Glueball dark matter, precisely

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We delve deeper into the potential composition of dark matter as stable scalar glueballs from a confining dark $SU(N)$ gauge theory, focusing on $N = \{3, 4, 5\}$. To predict the relic abundance of glueballs for the various gauge groups and scenarios of thermalization of the dark gluon gas, we employ a thermal effective theory that accounts for the strong-coupling dynamics in agreement with lattice simulations. We compare our methodology with previous works and find that our approach is more comprehensive and reliable. The results are encouraging and show that glueballs can account for the totality of dark matter in many unconstrained scenarios with a phase transition scale 20 MeV $\lesssim \Lambda \lesssim 10^{10}$ GeV, thus opening the possibility of exciting future studies.

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The effective lagrangian

Polyakov loop: $$\ell(x) = \frac{1}{N}\mathrm{Tr}[\mathbf{L}] \equiv \frac{1}{N}\mathrm{Tr}\left\{\mathcal{P}\exp\left[i\,g\int_0^{1/T} A_0(\tau,\mathbf{x})d\tau\right]\right\}$$

$$\mathcal{H} \propto \mathrm{tr}(G^{\mu\nu}G_{\mu\nu}), \qquad V[\mathcal{H},\ell] = \frac{\mathcal{H}}{2}\ln\left[\frac{\mathcal{H}}{\Lambda^4}\right] + T^4\mathcal{V}[\ell] + \mathcal{H}\mathcal{P}[\ell] + V_T[\mathcal{H}]\ .$$

critical temperature of the phase transition $$T_c = (1.59 + 1.22/N^2)\Lambda \text{ for } N = \{3,4,5\}$$ From lattice simulations

glueball mass $$m_{gb} = 6\Lambda$$

confinement scale

$$\mathcal{H} = 2^{-8} c^{-2} \phi^4$$

$$\mathcal{L} = \frac{1}{2} \partial_\mu \phi \partial^\mu \phi - V[\phi, \ell] \,,$$

$$c = (\Lambda / m_{\mathrm{gb}})^2 / 2\sqrt{e}$$

$$V[\phi, \ell] = \frac{\phi^4}{2^8 c^2} \left[2 \ln \left(\frac{\phi}{\Lambda} \right) - 4 \ln 2 - \ln c \right] + \frac{\phi^4}{2^8 c^2} \mathcal{P}[\ell] + T^4 \mathcal{V}[\ell]$$

$$\mathcal{P}[\ell] = c_1 |\ell|^2$$

$$\mathcal{V}[\ell] = T^4 \left(-\frac{b_2(T)}{2} |\ell|^2 + b_4 |\ell|^4 + - b_3 (\ell^N + \ell^{*N}) + b_6 |\ell|^6 + b_8 |\ell|^8 \right),$$

$$b_2(T) = a_0 + a_1 \left(\frac{T_c}{T} \right) + a_2 \left(\frac{T_c}{T} \right)^2 + a_3 \left(\frac{T_c}{T} \right)^3 + a_4 \left(\frac{T_c}{T} \right)^4,$$

N	3	4	5
a_0	3.72	9.51	14.3
a_1	-5.73	-8.79	-14.2
a_2	8.49	10.1	6.40
a_3	-9.29	-12.2	1.74
a_4	0.27	0.489	-10.1
b_3	2.40	-	-5.61
b_4	4.53	-2.46	-10.5
b_6	-	3.23	-

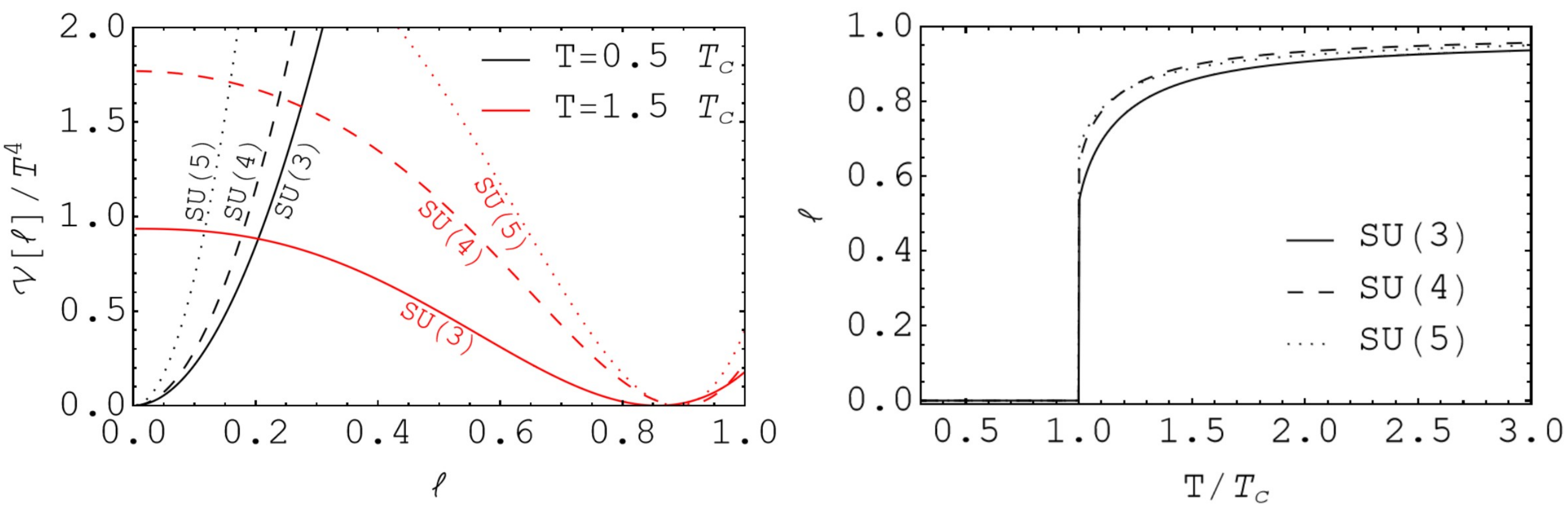


FIG. 1. *Left panel*: Polyakov loop potential $\mathcal{V}[\ell]$ for different gauge groups: $SU(3)$ solid lines, $SU(4)$ dashed lines and $SU(5)$ dotted lines. The colors correspond to the confined (black) or deconfined (red) phase. Note that the minimum of the potential is arbitrarily set to zero.
Right panel: Polyakov loop evolution as function of the temperature for different gauge groups: $SU(3)$ solid lines, $SU(4)$ dashed lines and $SU(5)$ dotted lines.

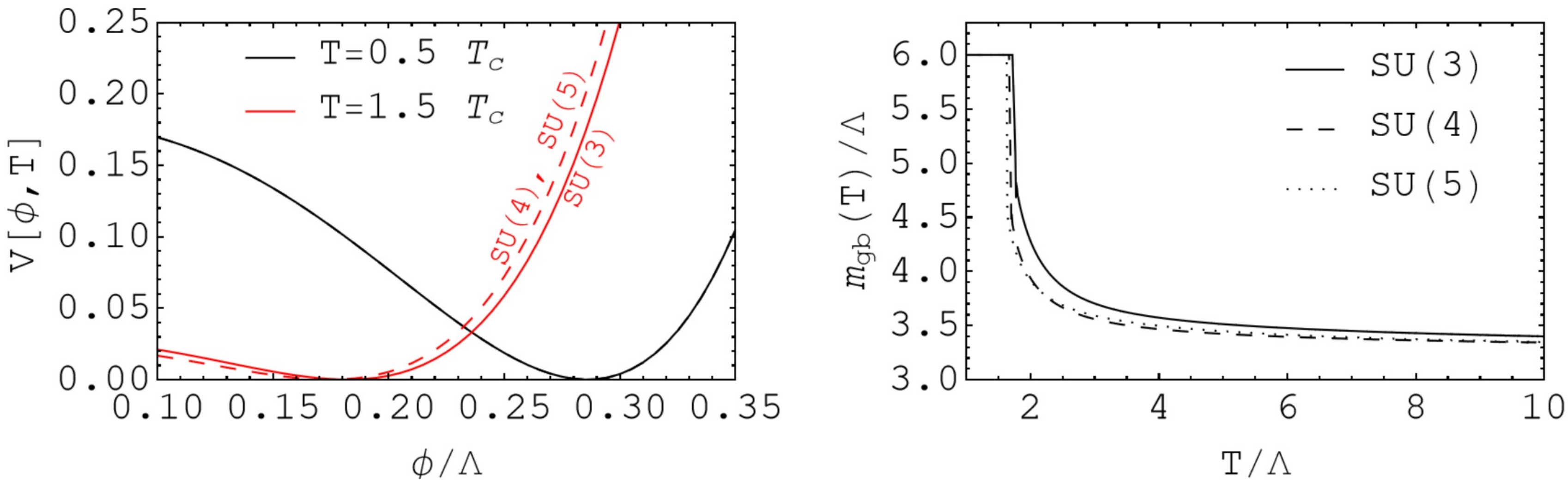


FIG. 2. *Left panel*: glueball potential $V[\phi, T]$ for different gauge groups: $SU(3)$ solid lines, $SU(4)$ and $SU(5)$ dashed lines. The colors correspond to the confined (black) or deconfined (red) phase. In the confined phase the potential is independent on the gauge group, while it is weakly dependent in the deconfined phase. Note that in this case the potentials for $SU(4)$ and $SU(5)$ are indistinguishable.
Right panel: effective glueball mass as function of the temperature for various gauge groups: $SU(3)$ solid line, $SU(4)$ dashed line and $SU(5)$ dotted line.

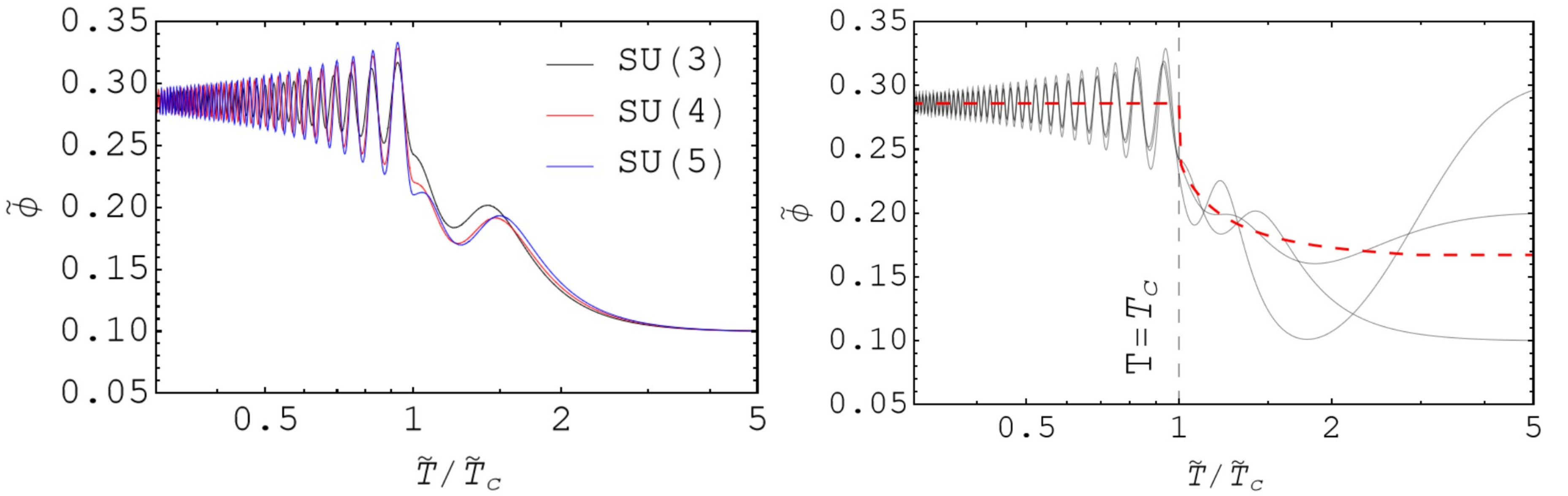
Glueball field evolution

glueball field evolution

$$\mu^2 \tilde{T}^6 \frac{d^2\tilde{\phi}}{d\tilde{T}^2} + \partial_{\tilde{\phi}} \tilde{V}[\tilde{\phi}, \tilde{T}] = 0\,,$$

energy density of the glueball field

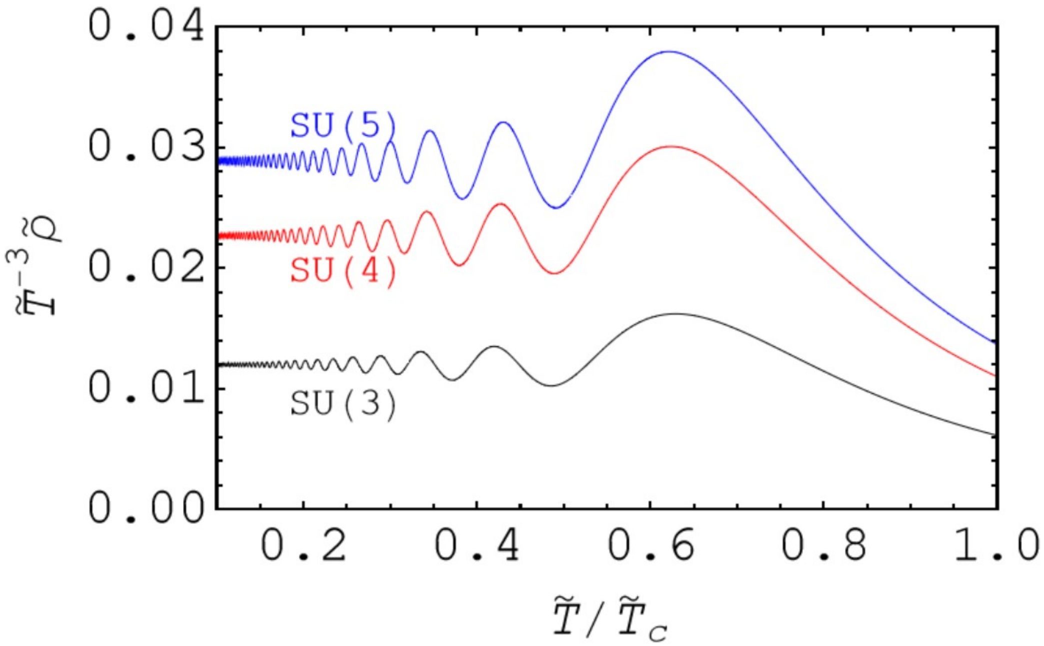
$$\tilde{\rho} = \frac{\mu^2 \tilde{T}^6}{2} \left(\frac{d\tilde{\phi}}{d\tilde{T}}\right)^2 + \tilde{V}[\tilde{\phi}, \tilde{T}]\,,$$



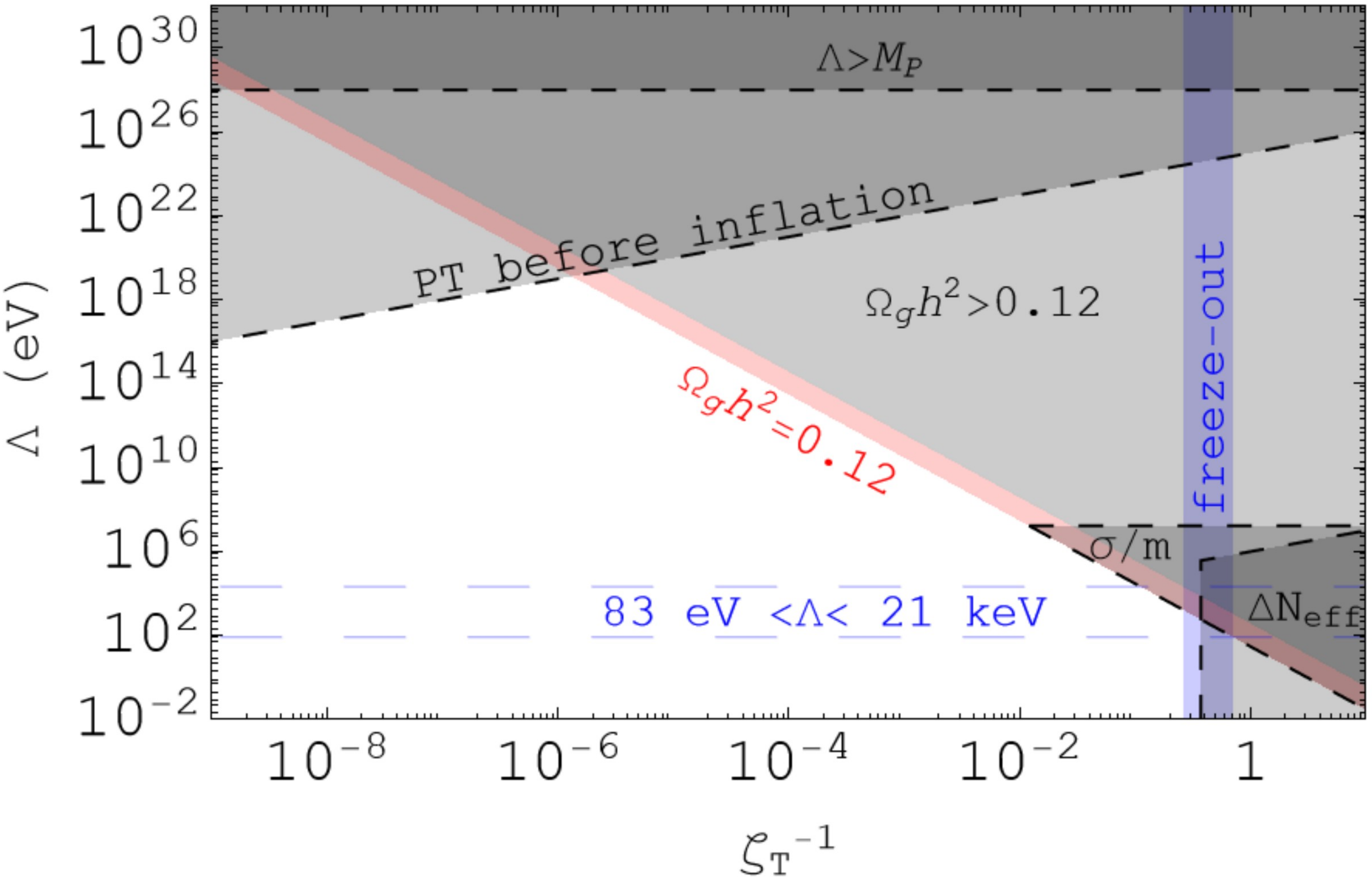
Relic density

$$\Omega_g h^2 = 0.12\zeta_T^{-3}\frac{\Lambda}{\Lambda_0}$$

$$\Lambda_0 \sim \left\langle \frac{\widetilde{\rho}}{\widetilde{T}^3} \right\rangle^{-1}, \qquad \zeta_T = \frac{T_\gamma}{T}$$



N	c_1	$100 \times \left\langle \frac{\tilde{\rho}}{\tilde{T}^3} \right\rangle_f$	Λ_0 (eV)
3	1.225 ± 0.19	$0.59^{+0.15}_{-0.14}$	133 ± 32
4	1.225 ± 0.8	$1.1^{+1.0}_{-0.9}$	204 ± 168
5	1.225 ± 0.8	$1.3^{+1.2}_{-1.0}$	139 ± 109



Λ>M_P
PT before inflation
Ω_g h^2>0.12
Ω_g h^2=0.12
freeze-out
σ/m
83 eV <Λ< 21 keV
ΔN_eff
Λ (eV)
ζ_T^-1

Thank you for your attention!