Gluequark Dark Matter

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Gluequark DM

Gauge group	Adjoint Weyl fermions
$\mathrm{SU}(N)_{\mathrm{DC}} \times G_{\mathrm{SM}}$	$\mathcal{Q} = (\mathrm{adj}, \mathrm{r})$

adj : adjoint of $\mathrm{SU}(N)_{\mathrm{DC}}$

r : representation of G_{SM}

$$\delta\mathcal{L} = \mathcal{Q}^\dagger \sigma^\mu i D_\mu \mathcal{Q} - M\mathcal{Q}\mathcal{Q}$$

GlueQuark

$$\chi \sim (\mathcal{Q}g)$$

- Explicit mass term $M_{\mathcal{Q}}$
- Confinement scale Λ_{DC}

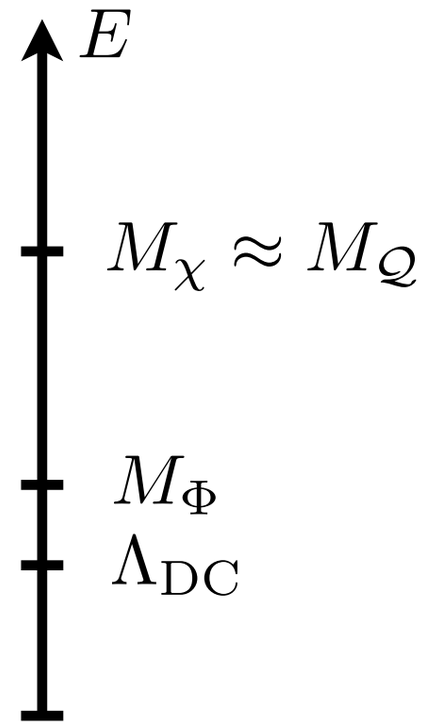
<u>Accidental stability</u>

- $\mathbb{Z}_2$ symmetry: $\mathcal{Q} \longrightarrow -\mathcal{Q}$

- Lightest $\mathbb{Z}_2$ odd states are accidentally stable

Gluequark DM

$$M_{\mathcal{Q}} > \Lambda_{\mathrm{DC}}$$



- Dark glueball Φ : gluonium bound state

$$\mathcal{O}_\Phi \sim \mathrm{Tr}[\mathrm{G}^{\mathrm{a}}_{\mu\nu}\mathrm{G}^{\mu\nu}_{\mathrm{a}}] \rightarrow M_\Phi \sim 7\,\Lambda_{\mathrm{DC}}$$

$\mathrm{SU}(3)_{\mathrm{DC}}$

- Gluequark χ : dark quark - dark gluon bound state

$$\chi \sim (\mathcal{Q}g)$$

$$\mathcal{O}_\chi \sim \sigma^{\mu\nu}\,\mathrm{Tr}[\mathrm{G}^{\mathrm{a}}_{\mu\nu}\mathrm{Q}_{\mathrm{a}}]$$

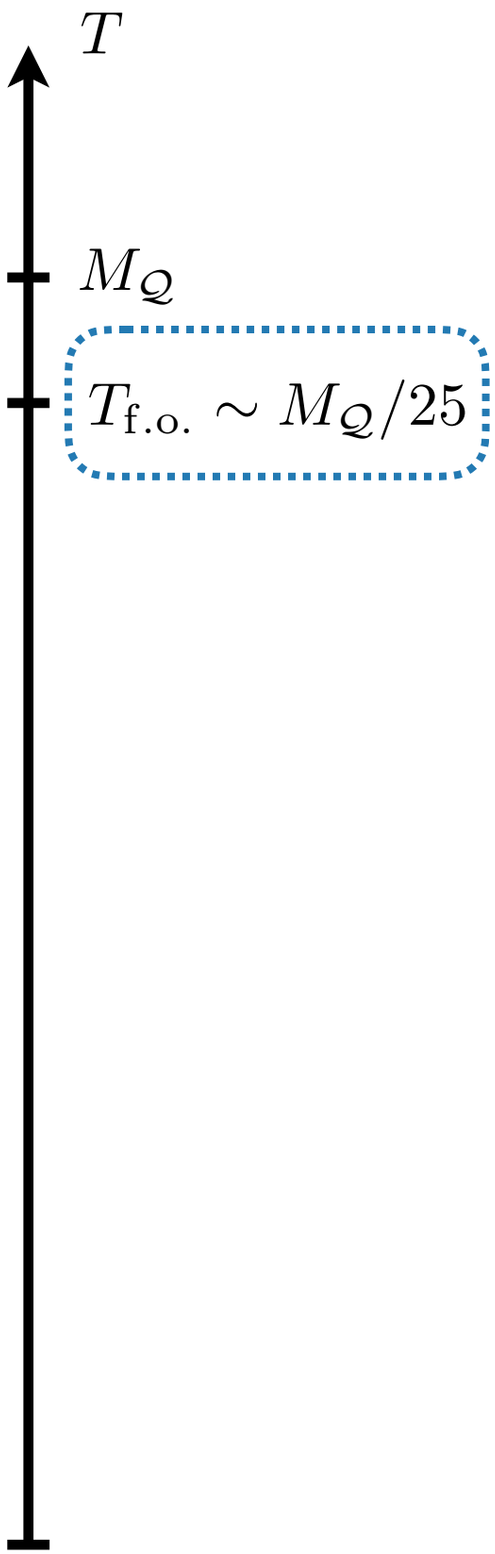
$$\rightarrow \quad M_{\mathcal{Q}} \gg \Lambda_{\mathrm{DC}} \Rightarrow M_\chi \approx M_{\mathcal{Q}}$$

Viable Gluequark DM models

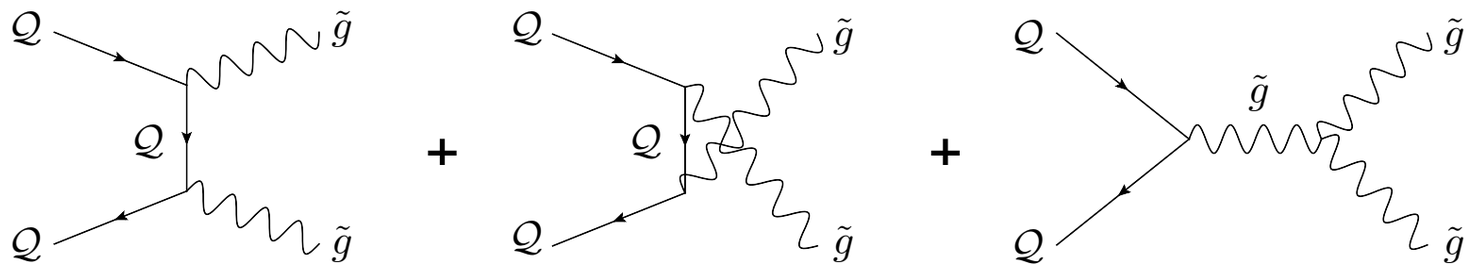
- DM candidate EM neutral
- No Landau poles below $M_{\rm Pl}$

	$\mathrm{SU}(2)_\mathrm{L} \times \mathrm{U}(1)_\mathrm{Y}$	Accidental symmetry	$N_{\rm DC}$
	SUSY		
$N_f = 1$	$1_0 = N$	$\mathbb{Z}_2$ broken by dim-6	
	Best candidate		
✓ $N_f = 3$	$3_0 = V$	$\mathbb{Z}_2$ broken by dim-6	≤ 3
$N_f = 4$	$2_{+\frac{1}{2}} \oplus 2_{-\frac{1}{2}} = L + \bar{L}$	$\mathrm{U}(1)$ broken by dim-5	≤ 4
$N_f = 5$	$5_0 = F$	$\mathbb{Z}_2$ broken by dim-7	✗
$N_f = 6$	$3_{+1} \oplus 3_{-1} = T + \bar{T}$	$\mathrm{U}(1)$ broken by dim-6	≤ 2
⋮	⋮	⋮	⋮

Thermal history



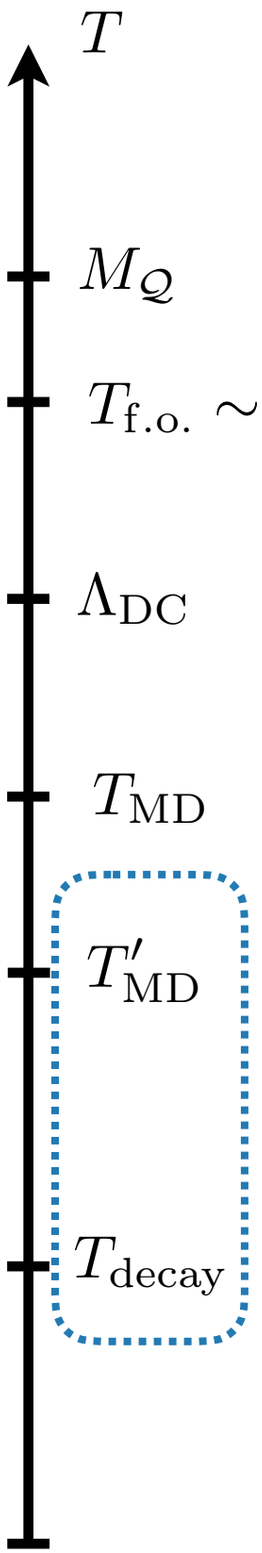
Perturbative freezeout: $n_{\mathcal{Q}}\,\sigma_{\rm ann}\,v \lesssim H$



$$\langle \sigma\, v \rangle = \frac{27\,\pi}{32}\frac{\alpha_{\rm DC}^2}{M_{\mathcal{Q}}^2} + \mathcal{O}(v)$$

$$n_{\mathcal{Q}}\, a^3 \sim \text{const}$$

Thermal history

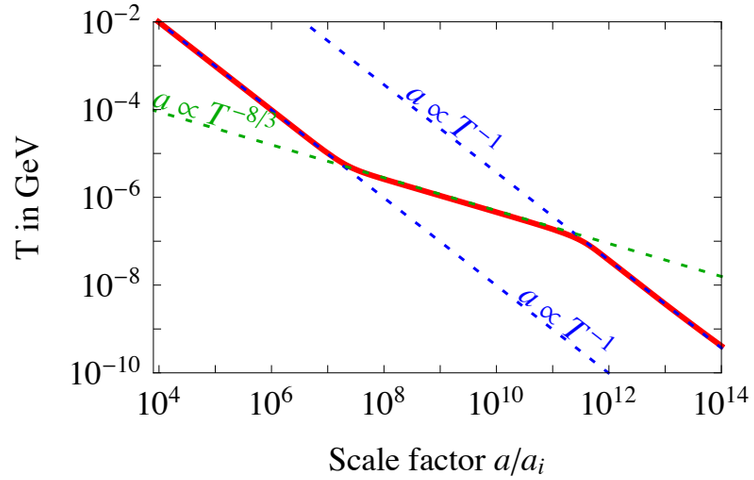


Confinement

Dark gluons → Dark glueballs

$$\rho_G = (N_{\rm DC}^2 - 1)\frac{\pi^2}{30} T_{\rm conf}^4 \qquad \rho_{\rm M,i}$$

$$\begin{cases} \dot{\rho}_M = -3H\rho_M - \Gamma_\phi\,\rho_M \\ \dot{\rho}_R = -4H\rho_R + \Gamma_\phi\,\rho_M \end{cases}$$

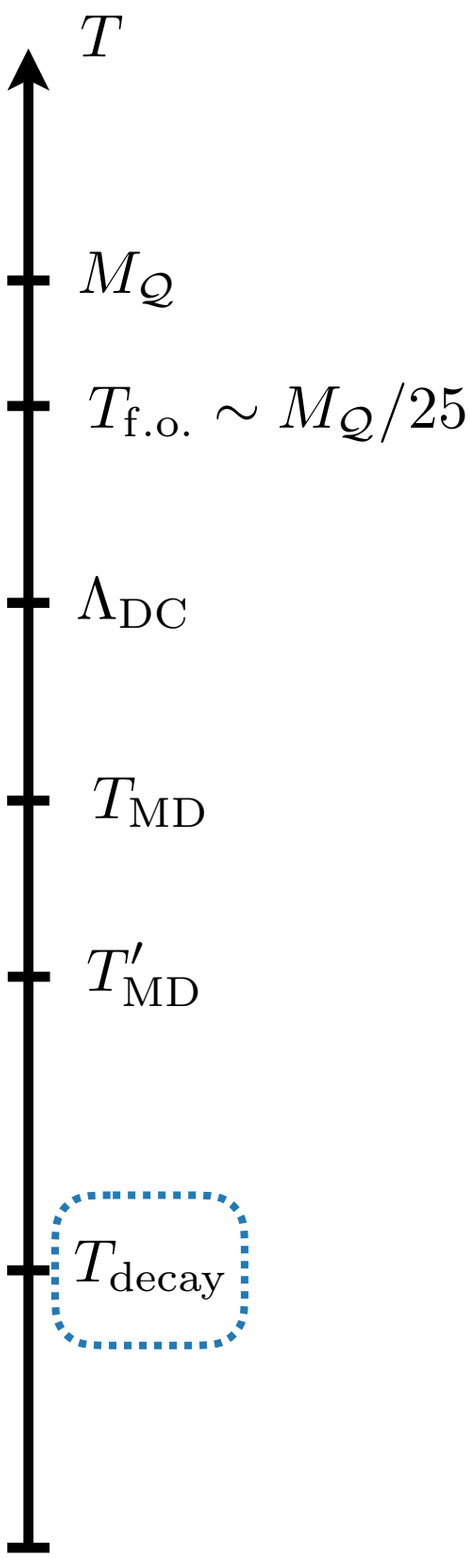


$$a \propto T^{-\frac{8}{3}}$$

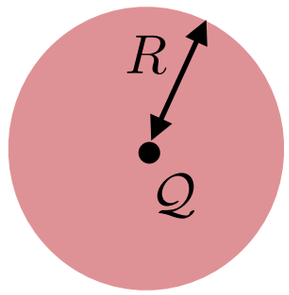
Dilution !

$$\Omega_{\rm DM} = \Omega_{\rm DM}^{\rm naive} \left(\frac{T_{\rm decay}}{T'_{\rm MD}}\right)^5$$

Thermal history



Non-perturbative annihilation:



$$R \sim \frac{1}{\Lambda_{\rm DC}} \qquad \text{but} \qquad M_{\mathcal{Q}} \gg \Lambda_{\rm DC}$$

Gluequark is heavy and large !

$$\chi\,\chi \longrightarrow (\mathcal{Q}\mathcal{Q})^* + \Phi \longrightarrow n\,\Phi \quad \longrightarrow \quad \sigma \sim \frac{\pi}{\Lambda_{\rm DC}^2}$$

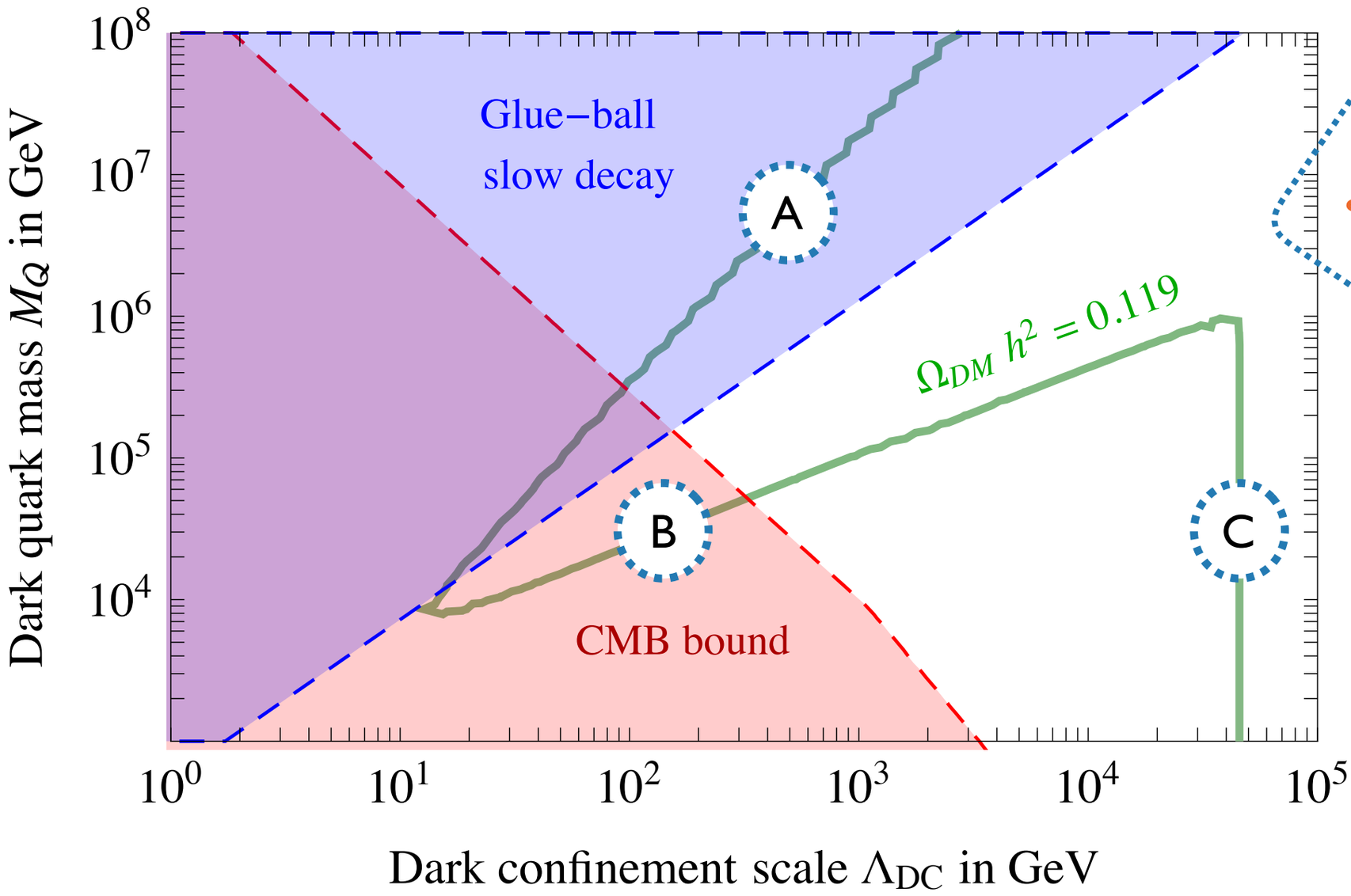
Efficient when glueballs decay

↓

2nd phase of annihilation

$$\Omega_{\rm DM} \propto \frac{M_{\mathcal{Q}}}{T_{\rm decay}} \frac{1}{\langle \sigma v \rangle}$$

Results - benchmark model: $\mathrm{SU}(3)_{\mathrm{DC}} \quad \mathcal{Q} = 3_0 = V$



A — Dilution from glueball decay dominates

B — Non-perturbative annihilation occurs

C — Perturbative freeze-out does not occur