Title: A robust constraint on cosmic textures from the cosmic microwave background

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Abstract: Fluctuations in the cosmic
microwave background (CMB) contain information which has been pivotal in
establishing the current cosmological model. These data can also be used to
test well-motivated additions to this model, such as
cosmic textures. Textures are a type of topological defect that
can be produced during a cosmological phase transition in the early universe,
and which leave characteristic hot and cold spots in the CMB. We apply Bayesian
methods to carry out an optimal test of the texture hypothesis, using
full-sky data from the Wilkinson Microwave Anisotropy Probe. We conclude that
current data do not warrant augmenting the standard cosmological model
with textures. We rule out at 95% confidence models that predict more than
6 detectable cosmic textures on the full sky.

Are There Cosmic Textures in the CMB?

Stephen Feeney

University College London

arXiv:1203.1928 (PRL) & arXiv:1210.2725

With: Hiranya Peiris (UCL), Matt Johnson (Perimeter Institute), Jason McEwen (UCL), Daniel Mortlock (Imperial College London)

Image credit: V. Travieso and N. Turok

Outline

- Background
  - Topological defects
  - Textures
  - Modeling textures
- Analysis
  - Framework
  - Implementation
  - Testing
  - Calibration & Sensitivity
  - Results

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- Formed when medium undergoes symmetry-breaking phase transition
- Medium can take multiple configurations afterwards
- Large separations ⇒ different configurations
- Defects form at interfaces
  - (usually) stable
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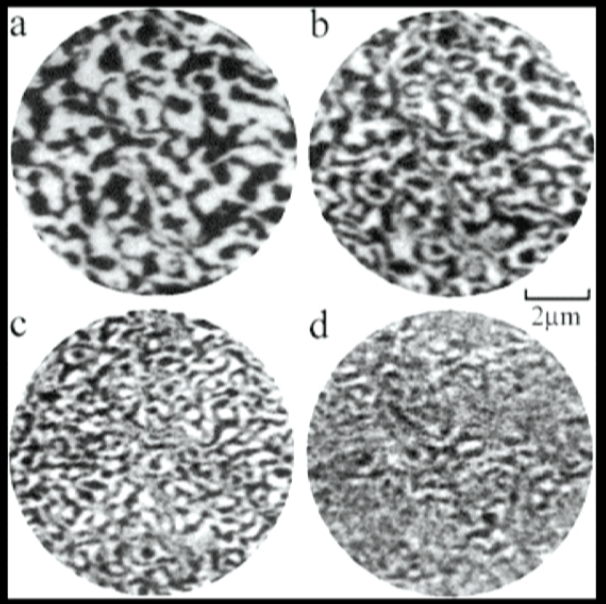
Terrestrial Defects

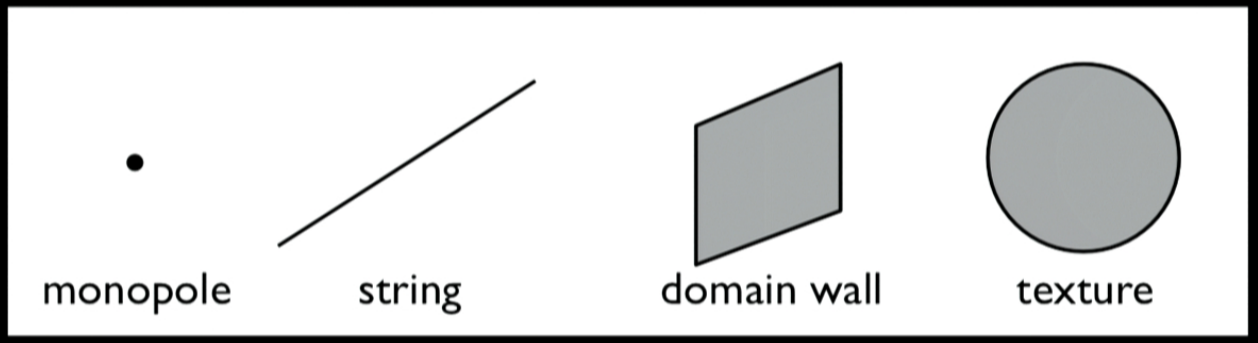
- Ferromagnetic materials
- Above Curie temperature (T_c) magnetic field randomly oriented
- Below T_c, field ordered locally, but different directions in different domains
- Defects at domain walls



Credit: Man, Altman & Poppa Surface Science (2001)

Cosmological Defects

- The Universe is cooling
- Undergoes phase transitions
- If symmetries broken: cosmological defects!



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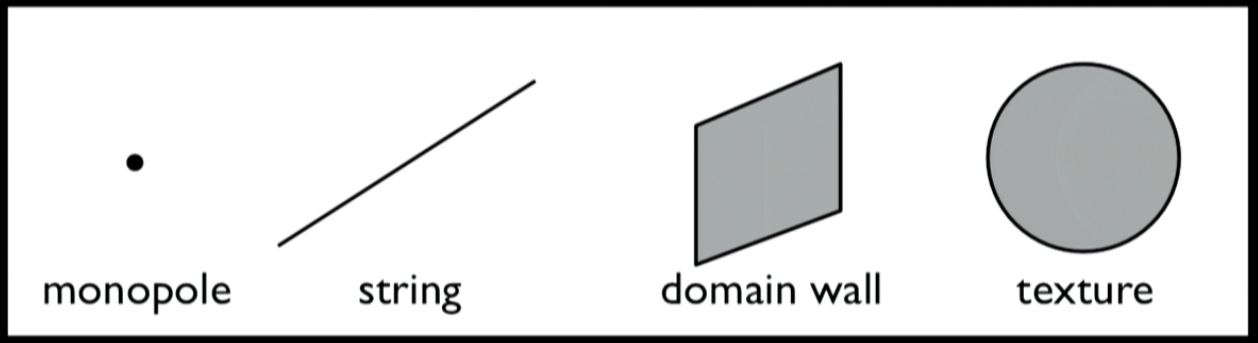

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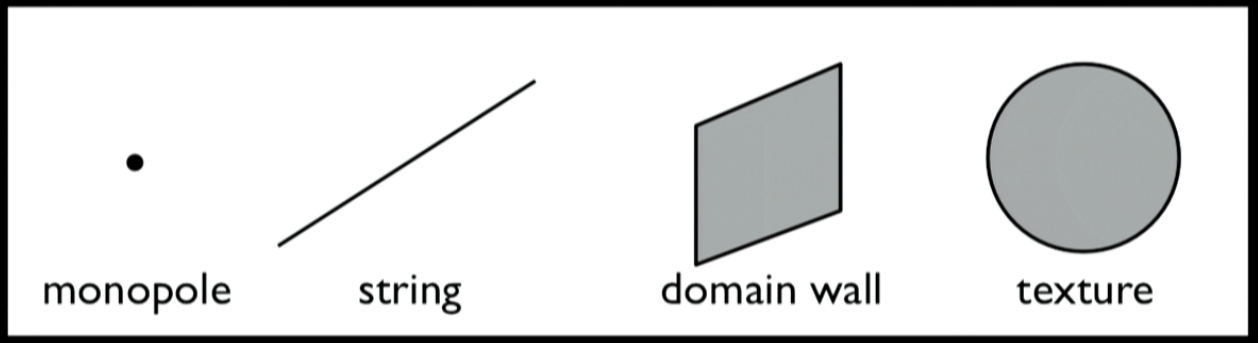

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Cosmic Textures

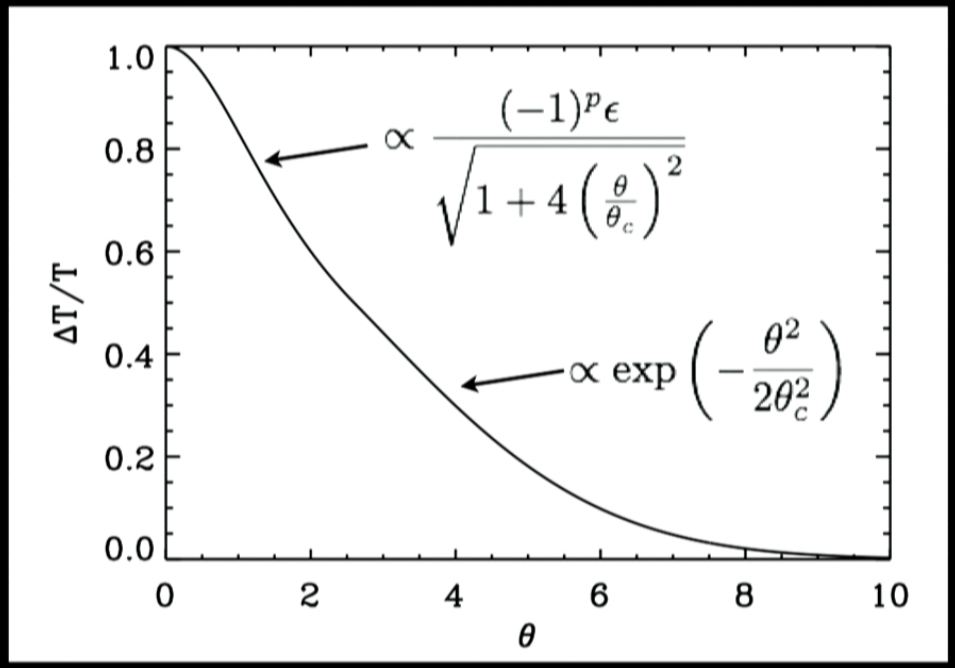
- Formed when complex global symmetries are broken (e.g. SU(2))
- Extended, dynamical tangles of fields
- Eventually collapse and explode
- (see Turok, PRL, 63, 2625, 1989)

Textures in the CMB

- Cosmic Microwave Background (CMB) back-lights textures
- Collapse / explosion creates time-varying potential
  - collapse ⇒ red-shift ⇒ cold spot
  - explosion ⇒ blue-shift ⇒ hot spot
- Roughly spherically symmetric: circular, additive modulation

Texture Profile

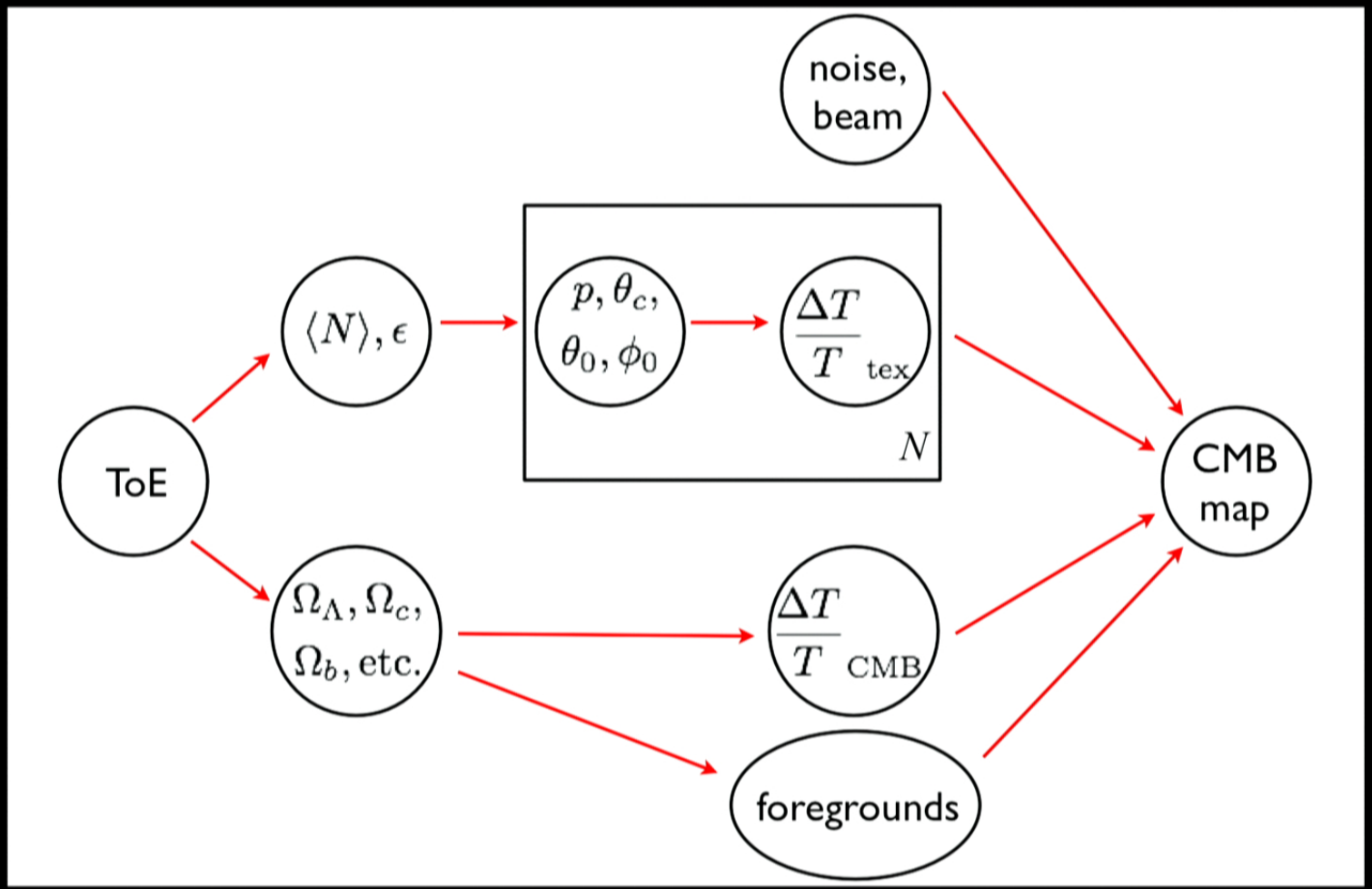
- Described by $\theta_0, \phi_0, \theta_c, p, \epsilon$



Texture Populations

- Single phase transition, common amplitude, ε
  - related to energy scale of transition (up to inflation!)
- Different average number, $\langle N \rangle$, of textures produced
  - ΛCDM is $\langle N \rangle = 0$
- Differentiate theories with "global" parameters: $\langle N \rangle$, ε
- Other "local" params describe individual properties

CMB Textures as a Hierarchical Model



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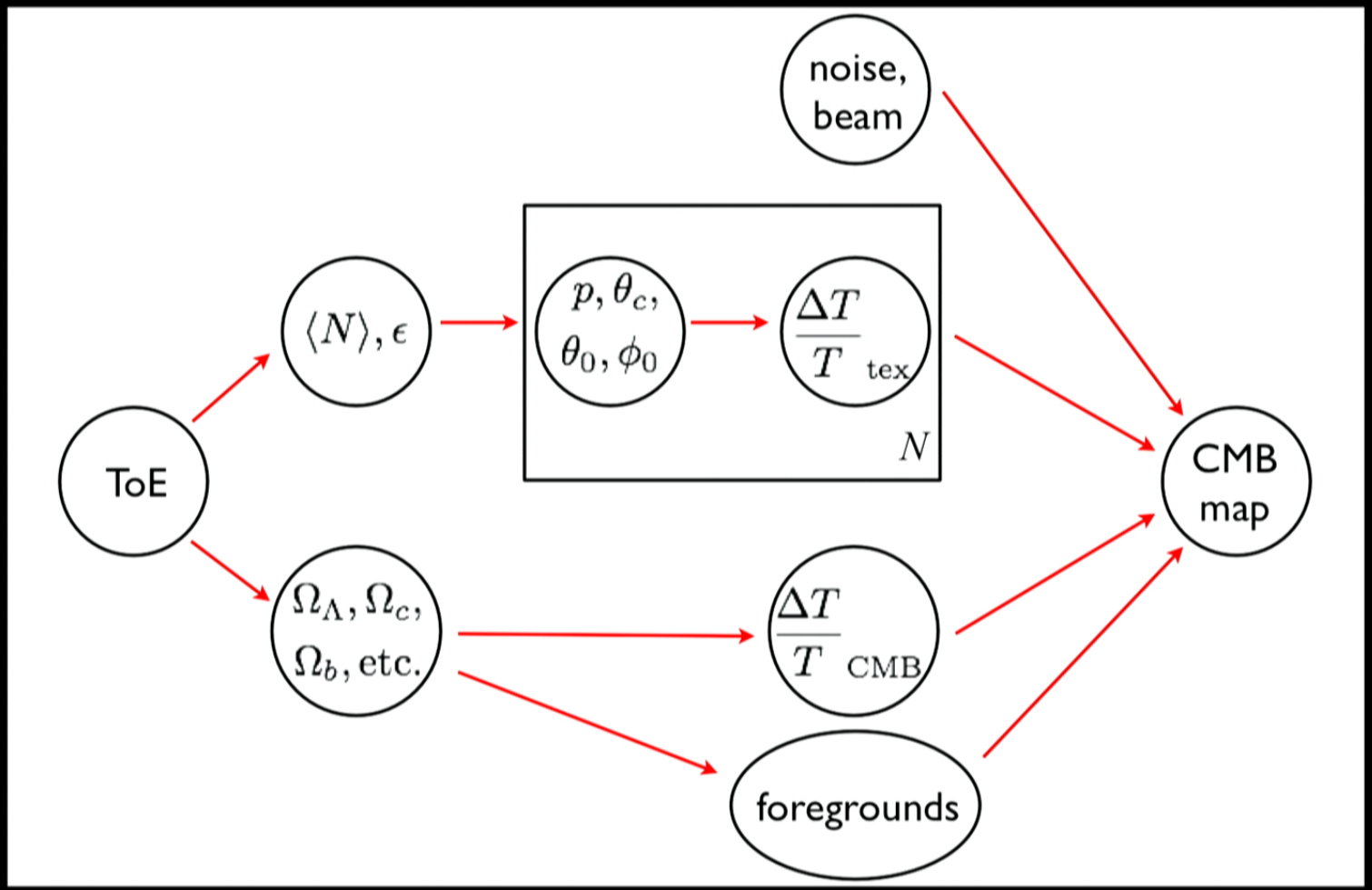

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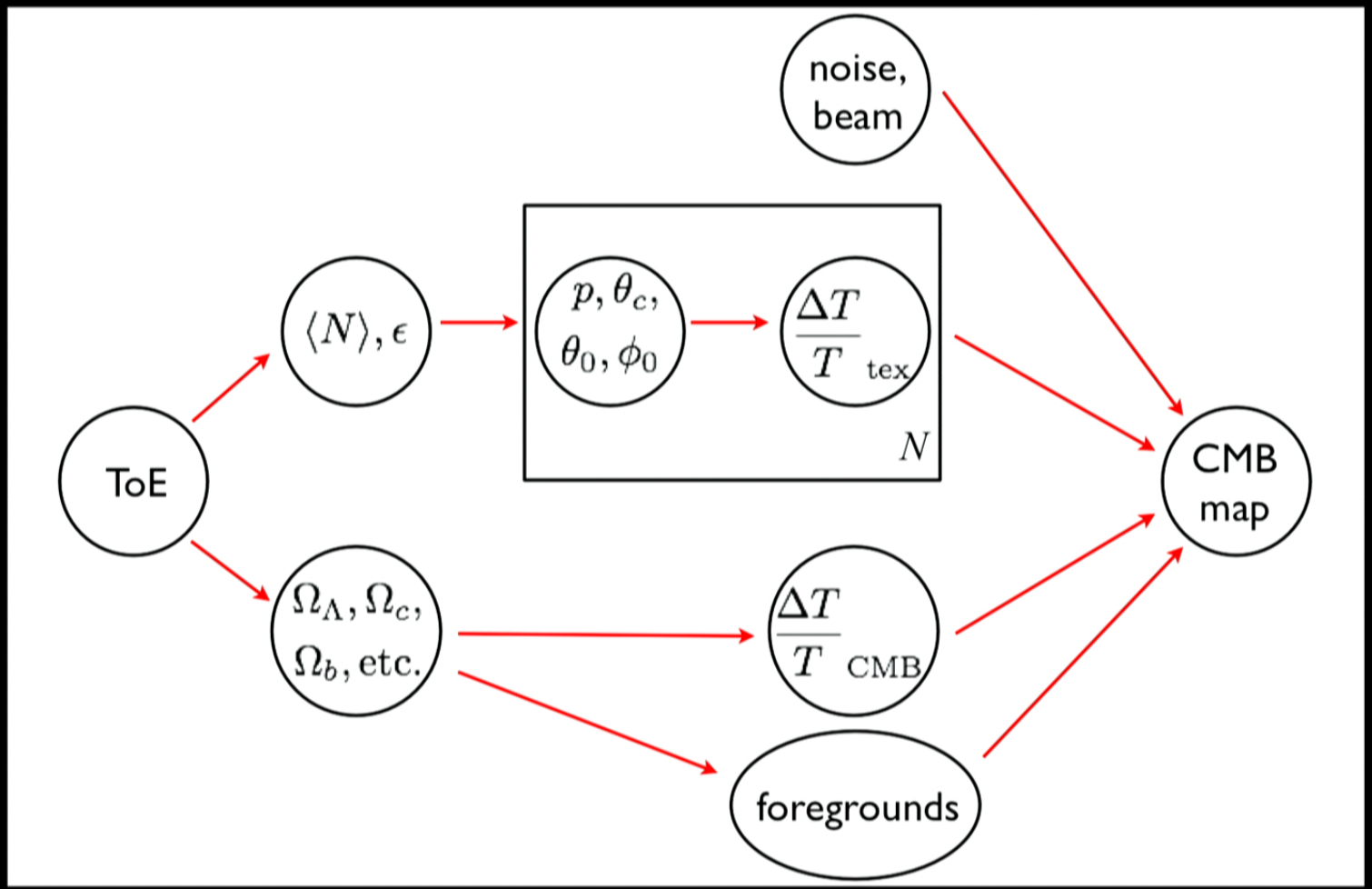

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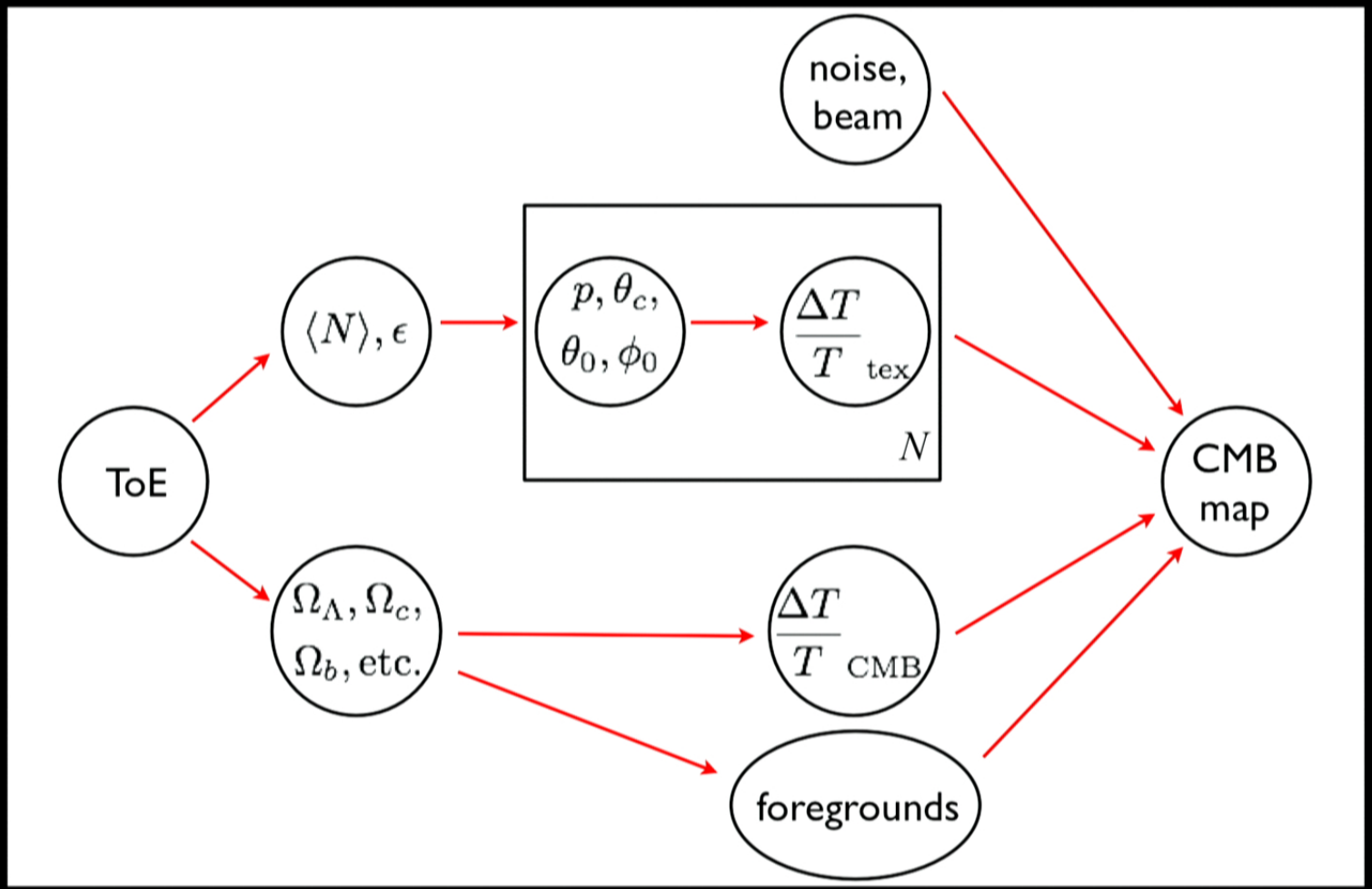


Comparing Theories

- Given current data, is Universe ΛCDM plus textures or pure ΛCDM?
- Model selection! Need $\Pr(\langle N \rangle, \epsilon | \mathbf{d})$
- If peak is at $\langle N \rangle = 0$, we conclude ΛCDM favoured
- Marginalize over local params as they don't distinguish theories

Analysis Framework

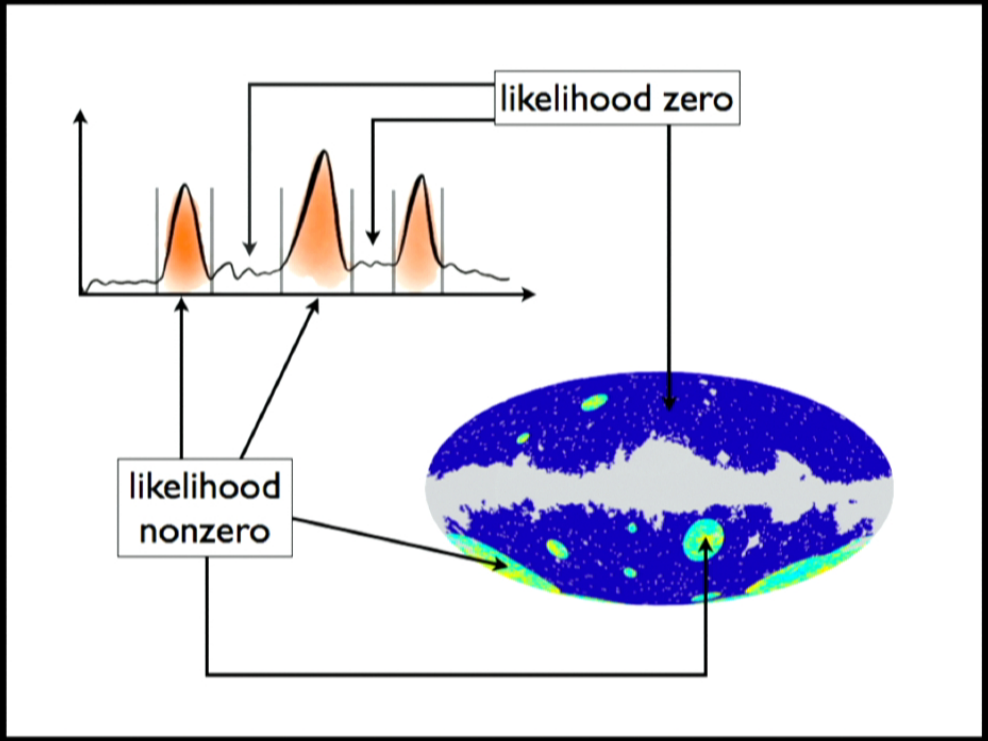
- Model selection: need Bayesian methods

$$\Pr(\langle N \rangle, \epsilon | \mathbf{d}) \propto \Pr(\langle N \rangle, \epsilon) \times \Pr(\mathbf{d} | \langle N \rangle, \epsilon)$$

- d = CMB data: specifically WMAP 7-year data
- Likelihood is very complex:

$$\Pr(\mathbf{d}|N,\epsilon) \propto \int \exp\left[-\frac{1}{2}\left(\mathbf{d} - \frac{\Delta T}{T}_1 - \frac{\Delta T}{T}_2 \ldots\right)\mathbf{C}^{-1}\left(\mathbf{d} - \frac{\Delta T}{T}_1 - \frac{\Delta T}{T}_2 \ldots\right)^T\right]$$

Assumptions



1) likelihood zero outside most-texture-like patches

2) these patches are uncorrelated

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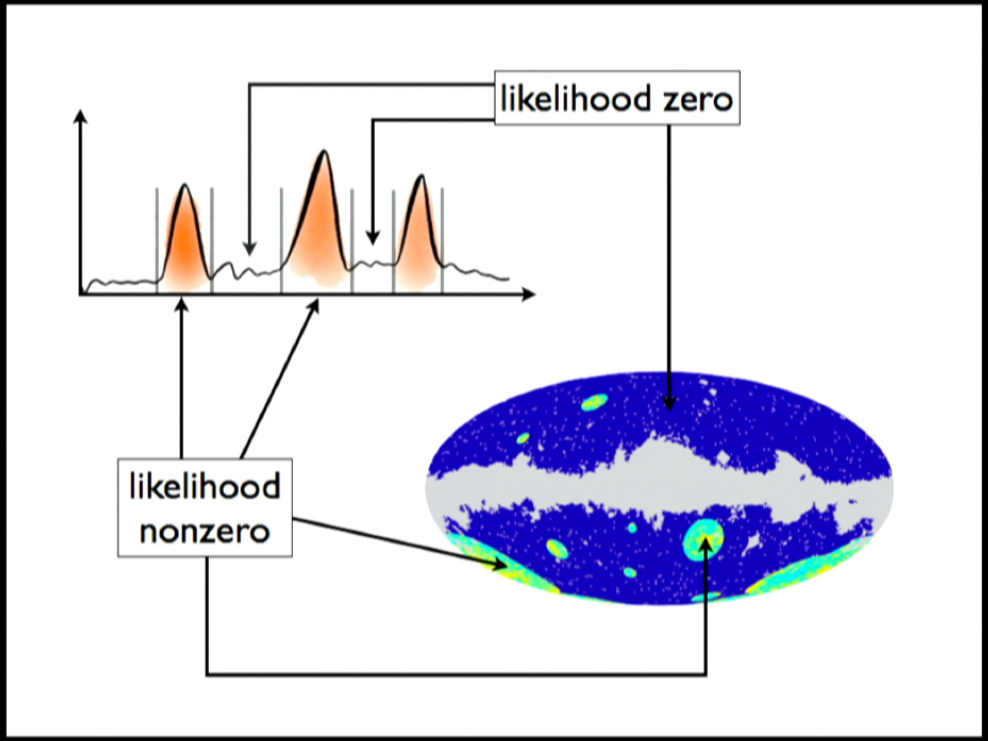

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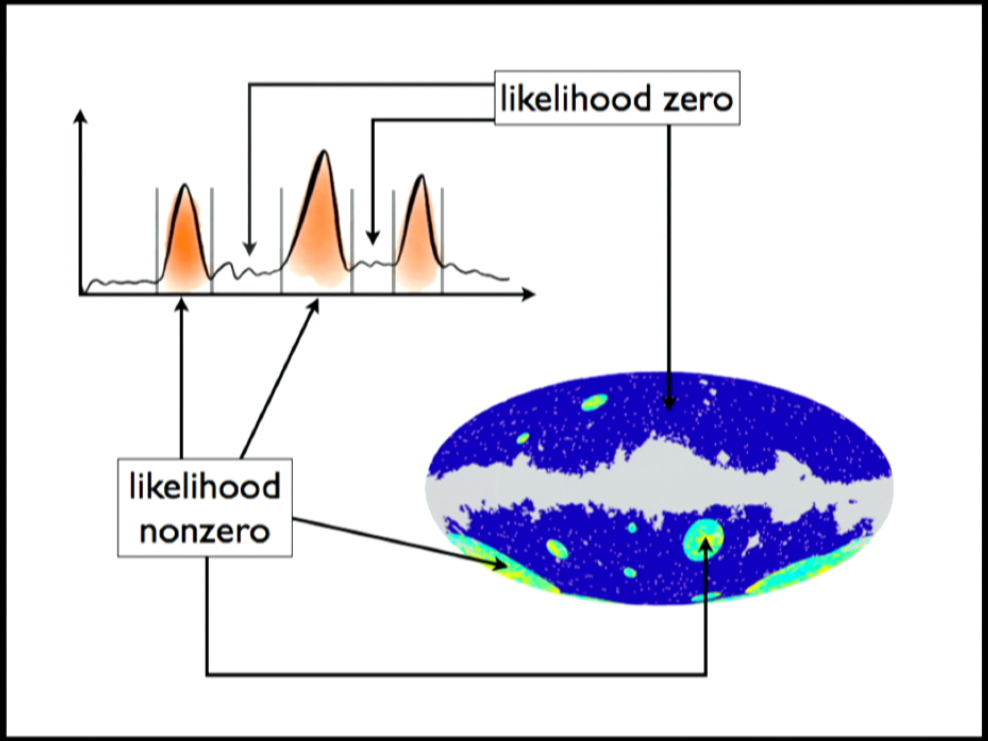

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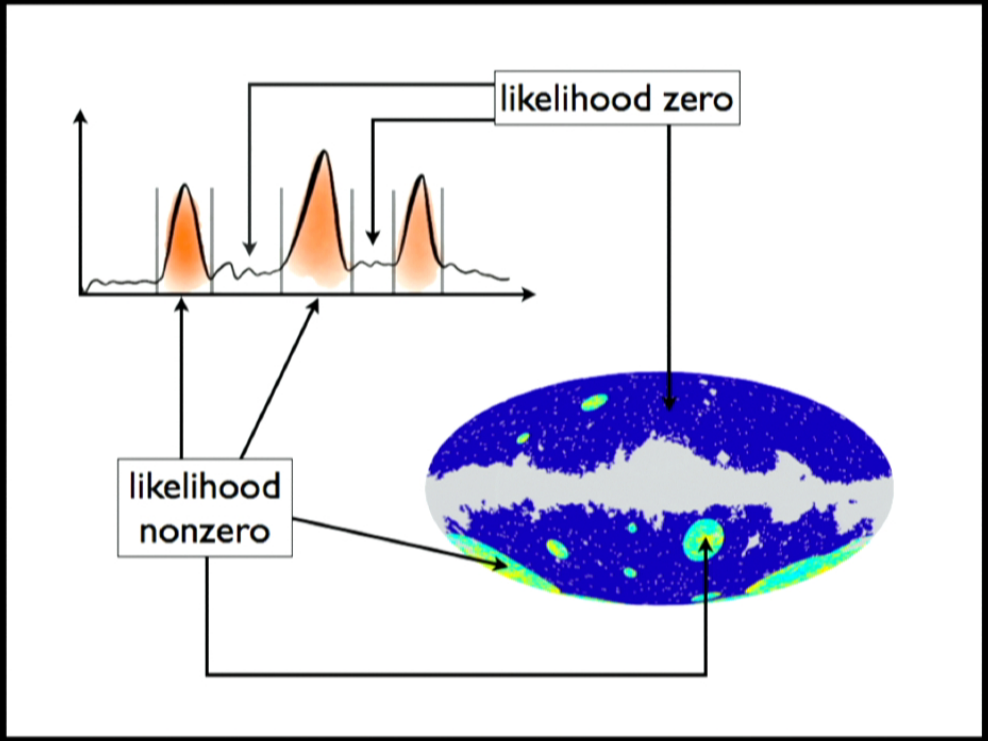

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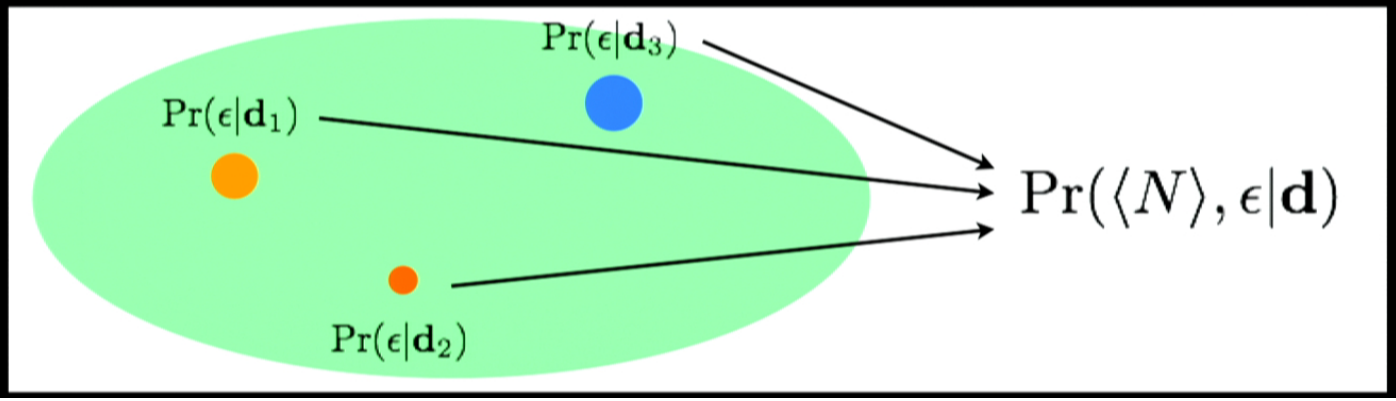
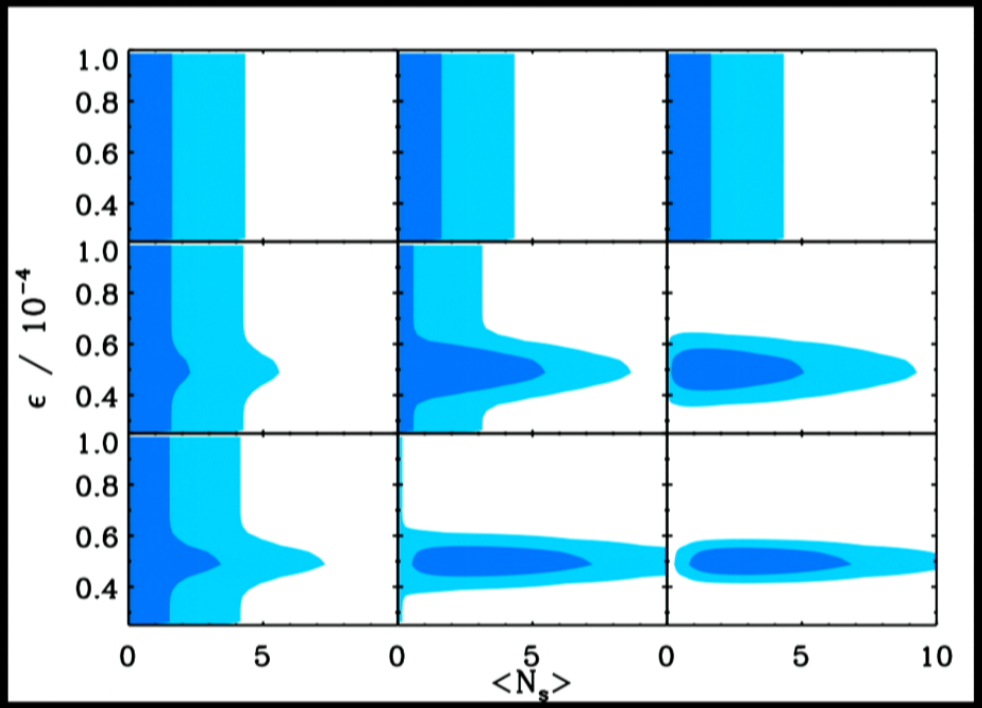
Approximated Posterior

- Process each patch separately, fitting single texture template
- Calculate Pr(1 texture, $\varepsilon | d_{patch}$)
- Combine to approximate full posterior



Example Posteriors



- Combinations of artificial Gaussian posteriors

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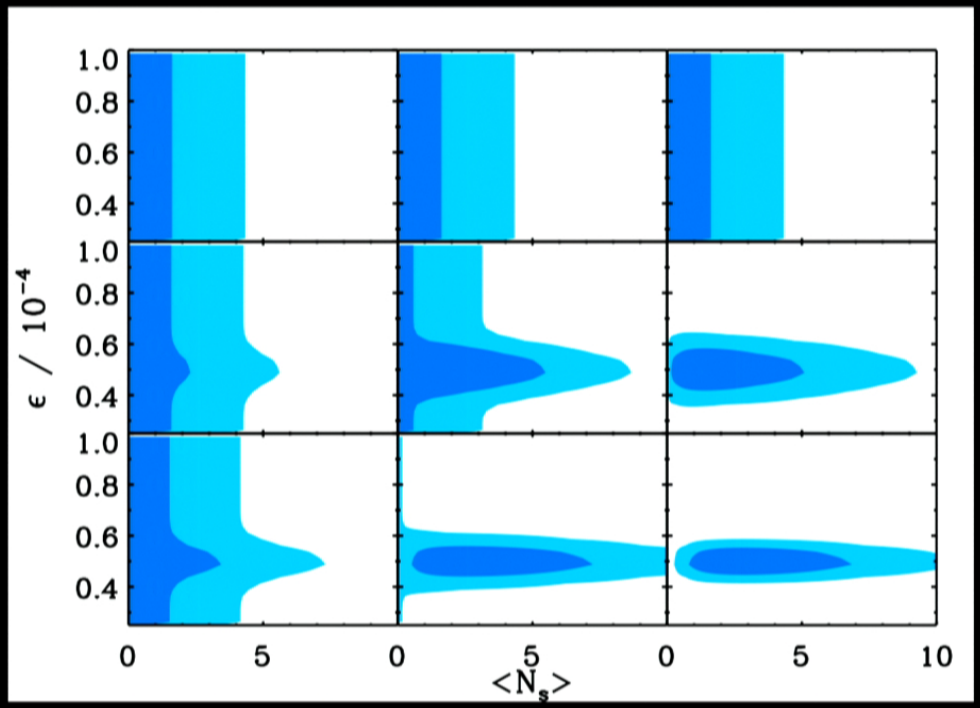

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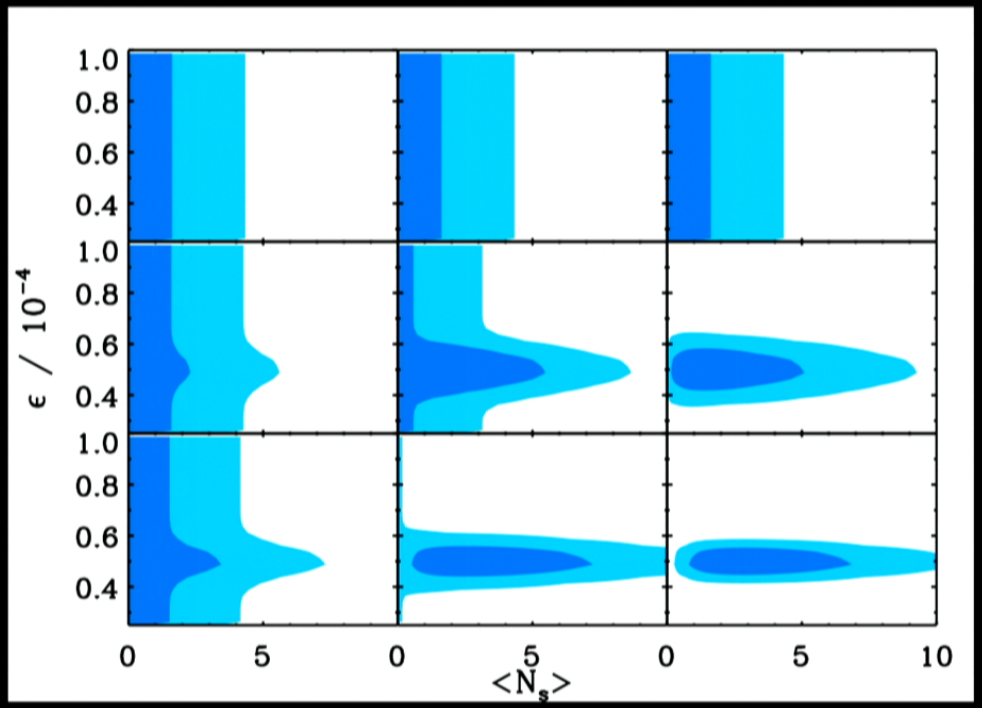

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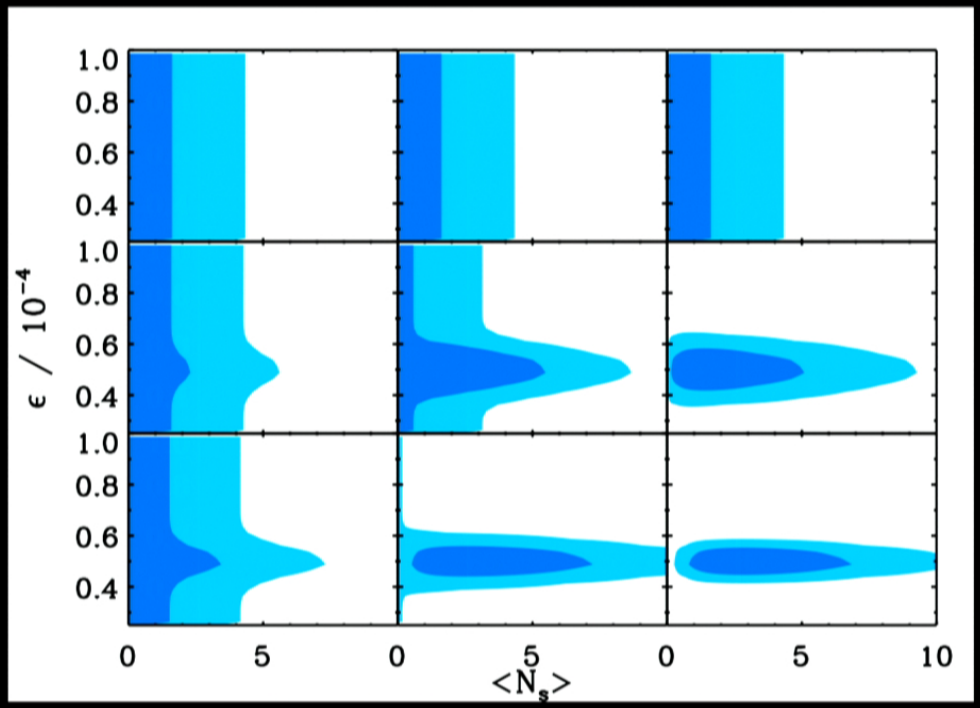

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Priors

- Locations: isotropic (theory)
- Sign: either hot or cold (theory)
- Size: $1/\theta_c^3$ between 2^o (swamped by CMB) and 50^o (template overlaps)
- Number: uniform between 0 and 10
  - Turok sims: ~7 per CMB
  - assume order of mag for similar theories
- Amplitude: uniform in range 2.5E-5 (swamped by CMB) to 1E-4 (post-inflationary)

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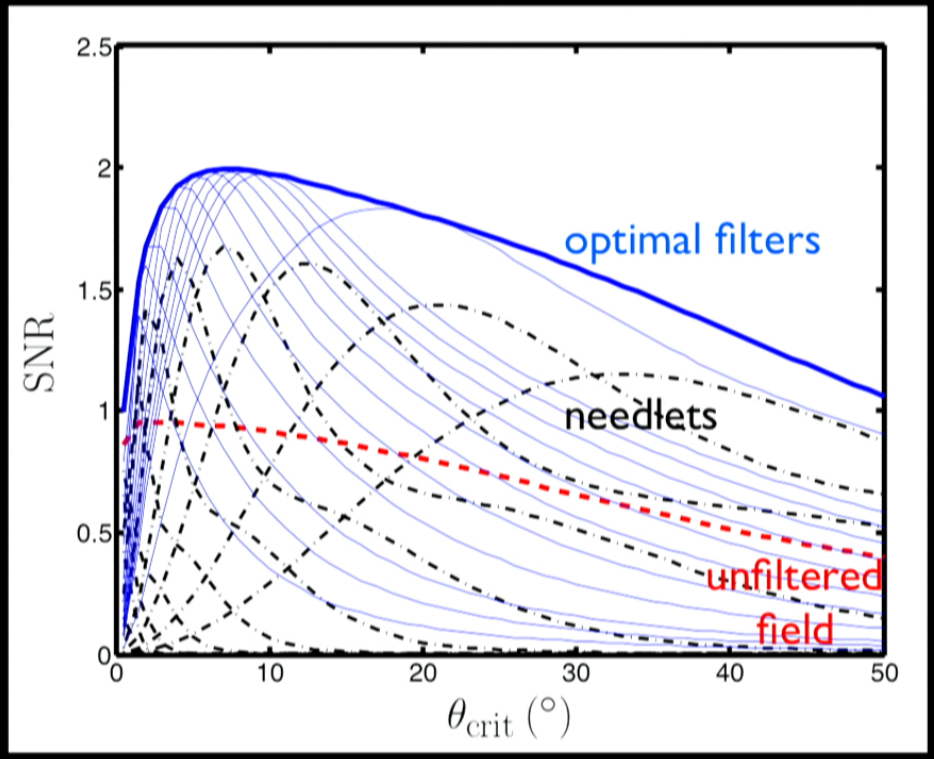
Patch Definition



- Convolve with grid of different-sized filters
- Candidates = scales & locations where filtered map > threshold

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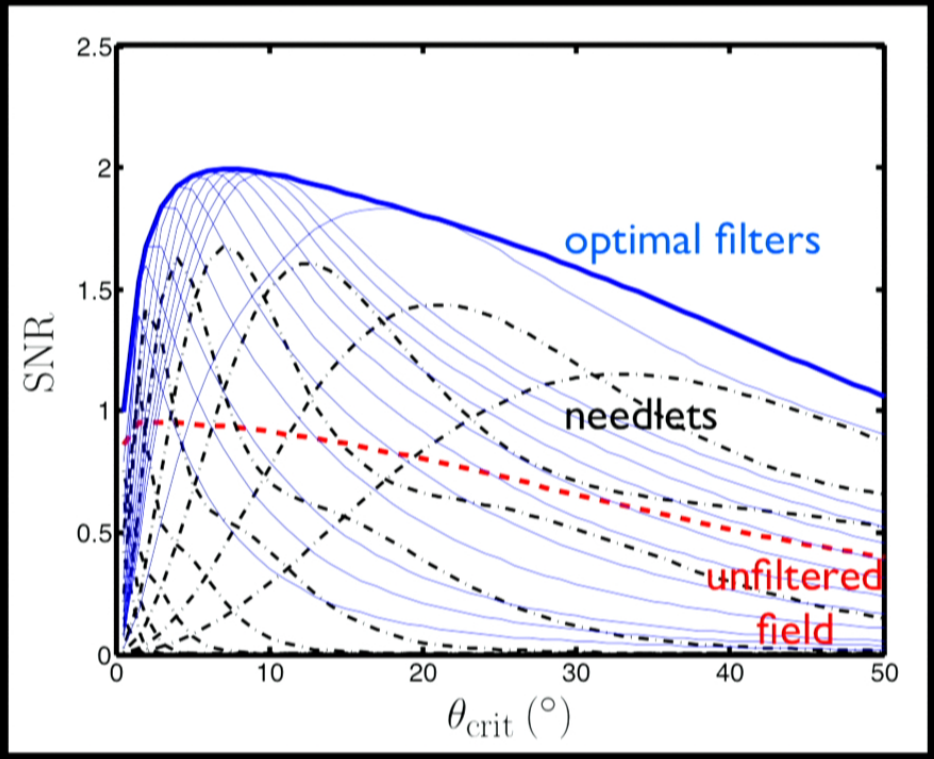

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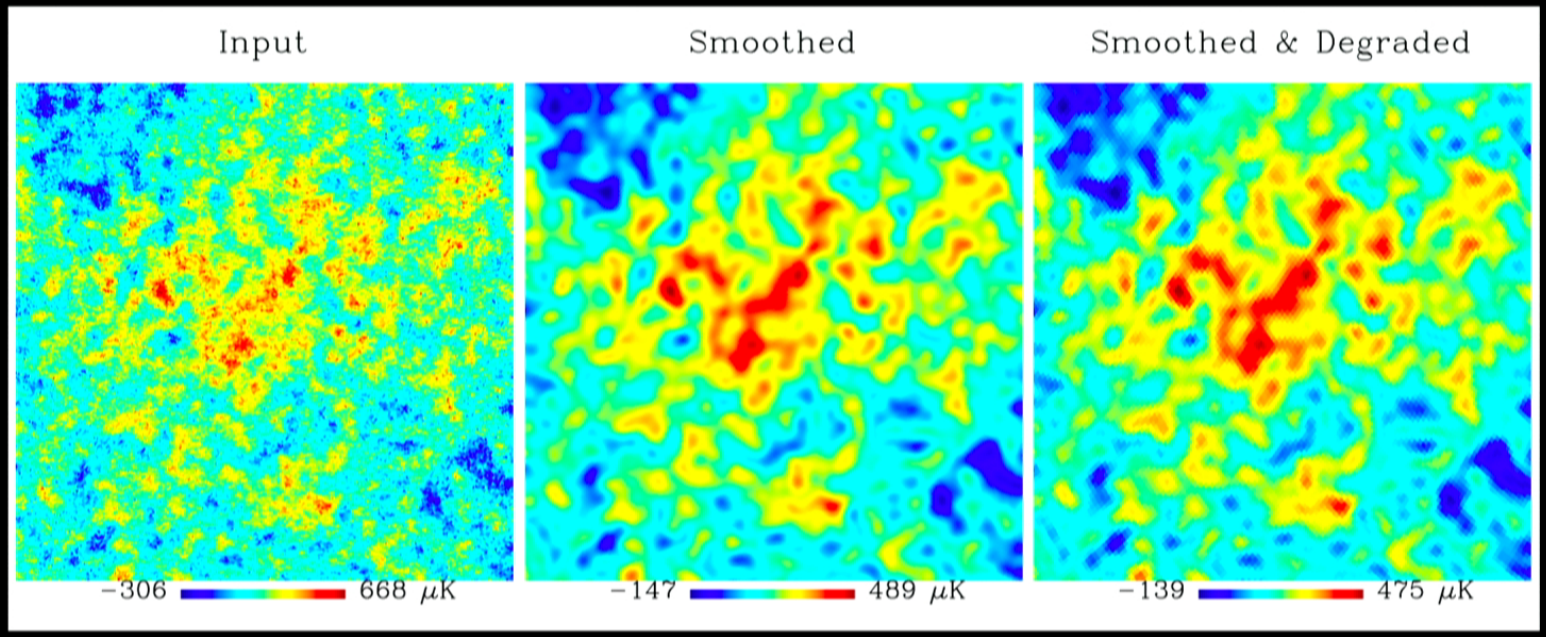

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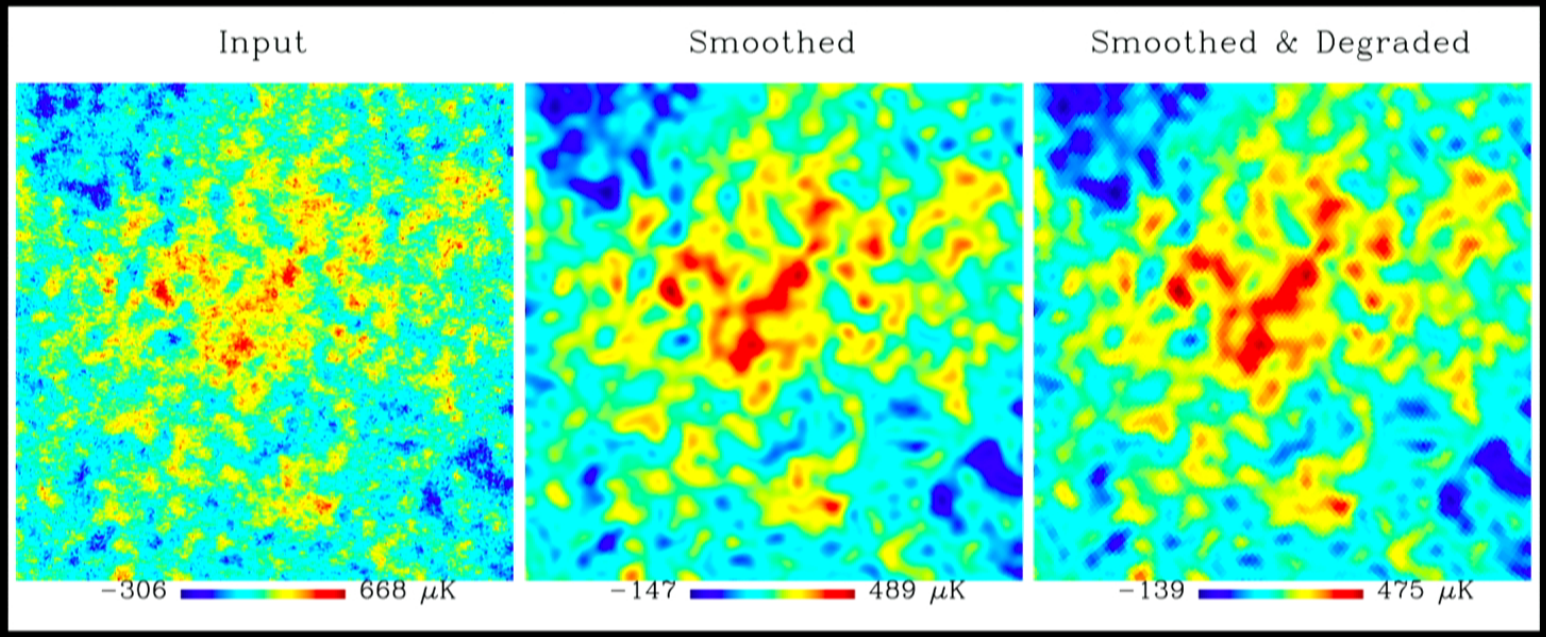

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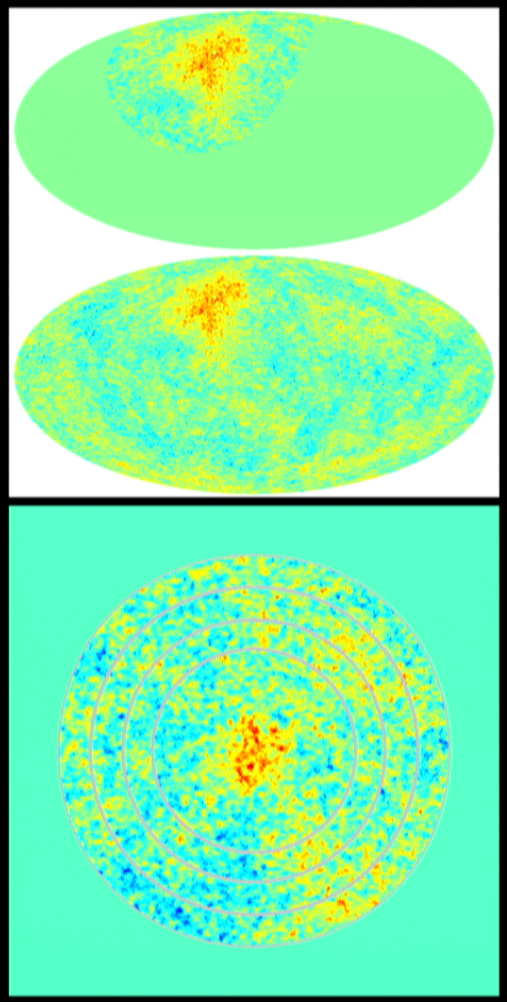
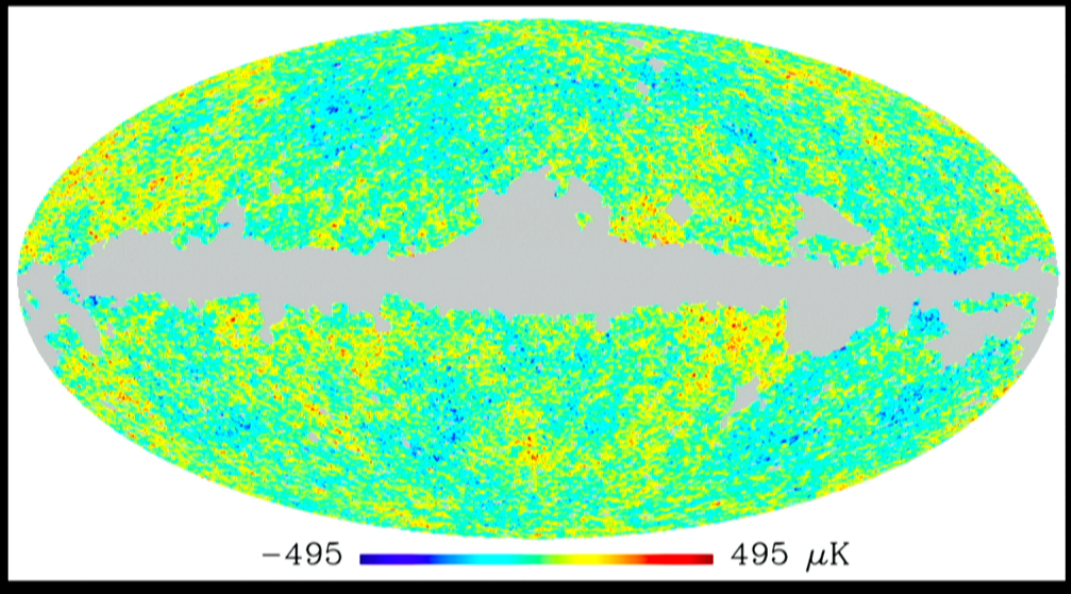
3rd Test: Neglected Correlations

- Large-scale: compare patch versus full-sky
- Small-scale: compare results for patches up to 30° radius
- All cases: consistent to sampling precision

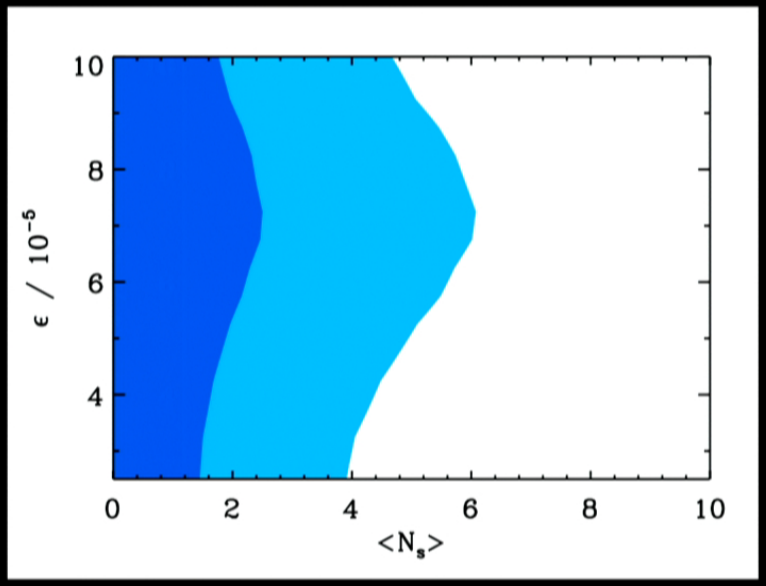


Calibration: Unknown Systematics

- Can't include all systematics in likelihood: some not released
- Calibrate effects using WMAP7 W-band end-to-end sim



WMAP 7-Year Conclusions



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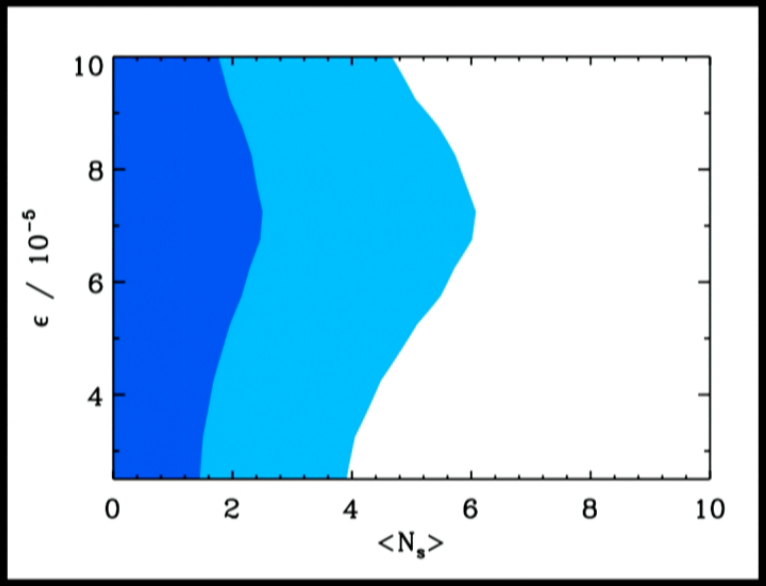

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