Can dark energy be dynamic?

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Eoin O Colgain, M. M. Sheikh-Jabbari

outline

- Dynamical Dark Energy (DDE) models and the evolution of DDE
- Non-parametric DDE method– wiggles
- Summary

What is Dynamical Dark Energy (DDE)?

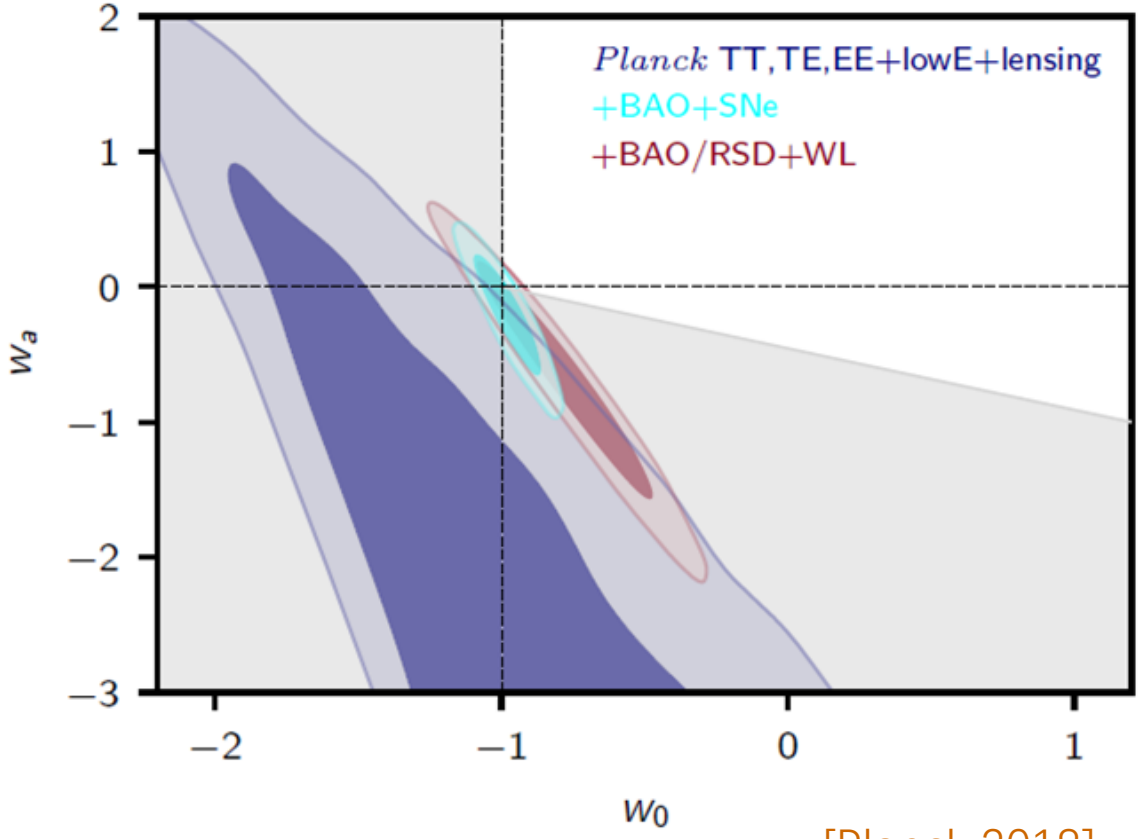
In general, it is the energy density of DE evolution with redshift z

If you read Planck's paper, it will give one example of DDE: CPL

$$w(a) = w_0 + (1 - a)w_a$$

A very important feature for DDE is $w_a \neq 0$

$$w(z) = w_0 + w_a f(z)$$



[Planck 2018]

Models of DDE

$$w(z) = w_0 + w_a f(z)$$

$$X(z) := \frac{\rho_{\rm de}(z)}{\rho_{\rm de,0}} = \exp\left(3\int_0^z \frac{1+w(z')}{1+z'}{\rm d}z'\right)$$

$$H(z) = H_0\sqrt{X(z)(1-\Omega_{m0}-\Omega_{r0}) + \Omega_{m0}(1+z)^3 + \Omega_{r0}(1+z)^4}$$

Model	$w(z)$	$X(z)$
CPL	$w_0 + w_a \frac{z}{1+z}$	$(1+z)^{3(1+w_0+w_a)} e^{-\frac{3w_a z}{1+z}}$

[M. Chevallier and D. Polarski, Int. J. Mod. Phys. D 10, 213 (2001)]

Models of DDE

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Model	$w(z)$	$X(z)$	
"Redshift"	$w_0 + w_a z$	$(1+z)^{3(1+w_0-w_a)}e^{3w_a z}$	[R. Cooray and D. Huterer, Astrophys. J. Lett. 513 (1999)]
CPL	$w_0 + w_a \frac{z}{1+z}$	$(1+z)^{3(1+w_0+w_a)}e^{-\frac{3w_a z}{1+z}}$	[M. Chevallier and D. Polarski, Int. J. Mod. Phys. D 10, 213 (2001)]
Efstathiou	$w_0 + w_a \ln(1+z)$	$(1+z)^{3(1+w_0)}e^{\frac{3}{2}w_a[\ln(1+z)]^2}$	[G. Efstathiou, Mon. Not. Roy. Astron. Soc. 310 (1999)]
JBP	$w_0 + w_a \frac{z}{(1+z)^2}$	$(1+z)^{3(1+w_0)}e^{\frac{3w_a}{2}\frac{z^2}{(1+z)^2}}$	[H. K. Jassal, J. S. Bagla and T. Padmanabhan, Phys. Rev. D 72 (2005)]
BA	$w_0 + w_a \frac{z(1+z)}{1+z^2}$	$(1+z)^{3(1+w_0)}(1+z^2)^{3w_a/2}$	[E. M. Barboza, Jr. and J. S. Alcaniz, Phys. Lett. B 666 (2008)]

The evolution of DDE

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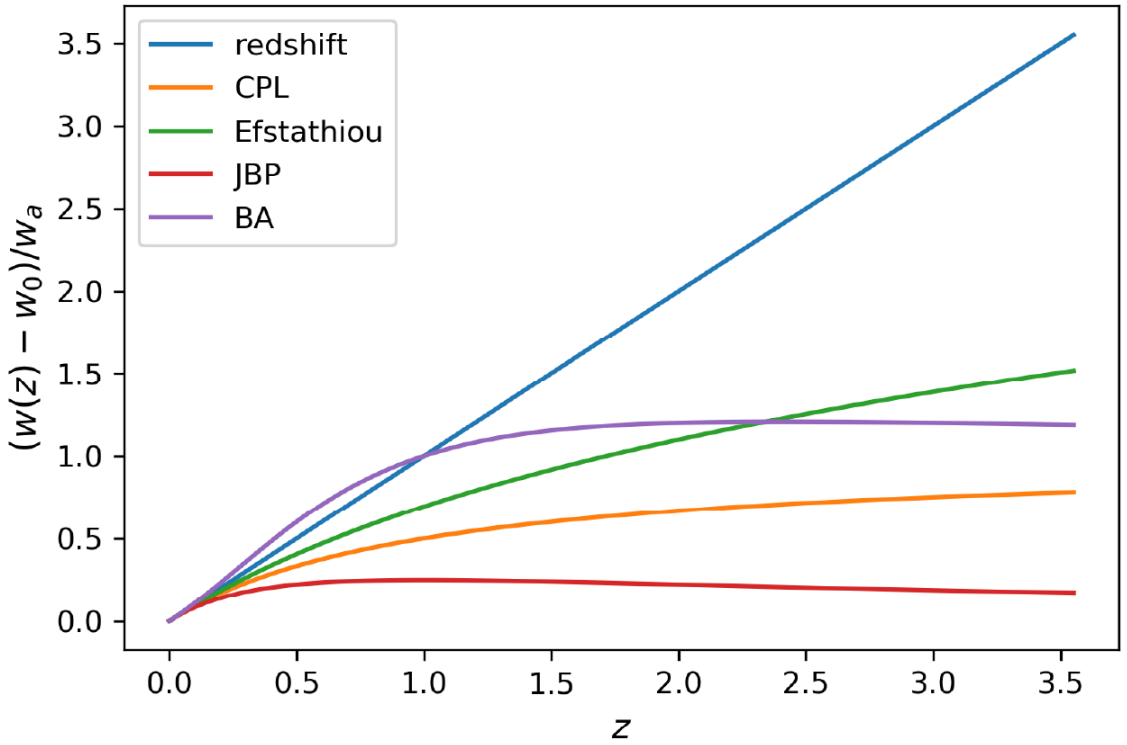

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The redshift dependence of various DDE models

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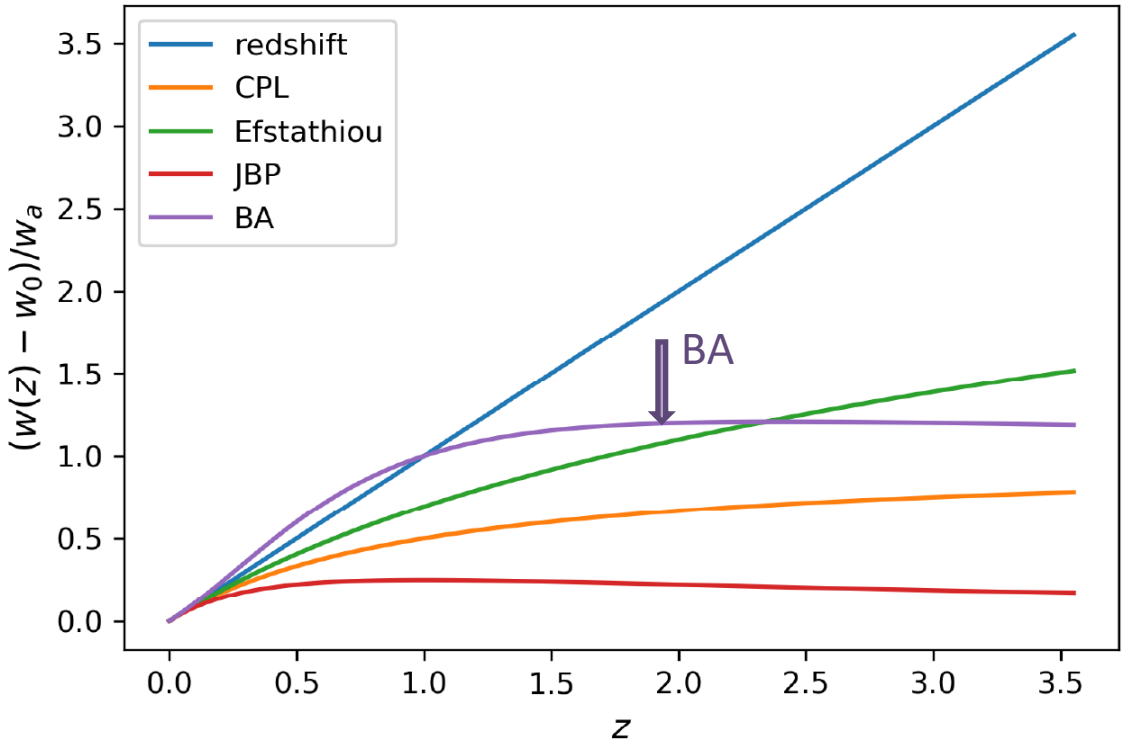

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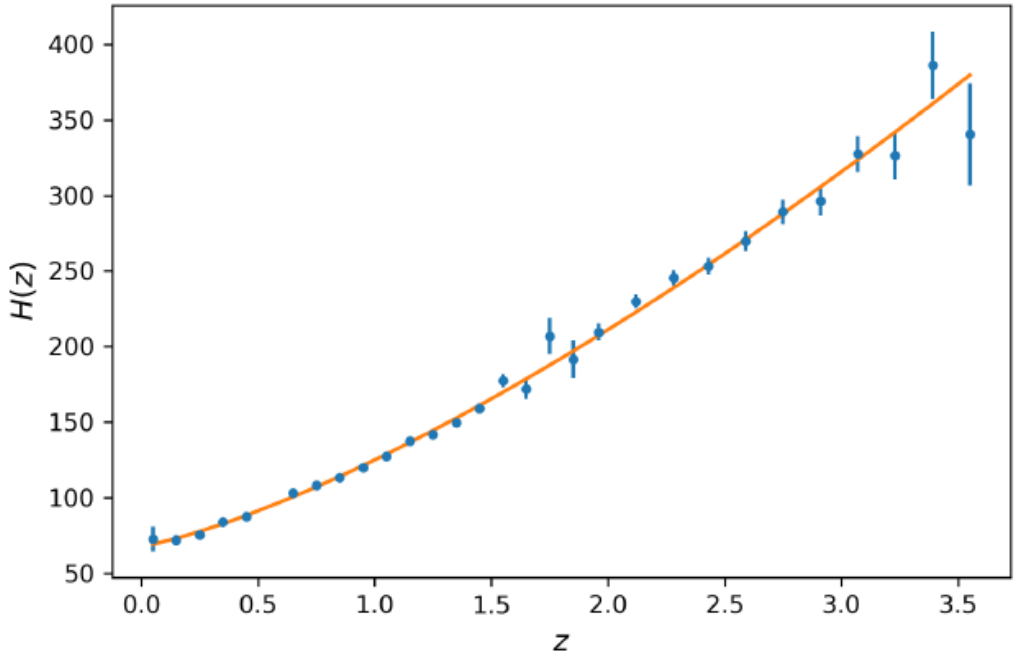
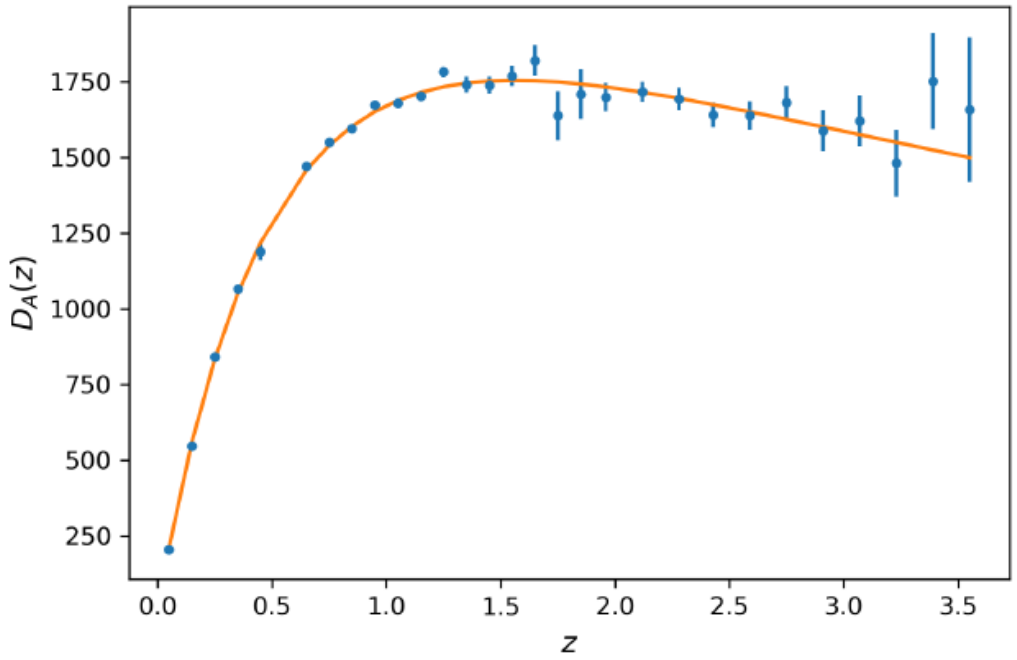
The redshift dependence of various DDE models

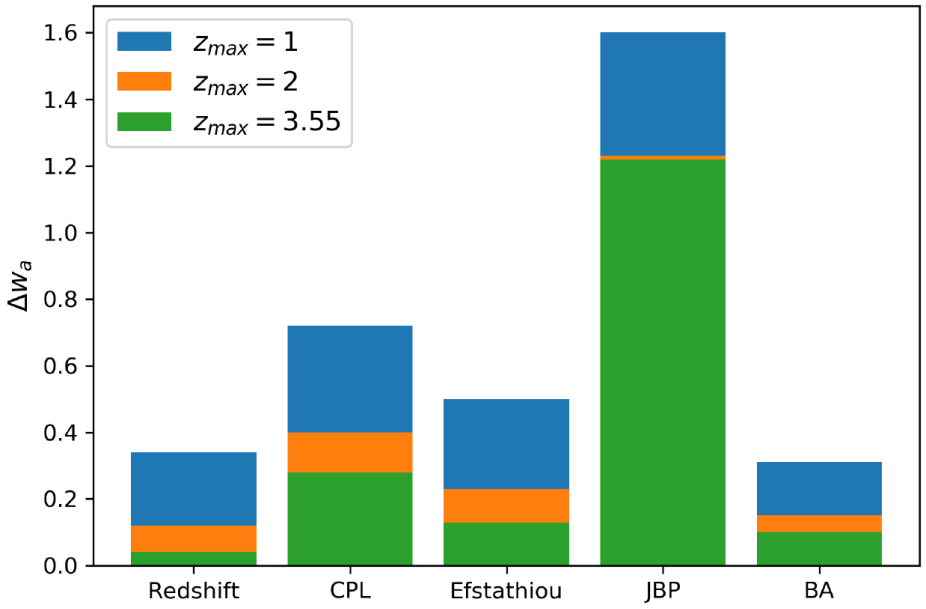
Use magic to defeat magic!
--Use mock data to fit DDE





We mock DESI data up on a particular DDE model and then
fit the same model to the mock data to recover the cosmological parameters.

Constraints result for DDE by mock data



Model	$z_{\max}$	H_0	Ω_{m0}	w_0	w_a
Redshift	1	$67.55^{+1.53}_{-1.46}$	$0.314^{+0.014}_{-0.014}$	$-1.02^{+0.16}_{-0.16}$	$0.52^{+0.34}_{-0.34}$
	2	$67.20^{+0.96}_{-0.94}$	$0.317^{+0.009}_{-0.009}$	$-0.99^{+0.08}_{-0.07}$	$0.48^{+0.12}_{-0.12}$
	3.55	$67.38^{+0.70}_{-0.70}$	$0.315^{+0.007}_{-0.007}$	$-1.00^{+0.04}_{-0.04}$	$0.50^{+0.04}_{-0.04}$
CPL	1	$67.21^{+1.74}_{-1.65}$	$0.317^{+0.016}_{-0.016}$	$-0.98^{+0.21}_{-0.21}$	$0.43^{+0.72}_{-0.72}$
	2	$67.39^{+1.31}_{-1.27}$	$0.315^{+0.013}_{-0.012}$	$-1.00^{+0.13}_{-0.13}$	$0.49^{+0.39}_{-0.40}$
	3.55	$67.18^{+1.09}_{-1.08}$	$0.317^{+0.011}_{-0.010}$	$-0.98^{+0.10}_{-0.10}$	$0.46^{+0.27}_{-0.29}$
Efstathiou	1	$67.04^{+1.61}_{-1.54}$	$0.318^{+0.015}_{-0.015}$	$-0.96^{+0.18}_{-0.18}$	$0.37^{+0.50}_{-0.51}$
	2	$67.15^{+1.13}_{-1.10}$	$0.317^{+0.011}_{-0.011}$	$-0.98^{+0.10}_{-0.10}$	$0.45^{+0.23}_{-0.23}$
	3.55	$67.22^{+0.88}_{-0.86}$	$0.317^{+0.009}_{-0.008}$	$-0.99^{+0.07}_{-0.07}$	$0.49^{+0.13}_{-0.13}$
JBP	1	$67.26^{+2.06}_{-1.95}$	$0.317^{+0.019}_{-0.019}$	$-0.98^{+0.31}_{-0.31}$	$0.38^{+1.59}_{-1.60}$
	2	$67.27^{+1.85}_{-1.74}$	$0.317^{+0.017}_{-0.017}$	$-0.98^{+0.25}_{-0.25}$	$0.40^{+1.23}_{-1.23}$
	3.55	$67.40^{+1.85}_{-1.76}$	$0.315^{+0.018}_{-0.017}$	$-0.99^{+0.25}_{-0.25}$	$0.43^{+1.21}_{-1.22}$
BA	1	$67.58^{+1.58}_{-1.50}$	$0.314^{+0.015}_{-0.014}$	$-1.01^{+0.16}_{-0.16}$	$0.51^{+0.31}_{-0.31}$
	2	$67.39^{+1.14}_{-1.11}$	$0.315^{+0.011}_{-0.011}$	$-1.00^{+0.10}_{-0.10}$	$0.51^{+0.15}_{-0.15}$
	3.55	$67.40^{+0.97}_{-0.95}$	$0.315^{+0.009}_{-0.009}$	$-1.00^{+0.075}_{-0.074}$	$0.50^{+0.10}_{-0.10}$

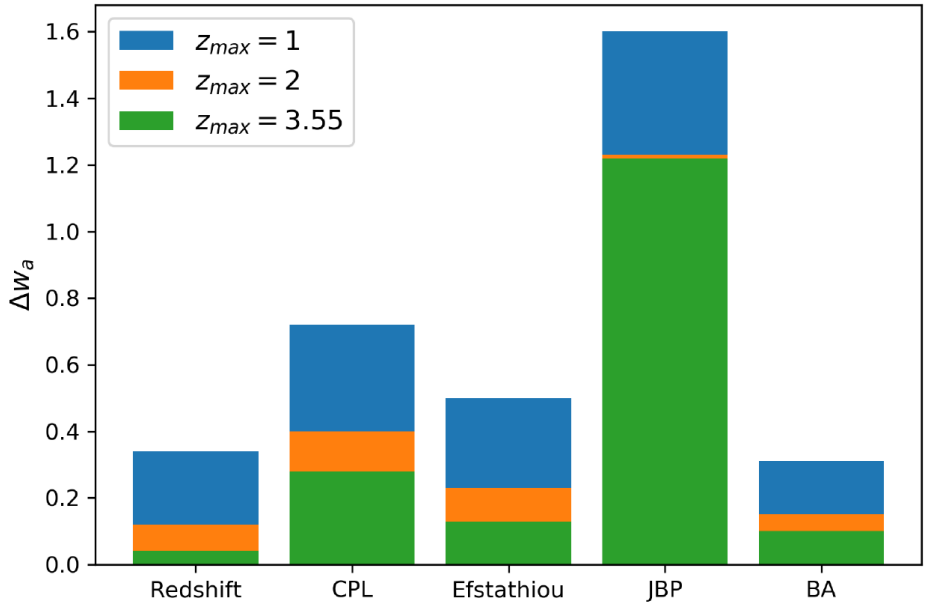
Note, Planck, DES, Euclid are all using CPL!

[Euclid preparation [arxiv 2106.08346]]

[Planck 2018 results [arxiv 1807.06209v2]]

[Dark Energy Survey Year 3 Results [arxiv 2105.13549]]

Constraints result for DDE by mock data



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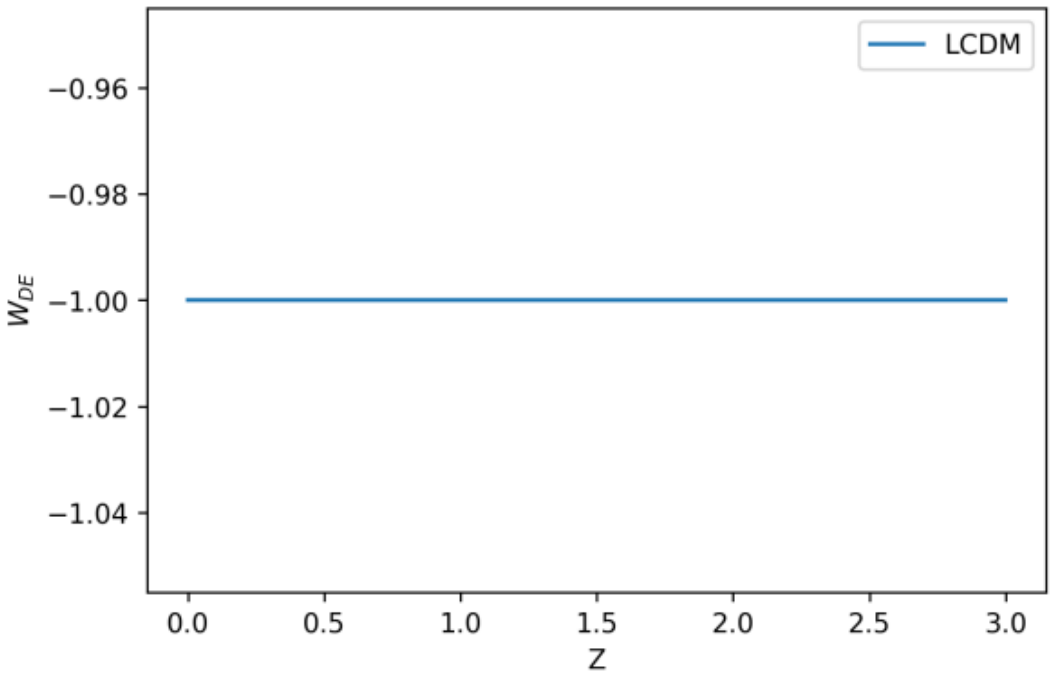
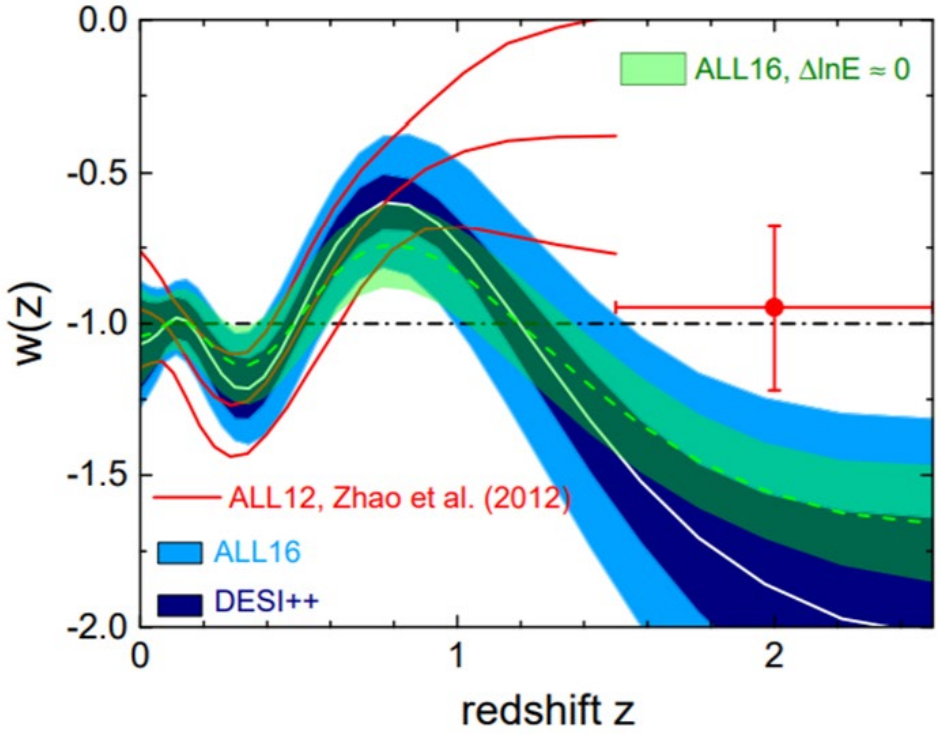
Non-parametric EoS - wiggles



LCDM



DDE

[Gong-Bo Zhao, Marco Raveri, Levon Pogosian, Yuting Wang, Robert G. Crittenden., et al. 2017, Nature Astronomy]

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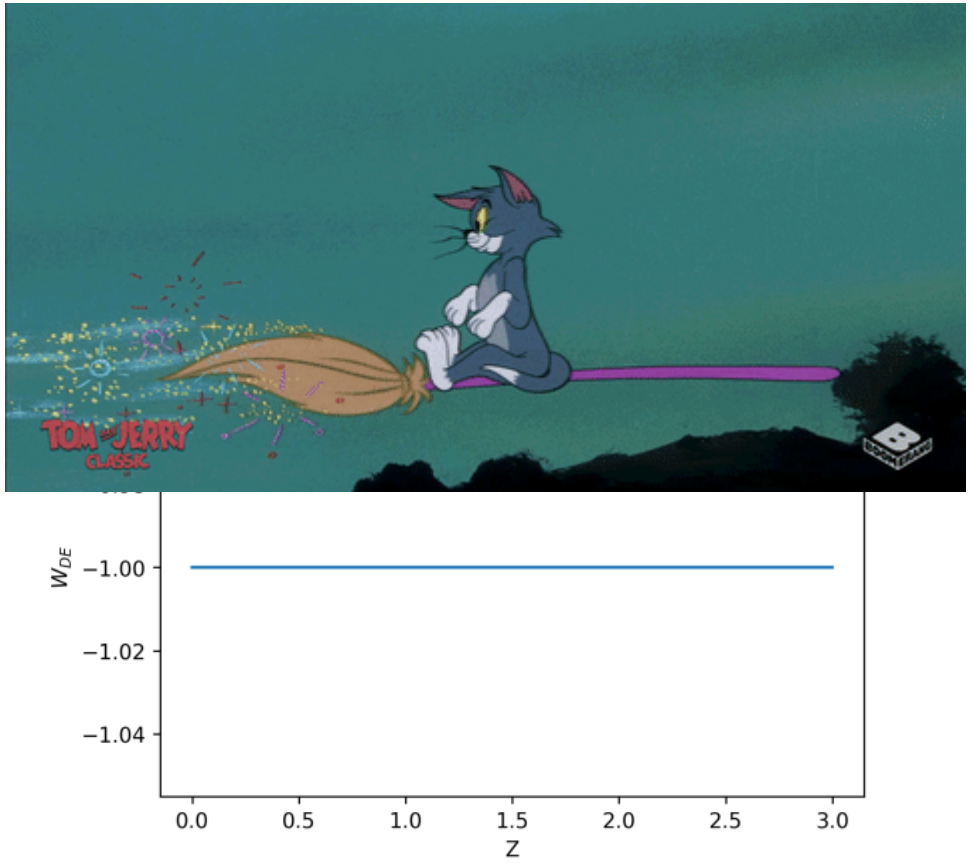

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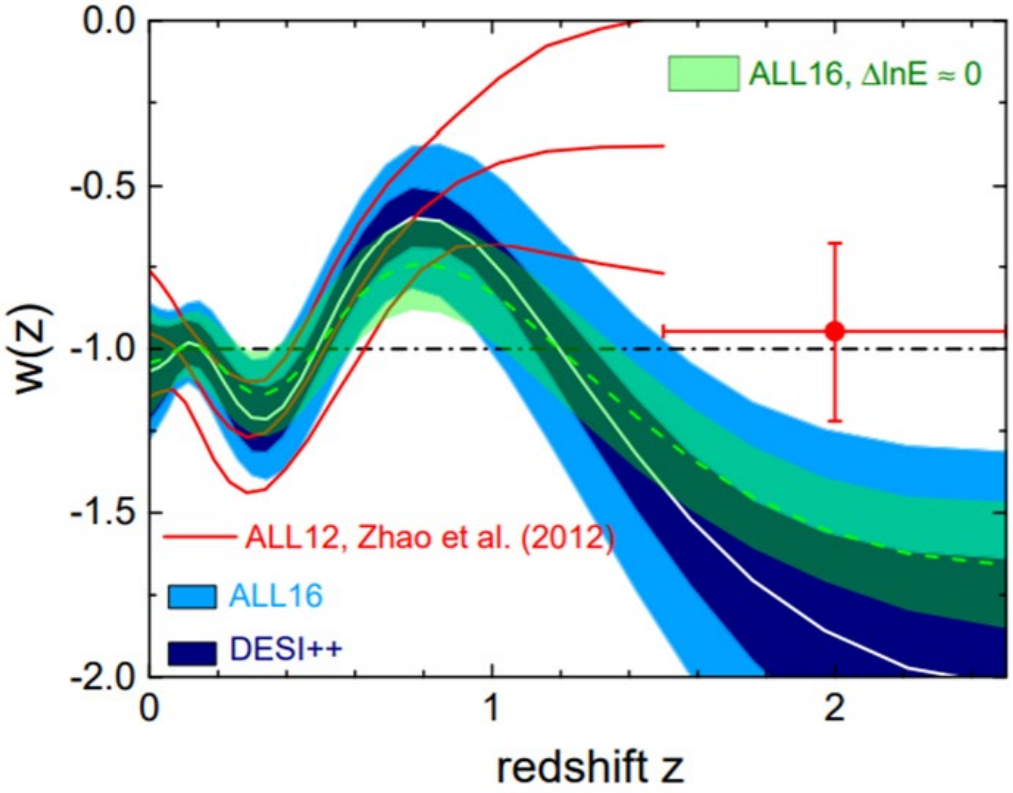

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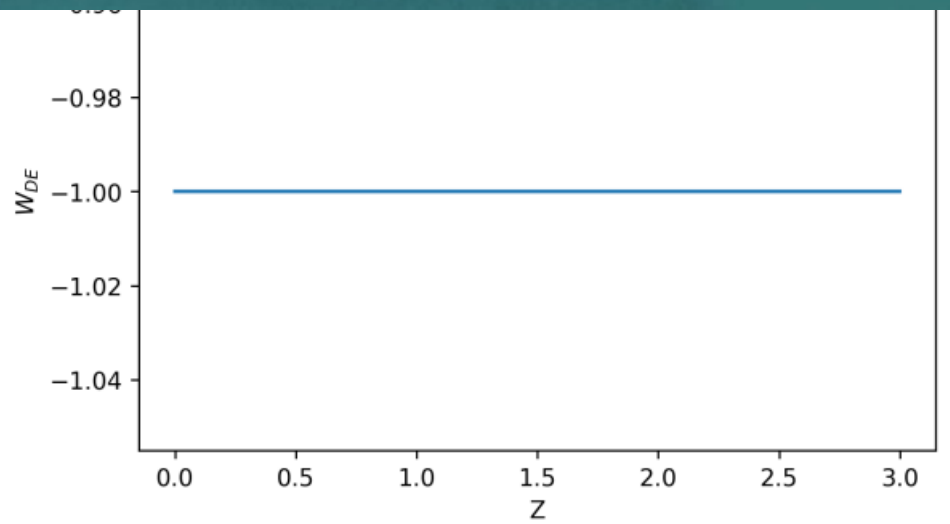

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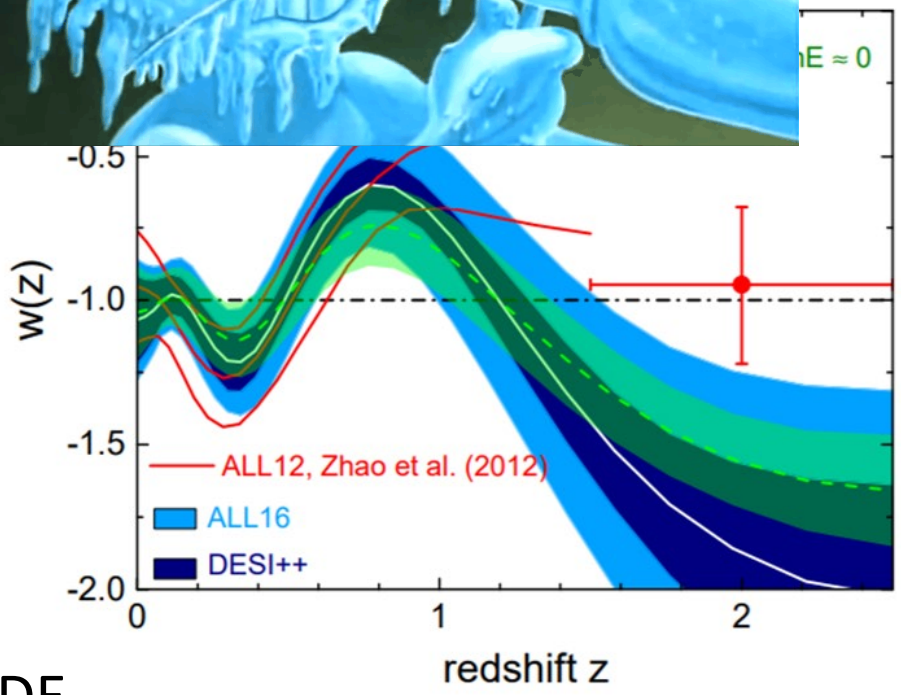

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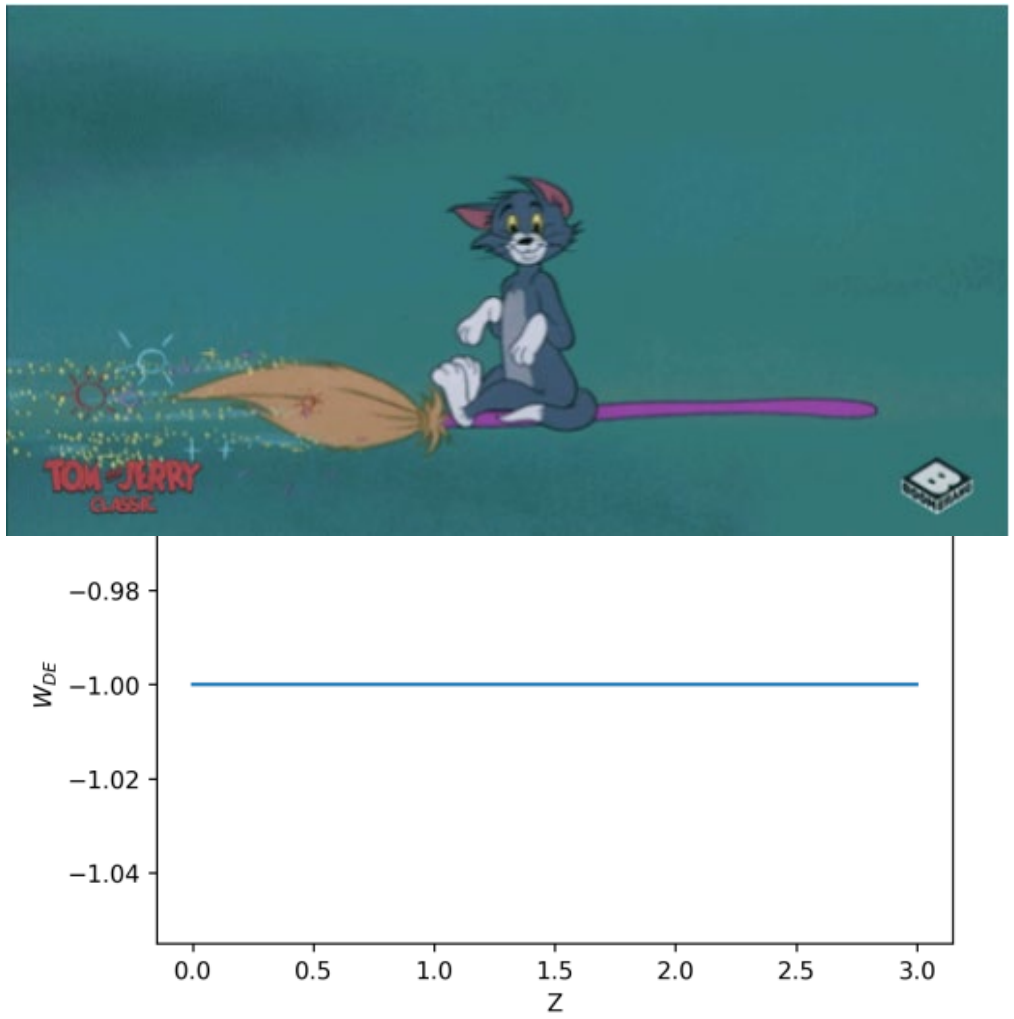

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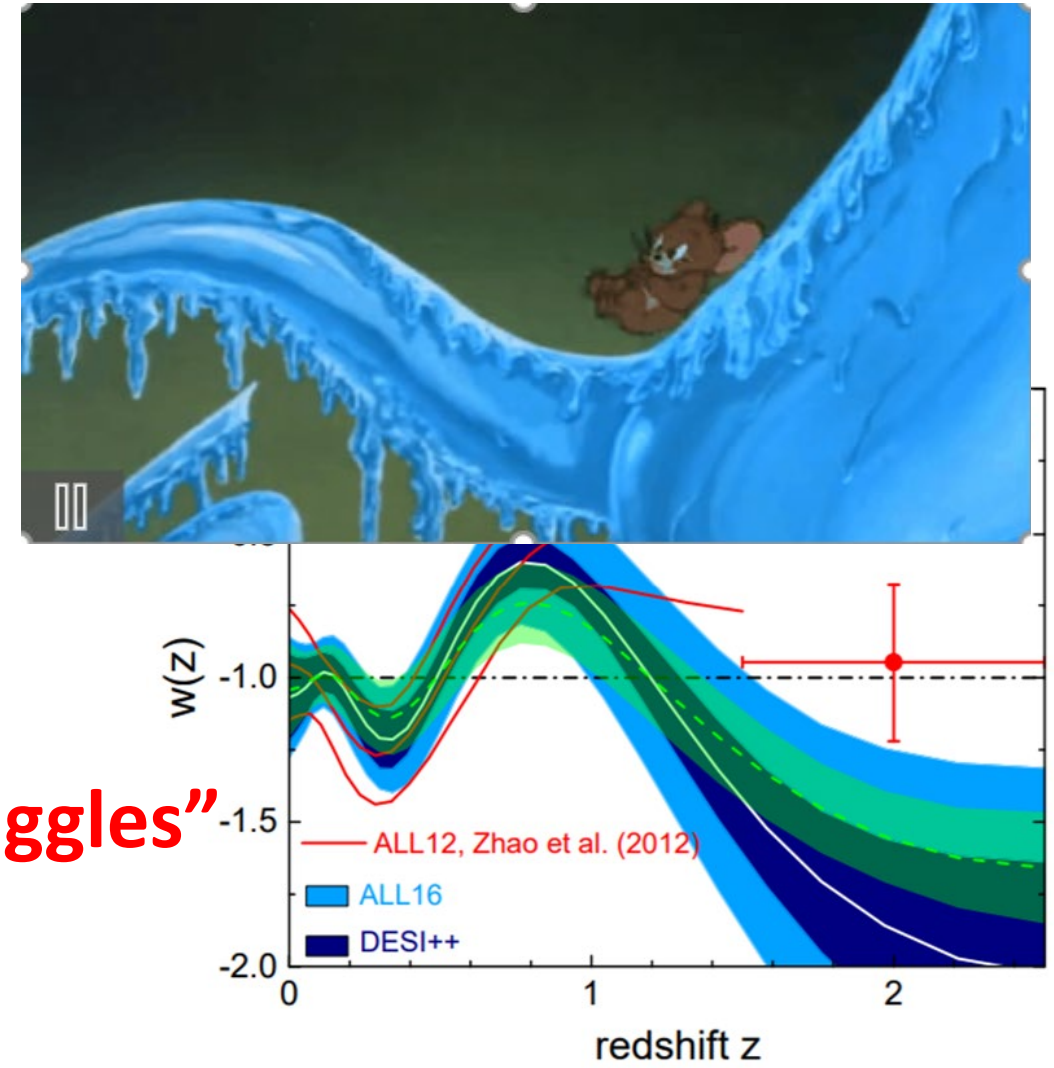
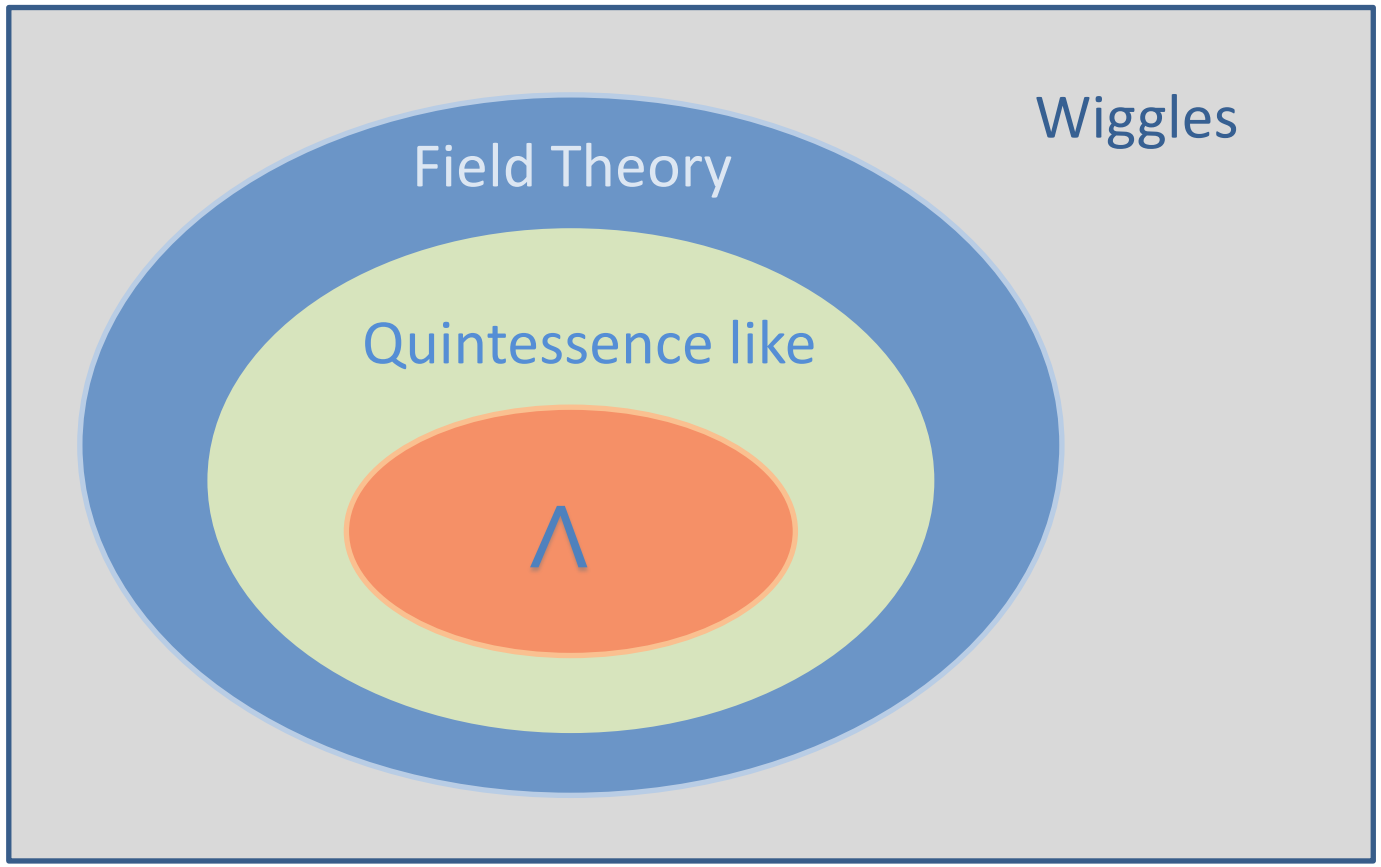


“wiggles”

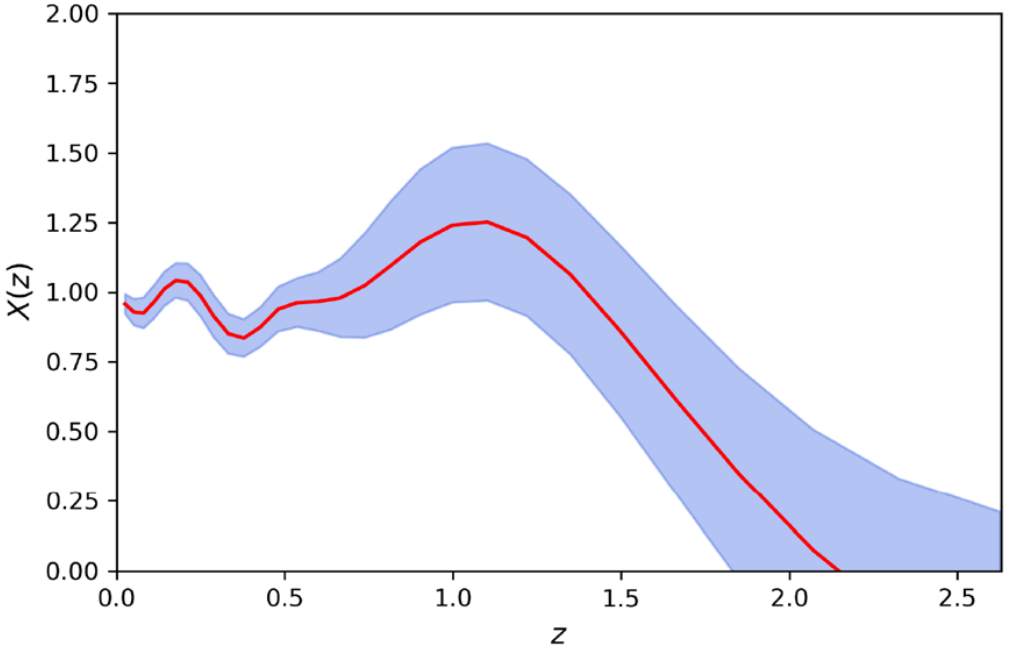
DDE

The relationship of w_{de} in different theory



Q to audience: Can the field theory give a wiggle EoS?

Can release the H0 tension by wiggles?



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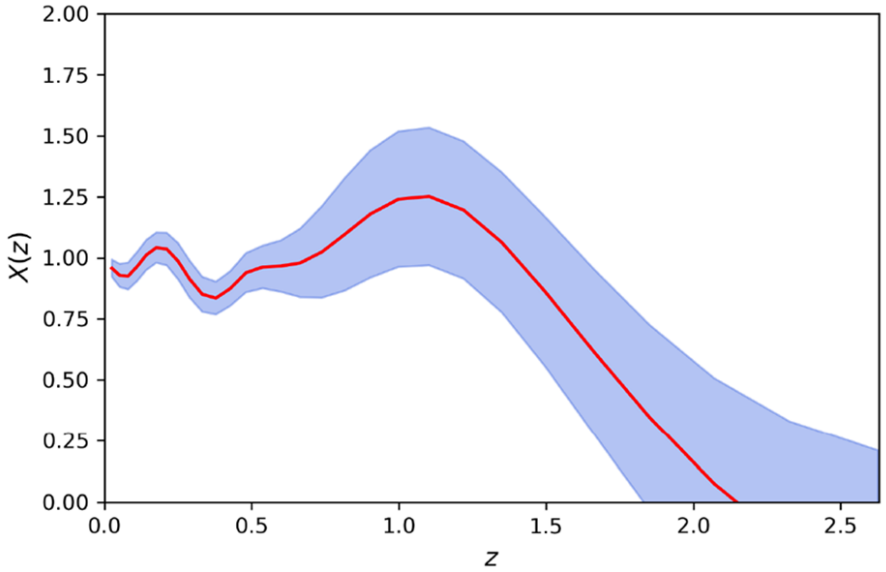

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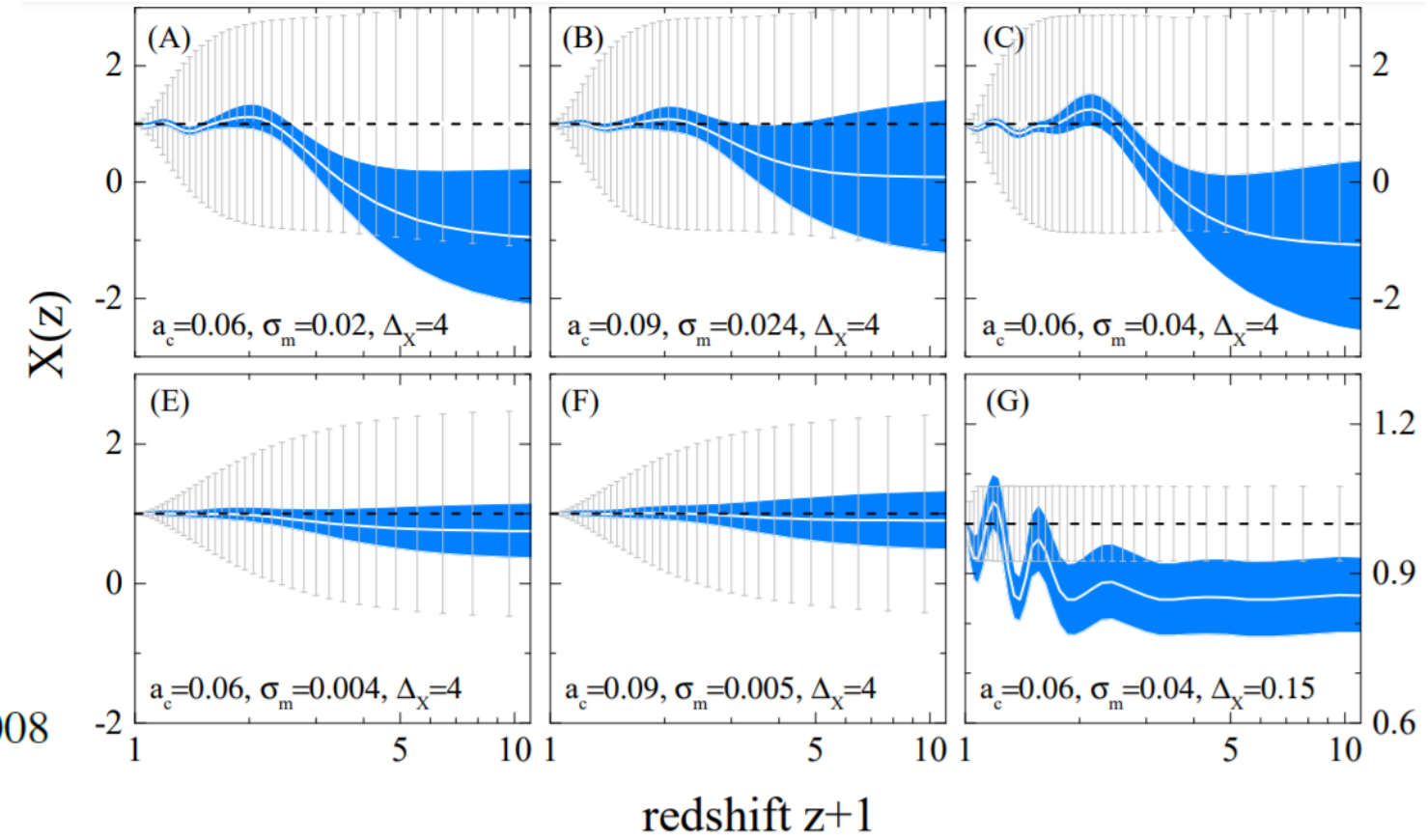

[Y. Wang, L. Pogosian, GB Zhao and A Zucca, Astrophys.J.Lett. 869 (2018) L8]

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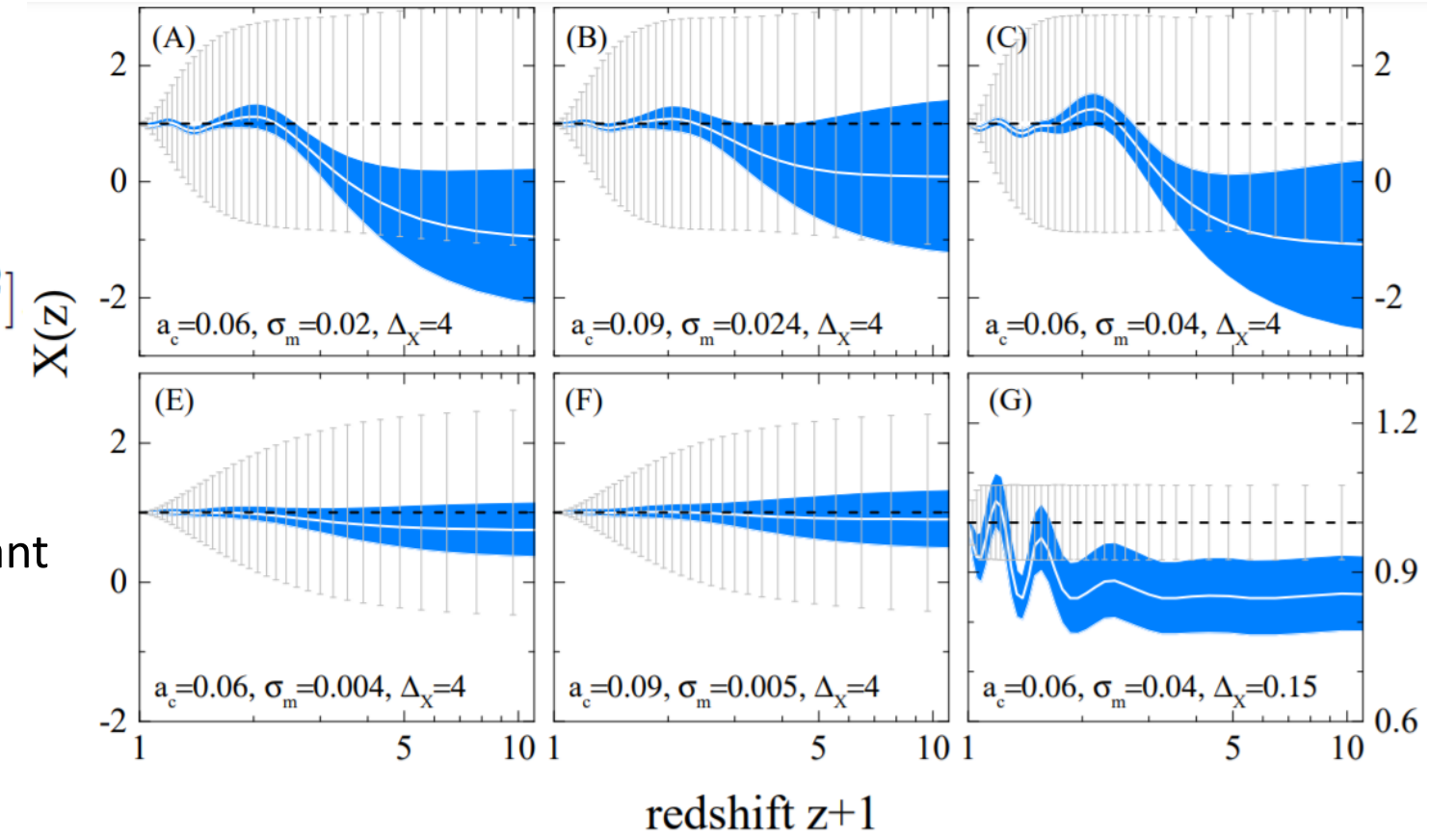
a_c is correlation length

$$\xi(|a-a'|) = \xi(0)/[1+(|a-a'|/a_c)^2]$$

$$\sigma_m^2 \simeq \pi\xi(0)a_c/(a_{\rm max}-a_{\rm min})$$

$a_c \to 1$ or $\sigma_m \to 0$ X(z) become constant



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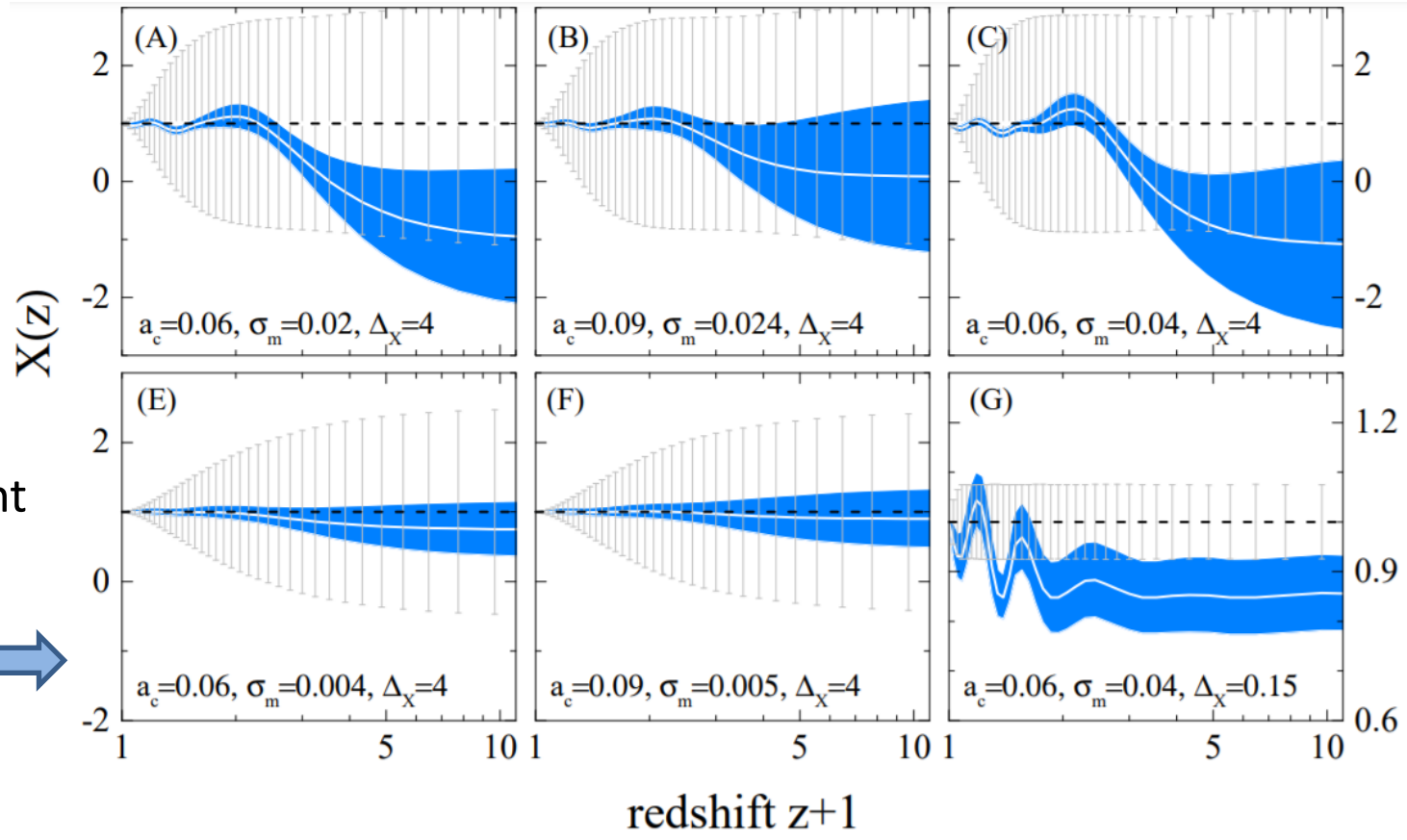

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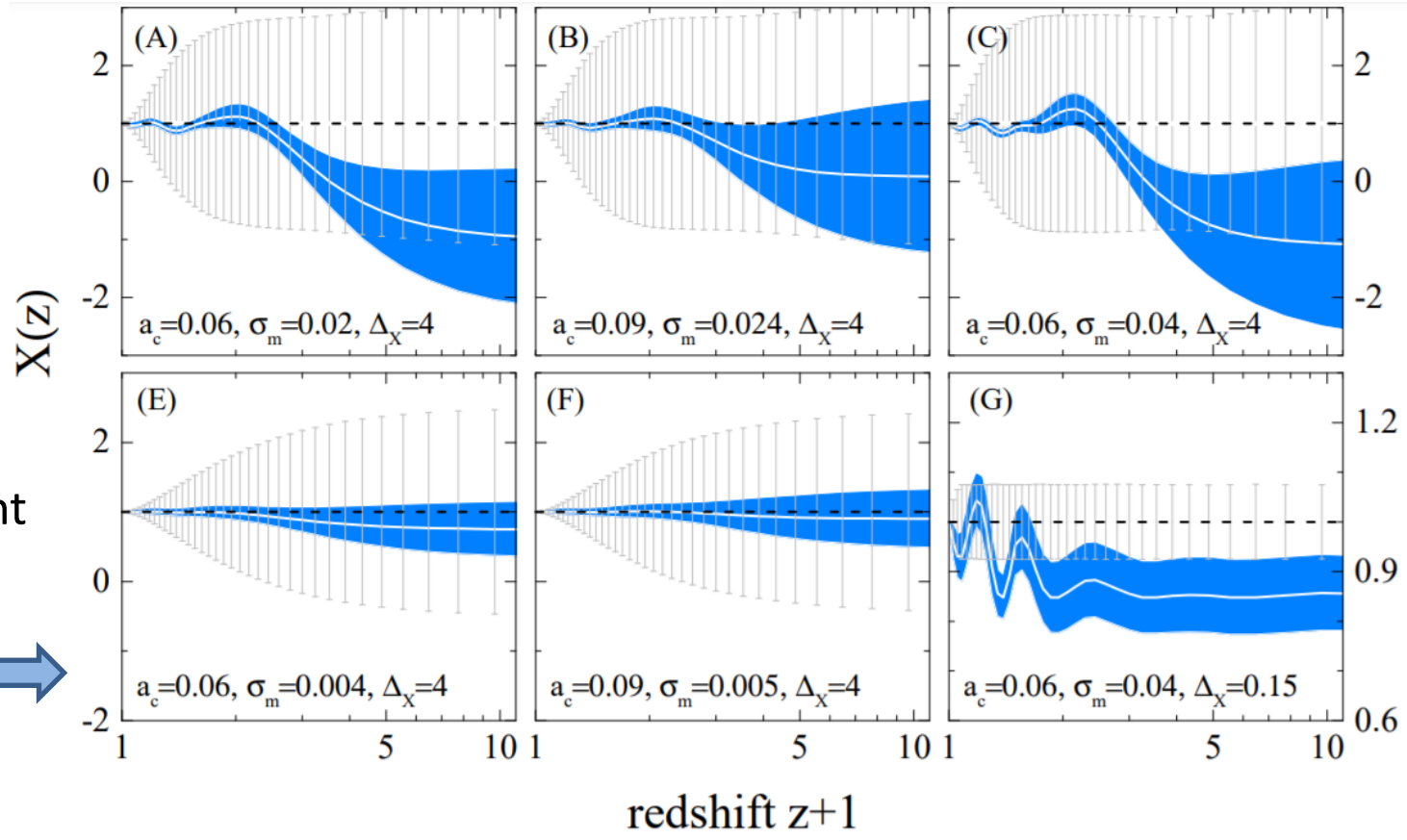

Back to LCDM again?

[Y. Wang, L. Pogosian, GB Zhao and A. Zucca, Astrophys.J.Lett. 869 (2018) L8]

Summary

- The “Sensitivity” of DDE depends on the function multiplying the parameter w_a in the usual two-parameter approach ($w_0;\ w_a$).

- Wiggles used a non-parametric method to build the EoS,
  but it still depend on parameters.

- New field theory or structure of Universe (FLRW broken?) are needed to explain this phenomena of wiggles.

Thank you!