SFB 1258 Neutrinos Dark Matter Messengers

Exploring dark QCD dark matter models with heavy quarks

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INVISIBLES‘23 Workshop

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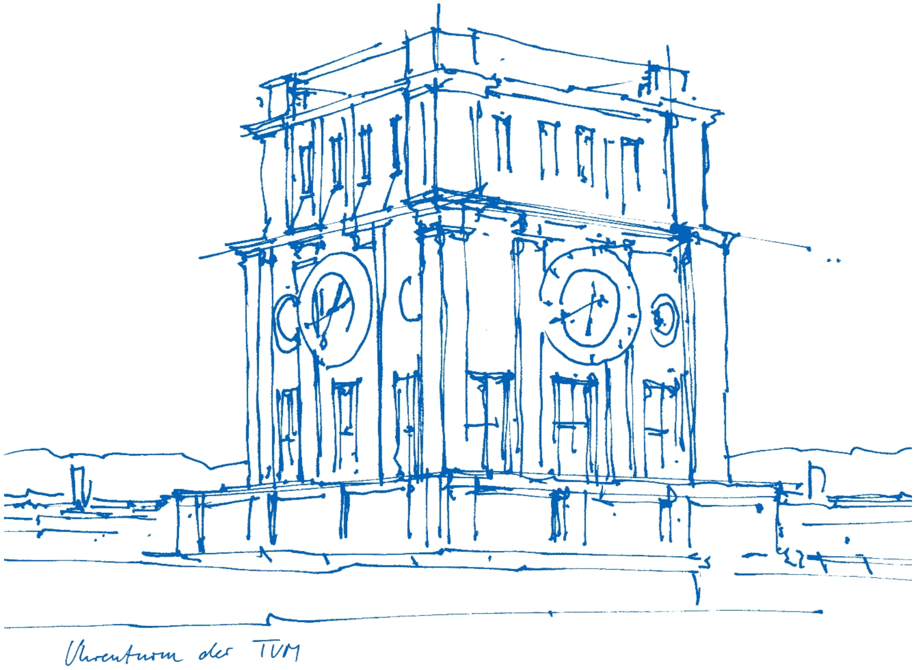

General Setup

Lagrangian of a dark SU(N_d) gauge theory with heavy quarks ($m_Q > \Lambda_{\mathrm{dQCD}}$), which can be charged under the SM or which are SM singlets.

$$\mathcal{L}_{\text{dark}} \supset -\frac{1}{2}\operatorname{tr}\left(G_{d,\mu\nu}G_d^{\mu\nu}\right) + \sum_{j=1}^{N_F} \overline{Q}_{d,j}\left(i\gamma^\mu D_\mu - m_{Q,j}\right)Q_{d,j}$$

Gauge groups SO(N) and Sp(2N) have also been considered in the literature

Accidental Composite Dark Matter, O. Antipin et al. (2015)

Low-enegy effective description of dark Sp(4) theories, S. Kulkarni et al. (2022)

Confinement scale Λ_{dQCD} is identified with the one-loop Landau pole

$$\alpha_d(m_Q) = \frac{2\pi}{\beta_0 \ln\left(\frac{m_Q}{\Lambda_{\mathrm{dQCD}}}\right)}, \quad \beta_0 = \frac{11N_d - 2N_F}{3}$$

If no other portal to the SM is included, confinement scale and quark mass(es) fix all the parameters of the theory.

Dark baryon number and dark species number are *accidental global symmetries* that ensure stability of dark hadrons.

Particle spectrum

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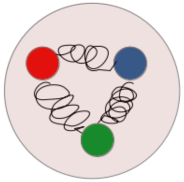

Baryons made of N_d dark quarks → **DM candidate**.
Stable up to dimension $3/2*(N_d + 1)$ operators for SU(N_d odd) (fermionic DM).
and stable up to dimension $(3/2*N_d + 2)$ operators for SU(N_d even) (bosonic DM).

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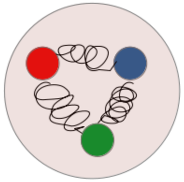

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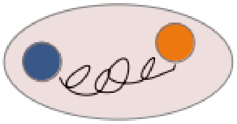

Mesons made of quark-antiquark: Stable against a decay into the SM up to dimension 5. Without accidental symmetries (G-parity, flavour conservation) protecting them, they decay quickly into glueballs.

Model for Thermal Relic Dark Matter of Strongly Interacting Massive Particles, Y. Hochberg et al. (2015)
A Theory of Dark Pions, H.C. Cheng et al. (2022)

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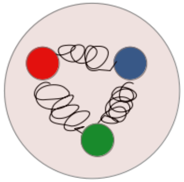

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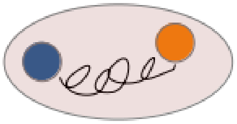
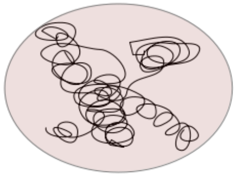


Glueballs (GBs) as the lightest hadrons in the heavy quark case. Stable up to dimension 6.
Pure glue *thermal* dark matter is excluded by overclosure.

Hidden SU(N) glueball dark matter, A. Soni and Y. Zhang (2016)
Non-Abelian Dark Forces and the Relic Densities of Dark Glueballs, L. Forestell et al. (2017)
Glueball dark matter, precisely, P. Carenza et al. (2023)



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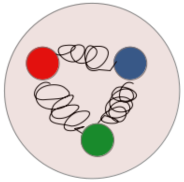

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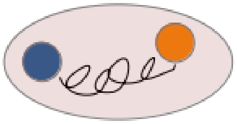

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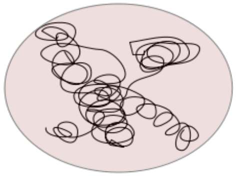
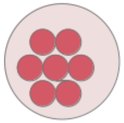


Dark nuclei: If a light mediator is added to the model, dark nucleosynthesis is feasible.

Big Bang Darkleosynthesis, G. Krnjaic and K. Sigurdson (2014)
Dark Nuclei I & II, W. Detmold et al. (2014)
Big Bang Synthesis of Nuclear Dark Matter, E. Hardy et al. (2014)



Squeezeout of Dark Matter

It has been found that in the case of a **first order** confining phase transition with **heavy quarks**, the phase transition drastically depletes the dark matter abundance via the squeezeout effect.

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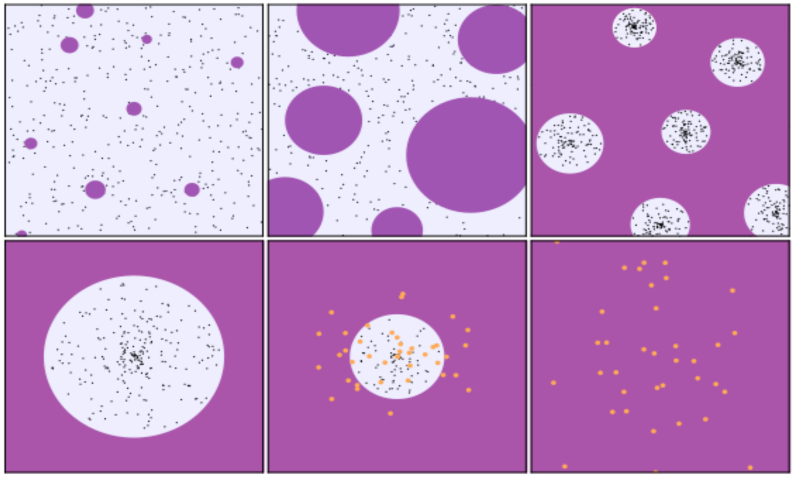

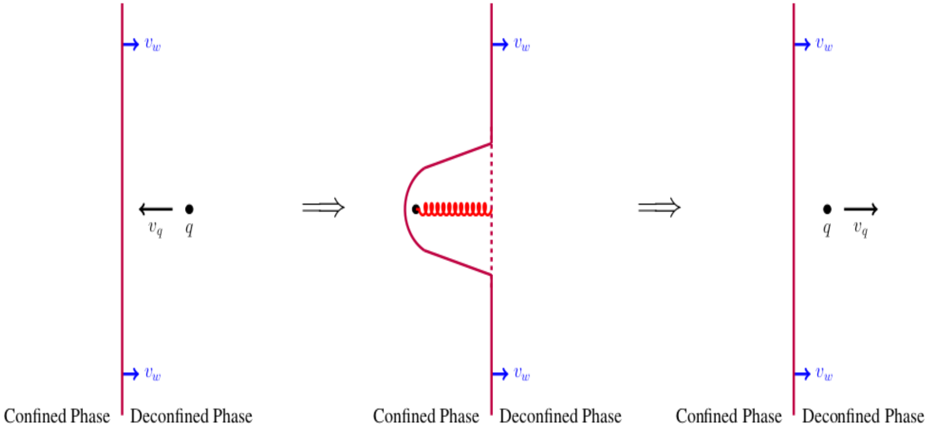

Heavy fundamental quarks can not enter the confined-phase bubble since colour string breaking is exponentially suppressed. Only a statistical excess fraction of $\sqrt{N_q^{\text{initial}}}$ quarks in the deconfined pockets survives the phase transition → **dramatic decrease of the dark matter abundance!**

Thank you for your attention