- Phys.Dark Univ. 31 (2021) 100766 D. Benisty
- 2202.04677 (D. Benisty, J. Mifsud, J. Said, D. Staicova)

Quantifying the tensions with Machine Learning

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Gaussian Process Regression

- Unsupervised learning. Assumes Kernel distribution between two points.

- A Kernel dependent $cov\big(f(x), f(x')\big) = K(x, x')$

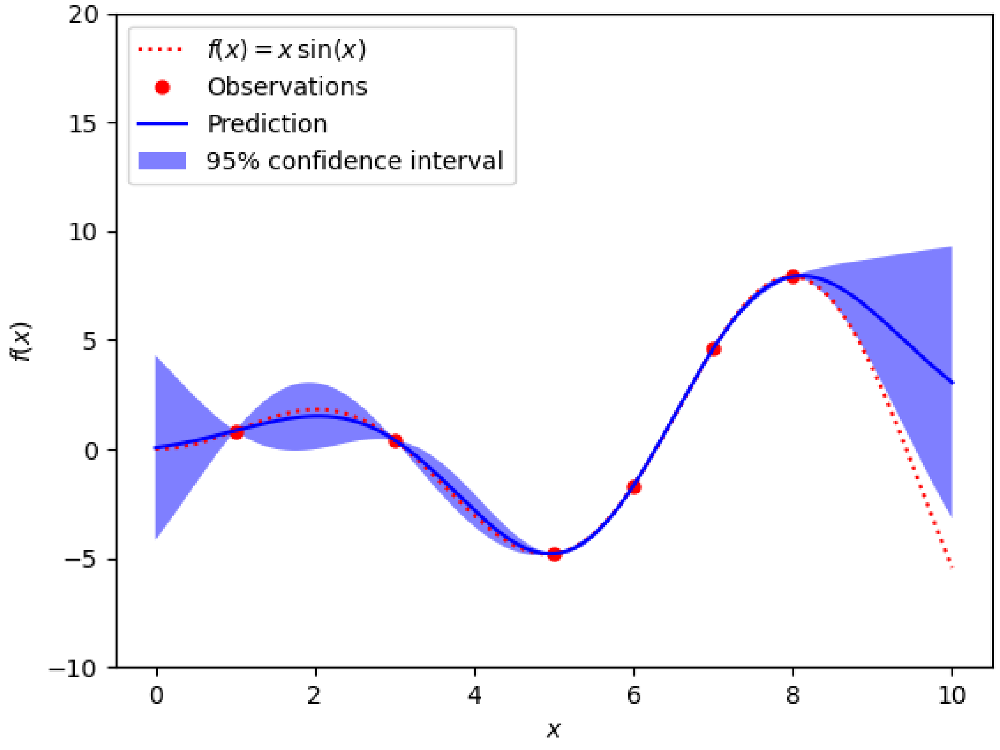
$$k(x,\tilde{x}) = \sigma_f^2 \exp(-\frac{(x-\tilde{x})^2}{2l^2}),$$

The Matern kernel with $\nu = 7/2$:

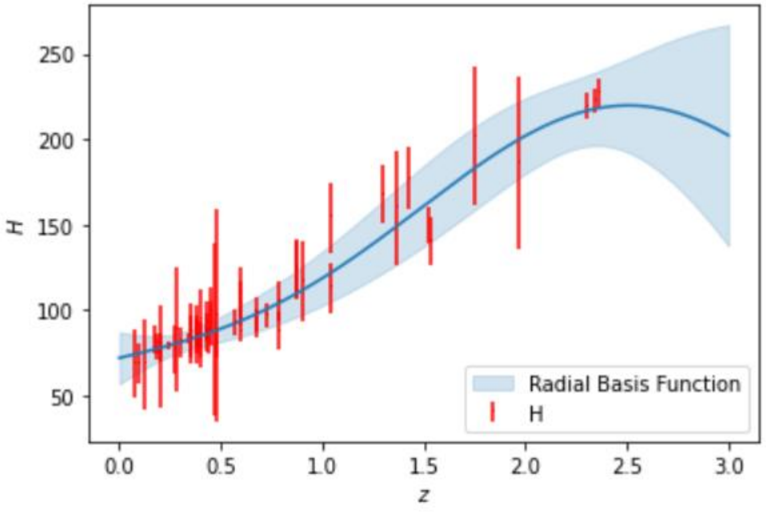
$$k(x,\tilde{x}) = \sigma_f^2 \exp(-\sqrt{7}\frac{|x-\tilde{x}|}{l})$$
$$(1+\sqrt{7}\frac{|x-\tilde{x}|}{l} + 14\frac{(x-\tilde{x})^2}{5l^2} + 7\sqrt{7}\frac{|x-\tilde{x}|^3}{15l^3}),$$

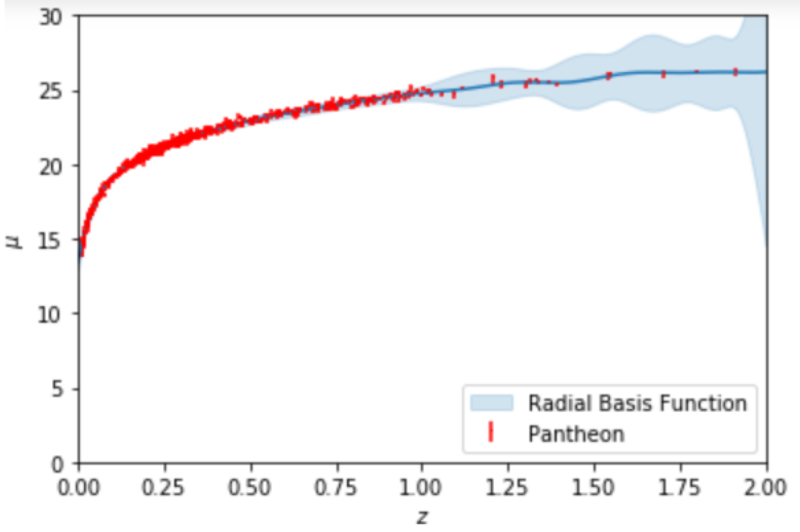
and Matern kernel with $\nu = 9/2$:

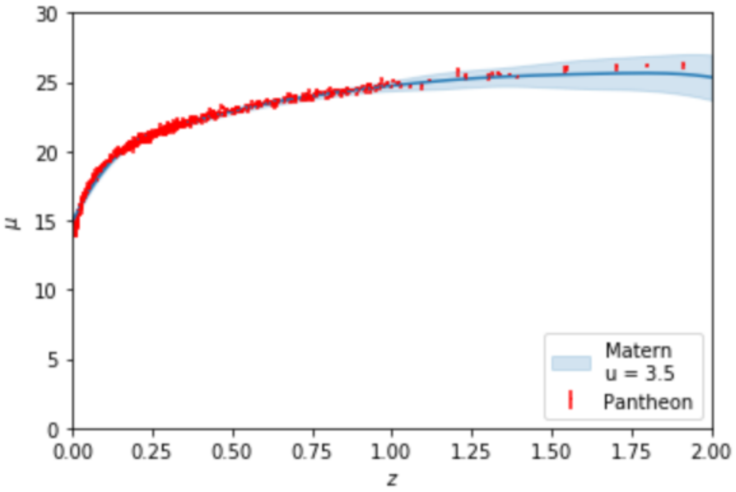
$$k(x,\tilde{x}) = \sigma_f^2 \exp(-3\frac{|x-\tilde{x}|}{l})$$
$$(1+3\frac{|x-\tilde{x}|}{l} + 27\frac{(x-\tilde{x})^2}{7l^2} + 18\frac{|x-\tilde{x}|^3}{7l^3} + 27\frac{(x-\tilde{x})^4}{35l^4}).$$

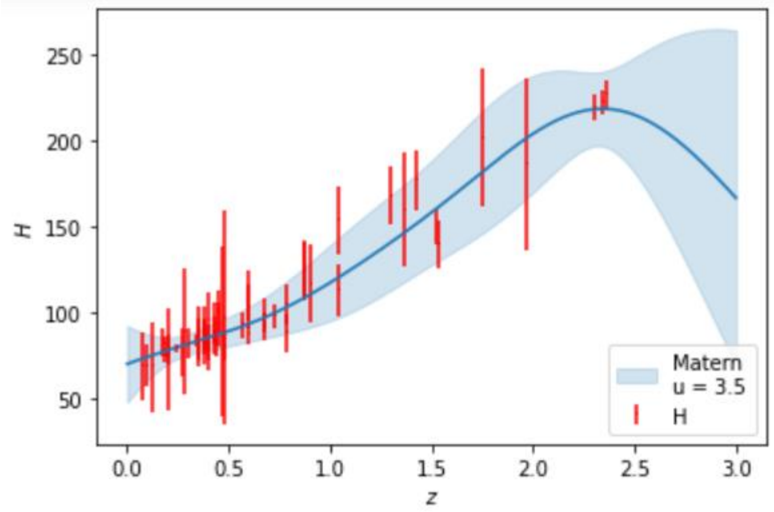


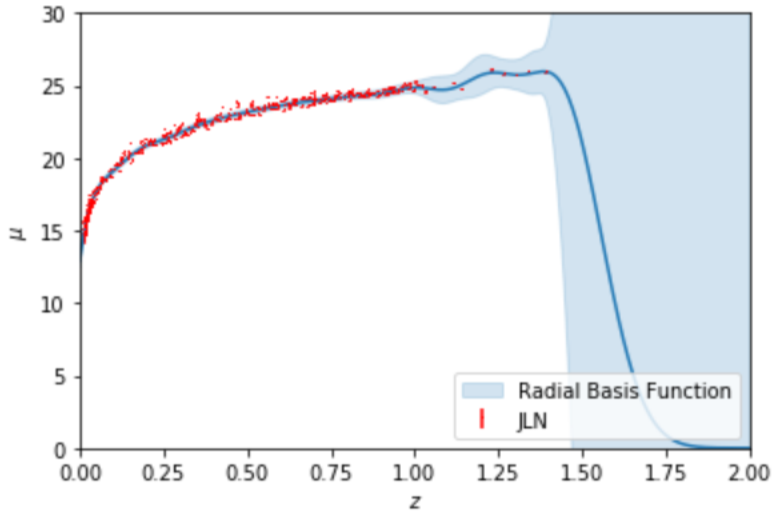
Kernel Dependent

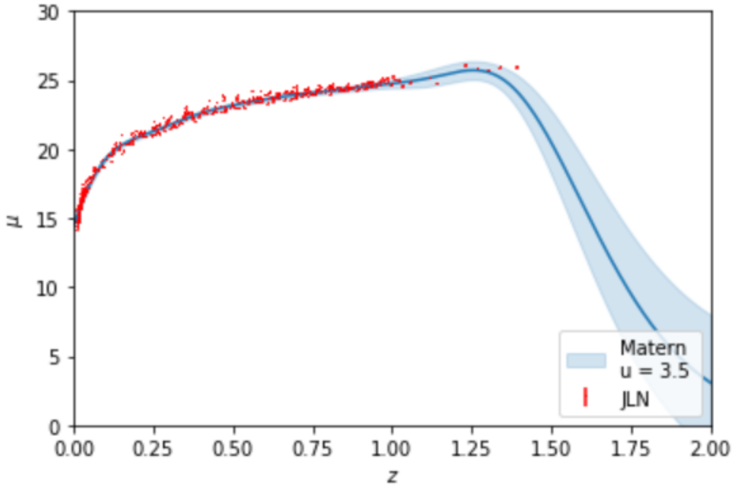






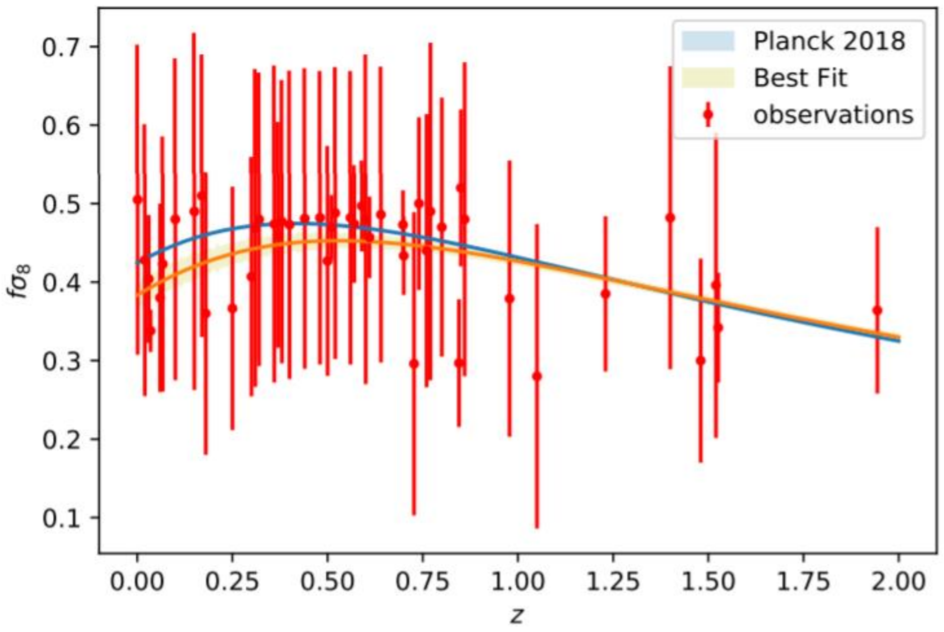






The S_8 tension

- σ_8 - matter fluctuations averaged in spheres of radius $8\ h^{-1} Mpc$
- $S_8 = \sigma_8 \sqrt{\frac{\Omega_m}{0.3}}$



- ~ 50 data points from the latest experiments: $0.01 \leq z \leq 1.994$
- More then 3σ difference between early and late measurements? (CMB & LSS)

Less then 1σ difference between early and late measurements (Amon, Efstathiou)

Homogenous and perturbative late Cosmology

- The Freidmann Eq. is normalized with:

$$H(z)^2 = H_0^2(\Omega_m(1+z)^3 + (1-\Omega_m)(1+z)^{-3(1+w)})$$

- Matter perturbations: $\delta_m = \delta\rho/\rho$

The linear matter perturbations (in Fourier space):

$$\delta''_m(a) + \left(\frac{3}{a} + \frac{E'(a)}{E(a)}\right)\delta'_m(a) = \frac{3}{2}\frac{\Omega_m(a)}{a^2}\delta_m(a)$$

assumption of small scales approximation (no k).

$$f(a) = \frac{d\log\delta_m}{d\log a}, \sigma_8(a) = \sigma_8\frac{\delta_m(a)}{\delta_m(1)}$$

$$f\sigma_8(a) = a\frac{\delta'_m(a)}{\delta_m(1)}\sigma_8$$

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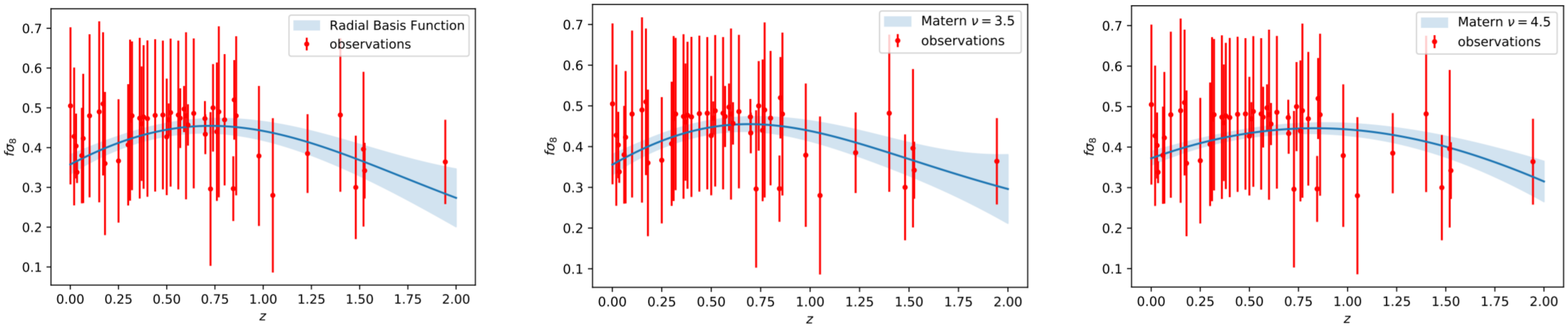
GP for the $f\sigma_8$ data

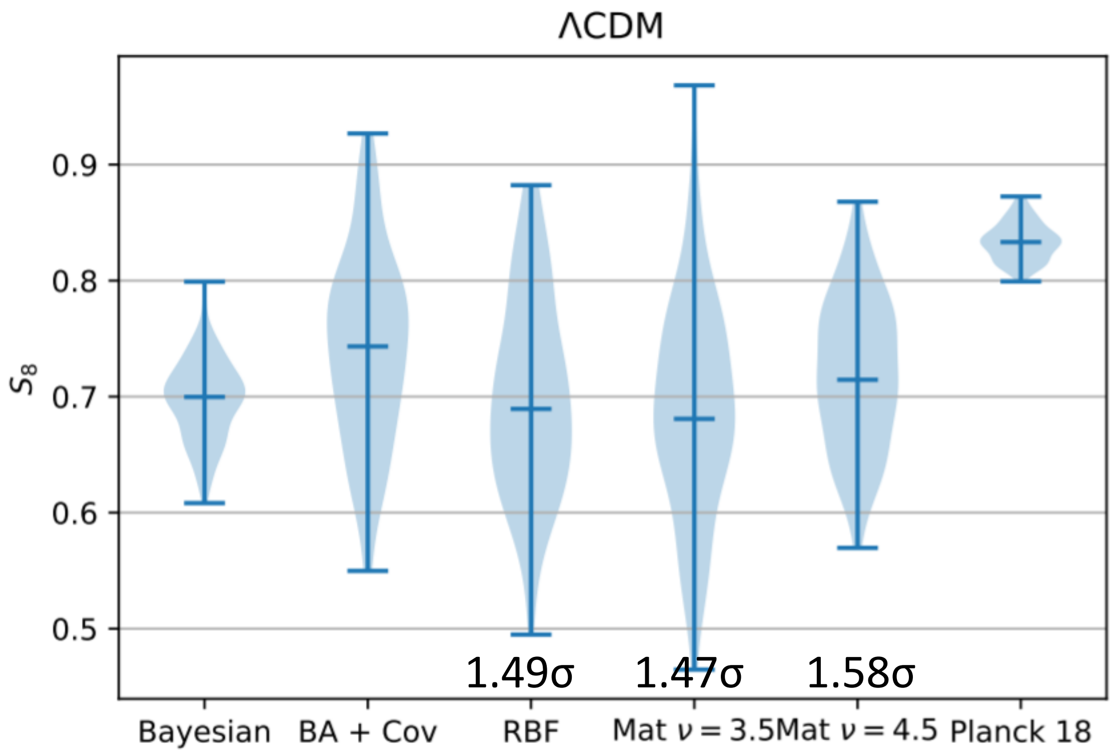


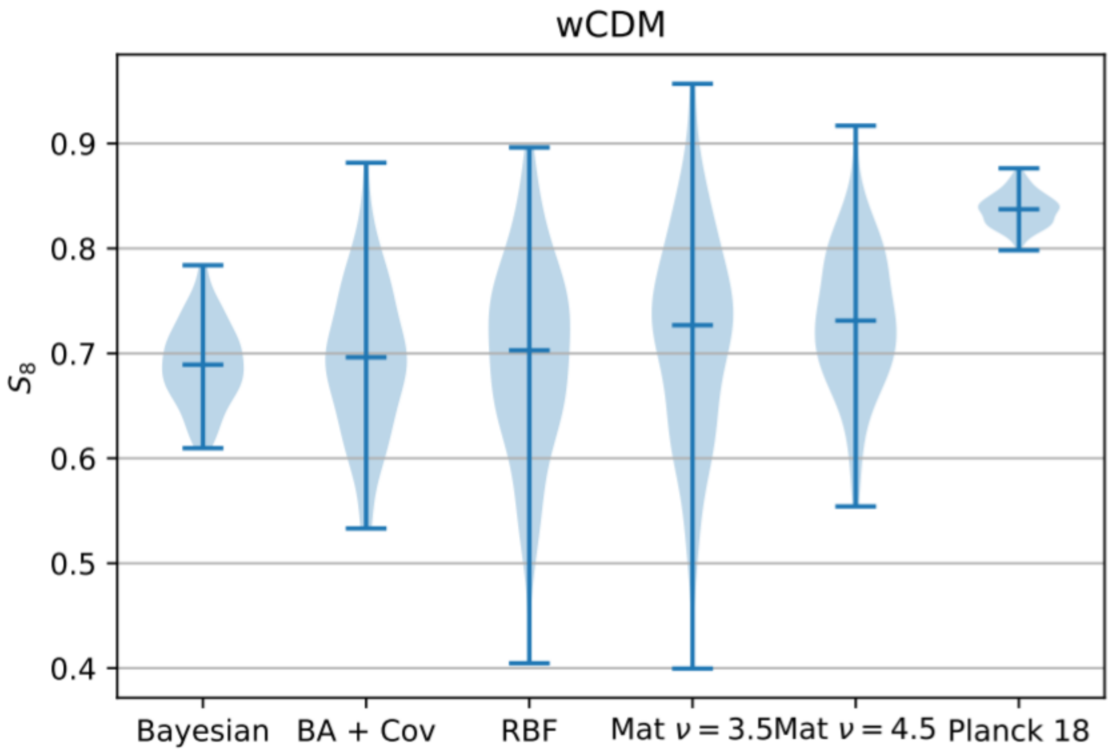
Kernel	RBF	Matern $\nu = 3.5$	Matern $\nu = 4.5$
$f\sigma_8(0)$	0.358 ± 0.0241	0.356 ± 0.025	0.372 ± 0.017

$f\sigma_8(0.001) = 0.505 \pm 0.0852$ MTF Mon. Not. Roy. Astron. Soc. 471, 3135 (2017)

$f\sigma_8(0.02) = 0.428 \pm 0.04652$ 6dFGS JCAP 1705, 015 (2017)

Results for the S_8 values





ΛCDM	RBF	Matern $\nu = 3.5$	Matern $\nu = 4.5$
σ_8	$0.77^{+0.21}_{-0.16}$	$0.77^{+0.21}_{-0.16}$	$0.79^{+0.19}_{-0.17}$
Ω_m	$0.27^{+0.12}_{-0.11}$	$0.26^{+0.13}_{-0.11}$	$0.27^{+0.12}_{-0.10}$
S_8	$0.707^{+0.085}_{-0.085}$	$0.701^{+0.089}_{-0.089}$	$0.731^{+0.063}_{-0.062}$

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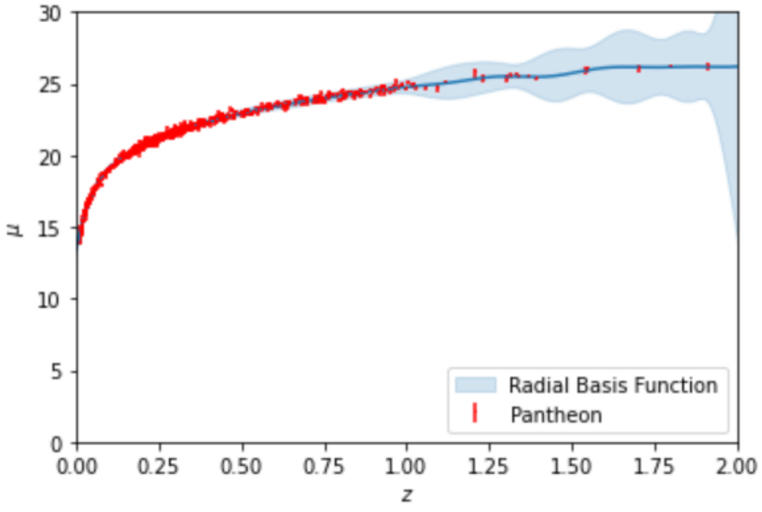
Absolute Magnitude is really a Constant?

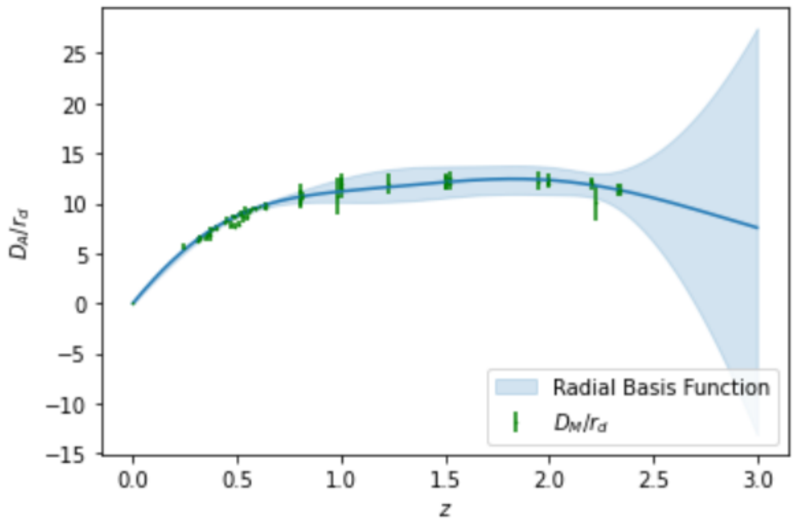
- Supernova $$\mu_{Ia}(z) = 5\log_{10}[d_L(z)] + 25 + M_B(z)$$



- "Canceling" the expansion rate by BAO

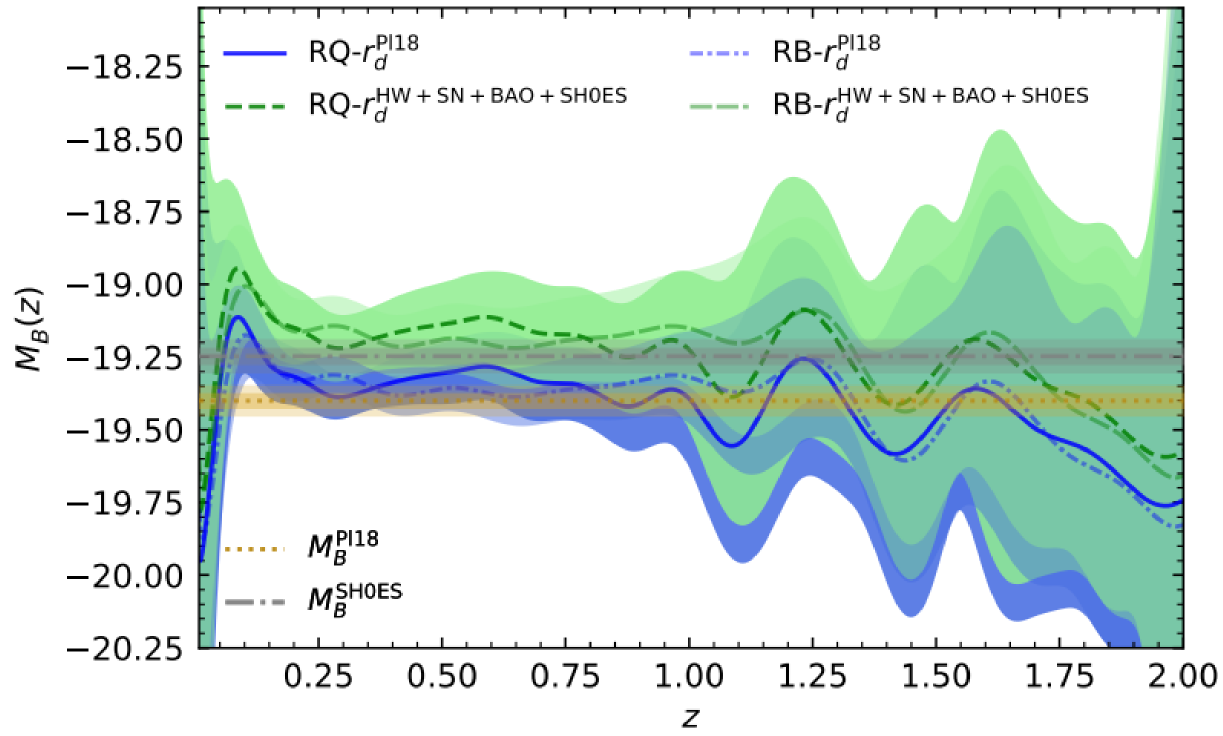
$$M_B = \mu_{Ia} - 5\log_{10}\left[(1+z)^2\left(\frac{D_A}{r_d}\right)_{\rm BAO}\cdot r_d\right] - 25\,,$$

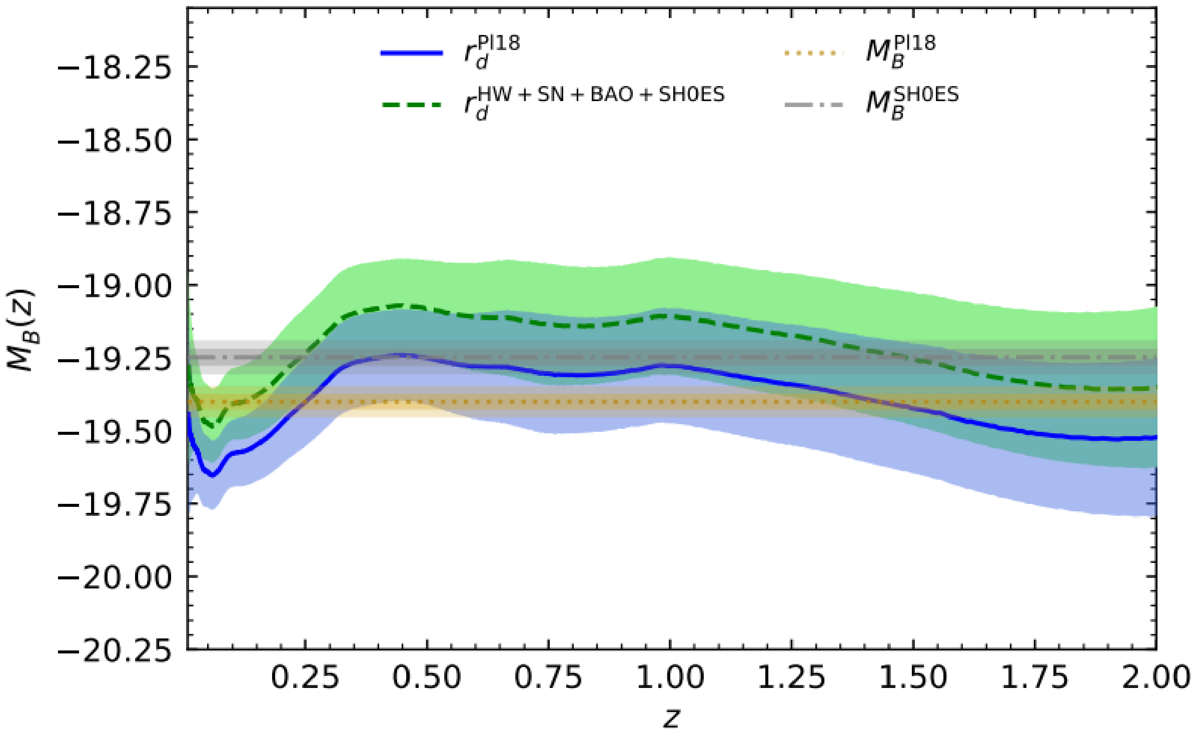
$$\Delta M_B = \Delta\mu_{Ia} + \frac{5}{\ln 10}\left[\frac{\Delta r_d}{r_d} + \frac{\Delta\left(D_A/r_d\right)_{BAO}}{\left(D_A/r_d\right)_{BAO}}\right]$$



- A degeneracy M - H0: is replaced by M - rd.

Numerical Results



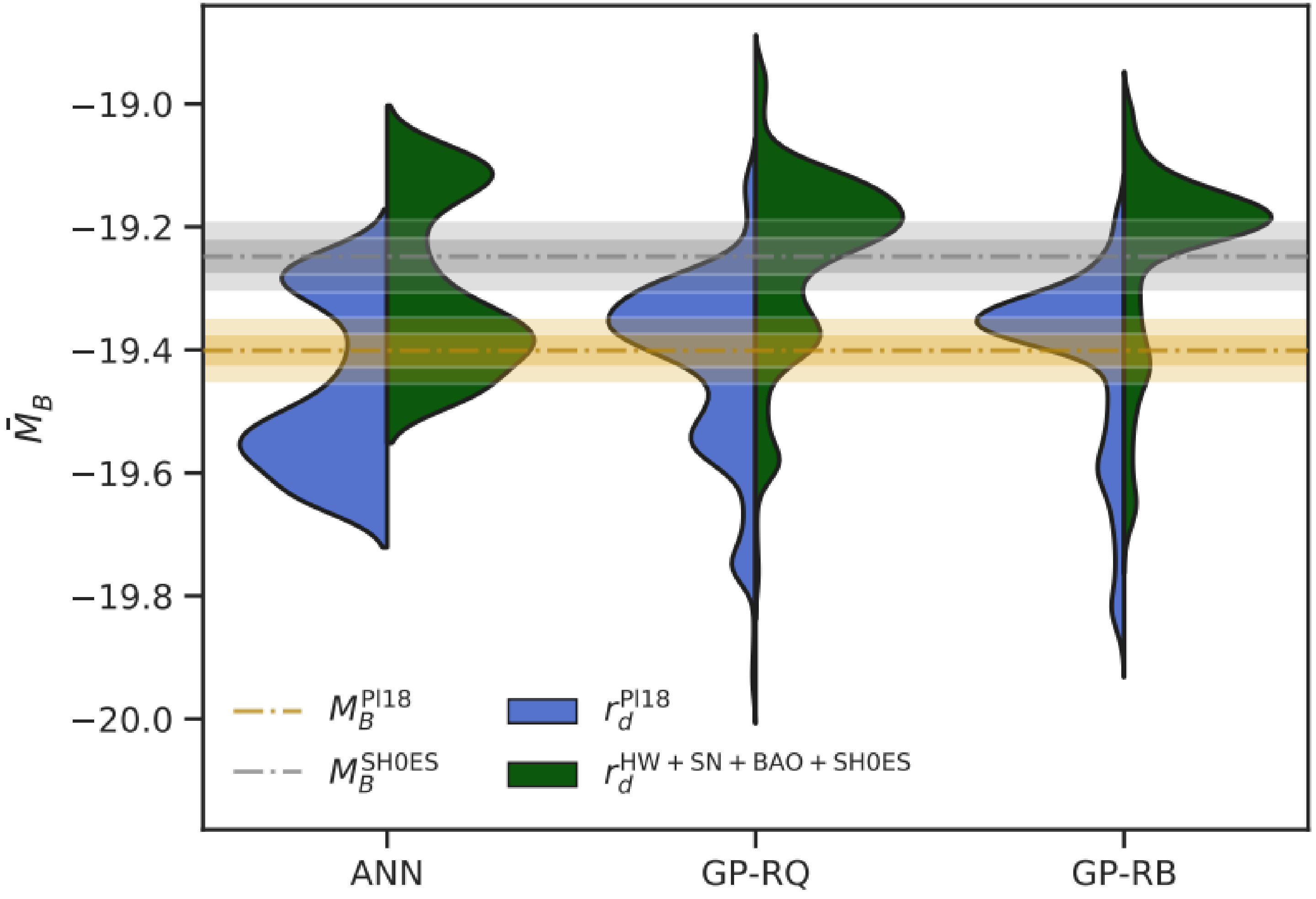


M vs. z?

Technique	r_d^{Pl18}	$r_d^{\mathrm{H0LiCOW+SN+BAO+SH0ES}}$
ANN	-19.38 ± 0.20	-19.22 ± 0.20
GP-RQ	-19.42 ± 0.35	-19.25 ± 0.39
GP-RB	-19.42 ± 0.29	-19.25 ± 0.33

- Different M

corresponds to different rd.



Final Results

- It is possible to quantify the tensions with model independent approach.
- With ML the S_8 tension is reduces to $\sim 1.5\sigma$ for some kernels.
- M_b from Type IA + BAO data changes for different r_d, but is a constant up to $\sim 1\sigma$.