Highlights of the Moriond conference Cosmology Session

29/04

DPHP Seminar

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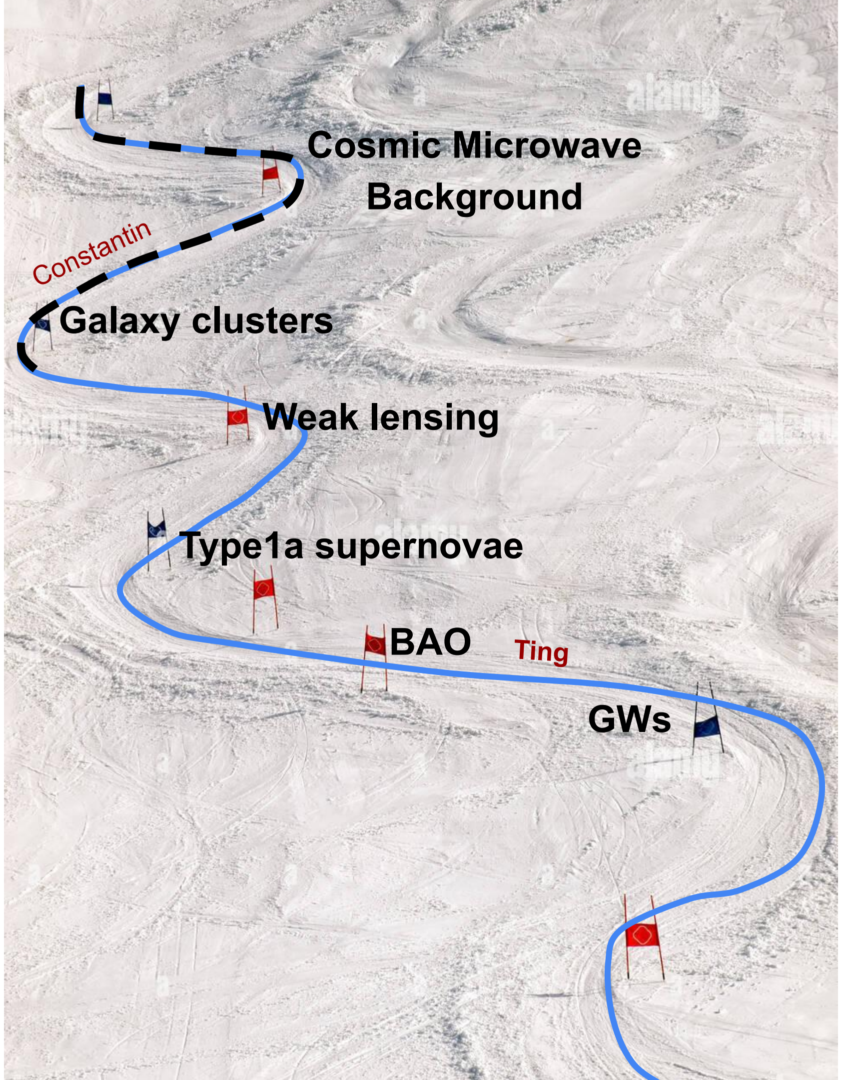
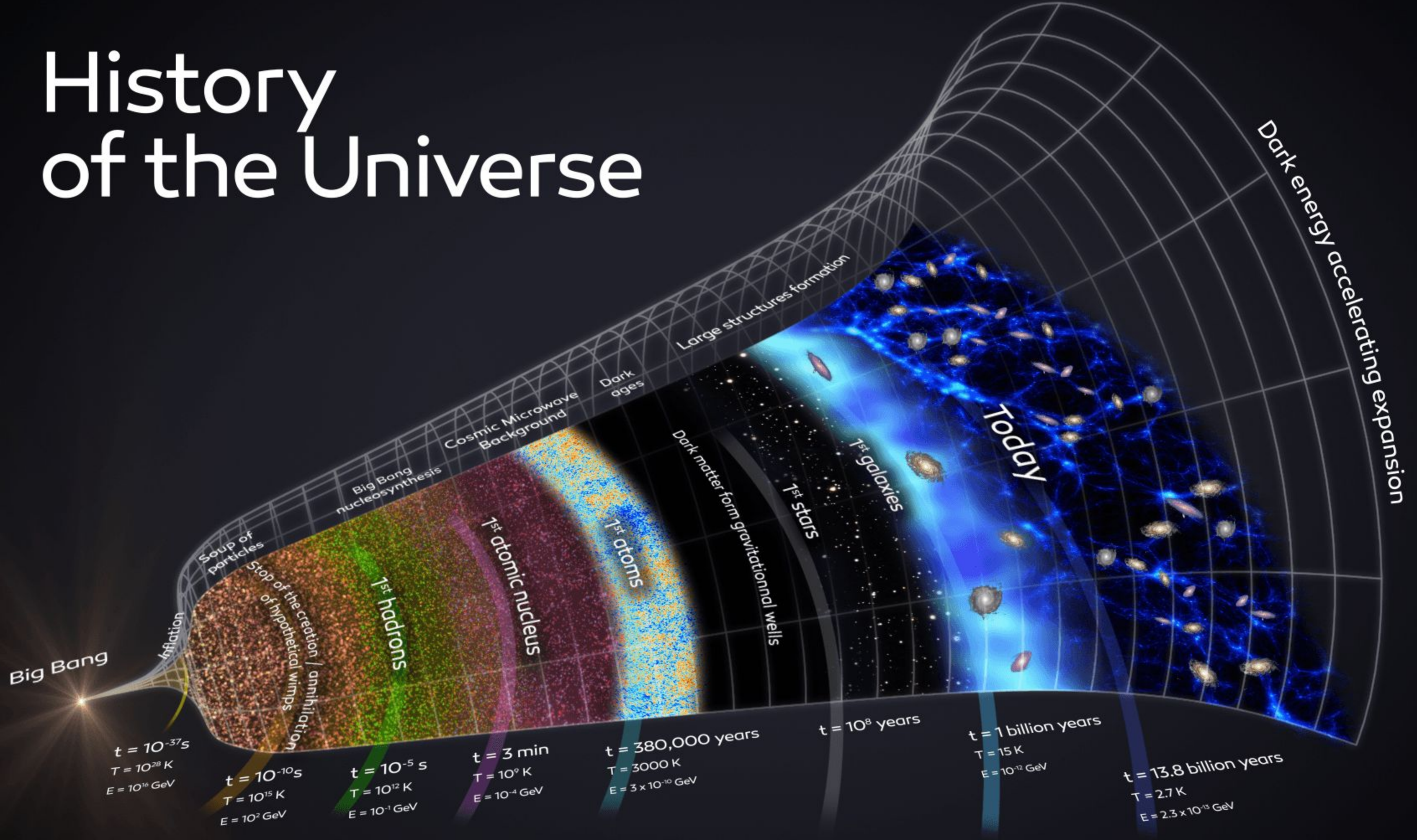
Cosmology@Moriond ❄️ 🏂 🎿 🌨️ 🏔️

❖ Good ski sessions 😃 (only 1 rainy day)
❖ A lot of interesting talks and amazing results !
  ➢ \sim 80 talks
  ➢ Non-exhaustive list today, both personal preference
  ➢ We are both not expert on every topics, more details on dedicated papers ! clickable links to papers in the titles.
  ➢ Find the full program here



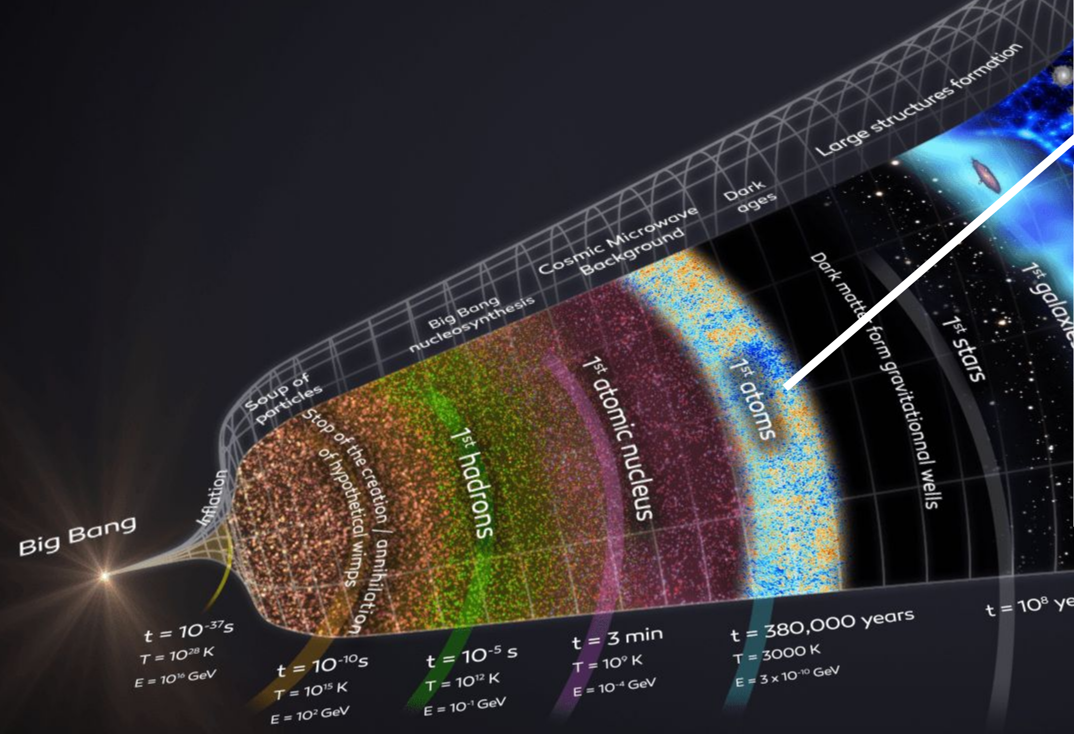
History of the Universe

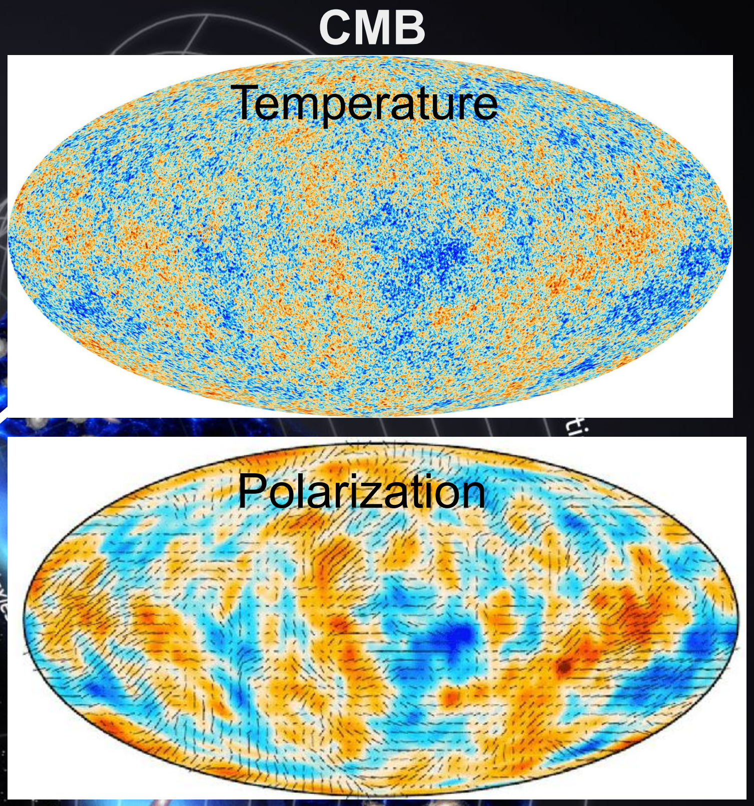


0 K = -273 °C

hadron = bound quarks system (proton, neutron, etc.)

History of the Universe





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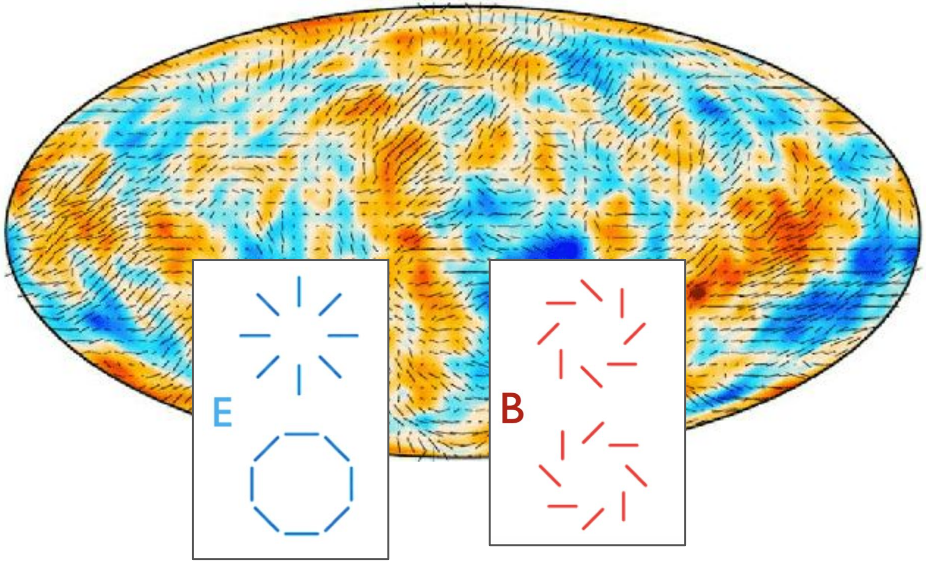
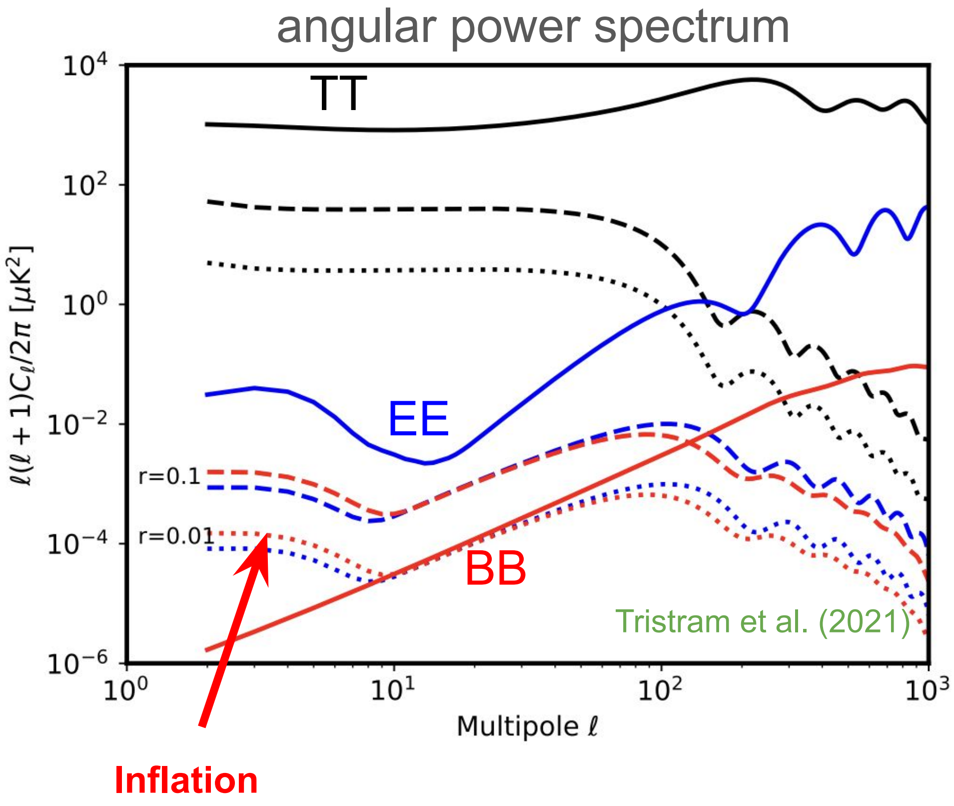
Primary CMB

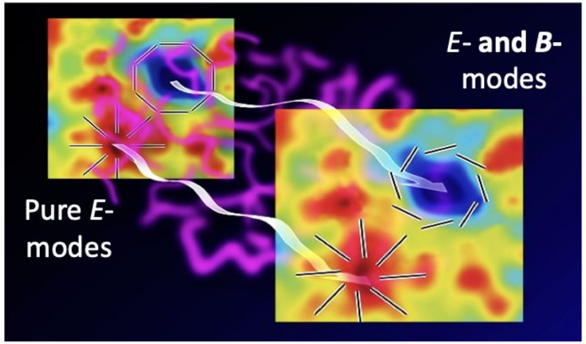
- ❖ CMB power spectra probes physics in the early Universe (position of peaks, size, ratio, etc)
- ❖ Black body emission: observation in many bands
- ❖ Inflation => origin of quantum perturbations
  - ➢ from tensor (GWs) + scalar (density) fields
  - ➢ GWs create B-modes
  - ➢ r = Power(tensor)/Power(scalar)
- ❖ measure r ± σ(r) smoking gun of inflation models
- ❖ large scales of the CMB





Secondary CMB

- Light from CMB travels through the inhomogeneous Universe
- Arc-minute deflections, traces matter distribution along the line-of-sight
- smearing of CMB spectra+Creates stat. anisotropies in CMB 2pt TT/EE/EB
- lensed E-modes sources B-modes (even without inflation)

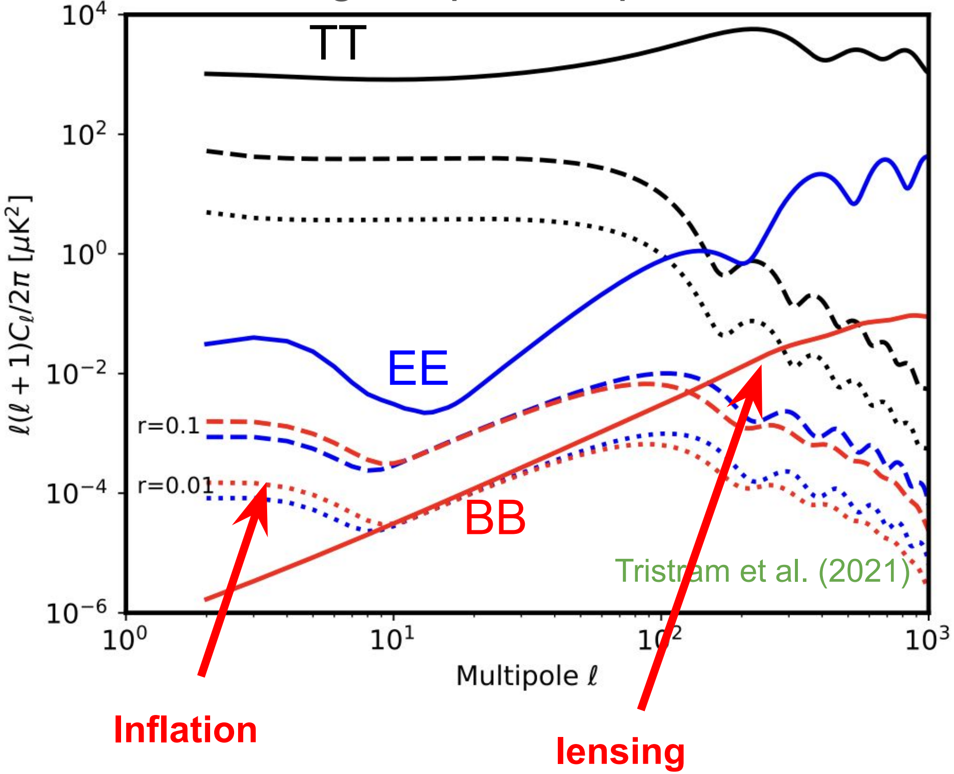


- Method: extract non-zero correlation between different modes (QE) of E, T and B fields

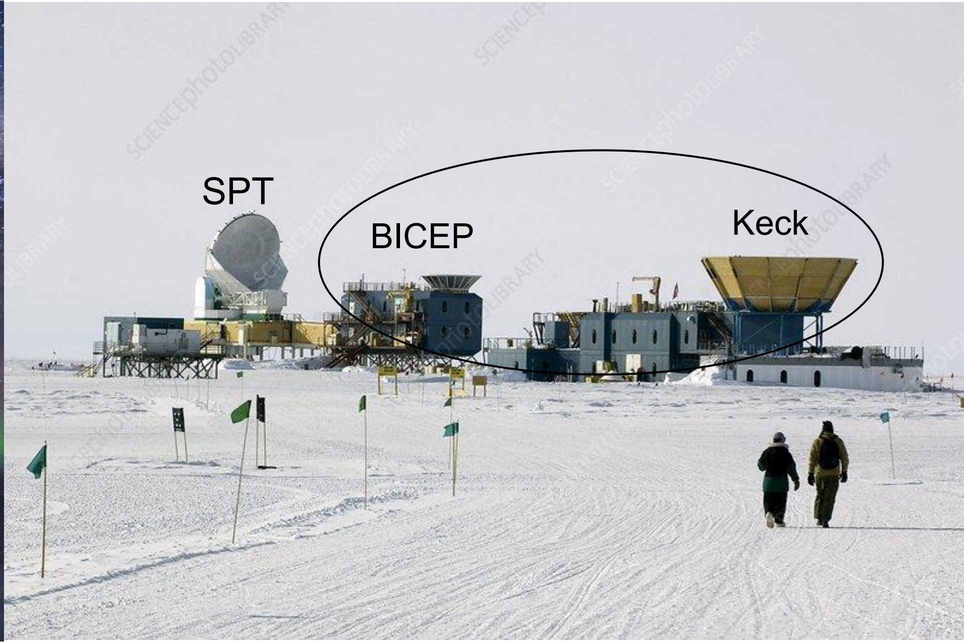
$$\langle X_{\boldsymbol{\ell}} Y^*_{\boldsymbol{\ell}'} \rangle_{\rm CMB} = \delta(\boldsymbol{\ell}-\boldsymbol{\ell}')C_\ell^{XY} + W^{XY}_{\boldsymbol{\ell},\boldsymbol{\ell}'}\,\phi_{\boldsymbol{\ell}-\boldsymbol{\ell}'}$$

$$\bar{\phi}_{\boldsymbol{L}}^{T_\nu T_\mu} = \int d^2\boldsymbol{\ell} W^{TT}_{\boldsymbol{\ell},\boldsymbol{\ell}-\boldsymbol{L}} \bar{T}_{\nu,\boldsymbol{\ell}} \bar{T}^*_{\mu,\boldsymbol{\ell}-\boldsymbol{L}}$$

angular power spectrum



Focus of this talk on CMB results presented @Moriond



CMB experiments

- ❖ Space: WMAP, *Planck*, LiteBIRD
- ❖ Ground: Atacama Cosmology Telescope, QUBIC, South Pole Telescope, BICEP/Keck

This talk

BICEP/Keck CMB experiments (J. Cheshire, MIA, Minneapolis)

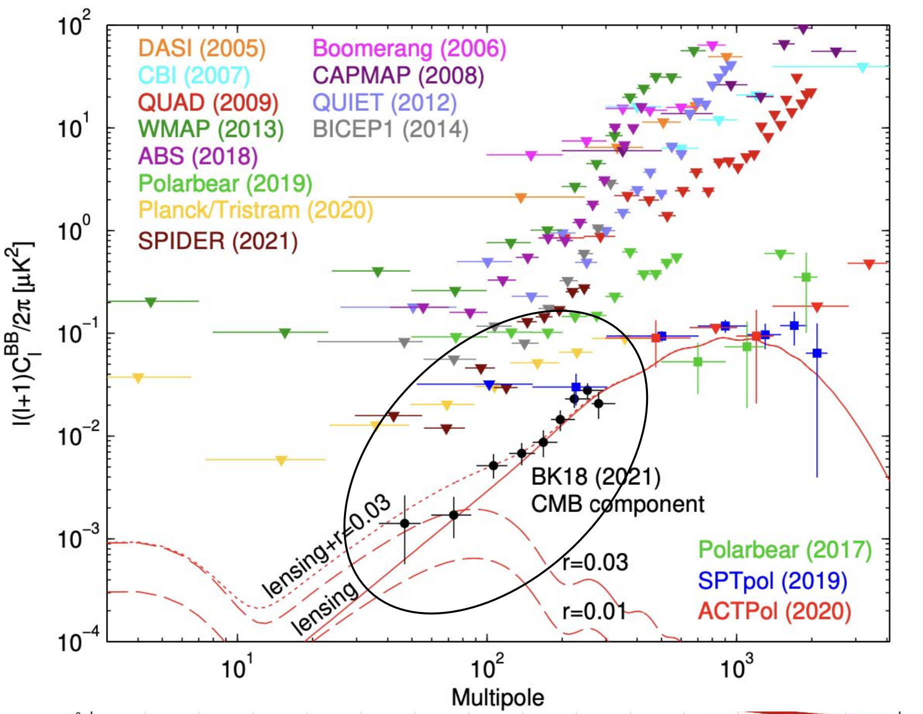
- South Pole, 5 generations of telescope since 2012
- 4 bands, handle foregrounds and contaminants
- **Challenges:** Foreground + delensing
  - dust: refutation of 5σ-detection (r=0.2) in 2014!
  - lensing: dominant contribution to σ(r)

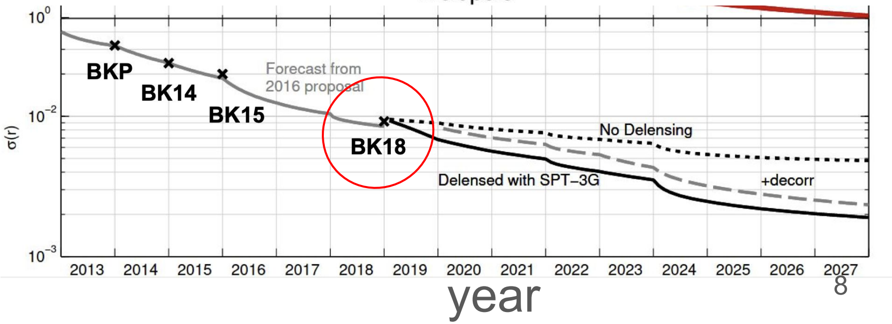
Cosmological analysis

- Data up to 2018 (BK18)
- BK18 + external Planck/WMAP B modes
- Model: joint lensed-ΛCDM + foregrounds + r
- **r < 0.036 at 95% CL, σ(r)=0.009**
- Tightest constraints on primordial GWs up-to-date

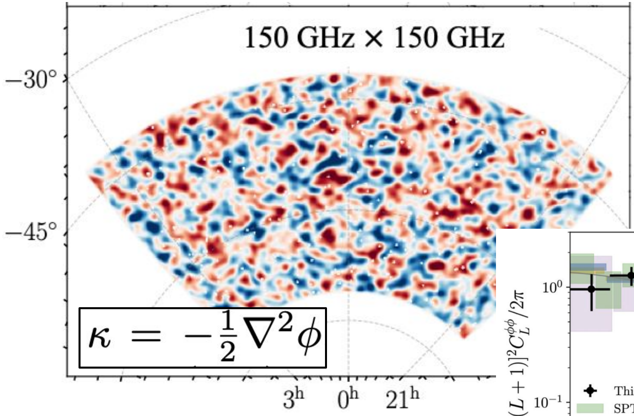
Future

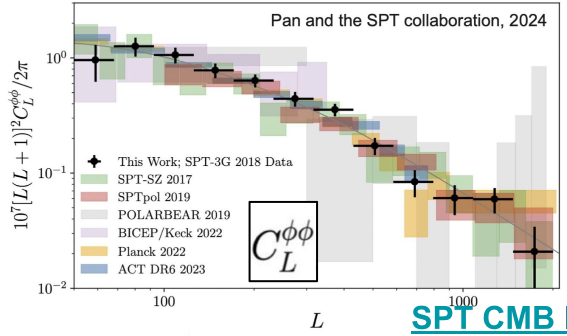
- Since 2018 large new dataset in diff bands
- Plan adding a “lensing template” derived from SPT-3G, σ(r)=0.003 by 2030

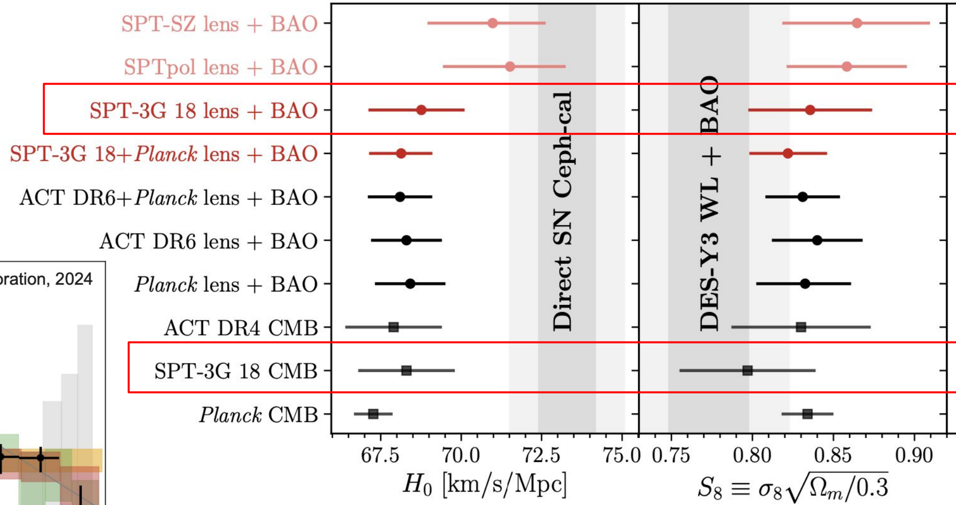




Cosmology with SPT-3G early data (F. Guidi, IAP, Paris)







SPT - South Pole:

- ❖ High angular resolution (~1 arcmin), sensitive to small scale of T/E anisotropies
- ❖ 3 bands, primary+CMB lensing
- ❖ SPT-3G: 2017-2027, 1,500 deg^2

Results for TT/TE/EE (**<=**2018 data release)

- ❖ Very good consistency with *Planck* ΛCDM, < 1σ
- ❖ Confirm H_0 2.6σ tension, H_0(CMB) < H_0(DL)
- ❖ S_8 agrees with low-z probes and *Planck* (error bars)

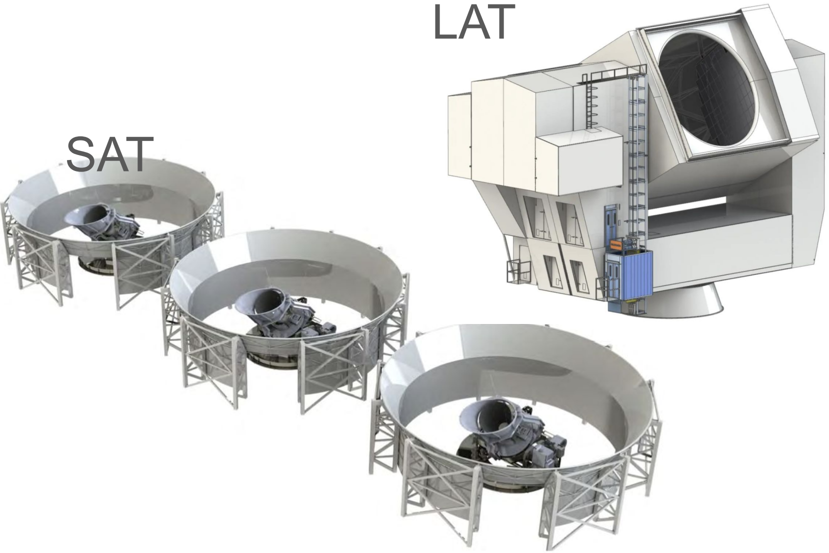
SPT CMB lensing (Temperature only, 2 bands, <2018)

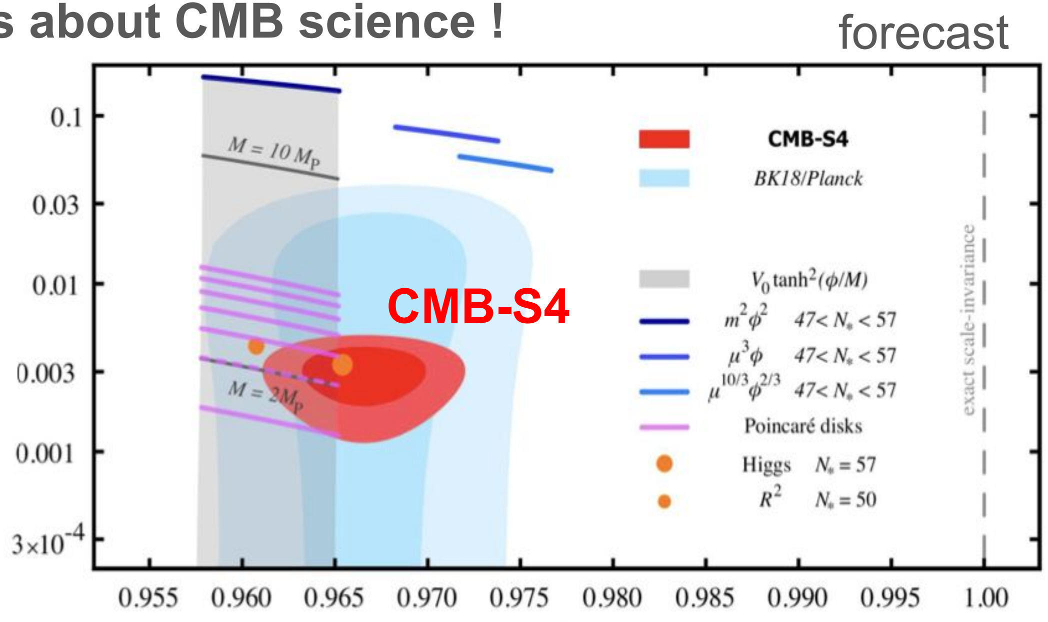
- ❖ Alone: Very good consistency with ΛCDM, $\sigma_8\mathbf{\Omega}_m^{0.25}$ compatible with other CMB experiments
- ❖ +BAO: S8, H0 compatible with Planck lens/primary
- ❖ still 2.6σ H_0 tension with DL (SH0ES)
- ❖ 1.6σ tension with S8 cosmic shear meas.+BAO

Forecast for future data release TT/EE/TE+ϕϕ

- ❖ 4K+2019/20: improve noise level 3 x smaller, 4,5K deg2
  - ➢ ≃Planck power, Primary: $\sigma(H_0)_{SPT}$= 0.7, $\sigma(H_0)_{Planck}$ = 0,6
- ❖ 10K+2019/26: 10K deg2, x2 improvement in ΛCDM

A lot more interesting Moriond talks about CMB science !





Simons Observatory Chile, nominal > 2024+

- 6 bands, 3 SATs (commissioning) + 1 LAT
- Aims **$\sigma_{SO}(r)$ = 0.009 => 0.0012**
- Current: **$\sigma_{BK18}(r)$ = 0.009, r_{BK18} < 0.036**
- Sophisticated component separation, de-lensing with LAT(crucial for small scales)

CMB-S4, Chile+South Pole > 2030+

- Tandem of CMB experiments (2 LATs in Chile, SAT+LAT in SP)
- More bands (remove contamination from foregrounds)
- A order in magnitude in the number of detector, high sensitivity
- **$\sigma_{CMB\text{-}S4}(r)$=0.0005** x20 below current constraints

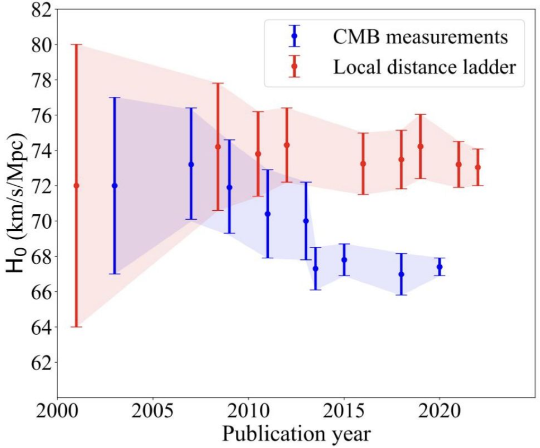
Updates on the Hubble Tension (A. R. Khalife, IAP, Paris)

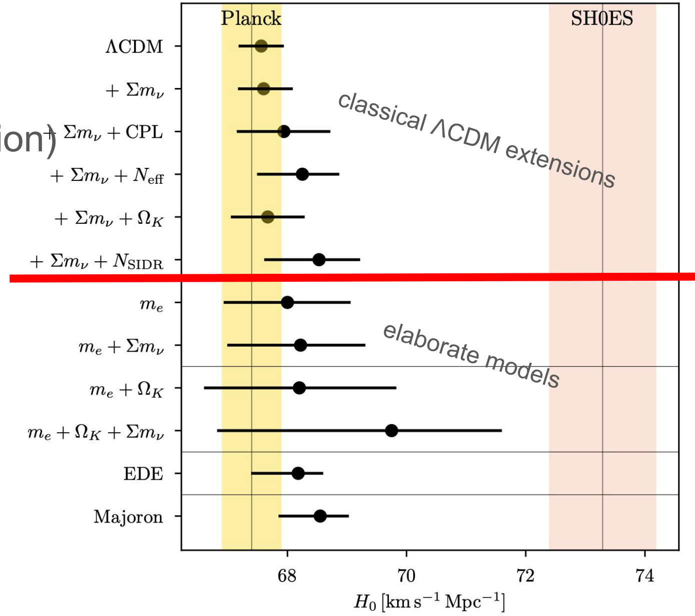
the H_0 puzzle

- Disagreement between “direct” H_0 meas. from local Distance Ladders and “indirect” from CMB+BAO => H_0(DL) > H_0(CMB+BAO)
- a) Possible hidden systematics in data ?
- b) Because of cosmological model ? => H_0 olympics !
  - Try to explain the discrepancy from a theoretical POV

This work

- Large variety of data
  - CMB: Planck TT/TE/EE+SPT-3G+ACT
  - SDSS BAO data + Pantheon SN
  - To compare with latest SH0ES SN1a measurements (6σ tension)
- 11 cosmological models
  - Motivation: change early/late physics to match SH0ES H_0
  - 5 classical ΛCDM extensions ($\sum m\nu$, CPL, Ω_K, Neff, NSIDR)
  - 6 elaborate extensions (varying m_e, EDE, Majoron)
- **Results**
  - Different tension metrics, big discrepancy !
  - Not enough statistical significance to become the next concordance model of Cosmology, except for ($m_e+\Omega_K$), ($m_e+\Omega_K+\sum m\nu$), EDE (3 to 2σ tension), possible candidates

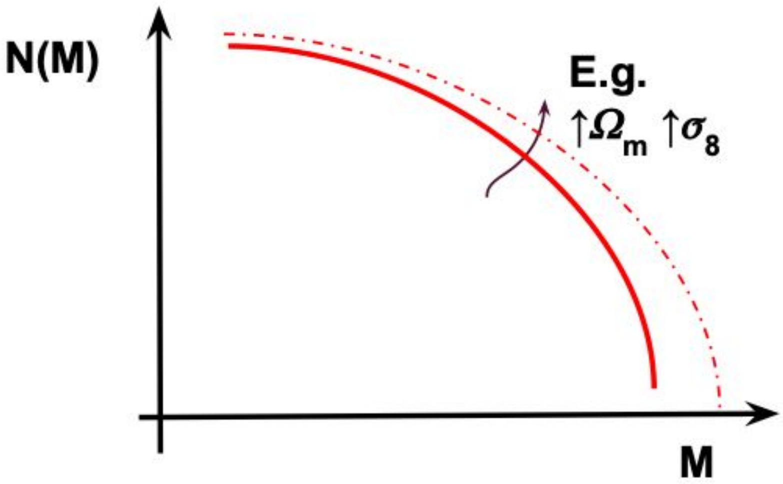


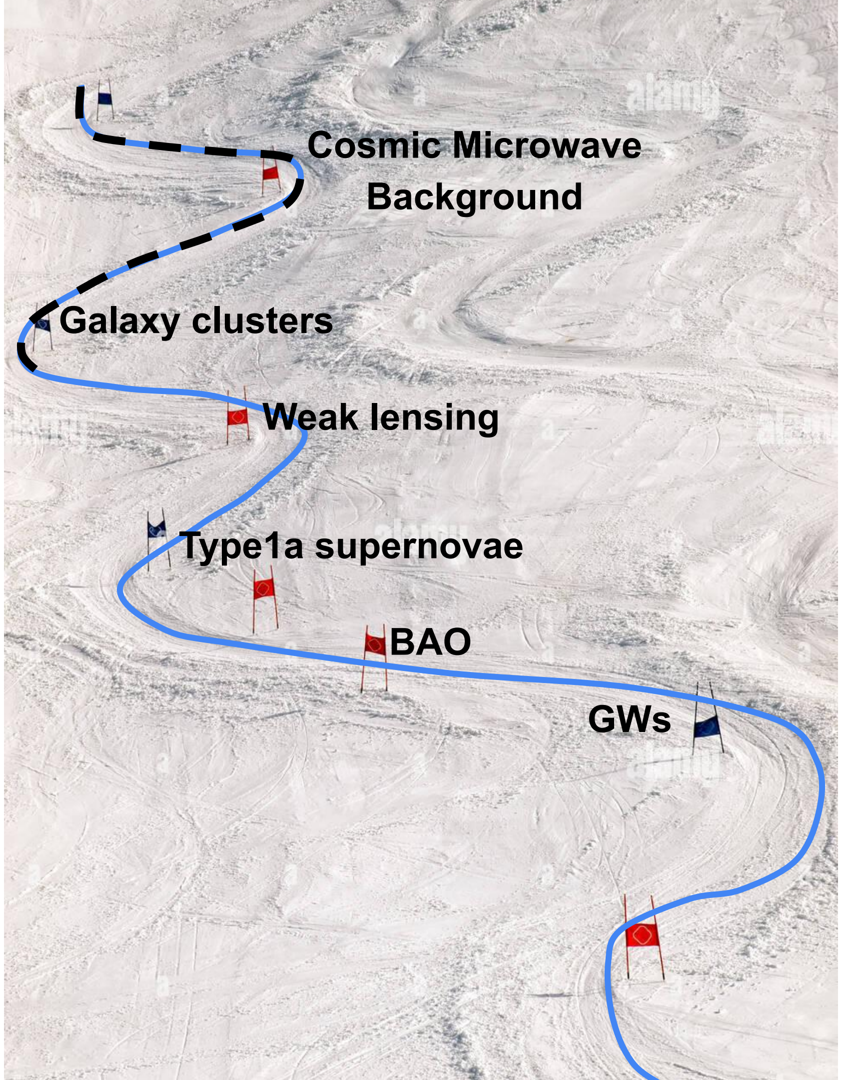


LSS probes (redshift < 2-3)

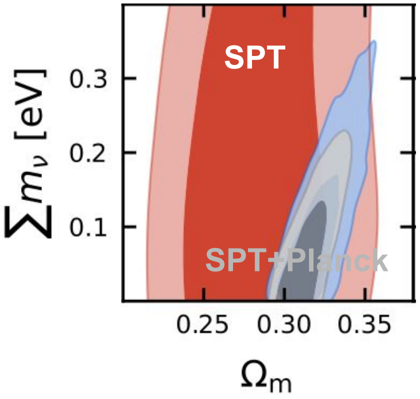
Clusters of galaxies

- ❖ Most massive collapsed objects in the universe, M > 10^{14} M_{SUN}, can be detected in optical, X-rays, millimeter wavelengths, 80% of dark matter
- ❖ Their abundance in (M,z) sensitive probe to growth of structure and geometry
- ❖ Also massive gravitational lenses



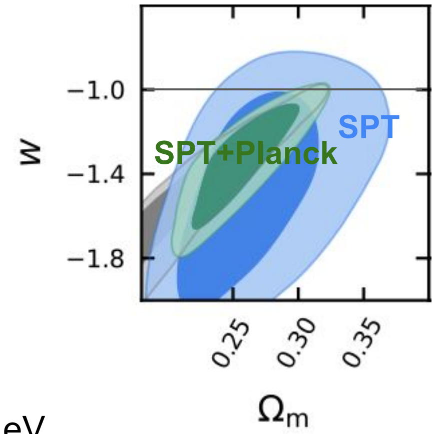


Cluster cosmology with SPT/eROSITA (M. Klein, LMU, Munich)



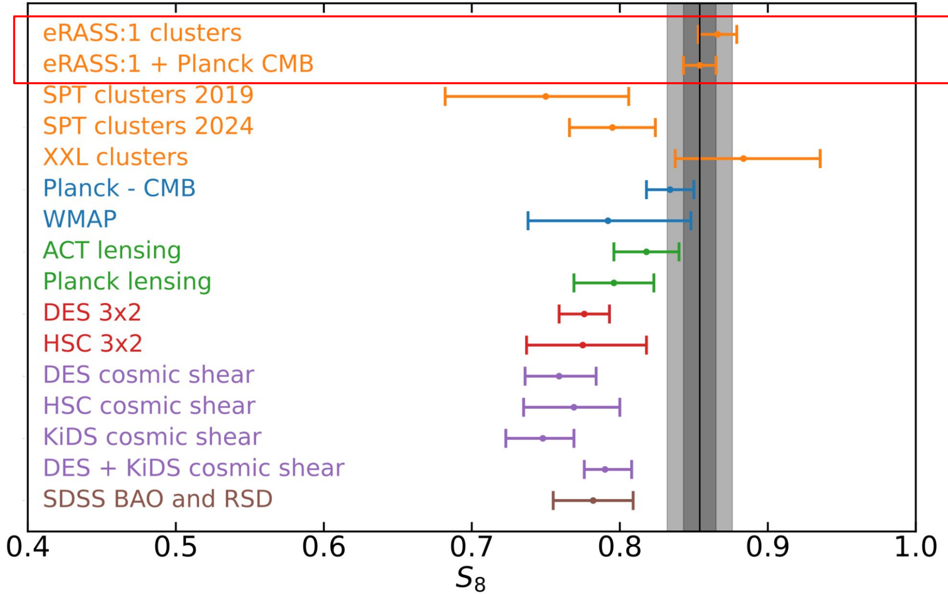
νCDM: $(\sum m\nu)_{SPT+Planck} < 0.18$ eV

νwCDM: $(\sum m\nu)_{SPT+Planck} < 0.6$ eV



w_{SPT}=-1.45±0.31

$w_{SPT+Planck}$=-1.34±0.22



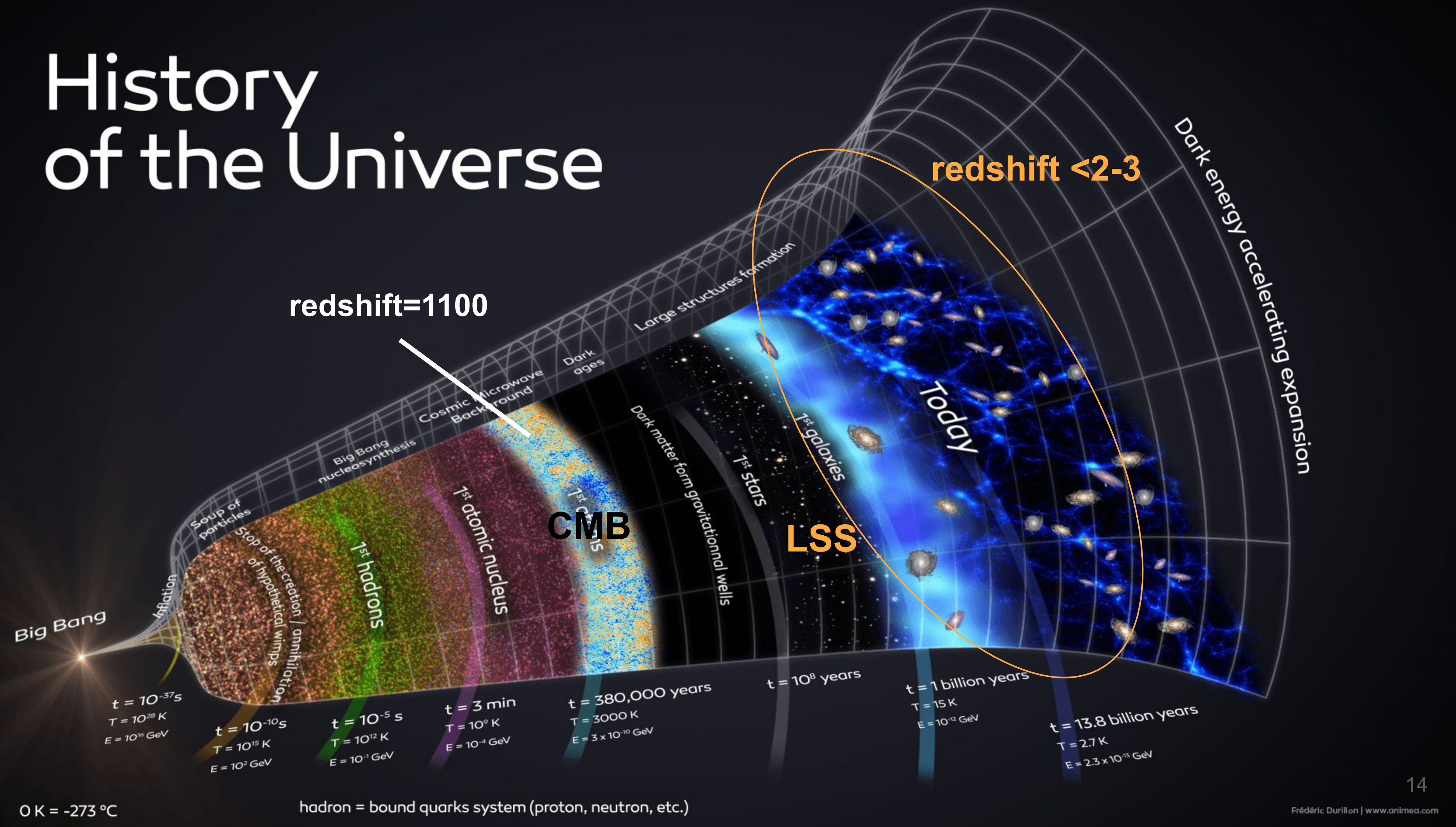
South Pole Telescope (mm)

- 1000 clusters, SZ + optical selection
- WL-to-halo-mass calibration with DES+HST
- sigma($\sigma_8 \Omega_m^{0.25}$) similar to P18
- S8 with Planck TT/TE/EE, S8 no tension (<1.1σ)
- **νCDM: + Planck, $\sum m\nu$ < 0.18 eV**
- wCDM: **SPT or SPT+Planck favor wDE, w<1 at 1.7-2σ**

eROSITA (X-rays, space) - eRASS sample

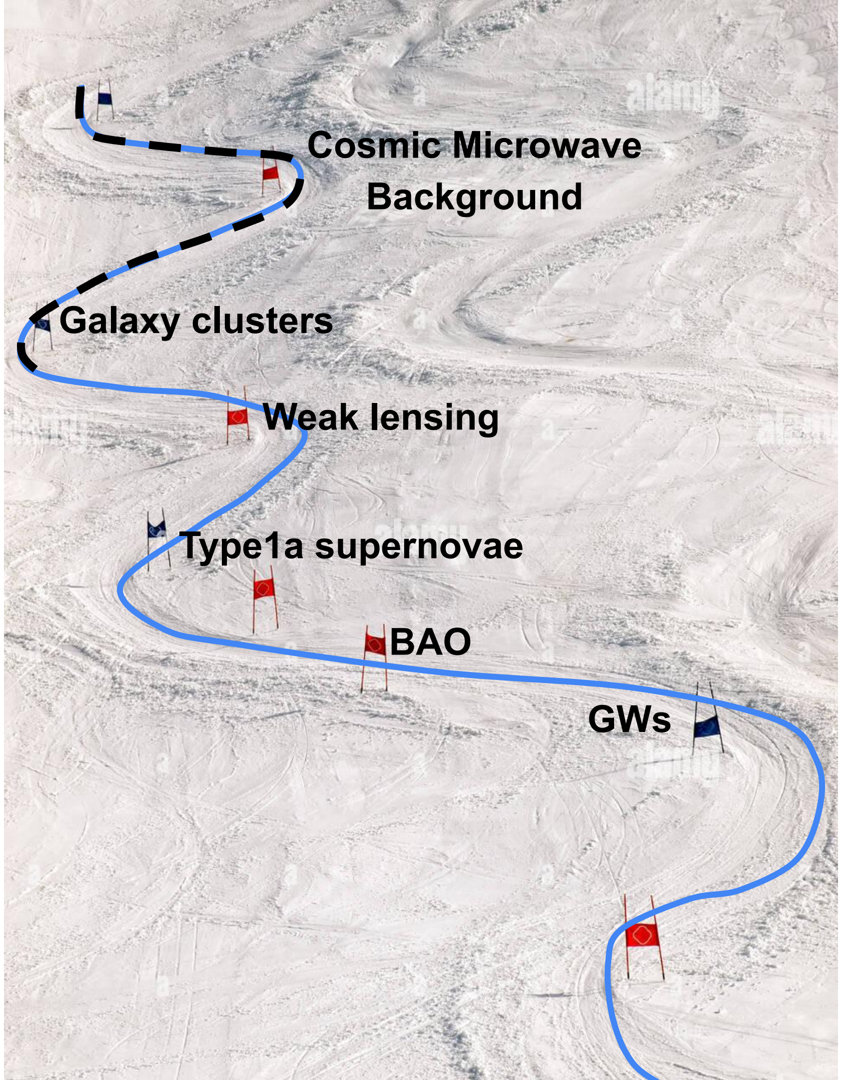
- 12,000 clusters (eFEDS, 2023 - 500 clusters)
- DES & HSC & KiDS lensing
- high S_8 3σ discrepancy w. most other LSS probes
- wCDM: w=-1.12±0.12
- **νCDM $\sum m\nu$ < 0.22 eV alone ! (<0.26 Planck)**
- **+ Planck, $\sum m\nu$ < 0.11 eV (CL 95%)**
- No inverted hierarchy at CL > 93% (req. > 0.101 eV)

History of the Universe



LSS probes (redshift < 2-3)

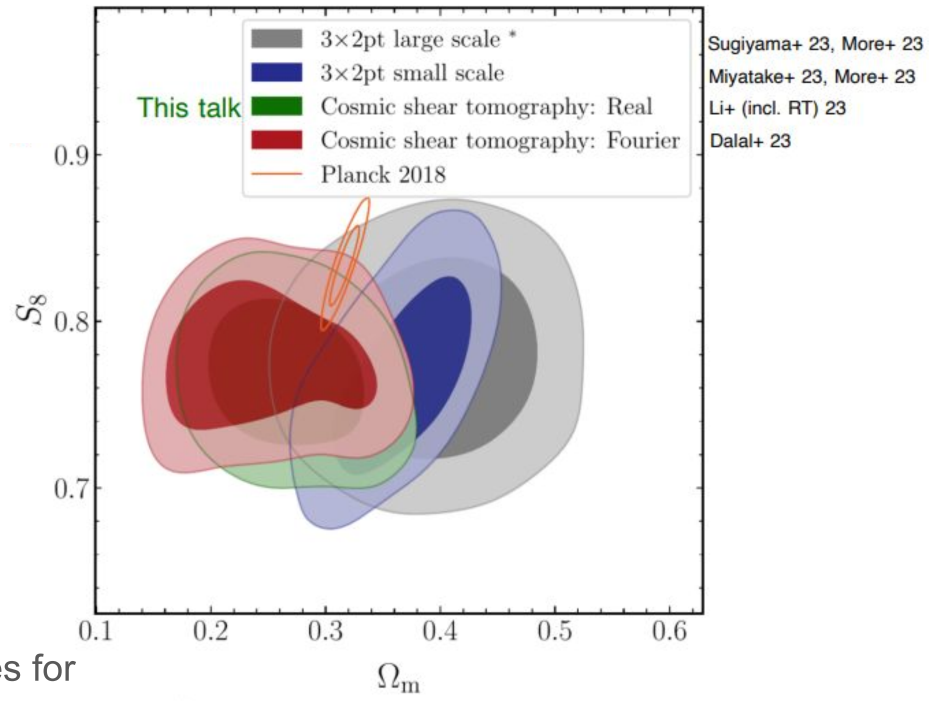
- ★ Galaxy clusters
- ★ Weak-lensing (WL)
- ★ Type1a Supernovae (SN)
- ★ Baryon Acoustic Oscillations (BAO)
- ★ Gravitational waves (GW)



HSC-Y3 cosmic shear data analysis (R.Terasawa, Kavli IPMU, Tokyo)

Hyper-Suprime Camera (Hawaii)

- Y3: 400 deg^2, ngal = 15 arcmin-2 (LSST/Euclid - 25/30 arcmin-2, i < 24.5)
- 4 tomographic bins: free residual error Δz in the n(z), fit with cosmology, conservative

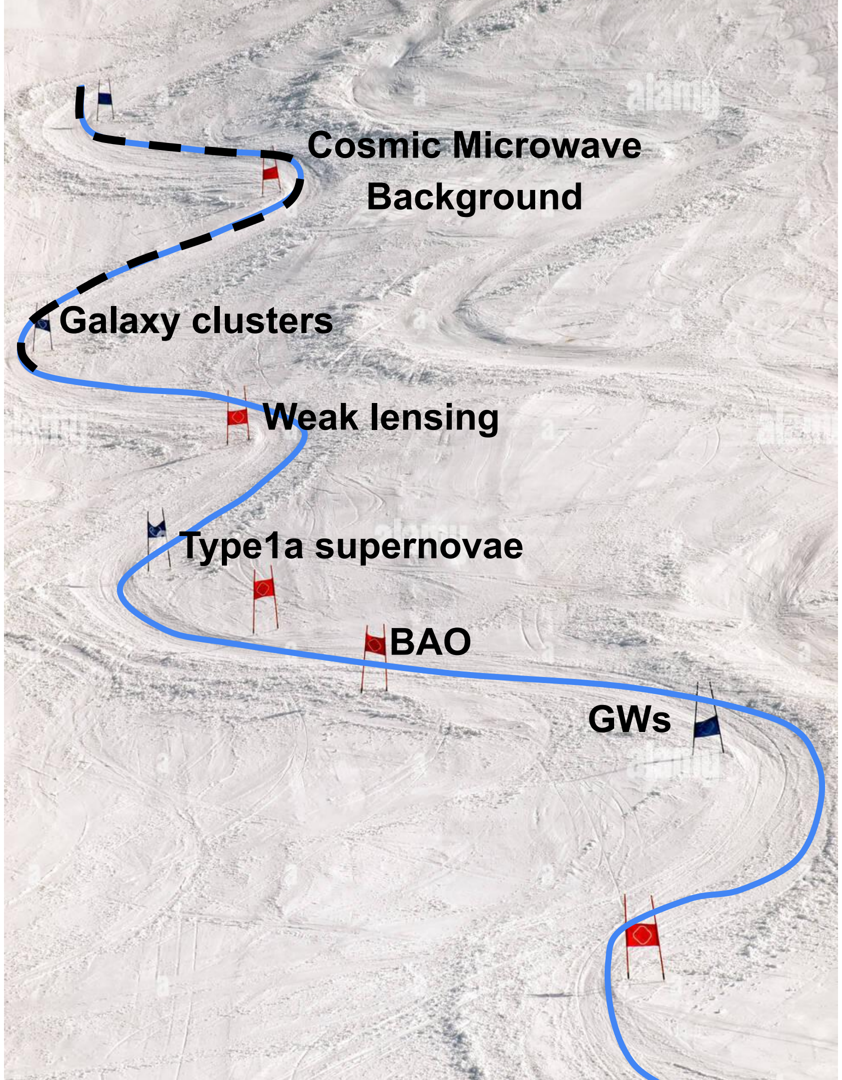


Results: 4% precision measurement

- S8(CL)=$0.776^{+0.032}_{-0.033}$
- S8(ξ)=$0.769^{+0.031}_{-0.034}$
- Confirm S8 tension 2σ-2.5σ with Planck 2018
- S8 tension remains considering various analyses for Baryonic effects
- The HSC-Y3 cosmic shear data does not show any clear signature of the baryonic effect

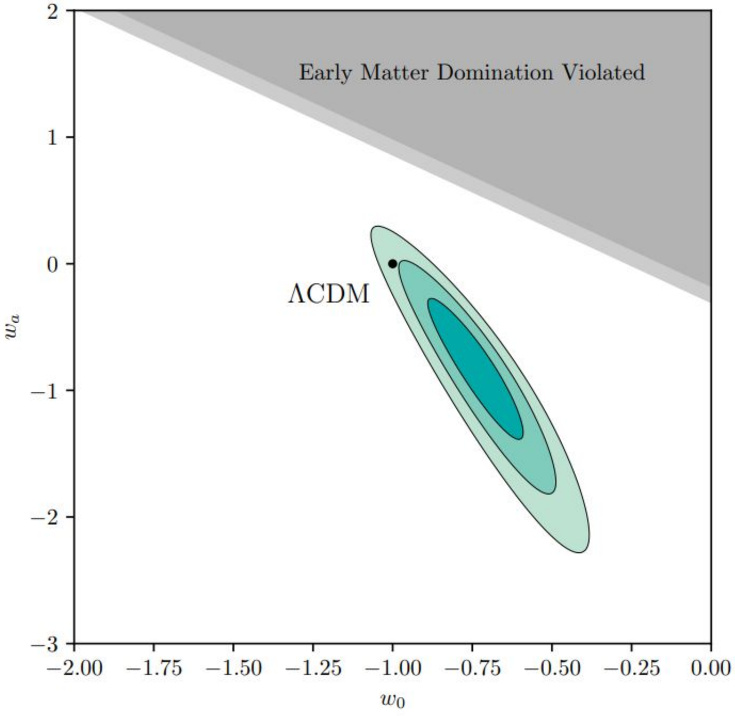
LSS probes (redshift < 2-3)

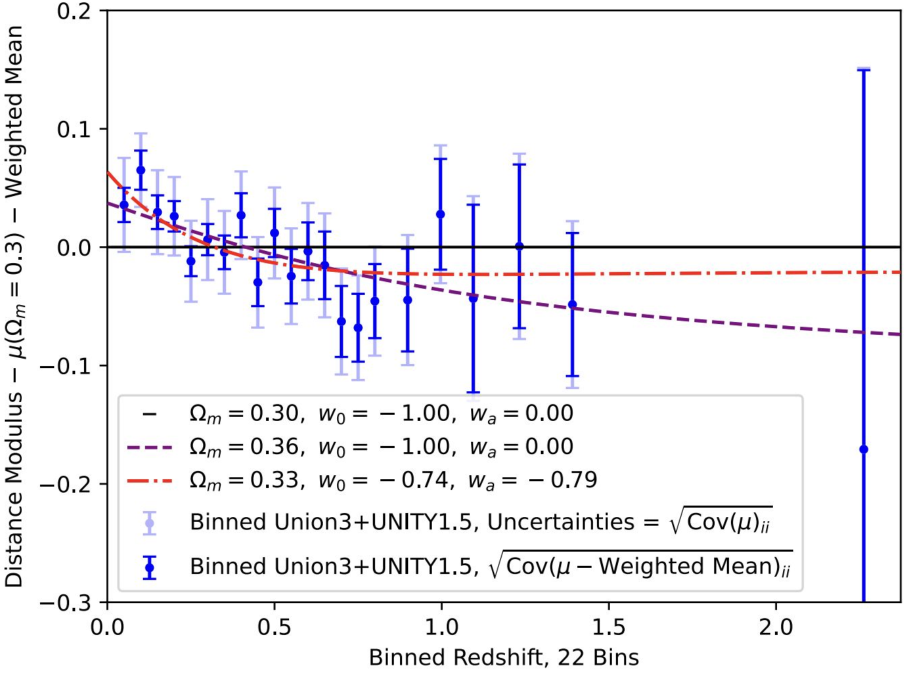
- ★ Galaxy clusters
- ★ Weak-lensing (WL)
- ★ Type1a Supernovae (SN)
  - Union3
  - DES Y5
  - LSST+ZTF
- ★ Baryon Acoustic Oscillations (BAO)
- ★ Gravitational waves (GW)



Type1a Supernovae cosmology from Union3 (David Rubin, arxiv: 2311.12098)

Union3: 2087 SNe from 24 datasets passing selection cuts.

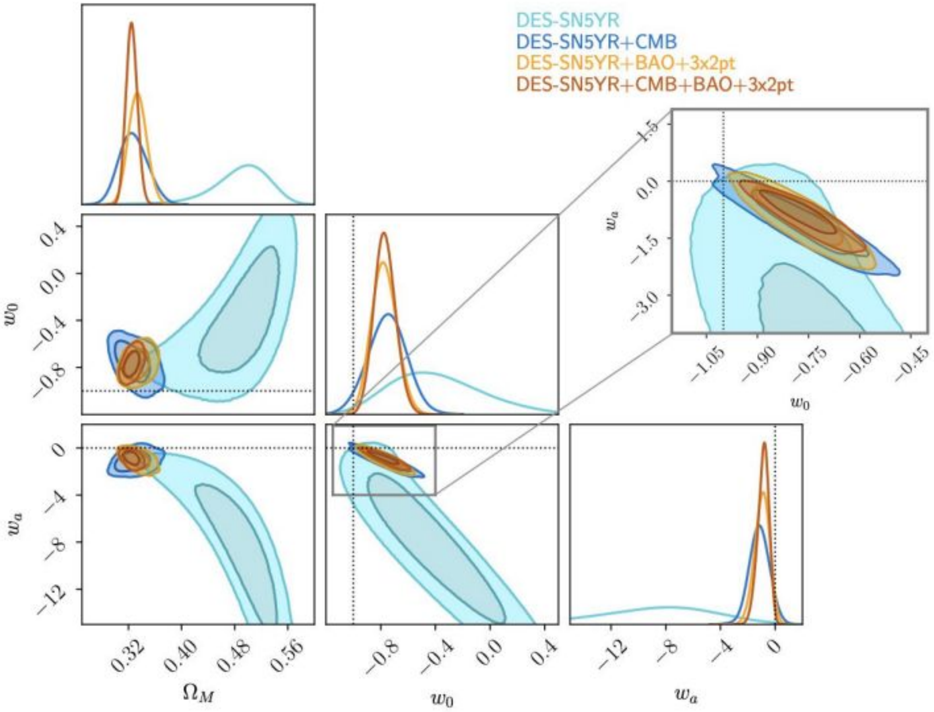




1.7—2.6 **σ** evidence of time-varying dark energy (flat universe).

Type1a Supernovae cosmology from DESY5 (Dillon Brout):

largest and deepest SN sample (0.1<z<1.2), ~1600 SNe Ia



DES5YR + CMB + BAO + 3x2pt

$$w_a = -0.83 \pm 0.38$$

$$w = -0.941 \pm 0.026$$

Deceleration parameter q0 < 0 at 5.2σ. Dark energy: w_0=-1, w_a=0 at 2-2.5σ.

Type1a Supernovae cosmology future surveys (Jérémy Neveu):

Vera Rubin Observatory – LSST survey (LSST): entering sub-percent cosmology era.

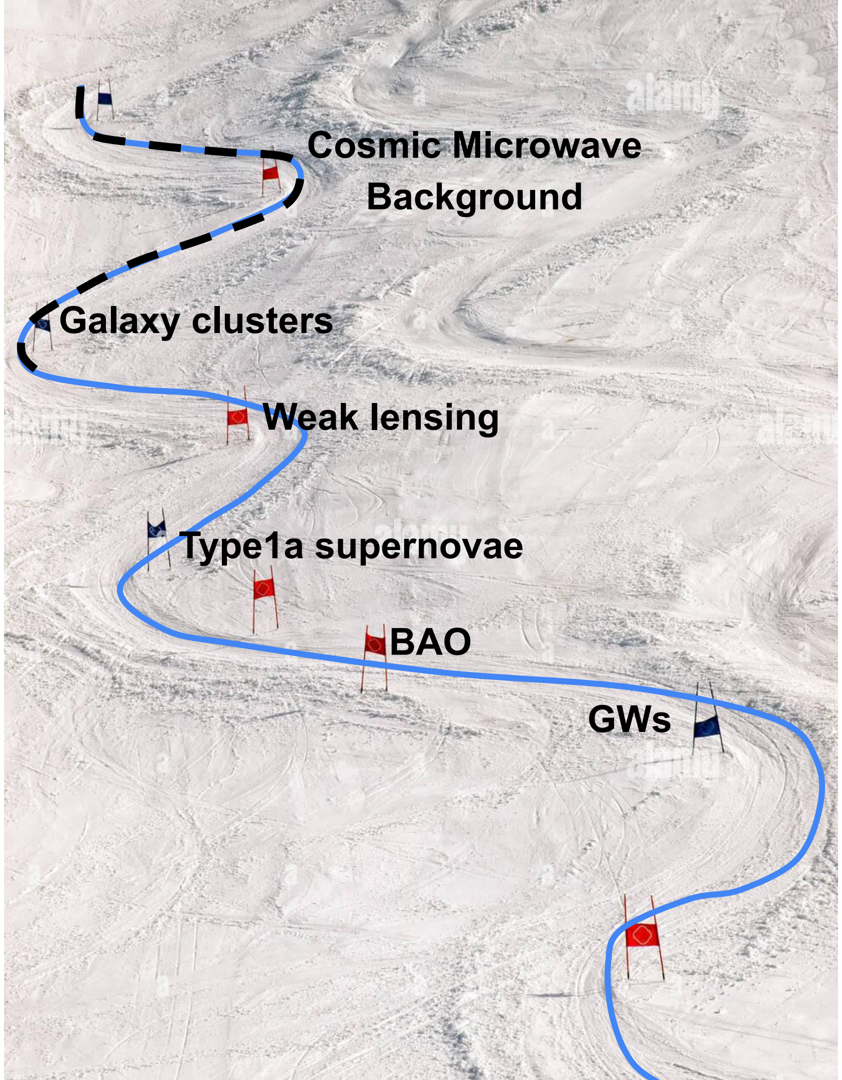
- On-sky commissioning starts July 2024, science survey starts mid-2025
- Data Release 1 scheduled between mid-2026 early 2027
- 20 000 good SNIa in Deep survey, with ~700 SN at $z>0.8$

Zwicky Transient Facility (ZTF) DR2-2.5 (Madeleine Ginolin, Leander Lacroix, Thierry Souverin):

- 3628 SNe for DR2
- Precision photometry
- Huge systematic analyses under going
- Cosmology for DR2.5

LSS probes (redshift < 2-3)

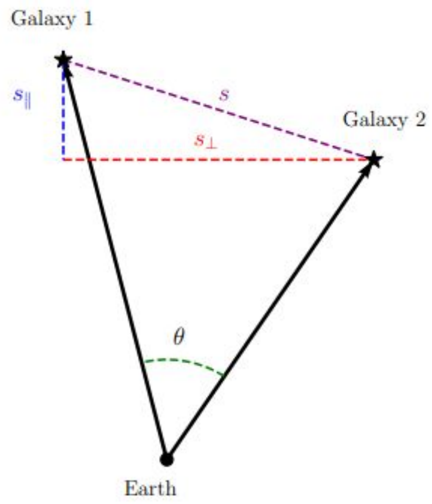
- ★ Galaxy clusters
- ★ Weak-lensing (WL)
- ★ Type1a Supernovae (SN)
- ★ Baryon Acoustic Oscillations (BAO)
  - DES Y6
  - DESI Y1
- ★ Gravitational waves (GW)



DES: BAO scale measurement from the Y6 dataset (J. Mena-Fernandez, LPSC, Grenoble)

Dark Energy Survey (Chile)

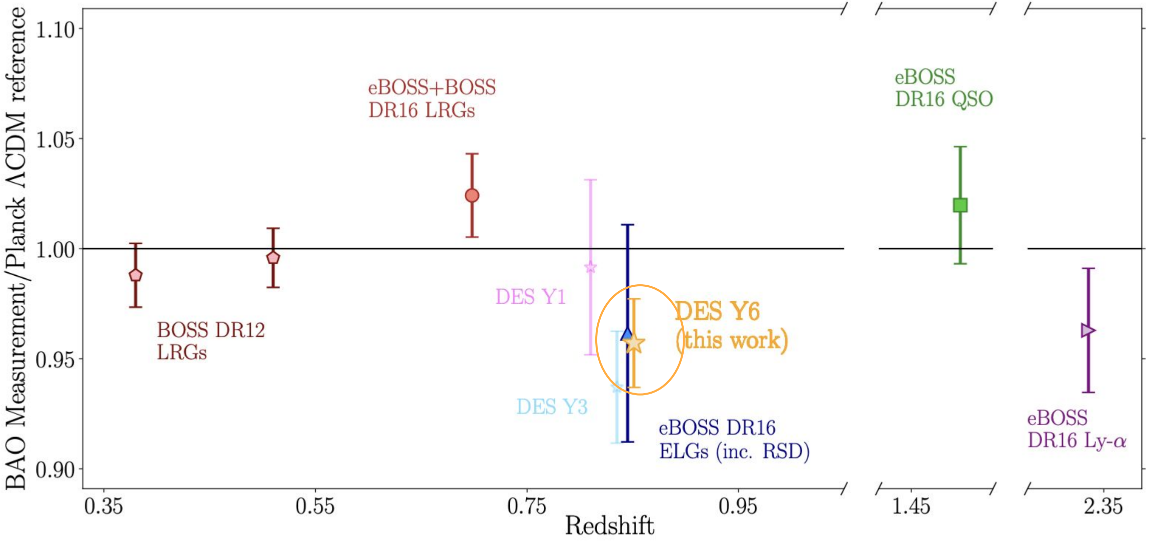
- 5,000 deg^2 visible-infrared, Y6, 16 million galaxies
- Data:
  - TS: griz bands + photoz
  - zeff = 0.85, 6 redshift bins



Angular estimators to measure the BAO

- Angular correlation function (ACF) or w(θ).
- Angular power spectrum (APS) or Cℓ.
- Projected correlation function (PCF) or $\xi p(s_\perp)$.

DES: BAO scale measurement from the Y6 dataset (J. Mena-Fernandez, LPSC, Grenoble)



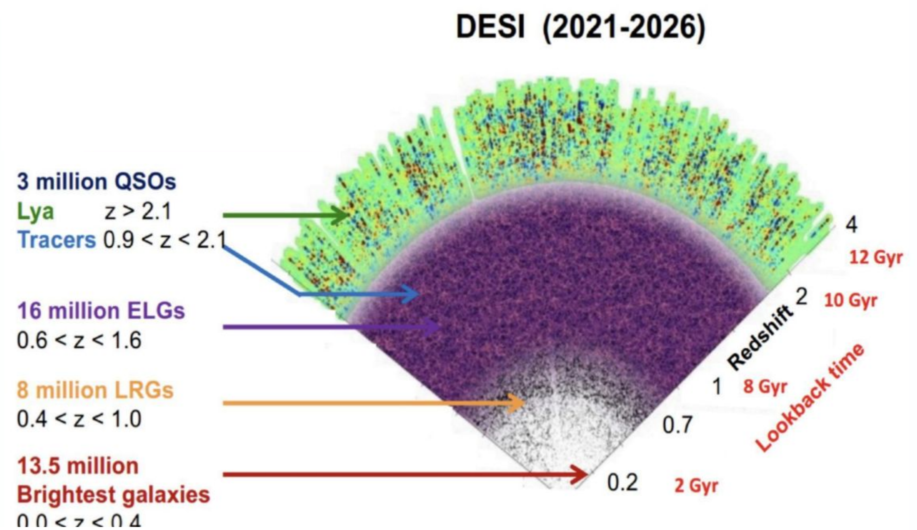
Fit of BAO scale

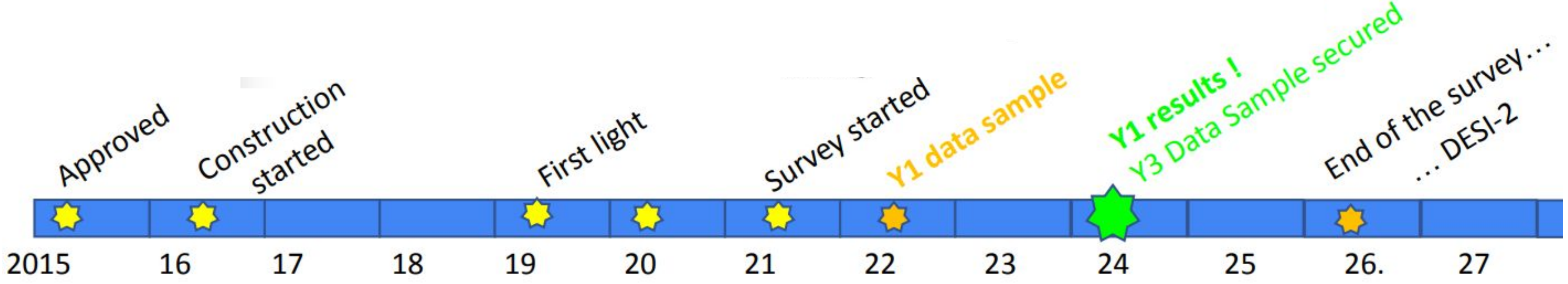
- **Result $\alpha(0.85)$ = 0.957 +- 0.020, 2.1% precision**
  - 2σ compatible with Planck
  - Thanks to better quality in photoz, optimisation of the sample + multi-corr analysis
  - Best BAO scale constraint for photometric surveys

DESI: BAO scale measurement from the Y1 dataset (A. de Mattia)

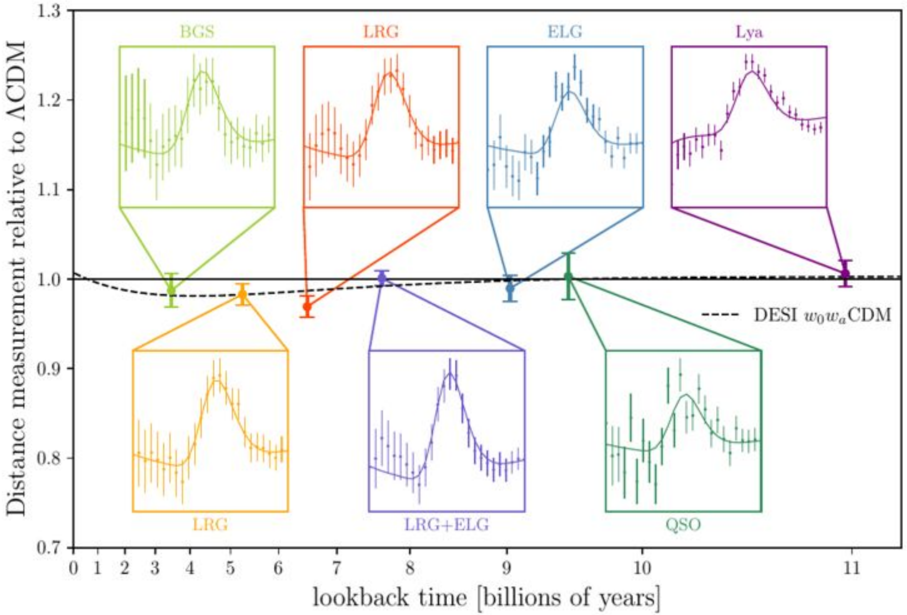
Dark Energy Spectroscopic Instrument (Tucson, AZ)

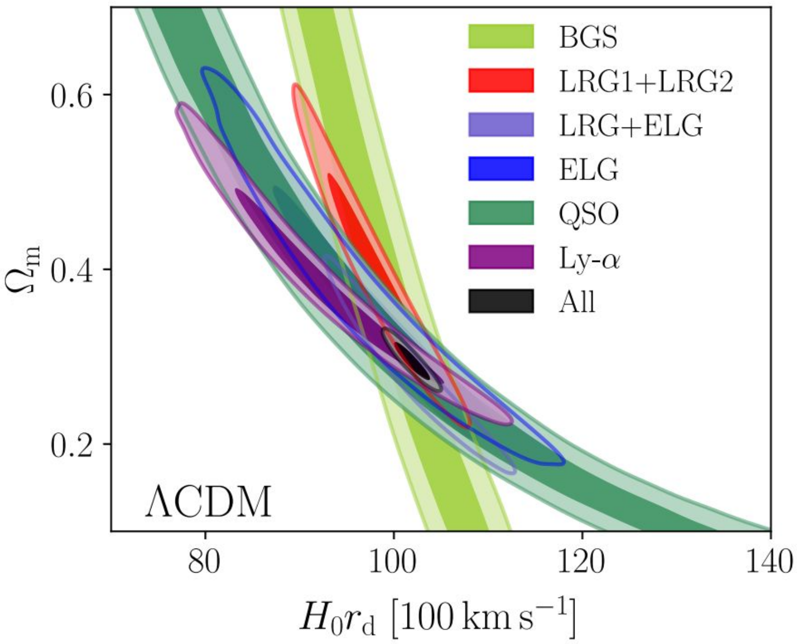
- ❖ 14,200 deg^2, 40 million galaxies in 5 years
- ❖ 5 target classes, a wide redshift range





DESI: BAO scale measurement from the Y1 dataset (A. de Mattia)

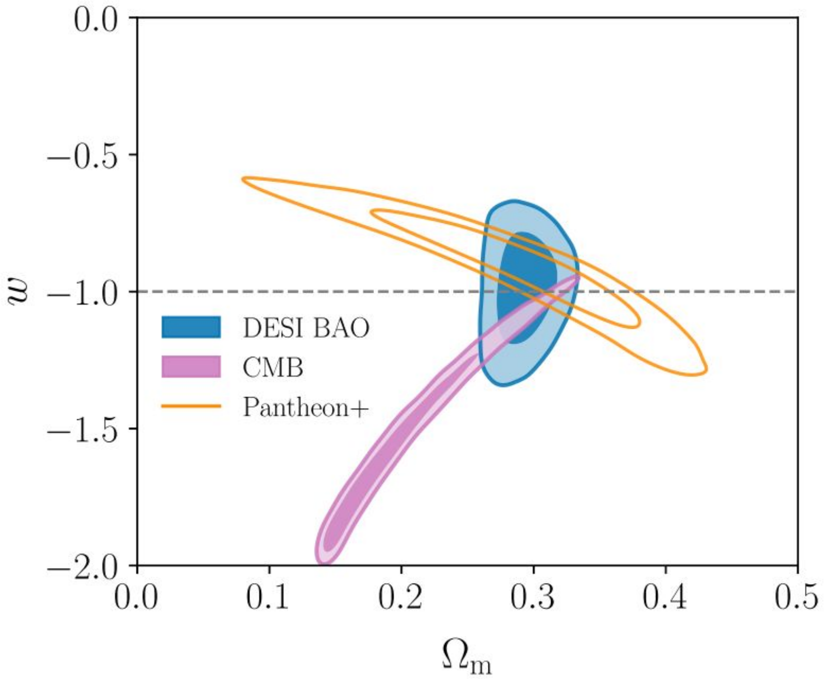


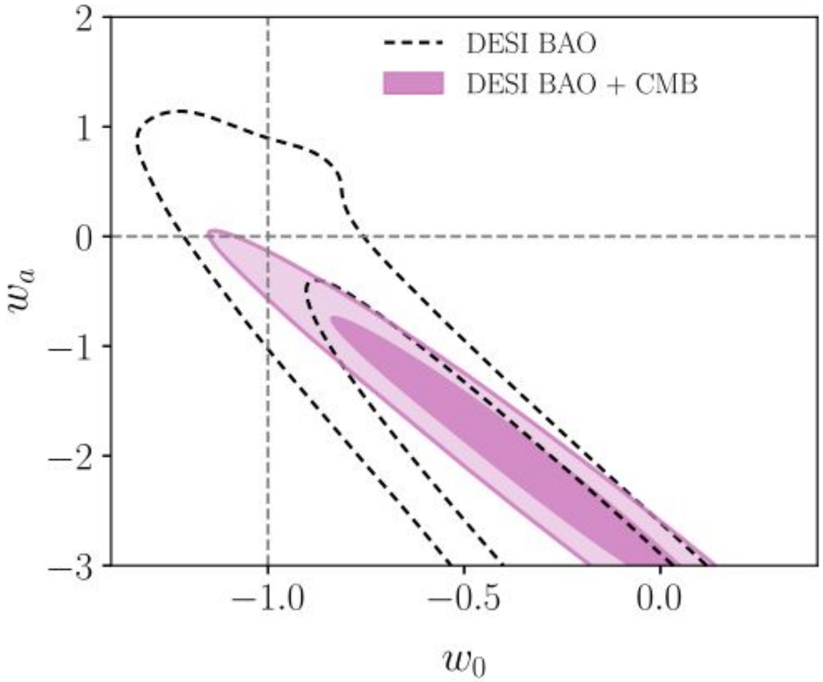


$$\Omega_m = 0.295 \pm 0.015 \qquad (\mathbf{5.1\%})$$

$$H_0 r_d = (101.8 \pm 1.3)\,[100\,\mathrm{km\,s^{-1}}] \qquad (\mathbf{1.3\%})$$

DESI: Dark Energy Equation of State (A. de Mattia)





BAO+CMB favors a time dependent EoS:

$$\underbrace{w_0 = -0.45^{+0.34}_{-0.21} \qquad w_a = -1.79^{+0.48}_{-1.00}}_{\text{DESI + CMB} \implies 2.6\sigma}$$

LSS probes (redshift < 2-3)

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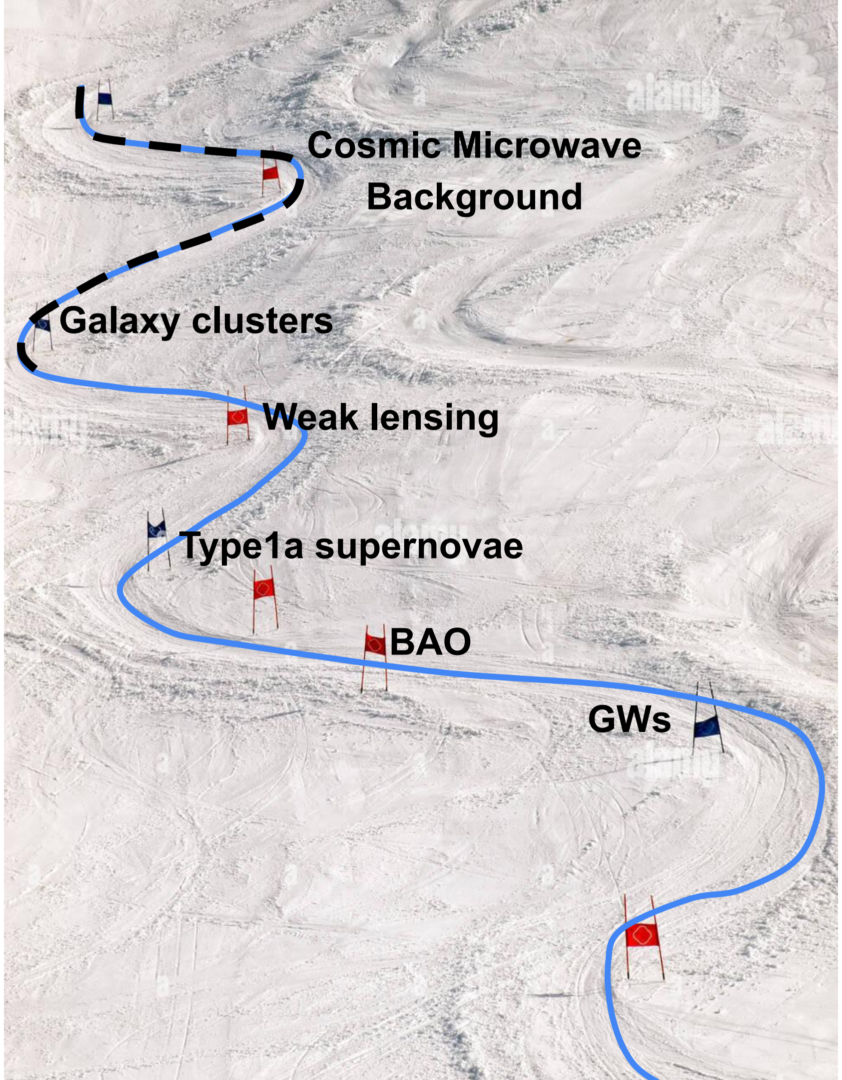


Status of Gravitational Waves

"Recent" Pulsar Timing Array (PTA) observations

Antoniadis et al. [arXiv:2306.16224] Zic et al. [arXiv:2306.16230] Tarafdar et al. [arXiv:2206.09289] Agazie et al. [arXiv:2306.16217]

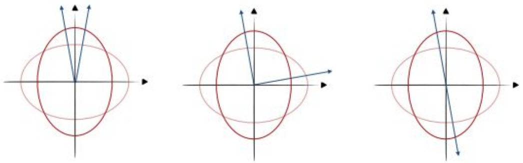
EPTA PPTA InPTA NANOGrav

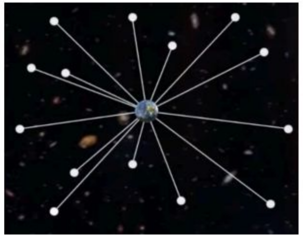
+Chinese PTA collaboration, Meerkat

Xu et al. [arXiv:2306.16216] Miles et al. [arXiv:2212.04648]

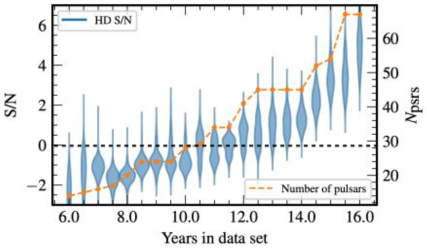
Hellings-Downs correlation pattern

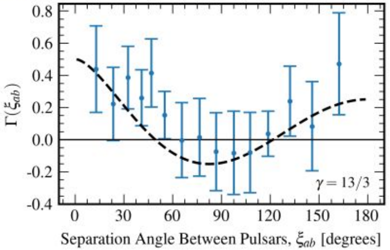
Naive intuition for a quadrupolar correlation





G. Agazie *et al.* [NANOGrav], Astrophys. J. Lett. **951** (2023) no.1, L8 [arXiv:2306.16213]





>3 sigma evidence for HD in NANOGrav 15 yr dataset, similar evidence in other datasets

- PTA observations can be used to detect GWs from many sources, QCD 1-st order phase transition, SMBH, etc…
- Binaries from PTAs can be the most sensitive probes of ULDM (Kůs, López Nacir, FU arXiv:2402.04099)
- Strategies to search very high frequency GW signals using axion detectors (Valerie Domcke)
- Search gravitational waves from first-order phase transitions (Isak Stomberg, 2209.04369) and (Alberto Roper Pol 2307.10744)

Thank you!