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Evolution of the Universe in the Inert Doublet Model

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We consider evolution of the Universe after the electroweak symmetry breaking (EWSB) leading to the present inert phase, with a SM-like Higgs boson and scalar dark particles, among them a Dark Matter candidate. We discuss the possibility to have a sequences of the phase transitions instead of a single one leading directly from EW symmeric phase to the inert one.

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1. Thermal evolution of the Universe in the IDM

The Inert Doublet Model (IDM) is a Z_2-symmetric 2HDM that may provide the Dark Matter (DM) candidate [1]. There are two scalar $SU(2)$ doublets: a *Higgs doublet* Φ_S and a *dark doublet* Φ_D. In this model the Z_2-type symmetry (called the D-symmetry) is present: $\Phi_S \xrightarrow{D} \Phi_S$, $\Phi_D \xrightarrow{D} -\Phi_D$, *SM* fields $\xrightarrow{D}$ *SM* fields, leading to the D-parity conservation. All components of Φ_D are realized as the massive D-odd scalars: two charged $D^\pm$ and two neutral D_H and D_A. The lightest particle among them is stable and can be considered as a candidate for the DM particle. This model can be used to describe the evolution of the Universe [2].

The D-symmetric potential V, which can describe IDM, has the following form:

$$V = -\frac{m_{11}^2}{2}|\Phi_S|^2 - \frac{m_{22}^2}{2}|\Phi_D|^2 + \frac{\lambda_1}{2}|\Phi_S|^4 + \frac{\lambda_2}{2}|\Phi_D|^4 + \lambda_3|\Phi_S|^2|\Phi_D|^2 + \lambda_4|\Phi_S^\dagger\Phi_D|^2 + \left(\frac{\lambda_5}{2}(\Phi_S^\dagger\Phi_D)^2 + h.c\right),$$

with all parameters real and $\lambda_5 < 0$ [2]. *Positivity conditions* imposed on V guarantee that the extremum with the lowest energy will be the global minimum of the potential (vacuum). We set *the Yukawa interaction* to Model I of general 2HDM (only one doublet, Φ_S, couples to SM fermions).

We consider *thermal evolution of the Lagrangian* as in [2], where only the quadratic parameters m_{ii}^2 $(i = 1,2)$ vary with temperature T:

$$m_{ii}^2(T) = m_{ii}^2 - c_i T^2 \;(i = 1,2),$$

where $c_i = c_i(\lambda_{1-4}; g, g'; g_t^2 + g_b^2 \text{ for } i = 1)$, g, g' – EW gauge couplings, g_t, g_b – SM Yukawa couplings) [2].

During the evolution the potential V with $m_{ii}^2(T)$ may have different ground states [2]. The most general neutral EWSB solution $\langle\Phi_S\rangle^T = \frac{1}{\sqrt{2}}(0, v_S)$, $\langle\Phi_D\rangle^T = \frac{1}{\sqrt{2}}(0, v_D)$ gives three extrema:

- *EW symmetric extremum* (EWs) is realized if $v = v_D = v_S = 0$. Here all fermions and bosons are massless and EW symmetry is conserved.
- *Inert extremum* (I_1) can be realized if $v_D = 0$, $v_S^2 = v^2 = m_{11}^2/\lambda_1$. In this vacuum state there is the SM-like Higgs particle h_S and four dark scalar particles $D_H, D_A, D^\pm$. We consider IDM with the DM candidate D_H, where $M_{D^\pm}, M_{D_A} > M_{D_H}$. Various theoretical and experimental constraints apply for the IDM [1, 2]. The scalar masses are constrained by EWPT and collider data (LEP II, Tevatron, LHC). The relic density measurements and the direct detection experiments can be used to constrain the DM mass and the DM-Higgs self-coupling λ_{345}. However, the DM quartic self-coupling λ_2 cannot be limited this way [2].
- *Inertlike extremum* (I_2) is mirror-symmetric to I_1 as $v_S = 0$, $v_D^2 = v^2 = m_{22}^2/\lambda_2$. There are four scalars $S_H, S_A, S^\pm$ (no DM candidate due to the spontaneous violation of the D-symmetry) and the Higgs particle h_D with no interaction with the massless fermions (Model I).
- *Mixed extremum* (M) is a standard 2HDM extremum with $v_S, v_D \neq 0$, $v^2 = v_S^2 + v_D^2$. Fermions and bosons are massive and there are 5 physical Higgs particles: CP-even h and H, CP-odd A and charged $H^\pm$, none of them can be a DM candidate.

We assume that the Universe today is in the inert phase I_1 with the DM candidate D_H. However, various sequences of transitions between different vacua (represented by *rays*) were possible in the past [2]:

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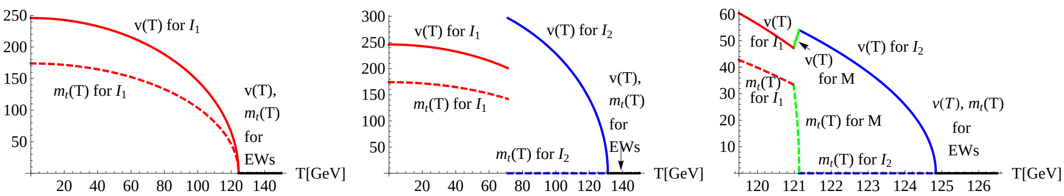
- $EWs \to I_1$: rays **Ia-c**, **IIa-b** (no I_2, M minima during evolution), **III** (I_2 is a local minimum today);
- $EWs \to I_2 \to I_1$: rays **IV** (I_2 is not a local minimum today) and **V** (I_2 is a local minimum today);
- $EWs \to I_2 \to M \to I_1$: ray **VI** ($I_2, M$ were global minima in the past).

2. Numerical study

For numerical studies we fix the values of the scalar masses that correspond to the medium DM mass region in IDM: $M_{h_S} = 120$ GeV, $M_{D_H} = 45$ GeV, $M_{D_A} = 115$ GeV, $M_{D^\pm} = 125$ GeV, choosing the values of self-couplings λ_{345}, λ_2 for each ray [2]. Below we discuss the evolution of mass parameters for three types of sequences (for rays III, V and VI) [2]. In fig.1 mass evolutions of the $W^\pm$ boson (proportional to $v(T)$) and t quark are shown.

- **Ray III**: $\lambda_{345} = 0.117$, $\lambda_2 = 0.02$, $\Omega_{DM}h^2 = 0.0107$ (inside 3σ WMAP limit). There is a single 2nd-order phase transition $EWs \to I_1$ (EWSB). Local minimum I_2 appears at later stages of the evolution of Universe , but it is never a global minimum.
- **Ray V**: $\lambda_{345} = 0.17$, $\lambda_2 = 0.05$, $\Omega_{DM}h^2 = 0.0053$ (below 3σ WMAP limit). The EWSB is a 2nd-order phase transition, while the final transition $I_2 \to I_1$ is of the 1st-order. I_1 and I_2 coexist for $T < 120$ GeV and local minimum I_2 still exists for $T = 0$. The discontinuity in $v(T)$ and $m_t(T)$ is visible (fig.1b).
- **Ray VI**: $\lambda_{345} = 0.17$, $\lambda_2 = 0.125$, $\Omega_{DM}h^2 = 0.0053$ (below 3σ WMAP limit). There are three 2nd-order phase transitions $EWs \to I_2 \to M \to I_1$, which lead to the continuous evolution of the physical parameters (fig.1c) and no coexistence of minima for any T.



(a) ray III (b) ray V (c) ray VI

Figure 1: Evolution of v.e.v $v(T)$ and top mass $m_t(T)$ for different rays [2].

References

[1] N. G. Deshpande and E. Ma, Phys. Rev. D **18** (1978) 2574; R. Barbieri et al., Phys. Rev. D **74** (2006) 015007; L. Lopez Honorez et al., JCAP **0702** (2007) 028; T. Hambye et al., JHEP **0907** (2009) 090 [Erratum-ibid. **1005** (2010) 066]; E. M. Dolle and S. Su, Phys. Rev. D **80** (2009) 055012; E. Dolle et al., Phys. Rev. D **81**, 035003 (2010).

[2] I. F. Ginzburg et al., Phys. Rev. D **82**, 123533 (2010); D. Sokołowska, arXiv:1107.1991 [hep-ph], arXiv:1104.3326 [hep-ph].

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