Dark energy

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Dautreppe 2018
Dernières nouvelles de l'Univers

Some cosmological probes (and dark energy)

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Introduction

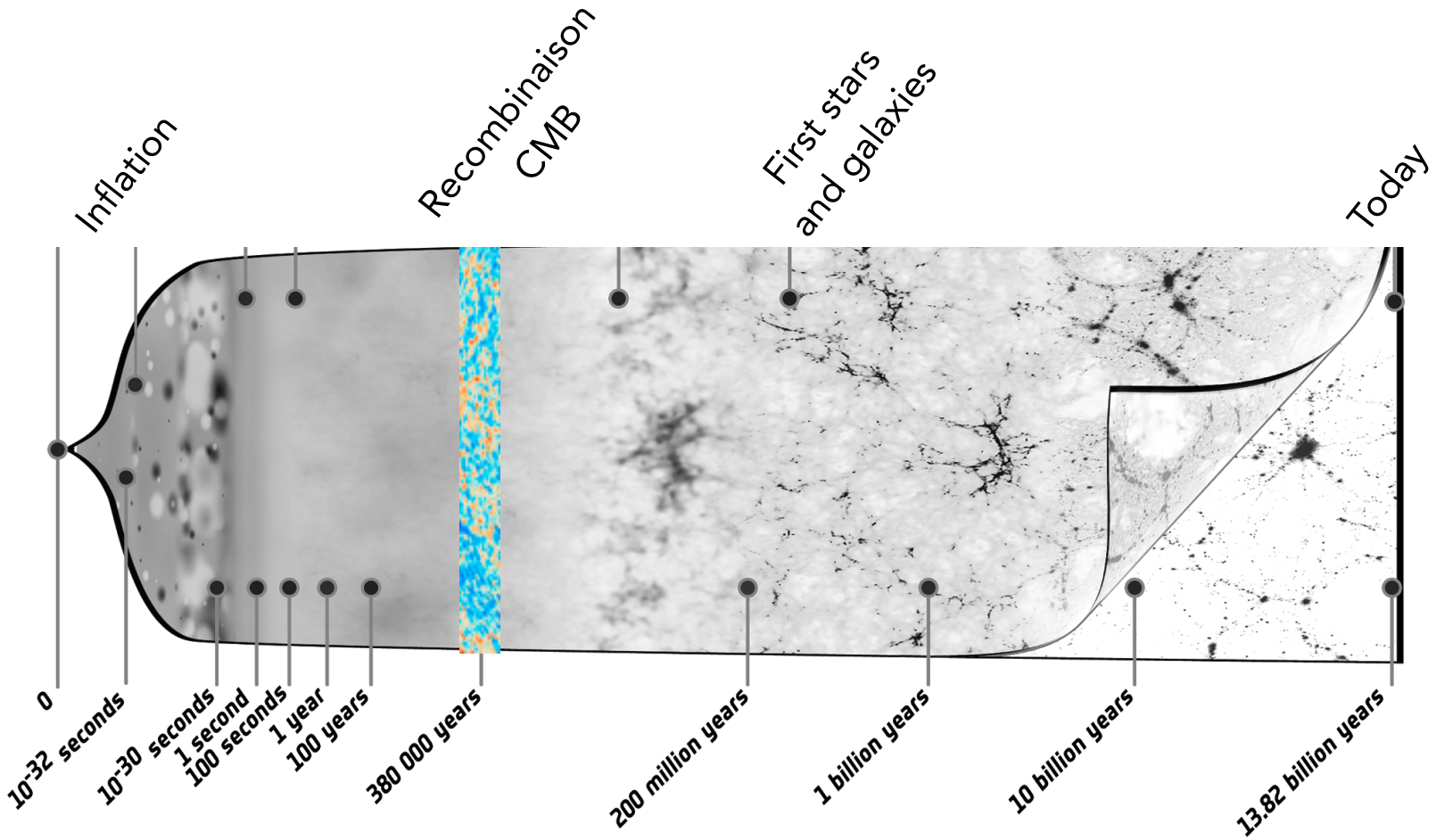
- History of the universe
- Expansion
- Concordance model

Measuring the expansion of the universe

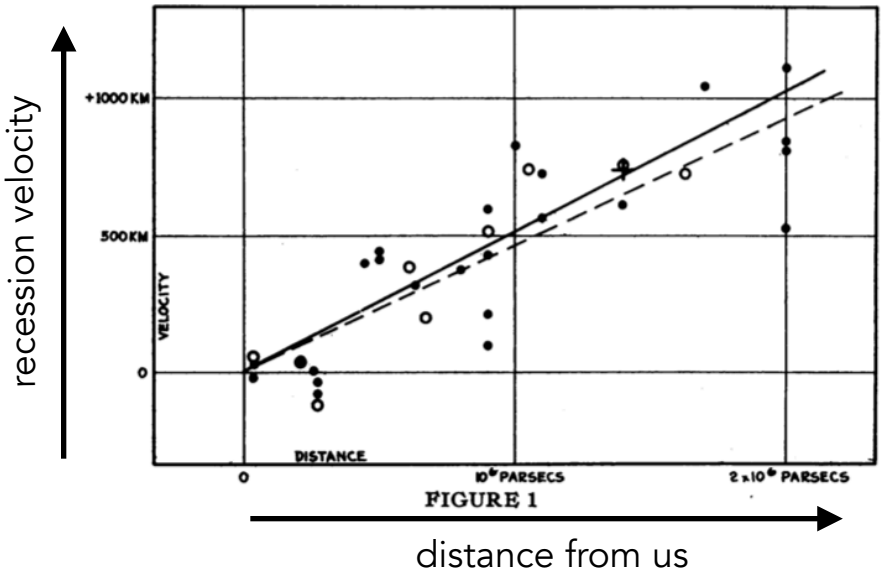
- Type Ia supernovae
- Baryon acoustic oscillations

Experimental highlight: the LSST project

History of the universe



A universe in expansion - 1927–1929



Lemaître 1927, Hubble 1929 :

- linear relation between recession velocity and distance of nearby galaxies

$$v = H \times d$$

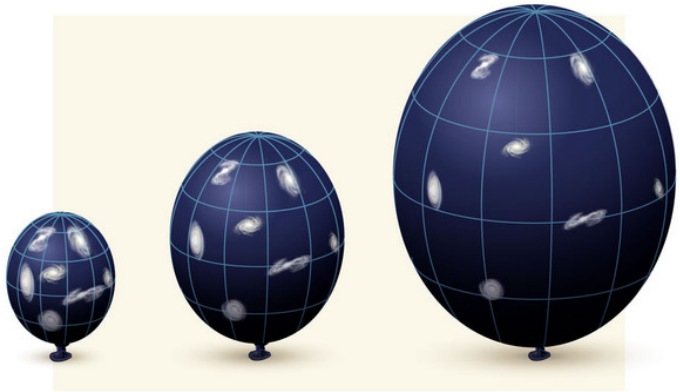
Hubble constant

- the universe is not static but in expansion (Einstein's cosmological constant not needed anymore)

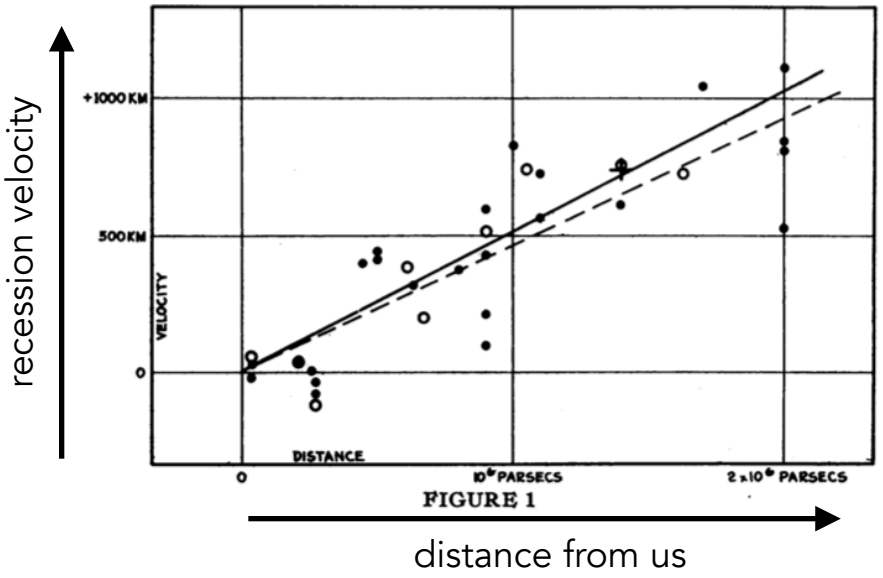
In all directions, galaxies move away from us

↓

The universe is expanding



A universe in accelerated expansion - 1998



Lemaître 1927, Hubble 1929 :

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Hubble constant

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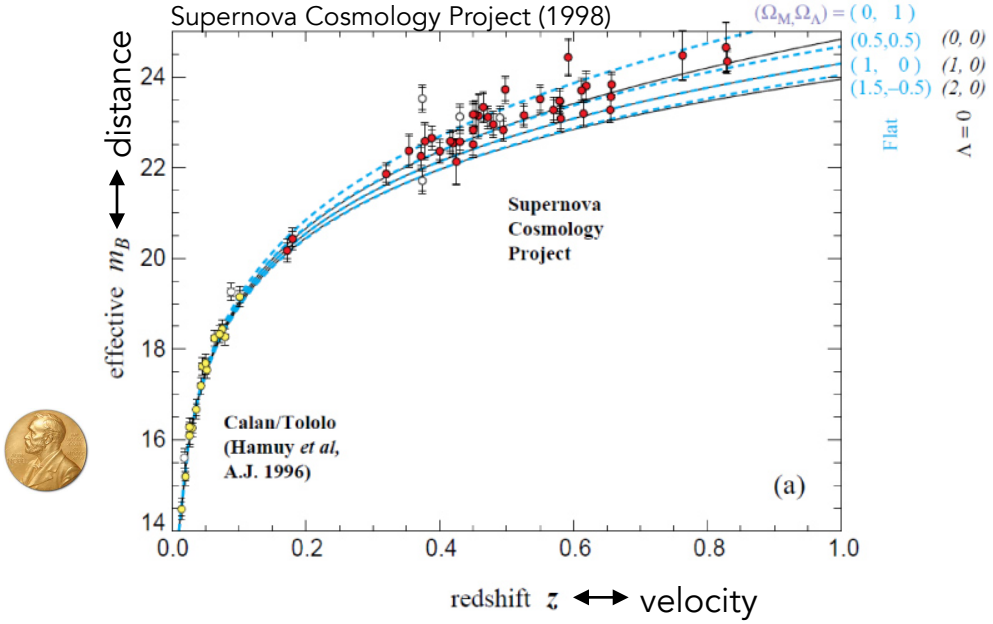
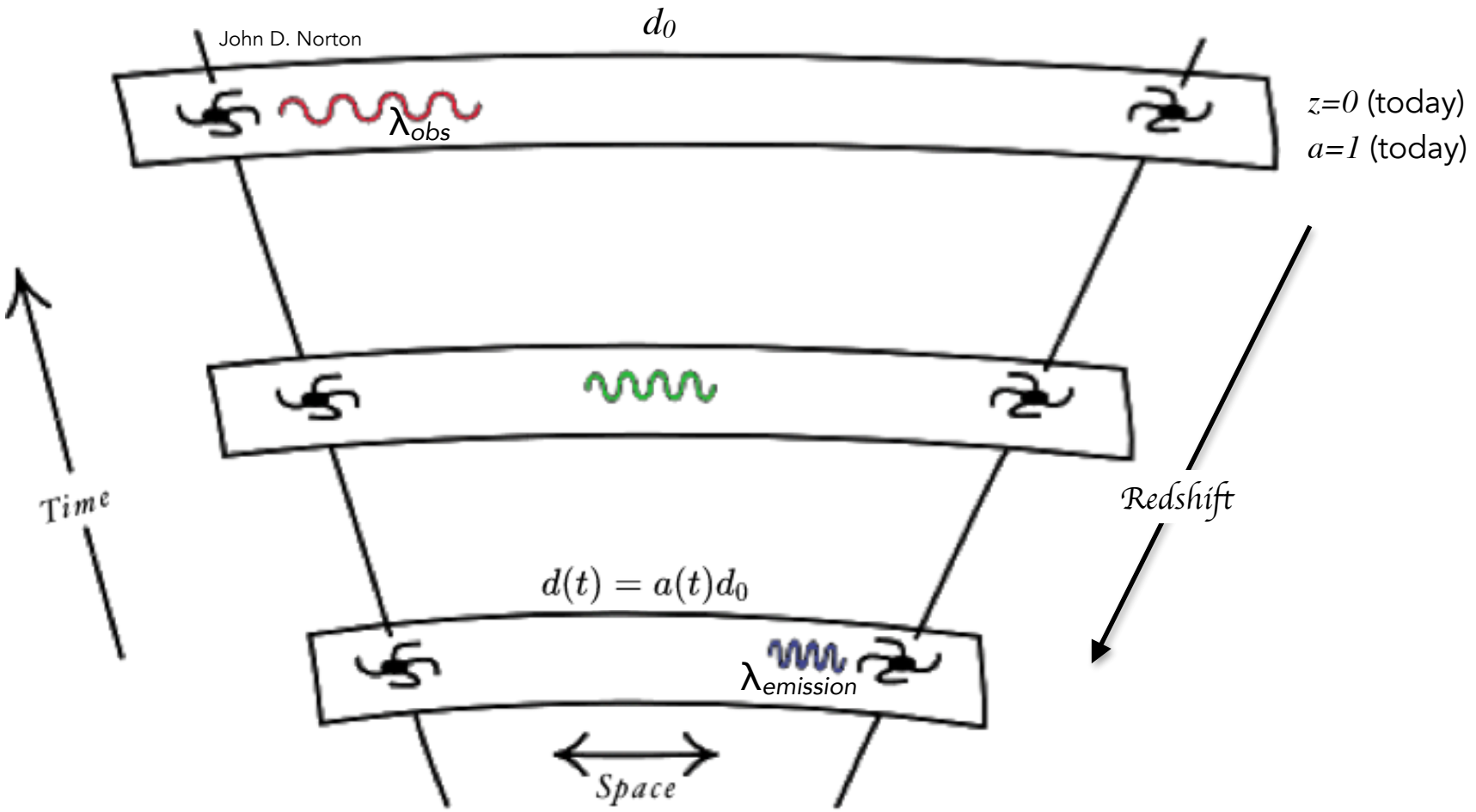
1998 : 2 independent teams produce a Hubble diagram from supernovae (SNIa)

- the expansion is accelerating
- incompatible with a matter-dominated universe
- need to (re-)invoked contribution of a **cosmological constant = dark energy**



Expansion of the universe



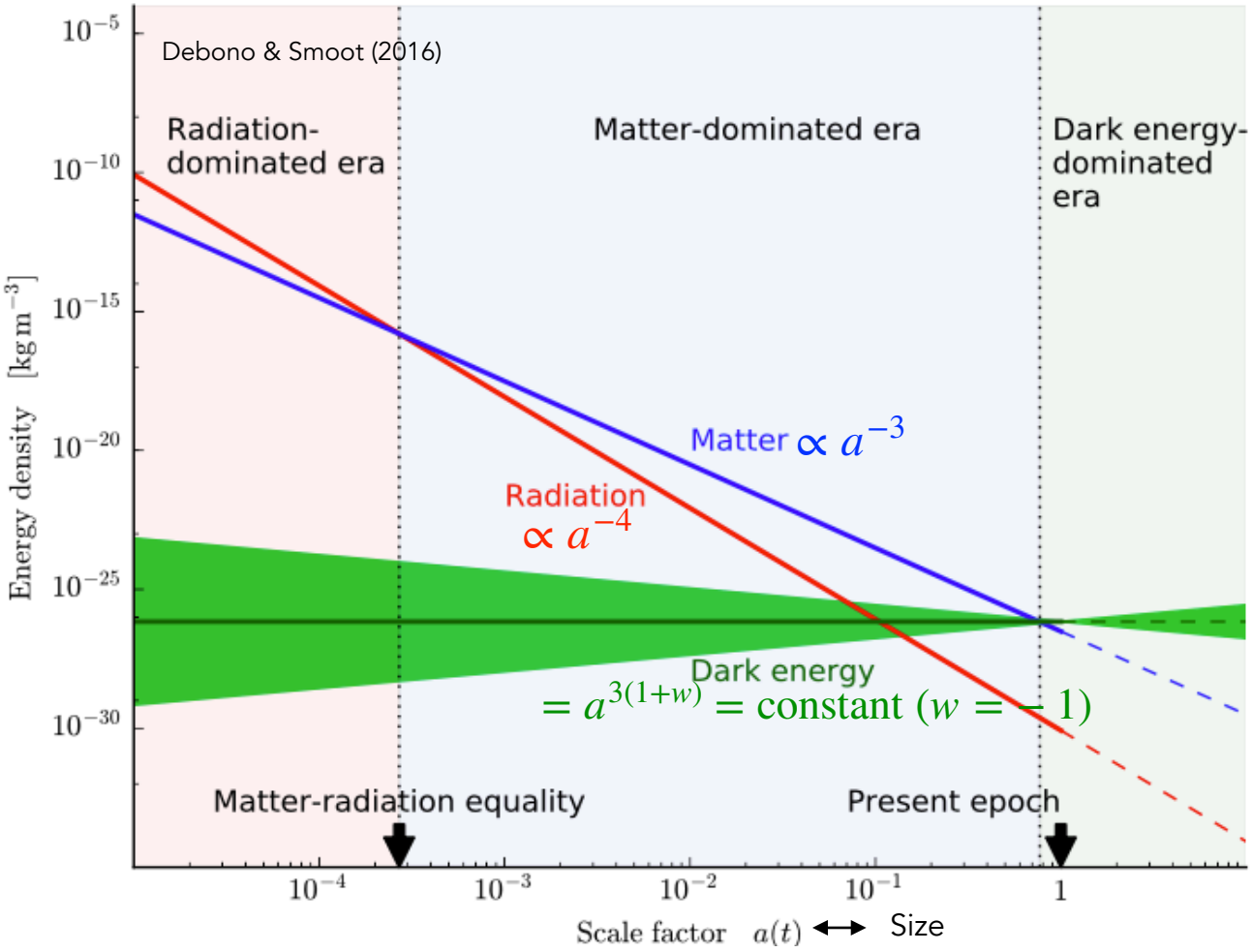
Redshift $1+z = \lambda_{obs} / \lambda_{emission}$

$$a(t) = \frac{1}{1+z}$$

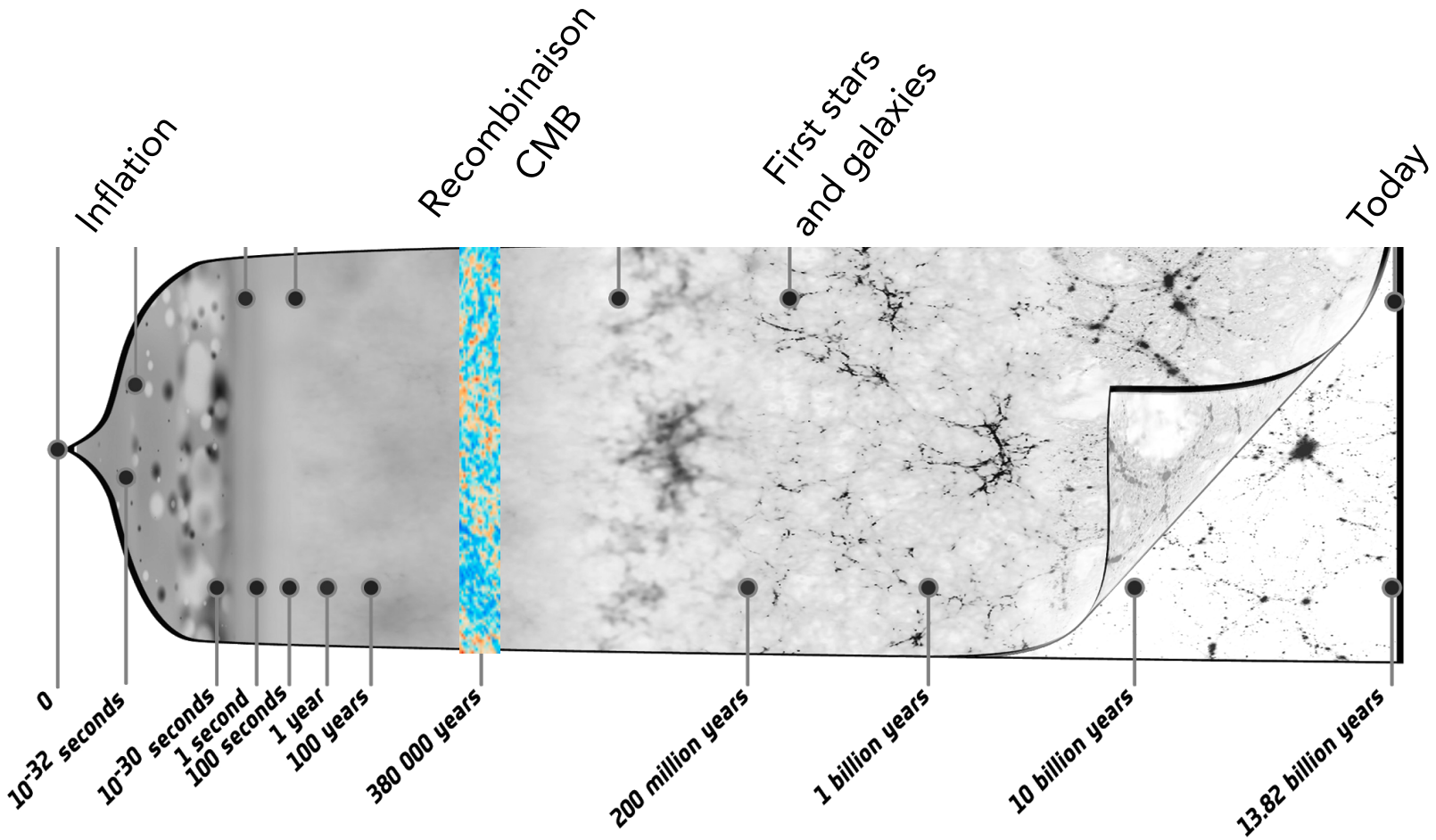
Scale factor

Evolution of the energy densities

matter = dark matter, ordinary matter (baryons)
radiation = relativistic particles = photons, neutrinos
dark energy = ?



History of the universe



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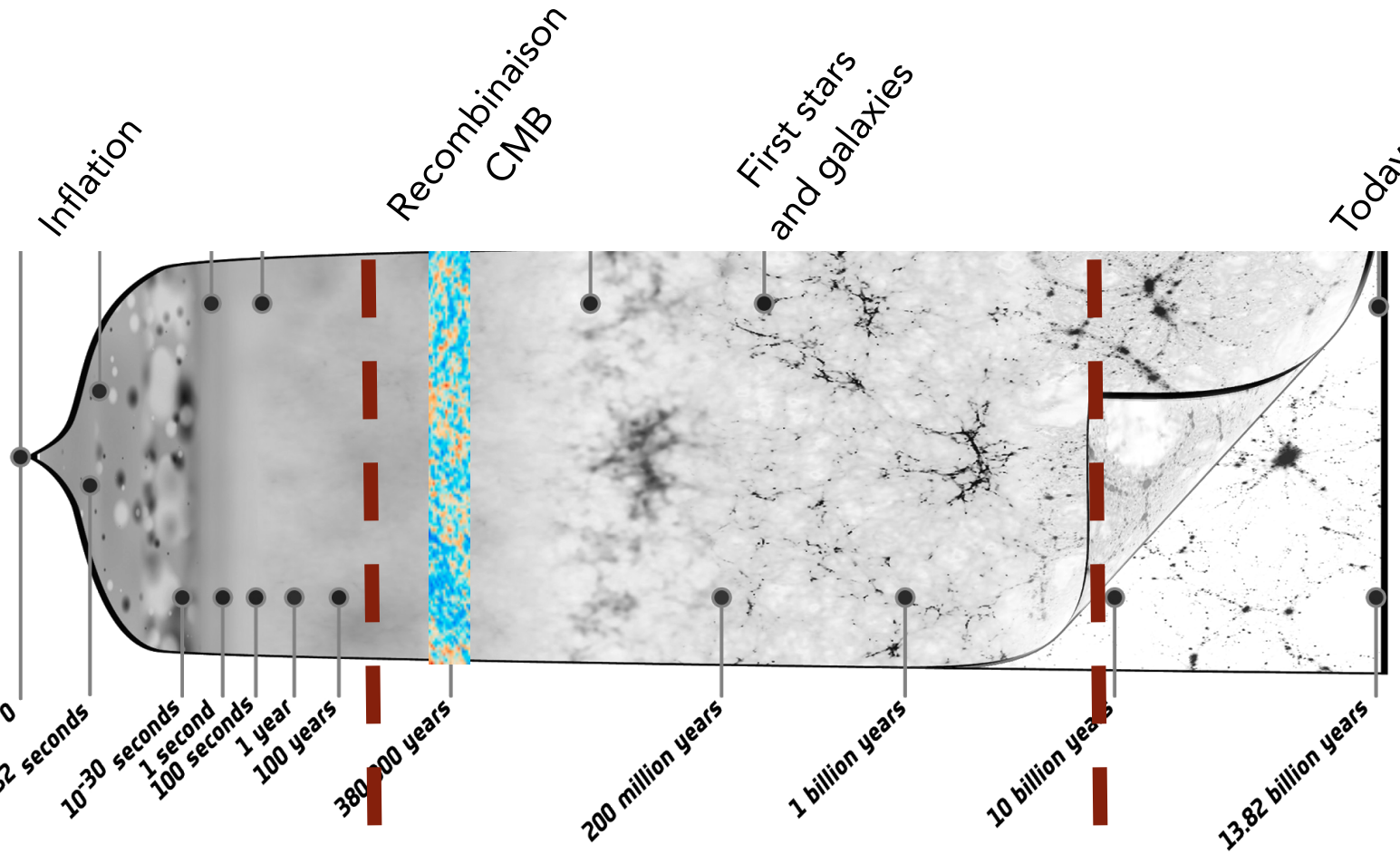
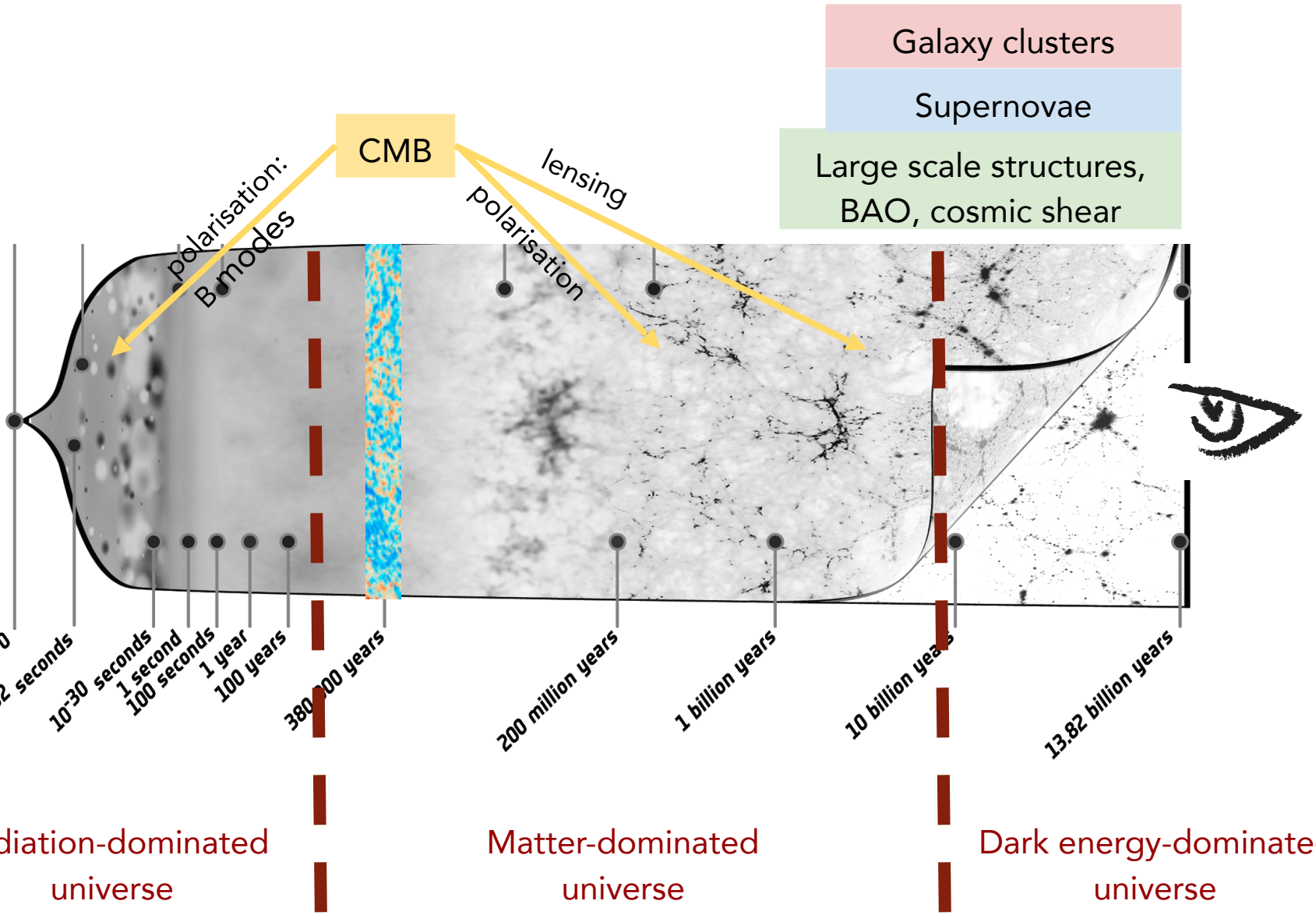


Radiation-dominated universe

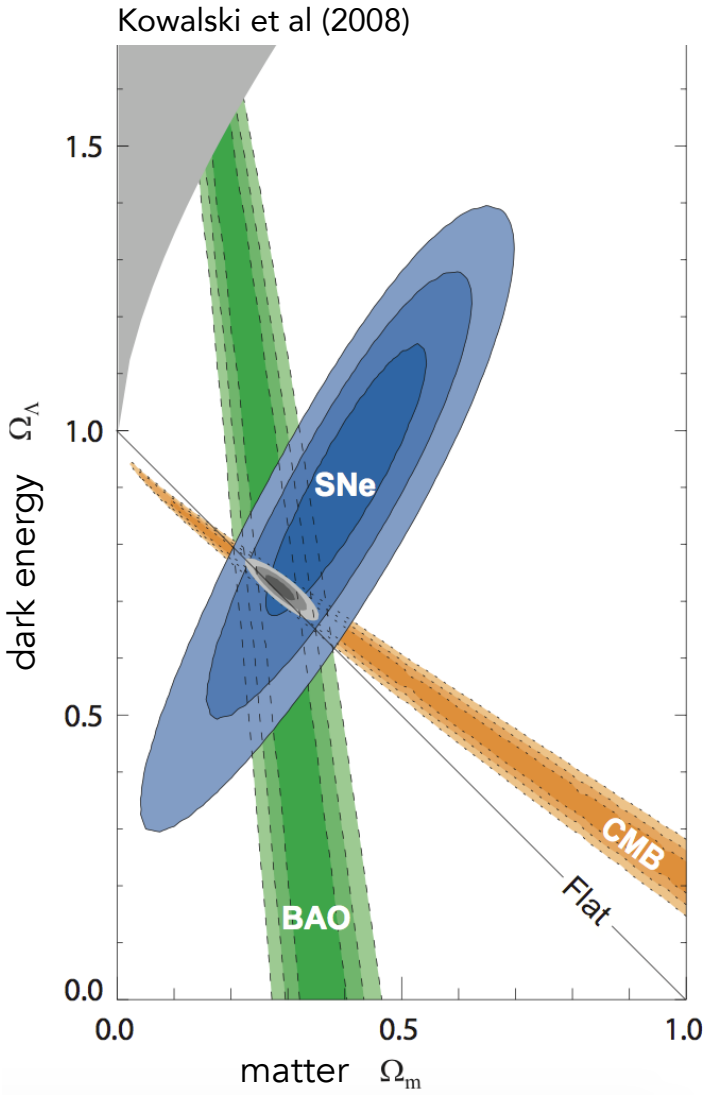
Matter-dominated universe

Dark energy-dominated universe

What probes and when?



Concordance model

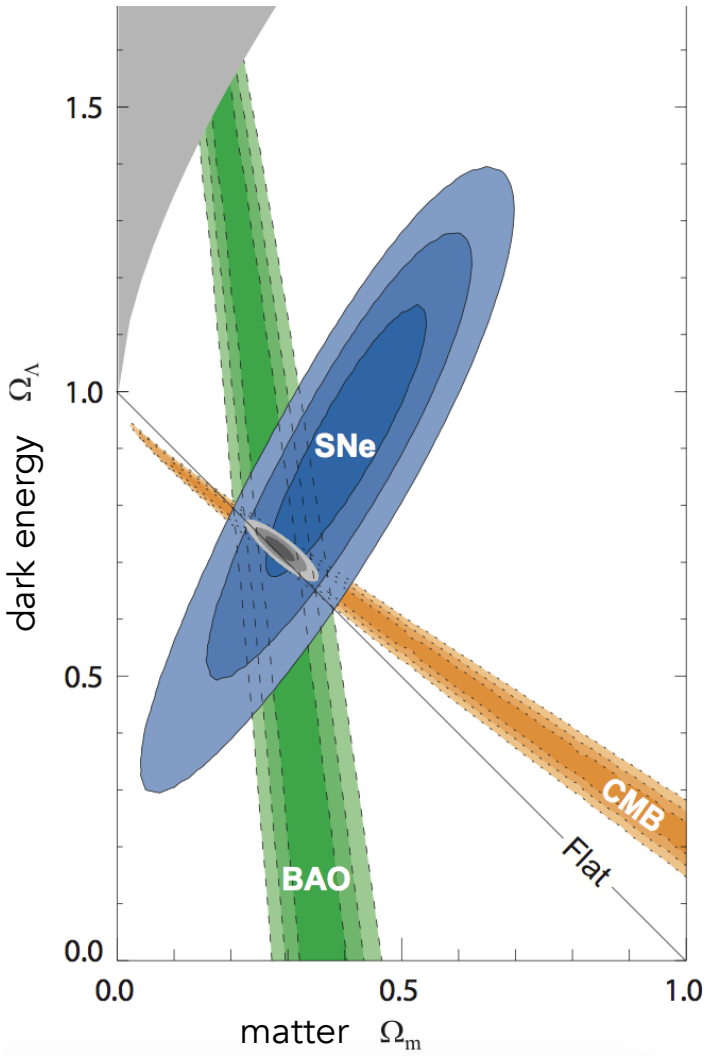


Observations agree with a ΛCDM model with, today:

- ~69% dark energy (Λ = cosmological constant)
- ~26% cold dark matter (CDM)
- ~5% ordinary matter

Concordance model

Kowalski et al (2008)



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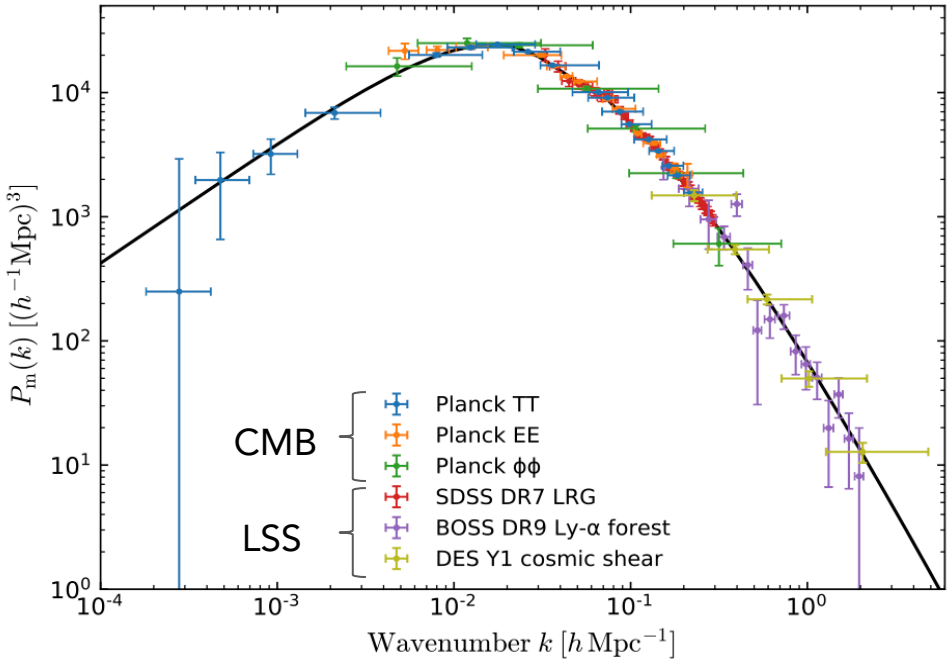
Model has only 6 free parameters

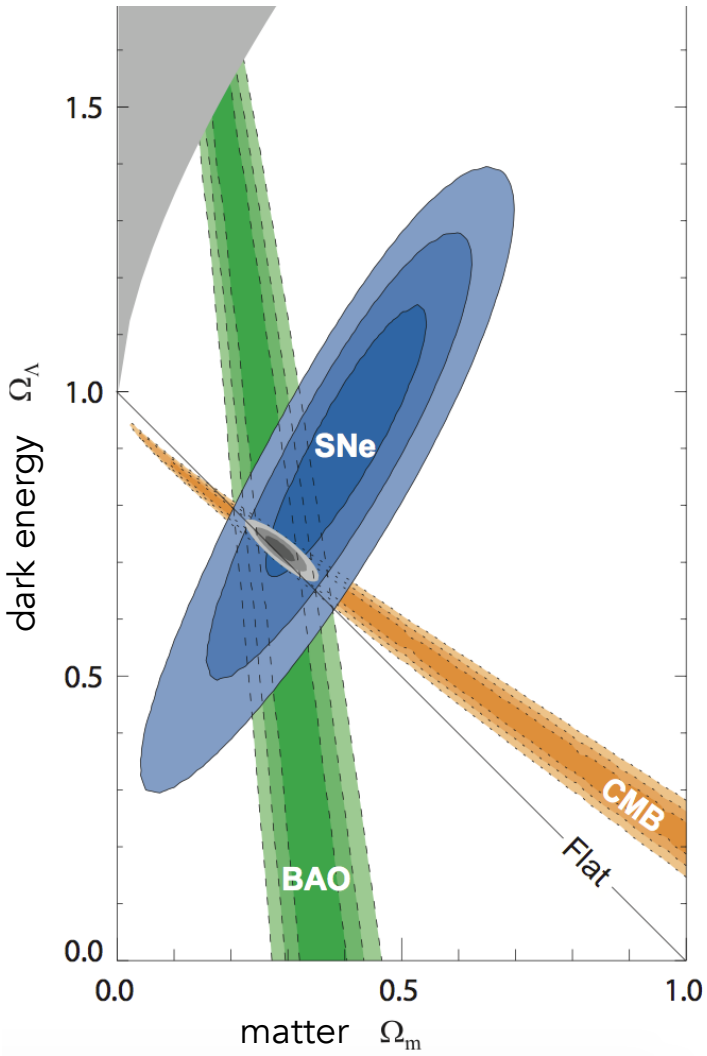
Planck collaboration (2018)



The ΛCDM is sufficient to describe all observations

Concordance model

Kowalski et al (2008)



Observations agree with a ΛCDM model with, today:

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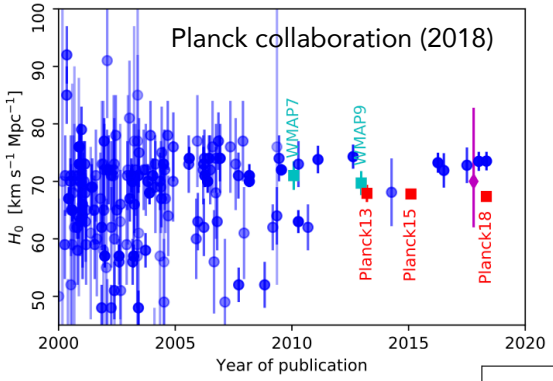
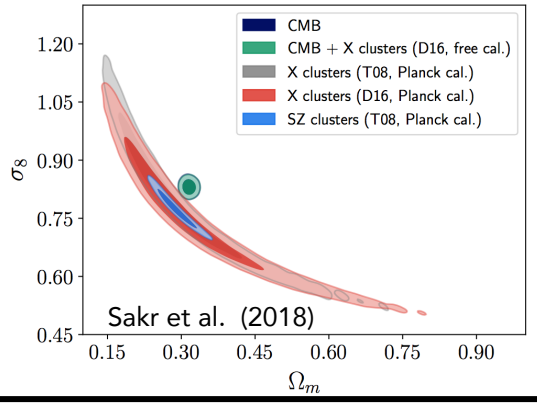
Concordance ? Yes, but some tension remain, e.g



Taux d'expansion de l'univers H_0

Tension CMB - comptage d'amas de galaxies



So, to go further…

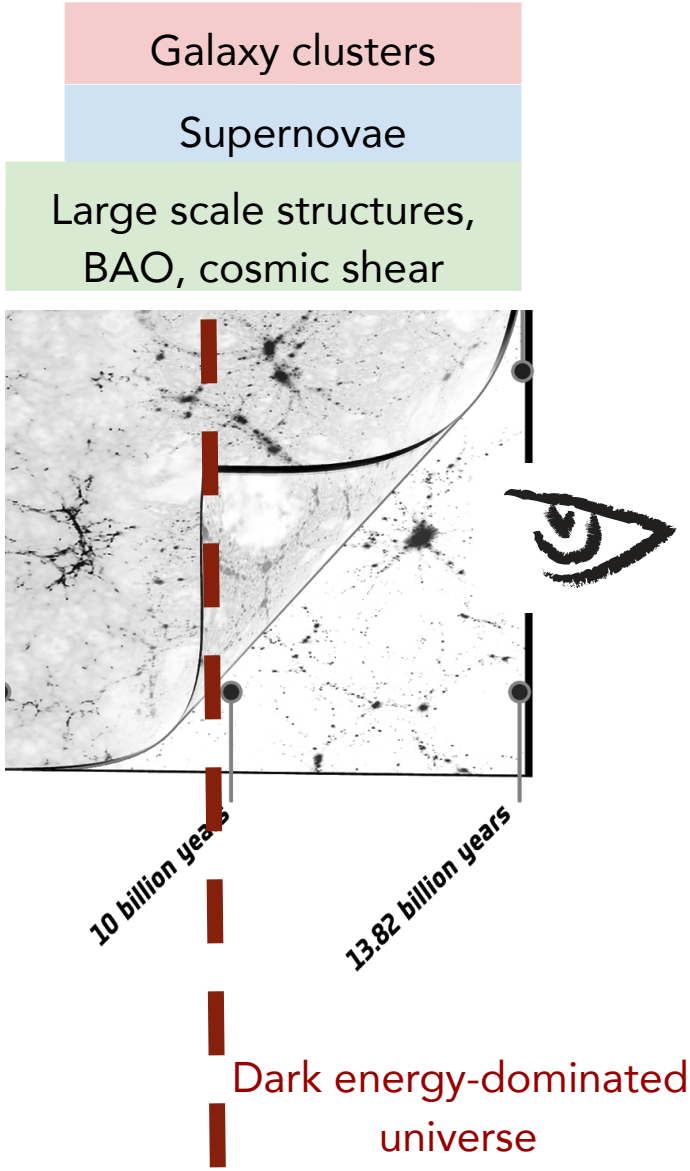
Focus on the "recent" cosmological probes

→ dark energy

→ dark matter

Dark energy impacts

- the geometry of the universe
  - → Supernovae
  - → Baryon acoustic oscillations
- the way structures grow
  - → Cluster abundance
  - → Cosmic shear



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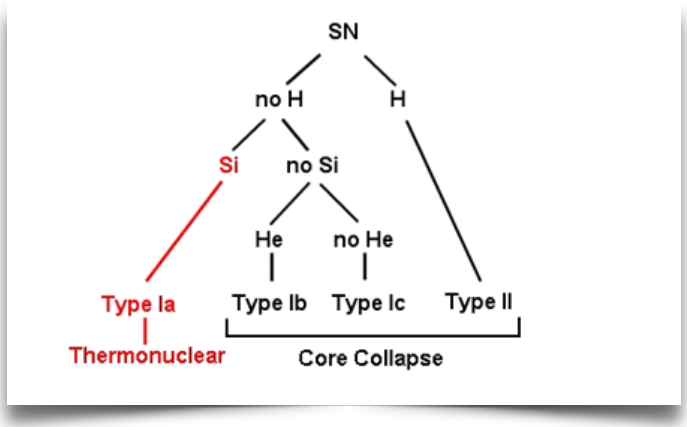
Experimental highlight: the LSST project

Measuring the expansion of the universe

Type Ia supernovae as standard candles

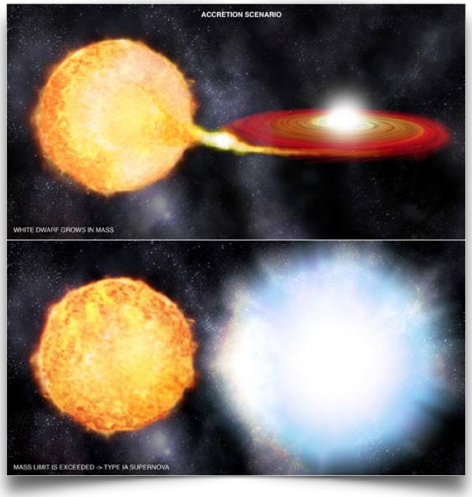
Supernova = "stellar explosion"

Supernova classification based on their light curve and spectra



Type Ia supernovae: binary system including a white dwarf

- single degenerate system: 1 WD accreting material from a companion
- double degenerate system: merger of 2 WD

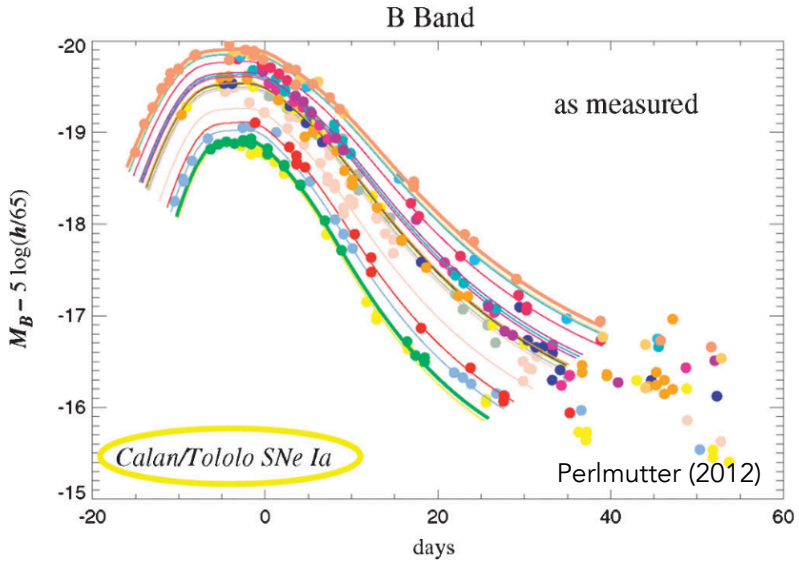


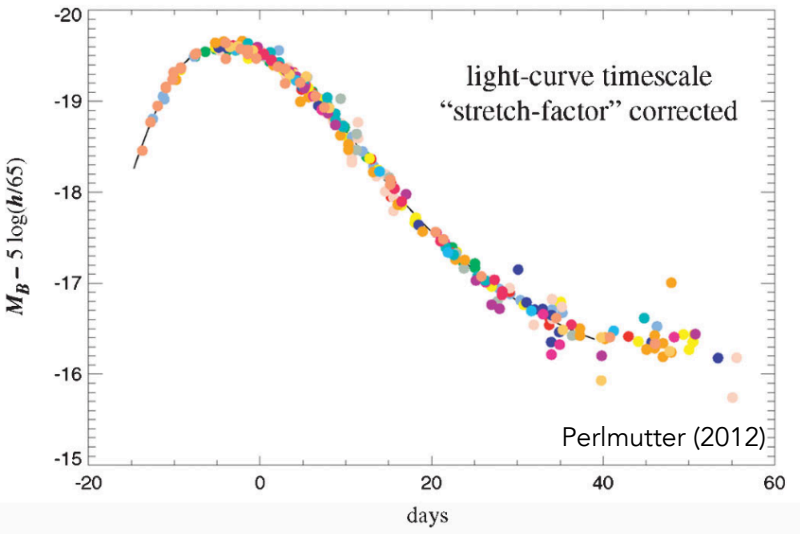
If mass accreted on the **WD > 1.4 Msun**: explosion

Explosion always at the same mass = same peak luminosity

so, **"standard" candle**

Type Ia supernovae as standard(isable) candles





Standardisation

Measured

Known because standard candle

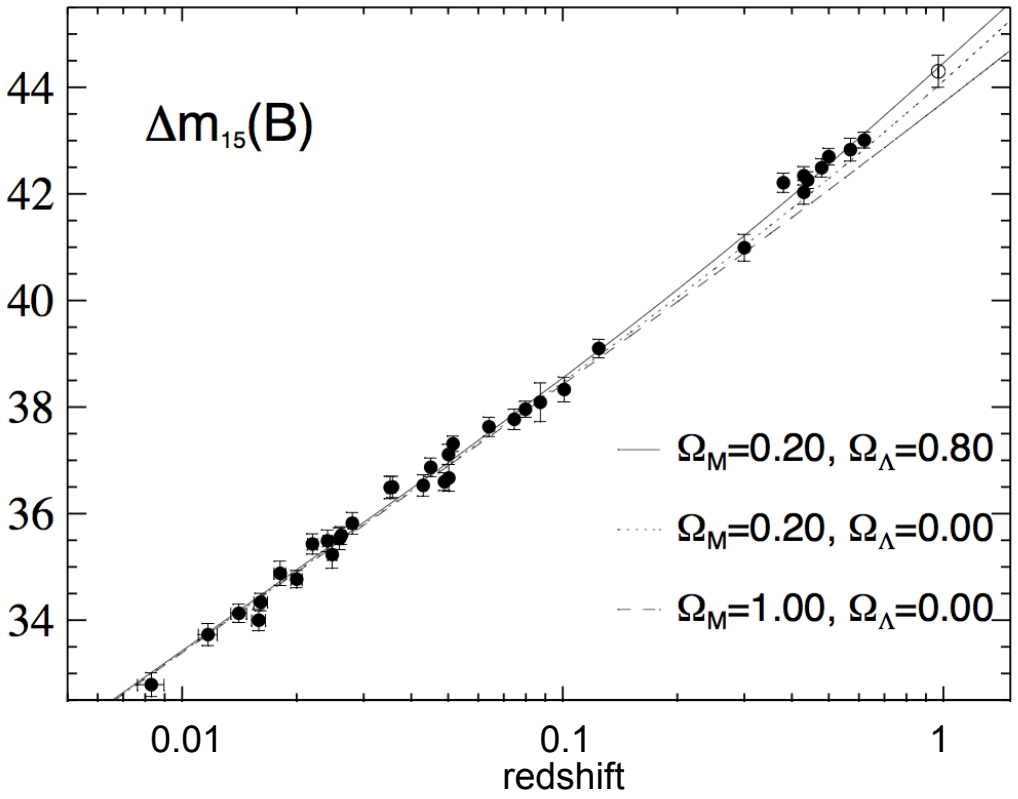
$$F = \frac{L}{4\pi D_L^2}$$

D_L = luminosity distance = f(cosmology)

Type Ia supernovae Hubble diagram - then

Riess et al. SCP (1998) - 34 supernovae

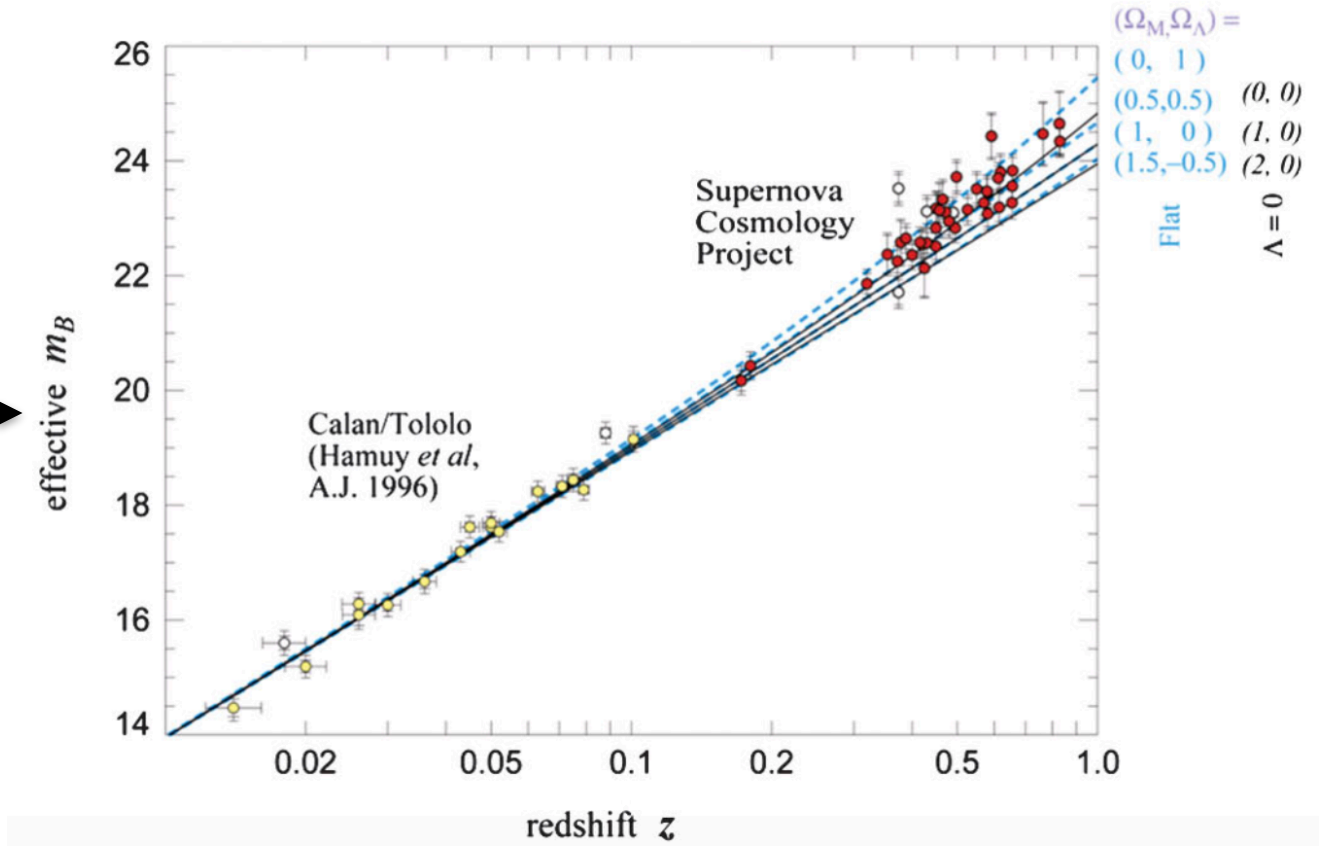
D_L ⟷ m-M (mag)



Type Ia supernovae Hubble diagram - then

Perlmutter et al. SCP (1998) - 42 supernovae

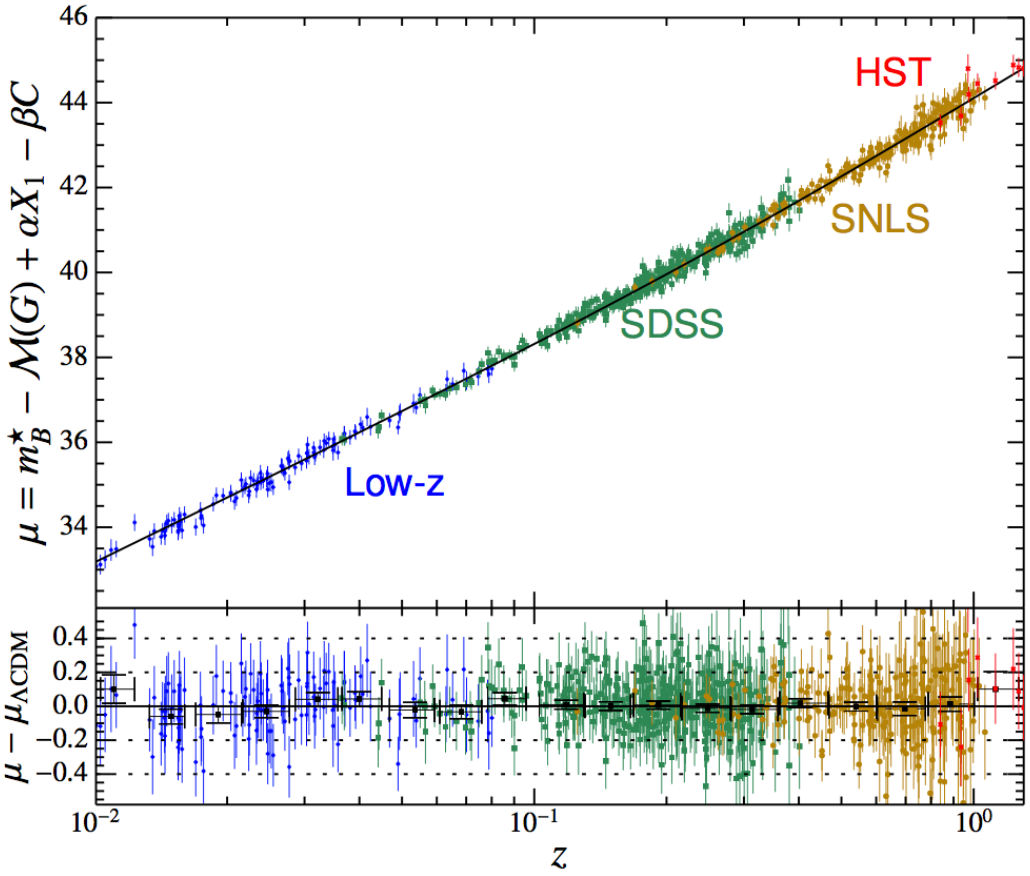
D_L ⟷



Type Ia supernovae Hubble diagram - now

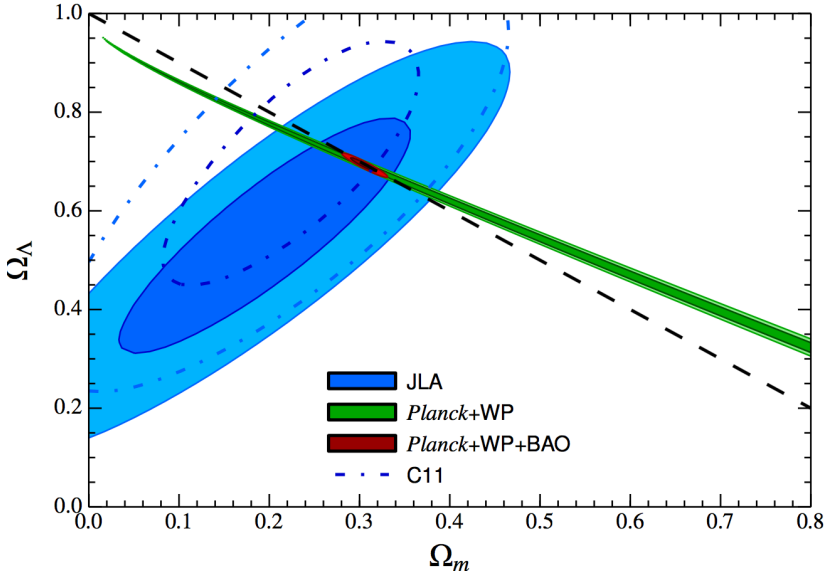
Betoule et al. JLA (2014) - 740 supernovae

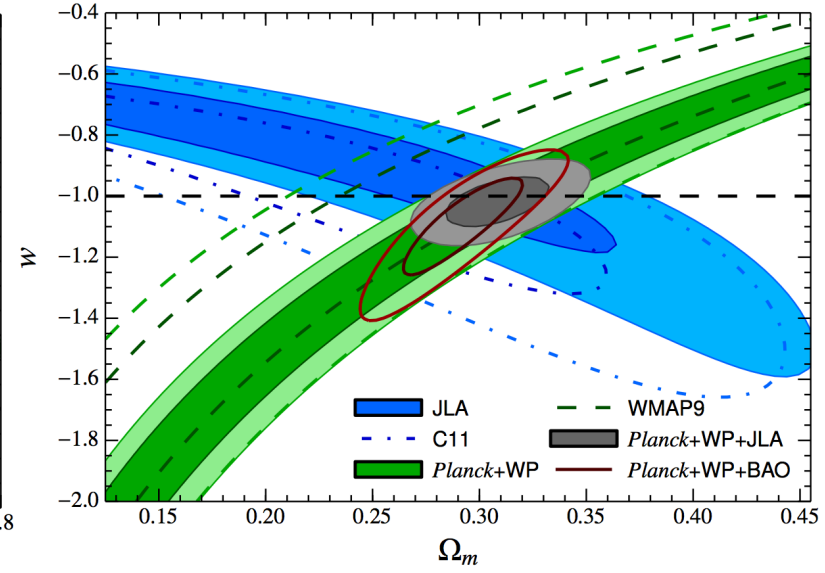
D_L ⟷

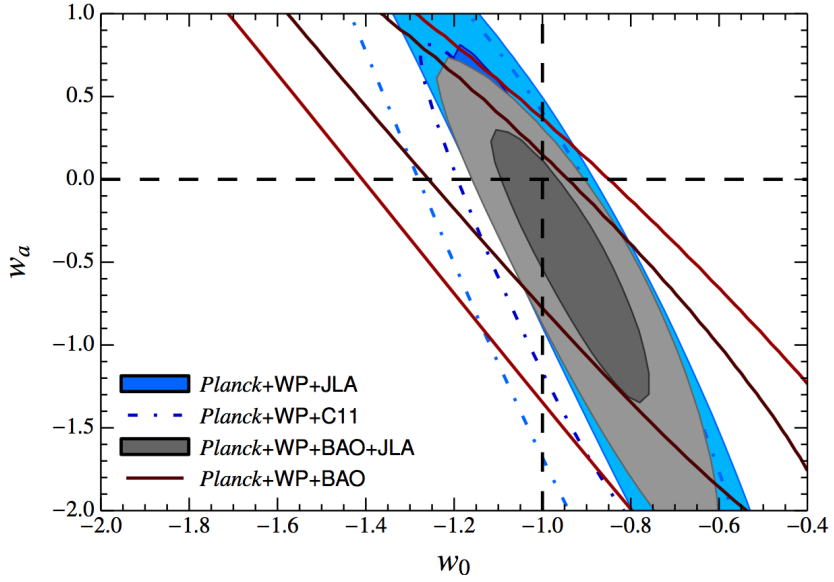


Type Ia supernovae and dark energy

Betoule et al. JLA (2014) - 740 supernovae







$$w = \frac{p}{\rho}.$$ Equation of state

$$w(z) = w_0 + w_a \frac{z}{1+z}$$

With current data, dark energy compatible with a cosmological constant

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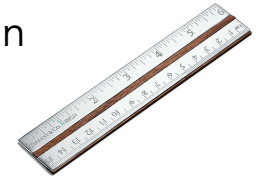
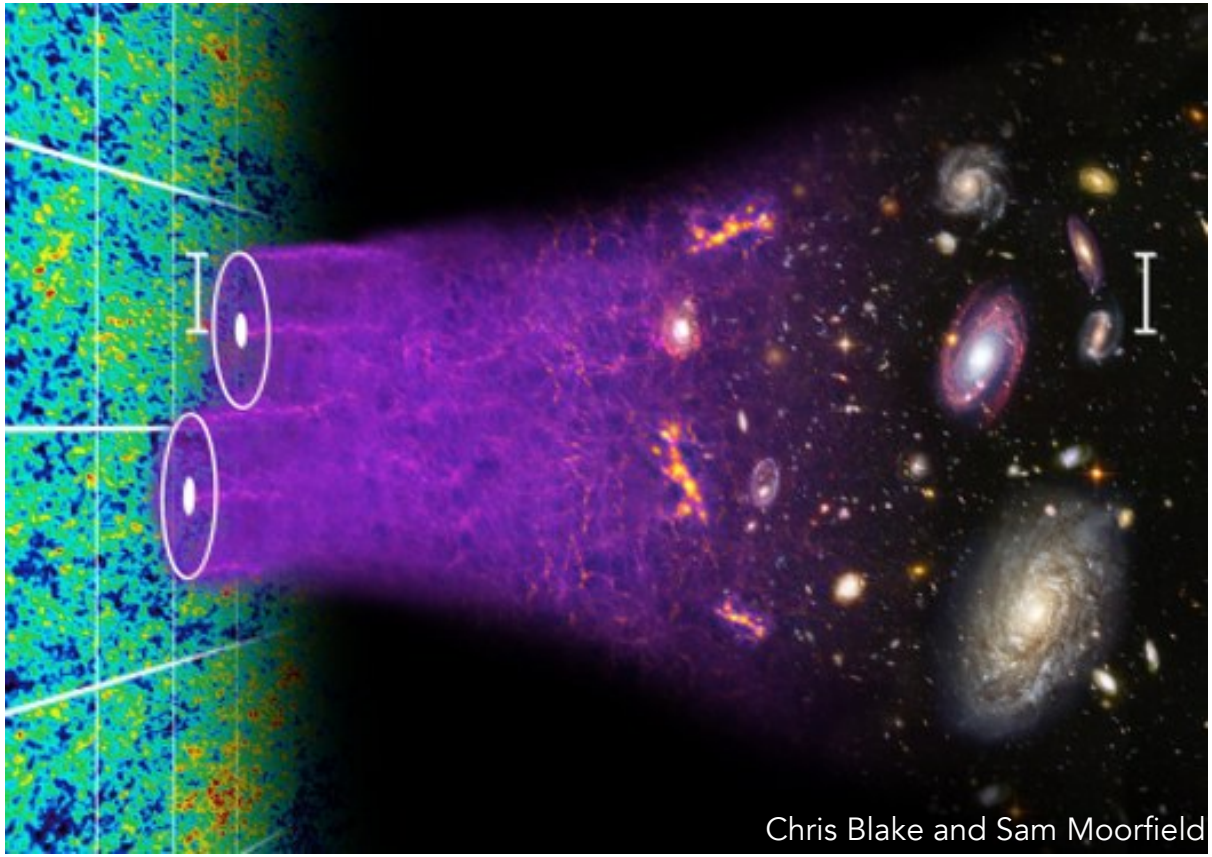
Baryon acoustic oscillations as standard ruler

BAO = density waves propagating the primordial plasma in the early universe

BAO scale = maximum distance that wave could propagate before recombination

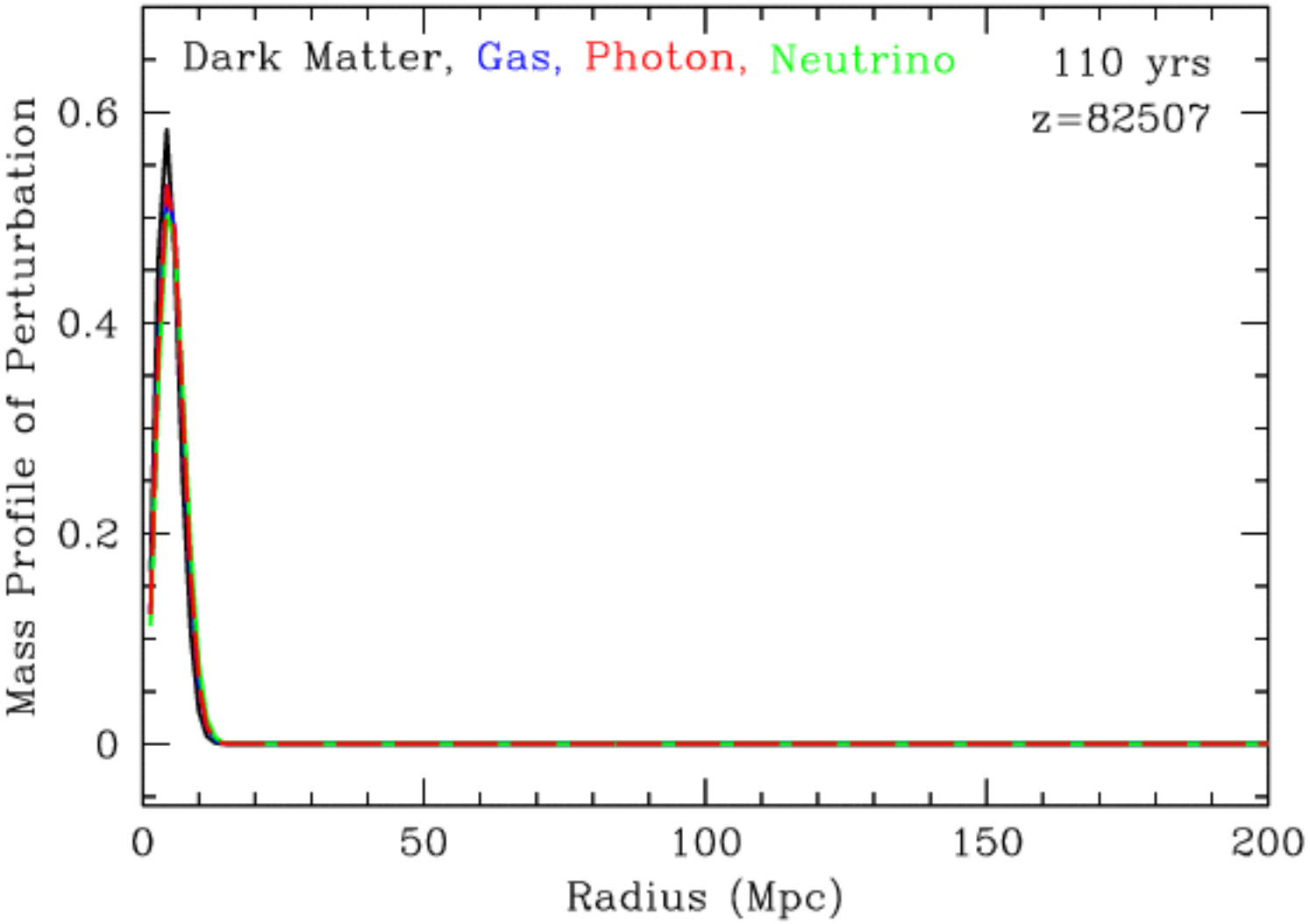
- imprint is left in the CMB
- imprint is left in the matter distribution today





BAO scale - the cartoon

https://www.cfa.harvard.edu/~deisenst/acousticpeak/acoustic_physics.html



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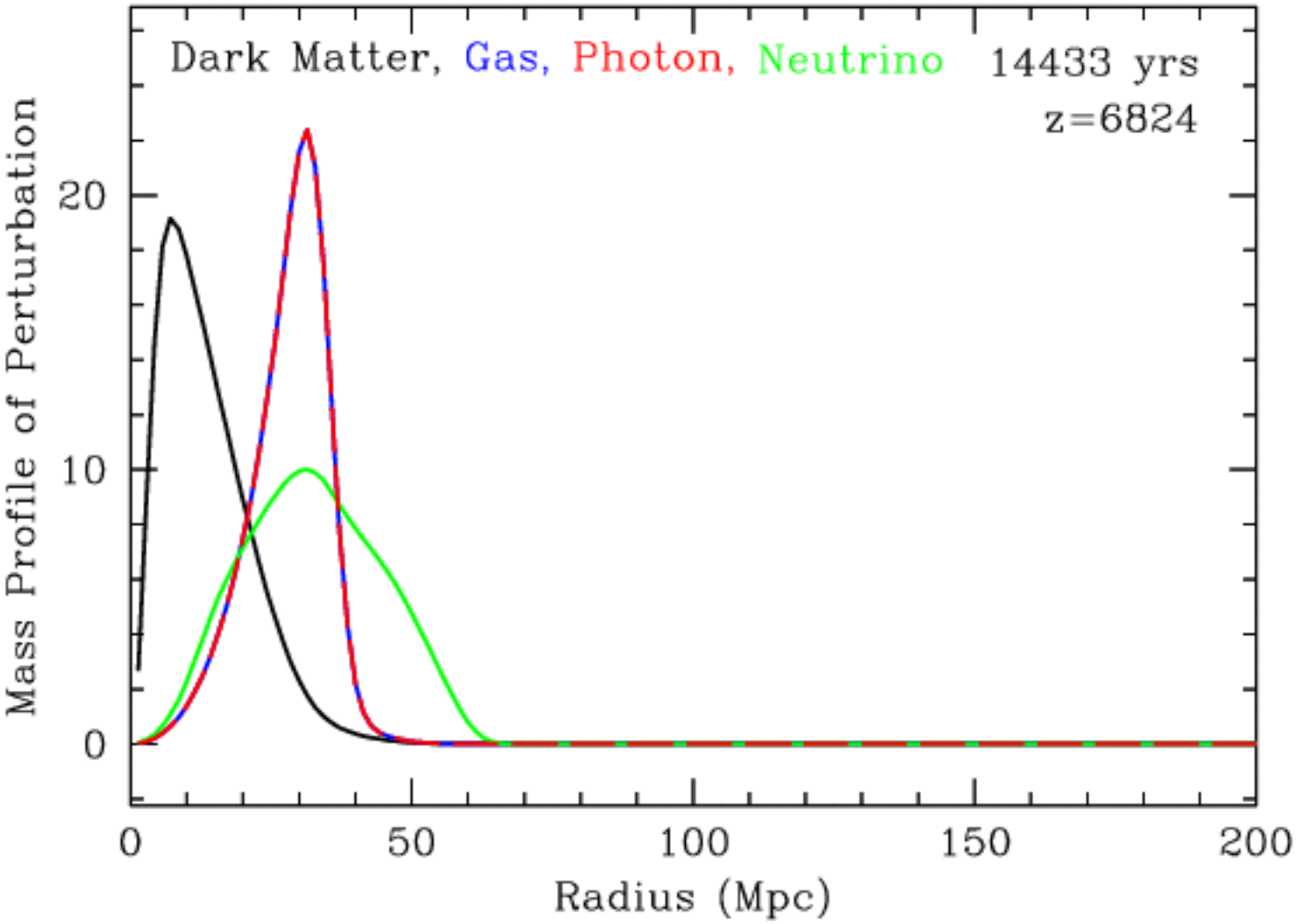

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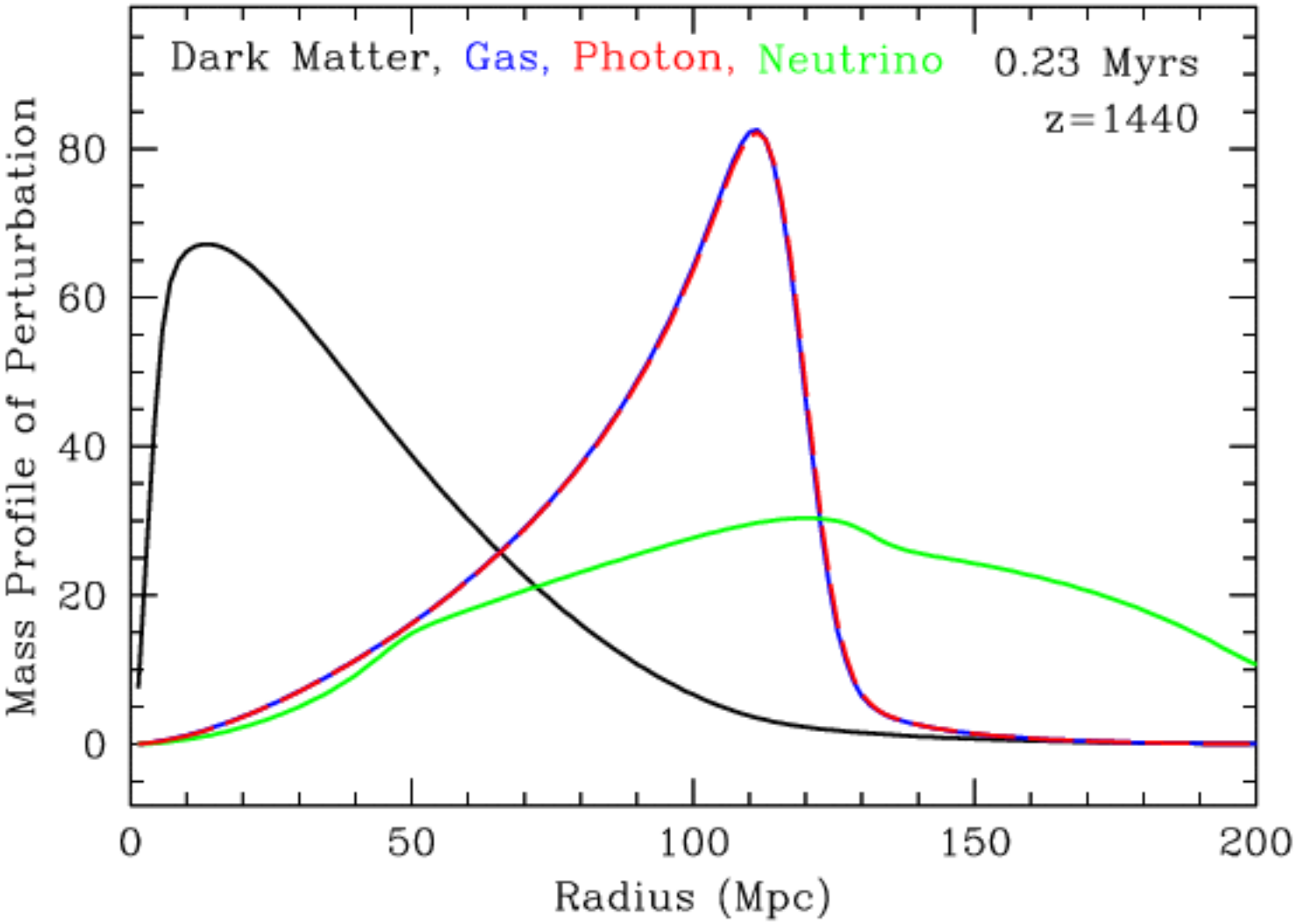

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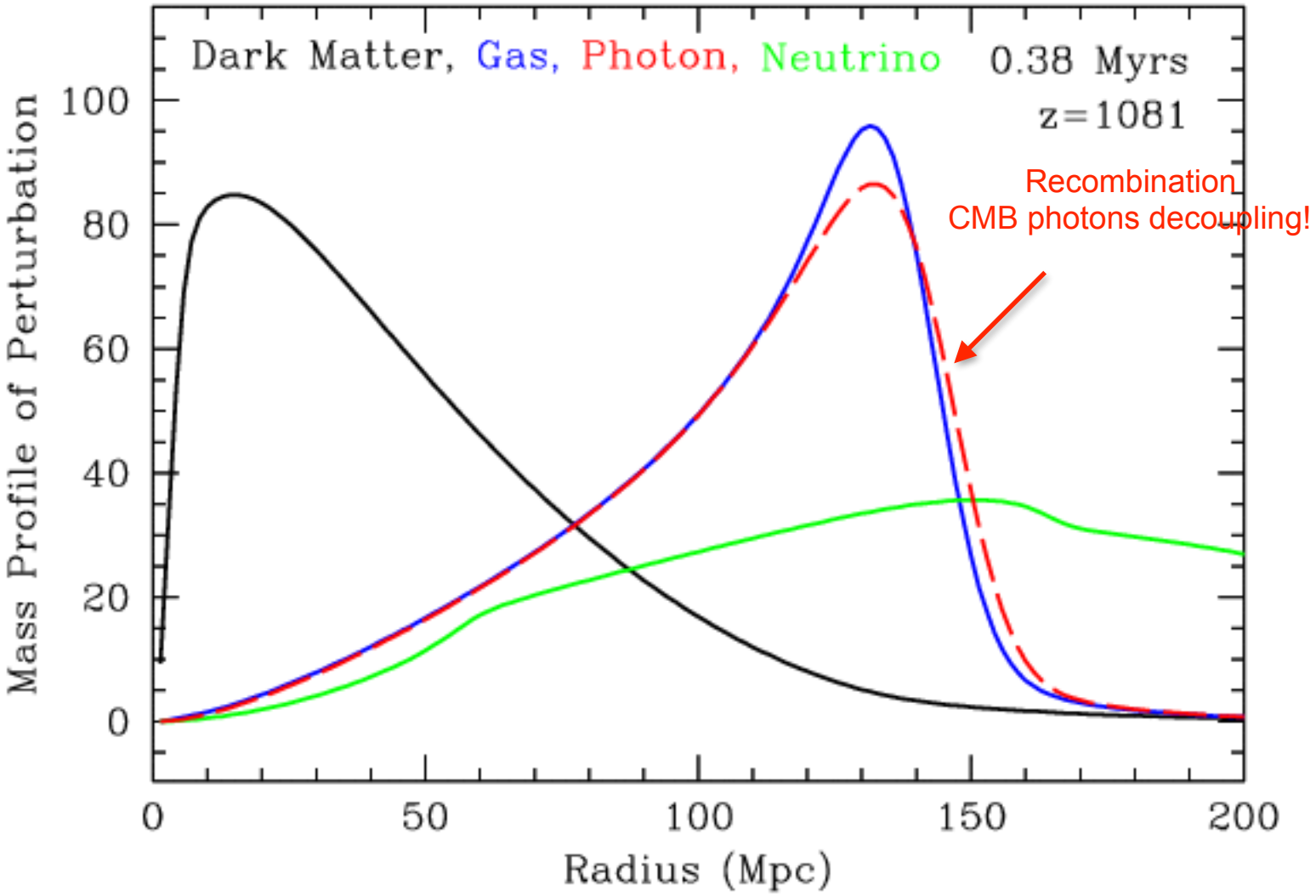

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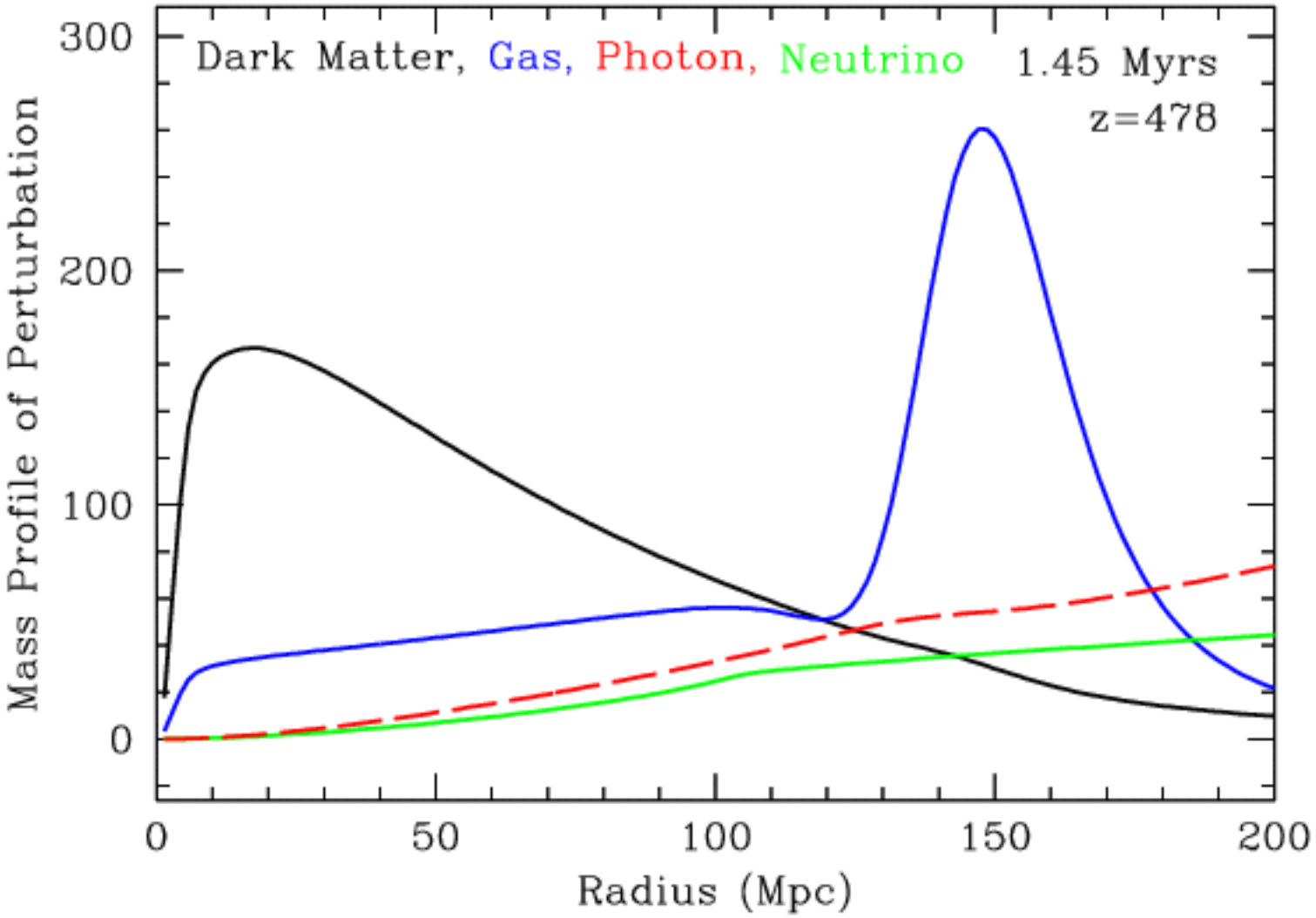

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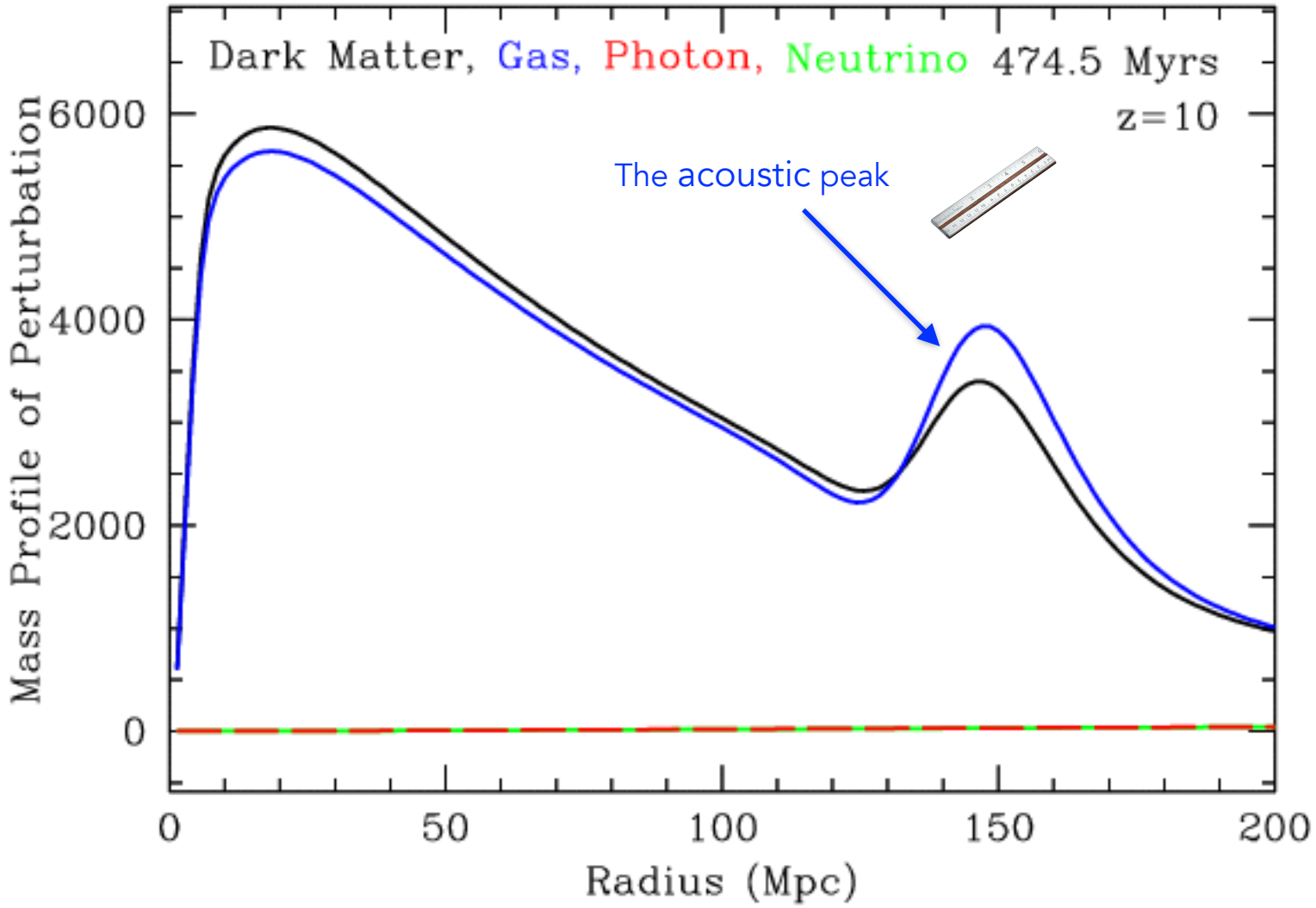
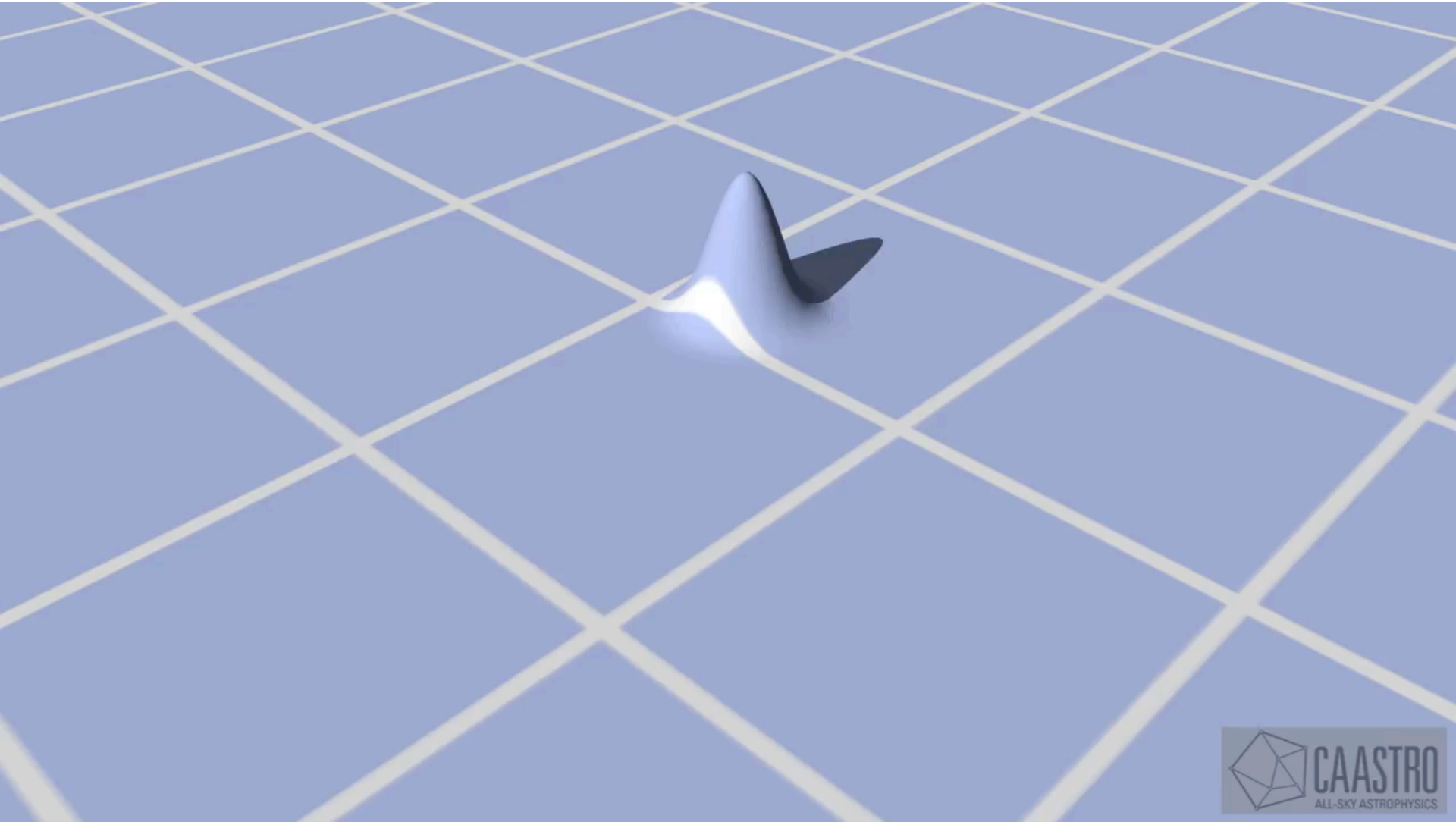
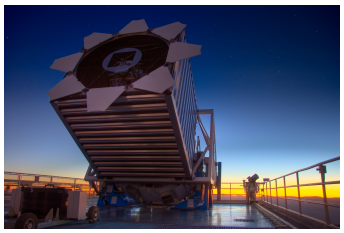


BAO scale - the movie



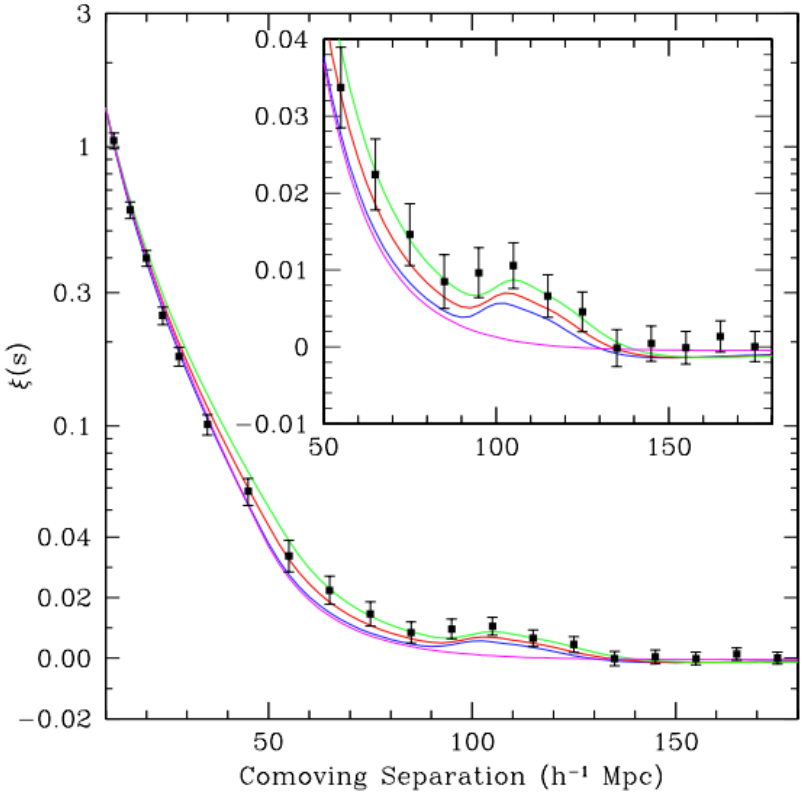
BAO scale - for real



Sloan Digital Sky Survey (SDSS, 2005-2020)
BOSS, eBOSS

Eisentein et al. (2005), using SDSS DR3 - hooray! The BAO peak is here!

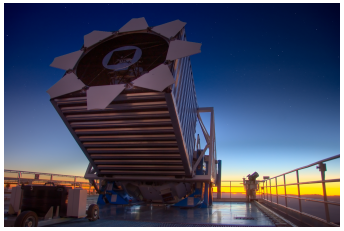
Eisenstein et al. (2005)



46748 luminous red galaxies

$0.16 < z < 0.47$

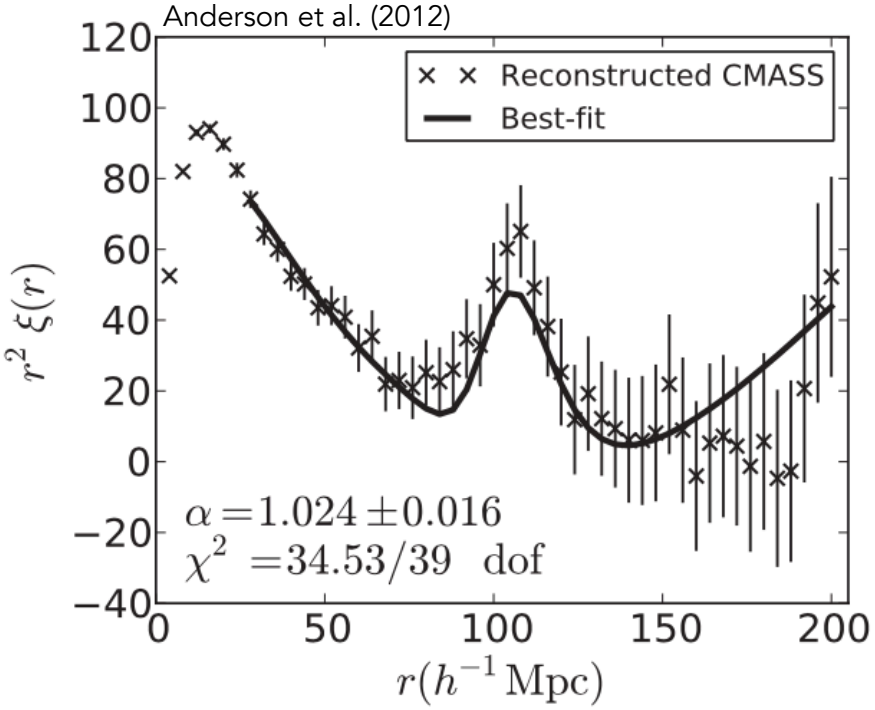
BAO scale - for real



Sloan Digital Sky Survey (SDSS, 2005-2020)
BOSS, eBOSS

Anderson et al. (2012), using SDSS DR9

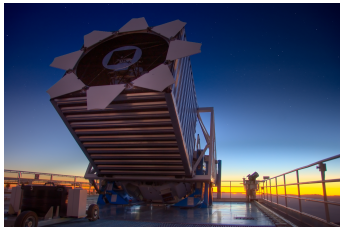
Anderson et al. (2012)



264283 massive galaxies

$0.43 < z < 0.7$

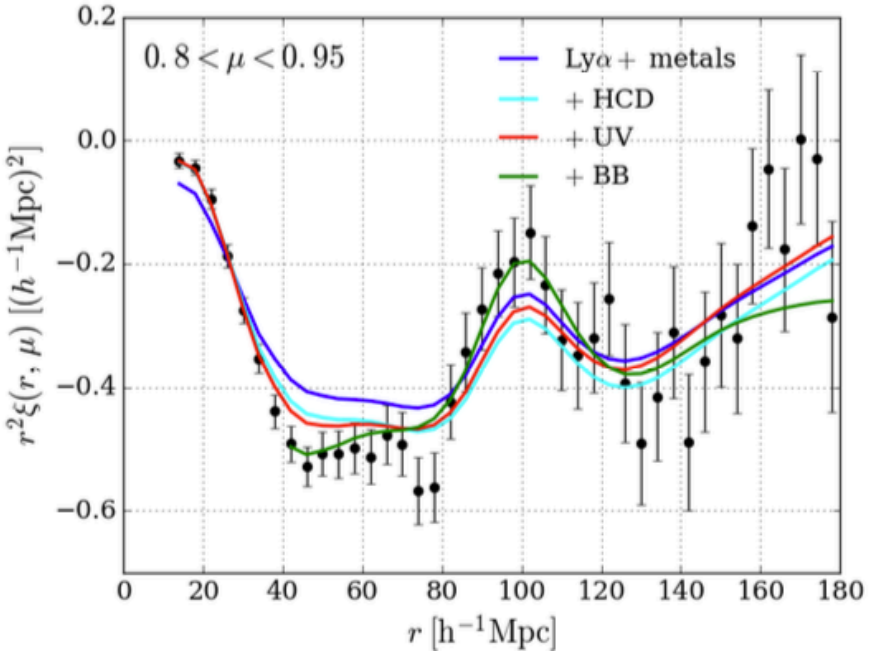
BAO scale - for real



Sloan Digital Sky Survey (SDSS, 2005-2020)
BOSS, eBOSS

Bautista et al. (2017), using SDSS DR12

Anderson et al. (2012)



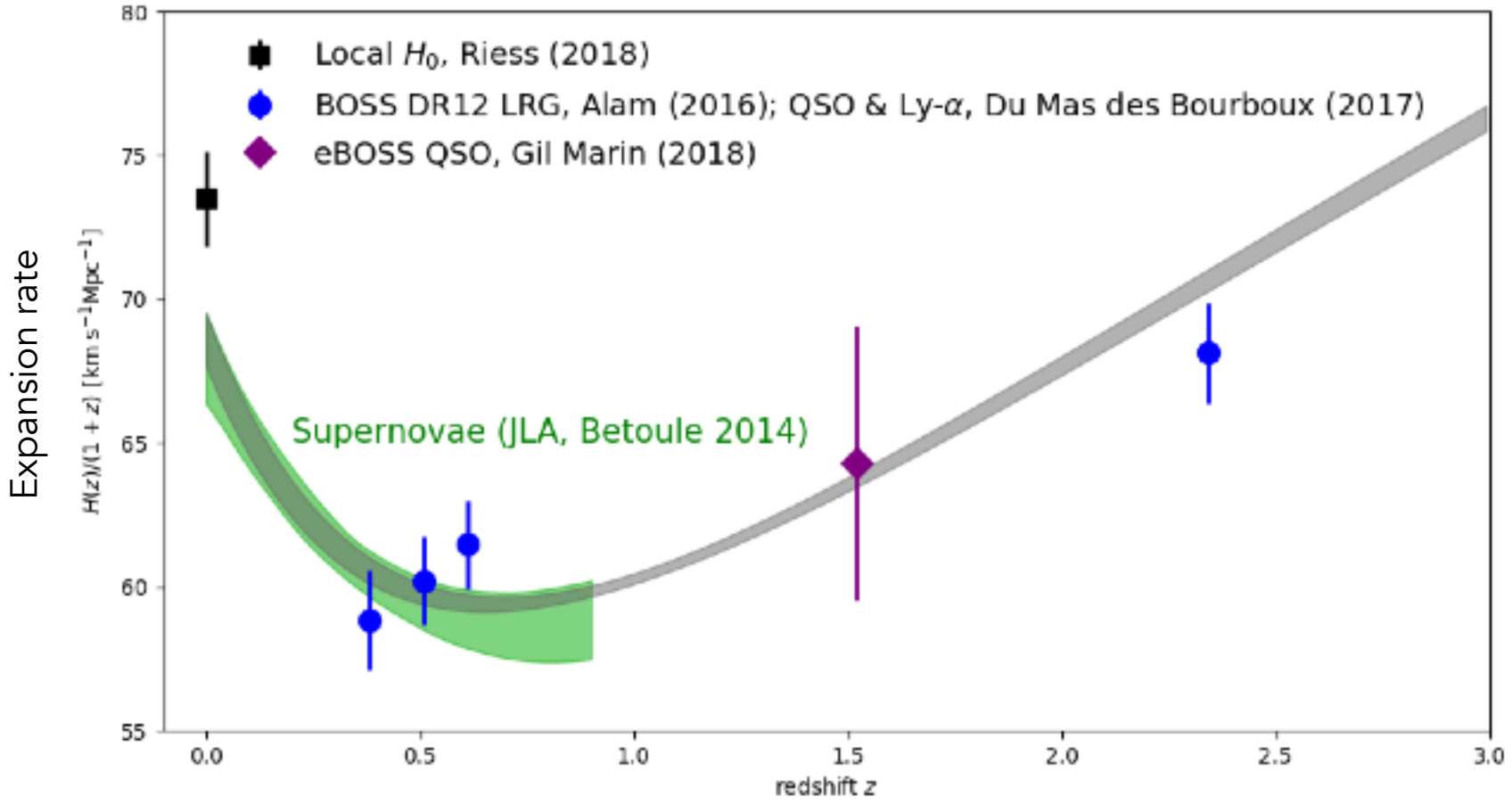
157783 quasar spectra

$2.1 < z < 3.5$

BAO - expansion history as of now

BAO scale: 2 measurements

- along the line of sight — H(z)
- transverse to the line of sight — $D_A(z)$



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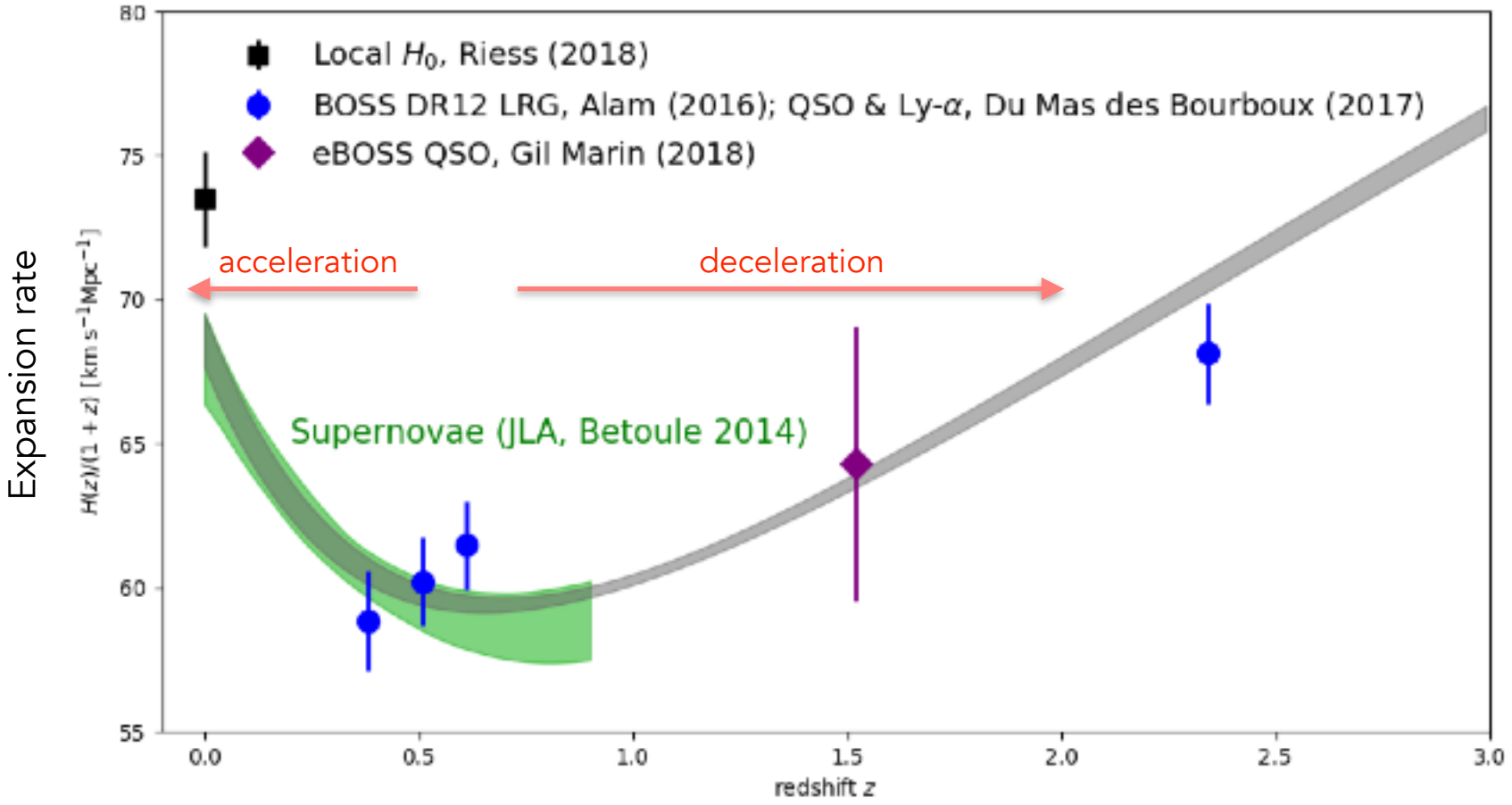
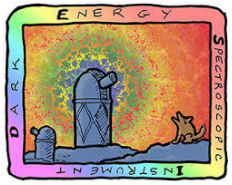
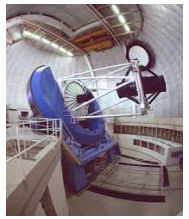
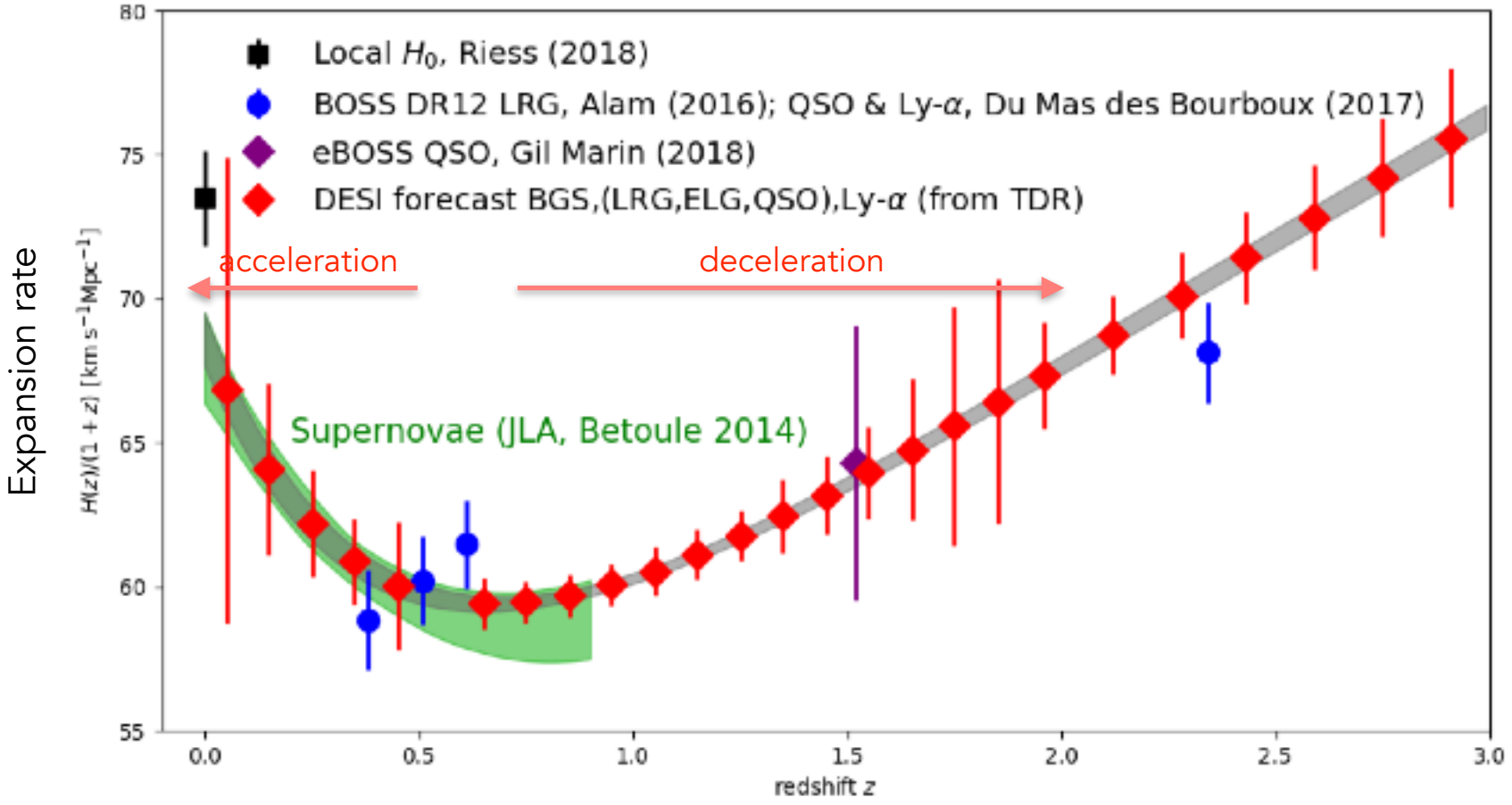


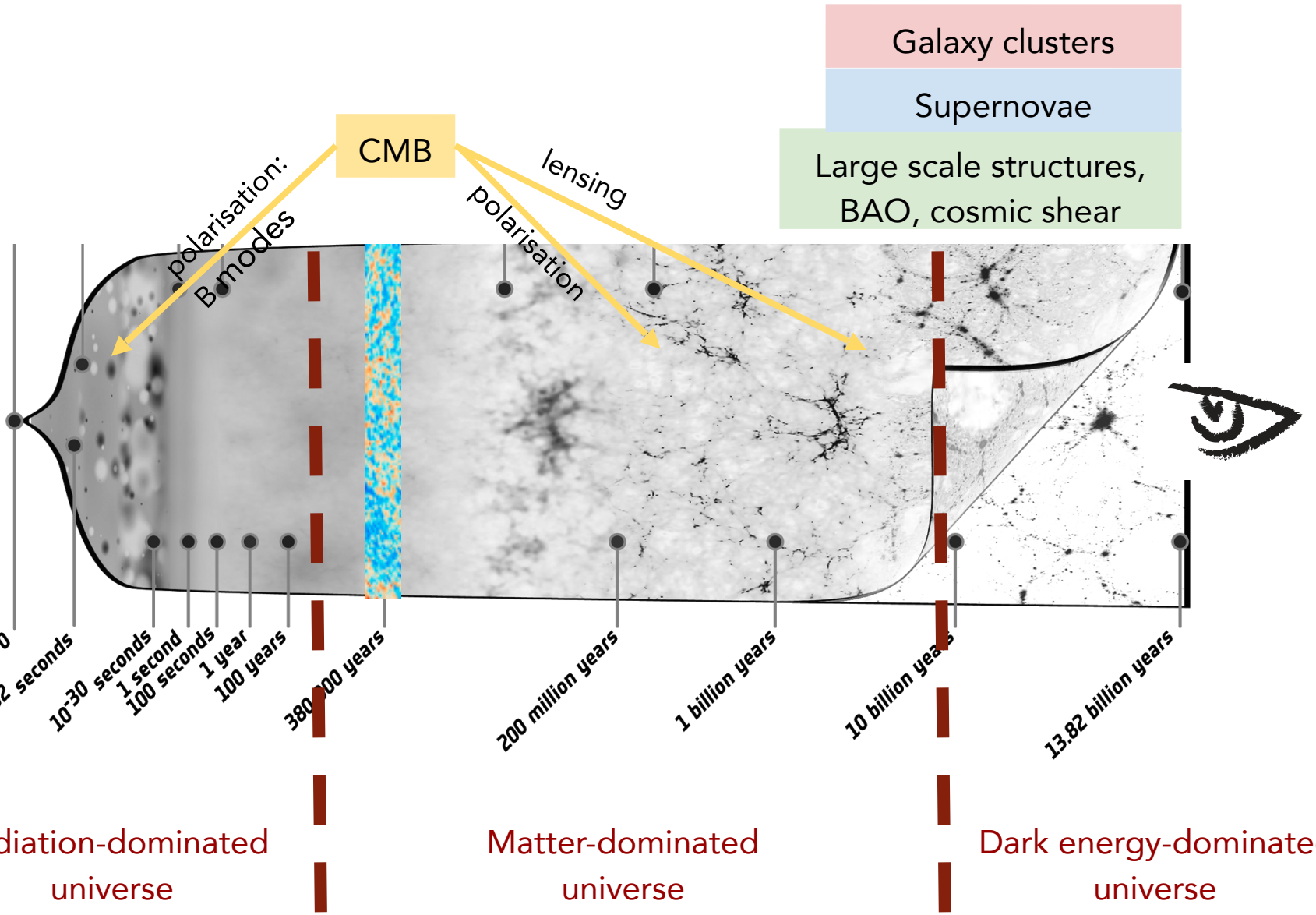
BAO - expansion history with DESI (near future)







What probes and when?



Introduction

- History of the universe
- Expansion
- Concordance model

Measuring the expansion of the universe

- Type Ia supernovae
- Baryon acoustic oscillations

Experimental highlight: the LSST project

A lot of (optical) surveys

SDSS

DARK ENERGY SURVEY

HSC

DARK ENERGY SPECTROSCOPIC INSTRUMENT

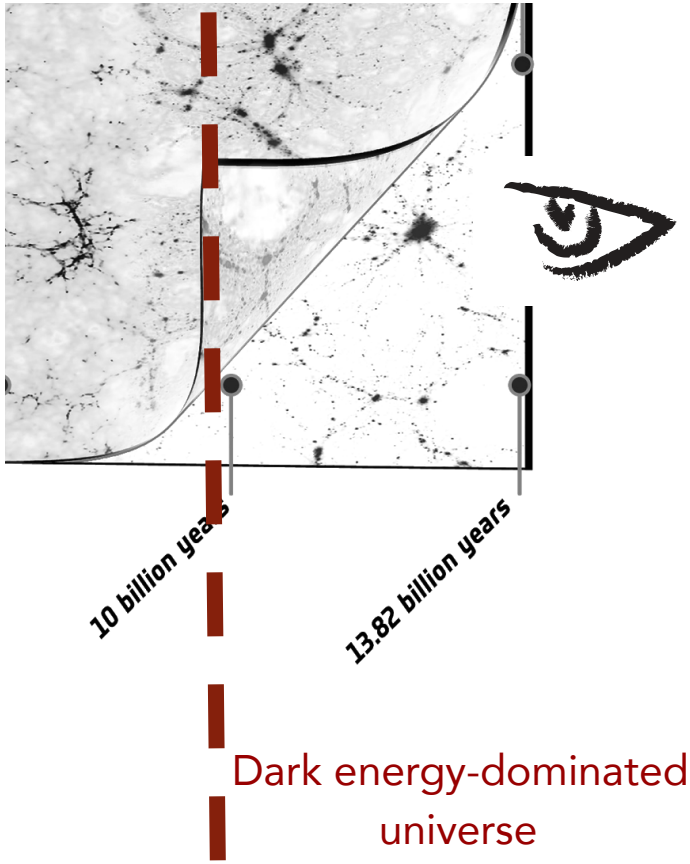
LSST
Large Synoptic Survey Telescope

Euclid consortium

Galaxy clusters

Supernovae

Large scale structures, cosmic shear



Dark energy-dominated universe

The LSST project

US-lead project

Site: Cerro Pachon, Chili (~2700m)

Telescope: 8-m primary mirror, 9.6 deg² field of view

Caméra: 3.2 Gigapixels (CCD)

Survey:

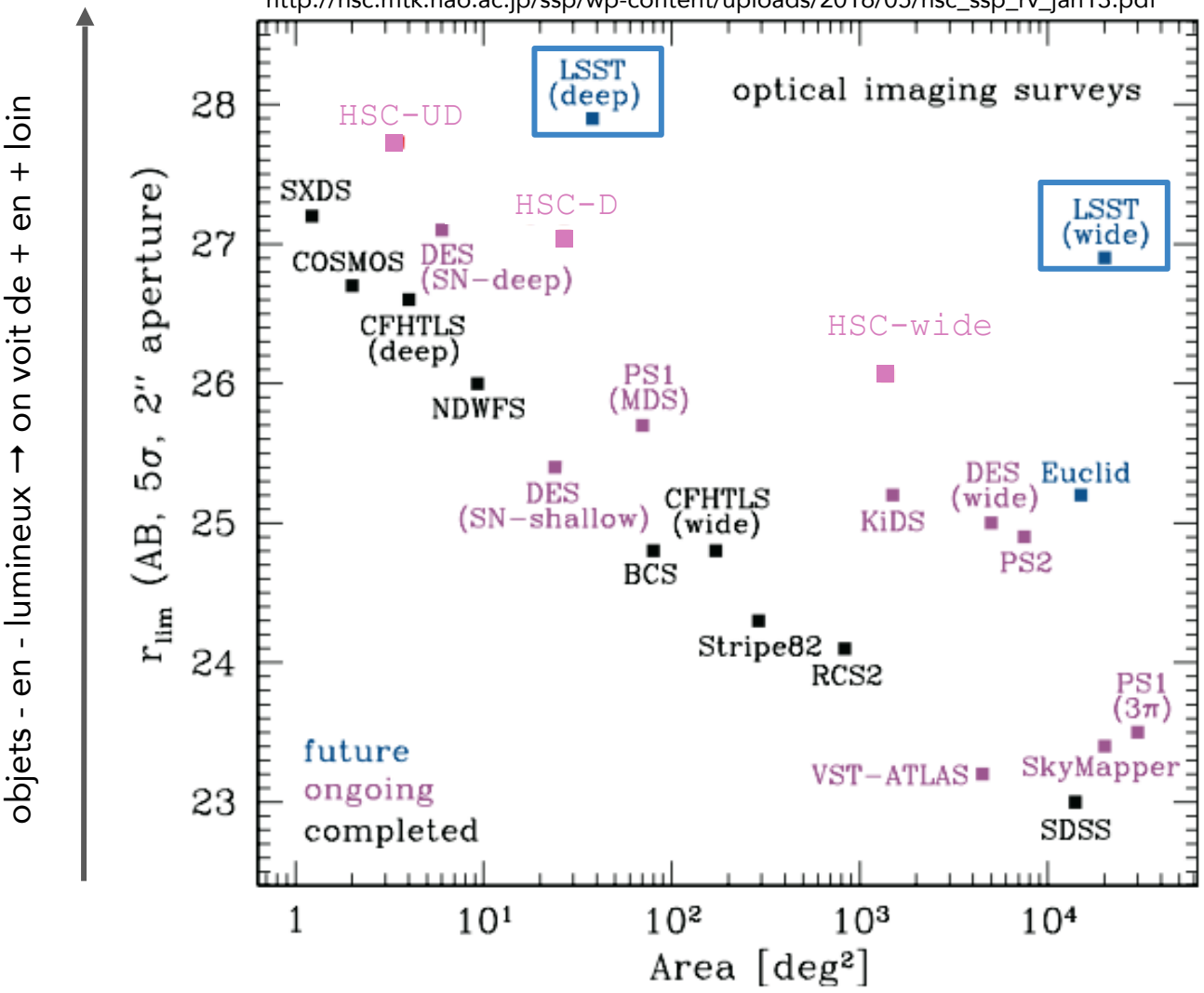
- 18000 deg²
- during10 ans
- in six filters (UV - near IR)
- cadence optimised for transients - SNIa machine!!

Data:

- 20 billions galaxies
- 20 TB /night = 4200 DVD or 800 blue-ray /night
- 15 PB database after 10 years

Couverture - profondeur

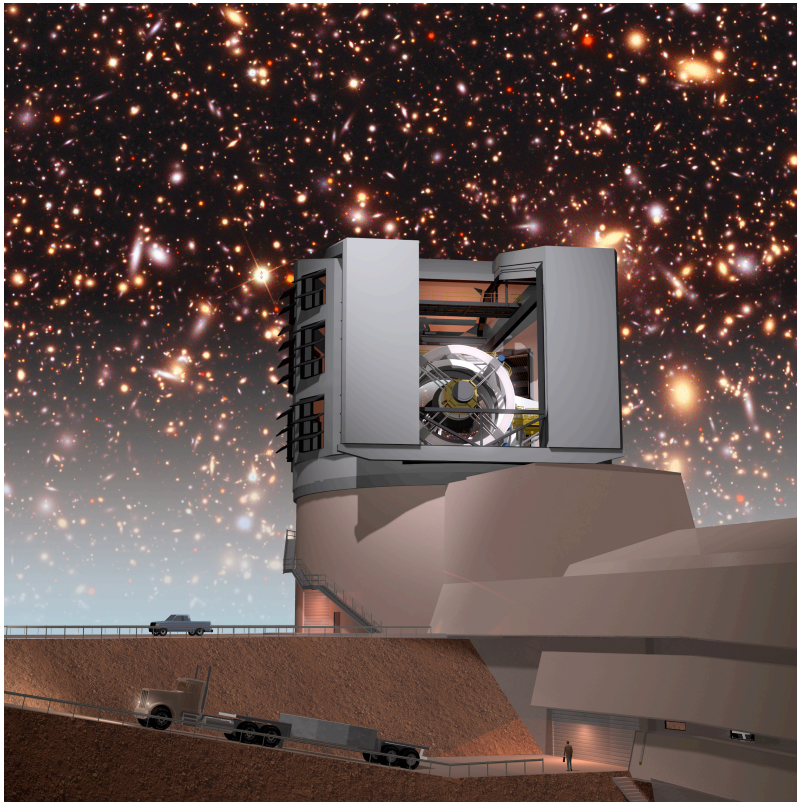
http://hsc.mtk.nao.ac.jp/ssp/wp-content/uploads/2016/05/hsc_ssp_rv_jan13.pdf



Science with LSST (Large Synoptic Survey Telescope)

If it's in the sky at optical wavelength, you can study it with LSST.

Science preparation is taking place in independent scientific collaborations



Galaxies (>~100)

Stars, Milky Way, and Local Volume (>~100)

Solar System

Dark Energy (842)

Strong Lensing

Active Galactic Nuclei (~50)

Transients/variable stars (>~100)

Informatics and Statistics (~50)


Stay tuned, it's gonna be awesome!