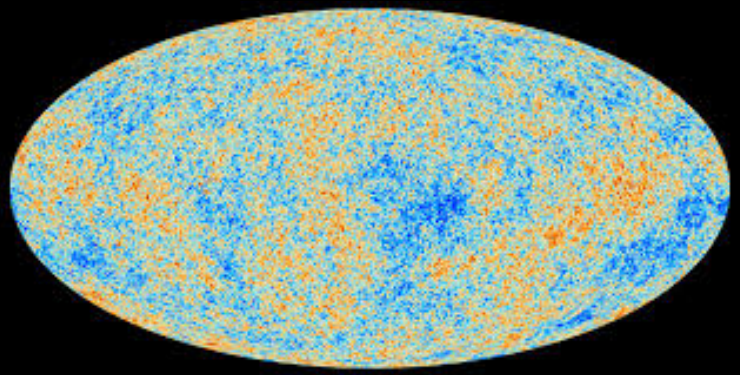
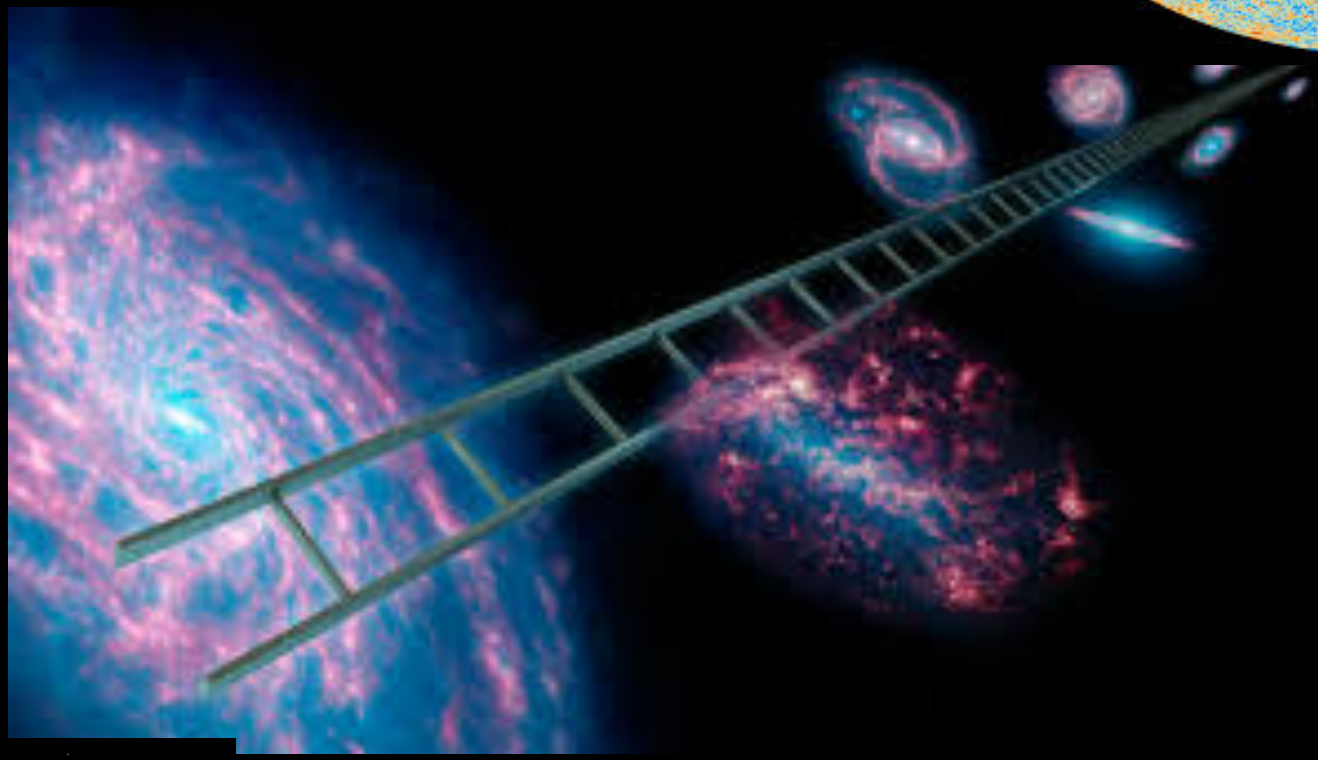
The H0 game: E2E test

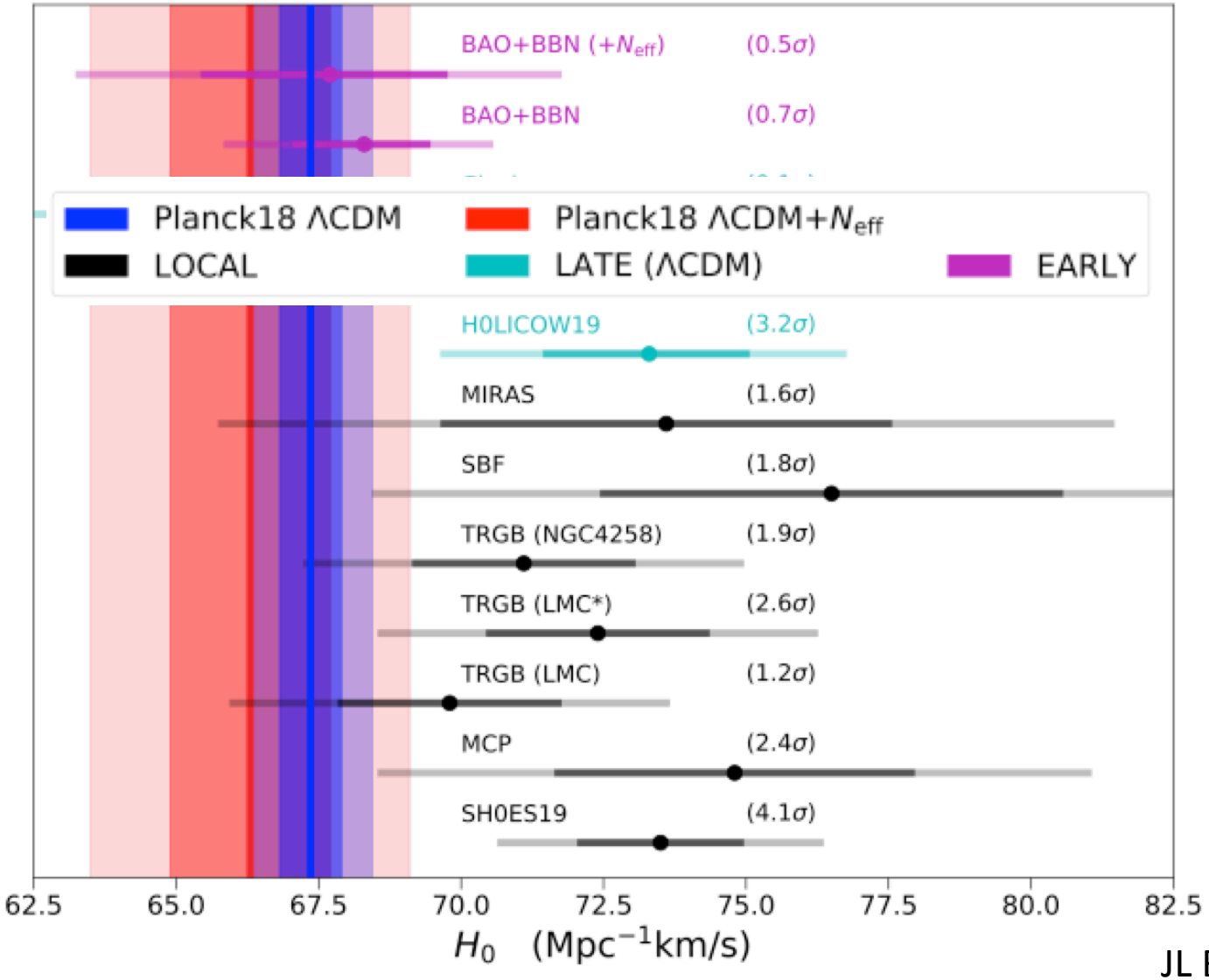




Licia Verde
ICREA & ICCUB

Is there a problem?

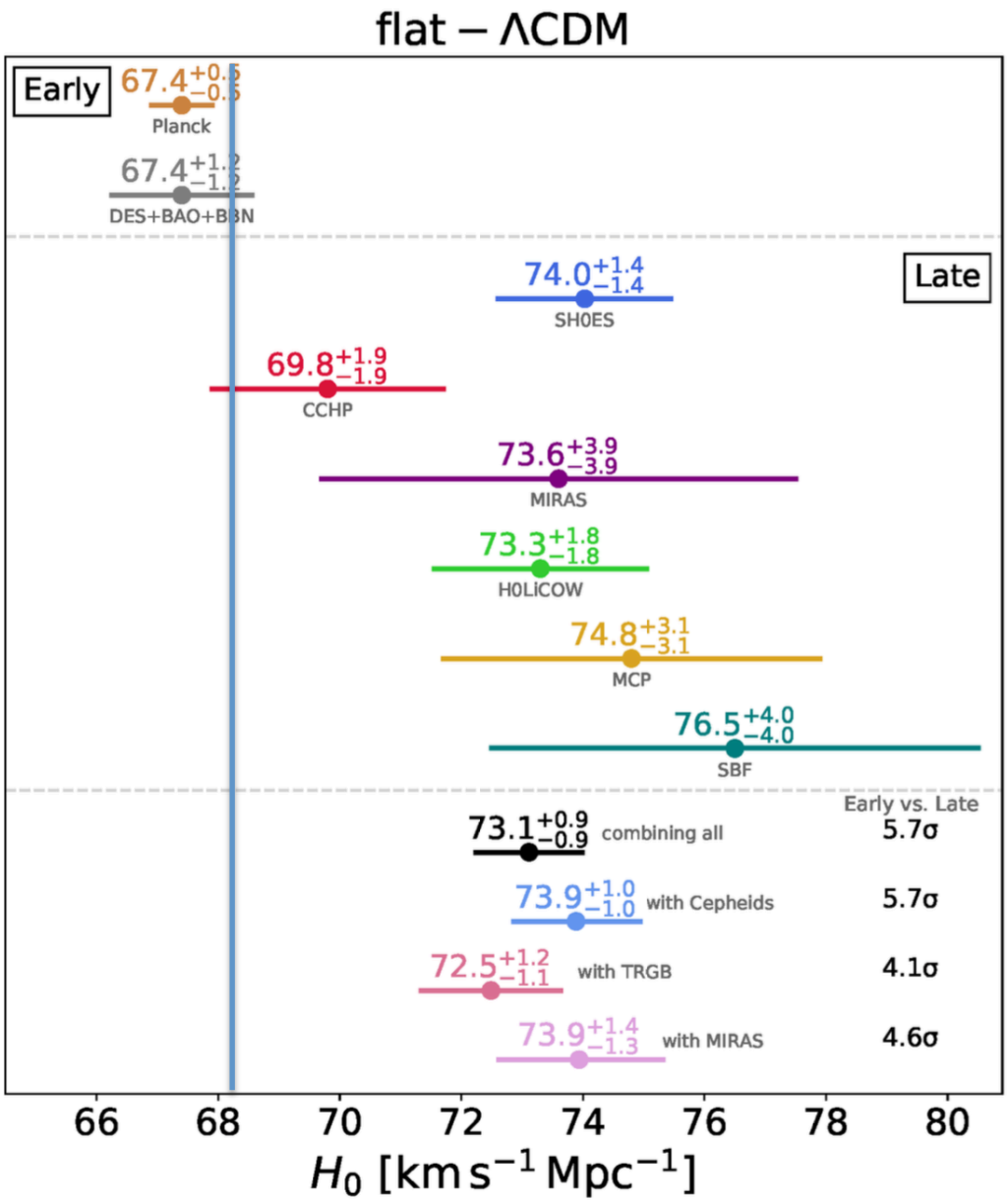
First, be quantitative



Cosmological-model dependent

JL Bernal thesis defense

Is there a problem?



First, be quantitative

Between 4 and 6 sigmas*

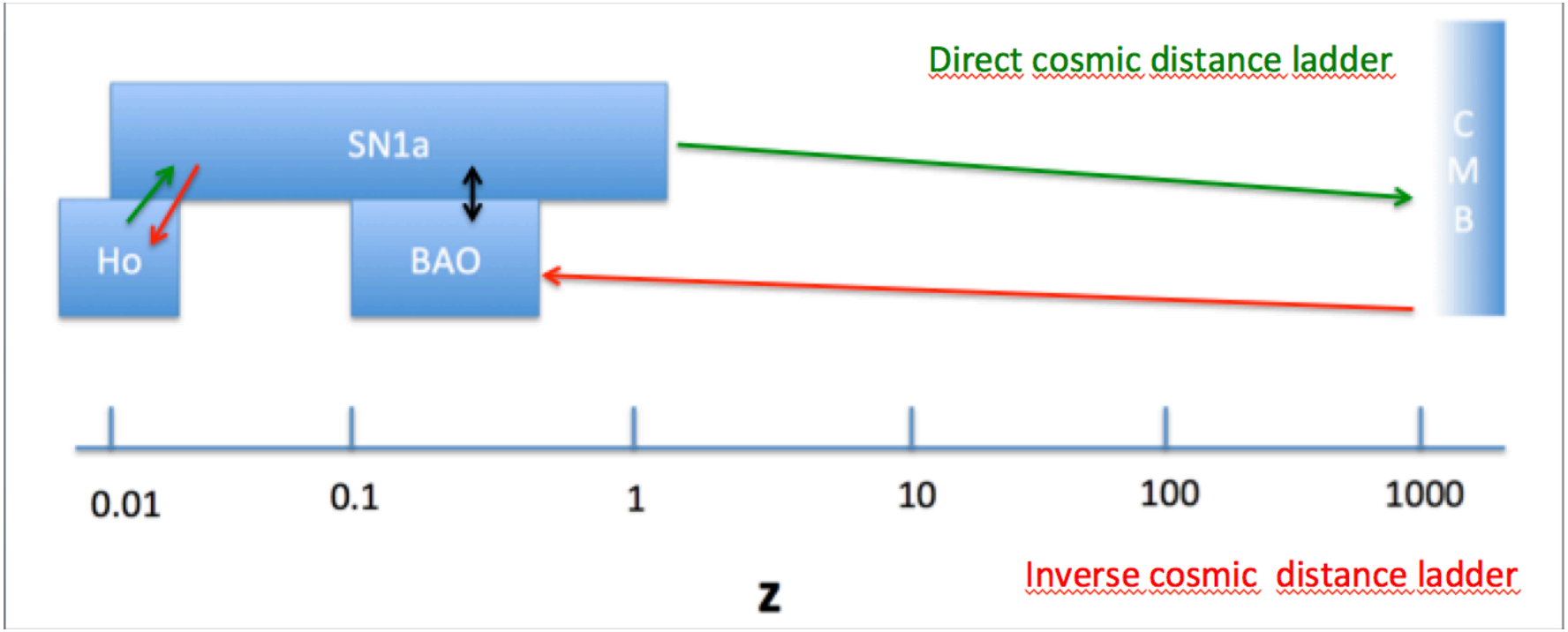
Summary of July 2019 KITP conference

courtesy of Vivien Bonvin
https://github.com/vbonvin/

Nature Astronomy 2019

Working hypothesis: early vs late

WHY?



H0

rs

But there is not much wiggle room in the middle!

Bernal e tal 2016, Aylor et al 2017

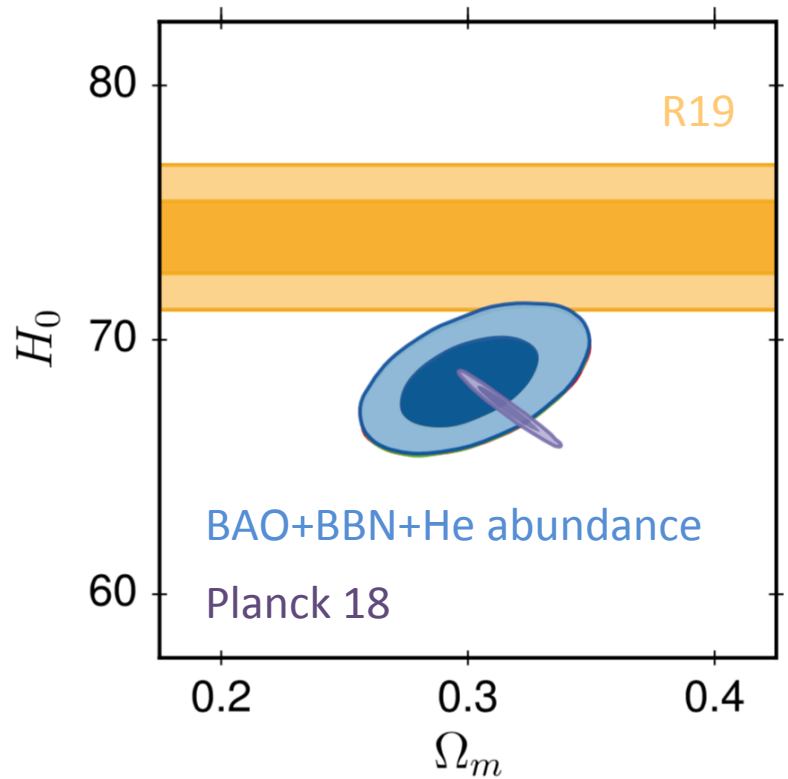
Where is the problem?

Is it in any specific **data** set? (keeping the standard LCDM context)

Early. For a while some people put the blame on Planck….

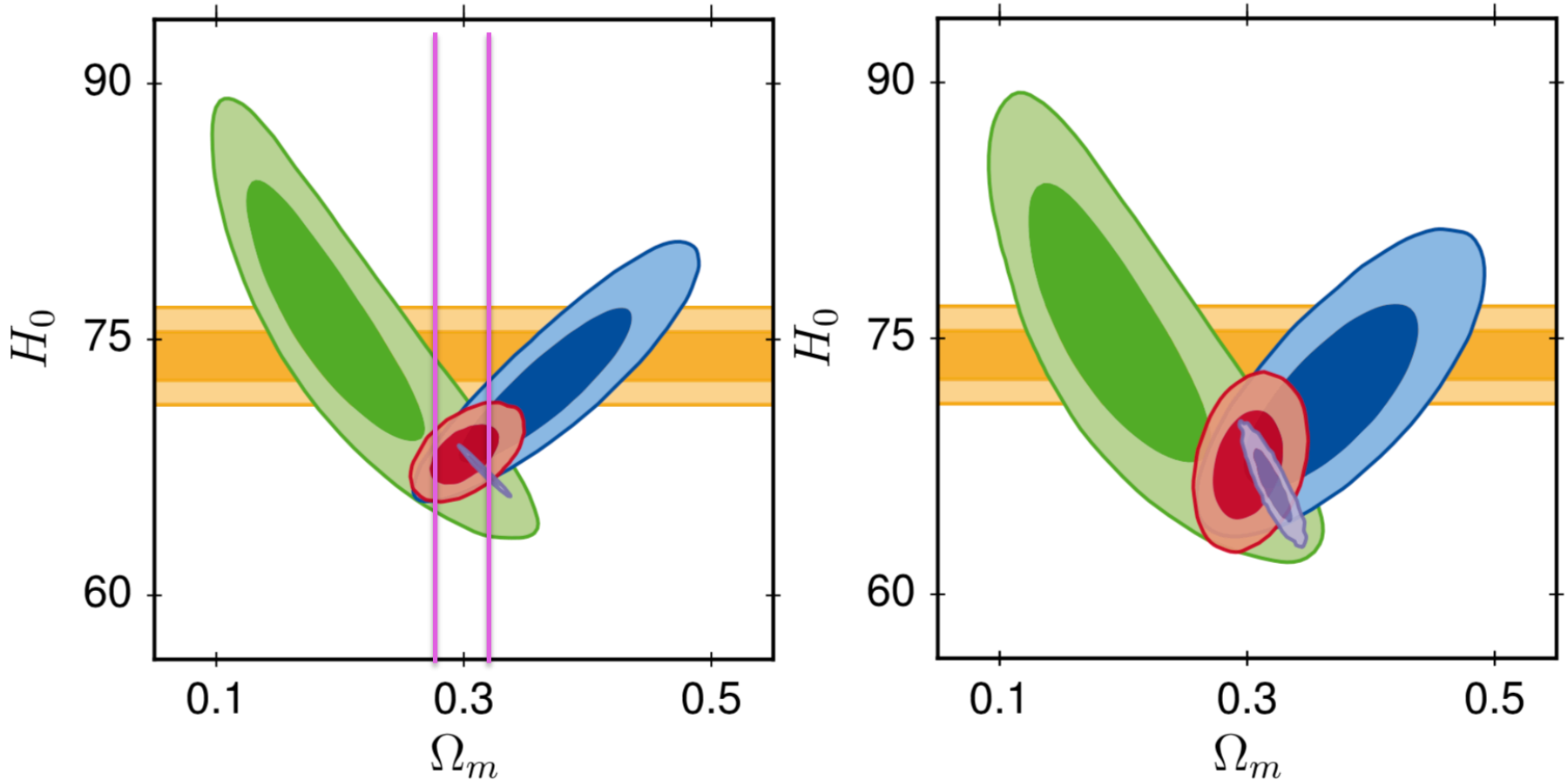
BUT H0(Early) does not budge if
you take Planck (or CMB data) out
Completely (even for Neff-extended models
Shonenberg et al 2019)

Before who dropped Planck used instead
WMAP+ACT/SPT.



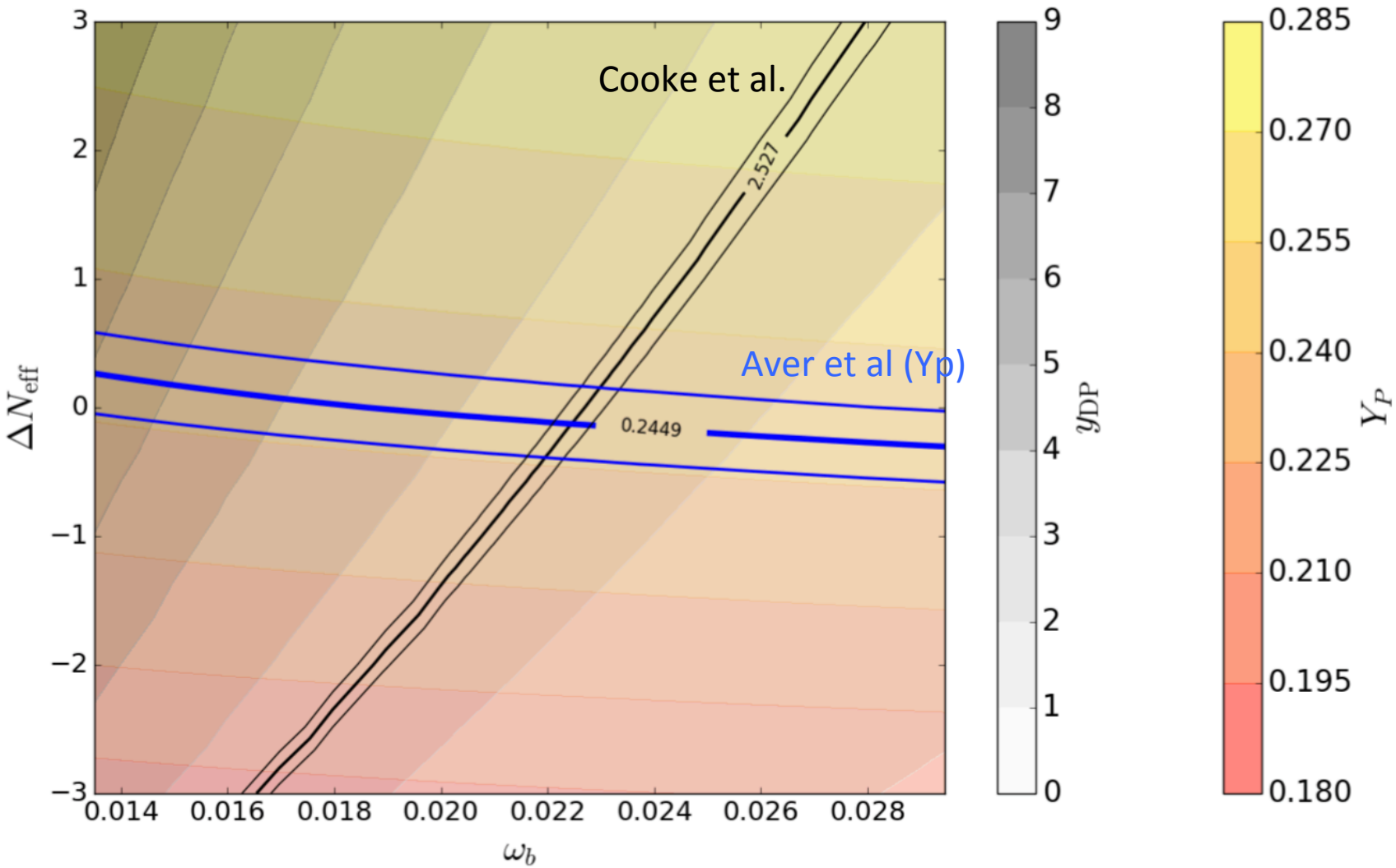
NOT in CMB data

Aside: if not Lya BAO, use SNe



Shonenberg et al 2019

Neff free

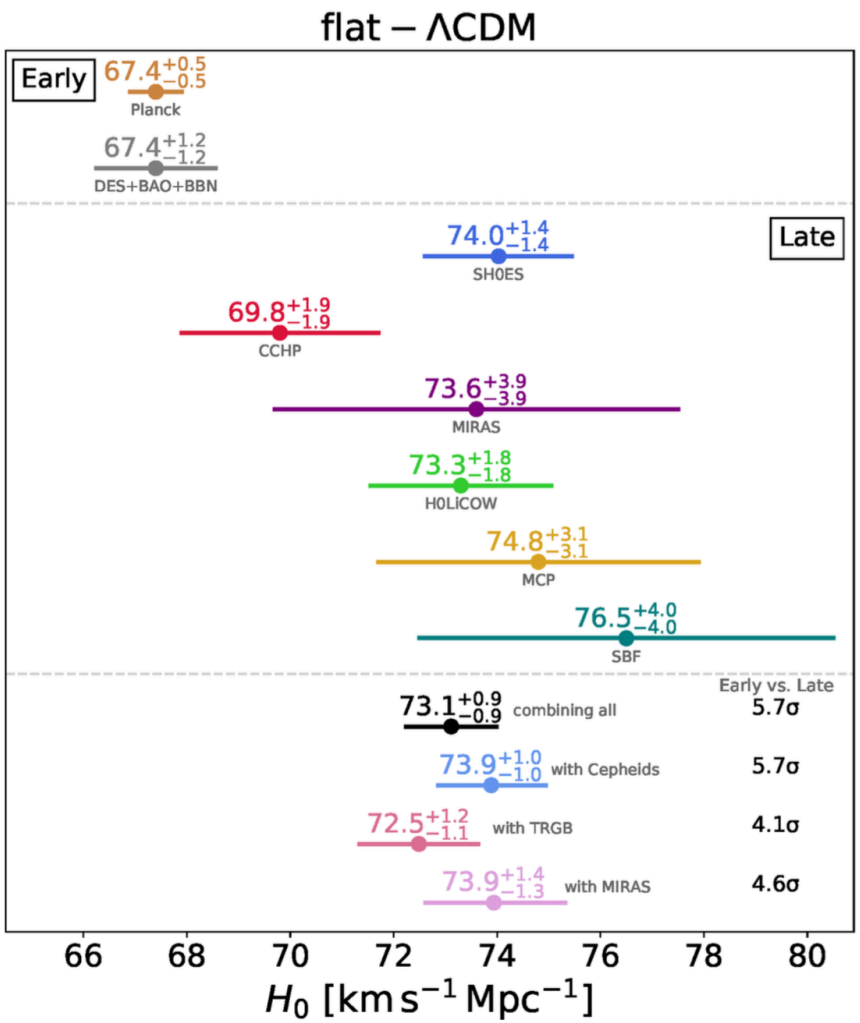


Deuterium Helium

Where is the problem?

Is it in any specific **data** set?

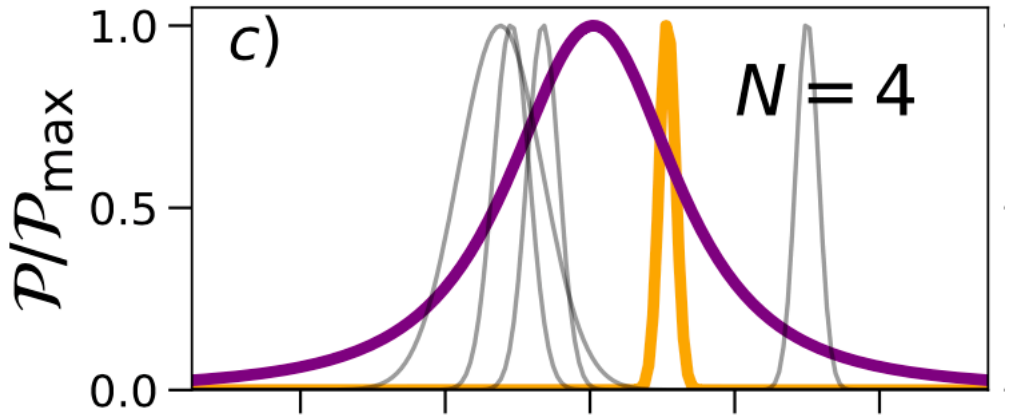
All low z determinations (except 1) hoover above 70.



Let's invoke BACCUS

Bernal & Peacock 2018

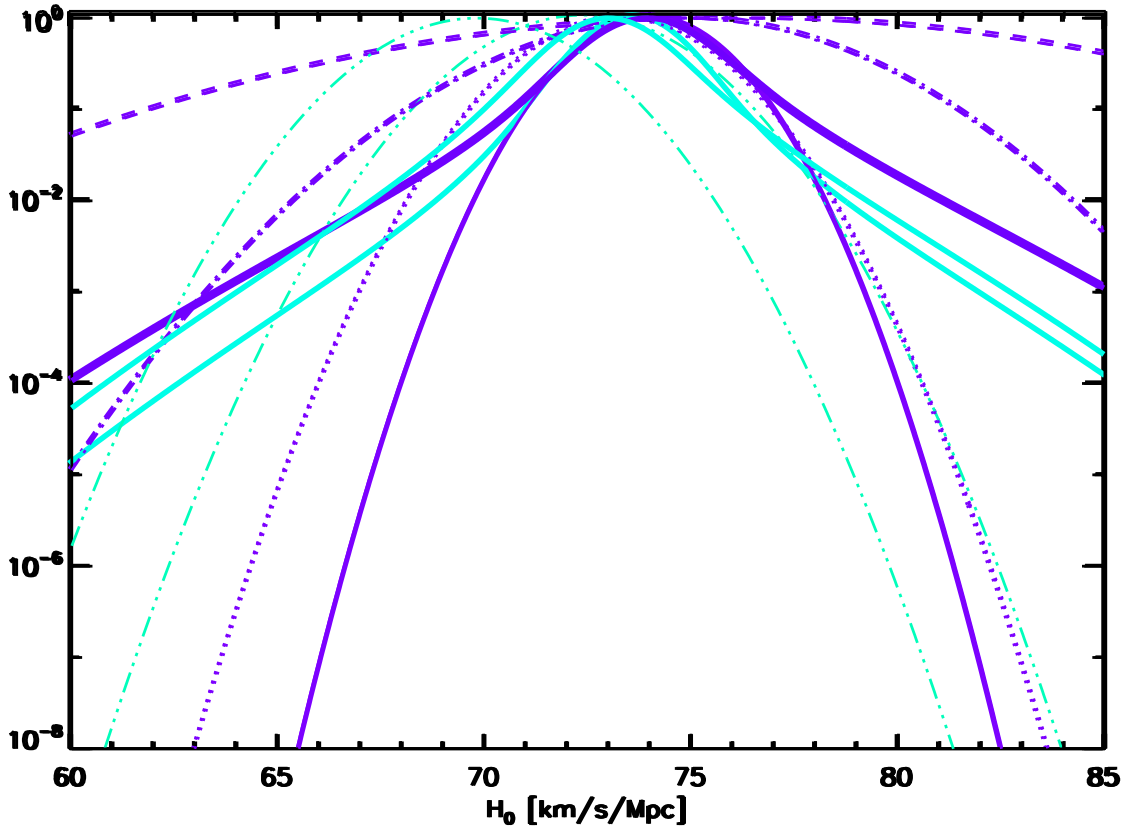
BACCUS allows an unknown shift (systematic error) in each measurement e.g.,:



Let's invoke BACCUS

Bernal & Peacock 2018

BACCUS allows an unknown shift (systematic error) in each (low z) measurement:



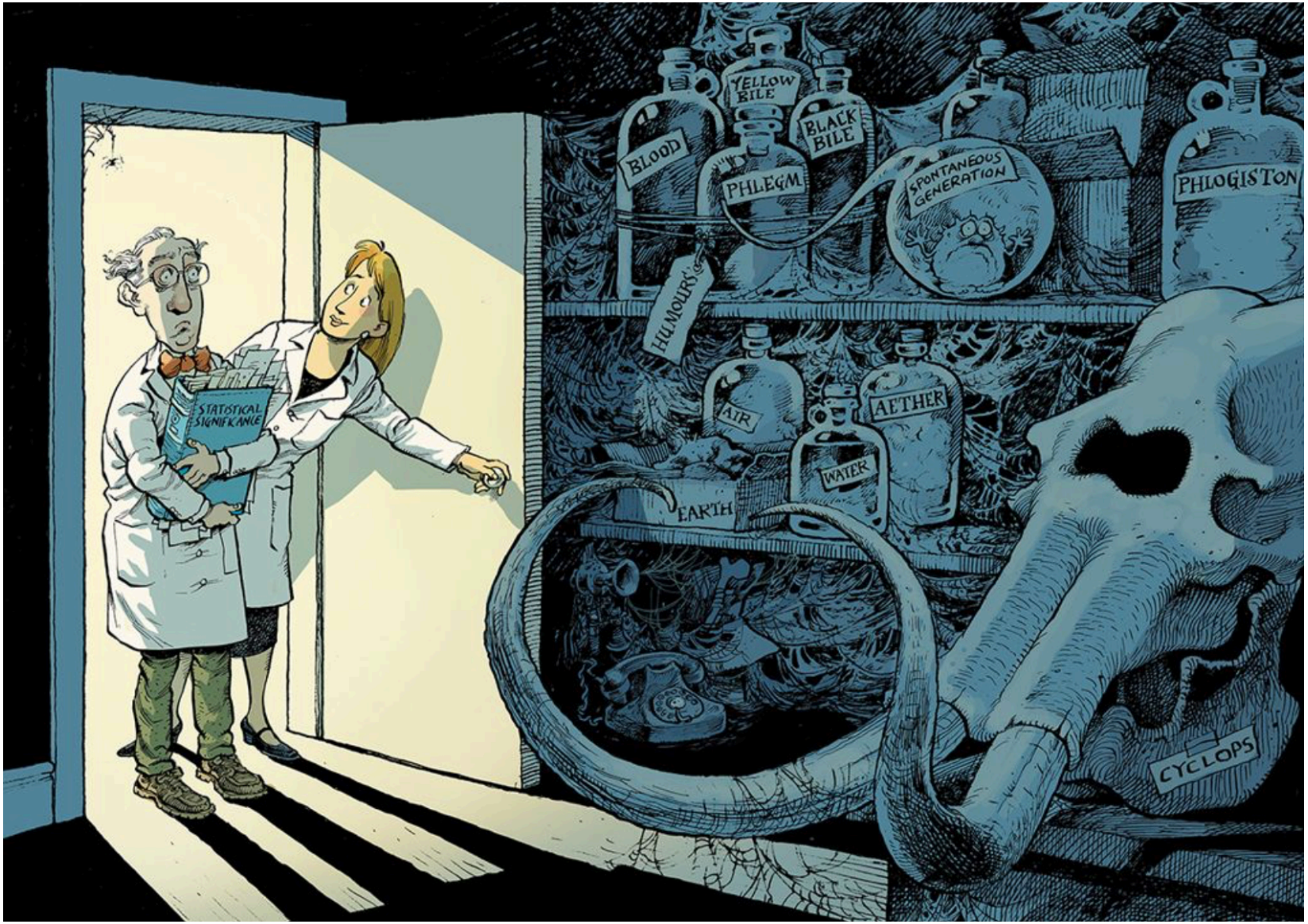
SH0ES+
H0LiCOW+
SBF+
Masers

+TRGB/
ExtinctionI I

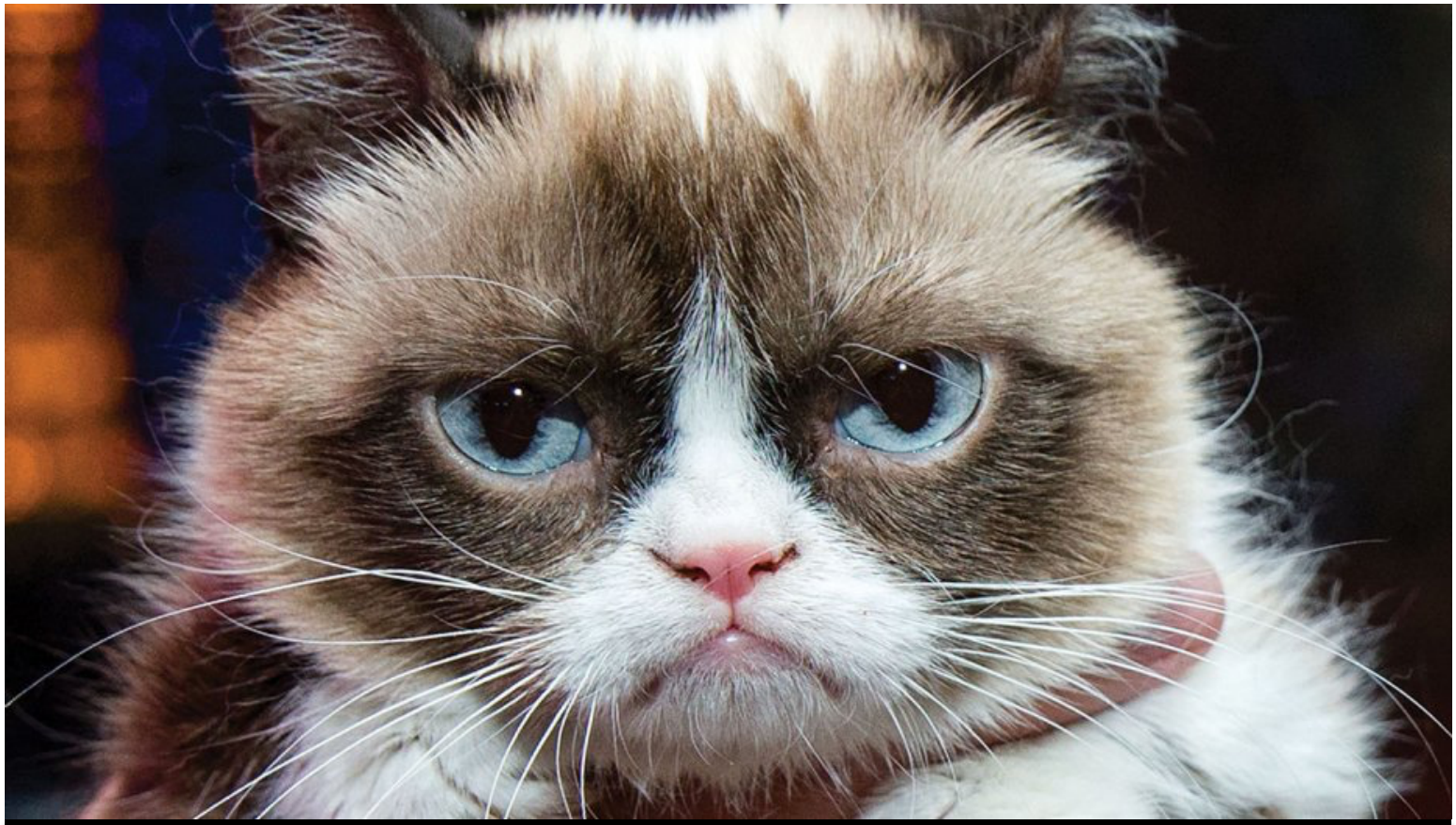
2.6(2.8) or 99.1%(99.5%) CL away from a **H**0 value of 68 (67.4) km/s/ Mpc

A word on the meaning of these percentages

Both 5 σ discovery level and BACCUS were motivated by



Doing both would be



ONE TOO MANY

Where is the problem?

If not in the data then in the model…?

DIALOGO
DI
GALILEO GALILEI LINCEO
MATEMATICO SOPRAORDINARIO
DELLO STVDIO DI PISA.
E Filosofo, e Matematico primario del
SERENISSIMO
GR.DVCA DI TOSCANA.
Doue ne i congressi di quattro giornate si discorre sopra i due
MASSIMI SISTEMI DEL MONDO
TOLEMAICO, E COPERNICANO;
Proponendo indeterminatamente le ragioni Filosofiche, e Naturali tanto per l'vna, quanto per l'altra parte.

CON PRI VILEGI.

IN FIORENZA, Per Gio:Batista Landini MDCXXXII.
CON LICENZA DE' SVPERIORI.

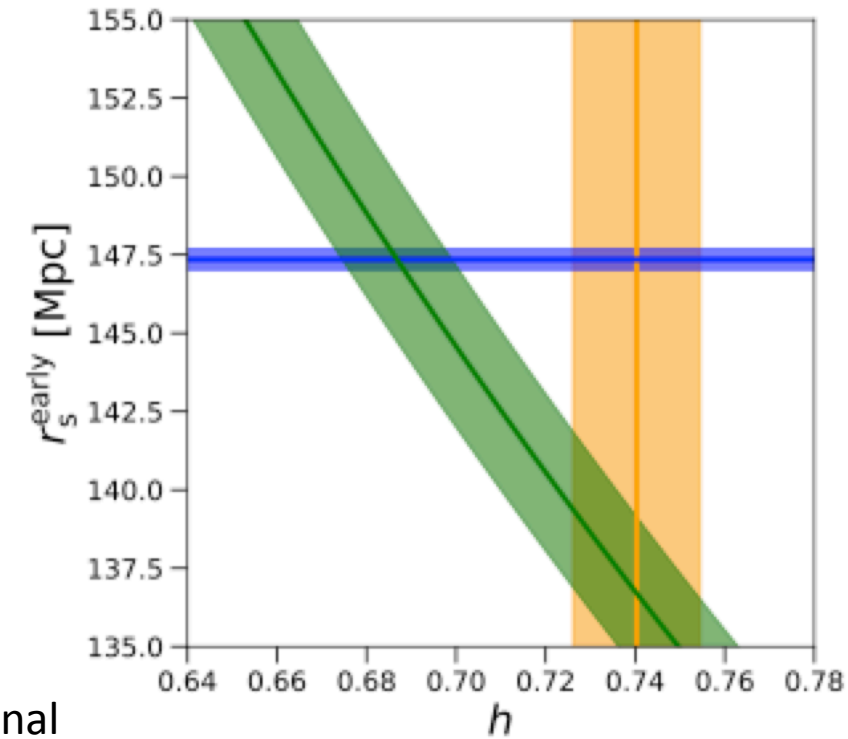
Where is the problem?

If not in the data then in the model…?

Early-time measurements assume standard LCDM.
Effectively this yields rd (the length of the standard ruler)

$$r_s(z_D) = \int_0^{\tau_D} c_s(\tau) d\tau$$

z ~0 measurements do not do assumptions about cosmology



BAO+SNE

SH0ES

Shall we look
pre or after recombination?

See L. Knox talk and
Knox Millea 2019

Fig.J.L. Bernal

Post recombination?

I leave to ADAM to discuss what can be changed in SN, Cepheids, etc.
Including screening and MG (creative attempt in H. Desmond talk) etc.

My take: it's complicated as it would have to affect several different things at once, including time-delay distances

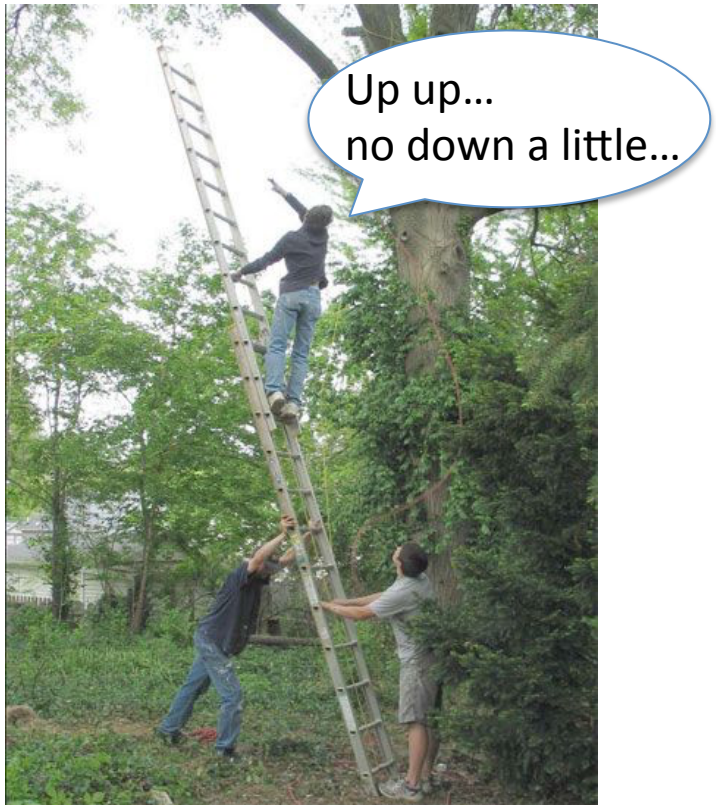
Increase the freedom of H(z); Bernal, Raveri, Joudaki, Keeley…
The price is high: many extra degrees of freedom (epicycles?)

It is also very hard to change rs by 7% one has to tinker with wb (hard) , wm (by ~20%)
Without changing matter radiation equality scale in the CMB…

It is also hard to just mess around with the standard ruler *as seen in BAO*

My slides from 2017

The anchoring is uncomfortable



But not quite at this stage yet…

Maybe now we are at this stage…

Some solutions avoid Shonenberg et al 2019 constraint

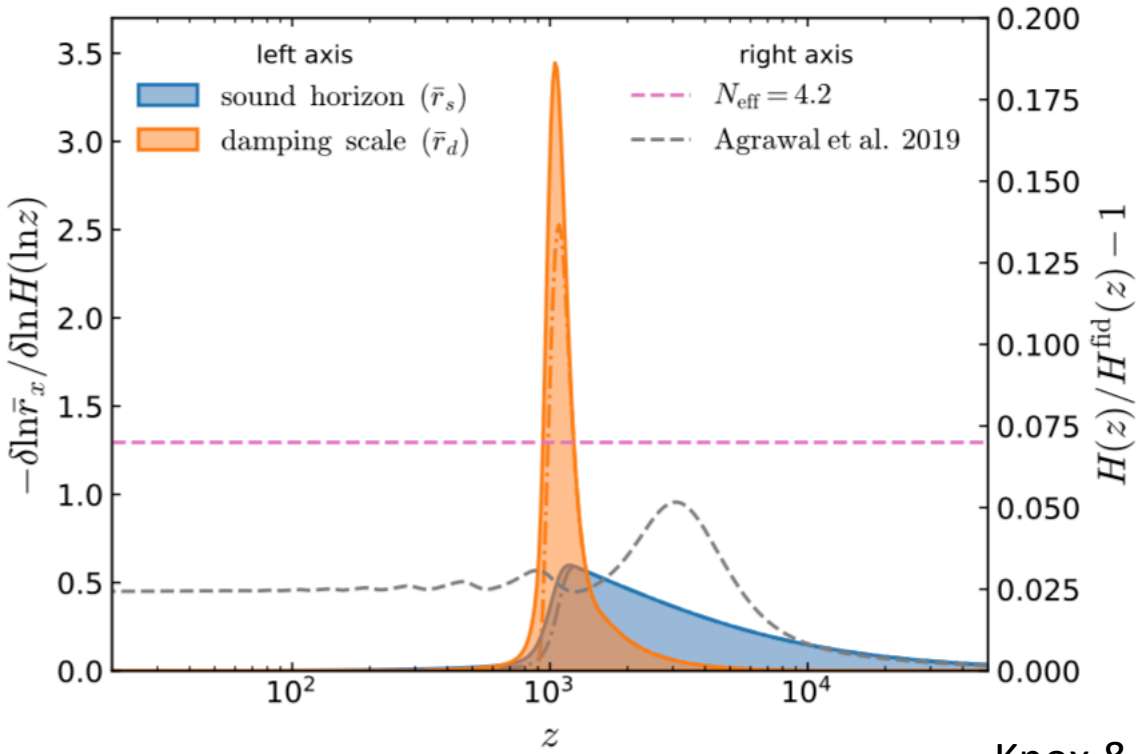
Change sound speed
Change the initial conditions
Extra components
Extra interactions among (early) components
Change H(z)

pre-recombination solutions

Modify the model right where we most like it

Decrease the sound horizon, by 7%
without wreaking havoc on damping tail… and everything else

A tall order



Reminds me of fine tuning

Knox & Millea 2019

pre-recombination solutions

Modify the model right where we most like it

Decrease the sound horizon, by 7%
without wreaking havoc on damping tail… and everything else

Early dark energy… affects the damplig tail (can look for signatures)

Change initial conditions

Extra components/ Extra interactions/Energy injection (localized!)

High T recombination

Change H(z) → change of inferred wm with scale

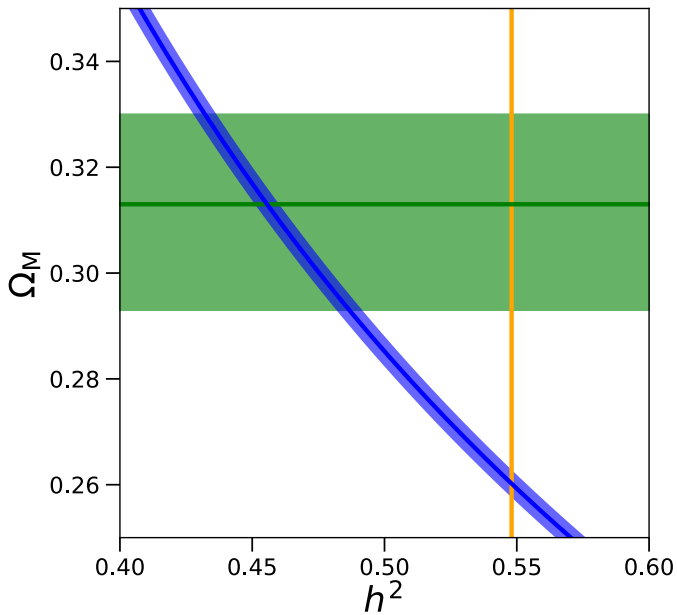
Cyr-Racine, Knox talks

These are not all equivalent!

Beyond H0

This is not just a H0 problem.

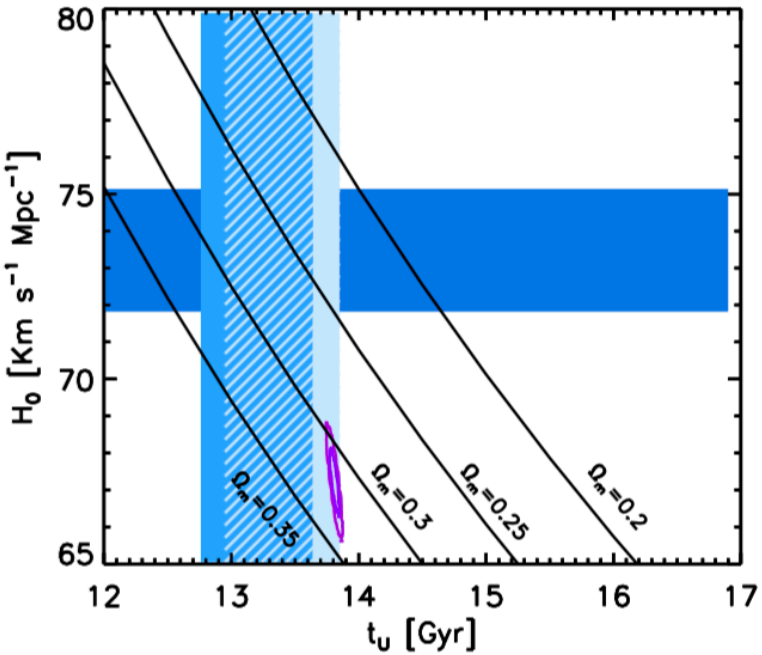
It is a Ω_m problem too

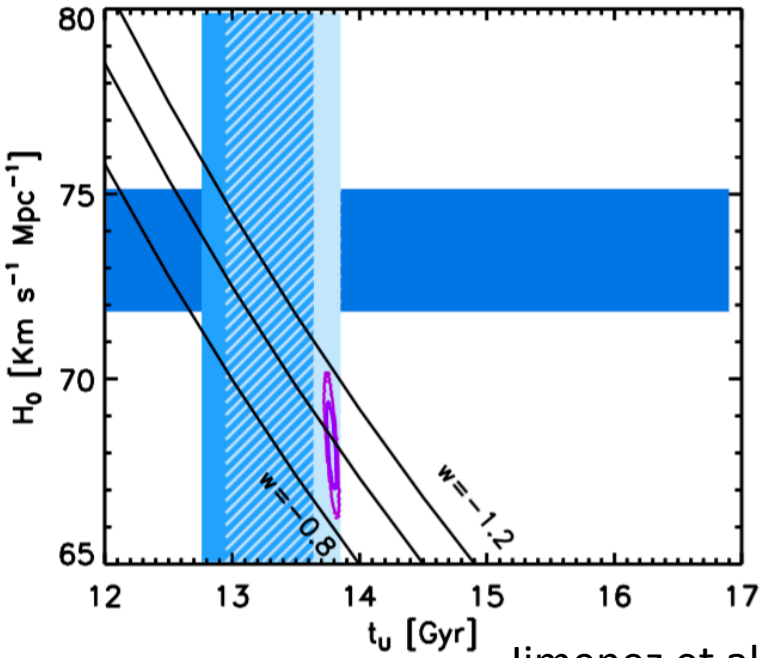


Bernal et al in prep.

And.. What's the age of the Universe anyway?

How old is the Universe?





Jimenez et al 2019

very-low-metallicity stars

HD140283 (Bond et a l2013)

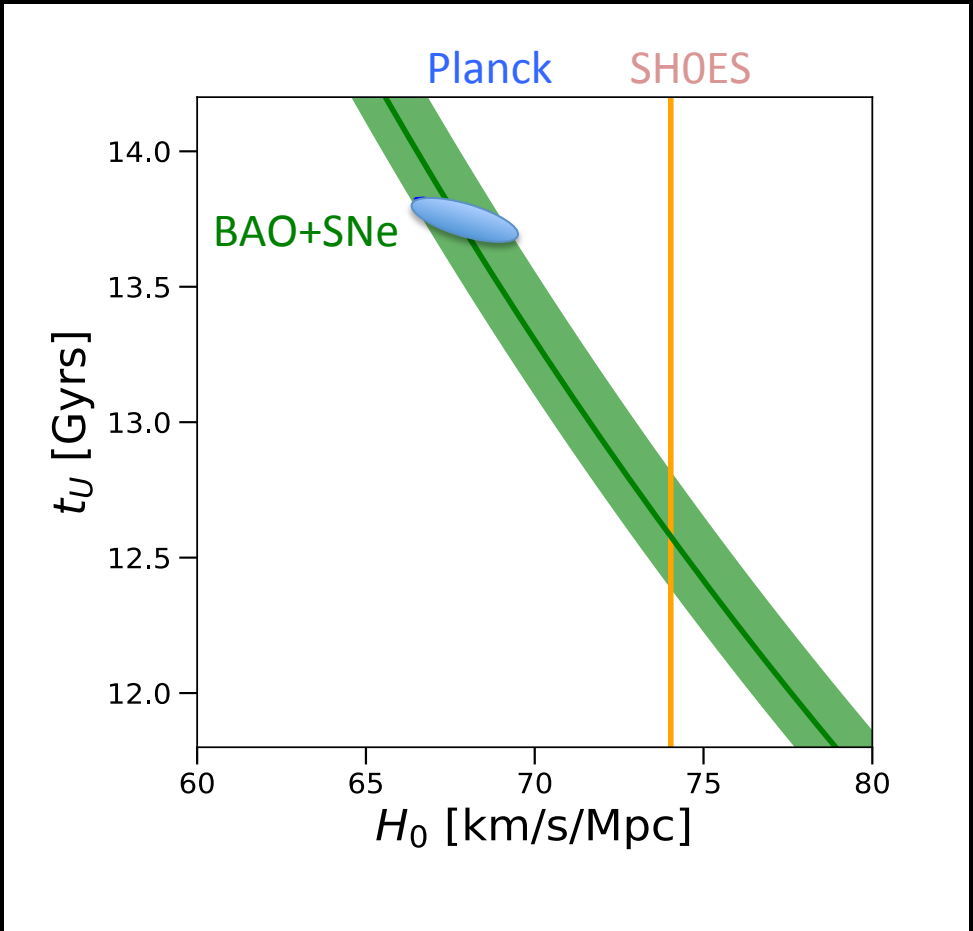
J18082002-5104378 A (Schlaufman et al 2018)

O'Malley et al '18 22 GC

How old is the Universe anyway?

Early : high t_0
Late: low t_0

?



D. Valcin

Theoretical solutions

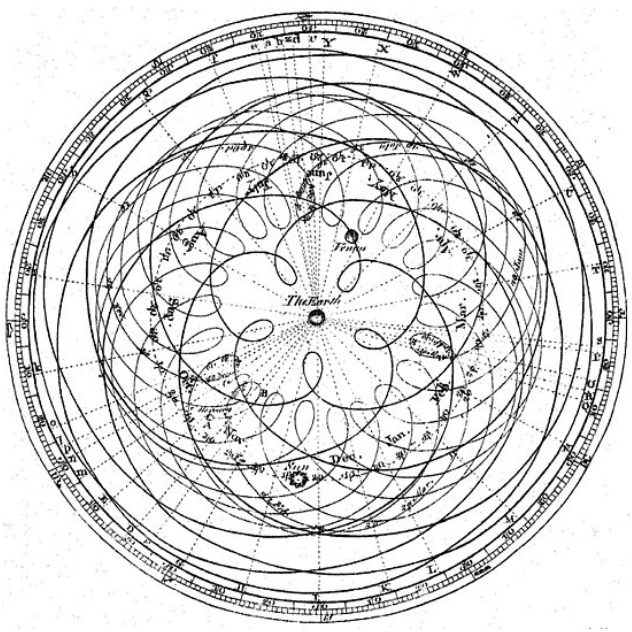
Should improve (or not worsen) other tensions

We should quantify improvement vs predictability (degrees of freedom)

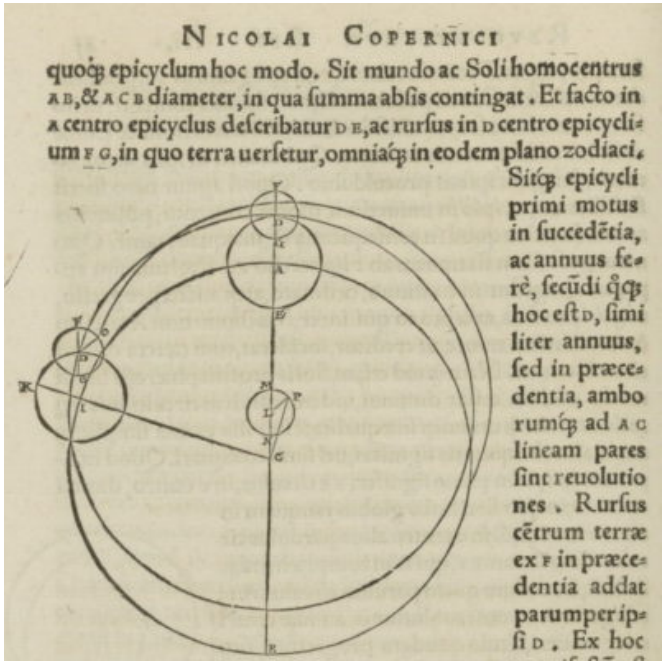
Parallelism with Λ.....

Model-dependent vs model independent approaches

At what point are we adding epicycles?



Cassini



NICOLAI COPERNICI

quoq; epicyclum hoc modo. Sit mundo ac Soli homocentrus A B, & A C B diameter, in qua summa absis contingat. Et facto in A centro epicyclus describatur D E, ac rursus in D centro epicyclium F G, in quo terra uersetur, omniaq; in eodem plano zodiaci. Sitq; epicycli primi motus in succedētia, ac annuus ferè, secūdi q̄q; hoc est D, similiter annuus, sed in præcedentia, ambo rumq; ad A C lineam pares sint reuolutiones. Rursus cētrum terræ ex F in præcedentia addat parumper ipsi D. Ex hoc