On s-confining SQCD with Anomaly Mediation

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SUSY 2023

Summary

- **Motivation**
- **Anomaly Mediated SUSY breaking (AMSB)**
- **S-confining SQCD $\mathrm{N_c} > 2$ with AMSB**
- **S-confining SU(2) ASQCD**
- **Conclusion**

Motivation

- Understanding the vacuum structure of strongly coupled gauge theories has been a longstanding goal in theoretical physics.
- SQCD, for $\mathrm{N_f} = \mathrm{N_c} + 1$ has a rich moduli space, and chiral symmetry is not broken (**s-confining**).
- Introduce ~~SUSY~~ to s-confining SQCD.
- UV insensitivity of anomaly-mediated ~~SUSY~~ makes it uniquely suited for studying confining theories!

Motivation

arXiv > hep-th > arXiv:2104.01179

High Energy Physics - Theory

[Submitted on 2 Apr 2021 (v1), last revised 19 Jun 2021 (this version, v3)]

Some Exact Results in QCD-like Theories

Hitoshi Murayama

Motivation

arXiv > hep-th > arXiv:2104.01179

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arXiv > hep-th > arXiv:2104.10171

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Some Exact Results in Chiral Gauge Theories

Csaba Csáki, Hitoshi Murayama, Ofri Telem

Motivation

arXiv > hep-th > arXiv:2104.01179

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arXiv > hep-th > arXiv:2104.10171

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arXiv > hep-th > arXiv:2105.03444

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More Exact Results on Chiral Gauge Theories: the Case of the Symmetric Tensor

Csaba Csáki, Hitoshi Murayama, Ofri Telem

arXiv > hep-th > arXiv:2106.10288

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Demonstration of Confinement and Chiral Symmetry Breaking in $SO(N_c)$ Gauge Theories

Csaba Csáki, Andrew Gomes, Hitoshi Murayama, Ofri Telem

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The Phases of Non-supersymmetric Gauge Theories: the $SO(N_c)$ Case Study

Csaba Csáki, Andrew Gomes, Hitoshi Murayama, Ofri Telem

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arXiv > hep-th > arXiv:2111.09690

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Broken Conformal Window

Hitoshi Murayama, Bea Noether, Digvijay Roy Varier

arXiv

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arXiv > hep-th > arXiv:2111.09690

arXiv > hep-th > arXiv:2111.11214

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Phases of Confining SU(5) Chiral Gauge Theory with Three Generations

Yang Bai, Daniel Stolarski

High Energy Physics - Theory

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More Exact Results on Chiral Gauge Theories: the Case of the Symmetric Tensor

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On the Derivation of Chiral Symmetry Breaking in QCD-like Theories and S-confining Theories

Andrea Luzio, Ling-Xiao Xu
Csaba Csáki, Hitoshi Murayama, Ofri Telem

arXiv > hep-th > arXiv:2106.10288

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arXiv > hep-ph > arXiv:2205.00115

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Challenges to Obtaining Results for Real QCD from SUSY QCD

Michael Dine, Yan Yu

High Energy Physics - Theory

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Dynamics of Simplest Chiral Gauge Theories

Dan Kondo, Hitoshi Murayama, Cameron Sylber

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arXiv > h

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A Guide to AMSB QCD

Csaba Csáki, Andrew Gomes, Hitoshi Murayama, Bea Noether, Digvijay Roy Varier, Ofri Telem

ning

Theories

Andrea Luzio, Ling-Xiao Xu

Csaba Csáki, Hitoshi Murayama, Ofri Telem

Anomaly Mediated SUSY breaking (AMSB)

- AMSB is directly connected with the conformal violation of the theory.

- Both classical and quantum conformal violations contribute to ~~SUSY~~. One parameter $m_{3/2}$.

$$\Phi = 1 + \theta^2 m_{3/2}$$

- UV insensitive!

$$\mathcal{L}_{\cancel{\text{susy}}} = \int d^4\theta \Phi^* \Phi K + \int d^2\theta \Phi^3 W + \text{ h.c.}$$

S-confining SQCD

- $SU(N_c)$ gauge theories with $\mathbf{N_f = N_c + 1}$ vectorlike fundamental flavors.

UV

$$\mathbf{q}\,,\bar{q}, W_\alpha$$

$$\mathbf{W} = 0$$

IR

$$B \sim q^{N_f}, \tilde{B} \sim \bar{q}^{N_f}, M \sim q\bar{q}$$

$$\mathbf{W} = \lambda \frac{\det M}{\Lambda^{N_c-2}} - \kappa \tilde{B} M B$$

S-confining SQCD with AMSB

- In the UV AMSB generates masses for the gaugino and squarks:

$$m_\lambda = (2N_c - 1)\frac{g^2}{16\pi^2}m_{3/2} \qquad m_q^2 = \frac{(N_c^2-1)(2N_c-1)}{N_c}\frac{g^4}{64\pi^4}$$

- The masses are positive and drive the fields below Λ!

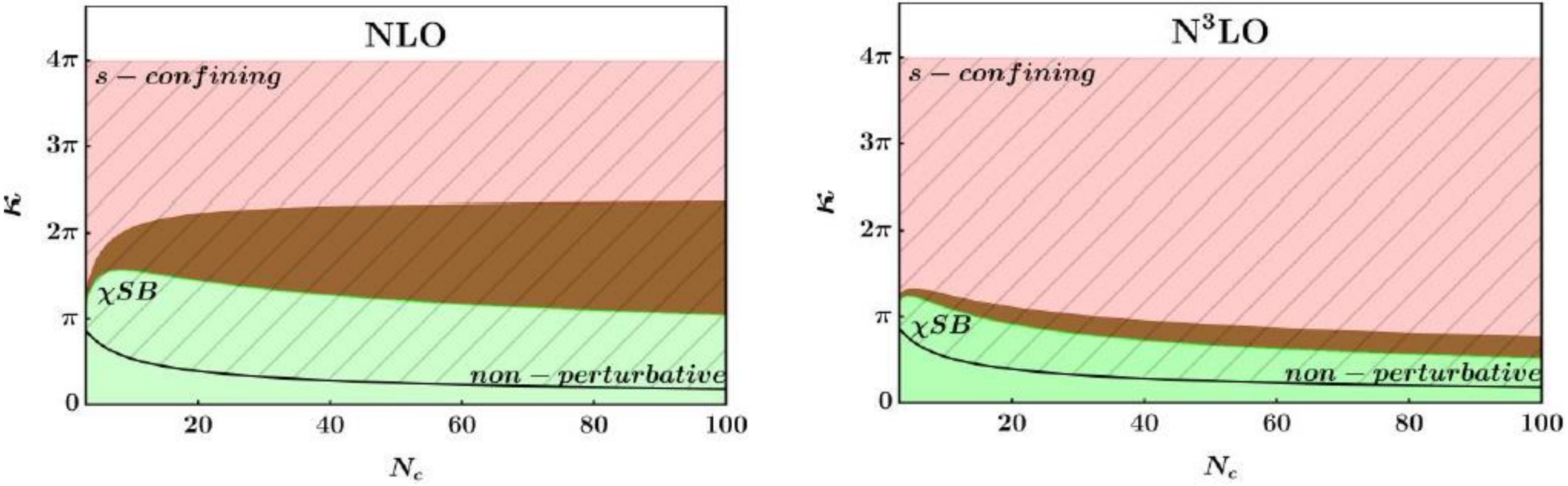
- In the IR, AMSB generates masses for the mesons and baryons and tri-linear interactions:

$$m_M^2 = \frac{2N_f+1}{128\pi^4}|\kappa|^4|m_{3/2}|^2 \qquad m_B^2 = m_{\tilde{B}}^2 = \frac{N_f(2N_f+1)}{128\pi^4}|\kappa|^4|m_{3/2}|^2$$

Numerical scan of the phase diagram

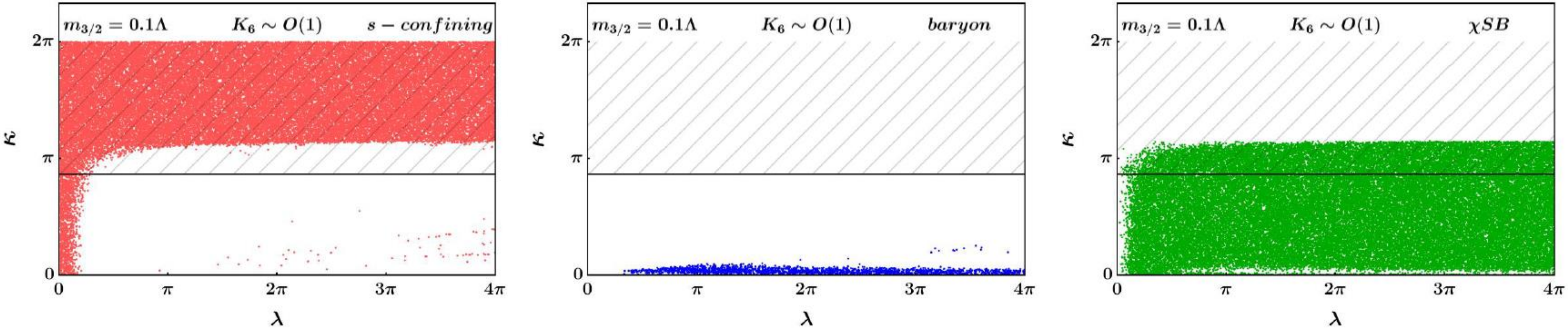
- Numerical minimization shows that there are only two possible global minima:
  - s-confining vacuum at the origin: $\mathrm{B} = \tilde{B} = 0, M = 0.$
  - The QCD-like χSB vacuum with $\mathrm{B} = \tilde{B} = 0, M \propto I$
- $m_{3/2}$ independent!

Numerical scan of the phase diagram



Kähler corrections for $N_c = 3$

$$
\begin{aligned}
\Lambda^2 K_6 = & \frac{c_{M_1}}{N_f^2} \mathrm{Tr}\left(M^\dagger M\right)^2 + \frac{c_{M_2}}{N_f} \mathrm{Tr}\left(M^\dagger M M^\dagger M\right) + \frac{c_B}{N_f}\left((B^\dagger B)^2 + (\tilde{B}^\dagger \tilde{B})^2\right) \\
& + \frac{c_{B\tilde{B}}}{N_f}(B^\dagger B)(\tilde{B}^\dagger \tilde{B}) + \frac{c_{MB}}{N_f^2} \mathrm{Tr}\left(M^\dagger M\right)\left(B^\dagger B + \tilde{B}^\dagger \tilde{B}\right) \\
& + \frac{c_{BMMB}}{N_f}\left(B M M^\dagger B^\dagger + \tilde{B} M M^\dagger \tilde{B}^\dagger\right).
\end{aligned}
$$



S-confining SU(2) ASQCD

- SU(2) s-confining QCD is special, It is one of only two theories that are both classically conformal and s-confining. In the IR we have the composite: $\boldsymbol{V \sim qq} \quad \mathbf{W} \boldsymbol{\sim \kappa\, q^3}$

- Theory is classically conformal and coupling with AMSB we have **no** symmetry breaking if: $-2\dot{\gamma}_V - \gamma_V^2 > 0$

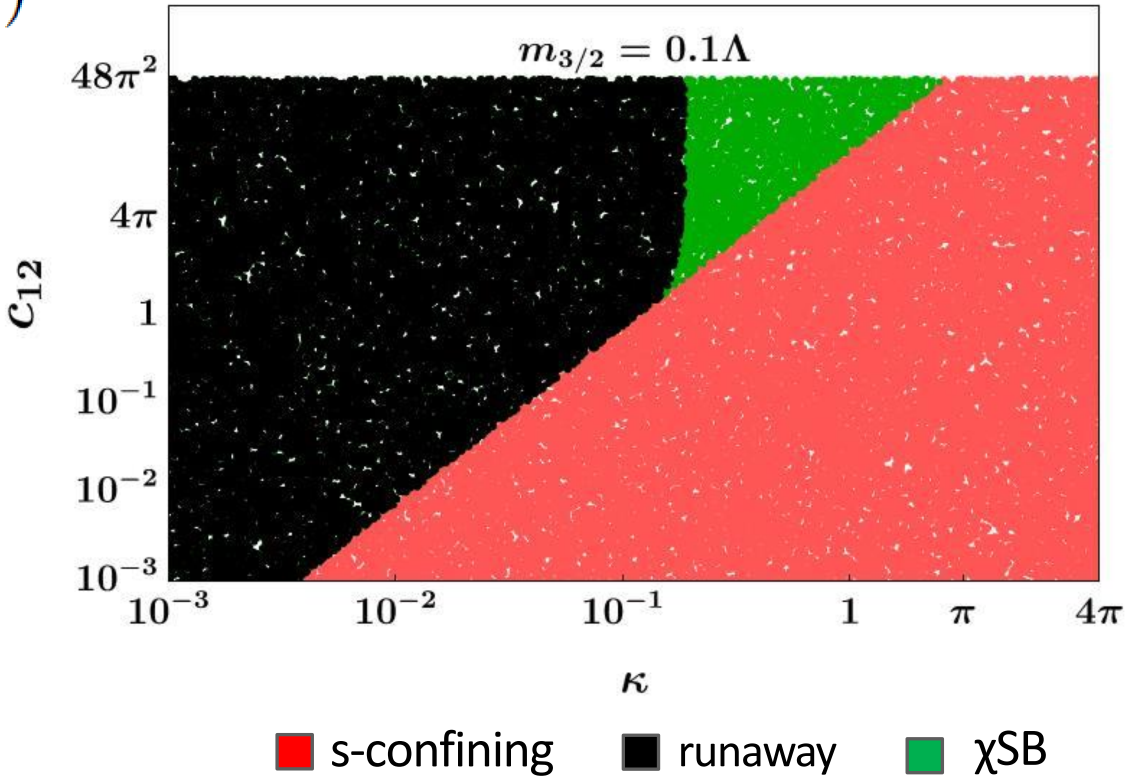
$$\gamma_V = -\frac{3\kappa^2}{8\pi^2} + \frac{9\kappa^4}{64\pi^4} - \frac{27\kappa^6\,(5-2\zeta(3))}{4096\pi^6} \quad \dot{\gamma}_V = -\frac{27\kappa^4}{64\pi^4} + \frac{243\kappa^6}{512\pi^6} - \frac{243\kappa^8(9-2\zeta(3))}{8192\pi^8}$$

Kähler corrections for s-confining SU(2) ASQCD

$$\Lambda^2 K_6^{N_c=2} = \frac{c_1}{9}\,\mathrm{Tr}(V^\dagger V)^2 + \frac{c_2}{3}\,\mathrm{Tr}(V^\dagger V V^\dagger V)$$

$$c_{12} = 2c_1 + c_2$$

- Numerical minimization shows that there are only two possible global minima:
  - s-confining vacuum at the origin: $\mathrm{V} = 0$.
  - The symmetric χSB vacuum with $\mathrm{V} \propto I_{Skew}$.



Conclusion

- Inclusion of two and three-loop contributions and higher-order Kähler corrections improve the robustness of the analysis.
- Phase diagram of s-confining ASQCD is richer than expected, theory remains in symmetry breaking phase as we cross the perturbativity boundary for $N_c > 2$.
- SU(2) s-confining AMSB theory has some interesting structure once we include higher-order Kähler terms. Further exploration necessary to probe large ~~SUSY~~ phase transition.

Extra material

$$\beta(\kappa^2) = -\left(\gamma_M + 2\gamma_B\right)\kappa^2 \qquad \beta(\lambda^2) = -\left(N_f \gamma_M\right)\lambda^2$$

$$\gamma_M = \frac{1}{16\pi^2}\gamma_M^{(1)} + \frac{1}{(16\pi^2)^2}\gamma_M^{(2)} + \frac{1}{(16\pi^2)^3}\gamma_M^{(3)}$$

$$\gamma_B = \frac{1}{16\pi^2}\gamma_B^{(1)} + \frac{1}{(16\pi^2)^2}\gamma_B^{(2)} + \frac{1}{(16\pi^2)^3}\gamma_B^{(3)}$$

$$\gamma_M^{(1)} = -2|\kappa|^2 \qquad \gamma_M^{(2)} = 4N_f|\kappa|^4$$

$$\gamma_M^{(3)} = -2\left(N_f(4+N_f) + 6\zeta(3)\right)|\kappa|^6$$

$$\gamma_B^{(1)} = -2N_f|\kappa|^2$$

$$\gamma_B^{(2)} = 2N_f(N_f+1)|\kappa|^4$$

$$\gamma_B^{(3)} = -2N_f(-1 + N_f(5+N_f) + 6\zeta(3))|\kappa|^6$$

Extra material

$$\dot{\gamma}_M \geq -\frac{(N_c-2)^2}{N_c}$$

$$0 < \kappa < 2\sqrt{2}\pi \left(\frac{(N_c-2)^2}{N_c(2N_c+3)}\right)^{1/4}$$

$$\dot{\gamma}_M < -\frac{4(N_c-2)^2}{(N_c+1)^2}$$

$$0 \leq \kappa < \frac{4\pi\sqrt{N_c-2}}{((N_c+1)^2(2N_c+3))^{1/4}}$$

Extra material

$$
\begin{aligned}
v_{\mathrm{MIN}} &= \xi^{1/(N_c-1)} \\
\xi &= \frac{m_{3/2}}{2\Lambda^{N_c-2} N_c \lambda} \left(N_c - 2 \pm \sqrt{4 + N_c \left(N_c - 4 + \dot{\gamma}_M\right)} \right)
\end{aligned}
$$

Extra material

$$\gamma_i^{(1)} = -\frac{1}{16\pi^2}\left(y^{ijk}y_{ijk}\right)$$

$$\gamma_i^{(2)} = \frac{1}{(16\pi^2)^2}\left(y_{imn}y^{mpi}y^{nkl}y_{pkl}\right)$$

$$\gamma_i^{(3)} = -\frac{1}{(16\pi^2)^3}\left(3\zeta(3)M_i^i + 4\,(y.S_4.y)_i^i - S_{7\,i}^{\,i} - 2S_{8\,i}^{\,i}\right)$$

$$M_j^i = y^{ikl}y_{kmn}y_{lrs}y^{pmr}y^{qns}y_{jpq}$$

$$S_{4\,j}^{\,i} = \frac{1}{2}y^{imn}y^{pkl}y_{mkl}y_{jpn}$$

$$S_{7\,j}^{\,i} = \frac{1}{4}y^{imn}y^{pkl}y_{mkl}y^{qst}y_{nst}y_{jpq}$$

$$S_{8\,j}^{\,i} = \frac{1}{4}y^{imn}y^{pkl}y_{qkl}y^{qrs}y_{mrs}y_{jpn}$$

Extra material

$$V_{\cancel{\text{tree}}} = m_{3/2}\left(\partial_i W g^{ij^*}\partial_j^* K - 3W\right) + \text{h.c.} + |m_{3/2}|^2\left(\partial_i K g^{ij^*}\partial_j^* K - K\right)$$

$$m_\lambda = -\frac{\beta\left(g^2\right)}{2g^2} m_{3/2} \qquad m_i^2 = -\frac{1}{4}\dot{\gamma}_i |m_{3/2}|^2 \qquad A_{ijk} = -\frac{1}{2}\left(\gamma_i + \gamma_j + \gamma_k\right) m_{3/2}$$

Extra material

$$\kappa < 2\pi\sqrt{\frac{4N_c+6}{5N_c^2+14N_c+9}}\,.$$

$$B = \begin{pmatrix} b \\ 0 \\ \vdots \\ 0 \end{pmatrix} \quad \tilde{B} = \begin{pmatrix} \bar{b} \\ 0 \\ \vdots \\ 0 \end{pmatrix}$$

$$V_{\mathrm{ASQCD}} = V_{\mathrm{tree+\cancel{tree}}} + V_{\mathrm{\cancel{loop}}}$$

$$V_{\mathrm{tree+\cancel{tree}}} = \left(\lambda\Lambda^{2-N_c}v^{N_c} - b^2\kappa\right)^2 + 2b^2\kappa^2x^2 + 2\lambda m_{3/2}(N_c-2)x\Lambda^{2-N_c}v^{N_c} + \lambda^2N_cx^2\Lambda^{4-2N_c}v^{2(N_c-1)}$$

$$V_{\mathrm{\cancel{loop}}} = -\frac{1}{2}b^2\dot{\gamma}_Bm_{3/2}^2 - \frac{1}{2}b^2x\kappa m_{3/2}(-\gamma_M - 2\gamma_B) - \frac{1}{4}\dot{\gamma}_Mm_{3/2}^2\left(N_cv^2+x^2\right)$$

$$M = \begin{pmatrix} x & & & \\ & v & & \\ & & \ddots & \\ & & & v \end{pmatrix}$$

Extra material

$$V = \begin{pmatrix} 0 & \xi_1 & 0 & 0 & 0 & 0 \\ -\xi_1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & \xi_2 & 0 & 0 \\ 0 & 0 & -\xi_2 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & \xi_3 \\ 0 & 0 & 0 & 0 & -\xi_3 & 0 \end{pmatrix}$$

$$V = \left(\kappa\xi_1\xi_2 - \frac{1}{4}\gamma_V m_{3/2}\xi_3\right)^2 + \left(\kappa\xi_1\xi_3 - \frac{1}{4}\gamma_V m_{3/2}\xi_2\right)^2 + \left(\kappa\xi_2\xi_3 - \frac{1}{4}\gamma_V m_{3/2}\xi_1\right)^2$$
$$- \frac{1}{16} m_{3/2}^2 \left(2\dot{\gamma}_V + \gamma_V^2\right)\left(\xi_1^2 + \xi_2^2 + \xi_3^2\right)$$