FROM COSMOS TO PSYCHE

PENNSTATE 1855

Is Our Universe a Biased Sample?

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EN & S. Shandera, 1212.4550 (PRL)
M. LoVerde, EN, & S. Shandera, 1303.3549 (JCAP)
J. Bramante, J. Kumar, EN, & S. Shandera, 1307.3549 (JCAP)
B. Beytas, A. Kesavan, EN, S. Park, S. Shandera, work in progress.

Related work:
Nurmi, Byrnes, & Tasinato, 1301.3128
LoVerde, 1310.5739

The Early Universe

Almost exactly homogeneous

But...tiny perturbations: $\nabla^2\Phi = 4\pi G\delta\rho$ (Poisson equation)

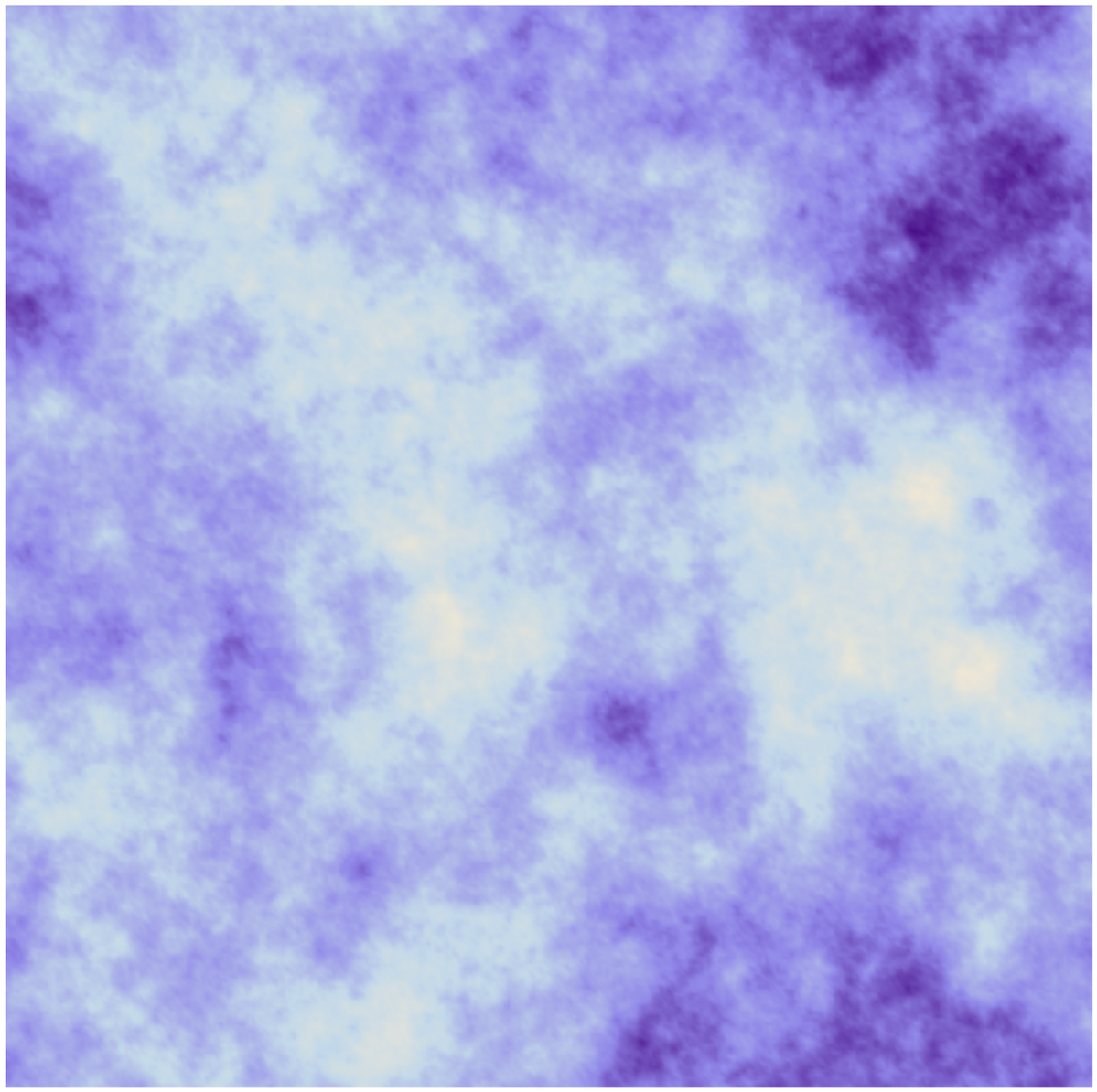
gravitational potential

matter density

10^{-5} !!

"Snapshot" of the initial conditions:

$\Phi(\mathbf{x}) =$

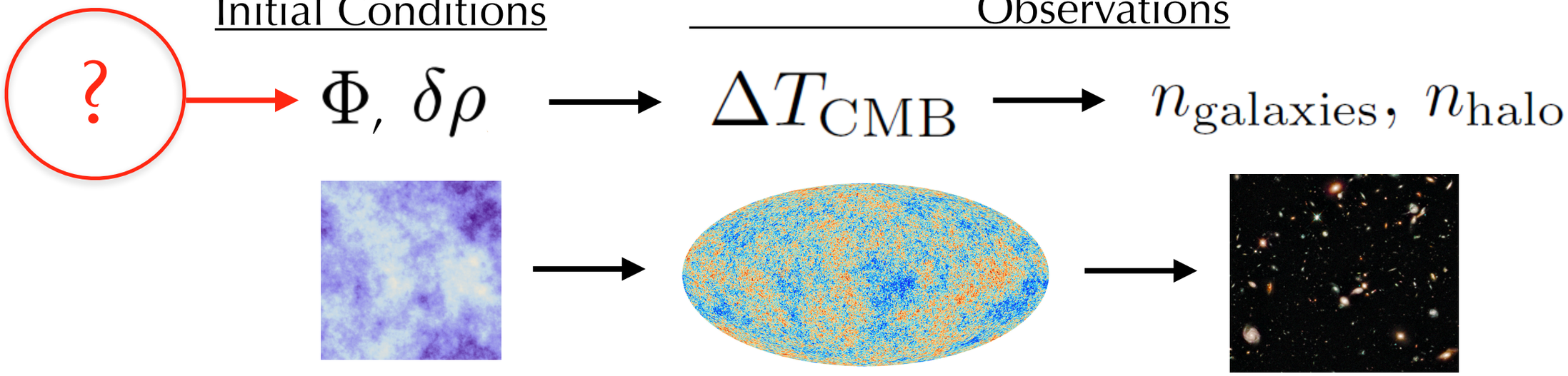


$\Phi < 0$ (valley)

$\Phi > 0$ (hill)

Searching for the Initial Conditions

Initial Conditions | Observations



small (linear) perturbations at initial time → gravitational collapse → nonlinear structure formation

Observed structure forms from initial conditions

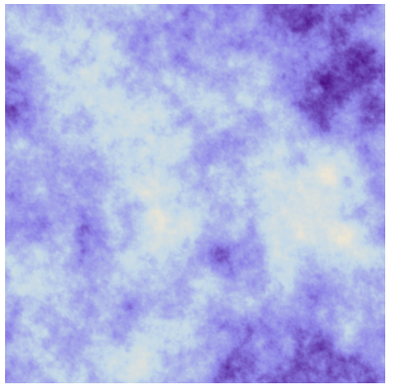
Goal:

Extract initial conditions from observations

↓

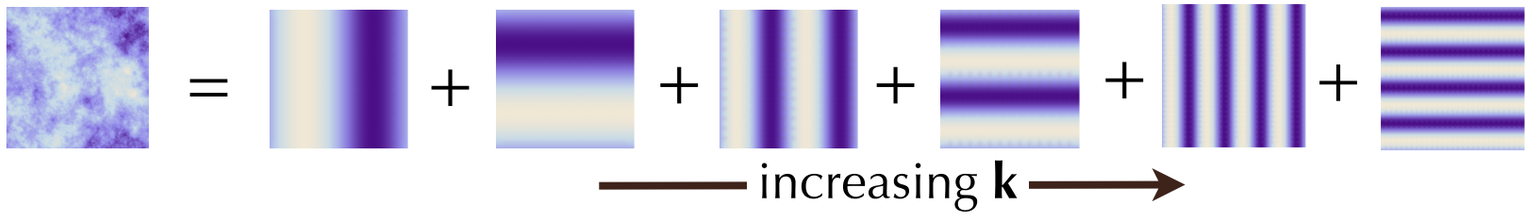
What particle physics in the early universe can produce those initial conditions? Inflation vs. alternatives?

Statistics for Initial Conditions

$\Phi(\mathbf{x}) =$ 

We can only predict probability distributions!

Fourier decomposition: $\Phi(\mathbf{x}) = \int d^3k \Phi_{\mathbf{k}} e^{i\mathbf{k}\cdot\mathbf{x}}$



(with $\Phi_{\mathbf{k}}$ coefficients)

Gaussian Random Field: *uncorrelated*, Gaussian random variables:

$$\langle \Phi_{\mathbf{k}} \rangle = 0$$

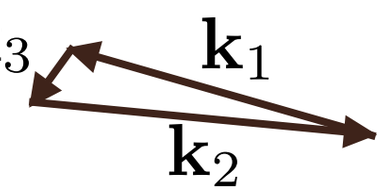
Power spectrum = amplitude of fluctuations at any scale

$$\langle \Phi_{\mathbf{k}_1} \Phi_{\mathbf{k}_2} \rangle = \delta_{\mathbf{k}_1,-\mathbf{k}_2} P_\Phi(k)$$

Spatial averages
...over what volume?

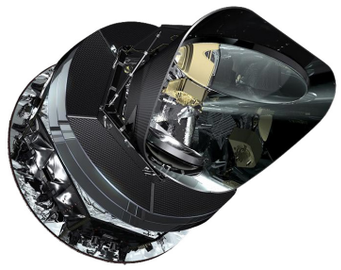
Non-Gaussianity correlates fluctuations on different scales

Eg., 3-point function $\langle \Phi(\mathbf{k}_1)\Phi(\mathbf{k}_2)\Phi(\mathbf{k}_3) \rangle = f_{\rm NL} S(k_1, k_2, k_3)$

=function of "shapes" 

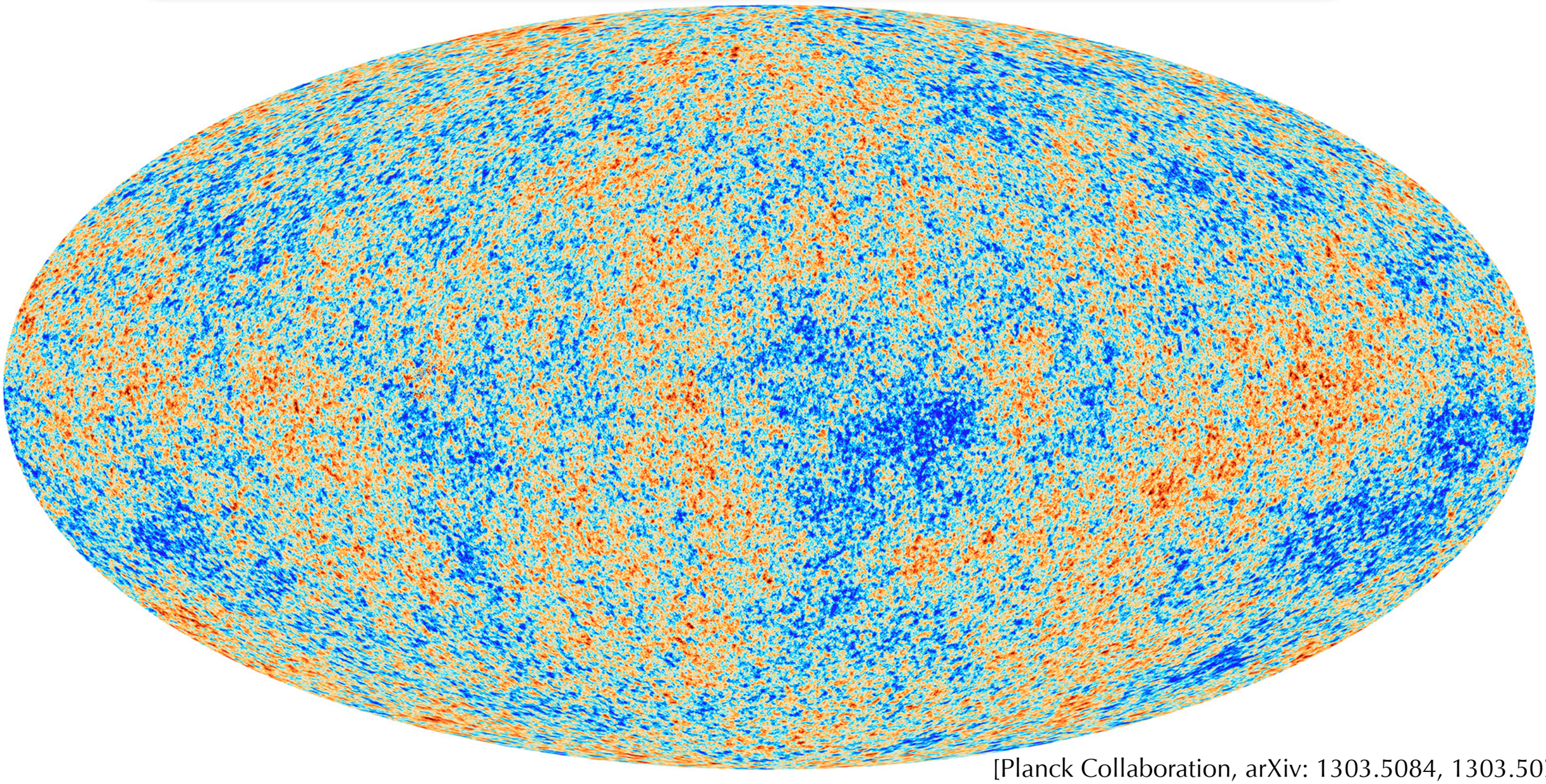
Non-Gaussianity (mode coupling) comes from interactions, carries information about early-universe, high-energy physics

Statistics in the CMB



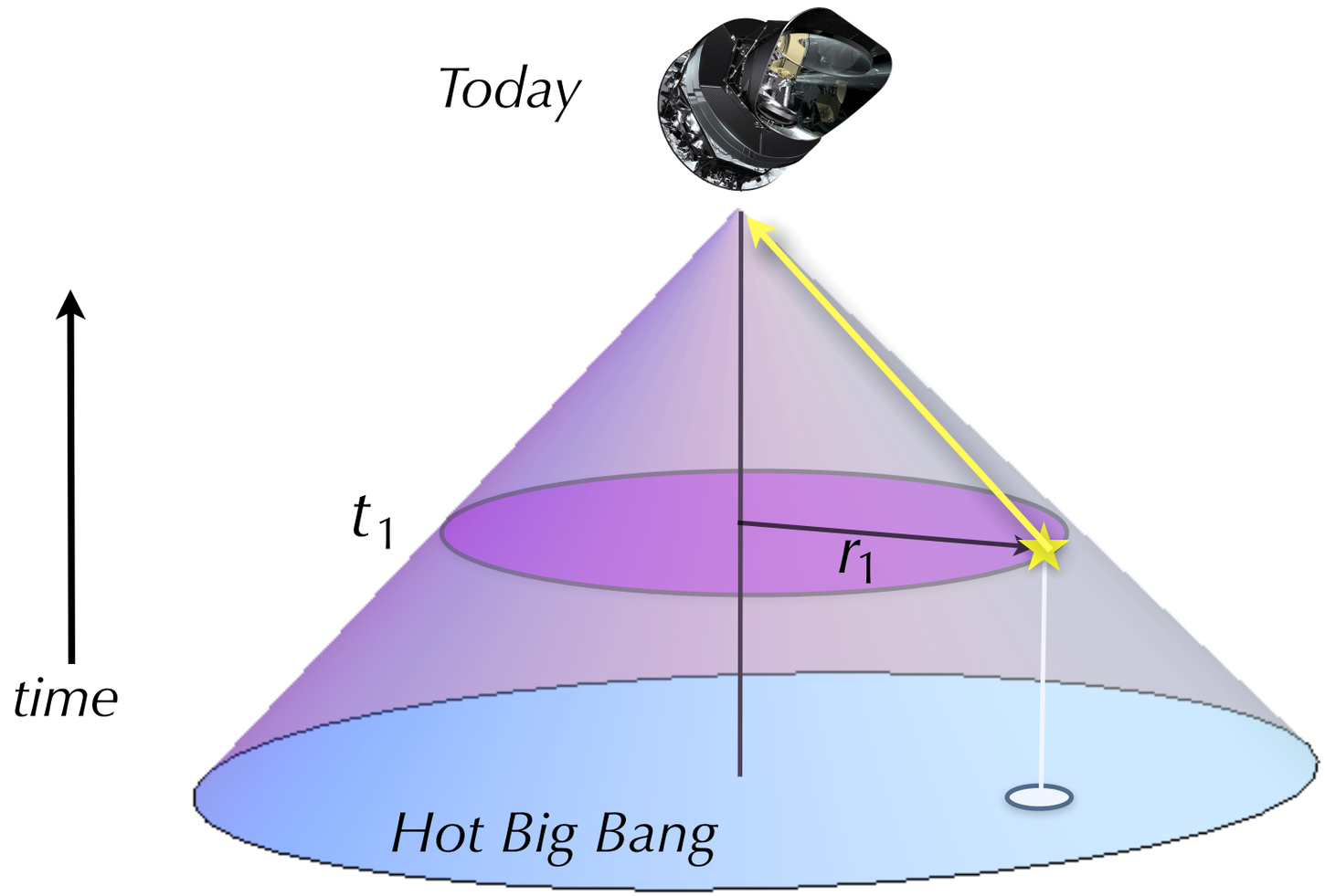
Planck satellite measurements of cosmic microwave background:

$$f_{\rm NL}^{\rm local} = 2.7 \pm 5.8 \quad \text{[=Gaussian fluctuations]}$$
$$n_s = 0.9603 \pm 0.0073 \ \text{[=}\textit{nearly}\text{ scale-invariant } P_\Phi(k)\ \text{]}$$

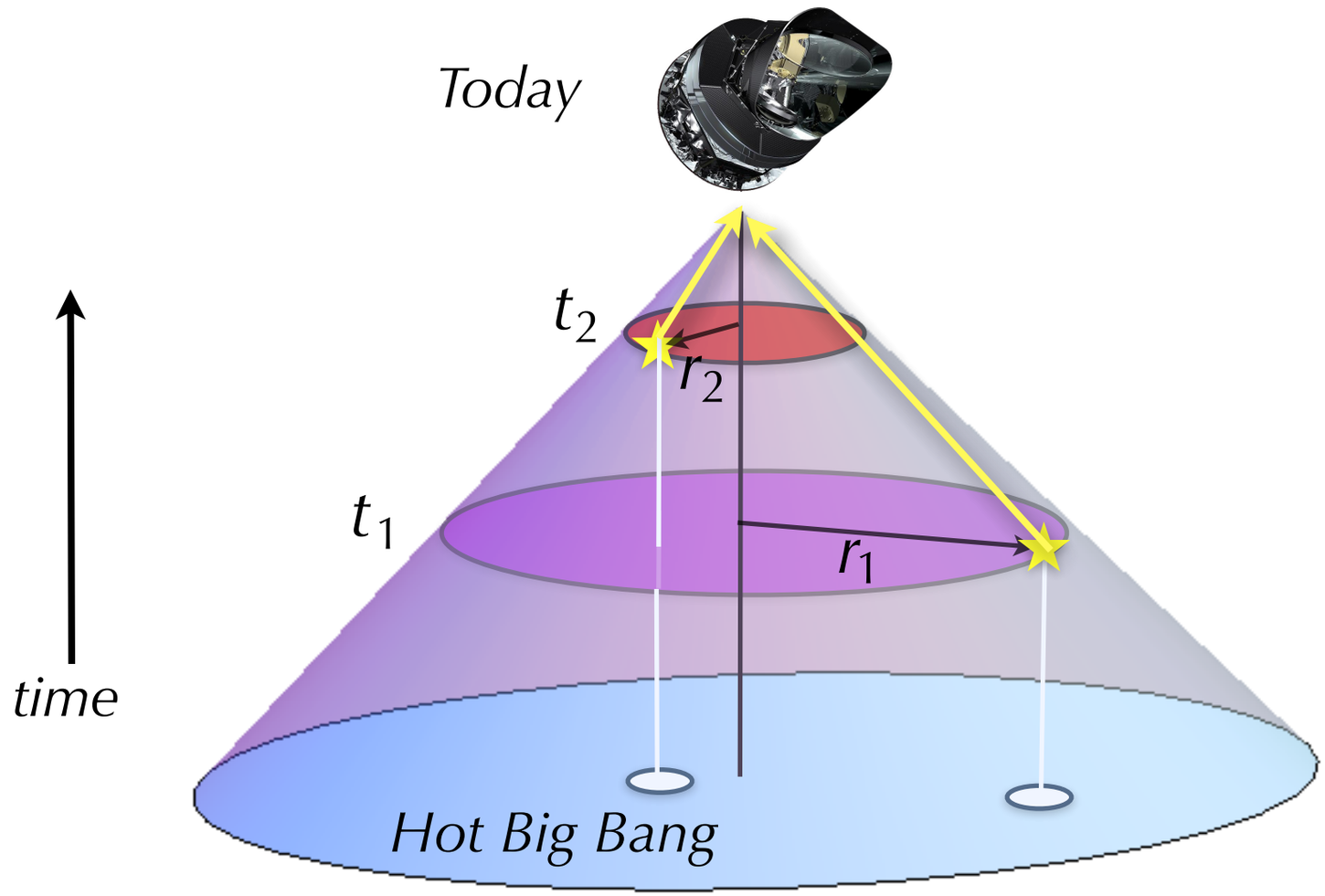


[Planck Collaboration, arXiv: 1303.5084, 1303.5076]

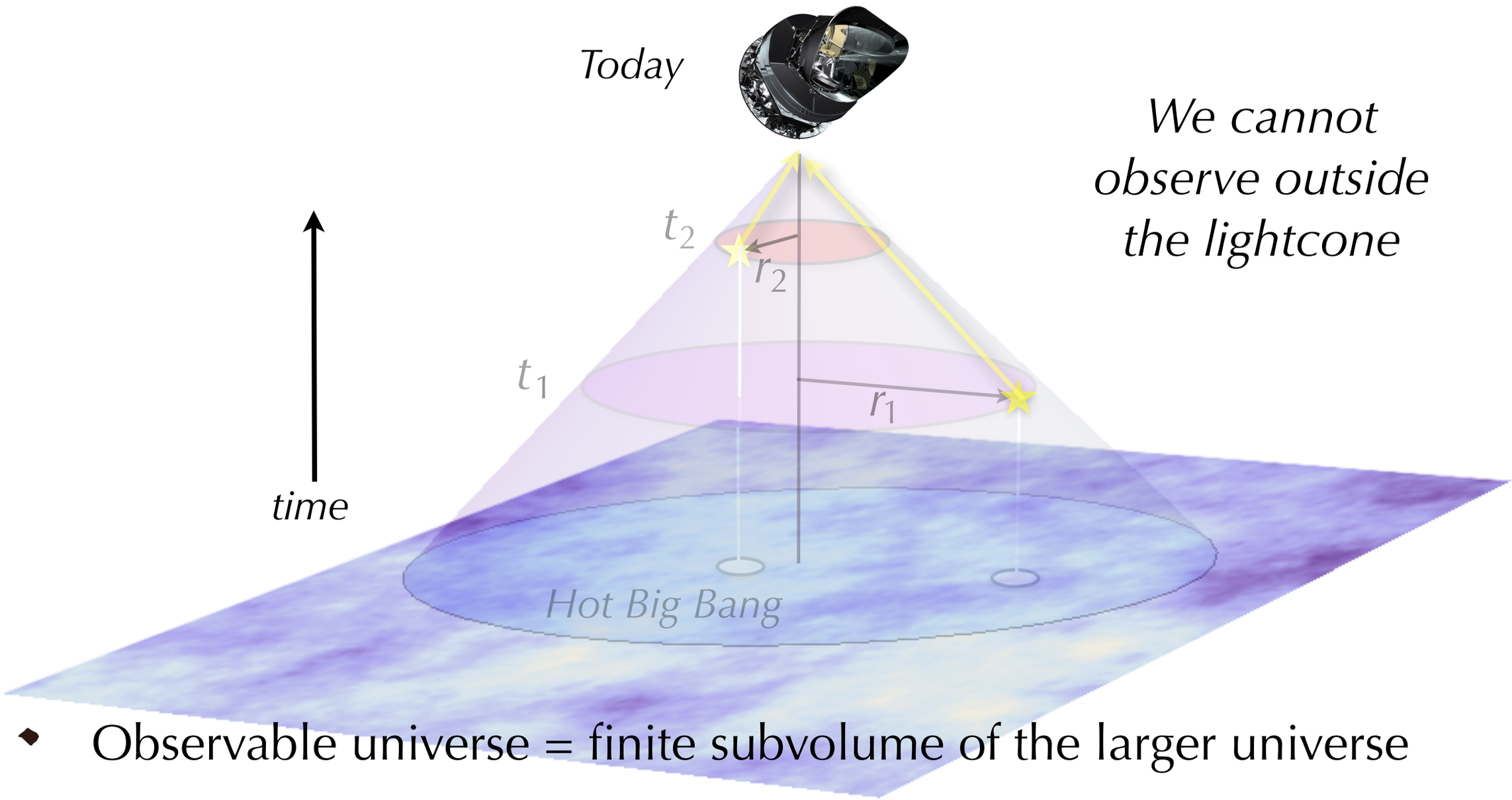
The Observable Universe



The Observable Universe



The Observable Universe



We cannot observe outside the lightcone

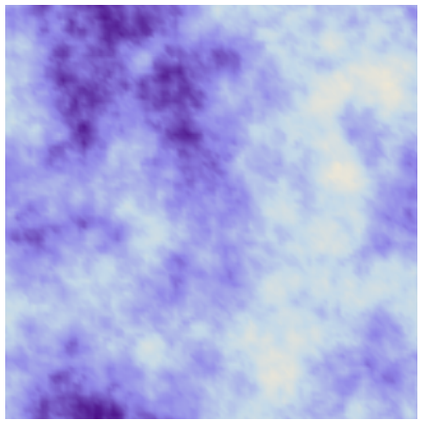
- Observable universe = finite subvolume of the larger universe
- Sampling probability distributions within this volume
- **Is our volume a representative or biased sample? How limited is our access to global statistics?**

Splitting the Field

Long-short wavelength split:

$$\Phi(\mathbf{x}) = \Phi_l(\mathbf{x}) + \Phi_s(\mathbf{x}) = \int_{L^{-1}}^{M^{-1}} d^3k \Phi(\mathbf{k}) e^{i\mathbf{k}\cdot\mathbf{x}} + \int_{M^{-1}}^{k_{\rm max}} d^3k \Phi(\mathbf{k}) e^{i\mathbf{k}\cdot\mathbf{x}}$$

Gaussian:



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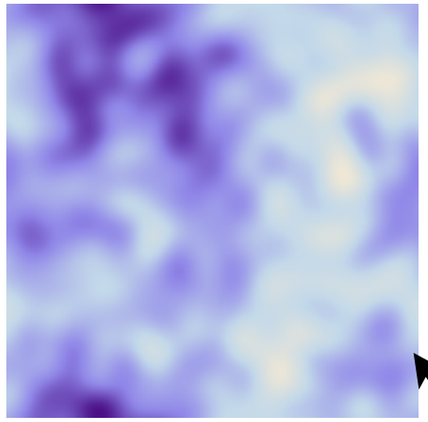

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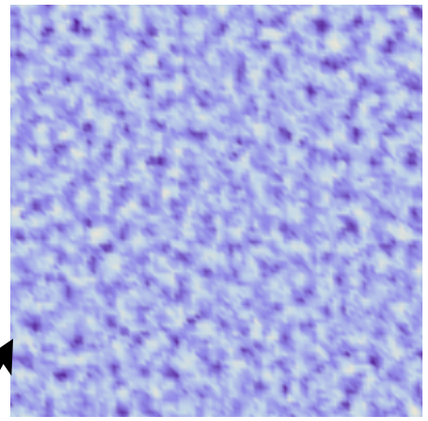
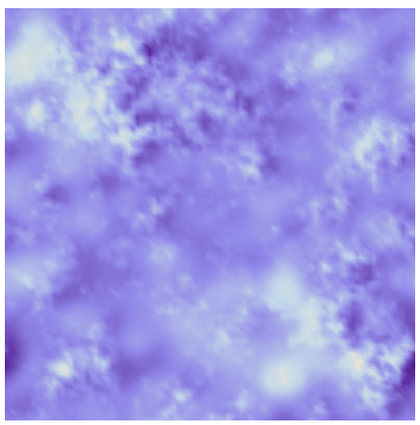


Uncorrelated

Non-Gaussian:



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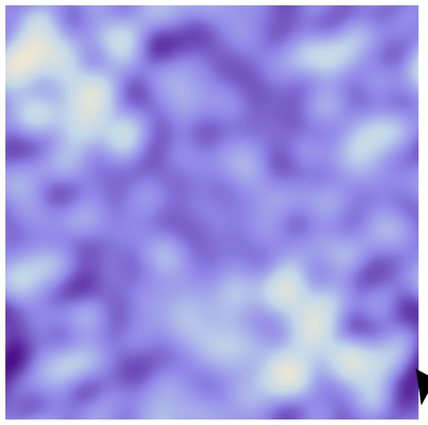

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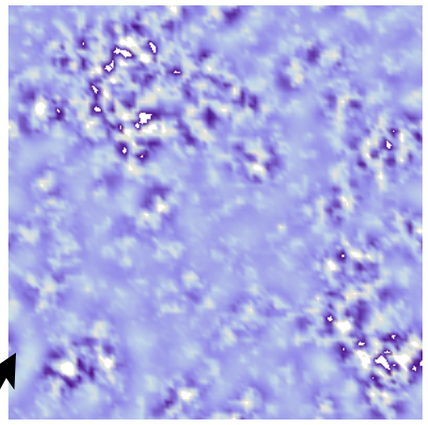


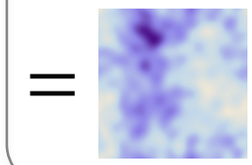
Correlated

Case Study: Local Non-Gaussianity

- "Local-type" non-Gaussianity:

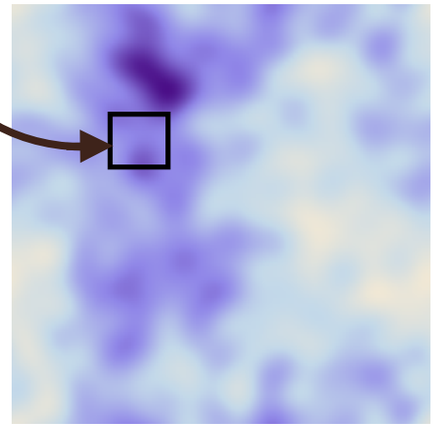
$$\Phi(\mathbf{x}) = f(\Phi_G(\mathbf{x})) \quad \Phi(\mathbf{x}) = \Phi_G(\mathbf{x}) + f_{\rm NL}\Phi_G^2(\mathbf{x}) + \ldots$$

$$= \Phi_{Gl} + \Phi_{Gs}$$

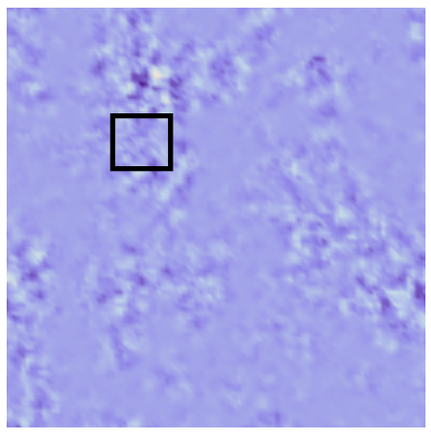


Observer's volume

$\Phi_{Gl} =$



$\Phi_{Gl}\Phi_{Gs} =$



Field as seen in subvolume:

$$\Phi^{\rm obs}(\mathbf{x}) = \Phi_G^{\rm obs}(\mathbf{x}) + f_{\rm NL}^{\rm obs}\Phi_G^{\rm obs}(\mathbf{x})^2$$

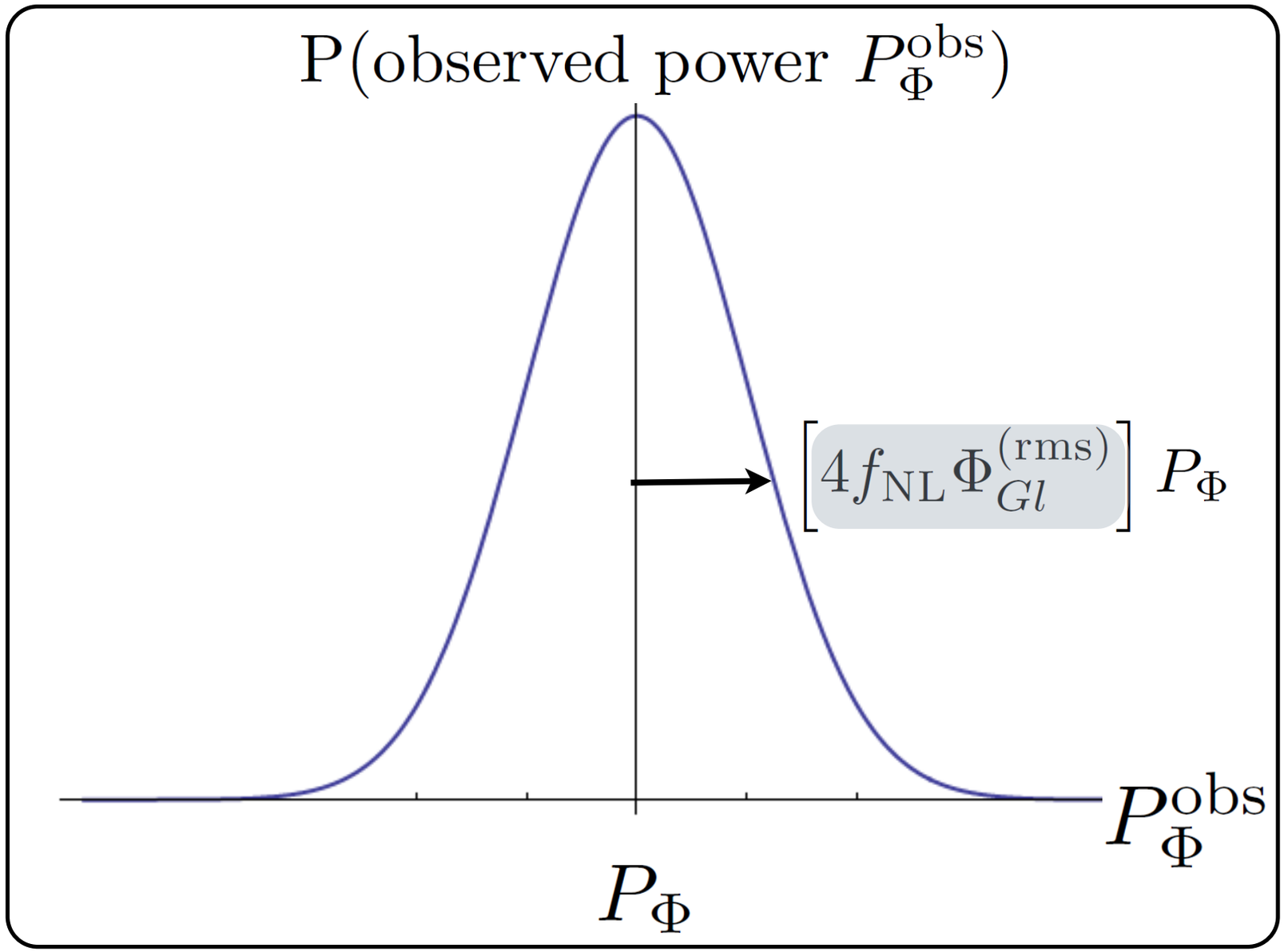
$$(1 + 2f_{\rm NL}\Phi_{Gl})\Phi_{Gs} + \ldots$$

The power in any given subvolume is sensitive to the local background

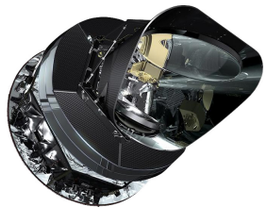
[M. LoVerde, EN, & S. Shandera, 1303.3549]
[Nurmi, Byrnes, & Tasinato, 1301.3128]

Case Study: Local Non-Gaussianity

Locally observed statistics can be biased by local background



Bias grows with size of universe, range of unobservable scales



Observational Significance?

- *"Statistical landscape":* Can we safely deduce parameters of inflation or early-universe physics from primordial perturbations in CMB, etc.?

- Non-Gaussian field can appear Gaussian in small subvolumes

Observed Gaussianity due to observing a small volume?

. . .but $\left|f_{\rm NL}^{\rm obs}\right| \gtrsim 1$ if $\left|\Phi\right| < 1$ [J. Bramante, J. Kumar, EN, & S. Shandera, arXiv: 1307.3549]

Planck constraint $f_{\rm NL}^{\rm obs} = 2.7 \pm 5.8$ *is close to this!*

- Other observables:

→ $n_s \equiv \dfrac{d \ln P_\Phi}{d \ln k}$ = scale-dependence of power: does $n_s^{\rm obs} \approx 0.96$ reflect global average?

→ Amplitude and scale-dependence of primordial gravitational wave perturbations

Summary

- **Limited sampling problem**: We observe a finite volume.

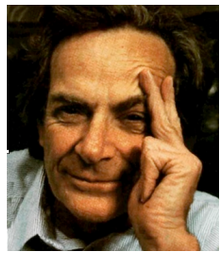
  → Are probability distributions of initial conditions (and hence, structure formation) representative or biased?

- Outlook: observations (level of non-Gaussianity) could tell us if this uncertainty is relevant to our interpretation of data

Cosmic Limitations and Theology

- Is our place in the universe *typical*? Are we biased by our cosmic environment? Role of observational selection?
- Similar questions for theology... Where are we in God's unfolding Story? Why do we find ourselves at the beginning?
- *Can we learn from cosmology?*

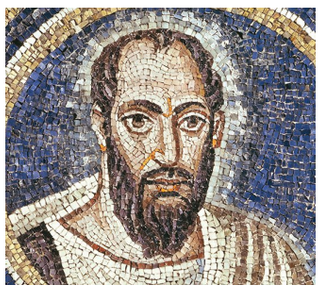
Feynman:



"It's too local, too provincial...look at what's out there!...it isn't in proportion."

(*The Pleasure of Finding Things Out*)

Paul:



"God's plan was to sum up the whole cosmos in the King!"

(Eph 1:10; N. T. Wright, *The Kingdom New Testament*)

The Challenge of Cosmology

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Tags: Christ & New Creation, Earth, Universe & Time, Image of God — **October 23, 2013**

Today's entry was written by Elliot Nelson. Please note the views expressed here are those of the author, not necessarily of The BioLogos Foundation. You can read more about what we believe here.

The Challenge of Cosmology

In the past century, our knowledge of the universe has grown at an extraordinary rate. Distant "nebulae" thought to be objects in our own galaxy were found to be entire galaxies of their own. Later observations unveiled galaxy clusters, clusters of clusters, massivefilaments and superclusters, and giant walls of galaxies millions of light-years in length. On the largest scales, these structures are distributed uniformly, and nothing seems to distinguish our galaxy as a unique vantage point. What's more, observations of the cosmic microwave background - the dim "afterglow" of the Big Bang—continue to point towards cosmological inflation as a likely event in the early universe, and inflation naturally generates a universe in which the portion that we can observe is only a tiny fraction of the whole. Not surprisingly, some have portrayed the history of cosmology as a history of our demotion from the center of the universe to complete insignificance.

http://biologos.org/blog/the-challenge-of-cosmology

Thank You