The Higgs instability during inflation

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beer
PALS
strong
8,5
Pals Strong

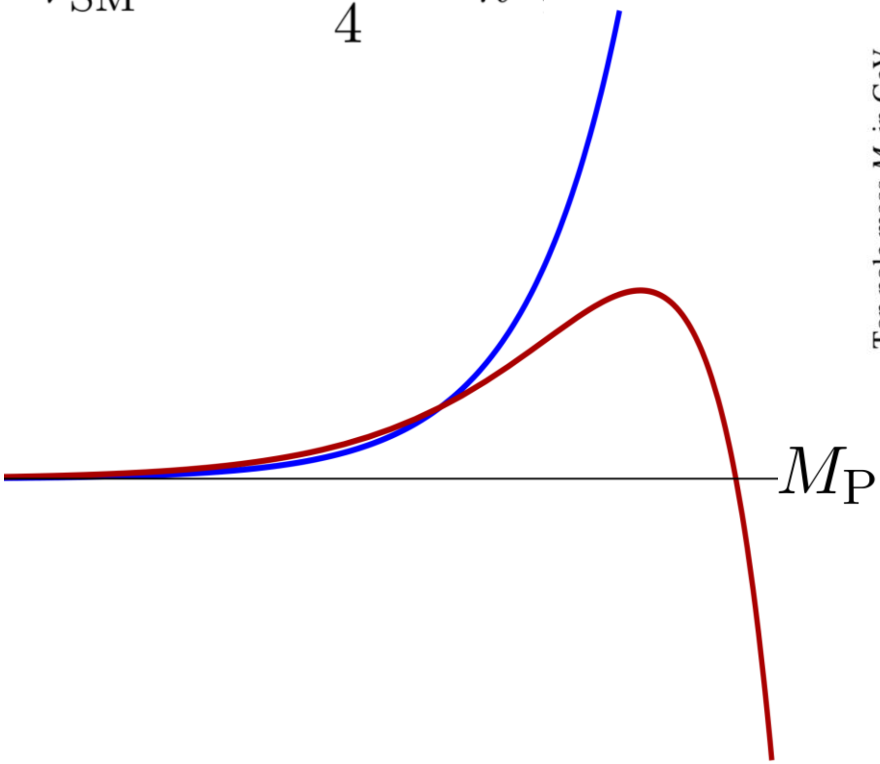
Framework : SM up to the Planck scale

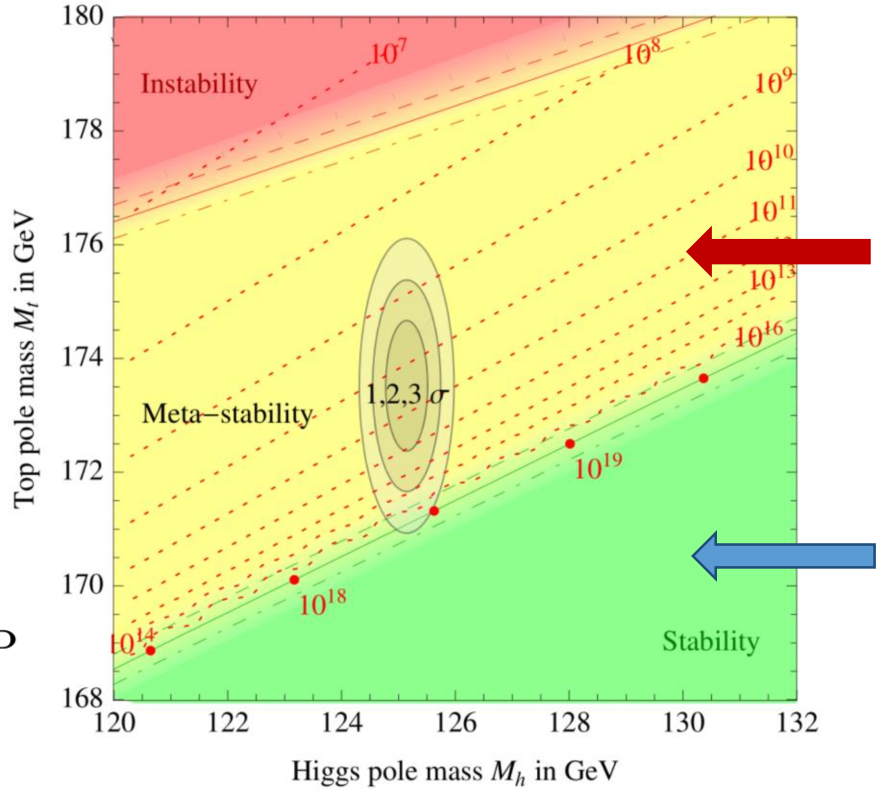
- No physics beyond the SM found so far
- Standard Model up to the Planck scale? (Assumption #1)

Degrassi et al. ‘12
Buttazzo et al. ’13
M. Herranen et al ‘ 14
etc..

The Higgs instability

$$V_{\rm SM} = \frac{\lambda_{\rm eff}(\mu(h))}{4} h^4$$





Buttazzo et al. ’13

The Higgs instability

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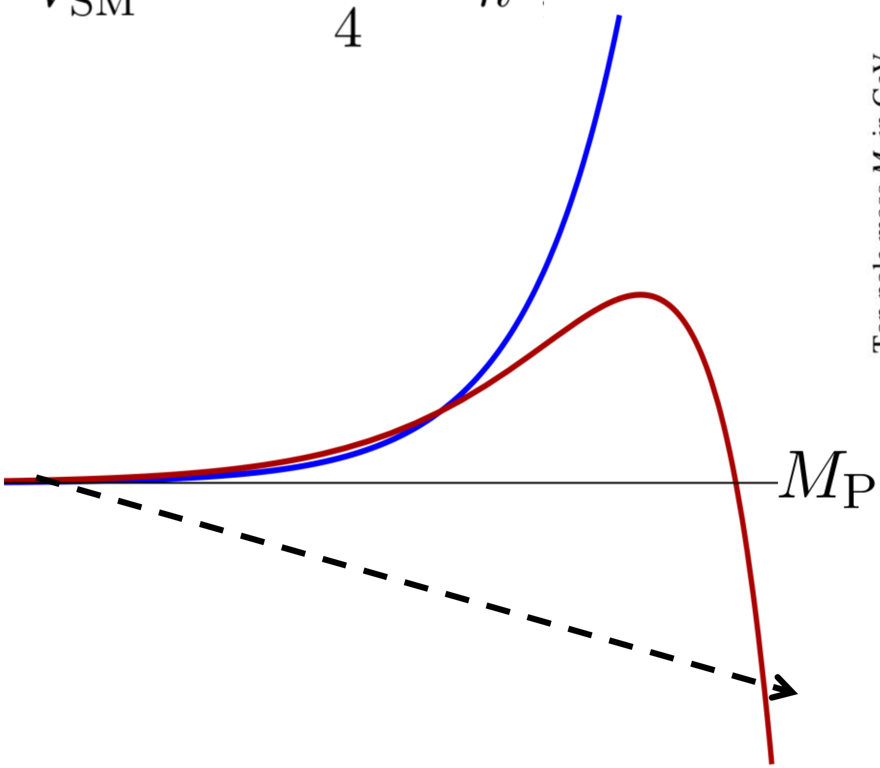
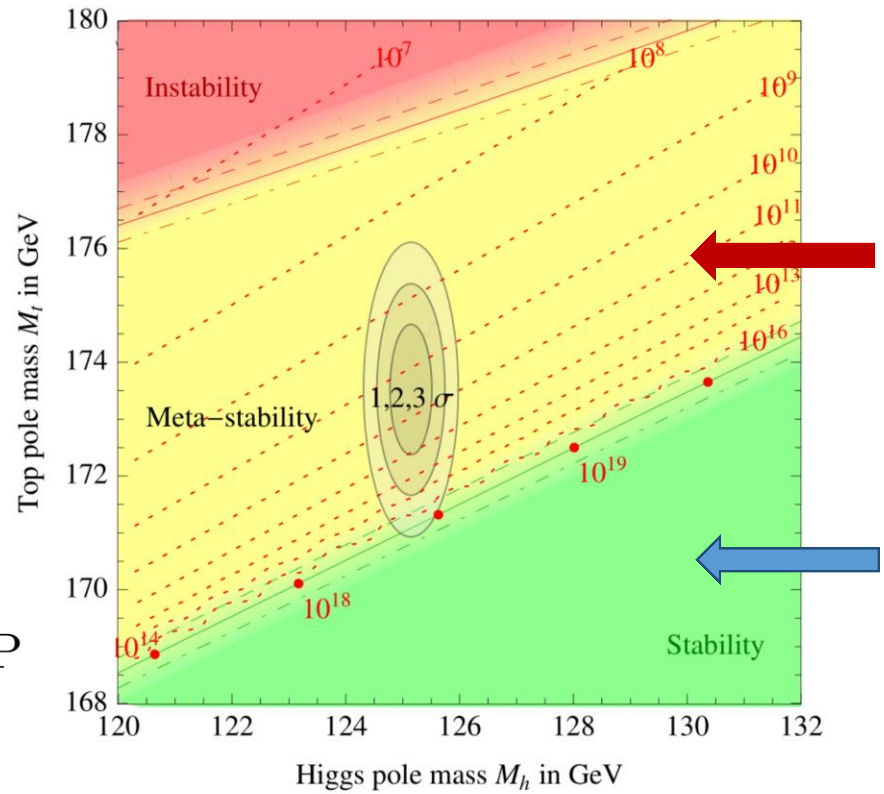




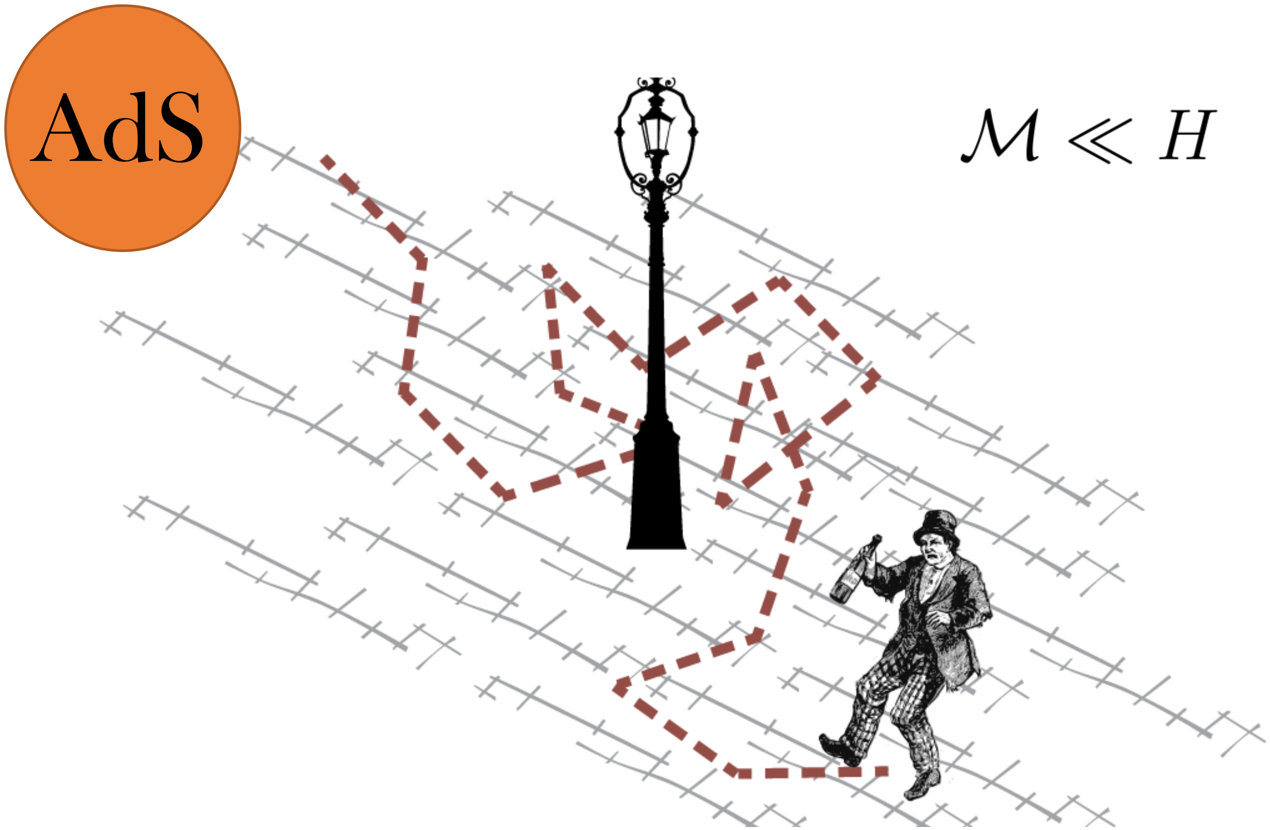
Buttazzo et al. ’13

… during inflation

- Our vacuum is Metastable ⟹ Cosmological history

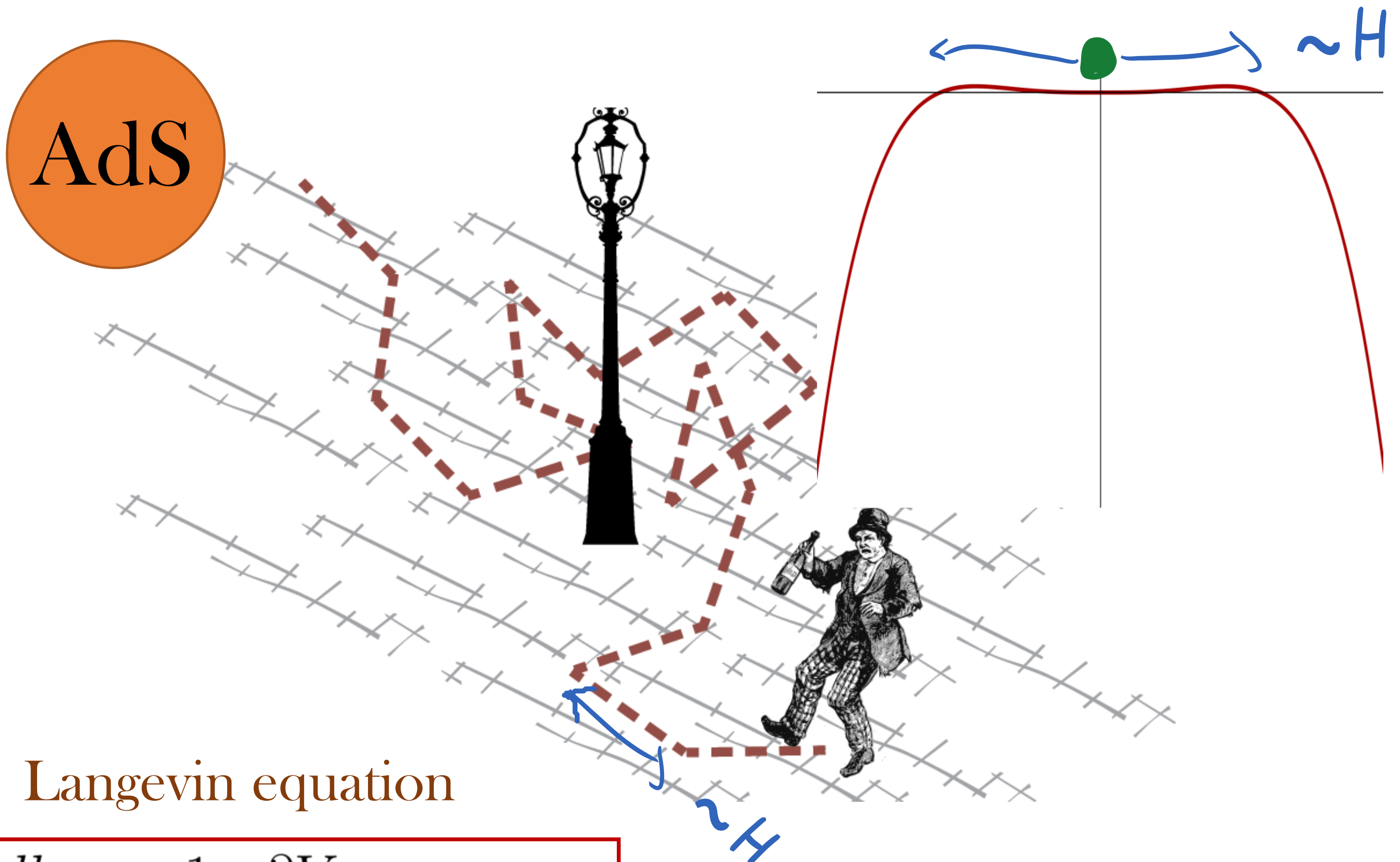
- Assumption #2: a period of inflation

The Higgs during inflation



$\mathcal{M} \ll H$

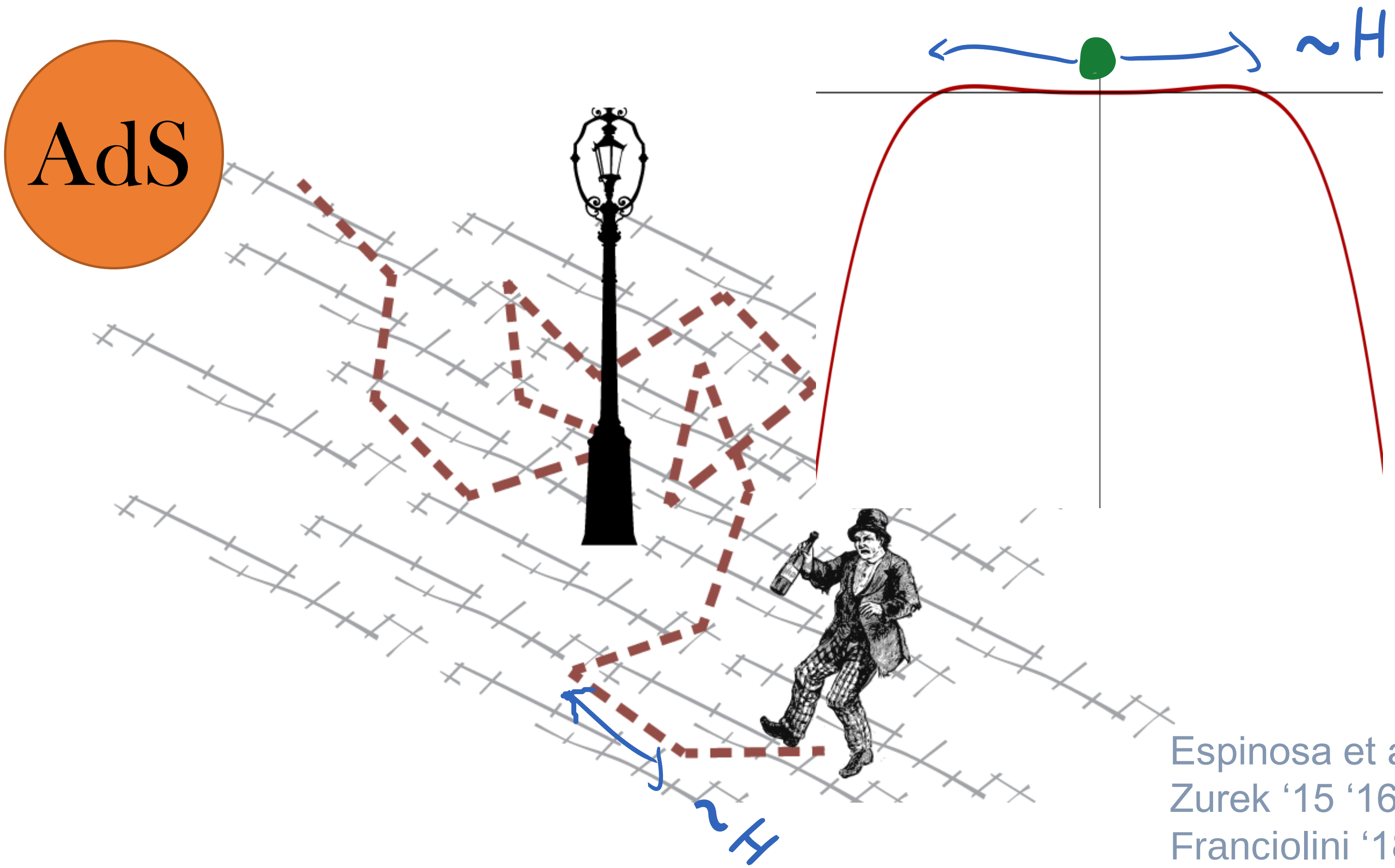
The Higgs during inflation



Langevin equation

$$\frac{dh}{dN} + \frac{1}{3H^2}\frac{\partial V_{\text{eff}}}{\partial h} = \eta(N)$$

The Higgs during inflation



Espinosa et al. ’07 ‘ 15
Zurek ‘15 ‘16
Franciolini ‘18

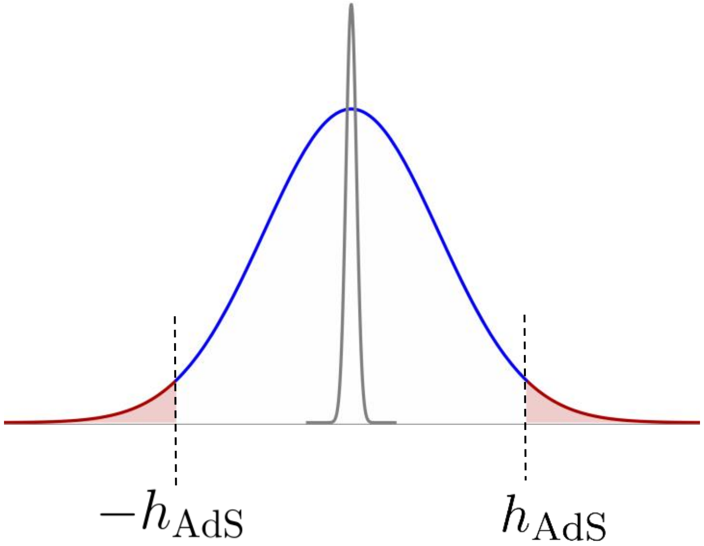
Constraints on SM Parameters vs Scale of inflation

Survival Probability

$$\frac{\partial P}{\partial N} = \frac{\partial^2}{\partial h^2}\left(\frac{H^2}{8\pi^2}P\right) + \frac{\partial}{\partial h}\left(\frac{\partial V_{\rm eff}/\partial h}{3H^2}P\right)$$

$$P(h, N)$$

$$P(|h| > h_{\rm AdS}, 60) \times \mathcal{N} < 1$$



- Ass.#1 SM up to Planck

- Ass. #2: a period of inflation

Novelty introduced

- Ass.#1 SM up to Planck ⟹ Effective field theory
- Ass. #2: a period of inflation ⟹ Quasi de-Sitter

Full slow roll

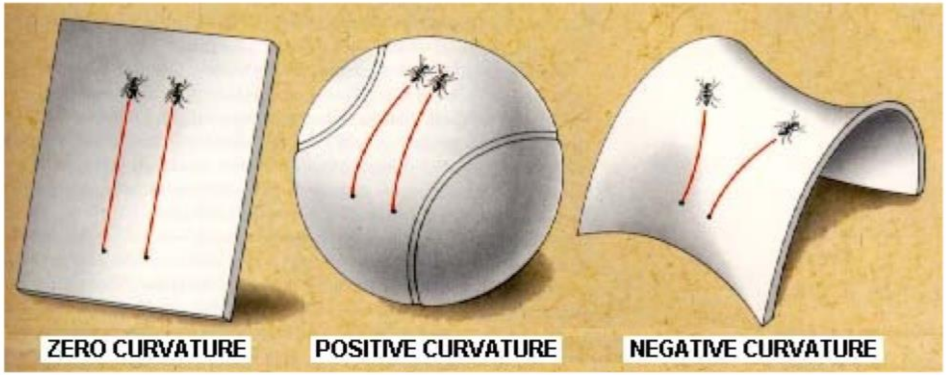
Noise for non massless

Planck suppressed operators

$$\mathcal{O}_{n+4} = C\frac{(\mathcal{H}^\dagger\mathcal{H})^n}{M_P^n}(\partial\phi)^2$$

Planck suppressed operators

$$\mathcal{O}_{n+4} = C\frac{(\mathcal{H}^\dagger\mathcal{H})^n}{M_P^n}(\partial\phi)^2 \Longrightarrow -\frac{1}{2}G_{IJ}\partial\varphi^J\partial\varphi^I$$



S. Renaux-Petel,
K. Turzinsky '15

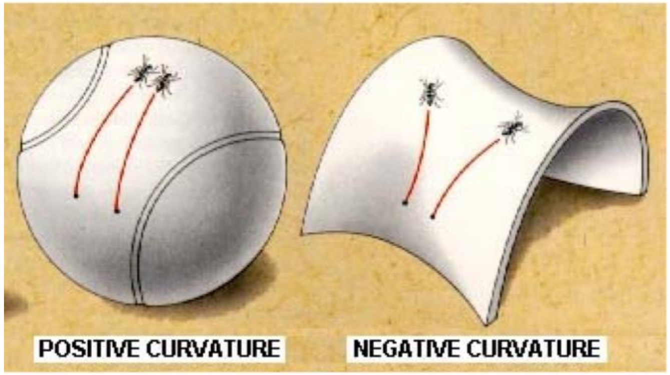
Geometry of the field space manifold can easily destabilize inflationary trajectories

Geometrical (de)stabilization of the Higgs

$$\mathcal{L} = -\frac{1}{2} G_{IJ} \partial\varphi^J \partial\varphi^I - V(h) - V(\phi), \qquad \varphi^I = \{\phi, h\},$$

$$\frac{\mathcal{O}^n(h,\phi)}{M_{\rm P}^n} \qquad\qquad V_{\rm SM} - \frac{\xi h^2}{2} R$$

$$\Longrightarrow \quad \mathcal{M}^2 = V_{;hh} + \epsilon R_{\rm sf} H^2 M_{\rm P}^2,$$



Geometrical (de)stabilization of the Higgs

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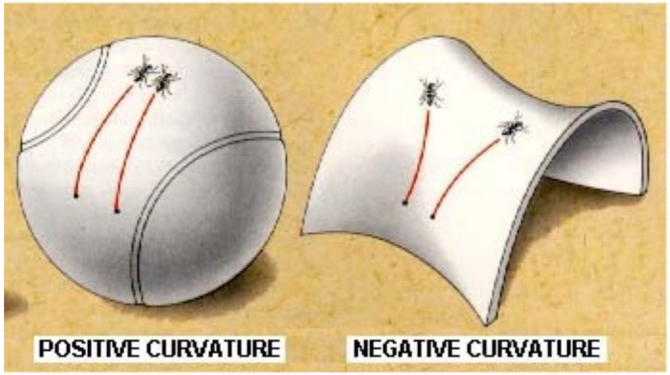
$$\frac{\mathcal{O}^n(h,\phi)}{M_P^n} \qquad\qquad V_{SM} - \frac{\xi h^2}{2} R$$

$$G_{IJ} = \mathrm{diag}(1 - 2Ch^2/M_P^2, 1)$$

$$R_{sf} \simeq 4C/M_P^2$$

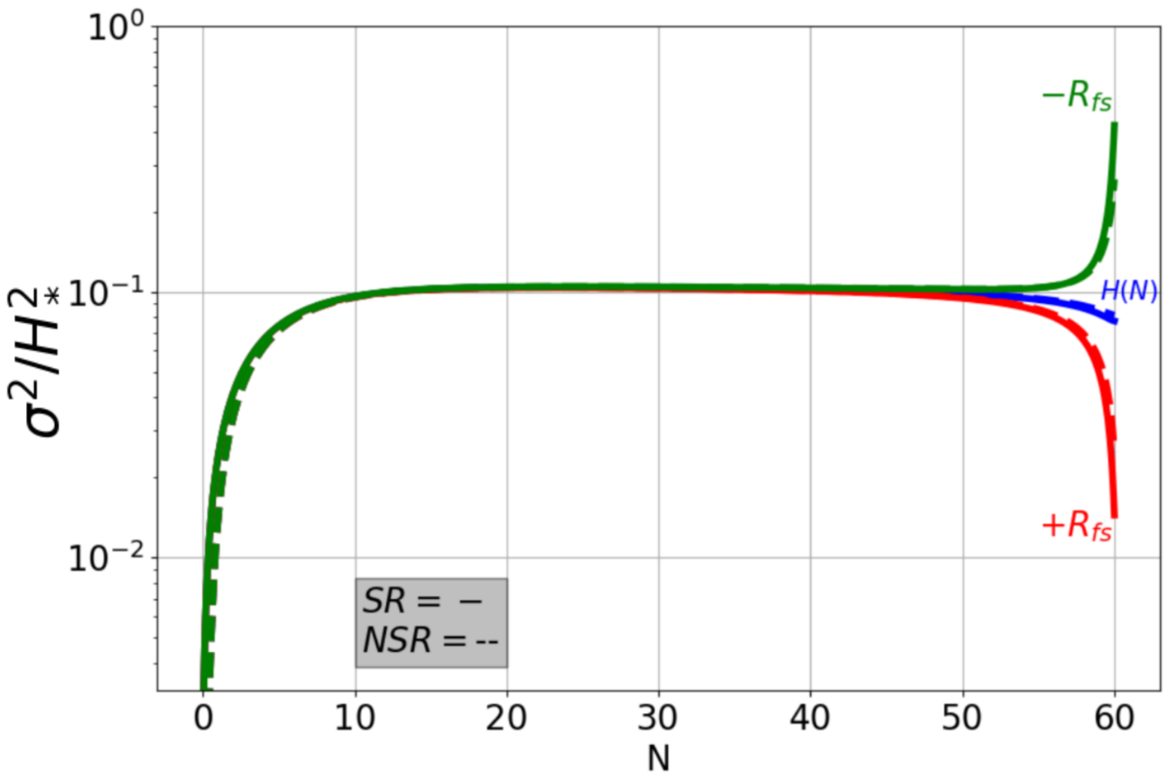


$$\mathcal{M}^2 = V_{;hh} + \epsilon R_{sf} H^2 M_P^2,$$

$$= \frac{\partial^2 V_{SM}}{\partial h^2} - \left(1 - \frac{\epsilon}{2}\right) 12\xi H^2 + 4C\epsilon H^2$$

Effect of Planck suppressed operators

$$\mathcal{M}^2 \simeq -\left(1-\frac{\epsilon}{2}\right)12\xi H^2 + 4C\epsilon H^2 \qquad \mathcal{O}_6 = C\frac{2\mathcal{H}^\dagger\mathcal{H}}{M^2}(\partial\phi)^2$$



H *not* constant

$$N_{\rm rel} \simeq \frac{H^2}{\mathcal{M}^2} < \frac{1}{\epsilon} = N_H .$$

Hardwick, Vennin et al. ‘17

H *not* constant

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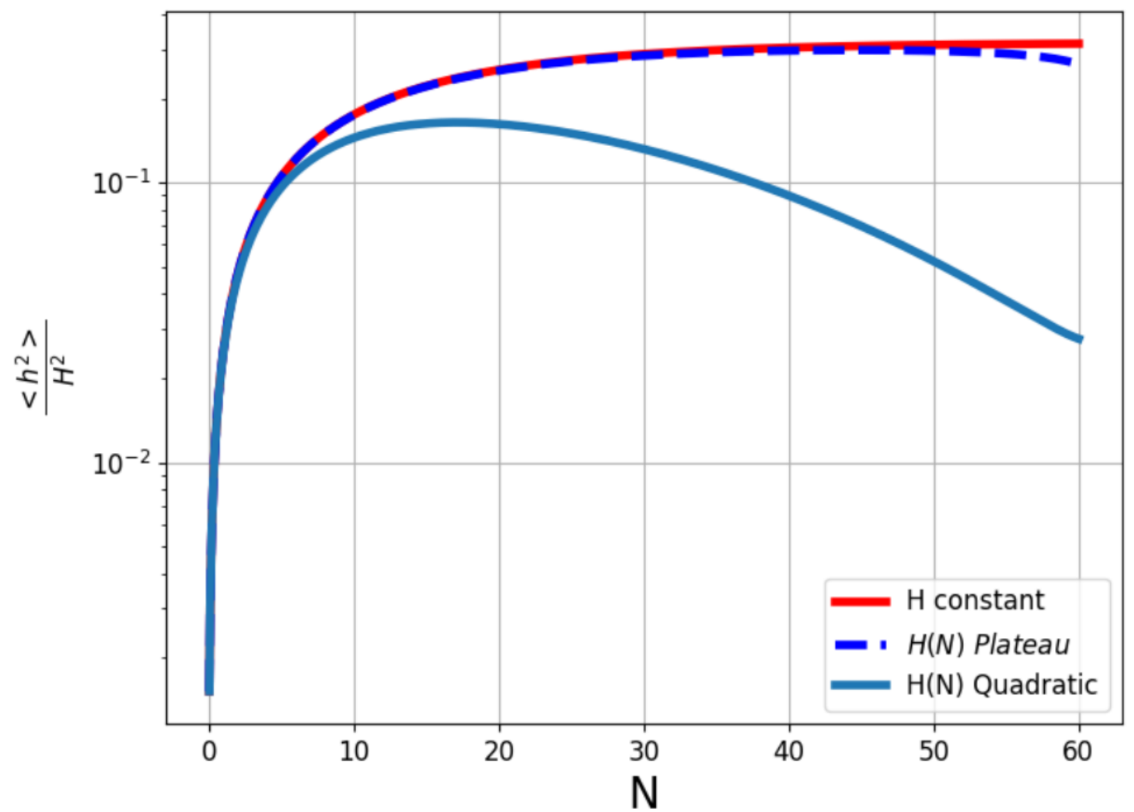
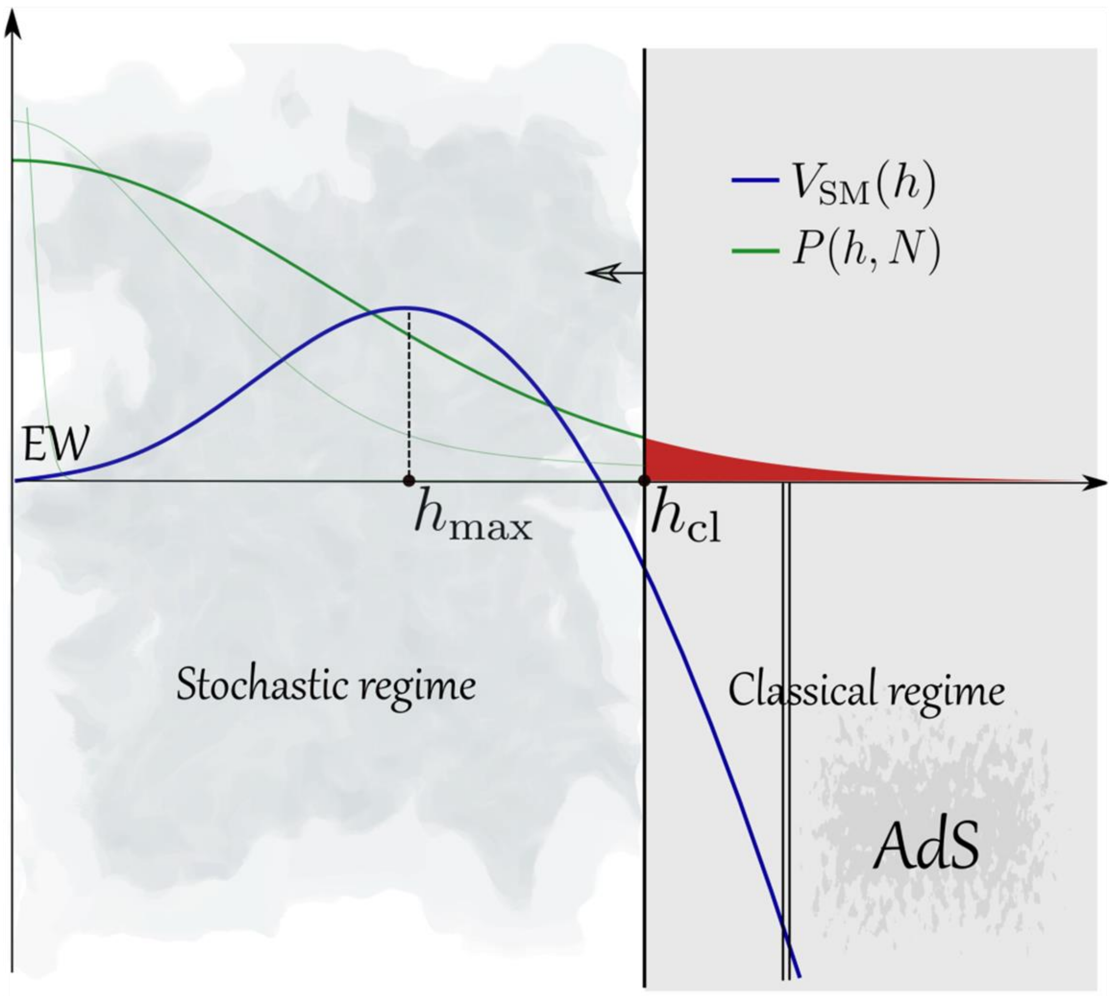
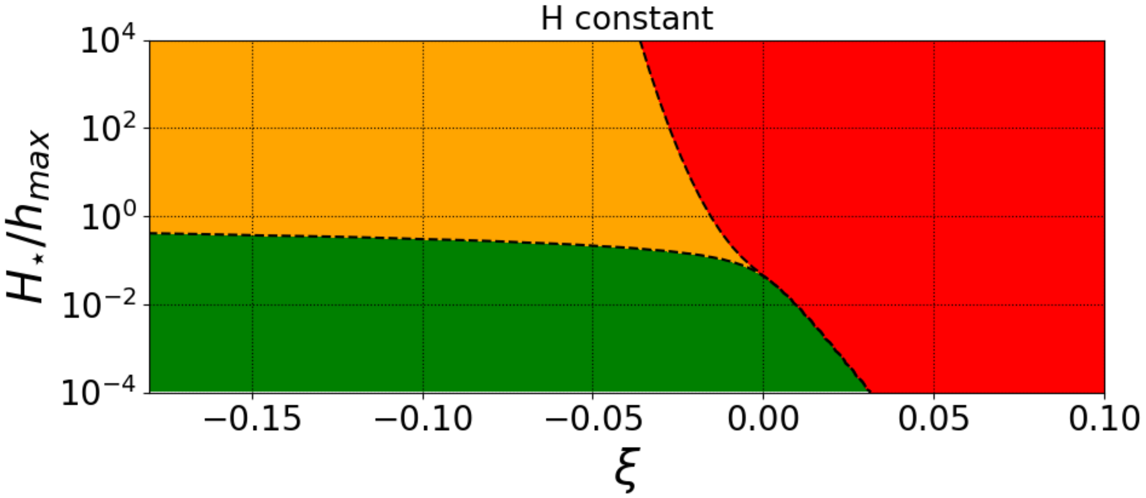
Hardwick, Vennin et al. ‘17





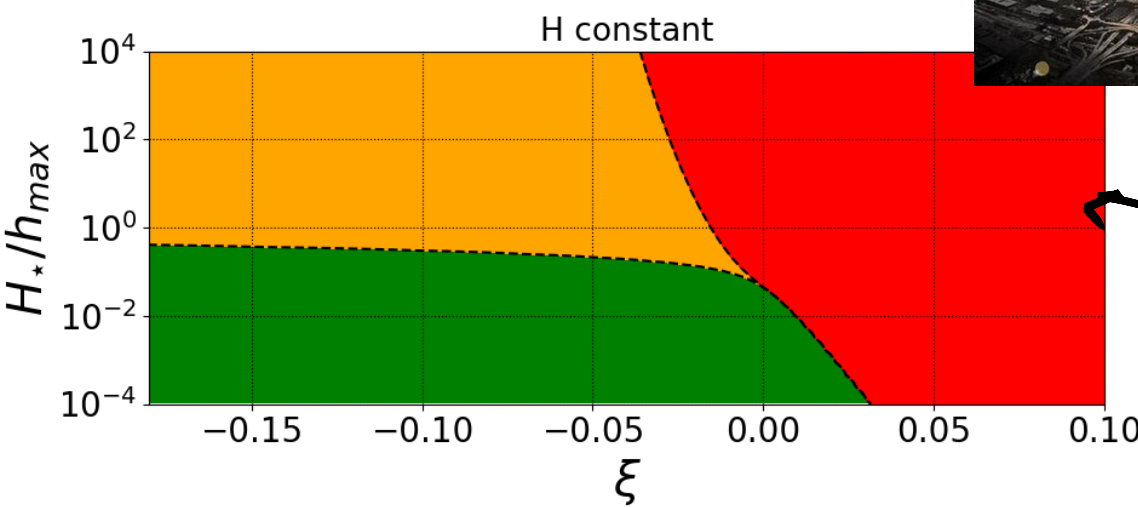
$V_{\rm SM}(h)$
$P(h,N)$
EW
$h_{\rm max}$
$h_{\rm cl}$
Stochastic regime
Classical regime
AdS

Survival probability



Espinosa, Giudice, Morgante, Riotto, Senatore, Strumia, Tedradis ’15

Survival probability



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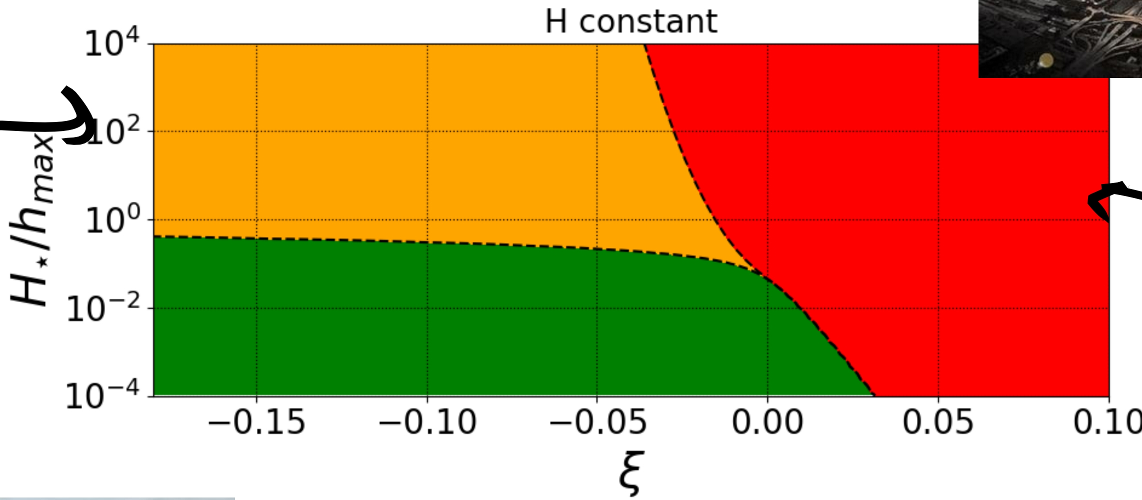

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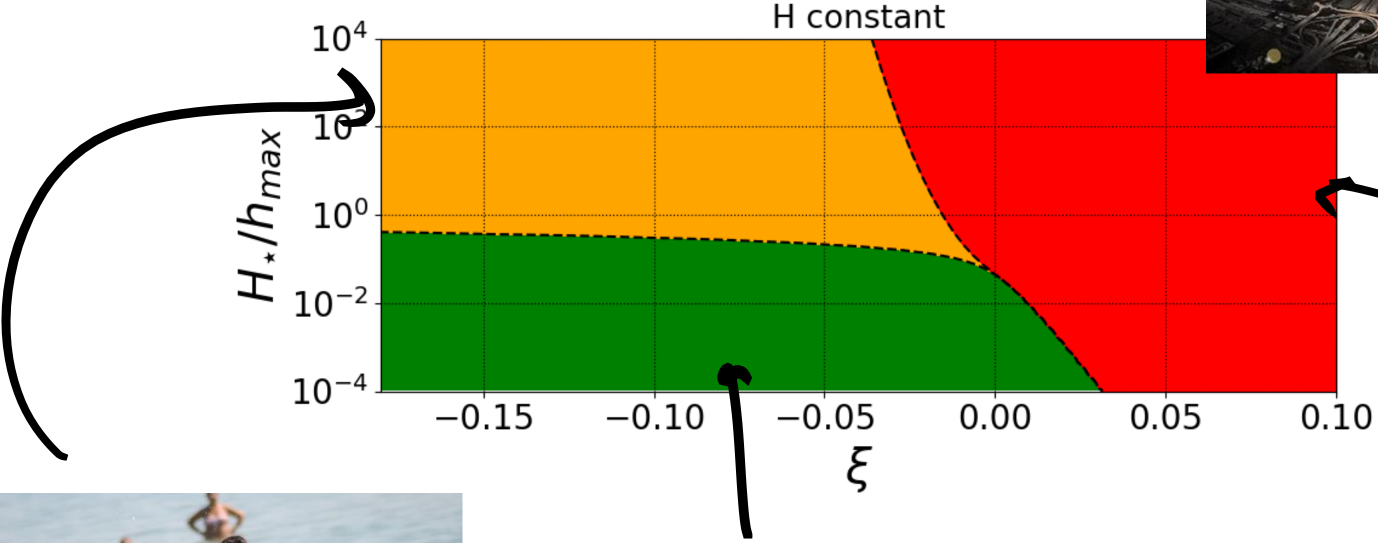
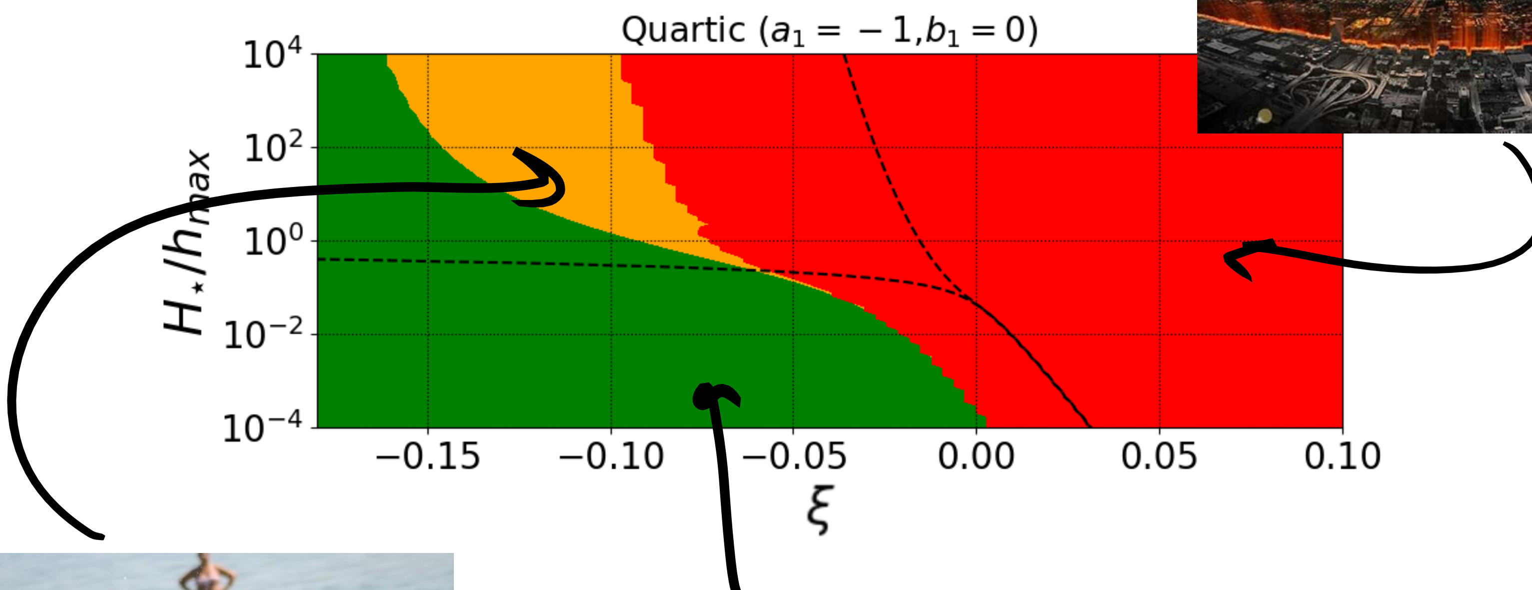
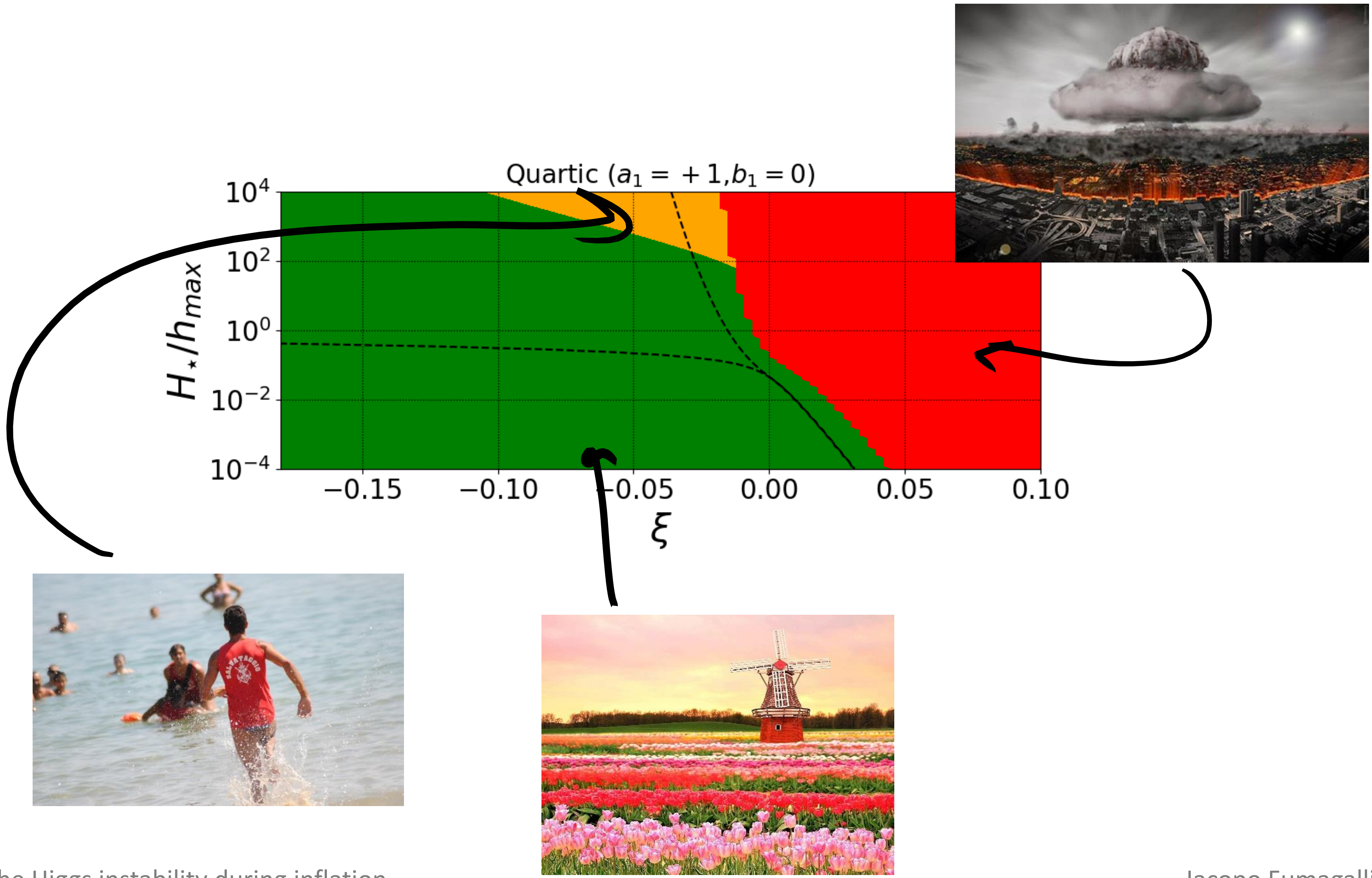


Espinosa, Giudice, Morgante, Riotto, Senatore, Strumia, Tedradis '15

Example: Negative curvature

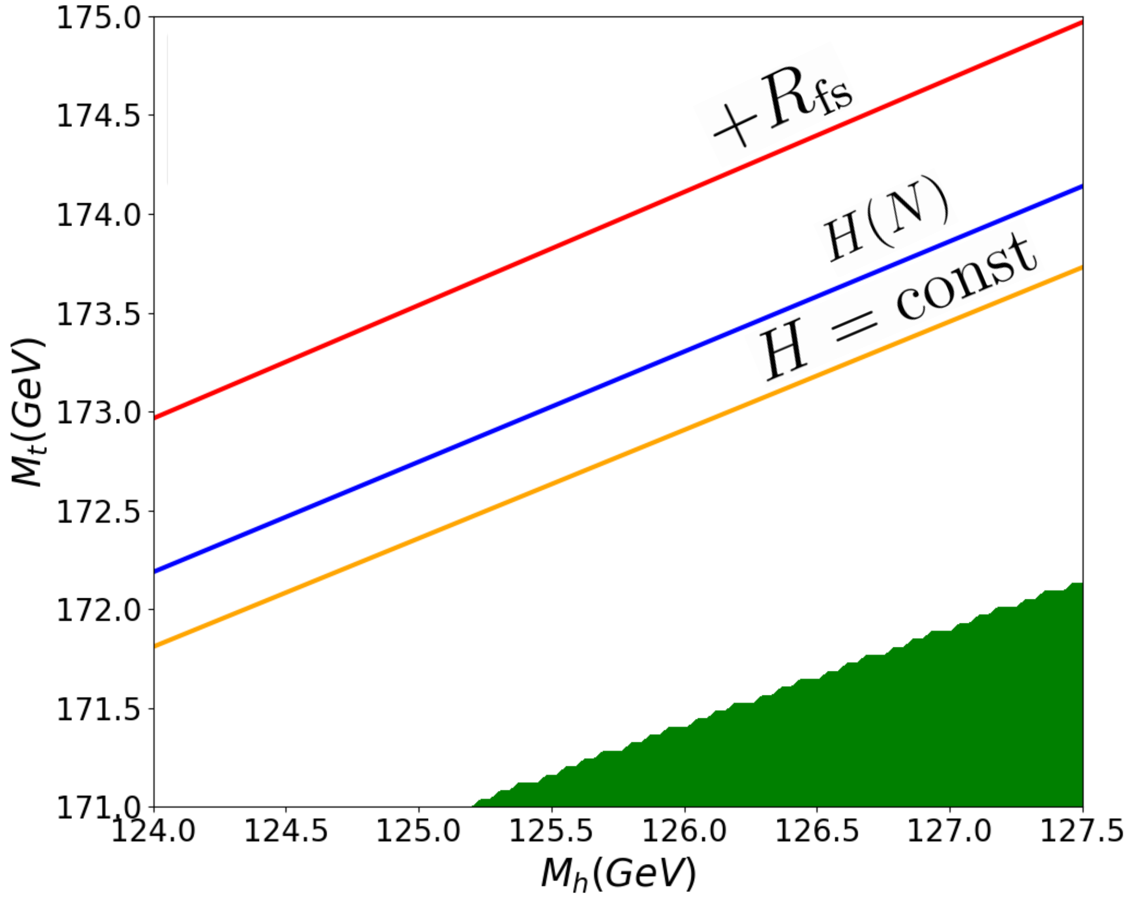


Example: Negative curvature



Bounds on SM parameters (Example)

$$H_* = 10^{12}\,\mathrm{GeV}$$



$$\alpha_s = 0.1184$$

$$\xi = -0.05$$

$$T_{RH} \lesssim 10^4\,\mathrm{GeV}$$

Conclusions and outlook

- Vacuum metastable needs study in the context of the Cosmological story

- Departure from de Sitter and Planck suppressed operators can affect the fate of the vacuum stability
  - Full stochastic approach, *beyond Slow roll*
  - Induce effective mass on the Higgs, quantum kicks

- Implications for the bounds on the SM parameters

Stochastic motion of a light scalar field during inflation

Flows of sub-Hubble modes joining the super-Hubble (IR)

→ Langevin equation

$$\frac{dh}{dN} + \frac{1}{3H^2}\frac{\partial V_{\text{eff}}}{\partial h} = \eta(N)$$

$$\langle \eta(N)\eta(N') \rangle = \mathcal{P}_h \delta(N - N')$$ Gaussian white noise

Not suppressed if

$$\mathcal{M}^2 = \frac{\partial^2 V_{\text{eff}}}{\partial h^2} \ll \frac{9H^2}{4}, \qquad \mathcal{P}_h \simeq \left(\frac{H}{2\pi}\right)^2,$$

→ Crucial when SM alone + corrections

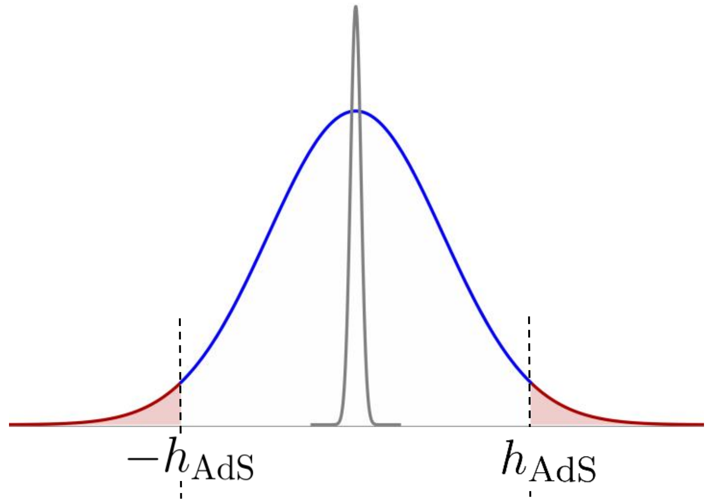
Model independent bound

$$P(|h| > h_{\rm AdS}, 60) \times \mathcal{N} < 1$$

Espinosa et al. '15

$$1 - P_{\rm Gauss}(|h| < h_{\rm AdS})$$

$$\left| \frac{\partial_h V_{\rm SM}}{3H_*^2} \right| > \frac{H_*}{2\pi}$$



$$\Longrightarrow \boxed{\frac{H_*}{h_{\rm max}} < \frac{1}{\sqrt{6N\hat{\sigma}}}\, e^{\beta \hat{\sigma}^{-3/2}}} \qquad \hat{\sigma} \equiv \frac{\sigma_{\rm end}^2}{H_*^2}$$

E.G. $\quad H_*/h_{\rm max} < 10^4 \;\text{for}\; \hat{\sigma} \simeq 0.02$

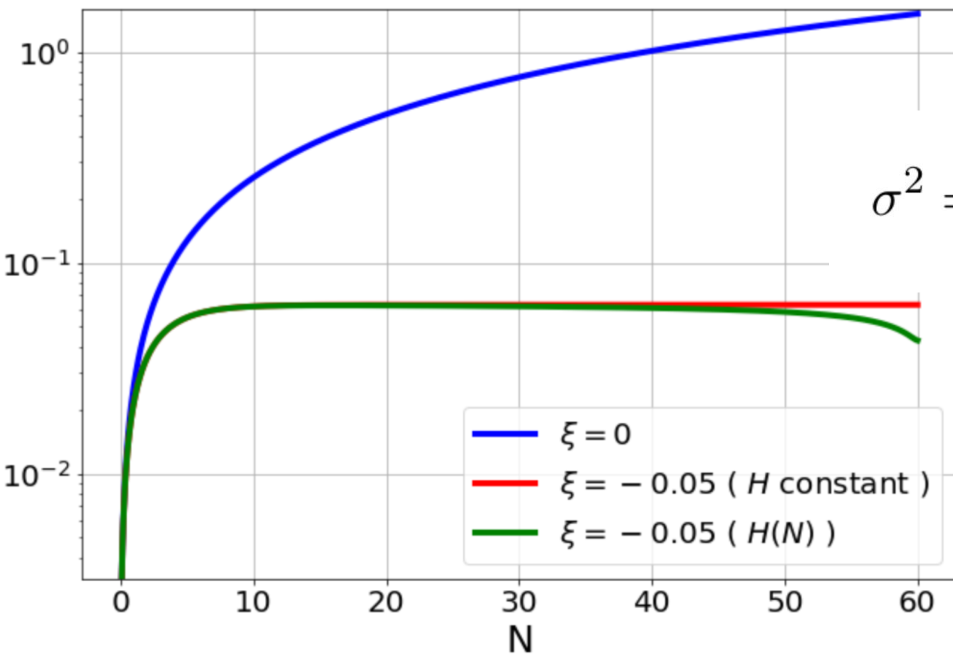
$\quad H_*/h_{\rm max} < 1 \;\text{for}\; \hat{\sigma} \simeq 0.075$

Evolution of the variance

$V_{\text{SM}} \simeq 0 \text{ for } |h| < h_{\text{AdS}}$

Fokker-Planck $\Longrightarrow$

$$\frac{\partial \sigma^2}{\partial N} = -\frac{2\mathcal{M}^2}{3H^2}\sigma^2 + \frac{H^2}{4\pi^2}$$



$$\sigma^2 = \frac{3H^4}{8\pi^2\mathcal{M}^2}\left[1 - \exp\left(-\frac{2\mathcal{M}^2}{3H^2}N\right)\right]$$

$$\mathcal{M}^2 = -12\xi H^2$$

$$\mathcal{P}_h(k=\bar{k}\ll aH)=\left(\frac{H}{2\pi}\right)^2\frac{\pi}{2}\left(\frac{\bar{k}}{aH}\right)^3\left|H_\nu^{(1)}\left(\frac{\bar{k}}{aH}\right)\right|^2\equiv\left(\frac{H}{2\pi}\right)^2\cdot f,$$

$$\nu=\sqrt{\frac{9}{4}-\frac{\partial^2 V_{\rm eff}/\partial h^2}{H^2}},$$