Thermal Effects Induced Freeze-in Dark Matter and the Gravitational Wave

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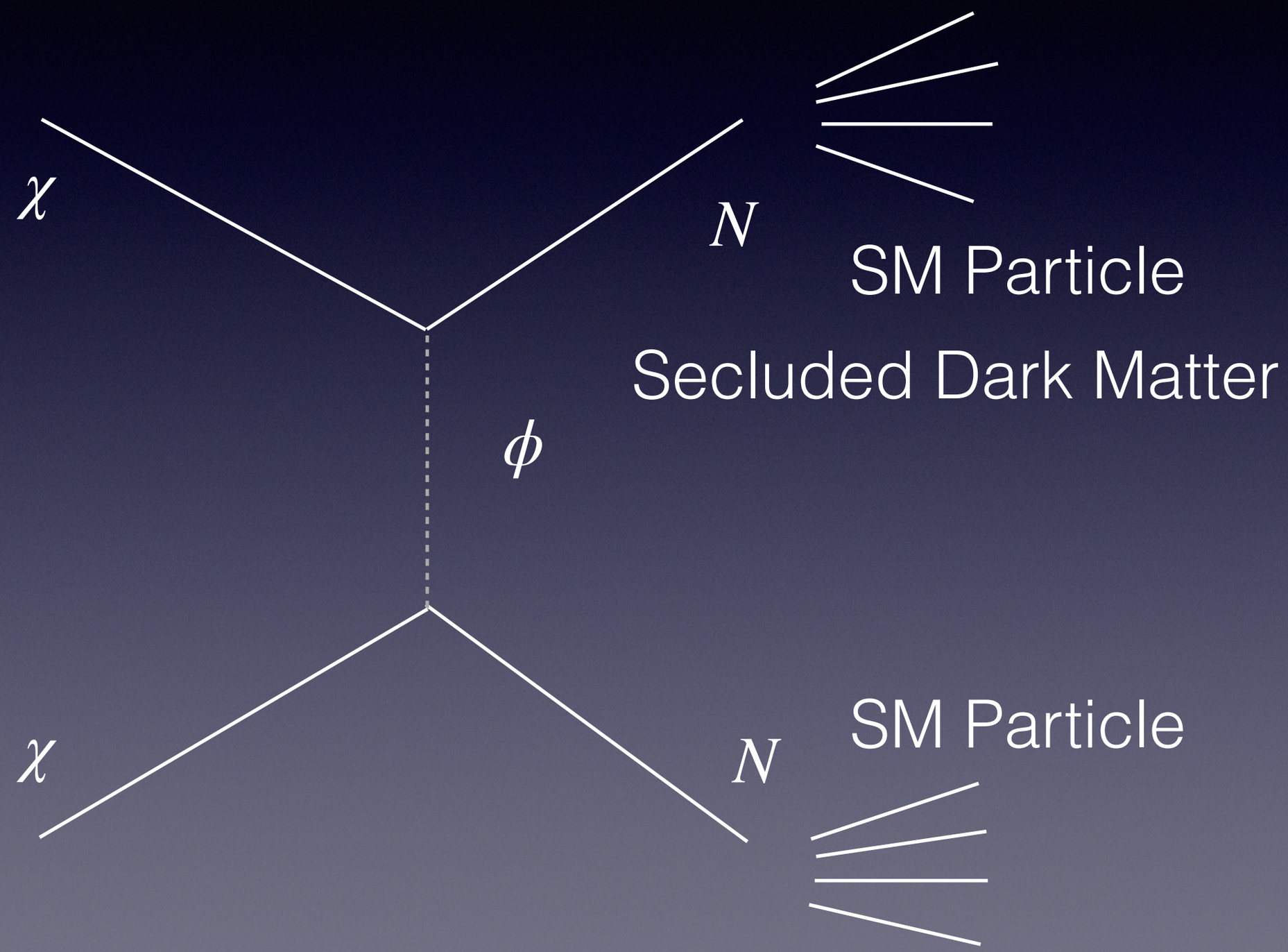
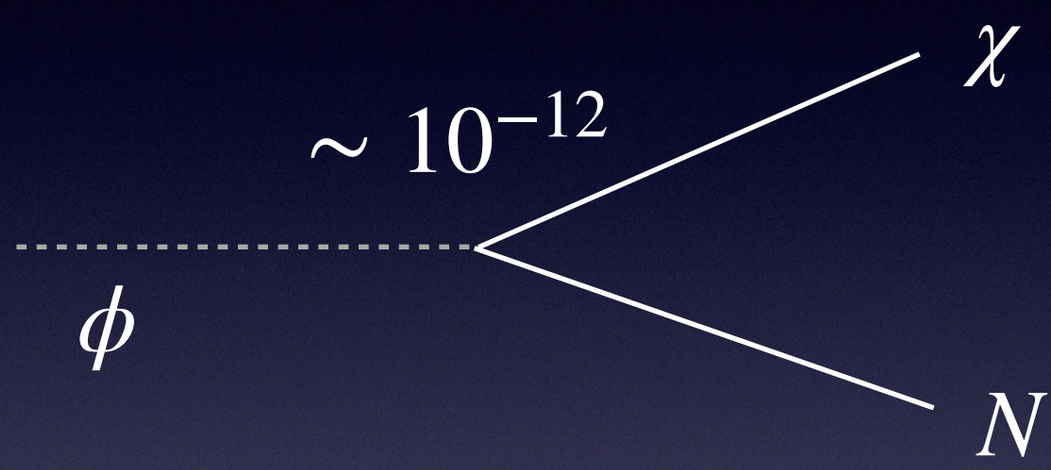
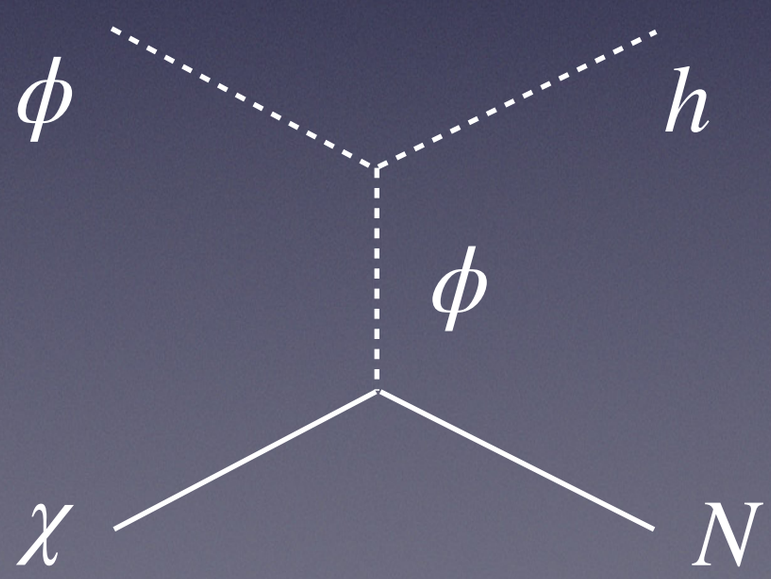
Sterile Neutrino and Dark Matter



Another Choice: Feebly-Interacting Massive Particle



$1 \leftrightarrow 2$

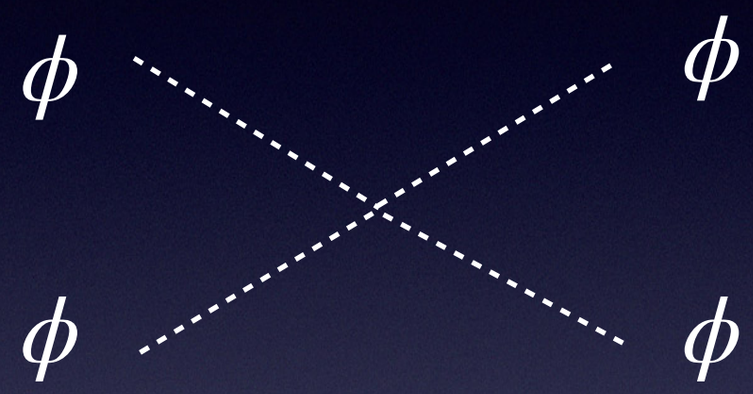


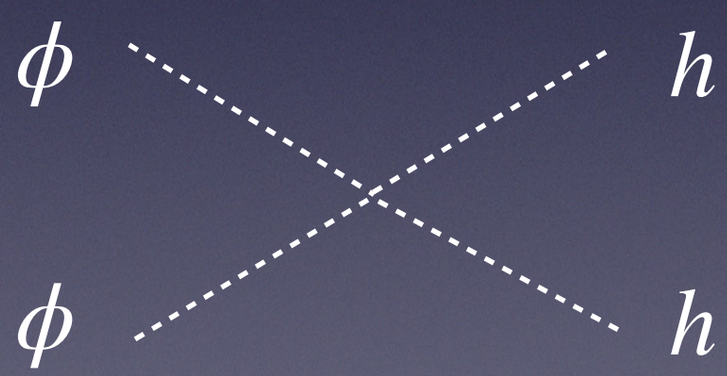
$2 \leftrightarrow 2$

Field	χ	ϕ	SM+N
Z_2	-	-	+

Vertices:

χ – Freeze In





ϕ – Freeze Out

h-vacuum:

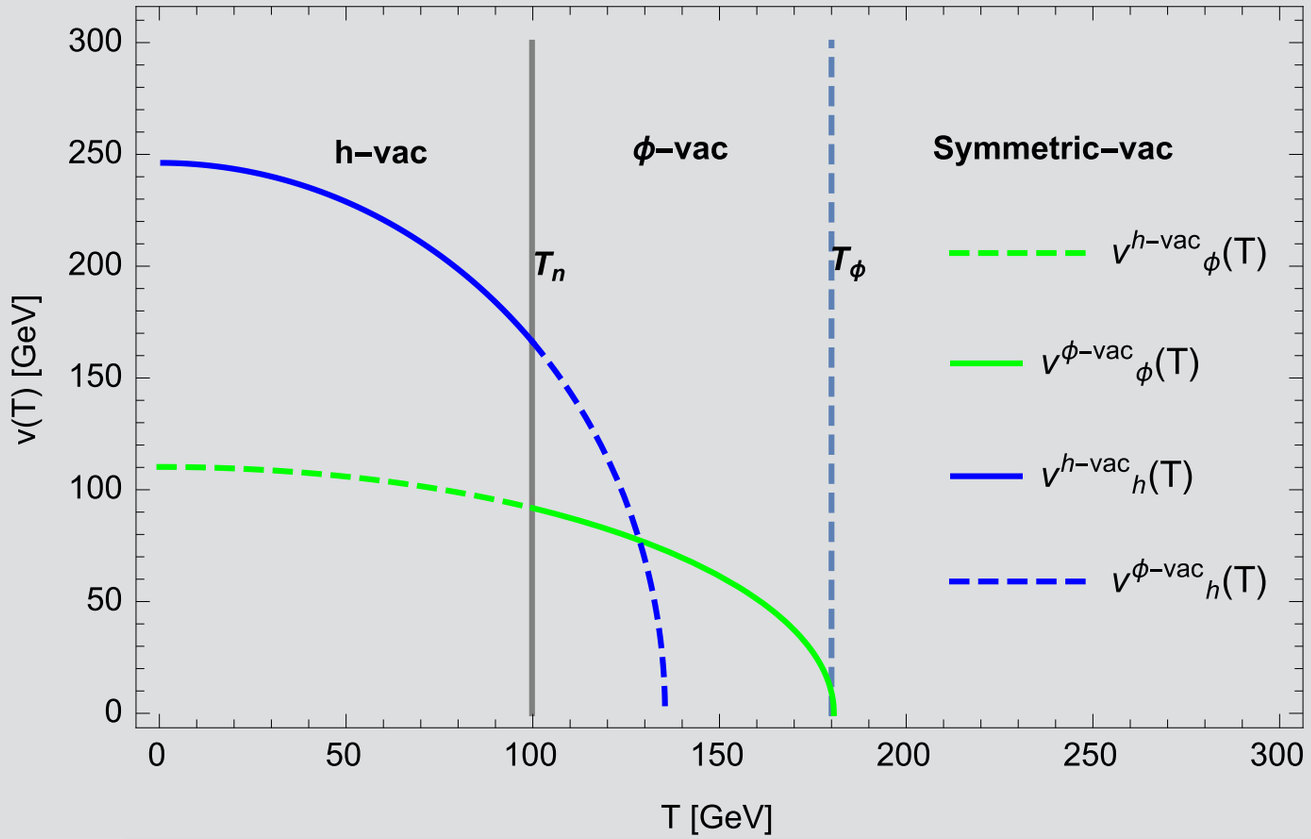
Another Choice: Feebly-Interacting Massive Particle

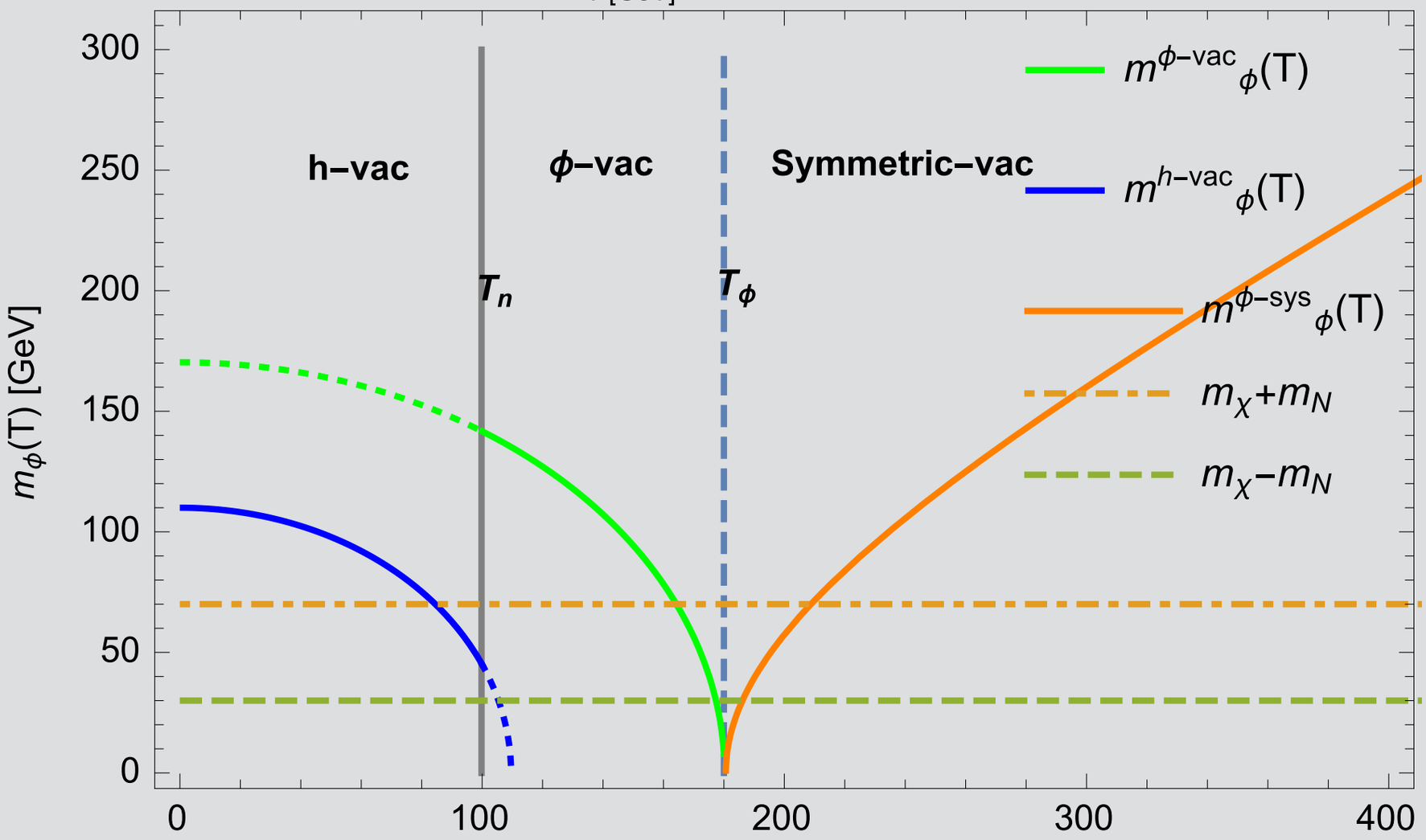
- In the situation of the WIMP, the freeze-out temperature is pretty low. $\sim \frac{m_{\mathrm{DM}}}{26}$
- In the FIMP situation, dark matter production happens at $T = 0.5 m_{\mathrm{DM}} \sim 2 m_{\mathrm{DM}}$
- Phase transition? Gravitational Wave?

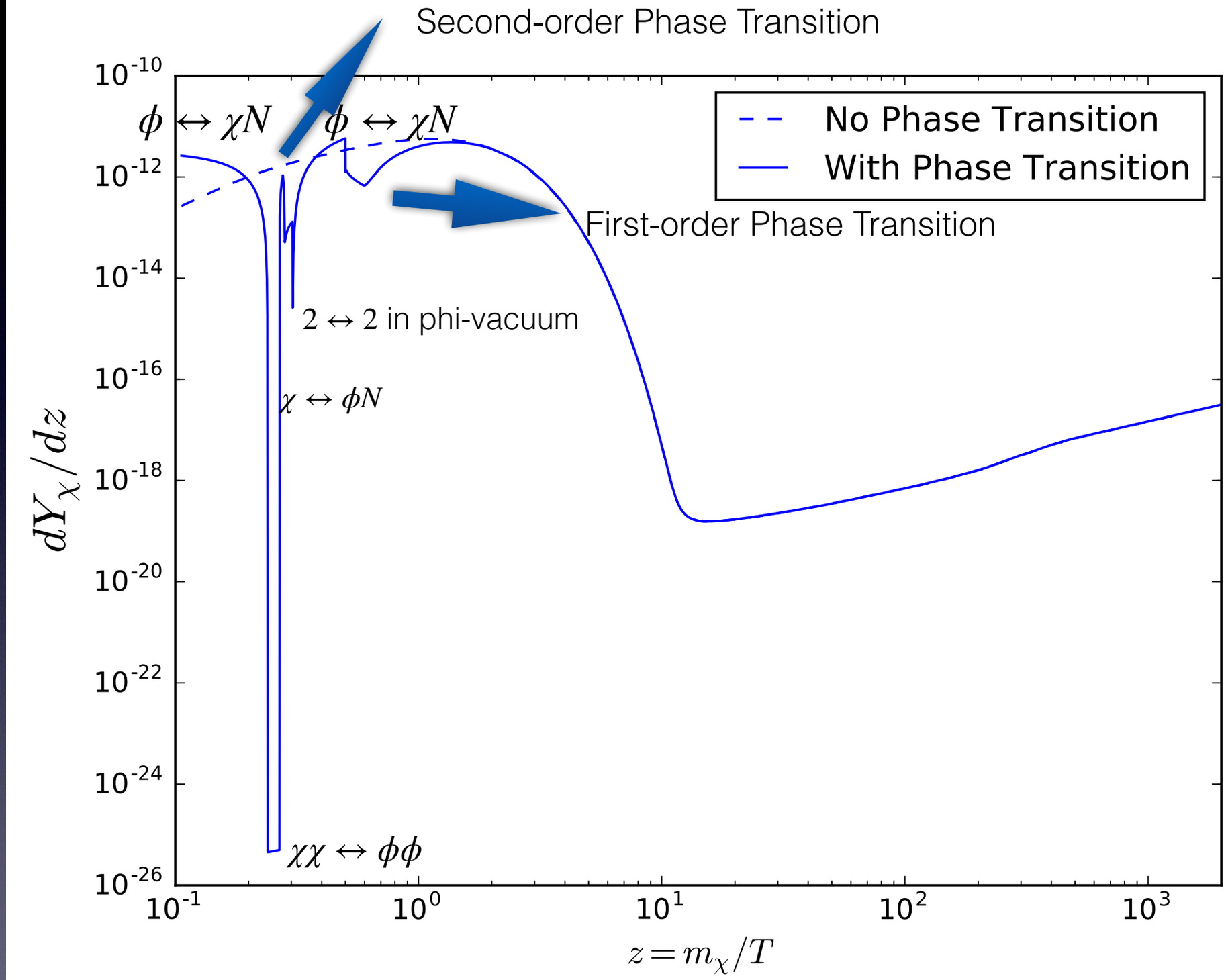
Effective Potential

$$c_h = \frac{1}{16}(g_1^2 + 3g_2^2) + \frac{1}{4}y_t^2 + \frac{\lambda}{2} + \frac{\lambda_{\phi h}}{12}\ ,\ c_\phi = \frac{1}{4}\lambda_\phi + \frac{1}{3}\lambda_{\phi h}$$

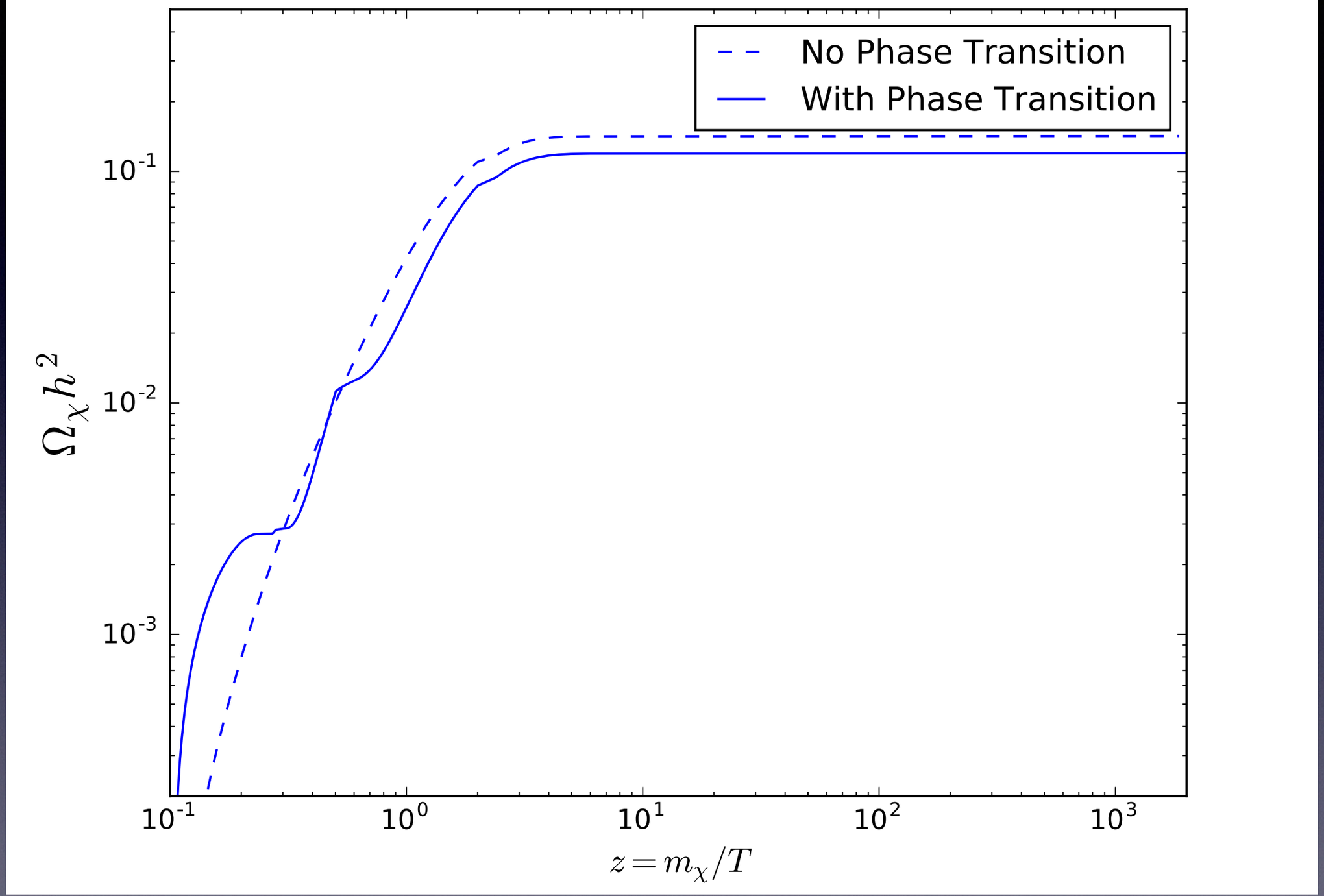
$$V_T(h,\phi) = -\frac{\mu^2 - c_h T^2}{2}h^2 + \frac{\lambda_h}{4}h^4 + \frac{\mu_\phi^2 + c_\phi T^2}{2}\phi^2 + \frac{\lambda_\phi}{4}\phi^4 + \frac{\lambda_{h\phi}}{2}h^2\phi^2$$


h–vac
ϕ–vac
Symmetric–vac
T_n
T_ϕ
$v^{h\text{–vac}}{}_\phi(T)$
$v^{\phi\text{–vac}}{}_\phi(T)$
$v^{h\text{–vac}}{}_h(T)$
$v^{\phi\text{–vac}}{}_h(T)$
v(T) [GeV]
T [GeV]
0
50
100
150
200
250
300


h–vac
ϕ–vac
Symmetric–vac
T_n
T_ϕ
$m^{\phi\text{–vac}}{}_\phi(T)$
$m^{h\text{–vac}}{}_\phi(T)$
$m^{\phi\text{–sys}}{}_\phi(T)$
$m_\chi+m_N$
$m_\chi-m_N$
m_ϕ(T) [GeV]
0
50
100
150
200
250
300
400



mS=110 GeV, mChi=50GeV, mRHN=20 GeV
yD=2.8e-12



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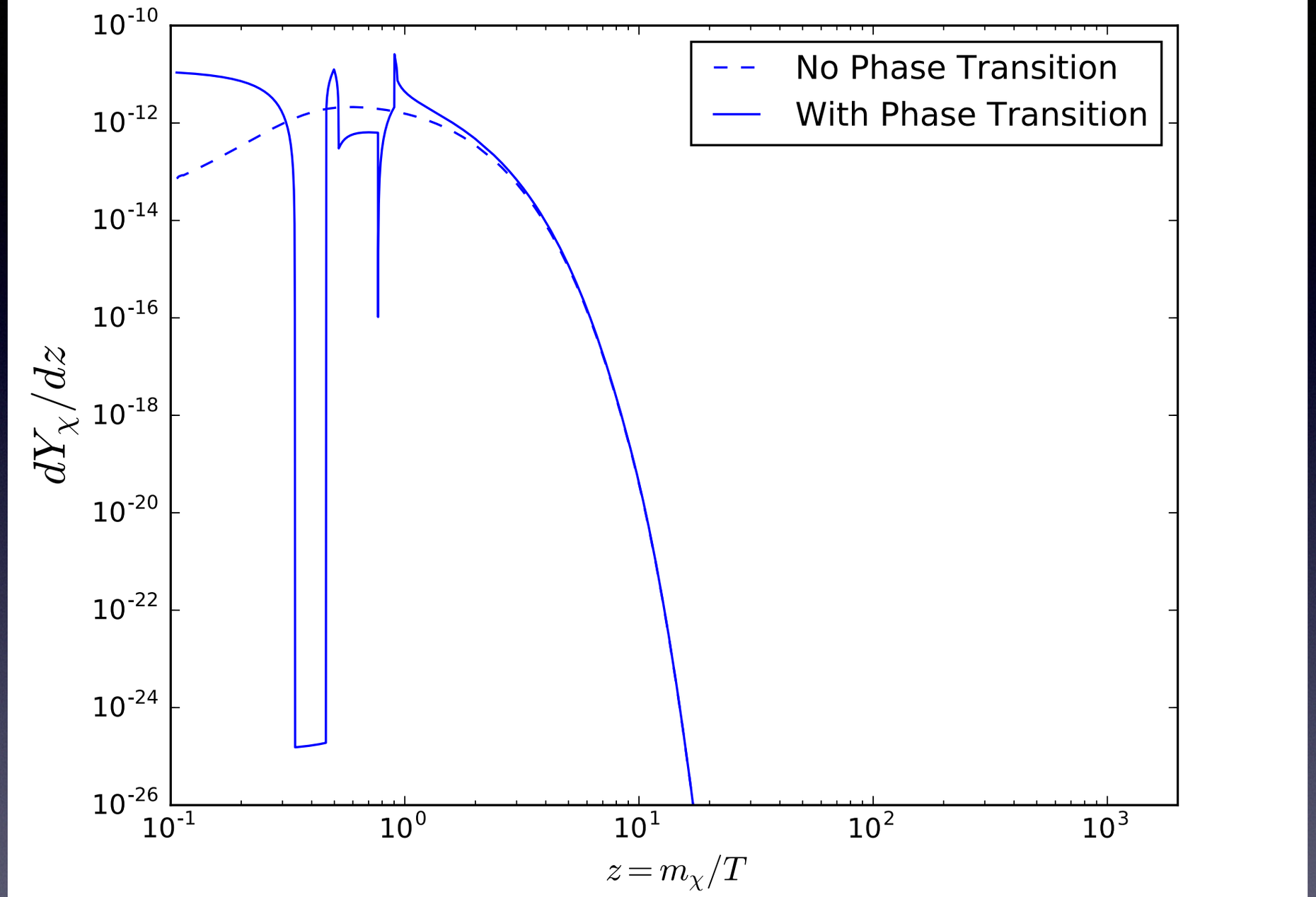
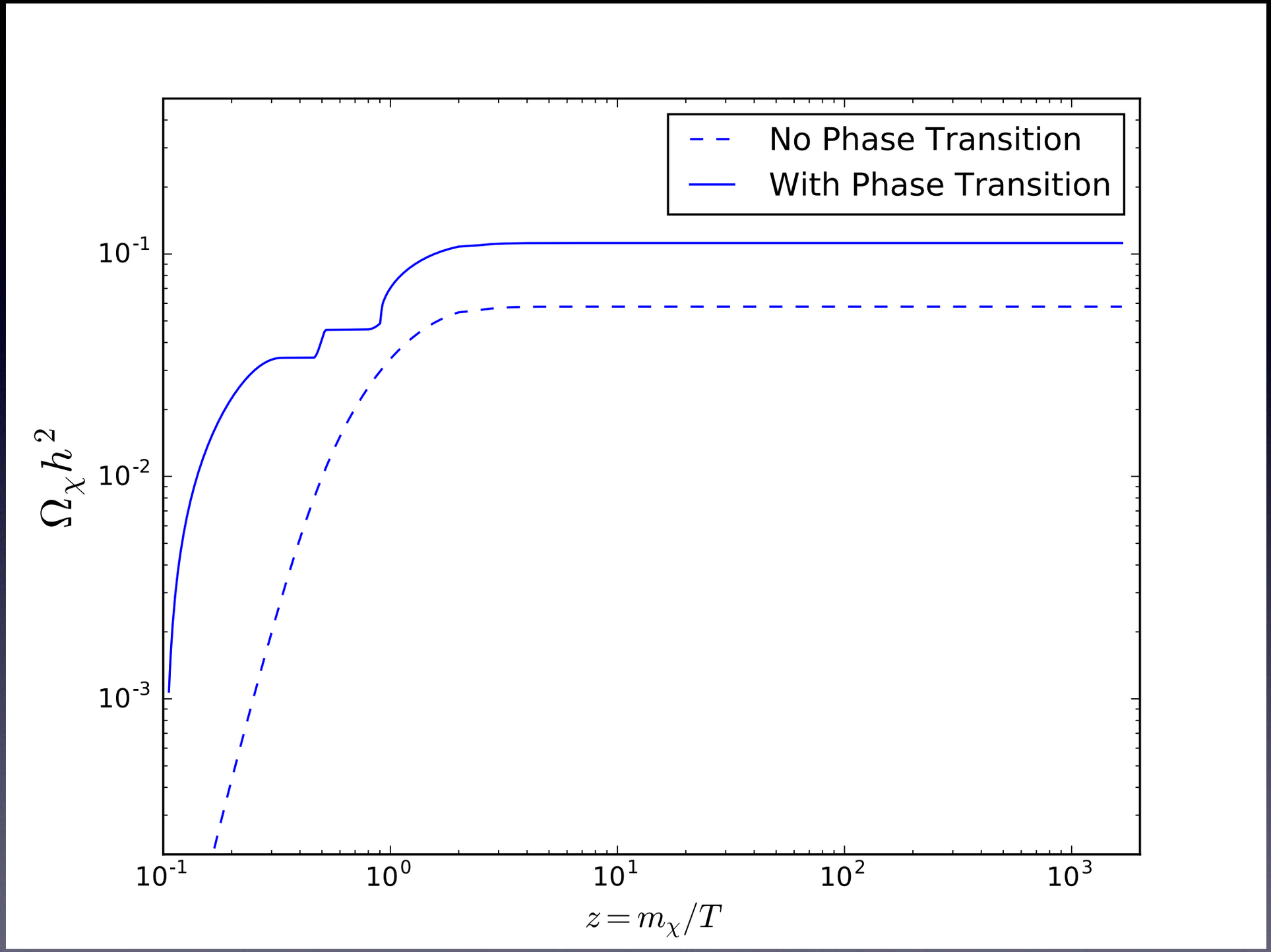
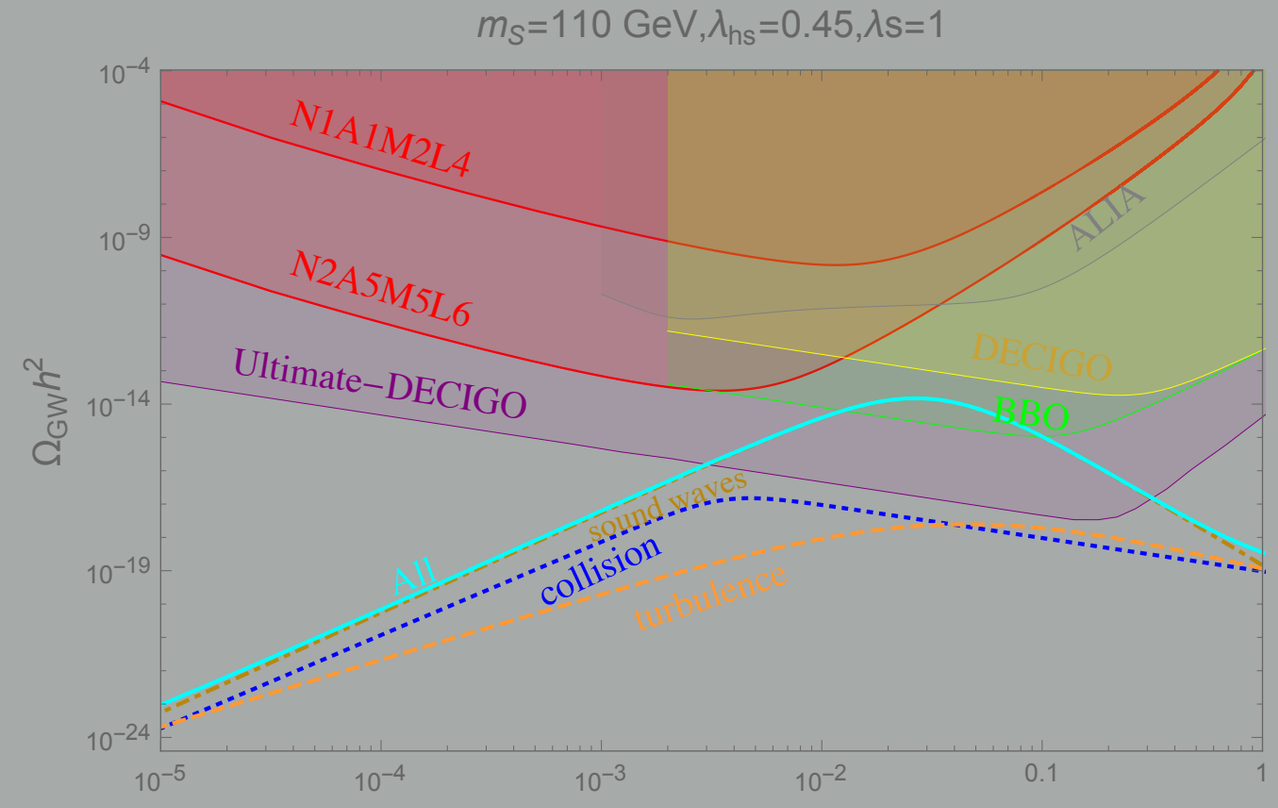


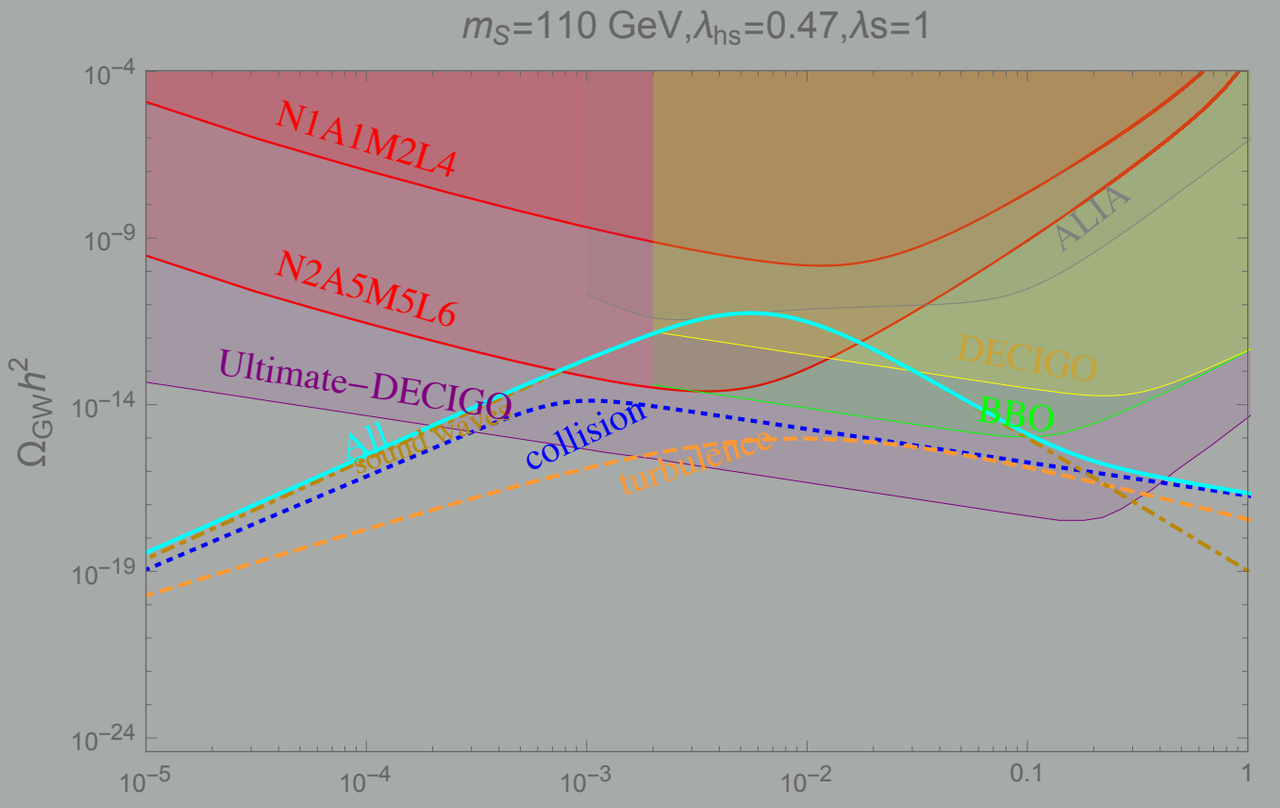
mS=110 GeV, mChi=90GeV, mRHN=40 GeV
yD=7.3e-12

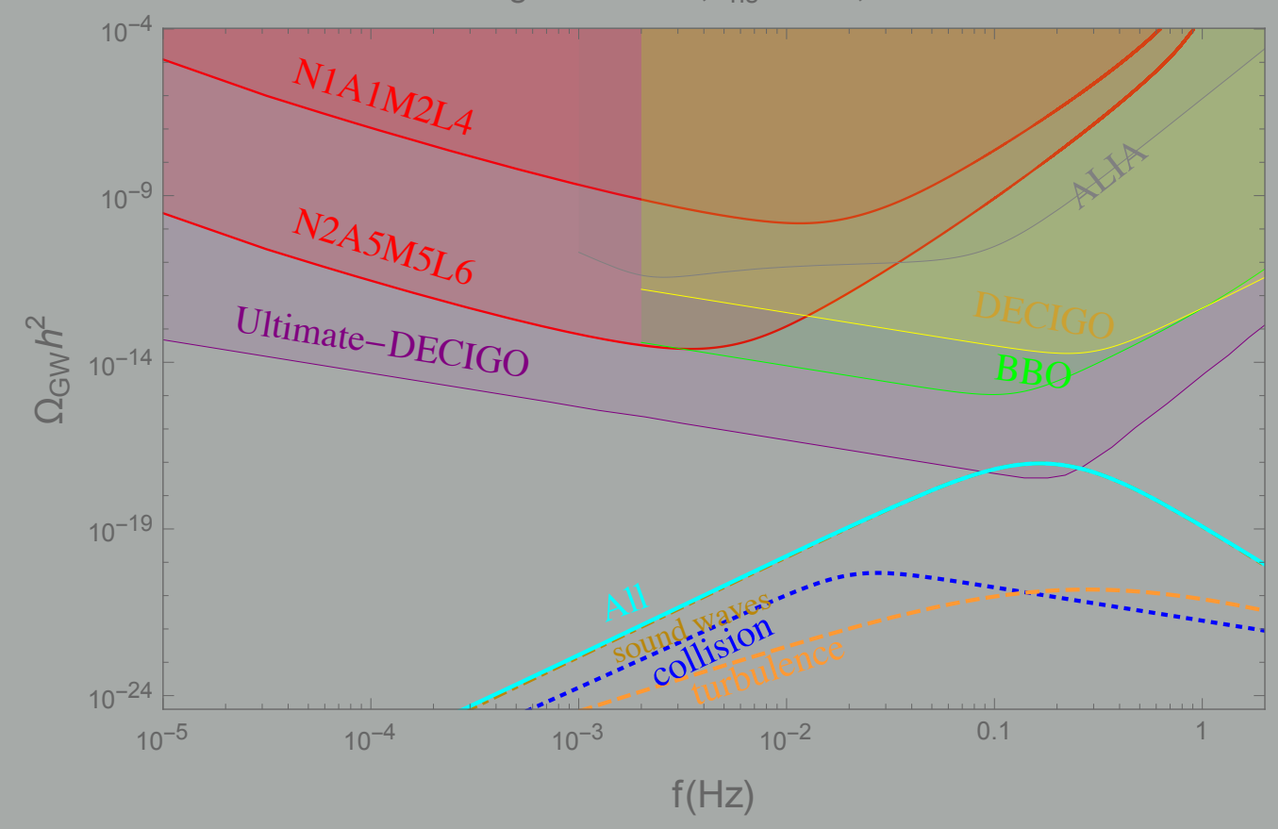


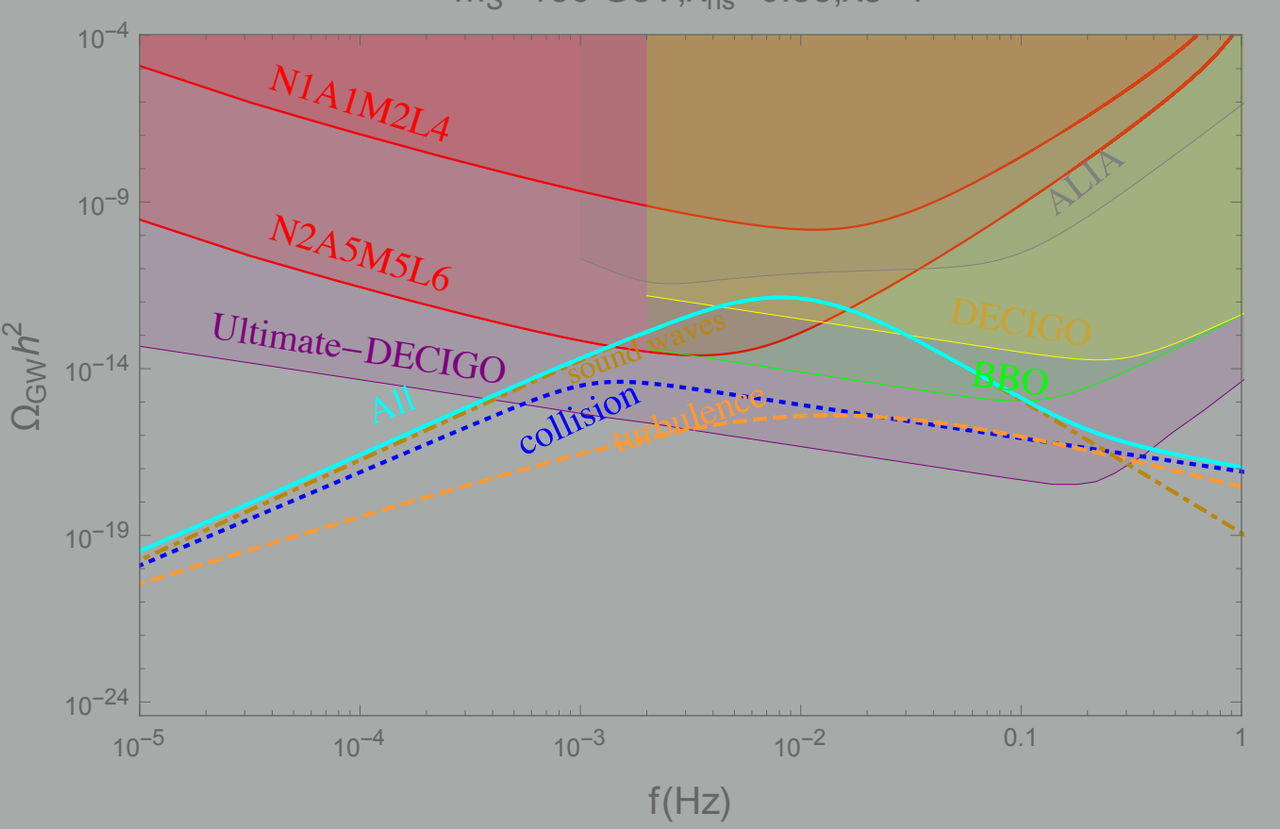
mS=110 GeV, mChi=90GeV, mRHN=40 GeV
yD=7.3e-12

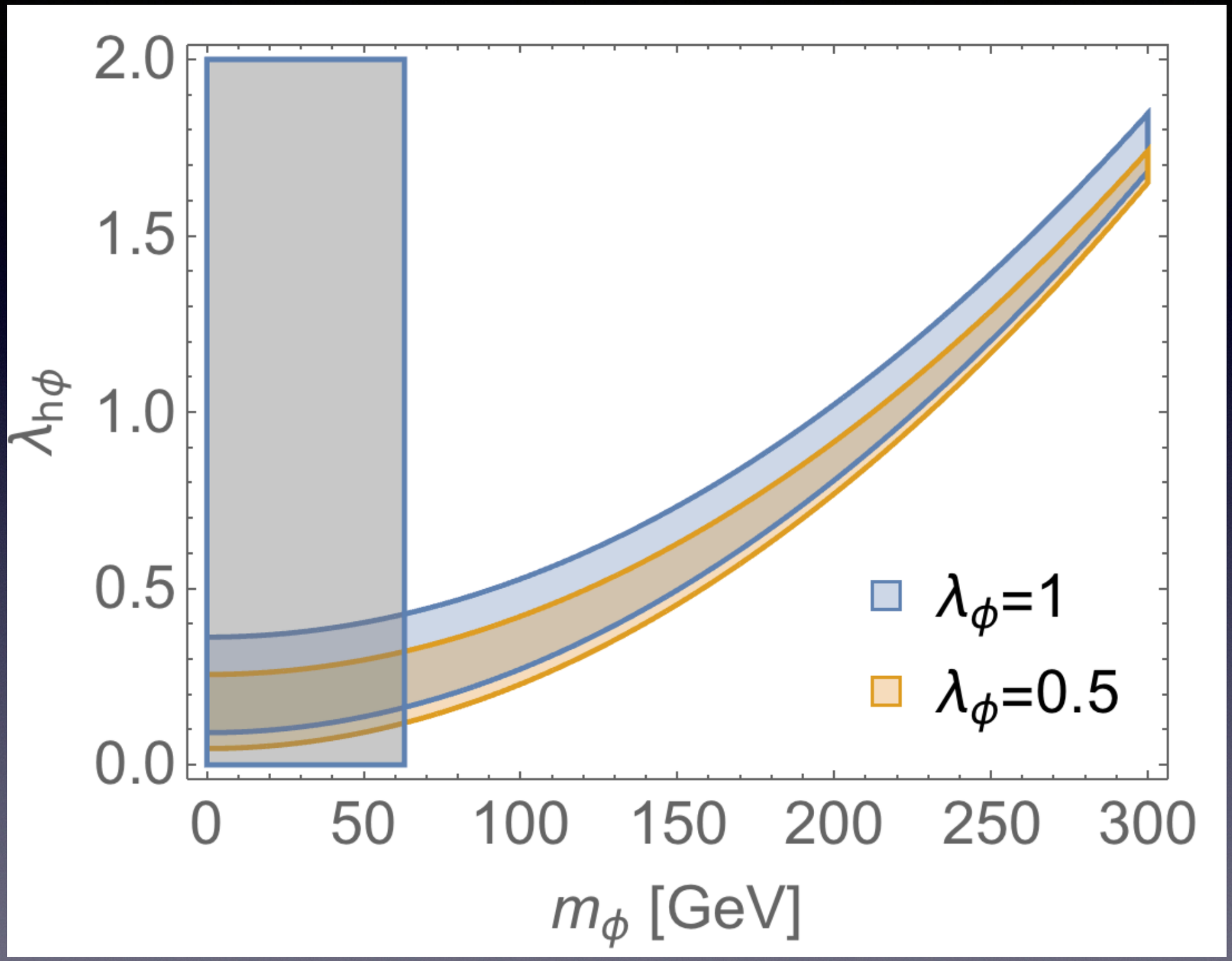
Gravitational Wave Signals










2.0
1.5
1.0
0.5
0.0
$\lambda_{h\phi}$
0
50
100
150
200
250
300
m_ϕ [GeV]
λ_ϕ=1
λ_ϕ=0.5

Larger scalar mass gives lower GW signals.
Larger Higgs portal coupling of $\lambda_{\phi h}$, smaller peak frequency, higher magnitude of GW signals.