Sébastien Clesse
(Namur University, Belgium)
based on
S.C., B. Garbrecht (TU-Munich), Y. Zhu (TU-Munich)
arXiv:1402.2257

Testing Inflation and Curvaton scenarios with CMB distortions

COrE / PRISM workshop for a M4 ESA mission,
February 10-11 2014, APC, Paris

Motivations

Motivations

* Silk damping: dissipation of acoustic waves into the monopole

Motivations

* Silk damping: dissipation of acoustic waves into the monopole
* This results in spectral distortions of the CMB, of μ-type, y-type and intermediate i-type

Motivations

* **Silk damping: dissipation of acoustic waves into the monopole**
* **This results in spectral distortions of the CMB, of *μ*-type, *y*-type and intermediate *i*-type**
* **Scales** $8 \lesssim k \lesssim 10^4 \mathrm{Mpc}^{-1}$ **can be probed** (e.g. Chluba et al, 1202.0057)
  => extends by 10 e-folds the period of inflation accessible to observations

Motivations

- **Silk damping: dissipation of acoustic waves into the monopole**
- **This results in spectral distortions of the CMB, of *μ*-type, *y*-type and intermediate *i*-type**
- **Scales** $8 \lesssim k \lesssim 10^4 \mathrm{Mpc}^{-1}$ **can be probed** (e.g. Chluba et al, 1202.0057)
  => extends by 10 e-folds the period of inflation accessible to observations
- **Fisher Matrix analysis: scalar power spectrum (amplitude + spectral index + running) on pivot scale** $k_{\mathrm{p}} = 42 \mathrm{Mpc}^{-1}$ **. For** $1 < n_{\mathrm{s}} \lesssim 1.2$ **, the 95% C.L. detection levels are**

$$\mathcal{P}_\zeta(k_{\mathrm{d}} = 42 \ \mathrm{Mpc}^{-1}) \approx 7 \times 10^{-9} \ \text{for PIXIE}$$

$$\mathcal{P}_\zeta(k_{\mathrm{d}} = 42 \ \mathrm{Mpc}^{-1}) \approx 4 \times 10^{-9} \ \text{for PRISM}$$

Khatri, Sunyaev, 1303.7212

Motivations

* Silk damping: dissipation of acoustic waves into the monopole
* This results in spectral distortions of the CMB, of *μ*-type, *y*-type and intermediate *i*-type
* Scales $8 \lesssim k \lesssim 10^4 \mathrm{Mpc}^{-1}$ can be probed (e.g. Chluba et al, 1202.0057)
=> extends by 10 e-folds the period of inflation accessible to observations
* Fisher Matrix analysis: scalar power spectrum (amplitude + spectral index + running) on pivot scale $k_\mathrm{p} = 42 \mathrm{Mpc}^{-1}$. For $1 < n_\mathrm{s} \lesssim 1.2$, the 95% C.L. detection levels are

$$\mathcal{P}_\zeta(k_\mathrm{d} = 42 \text{ Mpc}^{-1}) \approx 7 \times 10^{-9} \text{ for PIXIE}$$

$$\mathcal{P}_\zeta(k_\mathrm{d} = 42 \text{ Mpc}^{-1}) \approx 4 \times 10^{-9} \text{ for PRISM}$$

Khatri, Sunyaev, 1303.7212

* What implications for inflation (and curvaton) scenarios?
Need of a model oriented approach...

Motivations

- **Silk damping: dissipation of acoustic waves into the monopole**
- **This results in spectral distortions of the CMB, of *μ*-type, *y*-type and intermediate *i*-type**
- **Scales** $8 \lesssim k \lesssim 10^4 \mathrm{Mpc}^{-1}$ **can be probed** (e.g. Chluba et al, 1202.0057)
  => extends by 10 e-folds the period of inflation accessible to observations
- **Fisher Matrix analysis: scalar power spectrum (amplitude + spectral index + running) on pivot scale** $k_\mathrm{p} = 42 \mathrm{Mpc}^{-1}$ **. For** $1 < n_\mathrm{s} \lesssim 1.2$ **, the 95% C.L. detection levels are**

$$\mathcal{P}_\zeta(k_\mathrm{d} = 42\ \mathrm{Mpc}^{-1}) \approx 7 \times 10^{-9}\ \text{for PIXIE}$$

$$\mathcal{P}_\zeta(k_\mathrm{d} = 42\ \mathrm{Mpc}^{-1}) \approx 4 \times 10^{-9}\ \text{for PRISM}$$

Khatri, Sunyaev, 1303.7212

- **What implications for inflation (and curvaton) scenarios?**
  Need of a model oriented approach...

Analysis of

- **49 single-field models of the *Encyclopaedia Inflationaris*** Martin et al, 1303.3787
- **3 effective multi-field models - softly turning trajectory** Pi, Sasaki, 1205.0561
  - suddenly turning trajectory Noumi et al, 1307.7110
  - waterfall trajectory S.C., Garbrecht, Zhu, 1304.7042
- **1 simple curvaton model**

Model analysis

* Single-field models : Methodology for model selection - 3 criteria

Model analysis

* **Single-field models : Methodology for model selection - 3 criteria**

1. There must exist a phase during which $n_\mathrm{s}(k) = 1 - 2\epsilon_{1k} - \epsilon_{2k} > 1$

where $\epsilon_1 = \frac{M_p^2}{2}\left(\frac{\frac{\mathrm{d}V}{\mathrm{d}\phi}}{V}\right)^2$ and $\epsilon_2 = 2M_p^2\left[\left(\frac{\frac{\mathrm{d}V}{\mathrm{d}\phi}}{V}\right)^2 - \frac{1}{V^2}\frac{\mathrm{d}^2V}{\mathrm{d}\phi^2}\right]$.

2. A phase with $n_\mathrm{s} > 1$ must follow a phase with $n_\mathrm{s} < 1$ and $\epsilon_1 \neq 0$ between them

Model analysis

* **Single-field models : Methodology for model selection - 3 criteria**

1. There must exist a phase during which $n_\mathrm{s}(k) = 1 - 2\epsilon_{1k} - \epsilon_{2k} > 1$

where $\epsilon_1 = \frac{M_p^2}{2}\left(\frac{\frac{\mathrm{d}V}{\mathrm{d}\phi}}{V}\right)^2$ and $\epsilon_2 = 2M_p^2\left[\left(\frac{\frac{\mathrm{d}V}{\mathrm{d}\phi}}{V}\right)^2 - \frac{1}{V^2}\frac{\mathrm{d}^2V}{\mathrm{d}\phi^2}\right]$.

2. A phase with $n_\mathrm{s} > 1$ must follow a phase with $n_\mathrm{s} < 1$ and $\epsilon_1 \neq 0$ between them

Exclusion of most models

Only Hybrid Inflation in the valley (HVI), Non canonical Kähler Inflation (NCKI) Generalized MSSM (GMSSM), Generalized Renormalisable Inflection Point (GRIP) and Running Mass Inflation (RMI) survive

Model analysis

- **Single-field models : Methodology for model selection - 3 criteria**

1. There must exist a phase during which $n_s(k) = 1 - 2\epsilon_{1k} - \epsilon_{2k} > 1$

where $\epsilon_1 = \frac{M_p^2}{2}\left(\frac{\frac{dV}{d\phi}}{V}\right)^2$ and $\epsilon_2 = 2M_p^2\left[\left(\frac{\frac{dV}{d\phi}}{V}\right)^2 - \frac{1}{V^2}\frac{d^2V}{d\phi^2}\right]$.

2. A phase with $n_s > 1$ must follow a phase with $n_s < 1$ and $\epsilon_1 \neq 0$ between them

Exclusion of most models

Only Hybrid Inflation in the valley (HVI), Non canonical Kähler Inflation (NCKI) Generalized MSSM (GMSSM), Generalized Renormalisable Inflection Point (GRIP) and Running Mass Inflation (RMI) survive

3. $n_s = 0.960 \pm 0.007$ on CMB angular scales AND $n_s > 1$ at $k_d = 42\mathrm{Mpc}^{-1}$

- Slow-roll dynamics has been solved numerically

- Modified version of idistort template (Khatri, Sunyaev, 1207.6654) for the calculation of distortions

Model analysis

* **Single-field models : Methodology for model selection - 3 criteria**

1. There must exist a phase during which $n_{\rm s}(k) = 1 - 2\epsilon_{1k} - \epsilon_{2k} > 1$

where $\epsilon_1 = \frac{M_p^2}{2}\left(\frac{\frac{\mathrm{d}V}{\mathrm{d}\phi}}{V}\right)^2$ and $\epsilon_2 = 2M_p^2\left[\left(\frac{\frac{\mathrm{d}V}{\mathrm{d}\phi}}{V}\right)^2 - \frac{1}{V^2}\frac{\mathrm{d}^2V}{\mathrm{d}\phi^2}\right]$.

2. A phase with $n_{\rm s} > 1$ must follow a phase with $n_{\rm s} < 1$ and $\epsilon_1 \neq 0$ between them

Exclusion of most models

Only Hybrid Inflation in the valley (HVI), Non canonical Kähler Inflation (NCKI) Generalized MSSM (GMSSM), Generalized Renormalisable Inflection Point (GRIP) and Running Mass Inflation (RMI) survive

3. $n_{\rm s} = 0.960 \pm 0.007$ on CMB angular scales AND $n_{\rm s} > 1$ at $k_{\rm d} = 42\mathrm{Mpc}^{-1}$

- Slow-roll dynamics has been solved numerically

- Modified version of idistort template (Khatri, Sunyaev, 1207.6654) for the calculation of distortions

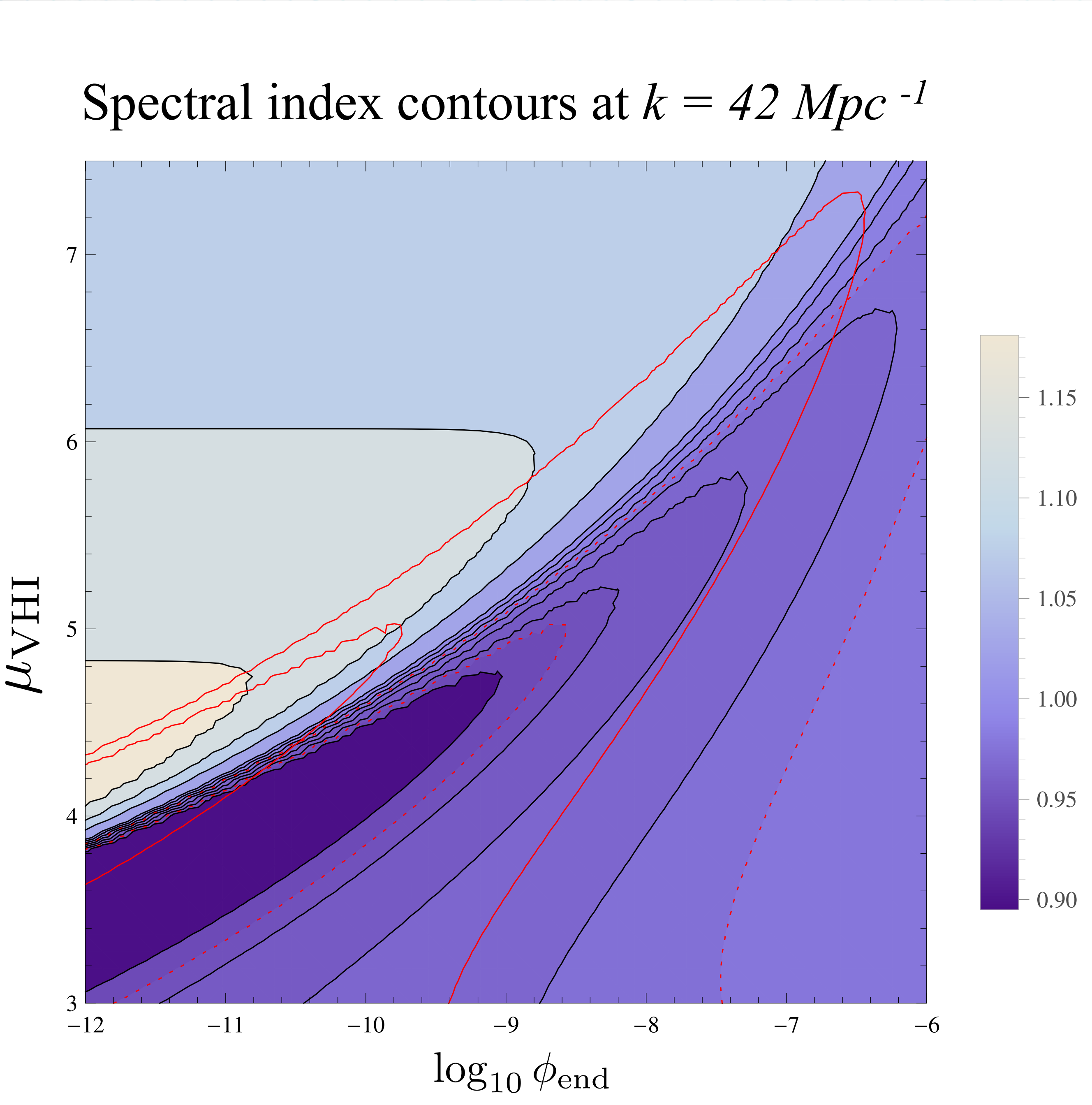
Only HVI and RMI survive

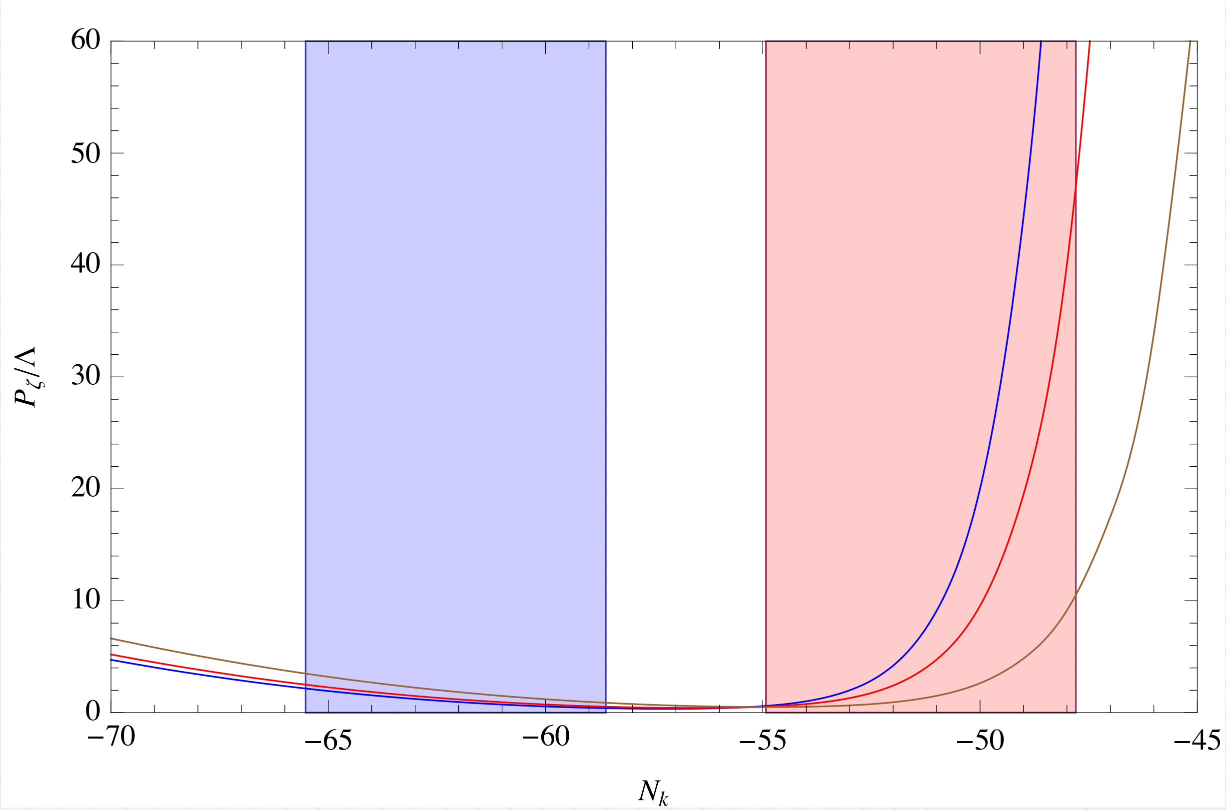
and only HVI leads to a sufficient enhancement of the scalar power spectrum for distortions to be detectable

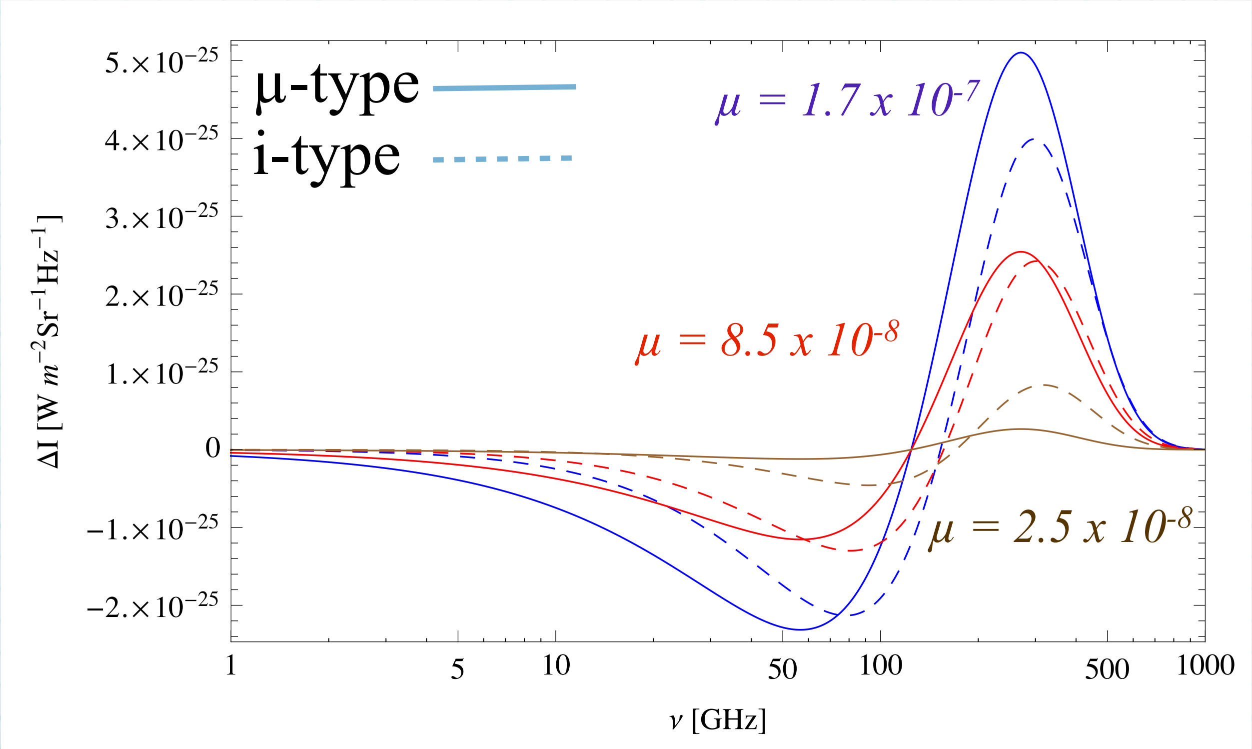
Model analysis

* **Single-field models : Methodology for model selection - 3 criteria**

Hybrid potential : $V(\phi) = \Lambda\left(1 + \frac{\phi^2}{\mu_{\rm VHI}^2}\right)$







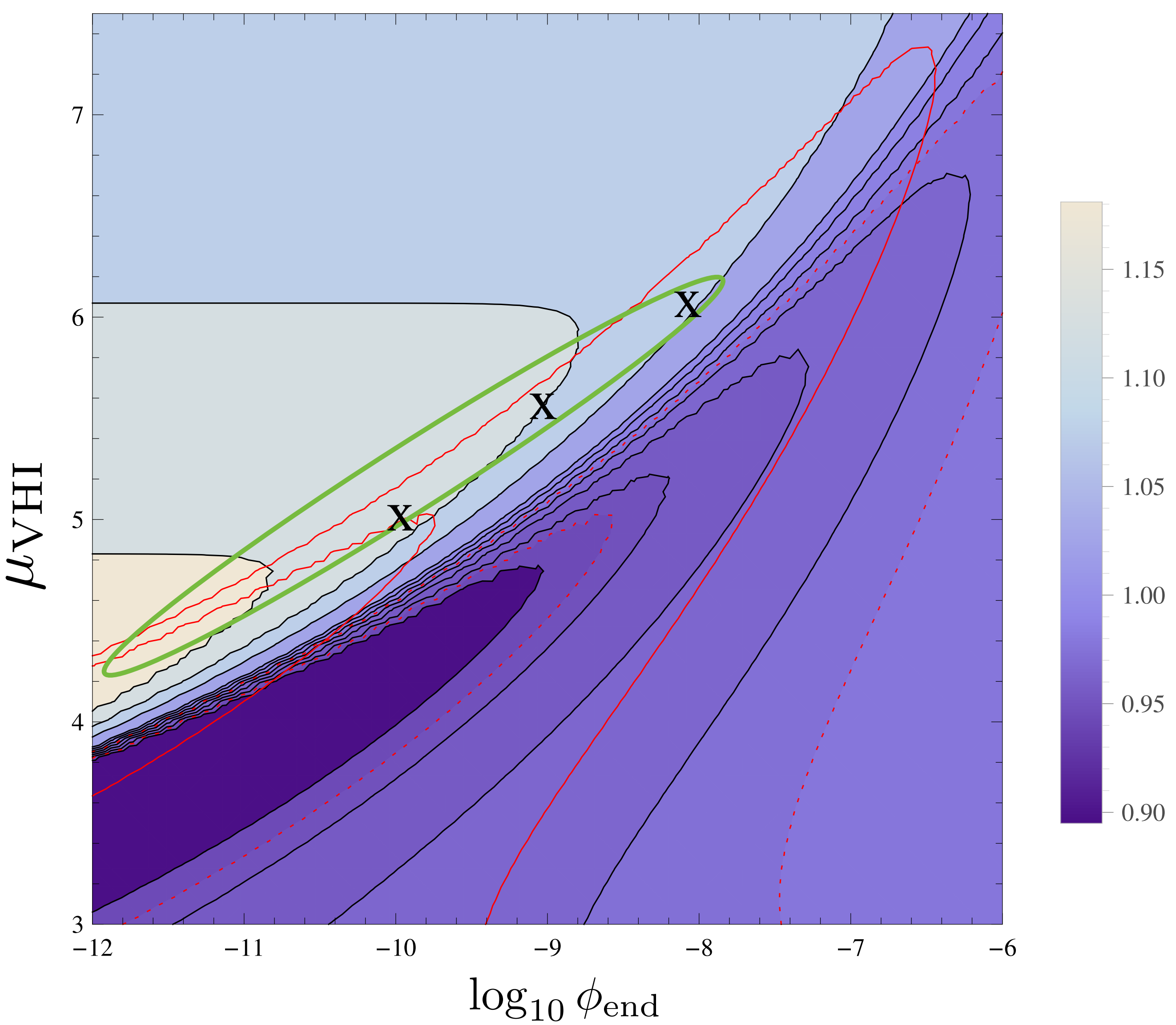
NEED OF SUPER PLANCKIAN FIELD

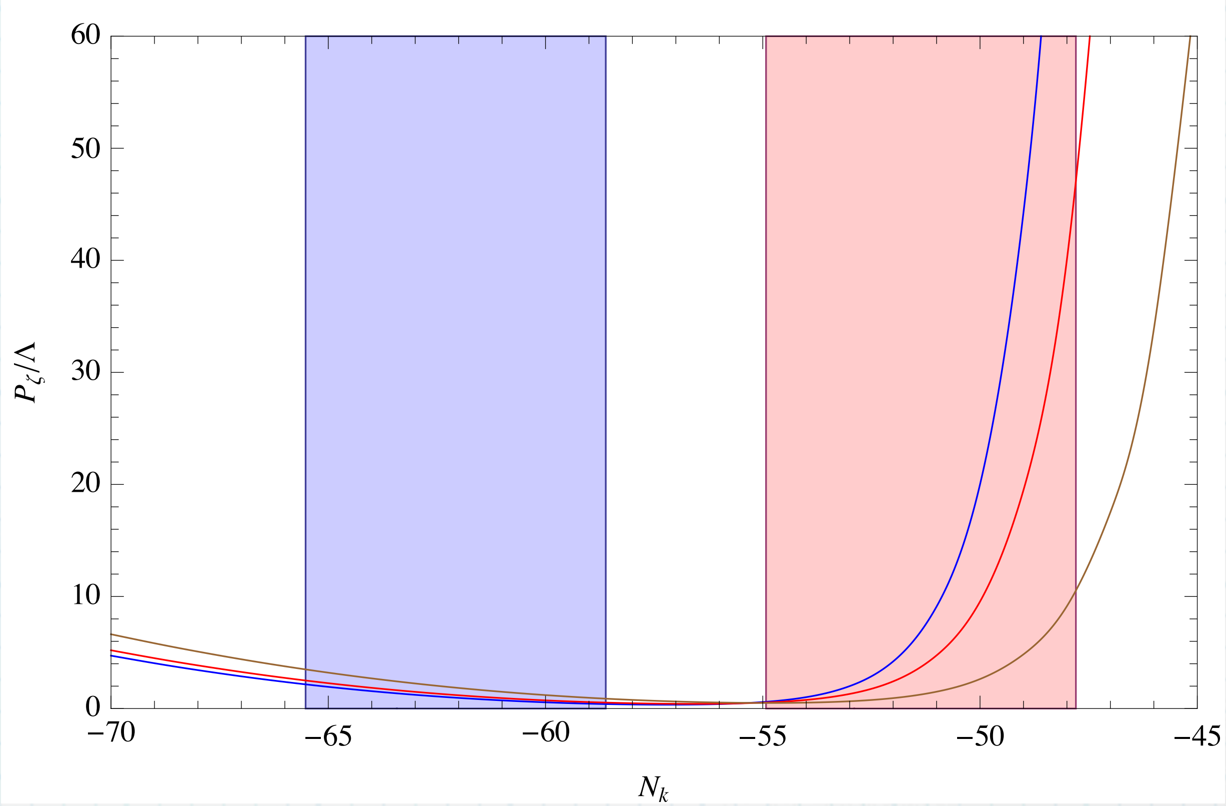
Model analysis

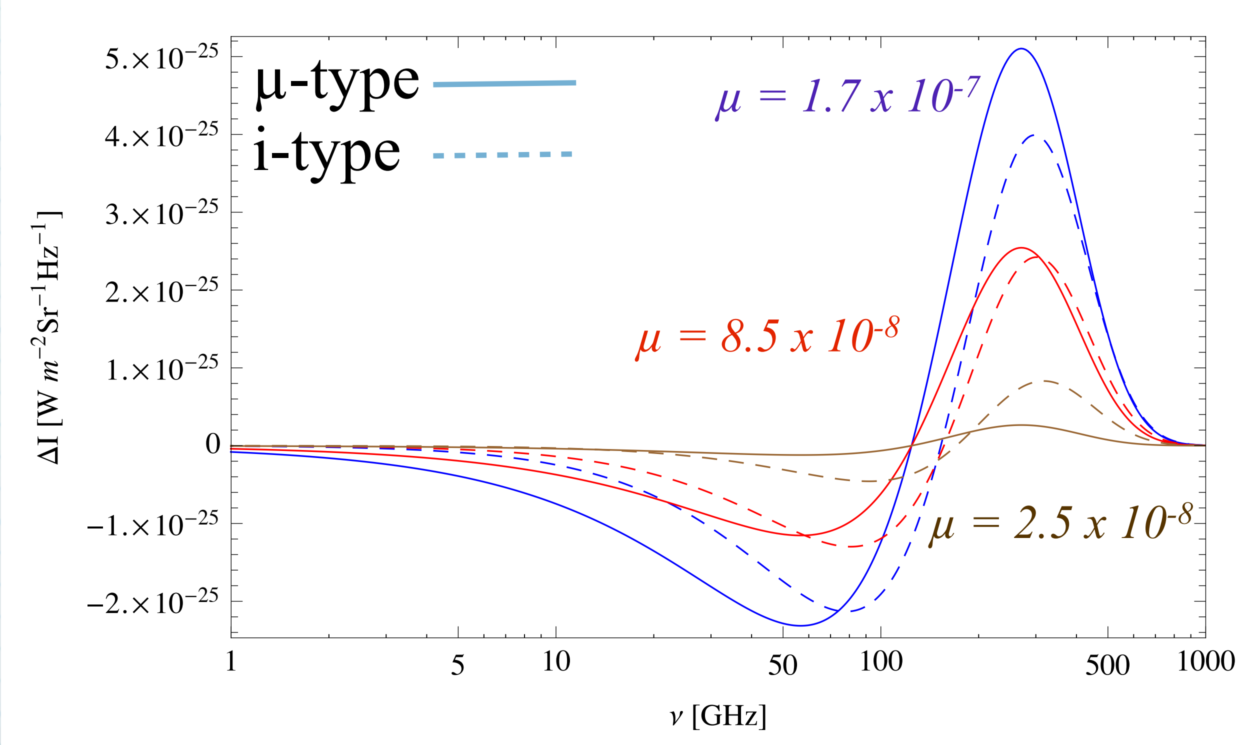
* **Single-field models : Methodology for model selection - 3 criteria**

Hybrid potential : $V(\phi) = \Lambda \left(1 + \frac{\phi^2}{\mu_{\mathrm{VHI}}^2}\right)$

Spectral index contours at $k = 42\ Mpc^{-1}$







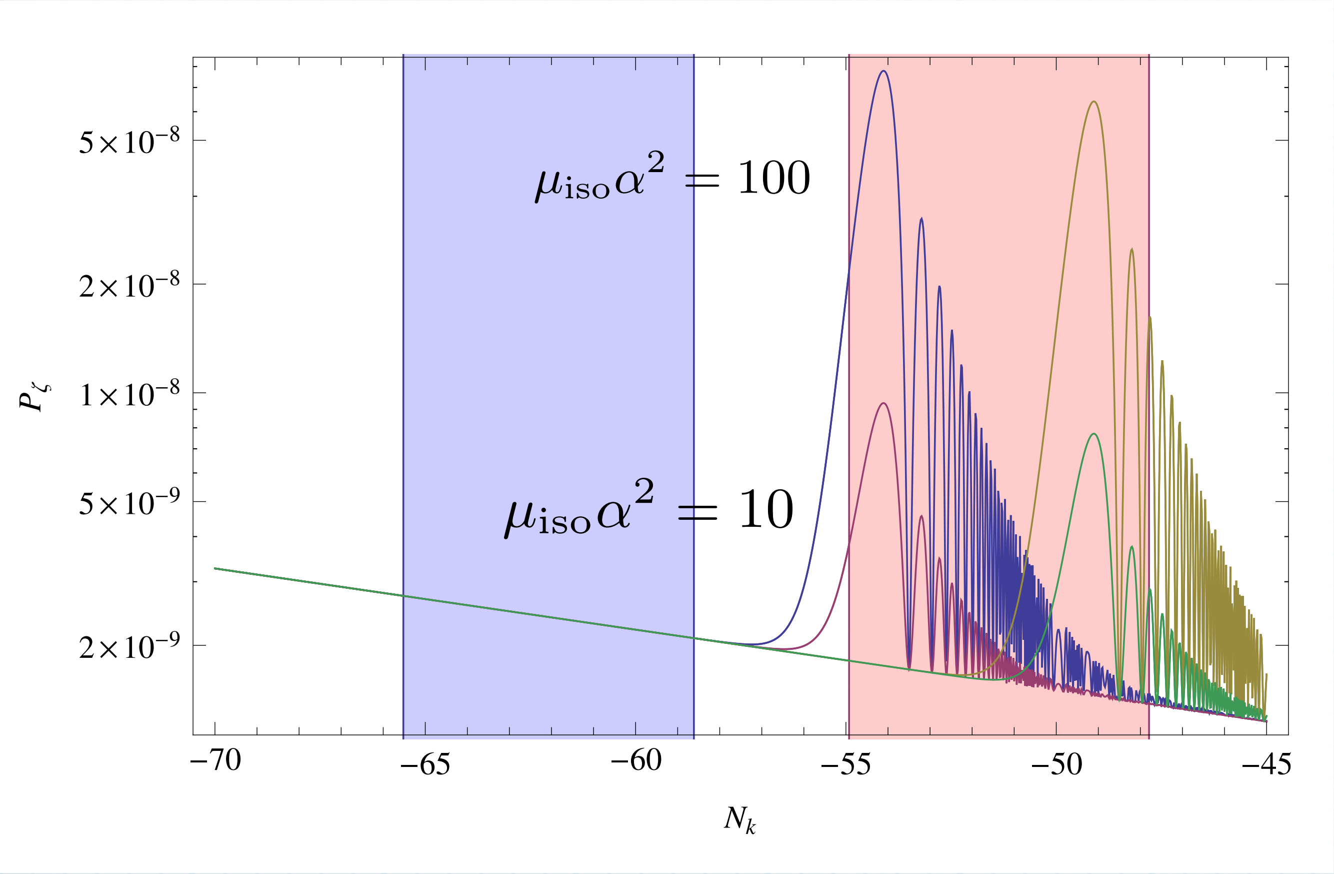
NEED OF SUPER PLANCKIAN FIELD

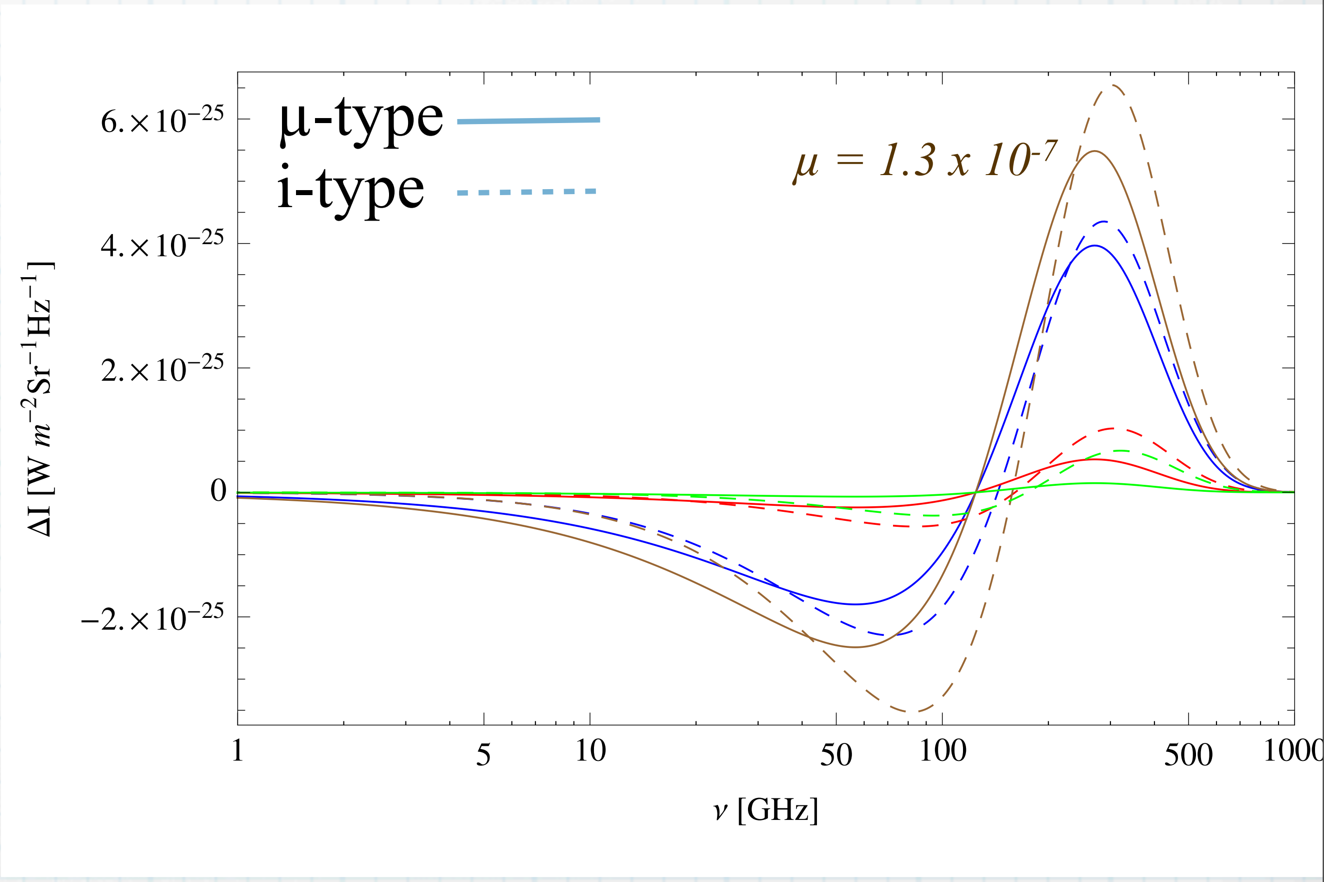
Model analysis

* Single-field models : Methodology for model selection - 3 criteria
* 3 Effective models of multi-field inflation :
    * Softly turning trajectory NOT DETECTABLE

Model analysis

- Single-field models : Methodology for model selection - 3 criteria
- 3 Effective models of multi-field inflation :
    - Softly turning trajectory **NOT DETECTABLE**
    - Suddenly turning trajectory **DETECTABLE**



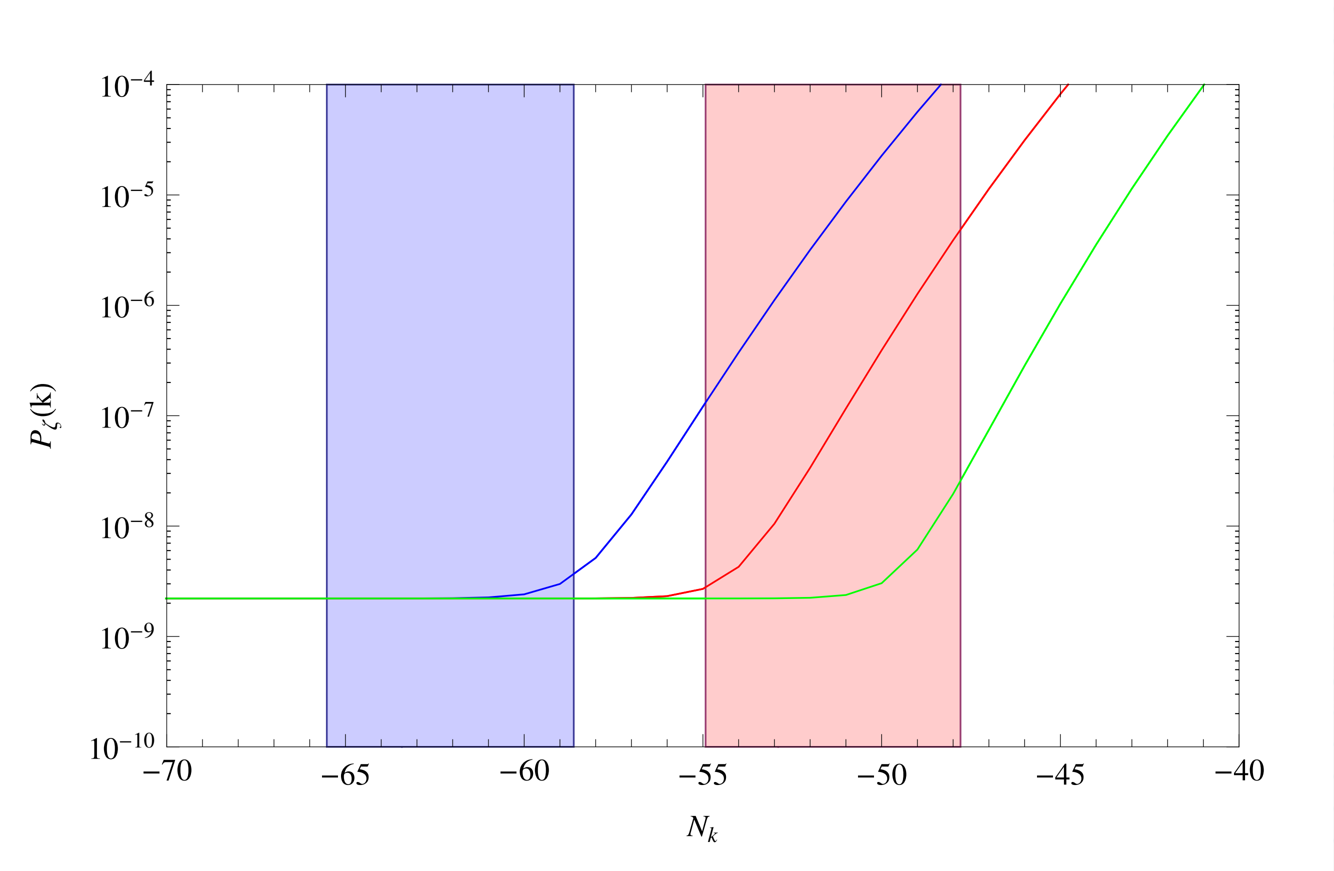


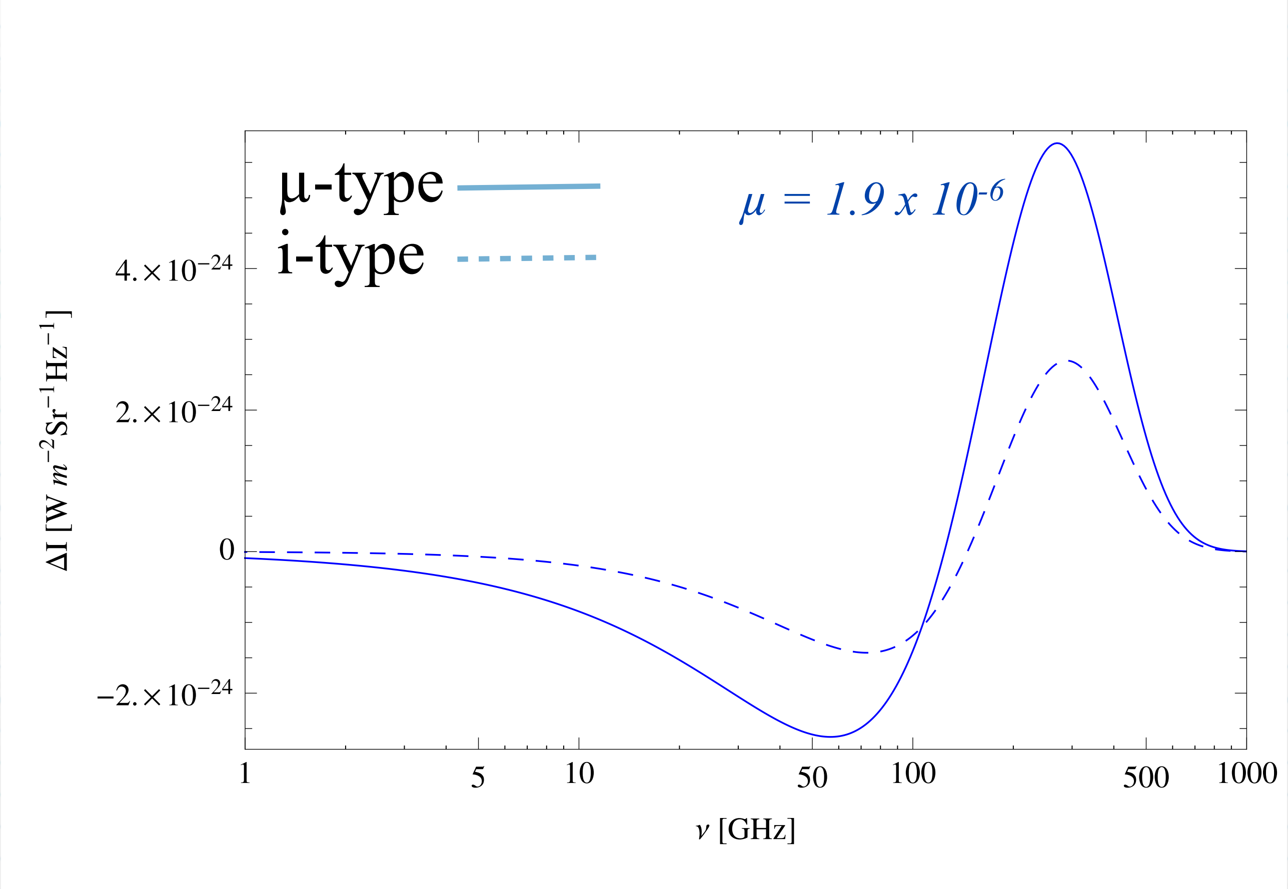
The peak increases ~ $\mu_{\rm iso}\alpha^2$ with $\mu_{\rm iso} \equiv \sqrt{m^2_{\rm iso}/H^2 - 9/4}$

i-type > μ-type

Model analysis

- Single-field models : Methodology for model selection - 3 criteria
- 3 Effective models of multi-field inflation :
  - Softly turning trajectory **NOT DETECTABLE**
  - Suddenly turning trajectory **DETECTABLE**
  - Mild waterfall trajectory **DETECTABLE**

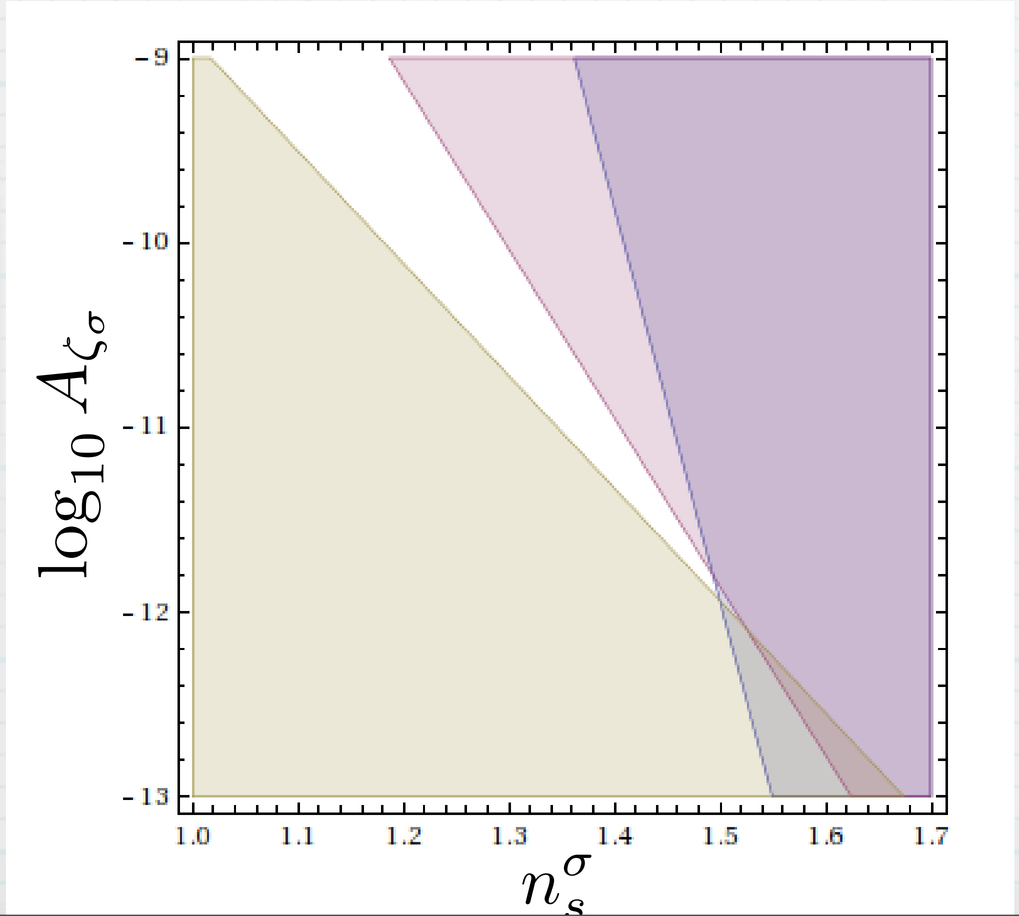


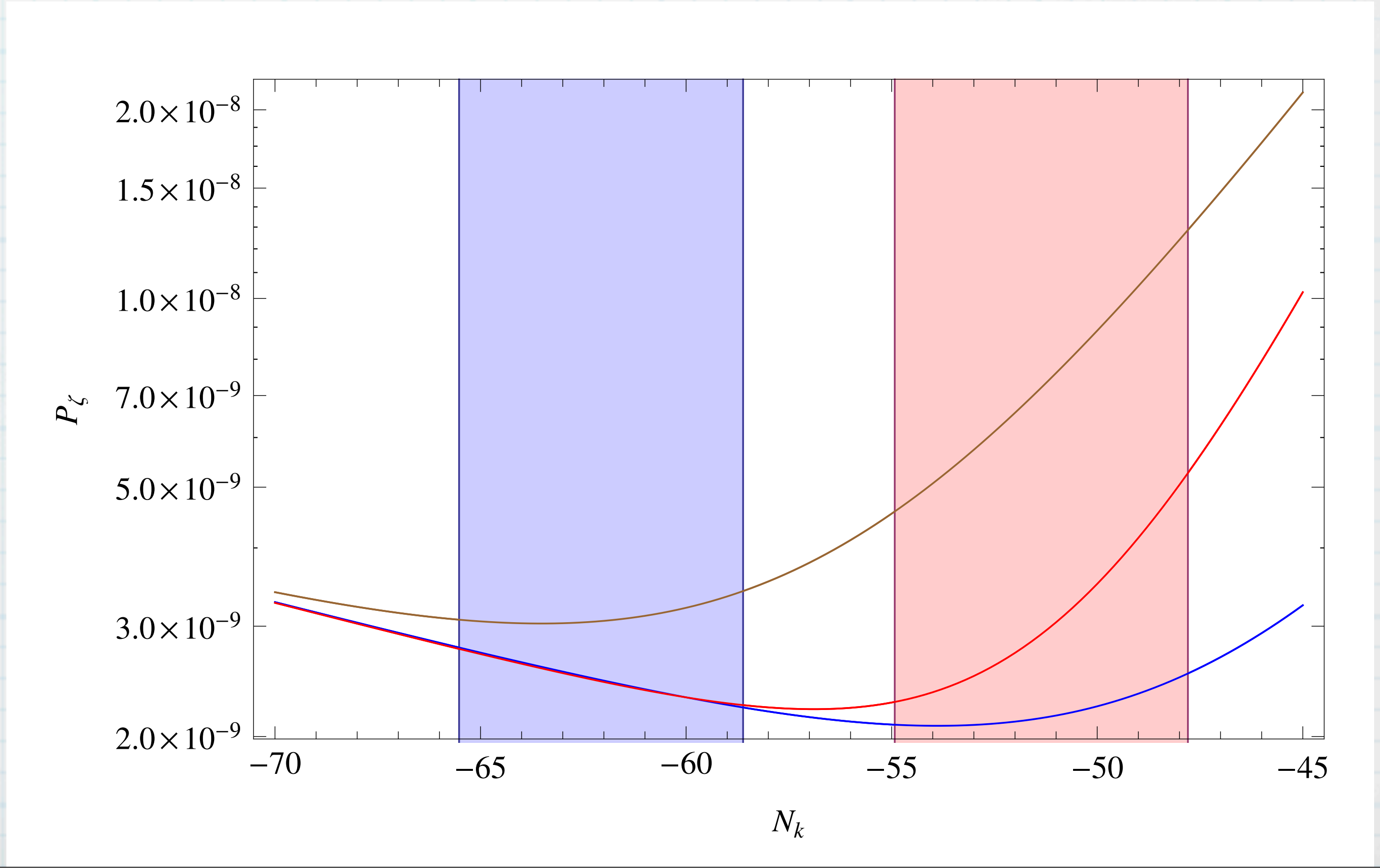


Model analysis

* Single-field models : Methodology for model selection - 3 criteria
* 3 Effective models of multi-field inflation :
    * Softly turning trajectory **NOT DETECTABLE**
    * Suddenly turning trajectory **DETECTABLE**
    * Mild waterfall trajectory **DETECTABLE**

* Simple curvaton model $\mathcal{P}_\zeta(\mathbf{k}) = \mathcal{P}_{\zeta\text{inf}}(\mathbf{k}) + \mathcal{P}_{\zeta_\sigma}(\mathbf{k})$ **NOT DETECTABLE if ultracompact mini-halos constraints are imposed** Bringmann et al, 1110.2484

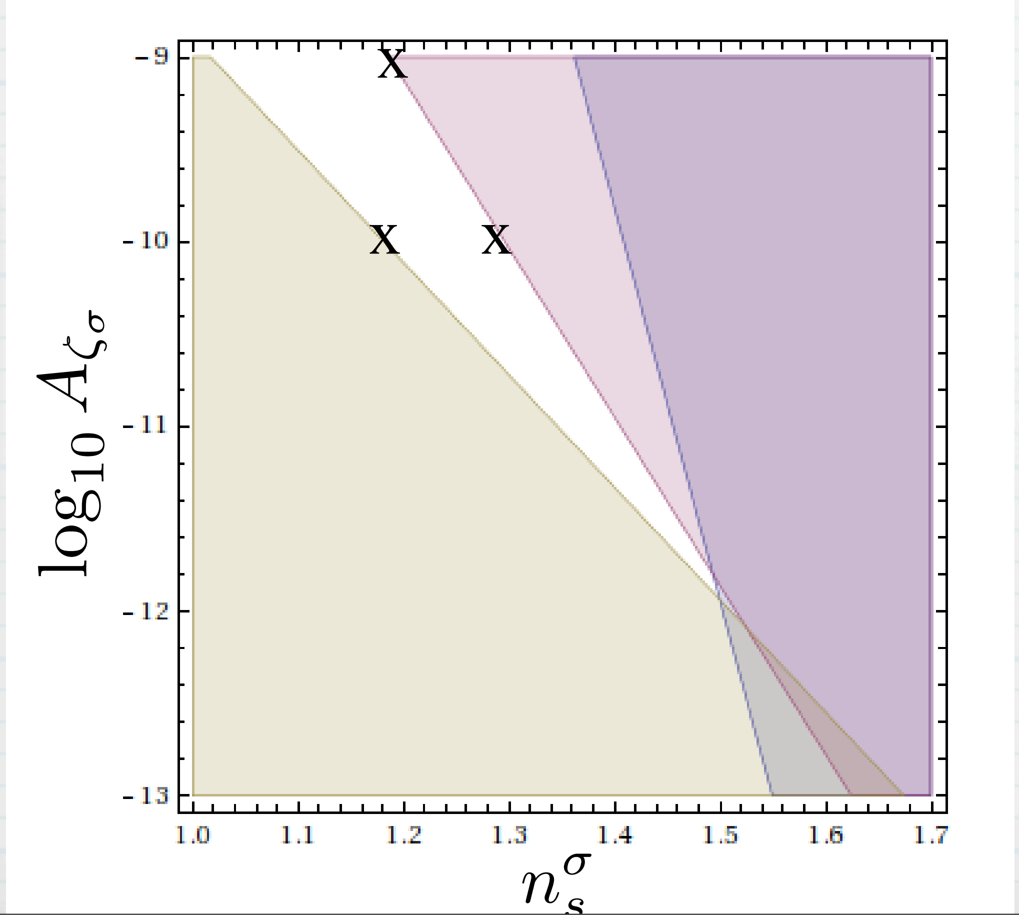


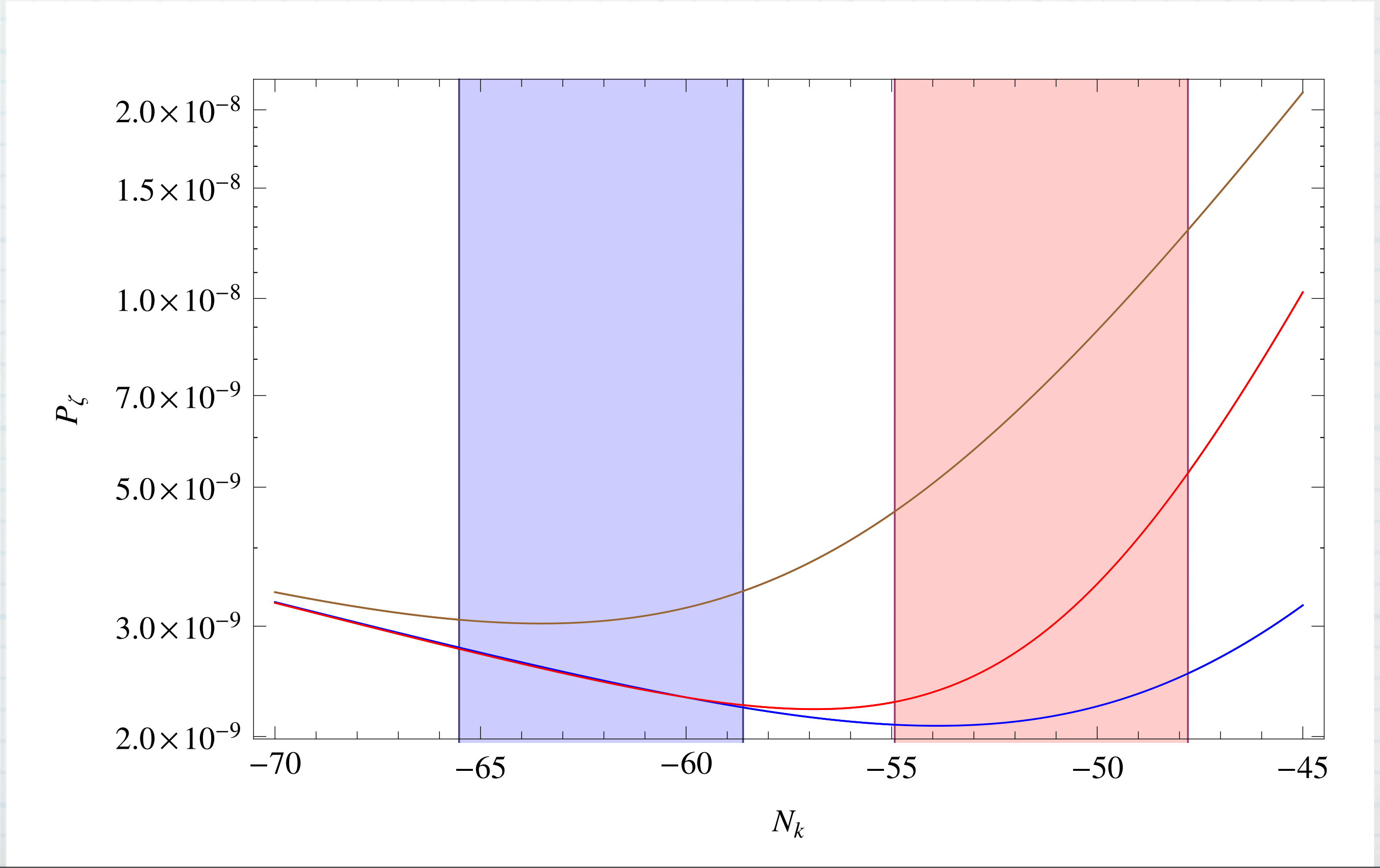


Model analysis

* Single-field models : Methodology for model selection - 3 criteria
* 3 Effective models of multi-field inflation :
    * Softly turning trajectory **NOT DETECTABLE**
    * Suddenly turning trajectory **DETECTABLE**
    * Mild waterfall trajectory **DETECTABLE**

* Simple curvaton model $\mathcal{P}_\zeta(\mathbf{k}) = \mathcal{P}_{\zeta\mathrm{inf}}(\mathbf{k}) + \mathcal{P}_{\zeta_\sigma}(\mathbf{k})$ **NOT DETECTABLE if ultracompact mini-halos constraints are imposed** Bringmann et al, 1110.2484





Conclusion

- **For single field inflation models, it seems rather fortuitous that detectable CMB distortions are produced.**
- **Detectable distortions more likely produced by multi-field inflation**
  e.g. : sudden turn, mild waterfall.
  This requires some tuning of the parameters.
- **Distortions from a simple curvaton model not detectable** (due to constraints from ultracompact mini-halos)
- **μ-type and i-type distortions could help to distinguish models**
- **Perspective: Fisher Matrix or MCMC analysis on specific models**
- **A new window on the very early Universe is open...**

Conclusion

- **For single field inflation models, it seems rather fortuitous that detectable CMB distortions are produced.**

- **Detectable distortions more likely produced by multi-field inflation**
  e.g. : sudden turn, mild waterfall.
  This requires some tuning of the parameters.

- **Distortions from a simple curvaton model not detectable** (due to constraints from ultracompact mini-halos)

- **μ-type and i-type distortions could help to distinguish models**

- **Perspective: Fisher Matrix or MCMC analysis on specific models**

- **A new window on the very early Universe is open...**

See arXiv:1402.2257 for more details

Conclusion

* **For single field inflation models, it seems rather fortuitous that detectable CMB distortions are produced.**

* **Detectable distortions more likely produced by multi-field inflation**
  e.g. : sudden turn, mild waterfall.
  This requires some tuning of the parameters.

* **Distortions from a simple curvaton model not detectable** (due to constraints from ultracompact mini-halos)

* **μ-type and i-type distortions could help to distinguish models**

* **Perspective: Fisher Matrix or MCMC analysis on specific models**

* **A new window on the very early Universe is open...**

See arXiv:1402.2257 for more details

Thank you for your attention....