Andrei Frolov, JGRG 22(2012)111301

“Primordial non-gaussianity from preheating”

RESCEU SYMPOSIUM ON

GENERAL RELATIVITY AND GRAVITATION

JGRG 22

November 12-16 2012

Koshiba Hall, The University of Tokyo, Hongo, Tokyo, Japan

Primordial Non-Gaussianity from Preheating

arXiv:0903.3407 (BFHK); arXiv:1004.3559 (REVIEW)

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&

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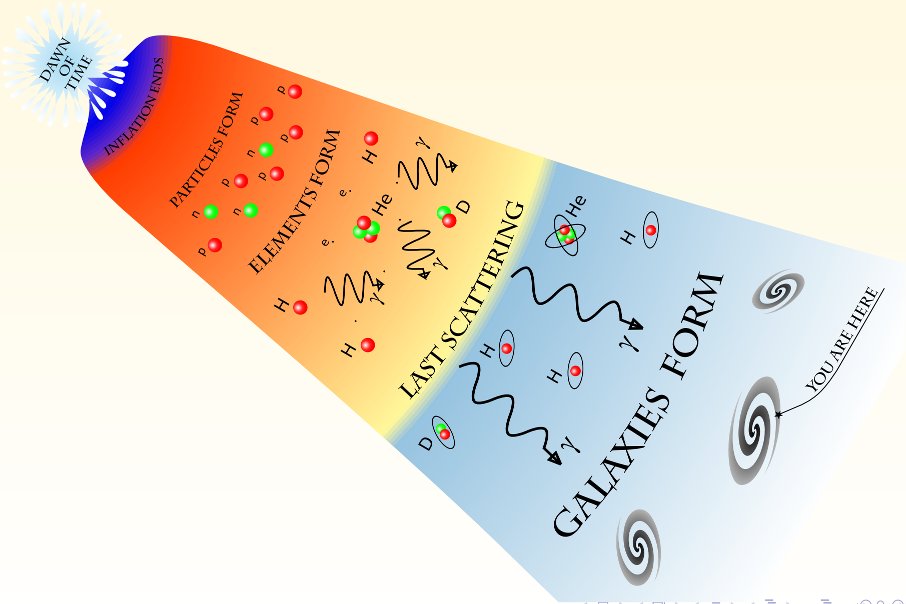
RESCEU Symposium on General Relativity and Gravitation

University of Tokyo, Tokyo, Japan
13 November 2012

Brief History of the Universe



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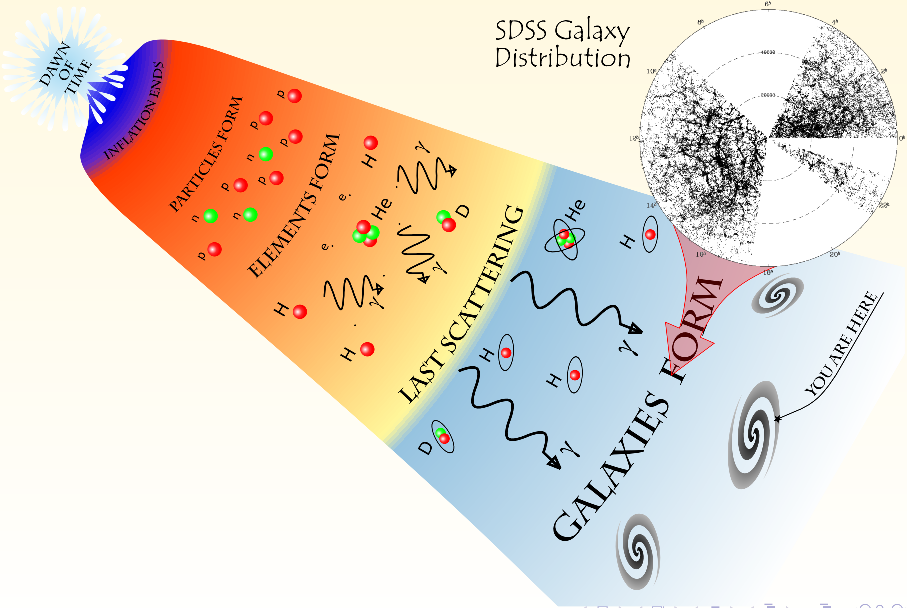

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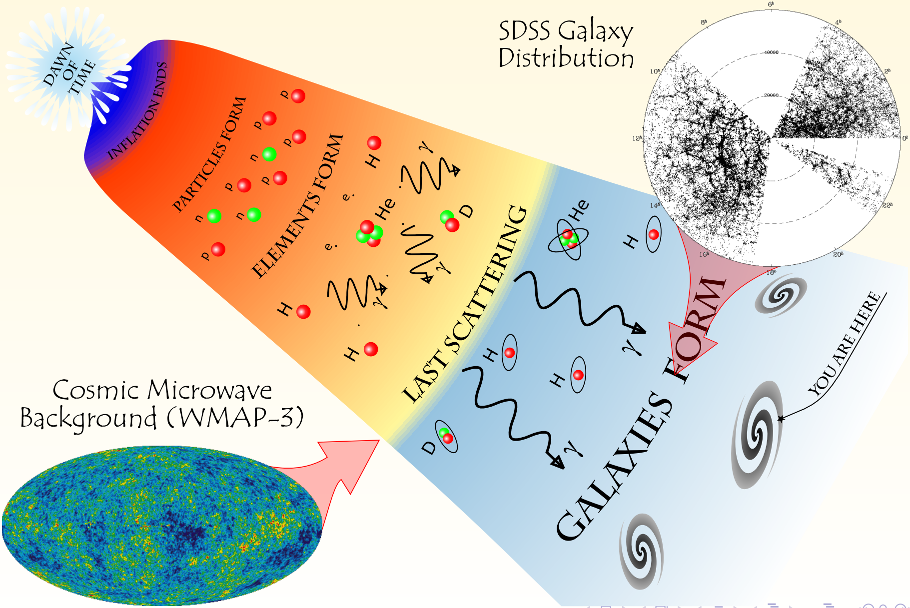

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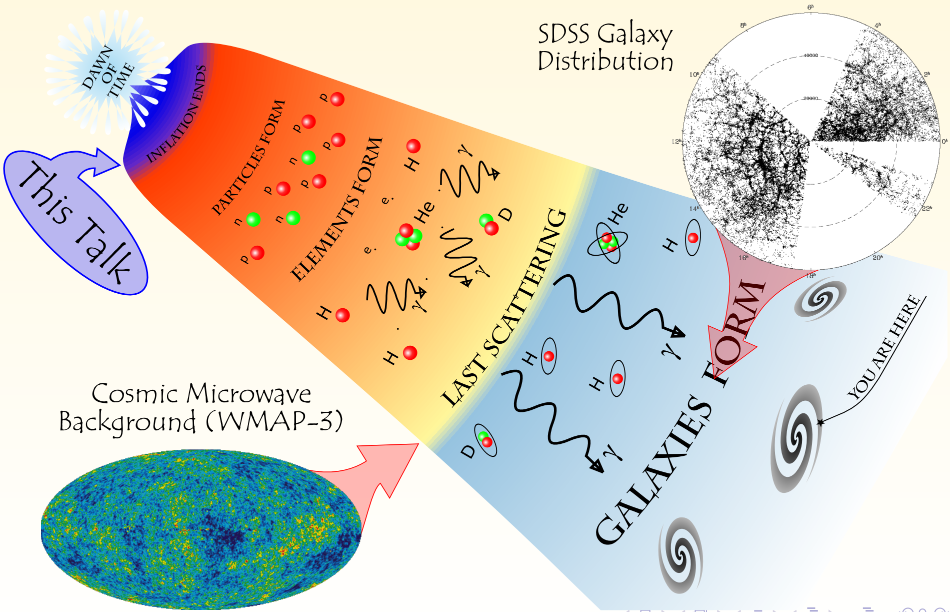


A Simple Model of Inflation...

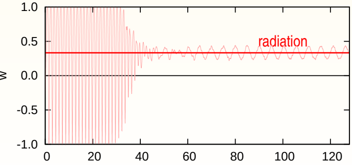
Model with potential

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

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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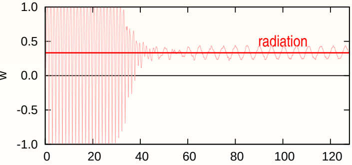
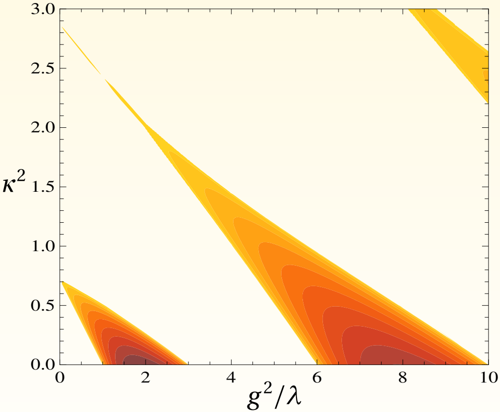
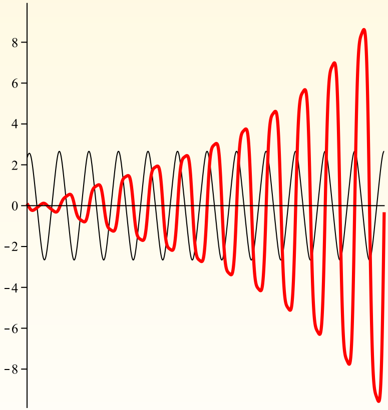


Stability of Lame equation:

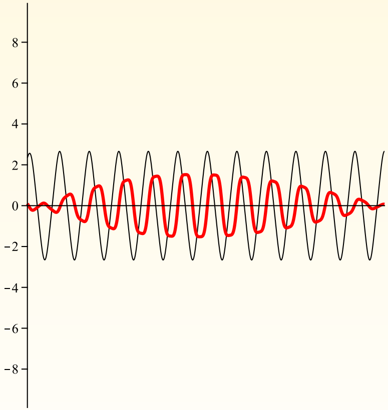


$$(a\chi_k)'' + \left[\kappa^2 + \frac{g^2}{\lambda}\mathrm{cn}^2\left(x, 2^{-1/2}\right)\right](a\chi_k) = 0$$

Development of Linear Instability



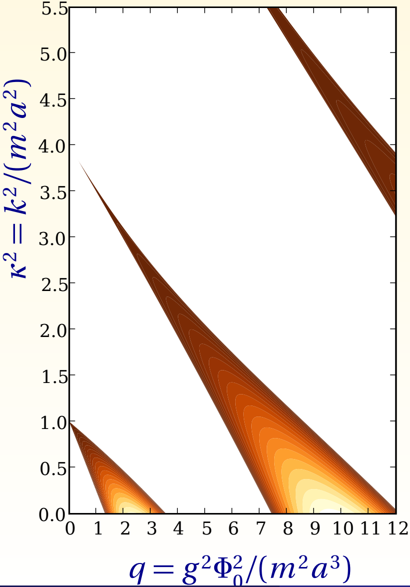
$g^2/\lambda = 2.99,\ \kappa^2 = 0$



$g^2/\lambda = 3.01,\ \kappa^2 = 0$

Parametric Resonance is a Generic Feature

$$\chi_k'' + \left[\kappa^2 + q\cos^2(\tau)\right]\chi_k = 0$$



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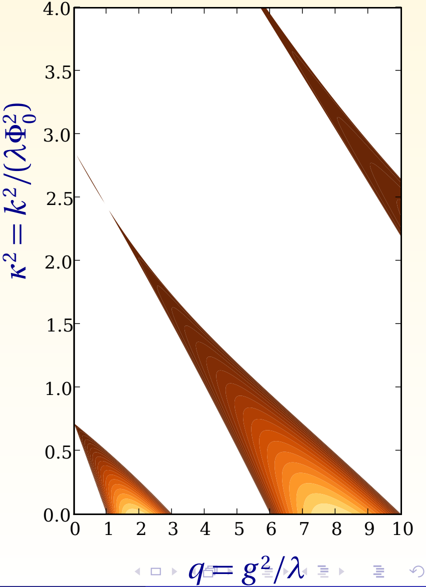
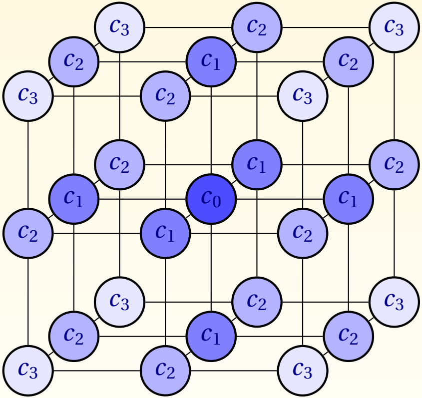


DEFROST: A New 3D Numerical Solver



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]

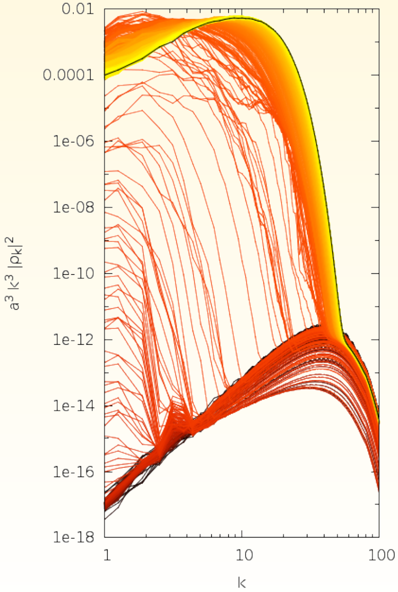
Field Evolution as a Chaotic Billiard

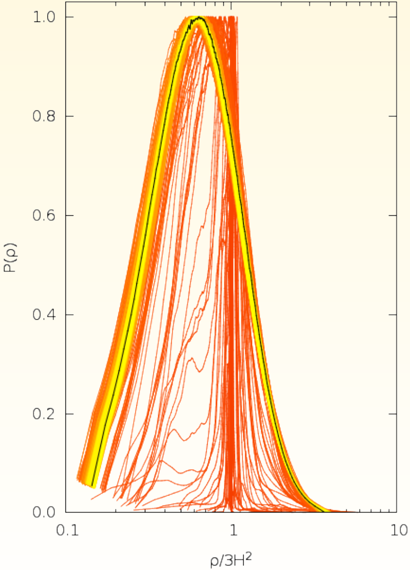
DENSITY EVOLUTION $\left[V(\phi,\chi)=\frac{1}{4}\lambda\phi^4+\frac{1}{2}g^2\phi^2\chi^2\right]$

DENSITY EVOLUTION $\left[V(\phi,\chi) = \frac{1}{2}m^2\phi^2 + \frac{1}{2}g^2\phi^2\chi^2\right]$

Density Evolution $\left[V(\phi,\chi)=\frac{1}{2}m^2\phi^2+\frac{1}{2}\sigma\phi\chi^2+\frac{1}{4}\lambda\chi^4\right]$

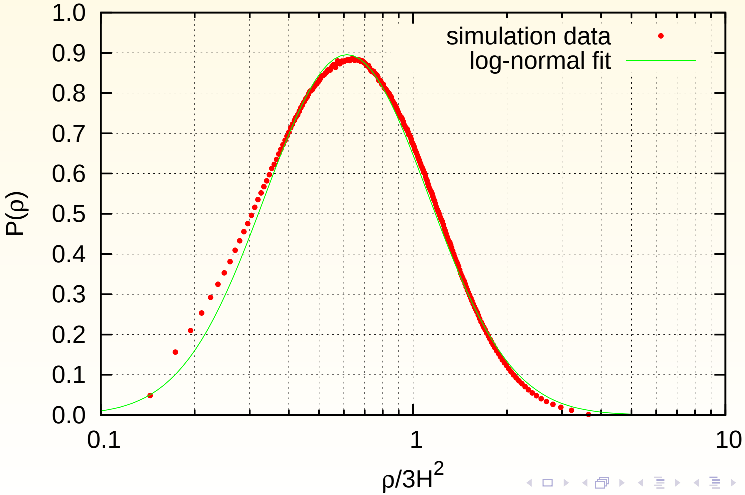
HERE IS HOW INSTABILITY DEVELOPS!





In Fact, It's Quite Log-Normal!

$$V(\phi,\chi)=\frac{1}{4}\lambda\phi^4+\frac{1}{2}g^2\phi^2\chi^2$$



In Fact, It's Universally Log-Normal!

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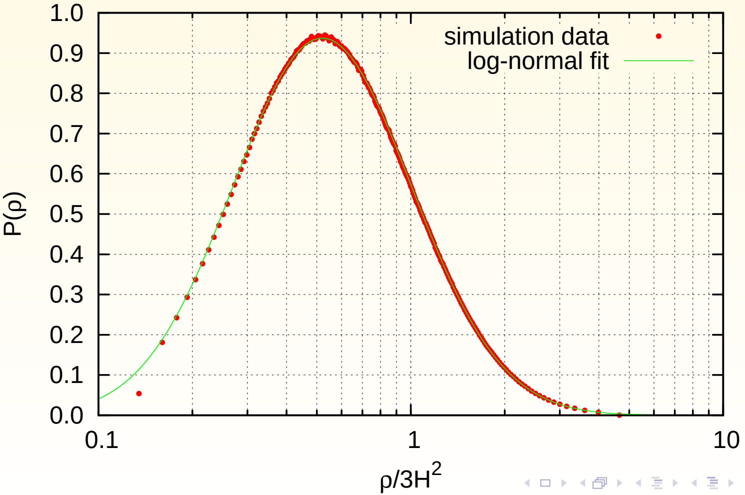
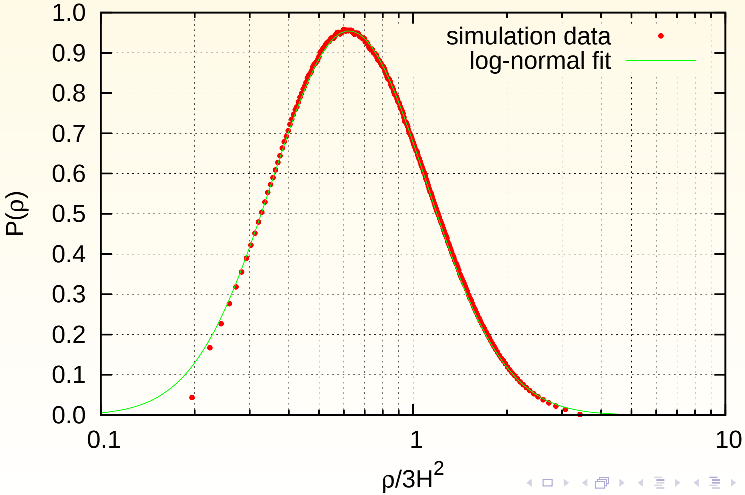


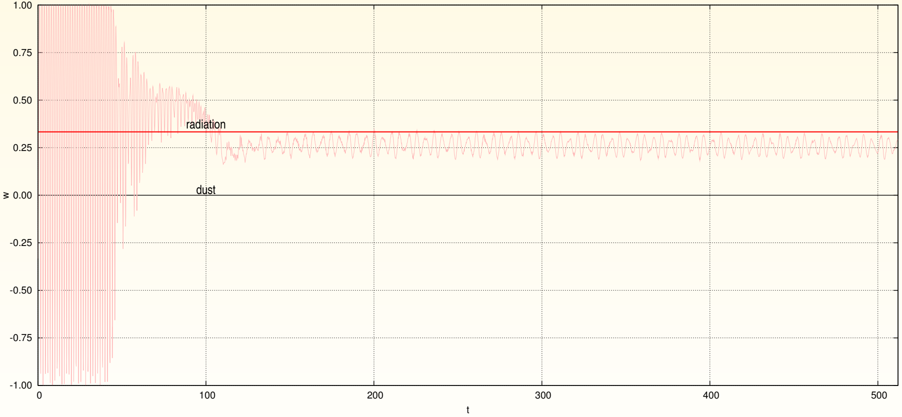
In Fact, It's Universally Log-Normal!

$$V(\phi,\psi) = \frac{1}{2}m^2\phi^2 + \frac{1}{2}\sigma\phi\chi^2 + \frac{1}{4}\lambda\chi^4$$



(Non-Thermal) Scalar Field Fixed Point?

$$V(\phi,\chi) = \frac{1}{4}\lambda\left(\phi^2+\chi^2-v^2\right)^2$$



A universal characteristic of random scalar field evolution?!

What's Going On Here?

Very tempting to blame scalar field turbulence!..

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Very tempting to blame scalar field turbulence!..

Are We Going to Ever See Any of This?

Thermal Bath

Wipes Out Everything?!

Scales Too Small?!

We should look for things that can survive thermalization:

1. stable relics (primordial black holes)
2. decoupled fields (gravitational waves)
3. anomalies in expansion history (non-gaussianity)

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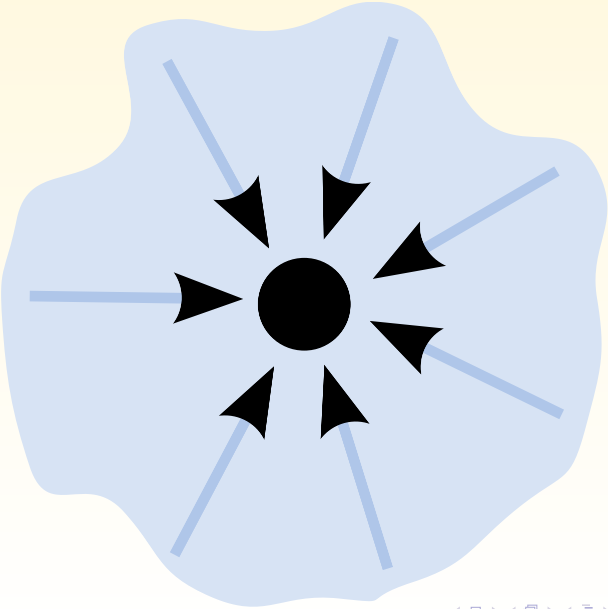
Can Primordial Black Holes Form? No...



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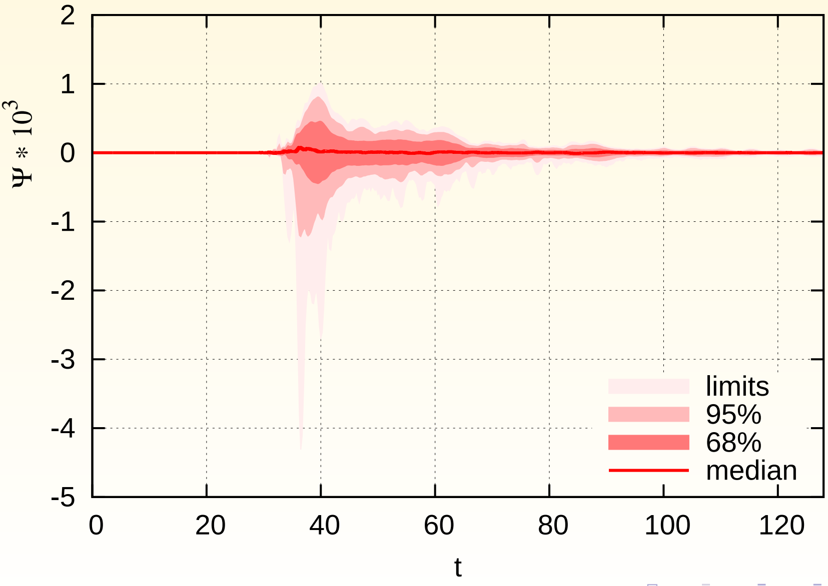
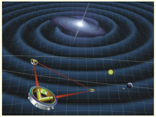
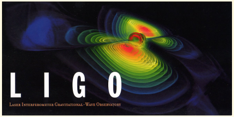
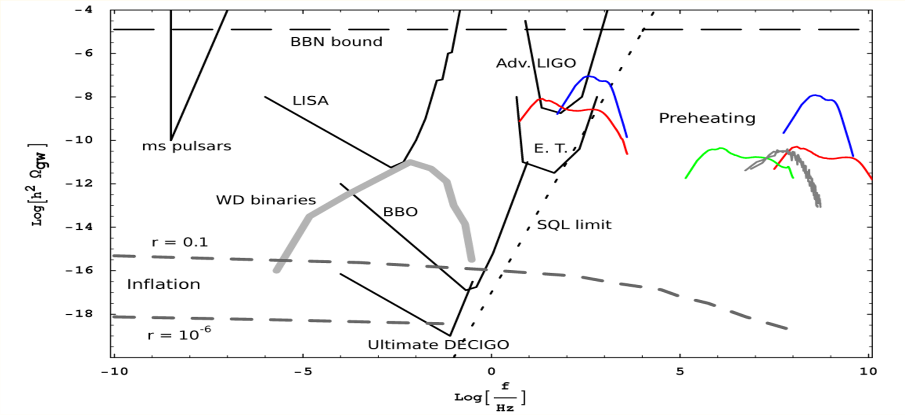


Gravitational Waves from Preheating?



Dufaux, Felder, Kofman & Navros (2009)

Non-Gaussianity from Preheating?

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

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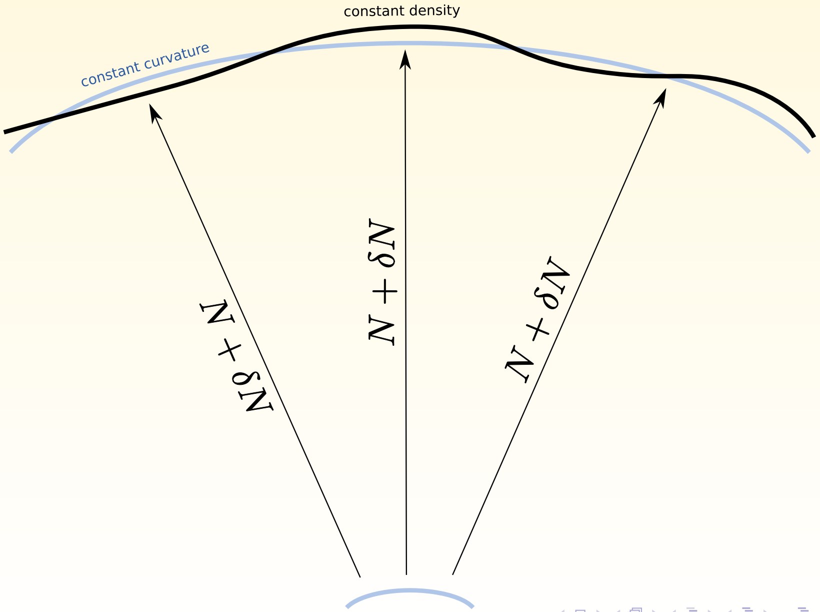
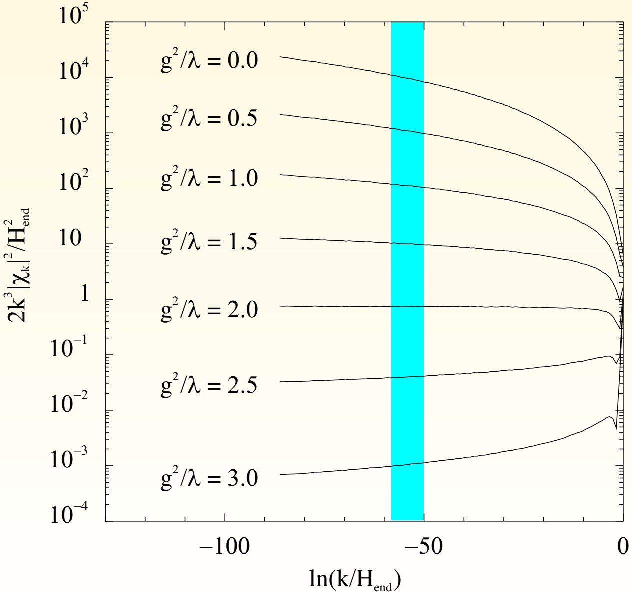
CMB and Reheating scales different by 50+ e-folds!

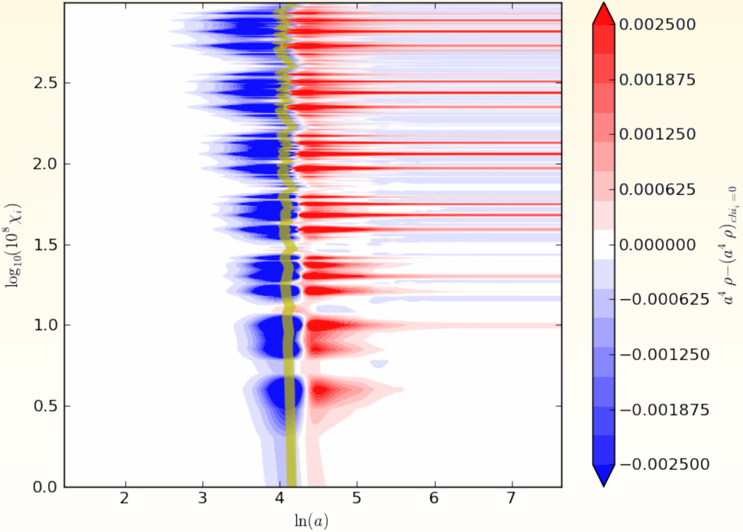
Differences in Expansion can Modulate CMB



Modulation Comes from Isocurvature Mode



Evolution Depends on Initial Isocon Value

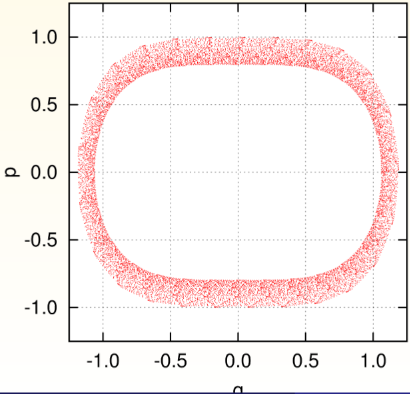


Problem:

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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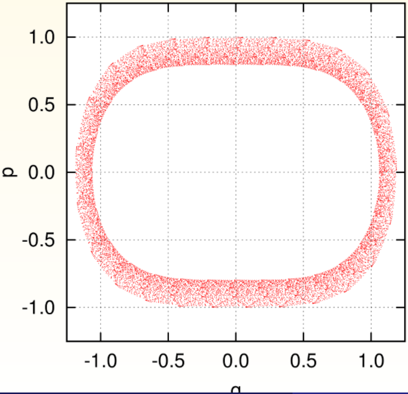
4th order Runge-Kutta

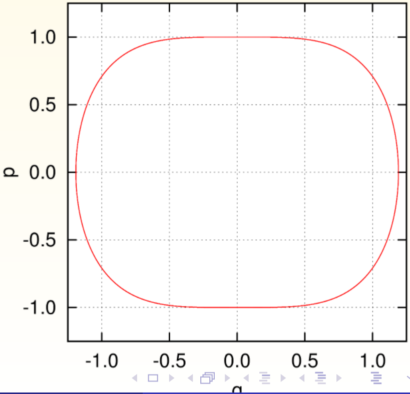


Solution:

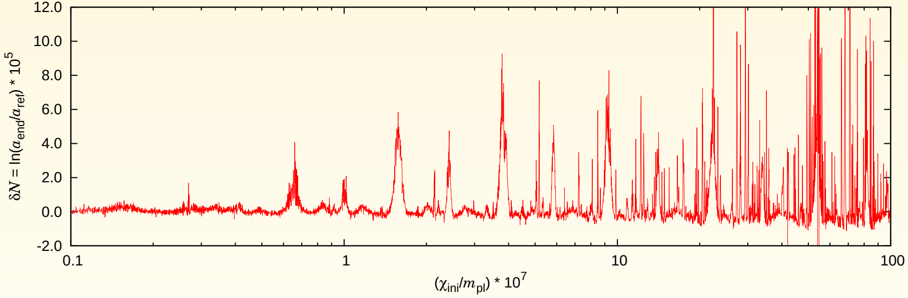
enforce energy conservation

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

4th order Symplectic



Isocurvature Mode Converts to Curvature



Are these peaks Real? Yes...

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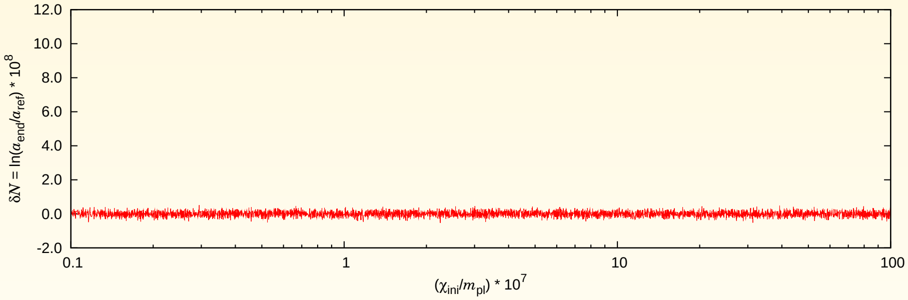

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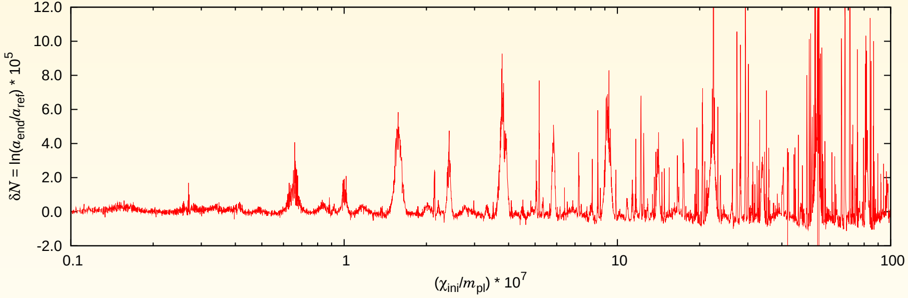
Primordial Non-Gaussianity is Produced!

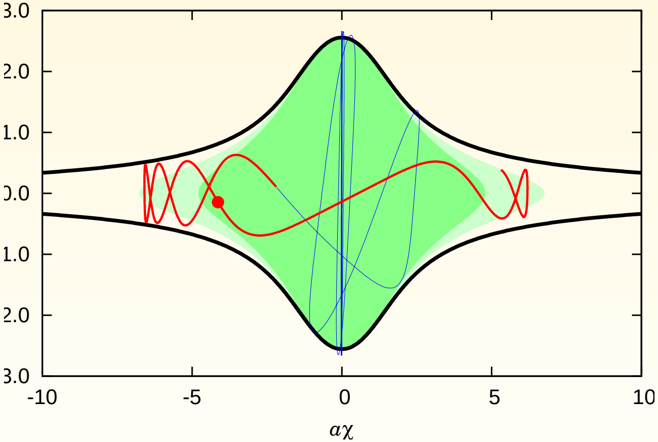


$$\Phi(\vec{x}) = \Phi_G(\vec{x}) + F_{NL}(\chi_G)$$

very different from f_{NL} parametrization!

Here is a Trajectory from the Peak

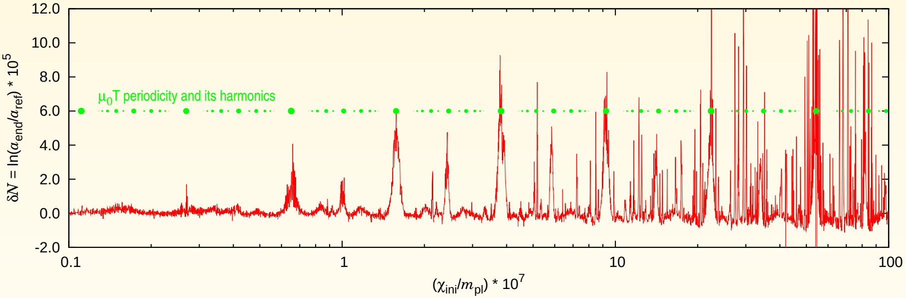
A Simple Analytical Model



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

Time Evolution of Effective Potential

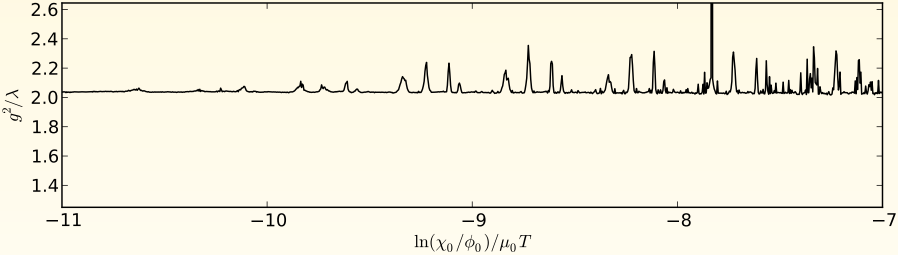
This Explains why Peaks are Log-Periodic!



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

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

Let's Explore the Parameter Space...



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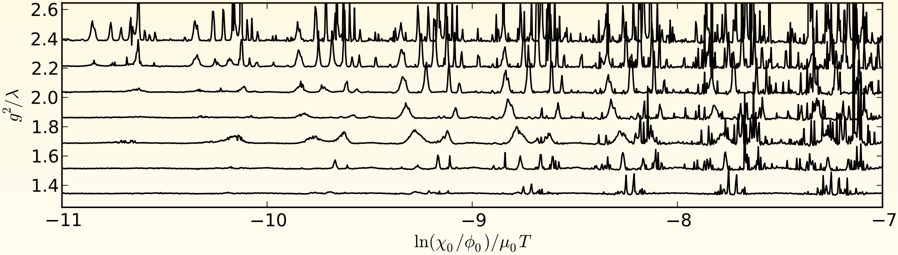

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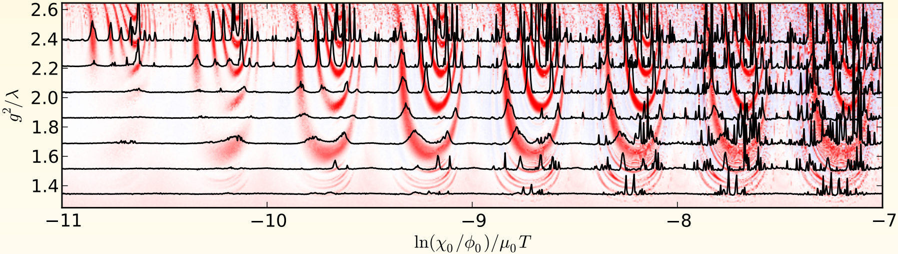

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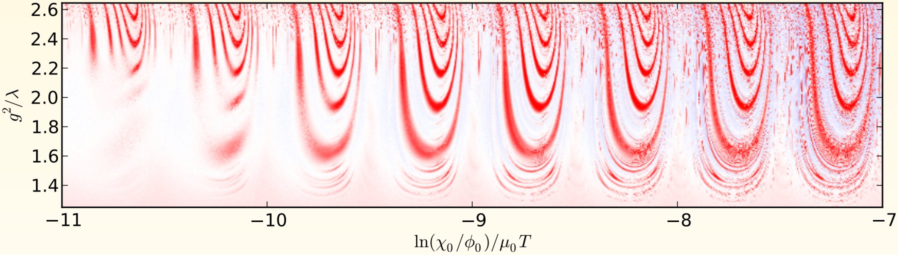

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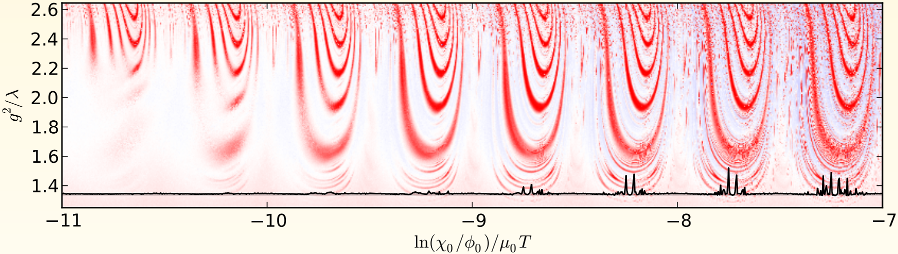
… and Here's How Peaks Split & Multiply!



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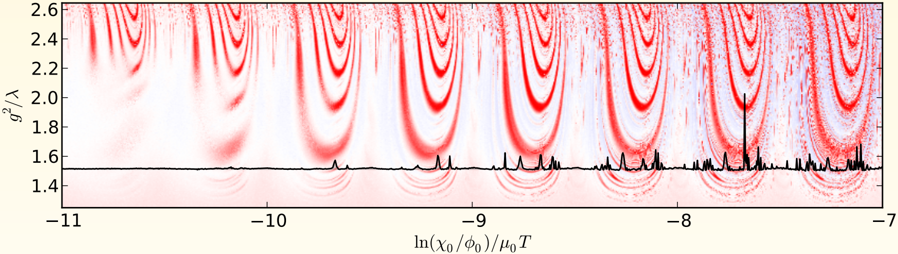

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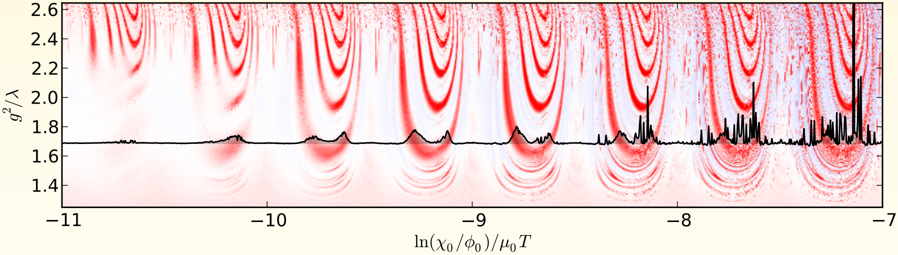

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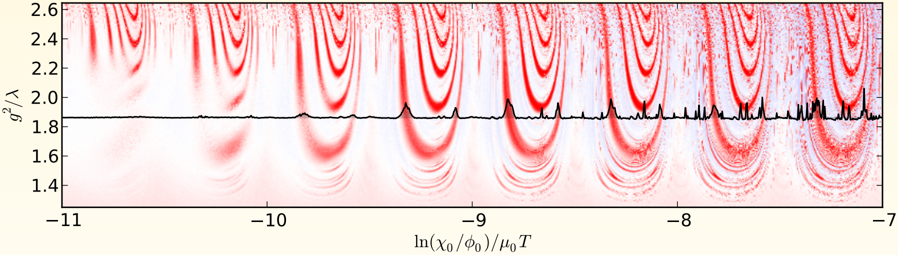

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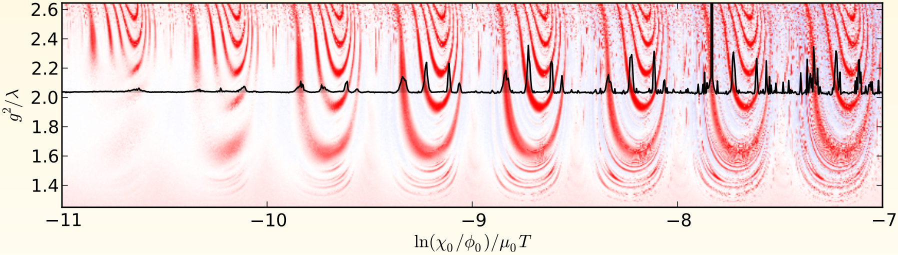

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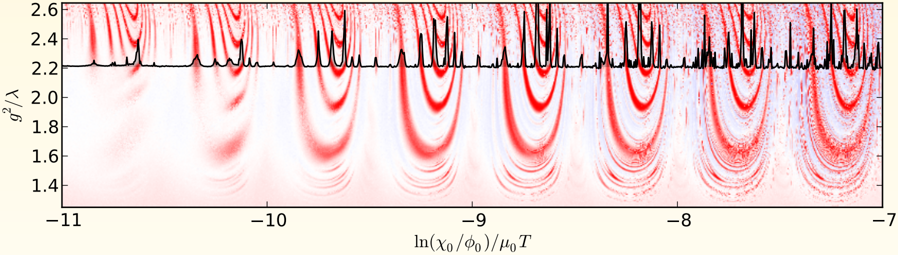

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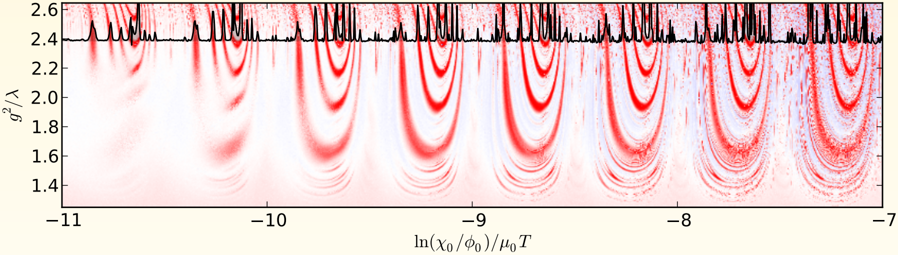

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Preheating Can Leave a Signature in CMB Sky!

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

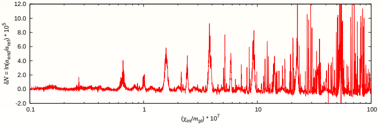
usual non-Gaussianity:

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

new from preheating:

$$\Phi(\vec{x}) = \Phi_{\mathrm{G}}(\vec{x}) + F_{\mathrm{NL}}(\chi_{\mathrm{G}})$$

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



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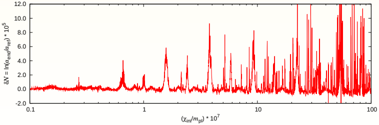
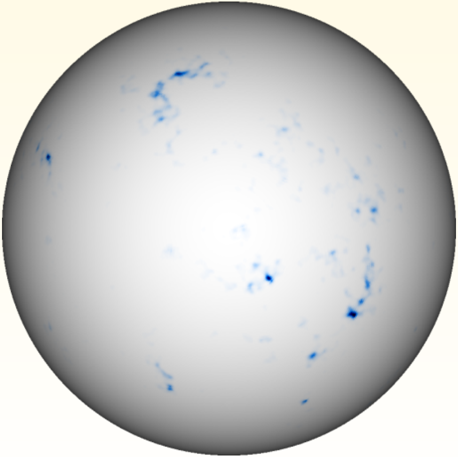
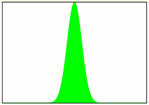
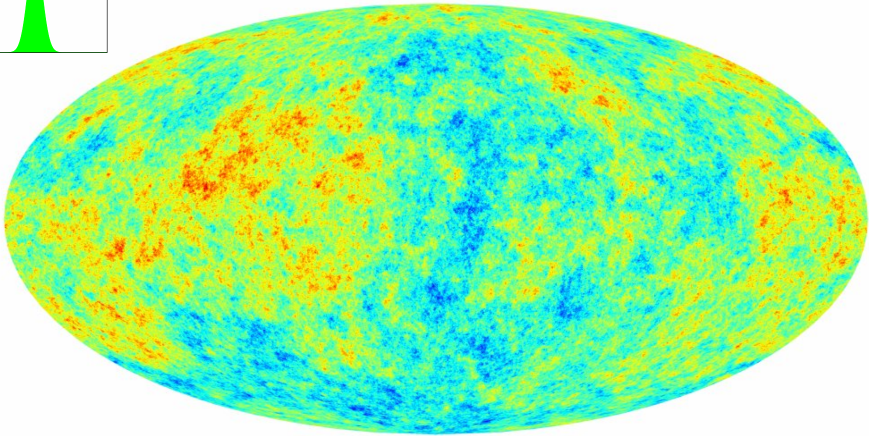


realization of *excursion set* can naturally give cold spots!

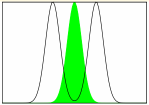


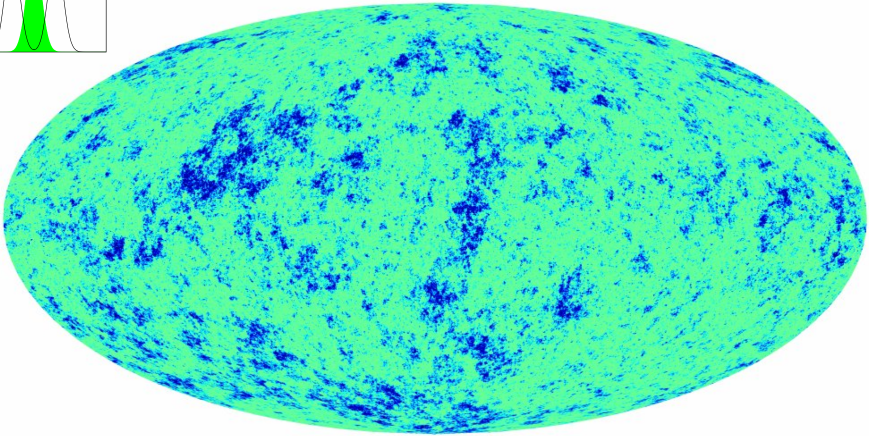
How Would It Look Like on the Sky?





How Would It Look Like on the Sky?





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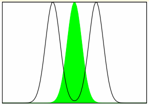

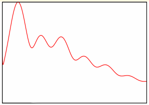

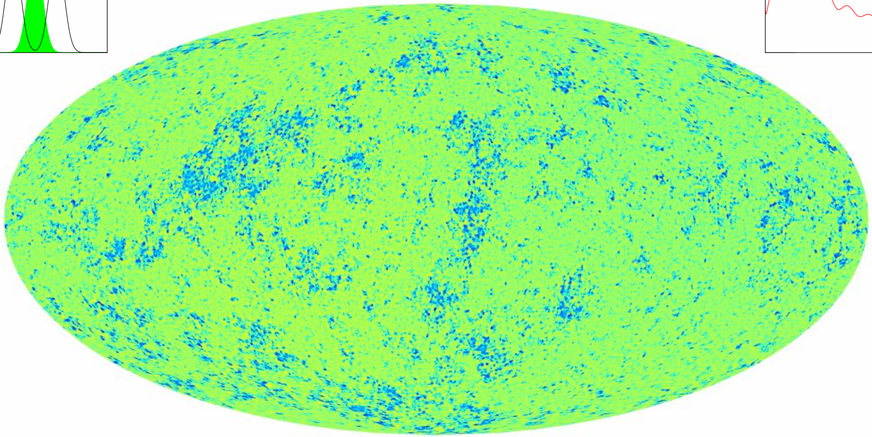

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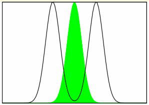

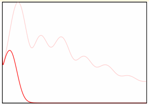

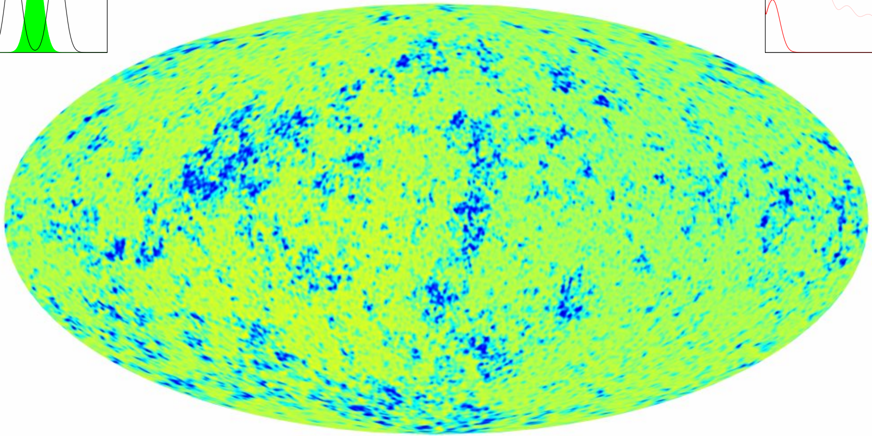

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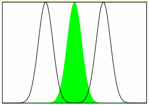

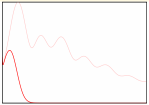

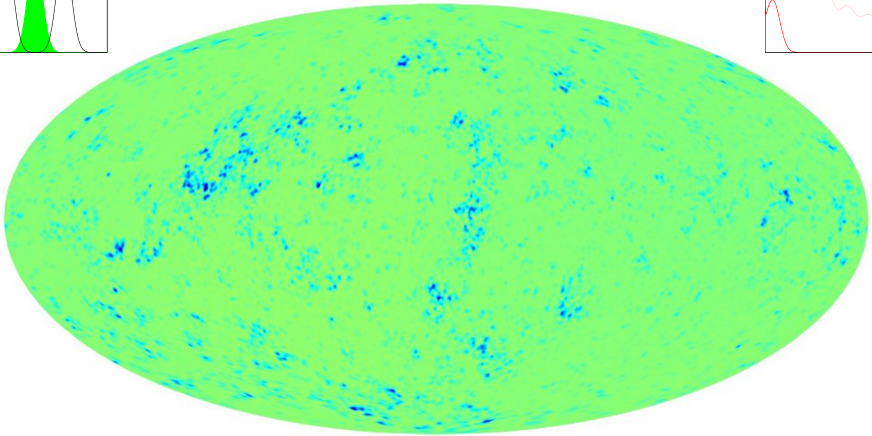

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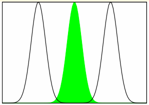
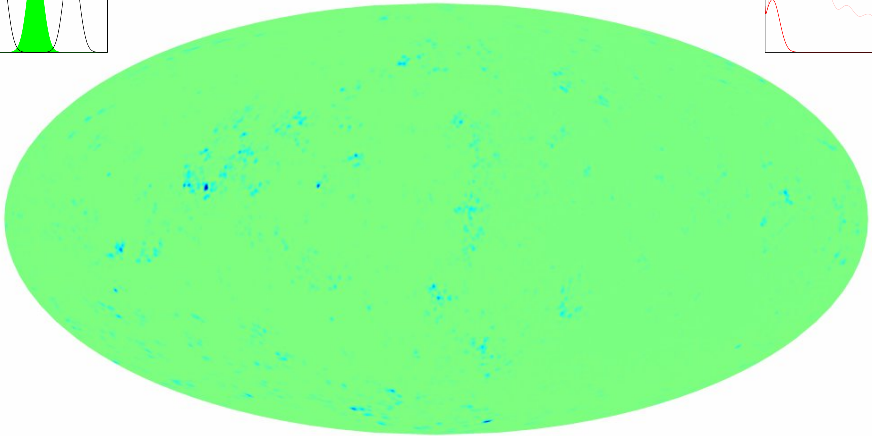
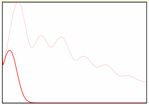
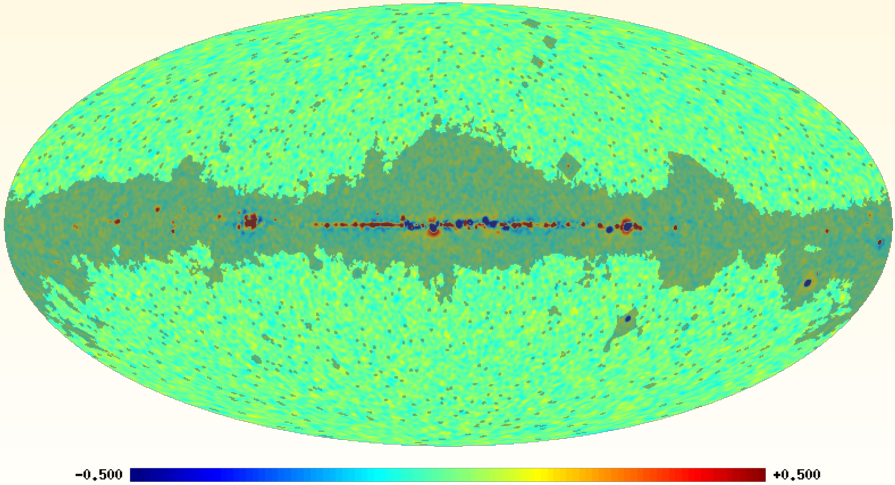






Err, There is a Cold Spot on CMB Sky!..



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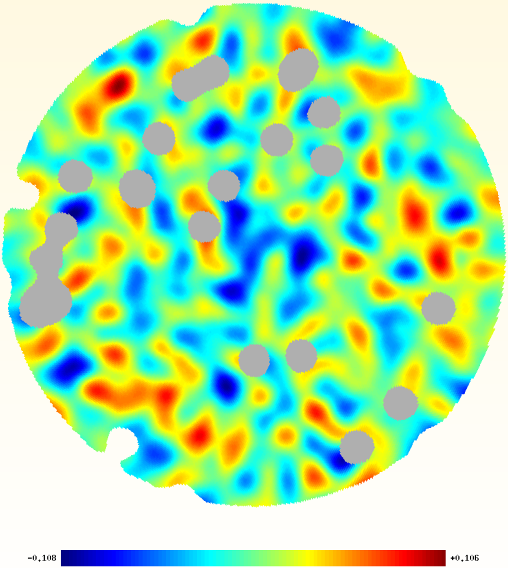

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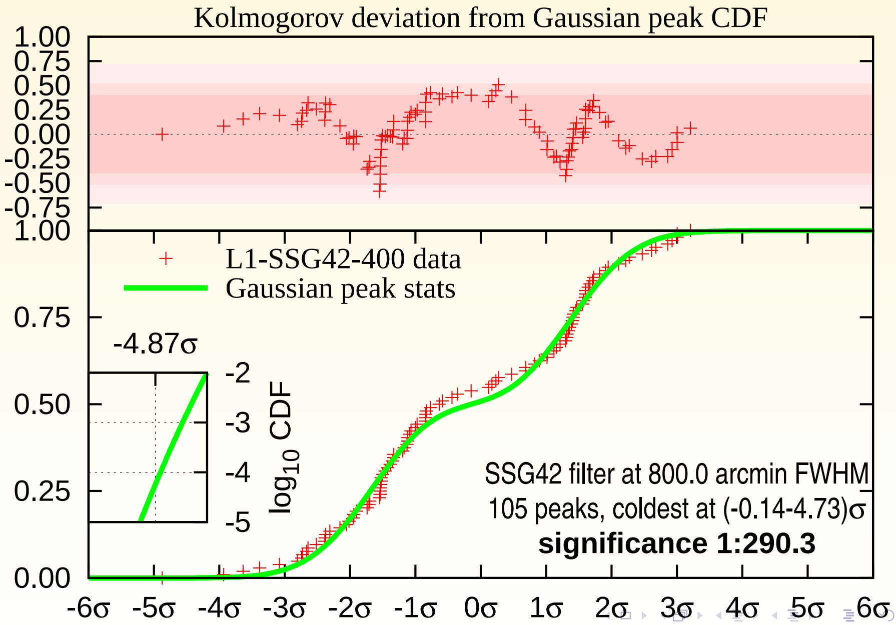

Polarization will Tell if it's Primordial!

Komatsu et. al. (2010)