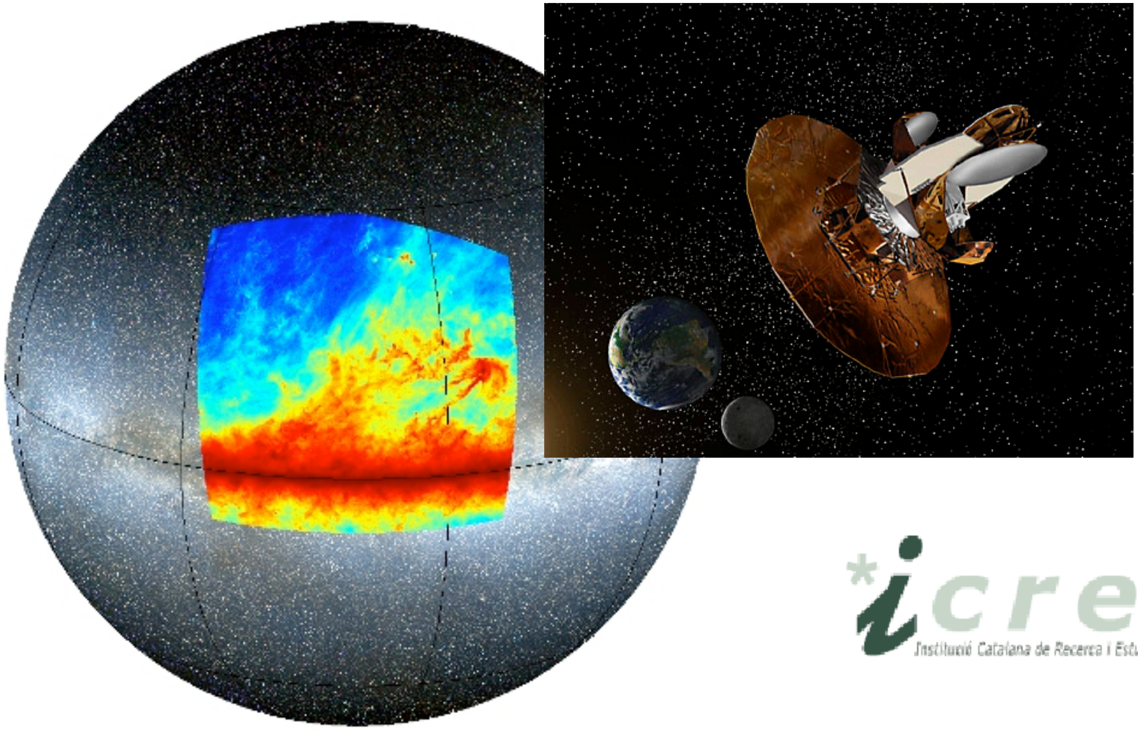
What is ν? news from cosmology



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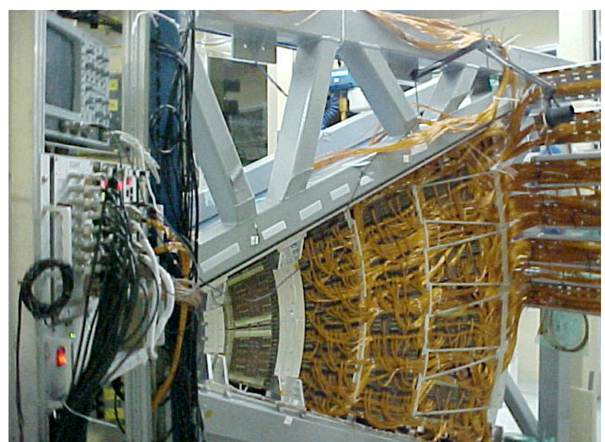


Courtesy of Planck and SKA teams

Ultimate Observations

In cosmology one can actually perform **ultimate** observations, i.e. those which contain ALL information available for measurement in the sky. The first one of its kind is Planck (in Temperature) and in this decade we will also have such experiments mapping the galaxy field. Question is: how much can we learn about fundamental physics, if any, from such experiments?

There are many examples:

1. Dark Energy
2. Inflation
3. Number of Neutrino Families
4. Nature of initial conditions
5. Beyond the Standard Model Physics

Conclusions

Cosmology does not support the existence of any extra neutrino families beyond 4. In fact it excludes > 4 families at 95%. What cosmology tells us is that the number of neutrino families is 2.8 < Neff < 4 at 95% confidence

New developments: data

CMB damping tail (ACT, SPT)

Sloan Digital Sky Survey BOSS, WIGGLEZ

Baryon Acoustic Oscillations & clustering

Direct measurement of expansion history

NEWS: FUTURE DATA: Euclid, recycled spy satellite, WFIRST

New developments: theory

Better modeling of non-linearities via N-body simulations (and perturbation theory)

N_{eff}: number of effective species

$$H^2(t) \simeq \frac{8\pi G}{3}\left(\rho_\gamma + \rho_\nu\right) \qquad \rho_\nu \propto T^4 N_{\rm eff}$$

Standard: N_{eff}=3.045

Any thermal background of light particles, anything affecting expansion rate

Look at BBN

Neff around 3 to 4

Systematics!

Nollett, Holder 2011: Yp difficult, better use CMB ($\Omega_b h^2$)+D/H

Pettini, Cooke 2012 $\mathrm{N}_\nu = 3.0 \pm 0.5$

$N_{\nu:}$ number of effective species

$$H^2(t) \simeq \frac{8\pi G}{3}(\rho_\gamma + \rho_\nu) \qquad \rho_\nu \propto T^4 N_{\rm eff}$$

Standard: N_{eff}=3.045

Any thermal background of light particles, anything affecting expansion rate

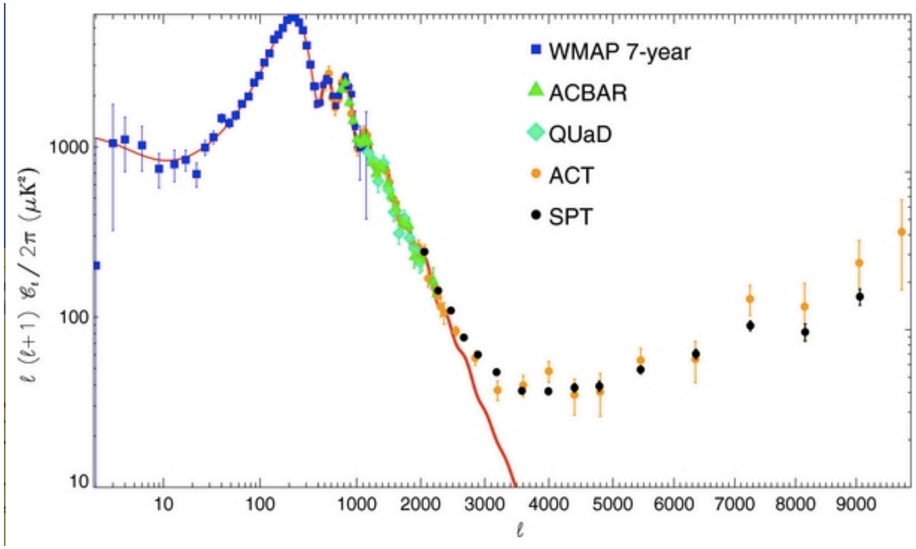
Look at BBN

Neff= 3 to 4

Systematics!

Look at CMB:
effects matter-radn equality
and so sound horizon at decoupling
-> degeneracy with ω_m and H

Anisotropic stress,
z_{eq} on diffusion damping



Literature review

Cosmological analyses consistently give best fit values >3.04.
"dark radiation"
But analyses are NOT independent
(WMAP is always in common, H0 many times in common)

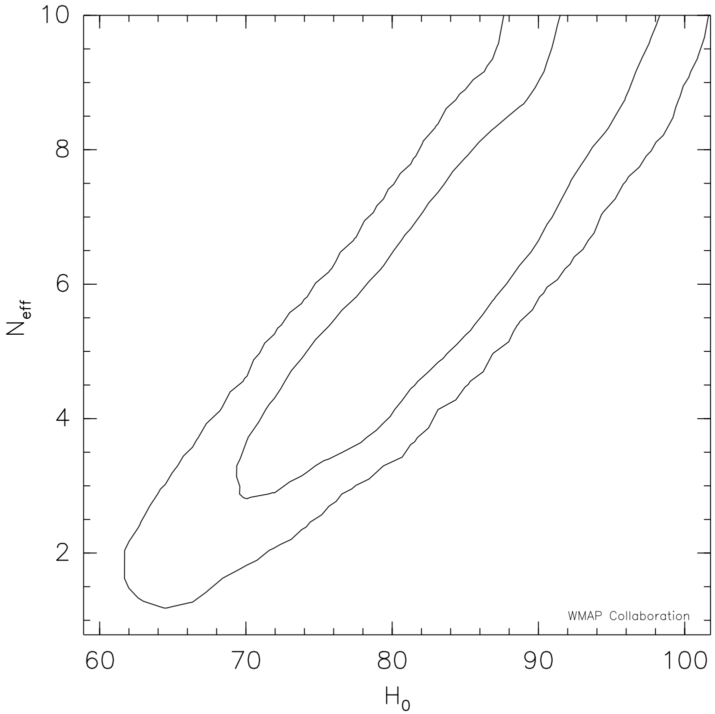
It's barely 2 sigmas (except for one data set: ACT)

Also,
beware of degeneracies

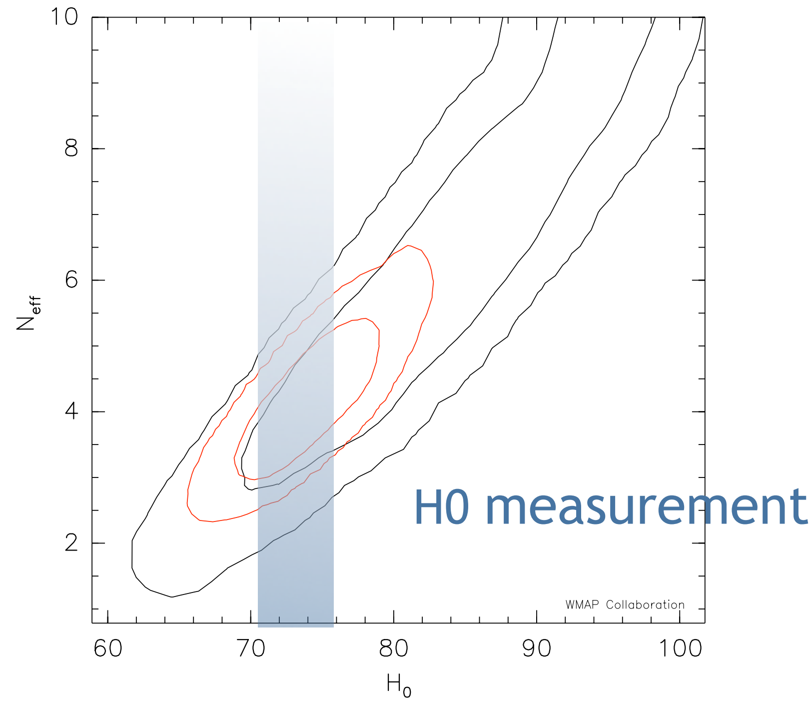
Tab 3 white paper
1204.5379

Model	Data	N_{eff}	Ref.	
N_{eff}	W-5+BAO+SN+H_0	$4.13^{+0.87(+1.76)}_{-0.85(-1.63)}$	[346]	Reid et al '10
	W-5+LRG+H_0	$4.16^{+0.76(+1.60)}_{-0.77(-1.43)}$	[346]	
	W-5+CMB+BAO+XLF+f_{gas}+H_0	$3.4^{+0.6}_{-0.5}$	[349]	Mantz et al 10
	W-5+LRG+maxBCG+H_0	$3.77^{+0.67(+1.37)}_{-0.67(-1.24)}$	[346]	Reid et al '10
	W-7+BAO+H_0	$4.34^{+0.86}_{-0.88}$	[338]	Komatsu et al 11
	W-7+LRG+H_0	$4.25^{+0.76}_{-0.80}$	[338]	(WMAP7)
	W-7+ACT	5.3 ± 1.3	[343]	Dunkley et al 10
	W-7+ACT+BAO+H_0	4.56 ± 0.75	[343]	(ACT)
	W-7+SPT	3.85 ± 0.62	[344]	Keisler et al 11
	W-7+SPT+BAO+H_0	3.85 ± 0.42	[344]	(SPT)
	W-7+ACT+SPT+LRG+H_0	$4.08^{(+0.71)}_{(-0.68)}$	[350]	Archidiacono et al 20
	W-7+ACT+SPT+BAO+H_0	3.89 ± 0.41	[351]	
$N_{eff}+f_\nu$	W-7+CMB+BAO+H_0	$4.47^{(+1.82)}_{(-1.74)}$	[352]	Hamann et al 2010
	W-7+CMB+LRG+H_0	$4.87^{(+1.86)}_{(-1.75)}$	[352]	
$N_{eff}+\Omega_k$	W-7+BAO+H_0	4.61 ± 0.96	[351]	Smith et al 2011
	W-7+ACT+SPT+BAO+H_0	4.03 ± 0.45	[352]	Hamann et al 2010
$N_{eff}+\Omega_k+f_\nu$	W-7+ACT+SPT+BAO+H_0	4.00 ± 0.43	[351]	Smith et al 2011
$N_{eff}+f_\nu+w$	W-7+CMB+BAO+H_0	$3.68^{(+1.90)}_{(-1.84)}$	[352]	Hamann et al 201
	W-7+CMB+LRG+H_0	$4.87^{(+2.02)}_{(-2.02)}$	[352]	
$N_{eff}+\Omega_k+f_\nu+w$	W-7+CMB+BAO+SN+H_0	$4.2^{+1.10(+2.00)}_{-0.61(-1.14)}$	[353]	Gonzalez-Garcia
	W-7+CMB+LRG+SN+H_0	$4.3^{+1.40(+2.30)}_{-0.54(-1.09)}$	[353]	et al. 2010

What may be going on?



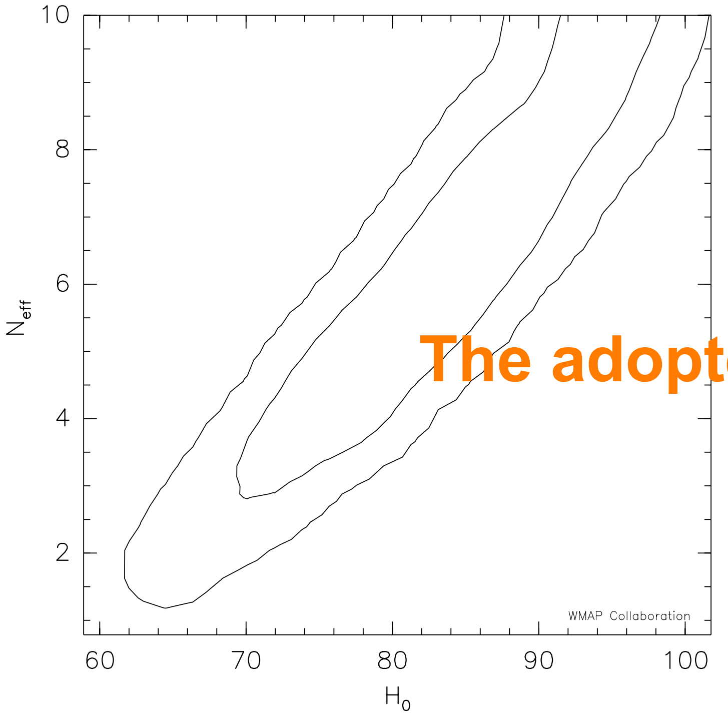
WMAP only

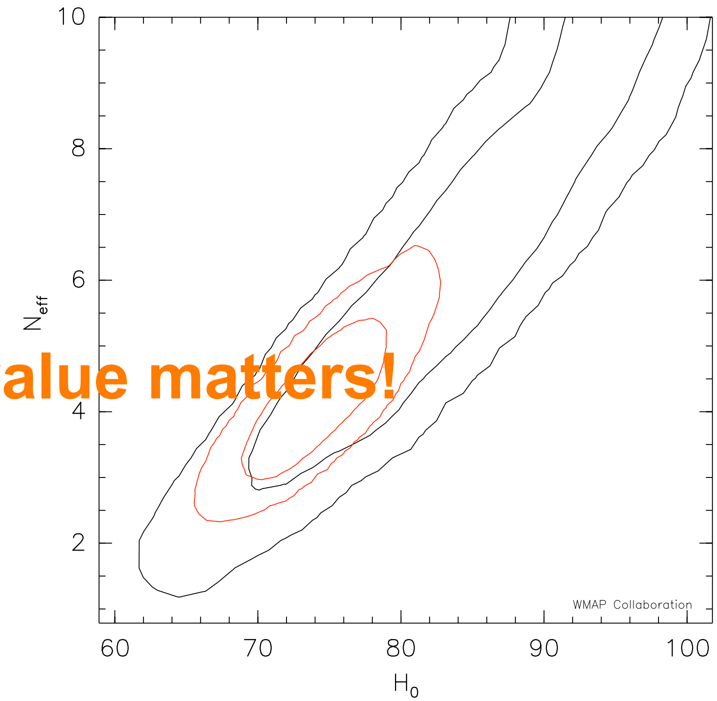


WMAP+H0+BAO

Straight from the on-line LAMBDA cosmological parameters plotter (lambda.gsfc.nasa.gov)

What may be going on?





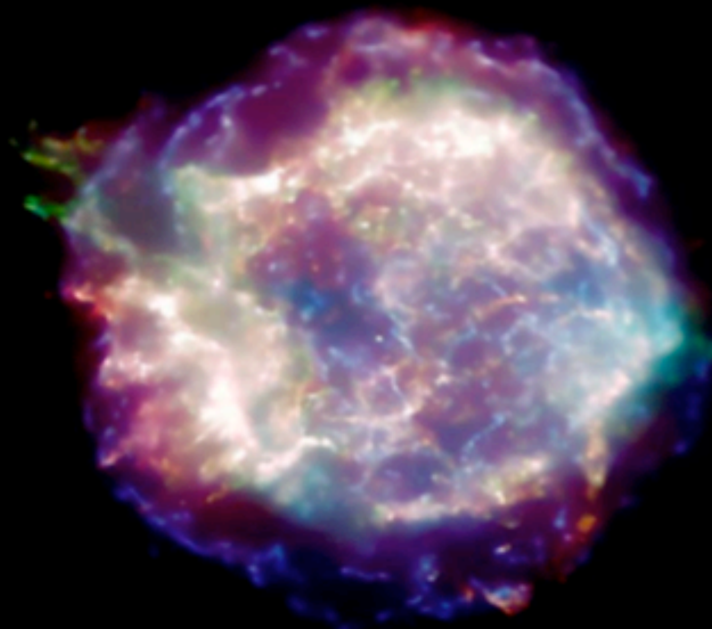
The adopted H0 value matters!

WMAP only

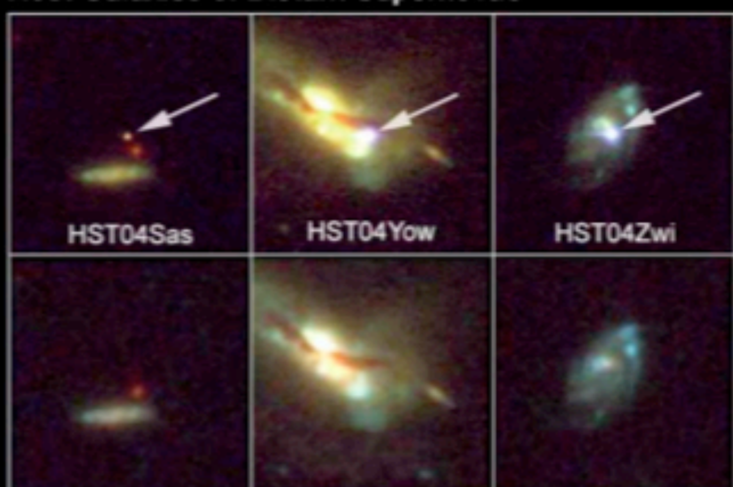
WMAP+H0+BAO

Straight from the on-line LAMBDA cosmological parameters plotter

Standard Candle

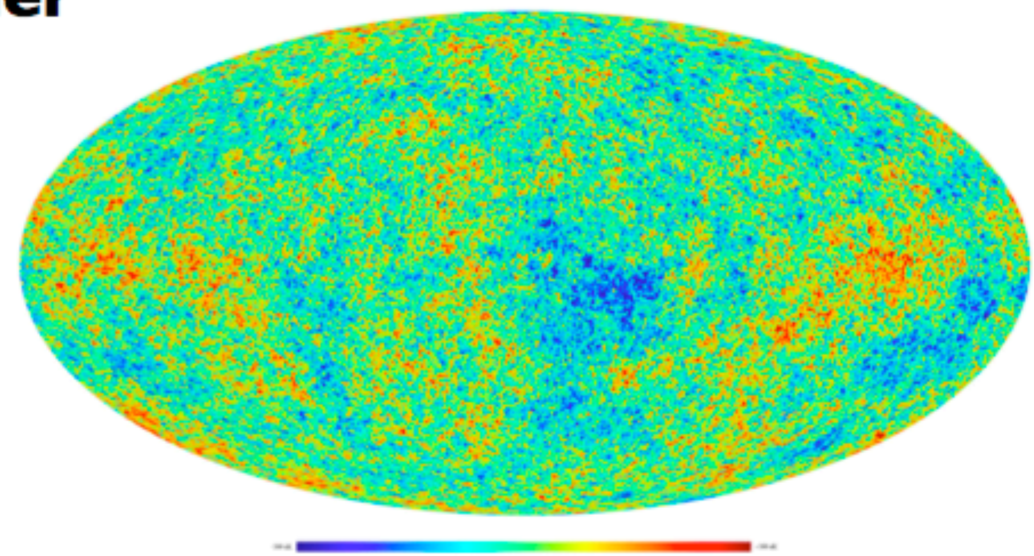


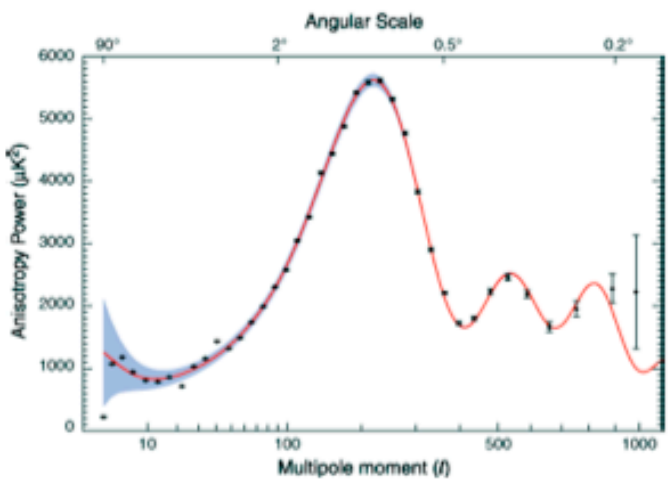
Host Galaxies of Distant Supernovae



NASA, ESA, and A. Riess (STScI)

Standard Ruler





baryon acoustic oscillations
(radio galaxies)

Rotate Image Right

Standard Clock

$$H(z) = -\frac{1}{(1+z)}\frac{dz}{dt}$$

early-type galaxies

Experimental concerns

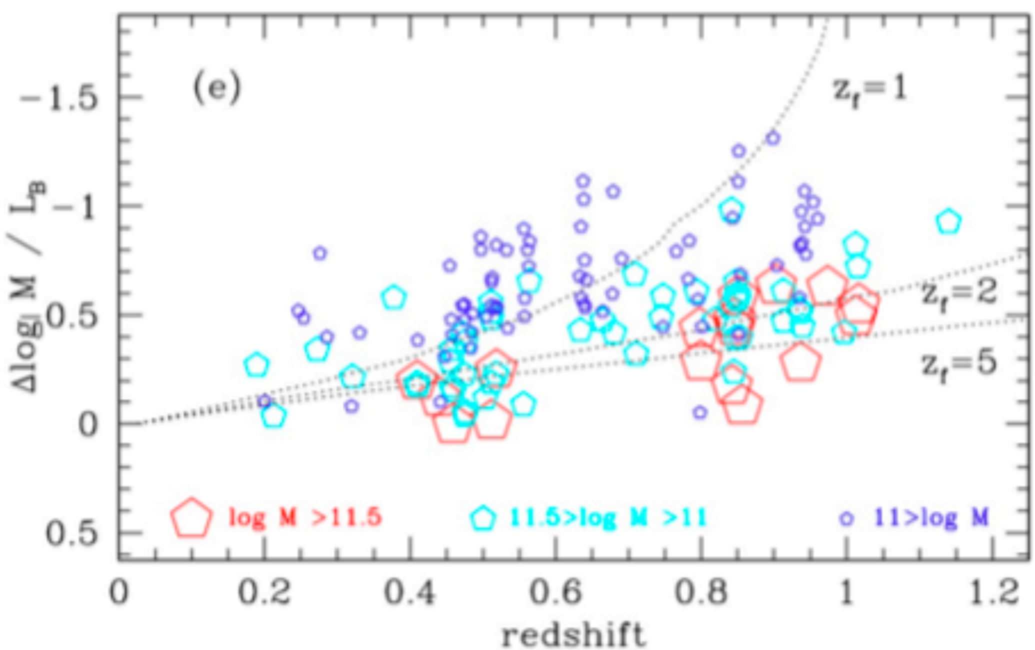
How well can gE's be approximated as passively evolving, old systems?
- mergers; early-type galaxies still assembling at $z<1$?
- on-going star formation ("frosting")

How can we best model the stellar ages?
- systematics between stellar synthesis models

How can we best measure the stellar ages?
- ability to measure accurate stellar ages
- efficiency at obtaining spectra

gE's as passively evolving, old systems

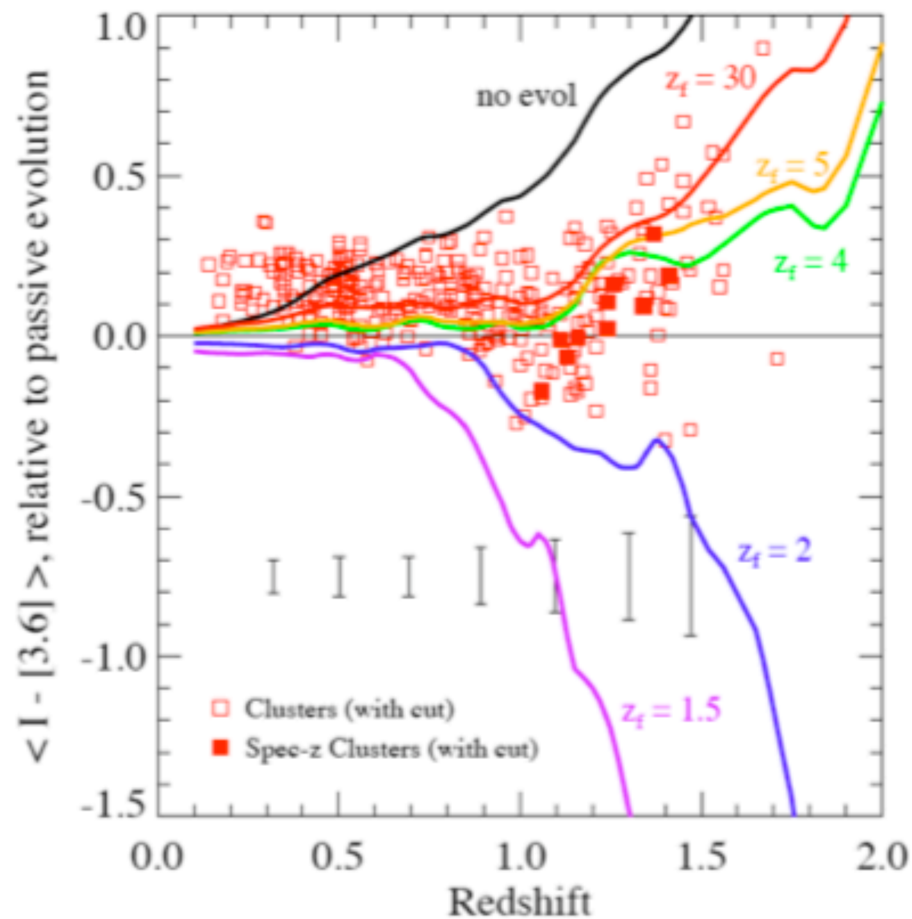
the most massive early-type galaxies are the oldest



Treu et al. (2005; ApJ, 622, L5)

gE's as passively evolving, old systems

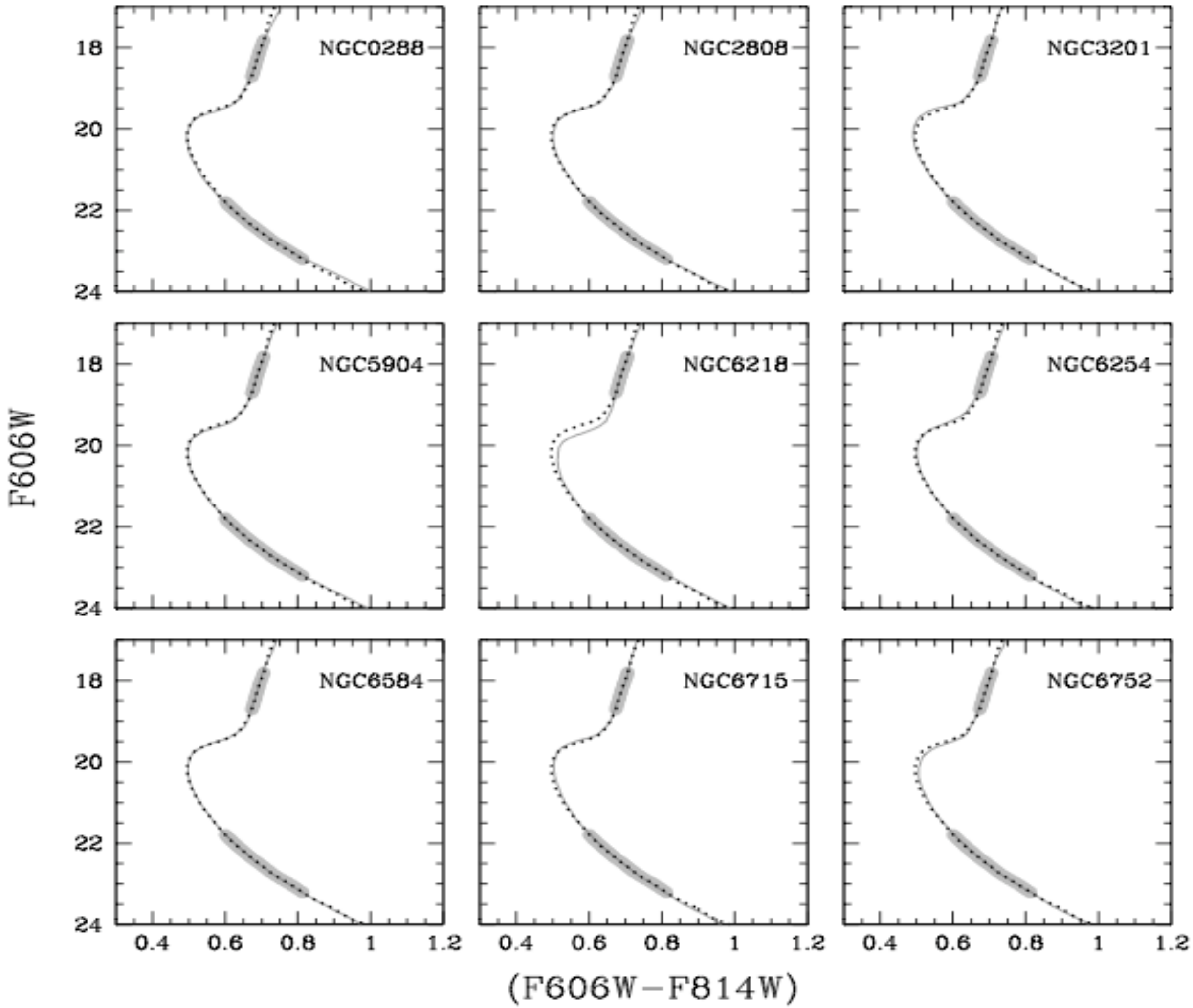
colors indicate a high formation redshift (for cluster gE's)



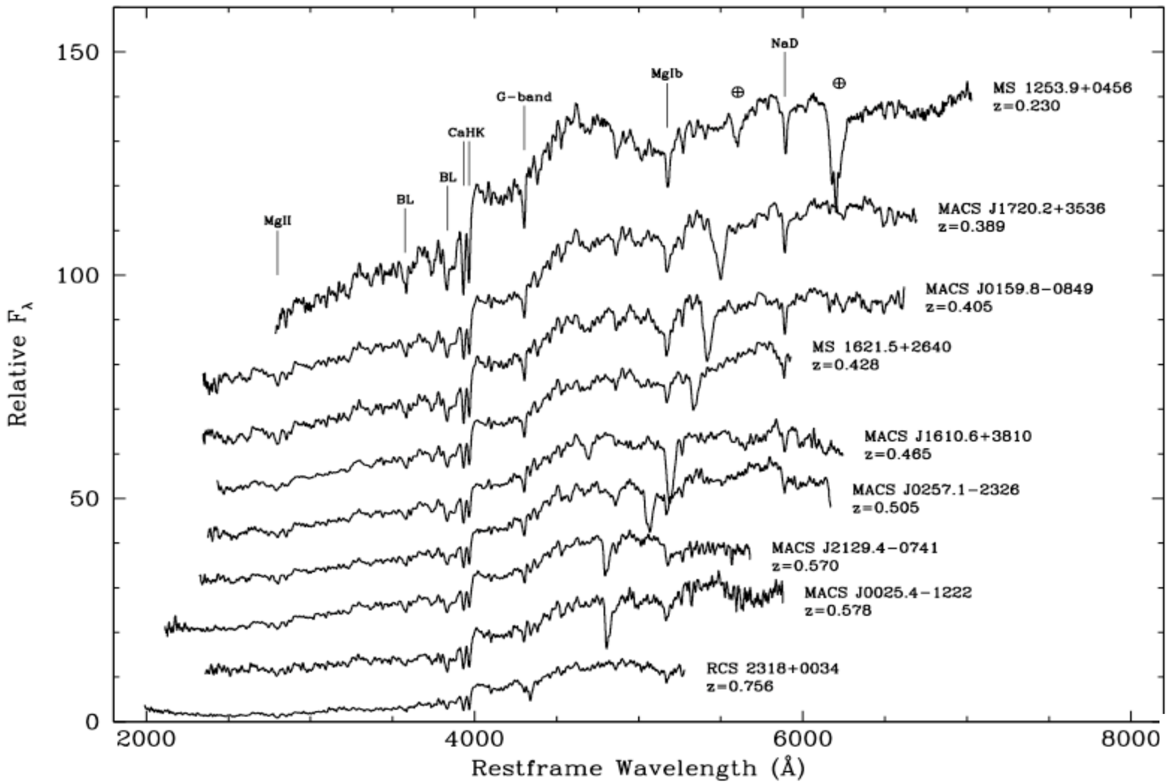
Eisenhardt et al. (ApJ, submitted)

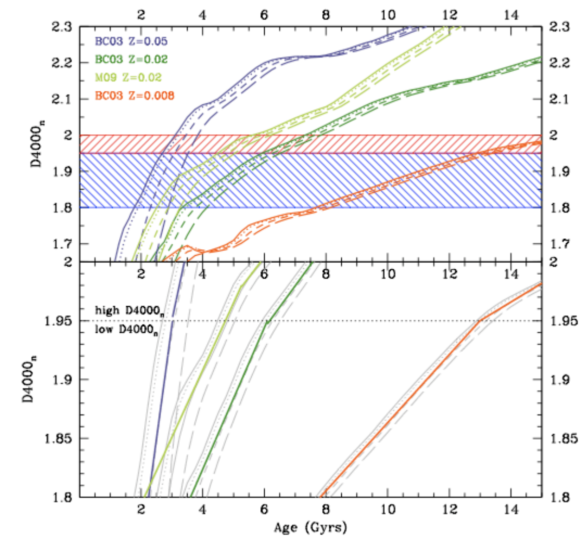
A Lesson from the past: Globular Cluster **RELATIVE AGES**

“This method provides relative ages to a formal precision of 2–7%. We demonstrate that the calculated relative ages are independent of the choice of theoretical model.” (0812.4541)

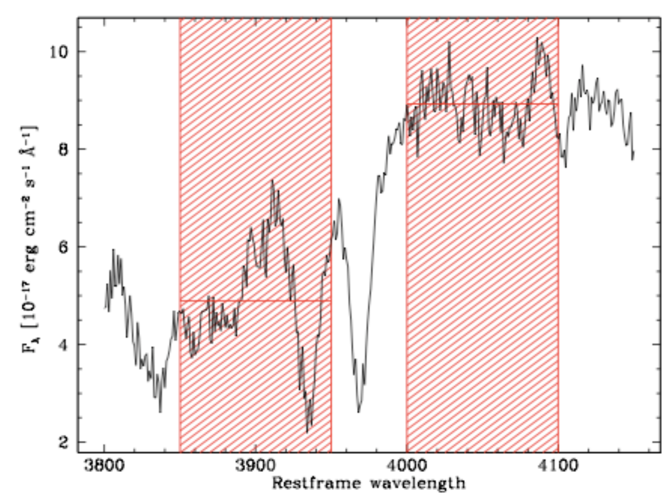


Relative aging of galaxies





$$H(z) = -\frac{A}{1+z}\frac{dz}{dD4000_n}$$

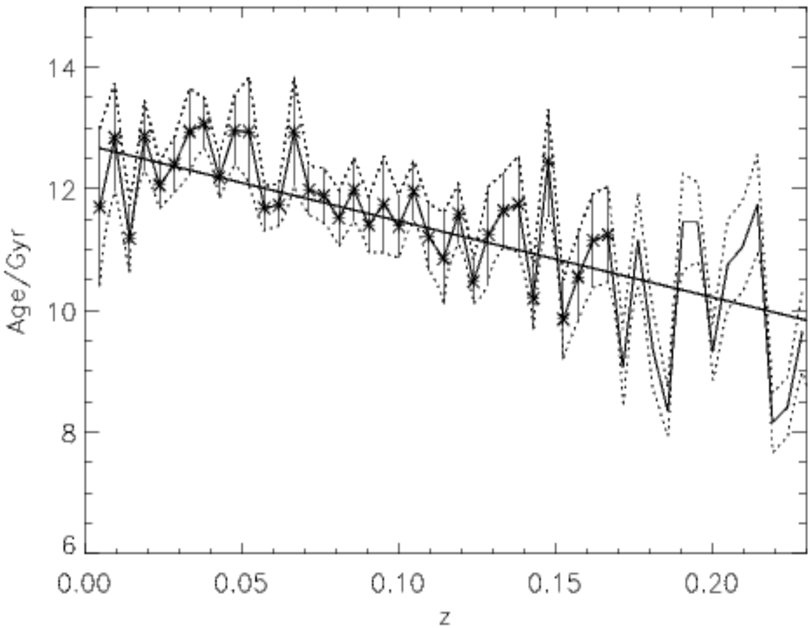


Moresco, RJ, Cimatti, Pozzetti JCAP (2010)

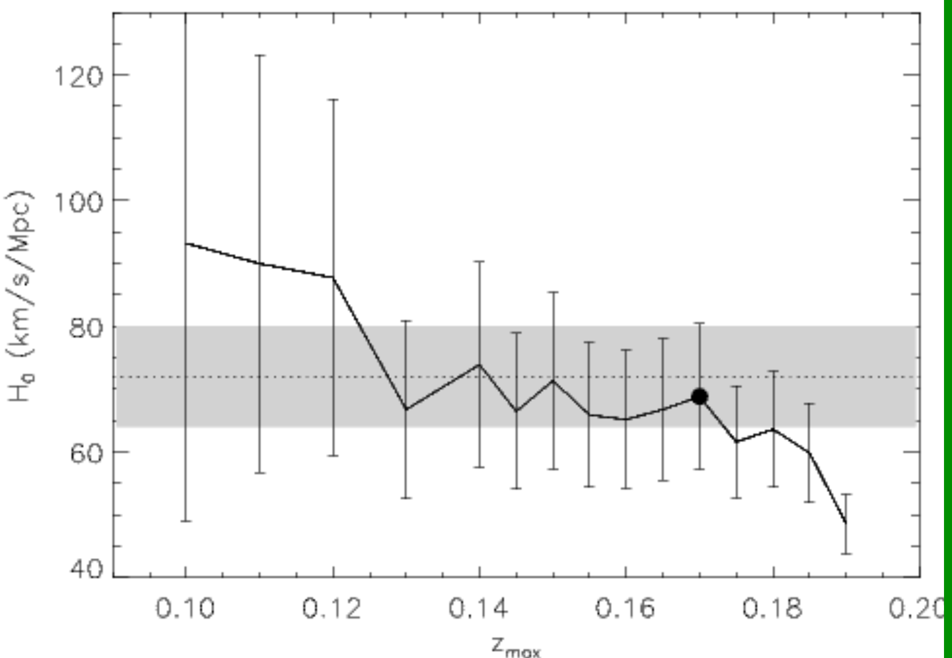
Reconstruct w(z): CAN IT work?

At z=0 dz/dt gives Ho and we have SDSS galaxies:

$$H(z) = -\frac{1}{(1+z)}\frac{dz}{dt}$$

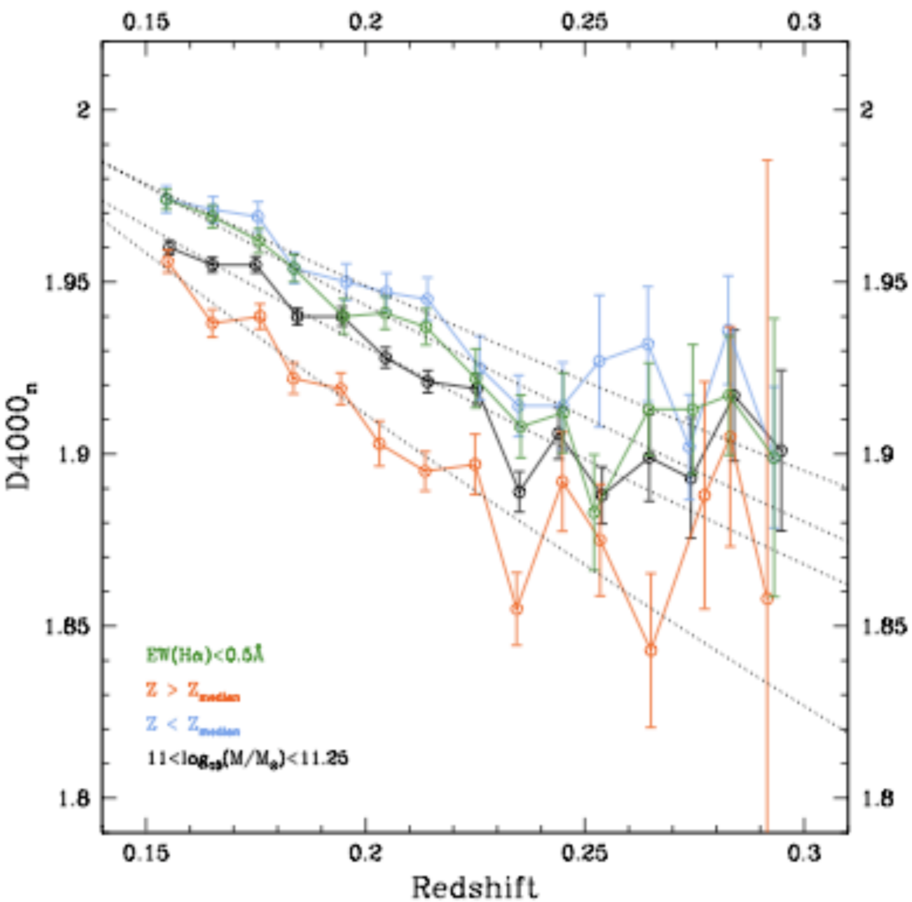


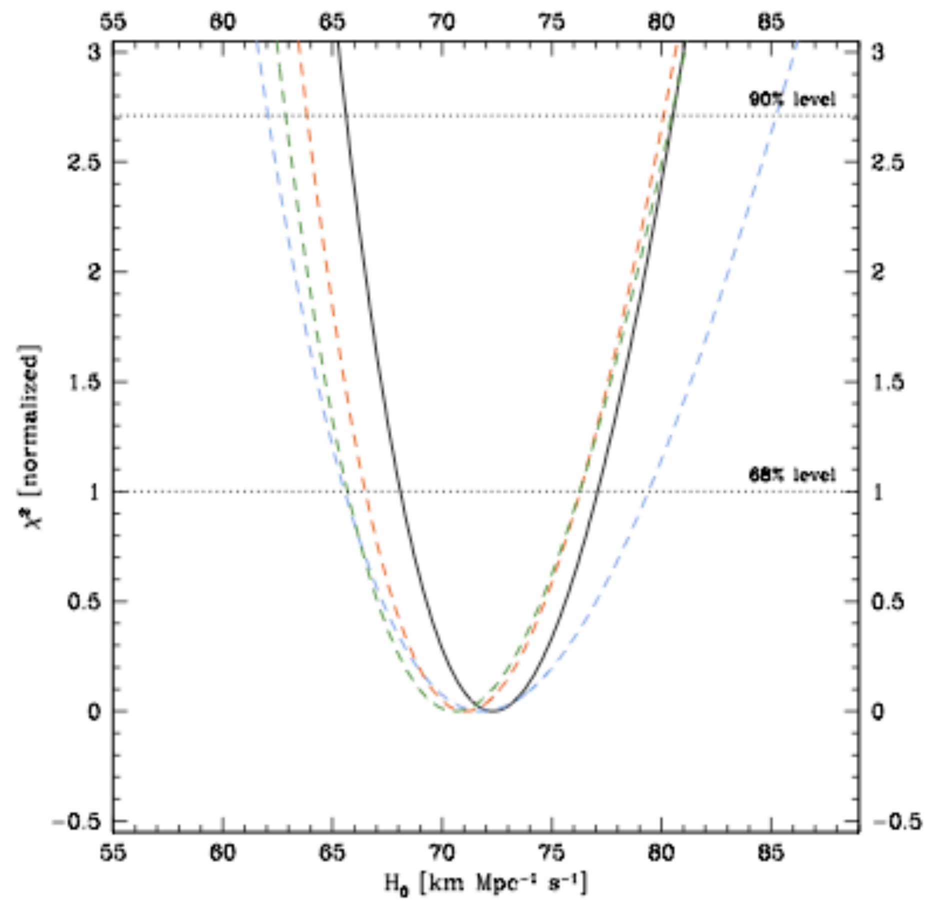
The edge for z<0.2



The value of H0

A good test, to determine H(z=0)





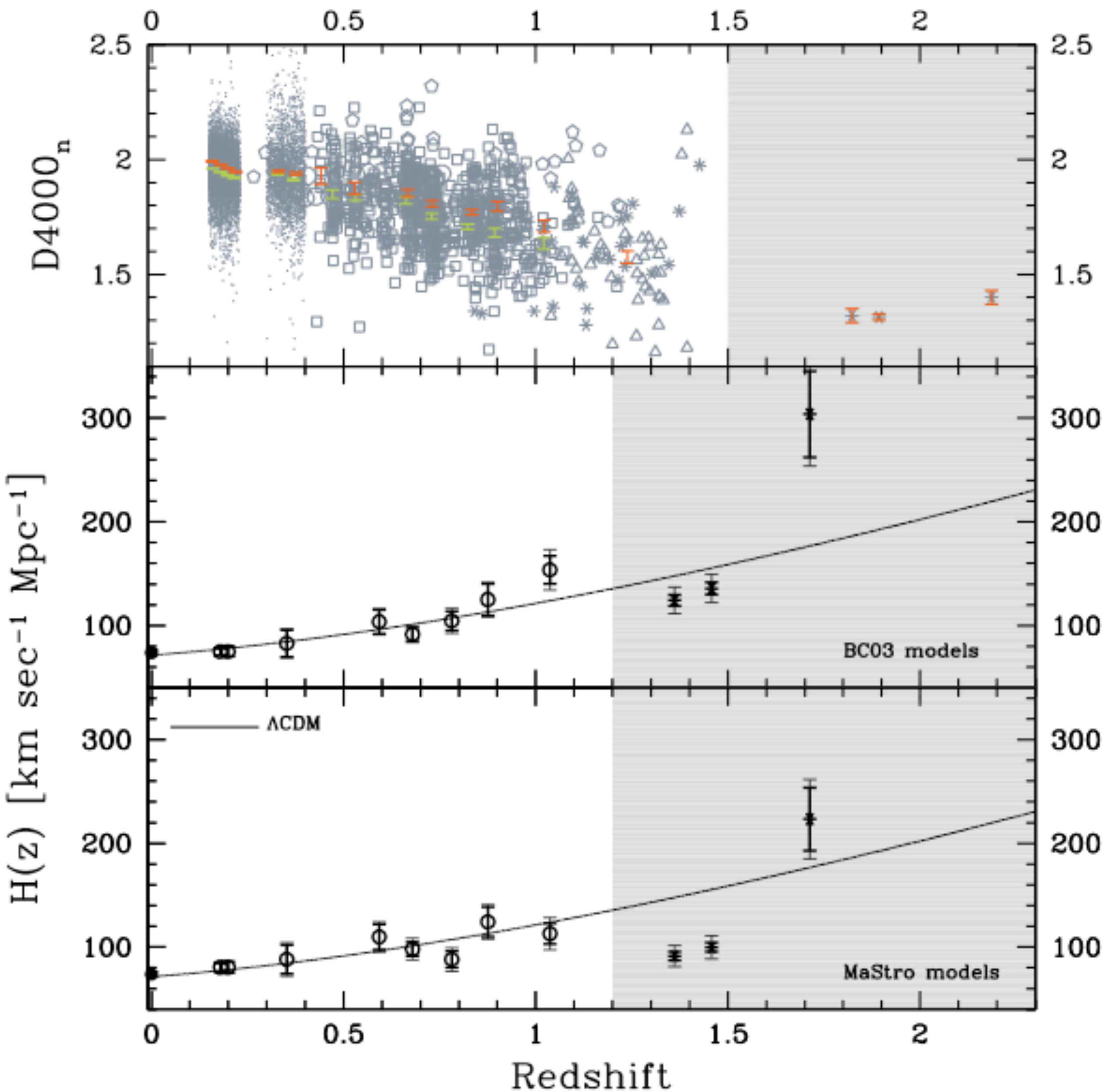
Moresco, RJ, Cimatti, Pozzetti JCAP (2010)

H(0) = 72.3 ± 2.8

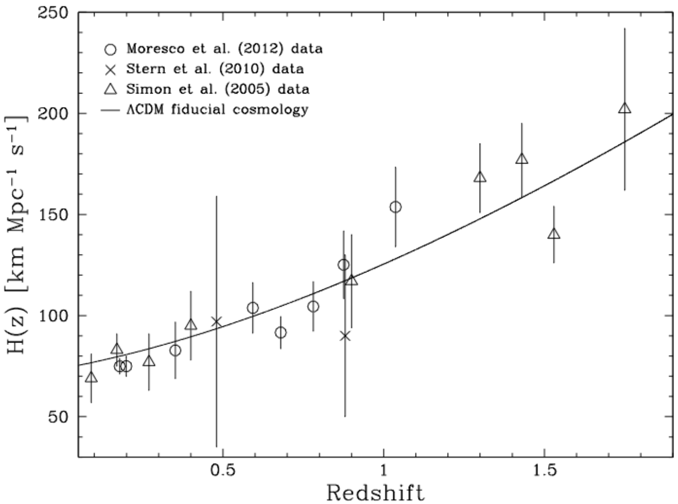
The data at z>0

Stern, RJ et al. JCAP 2011
Moresco et al. 2012

$$H(z) = -\frac{A}{1+z}\frac{dz}{dD4000_n}$$



H(z) estimates

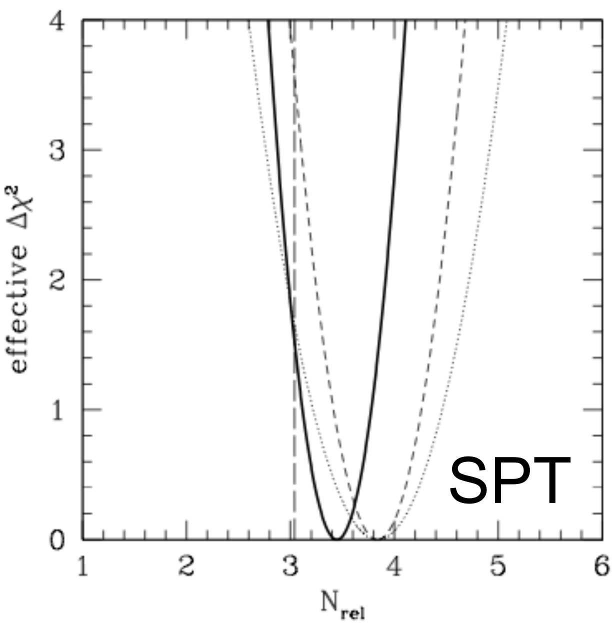


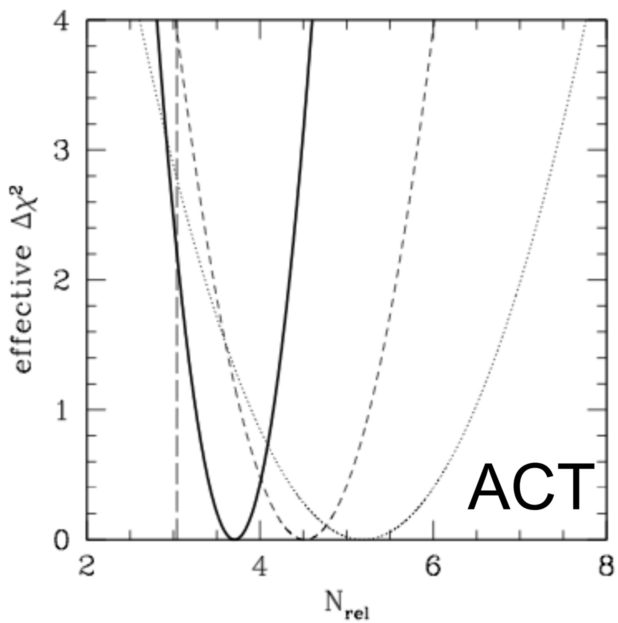
$$N_\nu = 3.59 \pm 0.48(\pm 0.94) \quad \mathrm{WMAP + ACT + H(z)}$$

$$N_\nu = 3.37 \pm 0.34(\pm 0.67) \quad \mathrm{WMAP + SPT + H(z)}$$

$$N_\nu = 3.38 \pm 0.50(\pm 1) \quad \mathrm{WMAP + H(z)}$$

$$N_\nu < 4 \ \text{ at } 95\%(74\%) \ \text{C.L.}$$



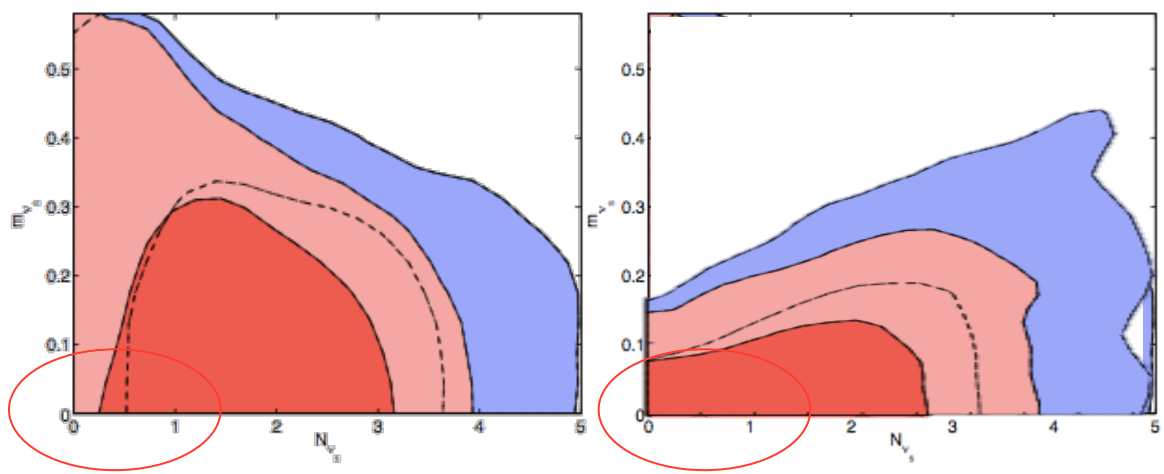


Moresco et al. 2012

In summary:

- Neff consistent with 3 (but also with 4) at 2 σ
- These are "light" neutrinos (<0.5 eV)
- more wiggle room: go beyond the minimal LCDM (errors gets slightly larger, but… epicycles)
- Avoid thermalization (some v. radical options)

m ν sterile



m ν

Nsterile

Nsterile

The pros and cons of being Bayesian

Giusarma et al 2011