Cosmology session overview

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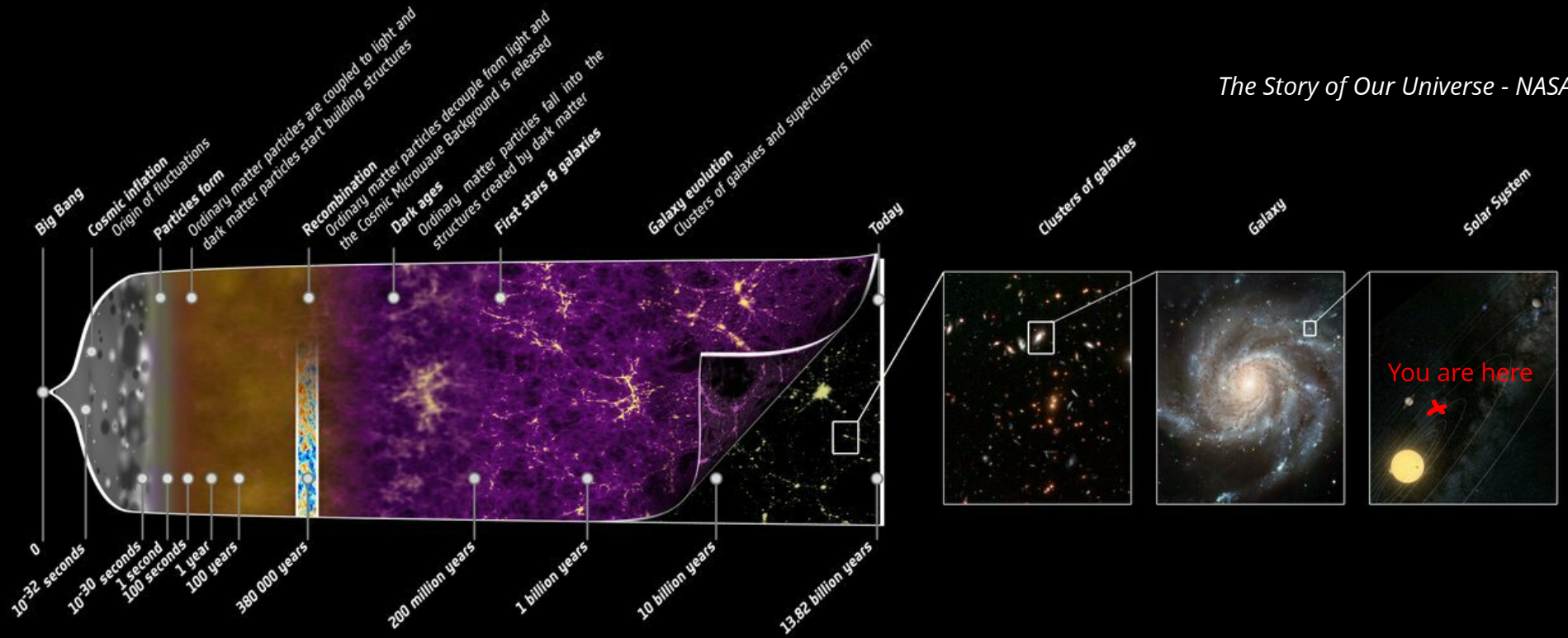
Journée de Rencontre Jeunes Chercheur.se.s 2024

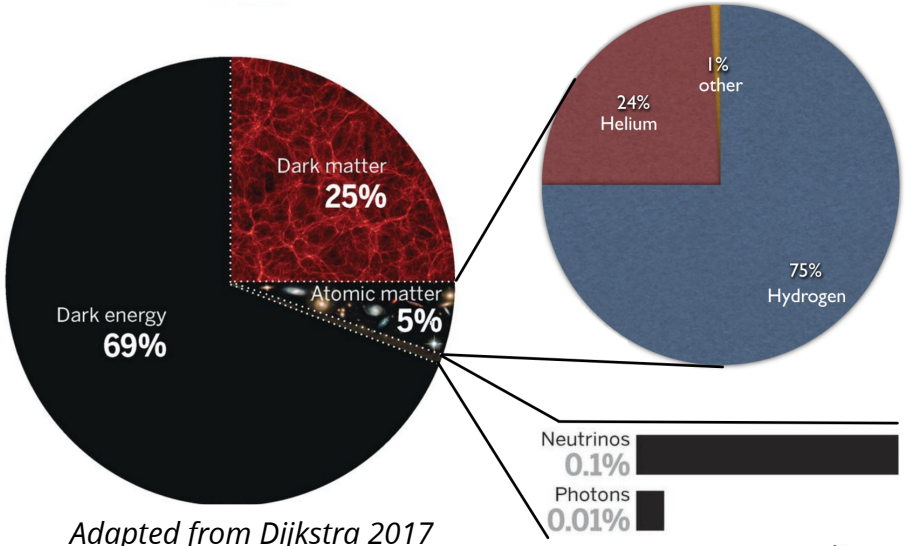
Cosmological context



The Story of Our Universe - NASA

How did the Universe evolve to its current state?
What are the fundamental constituents of our Universe?
How is matter distributed in the Universe?

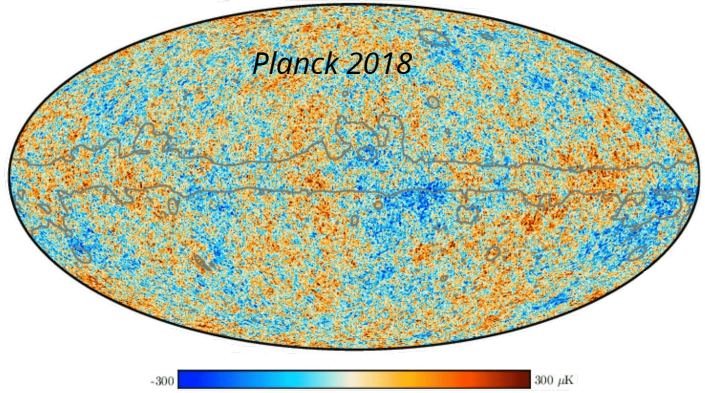
Global Universe description

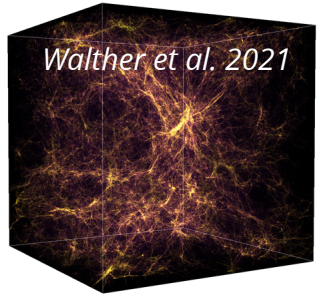


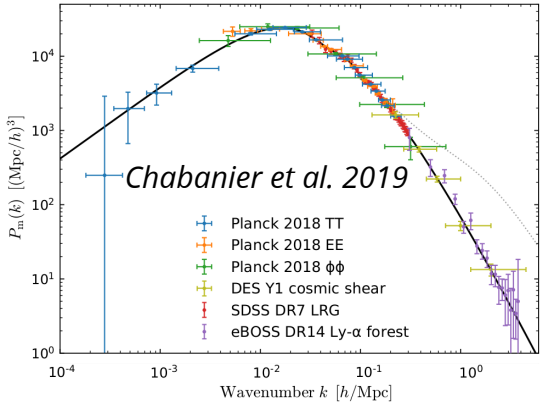
Adapted from Dijkstra 2017

Cosmic Krampouz

Structures in the Universe

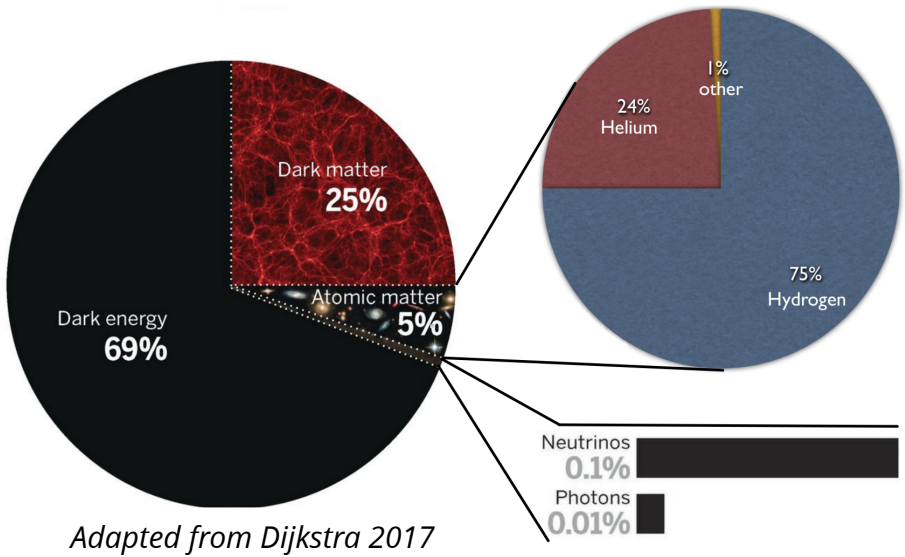






flat ΛCDM

Global Universe description



Adapted from Dijkstra 2017

Einstein equation

$$G_{\mu\nu} + \Lambda g_{\mu\nu} = 8\pi G_{\mathrm{N}} T_{\mu\nu}$$

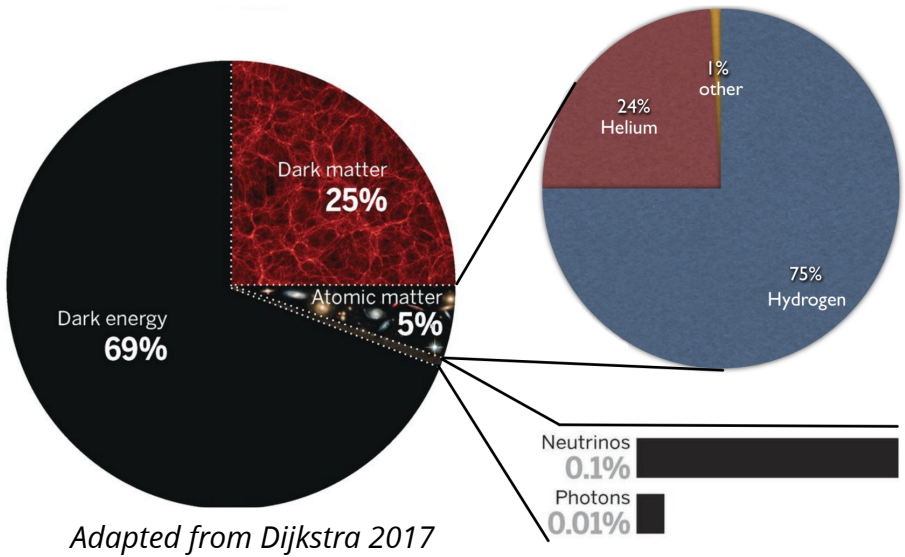
Flat FLRW metric — Cosmological constant — Energy-momentum tensor

Components of the Universe (dark energy, dark matter, baryons, neutrinos, photons) modify the Universe expansion (Only 5% known)

$$\text{flat } \Lambda\text{CDM} = \{\Omega_{\mathrm{b}}; \Omega_{\mathrm{cdm}} \quad \}$$

Global Universe description

Structures in the Universe



Adapted from Dijkstra 2017

Einstein equation

$$G_{\mu\nu} + \Lambda g_{\mu\nu} = 8\pi G_{\mathrm{N}} T_{\mu\nu}$$

Flat FLRW metric — Cosmological constant — Energy-momentum tensor

Friedmann equation

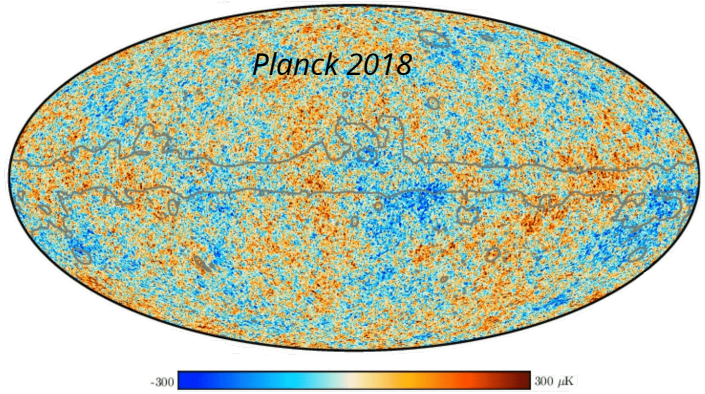
$$H^2 = \frac{8\pi G\rho}{3} + \frac{\Lambda}{3}$$

Hubble constant

$$\text{flat } \Lambda\text{CDM} = \{\Omega_{\mathrm{b}}; \Omega_{\mathrm{cdm}}; H_0\}$$

Structures in the Universe

Cosmic Microwave Background = First light after recombination (e^-,p)



- Initial density perturbations in the primordial Universe seen on CMB
- Measuring CMB provides information on the opacity of the Universe = optical depth to reionisation

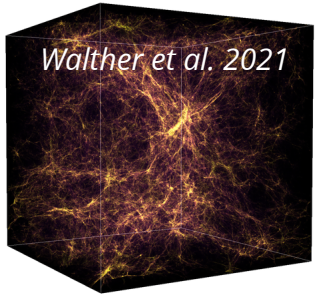
$$\text{flat } \Lambda\text{CDM} = \{\Omega_\text{b}; \Omega_\text{cdm}; H_0; \boxed{\tau}\}$$

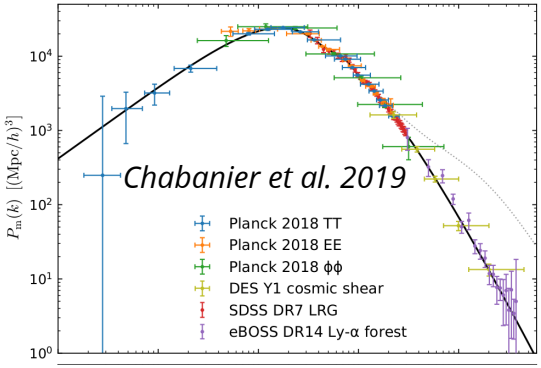
Perturbed Einstein equation

$$\delta G_{\mu\nu} = \kappa \delta T_{\mu\nu}$$

... or full simulation

- Perturbations grows to form the cosmic web: Nodes, filaments, walls and voids
- Large-scale distribution of matter characterized by the linear power spectrum amplitude and slope



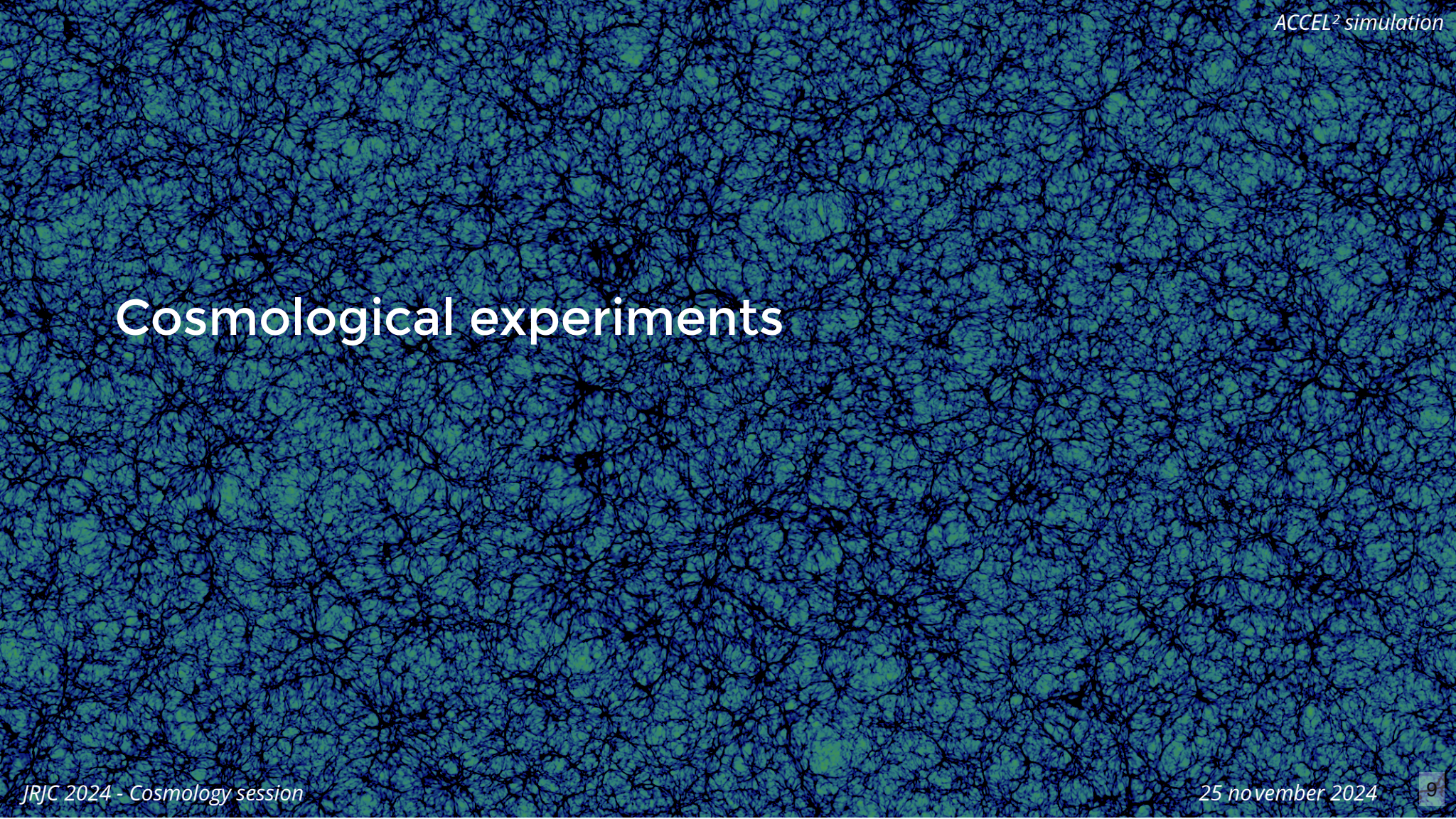


$$\text{flat } \Lambda\text{CDM} = \{\Omega_\text{b}; \Omega_\text{cdm}; H_0; \tau; \boxed{A_\text{s}; n_\text{s}}\}$$

Only the simplest model !

Current questions in Cosmology

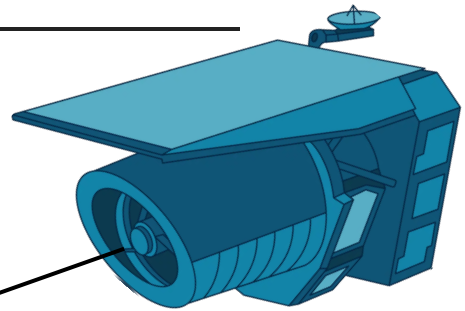
- **Dark energy**: Nature (cosmological constant? particle? field? fifth force?) and Behavior (evolution? interaction?)
- **Dark matter**: Nature (particle? field?) and Behavior (cold? warm? interaction?)
- **Testing general relativity**: modified gravity at large scale could explain unknowns?
- **Neutrinos**: Impact on cosmology can constrain neutrino mass
- **Inflation**: Indirect detection, constraining theories
- **Hubble tension**: mismatch between early and late-time probe (up to 5σ)



Cosmological experiments

Types of telescope

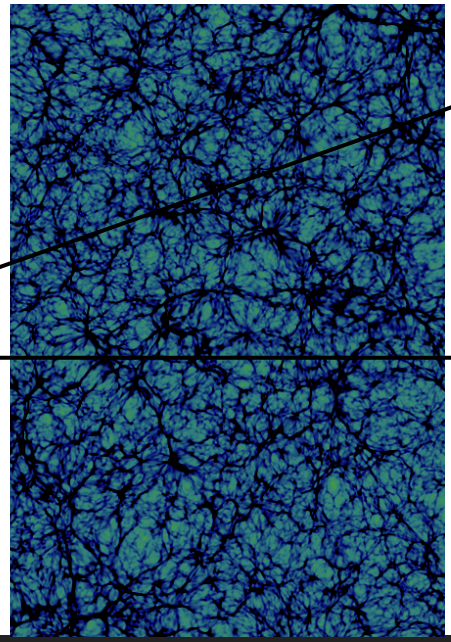
Electromagnetic radiation observations
(from gamma to radio)

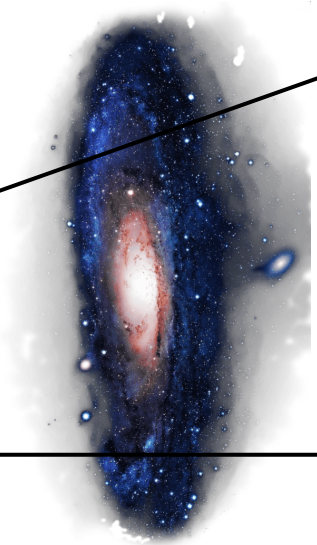


Cosmic web

CMB, Supernova, galaxy...

Source





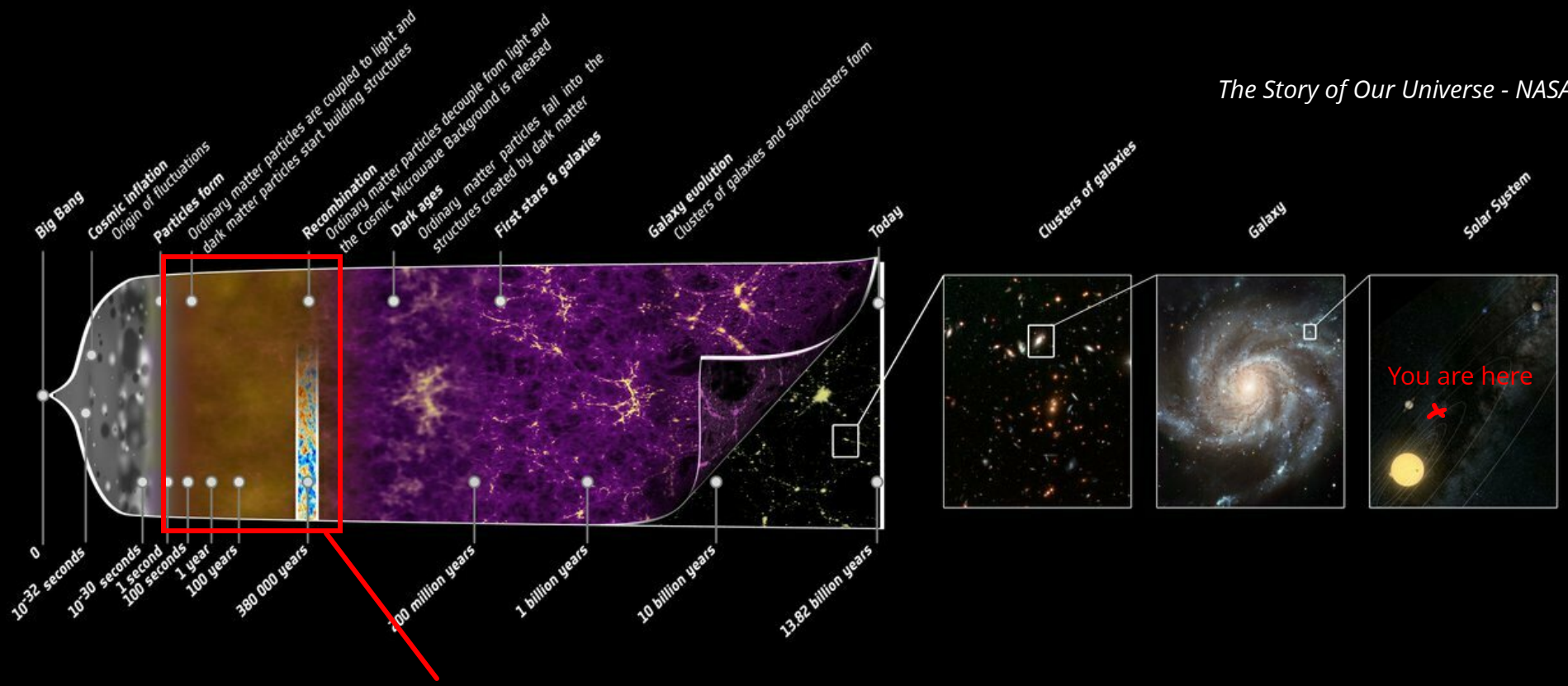
Milky Way

Atmosphere

ground/space

Telescope

CMB experiments

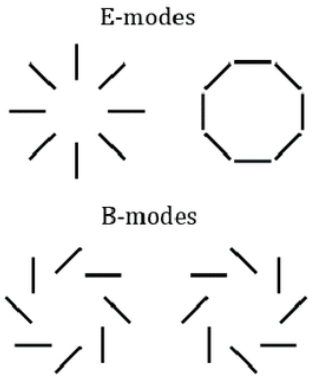


The Story of Our Universe - NASA

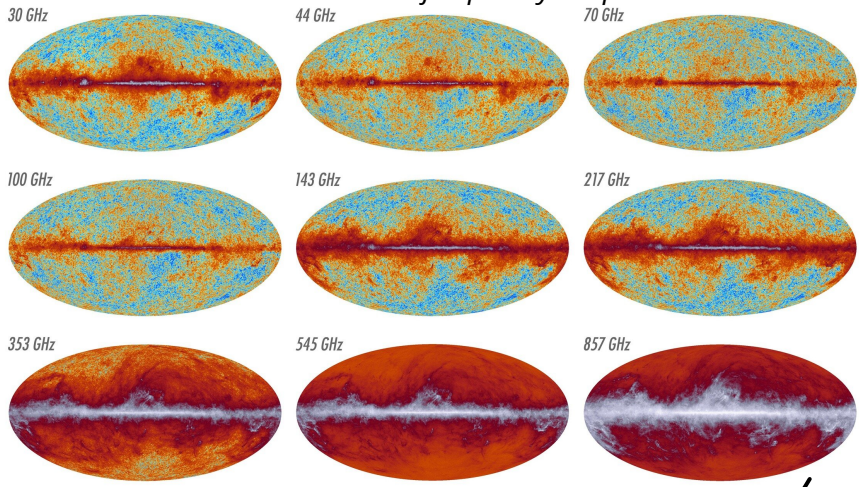
Cosmic Microwave Background (CMB)

Cosmic Microwave Background

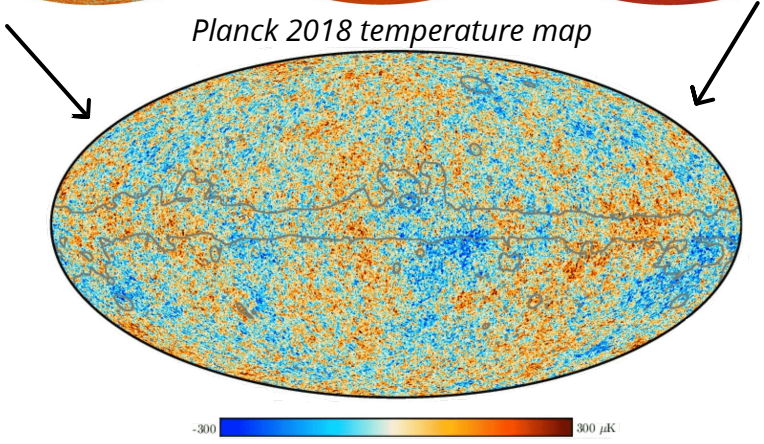
- CMB = **quasi**-perfect black body at 2.73 K
- Telescopes generally use bolometers to measure frequency maps (microwave range)
- Variation in the temperature map used to constrain primordial Universe:
  - Spatial variations (T)
  - Polarization (E, B)



Planck 2015 frequency maps

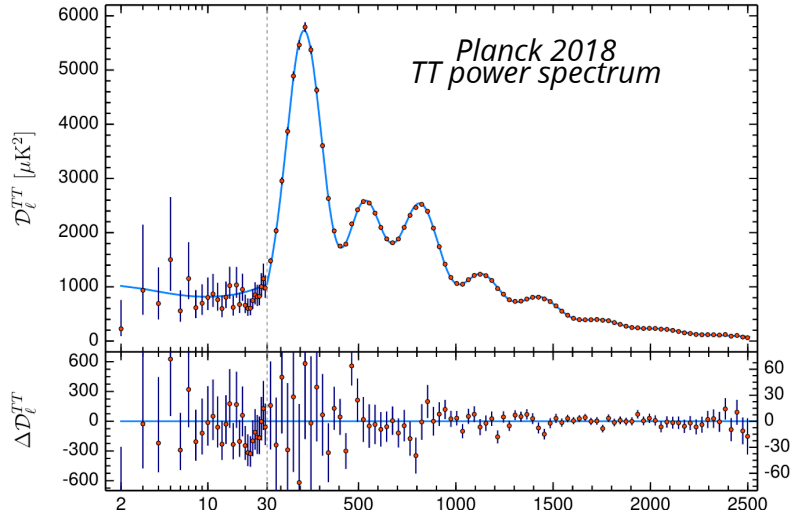


Planck 2018 temperature map

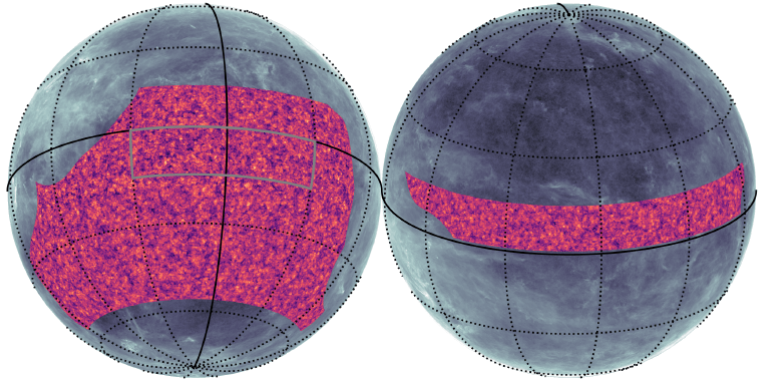


Current and future CMB experiments

- **COBE, WMAP, Planck**: Space telescopes that gave precise temperature maps and stringent CMB constraints.
- **Current**: Atacama Cosmology Telescope, Simons Observatory, BICEP
- **Future**: CMB-S4 (2032)
- **Science cases**:
  - Inflation constraints (T, E, B maps)
  - ΛCDM constraints (Neff, τ)
  - CMB lensing
  - Cluster detection



ACT DR6 CMB lensing mass map



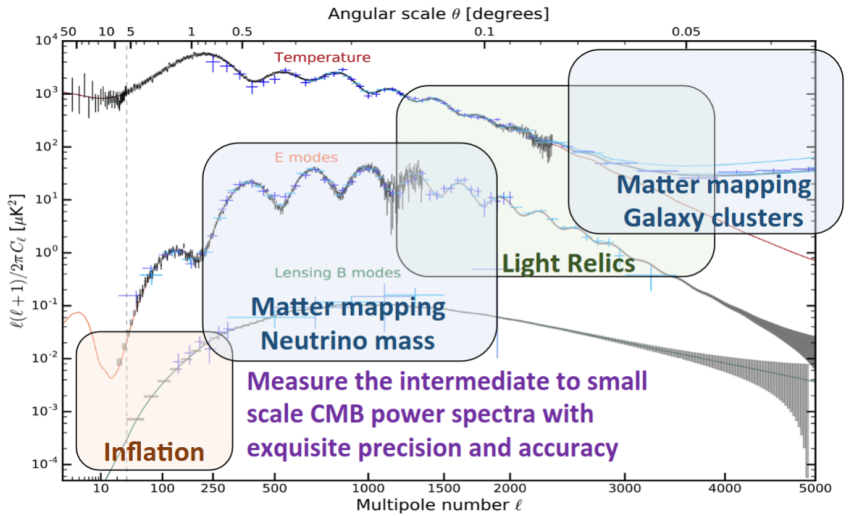
Signature from inflation

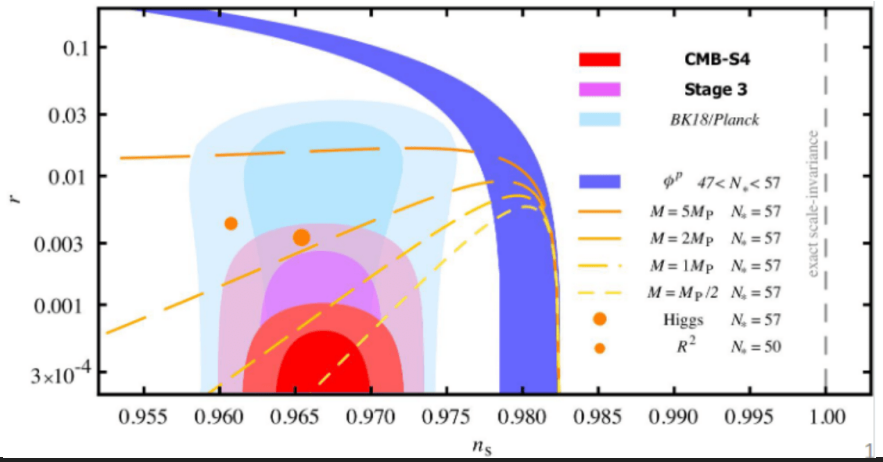
- Most of inflation theories predict primordial gravitational waves, which create B-type polarization on CMB maps
- CMB measurement put constraints on the **scalar-to-tensor ratio**

$$r = A_{\mathrm{t}} / A_{\mathrm{s}}$$

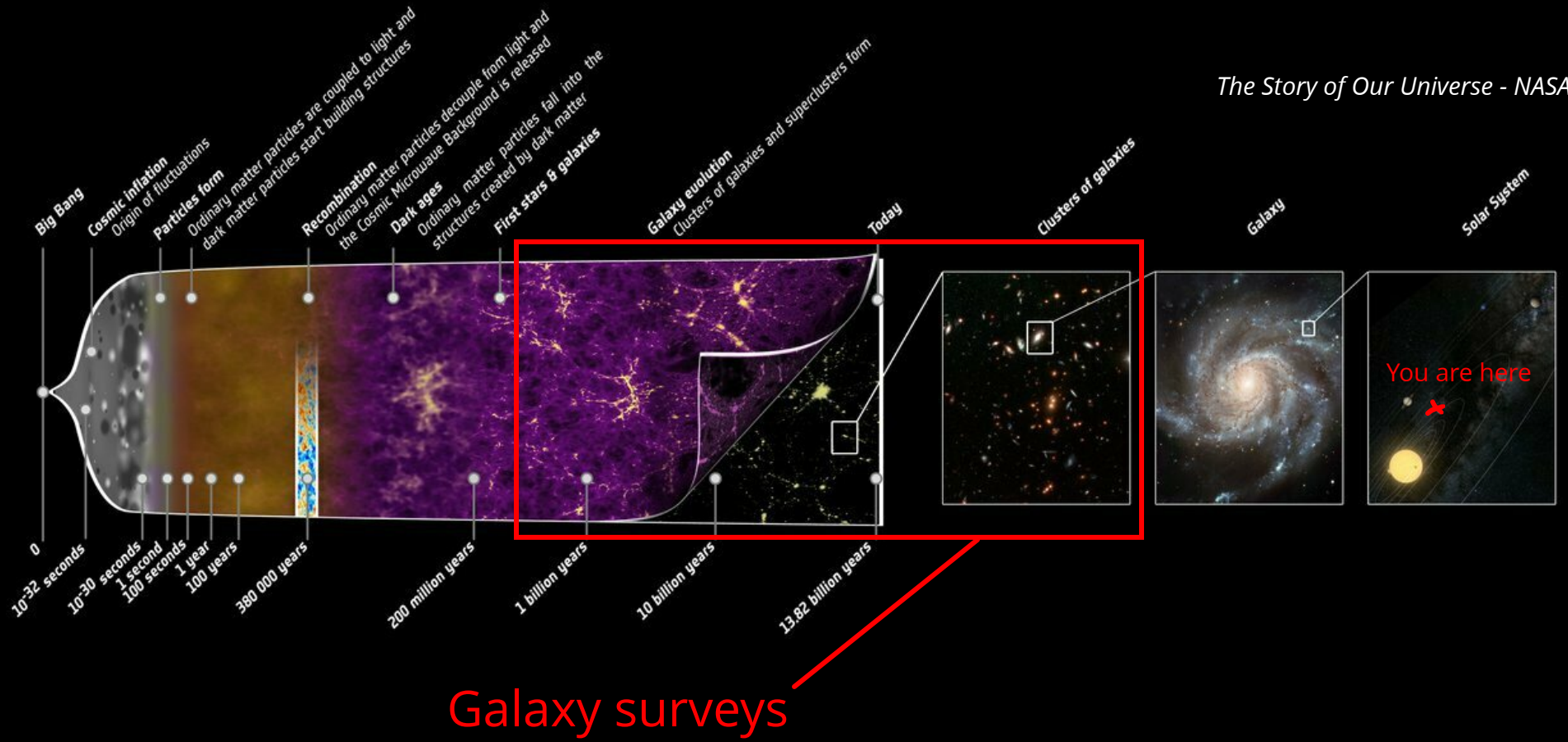
- A lot of contaminants: lensing, dust, atmosphere, galactic synchrotron, systematics, noise…

See talk from Leonora Kardum





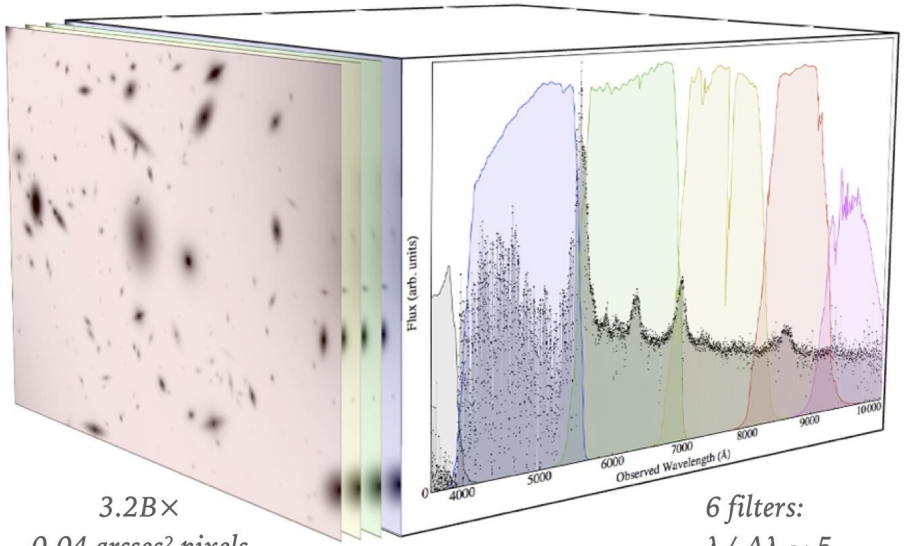
Galaxy experiments



The Story of Our Universe - NASA

Photometric surveys

Source: DESI communication figures

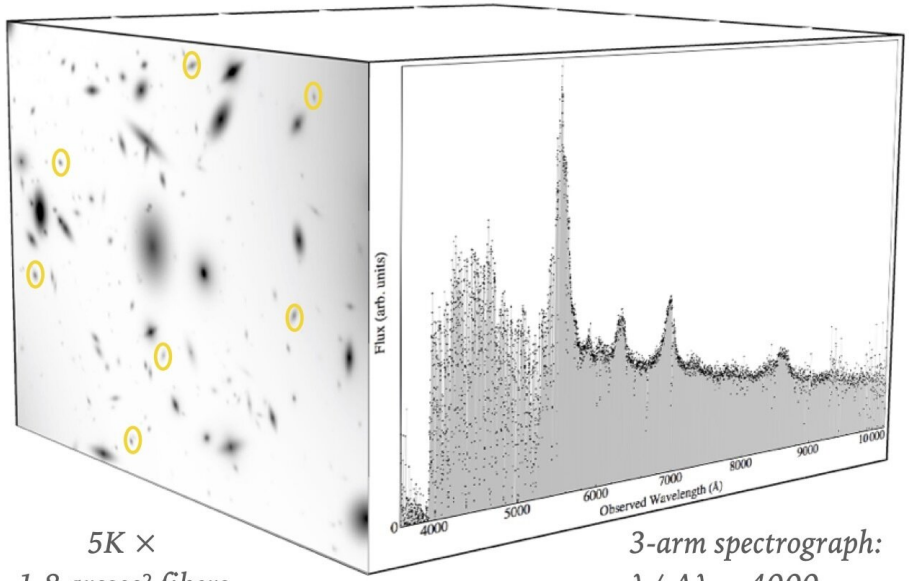


3.2B×
0.04 arcsec² pixels

6 filters:
λ / Δλ ~ 5

- Measure the object flux through a filter
- **Examples**: DES, ZTF, CFHT, LSST, Euclid VIS, Euclid NISP (photo)

Spectroscopic surveys



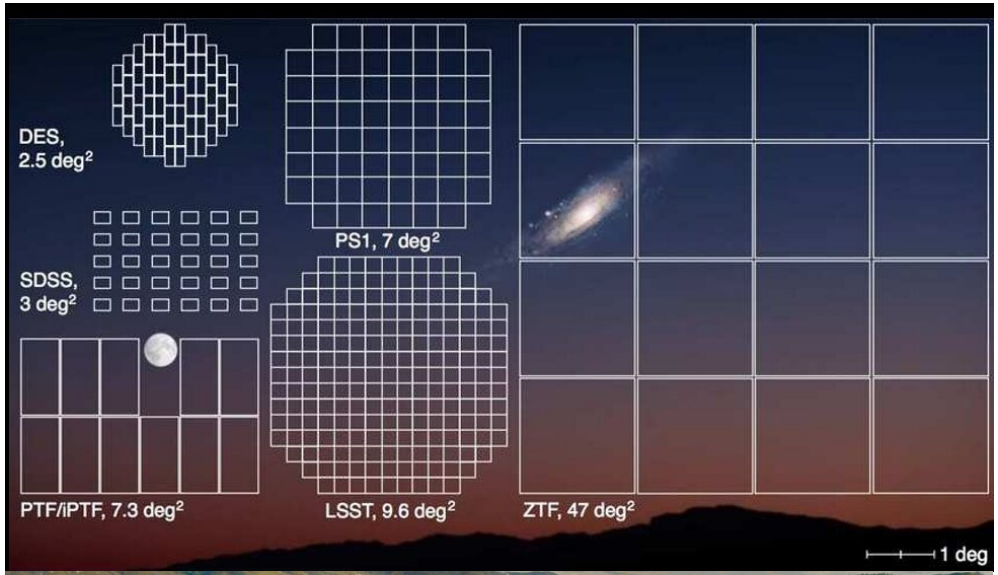
5K ×
1.8 arcsec² fibers

3-arm spectrograph:
λ / Δλ ~ 4000

- Measure the spectra of objects (selected or not)
- **Examples**: SDSS, 6dFGS, DESI, 4MOST, Euclid NISP (spectro)

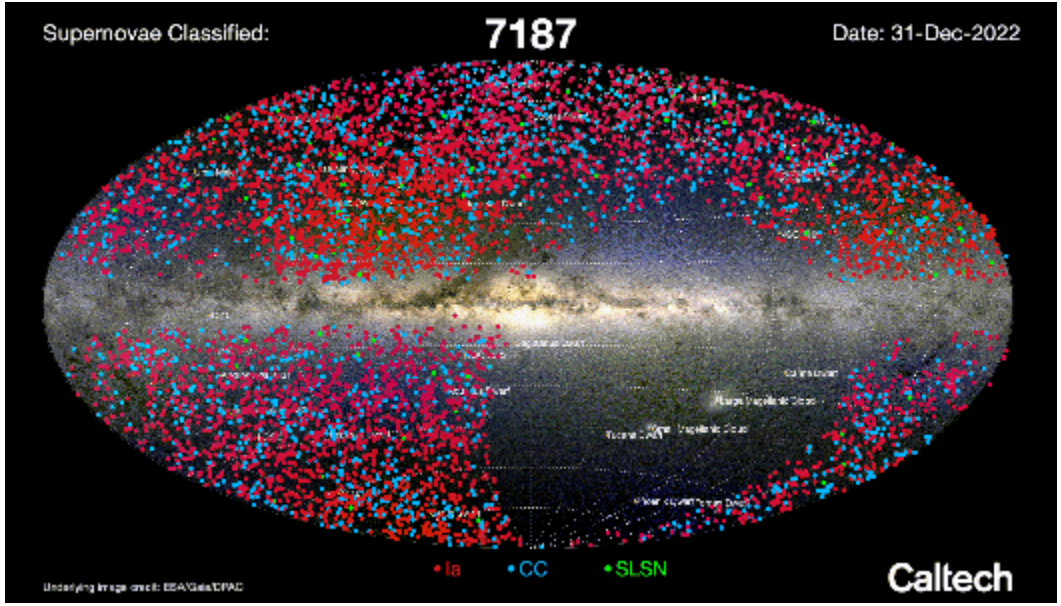
Zwicky Transient Facility (ZTF)

- ZTF = high-cadence photometric telescop in the Palomar observatory
- Very large field of view (47 deg²)
- Observing 3/4 of the sky every nights with 3 filters (g, r, i)



Zwicky Transient Facility (ZTF)

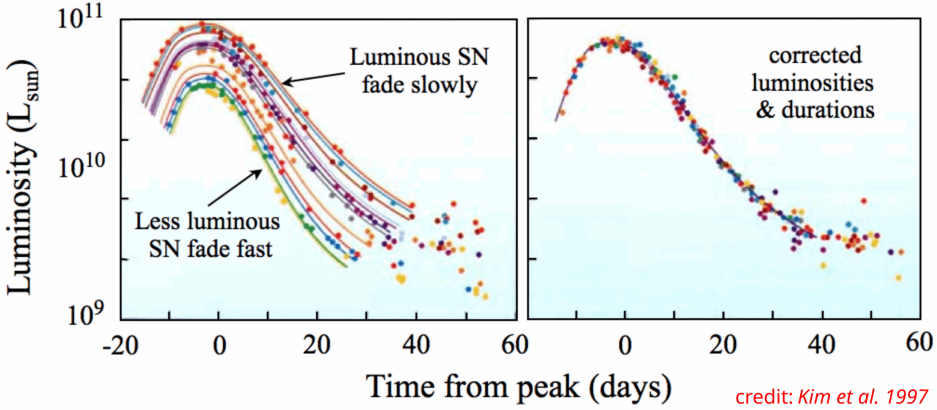
- **Transient sky**: Supernovae, gamma ray burst, tidal distruptive events, comets, asteroids
- Dedicated spectroscopic telescope measuring transient spectra
- **Latest release**: More than 3000 classified supernovae of type Ia



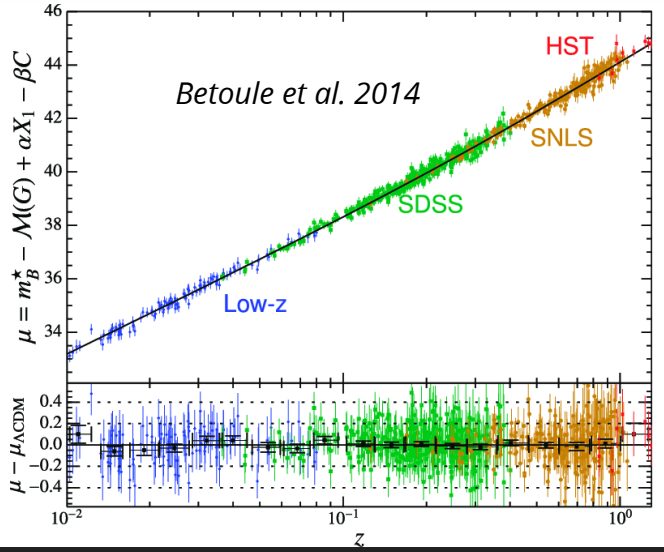
ZTF - supernovae of type Ia

- **SNIa**: White dwarf in a binary system reaches Chandrasekhar mass
- **Standardizable candle**: can be used to measure distance
- **Science cases**:
  - Hubble constant measurement
  - Dark energy constraints (with high-z)
  - Modified gravity constraints

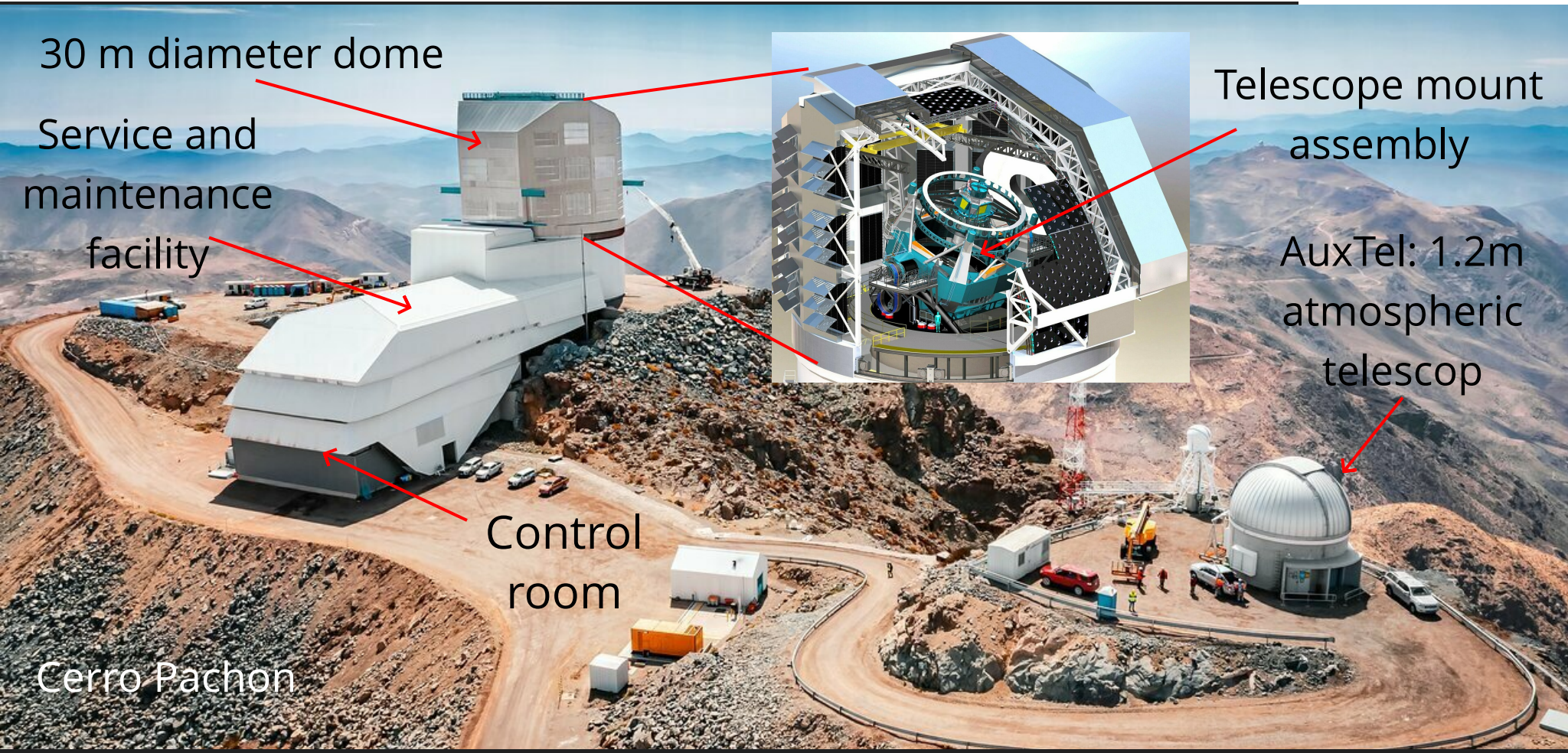
See talk from Constance Ganot



credit: *Kim et al. 1997*

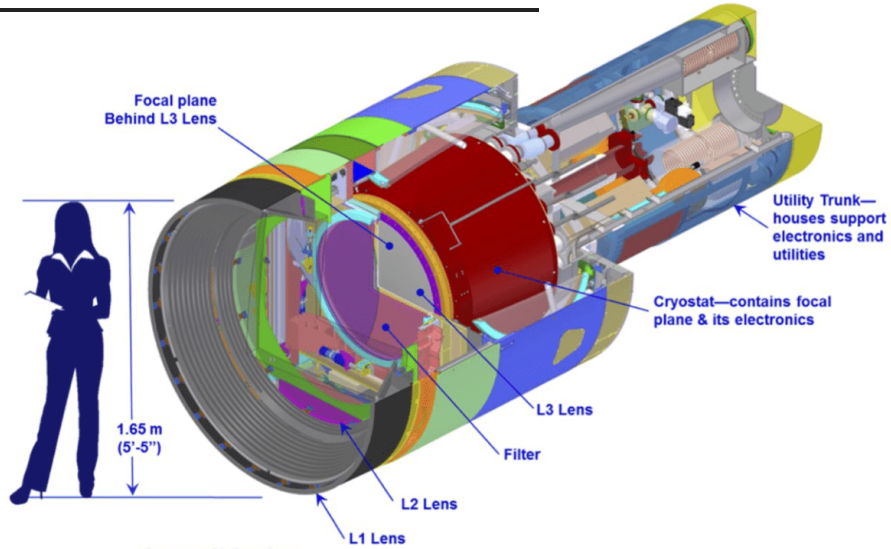


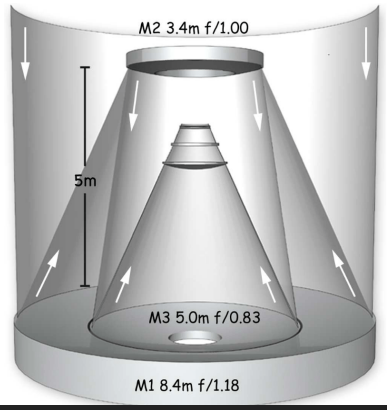
Rubin - LSST

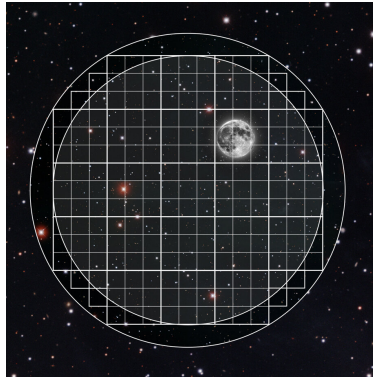

30 m diameter dome
Service and maintenance facility
Telescope mount assembly
AuxTel: 1.2m atmospheric telescop
Control room
Cerro Pachon

Rubin - LSST: instrument

- **Largest numerical camera in the world**: 3.2 Gpixels with 2s readout time
- 8.4 m primary mirror and 9.6 deg² field of view
- 6 filters: (u, g, r, i, z, y)
- 10-year photometric survey of half of the sky (~ 20 000 deg²)
- Complete coverage every 4 nights (static and transient survey)
- In commissioning, expected start in september 2025



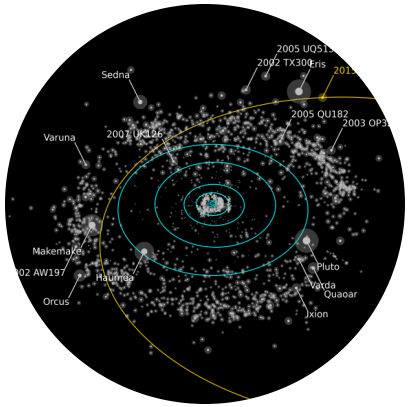




LSST survey: science

Dark matter & Dark energy

- Strong & Weak lensing
- BAO (angular and photo-z)
- Clusters, Supernovae cosmology

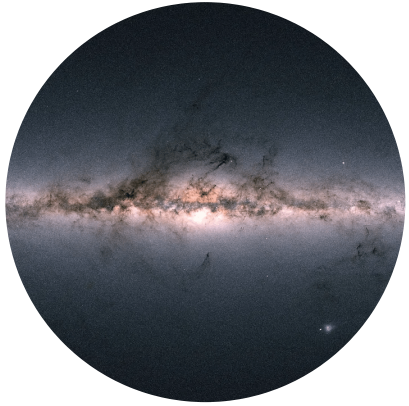


Solar System science

- Comets & asteroids
- Small body census

Mapping the Milky Way

- Structure and evolution
- Stellar properties

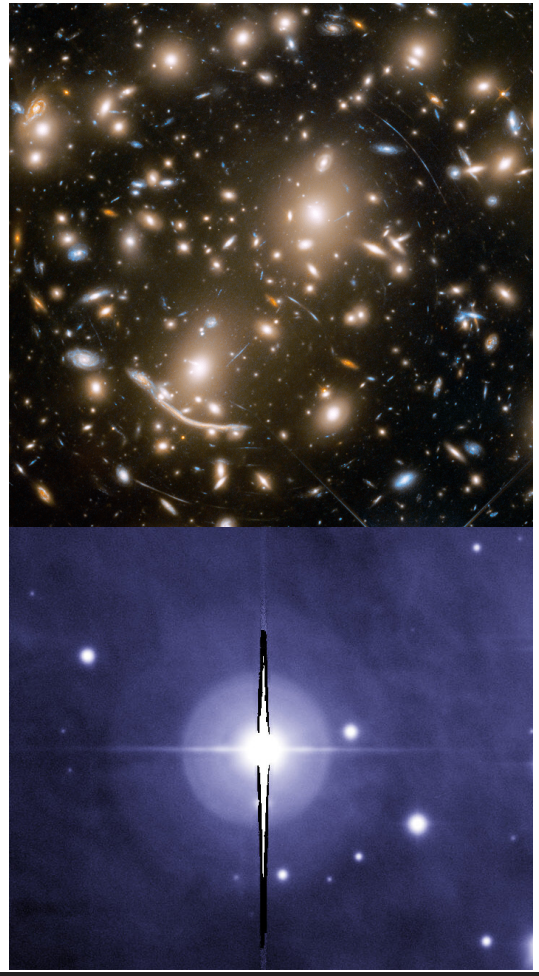


Transient sky

- Supernovae, variable stars
- Rare events (kilonovae, TDE)
- New classes of transients

LSST survey: clusters

- Cluster = group of galaxies bounded by gravity
- **Cluster science**:
  - Abundance = Number as a function of redshift and mass (ΛCDM constraints)
  - Cluster structure and history (DM constraints)
  - Cluster clustering
- Bright object saturates on LSST camera and masking them can impact cluster science



See talk from Nathan Amouroux

Conclusion

- Still a lot of questioning concerning the "not-so-standard" model of Cosmology
- Current cosmological experiments (CMB, SNIa, galaxy surveys...) help tightening constraints and provide feedback to theory
- Improvement of analysis methods is necessary as we are getting more and more data (see next talks)