An introduction to multi-field models of inflation

David Mulryne

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arXiv:1307.7095 with Joe Elliston, Reza Tavakol

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Intro to Multi-field models

- Inflation, but more than one field - usually we think of light fields, but additional quasi-light or even additional heavy fields can matter.
- Two motivations:
  - Model driven - string theory, supergravity, MSSM, Standard Model(?).
  - Phenomenological - how do multi-field dynamics differ from single field dynamics - what range of behavior is then allowed.

Intro to Multi-field models

- Two questions:

  1. What changes when we move from one to many fields?

  2. How can we tell?

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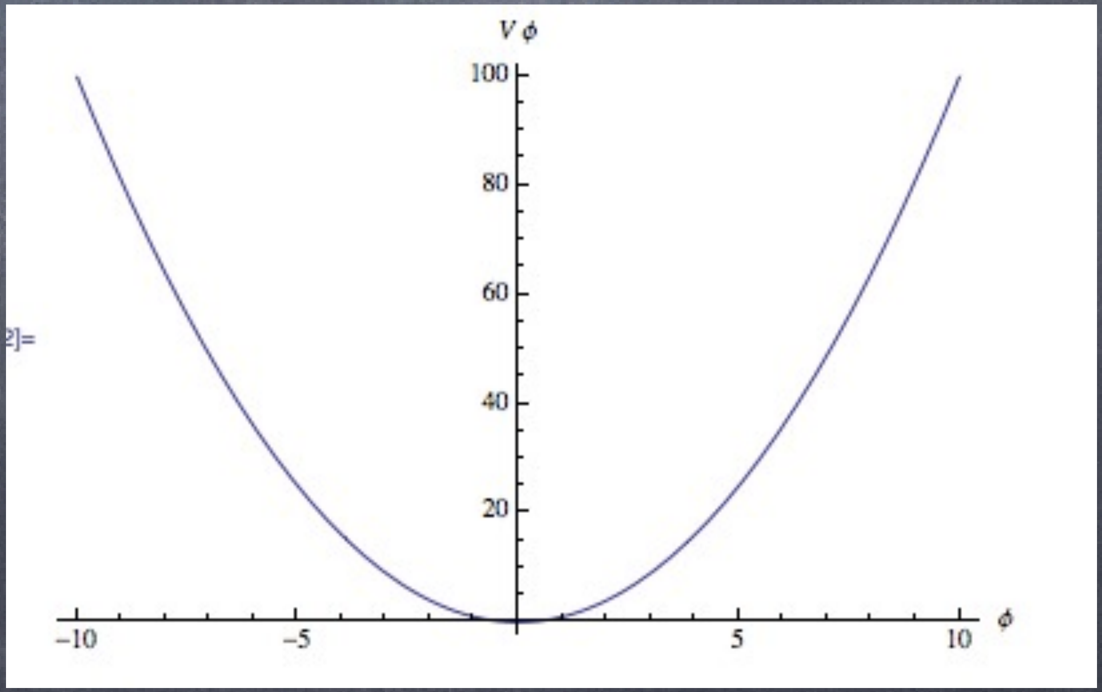
$$V(\phi) = \frac{1}{2}m_\phi^2\phi^2$$



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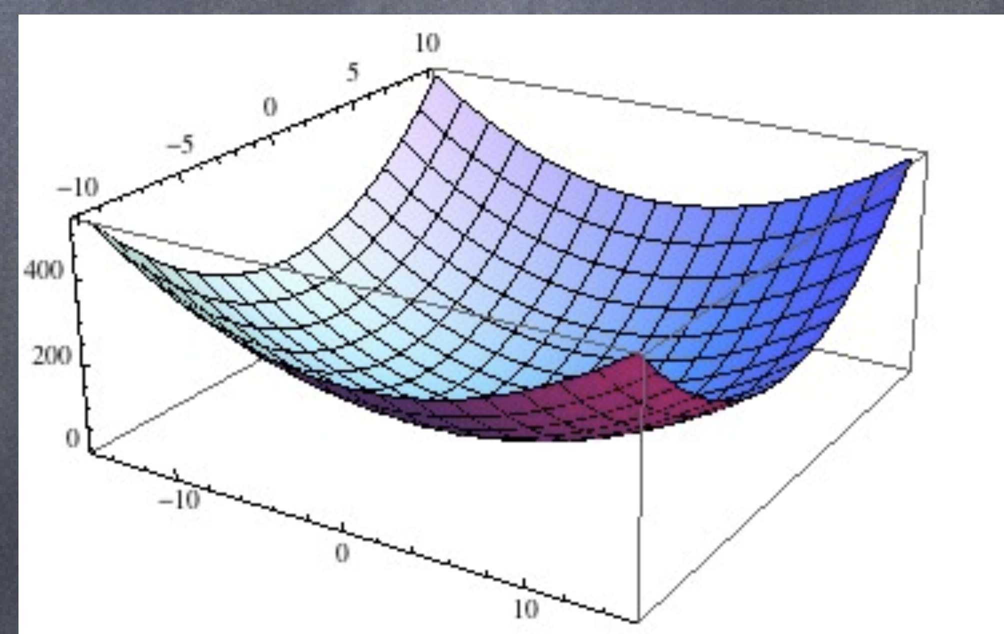
$$V(\phi, \chi) = \frac{1}{2} m_\phi^2 \phi^2 + \frac{1}{2} m_\chi^2 \chi^2$$



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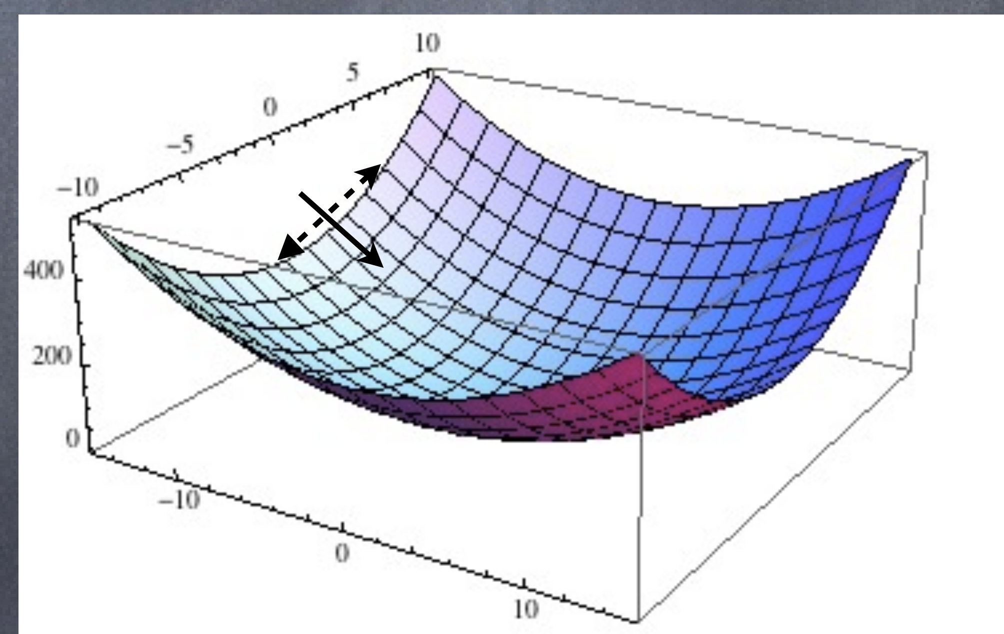

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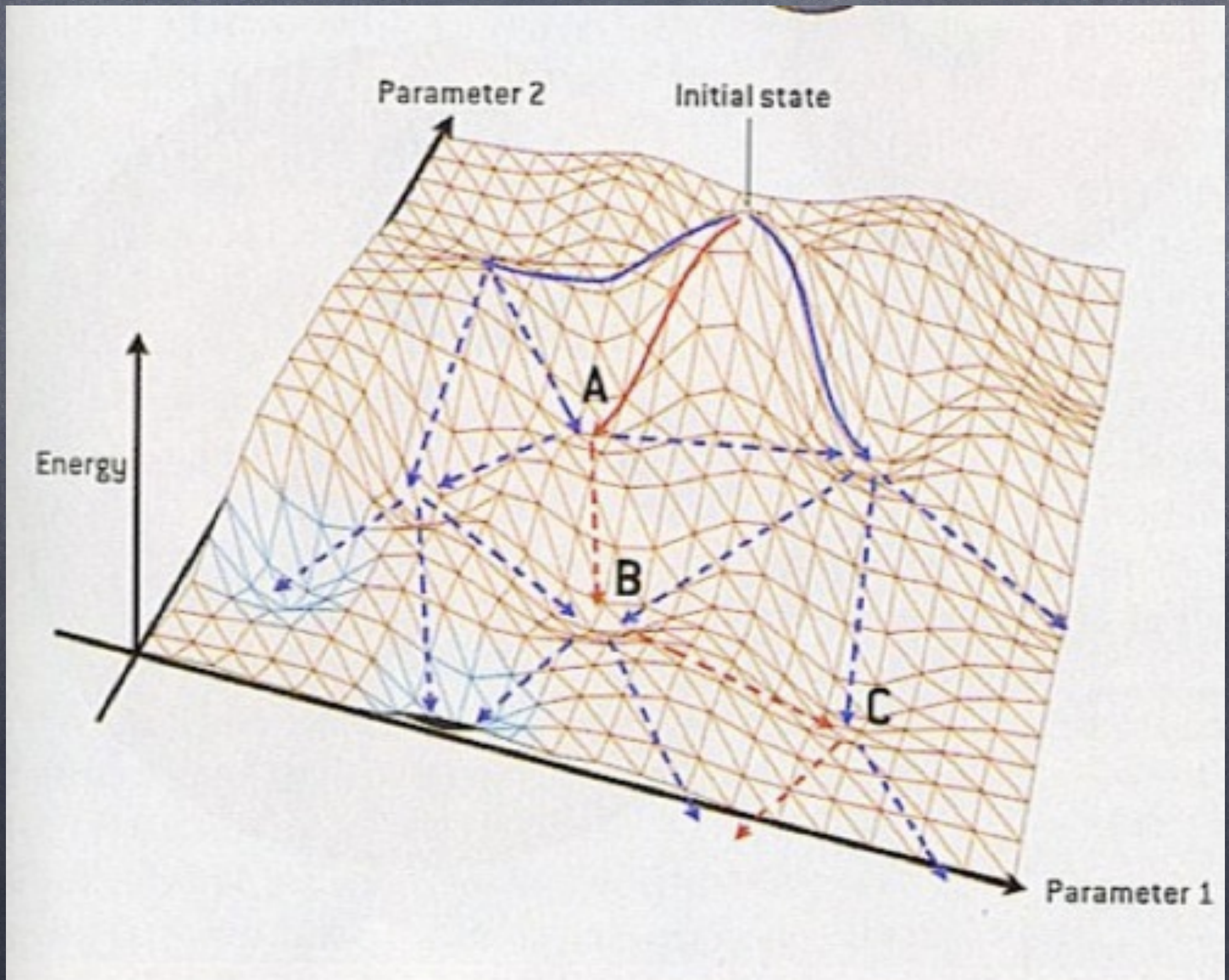

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  1. ‘Everything’ - many initial conditions, isocurvature modes feed curvature mode, curved field-space metric, mass hierarchy -> isocurvature after inflation, non-Gaussianity.

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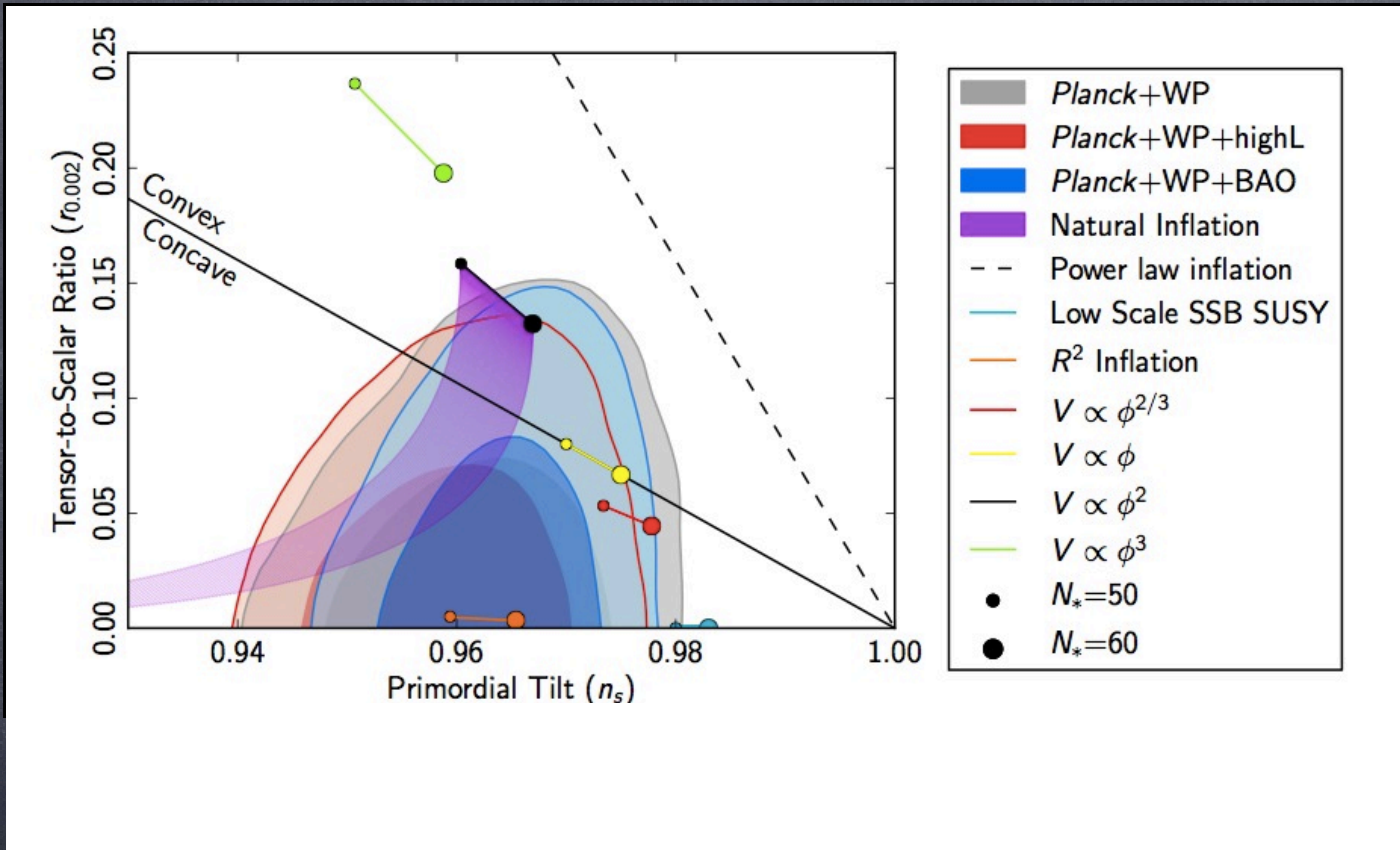
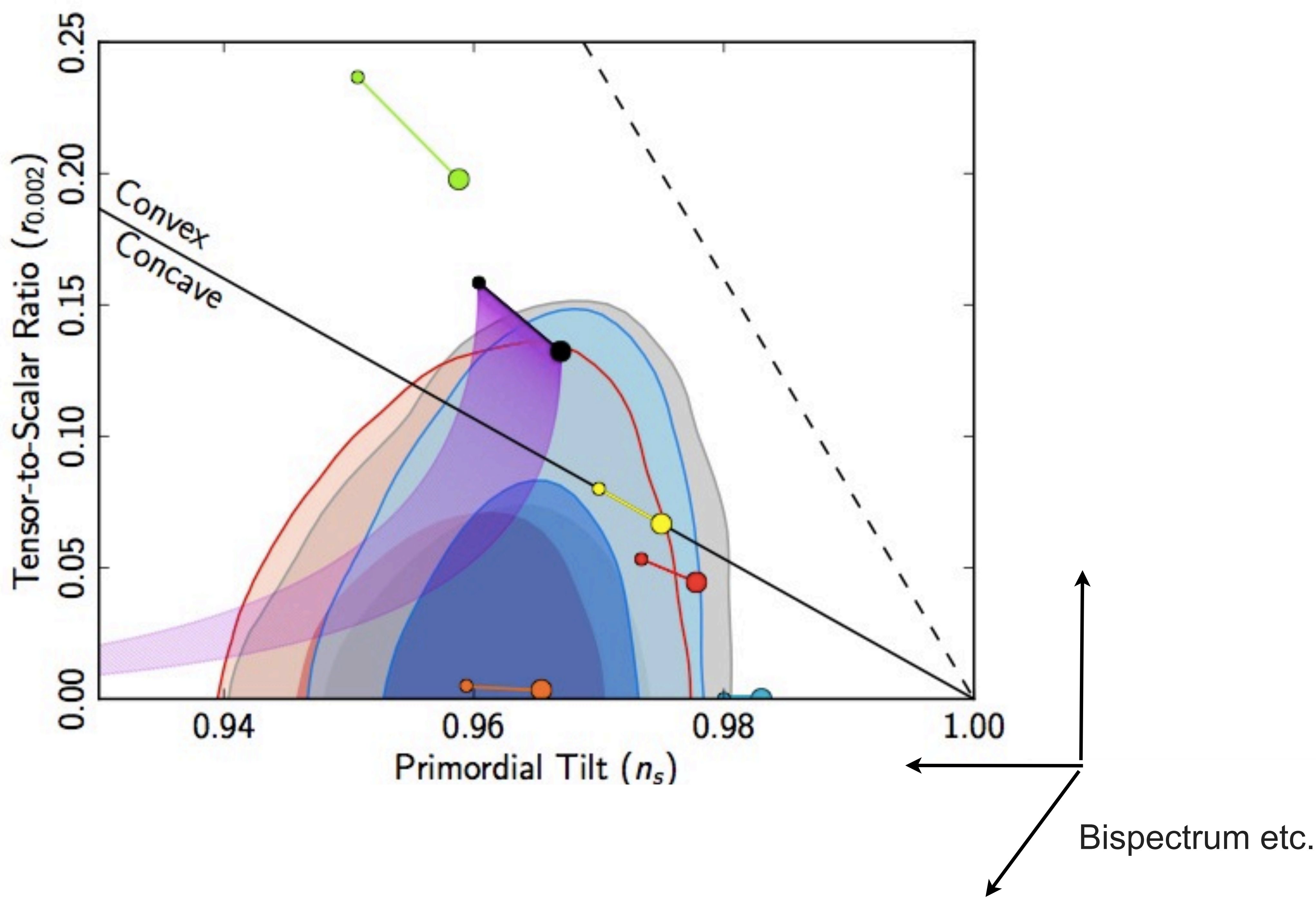
  1. ‘Everything’ - many initial conditions, isocurvature modes feed curvature mode, curved field-space metric, mass hierarchy -> isocurvature after inflation, non-Gaussianity.

  2. It’s really hard - isocurvature can decay before or after inflation ends, ‘detectable’ non-Gaussianity is possible but perhaps ‘unlikely’.



The Planck team - Ade et al. 2013



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Intro to calculating observables

- Want to track correlations of the fluctuations, $\delta\phi$ etc, ultimately want curvature perturbation, ζ , power-spectrum, bispectrum etc.
- Community mainly uses δN (e.g. Lyth and Rodriguez 2005).
- Could/should be using perturbation theory (perturbed action or field equations), and QFT -> In-In (Maldacena 2003) or a differential version

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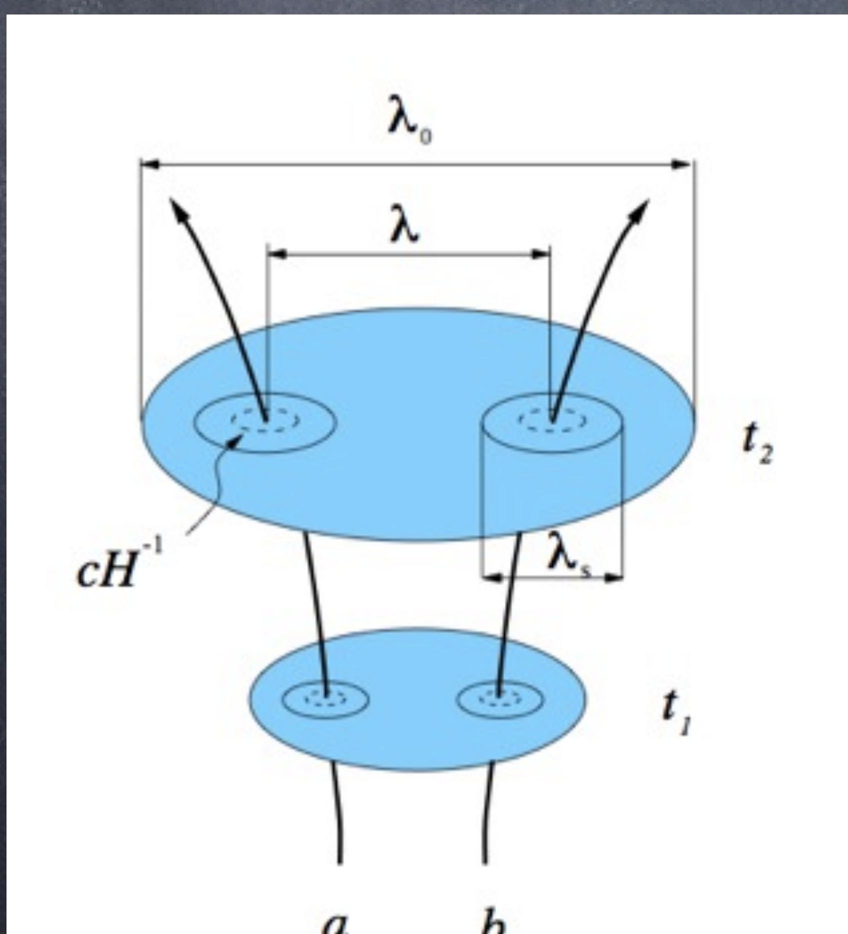

Wands et al. 2000

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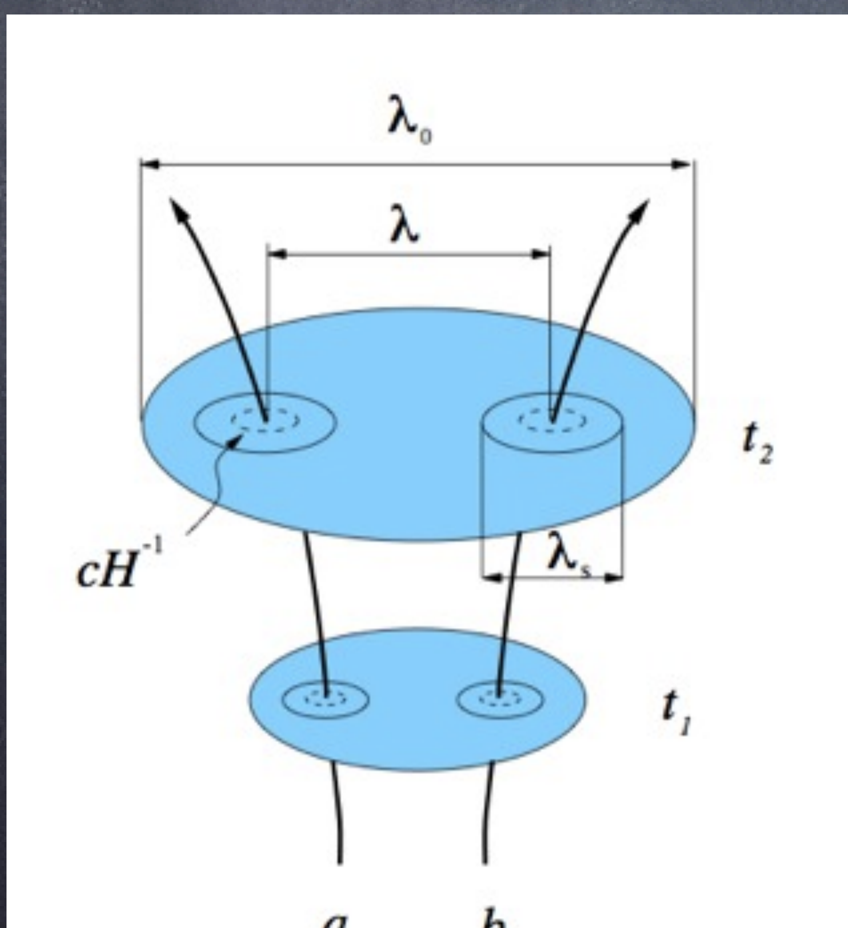

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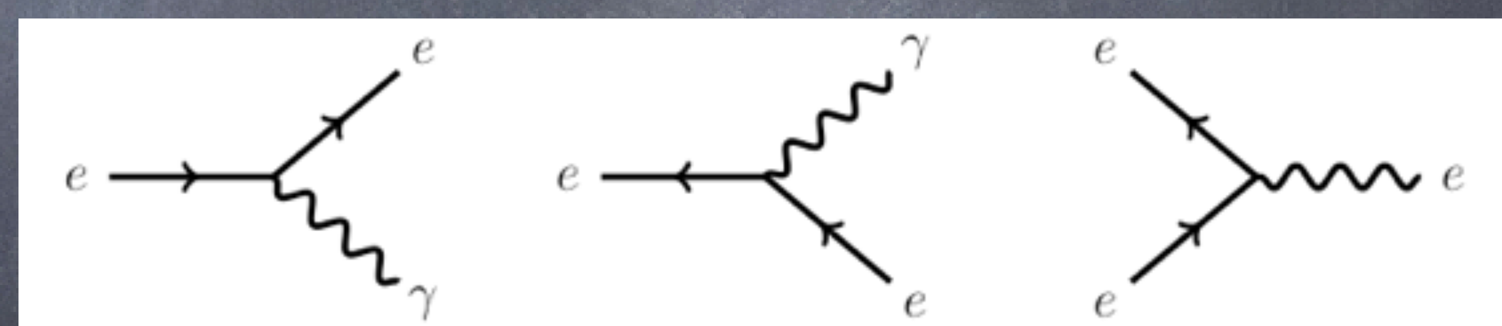

What Planck does not tell us about inflation - arXiv:1307.7095

- Planck (Ade et al. 2013) "severely limits the extensions of the simplest paradigm" ?
- 4 types of behaviour...

1. Isocurvature drives evolution of curvature during inflation.
2. Isocurvature drives evolution after inflation during 'reheating'.
3. Isocurvature converts to curvature suddenly at end of inflation.
4. Isocurvature modulates the reheating rate of inflation.

1) Multi-field slow-roll inflation

- A large non-Gaussianity can be generated during slow-roll (Byrnes, Choi, Hall 2008, Elliston, Mulryne, Seery, Tavakol 2011 and others...).
- Requires particular initial conditions, relating to specific features.
- Can disappear in adiabatic limit (Meyers and Sivanandrum 2010, Elliston et al. 2011).

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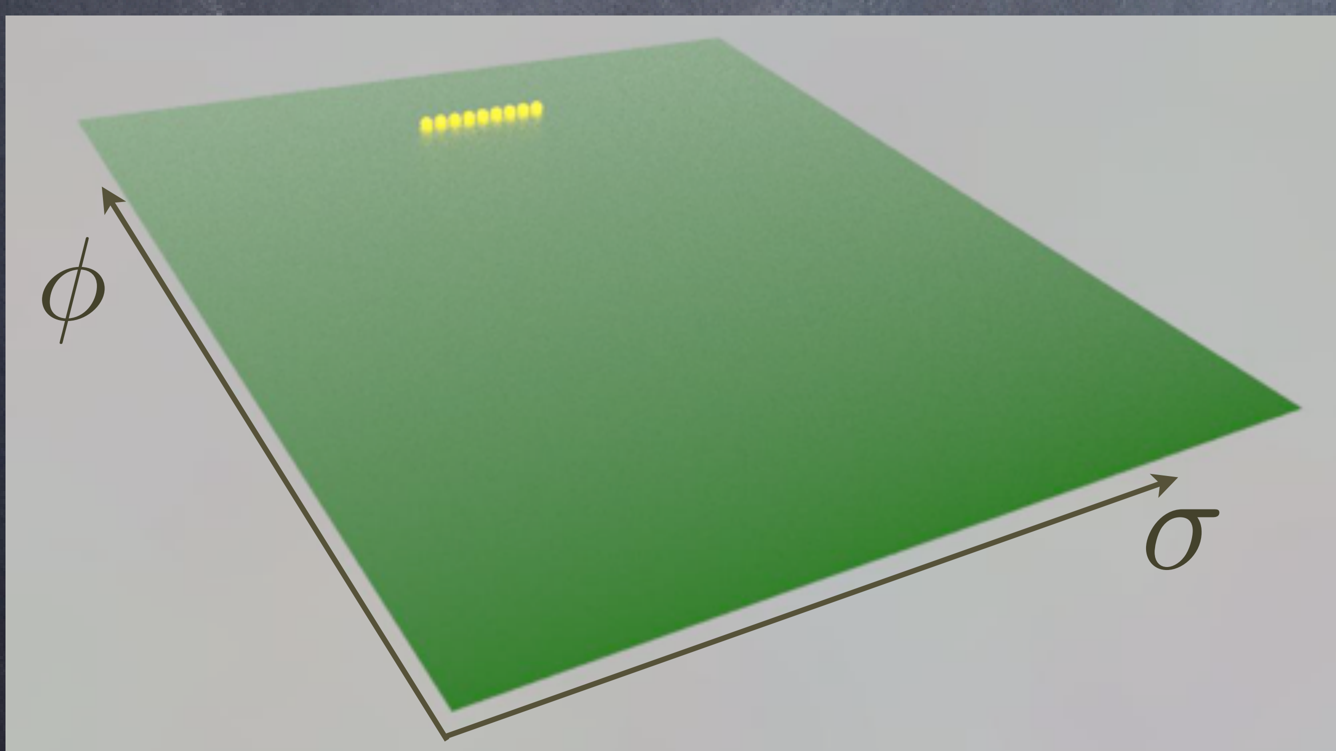

Pretty pictures thanks to J. Elliston

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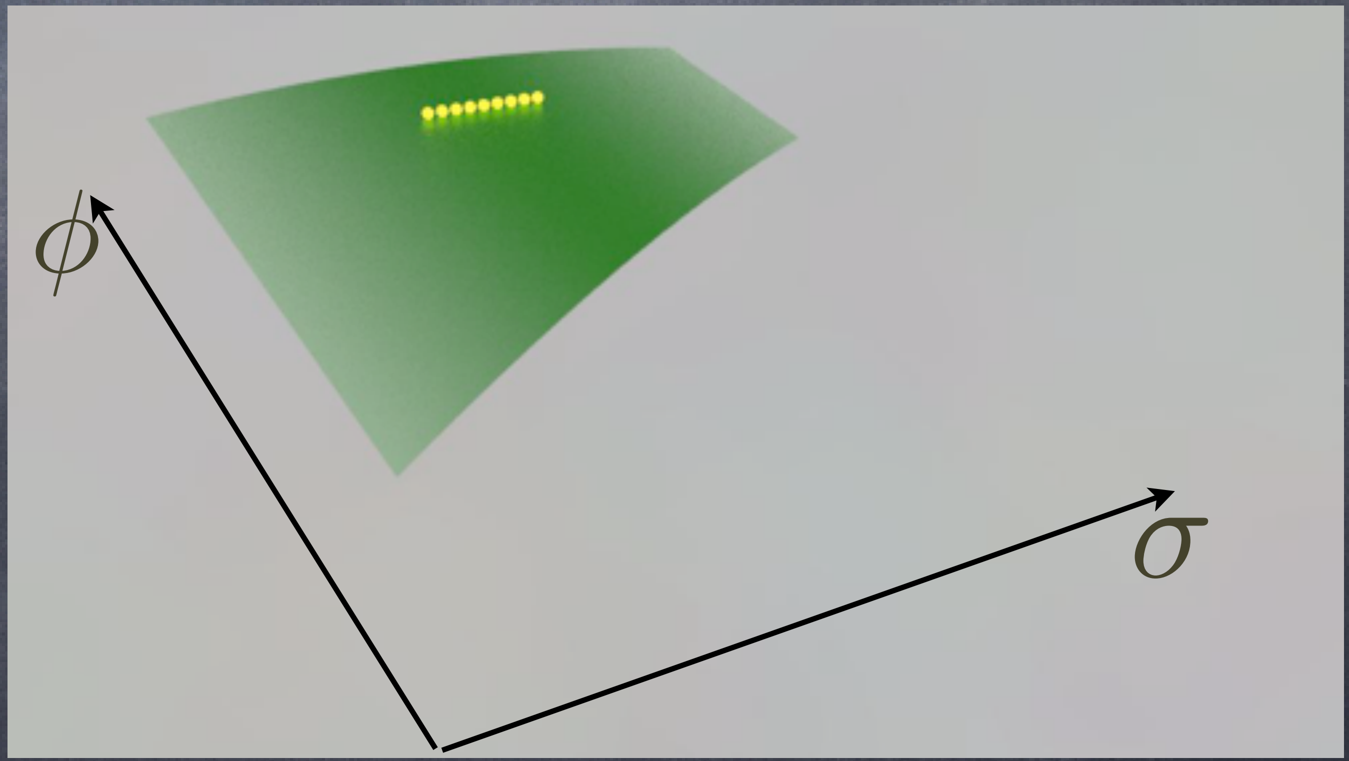

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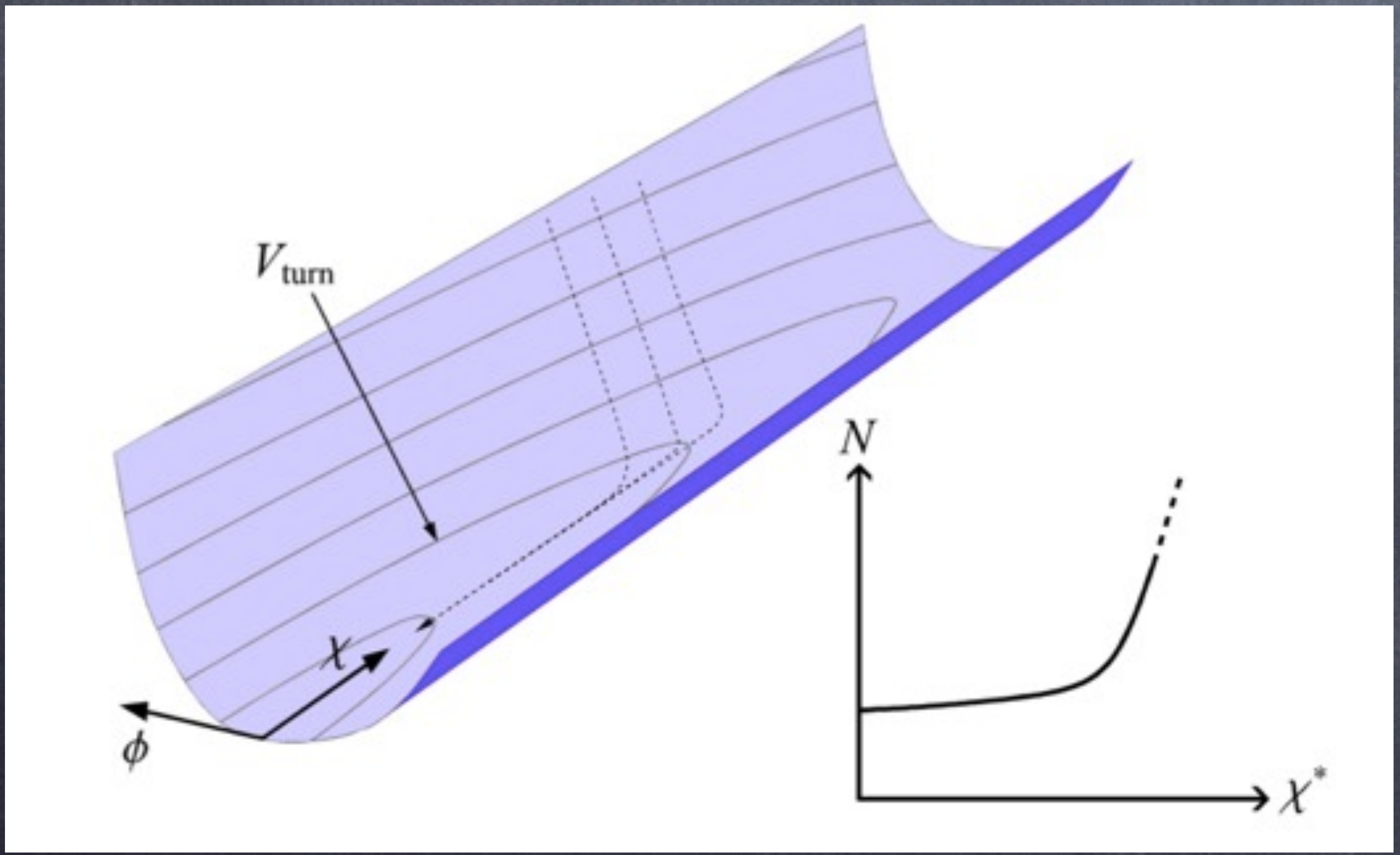

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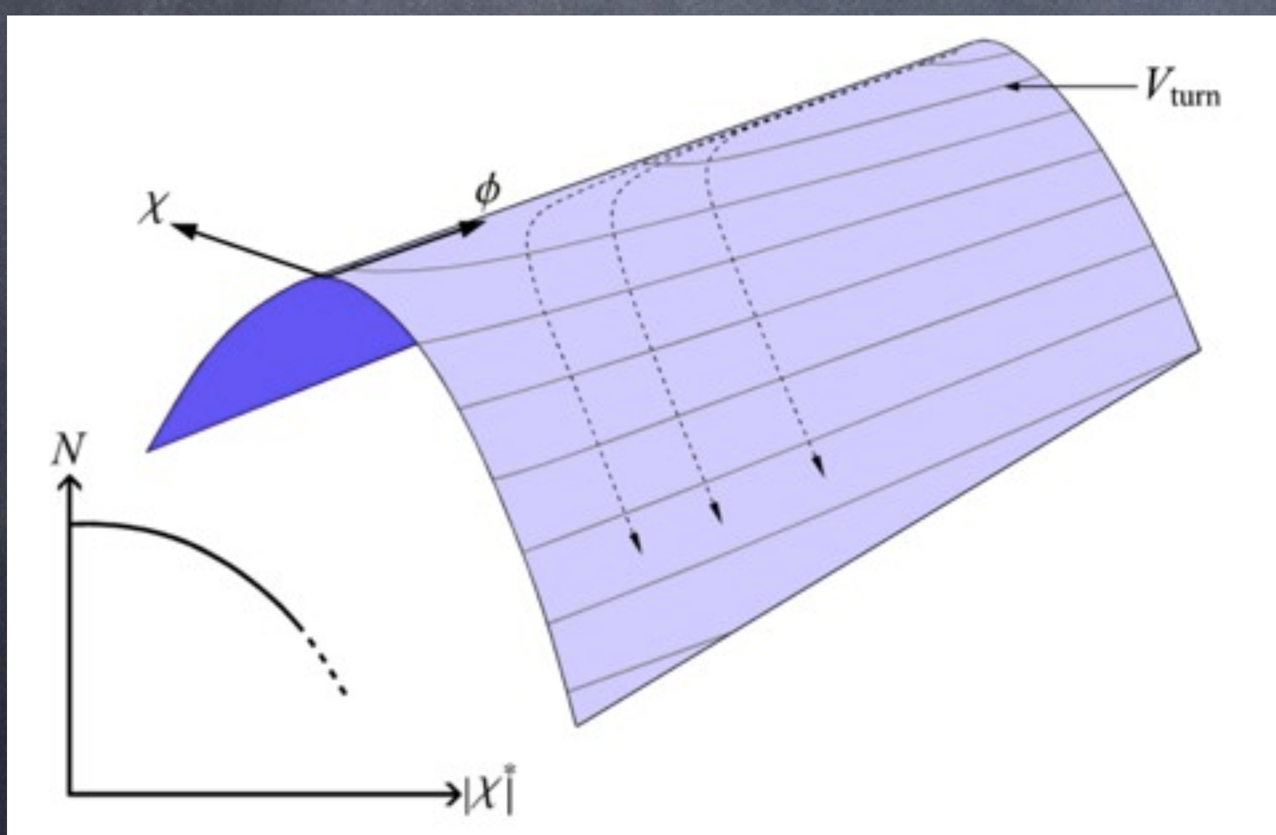

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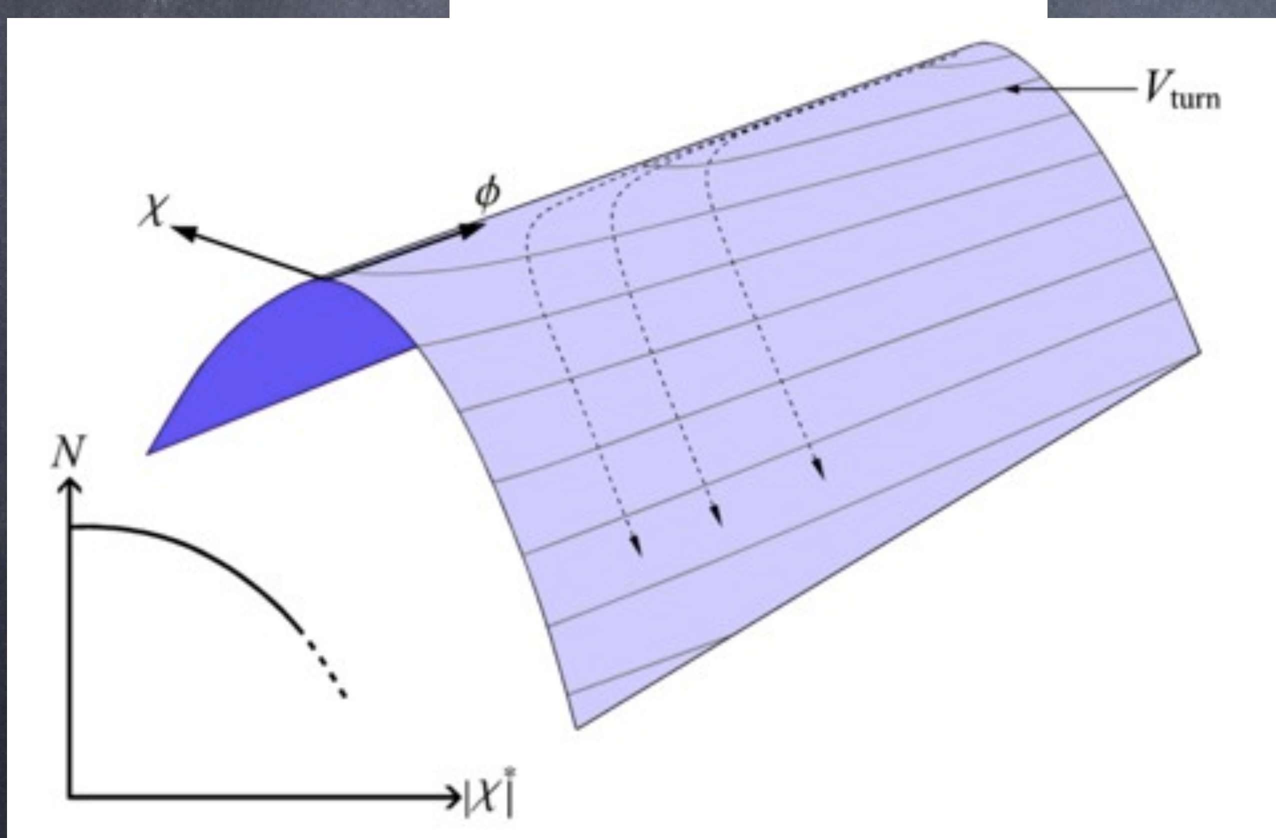

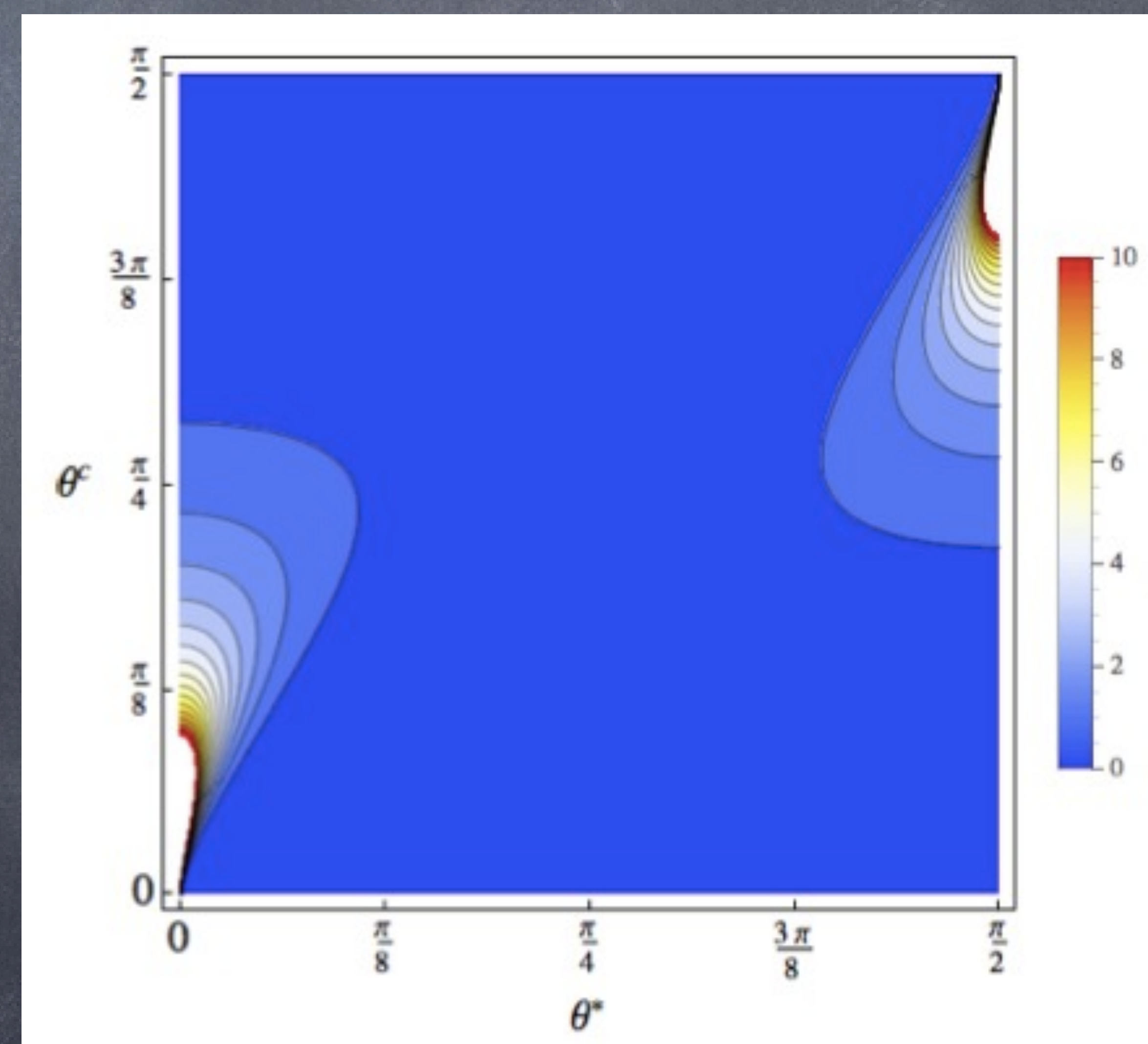

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2) Curvaton-type behaviour

- A subdominant field at the end of inflation can become important if it decays later than other field(s), and oscillates such that it redshifts more slowly than radiation -> 'Curvaton' (Lyth and Wands 2001).
- This can lead to large non-Gaussianity requires particular initial conditions, very similar to those for slow-roll effects.
- For two quadratics

$$\frac{6}{5} f_{\rm NL}\Big|_{\rm peak} = \frac{3\sqrt{3}}{16} \frac{\eta^*_{\sigma\sigma}}{\theta *}$$

3) Sudden end (IEI) scenario

- Inflation can end (suddenly on a non uniform density hypersurface (Lyth 2005, many others).

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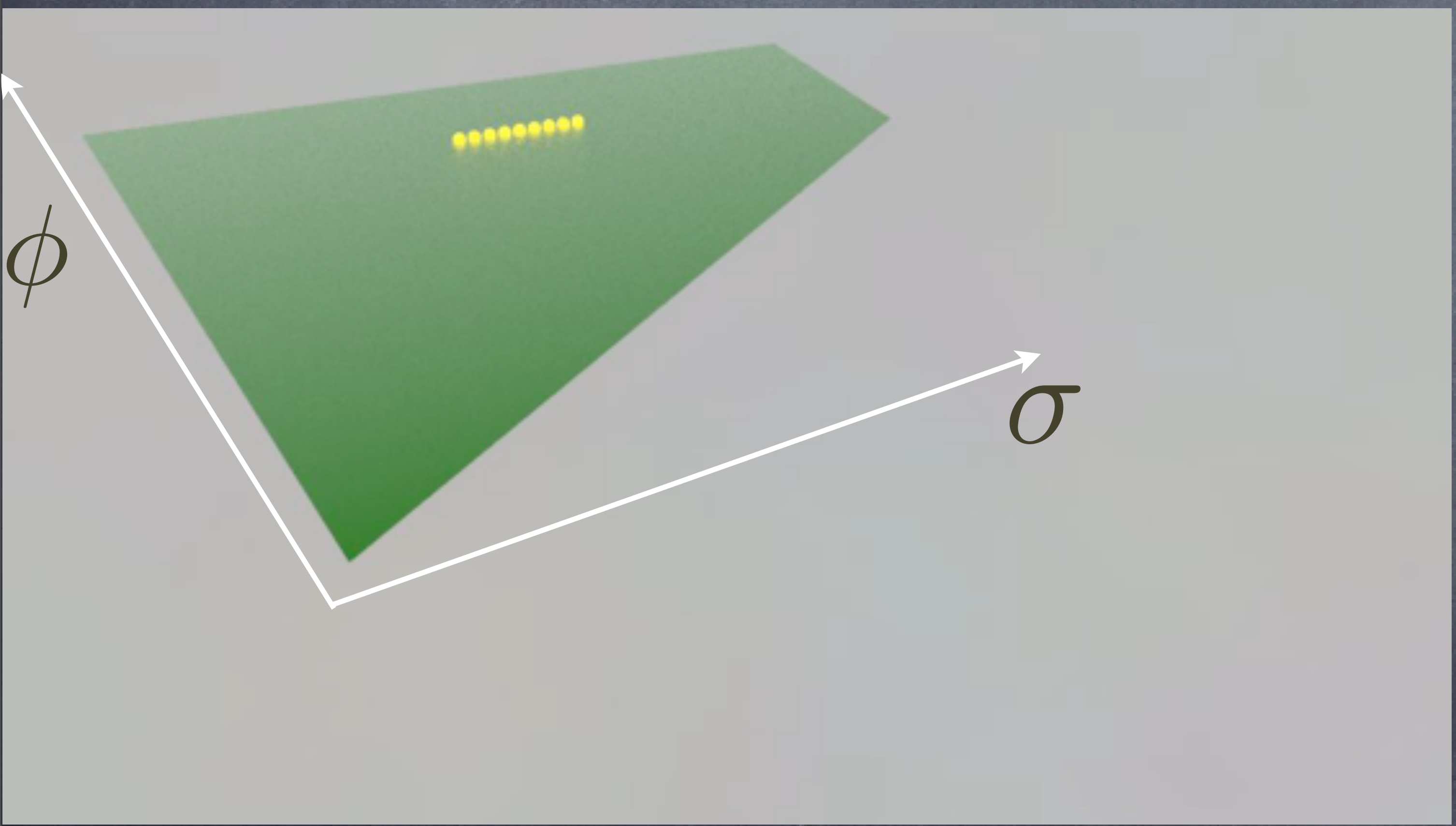

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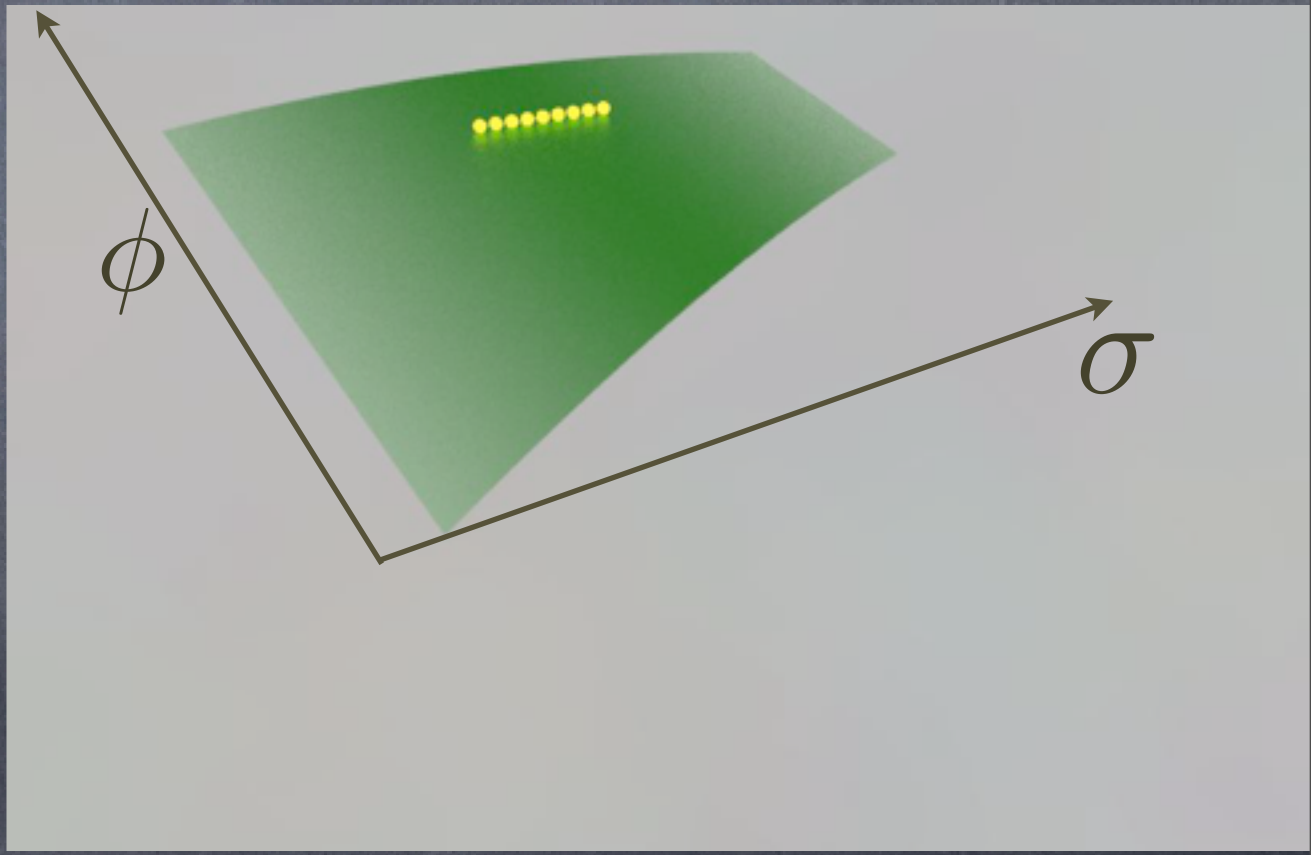
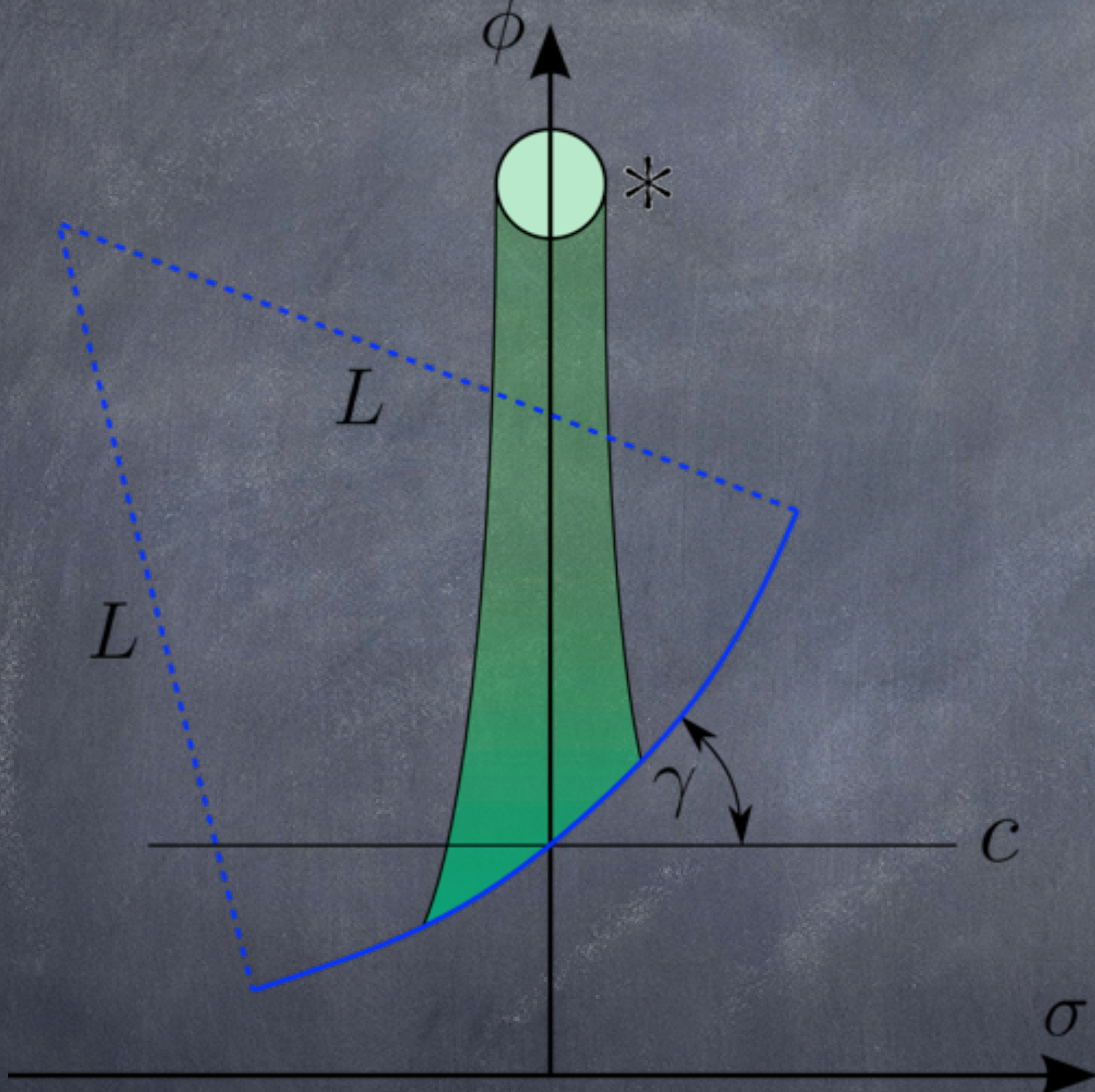


Geometry of the IEI scenario



Extrinsic curvature

$$K = 1/L = \frac{d\gamma}{d\sigma}$$

Linear statistics

$$\gamma, \ \frac{\partial \sigma^c}{\partial \sigma^*}$$

Non-linear statistics

$$K, \ \frac{\partial^2 \sigma^c}{\partial \sigma_*^2}$$

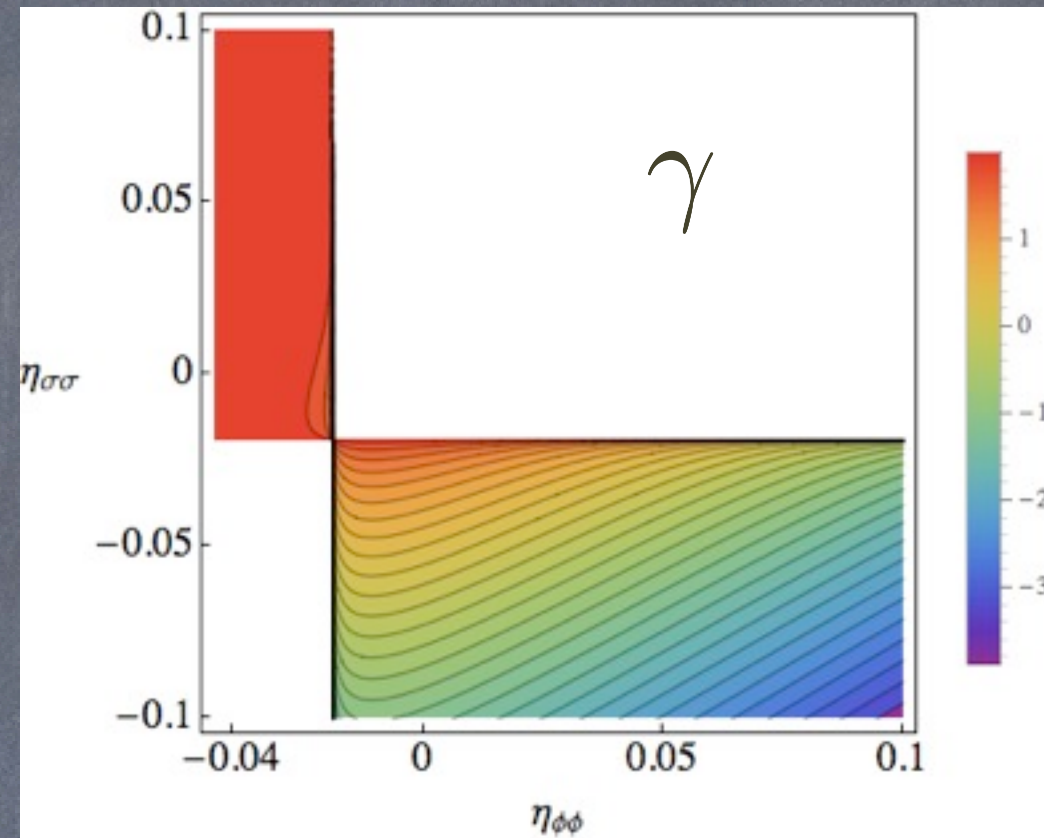
A. Naruko and M. Sasaki, Prog.Theor.Phys. **121**, 193 (2009), 0807.0180.
Q.-G. Huang, JCAP **0906**, 035 (2009), 0904.2649.
T. Matsuda, JCAP **1204**, 020 (2012), 1204.0303.
D. Battefeld and T. Battefeld, JCAP **1307**, 038 (2013), 1304.0461.

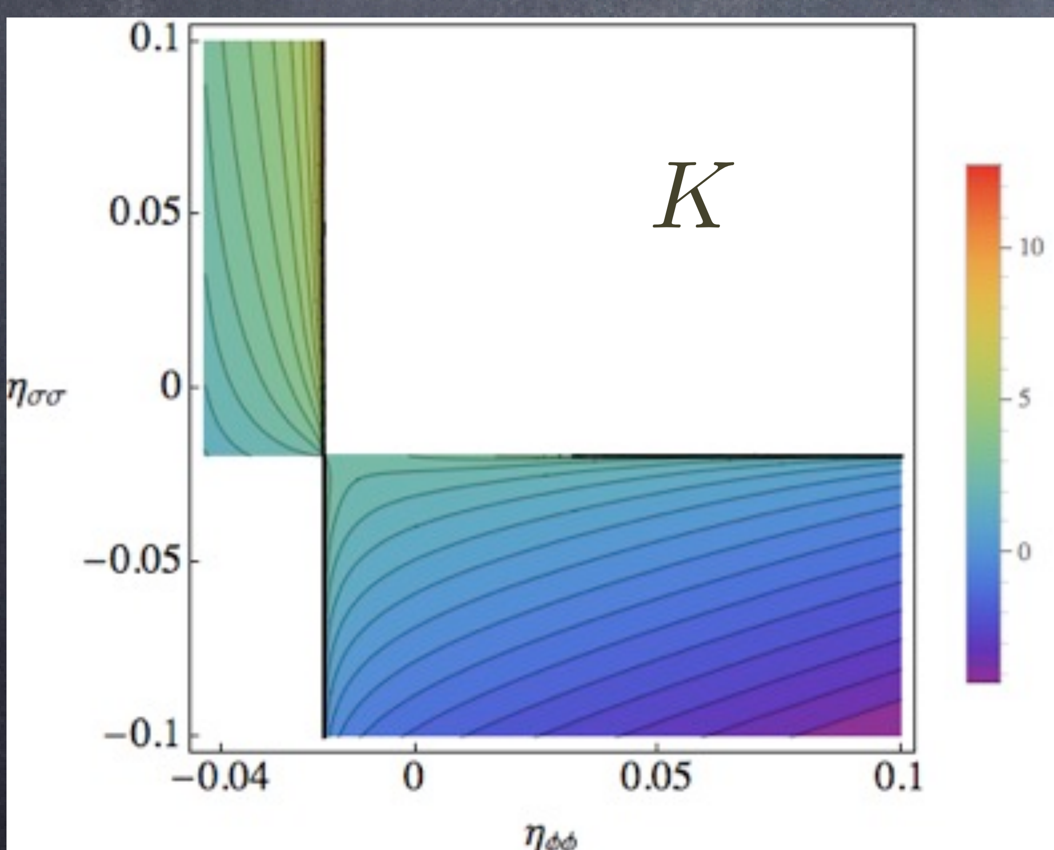
This and next few slide shamelessly stolen from J. Elliston

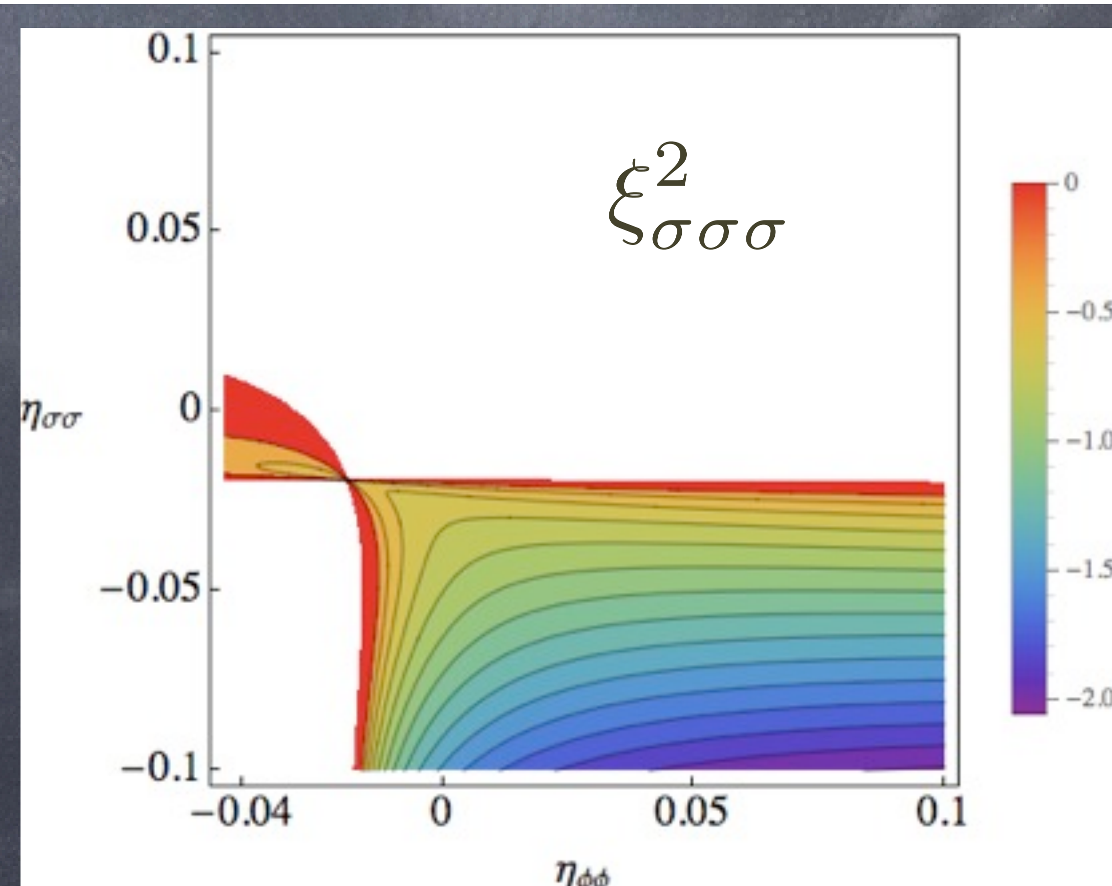
Inhomogeneous end to Hybrid

$$\eta_{\phi\phi}, \eta_{\sigma\sigma}, \xi^2_{\sigma\sigma\sigma}$$
$$\epsilon^* = 10^{-4}$$

$$\frac{\partial \sigma^c}{\partial \sigma^*} = \exp\left[-\int_*^c \frac{V_{,\sigma\sigma}}{3H^2}\,\mathrm{d}N\right],$$
$$\frac{\partial^2 \sigma^c}{\partial \sigma_*^2} = -\frac{\partial \sigma^c}{\partial \sigma^*}\int_*^c \frac{V_{,\sigma\sigma\sigma}}{3H^2}\frac{\partial \sigma}{\partial \sigma^*}\,\mathrm{d}N\,.$$







4) One field can modulate decay of other - MR scenario (e.g. Zaldarriaga 2003)

$$H = \Gamma(\sigma)$$

Decay width

Radiation

Matter

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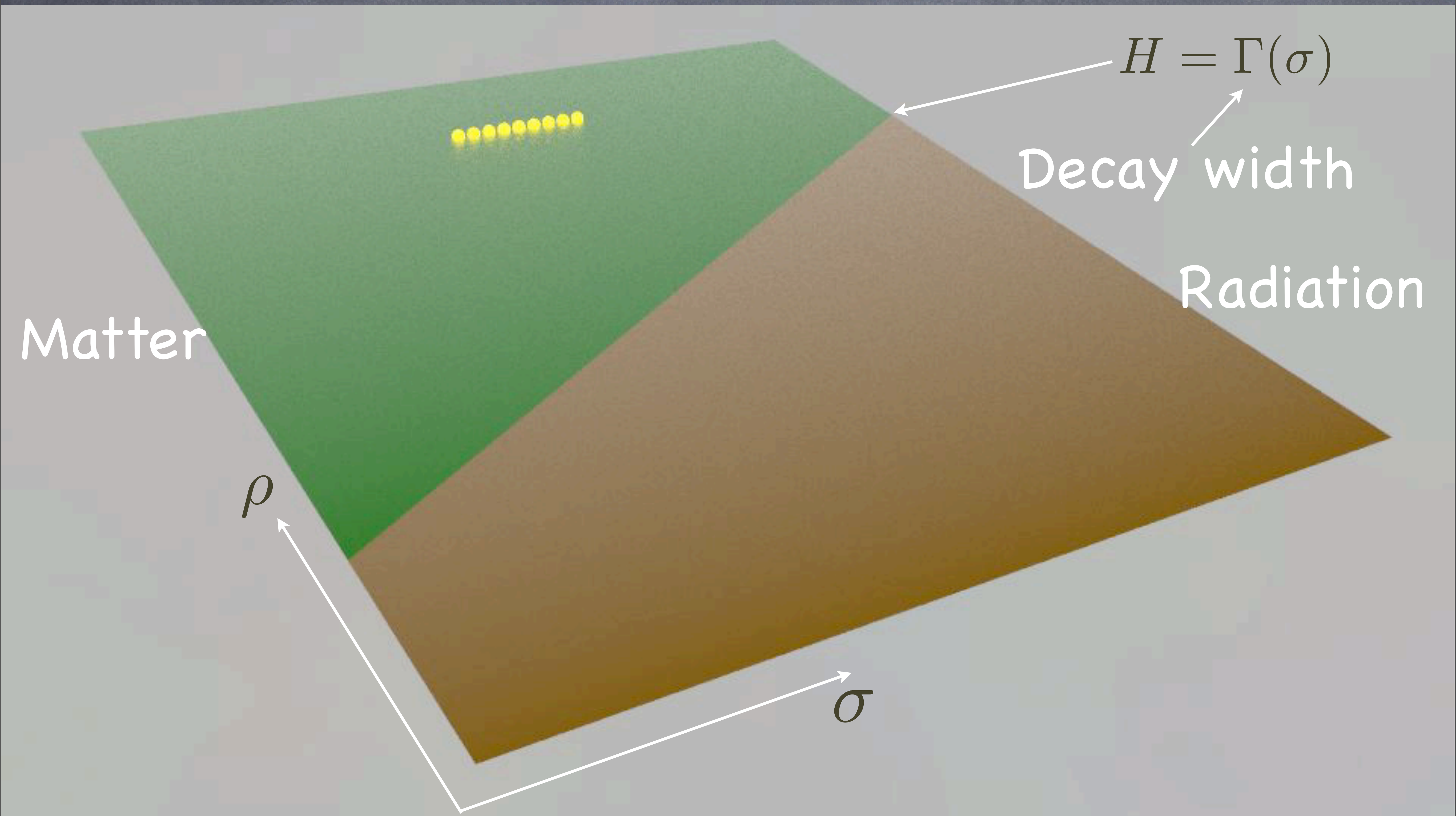
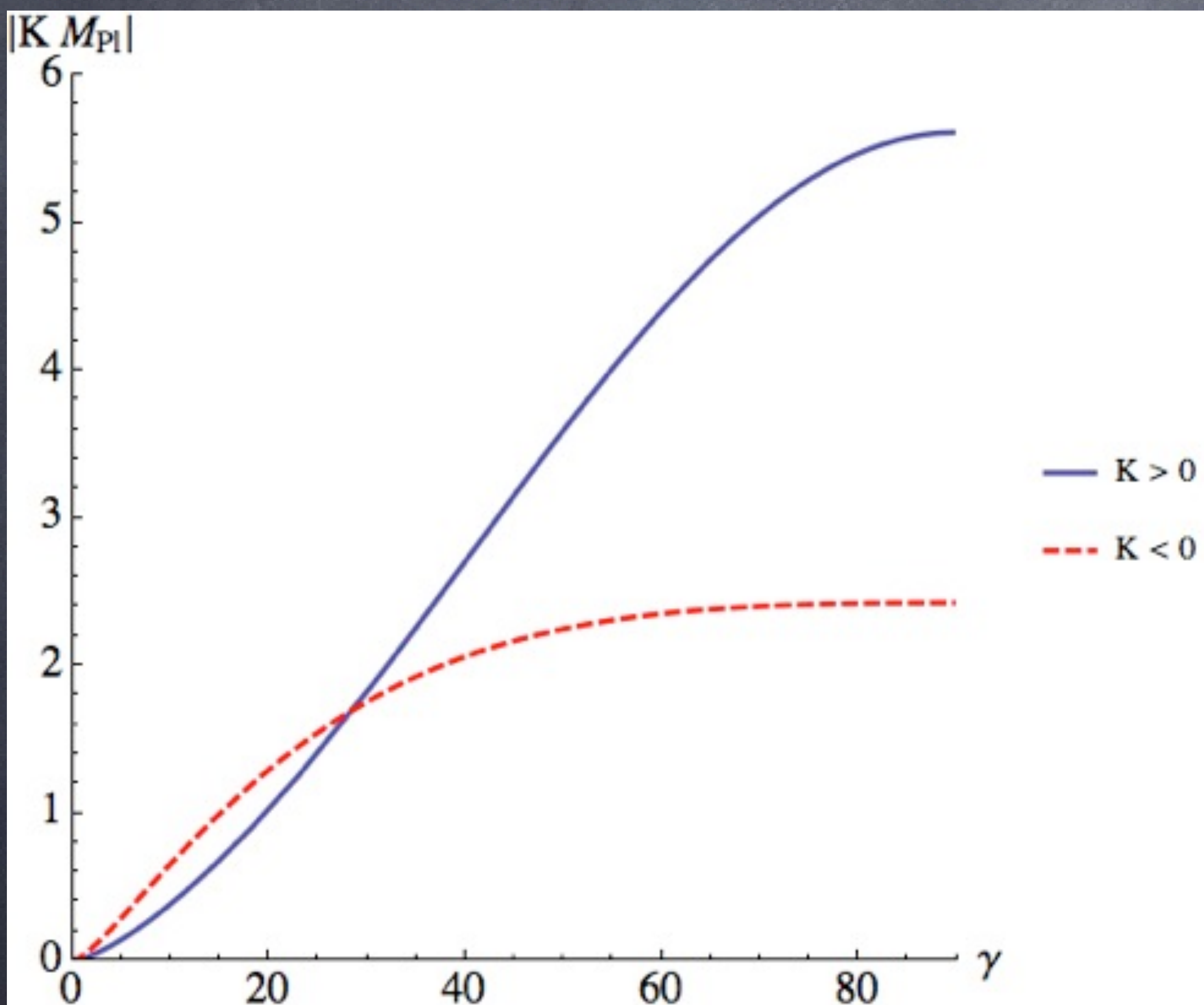
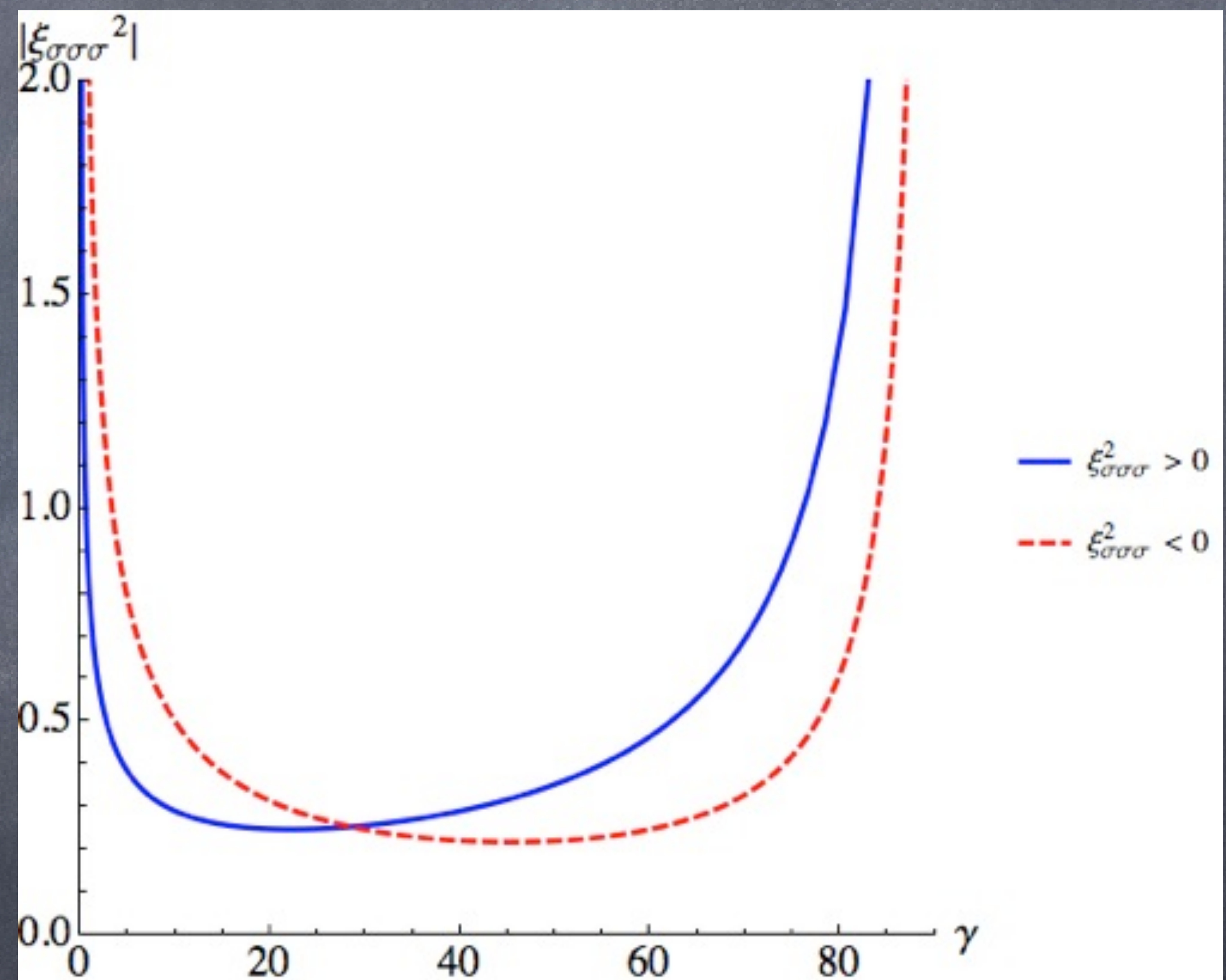


Modulated reheating of Vanilla Inflation





Summary

- Multi-field models are generic. e.g., D-brane models (Dias et al. 2012, McAllister et al. 2012). Calculating observables is now much harder (see Jonny's talk).

- Multi-field models can behave differently from single field models, but it can be very hard to tell them apart. Even with the much improved Planck constraints.

- Multi-field inflation can produce NG which is in tension with data, but for many scenarios this requires particular initial conditions - while constraints on other scenarios are quite strong.

- Previous work focused on what behaviour is allowed, mainly two field.

- Future will be more driven by realistic models - more fields (Marsh et al. 2013).