




DARK ENERGY SPECTROSCOPIC INSTRUMENT

e o futuro dos grandes levantamentos espectroscópicos

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University of Michigan

DARK ENERGY SPECTROSCOPIC INSTRUMENT

- Telescópio Nicholas Mayall
- Kitt Peak, Arizona, EUA
- 40M de espectros
- Construção
 - \$56M (US DOE)
 - \$19M outras fontes
- 69 instituições
-  LIneA/INCT e-Universo



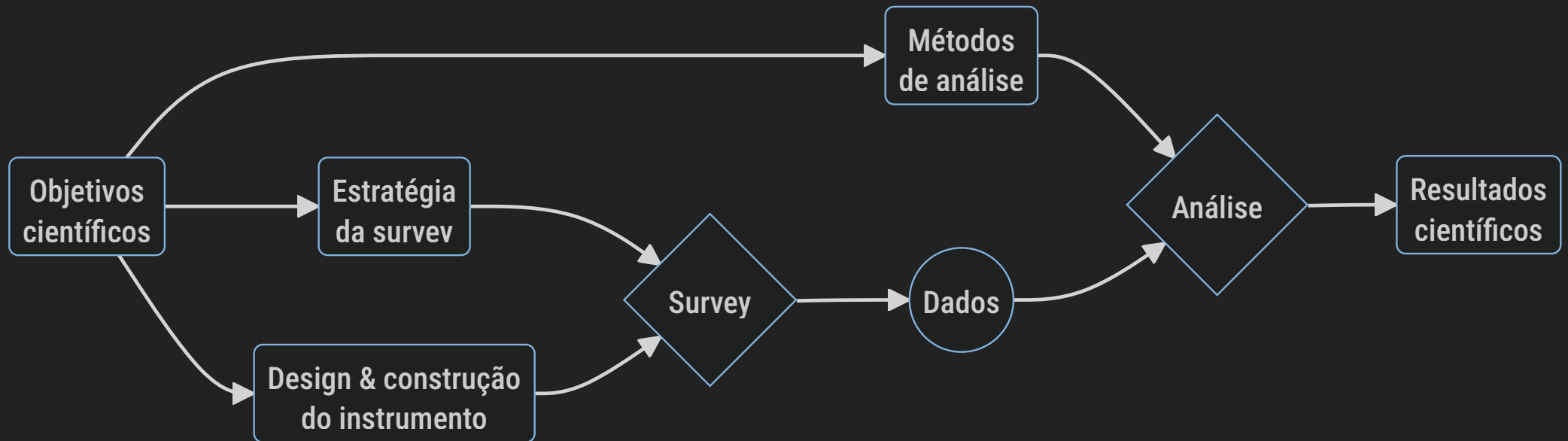
O Kitt Peak National Observatory opera
há mais de seis décadas em território da nação

TOHONO O'ODHAM

Dr. Jacelle Ramon-Sauberan (2021)



PLANEJAMENTO DE UMA SURVEY



OBJETIVOS CIENTÍFICOS

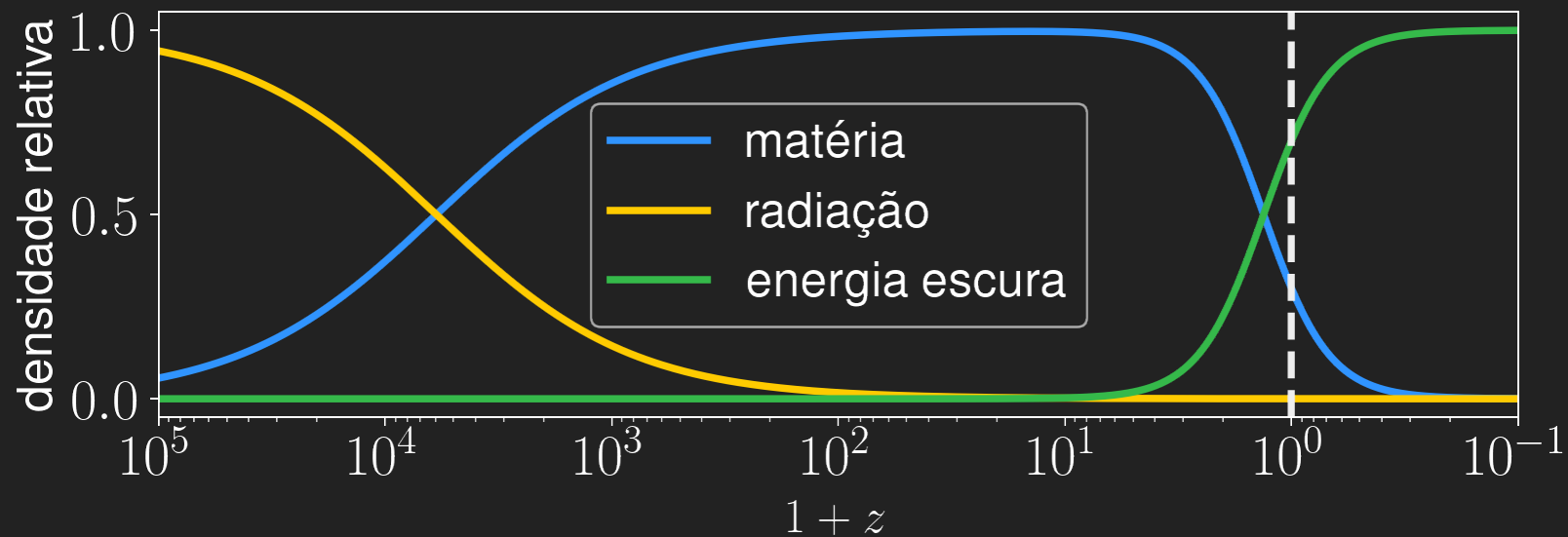
ENERGIA ESCURA É O PRINCIPAL ALVO DO DESI

Caracterizar a expansão do Universo na era da *Energia Escura*

Medir o crescimento da estrutura em larga escala do Universo

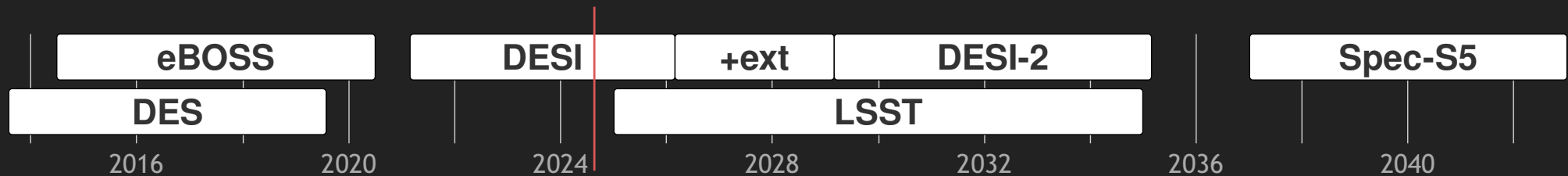
Baryon acoustic oscillations

Redshift-space distortions

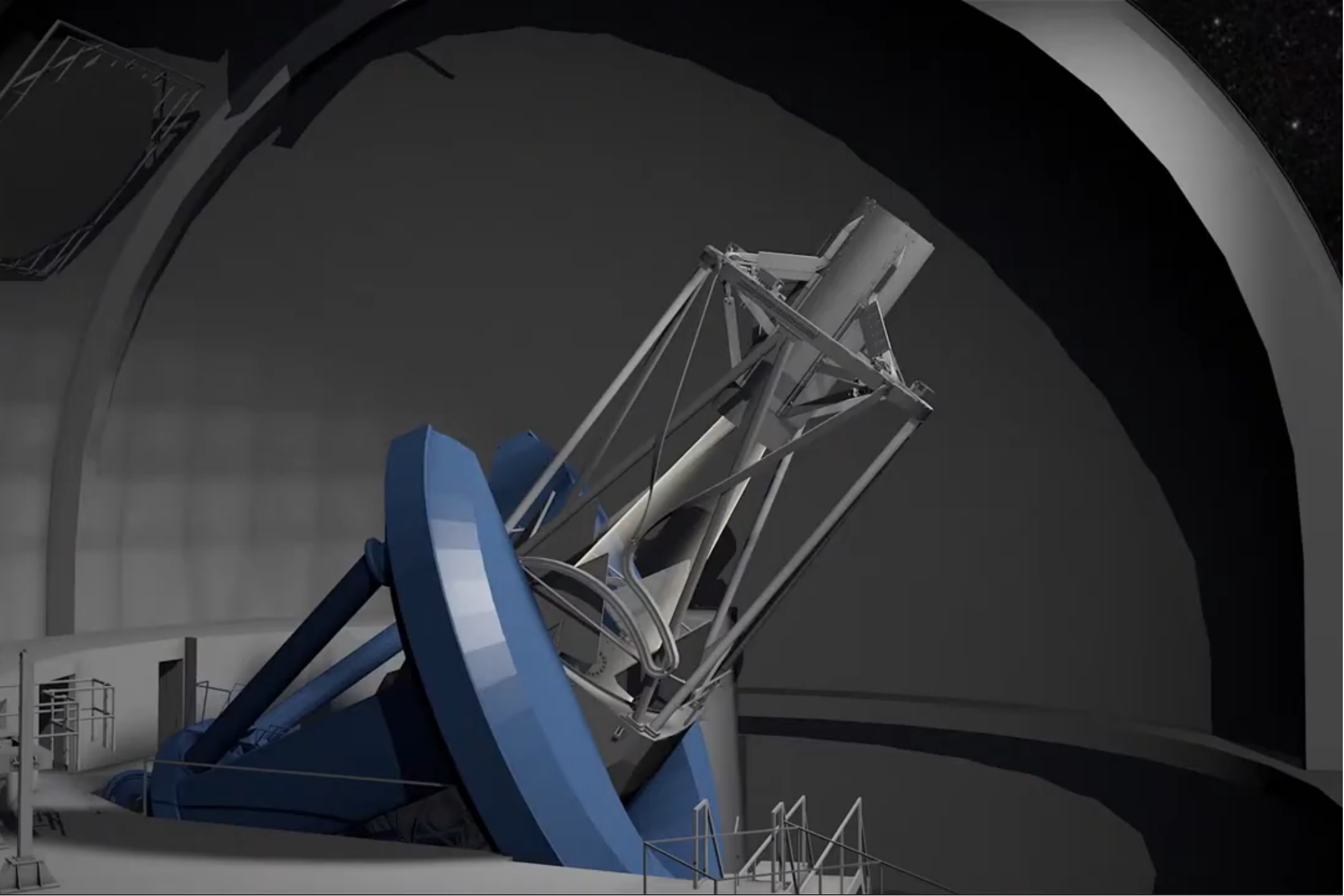


DARK ENERGY TASK FORCE (2006, 2012)

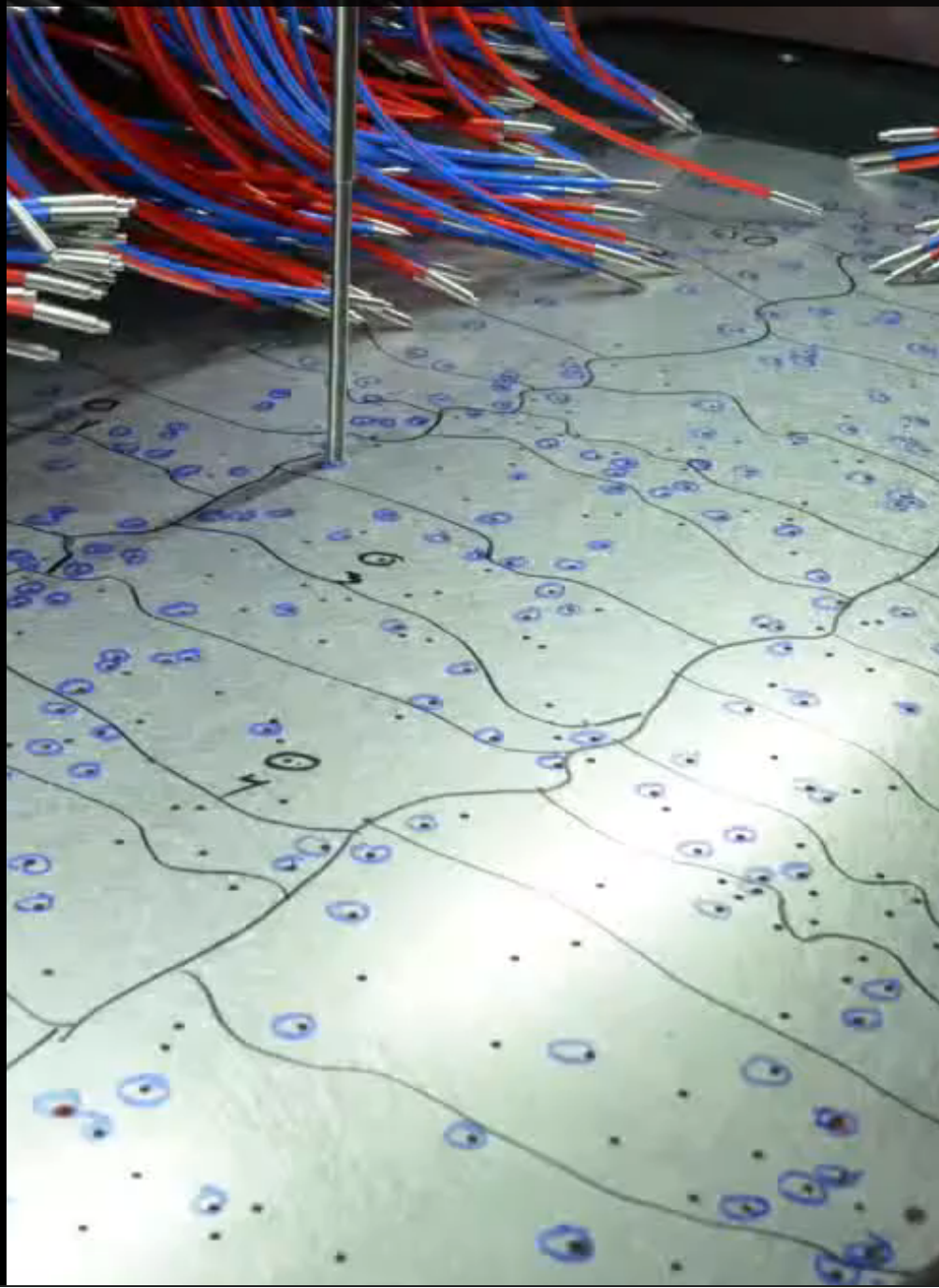
- Stages I & II: Fase de descoberta & 2000s
- Stage III: projetos de curto prazo, custo médio — BOSS, DES, +
- **Stage IV: projetos de grande alcance — DESI, LSST, +**



O INSTRUMENTO



SDSS

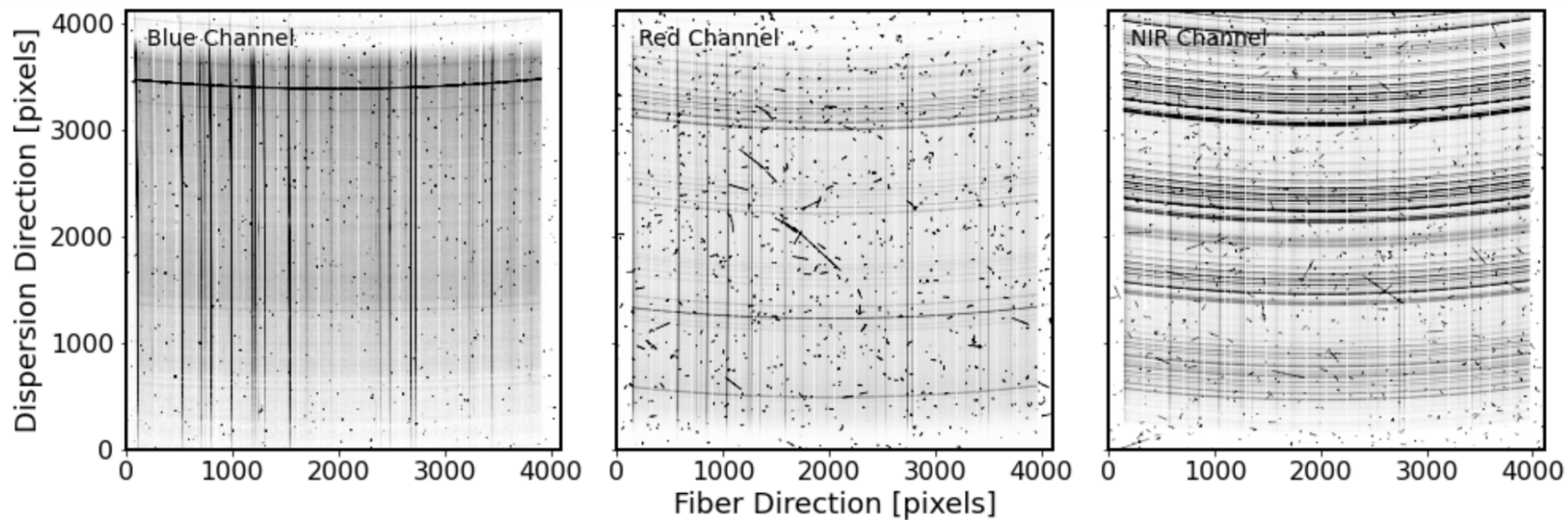


DESI

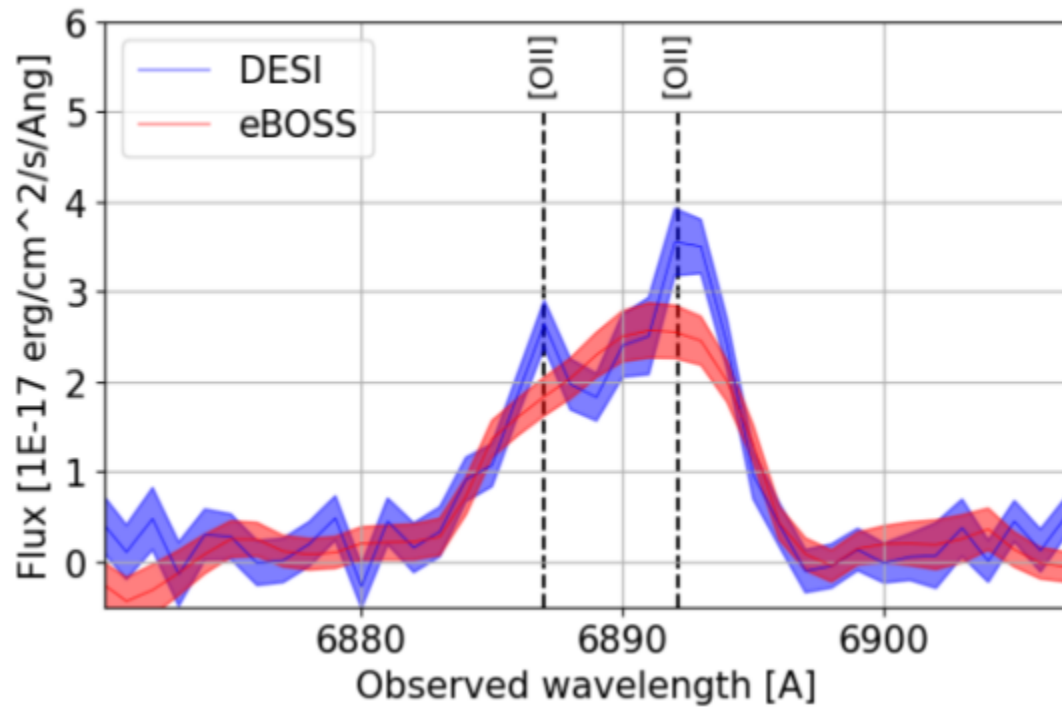




5000 ESPECTROS A CADA 30 MINUTOS



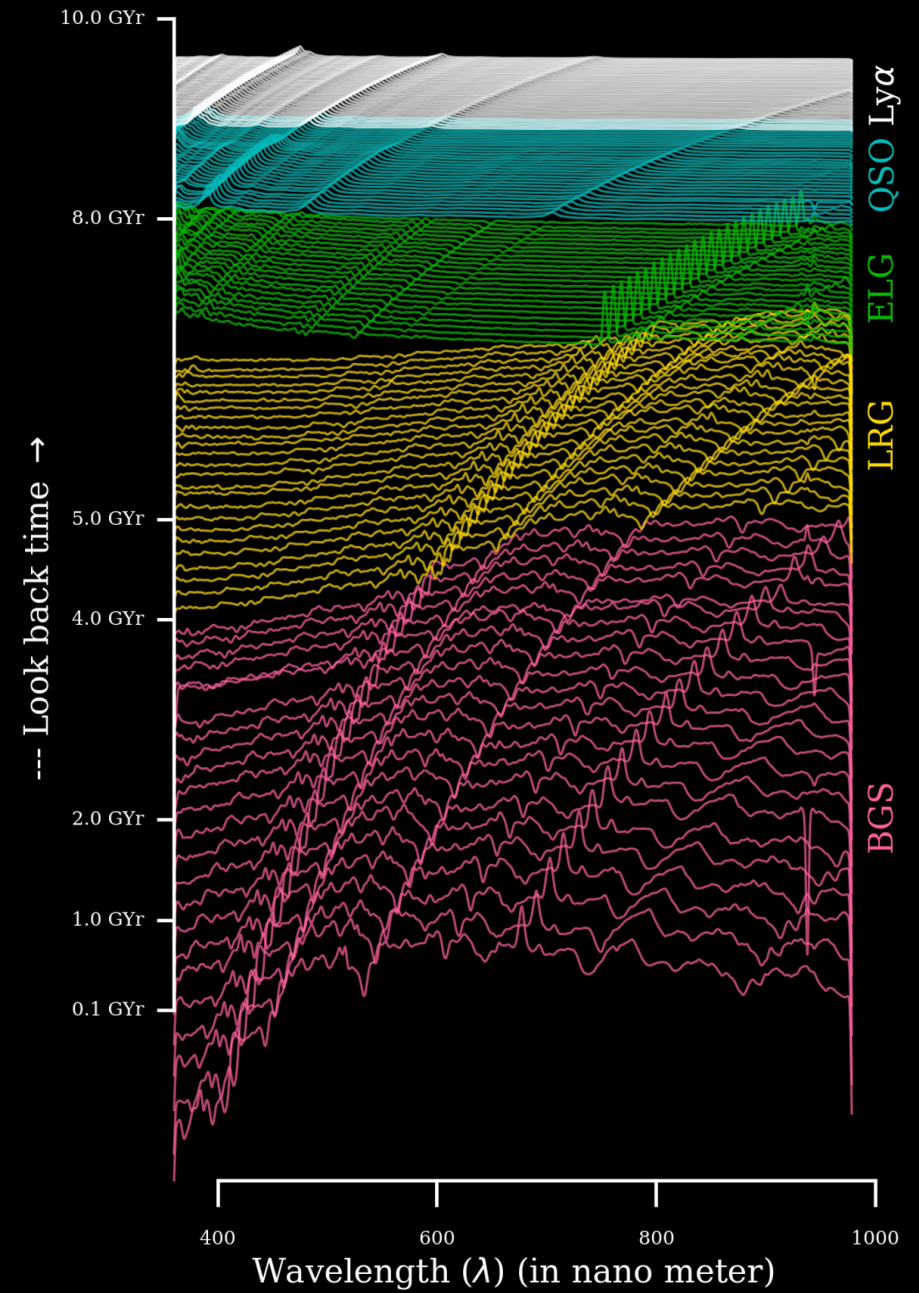
COM ALTA RESOLUÇÃO



Tempos de exposição:

- **DESI:** 15 minutos
- **eBOSS:** 1 hora

Resultando em um mapa 3D de galáxias entre os redshifts $0.1 < z < 4.16$



ESTRATÉGIA DE OBSERVAÇÃO

Bright Galaxy Sample (BGS)

$$0.1 < z < 0.4$$

Luminous Red Galaxies (LRG)

$$0.4 < z < 1.1$$

Emission Line Galaxies (ELG)

$$0.8 < z < 1.6$$

Quasars (QSO)

$$0.8 < z < 2.1$$

Lyman-alpha forest (Ly- α)

$$1.77 < z < 4.16$$

LEGACY SURVEYS

THE ASTRONOMICAL JOURNAL, 157:168 (29pp), 2019 May

Dey et al.

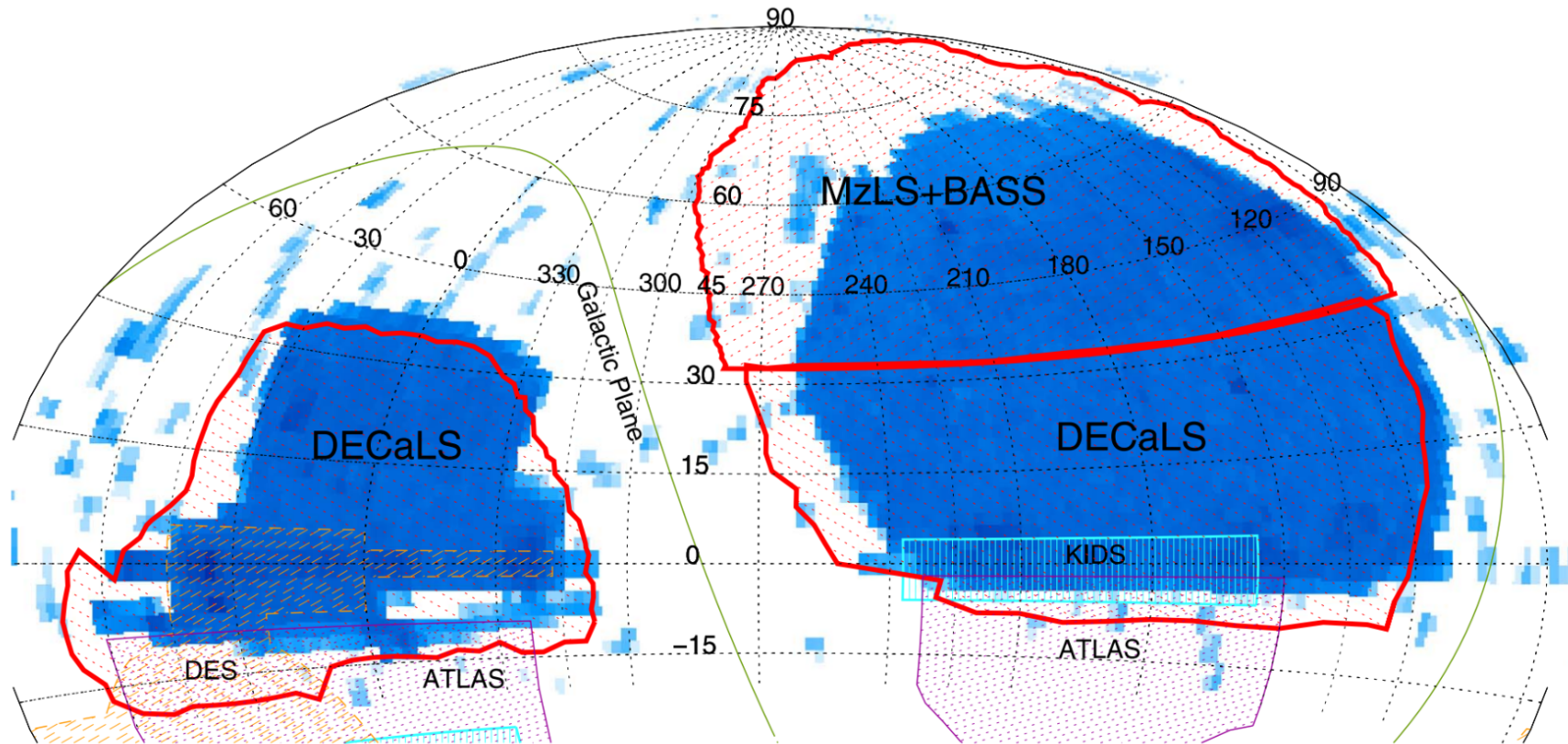


Figure 1. Footprints of the optical imaging surveys contributing to DESI imaging, demarcated by the thick red outlines, are shown here in an equal-area Aitoff projection in equatorial coordinates. The region covered by the BASS and MzLS surveys is almost entirely in the North Galactic Cap (NGC) at declinations $\delta \geq +32^\circ$, and DECaLS covers the entire South Galactic Cap and the $\delta \leq +34$ regions in the NGC. The regions covered by existing wide-area spectroscopic redshift surveys (SDSS, 2dF, and BOSS; Colless et al. 2001; Abazajian et al. 2009; Abolfathi et al. 2018) are shown in the blue gray scale in the map provided, where the darker colors represent a higher density of spectroscopic redshifts. The Legacy Surveys provide deeper imaging and can leverage the existing spectroscopy in these regions, unlike most other existing or ongoing deep imaging surveys (e.g., DES, ATLAS, KIDS, etc.; The Dark Energy Survey Collaboration 2005; de Jong et al. 2015; Shanks et al. 2015).

>70% DAS OBSERVAÇÕES CONCLUÍDAS

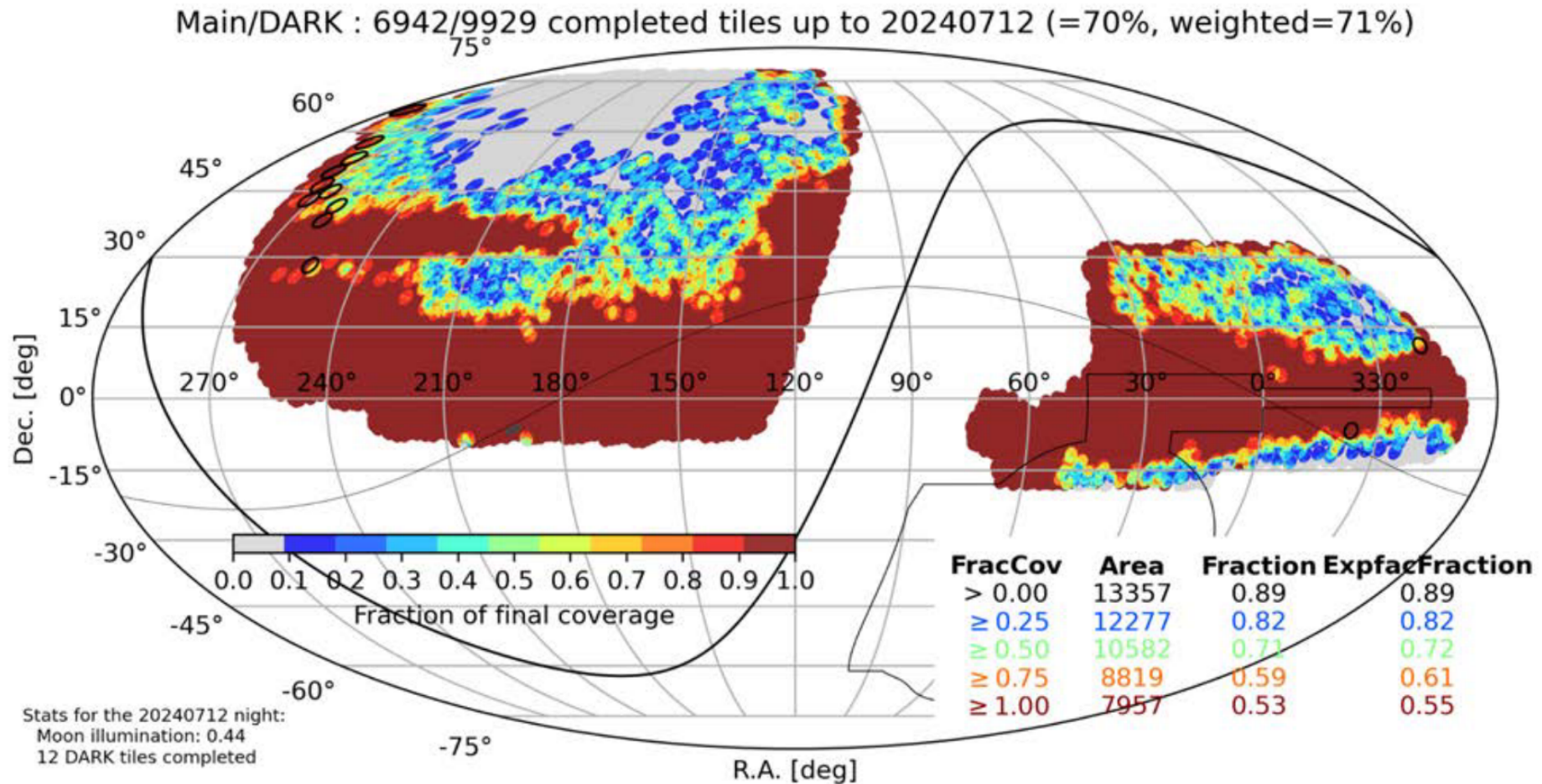
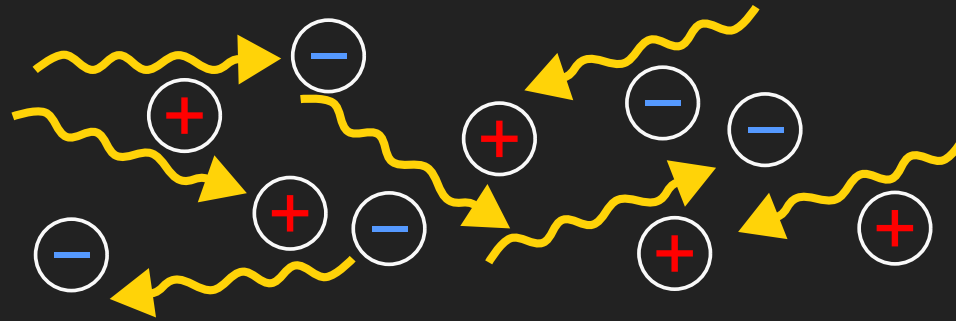


Figure 5. Fraction completed for the dark-time program, with red indicating areas that have achieved full coverage.

BARYON ACOUSTIC OSCILLATIONS

MECANISMO FÍSICO

- Do Big Bang até $z \approx 1100$, bárions e fótons interagem fortemente e sua pressão atua como força restauradora contra o colapso gravitacional.

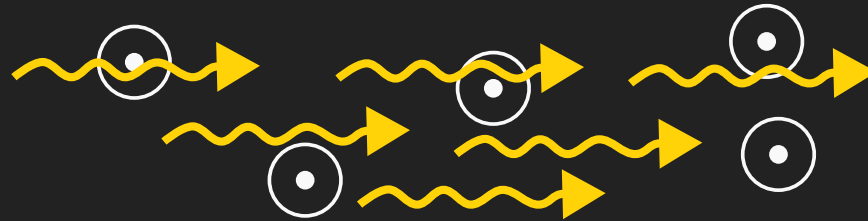


- Temos, então, a propagação de ondas acústicas com velocidade:

$$c_s(z) = \frac{c}{\sqrt{3 \left(1 + \frac{3}{4} \frac{\rho_B(z)}{\rho_\gamma(z)} \right)}}$$

MECANISMO FÍSICO

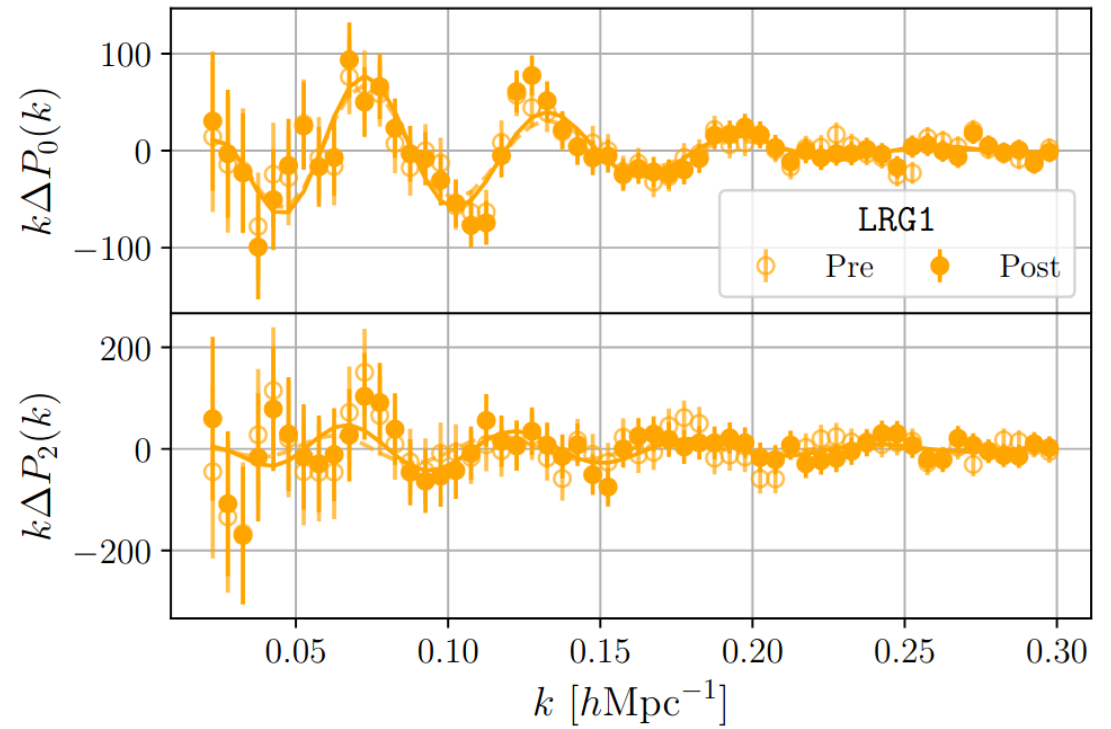
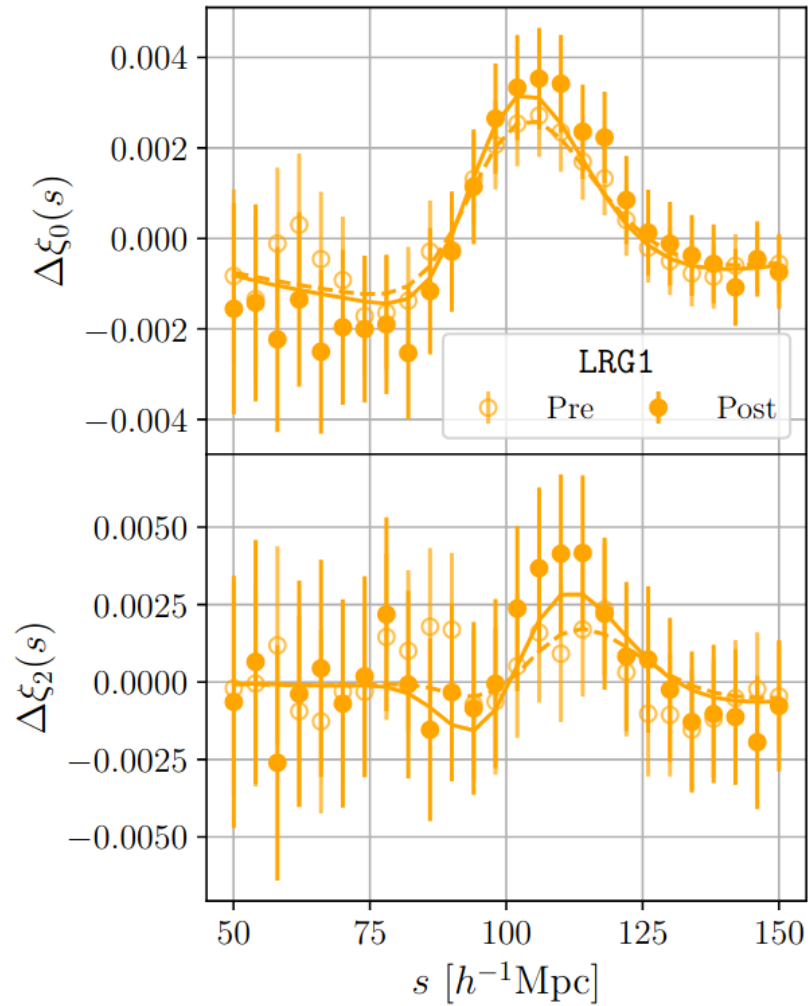
- Em $z \approx 1100$, a temperatura abaixa o suficiente para que elétrons e prótons se combinem em HI. As oscilações cessam, mas seus modos harmônicos ficam preservados nas distribuição de fótons e de matéria.



- O modo fundamental corresponde à distância máxima percorrida pelas ondas acústicas do Big Bang até $z \approx 1100$.

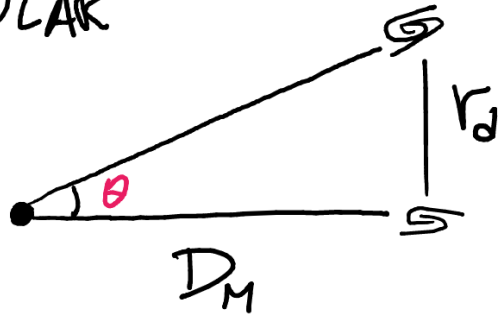
$$r_d = \int_{z_d}^{\infty} \frac{c_s(z)}{H(z)} dz$$

BAO NA DISTRIBUIÇÃO DE GALÁXIAS



A ESCALA DO BAO COMO UMA RÉGUA PADRÃO

ANGULAR



$$\frac{1}{\theta} = \frac{D_M(z)}{r_d} = \frac{c}{r_d} \int_0^z \frac{dz}{H(z)}, \quad H(z) = H_0 \sqrt{\Omega_m (1+z)^3 + \dots}$$

RADIAL

$$\frac{c \Delta z}{H(z)} = r_d \Rightarrow \frac{1}{\Delta z} = \frac{c}{H(z) r_d} \equiv \frac{D_H(z)}{r_d}$$

ANOTHER BASIS :

$$\left\{ \begin{array}{l} \text{ISOTROPIC} \quad \odot \quad \frac{D_V}{r_d} = \left[z \left(\frac{D_H}{r_d} \right)^2 \left(\frac{D_H}{r_d} \right) \right]^{1/3} \\ \text{ANISOTROPIC} \quad \oplus \quad \frac{D_M}{D_H} \end{array} \right.$$

RESULTADOS




Johannes Lange
DESI x lensing

Minh Nguyen
Cosmology analysis

Sikandar Hanif
Fiber assignment



Greg Tarlé
Positioners



Humna Awan
Ly-alpha

Uendert Andrade
Blinding validation



Michael Schubnell
Positioners



Monica Valluri
Milky-way science

Tianke Zhuang
Cosmology analysis

Otávio Alves
Covariance matrix



Tim Fanning
Positioners



Sean MacBride
Focal plane, detectors

Dragan Huterer
co-lead Cosmology analysis



Rebekah Sebok
Focal plane



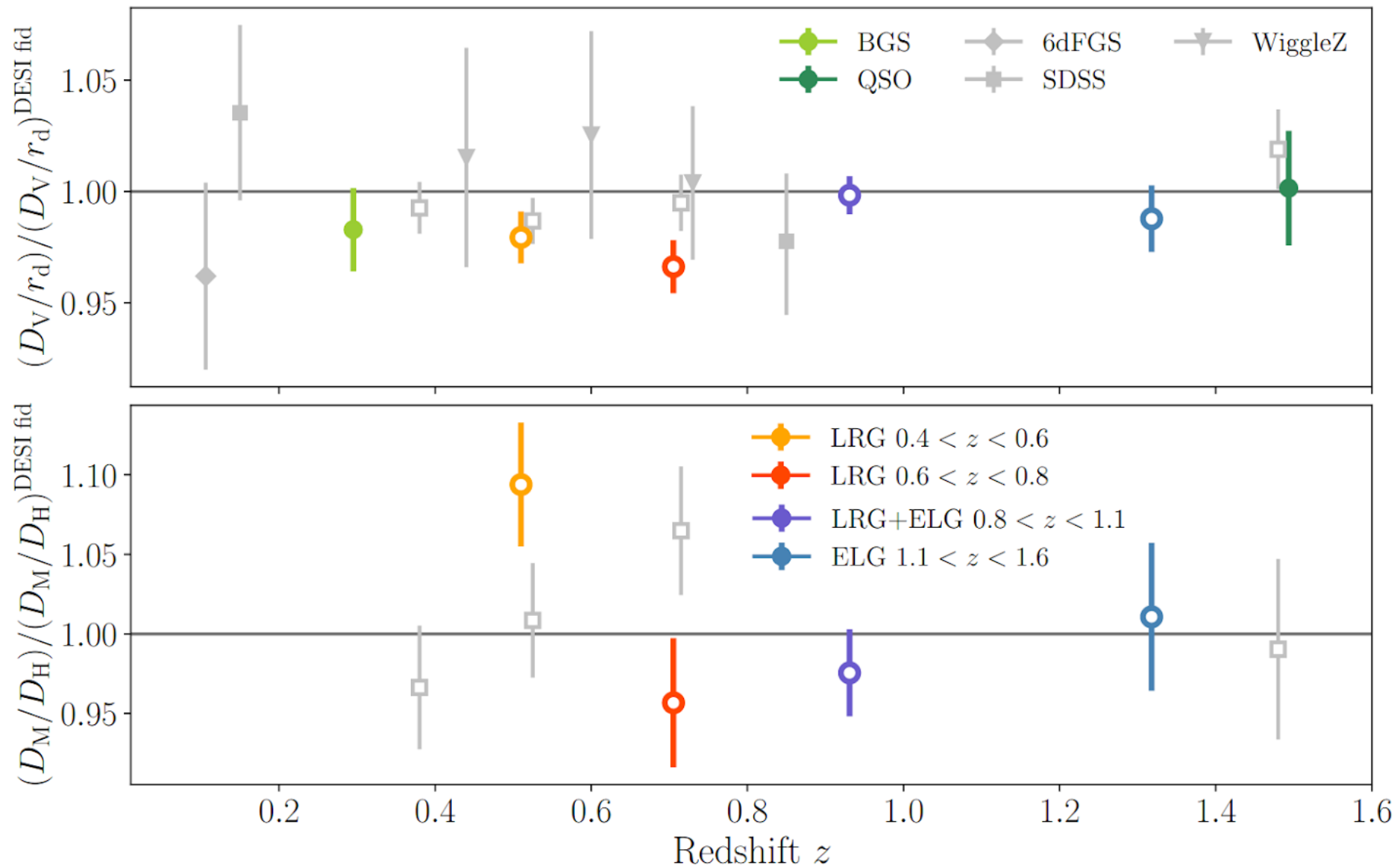
Jiaming Pan
Cosmology analysis

AS MEDIDAS

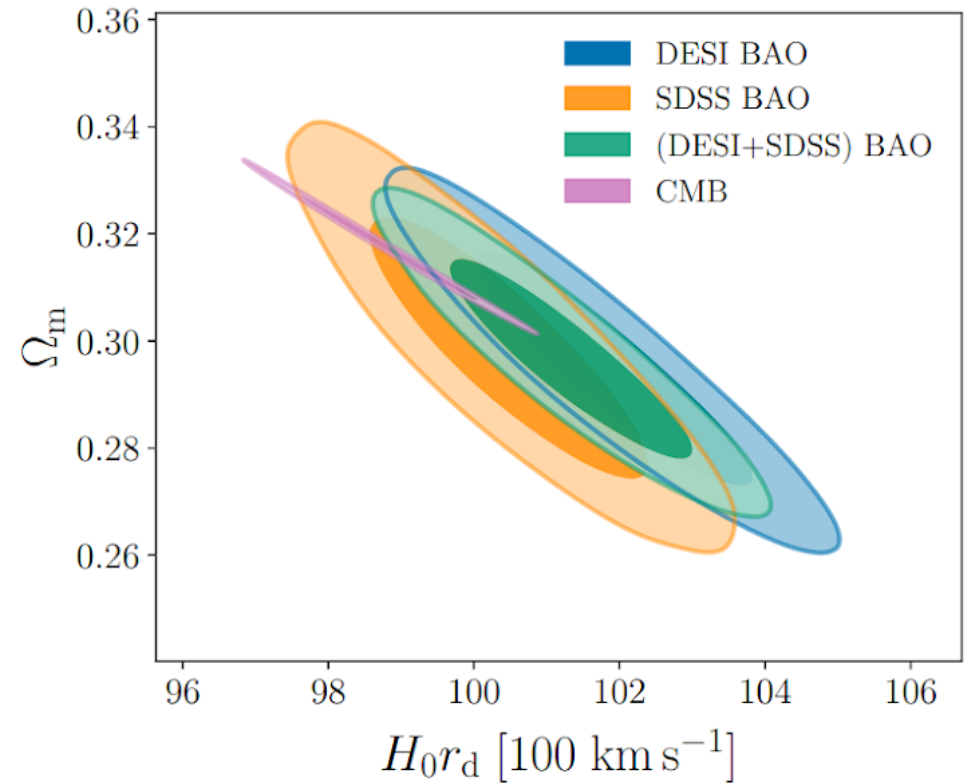
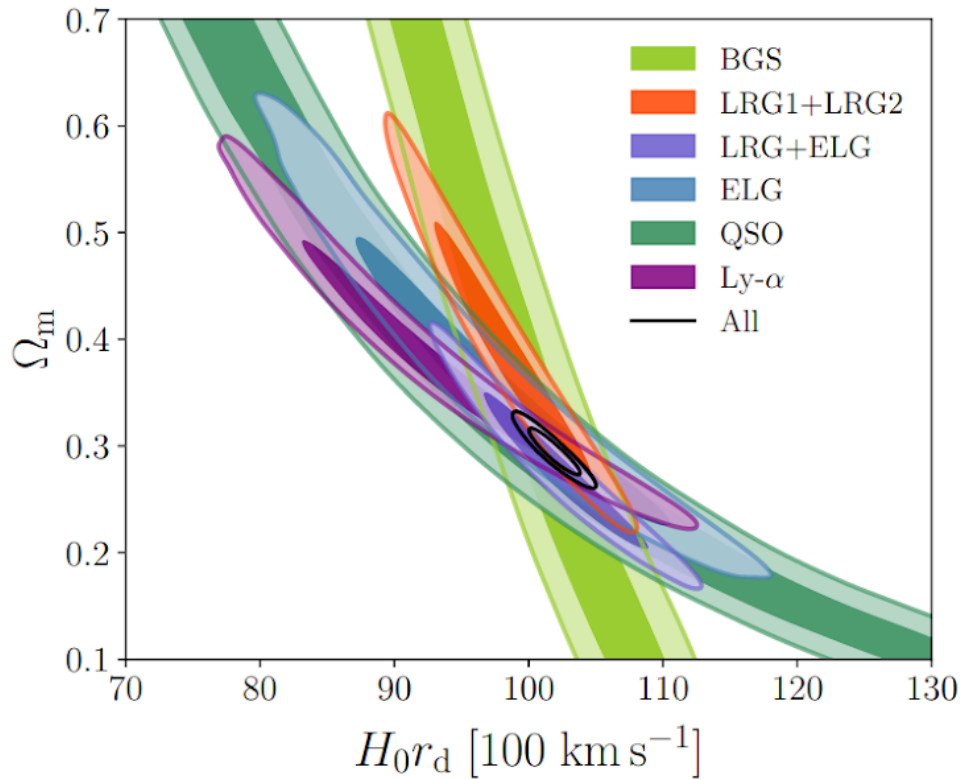
tracer	redshift	N_{tracer}	z_{eff}	$D_{\text{M}}/r_{\text{d}}$	$D_{\text{H}}/r_{\text{d}}$	r or $D_{\text{V}}/r_{\text{d}}$	V_{eff} (Gpc ³)
BGS	0.1 – 0.4	300,017	0.30	—	—	7.93 ± 0.15	1.7
LRG	0.4 – 0.6	506,905	0.51	13.62 ± 0.25	20.98 ± 0.61	−0.445	2.6
LRG	0.6 – 0.8	771,875	0.71	16.85 ± 0.32	20.08 ± 0.60	−0.420	4.0
LRG+ELG	0.8 – 1.1	1,876,164	0.93	21.71 ± 0.28	17.88 ± 0.35	−0.389	6.5
ELG	1.1 – 1.6	1,415,687	1.32	27.79 ± 0.69	13.82 ± 0.42	−0.444	2.7
QSO	0.8 – 2.1	856,652	1.49	—	—	26.07 ± 0.67	1.5
Ly α QSO	1.77 – 4.16	709,565	2.33	39.71 ± 0.94	8.52 ± 0.17	−0.477	—

Table 1. Statistics for the DESI samples used for the DESI DR1 BAO measurements used in this paper. For each tracer and redshift range we quote the number of objects (N_{tracer}), the effective redshift (z_{eff}) and effective volume (V_{eff}). Note that for each sample we measure either both $D_{\text{M}}/r_{\text{d}}$ and $D_{\text{H}}/r_{\text{d}}$, which are correlated with a coefficient r , or $D_{\text{V}}/r_{\text{d}}$. Redshift bins are non-overlapping, except for the shot-noise-dominated measurements that use QSO (both as tracers and for Ly α forest).

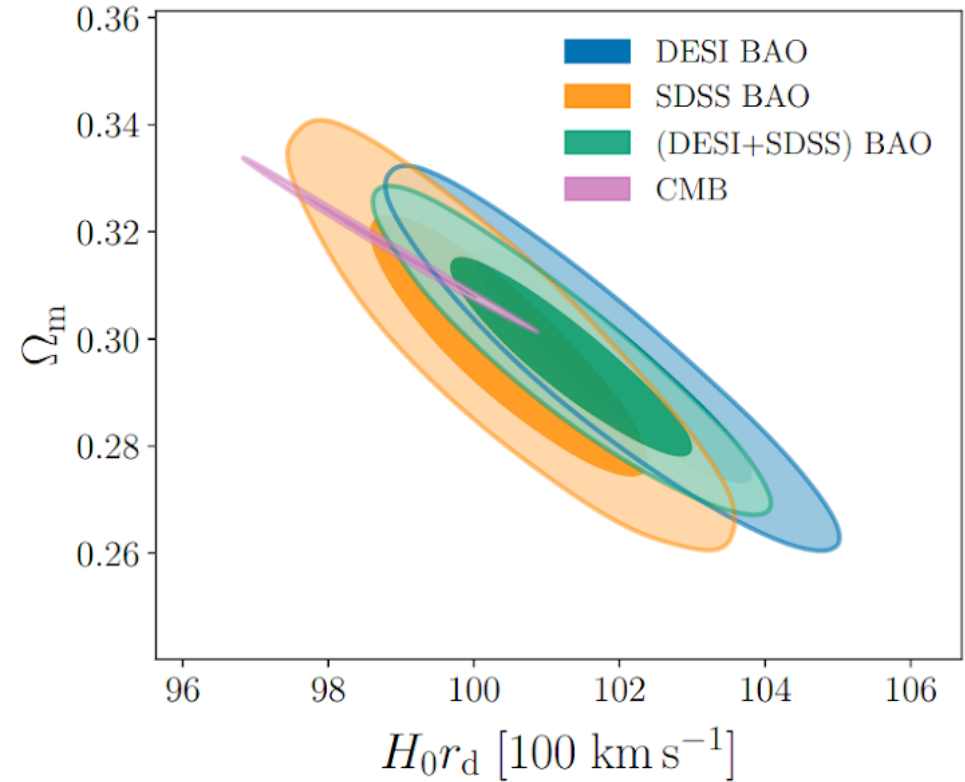
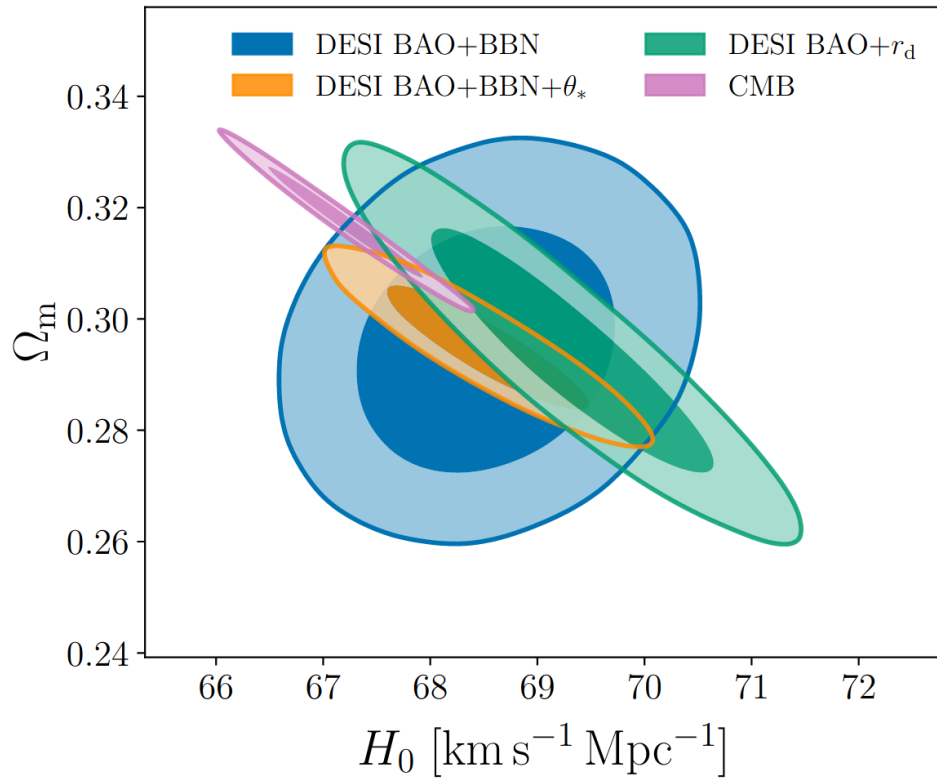
AS MEDIDAS



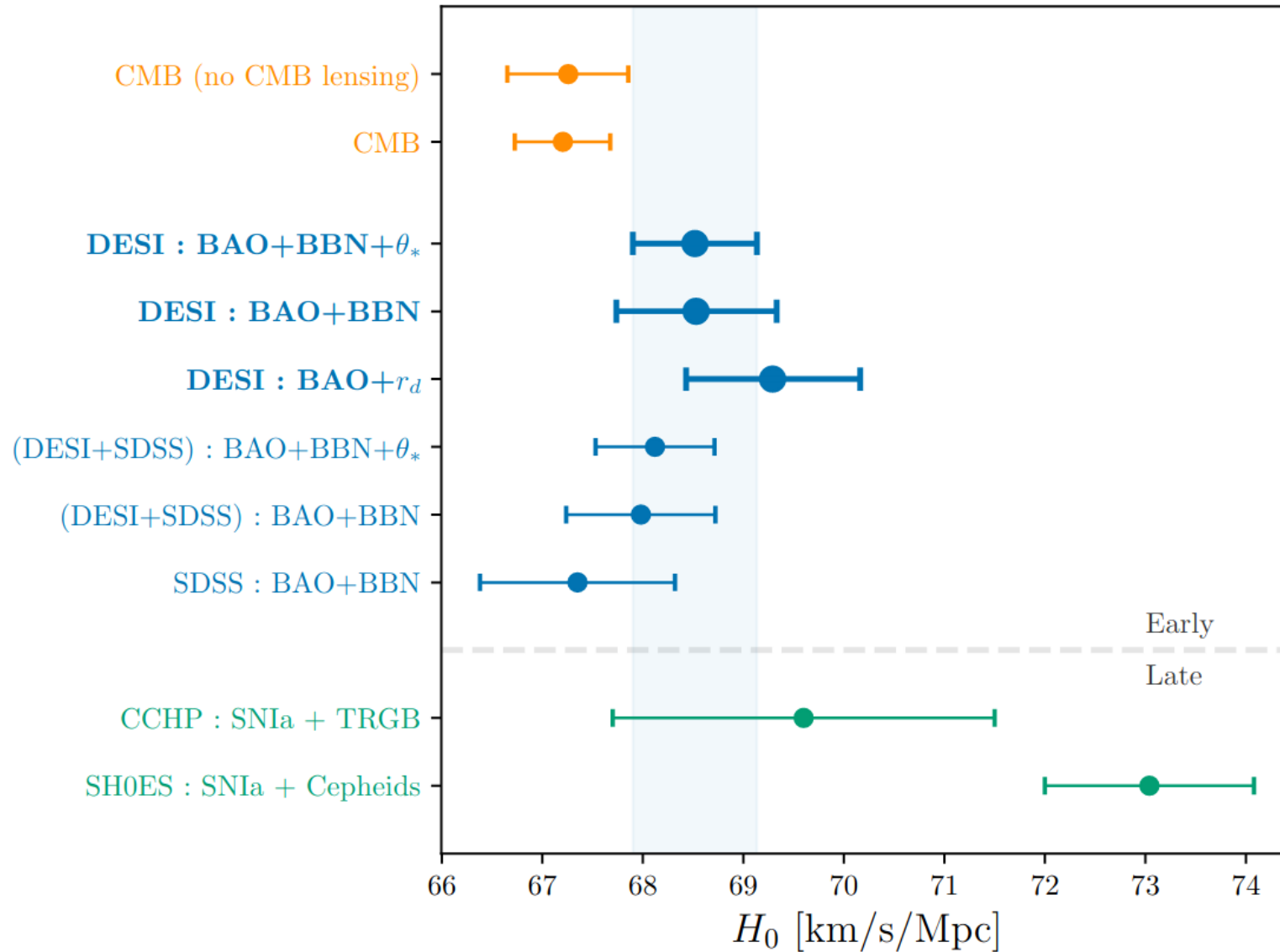
COMBINANDO BAO EM MÚLTIPLOS REDSHIFTS



COM INFORMAÇÕES DA ESCALA DO HORIZONTE



OBTEMOS A CONSTANTE DE HUBBLE



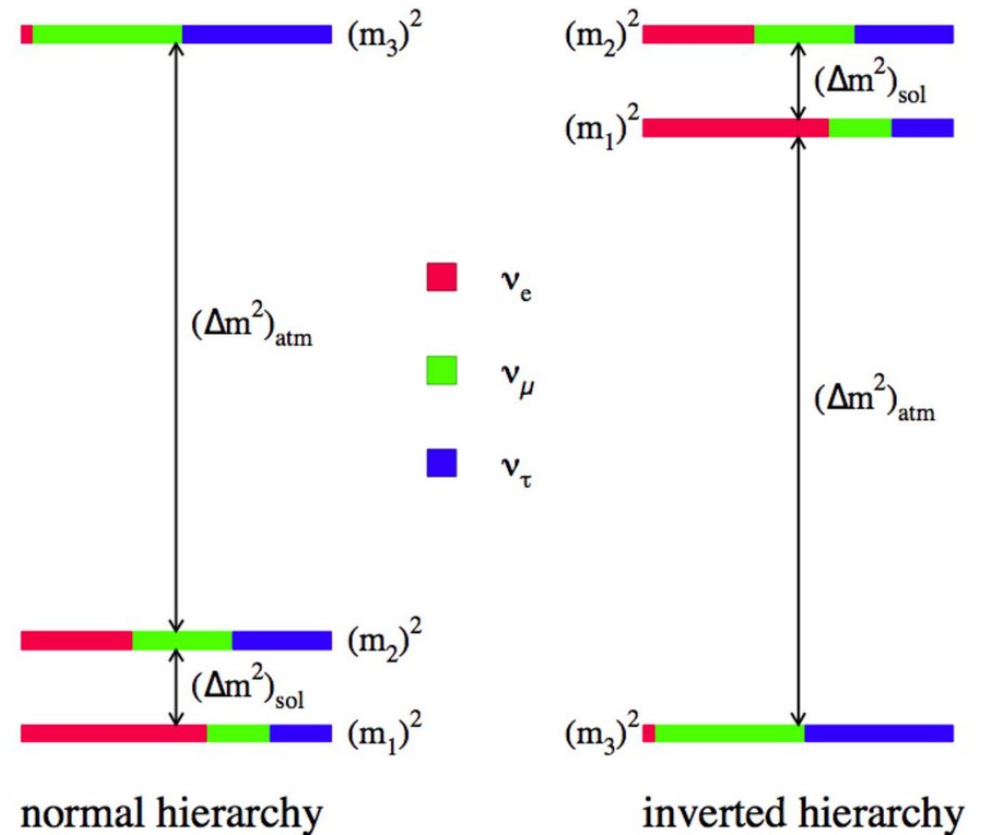
NEUTRINOS

MASSA DOS NEUTRINOS

Oscilações de sabor detectadas em neutrinos solares e atmosféricos medem a **diferença das massas quadradas** dos 3 tipos.

A massa mínima permitida por esses resultados é:

- Hierarquia normal: 0.059 eV
- Hierarquia invertida: 0.10 eV

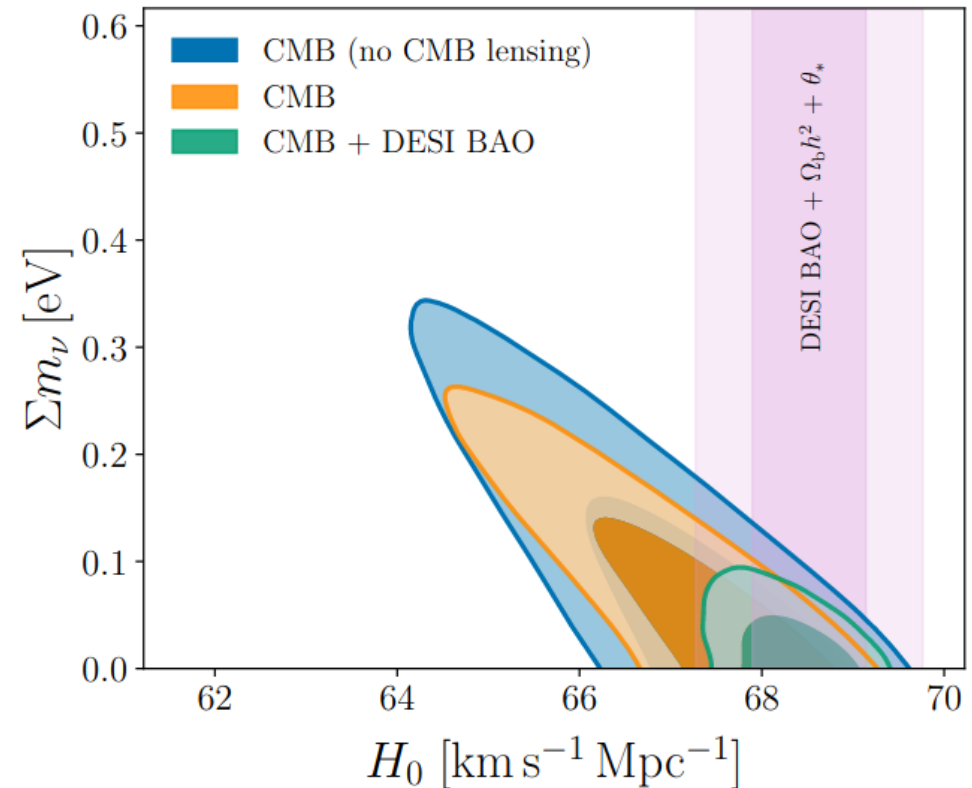


A CMB É SENSÍVEL À MASSA TOTAL ATRAVÉS DA

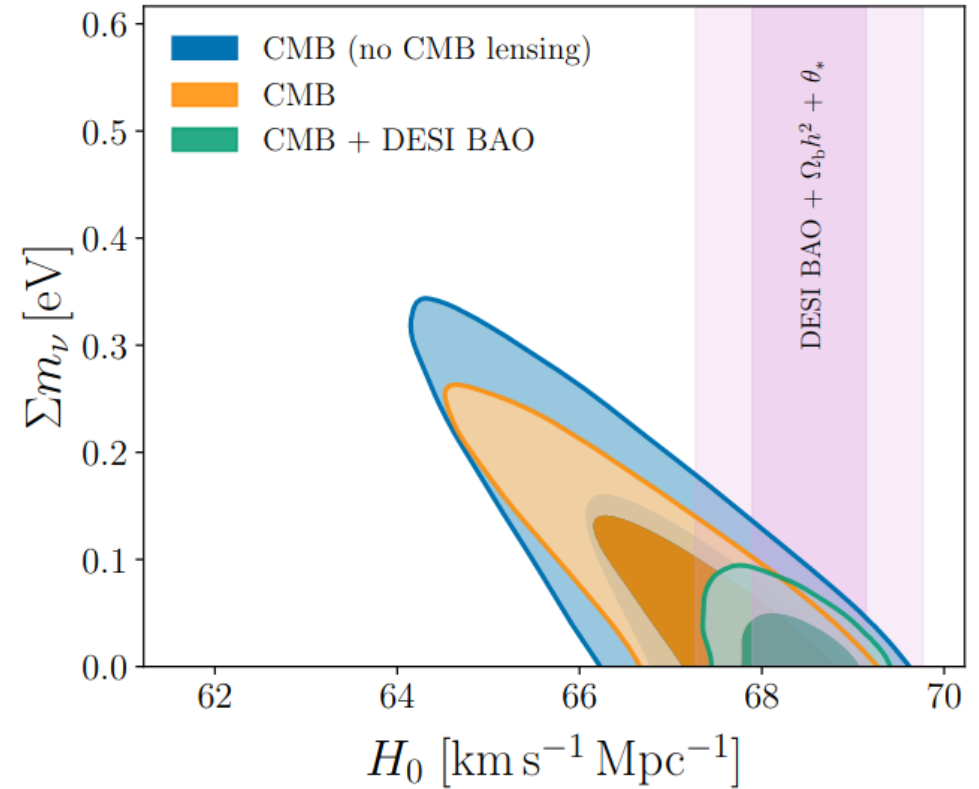
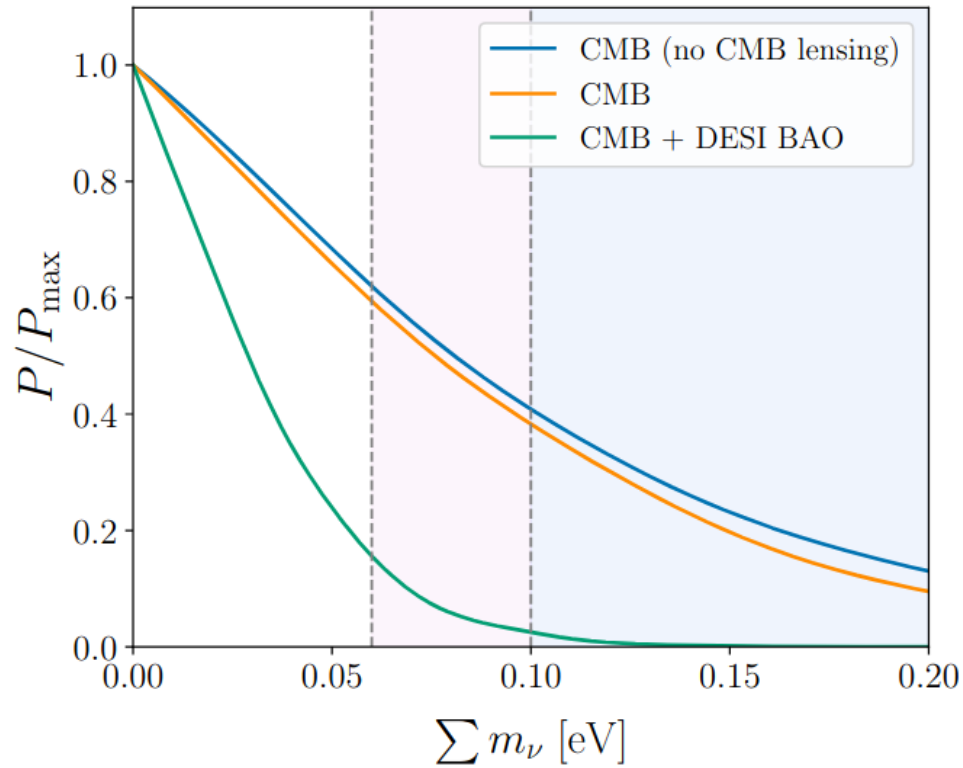
distância de diâmetro angular
até a recombinação

lenteamento gravitacional
da CMB

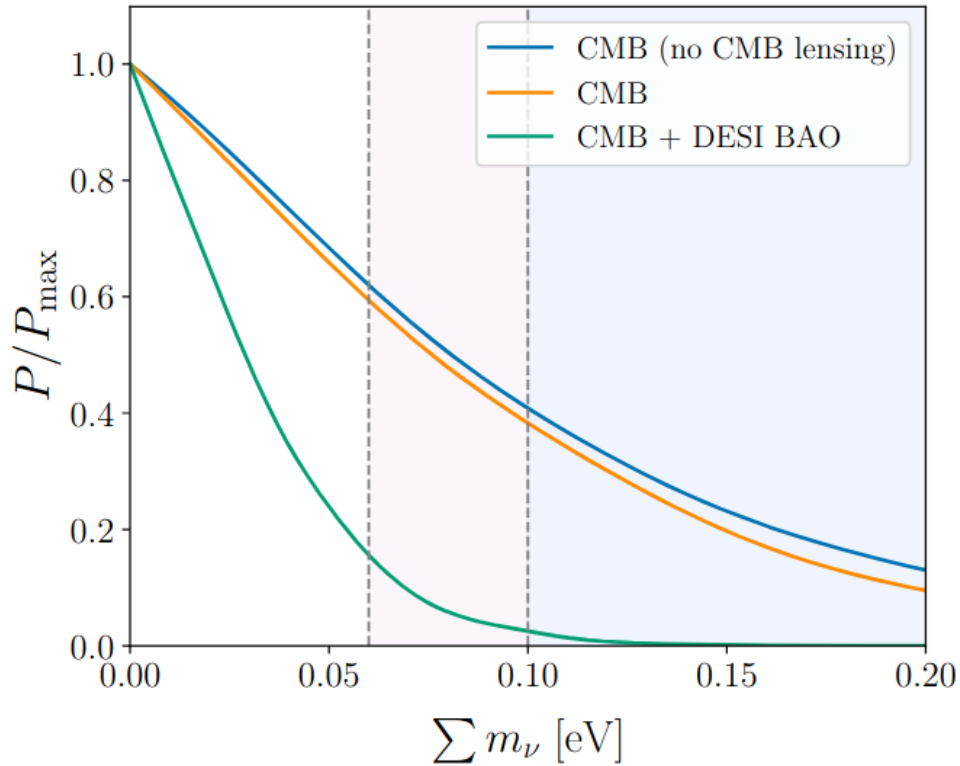
Efeitos que são degenerados com a
constante de Hubble e a **densidade
de matéria**.



DESI MOVE O VÍNCULO PARA MASSAS MENORES



DESI MOVE O VÍNCULO PARA MASSAS MENORES



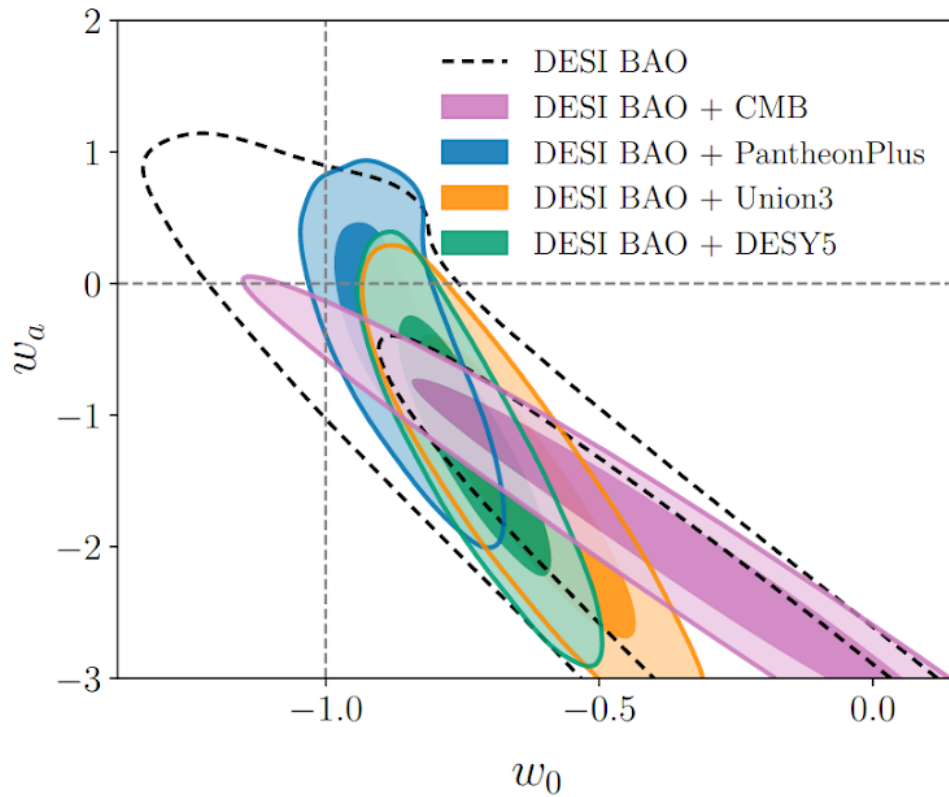
$$\sum m_\nu < 0.072 \text{ eV} \quad (95\%, \text{ DESI BAO+CMB}),$$

$$\sum m_\nu < 0.113 \text{ eV} \quad (95\%, \text{ DESI BAO+CMB}; \sum m_\nu > 0.059 \text{ eV}),$$

$$\sum m_\nu < 0.145 \text{ eV} \quad (95\%, \text{ DESI BAO+CMB}; \sum m_\nu > 0.10 \text{ eV}).$$

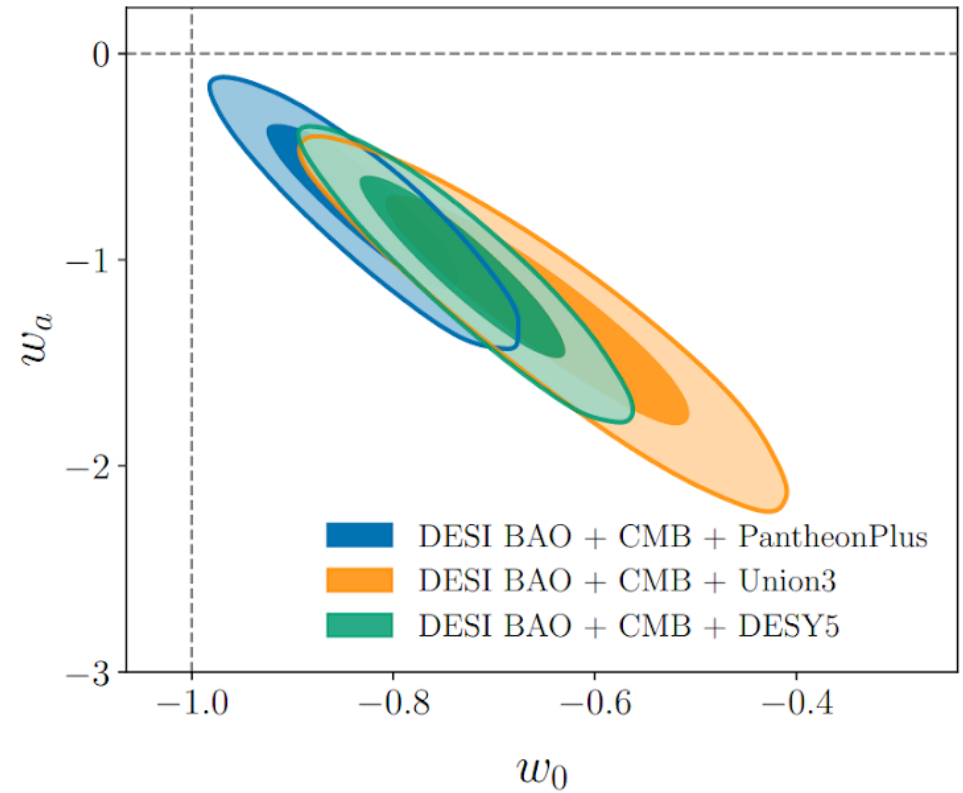
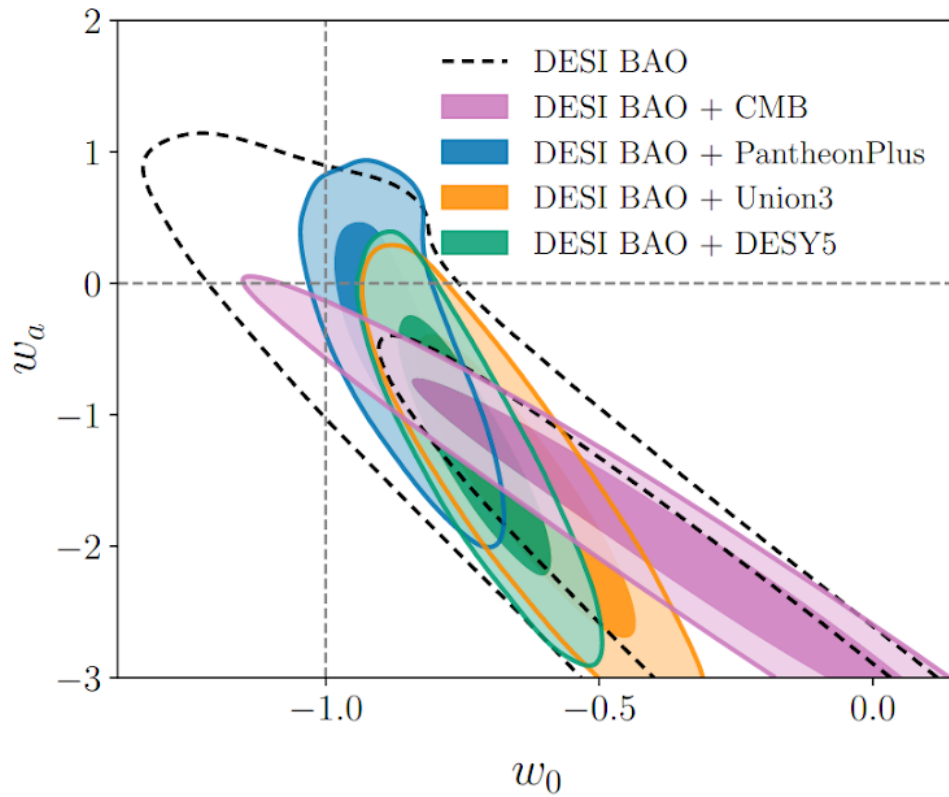
ENERGIA ESCURA

SEPARADAMENTE, DESI É CONSISTENTE COM Λ



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

DESI+SN+CMB SUGEREM ENERGIA ESCURA DINÂMICA



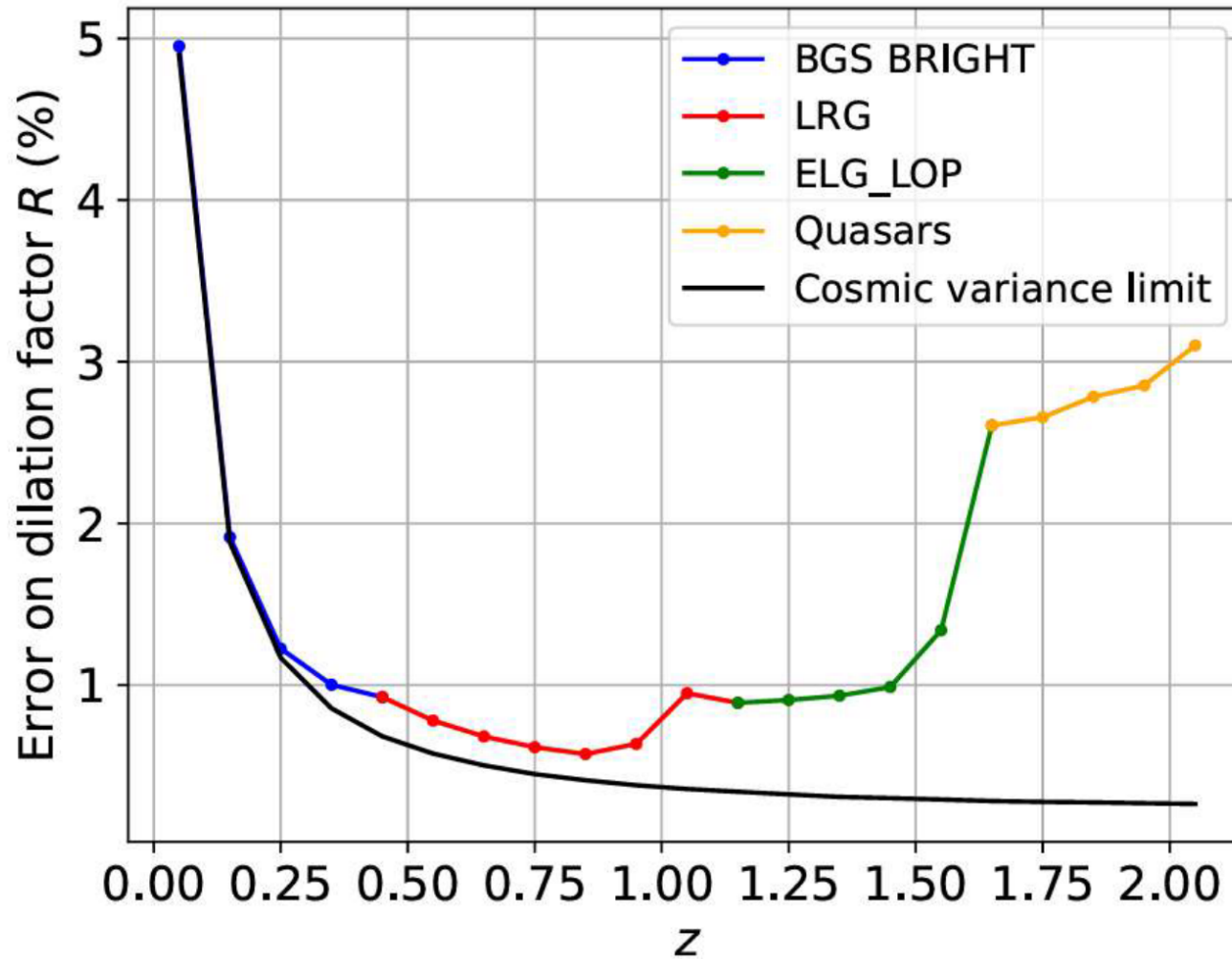
DESI YEAR 1

- DESI 2024 I: First year data release
- DESI 2024 II: DR1 catalogs
- **DESI 2024 III: BAO from Galaxies and Quasars at $z < 2$**
- **DESI 2024 IV: BAO from the Lyman- α Forest at $z > 2$**
- DESI 2024 V: RSD from Galaxies and Quasars at $z < 2$
- **DESI 2024 VI: Cosmological constraints from BAO measurements**
- DESI 2024 VII: Cosmological constraints from RSD measurements
- + vários artigos de apoio.

P.S.: DESI Year 3 BAO não tarda.

FUTURO

HÁ MARGEM PARA MELHORA NO DESI



BGS

limitado pela variância cósmica

LRG

fácil obter novas targets e bons redshifts

ELG

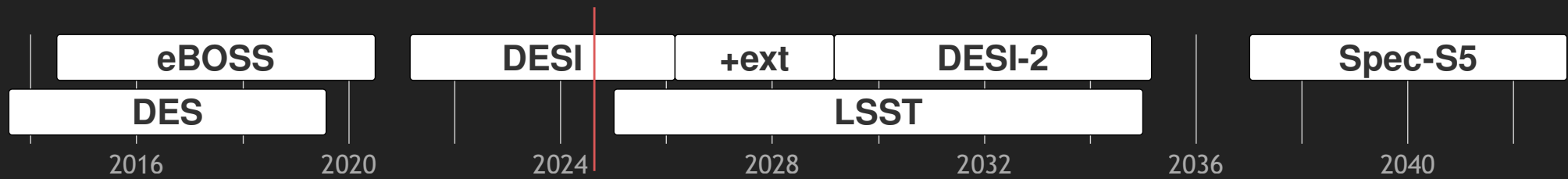
muitas targets pra poucas fibras

QSO

difícil obter novas targets

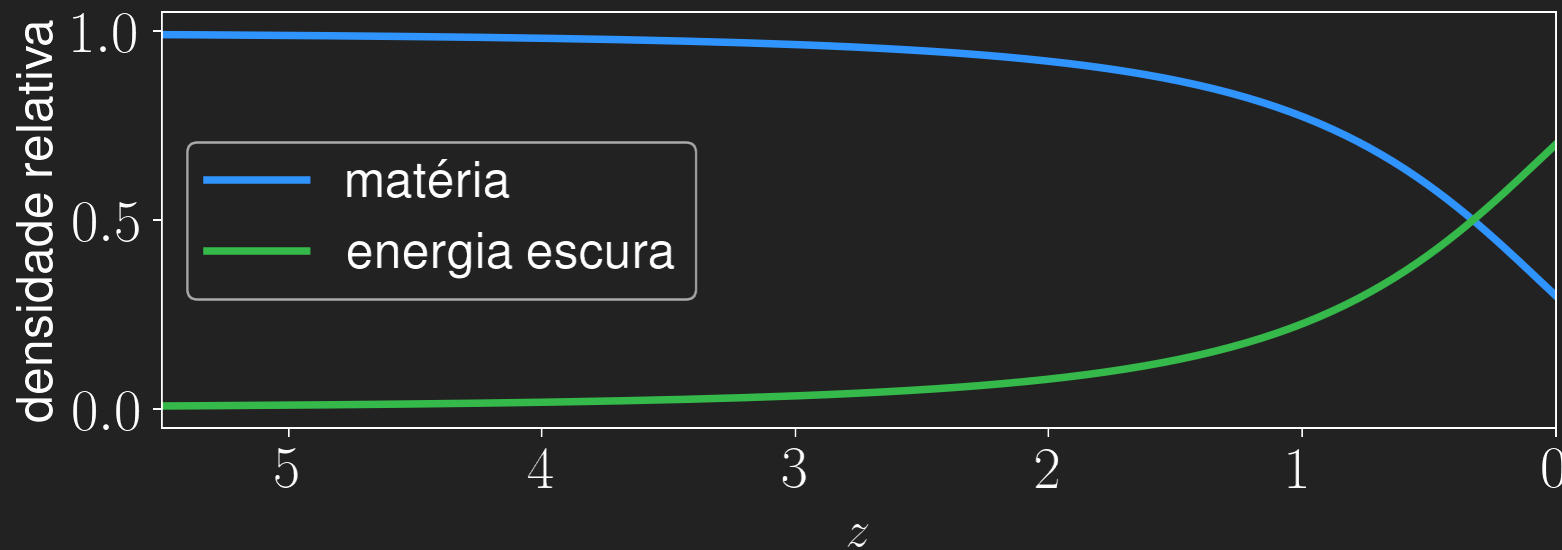
DESI EXTENSION

- Mesmo instrumento
- +20% área
- +50% interseção com LSST
- +50% LRG targets



DESI-2

- Foco em altos redshifts: $2.2 < z < 5$
 - Mais modos lineares para estudo de física primordial
 - Energia Escura na era da matéria



- Melhoras no instrumento: Skipper CCDs na faixa do azul
- Novos tracers: Lyman-break galaxies (LBG) & Lyman- α emitters (LAE)

EARLY RESULTS FROM BOTH **DESI** AND LSST WILL **SHAPE** FUTURE PRIORITIES

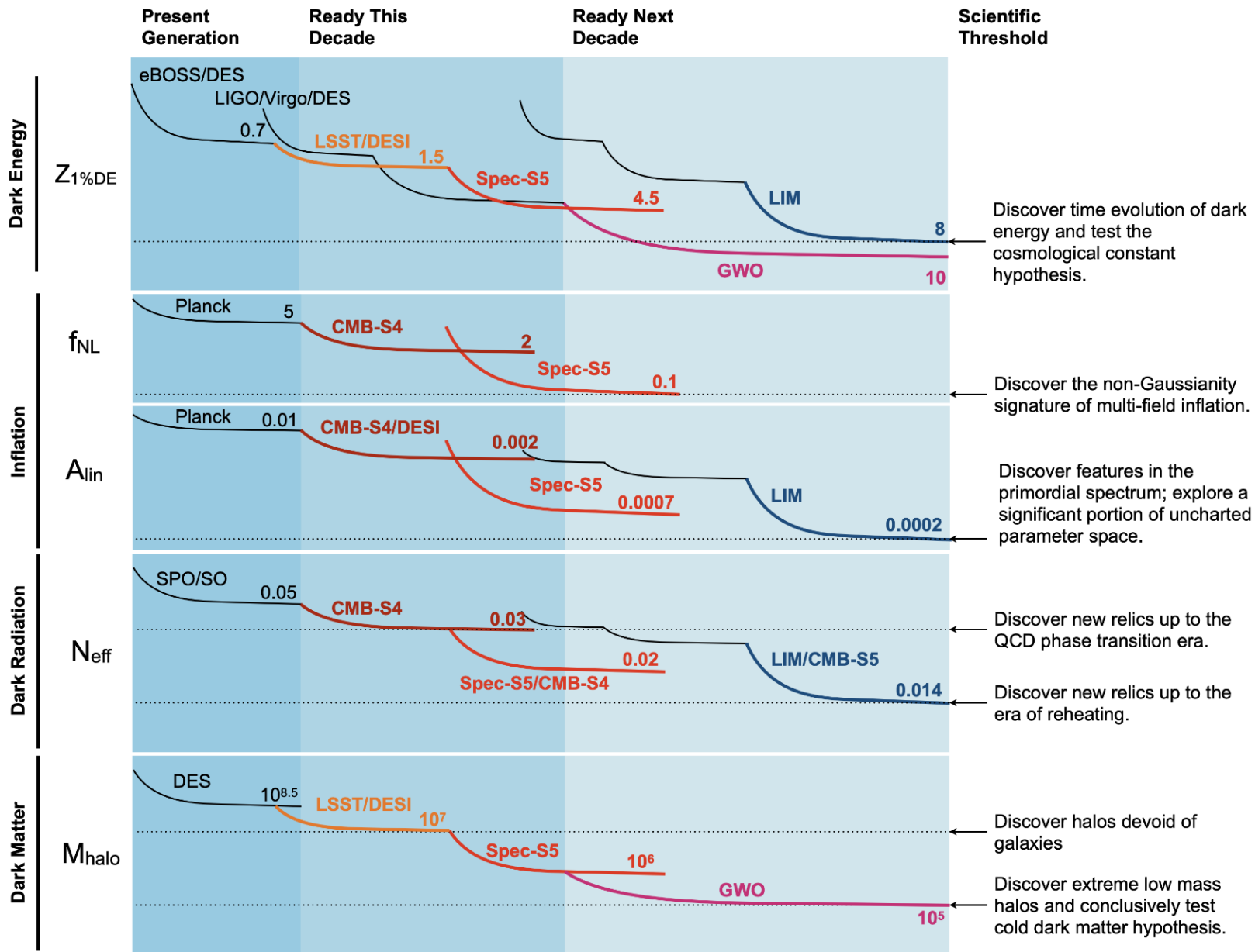
Together with a potential **DESI upgrade**, they will inform the design of a **next-generation spectroscopic survey** by telling us **which** potential **science goals** should be emphasized.

P5 2023 report



SPEC-S5

- 2 telescópios: Mayall + Blanco
- Upgrade dos espelhos de 4m para 6m
- Novos positioners que controlam 3 fibras cada = 26k fibras por telescópio
- Focos:
 - Altos redshifts para estudo da *Inflação e Energia Escura*
 - Alta densidade de objetos em $z < 2$
 - Via Láctea (50M espectros estelares), stellar streams, matéria escura



CONCLUSÕES

- A espectroscopia de galáxias entrou numa nova era com o DESI++
- Propõe um programa robusto e viável para as próximas décadas
- DESI já é o maior levantamento espectroscópico de galáxias existente
- Medidas de BAO do DESI Y1 têm tido forte impacto na comunidade
- DESI-2 vai pioneiramente explorar redshifts mais altos
- Spec-S5 trará contribuições para estudos do Universo primordial++

