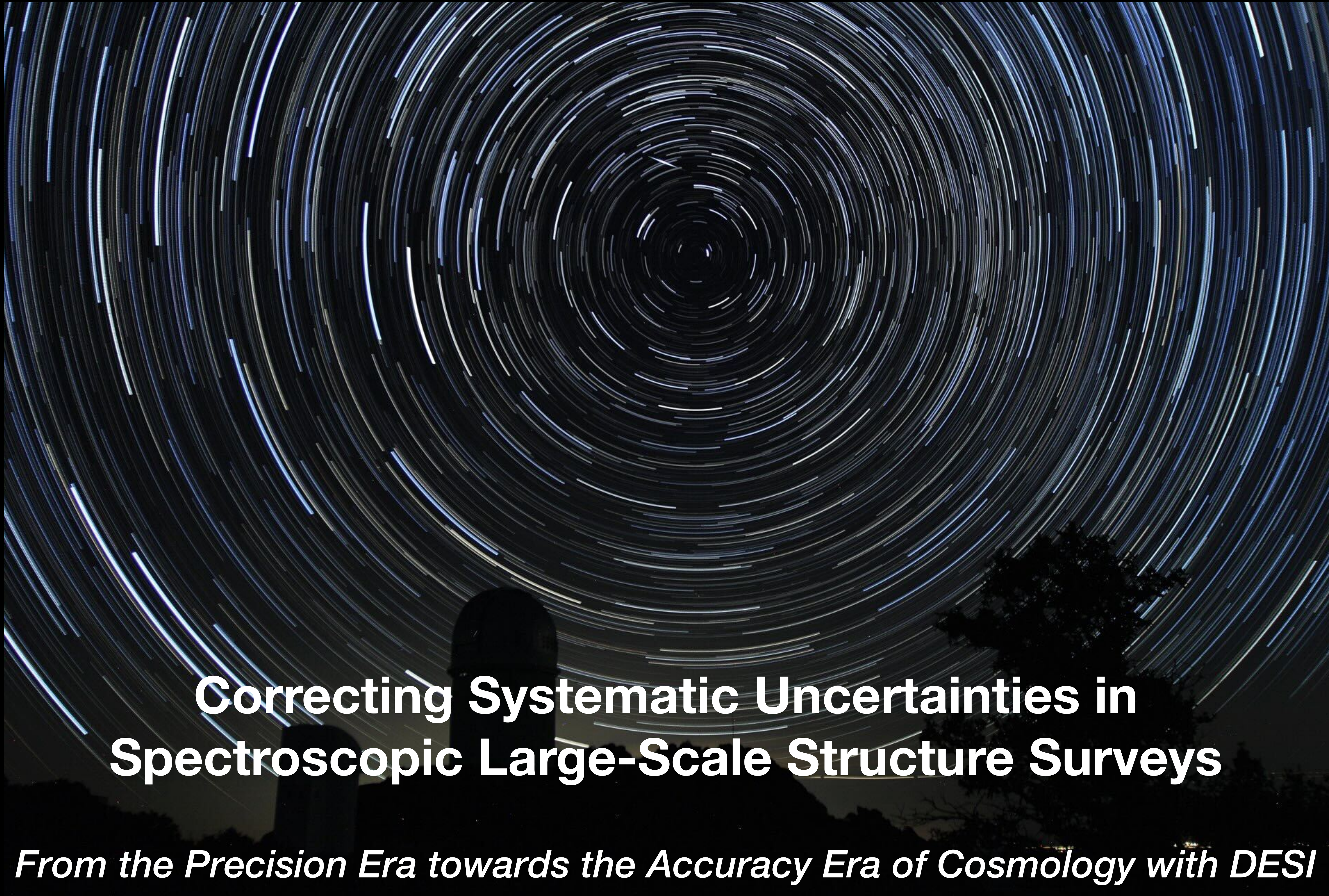

Correcting Systematic Uncertainties in Spectroscopic Large-Scale Structure Surveys

From the Precision Era towards the Accuracy Era of Cosmology with DESI

Samuel Brieden, University of Edinburgh

Precision vs Accuracy

Image Credits:
Luke Tyas

Precision vs Accuracy

Accurate
Precise

Image Credits:
Luke Tyas

Precision vs Accuracy

Accurate
Not Precise

Image Credits: Luke Tyas

Precision vs Accuracy

Not Accurate
Not Precise

Image Credits:
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Precision vs Accuracy

Not Accurate
Precise

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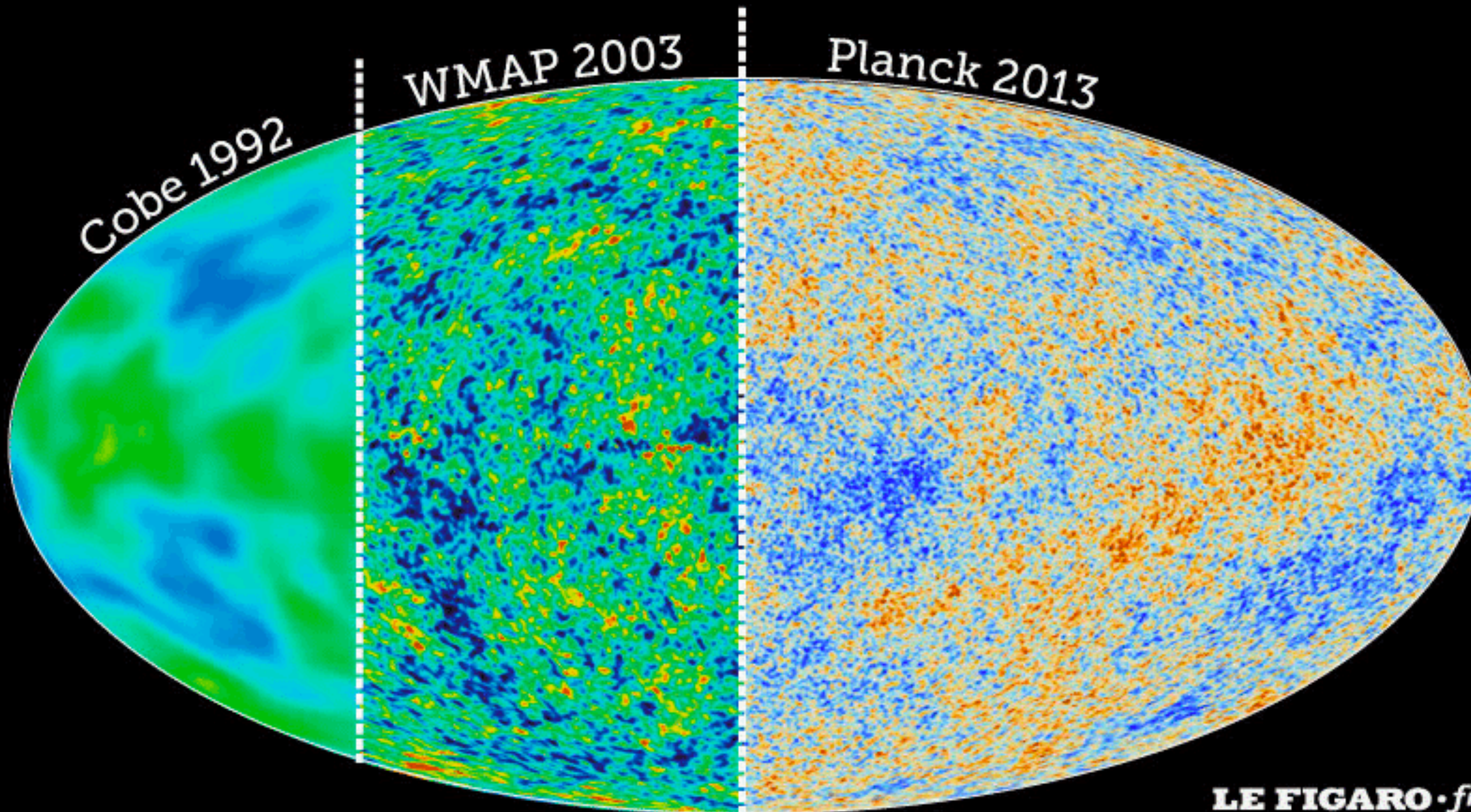
Precision Era of Cosmology



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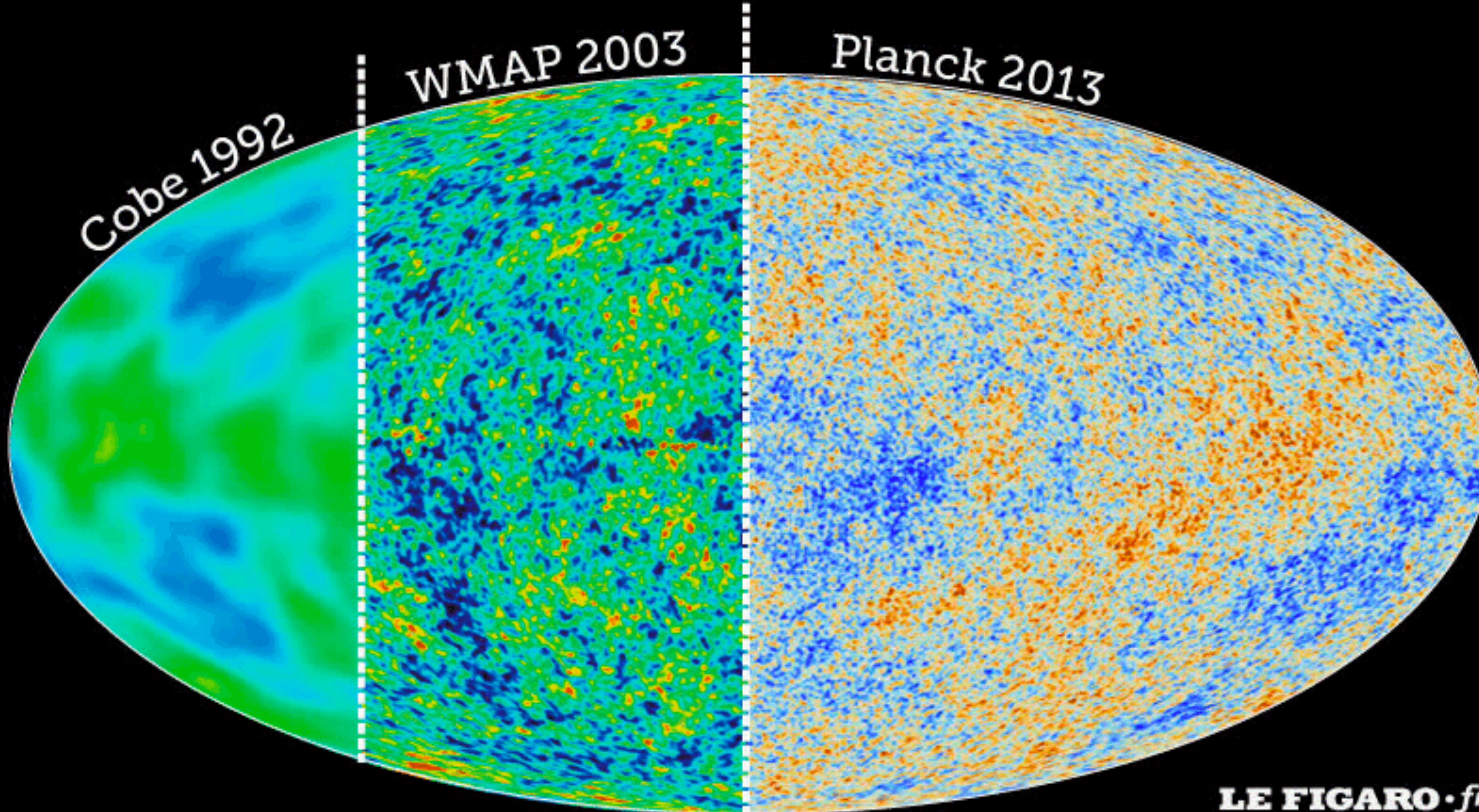
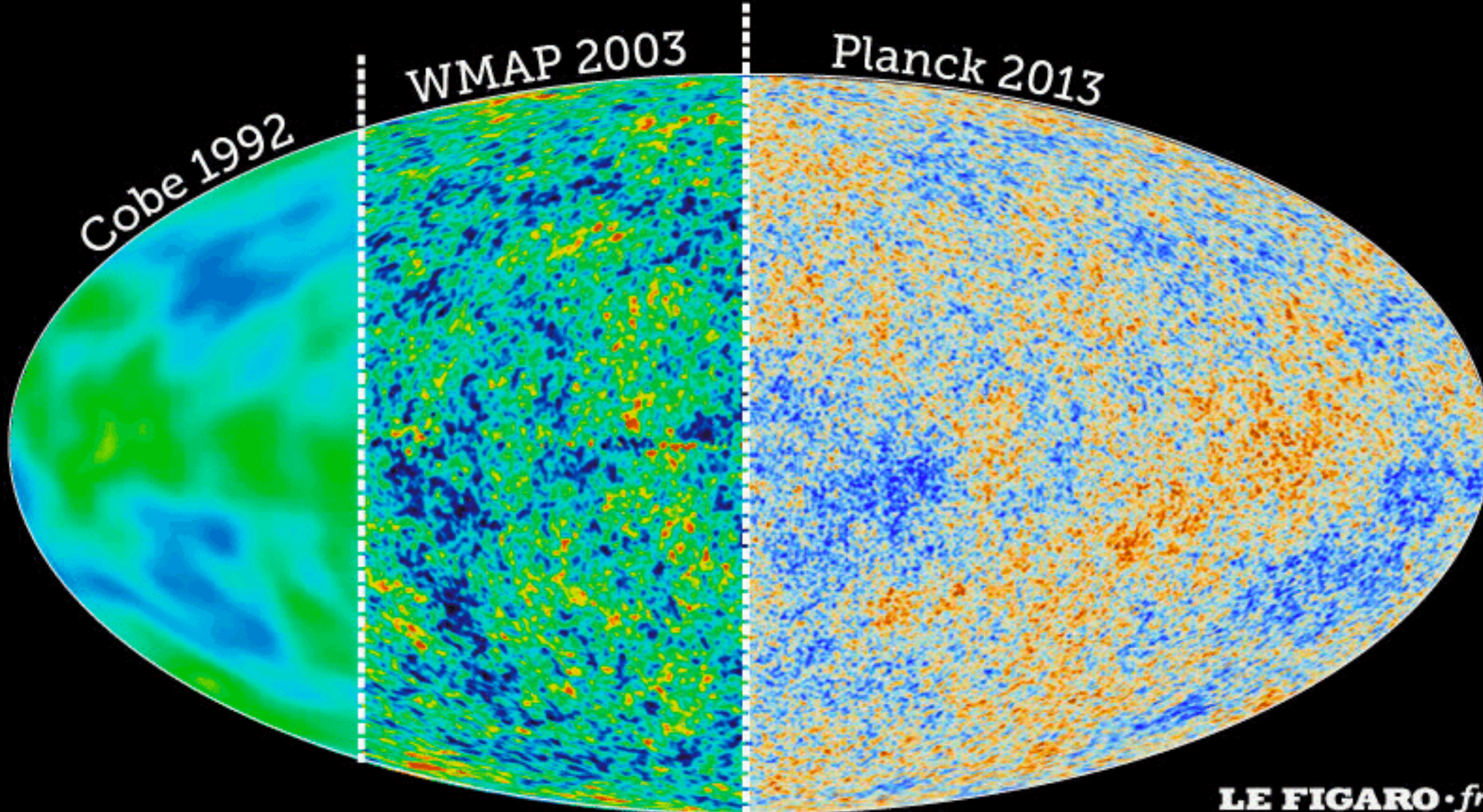


$$\overline{T}_\gamma = 2.7255\,\mathrm{K}$$

Precision Era of Cosmology



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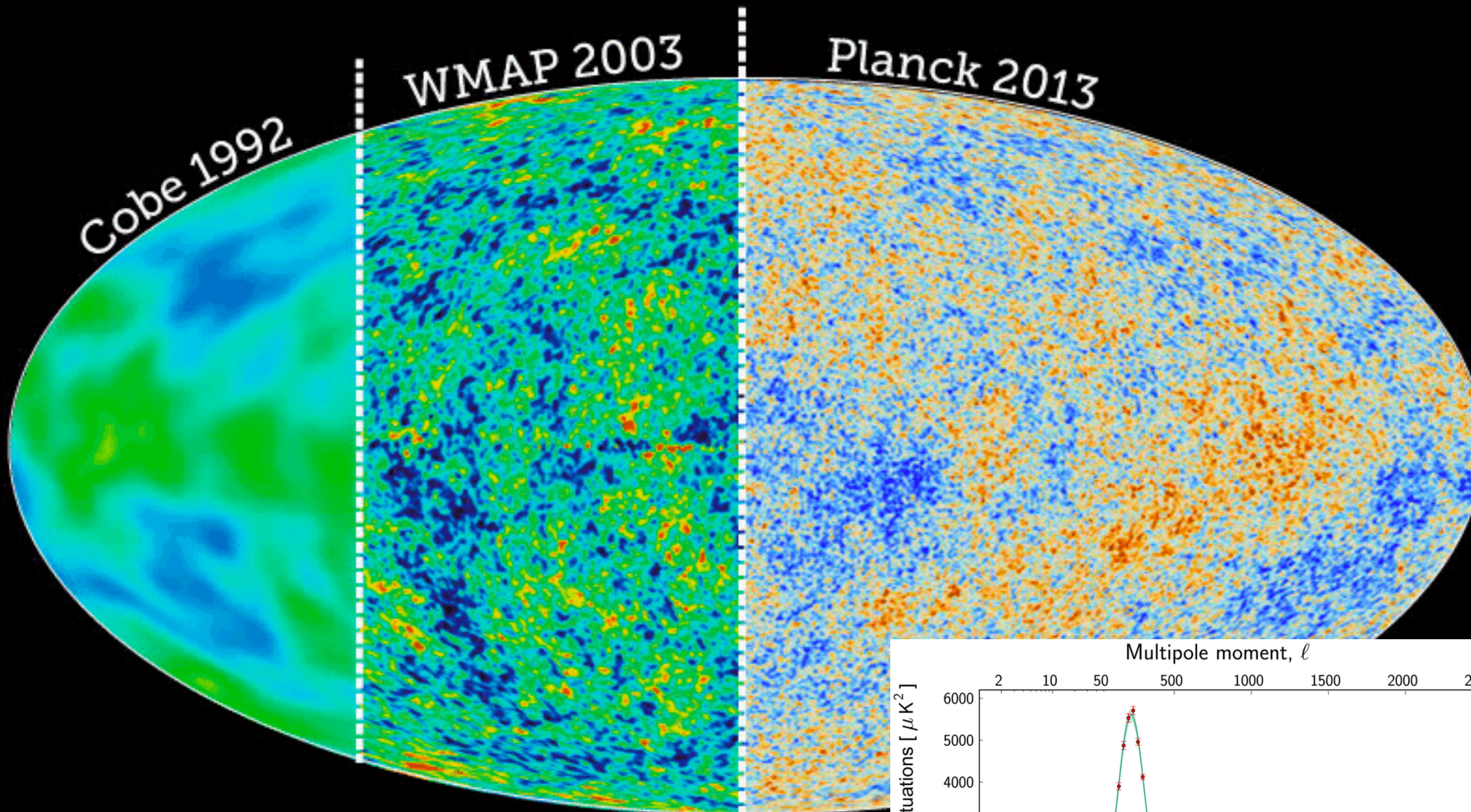
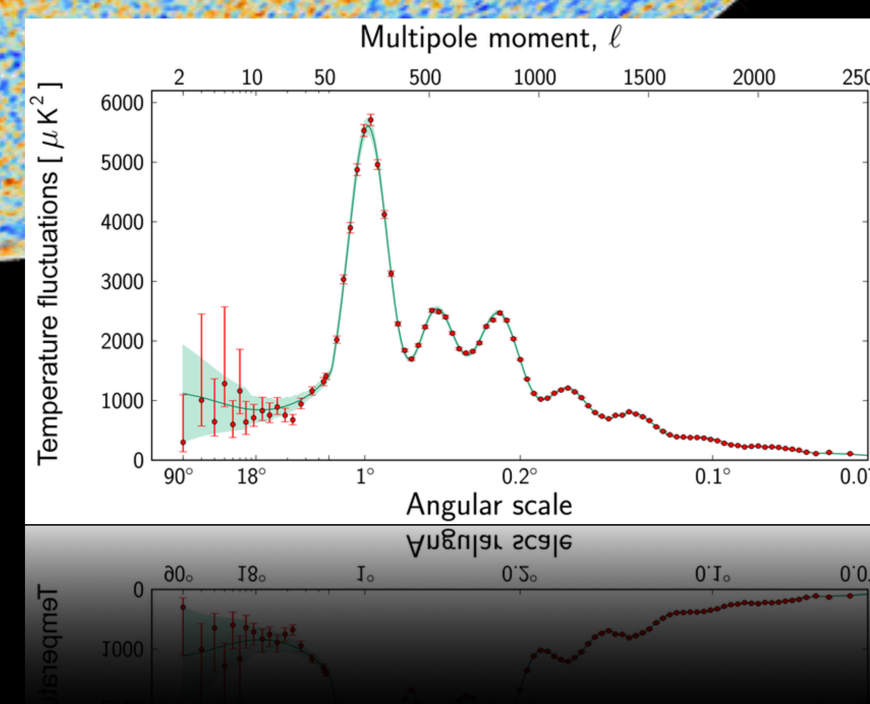
$$\Theta_\gamma = \frac{\delta T_\gamma}{\bar{T}_\gamma} \approx 10^{-5}$$

Precision Era of Cosmology





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Precision Era vs Accuracy Era of Cosmology

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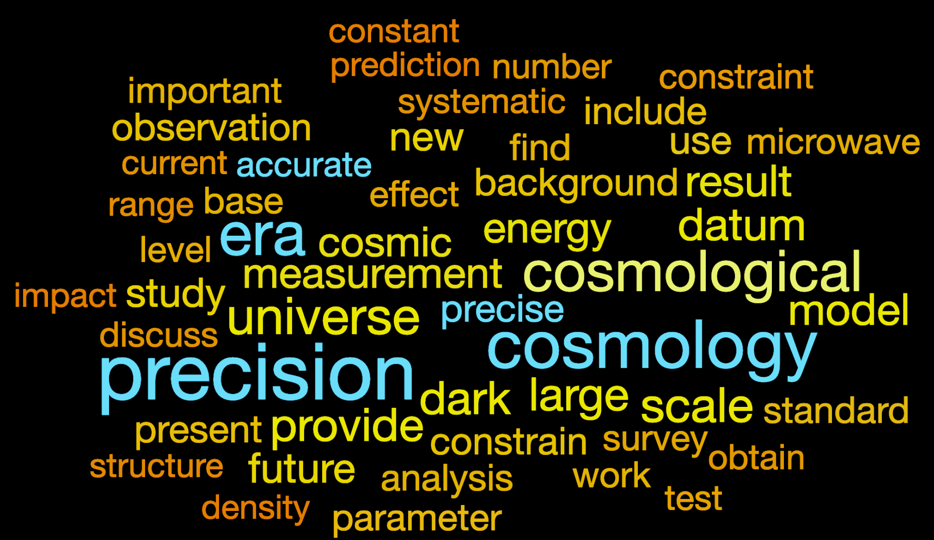

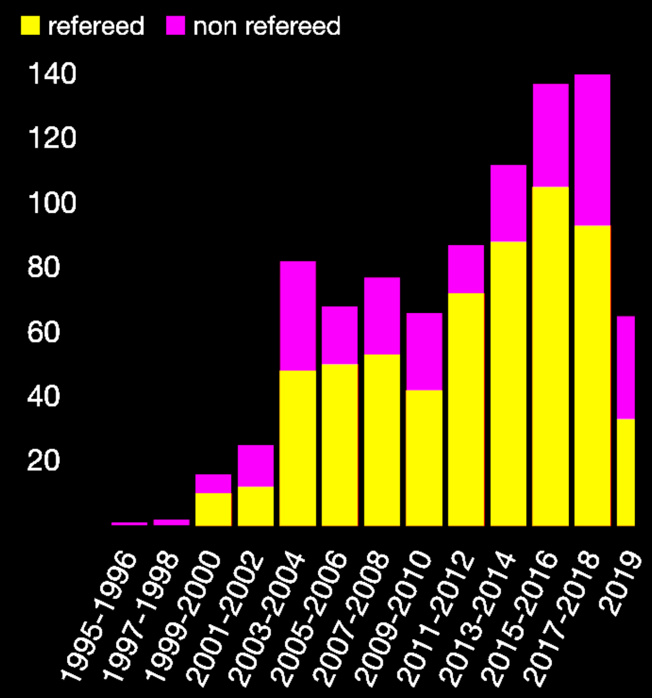

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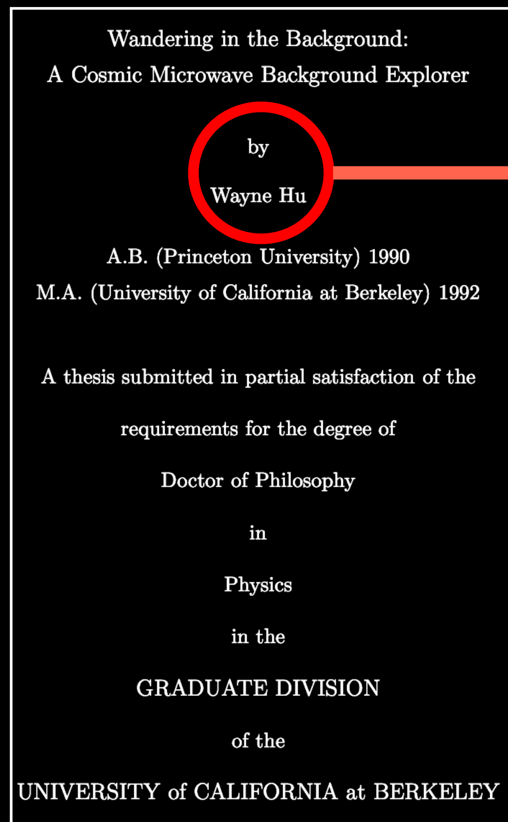

Wandering in the Background:
A Cosmic Microwave Background Explorer

by

Wayne Hu

A.B. (Princeton University) 1990
M.A. (University of California at Berkeley) 1992

A thesis submitted in partial satisfaction of the

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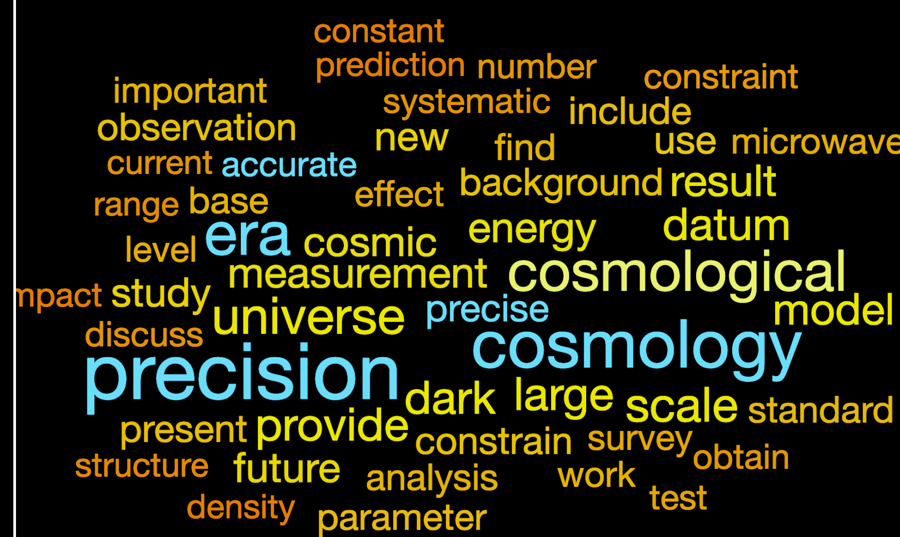

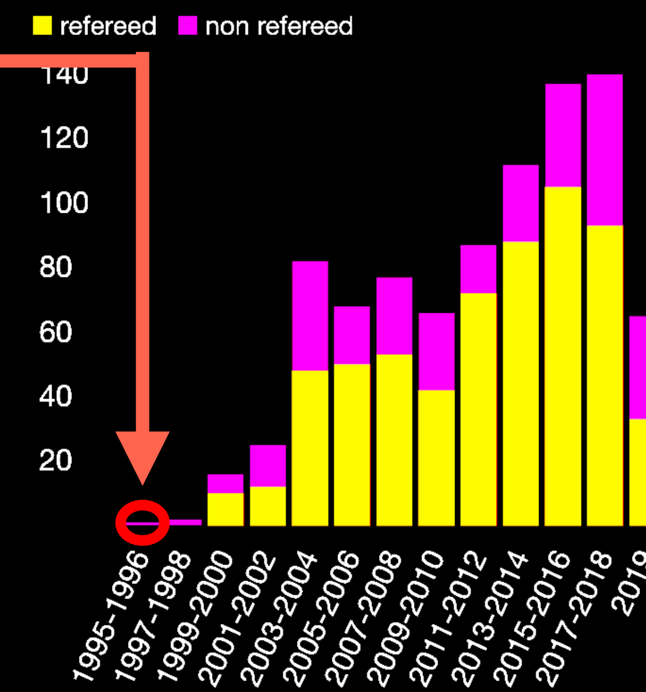

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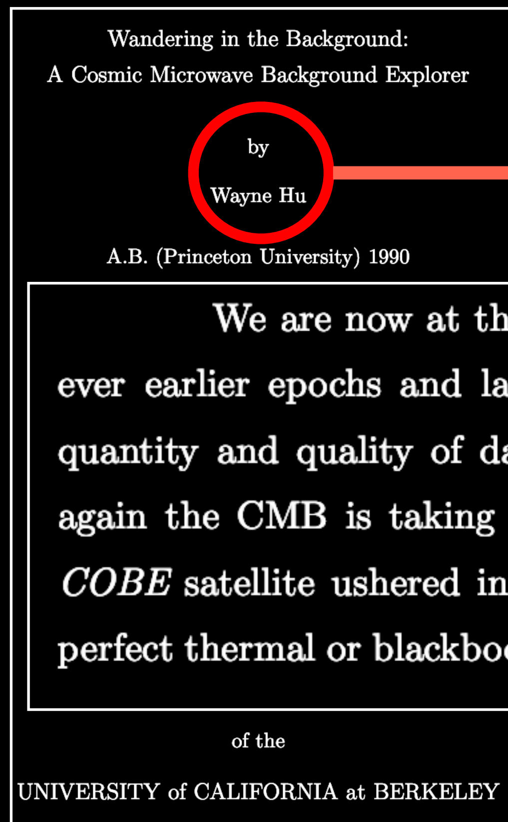
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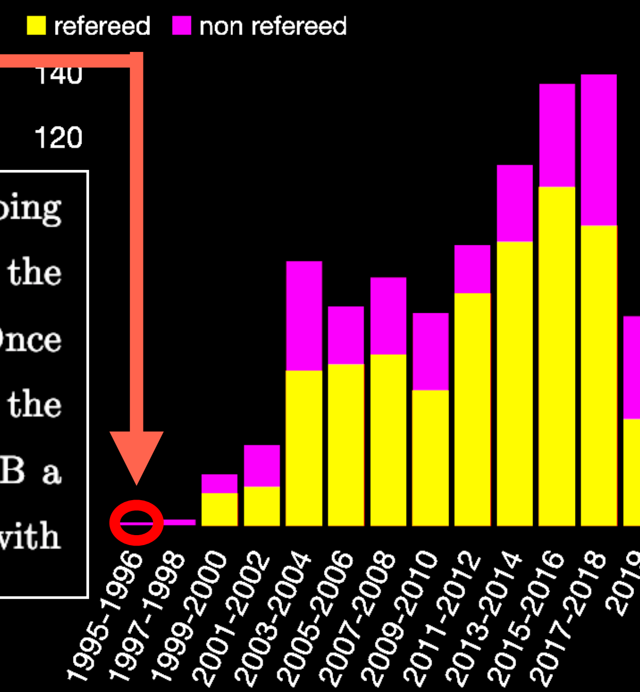
constant
density
parameter
test

We are now at the threshold of a new era in cosmology. With telescopes probing ever earlier epochs and larger volumes, we are making rapid progress in improving the quantity and quality of data. Cosmology is at last becoming a precision science. Once again the CMB is taking a central place in this transition. Launched in late 1989, the *COBE* satellite ushered in the era of precision cosmology. It has revealed in the CMB a perfect thermal or blackbody spectrum of temperature $T_0 = 2.726 \pm 0.010$K (95% CL), with



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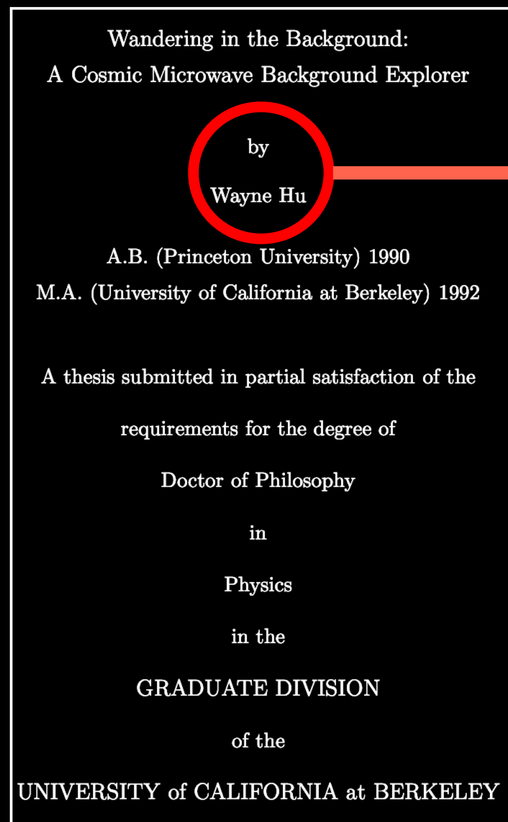

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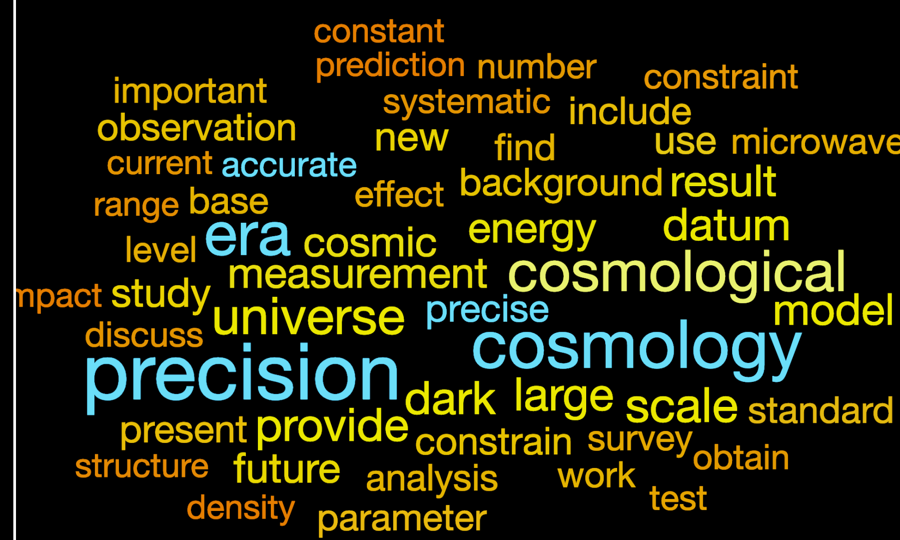

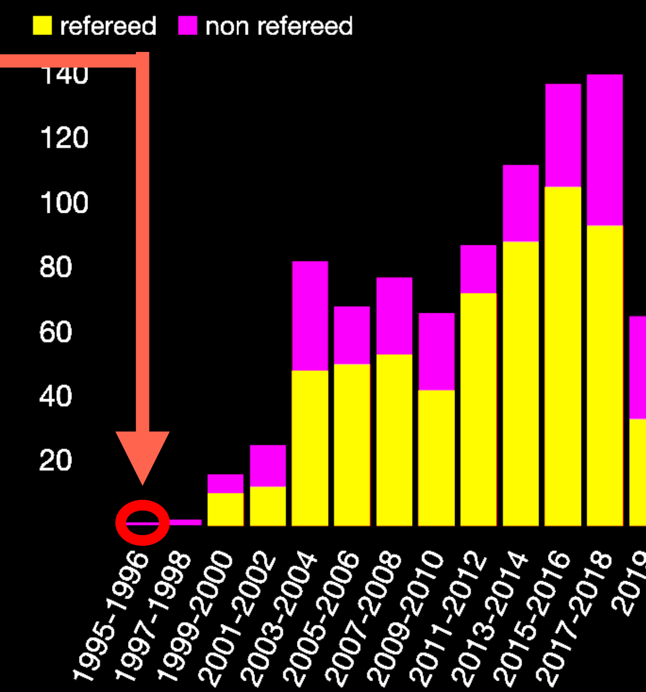

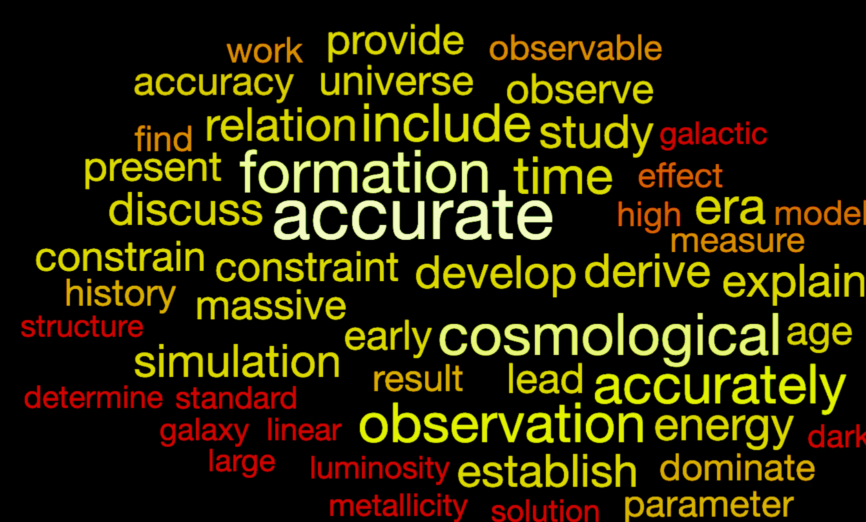

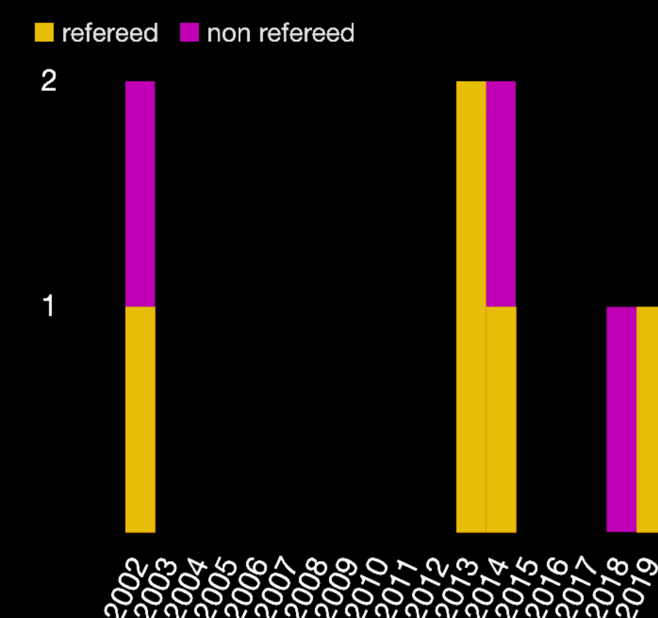

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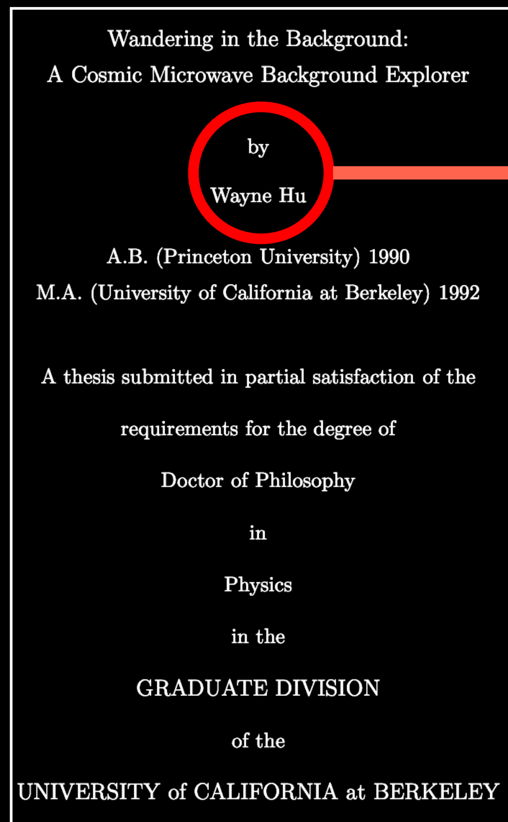

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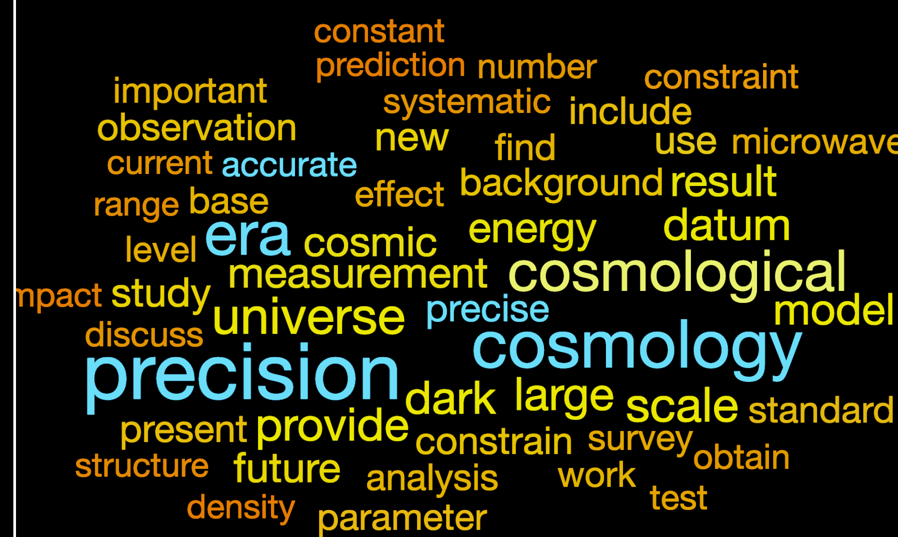
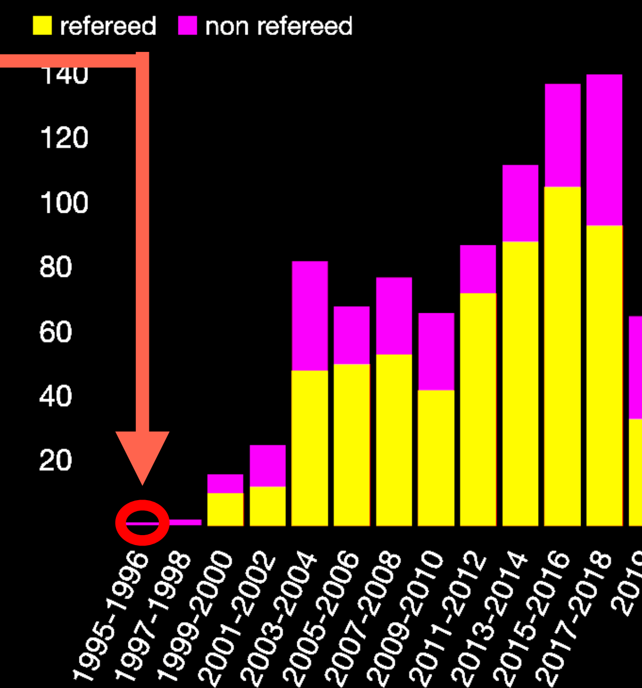
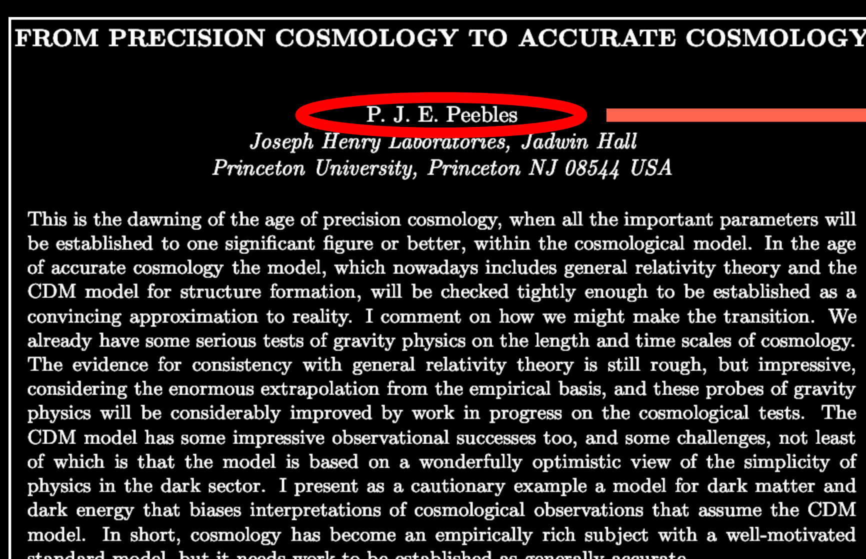


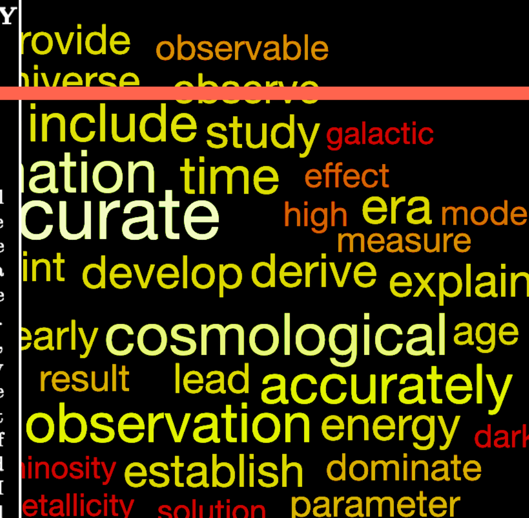


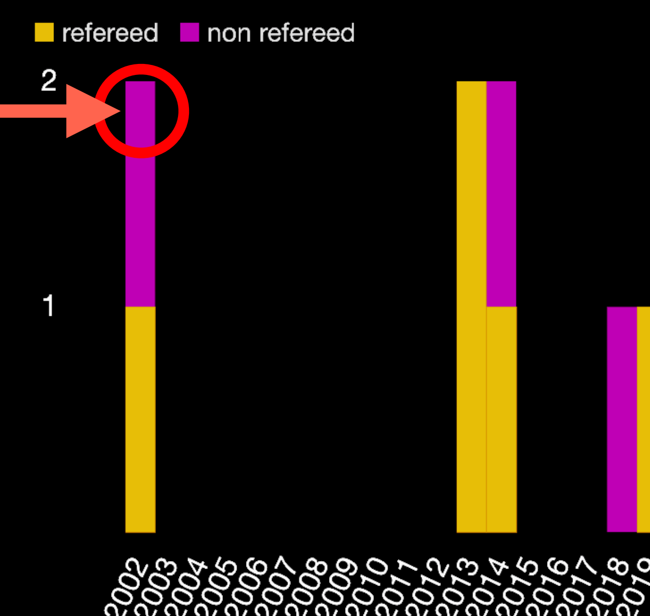


FROM PRECISION COSMOLOGY TO ACCURATE COSMOLOGY

P. J. E. Peebles
Joseph Henry Laboratories, Jadwin Hall
Princeton University, Princeton NJ 08544 USA

This is the dawning of the age of precision cosmology, when all the important parameters will be established to one significant figure or better, within the cosmological model. In the age of accurate cosmology the model, which nowadays includes general relativity theory and the CDM model for structure formation, will be checked tightly enough to be established as a convincing approximation to reality. I comment on how we might make the transition. We already have some serious tests of gravity physics on the length and time scales of cosmology. The evidence for consistency with general relativity theory is still rough, but impressive, considering the enormous extrapolation from the empirical basis, and these probes of gravity physics will be considerably improved by work in progress on the cosmological tests. The CDM model has some impressive observational successes too, and some challenges, not least of which is that the model is based on a wonderfully optimistic view of the simplicity of physics in the dark sector. I present as a cautionary example a model for dark matter and dark energy that biases interpretations of cosmological observations that assume the CDM model. In short, cosmology has become an empirically rich subject with a well-motivated standard model, but it needs work to be established as generally accurate.





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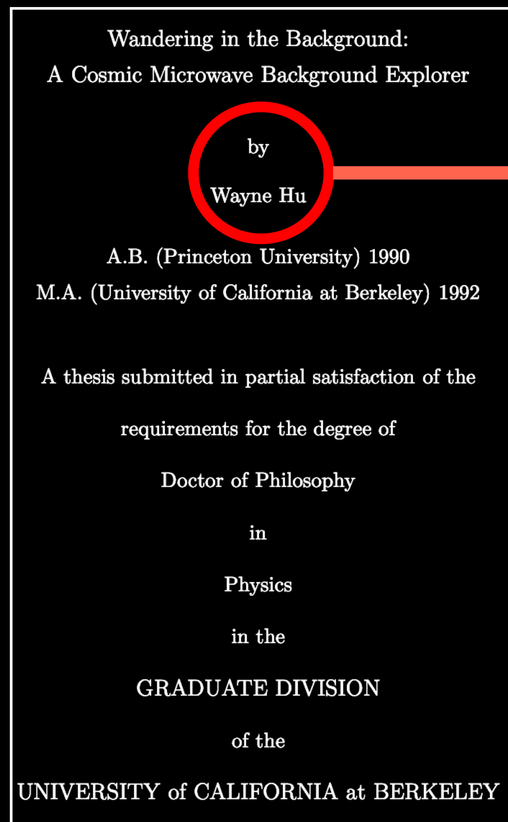
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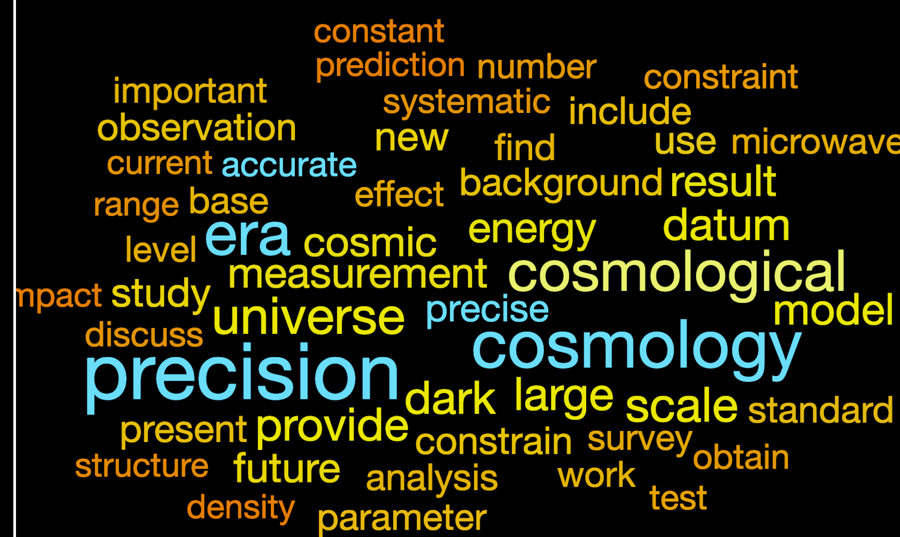

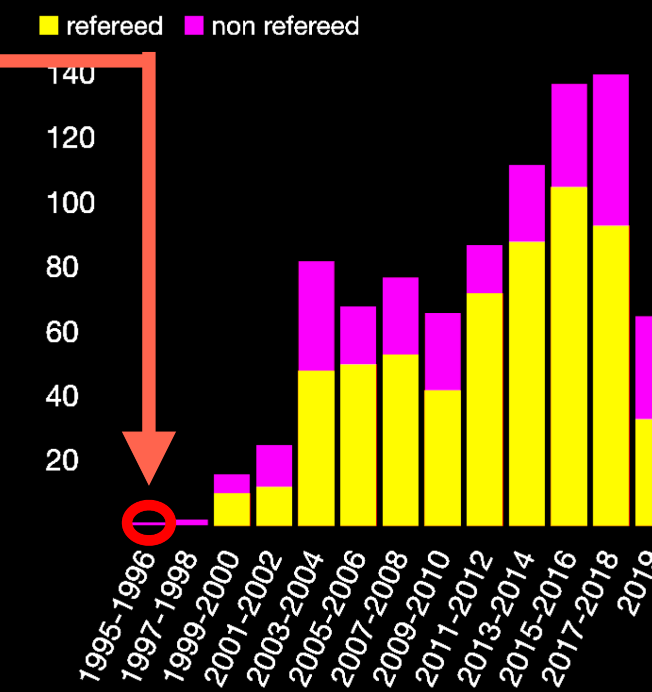

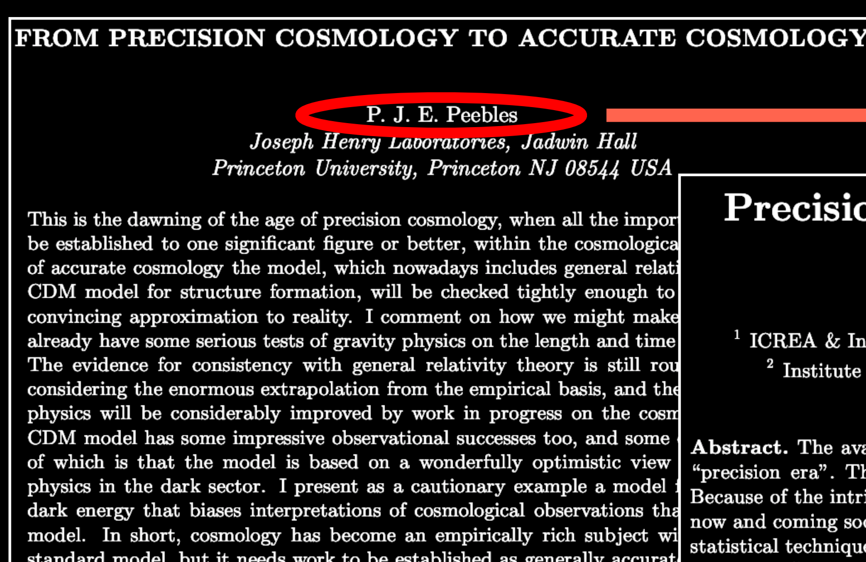
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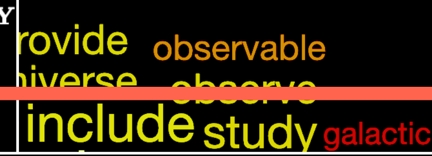
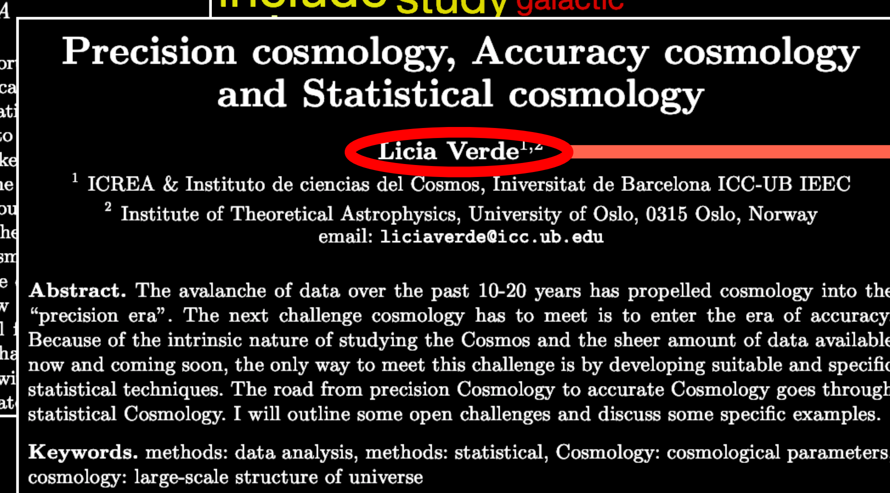


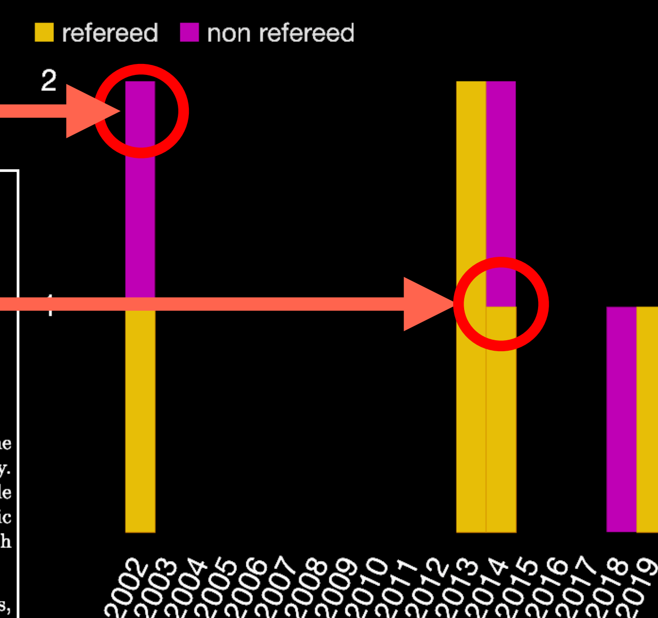

Precision cosmology, Accuracy cosmology and Statistical cosmology

Licia Verde[1,2]

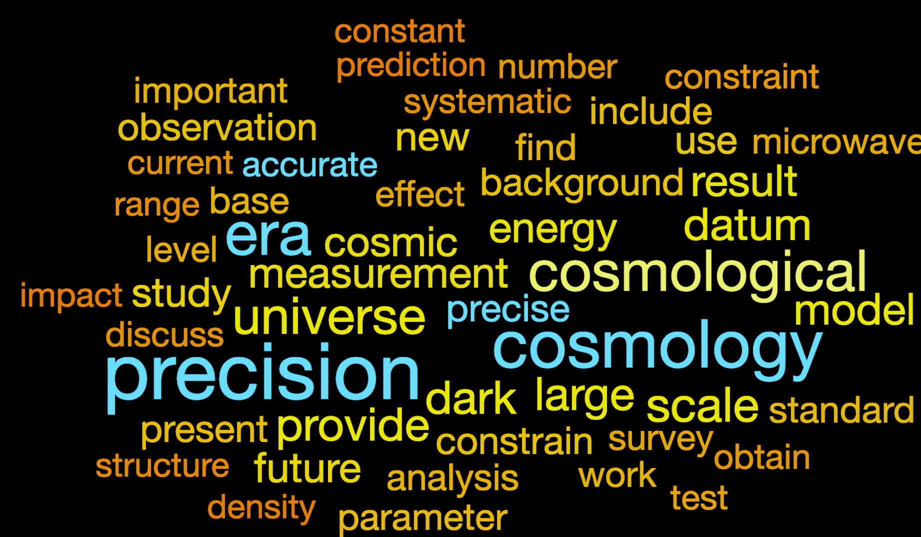
[1] ICREA & Instituto de ciencias del Cosmos, Universitat de Barcelona ICC-UB IEEC
[2] Institute of Theoretical Astrophysics, University of Oslo, 0315 Oslo, Norway
email: liciaverde@icc.ub.edu

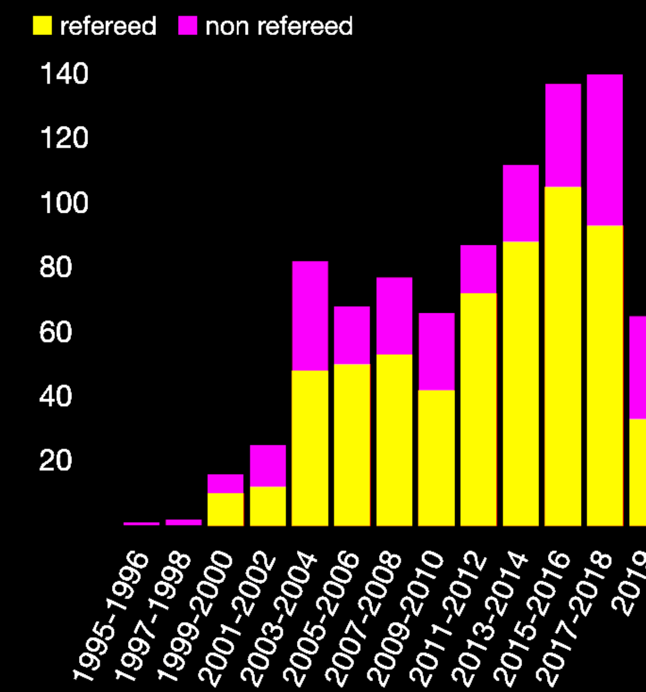
Abstract. The avalanche of data over the past 10-20 years has propelled cosmology into the "precision era". The next challenge cosmology has to meet is to enter the era of accuracy. Because of the intrinsic nature of studying the Cosmos and the sheer amount of data available now and coming soon, the only way to meet this challenge is by developing suitable and specific statistical techniques. The road from precision Cosmology to accurate Cosmology goes through statistical Cosmology. I will outline some open challenges and discuss some specific examples.

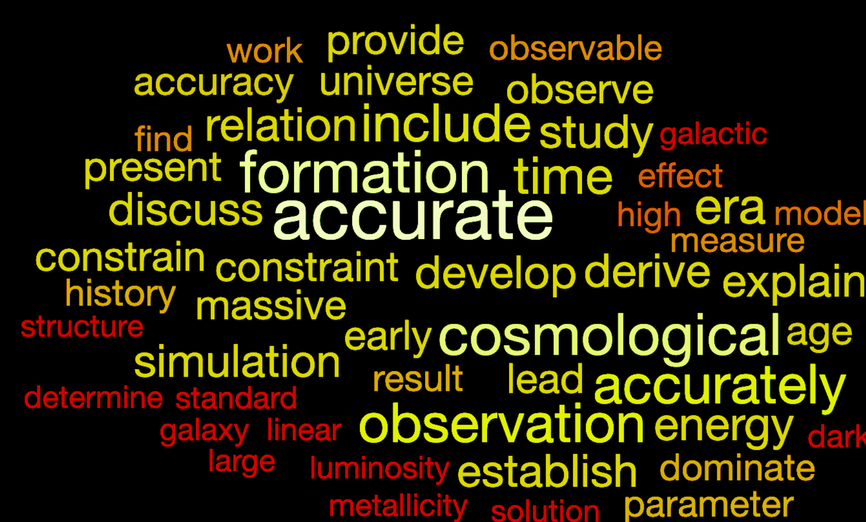
Keywords. methods: data analysis, methods: statistical, Cosmology: cosmological parameters, cosmology: large-scale structure of universe

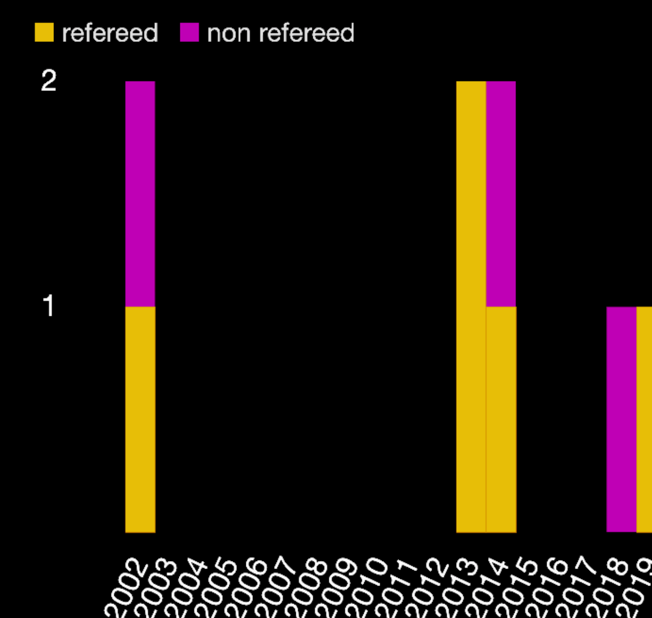


Precision Era vs Accuracy Era of Cosmology









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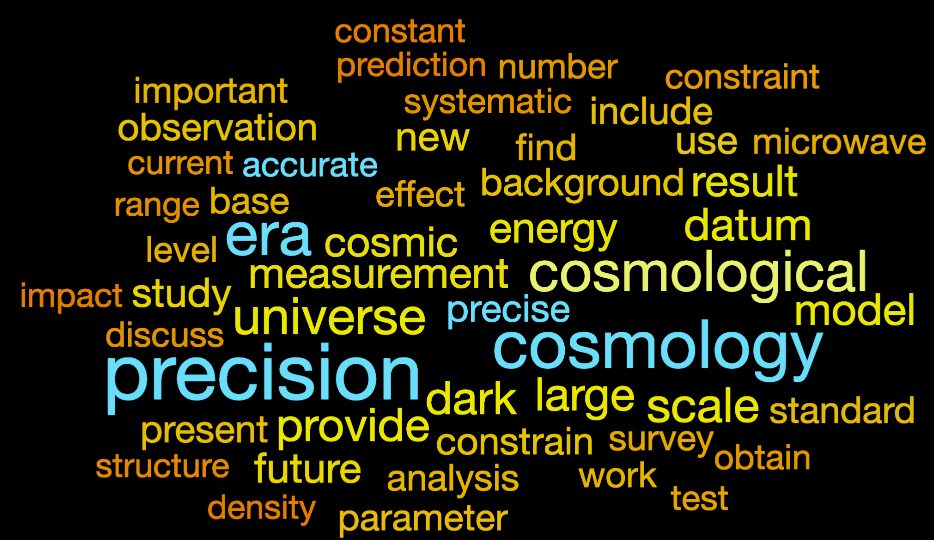

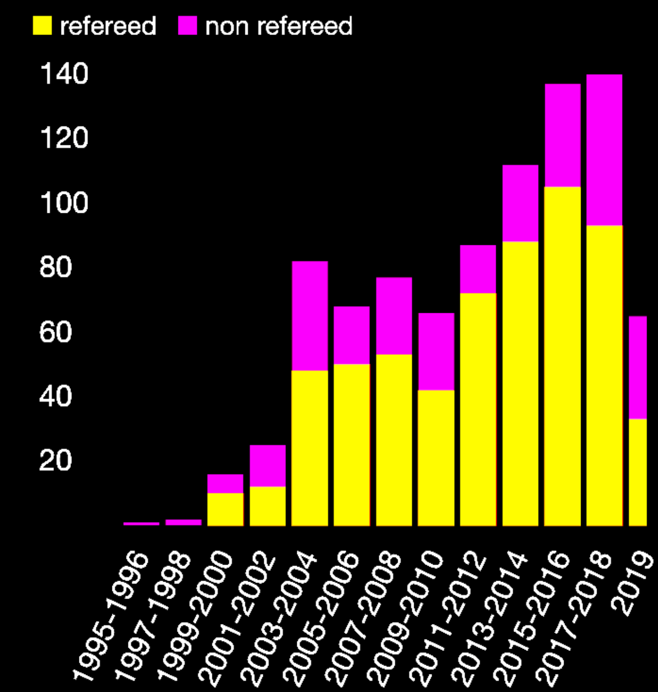

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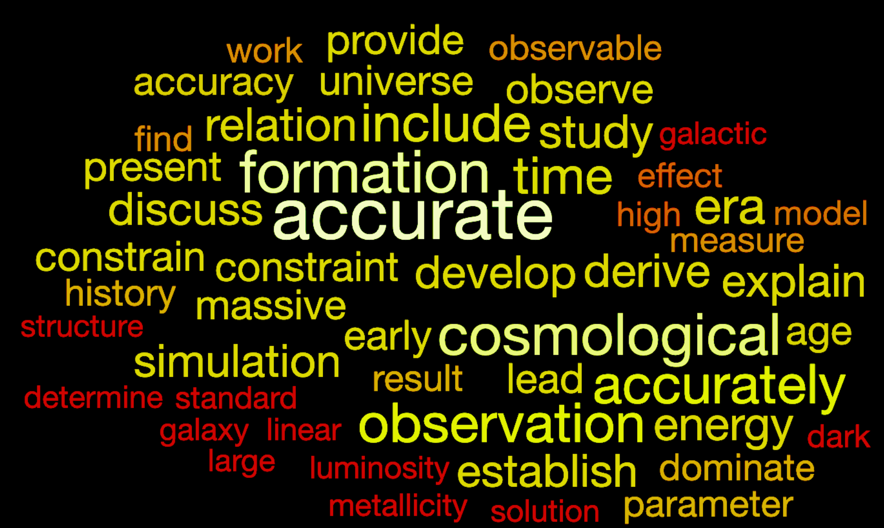
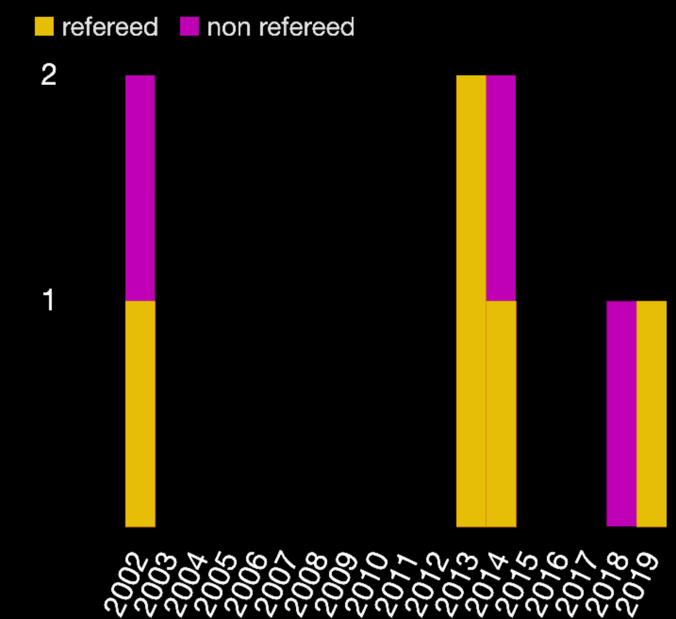




Precision Era vs Accuracy Era of Cosmology

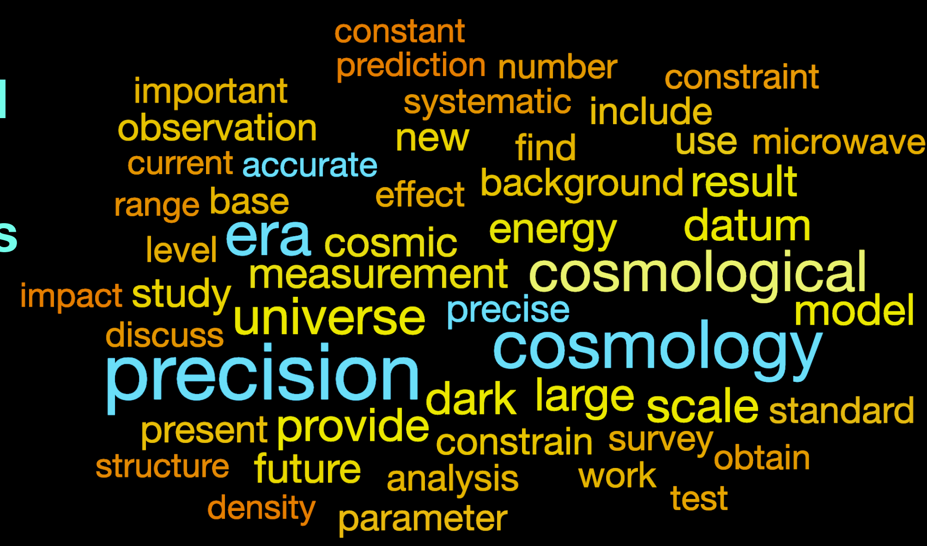
Claiming Precision:

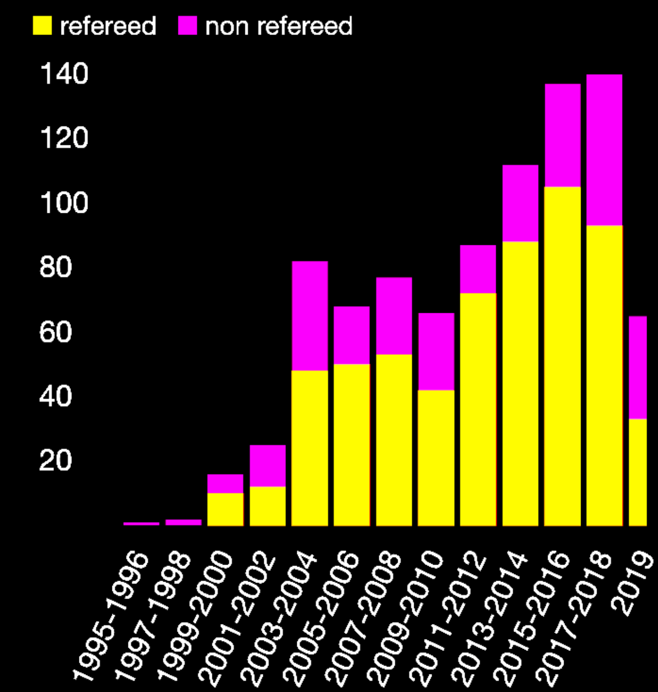
- small statistical error

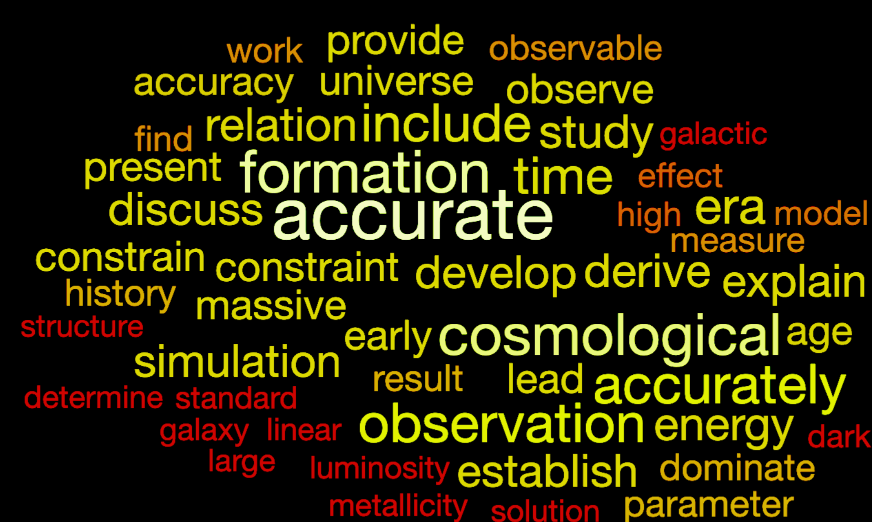
- tight constraints on model parameters

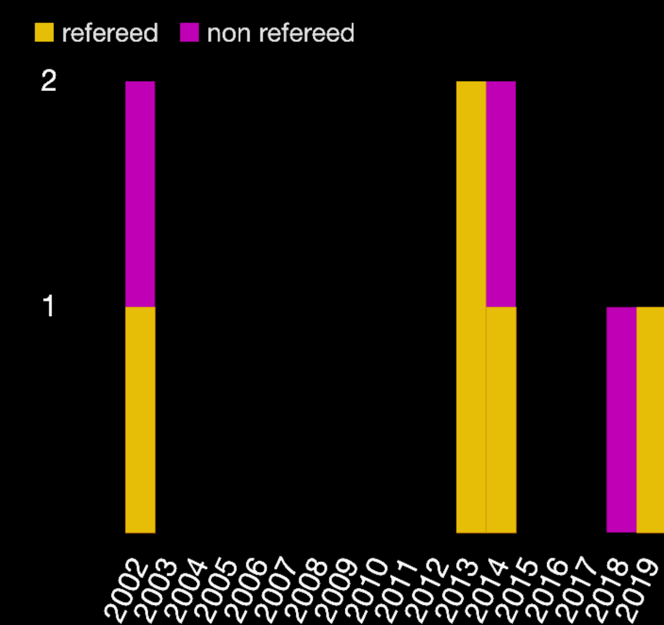
“Easy”

WHY ???









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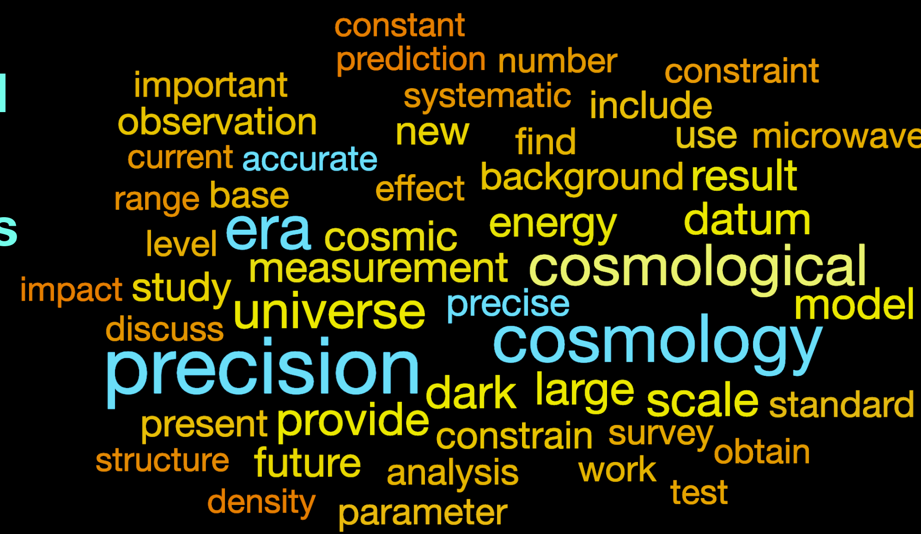
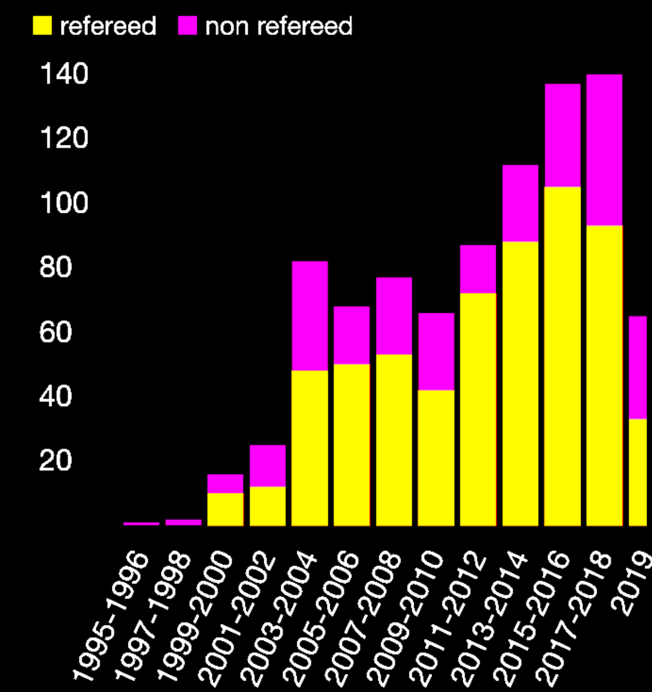


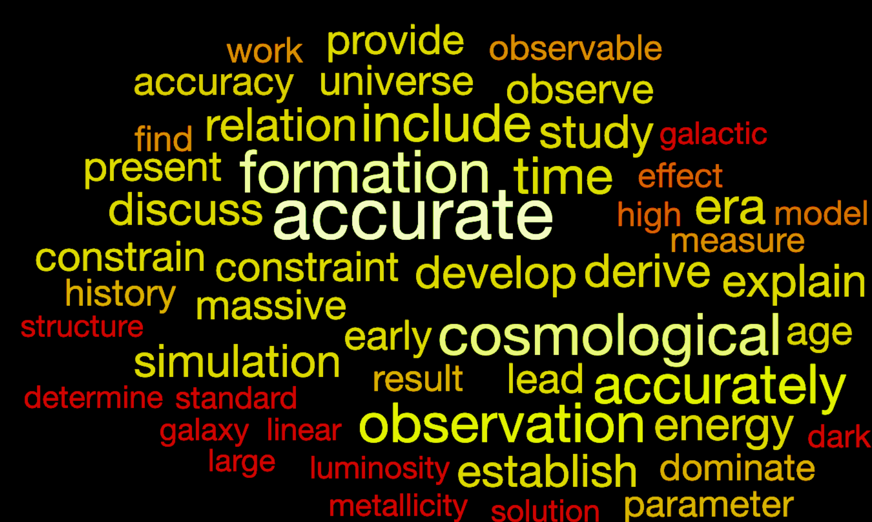


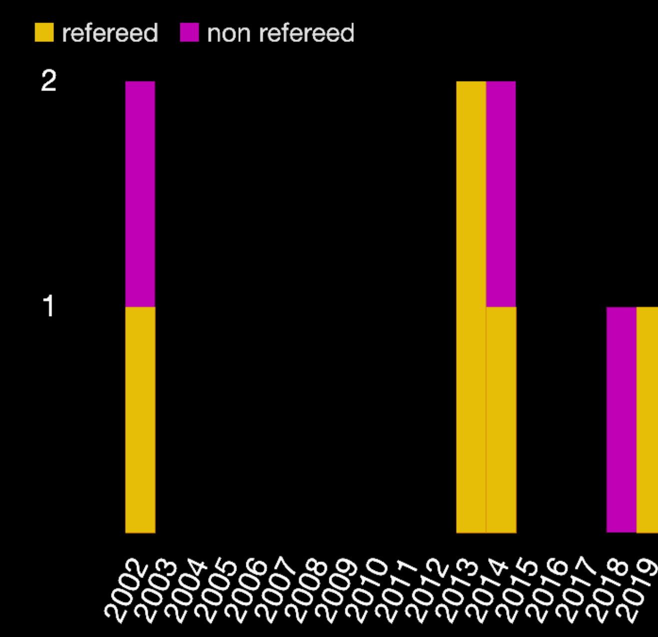
WHY ???

Claiming Accuracy:

- small systematic error
- model good description of reality

"Hard"





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3. From observations to LSS catalogue:
   DESI **End-to-end** pipeline and systematics

4. Testing Systematics for DESI BAO analysis

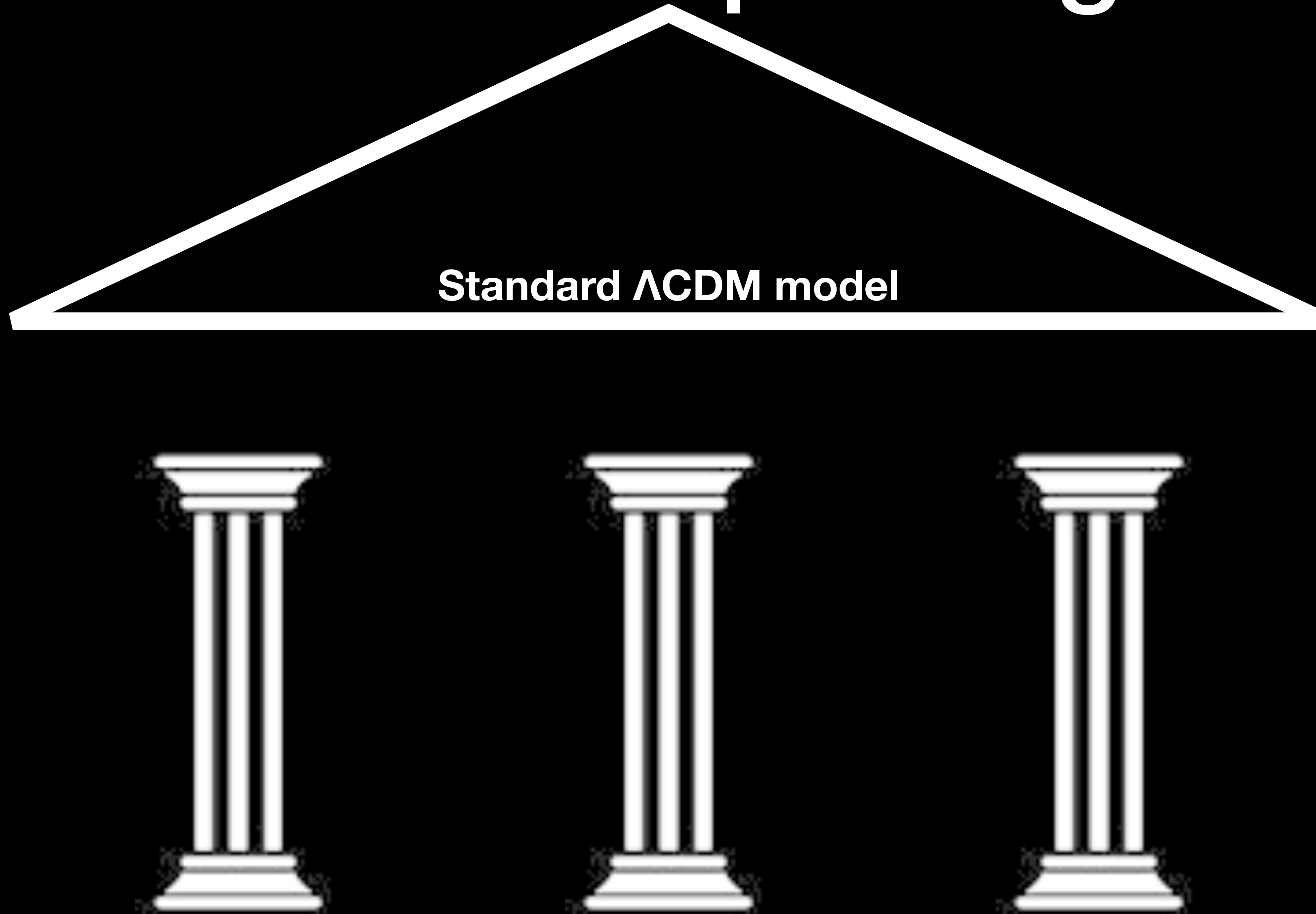
5. Outlook and Conclusion

Introduction to Cosmology:

From Alpha to Ω

The ΛCDM paradigm

The ΛCDM paradigm



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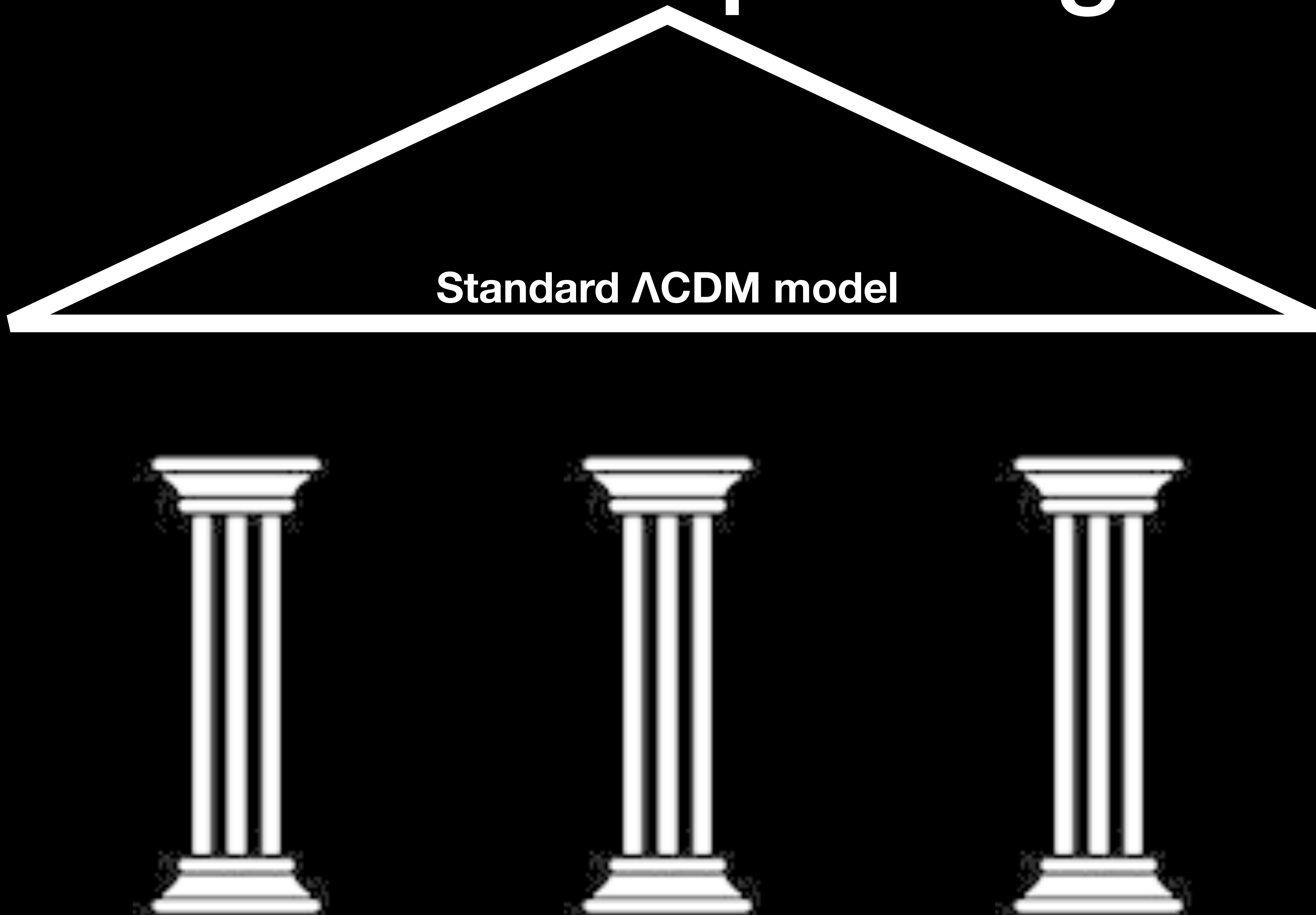


CP

(Cosmological Principle)

The ΛCDM paradigm

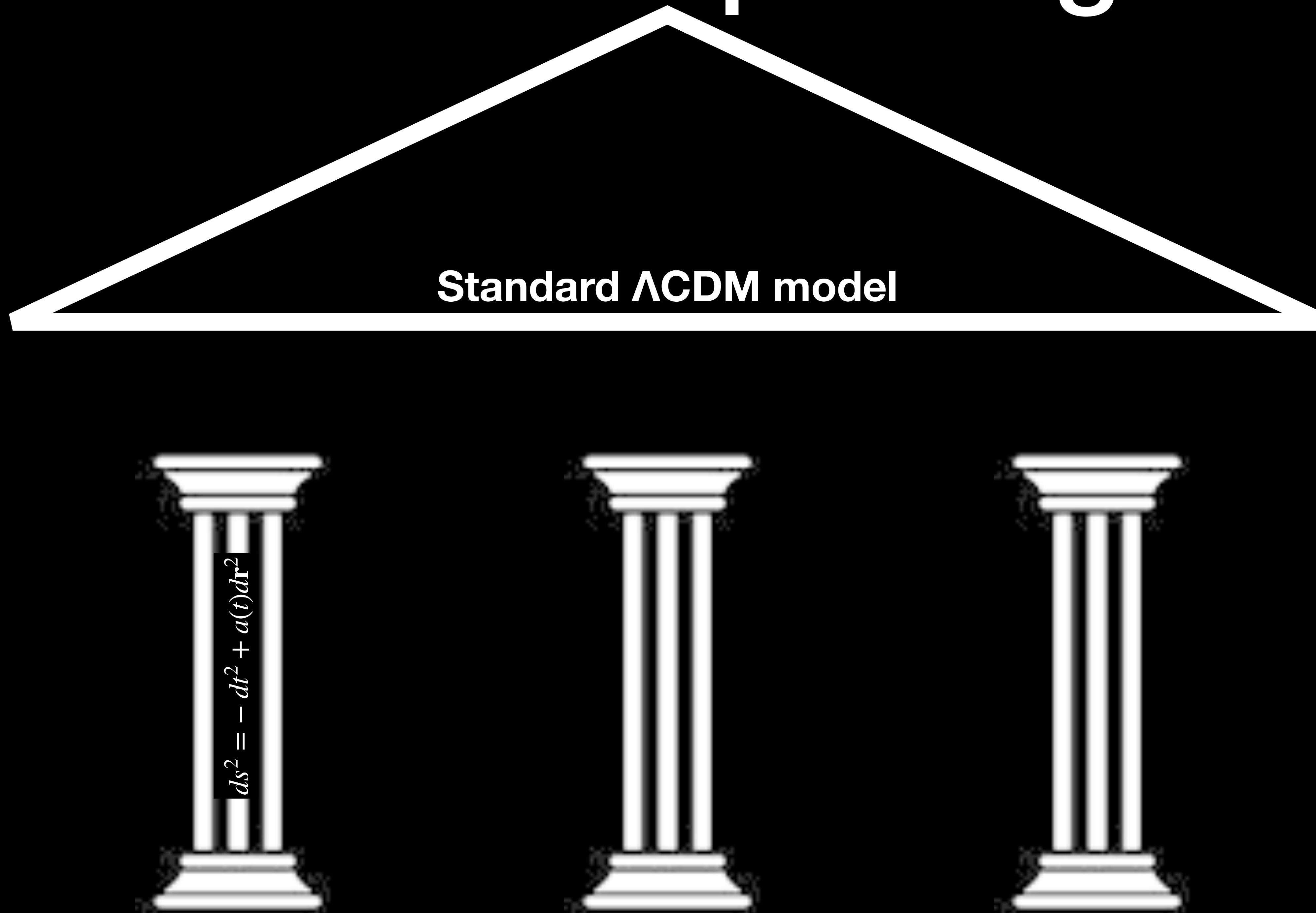
Standard ΛCDM model

$$ds^2 = -\,dt^2 + a(t)d\mathbf{r}^2$$

CP

(Cosmological Principle)

The ΛCDM paradigm



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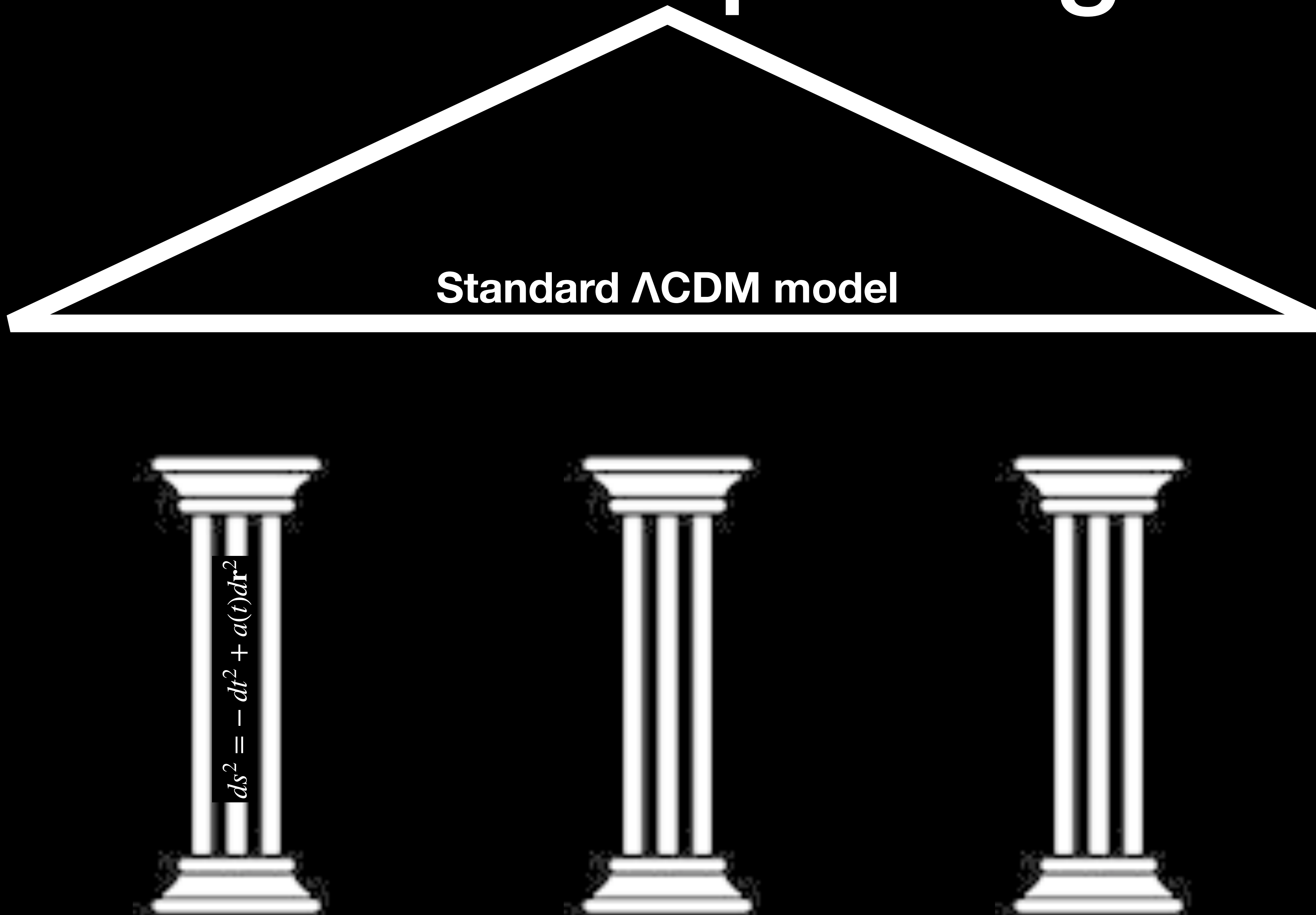

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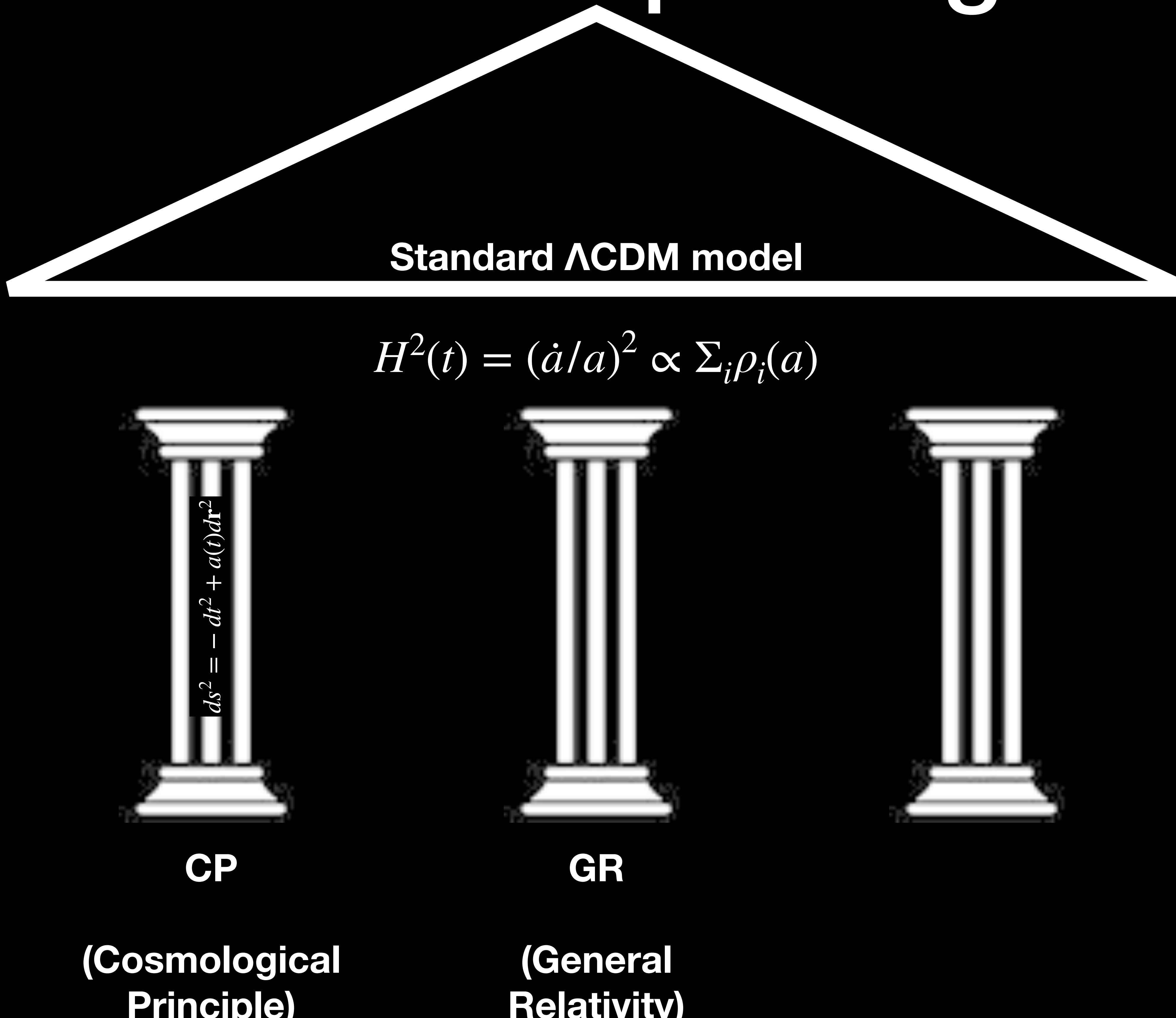

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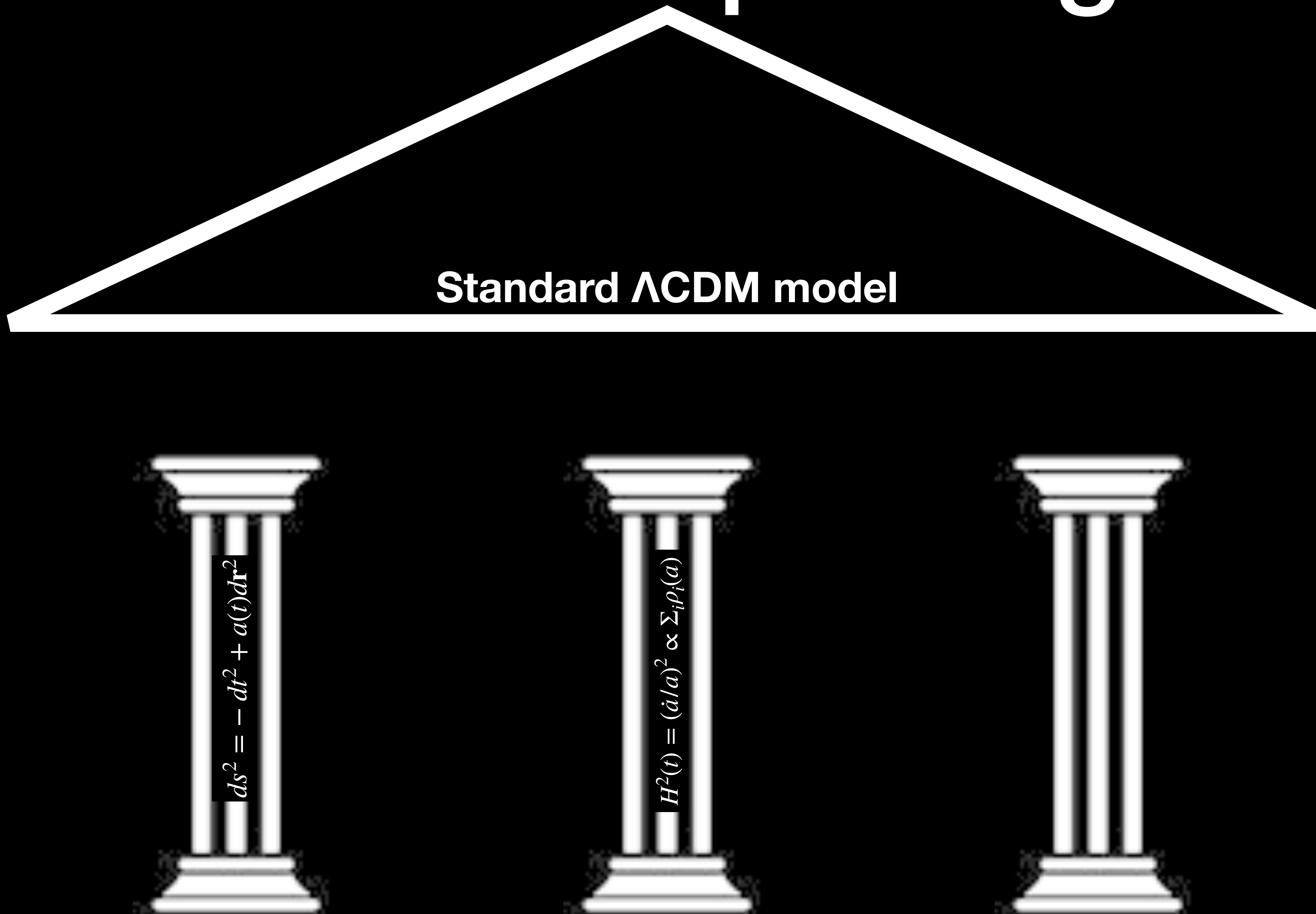

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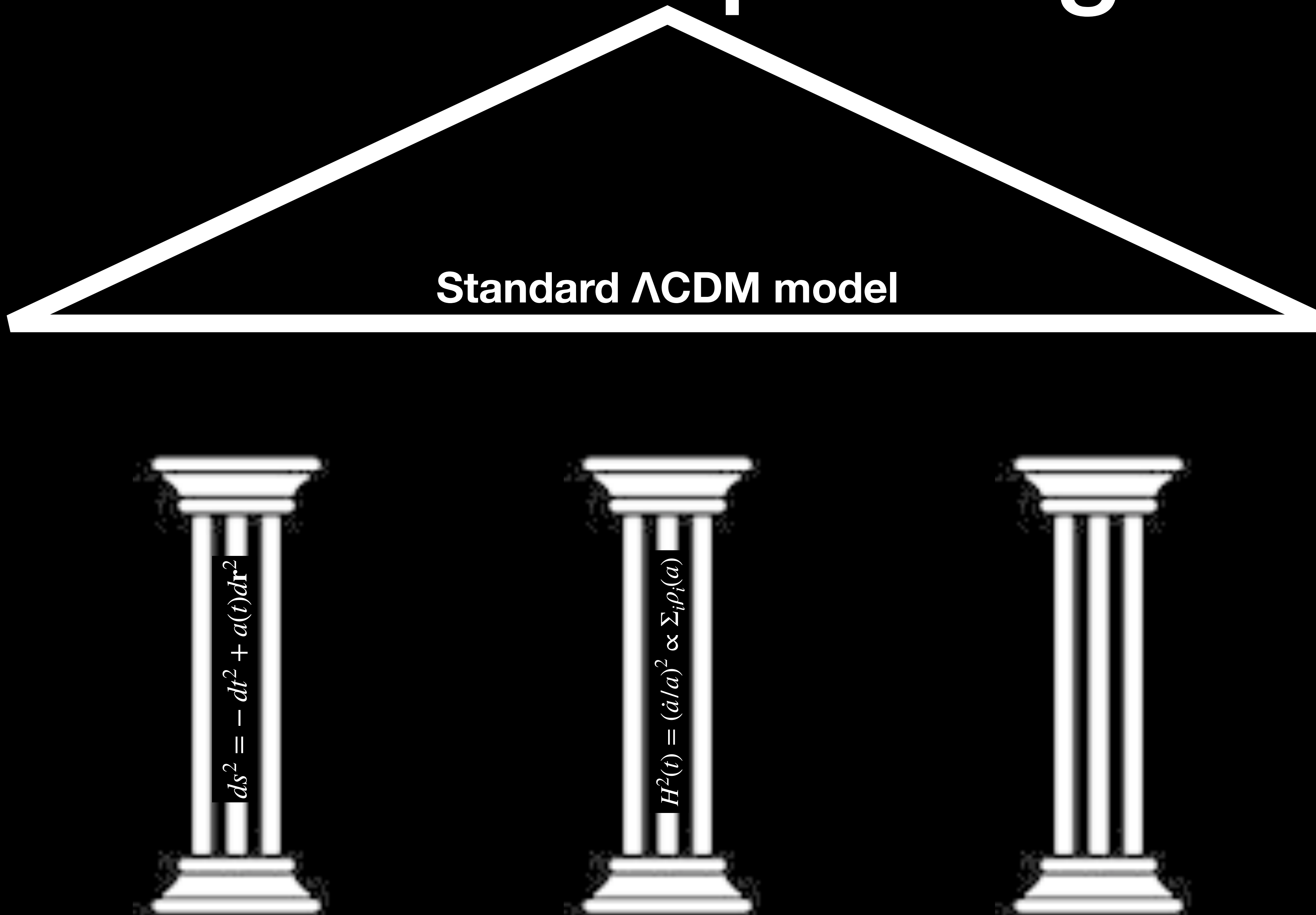
GR

(General Relativity)

The ΛCDM paradigm



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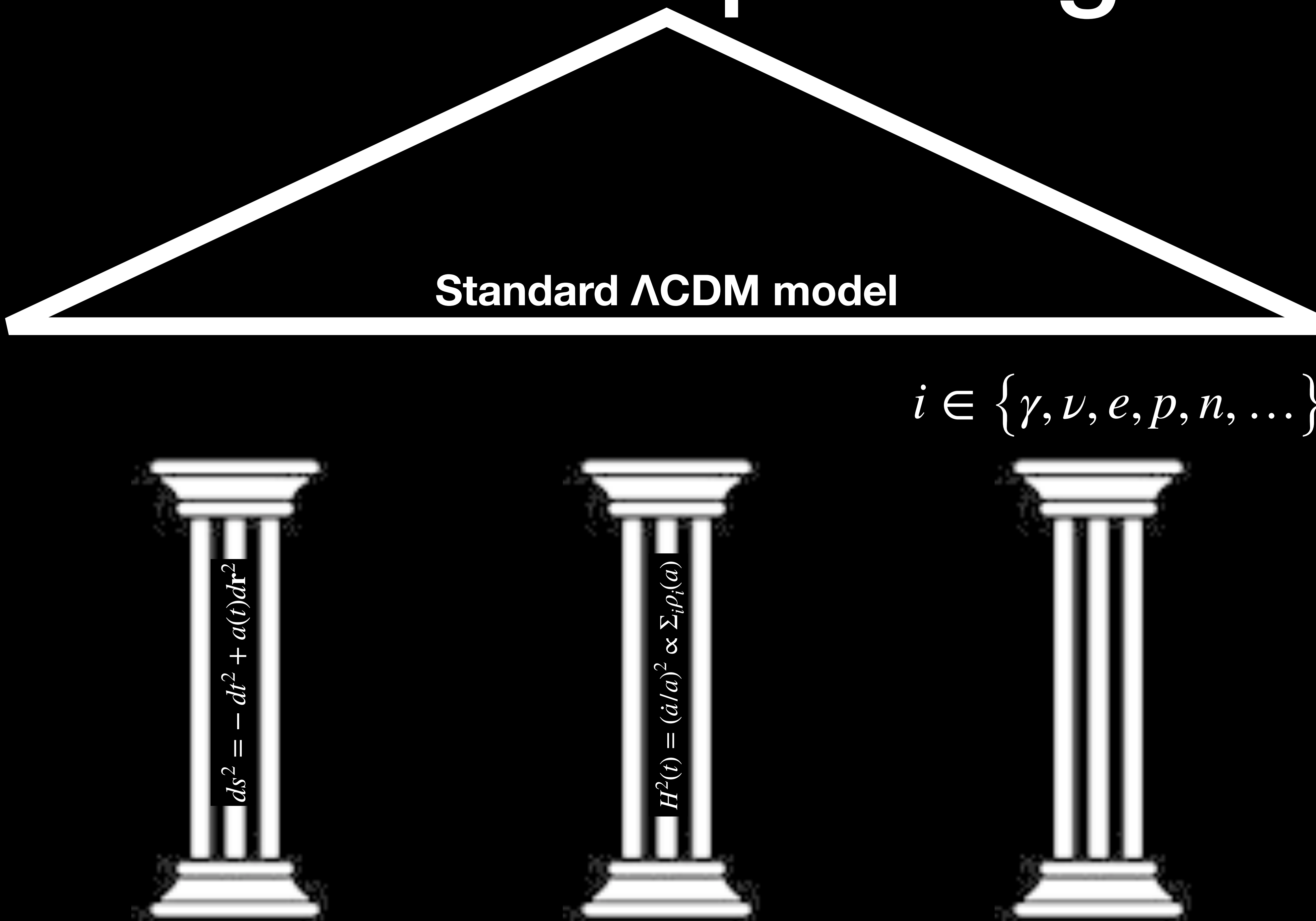

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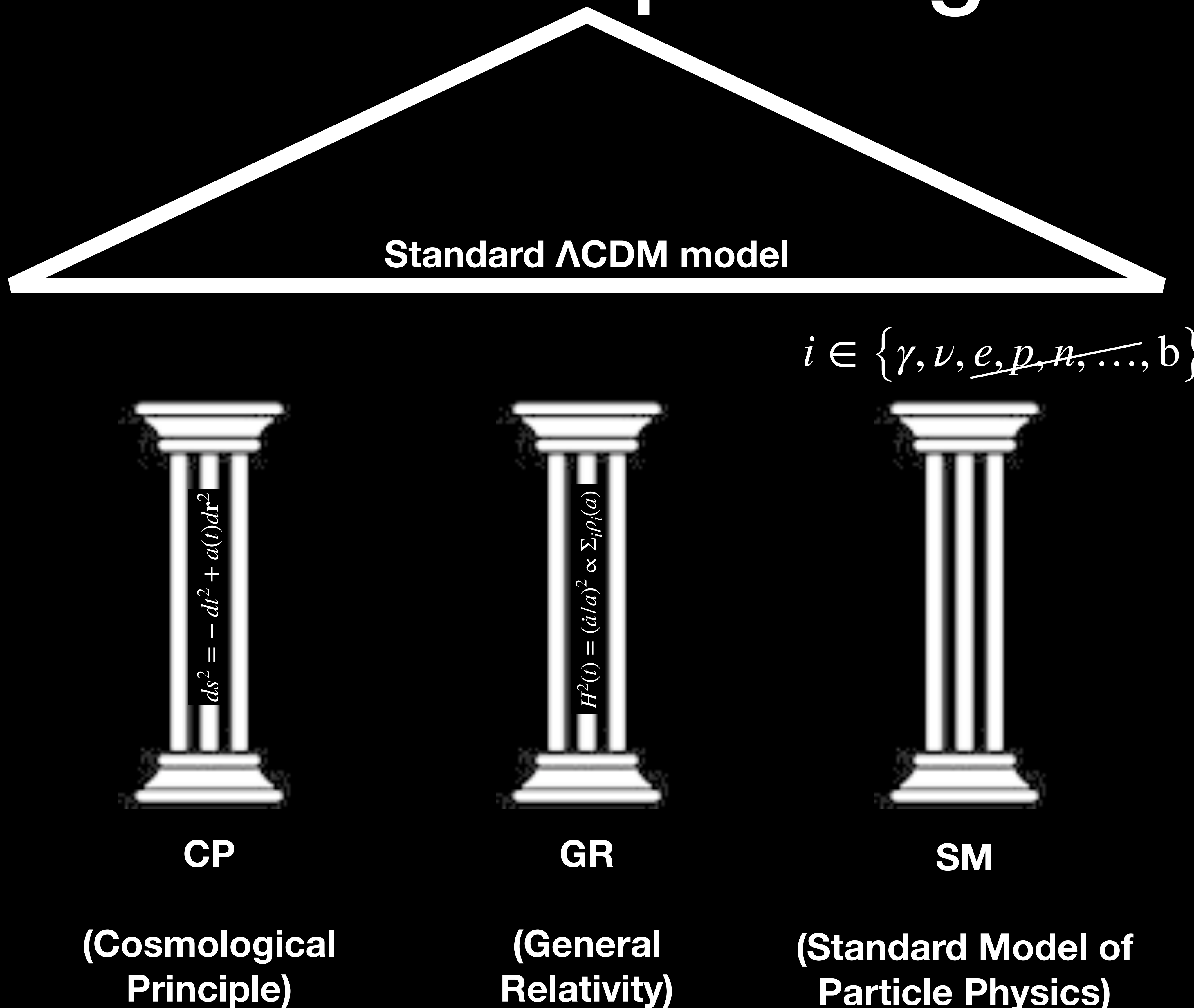
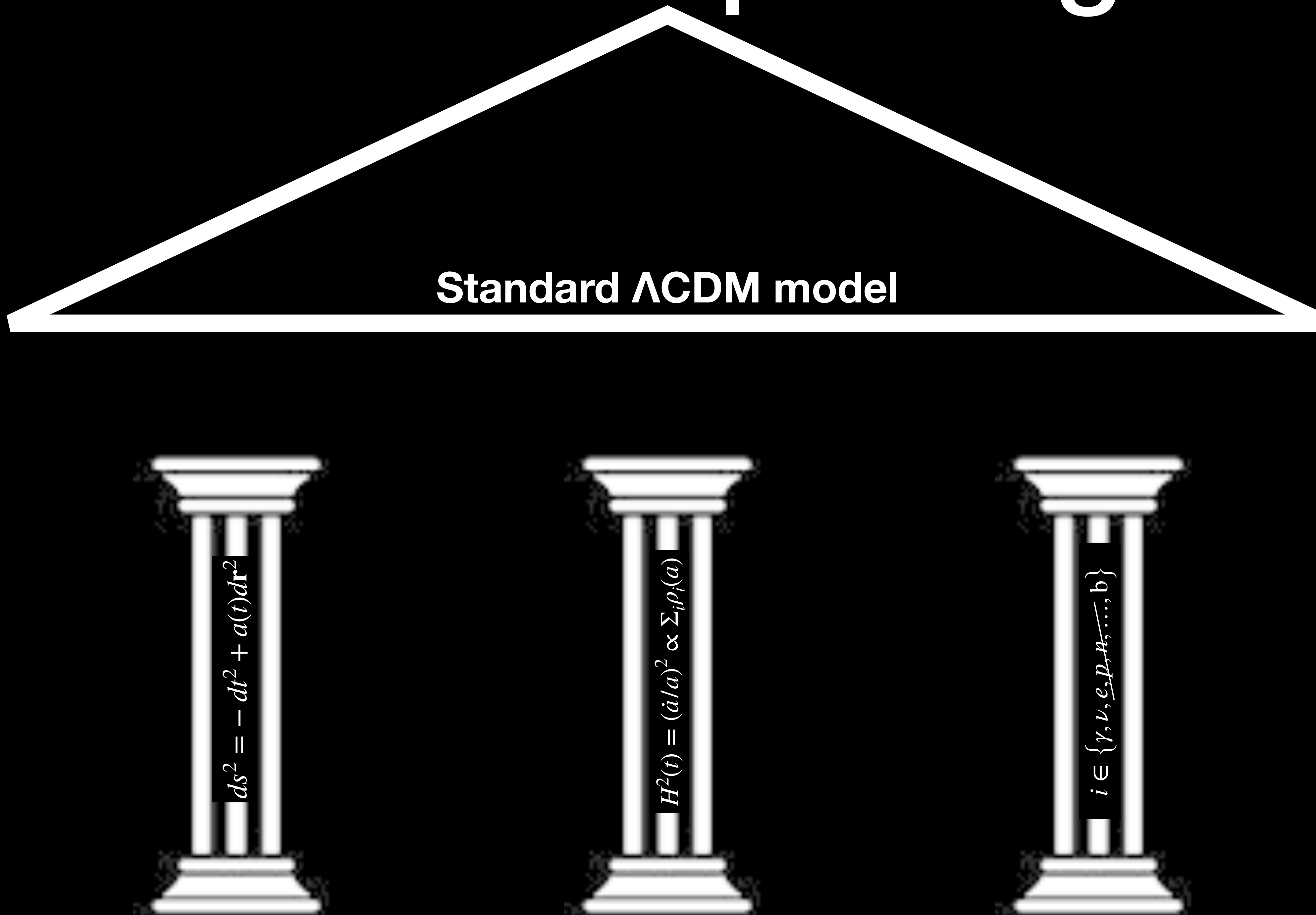


The ΛCDM paradigm



CP

(Cosmological Principle)

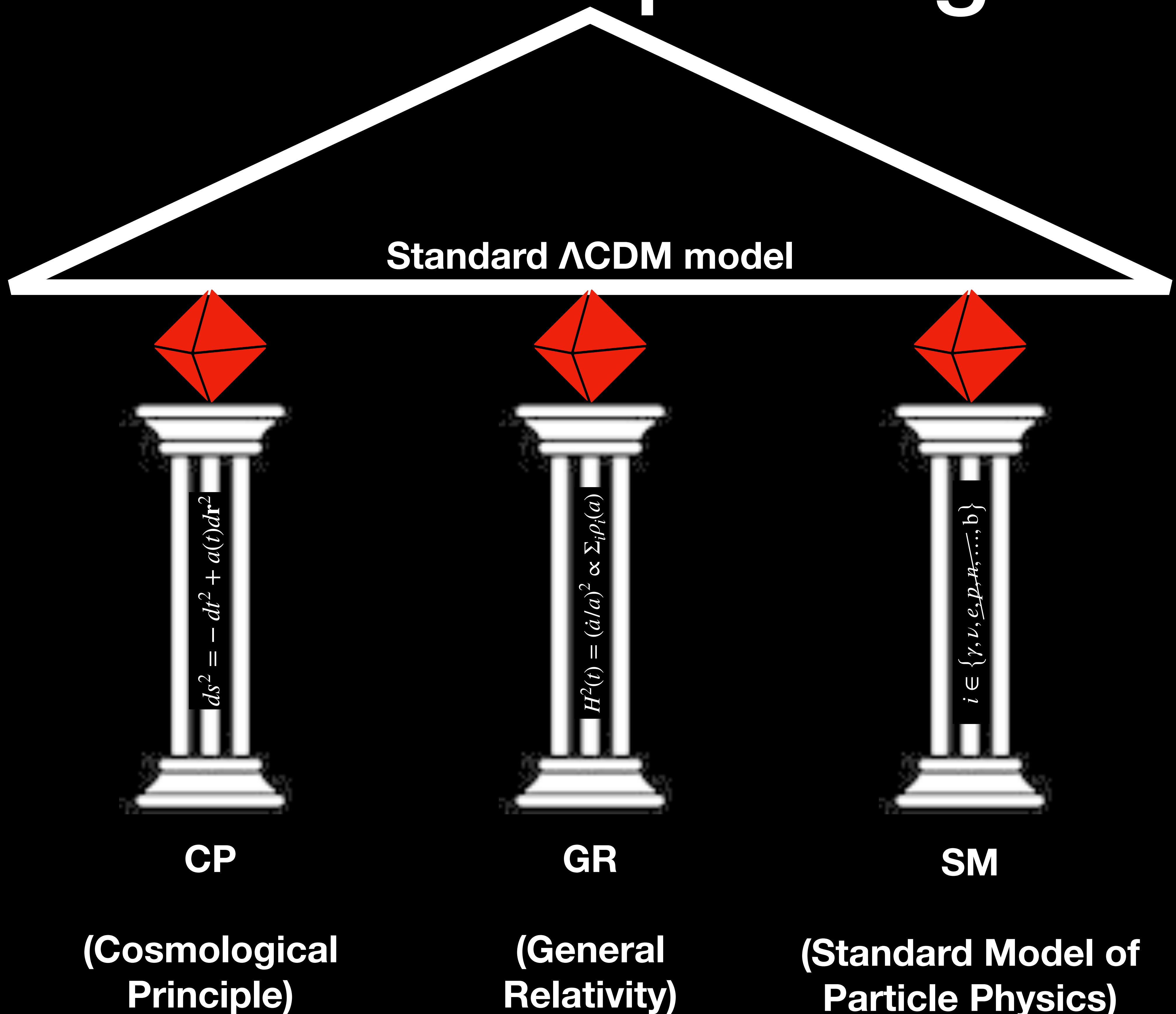
GR

(General Relativity)

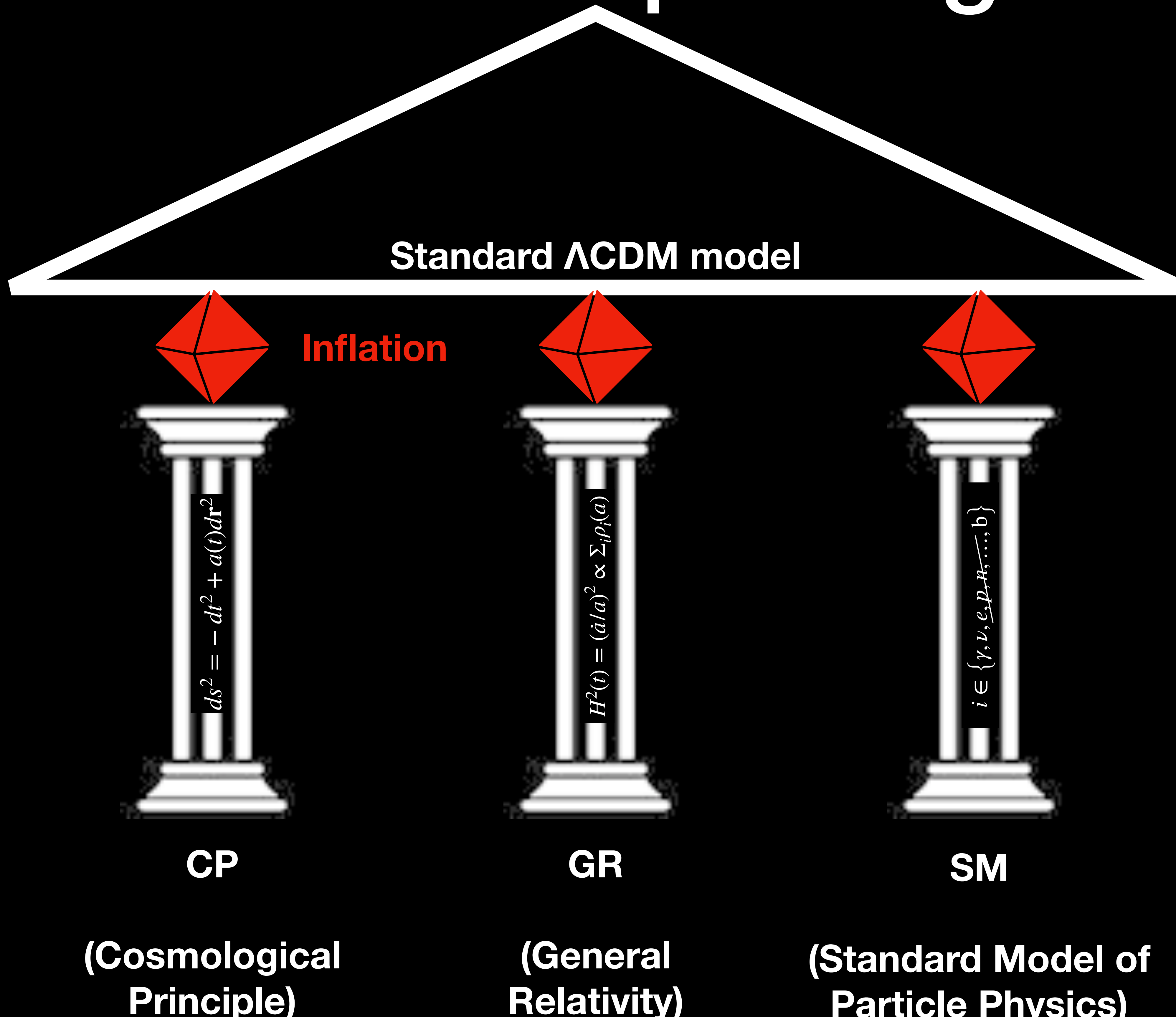
SM

(Standard Model of Particle Physics)

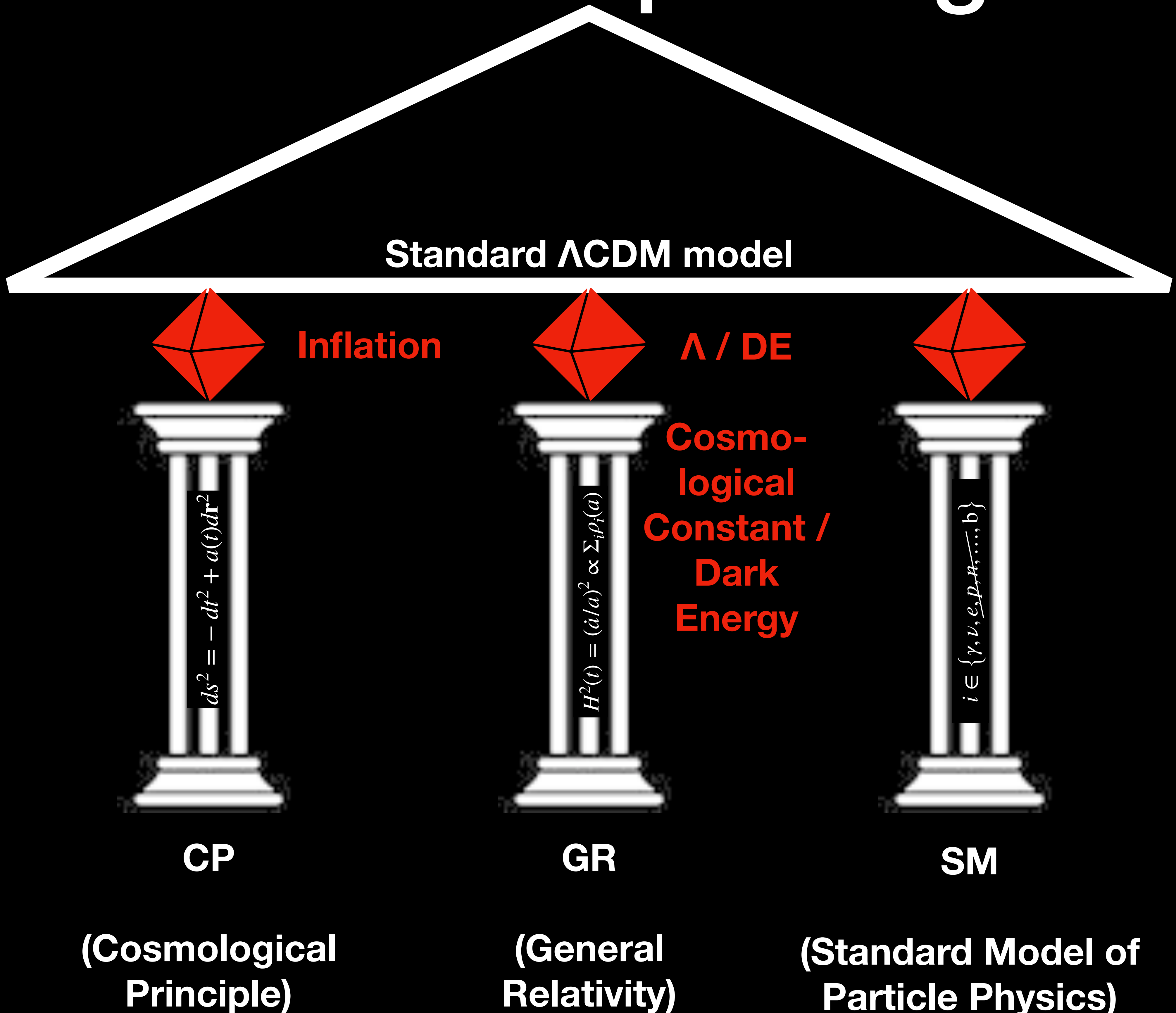
The ΛCDM paradigm



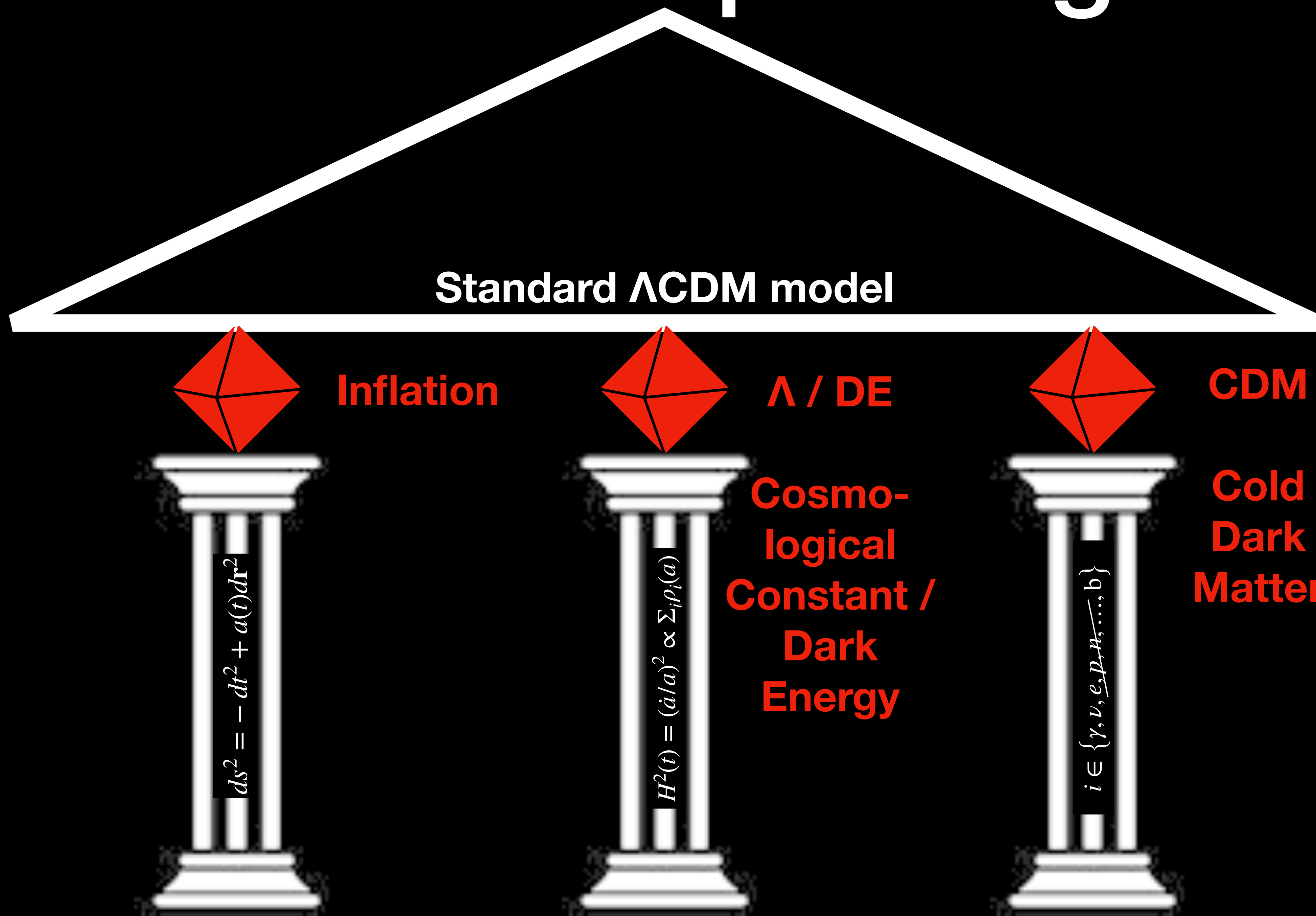
The ΛCDM paradigm



The ΛCDM paradigm

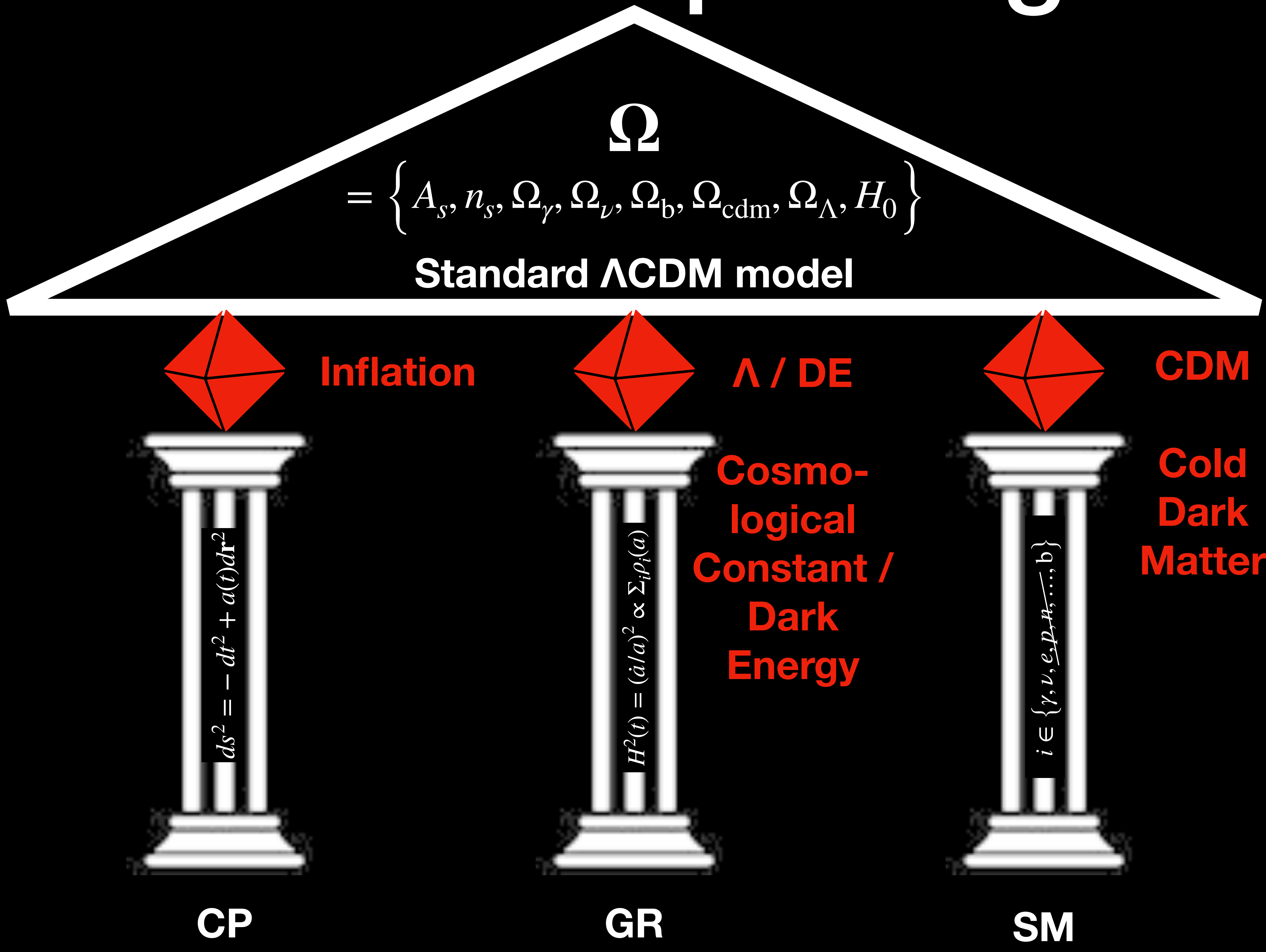


The ΛCDM paradigm

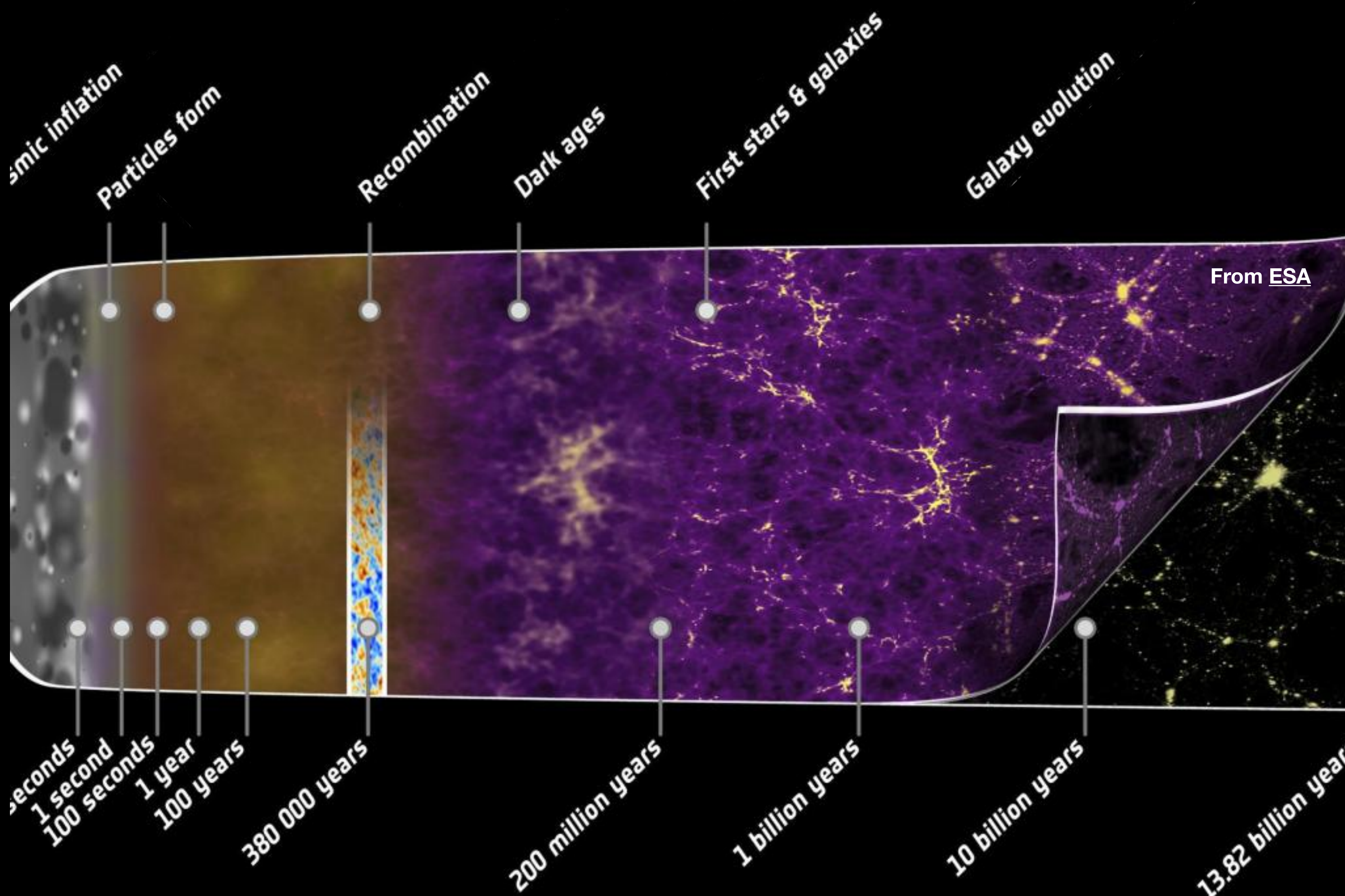


CP	**GR**	**SM**
(Cosmological Principle)	**(General Relativity)**	**(Standard Model of Particle Physics)**

The ΛCDM paradigm

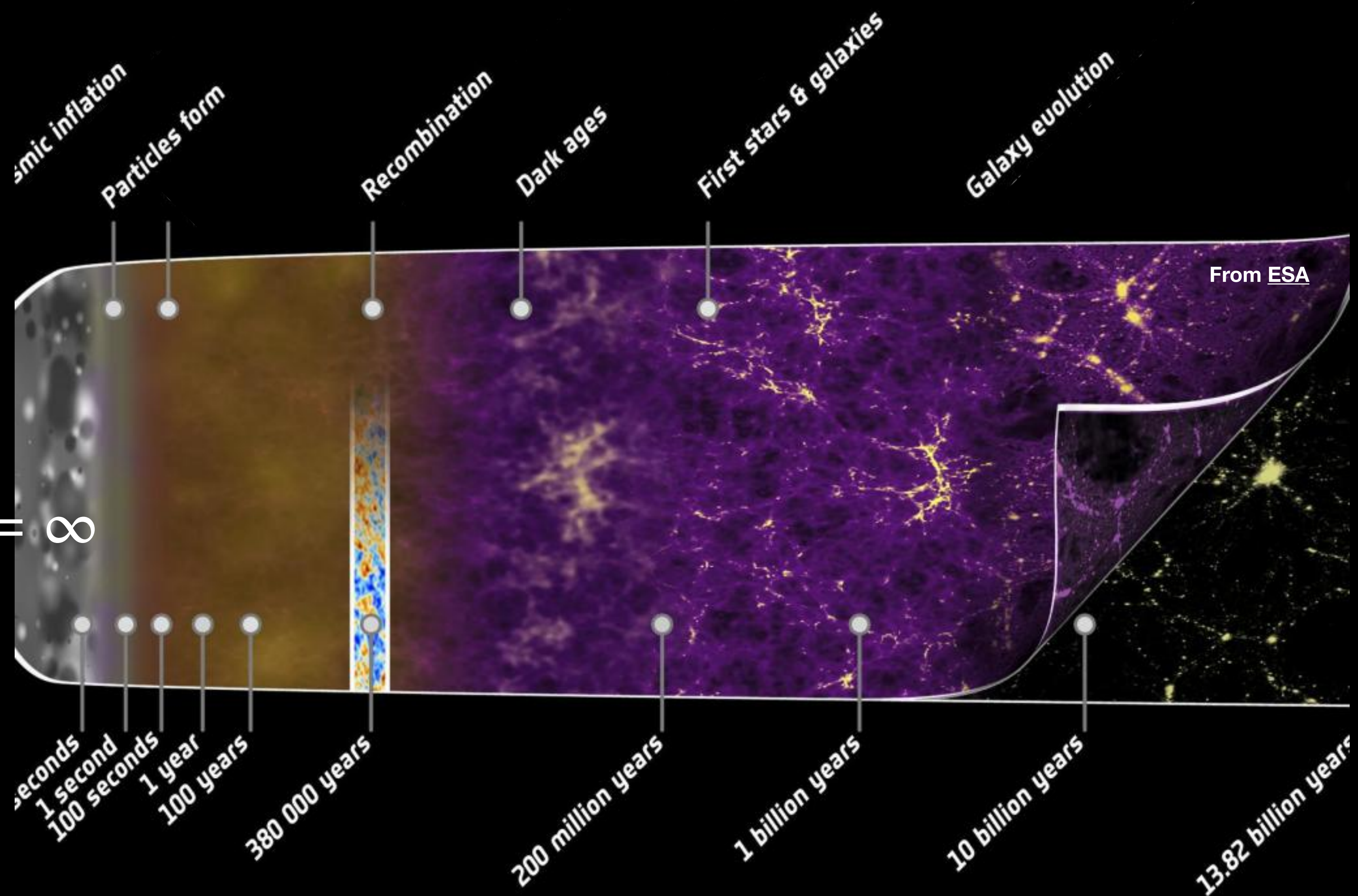


Standard ΛCDM model



$$\mathbf{\Omega} = \left\{ A_s, n_s, \Omega_\gamma, \Omega_\nu, \Omega_{\rm b}, \Omega_{\rm cdm}, \Omega_\Lambda, H_0 \right\}$$

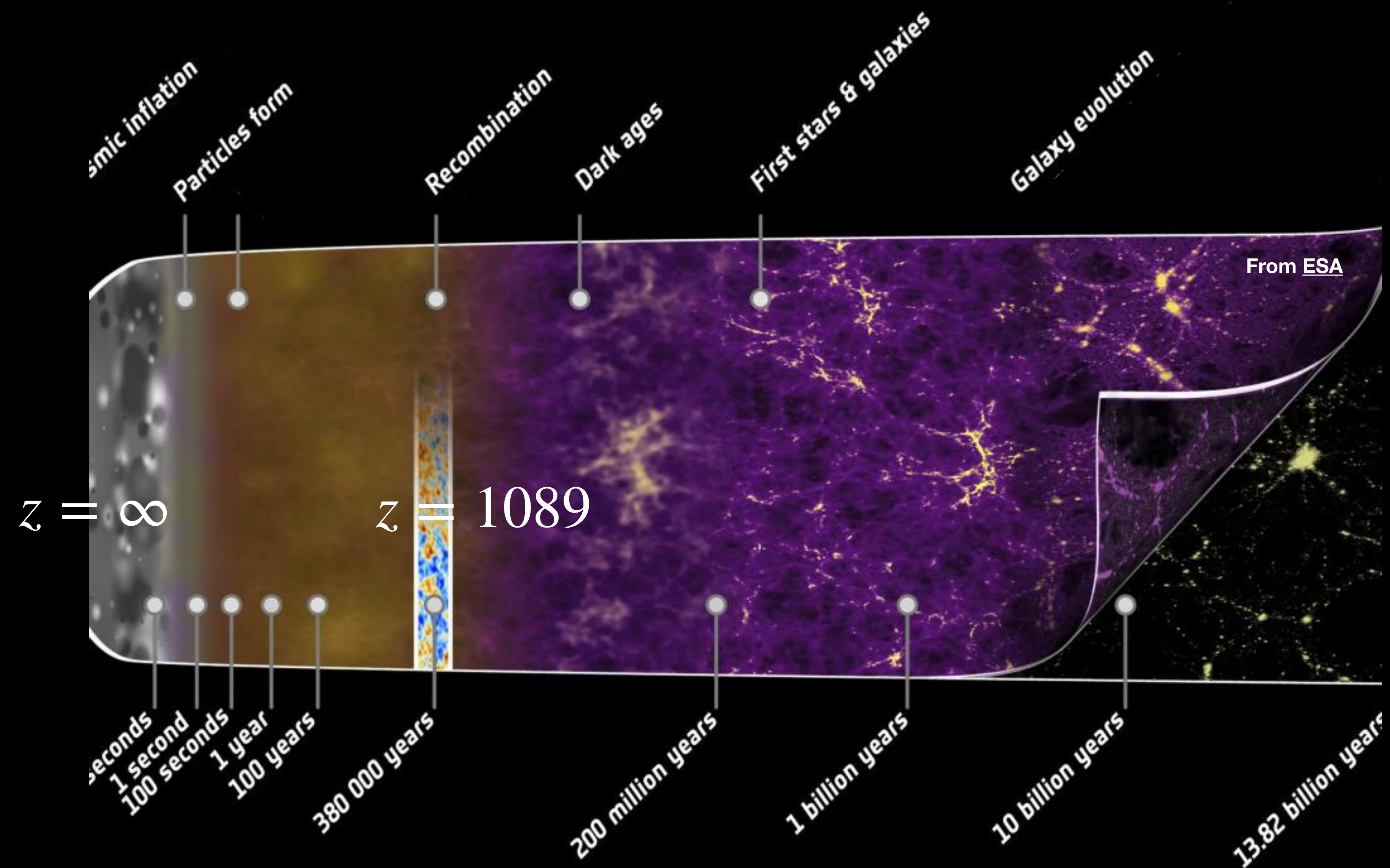
Standard ΛCDM model



$z = \infty$

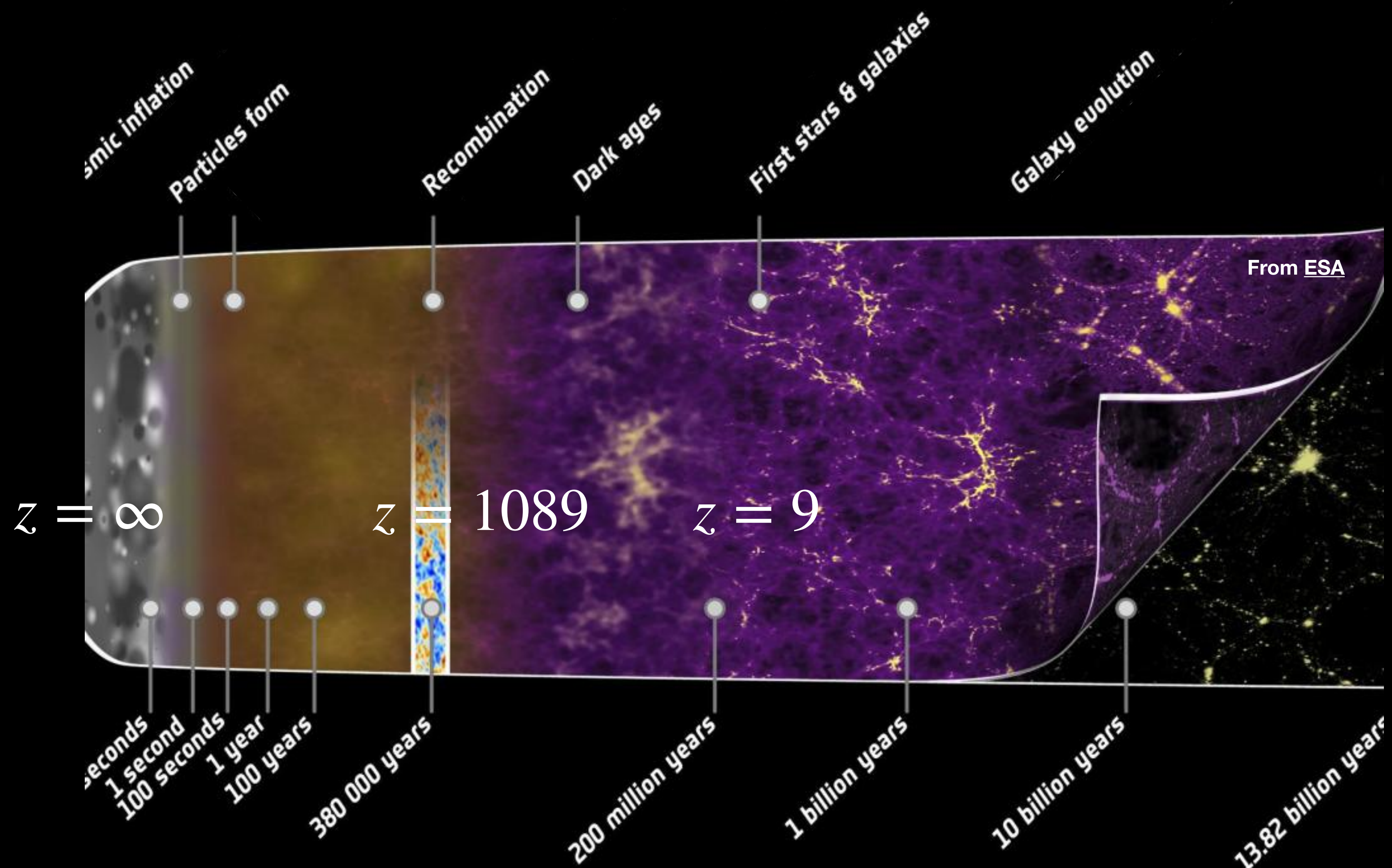
$$\boldsymbol{\Omega} = \left\{A_s, n_s, \Omega_\gamma, \Omega_\nu, \Omega_{\rm b}, \Omega_{\rm cdm}, \Omega_\Lambda, H_0\right\}$$

Standard ΛCDM model



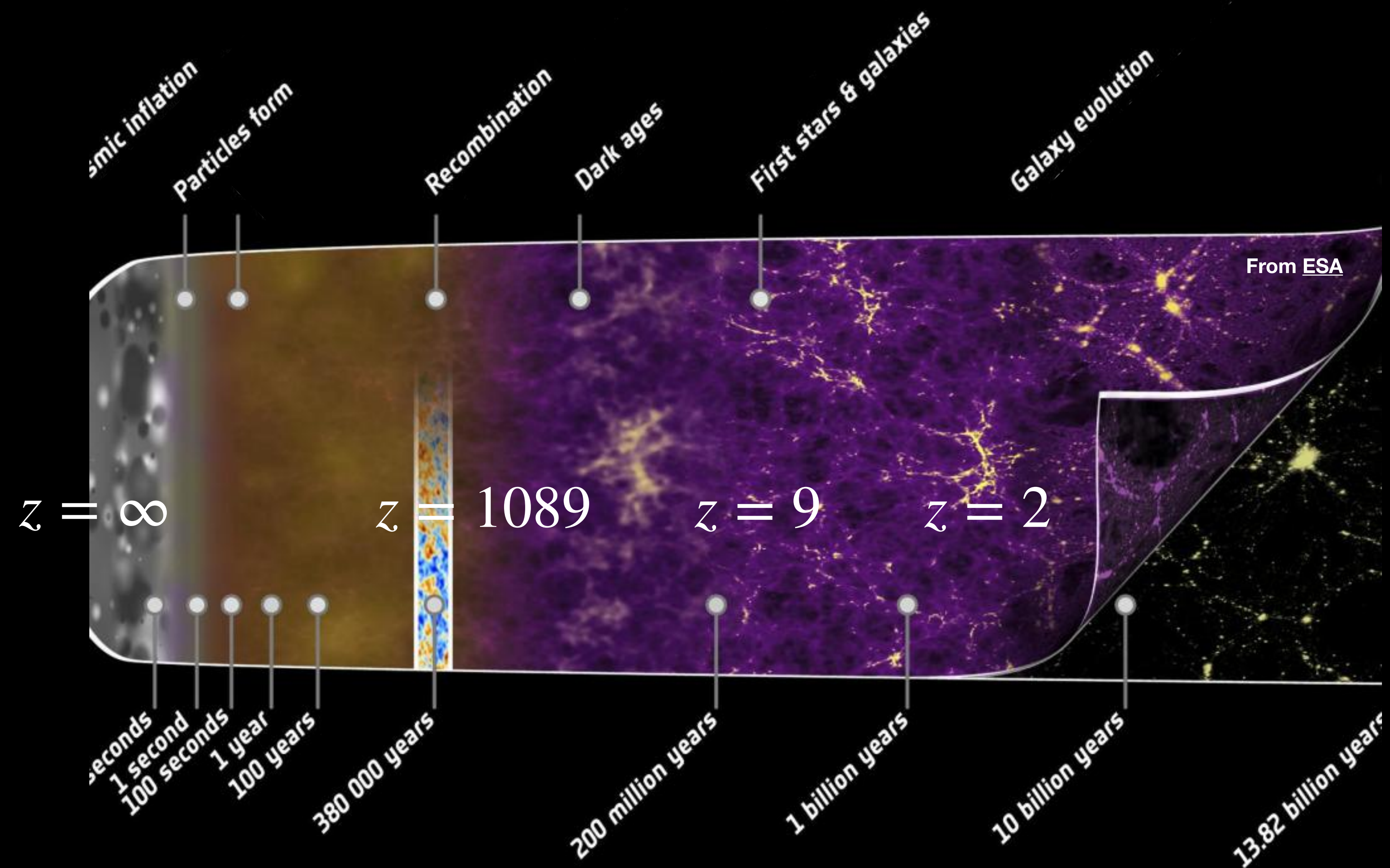
$$\mathbf{\Omega} = \left\{ A_s, n_s, \Omega_\gamma, \Omega_\nu, \Omega_{\mathrm{b}}, \Omega_{\mathrm{cdm}}, \Omega_\Lambda, H_0 \right\}$$

Standard ΛCDM model



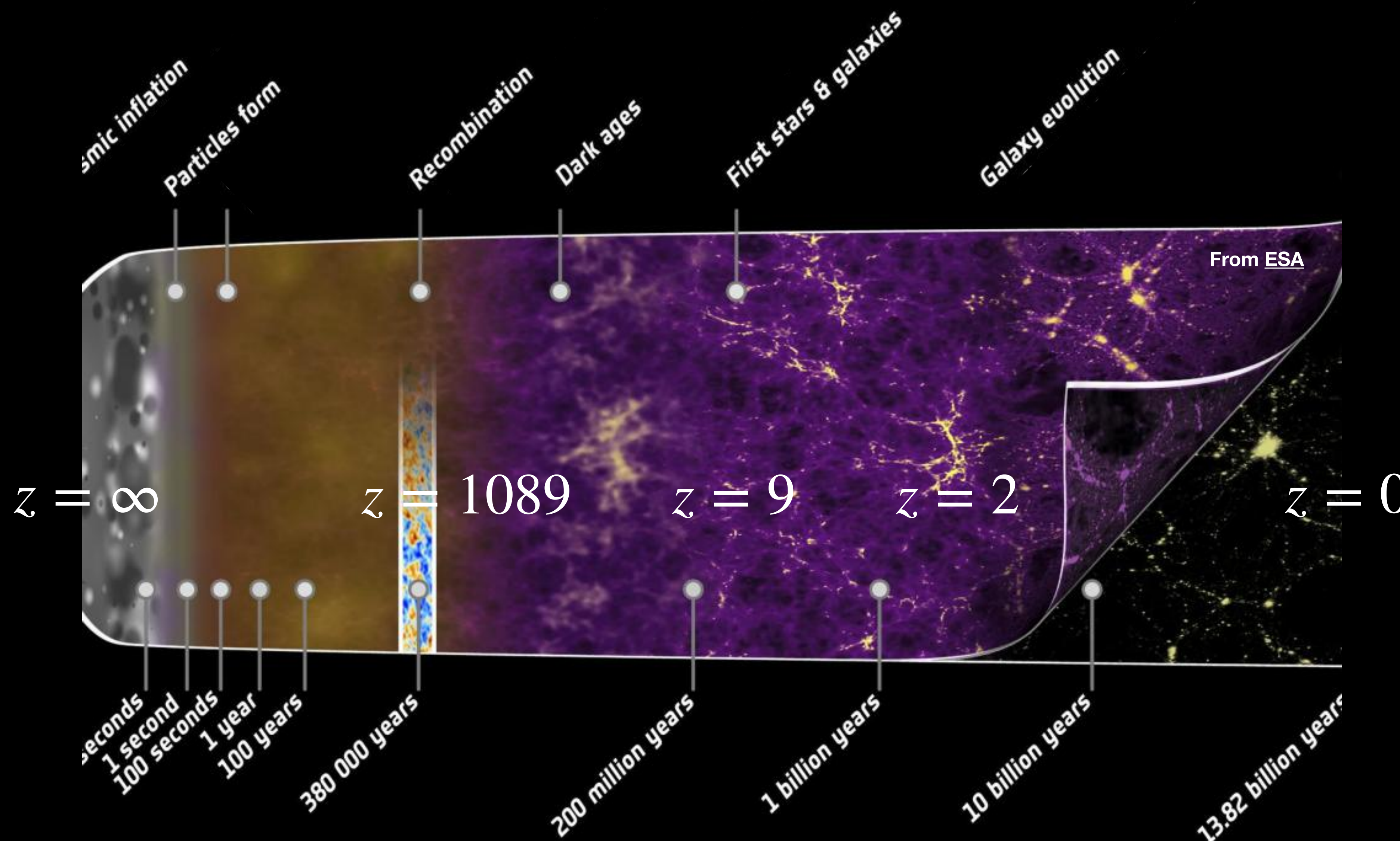
$$\mathbf{\Omega} = \left\{ A_s, n_s, \Omega_\gamma, \Omega_\nu, \Omega_\mathrm{b}, \Omega_\mathrm{cdm}, \Omega_\Lambda, H_0 \right\}$$

Standard ΛCDM model



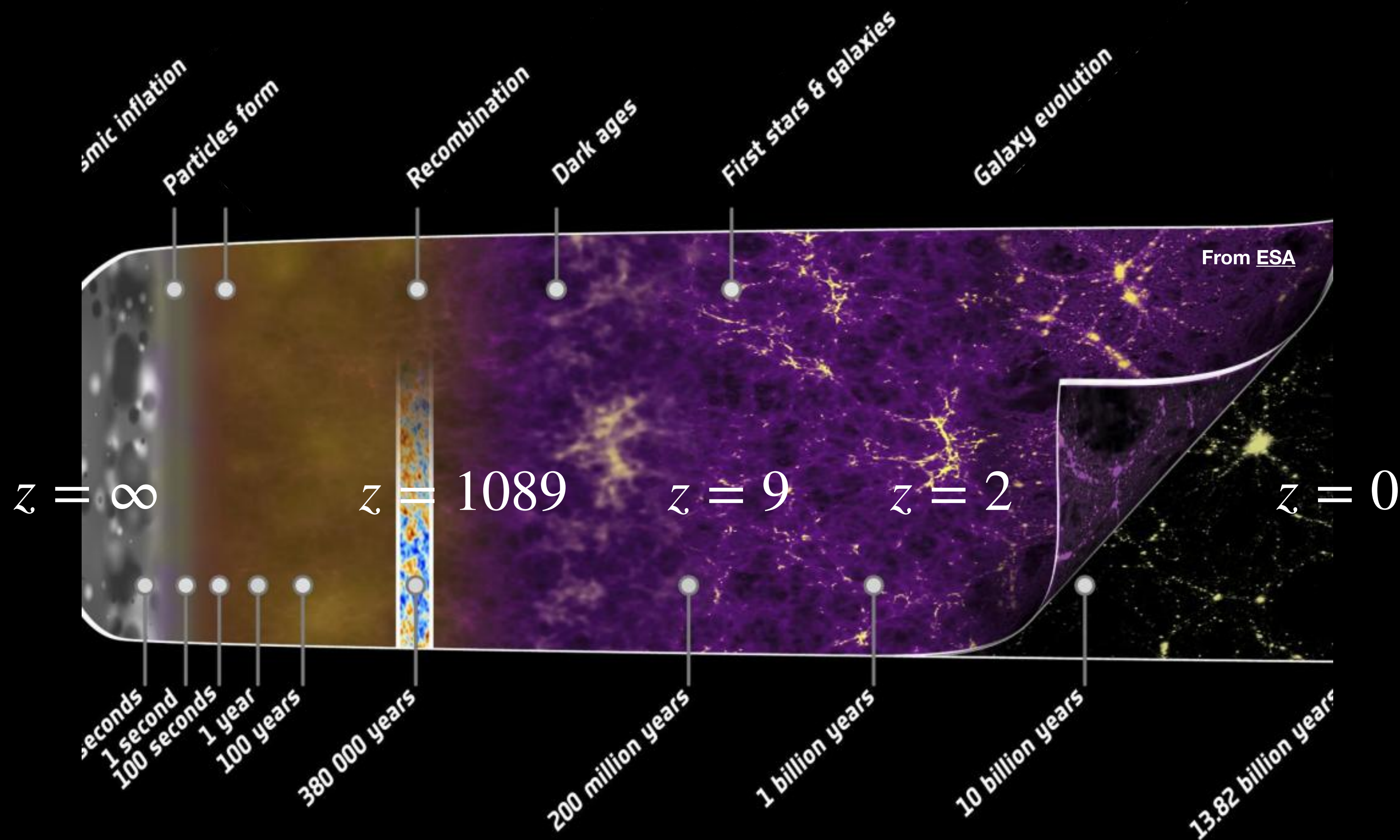
$$\boldsymbol{\Omega} = \left\{ A_s, n_s, \Omega_\gamma, \Omega_\nu, \Omega_\mathrm{b}, \Omega_\mathrm{cdm}, \Omega_\Lambda, H_0 \right\}$$

Standard ΛCDM model



$$\boldsymbol{\Omega} = \left\{ A_s, n_s, \Omega_\gamma, \Omega_\nu, \Omega_{\rm b}, \Omega_{\rm cdm}, \Omega_\Lambda, H_0 \right\}$$

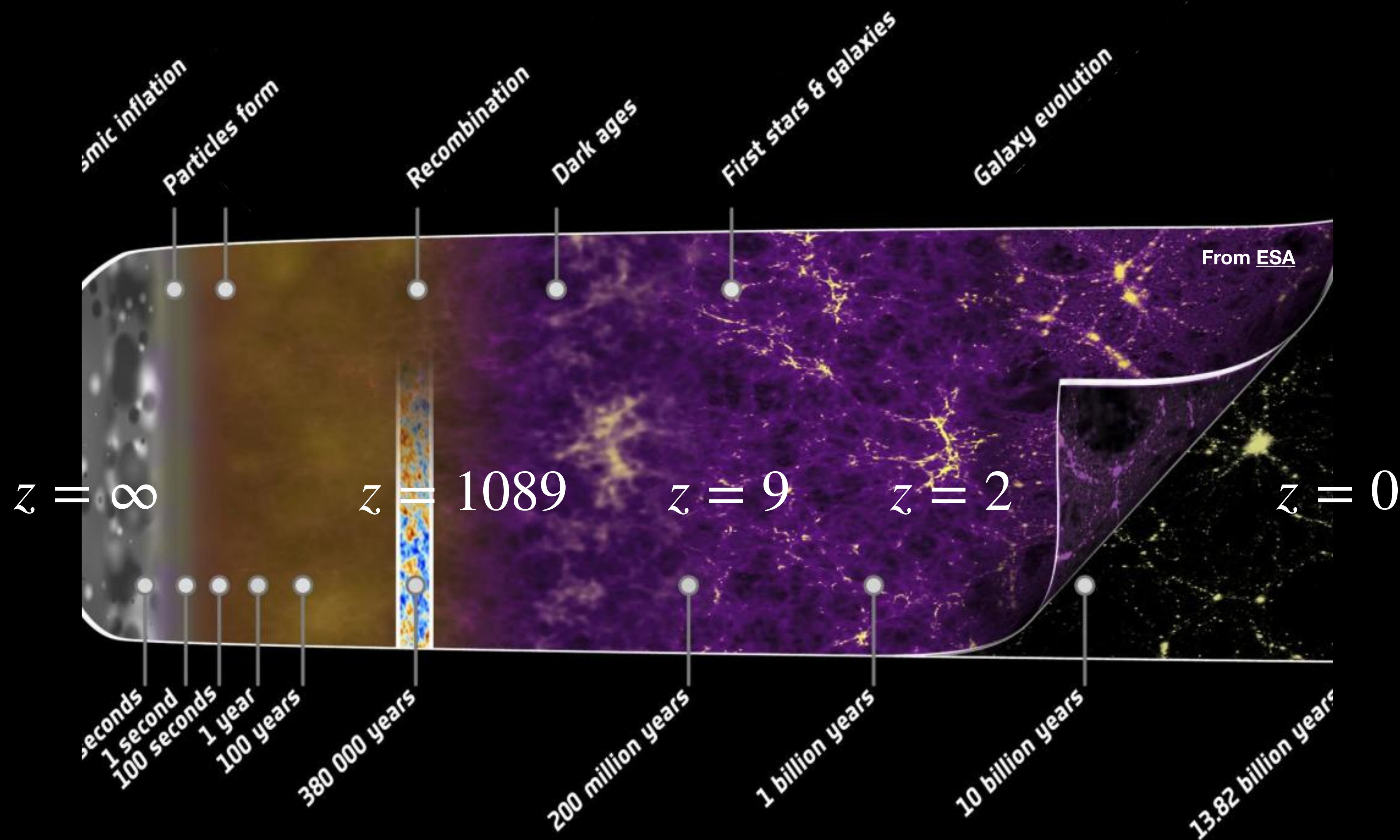
Standard ΛCDM model



Directly measured?

$$\mathbf{\Omega} = \left\{ A_s, n_s, \Omega_\gamma, \Omega_\nu, \Omega_{\rm b}, \Omega_{\rm cdm}, \Omega_\Lambda, H_0 \right\}$$

Standard ΛCDM model

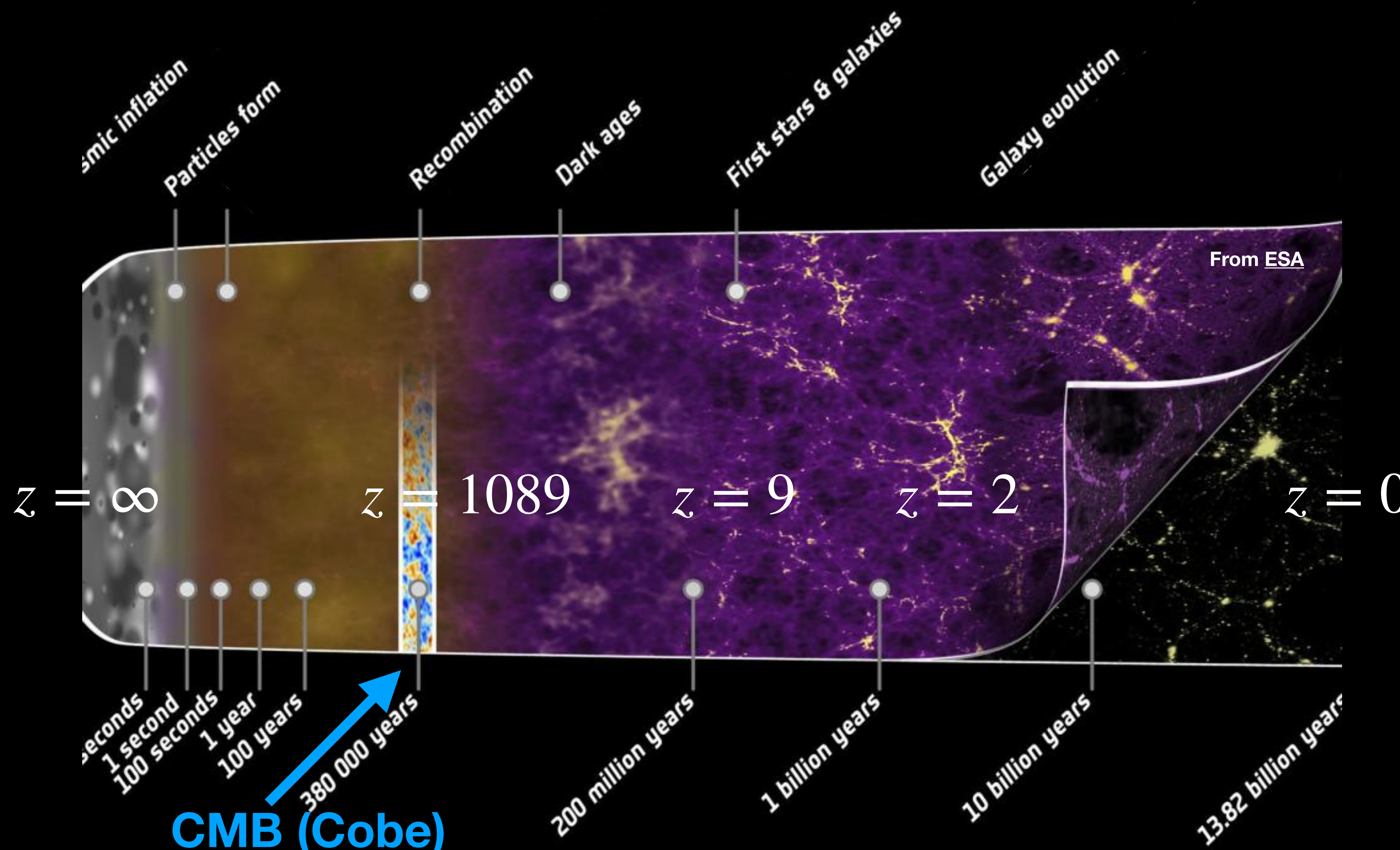


Directly measured?

$$\boldsymbol{\Omega} = \left\{A_s, n_s, \Omega_\gamma, \Omega_\nu, \Omega_\mathrm{b}, \Omega_\mathrm{cdm}, \Omega_\Lambda, H_0\right\}$$

Indirectly inferred?

Standard ΛCDM model

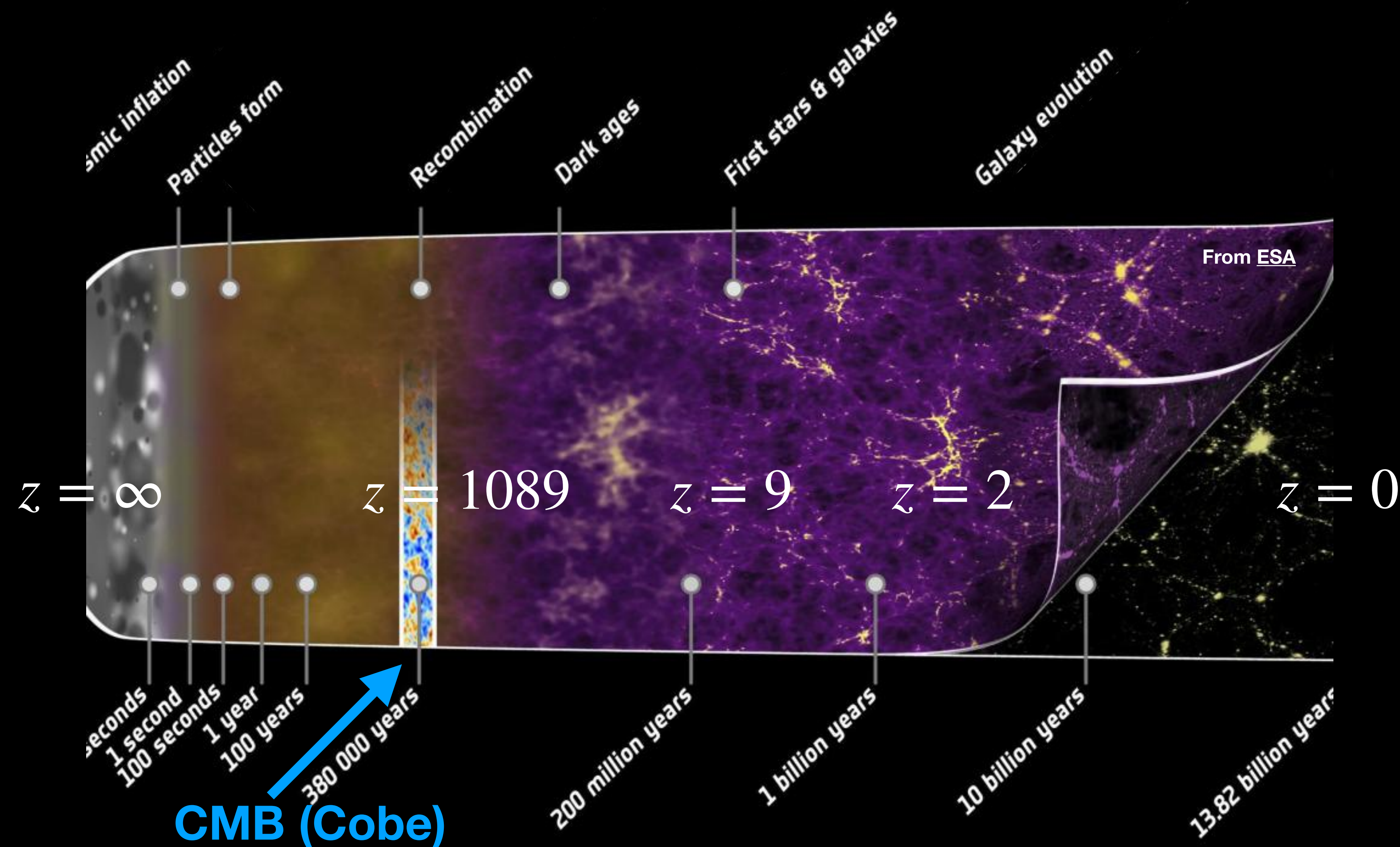


Directly measured?

$$\boldsymbol{\Omega} = \left\{A_s, n_s, \Omega_\gamma, \Omega_\nu, \Omega_{\rm b}, \Omega_{\rm cdm}, \Omega_\Lambda, H_0\right\}$$

Indirectly inferred?

Standard ΛCDM model



Directly measured?

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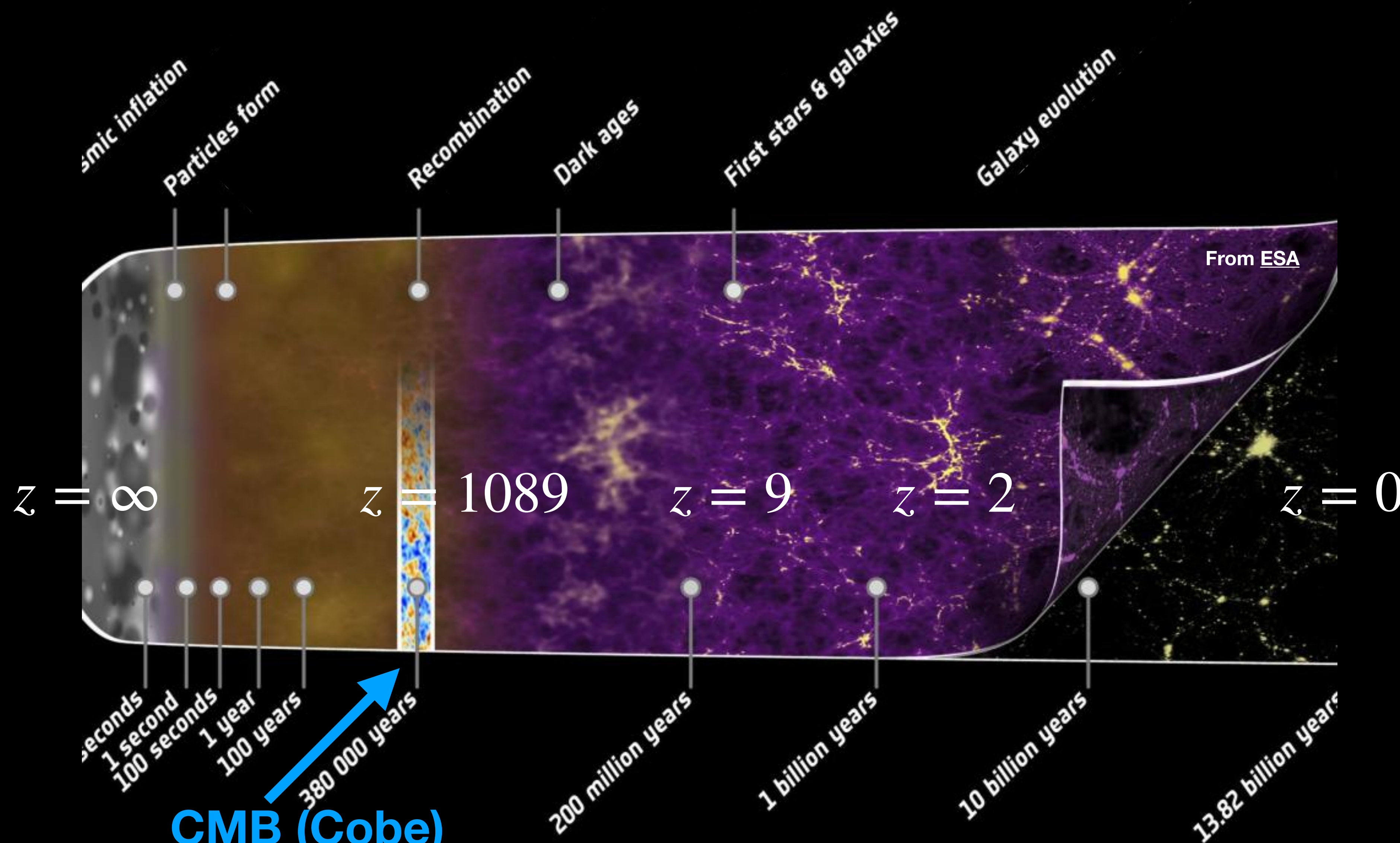
Indirectly inferred?

Standard ΛCDM model



CMB (Cobe)

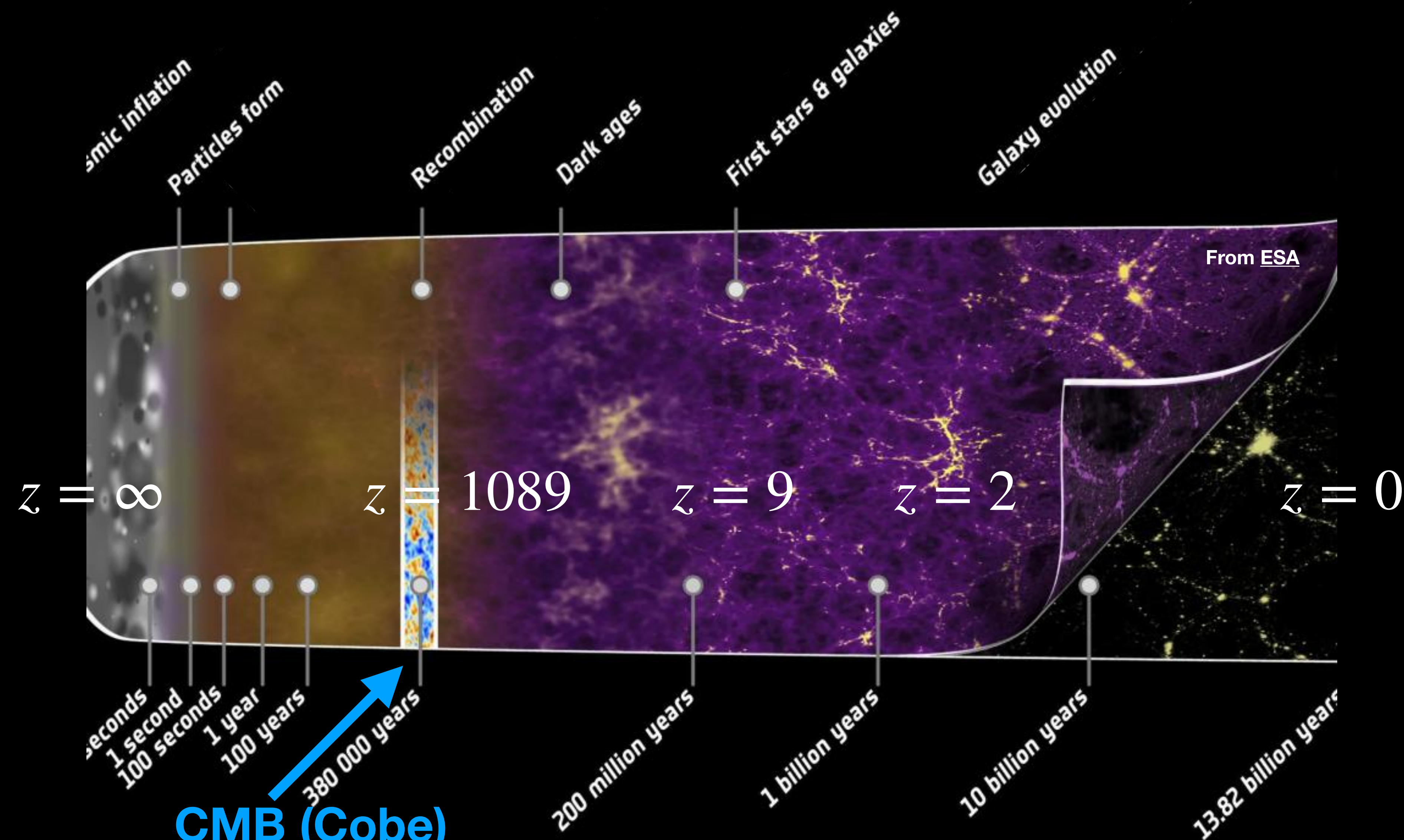
CMB anisotropies
(Planck, …)

Directly measured?

$$\mathbf{\Omega} = \left\{ A_s, n_s, \Omega_\gamma, \Omega_\nu, \Omega_\mathrm{b}, \Omega_\mathrm{cdm}, \Omega_\Lambda, H_0 \right\}$$

Indirectly inferred?

Standard ΛCDM model



CMB (Cobe)

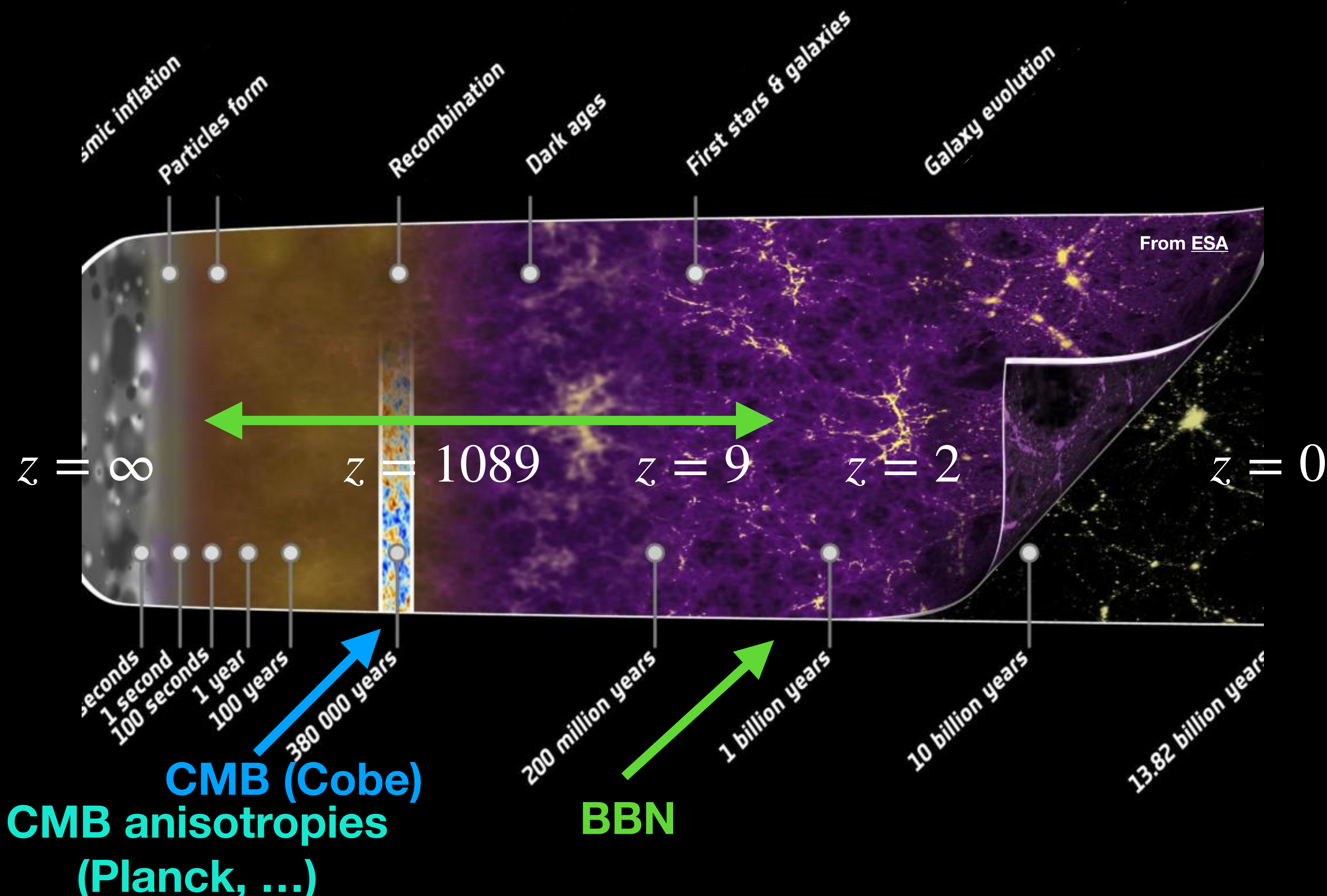
CMB anisotropies
(Planck, …)

Directly measured?

$$\boldsymbol{\Omega} = \left\{A_s, n_s, \Omega_\gamma, \Omega_\nu, \Omega_{\rm b}, \Omega_{\rm cdm}, \Omega_\Lambda, H_0\right\} \qquad \theta_s$$

Indirectly inferred?

Standard ΛCDM model

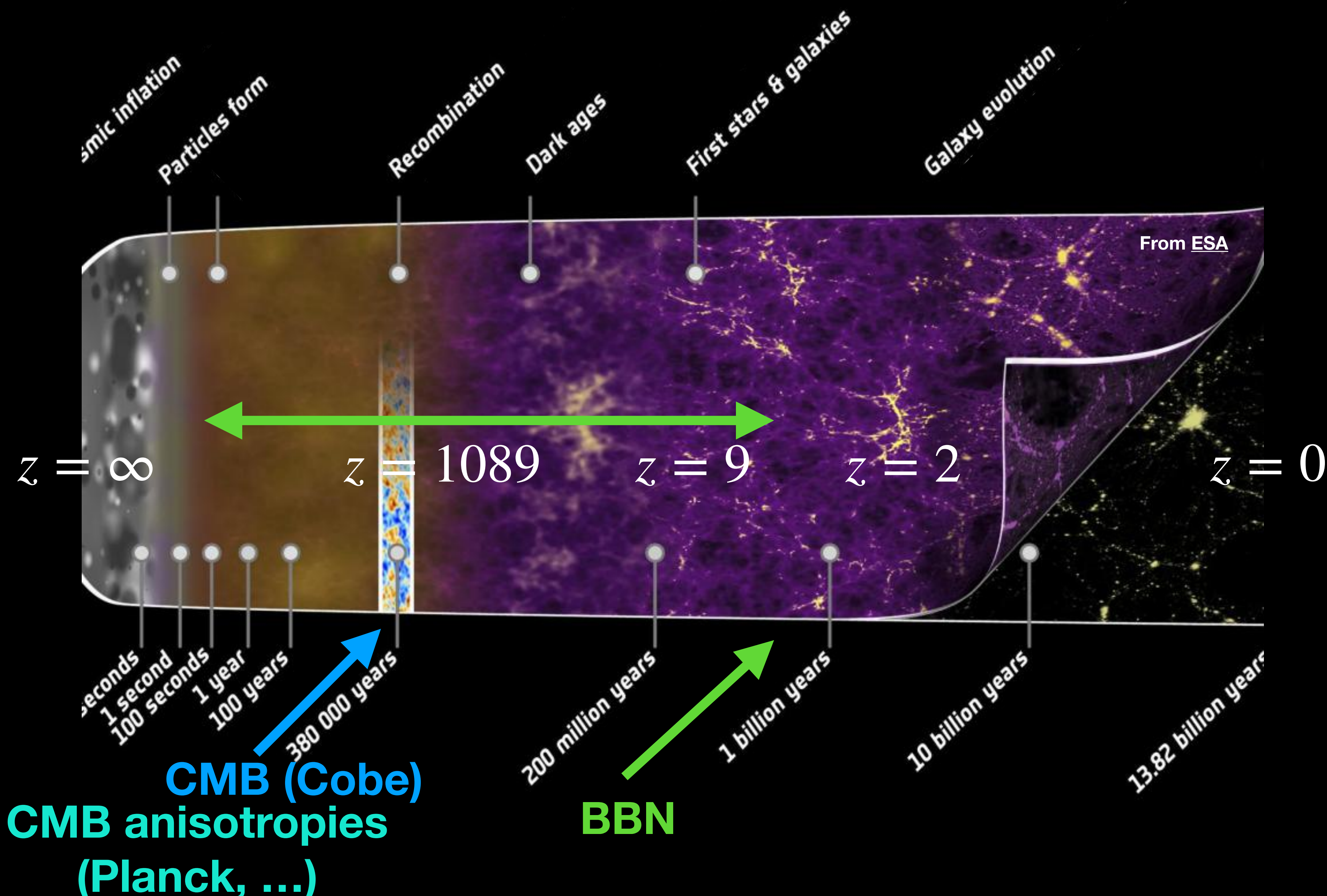


Directly measured?

$$\boldsymbol{\Omega} = \left\{A_s, n_s, \Omega_\gamma, \Omega_\nu, \Omega_\mathrm{b}, \Omega_\mathrm{cdm}, \Omega_\Lambda, H_0\right\} \qquad \theta_s$$

Indirectly inferred?

Standard ΛCDM model

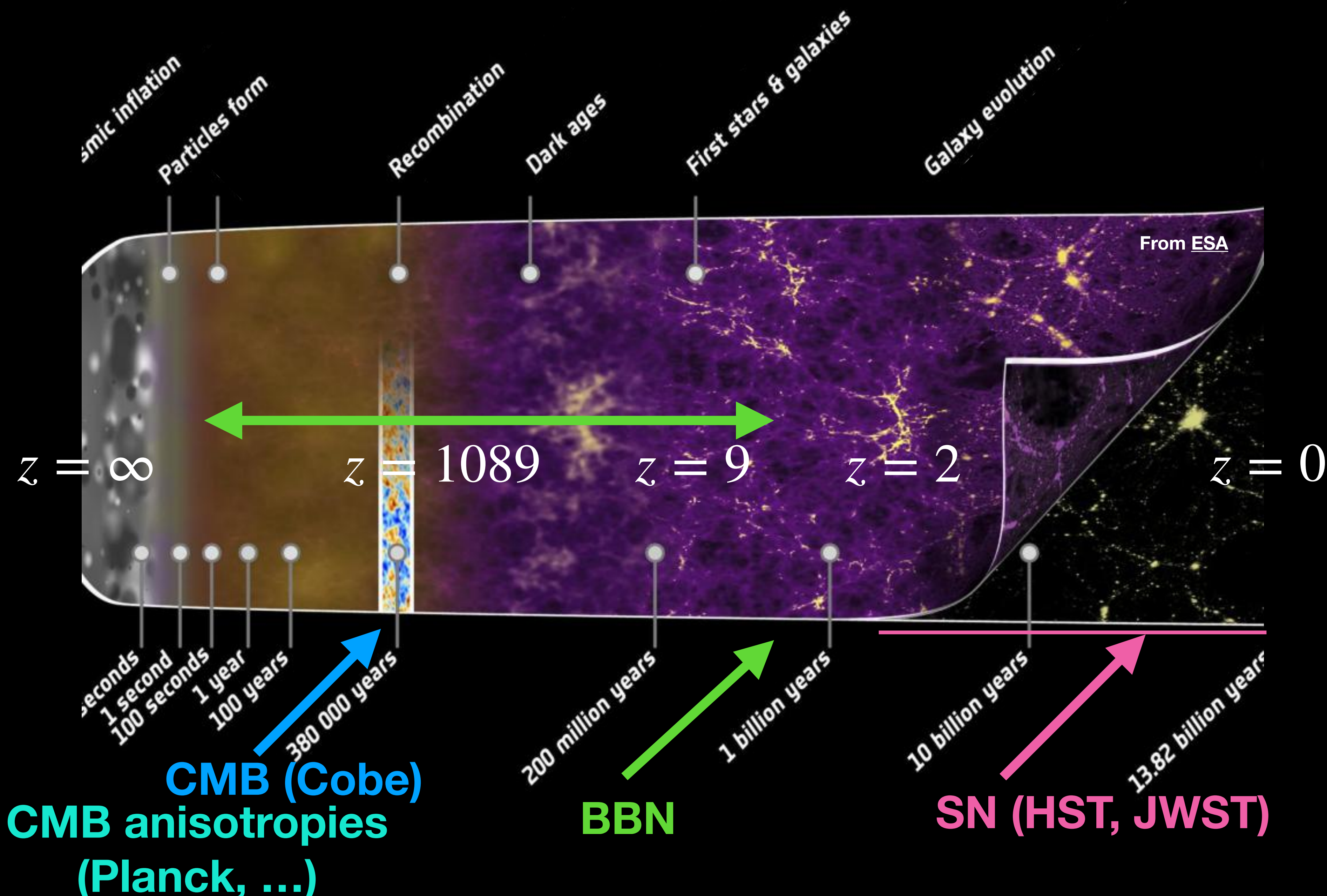


Directly measured?

$$\boldsymbol{\Omega} = \left\{ A_s, n_s, \Omega_\gamma, \Omega_\nu, \Omega_b, \Omega_{cdm}, \Omega_\Lambda, H_0 \right\} \qquad \theta_s$$

Indirectly inferred?

Standard ΛCDM model



Directly measured?

$$\boldsymbol{\Omega} = \left\{A_s, n_s, \Omega_\gamma, \Omega_\nu, \Omega_\mathrm{b}, \Omega_\mathrm{cdm}, \Omega_\Lambda, H_0\right\} \qquad \theta_s$$

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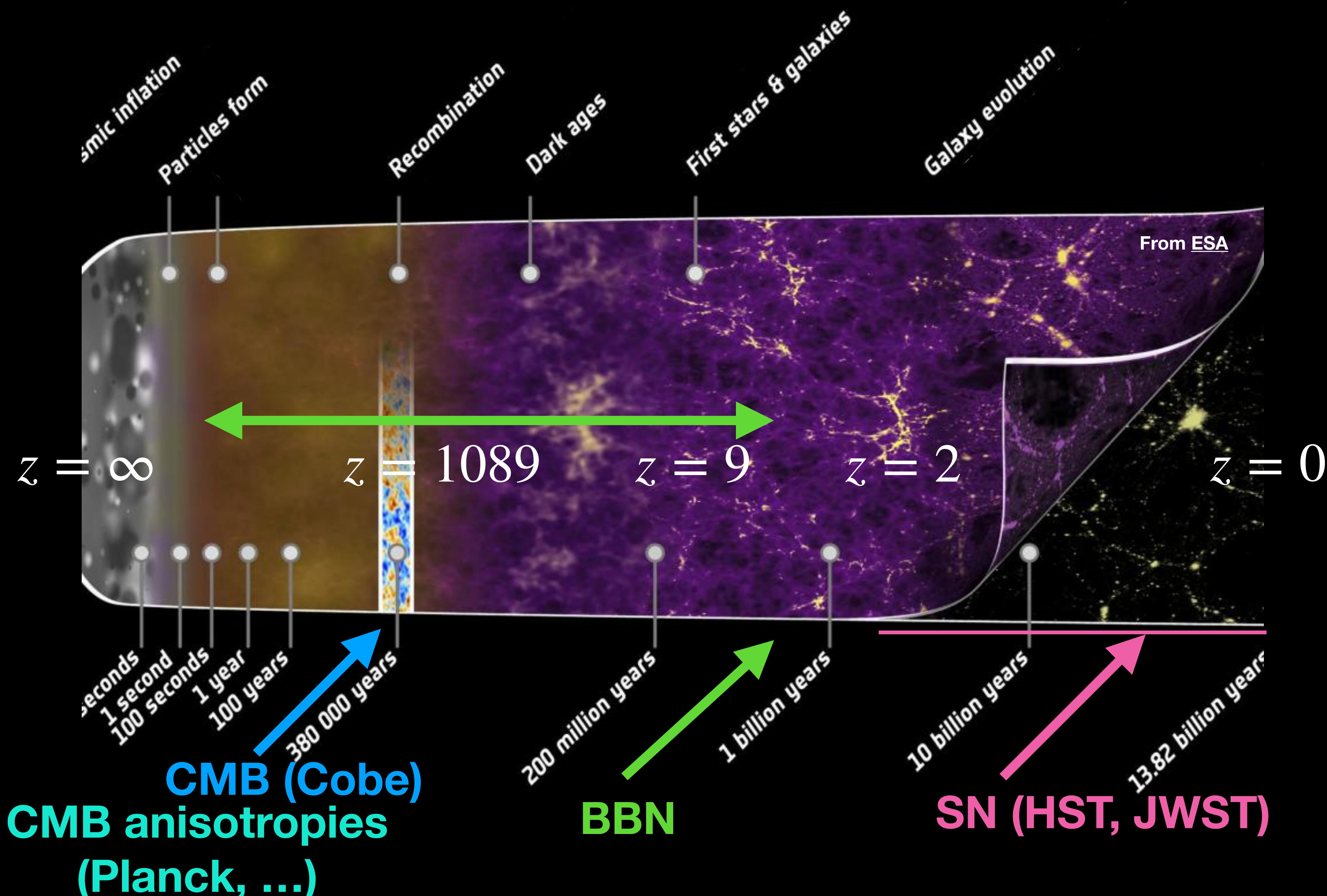
Standard ΛCDM model



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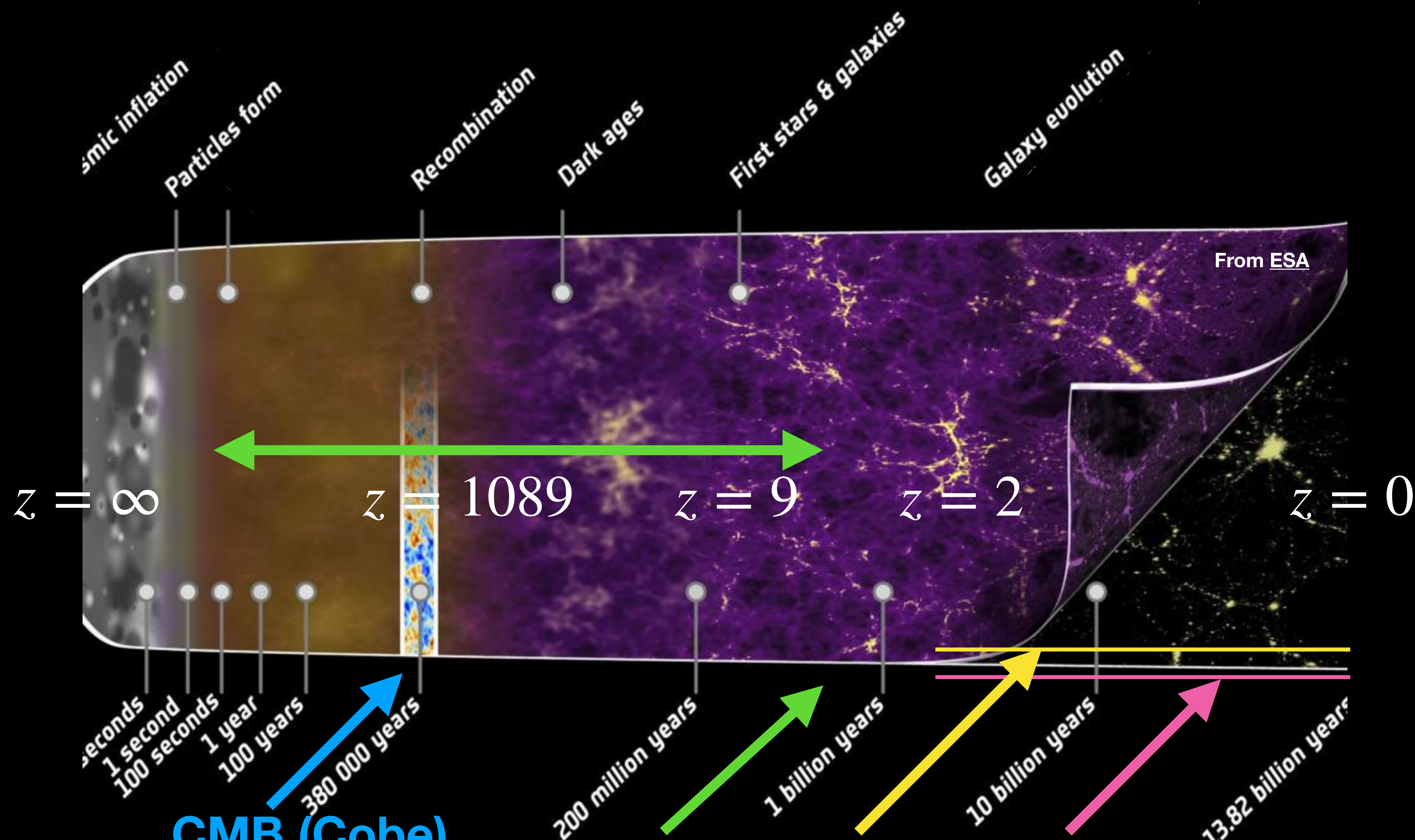
$$\mathbf{\Omega} = \left\{A_s, n_s, \Omega_\gamma, \Omega_\nu, \Omega_\mathrm{b}, \Omega_\mathrm{cdm}, \Omega_\Lambda, H_0\right\} \qquad \theta_s$$

Indirectly inferred?

Standard ΛCDM model



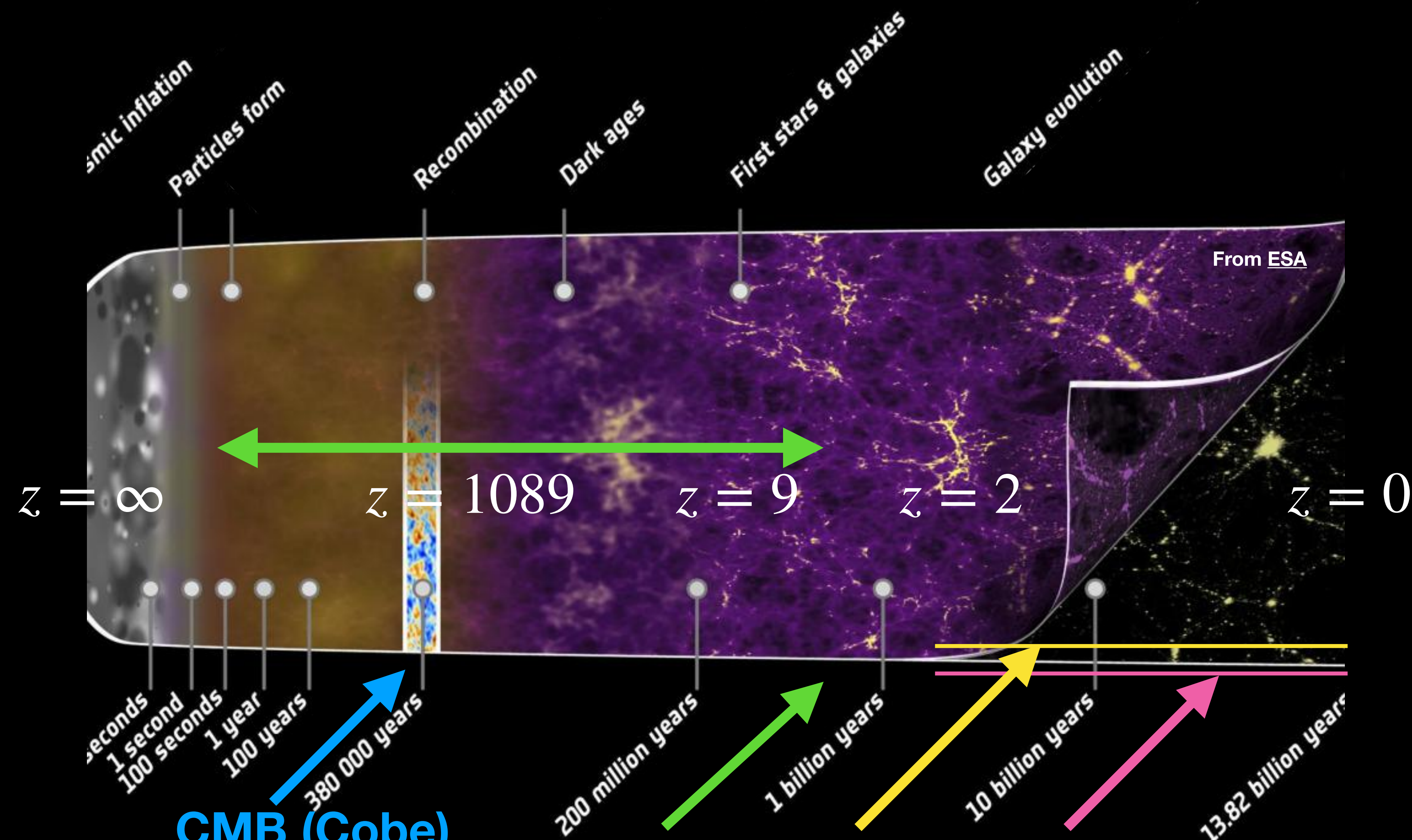
CMB (Cobe)
CMB anisotropies
(Planck, ...)
BBN
FS+BAO
((e)BOSS, DESI)
SN (HST, JWST)

Directly measured?

$$\boldsymbol{\Omega} = \left\{ A_s, n_s, \Omega_\gamma, \Omega_\nu, \Omega_\mathrm{b}, \Omega_\mathrm{cdm}, \Omega_\Lambda, H_0 \right\} \qquad \theta_s$$

Indirectly inferred?

Standard ΛCDM model



CMB (Cobe)

CMB anisotropies
(Planck, …)

BBN

FS+BAO
((e)BOSS, DESI)

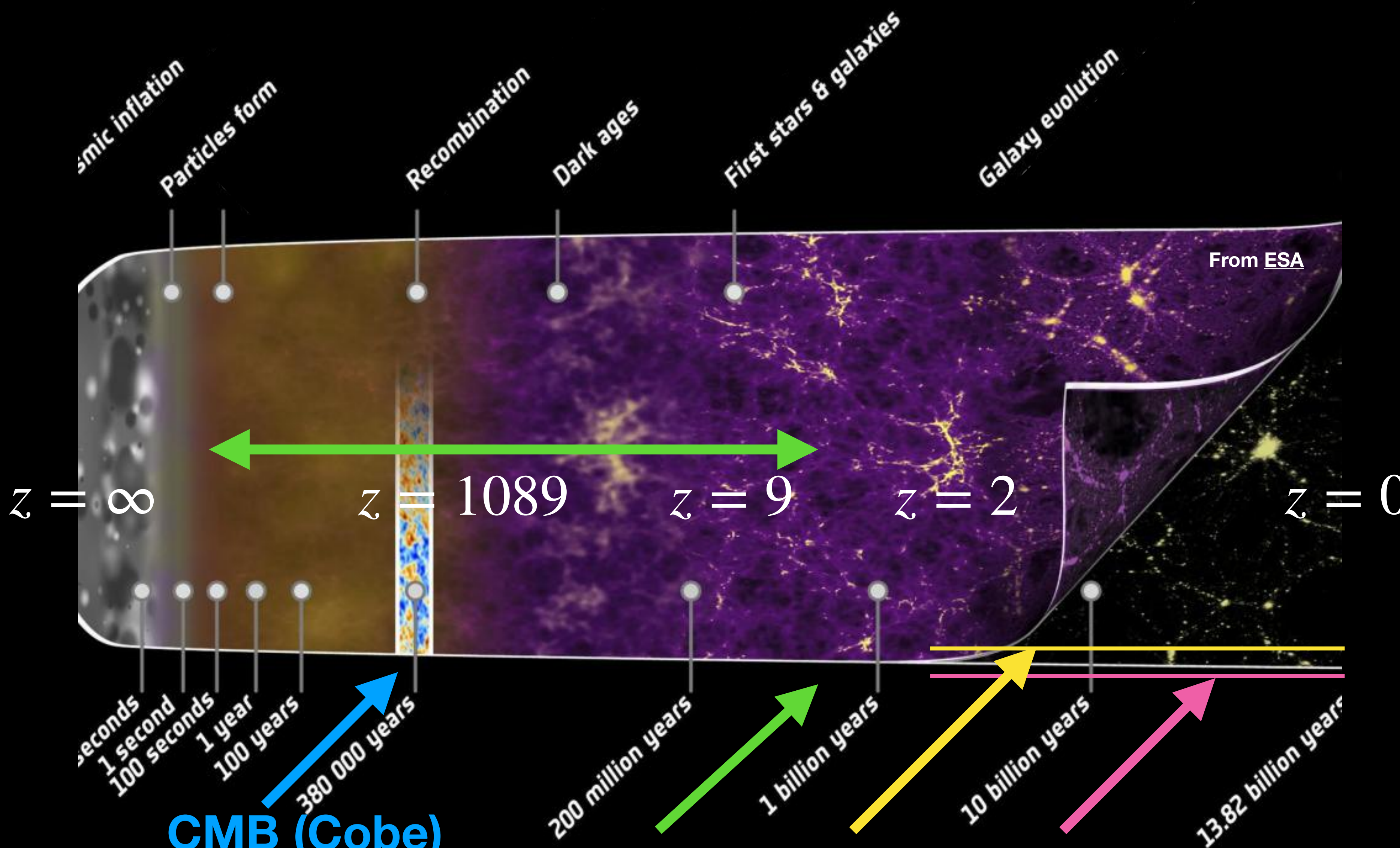
SN (HST, JWST)

Directly measured?

$$\boldsymbol{\Omega} = \left\{ A_s, n_s, \Omega_\gamma, \Omega_\nu, \Omega_\mathrm{b}, \Omega_\mathrm{cdm}, \Omega_\Lambda, H_0 \right\} \quad H_0 r_d \quad \theta_s$$

Indirectly inferred?

Standard ΛCDM model



CMB (Cobe)

CMB anisotropies (Planck, …)

BBN

FS+BAO ((e)BOSS, DESI)

SN (HST, JWST)

Directly measured?

$$\boldsymbol{\Omega} = \left\{A_s, n_s, \Omega_\gamma, \Omega_\nu, \Omega_{\rm b}, \Omega_{\rm cdm}, \Omega_\Lambda, H_0\right\} \quad H_0 r_d \quad \theta_s$$

Indirectly inferred?

Physical parameters $\mathbf{A}$

CMB (Cobe)

CMB anisotropies (Planck, ...)

BBN

SN (HST, JWST)

FS+BAO (BOSS+eBOSS, DESI)

Raw Data

Reduced Data

Directly measured? $\mathbf{A} = \left\{ \theta_s \quad H_0 r_d \right\}$

Indirectly inferred? $\mathbf{\Omega} = \left\{ A_s, n_s, \Omega_\gamma, \Omega_\nu, \Omega_\mathrm{b}, \Omega_\mathrm{cdm}, \Omega_\Lambda, H_0 \right\}$

Physical parameters $\mathbb{A}$

CMB (Cobe)

BBN

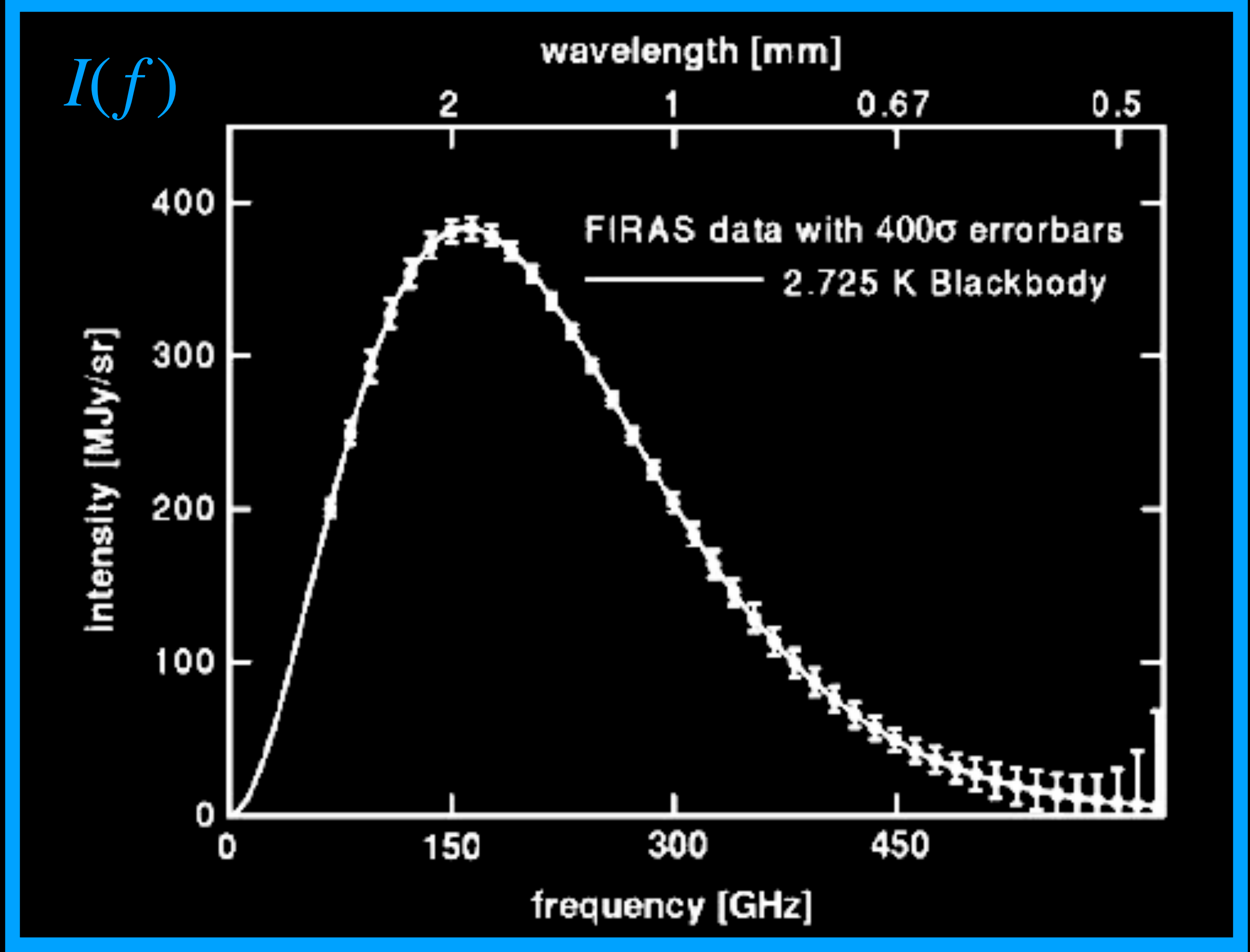
SN (HST, JWST)

FS+BAO (BOSS+eBOSS, DESI)

CMB anisotropies (Planck, ...)

Raw Data

Reduced Data



Directly measured? $\quad \mathbb{A} = \left\{ \quad \theta_s \quad\quad H_0 r_d \right\}$

Indirectly inferred? $\quad \mathbf{\Omega} = \left\{ A_s, n_s, \Omega_\gamma, \Omega_\nu, \Omega_\mathrm{b}, \Omega_\mathrm{cdm}, \Omega_\Lambda, H_0 \right\}$

Physical parameters $\mathbf{A}$

CMB (Cobe)

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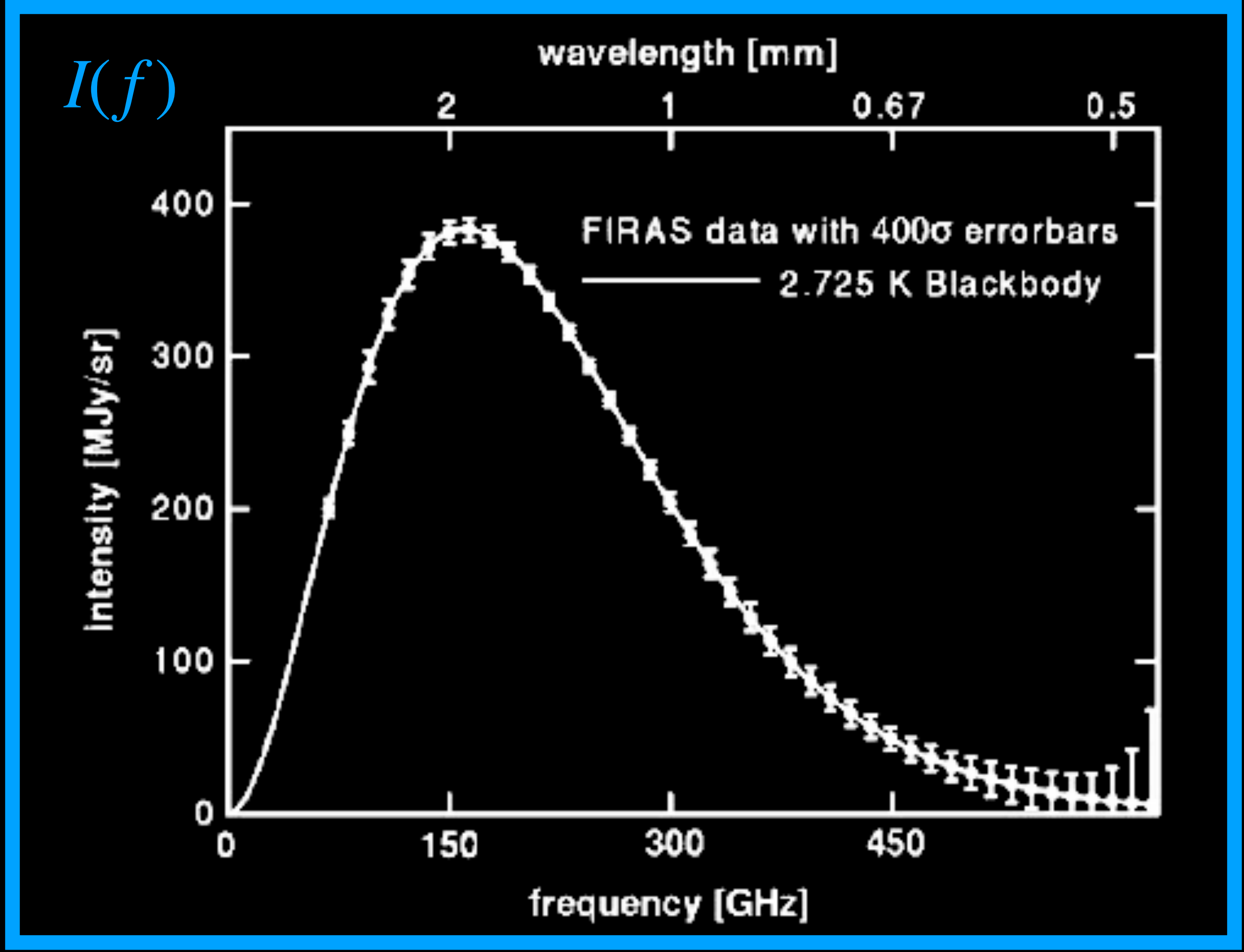


Raw Data

Reduced Data

Directly measured?

$$\mathbf{A} = \left\{ T_\gamma \quad \theta_s \quad H_0 r_d \right\}$$

Indirectly inferred?

$$\boldsymbol{\Omega} = \left\{ A_s, n_s, \Omega_\gamma, \Omega_\nu, \Omega_\mathrm{b}, \Omega_\mathrm{cdm}, \Omega_\Lambda, H_0 \right\}$$

Physical parameters $\mathbf{A}$

CMB (Cobe)

CMB anisotropies (Planck, ...)

BBN

SN (HST, JWST)

FS+BAO (BOSS+eBOSS, DESI)

Raw Data $I(f)$

Reduced Data

Directly measured? $$\mathbf{A} = \left\{ T_\gamma \quad \theta_s \quad H_0 r_d \right\}$$

Indirectly inferred? $$\mathbf{\Omega} = \left\{ A_s, n_s, \Omega_\gamma, \Omega_\nu, \Omega_\mathrm{b}, \Omega_\mathrm{cdm}, \Omega_\Lambda, H_0 \right\}$$

Physical parameters $\mathbf{A}$

CMB (Cobe)

BBN

SN (HST, JWST)

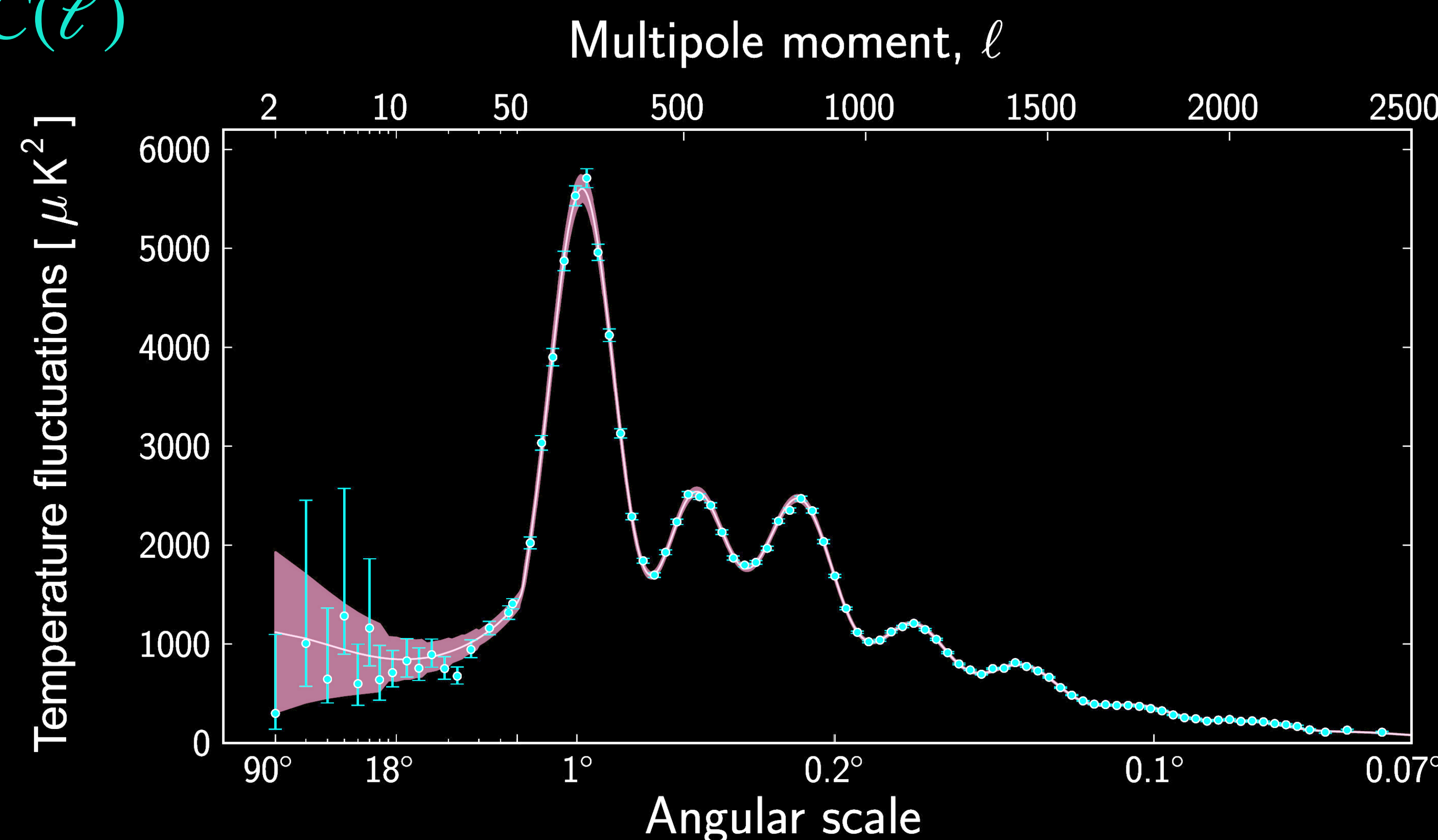
FS+BAO (BOSS+eBOSS, DESI)

CMB anisotropies (Planck, …)

Raw Data $I(f)$

Reduced Data

$C(\ell)$



Directly measured? $\mathbf{A} = \{T_\gamma \quad \theta_s \quad H_0 r_d\}$

Indirectly inferred? $\mathbf{\Omega} = \{A_s, n_s, \Omega_\gamma, \Omega_\nu, \Omega_\mathrm{b}, \Omega_\mathrm{cdm}, \Omega_\Lambda, H_0\}$

Physical parameters $\mathbf{A}$

CMB (Cobe)

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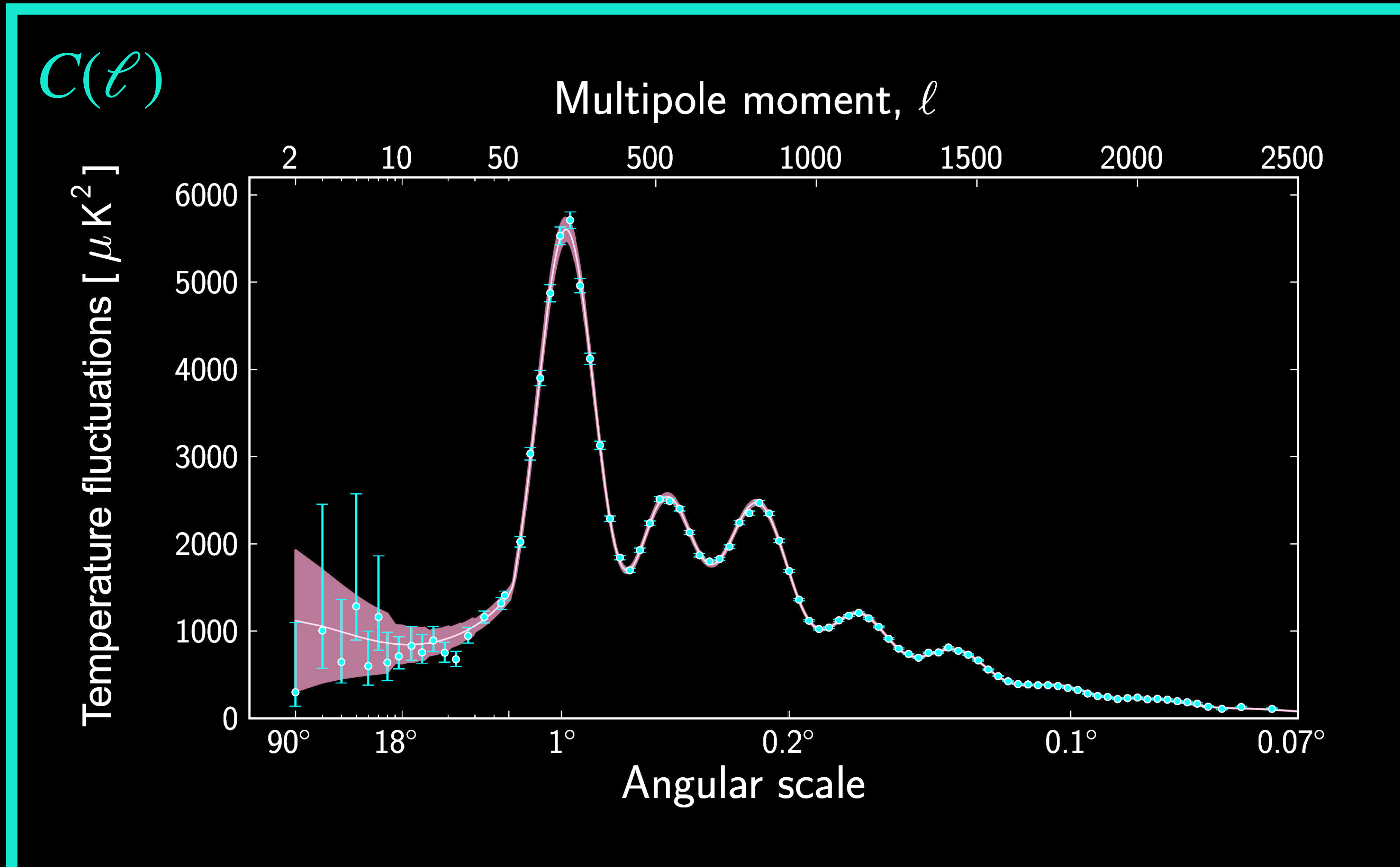
FS+BAO (BOSS+eBOSS, DESI)

CMB anisotropies (Planck, ...)

Raw Data $I(f)$

Reduced Data



Directly measured? $$\mathbf{A} = \left\{ T_\gamma \; \frac{\delta T_\gamma}{T_\gamma}(\hat{r}) \; \theta_s \qquad H_0 r_d \right\}$$

Indirectly inferred? $$\mathbf{\Omega} = \left\{ A_s, n_s, \Omega_\gamma, \Omega_\nu, \Omega_\mathrm{b}, \Omega_\mathrm{cdm}, \Omega_\Lambda, H_0 \right\}$$

Physical parameters $\mathbf{A}$

CMB (Cobe)

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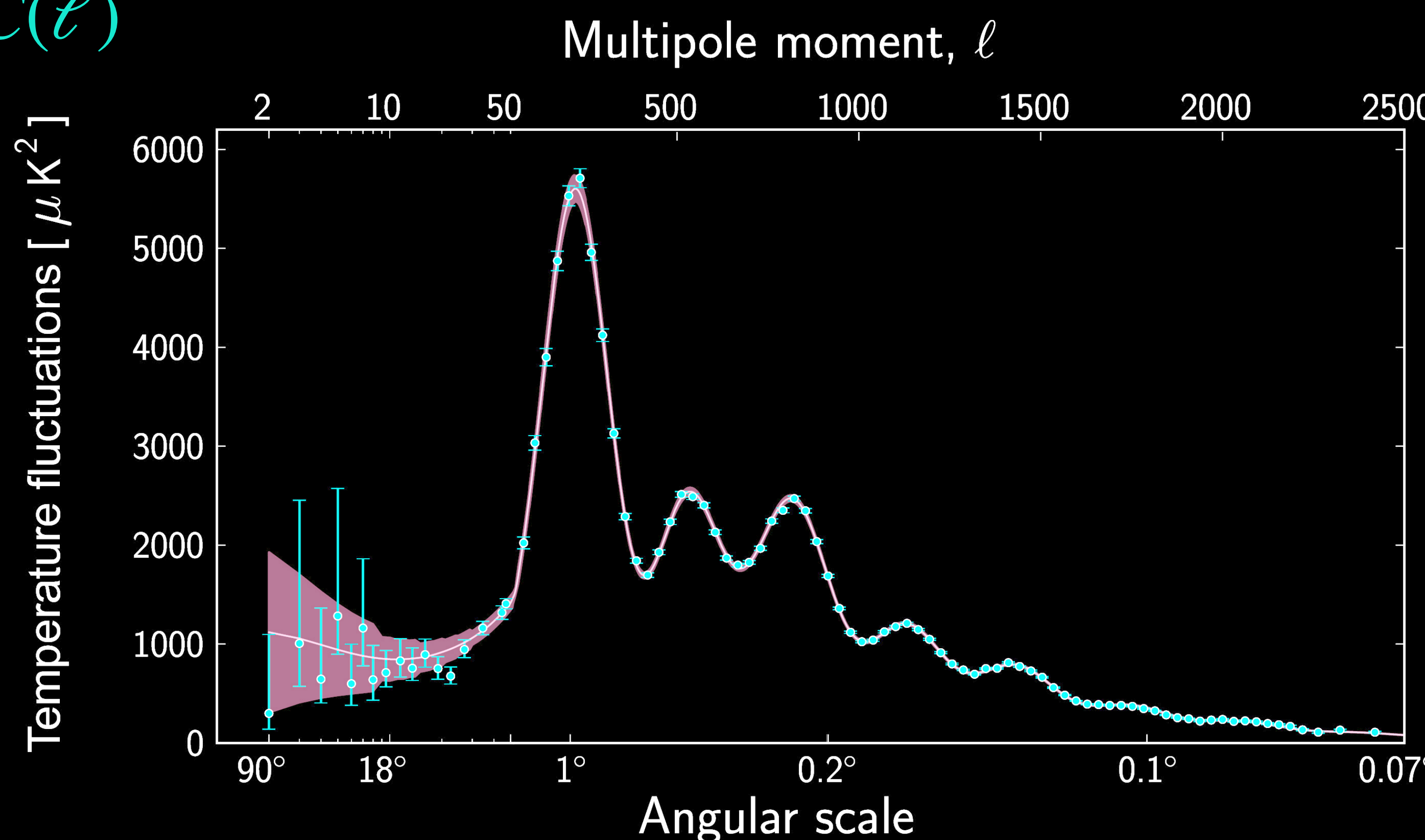
CMB anisotropies (Planck, ...)

$C(\ell)$



Raw Data $I(f)$

Reduced Data

Directly measured? $$\mathbf{A} = \left\{ T_\gamma \; \frac{\delta T_\gamma}{T_\gamma}(\hat{r}) \; \theta_s \qquad H_0 r_d \right\}$$

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Physical parameters $\mathbf{A}$

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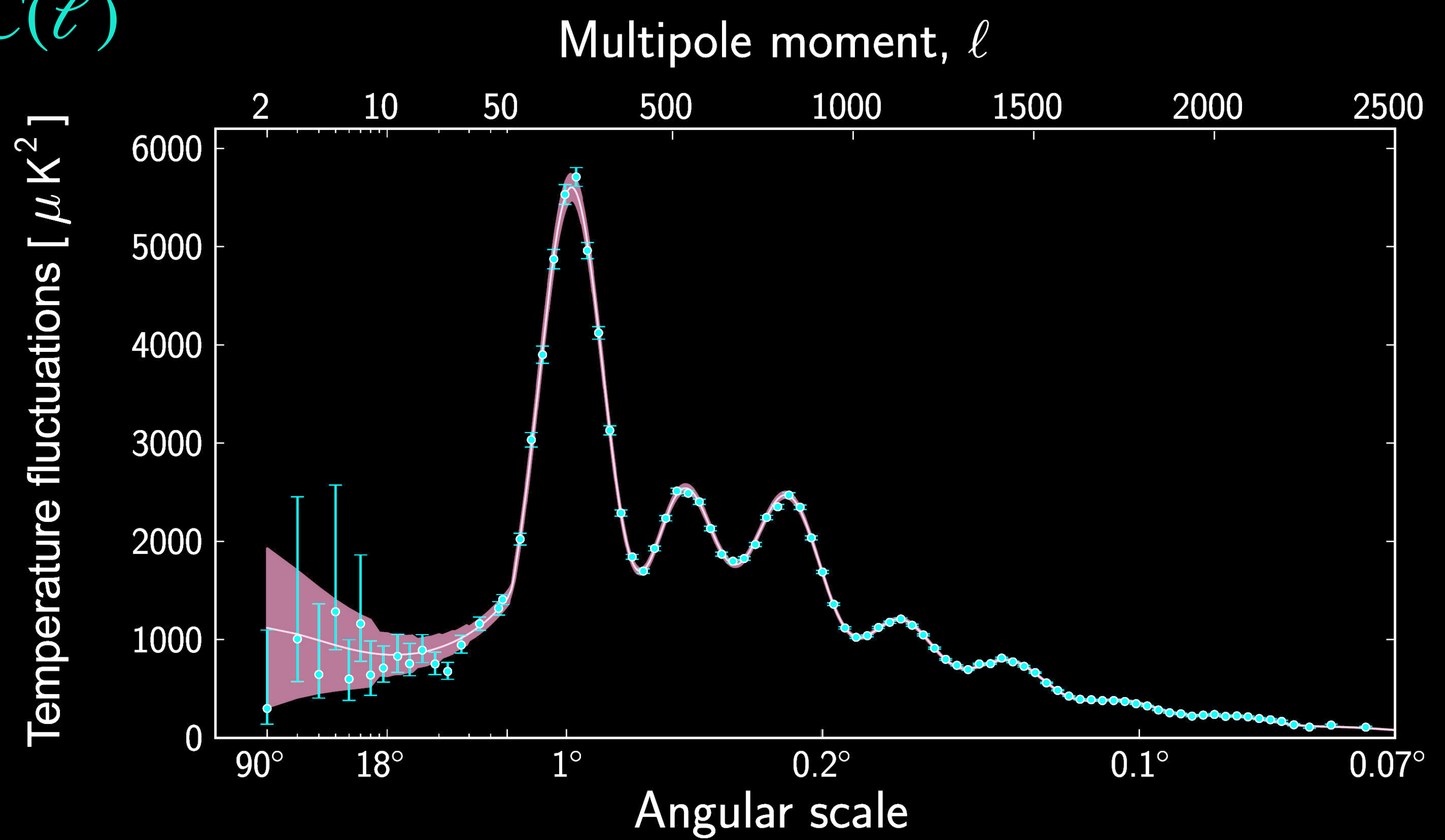

Raw Data $I(f)$

Reduced Data

Directly measured?

$$\mathbf{A} = \left\{ T_\gamma \; \frac{\delta T_\gamma}{T_\gamma}(\hat{r}) \; \theta_s \ldots \qquad H_0 r_d \right\}$$

Indirectly inferred?

$$\boldsymbol{\Omega} = \left\{ A_s, n_s, \Omega_\gamma, \Omega_\nu, \Omega_{\rm b}, \Omega_{\rm cdm}, \Omega_\Lambda, H_0 \right\}$$

Physical parameters $\mathbf{A}$

CMB (Cobe)

CMB anisotropies (Planck, …)

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SN (HST, JWST)

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Raw Data $I(f)$

Reduced Data $C(\ell)$

Directly measured? $$\mathbf{A} = \left\{ T_\gamma \; \frac{\delta T_\gamma}{T_\gamma}(\hat{r}) \; \theta_s \ldots \qquad H_0 r_d \right\}$$

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Physical parameters $\mathbf{A}$

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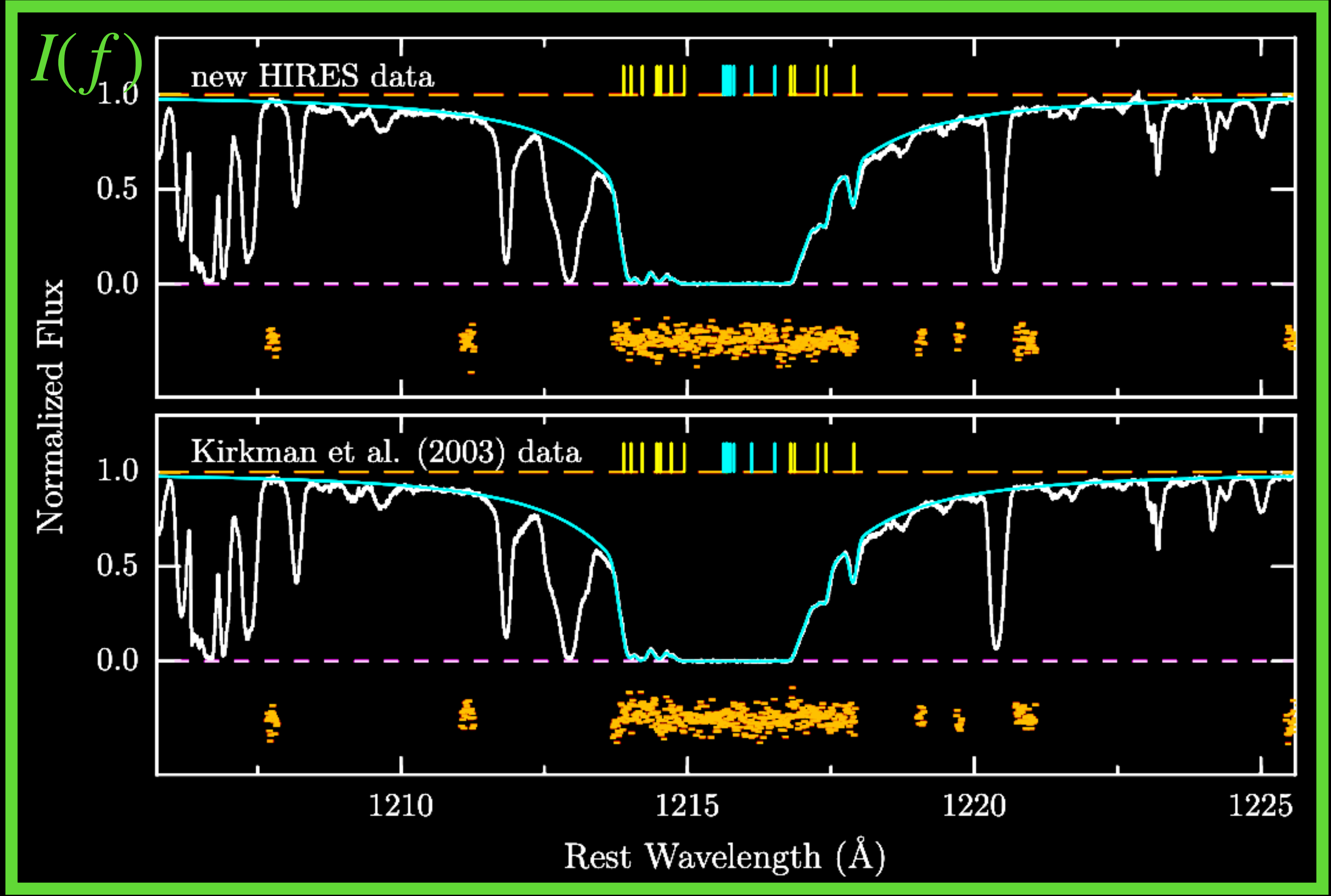
CMB anisotropies (Planck, ...)



Raw Data $I(f)$

Reduced Data $C(\ell)$

Directly measured? $$\mathbf{A} = \left\{ T_\gamma \; \frac{\delta T_\gamma}{T_\gamma}(\hat{r}) \; \theta_s \ldots \qquad H_0 r_d \right\}$$

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Physical parameters $\mathbf{A}$

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CMB anisotropies (Planck, ...)

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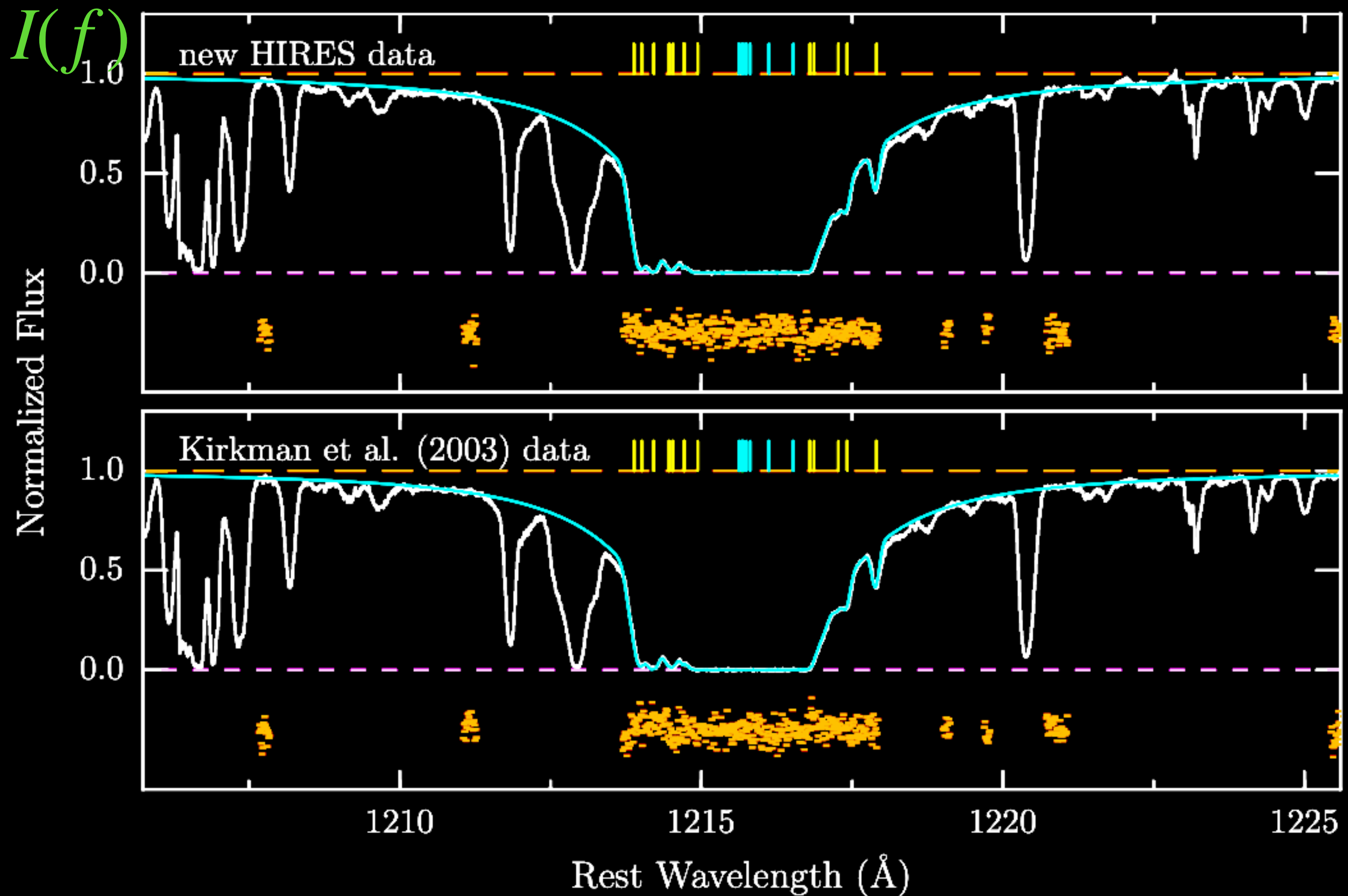
FS+BAO (BOSS+eBOSS, DESI)

$I(f)$



Raw Data $I(f)$

Reduced Data $C(\ell)$

Directly measured?

$$\mathbf{A} = \left\{ T_\gamma \; \frac{\delta T_\gamma}{T_\gamma}(\hat{r}) \; \theta_s \ldots \; Y_{\mathrm{D}} \qquad H_0 r_d \right\}$$

Indirectly inferred?

$$\mathbf{\Omega} = \left\{ A_s, n_s, \Omega_\gamma, \Omega_\nu, \Omega_{\mathrm{b}}, \Omega_{\mathrm{cdm}}, \Omega_\Lambda, H_0 \right\}$$

Physical parameters $\mathbf{A}$

CMB (Cobe)

CMB anisotropies (Planck, ...)

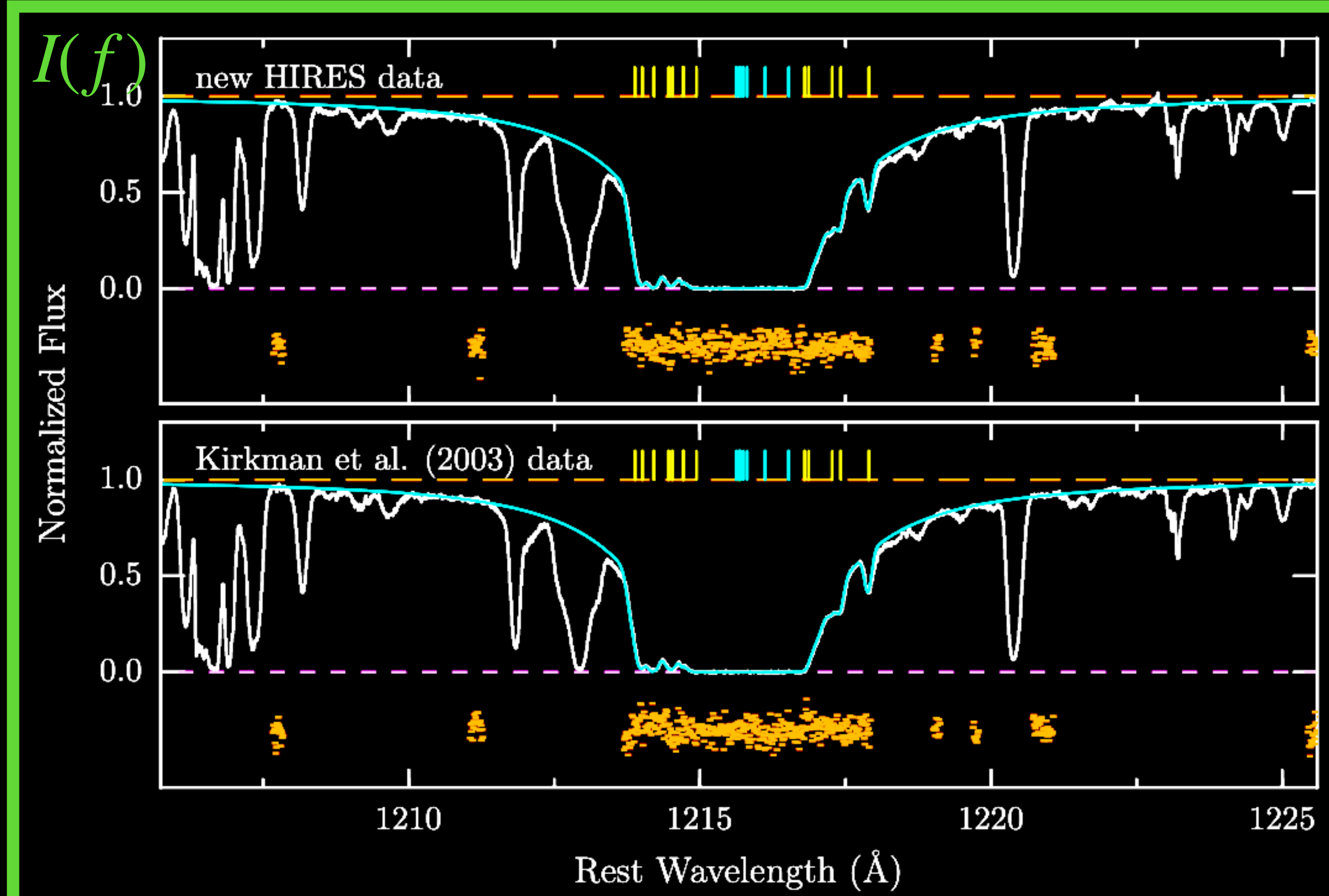
BBN

SN (HST, JWST)

FS+BAO (BOSS+eBOSS, DESI)

Raw Data $I(f)$

Reduced Data $C(\ell)$



Directly measured? $\mathbf{A} = \left\{ T_\gamma \, \frac{\delta T_\gamma}{T_\gamma}(\hat{r}) \, \theta_s \ldots \, Y_{\rm D} Y_{\rm He} \qquad H_0 r_d \right\}$

Indirectly inferred? $\mathbf{\Omega} = \left\{ A_s, n_s, \Omega_\gamma, \Omega_\nu, \Omega_{\rm b}, \Omega_{\rm cdm}, \Omega_\Lambda, H_0 \right\}$

Physical parameters $\mathbf{A}$

CMB (Cobe)

CMB anisotropies (Planck, …)

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SN (HST, JWST)

FS+BAO (BOSS+eBOSS, DESI)

	CMB	BBN
Raw Data	$I(f)$	$I(f)$
Reduced Data	$C(\ell)$	

Directly measured?

$$\mathbf{A} = \left\{ T_\gamma \, \frac{\delta T_\gamma}{T_\gamma}(\hat{r}) \, \theta_s \ldots \, Y_{\mathrm{D}} Y_{\mathrm{He}} \qquad H_0 r_d \right\}$$

Indirectly inferred?

$$\mathbf{\Omega} = \left\{ A_s, n_s, \Omega_\gamma, \Omega_\nu, \Omega_{\mathrm{b}}, \Omega_{\mathrm{cdm}}, \Omega_\Lambda, H_0 \right\}$$

Physical parameters $\mathbf{A}$

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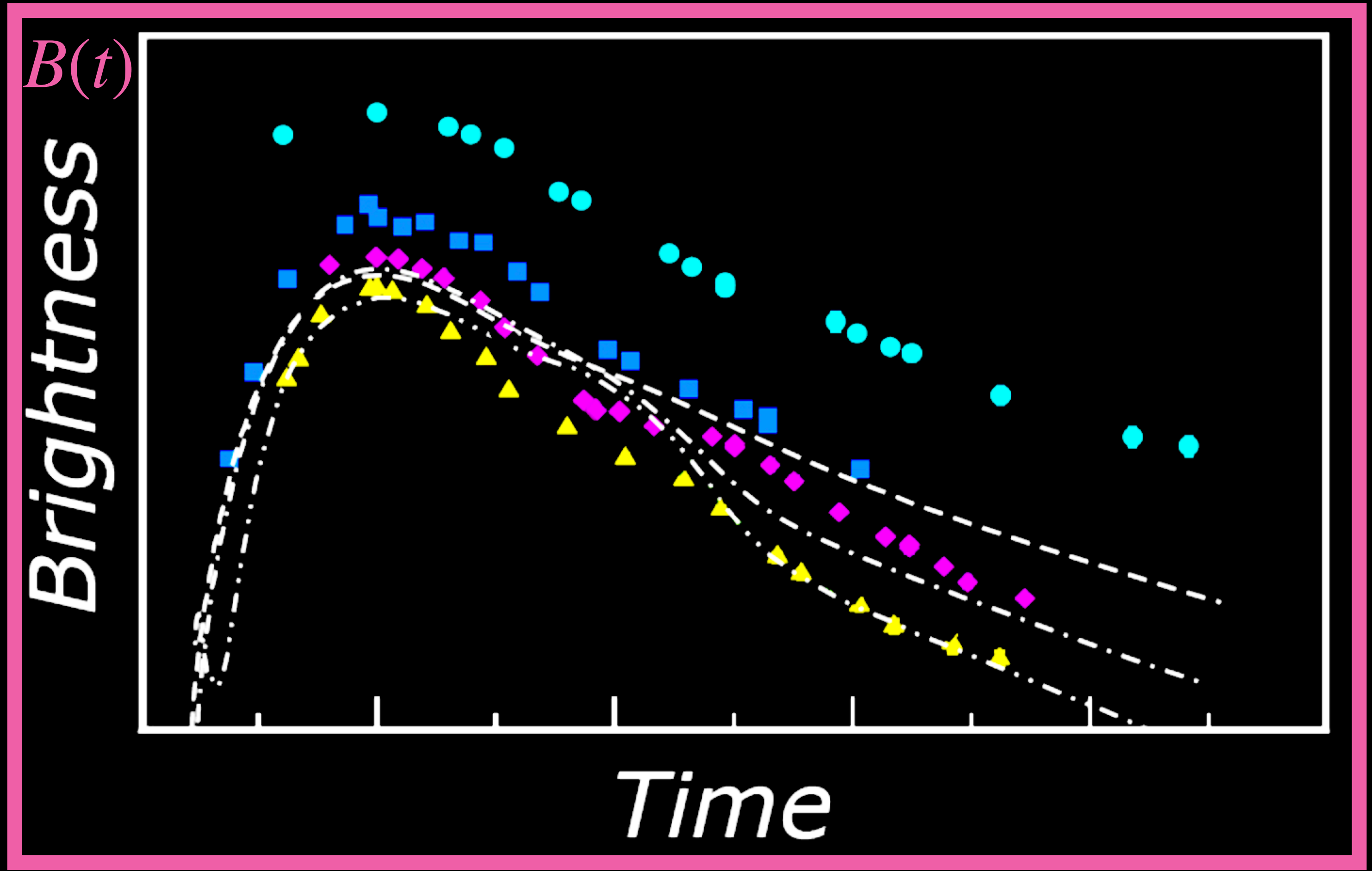


Raw Data $I(f)$

Reduced Data $C(\ell)$

Directly measured? $\mathbf{A} = \left\{ T_\gamma \, \frac{\delta T_\gamma}{T_\gamma}(\hat{r}) \, \theta_s \ldots \, Y_\mathrm{D} Y_\mathrm{He} \quad H_0 r_d \right\}$

Indirectly inferred? $\mathbf{\Omega} = \left\{ A_s, n_s, \Omega_\gamma, \Omega_\nu, \Omega_\mathrm{b}, \Omega_\mathrm{cdm}, \Omega_\Lambda, H_0 \right\}$

Physical parameters $\mathbf{A}$

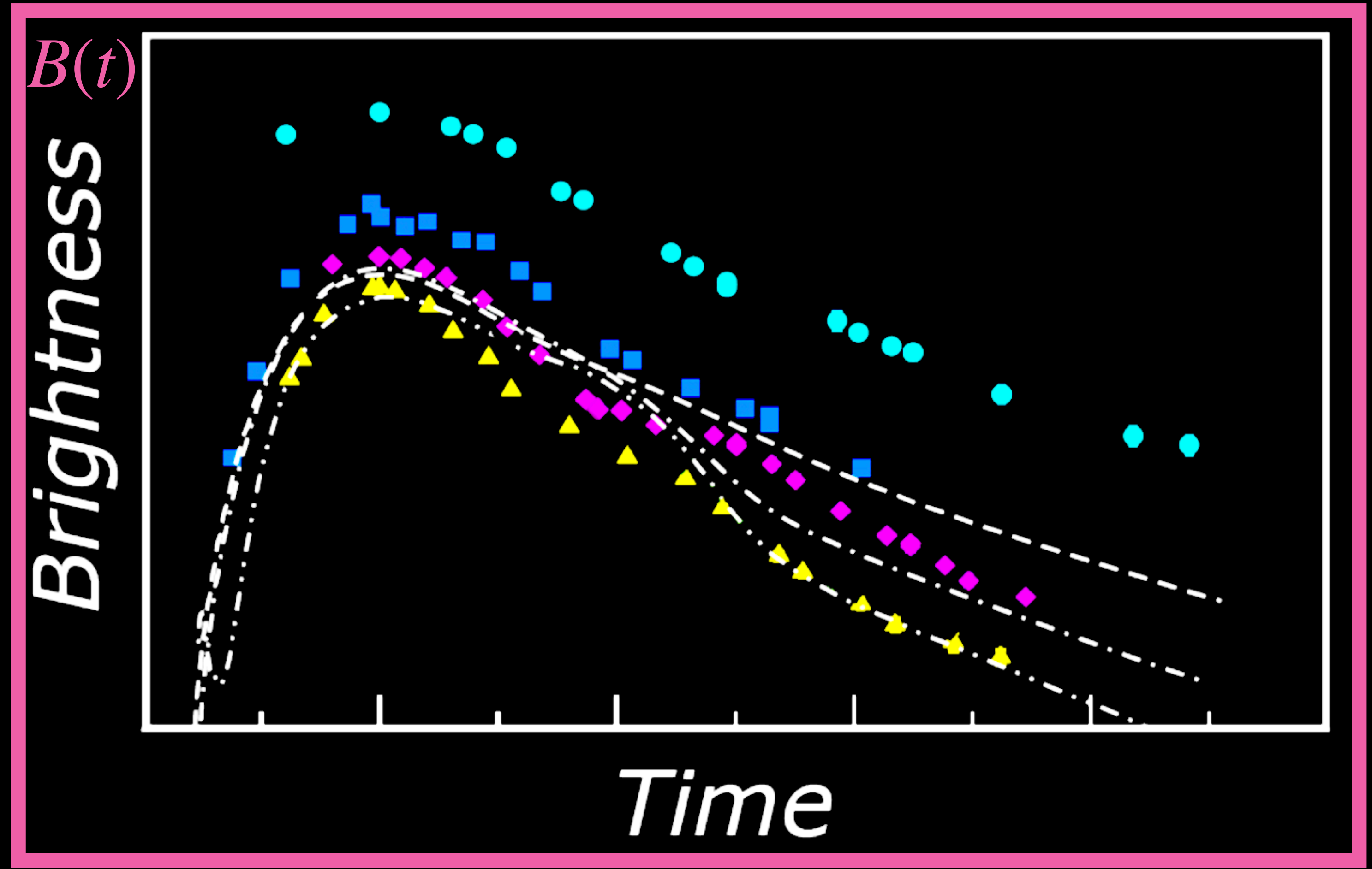
CMB (Cobe)

CMB anisotropies (Planck, …)

BBN

SN (HST, JWST)

FS+BAO (BOSS+eBOSS, DESI)



Raw Data	$I(f)$
Reduced Data	$C(\ell)$

Directly measured? $$\mathbf{A} = \left\{ T_\gamma \, \frac{\delta T_\gamma}{T_\gamma}(\hat{r}) \, \theta_s \ldots \; Y_\mathrm{D} Y_\mathrm{He} \; m_B \qquad H_0 r_d \right\}$$

Indirectly inferred? $$\mathbf{\Omega} = \left\{ A_s, n_s, \Omega_\gamma, \Omega_\nu, \Omega_\mathrm{b}, \Omega_\mathrm{cdm}, \Omega_\Lambda, H_0 \right\}$$

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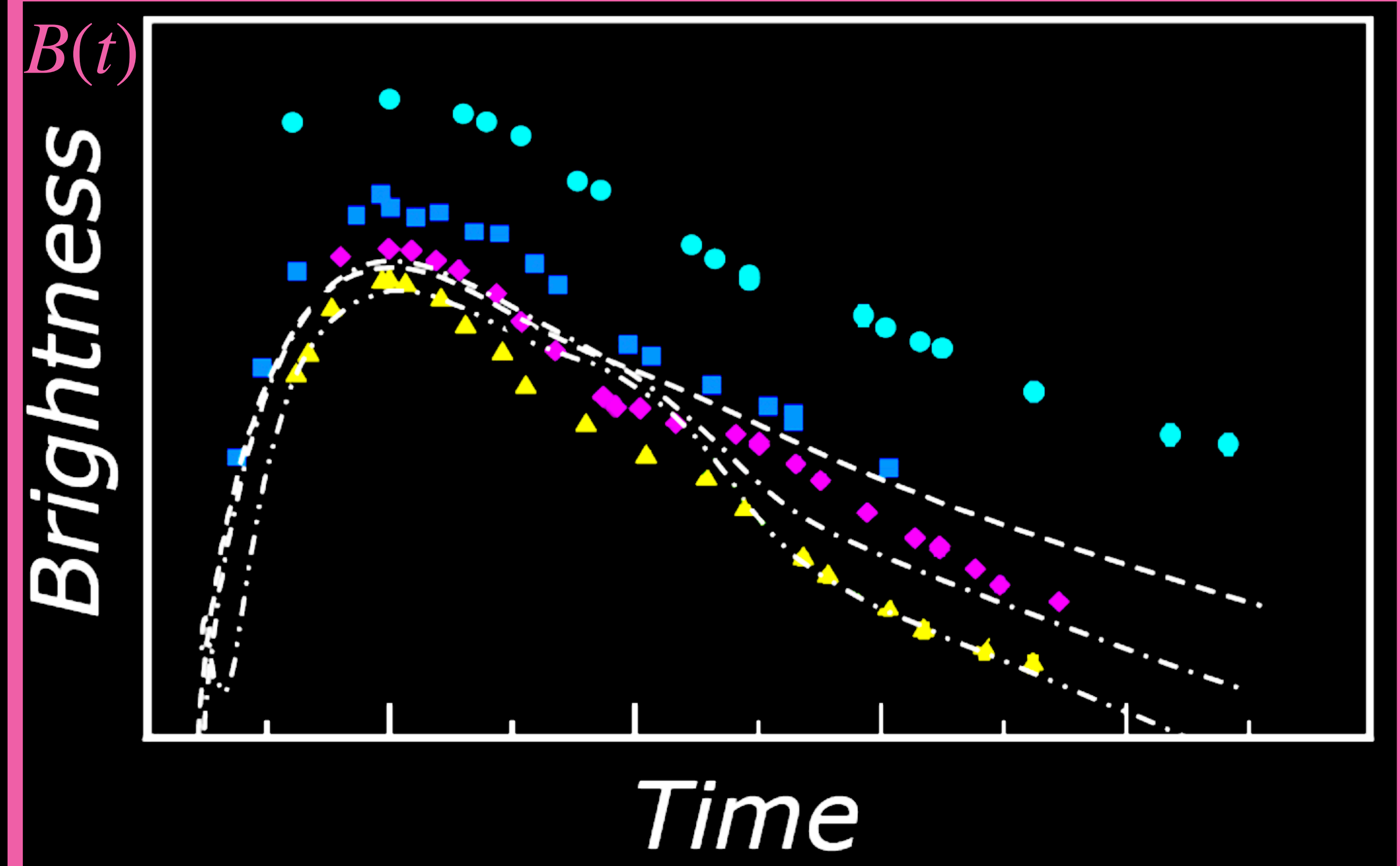
Raw Data $I(f)$

Reduced Data $C(\ell)$

$B(t)$



Directly measured? $\mathbf{A} = \left\{ T_\gamma \, \frac{\delta T_\gamma}{T_\gamma}(\hat{r}) \, \theta_s \ldots \, Y_{\rm D} Y_{\rm He} \, m_B \, \frac{H(z)}{H_0} \, H_0 r_d \right\}$

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Raw Data	$I(f)$	$I(f)$	$B(t)$	
Reduced Data	$C(\ell)$			

Directly measured?

$$\mathbf{A} = \left\{ T_\gamma \ \frac{\delta T_\gamma}{T_\gamma}(\hat{r}) \ \theta_s \ldots \ Y_{\mathrm{D}} Y_{\mathrm{He}} \ m_B \ \frac{H(z)}{H_0} \ H_0 r_d \right\}$$

Indirectly inferred?

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CMB anisotropies (Planck, …)

BBN

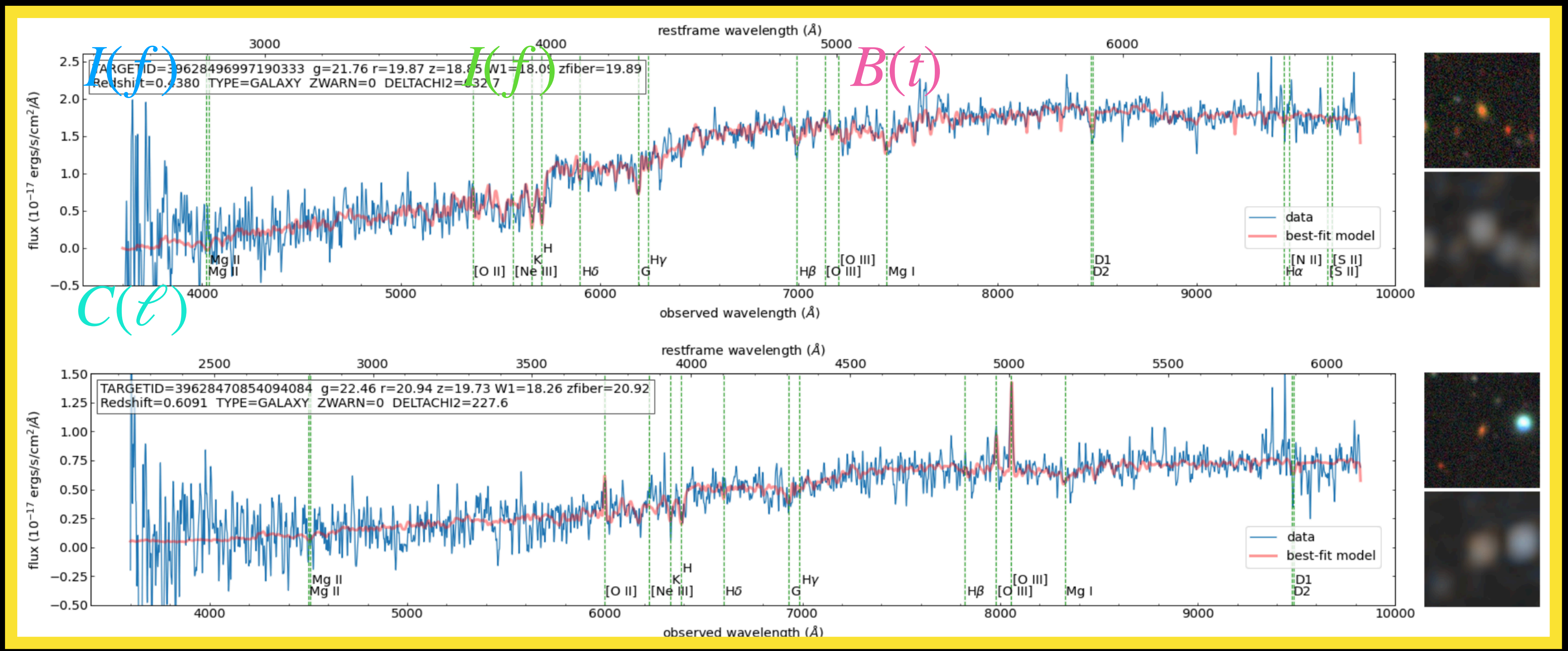
SN (HST, JWST)

FS+BAO (BOSS+eBOSS, DESI)

$N_g \cdot I(f)$

Raw Data

Reduced Data



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$$\mathbf{A} = \left\{ T_\gamma \ \frac{\delta T_\gamma}{T_\gamma}(\hat{r}) \ \theta_s \ldots \ Y_\mathrm{D} Y_\mathrm{He} \ m_B \ \frac{H(z)}{H_0} \ H_0 r_d \right\}$$

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Raw Data	$I(f)$	$I(f)$	$B(t)$	$N_g \cdot I(f)$
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Physical parameters $\mathbf{A}$

CMB (Cobe)

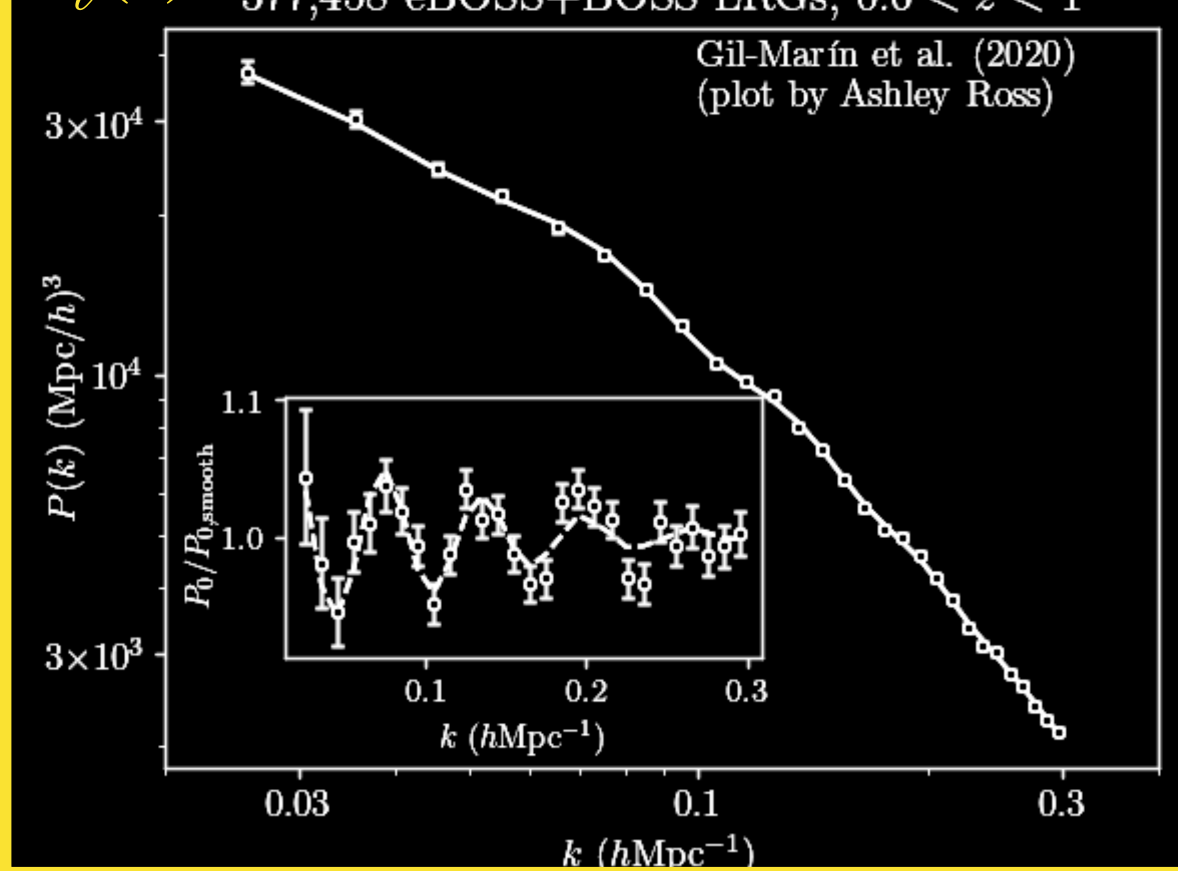
BBN

SN (HST, JWST)

FS+BAO (BOSS+eBOSS, DESI)

CMB anisotropies (Planck, …)

$P_\ell(k)$



Raw Data $I(f)$ $I(f)$

Reduced Data $C(\ell)$

Directly measured?

$$\mathbf{A} = \left\{ T_\gamma \, \frac{\delta T_\gamma}{T_\gamma}(\hat{r}) \, \theta_s \ldots \, Y_{\mathrm{D}} Y_{\mathrm{He}} \; m_B \, \frac{H(z)}{H_0} \; H_0 r_d \right\}$$

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Raw Data $I(f)$ $I(f)$

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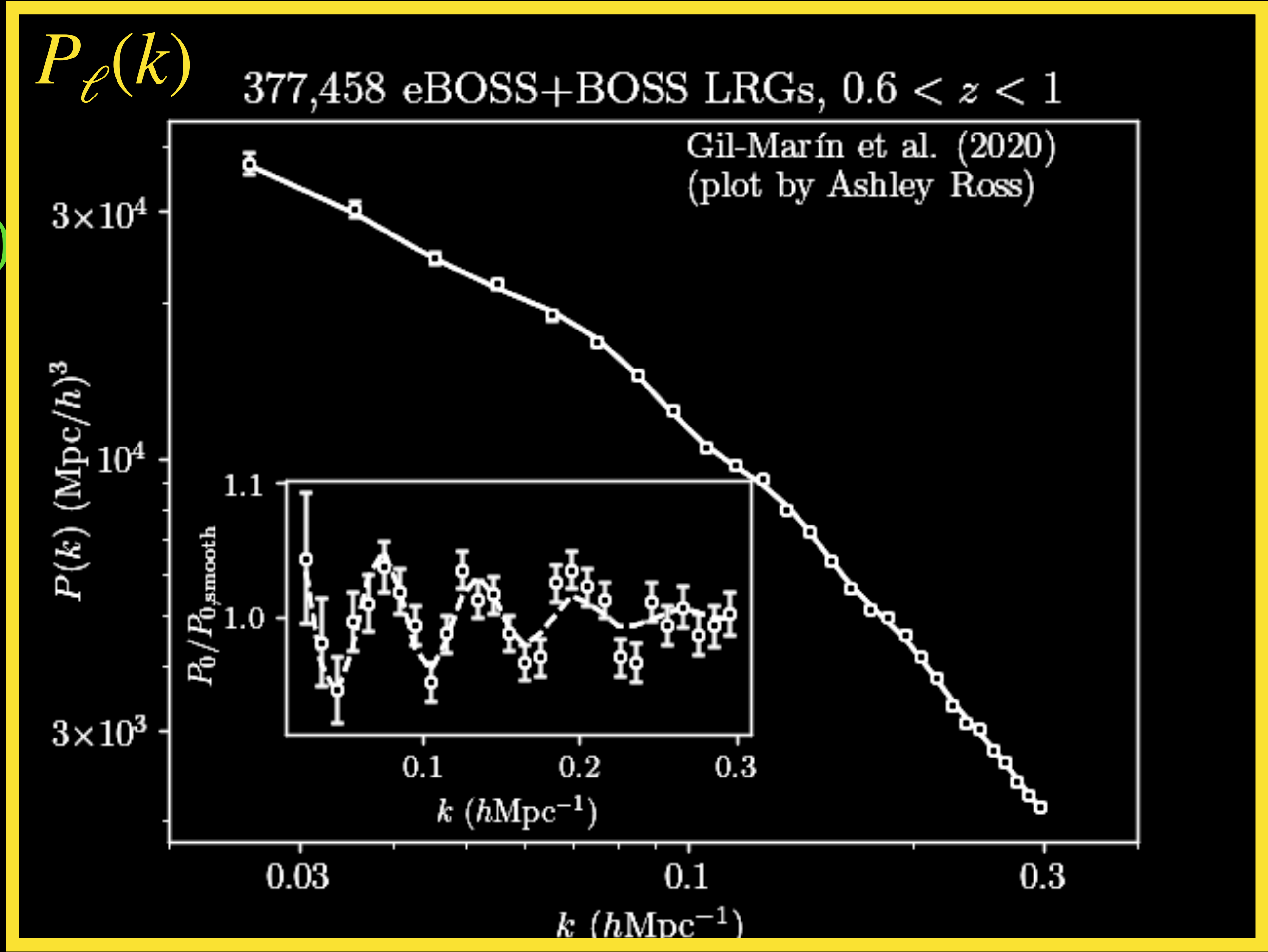

Directly measured? $$\mathbf{A} = \left\{ T_\gamma \, \frac{\delta T_\gamma}{T_\gamma}(\hat{r}) \, \theta_s \ldots \, Y_{\rm D} Y_{\rm He} \, m_B \, \frac{H(z)}{H_0} \, H_0 r_d \right\}$$

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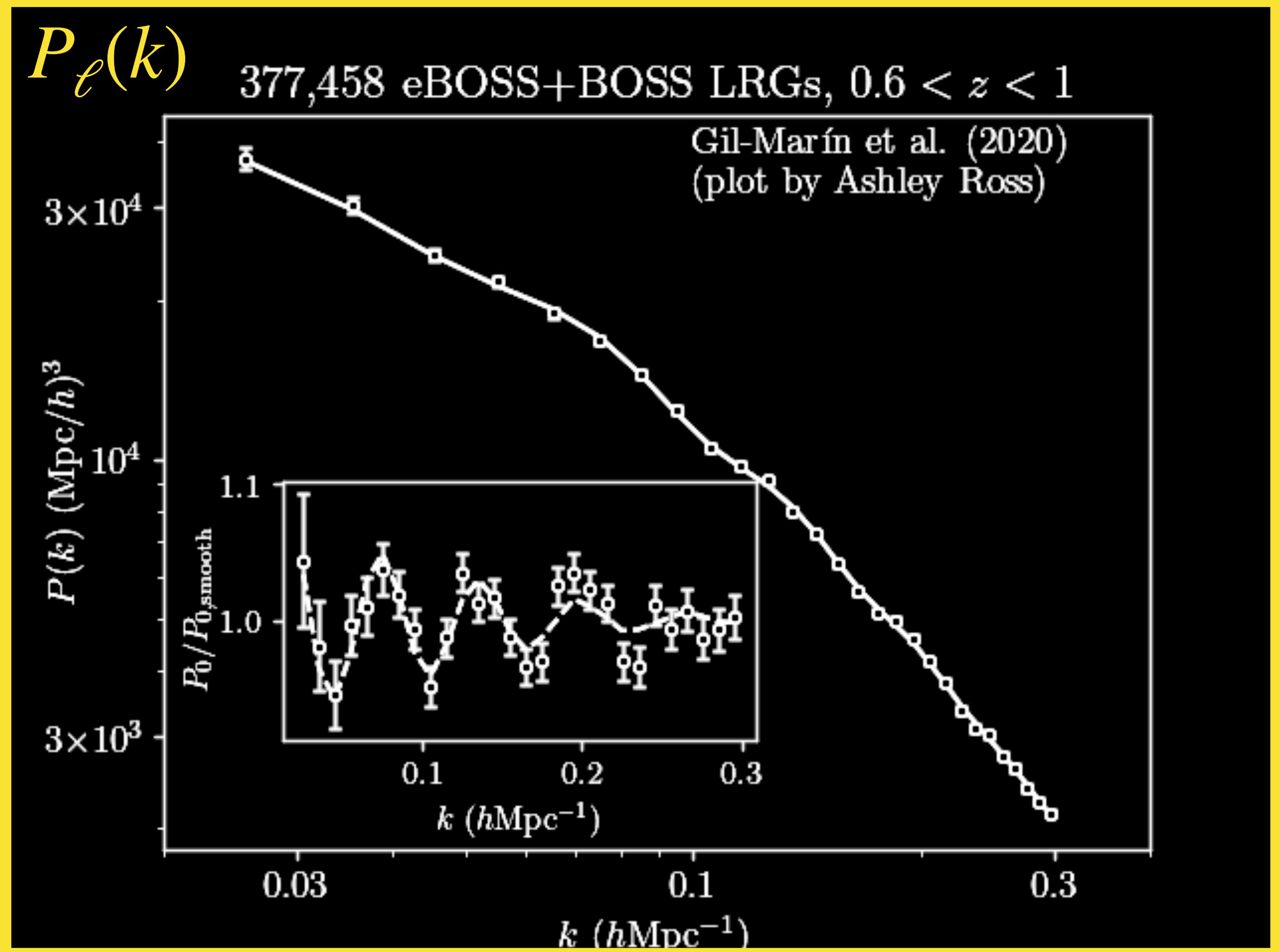

Directly measured?

$$\mathbf{A} = \left\{ T_\gamma \; \frac{\delta T_\gamma}{T_\gamma}(\hat{r}) \; \theta_s \ldots \; Y_{\mathrm{D}} Y_{\mathrm{He}} \; m_B \; \frac{H(z)}{H_0} \; H_0 r_d \right\}$$

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	CMB (Cobe) / CMB anisotropies (Planck, ...)	BBN	SN (HST, JWST)	FS+BAO (BOSS+eBOSS, DESI)
Raw Data	$I(f)$	$I(f)$	$B(t)$	$N_g \cdot I(f)$
Reduced Data	$C(\ell)$			$P_\ell(k)$

Directly measured?

$$\mathbf{A} = \left\{ T_\gamma \ \frac{\delta T_\gamma}{T_\gamma}(\hat{r}) \ \theta_s \ldots \ Y_{\mathrm{D}} Y_{\mathrm{He}} \ m_B \ \frac{H(z)}{H_0} \ H_0 r_d \right\}$$

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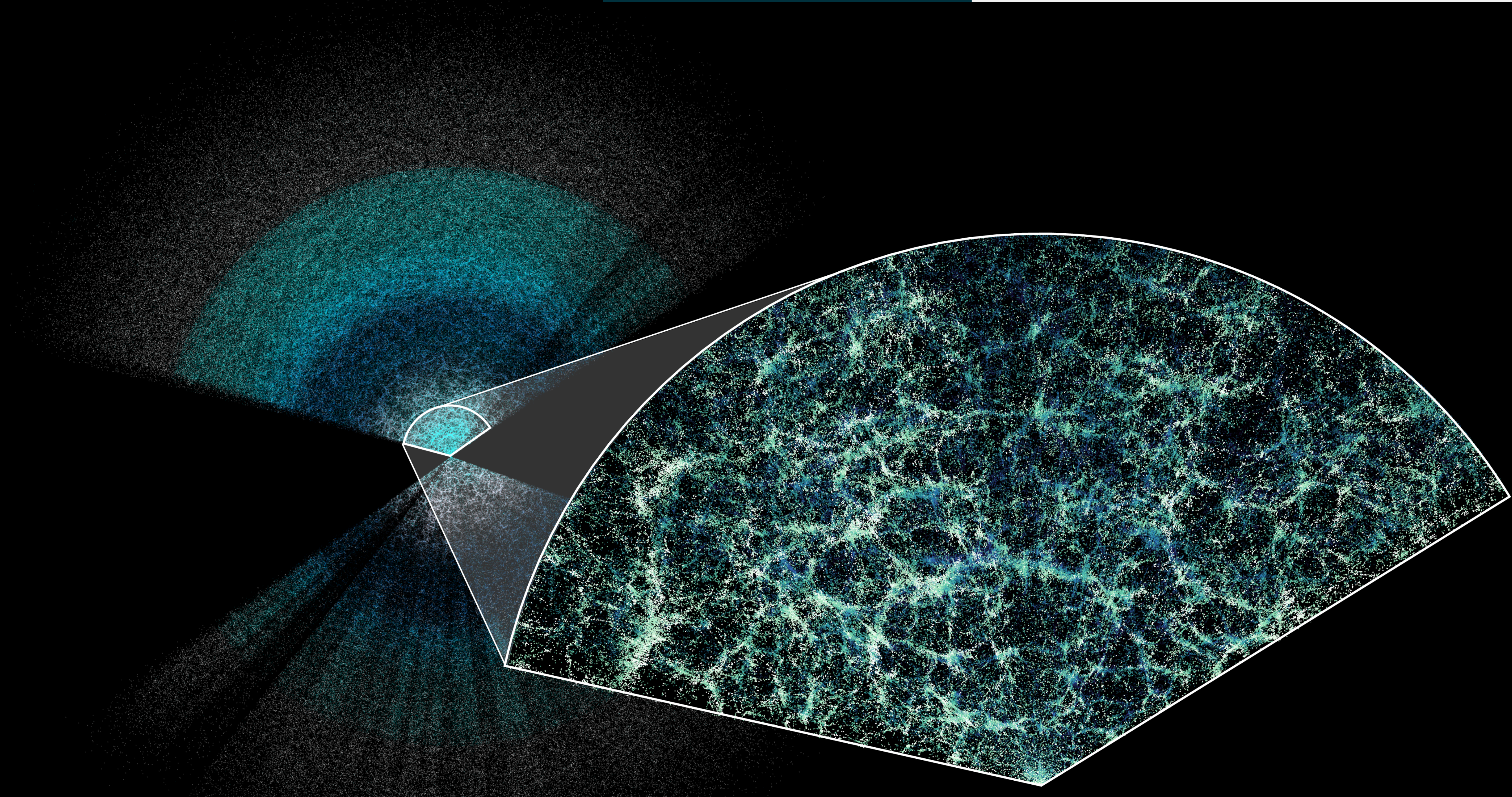
Intermezzo:

DESI Cosmology Results

April 2024: DESI DR1 BAO Results

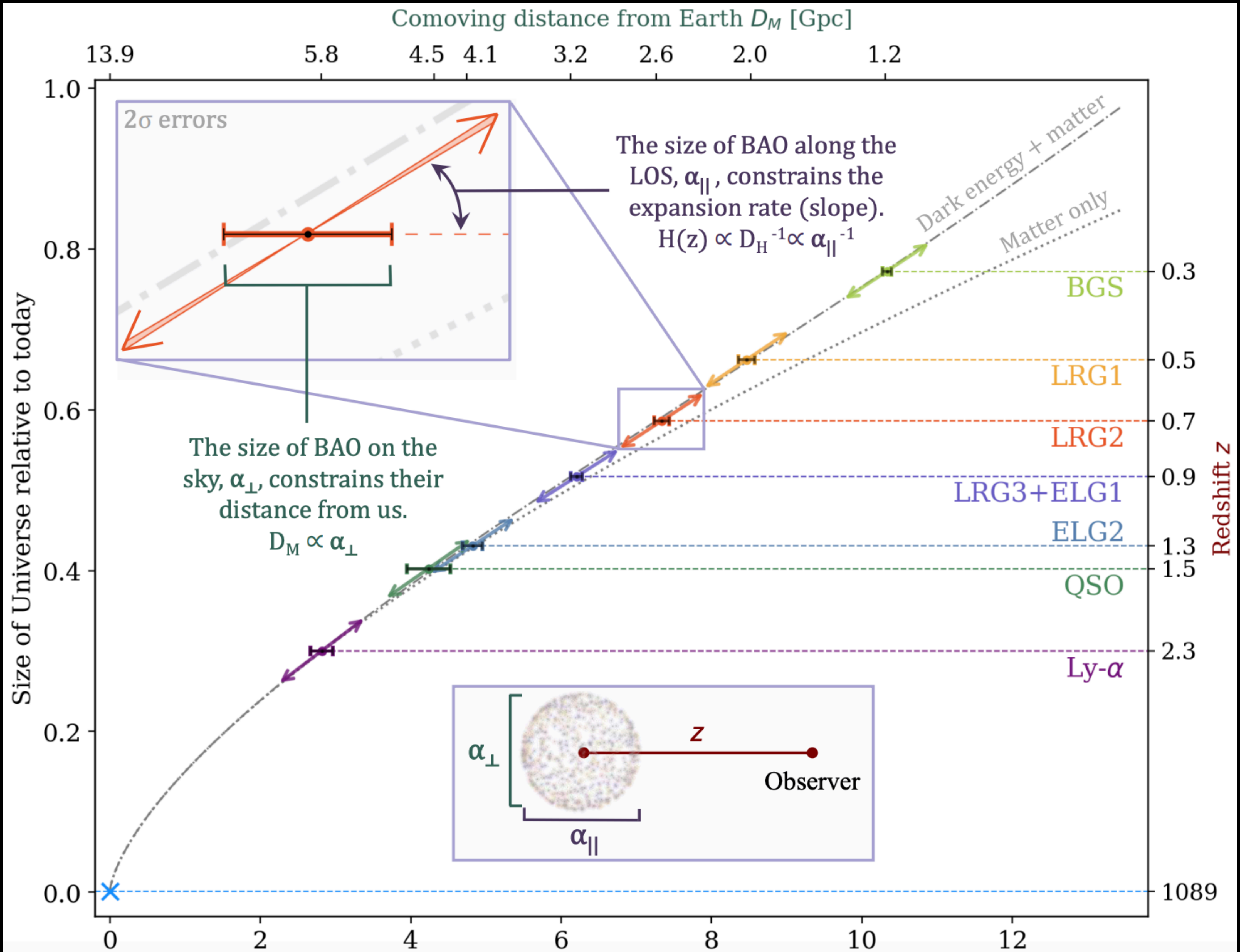
BERKELEY LAB

First Results from DESI Make the Most Precise Measurement of Our Expanding Universe



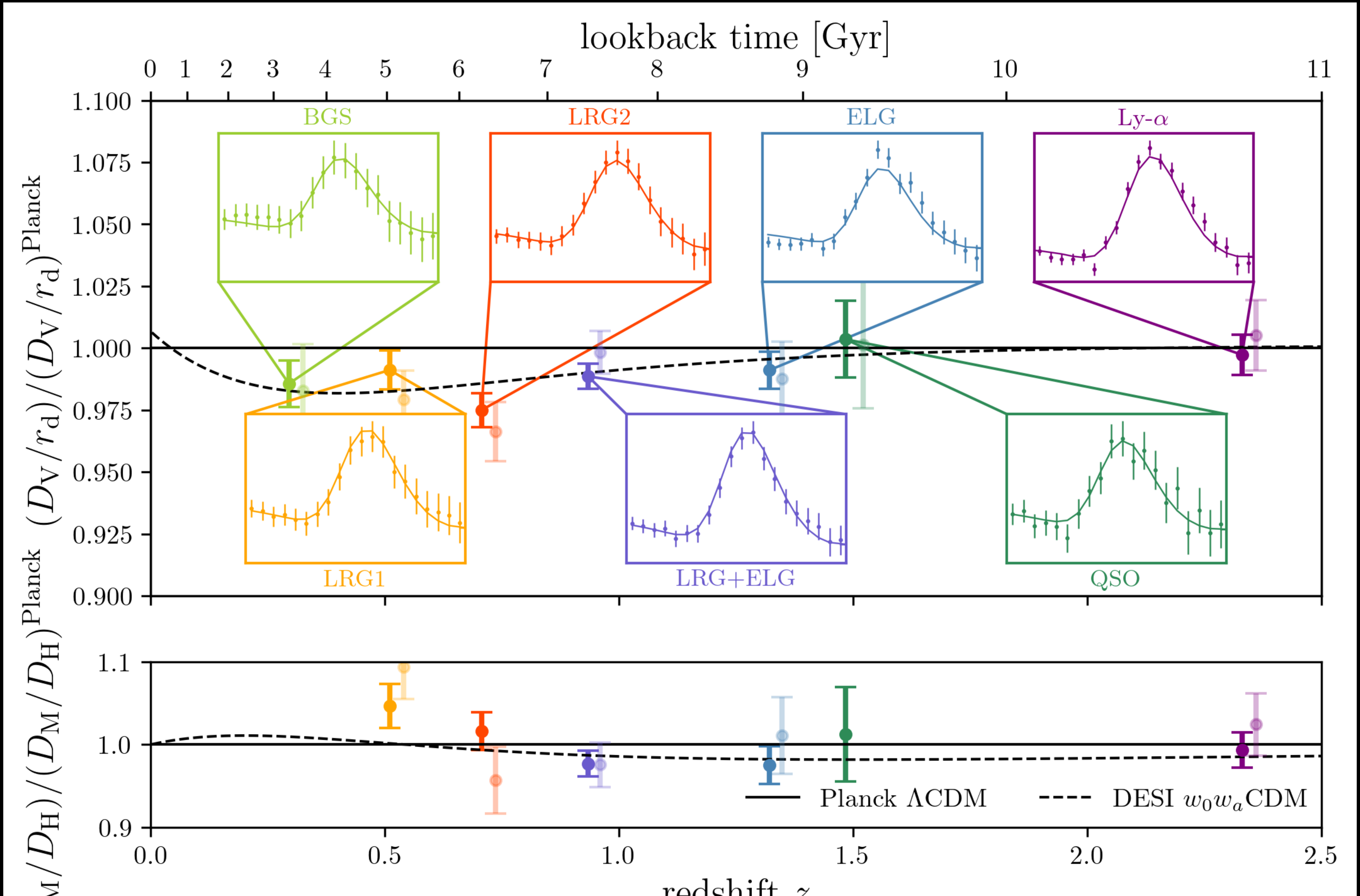
Credits: Claire Lamman I DESI collaboration. Poster available on our RedBubble Store

March 2025: DESI DR2 BAO Results



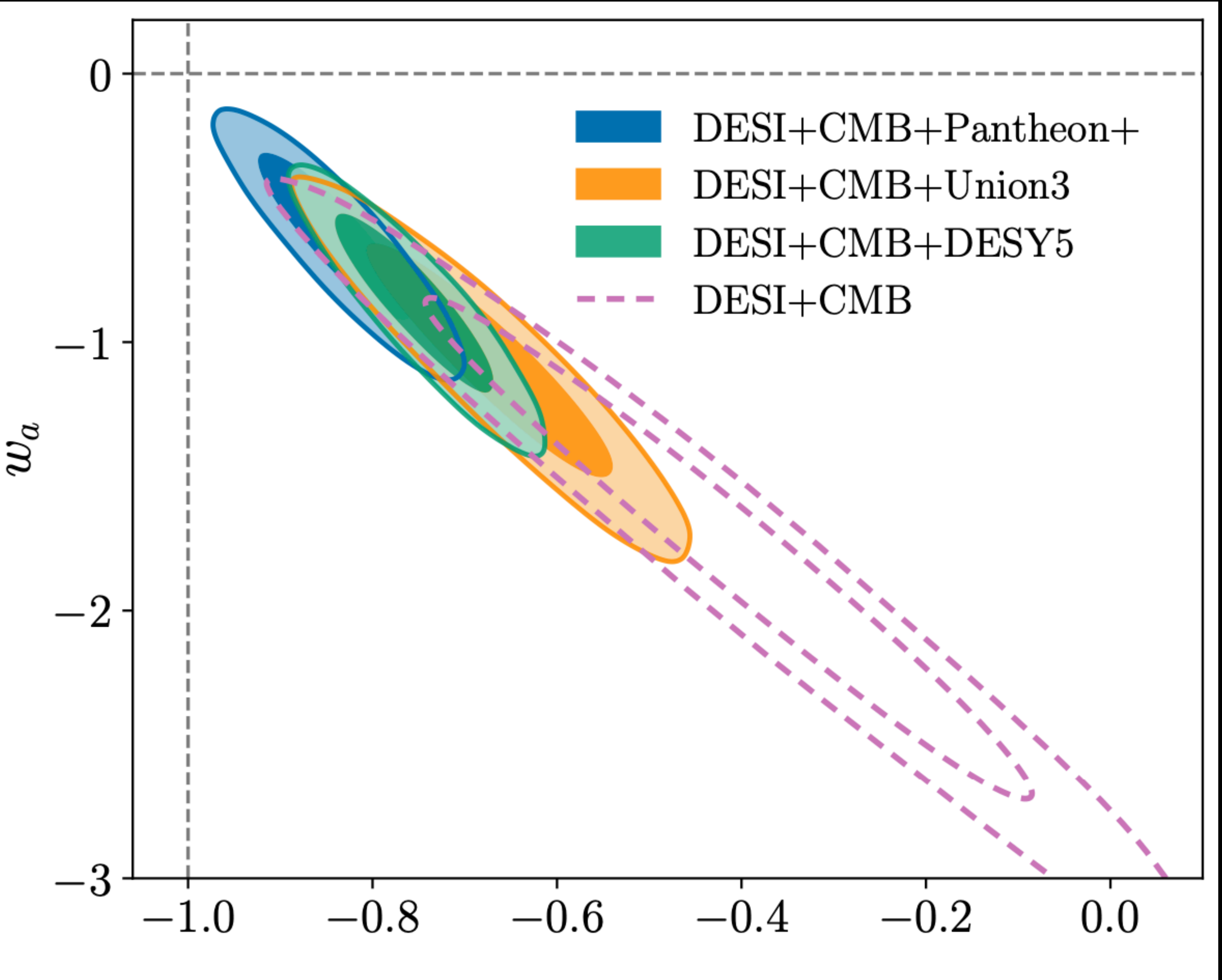
From DESI DR2 Key Paper

DESI 2025 (DR2) BAO Results



Credits: Arnaud de Mattia | DESI collaboration

DESI 2025 (DR2) BAO: w0wa plane



From DESI DR2 Key Paper

A new w0waCDM paradigm?

A new w0waCDM paradigm?

Credits:
Claire Lamman

From observations to LSS catalogue:

DESI **End-to-end** pipeline and systematics

Dark Energy Spectroscopic Instrument

Dark Energy Spectroscopic Instrument

Credits:
Claire Lamman

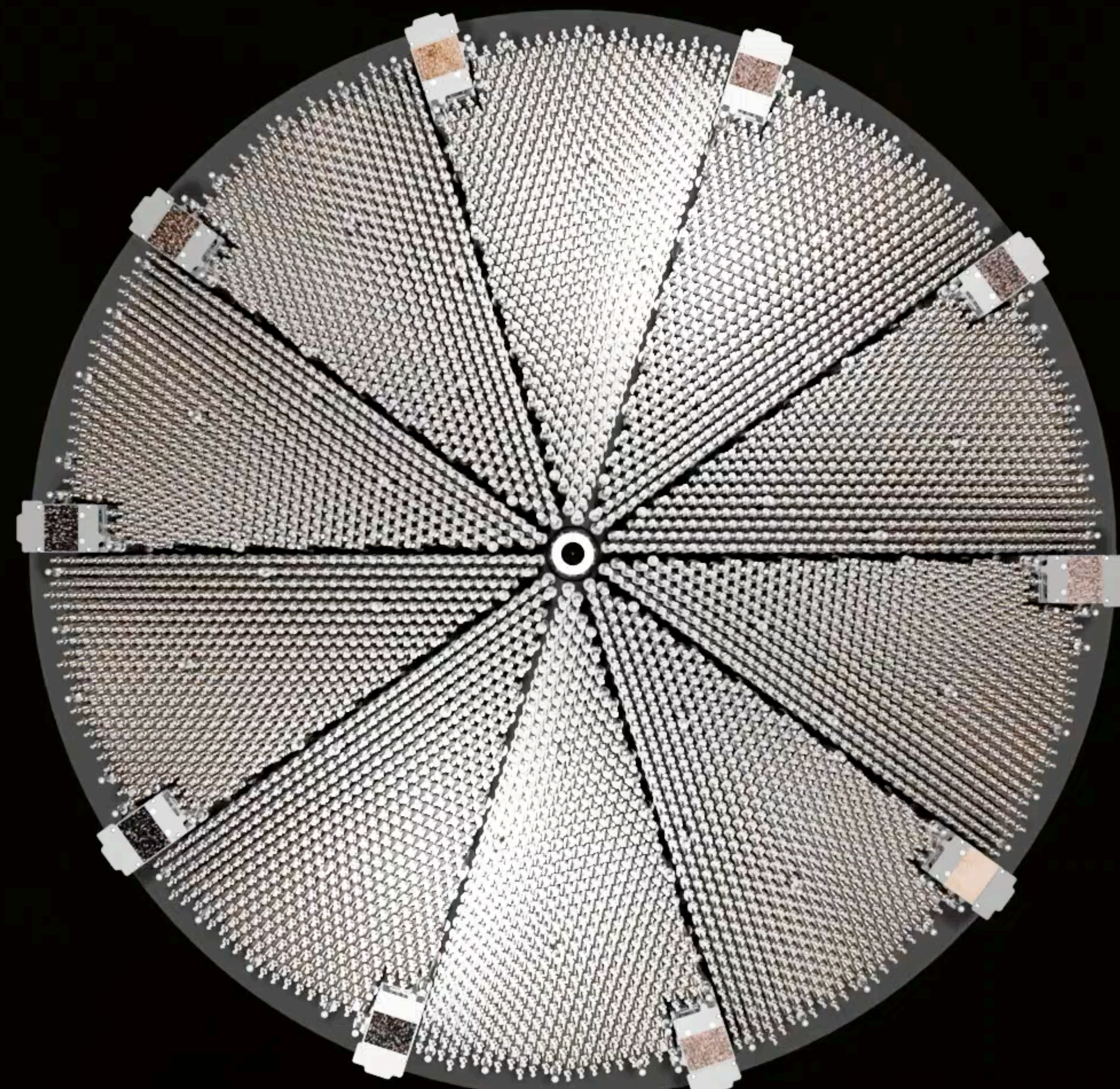
Dark Energy Spectroscopic Instrument

DESI coyote "BaoBan"

See my blog post: [the-new-desi-ambassador-baoban]

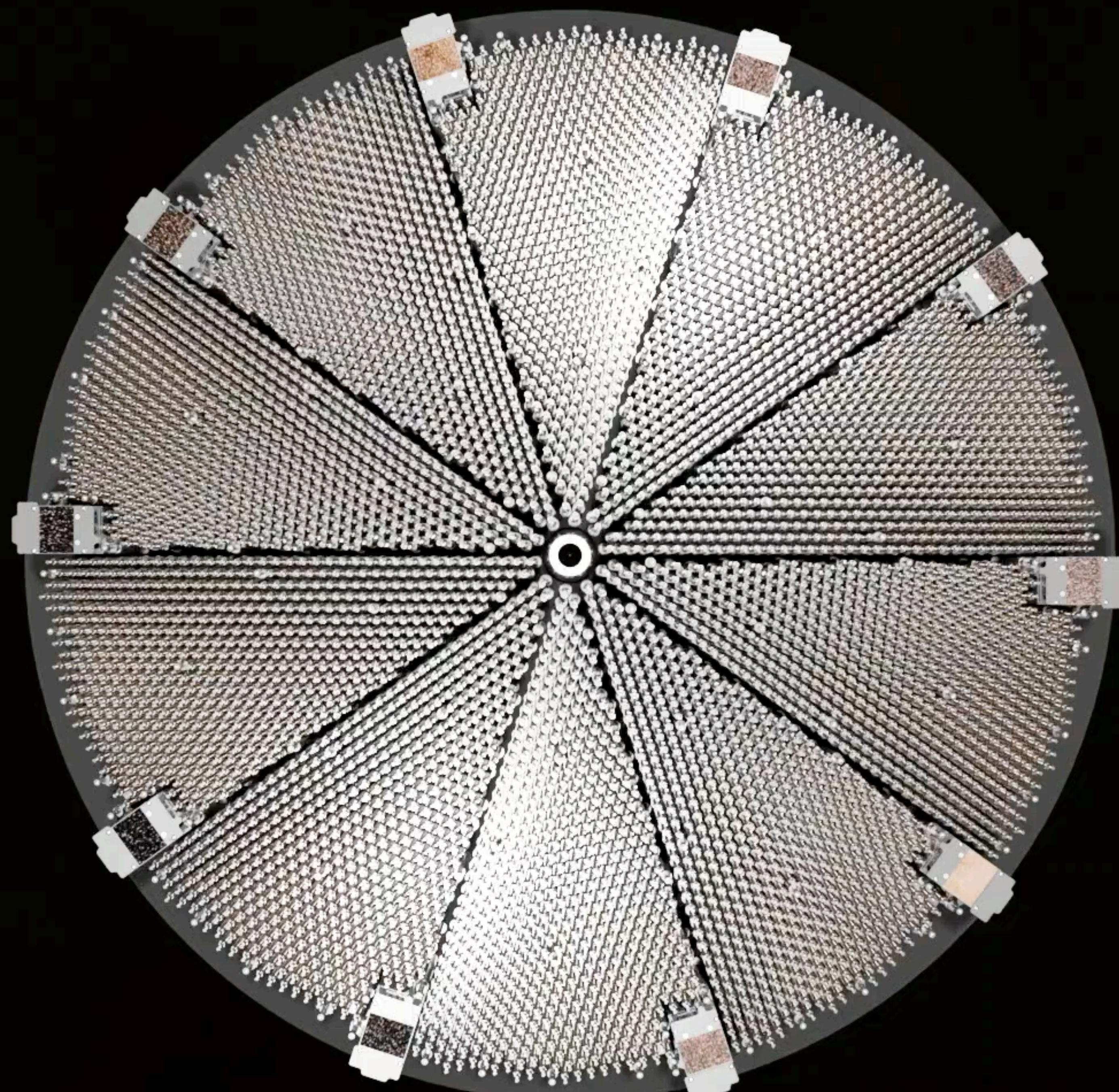
Credits: Claire Lamman

DESI Focal Plane: 5000 eyes …



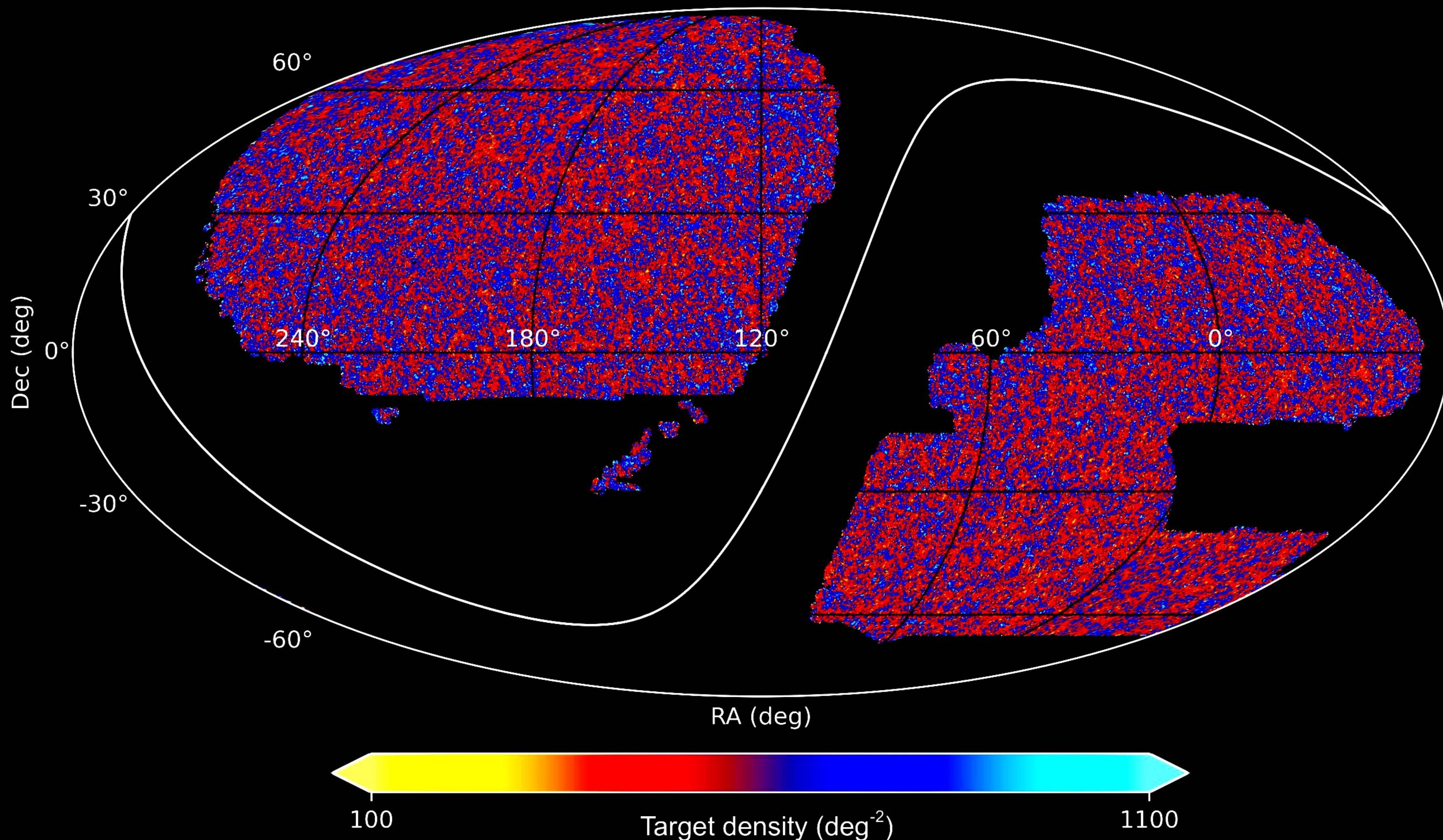
Credits: David Kirkby

DESI Focal Plane: 5000 eyes …



Credits: David Kirkby

DESI photometric targets

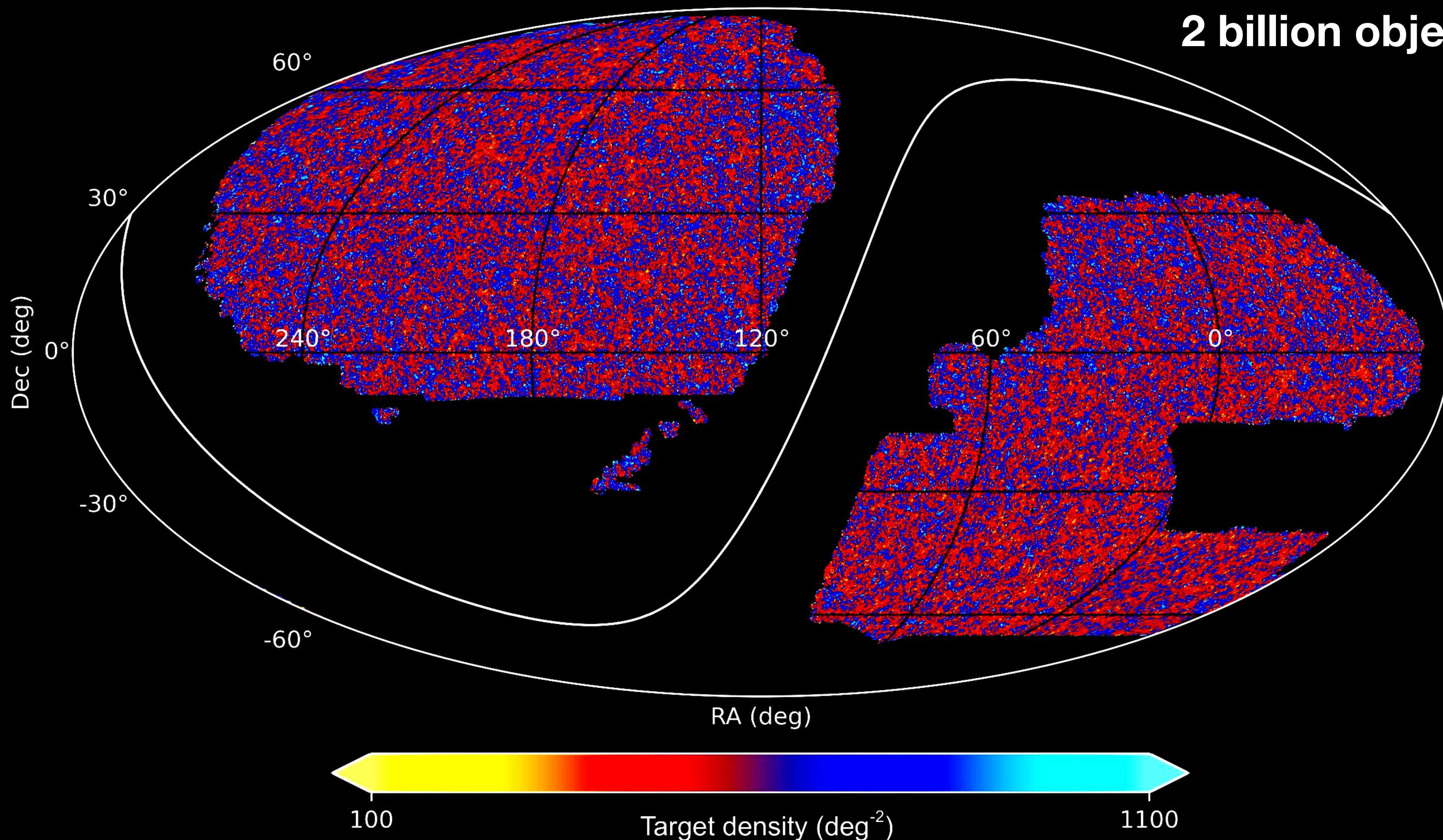


Zhou et al., 2208.08515

Imaging survey

DESI photometric targets

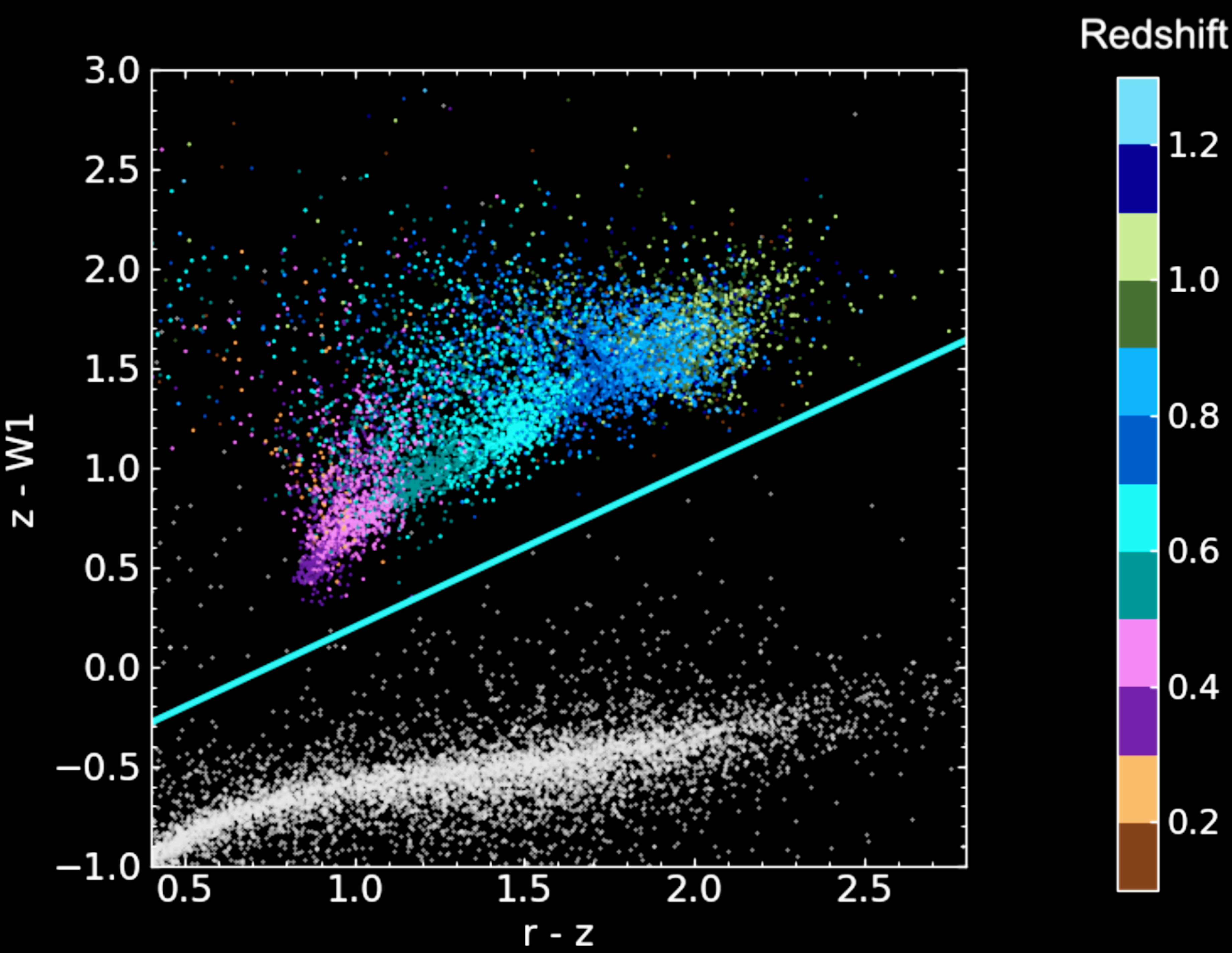
2 billion objects!



Zhou et al., 2208.08515

Imaging survey

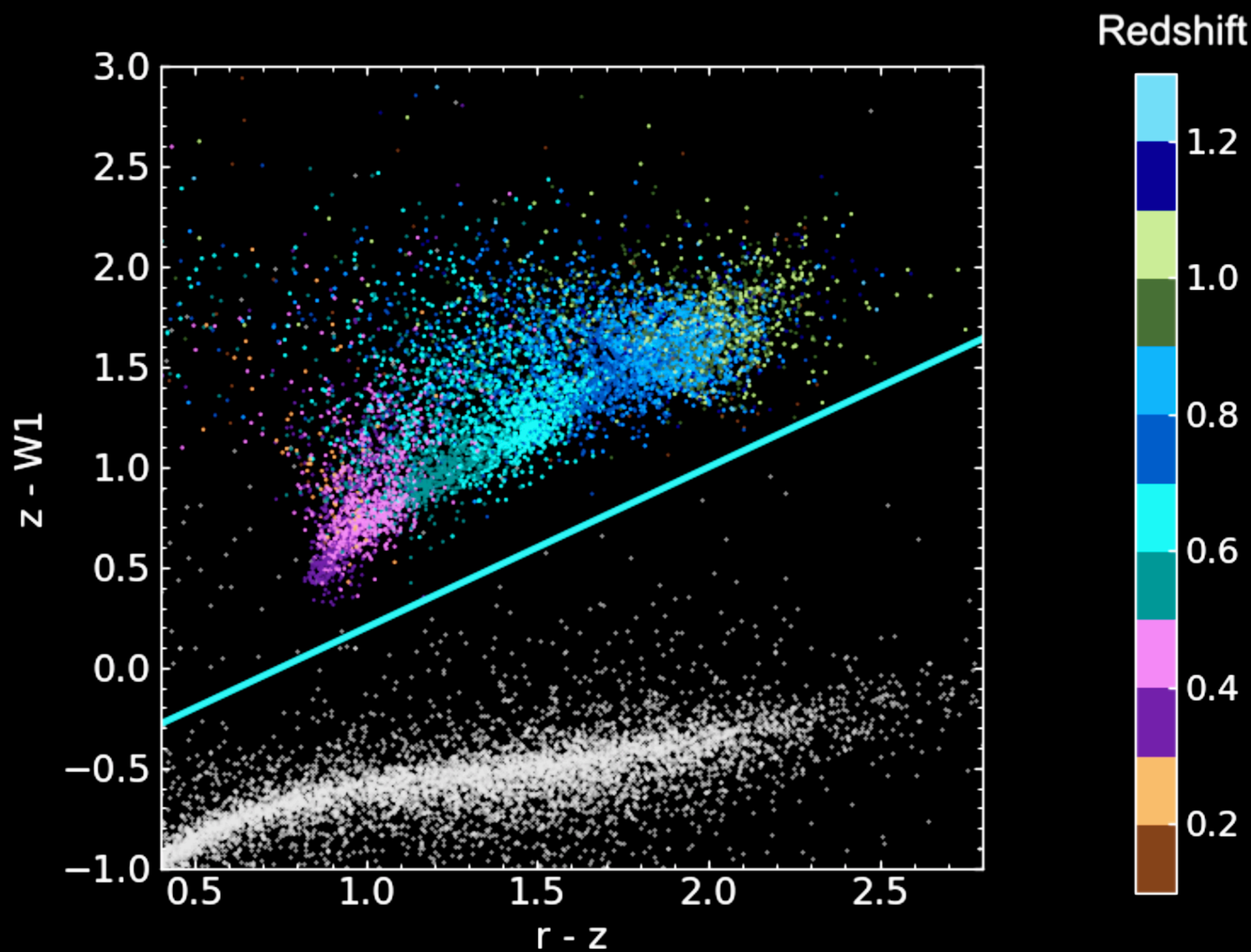
DESI target selection



Example: Stellar rejection Cut for LRGs

Zhou et al., 2208.08515

DESI target selection



From
2 billion
to
50 million
objects!

Example: Stellar rejection Cut for LRGs

Zhou et al., 2208.08515

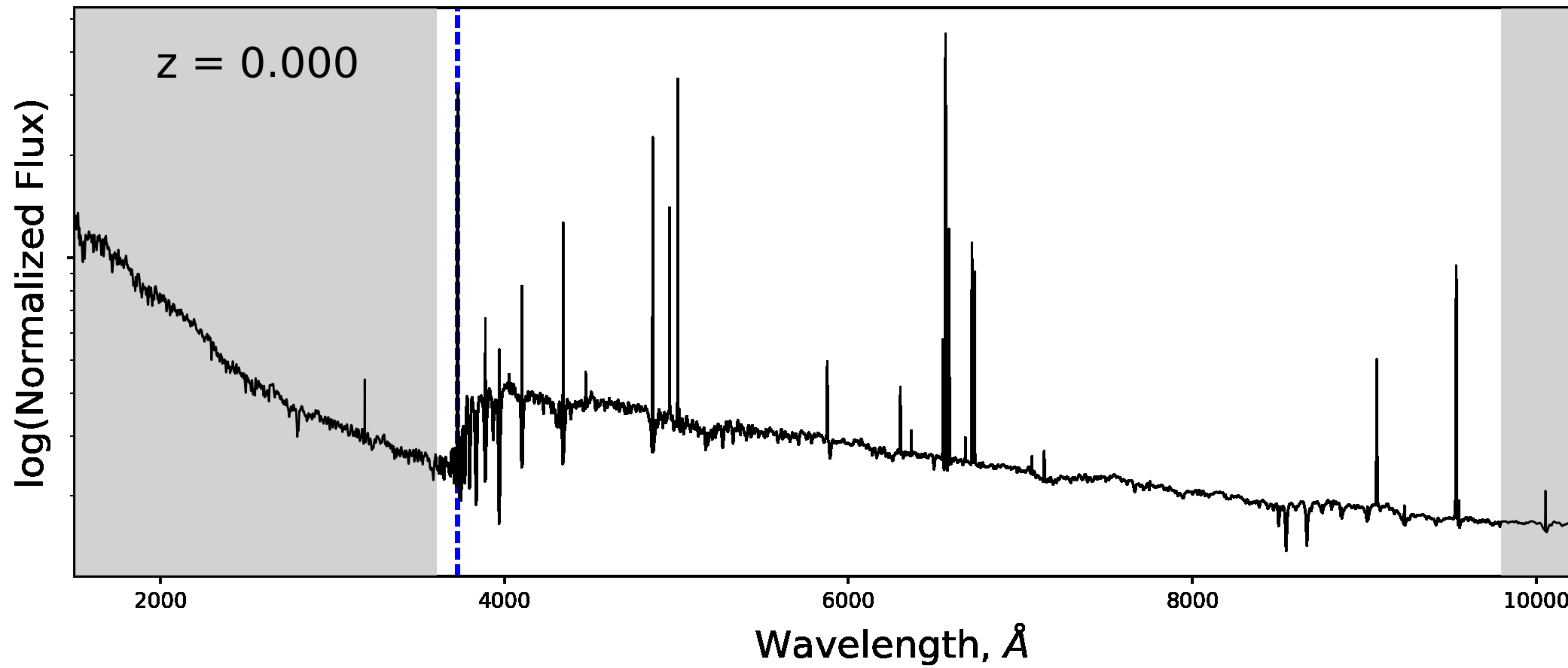
… pointing into the sky

Credits: Noirlab

… pointing into the sky

Credits: Noirlab

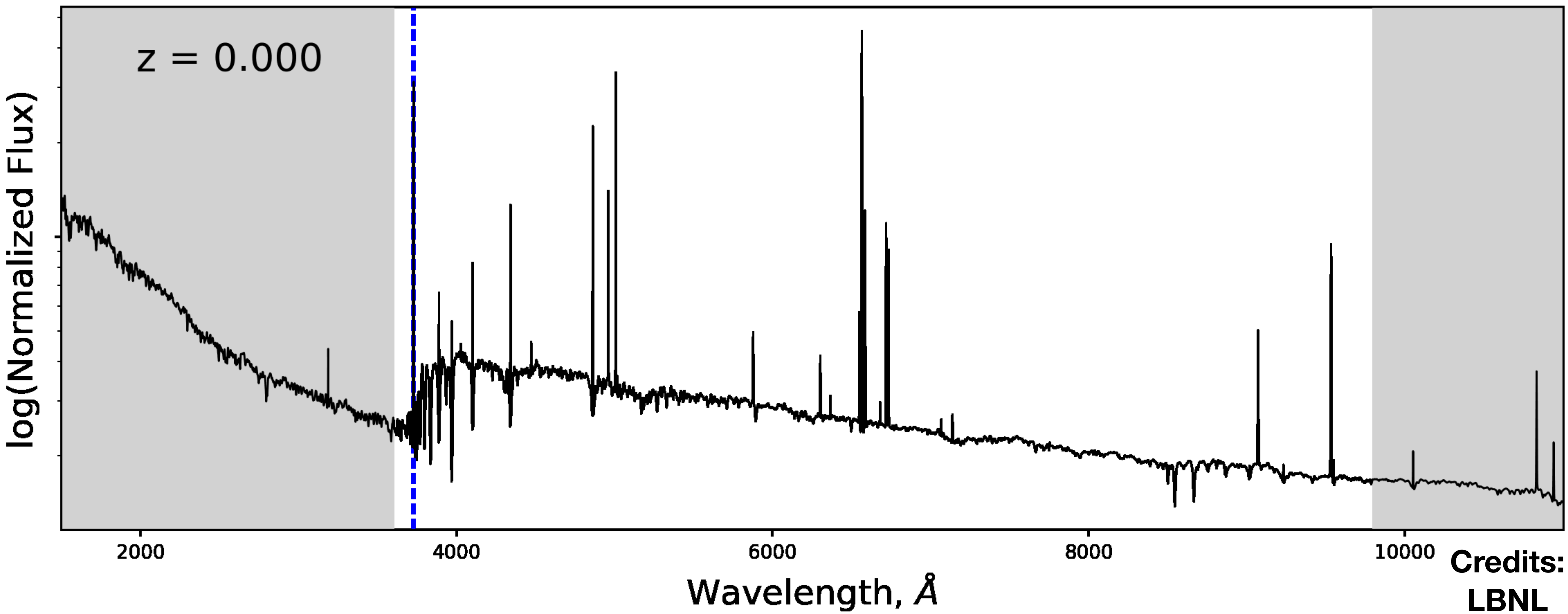
Measure redshift from spectra



Credits: LBNL

Fit template spectra with Redrock
From repeat observations:
sigma_z ~ 10 km/s (BGS, ELG) - 50 km/s (LRG, QSO)
0.27% of ELG have catastrophic z-failures > 1000 km/s

Measure redshift from spectra



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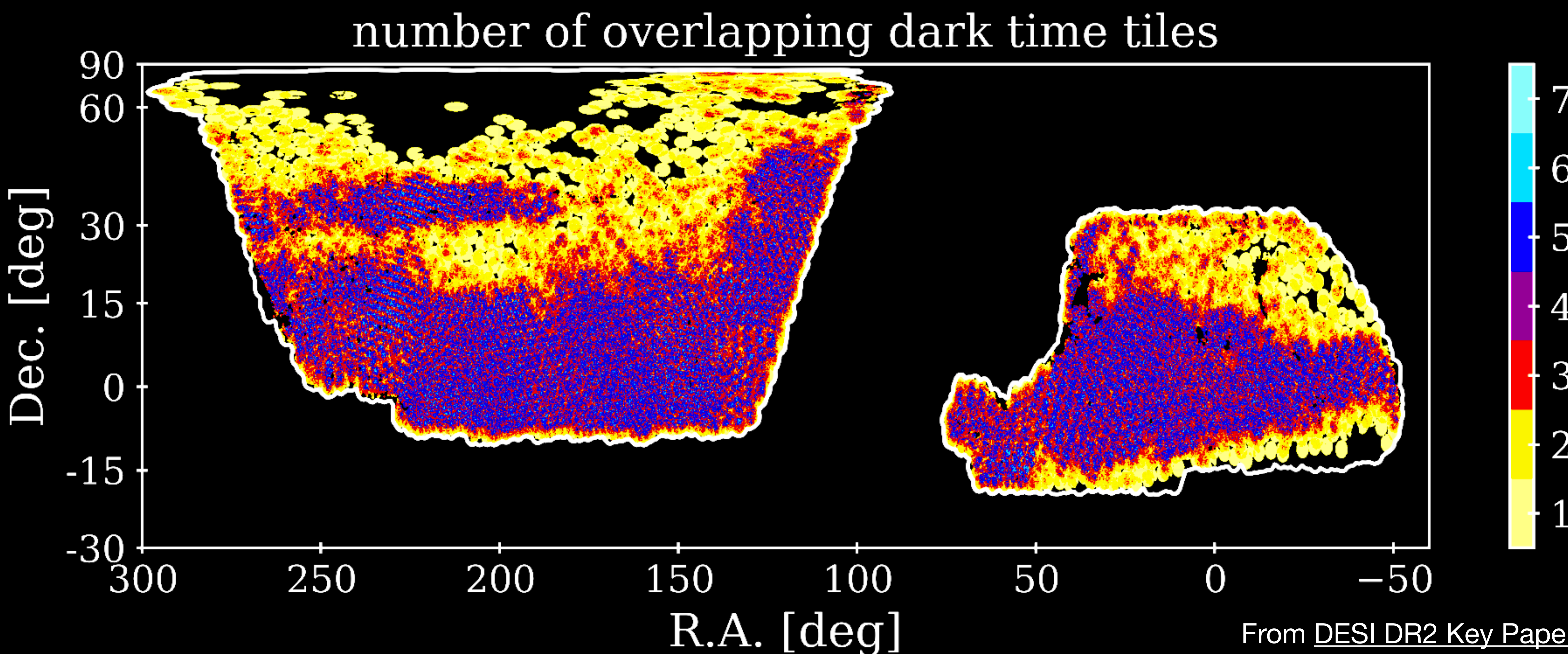
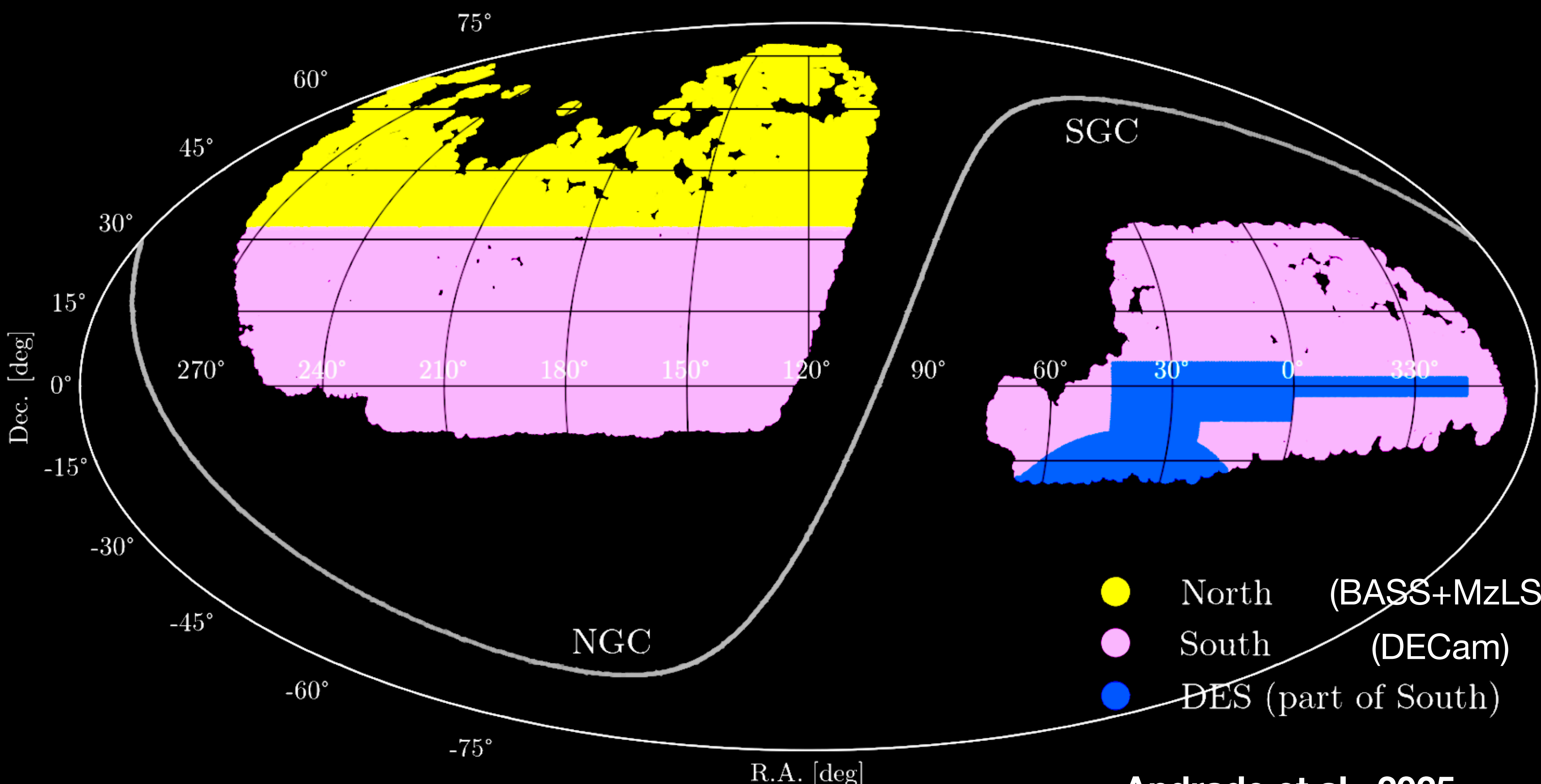
DESI DR2 Footprint



From DESI DR2 Key Paper

Density fluctuations in targets -> Imaging systematics
Density fluctuations in footprint -> Incompleteness systematics

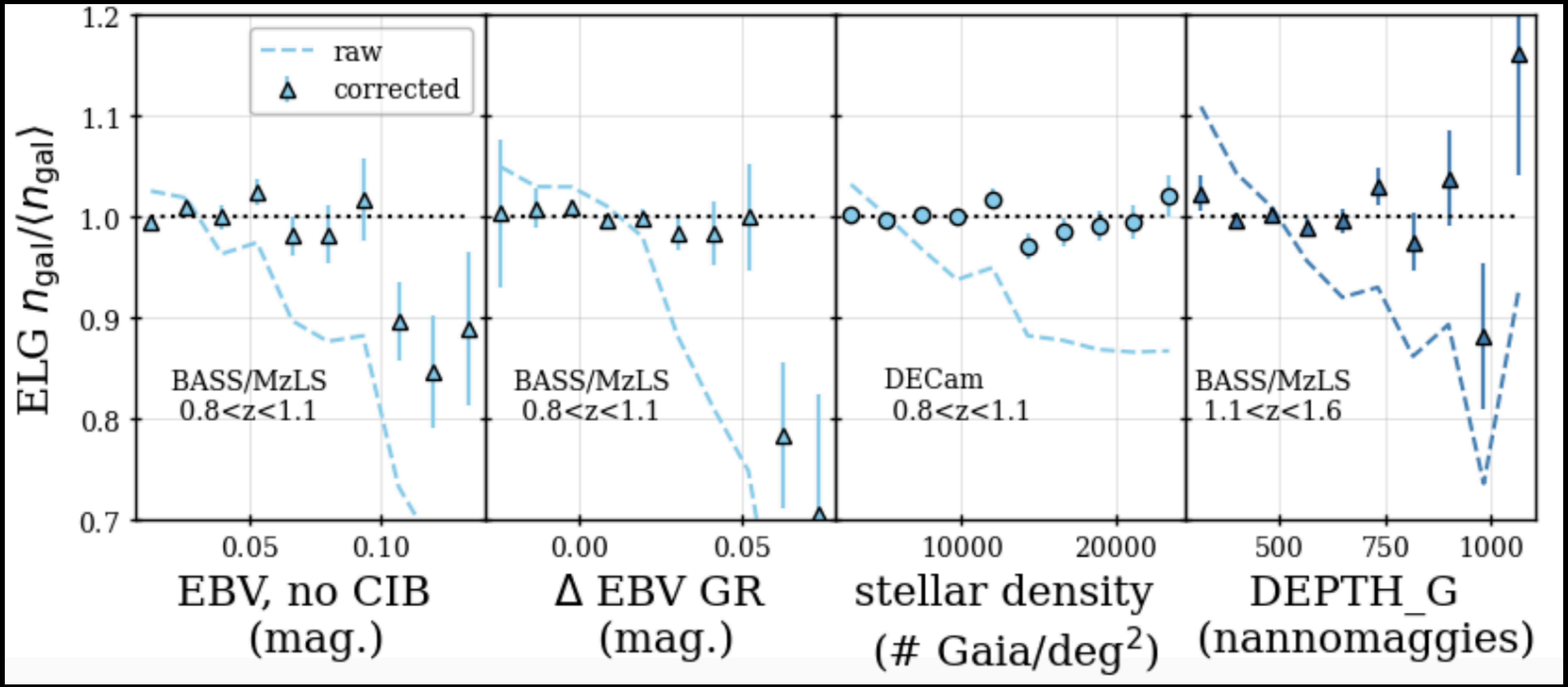
Imaging systematics



Andrade et al., 2025

Different Imaging campaigns across sky

Imaging systematics

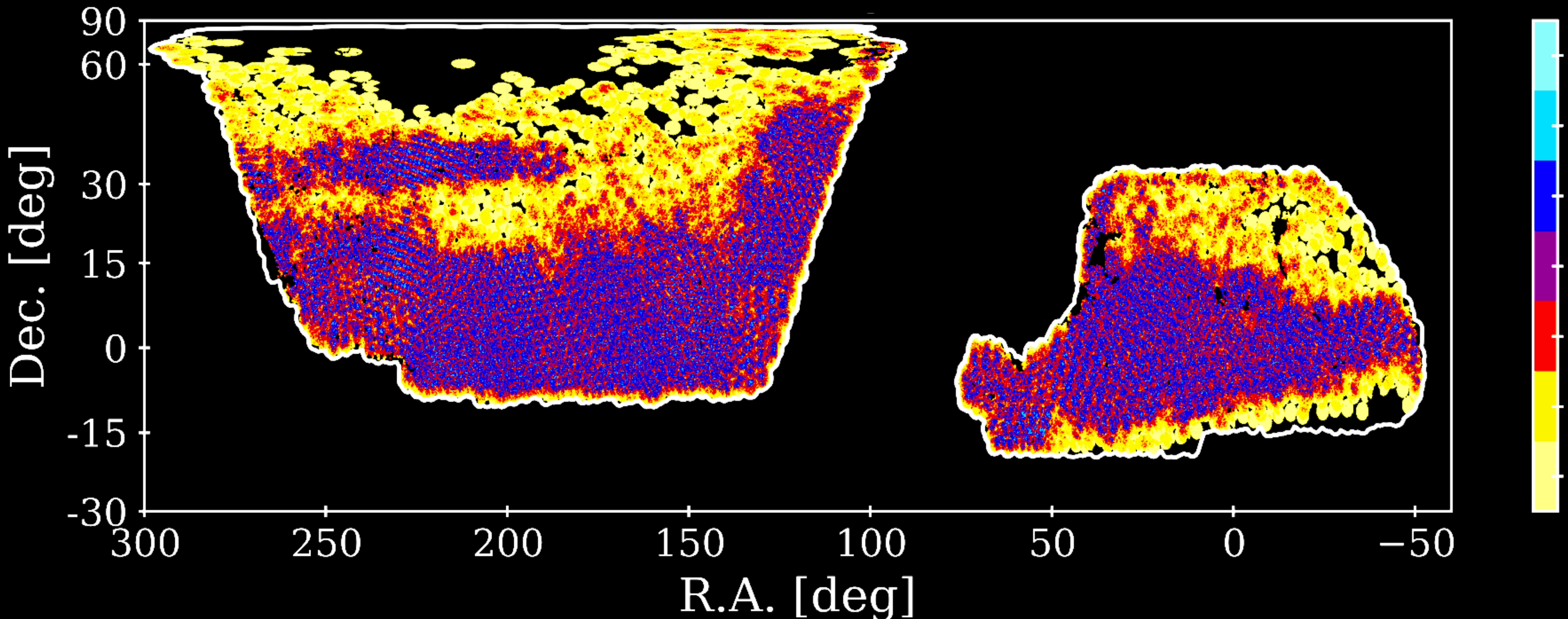


DESI 2024 II

Need to correct for trends of target density with imaging properties with weights.

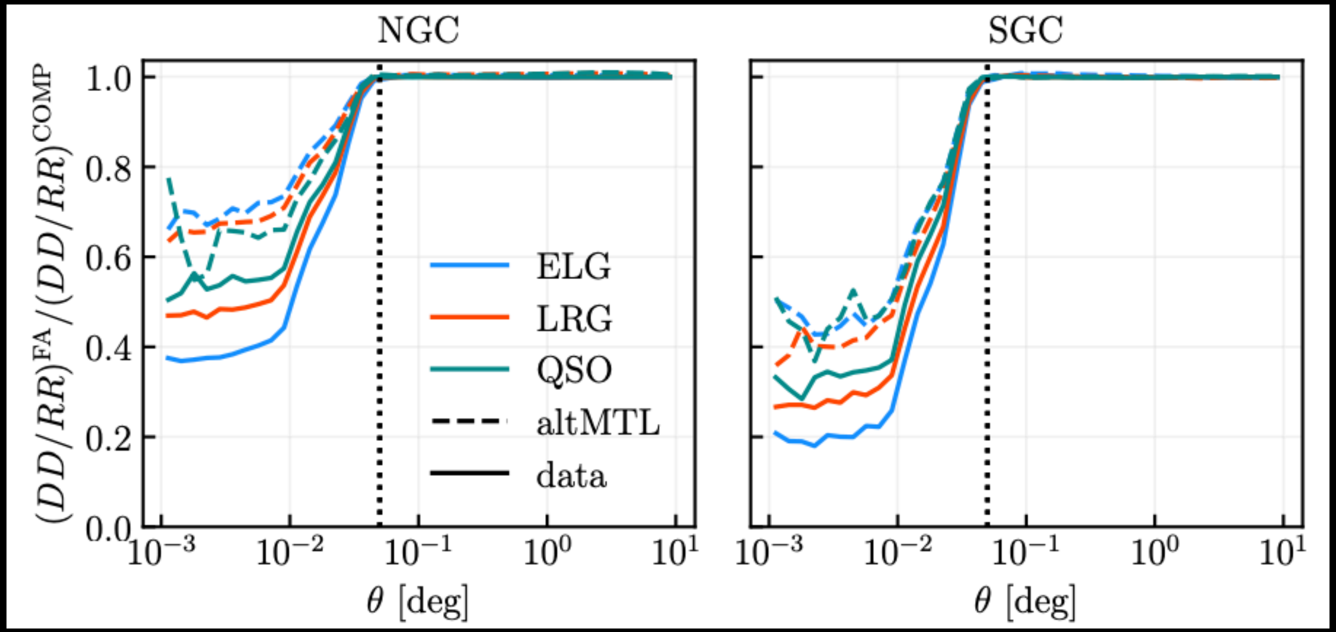
Incompleteness systematics

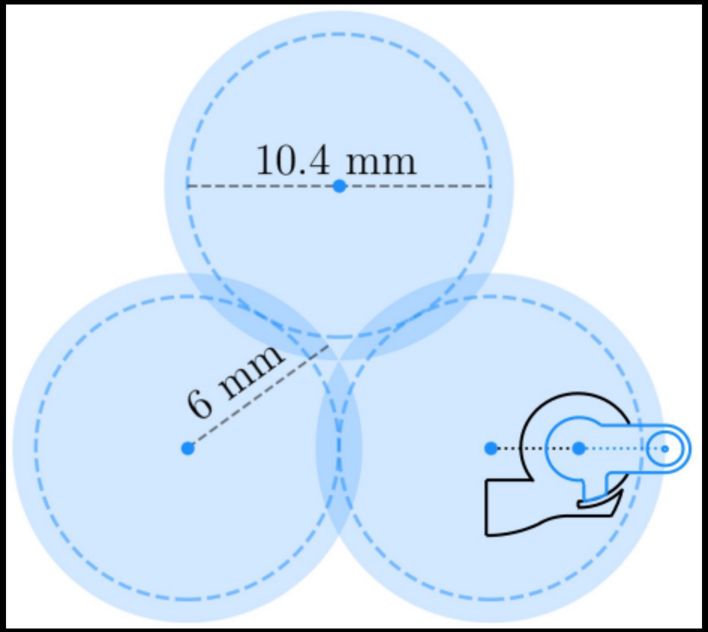
Non-uniform Footprint

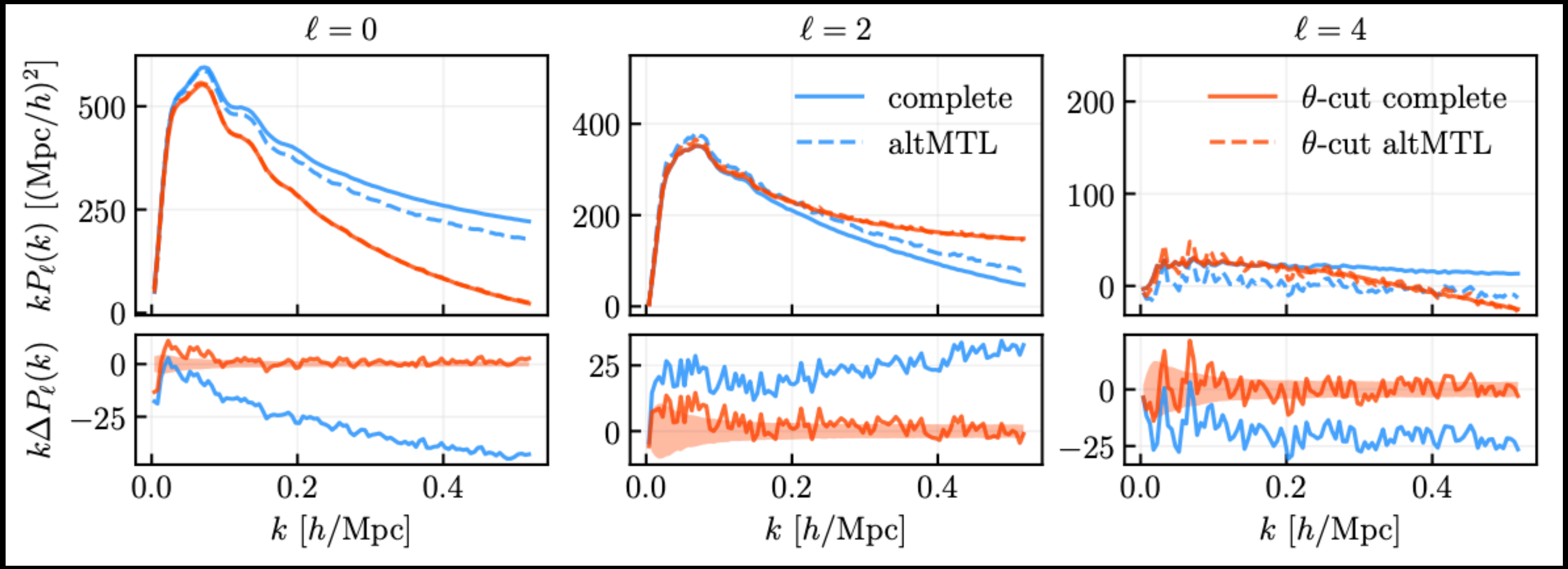


Compute clustering with respect to <u>Random catalogue</u> with our clustering, but with same footprint and mean n(z) as data
-> Window function

Incompleteness systematics



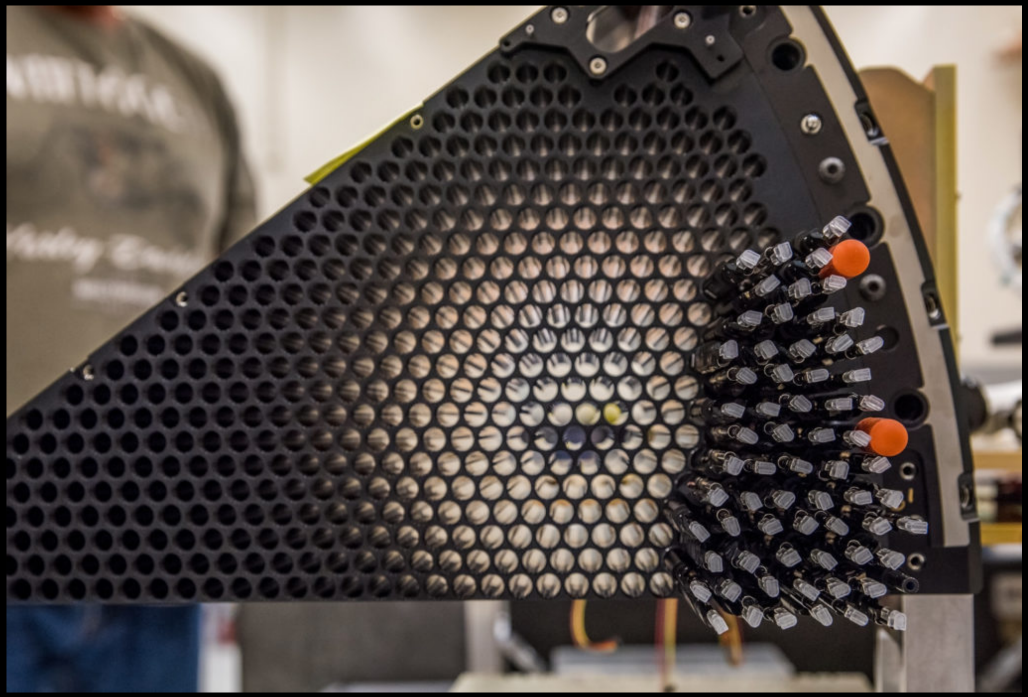


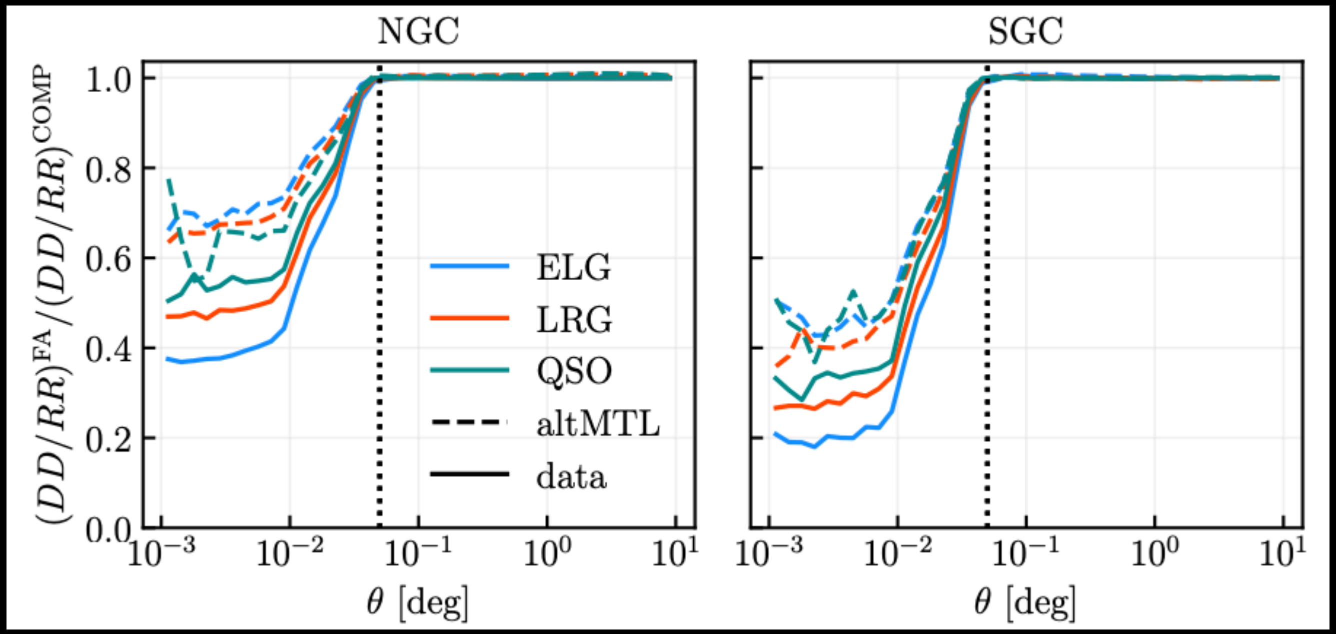


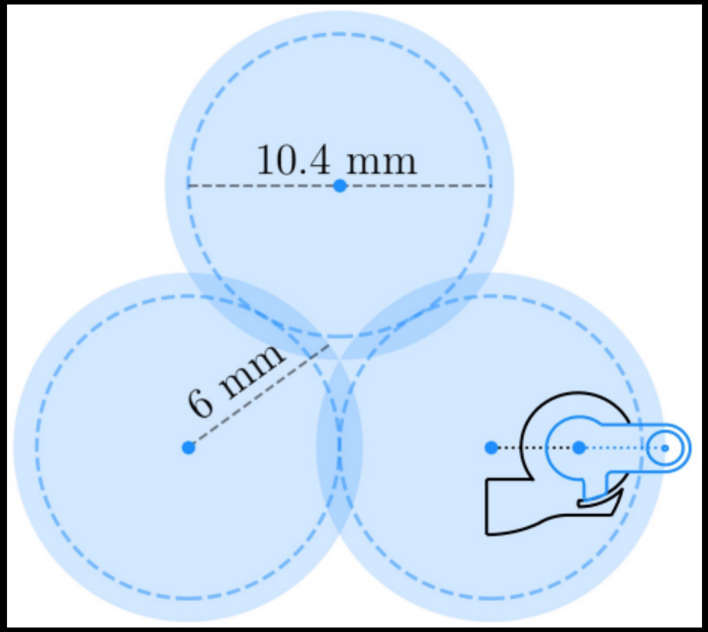
Pinon et al, 2406.04804

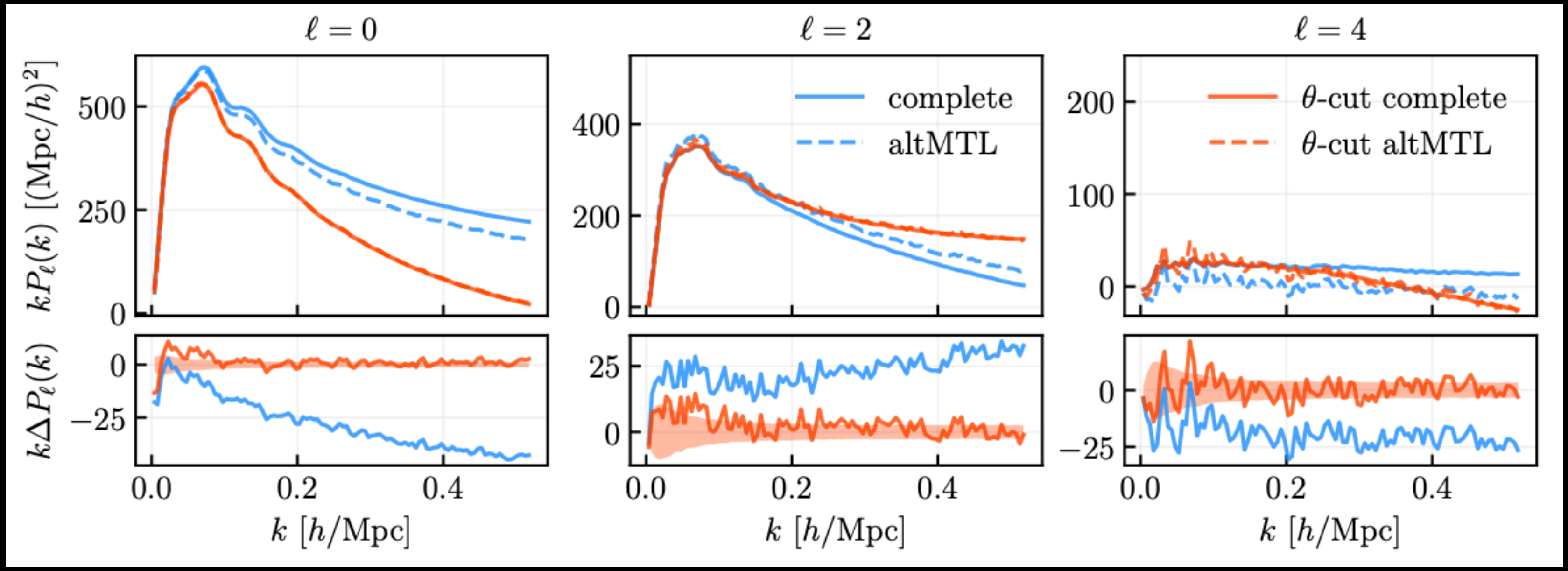
Incompleteness systematics

Fiber collisions



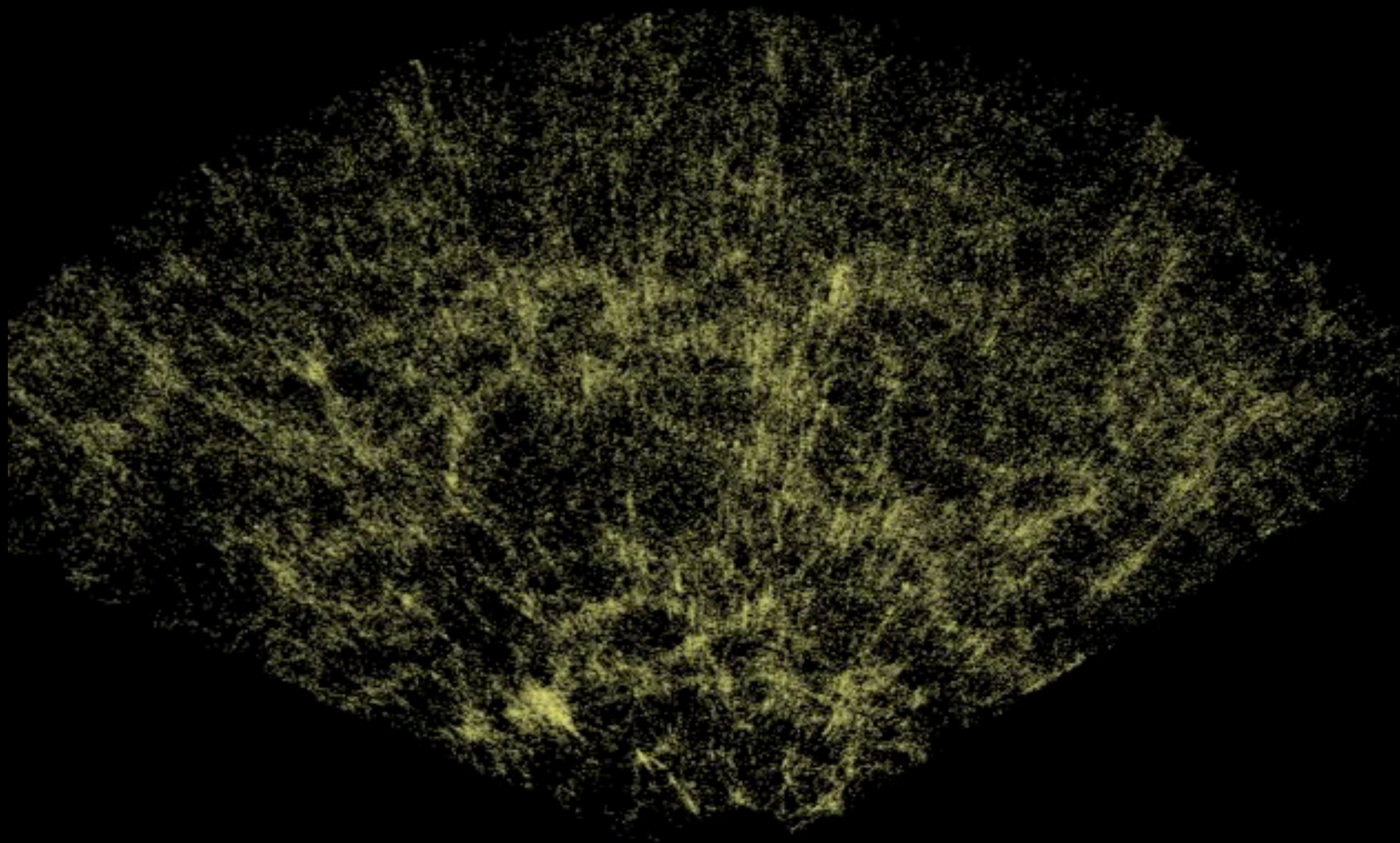






Pinon et al, [2406.04804]

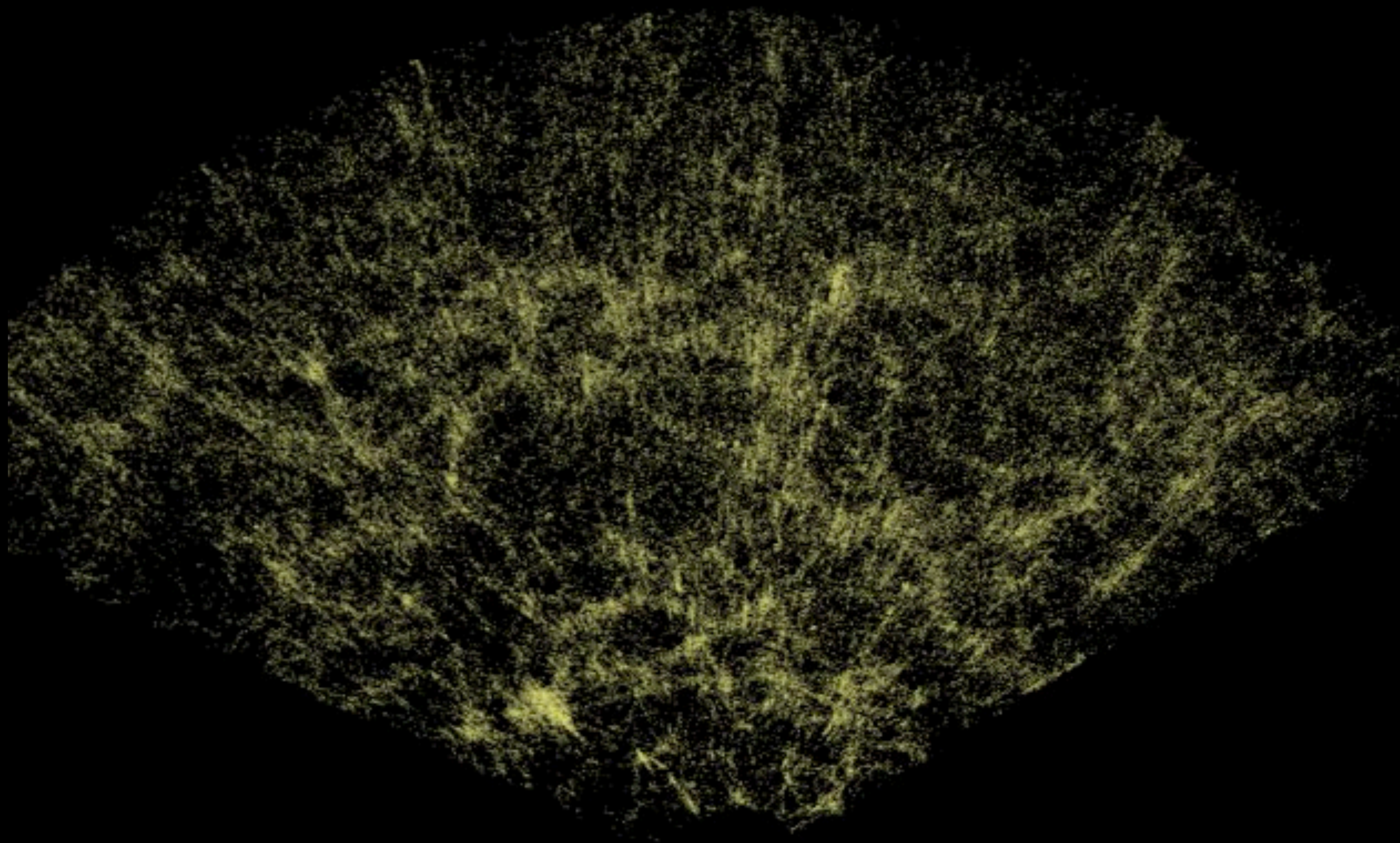
From field to summary statistics



From 3D map compute clustering statistics with pair counts

SubbaRao et al., SDSS, 2008, 10.1088/1367-2630/10/12/125015/

From field to summary statistics



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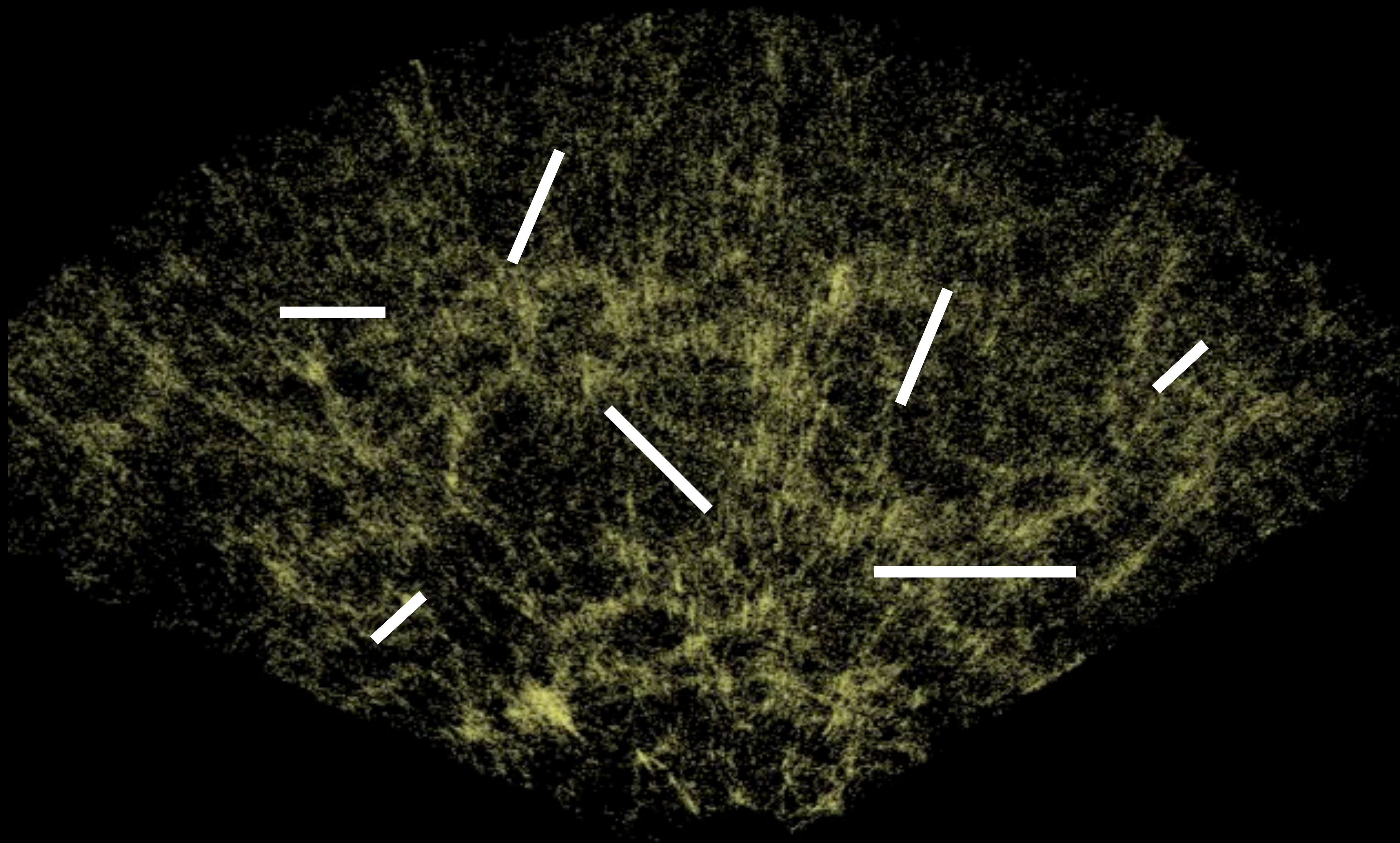

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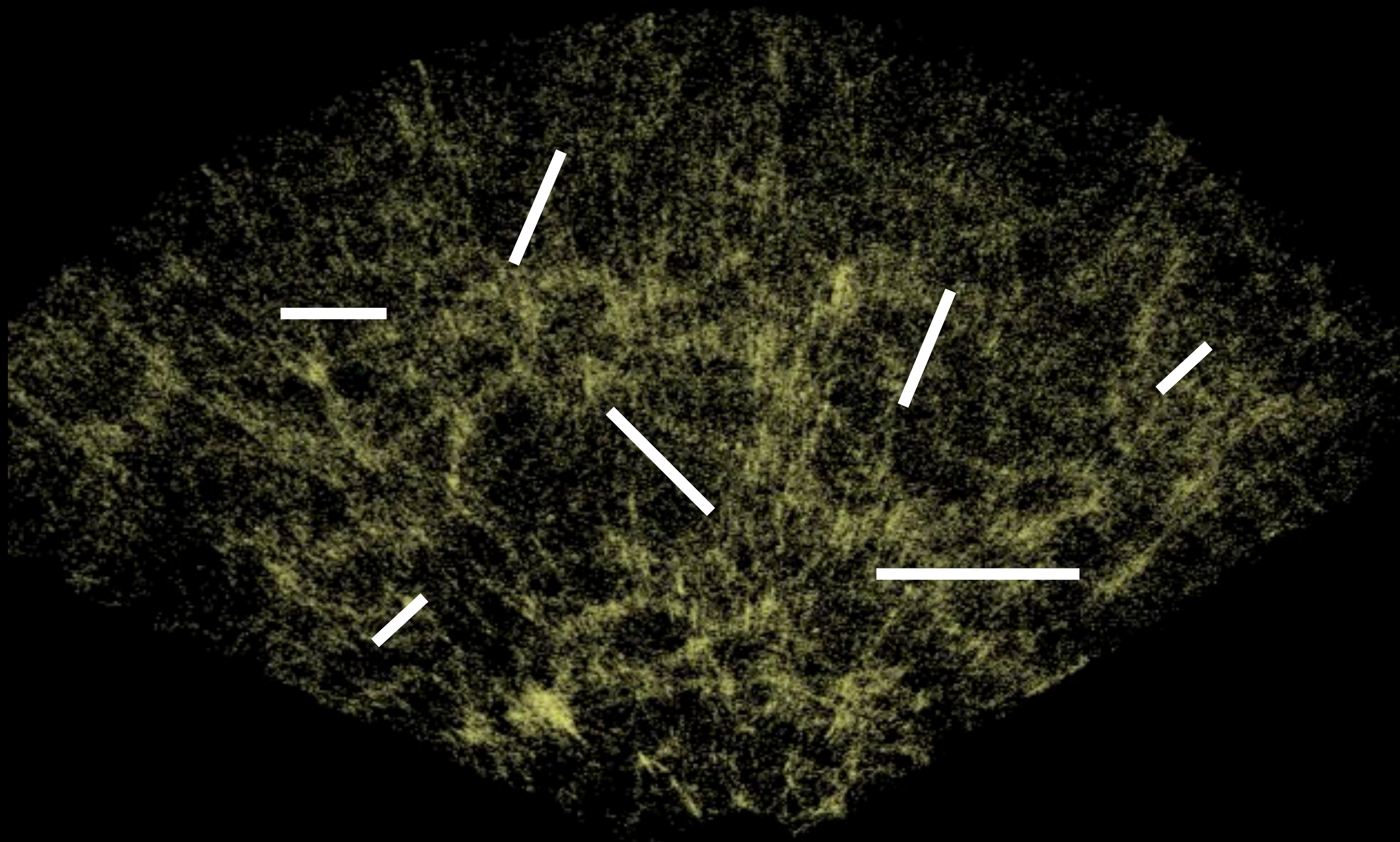
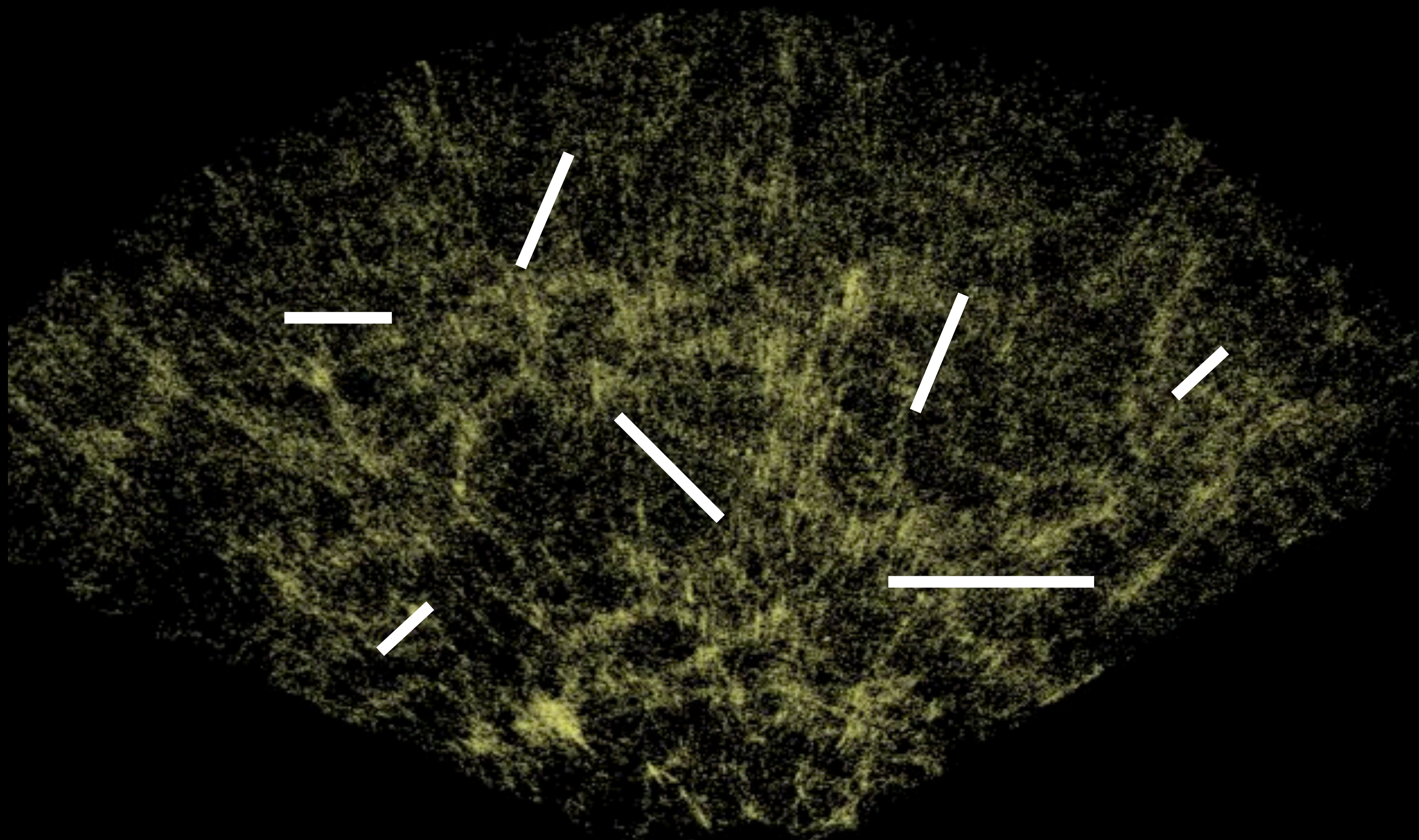


$\xi(s, \cos\theta)$

From 3D map compute clustering statistics with pair counts

SubbaRao et al., SDSS, 2008, 10.1088/1367-2630/10/12/125015/

From field to summary statistics



$\xi(s, \cos\theta)$ $\xrightarrow{\text{Legendre Transform}}$

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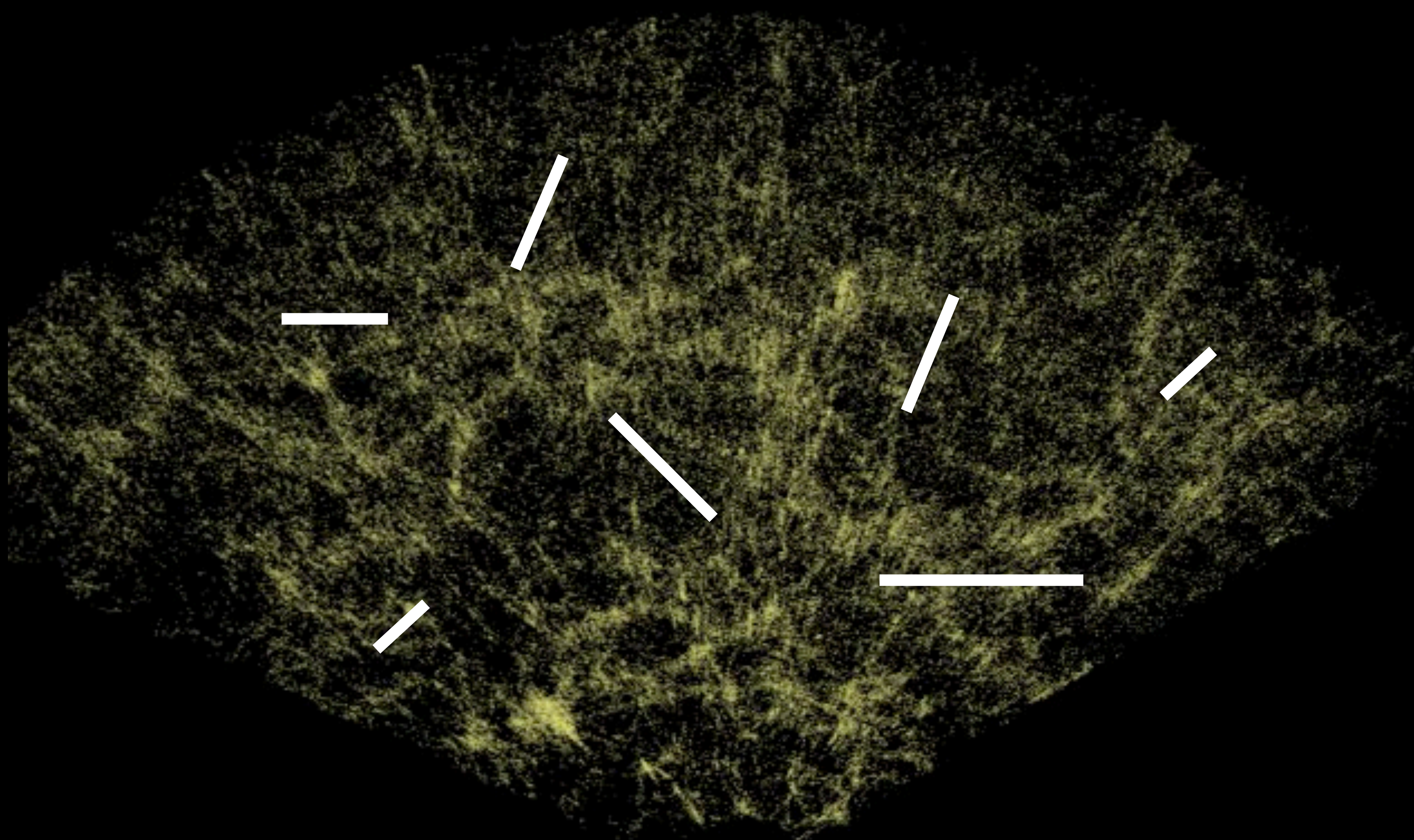
SubbaRao et al., SDSS, 2008, 10.1088/1367-2630/10/12/125015/

From field to summary statistics



$$\xi(s, \cos\theta) \xrightarrow{\text{Legendre Transform}} \xi_\ell(s)$$

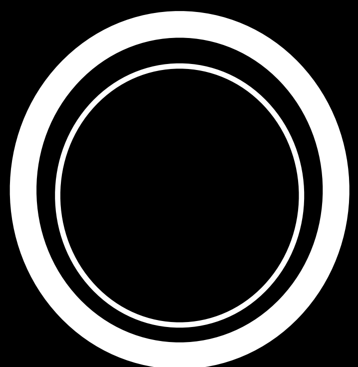
From 3D map compute clustering statistics with pair counts

SubbaRao et al., SDSS, 2008, 10.1088/1367-2630/10/12/125015/

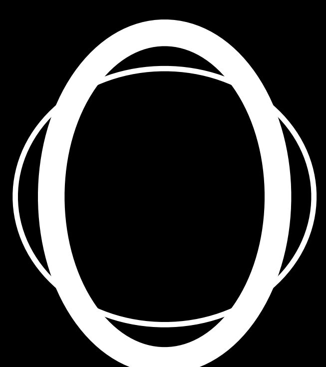
Summary Statistics

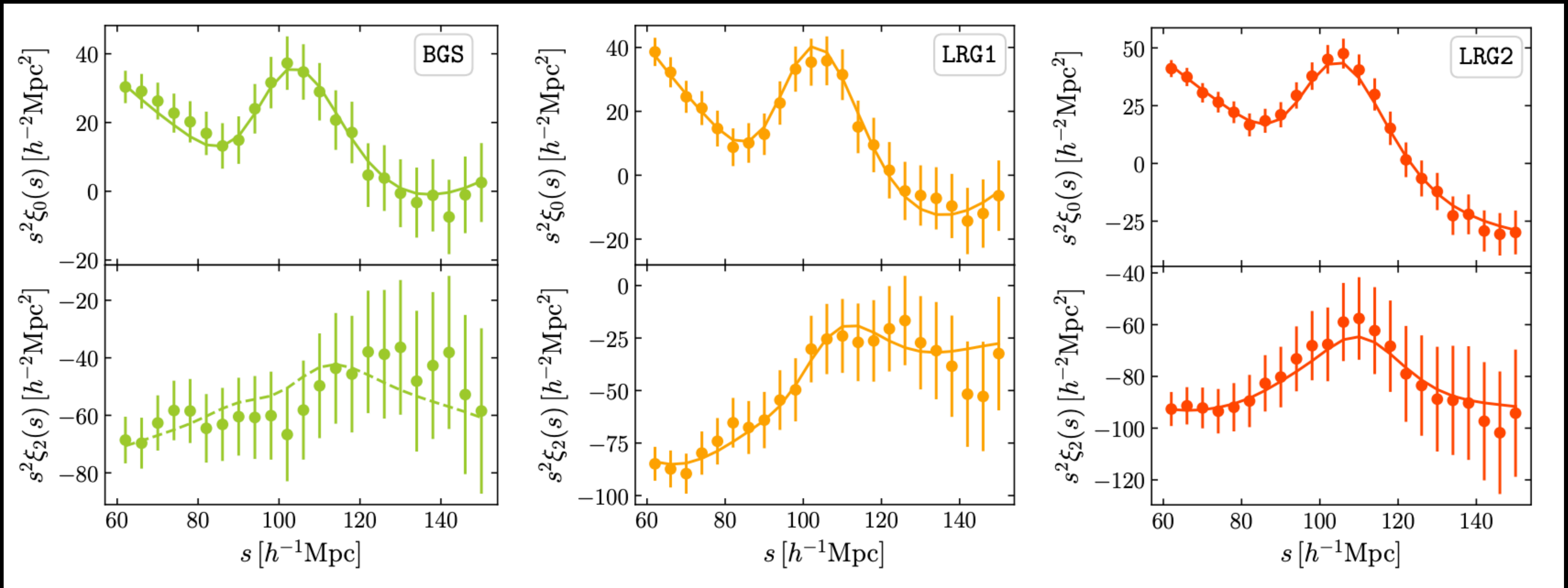
Two-point correlation function multipoles

Monopole ξ_0



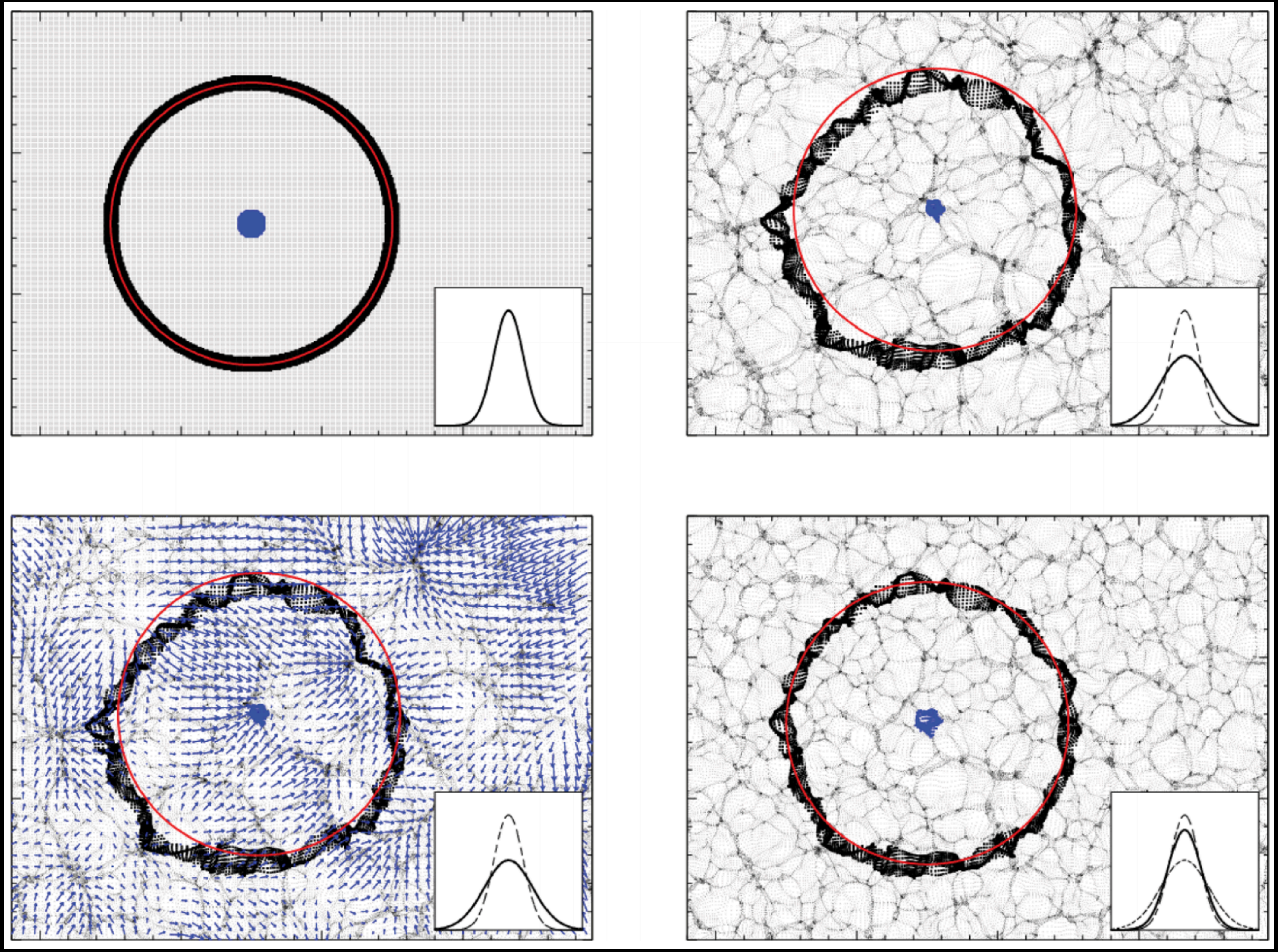
Quadrupole ξ_2





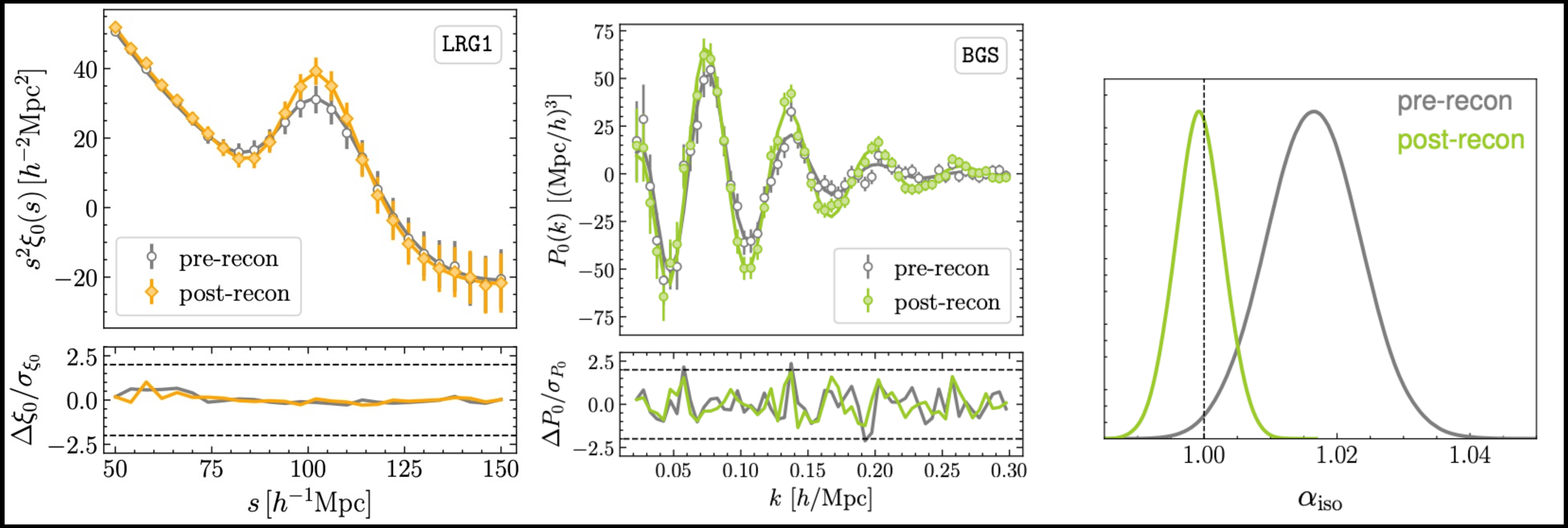
From DESI DR2 Key Paper

BAO reconstruction

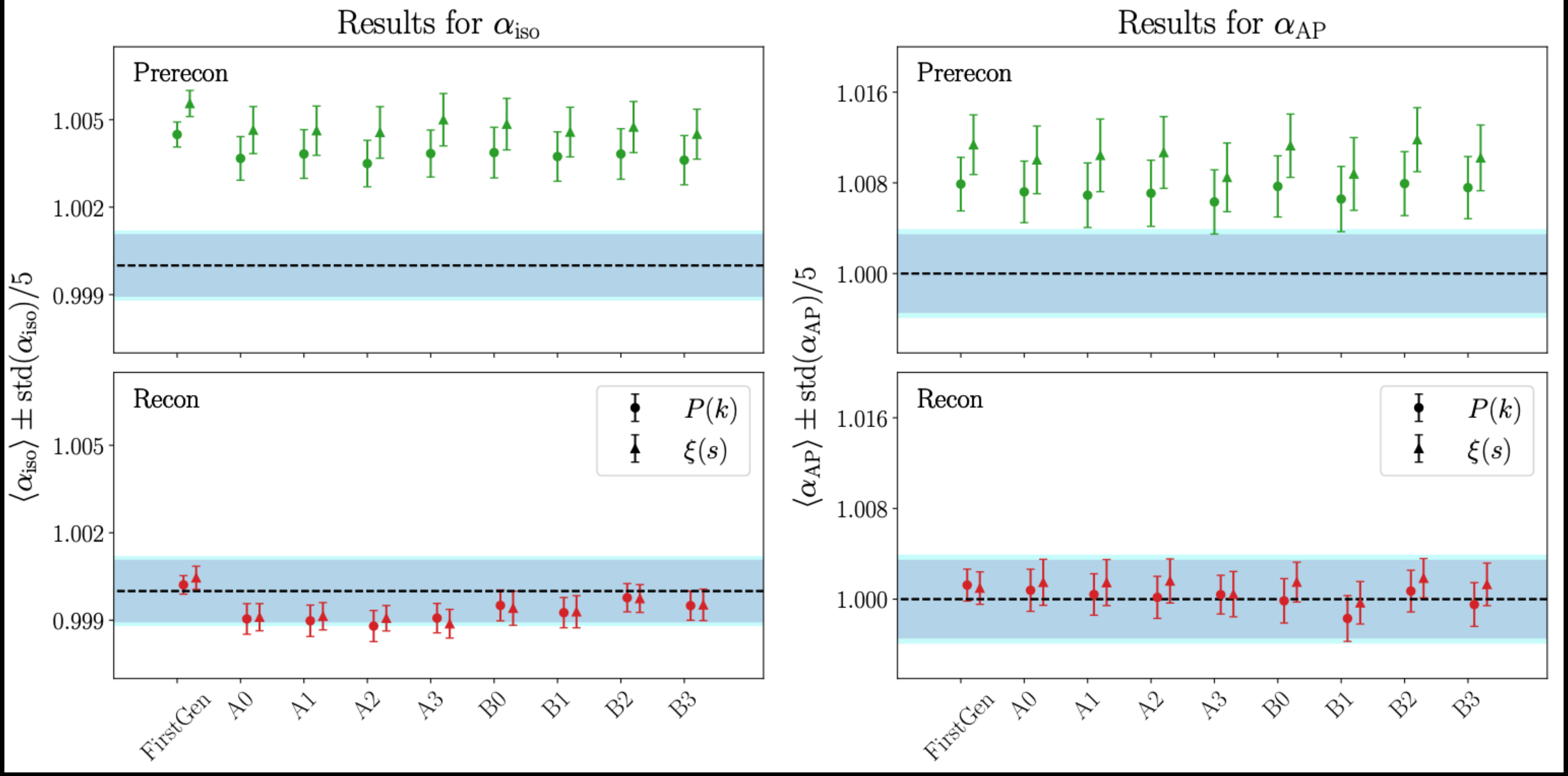


Padmanabhan et al., 1202.0090

BAO Reconstruction



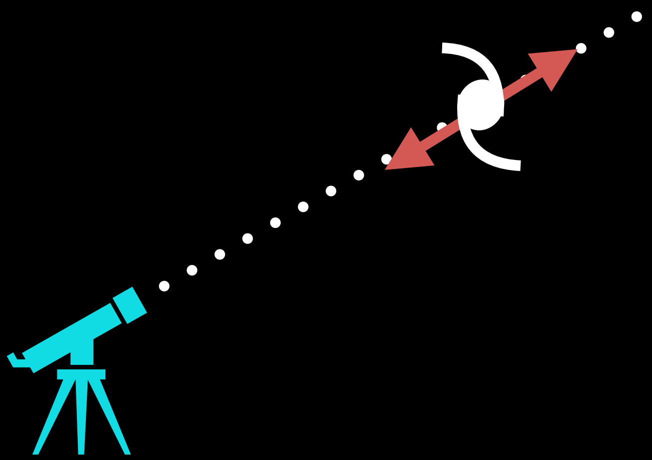
Paillas et al., 2024



Mena Fernandez et al., 2024

Blinding at Catalog level

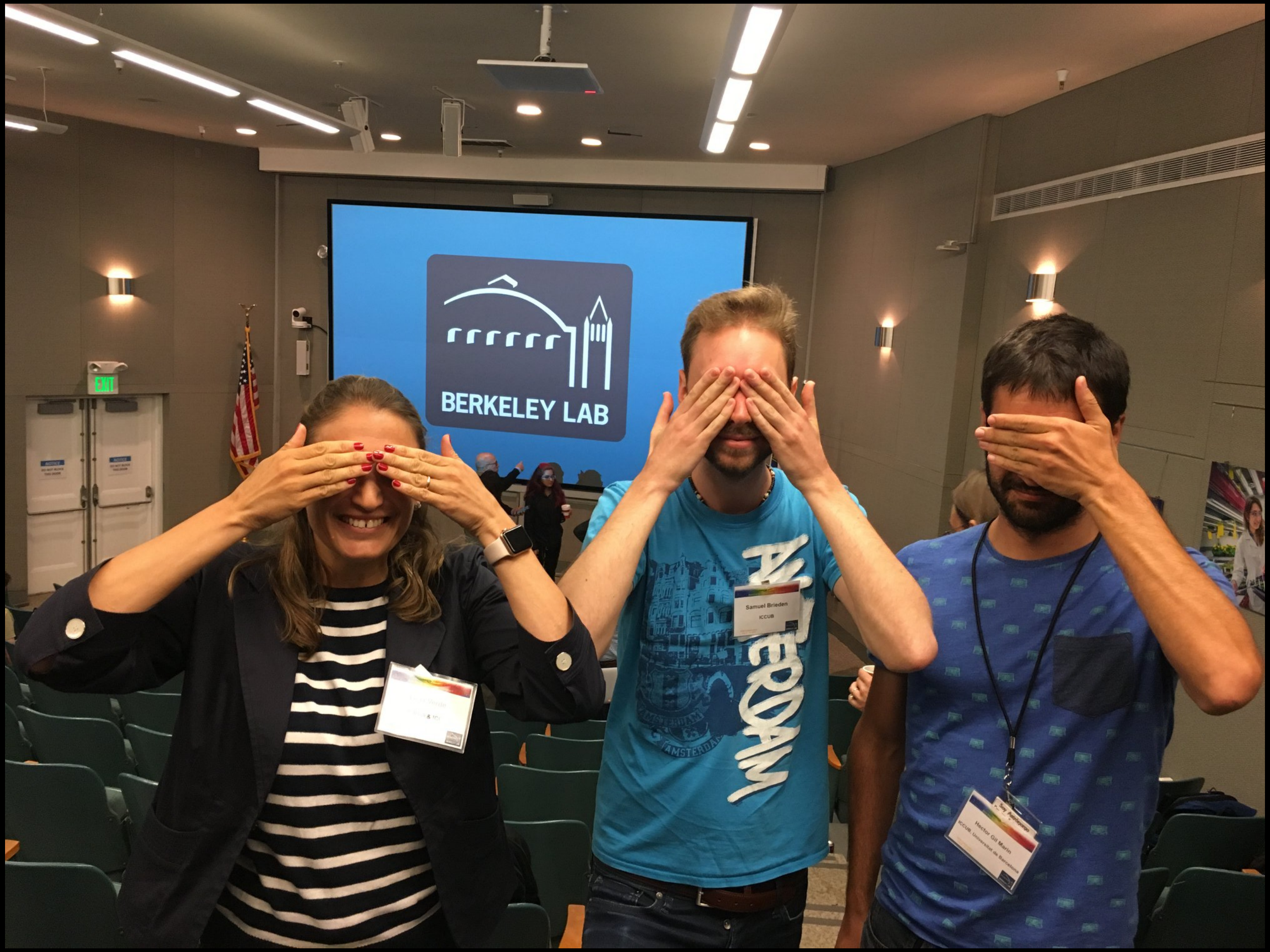
Shift galaxies along the line of sight



Blind BAO+RSD signal
in a controlled way by applying:

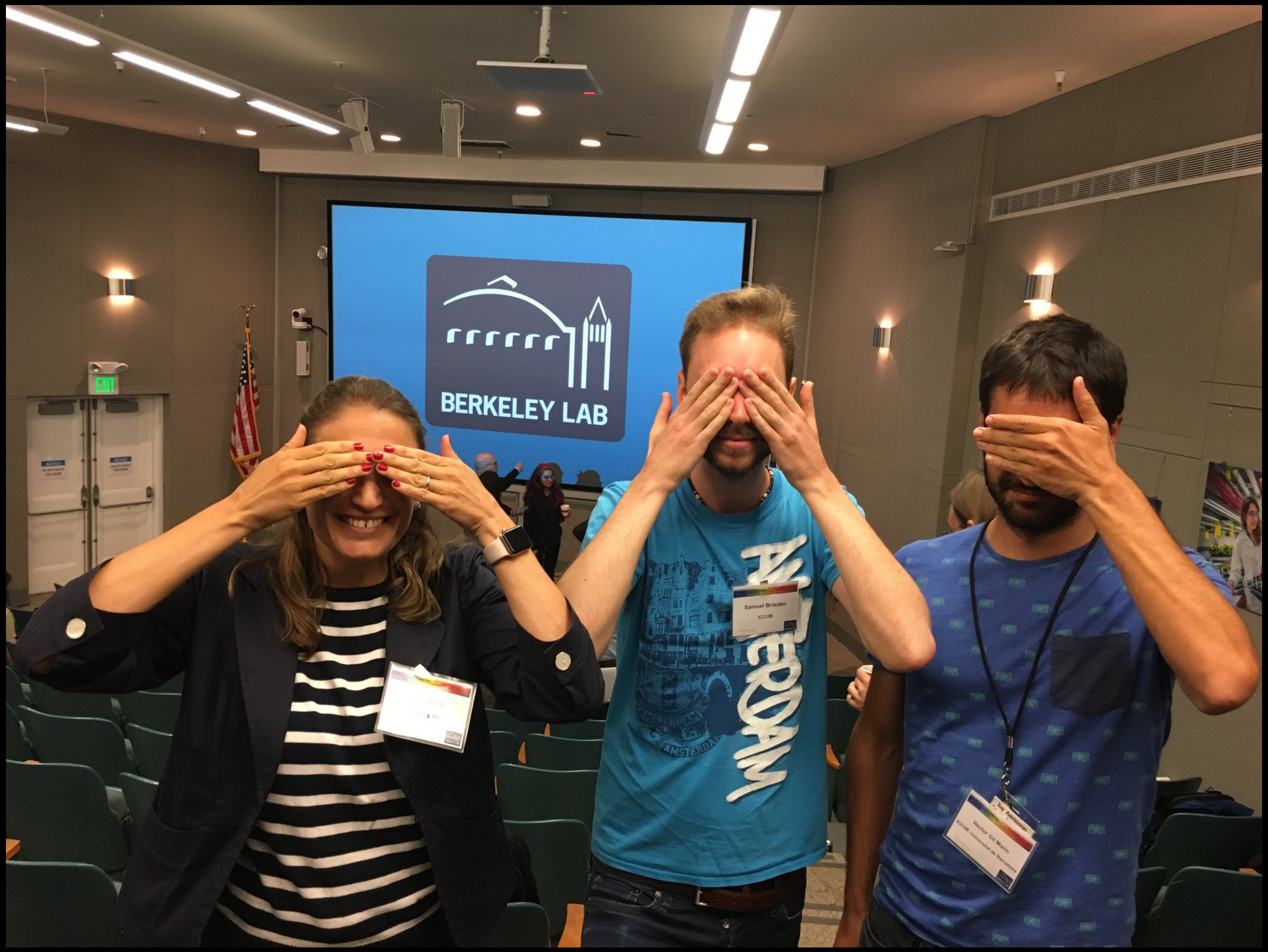
1. geometrical BAO shift
   (expansion history)
2. density-dependent RSD shift
   (growth history)

Blinding at Catalog Level



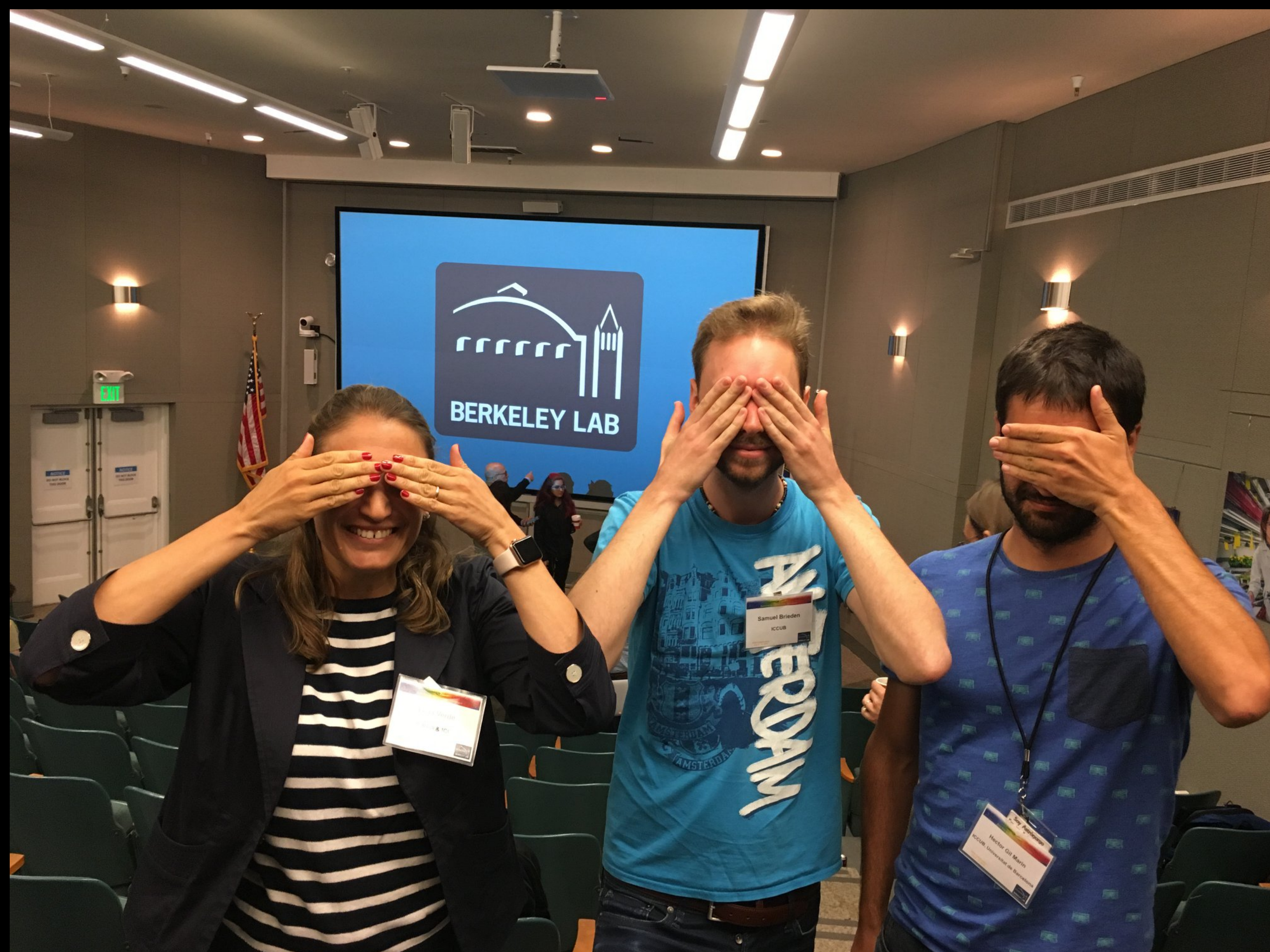
DESI meeting, Berkeley, July 2019

Blinding at Catalog Level

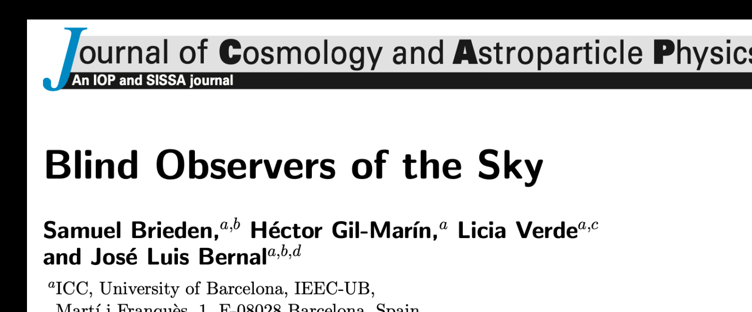


DESI meeting, Berkeley, July 2019

Blinding at Catalog Level



DESI meeting, Berkeley, July 2019


Journal of Cosmology and Astroparticle Physics
An IOP and SISSA journal

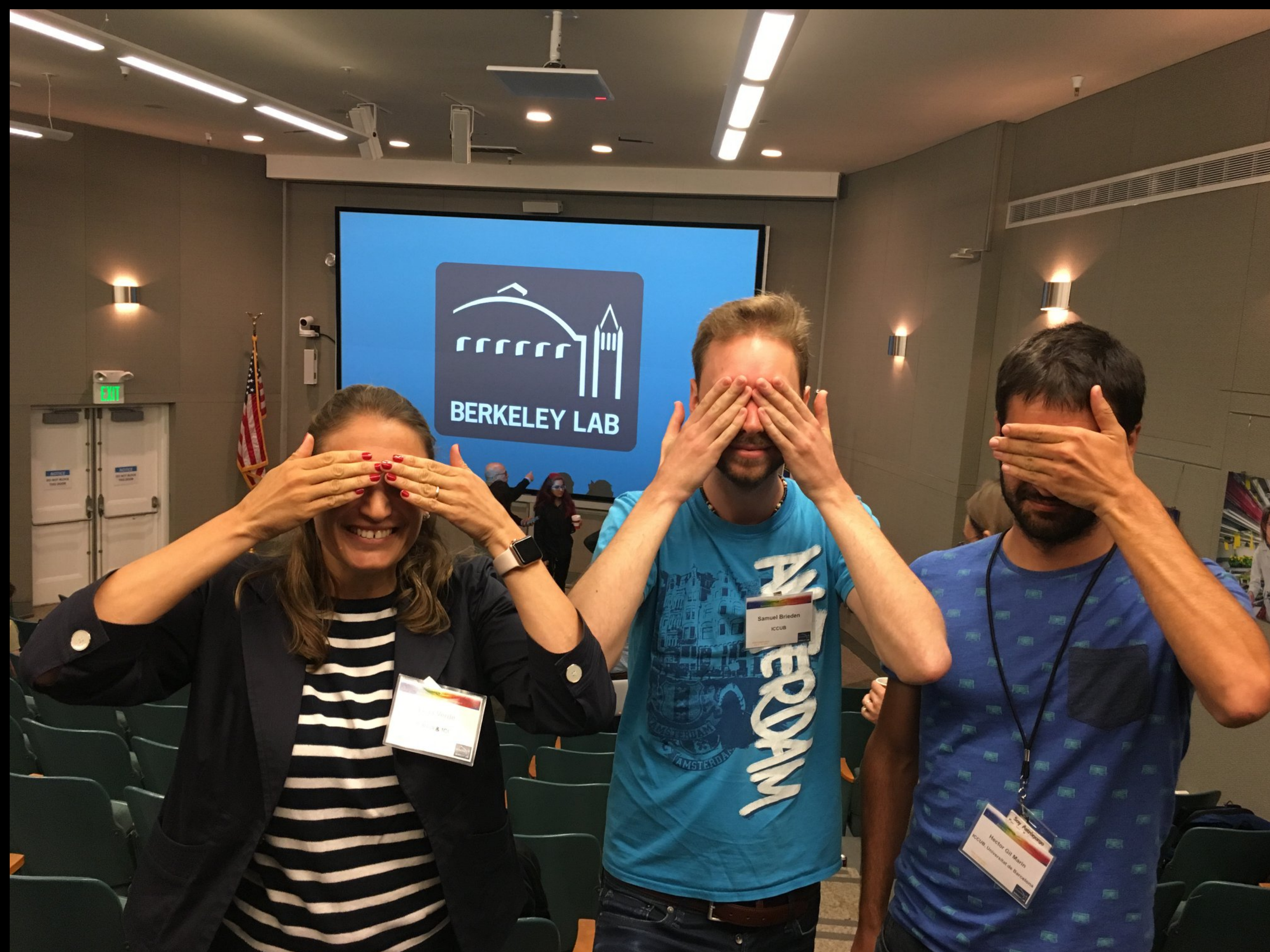
Blind Observers of the Sky

Samuel Brieden,[a,b] Héctor Gil-Marín,[a] Licia Verde[a,c] and José Luis Bernal[a,b,d]

[a]ICC, University of Barcelona, IEEC-UB, Martí i Franquès, 1, E-08028 Barcelona, Spain

Brieden et al, 2006.10857

Blinding at Catalog Level



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Credits: Claire Lamman

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U. Andrade,[1,2] J. Mena-Fernández,[3] H. Awan,[1]
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Prepared for submission to JCAP

Blinding scheme for the scale-dependence bias signature of local primordial non-Gaussianity for DESI 2024

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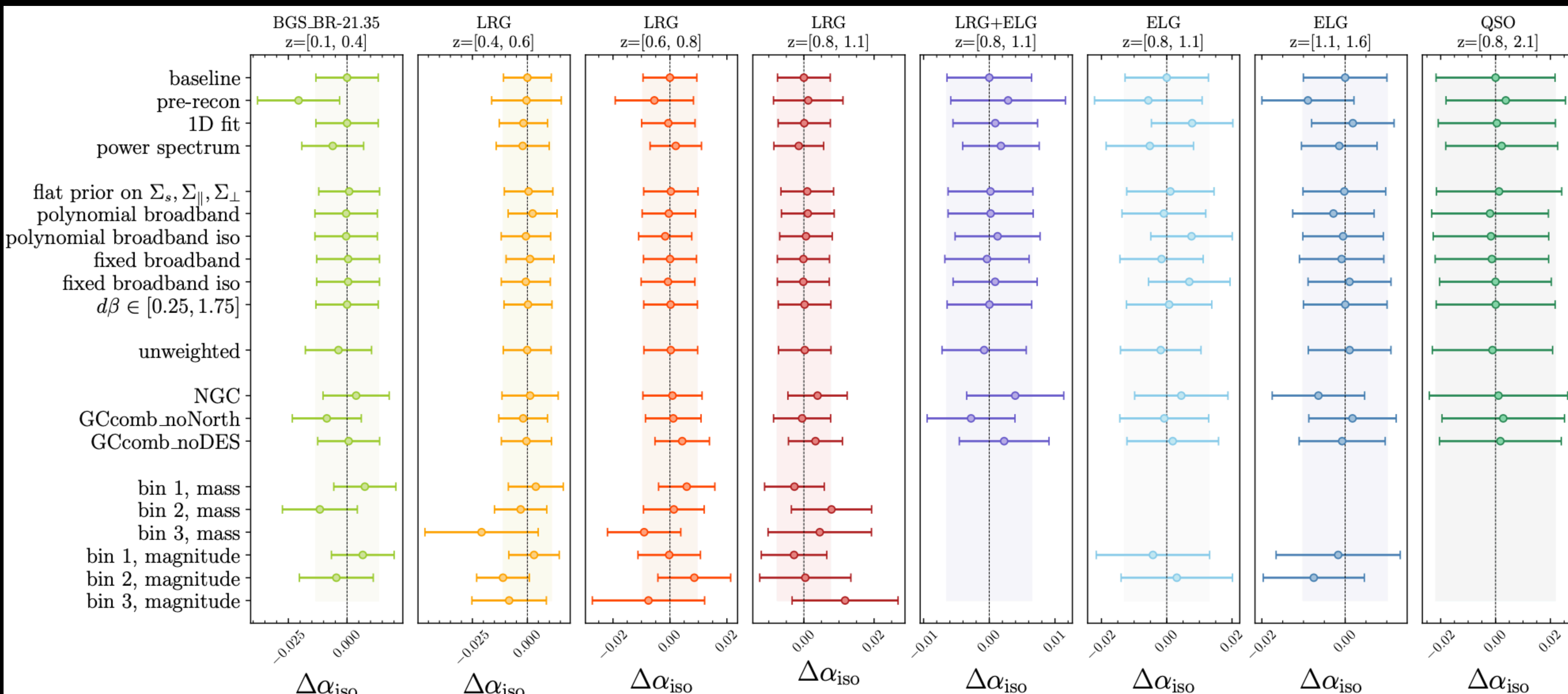
Catalog-level blinding on the bispectrum for DESI-like galaxy surveys

Sergi Novell-Masot,[1,2] Héctor Gil-Marín,[1,2,3] Licia Verde[1,4]
J. Aguilar,[5] S. Ahlen,[6] S. Brieden,[23] D. Brooks,[7] T. Claybaugh,[5]

Novell-Masot et al, 2407.12931

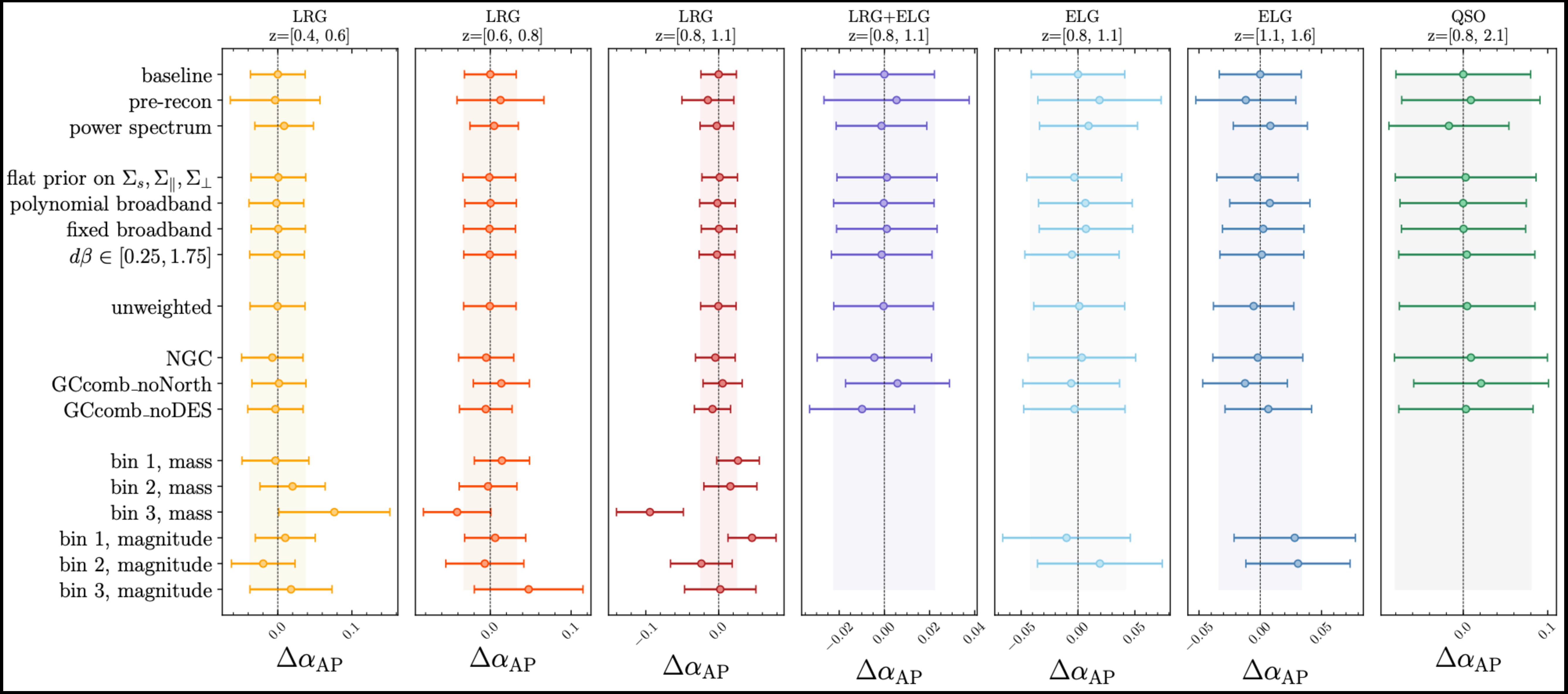
Testing systematics for DESI BAO analysis

Isotropic Distance Scaling



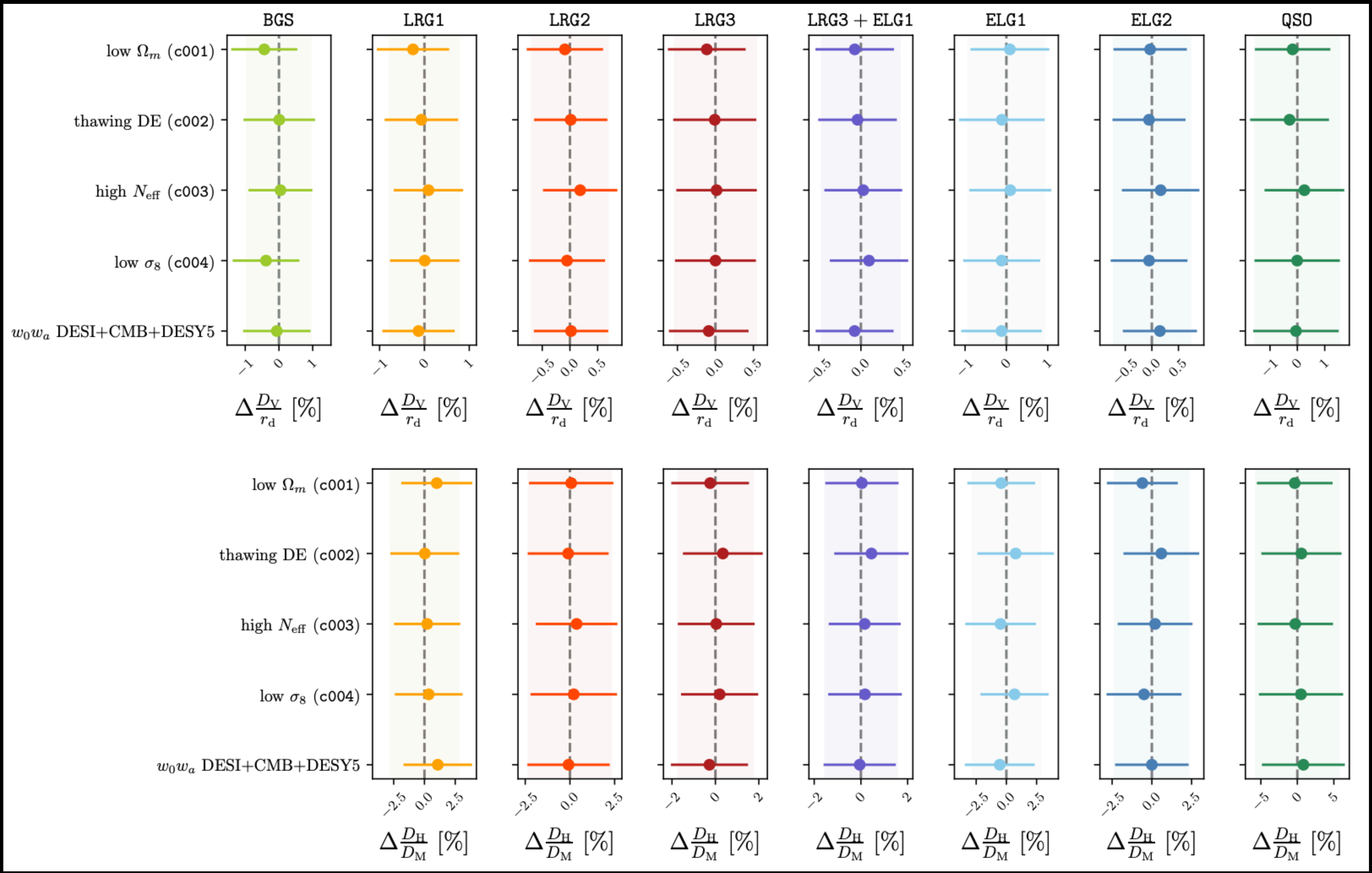
Andrade et al., 2025

Anisotropic Distance Scaling



Andrade et al., 2025

Fiducial Cosmology assumption



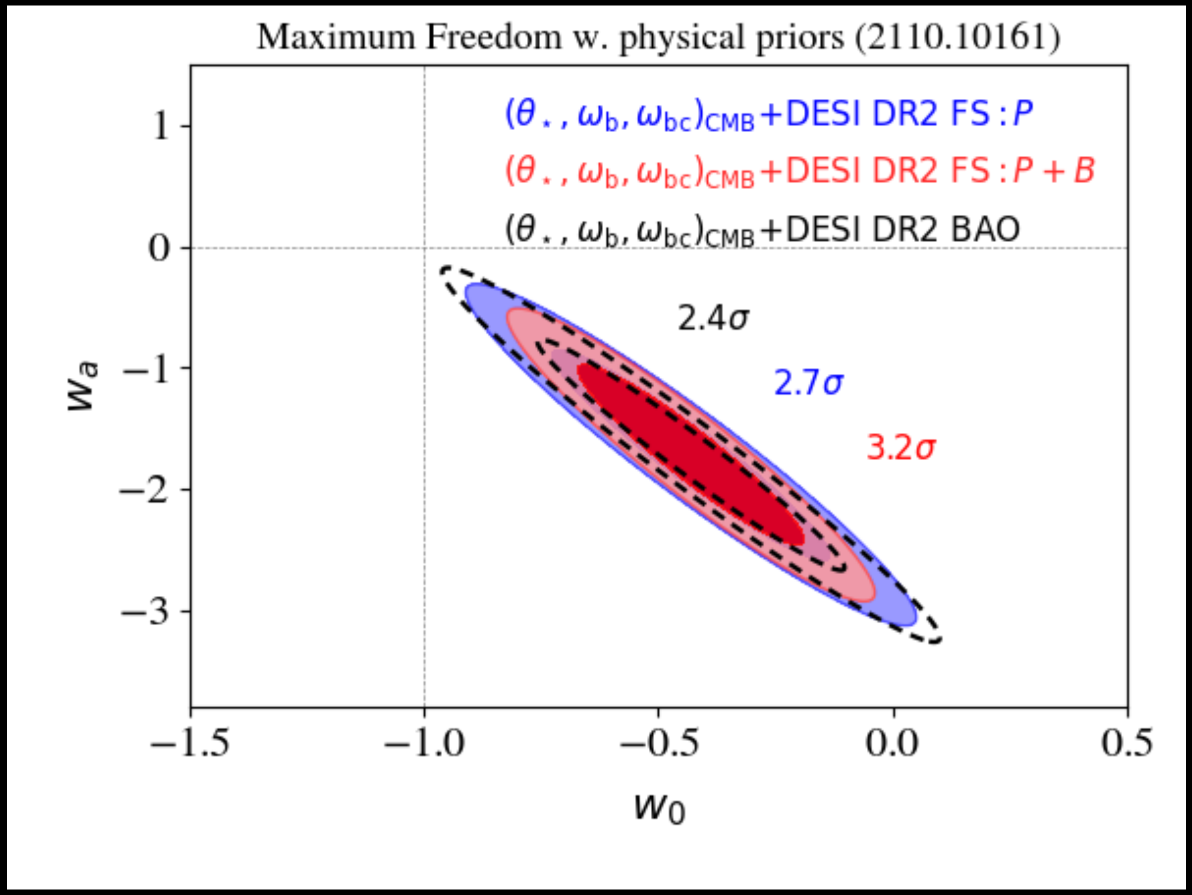
Andrade et al., 2025

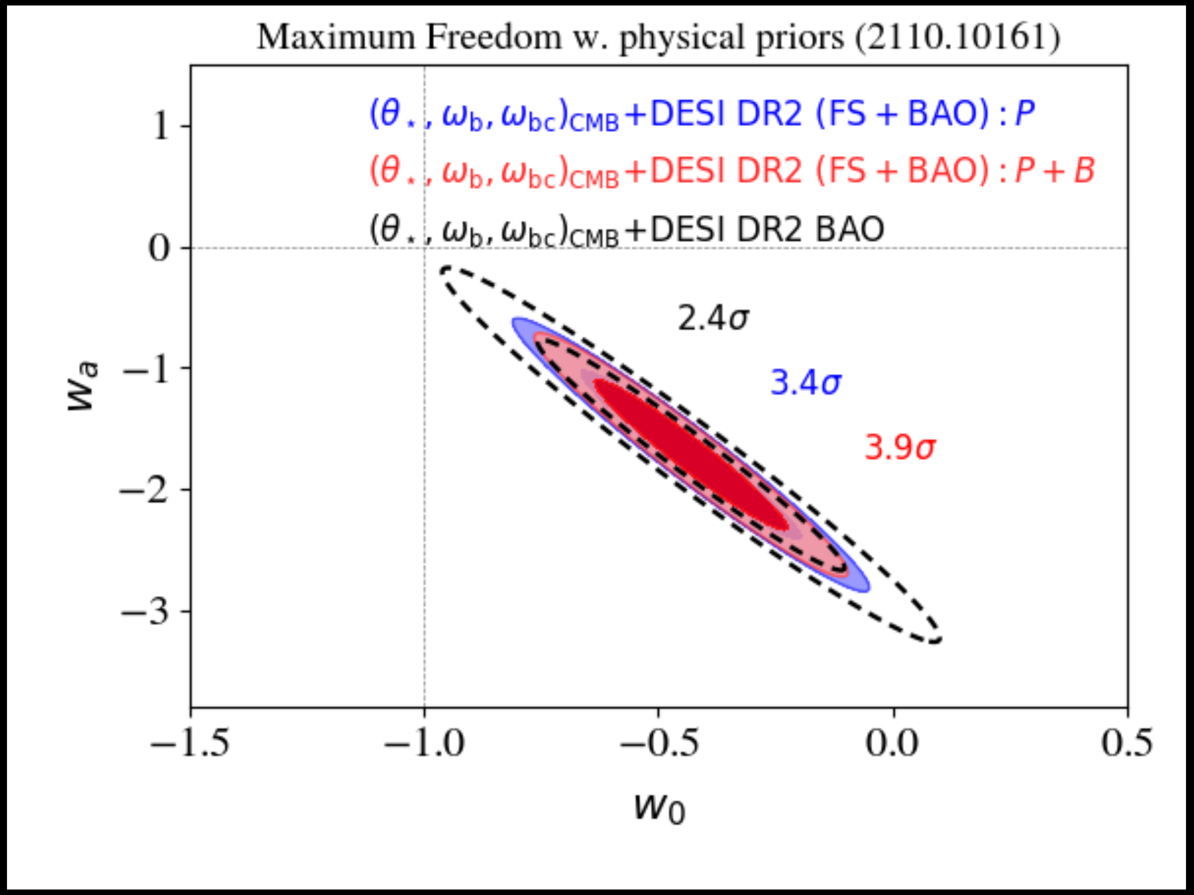
Outlook

- DESI DR2 BAO is just the start!
- Still some DESI DR1 analyses ongoing:
  - Systematic error from fiducial cosmology assumption both for
    1. ShapeFit analysis (BAO+RSD+Shape) -> $\mathbf{A}$
    2. Full Modelling -> $\mathbf{\Omega}$
  - Cosmology from Higher order statistics (bispectrum)
- And full shape from DESI DR2 also coming soon!

What to expect from DR2 Full Shape

Preliminary Fisher Forecasts for P(k) + B(k) using the tripolar spherical harmonic bispectrum estimator by Sugiyama, Saito, Beutler, Seo, 2019





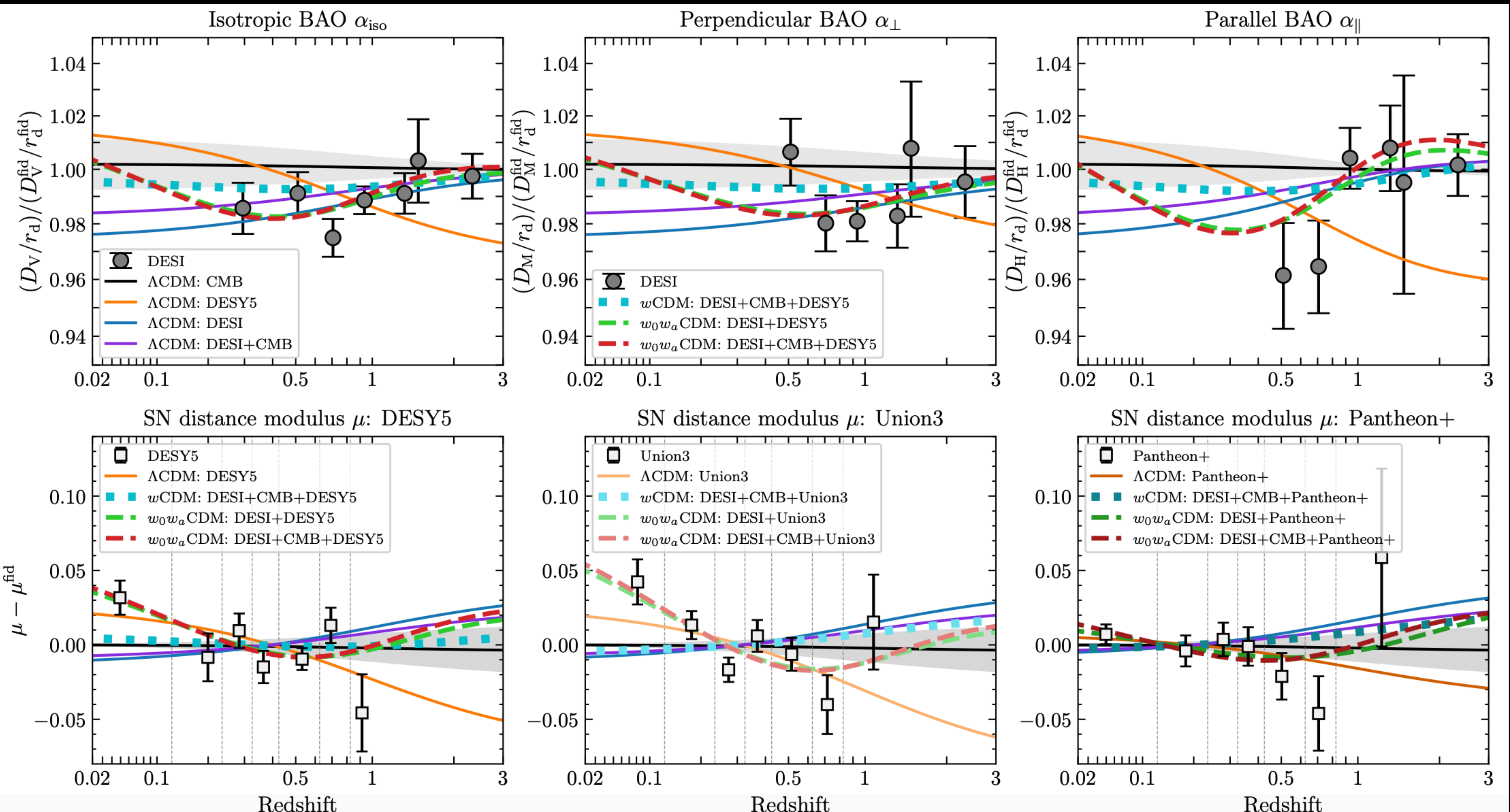
Summary and Conclusion

- Presented different types of systematics and their mitigation schemes:
  - Survey Related:
    - Spectroscopic systematics
    - Photometric systematics
    - Incompleteness systematics
      - -> none of these impacts BAO
  - Modeling Related:
    - Confirmation Bias (mitigated by Blinding)
    - Non-linear evolution (mitigated by BAO Reconstruction)
    - Theoretical modeling choices (almost zero)
    - Fiducial cosmology assumption (negligible, and redone using bestfit w0wa cosmology)
      - -> BAO analysis robust

Tensions within a model ($\mathbf{\Omega}$) are not as intriguing as tensions arising before assuming a model ($\mathbf{A}$)

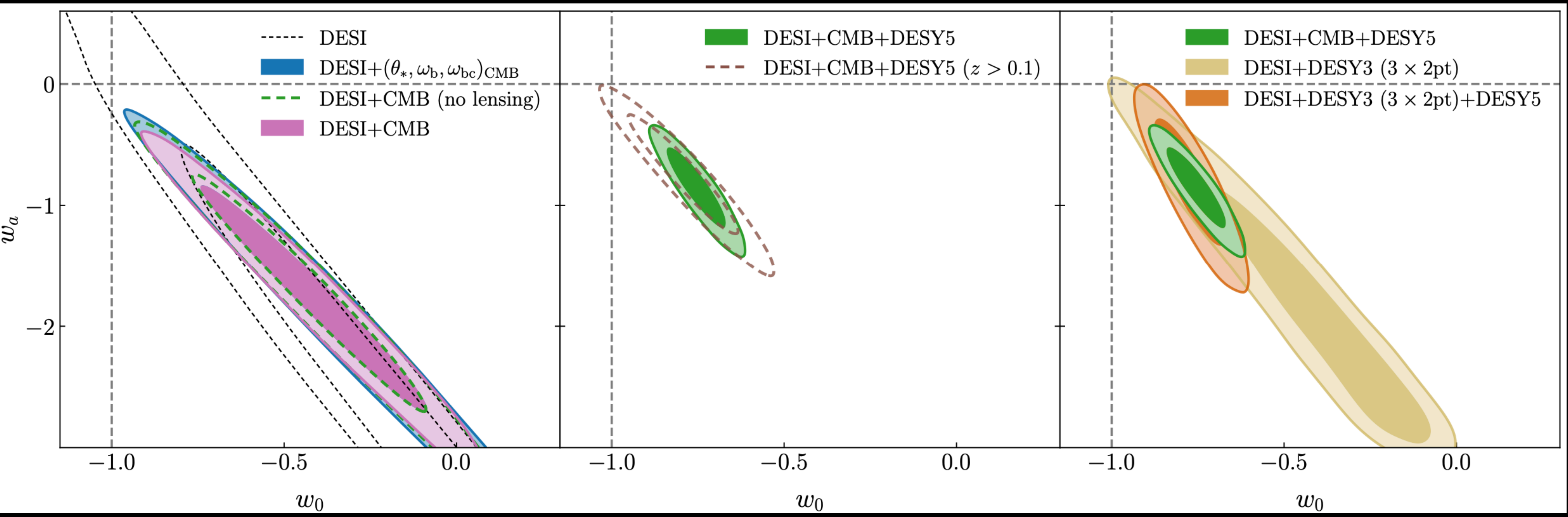
Backup Slides

DESI DR2 BAO + CMB + SN



From DESI DR2 Key Paper

DESI DR2 BAO: w0wa plane



From DESI DR2 Key Paper