Oscillatory Features in CMB Temperature Anisotropies

ENCUENTRO COSMOCONCE Y PARTÍCULAS

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Domenico Sapone

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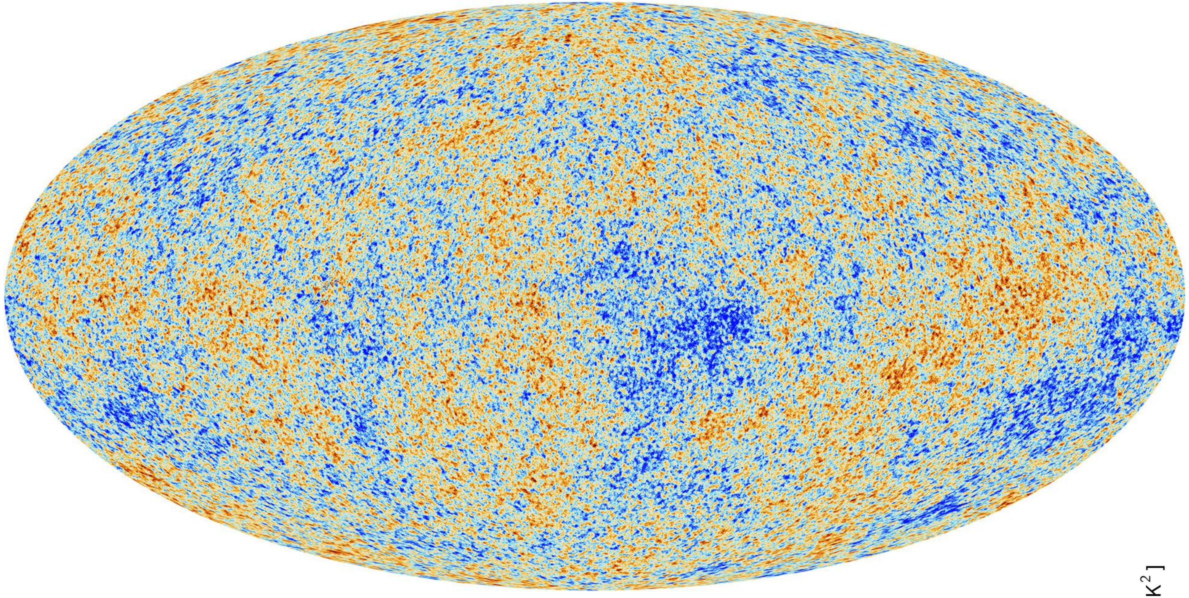
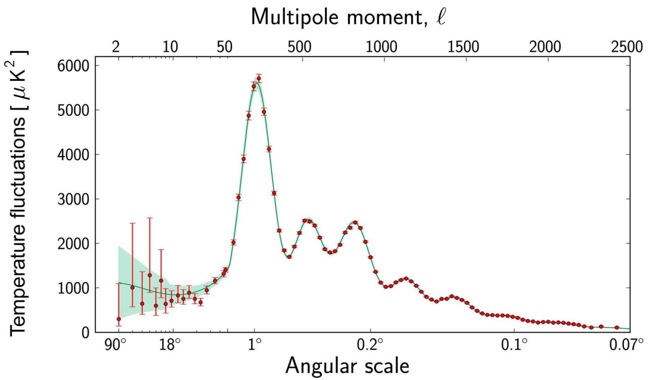
Introduction: Cosmic Microwave Background and Angular Power Spectra





CMB - ESA and Planck Collaboration

Motivation

PHYSICAL REVIEW LETTERS **121,** 161302 (2018)

Reconstructing the Inflationary Landscape with Cosmological Data

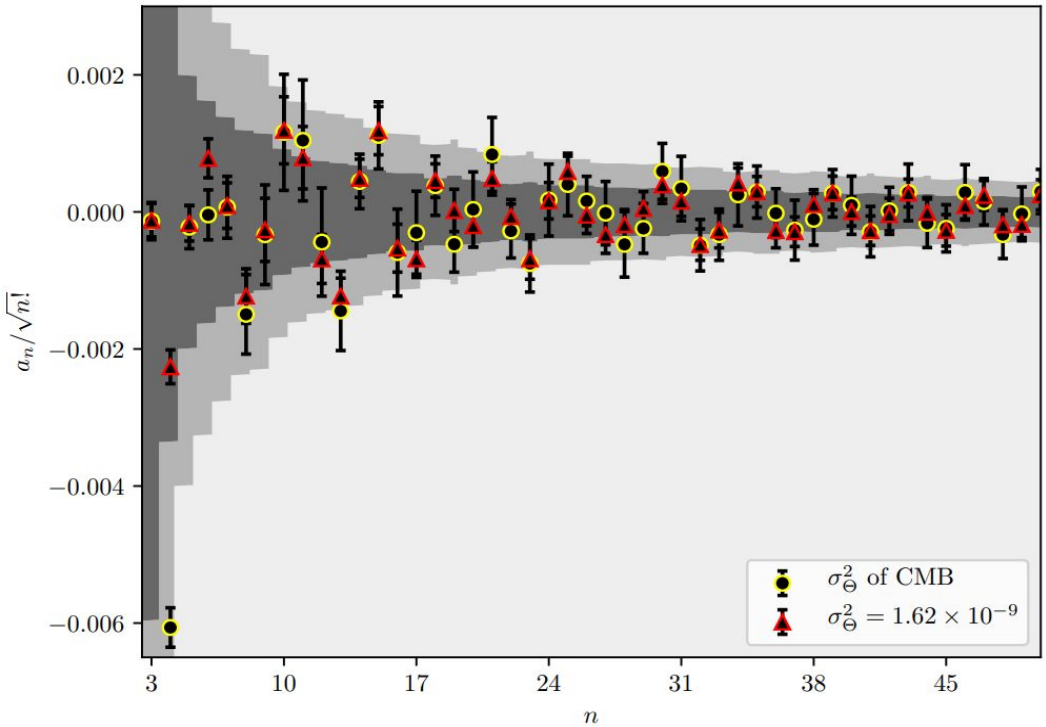
Xingang Chen,[1] Gonzalo A. Palma,[2] Bruno Scheihing H.,[2] and Spyros Sypsas[2]
[1]*Institute for Theory and Computation, Harvard-Smithsonian Center for Astrophysics, 60 Garden Street, Cambridge, Massachusetts 02138, USA*
[2]*Grupo de Cosmología y Astrofísica Teórica, Departamento de Física, FCFM, Universidad de Chile, Blanco Encalada 2008, Santiago, Chile*

(Received 22 June 2018; published 17 October 2018; corrected 23 October 2018)

- Used for multifield inflation with isocurvature fields orthogonal to landscape potential
- Tomographic Non gaussianities
- Non gaussianities that can no be characterized through bispectrum or trispectrum
- Requires the complete PDF

Phys. Rev. Lett. 121, 161302

Motivation



- Apparent oscillatory behavior of a_n coefficients as n increases.
- The behavior appears in the observational data and in the simulated data
- Pattern or Noise

$$a_n \equiv \int d\Theta \rho(\Theta) He_n(\Theta/\sigma_\Theta)$$

Phys. Rev. Lett. 121, 161302

Motivation: Edgeworth Expansion

$$a_n \equiv \int d\Theta \rho(\Theta) He_n(\Theta/\sigma_\Theta)$$

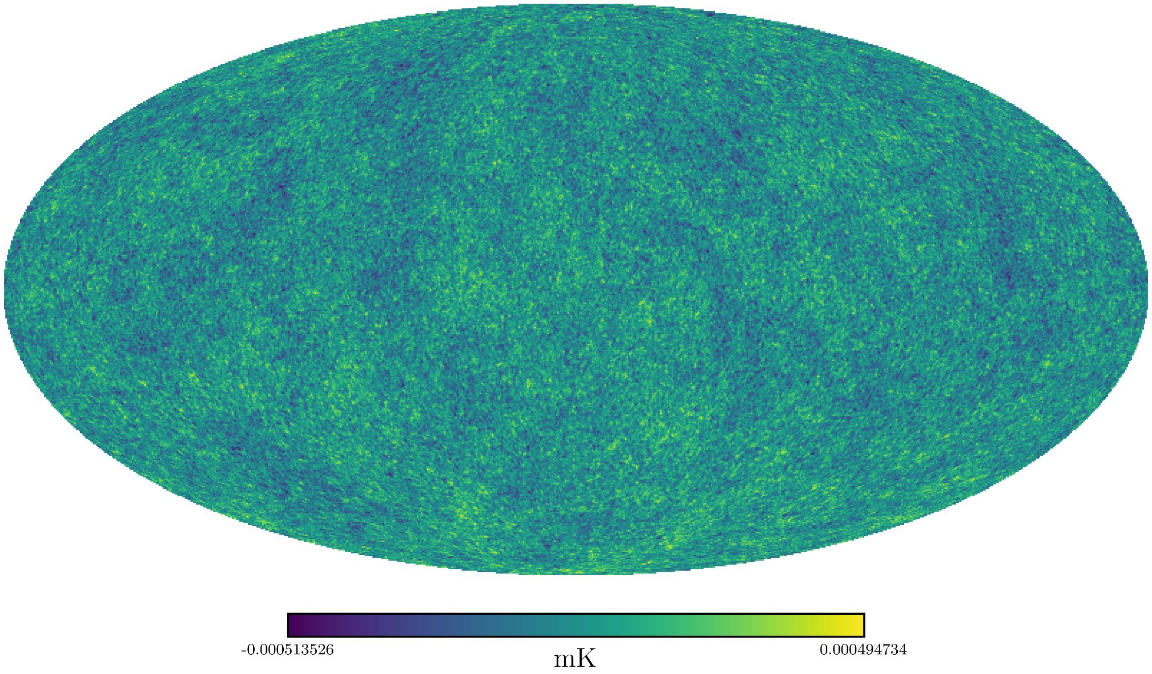
$$P(\Theta) = P_G(\Theta)\left[1 + \sum_{n=3}^{N} \frac{a_n}{n!} \mathrm{He}_n\left(\frac{\Theta}{\sigma_\Theta}\right)\right]$$

- Approximation to describe non-gaussian distributions
- In function of cumulants coded in a_n
- Using a base of Hermite functions
- Orthogonal between different orders

Thomas Buchert *et al* 2017 *Class. Quantum Grav.* **34** 094002
Phys. Rev. Lett. 121, 161302

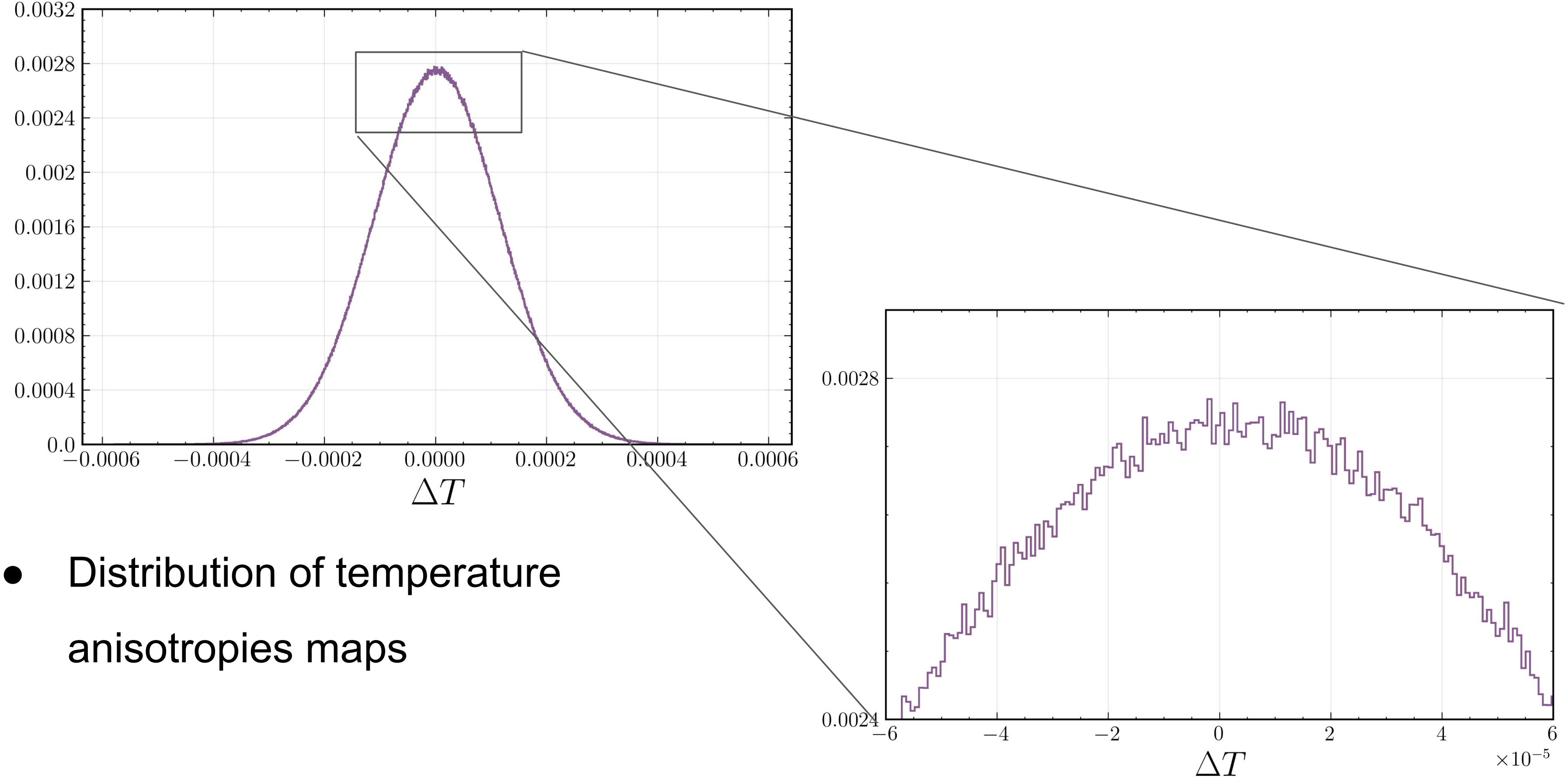
CMB Maps Generation

- Healpix and Healpy
- Reconstruction of CMB maps
- Using C_ℓ generated from CAMB to reconstruct $a_{\ell m}$ coefficients.



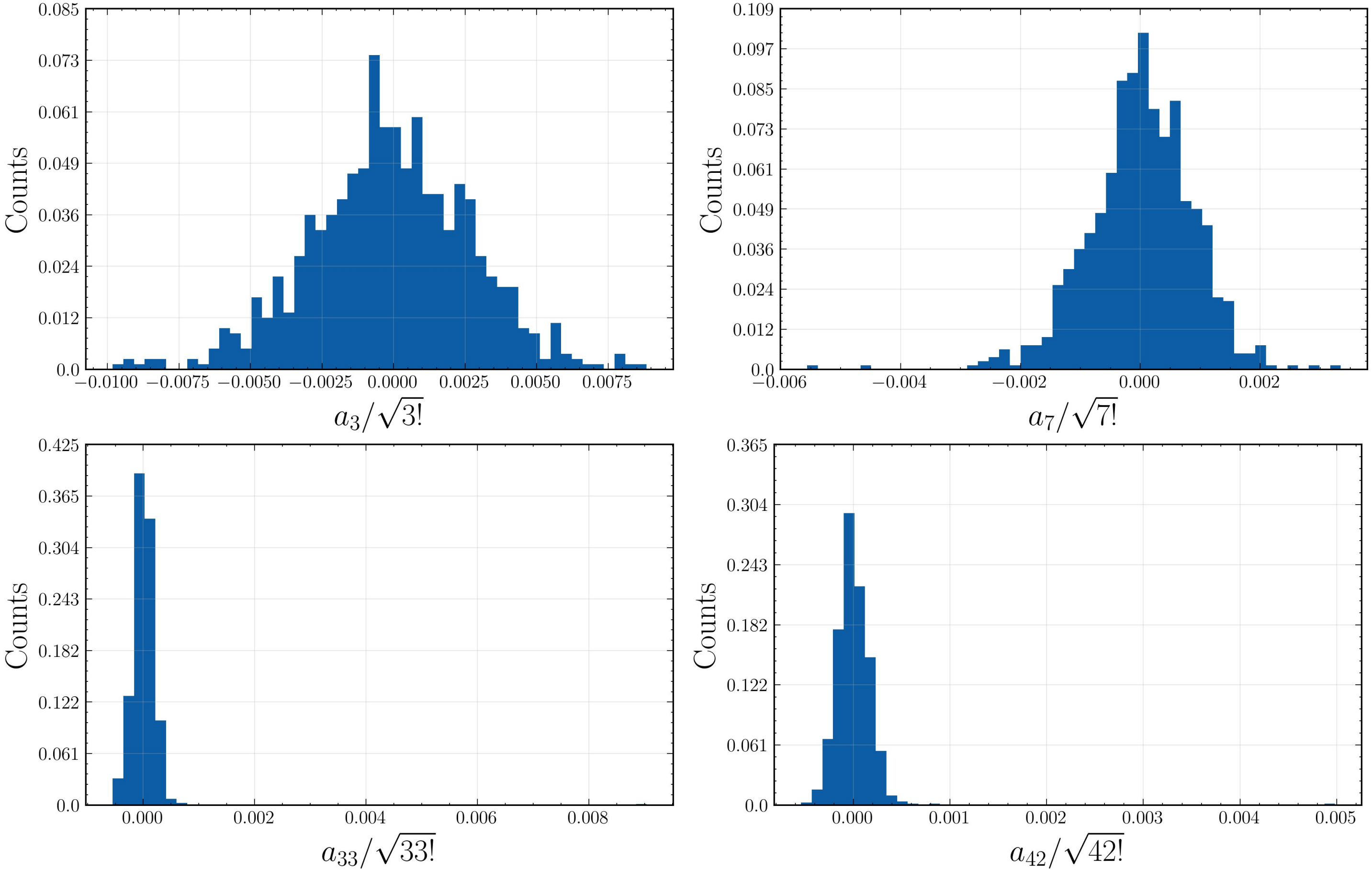
K. M. Górski *et al* 2005 *ApJ* 622 759
10.21105/joss.01298

CMB Maps Generation

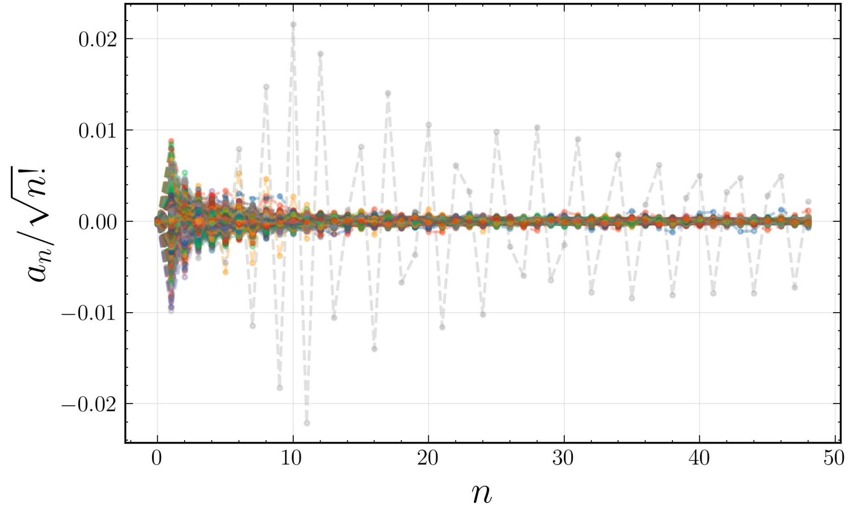


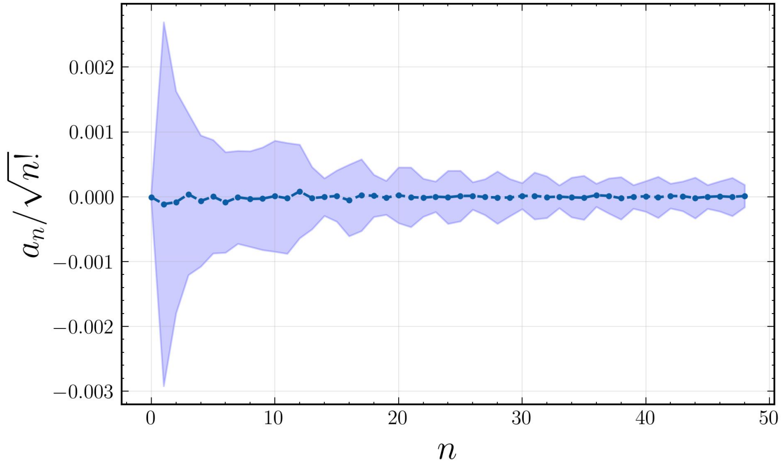
- Distribution of temperature anisotropies maps

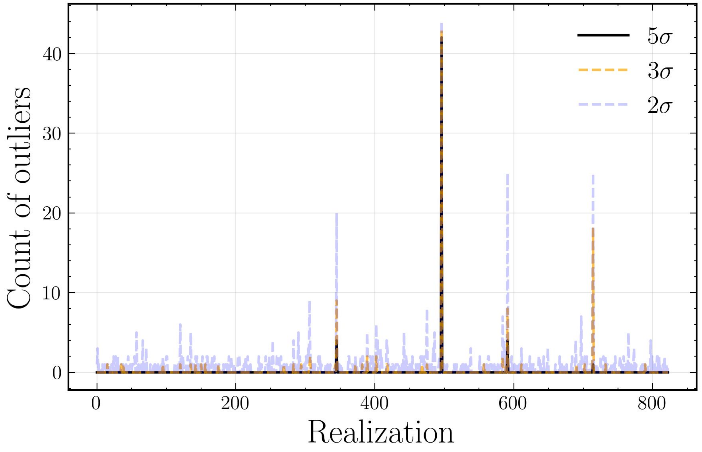
Calculation of a_n coefficients



Calculation of a_n coefficients

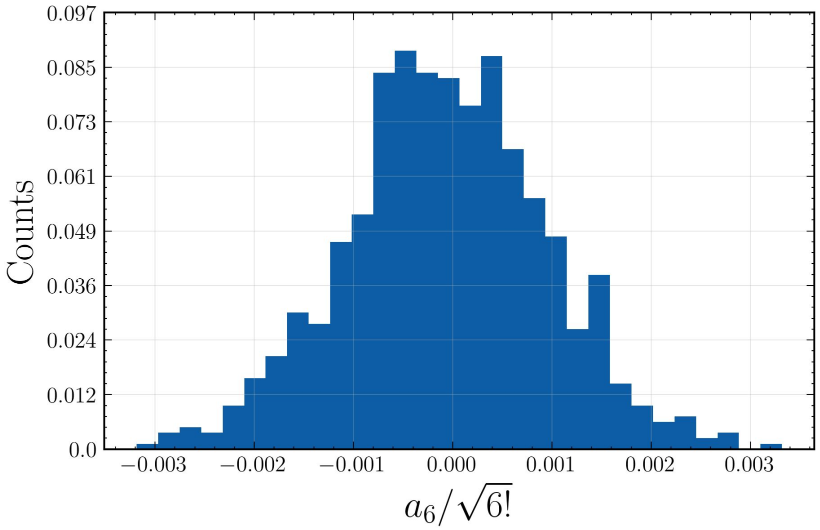




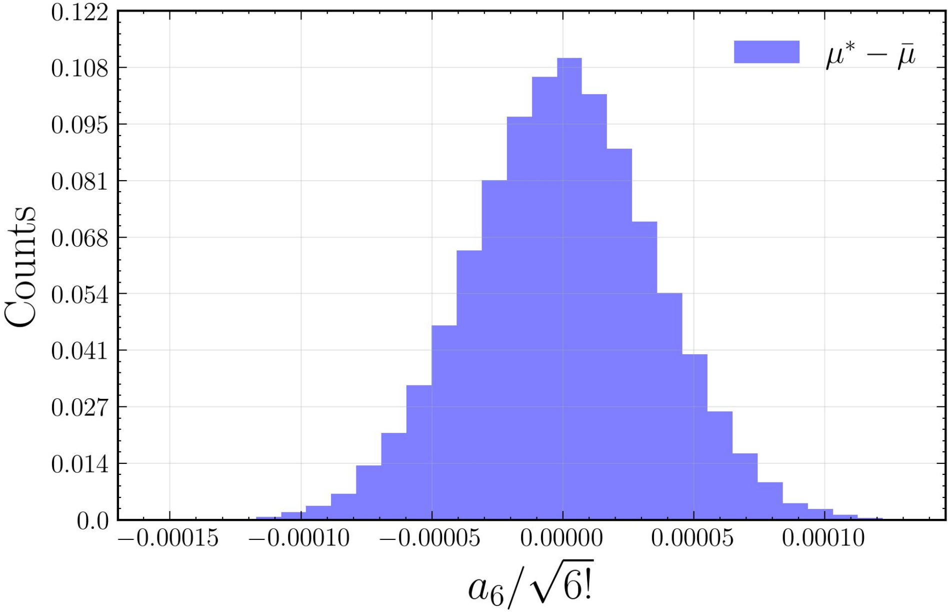


- Outliers when plotting every realization
- Presence of them agrupated in specific realizations
- Numerical? Sensitivity to some seed values?

Bootstrap method and Confidence intervals

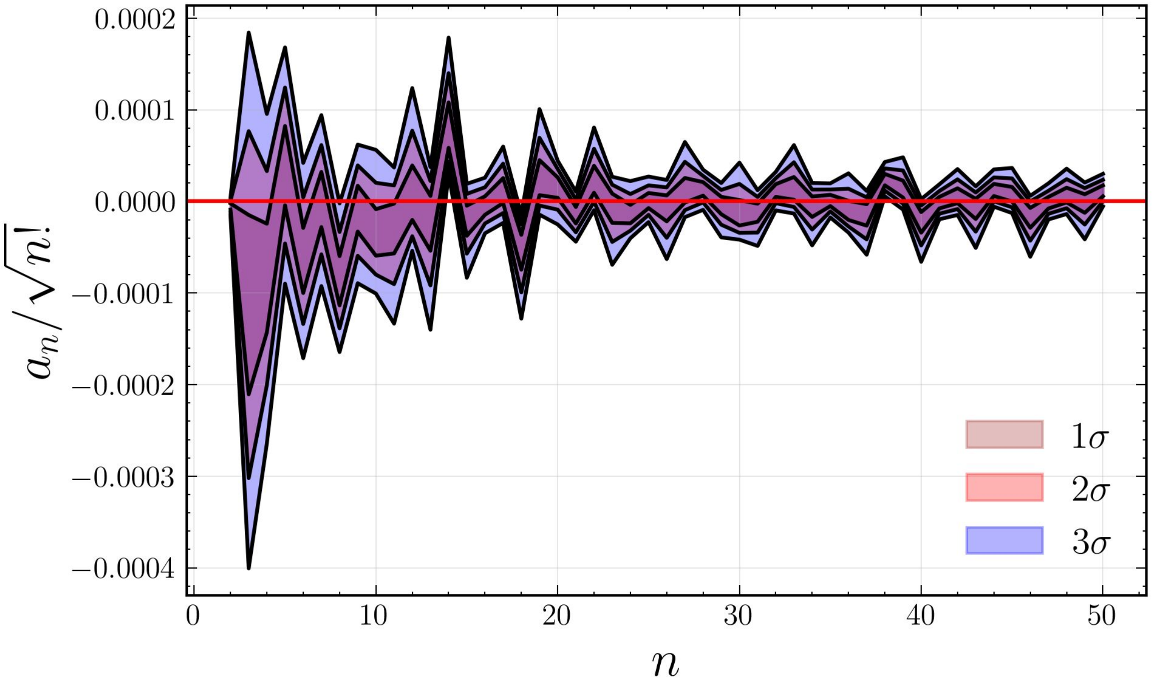


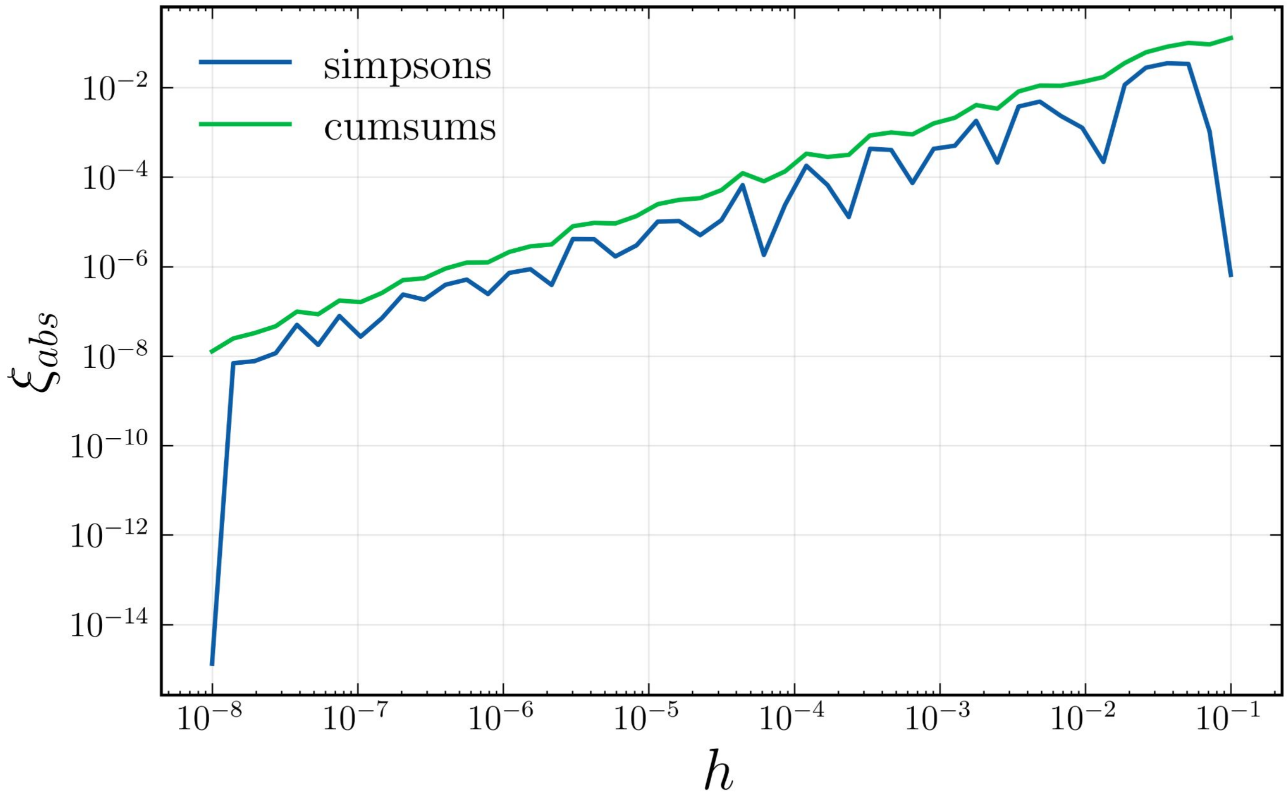
- Bootstrap resampling method
- Estimate confidence intervals for distributions



Bootstrap method and Confidence intervals

- Different Confidence intervals
- Pattern?

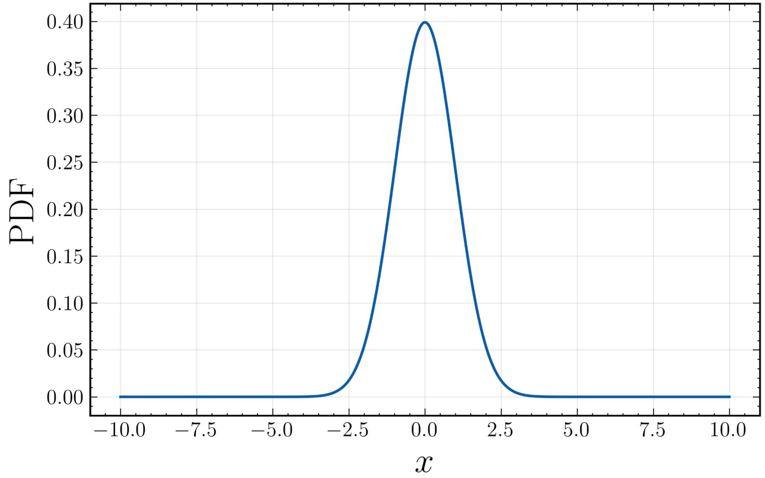


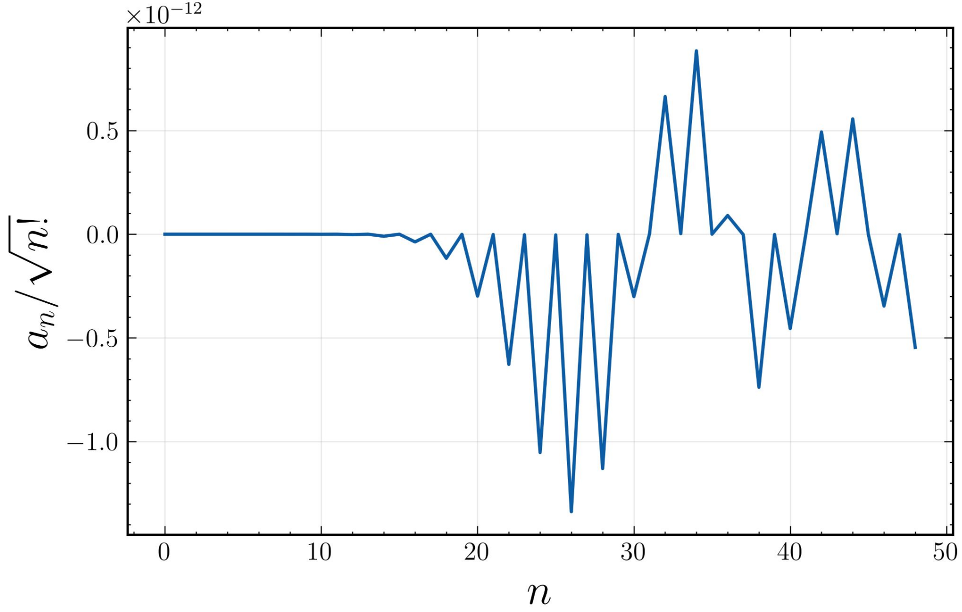

simpsons
cumsums
10^{-2}
10^{-4}
10^{-6}
10^{-8}
10^{-10}
10^{-12}
10^{-14}
ξ_{abs}
10^{-8}
10^{-7}
10^{-6}
10^{-5}
10^{-4}
10^{-3}
10^{-2}
10^{-1}
h

Theoretical Gaussian Profile

- Gaussian Function
- a_n are ~ 0

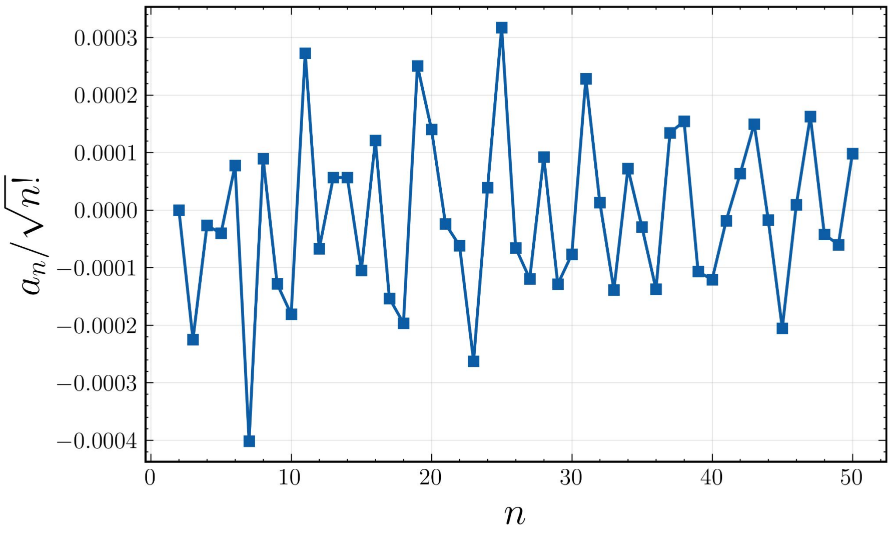
$$P(x) = \frac{1}{\sqrt{2\pi}\sigma} e^{\frac{-(x-\mu)^2}{2\sigma^2}}$$



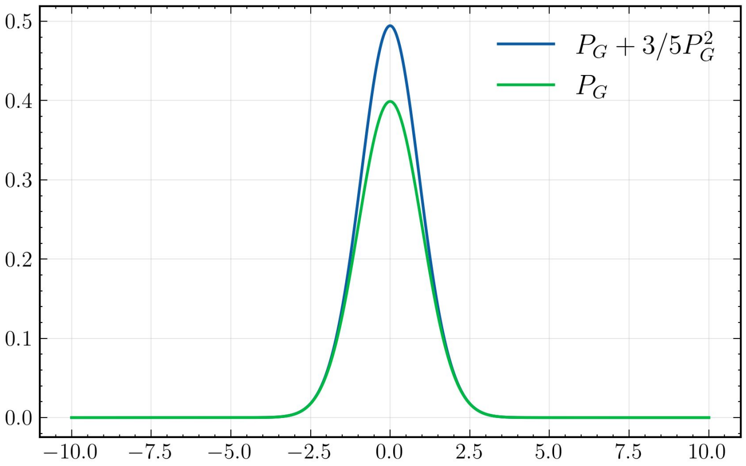


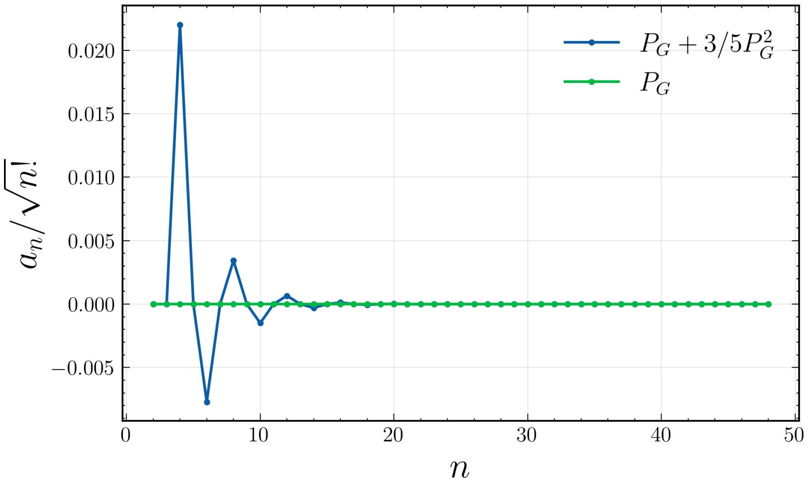
Numerical Gaussian Distribution

- Numerical Gaussian
- No decaying pattern
- Oscillation? Random?



Perturbed Theoretical Gaussian Profile





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Departamento de Física

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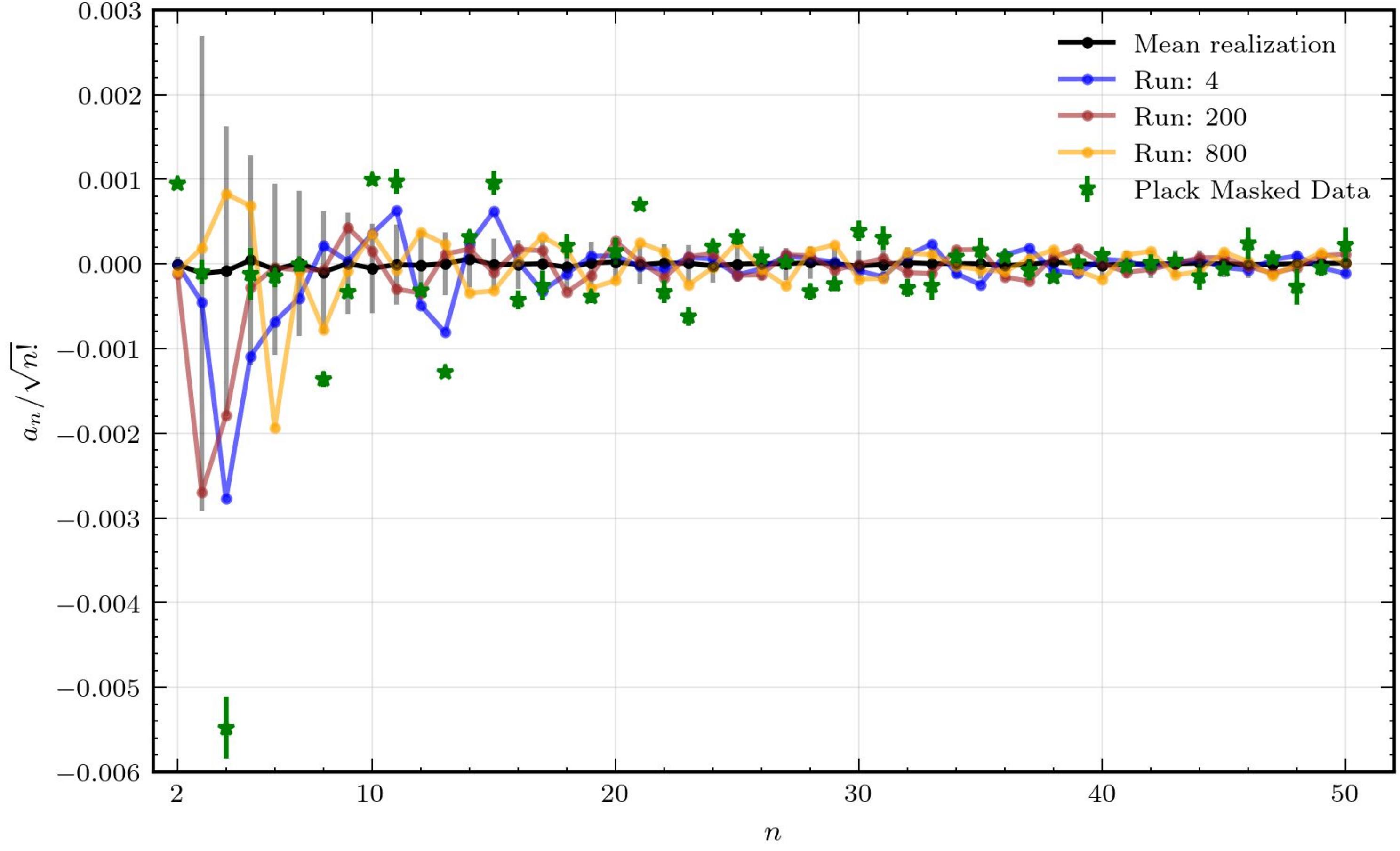
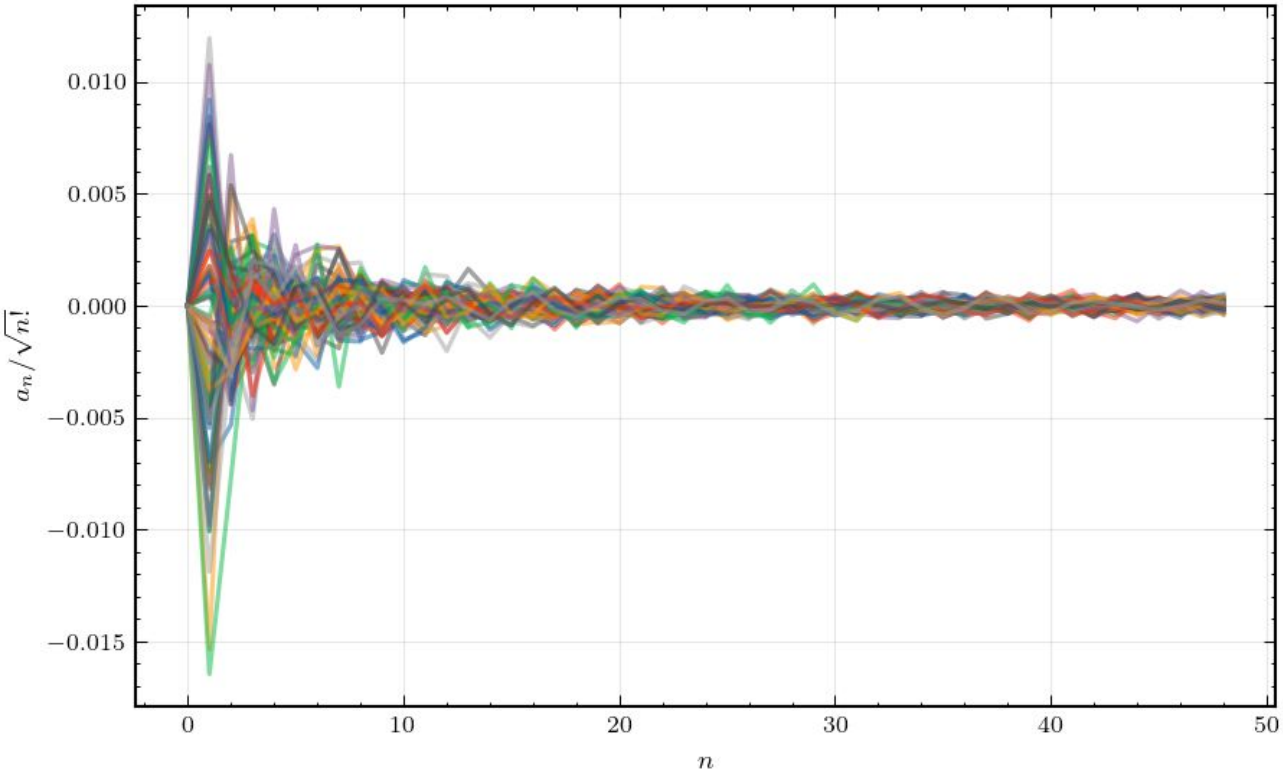
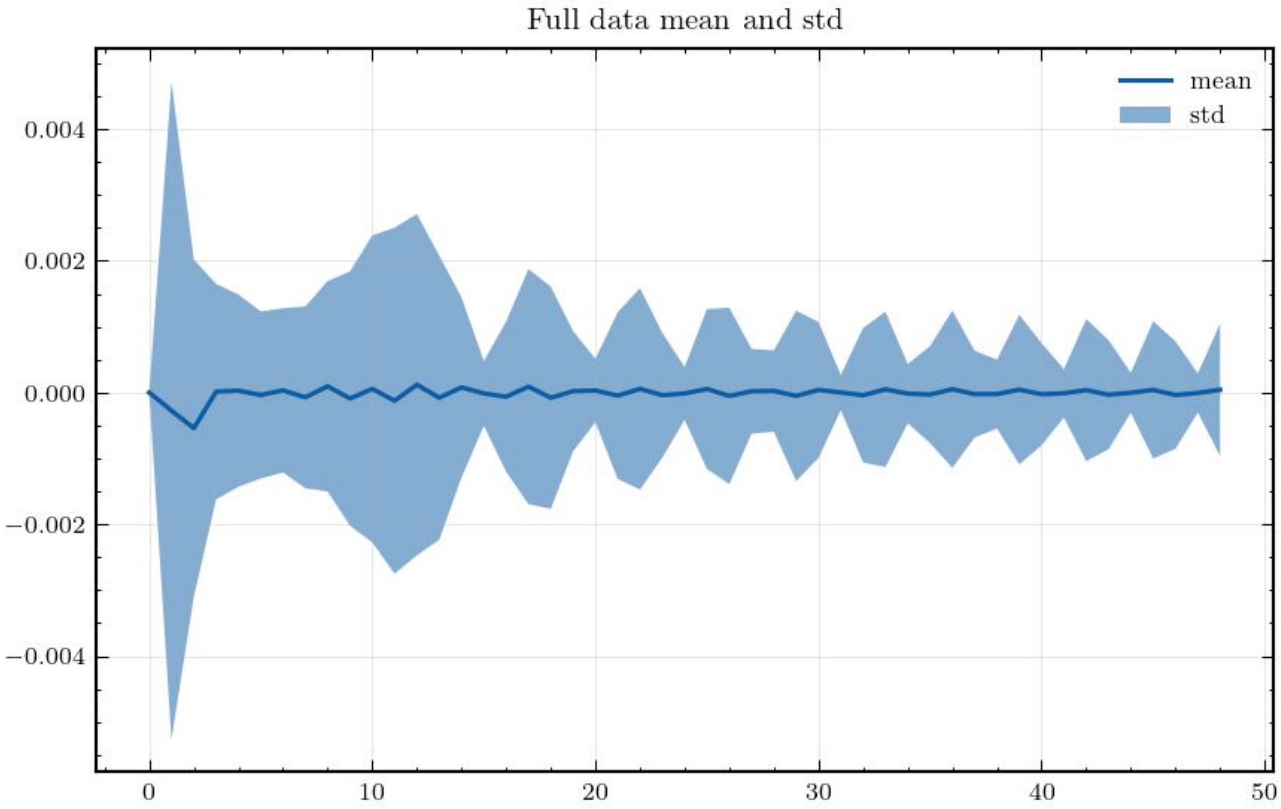
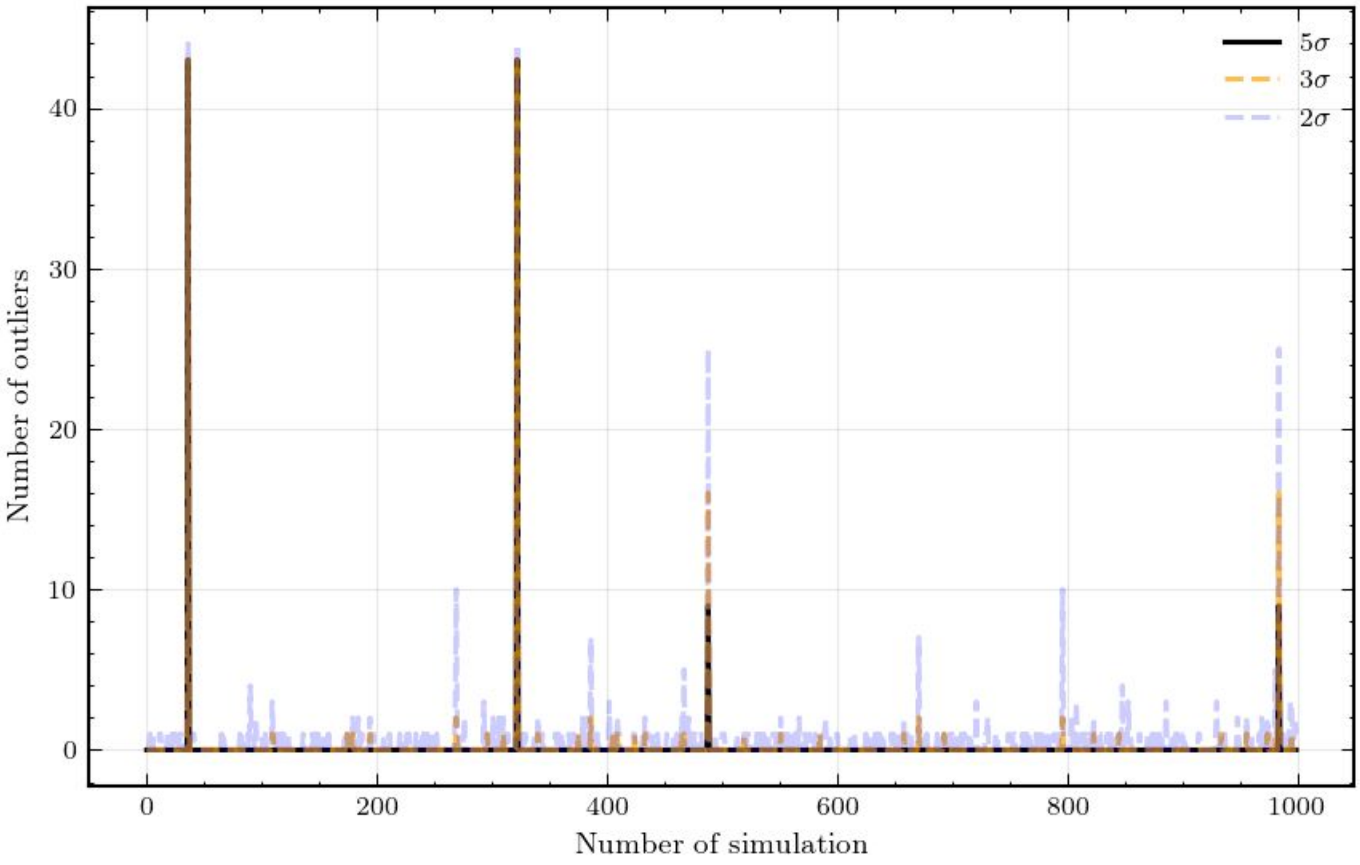
Thanks

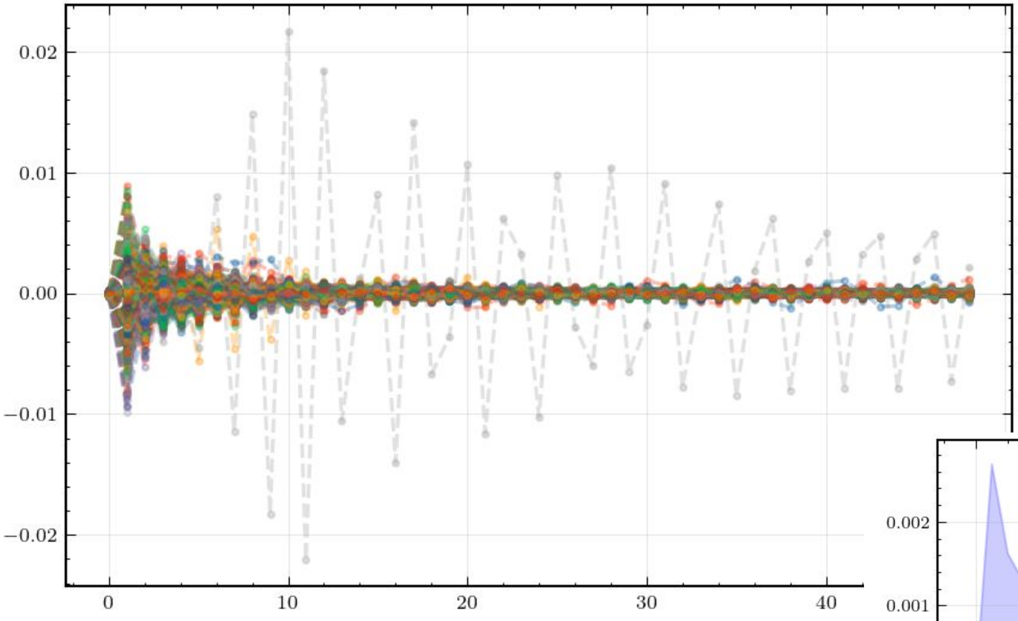
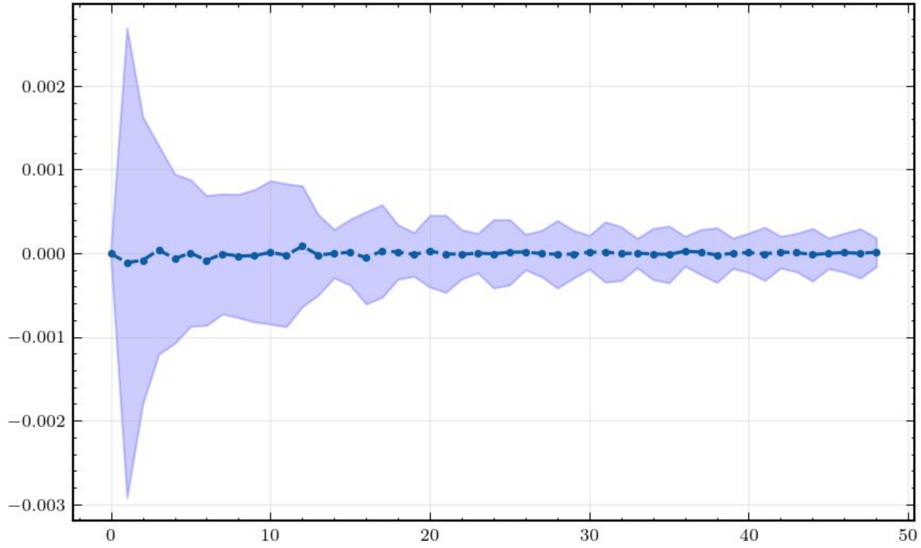

Mean realization
Run: 4
Run: 200
Run: 800
Plack Masked Data
$a_n/\sqrt{n!}$
n
0.003
0.002
0.001
0.000
−0.001
−0.002
−0.003
−0.004
−0.005
−0.006
2
10
20
30
40
50

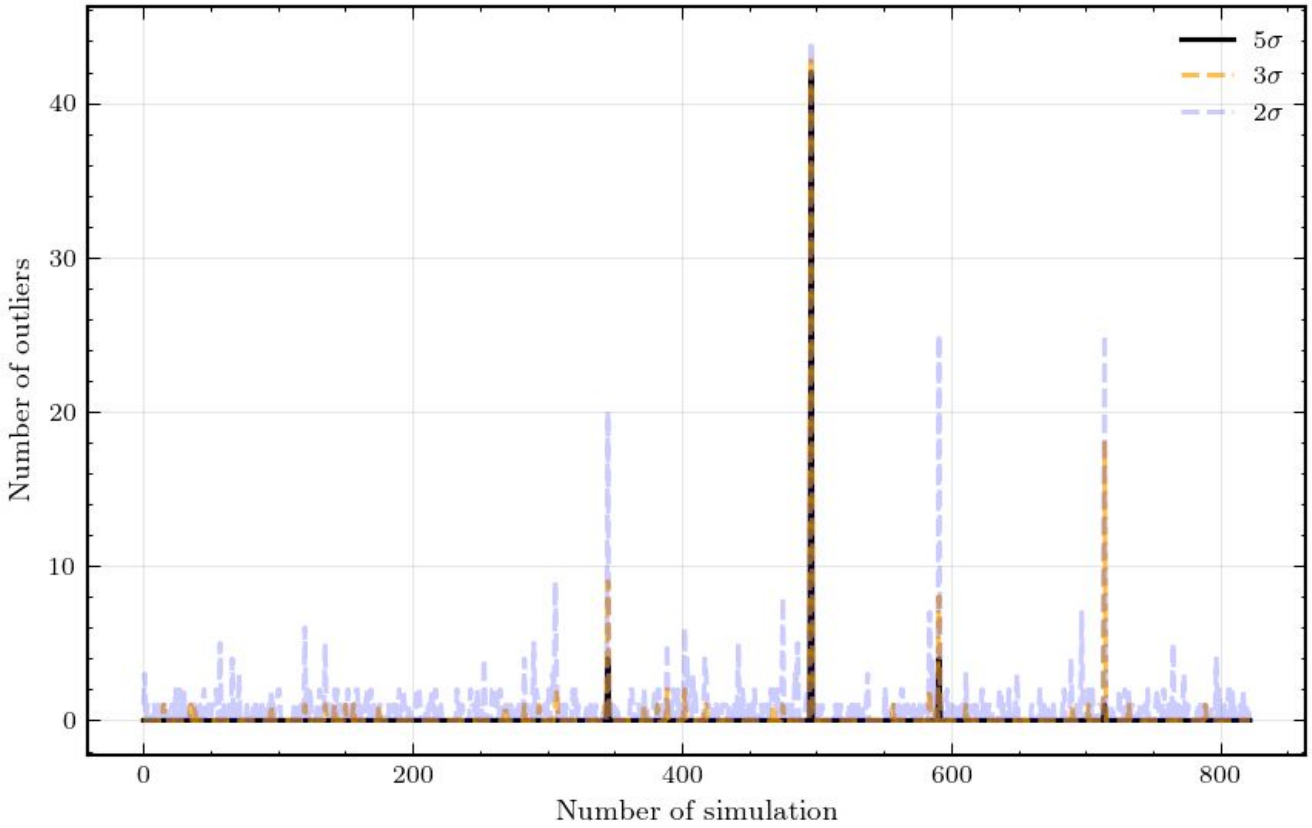

0.010
0.005
0.000
−0.005
−0.010
−0.015
$a_n/\sqrt{n!}$
0
10
20
30
40
50
n

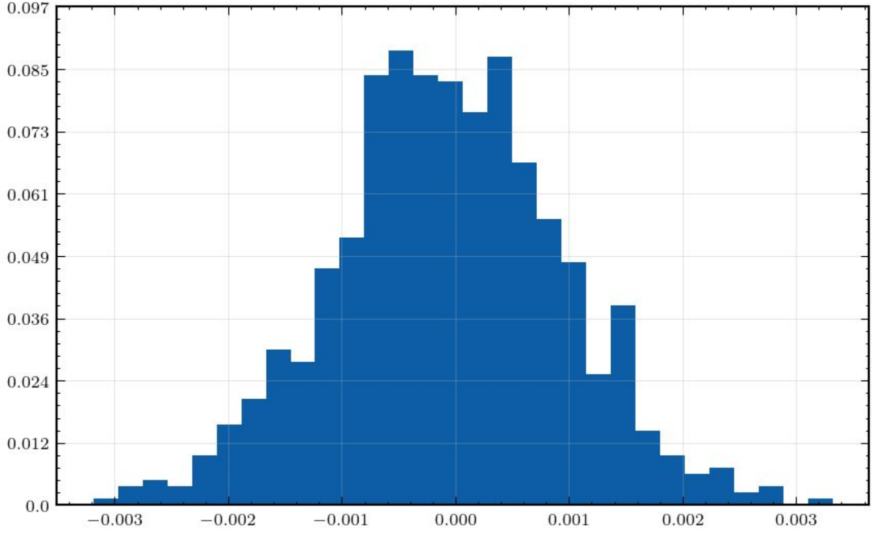

Full data mean and std
mean
std
0.004
0.002
0.000
−0.002
−0.004
0
10
20
30
40
50

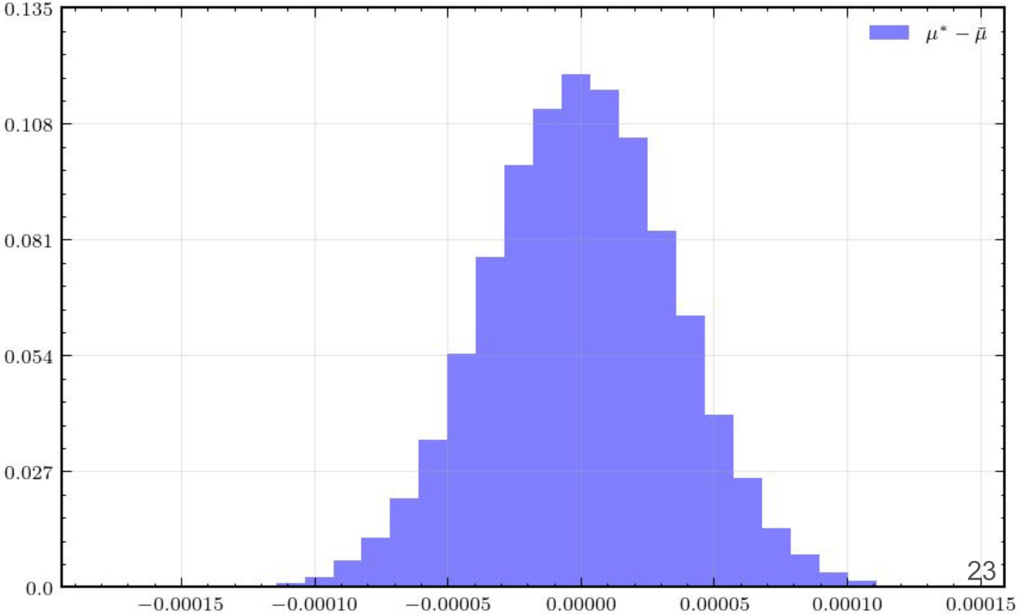


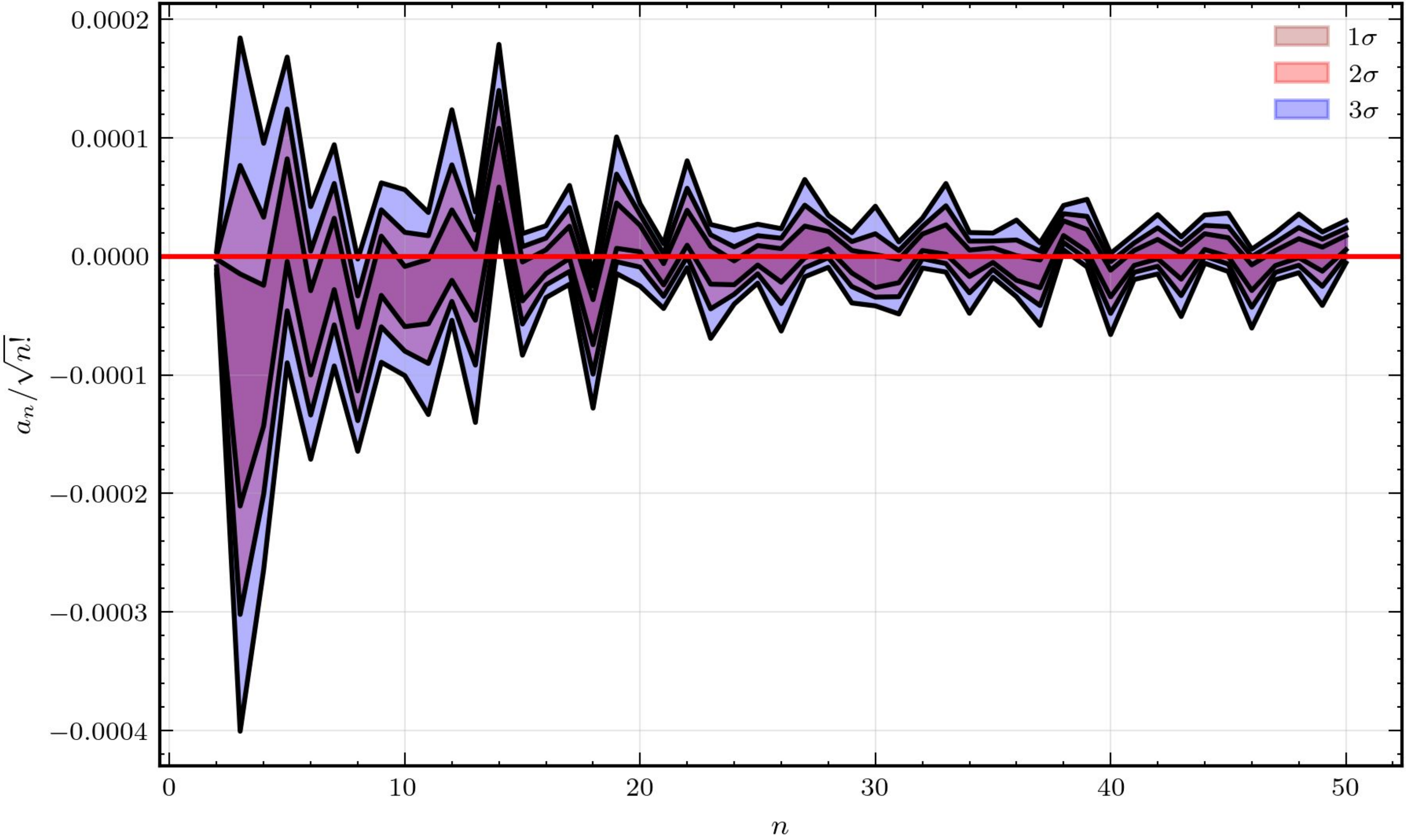
5σ
3σ
2σ
Number of outliers
Number of simulation
0
10
20
30
40
0
200
400
600
800
1000

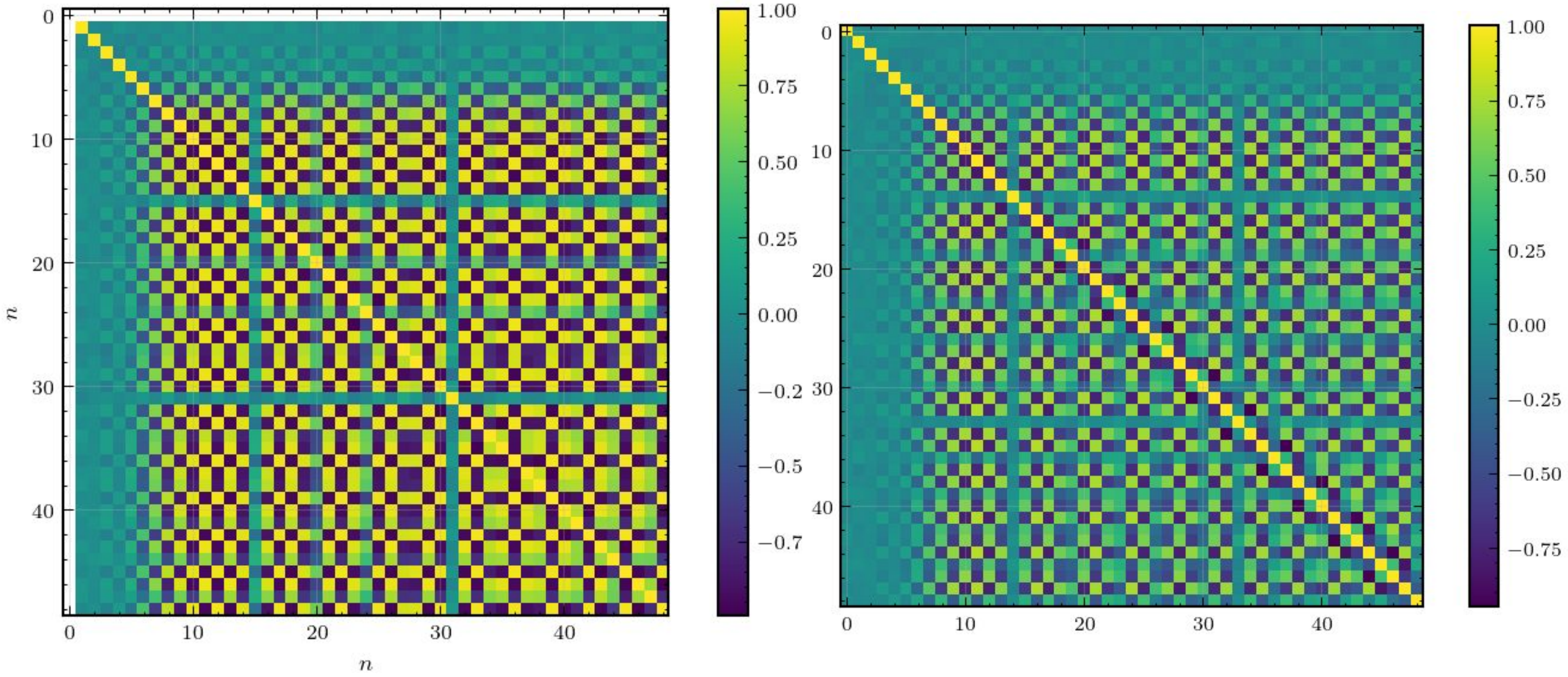

0.02
0.01
0.00
−0.01
−0.02
0
10
20
30
40

0.002
0.001
0.000
−0.001
−0.002
−0.003
0
10
20
30
40
50


5σ
3σ
2σ
Number of outliers
0
10
20
30
40
0
200
400
600
800
Number of simulation

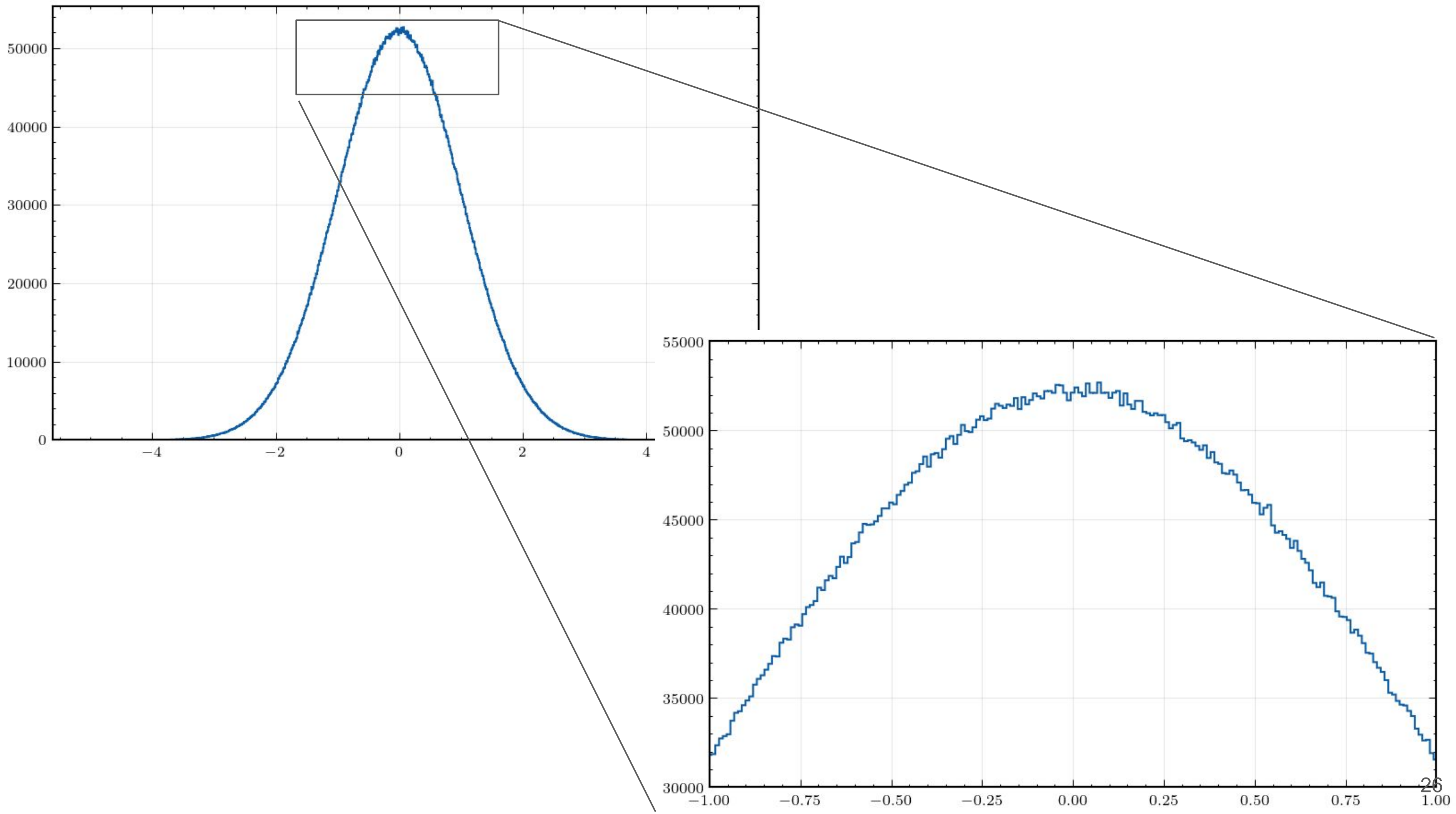

0.097
0.085
0.073
0.061
0.049
0.036
0.024
0.012
0.0
−0.003
−0.002
−0.001
0.000
0.001
0.002
0.003


$\mu^* - \bar{\mu}$
0.135
0.108
0.081
0.054
0.027
0.0
−0.00015
−0.00010
−0.00005
0.00000
0.00005
0.00010
0.00015

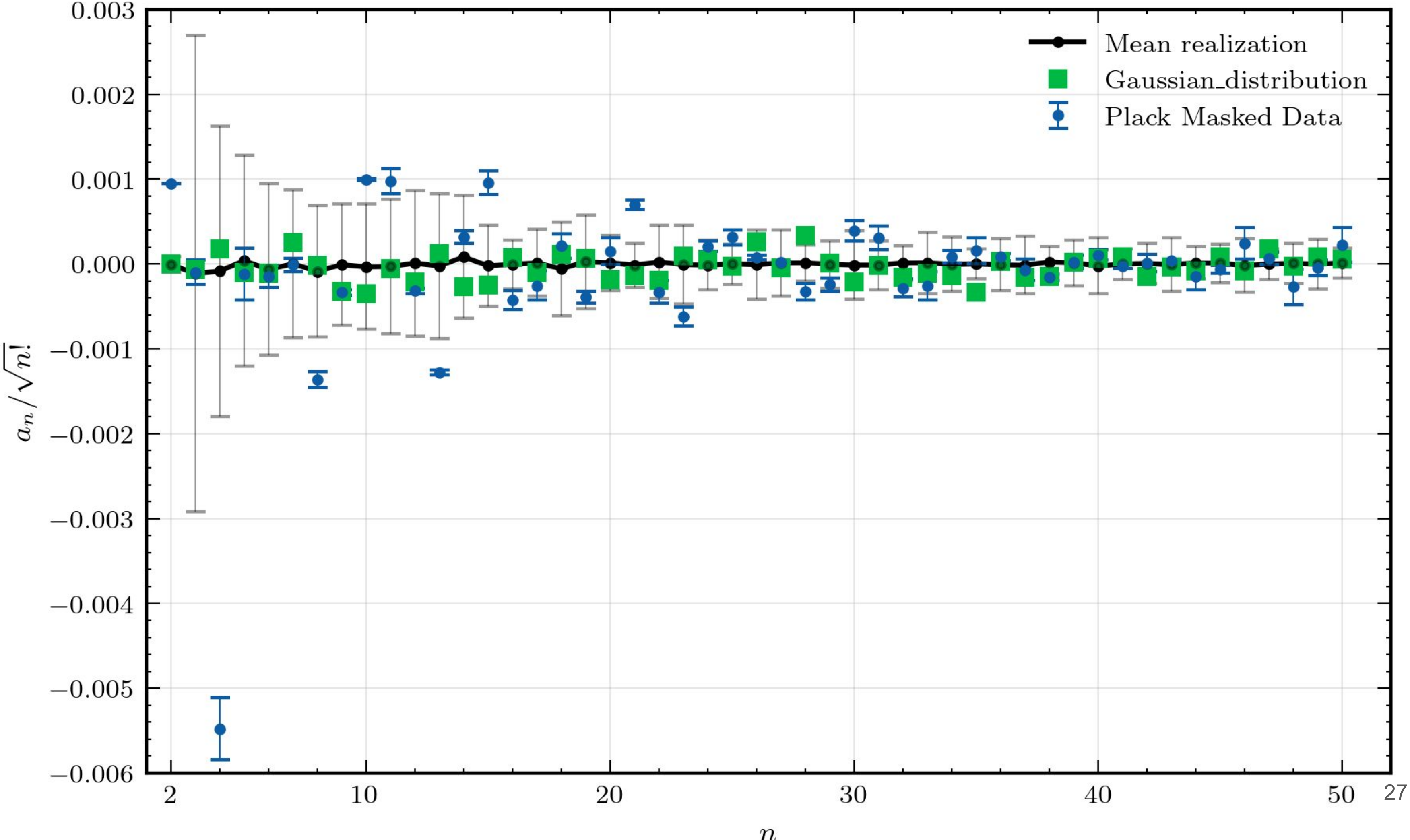

1σ
2σ
3σ
0.0002
0.0001
0.0000
−0.0001
−0.0002
−0.0003
−0.0004
$a_n/\sqrt{n!}$
0
10
20
30
40
50
n



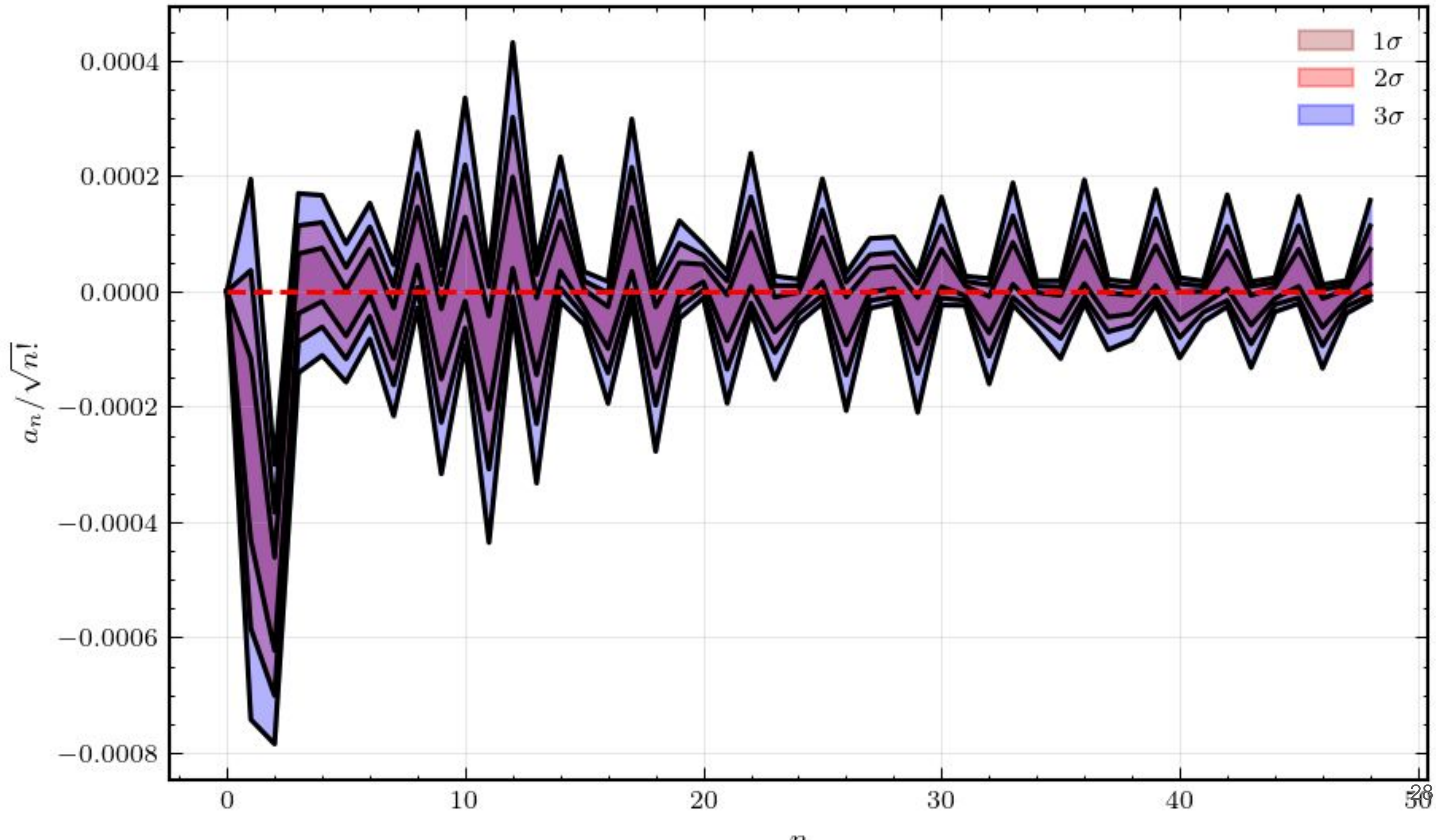
n
n
1.00
0.75
0.50
0.25
0.00
−0.2
−0.5
−0.7
1.00
0.75
0.50
0.25
0.00
−0.25
−0.50
−0.75

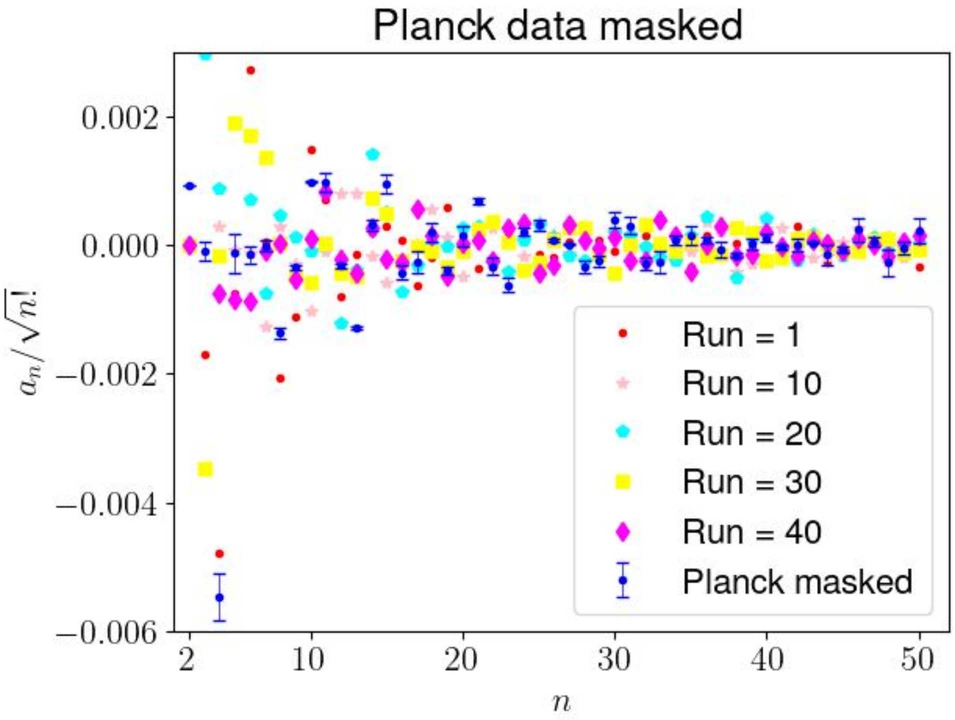


50000
40000
30000
20000
10000
0
−4
−2
0
2
4
55000
50000
45000
40000
35000
30000
−1.00
−0.75
−0.50
−0.25
0.00
0.25
0.50
0.75
1.00



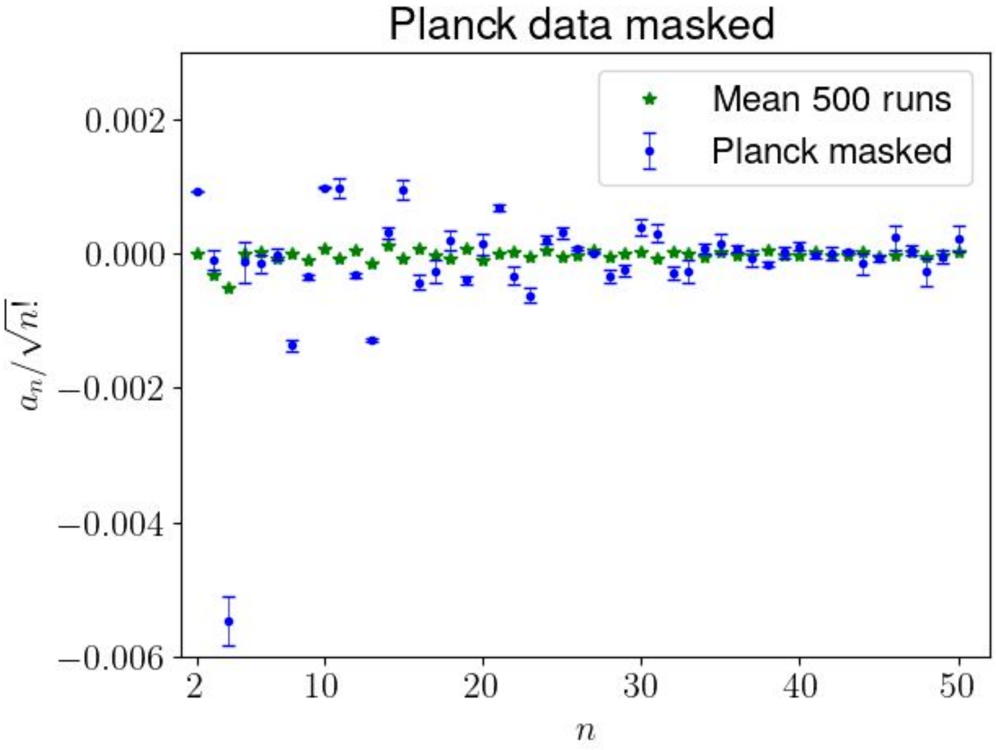
Mean realization
Gaussian_distribution
Plack Masked Data
$a_n/\sqrt{n!}$
n
0.003
0.002
0.001
0.000
−0.001
−0.002
−0.003
−0.004
−0.005
−0.006
2
10
20
30
40
50


0.0004
0.0002
0.0000
−0.0002
−0.0004
−0.0006
−0.0008
0
10
20
30
40
50
$a_n/\sqrt{n!}$
1σ
2σ
3σ



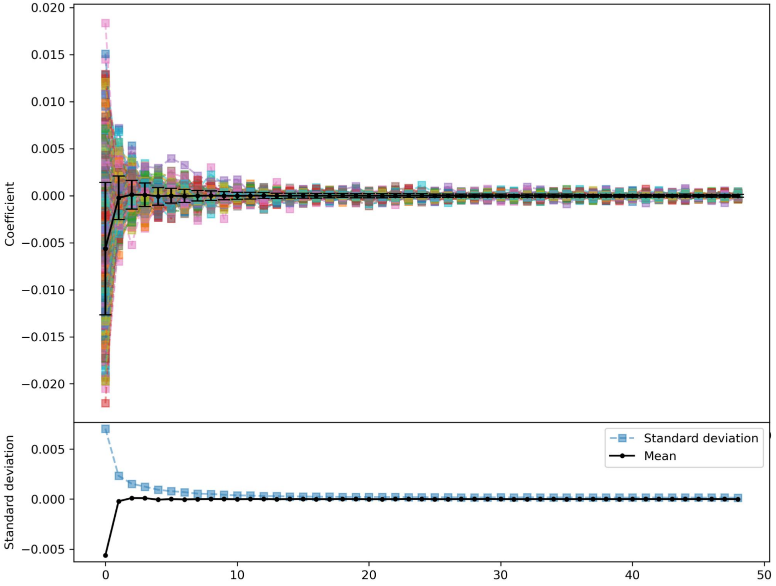
- Behavior stays after many realizations in simulated data
- Amplitude of Oscillations is reduced with more realizations in simulated data
- Each is an individual run of 50 H_n parameters

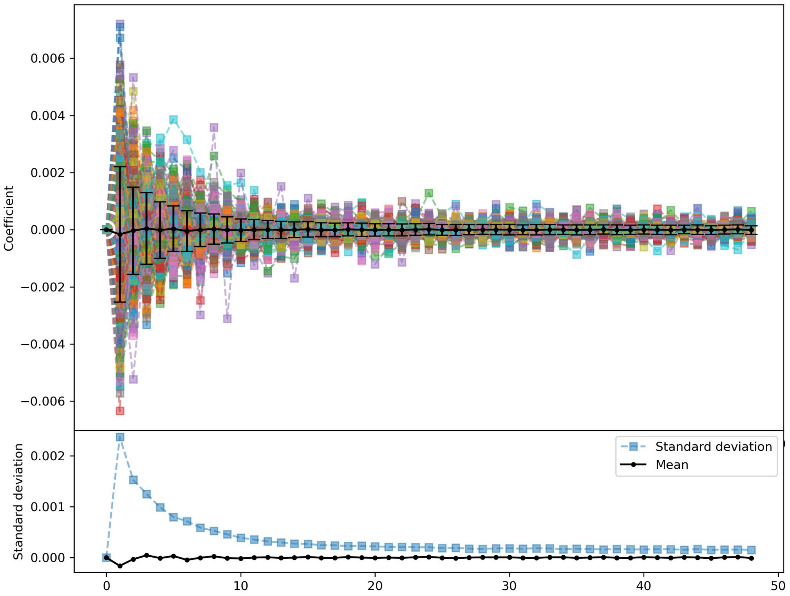
Preeliminar data: Domenico Sapone

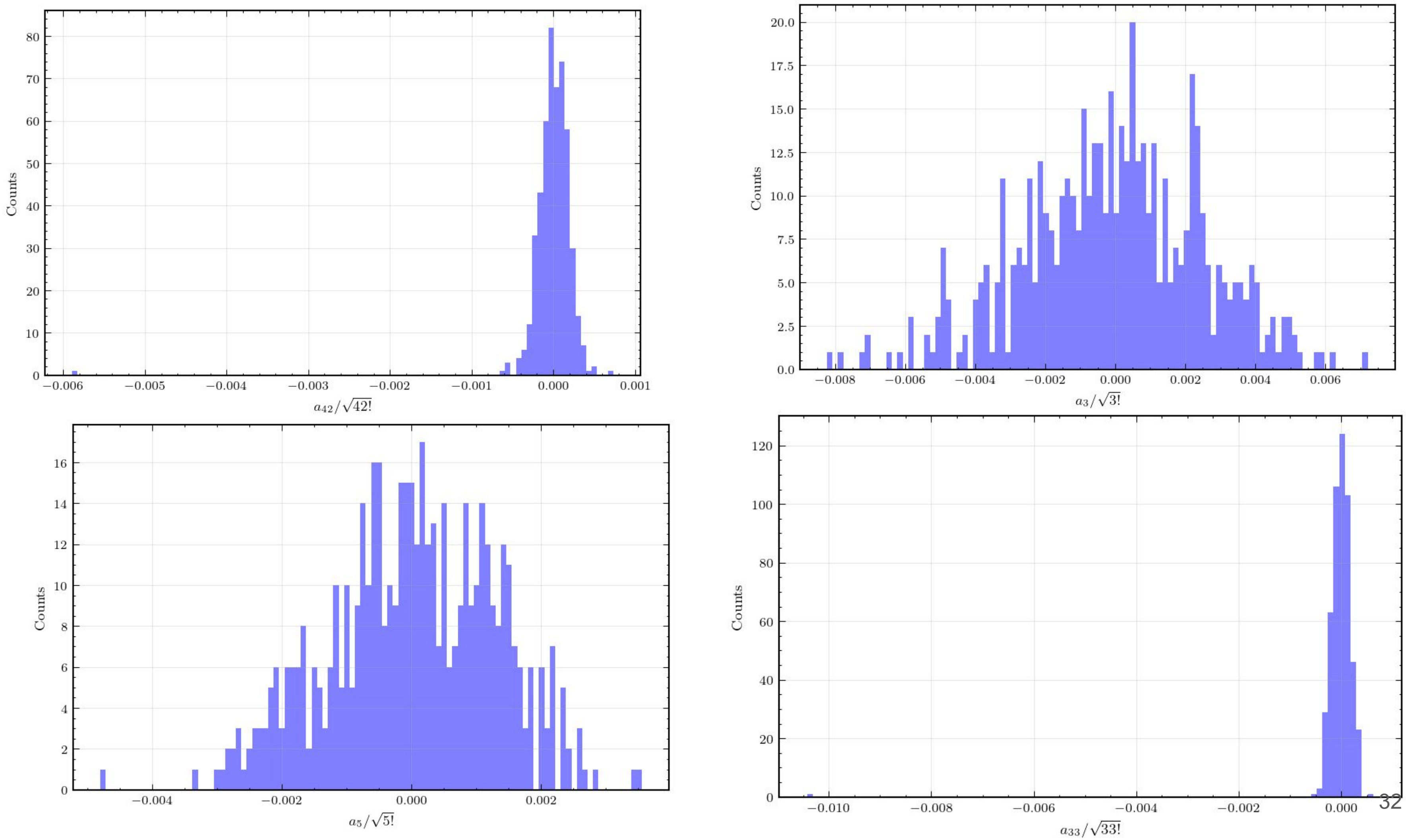


- Mean of 500 runs for each H_{n}

Preeliminar data: Domenico Sapone


0.020
0.015
0.010
0.005
0.000
−0.005
−0.010
−0.015
−0.020
Coefficient
Standard deviation
Mean
0.005
0.000
−0.005
Standard deviation
0
10
20
30
40
50


0.006
0.004
0.002
0.000
−0.002
−0.004
−0.006
Coefficient
Standard deviation
Mean
0.002
0.001
0.000
Standard deviation
0
10
20
30
40
50


Counts
$a_{42}/\sqrt{42!}$
Counts
$a_3/\sqrt{3!}$
Counts
$a_5/\sqrt{5!}$
Counts
$a_{33}/\sqrt{33!}$

Info from Healpix Library conventions

$$\hat{a}_{\ell m} = \frac{4\pi}{N_{\rm pix}} \sum_{p=0}^{N_{\rm pix}-1} Y^*_{\ell m}(\gamma_p) f(\gamma_p),$$

$$Y_{\ell m}(\theta,\phi) = \lambda_{\ell m}(\cos\theta) \mathrm{e}^{im\phi}$$

$$f(\gamma) = \sum_{\ell=0}^{l_{max}} \sum_{m} a_{\ell m} Y_{\ell m}(\gamma),$$

$$\lambda_{\ell m}(x) = \sqrt{\frac{2\ell+1}{4\pi}\frac{(\ell-m)!}{(\ell+m)!}} P_{\ell m}(x), \quad \text{for } m \geq 0$$

$$\hat{C}_\ell = \frac{1}{2l+1} \sum_m |\hat{a}_{\ell m}|^2.$$

- Dependance of Y_{lm} spherical harmonics in oscillatory exponential [1]
- Approximation of Y_{lm} to an oscillatory expression

$$\frac{\Delta T}{T}(\mathbf{n}) = \sum_{\ell m} a_{\ell m} Y_{\ell m}(\mathbf{n}).$$

$$a_{\ell m} = 4\pi(-i)^{\ell} \int \frac{d^3k}{(2\pi)^3} \mathcal{T}(k,\ell) Y^*_{\ell m}(\widehat{\mathbf{k}}) \zeta(\mathbf{k}). \quad (6.49)$$

$$C_{\ell} = \langle a_{\ell m} a^*_{\ell m} \rangle = \frac{2}{\pi} \int dk\, k^2\, |\mathcal{T}(k,\ell)|^2\, P_{\zeta}(k). \quad (6.50)$$

Preeliminar data: Domenico Sapone

Hermitian functions

$$
\begin{aligned}
\mathrm{He}_0(x) &= 1, \\
\mathrm{He}_1(x) &= x, \\
\mathrm{He}_2(x) &= x^2 - 1, \\
\mathrm{He}_3(x) &= x^3 - 3x, \\
\mathrm{He}_4(x) &= x^4 - 6x^2 + 3, \\
\mathrm{He}_5(x) &= x^5 - 10x^3 + 15x, \\
\mathrm{He}_6(x) &= x^6 - 15x^4 + 45x^2 - 15, \\
\mathrm{He}_7(x) &= x^7 - 21x^5 + 105x^3 - 105x, \\
\mathrm{He}_8(x) &= x^8 - 28x^6 + 210x^4 - 420x^2 + 105, \\
\mathrm{He}_9(x) &= x^9 - 36x^7 + 378x^5 - 1260x^3 + 945x, \\
\mathrm{He}_{10}(x) &= x^{10} - 45x^8 + 630x^6 - 3150x^4 + 4725x^2 - 945.
\end{aligned}
$$