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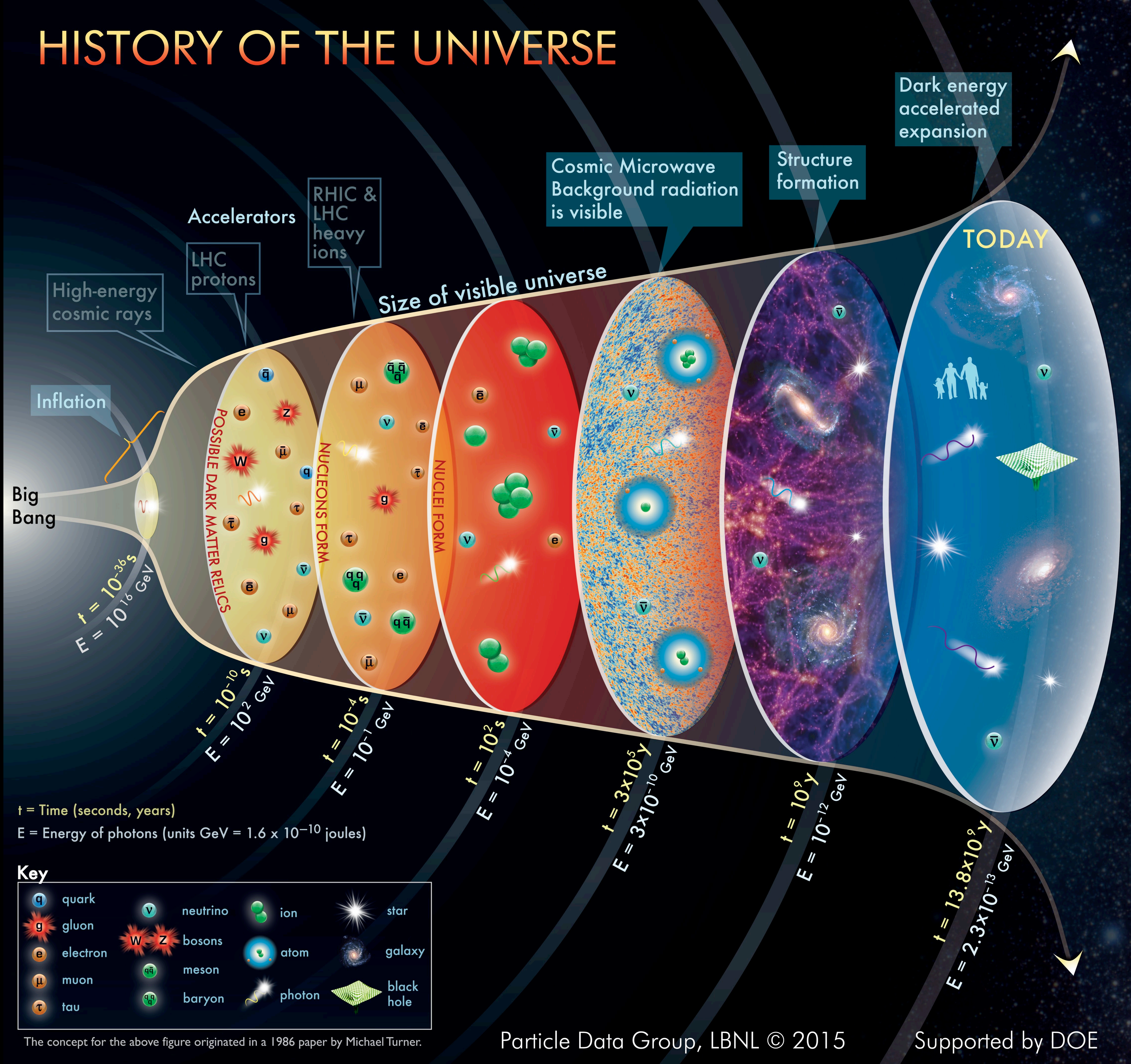
Université catholique de Louvain

CMB CONSTRAINTS ON THE INFLATON COUPLINGS IN α-ATTRACTOR INFLATION

28.09.2017

DESY Theory Workshop

based on arXiv:1708.01197 and arXiv:1511.03280
in collaboration with Jin U Kang and Ui Ri Mun


HISTORY OF THE UNIVERSE
Dark energy accelerated expansion
Cosmic Microwave Background radiation is visible
Structure formation
Accelerators
RHIC & LHC heavy ions
LHC protons
High-energy cosmic rays
Size of visible universe
TODAY
Inflation
Big Bang
POSSIBLE DARK MATTER RELICS
NUCLEONS FORM
NUCLEI FORM
t = 10^-36 s
E = 10^16 GeV
t = 10^-10 s
E = 10^2 GeV
t = 10^-4 s
E = 10^-1 GeV
t = 10^2 s
E = 10^-4 GeV
t = 3x10^5 y
E = 3x10^-10 GeV
t = 10^9 y
E = 10^-12 GeV
t = 13.8x10^9 y
E = 2.3x10^-13 GeV
t = Time (seconds, years)
E = Energy of photons (units GeV = 1.6 x 10^-10 joules)
Key
quark
gluon
electron
muon
tau
neutrino
bosons
meson
baryon
ion
atom
photon
star
galaxy
black hole
The concept for the above figure originated in a 1986 paper by Michael Turner.
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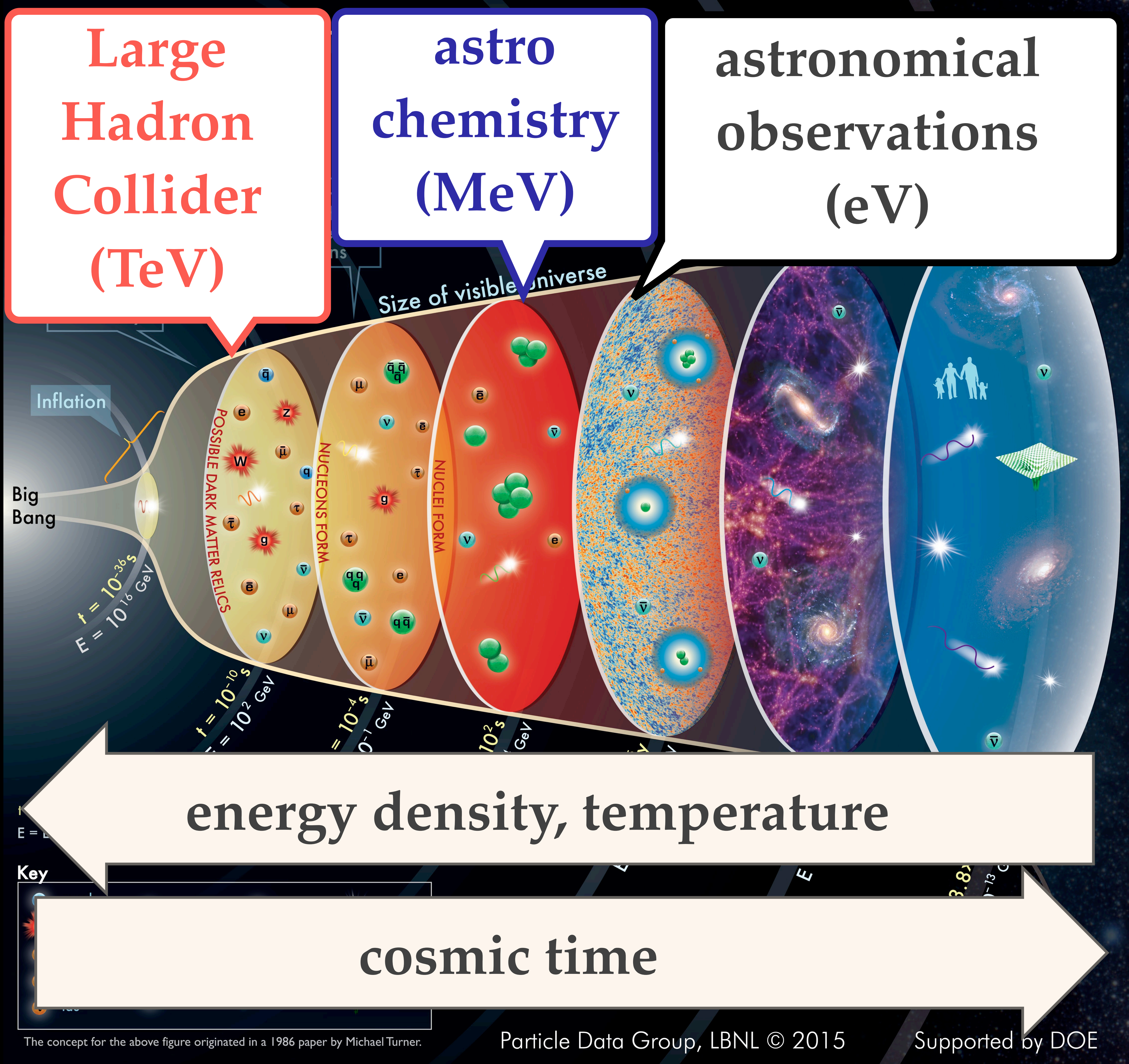
Large Hadron Collider (TeV)
astro chemistry (MeV)
astronomical observations (eV)
Inflation
Big Bang
t = 10^-36 s
E = 10^16 GeV
POSSIBLE DARK MATTER RELICS
NUCLEONS FORM
NUCLEI FORM
t = 10^-10 s
energy density, temperature
cosmic time
Key
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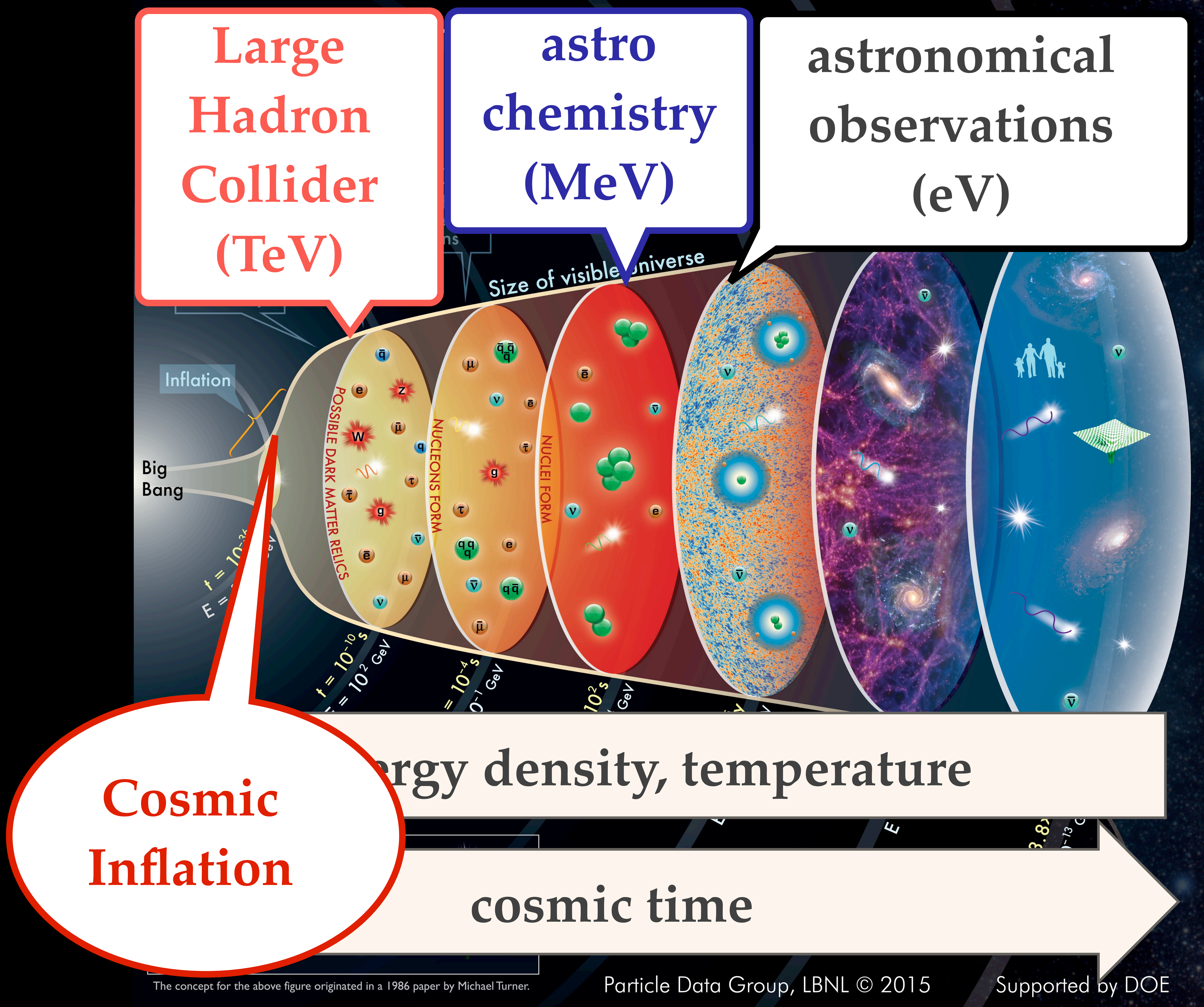

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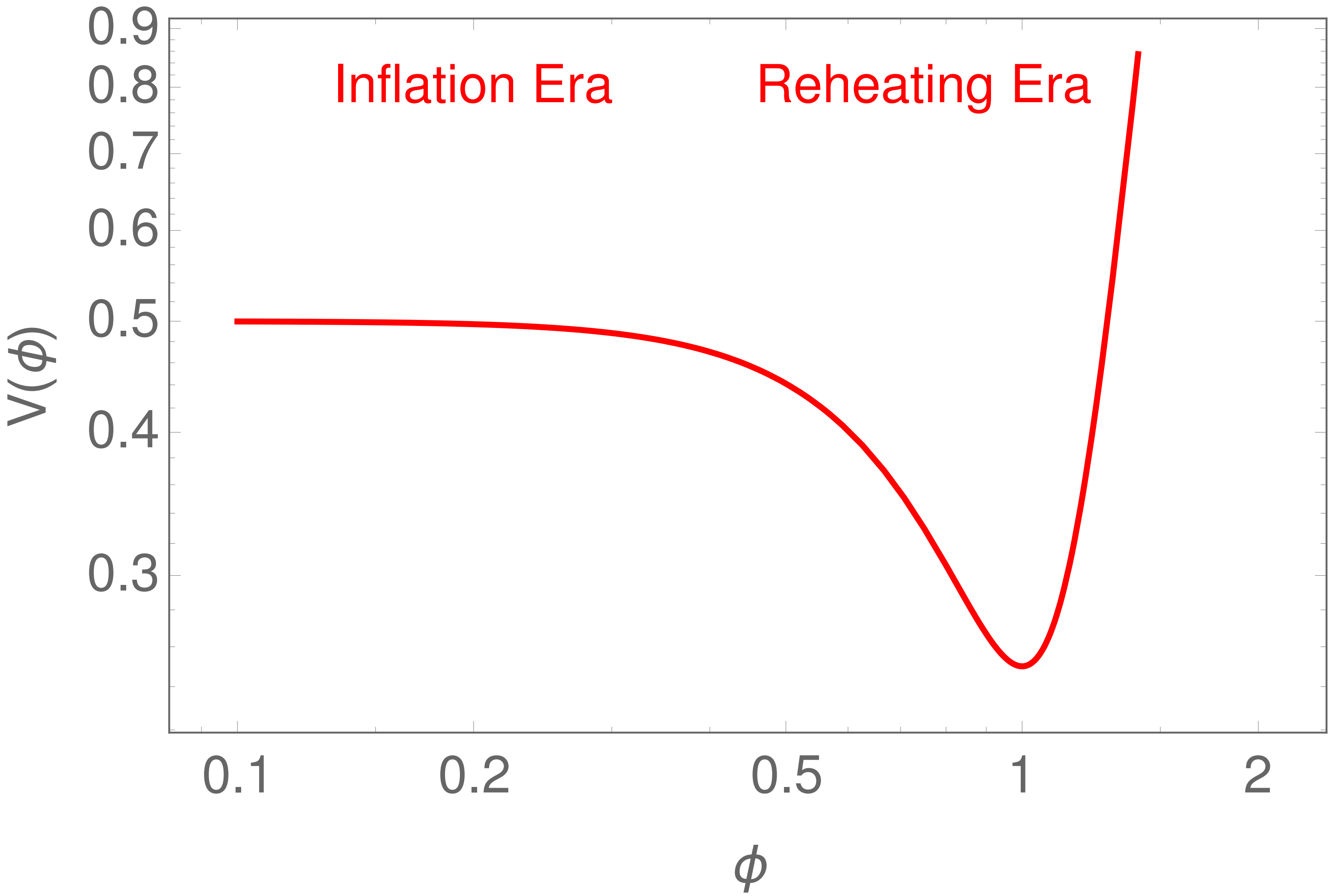


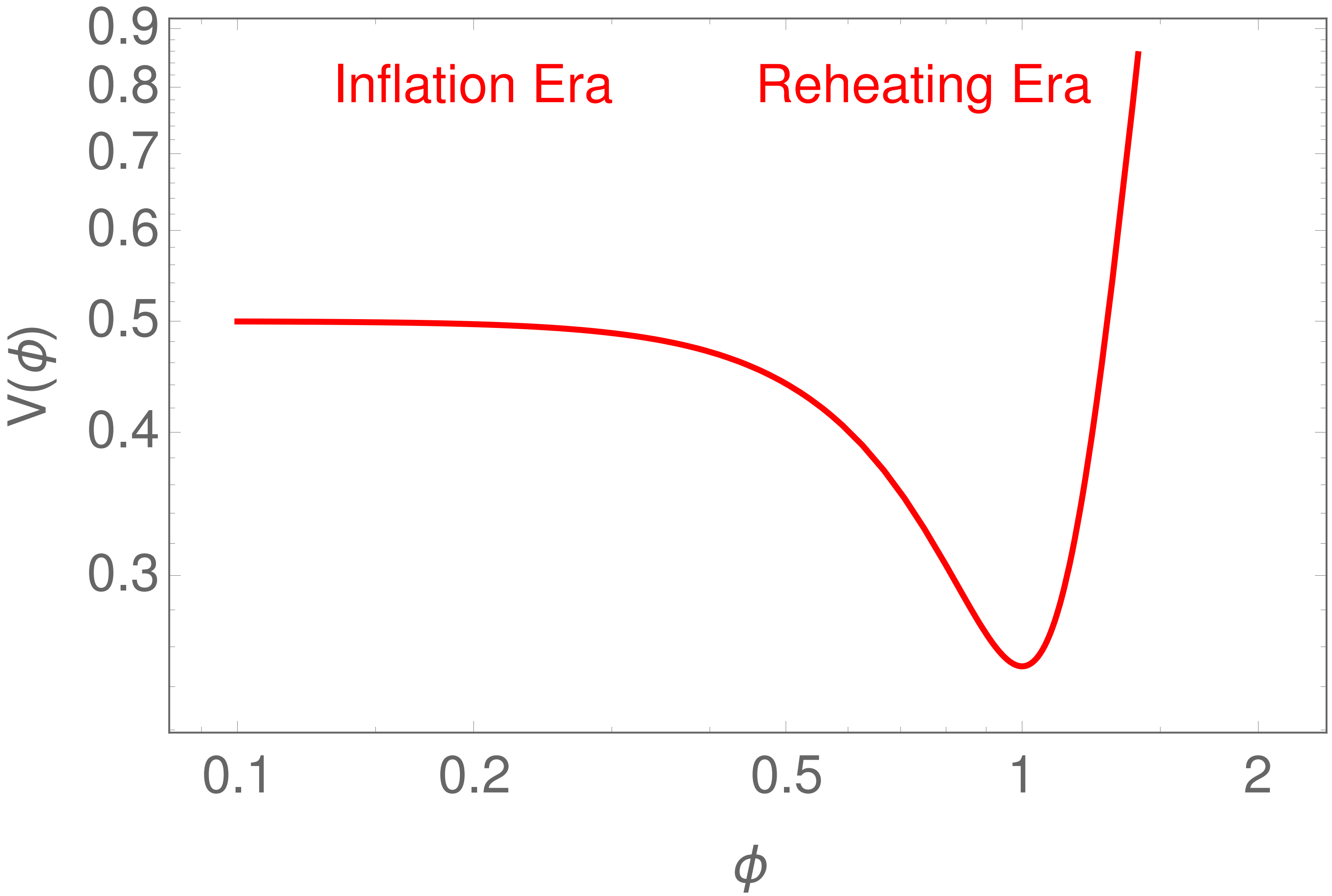
Inflation

- explains homogeneity, isotropy and flatness of the universe
- explains origin of density fluctuations from blown-up quantum fluctuations

Reheating

dissipative processes fill the universe with radiation ("hot big bang")

$$\ddot{\phi} + (3H + \Gamma)\dot{\phi} + \partial_\phi V(\phi) = 0$$



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dissipation rate

effective potential

The Reheating Era

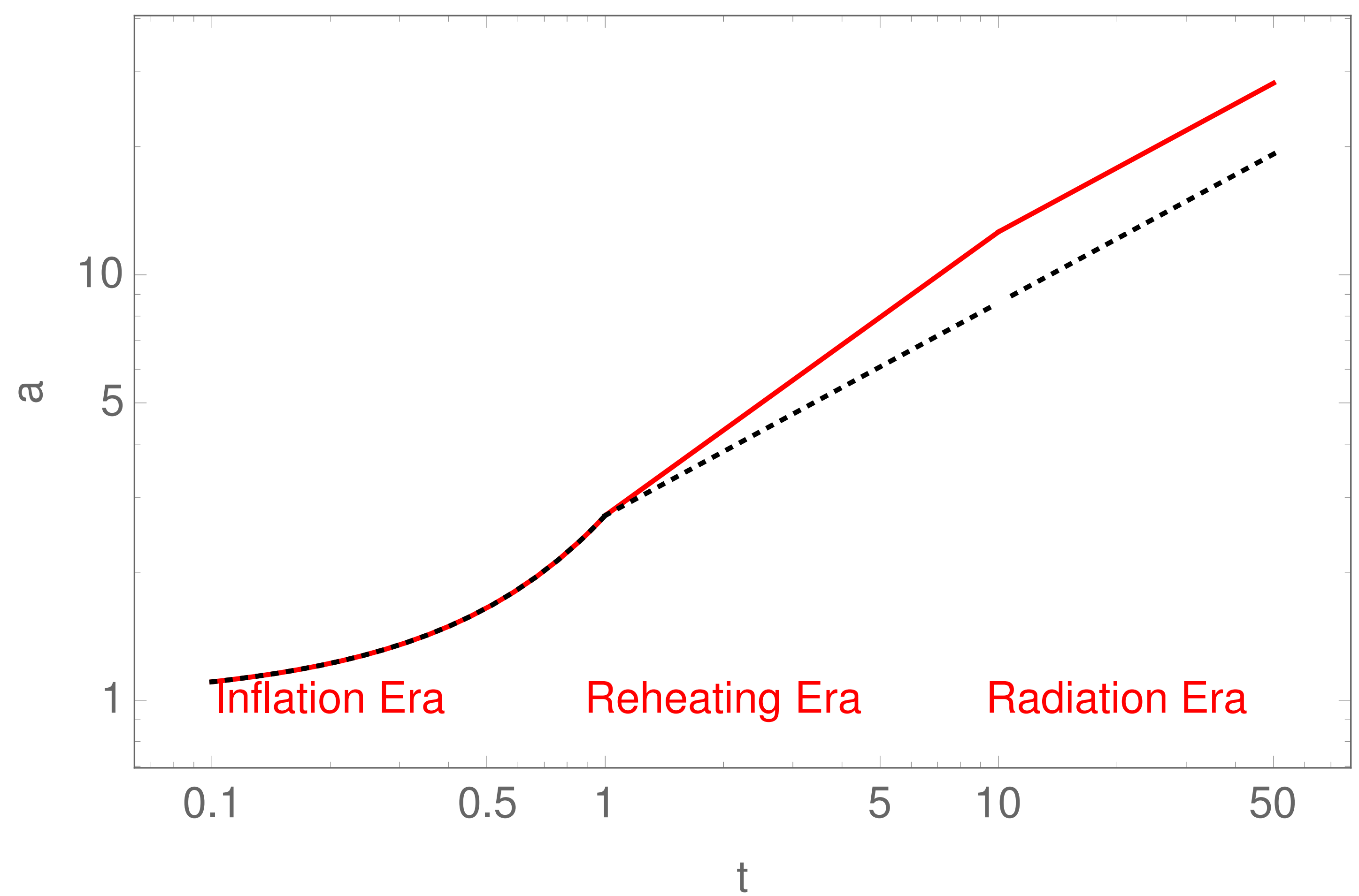
$$\ddot{\phi} + (3H + \Gamma_\varphi)\dot{\phi} + \partial_\phi V(\phi) = 0$$

- **inflation ends when kinetic energy is sizeable**

  w > -1/3

- **reheating ends when dissipation exceeds Hubble damping**

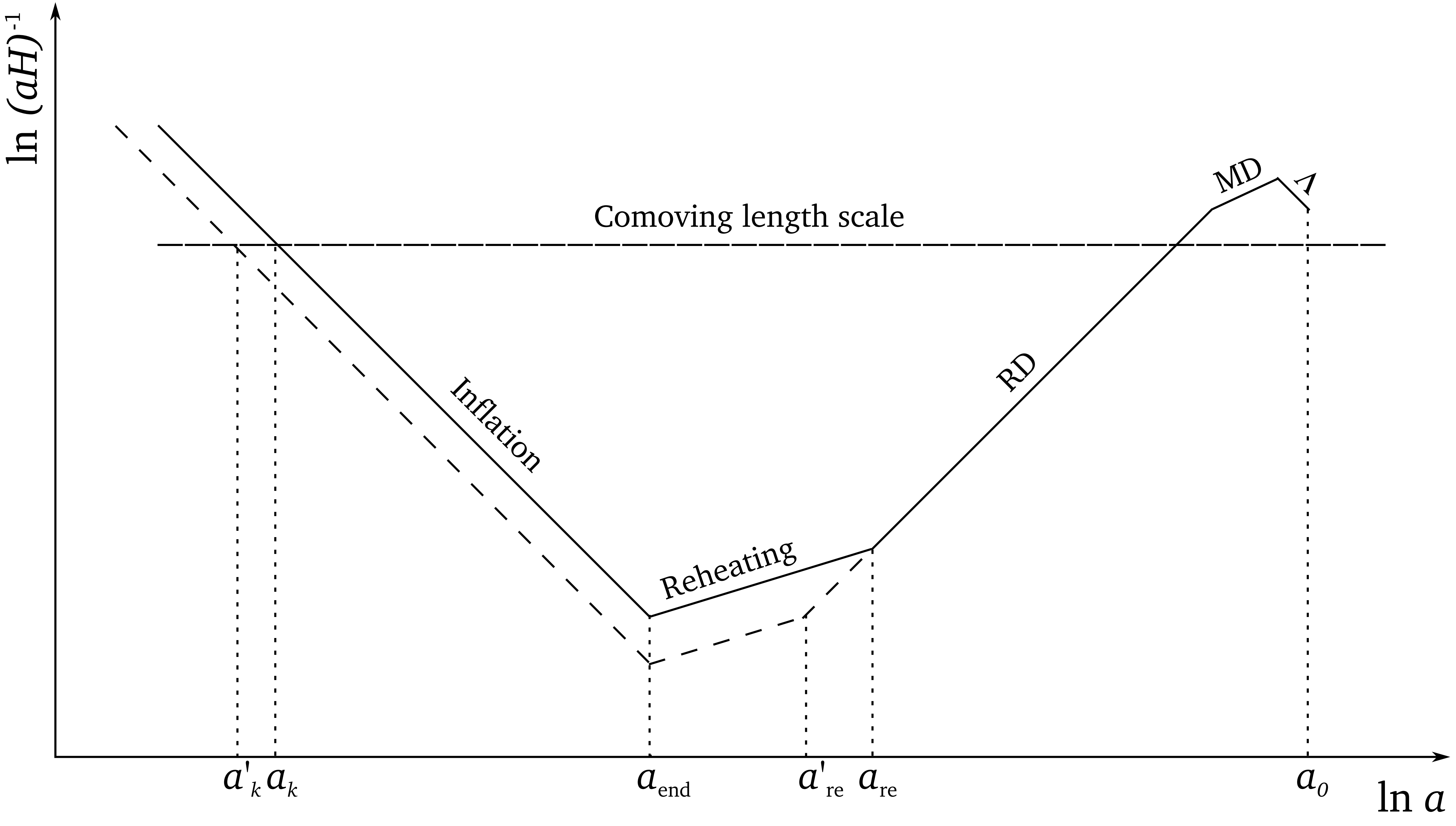
  Γ = H



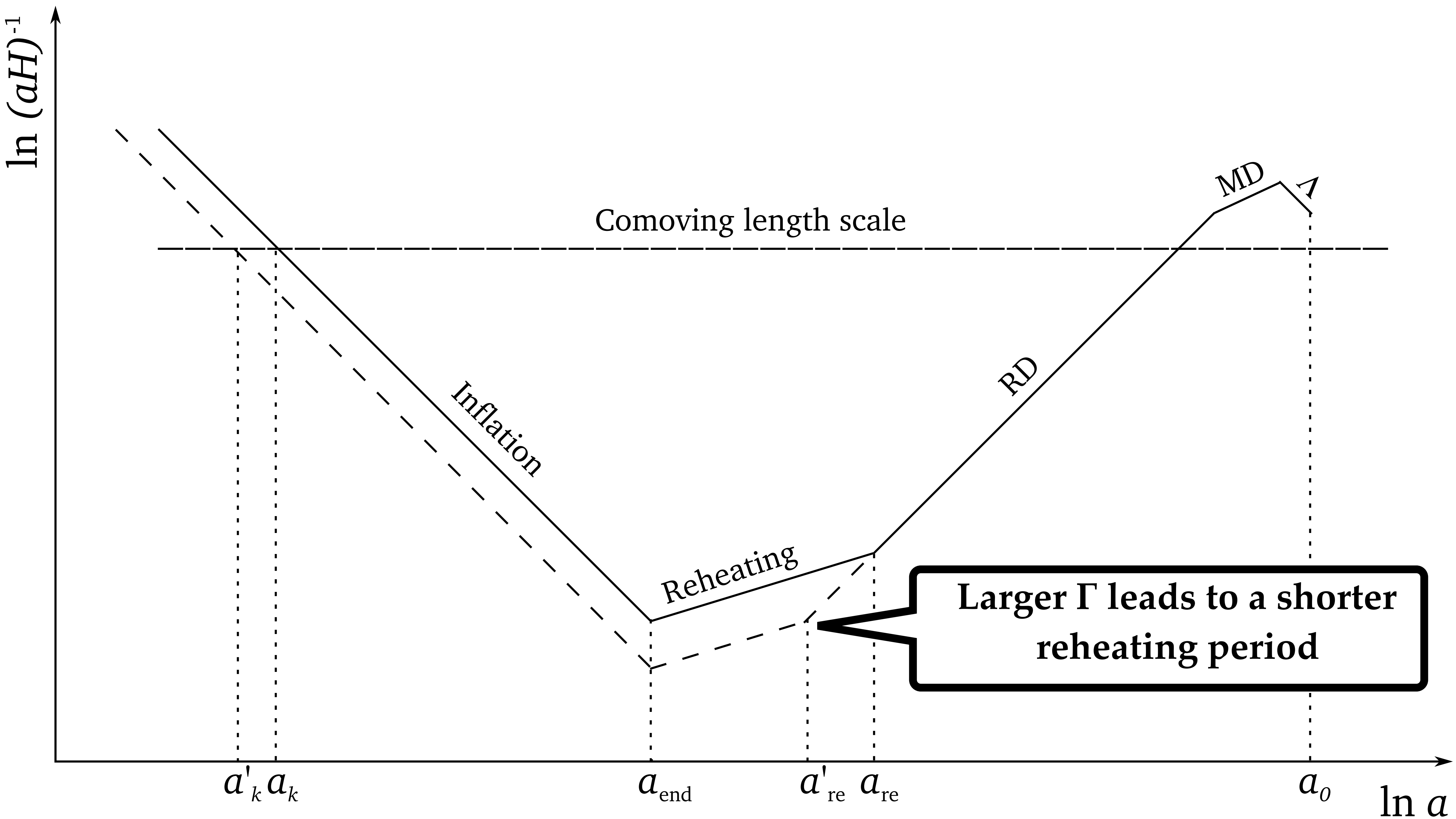
In between: -1/3 < w < 1/3

⇒ affects expansion history and redshirting of CMB modes!

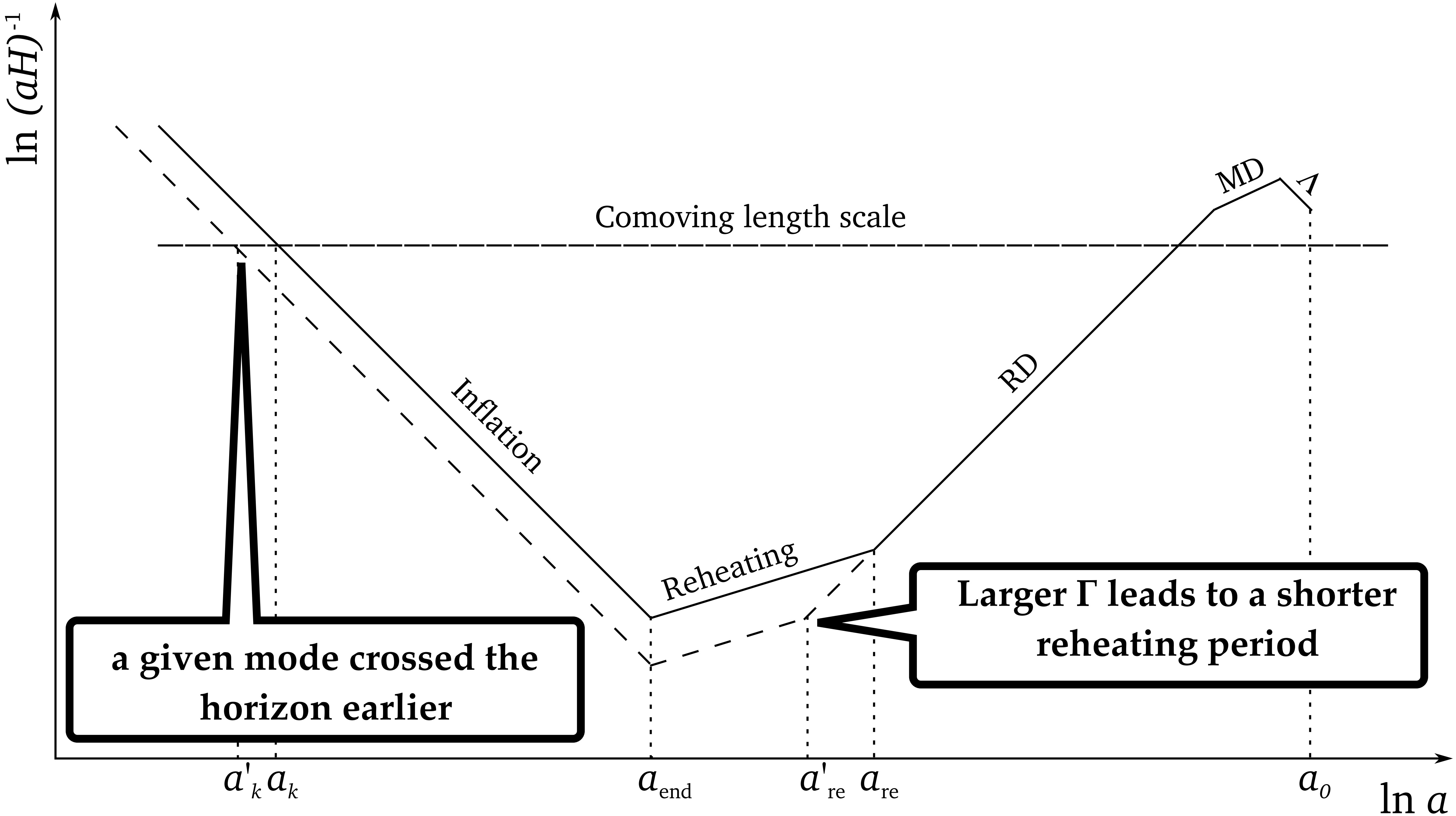
Effect on CMB Modes



Effect on CMB Modes



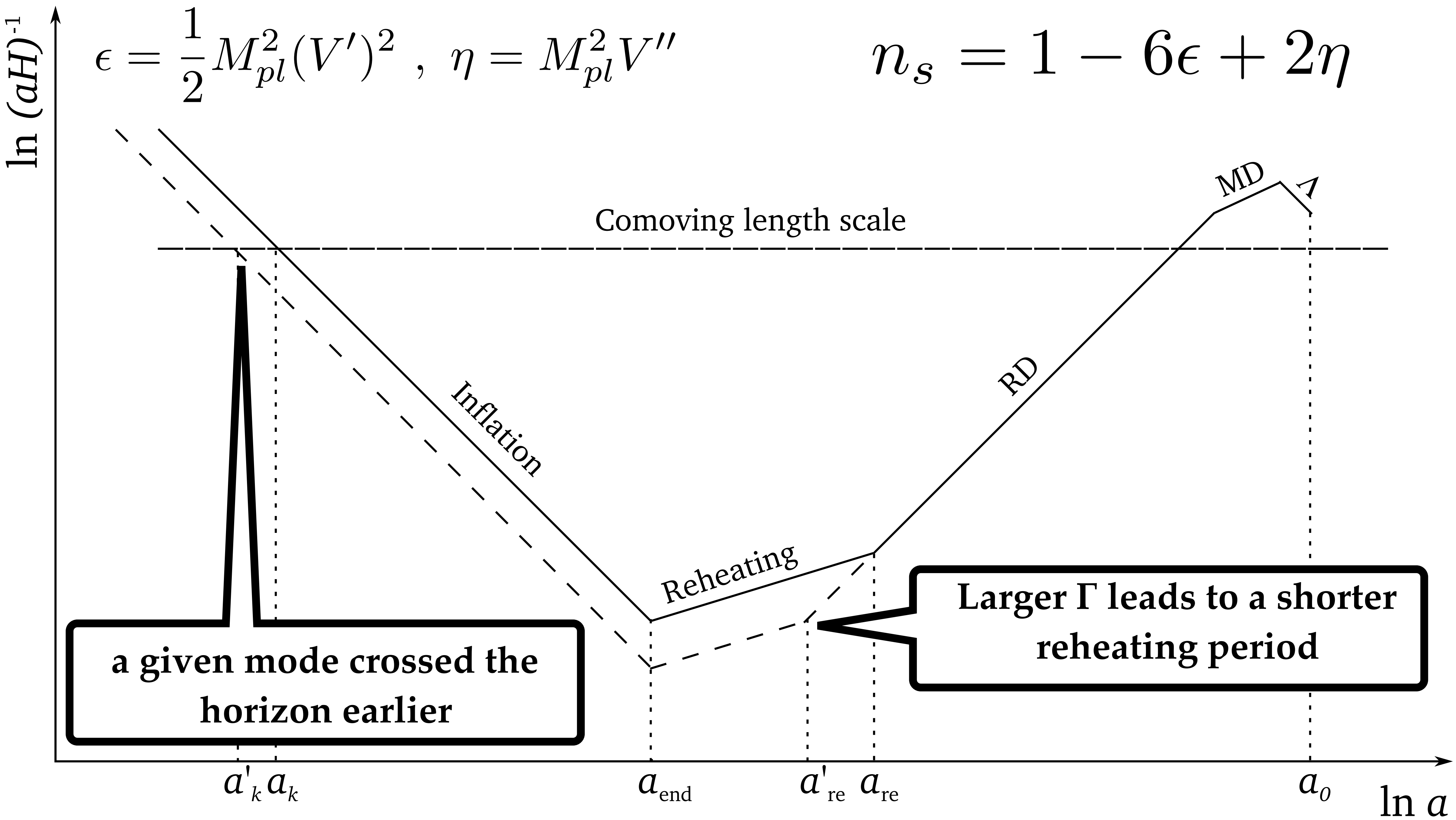
Effect on CMB Modes



Effect on CMB Modes

$$\epsilon = \frac{1}{2} M_{pl}^2 (V')^2 \ , \ \eta = M_{pl}^2 V''$$

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



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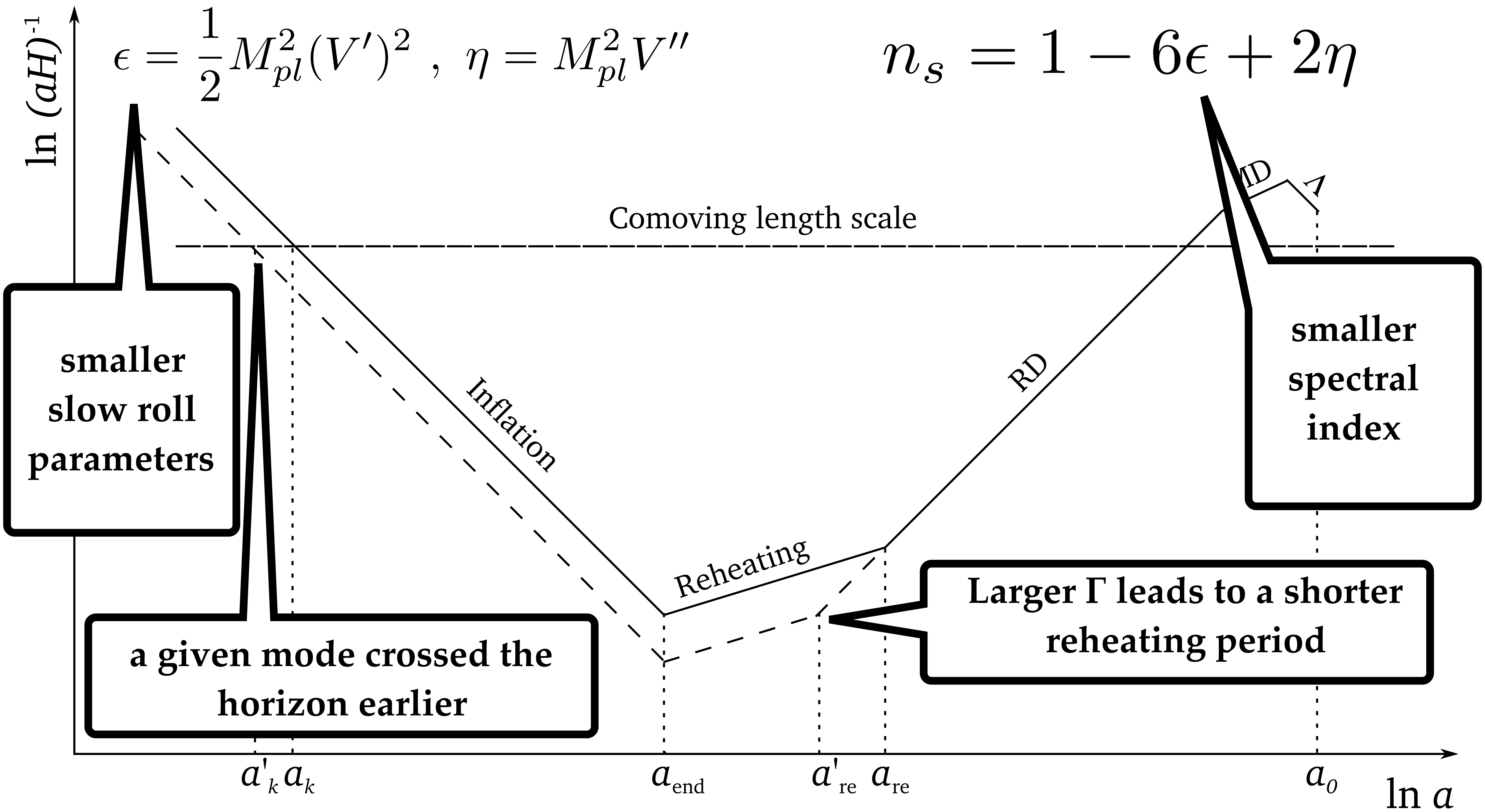
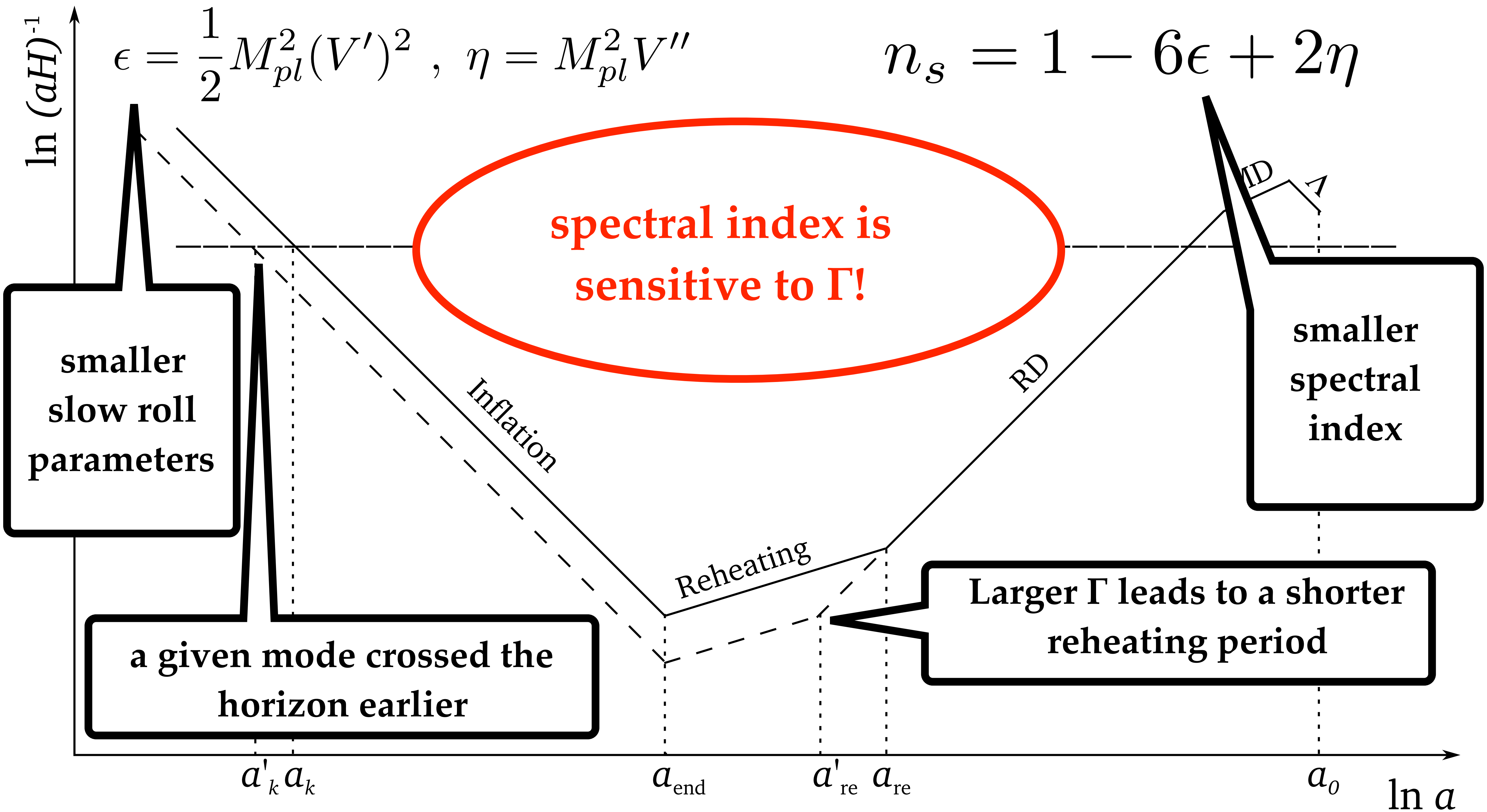


Effect on CMB Modes



This is not really new, see e.g. Kinney/Riotto 2006.

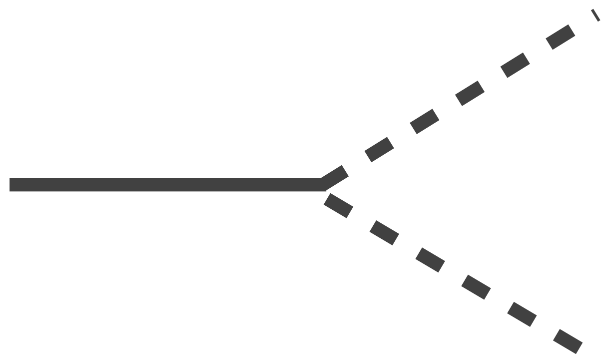
But one may ask

Can one translate a “measurement” of Γ into a “measurement” of microphysical parameters?

Inflaton Decay

Consider a simple scalar interaction $g\phi\chi^2$

In vacuum, the inflaton decays via $1 \to 2$ decays



$$\Gamma = \frac{g^2}{8\pi m_\phi}$$

But what about the feedback of the produced particles on Γ?

Feedback will lead to a very complicated relation between g and $\Gamma(t)$.

Parametric Resonance

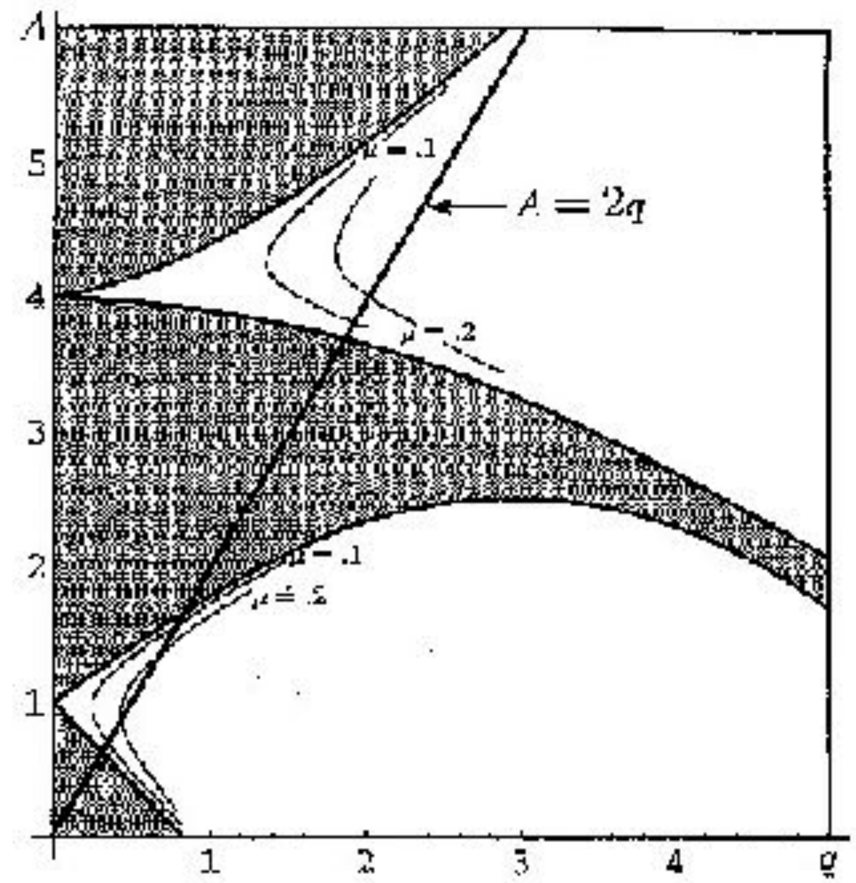
Mode equation for produced particles

$$\ddot{\chi}_k + [k^2 + m_\chi^2 + 2\tilde{g} m_\phi \Phi \sin(m_\phi t)]\chi_k = 0$$

Can are rewritten as Mathieu equation

$$\chi_k'' + [A_k - 2q\cos(2x)]\chi_k = 0$$

with $A_k = 4(k^2 + m_\chi^2)/m_\phi^2$, $q = 4\tilde{g}\Phi/m_\phi$



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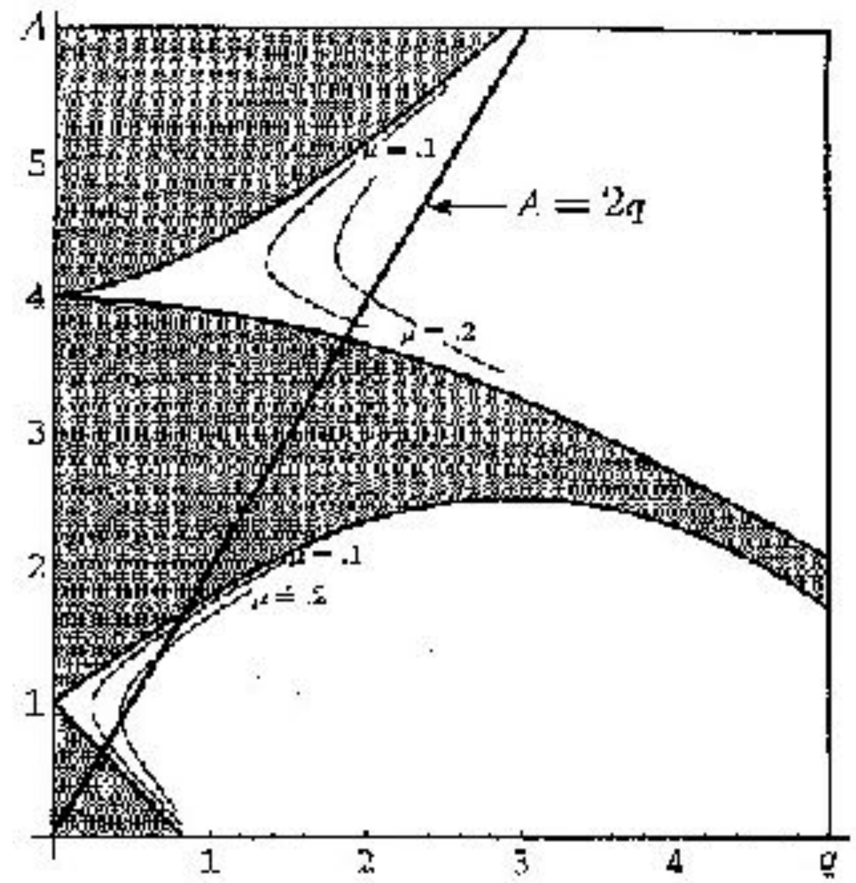
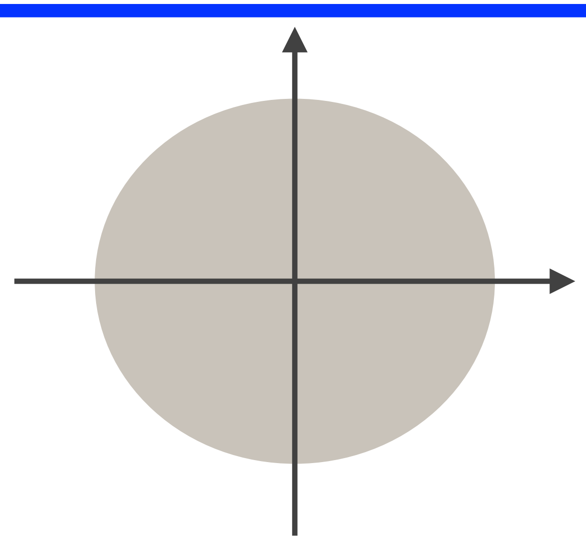


“broad resonance” for *q > 1*, i.e. $\tilde{g} > m_\phi/\Phi$

non-perturbative production of particles
with momenta $k < (m_\phi^2 \tilde{g} \Phi)^{1/3}$



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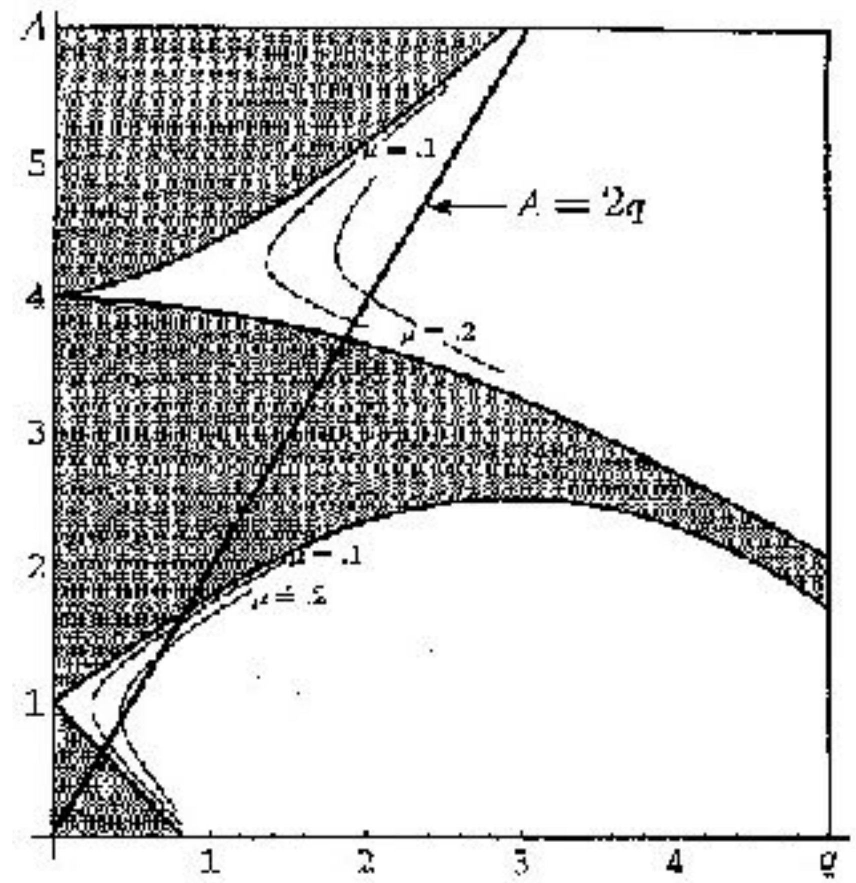

Can are rewritten as Mathieu equation

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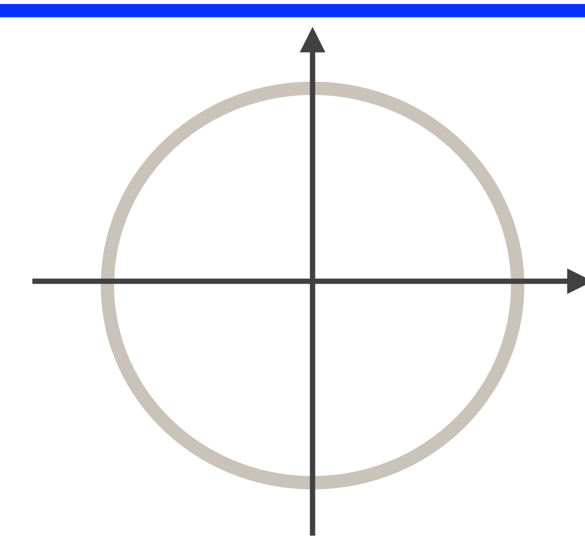
with $A_k = 4(k^2 + m_\chi^2)/m_\phi^2$, $q = 4\tilde{g}\Phi/m_\phi$

"narrow resonance" for *q* < *1,* i.e. $\tilde{g} < m_\phi/\Phi$

Bose-enhanced production of particles with momenta $k = m_\phi/2$



Parametric Resonance

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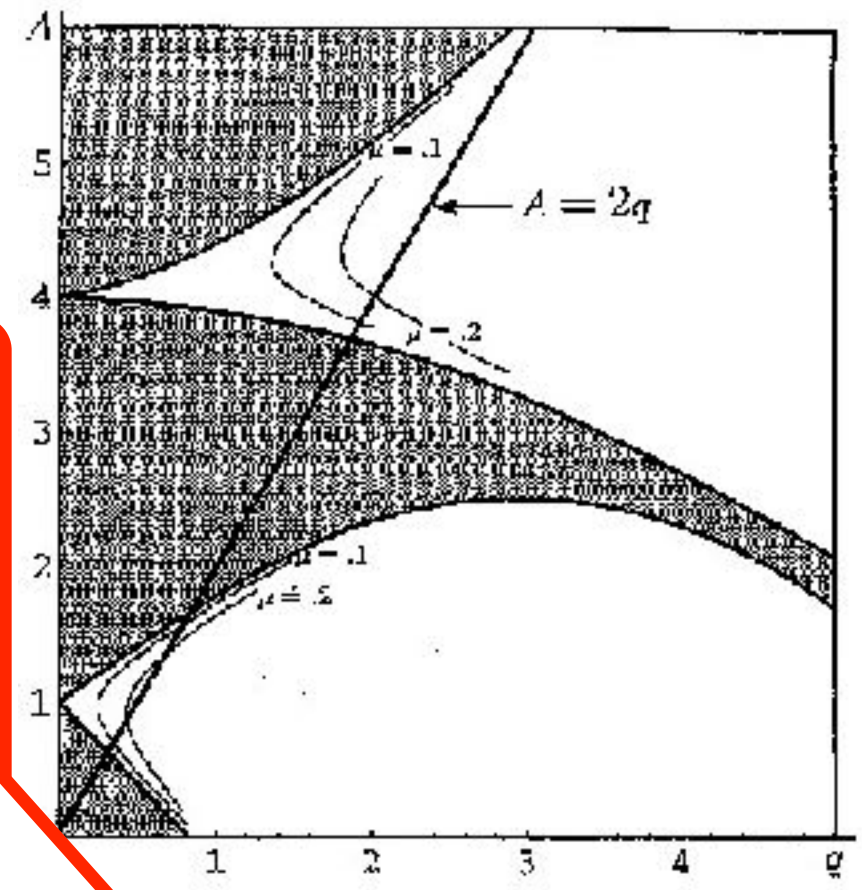


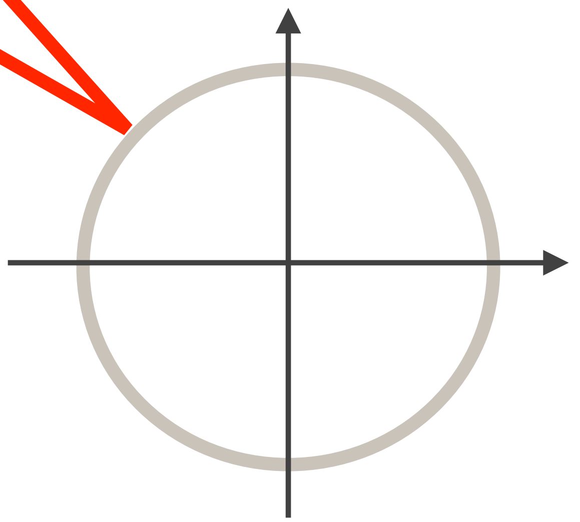
Can be avoided due to redshifting if $\Gamma < H$ or

$$\tilde{g} < \frac{V_{\rm end}^{1/4}}{\rho_{\rm end}} \left(\frac{m_\phi}{24 M_{pl}} \right)^{1/2}$$

“narrow resonance” for *q* < 1, i.e. $\tilde{g} < m_\phi / \Phi$

Bose-enhanced production of particles

with momenta $k = m_\phi / 2$



Perturbative Reheating

But: Big Bang Nucleosynthesis requires T > 10 MeV when $\Gamma = H$.

This implies $$\tilde{g} > (8\pi m_\phi)^{1/2} \left(\frac{\pi^2 g_*}{90 M_{pl}} \right)^{1/4} T_{\rm BBN}$$

The vacuum decay rate can be used to describe reheating if

$$(8\pi m_\phi)^{1/2} \left(\frac{\pi^2 g_*}{90 M_{pl}} \right)^{1/4} T_{\rm BBN} < \tilde{g} < \frac{V_{\rm end}^{1/4}}{\rho_{\rm end}} \left(\frac{m_\phi}{24 M_{pl}} \right)^{1/2}$$

Example: α Attractor E Model

$$V = \Lambda^4 \left(1 - e^{-\sqrt{\frac{2}{3\alpha}}\frac{\phi}{M_{pl}}}\right)^{2n}$$

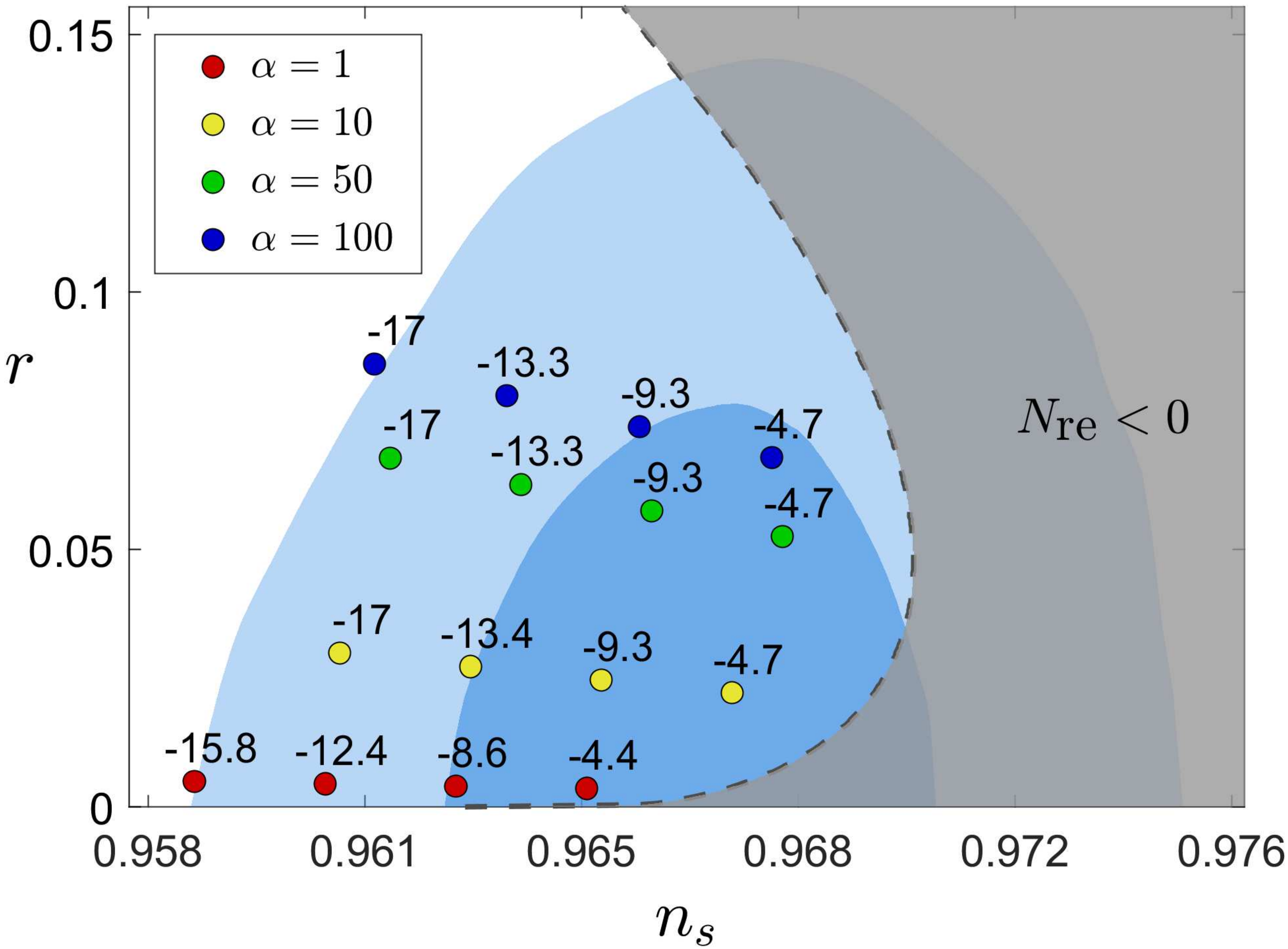
Kallosh / Linde 2013 …

$$\text{unknowns} \;:\; (\Lambda, \alpha, n, g)$$

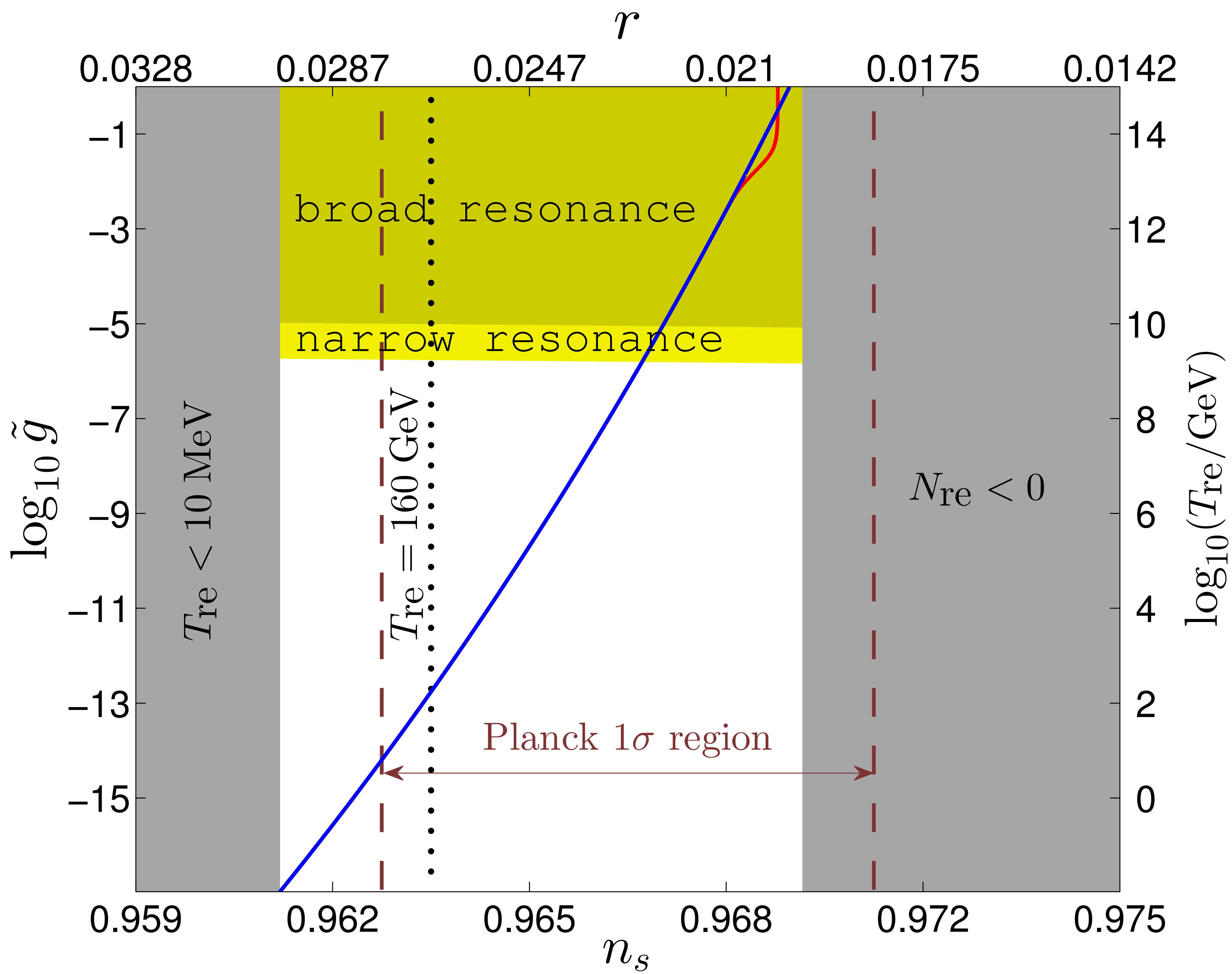
$$\text{observables} \;:\; (A_s, n_s, r)$$

- **We fix *n=1* and study different values of *α***
- ***r* is uniquely determined by the spectral index**
- **reheating temperature is fixed by *g***

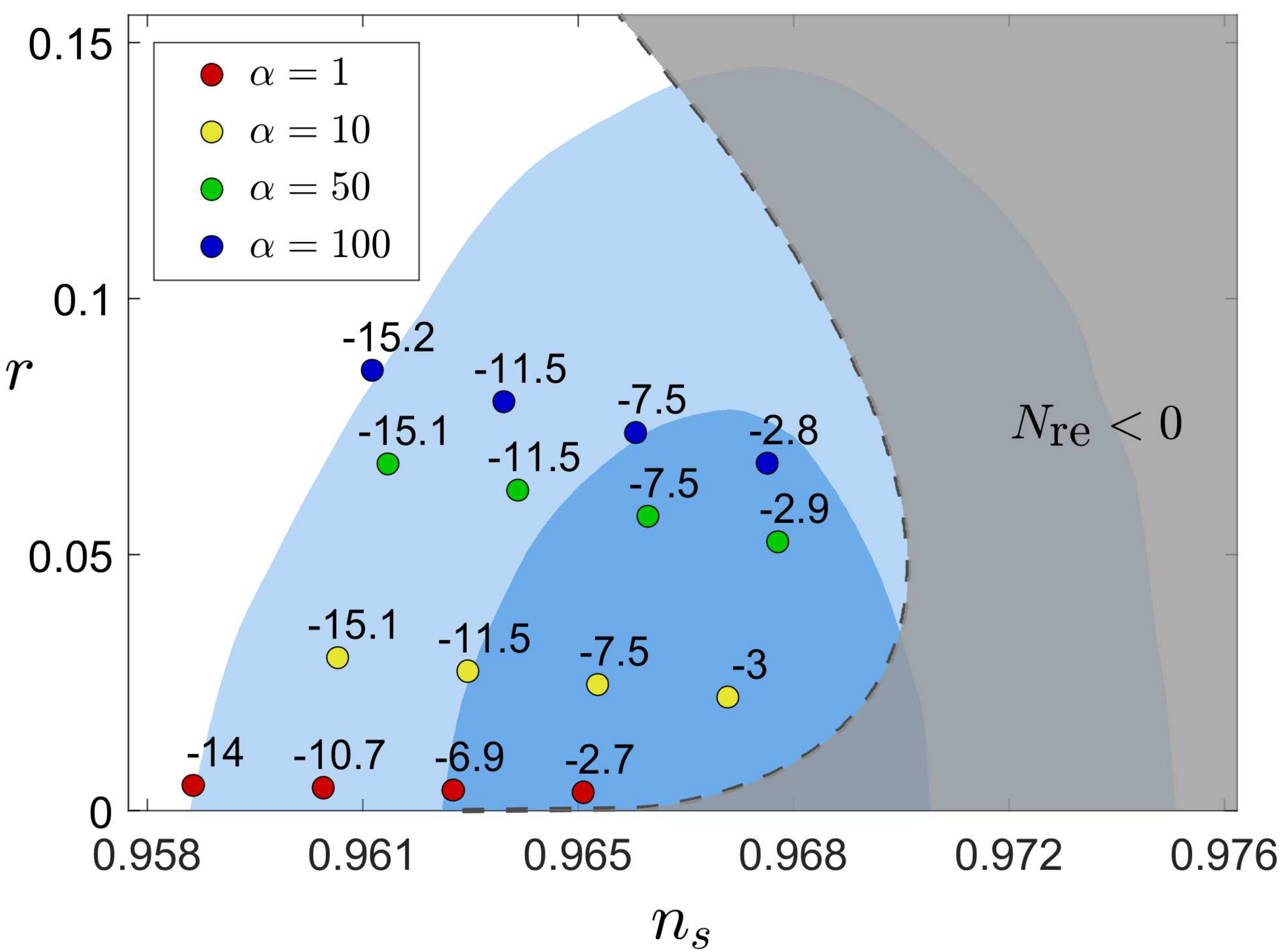
Results for gφχ² Interaction



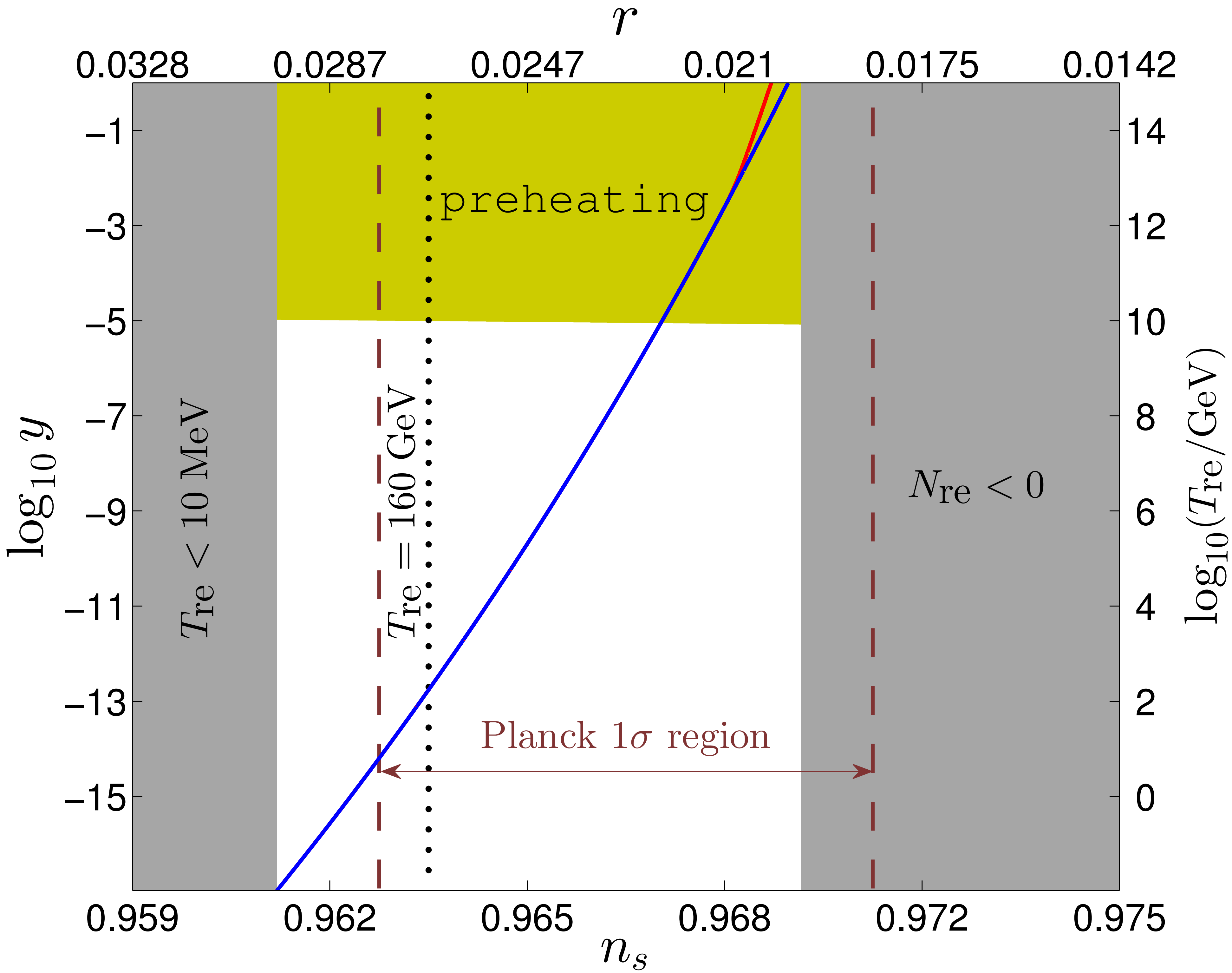
Results for $g\varphi\chi^2$ Interaction



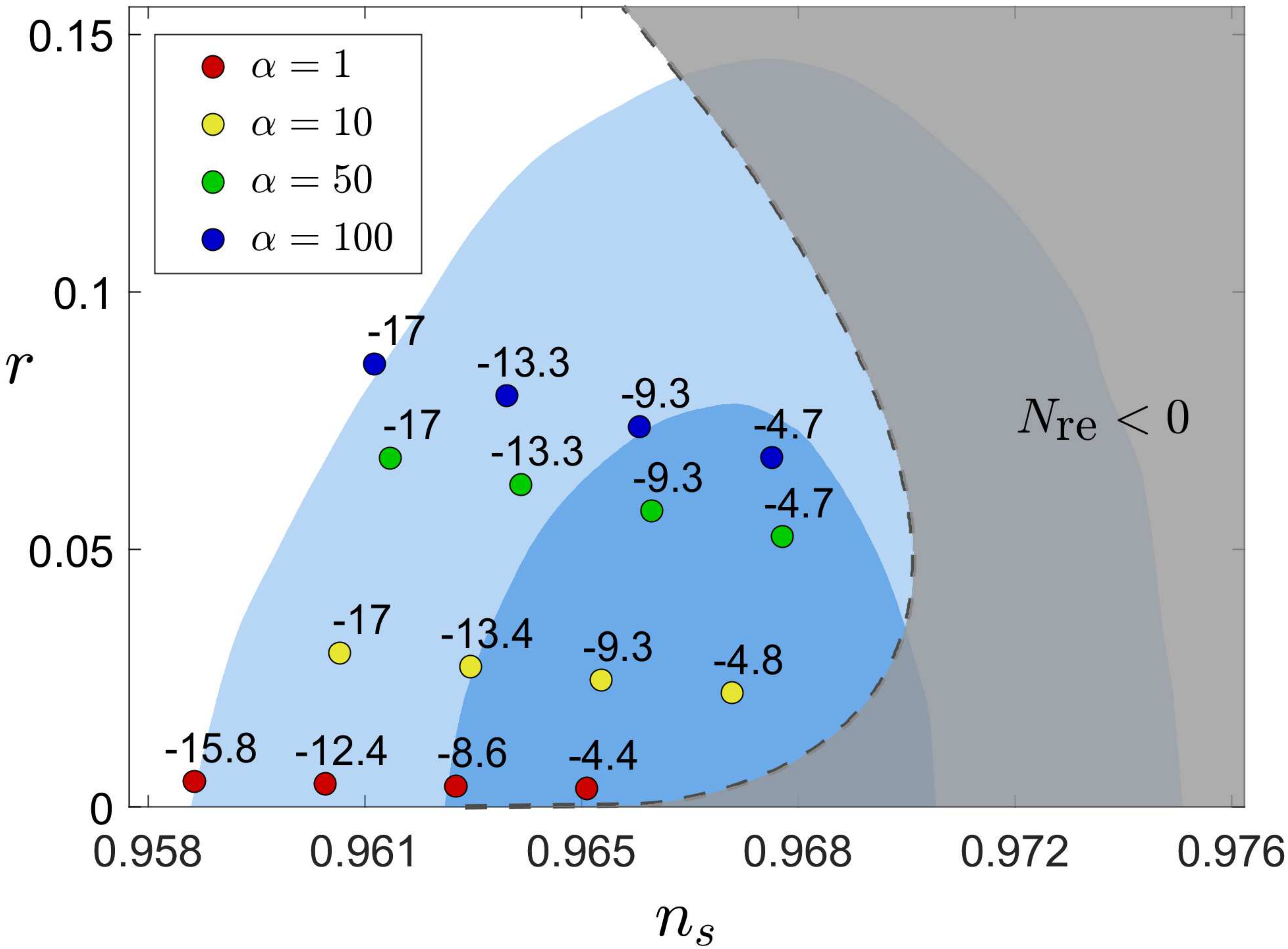
Results for hφχ³ Interaction



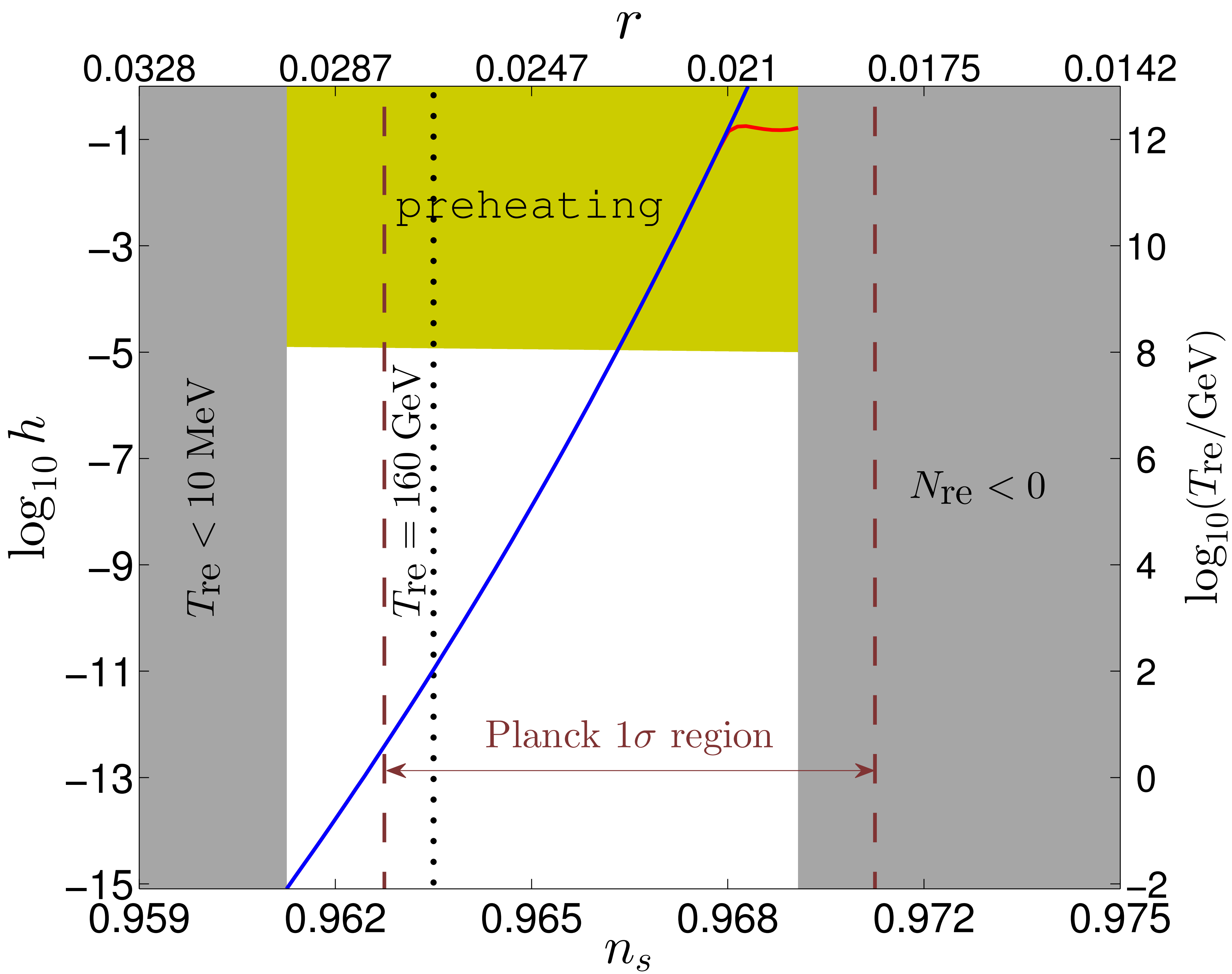
Results for hφχ³ Interaction



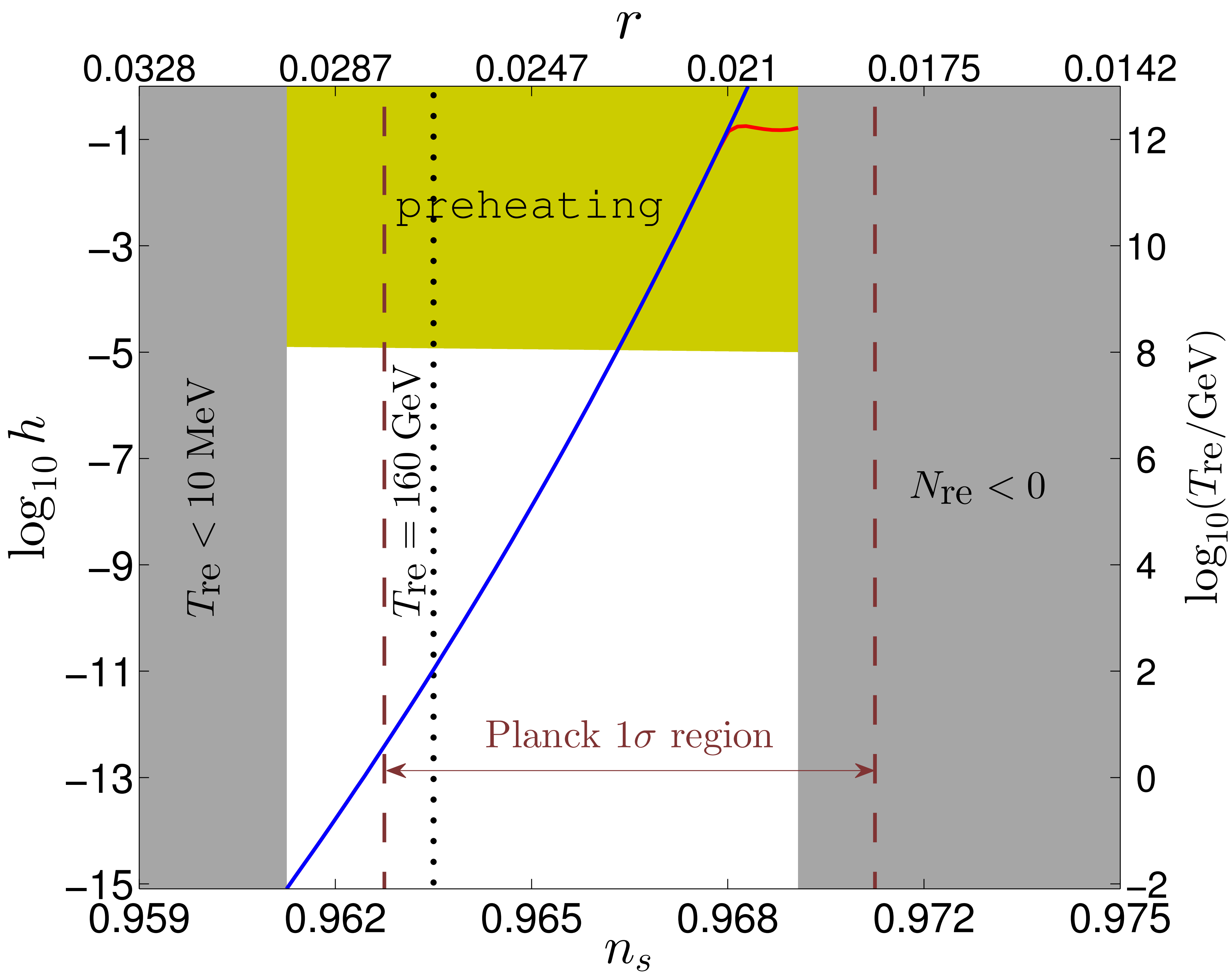
Results for Yukawa Interaction



Results for Yukawa Interaction



Results for Yukawa Interaction



Conclusions

- **CMB data allows to constrain the inflaton couplings in a given model of inflation**
- **We have done this for α Attractor E models**
- **The coupling constants can be related to the spectral index via simple analytic formulae if they are smaller than ~ 10^{-5}**
- **Currently the constraints are weak, but will improve with better measurements of the spectral index**

PRO:
"measure" fundamental parameters at the scale of inflation!

CON:
Only possible within a given model