Interacting Dark Energy Models with Late Cosmological Data

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Introduction

The extensive release of accurate astronomical data has opened avenues for answering questions about modern cosmology. Its level of precision enables us to evaluate cosmological models and accurately determine cosmological parameters. One model, namely the ΛCDM adequately explains most observations that there currently are, with the cosmological constant (Λ) explaining the observed acceleration of the Universe and cold dark matter (CDM) generating gravitational wells that align with observations on both galactic and cosmological scales. For instance, the observation of supernova type Ia (SNIa) made researchers aware in 1998 of such expansion and acceleration of the Universe after the unexpected faintness in the data. Better yet, most independent observations, including cosmic background microwave (CMB) [1], baryon acoustic oscillations (*BAO*), weak lensing (WL) and many more, confirmed the fact that the Universe indeed is expanding.

- Addressing the shortcomings of the standard cosmological model (ΛCDM).
- Exploring whether a non gravitational interaction in the dark sector is supported by data.
- Testing the viability of the IDE model using observational data.

Dark Enegy and Dark Matter Interaction

Dark energy and Dark matter are the two fundamental forces shaping how the universe behaves. As their names imply, they cannot be directly observed even with the most advanced instruments capable of detecting various wavelengths of light. We can only study them indirectly by examining how they interact with other types of matter throughout the universe.

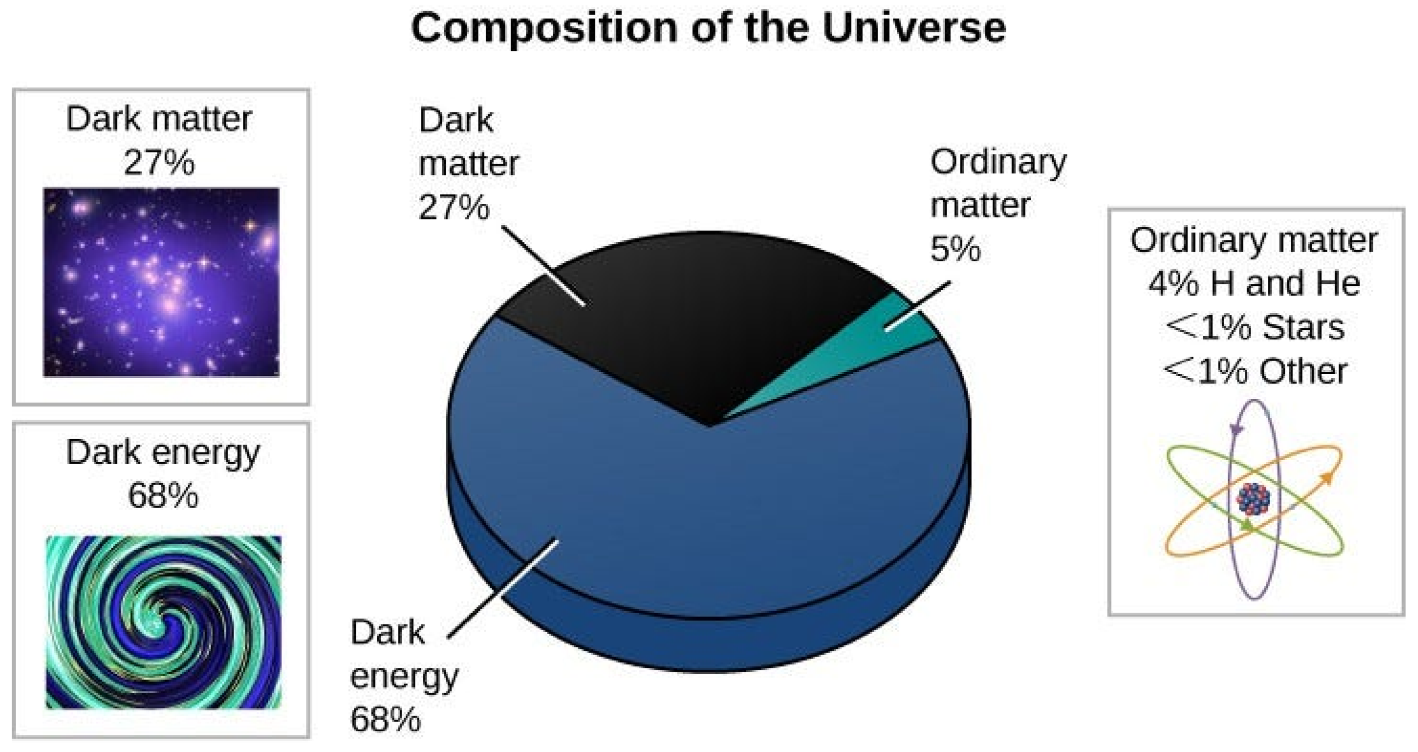

Figure 1: The Composition of the Universe: We can only see and interact with 5% of the matter in the universe, while a little over two-thirds of it is composed of dark energy. (Image credit: Lumen Learning Astronomy)

- Dark energy and dark matter evolve independently with energy densities managed separately in ΛCDM.

$$\nabla_\mu T^{\mu\nu}_{(dm)} = Q^\nu, \qquad \nabla_\mu T^{\mu\nu}_{(de)} = -Q^\nu, \tag{1}$$

The conservation equations as;

$$\dot{\rho}_{dm} + 3H\rho_{dm} = Q, \tag{2}$$

$$\dot{\rho}_{de} + 3H\rho_{de}(1+\omega_{de}) = -Q\ , \tag{3}$$

ΛCDM Constraints

ΛCDM

- Here ΛCDM shows tightly constrained parameters Ω_m and H_0.
- The combination of all datasets, *CC* + *PantheonP* + *SH0ES* maintains the H_0 tension at 5σ, reducing the calibrated *PantheonP* + *SH0ES*.
- Despite the degeneracies that lie within the *BAO* and *PantheonP* + *SH0ES*, we cannot rule out ΛCDM before cross-checking other available datasets.

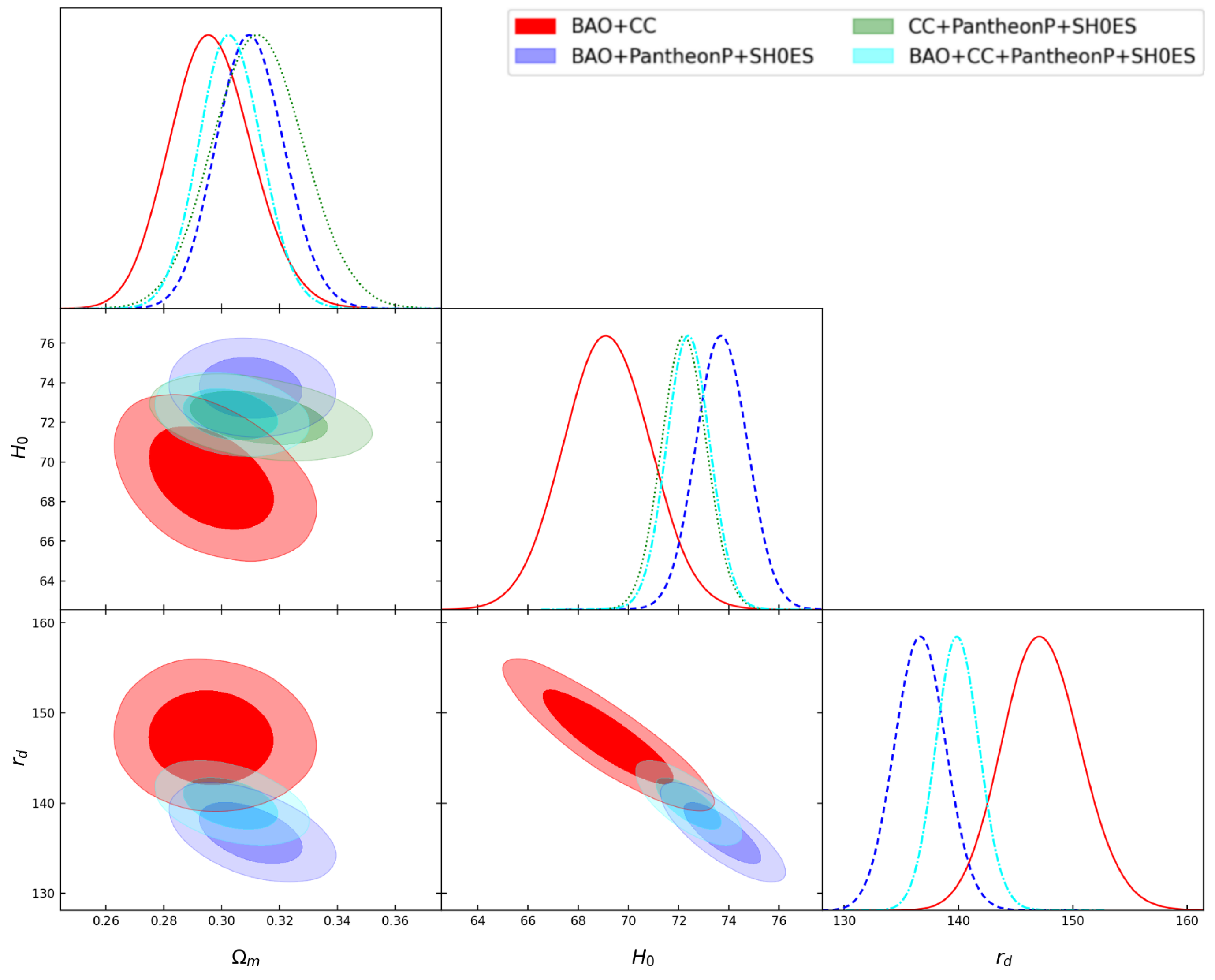

Figure 2: Two-dimensional plots illustrating 1D marginalized distributions with 1σ and 2σ contours of cosmological parameters for the ΛCDM model from the combination of all.

IDE1: $Q = H\xi\rho_{de}$ Constraints

- It can be seen that the parameter ξ for the joint datasets favours the quintessence in which DE decays into DM, contributing to the accelerating expansion of the universe at present.
- This combination provides strong constraints on all parameters, but *BAO* + *CC*, *BAO* + *PantheonP* + *SH0ES*, and *CC* + *PantheonP* + *SH0ES* weakly constrain the parameters except for H_0.
- Thus, the constraint estimate value H_0 from *CC* + *PantheonP* + *SH0ES* shows alignment with the value found in when combined with SNIa and *BAO*.
- This model does not reconcile the tension H_0, as can be seen from the inconsistencies in the values.
- In summary, this interacting model shows mild interaction in the dark sector and shows consistency with the non-interacting cosmology.

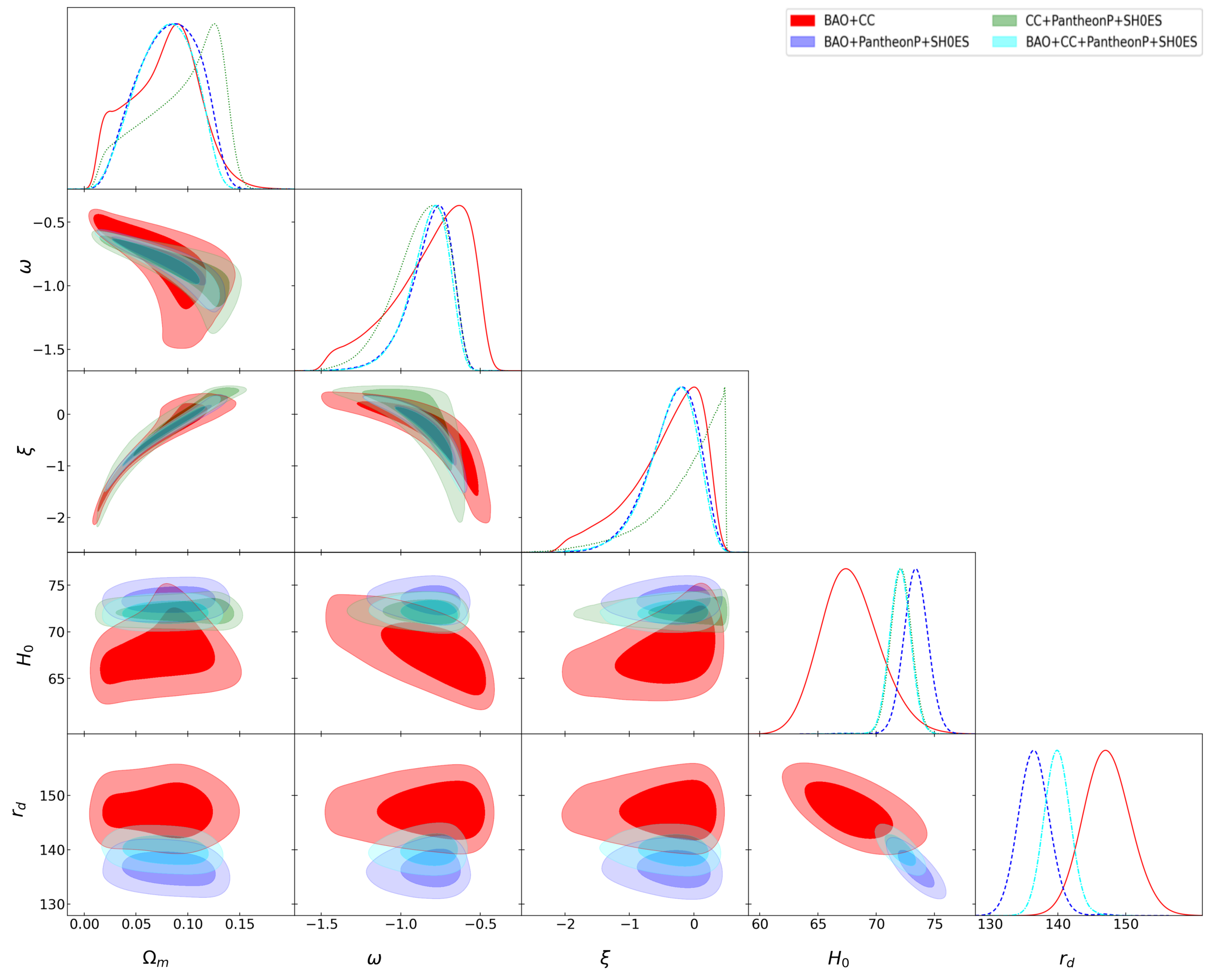

Figure 3: Two-dimensional plots illustrating 1D marginalized distributions with 1σ and 2σ contours of cosmological parameters for the IDE1 model from the combination of all.

IDE2: $Q = 3H\xi\frac{\rho_{dm}\rho_{de}}{\rho_{dm}+\rho_{de}}$ Constraints

- The observational constraints on the parameters are weakly constrained, apart from the H_0 parameter showing compatibility among the combined datasets with a smooth Gaussian distribution.
- We look at the contours of $\{\Omega_m, \omega\}$, $\{\Omega_m, \xi\}$ and $\{\omega, \xi\}$ they have a tilted form showing the degeneracy between the parameters. This comes from the set priors for each parameter. Despite the degeneracies shown from the contours, this model reveals weak observational support for the interaction between DM and DE. Moreover, the model can help alleviate the H_0 tension due to the recorded uncertainties.
- The model, not only fits current observational data better than other IDE model, but also is statistically viable, a key challenge in contemporary cosmology.
- This model demonstrated competitive performance against ΛCDM and performed better than the IDE1.

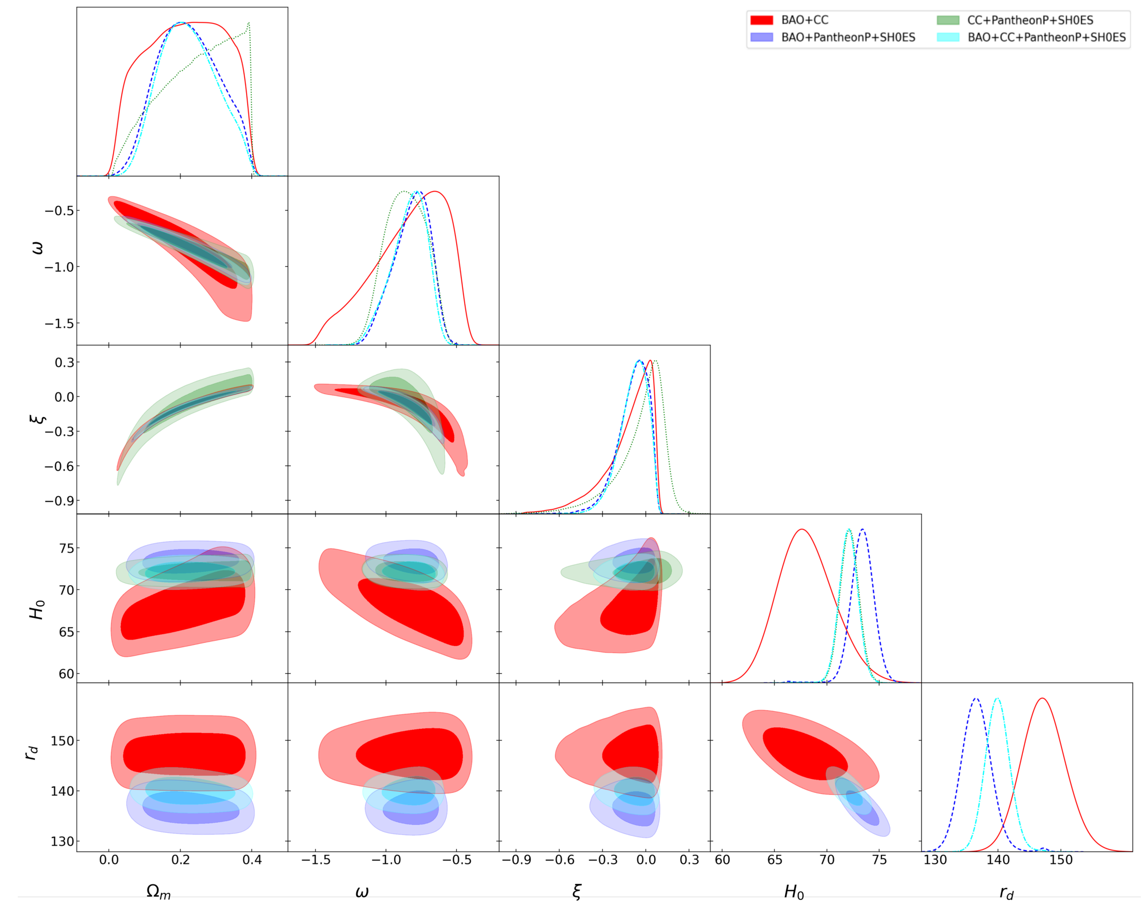

Figure 4: Two-dimensional plots illustrating 1D marginalized distributions with 1σ and 2σ contours of cosmological parameters for the IDE2 model from the combination of all.

Conclusion

- We investigated the non-linear model using the combination of the cosmological datasets: DESI *BAO*, *PantheonP* + *SH0ES*, and *CC* data.
- Taking responsibility for the known parameter degeneracies in the literature, particularly those arising from the joint use of DESI-*BAO* and *PantheonP* + *SH0ES* data.
- Our results indicate that this model, which is a nonlinear model, not only fits current observational data better than other IDE models, but also is statistically viable, a key challenge in contemporary cosmology.
- These findings support the viability of nonlinear interactions in the dark sector as a promising extension of the standard cosmological model.

References

[1] David N Spergel, Licia Verde, Hiranya V Peiris, Eiichiro Komatsu, MR Nolta, Charles L Bennett, Mark Halpern, Gary Hinshaw, Norman Jarosik, Alan Kogut, et al. First-year wilkinson microwave anisotropy probe (wmap)* observations: determination of cosmological parameters. *The Astrophysical Journal Supplement Series*, 148(1):175, 2003.