# Large tensor-to-scalar ratio from supersymmetric hybrid inflation potential

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# § Inflation

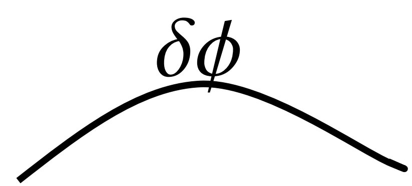
Inflation solves [Guth, Sato … (1981)]

- the flatness problem
- the horizon problem
- …

provides

- seeds of the density perturbation

  [Hawking, Starobinsky, Guth and Pi (1982)]



# § Inflation

Inflation solves [Guth, Sato … (1981)]

- the flatness problem
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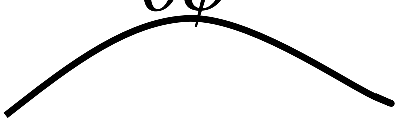
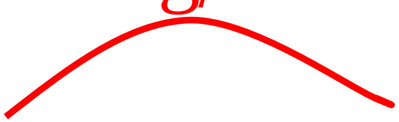
- seeds of the density perturbation $\delta\phi$

  [Hawking, Starobinsky, Guth and Pi (1982)]

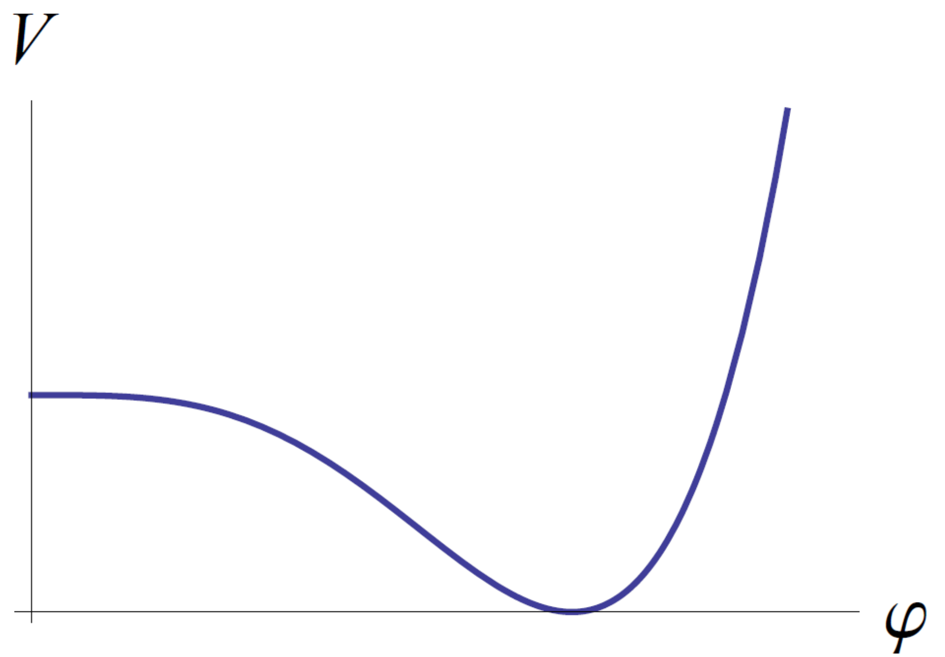
- gravitational wave background $\delta g_{\mu\nu}$

  [Starobinsky (1979), Rubakov et al (1982)]

# § Slow roll inflation

- Potential for inflaton needs to be flat




- Slow roll parameters

$$\epsilon = \frac{1}{2}\left(\frac{V_\varphi}{V}\right)^2$$

$$\eta = \frac{V_{\varphi\varphi}}{V}$$

$$\xi = \frac{V_\varphi V_{\varphi\varphi\varphi}}{V^2}$$

# § § Perturbation from inflation

- Power spectrum of density (scalar) perturbation

$$\mathcal{P}_\zeta = \left(\frac{H^2}{2\pi|\dot{\varphi}|}\right)^2 = \frac{V}{24\pi^2\epsilon}$$

- Spectral index

$$n_s = 1 + 2\eta - 6\epsilon$$

- Running of the spectral index

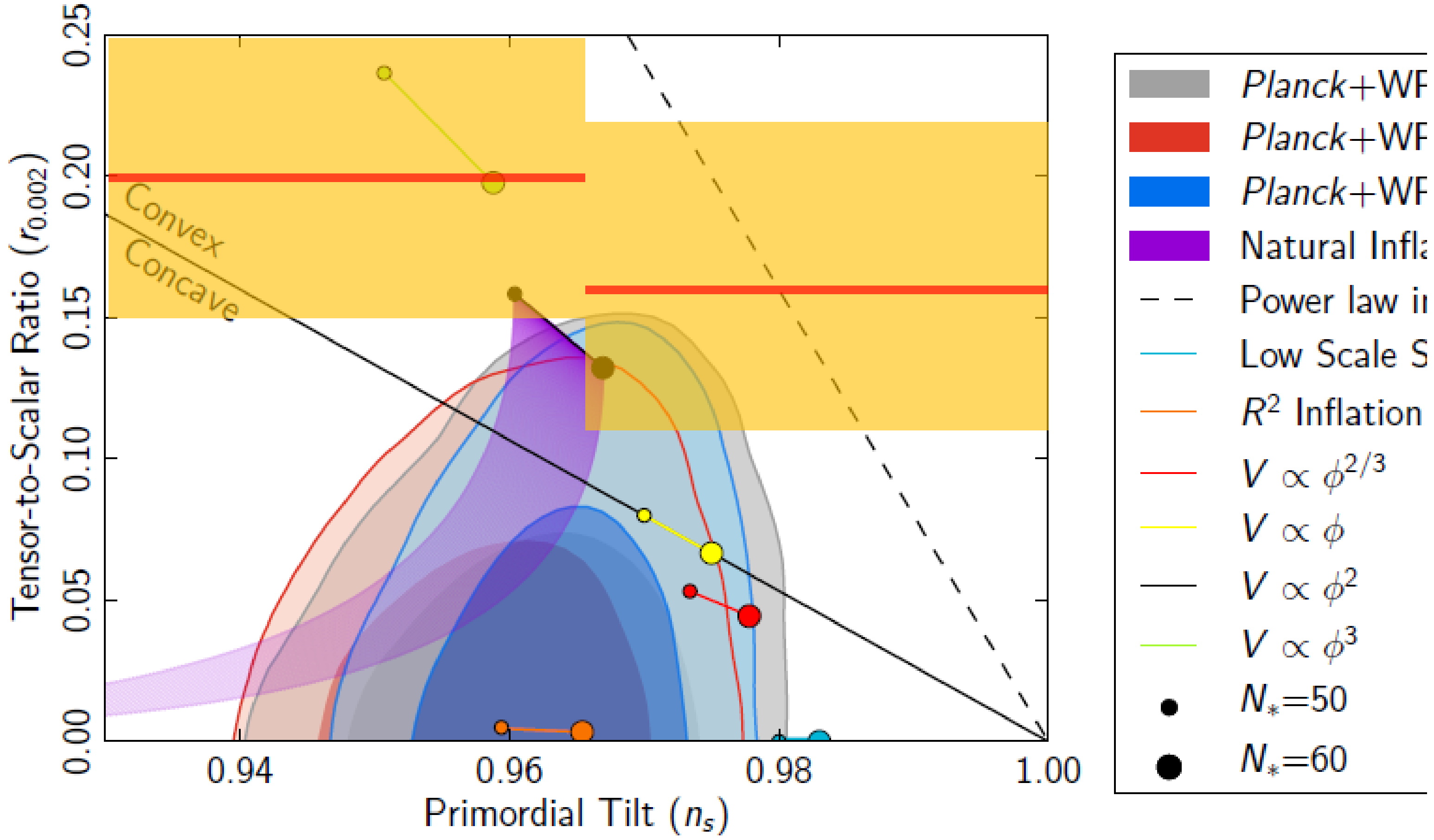
$$\alpha_s = 16\epsilon\eta - 24\epsilon^2 - 2\xi$$

- Tensor-to-scalar ratio

$$r_T = 16\epsilon$$

# § With BICEP2 data

- Large tensor??? [BICEP2 (2014)]



# § Hybrid inflation

- Hybrid inflation [Linde, Copeland et al (1994)]
- Pros

  easy construction (in SUSY [Dvali et al (1994)])

  field value $\lesssim$ Planck scale
- Pros? or Cons?

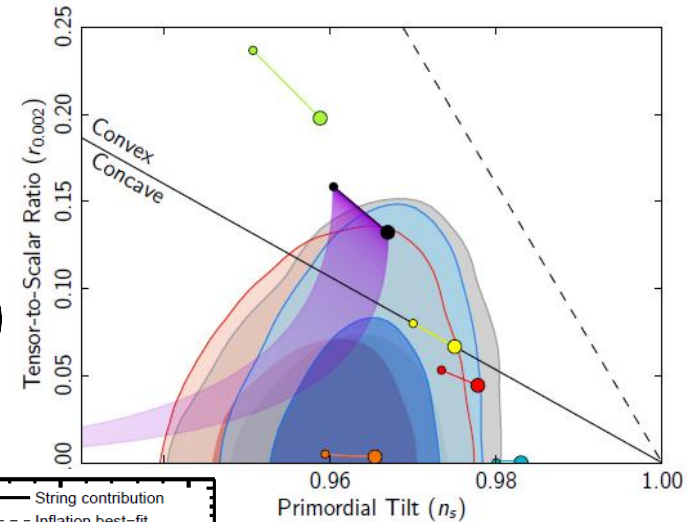
  associate with phase transition
- Cons

  apparently disfavored by current data.

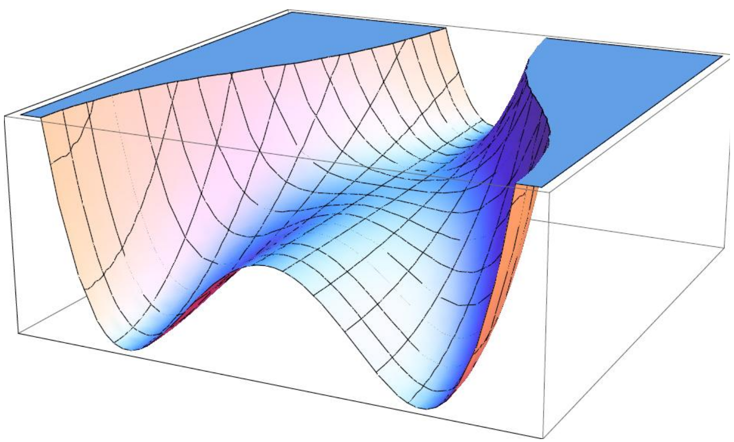
# SUSY Hybrid inflation is disfavored, isn't it?

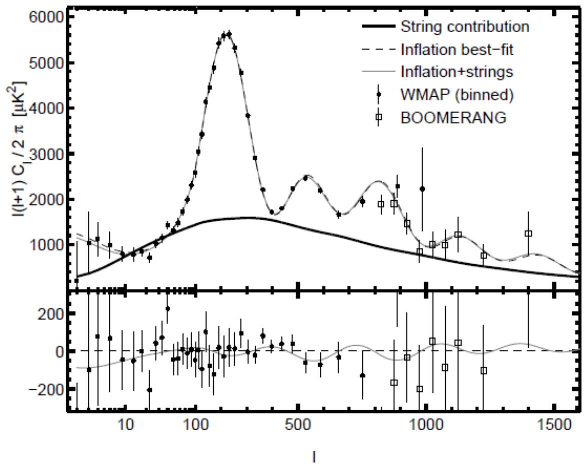
- Spectral index $n_s = 1 - 1/N$,

  $n_s \cong 0.98$ for $N = 50$




- Topological defect



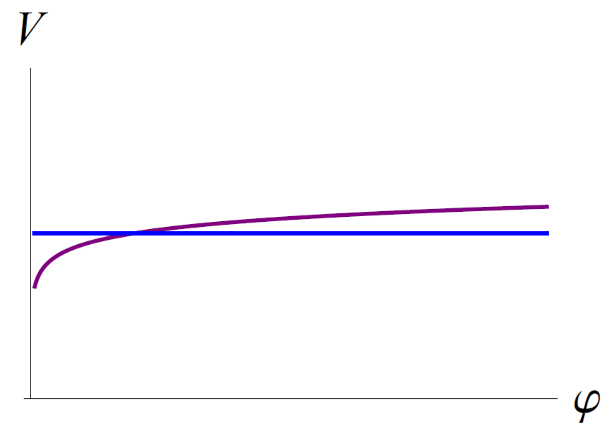



[Bevis et al(2008)]

- Tiny tensor < 0.02 [Civiletti et al (2014)] (for BICEP2)

# SUSY Hybrid inflation is disfavored How did we find this?

- $n_s = 1 - 1/N \cong 0.98$, $r_T \ll 1$ from




$n_s = 1 + 2\eta - 6\epsilon$

$r_T = 16\epsilon$ with

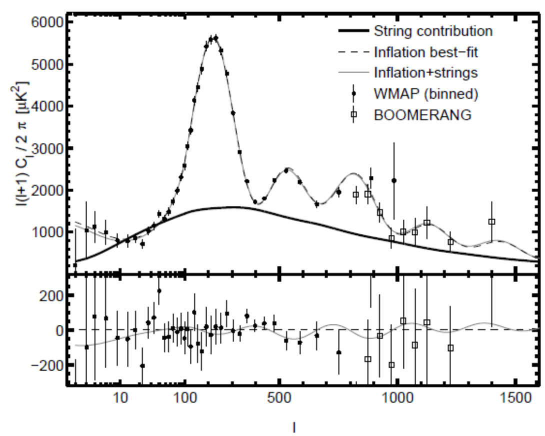
$\eta \sim -(y^2/4\pi^2)/\sigma^2$,

$\epsilon \sim (y^2/4\pi^2)^2/2\sigma^2$ $\underline{\ll \eta}$ true for $(y^2/4\pi^2) \ll \mathcal{O}(1)$

$\sigma^2/2 \sim (y^2/4\pi^2)\, N$

and

<u>N=50</u>



# SUSY Hybrid inflation is disfavored
# Toward $r_T \sim 0.1$…

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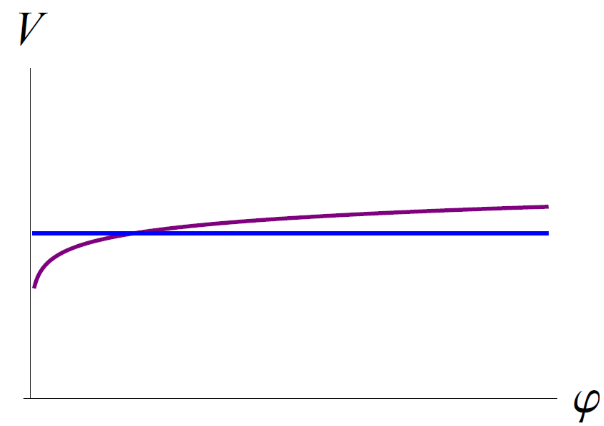


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$\sigma^2/2 \sim (y^2/4\pi^2)\, N$ → $r_T$ ⇑

and

<u>$N<50$</u> → $n_s$ ⇓ ⇓ ⇑ supergravity

# Is N<50 O.K?

- What to do with the horizon and flatness problem?
- N < 50 is by ONLY first hybrid inflation.

the Universe might undergo inflation twice.

``Double inflation'' [mid 80's ~ ]

- e.g.,

Any primordial inflation +``thermal inflation''
[Lyth and Stewart (1995)]

Chaotic inflation + new inflation [Yokoyama (1998),…]

# ``Double inflation''

- Total inflation = hybrid inflation(N~10)
  + any other inflation(N~40-50)

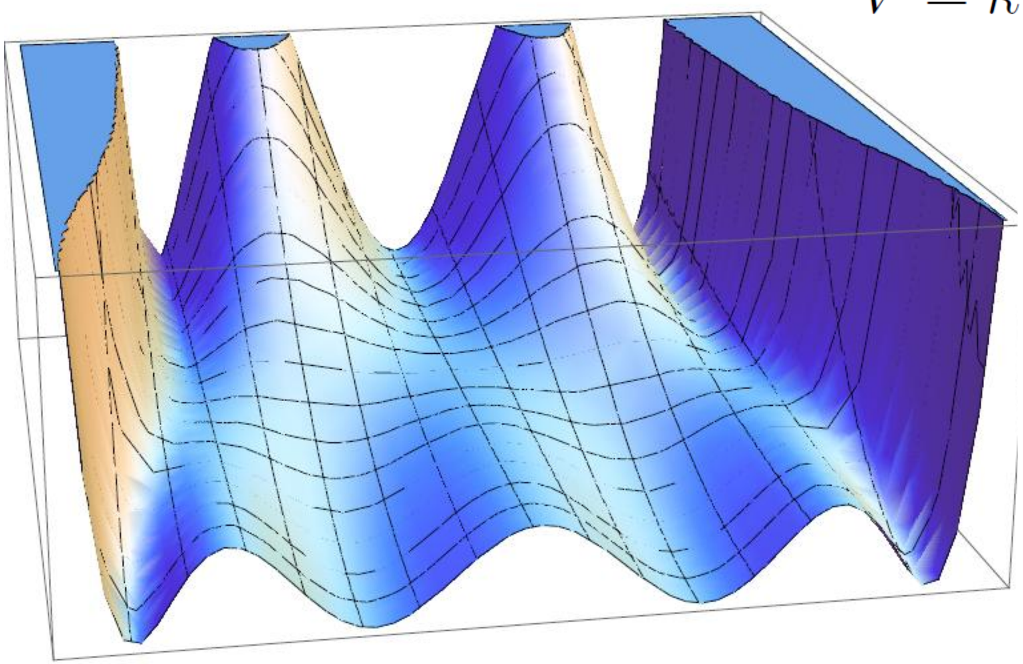
  hybrid(N~7)+hybrid(N~50) [Choi and Kyae (2014)]

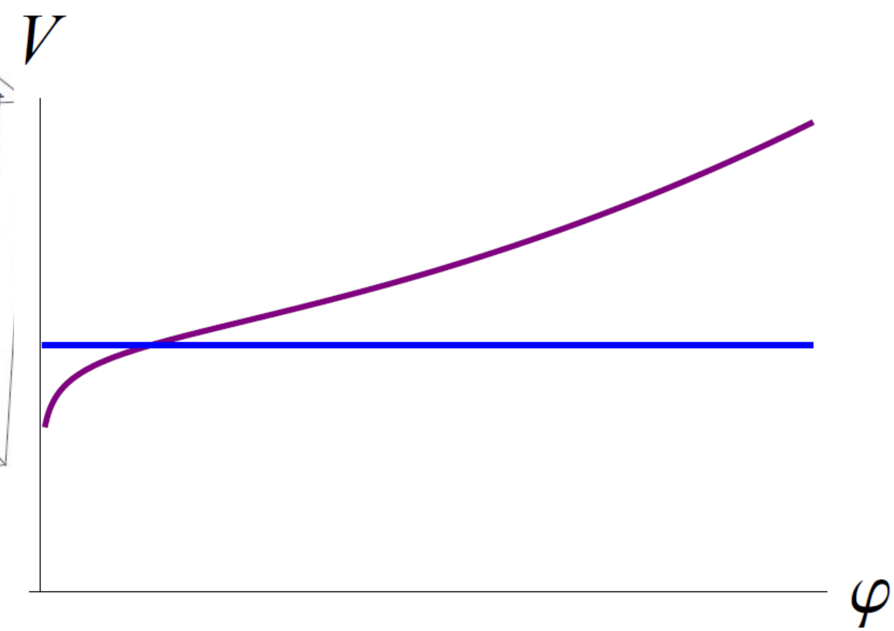
- Let me concentrate ``first hybrid inflation part''

# § SUSY hybrid inflation

- Potential

$$V = \kappa^2 \sigma_c^4 \left[ 1 + \frac{\kappa^2}{8\pi^2} \ln \frac{\sigma}{\Lambda} + \frac{1}{2} m^2 \sigma^2 + \ldots \right]$$

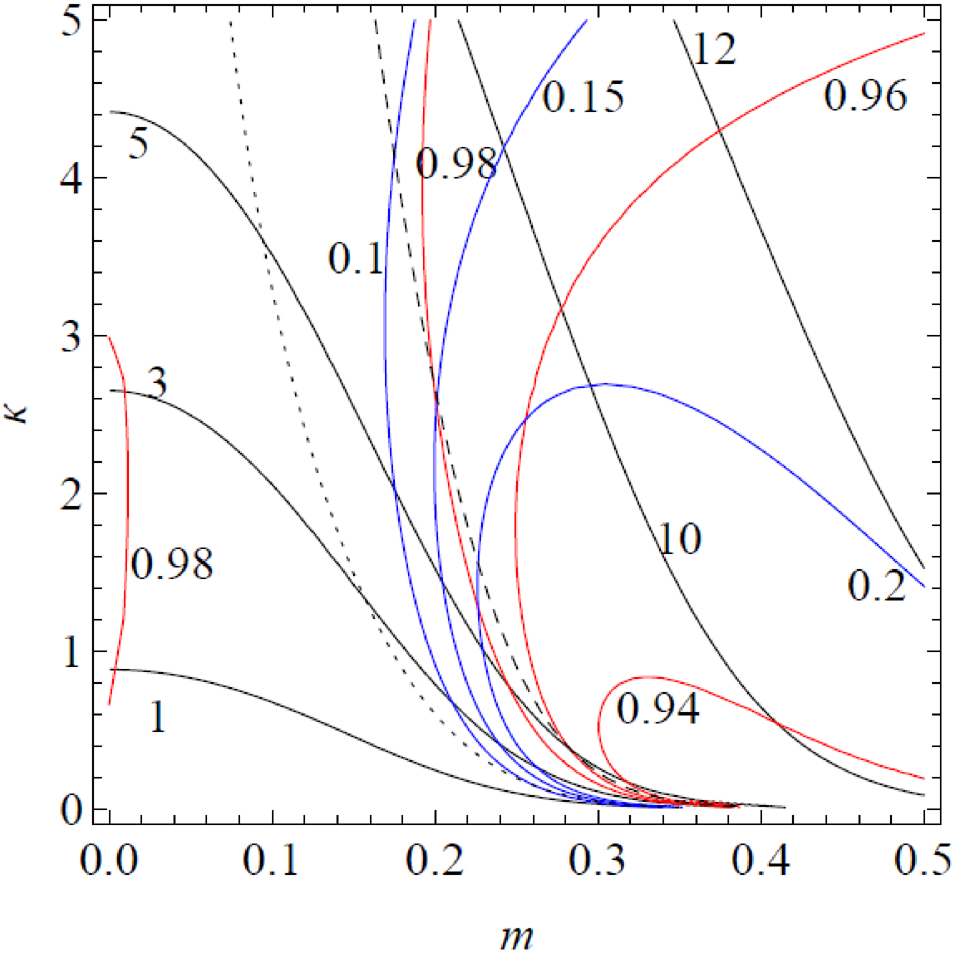


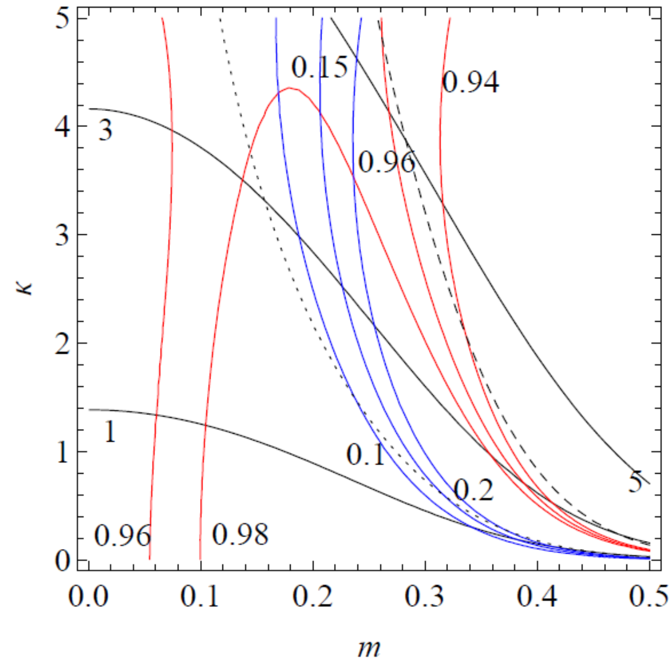



Shifted hybrid inflation [Jeannerot et al(2000)]

# § SUSY hybrid inflation

- Results N=50

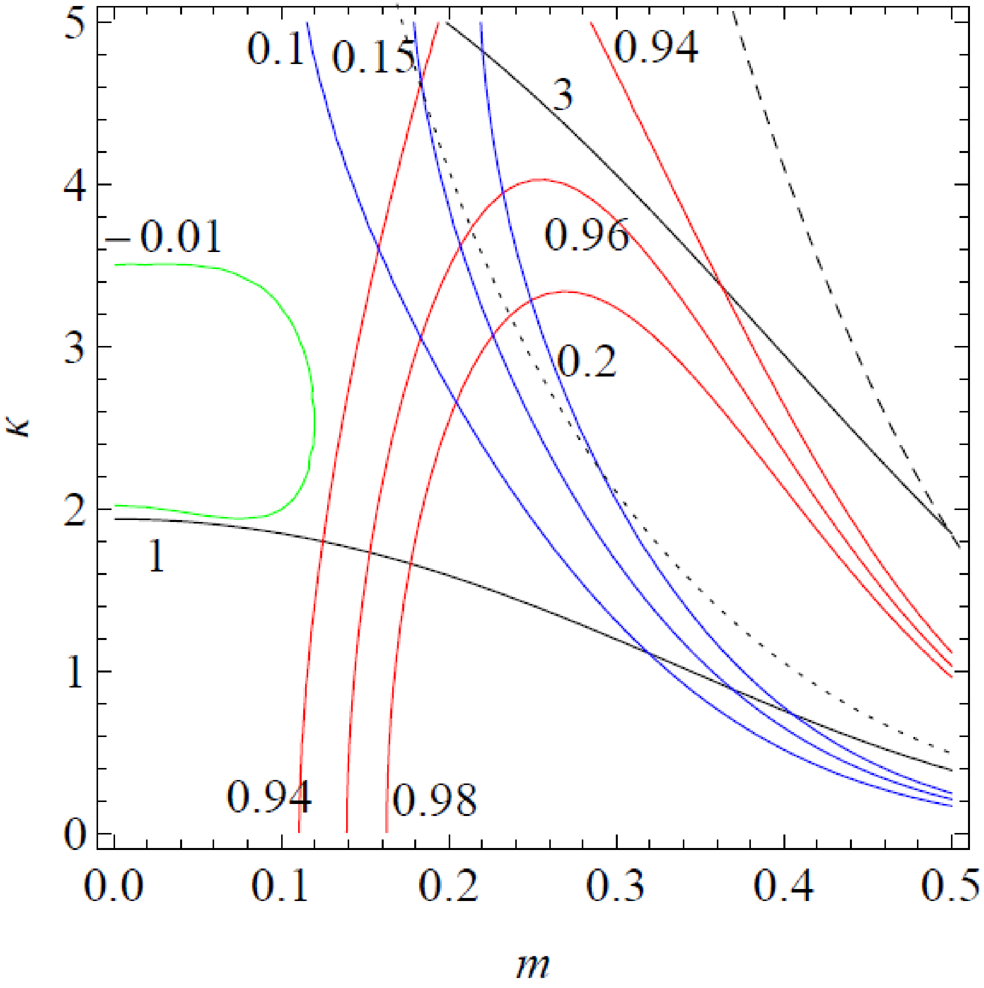



N=20

# § SUSY hybrid inflation

- Results     N=10

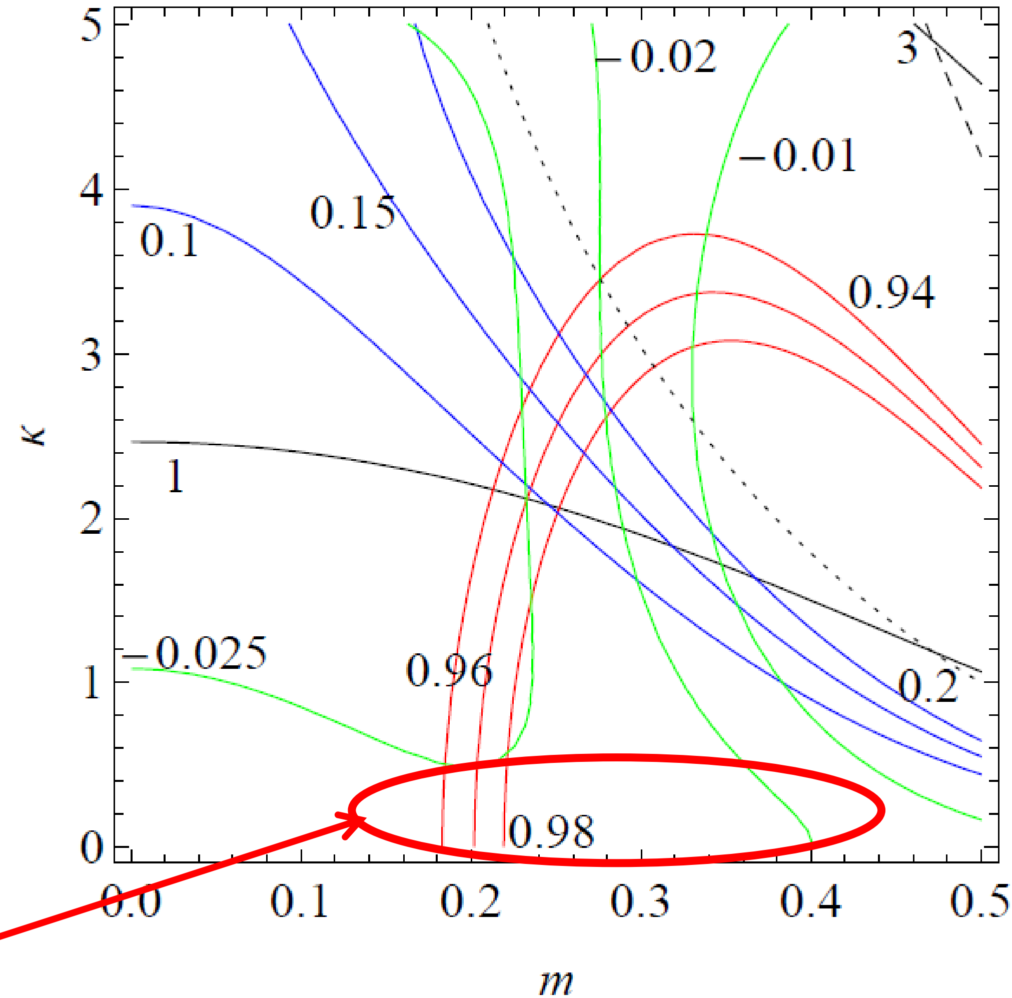


# § SUSY hybrid inflation

- Results N=6

One obvious modification is to allow the initial scalar perturbation spectrum to depart from the simple power law form which is assumed in the base ΛCDM model. A standard way in which this is done is by introducing a "running" parameter $dn_s/d\ln k$. In Planck Collaboration XVI (2013) the constraint relaxes to $r < 0.26$ (95% confidence) when running is allowed with $dn_s/d\ln k = -0.022 \pm 0.010$ (68%) (for the *Planck*+WP+highL data combination). In Figure 13 we show the constraint contours when allowing running as taken from Figure 23 of Planck Collaboration XVI (2013), and how these change when the BICEP2 data are added. The red contours on the plot are simply the Monte Carlo Markov Chains

BICEP2 ♥♥ Planck ?




[Kawasaki et al (2003)]

# § Summary

- SUSY hybrid inflation (non super-Plankian model) is still in part available and is able to reproduce $r_T$ of $\mathcal{O}$**(0.1)** (and/or $\alpha_s$).

  c.f. Tiny tensor < 0.02 [Civiletti et al (2014)]

- **What's new? N~10 and $\kappa$=$\mathcal{O}$(1)**

Note : a paper after ours [Pallis and Shafi (2014)]