# Comprendre l'infiniment grand

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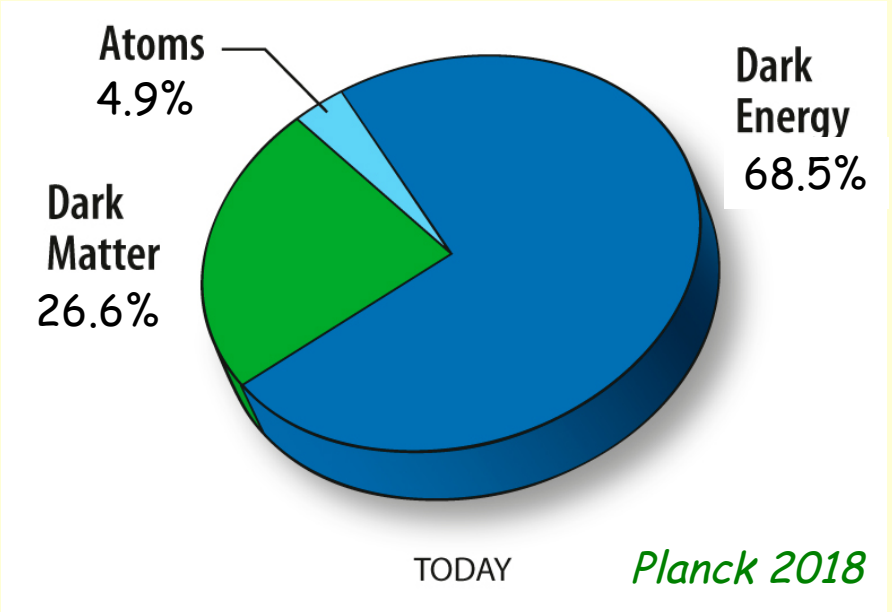
1) Du modèle du Big Bang au contenu de l'Univers
2) Mesures cosmologiques
3) **Les grandes structures de l'Univers**

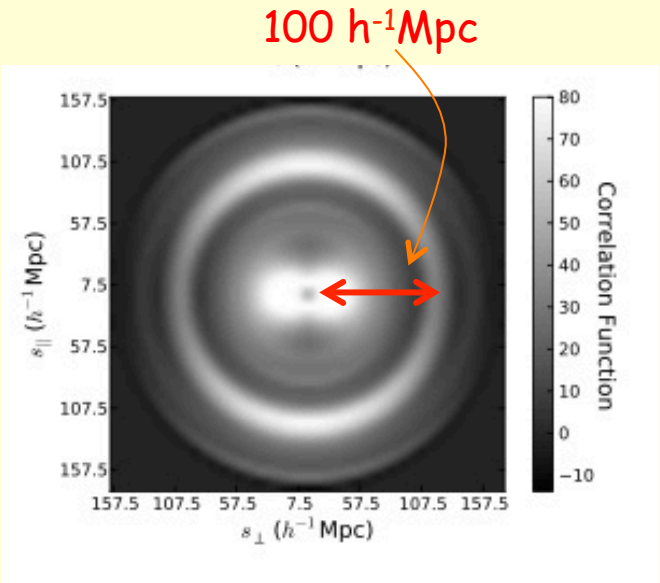
# Large scale structures

- Summary :

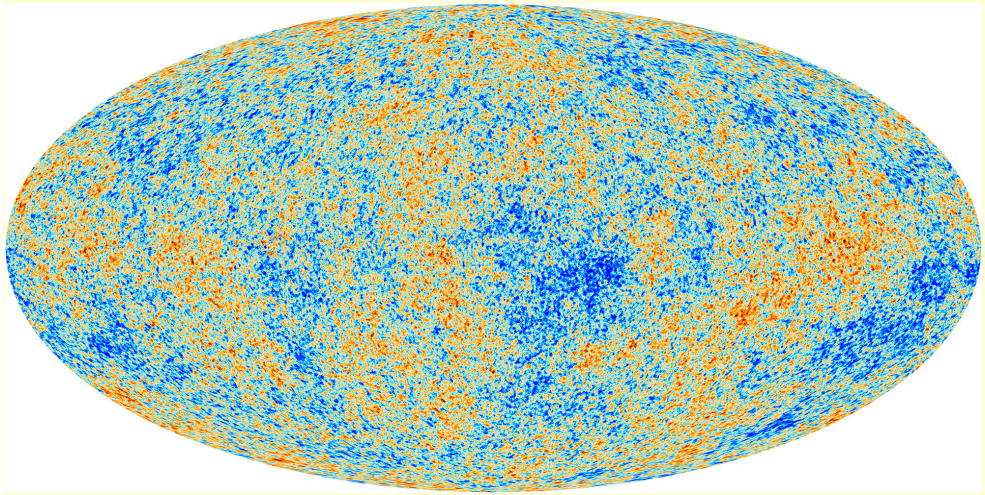
General Relativity + Λ and CMB, SNeIa, BAO data

=> **Concordance model = $\Lambda_{CDM}$**




- Beyond BAO: LSS
  - Structure formation
  - Testing gravity with LSS
  - Future LSS surveys : e.g. DESI



Planck (2013), all foregrounds subtracted

## Observational facts

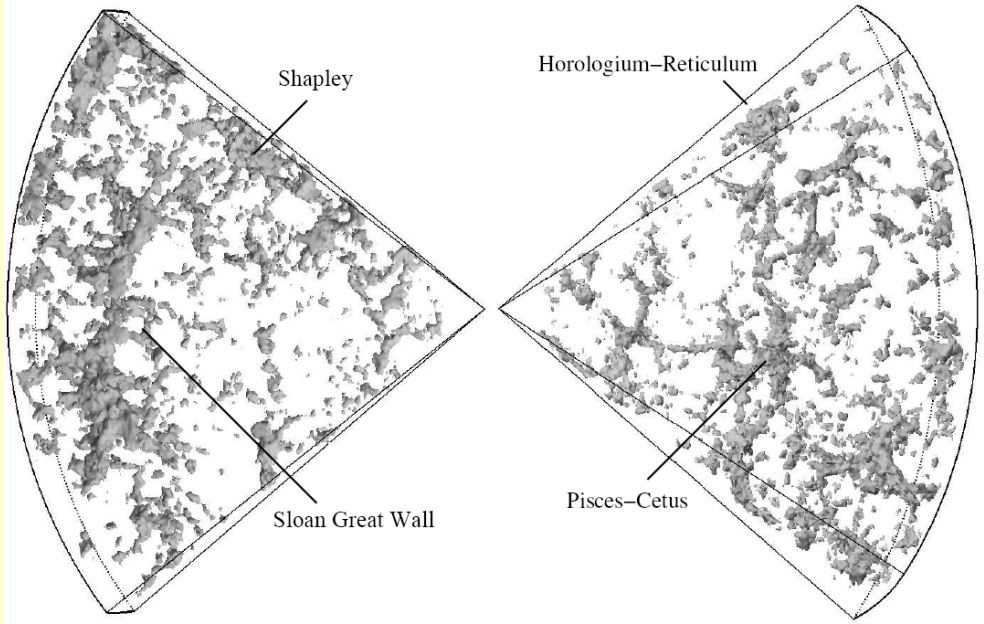
- CMB: very small anisotropies

$$\Delta T/T = 10^{-5}$$

- matter density inhomogeneities,

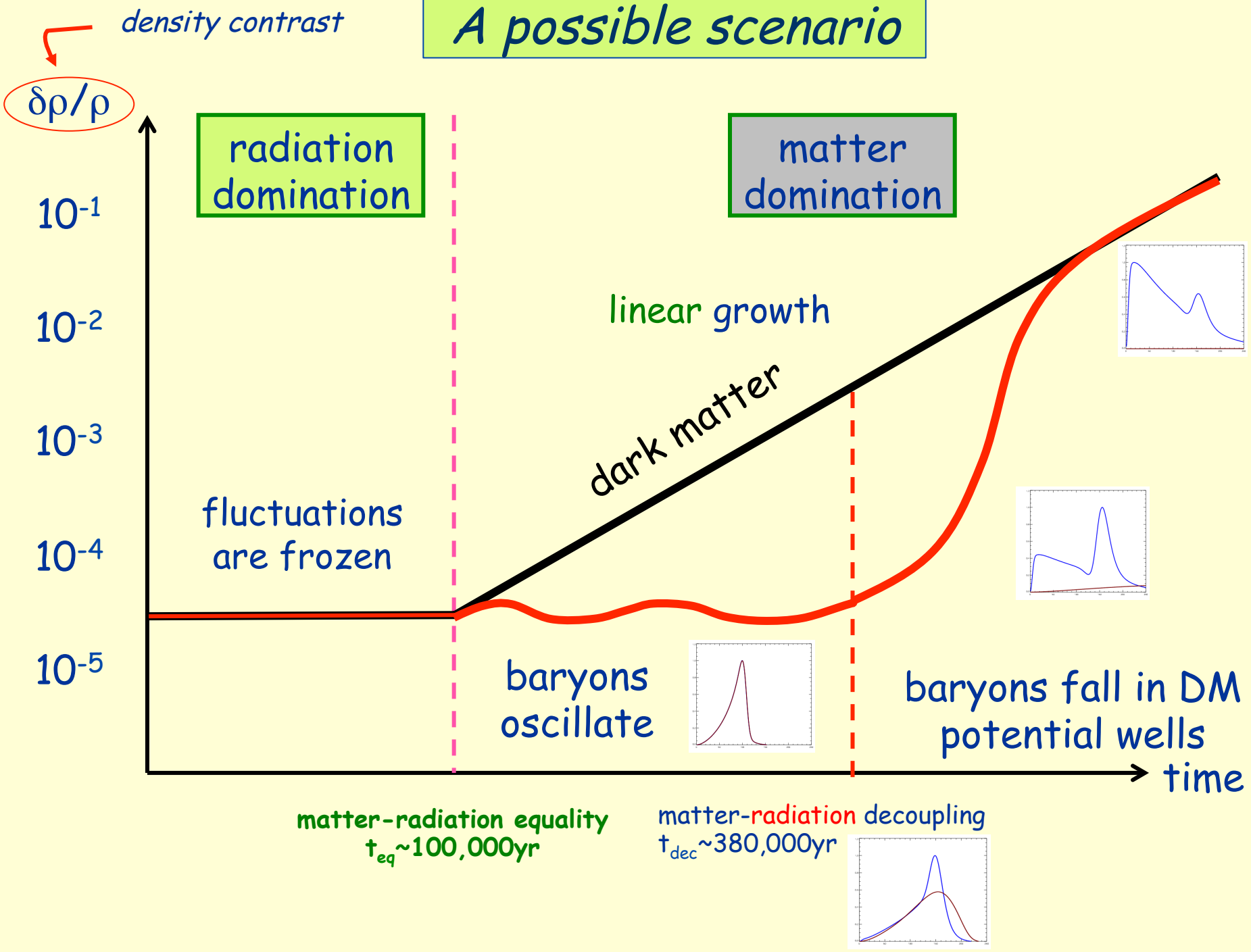
amplified by gravitation after decoupling → structures

- Large scale structures today: galaxies, clusters, superclusters, voids and filaments
- Formation of structures: cold dark matter mandatory




2dF Galaxy Redshift Survey, (2007)

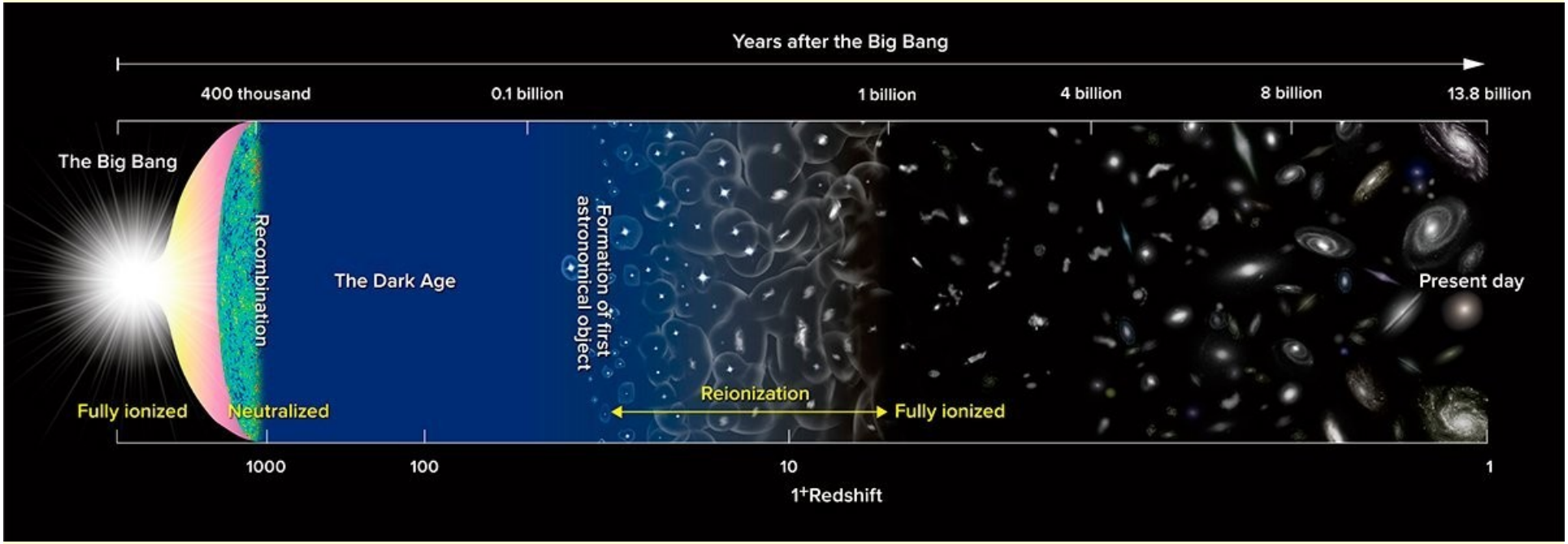
# A possible scenario



# Cosmic timeline

Dark ages

Galaxy evolution




first stars & galaxies form

~ 300-500million years

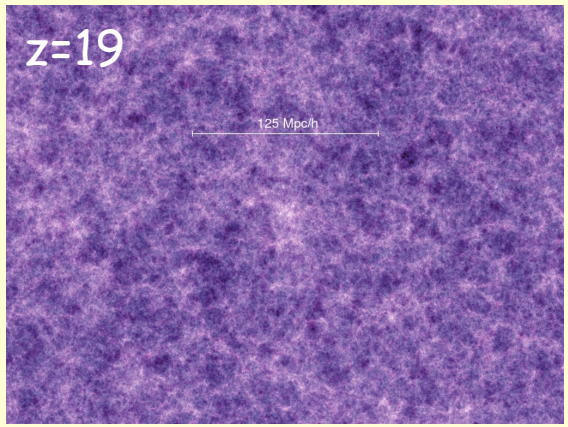
clusters & superclusters

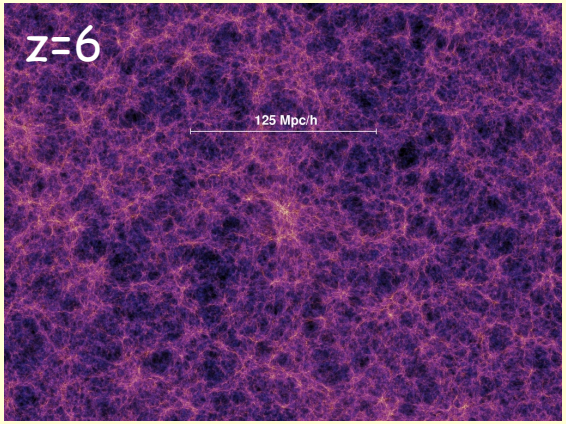
- Hierarchical formation structure, smaller structures (stars, dwarf galaxies…) collapse earlier than larger ones (clusters)

# Numerical simulations, examples

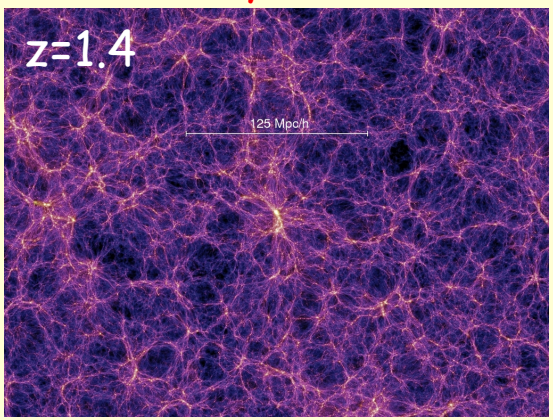
Needed to describe the non-linear ($\delta\rho/\rho > 1$) regime of structure growth (galaxies, clusters….).

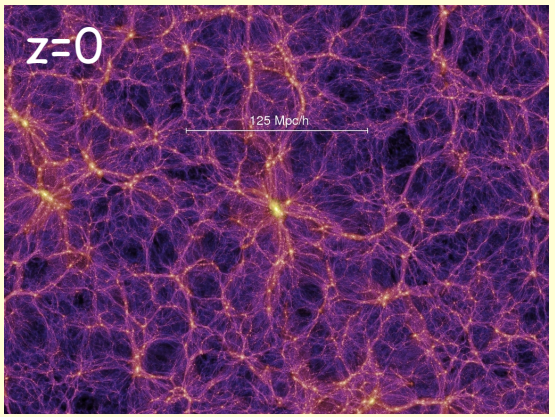
*Scale: 125 Mpc/h*




0.2 Gyr — 1 Gyr




4.7 Gyr — 13.6 Gyr

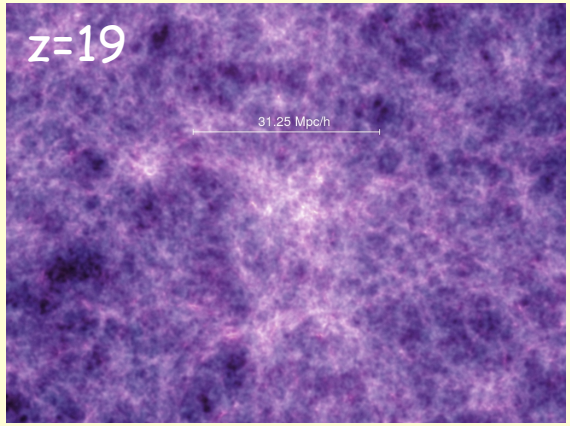
*Millennium simulation, Springel et al., 2005.*

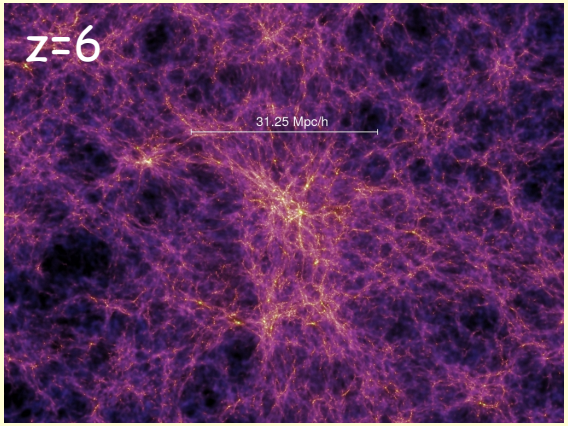
- DM particles
- gravitation
- cosmology
- hydrodynamics

# Numerical simulations, examples

Needed to describe the non-linear ($\delta\rho/\rho > 1$) regime of structure growth (galaxies, clusters….).

*Scale: 31.5 Mpc/h*




- DM particles
- gravitation
- cosmology
- hydrodynamics

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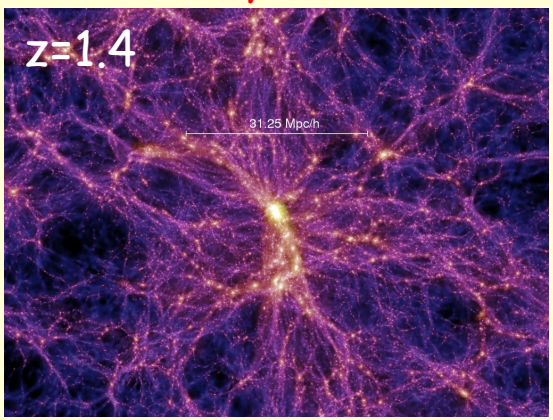
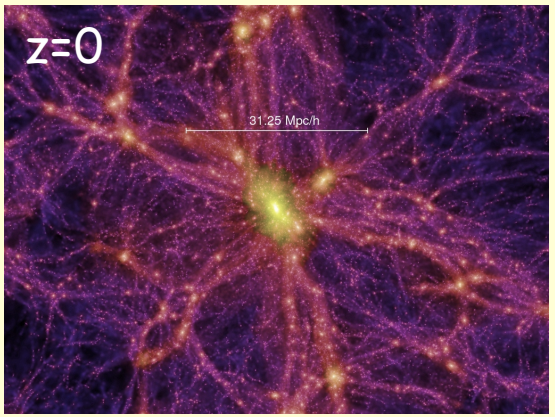


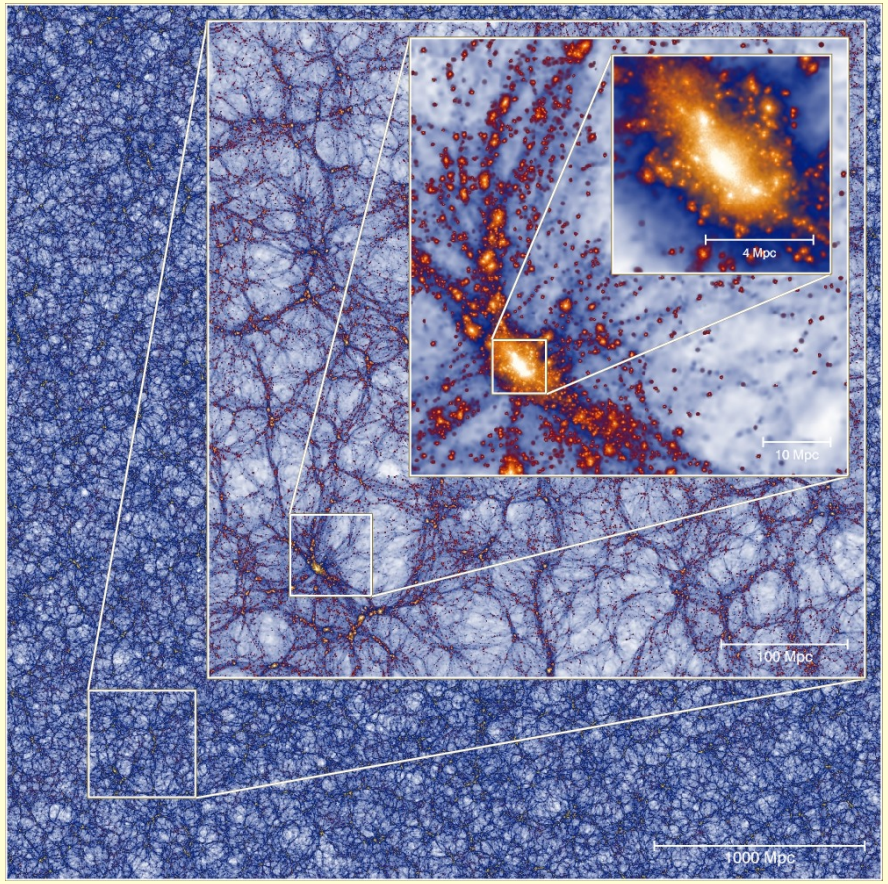



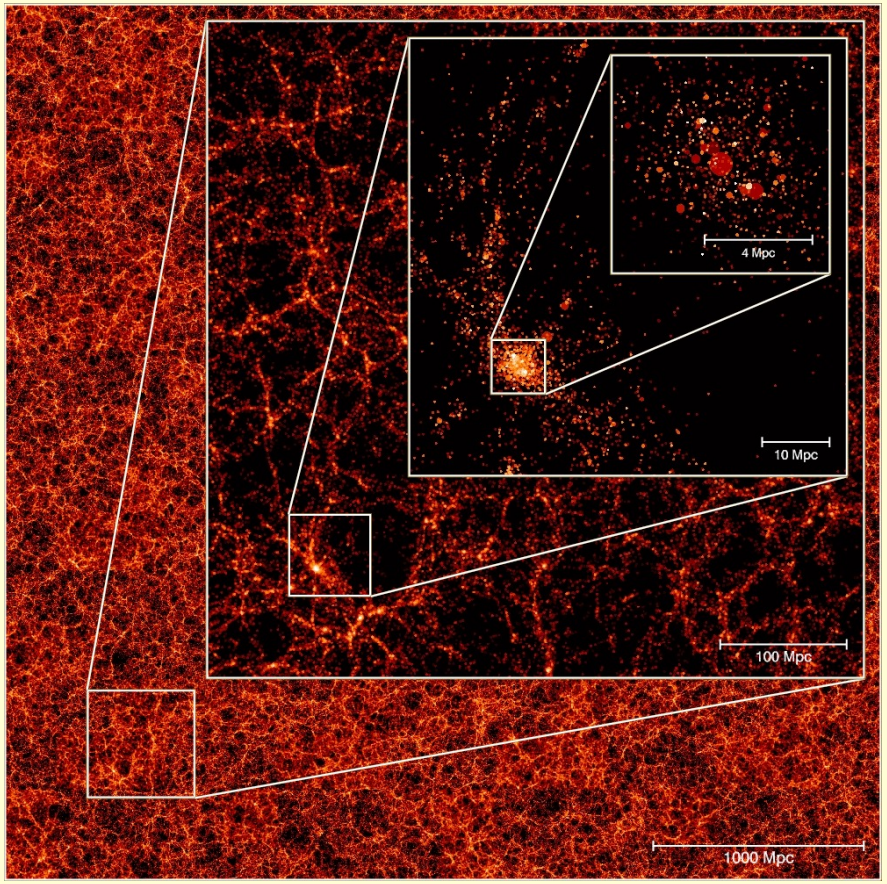

*Millennium simulation, Springel et al., 2005.*

4.7 Gyr — 13.6 Gyr

# *Millenium-XXL simulation (2011)*

$6720^3$ DM particles, 4.1 Gpc box, gravitation followed over 13 Gyr




DM density field, z=0 ⇒ galaxy distribution, z=0

# Structure formation, summary

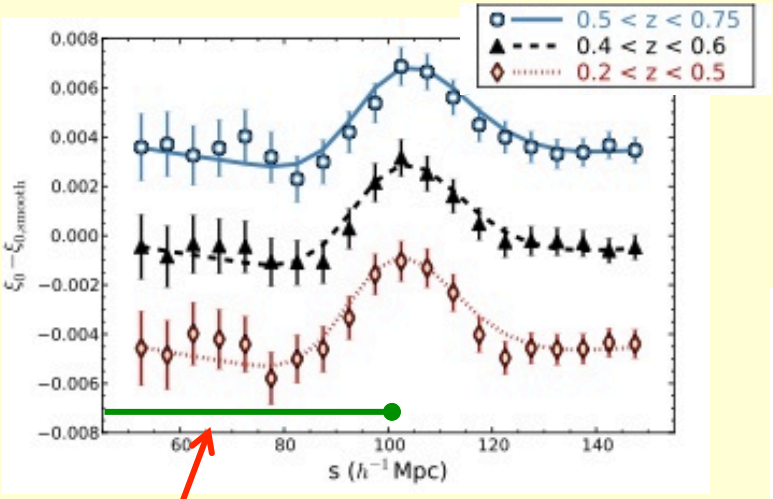
- Numerical simulations of large scale structure formation (down to galaxy dense halos) from cold dark matter :

  voids and filaments (the cosmic web) well reproduced

*Evolution of matter distribution from numerical simulations*

- Current status :
  - Large scale success: two-point correlation function and high z luminosity function correctly reproduced
  - Small scale issues: too many DM satellites expected, expected DM halo profile too cuspy in galaxy cores, galaxy rotation curves do not agree with data
  - By-product : link with particle physics through constraints on neutrinos from large scale structure data ($N_\nu$, $\Sigma m_\nu$)

## From BAO …

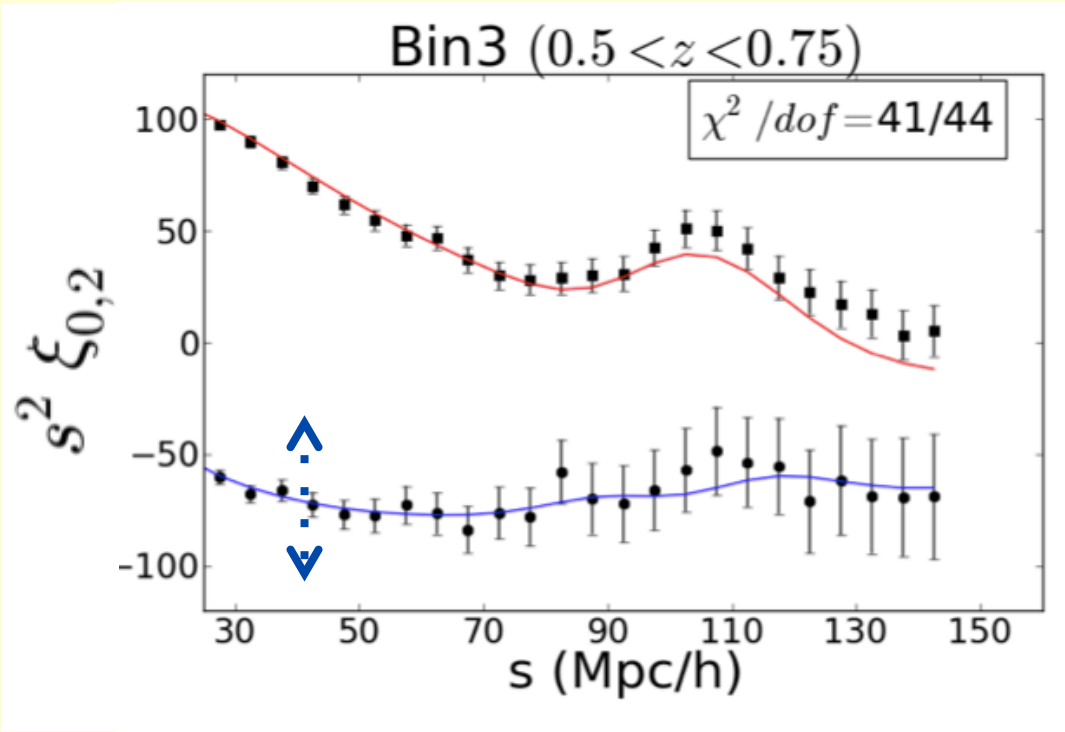



BAO scale

S. Alam et al., 2017, MNRAS,470, 2617A

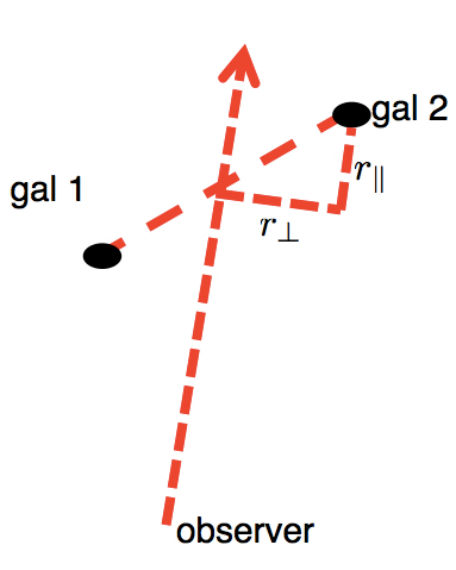
## … to full shape analysis

S. Satpathy et al., 2017, MNRAS, 469, 1369S

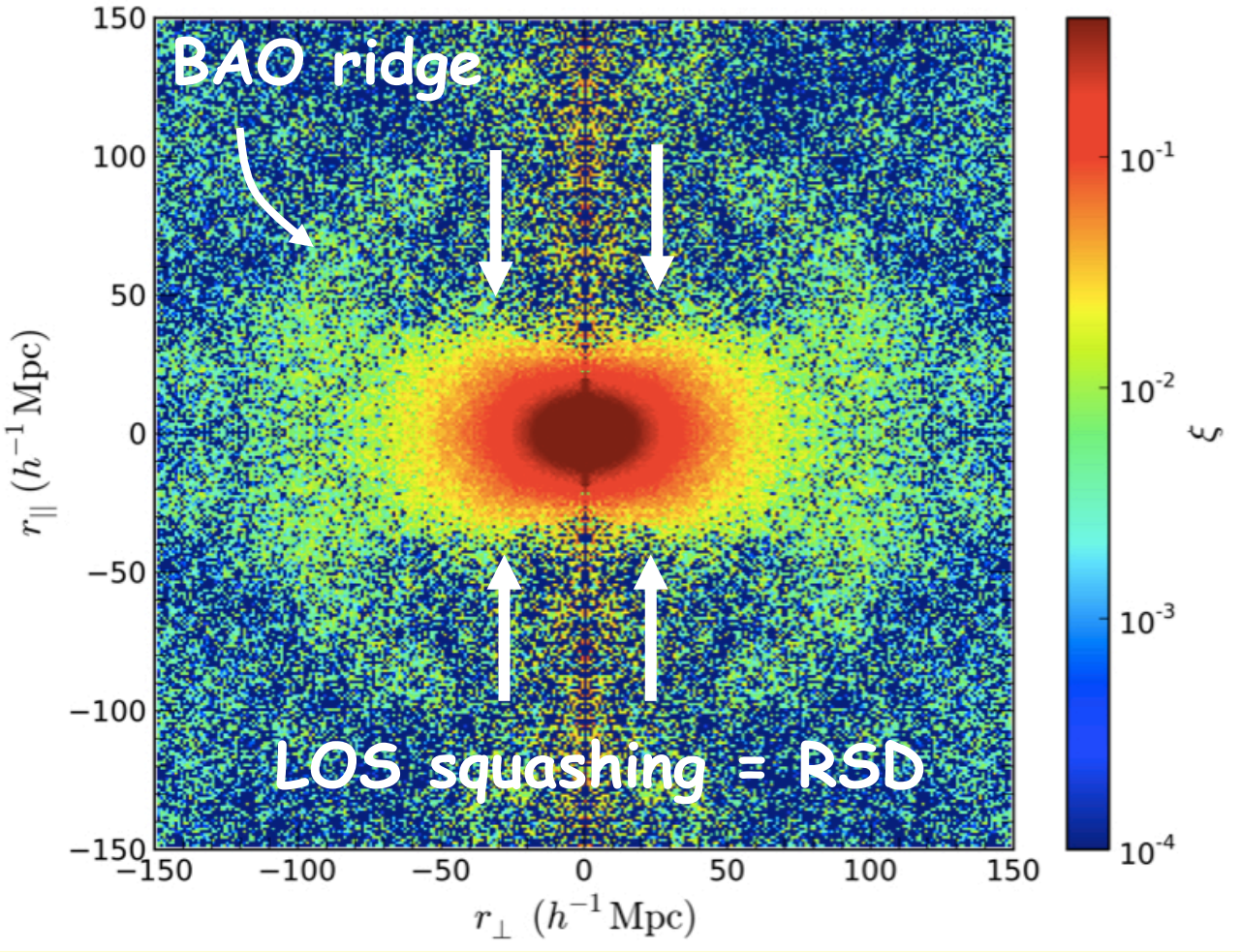



quadrupole amplitude = gravity strength

⇒ requires understanding of matter clustering on small scales (i.e. below BAO scale)




observed redshift: Hubble expansion + **peculiar velocity** due to gravity

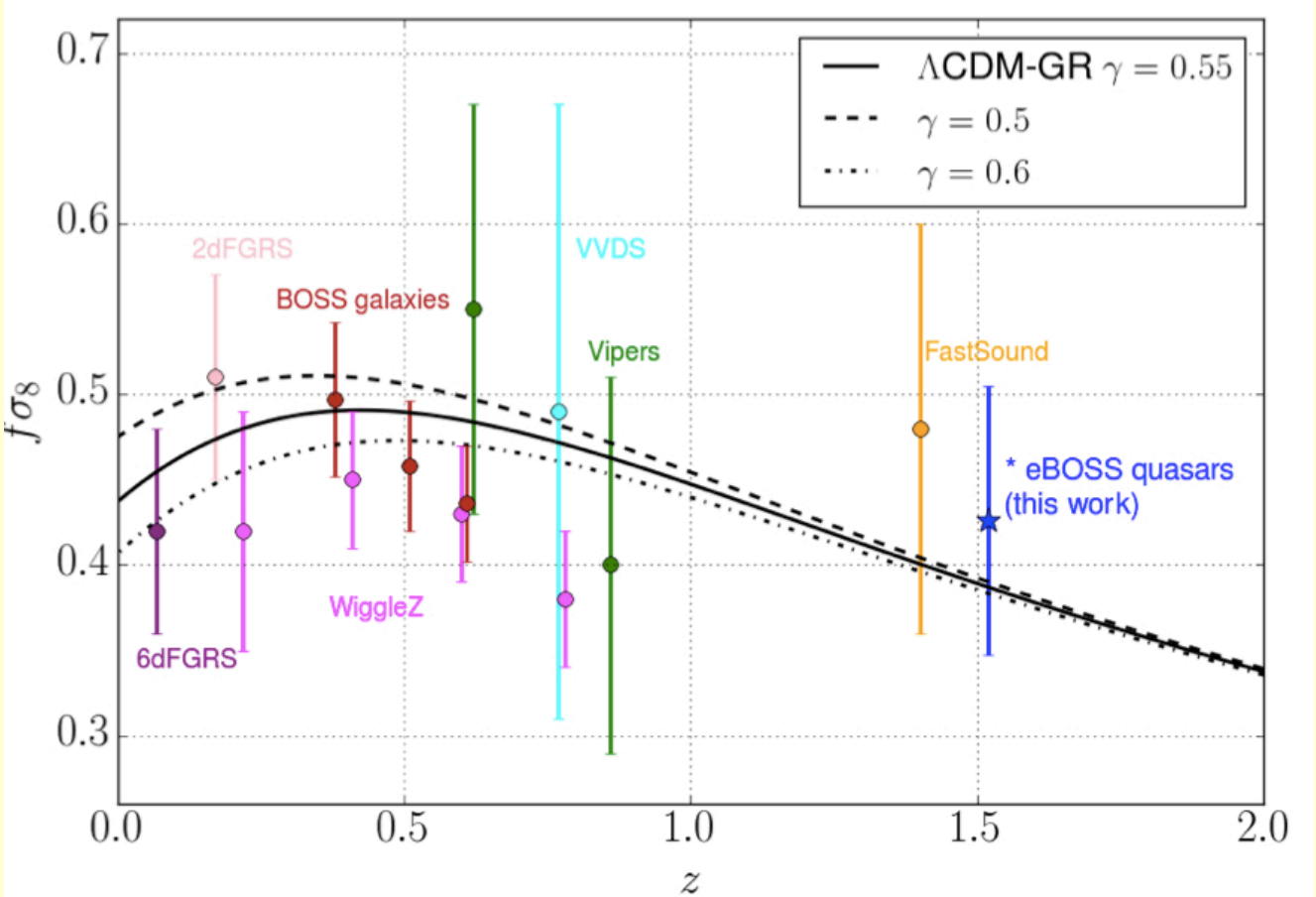



*L.Samushia et al, 2014, MNRAS, 439, 3504.*

Redshift Space Distortions : a way to test gravity -> full shape analysis and accurate modeling of correlation function required (numerical simulations)

# Results : growth rate of structure measurements

$f(z) \equiv \frac{d \ln D}{d \ln a}$, $D(a) \equiv \frac{\delta\rho(a)}{\delta\rho_0}$, $\sigma_8 \equiv$ *power spectrum normalization today*




*P. Zarrouk et al., 2018, MNRAS,477, 1639*

At present : few measurements, best accuracy ≈ 6-10%

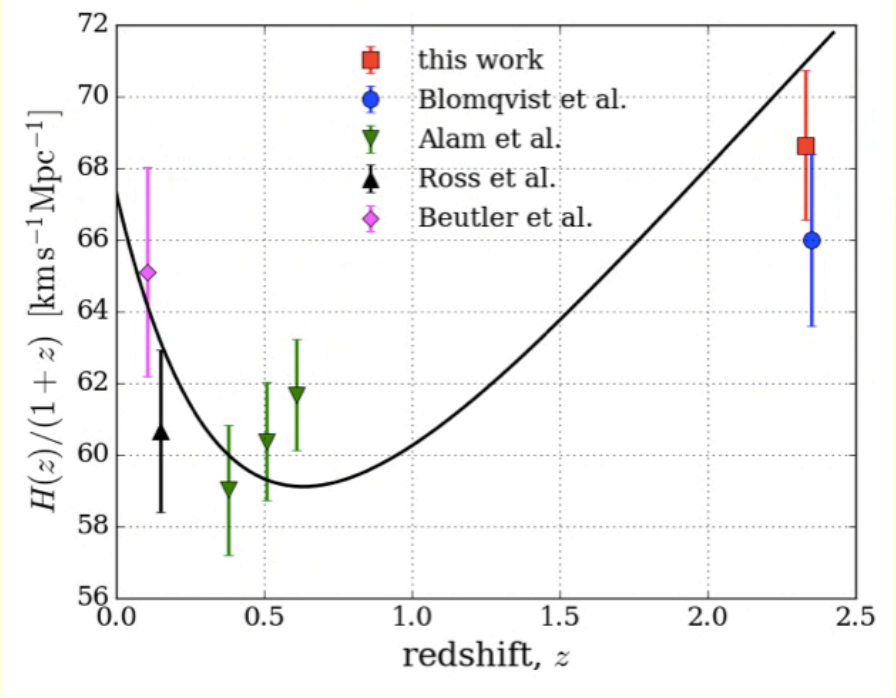
# The Dark Energy Spectroscopic Instrument (2020)

- From SDSS to DESI: data x 15

  35 million galaxies, quasars / 14,000 sq.degrees / 0<z<4

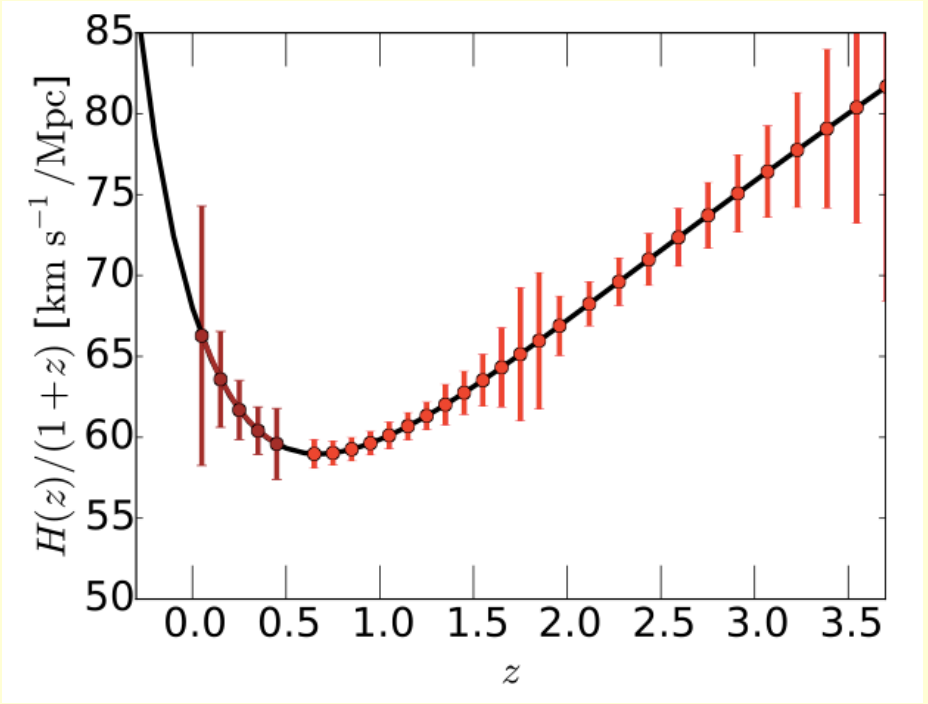
BAO along the line of sight => H(z)

2019




V.de Sainte Agathe et al., arXiv:1904.03400

DESI




DESI prospects, arXiv:1611.00036

# *The Dark Energy Spectroscopic Instrument (2020)*

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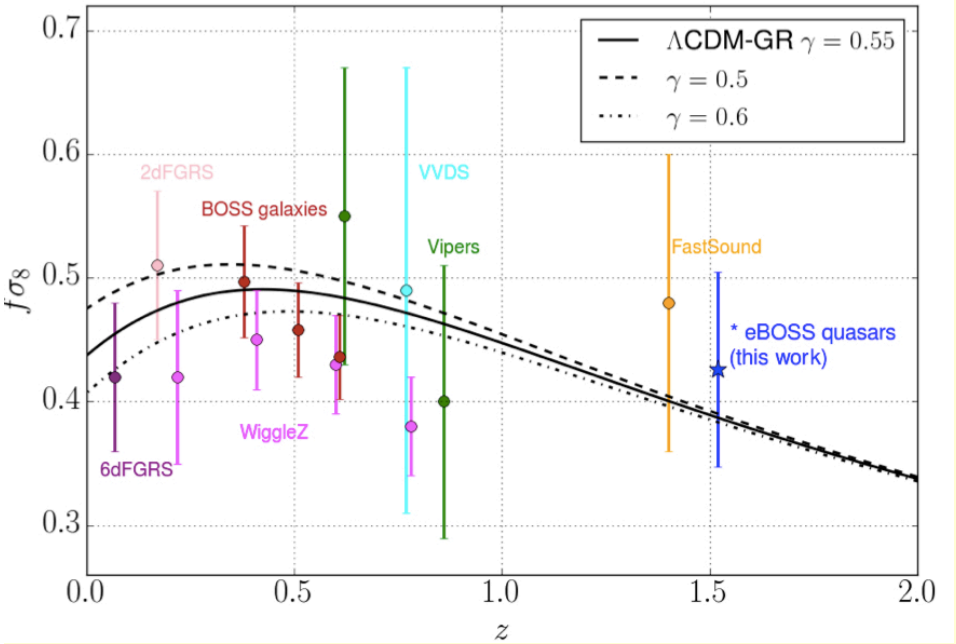
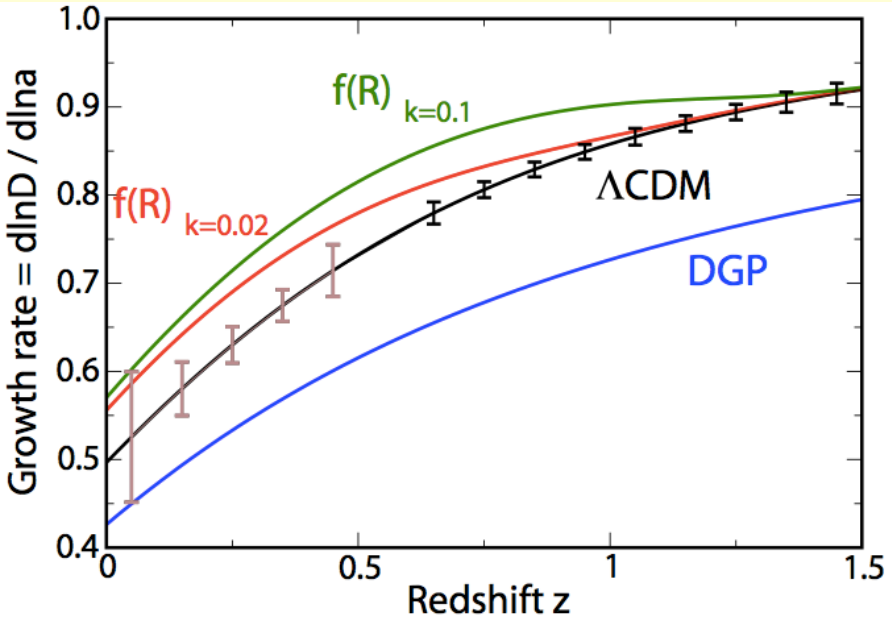
Linear growth of structure rate

2018

DESI

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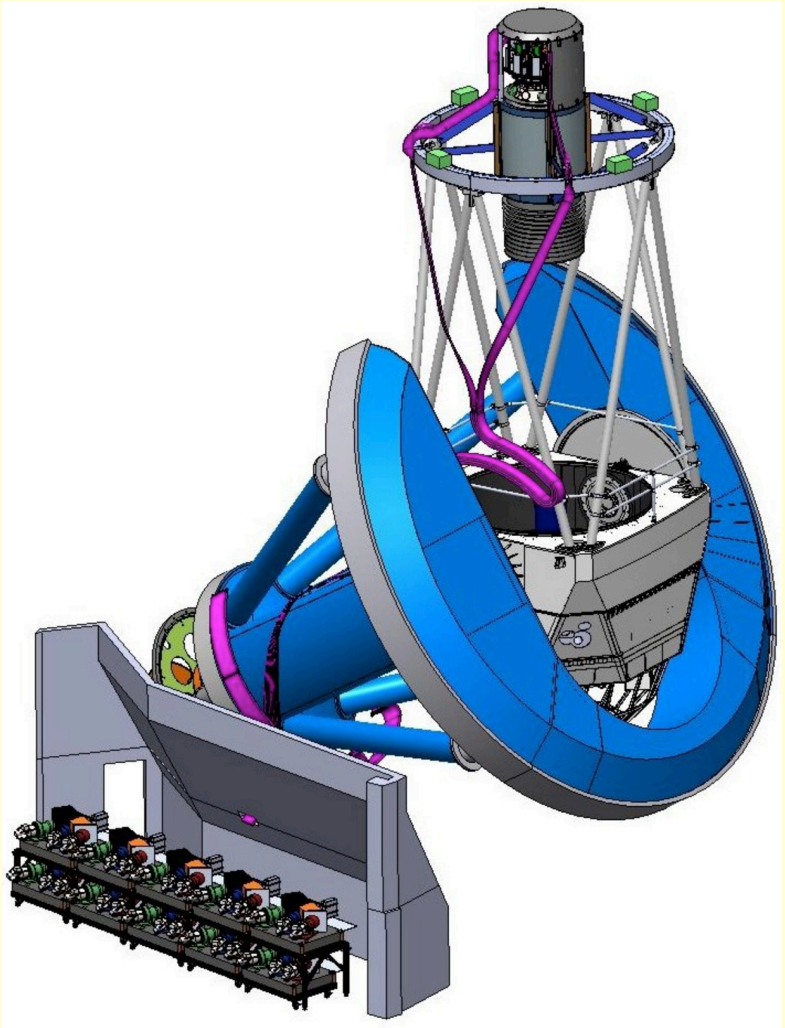
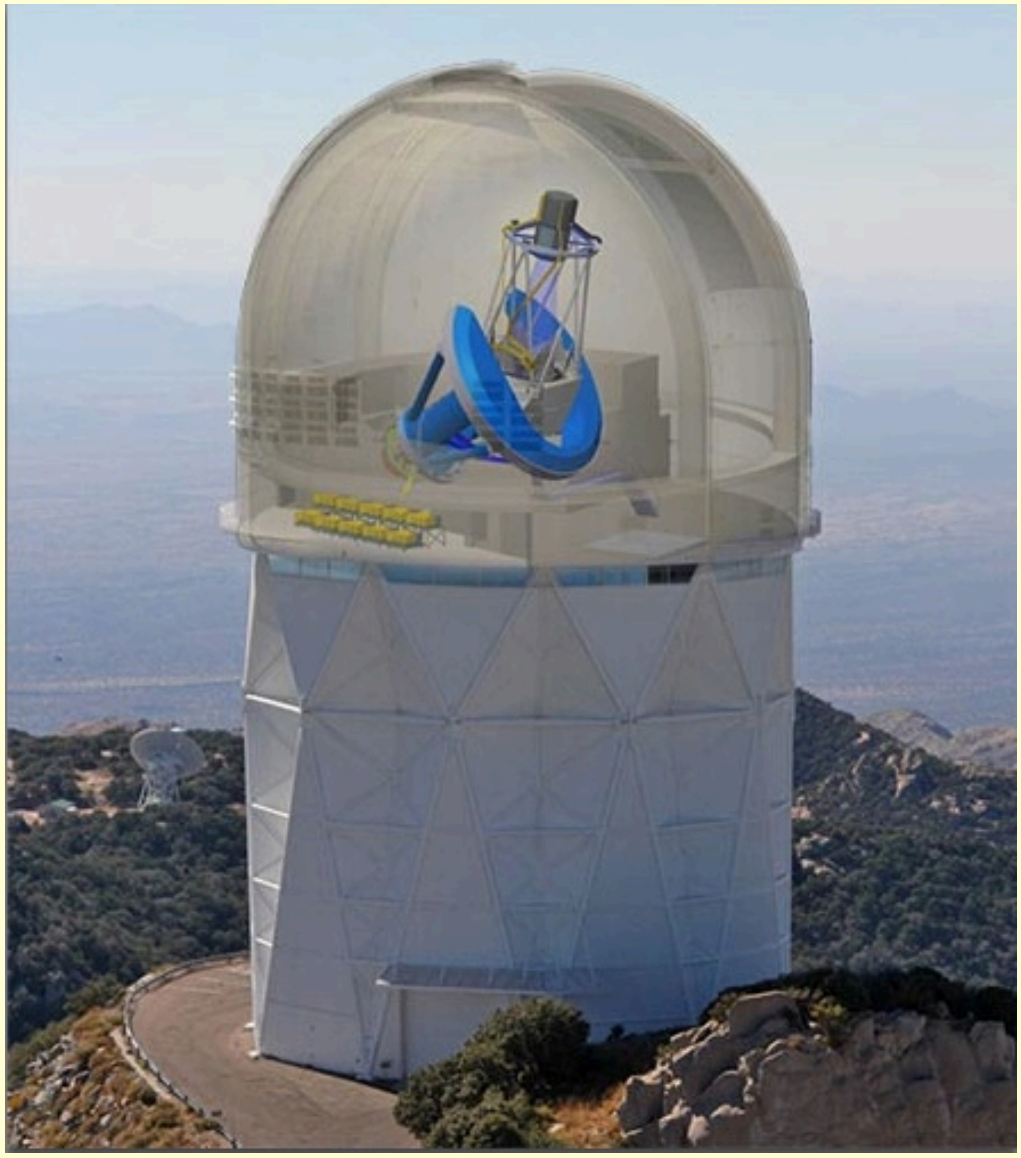


Dark Energy Spectroscopic Instrument

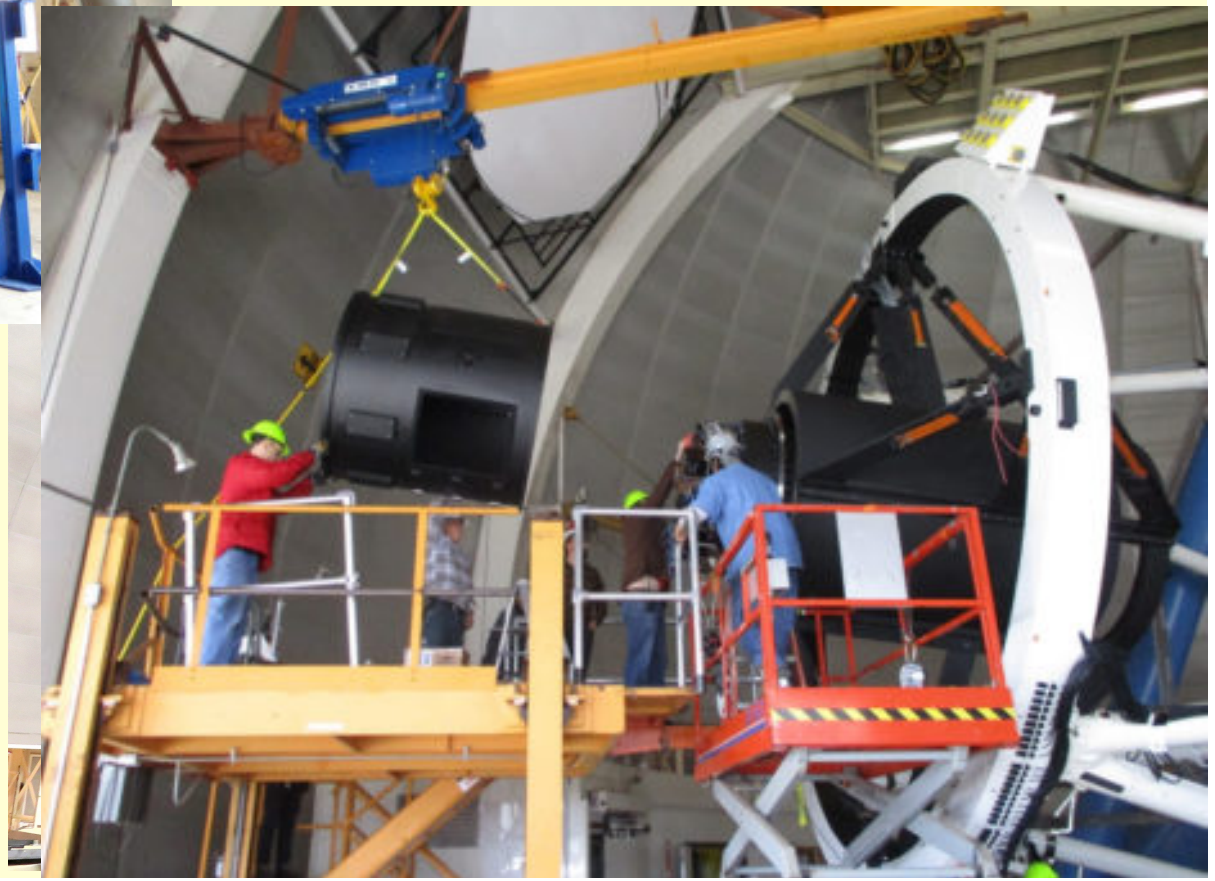
DESI



# The Mayall telescope at Kitt Peak observatory

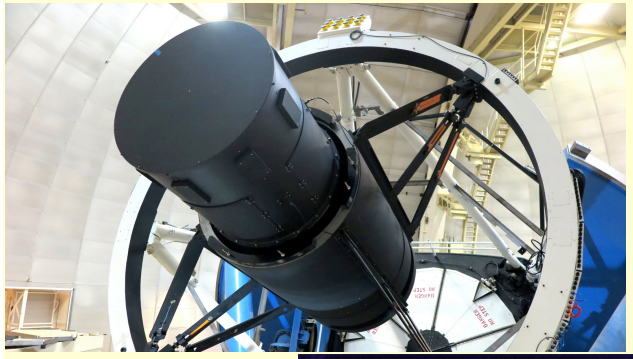
## *DESI corrector*

summer 2018



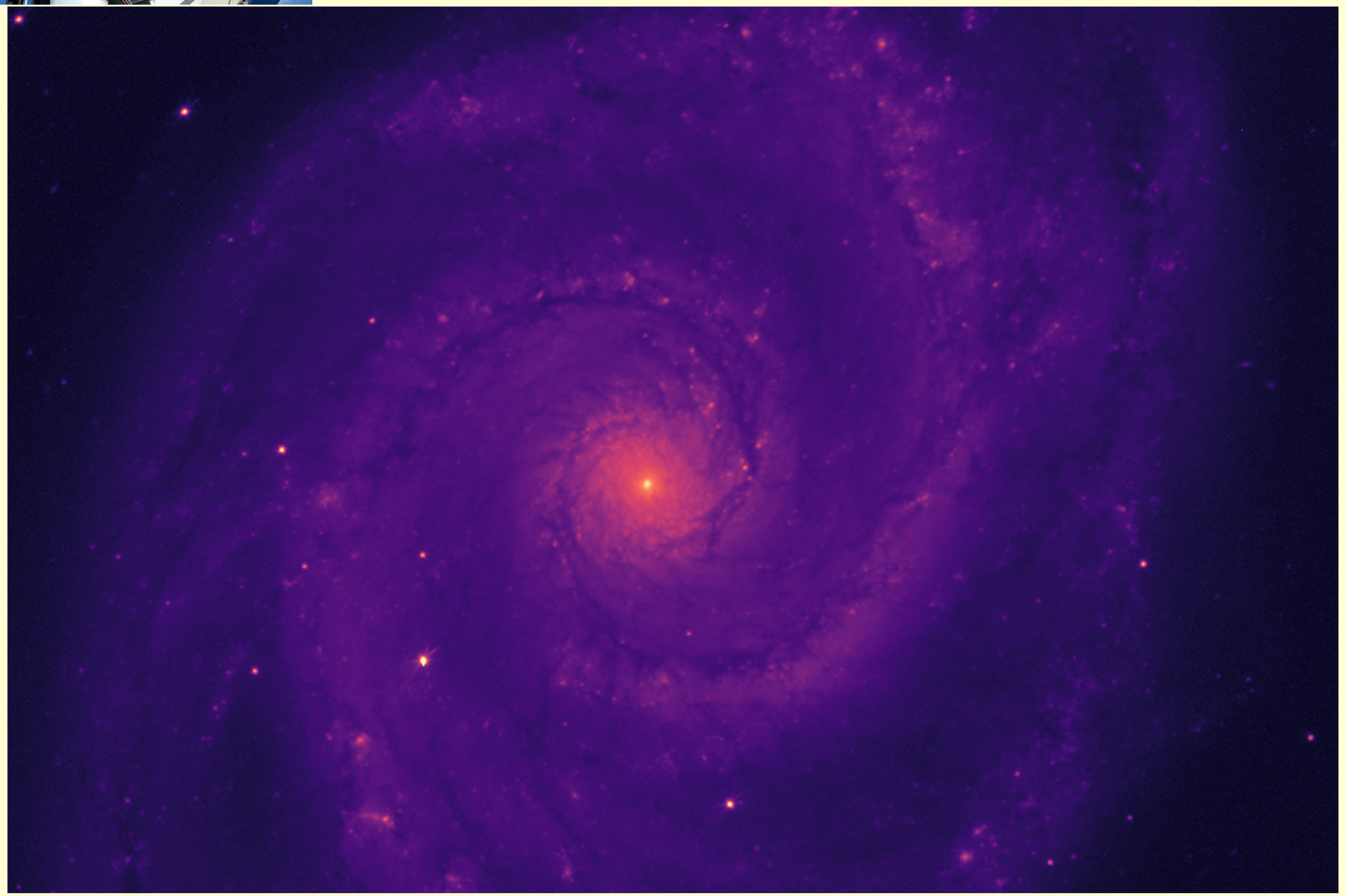
## *+ commissioning instrument*

spring 2019



# DESI corrector commissioning

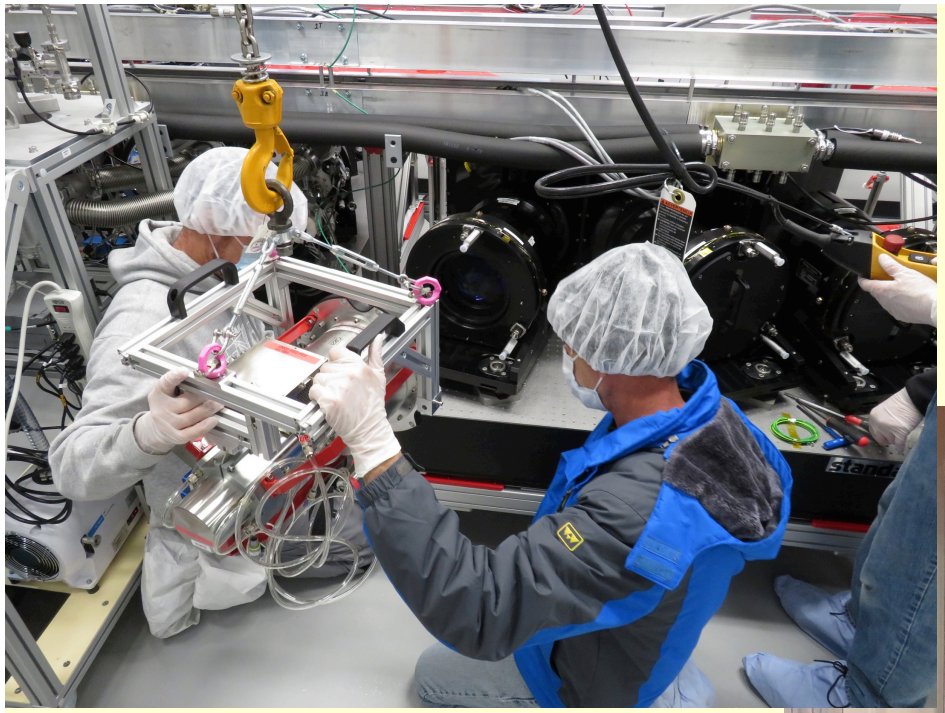
April 2019



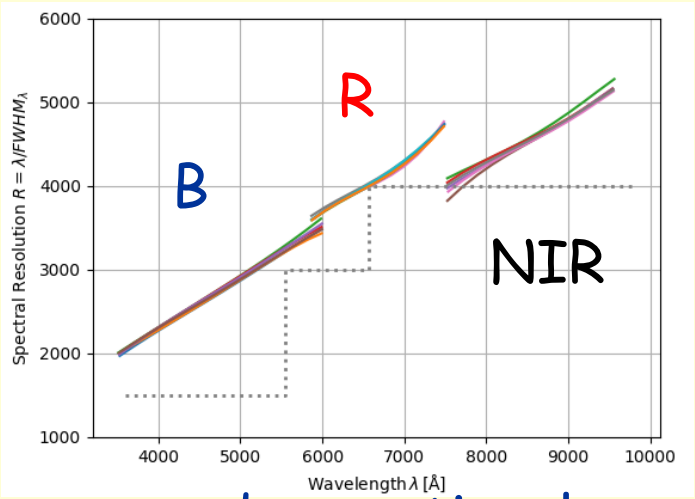
the Whirlpool galaxy seen through the DESI corrector lenses

February 2019

# DESI spectrographs

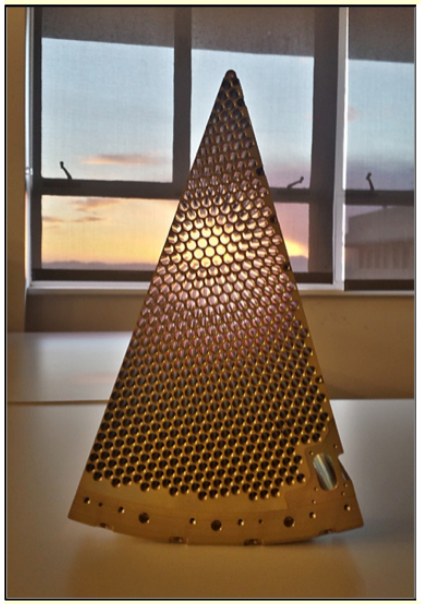


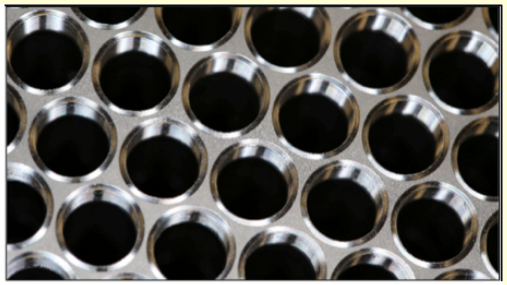
6 spectrographs installed

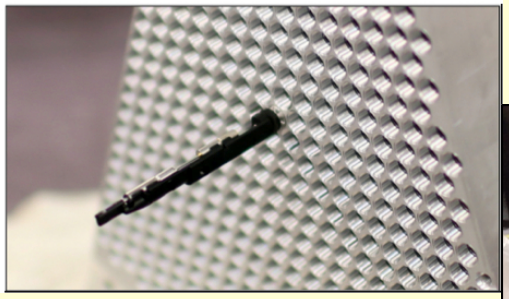



and operational

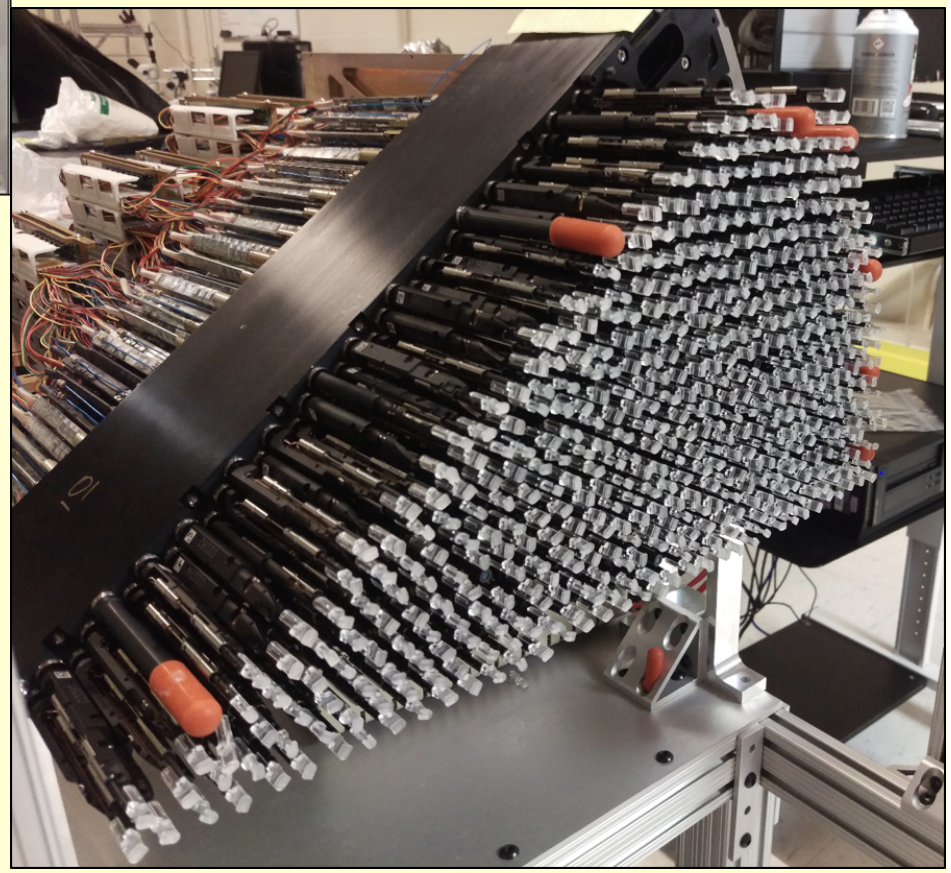
June 2019







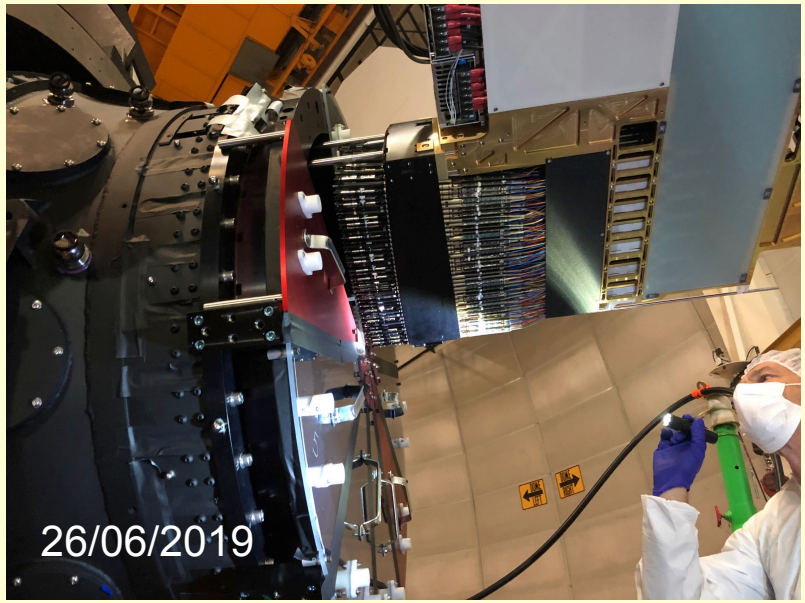
# DESI focal plane



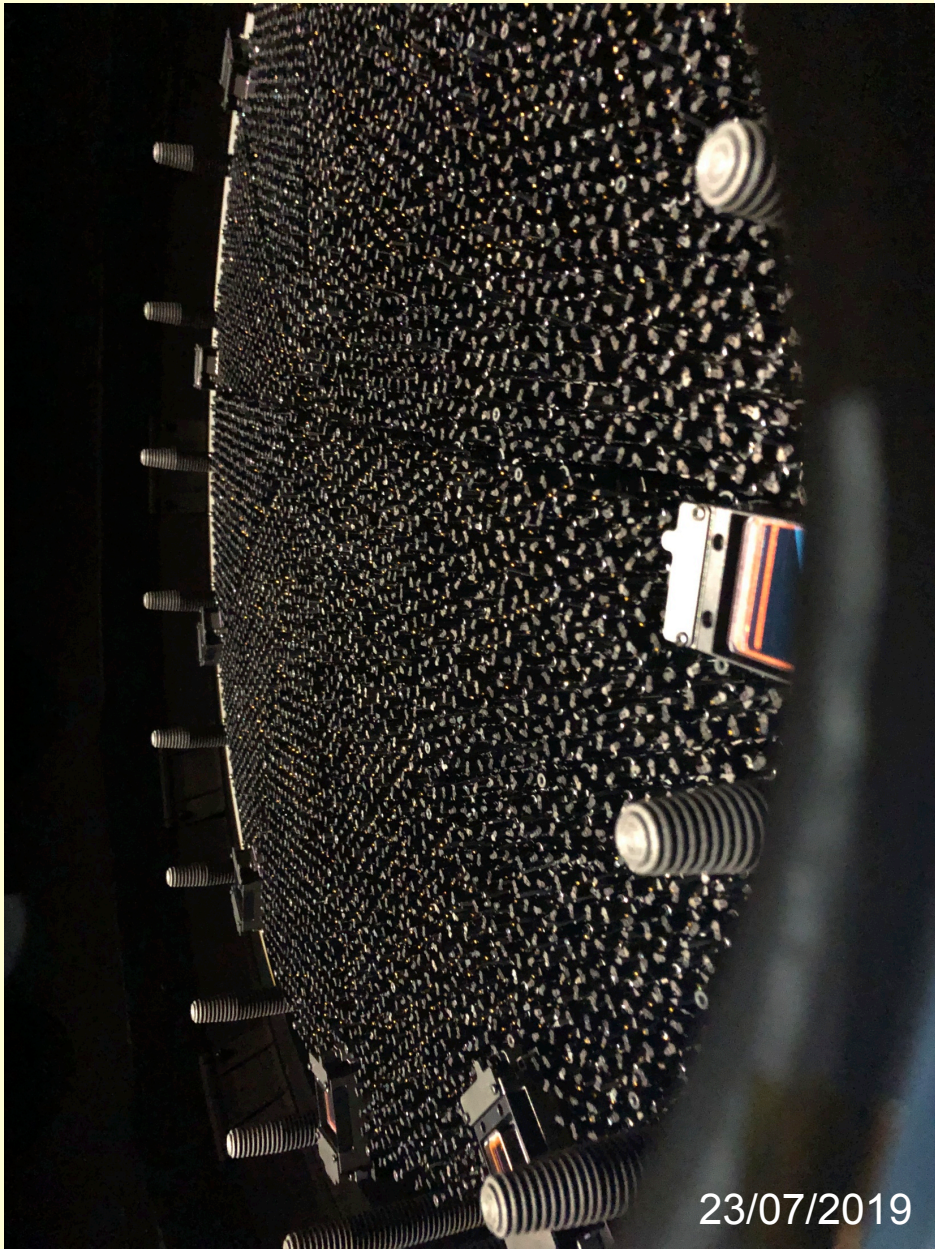
Focal Plane = 10 petals, each with 500 fiber-optic cables moved by robotic positioners

each fiber collects light from a separate sky object

# DESI focal plane installation

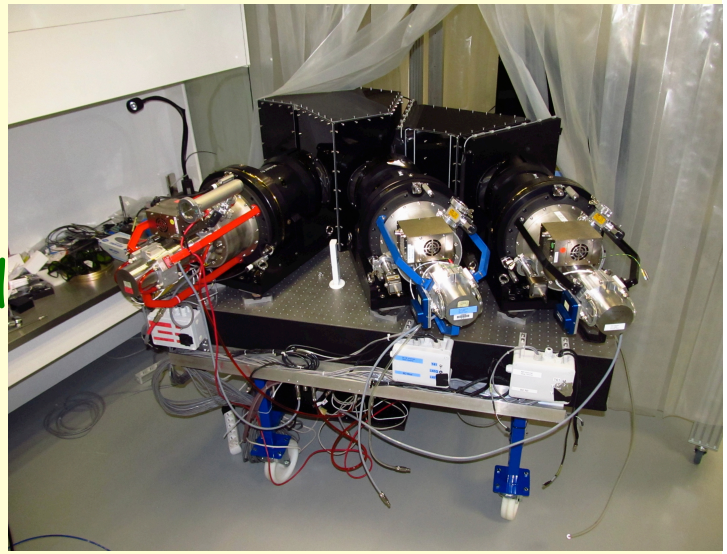


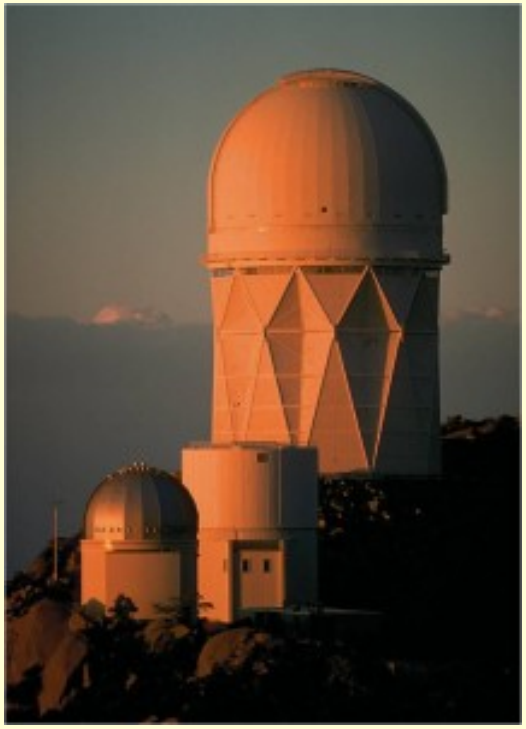




# DESI timeline

- 2010: proposal for a large science program on the Mayall telescope at Kitt Peak observatory (Arizona)
- 2010-2016: R&D and prototype period
- 2016-2017: construction





- 2018-2019: installation at the telescope
- Oct 2019-Feb 2020: commissioning
- Feb 2020-summer 2020: validation survey
- 2020-2025: science survey

# CONCLUSIONS (4)

- Cosmological measurements today: CMB, SNeIa, BAO
- Standard cosmological model: $\Lambda_{CDM}$
- Very near future: go beyond BAO with large scale structure surveys (DESI, Euclid, LSST, WFIRST…)

*The Mayall telescope*

*DESI prospects*