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The cosmic inverse distance ladder: baryon acoustic oscillations and type-Ia supernovae.

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Abstract

Recent measurements of the cosmic microwave background from *Planck* satellite, extrapolated in the context of the ΛCDM cosmological model, predict a value of the Hubble constant that seems at odds with local measurements of the expansion rate. This discrepancy has opened some debate about the estimation of systematic errors in both sides, as well as the existence of new physics that could bring both measurements into agreement, in particular by invoking a modification in the neutrino sector. Luckily we can also use additional sources of complementary cosmological information that have something to say in this debate since they trace the expansion of the Universe at intermediate redshifts. In this talk we show the value of combining the distance-redshift relation measurements from baryon acoustic oscillations together with type-Ia supernovae covering a wide redshift range. In particular we highlight the importance of the precision measurements by the Baryon Oscillation Spectroscopic Survey (BOSS-DR11) in our results.

1 Introduction

The discrepancy between recent measurements of the Hubble constant from the Local Universe [12] and extrapolations from Cosmic Microwave Background measurements [11] have fueled a heated debate about the need for new physics beyond the ΛCDM cosmological model (e.g. [14]). However, this discrepancy has been alleviated by re-calibrations in local expansion rate measurements [6, 9] as well as by possible systematic effects unaccounted for in *Planck* data [13]. In this context, the intermediate redshift Universe offers a new window to assess these discrepancies. Recent high-quality measurements of the distance-redshift relation, in galaxy surveys via the baryon acoustic oscillation feature in galaxy clustering statistics, as well as in type-Ia supernovae samples via their luminosity distance measurements, provide an alternative way to explore if there is any mis-match between the local $z = 0$ measurements and the extrapolated predictions from the Cosmic Microwave Background at $z = 1\,100$. This approach is also explored in [8], and the results shown here will be published in a forthcoming paper[1].

2 Methodology and datasets

In the analysis shown here, we use a compilation of BAO measurements from 6dFGS [4], and BOSS LOWZ and CMASS [1]. We also use a supernova compilation from samples at different redshifts by [3]. When a prior on H_0 is needed, we use the measurement of $73.8 \pm 2.4\,\mathrm{km\,s^{-1}\,Mpc^{-1}}$ by Riess et al. [12]. When a prior on the length of the standard ruler of the BAO (the sound horizon at drag epoch) is required, we use $147.5 \pm 0.6\,\mathrm{Mpc}$ (or the one for the corresponding cosmological model) as quoted by *Planck* [11]. The MCMC analysis is performed by the code COSMOMC [10], which is used to compute cosmological constraints in the expansion history of the Universe between redshifts $z = 0$ and $z = 2$. In order to do so, we modify slightly the code so that it outputs the value of the Hubble parameter at different redshifts uniformly spaced in $\log(1 + z)$.

3 The role of standard rulers and standard candles

In Fig. 1 we show the different way baryon acoustic oscillations and supernovae measurements constrain the expansion history of the Universe at different redshifts. On the left panel, we show that BAOs are able to constrain the amplitude of the expansion rate, due in particular to the precision of those measurements, although given that there are only a handful of measurements available, the shape of the expansion history is not very well constrained. On the other hand, the right panel shows how precisely the shape of the expansion history if measured by type-Ia supernovae data, since they probe very finely the entire redshift range. However, since the absolute magnitude of a fiducial supernova is an unknown parameter that has to be marginalized over, the value of H_0 is uncertain in this case.

The cartoon picture we have just described finds its quantitative counterpart in Fig. 2. Both panels show the constraints in the parameters Ω_m and H_0 assuming a ΛCDM model. The left panel shows the constraints obtained when we combine BAO and SN and we also assume a prior on the Hubble constant from direct measurements of the local expansion rate.

[1] All the results contained in these Proceedings should be considered preliminary work. Please refer to Reference [5] by the same authors (submitted to MNRAS) for a more complete, updated and revised discussion on this topic.

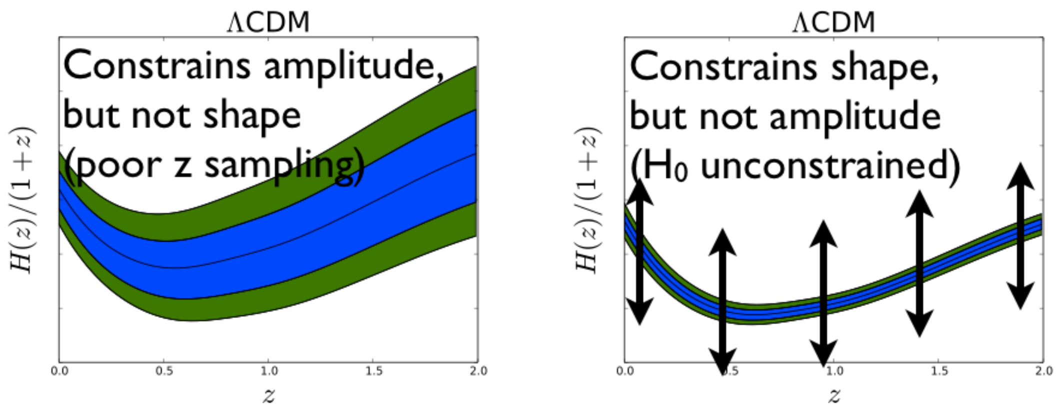

Figure 1: The role of baryon acoustic oscillation measurements (once the length of the standard ruler r_d is known) and type-Ia supernovae measurements in constraining the expansion history of the Universe.

This approach is dubbed the *direct* cosmic distance ladder. Solid blue contours show the constraints from the combination of BAO (green lines), SN (blue lines) and the H_0 prior (red lines). Although not completely inconsistent, this plot shows how the combined constraints have to accommodate all datasets. On the right panel, we show the combination of BAO and SN when a prior on the sound horizon at drag epoch is assumed. This approach is dubbed the *inverse* cosmic distance ladder. In this case, the constraints from the r_d prior (red lines) are almost orthogonal to the BAO constraints, following the $\Omega_m h^2$ dependence of r_d (e.g. [7]) and highly reducing the overall uncertainty in H_0.

4 Inverse distance ladder constraints on H_0

Table 1: The constraints in the Hubble constant H_0 (in km s^{-1} Mpc^{-1}) for different cosmological models and dataset combinations.

	BAO+SN	BAO+r_d	BAO+SN+r_d
ΛCDM	68.5±2.1	68.1±0.8	68.1±0.8
OΛCDM	64.4±7.4	66.8±1.5	67.7±1.2
wCDM	71.5±10.9	65.8±3.4	68.0±1.2
$N_{\rm eff}$CDM	75.5±4.5	69.3±1.3	68.8±1.0

In Table 1 we show the different constraints we obtain for the value of the Hubble constant H_0, in different cosmological models as well as different combinations of datasets. The cosmological models explored are the standard ΛCDM model with cold dark matter plus cosmological constant, and three extensions of it in which we allow for an additional degree of freedom, which are: a non-flat geometry (OΛCDM), an equation of state for dark energy

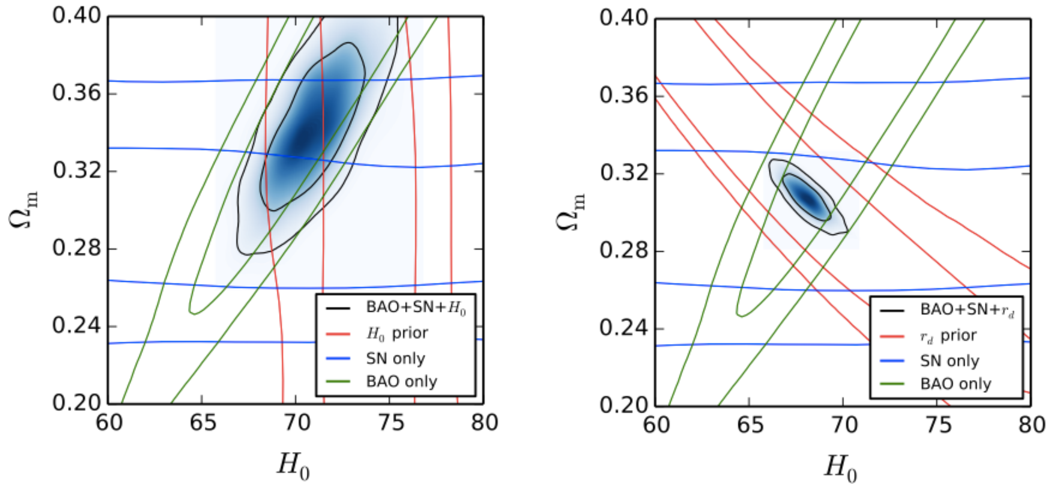

Figure 2: Constraints in the Ω_m–H_0 plane from the *direct* cosmic distance ladder (left panel), and the *inverse* cosmic distance ladder (right panel).

different from $w = -1$ (wCDM), or extra radiation density which can be interpreted as a non-standard value of the effective number of relativistic species ($N_{\rm eff}$CDM). The datasets considered are the combination of BAO and SN data, but without assuming any prior on the length of the standard ruler r_d; BAO only with a prior on r_d taken from *Planck* for that particular cosmological model; or all three datasets combined. We find that this *inverse* distance ladder approach usually returns a smaller uncertainty on H_0 than direct measurements only if a prior on r_d is assumed. Once all these three datasets are combined, the result is very stable with respect to these extensions of the ΛCDM model, resulting in a H_0 value of roughly $68\,\mathrm{km\,s^{-1}\,Mpc^{-1}}$.

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