Title: Cosmology from Galaxy Surveys

Speakers: Jessica Muir

Collection: SciComm Collider 2

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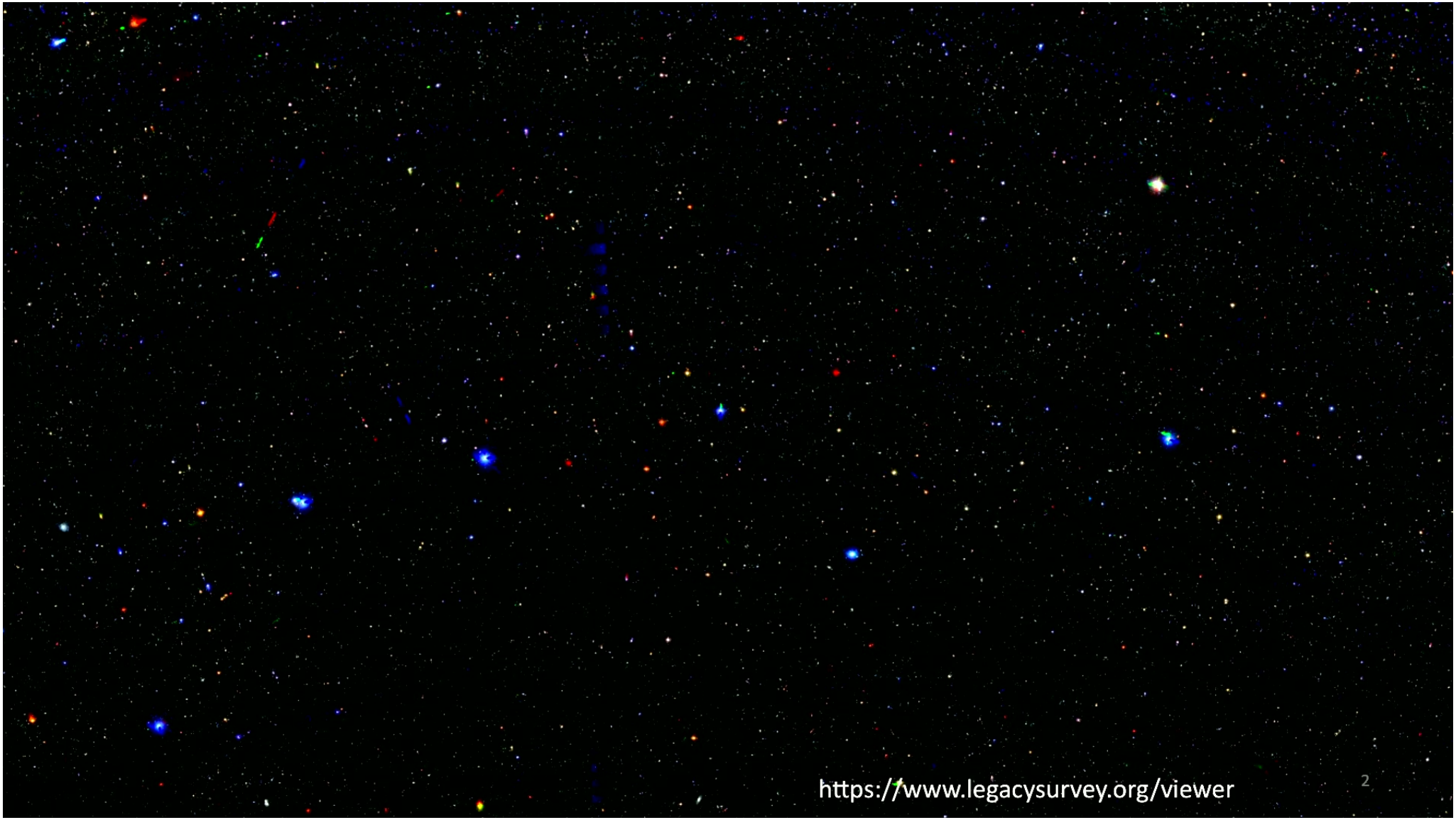
URL: https://pirsa.org/24050063

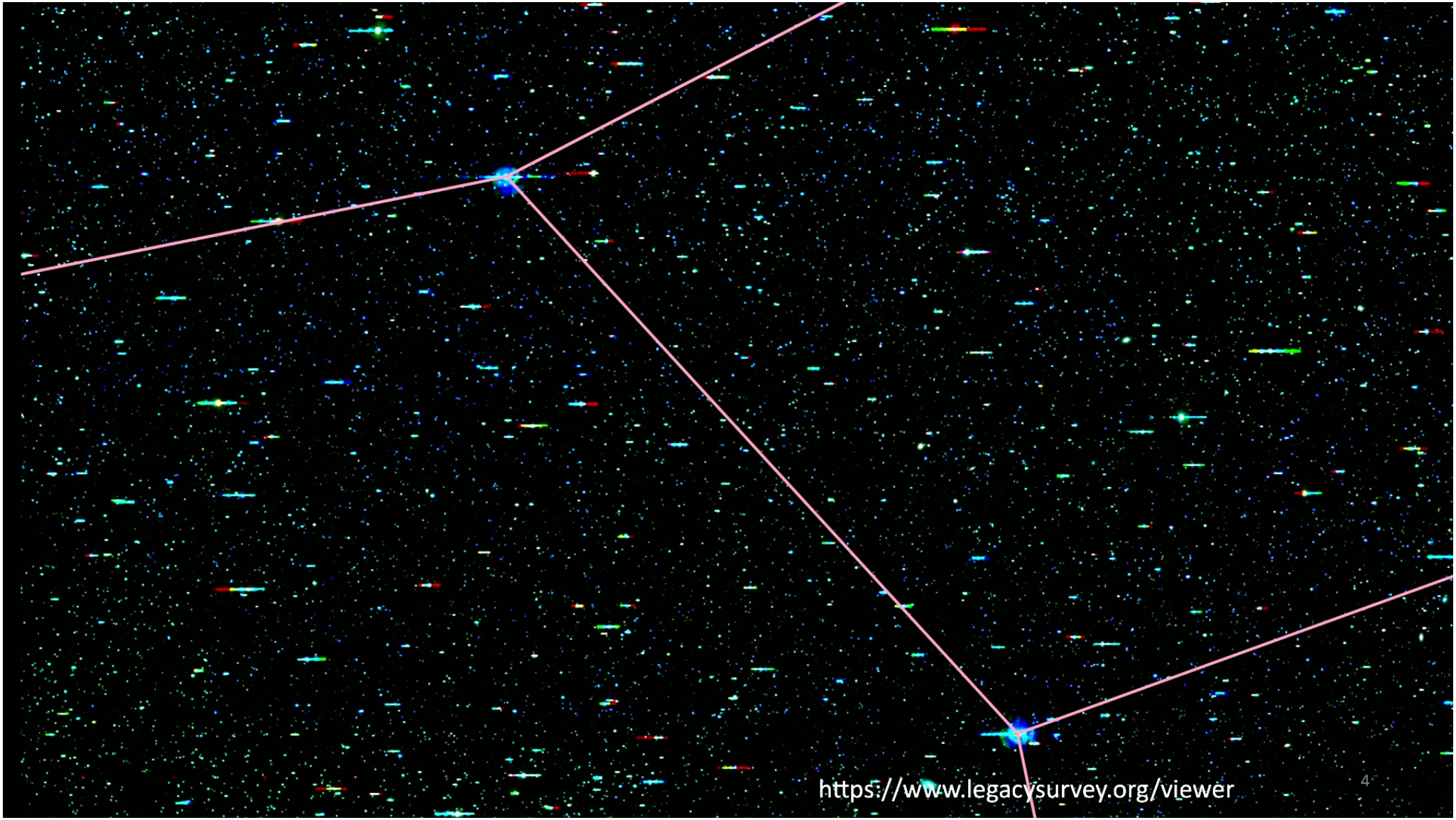
Cosmology from galaxy surveys

Scicomm Collider 2 – Perimeter Institute

Jessie Muir - Postdoctoral Fellow @ Perimeter Institute

May 9, 2024


https://www.legacysurvey.org/viewer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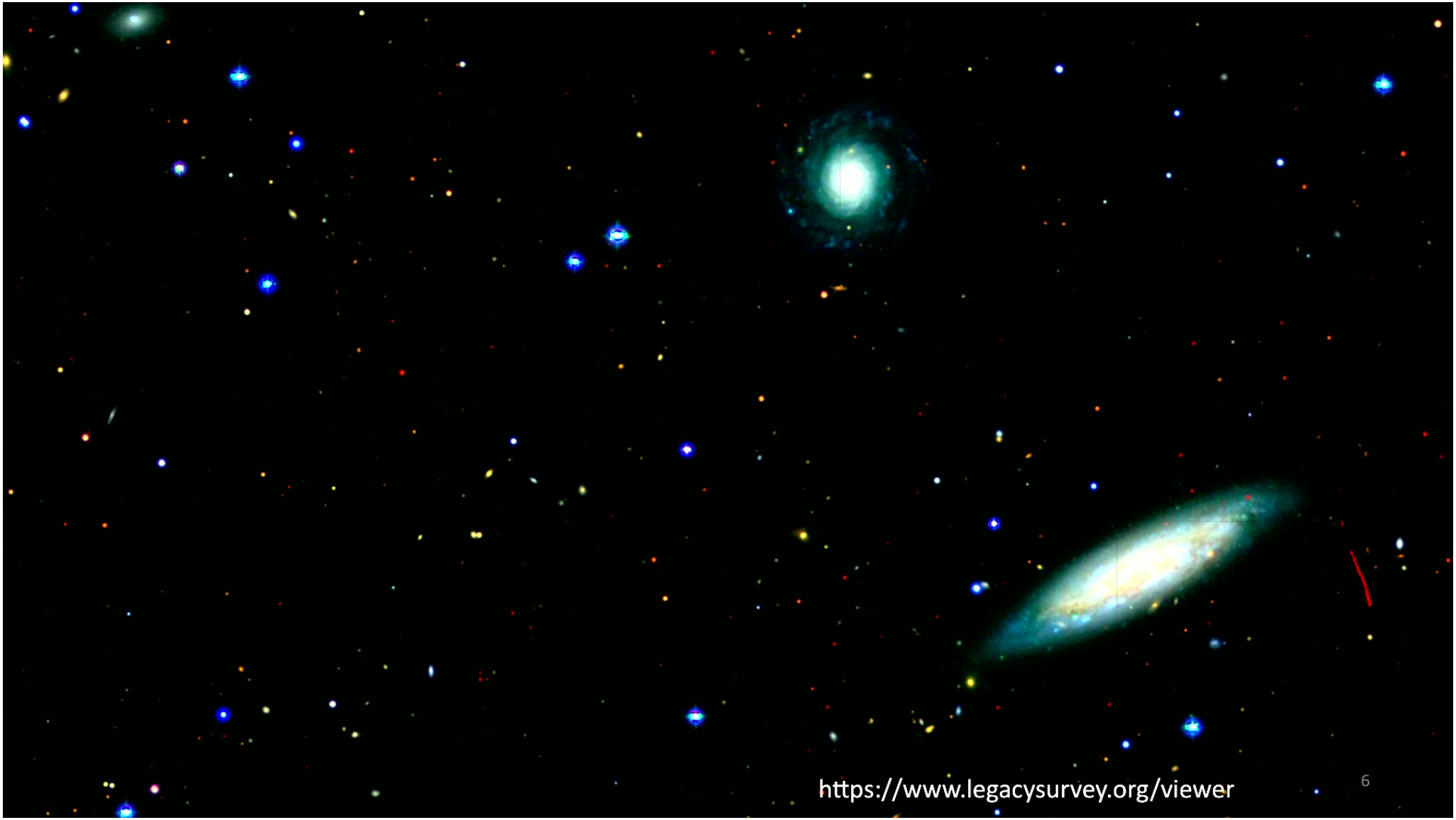
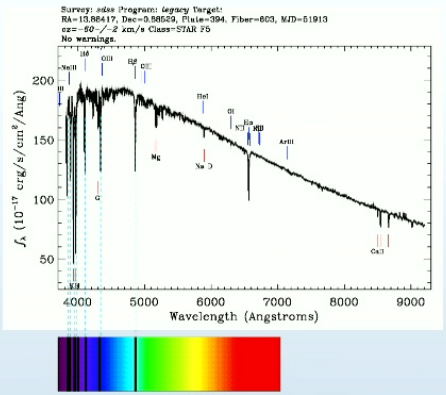

https://www.legacysurvey.org/viewer

Two classes of galaxy surveys

Spectroscopic surveys



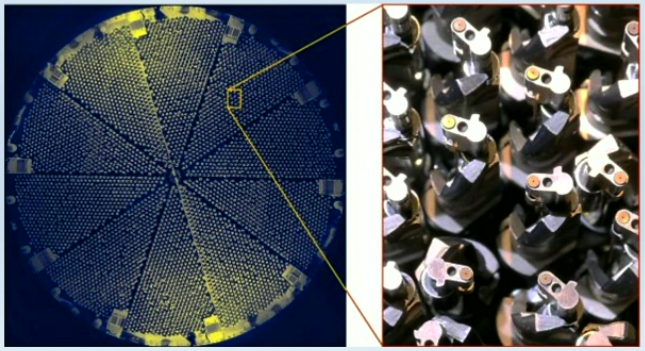
Select galaxies as targets, measure spectra .

Spectra → redshift → precise distances

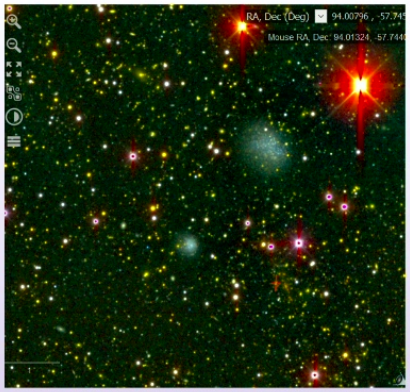
DESI
35M gal. by 2026

BOSS
1.3M gal., done 2014

Euclid
50M gal., planned 2024-2030



Imaging surveys



Find galaxies in images.

Distances from brightness in a few color filters.

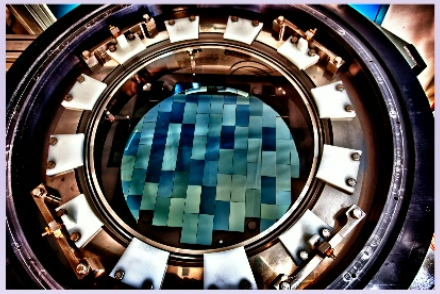
Less time per galaxy → more galaxies

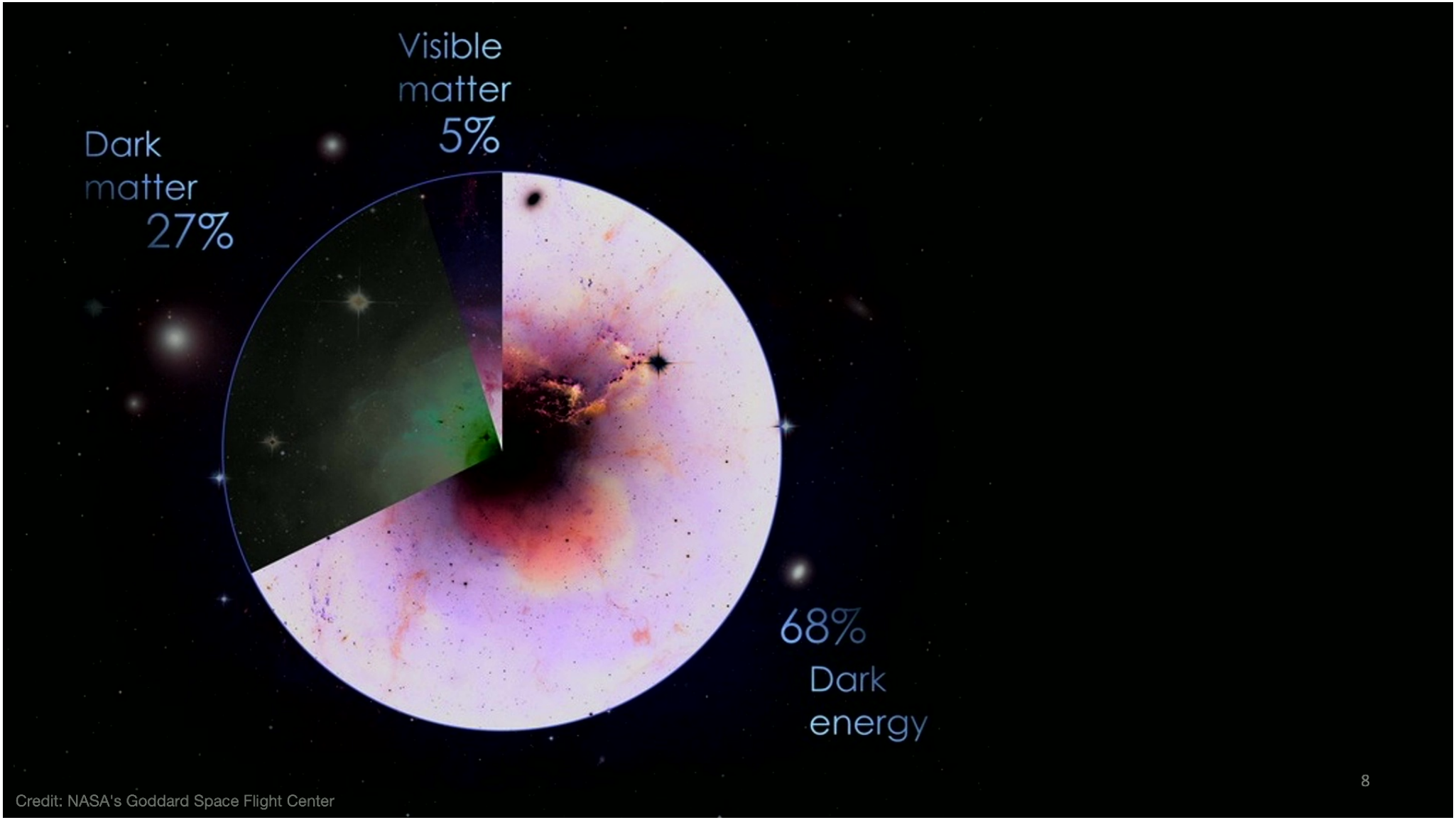
Can measure galaxy shapes

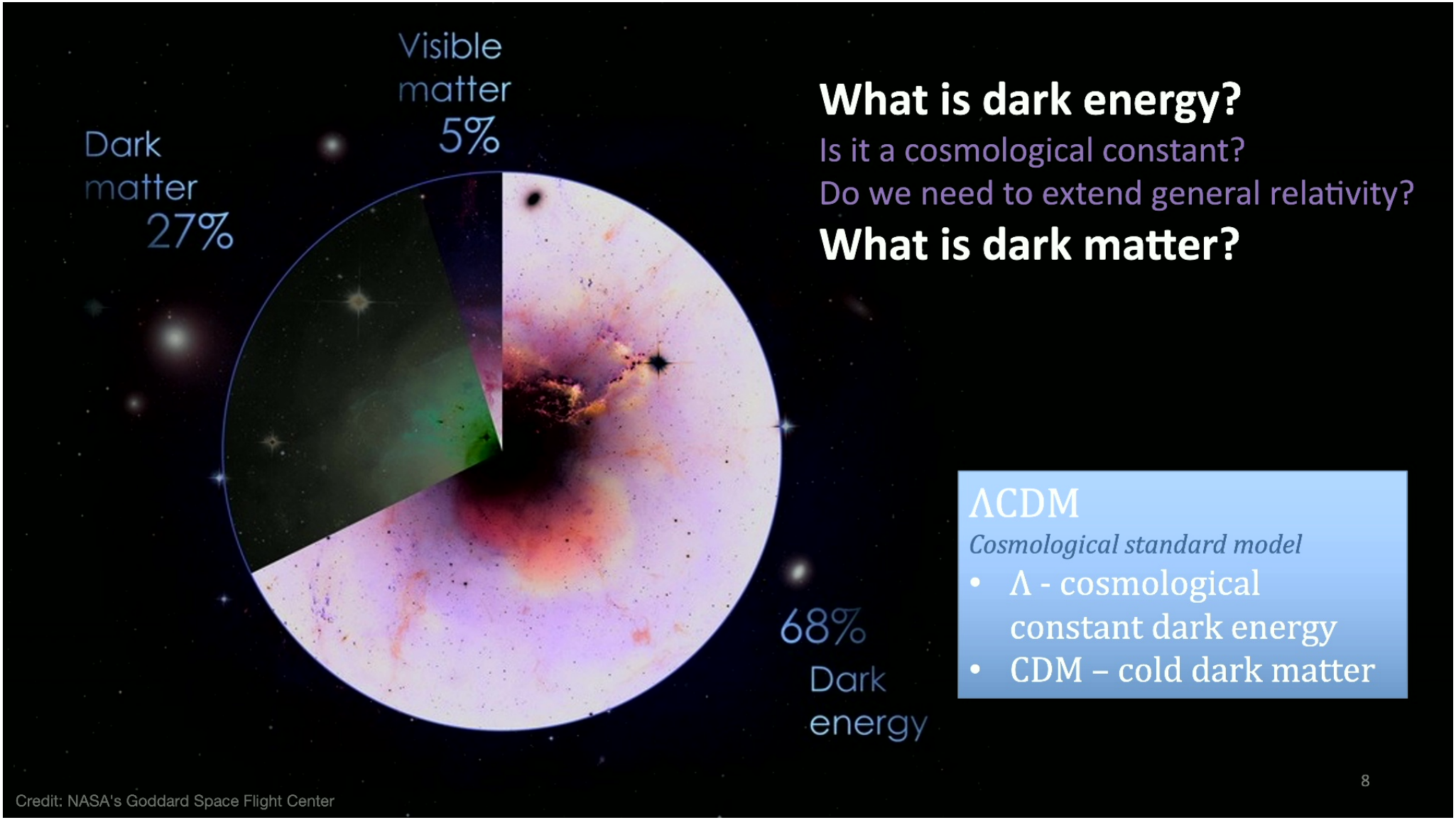
DES - 200M gal. completed 2019

KiDS , HSC, UNIONS

Rubin LSST
20B galaxies, planned 2024-2034




Visible
matter
5%
Dark
matter
27%
68%
Dark
energy
8
Credit: NASA's Goddard Space Flight Center



What is dark energy?

Is it a cosmological constant?

Do we need to extend general relativity?

What is dark matter?

ΛCDM

Cosmological standard model

- Λ - cosmological constant dark energy
- CDM – cold dark matter

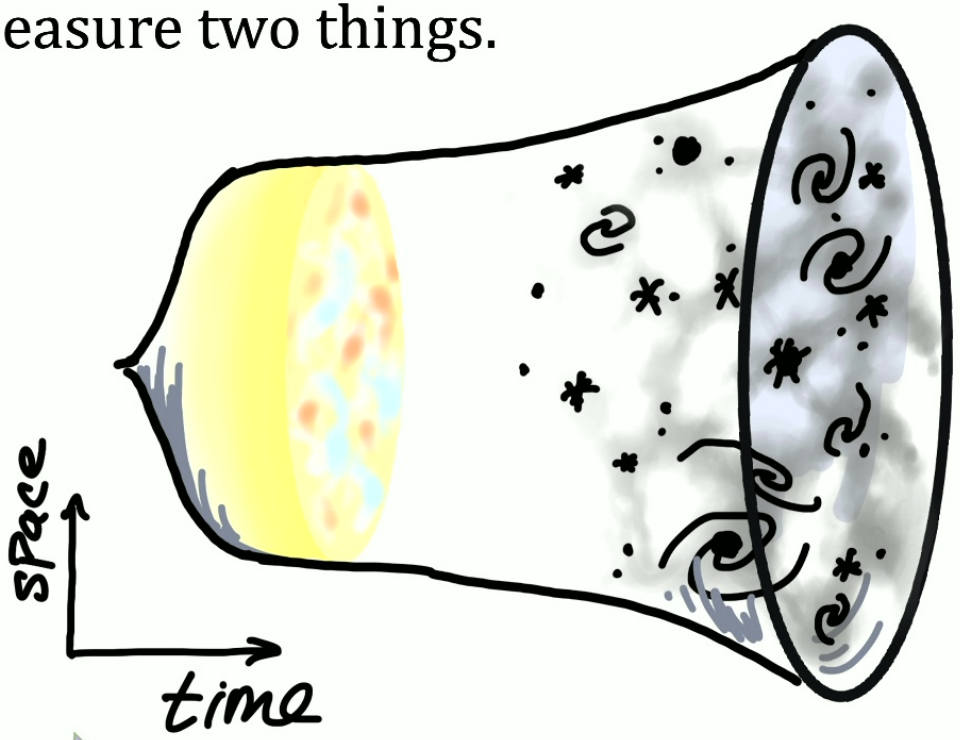
Broadly speaking, we can measure two things.

+ Theory of Gravity

+ Current rate of expansion

+ Initial fluctuation properties

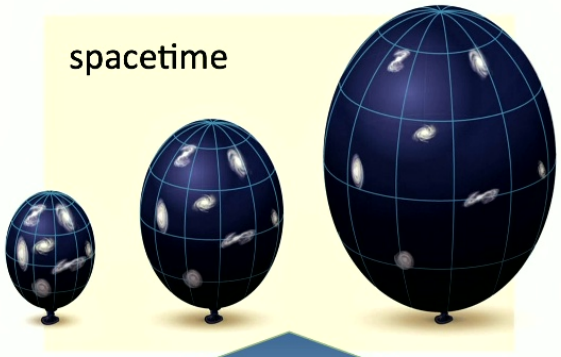
predictions



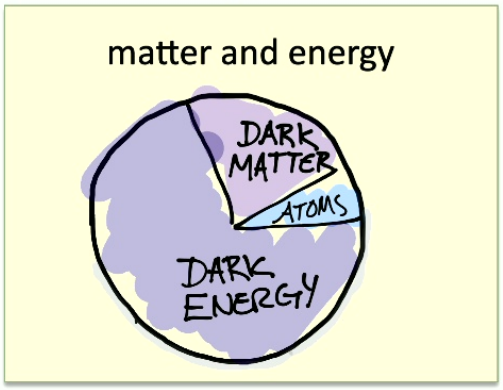
Expansion history

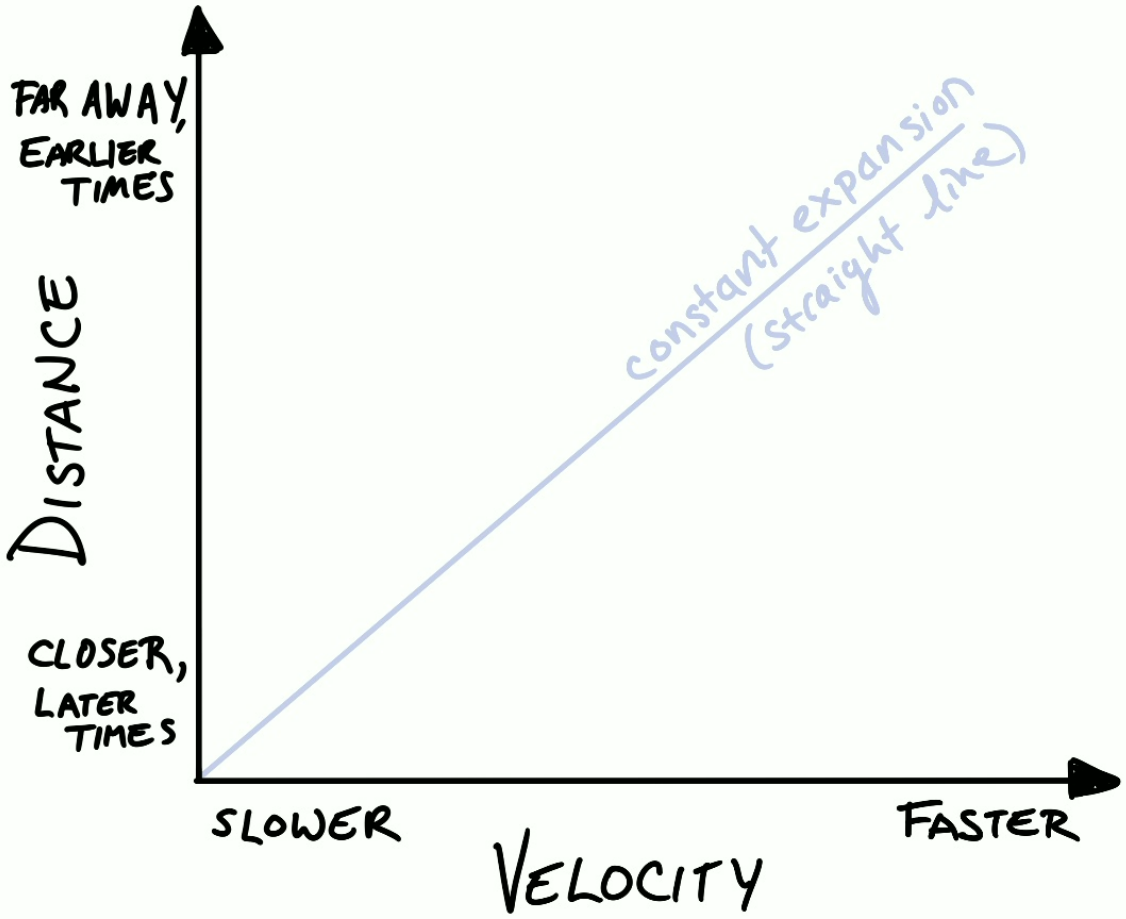
Evolution of density fluctuations

Expansion

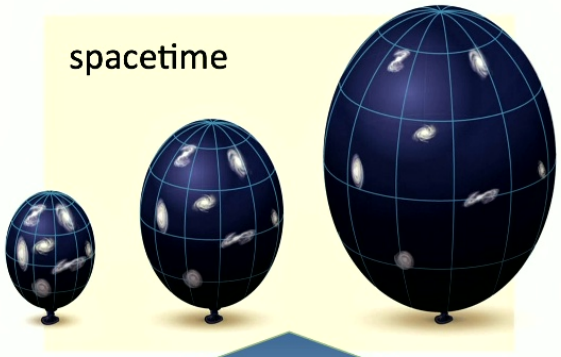


General relativity

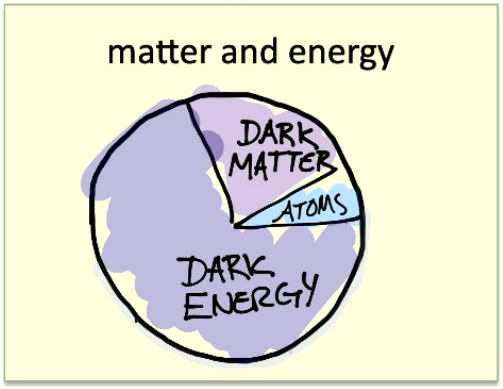


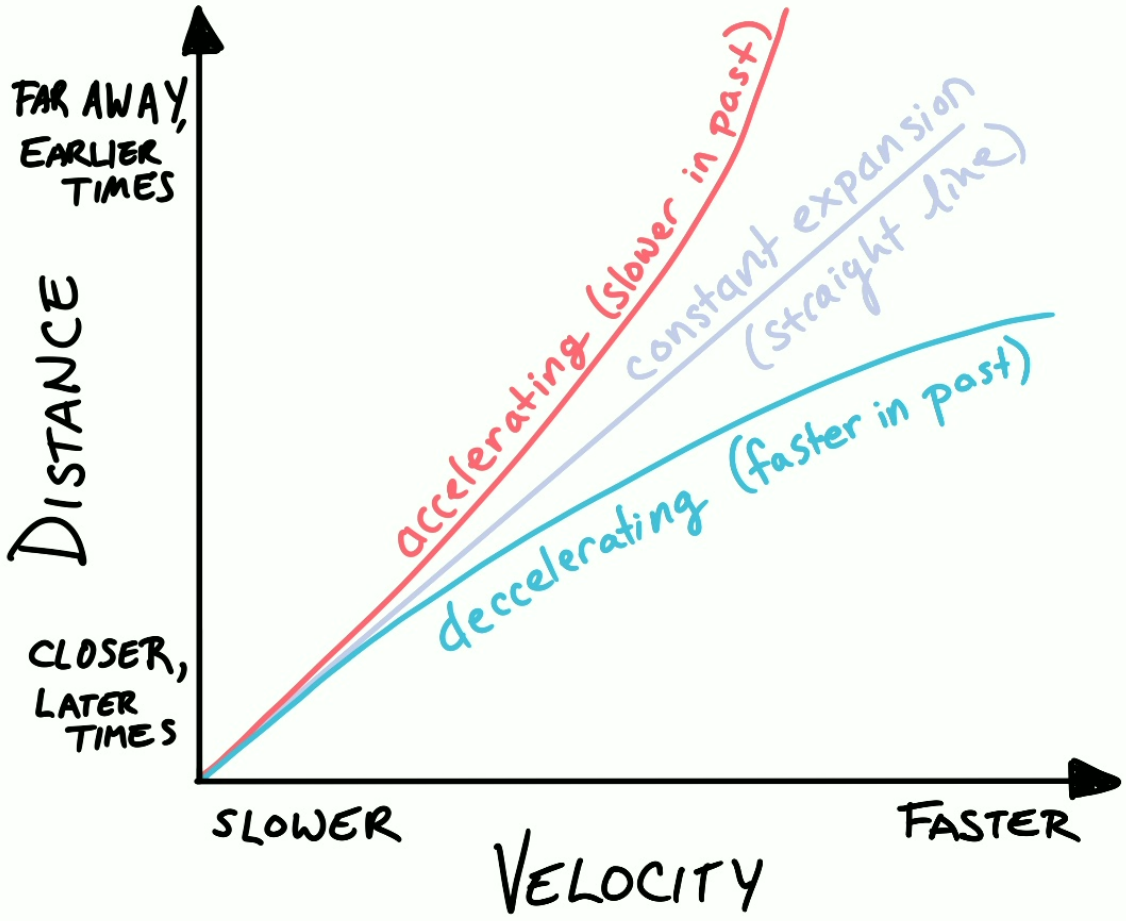


Expansion



General relativity





Expansion is probed with distance measurements

Standard(izable) candles: Type Ia Supernovae

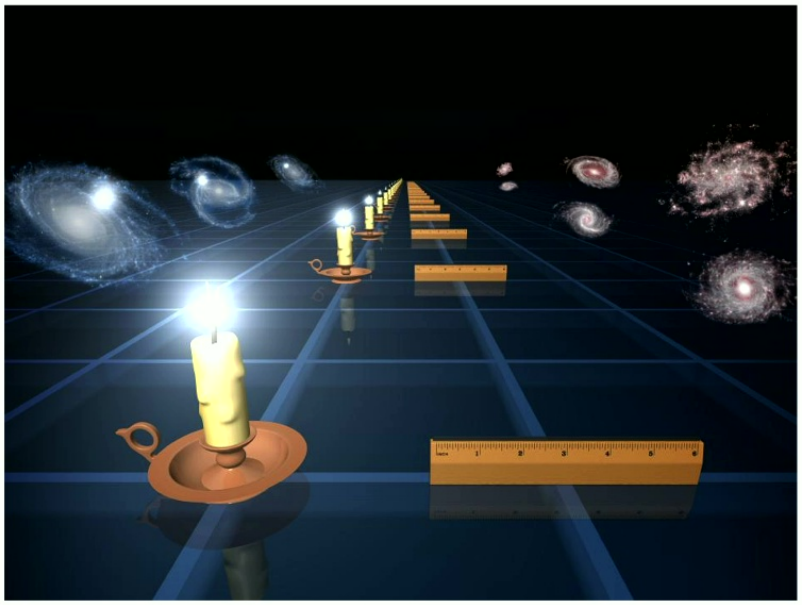
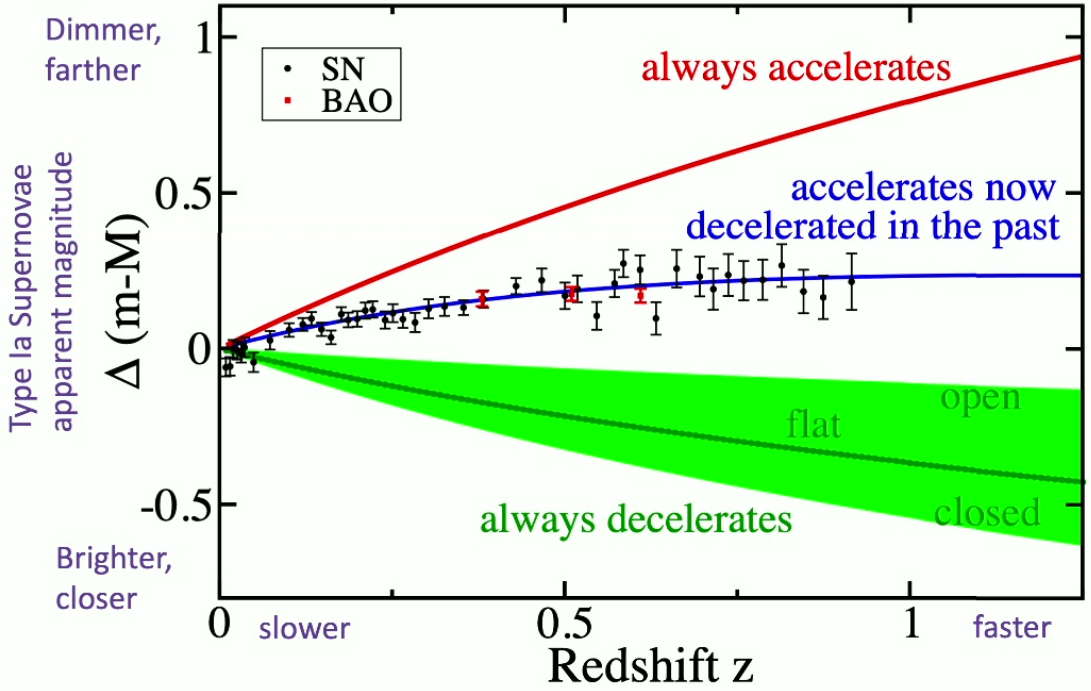


Image: NASA



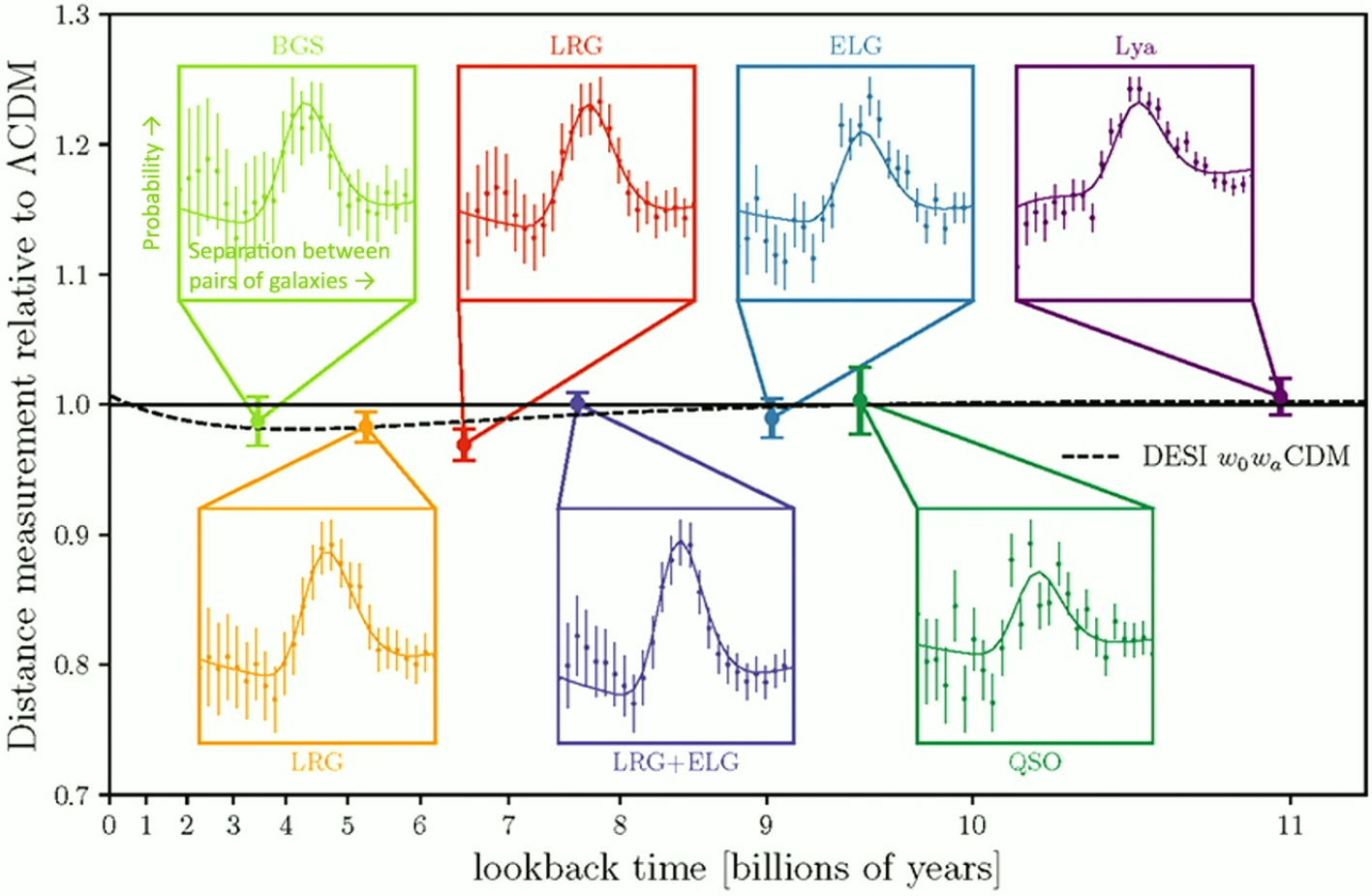
Huterer & Schafer, Rept.Prog.Phys. 2018, arXiv:1709.01091

The Dark Energy Spectroscopic Instrument (DESI) measures expansion history by using a feature in the distribution of galaxies as a standard ruler.

- Spectroscopic survey, started 2021
- Mayall telescope at Kitt Peak Observatory in Arizona.
- First cosmology results out April 2024.

Claire Lamman/DESI collaboration

Lots of excitement: model with time-evolving dark energy fits DESI & recent supernova measurements better than a cosmological constant.



Colors indicate measurements from different galaxy samples.

Subplots:
Probability of finding a pair of galaxies separated by some distance.

Peak at ~150Mpc
(~500M light years)

Solid line: best fit with cosmological constant

Dashed line: best fit with time-varying dark energy properties

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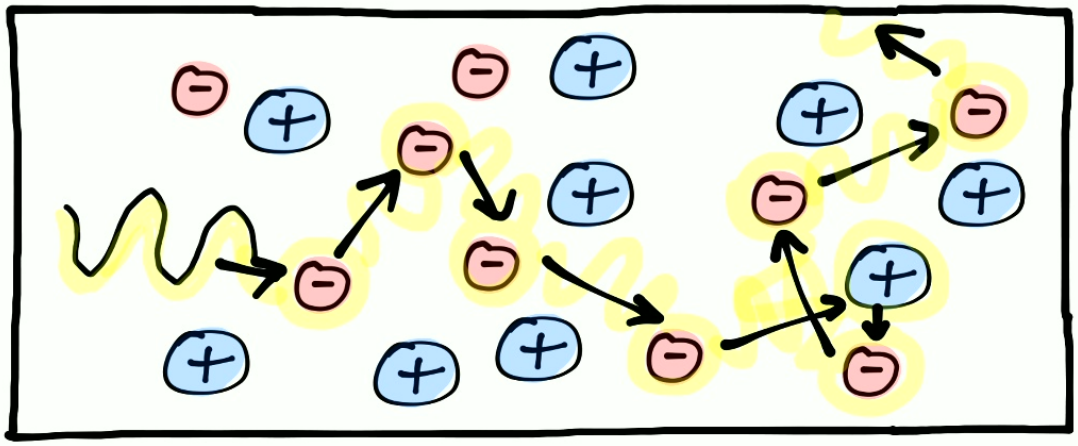
Credit: Arnaud de Mattia/DESI collaboration

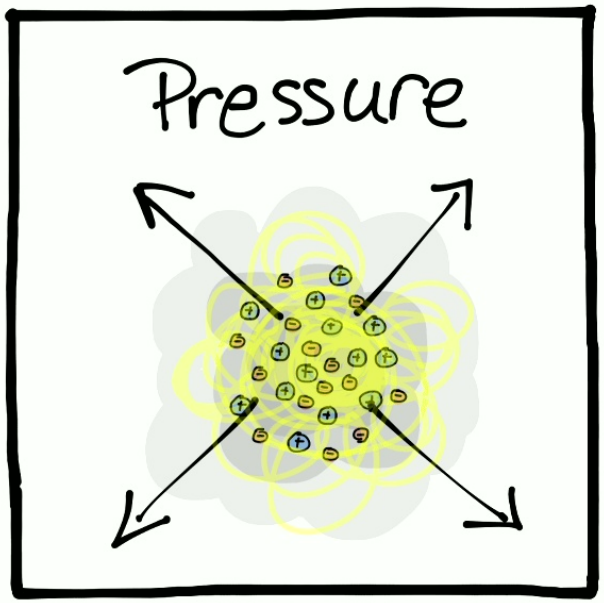
What is this feature?
Consider the Universe at <300,000 years old

- Ionized: Protons and electrons separated
  - Opaque: light can't travel far before interacting with a charged particle.



While the universe is ionized, density fluctuations oscillate.

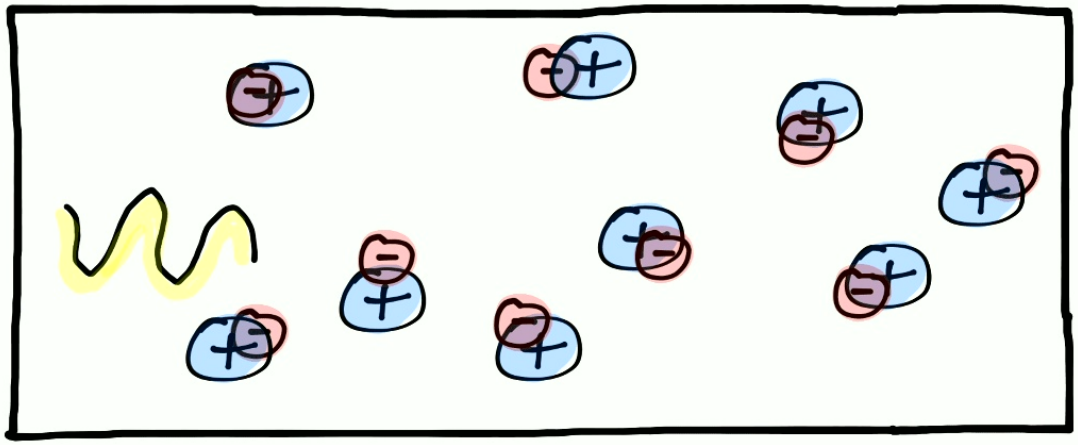
- Gravity pulls all matter into over-densities.
- Radiation pressure pushes photons and charged particles out.



"Baryon acoustic oscillations"

The Universe at 300,000 years old

- Once it cools enough for stable atoms, the universe becomes transparent.
- Photons become the cosmic microwave background.
- Baryons fall into overdensities.



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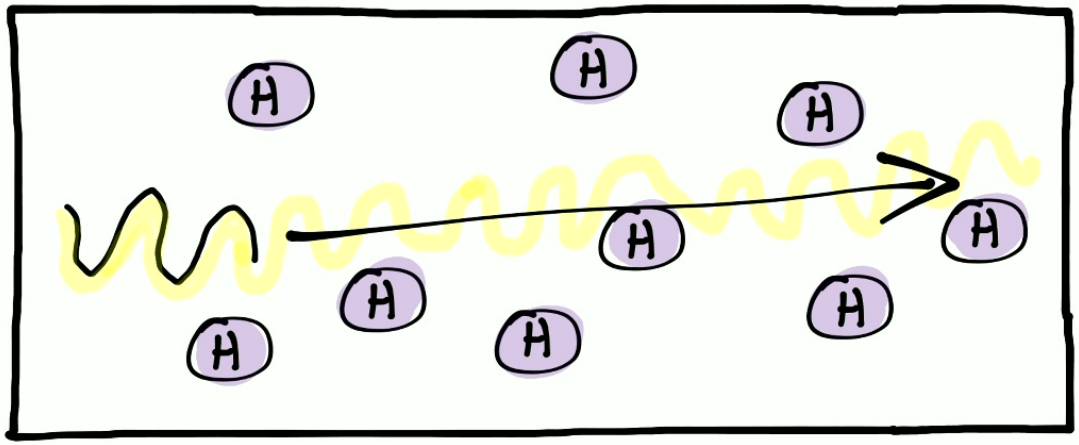
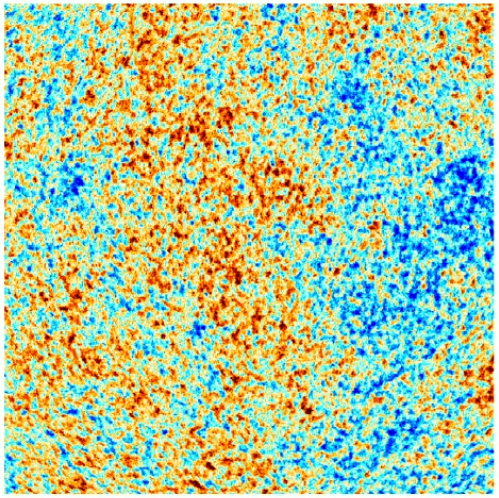
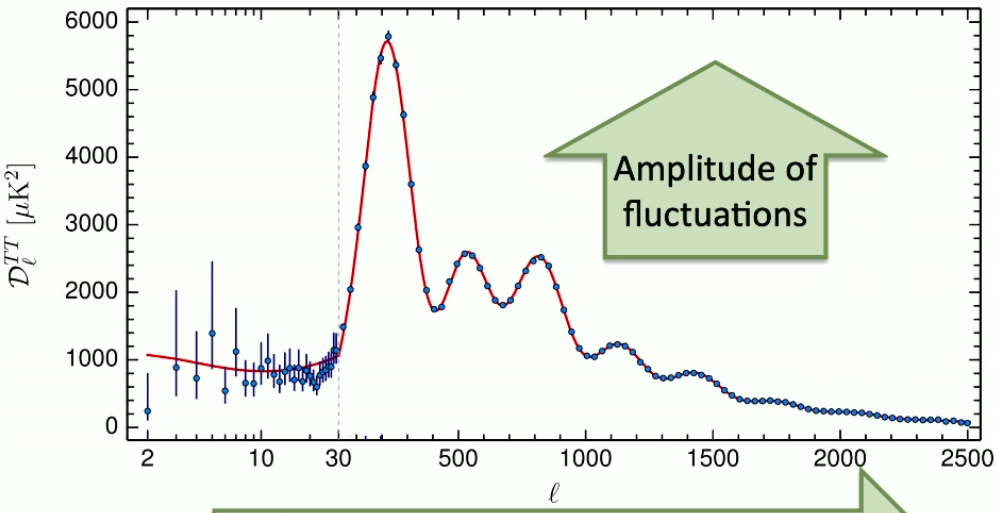


Oscillations lead to temperature fluctuations in the CMB



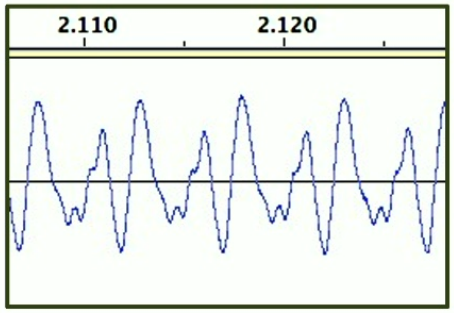
Credit: Planck survey, ESA



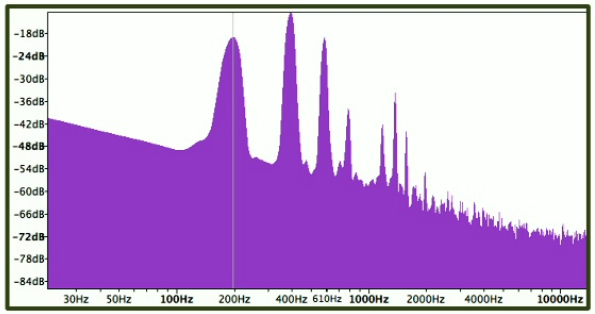
First peak:
↕
largest distance a sound wave could travel before the Universe became transparent

Higher Frequency = smaller wavelength

Amplitude vs time

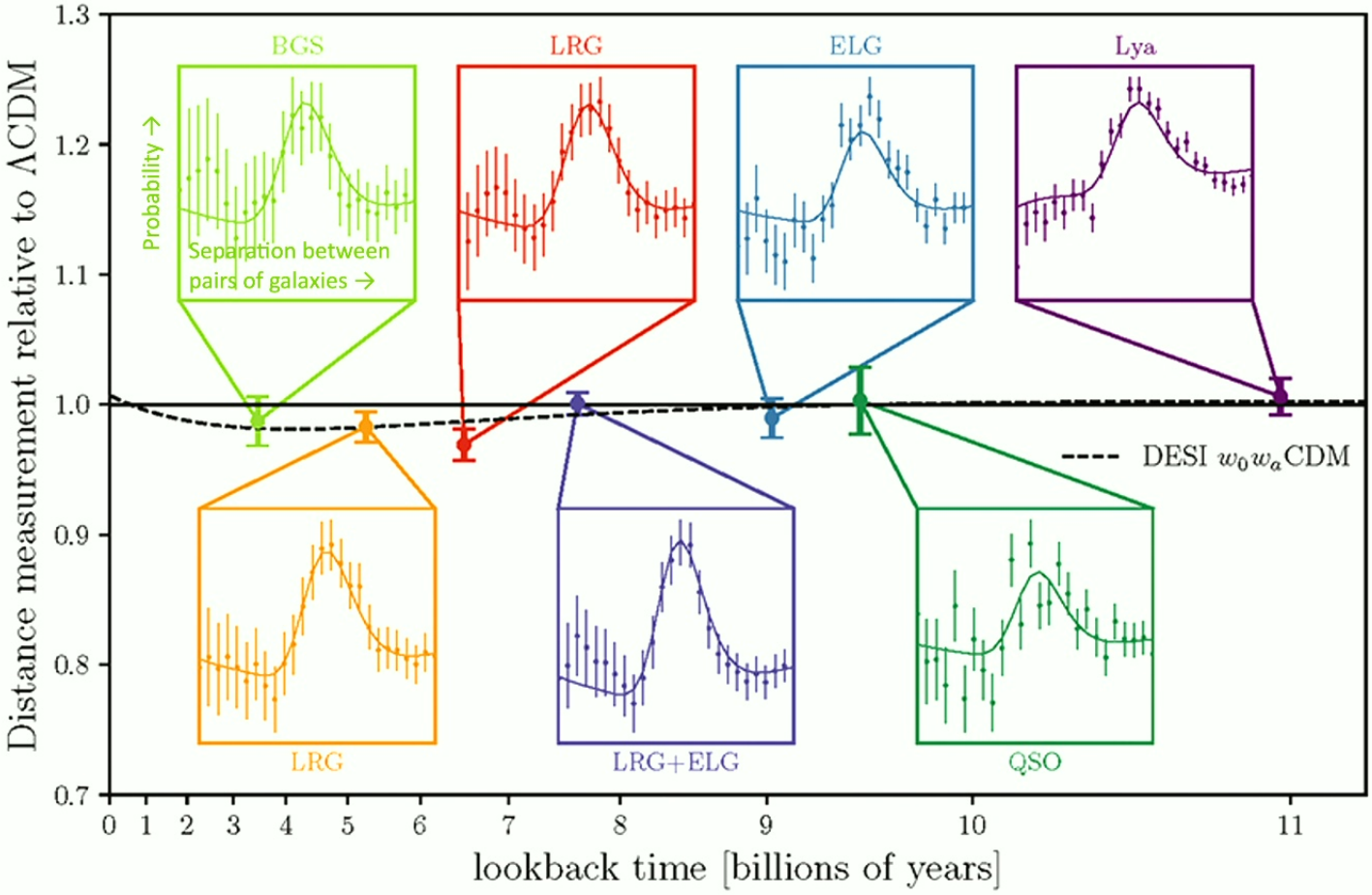


Amplitude vs frequency



Guitar, G3, ~196 Hz.

That BAO signal is imprinted on the distribution of matter & galaxies.



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Credit: Arnaud de Mattia/DESI collaboration

Probing Structure growth

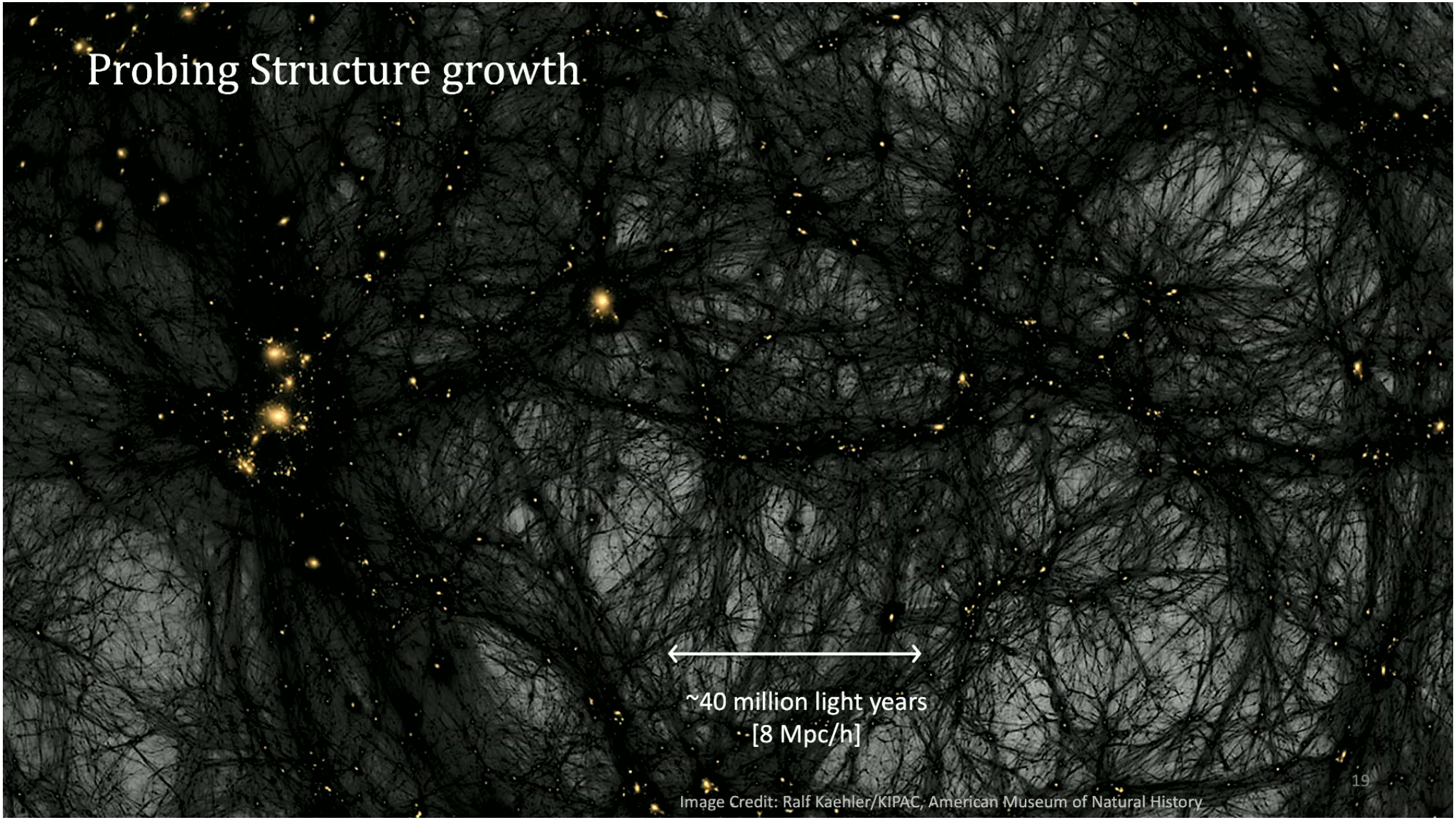
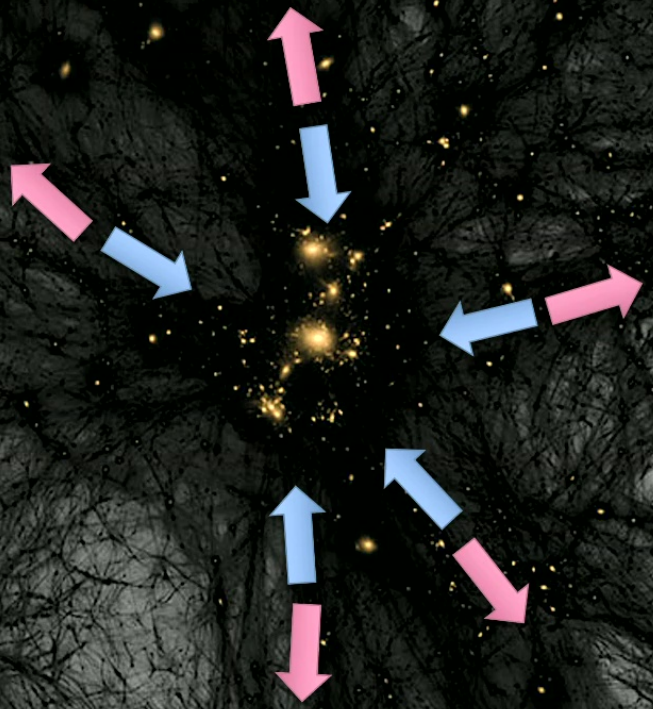


Image Credit: Ralf Kaehler/KIPAC, American Museum of Natural History

Probing Structure growth

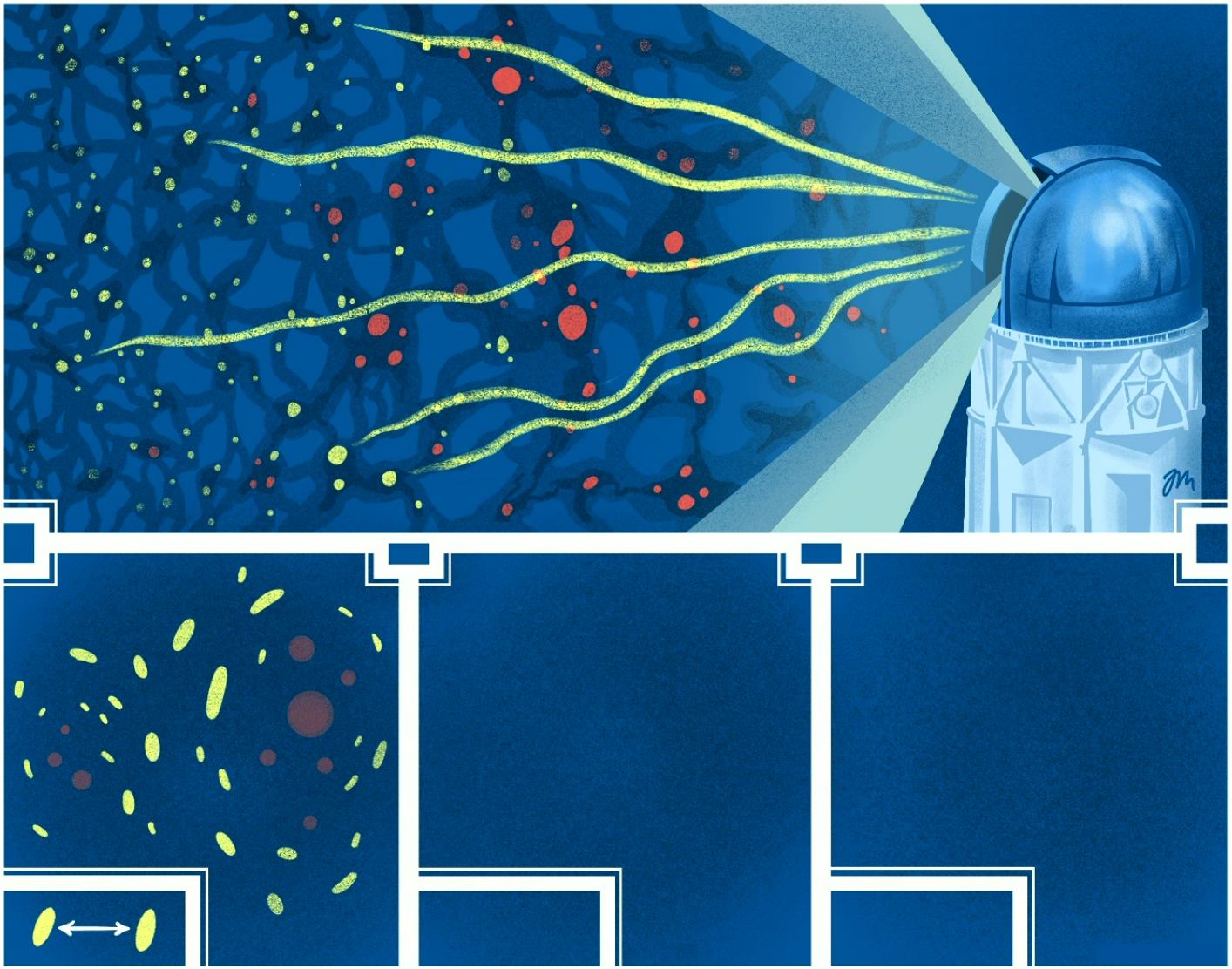


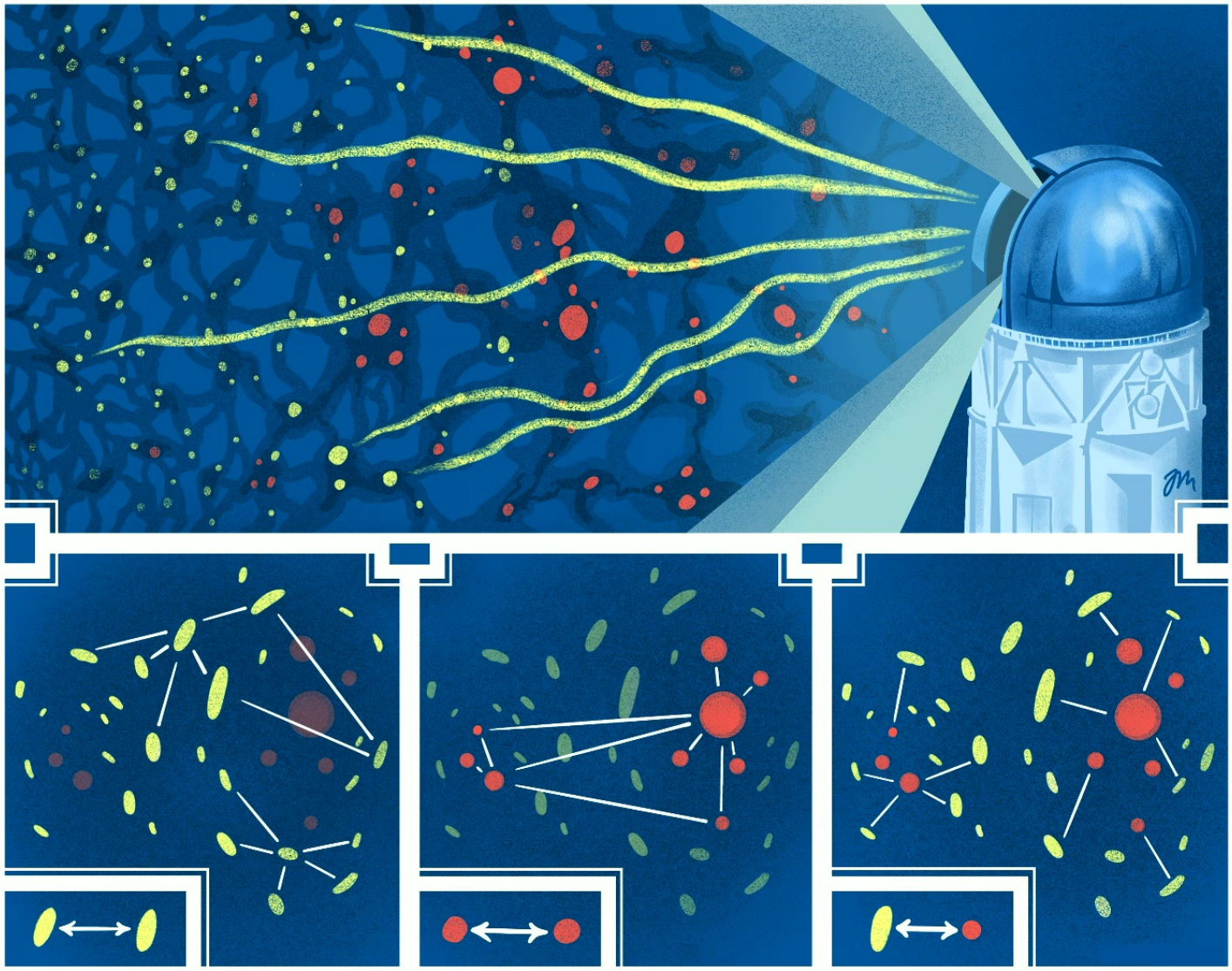
The distribution of matter and its evolution over time depend on:

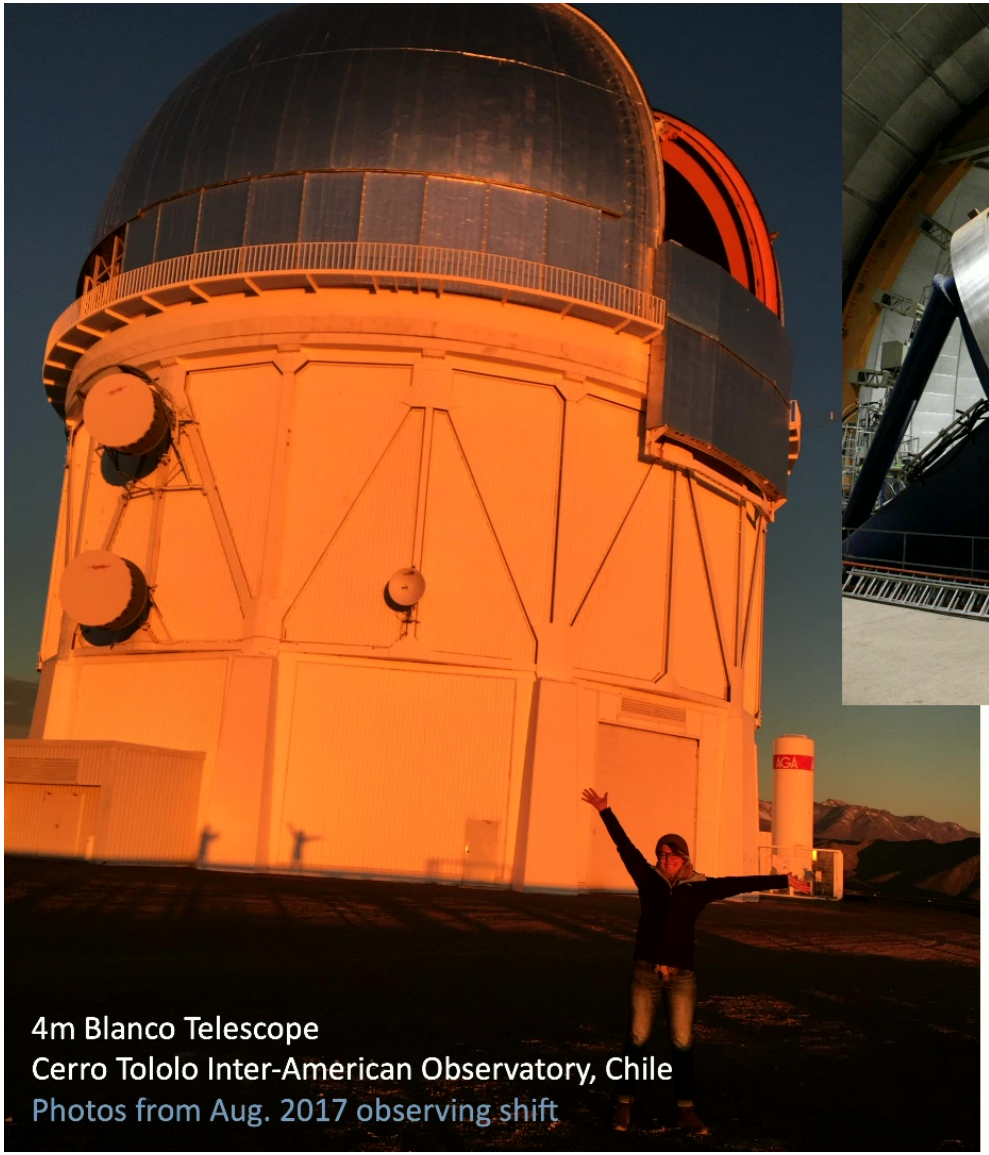
- **Gravity**
- Properties of **dark matter**
- **Expansion (dark energy)**

~40 million light years
[8 Mpc/h]

Image Credit: Ralf Kaehler/KIPAC, American Museum of Natural History







Dark Energy Survey (DES)

DARK ENERGY SURVEY

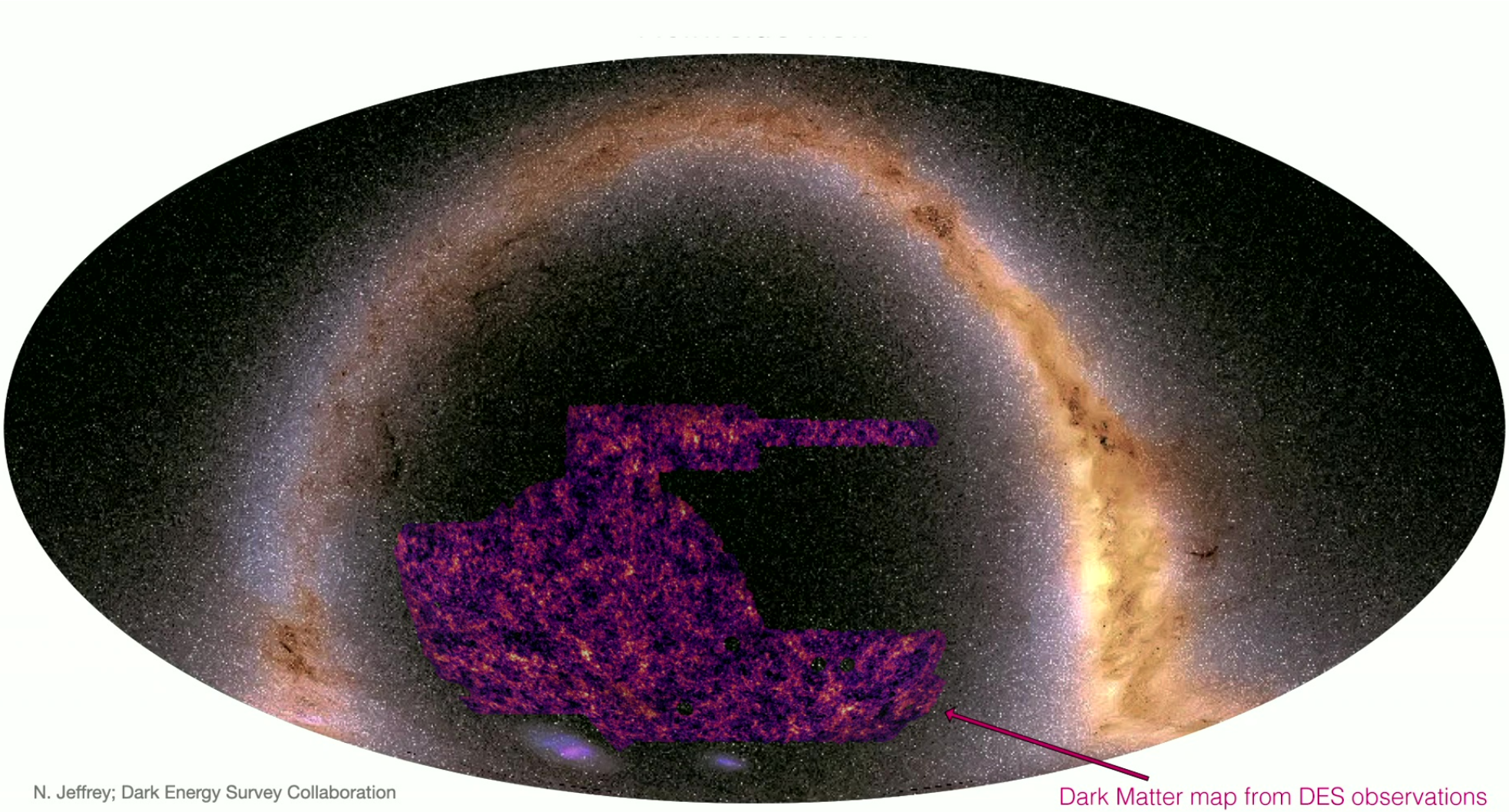
- Imaging survey 2013-2019
  - 758 nights observing
  - 5000 deg^2, ~10% of sky
- 400+ participants
- Cosmology analysis still underway!

Funding

NSF · U.S. DEPARTMENT OF ENERGY · Office of Science · UKRI Science and Technology Facilities Council · GOBIERNO DE ESPAÑA · MINISTERIO DE EDUCACIÓN Y FORMACIÓN PROFESIONAL

Member institutions

NCSA · The Ohio State University · ATM · ETH Eidgenössische Technische Hochschule Zürich Swiss Federal Institute of Technology Zurich · LMU · Berkeley Lab · University of Michigan · SLAC


N. Jeffrey; Dark Energy Survey Collaboration
Dark Matter map from DES observations

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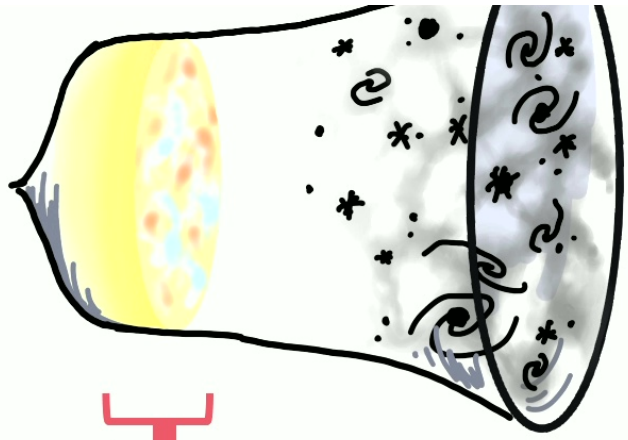
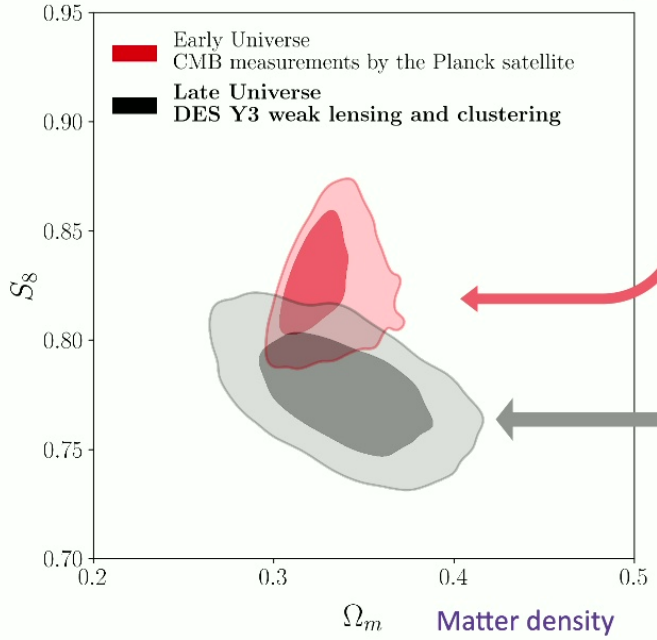
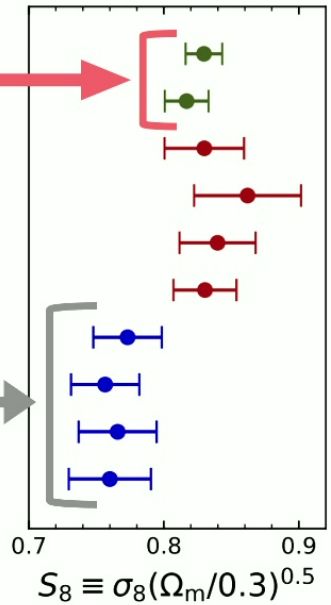




DES Collab. [inc. JM] 2021, PRD, arXiv:2105.13549



Planck CMB aniso.
Planck CMB aniso. (+A_{lens} marg.)
Planck CMB lensing + BAO
SPT CMB lensing + BAO
ACT CMB lensing + BAO
ACT+Planck CMB lensing + BAO
DES-Y3 galaxy lensing + BAO
KiDS-1000 galaxy lensing + BAO
HSC-Y3 galaxy lensing (Fourier) + BAO
HSC-Y3 galaxy lensing (Real) + BAO

ACT Collab. 2023, arXiv:2304.05203

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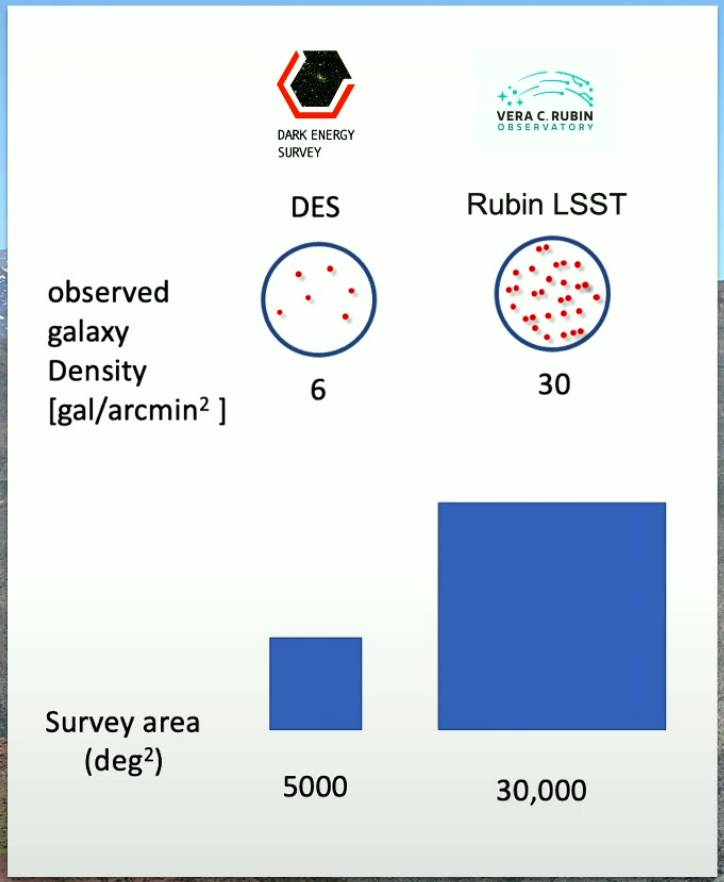
Even more exciting galaxy survey science is on the horizon!

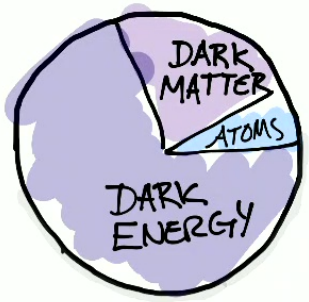


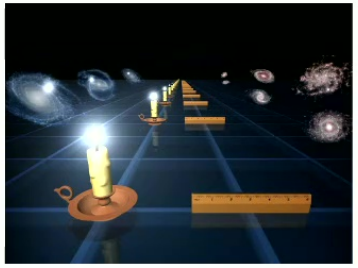
In 2025-2035 Rubin LSST will image ~30x more galaxies than DES.

Photo: View of Rubin Observatory from Cerro Tololo (DES site)

Summary

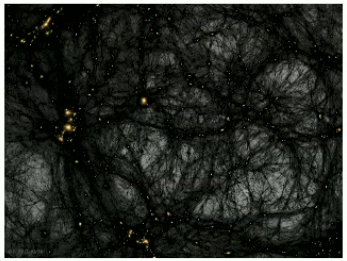
We test cosmological model predictions for…





Expansion history via distance measurements,

Growth of structure via CMB & galaxy surveys.



These tests can provide clues towards more fundamental descriptions of dark matter & energy.

- Some interesting tensions seen; community is working to understand them.
- Exciting data on the horizon from ongoing & future galaxy surveys.