# Spontaneous CP Violation at Finite Temperature in the MSSM

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## I. Introduction

3 requirements to generate BAU : $n_B/s \simeq 10^{-11}$

(1) baryon number violation
(2) $C$ and $CP$ violation
(3) departure from equilibrium

- EW theory satisfies these if the EWPT is first order.

$\Longrightarrow$ **Electroweak Baryogenesis**

- For sufficient CP violation, some extension of the Minimal SM is needed.

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for a review,
K.F., Prog.Theor.Phys.**96** ('96) 475.
V.A. Rubakov and M.E. Shaposhnikov, hep-ph/9603208.
A.Cohen, et al., Ann.Rev.Nucl.Part.Sci. **33** ('93) 27.

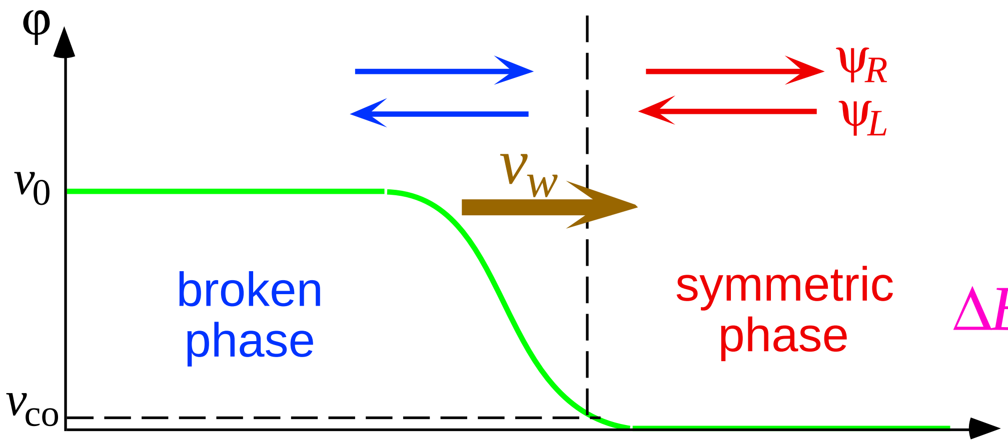
generated BAU (by the charge transport scenario)

$$\frac{n_B}{s} \simeq \mathcal{N}\frac{100}{\pi^2 g_*}\cdot\kappa\alpha_W^4\cdot\tau T\cdot\frac{F_Y}{v_w T^3}$$

$$\simeq 10^{-3}\times\frac{F_Y}{v_w T^3} \qquad \text{for an optimal case}$$

$F_Y$ : chiral charge flux $\Leftarrow$ $CP$ violation at EW bubble wall

$\Longleftrightarrow$ $\Delta R$ : reflection prob. of chiral fermions




CP violation effective for $F_Y$ at the lowest order

- relative phases of $\mu$, $M_2$, $M_1$, $A_t$ in the MSSM

  chargino, neutralino, stop transport

  [Huet and Nelson, PRD53('96); Aoki, et al. PTP98('97)]

- relative phase $\theta$ of the two Higgs doublets

$$\langle\Phi_i\rangle = \frac{1}{\sqrt{2}}\begin{pmatrix} 0 \\ \rho_i e^{i\theta_i}\end{pmatrix}$$

quarks and leptons $\Longleftarrow$ Yukawa coupl. $\propto \rho_i e^{i\theta}$

chargino, neutralino, stop    mass matrix

N.B. $\theta = \theta(x)$ $\therefore$ it cannot be rotated away

[Nelson et al. NPB373('92); FKOTT, PRD50('94), PTP95('96)]

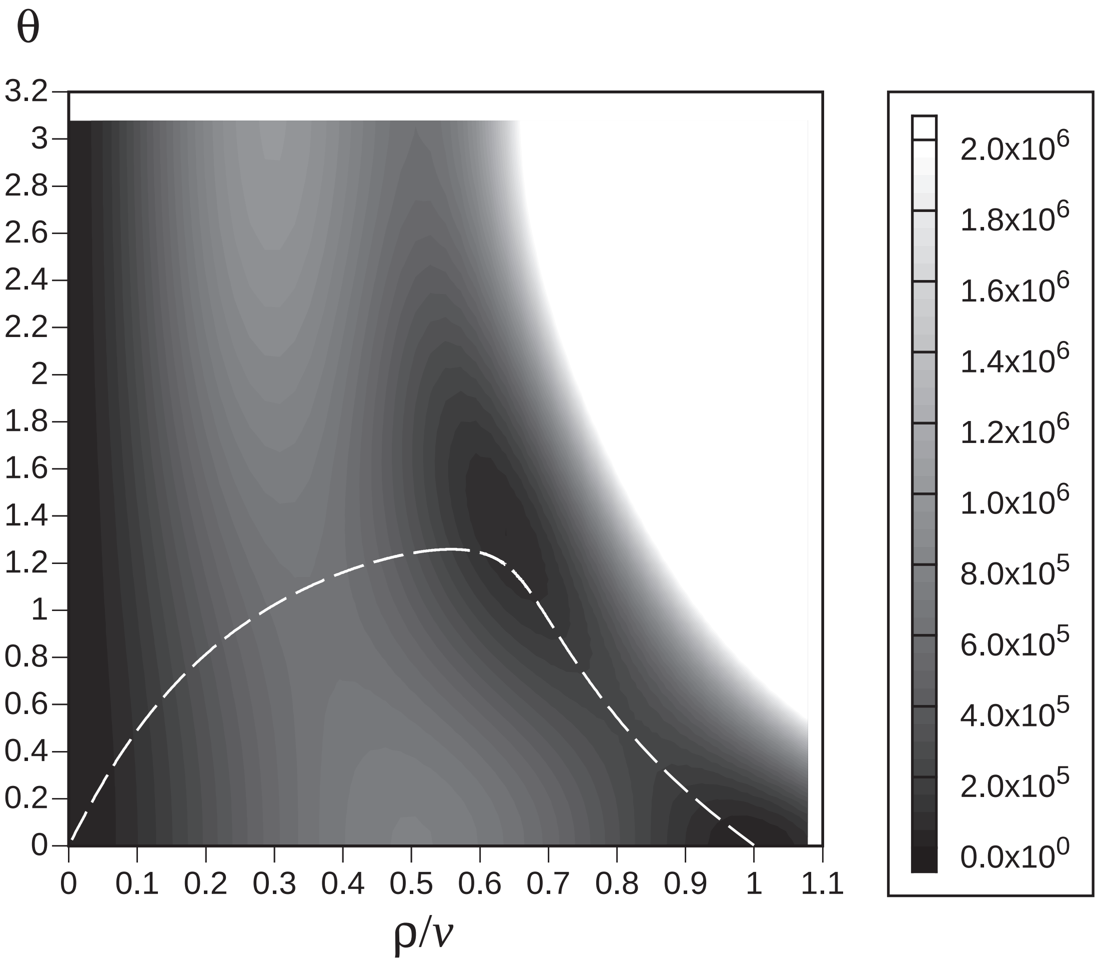
$CP$ violating $\theta$ at EWPT

dynamically determined $(\rho_i, \theta)$ [FKOT, PTP98('97)]

$\Uparrow$

EOM for $\rho_1 = \rho_2$ and $\theta = \theta_1 - \theta_2$ with $V_{\text{eff}}(\rho_i, \theta; T_C)$

e.g. $V_{\text{eff}}(\rho_1 = \rho_2 = \rho, \theta)$ vs $(\rho, \theta)$




a scenario to have large $\theta$ near the bubble wall

$=$ spontaneous $CP$ violation in the transient region

$+$ small explicit $CP$ violation

to resolve degeneracy between $CP$ conjugate bubbles net BAU

$$\frac{n_B}{s} = \frac{\sum_j \left(\frac{n_B}{s}\right)_j N_j}{\sum_j N_j}$$

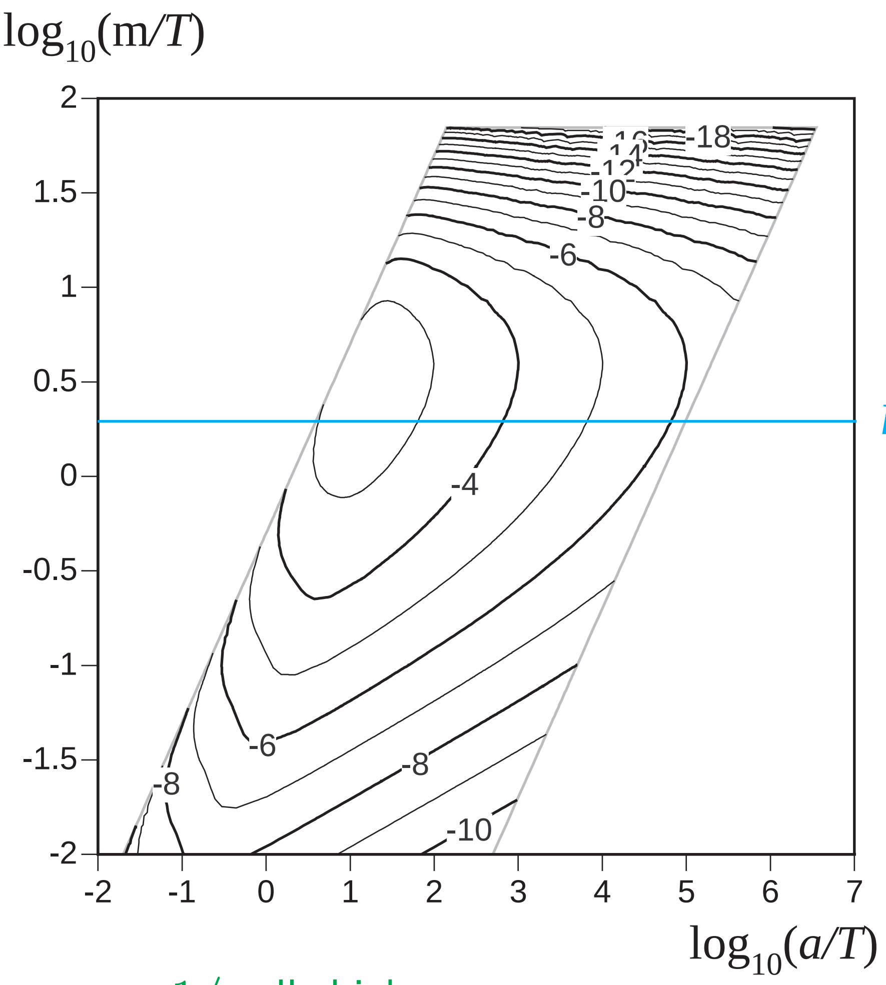
with

$$N_j = \exp(-4\pi R_C^2 \mathcal{E}_j / T_C)$$

$\mathcal{E}_j$ = energy density of the type-$j$ bubble

an example:

$$m_3^2 \longrightarrow m_3^2 e^{-\delta} \text{ with } \delta = 10^{-3}$$




chiral charge flux

$$\log_{10} \frac{F_Q}{uT^3(Q_L - Q_R)}$$

$m_t$

$T = 100\text{GeV}$

$u = 0.58$

$a = 1/$wall thickness

# II. Transitional CP Violation

Suppose that at $T \simeq T_C$,

$$
\begin{aligned}
& V_{\rm eff}(\rho_i, \theta = \theta_1 - \theta_2) \\
= \;& \frac{1}{2}m_1^2\rho_1^2 + \frac{1}{2}m_2^2\rho_2^2 - m_3^2\rho_1\rho_2\cos\theta + \frac{\lambda_1}{8}\rho_1^4 + \frac{\lambda_2}{8}\rho_2^4 \\
+ \;& \frac{\lambda_3+\lambda_4}{4}\rho_1^2\rho_2^2 + \frac{\lambda_5}{4}\rho_1^2\rho_2^2\cos 2\theta - \frac{1}{2}(\lambda_6\rho_1^2 + \lambda_7\rho_2^2)\rho_1\rho_2\cos\theta \\
- \;& [A\rho_1^3 + \rho_1^2\rho_2(B_0 + B_1\cos\theta + B_2\cos 2\theta) \\
& \qquad +\rho_1\rho_2^2(C_0 + C_1\cos\theta + C_2\cos 2\theta) + D\rho_2^3] \\
= \;& \left[\frac{\lambda_5}{2}\rho_1^2\rho_2^2 - 2(B_2\rho_1^2\rho_2 + C_2\rho_1\rho_2^2)\right] \\
& \qquad \times \left[\cos\theta - \frac{2m_3^2 + \lambda_6\rho_1^2 + \lambda_7\rho_2^2 + 2(B_1\rho_1 + C_1\rho_2)}{2\lambda_5\rho_1\rho_2 - 8(B_2\rho_1 + C_2\rho_2)}\right]^2 \\
& +\theta\text{-independent terms}
\end{aligned}
$$

where all the parameters are real

conditions for the transitional CP violation for a given $(\rho_1, \rho_2)$

$$
F(\rho_1,\rho_2) \equiv \frac{\lambda_5}{2}\rho_1^2\rho_2^2 - 2(B_2\rho_1^2\rho_2 + C_2\rho_1\rho_2^2) > 0,
$$

$$
-1 < G(\rho_1,\rho_2) \equiv \frac{2m_3^2 + \lambda_6\rho_1^2 + \lambda_7\rho_2^2 + 2(B_1\rho_1 + C_1\rho_2)}{2\lambda_5\rho_1\rho_2 - 8(B_2\rho_1 + C_2\rho_2)} < 1
$$

At $T \simeq T_C$, around the EW bubble wall

$$
(\rho_1, \rho_2) \;:\; (0,0) \longrightarrow (v_C\cos\beta_C, v_C\sin\beta_C)
$$

There may be a chance to satisfy the conditions in the transient region.

# III. Effective parameters of the MSSM

MSSM at the tree level:

$$\begin{aligned}\lambda_1 &= \lambda_2 = \frac{1}{4}(g_2^2 + g_1^2), \quad \lambda_3 = \frac{1}{4}(g_2^2 - g_1^2), \quad \lambda_4 = -\frac{1}{2}g_2^2, \\ \lambda_5 &= \lambda_6 = \lambda_7 = 0,\end{aligned}$$

the relevant parameters in $F$ and $G$ are induced by radiative and finite-temperature corrections

effective potential at the one-loop level

$$V_{\rm eff} = V_0 + V_1(\rho_i, \theta) + \bar{V}_1(\rho_i, \theta; T),$$

where

$$\begin{aligned}V_1(\rho_i, \theta) &= \sum_j n_j \frac{m_j^4}{64\pi^2}\left[\log\left(\frac{m_j^2}{M_{\rm ren}^2}\right) - \frac{3}{2}\right], \\ \bar{V}_1(\rho_i, \theta; T) &= \frac{T^4}{2\pi^2}\sum_j n_j \int_0^\infty dx\, x^2 \\ &\quad \times \log\left[1 - \mathrm{sgn}(n_j)\exp\left(-\sqrt{x^2 + m_j^2/T^2}\right)\right].\end{aligned}$$

N.B. $m_j^2 = m_j^2(\rho_i, \theta)$

with

$$\begin{aligned}\varphi_d &= \frac{1}{\sqrt{2}}\begin{pmatrix}\rho_1 \\ 0\end{pmatrix} = \frac{1}{\sqrt{2}}\begin{pmatrix}v_1 \\ 0\end{pmatrix}, \\ \varphi_u &= \frac{1}{\sqrt{2}}\begin{pmatrix}0 \\ \rho_2 e^{i\theta}\end{pmatrix} = \frac{1}{\sqrt{2}}\begin{pmatrix}0 \\ v_2 + iv_3\end{pmatrix}.\end{aligned}$$

We consider the contributions from the charginos and neutralinos ($\chi$), stops ($\tilde{t}$) and charged Higgs bosons ($\phi^\pm$).

relevant effective parameters:

$$\left(m_3^2\right)_{\rm eff} = -\left.\frac{\partial^2 V_{\rm eff}}{\partial v_1 \partial v_2}\right|_0 = m_3^2 + \Delta_\chi m_3^2 + \Delta_{\tilde{t}} m_3^2 + \Delta_{\phi^\pm} m_3^2,$$

$$\lambda_5 = \frac{1}{2}\left(\left.\frac{\partial^4 V_{\rm eff}}{\partial v_1^2 \partial v_2^2}\right|_0 - \left.\frac{\partial^4 V_{\rm eff}}{\partial v_1^2 \partial v_3^2}\right|_0\right),$$

$$\lambda_6 = -\frac{1}{3}\left.\frac{\partial^4 V_{\rm eff}}{\partial v_1^3 \partial v_2}\right|_0 = \Delta_\chi \lambda_6 + \Delta_{\tilde{t}} \lambda_6 + \Delta_{\phi^\pm} \lambda_6,$$

$$\lambda_7 = -\frac{1}{3}\left.\frac{\partial^4 V_{\rm eff}}{\partial v_1 \partial v_2^3}\right|_0 = \Delta_\chi \lambda_7 + \Delta_{\tilde{t}} \lambda_7 + \Delta_{\phi^\pm} \lambda_7$$

$\rho^3$-terms in $V_{\rm eff}$ $\Longleftarrow$ zero modes of the bosons at $T \neq 0$

$W^\pm$, $Z$, Higgs, squarks, sleptons

$\theta$-dependent $\rho^3$-terms ($B_i$ and $C_i$)

$\Longleftarrow m_{\tilde{t}} \simeq 0$

$$M_{\tilde{t}}^2 = \begin{pmatrix} m_{\tilde{q}}^2 + m_t^2 - \frac{3g_2^2 - g_1^2}{8}(\rho_1^2 - \rho_2^2) & \frac{y_t}{\sqrt{2}}(\mu\rho_1 + A_t\rho_2 e^{-i\theta}) \\ \frac{y_t}{\sqrt{2}}(\mu\rho_1 + A_t\rho_2 e^{i\theta}) & m_{\tilde{t}}^2 + m_t^2 + \frac{g_1^2}{6}(\rho_1^2 - \rho_2^2) \end{pmatrix}$$

and

$$\bar{V}_{\tilde{t}}(\rho_i, \theta; T) = 3\frac{T^4}{2\pi^2}\left[2I_B(a_+^2) + 2I_B(a_-^2)\right],$$

with

$$I_B(a_-^2) = \int_0^\infty dx\, x^2 \log\left(1 - e^{-\sqrt{x^2 + a_-^2}}\right)$$

$$= -\frac{\pi^4}{45} + \frac{\pi^2}{12}a_-^2 - \frac{\pi}{6}a_-^3 + \lambda_- a_-^4 + \ldots$$

$a_-^2 \equiv m_-^2/T^2$ ; $m_-^2(\rho) =$ smaller eigenvalue of $M_{\tilde{t}}^2$

- charginos and neutralinos

$$M_{\chi^\pm} = \begin{pmatrix} M_2 & -\frac{ig_2}{\sqrt{2}}\rho_2 e^{-i\theta} \\ -\frac{ig_2}{\sqrt{2}}\rho_1 & -\mu \end{pmatrix},$$

$$M_{\chi^0} = \begin{pmatrix} M_2 & 0 & -\frac{i}{2}g_2\rho_1 & \frac{i}{2}g_2\rho_2 e^{-i\theta} \\ 0 & M_1 & \frac{i}{2}g_1\rho_1 & -\frac{i}{2}g_1\rho_2 e^{-i\theta} \\ -\frac{i}{2}g_2\rho_1 & \frac{i}{2}g_1\rho_1 & 0 & \mu \\ \frac{i}{2}g_2\rho_2 e^{-i\theta} & -\frac{i}{2}g_1\rho_2 e^{-i\theta} & \mu & 0 \end{pmatrix}$$

chargino and neutralino contributions $(M_2 = M_1)$

$$\begin{aligned}
\Delta_\chi m_3^2 &= -2g_2^2\left(1+\frac{1}{\cos^2\theta_W}\right)\mu M_2\, L(M_2,\mu) \\
&\quad +\frac{g_2^2}{\pi^2}\left(1+\frac{1}{\cos^2\theta_W}\right)\mu M_2 f_2^{(+)}\left(\frac{M_2}{T},\frac{\mu}{T}\right), \\
\Delta_\chi \lambda_5 &= \frac{g_2^4}{8\pi^2}\left(1+\frac{2}{\cos^4\theta_W}\right) K\left(\frac{M_2^2}{\mu^2}\right) \\
&\quad -\frac{g_2^4}{\pi^2 T^4}\left(1+\frac{2}{\cos^4\theta_W}\right)\mu^2 M_2^2 f_4^{(+)}\left(\frac{M_2}{T},\frac{\mu}{T}\right), \\
\Delta_\chi \lambda_6 &= -\frac{g_2^4}{8\pi^2}\left(1+\frac{2}{\cos^4\theta_W}\right)\frac{\mu}{M_2}\left[-H\left(\frac{M_2^2}{\mu^2}\right)+K\left(\frac{M_2^2}{\mu^2}\right)\right] \\
&\quad +\frac{g_2^4}{\pi^2}\left(1+\frac{2}{\cos^4\theta_W}\right)\left[\frac{\mu M_2}{T^2} f_3^{(+)}\left(\frac{M_2}{T},\frac{\mu}{T}\right)\right. \\
&\quad \left. +\frac{\mu^3 M_2}{T^4} f_4^{(+)}\left(\frac{M_2}{T},\frac{\mu}{T}\right)\right] = \Delta_\chi \lambda_7
\end{aligned}$$

where

$$
\begin{aligned}
L(m_1,m_2) &= \frac{1}{16\pi^2}\left[1-\frac{m_1^2}{m_1^2-m_2^2}\log\frac{m_1^2}{M_{\rm ren}^2}+\frac{m_2^2}{m_1^2-m_2^2}\log\frac{m_2^2}{M_{\rm ren}^2}\right]\\
&> 0,\\
H(\alpha) &= \frac{\alpha}{\alpha-1}\left(\frac{1}{\alpha-1}\log\alpha-1\right)\ <0,\\
K(\alpha) &= \frac{\alpha}{(\alpha-1)^2}\left(\frac{\alpha+1}{\alpha-1}\log\alpha-2\right)\ >0,
\end{aligned}
$$

and

$$
\begin{aligned}
f_2^{(\mp)}(a,b) &= -\frac{1}{a^2-b^2}\int_0^\infty dx\Big(\frac{x^2}{\sqrt{x^2+a^2}}\frac{1}{e^{\sqrt{x^2+a^2}}\mp 1}\\
&\qquad -\frac{x^2}{\sqrt{x^2+b^2}}\frac{1}{e^{\sqrt{x^2+b^2}}\mp 1}\Big)>0,\\
f_3^{(\mp)}(a,b) &= \frac{1}{2(a^2-b^2)}\int_0^\infty \frac{dx}{\sqrt{x^2+a^2}}\frac{1}{e^{\sqrt{x^2+a^2}}\mp 1}\\
&\qquad -\frac{1}{a^2-b^2}f_2^{(\mp)}(a,b)<0,\\
f_4^{(\mp)}(a,b) &= \frac{1}{2(a^2-b^2)^2}\int_0^\infty dx\Big(\frac{1}{\sqrt{x^2+a^2}}\frac{1}{e^{\sqrt{x^2+a^2}}\mp 1}\\
&\qquad +\frac{1}{\sqrt{x^2+b^2}}\frac{1}{e^{\sqrt{x^2+b^2}}\mp 1}\Big)\\
&\qquad -\frac{2}{(a^2-b^2)^2}f_2^{(\mp)}(a,b)>0,
\end{aligned}
$$

- stops with $m_{\tilde t} \simeq 0$

$$
\begin{aligned}
\Delta_{\tilde t} m_3^2 &= N_c y_t^2 \mu A_t \, L(m_{\tilde q}, 0) + \frac{3T^2}{\pi^2}\frac{y_t^2 \mu A_t}{m_{\tilde q}^2}\left[ I_B'(a_{\tilde q}^2) - \frac{\pi^2}{12}\right] , \\
\Delta_{\tilde t} \lambda_5 &= -\frac{N_c y_t^4}{16\pi^2}\frac{\mu^2 A_t^2}{m_{\tilde q}^2 M_{IR}^2} K\left(\frac{m_{\tilde q}^2}{M_{IR}^2}\right) \\
&\quad + \frac{N_c y_t^4 \mu^2 A_t^2}{\pi^2 (m_{\tilde q}^2)^2}\left[ \frac{2T^2}{m_{\tilde q}^2}\left( -I_B'(a_{\tilde q}^2) + \frac{\pi^2}{12}\right) + I_B''(a_{\tilde q}^2) + 2\lambda_- \right] , \\
\Delta_{\tilde t} \lambda_6 &= \frac{N_c y_t^2}{16\pi^2}\frac{\mu A_t}{m_{\tilde q}^2}\left[ \frac{1}{4}\left(\frac{g_1^2}{3} - g_2^2\right) - \frac{g_1^2 m_{\tilde q}^2}{3M_{IR}^2} H\left(\frac{M_{IR}^2}{m_{\tilde q}^2}\right)\right. \\
&\quad \left. + \frac{y_t^2 \mu^2}{M_{IR}^2} K\left(\frac{m_{\tilde q}^2}{M_{IR}^2}\right)\right] \\
&\quad + \frac{N_c y_t^2 \mu A_t}{\pi^2 m_{\tilde q}^2}\left\{ \frac{2T^2}{m_{\tilde q}^2}\left(\frac{y_t^2\mu^2}{m_{\tilde q}^2} + \left(-\frac{5}{3} g_1^2 + g_2^2\right)\right)\left[ I_B'(a_{\tilde q}^2) - \frac{\pi^2}{12}\right]\right. \\
&\quad \left. - \left(\frac{y_t^2\mu^2}{m_{\tilde q}^2} + \frac{3g_2^2 - g_1^2}{12}\right) I_B''(a_{\tilde q}^2) + 2\left(\frac{g_1^2}{3} - \frac{y_t^2\mu^2}{m_{\tilde q}^2}\right)\lambda_- \right\} , \\
\Delta_{\tilde t} \lambda_7 &= \frac{N_c y_t^2}{16\pi^2}\frac{\mu A_t}{m_{\tilde q}^2}\left[ -\left( y_t^2 + \frac{1}{4}\left(\frac{g_1^2}{3} - g_2^2\right)\right)\right. \\
&\quad \left. - \left( y_t^2 - \frac{g_1^2}{3}\right)\frac{m_{\tilde q}^2}{M_{IR}^2} H\left(\frac{M_{IR}^2}{m_{\tilde q}^2}\right) + \frac{y_t^2 A_t^2}{M_{IR}^2} K\left(\frac{m_{\tilde q}^2}{M_{IR}^2}\right)\right] \\
&\quad + \frac{N_c y_t^2 \mu A_t}{\pi^2 m_{\tilde q}^2}\left\{ \frac{2T^2}{m_{\tilde q}^2}\left(\frac{y_t^2\mu^2}{m_{\tilde q}^2} - \left(-\frac{5}{3} g_1^2 + g_2^2\right)\right)\left[ I_B'(a_{\tilde q}^2) - \frac{\pi^2}{12}\right]\right. \\
&\quad - \left( y_t^2 + \frac{y_t^2\mu^2}{m_{\tilde q}^2} - \frac{3g_2^2 - g_1^2}{12}\right) I_B''(a_{\tilde q}^2)
\end{aligned}
$$

$$+2\left(y_t^2-\frac{g_1^2}{3}-\frac{y_t^2\mu^2}{m_{\tilde{q}}^2}\right)\lambda_-\}$$

and for $A_t/m_{\tilde{q}}, \mu/m_{\tilde{q}}, g_1/y_t \ll 1$,

$$C_1 \simeq \frac{T}{4\sqrt{2}\pi}|y_t|^3\frac{3\mu A_t}{m_{\tilde{q}}^2}\left[-1+\frac{1}{2}\left(\frac{A_t}{m_{\tilde{q}}}\right)^2+\frac{1}{6}\left(\frac{g_1}{y_t}\right)^2\right],$$

$$B_2 \simeq \frac{T}{4\sqrt{2}\pi}|y_t|^3\frac{3}{2}\left(\frac{\mu A_t}{m_{\tilde{q}}{}^2}\right)^2.$$

- charged Higgs bosons

$$\Delta_{\phi\pm}m_3^2 = \frac{1}{2}g_2^2m_3^2\,L(\mu_1,\mu_2)+\frac{1}{4\pi^2}g_2^2m_3^2f_2^{(-)}\left(\frac{\mu_1}{T},\frac{\mu_2}{T}\right),$$

$$\Delta_{\phi\pm}\lambda_5 = -\frac{g_2^4}{64\pi^2}\frac{m_3^4}{\mu_1^2\mu_2^2}K\left(\frac{\mu_1^2}{\mu_2^2}\right)-\frac{1}{8\pi^2T^4}g_2^4m_3^4f_4^{(-)}\left(\frac{\mu_1}{T},\frac{\mu_2}{T}\right),$$

$$\Delta_{\phi\pm}\lambda_6 = \frac{g_2^4}{64\pi^2}\frac{m_3^2}{\mu_1^2}\{-H\left(\frac{\mu_1^2}{\mu_2^2}\right)+[1-\frac{m_1^2}{2\mu^2\cos^2\theta_W}$$
$$-\left(1-\frac{1}{2\cos^2\theta_W}\right)\frac{m_2^2}{\mu_2^2}]K\left(\frac{\mu_1^2}{\mu_2^2}\right)\}$$
$$+\frac{g_2^4m_3^2}{8\pi^2T^2}[f_3^{(-)}\left(\frac{\mu_1}{T},\frac{\mu_2}{T}\right)+(\frac{\mu_2^2}{T^2}-\frac{m_1^2}{2T^2\cos^2\theta_W}$$
$$-\left(1-\frac{1}{2\cos^2\theta_W}\right)\frac{m_2^2}{T^2})f_4^{(-)}\left(\frac{\mu_1}{T},\frac{\mu_2}{T}\right)],$$

$$\Delta_{\phi\pm}\lambda_7 = \frac{g_2^4}{64\pi^2}\frac{m_3^2}{\mu_1^2}\{-H\left(\frac{\mu_1^2}{\mu_2^2}\right)+[1-\left(1-\frac{1}{2\cos^2\theta_W}\right)\frac{m_1^2}{\mu_2^2}$$
$$-\frac{m_2^2}{2\mu_2^2\cos^2\theta_W}]K\left(\frac{\mu_1^2}{\mu_2^2}\right)\}$$

$$+\frac{g_2^4 m_3^2}{8\pi^2 T^2}\Big[\, f_3^{(-)}\Big(\frac{\mu_1}{T},\frac{\mu_2}{T}\Big) \;+ \Big(\frac{\mu_2^2}{T^2}-\Big(1-\frac{1}{2\cos^2\theta_W}\Big)\frac{m_1^2}{T^2}$$

$$-\frac{m_2^2}{2T^2\cos^2\theta_W}\Big) f_4^{(-)}\Big(\frac{\mu_1}{T},\frac{\mu_2}{T}\Big)\,\Big]\,,$$

where

$$\mu_{1,2}^2 = \frac{\bar{m}_1^2+\bar{m}_2^2 \pm \sqrt{(\bar{m}_1^2-\bar{m}_2^2)^2+4m_3^4}}{2}$$

and

$$\begin{aligned}
\bar{m}_1^2 &= m_1^2+\frac{1}{16\pi^2}(3g_2^2+g_1^2)T^2,\\
\bar{m}_2^2 &= m_2^2+\frac{1}{16\pi^2}(3g_2^2+g_1^2+4y_t^2)T^2.
\end{aligned}$$

# III. Numerical Results

input parameters

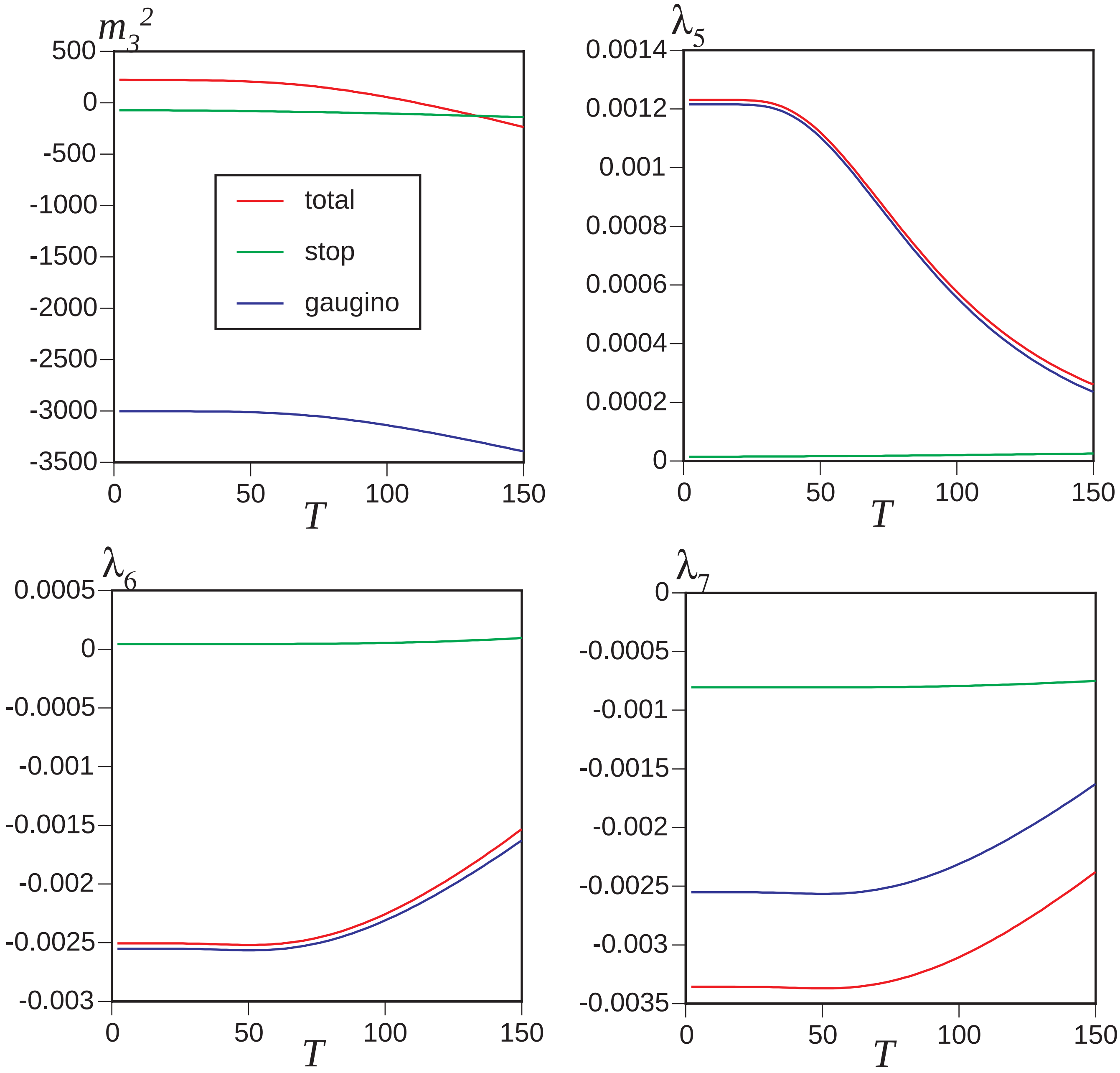
$v_0 = 246\text{GeV},\ m_t = 177\text{GeV},\ M_{\text{ren}} = 100\text{GeV},\ \tan\beta_0 = 5$

$$m_1^2 = m_3^2 \tan\beta_0 - \frac{1}{2} m_Z^2 \cos(2\beta_0),$$

$$m_2^2 = m_3^2 \cot\beta_0 + \frac{1}{2} m_Z^2 \cos(2\beta_0)$$

**(A)** $\mu A_t > 0$

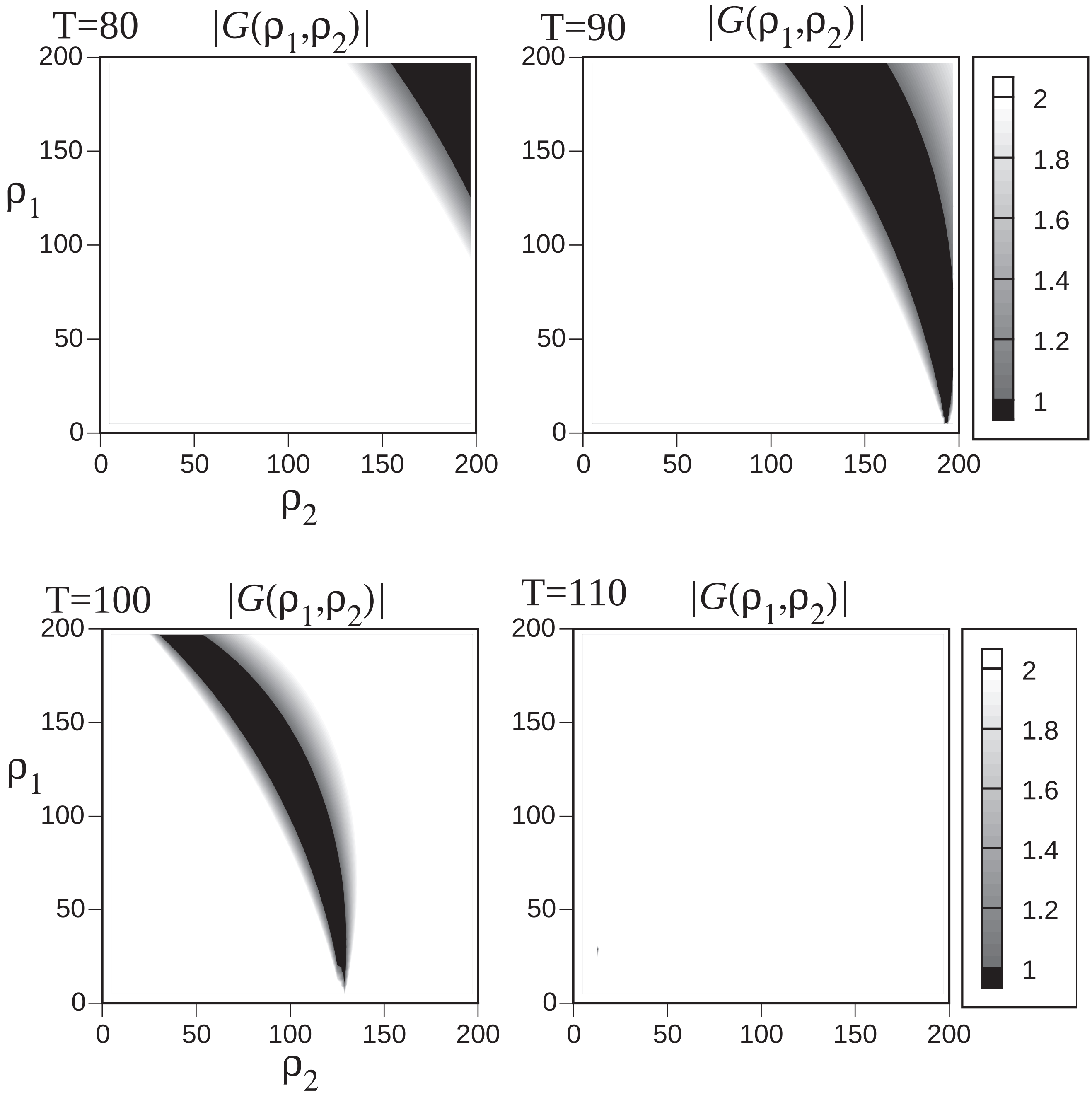
| $m_3^2$ | $A_t$ | $M_2$ | $\mu$ | $m_{\tilde{q}}$ |
|---|---|---|---|---|
| 3300 | 10 | $-400$ | 200 | 400 |



$$B_2/T = 7.368276 \times 10^{-6}, \qquad C_1/T = -2.313638 \times 10^{-3}$$

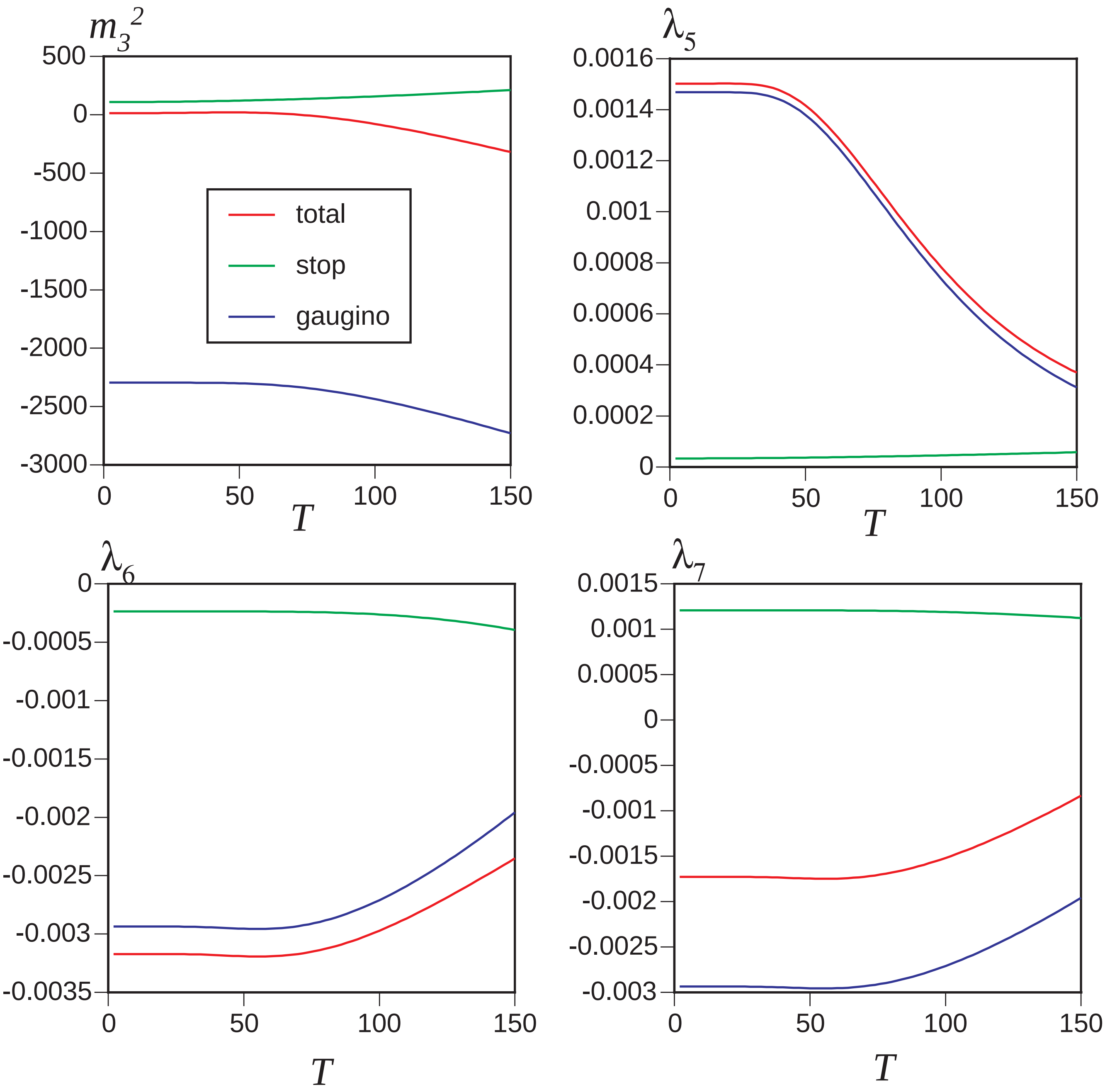
$\Longrightarrow$ $F(\rho_1, \rho_2) > 0$ for $\rho_2 > 5.104$ at $T = 100$

region in which $|G(\rho_1, \rho_2)| < 1$ is satisfied:



## (B) $\mu A_t < 0$

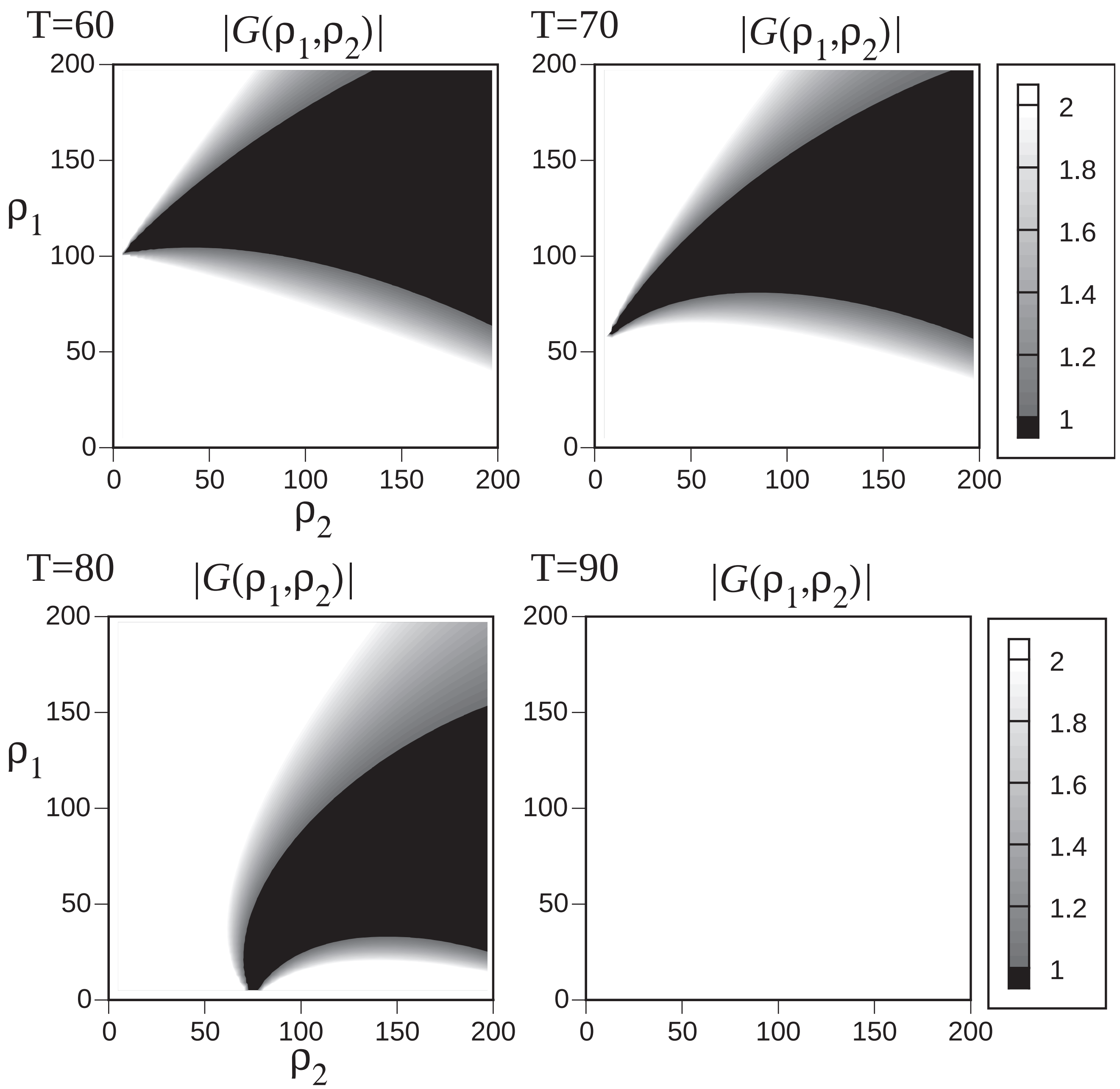
| $m_3^2$ | $A_t$ | $M_2$ | $\mu$ | $m_{\tilde{q}}$ |
|---|---|---|---|---|
| 2200 | 10 | 300 | $-300$ | 400 |



$$B_2/T = 1.657862 \times 10^{-5}, \qquad C_1/T = 3.470457 \times 10^{-3}$$

$\Longrightarrow F(\rho_1, \rho_2) > 0$ for $\rho_2 > 8.463$ at $T = 100$

region in which $|G(\rho_1, \rho_2)| < 1$ is satisfied:




$$\left.\begin{array}{r} |\lambda_6|_{(A)} \simeq |\lambda_6|_{(B)} \\ |\lambda_7|_{(A)} > |\lambda_7|_{(B)} \\ C_1|_{(A)} < 0, \quad C_1|_{(B)} > 0 \end{array}\right\} \Rightarrow$$

weaker $\rho$-dependence of $G(\rho_1, \rho_2)$ in case (B)

$$cf.\ G(\rho_1, \rho_2) = [2m_3^2 + \lambda_6 \rho_1^2 + \lambda_7 \rho_2^2 + 2C_1 \rho_2]/(\cdots)$$

# IV. Discussions

The conditions for the transitional $CP$ violation:

$$F(\rho_1, \rho_2) > 0 \quad \text{and} \quad |G(\rho_1, \rho_2)| < 1$$

are satisfied at $T \simeq T_C$ if

1. $|\mu| \simeq |M_2|$ [for $\Delta_\chi \lambda_5 > 0$]
2. $\mu M_2 < 0$ [to decrease $\left(m_3^2\right)_{\text{eff}}$ by the $\chi$-contributions]
3. $m_3^2$ is properly tuned at the tree-level
   [for $\left(m_3^2\right)_{\text{eff}}$ to become as small as $\lambda_{6,7}\rho^2$]

This mechanism of $CP$ violation

- is free from the constraints on $CP$ violation at $T = 0$,
- can generate sufficient BAU,
- is not bothered by the light scalar.

  At $T = 0$, spontaneous $CP$ viol. does not occur
  $\Longrightarrow$ no pseudo-Goldstone boson

  $m_A^{\text{tree}} = \sqrt{m_3^2(\tan\beta_0 + \cot\beta_0)} = 107$GeV for case (B)

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N.B.

- $CP$ violating minimum of $V_{\text{eff}}$ in the transient region need not be the global minimum.
- We still need to know the global structure of $V_{\text{eff}}$ to determine $T_C$ and the profile of the EW bubble wall.

  $\cdots$ numerical studies in progress