Measuring Hubble's Constant with the Inverse Distance Ladder

Ed Macaulay
www.ed-macaulay.com
edward.macaulay@gmail.com

Inverse Distance Ladder

MNRAS 000, 1–14 (2019) Preprint 29 May 2019 Compiled using MNRAS LATEX style file v3.0

First Cosmological Results using Type Ia Supernovae from the Dark Energy Survey: Measurement of the Hubble constant

E. Macaulay[1] ⋆, R. C. Nichol,[1] D. Bacon,[1] D. Brout,[2] T. M. Davis,[3] B. Zhang,[4,5] B. A. Bassett,[6,7] D. Scolnic,[8] A. Möller,[4,5] C. B. D'Andrea,[2] S. R. Hinton,[3] R. Kessler,[9,8] A. G. Kim,[10] J. Lasker,[9,8] C. Lidman,[5] M. Sako,[2] M. Smith,[11] M. Sullivan,[11] T. M. C. Abbott,[12] S. Allam,[13] J. Annis,[13] J. Asorey,[14] S. Avila,[1] K. Bechtol,[15] D. Brooks,[16] P. Brown,[17] D. L. Burke,[18,19] J. Calcino,[3] A. Carnero Rosell,[20,21] D. Carollo,[22] M. Carrasco Kind,[23,24] J. Carretero,[25] F. J. Castander,[26,27] T. Collett,[1] M. Crocce,[26,27] C. E. Cunha,[18] L. N. da Costa,[21,28] C. Davis,[18] J. De Vicente,[20] H. T. Diehl,[13] P. Doel,[16] A. Drlica-Wagner,[13,8] T. F. Eifler,[29,30] J. Estrada,[13] A. E. Evrard,[31,32] A. V. Filippenko,[33,34] D. A. Finley,[13] B. Flaugher,[13] R. J. Foley,[35] P. Fosalba,[26,27] J. Frieman,[13,8] L. Galbany,[36] J. García-Bellido,[37] E. Gaztanaga,[26,27] K. Glazebrook,[38] S. González-Gaitán,[39] D. Gruen,[18,19] R. A. Gruendl,[23,24] J. Gschwend,[21,28] G. Gutierrez,[13] W. G. Hartley,[16,40] D. L. Hollowood,[35] K. Honscheid,[41,42] J. K. Hoormann,[3] B. Hoyle,[43,44] D. Huterer,[32] B. Jain,[2] D. J. James,[45] T. Jeltema,[35] E. Kasai,[46,7] E. Krause,[29] K. Kuehn,[47] N. Kuropatkin,[13] O. Lahav,[16] G. F. Lewis,[48] T. S. Li,[13,8] M. Lima,[49,21] H. Lin,[13] M. A. G. Maia,[21,28] J. L. Marshall,[17] P. Martini,[41,50] R. Miquel,[51,25] P. Nugent,[10] A. Palmese,[13] Y.-C. Pan,[52,53] A. A. Plazas,[30] A. K. Romer,[54] A. Roodman,[18,19] E. Sanchez,[20] V. Scarpine,[13] R. Schindler,[19] M. Schubnell,[32] S. Serrano,[26,27] I. Sevilla-Noarbe,[20] R. Sharp,[5] M. Soares-Santos,[55] F. Sobreira,[56,21] N. E. Sommer,[4,5] E. Suchyta,[57] E. Swann,[1] M. E. C. Swanson,[24] G. Tarle,[32] D. Thomas,[1] R. C. Thomas,[10] B. E. Tucker,[4,5] S. A. Uddin,[58] V. Vikram,[59] A. R. Walker,[12] and P. Wiseman[11]

(DES Collaboration)

Author affiliations are shown in Appendix B

Accepted 2019 April 03. Received 2019 April 02; in original form 2018 November 08

ABSTRACT

We present an improved measurement of the Hubble constant (H_0) using the 'inverse distance ladder' method, which adds the information from 207 Type Ia supernovae (SNe Ia) from the Dark Energy Survey (DES) at redshift $0.018 < z < 0.85$ to existing distance measurements of 122 low redshift ($z < 0.07$) SNe Ia (Low-z) and measurements of Baryon Acoustic Oscillations (BAOs). Whereas traditional measurements of H_0 with SNe Ia use a distance ladder of parallax and Cepheid variable stars, the inverse distance ladder relies on absolute distance measurements from the BAOs to calibrate the intrinsic magnitude of the SNe Ia. We find $H_0 = 67.8 \pm 1.3$ km s^{-1} Mpc^{-1} (statistical and systematic uncertainties, 68% confidence). Our measurement makes minimal assumptions about the underlying cosmological model, and our analysis was blinded to reduce confirmation bias. We examine possible systematic uncertainties and all are below the statistical uncertainties. Our H_0 value is consistent with estimates derived from the Cosmic Microwave Background assuming a ΛCDM universe (Planck Collaboration et al. 2018).

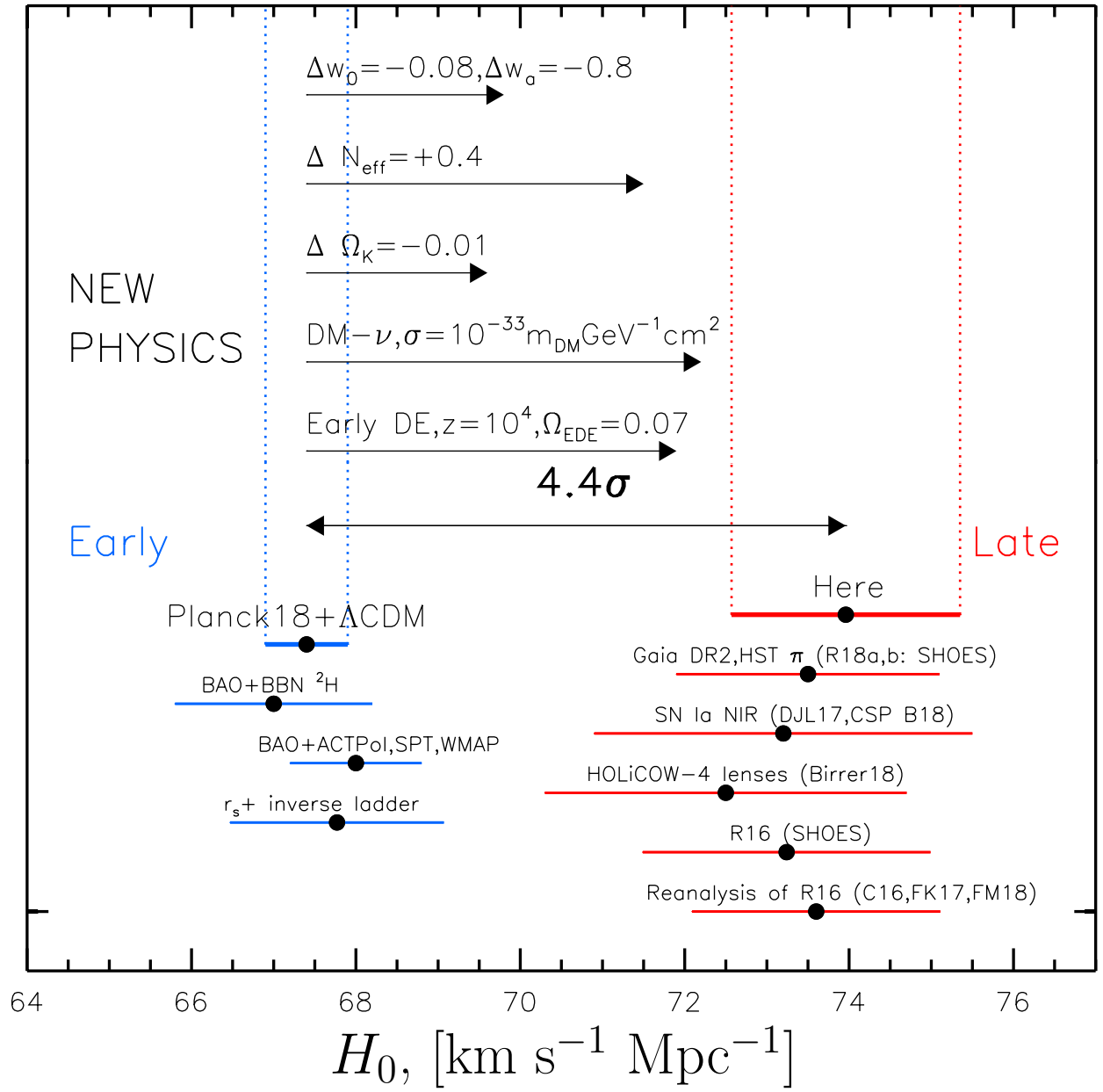
Key words: cosmology: observations – cosmology: cosmological parameters – cosmology: distance scale

⋆ email: edward.macaulay@port.ac.uk

- **Results from 3-year DES-SN sample in 2019**
- **Total of 329 spectroscopically observed SNe**
- **Blind analysis to reduce confirmation bias**
- **$H_0 = 67.8 \pm 1.3$ km s^{-1} Mpc^{-1}**

Macaulay et al. (2019)
arXiv:1811.02376

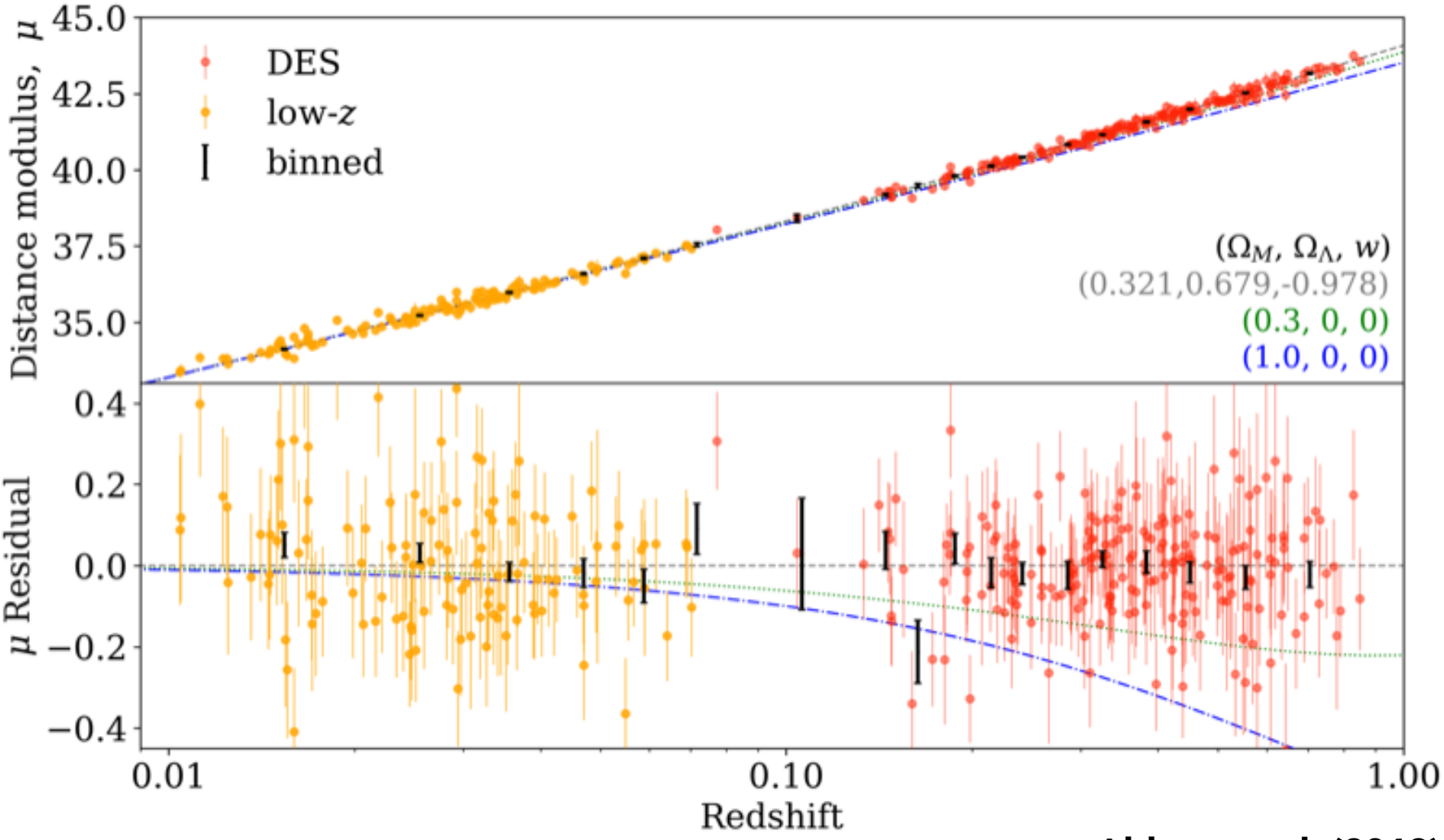
Overview of Tension



- **Difficult to reconcile results even observationally**

Riess et al. (2019) arXiv:1903.07603

DES 3-year SNe



Abbott et al. (2019)
arXiv: 1811.02374

Supernova H_0 - M_B Degeneracy

Supernova Observations

$$\mu = m_B^\star - (M_B - \alpha X_1 + \beta C)$$

Observed Measurements

Fitted Parameters

Distance Modulus

$$\mu = 25 + 5\log_{10}(D_{\rm L})$$

Degenerate

Luminosity Distance

$$D_{\rm L} = (1 + z_{\rm obs}) \int dz \frac{c}{H(z)}$$

Cosmographic Model

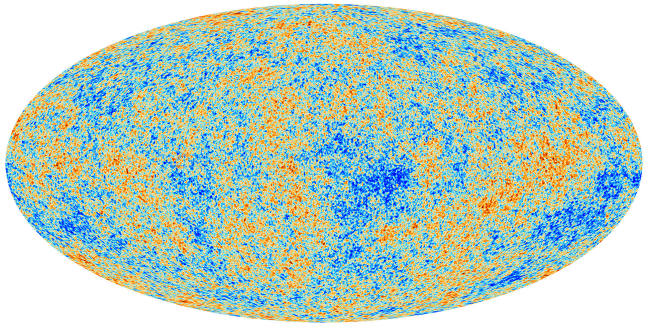
Agnostic to physics of distance-redshift relation

$$D_{\rm L} = \underbrace{\frac{c\,z}{H_0}}_{\text{'linear' Hubble's Law}} \underbrace{\left[1 + \frac{z}{2}(1 - q_0) - \frac{z^2}{6}\left(1 - q_0 - 3q_0^2 + j_0\right)\right]}_{\text{Extra terms, describe expansion history}}$$

eg., Feeney et al (2018) arXiv: 1802.03404

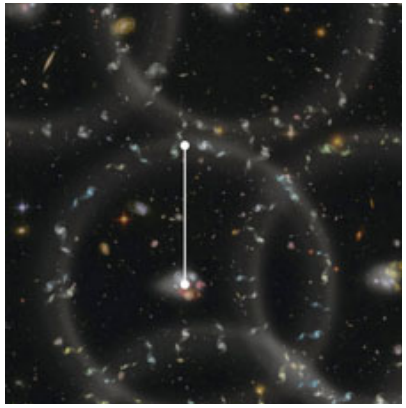
Inverse Distance Ladder

Planck



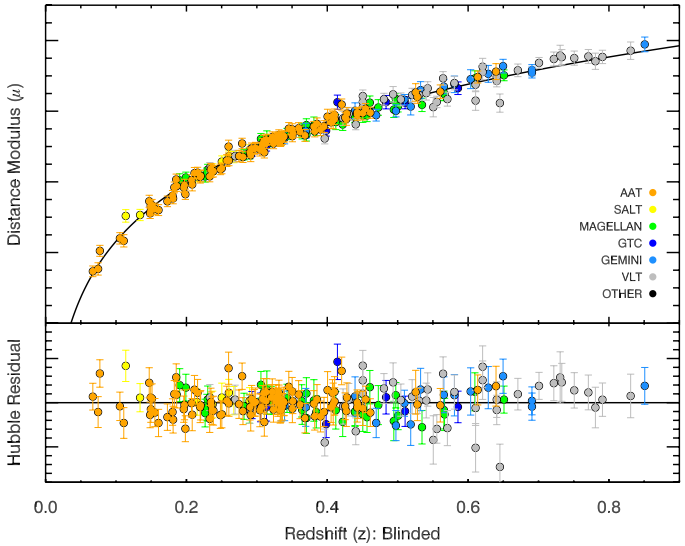
r_d = 147 Mpc

BOSS



$D_M(z)$, $D_H(z)$ or $D_V(z)$

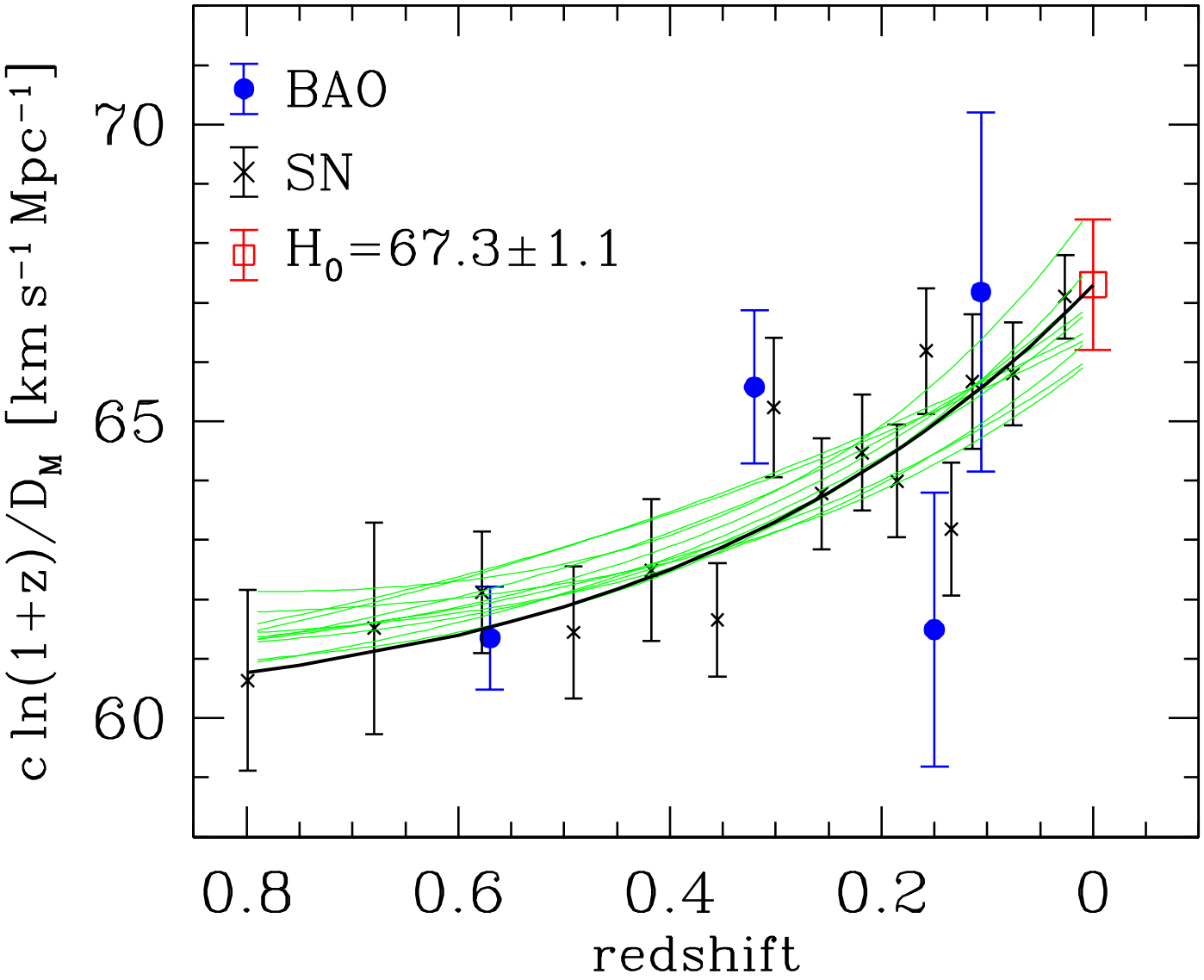
DES



$D_L(z)$

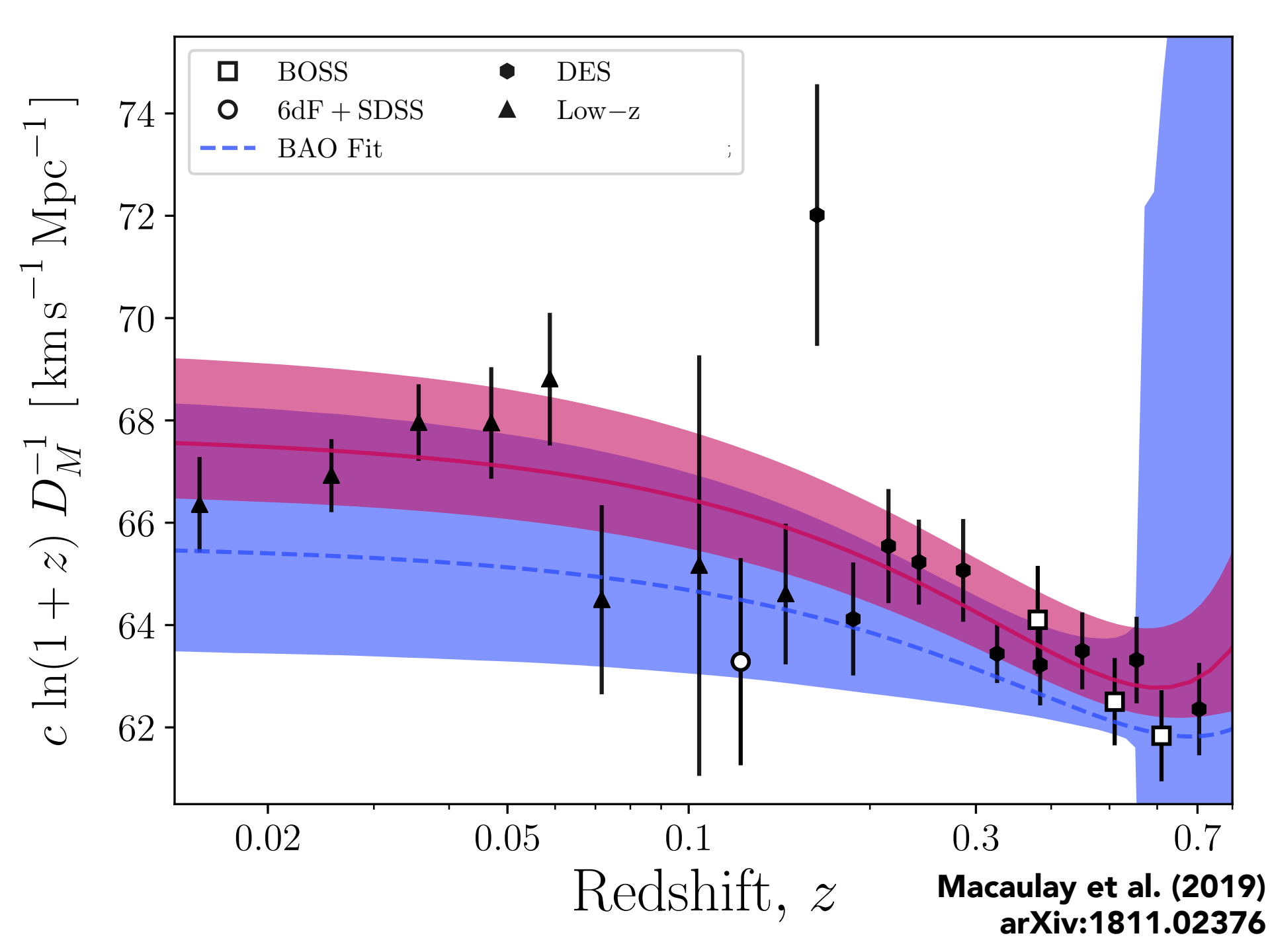
H_0

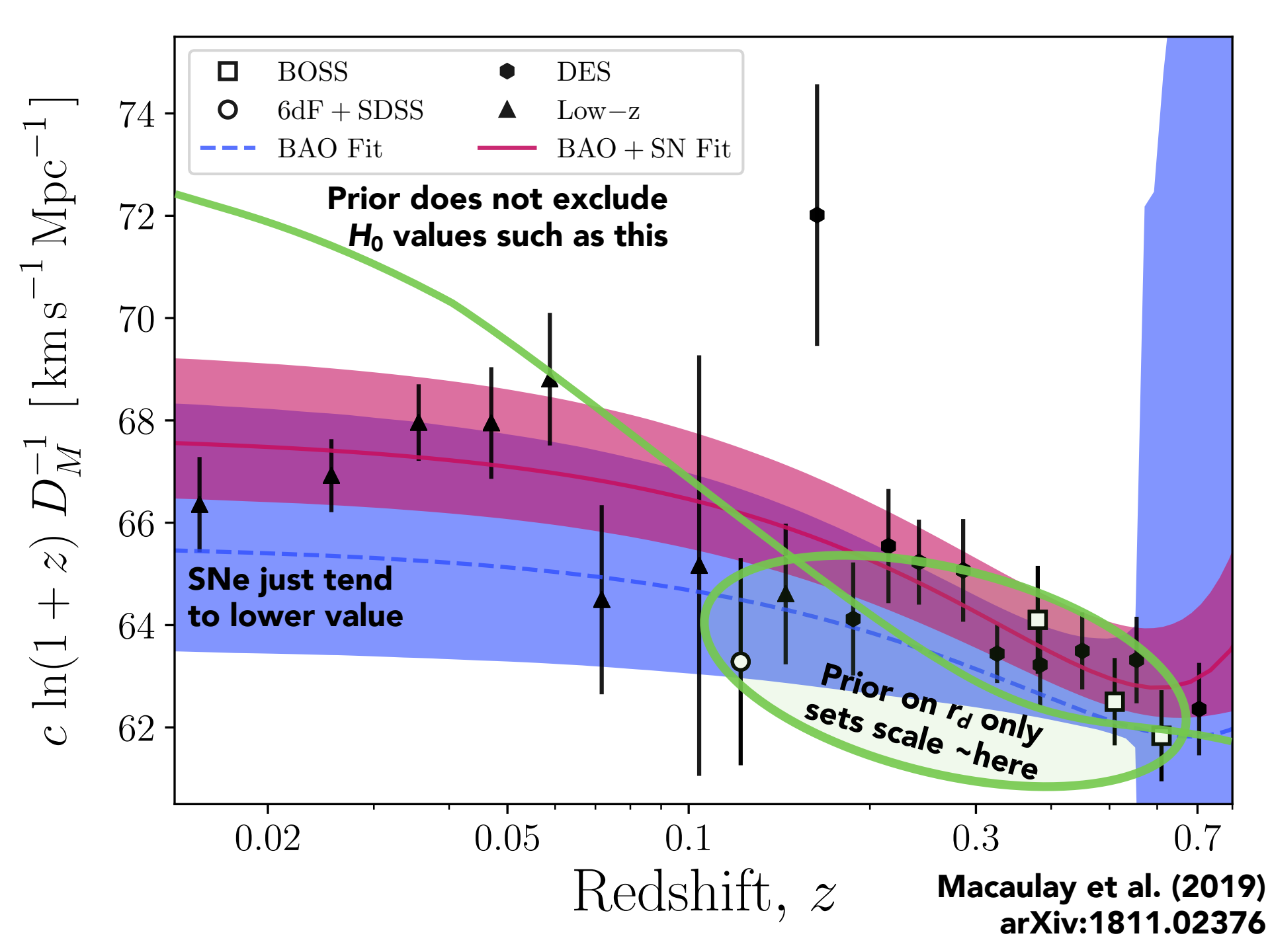
Results with JLA



Axis Converges to H_0 as $z \rightarrow 0$

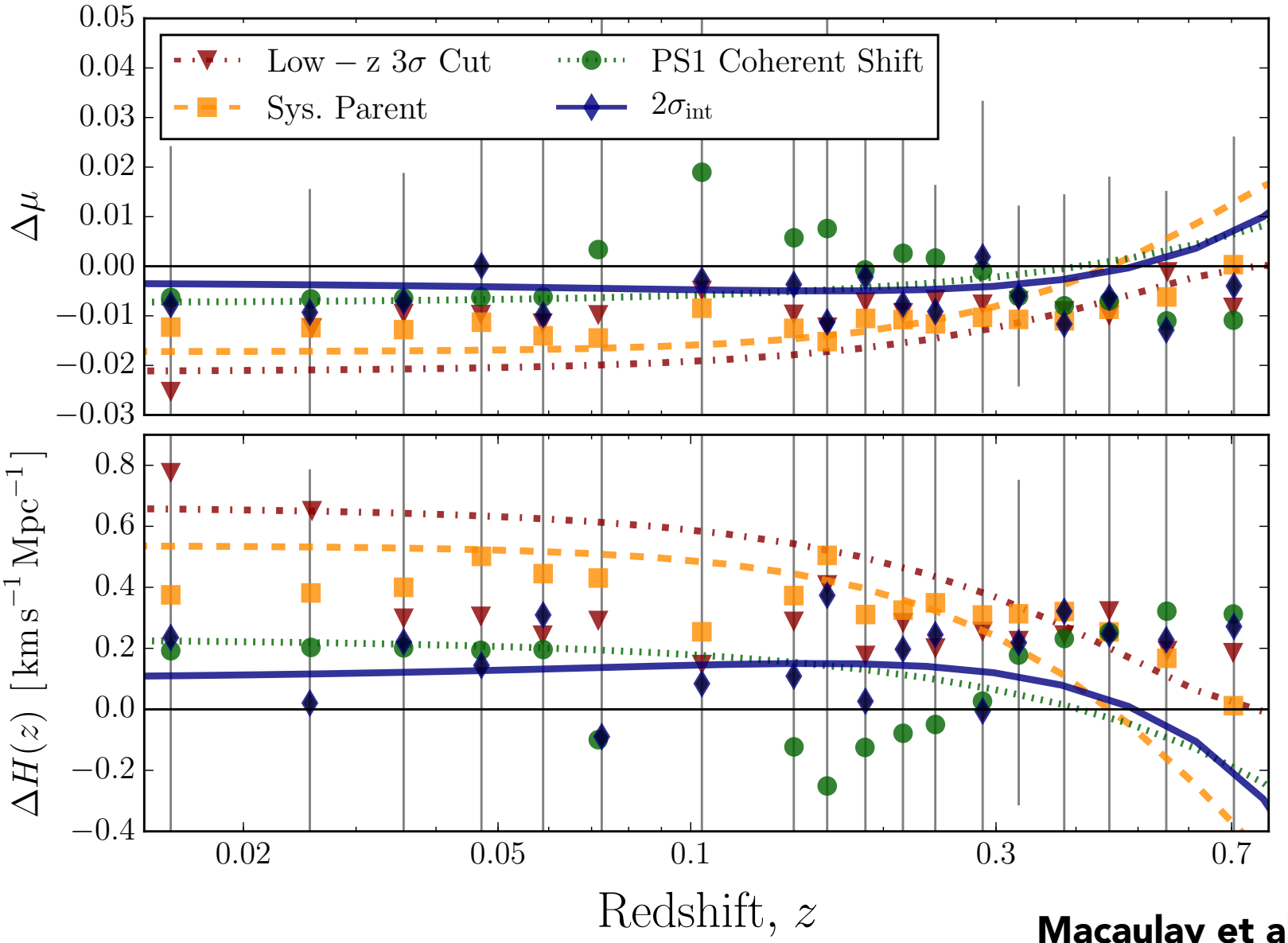
Aubourg et al. (2015)
arXiv: 1411.1075


BOSS
6dF + SDSS
BAO Fit
DES
Low−z
74
72
70
68
66
64
62
$c\ln(1+z)\ D_M^{-1}\ [\mathrm{km\,s^{-1}\,Mpc^{-1}}]$
0.02
0.05
0.1
0.3
0.7
Redshift, z
Macaulay et al. (2019)
arXiv:1811.02376



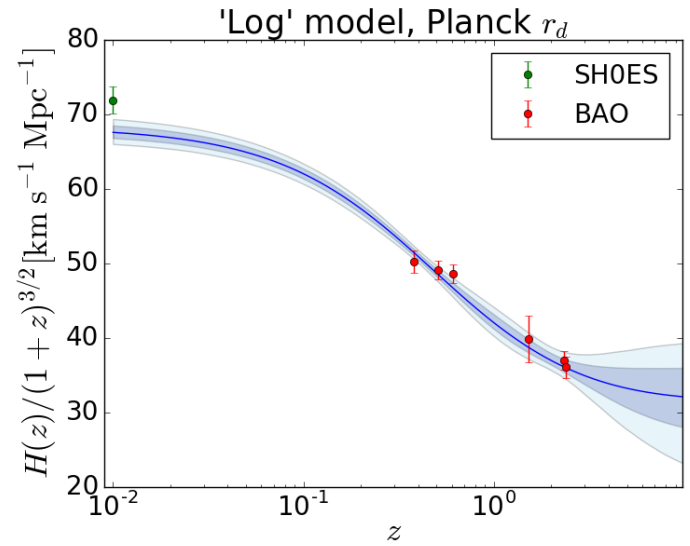
Macaulay et al. (2019)
arXiv:1811.02376

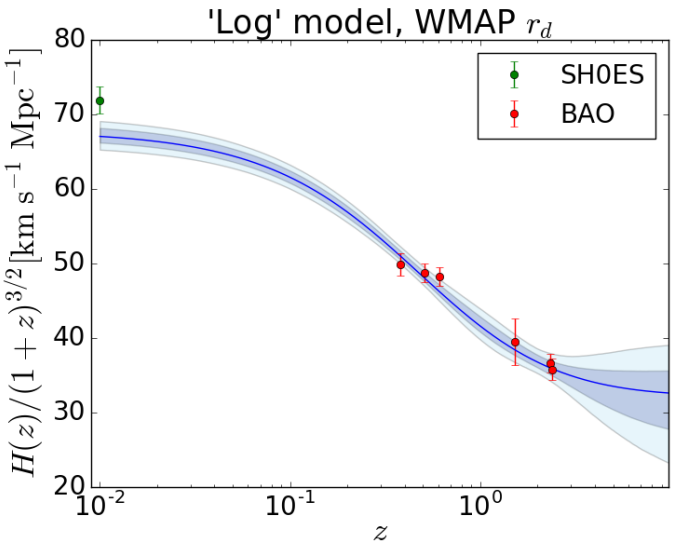
Sensitivity to Systematics

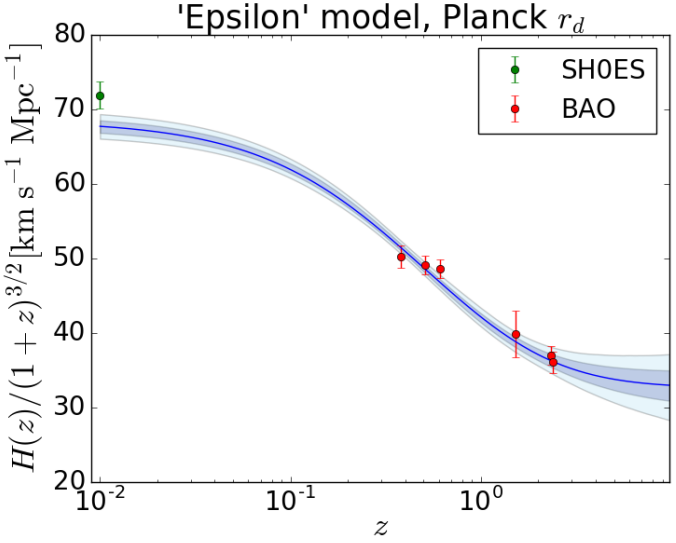


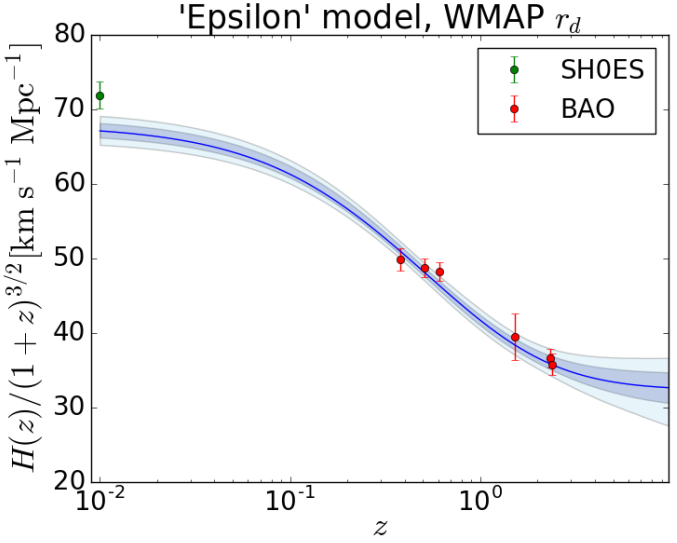
Macaulay et al. (2019)
arXiv:1811.02376

Model & Prior Sensitivity



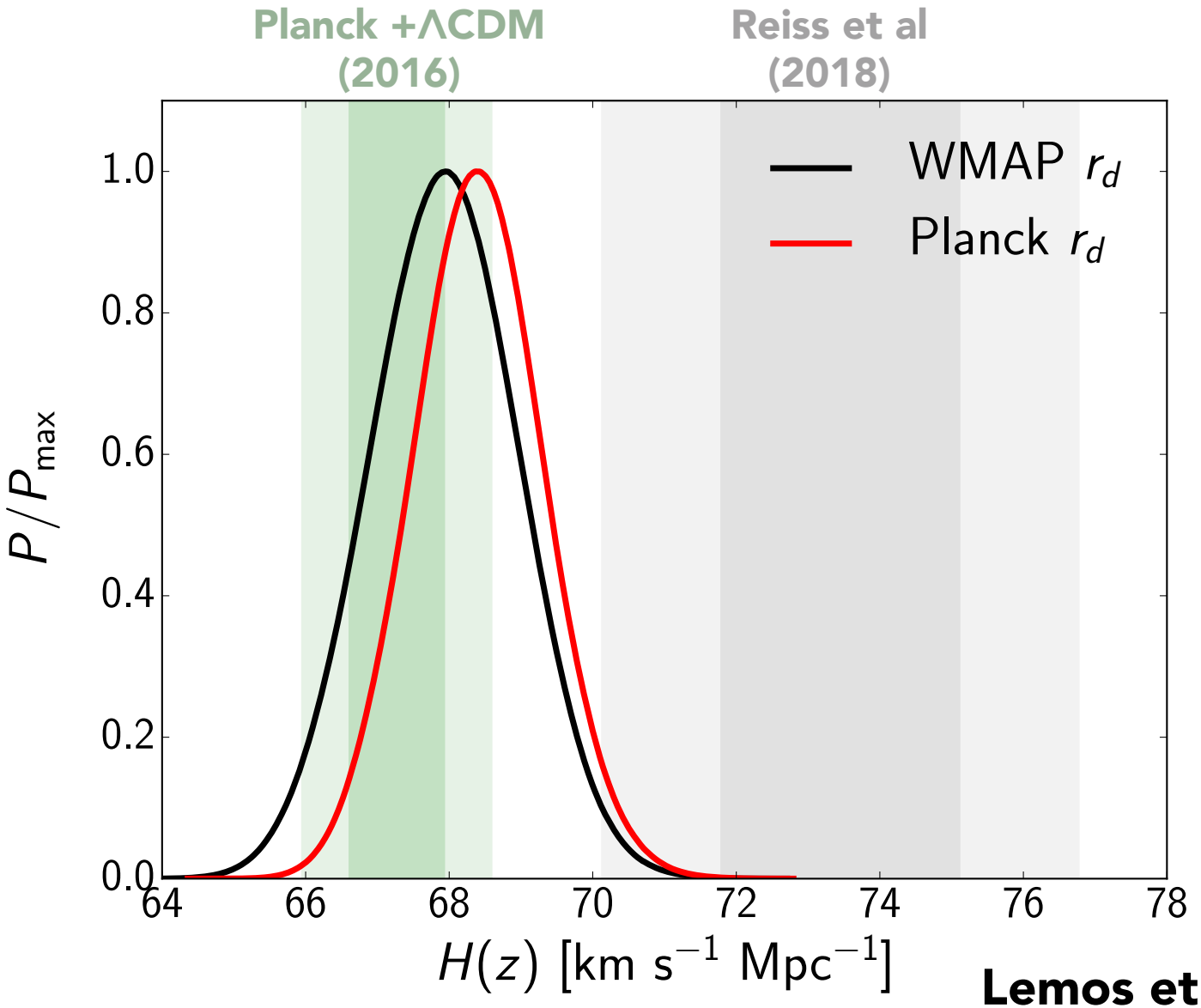






Lemos et al. (2019)
arXiv: 1806.06781

Model & Prior Sensitivity

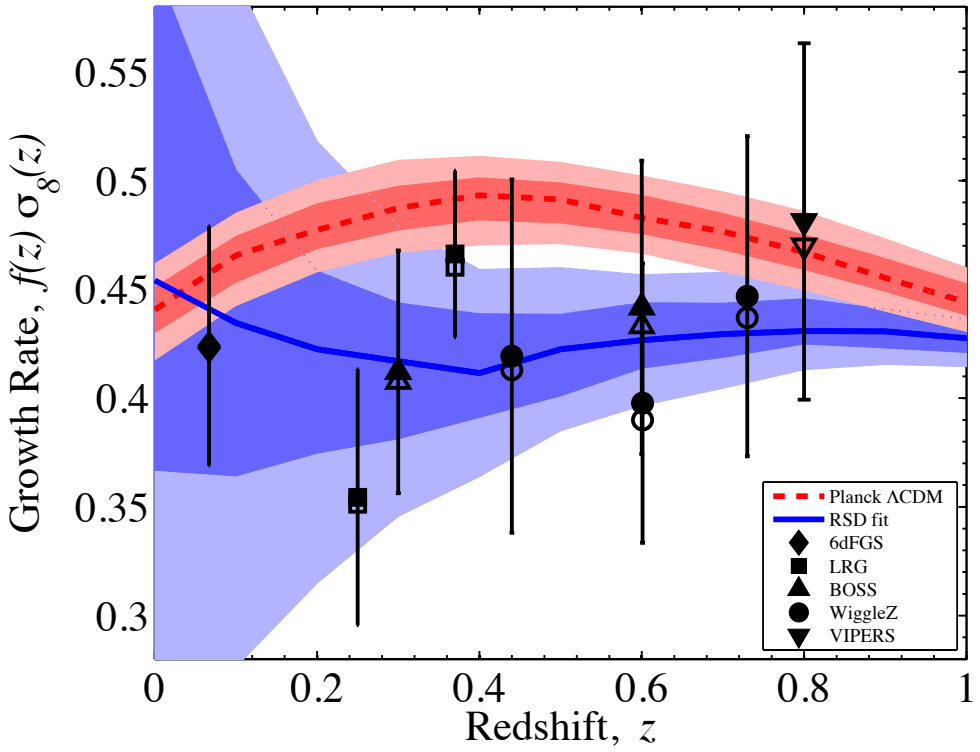


Lemos et al. (2019)
arXiv: 1806.06781

Take Home Points

- **Inverse Distance Ladder value of H_0 consistent with Planck+ΛCDM**
- **CMB: the value of r_d is not sensitive to late-time cosmology**
- **Statistical & systematic uncertainties not enough to reconcile with Distance Ladder measurements**
- **Robust to distance-redshift model and Planck/WMAP**

Speculation(?)



- **Difficult to reconcile observations with a single explanation.**
- **Several different observational effects?**
- **Are H_0 and σ_8 tensions related?**
- **Single theoretical explanation, or just different phenomena?**

Macaulay et al. (2013)
arXiv:1303.6583