Cosmological evolution of the SUSY scale

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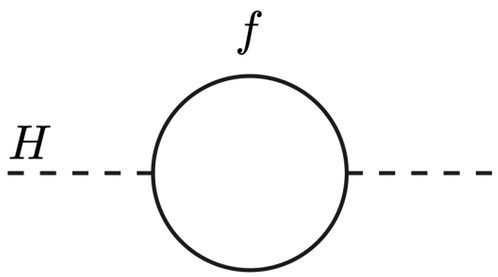
Based on 2610.XXXX with Tony Gherghetta and Kunio Kaneta

Astroparticle 2026

The Higgs and the bad divergence

$$V = m_H^2 |H|^2 + \lambda |H|^4 \qquad \langle H \rangle = 246\ GeV$$

Matter coupling

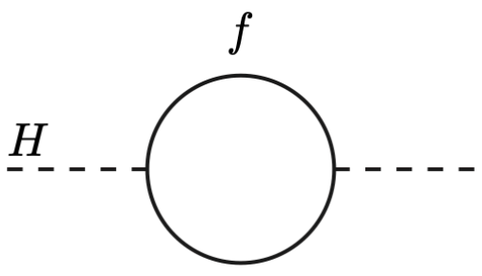


$y_f H \bar{f} f$

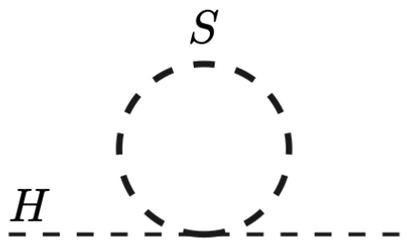
Quadratic divergences

$$\Delta m_H^2 = -\frac{y_f^2}{8\pi^2}\Lambda_{UV}^2 + \cdots$$

The ‘magic’ of SUSY



$y_f H \bar{f} f$



$-\lambda_S |H|^2 |S|^2$

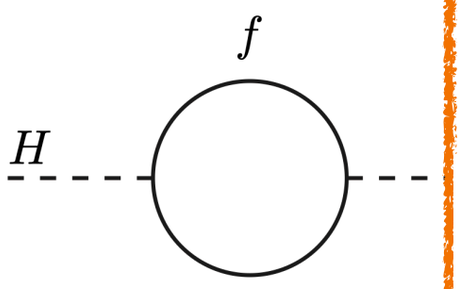
$$\Delta m_H^2 = -\frac{y_f^2}{8\pi^2}\Lambda_{UV}^2 + \frac{\lambda_S}{16\pi^2}\Lambda_{UV}^2 - \log\cdots$$

$$y_f^2 = \lambda_S$$

The Higgs and the bad divergence

$$V = m_H^2 |H|^2 + \lambda |H|^4 \qquad \langle H \rangle = 246\ GeV$$

Matter coupl



$$y_f H \bar{f} f$$

rgences

$$\Lambda_{UV}^2 + \cdots$$

You can find this in >60% of the SUSY textbook intro...

A Supersymmetry Primer

SUPERSPACE

or **One thousand and one lessons in supersymmetry**

TASI 2008 Lectures: Introduction to Supersymmetry and Supersymmetry Breaking

TASI 2012: Super-Tricks for Superspace

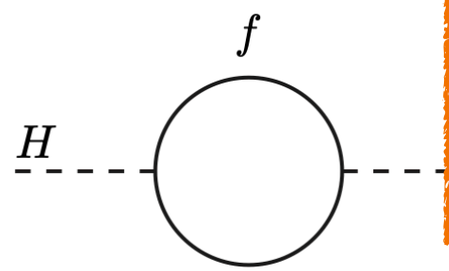
Supersymmetry in Particle Physics

An Elementary Introduction

oduction to Supersymmetry

Adel Bilal

The 'magic' of S



$$-\lambda_S |H|^2 |S|^2$$

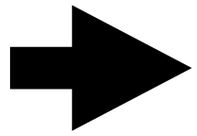
$$\Lambda_{UV}^2$$

$$+\frac{\lambda_S}{16\pi^2}\Lambda_{UV}^2 - \log\cdots$$

$$y_f^2 = \lambda_S$$

Fact of life: No evidence for SUSY so far

- SUSY does not exist!
- SUSY is very hidden
- SUSY scale is high >>TeV



Large Δm_H^2

Important tuning

Not so natural...

Fact of life: No evidence for SUSY so far

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→ Large Δm_H^2

→ Important tuning

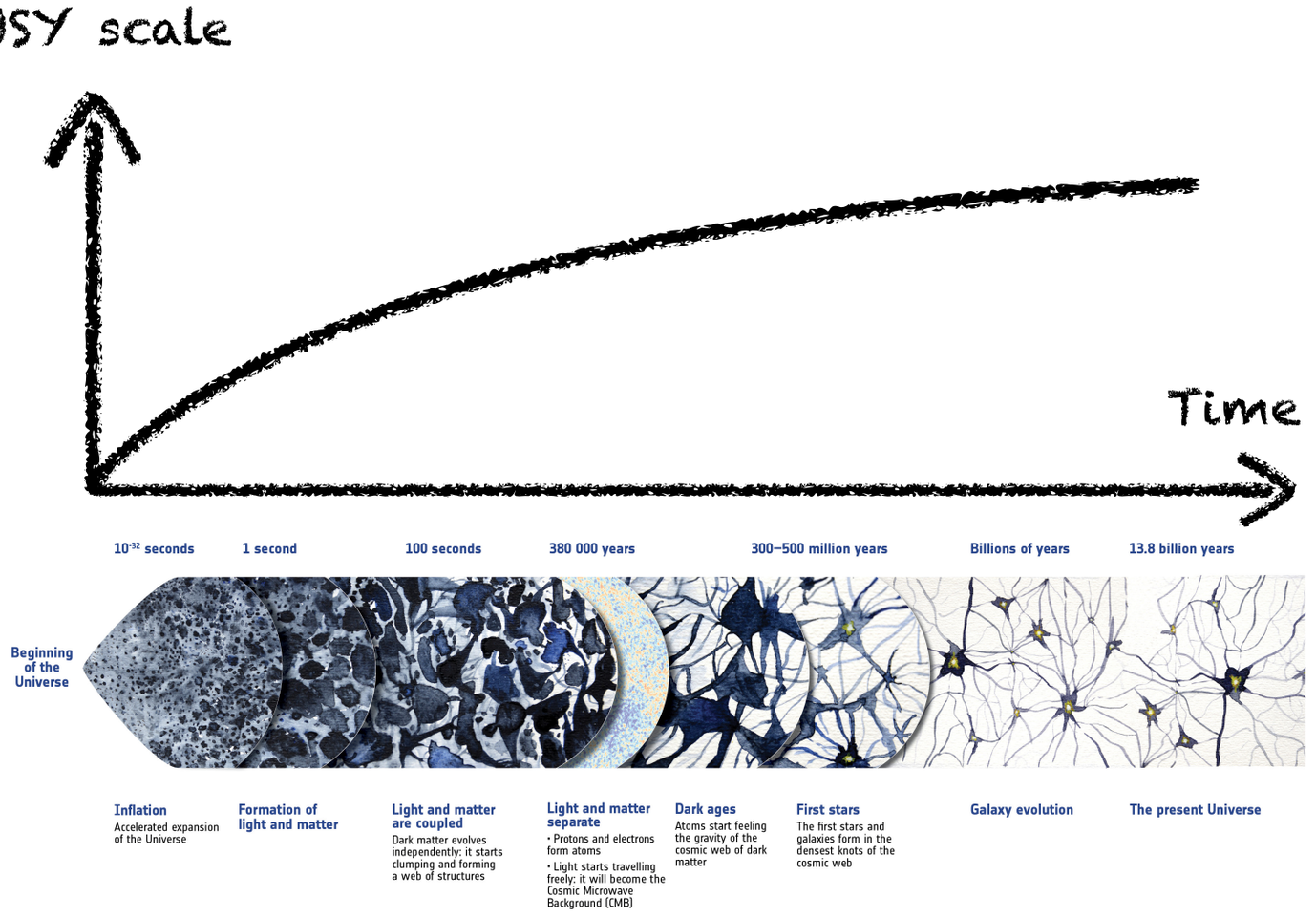
→ Not so natural...

What if…

SUSY scale WAS lower

It evolves with TIME

It WAS more ‘natural’ in the past



Dynamical SUSY scale from a rolling scalar

Supergravity model

with canonical scalar σ

Kähler pot. $K_Q = -3\log(T+\bar{T}),$

$\mathrm{Re}\, T = T_0\, e^{\sqrt{\frac{2}{3}}\sigma}$

Superpotential $W_Q = \mu_T^3\left(1 - \epsilon T^p - \epsilon' T^q\right)$

small parameters

The 'quintessence' potential — **The SUSY scale**

$\widetilde{V}_Q(\sigma) = \widetilde{V}_0^2\left(e^{\lambda_1\sigma} + e^{\lambda_2\sigma}\right)$

$m_{3/2}^2(\sigma) \propto e^{-\sqrt{6}\sigma}$

gravitino mass

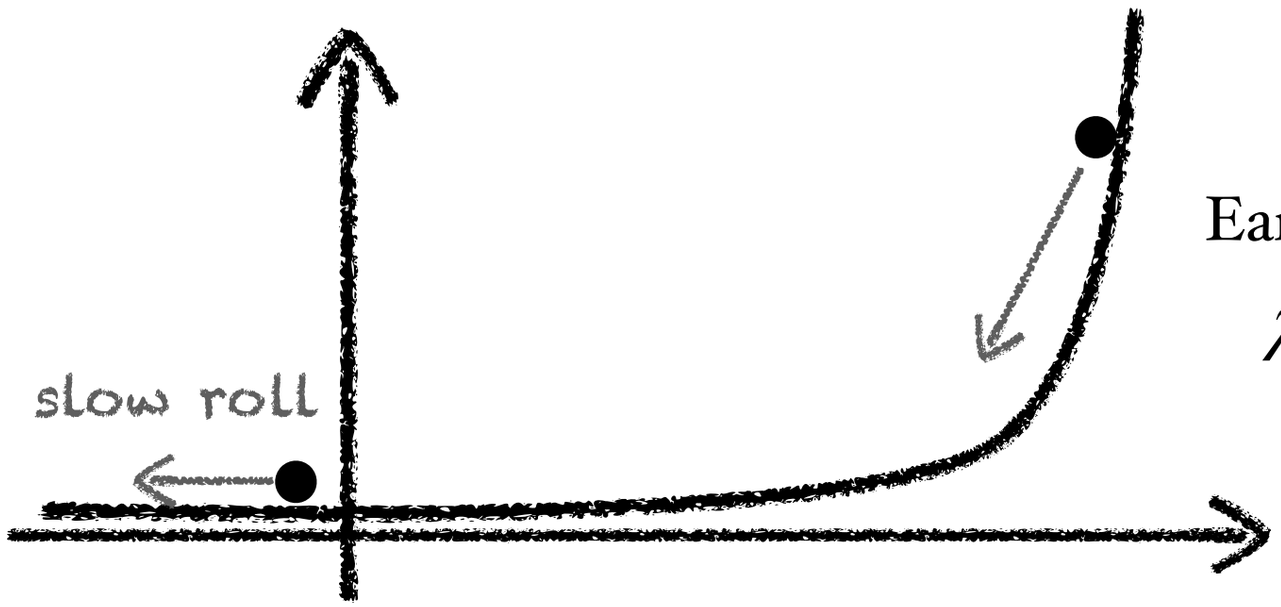
The scalar dynamics from a double exp

$$\widetilde{V}_{\rm Q}(\sigma) = \widetilde{V}_0^2\left(e^{\lambda_1\sigma} + e^{\lambda_2\sigma}\right)$$

Barreiro, Copeland, Nunes (00')

Sen, Sethi (02')

Rubano, Scudellaro (02') ...



Early time: steep exp

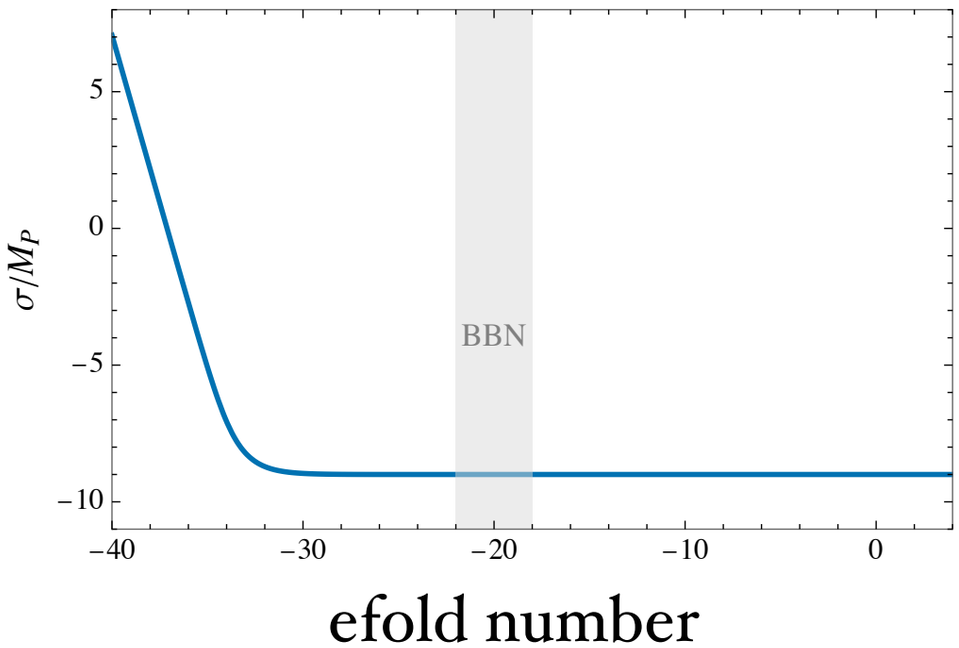
$$\lambda_1 = 12\sqrt{2/3}$$

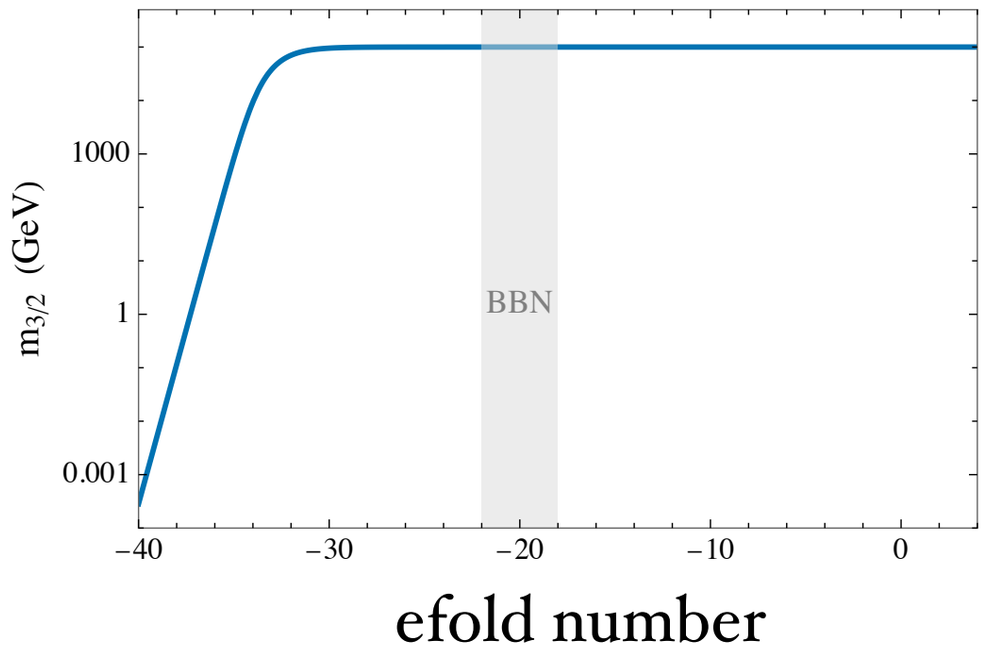
Late time: flat exp

$$\lambda_2 = \sqrt{2/3}\times 10^{-16}$$

Fix today's conditions: σ rolls extremely slowly

SUSY scale evolution





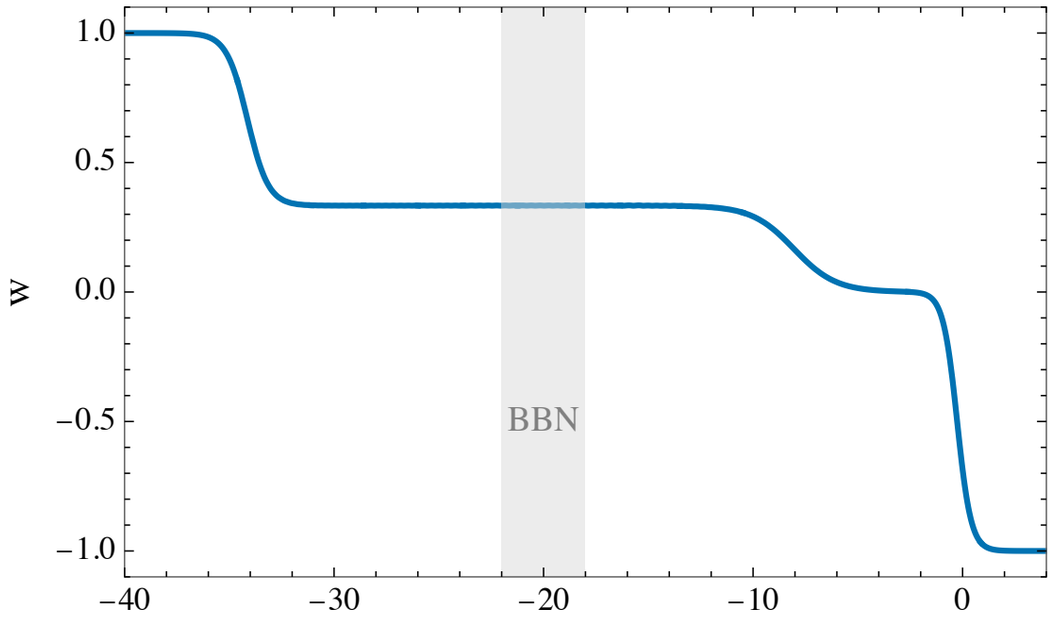
σ rolls down ⟶ SUSY scale ($m_{3/2}$) goes up

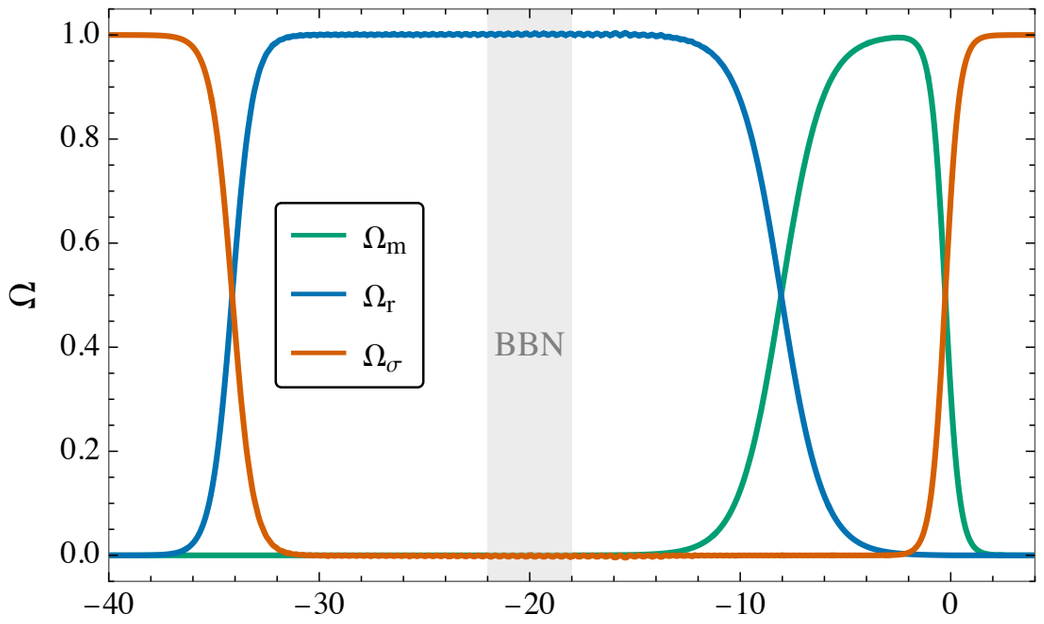
e.g.: today, the SUSY scale is 100 *TeV*

In the past (40 efolds ago), it was 10^{-4} *GeV*

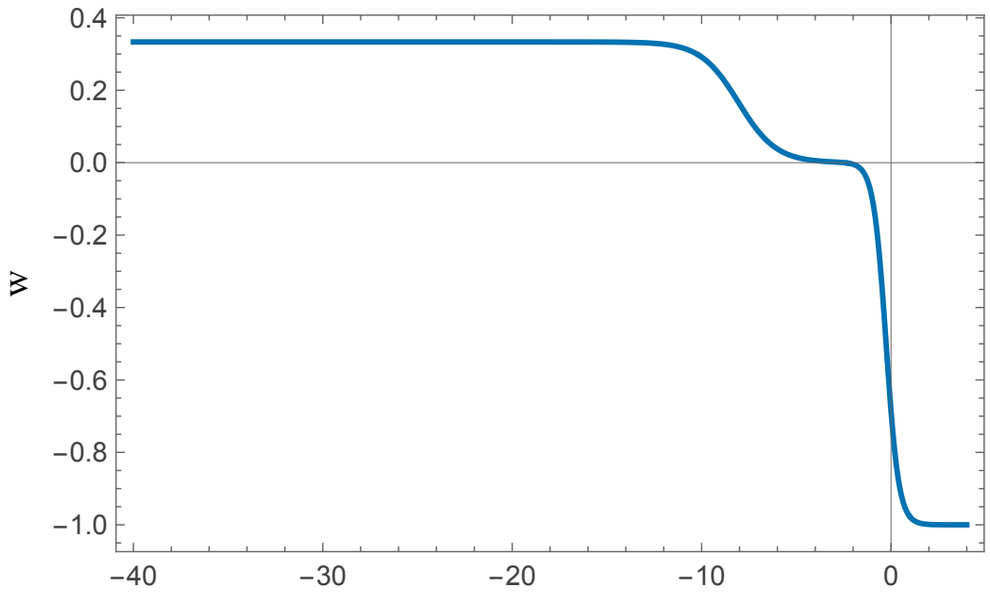
easier to see SUSY at that time...

What happens to cosmology?





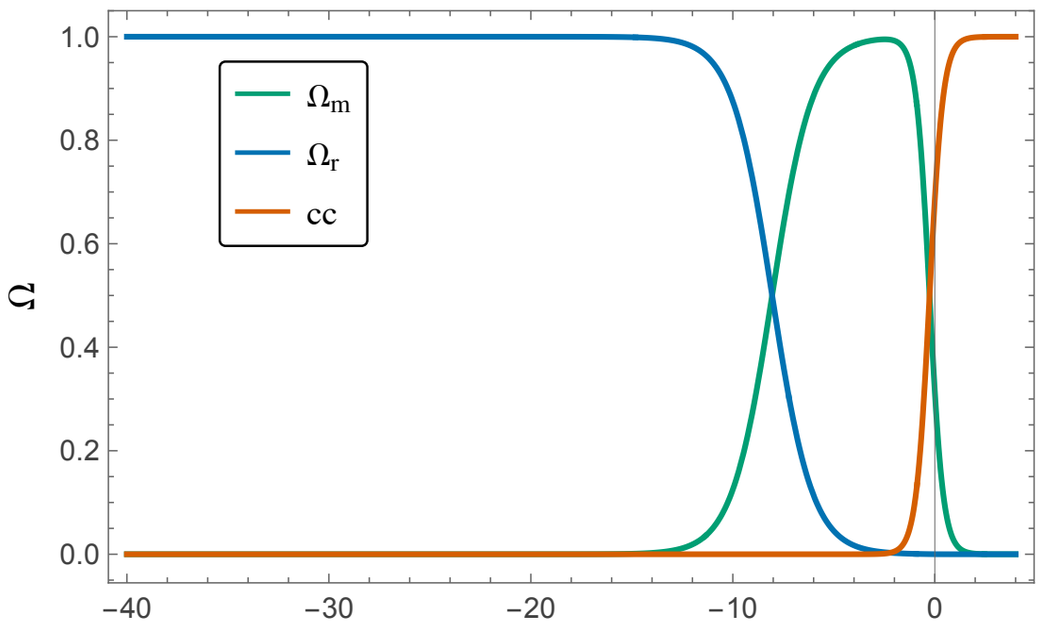
Evolving SUSY



efold number

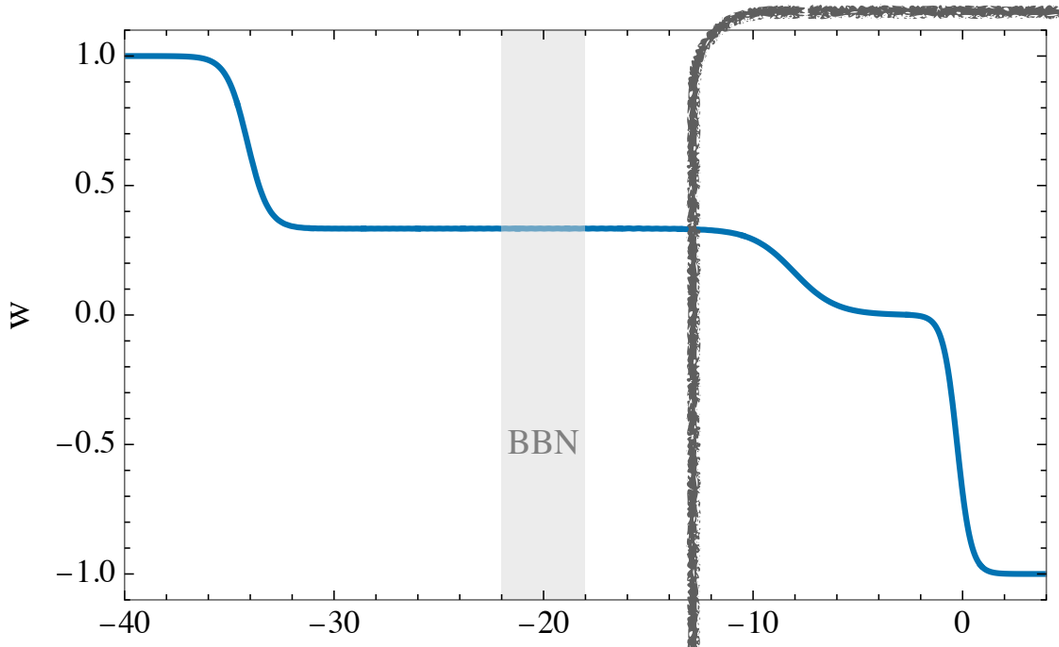
VS

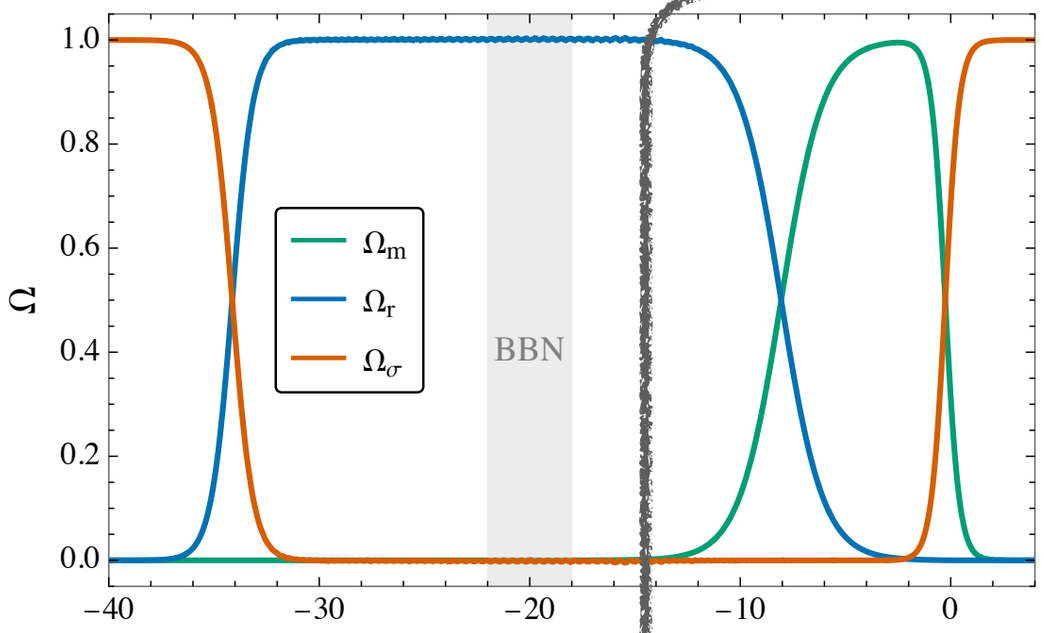
LambdaCDM



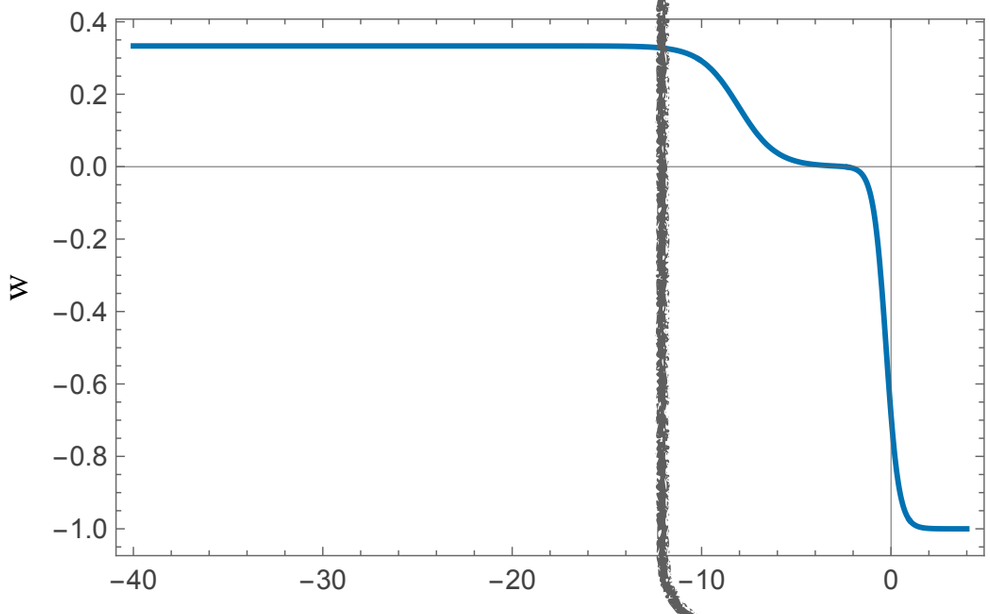
efold number

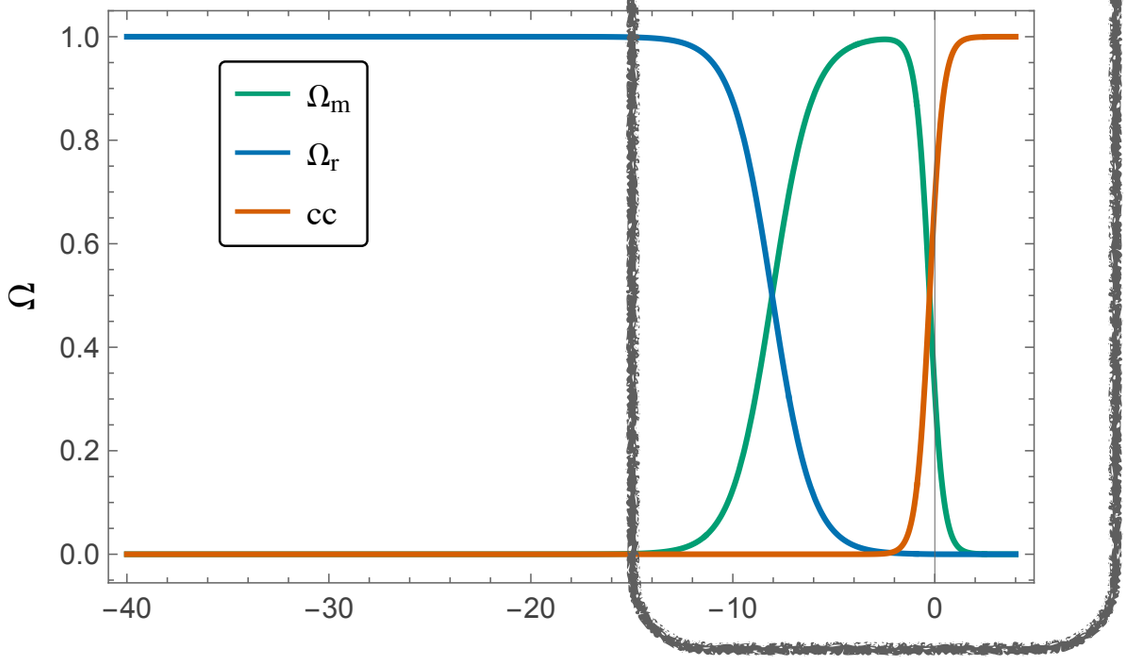
What happens to cosmology?



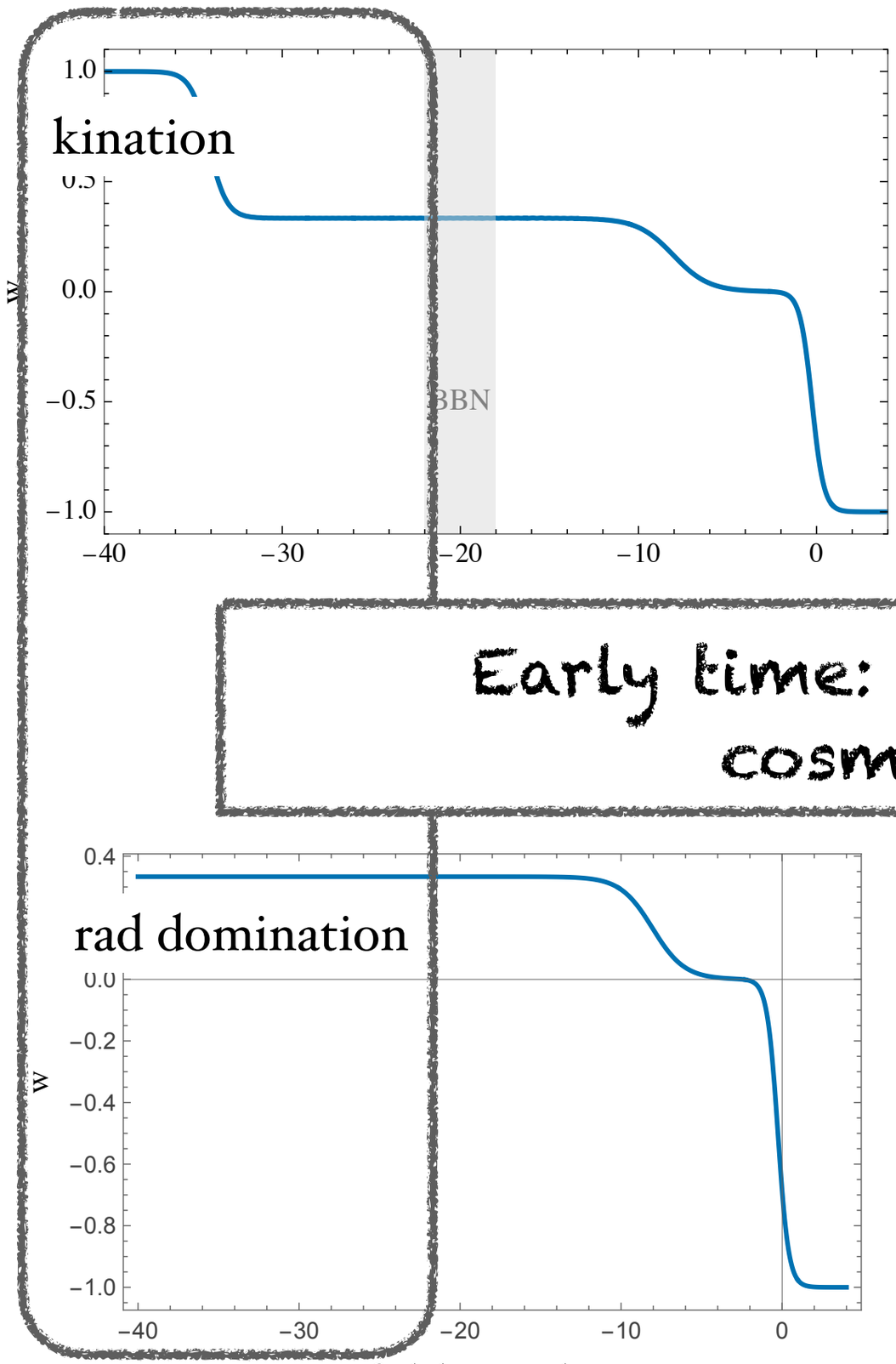


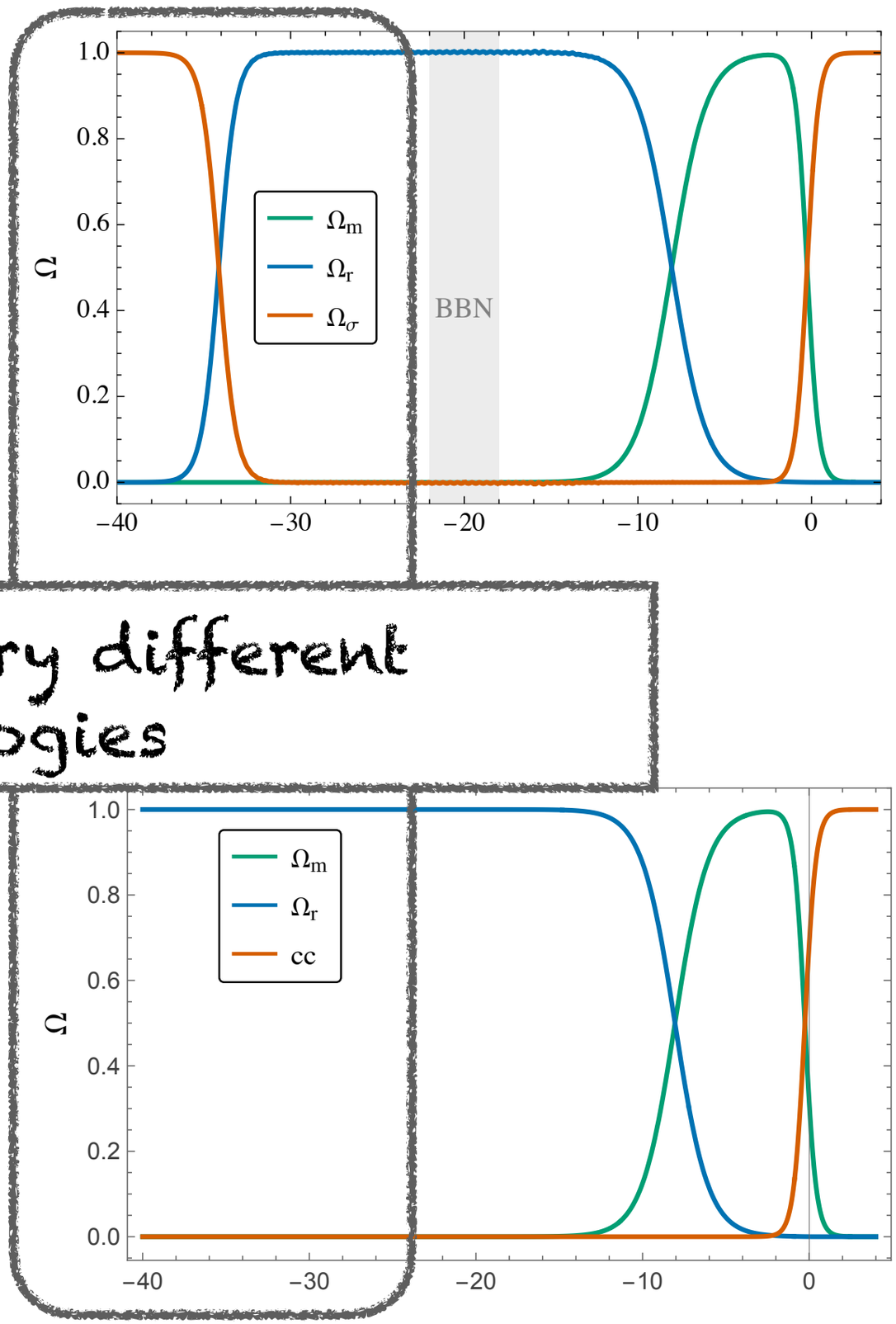
Near today: just like LambdaCDM





What happens to cosmology?



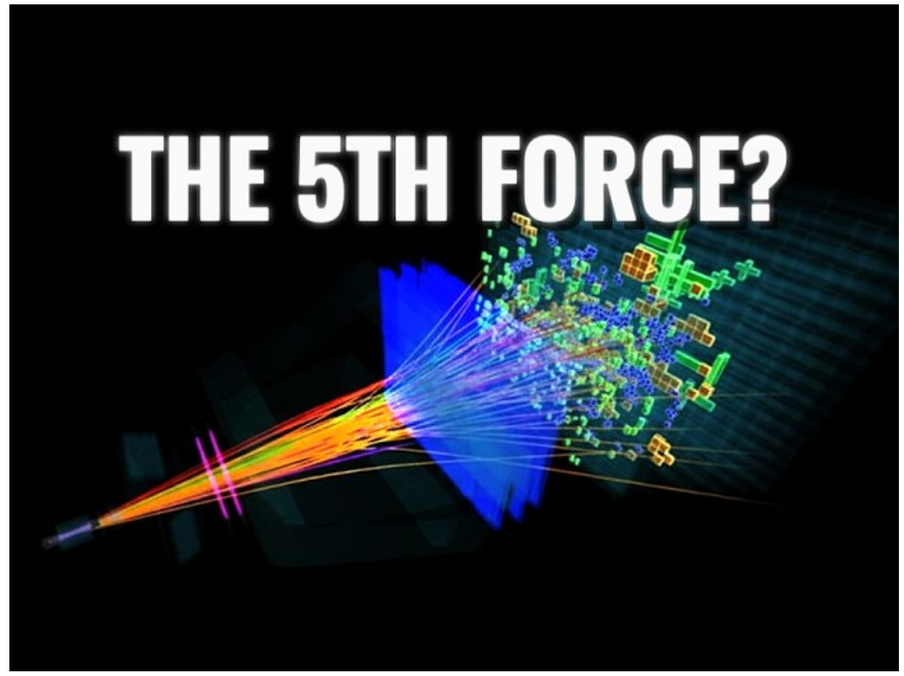


Early time: very different cosmologies

Problem: SUGRA mixes everything!

Very serious issues:

- **The VEV changes with time**
- **Matter masses can depend on σ**
- **Couplings can depend on σ**
- **Backreaction on $V(\sigma)$**



Brax, Martin (hep-th/0605228, hep-th/0612208)

↓

Unavoidable fine-tuning today!

Problem: SUGRA mixes everything!

Very serious issues:

- **The VEV changes with time**
- **Matter masses can depend on σ**
- **Couplings can depend on σ**
- **Backreaction on $V(\sigma)$**

There's a solution

Visible sector with *modular weights*

$$K_{\rm vis} = \sum_I \frac{|\Phi_I|^2}{(T+\bar{T})^{n_I}} + \frac{c_{ud}}{(T+\bar{T})^{n_\mu}}(H_u H_d + \text{h.c.})$$

Special weight choices cancel/ suppress fifth force

What happens to the Higgs?

$$V \simeq \frac{1}{2}\left(1 - n_{H_u} + (n_\mu - 1)^2 C_{ud}^2\right) m_{3/2}^2 h_u^2$$

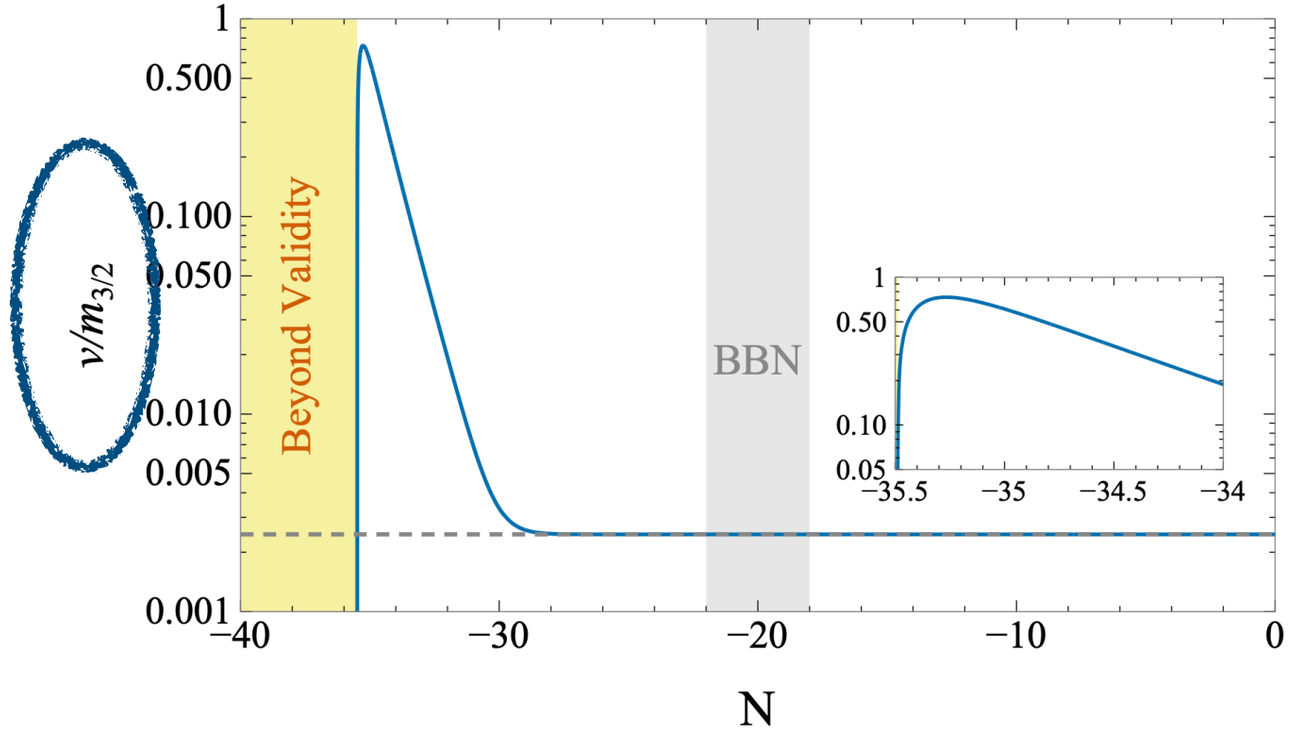
$$+\frac{1}{2}\left(1 - n_{H_d} + (n_\mu - 1)^2 C_{ud}^2\right) m_{3/2}^2 h_d^2 + \cdots$$

Higgs potential

depends on $m_{3/2}(\sigma)$

SUSY vs EW hierarchy was much weaker!

VEV evolution

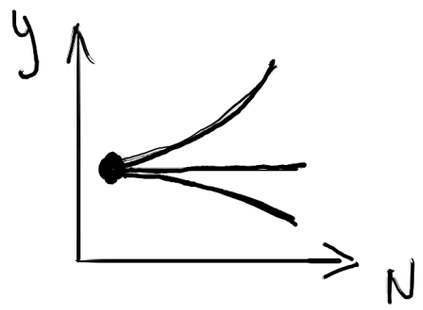


Very little change since BBN

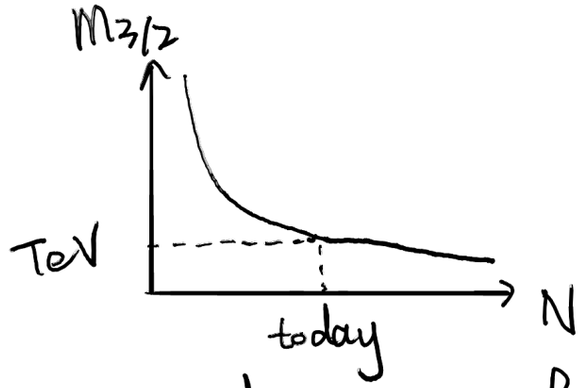
Experimental constraints ✔

Main points

- **This scenario implies very different cosmic history**



Yukawa unification?



Naturalness in the future?

kination?

phase transition?

- **Drawback: fine-tuning today is unsolved**

Worth further investigation

What if?

- **SUSY was more natural in the past**

- **We are born too late to observe it**

Backup slides

Constraints from fifth force

Coupling of σ to field strengths from one-loop running:

$$\left.\frac{1}{g_a^2(\mu)}\right|_\sigma = \frac{c_a}{16\pi^2}\frac{K_Q}{M_P^2} - \sum_r \frac{T_a(r)}{8\pi^2}\log\det Z_r + \frac{b_a}{16\pi^2}\log\frac{\Lambda^2}{\mu^2}\Bigg|_{\text{thresholds}}$$

Kaplunovsky, Louis, hep-th/9402005

$$\mathscr{L} = \frac{\delta\sigma}{M_P}\left[d_e\frac{1}{4e^2}F_{\mu\nu}F^{\mu\nu} - d_g\frac{\beta_3}{2g_3}G^a_{\mu\nu}G^{a\mu\nu} - \sum_{i=e,u,d,s}(d_{m_i}+\gamma_{m_i}d_g)m_i\bar{\psi}_i\psi_i\right]$$

d_g, d_e, d_{m_i} are sums of the modular weights → impose $d_g, d_e, d_{m_i} = 0$