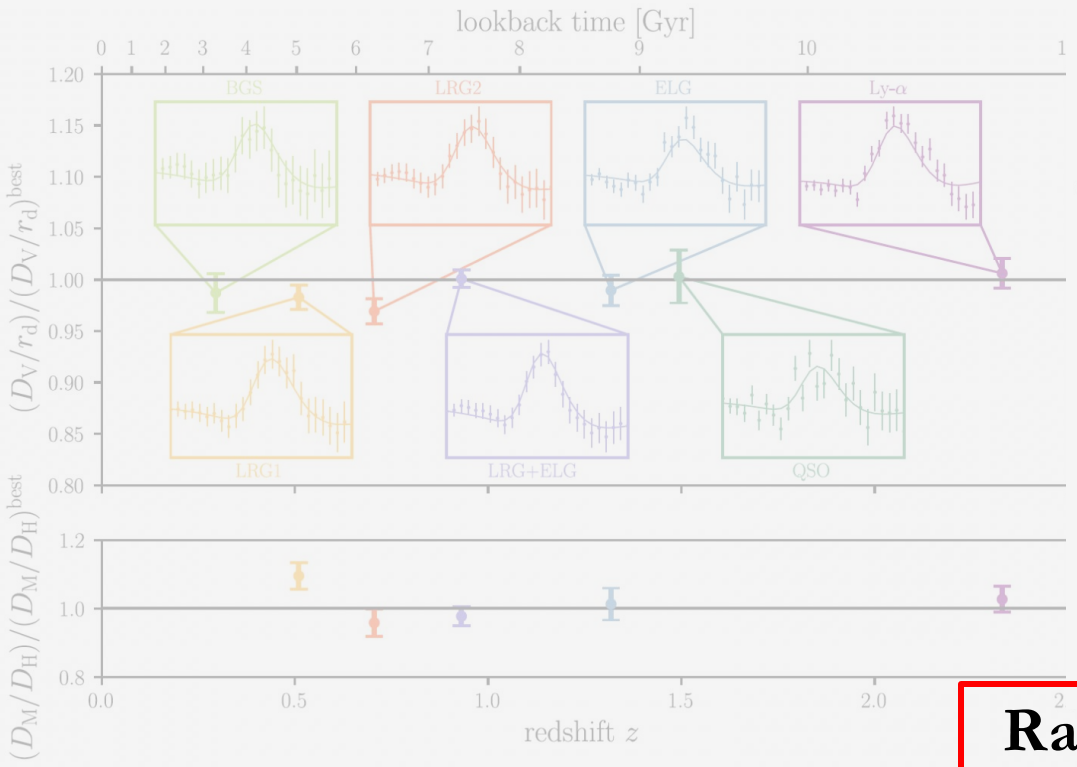
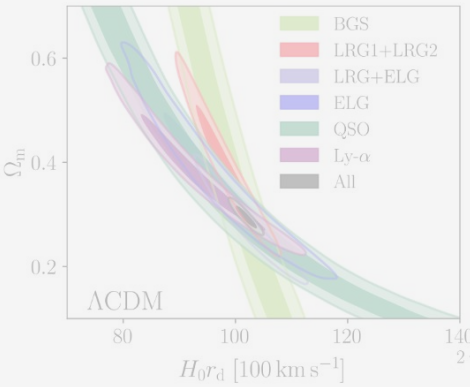
# Flash BAO results from DESI DR1




*Credit : DESI collaboration*

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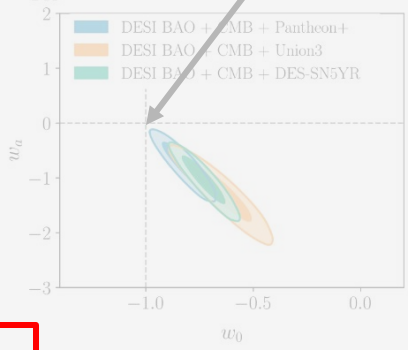
ΛCDM (w=-1)




When combined with SNe & CMB showed a preference for $w_0 w_a$CDM

**Rafaela's talk just after for more insights !**

Hint for Time dependent dark energy!

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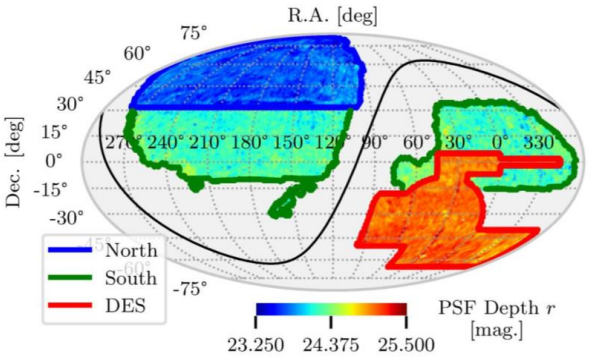
# Main observationnal systematic sources

arxiv: 2411.12020v1

*Chaussidon et al 2022*




**Systematic errors from the target selection** (imaging systematics):

- Target density variations due to photometric properties

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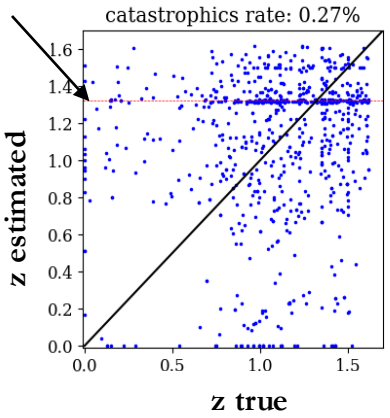
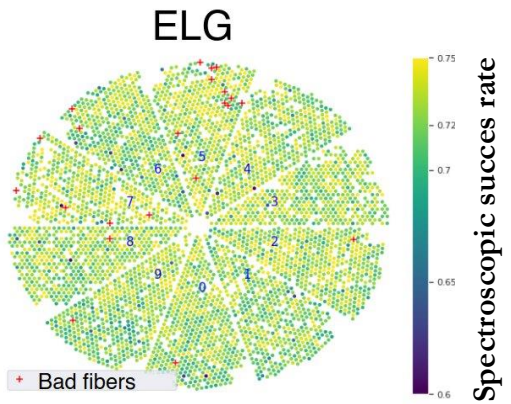
*Yu et al. 2024*
*Krolewski et al. 2024*

[OII] line confusion




- **Systematic errors from spectroscopic operations:**
  - Change in spectroscopic success rate (SSR) due to instrumentation or observing conditions

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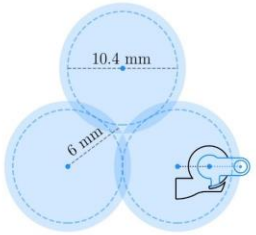
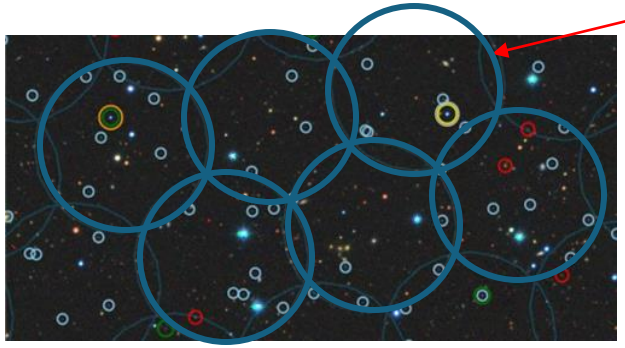
- **Fiber assignment effects:**
  - Miss close pairs of objects

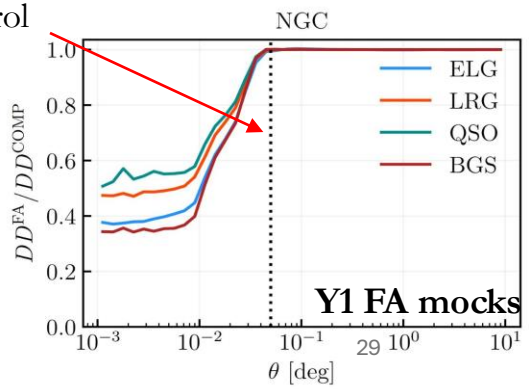



*Pinon et al 2024*



Fiber patrol radius

:BGS
:LRGs
:ELGs
:QSOs



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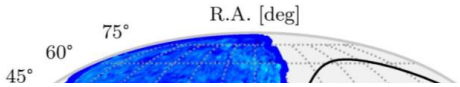
# Main observationnal systematic sources

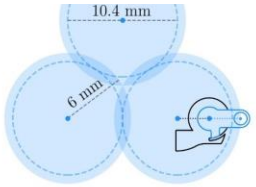
arxiv: 2411.12020v1

*Chaussidon et al 2022*

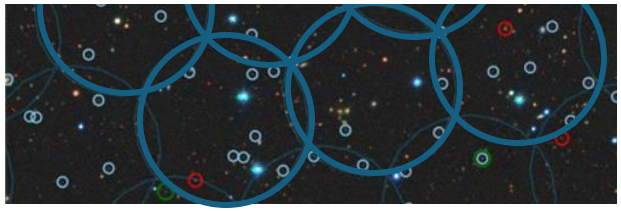


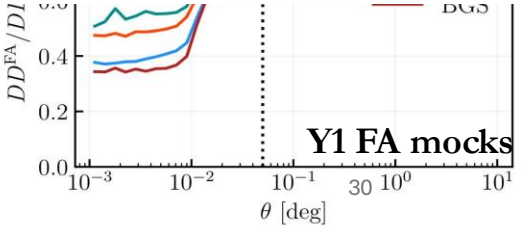

| Ref. | Topic | Section |
|---|---|---|
| [12] | DESI LSS catalogs | Sections 2.3, 4, 5.1 and 8 |
| [14] | Catalog-level blinding | Section 2.4 |
| [15] | Catalog-level blinding method for $f_{\rm NL}$ measurements | Section 2.4 |
| [22] | Incompleteness due to fiber assignment | Section 5 |
| [23] | Removing scales affected by fiber assignment incompleteness | Section 5 |
| [13] | Alternative realizations of DESI fiber assignment | Section 5.2 |
| [16] | Improved Galactic extinction maps from DESI Observations of stars | Section 6 |
| [17] | Forward modelling imaging systematics for DESI LRGs | Section 6 |
| [18] | Correcting for imaging systematics in DESI ELGs | Section 6 |
| [20] | DESI spectroscopic systematics | Section 7 |
| [21] | Correcting for spectroscopic systematics in DESI ELGs | Section 7 |
| [31] | Comparison between analytical and mock-based covariance matrices | Section 10.2 |
| [29] | Analytic covariance matrices for correlation functions | Section 10.2 |
| [30] | Analytic covariance matrices for power spectra | Section 10.2 |
| [24] | Simulations of DESI LSS | Section 11 |

**Table 1.** The list of the papers supporting this paper and the corresponding sections where their results are discussed.




*Pinon et al 2024*



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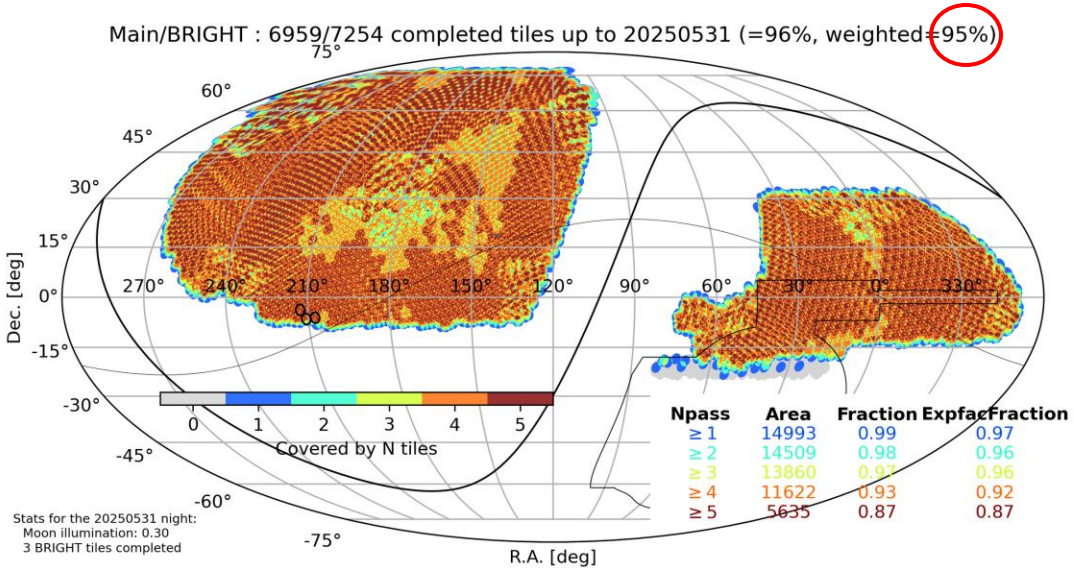
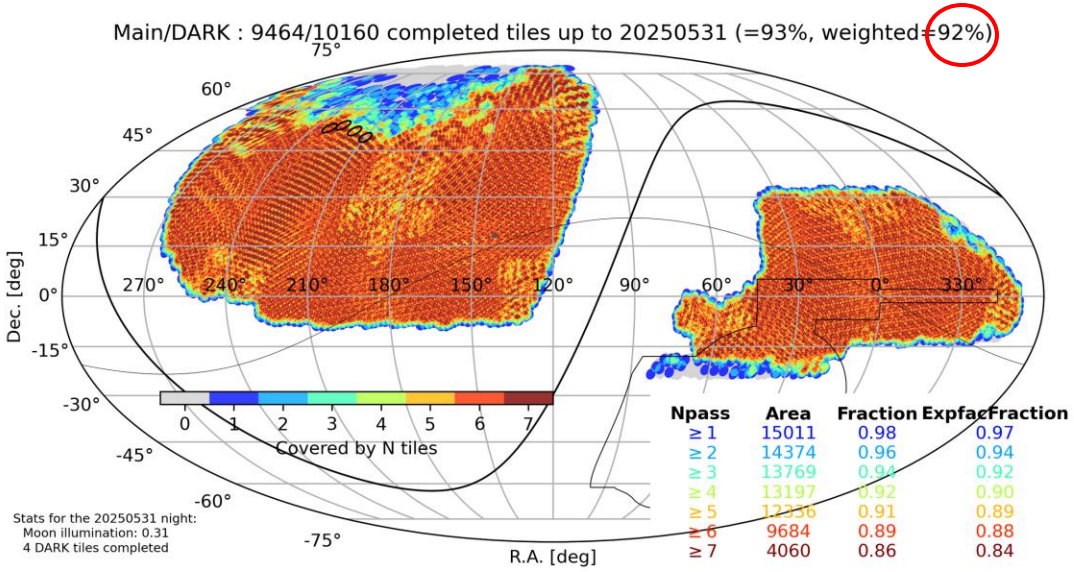
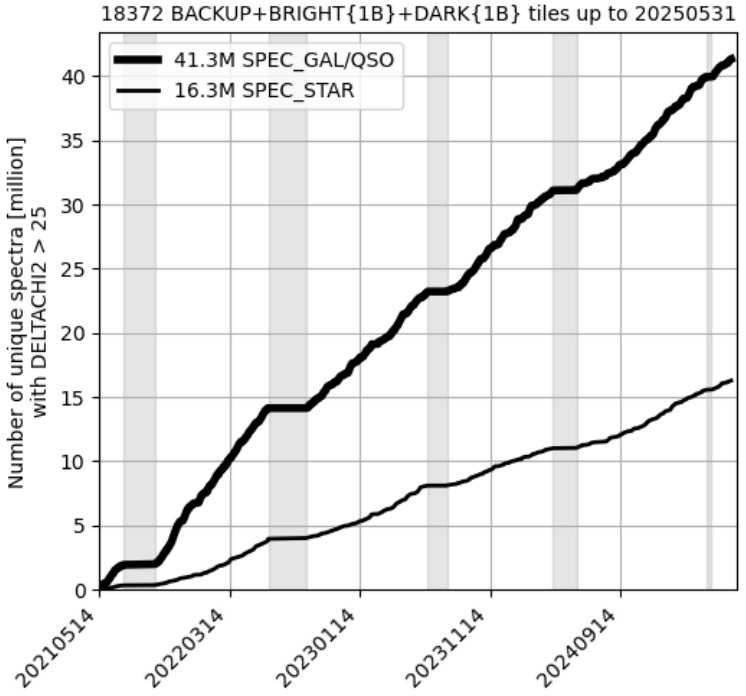
# DESI survey status




Main Survey almost finished after 4 years of observations !

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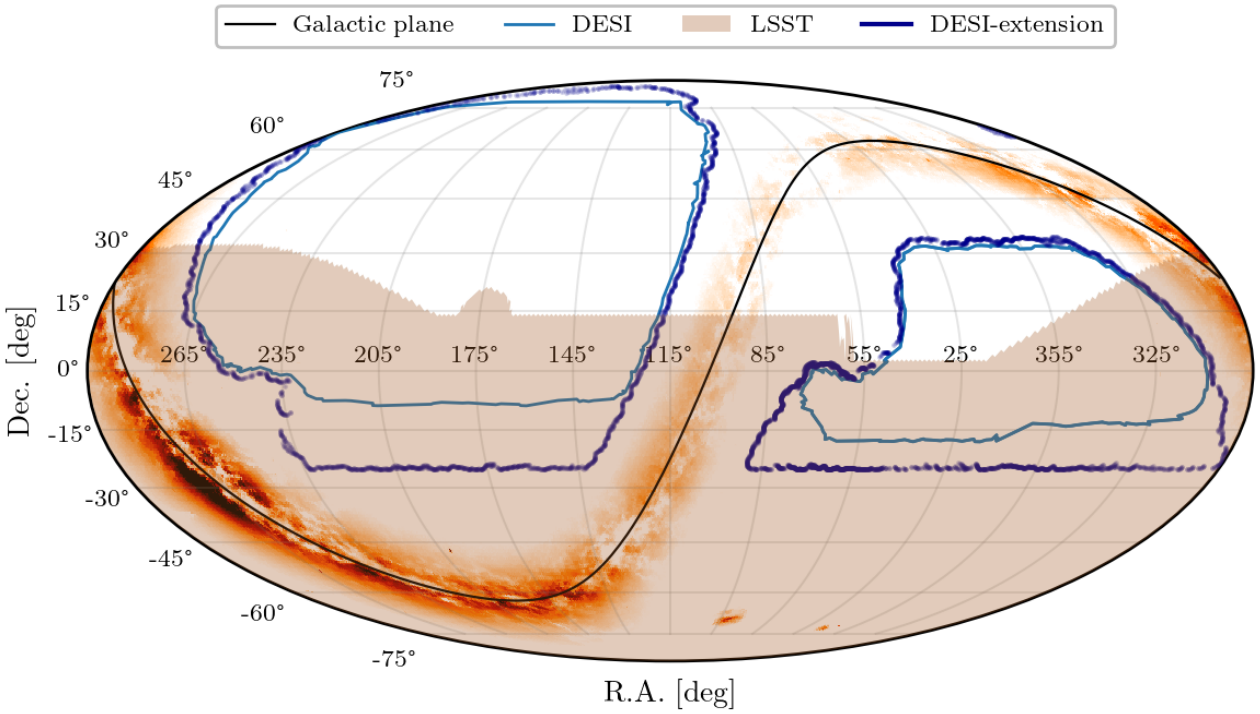
# DESI Extension

5 => **8 year survey** (until 2029)




Increase sky area 14'000 => **17'000 deg$^2$**

**Bigger Overlap with LSST**

**Expected ~60M extragalactic redshifts**

~~3M~~ 3.6M Quasars (QSOs) **0.8<z<2.6**

+ Ly-α **z > 2.1**

~~17M~~ 21M Emission line galaxies (ELGs) **0.6<z<1.6**

~~8M~~ 10M Luminous red galaxies (LRGs) **0.4<z<1.1**

~~13.5M~~ 16M Bright galaxies **0<z<0.5**

**+ ~5M** New sample of LRGs **Luminous Galaxies Extension (LGE)**

Increased density (+50%) **0.4<z<1.1**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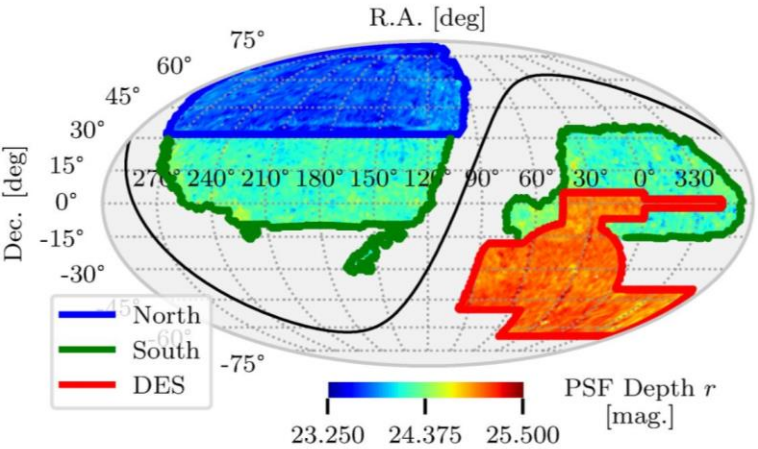
Thank you !
Stay tune for Rafaela presentation on cosmological results from DESI
Credit : DESI collaboration

# DESI Imaging systematics: QSO case

**TS use Legacy survey DR9:**

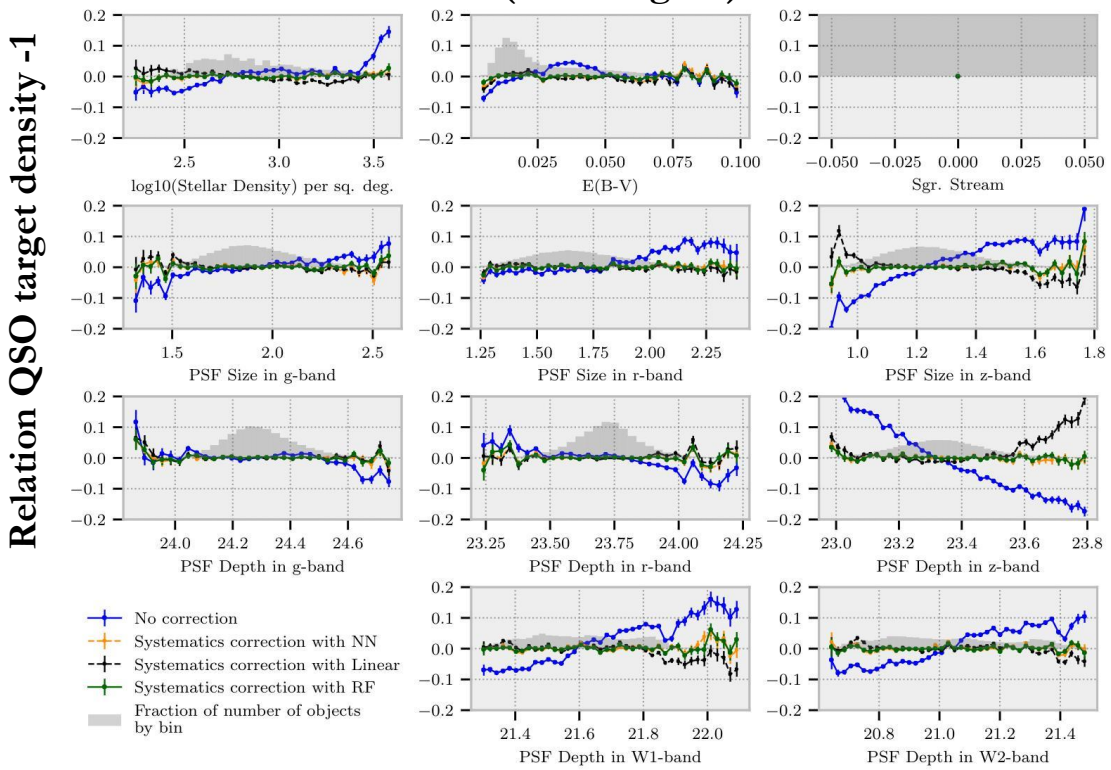



**Systematics need to be estimated for each photometric regions**

Trends are corrected using different regression techniques:

- **Linear**
- **Neural network (NN)**
- **Random forets**

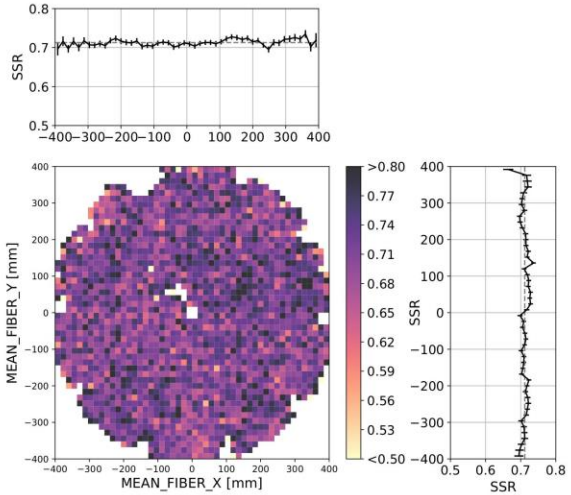
**Trends in the number density of QSO vs imaging features (north region)**



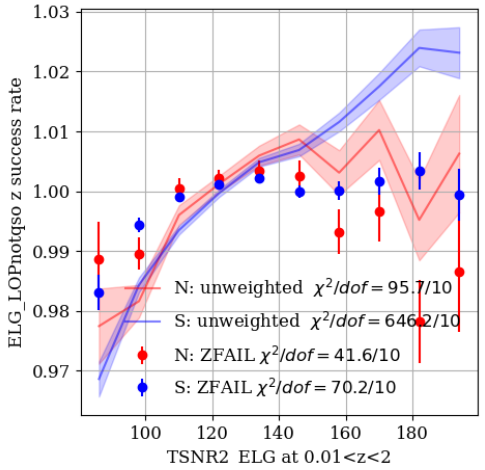

*Chaussidon et al. 2022*

# Spectroscopic systematics: ELG case

**Trends in the spectroscopic sucess rate vs spectroscopic features**




Across the focal plane

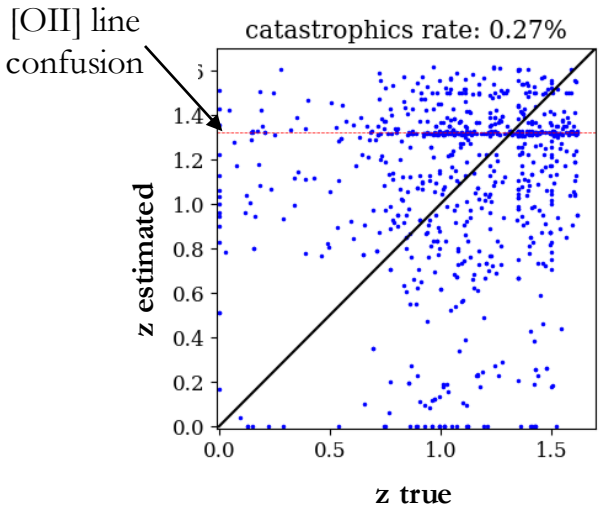



Vs the SNR

+ lots of other features...

=> We observed only **small trends according to spectroscopic features**

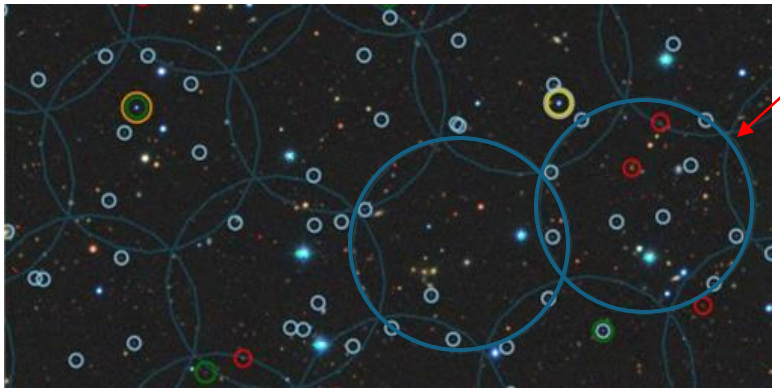
Redshift **catastrophics failure** with sky-residual lines confusion



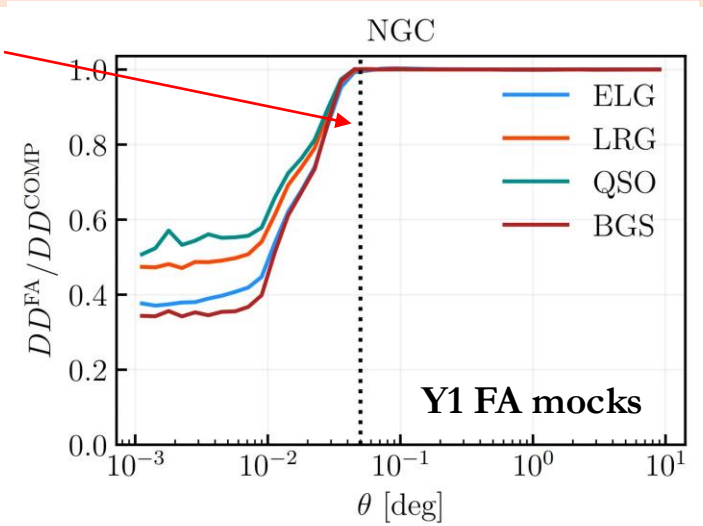

*Yu et al. 2024*
*Krolewski et al. 2024*

**Trends with spectroscopy are minors and have < 0.2σ impact on clustering measurements**

# Fiber assignment (FA)



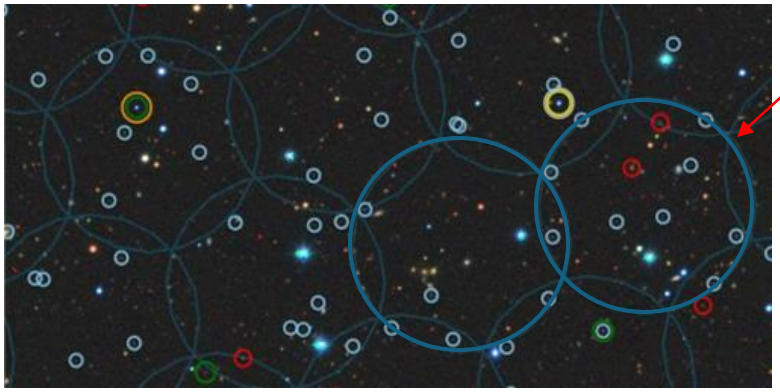
Fiber patrol radius



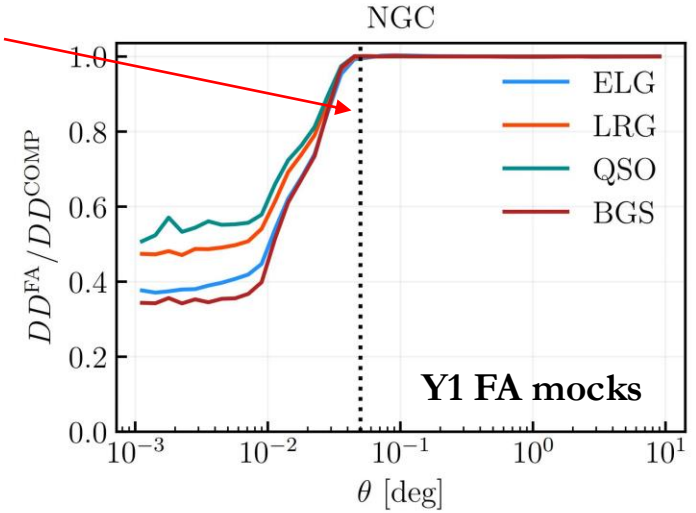

Missing pairs at small separations!

*Pinon et al. in 2024*

# Fiber assignment (FA)

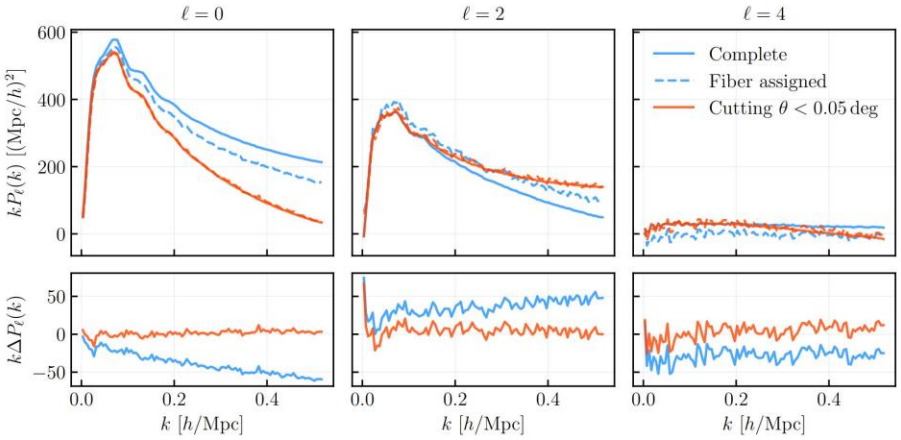


Fiber patrol radius




Missing pairs at small separations!

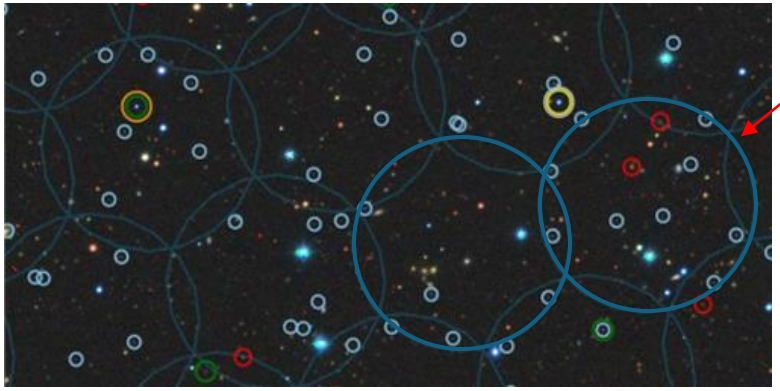
**Tests on ELG Y1 DESI mocks**




**Cut pair separation < 0.05 deg** (~ size of the patrol radius) leads to **unbiased measurement with FA**

*Pinon et al. in 2024*

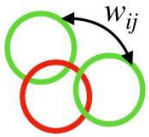
# Fiber assignment:
## **Pairwise-Inverse-Probability** (PIP) weighting scheme



Fiber patrol radius

*Bianchi & Percival 2017*
*Mohammad et al. 2020*

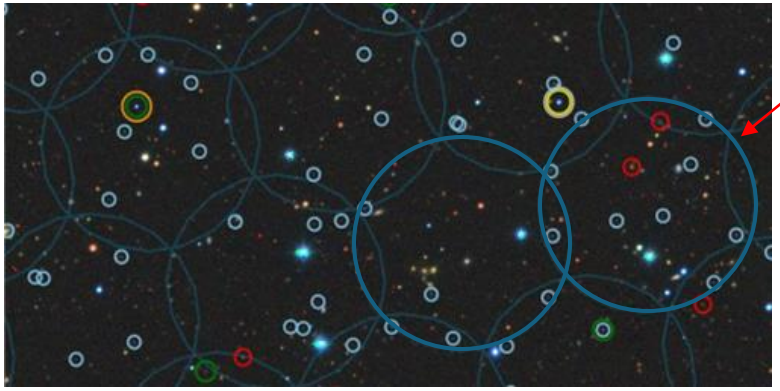
Statistical estimation to observe a **galaxy pair**:




$$w_{ij} = \frac{\text{Number of FA runs}}{\text{Number of time the galaxy pair has been observed}}$$

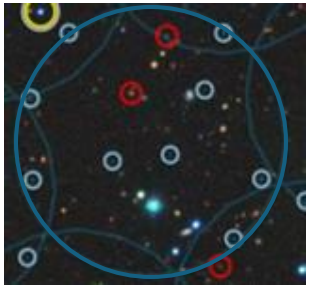
↳ = 0 for galaxy inside the same patrol radius

# Fiber assignment:
## **Pairwise-Inverse-Probability** (PIP) weighting scheme



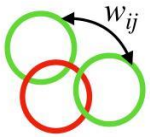
Fiber patrol radius

*Bianchi & Percival 2017*
*Mohammad et al. 2020*



Angular up-weight (ANG)

Statistical estimation to observe a **galaxy pair**:




$$w_{ij} = \frac{\text{Number of FA runs}}{\text{Number of time the galaxy pair has been observed}}$$

↳ = 0 for galaxy inside the same patrol radius

$$+$$

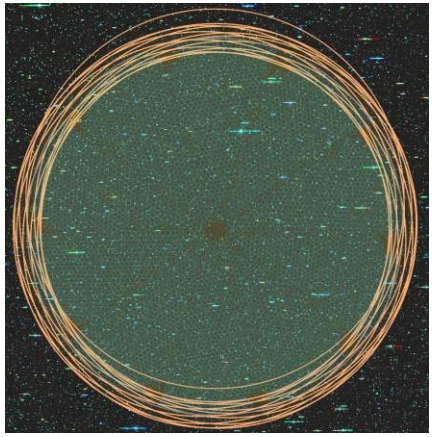
$$w_{\rm ang}^{DD}(\theta) = \frac{DD^{\rm par}(\theta)}{DD_{\rm PIP}^{\rm fib}(\theta)},$$

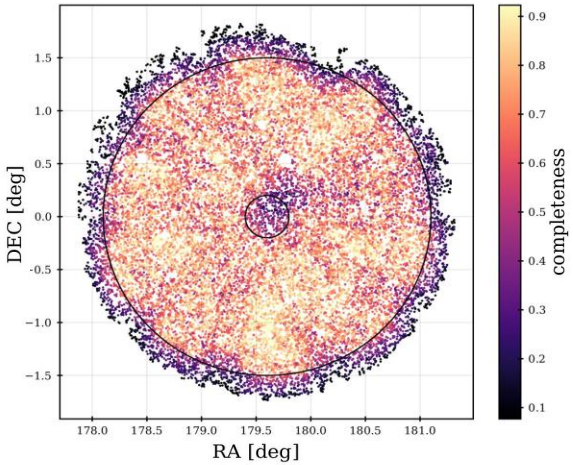
$$w_{\rm ang}^{DR}(\theta) = \frac{DR^{\rm par}(\theta)}{DR_{\rm IIP}^{\rm fib}(\theta)}.$$

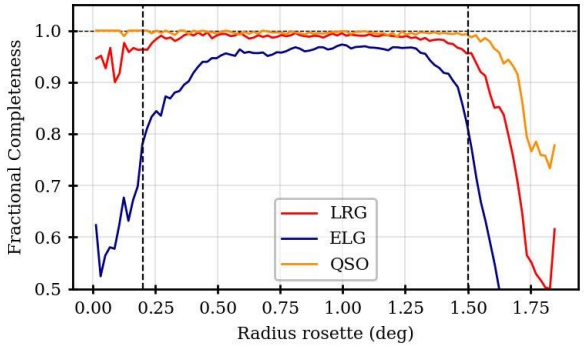
The pairs DD and DR at a given separation angle θ are up-weighted

# Fiber assignment: Impact on the 1% survey

1 rosettes

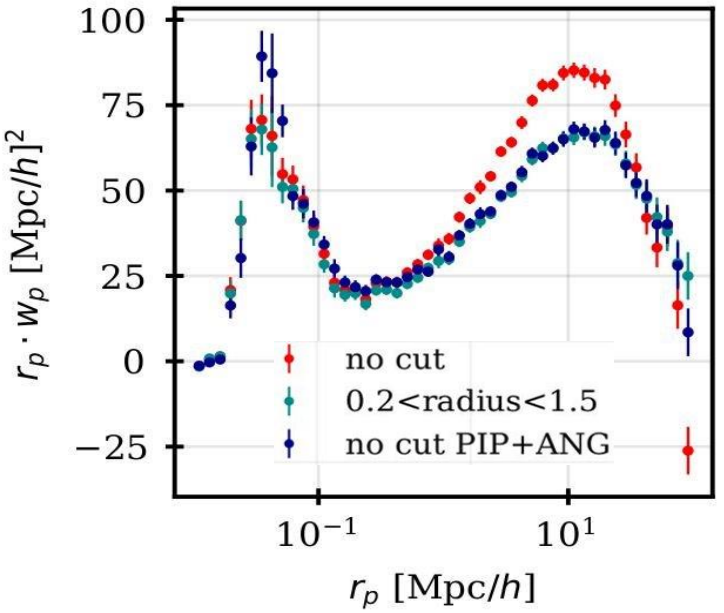





=> Missing targets at the border of the rosettes

ELG projected correlation function




PIP weighting scheme lead to 'unbiased' measurement