Tensions in cosmological measurements: a Standard Model crisis?

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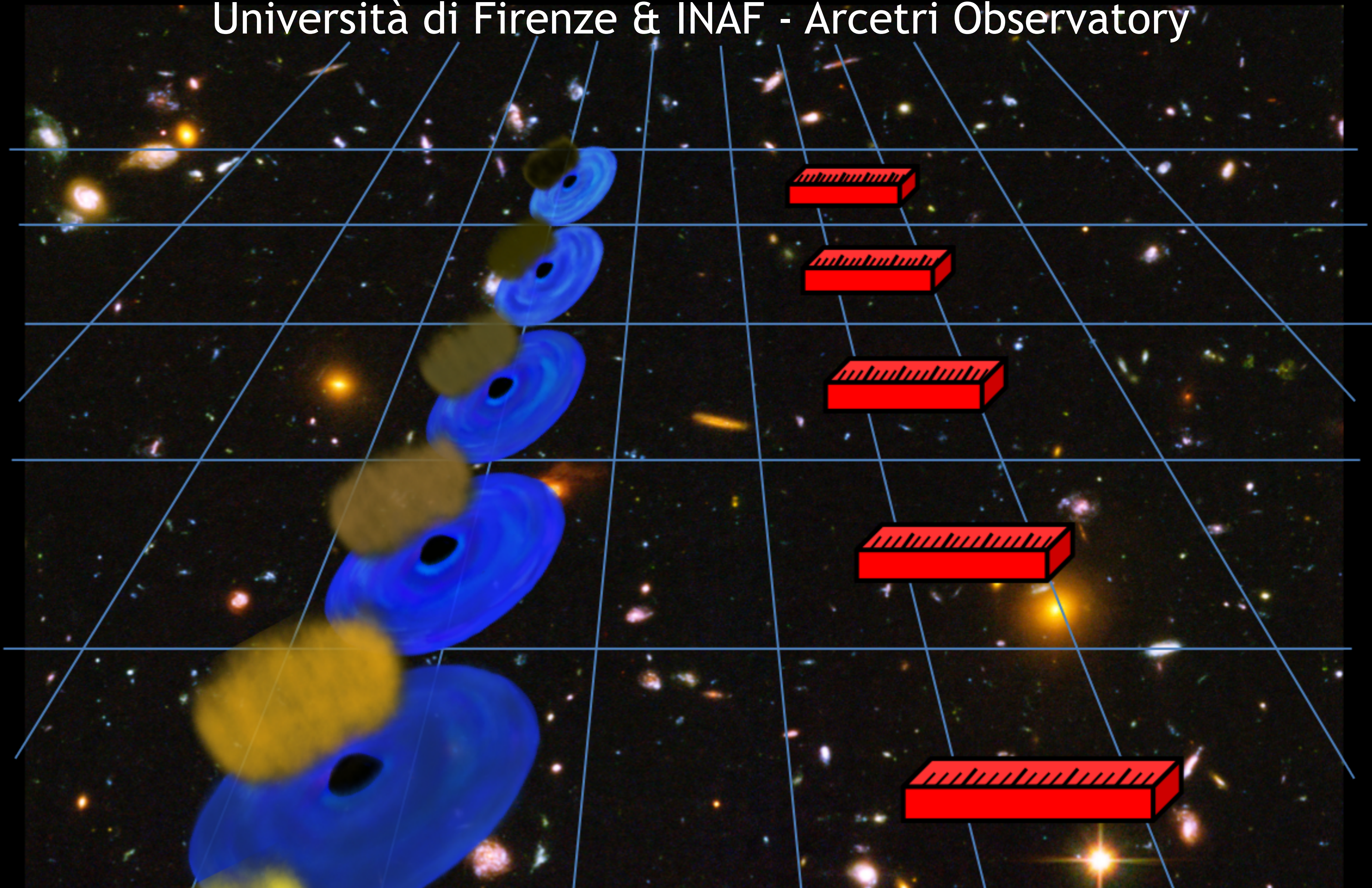


Measuring Cosmological Parameters

- **Why?** Are we in the era of “precision cosmology” or are we still missing the fundamental physical scenario?
- **Methods:**
  - CMB —> anisotropies, z~1100
  - SN1a — > Hubble Diagram, z~0-1.3
  - Baryonic Acoustic Oscillations, z~0.7, 2.3 (but echo of sound waves z ~ 1100)
  - Weak Lensing —> distortion of galaxy shapes by the overall matter distribution
  - Clusters of Galaxies (z<1)
  - Measurements of the Hubble Constant (Cepheids, Lensed quasars
  - Quasars as standard candles (z~0-6, our new method)

Physical origin of the acceleration term

Straightforward way: a scalar field:

$$u_\phi = \frac{1}{2}\frac{1}{\hbar c^3}\dot{\phi}^2 + V(\phi)$$

$$p_\phi = \frac{1}{2}\frac{1}{\hbar c^3}\dot{\phi}^2 - V(\phi)$$

If the kinetic term is not dominant, $p_\phi \sim -u_\theta$

Definition: $w \equiv \frac{p}{u}$ Cosmological constant: w=-1

Scalar fields models dominated by V(ϕ) are known as “quintessence”

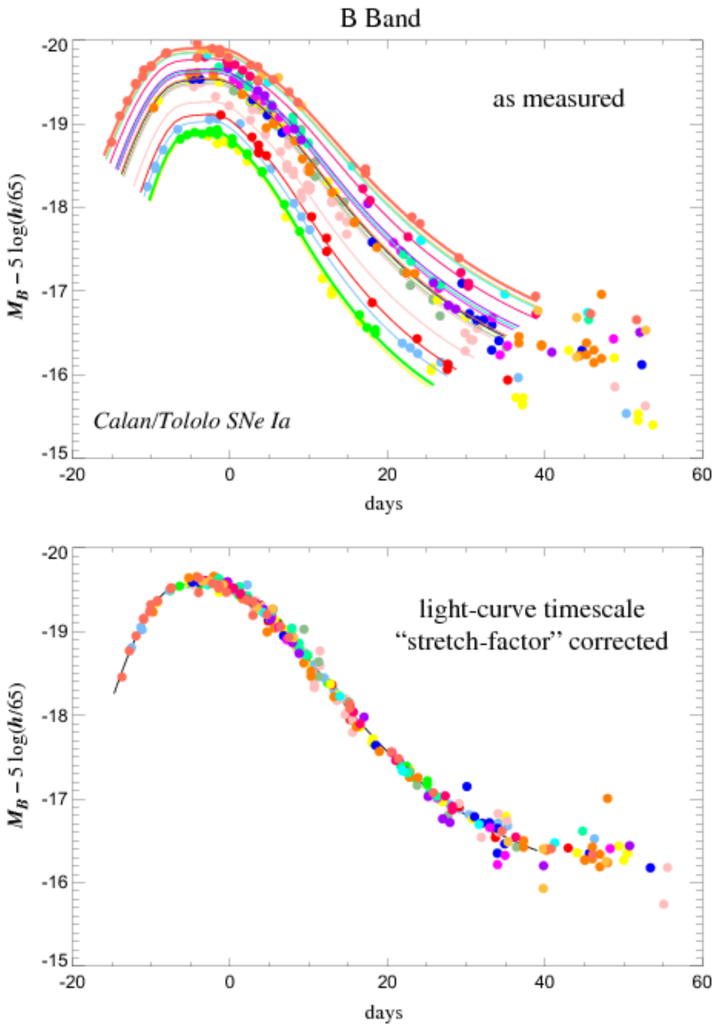
Observational cosmology

Questions:
1) Is acceleration due to some sort of dark energy within GR, or to a breakdown of GR at large scales ?
2) If it is due to dark energy, is the density of the dark energy constant in time (and space) ?

Current state:
- Quite precise measurements of CMB anisotropies, expansion of the Universe, distribution of matter
- Until a few years ago, all consistent with a standard "ΛCDM" model

Goals:
More precise measurements to either (1) confirm the model with higher accuracy :-(or (2) find small deviations indicative of the physical nature of the dark energy

Supernovae



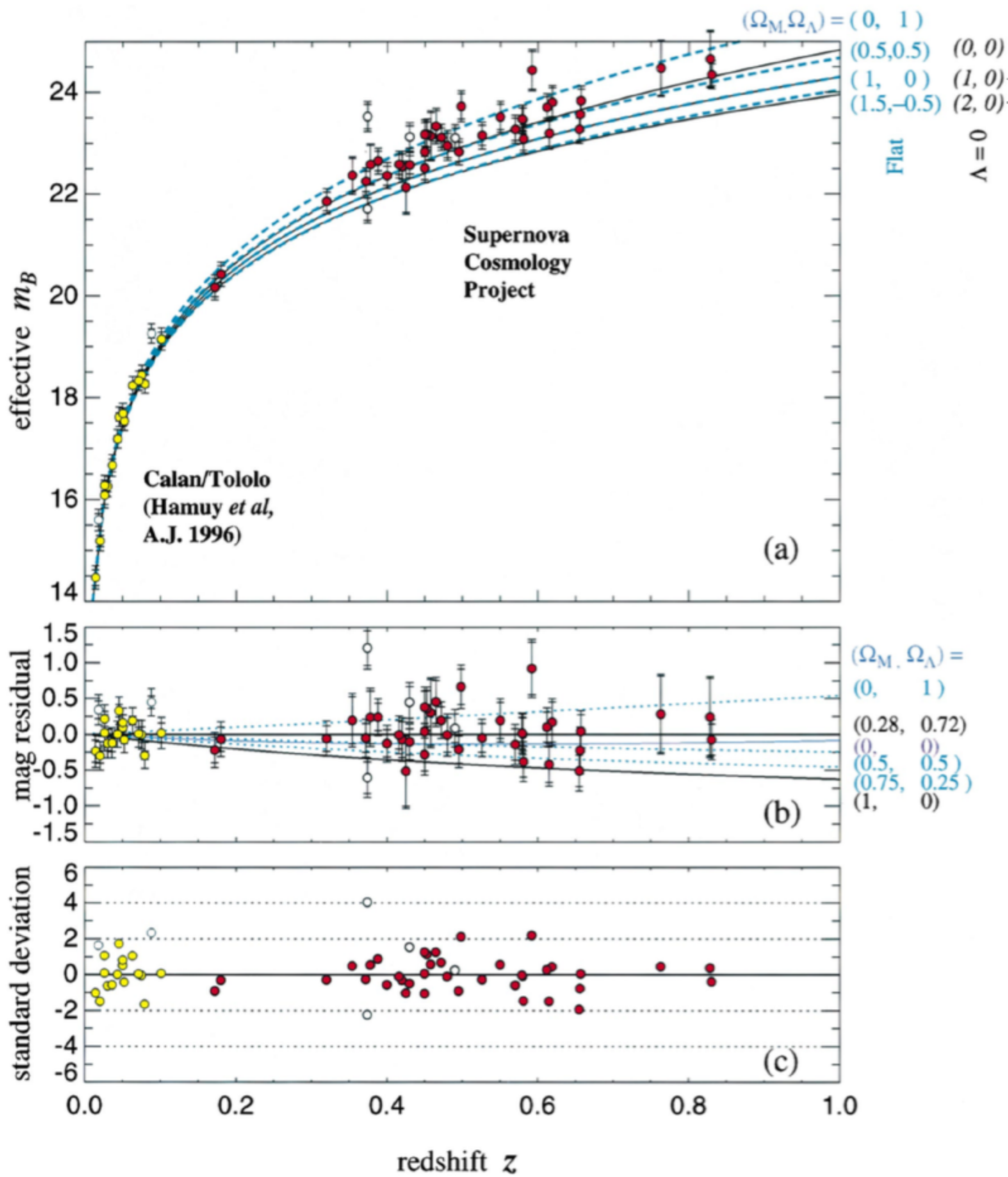
Kim, *et al.* (1997)

Phillips (1993):
relationship between peak luminosity and decay rate

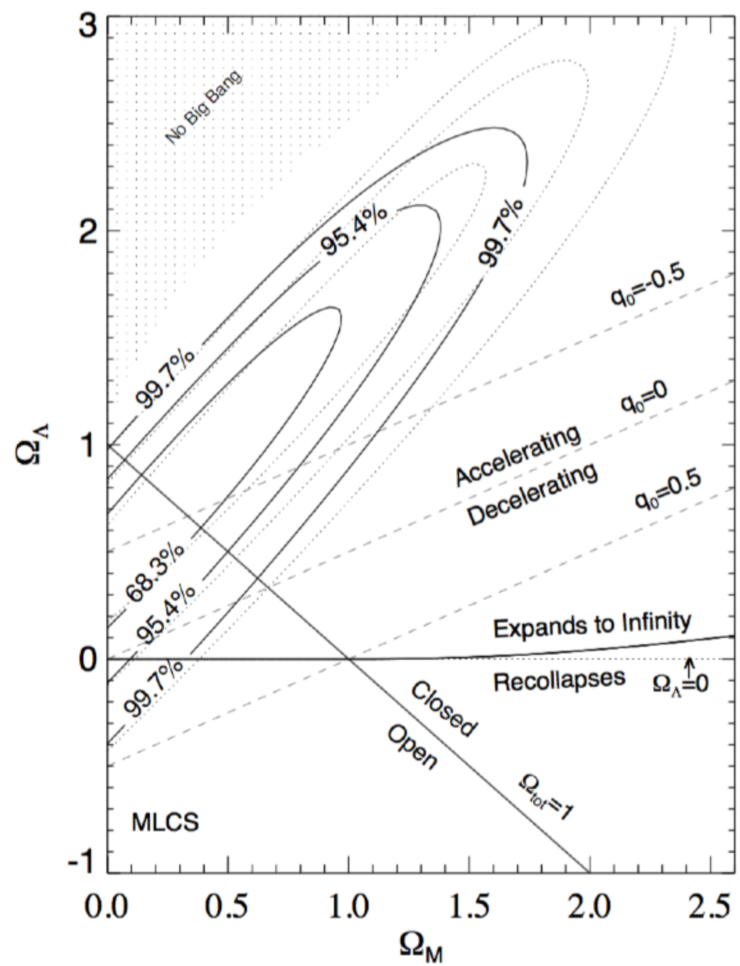
Least-Squares Fits

Bandpass	$M_{max} = a + b\,\Delta m_{15}(B)$		
	a	b	σ (mag)
B	−21.726(0.498)	2.698(0.359)	0.36
V	−20.883(0.417)	1.949(0.292)	0.28
I	−19.591(0.415)	1.076(0.273)	0.38

Supernovae

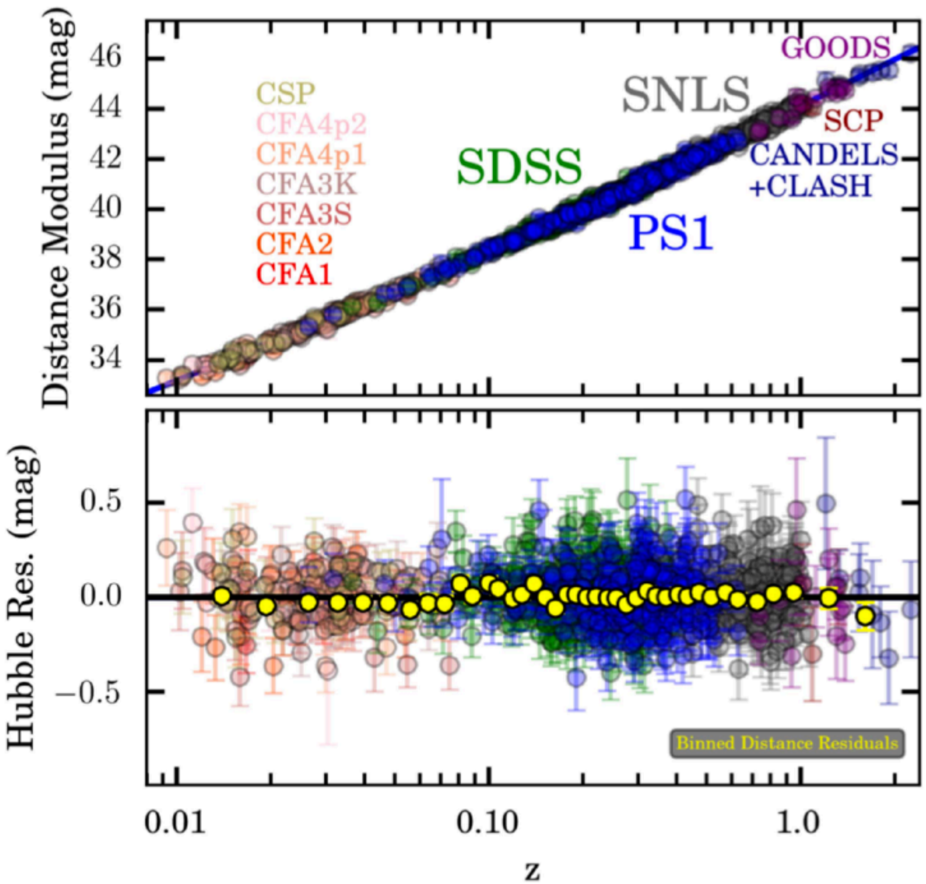


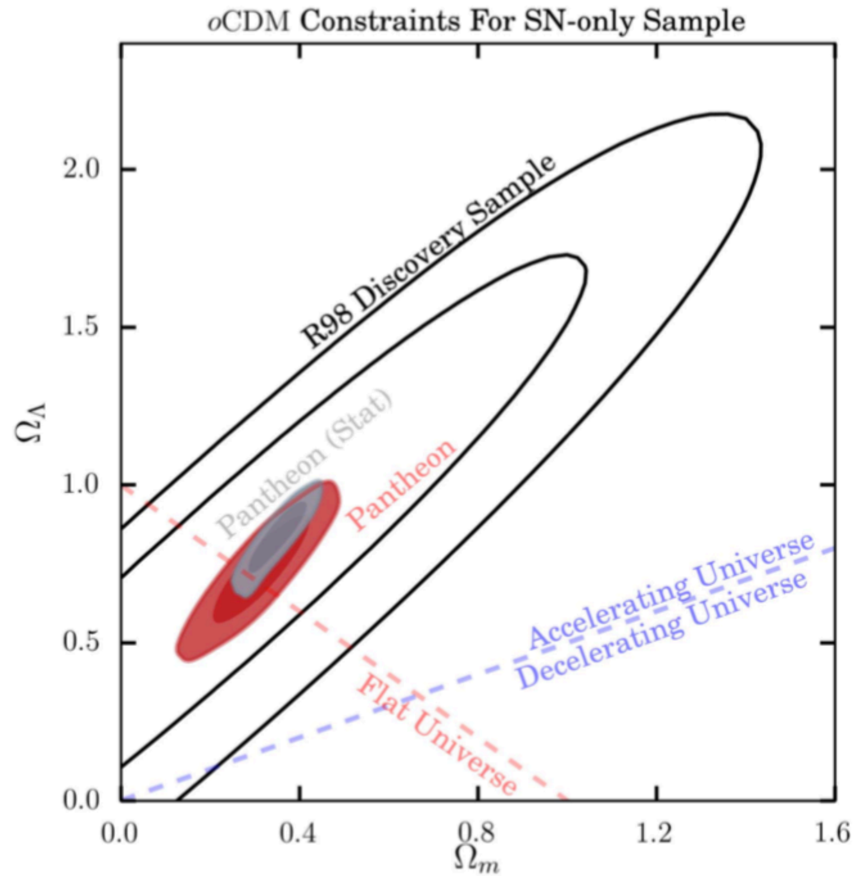
Perlmutter et al. 1999
Riess et al. 1998



Supernovae

Scolnic et al. 2018

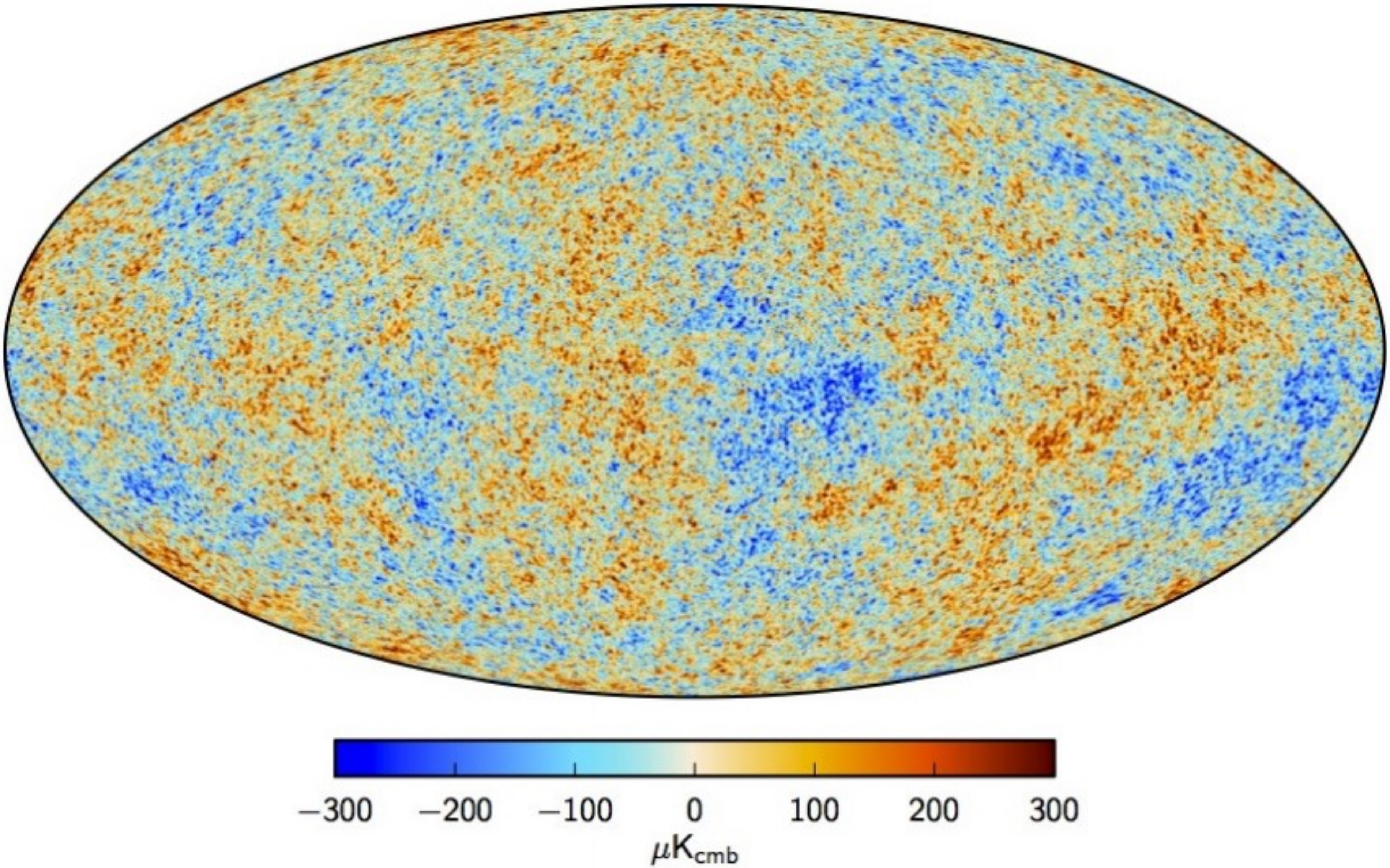




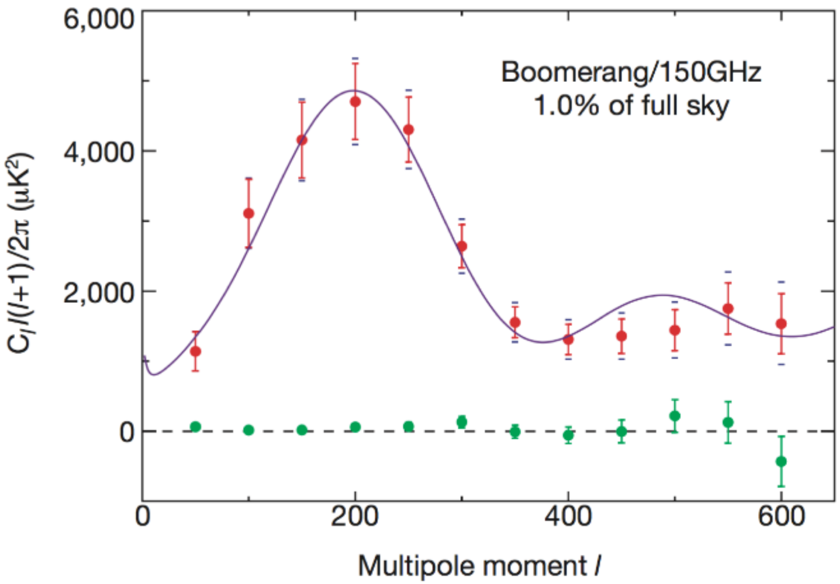
$$D_L = \frac{c(1+z)}{H_0} \int_0^z \frac{dz'}{\sqrt{\Omega_M(1+z')^3 + \Omega_\Lambda + \Omega_K(1+z')^2}}$$

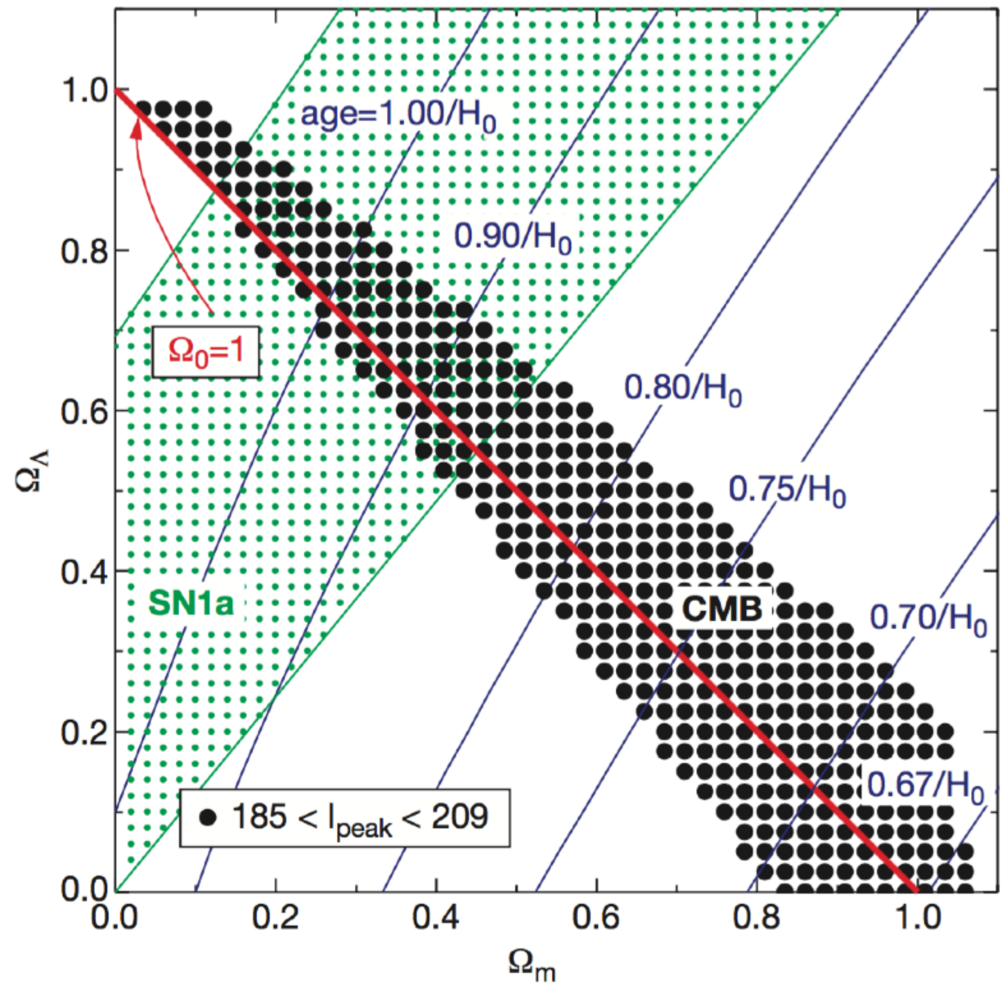
Observations: CMB

Planck



Observations: CMB

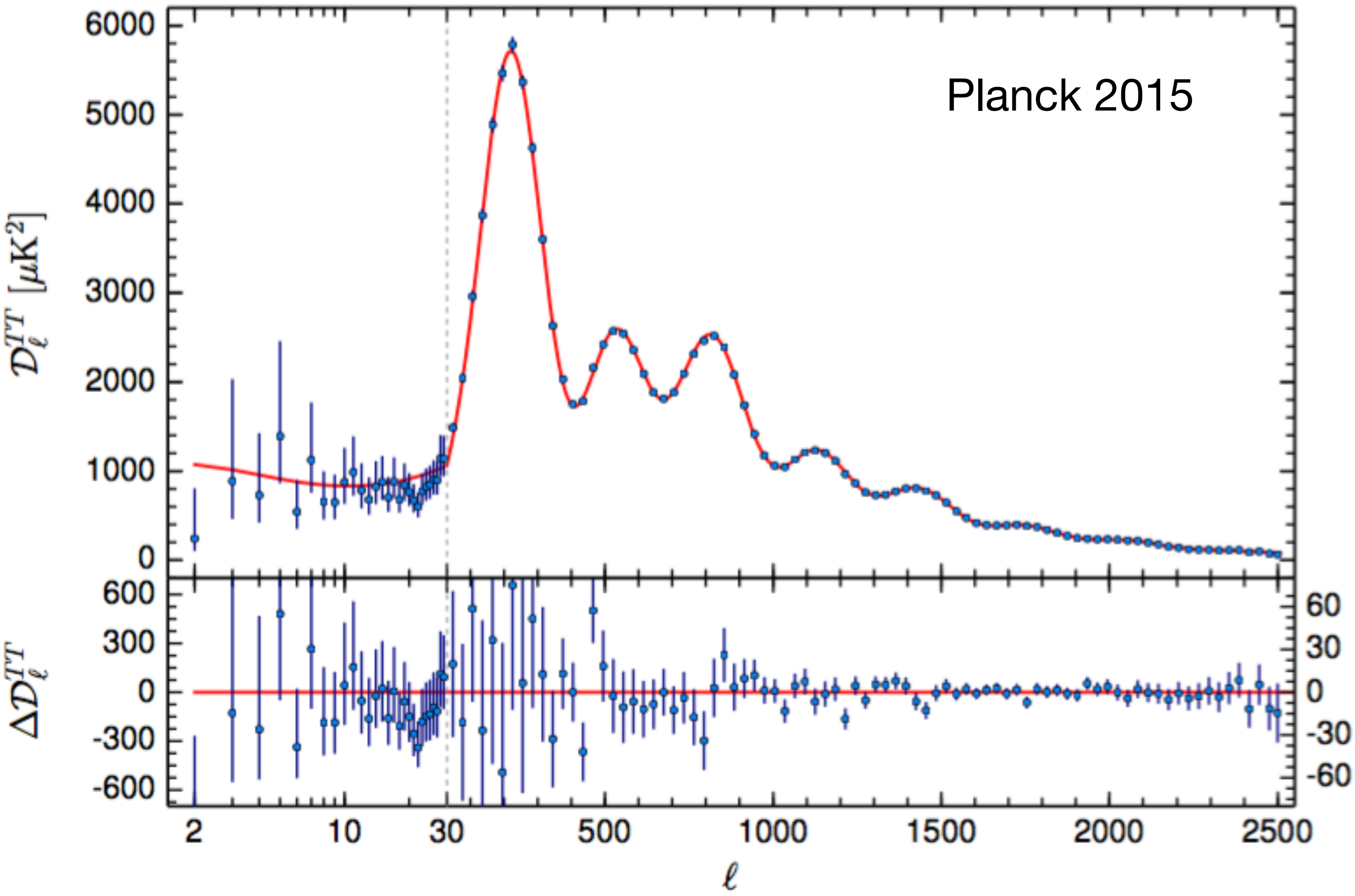




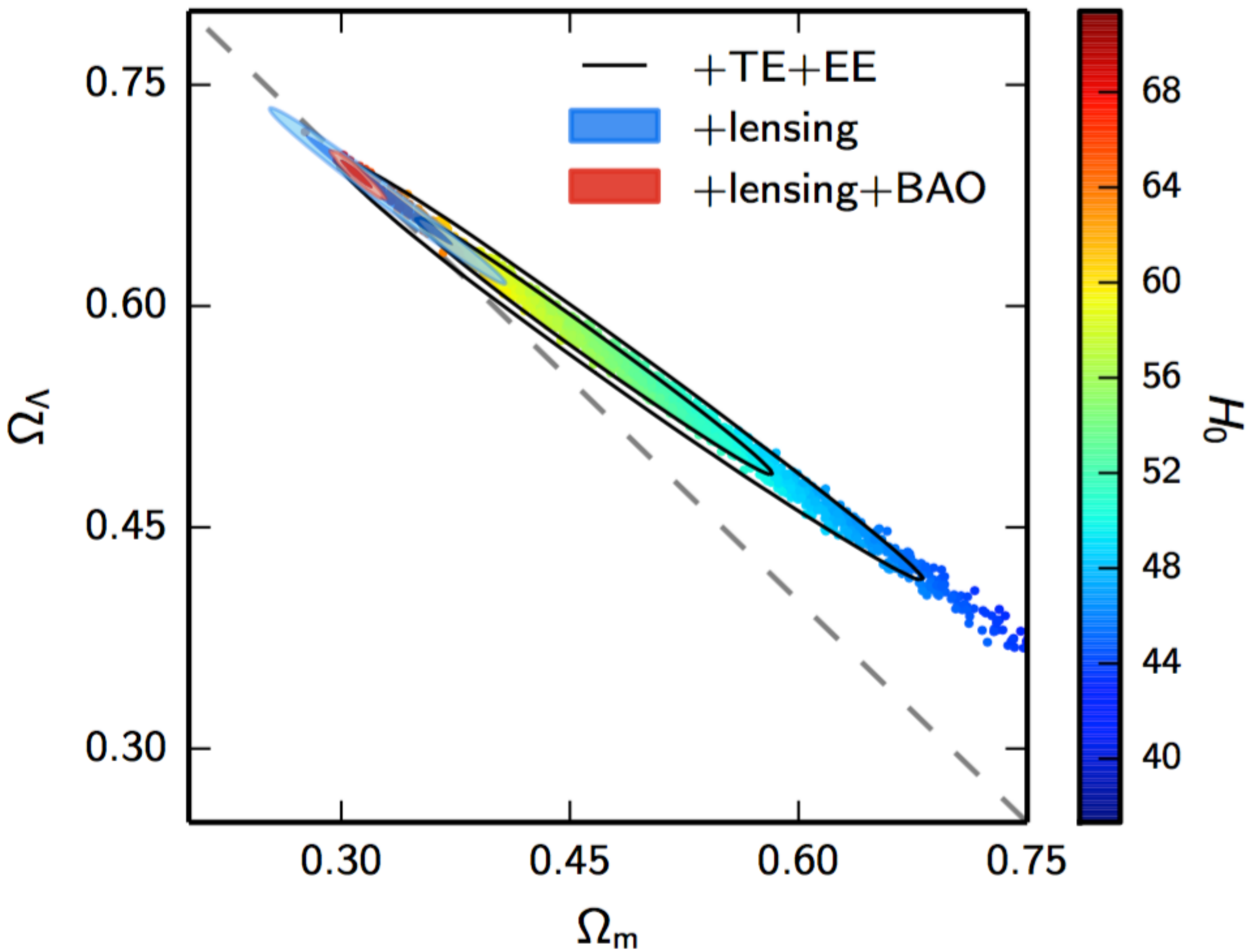
De Bernardis et al. 2000:
first acoustic peak at l~200

—> Flat Universe

Observations: CMB

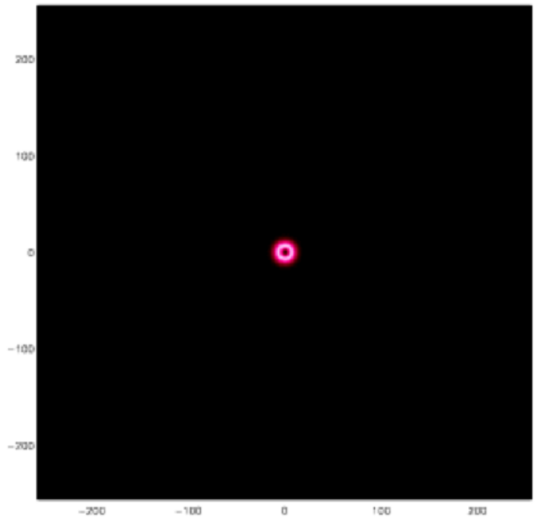


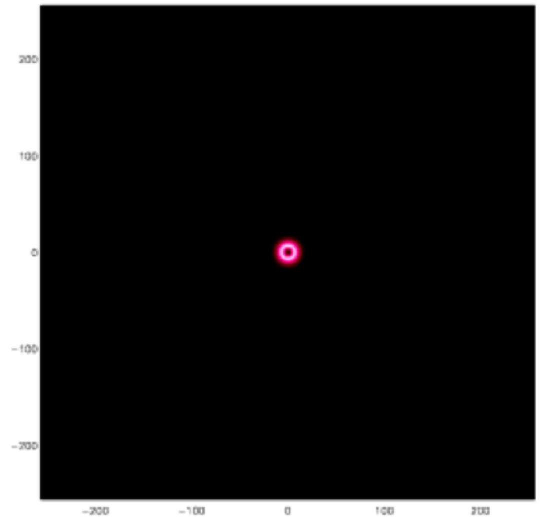
CMB: Results

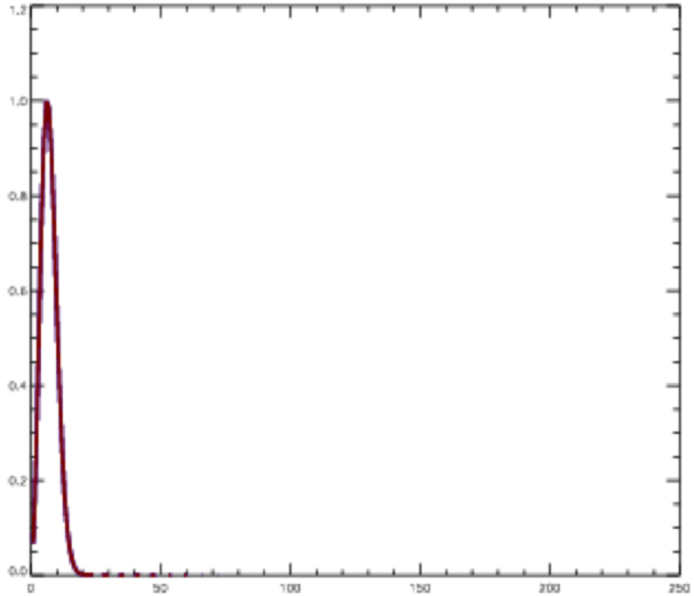


Planck 2015

Baryonic Acoustic Oscillations







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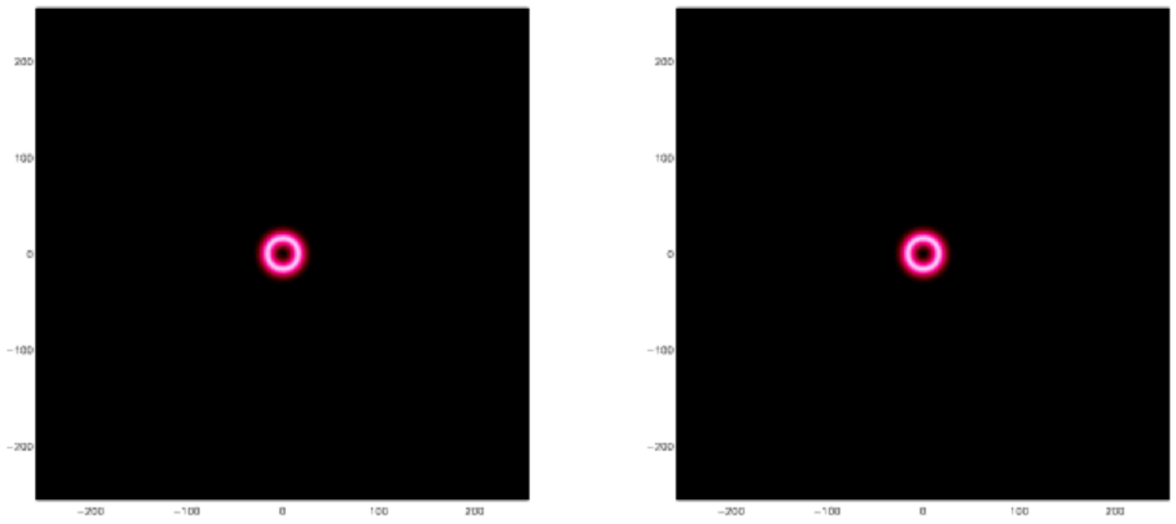

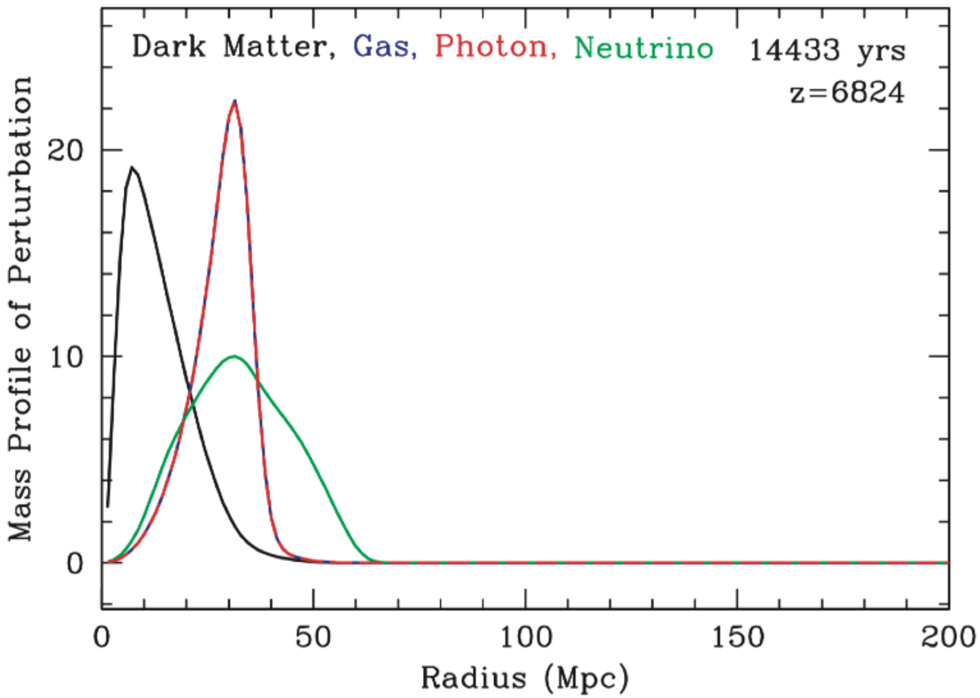

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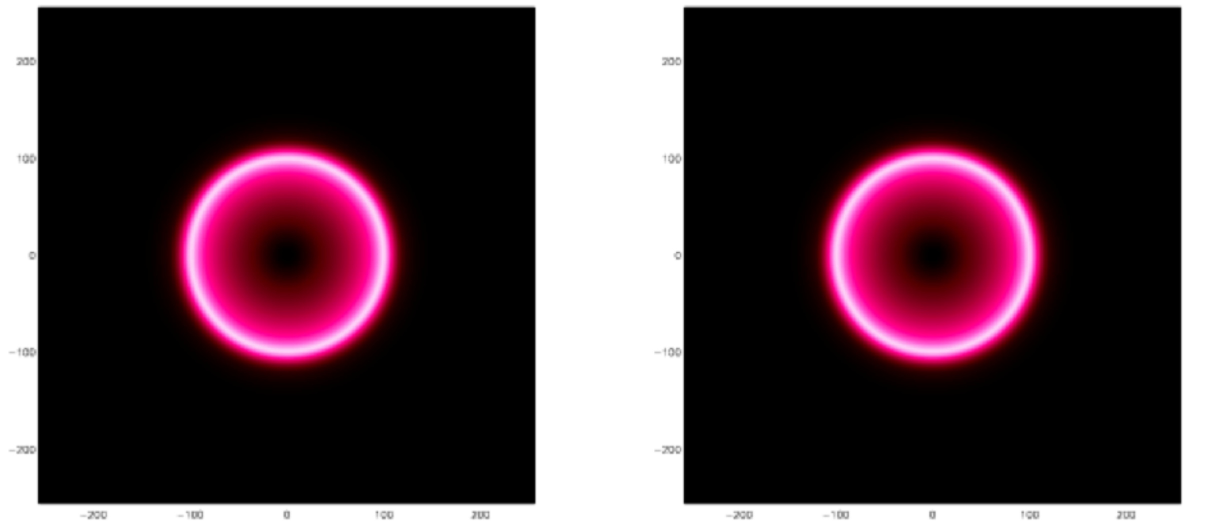

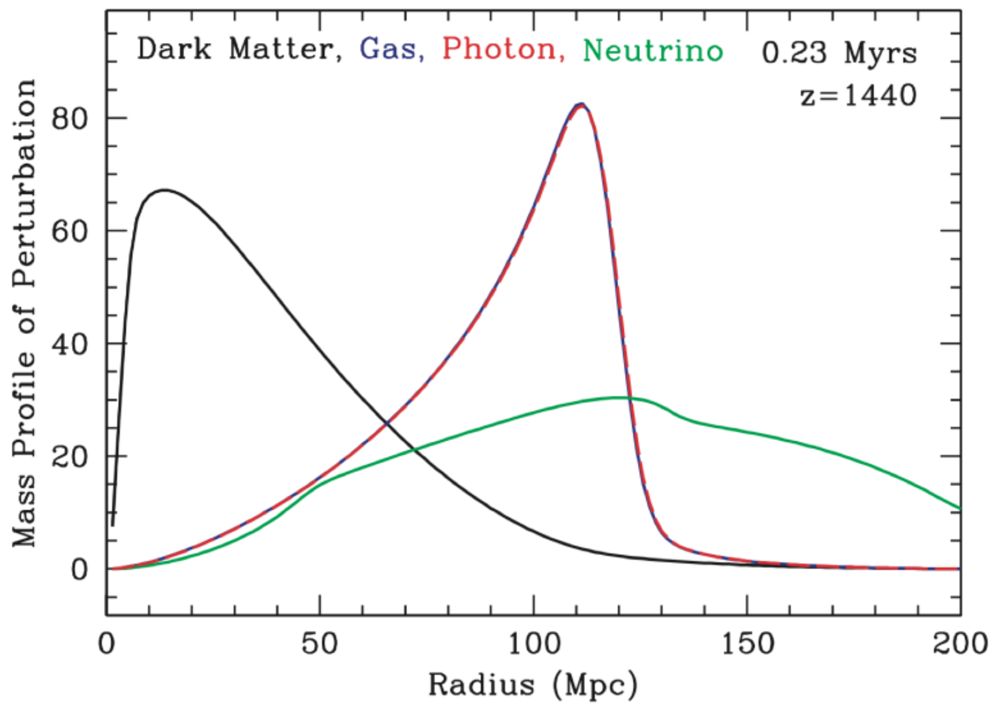

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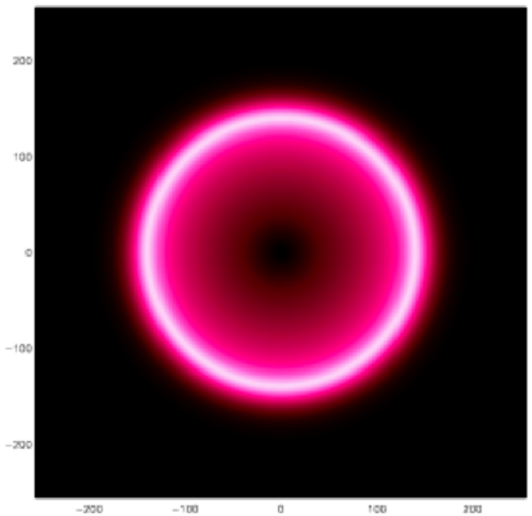
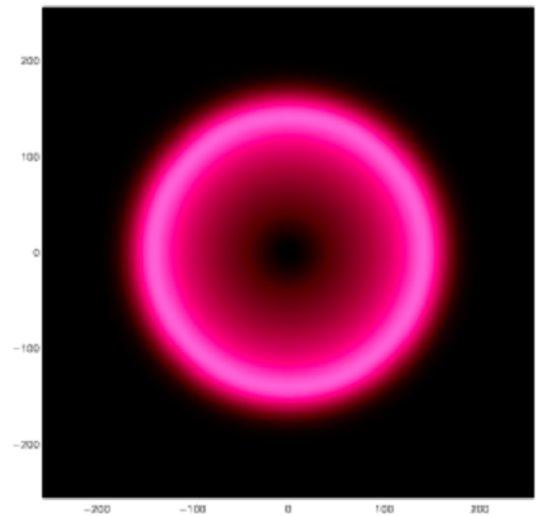
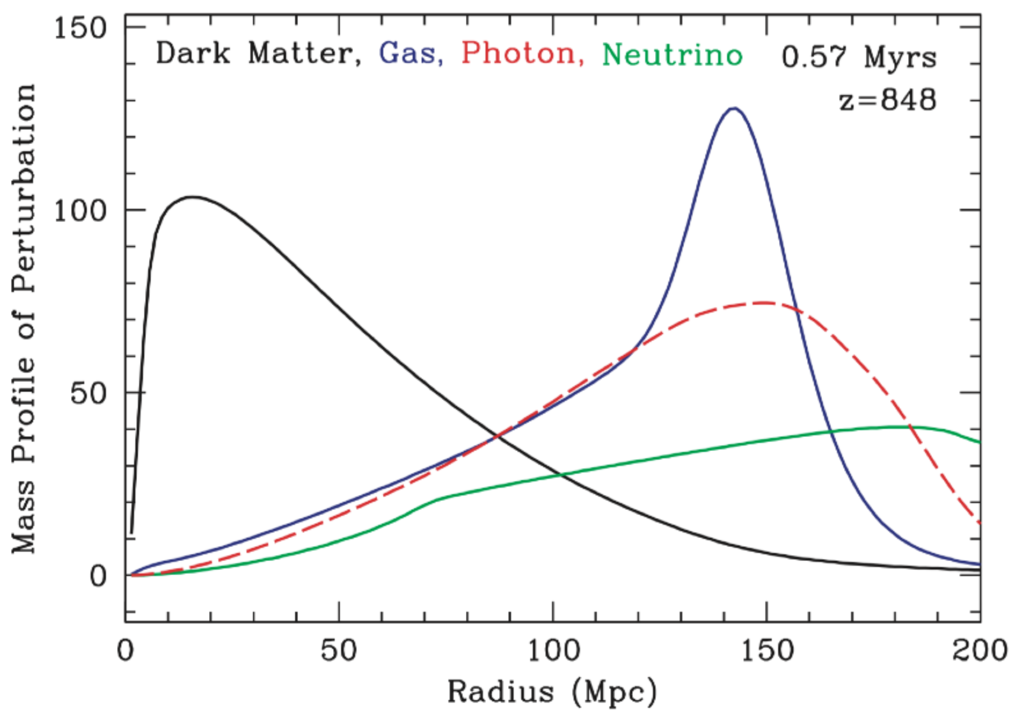
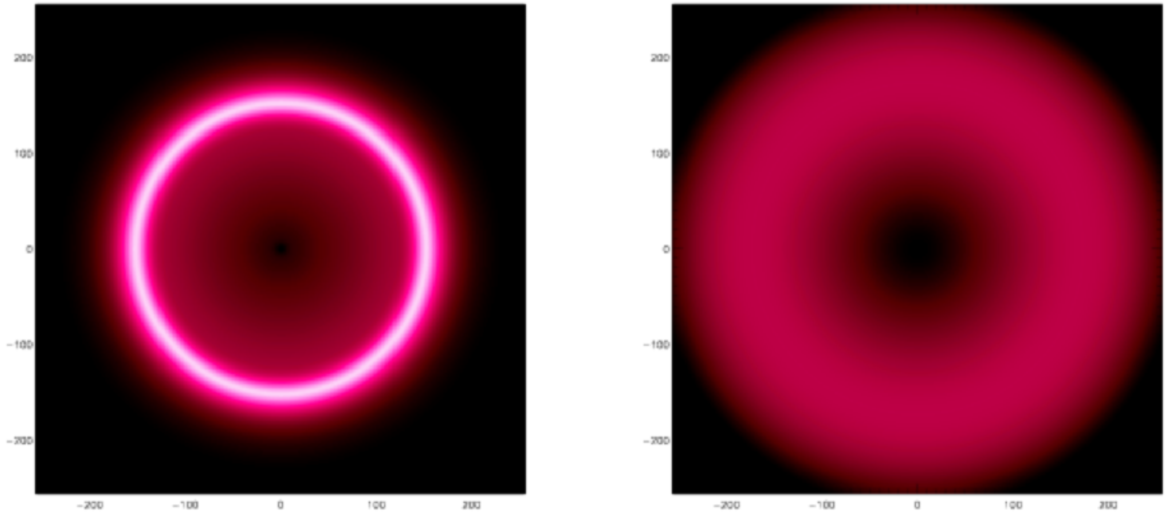
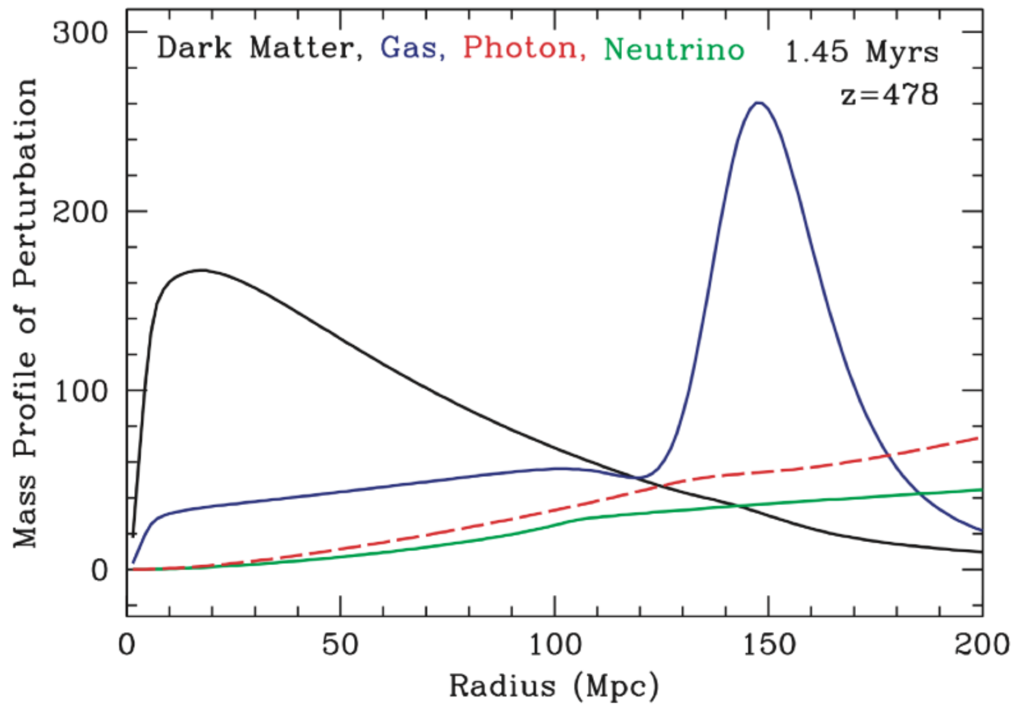




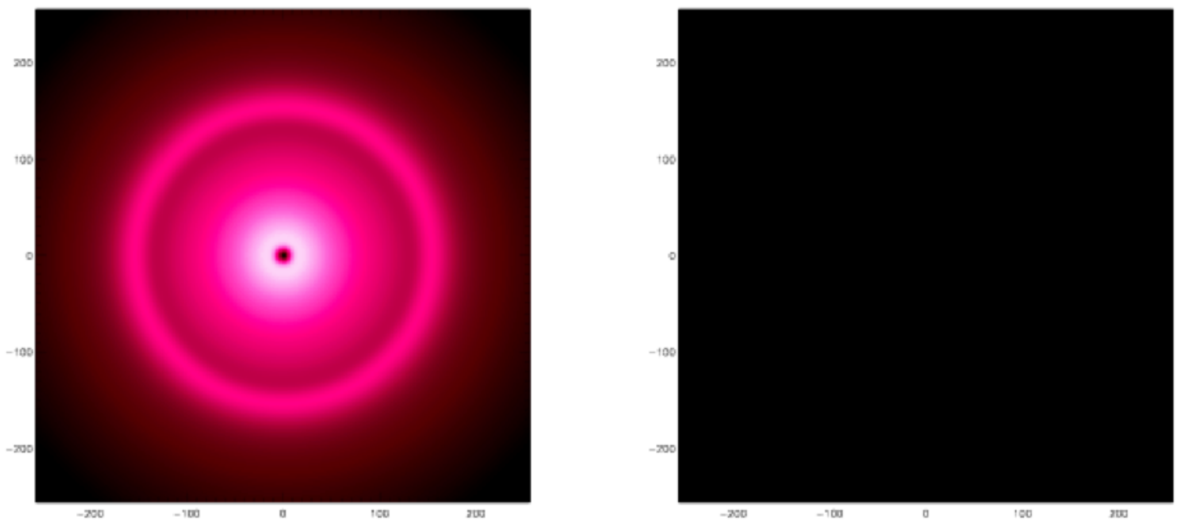


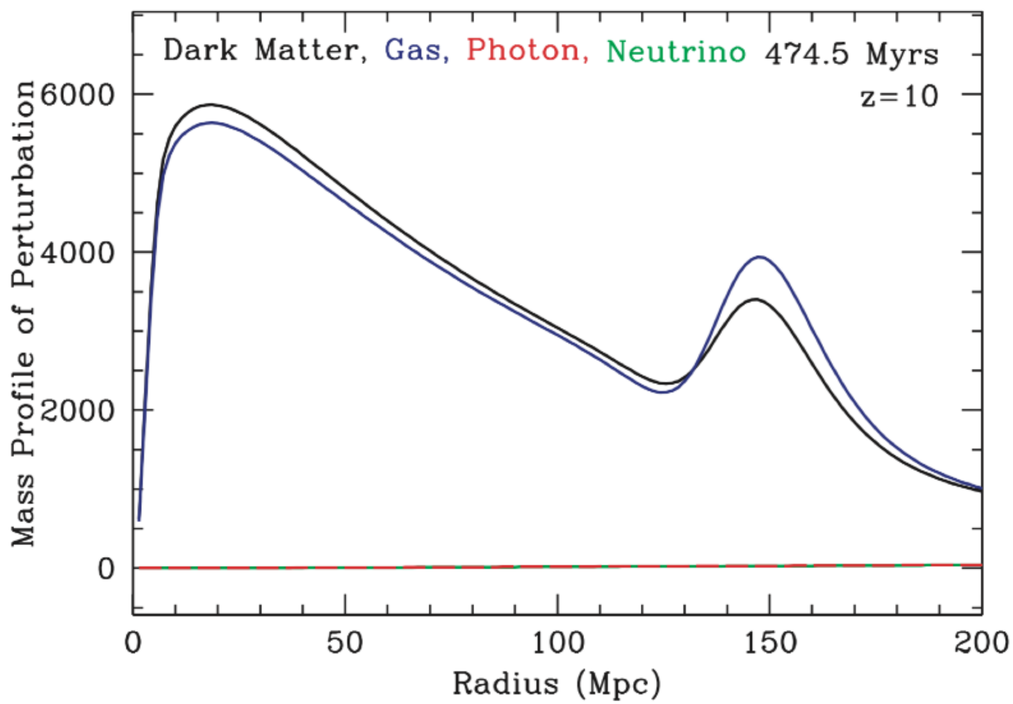
Baryonic Acoustic Oscillations





Baryonic Acoustic Oscillations





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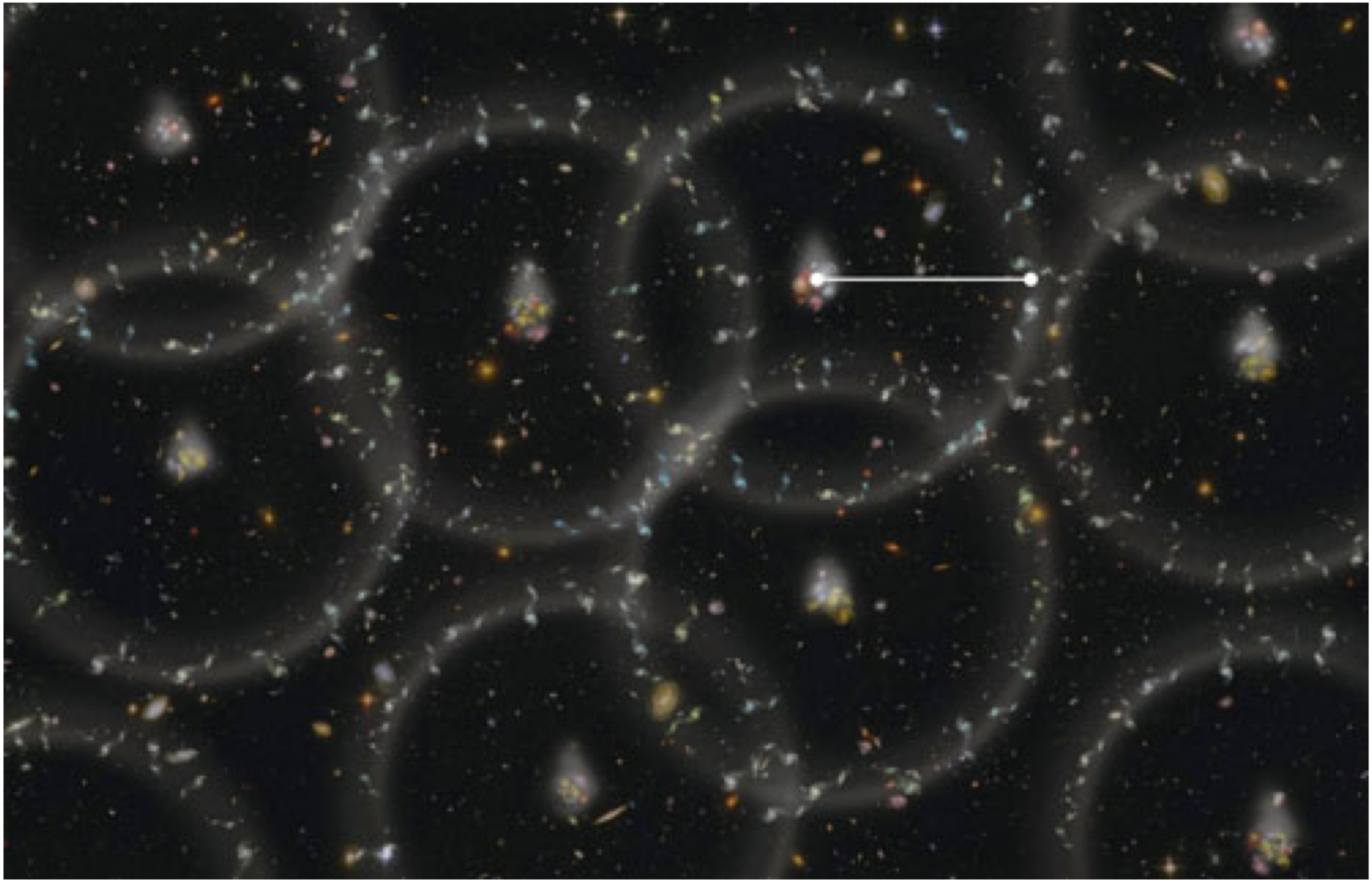
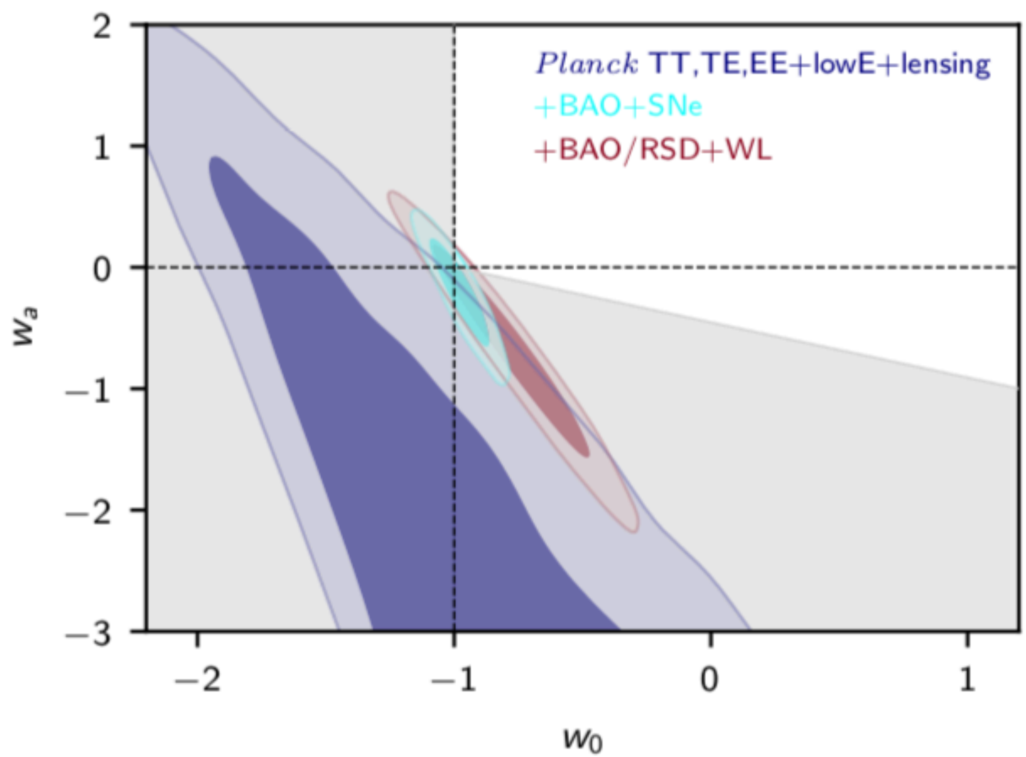


Check of the Standard model

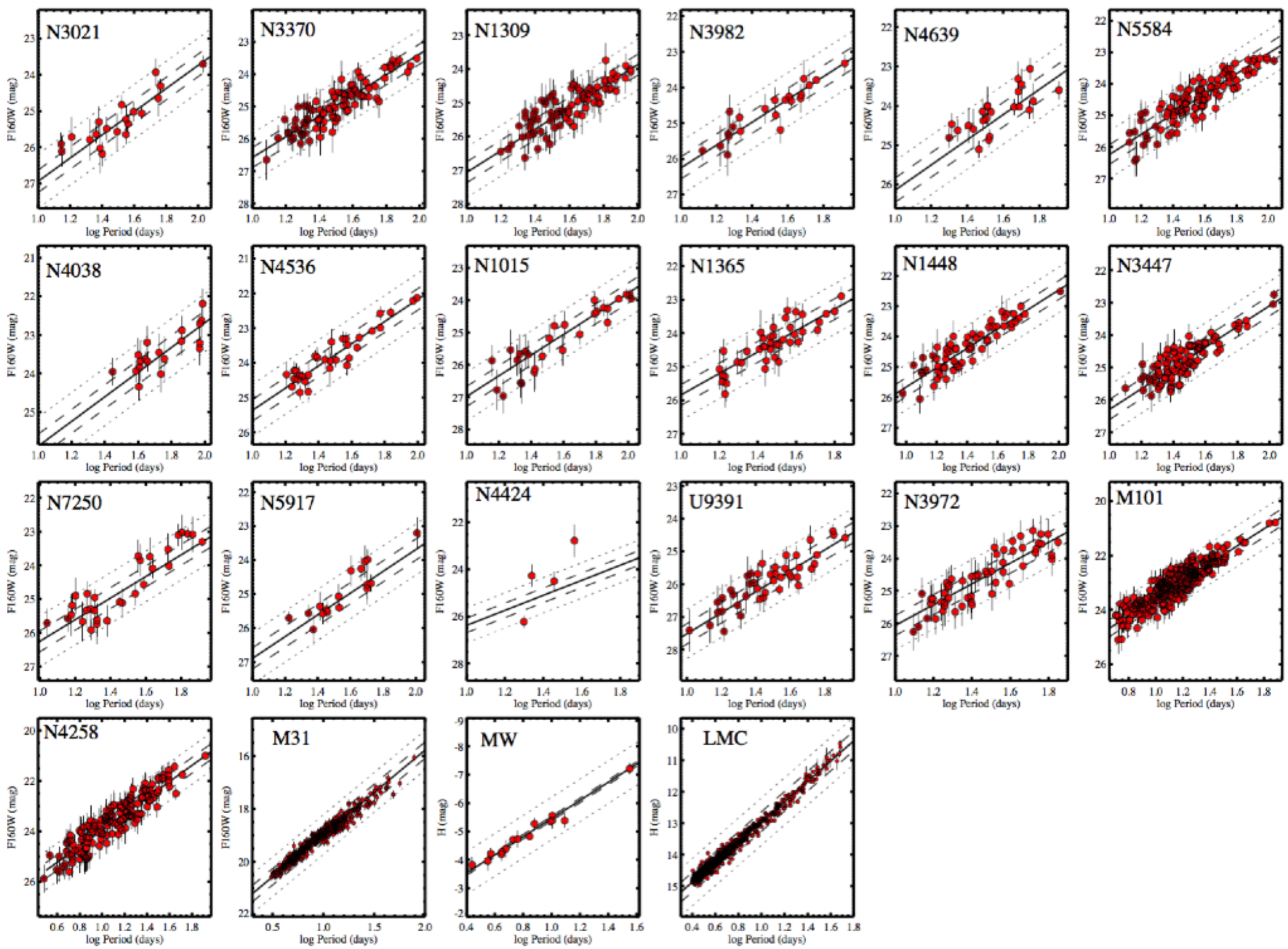
$$D_L = \frac{c(1+z)}{H_0}\int_0^z \frac{dz'}{\sqrt{\Omega_M(1+z')^3 + \Omega_\Lambda * f(z) + \Omega_K(1+z')^2}}$$

$$f(z) = (1+z)^{3(1+w)} \qquad w = w_0 + w_a\frac{z}{1+z}$$



Measurements of the Hubble Constant

Riess et al. 2016: Cepheids + Supernovae



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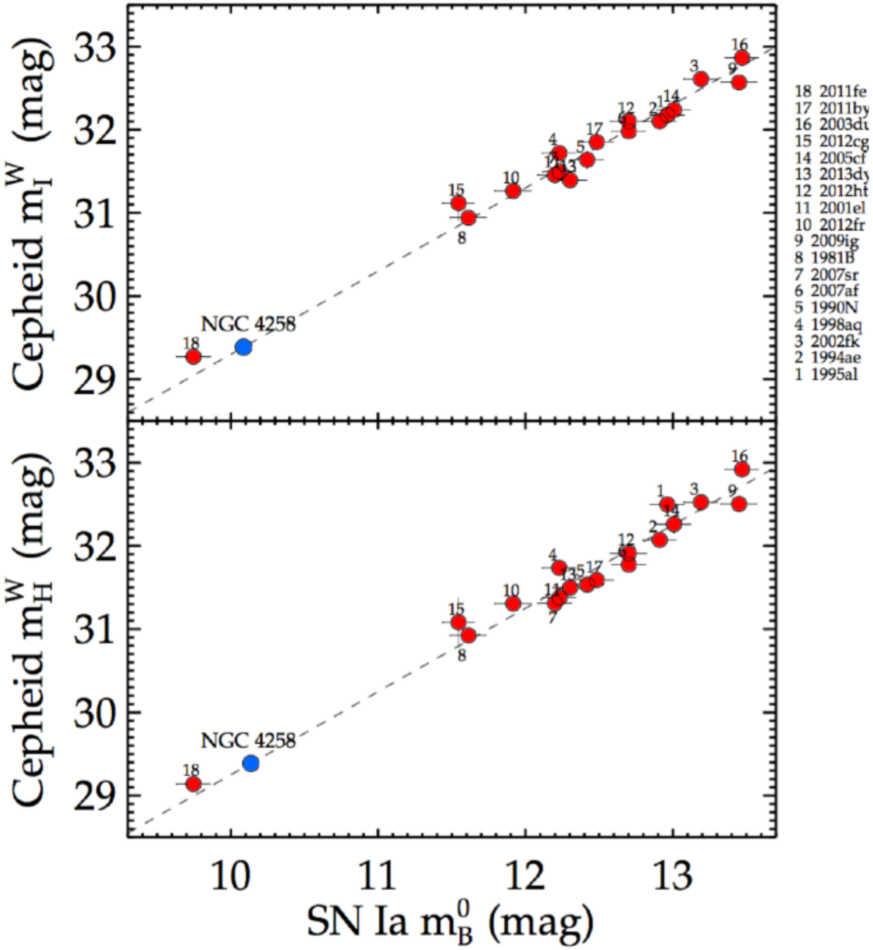
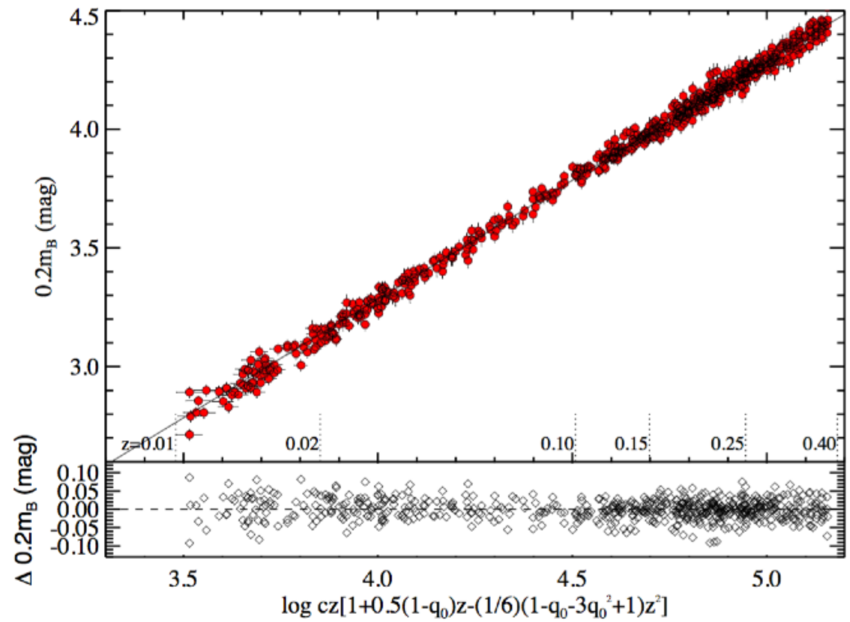
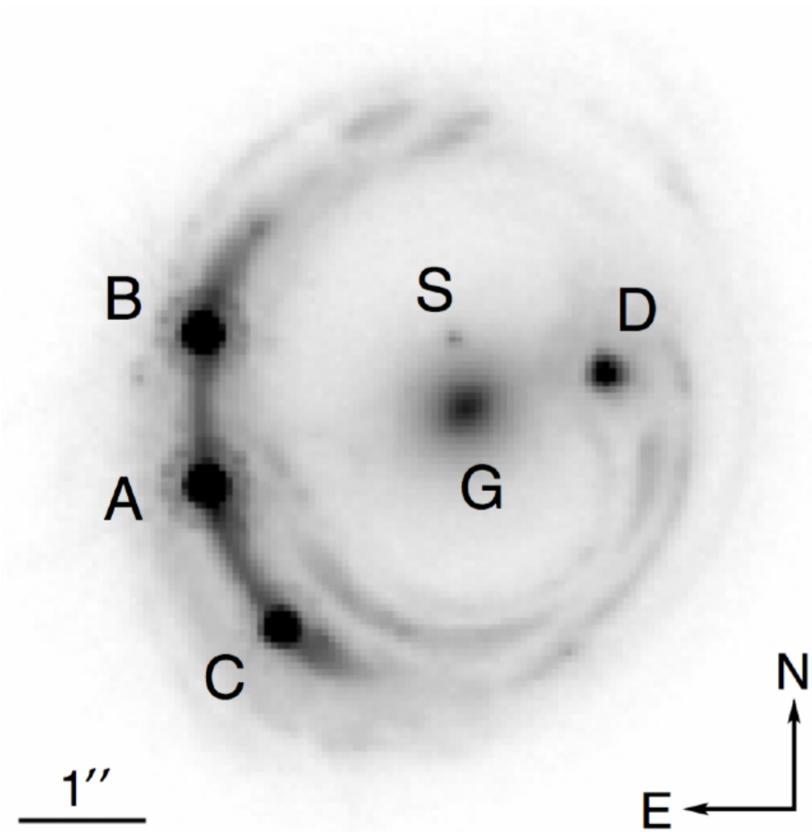




H0=74(1.5) km/s/Mpc
Planck: H0=67.5(0.7) Km/s/Mpc

Strong Lensing

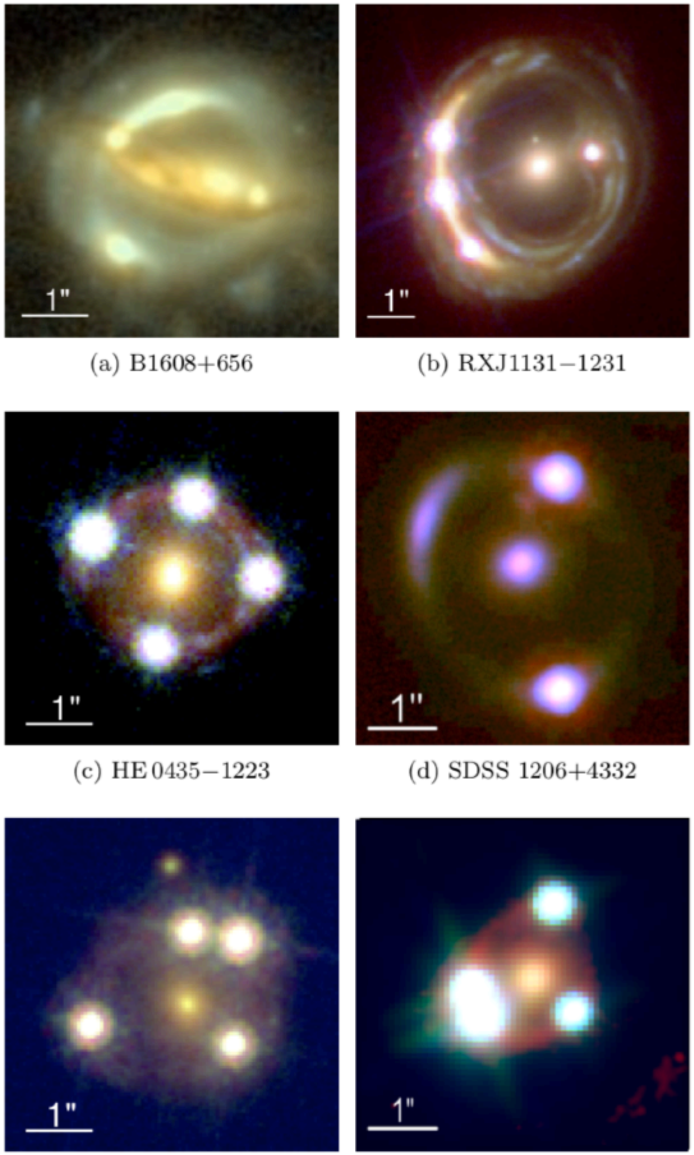


Multiple lenses of a variable source (quasar, supernova…) can be used as rods to measure the distance of the lenses.

$$t(\boldsymbol{\theta}, \boldsymbol{\beta}) = \frac{D_{\Delta t}}{c} \left[\frac{(\boldsymbol{\theta} - \boldsymbol{\beta})^2}{2} - \psi(\boldsymbol{\theta}) \right]$$

$$D_{\Delta t} \equiv (1 + z_{\mathrm{d}}) \frac{D_{\mathrm{d}} D_{\mathrm{s}}}{D_{\mathrm{ds}}}$$

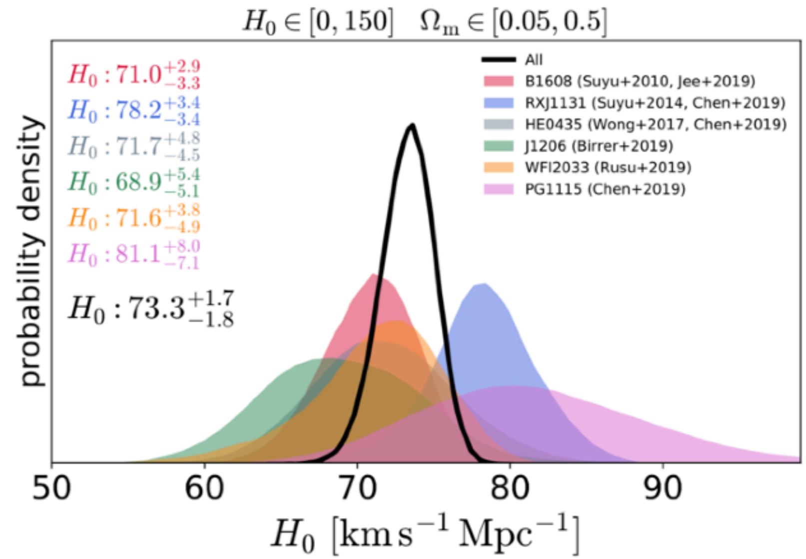
Strong Lensing

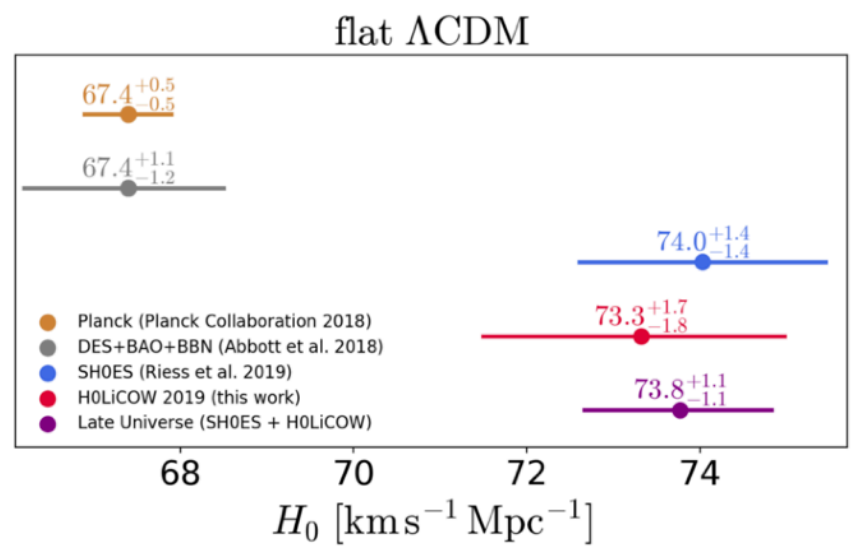


(a) B1608+656 (b) RXJ1131−1231

(c) HE 0435−1223 (d) SDSS 1206+4332

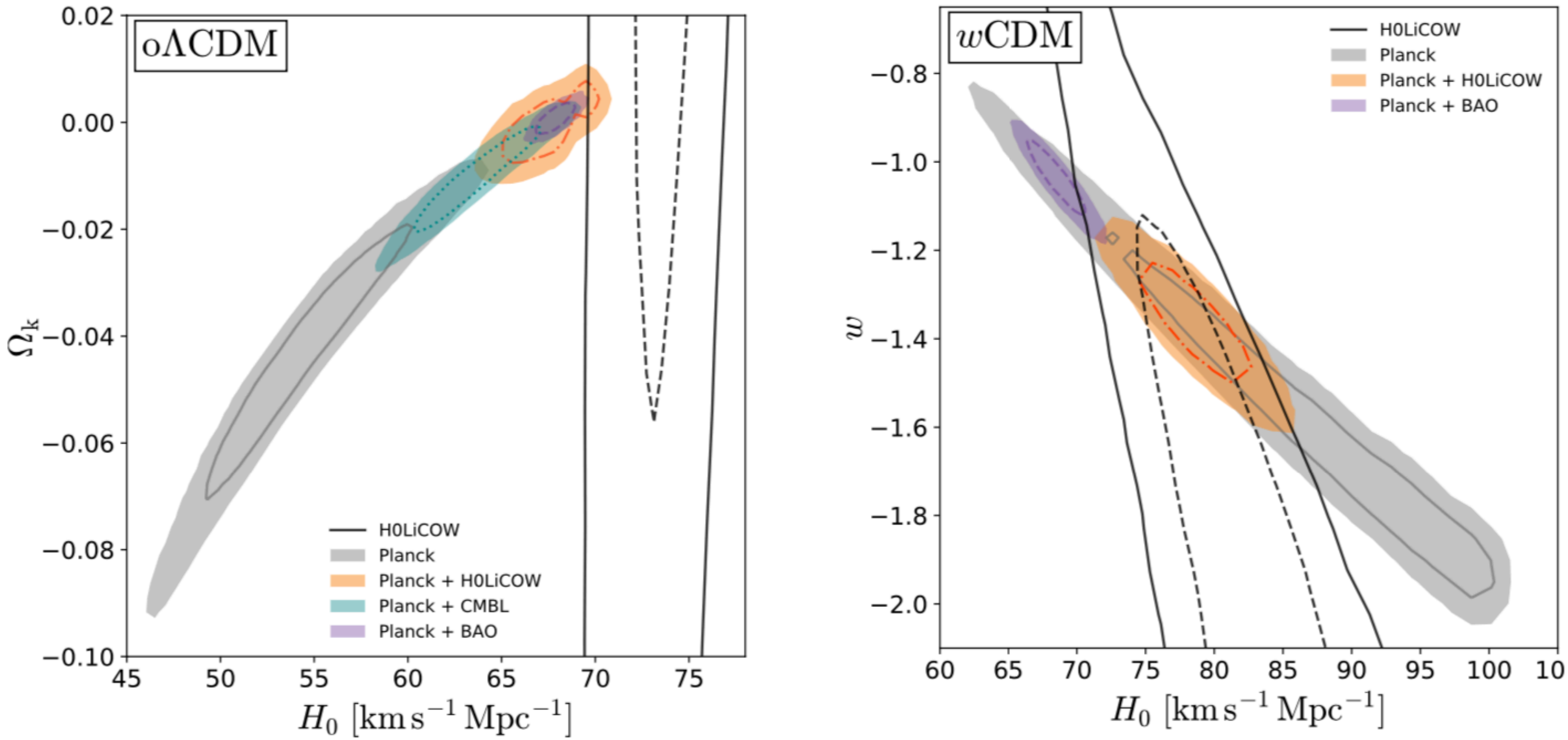
(e) WFI2033−4723 (f) PG 1115+080





Wong et al. 2019

Strong Lensing



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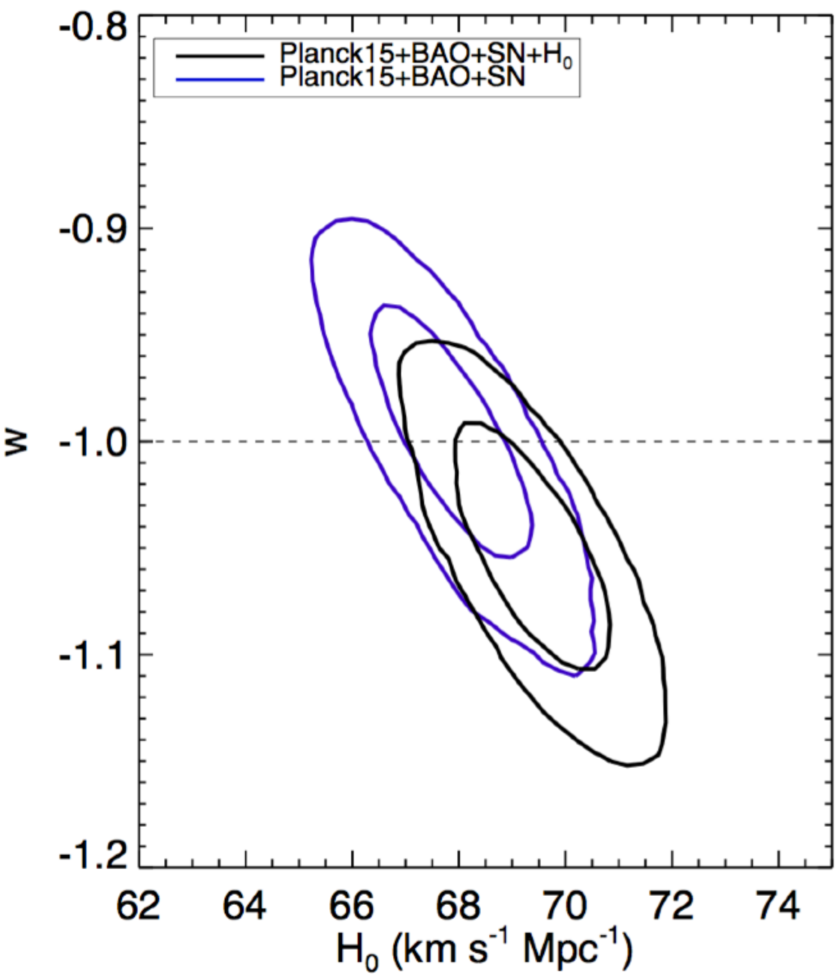
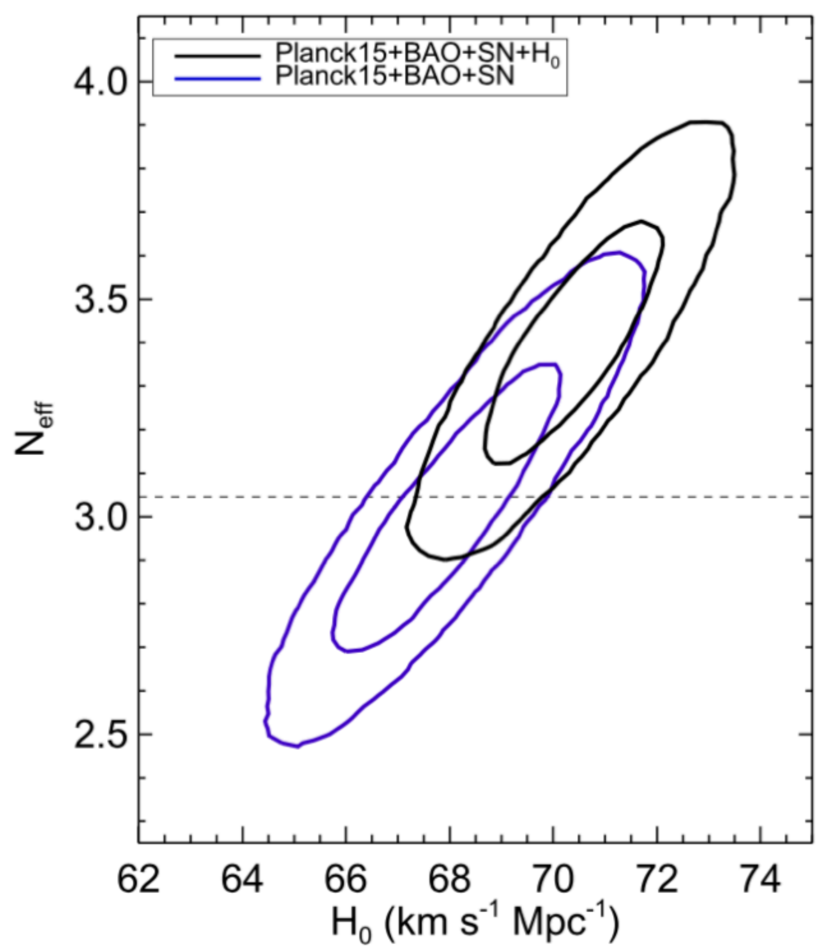
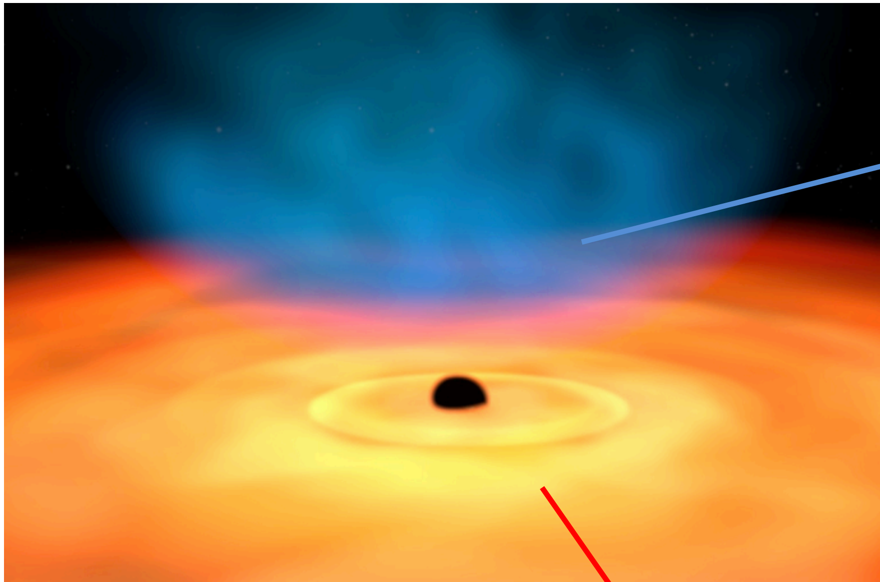
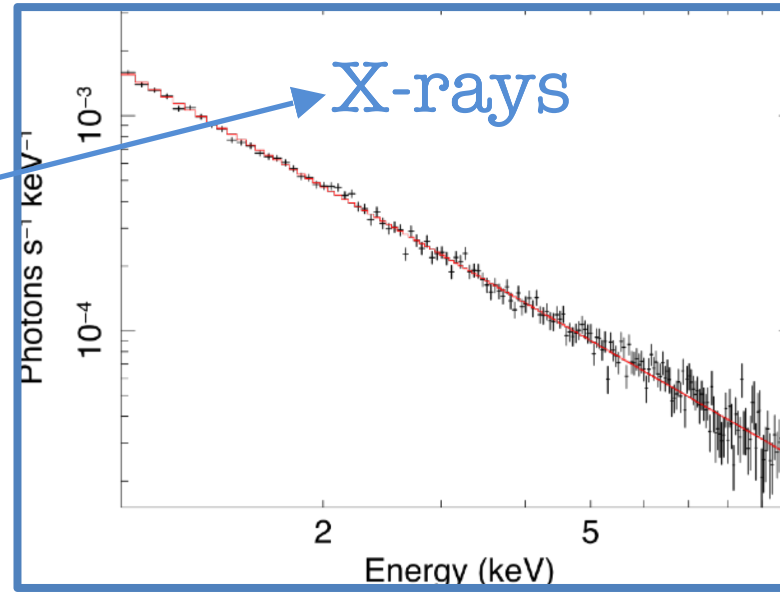
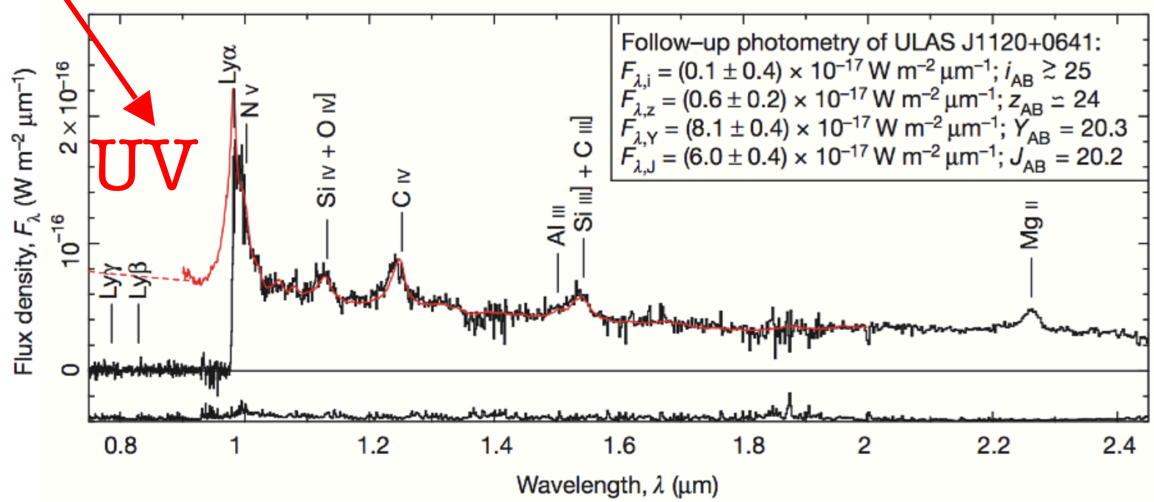




The inner emission regions in quasars

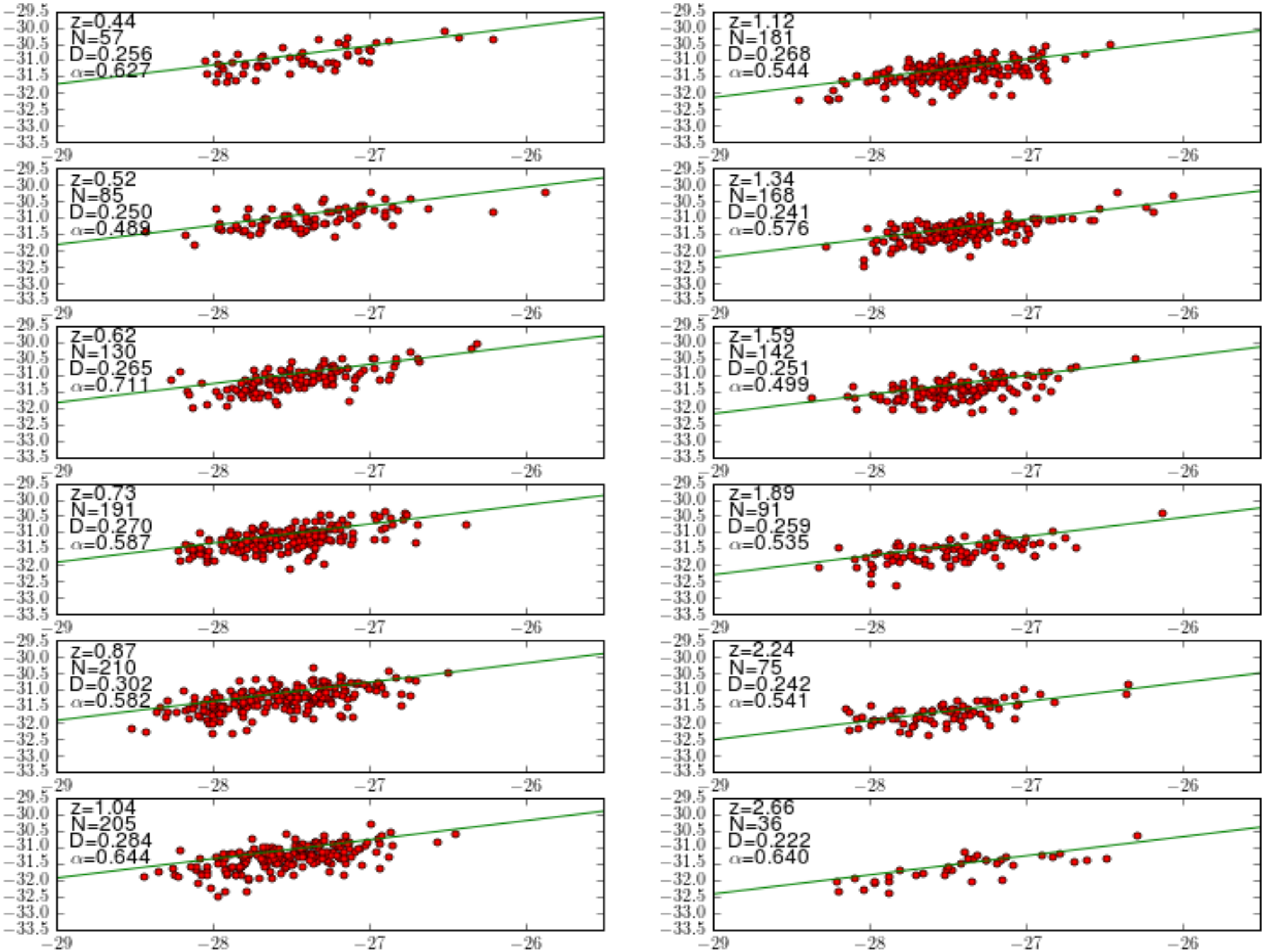




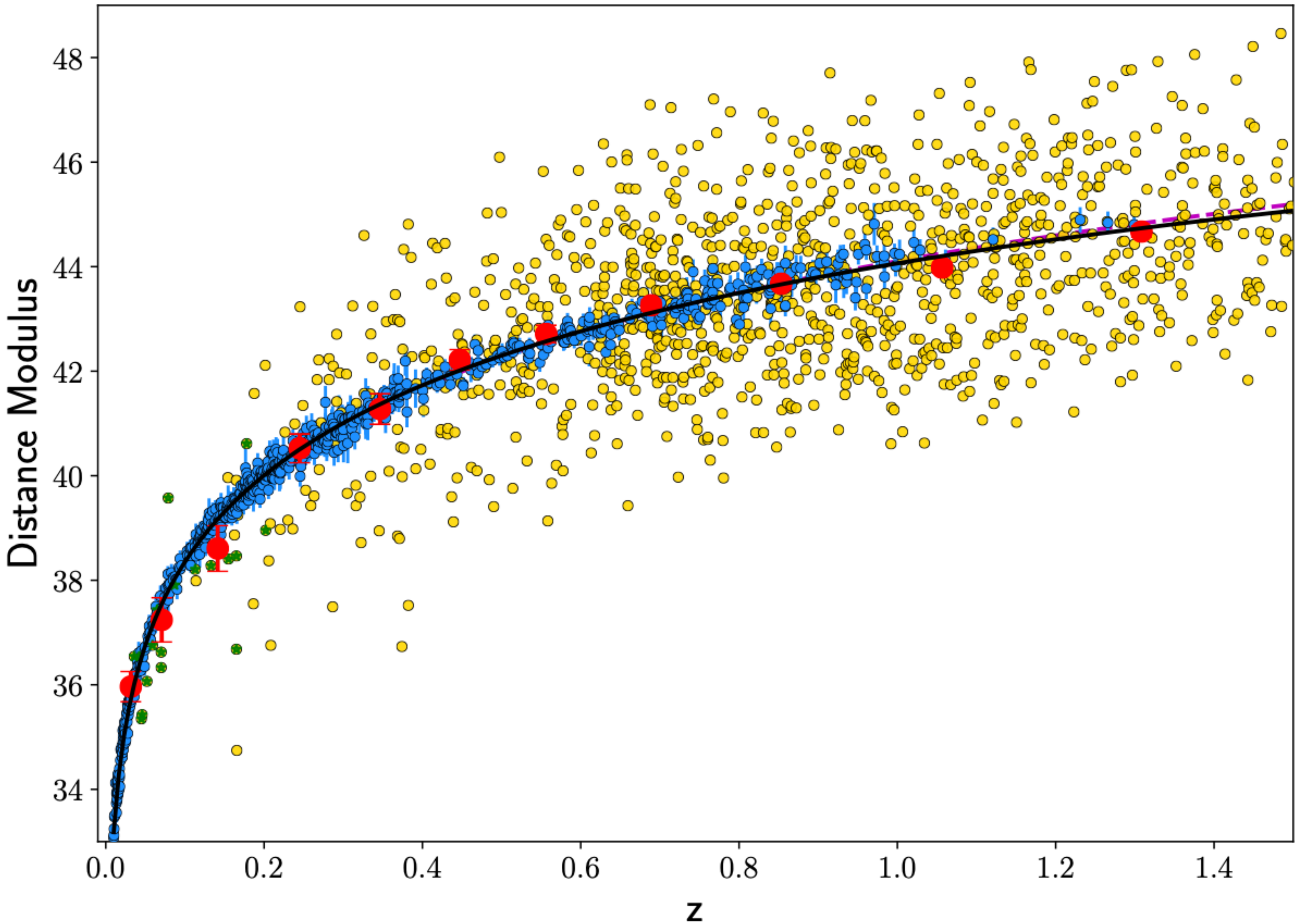


Mortlock et al. 2011

The L(UV)-L(X) relation in small redshift intervals



Match with supernovae



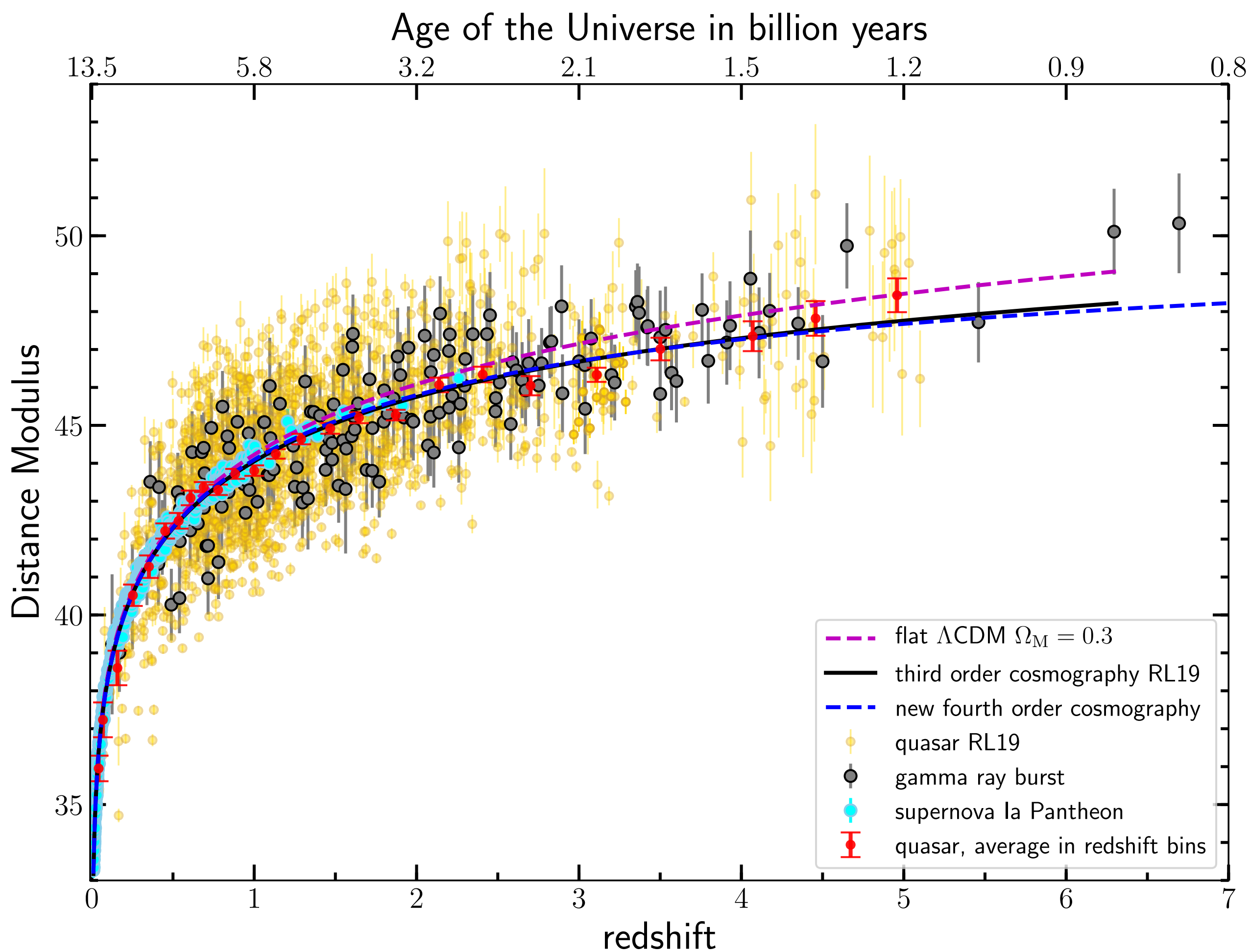
Risaliti & Lusso 2019, Nat. Astronomy

The Quasars + SNe + GRBs Hubble Diagram

1598 quasars (Risaliti & Lusso 2019)

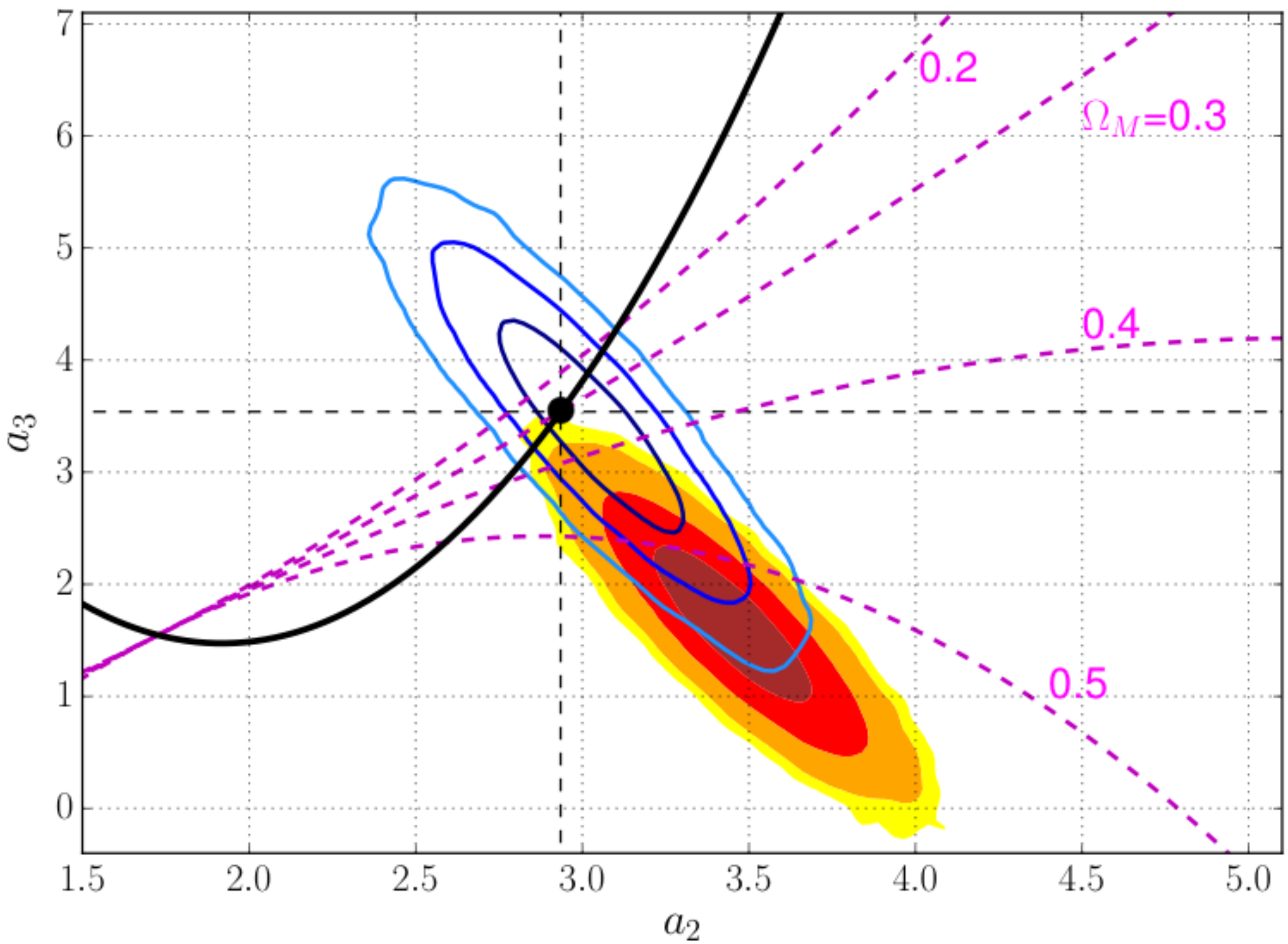
1048 Type Ia supernovae - *Pantheon* survey (Scolnic et al. 2018)

160 GRBs (Demianski et al. 2017)



Quasars as Standard Candles: tests of cosmology

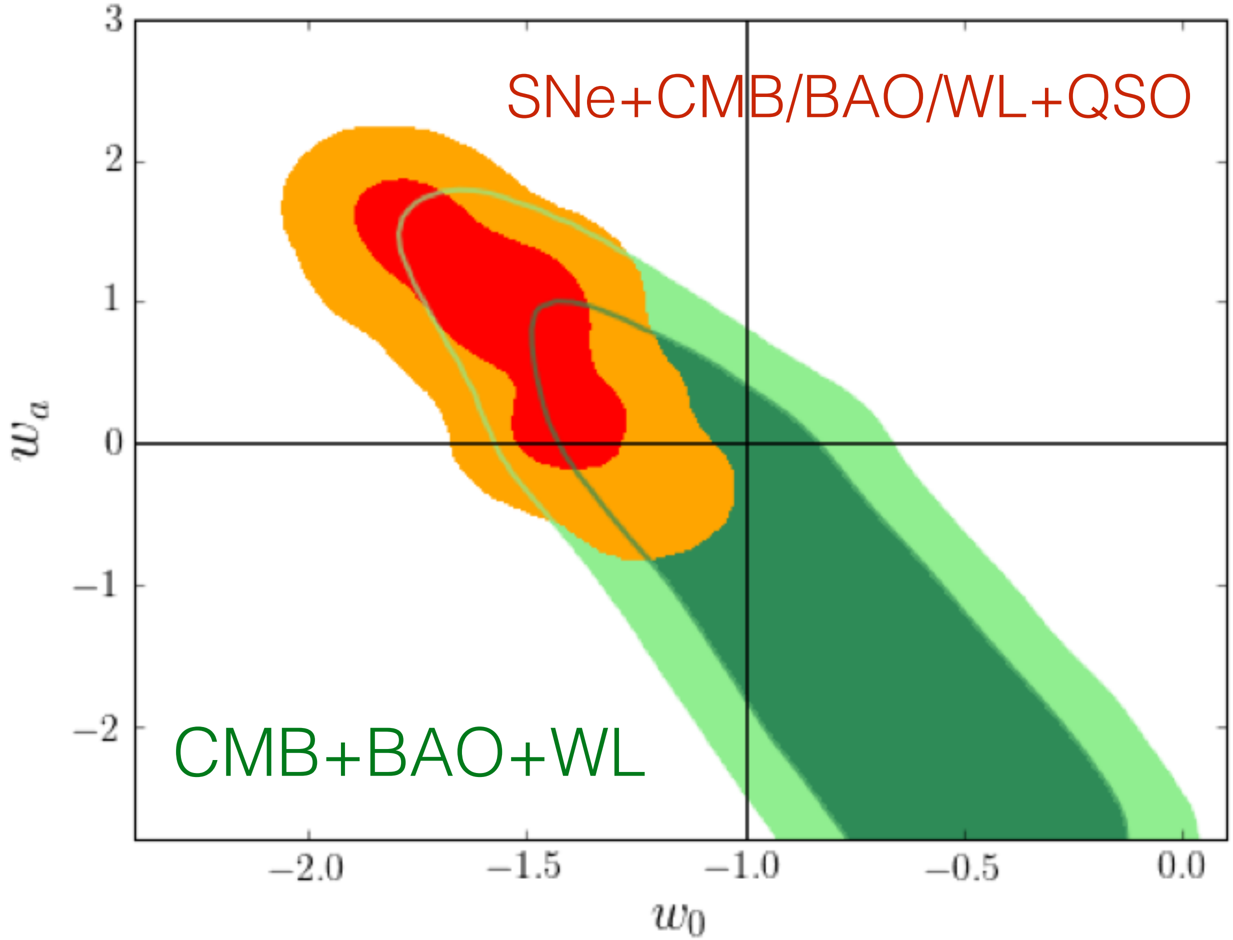
“Cosmographic” fits to the Hubble Diagram



Quasars as Standard Candles: tests of cosmology

physical fits to the Hubble Diagram

w_0-w_a plane where $w(z)=w_0+w_a{*}z/(1+z)$, w=-1 no evolution



Risaliti & Lusso 2019, Nat. Astronomy

Tension with the Standard model

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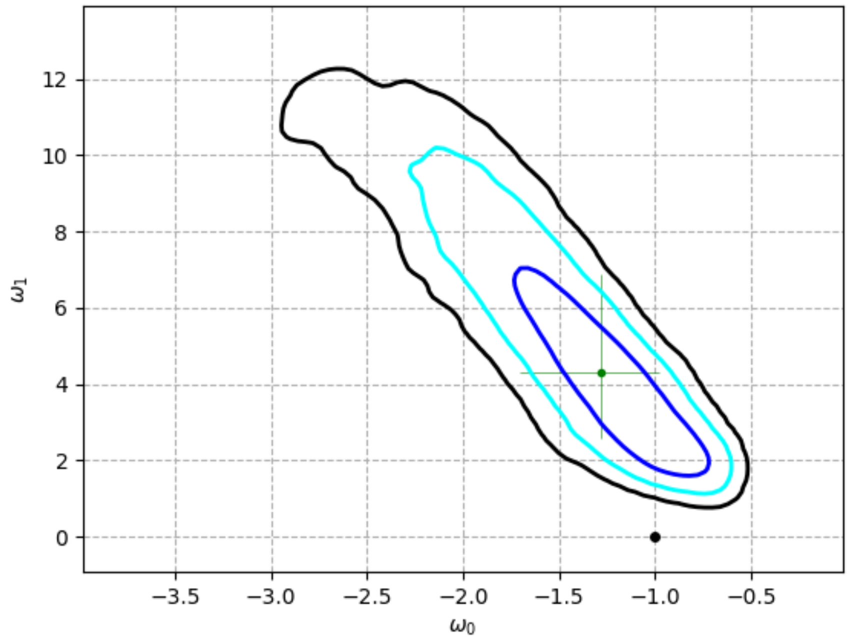
$$p_\phi = \frac{1}{2} \frac{1}{\hbar c^3} \dot{\phi}^2 - V(\phi)$$

$$z < z_0 \rightarrow w = w_0$$

$$z > z_0 \rightarrow w = w_1 (z - z_0)^2$$



Tension with the Standard model

nature astronomy

ARTICLES

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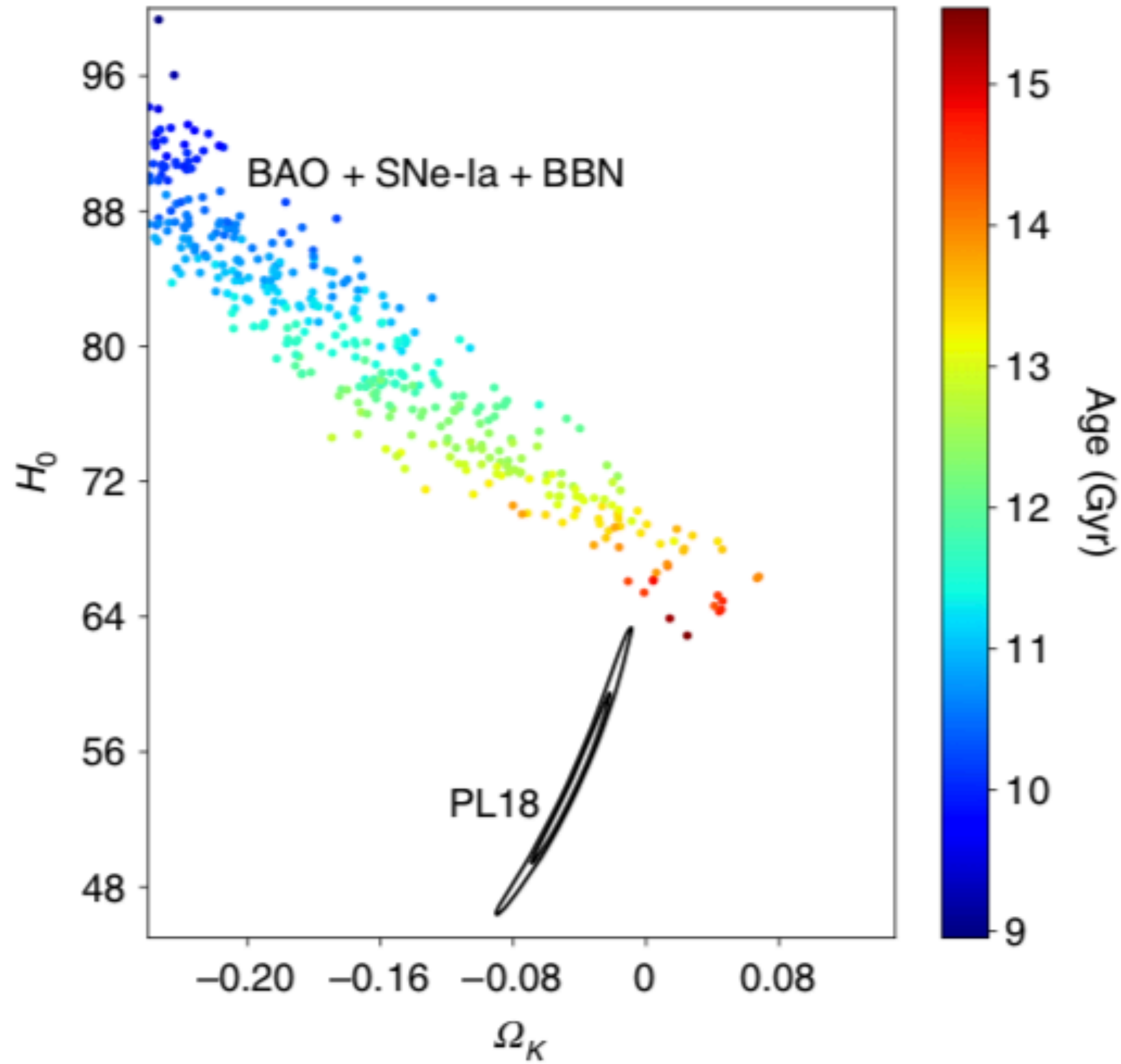
Planck evidence for a closed Universe and a possible crisis for cosmology

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

The recent Planck Legacy 2018 release has confirmed the presence of an enhanced lensing amplitude in cosmic microwave background power spectra compared with that predicted in the standard Λ cold dark matter model, where Λ is the cosmological constant. A closed Universe can provide a physical explanation for this effect, with the Planck cosmic microwave background spectra now preferring a positive curvature at more than the 99% confidence level. Here, we further investigate the evidence for a closed Universe from Planck, showing that positive curvature naturally explains the anomalous lensing amplitude, and demonstrating that it also removes a well-known tension in the Planck dataset concerning the values of cosmological parameters derived at different angular scales. We show that since the Planck power spectra prefer a closed Universe, discordances higher than generally estimated arise for most of the local cosmological observables, including baryon acoustic oscillations. The assumption of a flat Universe could therefore mask a cosmological crisis where disparate observed properties of the Universe appear to be mutually inconsistent. Future measurements are needed to clarify whether the observed discordances are due to undetected systematics, or to new physics or simply are a statistical fluctuation.

Tension with the Standard model



Conclusions

The Standard Cosmological model is creaking…

Local value of H0 confirmed in two completely independent ways

>5 sigma tension with the CMB+standard model prediction

The expansion at z>2 is different than predicted by the standard model

Maybe inconsistencies with the standard model *within* CMB measurements

Possible new physics include interacting dark sector, "quintessence" models…
modifications to GR