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Gravitational Waves and the Triple Higgs Boson Self-coupling in the 2HDM

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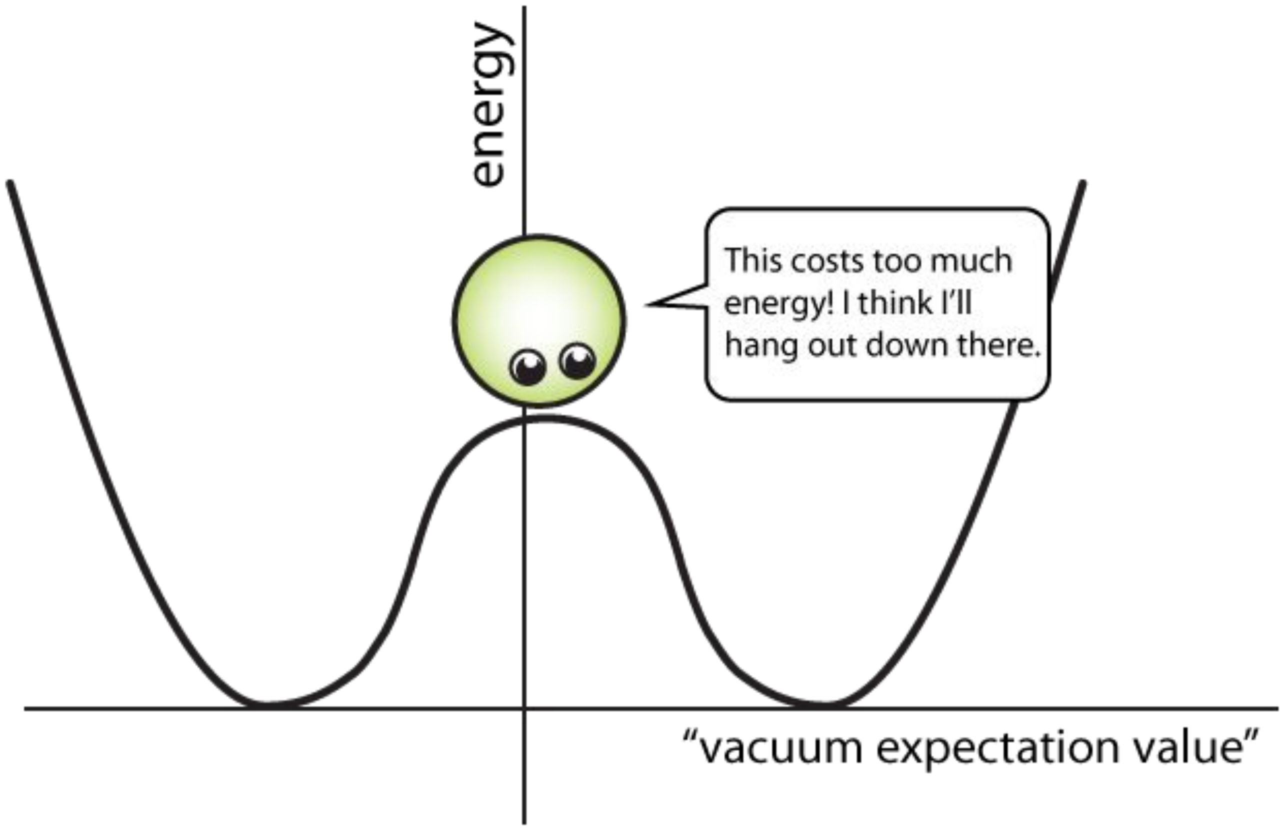
The Higgs potential at the present cosmological time

[Image taken from www.quantumdiaries.org]



Vacuum expectation value:
background Higgs field value that minimizes the Higgs/scalar potential

The Higgs boson: the only fundamental **scalar** particle discovered up to date!

This makes it very special!

Only Standard Model field allowed to have a non-zero vacuum expectation value

1. The Brout-Englert-Higgs mechanism makes the masses of gauge bosons and fermions proportional to v

$$m_f = y_f v/\sqrt{2}$$ **Fermions**

$$M_W = \frac{1}{2} g v$$ **Gauge bosons (W, for example)**

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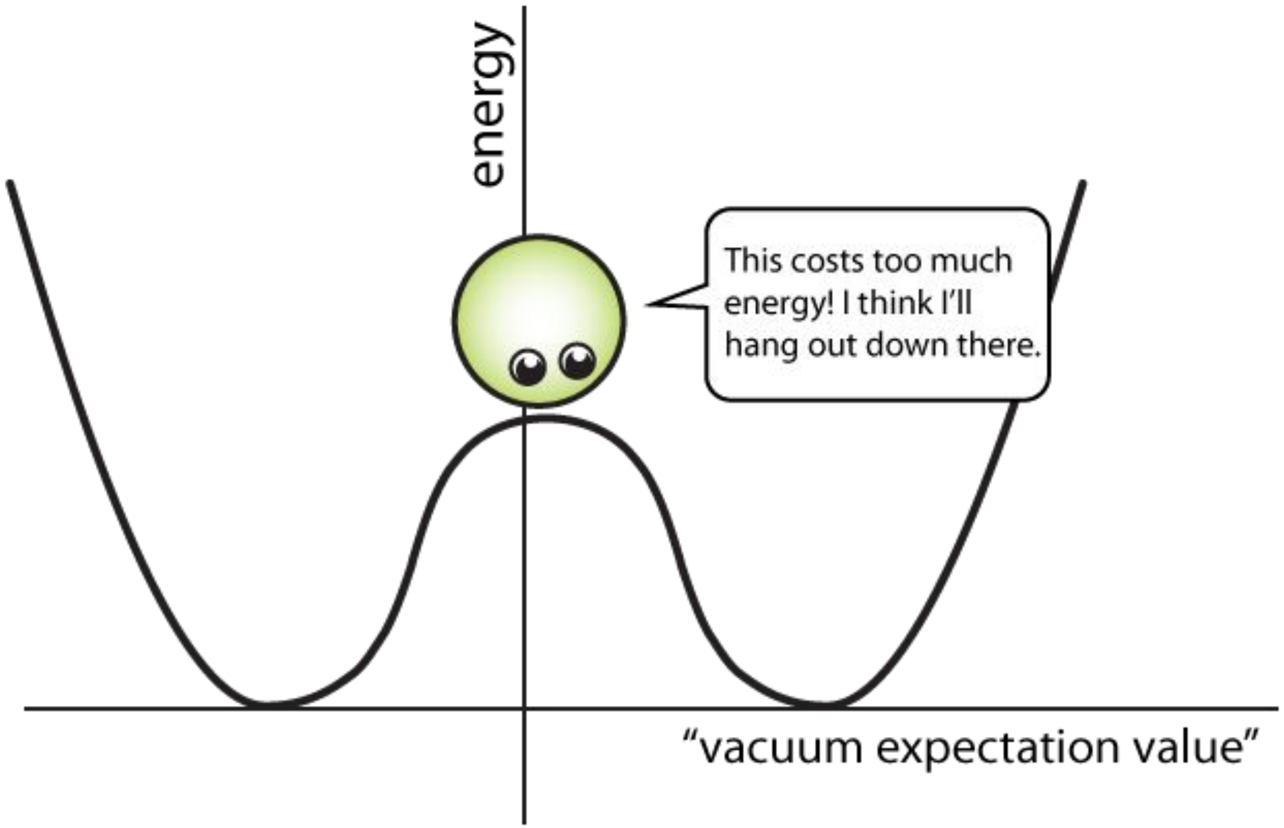
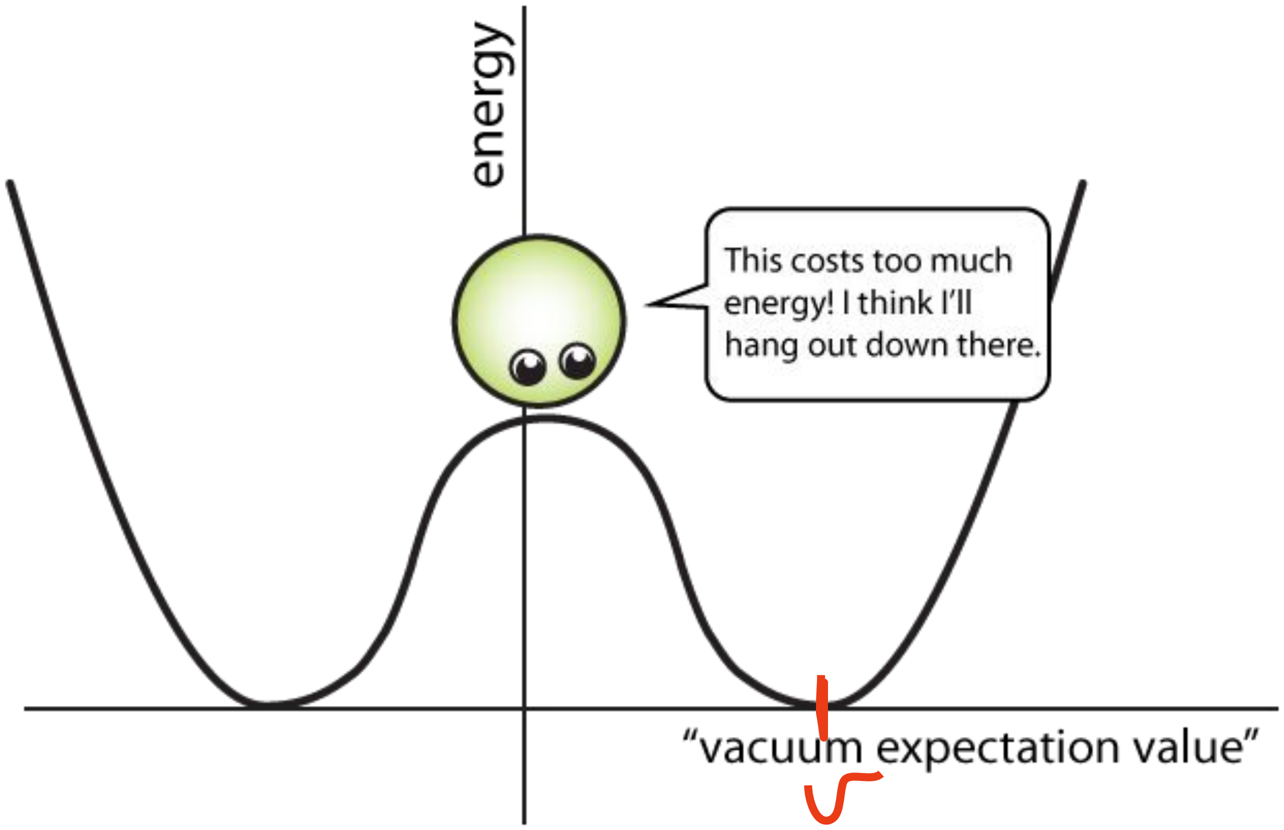


[Image taken from www.quantumdiaries.org]

The Higgs boson: the only fundamental **scalar** particle discovered up to date!

1. At the present cosmological era, we know the Higgs potential locally:

The Higgs potential at the present cosmological time



[Image taken from www.quantumdiaries.org]

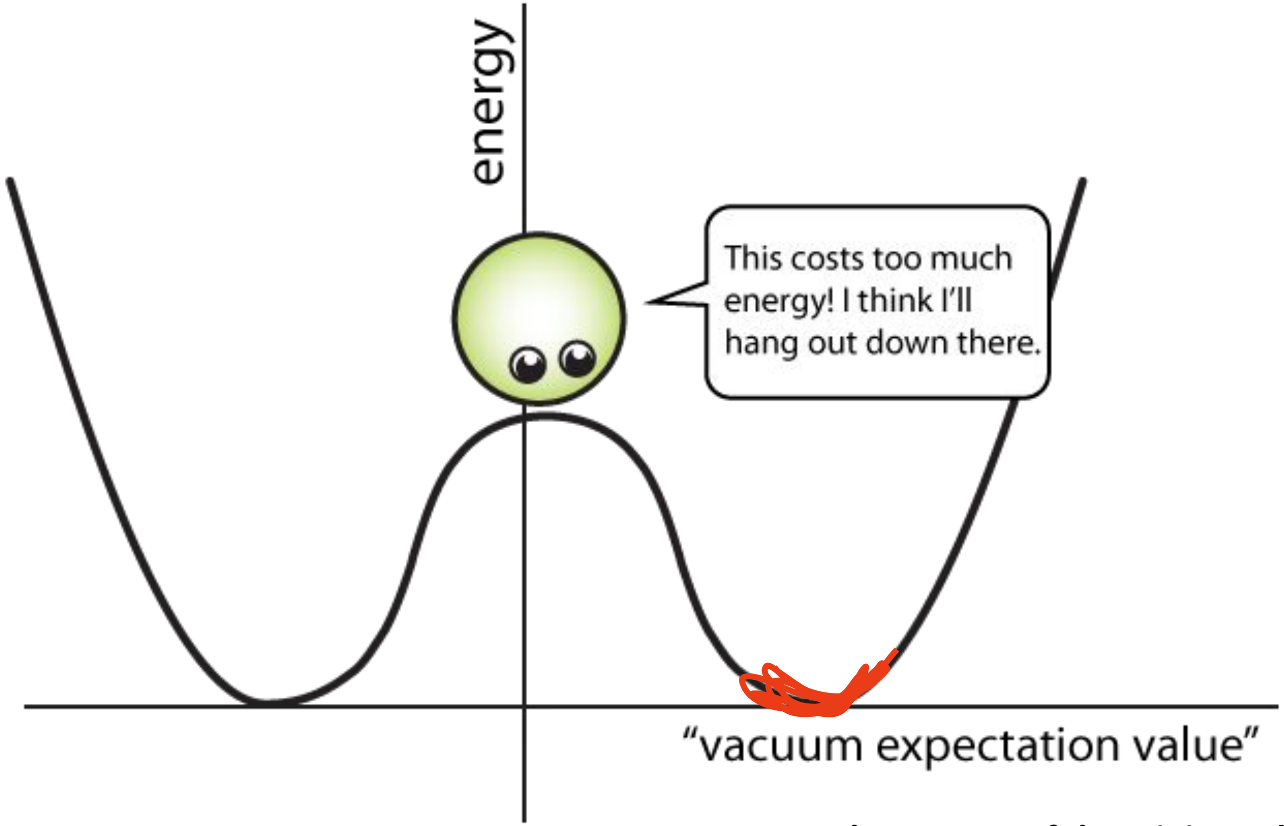
Position of the minimum!

The Higgs boson: the only fundamental **scalar** particle discovered up to date!

1. At the present cosmological era, we know the Higgs potential locally:

$$v \approx 246 \text{ GeV}$$

The Higgs potential at the present cosmological time



Local curvature of the minimum!

[Image taken from www.quantumdiaries.org]

The Higgs boson: the only fundamental **scalar** particle discovered up to date!

1. At the present cosmological era, we know the Higgs potential locally:

$$v \approx 246 \;\; \text{GeV}$$

$$M_h \approx 125 \;\; \text{GeV}$$

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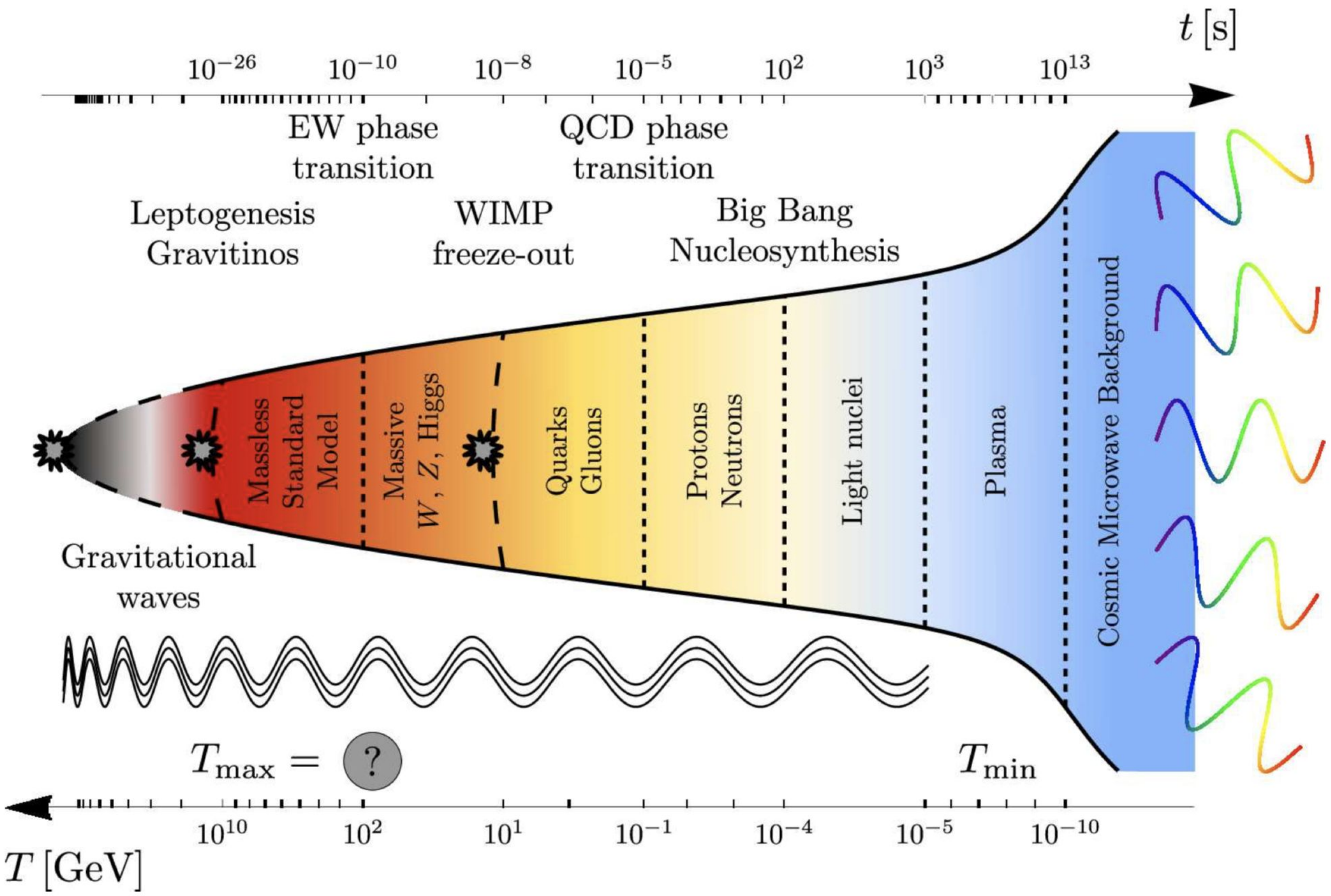
The Higgs potential at early cosmological times

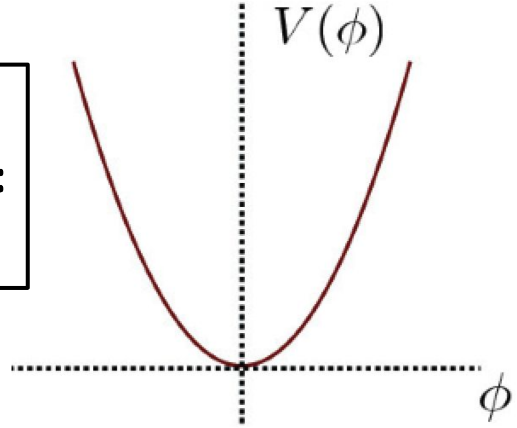
The shape of the scalar potential changes with the temperature of the Universe!



[Image by Kai Schmitz]

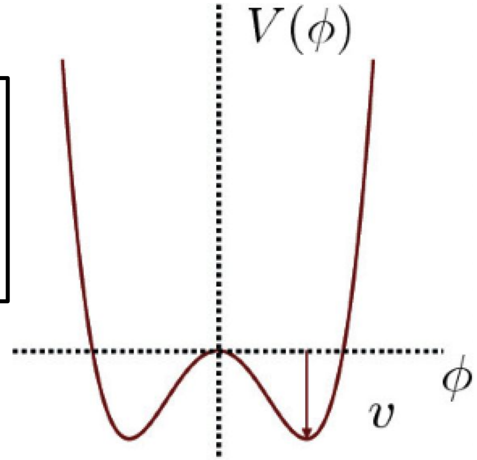
At very **early** cosmological times:

Massless particles: v = 0



At **late** cosmological times:

Massive particles: v ≠ 0



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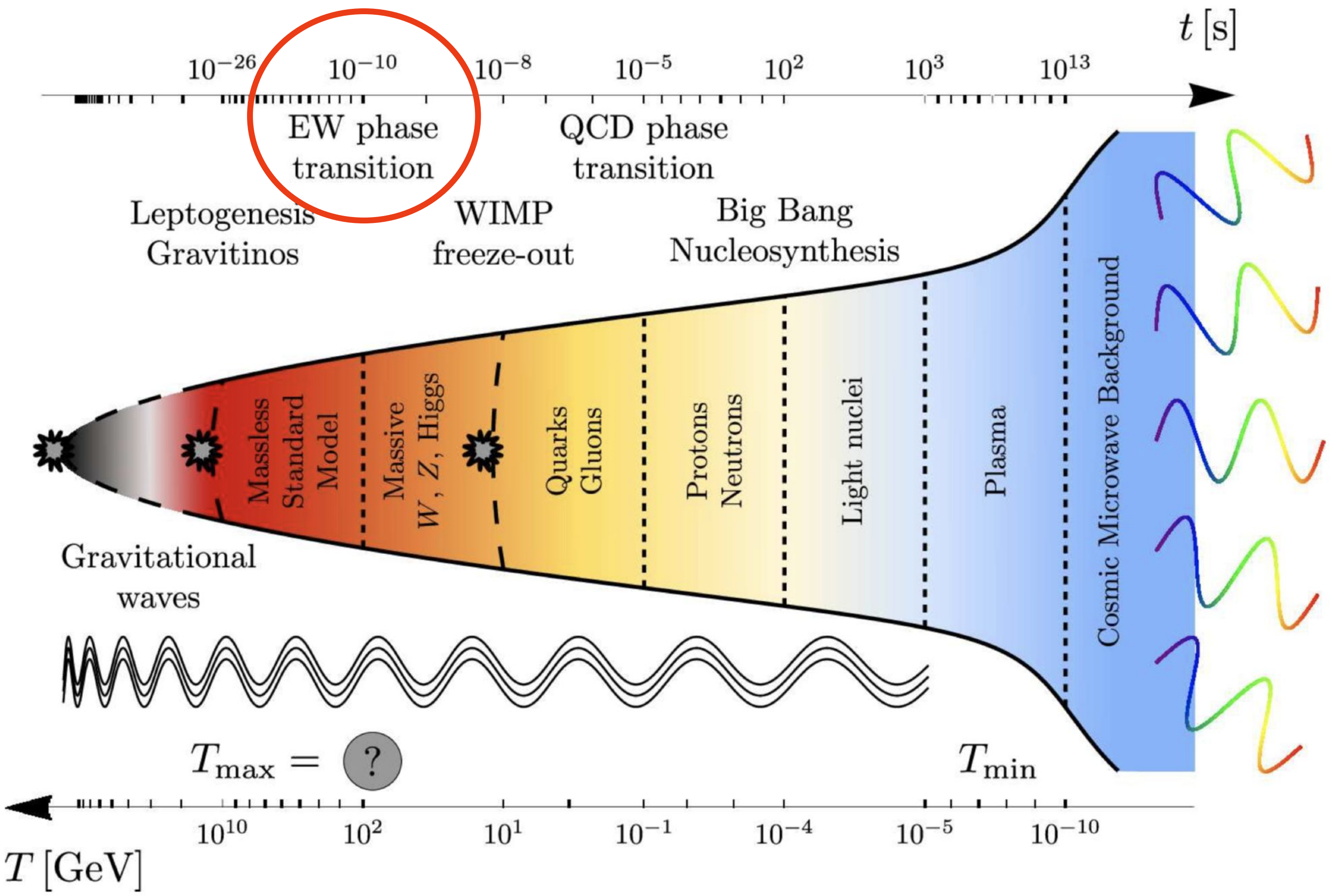
The Higgs potential at early cosmological times

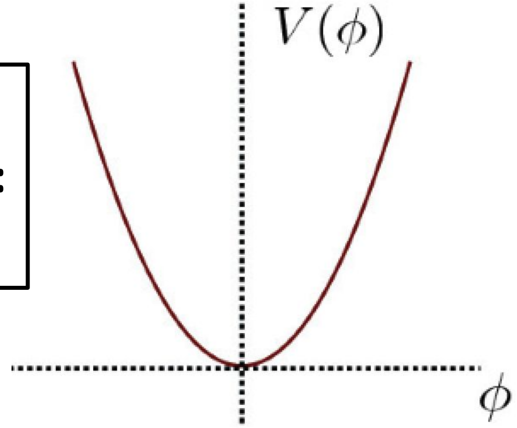
The shape of the scalar potential changes with the temperature of the Universe!



[Image by Kai Schmitz]

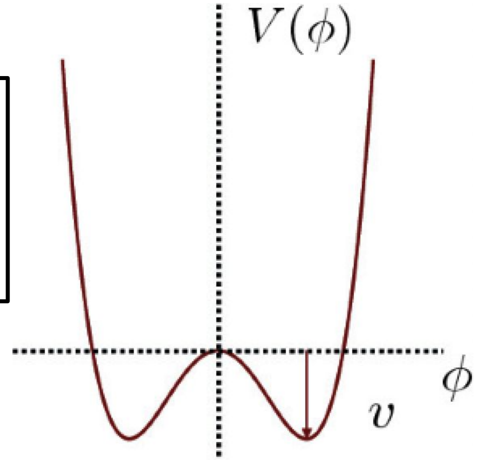
At very early cosmological times:

Massless particles: v = 0



At late cosmological times:

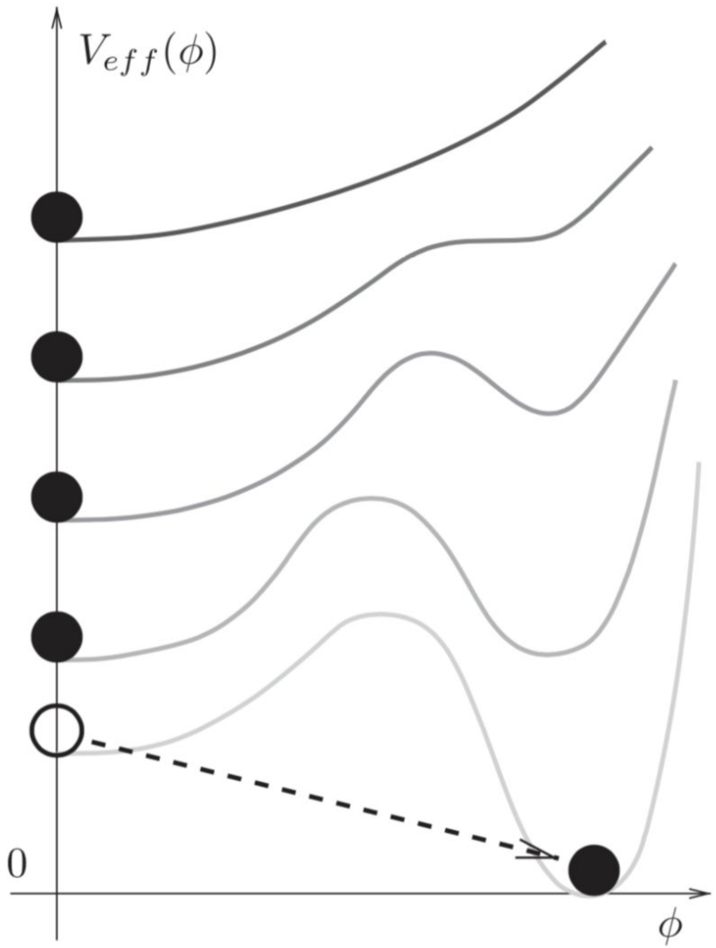
Massive particles: v ≠ 0



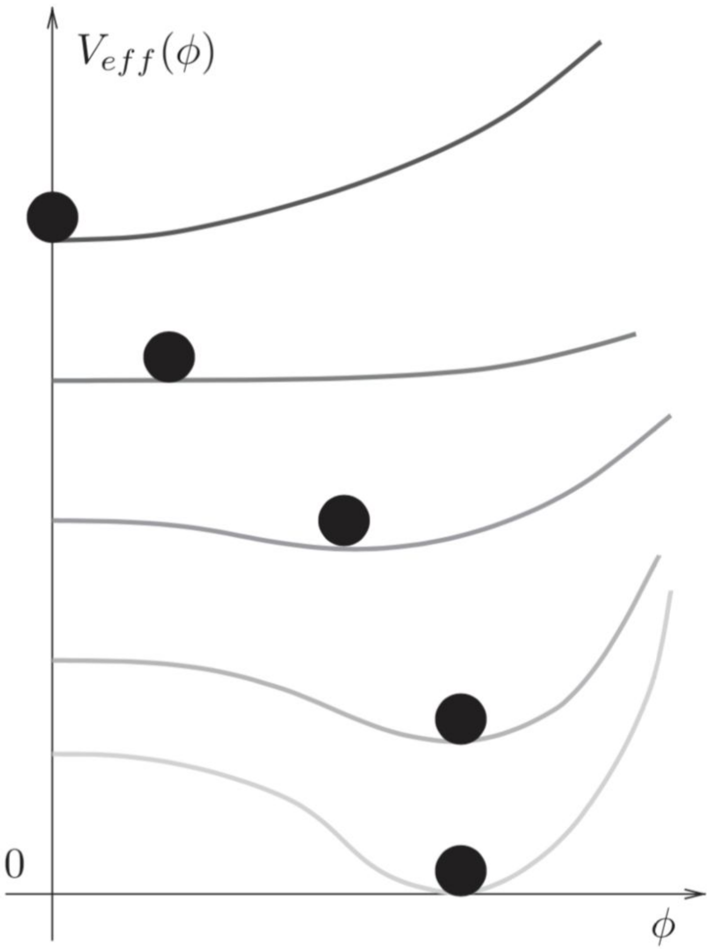
The electroweak phase transition

[Images by D. Gorbunov, V. Rubakov]

- BSM physics
- EW baryogenesis possible
- GW predictions



First-order electroweak phase transition

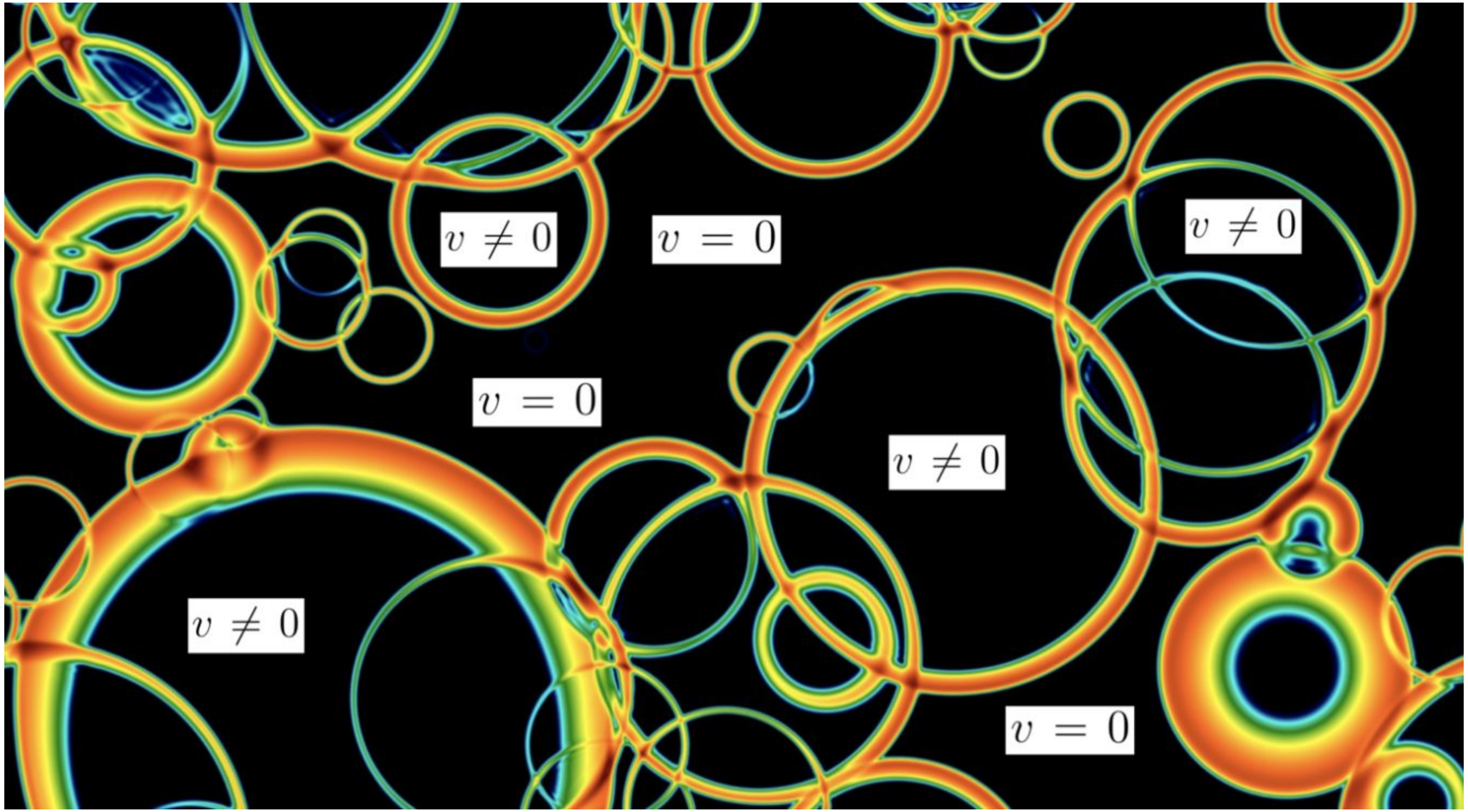


Second-order electroweak phase transition

- SM prediction
- No EW baryogenesis (see Lisa Biermann's talk)

The 1st-order electroweak phase transition: gravitational waves production

See Henda Mansour's talk!



[Image by D. Weir]

Future space-based gravitational wave interferometer: we expect to 2030s to see LISA start taking data!

The first-order electroweak phase transition and the triple Higgs boson self-coupling

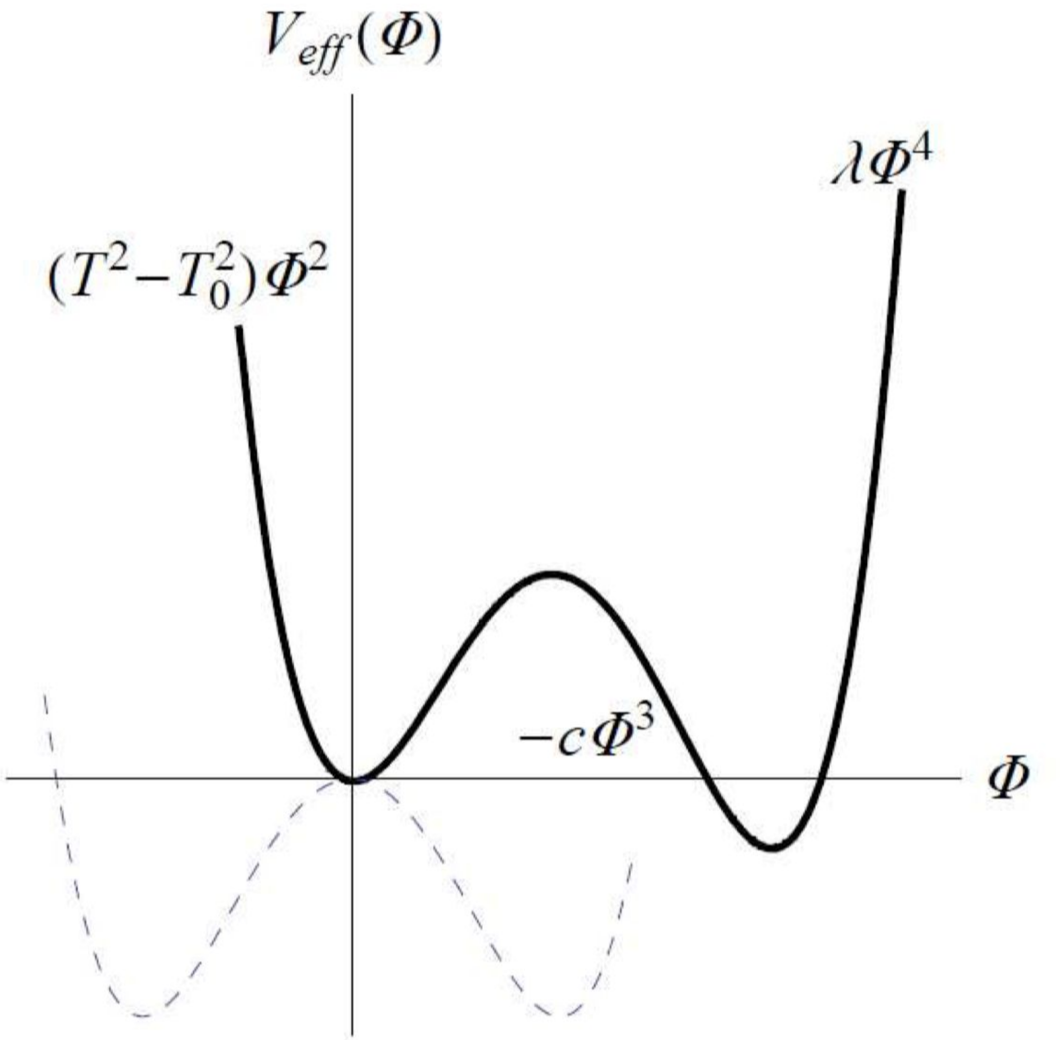
Why are they related?

- We need an energy barrier:
  only possible if a cubic term is present in the scalar potential

- The cubic term (at zero temperature) also controls the triple Higgs boson self-interaction that we can measure at colliders (High-Lumi LHC)
  (see Kateryna Radchenko's talk)

- **Multimessenger** approach to study the electroweak phase transition:
  GW interferometry
  Measurements of the triple Higgs self-coupling

[Image from arXiv: 1105.3694]



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The first-order electroweak phase transition and the triple Higgs boson self-coupling: a 2HDM glimpse

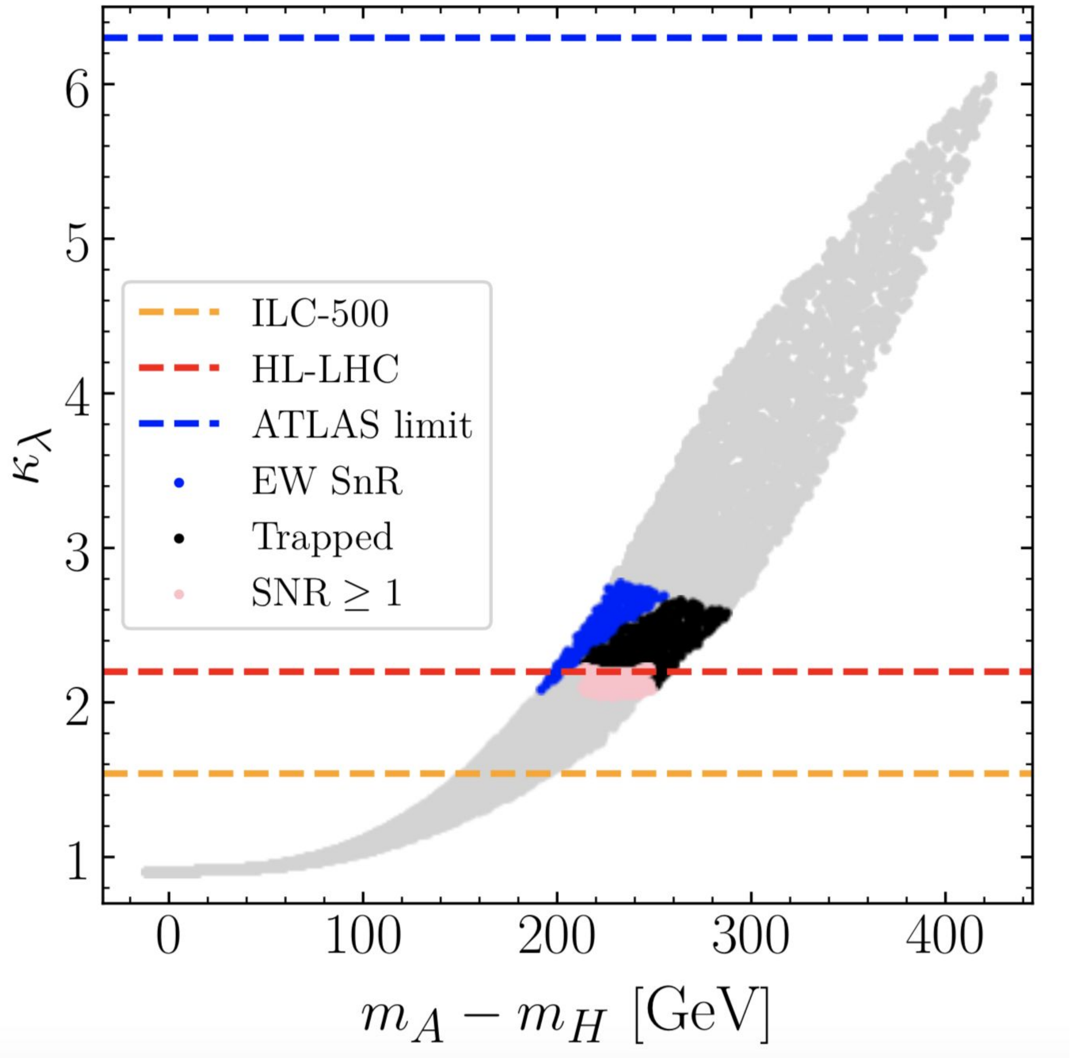
- 2HDM: scalar sector with 5 fundamental scalars
  (see Lisa Biermann's talk)

$$\kappa_\lambda := \lambda_{hhh}/(\lambda_{hhh}^{\mathrm{SM}})^0$$

Prediction in the 2HDM

Points in the 2HDM predicting detectable gravitational waves in LISA

All the pink points lie close to the projected upper limit for the High-Luminosity LHC!



[T. Biekötter, S. Heinemeyer, J. M. No, MOOR, G. Weiglein, 2208.14466]

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Conclusions

- Models with additional Higgs bosons/scalars can render the electroweak phase transition first order, which is interesting for several reasons:
  - Role in the explanation of the matter-antimatter asymmetry of the universe
  - New physics necessarily needed
- Multimessenger approach to study the first-order electroweak phase transition with experiments projected for construction:
  - Gravitational waves observatories (LISA)
  - High-luminosity LHC

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Thank you !

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