Addendum: Fitting the DESI BAO Data with Dark Energy Driven by the Cohen–Kaplan–Nelson Bound

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Abstract

Motivated by the recent Year-2 data release of the DESI collaboration, we update our results on time-varying dark energy models driven by the Cohen–Kaplan–Nelson bound. The previously found preference of time-dependent dark energy models compared to ΛCDM is further strengthend by the new data release. For our particular models, we find that this preference increases up to $\approx 2.6\,\sigma$ depending on the used supernova dataset.

1 Introduction

In this addendum, we update the results of our previous work [1] in the light of the recent Year-2 data release (DR2) of the Dark Energy Spectroscopic Instrument (DESI) collaboration [2]. We consider a dark energy scaling proportional to the squared Hubble parameter $H(z)$ as

$$\rho_{\mathrm{DE}}(z) = \Lambda_0 + \nu \frac{M_{\mathrm{Pl}} H^2(z)}{16\pi^2}\,, \tag{1}$$

where Λ_0 is the contribution of the classical cosmological constant to the dark energy density $\rho_{\mathrm{DE}}(z)$, M_{Pl} is the Planck mass, and ν is a free parameter of the model. As discussed in our previous work, this scaling is motivated by the Cohen–Kaplan–Nelson (CKN) bound [3], used to connect the quantum corrections of the dark energy density to the size of the universe. Hence, as introduced in Reference [1], we call the dark energy density evolving from Equation (1) νCKN model, or simply CKN model for the case $\nu = 1$.

In Section 2, we show the result of our combined analysis of the DESI baryonic acoustic oscillations (BAO) DR2 [2], supernova datasets [4, 5] and model-independent Hubble measurements [6, 7]. We compare the results of the (ν)CKN models with other dark energy models in the literature, and discuss the difference to the fit for which the DESI BAO Year-1 data release (DR1) [8] is used instead. Finally, we summarize and discuss the results in Section 3.

2 Updated Results

Analogously to the statistical procedure described in Reference [1], we perform a χ^2 fit and provide the resulting best-fit points of the CKN and νCKN model in Table 1. Since we use two different supernova datasets, DES-SN5YR (DESY5) and Pantheon+, we always combine the DESI BAO DR2 and Hubble data with one of them

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Table 1: Results of the best-fit points for the CKN and νCKN case to the datasets of DESI BAO DR2 and Hubble, once combined with DESY5 and once with Pantheon+ data. Shown are the results for Hubble-today H_0, the matter density parameter Ω_{M}^0, the drag epoch r_{d}, the parameter ν and the minimal χ^2_{min} over the degrees of freedom (DOF).

Model/Datasets	H_0/(km/s/Mpc)	Ω_{M}^0	r_{d}/Mpc	ν	χ^2_{min}/DOF
CKN					
+ DESY5	68.83 ± 2.35	0.352 ± 0.009	144.27 ± 4.85	–	1674/1871
+ Pantheon+	69.09 ± 2.36	0.347 ± 0.009	144.23 ± 4.85	–	1437/1632
$\boldsymbol{\nu}$**CKN**					
+ DESY5	68.90 ± 2.38	0.348 ± 0.018	144.26 ± 4.85	0.92 ± 0.35	1674/1870
+ Pantheon+	69.46 ± 2.40	0.330 ± 0.018	144.21 ± 4.85	0.64 ± 0.36	1436/1631

separately. The resulting χ^2 values show that both the CKN and the more general νCKN models are well compatible with the experimental measurements, as the goodness of the best-fit points over the degrees of freedom (DOF) are $\chi^2/\mathrm{DOF} \approx 0.89$ and $\chi^2/\mathrm{DOF} \approx 0.88$ for the DESY5 and Pantheon+ data, respectively.

For the comparison to other dark energy models, we provide the best-fit points of ΛCDM, ωCDM, and $\omega_0\omega_a$CDM [9, 10] in Table 2 and their χ^2 difference to the (ν)CKN models in Table 3. To compare between models with a different number of model parameters k, we use the Akaike information criterion (AIC)

$$\mathrm{AIC} = \chi^2_{\mathrm{min}} + 2k\,. \tag{2}$$

The results show that the CKN and νCKN models are preferred with respect to the ΛCDM model for both datasets. In case of the νCKN model, the χ^2 difference can be translated into a significance of $2.63\,\sigma$ and $1.75\,\sigma$ for the DESY5 and the Pantheon+ data, respectively. However, the $\Delta\chi^2$ and ΔAIC values show that the ωCDM and $\omega_0\omega_a$CDM models provide an even better fit to the data. Only according to the ΔAIC values for the combination with the Pantheon+ dataset, both, the CKN and νCKN models are slightly preferred with respect to the $\omega_0\omega_a$CDM model.

The differences between the χ^2 values of the DESI BAO DR1 and DR2 are presented in Table 4 and demonstrate that the fit of all models improved. However, the improvement of the fit for the ΛCDM model is non-significant, whereas the new measurements have a higher impact on the time-dependent dark energy models. In the case of the Pantheon+ data, the improvement of the ΛCDM model is larger than for the DESY5 data. The most significant change can be found for the ωCDM and νCKN models, for the DESY5 and Pantheon+ supernova dataset, respectively.

The improved statistics of the new measurements on the fit can also be seen in the correlation plots of the CKN and νCKN models for both supernova datasets in Figures 1 to 4, leading to a smaller 95 % and 68 % confidence level (CL) area compared to the results from DESI BAO DR1.

3 Discussion

As expected, the higher statistics coming with the DR2 leads to smaller uncertainties on the model parameters and is visible in their corresponding correlation plots for the (ν)CKN models. The widely discussed findings from DR1, that models featuring a time-varying dark energy are preferred with respect to ΛCDM, is further strengthened by the recent data release of the DESI experiment. Remarkably, this trend is also visible in the (ν)CKN models. For the Pantheon+ dataset, the νCKN model experiences a larger improvement in the fit between DR1 and DR2 compared to the CKN model. The trend revealed through the new DESI data release fuels the hope that we are moving towards a future where the mysteries of dark energy may at last begin to unfold.

Table 2: Results of the best-fit points from the ΛCDM, ωCDM and $\omega_0\omega_a$CDM model to the datasets of DESI BAO DR2 and Hubble, once with DESY5 and once with Pantheon+ data. Shown are the results for Hubble-today H_0, the matter density parameter $\Omega_{\rm M}^0$, the drag epoch $r_{\rm d}$, the parameters ω_0 and ω_a, and the minimal $\chi^2_{\rm min}$/DOF.

Model /Datasets	H_0 in km/s/Mpc	$\Omega_{\rm M}^0$	$r_{\rm d}$ in Mpc	ω or ω_0	ω_a	$\chi^2_{\rm min}$/DOF
ΛCDM						
+ DESY5	69.77 ± 2.38	0.309 ± 0.008	144.28 ± 4.85	–	–	1681/1871
+ Pantheon+	70.10 ± 2.39	0.303 ± 0.008	144.21 ± 4.85	–	–	1439/1632
ωCDM						
+ DESY5	68.71 ± 2.37	0.297 ± 0.009	144.11 ± 4.85	-0.88 ± 0.04	–	1670/1870
+ Pantheon+	69.32 ± 2.40	0.297 ± 0.008	144.10 ± 4.85	-0.92 ± 0.04	–	1435/1631
$\omega_0\omega_a$CDM						
+ DESY5	68.69 ± 2.50	0.321 ± 0.013	143.70 ± 5.01	-0.78 ± 0.07	-0.77 ± 0.39	1668/1869
+ Pantheon+	69.49 ± 2.28	0.302 ± 0.017	143.60 ± 4.58	-0.91 ± 0.06	-0.11 ± 0.43	1434/1630

Table 3: Comparison between CKN and νCKN and alternative cosmological models. Shown is the difference $\Delta\chi^2 = \chi^{2,(\nu)\rm CKN}_{\rm min} - \chi^{2,\rm alt.model}_{\rm min}$ for both datasets and the difference ΔAIC. The negative values indicate a preference of CKN and νCKN over the alternative models, respectively. See text for a comparison of the νCKN and ΛCDM model in terms of significances.

Models	$\Delta\chi^2_{\rm DESY5}$	$\Delta\rm AIC_{DESY5}$	$\Delta\chi^2_{\rm Pantheon+}$	$\Delta\rm AIC_{Pantheon+}$
CKN with				
ΛCDM	−6.90	−6.90	−2.05	−2.05
ωCDM	3.14	1.14	2.26	0.26
$\omega_0\omega_a$CDM	5.74	1.74	2.43	−1.57
νCKN with				
ΛCDM	−6.94	−4.94	−3.07	−1.07
ωCDM	3.09	3.09	1.24	1.24
$\omega_0\omega_a$CDM	5.69	3.69	1.41	−0.59

Table 4: Difference of the $\chi^2_{\rm min}$ values $\Delta\chi^2_{\rm DR2-DR1}$ between the fit with DESI BAO DR1 and DR2 combined with Hubble measurements and either the DESY5 or the Pantheon+ supernova dataset for different cosmological models considered in this work.

Models	$\Delta\chi^2_{\rm DR2-DR1}$	
	DESY5	Pantheon+
CKN	−2.85	−2.84
νCKN	−2.91	−3.76
ΛCDM	−0.52	−1.93
ωCDM	−3.72	−3.59
$\omega_0\omega_a$CDM	−3.29	−3.13

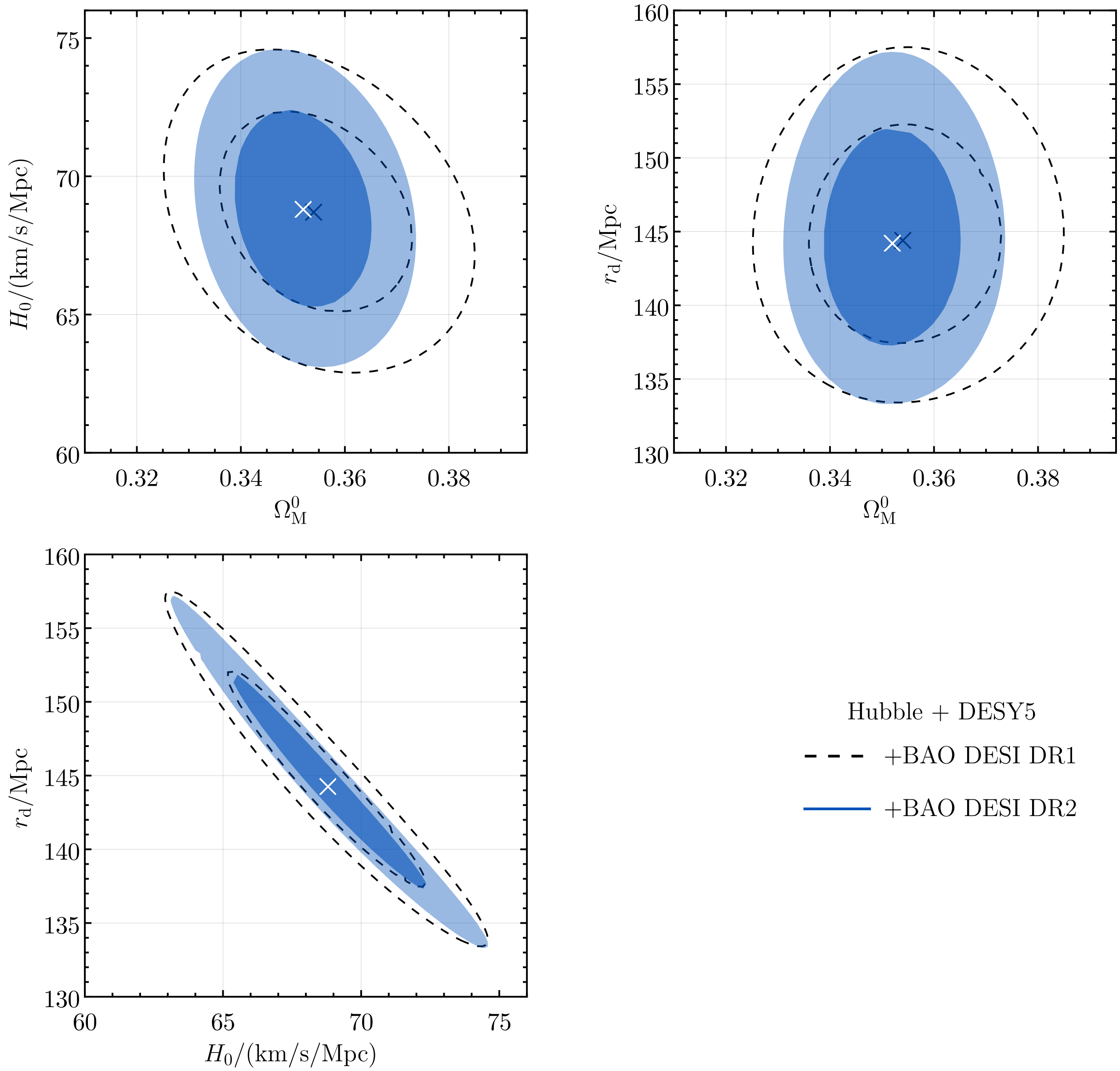

Figure 1: Correlations of H_0–Ω_{M}^0 (top left), H_0–r_{d} (top right), r_{d}–Ω_{M}^0 (bottom left) in the CKN model for the DESI BAO+Hubble+DESY5 DR1 (black dashed lines) and DESI BAO+Hubble+DESY5 DR2 (blue area) dataset at the 95 % and 68 % CL.

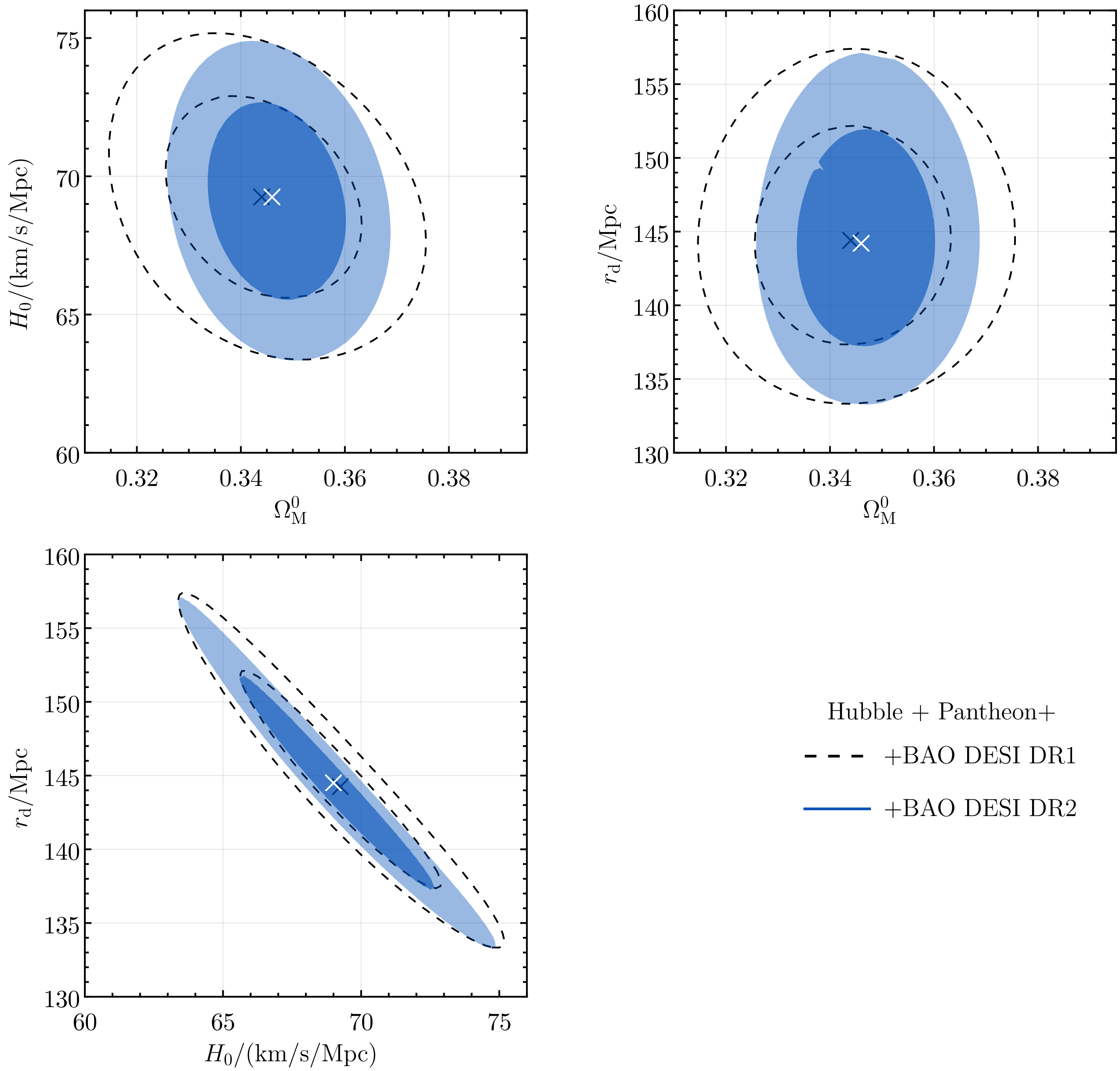

Figure 2: Correlations of H_0–$\Omega_{\rm M}^0$ (top left), H_0–$r_{\rm d}$ (top right), $r_{\rm d}$–$\Omega_{\rm M}^0$ (bottom left) in the CKN model for the DESI BAO+Hubble+Pantheon+ DR1 (black dashed lines) and DESI BAO+Hubble+Pantheon+ DR2 (blue area) dataset at the 95 % and 68 % CL.

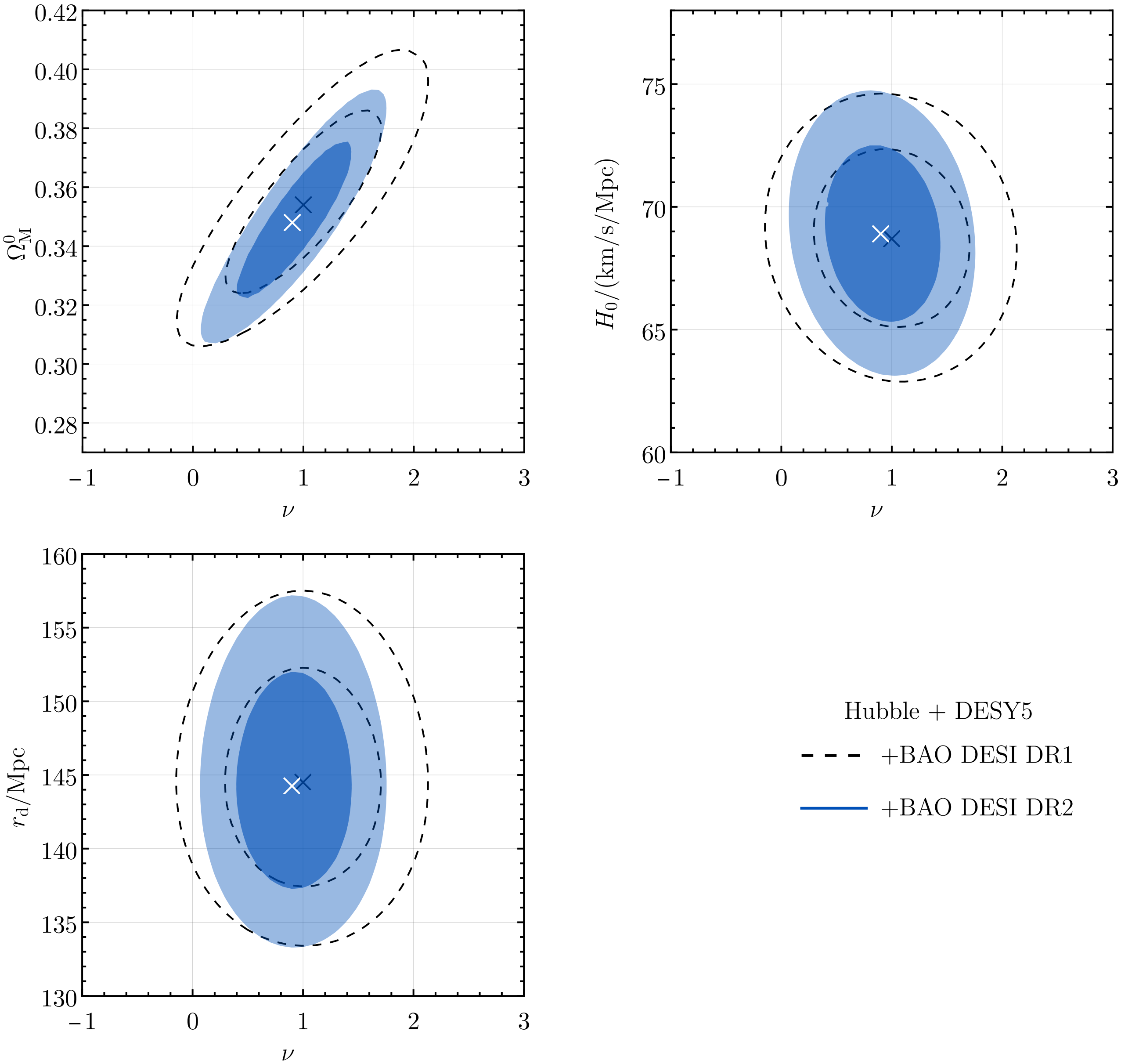

Figure 3: Correlations of ν–$\Omega^0_{\rm M}$ (top left), ν–H_0 (top right), ν–$r_{\rm d}$ (bottom left) in the νCKN model for the DESI BAO+Hubble+DESY5 DR1 (black dashed lines) and DESI BAO+Hubble+DESY5 DR2 (blue area) dataset at the 95 % and 68 % CL.

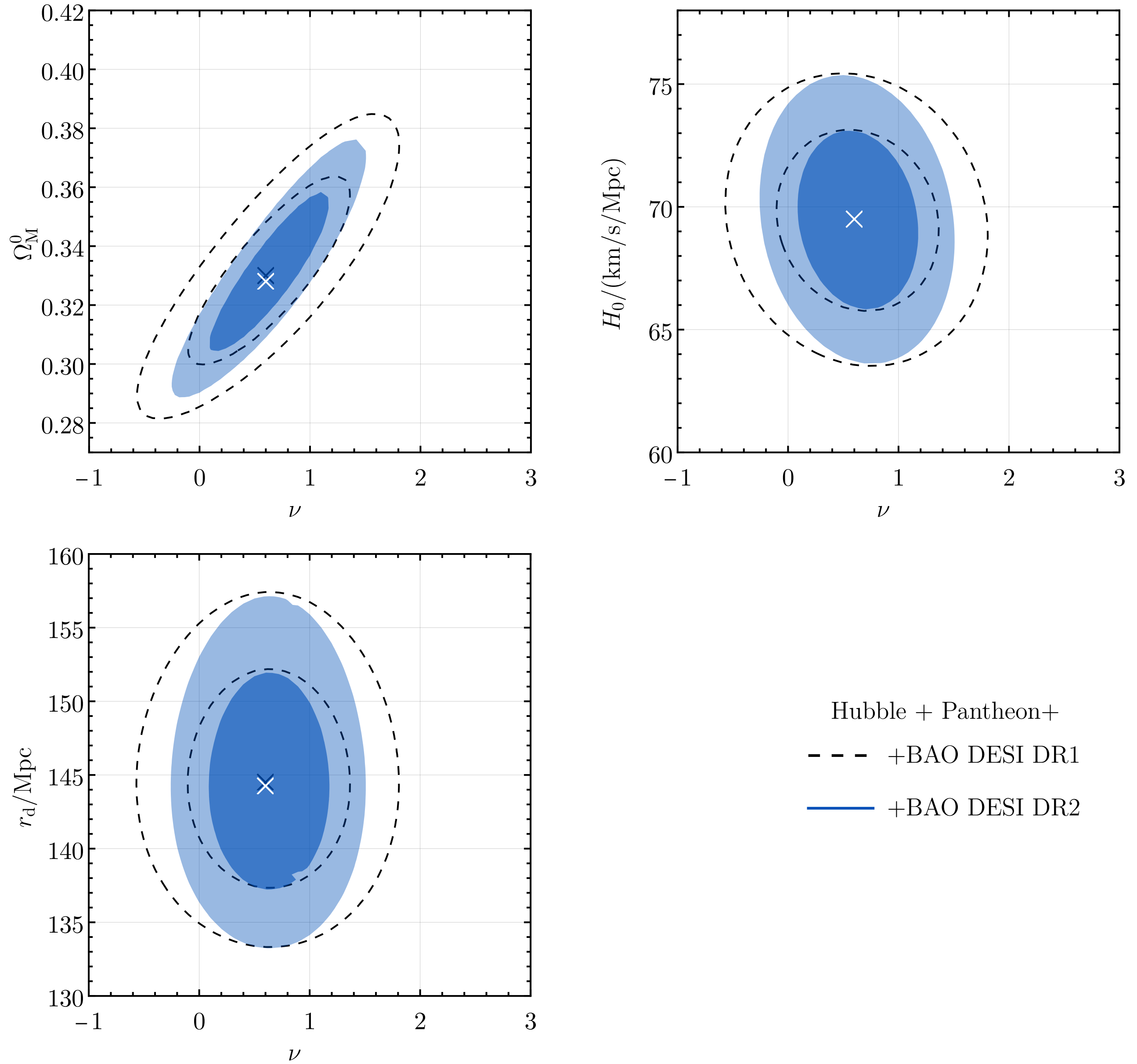

Figure 4: Correlations of ν–$\Omega_{\rm M}^0$ (top left), ν–H_0 (top right), ν–$r_{\rm d}$ (bottom left) in the νCKN model for the DESI BAO+Hubble+Pantheon+ DR1 (black dashed lines) and DESI BAO+Hubble+Pantheon+ DR2 (blue area) dataset at the 95 % and 68 % CL.

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