Hybrid Quintessential Inflation

- Inflation and dark energy: quintessential inflation
- Hybrid quintessential inflation
- Summary

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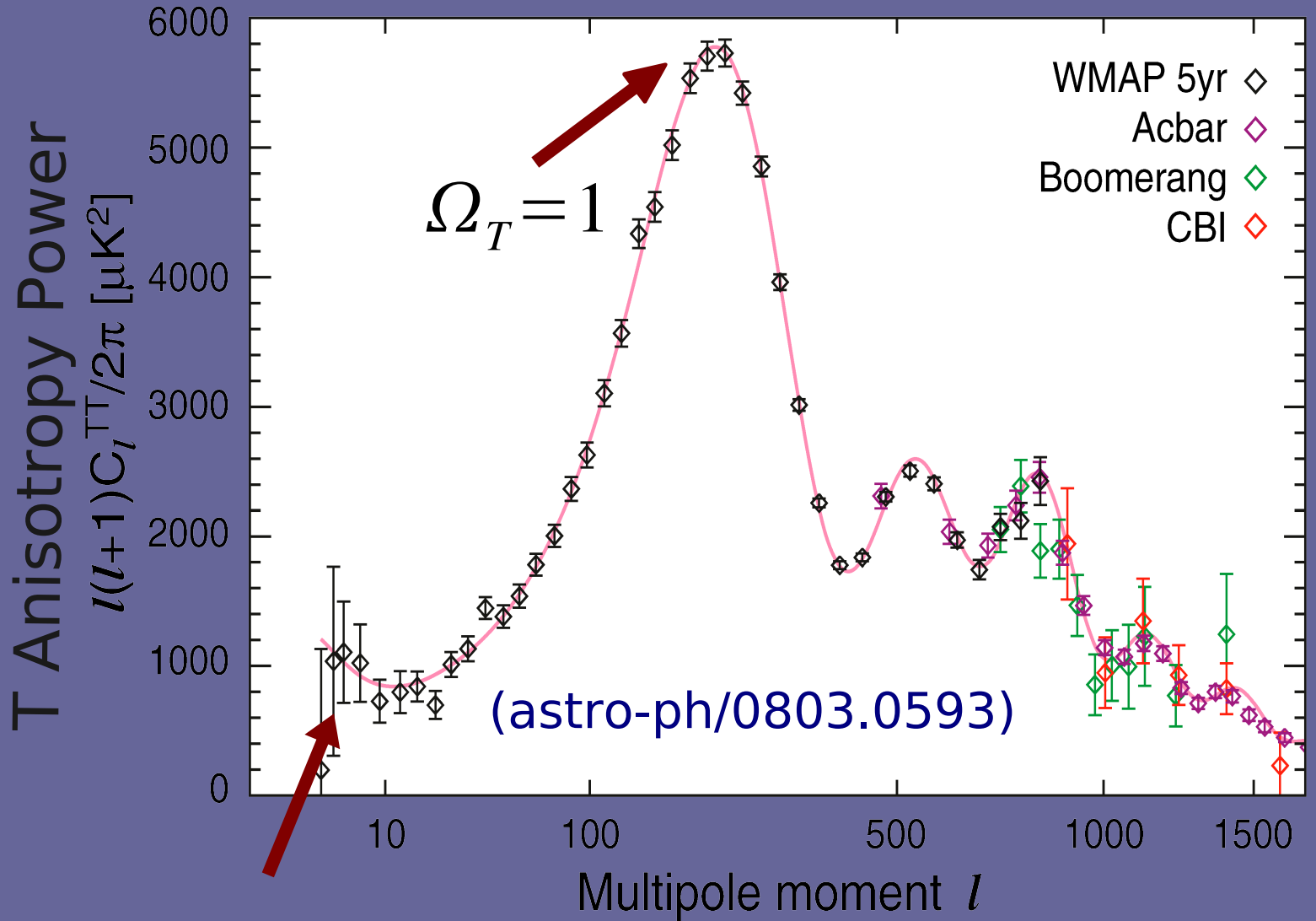
MBG, A. Berera, B. M. Jackson, A. Taylor, PLB 2009

Cosmic Microwave Background Radiation

Wilkinson Microwave Anisotropy Probe



COBE (1992)
Boomerang
Maxima
DASI
CBI
VSA
.
.
.
PLANCK
(14/05/09)

Largest observable scale
O(3000 Mpc)

Galaxy scale
O(Mpc)

Expanding Universe

- Flat Geometry → Flatness problem

  But if $\Omega_T = 1$ today then $\Omega_T(t_{nucl}) - 1 \approx 10^{-16}$

- Homogeneous and Isotropic → Horizon problem

  The observable Universe was larger than the **particle horizon** at LSS

- Δ T/T ~ 10^{-5} → Super-horizon perturbations?

  Too small sub-horizon (**causal**) perturbations

- Unwanted relics:

  monopoles, moduli, gravitinos,...

(Slow Roll) Inflation

Early period of accelerated expansion

$$\ddot{a} > 0 : P < -\rho/3$$

Scalar field rolling down its (flat) potential

Energy & pressure

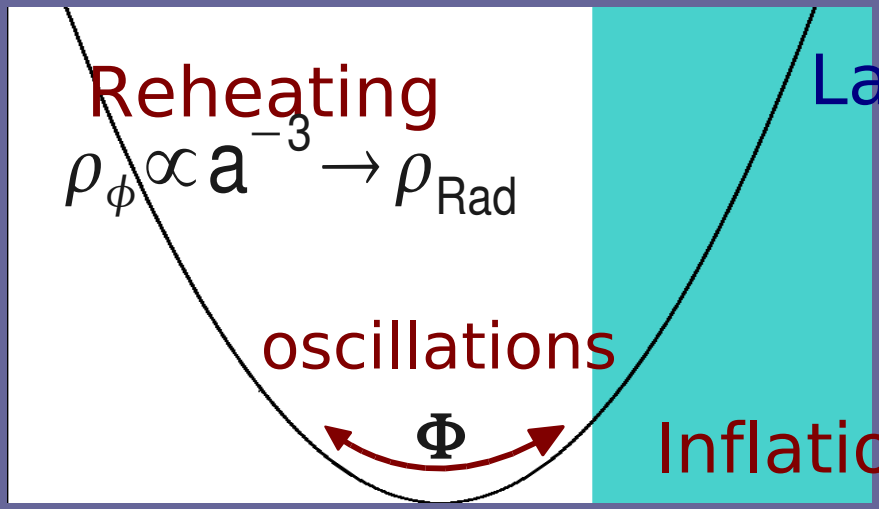
$$\rho = \dot{\phi}^2/2 + V(\phi) \approx V(\phi) \approx \text{Constant}$$

$$P = \dot{\phi}^2/2 - V(\phi) \approx -V(\phi)$$

e.o.s w= $P/\rho \simeq -1$

"Flat" potential

The curvature and the slope smaller than the (Hubble) expansion rate



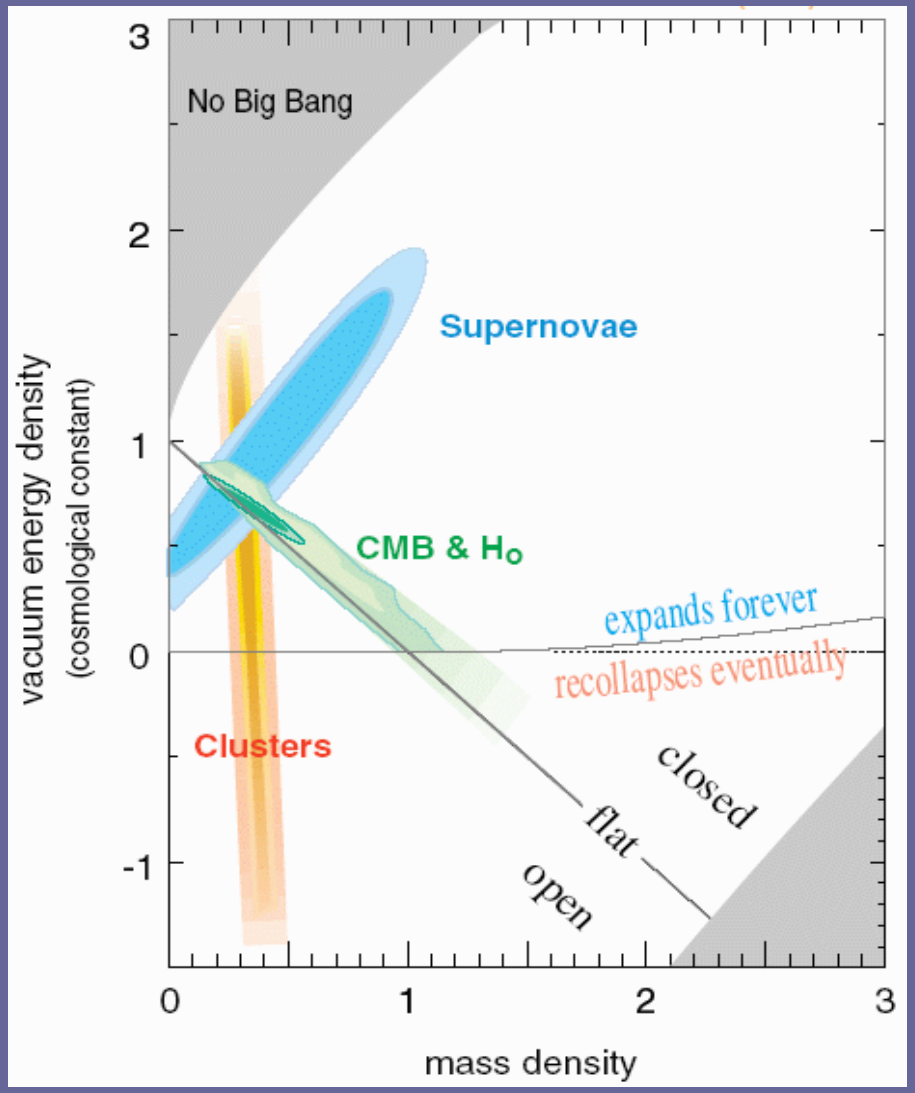
Large field models (chaotic inflation)

$$V(\phi) = V_0 \left(\frac{\phi}{M}\right)^p$$

(Linde, PLB'83)

"Slow roll" for large field values

Cosmic Budget



4% Atoms

Matter asymmetry?

22% "Dark" Matter ?

No candidate in the SM

No direct evidence

74% "Dark" Energy ?

Present accelerated expansion

Negative pressure

e.o.s $w_{DE} = P_{DE}/\rho_{DE} \simeq -1$

Cosmological Constant ?

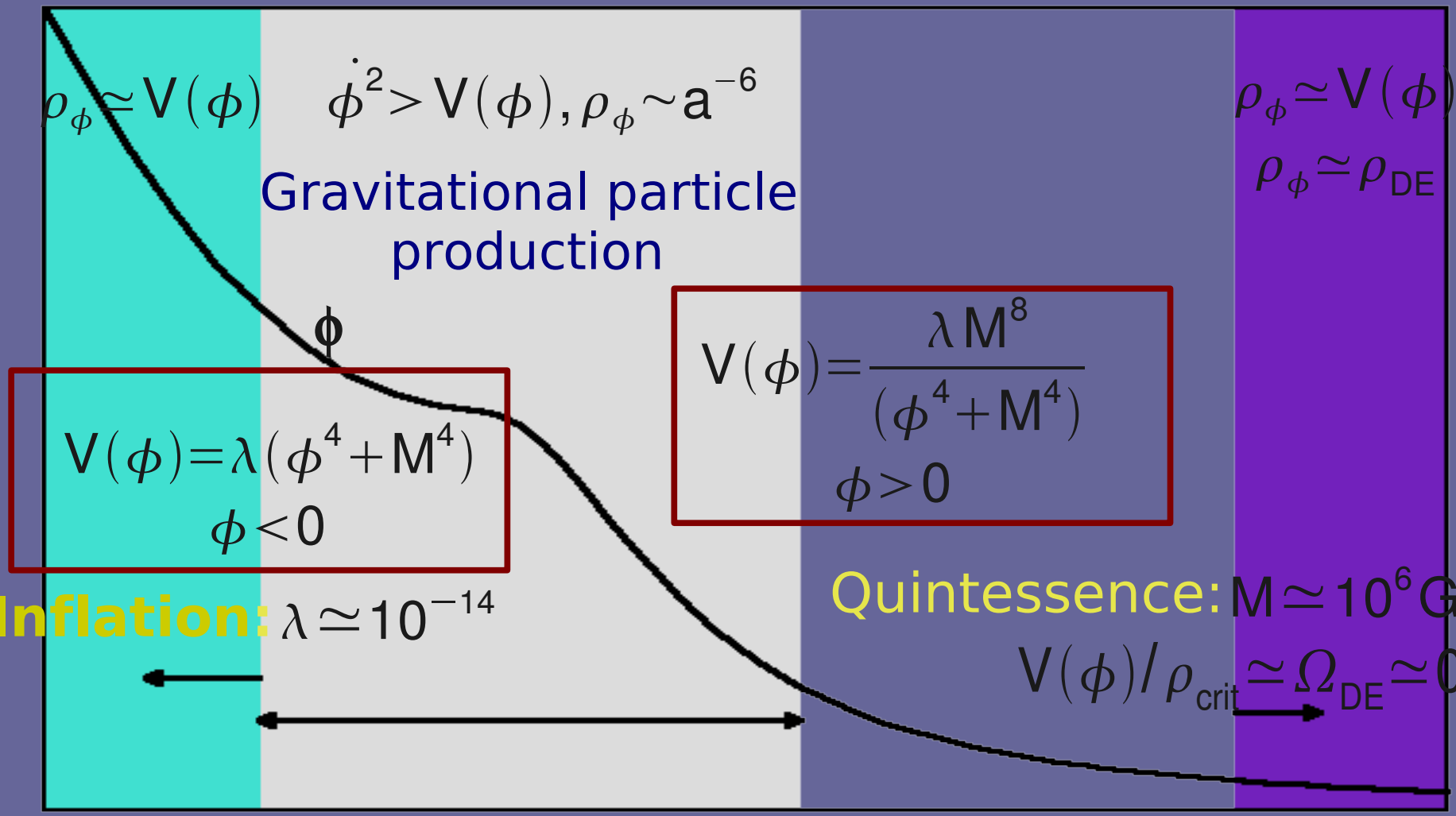
Quintessence field?

Ratra & Peebles, PRD '88; Wetterich NPB '88;
Ferreira & Joyce, PRD '98;

Quintessential Inflation

Peebles & Vilenkin PRD'99

Inflation → Kination → RD → MD → DE



(Primordial spectrum $P_R^{1/2} \simeq 5 \times 10^{-5}$)

Quintessential Inflation

- **Reheating:** (no oscillations, no decay)

Ford PRD '87;
Spokoiny PLB '93
Giovannini PRD'98

→ Gravitational particle production

- From inflation to kination: $\rho_R \simeq 10^{-2} N_s H_{inf}^4 (a_{inf}/a)^4$
- Thermalization: (interact. rate ~ H) $T_{th} \sim 10^9 N_s^{3/4}\,\mathrm{GeV}$
- Radiation domination $T_R \sim 10^3 N_s^{3/4}\,\mathrm{GeV}$

→ Gravity waves: $\rho_{GW} \simeq 10^{-2} N_{GW} H_{inf}^4 (a_{inf}/a)^4$ ($N_{GW}=2$)

(~ massless scalar field)

Starobinsky JTEP '79;
Allen PRD '88
Sahni PRD '90

- Nucleosynthesis: $(\rho_{GW}/\rho_R)_{BBN} < 0.2$
- To avoid overproduction of GW: $N_s > 100$

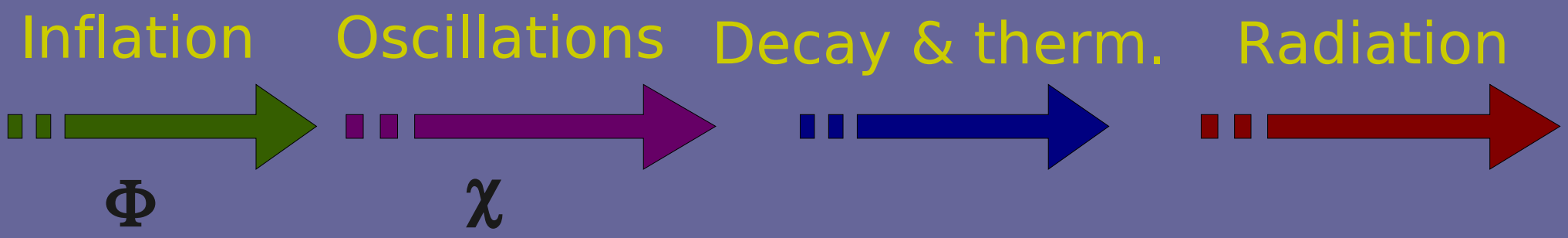
Quintessential Inflation

- More efficient reheating: $\rho_{GW} \ll \rho_R$

  - Instant “preheating” — Campos et al. PLB '03, Sami & Sahni PRD '04
  - “Curvaton” reheating: (curvaton= light scalar) — Feng&Li PLB '03, Dimopoulos PRD '03, Liddle&Ureña-Lopez PRD '03
  - Born-Infeld reheating — Sami et al. PLB '03

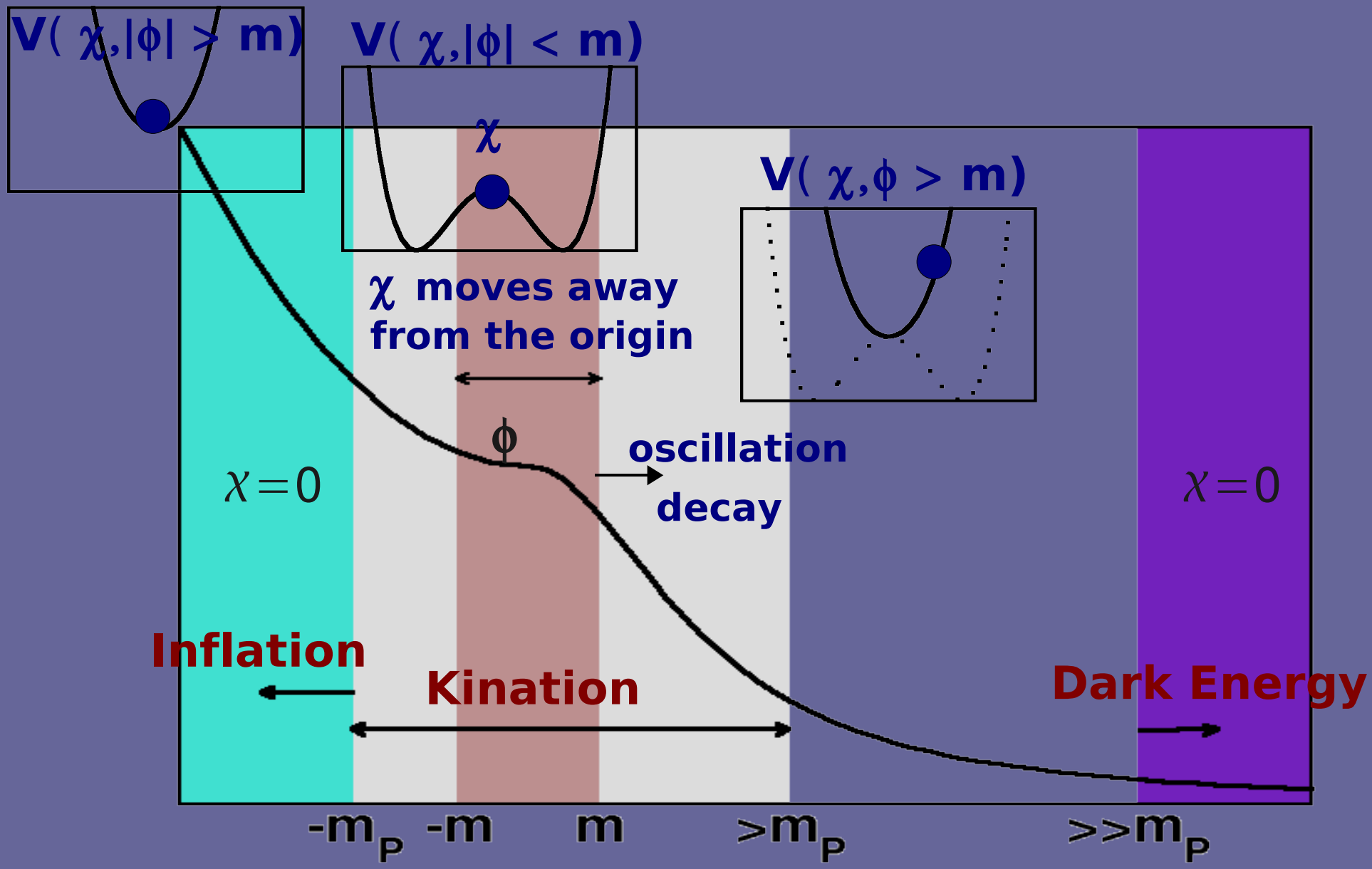
→ Extra d. of f. and/or couplings to the inflaton field

- Standard reheating ? $V = V(\phi)_{PV} + V(\phi, \chi)$



Hybrid Quintessential Inflation

$$V = V(\phi)_{PV} + \frac{g^2}{2}\chi^2(\phi^2 - m^2) + \frac{\lambda_\chi}{4}\chi^4$$



Hybrid Quintessential Inflation

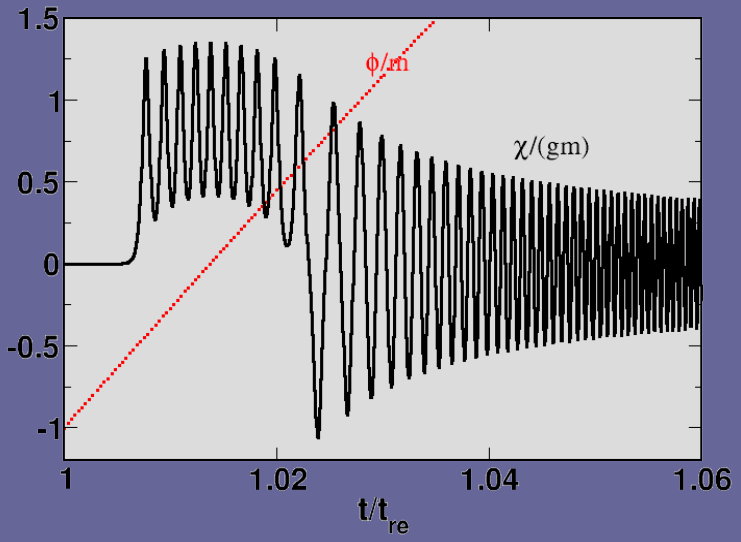
- χ field displaced from $\chi=0$

Energy available for reheating: $\rho_\chi^{(0)} \simeq f(g,m)(m^4 g^4/4\lambda_\chi)$

Fraction of the potential well depth: $f(g,m) \sim 10^{-3}(\lambda m_P^4/g^2 m^4)^{2/3}$

χ moves before $\phi \sim 0$ & f(m,g)<1 $\quad (m/m_P)^2 g > 10^{-9}$

- Oscillations and decay: $\Gamma_\chi = \alpha\, m_\chi$



$$\ddot{\phi} + 3H\dot{\phi} + V_\phi = 0$$

$$\dot{\rho}_\chi + 3H\rho_\chi + \Gamma_\chi \rho_\chi = (\dot{\phi}/\phi)\rho_\chi$$

$$\dot{\rho}_R + 4H\rho_R - \Gamma_\chi \rho_\chi = 0$$

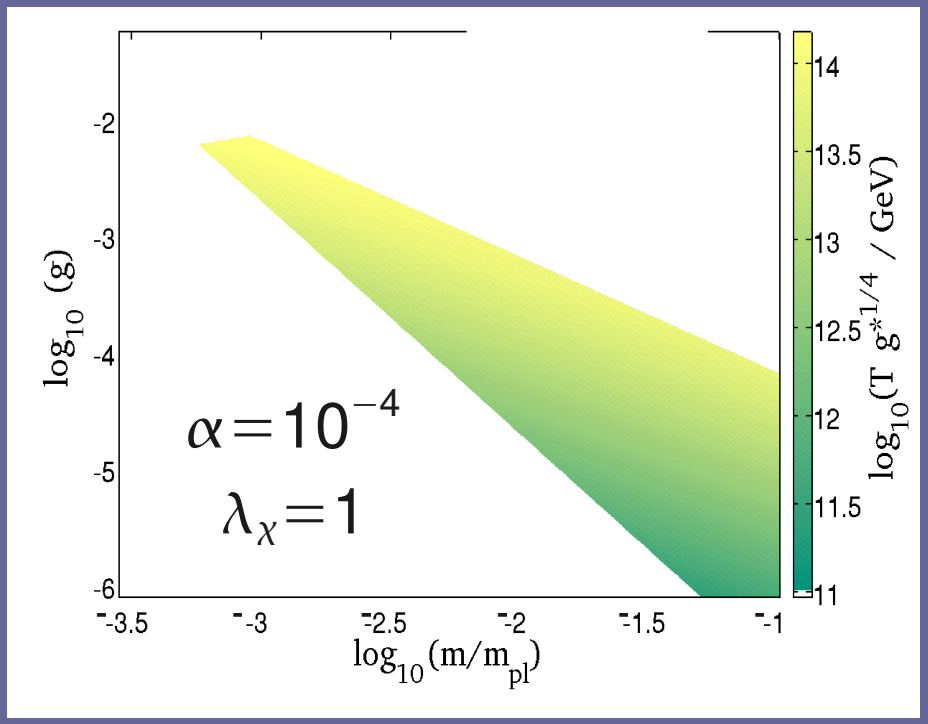
$g_*^{1/4} T_{RH} \sim (10^{11} - 10^{14})$ GeV

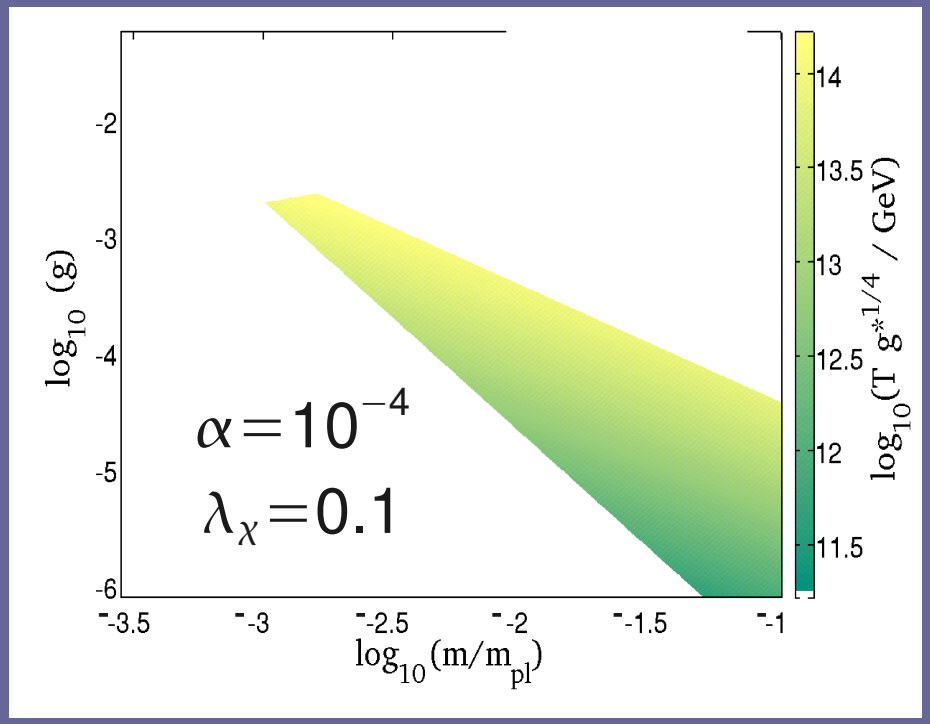
$\lambda_\chi \simeq 1, \quad \alpha \simeq 10^{-4}$

χ does not backreact on ϕ $\quad g^2/\lambda_\chi < 10^{-3}$

Hybrid Quintessential Inflation

Reheating T





Decreasing λ_χ reduces the allowed region (g,m)

Very weak coupling: $g \simeq 10^{-4}, \lambda_\chi 10^{-5}, m/m_P \simeq 10^{-2}$

$$\bar{g}^{1/4} T_{RH} \simeq 3 \times 10^{13}\,\mathrm{GeV}$$

Summary & Future prospects

- **Quintessential inflation:** unified picture of inflation & DE

  Reheating through gravitational particle productions

  $\rho_R \sim N_s \rho_{GW}$ Overproduction of GW?

- **Hybrid Quintessential inflation:**

  Reheating similar to hybrid inflation through decay of oscillating field χ $\rho_R \gg \rho_{GW}$

- Parameters: Inflation & DE $\lambda \simeq 10^{-14}, M \simeq 10^6 \text{GeV}$

  Reheating: $\lambda_\chi \geqslant 10^{-2}, 10^{-6} \leqslant g \leqslant 10^{-2}, m/m_P \leqslant 10^{-3}$

- (1-loop) Quantum corrections?: $\lambda_\chi, g \geqslant \lambda$ (work in progress)

χ is a very heavy field both during inflation and DE domination → **decoupled from RGEs and 1-loop improved effective potential**