Baryonic forces in SU(3) chiral effective field theory

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in collaboration with:

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Achievements and Perspectives in Low-Energy QCD with Strangeness
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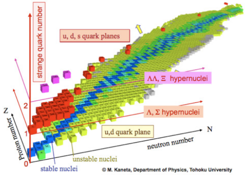
Motivation

- Goal: determine interactions between hyperons (Y) and nucleons (N), e.g. important for:
  - hyperon-nucleon scattering
  - hypernuclei
  - strange baryons in nuclear matter



- accurate description of nuclear interactions with SU(2) chiral effective field theory [Epelbaum, Glöckle, Meißner, Entem, Machleidt, . . .]

  extend SU(2) χEFT to include strangeness
  $\Rightarrow$ SU(3) chiral effective field theory

- Advantages:
  - can improve results systematically
  - can derive consistently two- and three-baryon forces

Motivation

- systematic *NLO* analysis of chiral *contact terms* and *one*- and *two-meson exchange* contributions to baryon-baryon interactions using SU(3) χEFT

  Leading order (LO):

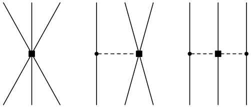
  [Polinder, Haidenbauer, Meißner, Nucl.Phys. A779, 2006]

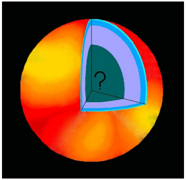
  Next-to-leading order (NLO):

  [Haidenbauer, Petschauer, Kaiser, Meißner, Nogga, Weise, Nucl.Phys. A915, 2013]

- repulsive ΛNN force suggested to get stiffer equation of state for neutron stars and to describe hypernuclei

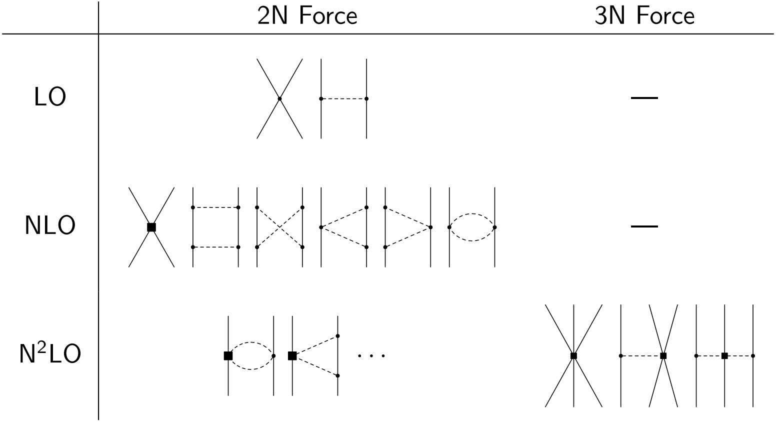
  [Gal et al.,Ann.Phys.63,1971] [Lonardoni et al.,Phys.Rev.C87,2013]





[http://www.astro.umd.edu/~miller/nstar.html]

Hierarchy of nuclear forces

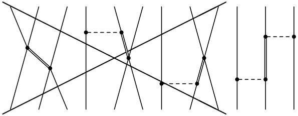
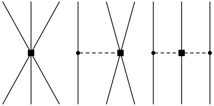


[van Kolck, Phys.Rev.C49, 1994]

[Epelbaum, Nogga, Glöckle, Kamada, Meißner, Witała, Phys.Rev.C66, 2002]

[Epelbaum, Hammer, Meißner, Rev.Mod.Phys.81, 2008]

Three-nucleon force including delta resonance

	3N Force with Δ isobar
LO	—
NLO	
N^2LO	 $+ \cdots$

[Epelbaum, Krebs and Meißner, Nucl.Phys.A806, 2008]

[Epelbaum, Hammer, Meißner, Rev.Mod.Phys.81, 2008]

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Chiral meson-baryon Lagrangian

Meson Lagrangian (in isospin limit $m_u = m_d \neq m_s$)

$$\mathscr{L}_{\mathrm{M}}^{(2)} = \frac{f_0^2}{4}\,\mathrm{tr}\left(\partial_\mu U \partial^\mu U^\dagger\right) + \frac{1}{2} B_0 f_0^2\,\mathrm{tr}\left(M U^\dagger + U M\right)$$

$$U(x) = \exp\left(\mathrm{i}\frac{\phi(x)}{f_0}\right), \quad \phi = \begin{pmatrix} \pi^0 + \frac{\eta}{\sqrt{3}} & \sqrt{2}\pi^+ & \sqrt{2}K^+ \\ \sqrt{2}\pi^- & -\pi^0 + \frac{\eta}{\sqrt{3}} & \sqrt{2}K^0 \\ \sqrt{2}K^- & \sqrt{2}\bar{K}^0 & -\frac{2\eta}{\sqrt{3}} \end{pmatrix}$$

Goldstone boson octet

$M \equiv \mathrm{diag}\left(m_u, m_d, m_s\right) \quad \Rightarrow \quad$ explicit SU(3)-breaking

Chiral meson-baryon Lagrangian

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Meson-baryon interaction

$$\mathscr{L}_{\mathrm{MB}}^{(1)} = \operatorname{tr}\left(\bar{B}\left(\mathrm{i}\not{D} - M_0\right) B - \frac{D}{2}\bar{B}\gamma^\mu\gamma_5\{u_\mu, B\} - \frac{F}{2}\bar{B}\gamma^\mu\gamma_5\left[u_\mu, B\right]\right)$$

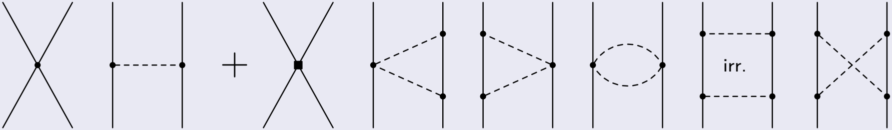
axial vector couplings:
$D \approx 0.8, \ F \approx 0.5$

$$B = \begin{pmatrix} \frac{\Sigma^0}{\sqrt{2}} + \frac{\Lambda}{\sqrt{6}} & \Sigma^+ & p \\ \Sigma^- & -\frac{\Sigma^0}{\sqrt{2}} + \frac{\Lambda}{\sqrt{6}} & n \\ \Xi^- & \Xi^0 & -\frac{2\Lambda}{\sqrt{6}} \end{pmatrix}$$

baryon octet

Deriving the T-matrix

Weinberg power counting for baryon-baryon potential



Deriving the T-matrix

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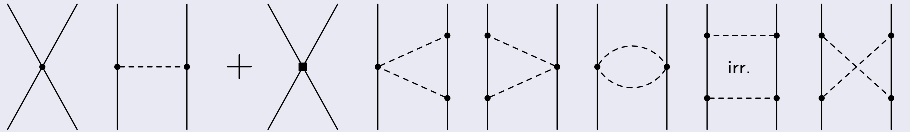
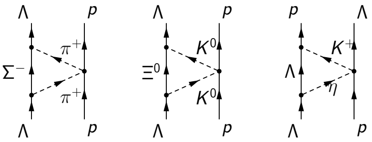


e.g.



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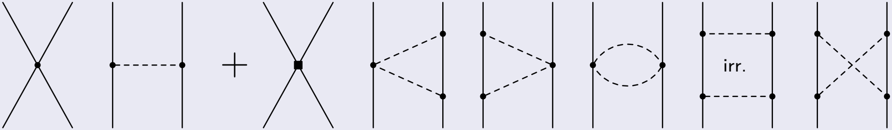
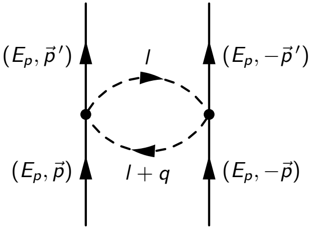


Coupled-channel Lippmann-Schwinger equation

$$T^{\rho''\rho',J}_{\nu''\nu'}(p'',p';\sqrt{s}) = V^{\rho''\rho',J}_{\nu''\nu'}(p'',p') +$$
$$+ \sum_{\rho,\nu} \int_0^\infty \frac{\mathrm{d}p\, p^2}{(2\pi)^3}\, V^{\rho''\rho,J}_{\nu''\nu}(p'',p) \frac{2\mu_\nu}{q_\nu^2 - p^2 + i\eta}\, T^{\rho\rho',J}_{\nu\nu'}(p,p';\sqrt{s})$$

ρ: partial wave $\qquad$ ν: particle channel

Example: Football Diagram



- m_1, m_2 masses of exchanged mesons
- $q = |\vec{q}|$ momentum transfer, $(\vec{q} = \vec{p}\,' - \vec{p})$
- $R = \frac{2}{d-4} + \gamma - 1 - \ln(4\pi)$
- scale λ introduced in dim. regularization

$$V_C(q) = -\frac{N}{3072\pi^2 f_0^4}\Bigg[\frac{1}{2}\left(3\left(m_1^2+m_2^2\right)+q^2\right)R - \frac{\left(m_1^2-m_2^2\right)^2}{2q^2} - 2\left(m_1^2+m_2^2\right) - \frac{5}{6}q^2 - \frac{m_1^2-m_2^2}{2q^4} + w^2(q)L(q) + \left(\left(m_1^2-m_2^2\right)^2 + 3\left(m_1^2+m_2^2\right)q^2\right)\ln\frac{m_1}{m_2} + \left(3\left(m_1^2+m_2^2\right)+q^2\right)\ln\frac{\sqrt{m_1 m_2}}{\lambda}\Bigg]$$

$$w(q) = \frac{1}{q}\sqrt{\left(q^2+(m_1+m_2)^2\right)\left(q^2+(m_1-m_2)^2\right)}, \quad L(q) = \frac{w(q)}{2q}\ln\frac{\left(qw(q)+q^2\right)^2-\left(m_1^2-m_2^2\right)^2}{4m_1 m_2 q^2}$$

SU(3) symmetry and contact terms

- poor database for YN interaction
- use SU(3) symmetric contact terms for reduction of LECs
- LO+NLO contact terms of NN interaction [Epelbaum, 2000] generalized by SU(3) flavor symmetry

$$\mathbf{8} \otimes \mathbf{8} = \mathbf{27} \oplus \mathbf{8_s} \oplus \mathbf{1} \oplus \mathbf{10} \oplus \mathbf{10}^* \oplus \mathbf{8_a}$$

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flavor symmetric $\mathbf{27}, \mathbf{8_s}, \mathbf{1}$
$\Rightarrow$ space-spin antisymmetric states

$$V^i(^1\mathrm{S}_0) = \tilde{C}^i_{^1\mathrm{S}_0} + C^i_{^1\mathrm{S}_0}(p^2 + p'^2)$$
$$V^i(^3\mathrm{P}_0) = C^i_{^3\mathrm{P}_0}(pp')$$
$$V^i(^3\mathrm{P}_1) = C^i_{^3\mathrm{P}_1}(pp')$$
$$V^i(^3\mathrm{P}_2) = C^i_{^3\mathrm{P}_2}(pp')$$

flavor antisymmetric $\mathbf{10}, \mathbf{10}^*, \mathbf{8_a}$
$\Rightarrow$ space-spin symmetric states

$$V^i(^3\mathrm{S}_1) = \tilde{C}^i_{^3\mathrm{S}_1} + C^i_{^3\mathrm{S}_1}(p^2 + p'^2)$$
$$V^i(^1\mathrm{P}_1) = C^i_{^1\mathrm{P}_1}(pp')$$
$$V^i(^3\mathrm{D}_1 - {}^3\mathrm{S}_1) = C^i_{^3\mathrm{D}_1 - {}^3\mathrm{S}_1} p'^2$$
$$V^i(^3\mathrm{S}_1 - {}^3\mathrm{D}_1) = C^i_{^3\mathrm{D}_1 - {}^3\mathrm{S}_1} p^2$$

spin singlet-triplet mixing from $\mathbf{8_s} \leftrightarrow \mathbf{8_a}$ neglected

$$V^i(^3\mathrm{P}_1 - {}^1\mathrm{P}_1) = C^i_{^3\mathrm{P}_1 - {}^1\mathrm{P}_1}(pp')$$

SU(3) symmetry and contact terms

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- LO+NLO contact terms of NN interaction [Epelbaum, 2000] generalized by SU(3) flavor symmetry

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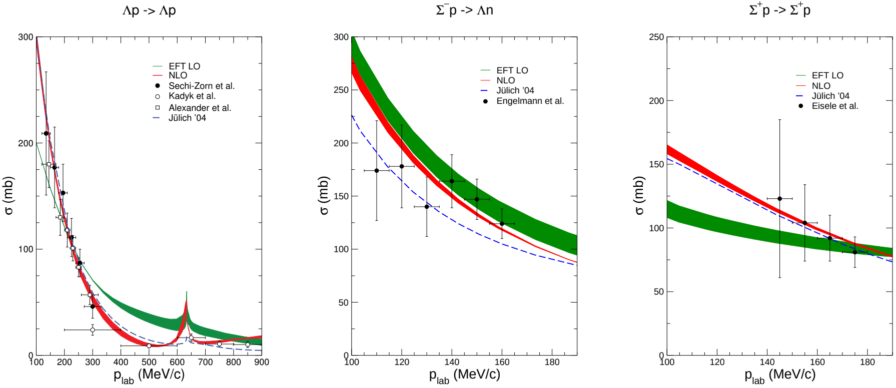
S	Channel	I	$V_{^1S_0,\,^3P_0,\,^3P_1,\,^3P_2}$	$V_{^3S_1,\,^3S_1\text{-}^3D_1,\,^1P_1}$	$V_{^1P_1\text{-}^3P_1}$
0	$NN \to NN$	0	–	C^{10^*}	–
	$NN \to NN$	1	C^{27}	–	–
-1	$\Lambda N \to \Lambda N$	$\frac{1}{2}$	$\frac{1}{10}\left(9C^{27} + C^{8_s}\right)$	$\frac{1}{2}\left(C^{8_a} + C^{10^*}\right)$	$\frac{-1}{\sqrt{20}} C^{8_s 8_a}$
	$\Lambda N \to \Sigma N$	$\frac{1}{2}$	$\frac{3}{10}\left(-C^{27} + C^{8_s}\right)$	$\frac{1}{2}\left(-C^{8_a} + C^{10^*}\right)$	$\frac{3}{\sqrt{20}} C^{8_s 8_a}$
	$\Sigma N \to \Lambda N$				$\frac{-1}{\sqrt{20}} C^{8_s 8_a}$
	$\Sigma N \to \Sigma N$	$\frac{1}{2}$	$\frac{1}{10}\left(C^{27} + 9C^{8_s}\right)$	$\frac{1}{2}\left(C^{8_a} + C^{10^*}\right)$	$\frac{3}{\sqrt{20}} C^{8_s 8_a}$
	$\Sigma N \to \Sigma N$	$\frac{3}{2}$	C^{27}	C^{10}	–

[Polinder, Haidenbauer, Meißner, Nucl.Phys. A779, 2006]

- does not include SU(3) breaking effects from quark masses $m_{u,d} \neq m_s$; full Lagrangian with SU(3) breaking available [Petschauer, Kaiser, NPA916, 2013]

Results for integrated cross sections

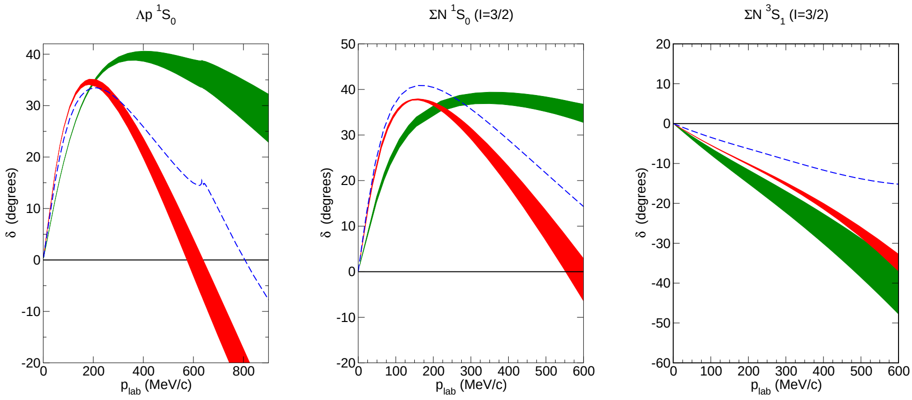


Included:

- one- and two-meson exchange; physical meson masses → SU(3) breaking
- LO and NLO contact terms • Cutoff: 500 - 650 MeV • LECs satisfy SU(3)

[Haidenbauer, Petschauer, Kaiser, Meißner, Nogga, Weise, Nucl.Phys. A915, 2013]

Results for phase shifts



- ΛN: stronger repulsion for higher momenta
- ΣN: description of YN data possible with attractive or repulsive $^3S_1$

[Haidenbauer, Petschauer, Kaiser, Meißner, Nogga, Weise, Nucl.Phys. A915, 2013]

S	I	transition	$j \in \{^1S_0, ^3P_0, ^3P_1, ^3P_2\}$	$j \in \{^3S_1, ^1P_1, ^3S_1 \leftrightarrow ^3D_1\}$	$^1P_1 \to ^3P_1$	$^3P_1 \to ^1P_1$
0	0	$NN \to NN$	0	$c_j^{10^*}$	0	0
	1	$NN \to NN$	c_j^{27}	0	0	0
-1	$\frac{1}{2}$	$\Lambda N \to \Lambda N$	$\frac{1}{10}(9c_j^{27} + c_j^{8s})$	$\frac{1}{2}(c_j^{10^*} + c_j^{8a})$	$-c^{8as}$	$-c^{8as}$
	$\frac{1}{2}$	$\Lambda N \to \Sigma N$	$-\frac{3}{10}(c_j^{27} - c_j^{8s})$	$\frac{1}{2}(c_j^{10^*} - c_j^{8a})$	$-3c^{8as}$	c^{8as}
	$\frac{1}{2}$	$\Sigma N \to \Sigma N$	$\frac{1}{10}(c_j^{27} + 9c_j^{8s})$	$\frac{1}{2}(c_j^{10^*} + c_j^{8a})$	$3c^{8as}$	$3c^{8as}$
	$\frac{3}{2}$	$\Sigma N \to \Sigma N$	c_j^{27}	c_j^{10}	0	0
-2	0	$\Lambda\Lambda \to \Lambda\Lambda$	$\frac{1}{40}(5c_j^{1} + 27c_j^{27} + 8c_j^{8s})$	0	0	0
	0	$\Lambda\Lambda \to \Xi N$	$\frac{1}{20}(5c_j^{1} - 9c_j^{27} + 4c_j^{8s})$	0	0	$2c^{8as}$
	0	$\Lambda\Lambda \to \Sigma\Sigma$	$-\frac{\sqrt{3}}{40}(5c_j^{1} + 3c_j^{27} - 8c_j^{8s})$	0	0	0
	0	$\Xi N \to \Xi N$	$\frac{1}{10}(5c_j^{1} + 3c_j^{27} + 2c_j^{8s})$	c_j^{8a}	$2c^{8as}$	$2c^{8as}$
	0	$\Xi N \to \Sigma\Sigma$	$\frac{\sqrt{3}}{20}(-5c_j^{1} + c_j^{27} + 4c_j^{8s})$	0	$2\sqrt{3}c^{8as}$	0
	0	$\Sigma\Sigma \to \Sigma\Sigma$	$\frac{1}{40}(15c_j^{1} + c_j^{27} + 24c_j^{8s})$	0	0	0
	1	$\Xi N \to \Xi N$	$\frac{1}{5}(2c_j^{27} + 3c_j^{8s})$	$\frac{1}{3}(c_j^{10} + c_j^{10^*} + c_j^{8a})$	$-2c^{8as}$	
	1	$\Xi N \to \Sigma\Sigma$	0	$\frac{1}{3\sqrt{2}}(c_j^{10} + c_j^{10^*} - 2c_j^{8a})$	0	$2\sqrt{2}c^{8as}$
	1	$\Xi N \to \Sigma\Lambda$	$\frac{\sqrt{6}}{5}(c_j^{27} - c_j^{8s})$	$\frac{1}{\sqrt{6}}(c_j^{10} - c_j^{10^*})$	$2\sqrt{\frac{2}{3}}c^{8as}$	0
	1	$\Sigma\Lambda \to \Sigma\Lambda$	$\frac{1}{5}(3c_j^{27} + 2c_j^{8s})$	$\frac{1}{2}(c_j^{10} + c_j^{10^*})$	0	
	1	$\Sigma\Lambda \to \Sigma\Sigma$	0	$\frac{1}{2\sqrt{3}}(c_j^{10} - c_j^{10^*})$	0	$\frac{4}{\sqrt{3}}c^{8as}$
	1	$\Sigma\Sigma \to \Sigma\Sigma$	0	$\frac{1}{6}(c_j^{10} + c_j^{10^*} + 4c_j^{8a})$	0	0
	2	$\Sigma\Sigma \to \Sigma\Sigma$	c_j^{27}	0	0	0
-3	$\frac{1}{2}$	$\Xi\Lambda \to \Xi\Lambda$	$\frac{1}{10}(9c_j^{27} + c_j^{8s})$	$\frac{1}{2}(c_j^{10} + c_j^{8a})$	$-c^{8as}$	$-c^{8as}$
	$\frac{1}{2}$	$\Xi\Lambda \to \Xi\Sigma$	$-\frac{3}{10}(c_j^{27} - c_j^{8s})$	$\frac{1}{2}(c_j^{10} - c_j^{8a})$	$-3c^{8as}$	c^{8as}
	$\frac{1}{2}$	$\Xi\Sigma \to \Xi\Sigma$	$\frac{1}{10}(c_j^{27} + 9c_j^{8s})$	$\frac{1}{2}(c_j^{10} + c_j^{8a})$	$3c^{8as}$	$3c^{8as}$
	$\frac{3}{2}$	$\Xi\Sigma \to \Xi\Sigma$	c_j^{27}	$c_j^{10^*}$	0	0
-4	0	$\Xi\Xi \to \Xi\Xi$	0	c_j^{10}	0	0
	1	$\Xi\Xi \to \Xi\Xi$	c_j^{27}	0	0	0

$$\mathbf{8} \otimes \mathbf{8} = \mathbf{27} \oplus \mathbf{8_s} \oplus \mathbf{1} \oplus \mathbf{10} \oplus \mathbf{10^*} \oplus \mathbf{8_a}$$

[Polinder, Haidenbauer, Meißner, Nucl.Phys.A779, 2006]
[Petschauer, Kaiser, Nucl.Phys.A916, 2013]

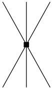
S	I	transition	${}^1S_0\ \chi$	${}^3S_1\ \chi$
0	0	$NN \to NN$	0	$\frac{c_\chi^7}{2}$
	1	$NN \to NN$	$\frac{c_\chi^1}{2}$	0
-1	$\frac{1}{2}$	$\Lambda N \to \Lambda N$	c_χ^2	c_χ^8
	$\frac{1}{2}$	$\Lambda N \to \Sigma N$	$-c_\chi^3$	$-c_\chi^9$
	$\frac{1}{2}$	$\Sigma N \to \Sigma N$	c_χ^4	c_χ^{10}
	$\frac{3}{2}$	$\Sigma N \to \Sigma N$	$\frac{c_\chi^1}{4}$	$-\frac{c_\chi^7}{4}$
-2	0	$\Lambda\Lambda \to \Lambda\Lambda$	$\frac{c_\chi^5}{2}$	0
	0	$\Lambda\Lambda \to \Xi N$	$\frac{3c_\chi^1}{4} - 3c_\chi^2 - c_\chi^3 + \frac{3c_\chi^5}{4}$	0
	0	$\Lambda\Lambda \to \Sigma\Sigma$	0	0
	0	$\Xi N \to \Xi N$	$\frac{2c_\chi^1}{3} - 3c_\chi^2 + \frac{c_\chi^4}{3} + \frac{9c_\chi^5}{8}$	c_χ^{11}
	0	$\Xi N \to \Sigma\Sigma$	$-\frac{c_\chi^1}{4\sqrt{3}} + \sqrt{3}c_\chi^3 + \frac{c_\chi^4}{\sqrt{3}}$	0
	0	$\Sigma\Sigma \to \Sigma\Sigma$	0	0
	1	$\Xi N \to \Xi N$	c_χ^6	c_χ^{12}
	1	$\Xi N \to \Sigma\Sigma$	0	$\sqrt{2}c_\chi^{10} - \frac{c_\chi^7}{2\sqrt{2}} - \sqrt{2}c_\chi^9$
	1	$\Xi N \to \Sigma\Lambda$	$-\frac{1}{3}\sqrt{\frac{2}{3}}c_\chi^1 + \sqrt{\frac{3}{2}}c_\chi^2 - \frac{c_\chi^4}{3\sqrt{6}} - \sqrt{\frac{2}{3}}c_\chi^6$	$\frac{c_\chi^{10}}{\sqrt{6}} + \sqrt{\frac{2}{3}}c_\chi^{12} + \frac{c_\chi^7}{2\sqrt{6}} - \sqrt{\frac{3}{2}}c_\chi^8 + \sqrt{\frac{2}{3}}c_\chi^9$
	1	$\Sigma\Lambda \to \Sigma\Lambda$	$-\frac{c_\chi^1}{9} + \frac{4c_\chi^3}{3} + \frac{4c_\chi^4}{9} + \frac{2c_\chi^6}{3}$	$\frac{4c_\chi^{10}}{3} + \frac{2c_\chi^{12}}{3} - \frac{c_\chi^7}{3} - \frac{4c_\chi^9}{3}$
	1	$\Sigma\Lambda \to \Sigma\Sigma$	0	0
	1	$\Sigma\Sigma \to \Sigma\Sigma$	0	0
	2	$\Sigma\Sigma \to \Sigma\Sigma$	0	0
-3	$\frac{1}{2}$	$\Xi\Lambda \to \Xi\Lambda$	$-\frac{55c_\chi^1}{72} + 2c_\chi^2 + \frac{7c_\chi^3}{6} + \frac{c_\chi^4}{18} + \frac{3c_\chi^5}{32} + \frac{c_\chi^6}{12}$	$\frac{11c_\chi^{10}}{12} + \frac{3c_\chi^{11}}{4} + \frac{25c_\chi^{12}}{12} + \frac{5c_\chi^7}{24} - \frac{7c_\chi^8}{4} - \frac{c_\chi^9}{6}$
	$\frac{1}{2}$	$\Xi\Lambda \to \Xi\Sigma$	$\frac{11c_\chi^1}{24} - \frac{3c_\chi^2}{2} - \frac{c_\chi^3}{2} - \frac{c_\chi^4}{3} + \frac{9c_\chi^5}{32} + \frac{c_\chi^6}{4}$	$\frac{9c_\chi^{10}}{4} - \frac{3c_\chi^{11}}{4} + \frac{5c_\chi^{12}}{4} - \frac{c_\chi^7}{8} - \frac{3c_\chi^8}{4} - \frac{c_\chi^9}{2}$
	$\frac{1}{2}$	$\Xi\Sigma \to \Xi\Sigma$	$\frac{11c_\chi^1}{24} - 3c_\chi^2 + \frac{5c_\chi^3}{2} + \frac{c_\chi^4}{6} + \frac{27c_\chi^5}{32} + \frac{3c_\chi^6}{4}$	$\frac{5c_\chi^{10}}{4} + \frac{3c_\chi^{11}}{4} + \frac{3c_\chi^{12}}{4} - \frac{c_\chi^7}{8} - \frac{3c_\chi^8}{4} - \frac{3c_\chi^9}{2}$
	$\frac{3}{2}$	$\Xi\Sigma \to \Xi\Sigma$	$-\frac{2c_\chi^1}{3} + \frac{3c_\chi^2}{2} + c_\chi^3 + \frac{c_\chi^4}{6}$	$\frac{3c_\chi^{10}}{2} - c_\chi^7 + \frac{3c_\chi^8}{2} - 3c_\chi^9$
-4	0	$\Xi\Xi \to \Xi\Xi$	0	$5c_\chi^{10} + 4c_\chi^{12} - 3c_\chi^8 - 2c_\chi^9$
	1	$\Xi\Xi \to \Xi\Xi$	$-\frac{4c_\chi^1}{3} + 3c_\chi^2 + 2c_\chi^3 + \frac{c_\chi^4}{3}$	0

[Petschauer, Kaiser, Nucl.Phys.A916, 2013]

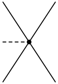
Table of Contents

Constructing the chiral Lagrangian

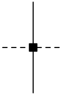
- symmetries of the effective Lagrangian:
  - chiral symmetry $\mathrm{SU}(3)_\mathrm{L} \times \mathrm{SU}(3)_\mathrm{R}$
  - C, P, T, Hermitian conjugation
  - Lorentz transformation
- degrees of freedom:
  - pseudoscalar Goldstone boson octet (π, K, η)
  - baryon octet $(N, \Lambda, \Sigma, \Xi)$
  - baryon decuplet $(\Delta, \Sigma^*, \Xi^*, \Omega)$
- antisymmetrized potential to respect generalized Pauli principle
- vertices:



18 low-energy constants
(SU(3) symmetric)

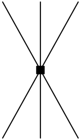


14 low-energy constants
[Petschauer, Kaiser, Nucl.Phys.A916, 2013]



10 low-energy constants
[Krause, Helv.Phys.Acta 63, 1990]

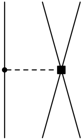
Potentials for leading three-baryon forces



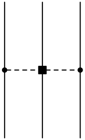
$$V^{\text{ct}} = N_1 \mathbb{1} + N_2 \vec{\sigma}_1 \cdot \vec{\sigma}_2 + N_3 \vec{\sigma}_1 \cdot \vec{\sigma}_3 + N_4 \vec{\sigma}_2 \cdot \vec{\sigma}_3 + N_5 \mathrm{i}\, \vec{\sigma}_1 \times \vec{\sigma}_2 \cdot \vec{\sigma}_3$$

example: $V^{\text{ct}, I=0}_{\Lambda NN \to \Lambda NN} = c_1 (\mathbb{1} + \frac{1}{3}\, \vec{\sigma}_2 \cdot \vec{\sigma}_3) + c_2 (\vec{\sigma}_1 \cdot \vec{\sigma}_2 + \vec{\sigma}_1 \cdot \vec{\sigma}_3)$

$V^{\text{ct}, I=1}_{\Lambda NN \to \Lambda NN} = c_3 (\mathbb{1} - \vec{\sigma}_2 \cdot \vec{\sigma}_3)$



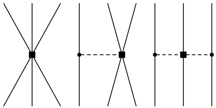
$$V^{1\phi} = -\frac{1}{2 f_0^2} \frac{\vec{\sigma}_1 \cdot \vec{q}_1}{\vec{q}_1^{\,2} + m_\phi^2} \left\{ N_6 \vec{\sigma}_2 \cdot \vec{q}_1 + N_7 \vec{\sigma}_3 \cdot \vec{q}_1 + N_8 \mathrm{i}\, (\vec{\sigma}_2 \times \vec{\sigma}_3) \cdot \vec{q}_1 \right\}$$



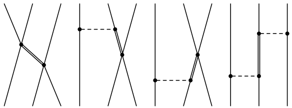
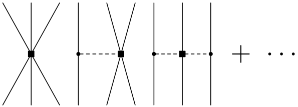
$$V^{2\phi} = \frac{1}{4 f_0^2} \frac{\vec{\sigma}_1 \cdot \vec{q}_1 \; \vec{\sigma}_3 \cdot \vec{q}_3}{(\vec{q}_1^{\,2} + m_{\phi_1}^2)(\vec{q}_3^{\,2} + m_{\phi_3}^2)} \times \left\{ N_9 m_\pi^2 + N_{10} m_K^2 + N_{11} \vec{q}_1 \cdot \vec{q}_3 + N_{12} \mathrm{i}\, \vec{\sigma}_2 \cdot (\vec{q}_1 \times \vec{q}_3) \right\}$$

$p_i(p_i')$ are initial (final) momenta of the baryon i and $\vec{q}_i \equiv \vec{p}_i^{\,\prime} - \vec{p}_i$

Hierarchy of three-baryon forces

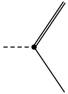
	3B Force
LO	—
NLO	—
N^2LO	

Hierarchy of three-baryon forces

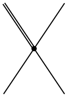
	3B Force with decuplet baryons
LO	—
NLO	
N^2LO	

Three-baryon forces and explicit decuplet baryons

- new vertices:



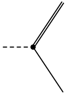
one constant ($C = \frac{3}{4} g_A \approx 1$ from $\Delta \to N\pi$)



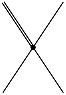
two constants (Pauli-forbidden in nucleonic sector)

Three-baryon forces and explicit decuplet baryons

- new vertices:



one constant ($C = \frac{3}{4} g_A \approx 1$ from $\Delta \to N\pi$)

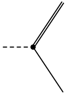


two constants (Pauli-forbidden in nucleonic sector)

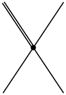
	tensor products in *flavor* space	and in *spin* space
final state	$\mathbf{10} \otimes \mathbf{8} = \mathbf{35} \oplus \mathbf{27} \oplus \mathbf{10} \oplus \mathbf{8}$	$\mathbf{3/2} \otimes \mathbf{1/2} = \mathbf{1} \oplus \mathbf{2}$

Three-baryon forces and explicit decuplet baryons

- new vertices:



one constant ($C = \frac{3}{4} g_A \approx 1$ from $\Delta \to N\pi$)

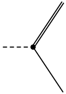


two constants (Pauli-forbidden in nucleonic sector)

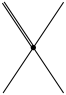
	tensor products in *flavor* space	and in *spin* space
final state	$\mathbf{10} \otimes \mathbf{8} = \mathbf{35} \oplus \mathbf{27} \oplus \mathbf{10} \oplus \mathbf{8}$	$\mathbf{3/2} \otimes \mathbf{1/2} = \mathbf{1} \oplus \mathbf{2}$
initial state	$\mathbf{8} \otimes \mathbf{8} = \underbrace{\mathbf{27} \oplus \mathbf{8_s} \oplus \mathbf{1}}_{\text{symmetric}} \oplus \underbrace{\mathbf{10} \oplus \overline{\mathbf{10}} \oplus \mathbf{8_a}}_{\text{antisymmetric}}$	$\mathbf{1/2} \otimes \mathbf{1/2} = \underbrace{\mathbf{0}}_{\text{a.sym.}} \oplus \underbrace{\mathbf{1}}_{\text{sym.}}$

Three-baryon forces and explicit decuplet baryons

- new vertices:



one constant ($C = \frac{3}{4} g_A \approx 1$ from $\Delta \to N\pi$)



two constants (Pauli-forbidden in nucleonic sector)

	tensor products in *flavor* space	and in *spin* space
final state	$\mathbf{10} \otimes \mathbf{8} = \mathbf{35} \oplus \mathbf{27} \oplus \mathbf{10} \oplus \mathbf{8}$	$\mathbf{3/2} \otimes \mathbf{1/2} = \mathbf{1} \oplus \mathbf{2}$
initial state	$\mathbf{8} \otimes \mathbf{8} = \underbrace{\mathbf{27} \oplus \mathbf{8_s} \oplus \mathbf{1}}_{\text{symmetric}} \oplus \underbrace{\mathbf{10} \oplus \overline{\mathbf{10}} \oplus \mathbf{8_a}}_{\text{antisymmetric}}$	$\mathbf{1/2} \otimes \mathbf{1/2} = \underbrace{\mathbf{0}}_{\text{a.sym.}} \oplus \underbrace{\mathbf{1}}_{\text{sym.}}$

- estimate chiral three-baryon forces via decuplet saturation:

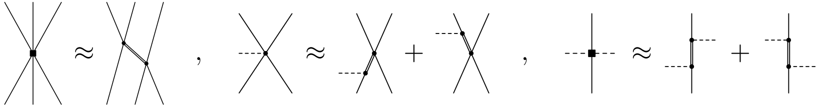


Table of Contents

Summary

- SU(3) heavy baryon chiral effective field theory
- Hyperon-nucleon potentials at NLO including one- and two-meson exchange and contact terms with SU(3) symmetric LECs
- good description of available YN data; comparable to phenomenological models
- leading three-baryon forces constructed
- constants estimated through decuplet exchange $\Rightarrow$ only 2 unknown low-energy constants left

Outlook

- future applications of YN potential: hypernuclei, neutron star matter, hyperons in nuclear matter
- quantify effect of three-baryon forces in light hypernuclei