Precise Cosmological Constraints from BOSS Galaxy Clustering using the Wavelet Scattering Transform

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Debating the Potential of Machine Learning
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Background from
Millennium Simulation, 2005

Based on
arXiv: 2310.16116, 2204.13717 & 2108.07821
in collaboration with **Cora Dvorkin & Sandy Yuan**

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The Wavelet Scattering Transform (WST)

"Scattering Network" image by G. Exarchakis (2018)

Convolution

Modulus

WST: $\left\langle \left| I_0 \star \psi^{j_1,l_1} \right| \right\rangle$ → Averaging

Input field

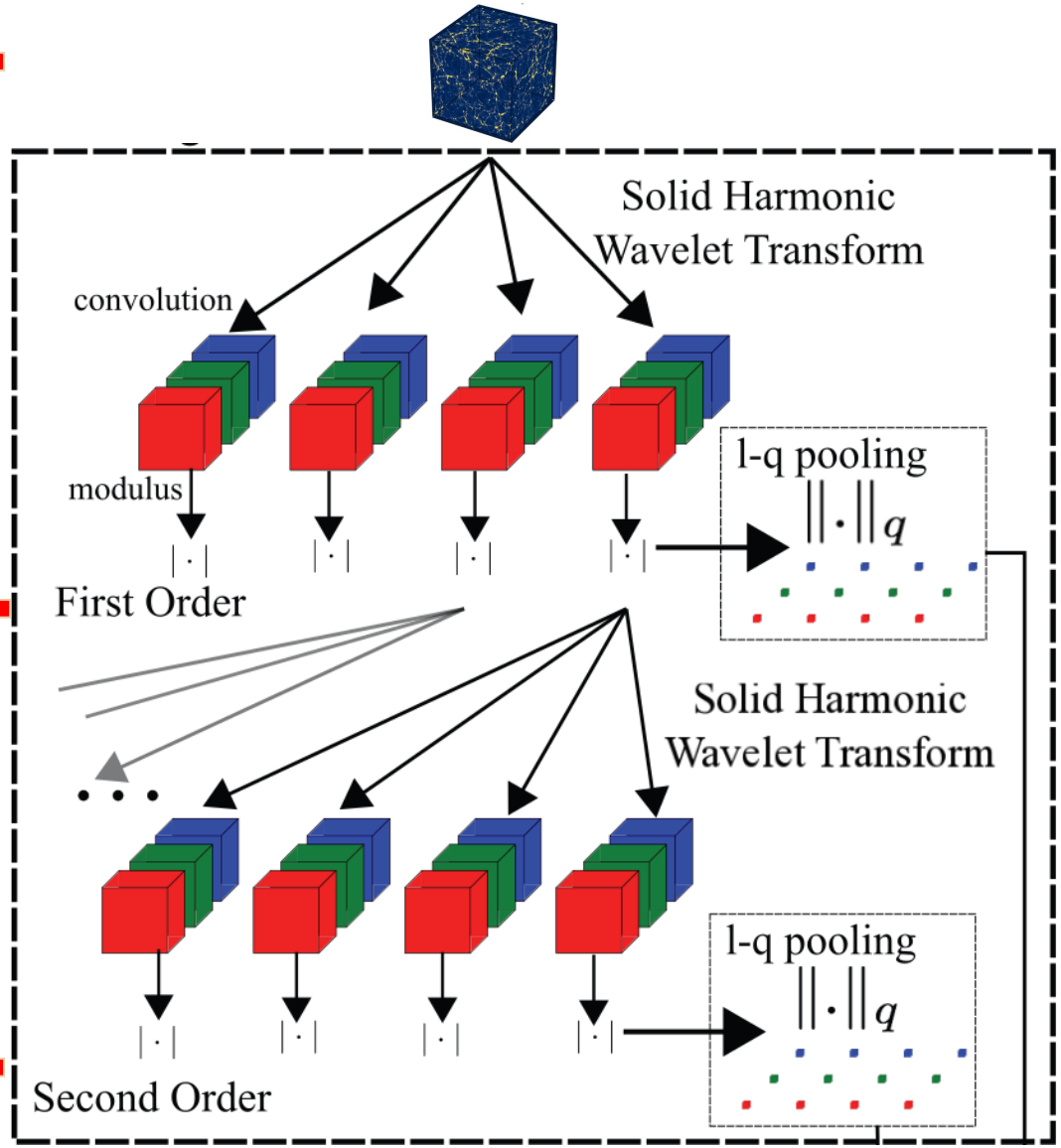
Family of Wavelets
- Dilated by 2^{j_1} - J scales
- Rotated by l_1 - L orientations

S. Mallat (2012)

$$S_0 = \langle |I_0| \rangle$$

$$S_1^{j_1,l_1} \equiv \langle I_1^{j_1,l_1} \rangle = \left\langle \left| I_0 \star \psi^{j_1,l_1} \right| \right\rangle$$

$$S_2^{j_1,l_1,j_2,l_2} \equiv \langle I_2^{j_1,l_1,j_2,l_2} \rangle = \left\langle \left| |I_0 \star \psi^{j_1,l_1}| \star \psi^{j_2,l_2} \right| \right\rangle$$



- Basis $S_0 + S_1 + S_2$ reflects clustering properties of target field $I_0(x)$
- Captures non-Gaussian information beyond P(k)
- Interpretable neural net with fixed kernels (wavelets)

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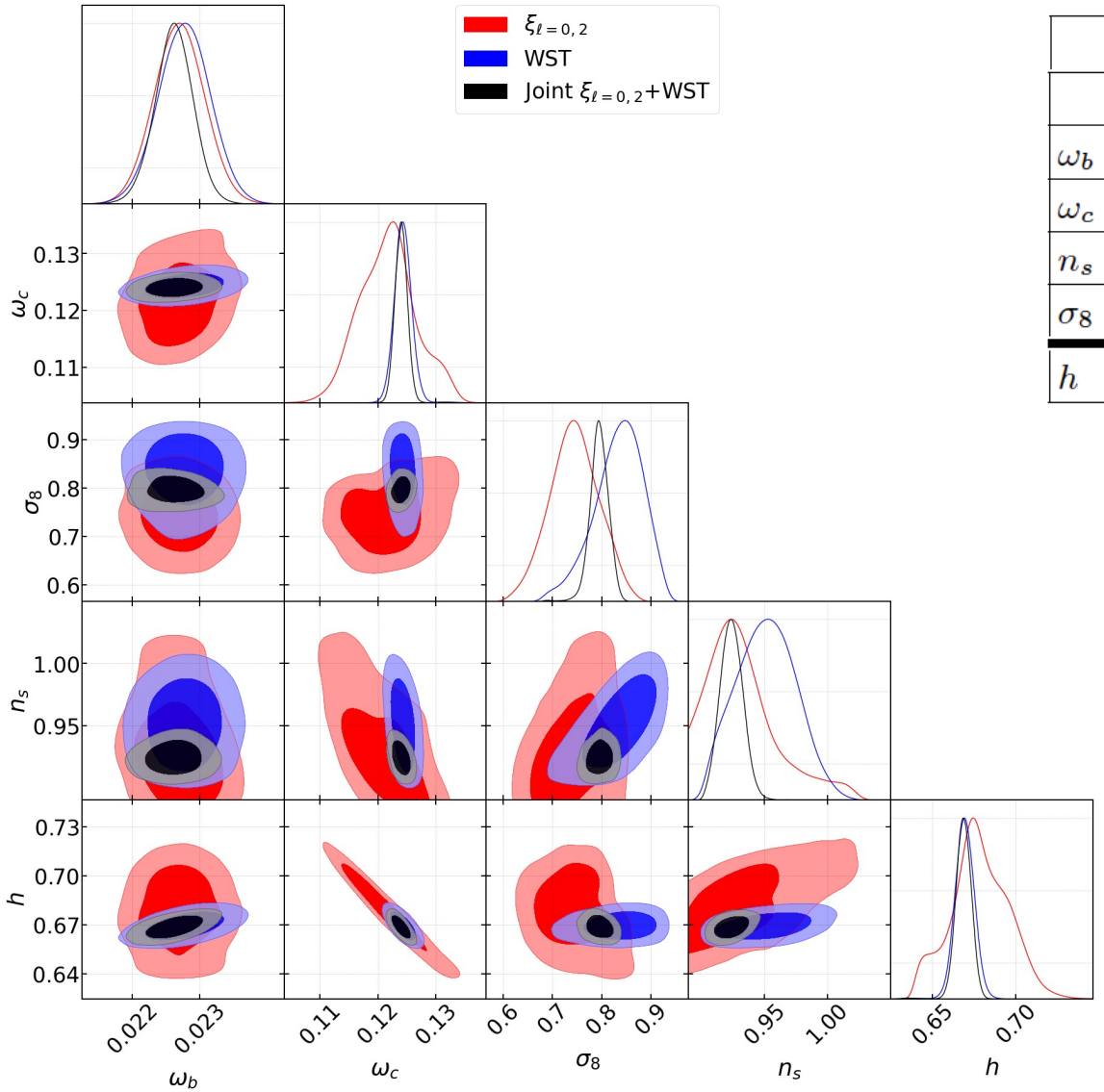
Precise WST Constraints from BOSS CMASS data!



	2-point c.f.		WST		Joint 2-point c.f.+WST	
	Best-fit	Mean$\pm\sigma$	Best-fit	Mean$\pm\sigma$	Best-fit	Mean$\pm\sigma$
ω_b	0.02261	$0.02270^{+0.00037}_{-0.00037}$	0.02274	$0.02277^{+0.00038}_{-0.00038}$	0.0225	$0.02262^{+0.00029}_{-0.00029}$
ω_c	0.1201	$0.1222^{+0.0040}_{-0.0063}$	0.1239	$0.1244^{+0.0015}_{-0.0015}$	0.1238	$0.1241^{+0.0011}_{-0.0011}$
n_s	0.925	$0.922^{+0.037}_{-0.037}$	0.961	$0.951^{+0.023}_{-0.023}$	0.927	$0.924^{+0.01}_{-0.01}$
σ_8	0.742	$0.746^{+0.051}_{-0.051}$	0.860	$0.834^{+0.058}_{-0.039}$	0.793	$0.795^{+0.019}_{-0.019}$
h	0.677	$0.677^{+0.022}_{-0.015}$	0.67	$0.669^{+0.0059}_{-0.0059}$	0.668	$0.669^{+0.0049}_{-0.0049}$

- **First** WST application to actual survey data of any kind!
- BOSS CMASS Dr12 spectroscopic galaxy dataset
- Joint WST+ξ(r) analysis *improves* 1σ errors by **2.5-6x** compared to ξ(r)-only analysis!
- Joint WST+ξ(r) analysis *improves* 1σ errors by 1.4-2.5x compared to WST-only analysis
- Competitive 0.9%, 2.3% & 1% determination of ω_c, σ_8 & n_s
- Upcoming application to DESI Year-1 data (& beyond)

Valogiannis, Yuan & Dvorkin, 2023, arXiv: 2310.16116

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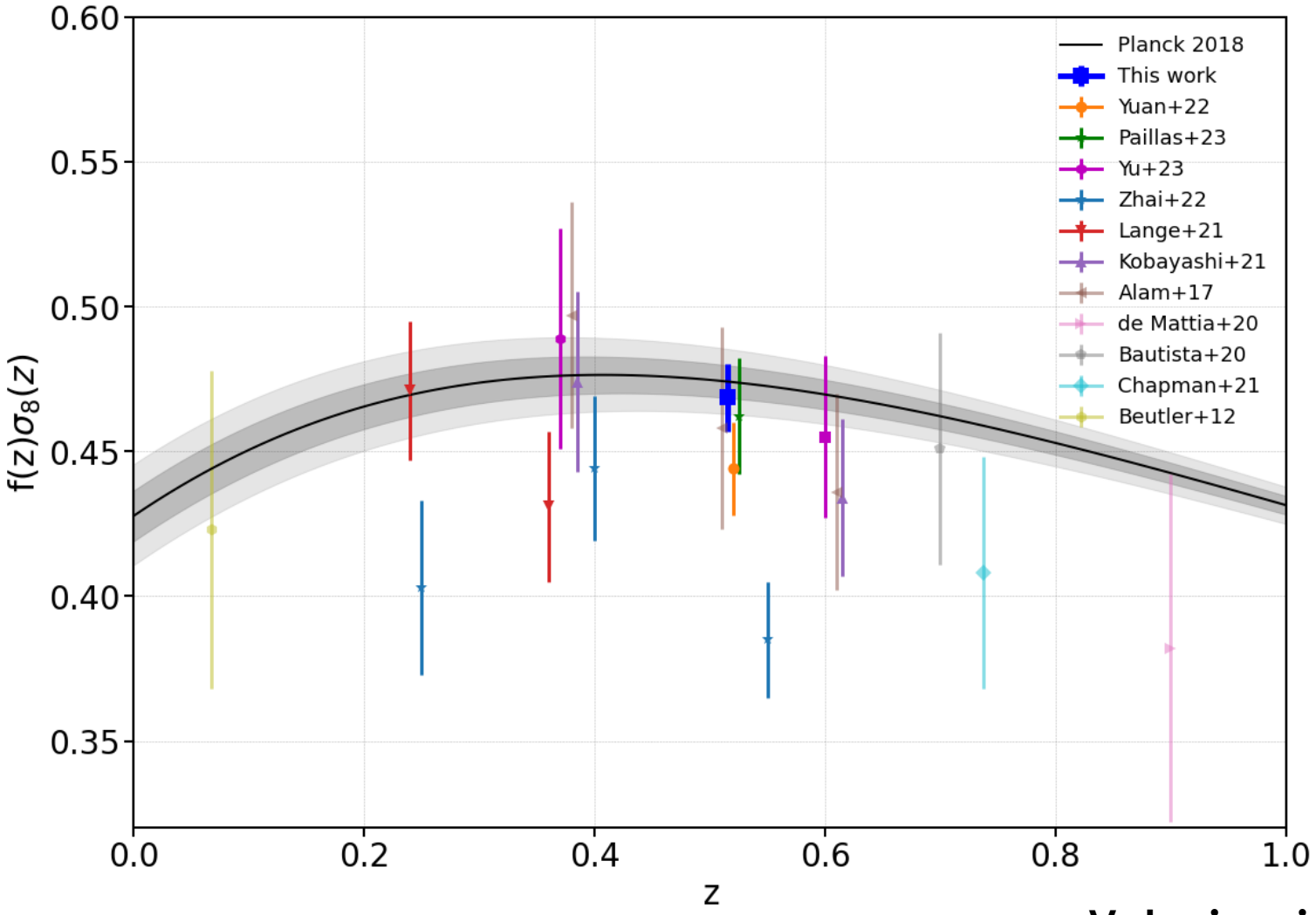
Structure Growth in agreement with Planck



- $\mathbf{f\sigma_8(z_{eff} = 0.515) = 0.469 \pm 0.012}$
- 2.5% level of determination in agreement with *Planck 2018*
- $\boldsymbol{S_8 = 0.833 \pm 0.023}$, in almost perfect agreement with Planck 2018 $S_8 = 0.832 \pm 0.013$

Valogiannis, Yuan & Dvorkin, 2023, arXiv: 2310.16116


Thank you!