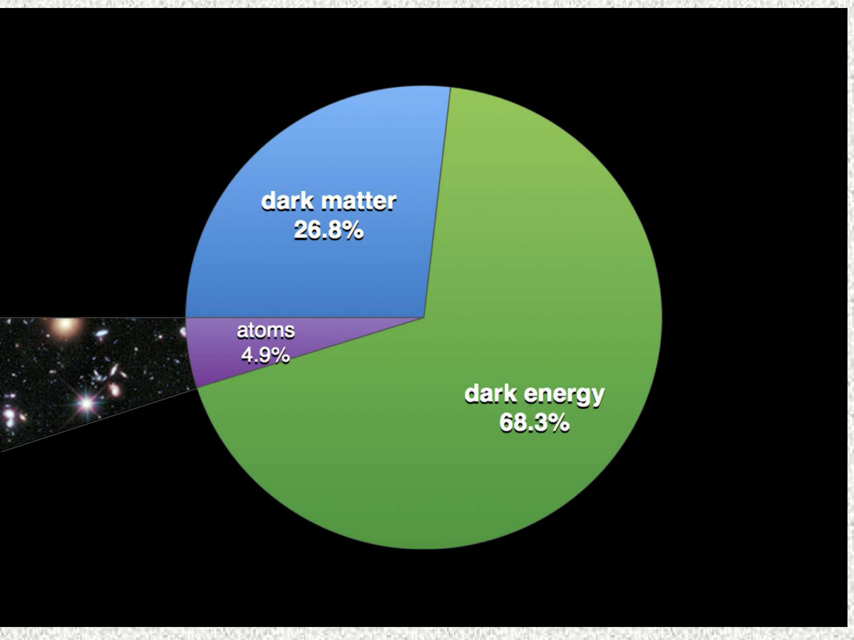
HITO y RETOS

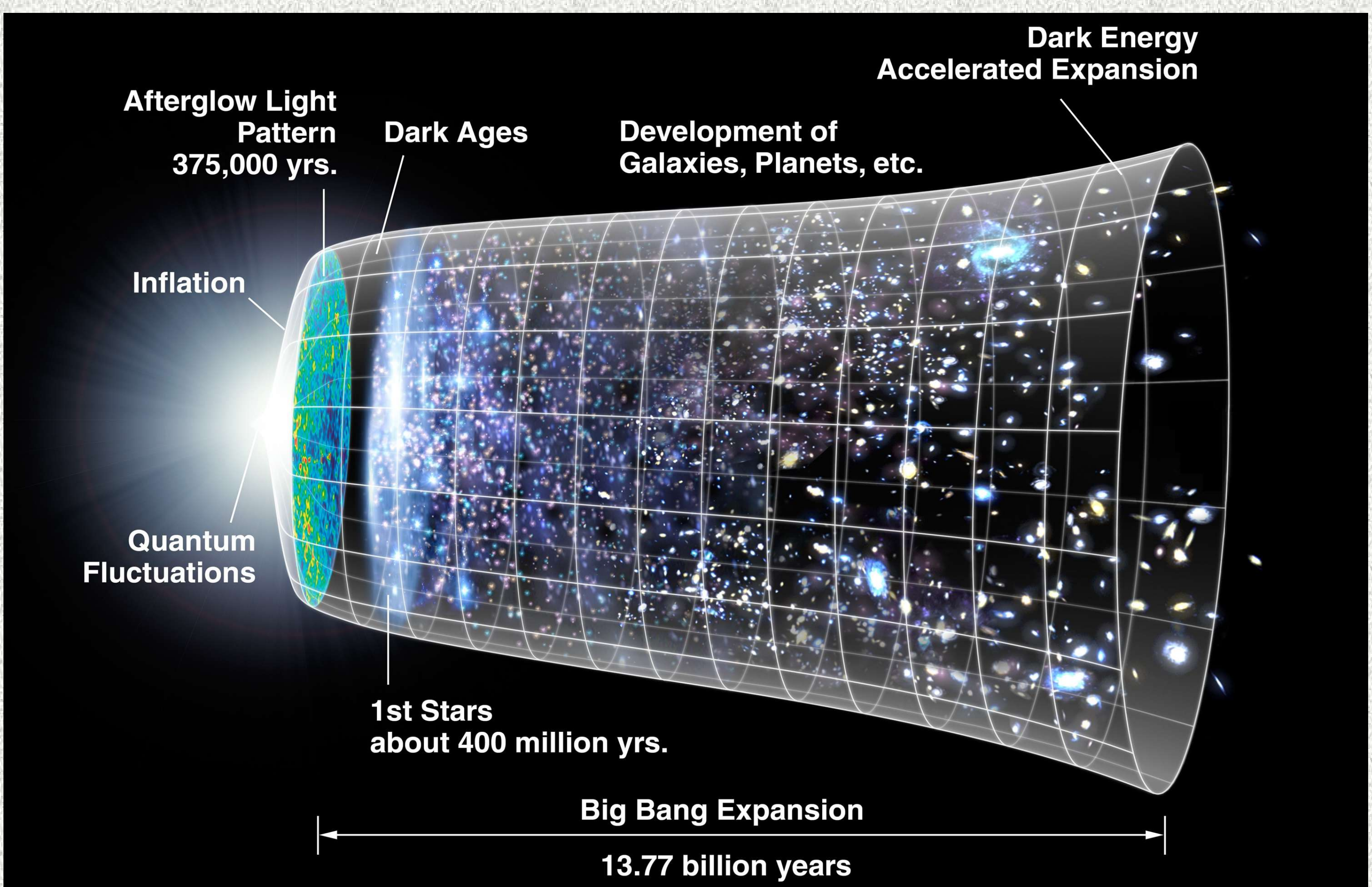
From “*Precision Cosmology*” to “*Cosmology under revision*”

K. Mack



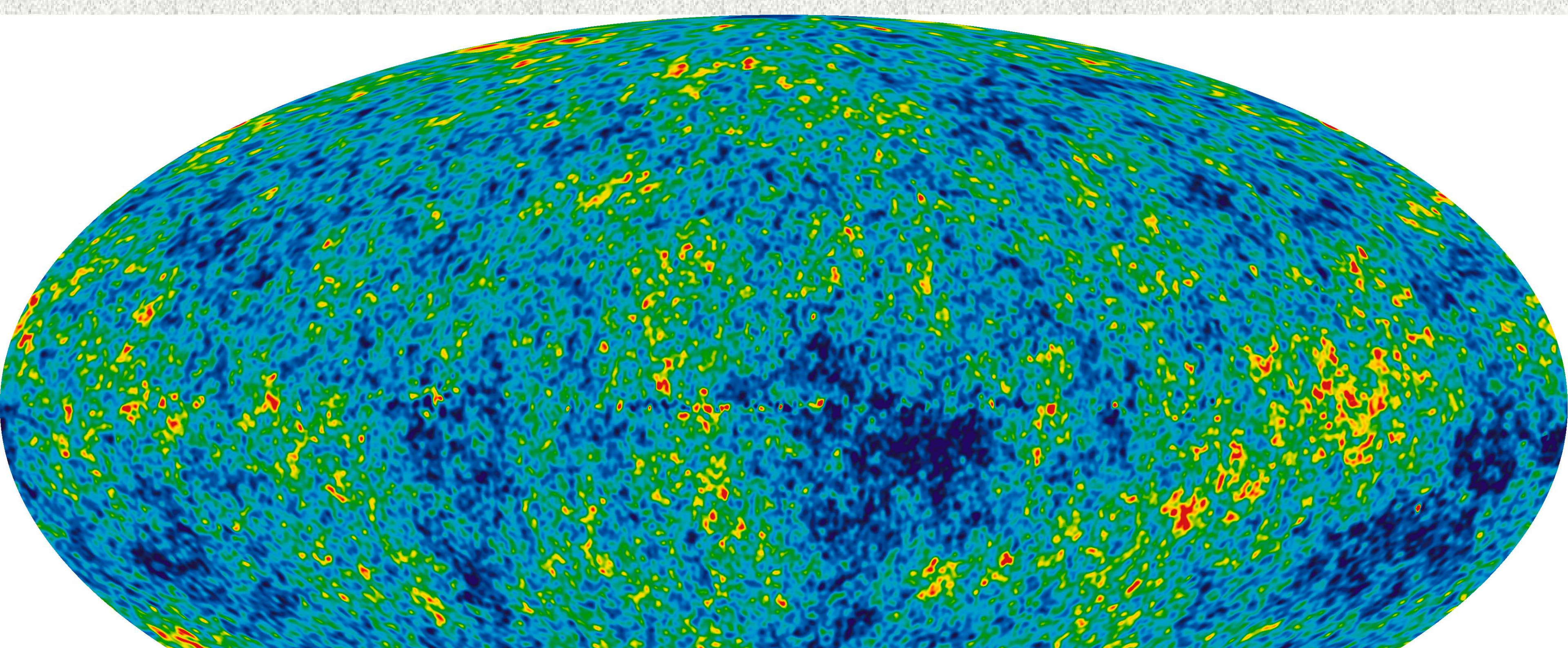
Carlos Hernández-Monteagudo
Centro de **E**studios de **F**ísica del **C**osmos de **A**ragón
[CEFCA]

Once upon a time … not so long ago (from 1997 up to ~2018), there was, amongst cosmologists, a so-called *Concordance cosmological model* upon which low redshift and high redshift cosmological observations agreed ...

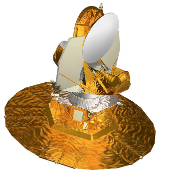


The Cosmic Microwave Background (CMB)

provided an image of our universe at its childhood that was consistent with a ***flat*** LCDM scenario, and which was also consistent with cosmological observations at recent epochs …



WMAP
mission



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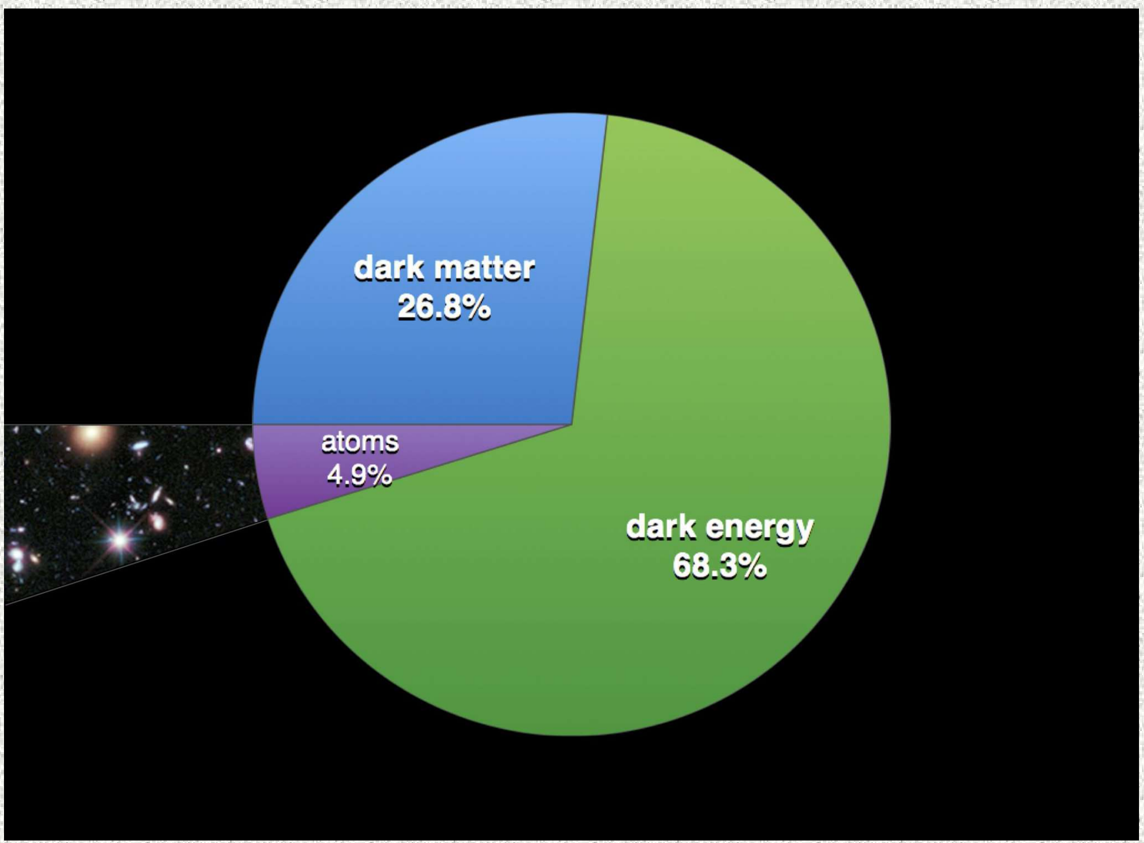
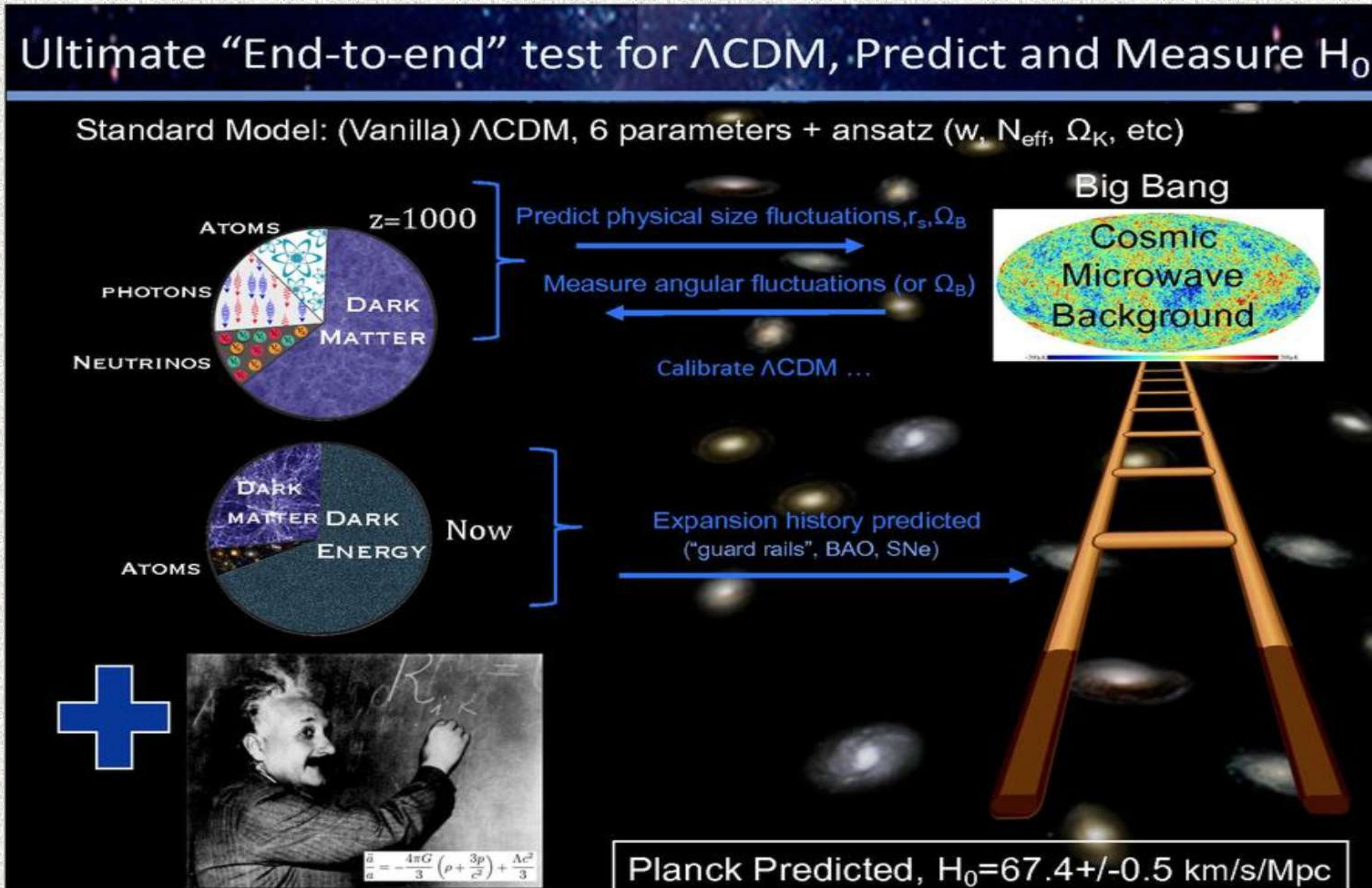


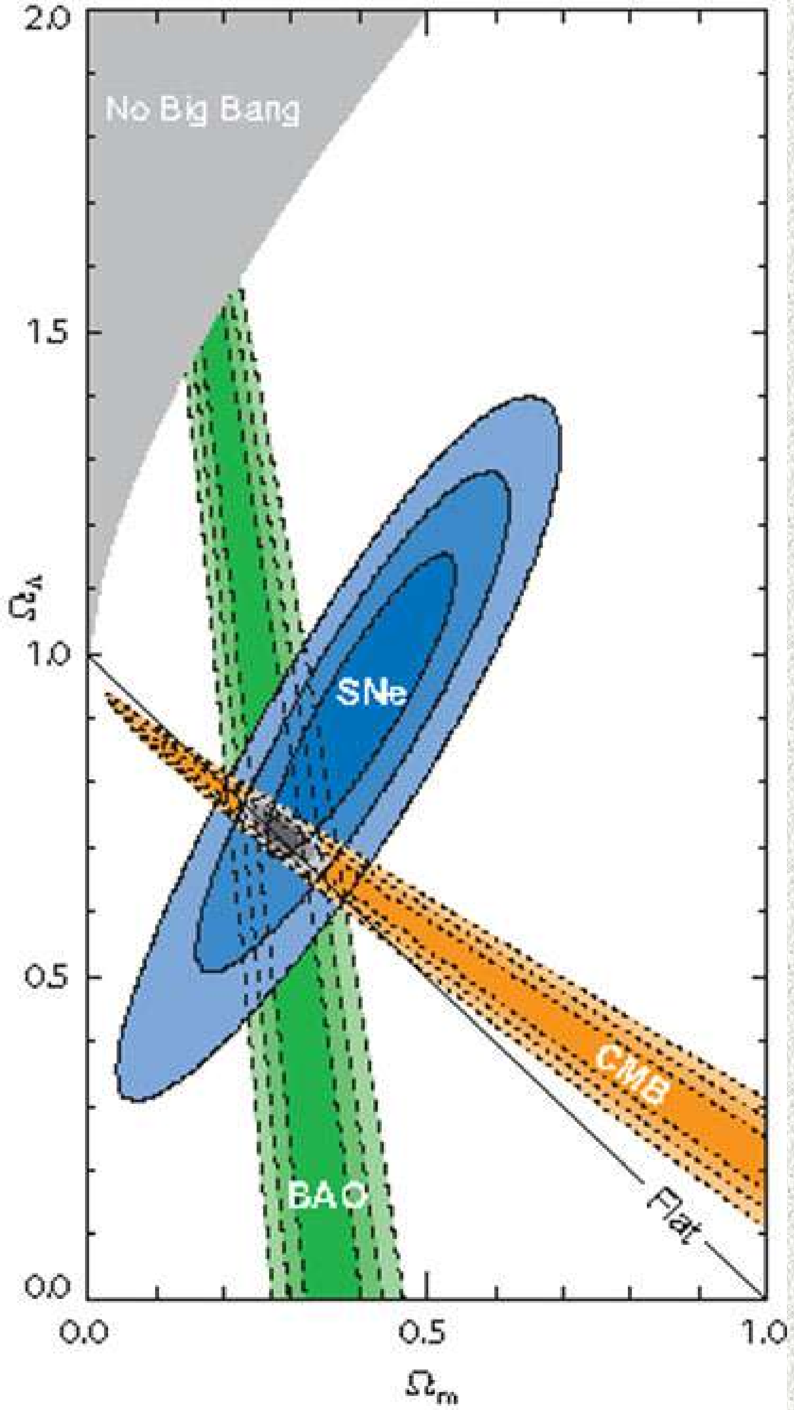
K. Mack



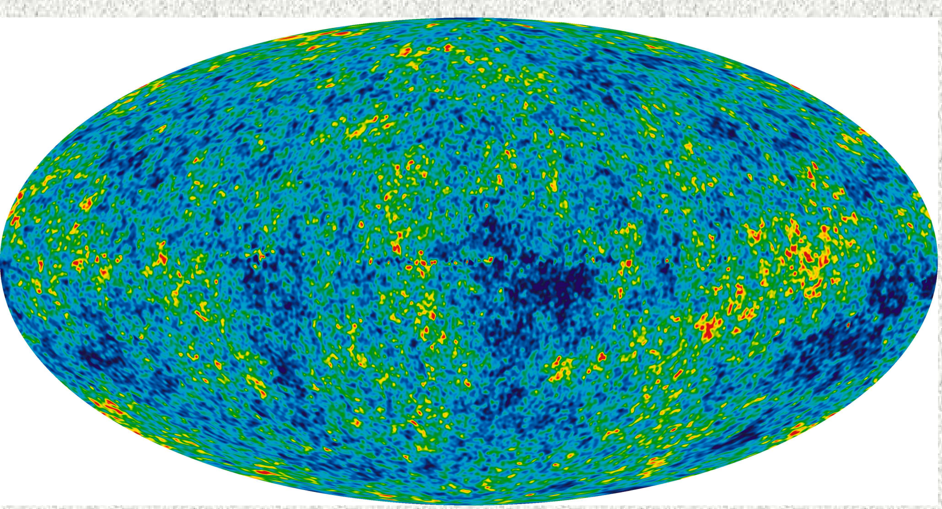
Silde from A. Riess (July 2019)

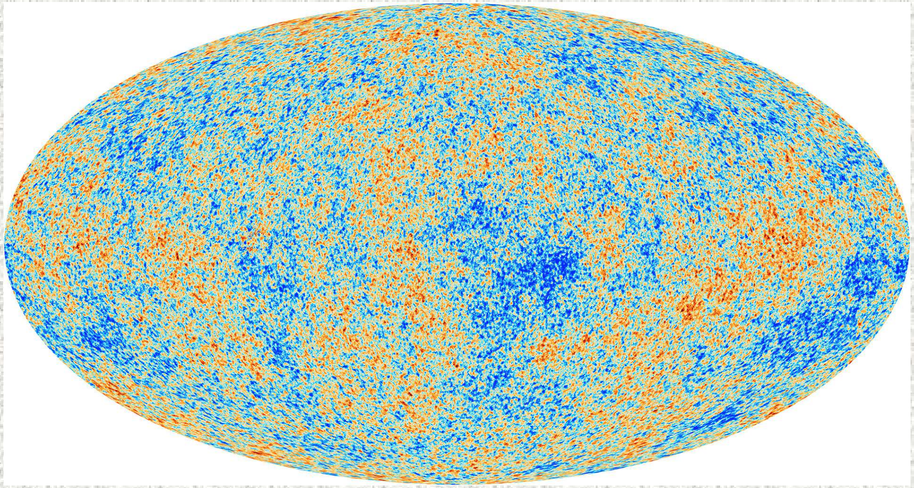
Cosmological *"concordance"* Model

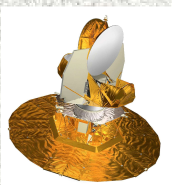
Kowalski 2008



However, when observations at either side of the history of the universe increased their precision,







WMAP, 2010

***Planck* 2018**

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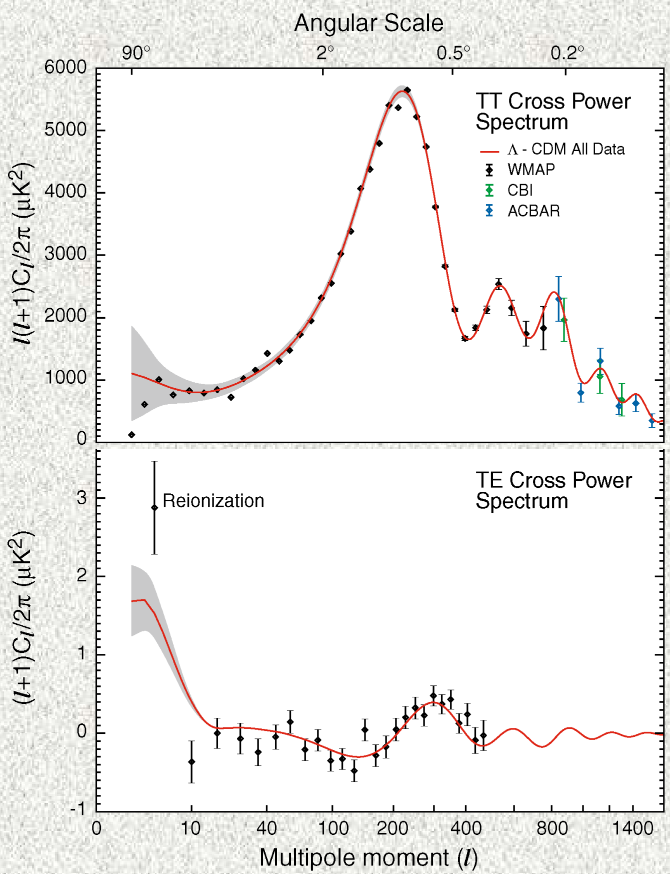
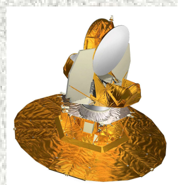
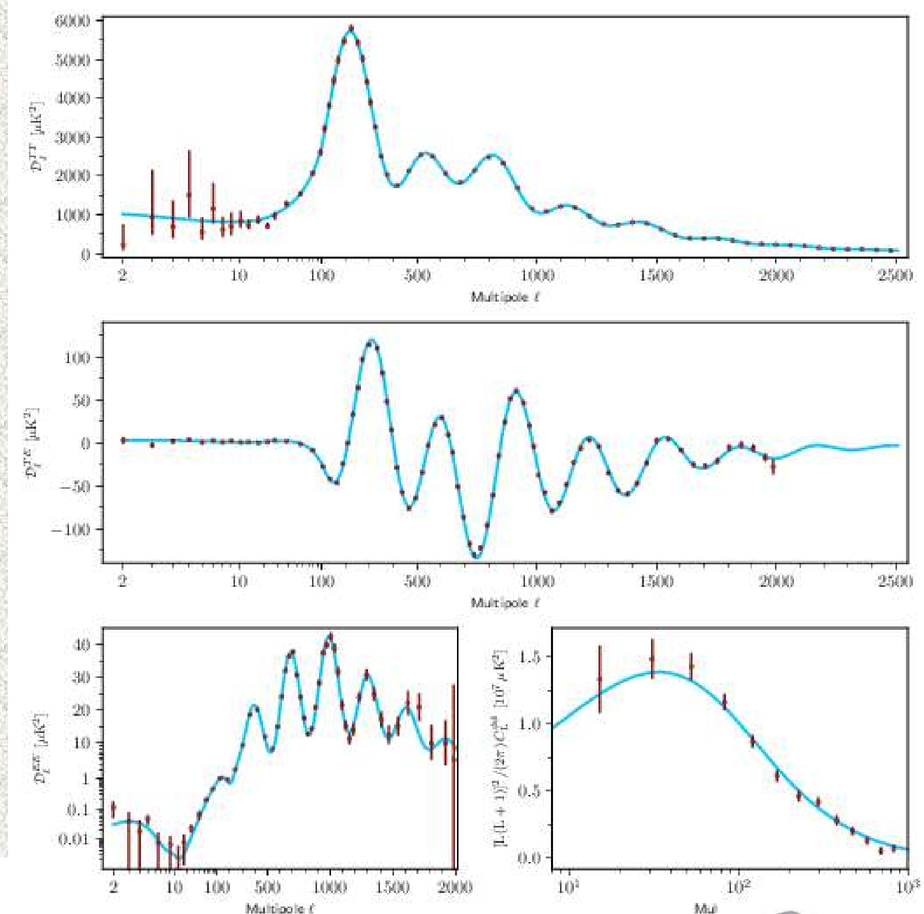


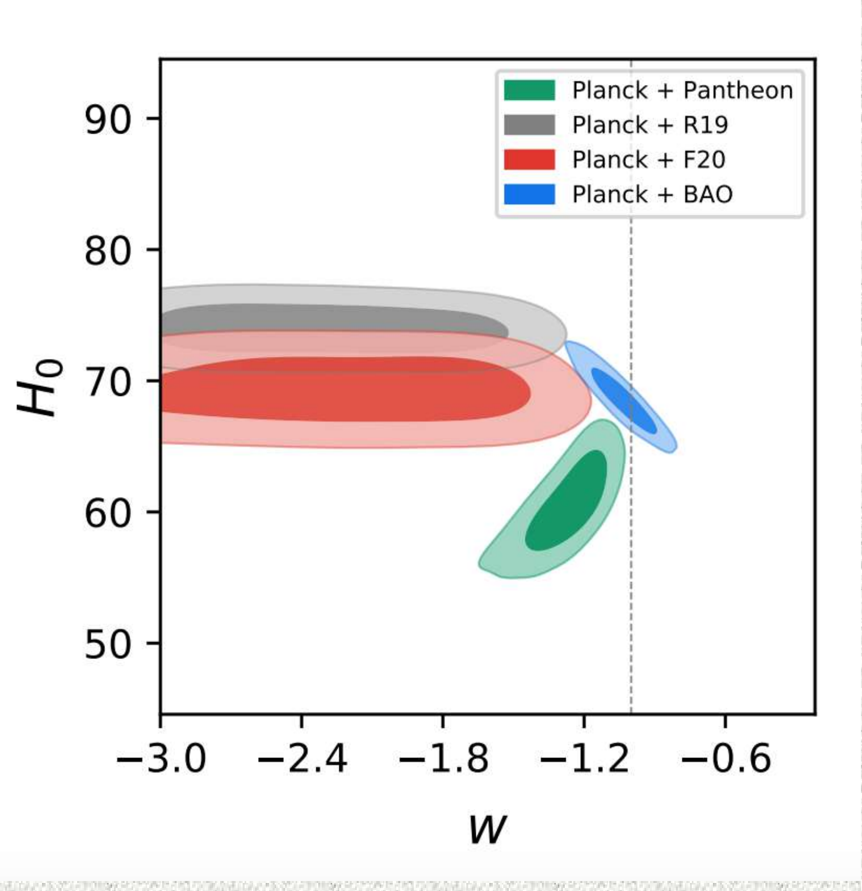


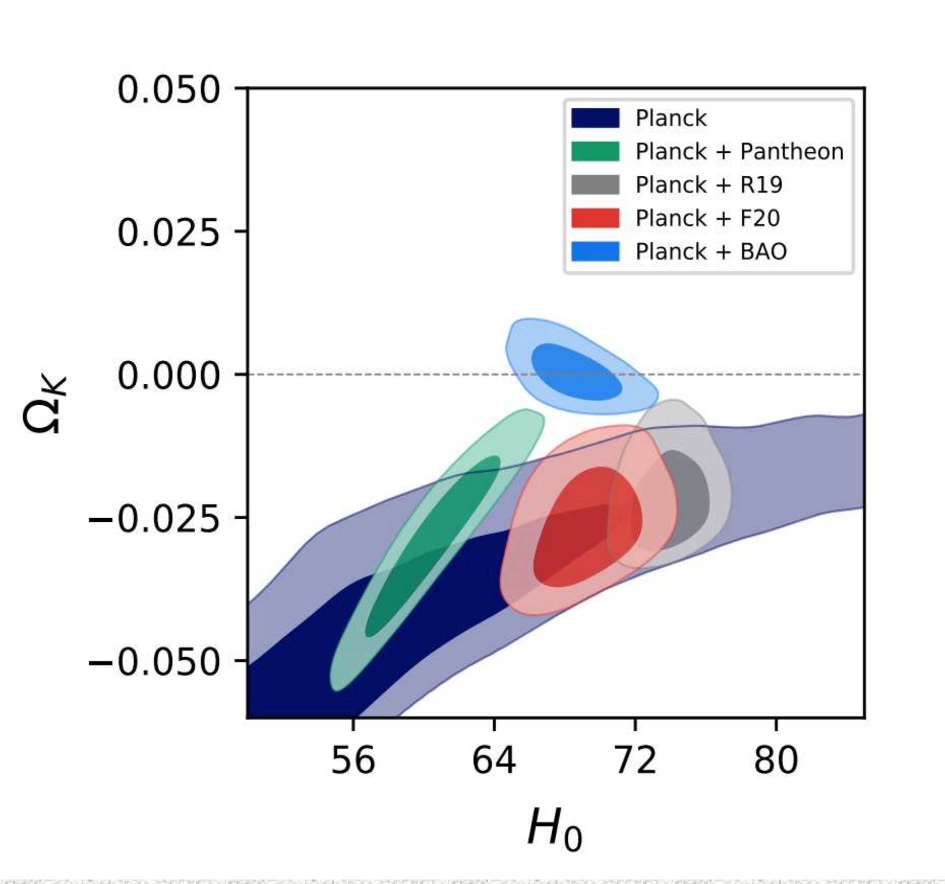
WMAP, 2010



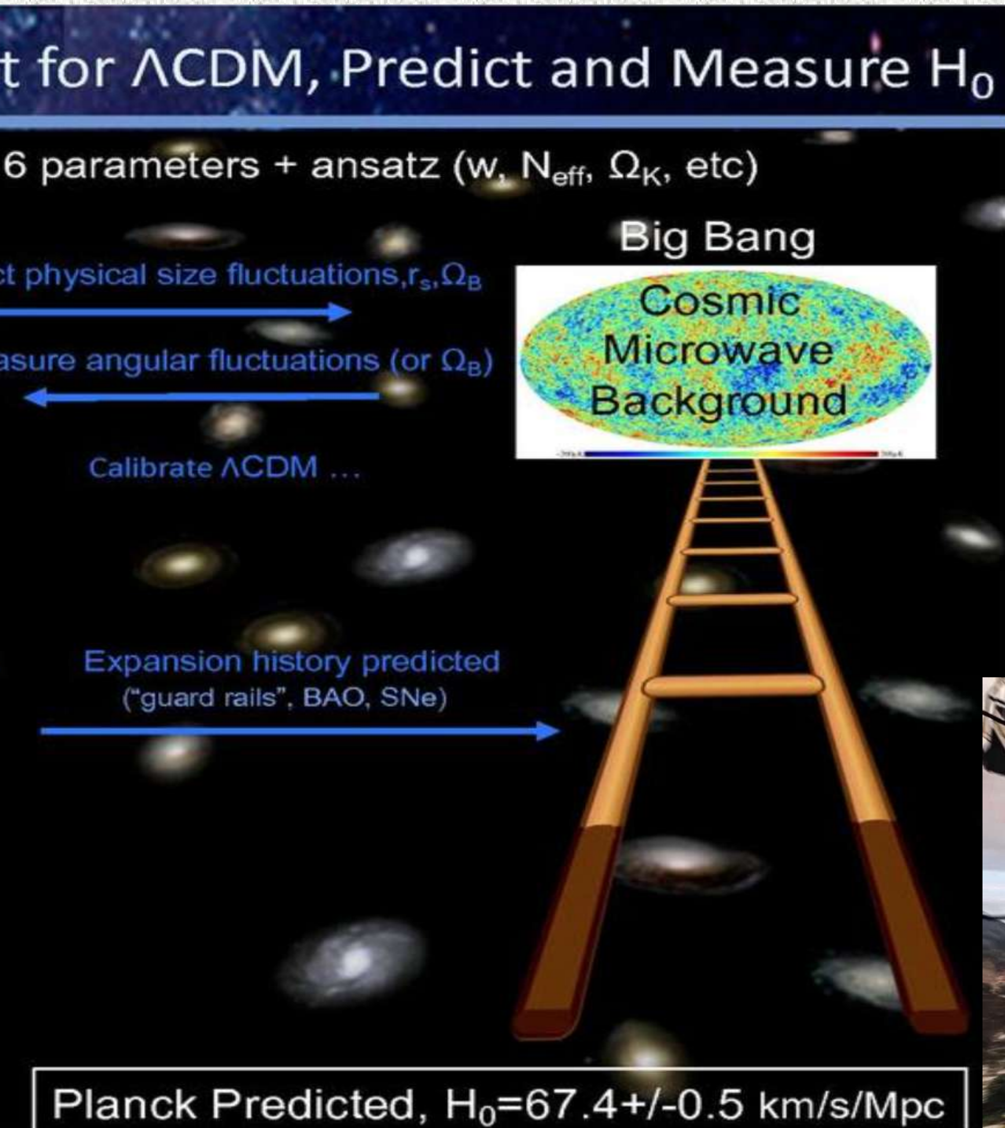
***Planck* 2018**

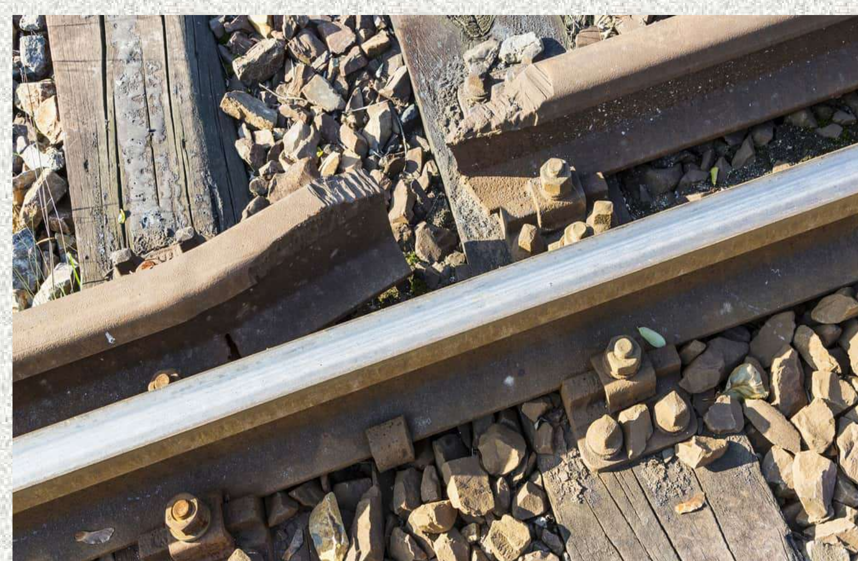
However, when observations at either side of the history of the universe increased their precision, ***tensions*** **(and maybe *more* than tensions) have arosen:**

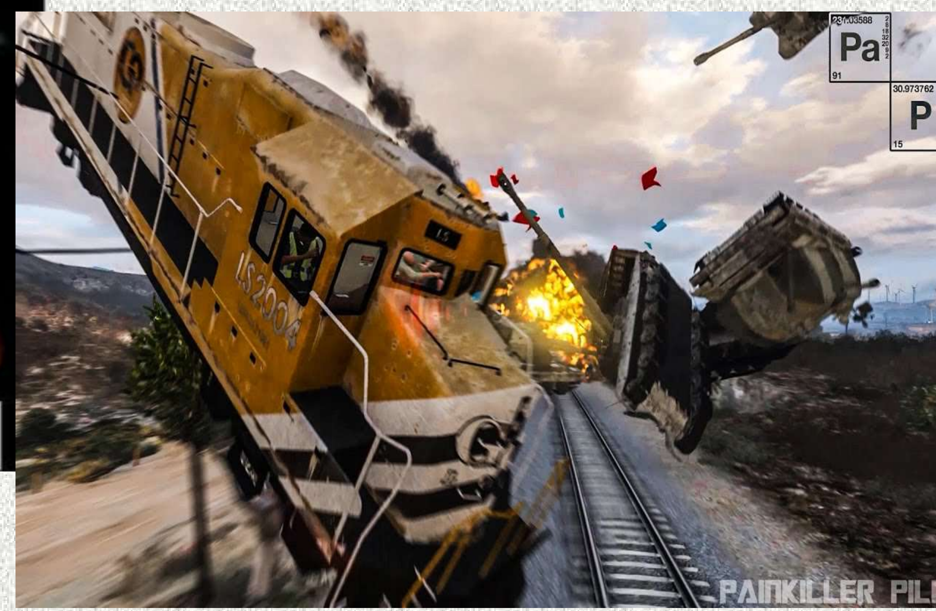




Di Valentino+20


t for ΛCDM, Predict and Measure H_0
6 parameters + ansatz (w, N_{eff}, Ω_K, etc)
Big Bang
Cosmic Microwave Background
ct physical size fluctuations, r_s, Ω_B
asure angular fluctuations (or Ω_B)
Calibrate ΛCDM …
Expansion history predicted
("guard rails", BAO, SNe)
Planck Predicted, H_0=67.4+/-0.5 km/s/Mpc

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The most significant sources of tension are:

- H_0 measurements at low and high redshifts:

  (3 – 5 σ, tension → ***problem, crisis?***)

- The amplitude of CMB lensing
- The amplitude of density perturbations at low redshifts (σ_8)

  (3 σ tension)

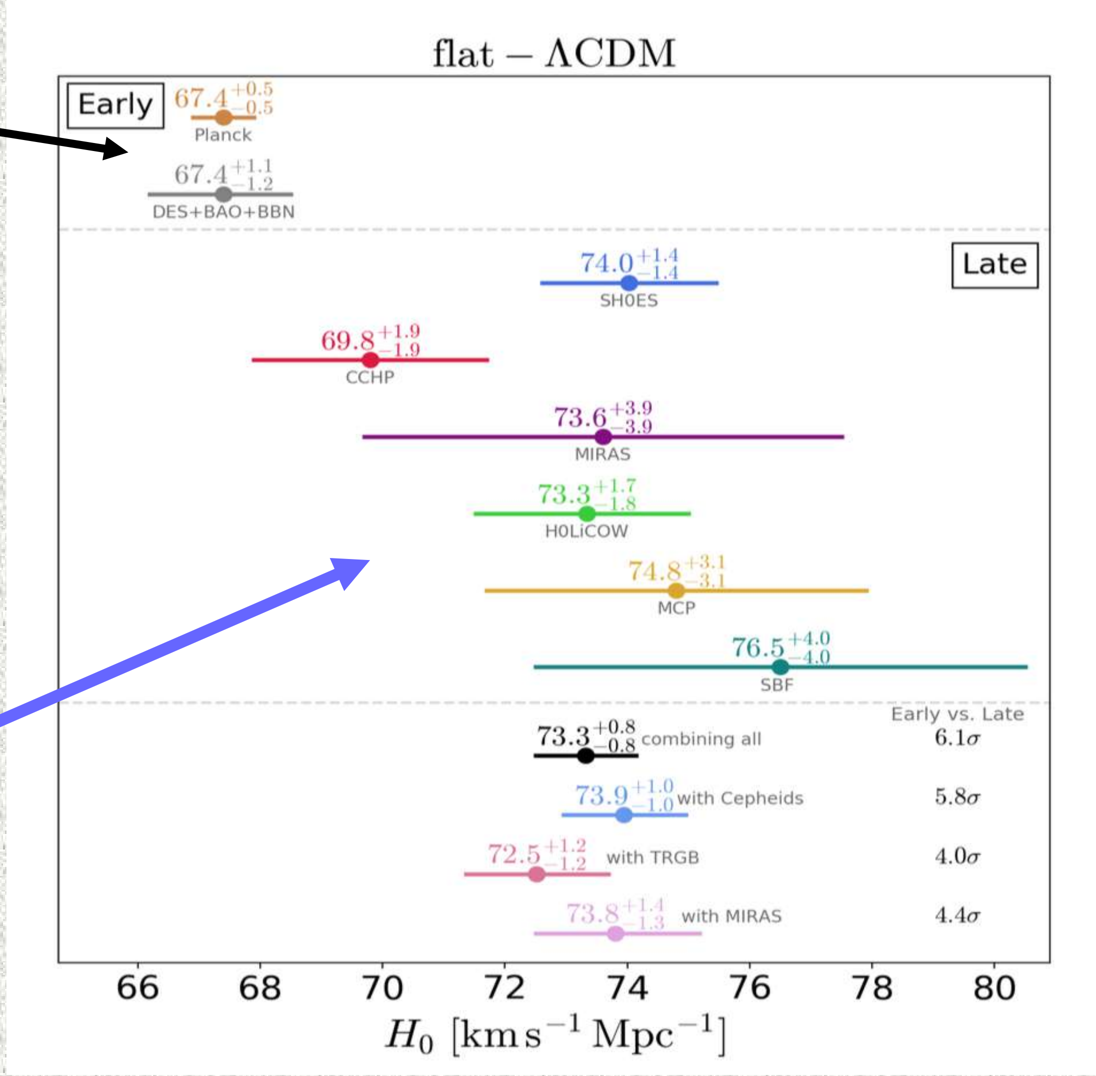
- The non-flat curvature of the universe ($\Omega_k = -0.04$)

  (3 σ tension)

Measuring the universe expansion rate H_0

- Indirectly, using the **angle projected by the sound horizon** at recombination at *z~1100* via CMB observations, and at *z~0.5* via clustering measurements of the Large Scale Structure (LSS)

- Directly, by (1) using ***standard candles* (SNIa)**, and calibrating their distance with Cepheids in LMC, Detached Eclipsing Binaries (DEB) in LMC, galactic parallaxes, the tip of the Red Giant Branch (TRGB), or (2) ***gravitational lensing*** at intermediate redshifts (*z~0.5)*



V. Bonvin, for Verde, Tommaso, & Riess 2019

Measuring the universe expansion rate H_0

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$$r_s(\eta) = \int_0^\eta d\eta' c_s = \int_0^\eta d\eta' \frac{1}{\sqrt{3(1+R)}}$$

$$R = (p_b + \rho_b)/(p_\gamma + \rho_\gamma) \approx 3\rho_b/4\rho_\gamma.$$

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Pros:

- Weak dependence of sound horizon on (well known) cosmological parameters,
- Measurements based upon a model that is relatively ***simple*** (linear order in perturbation theory) for CMB, mildly-non linear for LSS measurements
- Different probes (CMB and LSS) having very different (potential) systematics yield H_0 estimates in excellent agreement

Cons:

- They are all **indirect** measurements of the expansion rate that are **model dependent**

Measuring the universe expansion rate H_0

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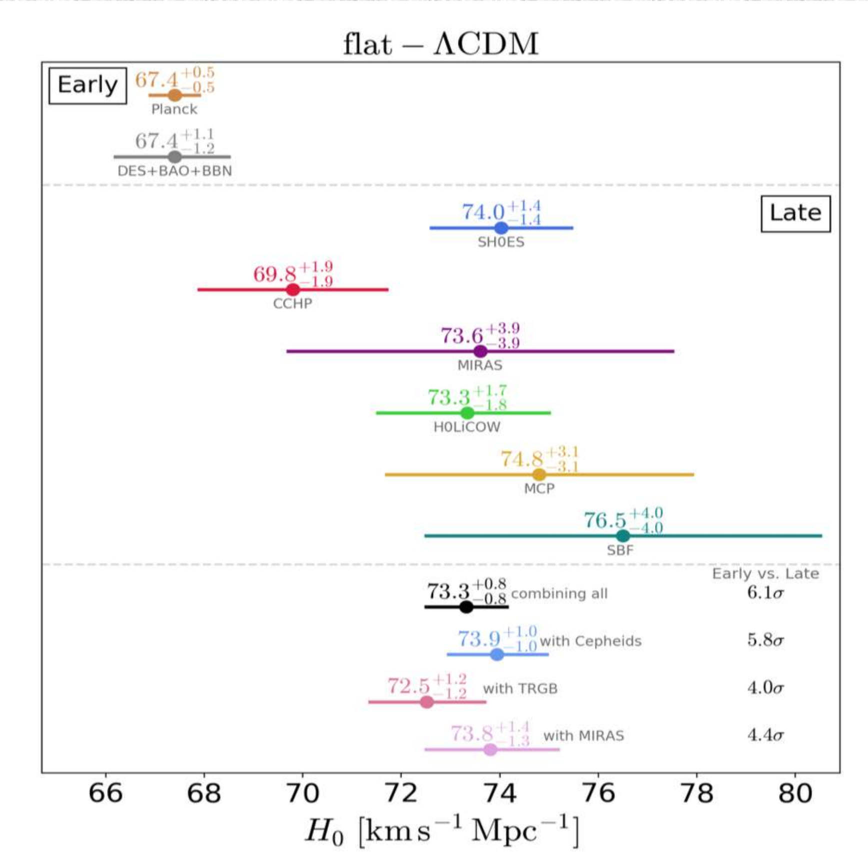
Pros:

- These are, for SNIa and Surface Brightness Fluctuation-based estimates, ***direct*** measurements of H_0 that are ***model independent***
- Lensing measurements, maser-based H_0 measurements,, and SNIa-based estimates, ***are all un-correlated, independent measurements of*** H_0 .

Cons:

- Measurements based on complex, highly non-linear systems (Cepheids, SNIa, clusters of galaxies) ***whose calibration are obtained empirically*** (more room for systematics)
- Results from the CCHP collaboration on the TRGB significantly off from those of SH0ES: ***evidence for hidden systematics?***

Measuring the universe expansion rate H_0



V. Bonvin, for
Verde, Tommaso, & Riess 2019

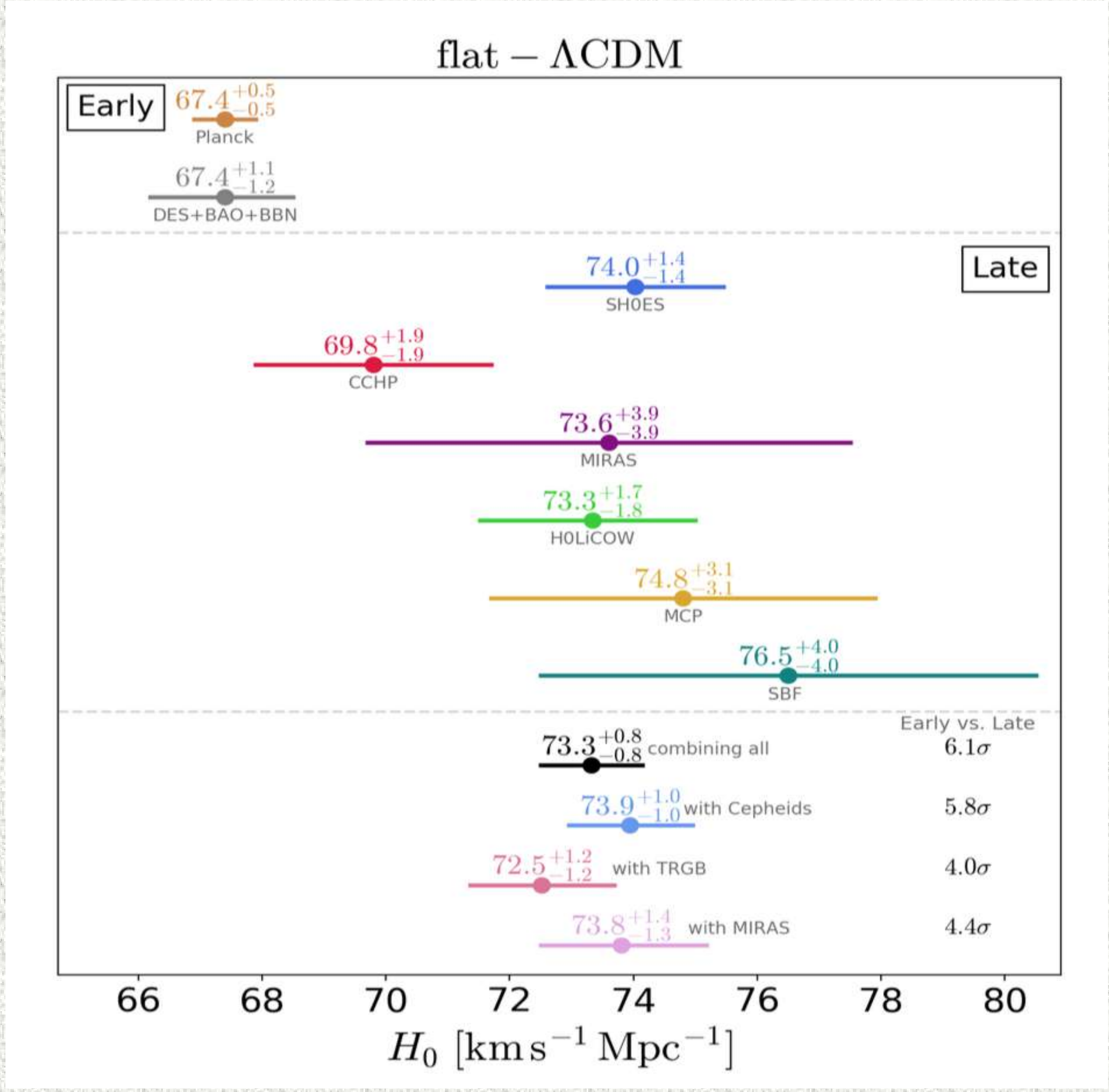
Possible solutions to this puzzle:

- Systematics in CMB observations: *unlikely,* provided different CMB experiments beyond *Planck* (like SPT, ACT) are providing very similar measurements of H_0

- ***New physics!*** : Emerging Dark Energy (EDE), Interacting Dark Energy, Übergravity, decaying Dark Matter, Rock 'n Roll models (RnR), Vacuum Dynamics, *what not!* – yet to be seen whether they can satisfy, some of them (EDE, RnR) already discarded …

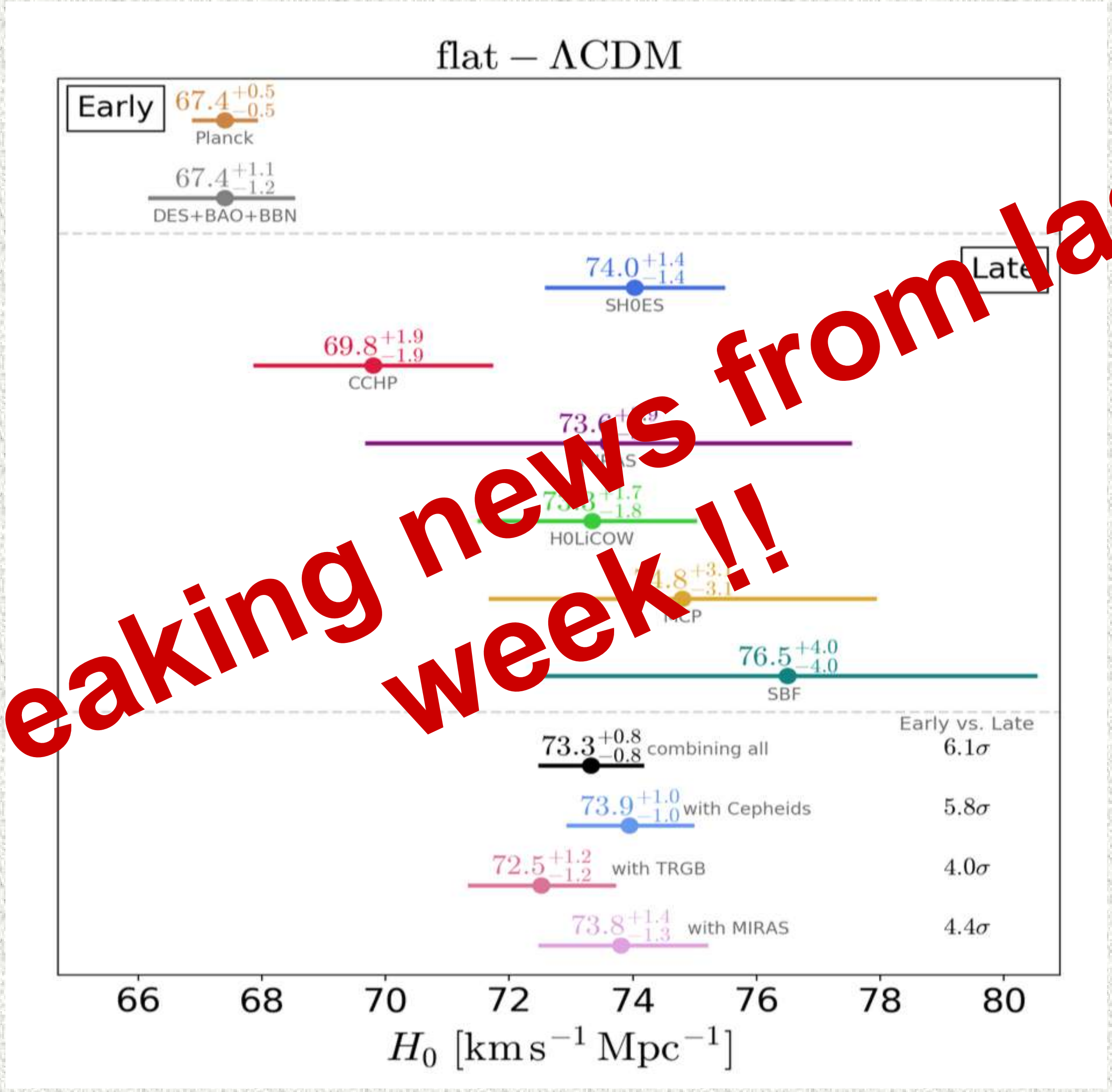
- Systematics in the direct H_0 measurements …

Measuring the universe expansion rate H_0



V. Bonvin, for Verde, Tommaso, & Riess 2019

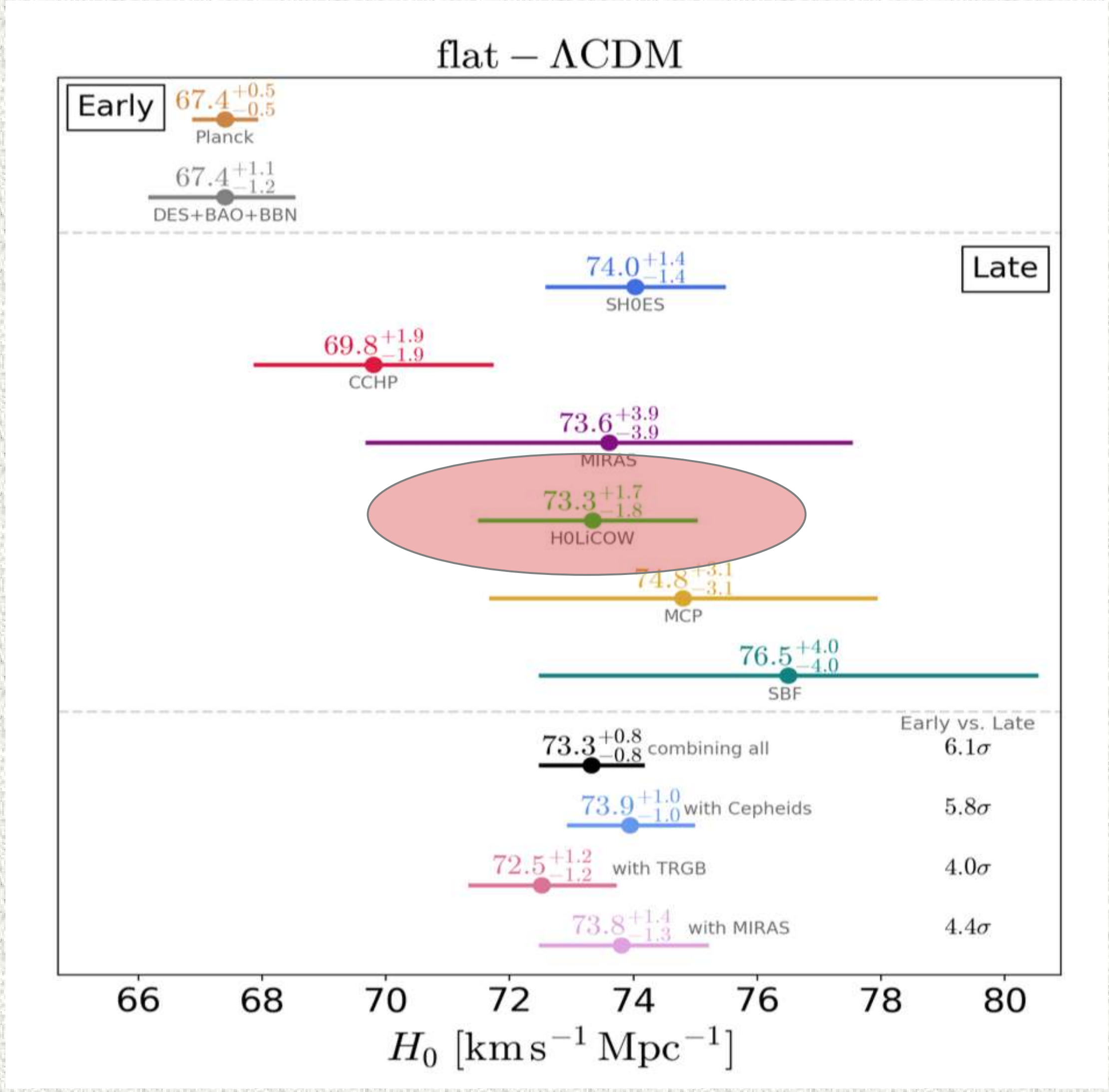
Measuring the universe expansion rate H_0



Breaking news from last week !!

V. Bonvin, for Verde, Tommaso, & Riess 2019

Measuring the universe expansion rate H_0



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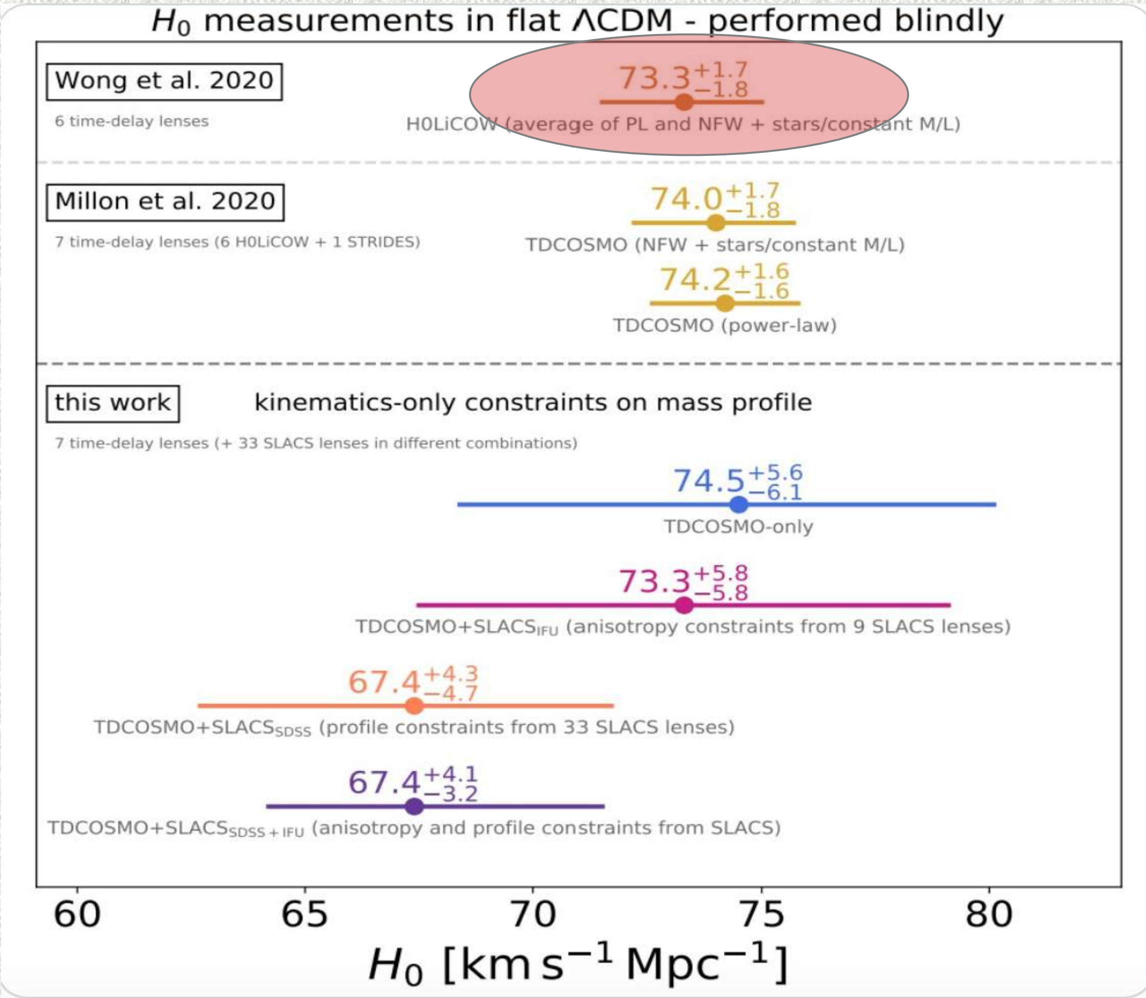

Birrer+ 2020, 2007.02941: TDCOSMO collaboration re-analyses cluster lenses accounting for uncertainties in mass distribution in clusters

Measuring the universe expansion rate H_0

Cornell University

We gratefully acknowledge support from
the Simons Foundation and member institutions.

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Astrophysics > Cosmology and Nongalactic Astrophysics

[Submitted on 12 Nov 2019]

Over-constrained Gravitational Lens Models and the Hubble Constant

C. S. Kochanek (1) ((1) Department of Astronomy, the Ohio State University)

nto nuevo

well known that measurements of H0 from gravitational lens time delays scale as H0~1-k_E where k_E is the mean convergence at the Einstein radius R_E but that all available lens data other than the delays provide no direct constraints on k_E. The properties of the radial mass distribution constrained by lens data are R_E and the dimensionless quantity x=R_E a''(R_E)/(1-k_E)$ where a''(R_E) is the second derivative of the deflection profile at R_E. Lens models with too few degrees of freedom, like power law models with densities ~r^(-n), have a one-to-one correspondence between x and k_E (for a power law model, x=2(n-2) and k_E=(3-n)/2=(2-x)/4). This means that highly constrained lens models with few parameters quickly lead to very precise but inaccurate estimates of k_E and hence H0. Based on experiments with a broad range of plausible dark matter halo models, it is unlikely that any current estimates of H0 from gravitational lens time delays are more accurate than ~10%, regardless of the reported precision.

Comments: submitted to MNRAS
Subjects: **Cosmology and Nongalactic Astrophysics (astro-ph.CO)**
DOI: 10.1093/mnras/staa344
Cite as: arXiv:1911.05083 **[astro-ph.CO]**
(or arXiv:1911.05083v1 **[astro-ph.CO]** for this version)

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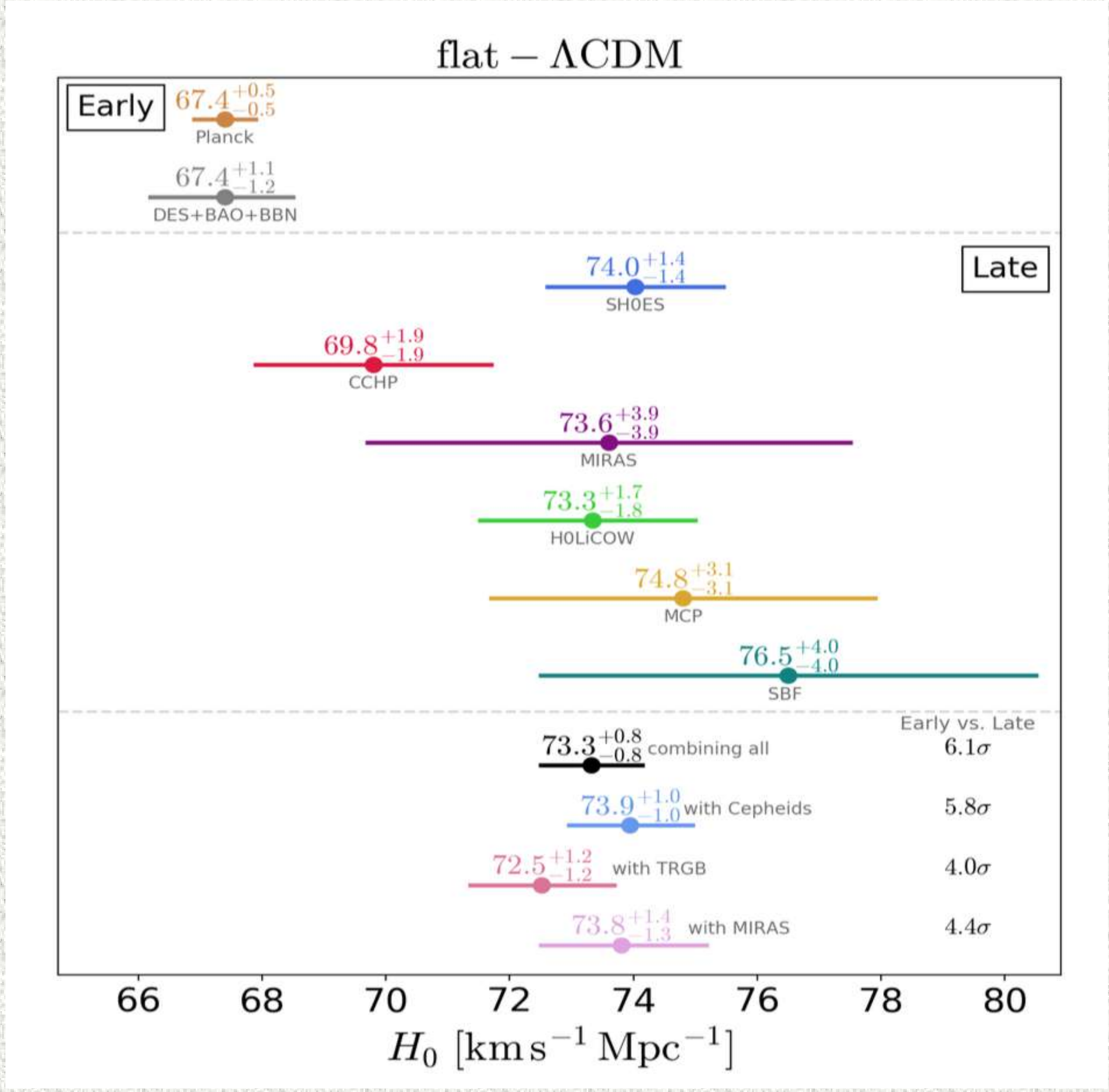
Birrer+ 2020, 2007.02941: TDCOSMO collaboration re-analyses cluster lenses accounting for uncertainties in mass distribution in clusters

Measuring the universe expansion rate H_0

But even if we drop cluster lensing …



V. Bonvin, for Verde, Tommaso, & Riess 2019

Measuring the universe expansion rate H_0

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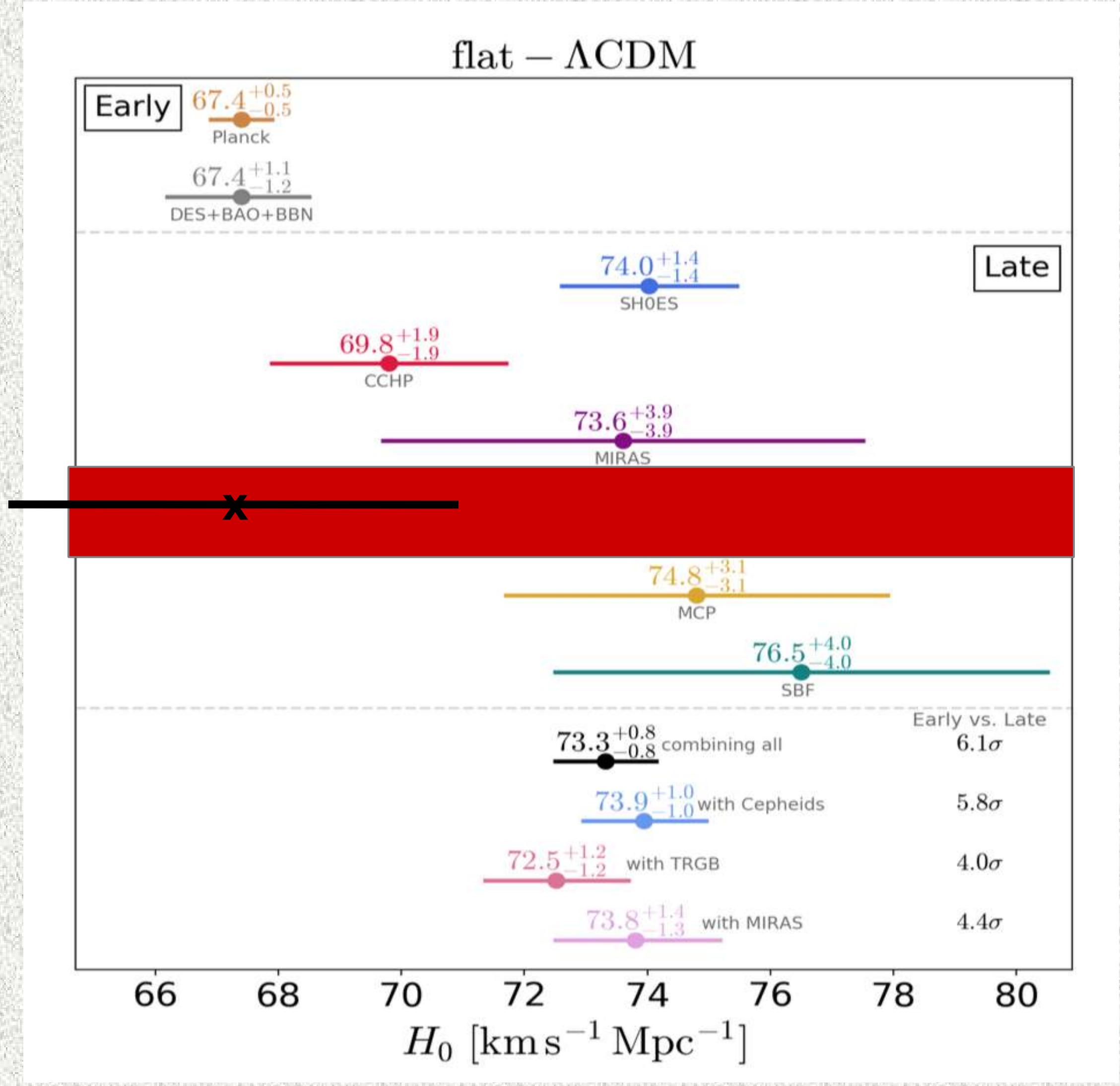
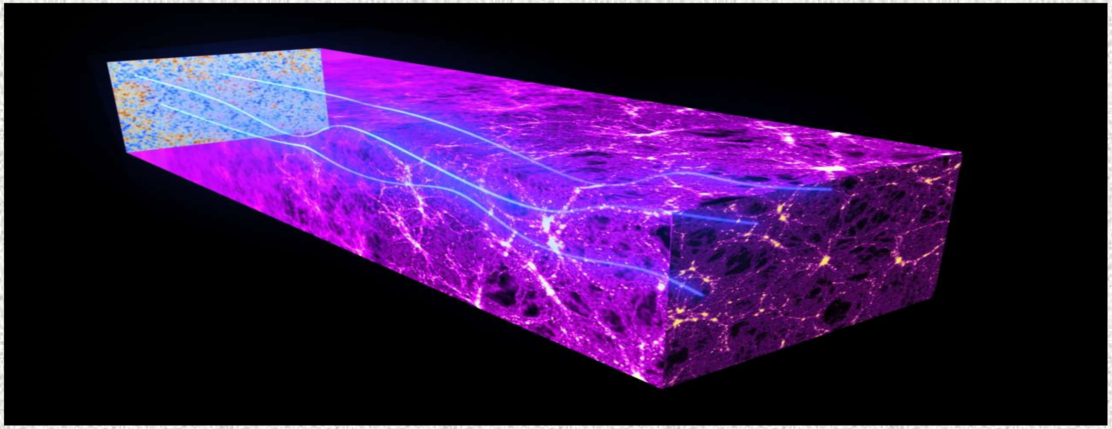


V. Bonvin, for Verde, Tommaso, & Riess 2019

Other (weaker) sources of tension …
(at 2 – 3 σ)

CMB gravitational lensing

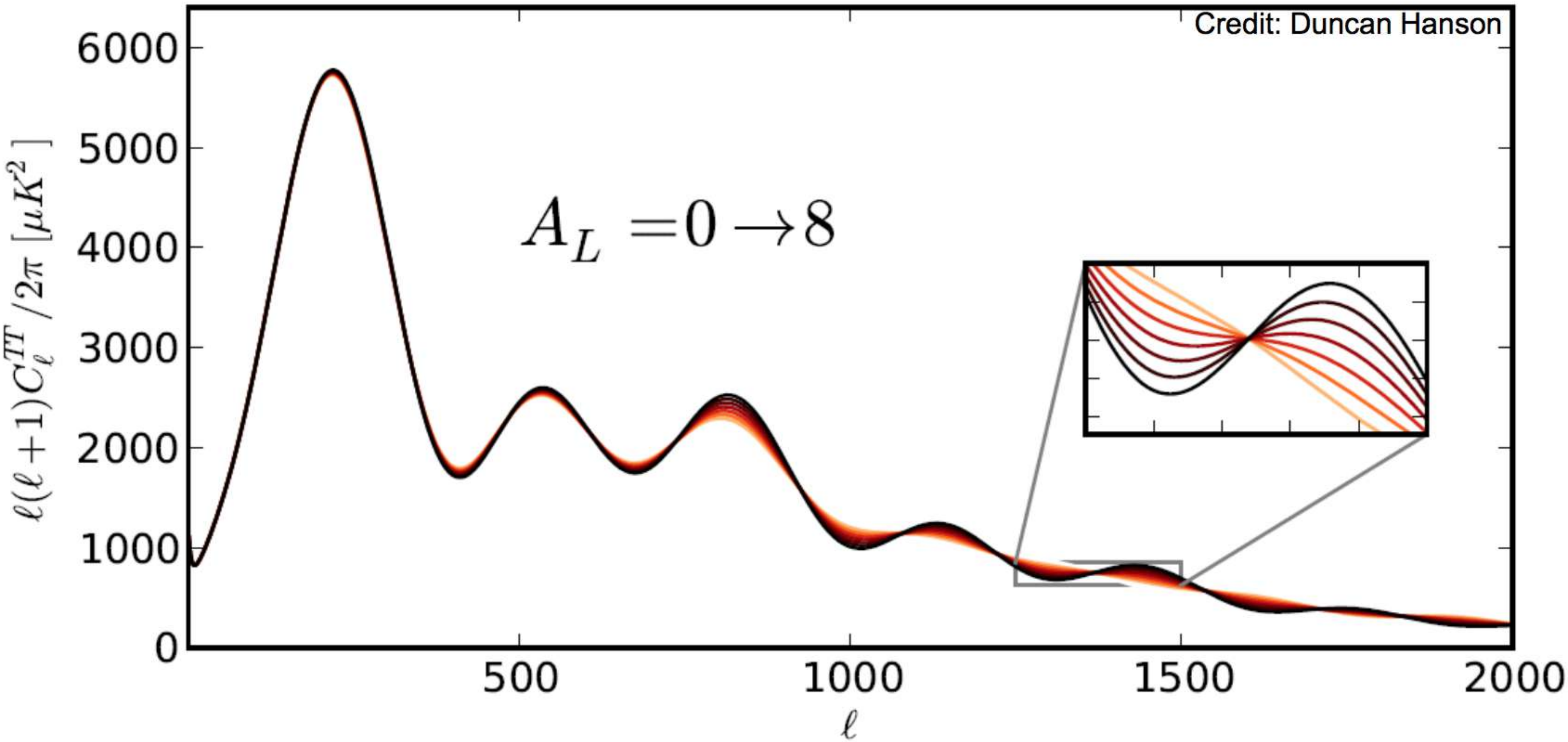


CMB photons are deflected in their journey to the observer. This effect can be accessed in two ways:

(Approach 1) Looking at non-Gaussianities induced by lensing on the smallest scales, using a *4-point function* $\langle T(n_1)T(n_2)T(n_3)T(n_4)\rangle$

(Approach 2) Looking at the *2-point function* ($\langle T(n_1)T(n_2)\rangle$ or angular power spectra $C_l = \langle a_{l,m} (a_{l,m})^* \rangle$): the impact of lensing-induced ray deflection *smears/softens* the acousting peaks

CMB 2-point function $\langle a_{l,m}\, a_{l,m}^{*} \rangle = C_l$ (angular power spectrum)



$A_L = 1$ is what our theory predicts …

CMB gravitational lensing

Problem: The amplitude of lensing inferred from Approach 2 ***is about 15% higher*** than for Approach 1, at *~3σ level*) – It's like if lensing was *more efficient* at smearing CMB acoustic peaks than predicted

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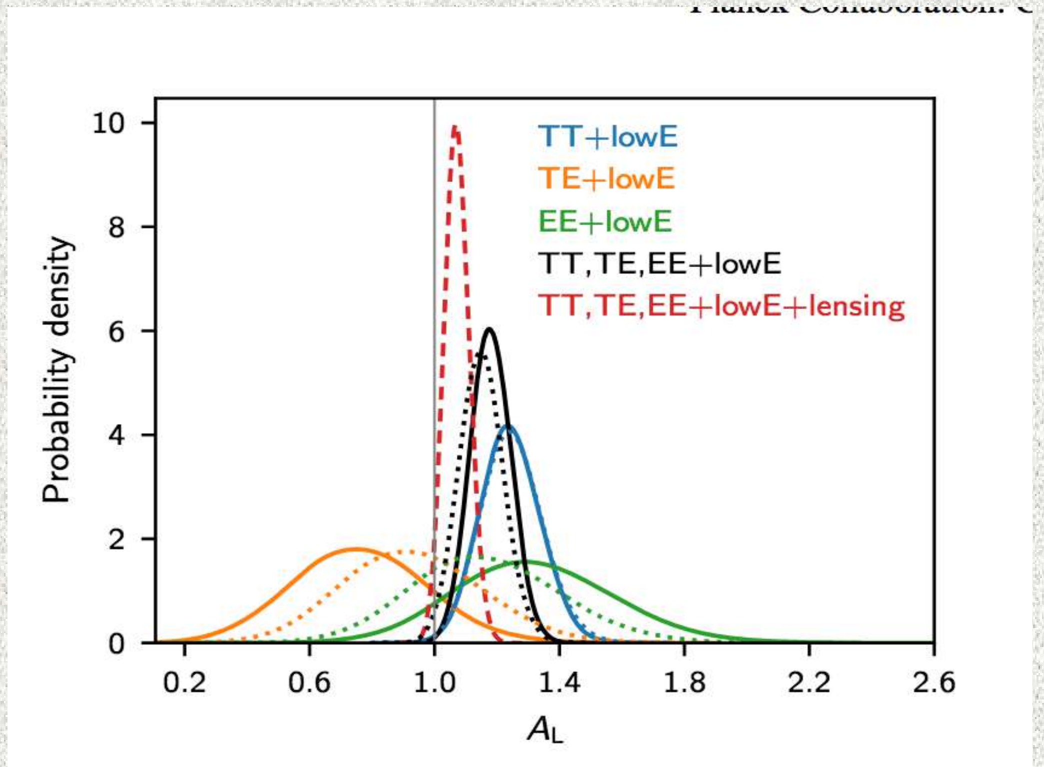

Planck 2018

CMB gravitational lensing + lensing shear from KiDs & CFHTLenS

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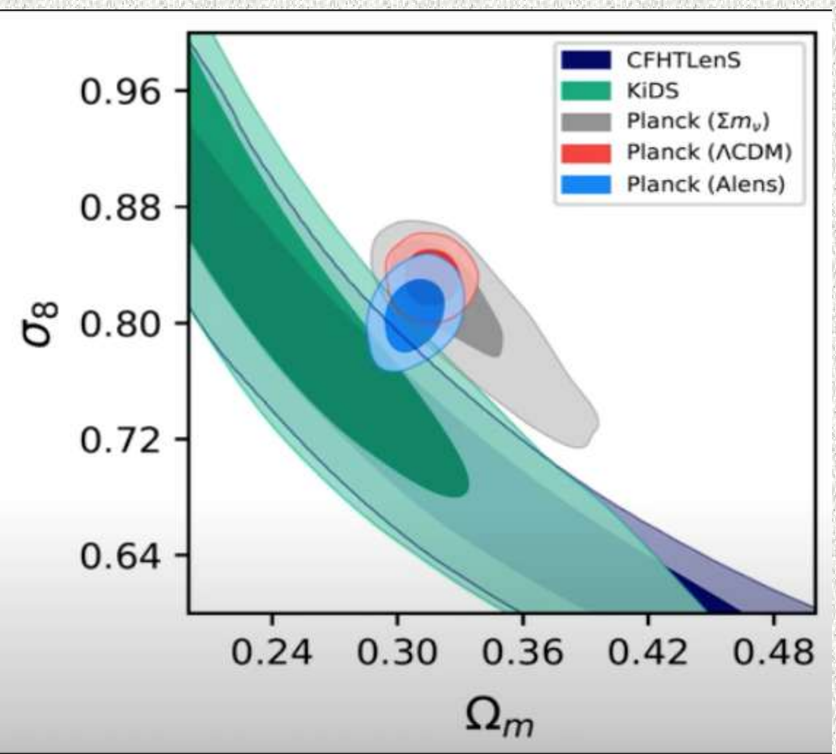


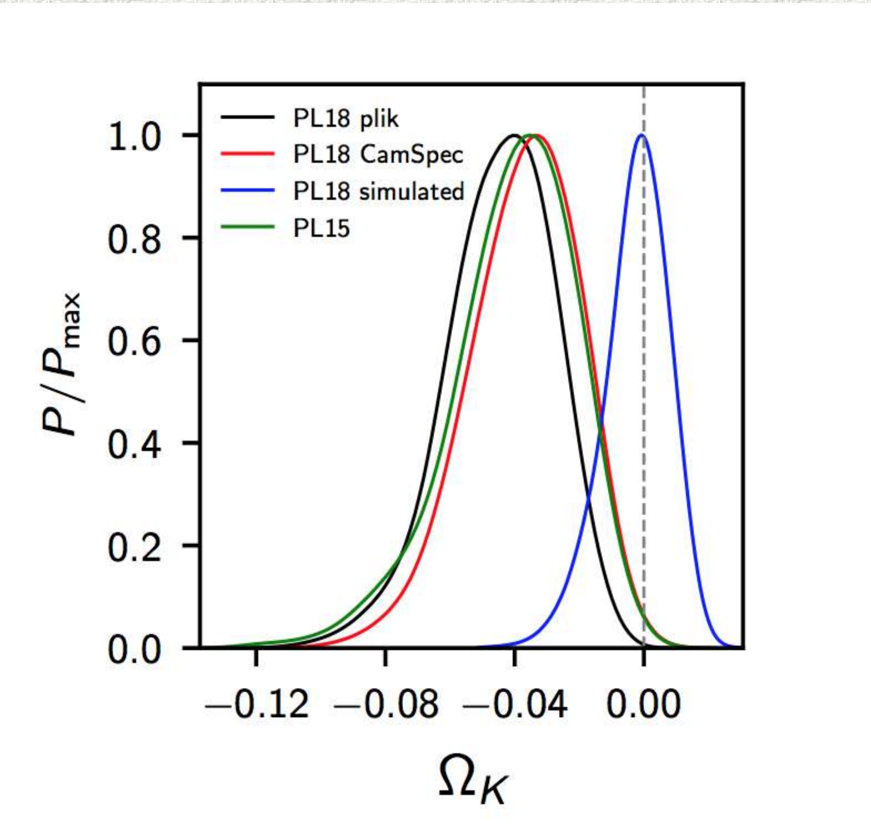
If CMB lensing were *more efficient* than what we predict, the 3σ tension with galaxy lensing shear would be alleviated

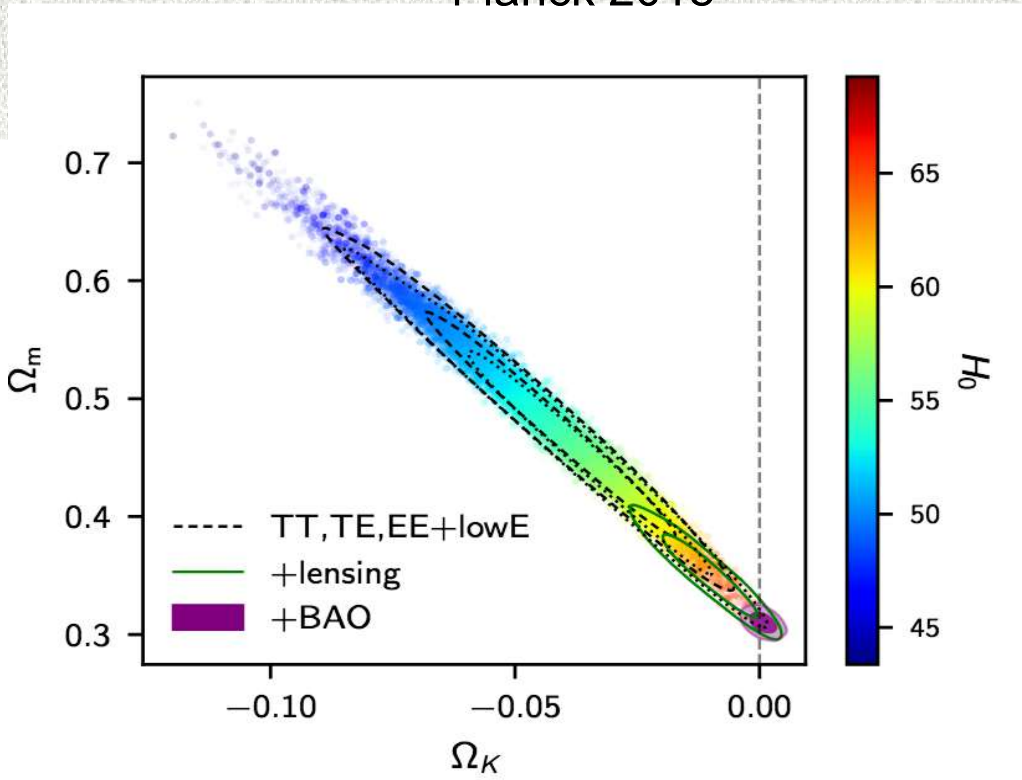
Di Valentino & Bridle 19

And finally, if we look at *Planck* 2018 only ...

The universe does not seem flat, but has strong preference (~2σ) for being ***closed instead of flat !***

Planck 2018





Di Valentino+20

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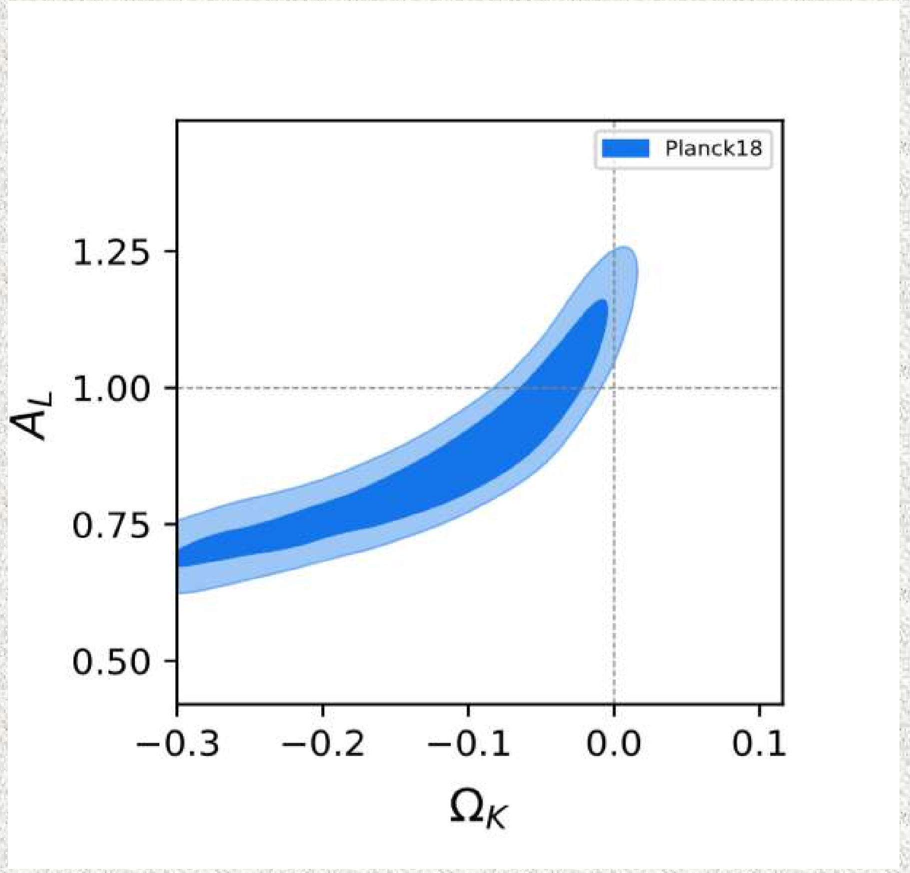
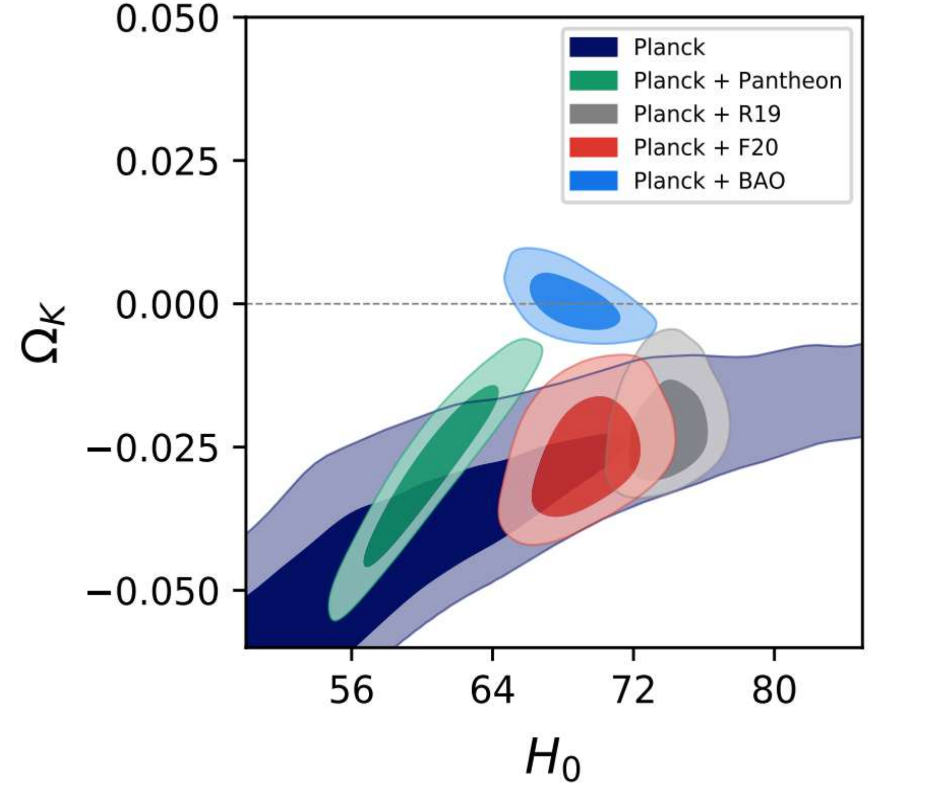


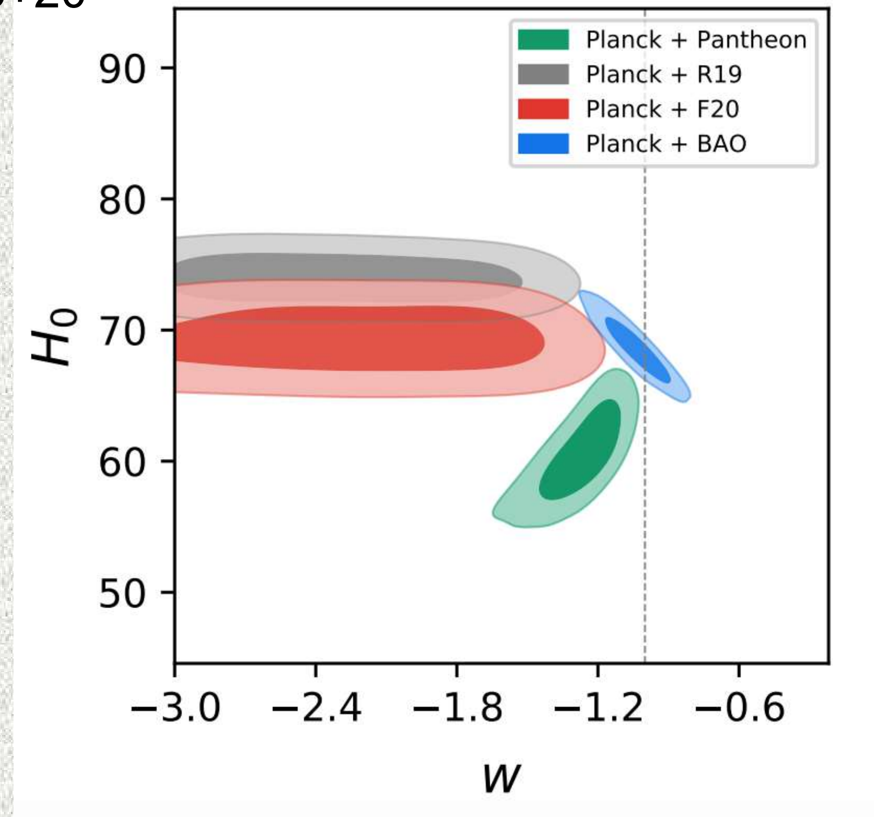
Di Valentino+ 20

This would **solve the problem with the lensing amplitude/efficiency and other internal *anomalies* in *Planck* data** (low quadrupole, alignment of low *l* multipoles, etc)

The universe does not seem flat, but has strong preference (~2σ) for being ***closed instead of flat !***

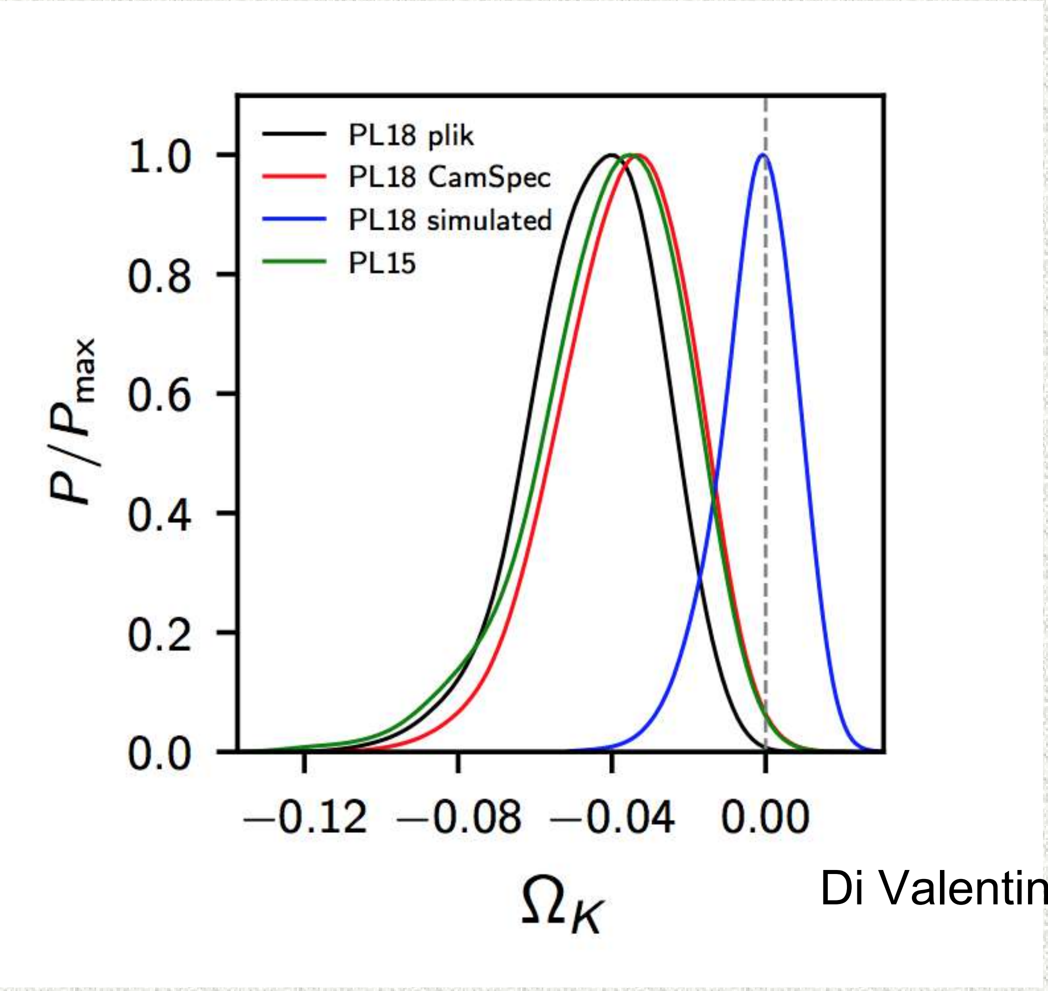
Di Valentino+20





But it falls apart with ***all*** *other cosmological observations at lower redshifts!*

The universe does not seem flat, but has strong preference (~2σ) for being ***closed instead of flat !***



Di Valentino+20

Can this be a fluke/result of chance??

Cosmic Discordance: Planck and luminosity distance data exclude LCDM.

Eleonora Di Valentino,[1,*] Alessandro Melchiorri,[2,†] and Joseph Silk[3,4,5,‡]

[1] *Jodrell Bank Center for Astrophysics, School of Physics and Astronomy, University of Manchester, Oxford Road, Manchester, M13 9PL, UK*
[2] *Physics Department and INFN, Università di Roma "La Sapienza", Ple Aldo Moro 2, 00185, Rome, Italy*
[3] *Institut d'Astrophysique de Paris (UMR7095: CNRS & UPMC- Sorbonne Universities), F-75014, Paris, France*
[4] *Department of Physics and Astronomy, The Johns Hopkins University Homewood Campus, Baltimore, MD 21218, USA*
[5] *BIPAC, Department of Physics, University of Oxford, Keble Road, Oxford OX1 3RH, UK*

(Dated: March 12, 2020)

We show that a combined analysis of CMB anisotropy power spectra obtained by the Planck satellite and luminosity distance data simultaneously excludes a flat universe and a cosmological constant at 99% C.L.. These results hold separately when combining Planck with three different datasets: the two determinations of the Hubble constant from Riess et al. 2019 and Freedman et al. 2020, and the Pantheon catalog of high redshift supernovae type-Ia. We conclude that either LCDM needs to be replaced by a drastically different model, or else there are significant but still undetected systematics. Our result calls for new observations and stimulates the investigation of alternative theoretical models and solutions.

Draft version March 28, 2019
Typeset using LaTeX **preprint** style in AASTeX62

Large Magellanic Cloud Cepheid Standards Provide a 1% Foundation for the Determination of the Hubble Constant and Stronger Evidence for Physics Beyond ΛCDM

Adam G. Riess,[1,2] Stefano Casertano,[1,2] Wenlong Yuan,[2] Lucas M. Macri,[3] and Dan Scolnic[4]

[1] *Space Telescope Science Institute, 3700 San Martin Drive, Baltimore, MD 21218, USA*
[2] *Department of Physics and Astronomy, Johns Hopkins University, Baltimore, MD 21218, USA*
[3] *Texas A&M University, Department of Physics and Astronomy, College Station, TX 77845, USA*
[4] *Duke University, Department of Physics, Durham, NC 27708, USA*

(Accepted ApJ, March 26, 2019)

The most significant sources of tension are:

- H_0 measurements at low and high redshifts:

  (3 – 5 σ, tension → ***problem, crisis ?***)

- The amplitude of CMB lensing
- The amplitude of density perturbations at low redshifts (σ_8)

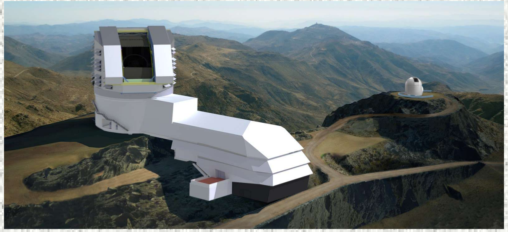
  (3 σ tension)

- The non-flat curvature of the universe (Ω_k = -0.04)

  (3 σ tension)

Looking at the future …

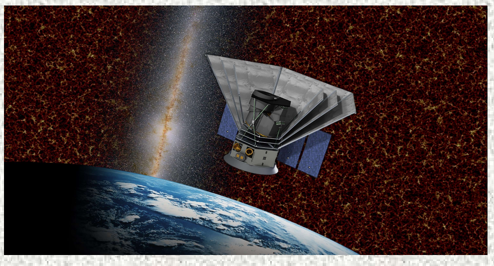
CMB:

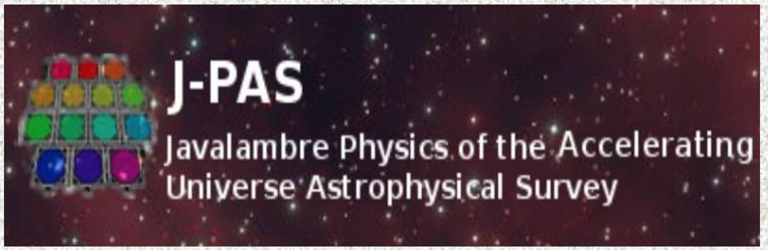


ACTPol
SPTPol
LiteBird
Future ESA space CMB mission (?)

LSS:

Euclid
DESI
Vera Rubin
J-PAS
SphereX
SKA



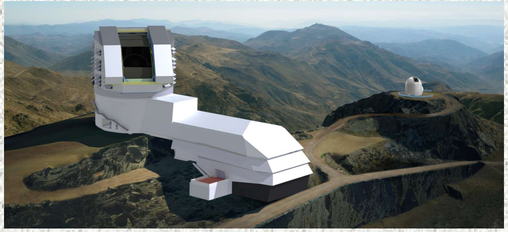


GWs

Looking at the future …

CMB:

ACTPol
SPTPol
LiteBird
Future ESA space CMB mission (?)

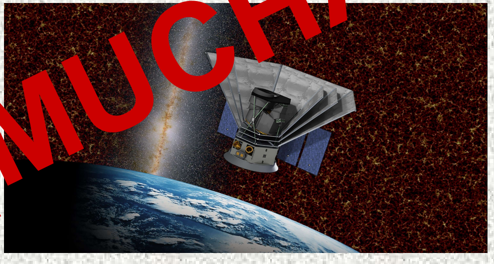


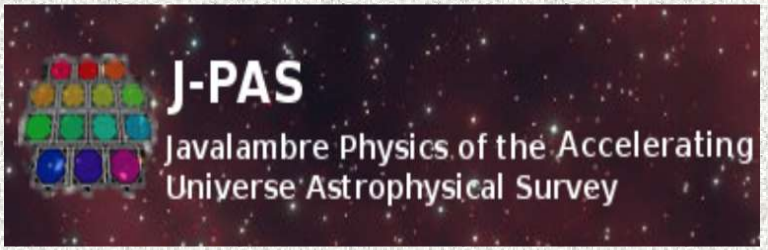
¡MUCHAS GRACIAS!

LSS:

Euclid
DESI
Vera Rubin
J-PAS
SphereX
SKA

Euclid consortium





GWs