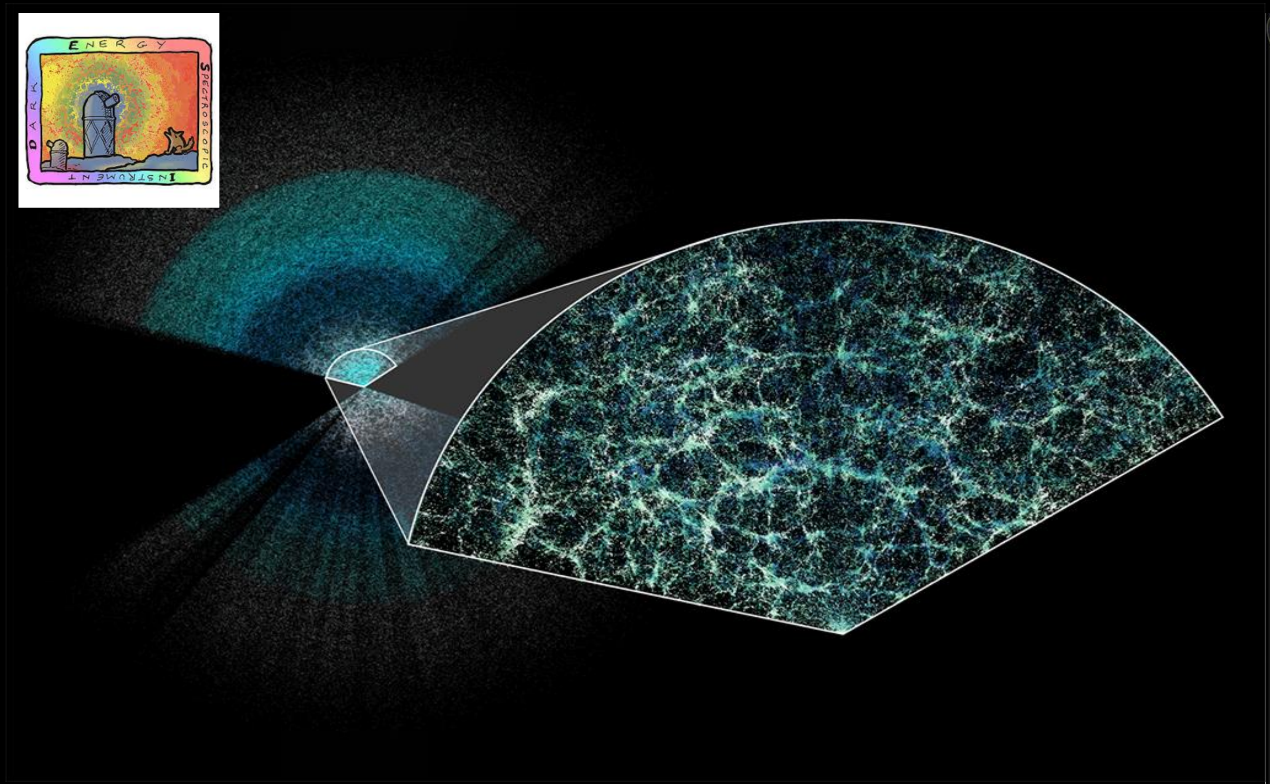
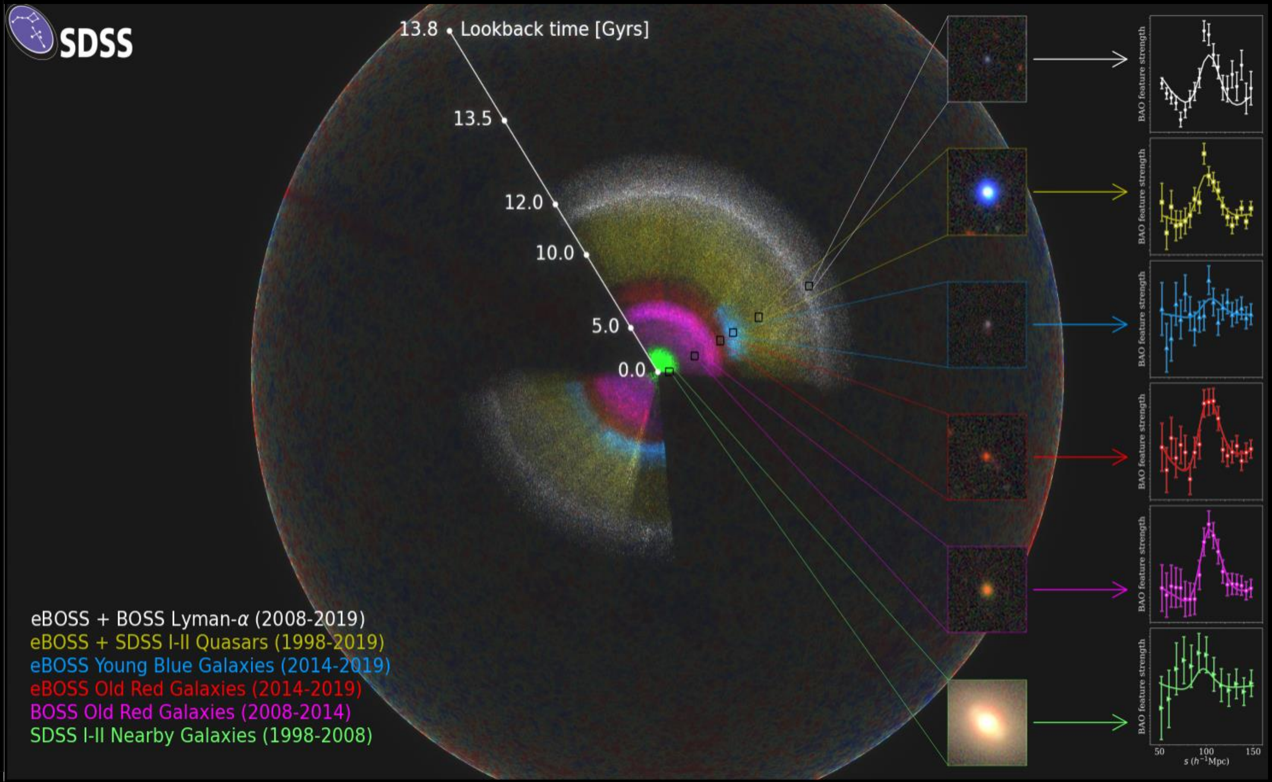



# Cosmological implications of massive galaxy surveys

**Gong-Bo Zhao**

**National Astronomical Observatories, CAS**

**October 21, 2025**

# Multiple cosmological probes

CMB

# Multiple cosmological probes

**CMB**

# Multiple cosmological probes

**CMB**


**SNe**

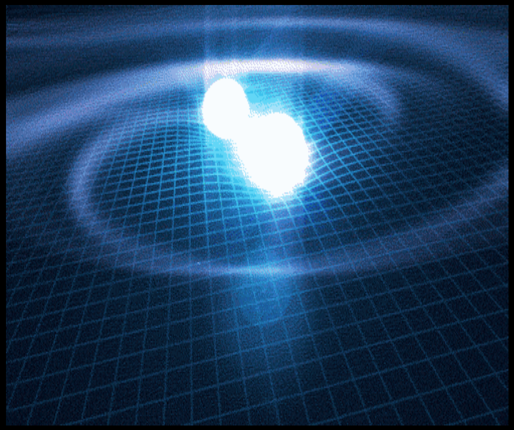
# Multiple cosmological probes

**CMB**


**SNe**

# Multiple cosmological probes

CMB

Gravitational waves

SNe

# Multiple cosmological probes

CMB



Gravitational waves

SNe

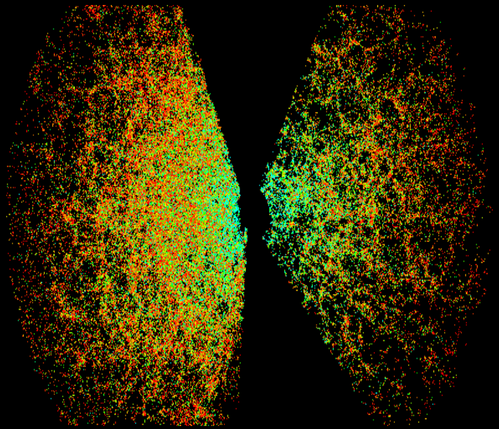
# Multiple cosmological probes

CMB



Gravitational waves

SNe

LSS

# Multiple cosmological probes

CMB

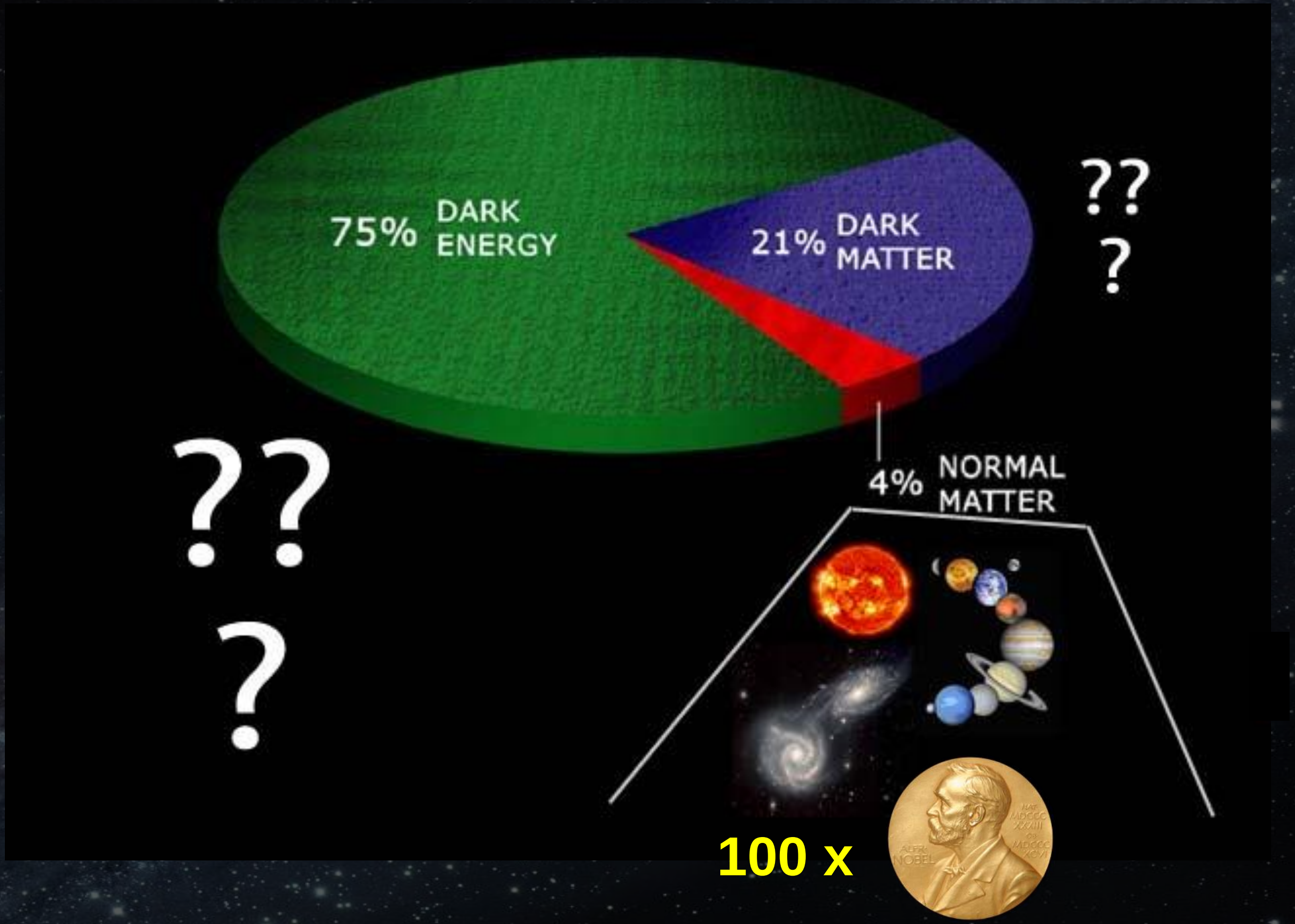


Gravitational waves

SNe



LSS


75% DARK ENERGY
21% DARK MATTER
4% NORMAL MATTER
???
???
100 x

CMB (1978)

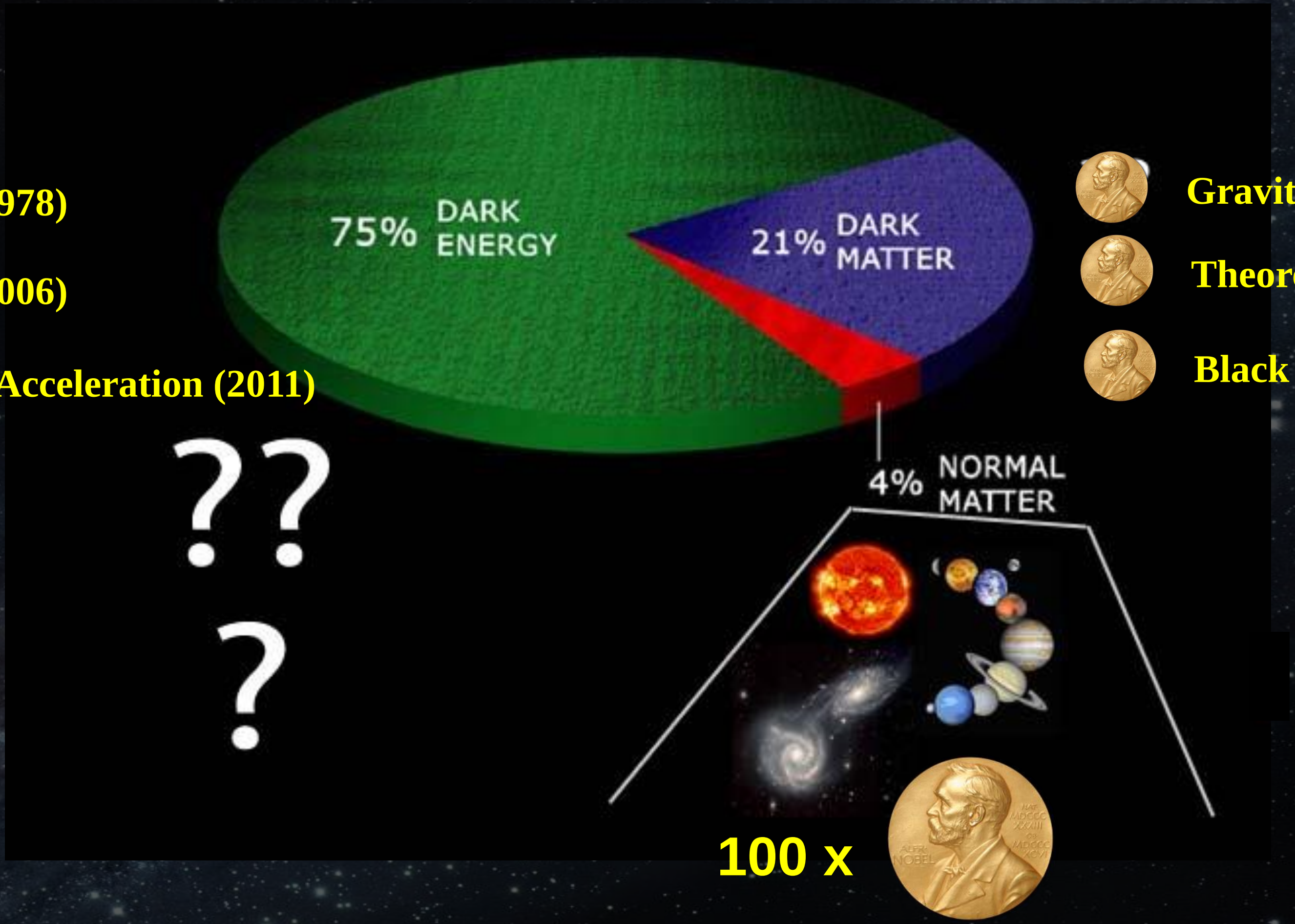
CMB (2006)

Cosmic Acceleration (2011)

Gravitational waves (2017)

Theoretical cosmology (2019)

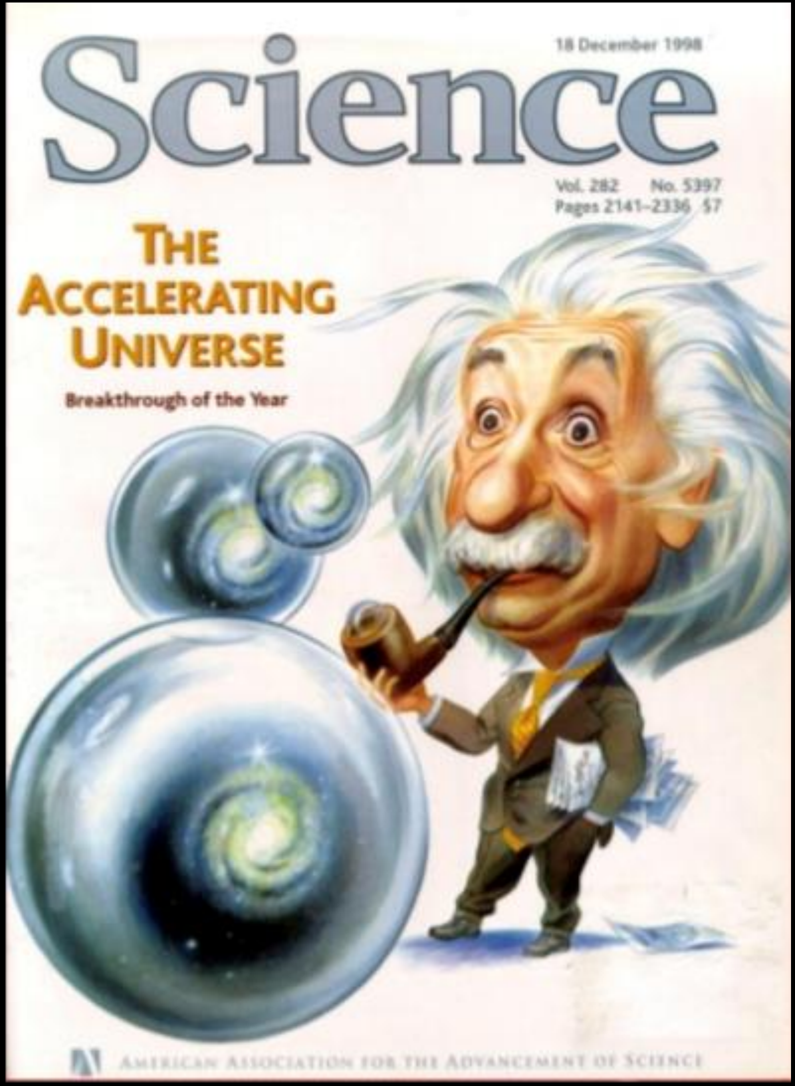
Black holes (2020)




100 x

# The accelerating Universe!

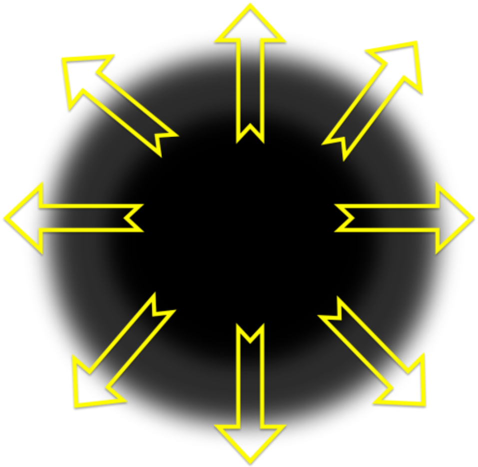
2011

The expansion of the Universe can **accelerate** if

In GR, to add new 'repulsive matter', which contributes 70% total energy

To modify General Relativity




**Dark Energy**

$$G_{\mu\nu} = 8\pi G \widetilde{T}_{\mu\nu}$$

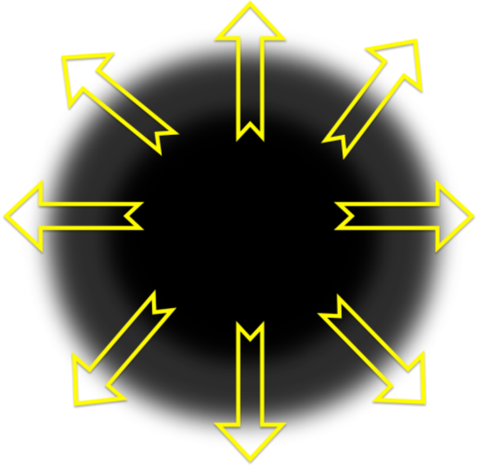
**Modified Gravity**

$$\widetilde{G}_{\mu\nu} = 8\pi G T_{\mu\nu}$$

The expansion of the Universe can **accelerate** if

In GR, to add new 'repulsive matter', which contributes 70% total energy

To modify General Relativity



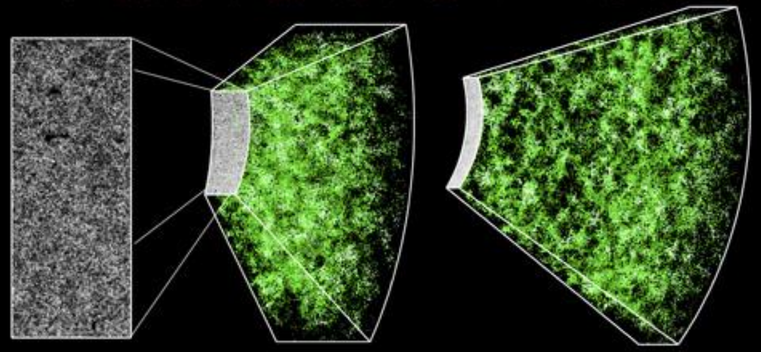

**Dark Energy**

$$G_{\mu\nu} = 8\pi G\widetilde{T}_{\mu\nu}$$

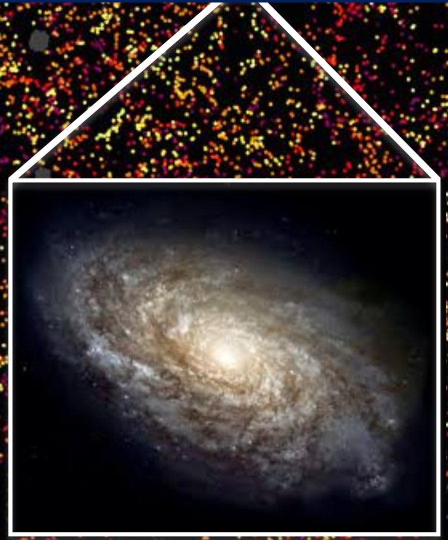
**Modified Gravity**

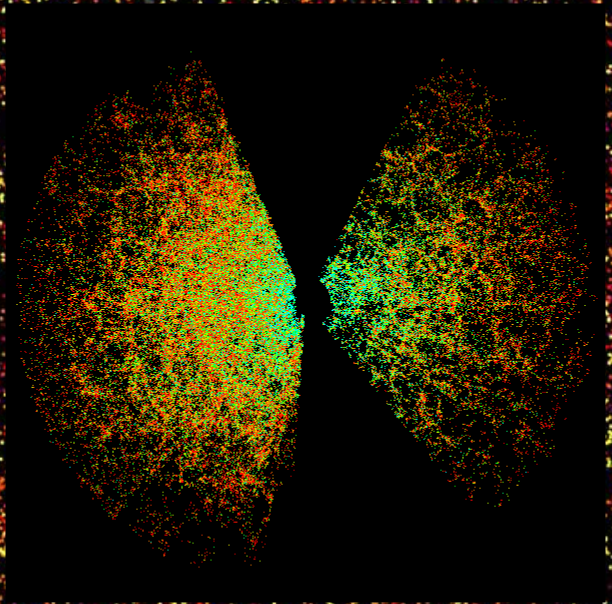
$$\widetilde{G}_{\mu\nu} = 8\pi G T_{\mu\nu}$$

**Galaxy surveys can break the dark degeneracy!**



# Massive redshift surveys as a key cosmological probe

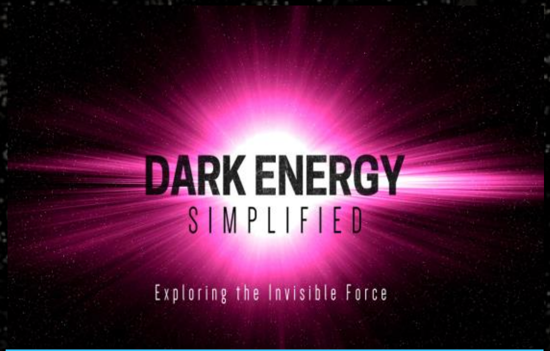




BOSS
SDSS III

# Large z-surveys : a key probe of the Universe

**Large-scale clustering**

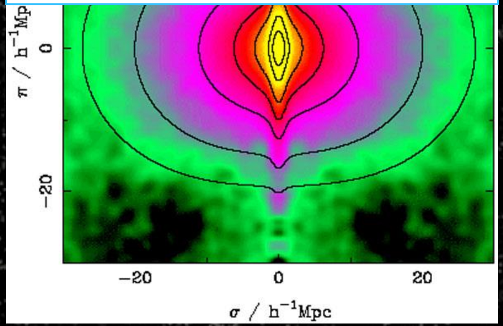


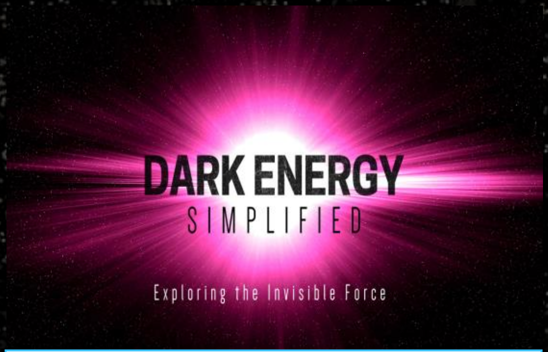

**Dark Energy**

# Large z-surveys：a key probe of the Universe

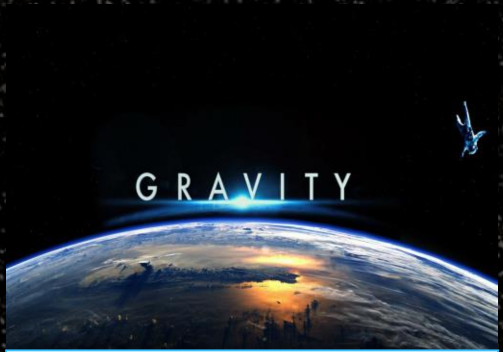
**Large-scale clustering**

**Mid-scale clustering**



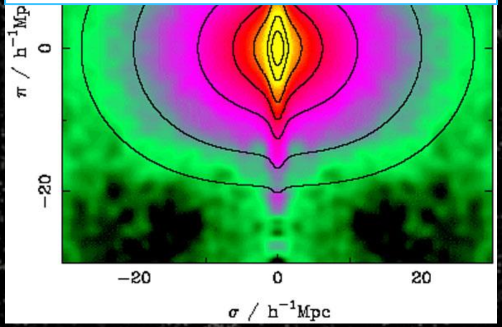

**Dark Energy**

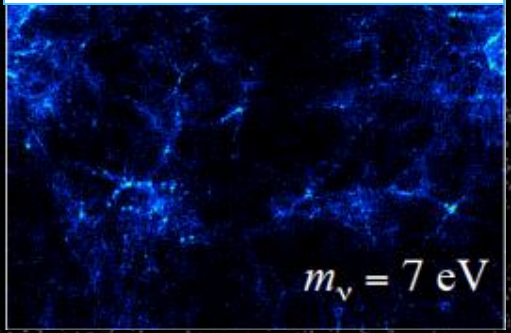


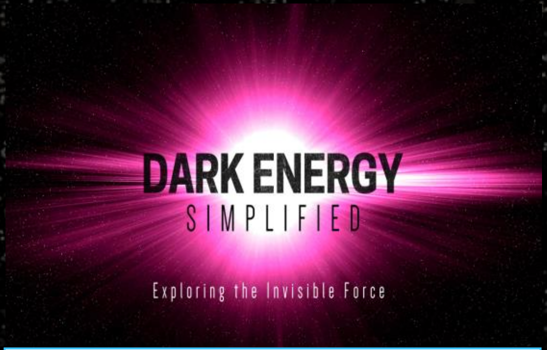

**Modified Gravity**

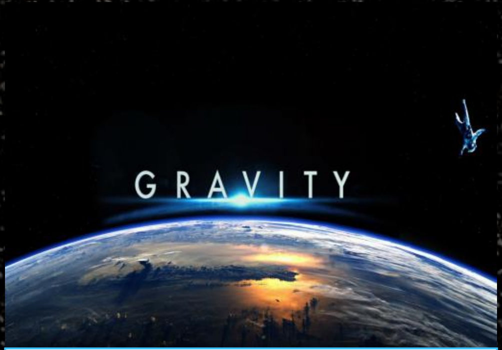
# Large z-surveys：a key probe of the Universe

| Large-scale clustering | Mid-scale clustering | Small-scale clustering |
|---|---|---|



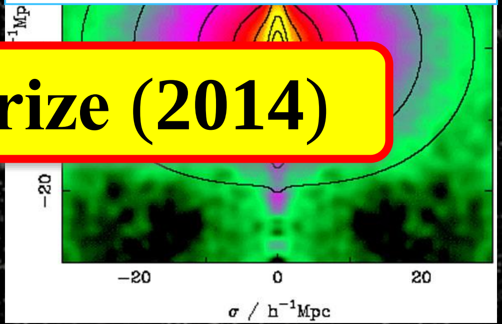


| Dark Energy | Modified Gravity | Neutrino masses |
|---|---|---|

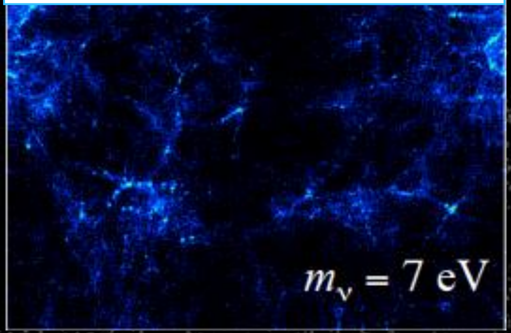
# Large z-surveys : a key probe of the Universe

**Large-scale clustering**

**Mid-scale clustering**




**Small-scale clustering**

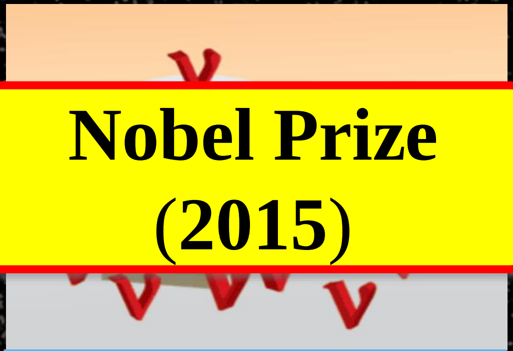



**Shaw's prize (2014)**


**Nobel Prize (2011)**

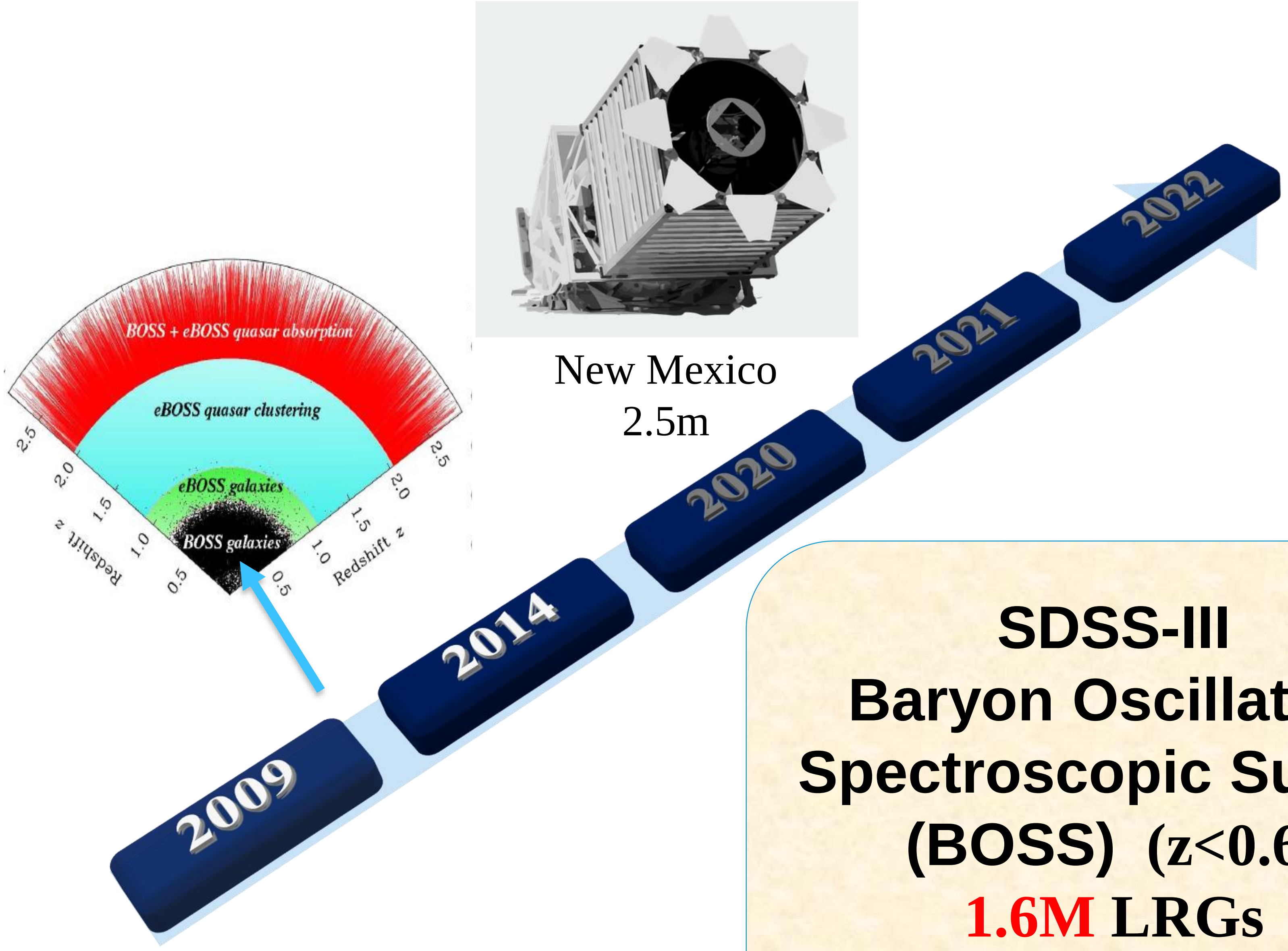
**Dark Energy**


**Modified Gravity**

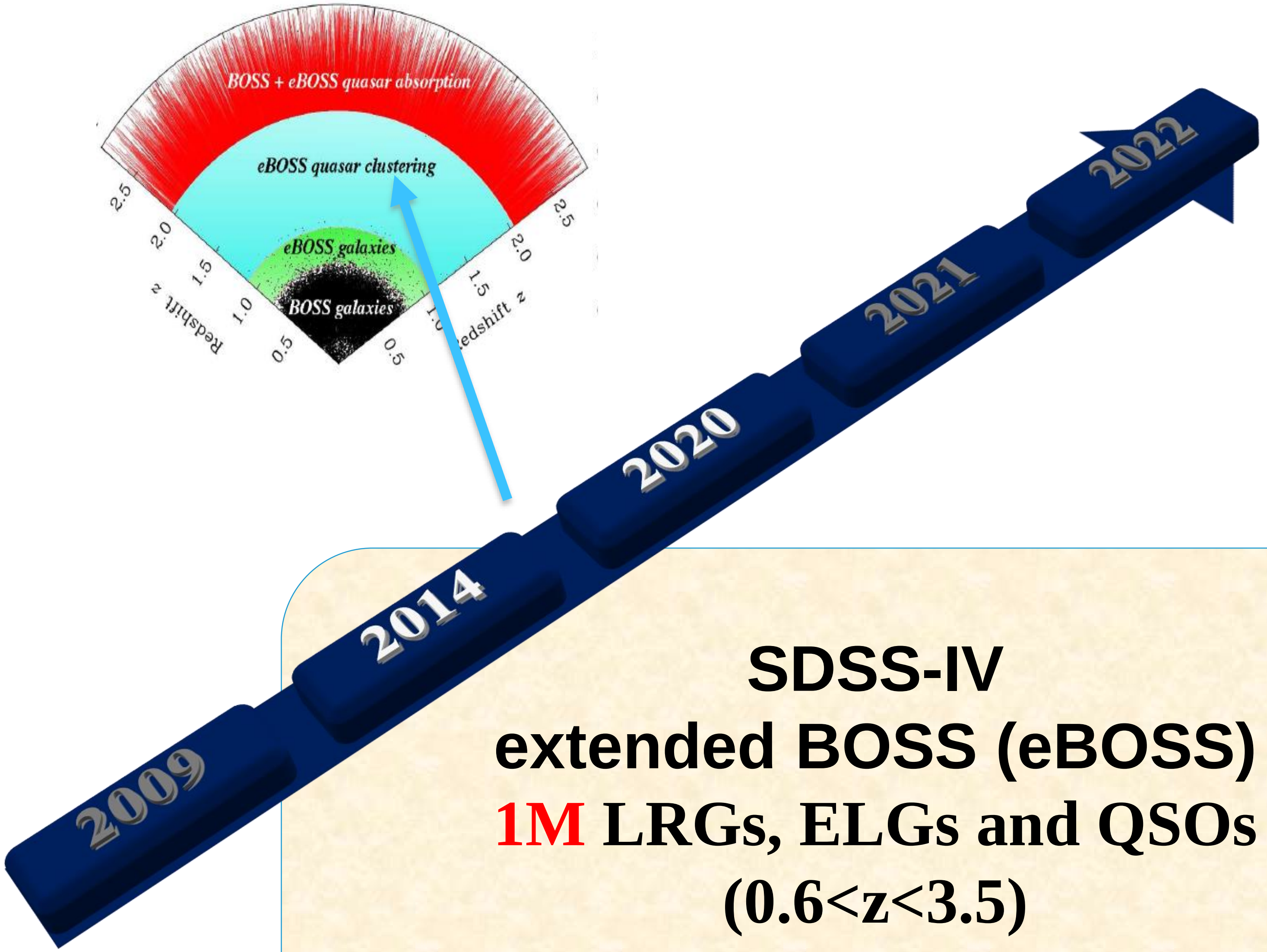


**Nobel Prize (2015)**

**Neutrino masses**




**SDSS-III**
**Baryon Oscillation**
**Spectroscopic Survey**
**(BOSS) (z<0.6)**
**1.6M LRGs**
**The largest in last decade**




**SDSS-IV**

**extended BOSS (eBOSS)**

**1M LRGs, ELGs and QSOs**

**($0.6<z<3.5$)**

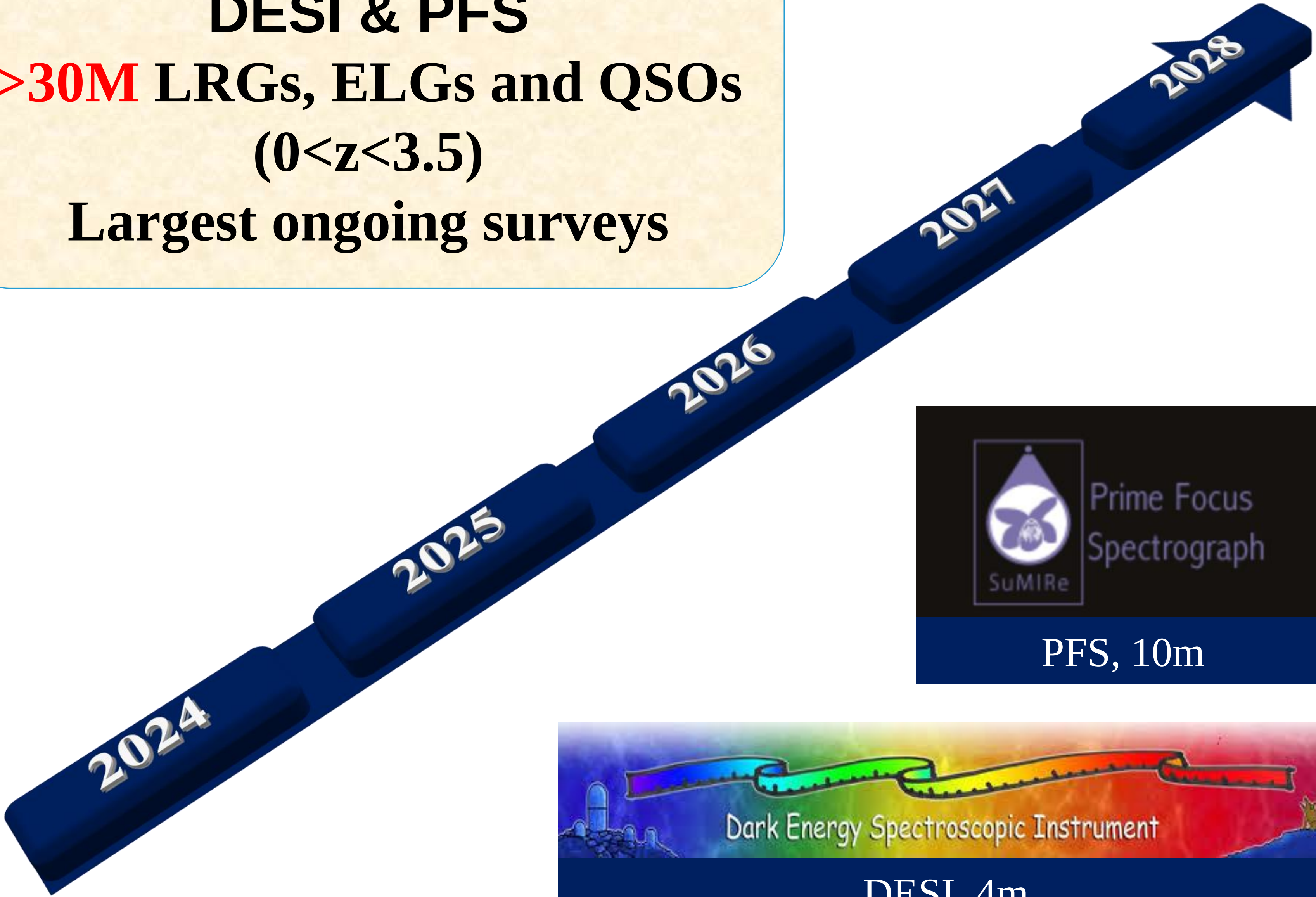
**The largest in the past 5 years**

**DESI & PFS**

**>30M LRGs, ELGs and QSOs**

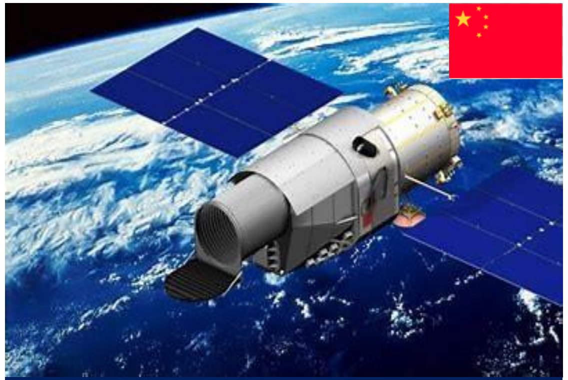
**(0<z<3.5)**

**Largest ongoing surveys**

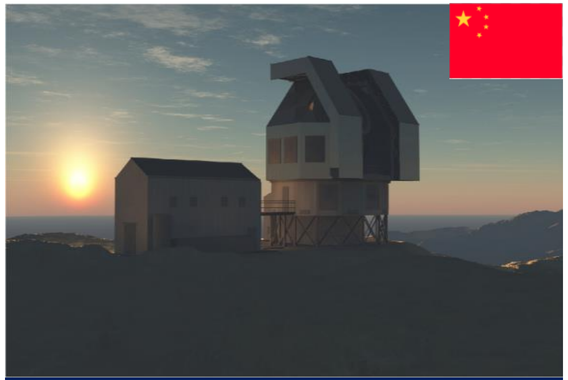



PFS, 10m

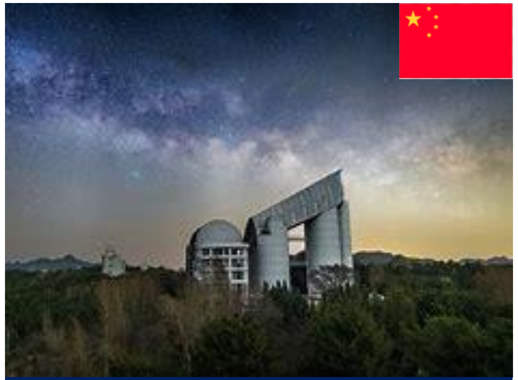
DESI, 4m



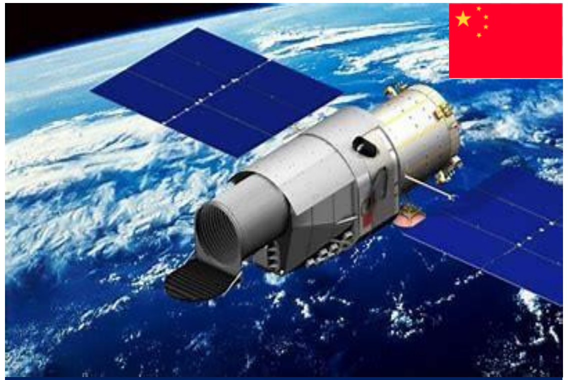
CSST, 2m in space



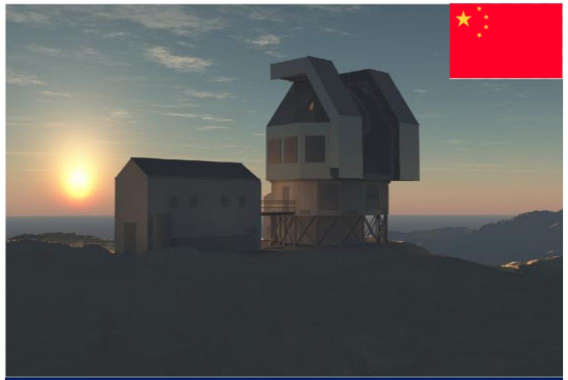
MUST, 6.5m



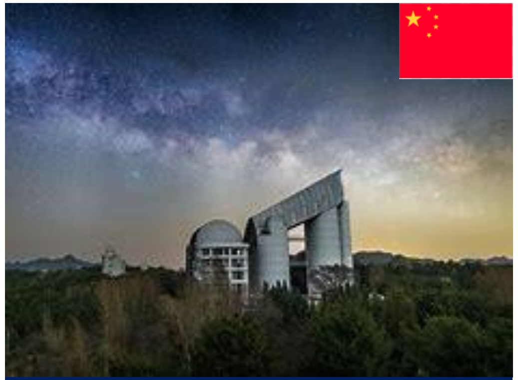
ESST, 10+m



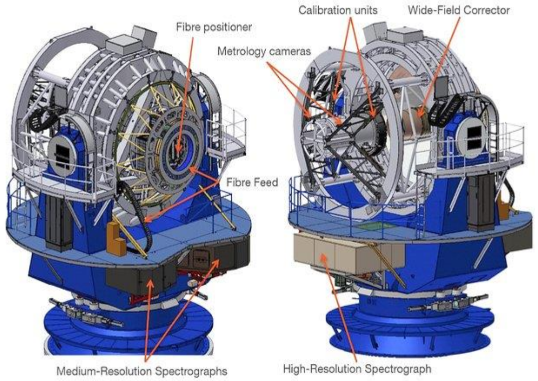
CSST, 2m in space



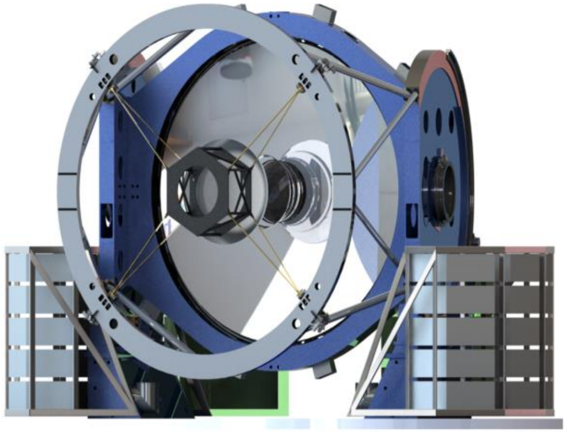
MUST, 6.5m



ESST, 10+m



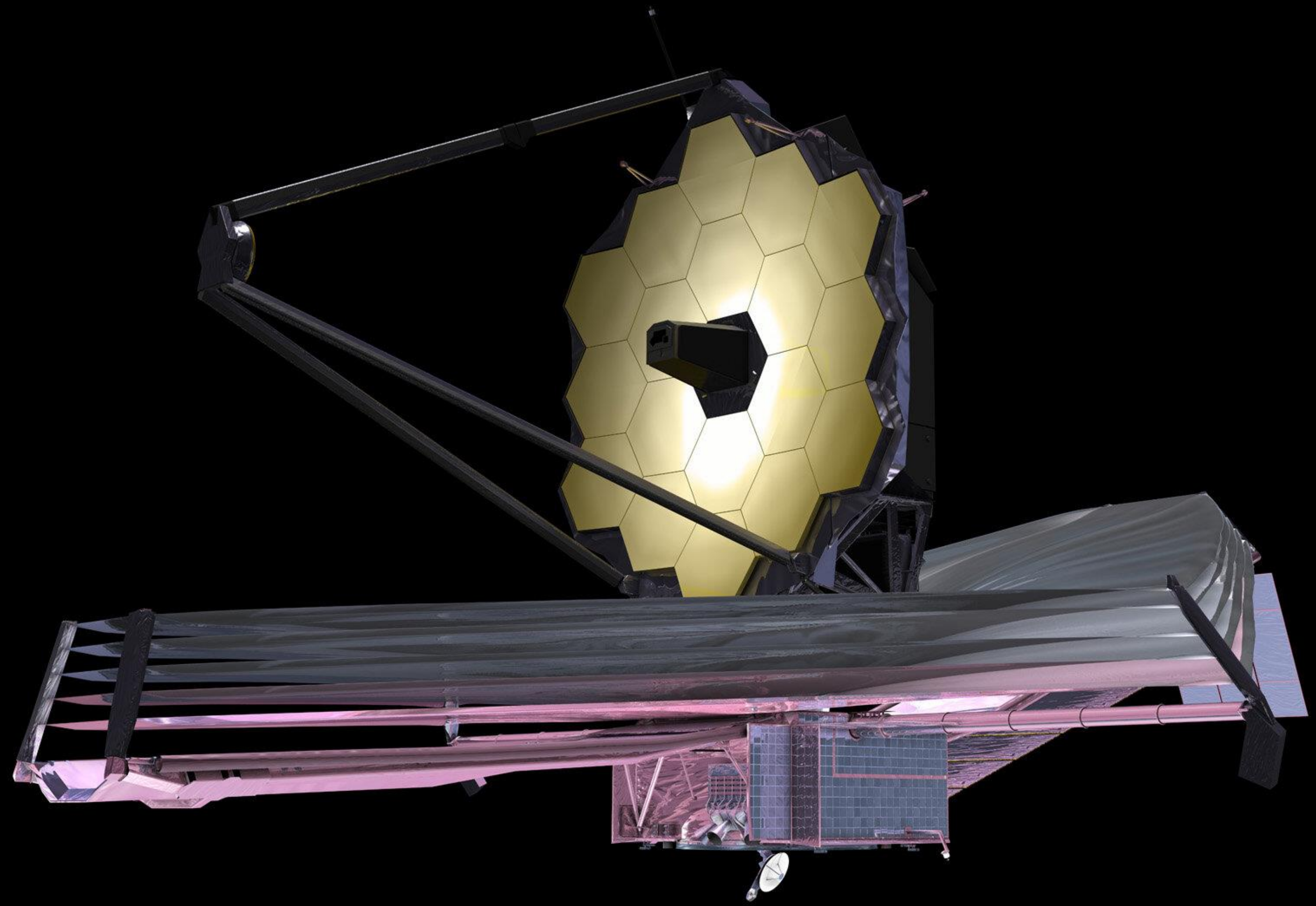

4MOST, 4m



MegaMapper, 6.5m

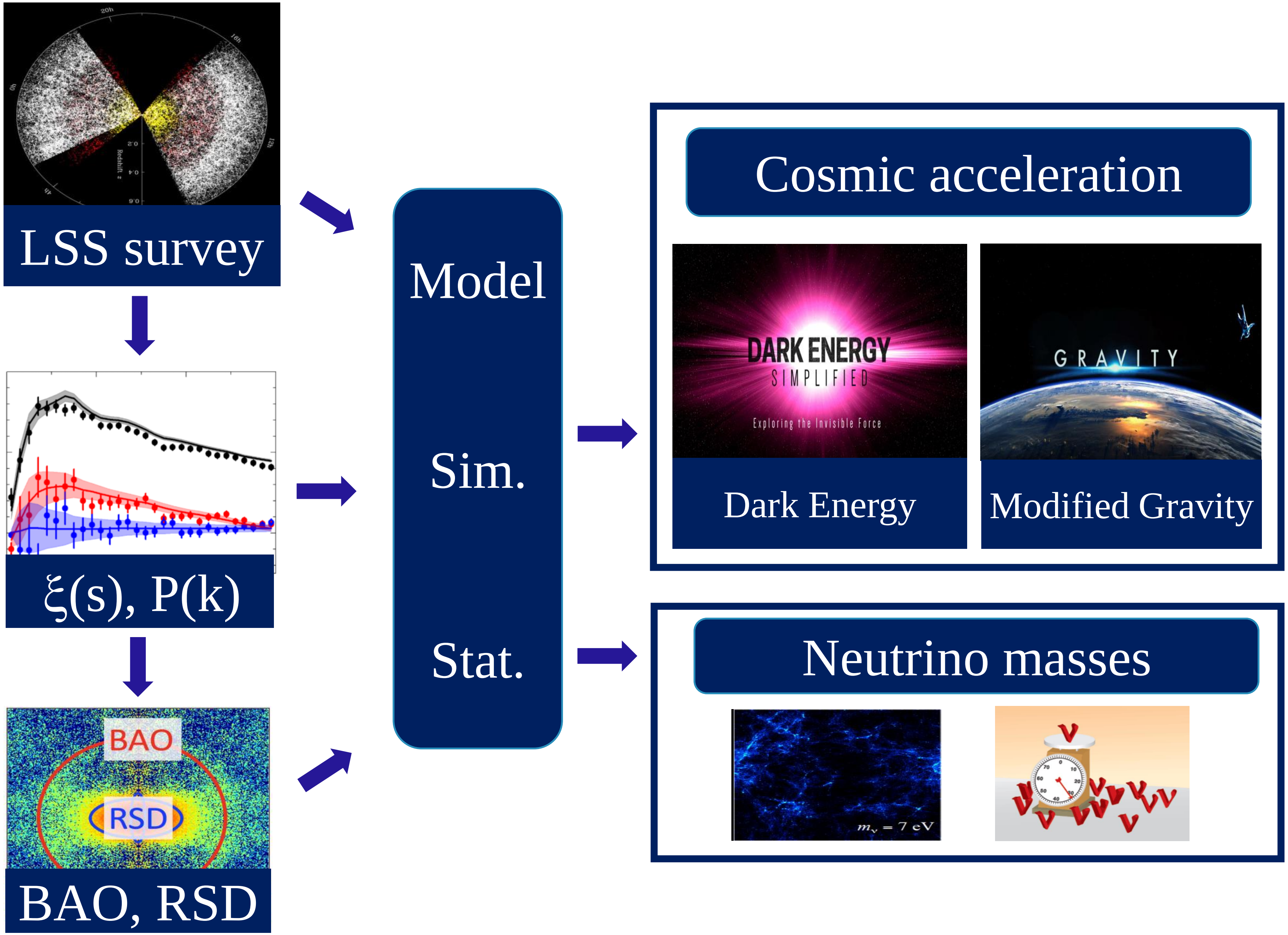
WST, 10+m

CSST

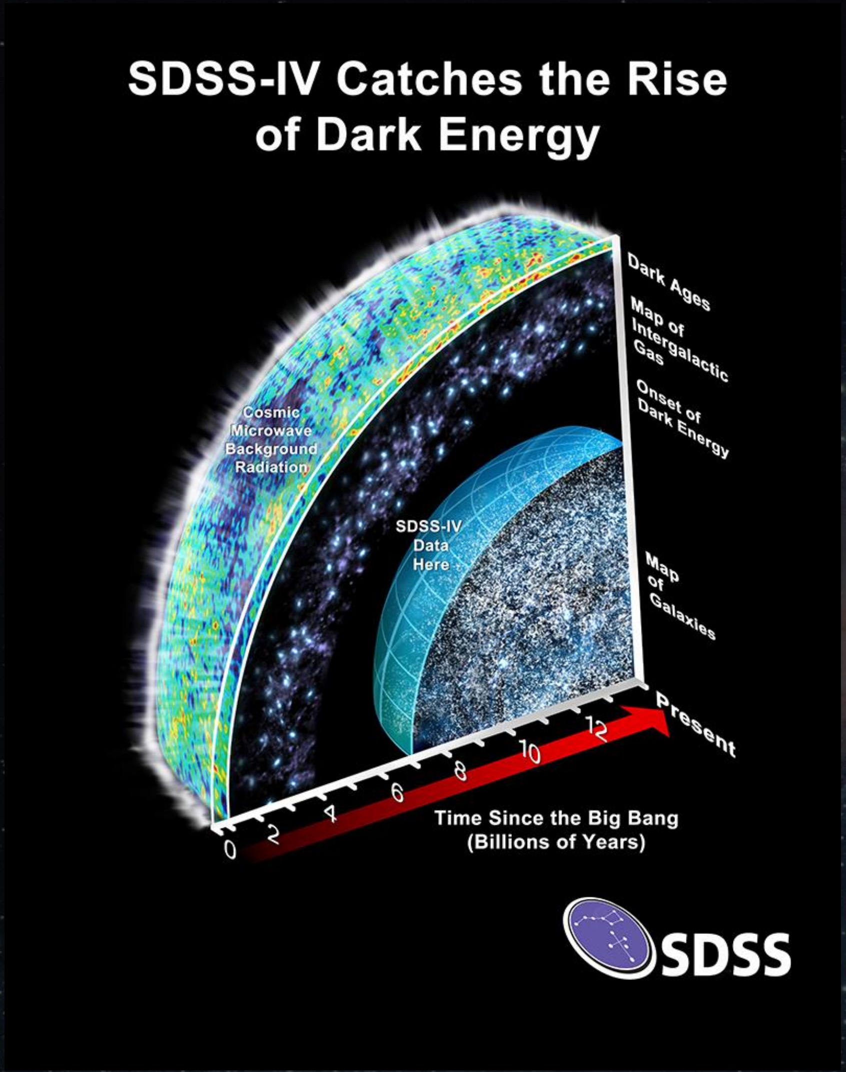


**280 m in space!!**

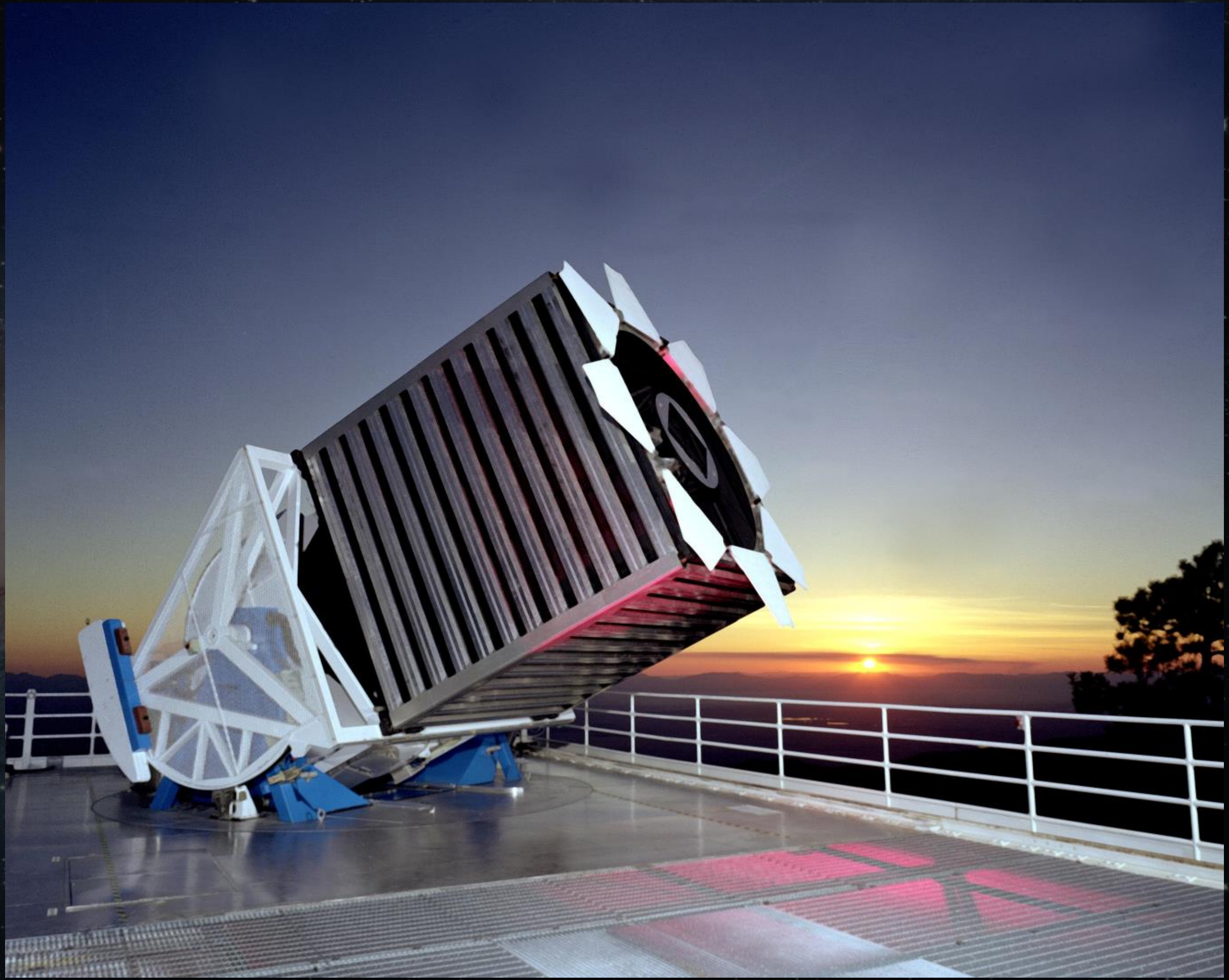
**arXiv: 2010.06064**


LSS survey
ξ(s), P(k)
BAO
RSD
BAO, RSD
Model
Sim.
Stat.
Cosmic acceleration
DARK ENERGY
SIMPLIFIED
Exploring the Invisible Force
GRAVITY
Dark Energy
Modified Gravity
Neutrino masses
$m_\nu = 7$ eV

NAOC 中国科学院国家天文台
NATIONAL ASTRONOMICAL OBSERVATORIES, CHINESE ACADEMY OF SCIENCES




eBOSS (2014-2020)



2.5 m SDSS telescope @ New Mexico

# eBOSS result released on July 20, 2020 in 20+ papers

SDSS

Data Surveys Instruments Collaboration Science

Search www

## No need to Mind the Gap: Astrophysicists fill in 11 billion years of our universe’s expansion history

July 19, 2020

The Sloan Digital Sky Survey (SDSS) released today a comprehensive analysis of the largest three-dimensional map of the Universe ever created, filling in the most significant gaps in our possible exploration of its history.

sdss.org

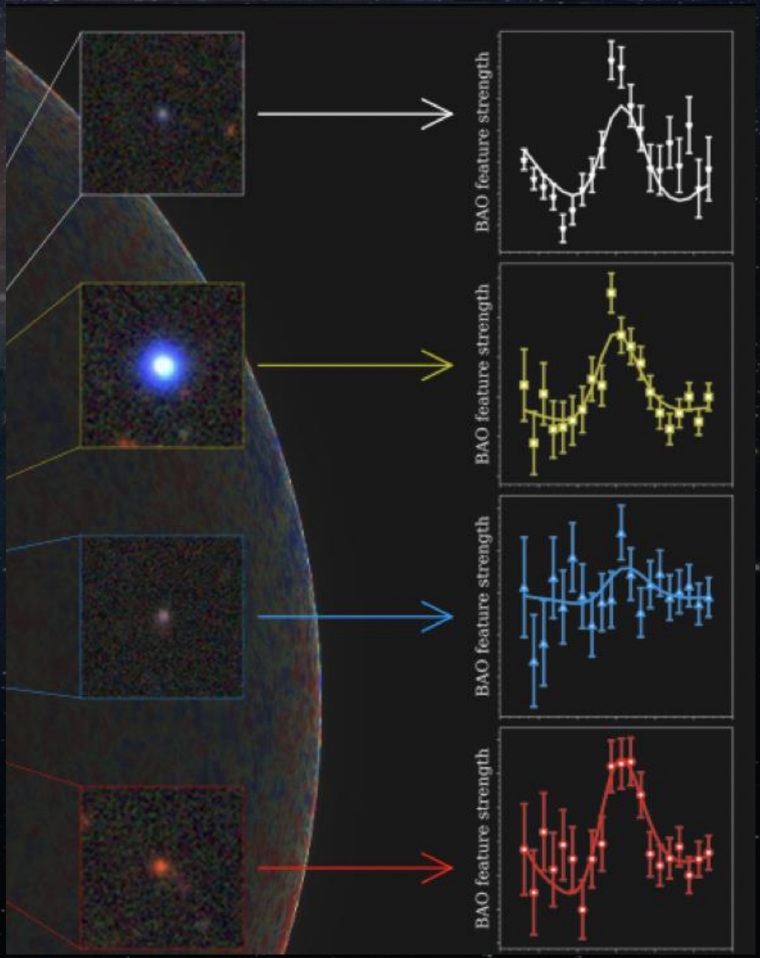
# eBOSS tracers

Lyman-a forest

Clustering quasars

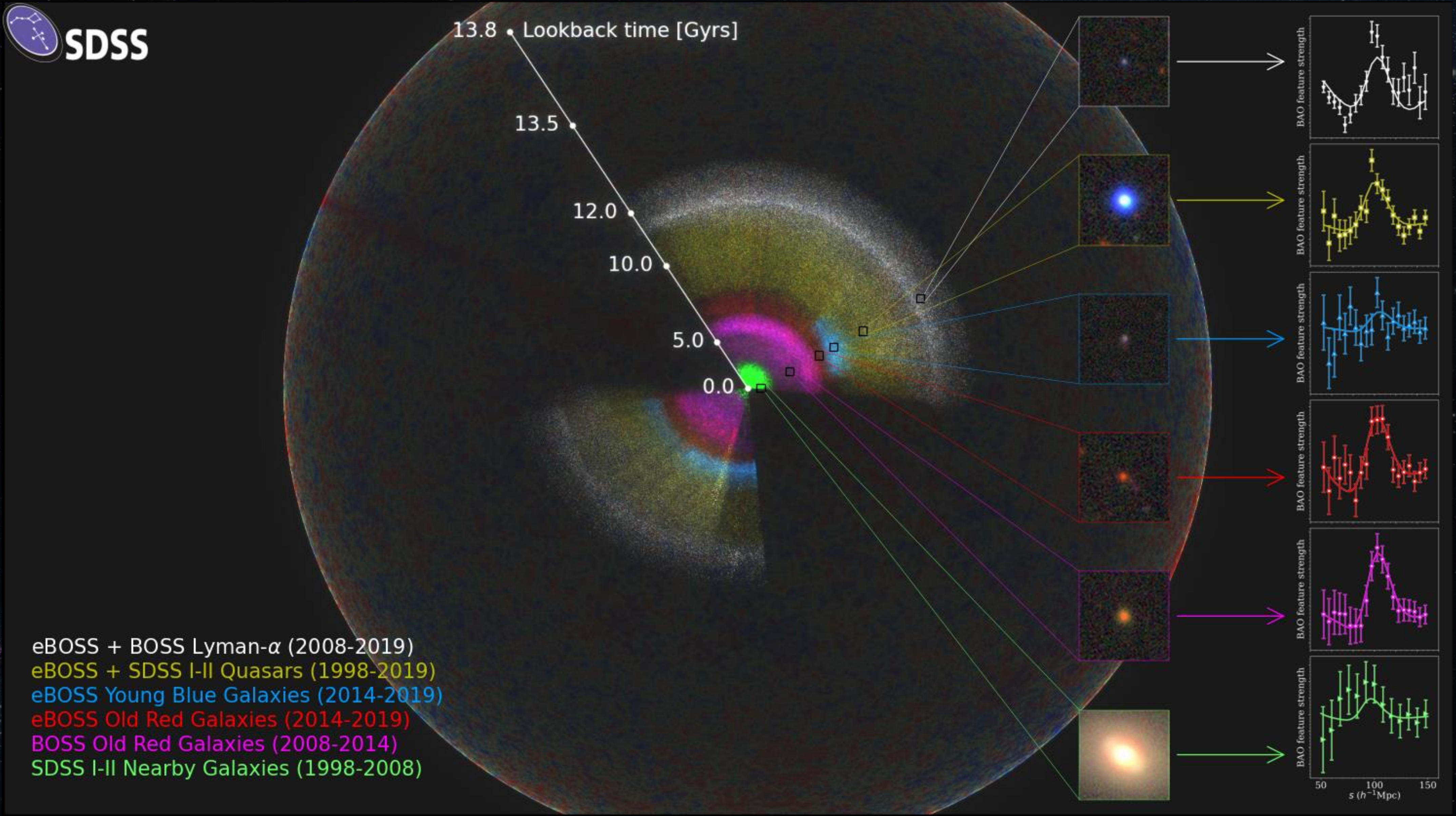
Emission Line Galaxies (ELGs)

Luminous Red Galaxies (LRGs)

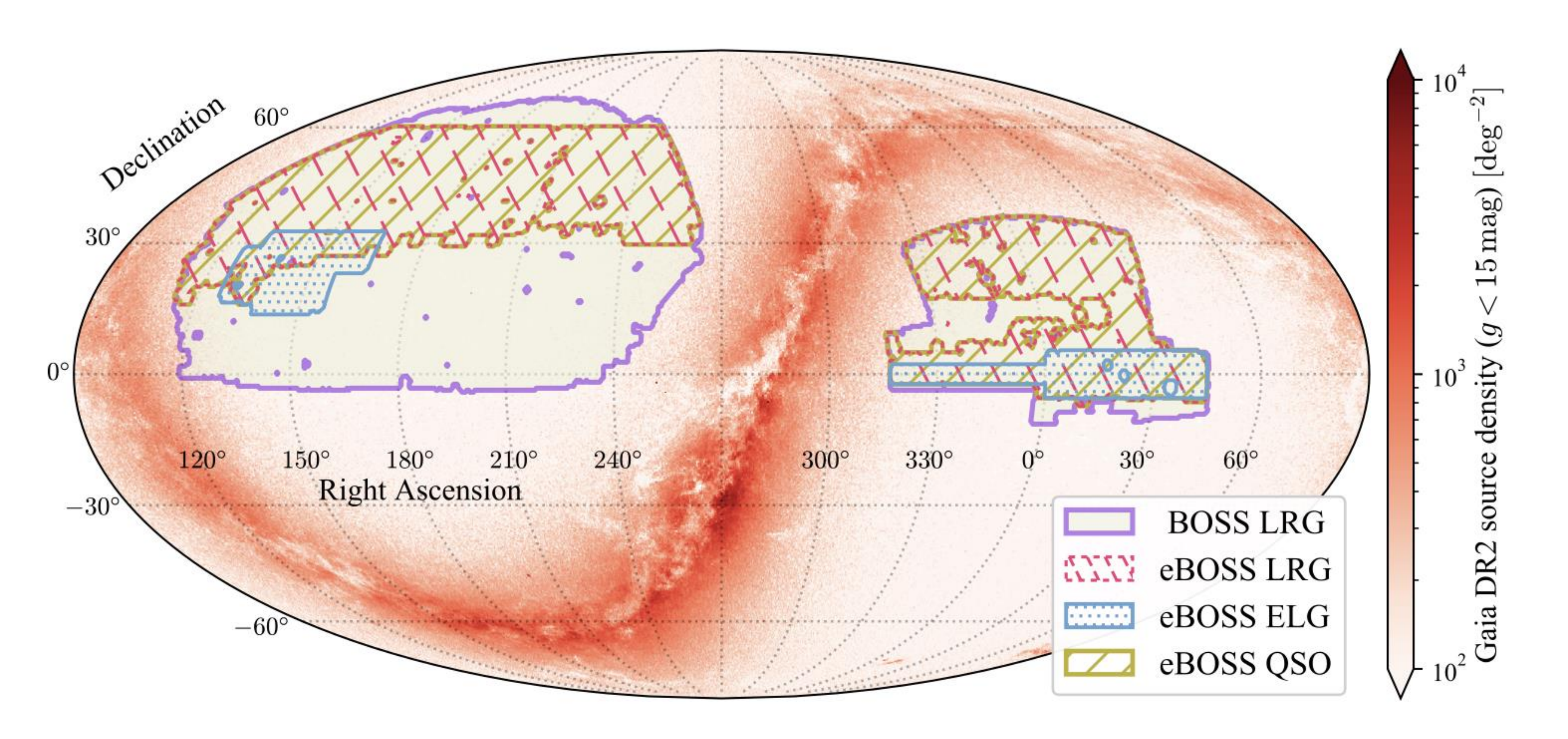


- **ELG (k-space): De Mattia et al, 2007.09008**
- **ELG (s-space): Tamone et al, 2007.09009**
- **LRG (k-space): Gil-Marin et al, 2007.08994**
- **LRG (s-space): Bautista et al, 2007.08993**
- **ELG x LRG (k-space): G-B. Zhao et al, 2007.09011**
- **ELG x LRG (s-space): Y. Wang et al, 2007.09010**

中国科学院国家天文台
NATIONAL ASTRONOMICAL OBSERVATORIES, CHINESE ACADEMY OF SCIENCES



# eBOSS footprint




C. Zhao+, 2020

中国科学院国家天文台
NATIONAL ASTRONOMICAL OBSERVATORIES, CHINESE ACADEMY OF SCIENCES

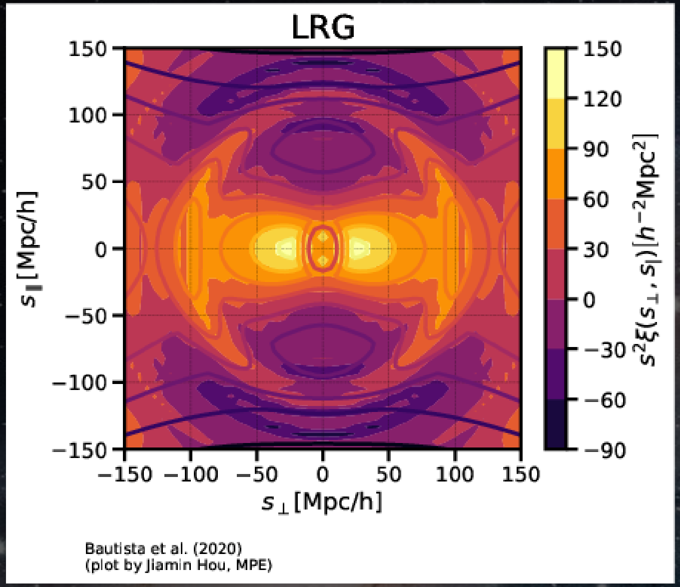
# Luminous Red Galaxies (LRGs)

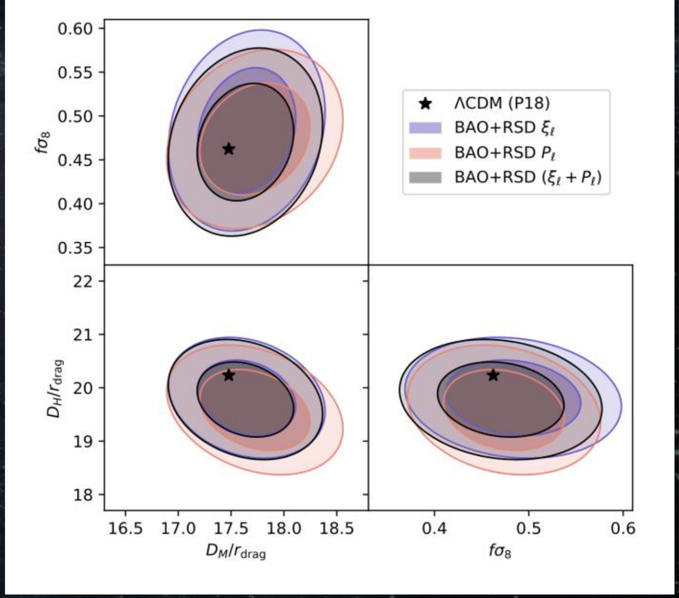
**$0.6 < z < 1.0$, $z_{eff} = 0.77$**

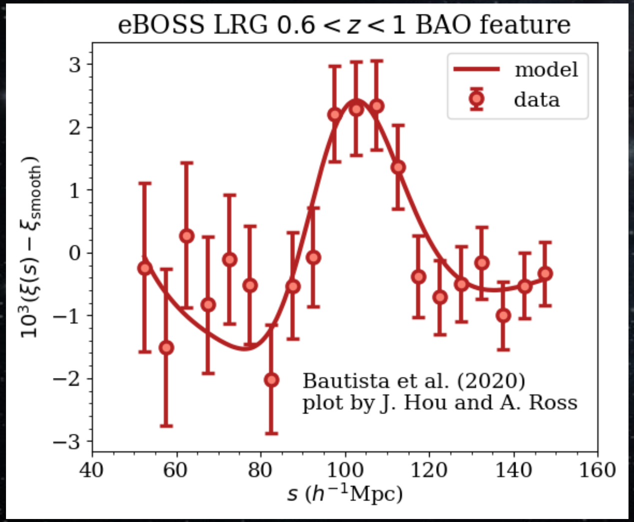
**~9500 $deg^2$**

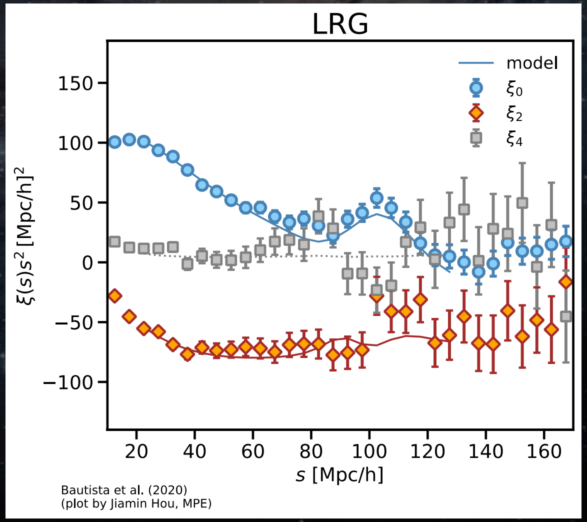
**~400 K spectra**

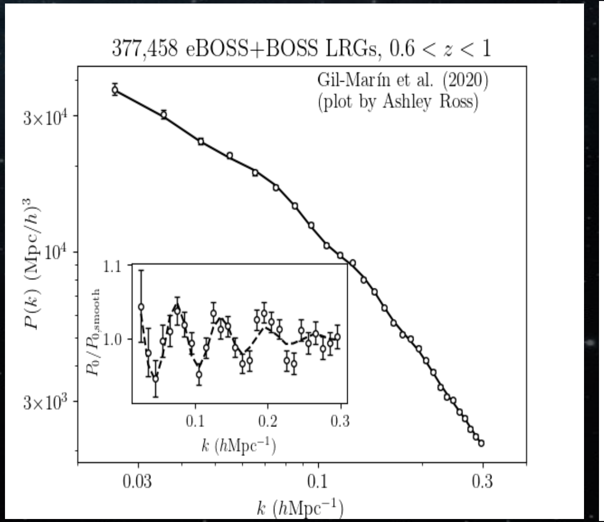
Bautista+, 2020; Gil-Marin+, 2020

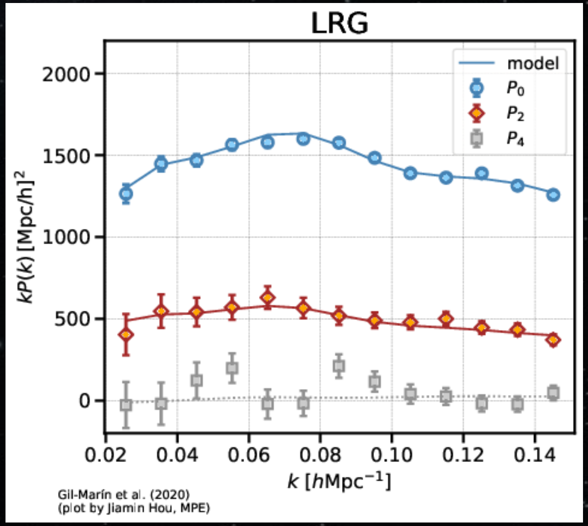


中国科学院国家天文台
NATIONAL ASTRONOMICAL OBSERVATORIES, CHINESE ACADEMY OF SCIENCES

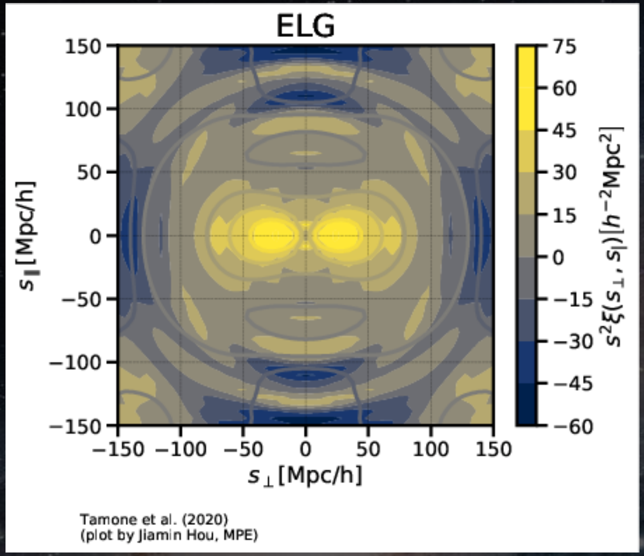
# Emission line Galaxies (ELGs)

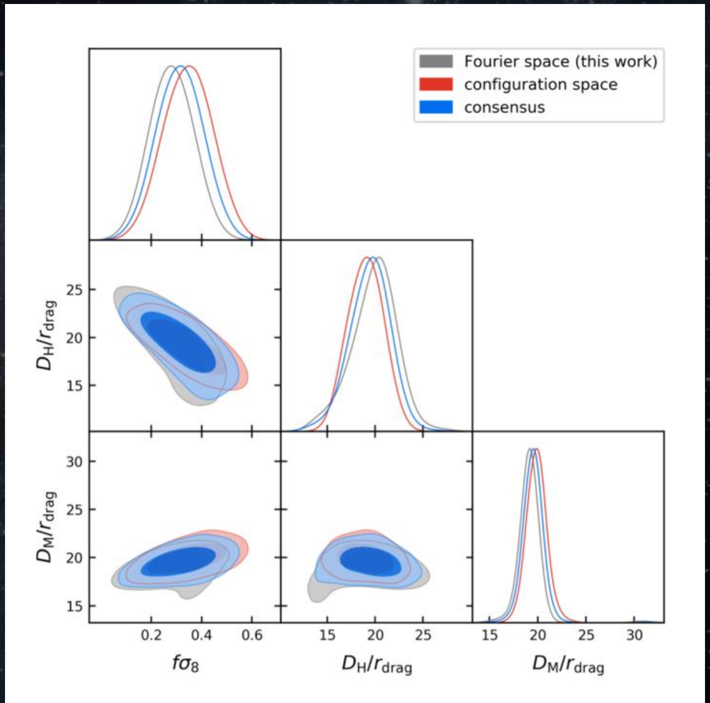
**$0.6 < z < 1.1$, $z_{eff} = 0.845$**

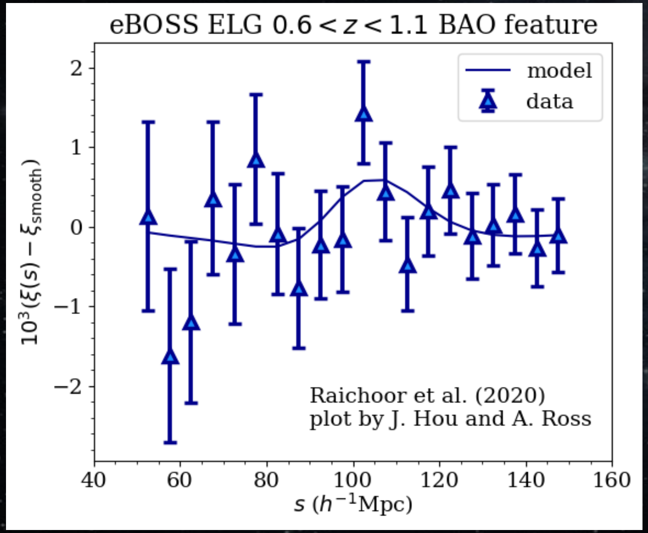
**~730 deg$^2$**

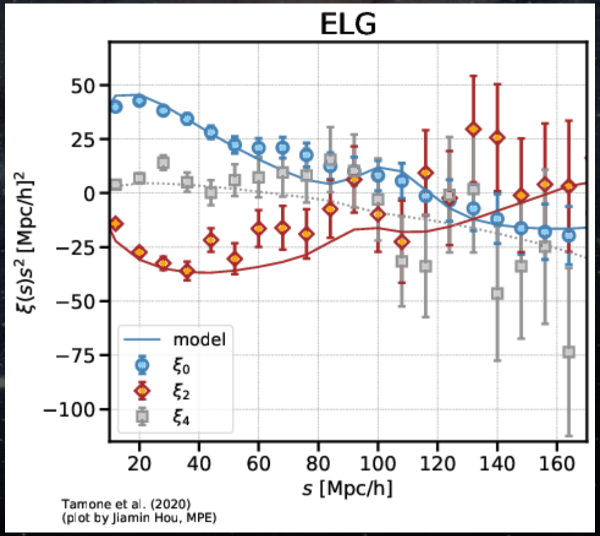
**~170 K spectra**

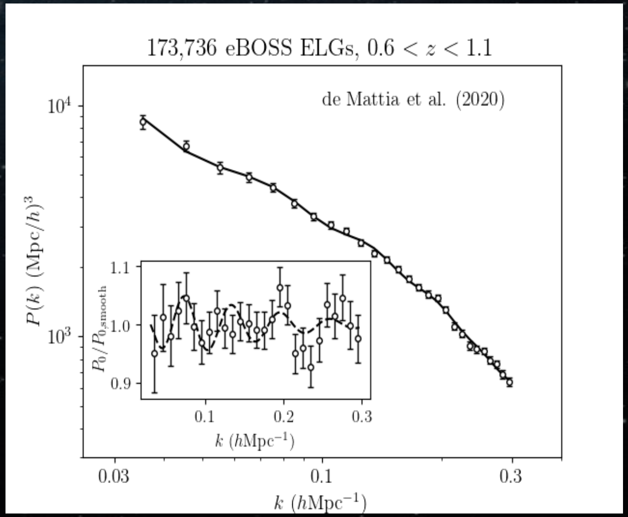
de Mattia+, 2020; Tamone+, 2020

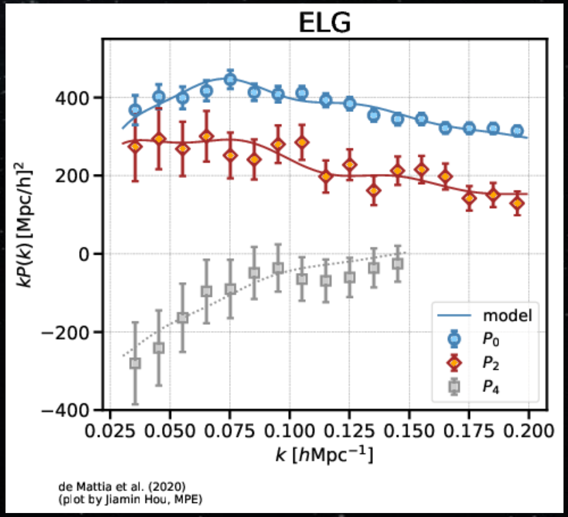


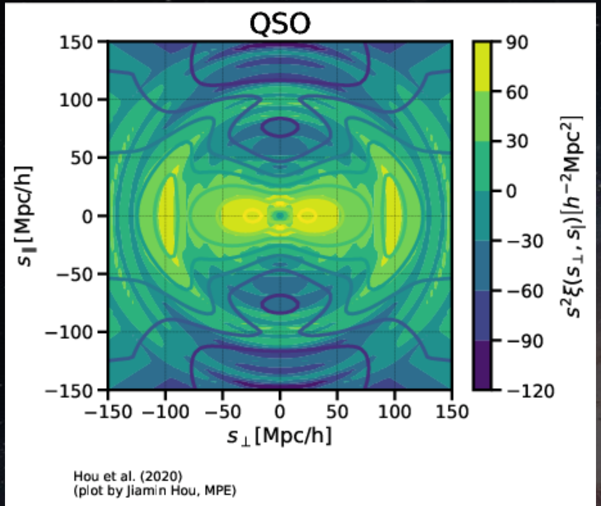
**Clustering quasars (QSOs)**

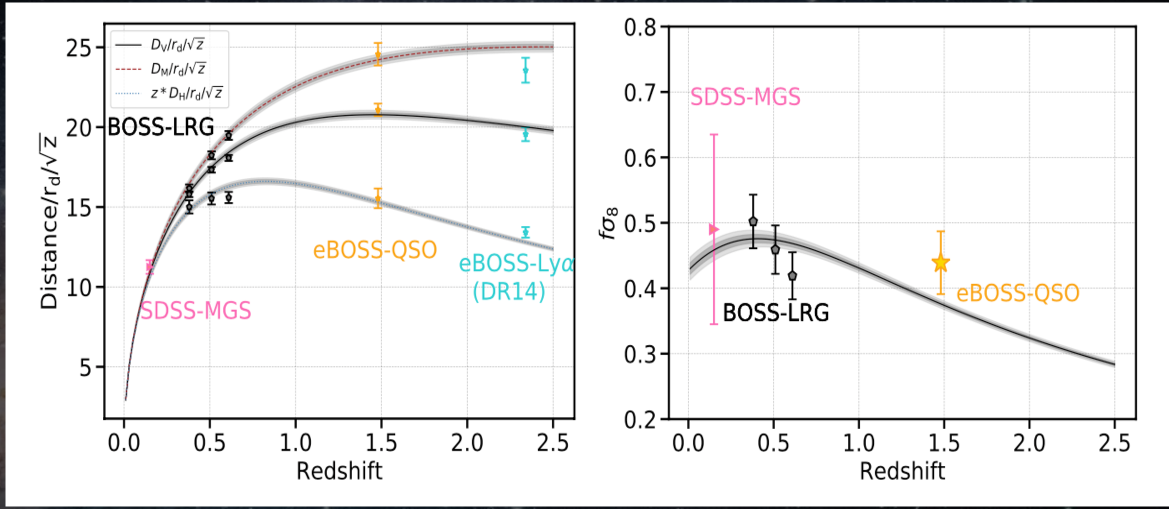
**$0.8 < z < 2.2$, $z_{eff} = 1.48$**

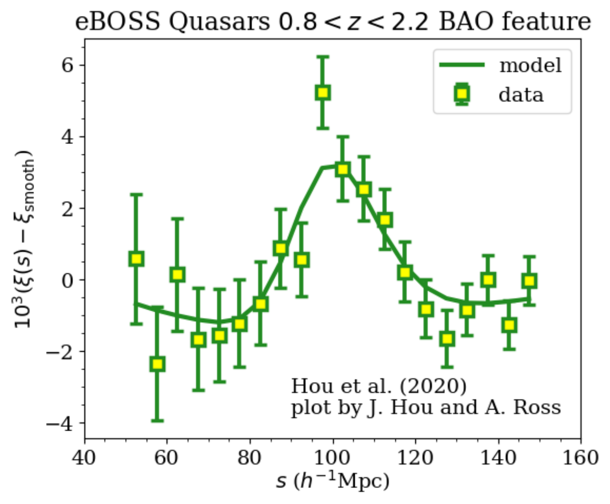
**~4700 deg$^2$**

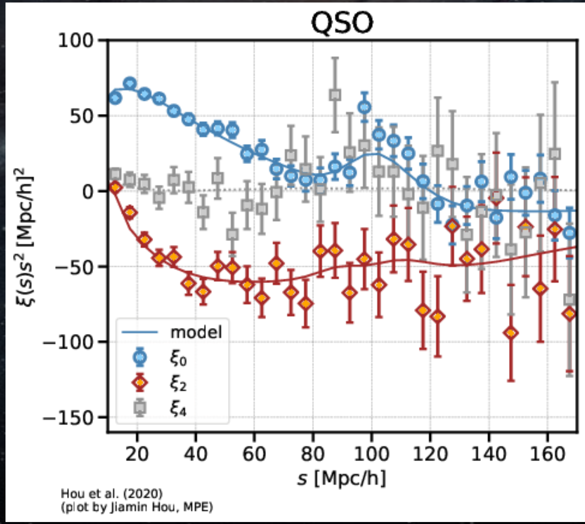
**~340 K spectra**

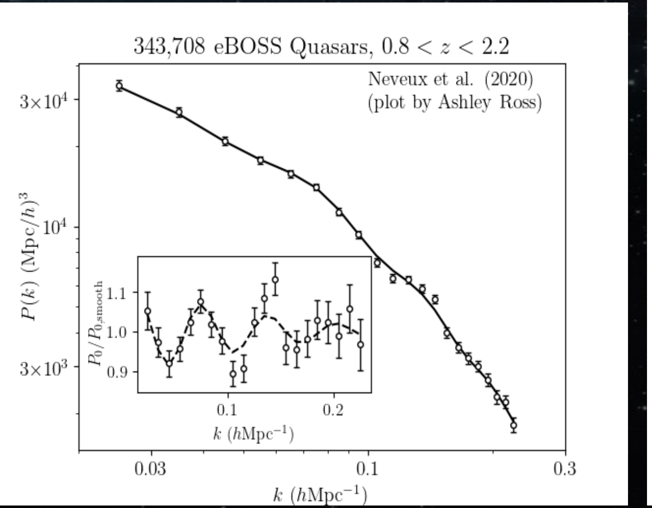
Hou+, 2020; Neveux+, 2020

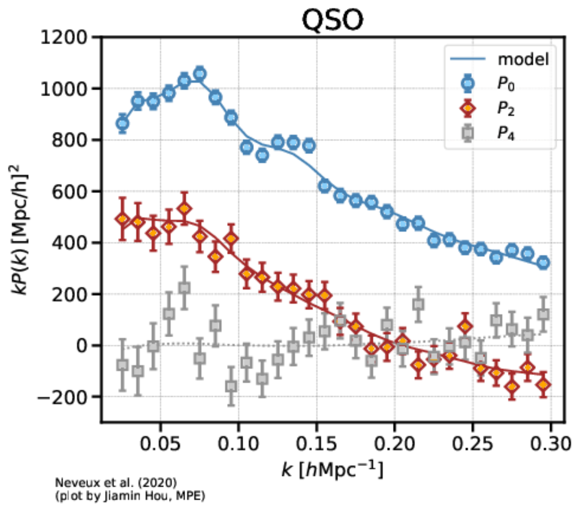


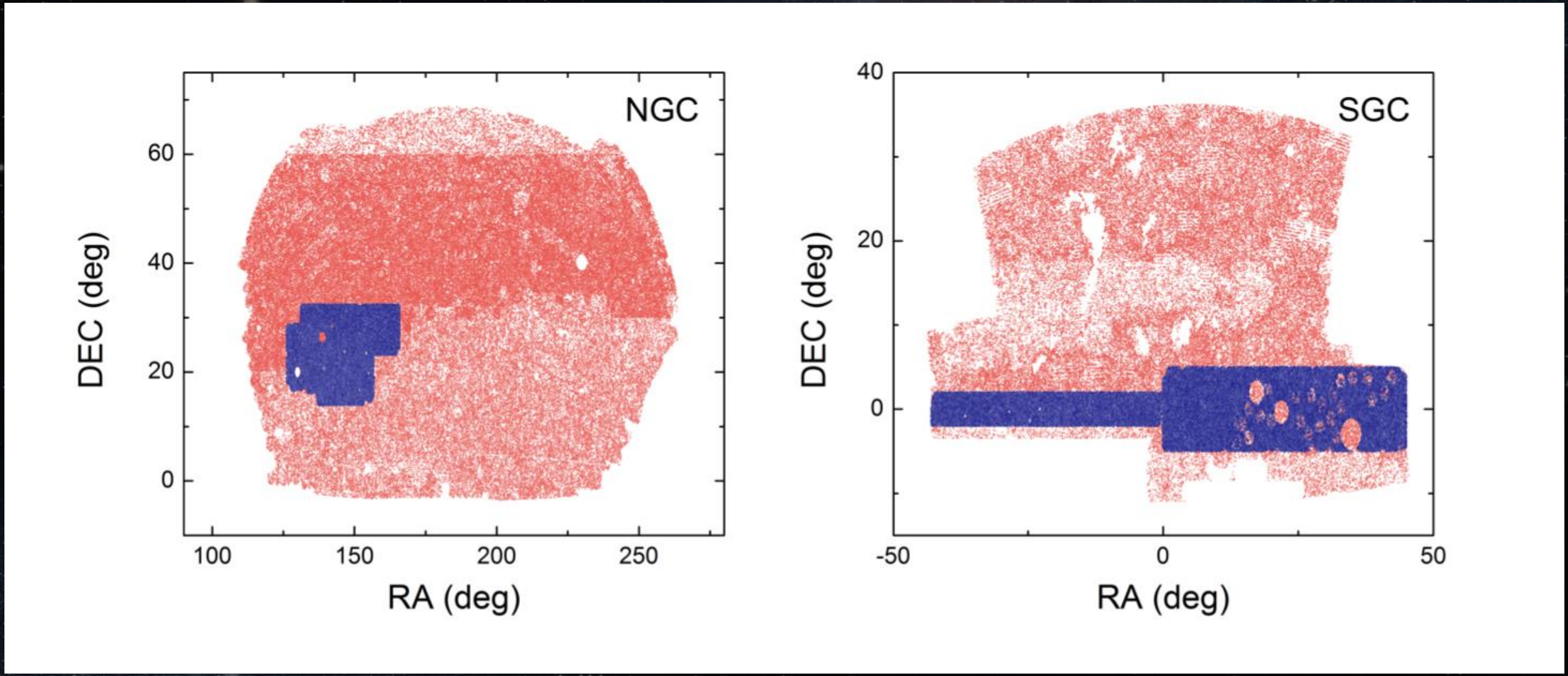



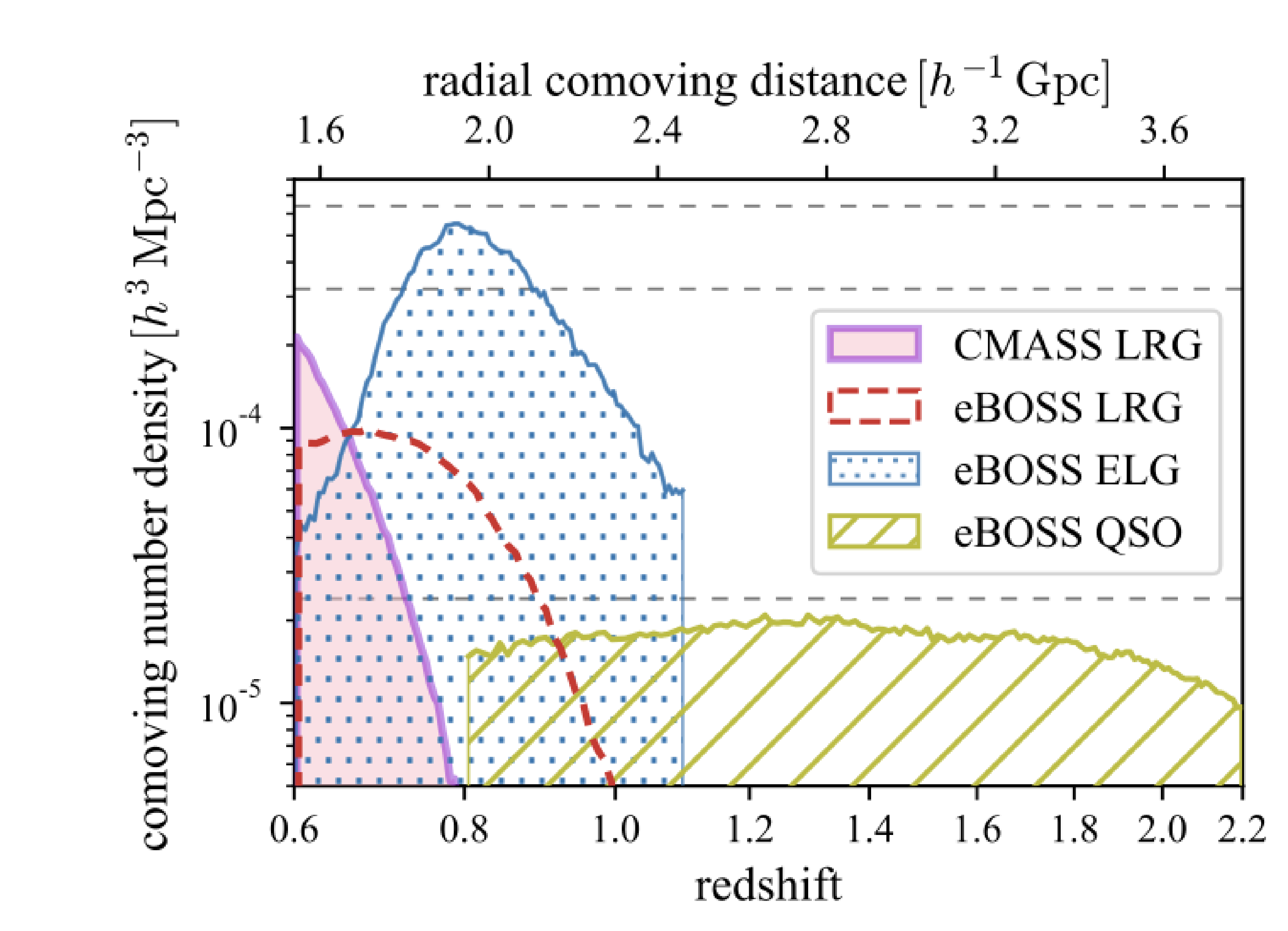



# Angular overlap




GBZ+, 2020

# Radial overlap



# Why cross-correlation is cool?

- It can remove the cosmic variance, thus reduce the statistical uncertainty!

1-tracer: $\delta_{g1} = (b_1 + f\mu^2)\delta + \epsilon_1 = f\left(\beta^{-1} + \mu^2\right)\delta + \epsilon_1$

$$C = 2\langle \delta_{g1}^2 \rangle \quad \frac{\sigma_\beta^2}{\beta^2} = \frac{(1+\beta)^2}{\beta^2}$$

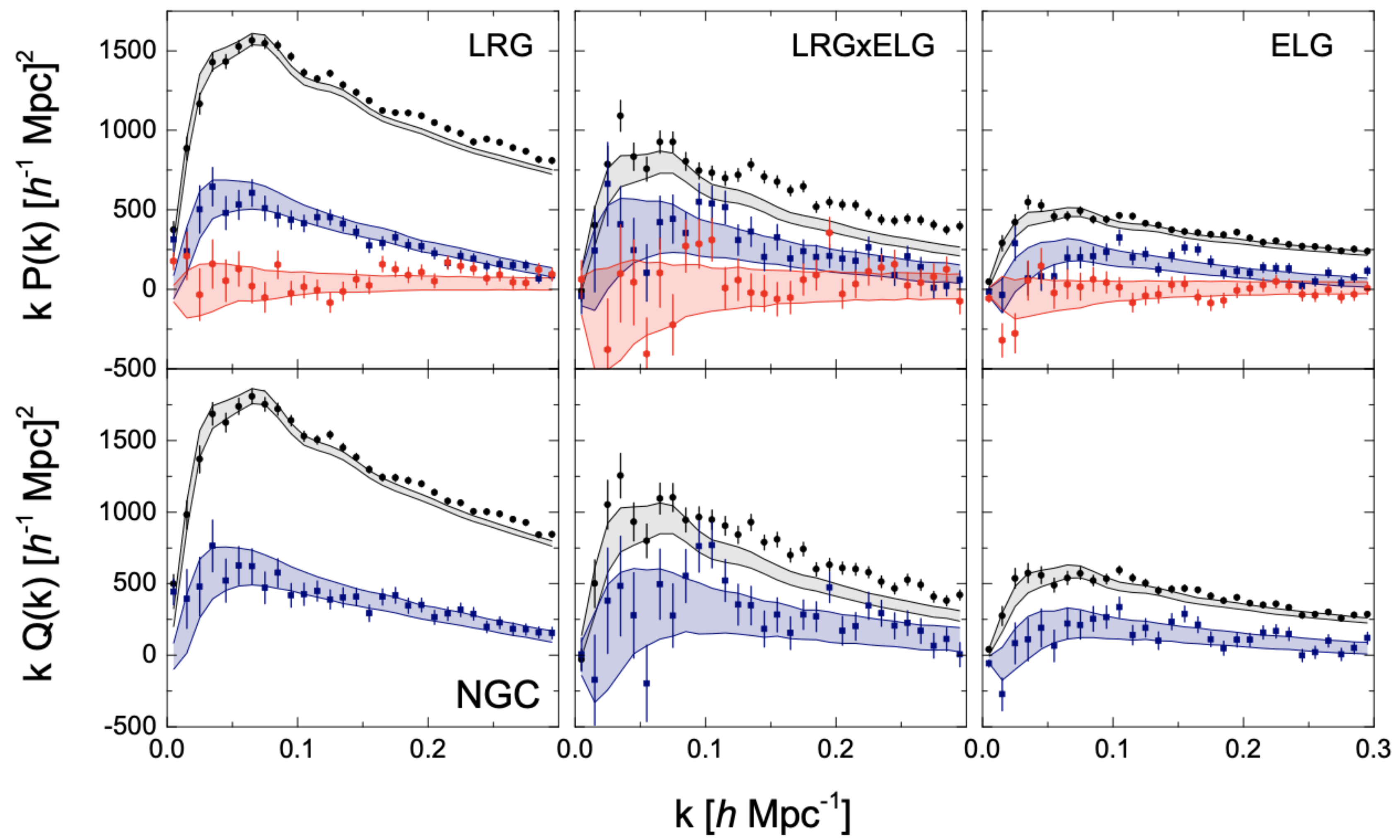
2-tracers: $\delta_{g1} = f\left(\beta^{-1} + \mu^2\right)\delta + \epsilon_1 \quad \delta_{g2} = f\left(\alpha\beta^{-1} + \mu^2\right)\delta + \epsilon_2$

$$C \equiv \begin{bmatrix} \langle \delta_{g1}^2 \rangle & \langle \delta_{g1}\delta_{g2} \rangle \\ \langle \delta_{g2}\delta_{g1} \rangle & \langle \delta_{g2}^2 \rangle \end{bmatrix} = \frac{P_{\theta\theta}}{2} \begin{bmatrix} \left(\beta^{-1} + \mu^2\right)^2 & \left(\beta^{-1} + \mu^2\right)\left(\alpha\beta^{-1} + \mu^2\right) \\ \left(\beta^{-1} + \mu^2\right)\left(\alpha\beta^{-1} + \mu^2\right) & \left(\alpha\beta^{-1} + \mu^2\right)^2 \end{bmatrix} + \frac{N}{2}$$

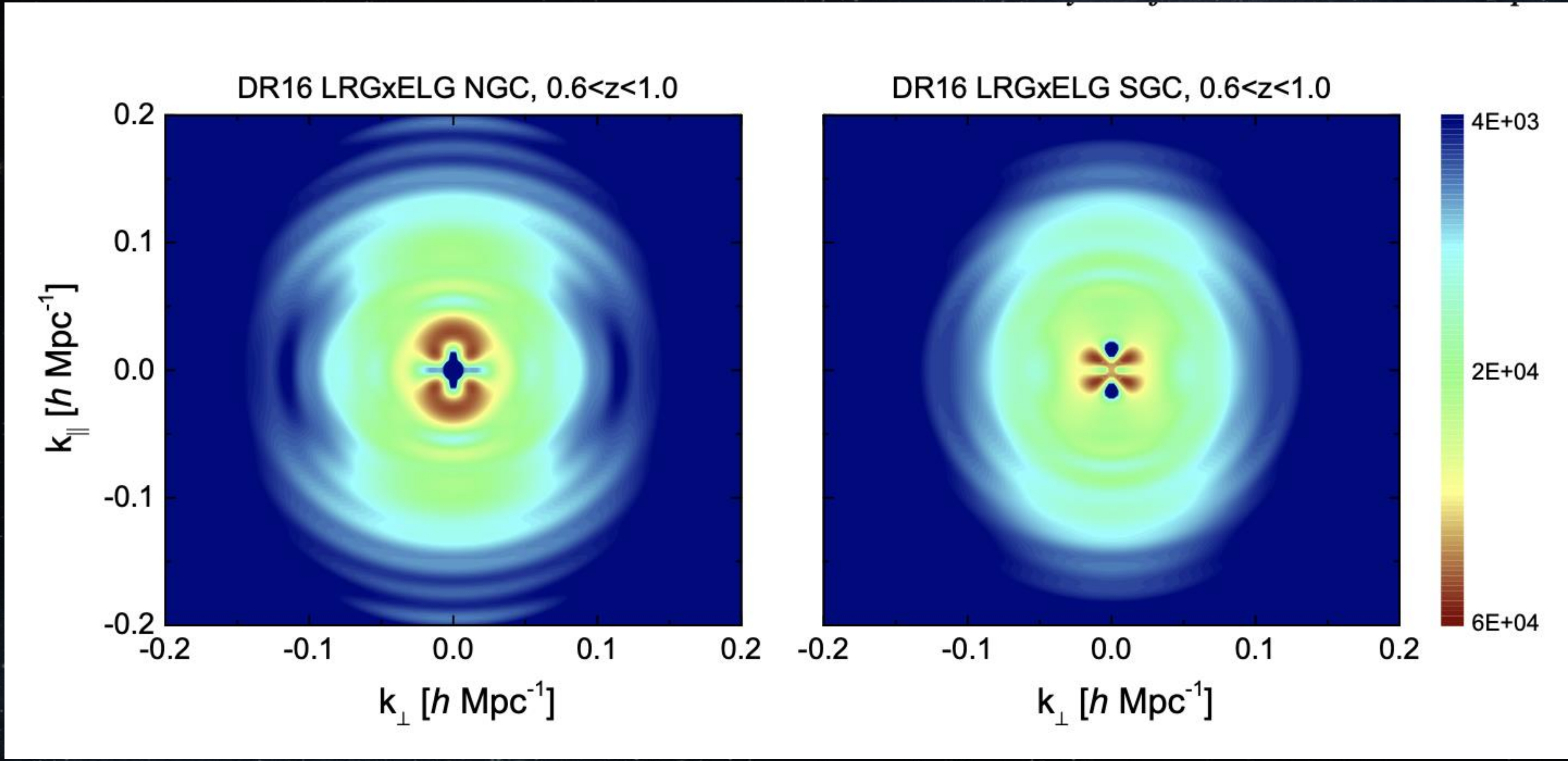
$$\frac{\delta_{g2}}{\delta_{g1}} = \frac{\alpha\beta^{-1} + \mu^2}{\beta^{-1} + \mu^2}.$$

McDonald & Seljak 2008; Seljak 2009

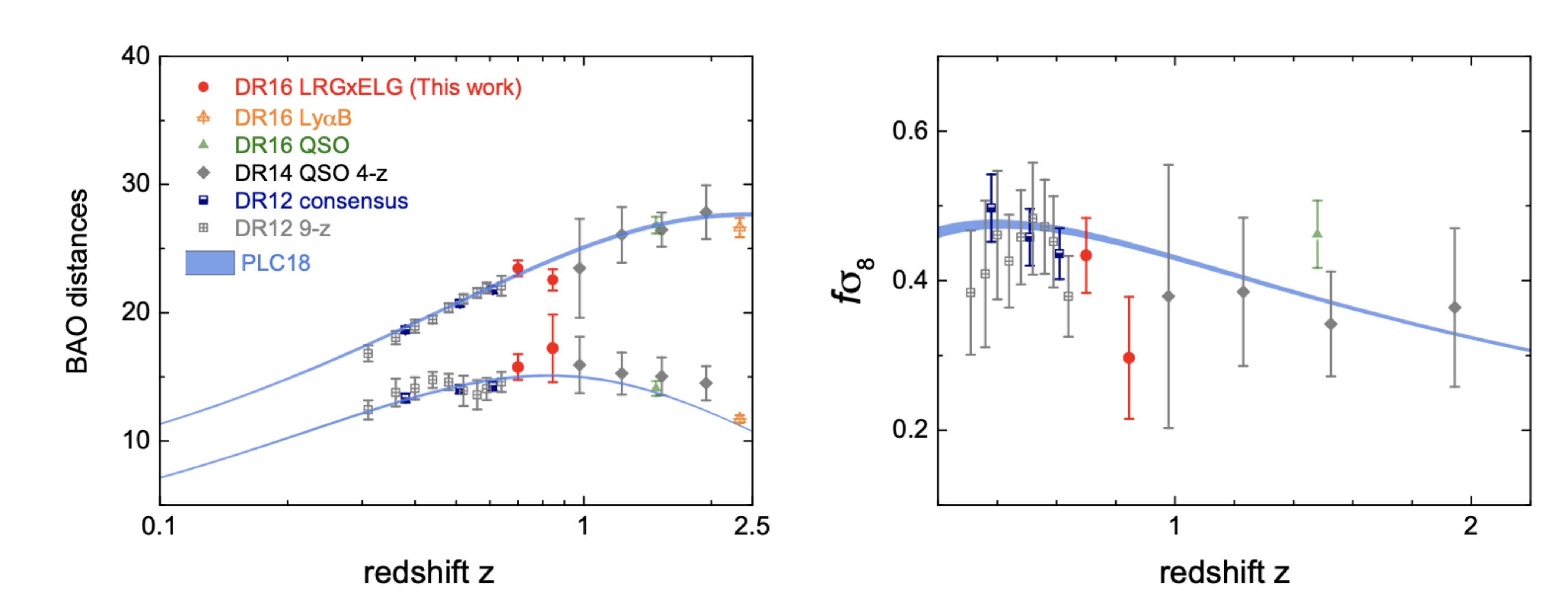
- It can reduce the systematics, as the photometry used for observing different tracers are usually uncorrelated!


LRG
LRGxELG
ELG
NGC
k P(k) [h^-1 Mpc]^2
k Q(k) [h^-1 Mpc]^2
k [h Mpc^-1]
1500
1000
500
0
-500
0.0
0.1
0.2
0.3

GBZ+, 2020

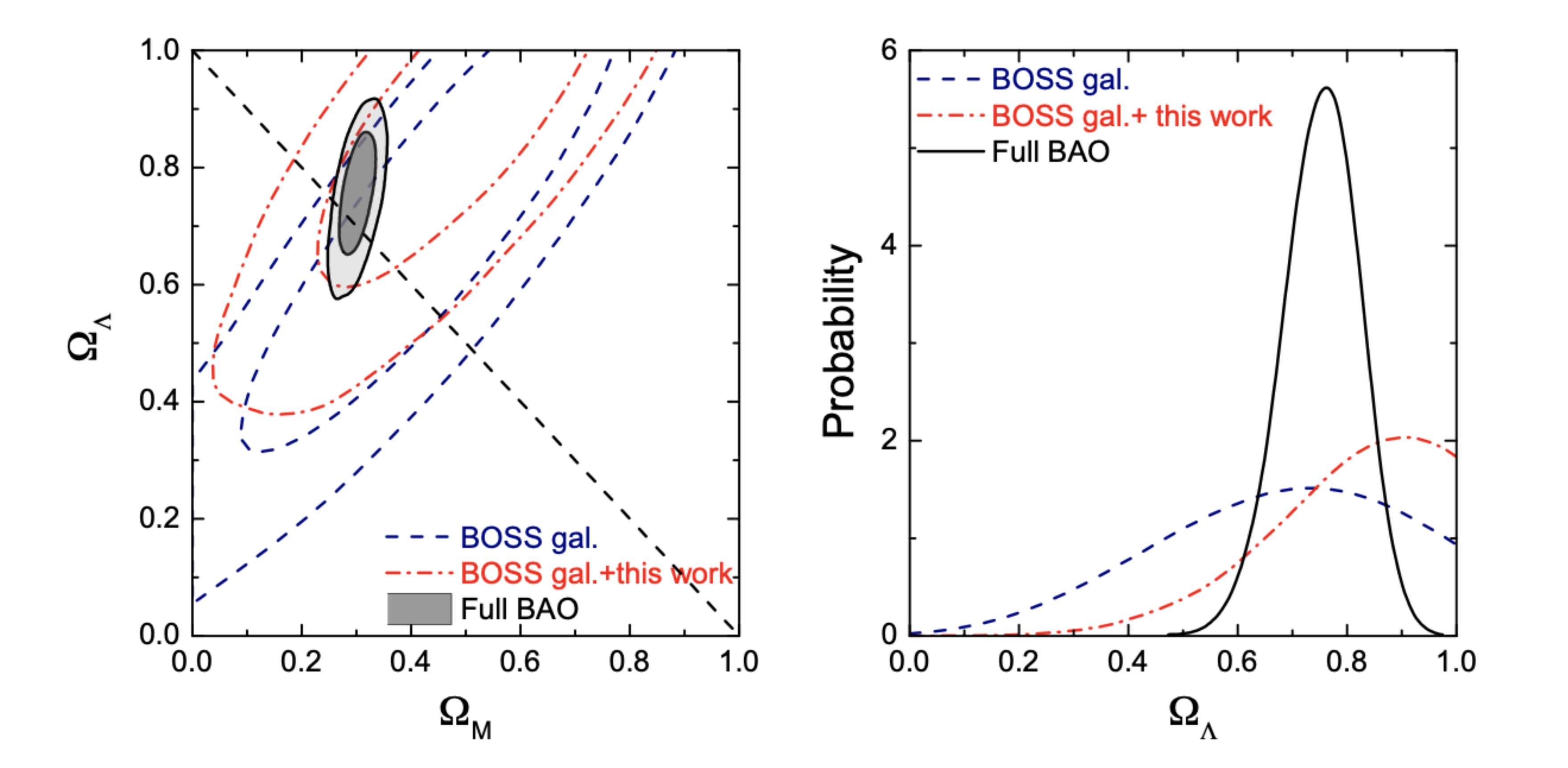

DR16 LRGxELG NGC, 0.6<z<1.0
DR16 LRGxELG SGC, 0.6<z<1.0
$k_{\parallel}$ [$h$ Mpc$^{-1}$]
$k_{\perp}$ [$h$ Mpc$^{-1}$]
0.2
0.1
0.0
-0.1
-0.2
4E+03
2E+04
6E+04

GBZ+, 2020


DR16 LRGxELG (This work)
DR16 LyαB
DR16 QSO
DR14 QSO 4-z
DR12 consensus
DR12 9-z
PLC18
BAO distances
redshift z
40
30
20
10
0.1
1
2.5
fσ8
0.6
0.4
0.2
1
2
redshift z

GBZ+, 2020

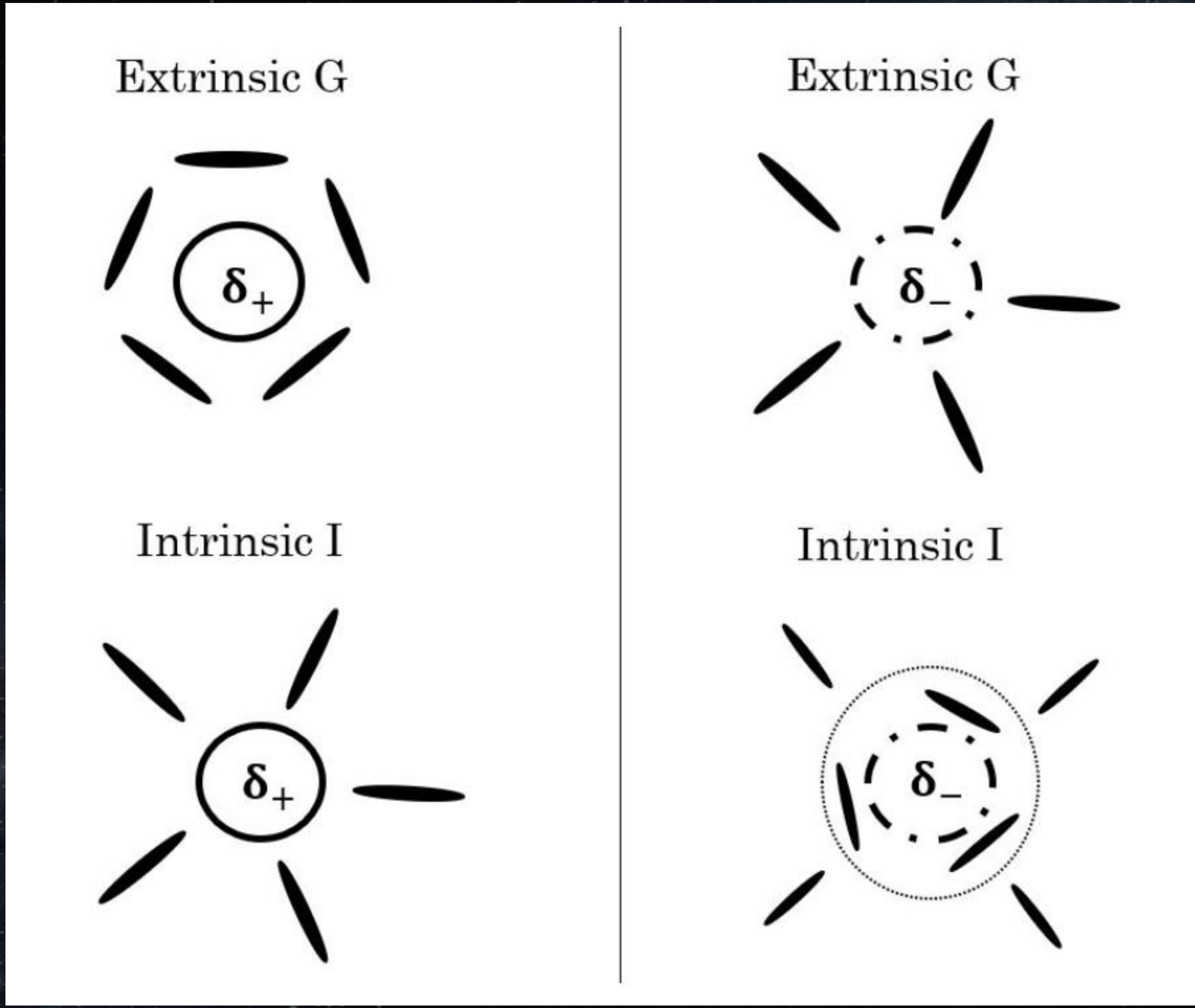
中国科学院国家天文台
NATIONAL ASTRONOMICAL OBSERVATORIES, CHINESE ACADEMY OF SCIENCES




A $11\sigma$ detection of $\Omega_\Lambda > 0$

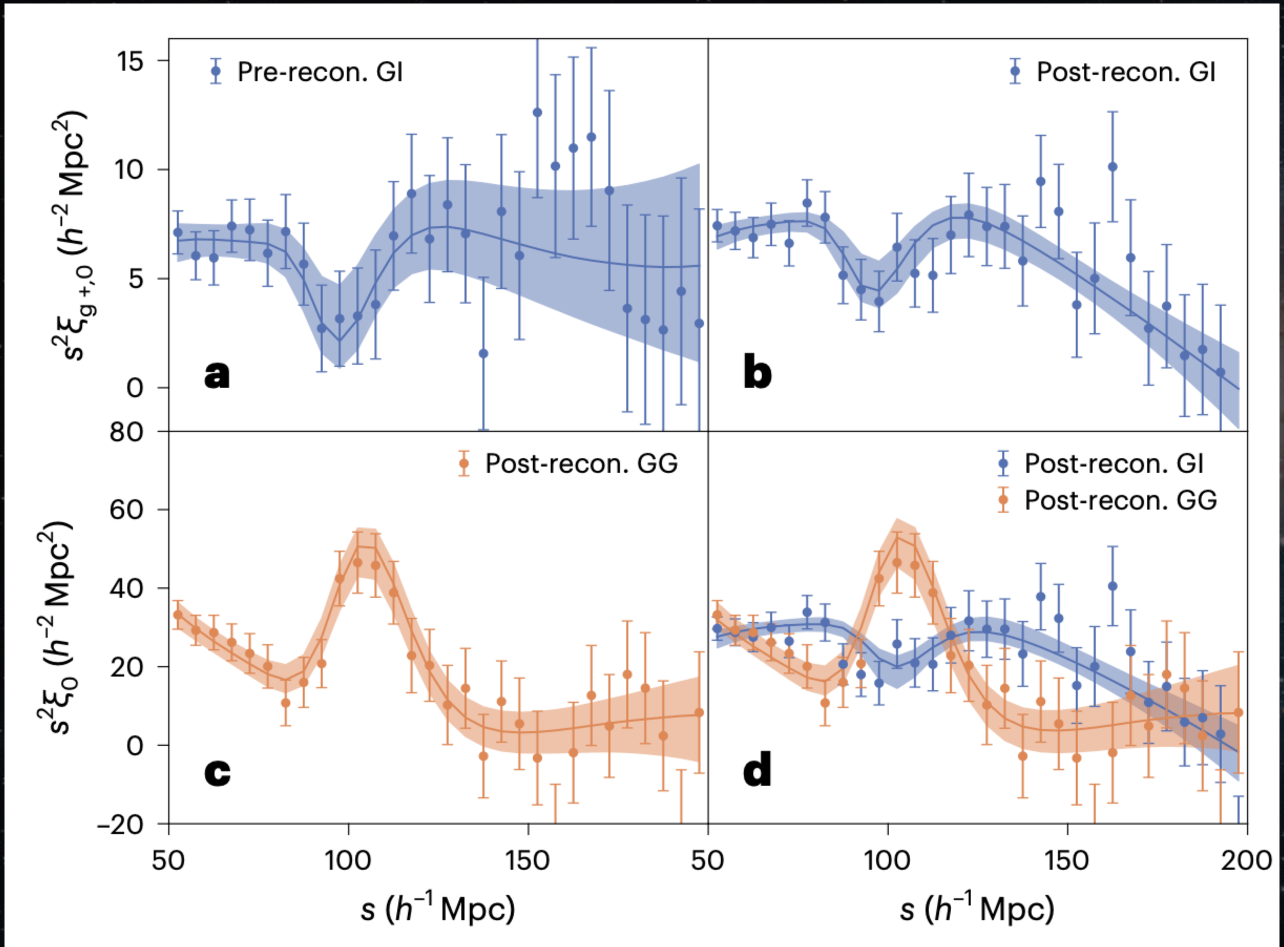
**Zhao**, Wang et al, (eBOSS), 2007.09011

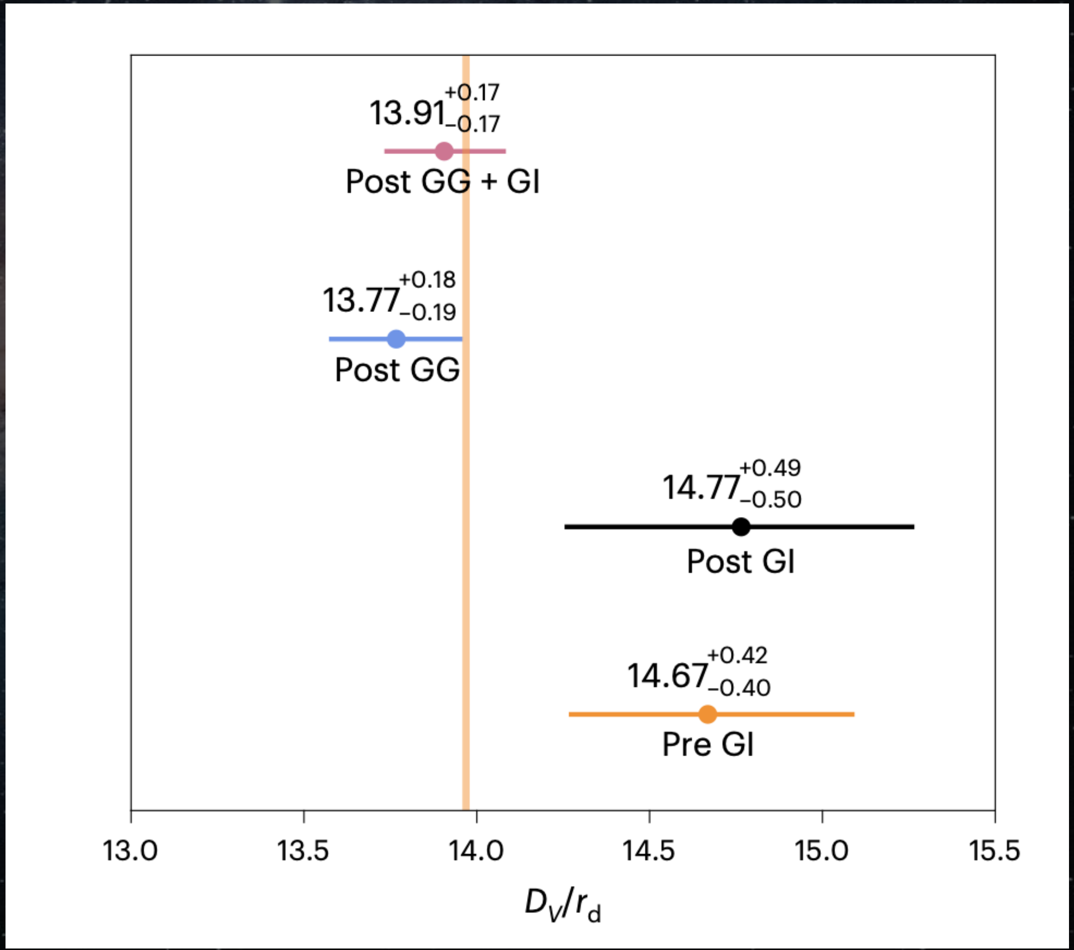
# A first detection of BAO from galaxy-ellipticity correlations




d'Assignies D. et al. 2021

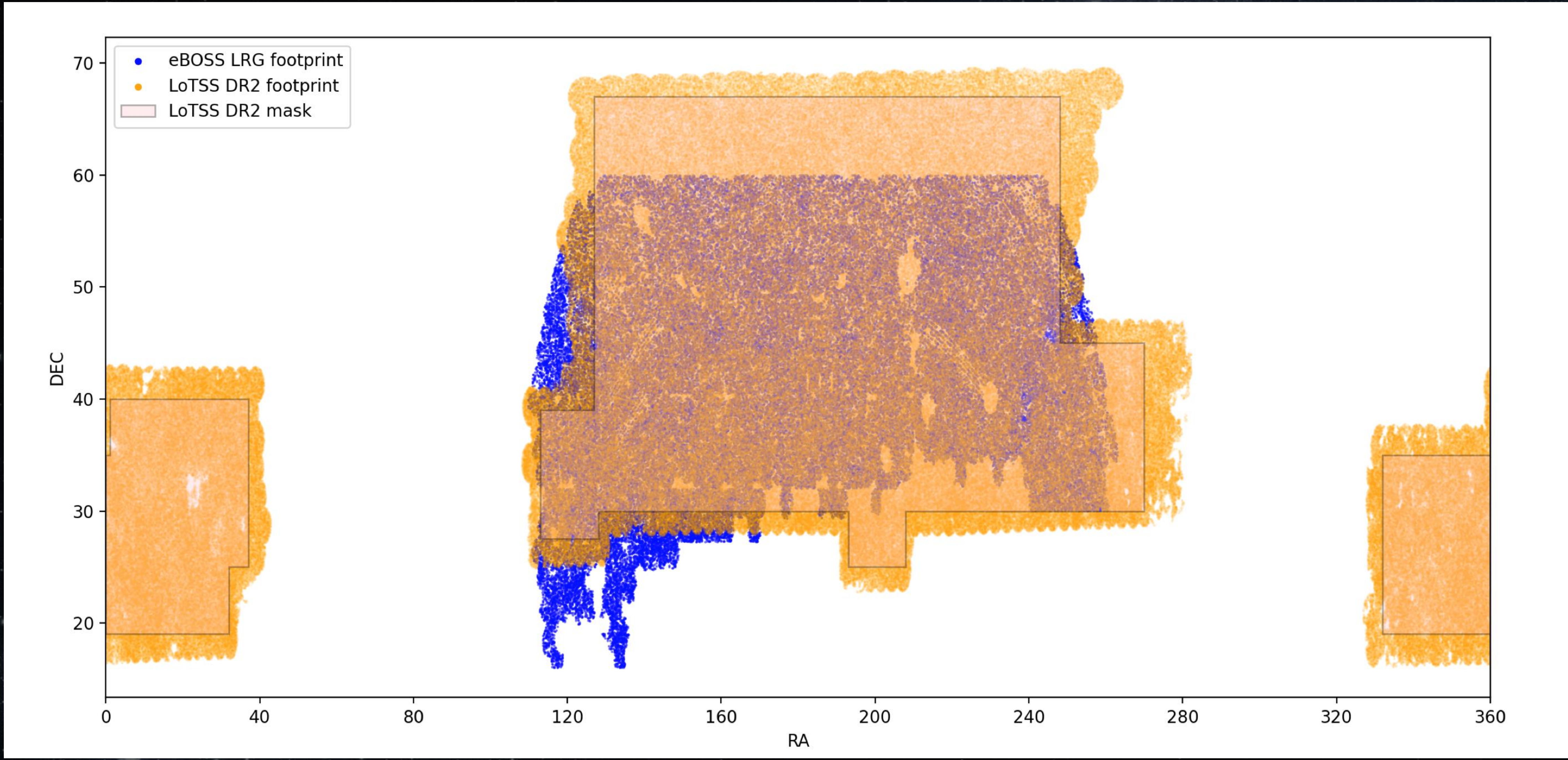
中国科学院国家天文台
NATIONAL ASTRONOMICAL OBSERVATORIES, CHINESE ACADEMY OF SCIENCES



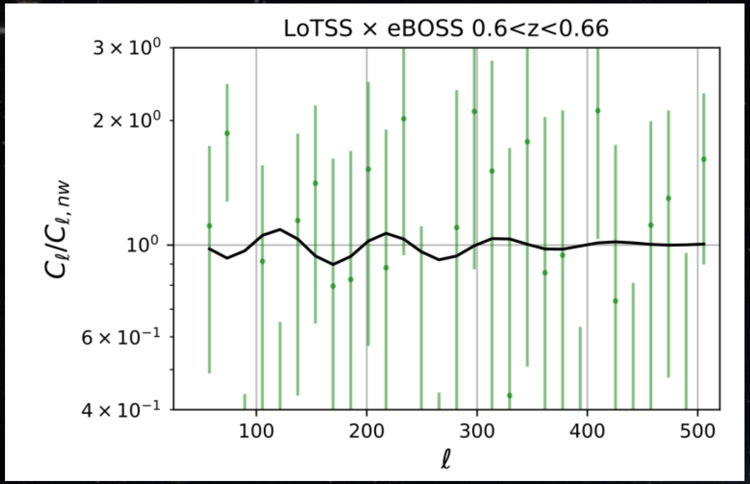



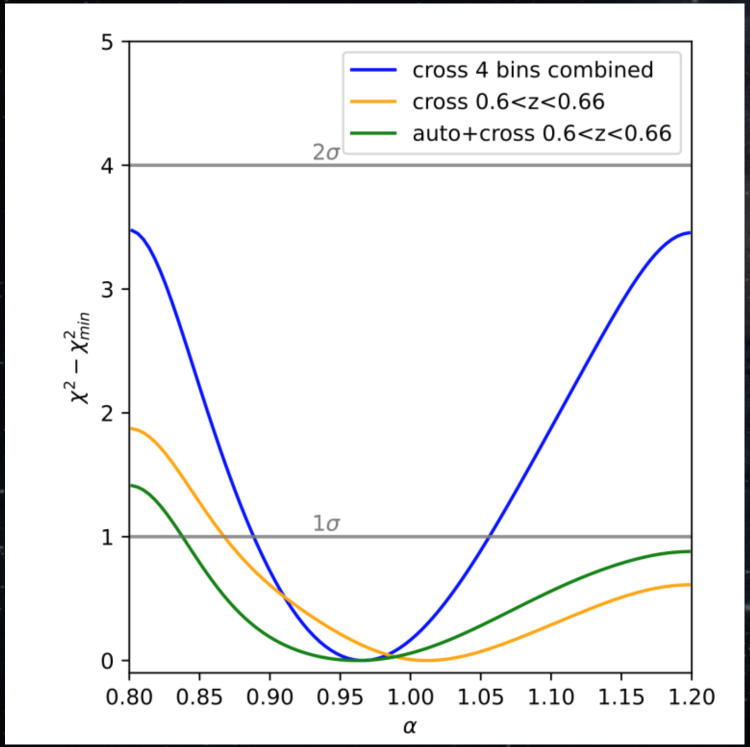

Xu, Jing, GBZ et al, Nature Astronomy (2023)

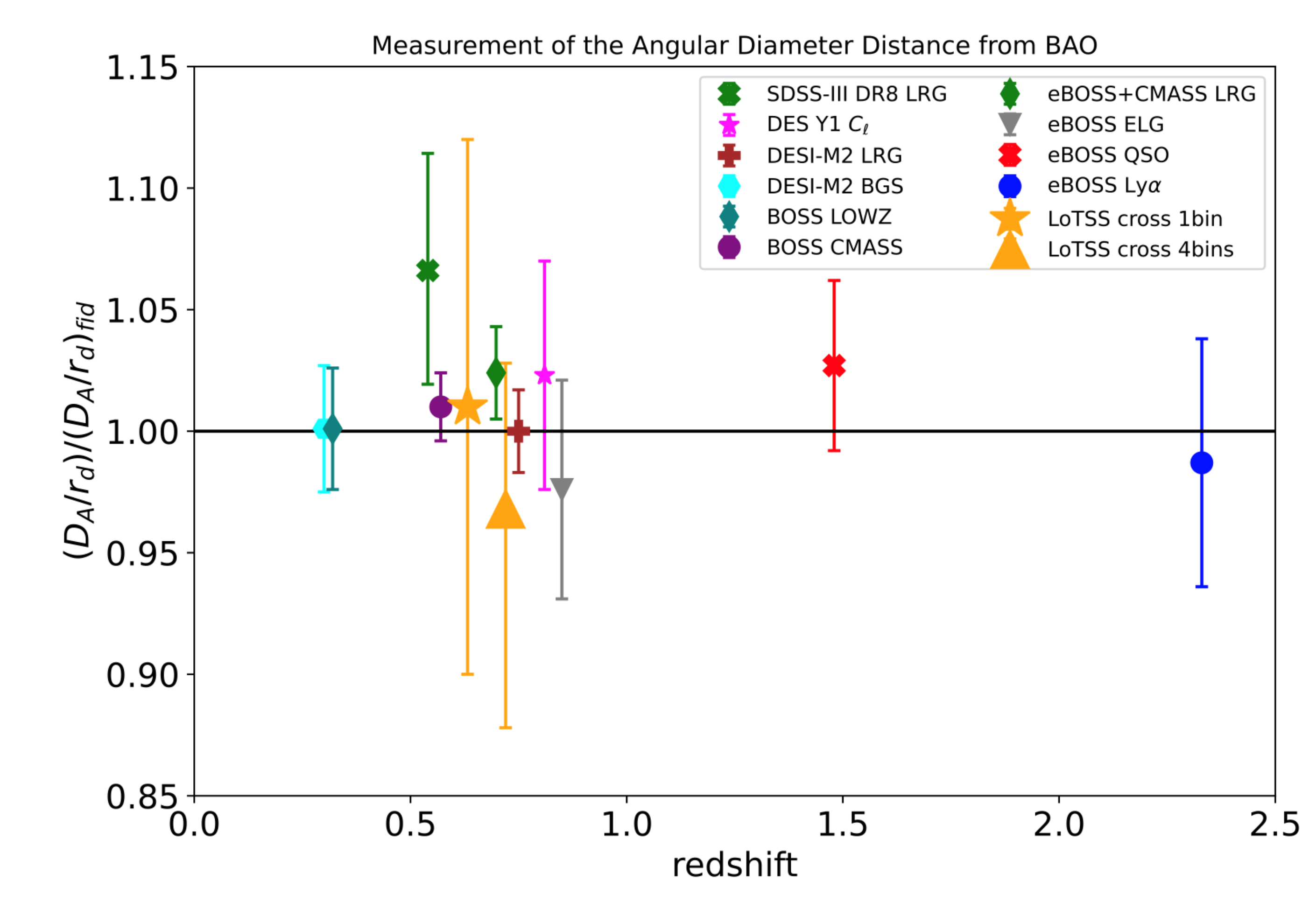
# A detection of BAO from radio-optical galaxy cross-power



# A detection of BAO from radio-optical galaxy cross-power

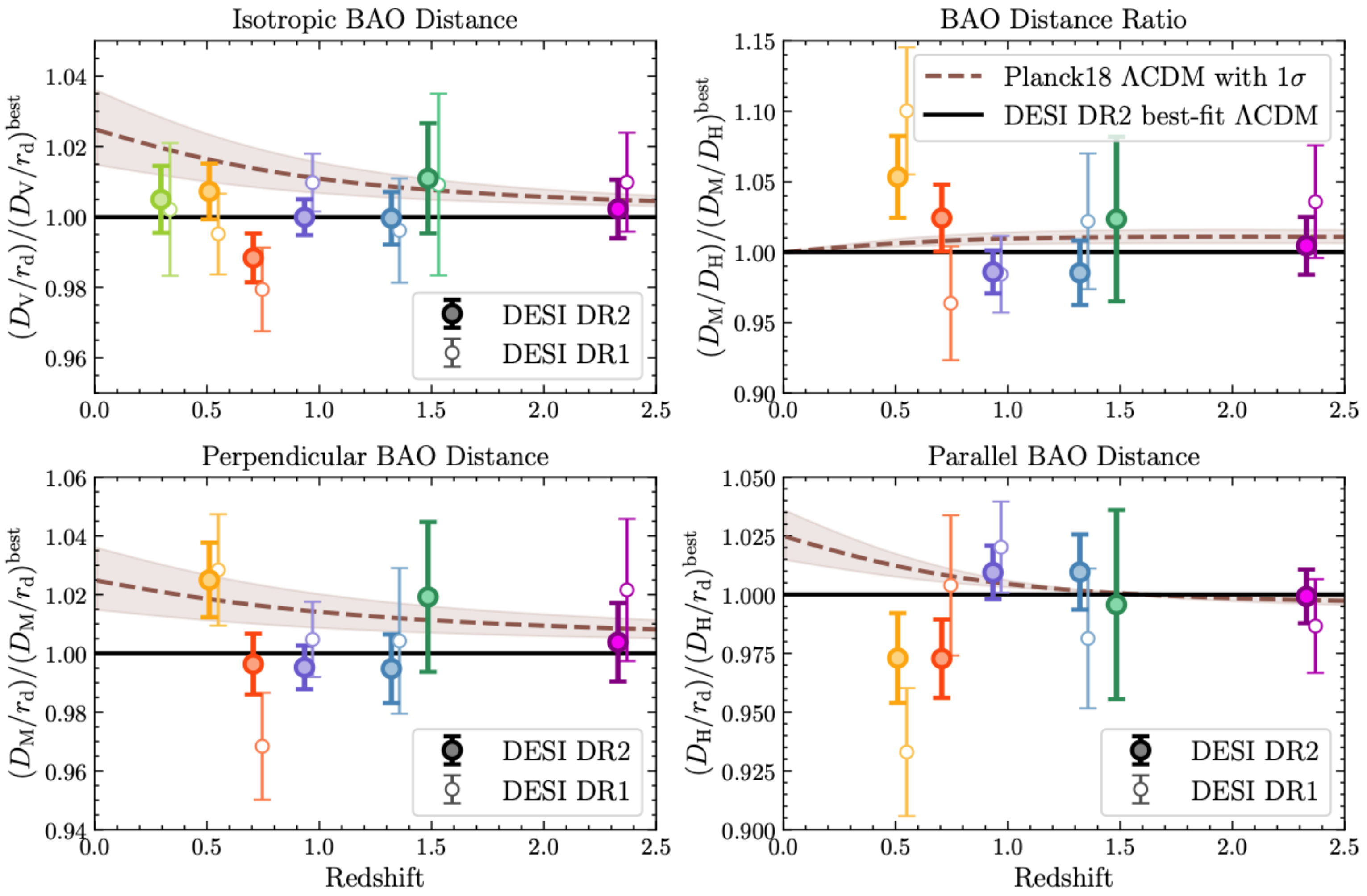



J. Zheng, P. Tiwari, GBZ, et al (LoTSS collaboration), 2504.20722, A&A (2025)

# A study of dynamical dark gravity using DESI




DESI paper: 2503.14738

# Two ways to study dynamics of dark energy

- **Indirect: get features of w(z) directly from distance measurements**

**✓ : cheap; no data combination needed**

**✗ : no w(z) derived**

# Two ways to study dynamics of dark energy

- Indirect: get features of w(z) directly from distance measurements

✓: cheap; no data combination needed

✗: no w(z) derived

- Direct: reconstruct w(z) from observations

✓: show w(z) with details

✗: expensive; usually requires datasets to be combined

# Probing dynamical DE from distance measurements

## (Gu et al, 2404.06303; Wang et al, 2404.06310)

$$\frac{D_{\mathrm{A}}(z)}{D_{\mathrm{A,fid}}(z)} = \alpha_0 \left(1 + \alpha_1 x + \frac{1}{2}\alpha_2 x^2 + \frac{1}{6}\alpha_3 x^3 + \frac{1}{24}\alpha_4 x^4\right)$$

(Zhu et al, 2015)

$$\frac{H_{\mathrm{fid}}(z)}{H(z)} = \alpha_0 \left[1 + \alpha_1 + (2\alpha_1 + \alpha_2)x + \left(\frac{3}{2}\alpha_2 + \frac{1}{2}\alpha_3\right)x^2 + \left(\frac{2}{3}\alpha_3 + \frac{1}{6}\alpha_4\right)x^3 + \frac{5}{24}\alpha_4 x^4\right]$$

$$1 + x \equiv D_{\mathrm{A,fid}}(z)/D_{\mathrm{A,fid}}(z_\star)$$

$$S(a) \equiv A\ H^2(a)a^3 = B\ X(a)a^3 + C$$

$$A = r_{\rm d}^2,\ B = AH_0^2(1 - \Omega_{\rm M}),\ C = AH_0^2\Omega_{\rm M} \quad X(a) \equiv \rho_{\rm DE}(a)/\rho_{\rm DE}(1)$$

$$S(a) \equiv A\ H^2(a)a^3 = B\ X(a)a^3 + C$$

$$A = r_{\rm d}^2,\ B = AH_0^2(1-\Omega_{\rm M}),\ C = AH_0^2\Omega_{\rm M} \quad X(a) \equiv \rho_{\rm DE}(a)/\rho_{\rm DE}(1)$$

$$S_0(a) \equiv a^3 - \frac{3\,[S(a)-S(1)]}{S'(1)} = a^3 + \frac{X(a)a^3-1}{w(1)} \xrightarrow{\Lambda} 1$$

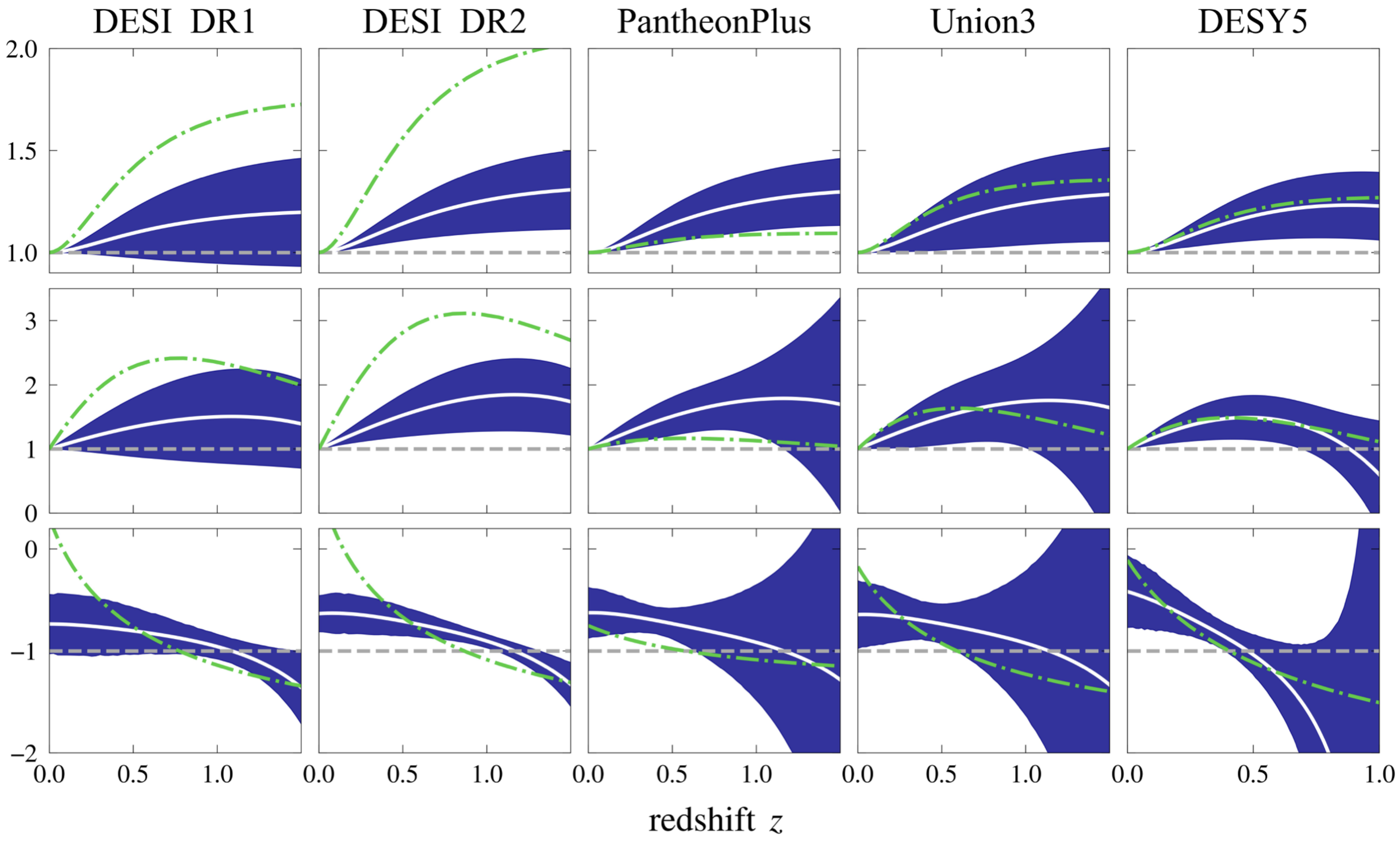
$$S_1(a) \equiv \frac{1}{a^3}\frac{S'(a)}{S'(1)} = \frac{P_{\rm DE}(a)}{P_{\rm DE}(1)} \xrightarrow{\Lambda} 1,$$

$$S_2(a) \equiv -\frac{S''(a)}{3S'(a)} = w(a) - \frac{w'(a)}{3w(a)} \xrightarrow{\Lambda} -1,$$

$$a^3 + \frac{X(a)a^3 - 1}{w(1)}$$

$$\frac{P_{\rm DE}(a)}{P_{\rm DE}(1)}$$

$$w(a) - \frac{w'(a)}{3w(a)}$$




Gu, Wang, Wang, GBZ, et al [DESI collaboration], 2504.06118, **Nature Astronomy (2025)**

# Reconstructing the evolution history of dark energy

Crittenden, Pogosian, GBZ (CPZ, JCAP 2009)
Crittenden, GBZ, Pogosian, Samushia, Zhang (JCAP 2012)

$$\xi_w(|a-a'|) \equiv \langle [w(a) - w^{\rm fid}(a)][w(a') - w^{\rm fid}(a')] \rangle$$

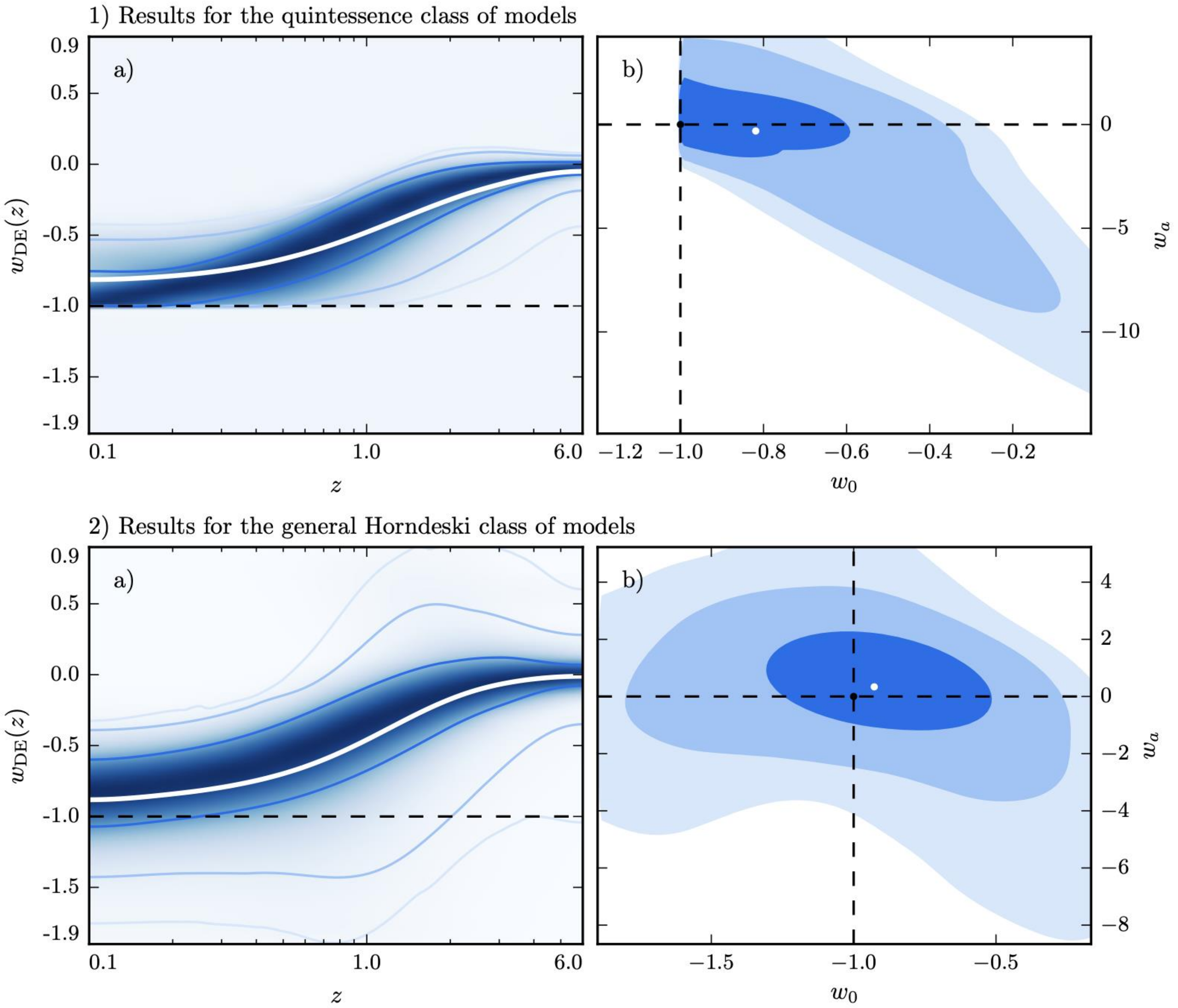
$$w_i = \frac{1}{\Delta}\int_{a_i}^{a_i+\Delta} da\, w(a)$$

$$C_{ij} \equiv \langle \delta w_i \delta w_j \rangle = \frac{1}{\Delta^2}\int_{a_i}^{a_i+\Delta} da \int_{a_j}^{a_j+\Delta} da' \xi_w(|a-a'|)$$

$$\chi^2_{\rm prior} = -2\ln \mathcal{P}_{\rm prior} = (\mathbf{w} - \mathbf{w}^{\rm fid})^T \mathbf{C}^{-1} (\mathbf{w} - \mathbf{w}^{\rm fid})$$

# Theory-motivated correlated prior on w(z) (Raveri et al, 1703.05297)

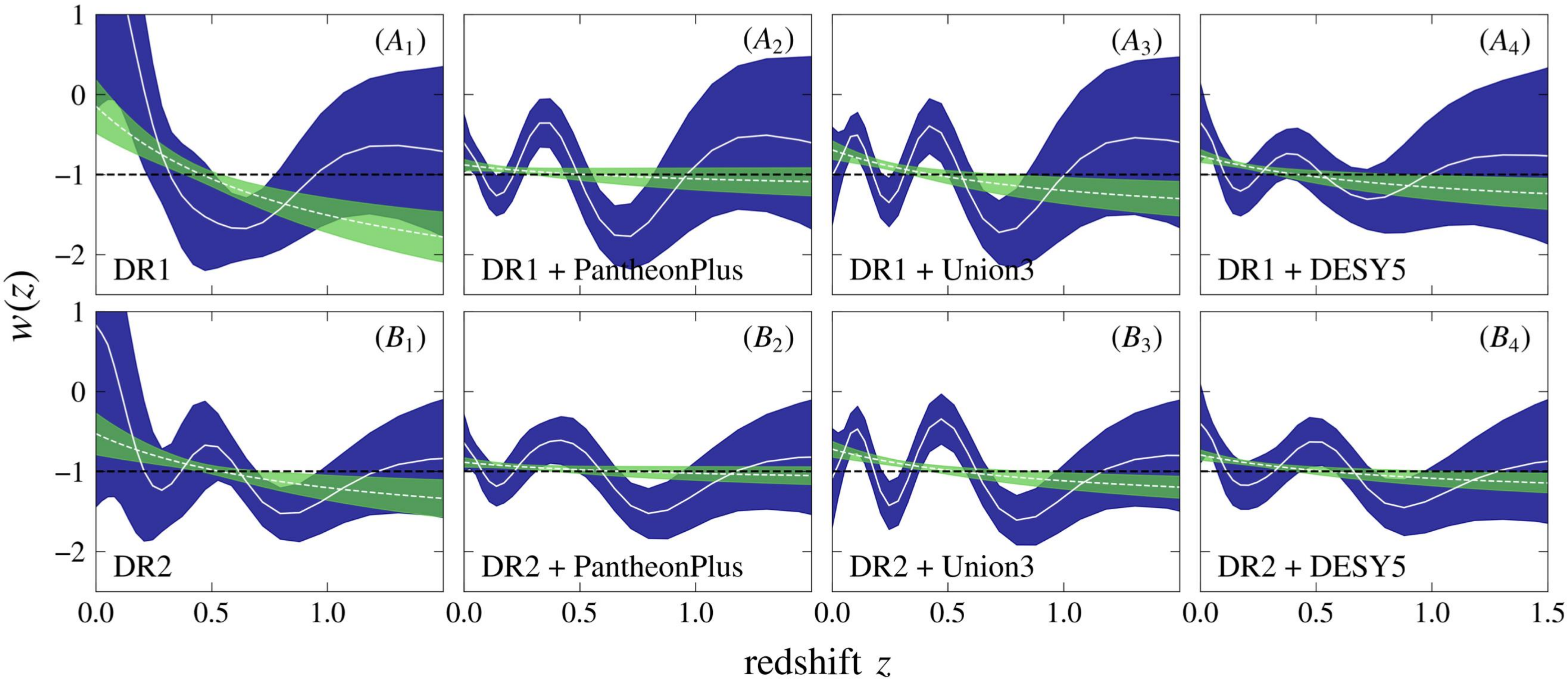
$$
\begin{aligned}
\mathcal{S} = \int d^4x \sqrt{-g} \Big\{ & \frac{m_0^2}{2} \left[1 + \Omega(\tau)\right] R + \Lambda(\tau) - c(\tau)\, a^2 \delta g^{00} \\
& + \frac{M_2^4(\tau)}{2} \left(a^2 \delta g^{00}\right)^2 - \frac{\bar{M}_1^3(\tau)}{2}\, a^2 \delta g^{00}\, \delta K_\mu^\mu \\
& + \frac{\bar{M}_3^2(\tau)}{2} \left[ \left(\delta K_\mu^\mu\right)^2 - \delta K_\nu^\mu\, \delta K_\mu^\nu - \frac{a^2}{2} \delta g^{00}\, \delta \mathcal{R} \right] + \dots \Big\} \\
& + S_m[g_{\mu\nu}, \chi_m], \qquad (1)
\end{aligned}
$$



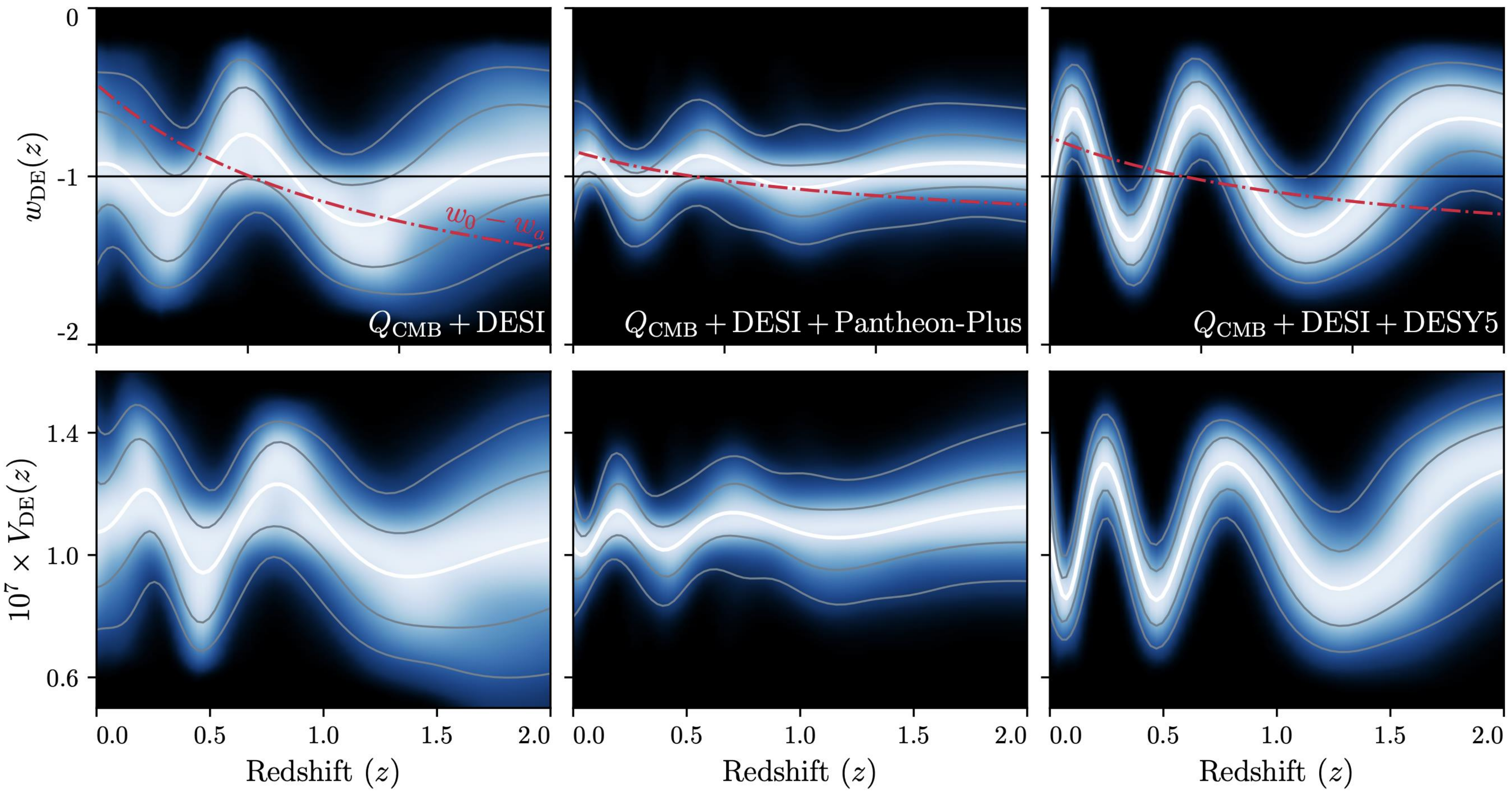

Raveri et al, 1703.05297

$$
\begin{aligned}
C(a,a') &\equiv \langle [w(a) - w_{\rm fid}(a)][w(a) - w_{\rm fid}(a')] \rangle \\
&= \sqrt{C(a)C(a')}R(a,a'),
\end{aligned}
$$

$$
\begin{aligned}
C(a) &= 0.05 + 0.8a^2, \\
R(a,a') &= \exp\left[ - \left( \left| \ln\ a - \ln\ a' \right| / 0.3 \right)^{1.2} \right]
\end{aligned}
$$

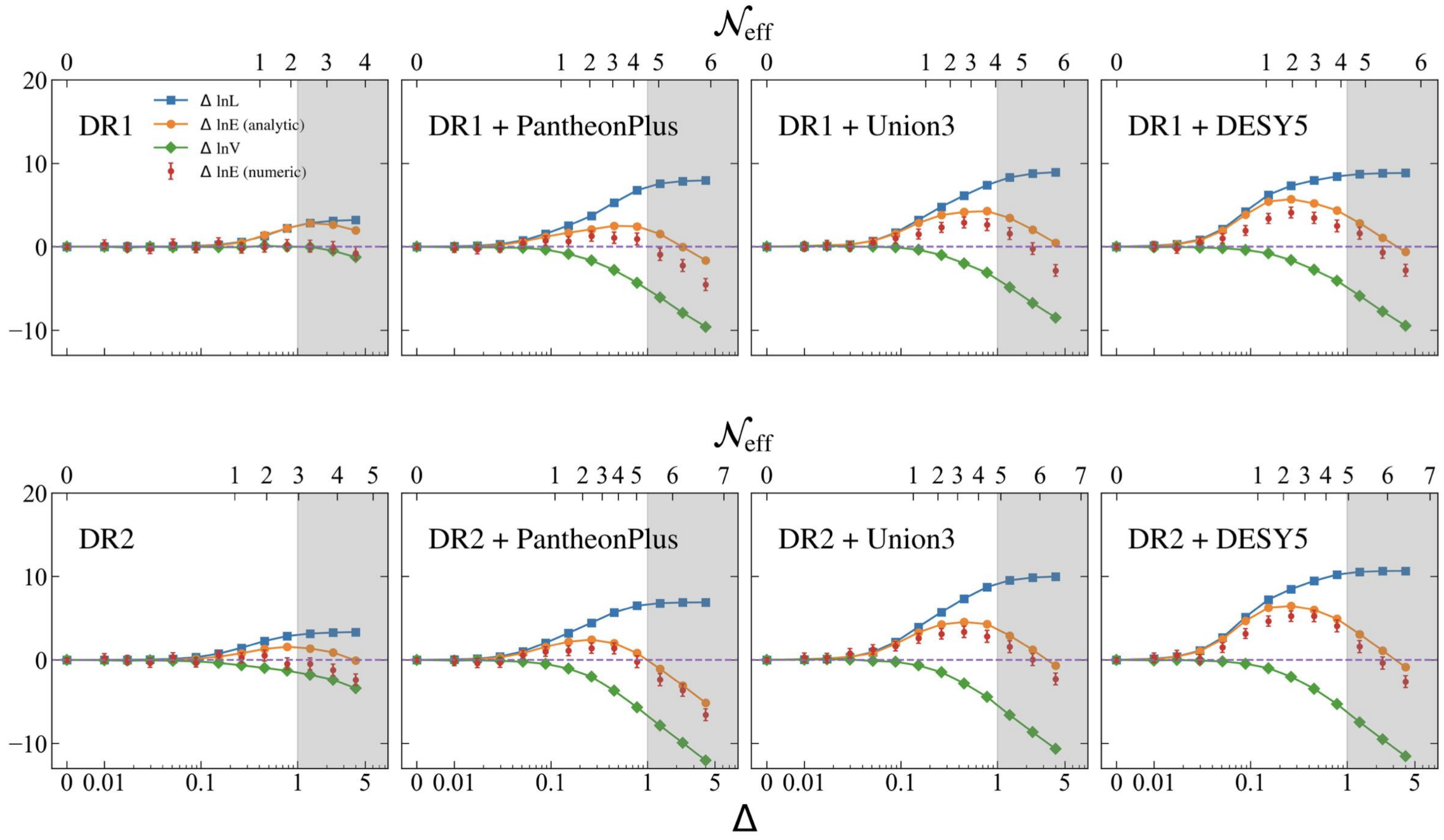



Gu, Wang, Wang, GBZ, et al [DESI collaboration], 2504.06118, **Nature Astronomy (2025)**



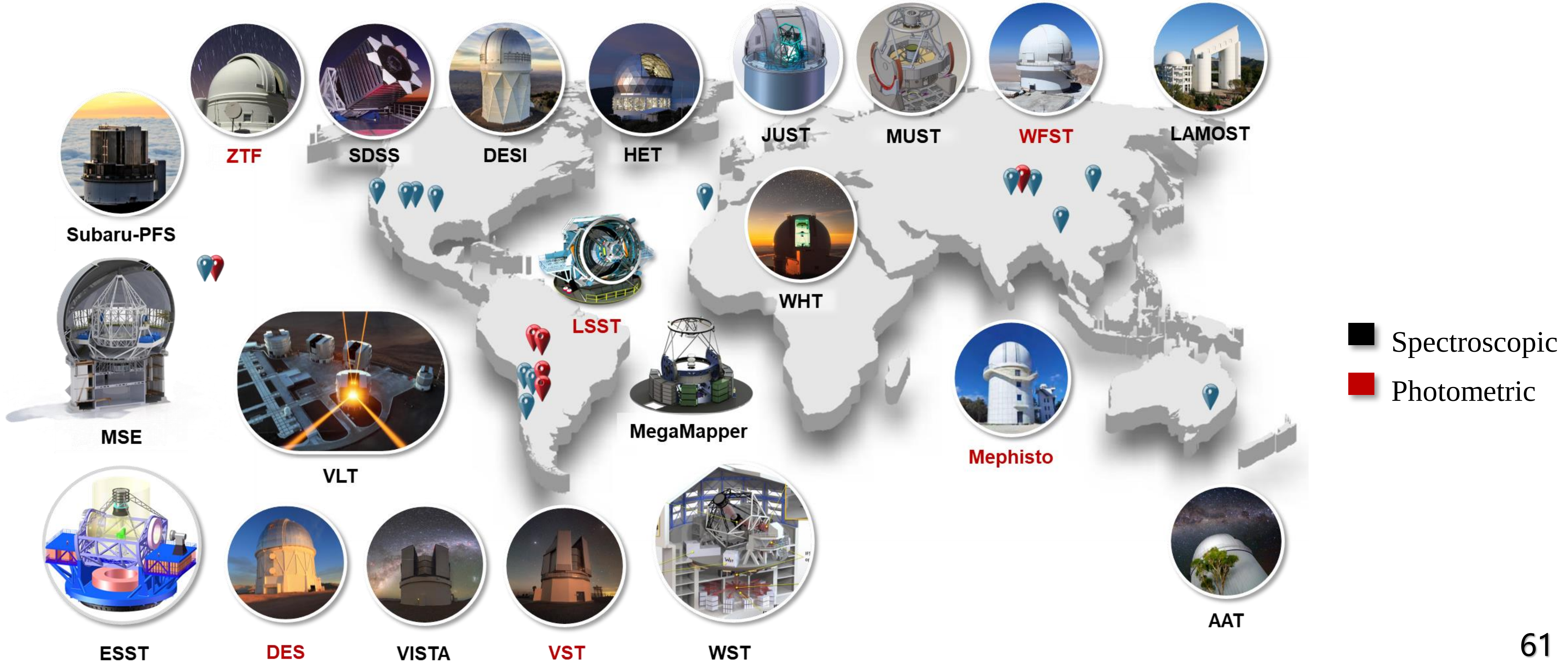

Goldstein, Celoria & Schmidt, arXiv: 2507.16970

# Bayesian Evidence

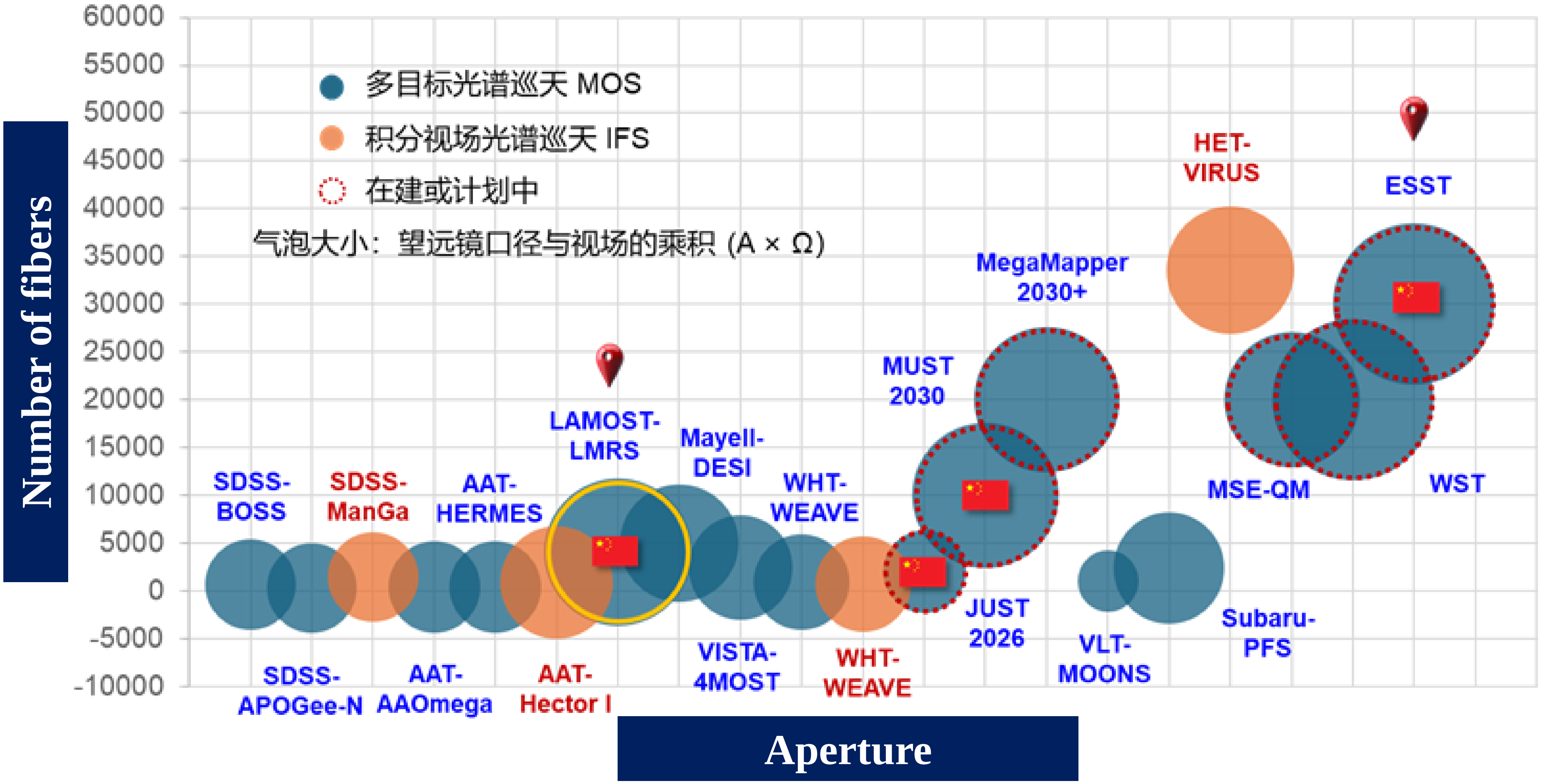


# Development of spectroscopic survey

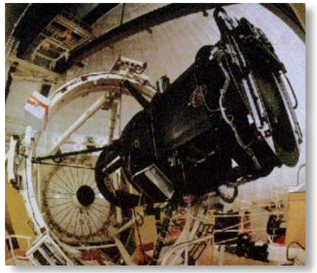
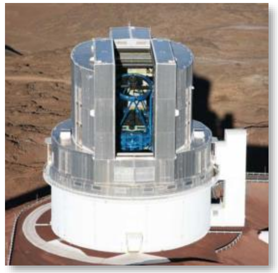
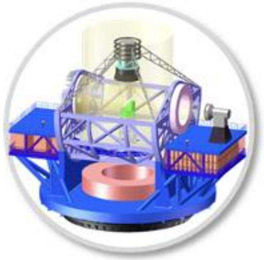
- Large-scale spectroscopic surveys are critical on studying dark matter, dark energy, large scale structure of the Universe, galaxy formation and evolution etc.
- A new round of technical revolution has been initiated by proposing WST and ESST.



- Ground-based survey telescopes will go into the era of 10m class
- The number of fibers increases up to tens of thousands

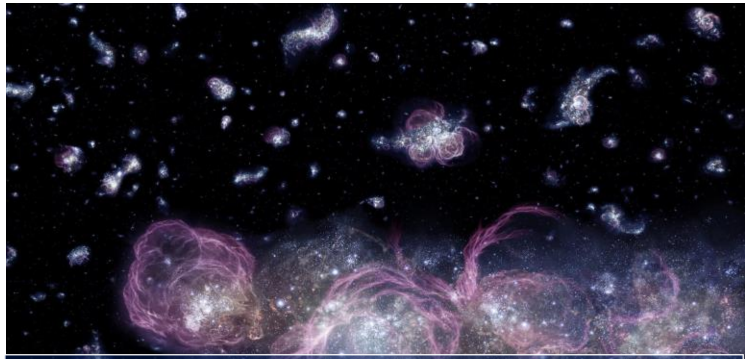


Hundreds of fibers | Thousands of fibers | Tens of thousands

| 1997 | 2000 | 2012 | | 2021 | 2025 | 2030+ |
|---|---|---|---|---|---|---|
| 2dfGRS | SDSS | LAMOST | | DESI | PFS | ESST, WST |
|  |  |  | … |  |  |  |
| 3.9m | 2.5m | 4m | | 4m | 8m | 12m |

# ESST science cases

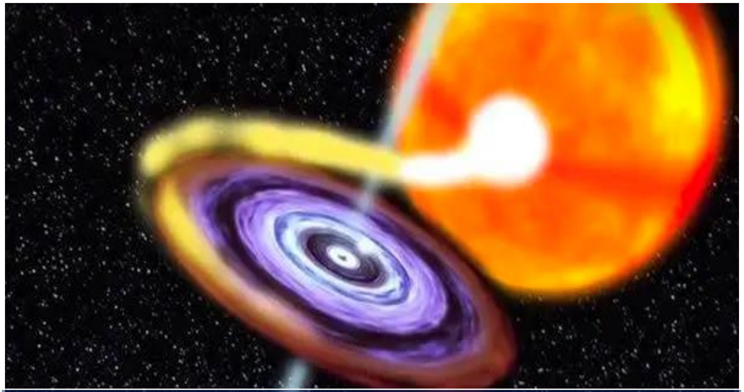
The Milky Way



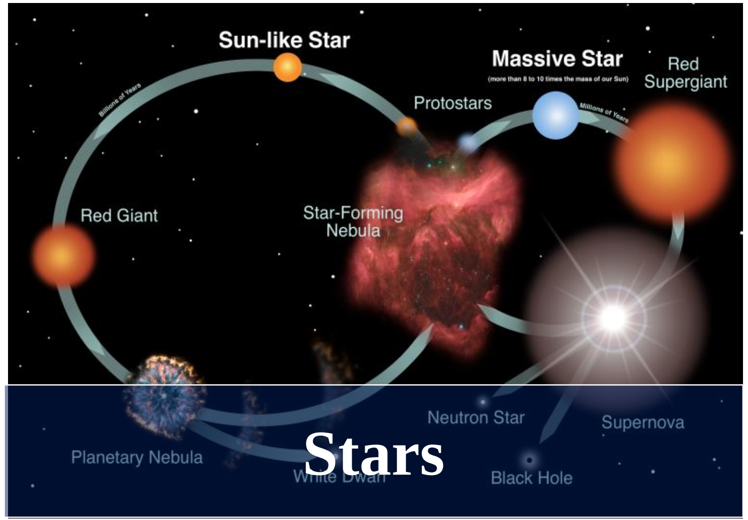
Dark matter
Dark energy

Galaxies

Exoplanets

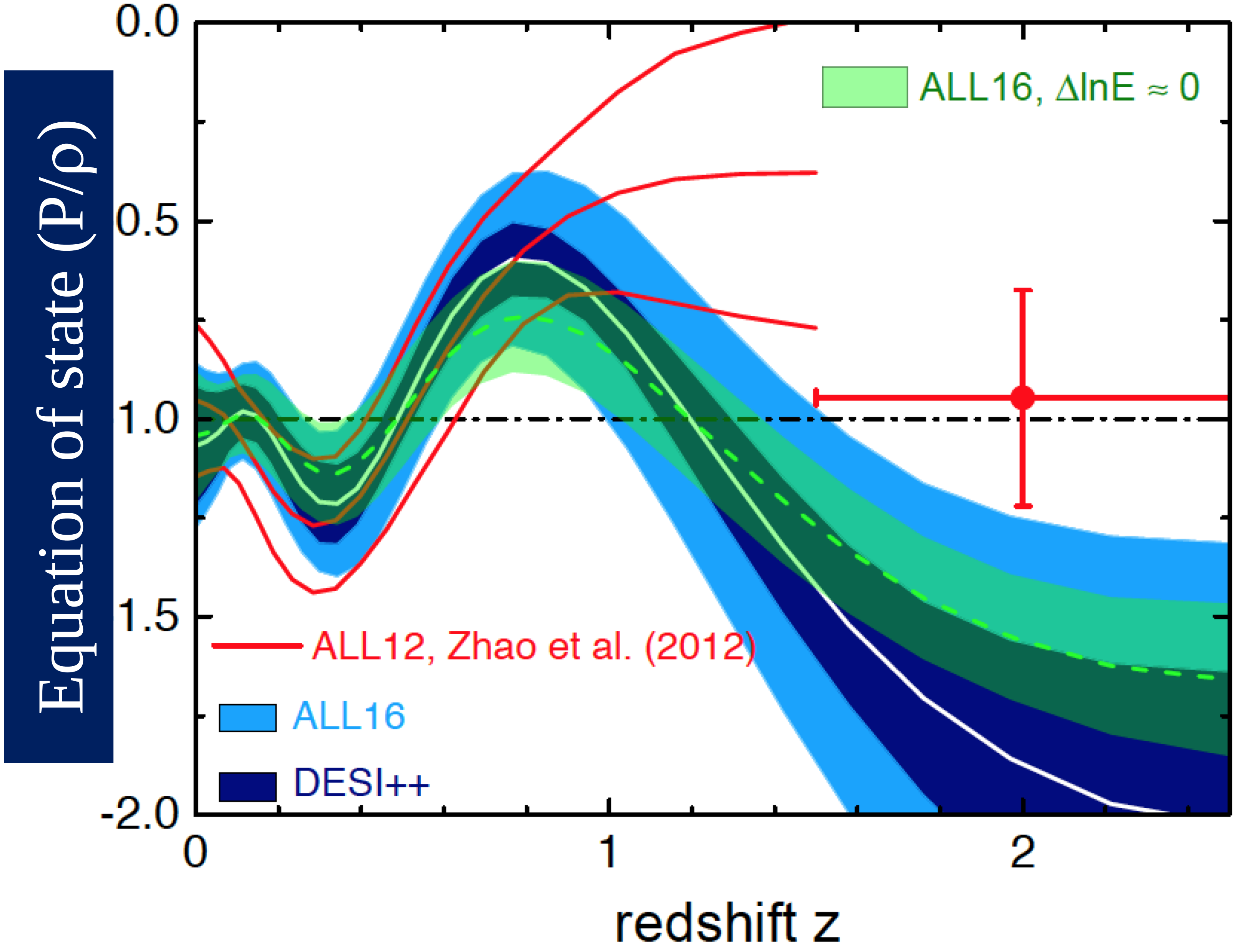


Black holes




Stars

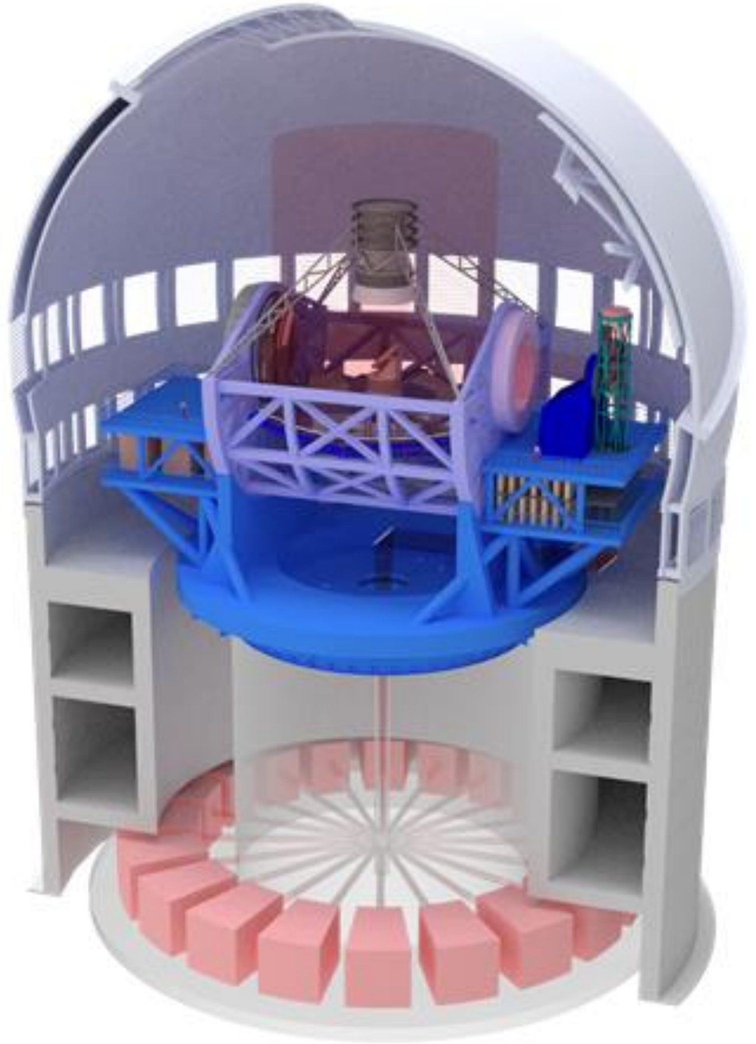
# Revealing the nature of dark energy



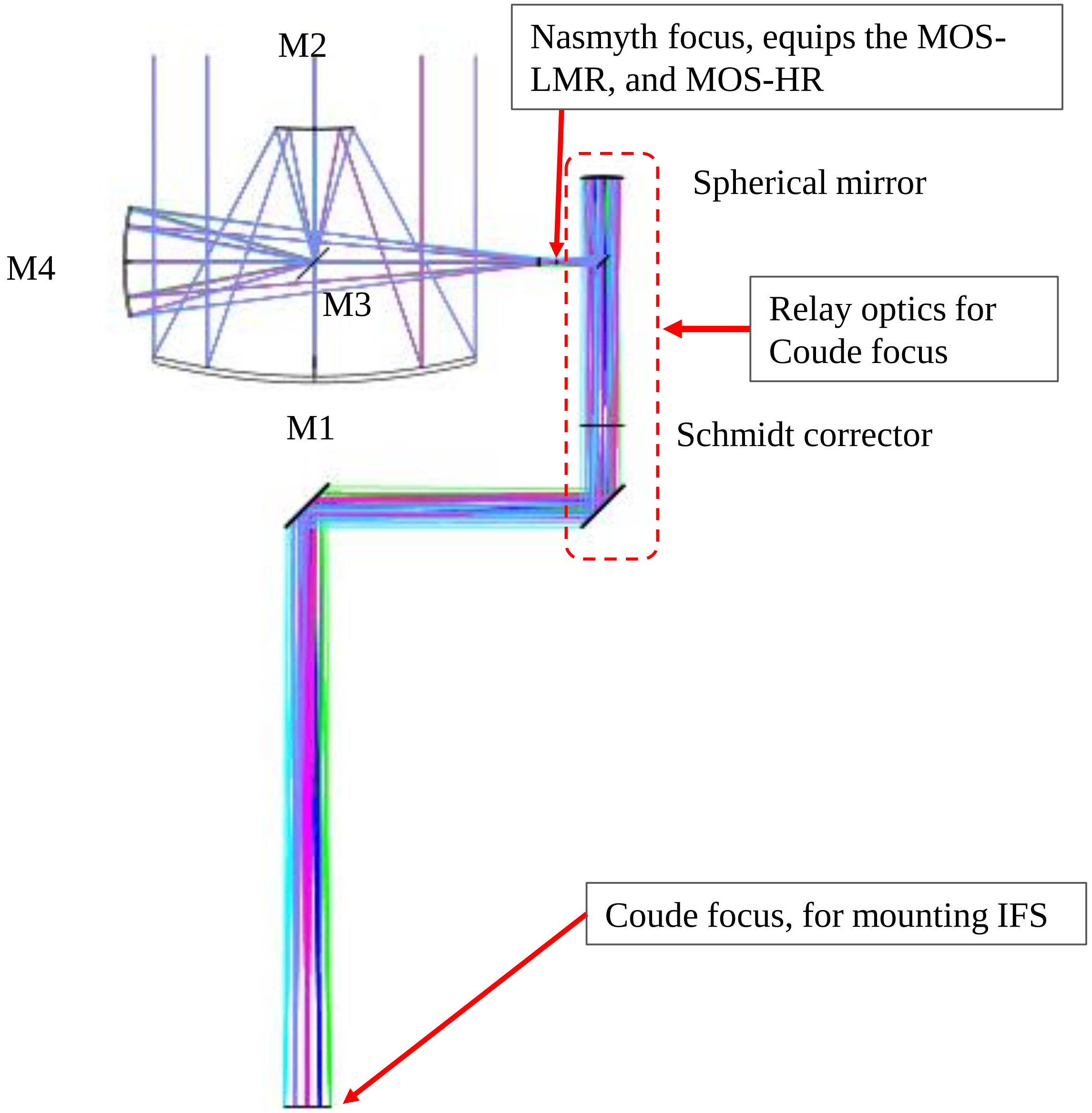

- **2012: 2.5 σ (Zhao *et al*, PRL)**
- **2017: 3.5 σ (Zhao *et al*, Nature Astronomy; SDSS-BOSS survey)**
- **2025: 4.3σ (Zhao's group *et al*, Nature Astronomy; DESI survey)**
- **>5 σ (ESST forecast)**

# Extremely-large Spectroscopic Survey Telescope (ESST)

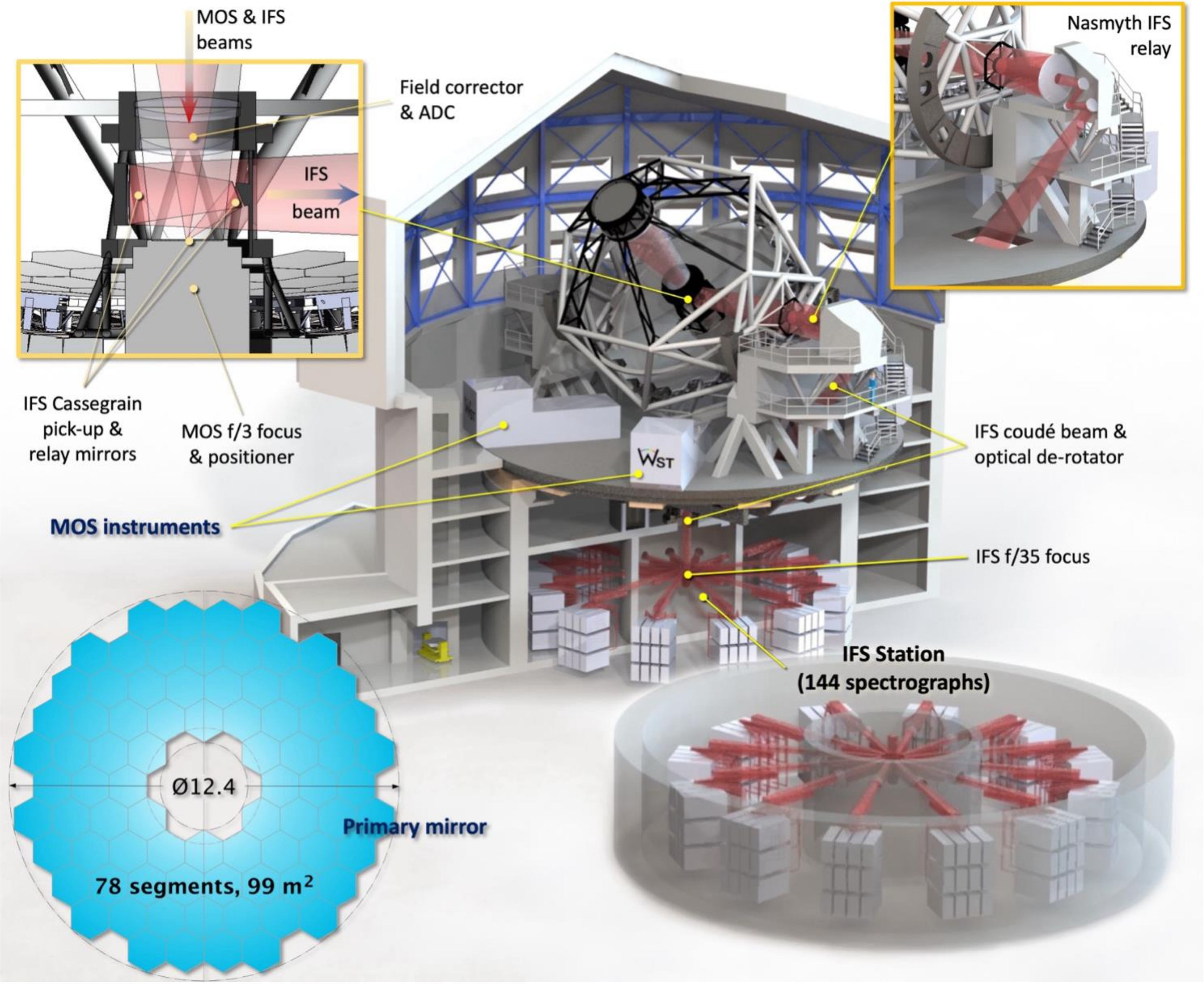
- Aperture： 12 meters
- Magnitude limit： V=23 (LR)
- FOV： 2°
- Fiber： 30000~50000
- Instruments： MOS-LMR
  MOS-HR
  PIFS
  New concept instruments
- Site: Chile (Paranal or Pachon)



# ESST Optical design




- A second mirror for multi-focus
- Compact optics with high throughput
- Simultaneously observation with wide field MOS and central field IFS
- Innovative S-ADC made by lens-prism segments can be used on large optical telescope




# WST

- Aperture: 12 meters
- FOV: 2.5~5 square degrees (MOS)
- Fiber capacity: 20000 (MOS)

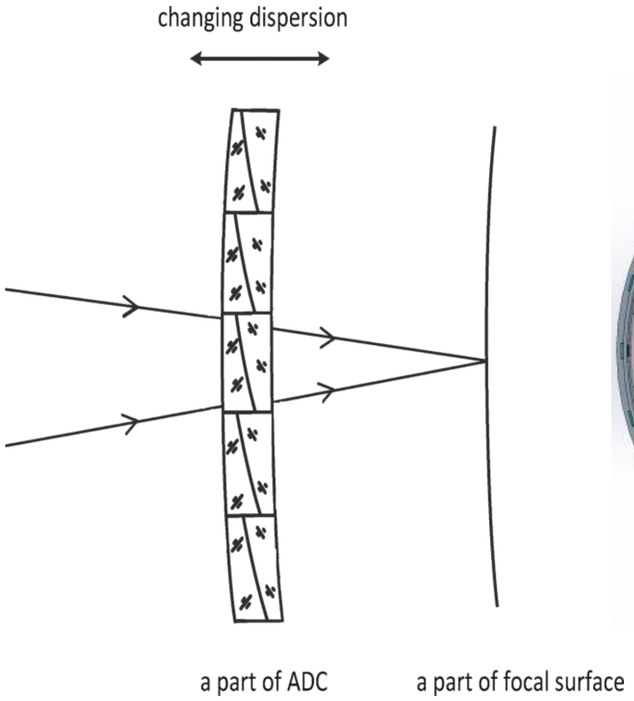
# Comparison between ESST and WST

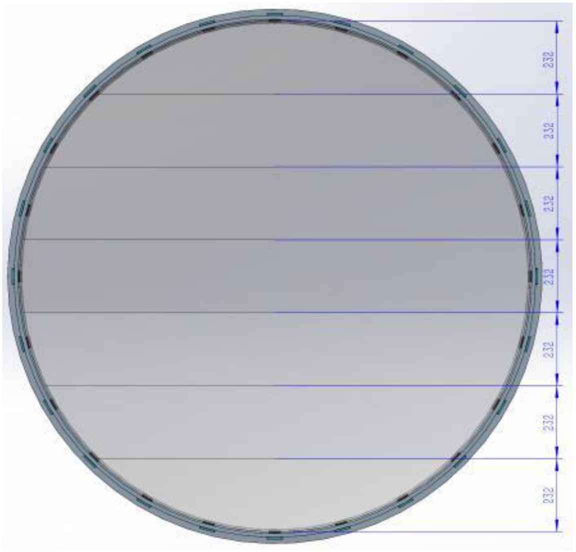
| Telescope | ESST | WST |
|---|---|---|
| Aperture | 12 m | 12 m |
| FOV | 2° (Nasmyth)<br>13’ (Coude) | 2° (Nasmyth)<br>13’ (Coude) |
| Focal ratio | F/4 (Nasmyth)<br>F/37.2 (Coude) | F/3 (Nasmyth)<br>F/35 (Coude) |
| Band | 0.36-1.8 μm （Nasmyth、Coude） | 0.37-1.0 μm （Nasmyth、Coude） |
| Number of fibers | 30000~50000 | ~20000 |
| Focal plane | 1.69 m | 1.27 m |
| Simultaneously observation with IFS | Yes | Yes |
| Image quality (EE80) | Nasmyth ≤0.40 arcsec | Nasmyth ≤0.8 arcsec |

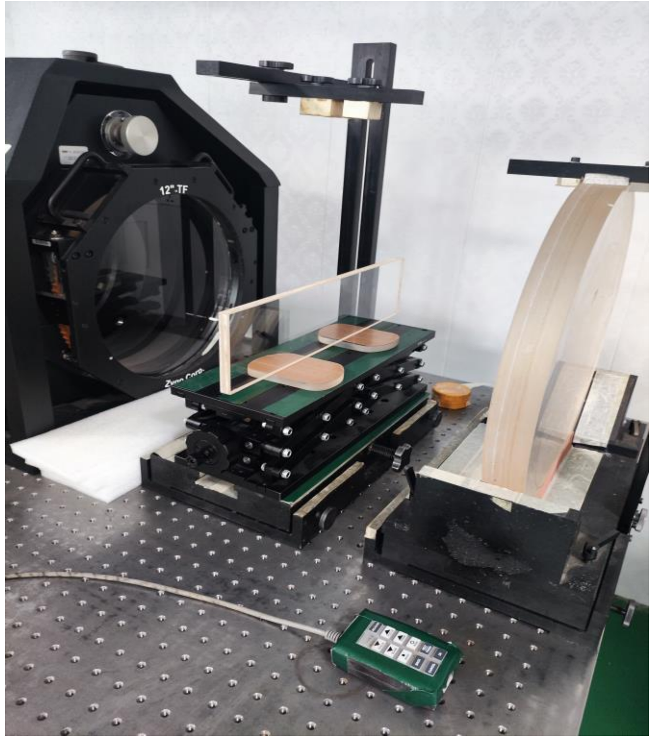
**ESST: Compact optics, Wide band, Large focal plane, More fibers, better image quality**

# ❖ Strip Atmospheric Dispersion Corrector (S-ADC)

The innovative S-ADC break through the glass material size limit of the lens ADC Removing the S-ADC during infrared observations does not affect imaging quality of the system



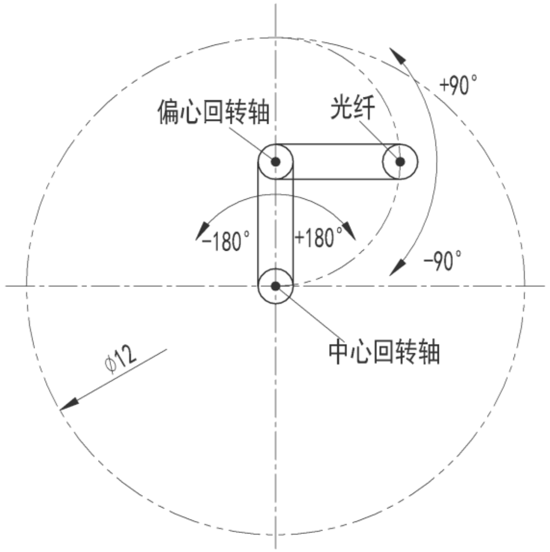


S-ADC prototype: φ360mm

- It consists of many lens–prism strips. All surfaces are spherical.
- By moving such a corrector along optical axis, the different dispersion can be produced and the atmospheric dispersion at different zenith distance can be compensated.

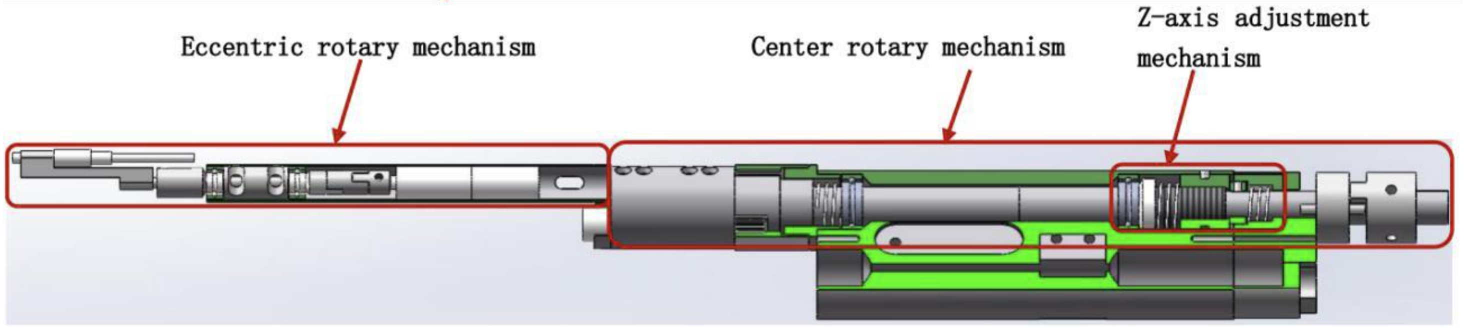
# ❖ Next generation fiber positioning system

Dual rotation fiber optic positioning system will be thinner for larger fiber scale, higher-positioning accuracy, and lower thermal effect.




Theory of dual rotation


Comparison with two generations of fiber positioners




- Central rotation： 0°~360°
- Off-axial rotation： 0°~180°
- On-axial translation： focusing

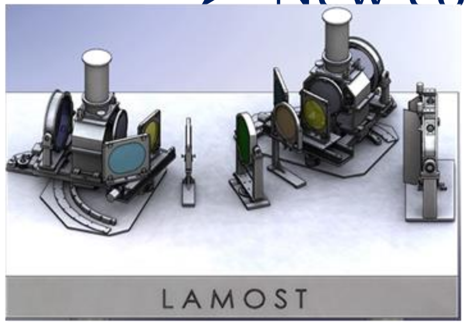
# Concept of instruments for ESST

## Large scale spectroscopic survey

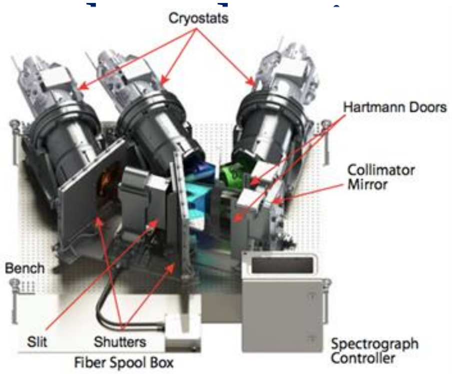
- Multi-object Low-Medium Resolution
- Multi-object High Resolution
- Panoramic Integral Field Spectrograph
- New conc r

## Key technologies

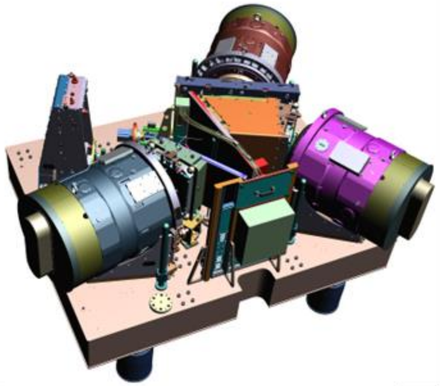
- Clustering technology based on 100+ spectrographs
- IFS Implement in spectroscopic survey




LAMOST - LMRS

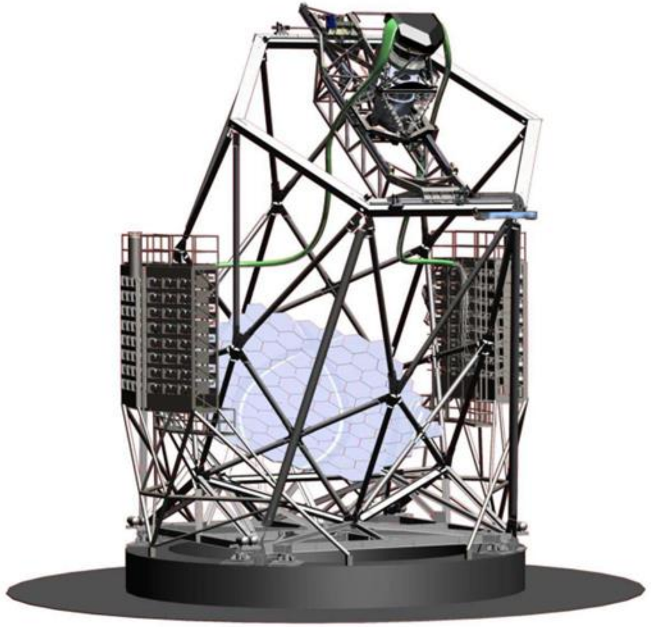



Mayall - DESI



Subaru - PFS

VLT - MOONS



HETDEX - VIRUS

# ESST — Multi-object Low-Medium Resolution spectrographs

Takes great challenges of MOS with 30000 fibers：

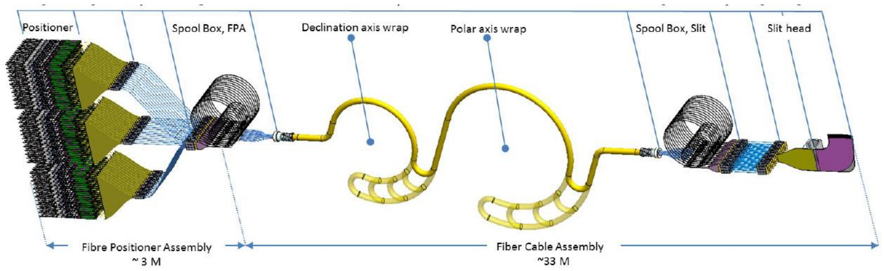
- ➢ Gets larger aperture, wider aperture, faster focal ratio, and broadband
- ➢ Spectrograph scale production and maintenance

ESST MOS-LMR：

- ➢ Adds a fiber relay station
- ➢ Build an instrument matrix to manage 60+ spectrographs
- ➢ Fiber capacity： 500 fibers/spec.
- ➢ Resolution： R = 3000~4000 @ φ1”fiber
- ➢ Wavelength coverage： 370-900nm at one shot

1st phase： a group of 40 spec. to build the basic

Capability of multi-object observation




Ref. DESI fiber transmission unit

Ref： DESI spectrograph array

# ESST — Multi-object High Resolution spectrographs

## Most of MOS-HR (*R*~20000) is mounted on 4-8m telescopes

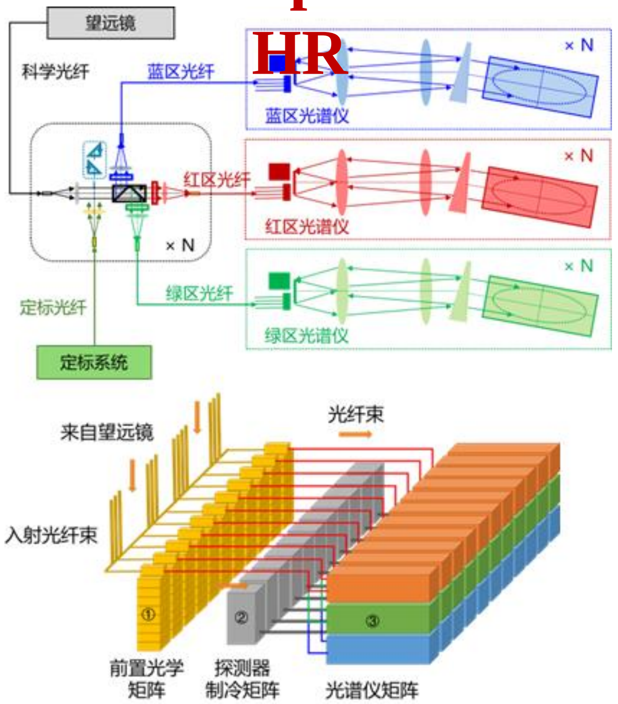
- Has taken full use of the existing capabilities in manufacture
- Higher resolution, narrower band（MSE requirement： R~40000， bandwi

## ESST MOS-HR：

- Fiber capacity： ~3000 fibers (~100 fibers / spec.)

| Instruments | HERMES | 4MOST | WEAVE | MOONS | MSE |
|---|---|---|---|---|---|
| Telescopes | AAT(3.9m) | VISTA(4m) | WHT(4.2m) | VLT(8.2m) | MSE(11.25m) |
| Resolution R | R=20K | R=18K | R=20K | R=18K | R=40K |
| Number of fibers | 784 | 2436 | 1000 | 1000 | 1083 |
| Collimated pupil Dc | Φ190mm | Φ250mm | Φ190mm | Φ265mm | Φ300mm |
| Blaze angles $\theta_b$ | 68° grating | 45° grating | 51.6° grating | 53° grating | 50° grating |
| Detectors | 4K@15um | 6K@15um | 8K@15um | 4K@15um | 6K@15um |

**New concept of MOS-HR**



# ESST — Integral Field Spectrographs

## Two instrument designs:

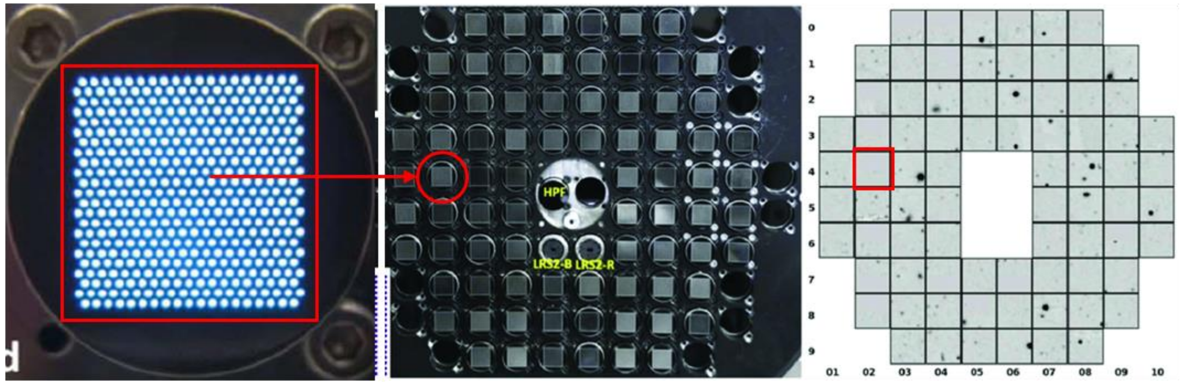
- Multi-object IFS（Tens of IFUs，large field of view，Reference: HETDEX-VIRUS）
- Panoramic IFS（a few amins，high duty rate，Reference：VLT-MUSE）

## ESST IFS concepts:

- Location: Coudé focus
- FOV：2’×2’，Seeing limit，sky aperture of FU：1”x1”；

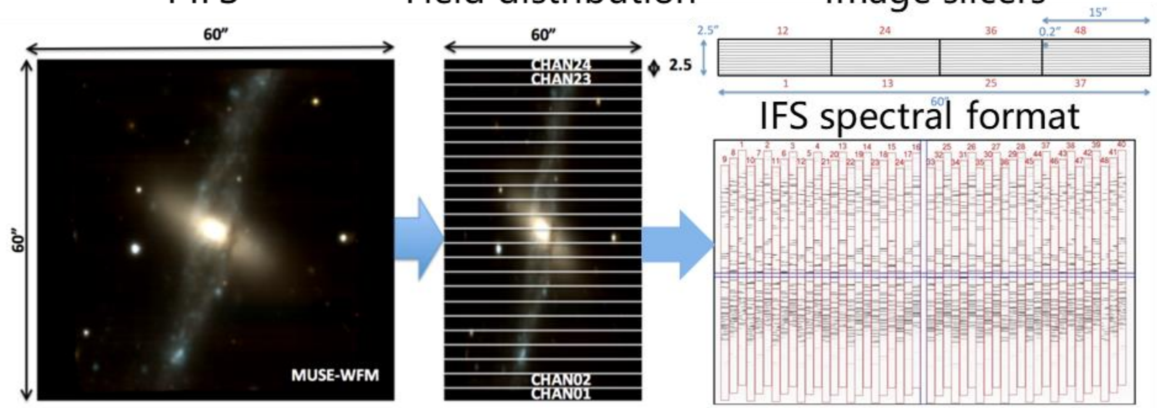
  GLAO condition，sky aperture of IFU：≤0.5”x0.5”
- Resolution：*R*=1000~3000 @ 500-900nm （370-900nm）

Fiber bundle IFU　　IFU array　　Field of multi-object IFU




HET-VIRUS Multi-object IFS group

PIFS　　Field distribution　　Image slicers




VLT-MUSE 1’x1’Panoramic IFS

# ESST — New instrument concept based on Integrated optics

Concept:

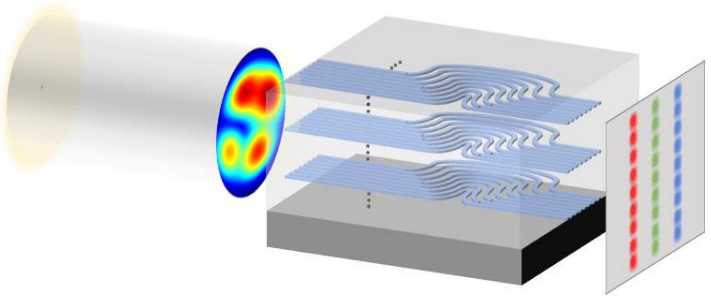
- To minimize the instrument, higher integration, shorten fiber length

Elementary parameters：

- Number of spec.：≥100 spec.
- Fiber capacity：500 fibers per spec.
- Fiber: 100~300 μm
- Resolution：R=3000~5000
- Wavelength coverage：450~900 nm
- Size：<0.1 $m^3$
- Weight：<10 kg

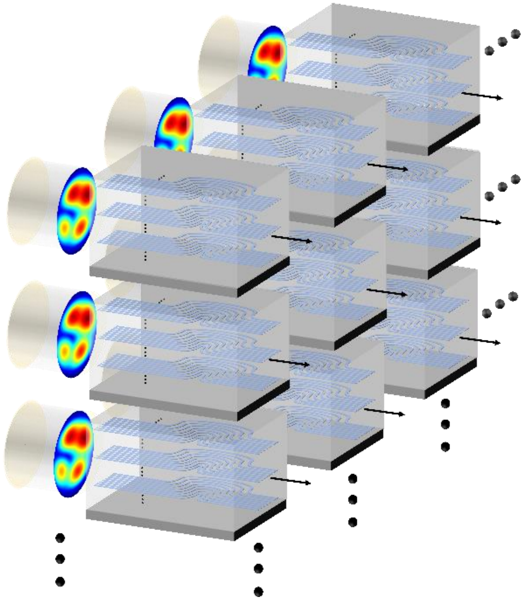
Characterization & innovation：

- Minimization, Weight-lighten
- 60% less
- High instrument stability



multimode spectroscopy chip

Based on Stacked waveguide array



Large scale instrument group

# Support from the Chinese astronomical community



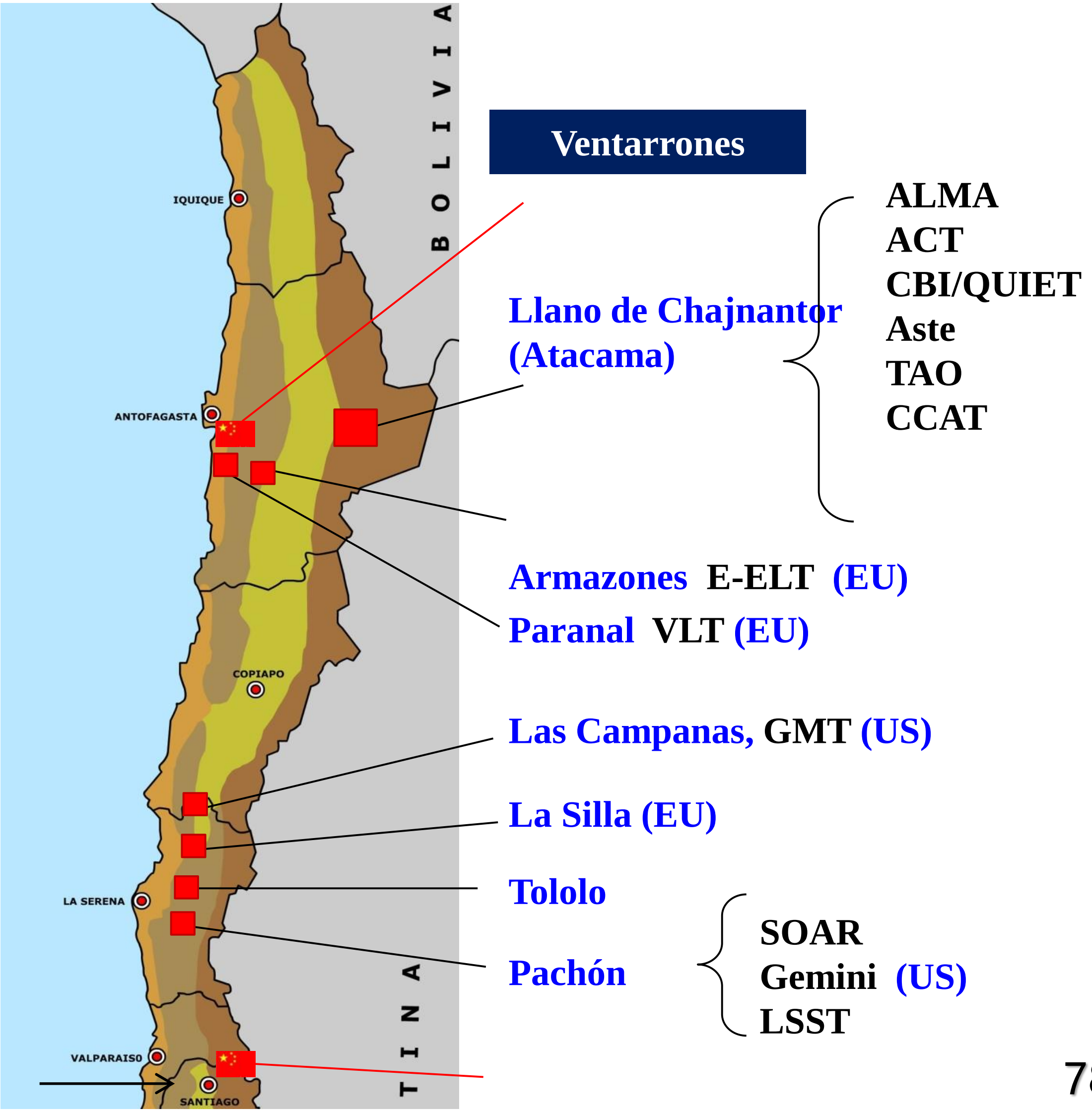
**ESST consortium**

**Strategic Guidance Committee (8 Academicians)**

**Scientific committee (30 representative astronomers)**

**12 Science Working Groups (40 young scientists)**

# CAS South America Center for Astronomy (CASSACA)



# Summary and next steps

- DESI BAO data show interesting signs of new physics, awaiting confirmation of Y5 and later observations (MUST, ESST, etc);
- As statistical errors get reduced, more work is needed to mitigate the systematics;
- New statistics (MFs, wavelets, etc) and new ideas (tests of parity, etc) are needed to probe new physics from future galaxy surveys.