Higgs Balls: Novel Non-Topological Solitons via Thermal Corrections

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Based on:
L. Pearce, G. White, and A. Kusenko
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Thank you to the organizers for allowing a remote talk!

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Typically, to minimize $\sqrt{V(\phi)/\phi^2}$ at nonzero ϕ_0 requires an attractive interaction (e.g., ϕ^3)...but is this necessary?

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- Potential issues: Finite temperature corrections also affect the mass; High T not valid unless $T \gg \phi_0$

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- Then consider gauged SM Higgs model; extra energy from the gauge interactions prevents thermal Higgs balls from existing
- What about extensions of SM?

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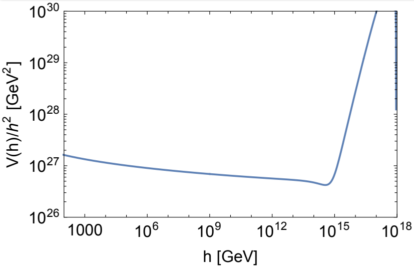

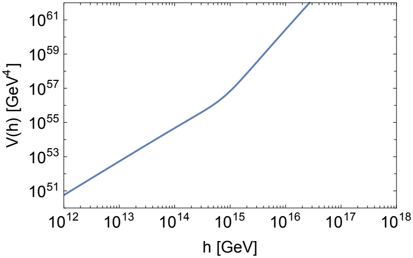

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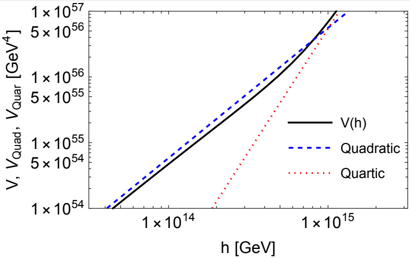

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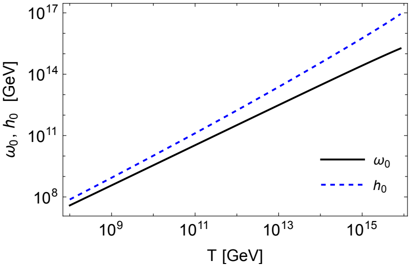

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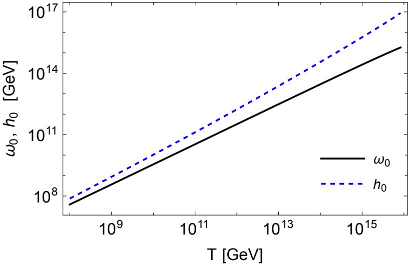

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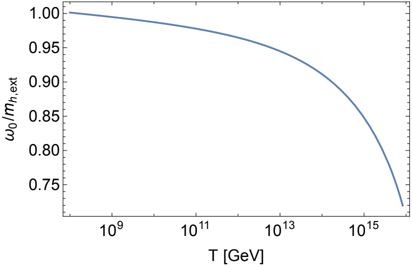

Q-balls for $T \gtrsim 10^9\,\mathrm{GeV}$

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$$\phi(x,t) = \frac{\phi_0}{\sqrt{2}} F(r) e^{i\omega t},$$
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- Breakdown of static charge approximation $\leftrightarrow$ confining nature of $\mathrm{SU}(N)$ gauge interactions
- Use static charge approximation only if Q-ball radius is much less than $\mathrm{SU}(2)$ confinement scale

Properties of Gauged Higgs Balls

Results:

- Energy per unit charge ω:

$$\omega = \frac{1}{2} R h_0 \omega_0 \sqrt{g_W^2 + g_Y^2} \coth\left(\frac{1}{2} R h_0 \sqrt{g_W^2 + g_Y^2} \right)$$

  where ω_0 is the "global" Q-ball energy per unit charge, h_0 is the global Q-ball VEV, and R is the radius.

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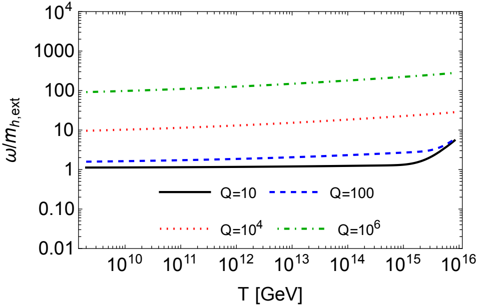
- VEV: Step function with $h = h_0$ (global value) inside.

Thermal Higgs Balls in the SM

No thermal Higgs balls in the Standard Model: Extra energy from gauge boson repulsion between charges makes the energy per unit charge ω greater than the mass of a free Higgs quanta:



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- Need to decouple these two things

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- Also introduce a scalar field:

$$V(H,S) = -\mu^2 H^\dagger H + \lambda_H (H^\dagger H)^2 + \frac{m_S^2}{2} S^2 + \lambda_S S^4 + \lambda_{HS} H^\dagger H S^2$$

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- SUSY has both: extra scalars & modified gauge coupling runnings

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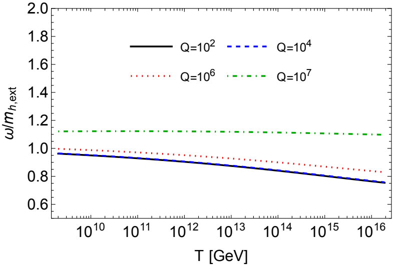

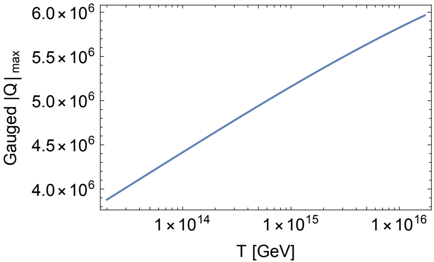

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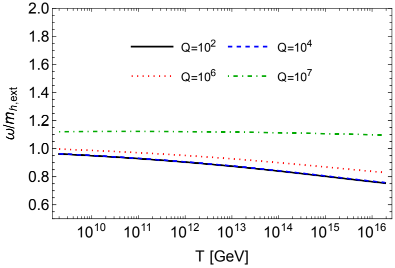

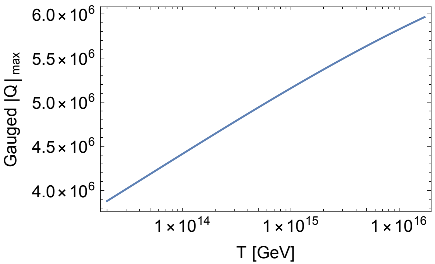

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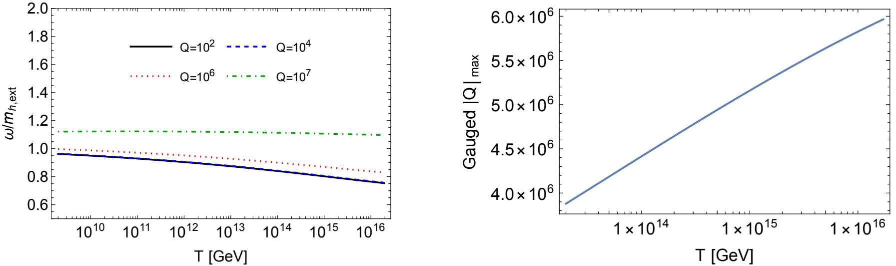

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- Quasi-stable: Higgs quanta can decay

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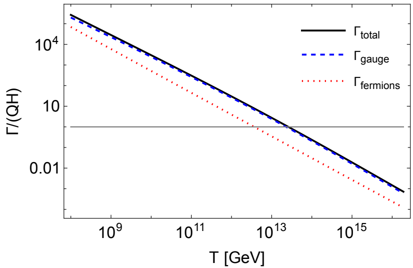
  - Equivalently, when $\Gamma_h \sim H$



$Q = 10^6$,
assuming radiation domination

Quasi-Stability

- Higgs Balls are only *quasi-stable*: can't fall apart into individual Higgs quanta, but the Higgs quanta themselves can decay.
- Decays occur throughout the volume of the Q-ball, so $\Gamma_{\mathrm{Q-ball}} = Q\Gamma_h$
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  - Higgs balls decay efficiently when $\Gamma_{\mathrm{Q-ball}} \sim QH$ (where H is Hubble coefficient)
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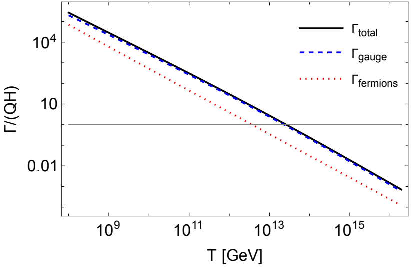

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Exist for wide range of temperatures, but stable against decay for $T \gtrsim 10^{13}\ \mathrm{GeV}$

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Area for future work...