Computing the Central Charge of the 3D Ising CFT Using Quantum Finite Elements

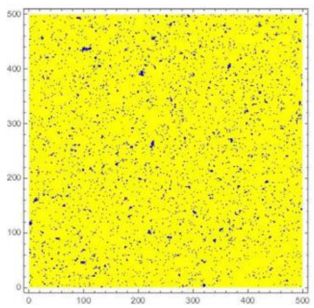
ANNA-MARIA E. GLÜCK – YALE UNIVERSITY & UNIVERSITÄT HEIDELBERG

LATTICE 2022 – THEORETICAL DEVELOPMENTS II

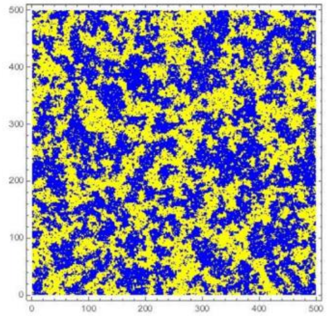
Introduction

Criticality in the 3D Ising Model and beyond

- 3D Ising model: interacting spins $\sigma = \pm 1$ in 3D



$T \ll T_C$



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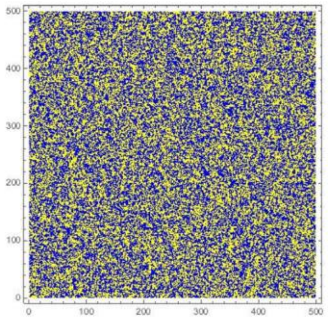
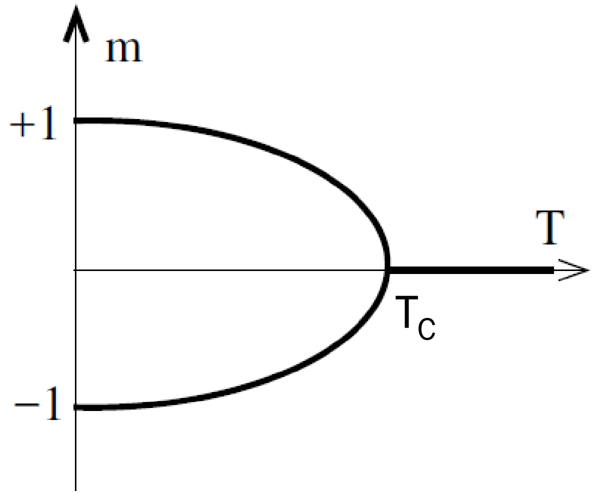


$T \gg T_C$

[Tong 2017]



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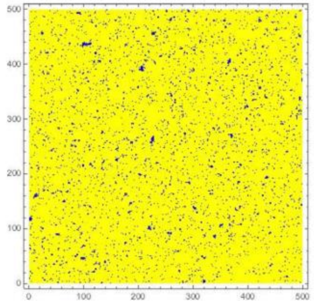
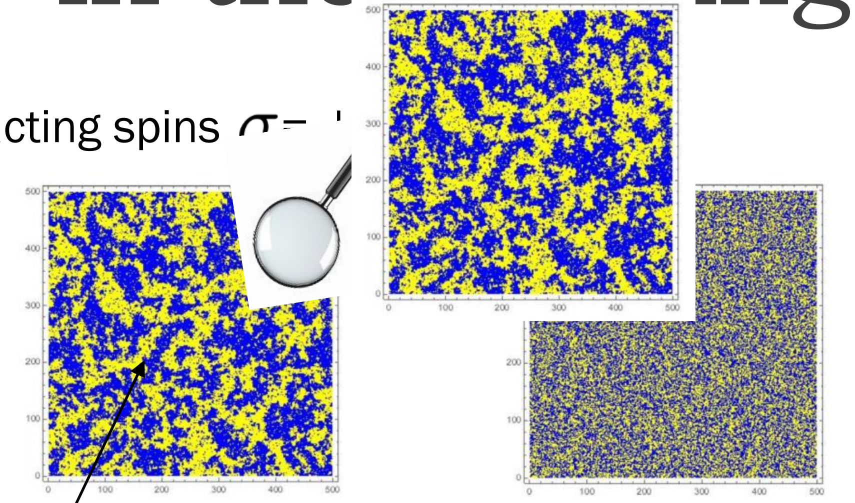
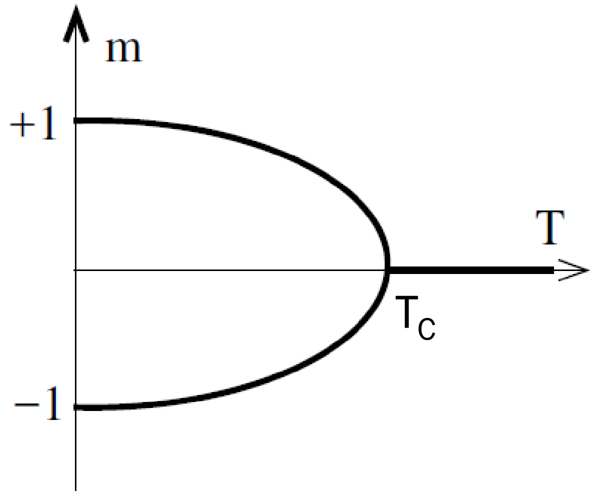




$T \ll T_C$ $\quad$ $T = T_C$ $\quad$ $T \gg T_C$

Scale invariance

[Tong 2017]



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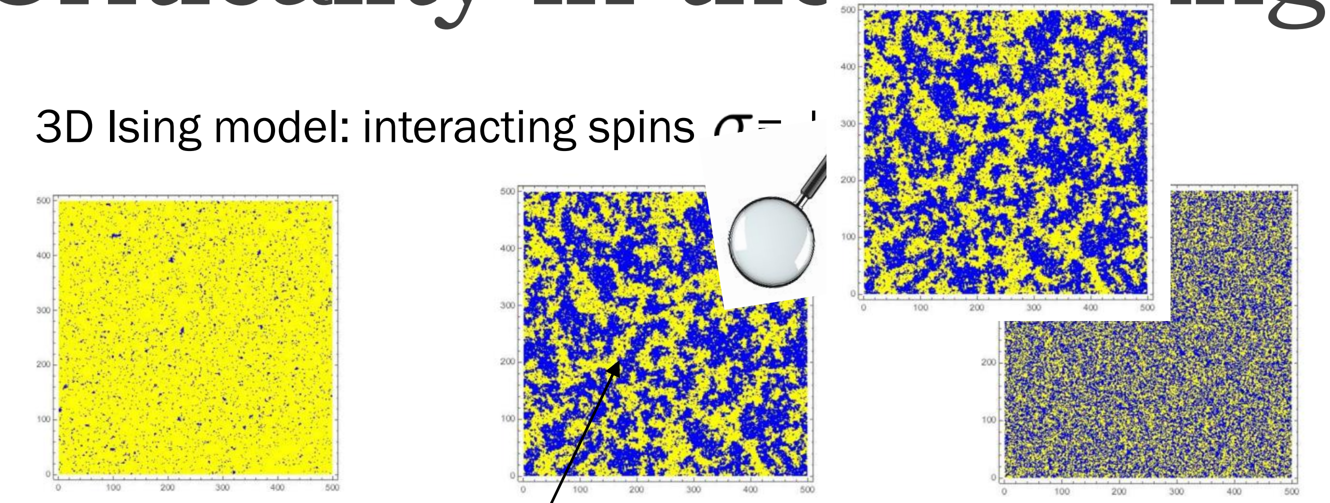

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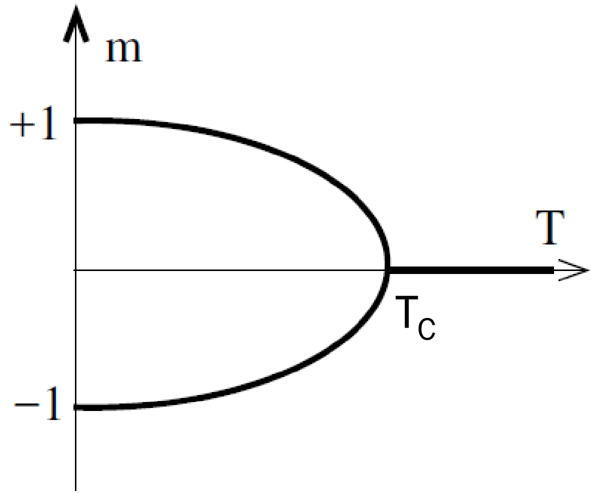
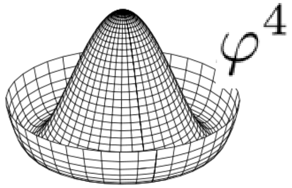
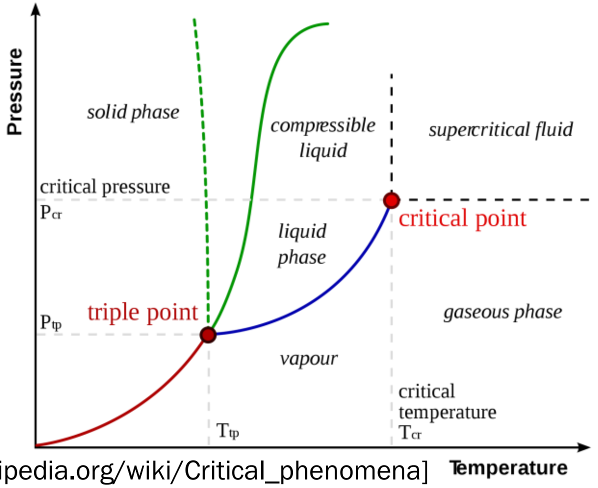


Universality





[https://en.wikipedia.org/wiki/Critical_phenomena]

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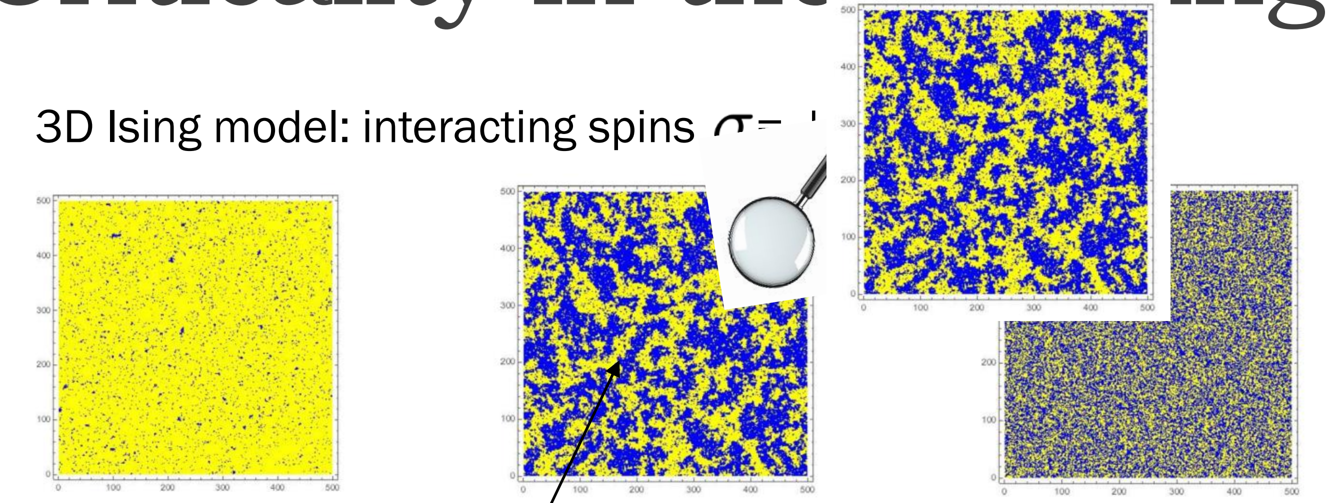

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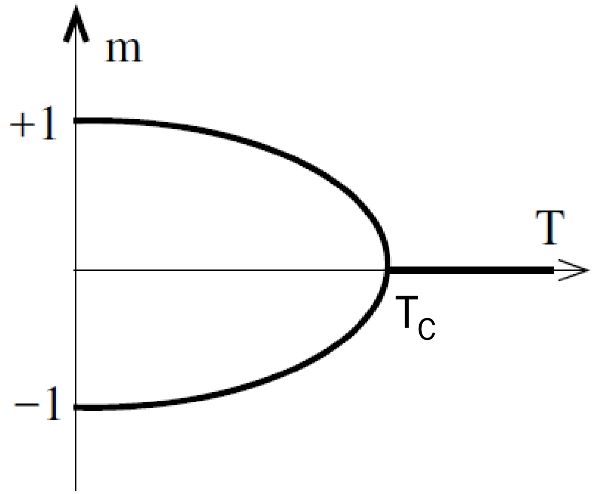

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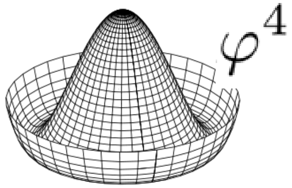

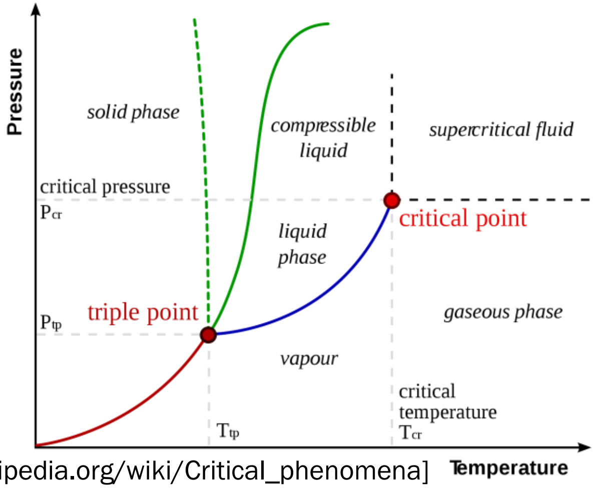

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(analytically in 3D)

⇨ Interesting for numerical studies

Investigating a system at criticality

POV Condensed Matter Physics

- Physical quantities: Power laws

$$C \propto t^{-\alpha} \quad m \propto t^{\beta} \quad \chi \propto t^{-\gamma} \quad \xi \propto t^{-\nu}$$

$$\langle \sigma(0)\sigma(\boldsymbol{r}) \rangle \propto r^{-d+2-\eta} \qquad \boxed{t = \frac{|T-T_c|}{T_c}}$$

Determination of critical exponents
using MC & finite size scaling

[Swendsen, Wang 1987],
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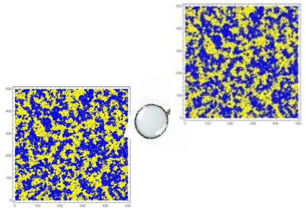

+ Poincaré

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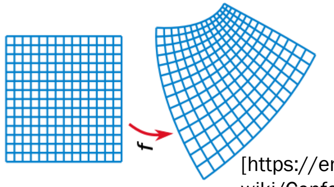

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⇨ Conformal Field Theory (CFT)

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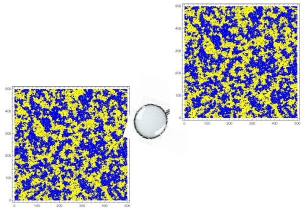

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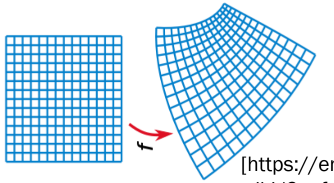

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Conformal Field Theory (CFT)

- Primary operators $\mathcal{O}$:

$$\begin{array}{cccccc} \sigma, & \epsilon, & \epsilon', & T, & T', & C, \ldots \\ 0^- & 0^+ & 0^+ & 2^+ & 2^+ & 4^+ \end{array}$$

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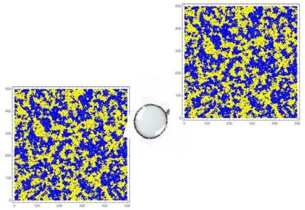

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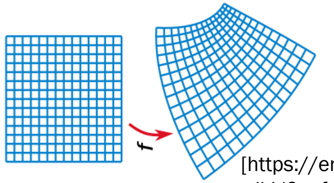

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(n>2)-point-functions

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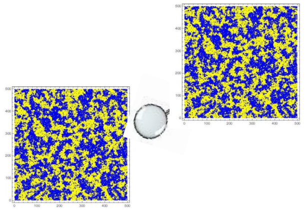

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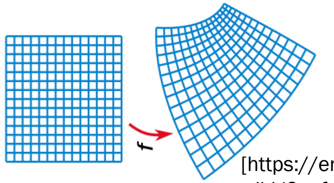

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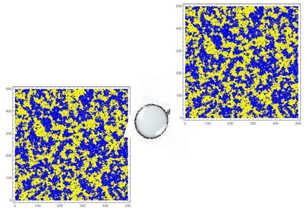

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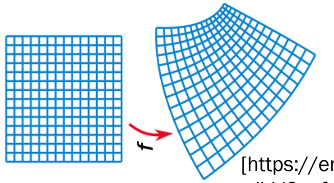

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Conformal bootstrap (crossing symmetry constraints on n-point functions)

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+ new quantities beyond FSS results
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This work: Lattice Method for calculating the same quantities as the conformal bootstrap and checking their values.

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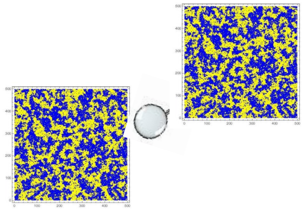

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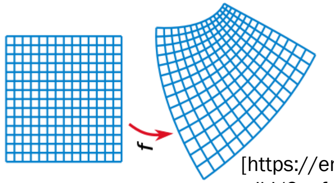

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Antipodal 4-point function on $\mathbb{R} \times \mathbb{S}^2 \ni (t, \vec{x})$

- OPE for the 4-point function of σ-operators in the 3D Ising CFT

Conformal blocks

$$\frac{\langle \sigma(x_1)\sigma(x_2)\sigma(x_3)\sigma(x_4)\rangle}{\langle \sigma(x_1)\sigma(x_2)\rangle\langle \sigma(x_3)\sigma(x_4)\rangle} = 1 + \sum_{\mathcal{O}} f^2_{\sigma\sigma\mathcal{O}} G_{\mathcal{O}}(\Delta_{\mathcal{O}}; x_1, x_2, x_3, x_4)$$

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- In special antipodal frame on $\mathbb{R} \times \mathbb{S}^2$, $G_{\mathcal{O}}$ are particularly simple [Costa et al., 2016]:

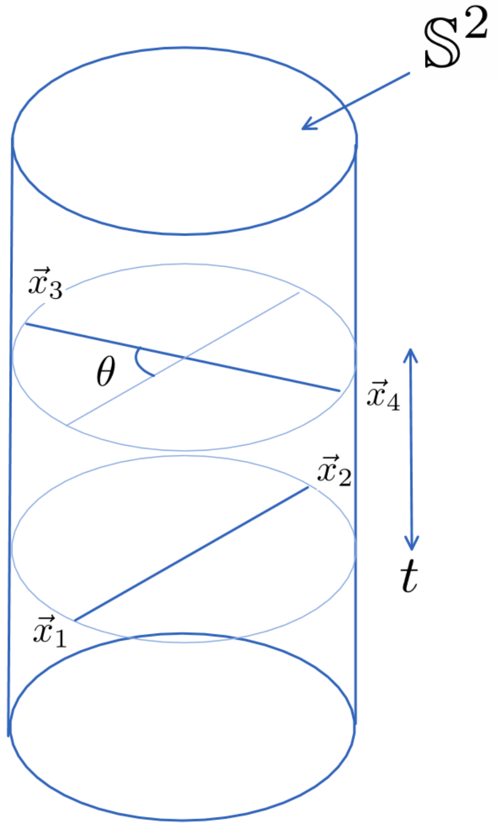
$$G_{\mathcal{O},l} = \sum_{n=0,2,4,\ldots} \sum_{j} e^{-(\Delta_{\mathcal{O}}+n)t} B_{n,j}(\Delta_{\mathcal{O}}) P_j(\cos(\theta))$$

Spin of the operator

$j \in \{\max(0, l-n), \ldots, l+n-2, l+n\}$

Calculated via a recursion relation

$\Rightarrow$ Partial wave expansion



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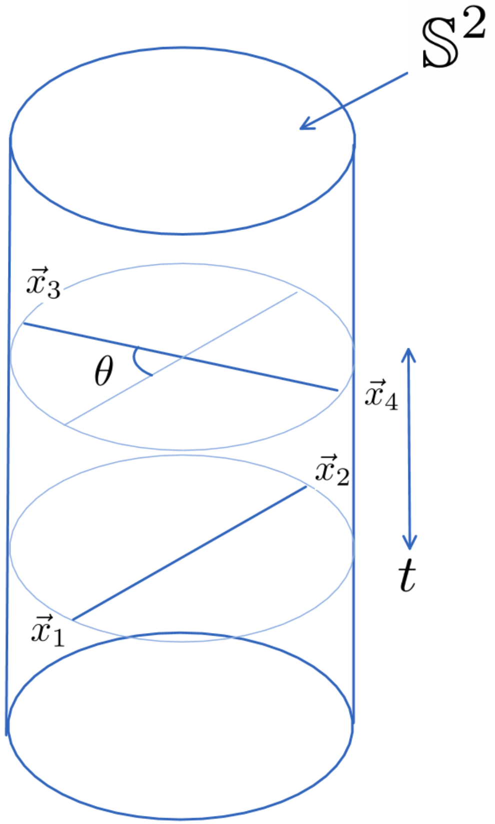

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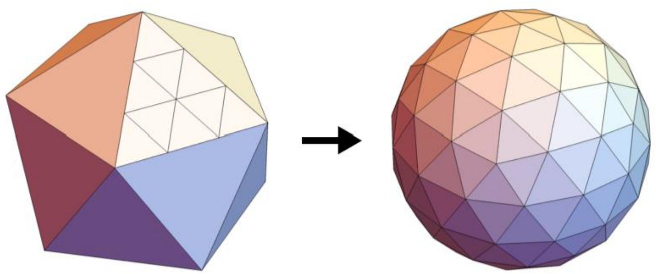
$\Rightarrow$ Obtain $f_{\sigma\sigma\mathcal{O}}$ and $\Delta_{\mathcal{O}}$ by fits to partial wave expansion coefficients for 4-pt function on $\mathbb{R} \times \mathbb{S}^2$

Quantum Finite Elements [Brower et al., 2018, 2021]

- LFT on curved manifolds (here: $\mathbb{R} \times \mathbb{S}^2$)

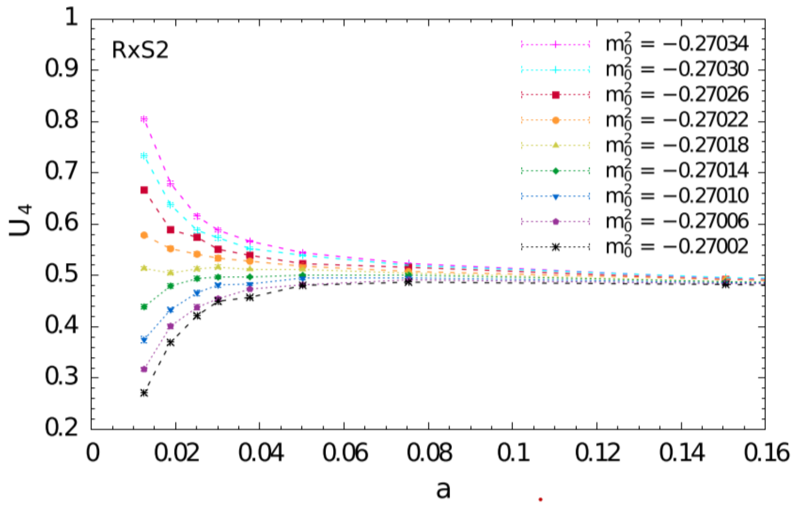
- Discretize φ^4-theory on $\mathbb{R} \times \mathbb{S}^2$ using Regge Calculus, DEC & FEM



- Introduce **Quantum Finite Elements (QFE)**

$\Rightarrow$ convergence to spherically symmetric continuum theory

- Tune to critical surface



$\Rightarrow$ Lattice simulations of critical φ^4-theory on $\mathbb{R} \times \mathbb{S}^2$ possible

Numerical Results

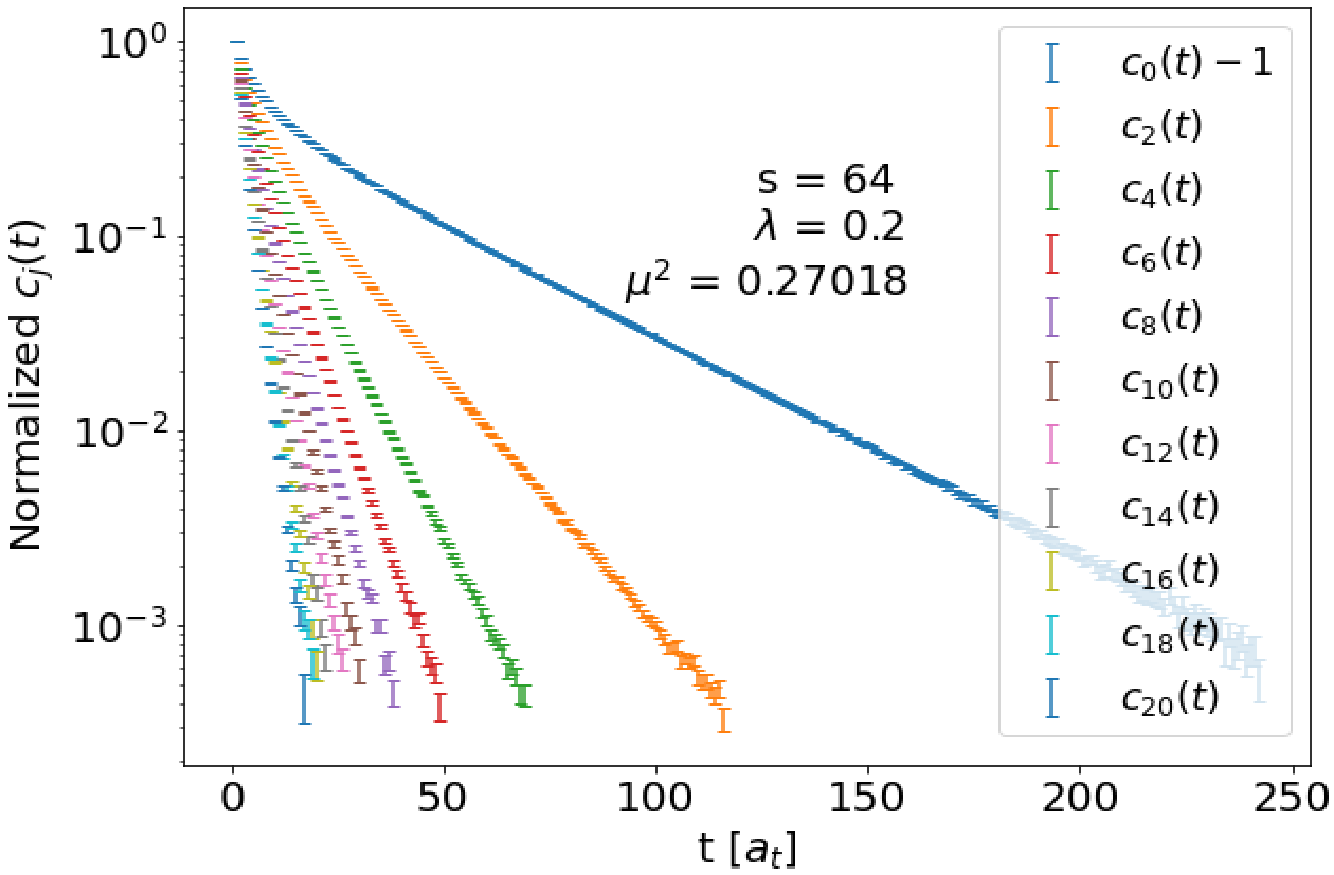
MONTE CARLO SIMULATIONS OF CRITICIAL φ^4-THEORY,

PERIODIC BOUNDARY CONDITIONS

Numerical results

$$j \in \{\max(0, l-n), ..., l+n-2, l+n\}$$

$$\frac{\langle\sigma(x_1)\sigma(x_2)\sigma(x_3)\sigma(x_4)\rangle}{\langle\sigma(x_1)\sigma(x_2)\rangle\langle\sigma(x_3)\sigma(x_4)\rangle} = \sum_{\text{even } j} c_j(\Delta t)P_j(\cos(\theta)) = 1 + \sum_{\mathcal{O}} f^2_{\sigma\sigma\mathcal{O}} \sum_{n=0,2,4,\ldots} \sum_j e^{-(\Delta_{\mathcal{O}}+n)c_R g t} B_{n,j}(\Delta_{\mathcal{O}})P_j(\cos(\theta))$$



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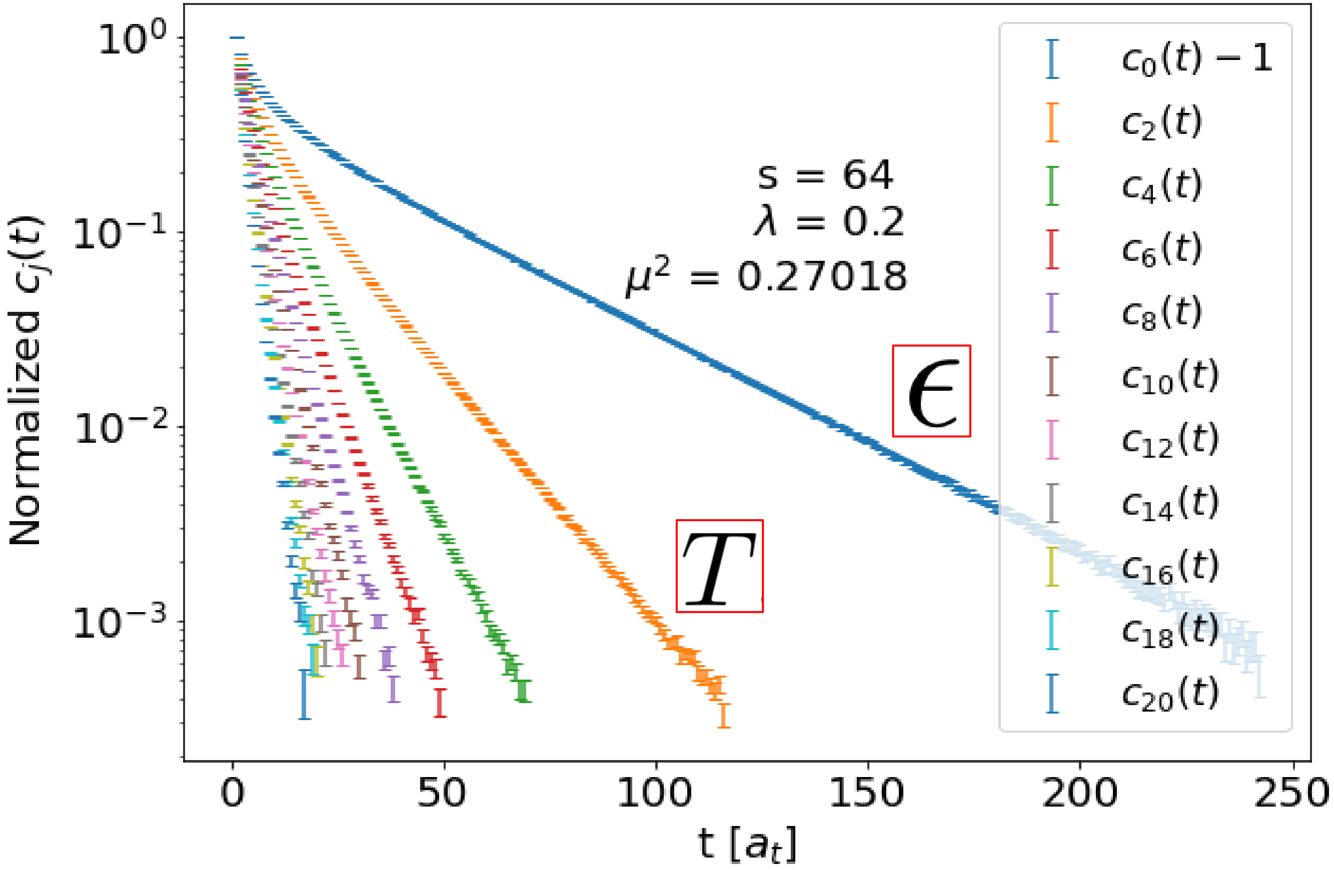

Simultaneous fits of c_0(t) and c_2(t)
using primaries $\epsilon, \quad T, \quad \epsilon', \quad T'$ up to n=20

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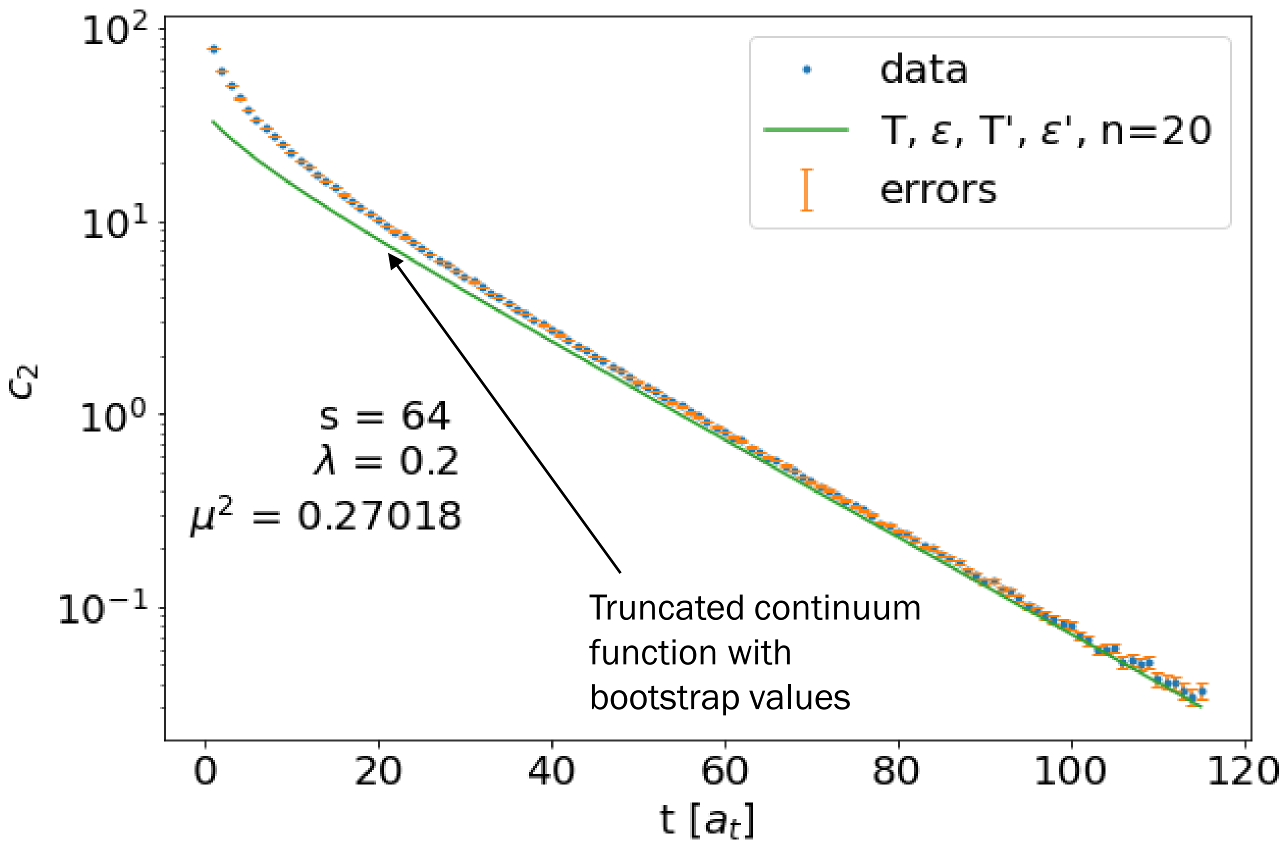


Simultaneous fits of $c_0(t)$ and $c_2(t)$ using primaries $\epsilon, \quad T, \quad \epsilon', \quad T'$ up to n=20

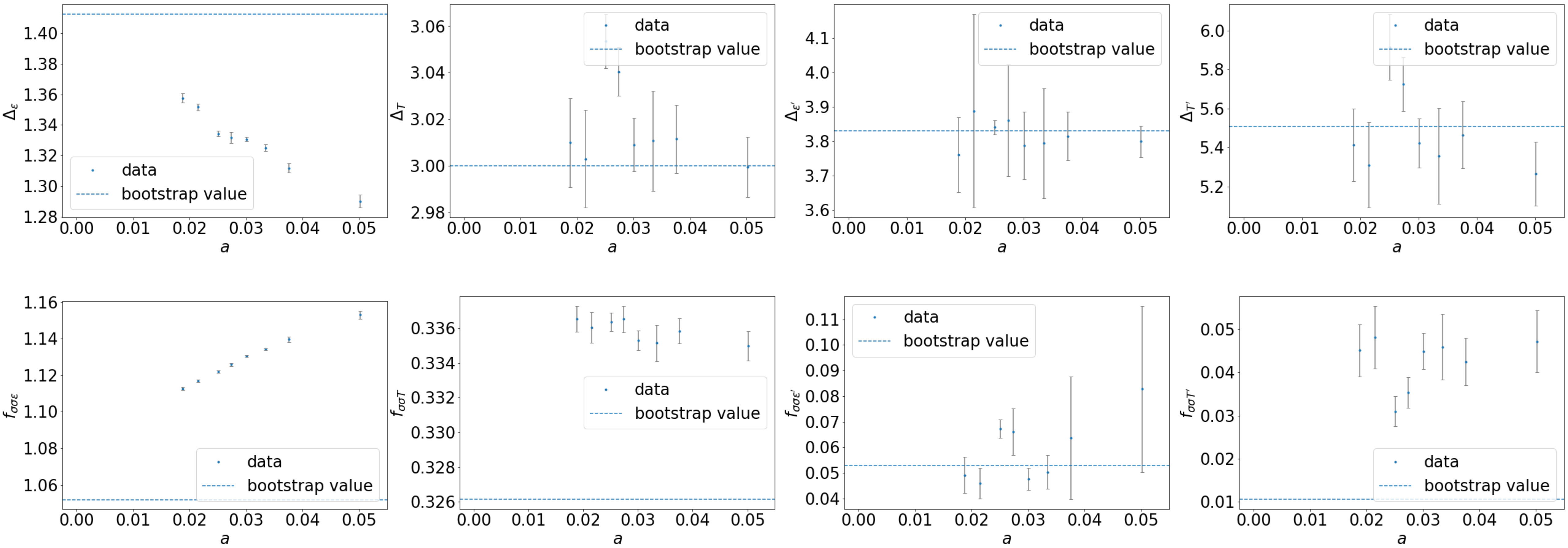
MODEL AVERAGING [Jay, Neil 2020]

$$\theta = \sum_{\text{model } i} \theta_{\text{fit}\, i}\; p(\text{model } i|\text{data})$$

Different number of timeslices included in fit

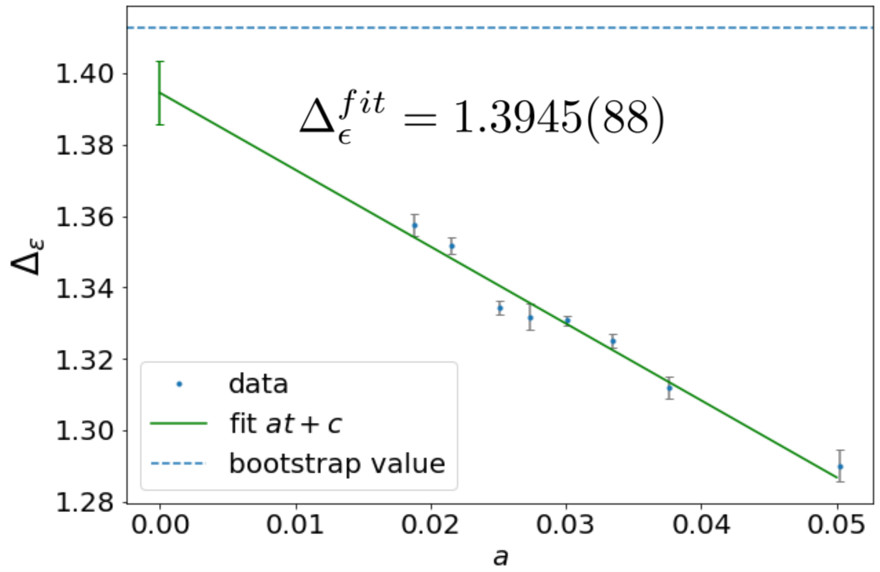
Model averaging results for c_0 and c_2

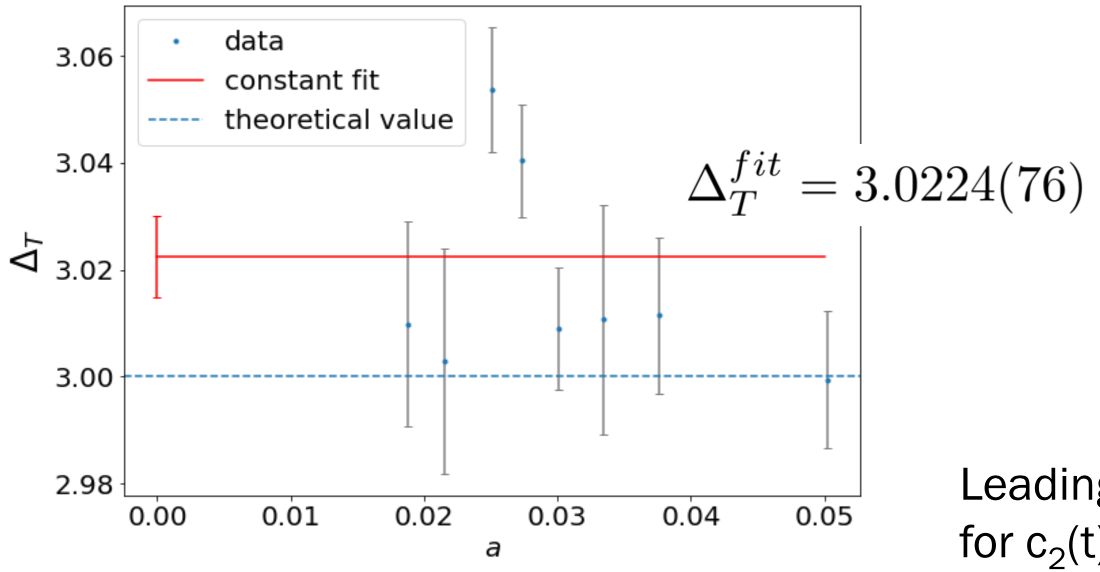
Simultaneous fits of $c_0(t)$ and $c_2(t)$ using 4 primaries $\epsilon, \quad T, \quad \epsilon', \quad T'$ & different t-ranges



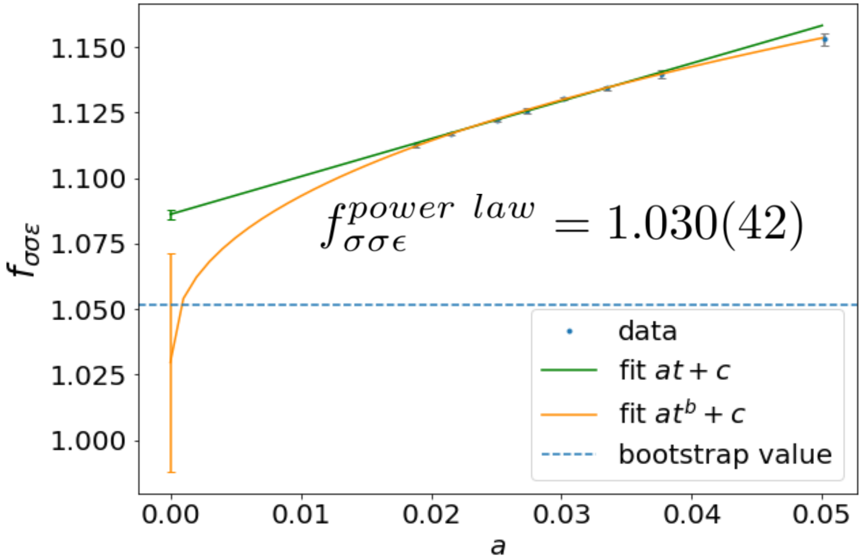
Model averaging – leading terms

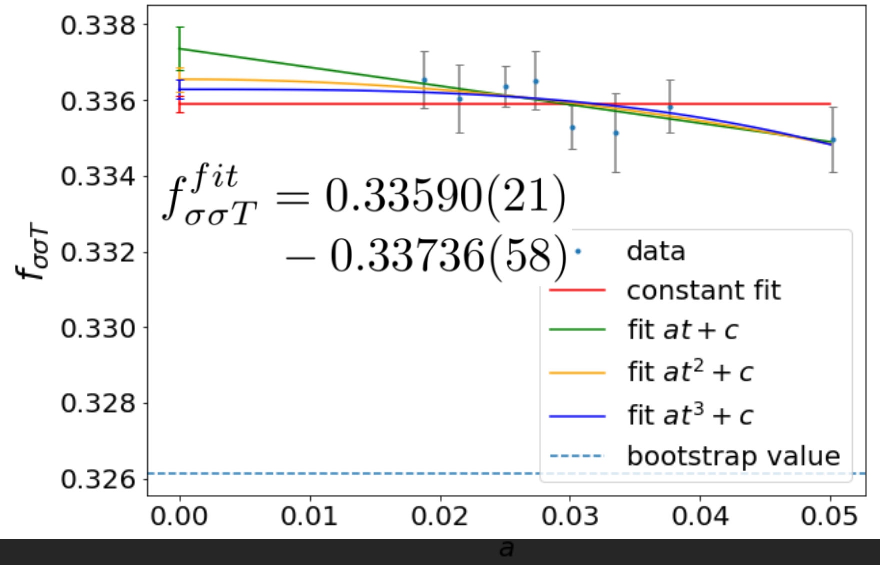
Leading for $c_0(t)$



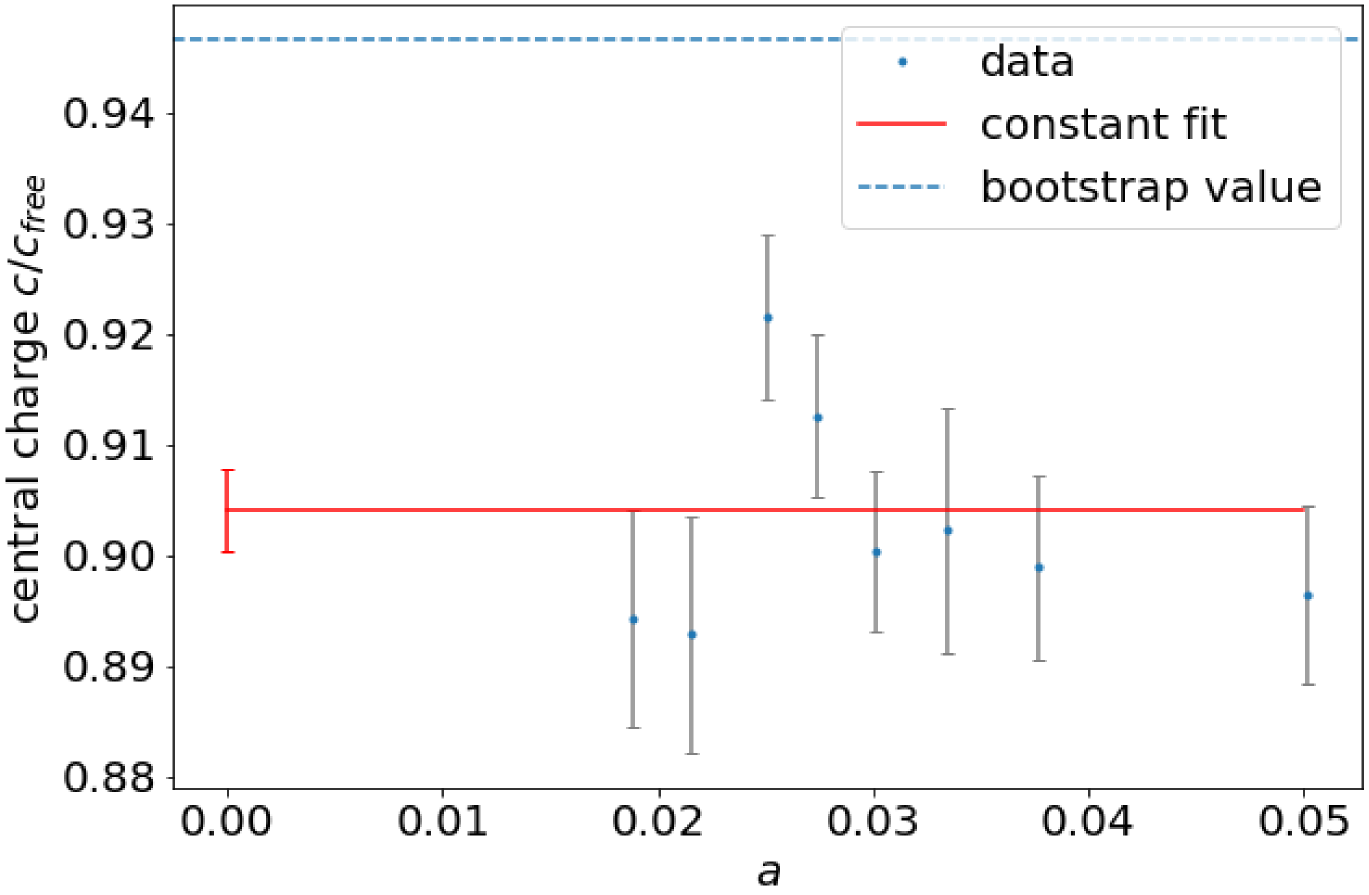


Leading for $c_2(t)$





Model averaging – central charge



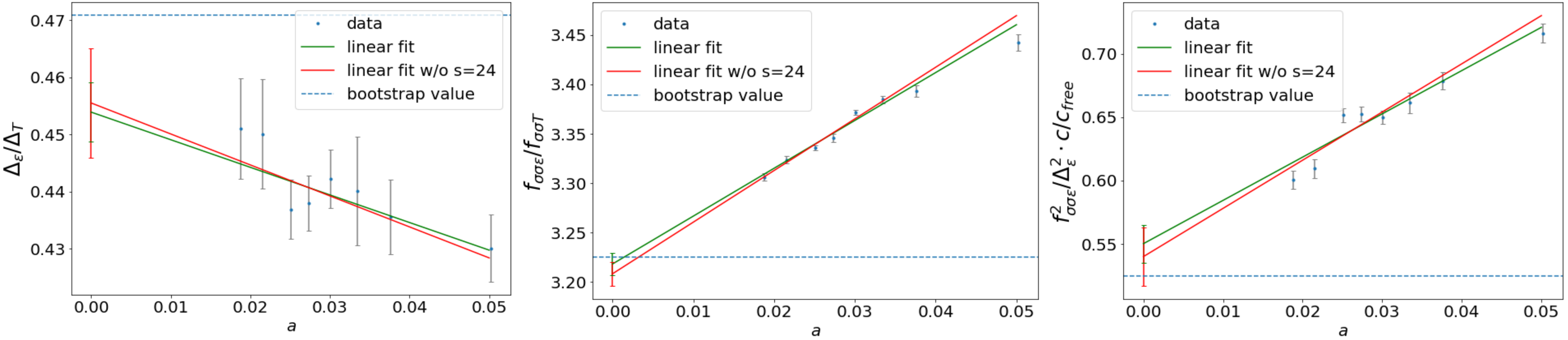
$$c/c_{free} = \frac{\Delta_\sigma^2 \Delta_T^2}{3 f_{\sigma\sigma T}^2}$$

$$c^{bootstrap}/c_{free} = 0.946534(11)$$

$$c^{fit}/c_{free} = 0.9041(37)$$

Model averaging - ratios

Simultaneous fits of $c_0(t)$ and $c_2(t)$ using 4 primaries $\epsilon, \quad T, \quad \epsilon', \quad T'$ & different t-ranges



$$c/c_{free} = \frac{\Delta_\sigma^2 \Delta_T^2}{3 f_{\sigma\sigma T}^2}$$

Conclusion and outlook

- Good agreeance for results already established in Monte Carlo

- Central charge result differs from bootstrap values

⇒ Improve estimates & elimate possible systematic errors by

1. Increasing statistics
2. Including more primaries -> less excited state contamination
3. Adding higher partial waves c_4, c_6, ... to the joined fits
4. Investigate other possible sources for systematic errors

- Soon: use slightly different approaches to investigate the CFT

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- Evan Owen, Boston University

- Timothy G. Raben, Michigan State University

- Chung-I Tan, Brown University

Thank you for your attention!

Sources

[1] Thomas Appelquist et al. "Lattice Gauge Theories at the Energy Frontier". In: (Sept. 4, 2013). arXiv: 1309.1206v1 [hep-lat].

[2] Thomas Appelquist et al. "Strongly interacting dynamics and the search for new physics at the LHC". In: *Phys. Rev. D 93, 114514 (2016)* (Jan. 15, 2016). DOI: 10.1103/PhysRevD.93.114514. arXiv: 1601.04027v2 [hep-lat].

[3] Richard C. Brower, Claudio Rebbi, and David Schaich. "Hybrid Monte Carlo simulation on the graphene hexagonal lattice". In: *PoS(Lattice 2011)056* (Apr. 24, 2012). arXiv: 1204.5424v1 [hep-lat].

[4] Richard C. Brower et al. "Lattice ϕ 4 field theory on Riemann manifolds: Numerical tests for the 2D Ising CFT on S 2". In: *Physical Review D* 98.1 (2018), p. 014502.

[5] Richard C. Brower et al. "Radial Lattice Quantization of 3D ϕ^4 Field Theory". In: (June 28, 2020). arXiv: 2006.15636v1 [hep-lat].

[6] Miguel S. Costa et al. "Radial expansion for spinning conformal blocks". In: (Mar. 17, 2016). DOI: 10.1007/JHEP07(2016)057. arXiv: 1603.05552v2 [hep-th].

[7] A. Deur, S. J. Brodsky, and G. F. de Teramond. "The QCD Running Coupling". In: *Prog. Part. Nuc. Phys. 90 1 (2016)* (Apr. 27, 2016). DOI: 10.1016/j.ppnp.2016.04.003. arXiv: 1604.08082v4 [hep-ph].

[8] Matthijs Hogervorst and Slava Rychkov. "Radial Coordinates for Conformal Blocks". In: (Mar. 5, 2013). DOI: 10.1103/PhysRevD.87.106004. arXiv: 1303.1111v2 [hep-th].

[9] William I. Jay and Ethan T. Neil. "Bayesian model averaging for analysis of lattice field theory results". In: *Phys. Rev. D* 103 (2020). ISSN: 2470-0010. DOI: 10.1103/physrevd.103.114502.

[10] Filip Kos, David Poland, and David Simmons-Duffin. "Bootstrapping mixed correlators in the 3D Ising model". In: *Journal of High Energy Physics* 2014.11 (2014), pp. 1–36.

[11] Andrea Pelissetto and Ettore Vicari. "Critical Phenomena and Renormalization-Group Theory". In: *Phys.Rept.368 727,2002* (Dec. 2000). DOI: 10.1016/S0370-1573(02)00219-3. arXiv: cond-mat/0012164 [cond-mat.stat-mech

[12] Sheer El-Showk et al. "Solving the 3d ising model with the conformal bootstrap ii. c-minimization and precise critical exponents". In: *Journal of Statistical Physics* 157.4 (2014), pp. 869–914.

[13] David Simmons-Duffin. "The Lightcone Bootstrap and the Spectrum of the 3d Ising CFT". In: (Dec. 27, 2016). DOI: 10.1007/JHEP03(2017)086. arXiv: 1612.08471v1 [hep-th].

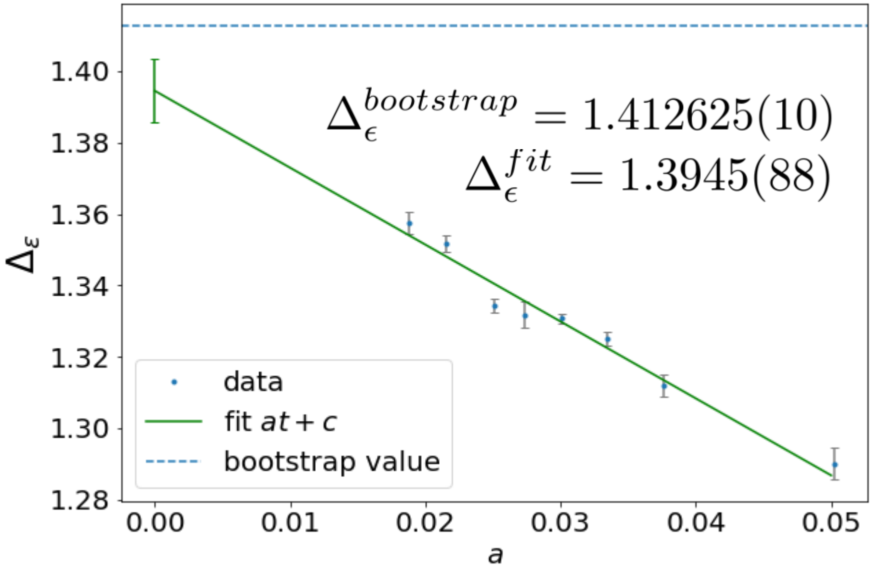
[14] Robert H. Swendsen and Jian-Sheng Wang. "Nonuniversal critical dynamics in Monte Carlo simulations". In: *Physical Review Letters* 58.2 (Jan. 1987), pp. 86–88. DOI: 10.1103/physrevlett.58.86.

[15] David Tong. "Lectures on Statistical Field Theory". In: (2017).

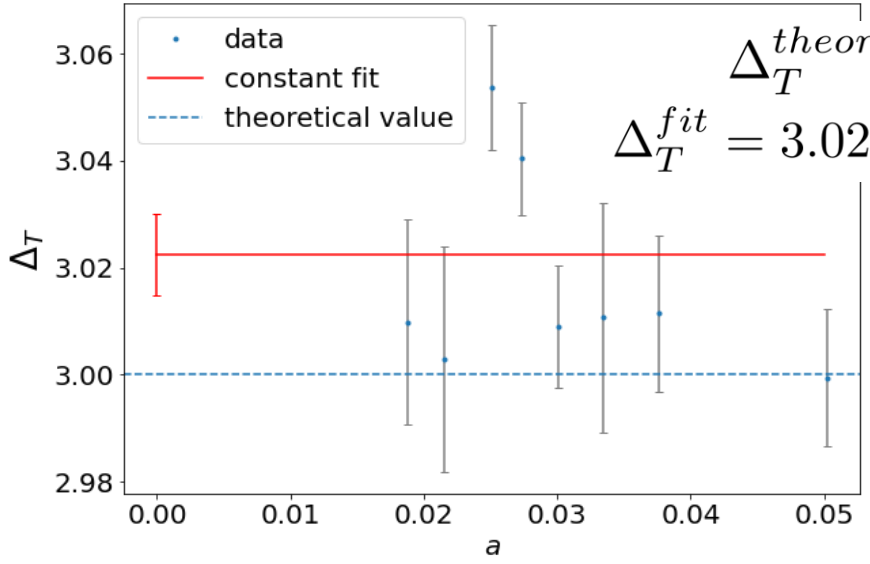
[16] Ulli Wolff. "Collective Monte Carlo Updating for Spin Systems". In: *Phys. Rev. Lett.* 62 (4 Jan. 1989), pp. 361–364. DOI: 10.1103/PhysRevLett.62.361. URL: https://link.aps.org/doi/10.1103/PhysRevLett.62.361.

Model averaging – leading terms

Leading for $c_0(t)$

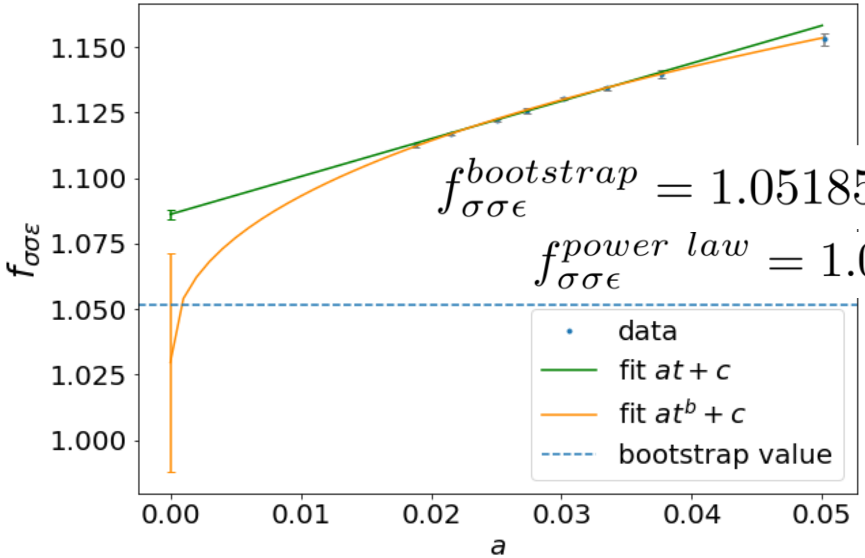


$$\Delta_\epsilon^{bootstrap} = 1.412625(10)$$
$$\Delta_\epsilon^{fit} = 1.3945(88)$$

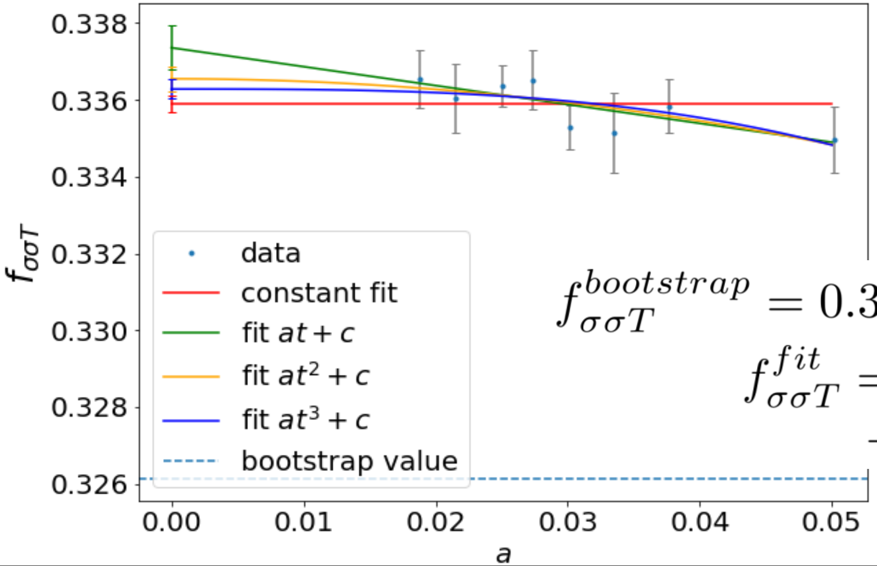


$$\Delta_T^{theory} = 3$$
$$\Delta_T^{fit} = 3.0224(76)$$

Leading for $c_2(t)$



$$f_{\sigma\sigma\epsilon}^{bootstrap} = 1.0518537(41)$$
$$f_{\sigma\sigma\epsilon}^{power\ law} = 1.030(42)$$



$$f_{\sigma\sigma T}^{bootstrap} = 0.32613776(45)$$
$$f_{\sigma\sigma T}^{fit} = 0.33590(21)$$
$$- 0.33736(58)$$

First recursive fits for c_4