JRJC 2023 22-28 OCTOBRE

Journées de Rencontre des Jeunes Chercheurs

SAINT-JEAN-DE-MONTS (85) France

LA RIVIÈRE

Village club Cap France

Société Française de Physique | 150 ANS D'ENGAGEMENT POUR LA PHYSIQUE

Cosmology Overview

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24/10/2023

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THE DARK ENERGY SURVEY

esa euclid

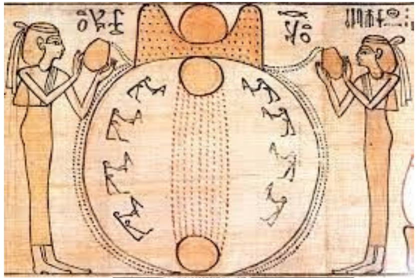
LSST DESC Dark Energy Science Collaboration

APC

LIneA

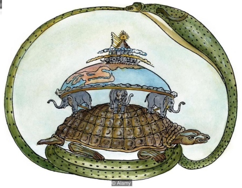
Where do we come from?











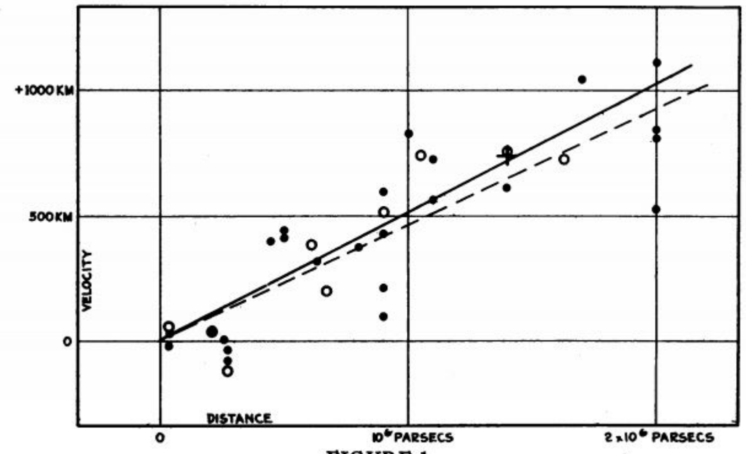


FIGURE 1
Velocity-Distance Relation among Extra-Galactic Nebulae.

Hubble, Edwin (1929). "A relation between distance and radial velocity among extra-galactic nebulae". *PNAS*. **15** (3): 168–173.

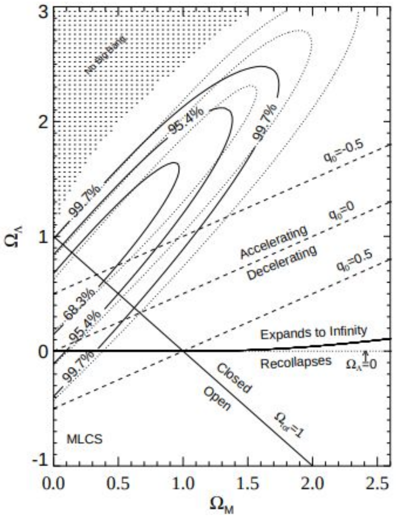
Evolution of the field of cosmology

1905 - 1990s

- Einstein's theory of GR
- Expansion of the Universe
- Discovery of the CMB
- Evidence of Dark Matter in Galaxies
- Theoretical development of cosmology
  - Description with fluid mechanics
  - Inflation
  - Perturbation theory
  - Large scale structure

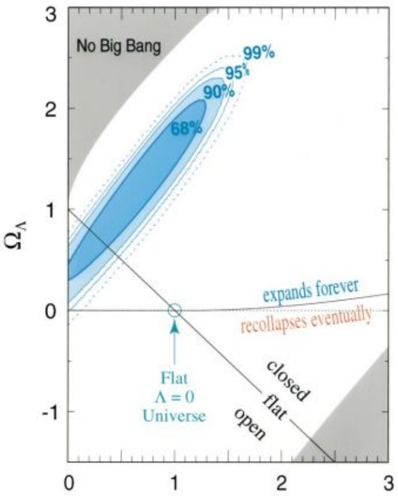
1990s

10 SN



Riess, A. G., "*Observational Evidence from Supernovae for an Accelerating Universe and a Cosmological Constant*", ApJ vol. 116, no. 3, pp. 1009–1038, 1998.

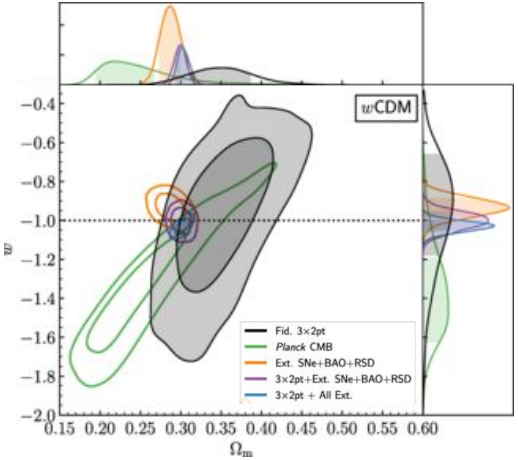
42 SN



Perlmutter, S., "*Measurements of Ω and Λ from 42 High-Redshift Supernovae*", ApJ vol. 517, no. 2, pp. 565–586, 1999.

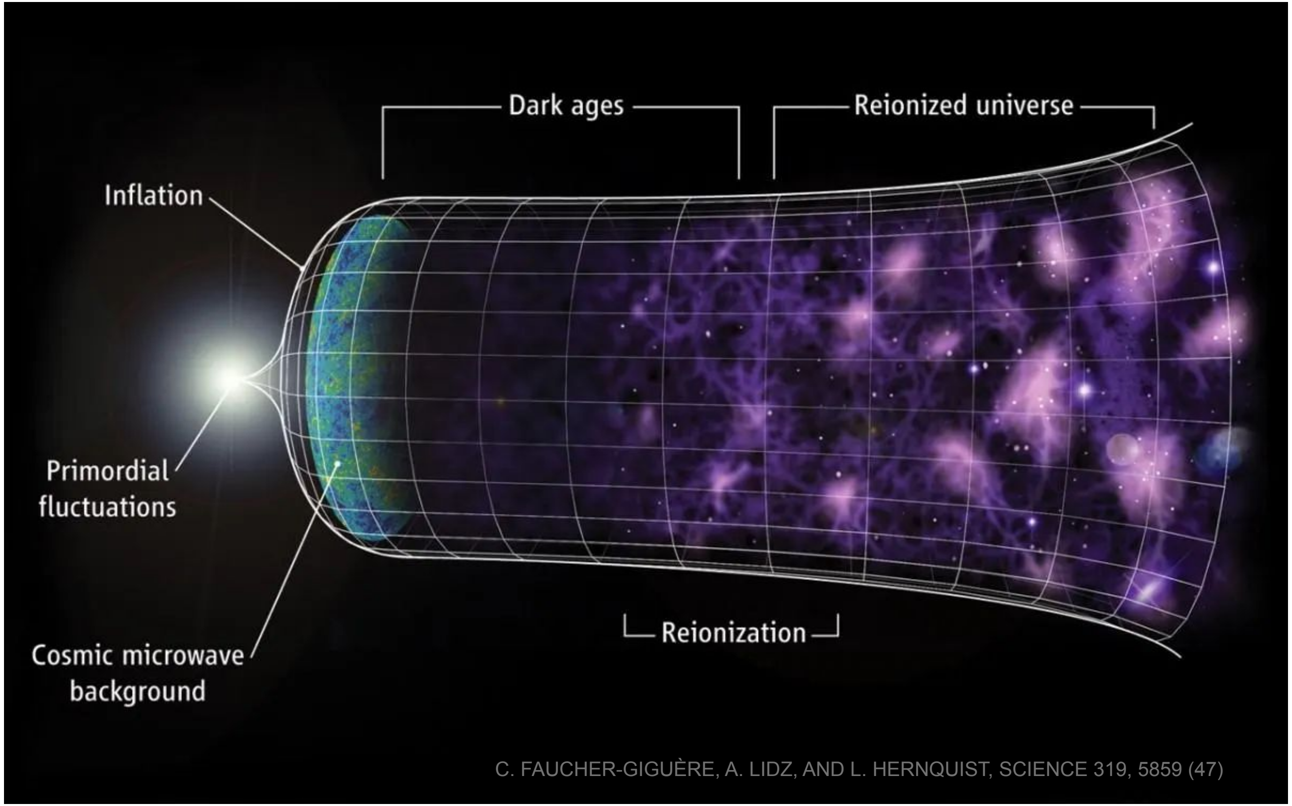
Today

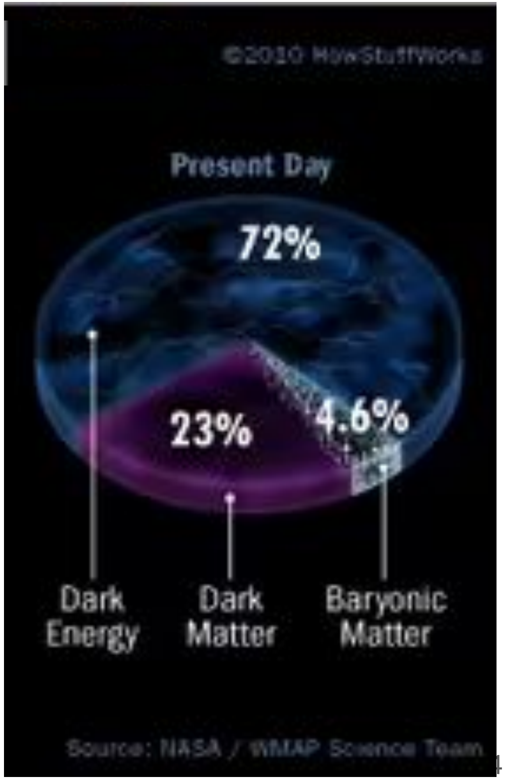
207 SNe, 100 million Galaxies



Abbott, T. M. C., "Dark Energy Survey Year 3 results: Cosmological constraints from galaxy clustering and weak lensing", PRD vol. 105, no. 2, 2022.

Current panorama





Theoretical Background

Basic Equations

Einstein's equation + FRW metric

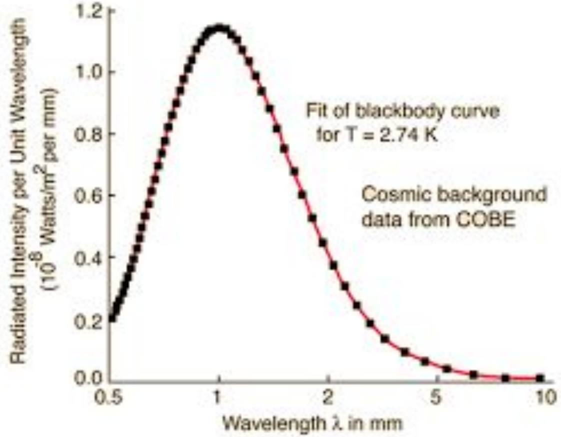
$$G_{\mu\nu}+\Lambda g_{\mu\nu}=\frac{8\pi G}{c^4}T_{\mu\nu}$$

$$ds^2=-dt^2+a^2(t)\left(\frac{dr^2}{1-kr^2}+r^2d\Omega^2\right)$$

Friedmann Equations

$$H^2=\left(\frac{\dot{a}}{a}\right)=\frac{8\pi G}{3}\rho$$

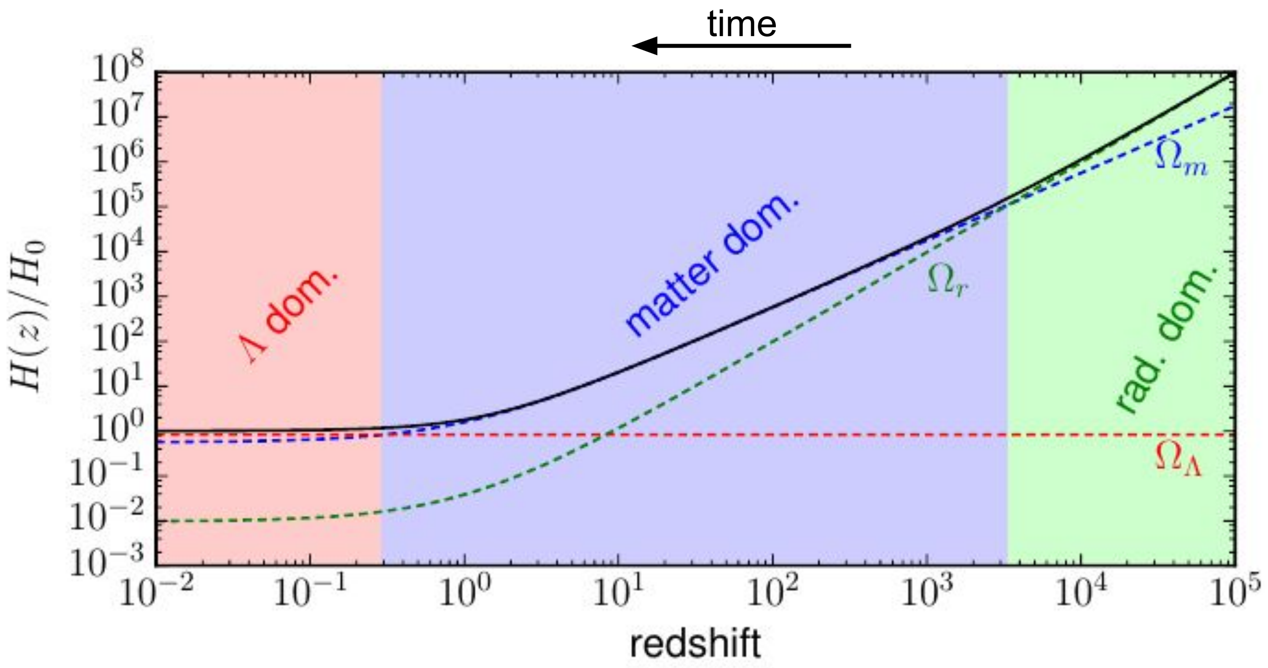
$$\left(\frac{\ddot{a}}{a}\right)=-\frac{4\pi G}{3}\left(\rho+\frac{3p}{c^2}\right)$$



Theoretical Background

Homogeneous Universe

$$H^2 = H_0^2 \left(\frac{\Omega_m}{a^3} + \frac{\Omega_r}{a^4} + \frac{\Omega_k}{a^2} + \Omega_\Lambda \right)$$

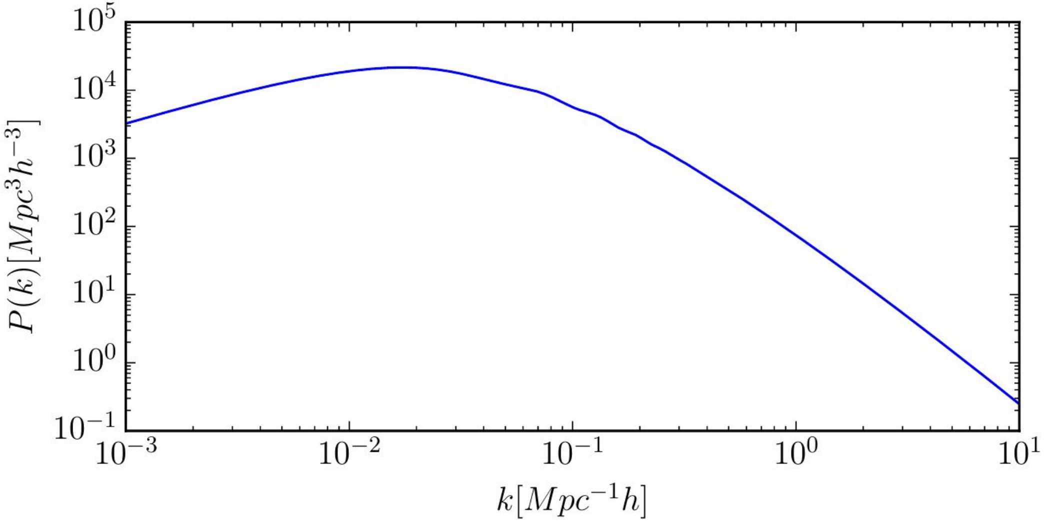


Theoretical Background

Structure formation

Perturbation Theory

$$\delta(\boldsymbol{x}) = \frac{\delta\rho(\boldsymbol{x})}{\bar{\rho}_m} \quad \Rightarrow \quad \left\langle \tilde{\delta}(\boldsymbol{k})\tilde{\delta}^*(\boldsymbol{k}') \right\rangle \equiv (2\pi)^3 \delta_D\left(\boldsymbol{k} - \boldsymbol{k}'\right) P(k)$$



- 2pt correlation function of galaxies
- Collapse of matter -> galaxy clusters

Theoretical Background

Main cosmological parameters today

Main parameters

H_0	$\approx 70\,\mathrm{km/s/Mpc}$	Expansion rate of the Universe today
Ω_m	$\approx 0.3\,(0.25)$	Energy fraction of (dark) matter in the Universe today
Ω_b	≈ 0.04	Energy fraction of baryonic matter in the Universe today
σ_8	≈ 0.8	Amplitude of matter fluctuations at 8Mpc
w	≈ -1	Exponent on the Dark Energy equation of state $(= -1 \Rightarrow$ Cosm. const.$)$
n_s	≈ 1	Spectral Index
τ	≈ 0.05	Optical Depth

Additional quantities

$H(z)$	Evolution of Expansion of the Universe
$D_a(z)$	Angular diameter distance

Observing the Universe

Radio

Current
- WISE
- TGSS

Future
- SKA – Square Kilometre Array
- LOFAR
- HERA – Hydrogen Epoch of Reionization Array – The Search for Cosmic Dawn
- Canadian Hydrogen Intensity Mapping Experiment (CHIME)
- MWA – Murchison Widefield Array

Microwave

Current
- COBE – Cosmic Background Explorer
- WMAP – Wilkinson Microwave Anisotropy Probe
- South Pole Telescope – SPT

Future
- Simons Observatory
- LiteBIRD
- CMB-S4 – Next Generation CMB Experiment

Optical/near-IR

Current
- SDSS
- CFHTLenS
- Pan-STARRS
- KiDS
- HSC
- The Dark Energy Survey

Future
- esa euclid
- Dark Energy Spectroscopic Instrument
- LSST – Legacy Survey of Space and Time
- WFIRST – Wide-Field Infrared Survey Telescope – Astrophysics • Dark Energy • Exoplanets
- Nancy Grace Roman Space Telescope
- SPHEREx

x-ray

Current
- Chandra X-ray Observatory
- esa xmm-newton

Future
- eROSITA
- Lynx X-ray Observatory
- eXTP – enhanced X-ray Timing and Polarimetry Mission

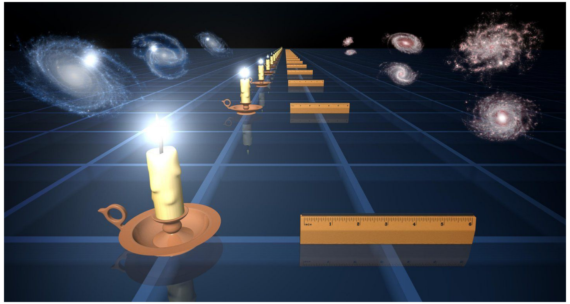
Cosmological Probes

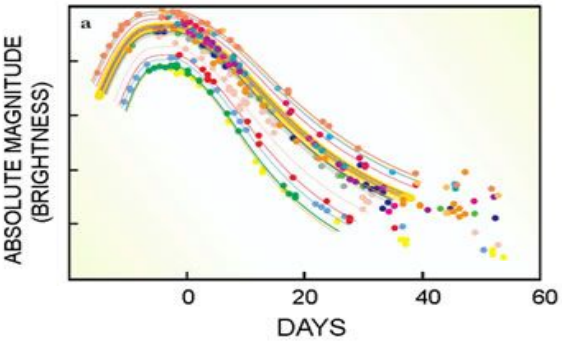
Supernova

See:
Madeleine Ginolin
Dylan KUHN

About

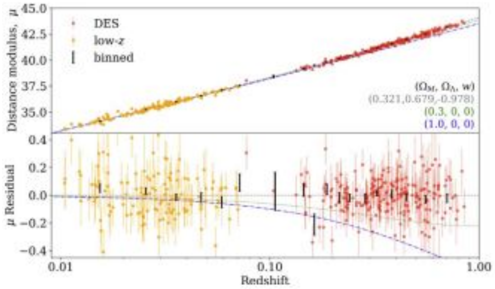
- SNe (type Ia) are standard candles
- There is a tight relation between peak brightness and absolute magnitude

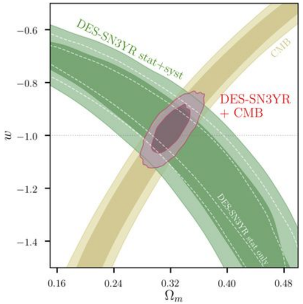




Cosmology

- Constrain: $H(z)$ and inform on Ω_m w





Abbott, T. M. C., [“First Cosmology Results using Type Ia Supernovae from the Dark Energy Survey: Constraints on Cosmological Parameters”], ApJ, vol. 872, no. 2, 2019.

Challenges

- Standardization
- Host Galaxy Properties (SF, metalicity)
- Selection Bias
- Evolution of SNe Ia
- Sample Size

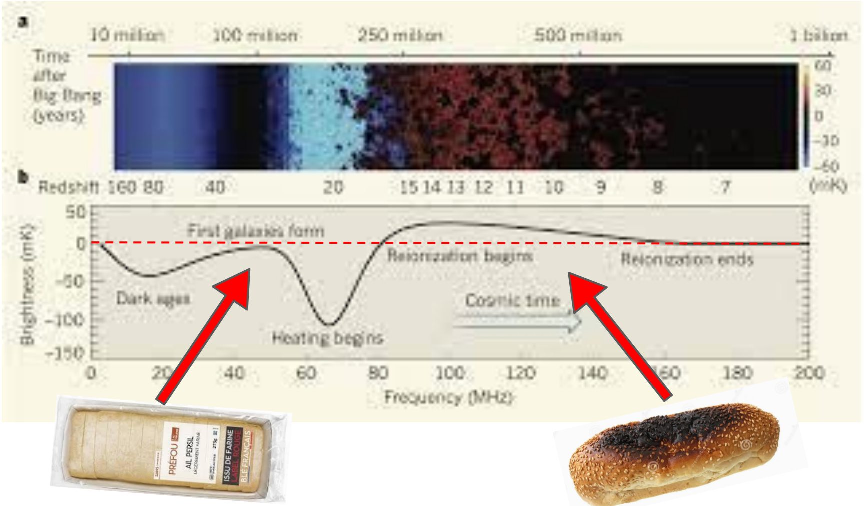
Cosmological Probes

21 cm line

See:
Hugo Plombat

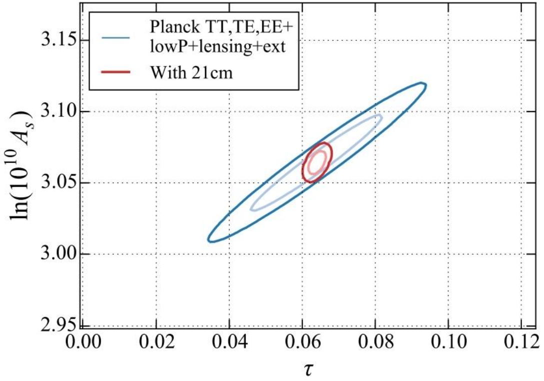
About

- Wavelength of emission/absorption of neutral hydrogen
- Observed from 200-1420MHz
- Traces neutral hydrogren across different times and epochs of the Universe
- Can be used to study the early Universe



Cosmology

- Help constrain: H_0, Ω_m, Ω_b, σ_8, w, n_s, Mnu
- Measure redshifts
- Map matter perturbations , BAO



Challenges

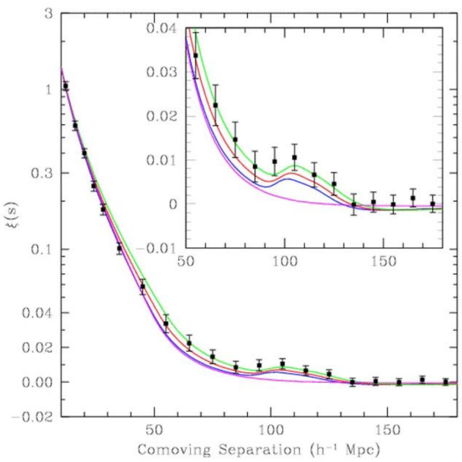
- Foreground removal (milky way)
- Radio interference
- Ionosphere
- Sensitivity (and duration)

Cosmological Probes

Galaxy position correlation (2pt) & Baryon Acoustic Oscillations (BAO)

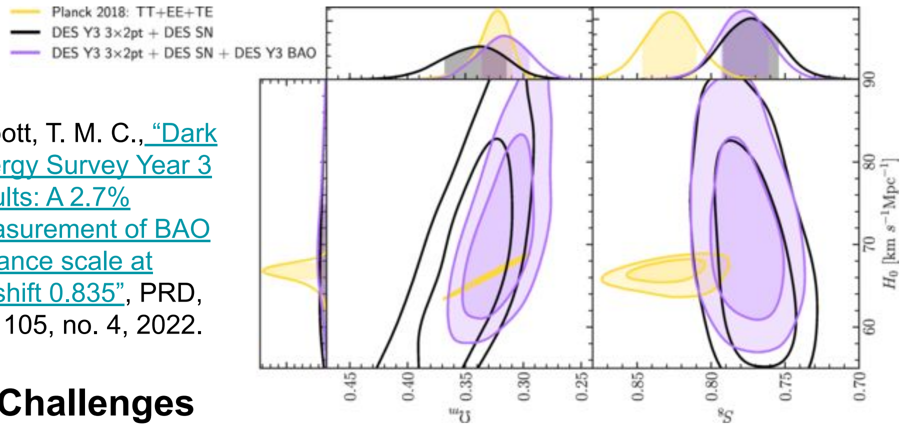
About

- The correlation between galaxy positions is linked to the power spectrum of the Universe
- The sound-waves of the primordial Universe "froze" during the recombination leading a signature at specific scales - BAO



Cosmology

- 2pt constrain: Ω_m, σ_8, n_s
- BAO constrain: $H_0, \Omega_m, \Omega_b, H(z), D_a(z)$



Abbott, T. M. C., "Dark Energy Survey Year 3 results: A 2.7% measurement of BAO distance scale at redshift 0.835", PRD, vol. 105, no. 4, 2022.

Challenges

- 2pt: Cosmic Variance; redshift dependence; non-linear regime; selection effects;
- BAO: redshift measurement; systematic effects (instrumental and survey); redshift-space distortions; modeling

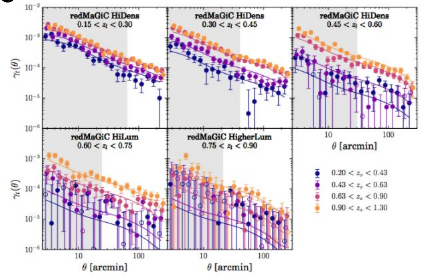
Cosmological Probes

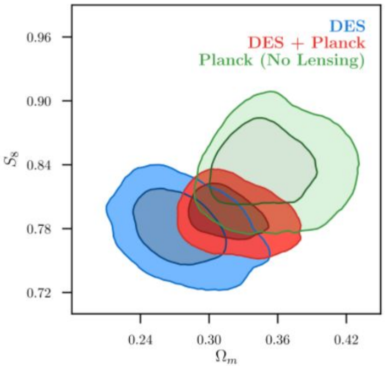
Weak Lensing

About

- The gravitational field distorts the space, deviating the path of light and distorting background images
- In the weak regime, the images of galaxies are sheared by the presence of matter on the line of sight
- Best estimation for the mass of Galaxy Clusters

Cosmology

- Constrain: H_0, Ω_m, σ_8, w, n_s, M_{nu}
- Map Dark Matter Distribution
- 



Challenges

- Intrinsic Galaxy Alignments
- Shape Measurement Biases
- Shear Calibration
- Non-Gaussianity
- Selection biases

Abbott, T. M. C.; et al. (2018). "Dark Energy Survey year 1 results: Cosmological constraints from galaxy clustering and weak lensing". *PRD*. **98** (4): 043526.

Cosmological Probes

Galaxy Clusters

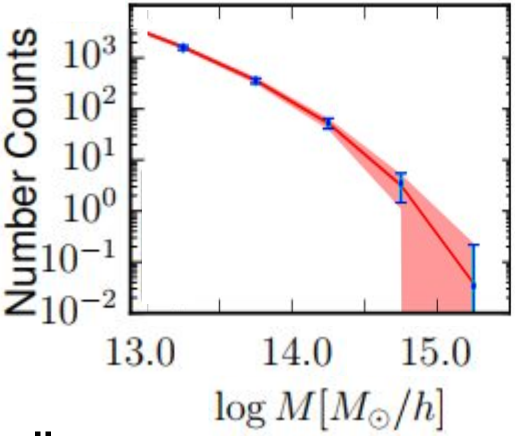
About

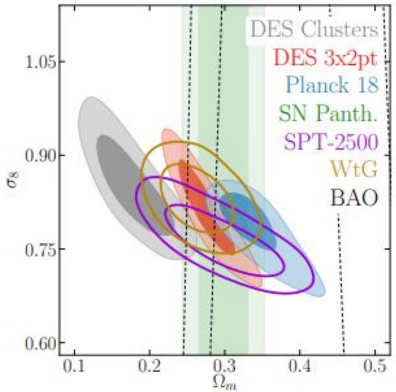
- Halos are formed from the collapses in the Dark Matter Field
- These halos are traced by the baryonic matter in the form of Galaxy Clusters
- Cluster abundance is sensitive to matter distribution and expansion rate
- Complex astrophysical objects that can be observed at several wavelengths

Abell 1835 (z = 0.25) at X-ray, optical and mm wavelengths

Cosmology

- Constrain: H_0, Ω_m, Ω_b, σ_8, w, Non-Gaussianity





Abbott, T. M. C., "Dark Energy Survey Year 1 Results: Cosmological constraints from cluster abundances and weak lensing", PRD, vol. 102, no. 2, 2020.

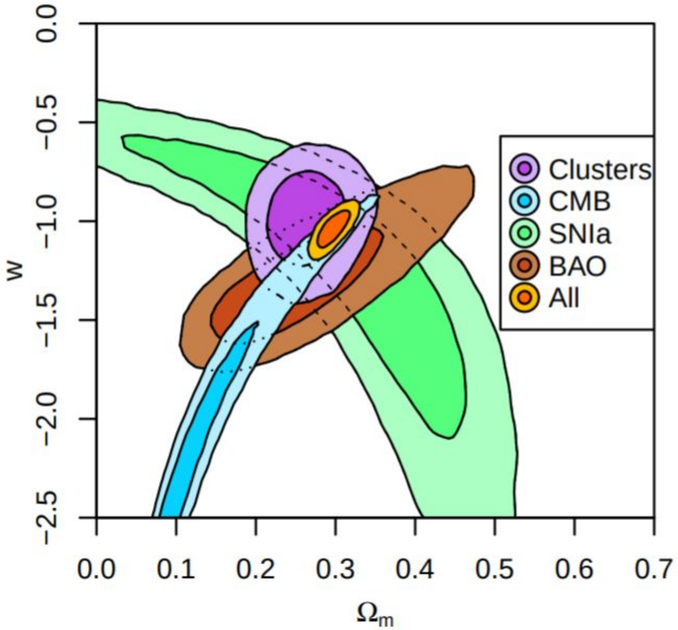
Challenges

- Mass Calibration
- Selection Effects
- Mass Misalignment
- Lower mass clusters
- Non-Gaussianity

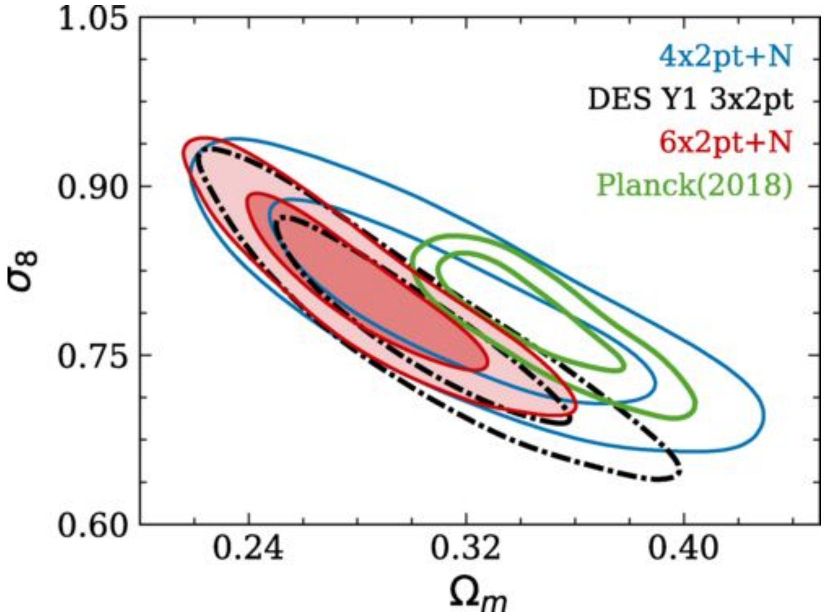
Cosmological Probes

Combining probes

- Complementarity of the different probes break degeneracies on constraints
- Main challenge is to account properly for correlation between probes



Mantz, A. B., "Weighing the giants - IV. Cosmology and neutrino mass", MNRAS, vol. 446, no. 3, pp. 2205–2225, 2015. doi:10.1093/mnras/stu2096.



To, C., "Dark Energy Survey Year 1 Results: Cosmological Constraints from Cluster Abundances, Weak Lensing, and Galaxy Correlations", PRL, vol. 126, no. 14, 2021.

Thank You