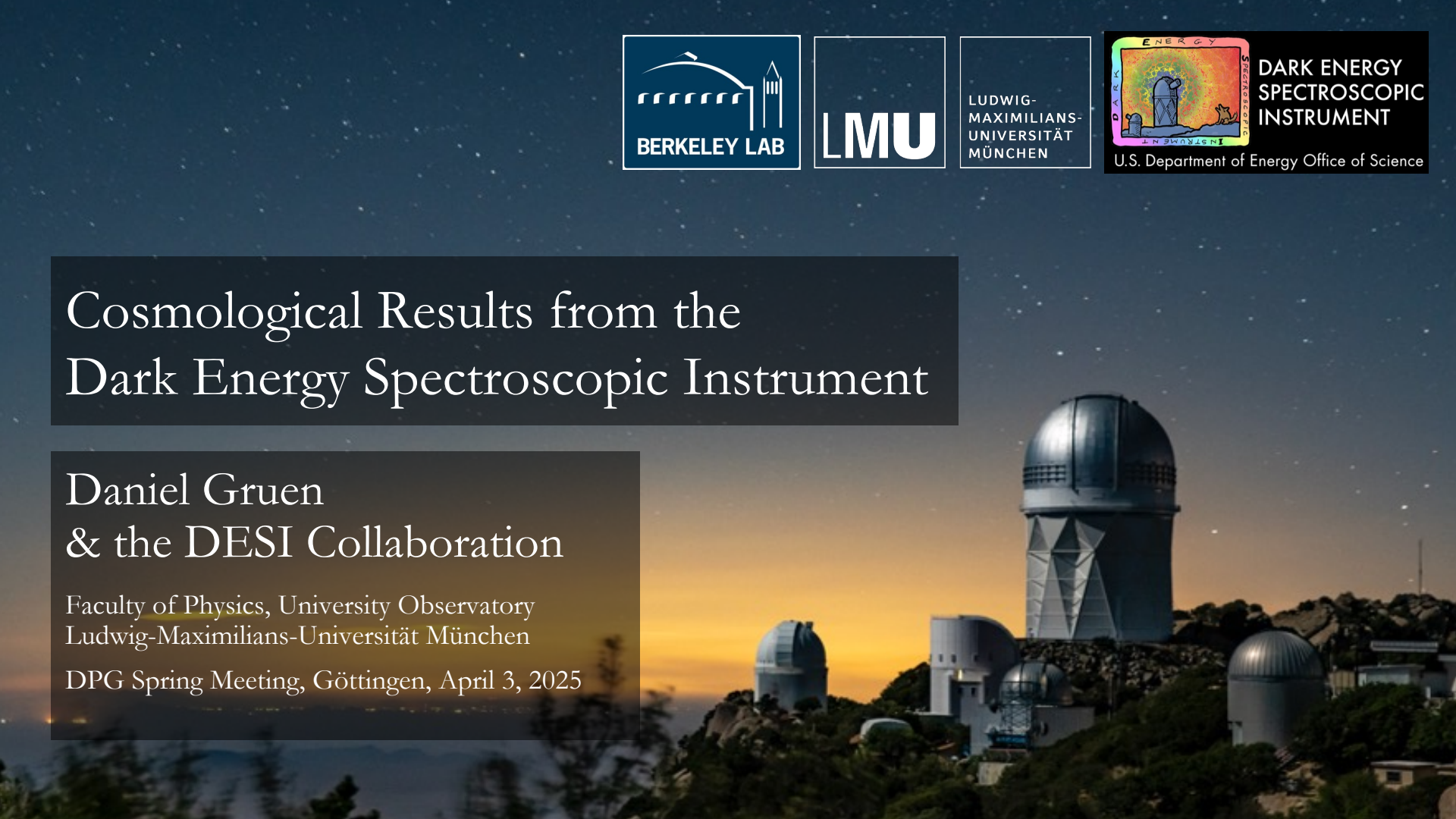


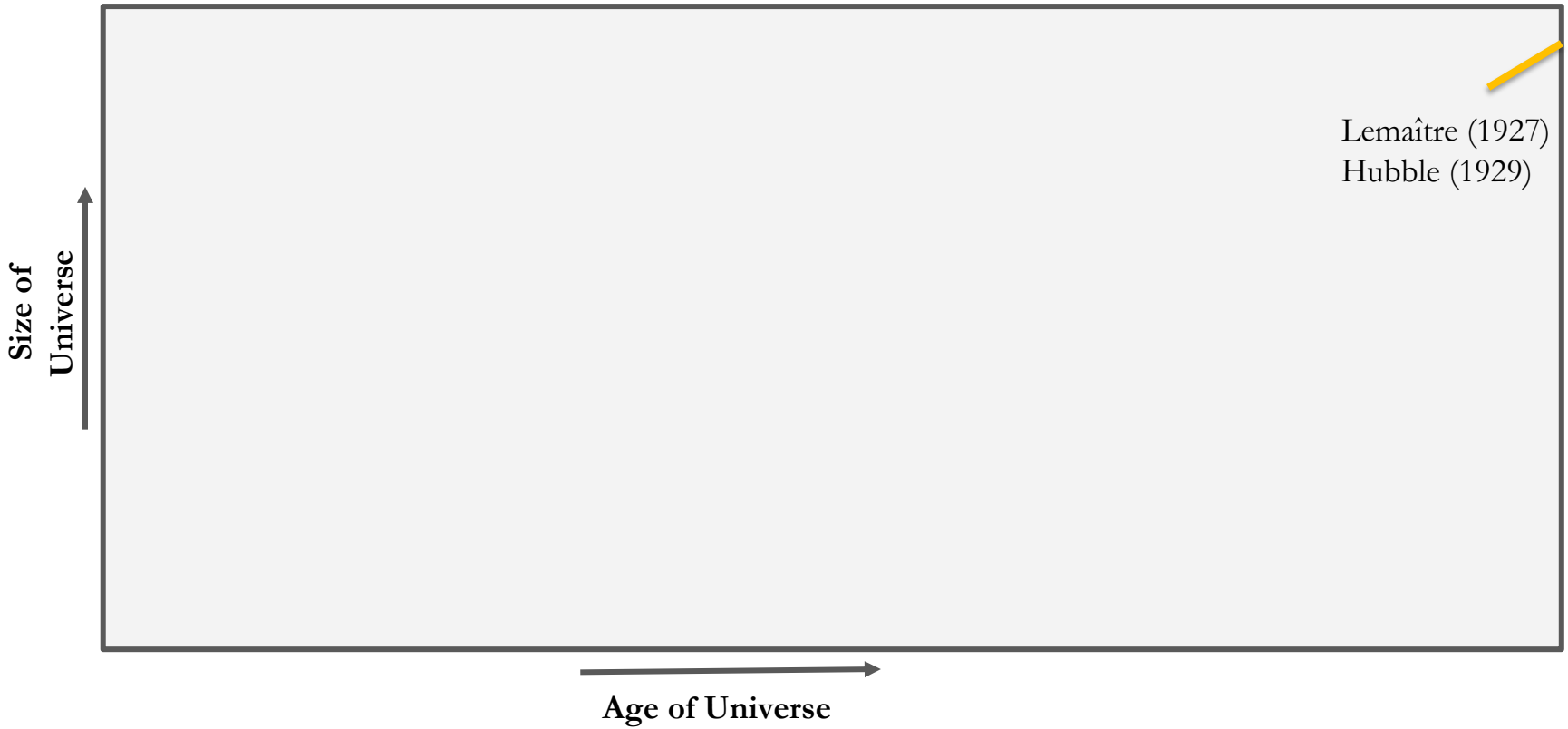
Cosmological Results from the Dark Energy Spectroscopic Instrument

Daniel Gruen
& the DESI Collaboration

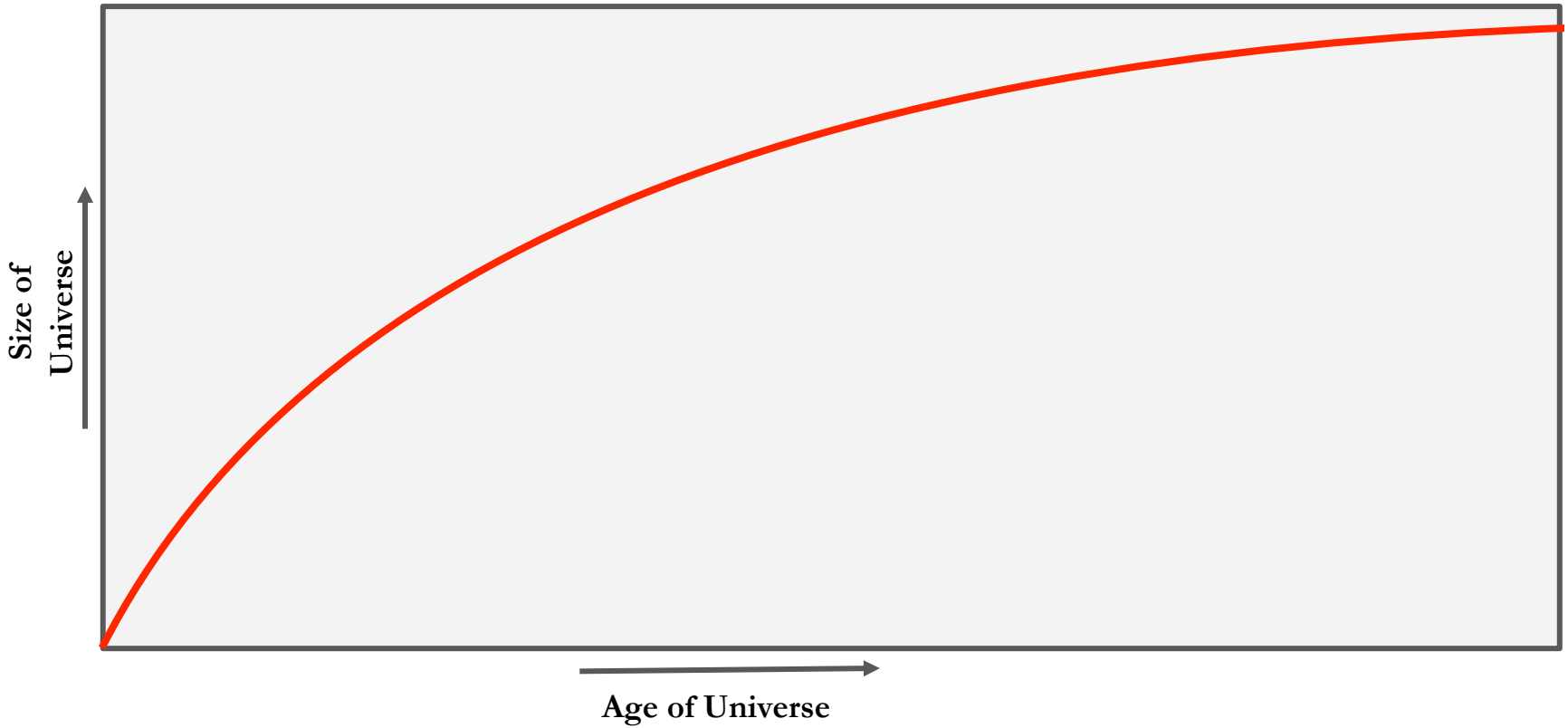
Faculty of Physics, University Observatory
Ludwig-Maximilians-Universität München

DPG Spring Meeting, Göttingen, April 3, 2025

The story of the Universe



The story of the Universe as told by its expansion history



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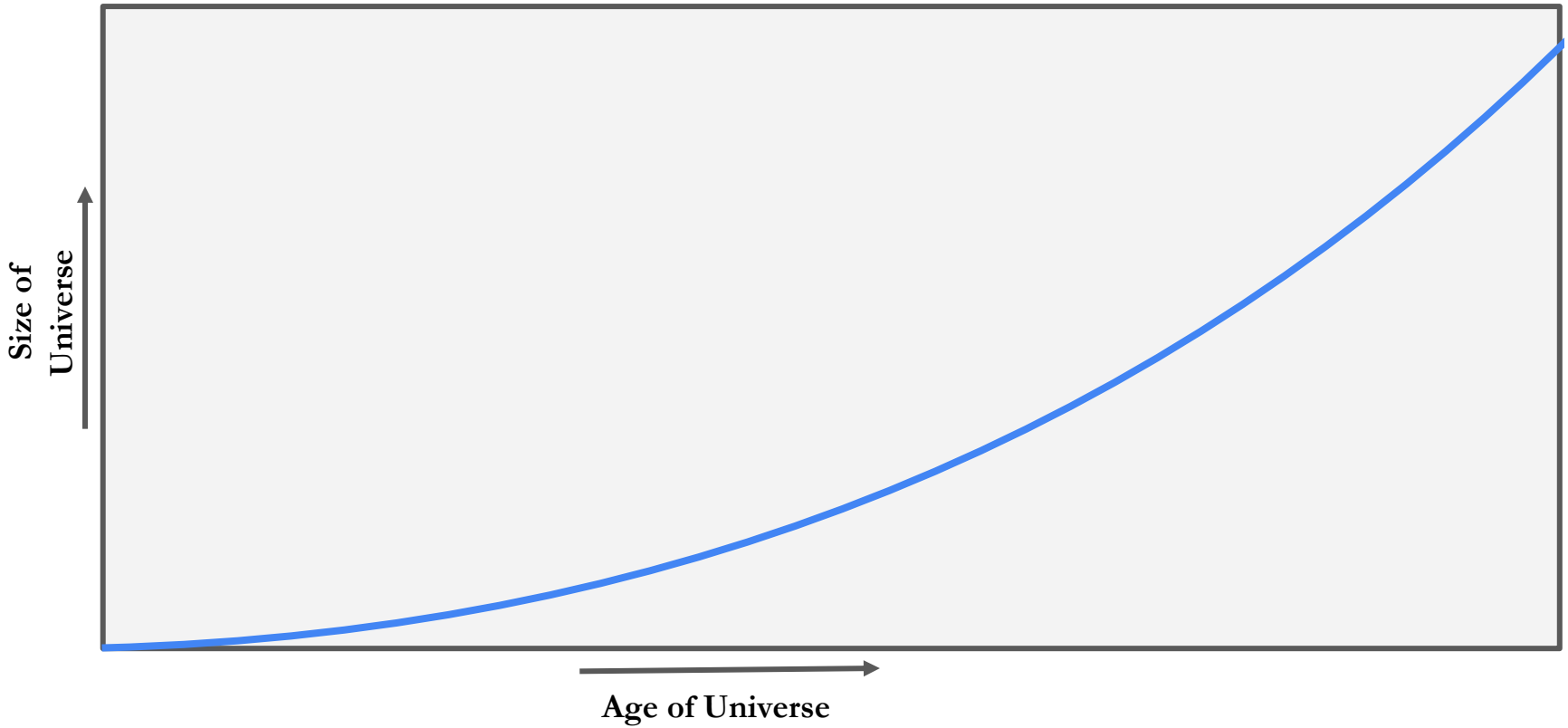

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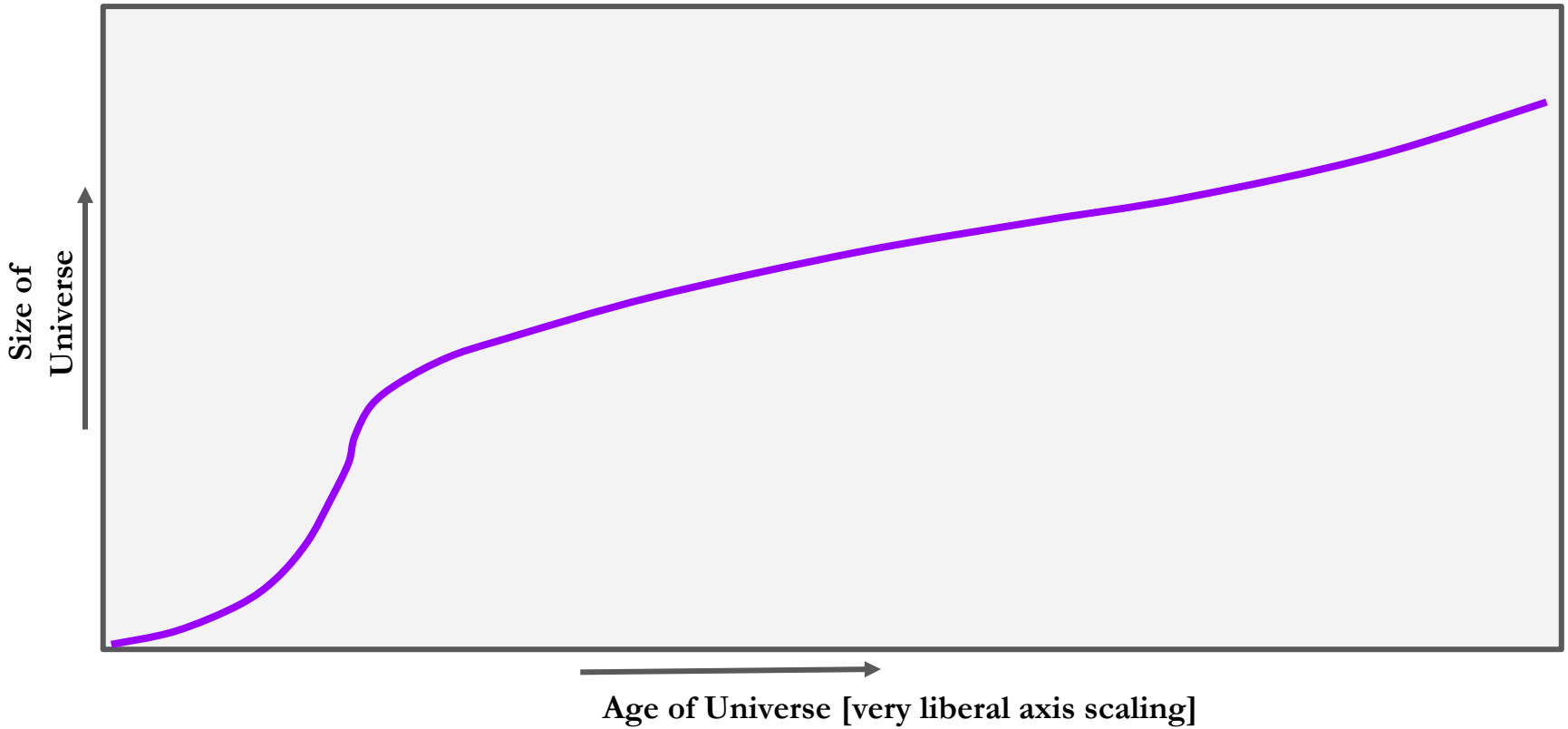
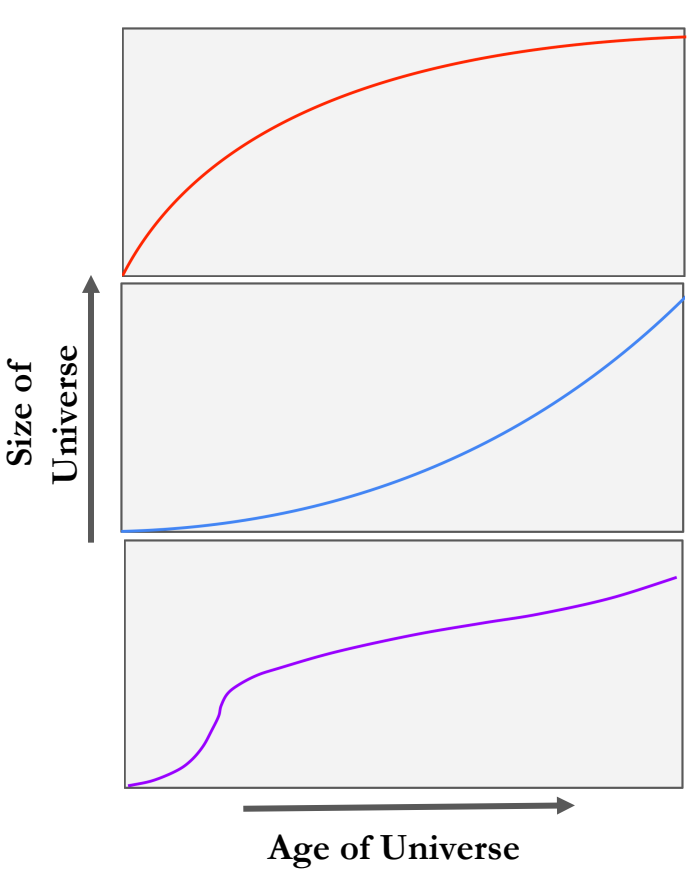


What does the size vs. age of the universe look like for ***our*** Universe?



vote

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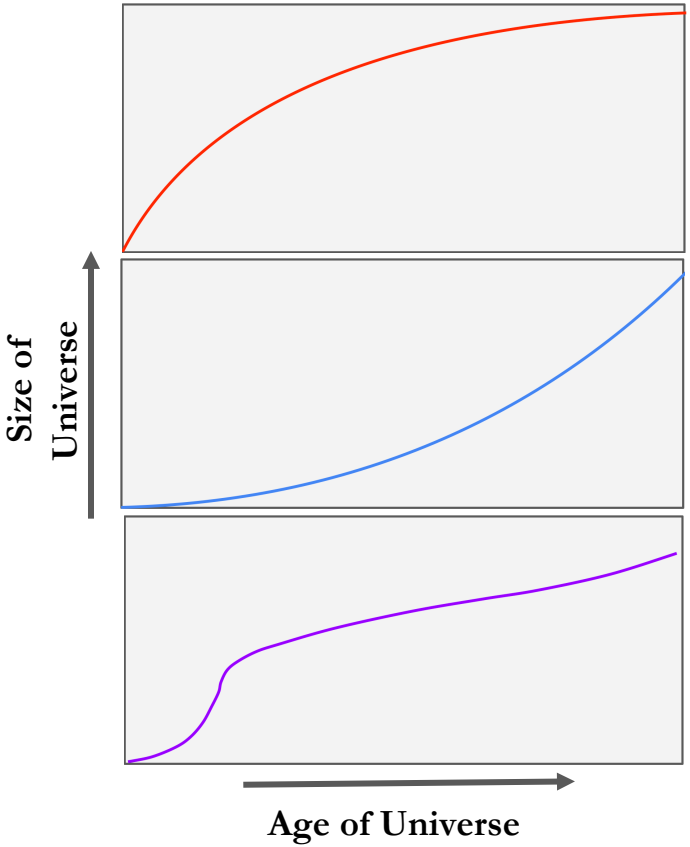
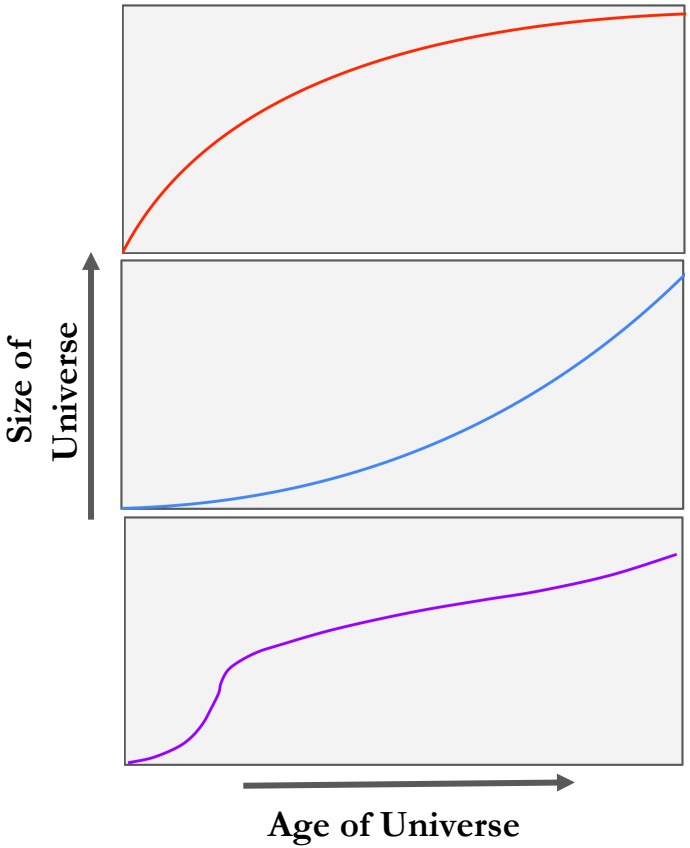


Behavior of a universe containing only matter (like a sphere under its own Newtonian gravity)

What does the size vs. age of the universe look like for ***our*** Universe?



Behavior of a universe containing only matter

Behavior of a universe containing only vacuum energy = cosmological constant

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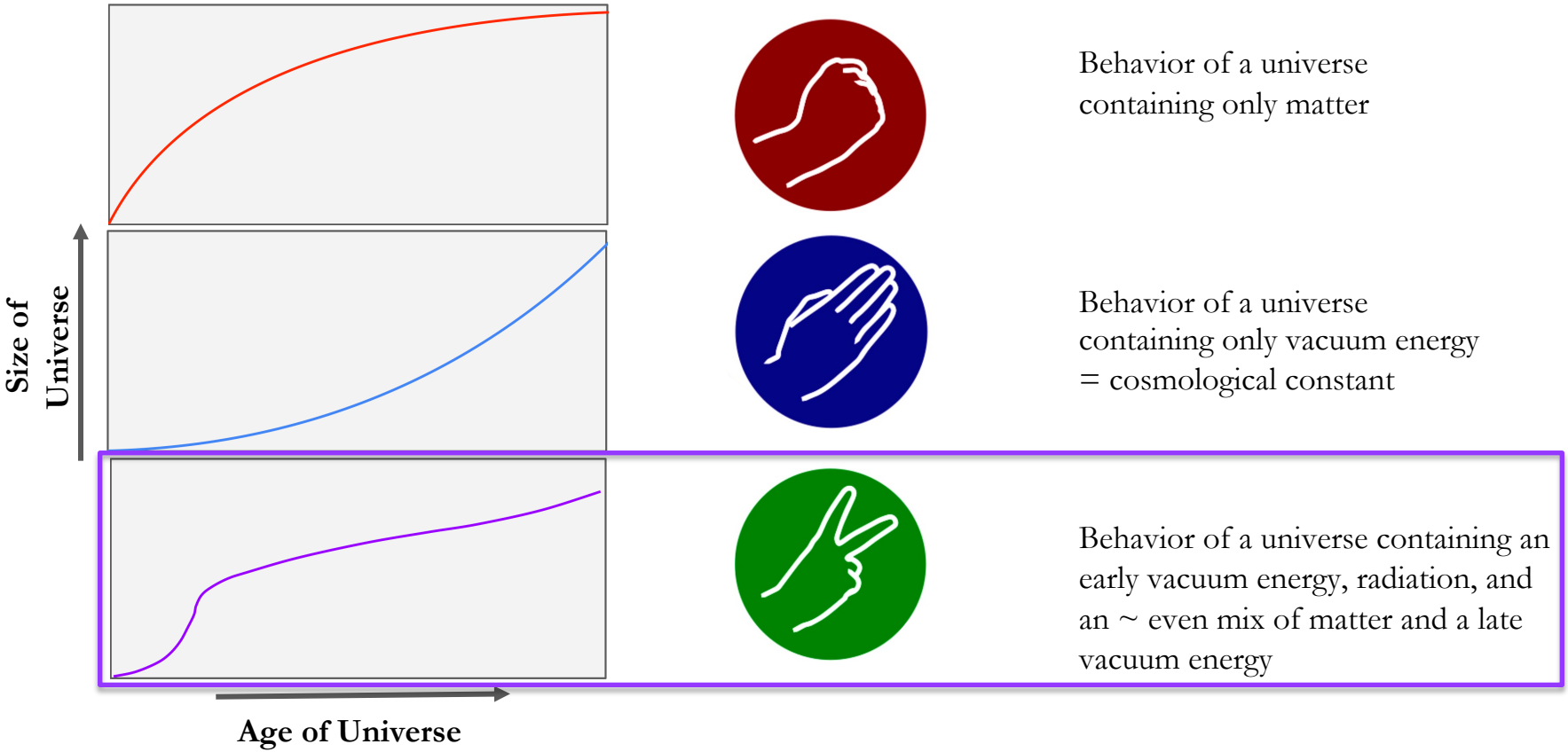
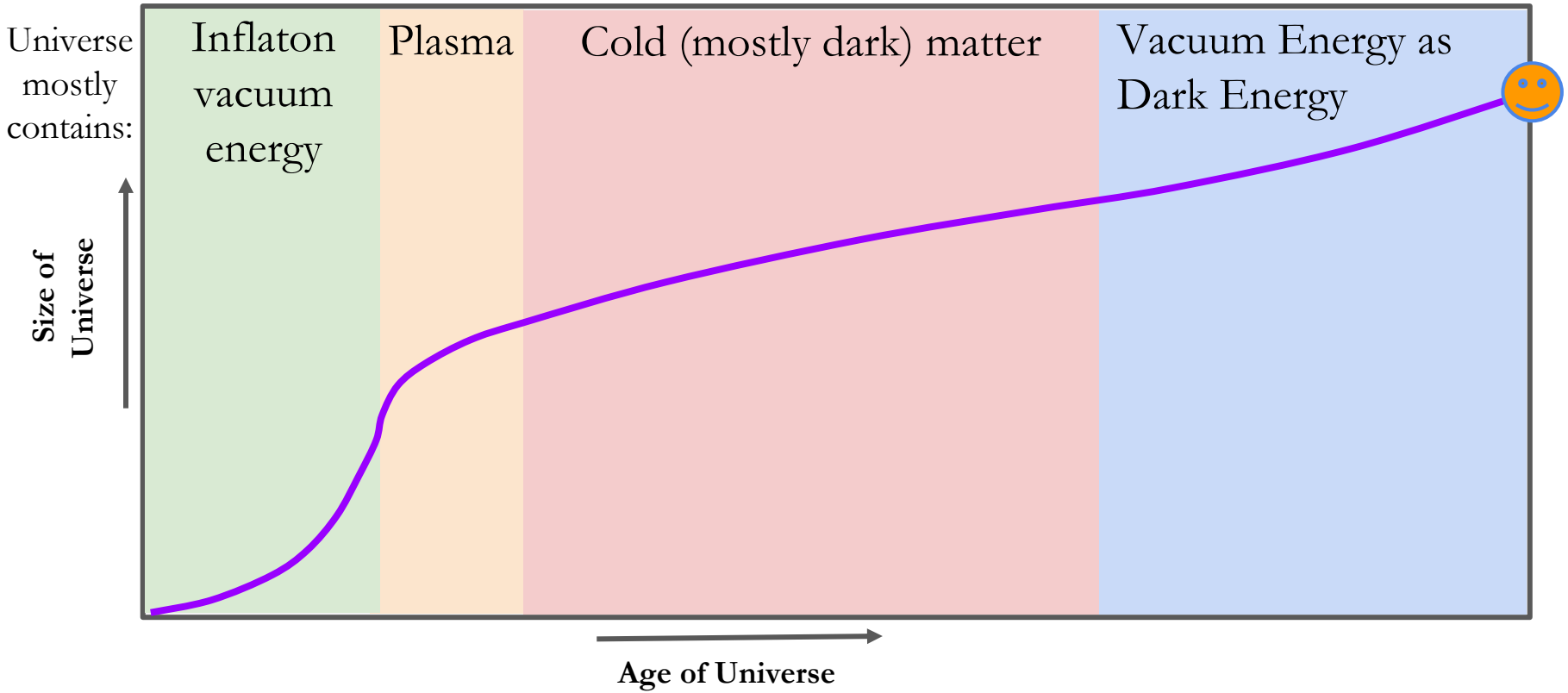


Behavior of a universe containing only matter

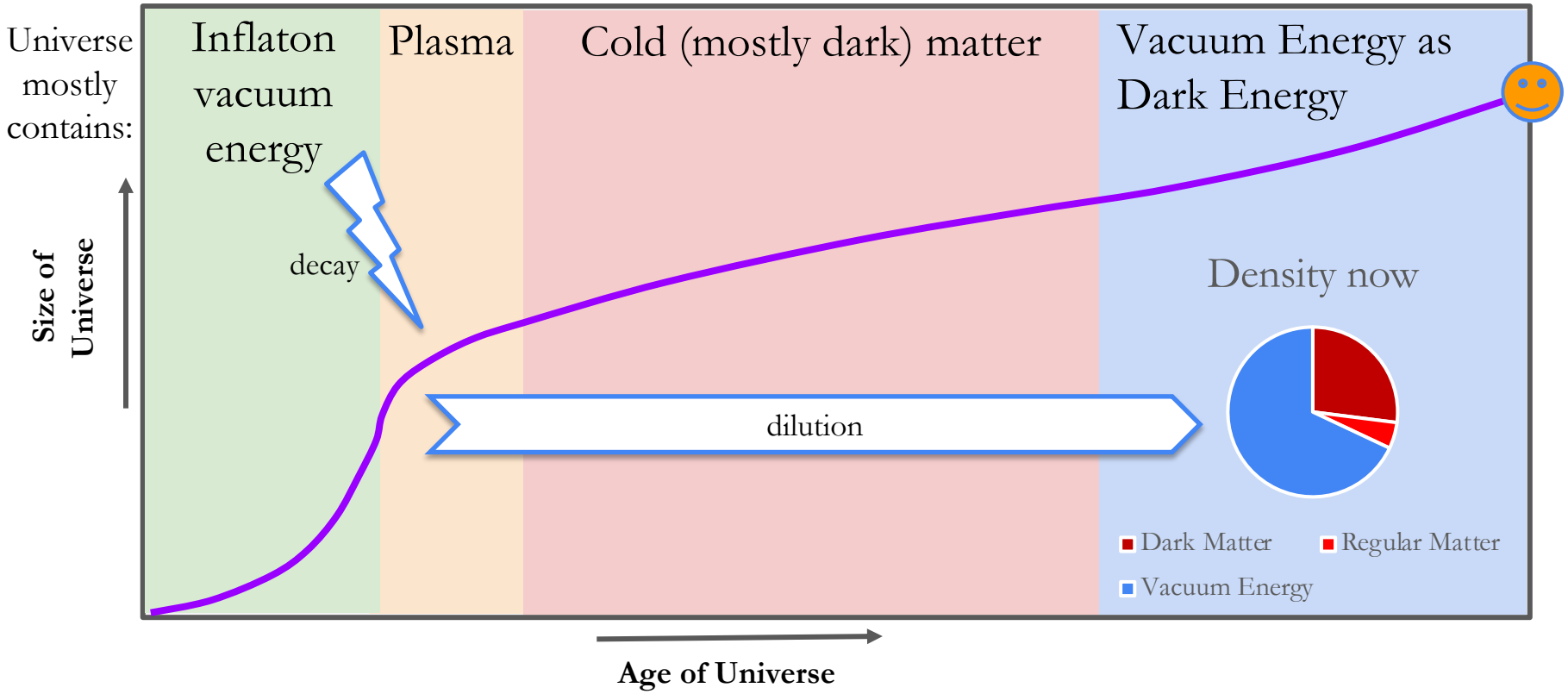
Behavior of a universe containing only vacuum energy = cosmological constant

Behavior of a universe containing an early vacuum energy, radiation, and an ~ even mix of matter and a late vacuum energy

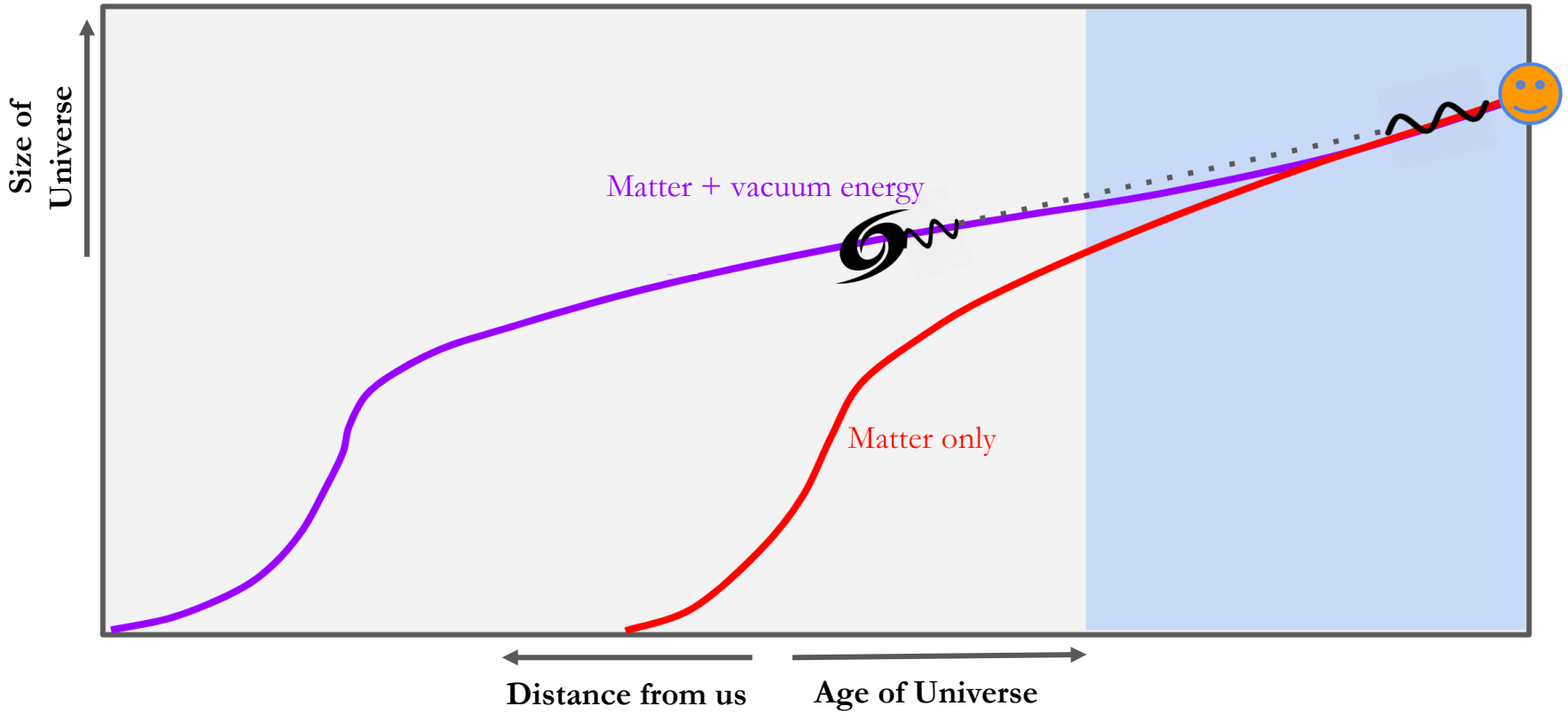
The story of the Universe as told by its expansion history



The story of the Universe as told by its expansion history



How do we know?
Connect distance to objects with size of universe when their light was emitted!



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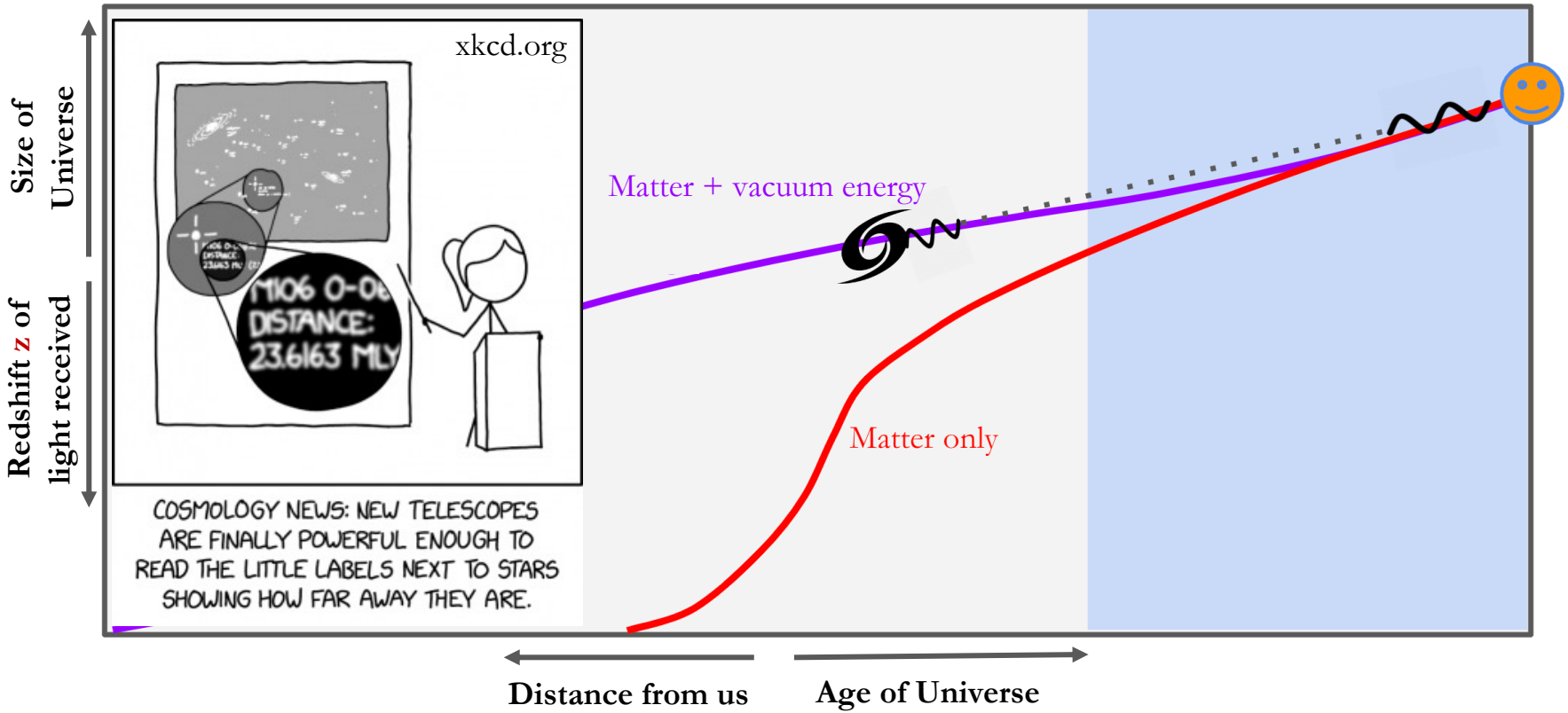
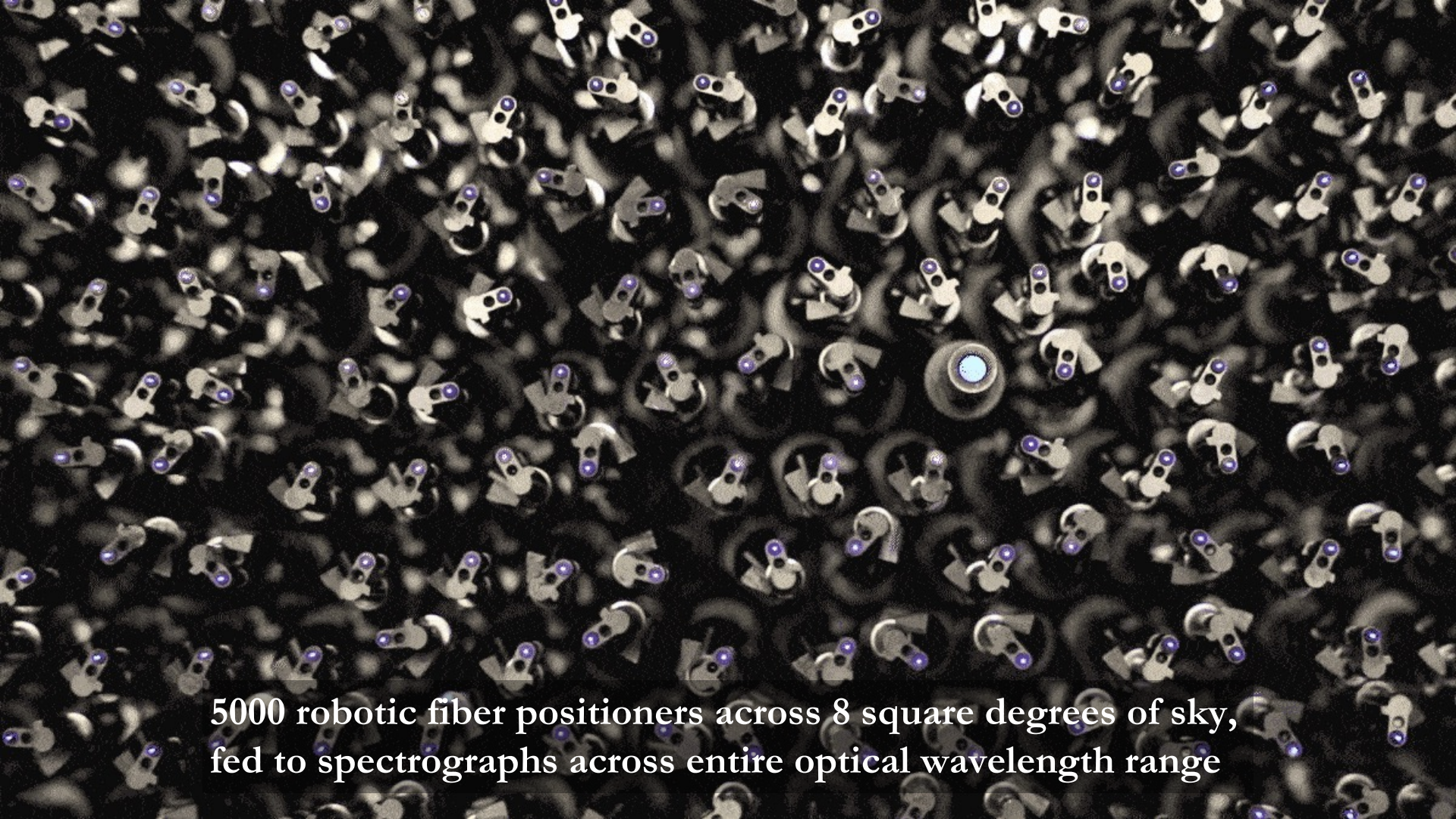




5000 robotic fiber positioners across 8 square degrees of sky,
fed to spectrographs across entire optical wavelength range

4m Mayall Telescope at Kitt Peak, Arizona

Daniel.Gruen@LMU.de

DARK ENERGY SPECTROSCOPIC INSTRUMENT

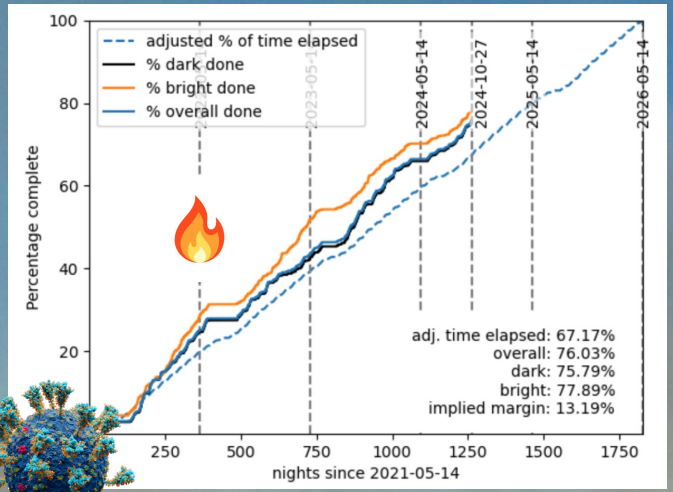
U.S. Department of Energy Office of Science

5-year survey started 2021
(with plans to extend)

1/3 of sky to be observed

40 million spectra obtained,
50 million expected in total

Thanks to our sponsors,
72 Participating Institutions,
and over 500 collaborators!



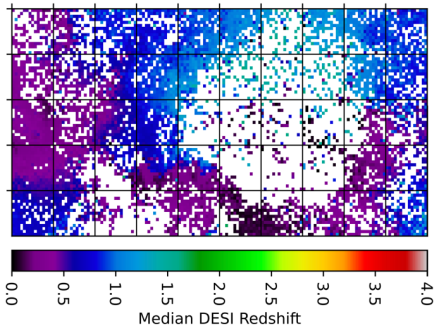
DESI is ahead of schedule despite adverse events

By far the most efficient galaxy spectrograph!

50 million spectra allow a variety of ground-breaking science

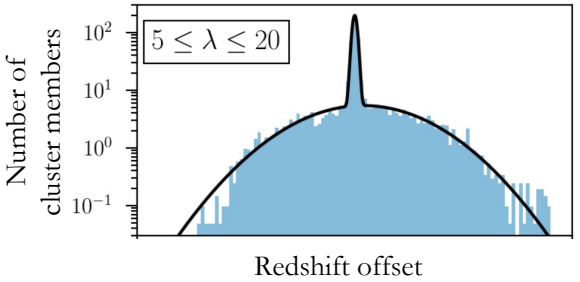
A selection of ongoing DESI research at LMU

Calibrate relation of apparent galaxy color to galaxy redshift



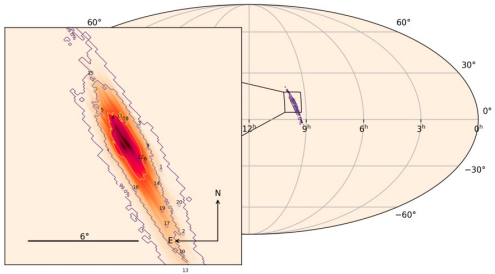
Gruen+ 2023
McCullough+ 2024
Tortorelli+ 2024
…

Understand selection effects in galaxy cluster samples



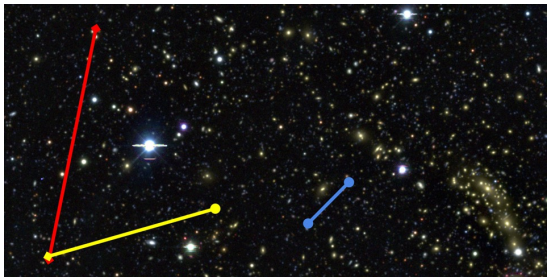
Myles+ 2021
Hsu+ under review
Myles+ under review
Hsu+ in preparation
…

Find galaxies hosting gravitational wave events

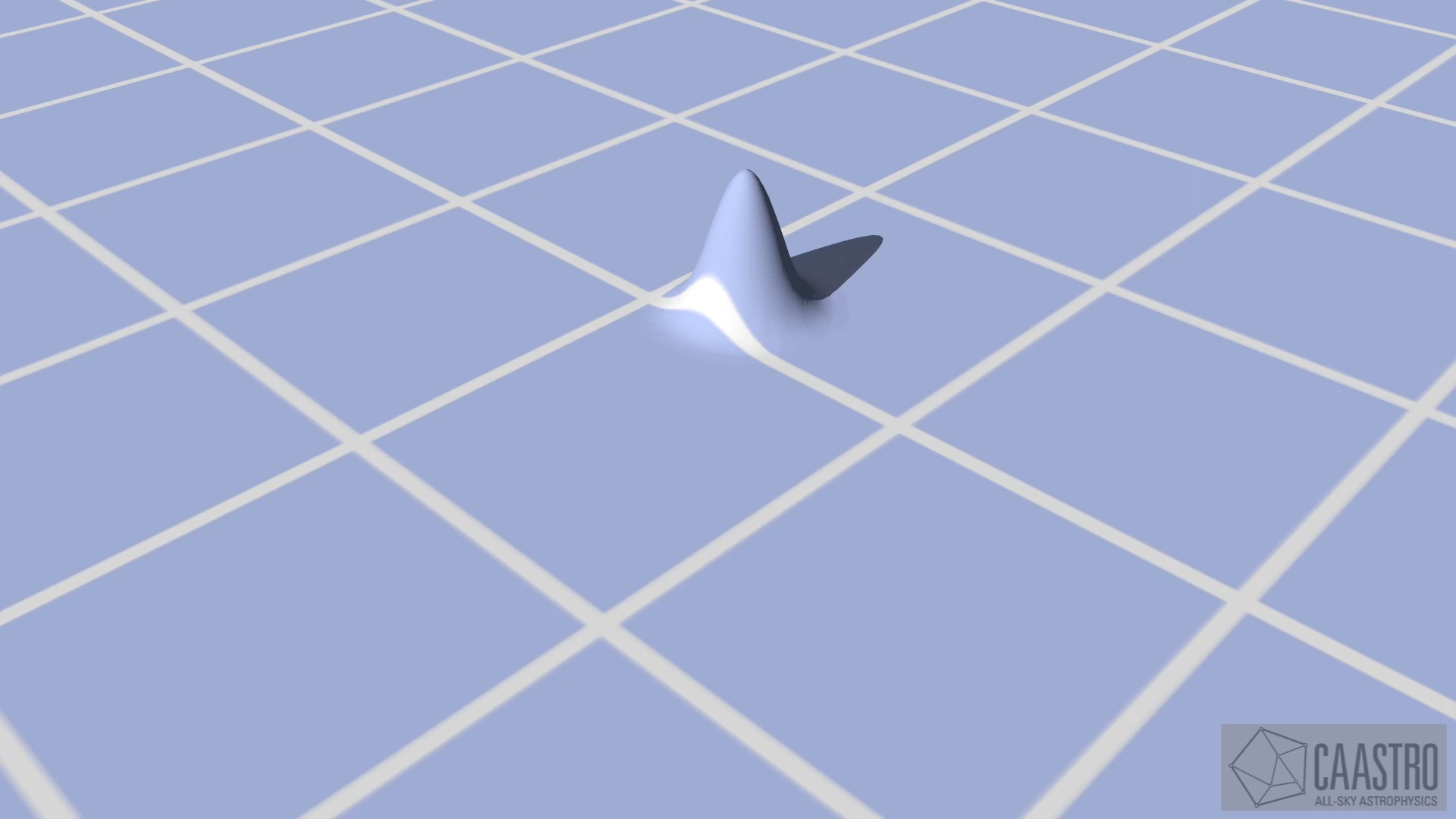


Sommer+ in preparation
…

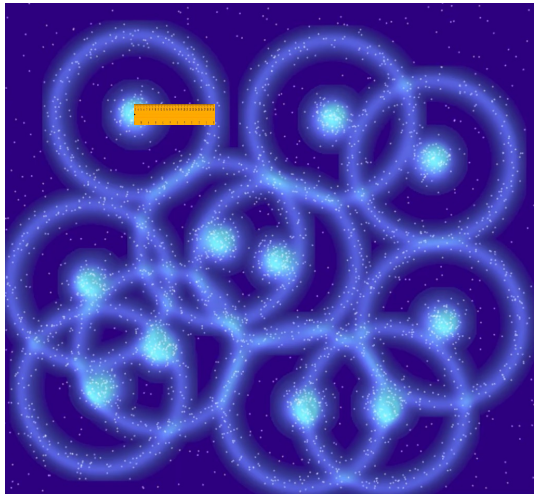
See cosmic structure grow with gravitational lensing



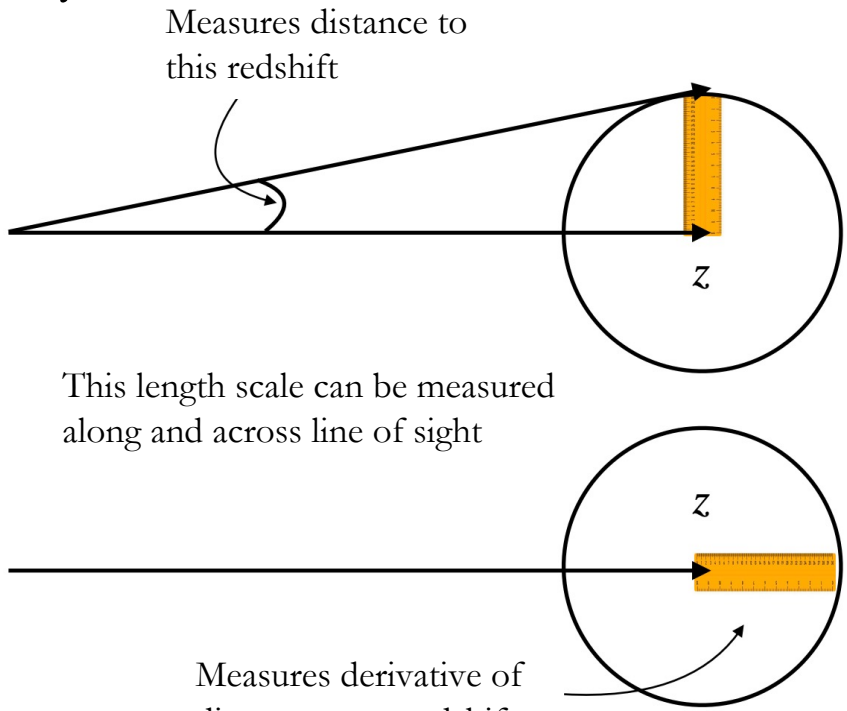
Homer+ 2025
Zhang+ in preparation
…


CAASTRO
ALL-SKY ASTROPHYSICS

How DESI measures expansion history

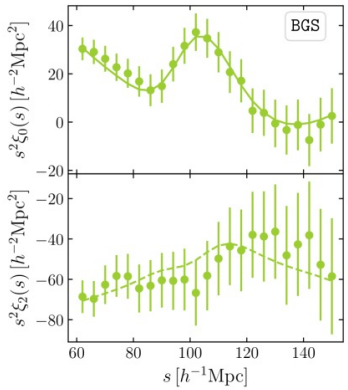


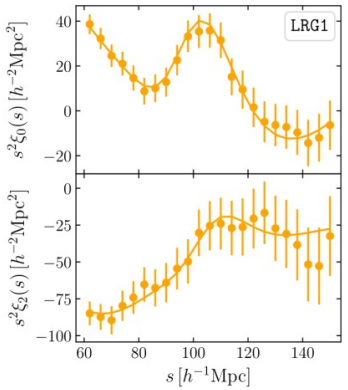
DESI measures excess number of galaxy pairs separated by Baryon Acoustic Oscillation scale

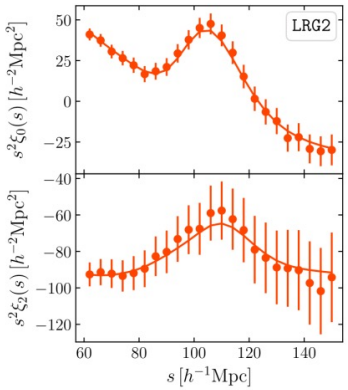


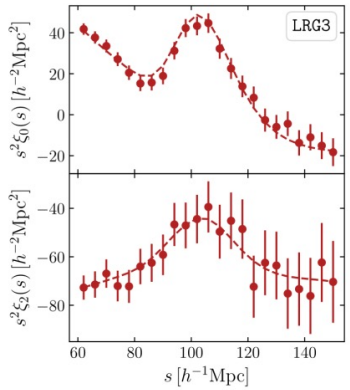
from Sesh Nadathur

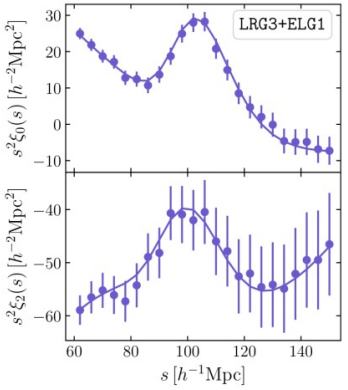
Measurements of ‘acoustic peak’ from 3 years of DESI data along and across line of sight

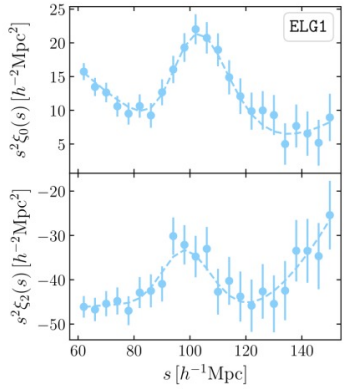


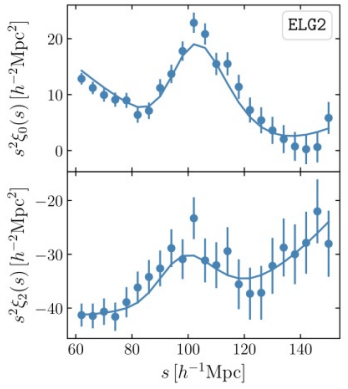


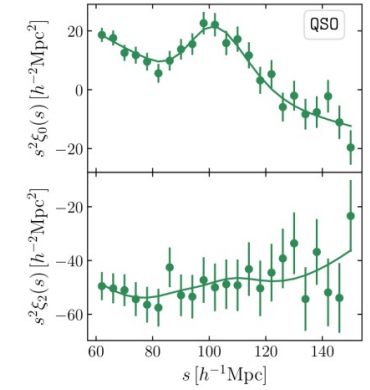


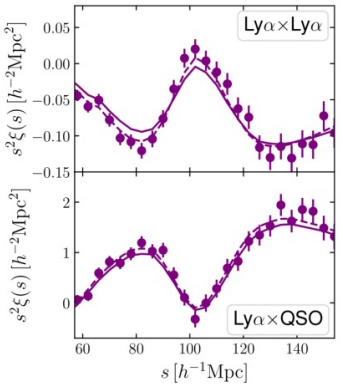




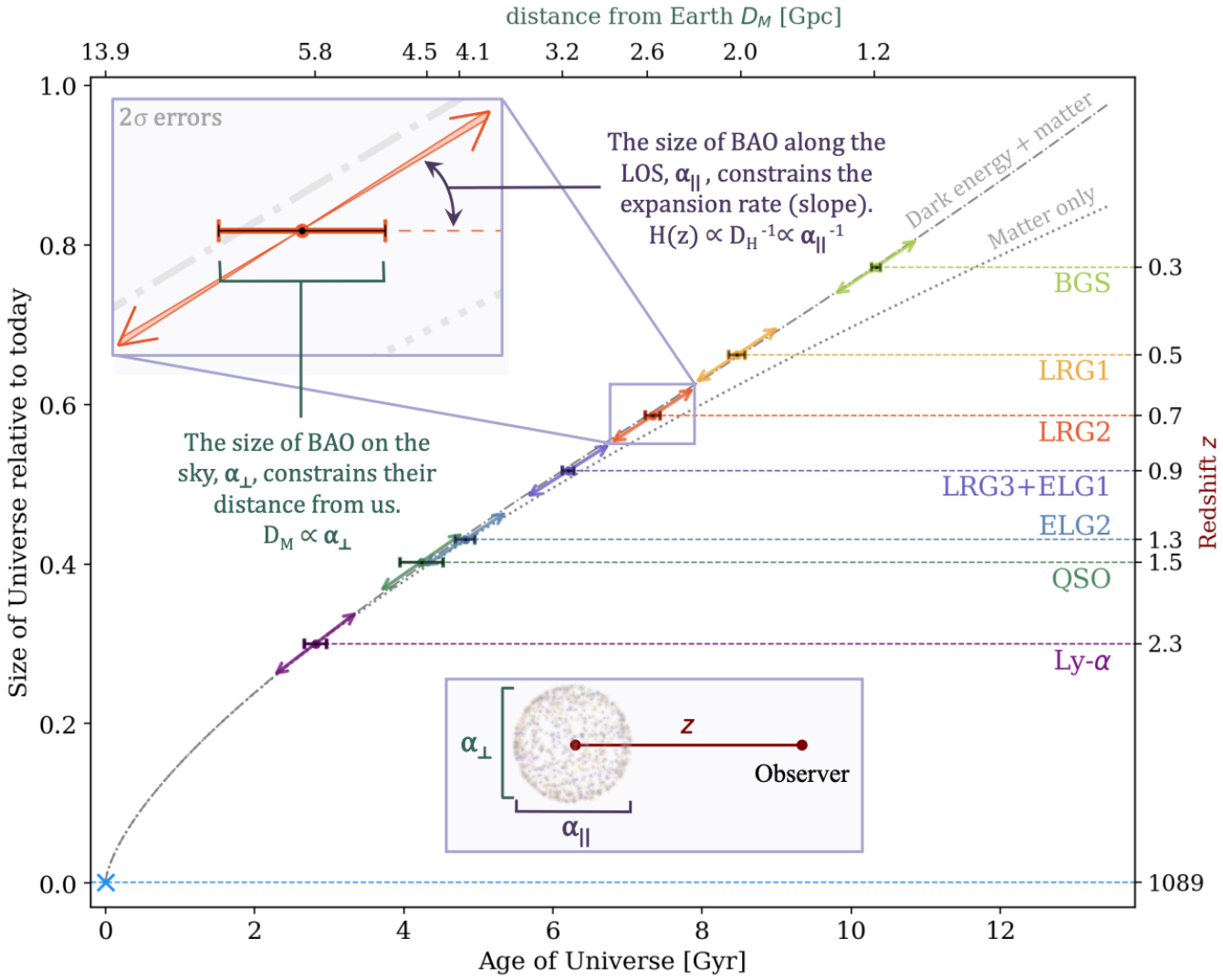






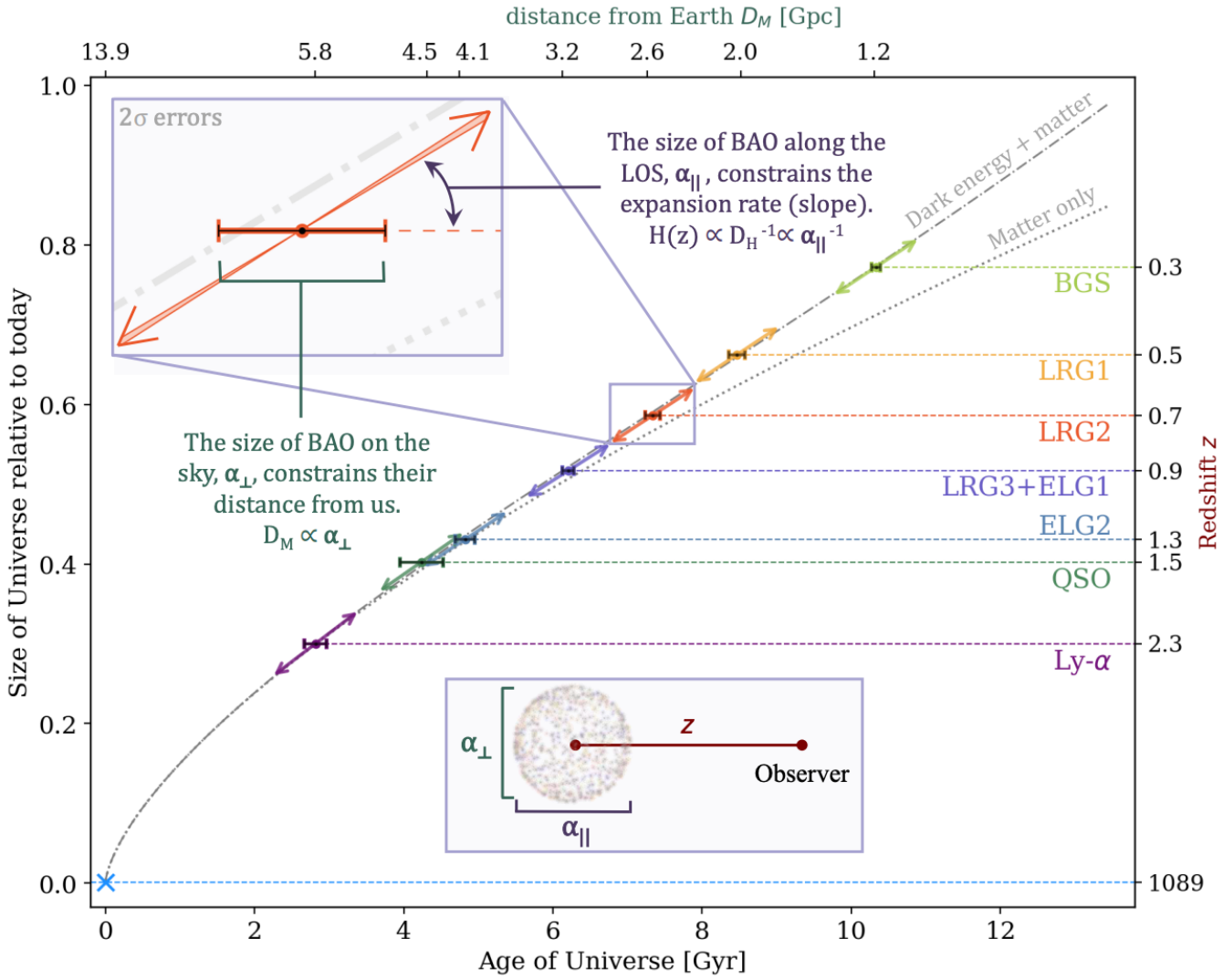


DESI 2025
arXiv:2503.14738



DESI measures expansion of the Universe over the past 10 Gyr

DESI 2025
arXiv:2503.14738



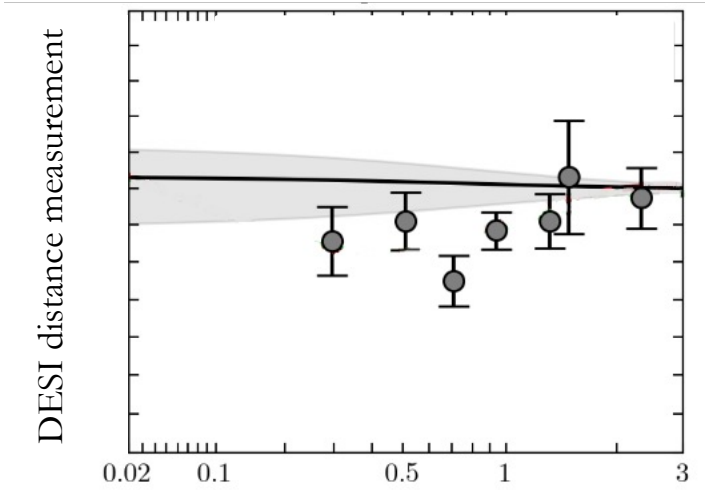
DESI measures expansion of the Universe over the past 10 Gyr

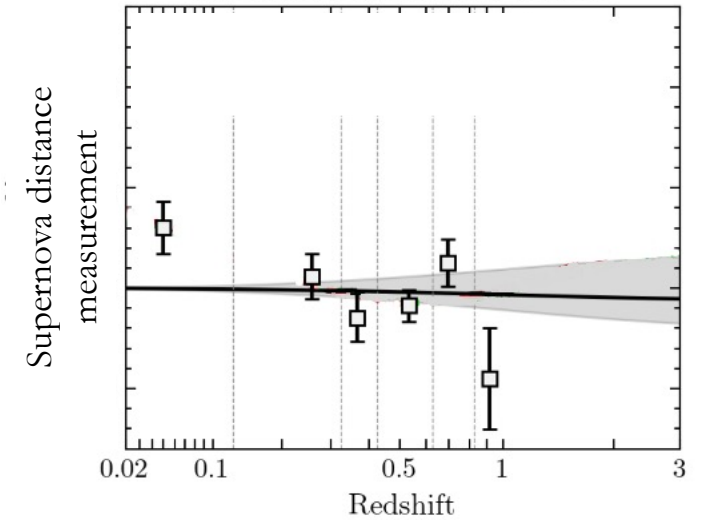
Supernova 'standard candles' measure expansion in recent times

Cosmic Microwave Background sees t=0 'standard ruler'

Do these all fit the same density of matter + vacuum energy?

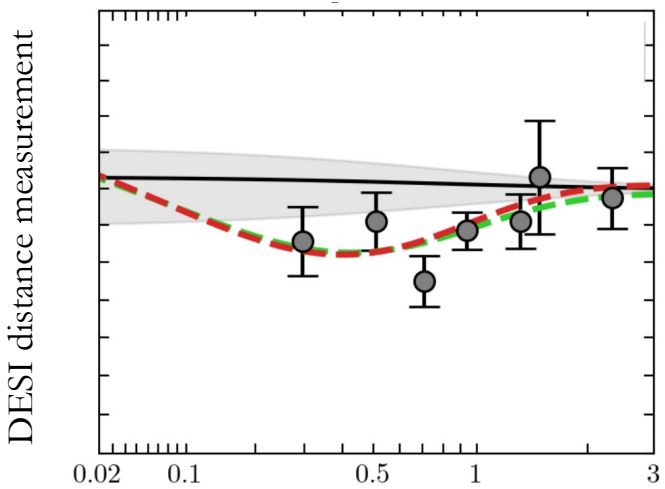
DESI 2025
arXiv:2503.14738

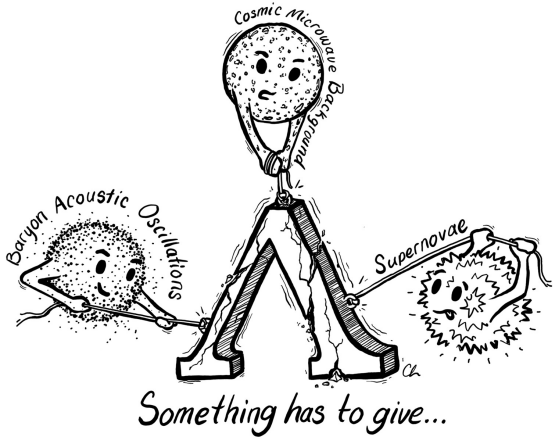


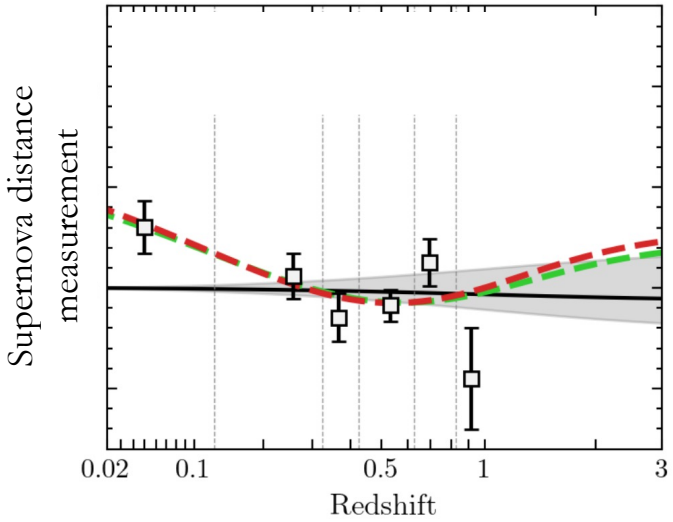


In a model with dark energy = vacuum energy density, DESI and Supernovae are pulling the Cosmic Microwave Background constraint in opposite directions.

Credit: Enrique Paillas / Claire Lamman / DESI 2025, arXiv:2503.14738







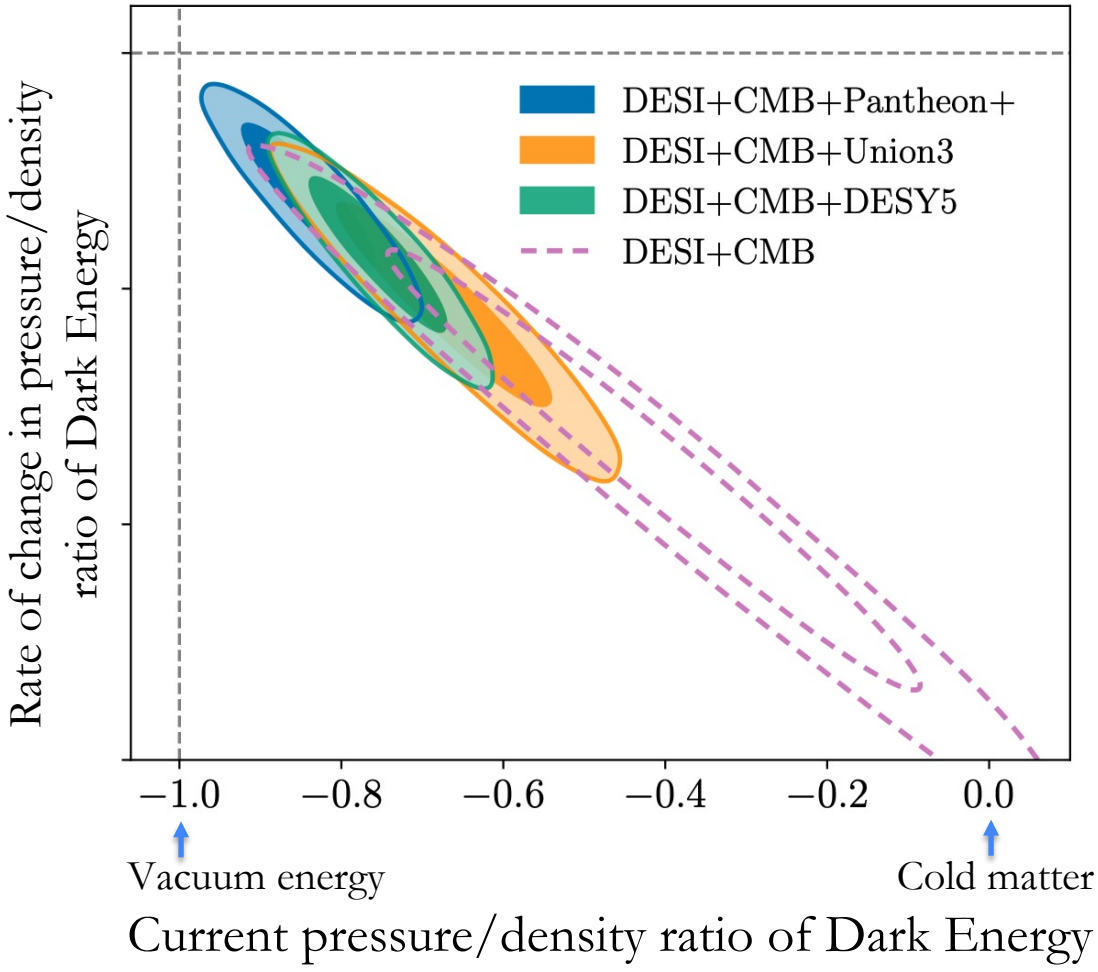
In a model with dark energy = vacuum energy density, DESI and Supernovae are pulling the Cosmic Microwave Background constraint in opposite directions.

The joint fit improves if dark energy is in the process of becoming more like matter

Credit: Enrique Paillas / Claire Lamman / DESI 2025, arXiv:2503.14738

Evolving Dark Energy?

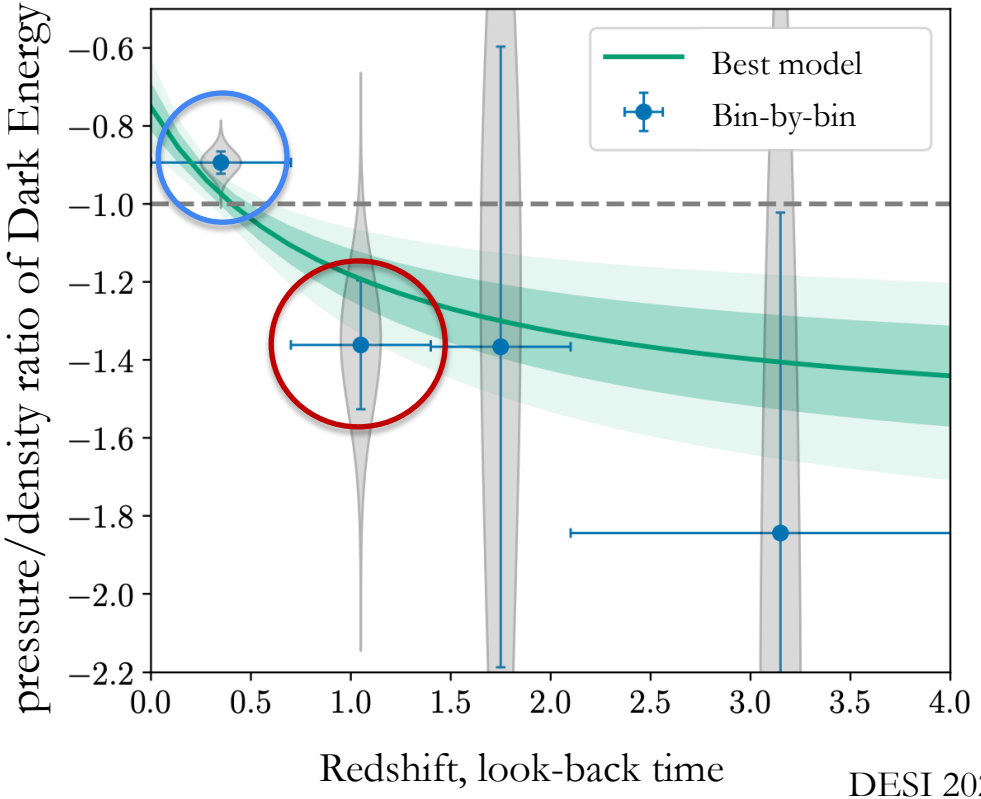
- DESI + Cosmic Microwave Background + Supernovae: 2.8 … 4.2σ evidence that Dark Energy is evolving
- Robust to removing individual data points from DESI, or to combinations with other data



DESI 2025
arXiv:2503.14738

Evolving Dark Energy?

- DESI + Cosmic Microwave Background + Supernovae: 2.8 … 4.2σ evidence that Dark Energy is evolving
- Robust to removing individual data points from DESI, or to combinations with other data
- Clear preference that dark energy is more matter-like now
- Preference for phantom dark energy (pressure/density<-1) earlier



DESI 2025
arXiv:2503.14738

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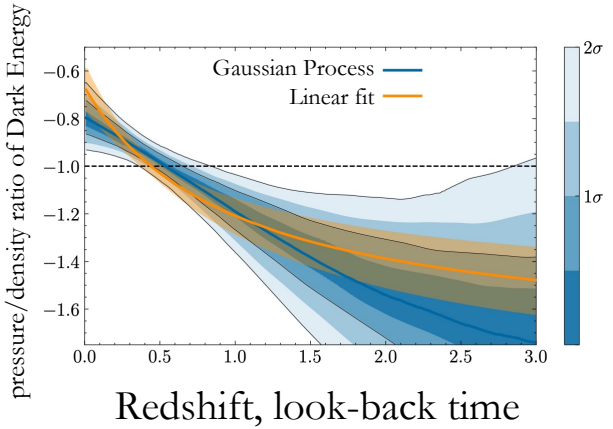
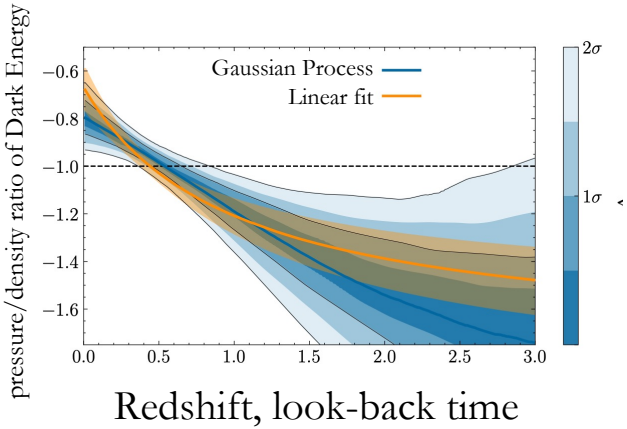
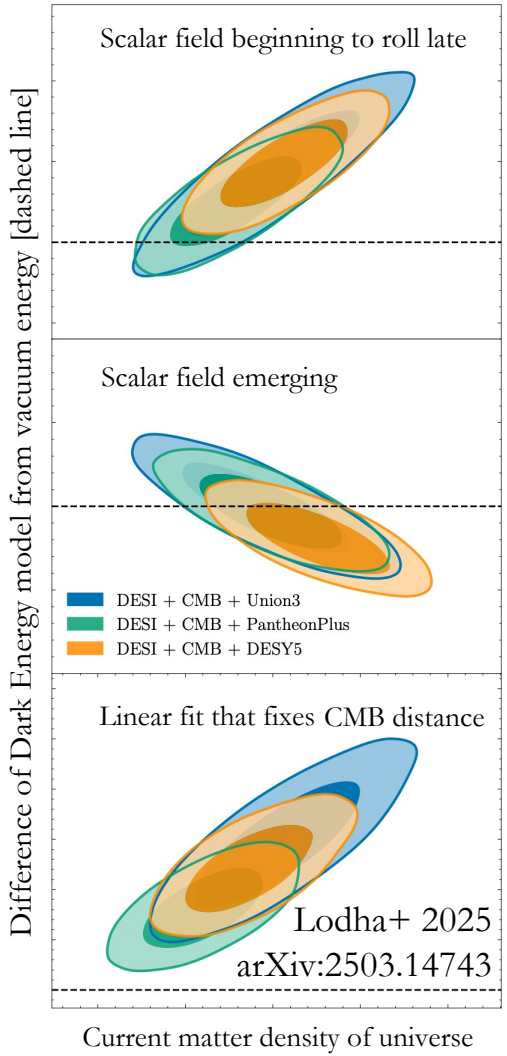


Evolving Dark Energy?

- DESI + Cosmic Microwave Background + Supernovae: 2.8 … 4.2σ evidence that Dark Energy is evolving
- Non-parametric fit still prefers evolution of Dark Energy, including phantom crossing
- Physically motivated models are not preferred w.r.t. linear fit or w.r.t. vacuum energy

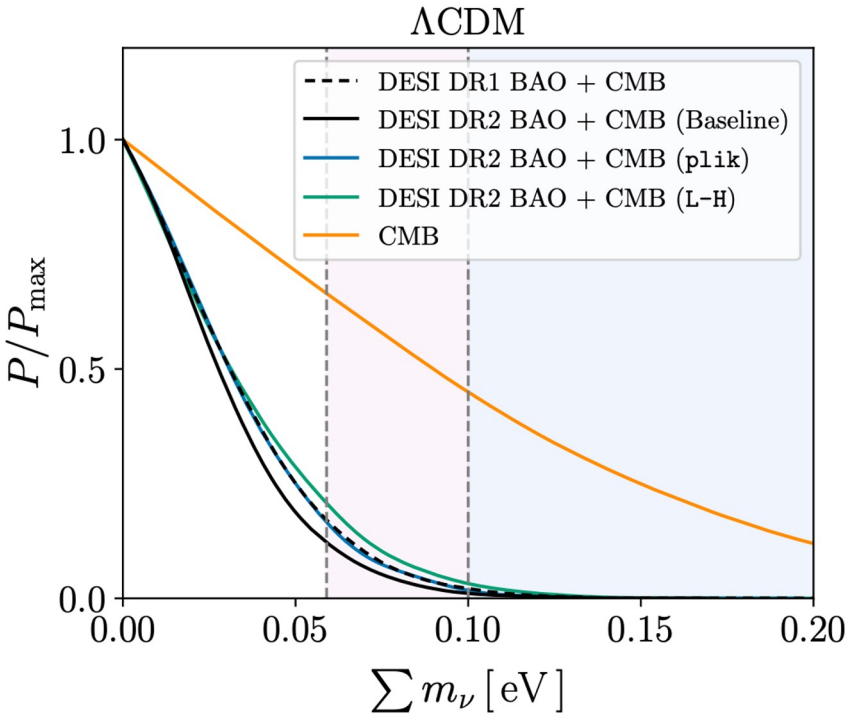




DESI, Neutrino Mass, and Dark Energy

- If we assume Dark Energy is a vacuum energy, DESI+CMB provide tight limit on neutrino mass – almost a tension – independent of CMB likelihood

$$\sum m_\nu < 0.0642\,\mathrm{eV} \quad (95\%)$$



Elbers+ 2025
arXiv:2503.14744

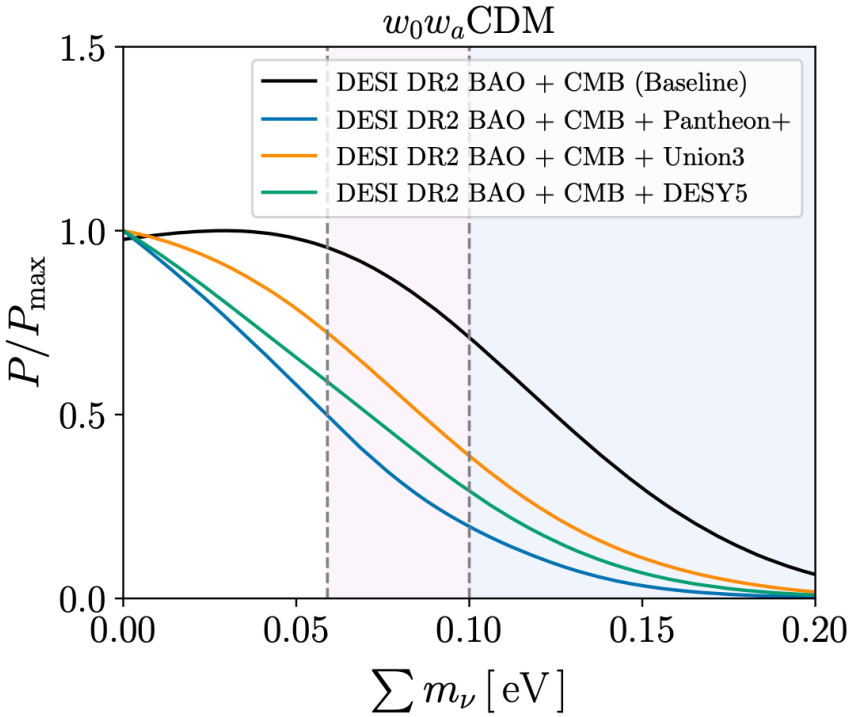
DESI, Neutrino Mass, and Dark Energy

- If we assume Dark Energy is a vacuum energy, DESI+CMB provide tight limit on neutrino mass – almost a tension – independent of CMB likelihood

$$\sum m_\nu < 0.0642\,\mathrm{eV} \quad (95\%)$$

- Evolving dark energy removes this tension – while neutrino mass barely affects the dark energy conclusions

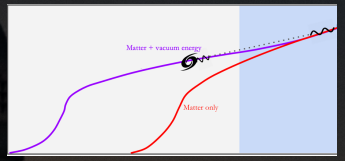
$$\sum m_\nu < 0.129\,\mathrm{eV}$$

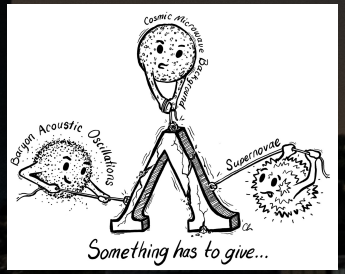


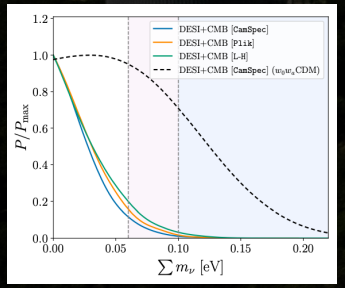
Elbers+ 2025
arXiv:2503.14744

Cosmology from DESI

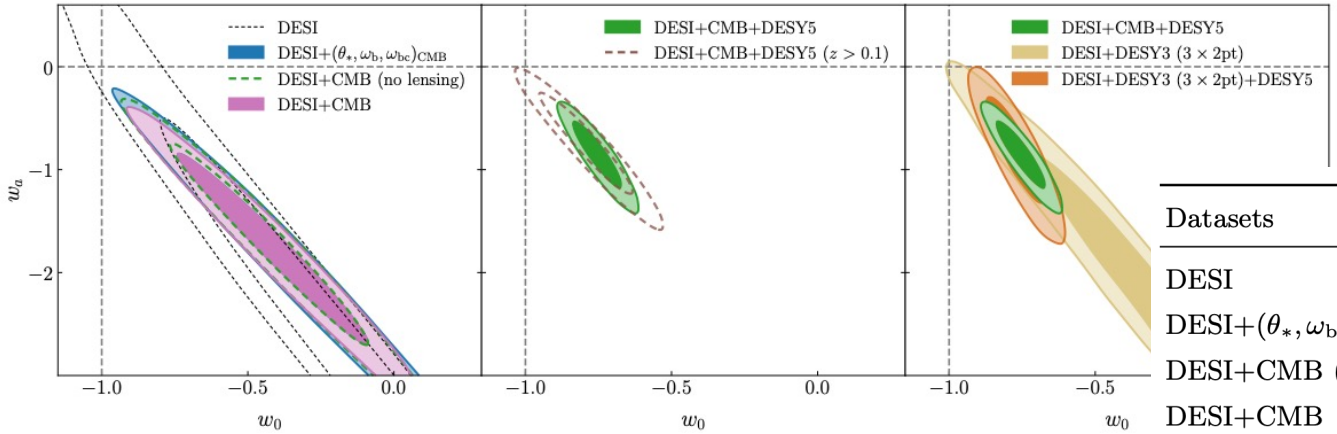
- Small signals in galaxy observations provide decisive tests of Dark Energy and neutrino mass
- Cosmic microwave background, Supernovae, and DESI each well fit by matter + vacuum energy – but tension in the parameters
- There is an up to 4.2σ challenge to vaccum energy from DESI++
- Neutrino mass limit is tight for vacuum energy – if neutrinos have non-minimal mass, cosmological tension increases
- Whether new fundamental physics or unknown systematics, tensions usually prompt intensive progress







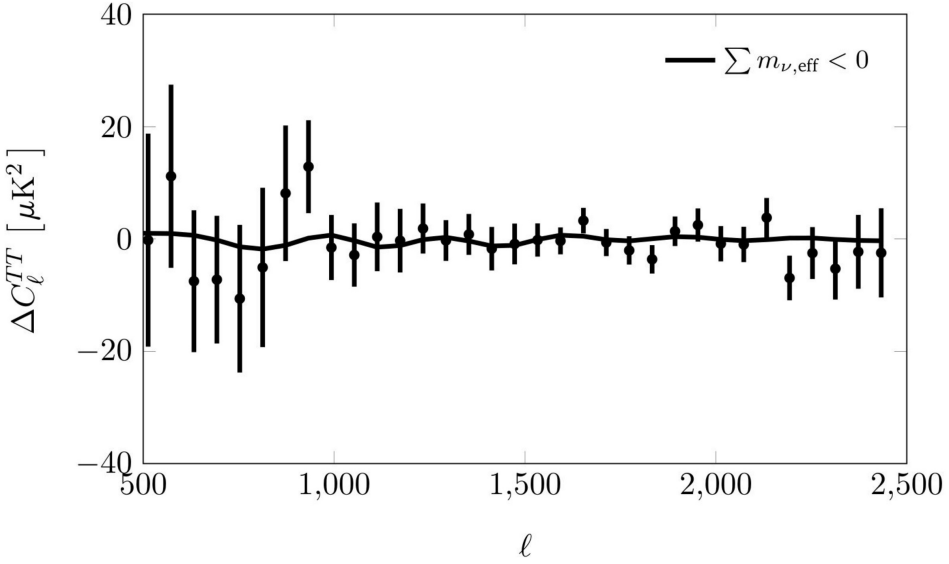
Combination of DESI with other data sets increase w(z) preference

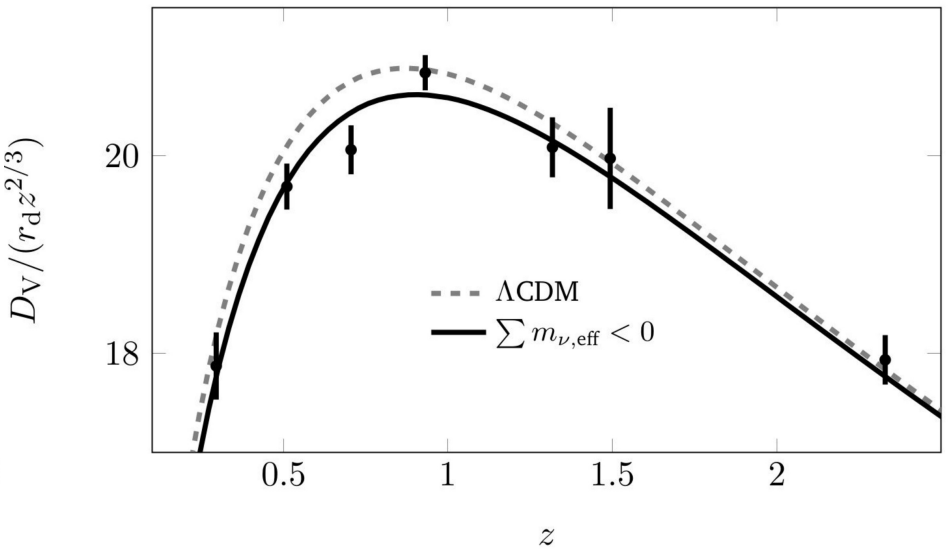


Datasets	$\Delta\chi^2_{MAP}$	Significance
DESI	−4.7	1.7σ
DESI+$(\theta_*, \omega_b, \omega_{bc})_{CMB}$	−8.0	2.4σ
DESI+CMB (no lensing)	−9.7	2.7σ
DESI+CMB	−12.5	3.1σ
DESI+Pantheon+	−4.9	1.7σ
DESI+Union3	−10.1	2.7σ
DESI+DESY5	−13.6	3.3σ
DESI+DESY3 (3×2pt)	−7.3	2.2σ
DESI+DESY3 (3×2pt)+DESY5	−13.8	3.3σ
DESI+CMB+Pantheon+	−10.7	2.8σ
DESI+CMB+Union3	−17.4	3.8σ
DESI+CMB+DESY5	−21.0	4.2σ

DESI results on neutrinos

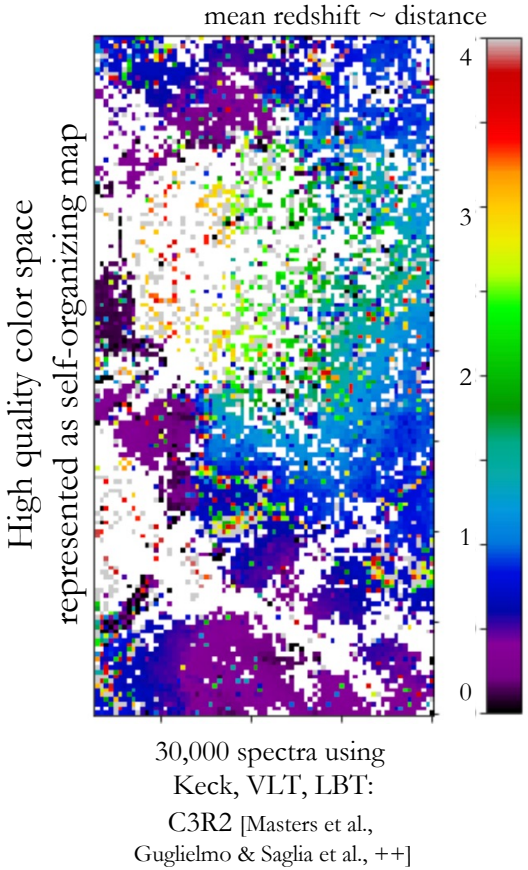
Willem Elbers





- Neutrino mass shifts scale of CMB acoustic peak and galaxy BAO distance-redshift relation

Accurate spectroscopic calibration of galaxy distances



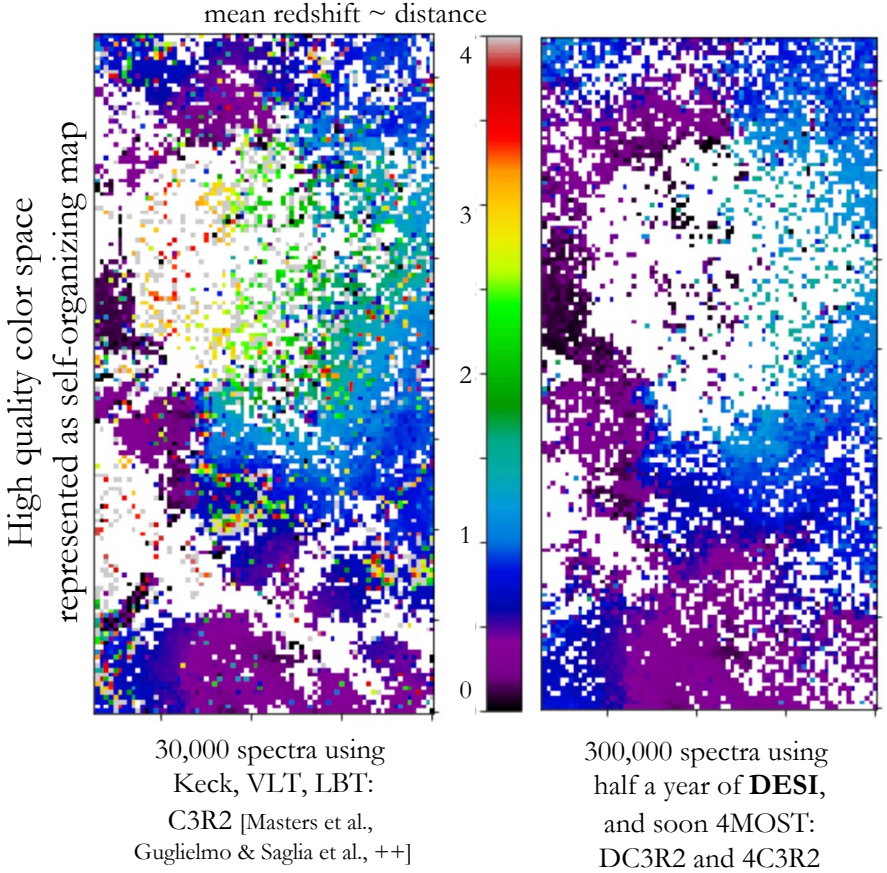
- distances needed for interpreting lensing signal
- wavelength of light stretched with expansion
- ➢ apparent color of galaxies is related to their distance from us: color-redshift relation.

Naively: need to measure redshifts with spectroscopy across "color space"

Limitations:

- previously small numbers of useable spectroscopy
- selection effects

Accurate spectroscopic calibration of galaxy distances



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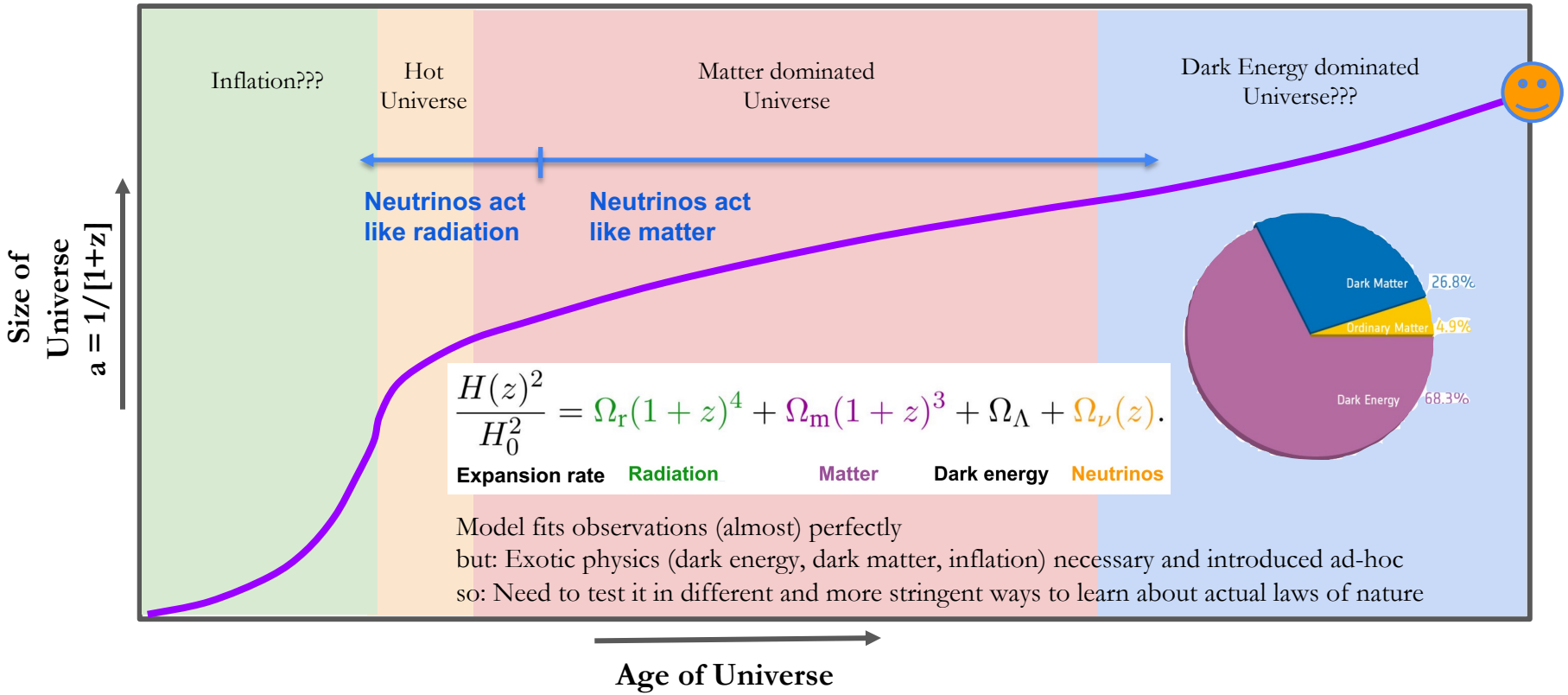
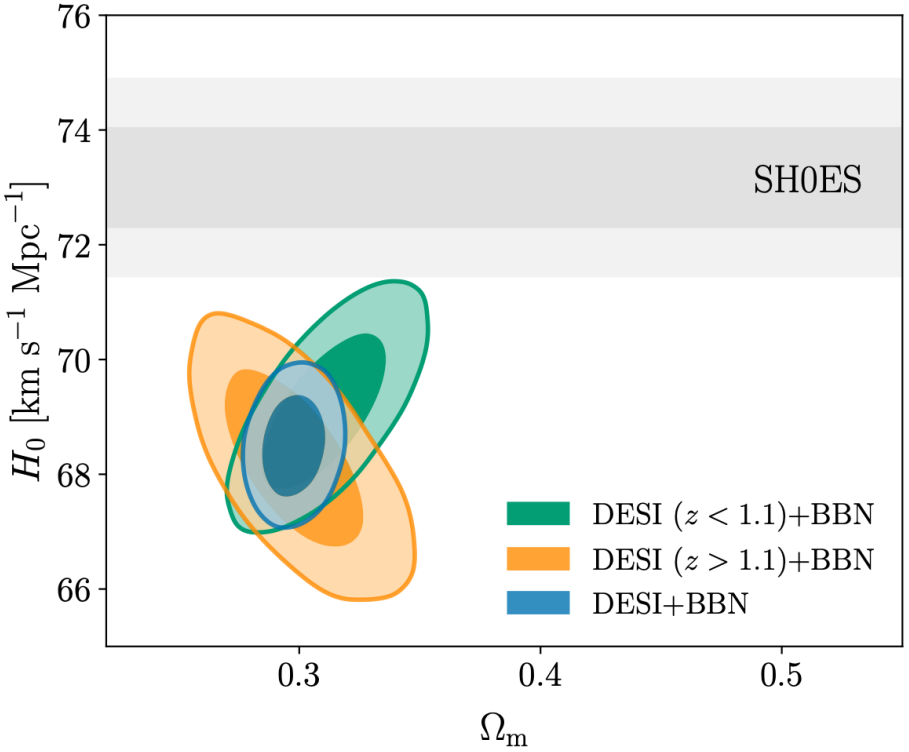
DESI & Co. and modeling of the galaxy population will change the game

[McCullough et al. 2023; DG & McCullough et al. 2024; Tortorelli, McCullough, DG 2024]

The story of the Universe as told by its expansion history



DESI and the Hubble tension



A matter density tension or evolving Dark Energy?

- The preference for evolving Dark Energy from the combination of DESI + CMB + Supernova is equivalent to a preference of different matter density values + vacuum energy by DESI and Supernovae, respectively