# Inflation after BICEP2

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VOI

L(B) = 474 / 3 - (3 + 43) = 411/2

 $V\left(\phi\right) = M^{4} \left[1 - 2e^{-2\phi\left(\sqrt{6}Mm\right)}\right]$ 

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V@ Mecol Mar

 $V(\phi) = M^4$ 

V(0)=

V.Q.M.

 $V(\phi) = M^*$ 

**IAP** Discussion on BICEP2 results February 21, 2014

NP1

60

(¢ (\$\$0)

 $\int_{[3-p^2]}^{10} \frac{(90)}{(3-p^2)} \frac{\phi}{(3-p^2)} \frac{1}{(3-p^2)} \frac{1}{(3-$ 

Ø

2(n-3) 1P1 (55

× c05

 $V(\phi) = M^{\alpha}$ 

 $\left(\phi | M_{\rm Pl} \right)^2$ 

 $\alpha + (\phi | M_{Pl})^2$ 

V (6)=

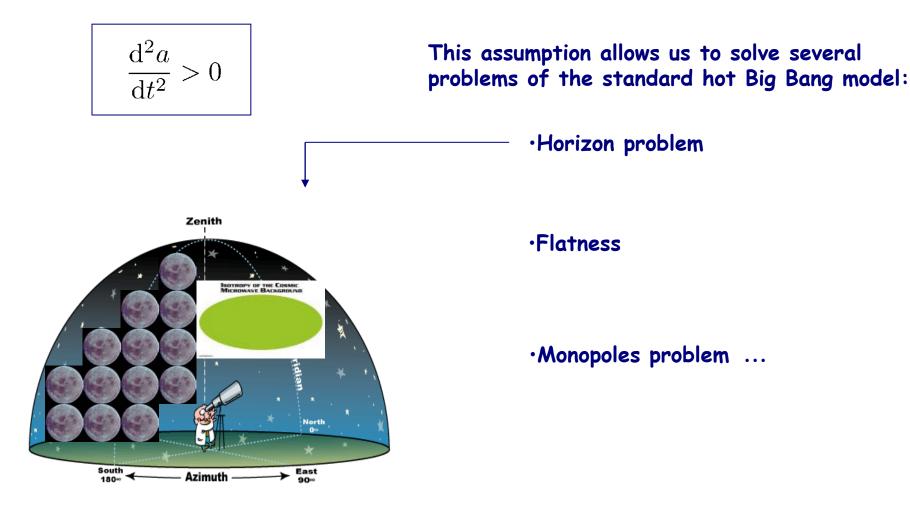
 $M^4(1)$ 

 $= M^4 \ln^2 \left( \frac{\phi}{\phi_0} \right)$ 

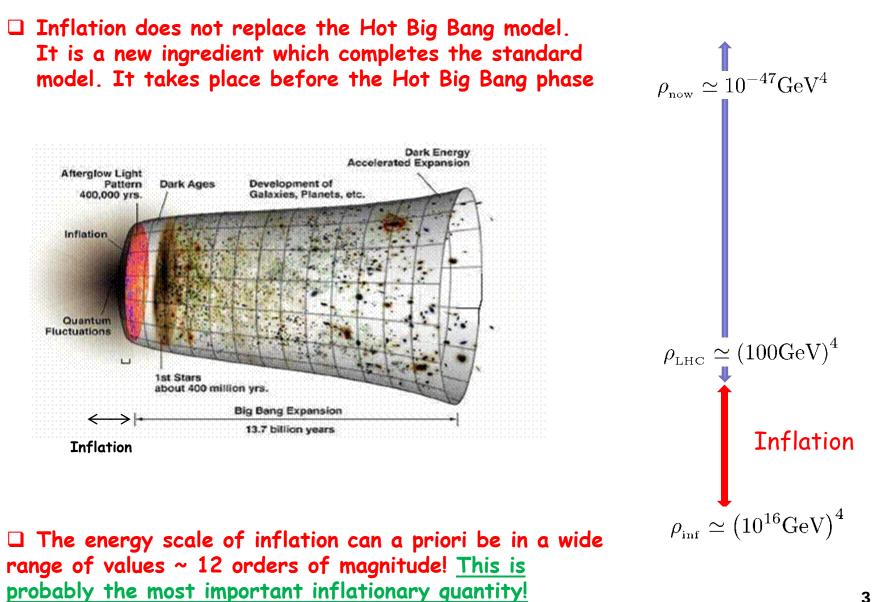
Thanks to C. Ringeval & V. Vennin for emergency figures, plots etc ...)



Inflation is a phase of <u>accelerated expansion</u> taking place in the very <u>early Universe</u>. The scale factor is such that

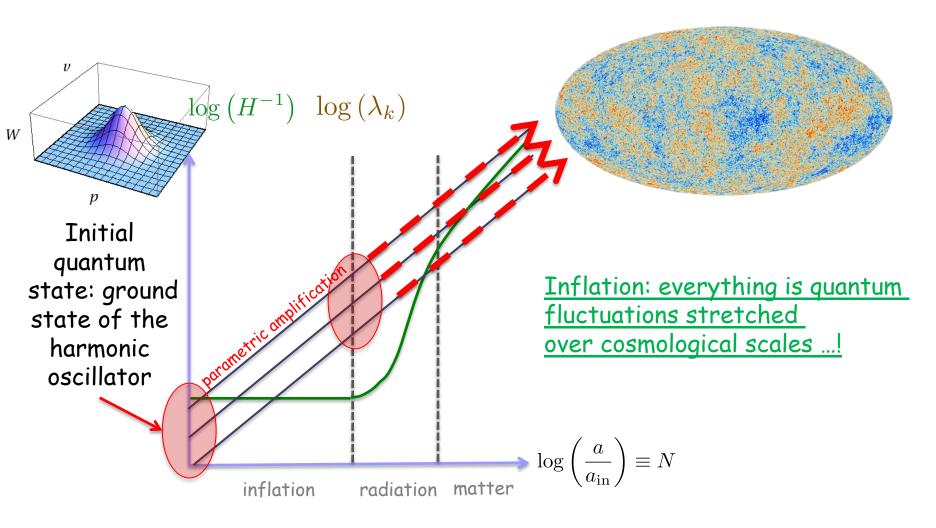






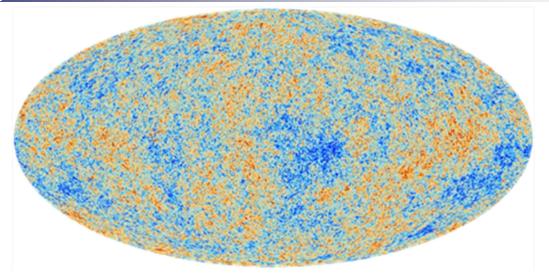


# Quantum fluctuations as seeds of CMB anisotropy and large scale structures



# Inflationary Observables



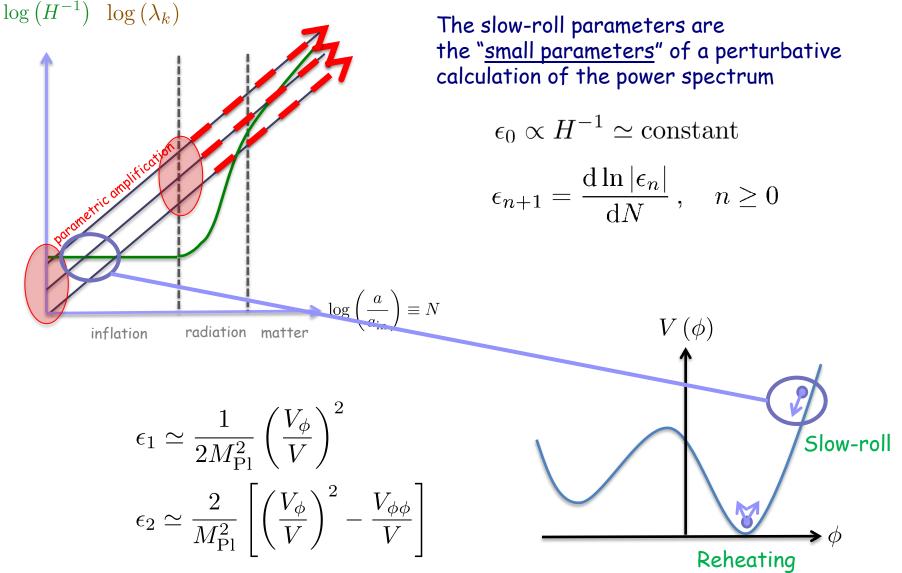


$$\frac{\delta T}{T}(\vec{e}) = \sum_{\ell m} a_{\ell m} Y_{\ell m}(\vec{e}) \longrightarrow \left\langle \frac{\delta T}{T}(\vec{e}_1) \frac{\delta T}{T}(\vec{e}_2) \right\rangle = \sum_{\ell=2}^{+\infty} \frac{2\ell+1}{4\pi} C_\ell P_\ell(\cos\theta)$$

with

$$C_{\ell} = \langle a_{\ell m} a_{\ell m}^* \rangle = \int_{0}^{+\infty} \frac{\mathrm{d}k}{k} j_{\ell}^2 (kr_{\mathrm{lss}}) T(k; \theta_{\mathrm{stand}}) \mathcal{P}_{\zeta} (k; \theta_{\mathrm{reh}}, \theta_{\mathrm{inf}})$$
Translate 3d into 2d   
Describes the evolution of the pertubations when they re-enter the Hubble radius 5





Inflationary predictions: the two-point correlation function



$$\mathcal{P}_{\zeta} = \frac{H^2}{\pi \epsilon_1 m_{_{\mathrm{Pl}}}^2} \left[ 1 - 2\left(C + 1\right)\epsilon_1 - C\epsilon_2 - \left(2\epsilon_1 + \epsilon_2\right)\ln\left(\frac{k}{k_{_{\mathrm{P}}}}\right) \right]$$

$$\mathcal{P}_h = \frac{16H^2}{\pi m_{_{\mathrm{Pl}}}^2} \left[ 1 - 2\left(C + 1\right)\epsilon_1 - 2\epsilon_1\ln\left(\frac{k}{k_{_{\mathrm{P}}}}\right) \right]$$
The amplitude is controlled by H

- For the scalar modes, the amplitude also depends on  $\epsilon_{\ 1}$ 

- C~ -0.7

The power spectra are scale-invariant plus logarithmic corrections the amplitude of which depend on the sr parameters, ie on the <u>microphysics of inflation</u>

#### **Consistency relation:**

$$r = \frac{T}{S} \equiv \frac{\mathcal{P}_h}{\mathcal{P}_{\zeta}} = 16\epsilon_1 = -8n_{\rm T}$$

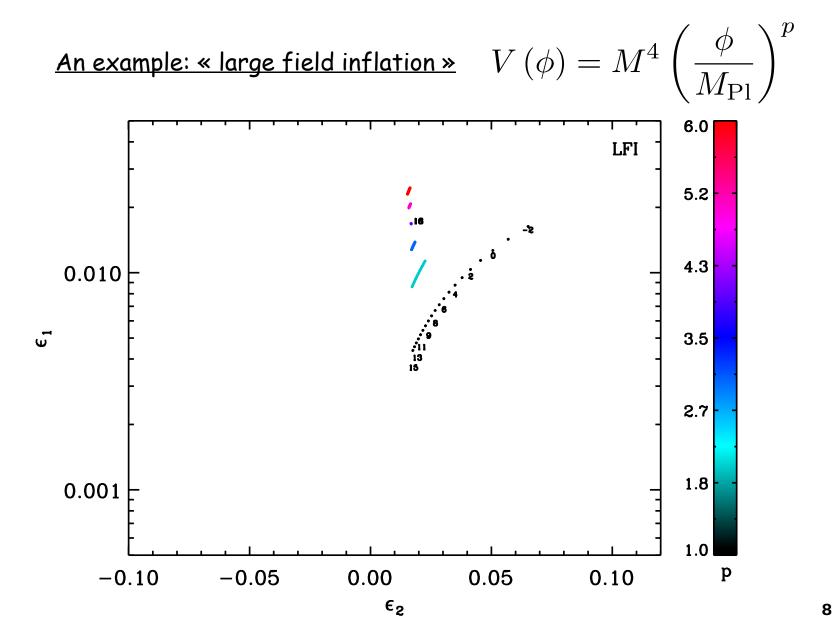
Gravitational waves are subdominant

The spectral indices are given by

$$n_{\rm s} - 1 \equiv \frac{\mathrm{d}\ln\mathcal{P}_{\zeta}}{\mathrm{d}\ln k}, \ n_{\rm T} \equiv \frac{\mathrm{d}\ln\mathcal{P}_{h}}{\mathrm{d}\ln k}$$

$$n_{\rm s} - 1 = -2\epsilon_1 - \epsilon_2, \quad n_{\rm T} = -2\epsilon_1$$

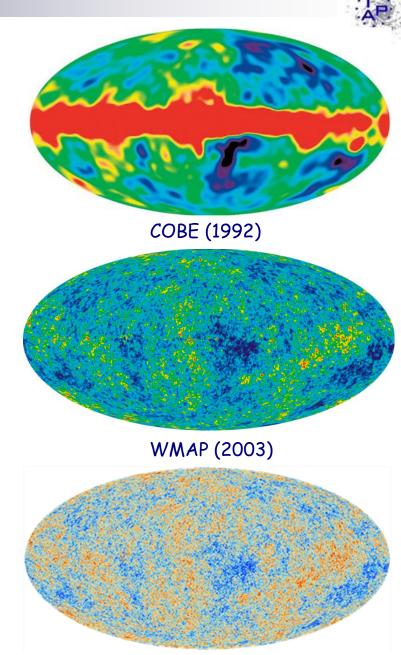




# Planck results in brief:

 $100 \,\Omega_{\kappa} = -0.05^{+0.65}_{-0.66}$  $\alpha_{\mathcal{R}CDI}^{(2,2500)} \in [-0.093, 0.014]$  $n_{\rm s} = 0.9603 \pm 0.0073$  $\frac{\mathrm{d}n_{\mathrm{s}}}{\mathrm{d}\ln k} = -0.0134 \pm 0.009$  $f_{_{\rm NIL}}^{
m loc} = 2.7 \pm 5.8$  $f_{\rm \tiny NL}^{\rm eq} = -42 \pm 75$  $f_{_{\rm NL}}^{
m ortho} = -25 \pm 39$ 

# Flat universe with adiabatic, Gaussian and almost scale invariant fluctuations





# Message 1: the energy scale of inflation

Before BICEP2

$$\mathcal{P}_{h} \simeq \left(\frac{H}{m_{\rm Pl}}\right)^{2} < \mathcal{O}(1) \left(\frac{\delta T}{T}\right)^{2} \simeq 10^{-10} \implies$$

Upper bound on the energy scale of inflation ~ less than the GUT scale



# Message 1: the energy scale of inflation

Before BICEP2

$$\mathcal{P}_h \simeq \left(\frac{H}{m_{_{\mathrm{Pl}}}}\right)^2 < \mathcal{O}(1) \left(\frac{\delta T}{T}\right)^2 \simeq 10^{-10} \quad \Longrightarrow$$

Upper bound on the energy scale of inflation ~ less than the GUT scale

After BICEP2

$$\mathcal{P}_h \simeq \left(\frac{H}{m_{_{\mathrm{Pl}}}}\right)^2 \simeq 0.2 \left(\frac{\delta T}{T}\right)^2 \simeq 0.2 \times 10^{-10} \longrightarrow$$

Energy scale of inflation measured to be ~ the GUT scale

$$H \simeq 1.23 \left(\frac{r}{0.2}\right)^{1/2} 10^{14} \text{GeV}$$
$$\rho^{1/4} \simeq 2.26 \left(\frac{r}{0.2}\right)^{1/4} 10^{16} \text{GeV}$$

### Planck vs BICEP2

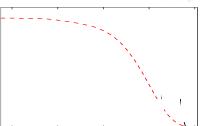


# Message 2: first derivative of the potential

Before BICEP2

$$r = \frac{T}{S} = 16\epsilon_1 = \frac{8}{M_{\rm Pl}^2} \left(\frac{V_\phi}{V}\right)^2 < \mathcal{O}(1) \quad -$$

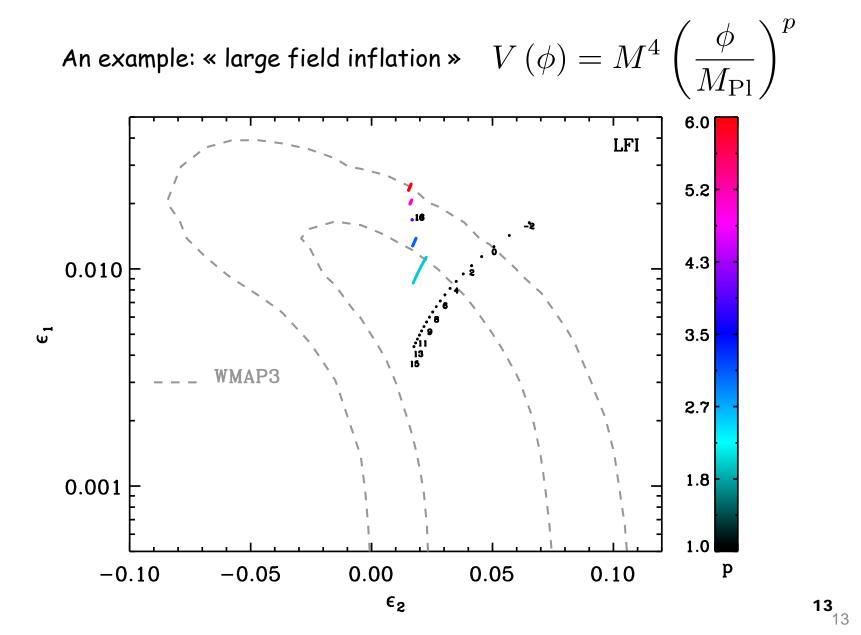
Upper bound
 on the value of
 the first
 derivative



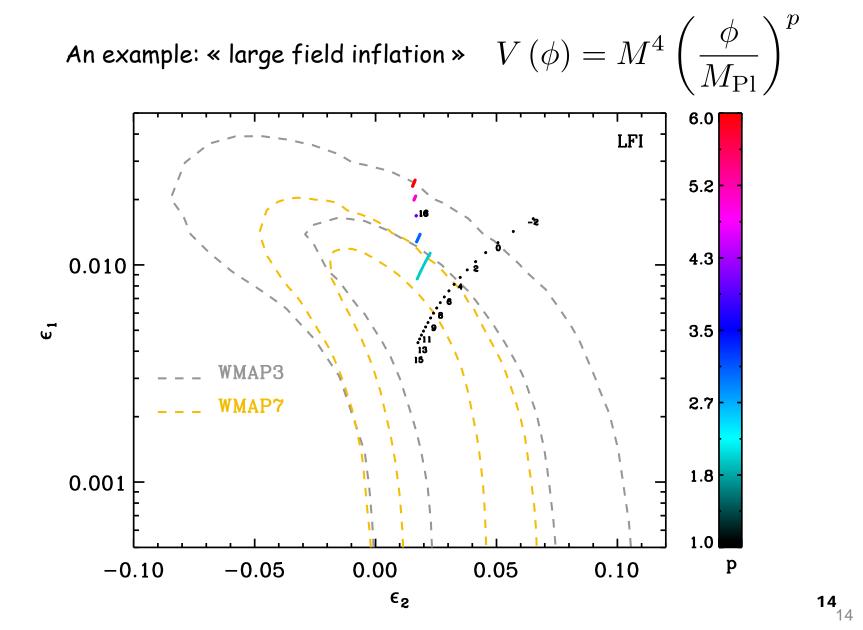
| $n_{\rm s}$ – | 1 = | $-2\epsilon_1$ | $-\epsilon_2 \simeq$ | 0.96 | $\rightarrow$ |
|---------------|-----|----------------|----------------------|------|---------------|
|---------------|-----|----------------|----------------------|------|---------------|

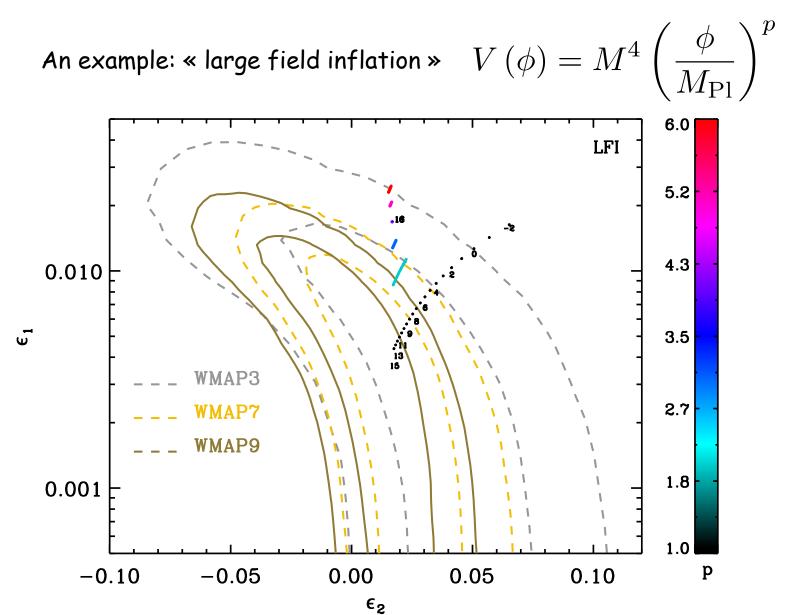
Second sr parameter measured!



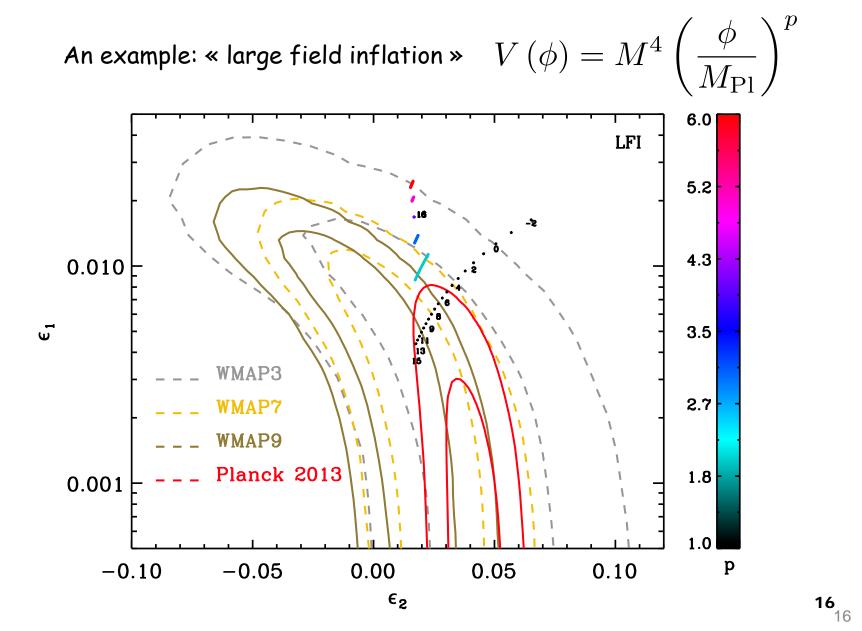








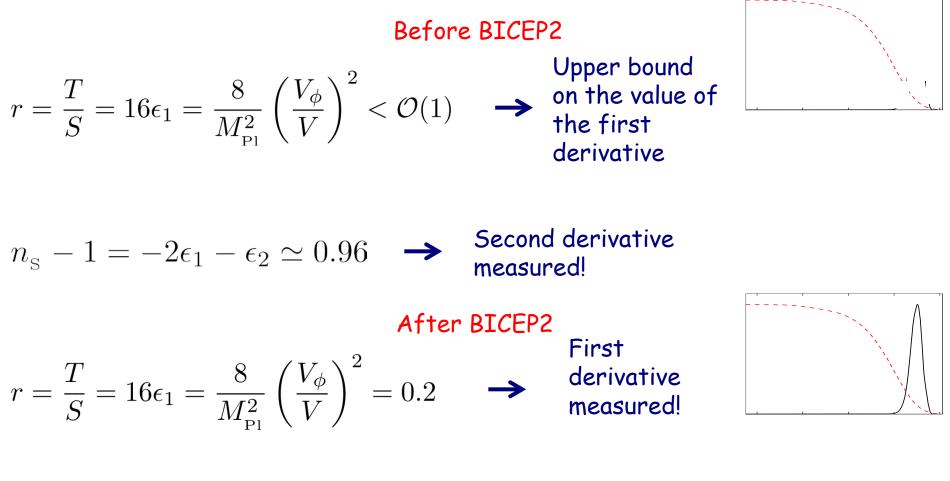




#### Planck vs BICEP2



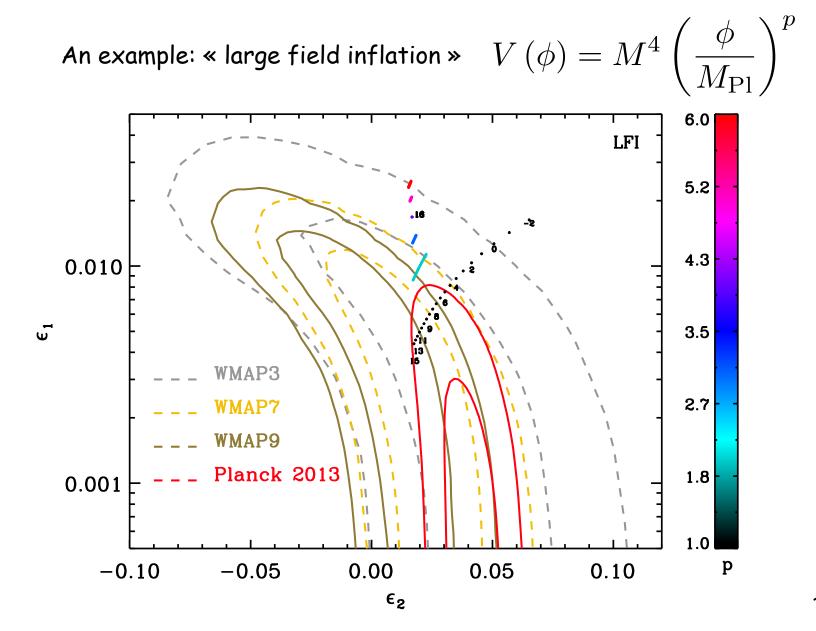
# Message 2: first derivative of the potential



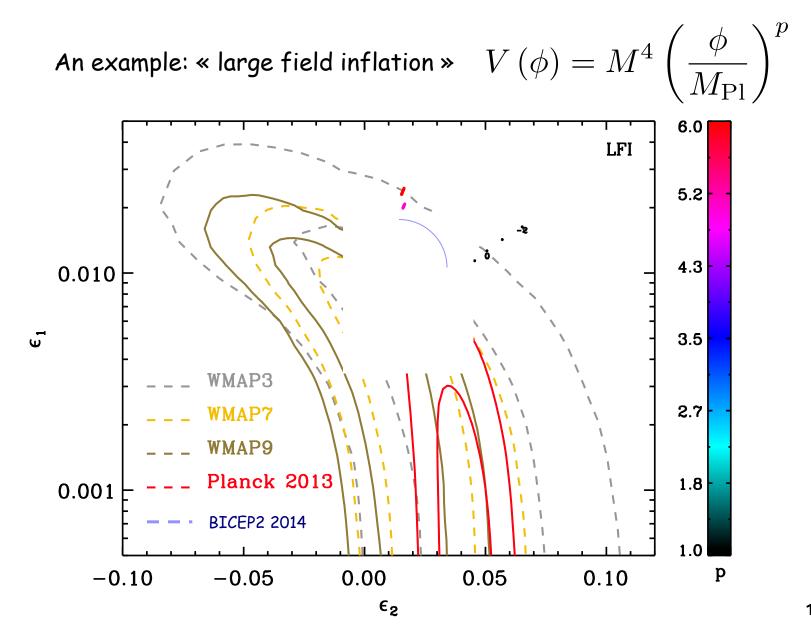
$$n_{\rm s} - 1 = -2\epsilon_1 - \epsilon_2 \simeq 0.96$$

Second derivative measured but different value











# Before BICEP2

#### Bayesian Evidences $\log(\mathcal{E}/\mathcal{E}_{\rm HI})$

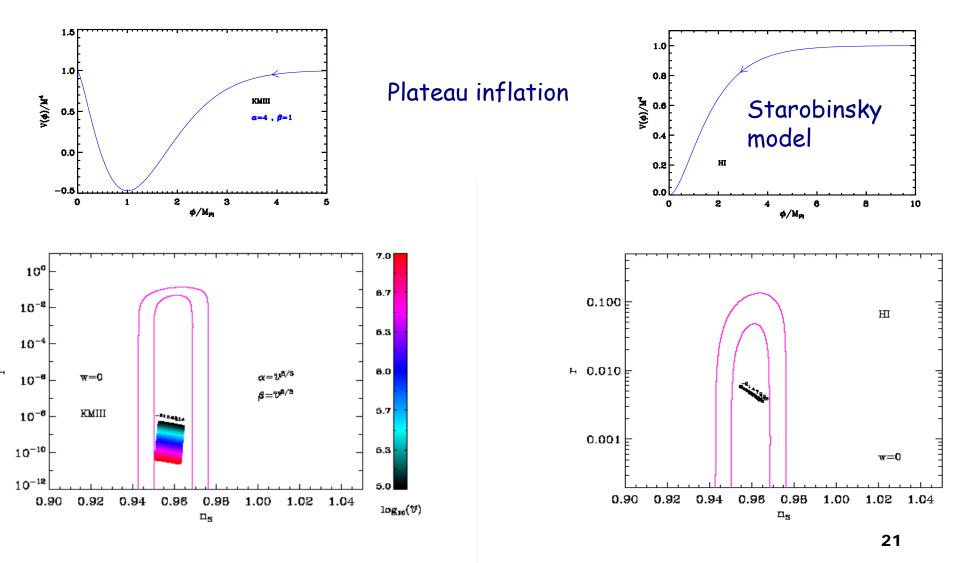
| ESI         0.0           ESI,         0.0           ESI,         0.0           ESI,77         0.0           GMSSME,0.0         0.0           GMSTME,0.0         0.0           GMSSME,0.0         0.0           KKUTT,0.0         0.0           KKUTI,0.0         0.0           KKMIT 0.0         0.0           KMIT 0.0         0.0           MSME,0.0         0.0           MSSME,0.0         0.0           MSSME,0.0         0.0           KCH,0.0         0.0           RCH,0.0         0.0           RCH,0.0         0.0           RCH,0.0         0.0           RCH,0.0         0.0           RCH,0.0         0.0 </th <th>SFLa       0.0         SFL       0.0         LMEL       0.0         LMEL       0.0         LMEL       0.0         LFSL       0.0         LFSL<th><math display="block">\begin{array}{c} &amp; &amp; &amp; &amp; &amp; &amp; &amp; \\ &amp; &amp; &amp; &amp;</math></th><th>(SNCI 0.0<br/>(SNEI 0.0<br/>(SNESME_1 0.0)<br/>(SNESME_1 0.0<br/>(SNESME_1 0.0)<br/>(SNESME_1 0.0)<br/>(S</th></th> | SFLa       0.0         SFL       0.0         LMEL       0.0         LMEL       0.0         LMEL       0.0         LFSL       0.0         LFSL <th><math display="block">\begin{array}{c} &amp; &amp; &amp; &amp; &amp; &amp; &amp; \\ &amp; &amp; &amp; &amp;</math></th> <th>(SNCI 0.0<br/>(SNEI 0.0<br/>(SNESME_1 0.0)<br/>(SNESME_1 0.0<br/>(SNESME_1 0.0)<br/>(SNESME_1 0.0)<br/>(S</th> | $\begin{array}{c} & & & & & & & \\ & & & &$  | (SNCI 0.0<br>(SNEI 0.0<br>(SNESME_1 0.0)<br>(SNESME_1 0.0<br>(SNESME_1 0.0)<br>(SNESME_1 0.0)<br>(S  |
|--|---|--|--|
| ESA         0.0           ESA,         0.0           ESA,77         0.0           GMSSME <sub>sph</sub> 0.0           KMIT         0.0           MSME         0.0           MSSME         0.0           MSSME         0.0           MSSME         0.0           KCMI, 0.0         RCH           RCH         0.0           RCH         0.0           RCH         0.0           RCH         0.0           RCH <t< td=""><td>SFL       0.0         SFL       0</td><td><math display="block">\begin{array}{cccccccccccccccccccccccccccccccccccc</math></td><td>(SHE) 0.0<br/>(SE 0.0)<br/>(SE 0.0<br/>(SE 0.0)<br/>(SE 0.0<br/>(SE 0.0)<br/>(SE 0.0<br/>(SE 0.0)<br/>(SE 0.0)</td></t<>   | SFL       0.0         SFL       0   | $\begin{array}{cccccccccccccccccccccccccccccccccccc$   | (SHE) 0.0<br>(SE 0.0)<br>(SE 0.0<br>(SE 0.0)<br>(SE 0.0<br>(SE 0.0)<br>(SE 0.0<br>(SE 0.0)<br>(SE 0.0)  |
| FSL         0.0           FSL         0.0           FSL         0.0           GMSSME <sub>mb</sub> 0.0           GMSSME <sub>mb</sub> 0.0           GREPLaps         0.0           KAUTT         0.0           KKRIT         0.0   | SFL       0.0         SFL       0   | $\begin{array}{cccccccccccccccccccccccccccccccccccc$   | (SHE) 0.0<br>(SE 0.0)<br>(SE 0.0<br>(SE 0.0)<br>(SE 0.0<br>(SE 0.0)<br>(SE 0.0<br>(SE 0.0)<br>(SE 0.0)  |
| FSL         0.0           FSL         0.0           FSL(T)         0.0           GMSSME <sub>max</sub> 0.0           GMSSME <sub>max</sub> 0.0           GMSSME <sub>max</sub> 0.0           GREPL <sub>ops</sub> 0.0           KKETT         0.0           KKETT         0.0           KKETT         0.0           KKET         0.0           MSE         0.0           MSE         0.0           MSE         0.0           MSE         0.0           KSE         0.0           SCKL         0.0           RCE         0.0           RCE         0.0   | SFL       0.0         SFL       0   | $\begin{array}{cccccccccccccccccccccccccccccccccccc$   | (SEE) 0.0<br>(SEE) 0.0   |
| FSL         0.0           FSL         0.0           FSL         0.0           GMSSME <sub>mb</sub> 0.0           GMSSME         0.0           GMSSME         0.0           KMIT         0.0           MSE         0.0           MSE         0.0           MSSME_         0.0           RCH         0.0  | SFL       0.0         LMEL       0.0         LMEL <td><math display="block">\begin{array}{cccccccccccccccccccccccccccccccccccc</math></td> <td>(SEE 0.0<br/>(SEE 0.0<br/>(SEE 0.0<br/>ISE 0.0</td>   | $\begin{array}{cccccccccccccccccccccccccccccccccccc$   | (SEE 0.0<br>(SEE 0.0<br>(SEE 0.0<br>ISE 0.0   |
| FSL         0.0           FSL         0.0           FSL(T)         0.0           GMSSME <sub>mb</sub> 0.0           GMSTM <sub>mb</sub> 0.0           GMSTM <sub>mb</sub> 0.0           GMSTM <sub>mb</sub> 0.0           GMSTM <sub>mb</sub> 0.0           KALTT         0.0           KALTT         0.0           KALTT         0.0           KALTT         0.0           KALTT <sub>s</sub> 0.0           KALTT <sub>s</sub> 0.0           KALTT <sub>s</sub> 0.0           KALT <sub>s</sub> 0.0           KALT <sub>s</sub> 0.0           MSME         0.0           MSME         0.0           MSSME         0.0           MSSME         0.0           MSSME         0.0           SCST         0.0           RCSH         0.0   | SFL       0.0         LMEL  | $\begin{array}{cccccccccccccccccccccccccccccccccccc$   | (SHE) 0.0<br>(SH 0.0)<br>(SH 0.0<br>(SH 0.0<br>(SH 0.0)<br>(SH 0.0<br>(SH 0.0)<br>(SH 0.0<br>(SH 0.0)<br>(SH 0.0<br>(SH 0.0)<br>(SH 0.0   |
| FSL         0.0           FSL         0.0           FSL(T)         0.0           GMSSME <sub>mb</sub> 0.0           GMSTM <sub>mb</sub> 0.0           GMSTM <sub>mb</sub> 0.0           KMTT         0.0           MSE         0.0           MSE         0.0           MSSME         0.0           MSSME         0.0           MSSME         0.0           SCH1 <sub>A10</sub> 0.0           MSCH1 <sub>A10</sub> 0.0           MSSME         0.0           SCH1         0.0  | SFLs       0.0         SFL       0.0         LMEL       0.0   | $\begin{array}{cccccccccccccccccccccccccccccccccccc$   | (SHE 0.0<br>(SHE 0.0<br>TOR 0.0<br>T   |
| FSL         0.0           FSL,         0.0           FSL,77         0.0           GMSSME_mA         0.0           GMSTM_mA         0.0           GMSTM_mA         0.0           KMIT         0.0           KMIT         0.0           KMIT         0.0           KMIT         0.0           MARA         0.0           MARA         0.0           MARA         0.0           MARA         0.0           MARA         0.0           MSSME_NO  | SFL       0.0         SFL       0   | IFI         0.0           IFINIA         0.0   | (SEE 0.0<br>(SEE 0   |
| ESL         0.0           ESL         0.0           ESL         0.0           ESL         0.0           GMSSME <sub>0.0</sub> 0.0           GMSTM <sub>0.00</sub> 0.0           GMSTM <sub>0.00</sub> 0.0           GMSTM <sub>0.00</sub> 0.0           KMT         0.0           MBE         0.0           MBE         0.0           MSEN         0.0           MSEN         0.0           MSEN         0.0           MSEN         0.0  | SFL       0.0         SFL       0.0         SFL       0.0         SFL       0.0         SFL       0.0         SHL2       0.0         SHL3       0.0         SHL4       0.0         SHL5       0.0         SHL5       0.0         SHL4       0.0         SHL5       0.0         SHL4       0.0         SHL5       0.0         SHL6       0.0         SHL6       0.0         SHL6       0.0         SHL6       0.0         SHL6       0.0         SHL6       0.0   | IFI         0.0           NK         0.0           NK         0.0           IFI         0.0           IFI         0.0           IFI         0.0           IFI         0.0           IFI         0.0           IFI         0.0           IFINIAL         0.0  | (SHE) 0.0<br>(SH |
| ESL         0.0           ESL         0.0           ESL         0.0           ESL         0.0           GMSSME_m         0.0           KMIT         0.0           KMIT         0.0           KMIT         0.0           KMIT         0.0           KMIT         0.0           KMIT         0.0           MSEME_m         0.0           MMEL         0.0           MMEL         0.0           MSEME_m         0.0           MSEME_m         0.0   | SFLa 0.0<br>SFL 0.0<br>SF  | IFI         0.0           IFIN         0.0   | (SHE) 0.0<br>(SH 0.0)<br>(SH 0.0<br>(SH 0.0<br>(SH 0.0)<br>(SH 0.0<br>(SH 0.0)<br>(SH 0.0<br>(SH 0.0)<br>(SH 0.0)   |
| ESL         0.0           ESL         0.0           ESL         0.0           ESL         0.0           GAMESNE <sub>RA</sub> 0.0           KKETT         0.0           KKETT         0.0           KKHT         0.0           MEK         0.0           MEK         0.0           MEK         0.0           MEK         0.0           MEK         0.0   | SFL       0.0         SFL       0.0         SFL       0.0         SFL       0.0         SFL       0.0         SHL2       0.0         SHL5       0.0         SHL6       0.0         SHL7       0.0         SHL8       0.0         SHL8       0.0         SHL9       0.0  | IFI         0.0           IFINI         0.0  | (SHD 0.0<br>(SHD 0.0<br>(SH 0.0<br>ISH 0.0<br>ISH 0.0<br>ISH 0.0<br>ISH 0.0<br>INI 0.0<br>I   |
| ESL         0.0           ESL         0.0           ESL         0.0           ESL         0.0           GMSSME <sub>0.0</sub> 0.0           GMSSME <sub>0.0</sub> 0.0           GMSSME <sub>0.0</sub> 0.0           GREPL <sub>0.0</sub> 0.0           GREPL <sub>0.0</sub> 0.0           GREPL <sub>0.0</sub> 0.0           GREPL <sub>0.0</sub> 0.0           KRLT         0.0           KRLT         0.0           KRLT         0.0           KRET_0.0         0.0           KRET_0.0         0.0           KRET_0.0         0.0           KMET         0.0           KMET         0.0           KMET         0.0           KMET         0.0           KMET         0.0           MER         0.0           MER         0.0           MER         0.0           MER         0.0   | SFL       0.0   | IFI         0.0           IFIN         0.0 <td< td=""><td>(SEE 0.0<br/>(SEE 0.0)<br/>(SEE 0.0<br/>(SEE 0.0)<br/>(SEE 0.0<br/>(SEE 0.0)<br/>(SEE 0.</td></td<> | (SEE 0.0<br>(SEE 0.0)<br>(SEE 0.0<br>(SEE 0.0)<br>(SEE 0.0<br>(SEE 0.0)<br>(SEE 0.   |
| ESL         0.0           ESL         0.0           ESL         0.0           ESL         0.0           GMSSME <sub>0.0</sub> 0.0           GMSSME <sub>0.0</sub> 0.0           GMSSME <sub>0.0</sub> 0.0           GREPL <sub>0.0</sub> 0.0           GREPL <sub>0.0</sub> 0.0           GREPL <sub>0.0</sub> 0.0           KKUT         0.0           KMIT         0.0           KMIT         0.0           KMIT         0.0           KMIT         0.0           KMIT         0.0           KMIT         0.0           MIH         0.0  | SFLs 0.0<br>SFL 0.0<br>SFL 0.0<br>SFL 0.0<br>SFL 0.0<br>SRH2 0.0  | IFI         0.0           IFINIA         0.0   | (SHE) 0.0<br>(SH 0.0)<br>(SH 0.0<br>(SH 0.0)<br>(SH 0.0<br>(SH 0.0)<br>(SH 0.0)<br>(SH 0.0<br>(SH 0.0)<br>(SH 0   |
| ESL         0.0           ESL         0.0           ESL         0.0           ESL         0.0           GMSSME <sub>0.0</sub> 0.0           GMSTP <sub>0.00</sub> 0.0           KKUTT         0.0           KKUTT         0.0           KKUT         0.0           KU         0.0  | SFL         0.0   | IFI         0.0           IFIN         0.0   | (SHI) 0.0<br>(SH 0.0)<br>(SH 0.0<br>(SH 0.0)<br>(SH 0.0<br>(SH 0.0)<br>(SH   |
| ESL         0.0           ESL         0.0           ESL         0.0           ESL         0.0           ESL         0.0           GAMESNE <sub>RA</sub> 0.0           KARTT <sub>RA</sub> 0.0           KARTT <sub>RA</sub> 0.0           KART <sub>RA</sub> 0.0   | SFL         0.0   | IFI         0.0           IFINI         0.0           IFINI         0.0           IFINI         0.0           IFINI         0.0           IFINI         0.0           IFINI         0.0  | (SHD 0.0<br>(SHD 0.0<br>(SH 0.0<br>ISH 0.0<br>I   |
| ESL         0.0           ESL         0.0           ESL         0.0           ESL         0.0           GMSSME <sub>0.0</sub> 0.0           KMIT         0.0  | SFLa         0.0           SFL         0.0           SFFL         0.0  | IFI         0.0           IFIN         0.0           IFIN         0.0           IFIN         0.0           IFIN         0.0  | (SEE 0.0<br>(SEE 0.0)<br>(SEE 0.0<br>(SEE 0.0)<br>(SEE 0.0)<br>(SEE 0.0)<br>(SEE 0.0)  |
| ESL         0.0           ESL         0.0           ESL         0.0           ESL         0.0           GMSSME <sub>0.0</sub> 0.0           GMSSME <sub>0.0</sub> 0.0           GMSSME <sub>0.0</sub> 0.0           GMSSME <sub>0.0</sub> 0.0           GMSTM <sub>0.00</sub> 0.0           GMSTM <sub>0.00</sub> 0.0           GMSTM <sub>0.00</sub> 0.0           GMSTM <sub>0.00</sub> 0.0           KMIT         0.0   | SFL 0.0<br>SFL 0.0<br>SFL 0.0<br>SFL 0.0<br>SFL 0.0<br>SERI2 0.0   | IFI         0.0           IFINIA         0.0           IFINIA         0.0           IFINIA         0.0   | (9811 0.0<br>(981 0.0<br>(981 0.0<br>(984 0.0<br>(984 0.0<br>(984 0.0<br>(984 0.0<br>(984 0.0)<br>(984 0.0<br>(984 0.0)<br>(984 0.0<br>(984 0.0)<br>(984 0.0)<br>(984 0.0)<br>(984 0.0)<br>(984 0.0)   |
| ESL         0.0           ESL         0.0           ESL,72         0.0           ESL,72         0.0           GMMSSNE <sub>0.00</sub> 0.0           GMMSSNE <sub>0.00</sub> 0.0           GENEFI <sub>0.00</sub> 0.0           GENEFI <sub>0.00</sub> 0.0           GENEFI <sub>0.00</sub> 0.0           KKRLTL         0.0           KKRLTL         0.0           KKRLTL         0.0           KKRLTL         0.0           KKRIT         0.0           KKRIT         0.0           KKRIT         0.0           KKRIT         0.0           KKRIT         0.0   | SFL         0.0   | IFI         0.0  | (3811)<br>(381)<br>(381)<br>(30)<br>(31)<br>(32)<br>(32)<br>(32)<br>(32)<br>(32)<br>(32)<br>(32)<br>(32)<br>(32)<br>(32)<br>(32)<br>(32)<br>(32)<br>(32)<br>(32)<br>(32)<br>(32)<br>(32)<br>(32)<br>(32)<br>(32)<br>(32)<br>(32)<br>(32)<br>(32)<br>(32)<br>(32)<br>(32)<br>(32)<br>(32)<br>(32)<br>(32)<br>(32)<br>(32)<br>(32)<br>(32)<br>(32)<br>(32)<br>(32)<br>(32)<br>(32)<br>(32)<br>(32)<br>(32)<br>(32)<br>(32)<br>(32)<br>(32)<br>(32)<br>(32)<br>(32)<br>(32)<br>(32)<br>(32)<br>(32)<br>(32)<br>(32)<br>(32)<br>(32)<br>(32)<br>(32)<br>(32)<br>(32)<br>(32)<br>(32)<br>(32)<br>(32)<br>(32)<br>(32)<br>(32)<br>(32)<br>(32)<br>(32)<br>(32)<br>(32)<br>(32)<br>(32)<br>(32)<br>(32)<br>(32)<br>(32)<br>(32)<br>(32)<br>(32)<br>(32)<br>(32)<br>(32)<br>(32)<br>(32)<br>(32)<br>(32)<br>(32)<br>(32)<br>(32)<br>(32)<br>(32)<br>(32)<br>(32)<br>(32)<br>(32)<br>(32)<br>(32)<br>(32)<br>(32)<br>(32)<br>(32)<br>(32)<br>(32)<br>(32)<br>(32)<br>(32)<br>(32)<br>(32)<br>(32)<br>(32)<br>(32)<br>(32)<br>(32)<br>(32)<br>(32)<br>(32)<br>(32)<br>(32)<br>(32)<br>(32)<br>(32)<br>(32)<br>(32)<br>(32)<br>(32)<br>(32)<br>(32)<br>(32)<br>(32)<br>(32)<br>(32)<br>(32)<br>(32)<br>(32)<br>(32)<br>(32)<br>(32)<br>(32)<br>(32)<br>(32)<br>(32)<br>(32)<br>(32)<br>(32)<br>(32)<br>(32)<br>(32)<br>(32)<br>(32)<br>(32)<br>(32)<br>(32)<br>(32)<br>(32)<br>(32)<br>(32)<br>(32)<br>(32)<br>(32)<br>(32)<br>(3))<br>(3))<br>(3))<br>(3))<br>(3))<br>(3))<br>(3))<br>(3))<br>(3))<br>(3))<br>(3))<br>(3))<br>(3))<br>(3))<br>(3))<br>(3))<br>(3))<br>(3))<br>(3))<br>(3))<br>(3))<br>(3))<br>(3))<br>(3))<br>(3))<br>(3))<br>(3))<br>(3))<br>(3))<br>(3))<br>(3))<br>(3))<br>(3))<br>(3))<br>(3))<br>(3))<br>(3))<br>(3))<br>(3))<br>(3))<br>(3))<br>(3))<br>(3))<br>(3))<br>(3))<br>(3))<br>(3))<br>(3))<br>(3))<br>(3))<br>(3))<br>(3))<br>(3))<br>(3))<br>(3))<br>(3))<br>(3))<br>(3))<br>(3))<br>(3))<br>(3))<br>(3))<br>(3))<br>(3))<br>(3))<br>(3))<br>(3))<br>(3))<br>(3))<br>(3))<br>(3))<br>(3))<br>(3))<br>(3))<br>(3))<br>(3))<br>(3))<br>(3))<br>(3))<br>(3))<br>(3))<br>(3))<br>(3))<br>(3))<br>(3))<br>(3))<br>(3))<br>(3))<br>(3))<br>(3))<br>(3))<br>(3))<br>(3))<br>(3))<br>(3))<br>(3))<br>(3))<br>(3))<br>(3))<br>(3))<br>(3))<br>(3))<br>(3))<br>(3))<br>(3))<br>(3))<br>(3))<br>(3))<br>(3))<br>(3))<br>(3))<br>(3))<br>(3))<br>(3))<br>(3))<br>(3))<br>(3))<br>(3))<br>(3))<br>(3))<br>(3))<br>(3))<br>(3))<br>(3))<br>(3))<br>(3))<br>(3))<br>(3))<br>(3))<br>(3))<br>(3))<br>(3))<br>(3))<br>(3))<br>(3))<br>(3))<br>(3))<br>(3))<br>(3))<br>(3))<br>(3))<br>(3))<br>(3))<br>(3))<br>(3))<br>(3))<br>(3))<br>(3))<br>(3))<br>(3))<br>(3))<br>(3))<br>(3))<br>(3))<br>(3))<br>(3))<br>(3))<br>(3))<br>(3))<br>(3))<br>(3))<br>(3))<br>(3))<br>(3))<br>(3))<br>(3))<br>(3))<br>(3))<br>(3))<br>(3))<br>(3   |
| ESL         0.0           ESL         0.0           ESL(T)         0.0           ESL(T)         0.0           GMSSME <sub>0.0</sub> 0.0           GMSTM <sub>0.0</sub> 0.0           GMSTM <sub>0.0</sub> 0.0           GMSTM <sub>0.0</sub> 0.0           GMSTM <sub>0.0</sub> 0.0           KMIT         0.0           KMIT         0.0           KMIT         0.0           KMIT         0.0  | SFL 0.0<br>SFL  | IFI         0.0  | (3811 0.0<br>(381 0.0<br>(381 0.0<br>(384 0.0<br>(384 0.0<br>(384 0.0<br>(384 0.0<br>(384 0.0<br>(384 0.0<br>(384 0.0<br>(384 0.0)<br>(384 0.0)<br>(384 0.0)   |
| ESL         0.0           ESL         0.0           ESL         0.0           ESL         0.0           GMSSME <sub>the</sub> 0.0           GMSTPL <sub>spi</sub> 0.0           KMRT         0.0           KMRT         0.0           KMRT         0.0           KMRT         0.0           KMRT         0.0   | SFL 0.0<br>SFL 0.0<br>SFL 0.0<br>SFL 0.0<br>SFL 0.0<br>SFL 0.0<br>SFFL 0.0<br>SF  | IFI         0.0  | (SHD 0.0<br>(SH 0.0)<br>(SH 0.0<br>(SH 0.0)<br>(SH 0.0<br>(SH 0.0)<br>(SH 0   |
| ESL         0.0           ESL         0.0           ESL         0.0           ESL         0.0           GMSSME <sub>0.0</sub> 0.0           GMSSME <sub>0.0</sub> 0.0           GMSSME <sub>0.0</sub> 0.0           GMSSME <sub>0.0</sub> 0.0           GMSFI <sub>0.00</sub> 0.0           GMSFI <sub>0.00</sub> 0.0           GMSFI <sub>0.00</sub> 0.0           GMSTI <sub>0.00</sub> 0.0           KMLTT         0.0           KMLTT <sub>0.00</sub> 0.0  | SFL 0.0<br>SFL 0.0<br>SFL 0.0<br>SFL 0.0<br>SFL 0.0<br>SERI2 0.0   | IFI         0.0           NKI         0.0  | (3811 0.0<br>(381 0.0<br>1681 0.0<br>1885 0.0<br>1885 0.0<br>1881 0.0<br>1883 0.0<br>1883 0.0<br>1883 0.0  |
| ESL         0.0           ESL         0.0           ESL         0.0           ESL         0.0           ESL         0.0           GMSEME <sub>0.0</sub> 0.0           KMLT         0.0           KKLT         0.0  | SFL 0.0<br>SFL  | IFT 0.0<br>IFT   | 0.0<br>0.0<br>0.0<br>0.0<br>0.0<br>0.0<br>0.0<br>0.0   |
| ESL         0.0           ESL         0.0           ESL         0.0           ESL         0.0           GMSSME_m         0.0  | SFL 0.0<br>SFL  | 137 0.0<br>137, 0.0<br>137, 0.0<br>137, 0.0<br>137, 0.0<br>137, 0.0<br>137, 0.0<br>137, 0.0<br>139, 0.0<br>139, 0.0<br>139, 0.0<br>139, 0.0<br>139, 0.0  | 0.0<br>0.0<br>0.0<br>0.0<br>0.0<br>0.0<br>0.0<br>0.0<br>0.0<br>0.0   |
| ESL         0.0           ESL         0.0           ESL(7)         0.0           ESL(7)         0.0           GMSSME <sub>0.0</sub> 0.0           GMSSME <sub>0.0</sub> 0.0           GREPL <sub>0.0</sub> 0.0           GREPL <sub>0.00</sub> 0.0           GREPL <sub>0.00</sub> 0.0   | SFLa 0.0<br>SFL 0.0<br>SFL 0.0<br>SFL 0.0<br>SFL 0.0<br>SRH2 0.0<br>SRH2 0.0<br>SRH3 0.0<br>SRH3 0.0<br>SRH3 0.0  | IFI 0.0<br>IFI, 0.0<br>IFI, 0.0<br>IFI, 0.0<br>IFI, 0.0<br>IFI, 0.0<br>IFI, 0.0<br>IFI, 0.0<br>IFI, 0.0<br>IFI, 0.0  | (SEE 0.0<br>(SEE 0.0<br>(SEE 0.0<br>(SEE 0.0<br>(SEE 0.0<br>(SEE 0.0<br>(SEE 0.0<br>(SEE 0.0)<br>(SEE 0.0<br>(SEE 0.0)<br>(SEE 0.0<br>(SEE 0.0)<br>(SEE   |
| ESL         0.0           ESL         0.0           ESL         0.0           ESL         0.0           GMSSNE_m         0.0           GMSSNE_m         0.0           GMSSNE_m         0.0           GMSSNE_m         0.0           GMSSNE_m         0.0   | SFLs 0.0<br>SFL 0.0<br>SFL 0.0<br>SFL 0.0<br>SEL 0.0<br>SEL 0.0<br>SEL 0.0<br>SEL 0.0<br>SEL 0.0<br>SEL 0.0   | 137 0.0<br>138, 0.0<br>137, 0.0<br>137, 0.0<br>137, 0.0<br>137, 0.0<br>137, 0.0<br>139, 0.   | (SHD1 0.0<br>(SH 0.0<br>168 0.0<br>168, 0.0<br>158, 0.0<br>184 0.0<br>184 0.0  |
| ESL         0.0           ESL, 0.0         0.0           ESL, τρ         0.0           GMSSNE <sub>max</sub> 0.0           GMSSNE <sub>max</sub> 0.0           GMSSNE <sub>max</sub> 0.0   | SFL 0.0<br>SFL 0.0<br>SFL 0.0<br>SFL 0.0<br>SFL 0.0<br>SHL2 0.0   | 137 0.0<br>137, 0.0<br>137, 0.0<br>137, 0.0<br>137, 0.0<br>137, 0.0<br>137, 0.0<br>137, 0.0<br>137, 0.0  | 0.0 HTR<br>0.0 HS<br>0.0 HS<br>0.0 HS<br>0.0 HS<br>MI<br>0.0 MI<br>0.0 HS  |
|  | SFL 0.0<br>SFL 0.0<br>SFL 0.0<br>SFL 0.0<br>SFL 0.0   | 137 0.0<br>137, 0.0<br>137, 0.0<br>137, 0.0<br>137, 0.0<br>137, 0.0<br>137, 0.0  | 0.0<br>0.0<br>100<br>100<br>100<br>100<br>100<br>100<br>100<br>100   |
| 854, 0.0<br>854, 0.0<br>854,7 (0.0<br>854,7 (0.0<br>645,9 (0.0)  | SFLa 0.0<br>SFL 0.0<br>3FL 0.0<br>SFL 0.0   | LFI 0.0<br>LFI, 0.0<br>LFI, 0.0<br>LFI, 0.0<br>LFI, 0.0<br>LFI, 0.0  | (NEI 0.0<br>(SE 0.0<br>ISE 0.0<br>ISE 0.0  |
| FSL 0.0<br>FSL 0.0<br>FSLT 0.0<br>FSLT 0.0   | SFL 0.0<br>SFL 0.0<br>SFL 0.0   | 1371 0.0<br>1391, 0.0<br>1374, 0.0<br>1374, 0.0  | CND1 0.0<br>CSI 0.0<br>TSH 0.0   |
| ESL 0.0<br>ESL 0.0<br>ESL7 0.0   | SFL 0.0<br>SFL 0.0  | 137 0.0<br>1371, 0.0<br>1375, 0.0  | CNEE 0.0   |
| FSL 0.0<br>FSL 0.0   | SF1_ 0.0  | 137 0.0<br>137, 0.0  | CNDI 0.0   |
| FSL 0.0  |   | 141 0.0  |  |
|  | SF1, 0.0  |  |  |
|  | SFI_ 0.0  | GMLFI <sub>LA</sub> 0.0  | REUSVIII, D.D  |
| DWI 0.0  | SFI <sub>8</sub> 0.0  | (IMLPI <sub>A3</sub> 0.0   | KOUSVIII, 0.0  |
| CWI; 0.0   | SF1, 0.0  | GMLFI <sub>A</sub> , 0.0   | PLJ, 0.0   |
| CWIr 0.0   | SFI <sub>s</sub> 0.0  | GMLFI <sub>N3.4.0</sub> 0.0  | PLI 0.0  |
| Bilag 0.0  | SFI, 0.0  | (MILPI <sub>6,6,1,0</sub> 0.0  | н, о.о   |
| H, 0.0   | SF1, 0.0  | QMLPI <sub>2,2</sub> 0.0   | п, о.о   |
| His 0.0  | SF1 0.0   | MLFI 0.0   | H <sub>F</sub> 0.0   |
| Hip. 0.0   | <sup>SH4</sup> 0.0  | GMLPI <sub>0.1</sub> 0.0   | 'TW1' 0.0  |
| Bin 0.0  | 584 0.0   | (MLPI, 0.0   | TW1 0.0  |
| <sup>24</sup> <sub>3</sub> 0.0   |   | GMEPI, 0.0   | TWE <sub>4</sub> 0.0   |
| 86 <sub>10</sub> 0.0   | RMIs 0.0<br>RMIs 0.0  | GMLPIL, 0.0  | TWI4, 0.0  |
| Hi., 0.0   | FBMI <sub>A</sub> 0.0   | GMLFI 0.0  | 77   |
|  | seri 0.0  | RPED 0.0   | Ti <sub>n</sub> 0.0  |
| 0.0 IA.<br>86 <sub>14</sub> 0.0  | KEP1, 0.0<br>RMI1 0.0   | TOTAL IN A   | 77. 1. 1   |



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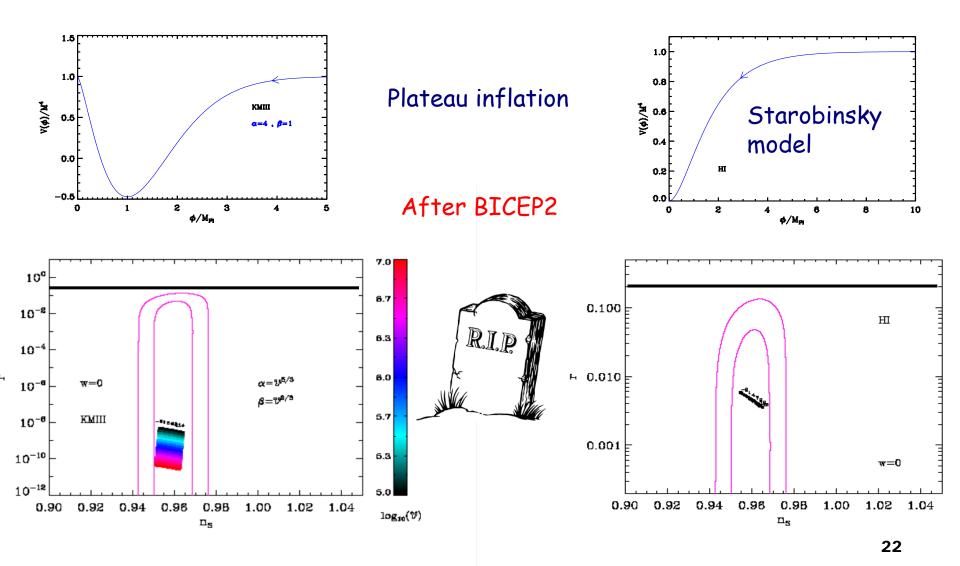


Before BICEP2



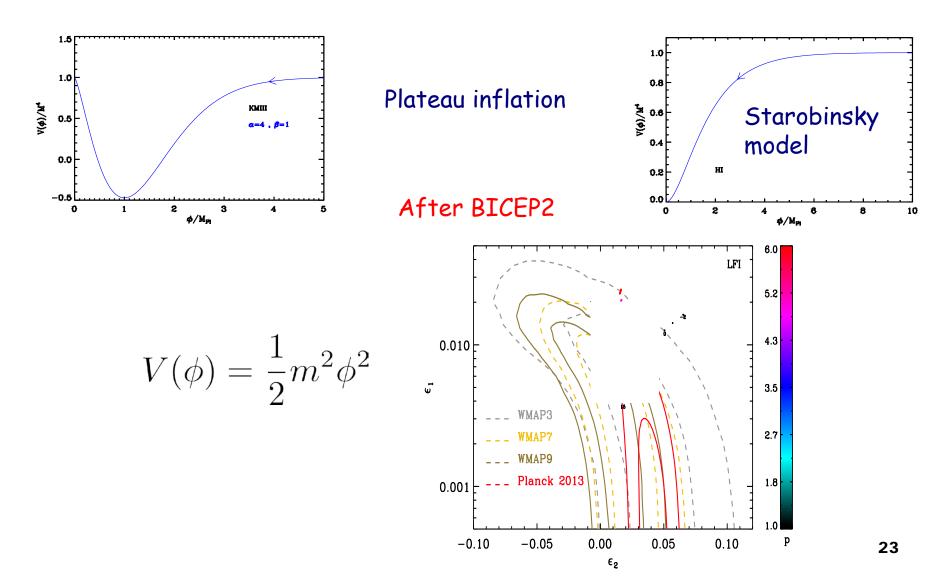


Before BICEP2





Before BICEP2





<u>Message 4: more complicated class of models</u>

Before BICEP2

Simplest models favored (ie more complicated not needed) because no isocurvature modes, no NG etc ...



<u>Message 4: more complicated class of models?</u>

Before BICEP2

Simplest models favored (ie more complicated not needed) because no isocurvature modes, no NG etc ...

# After BICEP2

- K-inflation  $r=-8n_{\rm \scriptscriptstyle T}c_{\rm \scriptscriptstyle S},\quad c_{\rm \scriptscriptstyle S}<1$
- Multiple field inflation  $r=-8n_{_{
  m T}}c_{_{
  m S}}\sin^2\Theta$

# Still true!



# <u>Message 5: model building issues</u>

Before BICEP2

No problem in principle, lot of activities trying to relate the Higgs with the inflaton



# Message 5: model building issues

Before BICEP2

No problem in principle, lot of activities trying to relate the Higgs with the inflaton

# After BICEP2

- New physics at the GUT scale, coupling with the Higgs??
- Difficult because of the Lyth bound:  $\Delta\phi\simeq 3.2\left(rac{r}{0.1}
  ight)^{1/2}M_{_{\rm Pl}}$
- Break-down of EFT??

- Inflation uses a scalar field but nobody has ever seen a scalar field
  - Higgs at the LHC
- No prediction of inflation, only post-dictions ...
  - ns ~ 0.96 ≠1
  - Presence of primordial gravity waves
- Alternatives to inflation??
  - Ekpyrotic model predicts no detectable gw ...
  - String gas cosmology, bouncing models??











Have we finally proven inflation????



# Have we finally proven inflation????

NO!



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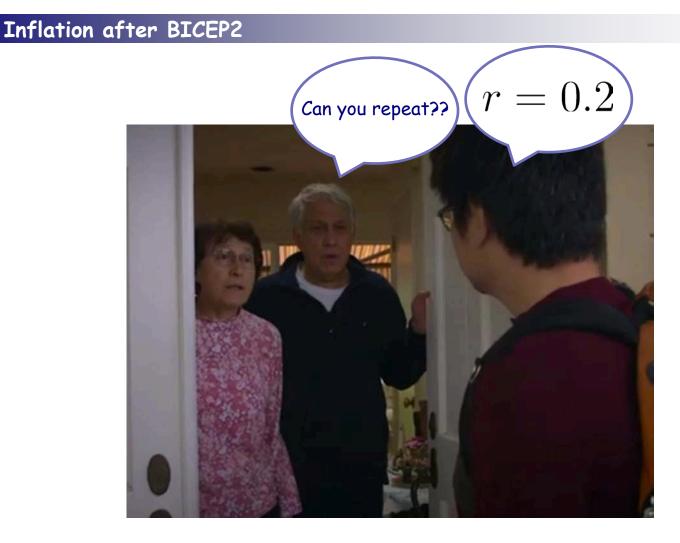
# Have we finally proven inflation????

#### NO!

# We need to check the consistency relations

$$n_{\rm T}=-\frac{r}{8}\simeq-0.025$$
 
$$\alpha_{\rm T}=\frac{r}{8}\left[\frac{r}{8}+(n_{\rm S}-1)\right]\simeq0.0016$$

We need to measure the tensor spectral index; since r is large, this seems feasible



- First calculation of gw production in curved spacetime, L. P. Grishchuk (1975)
- First application to an inflationary background, A. Starobinsky (1979)