Brout-Englert-Higgs monopoles: particlelike solutions in modified gravity

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Particlelike distributions of the Higgs field nonminimally coupled to gravity,
***A. Füzfa, M. Rinaldi, S.S.**, PRL **111** (2013) 121103*

Particlelike solutions of modified gravity: the Higgs monopoles,
***S.S., M. Rinaldi, F. Staelens, A. Füzfa**,*
arXiv:1405.5476 (accepted by PRD)

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Motivations

- General relativity (GR) and the Standard Model cannot explain (satisfactorily)
  - Current cosmic acceleration without coincidence issues
  - Dark matter effects
  - Flatness and horizon problems (**primordial inflation**)

  ... but never been faulted by observations/experiments as well !

  $\longrightarrow$ Modified gravity (**scalar-tensor theory**, F(R), massive gravity, extra dimensions...)?

- Constraints on deviations from GR
  - Solar-system constraints (e.g. Cassini probe)
  - Astrophysical tests (e.g. binary pulsar)
  - Experimental tests (e.g. torsion balance)

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BEH field, partner of the metric?

- Why the BEH field?
  - Only fundamental scalar field detected (up to now)
  - Elementary particles mass generation
  - Partner to gravity?
- Some simplifications
  - Unitary gauge

$$\phi(x) = \frac{1}{\sqrt{2}} \begin{pmatrix} 0 \\ v + h(x) \end{pmatrix}$$

  - Coupling between the BEH field to matter in modified gravity not considered so far

Greenwood, Kaiser, Sfakianakis, PRD 87 (2013): 064021
Rinaldi, Eur.Phys.J.Plus (2014) 129: 56

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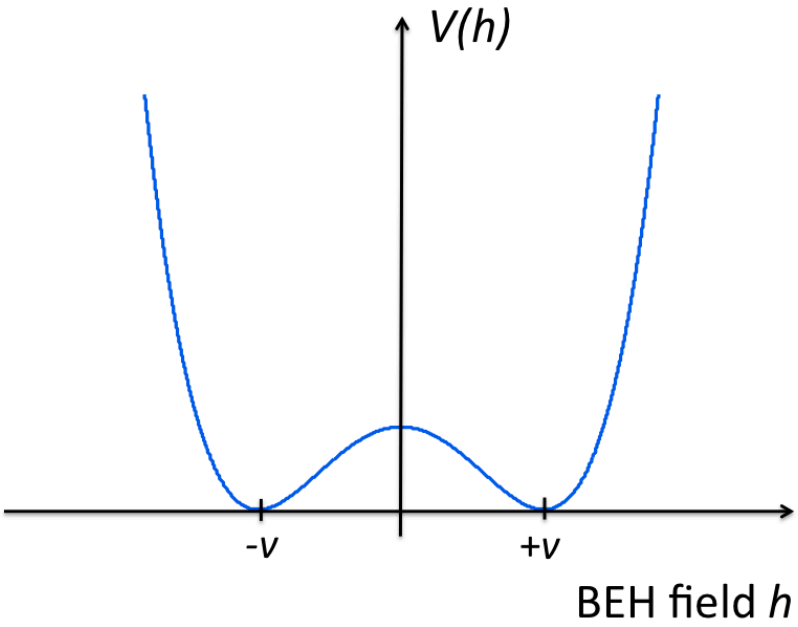
(New) Higgs inflation

The Standard Model Higgs boson as the inflaton,
Phys. Lett. B 659 (2008) 703,
F. L. Bezrukov and M. Shaposhnikov

Viable inflation?

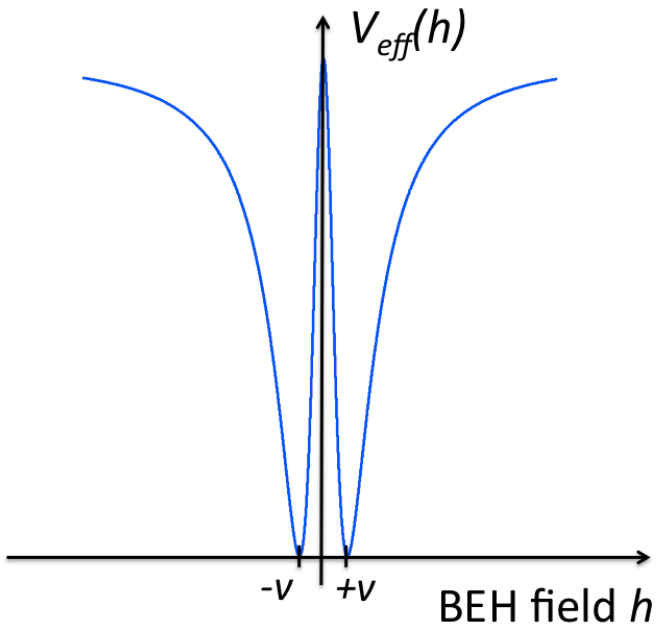
Very early model ('80):
"minimally coupled BEH field"

$$\mathcal{L} = \frac{m_{pl}^2}{16\pi} R - \frac{1}{2}(\partial\phi)^2 - V(\phi)$$



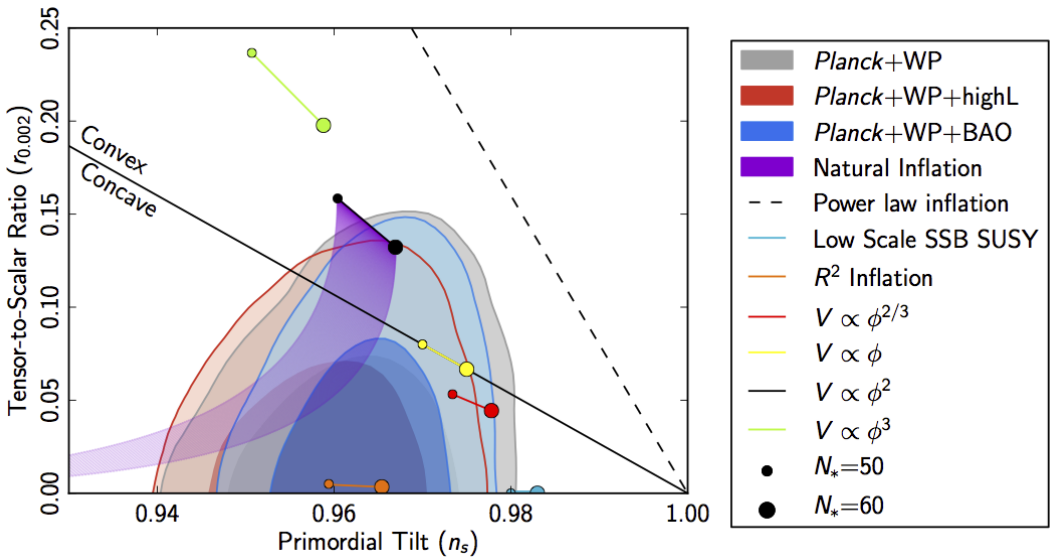
New Higgs inflation (2008):
"non-minimally coupled BEH field"

$$\mathcal{L} = \frac{m_{pl}^2}{16\pi}\left(1+\xi\phi^2\right) R - \frac{1}{2}(\partial\phi)^2 - V(\phi)$$

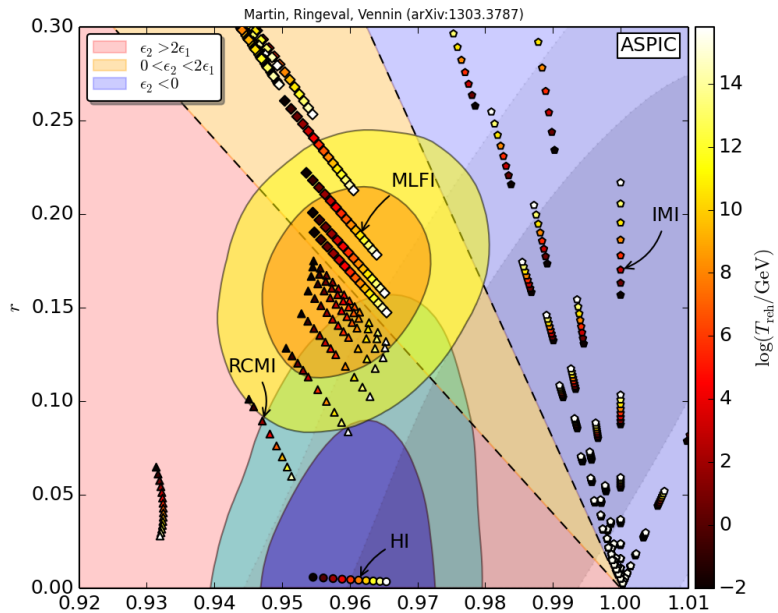


New Higgs inflation, a viable model?

- Constraint: Non-minimal coupling $\xi > 10^4$
- At high energy: equivalent to R^2 inflation
- Favoured by Planck data
- Ruled out by BICEP 2 results (no tensor modes)



Planck 2013 results.
XXII. Constraints on inflation



J. Martin, C. Ringeval, V. Venin
arXiv:1303.3787

Higgs monopoles

Introduction

- Solutions in static spherically symmetric spacetime

$$\mathcal{L} = \frac{m_{pl}^2}{16\pi}\left(1+\frac{\xi}{m_{pl}^2}H^2\right)R - \frac{1}{2}(\partial H)^2 - V(H) + \mathcal{L}_{mat}\left[\psi_m, g_{\mu\nu}\right]$$

with $\qquad H = m_{pl} h \tilde{v}, \qquad \tilde{v} = 246\ \text{GeV}/m_{pl}$

$$V(H) = \frac{\lambda}{4}\left(H^2 - v^2\right)^2$$

- Standard Model potential parameters
- Matter = top-hat density profile
- **Distribution of the BEH field around compact objects?**
- **Deviations from GR?**

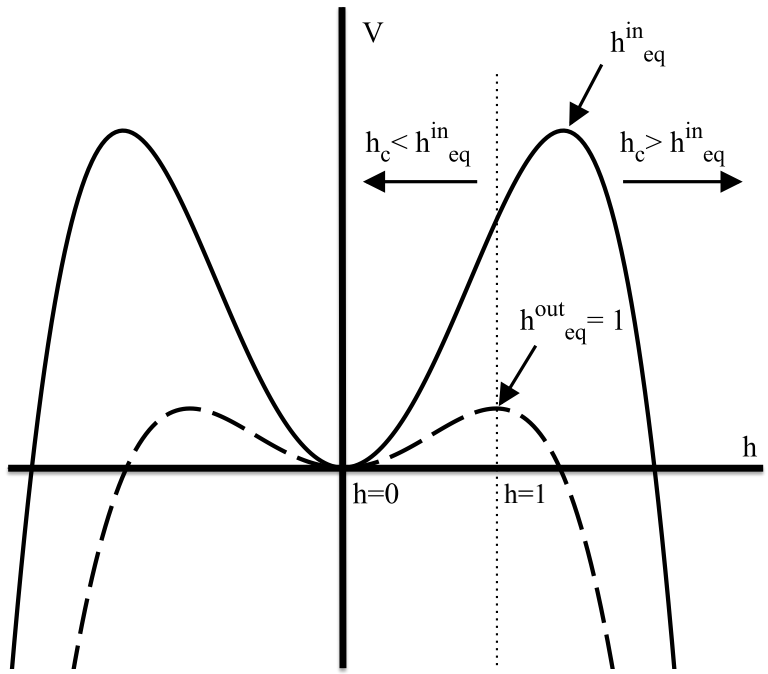
Effective dynamics

- Klein-Gordon equation $\Box h = -\frac{dV_{\text{eff}}}{dh}$ with $V_{\text{eff}} = -V + \frac{\xi h^2 R}{16\pi}$
- In cosmology (FLRW metric, scale factor $a(t)$)

$$\frac{d^2h}{dt^2} + \frac{3}{a}\frac{da}{dt}\frac{dh}{dt} = \frac{dV_{\text{eff}}}{dh}$$

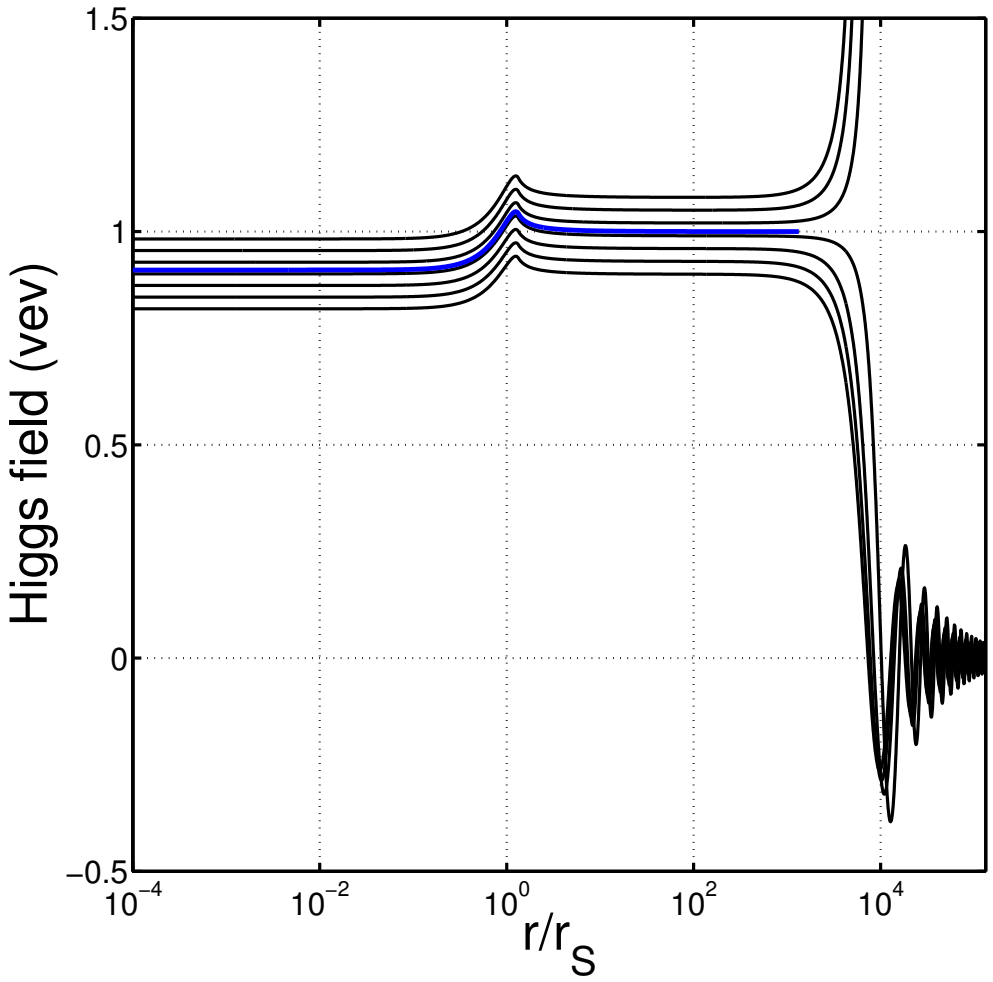
- For compact objects (Schwarzschild coordinates)

$$h'' - h'\left(\lambda' - \nu' - \frac{2}{r}\right) = -\frac{dV_{\text{eff}}}{dh}$$



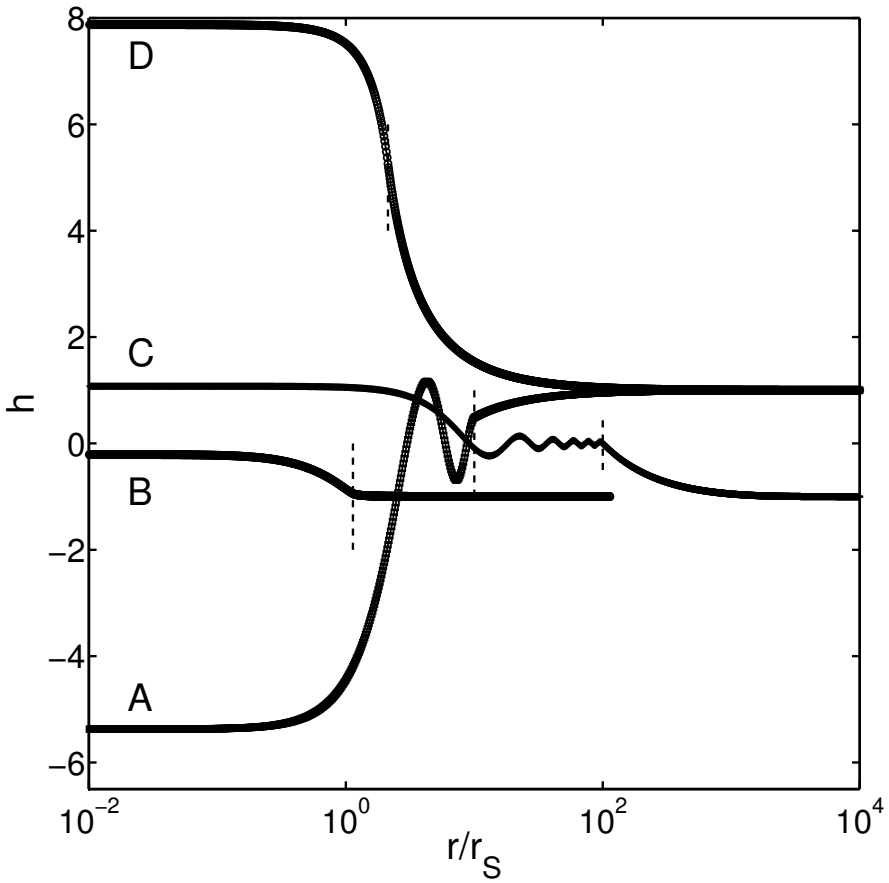
Higgs monopole solutions

$\xi = 10$, $m = 10^6$ kg, $s = 0.75$



- Particlelike solutions:
  - Convergence towards the vev
  - Globally regular
  - Finite energy
  - Asympotically flat
- In GR, unrealistic homogeneous solution only ($h = 1$ everywhere)
- Parameters
  - Compactness $s = \frac{r_s}{\mathcal{R}}$ with r_s, the Schwarzschild radius and $\mathcal{R}$, the radius
  - Baryonic mass m
  - Non-minimal coupling ξ

Monopole family



	h_c	ξ	m	s
A	- 5.37	10^4	10^3 kg	0.1
B	- 0.21	10	10^6 kg	0.88
C	1.077	10^6	10^6 kg	0.01
D	7.88	60	10^4 kg	0.47

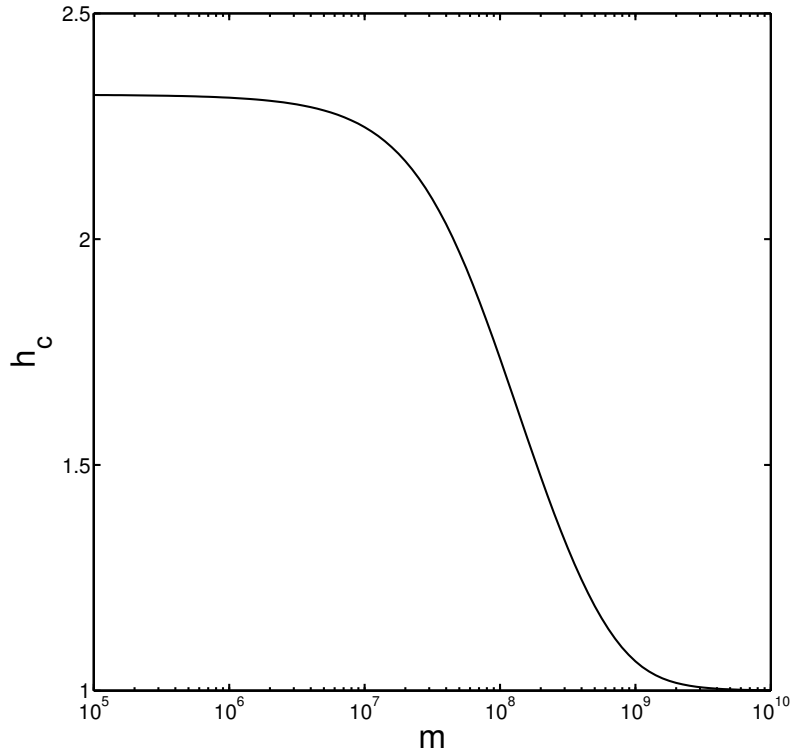
Notice: no astrophysical objects

Deviations from GR

- Astrophysical objects: $h_c \longrightarrow 1$
- No observable deviations from GR with SM potential parameters
- Even for big values of ξ
- Vev vs Planck scale ("hierarchy problem")

- **Only one solution, different than GR !**

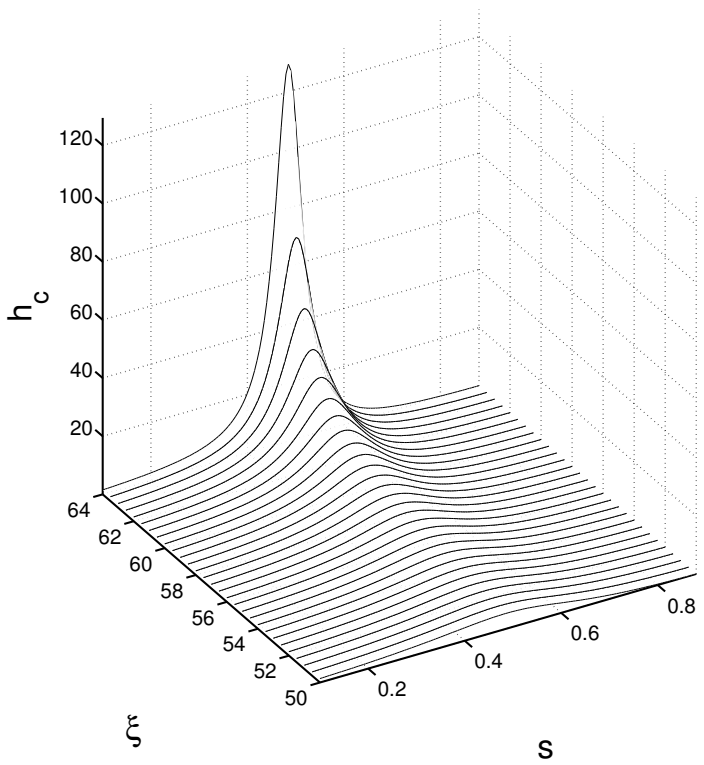
$\xi = 60$, $s = 0.2$ (neutron star)

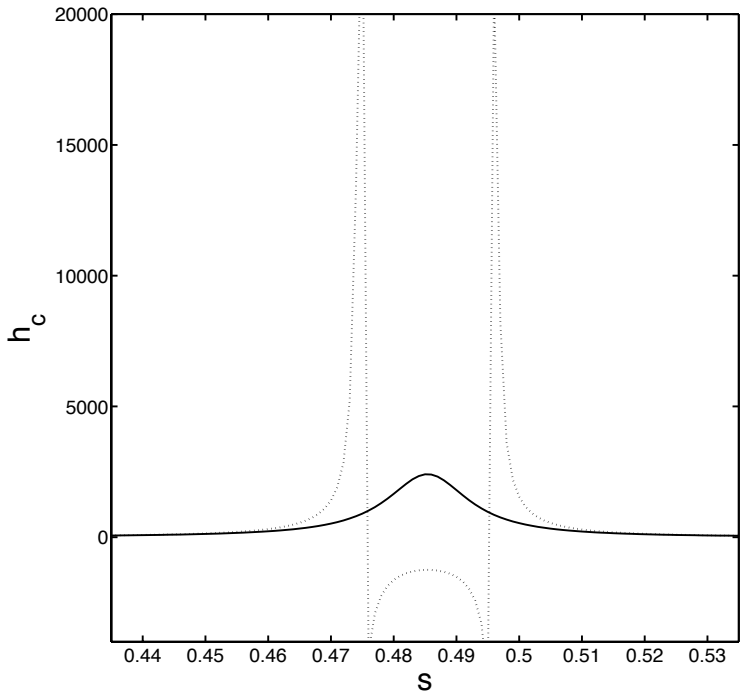


Amplification mechanism (I)

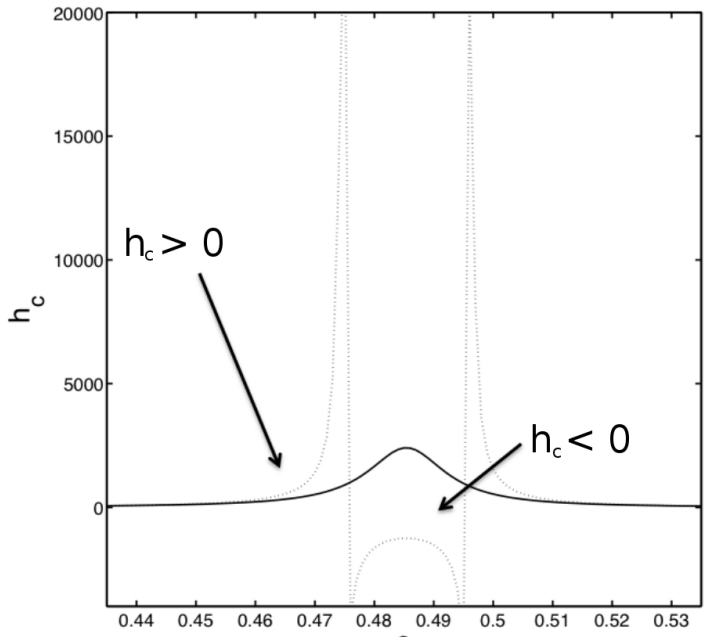
$$m = 10^3 \text{ kg}$$

$\xi = 64.6$ (solid line)
$\xi = 64.7$ (dotted line)

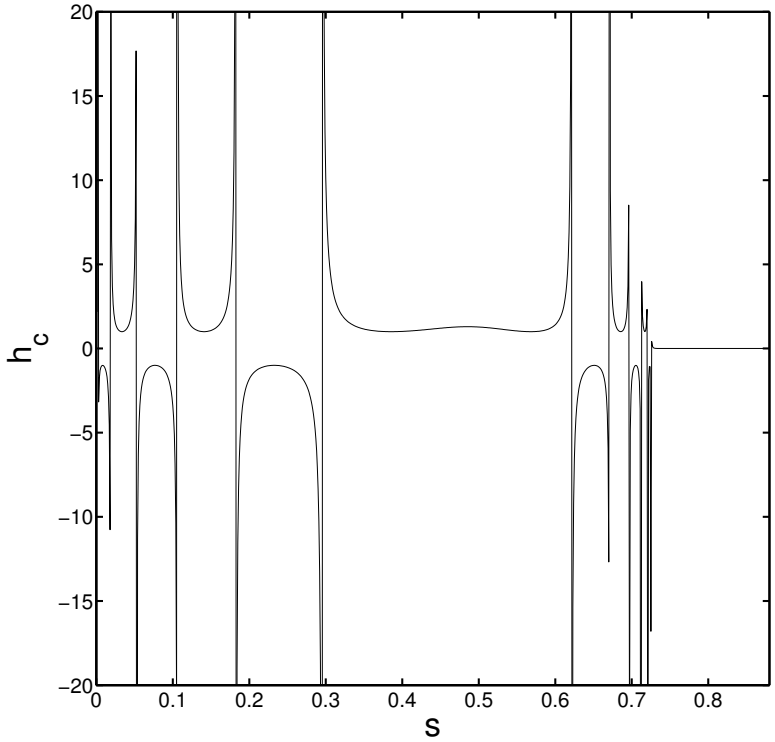




Amplification mechanism (II)



$m = 10^2$ kg, $\xi = 10^4$



- Critical ξ: $h_c \longrightarrow \infty$ for some s (or $\mathcal{R}$)
- Phase transition $h_\infty \longrightarrow \pm 1$
- Constraint on ξ: forbidden s (or $\mathcal{R}$)
  $\rightarrow$ No (monopole) solution !

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Conclusions and perspectives

Conclusion:

- New particlelike solution: Higgs monopole
- Different than GR and usual scalar-tensor theory (no potential)
- Negligible deviations from GR (SM potential parameters)
- General amplification mechanism

Perspectives:

- Coupling BEH field to matter (cosmology and compact objects)
- Unitary gauge
- Possible formation during gravitational collapse and stability? Remnants?
- Generalization of amplification mechanism (other potential)
- Application to boson stars

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