Primordial Non-Gaussianity from Preheating

arXiv:0903.3407 (BFHK); arXiv:0809.4904 (DEFROST)

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Simon Fraser University

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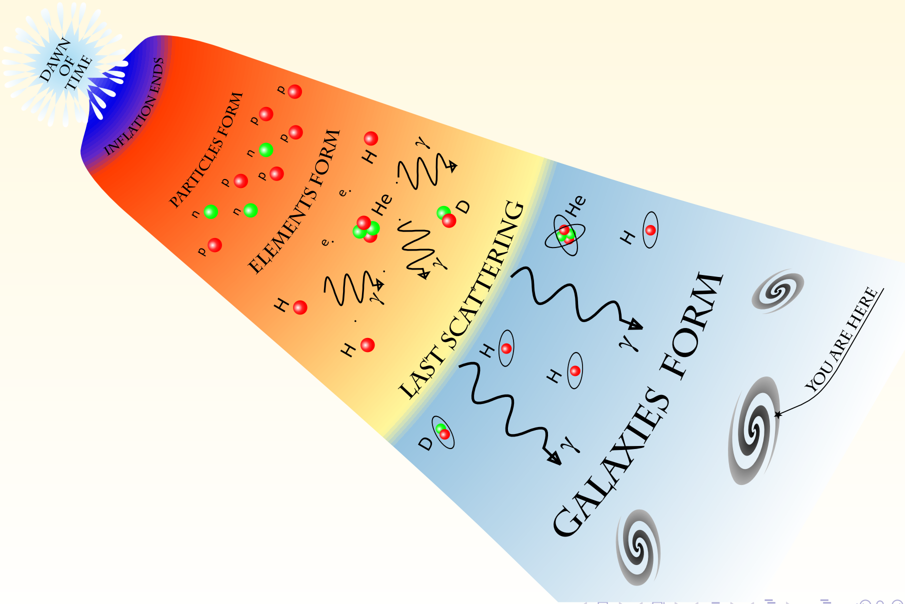
Lebedev Institute
Moscow, Russia
22 May 2009

Brief History of the Universe



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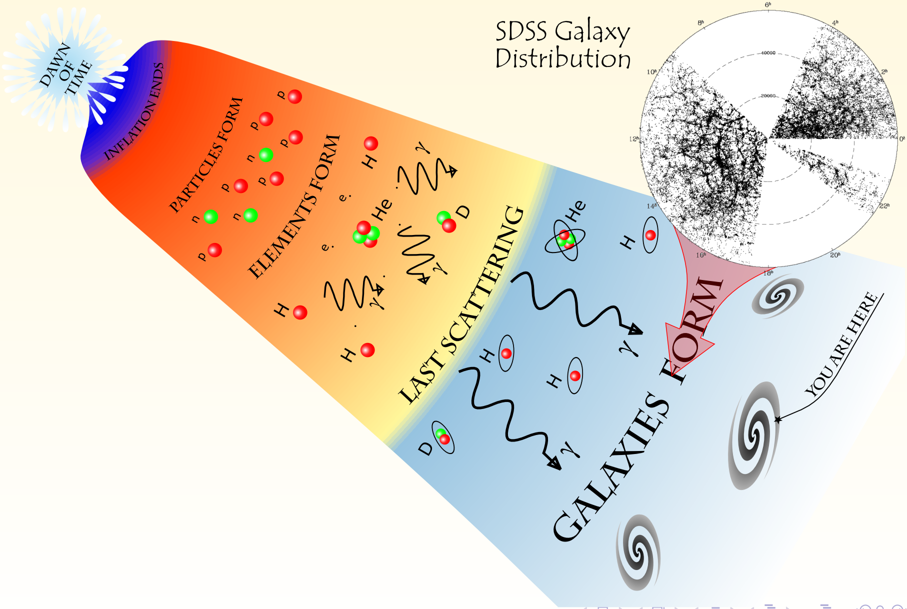

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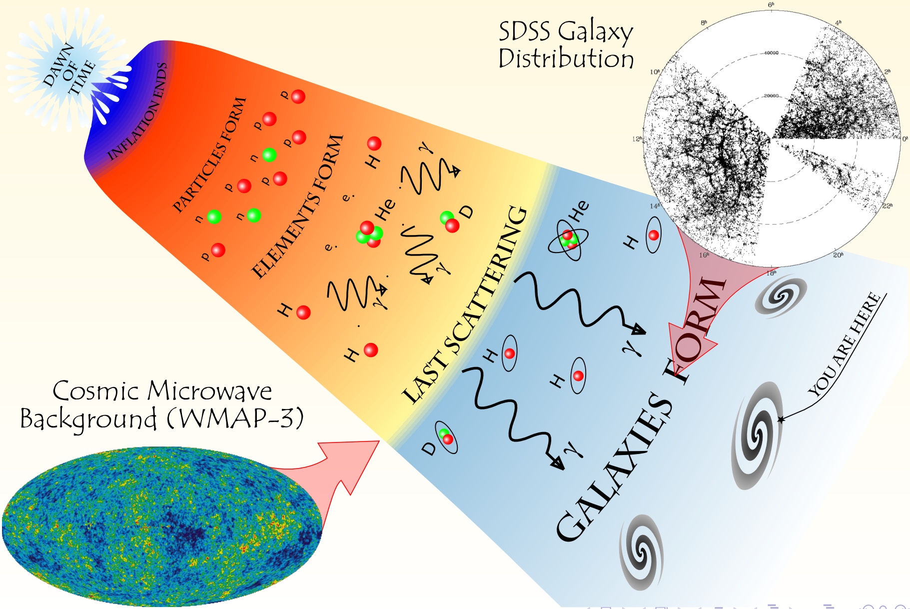

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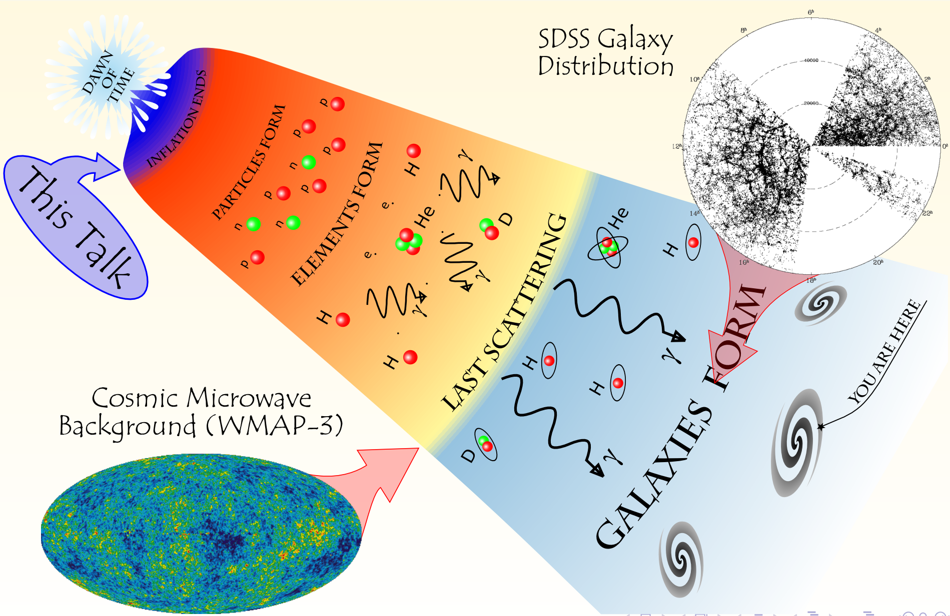
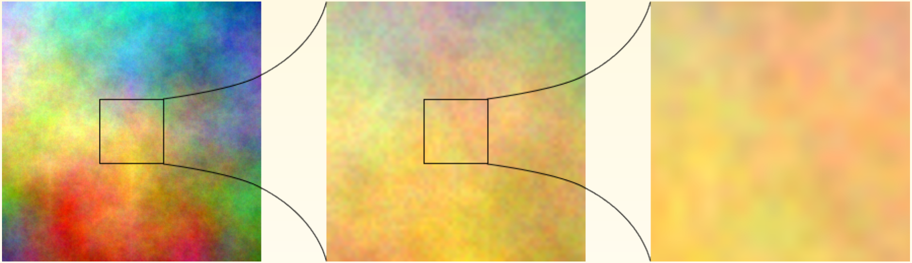


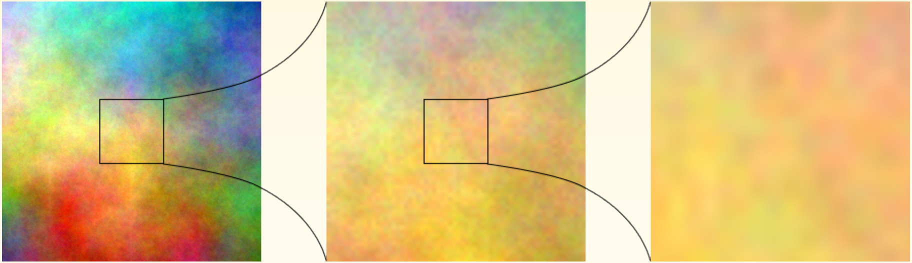
Inflation Solves Many Problems, But...



inflation wipes the slate clean and re-seeds the structure

... inflation has to end! But how?

Inflation is cold ? **Big Bang is hot**



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the *way* inflation ends
can lead to a new signal:

usual non-Gaussianity:

$$\Phi(\vec{x}) = \Phi_G(\vec{x}) + f_{NL}\Phi_G^2(\vec{x})$$

new from preheating:

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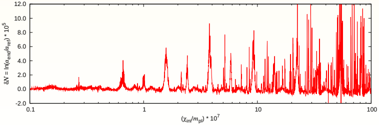
F_{NL} can be a *very* non-trivial function:



Preheating Can Leave a Signature in CMB Sky!

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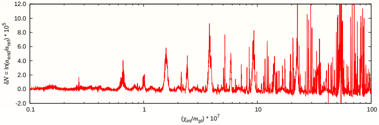
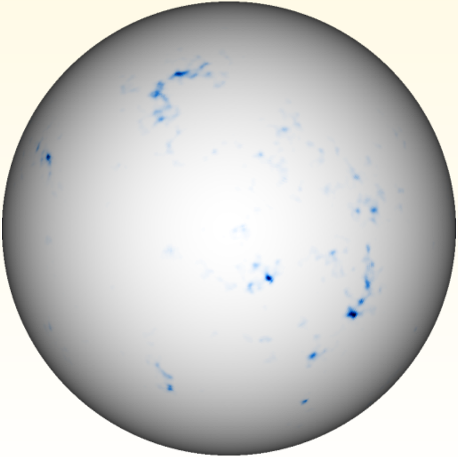
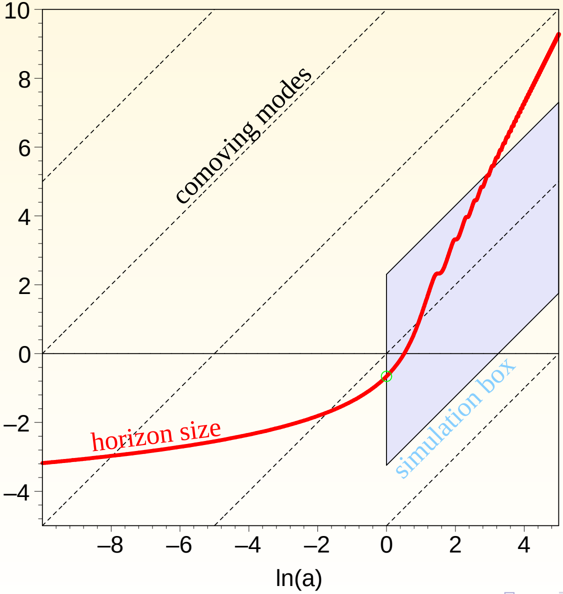


realization of *excursion set* can naturally give cold spots!



How Does Inflation End, Anyway?



A Simple Model of Inflation...

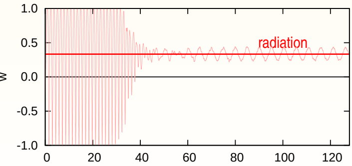
Model with potential

$$V(\phi,\chi) = \frac{\lambda}{4}\phi^4 + \frac{g^2}{2}\phi^2\chi^2$$

is invariant under

$$\begin{aligned} g_{\mu\nu} &\mapsto a^{-2} g_{\mu\nu}, \\ \phi &\mapsto a\phi, \\ \chi &\mapsto a\chi \end{aligned}$$

equation of state is $1/3$



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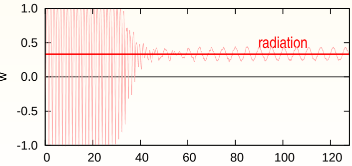
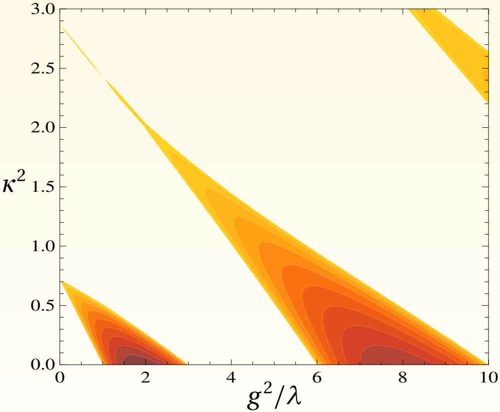
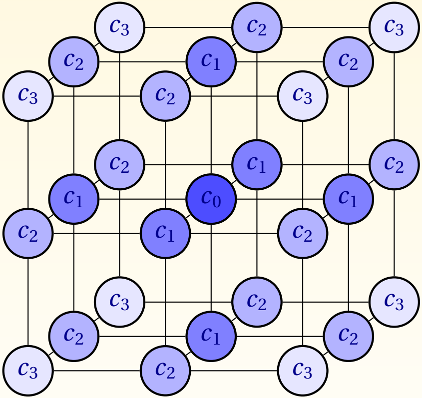


Stability of Lame equation:



$$(a\chi_k)'' + \left[\kappa^2 + \frac{g^2}{\lambda}\mathrm{cn}^2\left(x, 2^{-1/2}\right)\right](a\chi_k) = 0$$

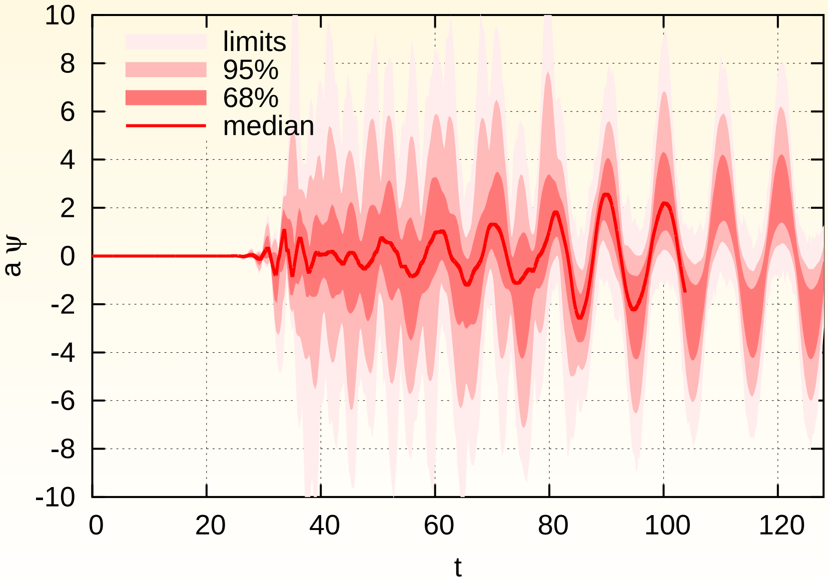


coefficient	c_3	c_2	c_1	$-c_0$
degeneracy	8	12	6	1
standard	0	0	1	6
isotropic A	0	$\frac{1}{6}$	$\frac{1}{3}$	4
isotropic B	$\frac{1}{12}$	0	$\frac{2}{3}$	$\frac{14}{3}$
isotropic C	$\frac{1}{30}$	$\frac{1}{10}$	$\frac{7}{15}$	$\frac{64}{15}$

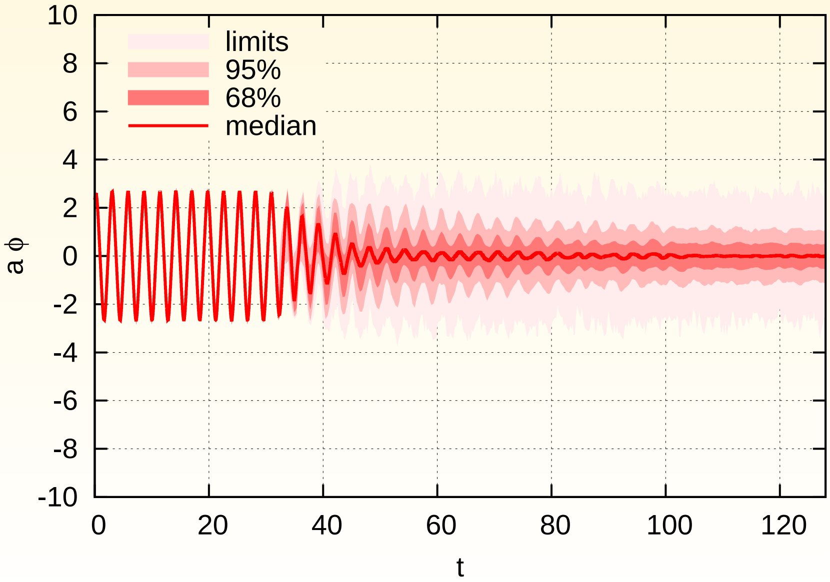
http://www.sfu.ca/physics/cosmology/defrost

[Fortran-90, 600 lines, very fast, instrumented for 3D]

Development of the Instability



Inflaton Decays as Energy is Drawn from It



Density Evolution during Preheating

Non-Gaussianity from Preheating?

CMB and Reheating scales different by 50+ e-folds!

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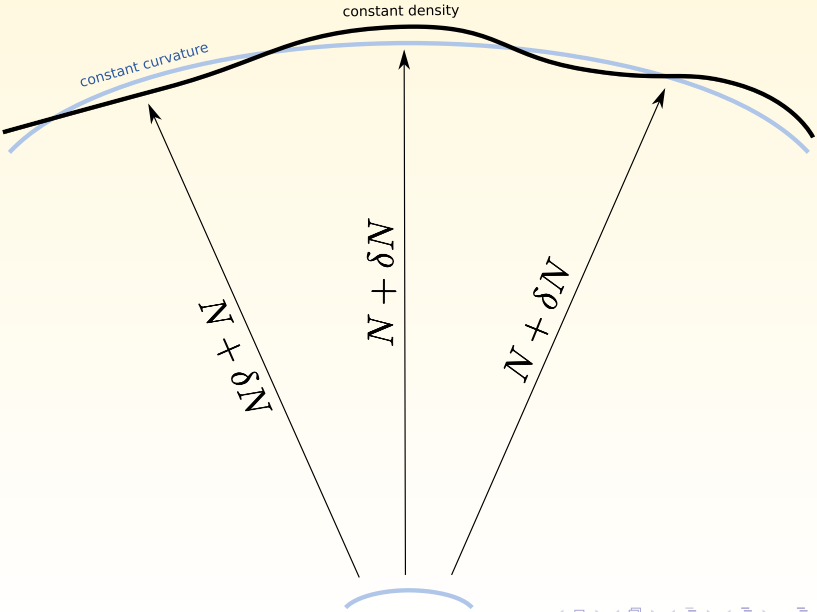
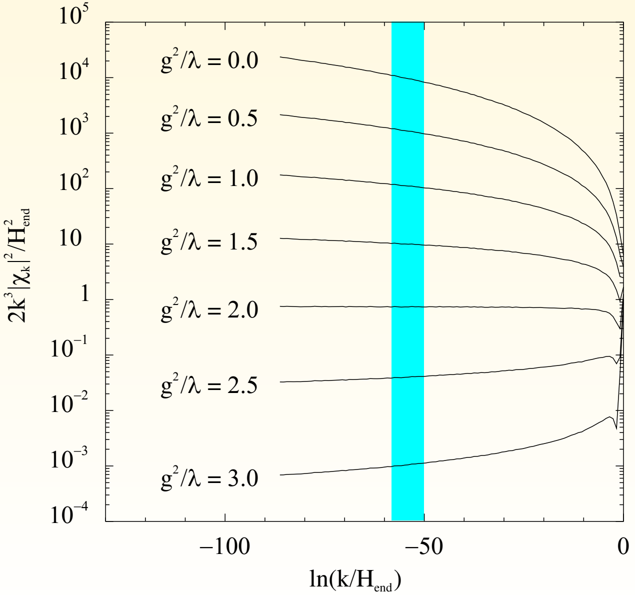
Differences in Expansion can Modulate CMB

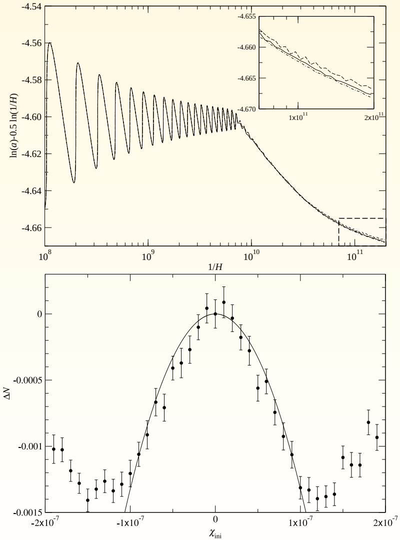


Modulation Comes from Isocurvature Mode



Carefull Here... Parts per Million Effect!

Chambers & Rajantie 0805.4795



Large Non-Gaussianity signal reported:

$$f_{\rm NL} \sim 10^{19^{+8}_{-5}} \quad (!)$$

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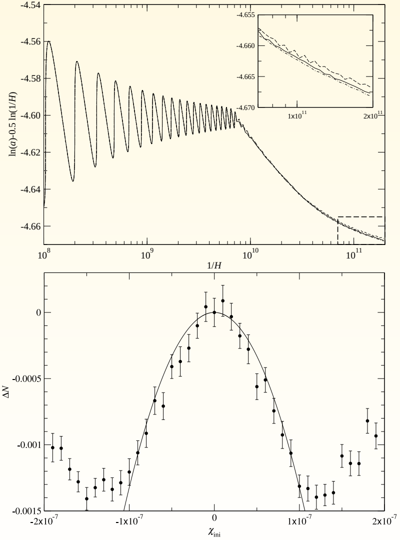
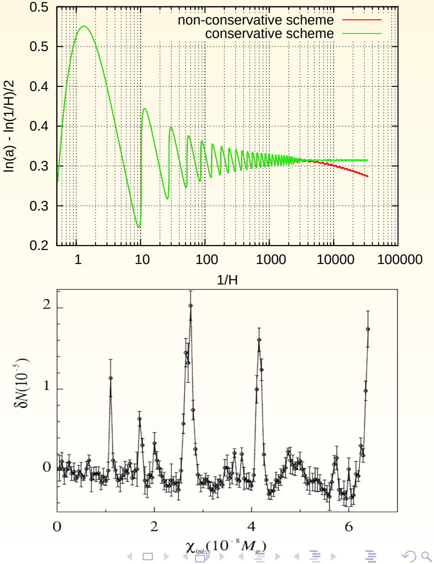


Bond, Frolov, Huang, and Kofman



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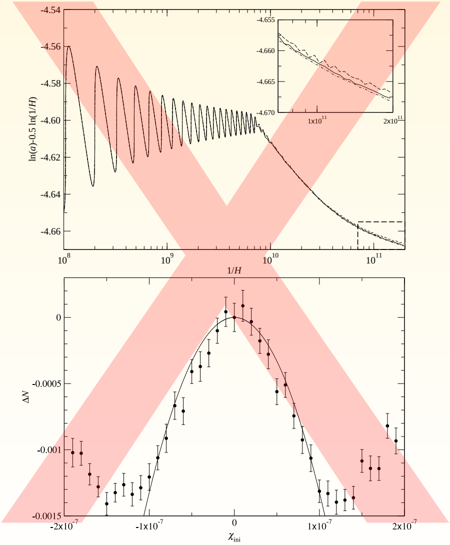

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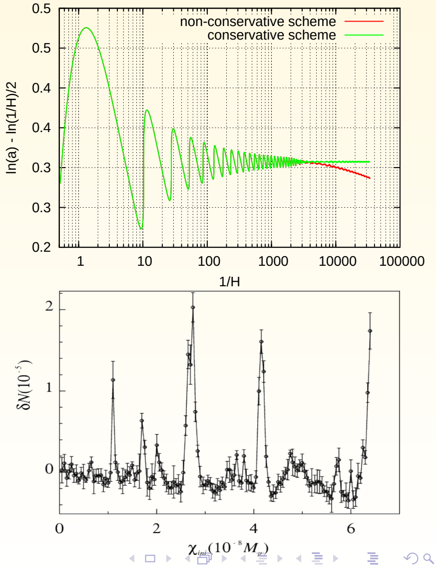

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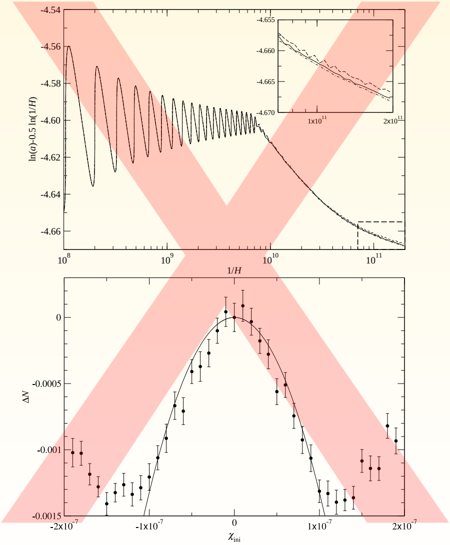

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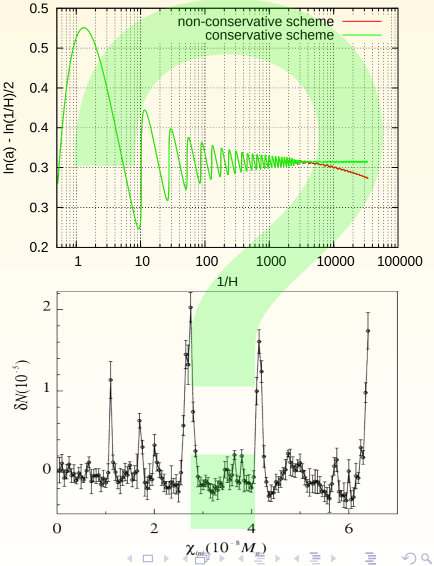
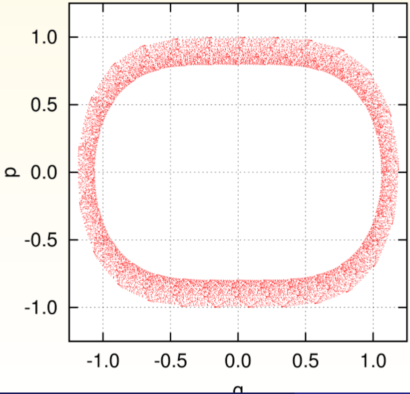


Problem:

long-term oscillator evolution

$$H = \frac{p^2}{2} + \frac{q^4}{4}$$

4^{th} order Runge-Kutta



Symplectic Integrator to the Rescue!

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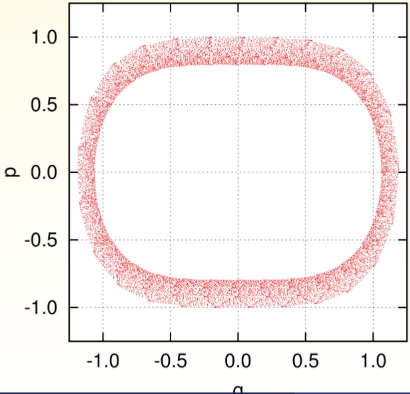
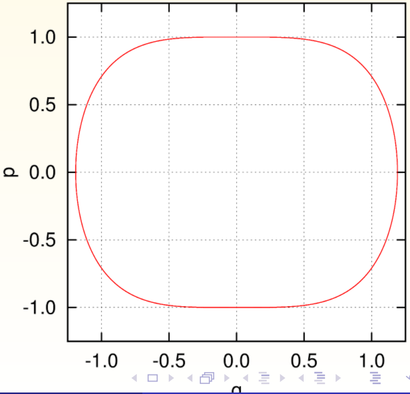


Solution:

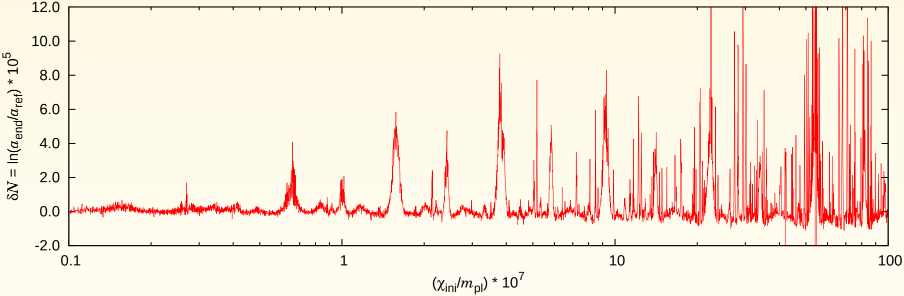
enforce energy conservation

$$e^{At/2} e^{Bt} e^{At/2} = e^{(A+B)t+O(t^3)}$$

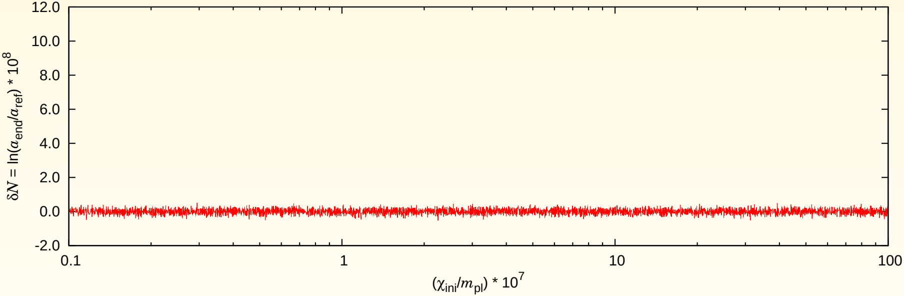
4^{th} order Symplectic



And the Answer Is... $O(10^{-5})$ Modulation!



Are these peaks Real? Yes...



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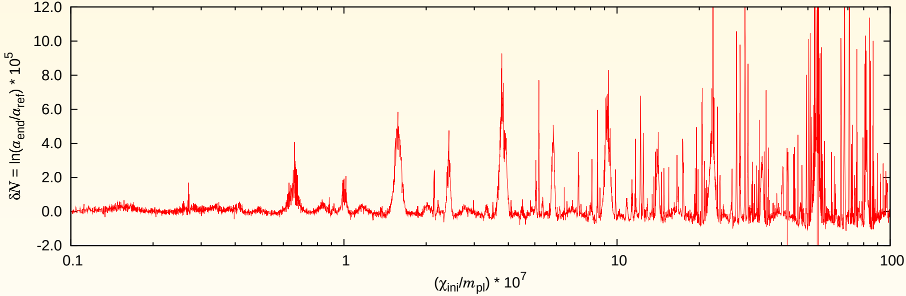
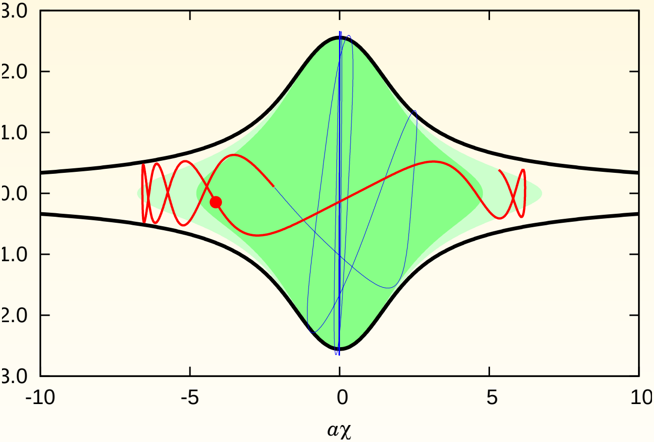


What is causing these peaks?

Field Evolution as a Chaotic Billiard

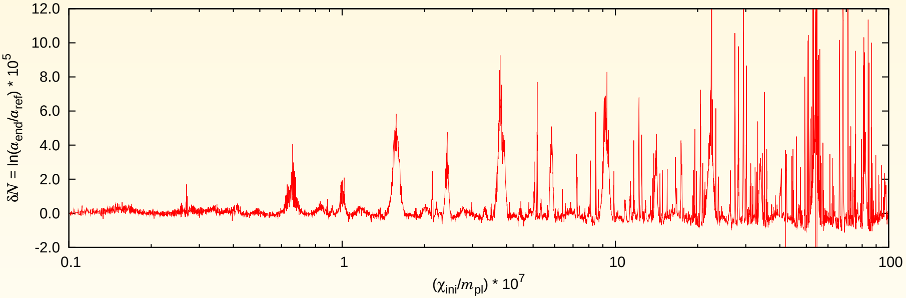
Here is a Trajectory from the Peak

A Simple Analytical Model



$$V_{\rm eff}(\phi,\chi) = \frac{\lambda}{4}\phi^4 + \frac{g^2}{2}\left(\phi^2 + \langle\delta\phi^2\rangle\right)\chi^2$$

This Explains why Peaks are Log-Periodic!



$$\phi(t+T) = \phi(t)$$

$$\chi(t+T) = \chi(t)e^{\mu_0 T}$$

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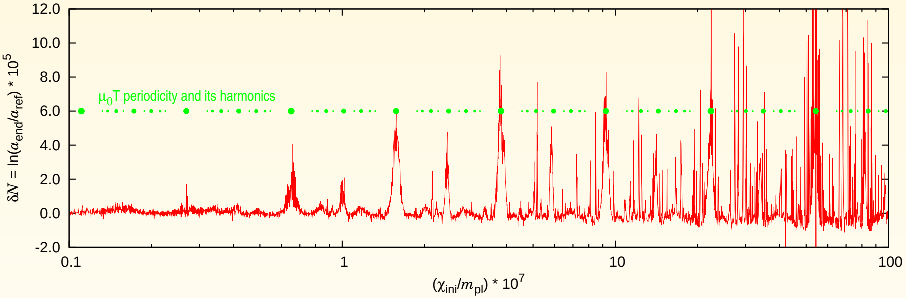

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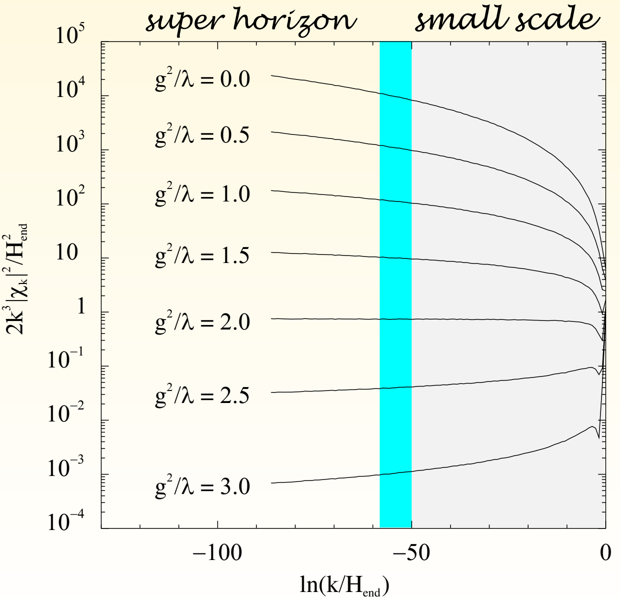
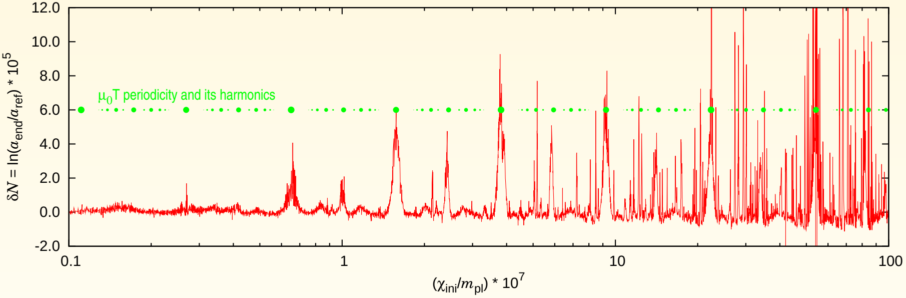
Large-Scale Fluctuations are Produced

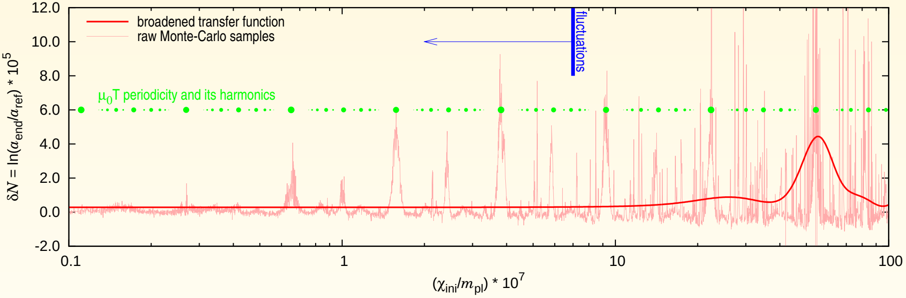


Non-Gaussian Contribution at CMB Scales



Have to marginalize over sub-structure!

Non-Gaussian Contribution at CMB Scales



Very different from $f_{\rm NL}$ parametrization!

$$\Phi(\vec{x}) = \Phi_G(\vec{x}) + F_{NL}(\chi_G)$$

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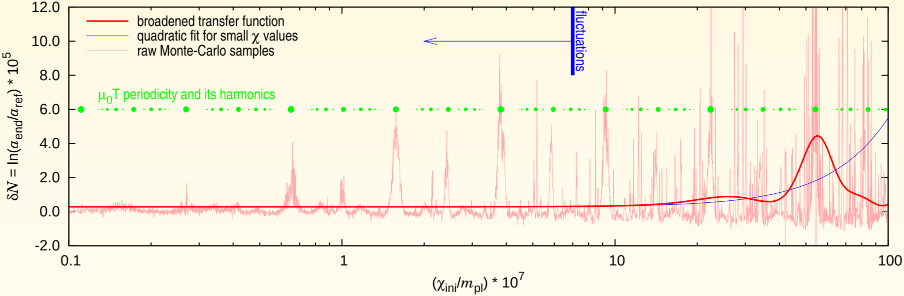
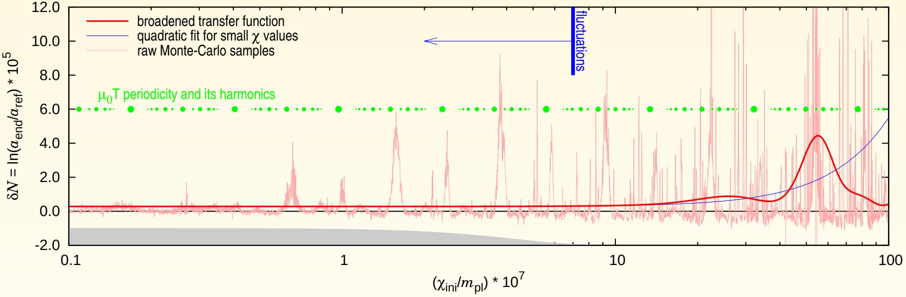


For small χ, *uncorrelated* quadratic!

$$\Phi(\vec{x}) = \Phi_{\mathrm{G}}(\vec{x}) + f_\chi\, \chi_{\mathrm{G}}^2(\vec{x})$$



Sampling depends on super-horizon modes

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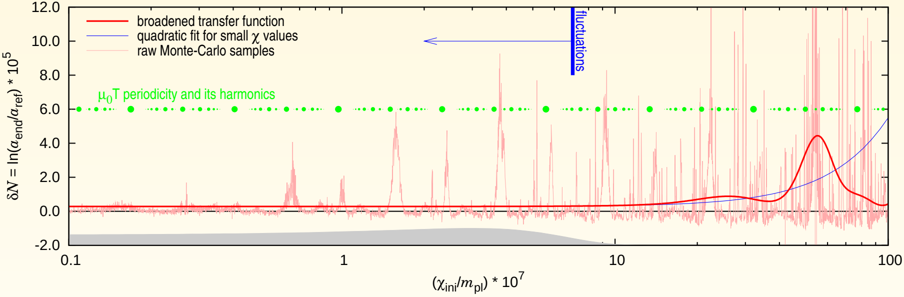

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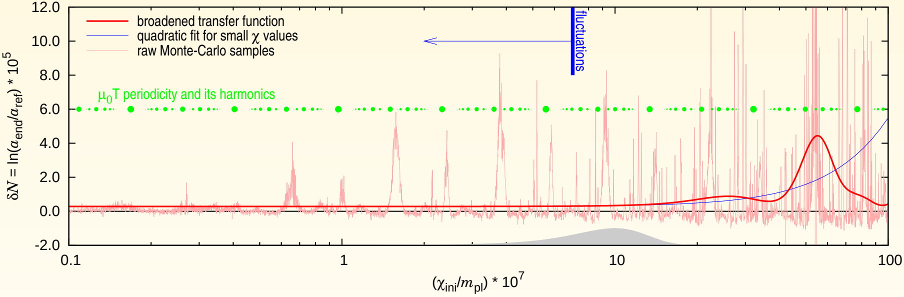

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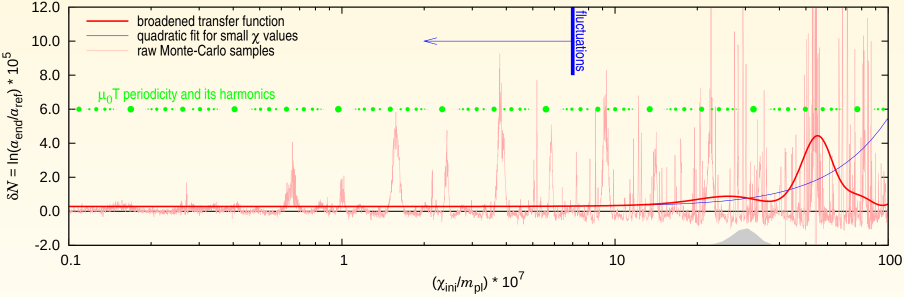

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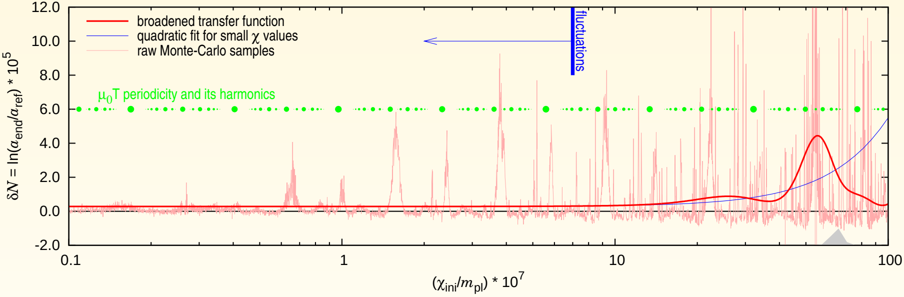

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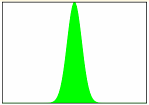
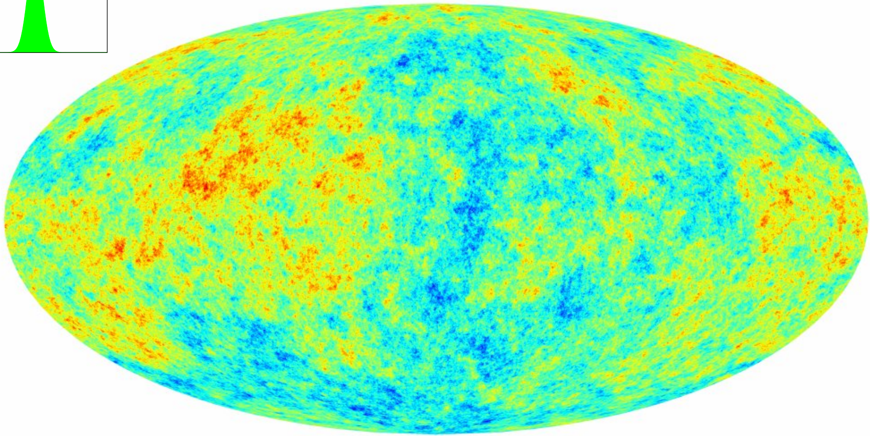
How Would It Look Like on the Sky?





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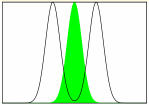

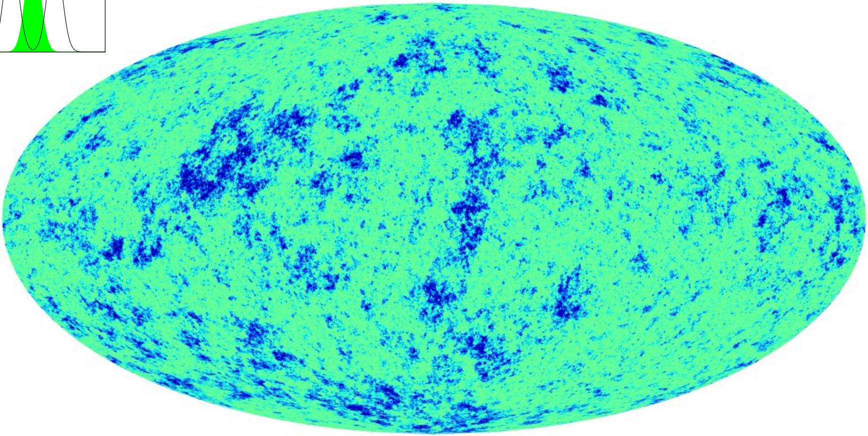

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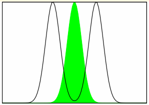

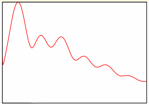

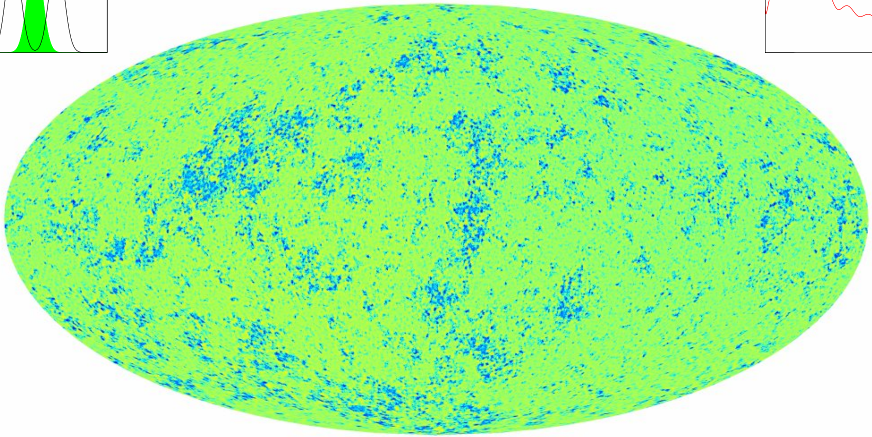

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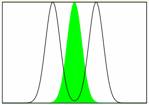

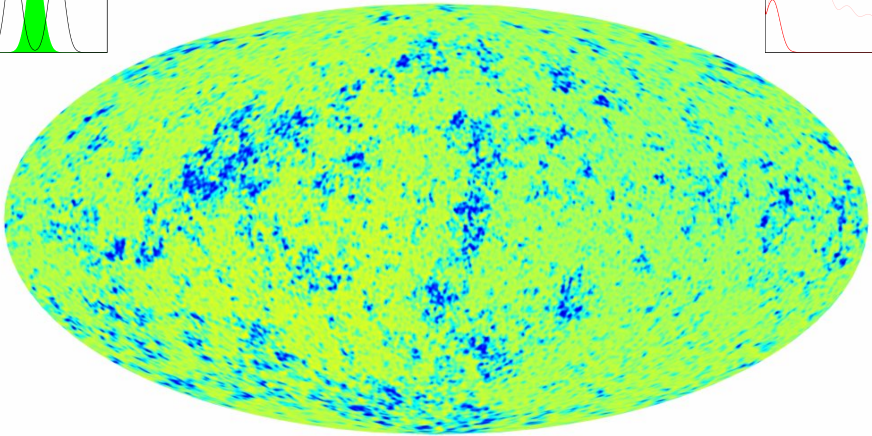

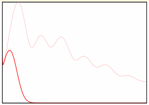

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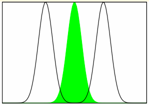

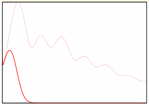

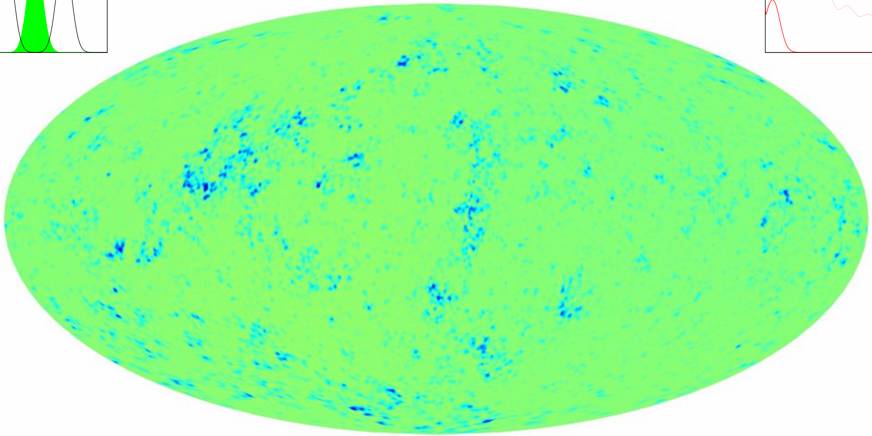

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