DESI: First results with early data

Antoine Rocher – 3rd year Ph.D. student

Supervisors : **Vanina Ruhlmann-Kleider, Etienne Burtin**

IRFU, CEA, Université Paris-Saclay, F-91191 Gif-sur-Yvette, France

antoine.rocher@cea.fr

université PARIS-SACLAY

cea

DARK ENERGY SPECTROSCOPIC INSTRUMENT

U.S. Department of Energy Office of Science

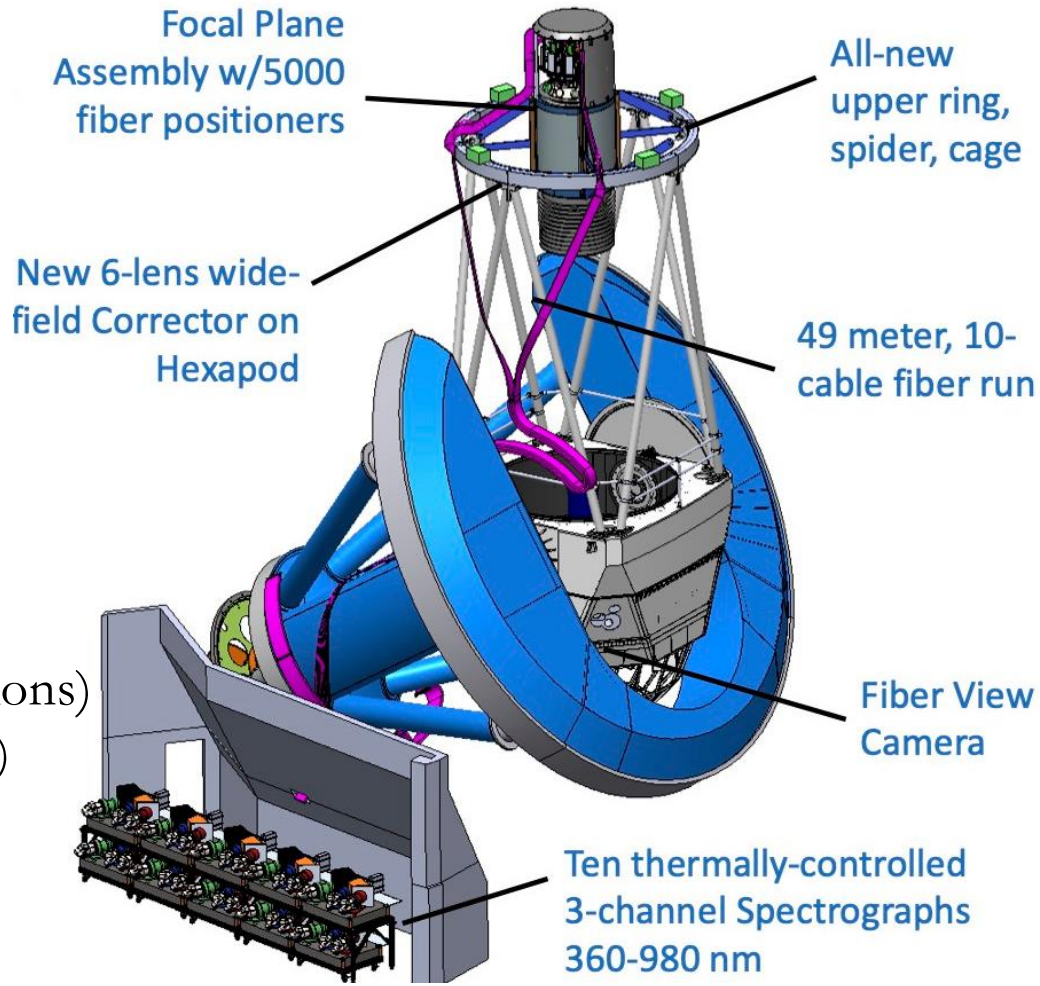
Dark Energy Spectroscopic Instrument (DESI)

- **Mayall Telescope (4m) at Kitt Peak (Arizona)**

- First stage 4 **Spectroscopic** survey:
  - Measure 3D distributions of galaxies (RA,DEC,Z)
  - **5000 spectra simultaneously**
  - 14000 deg² (~1/3 sky area)

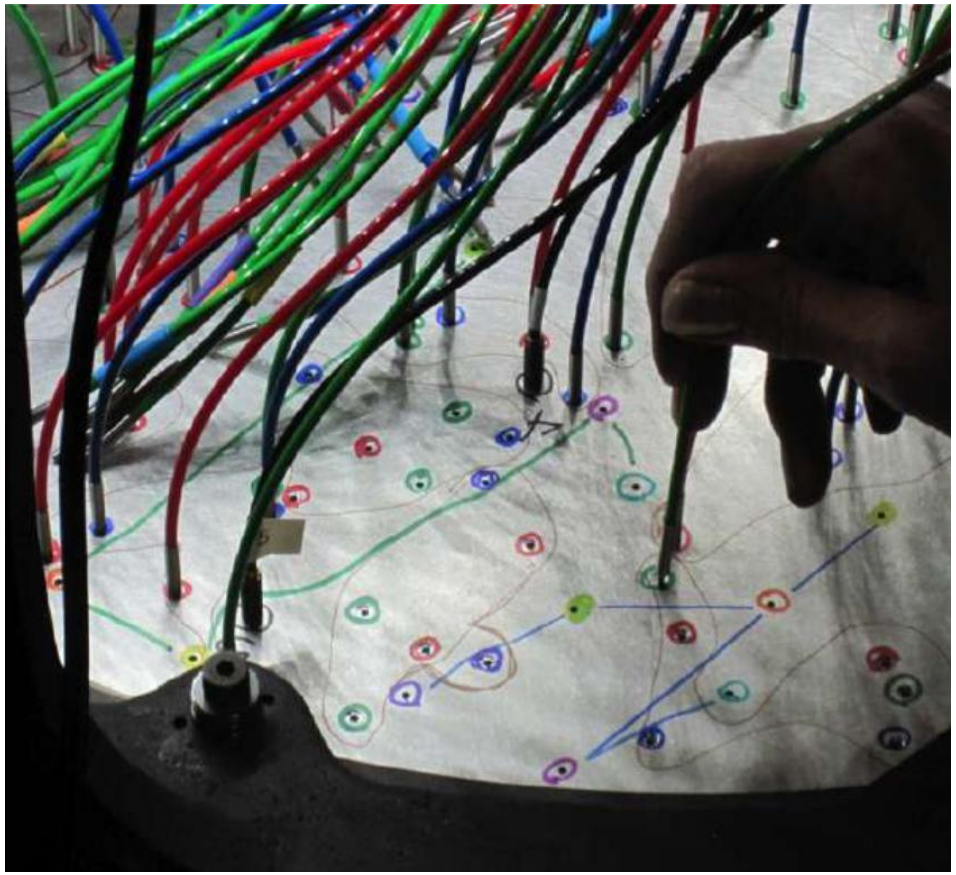
- **40M redshifts** at the end of the survey (5 years)
  - x13 previous spectroscopic surveys

- Probe the large scale structure of the Universe
  - **Universe expansion** with BAO (Baryonic Acoustic Oscillations)
  - **Growth rate of structure** RSD (Redshift Space Distortions)
  - Other science goals:
    - Primordial non-gaussianity (with f_{nl})
    - Sum of the neutrino masses
    - + many others ...

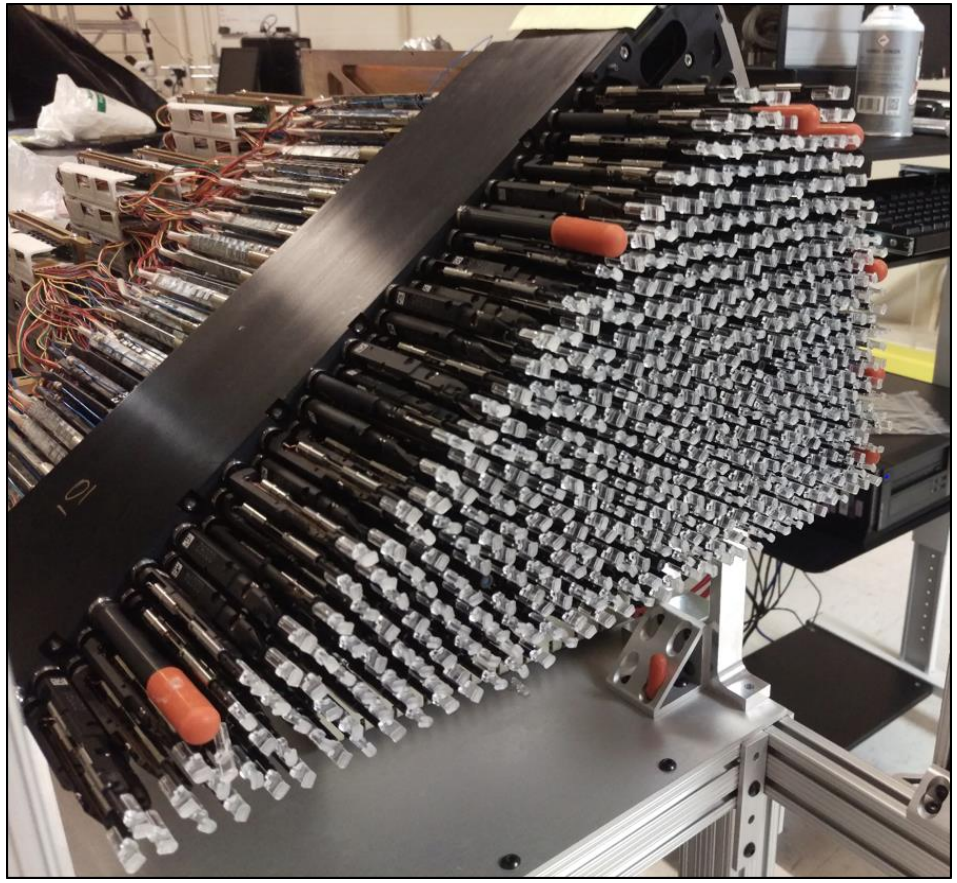


Fiber improvement

Major improvement !!

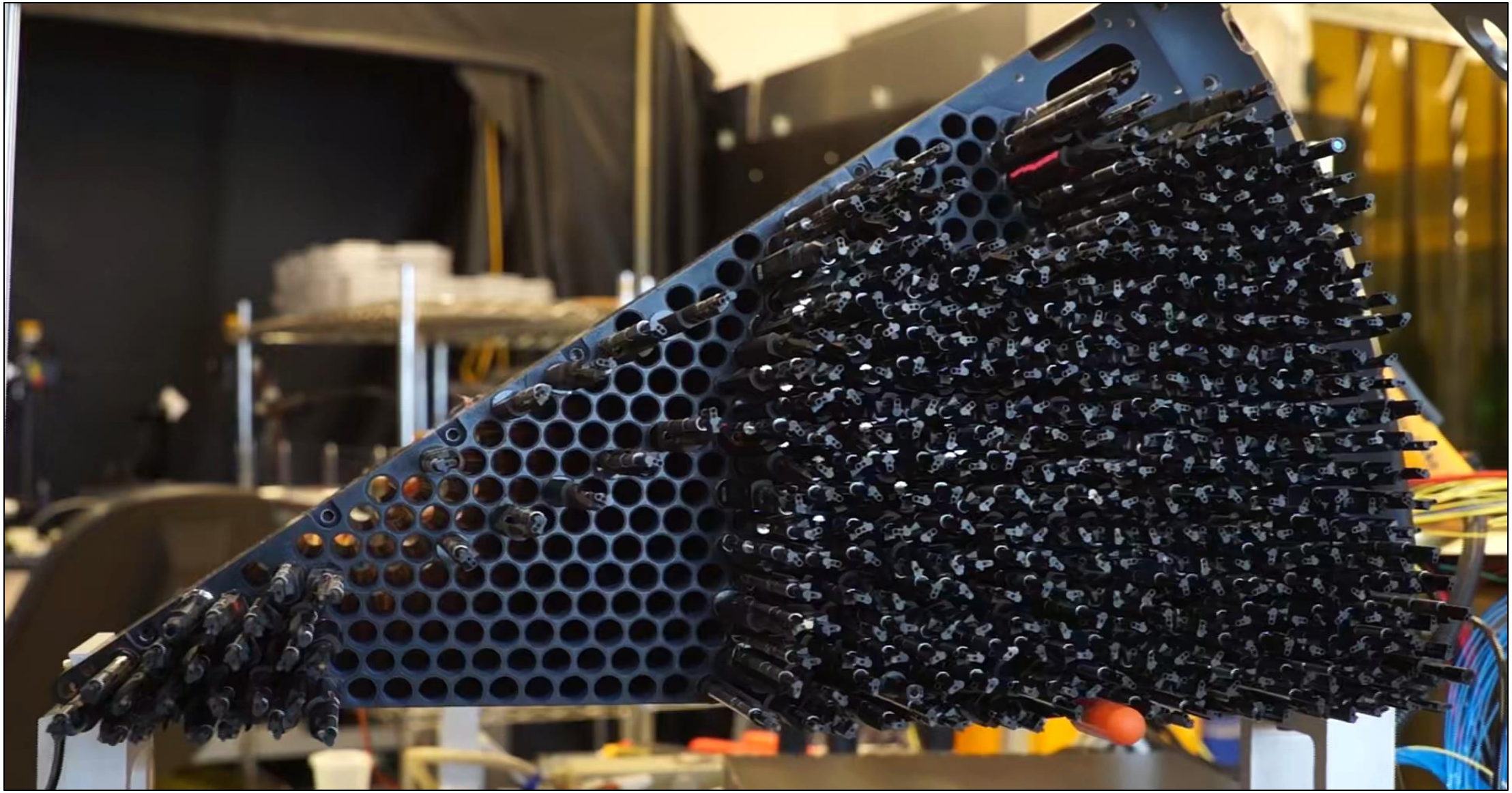


SDSS

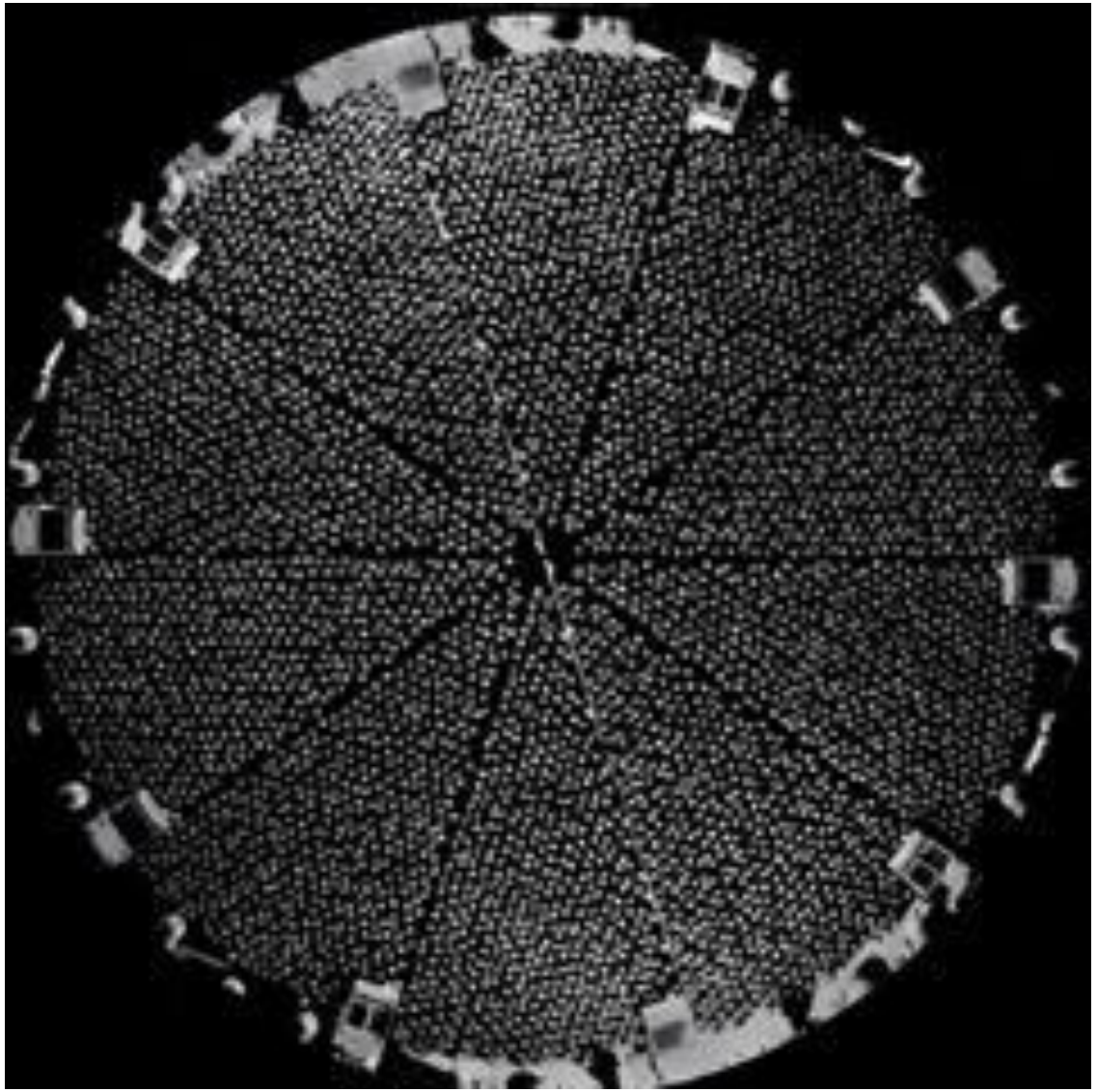


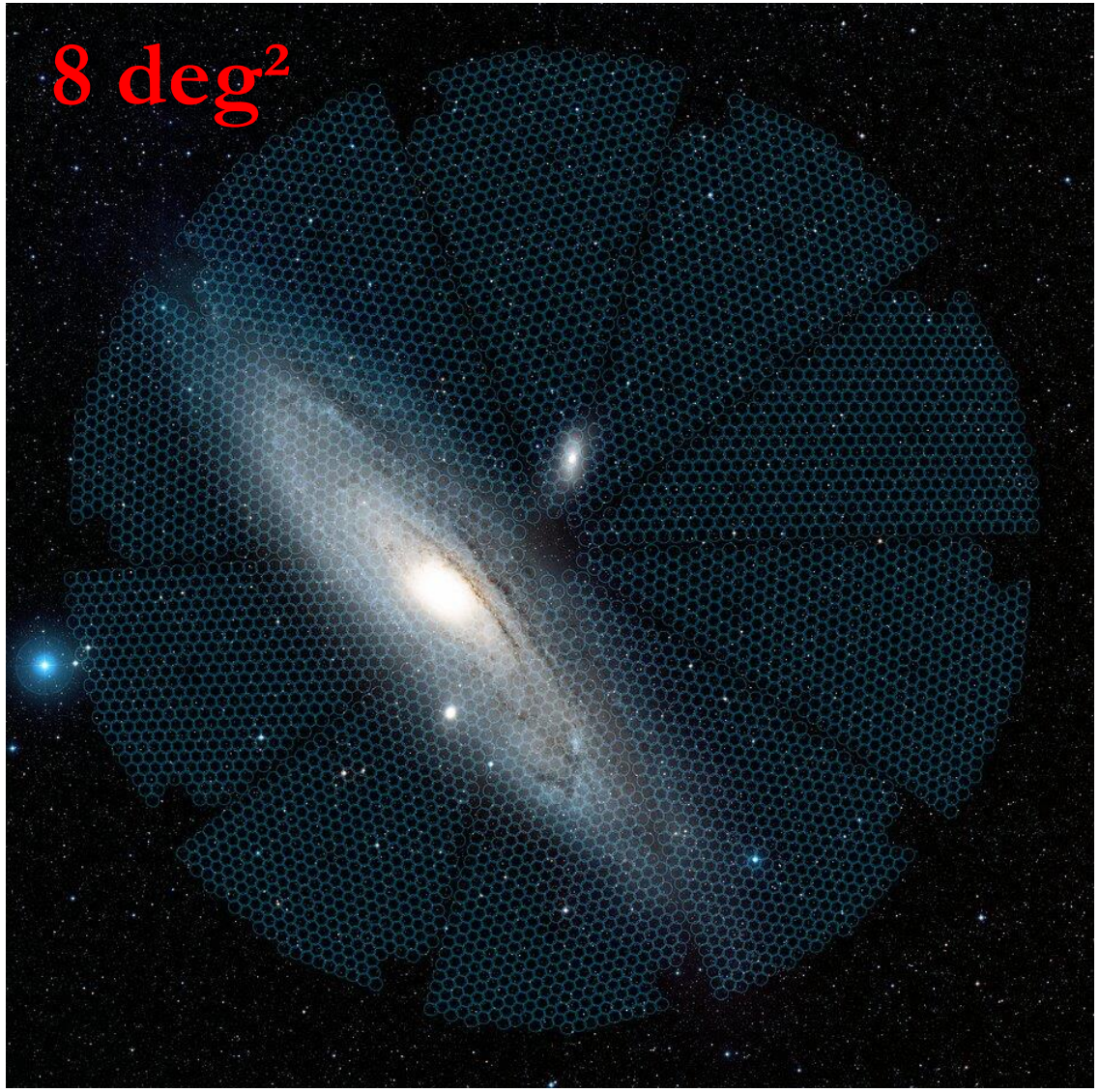
DESI

Fiber movie

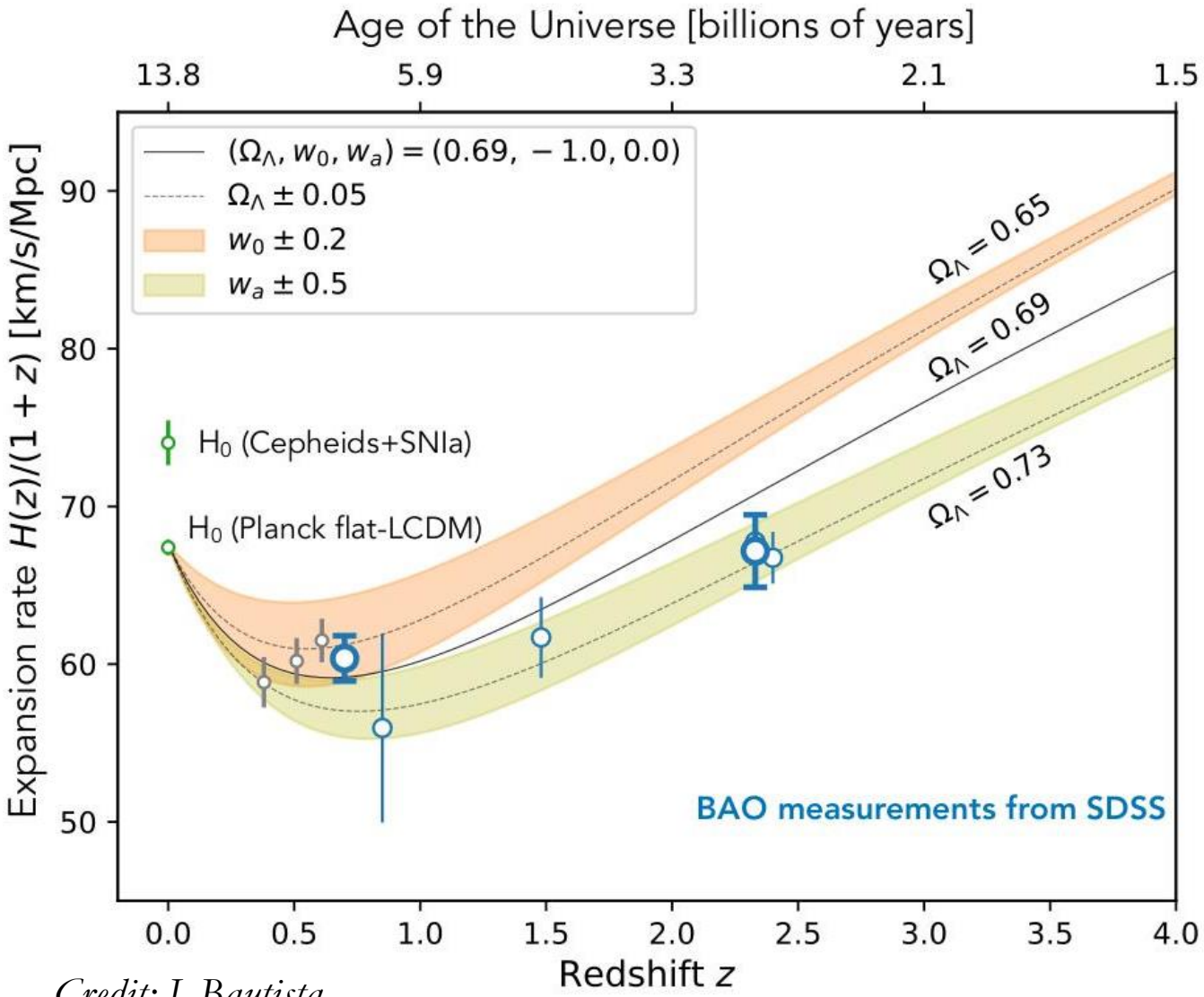


Focal plane



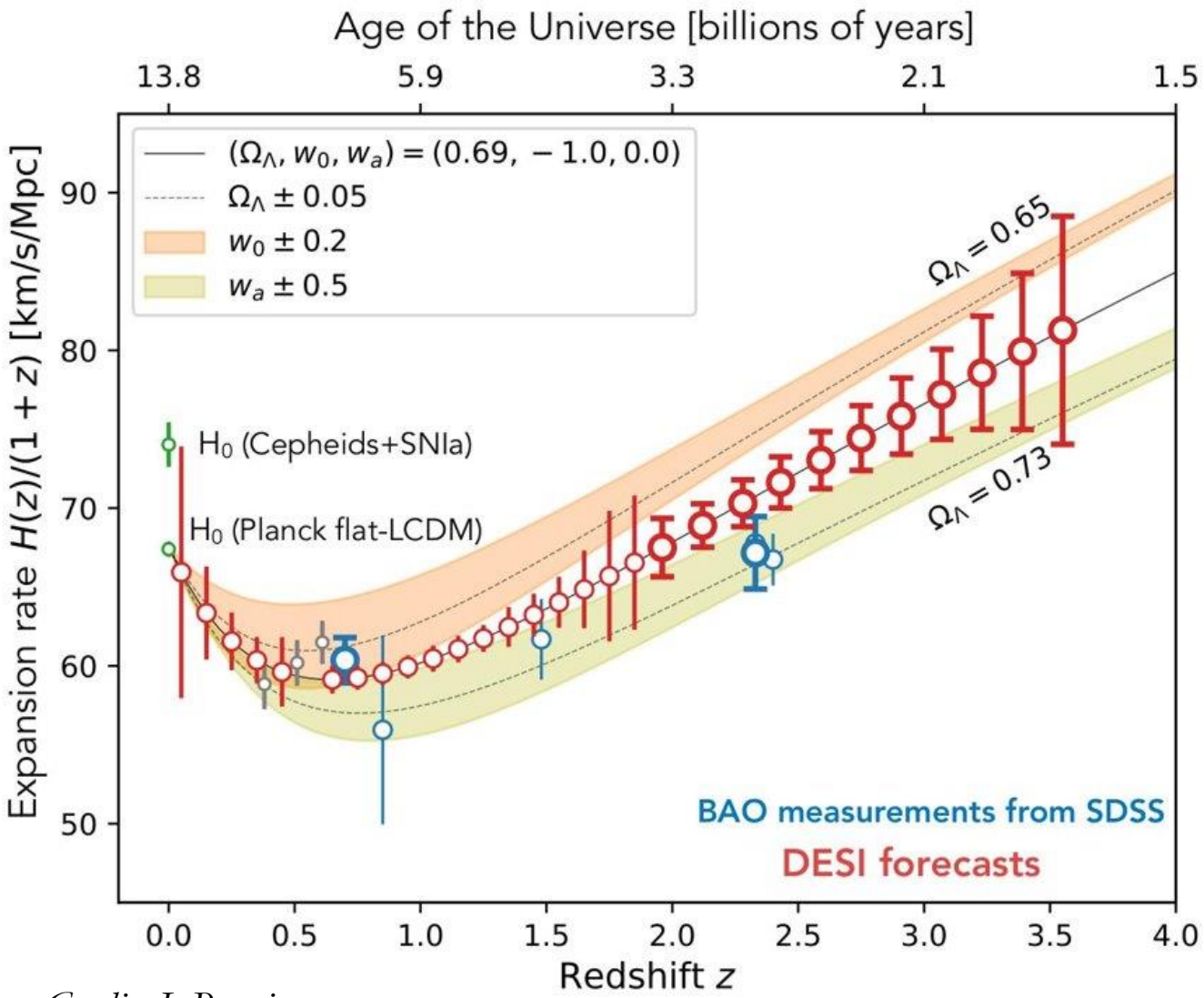


Dark Energy: current measurement from SDSS



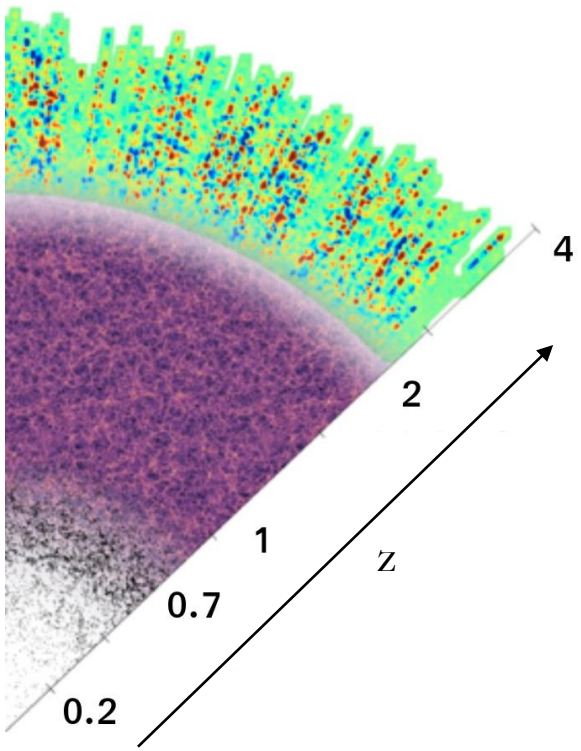
Credit: J. Bautista

Dark Energy: DESI forecasts

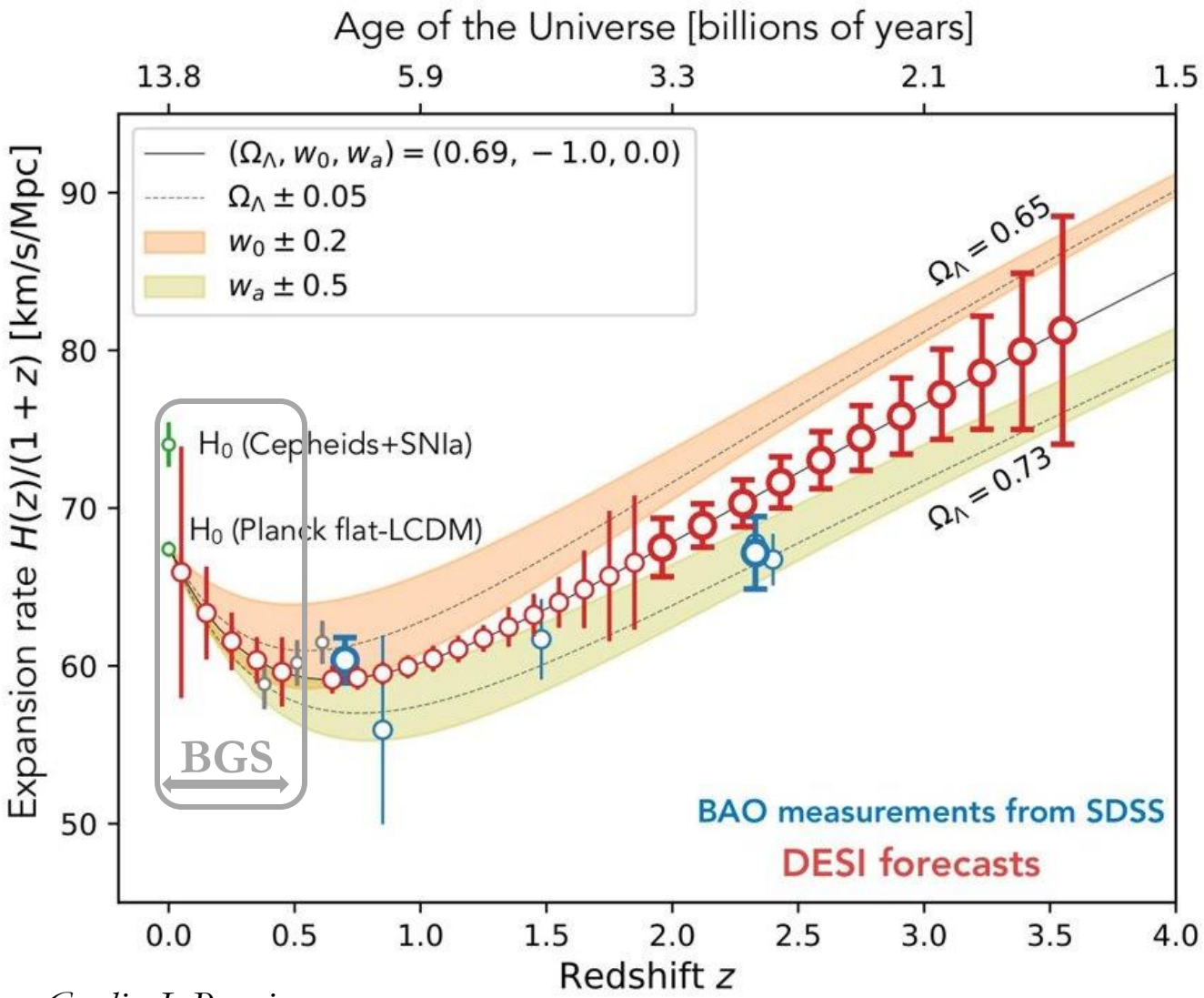


Credit: J. Bautista

4 different tracers to probe the universe z < 3.5

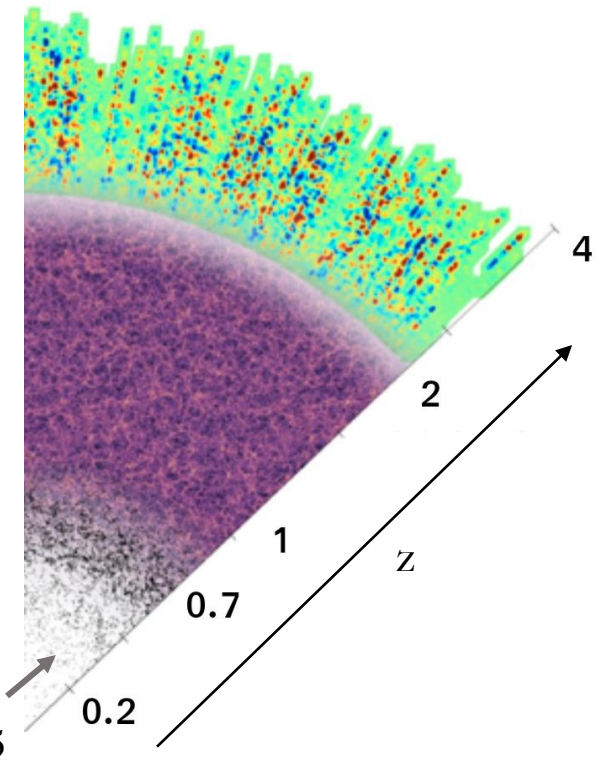


Dark Energy: DESI forecasts



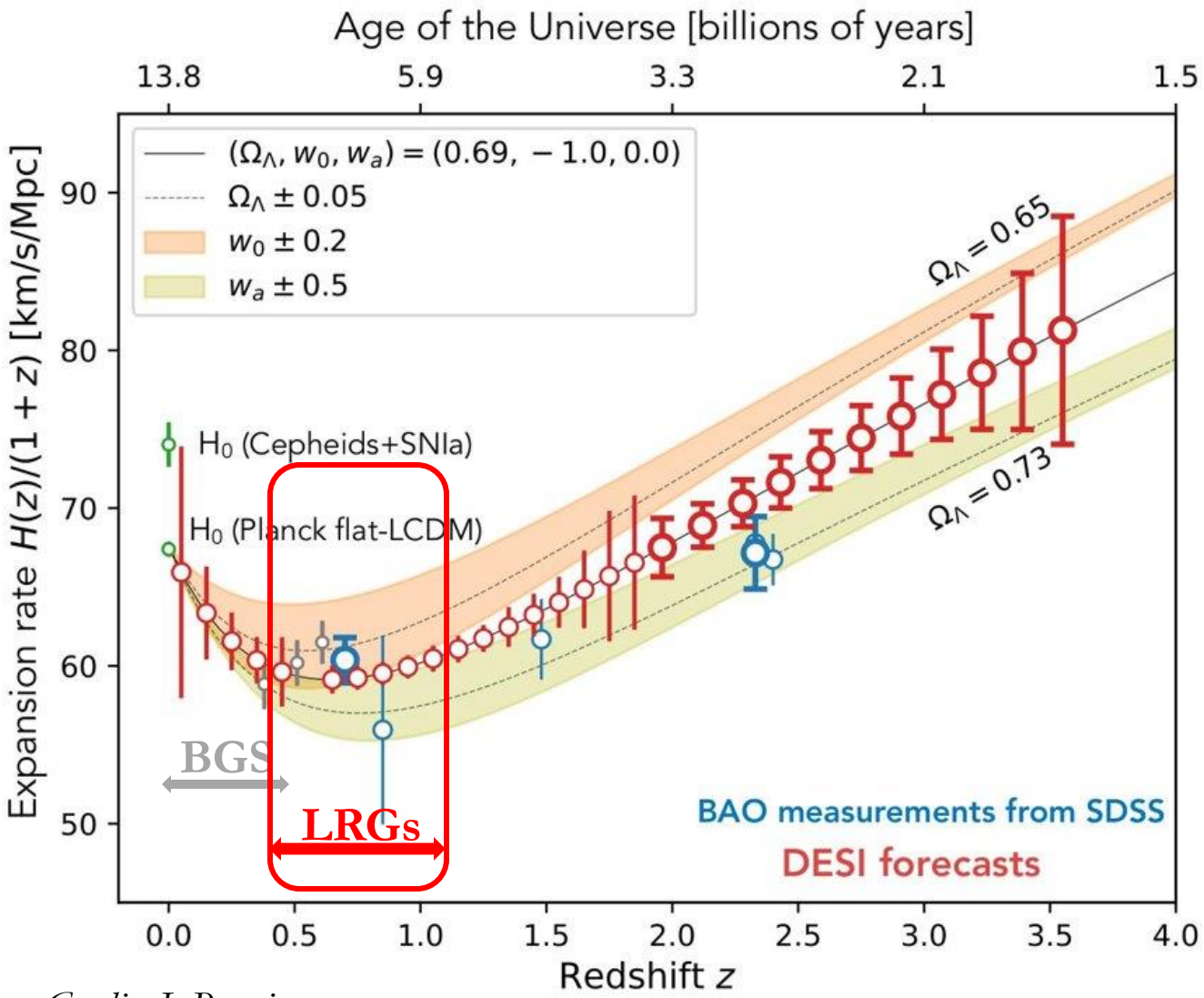
Credit: J. Bautista

4 different tracers to probe the universe z < 3.5



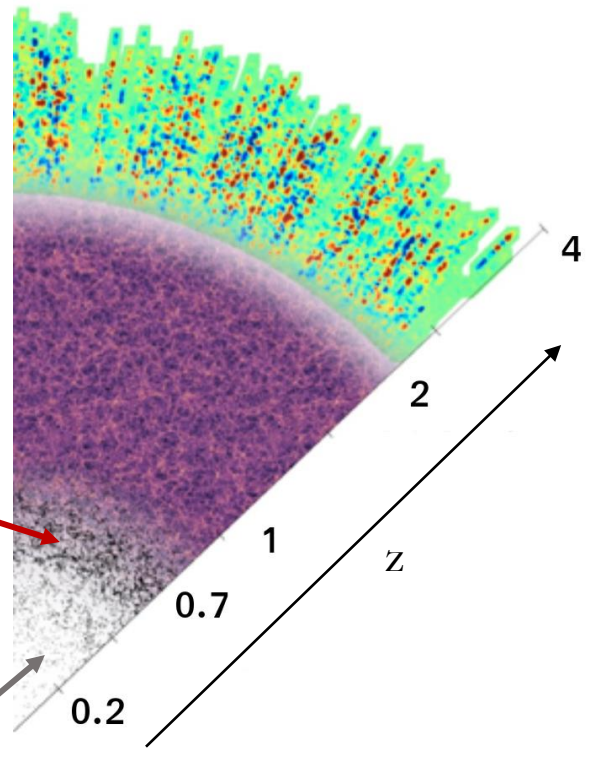
13.5M Bright galaxies
0<z<0.5

Dark Energy: DESI forecasts



Credit: J. Bautista

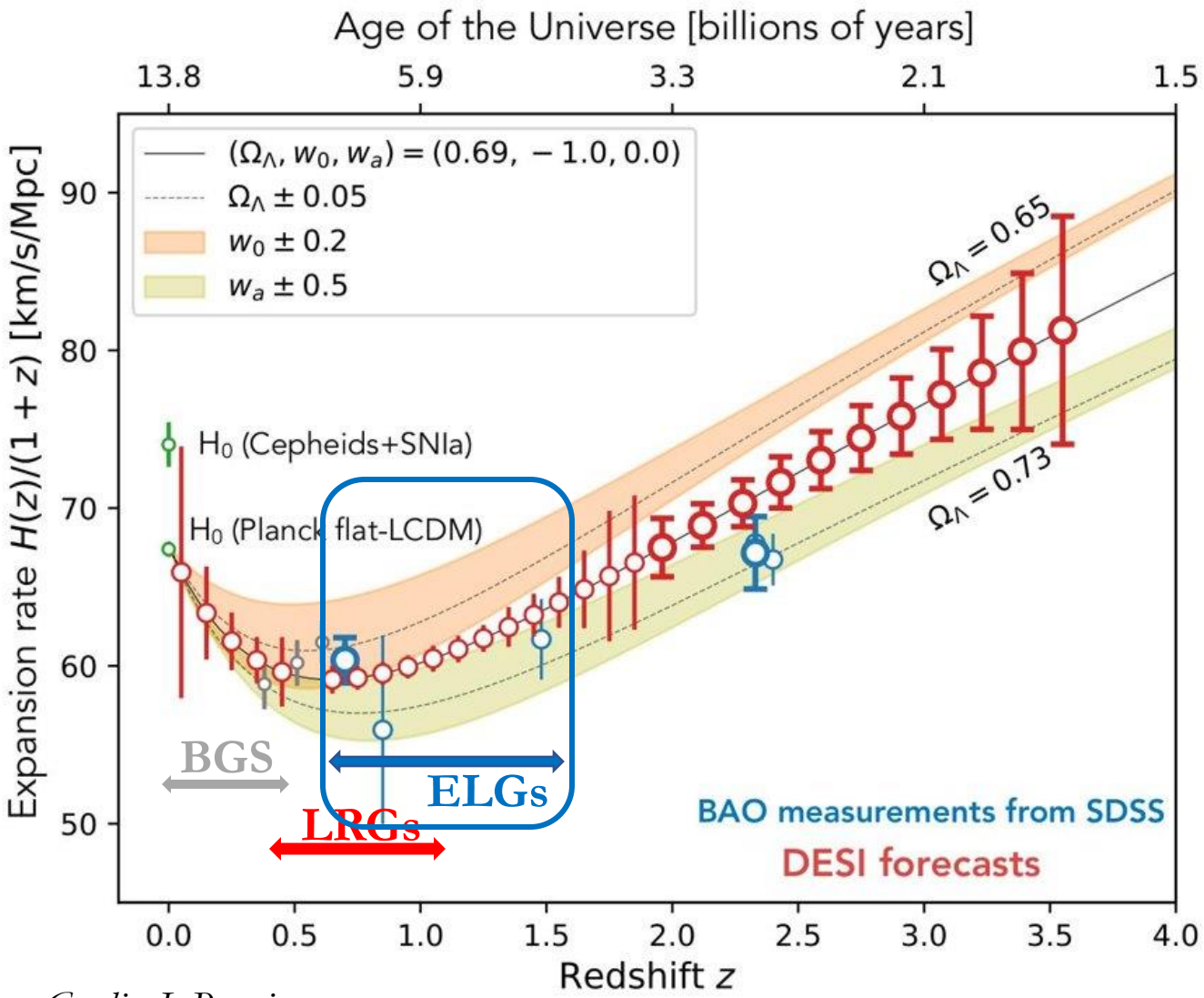
4 different tracers to probe the universe z < 3.5



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

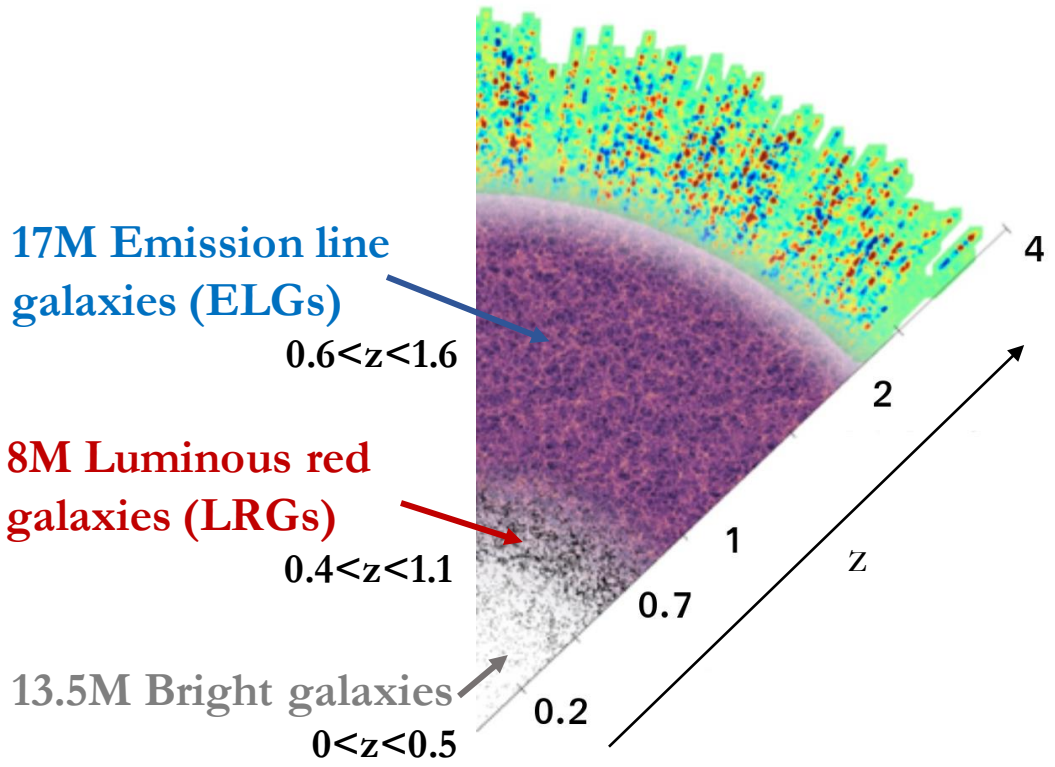
13.5M Bright galaxies
0<z<0.5

Dark Energy: DESI forecasts

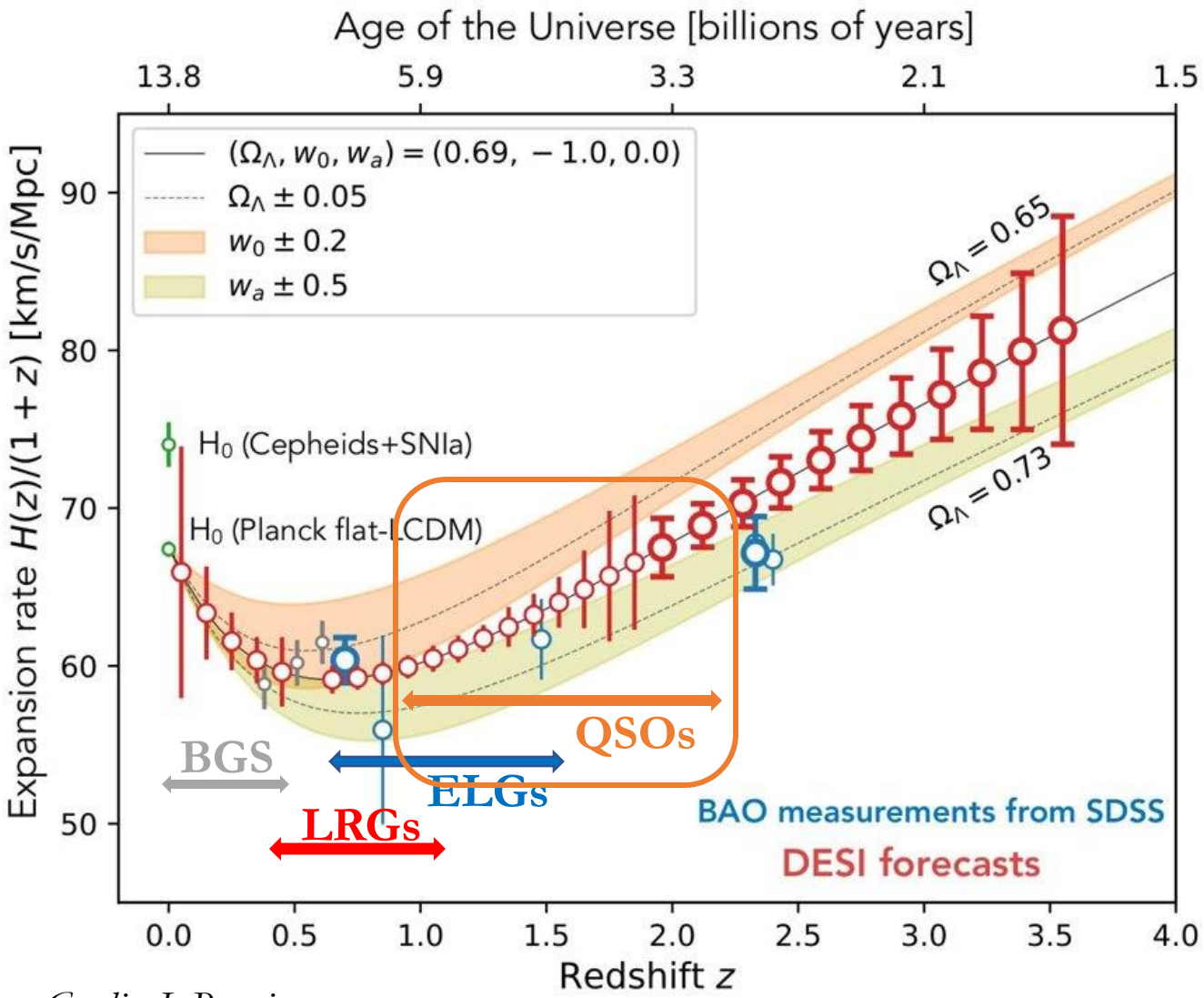


Credit: J. Bautista

4 different tracers to probe the universe z < 3.5

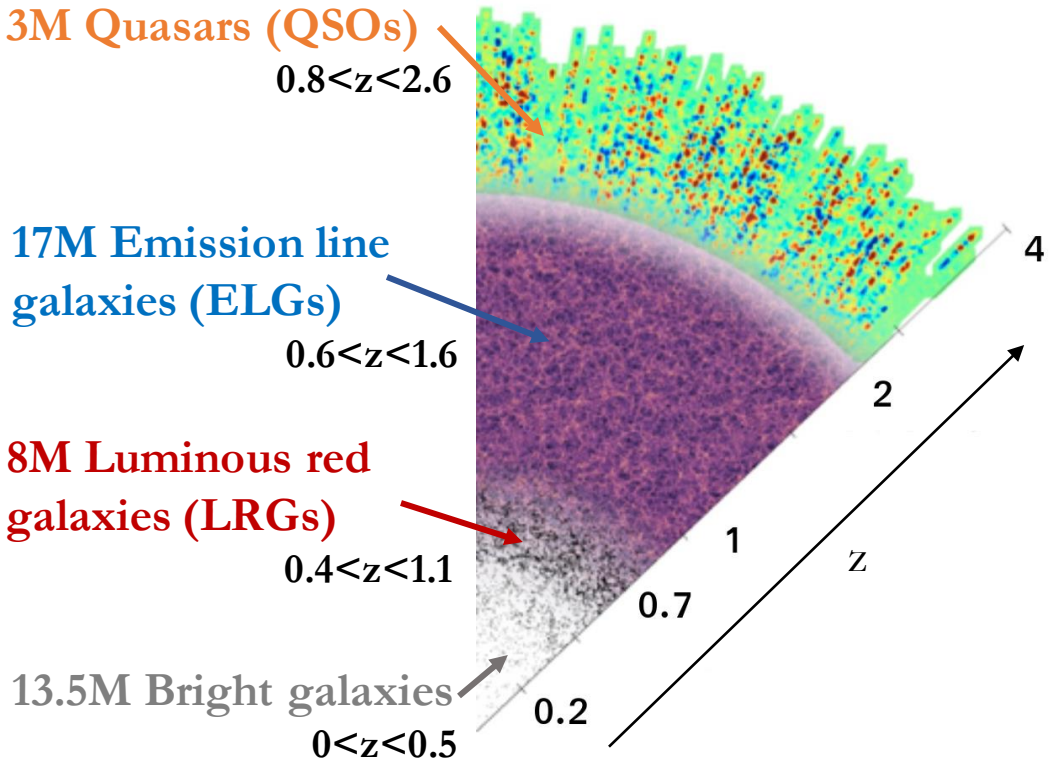


Dark Energy: DESI forecasts

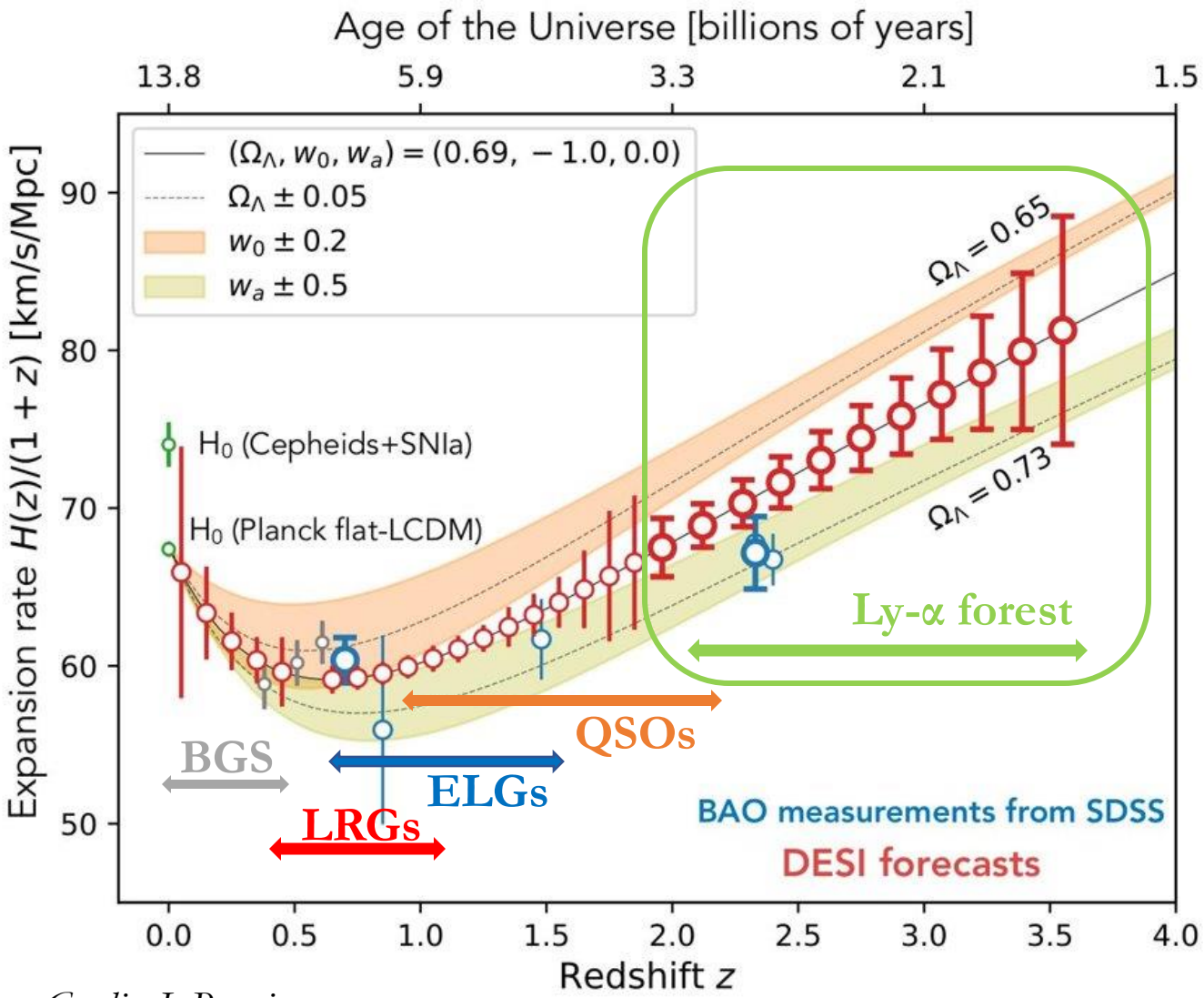


Credit: J. Bautista

4 different tracers to probe the universe z < 3.5

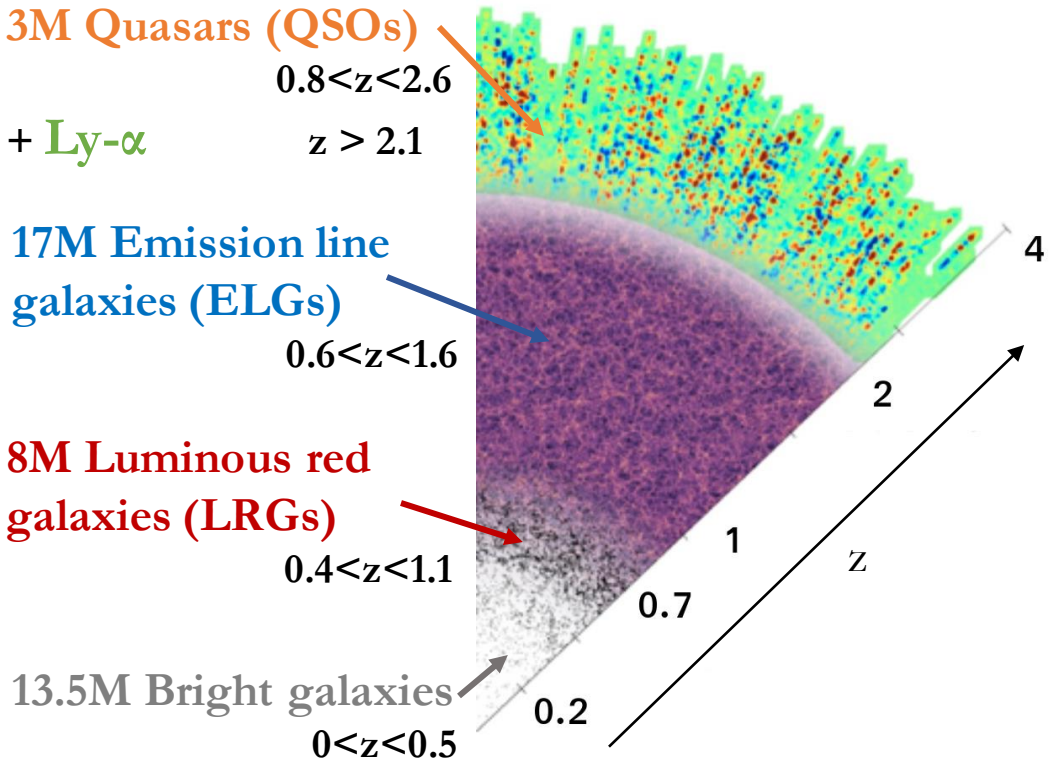


Dark Energy: DESI forecasts

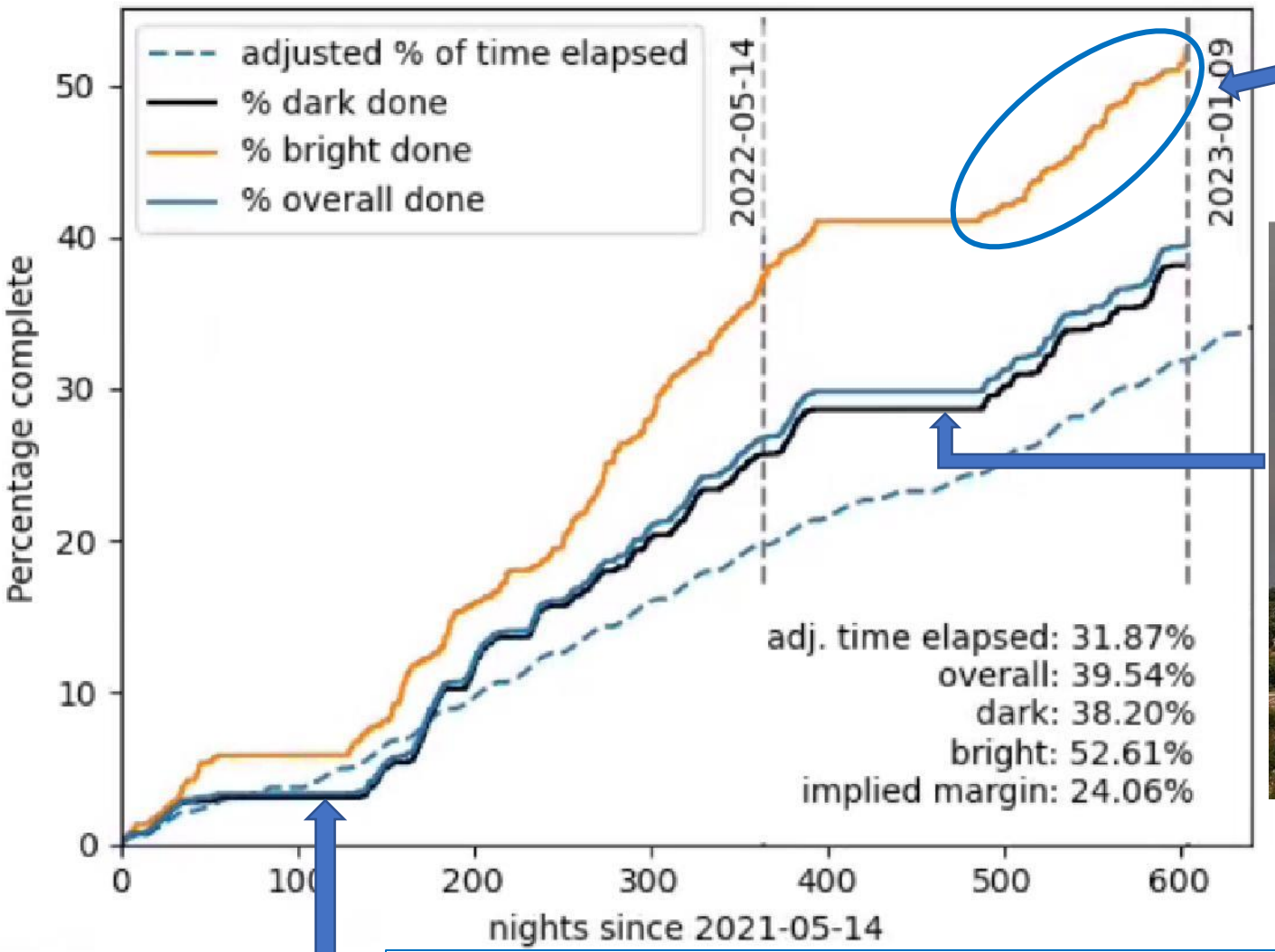


Credit: J. Bautista

4 different tracers to probe the universe z < 3.5



DESI survey progress

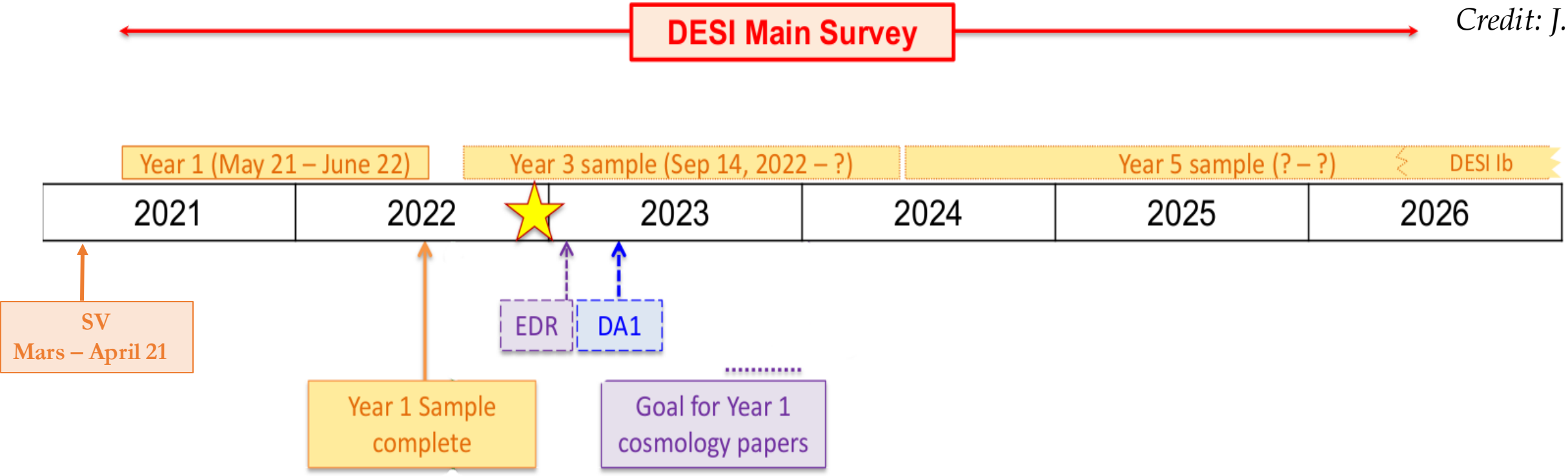


Ran for several months on power generators and data transfer with hard drives

Contreras fire + Monsoon

Planned Summer 2021 shutdown: replaced focal plane electronic boards

DESI timeline



Credit: J. Guy

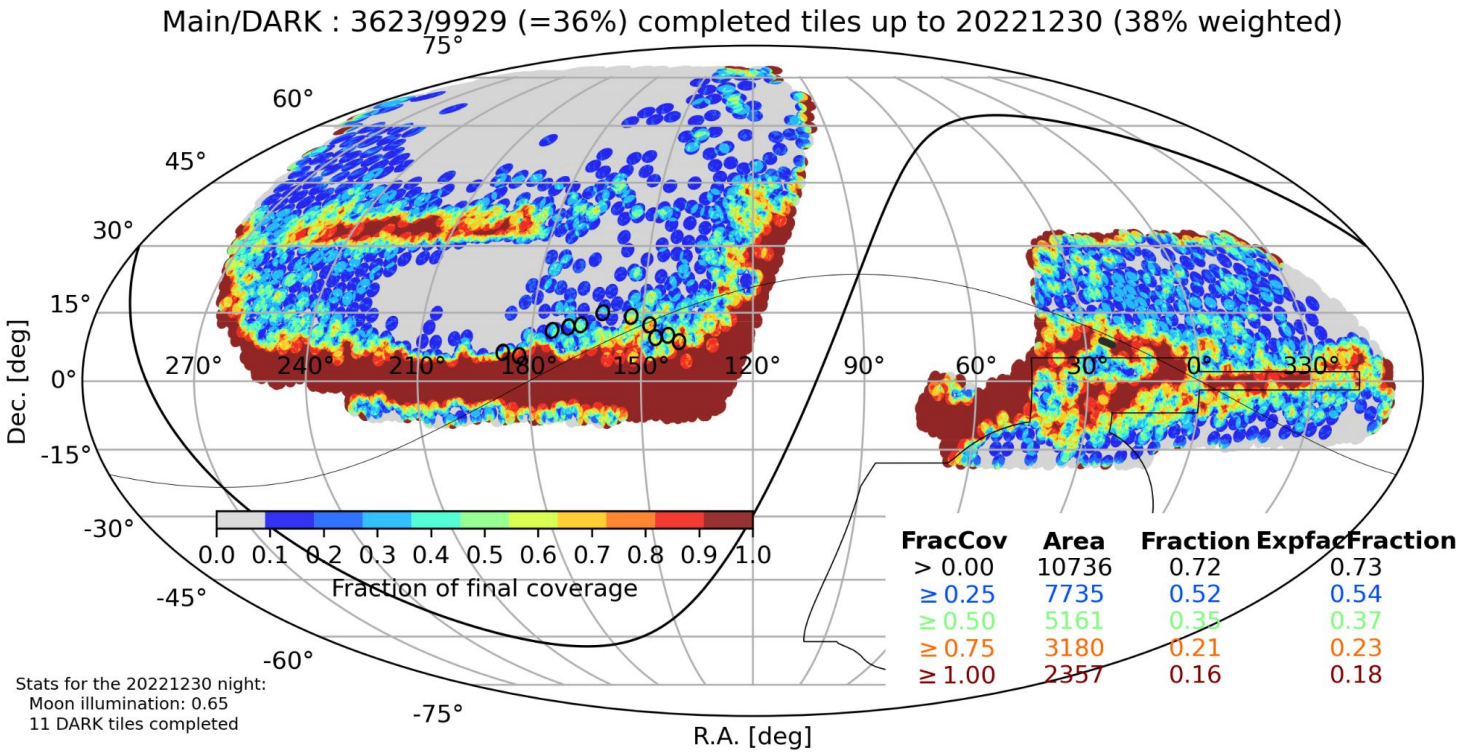
- **Finalizing the Early Data Release** (EDR)
  - **Survey validation (SV) data**, will be made public in the coming months

- Data acquisition for **Year 1 sample ended in June 2022**
  - Currently **preparing the Year 1 internal data assembly (DA1) for science analyses**

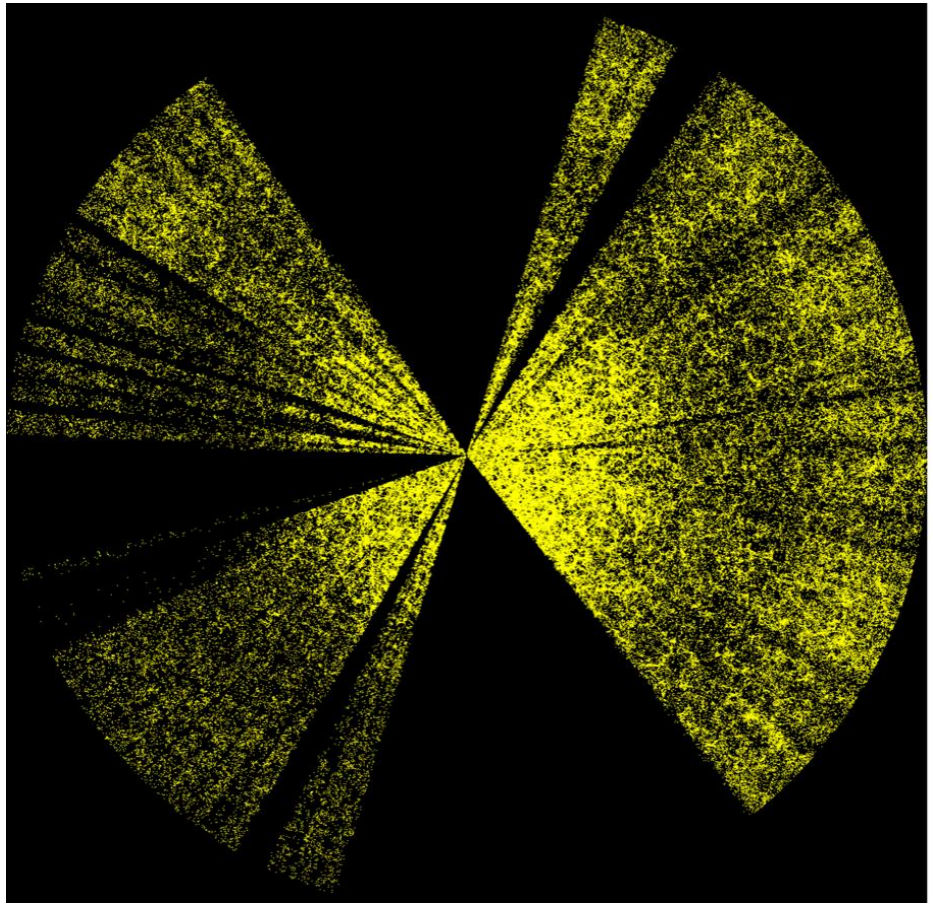
DESI survey progress

Jan 2023: 36% of dark time program, 50% bright program

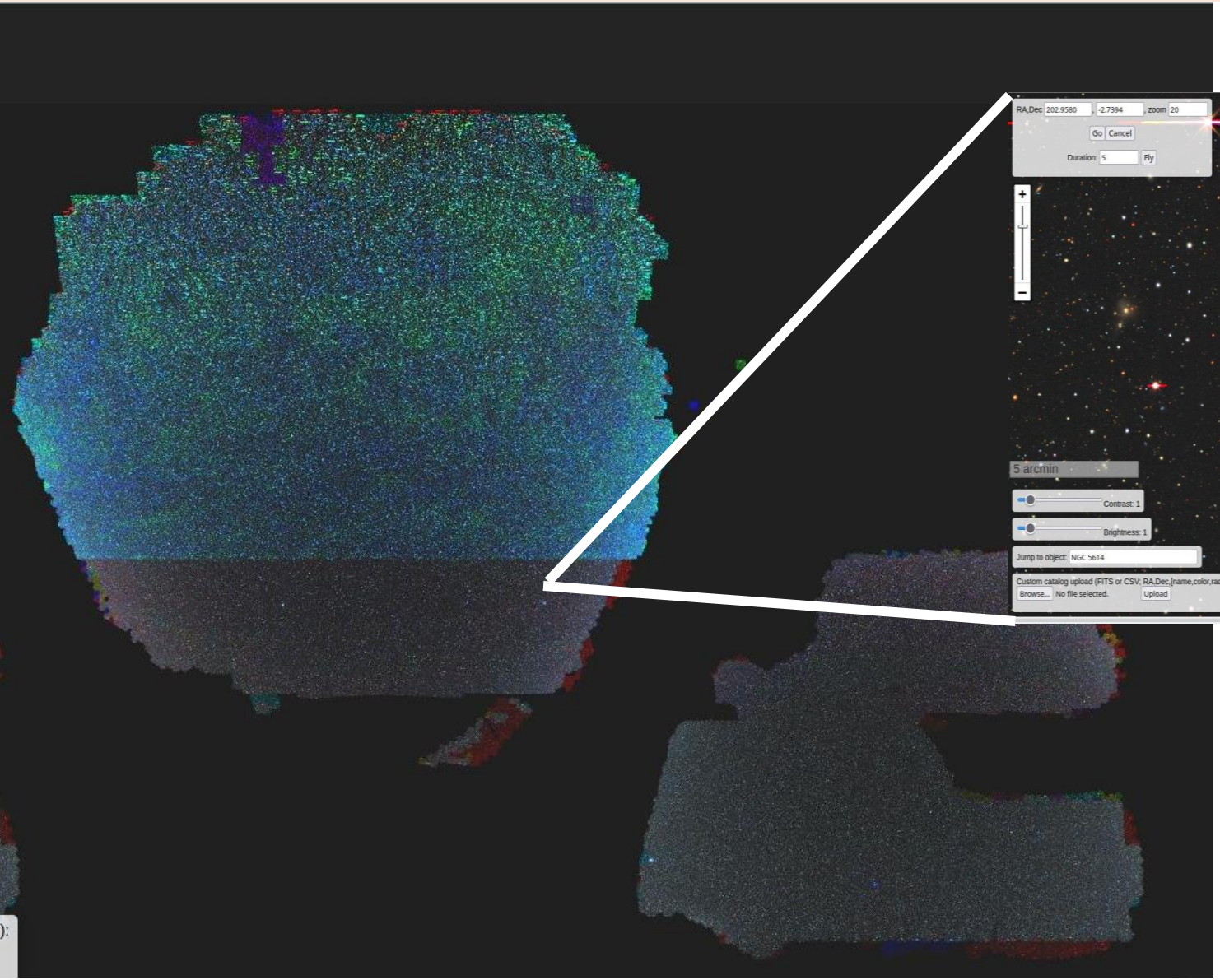
Already > 17M redshifts (eBOSS ~3.5M)



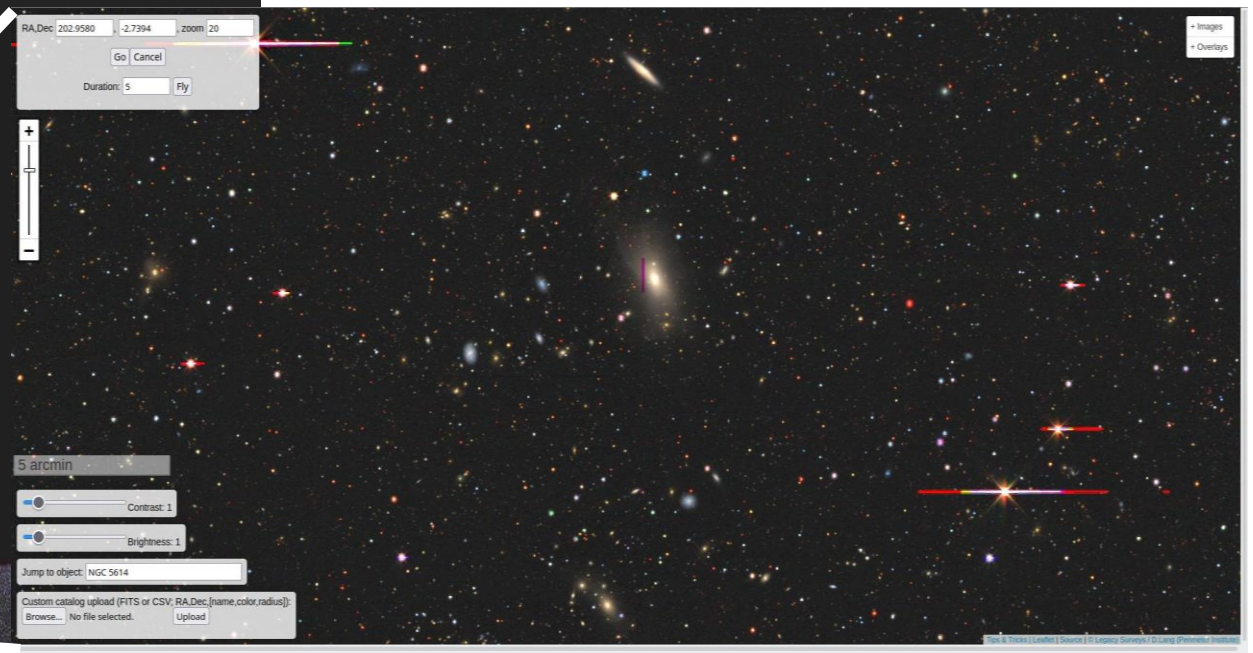
One slice in the DESI survey down to z=1



Target Selection



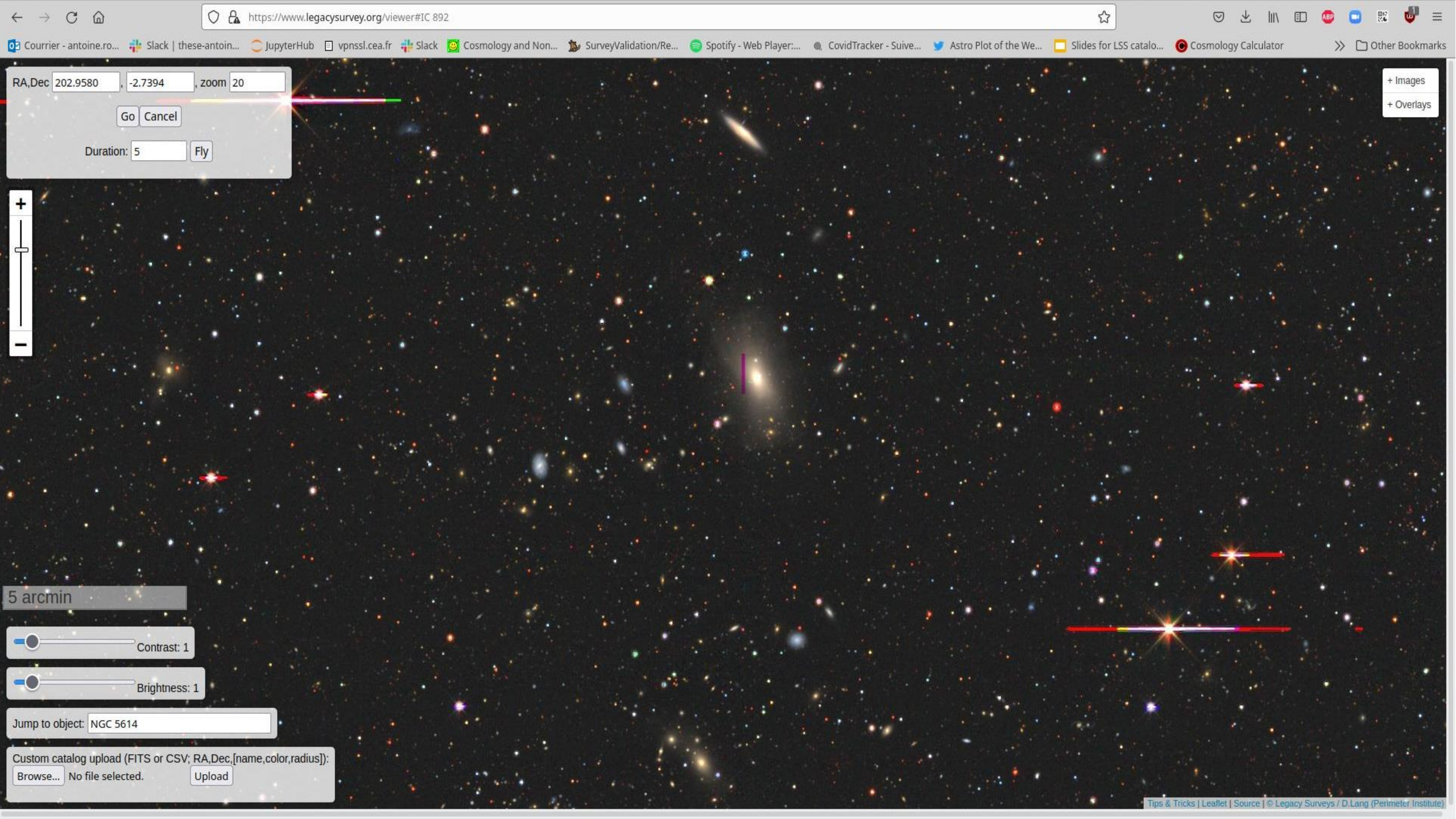
Sky viwer: https://www.legacysurvey.org/viewer

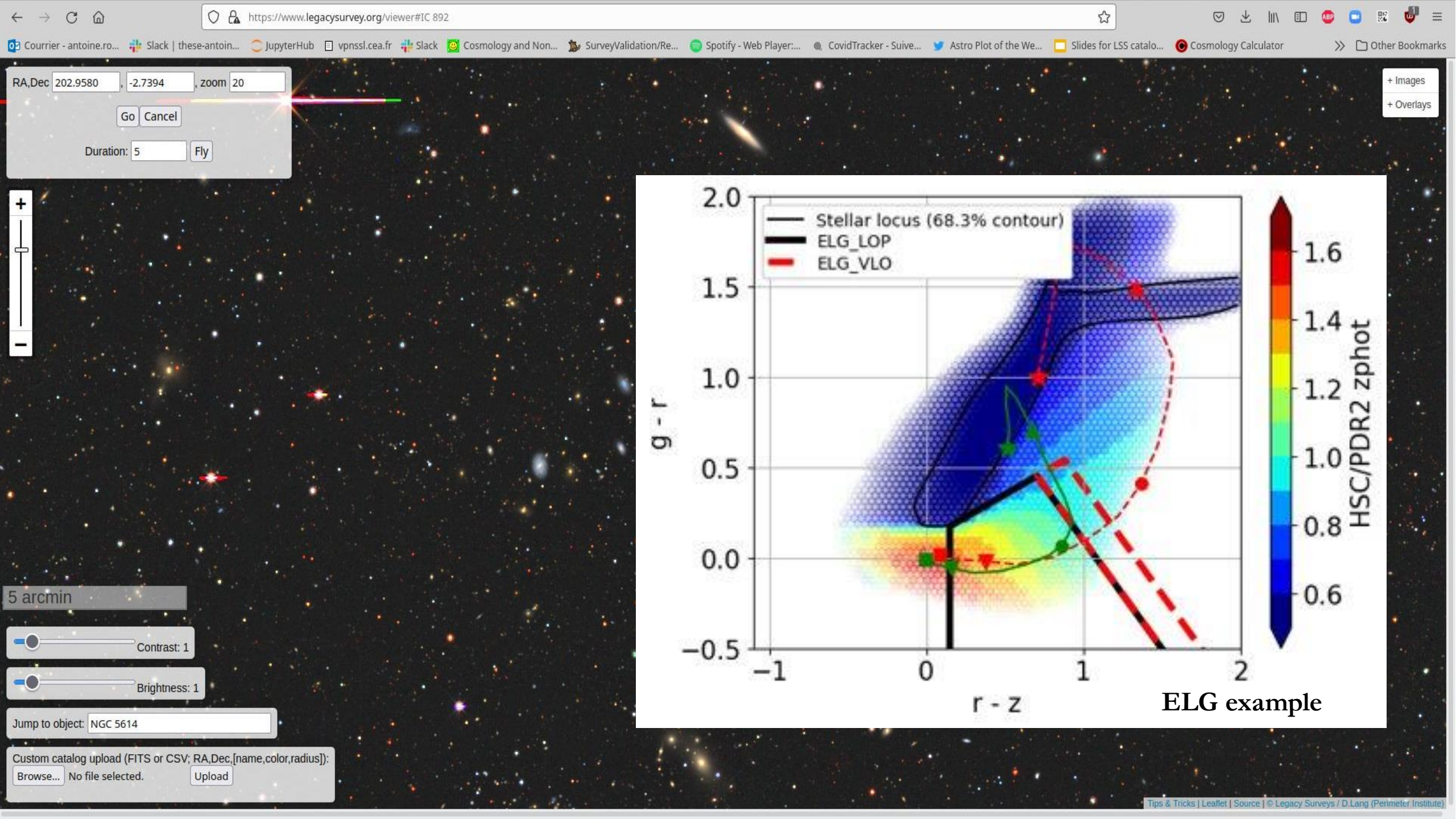


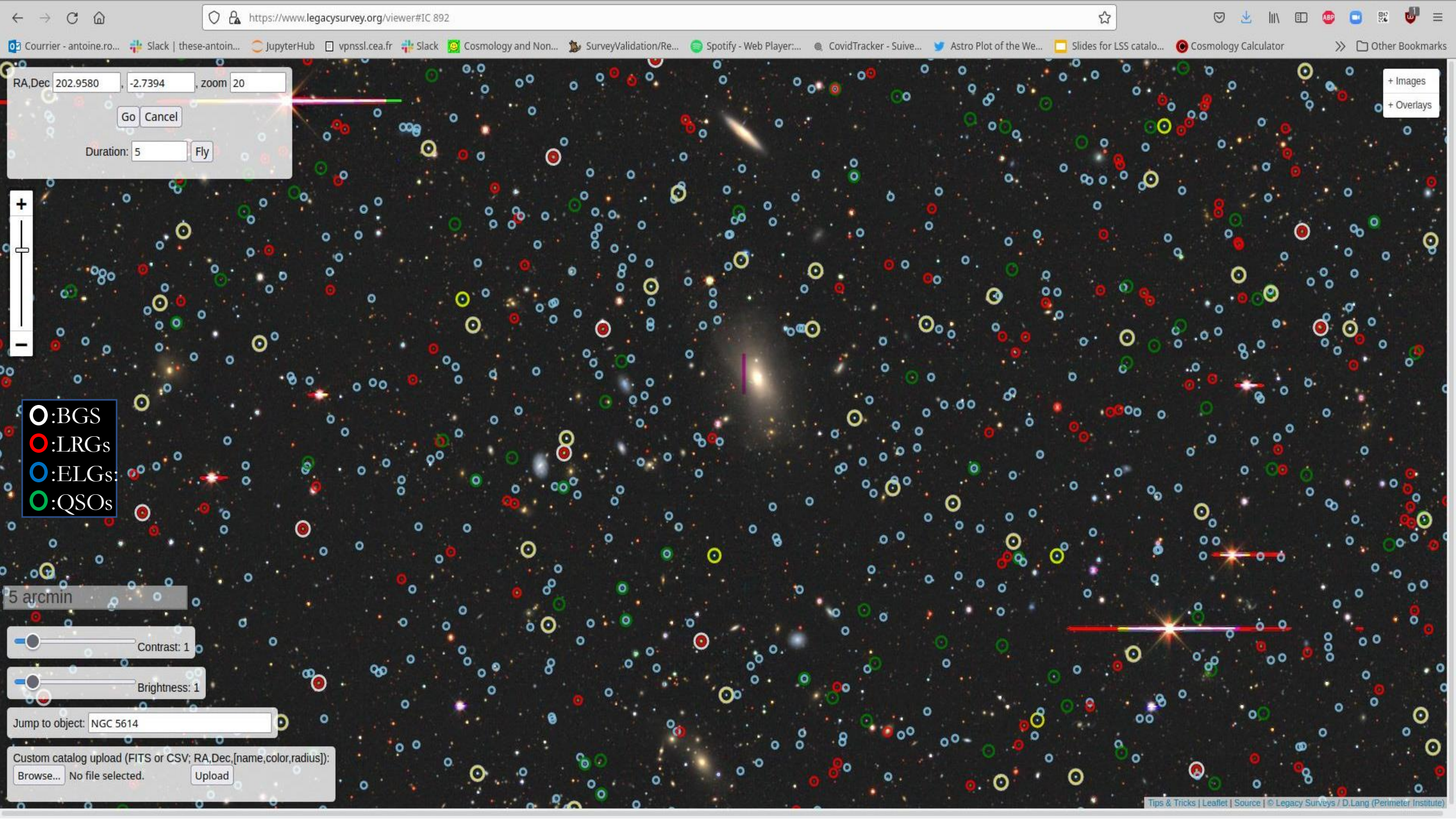
Target Selection made with DR9 DESI Legacy survey

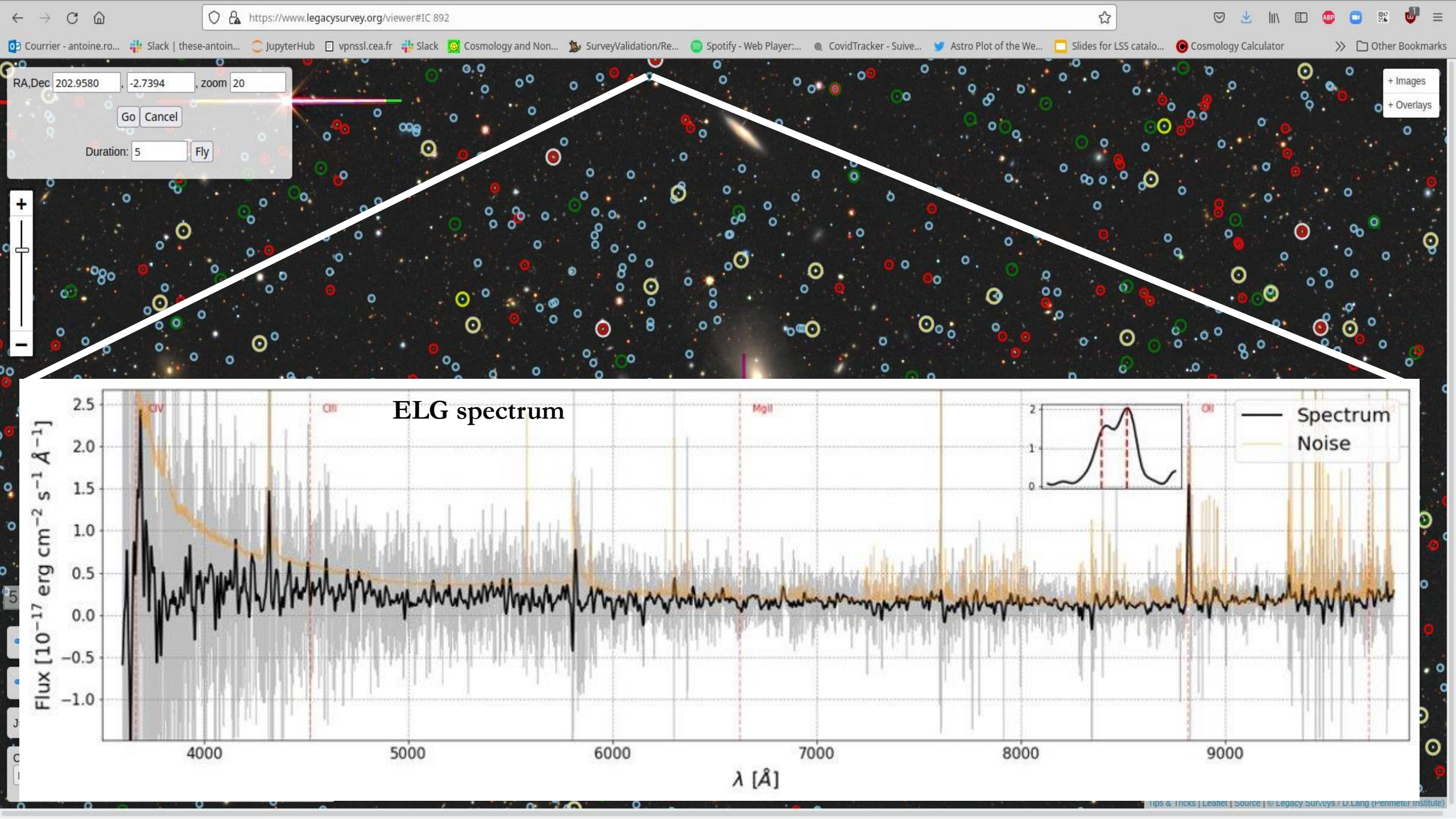
Survey area 14000 deg² (1/3 of the sky)

Legacy Survey Imaging DR10 now public as of Jan. 5!
https://www.legacysurvey.org/dr10/


https://www.legacysurvey.org/viewer#IC 892
Courrier - antoine.ro...
Slack | these-antoin...
JupyterHub
vpnssl.cea.fr
Slack
Cosmology and Non...
SurveyValidation/Re...
Spotify - Web Player:...
CovidTracker - Suive...
Astro Plot of the We...
Slides for LSS catalo...
Cosmology Calculator
Other Bookmarks
RA,Dec 202.9580 , -2.7394 , zoom 20
Go
Cancel
Duration: 5
Fly
+ Images
+ Overlays
5 arcmin
Contrast: 1
Brightness: 1
Jump to object: NGC 5614
Custom catalog upload (FITS or CSV; RA,Dec,[name,color,radius]):
Browse...
No file selected.
Upload
Tips & Tricks | Leaflet | Source | © Legacy Surveys / D.Lang (Perimeter Institute)


https://www.legacysurvey.org/viewer#IC 892
RA,Dec 202.9580 , -2.7394 , zoom 20
Go Cancel
Duration: 5 Fly
+ Images
+ Overlays
5 arcmin
Contrast: 1
Brightness: 1
Jump to object: NGC 5614
Custom catalog upload (FITS or CSV; RA,Dec,[name,color,radius]):
Browse... No file selected. Upload
Tips & Tricks | Leaflet | Source | © Legacy Surveys / D.Lang (Perimeter Institute)
Stellar locus (68.3% contour)
ELG_LOP
ELG_VLO
g - r
r - z
HSC/PDR2 zphot
ELG example


https://www.legacysurvey.org/viewer#IC 892
Courrier - antoine.ro...
Slack | these-antoin...
JupyterHub
vpnssl.cea.fr
Slack
Cosmology and Non...
SurveyValidation/Re...
Spotify - Web Player:...
CovidTracker - Suive...
Astro Plot of the We...
Slides for LSS catalo...
Cosmology Calculator
Other Bookmarks
RA,Dec 202.9580 , -2.7394 , zoom 20
Go
Cancel
Duration: 5
Fly
+ Images
+ Overlays
:BGS
:LRGs
:ELGs:
:QSOs
5 arcmin
Contrast: 1
Brightness: 1
Jump to object: NGC 5614
Custom catalog upload (FITS or CSV; RA,Dec,[name,color,radius]):
Browse...
No file selected.
Upload
Tips & Tricks | Leaflet | Source | © Legacy Surveys / D.Lang (Perimeter Institute)


https://www.legacysurvey.org/viewer#IC 892
RA,Dec 202.9580 , -2.7394 , zoom 20
Go Cancel
Duration: 5 Fly
+ Images
+ Overlays
ELG spectrum
CIV
CIII
MgII
OII
Spectrum
Noise
Flux [10^{-17} erg cm^{-2} s^{-1} Å^{-1}]
λ [Å]
2.5
2.0
1.5
1.0
0.5
0.0
−0.5
−1.0
4000
5000
6000
7000
8000
9000

Survey Validation papers (published or preprint)

Target selection (TS)

Zhou R., et al., Target Selection and Validation of DESI Luminous Red Galaxies, arXiv:2208.08515
Chaussidon E., et al., Target Selection and Validation of DESI Quasars, arXiv:2208.08511
Hahn C., et al., DESI Bright Galaxy Survey: Final Target Selection, Design, and Validation, arXiv:2208.08512
Cooper A. P., et al., Overview of the DESI Milky Way Survey, arXiv:2208.08514
Raichoor A., et al., Target Selection and Validation of DESI Emission Line Galaxies, arXiv:2208.08513
Myers A. D., et al., The Target Selection Pipeline for the Dark Energy Spectroscopic Instrument, arXiv:2208.08518

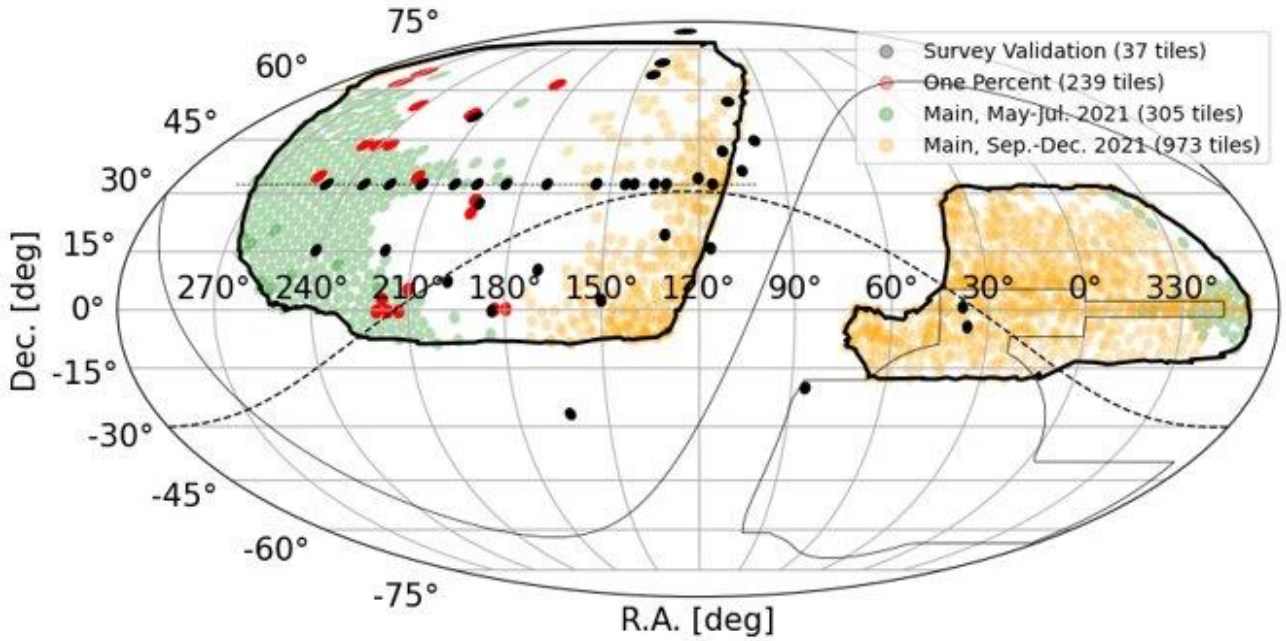
Visual inspection (VI)

Alexander D. M., et al., The DESI Survey Validation: Results from Visual Inspection of the Quasar Survey Spectra, arXiv:2208.08517
Lan T.-W., et al., The DESI Survey Validation: Results from Visual Inspection of Bright Galaxies, Luminous Red Galaxies, and Emission Line Galaxies, arXiv:2208.08516

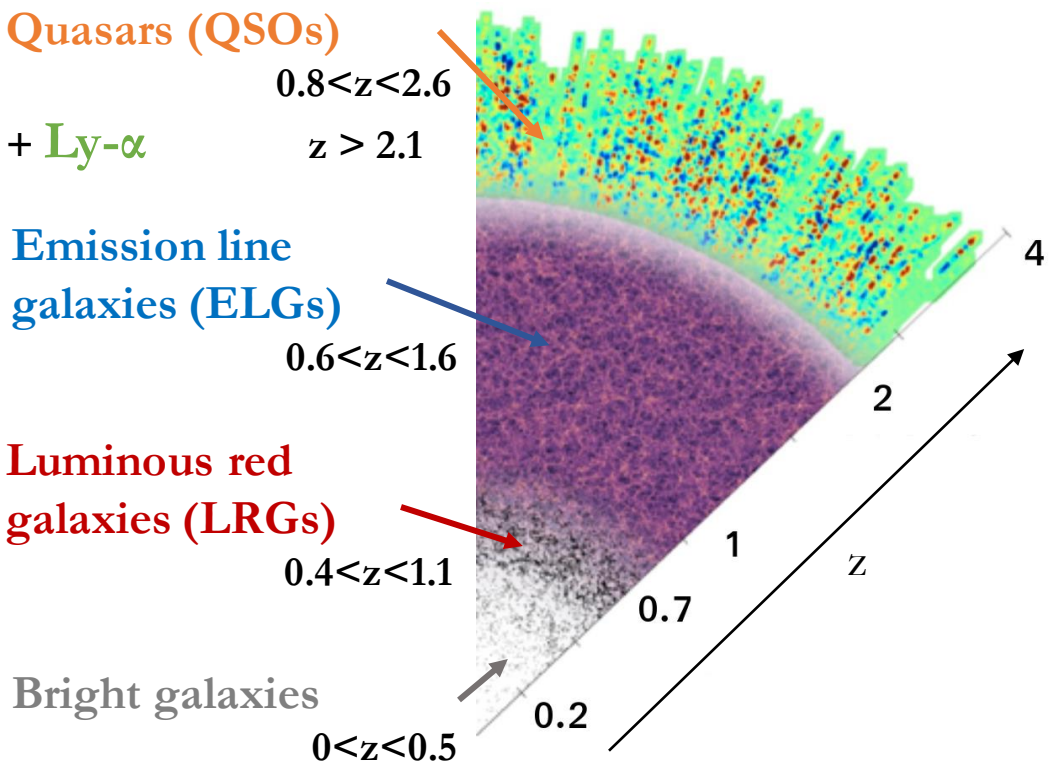
Instrumentation and pipeline papers (more in prep.)

Silber J., et al., The robotic multi-object focal plane system of DESI, arXiv:2205.09014
DESI Collaboration, Overview of the Instrumentation for the Dark Energy Spectroscopic Instrument, arXiv:2205.10939
Guy J., et al., The Spectroscopic Data Processing Pipeline for the Dark Energy Spectroscopic Instrument, arXiv:2209.14482

First science results with early data



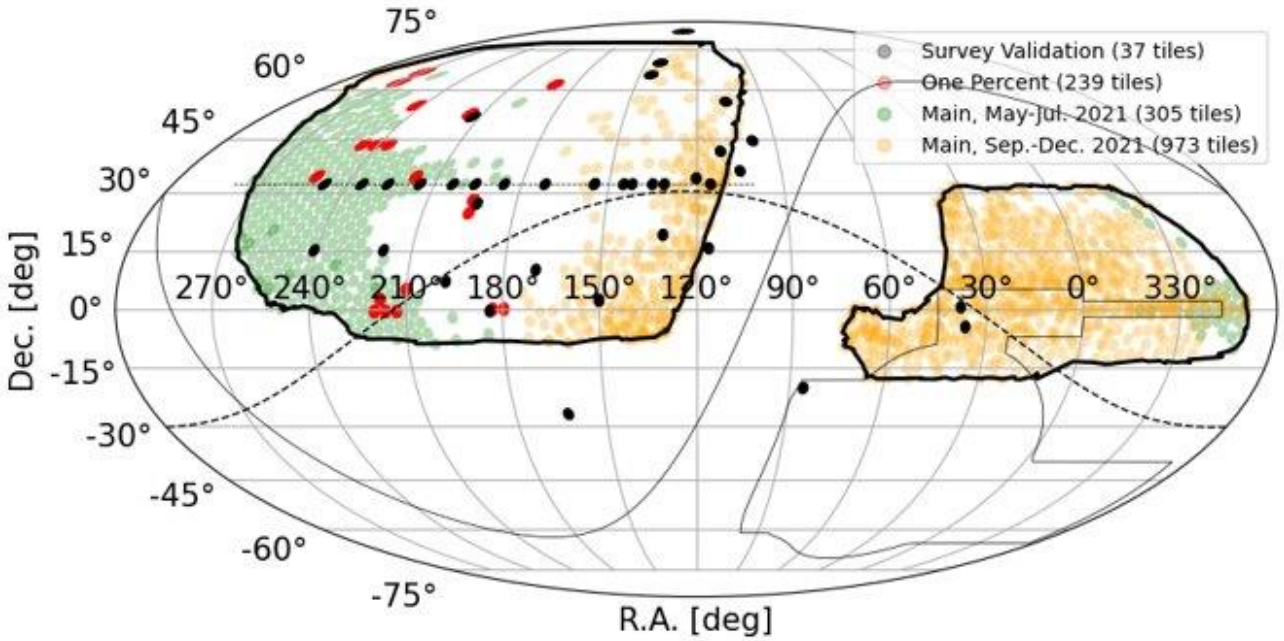
Raichoor et al. 2022



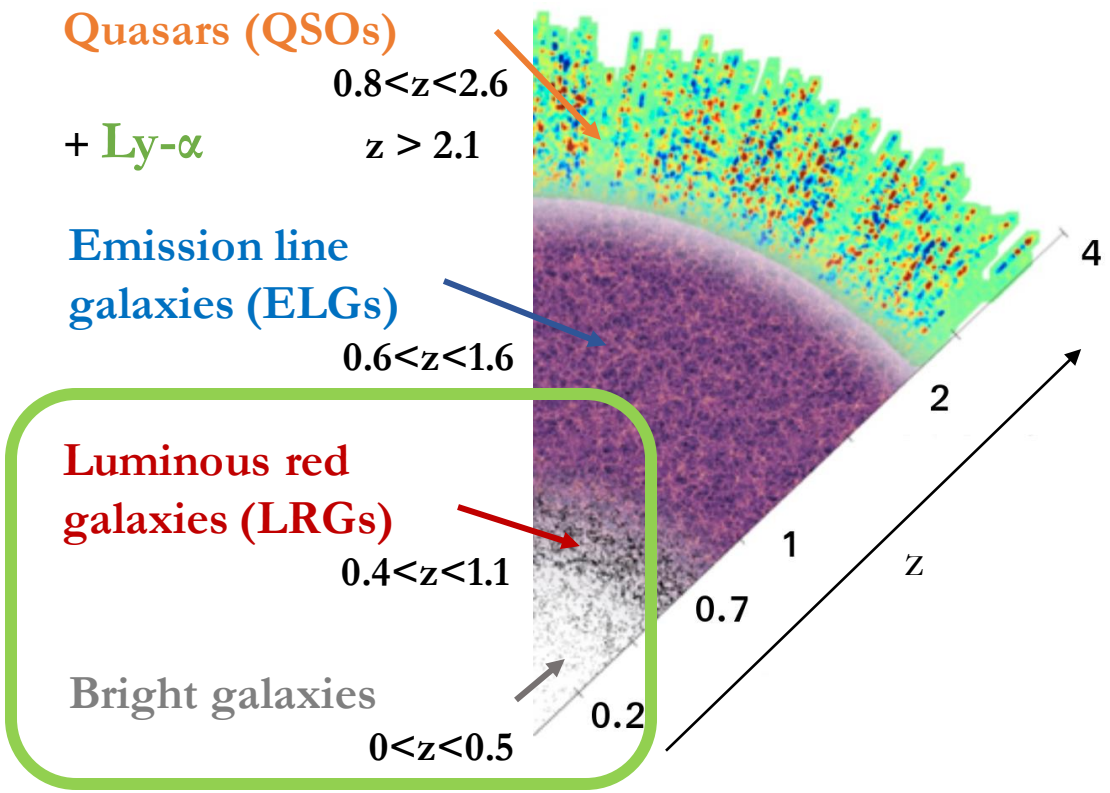
Early data, 2 samples:

- **1% survey**
- **DESI M2 : First 2 months of main survey observation**

First science results: BGS & LRGs



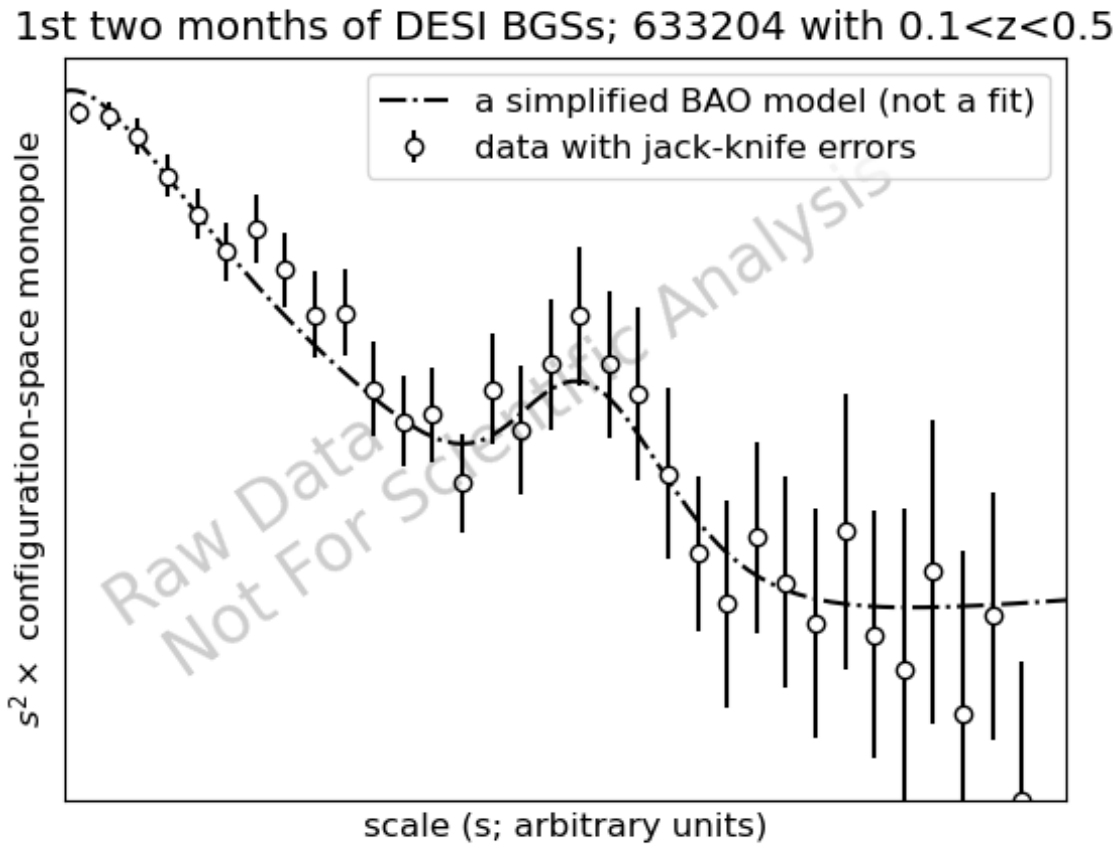
Raichoor et al. 2022

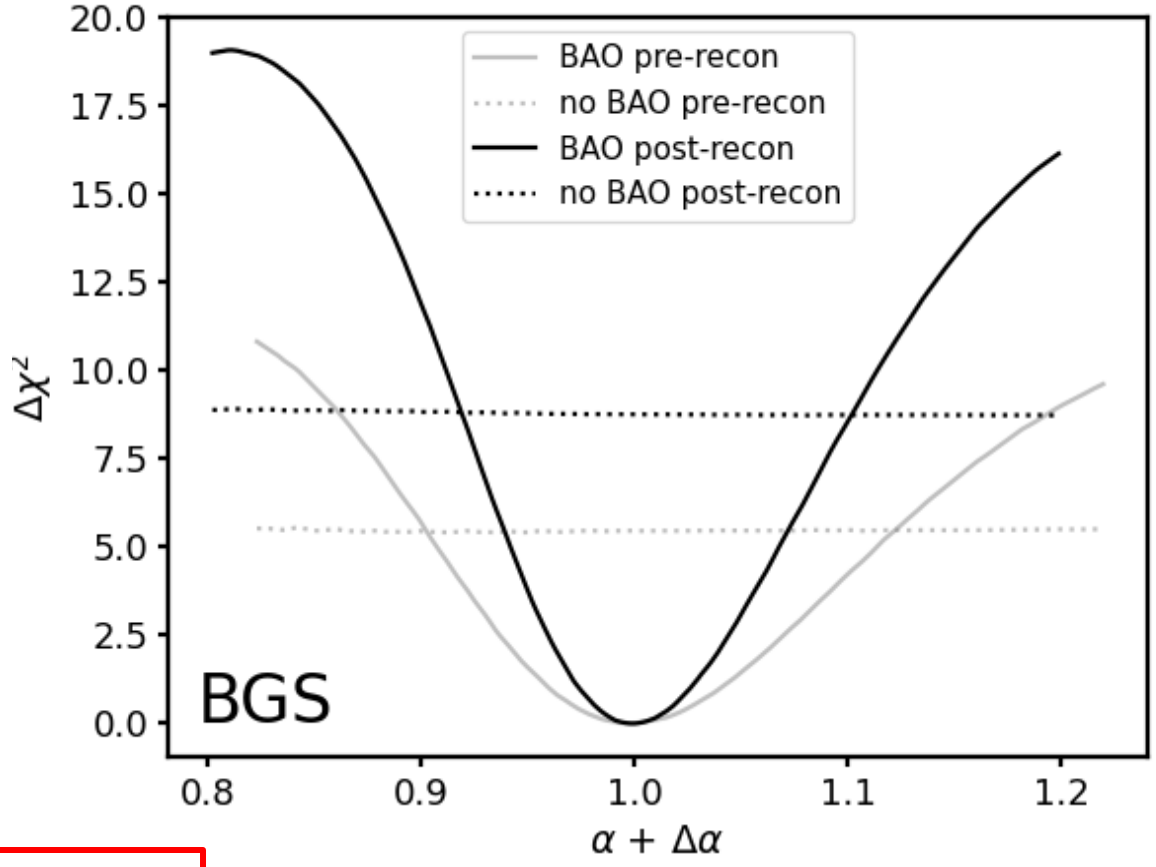


- **DESI M2 : First 2 months of main survey observation**
  - **633k BGS & 262k LRGs**

Detection of the BAO signal in BGS

(J. Moon, C. Saulder, D. Valcin, M. Rashkovetskyi + DESI collaboration in prep)

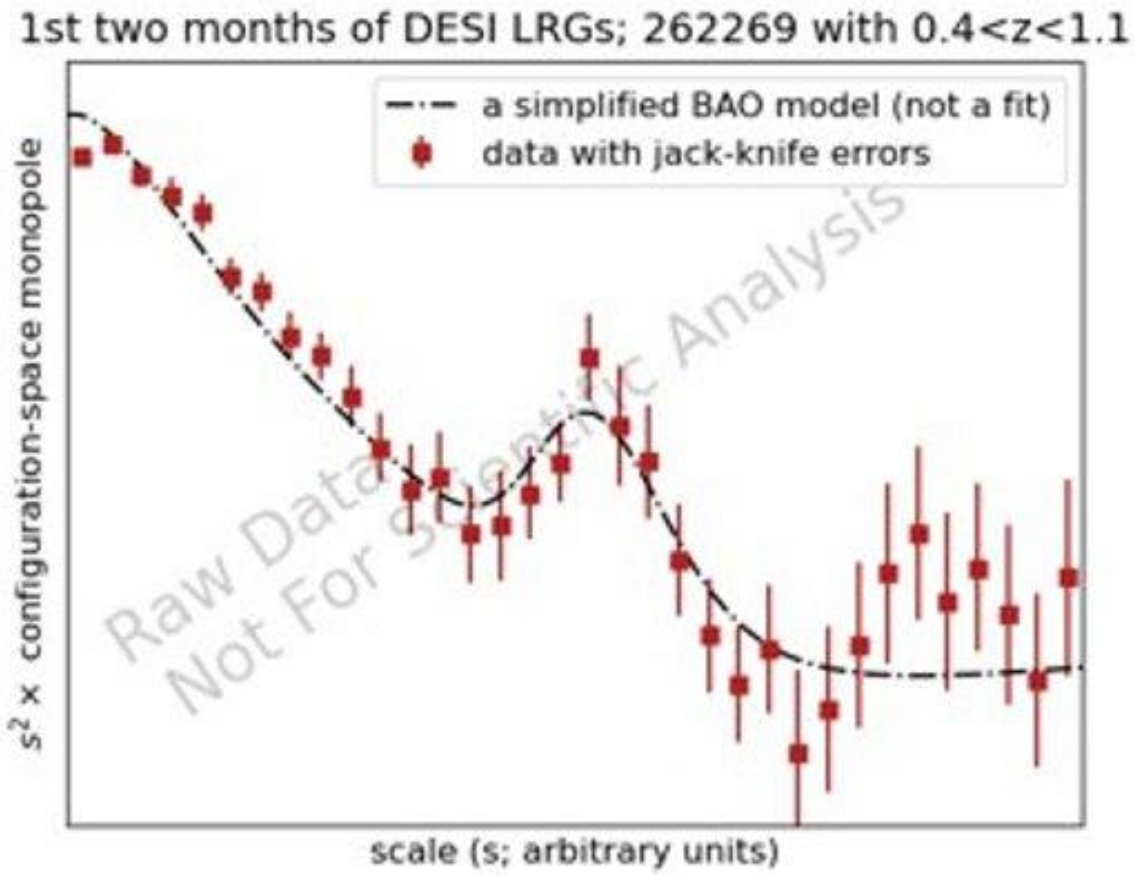


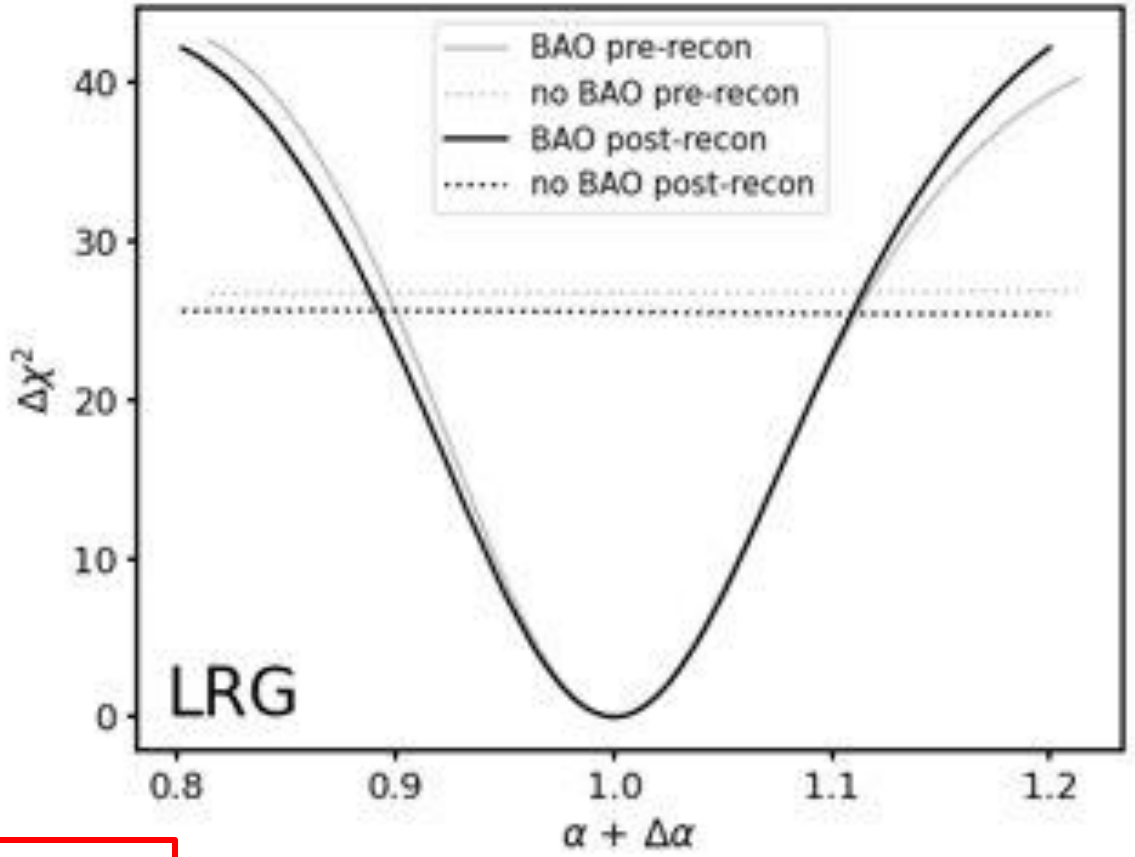


3σ detection

Detection of the BAO signal in LRGs

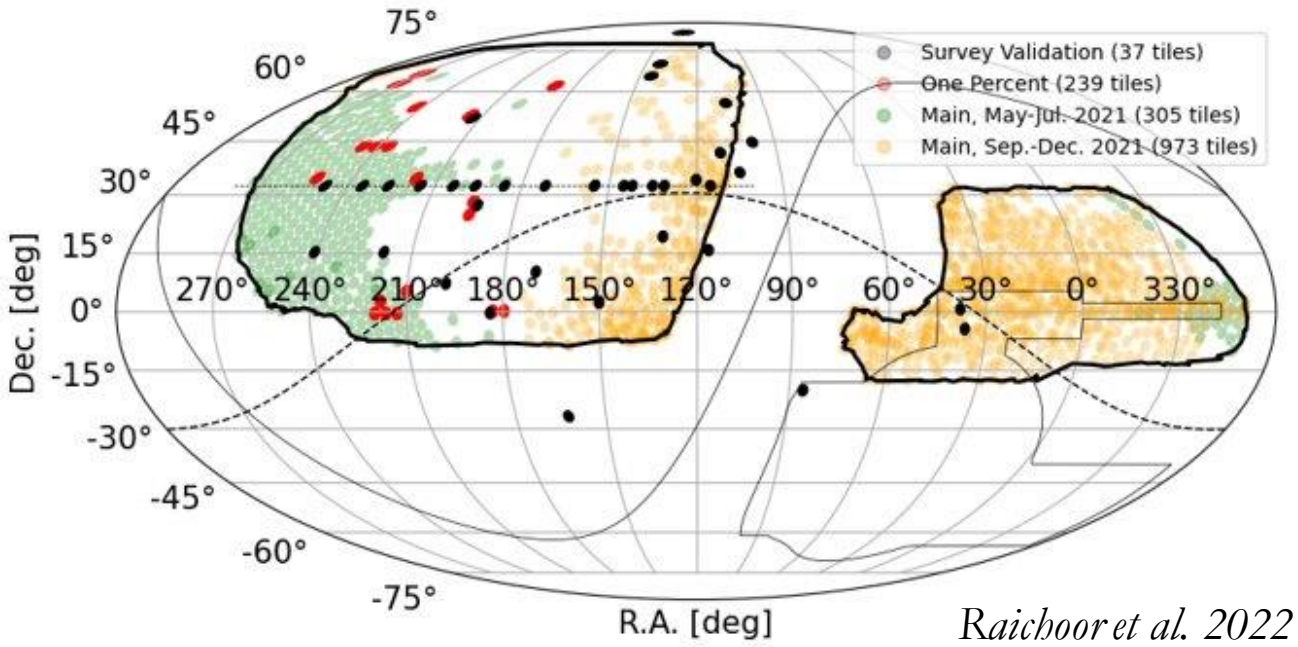
(J. Moon, C. Saulder, D. Valcin, M. Rashkovetskyi + DESI collaboration in prep)



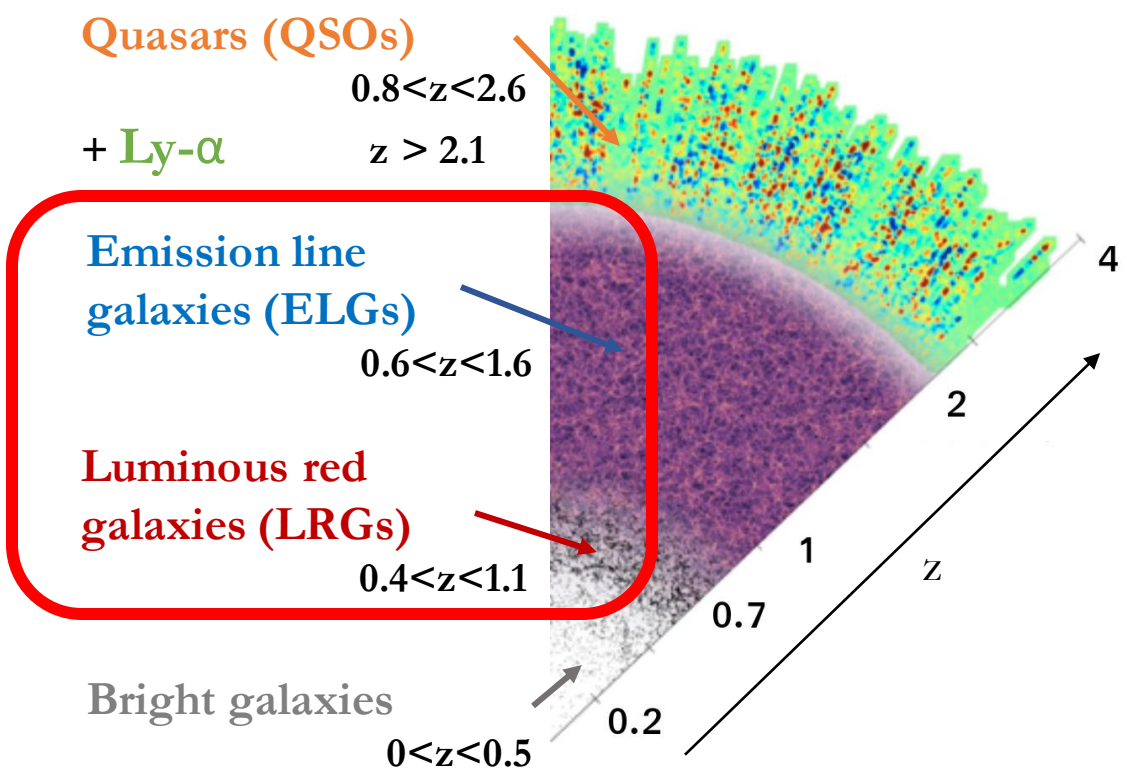


5σ detection

First science results: LRGs & ELGs



Raichoor et al. 2022



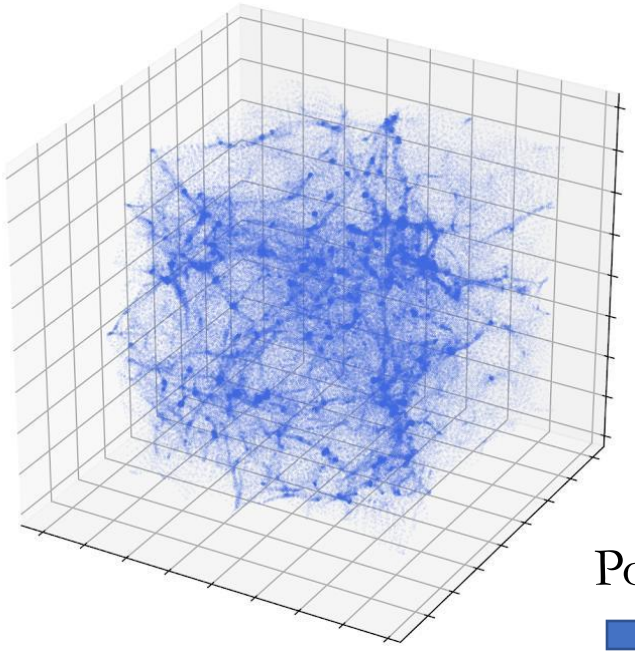
- **One % survey:** Last period of survey validation
  - 20 patches with ~12 passes/region

  => almost all targets observed
- **89k LRGs** & **224k ELGs**

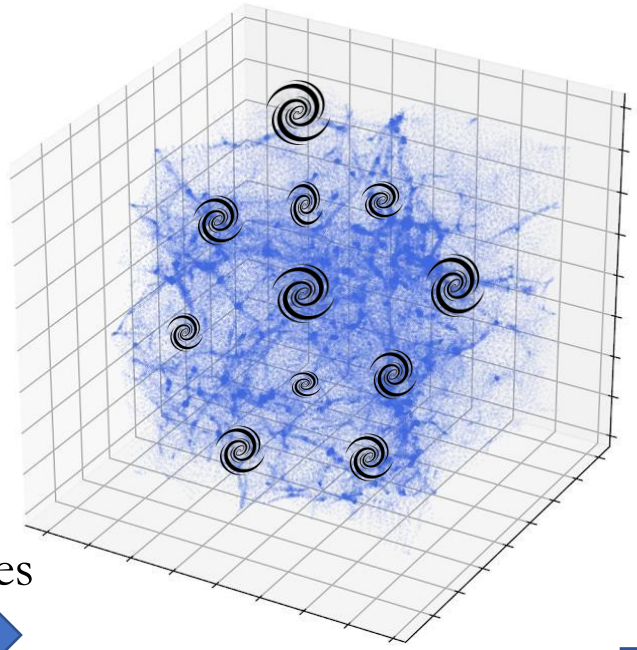
=> Lot of information at small scales !

Galaxy-halo connection studies

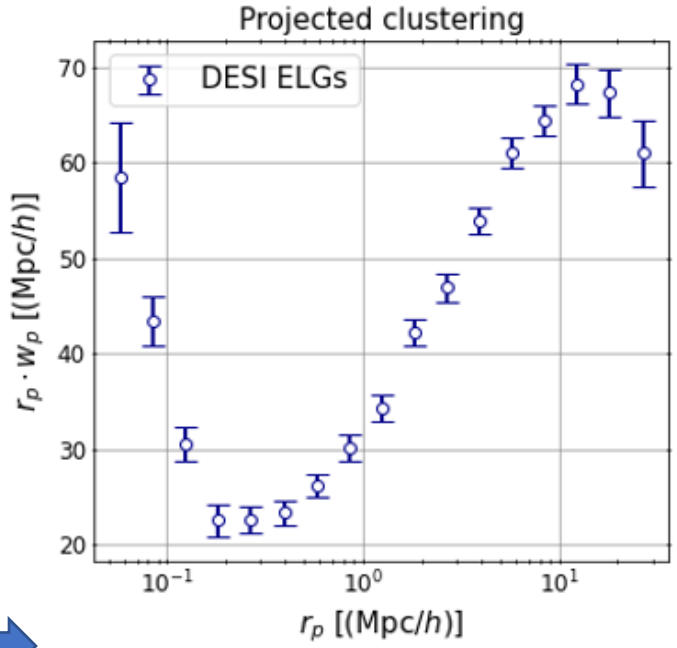
Late time dark matter field



Late time galaxy field



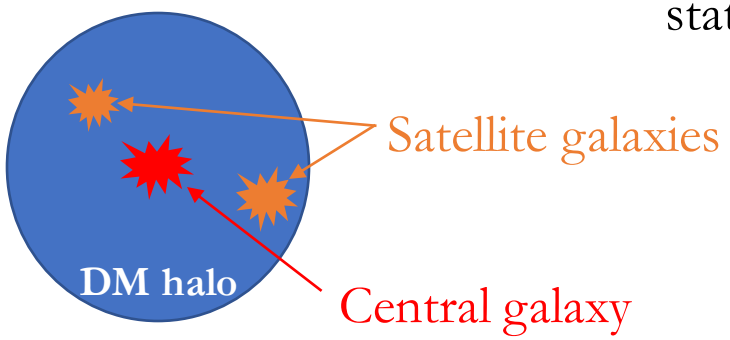
Populate galaxies



Compute clustering statistics

Halo Occupation Distribution (HOD)

$$P(N_{gal}|M_{halo})$$

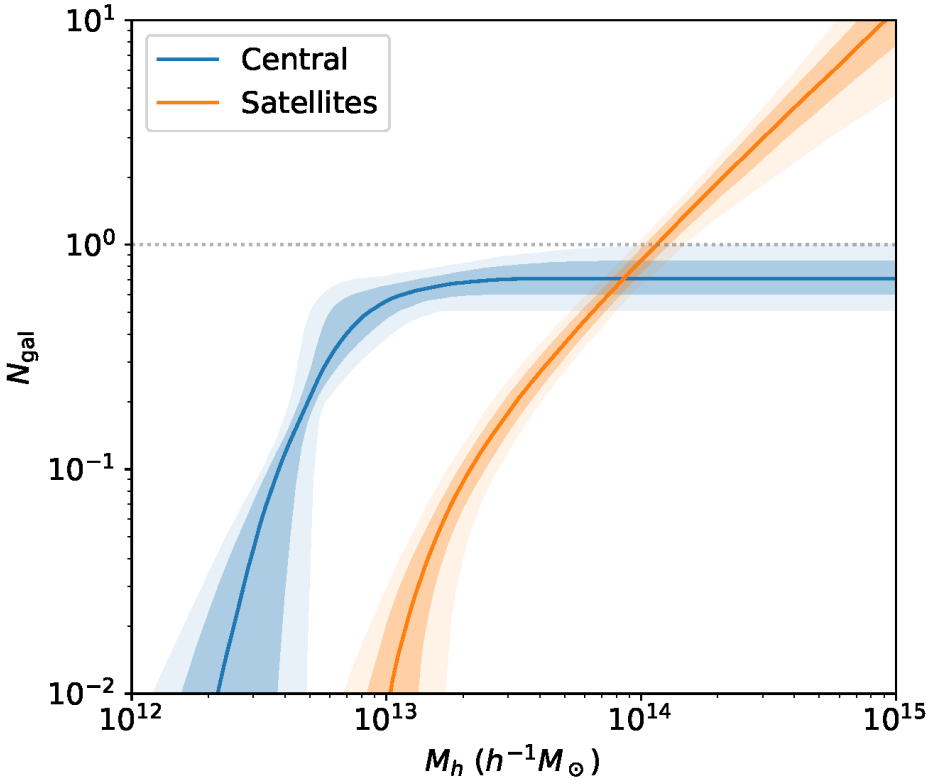


New HOD Fitting method !
Rocher et al. in prep

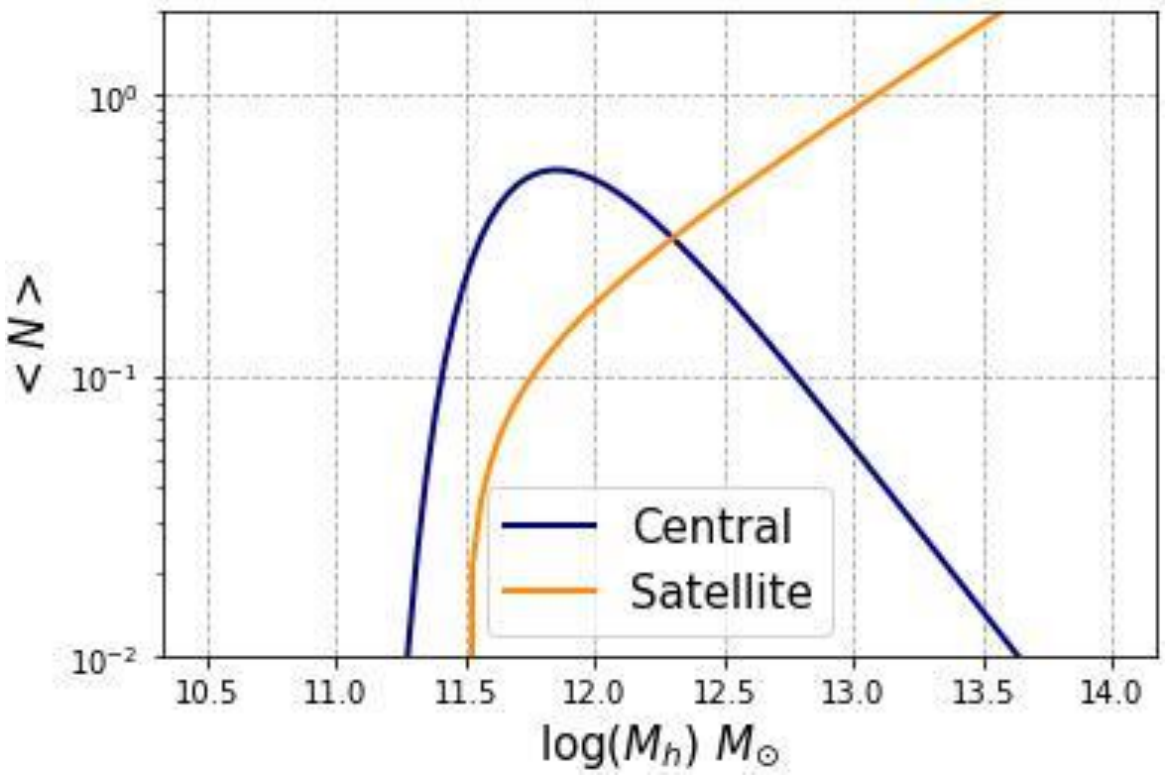
Halo occupation distribution

*(S. Yuan, H. Zhang, **A. Rocher** + DESI collaboration in prep)*

HOD for LRGs

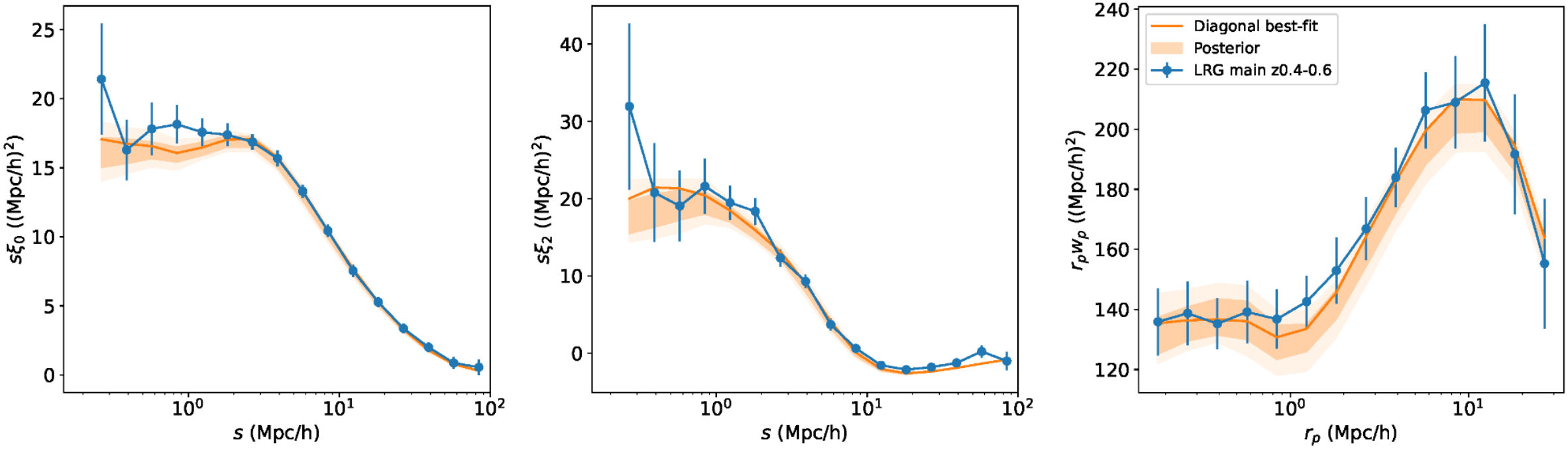


HOD for ELGs



HOD results for LRGs

*(S. Yuan, H. Zhang, **A. Rocher** + DESI collaboration in prep)*

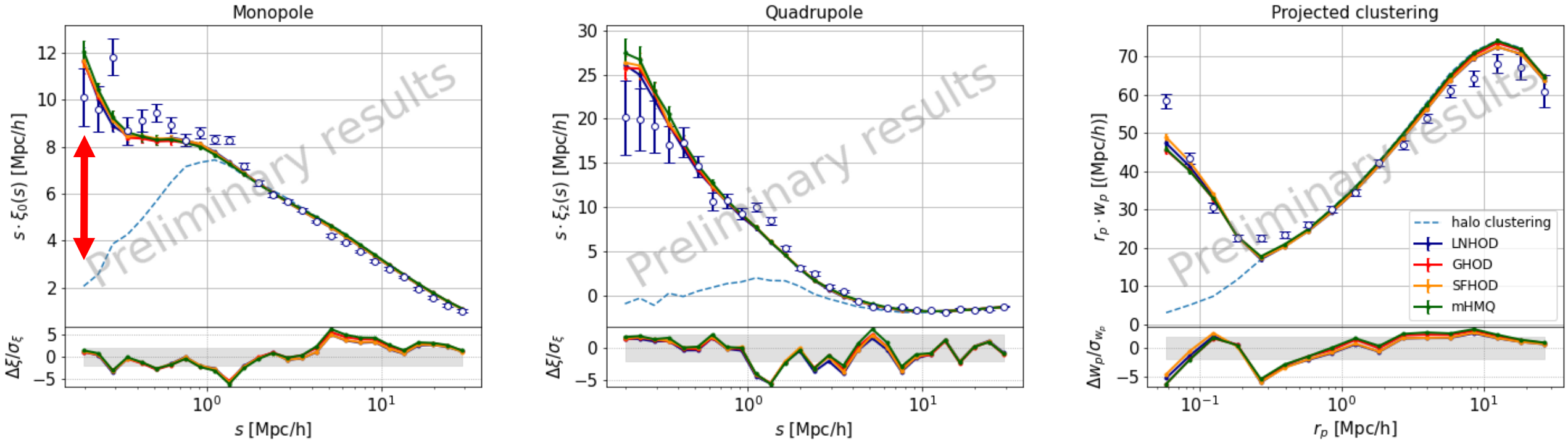


Good fits to observed clustering!

LRG	$0.4 < z < 0.6$	$0.6 < z < 0.8$
Model	χ^2/d.o.f.	χ^2/d.o.f.
Baseline	1.10	1.05
Baseline+A	1.12	1.04
Baseline+B	1.12	1.05
Baseline+s	1.13	1.07

HOD results for ELGs

*(**A. Rocher**, S. Yuan, H. Zhang + DESI collaboration in prep)*

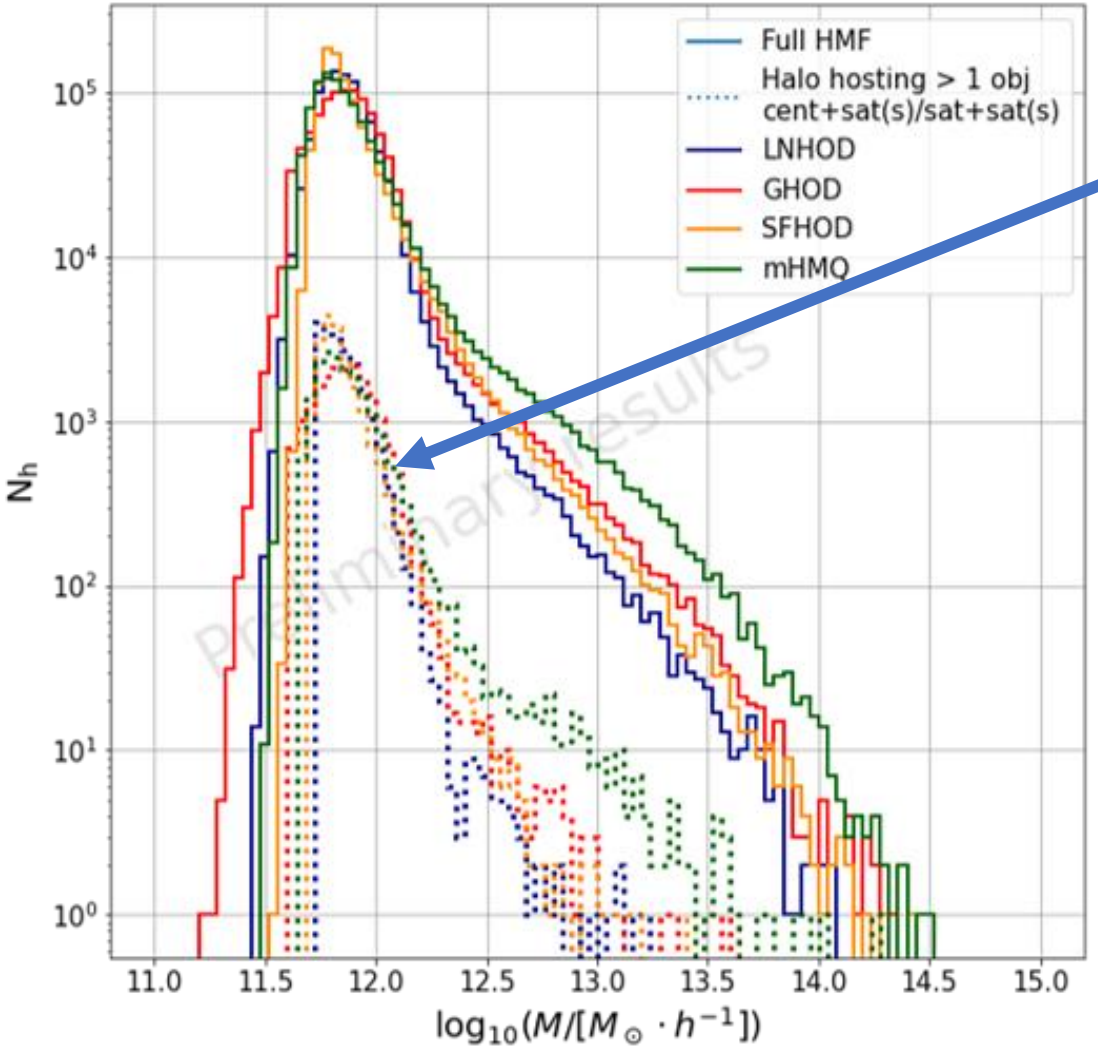


- 4 ≠ models for central occupation => consistent results and good fits to observed clustering
- **Strong 1 halo term (galaxy pairs inside halos)**

HOD results for ELGs

*(**A. Rocher**, S. Yuan, H. Zhang + DESI collaboration in prep)*

Populated Halo Mass Function (HMF)



Halos populated by ≥ 2 galaxies **mainly from halos with mass < 10^{12}** [$M_\odot$/h]

not expected from previous ELG studies

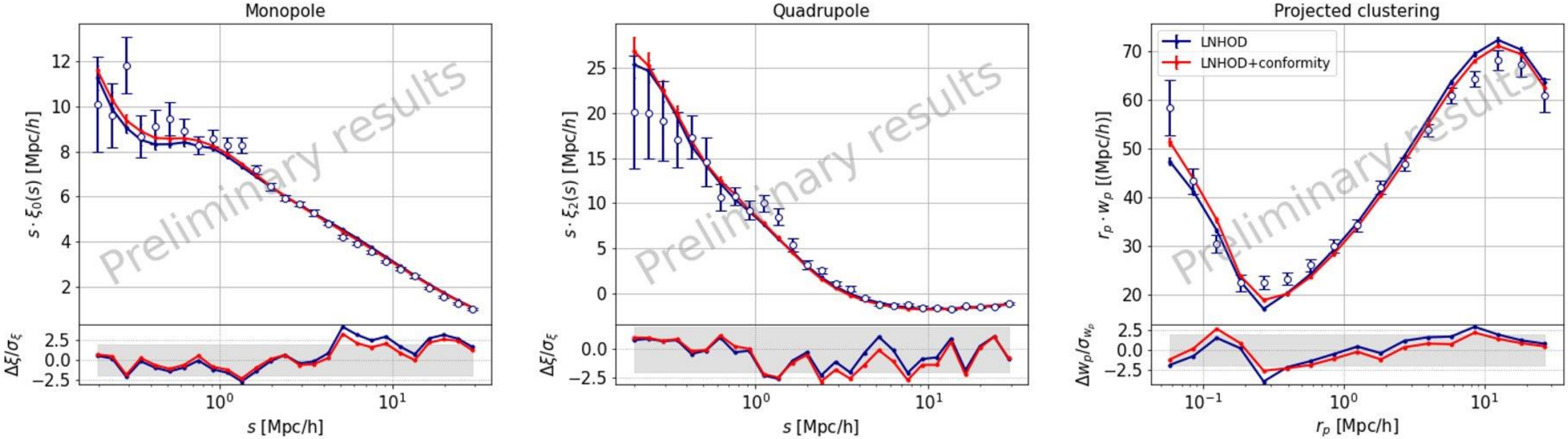
(Avilà 2020, Gonzalez-Perez 2018)

Trying to solve this ?
=> We add **conformity** to the HOD model

Conformity : <N_{sat}> is modified with prior information depending on the fact that the halo already hosts a central

HOD results for ELGs

*(**A. Rocher**, S. Yuan, H. Zhang + DESI collaboration in prep)*

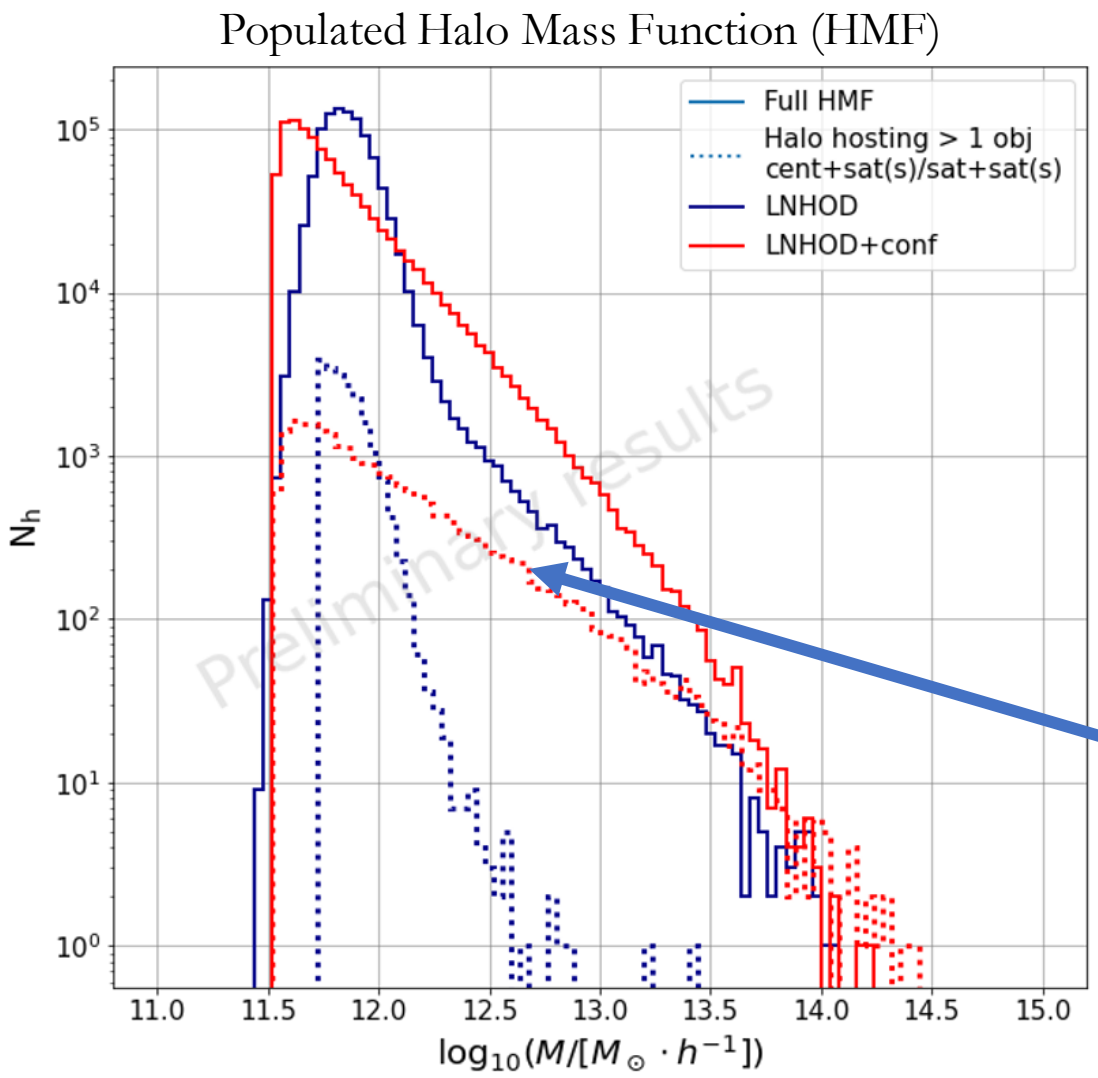


Here simple conformity model :

=> **$\langle N_{sat} \rangle = 0$ if no central**

HOD results for ELGs

*(**A. Rocher**, S. Yuan, H. Zhang + DESI collaboration in prep)*



HMFs are different but lead to ~ the **same clustering**

=> Galaxy pairs are spread over a larger range of halo masses

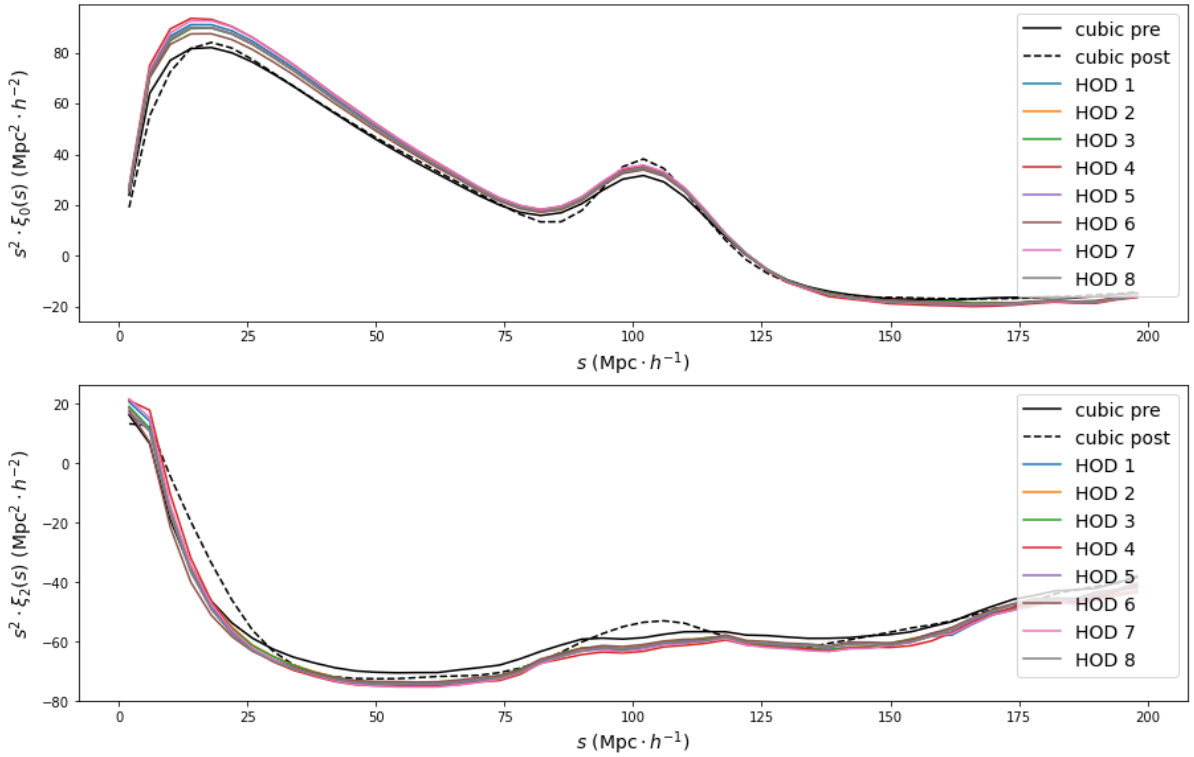
In better agreement with physically motivated ELG models

Systematic tests for BAO analysis

*(C. Garcia-Quintero, J. Mena-Fernández, **A. Rocher**, S. Yuan + DESI collaboration in prep)*

- **How prescription for galaxy-halo model bias cosmological results?**
  => We generate a variety of realistic galaxy mocks at the same cosmology but invoking different HOD models

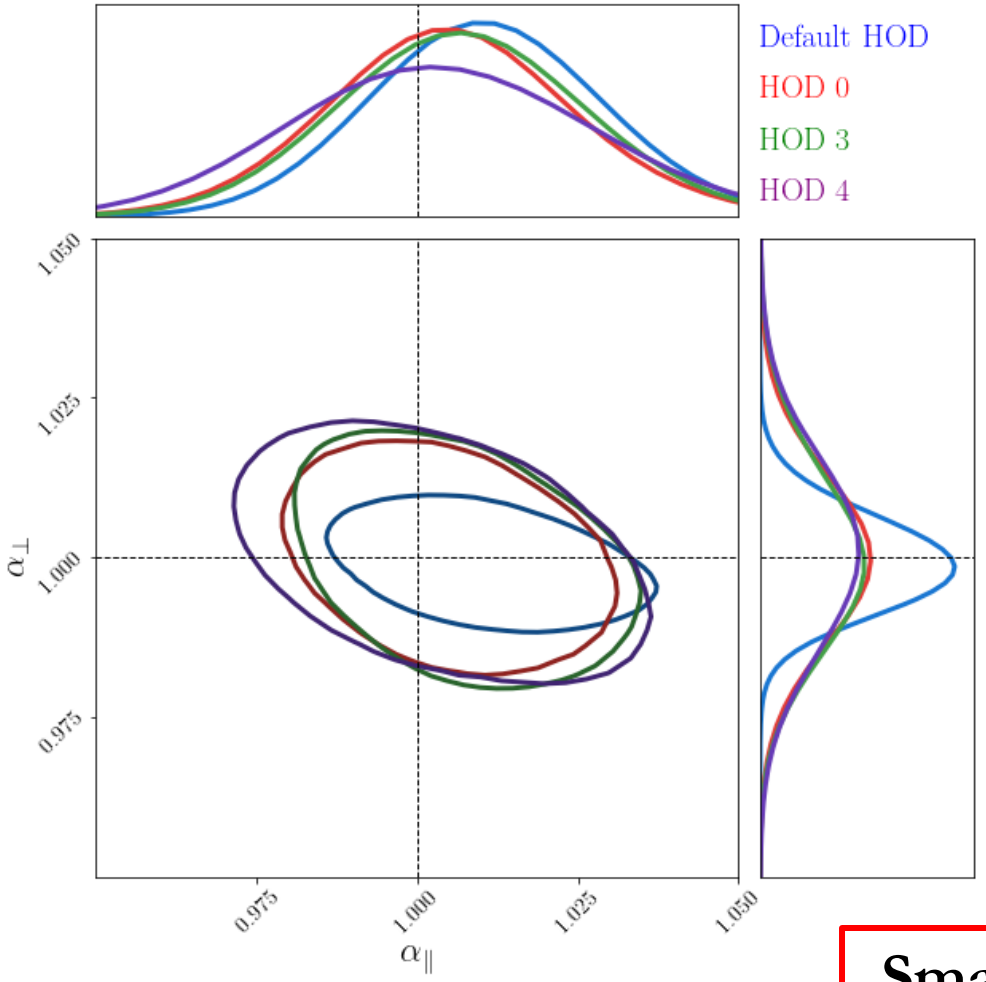
- We **run BAO fits** on the various mocks to check whether we recover the underlying cosmology

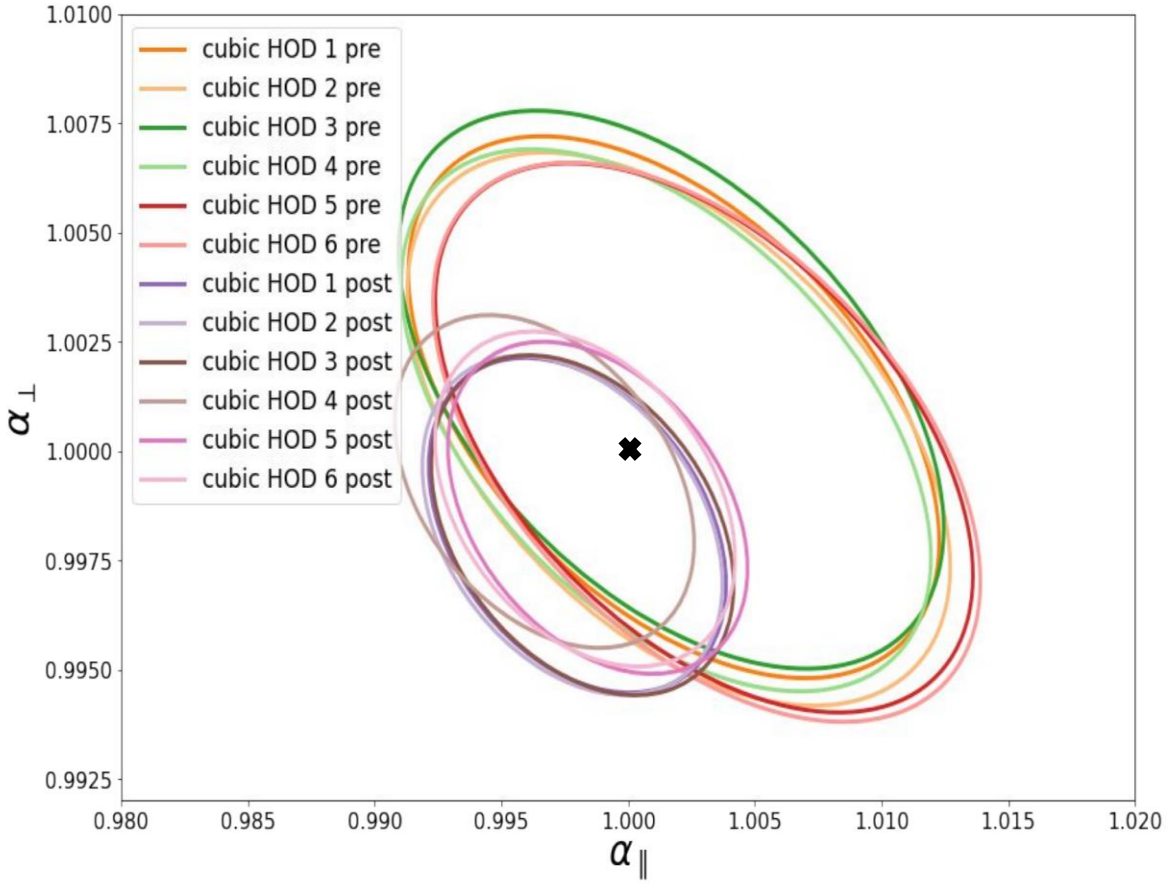


Systematic tests for BAO analysis

(C. Garcia-Quintero, J. Mena-Fernández, ***A. Rocher***, *S. Yuan + DESI collaboration in prep)*

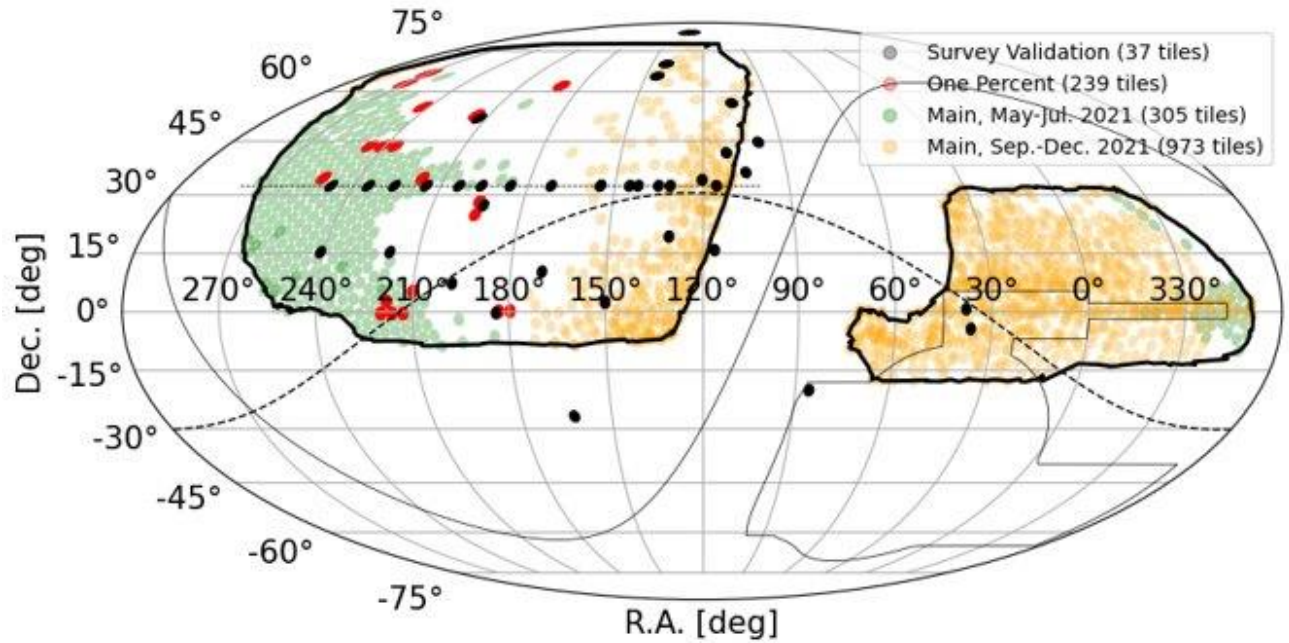
ELGs **Preliminary results** **LRGs**



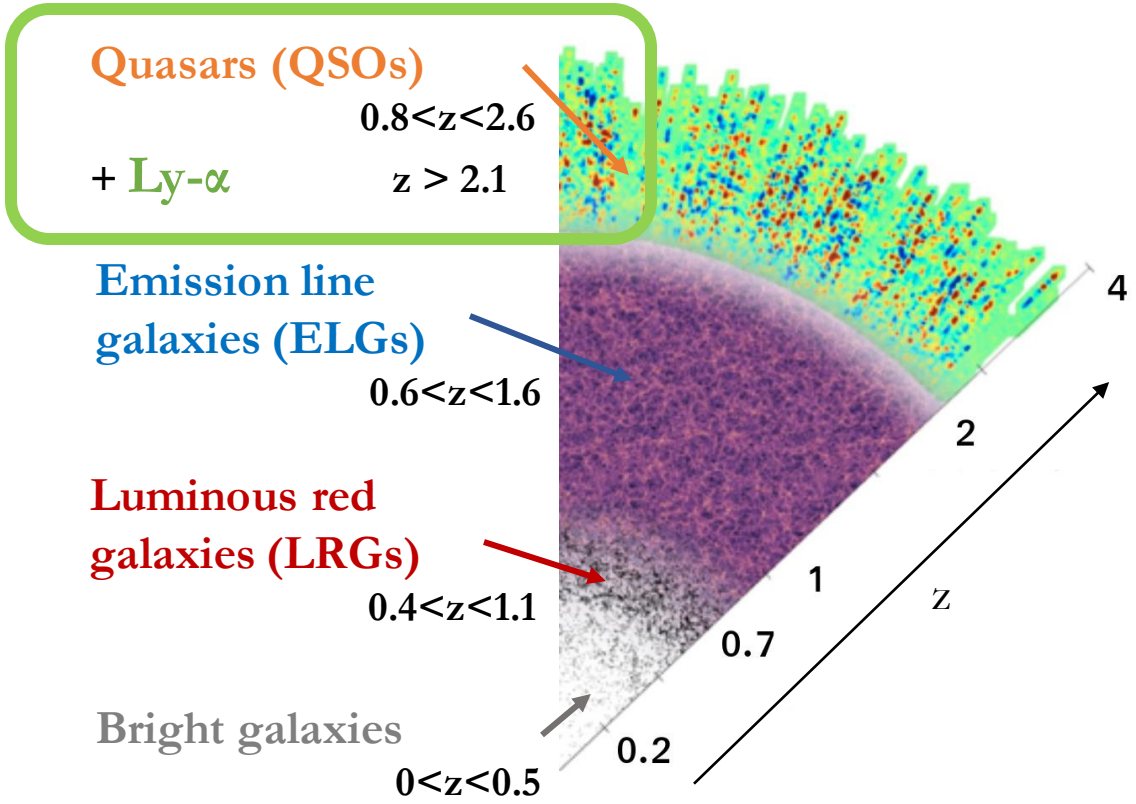


Small impact of HOD on cosmological parameters !

First science results: Ly-α

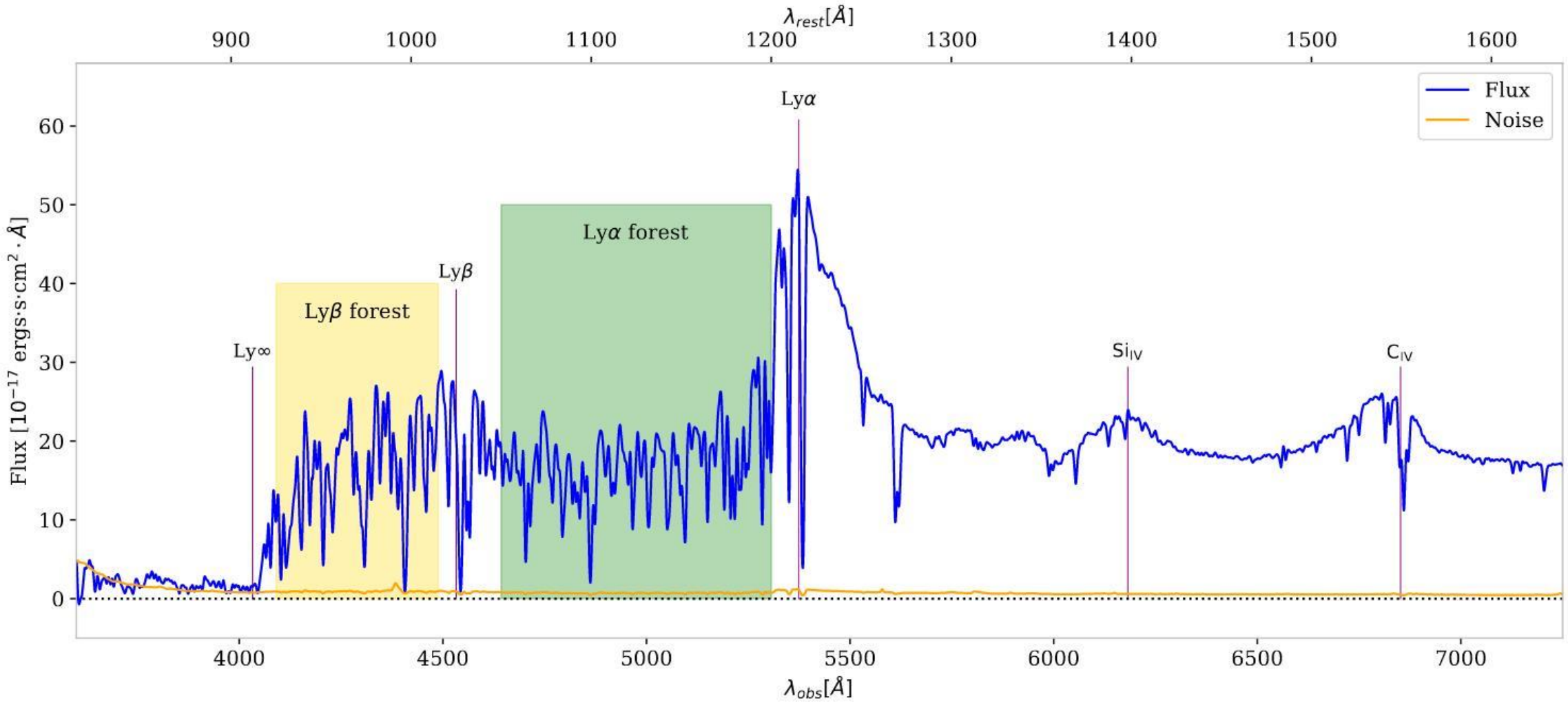


Raichoor et al. 2022



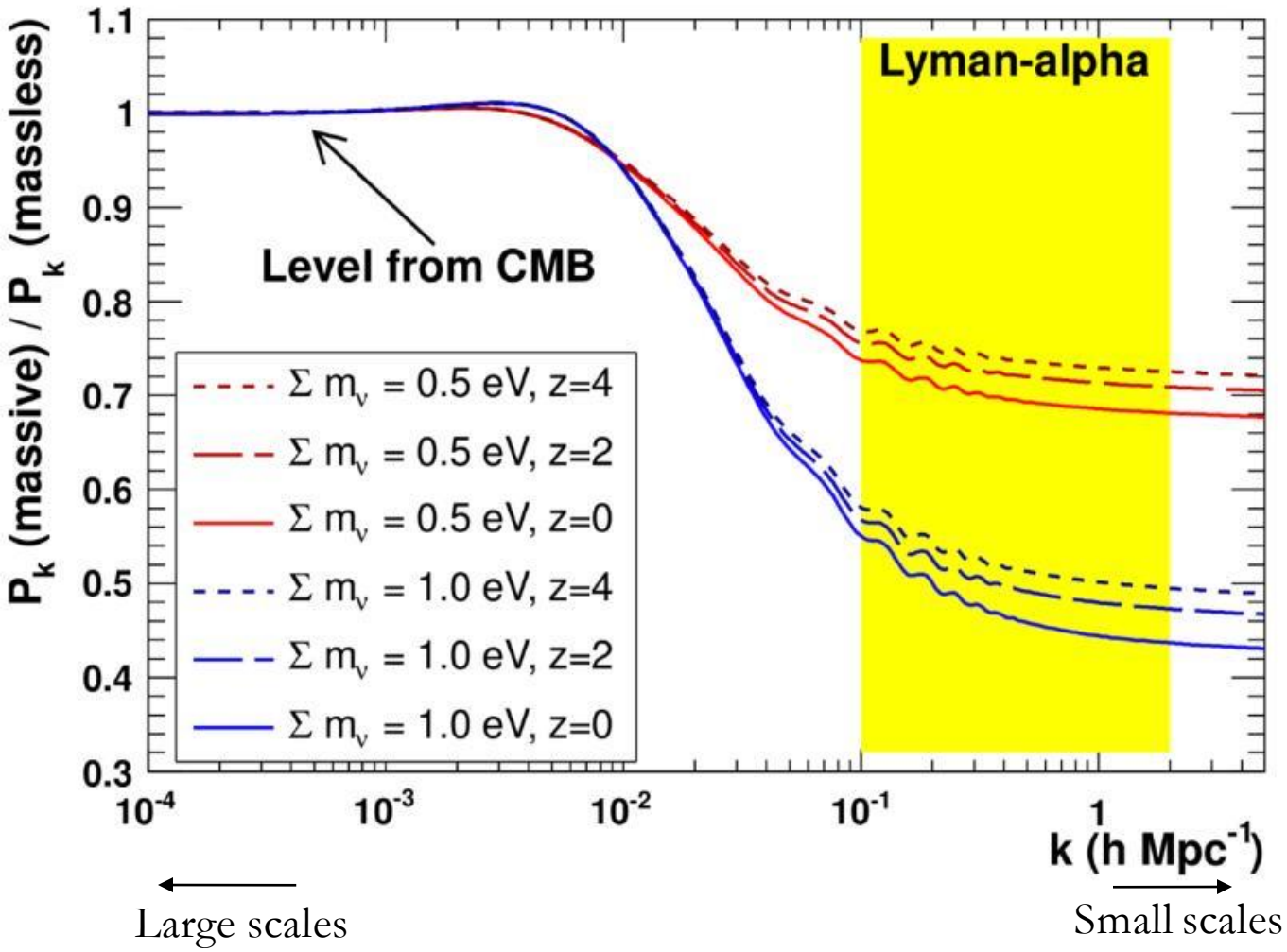
- **One 1% survey** + **DESI M2:**
  - **7000 Ly-α forest**

First science results: Ly-α



Ly-α forest for neutrino mass constraints

Palanque-Delabrouille et al. 2014



- Matter power spectrum impacted by sum of neutrino masses
- Ly-α probe intergalactic medium => non linear scales
- **Contraints on sum of neutrino masses**

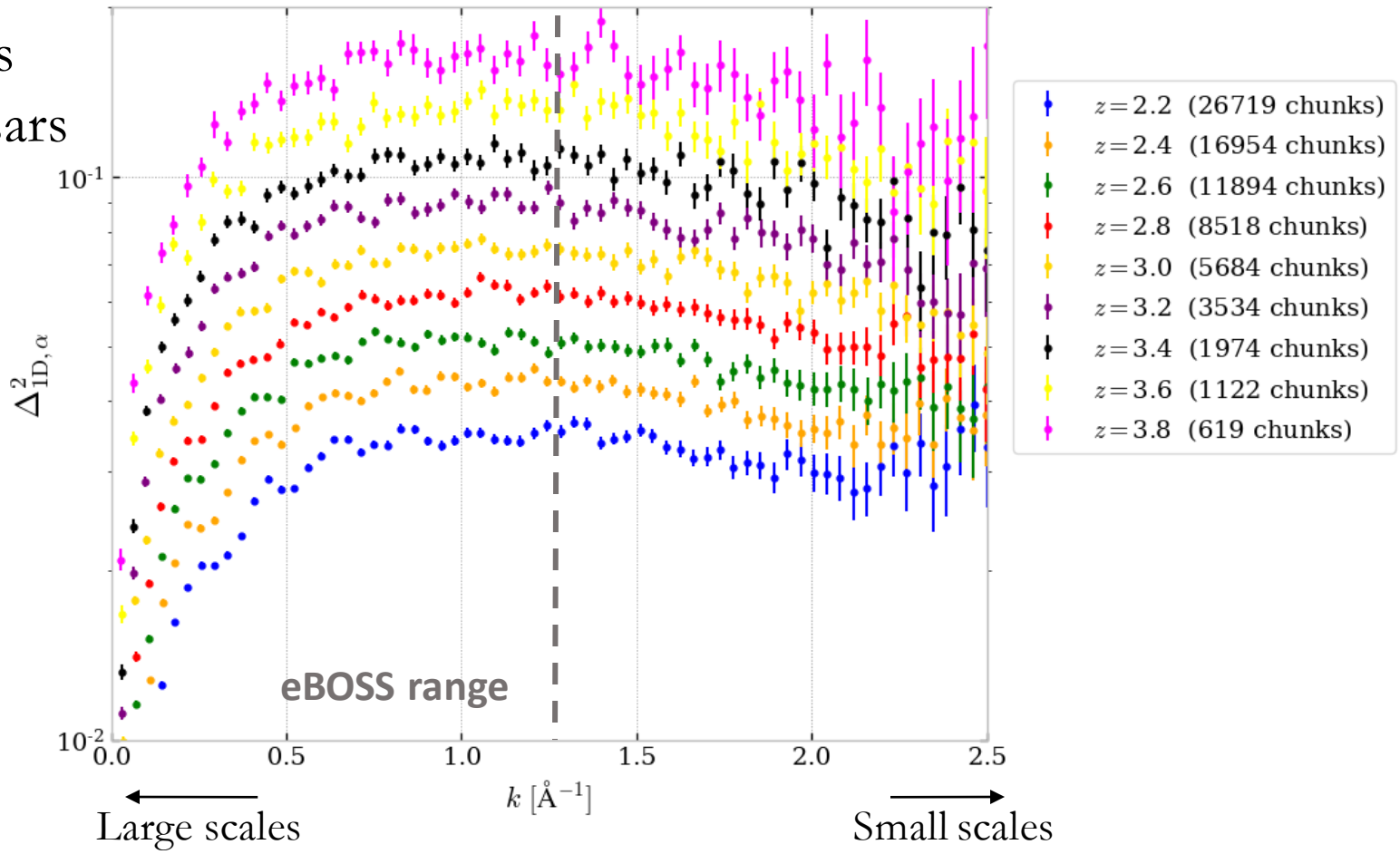
Ly-α Results: one dimentional power spectrum

(C. Ravoux, N. Karacayli, M. Abdulkarim + DESI collaboration in prep)

- P1D : Correlations between absorbers along the line of sight of distant quasars

- 7000 Ly-α forests

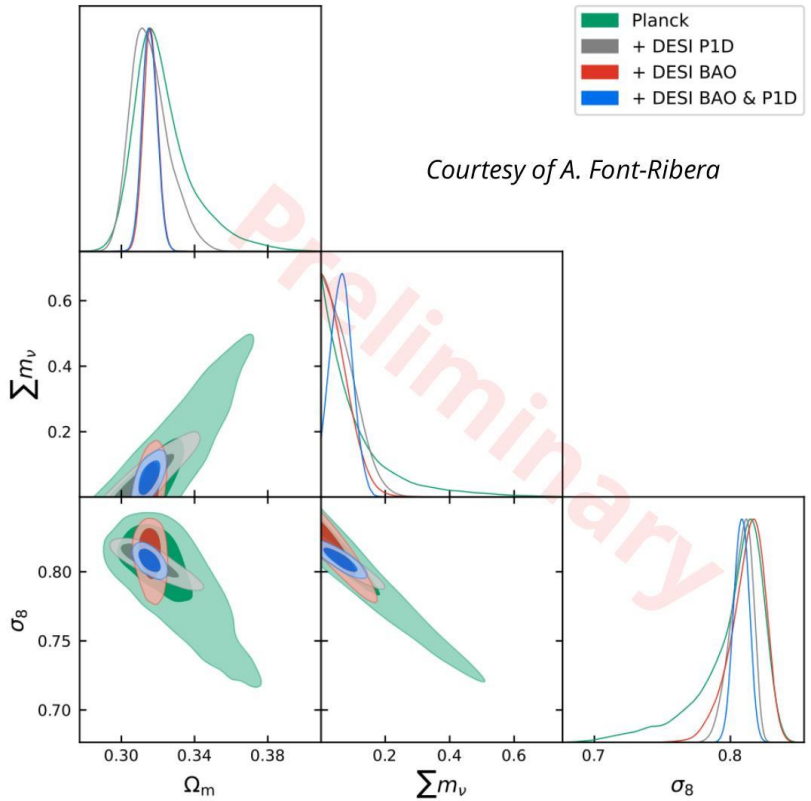
Preliminary results



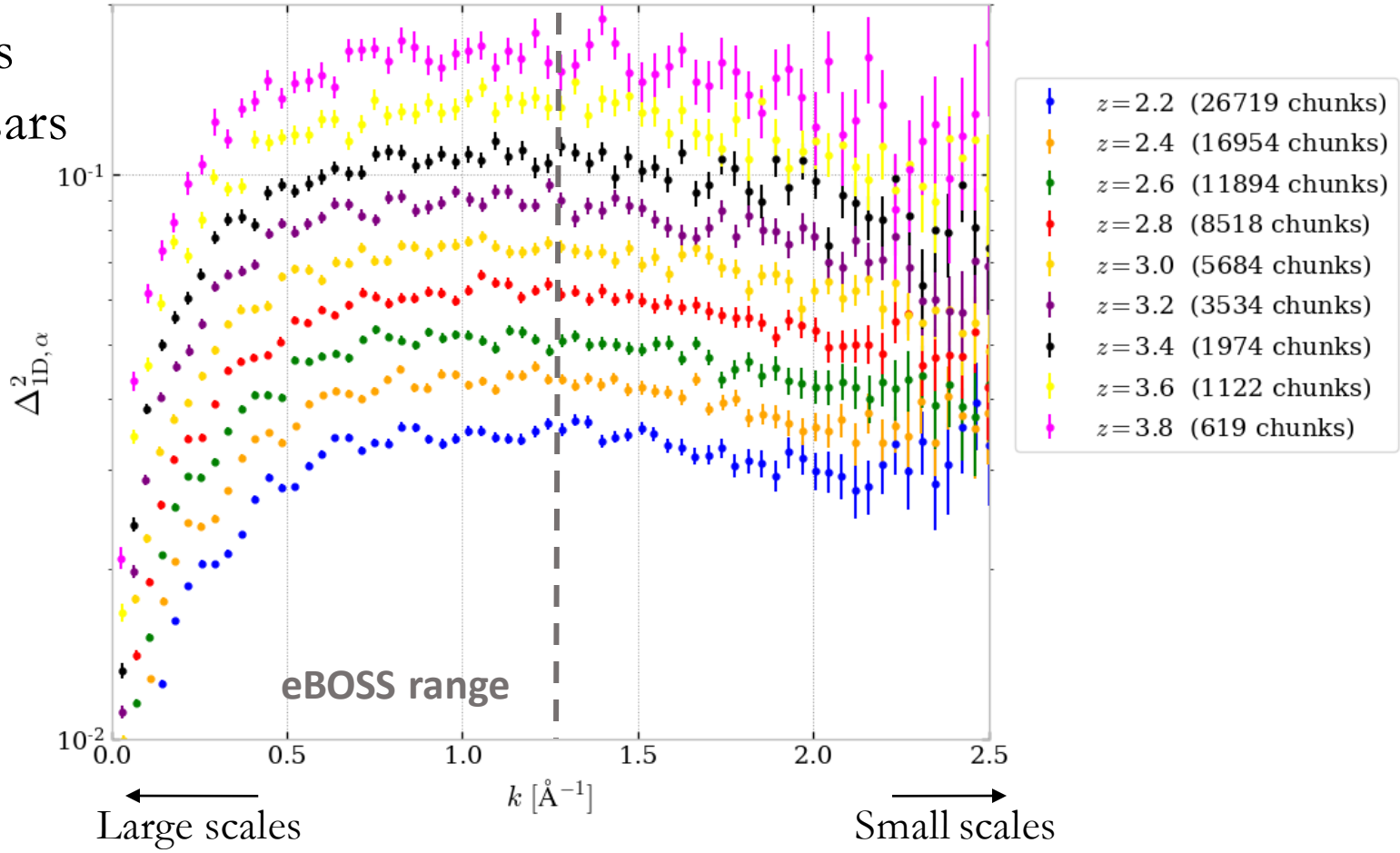
Ly-α Results: one dimentional power spectrum

(C. Ravoux, N. Karacayli, M. Abdulkarim + DESI collaboration in prep)

- P1D : Correlations between absorbers along the line of sight of distant quasars



Preliminary results



Science analysis in progress

<u>From SV + first 2 month of data (highlights):</u>

- M31 (Dey et. al, arXiv:2208.11683)
- Starburst galaxies (Setton et al, arXiv:2212.05070)
- GD1 stellar stream
- Peculiar Velocity Survey
- Galaxy-halo connection analysis
- Lyman-alpha P1D, early 3D correlation
- Primordial non-gaussianity with photometric sample calibrated with DESI redshifts (LRG,QSO)
- BAO analysis from BGS and LRG

<u>Year 1 analysis preparation:</u>

- Clustering catalog, Lya catalog
- Studies of instrumental systematics (imaging, fiber assignment and spectroscopy, redshift uncertainties)
- mock generation, pipeline developments, mock challenges
- Finalization of blinding strategy (for clustering, already in place for Lyman-alpha)
- Evaluation of theory models for optimal BAO/RSD analysis
- Alternative clustering methods
- Covariance estimation …

+ many many more analysis

(at the last collaboration meeting in December, **~100 independent projects** were presented in spotlight talks)

Conclusions

- DESI works very well:
  - **17M redshift in Jan. 23**
  - Survey Validation papers for TS and VI finalized
  - Finalizing the Early Data Release in few months

- Year 1 data acquisition ended June 22 & 1st internal Data Assembly release soon available to the collaboration
  - **1st expected public results end 2023/early 2024**

- **Already lots of science analysis with DESI Early Data**:
  - BAO detection in BGS and LRGs at 3 and 5σ
  - Galaxy-halo connection studies
    => Use to test cosmological analysis pipelines
  - P1D Ly-α analysis to constraint neutrino masses

DARK ENERGY SPECTROSCOPIC INSTRUMENT

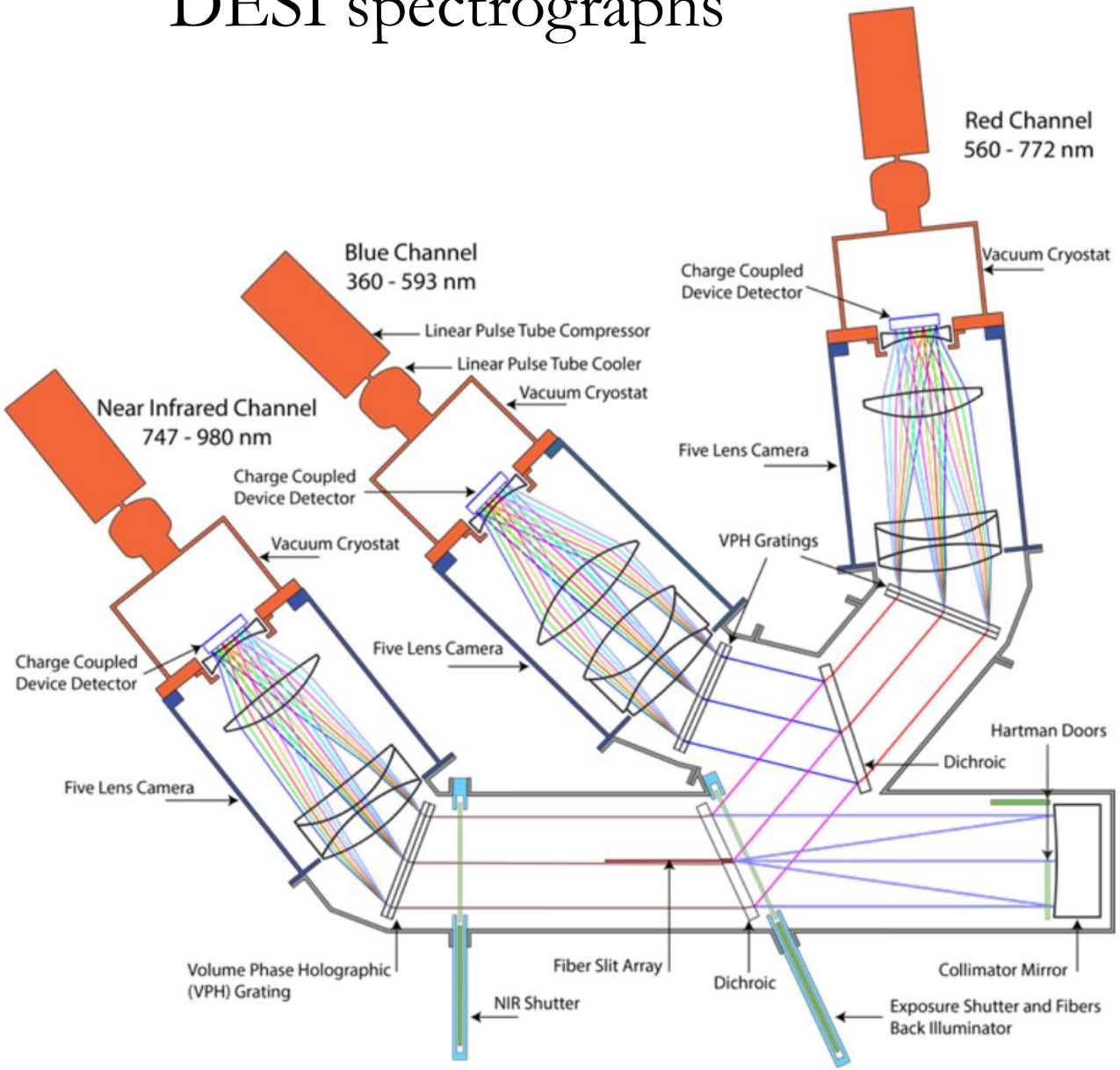
U.S. Department of Energy Office of Science

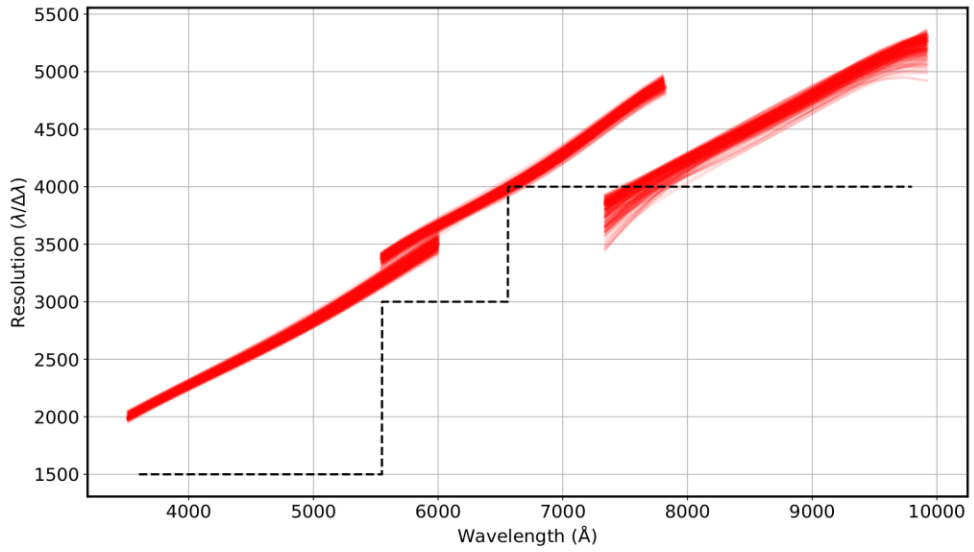
Thank you !

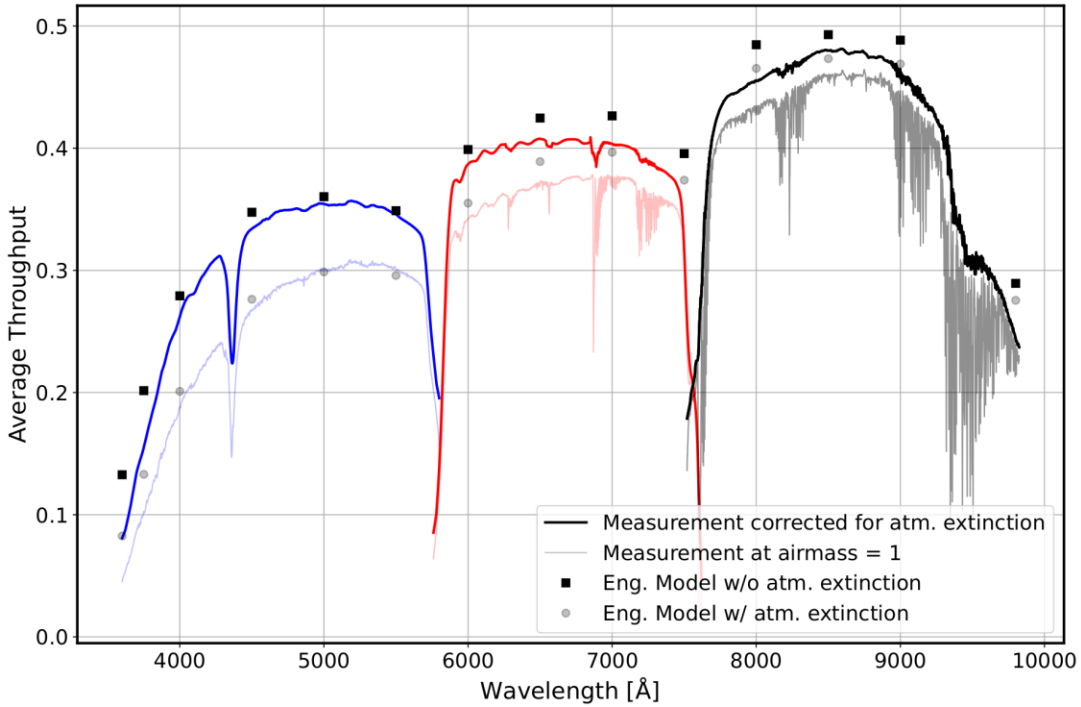
Thanks to our sponsors and 69 Participating Institutions!

Backup slides

DESI spectrographs







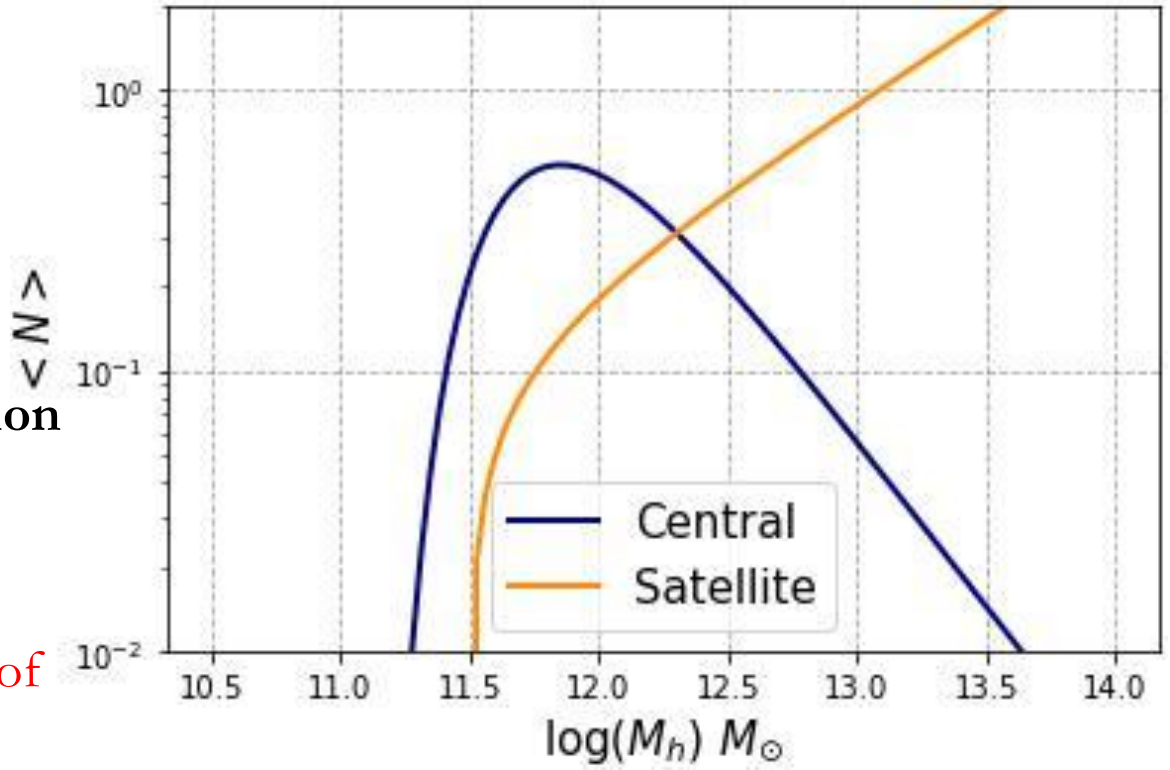
HOD for ELGs

- **Central galaxy**:
  - **4 Gaussian/Asymmetric model** *(Avila et al., Alam et al. 2020)*
  - Assign with Bernouilli distribution

$$\langle N_{cent} \rangle (M_h) = \frac{A_c}{\sqrt{2\pi}\sigma} \cdot e^{-\frac{(\log_{10}(M_h)-\log_{10}(M_c))^2}{2\sigma^2}}$$

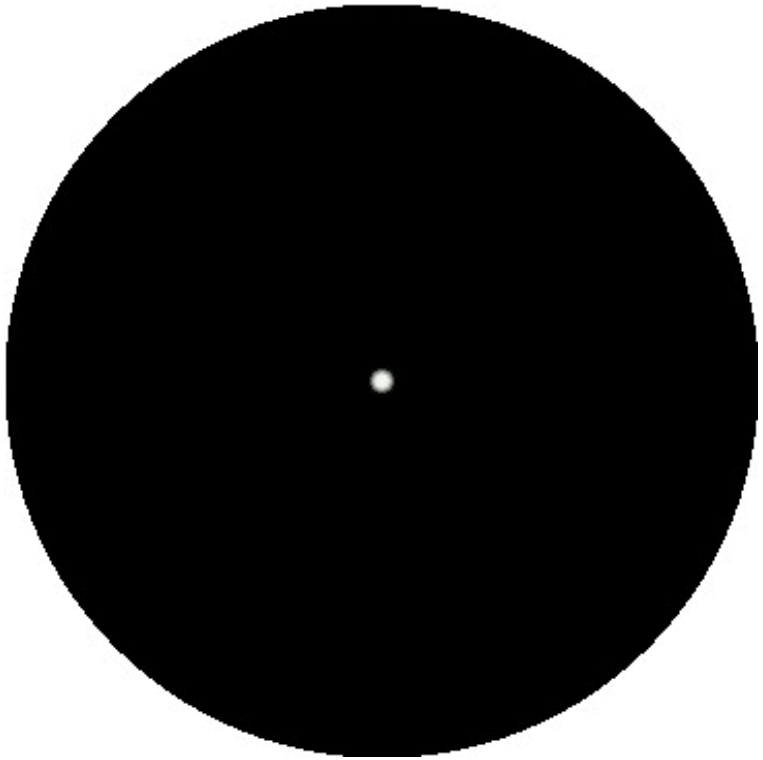
- **Satellite galaxy(ies)**:
  - Power law distribution
  - number of satellite galaxies following **Poisson distribution**
  - Placed assuming a **NFW** profile
  - **Velocity** drawn from **normal distribution**

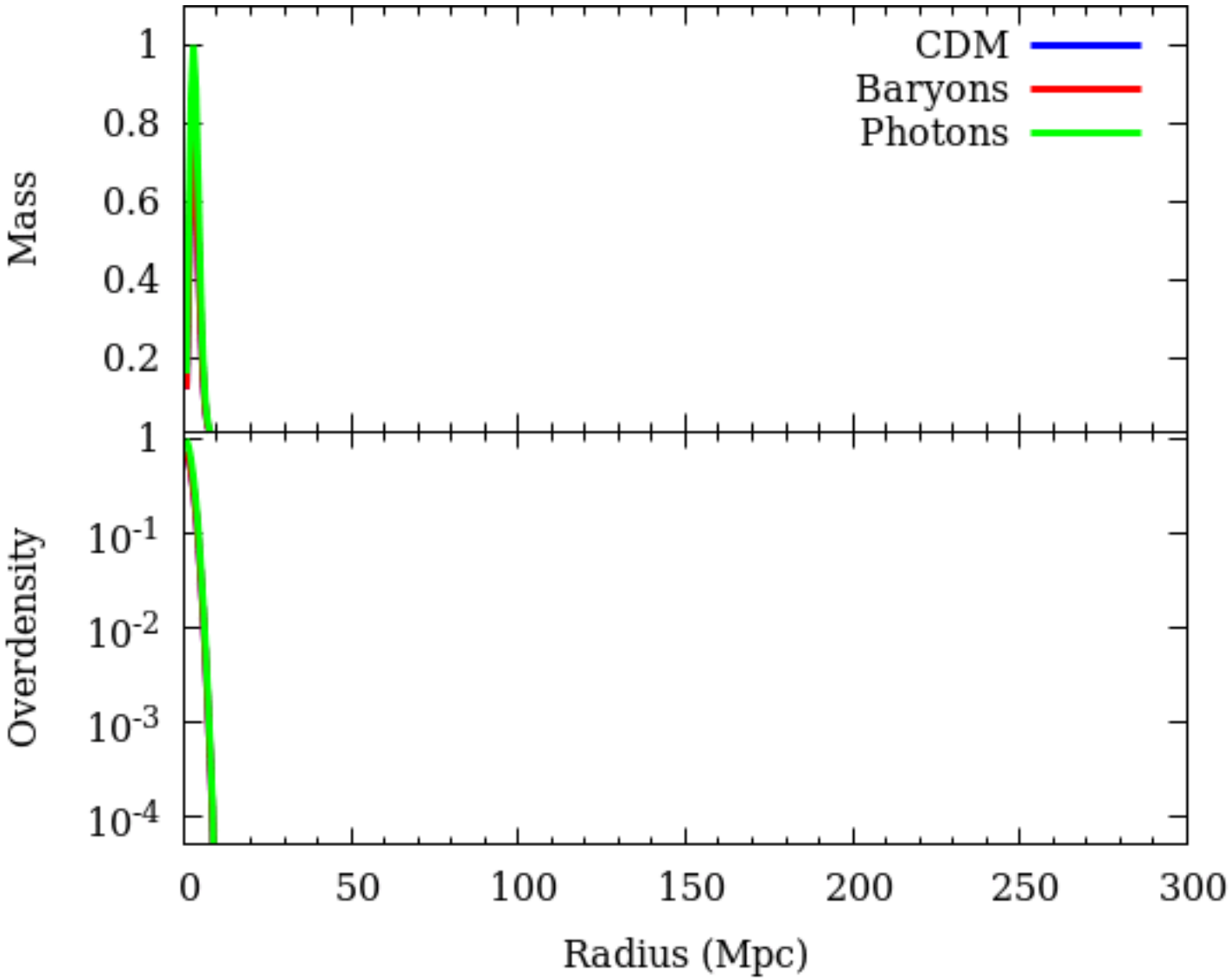
    $V_{sat,x}$ = rd.normal(Vhalo,x, σ_v.$\mathbf{f_{\sigma v}}$)
  - $\mathbf{f_{\sigma v}}$: **scaling factor** for satellite velocity dispersion (kind of velocity bias)



$$\langle N_{sat} \rangle (M) = A_s \left(\frac{M - M_0}{M_1} \right)^{\alpha}$$

(Zheng et al. 2005)




CDM
Baryons
Photons
Mass
1
0.8
0.6
0.4
0.2
Overdensity
1
10^{-1}
10^{-2}
10^{-3}
10^{-4}
0
50
100
150
200
250
300
Radius (Mpc)

Halo Occupation Distribution

HOD: Empirical relation to link DM halos in N-body simulations to tracers, **based on halo masses**

→ **AbacusSummit** *(Maksimova et al. 2021)*

Halo Occupation Distribution

HOD: Empirical relation to link DM halos in N-body simulations to tracers, **based on halo masses**

→ **AbacusSummit** *(Maksimova et al. 2021)*

- **Central galaxy**:
  - Probability to assign a galaxy at the halo center
  - **For ELGs Gaussian/Asymetric model** *(Avila et al. 2020)*
  - Central galaxy is assigned following a Bernouilli distribution (0/1)

Halo Occupation Distribution

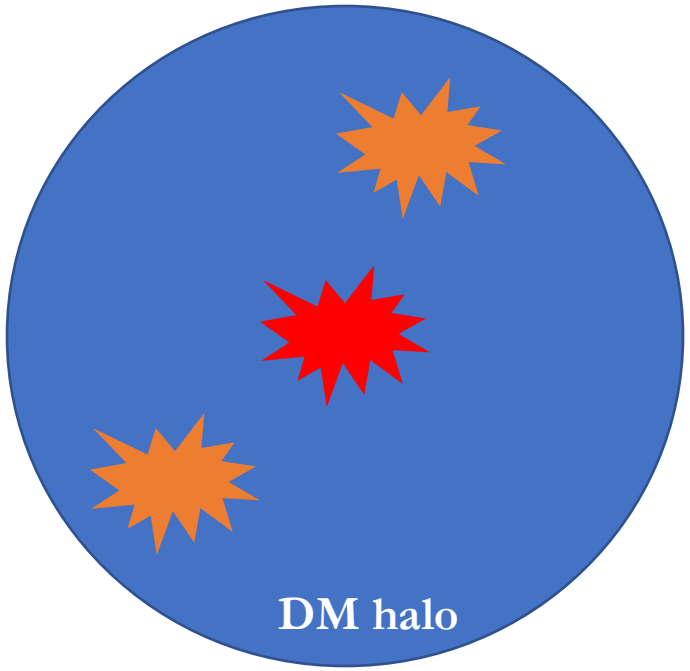
HOD: Empirical relation to link DM halos in N-body simulations to tracers, **based on halo masses**

→ **AbacusSummit** *(Maksimova et al. 2021)*

- **Central galaxy**:
  - Probability to assign a galaxy at the halo center
  - **For ELGs Gaussian/Asymetric model** *(Avila et al. 2020)*
  - Central galaxy is assigned following a Bernouilli distribution (0/1)
- **Satellite galaxy(ies)**:
  - Power law that determine the mean number of satellite galaxies in a halo

$$\langle N_{sat} \rangle (M) = A_s \left(\frac{M - M_0}{M_1} \right)^{\alpha}$$ *(Zheng 2005)*

  - Draw **Poisson distribution** to determine the number of satellite galaxies
  - Satellite galaxies are placed assuming a NFW profile of the DM halo



Halo Occupation Distribution

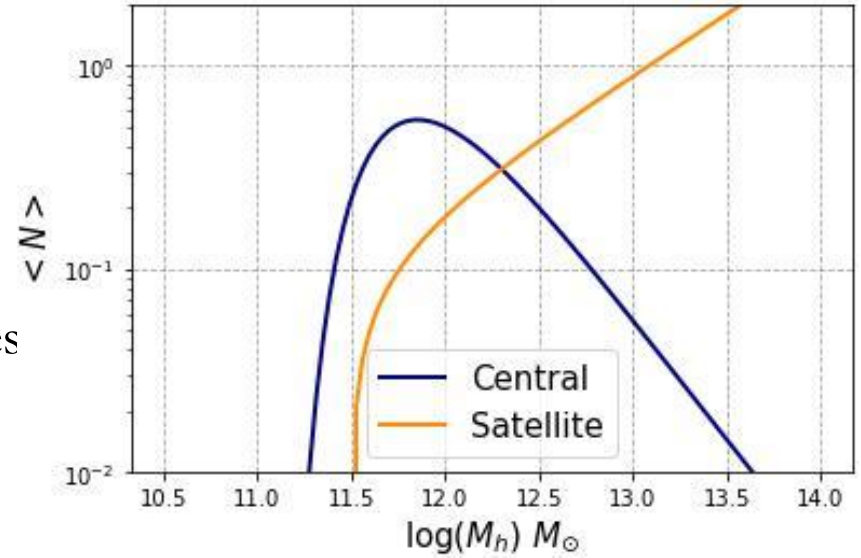
HOD: Empirical relation to link DM halos in N-body simulations to tracers, **based on halo masses**

AbacusSummit *(Maksimova et al. 2021)*

- **Central galaxy**:
  - Probability to assign a galaxy at the halo center
  - **For ELGs Gaussian/Asymetric model** *(Avila et al. 2020)*
  - Central galaxy is assigned following a Bernouilli distribution (0/1)

$$\langle N_{cent} \rangle (M_h) = \frac{A_c}{\sqrt{2\pi}\sigma} \cdot e^{-\frac{(\log_{10}(M_h)-\log_{10}(M_c))^2}{2\sigma^2}}$$

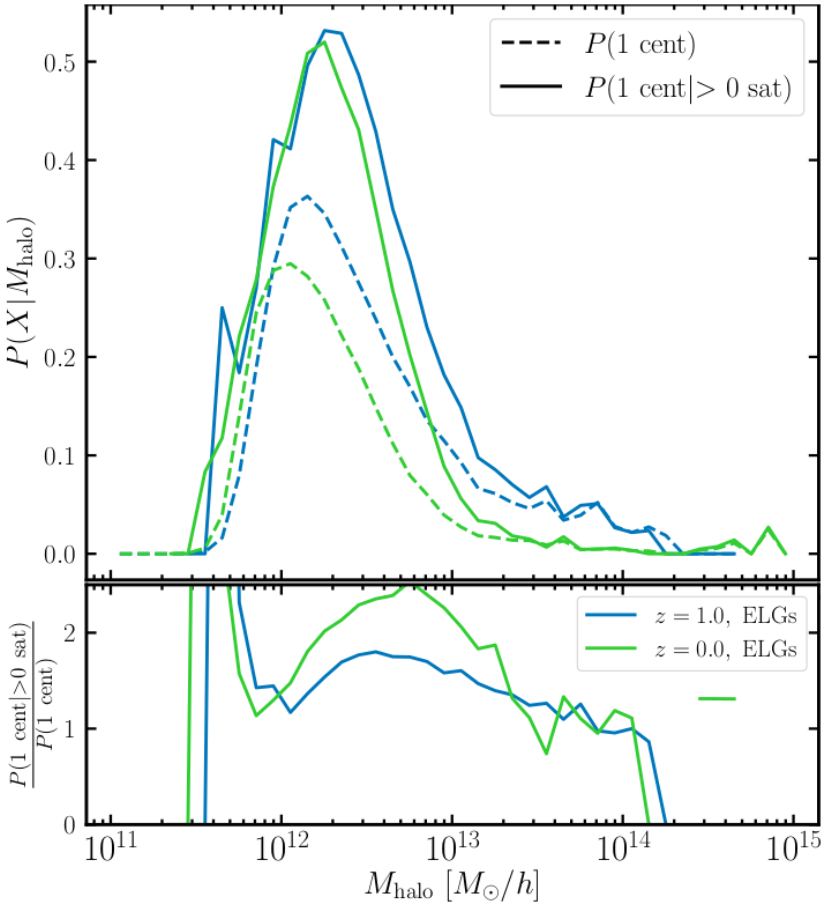
- **Satellite galaxy(ies)**: $\langle N_{sat} \rangle (M) = A_s \left(\frac{M - M_0}{M_1} \right)^{\alpha}$ *(Zheng at al. 2005)*
  - Power law that determine the mean number of satellite galaxies in a halo
  - Draw **Poisson distribution** to determine the number of satellite galaxies

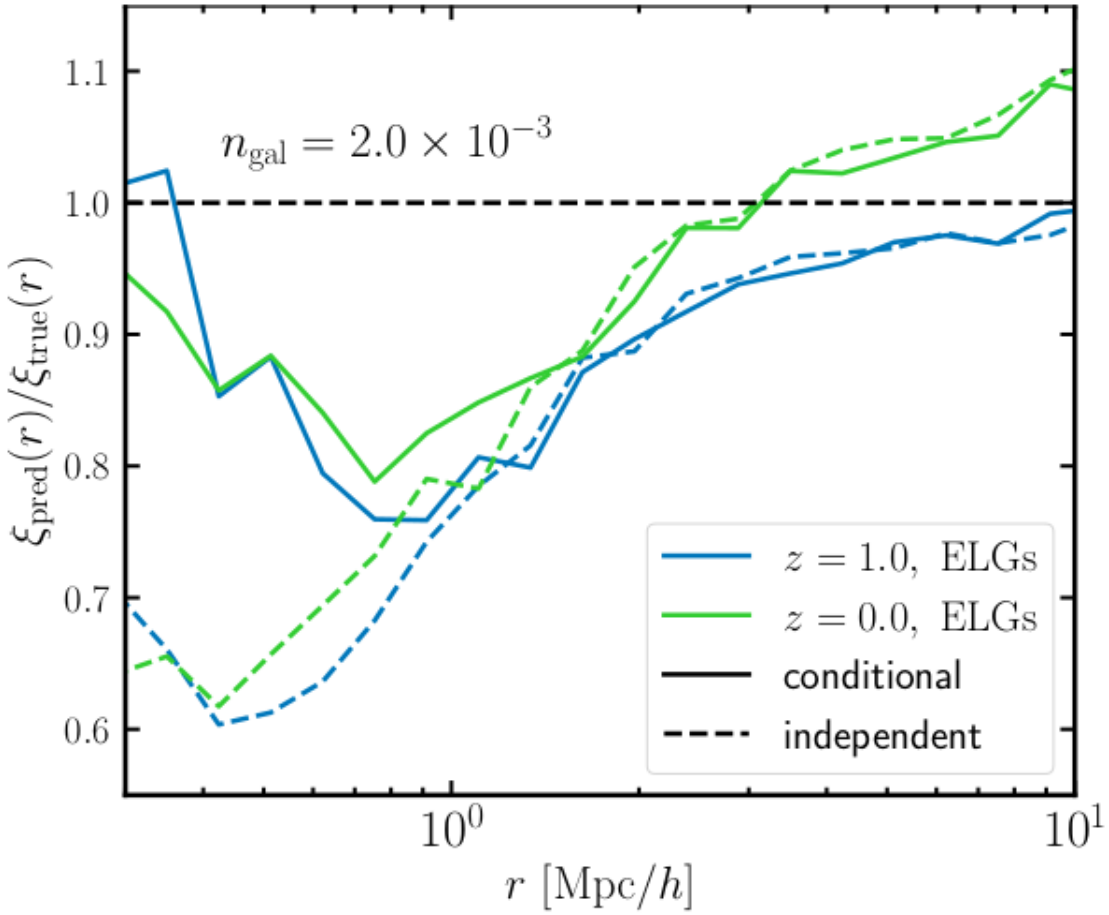


  - Satellite galaxies are placed assuming a NFW profile of the DM halo
  - **Velocity** drawn from **normal distribution**
  - $\mathbf{f_{\sigma v}}$: **scaling factor** for satellite velocity dispersion (kind of velocity bias)

$V_{sat,x} = \text{rd.normal}(V_{halo,x}, \sigma_v . \mathbf{f_{\sigma v}})$

Hydro-simulation results: conformity





- Dashed curves : Probability that a halo contains a central
- Solid lines: Probability that a halo contains a central given that it hosts satellites > 0.

MilleniumTNG project

(*Hadzhiyska et al. in prep*)

- Roughly twice more likely
- Clustering ratio when adopting our corrected model of the central-satellite pairing (one extra parameter).
- Corrected samples: substantial improvement near $r \sim 0.1$ Mpc/h.