Nuclear systems with strangeness.

From hypernuclei to kaonic nuclei

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Hypernuclei

- Hypernuclei = nuclear systems containing nucleons + 1 or more hyperons. (M.Danysz, J. Pniewski, Bull. Pol. Acad.Sci. 1 (1953) 42.)

BARYONS						
	Non-Strange		Hyperons			
Particle	N	Δ	Λ	Σ	Ξ	Ω
Mass	940	1232	1116	1190	1315	1672
Spin	1/2	3/2	1/2	1/2	1/2	1/2
Isospin	1/2	3/2	0	1	1/2	0
Strangeness	0	0	-1	-1	-2	-3
Quarks	uud udd	uuu uud udd ddd	uds	uus uds dds	uss dss	sss

Particle	Lifetime	Width	Decay
p	$> 10^{31}$years	≈ 0	—
n	896 s	$7.2 \times 10^{-19} eV$	—
Δ	$5.5 \times 10^{-24} s$	120 MeV	πN
Λ	$2.6 \times 10^{-10} s$	2.5 μeV	πN
$\Sigma^{\pm}$	$0.8 \times 10^{-10} s$	8.2 μeV	πN
Σ^0	$7.4 \times 10^{-20} s$	8.9 KeV	$\gamma\Lambda$
Ξ	$1.6 \times 10^{-10} s$	4.1 μeV	$k\Lambda$
Ω	$0.8 \times 10^{-10} s$	8.2 μeV	$k\Lambda$,$\pi\Xi$

Why to study hypernuclei?

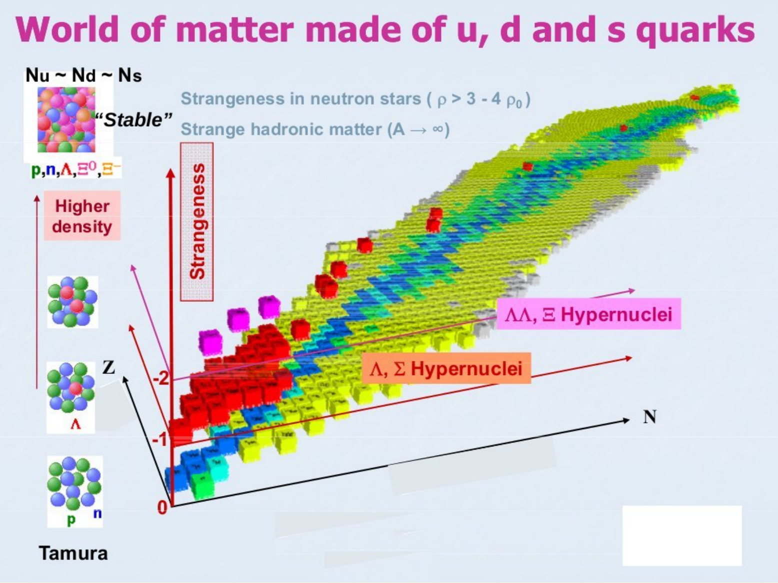
- Test models of baryon-baryon and meson-baryon interactions (meson exchange models, quark models, chiral models, ...)
- Test nuclear models (RMF,EDF,RPA ...)
- Test models of hadrons (SU(3)symmetry, quark models ...)
- Hypernuclear production – test reaction mechanisms
- Hypernuclear decays $\longrightarrow$ study of weak interaction

Hyperon X Nucleon $\rightarrow$ no Pauli blocking $\rightarrow$ Hyperon can penetrate deep into the nuclear interior, probe the nuclear interior, test the nuclear response

Implications for astrophysics (compact stars), HI collisions (strangeness production, medium modification od hadrons)

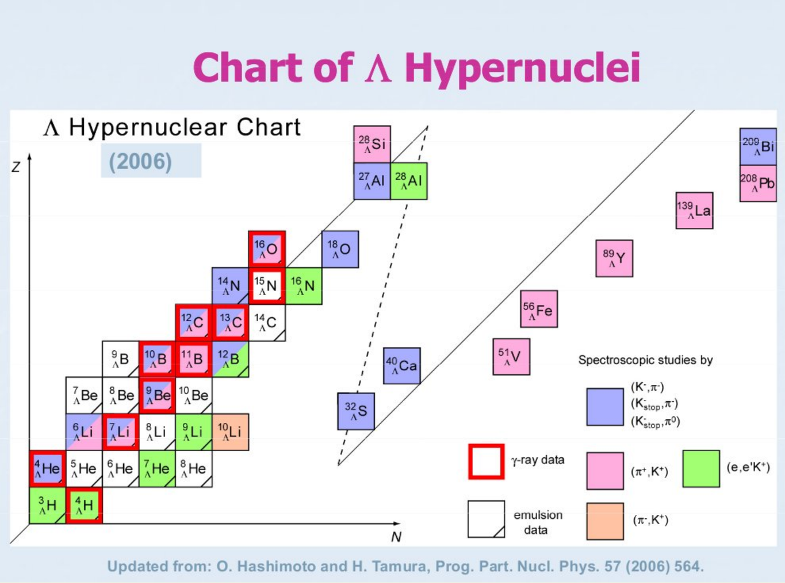
Λ *hypernuclei*

- >30 Λ-hypernuclei:



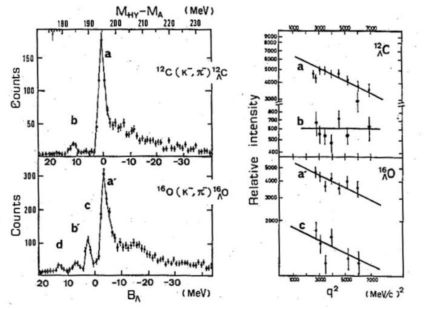
Λ *hypernuclei*

- $>$ 30 Λ-hypernuclei:



Λ *hypernuclei*

- (K^-, π^-) reaction (emulsions, CERN, BNL, KEK, Frascati, JParc):



$$a = a' = (p_{3/2}^{-1}, p_{3/2}^{\Lambda})_{J=0^+} \qquad B_\Lambda(a) = 0 \text{ MeV},\ B_\Lambda(a') = -3.5 \text{ MeV}$$

$$b = b' = (p_{3/2}^{-1}, s_{1/2}^{\Lambda})_{J=1^-} \qquad B_\Lambda(b) = 11 \text{ MeV},\ B_\Lambda(b') = 7 \text{ MeV}$$

$$c = (p_{1/2}^{-1}, p_{1/2}^{\Lambda})_{J=0^+} \qquad B_\Lambda(c) = 2.5 \text{ MeV}$$

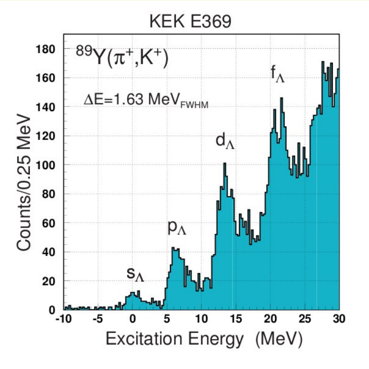
$$d = (p_{1/2}^{-1}, s_{1/2}^{\Lambda})_{J=1^-} \qquad B_\Lambda(d) = 13 \text{ MeV}$$

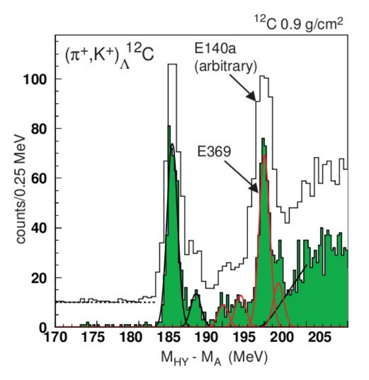
$B_\Lambda(b') - B_\Lambda(d) = 6$ MeV (n SO splitting), $B_\Lambda(a') - B_\Lambda(c) = 6$ MeV (n + Λ SO splitting)

$\Rightarrow \Delta(p_{1/2}^{\Lambda} - p_{3/2}^{\Lambda}) \lesssim 0.3$ MeV

Λ *hypernuclei*

- (π^+, K^+) reaction (BNL, KEK):





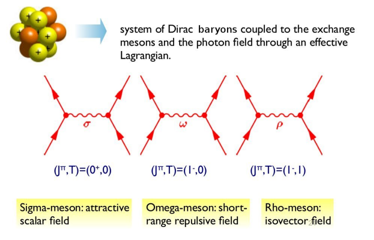
Hotchi et al, PRC 64 (2001) 044302

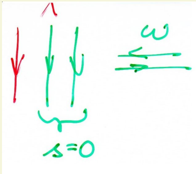
- Textbook example of single-particle structure
- Λ hyperon bound by $\sim$ 28 MeV in nuclear matter
- Negligible spin-orbit splitting

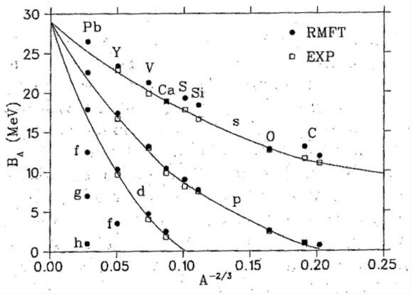
Λ *hypernuclei*

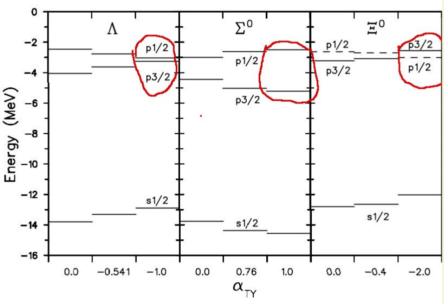
- RMF calculations (J.M., B.K. Jennings, PRC (1994):

  (+ quark model + $Y\omega$ tensor coupling $\frac{f_{\omega Y}}{2M_Y}\bar{\Psi}_Y\sigma^{\mu\nu}\partial_\nu V_\mu \Psi_Y$)









Λ hypernuclei

Table 2

Binding energies (in MeV) of single-Λ levels in ${}^{13}_{\Lambda}$C, ${}^{16}_{\Lambda}$O, ${}^{40}_{\Lambda}$Ca and ${}^{89}_{\Lambda}$Y. Experimental energies [1] are shown in comparison with the results of the present calculations, using the input parameters of Table 1 and $\zeta = 0.5$ (column FKVW). Also listed are results of five different models: Quark Meson Coupling (QMC) [12,13], Fermi Hypernetted Chain (FHNC) [18], Skyrme (SK) [16], Brueckner–Hartree–Fock (BHF) [19] with the Njimegen SC97F potential [50], and RMF models with a tensor coupling [11] (RMFI with $f^{\Lambda}_{\omega}/g^{\Lambda}_{\omega} = -1$) and density-dependent couplings [14] (RMFII).

Nucleus	$\epsilon_{s.p.}$	Expt.	FKVW	QMC	FHNC	SK	BHF	RMFI	RMFII
${}^{13}_{\Lambda}$C	$1s_{1/2}$	11.38 ± 0.05	12.3	–	8.3	11.7	13.7	12.5	11.7
	$1p_{3/2}$	0.38 ± 0.1	0.1	–	–	0.9	1.4	1.1	1.1
	$1p_{1/2}$		0.0					0.8	0.0
${}^{16}_{\Lambda}$O	$1s_{1/2}$	12.42 ± 0.05	12.6	16.2	12.00	13.3	15.5	12.9	12.8
	$1p_{3/2}$	1.85 ± 0.06	2.0	6.4	1.8	3.0	3.7	3.3	2.8
	$1p_{1/2}$		1.9	6.4				3.0	1.4
${}^{40}_{\Lambda}$Ca	$1s_{1/2}$	20.0 ± 1.0	18.9	20.6	20.0	18.0	20.7	19.0	17.6
	$1p_{3/2}$	12.0 ± 1.0	10.1	13.9	10.6	10.1	11.5	10.7	9.1
	$1p_{1/2}$		10.1	13.9				10.5	7.8
	$1d_{5/2}$	1.0 ± 1.0	1.6	5.5	1.6	1.6	2.0	2.7	1.5
	$1d_{3/2}$		0.9	5.5				2.4	1.5
${}^{89}_{\Lambda}$Y	$1s_{1/2}$	23.1 ± 0.5	23.4	24.0	23.3	21.1	24.1	23.7	23.2
	$1p_{3/2}$	16.5 ± 4.1	17.2	19.4	16.9	15.6	17.8	17.6	17.2
	$1p_{1/2}$		17.2	19.4				17.4	16.3
	$1d_{5/2}$	9.1 ± 1.3	10.2	13.4	10.1	9.1	10.4	10.7	10.3
	$1d_{3/2}$		9.8	13.4				10.5	8.9
	$1f_{7/2}$	2.3 ± 1.2	2.8	6.5	–	2.1	2.4	3.7	3.1
	$1f_{5/2}$		2.0	6.4				3.4	1.0

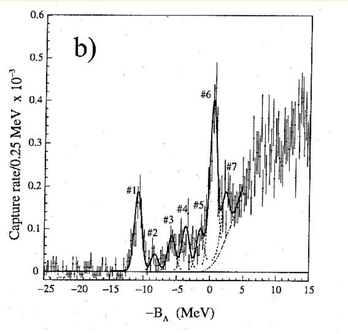
Λ hypernuclei

Table 4
P-shell spin–orbit splittings $\Delta \equiv \Delta\epsilon^{\Lambda}(p)$ for six hypernuclei ($^{13}_{\Lambda}$C, $^{16}_{\Lambda}$O, $^{40}_{\Lambda}$Ca, $^{89}_{\Lambda}$Y, $^{139}_{\Lambda}$La, $^{208}_{\Lambda}$Pb). Experimental values [44], or empirical estimates [1,47,48], are shown in comparison with our theoretical predictions (FKVW), using a broad range of ζ parameters (see Eq. (12)), and other relativistic calculations with (RMFI [11]) or without (RMFII [14]) tensor coupling. All energies are given in keV. The asterisk means that a local fit has been necessary.

Nucleus	Exp. Δ [keV]	FKVW $(0.4 \leqslant \zeta \leqslant 0.66)$	RMFI [11]	RMFII [14]
$^{13}_{\Lambda}$C	$152 \pm 54 \pm 36$ [44]	$-160 \leqslant \Delta \leqslant 510$	310	$\sim 1100^*$
$^{16}_{\Lambda}$O	$300 \leqslant \Delta \leqslant 600$ [47] $-800 \leqslant \Delta \leqslant 200$ [1]	$-210 \leqslant \Delta \leqslant 490$	270	~ 1400
$^{40}_{\Lambda}$Ca	–	$-140 \leqslant \Delta \leqslant 420$	210	~ 1400
$^{89}_{\Lambda}$Y	90 [48]	$-40 \leqslant \Delta \leqslant 180$	110	~ 700
$^{139}_{\Lambda}$La	–	$-20 \leqslant \Delta \leqslant 80$	50	~ 300
$^{208}_{\Lambda}$Pb	–	$-20 \leqslant \Delta \leqslant 70$	50	~ 300

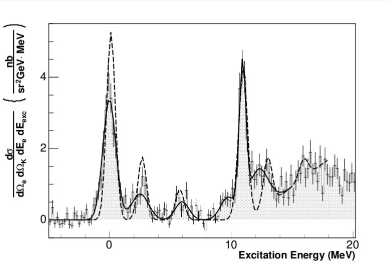
Λ *hypernuclei*

- $(K^-_{\text{stop}}, \pi^-)$ reaction (FINUDA, PLB 622 (2005) 35):



Λ binding energy spectrum in $^{12}_{\Lambda}$C

- $(e, e'K)$ reaction (JLab, PRL 99 (2007) 052501):

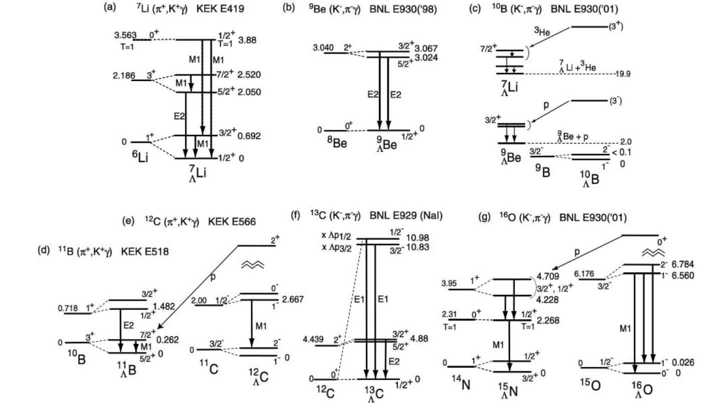


$^{12}_{\Lambda}$B excitation spectrum

Λ *hypernuclei*

- γ spectroscopy (BNL, KEK)

  ⇒ spin dependence of the effective ΛN interaction in the nuclear p shell



Level schemes of Λ hypernuclei from recent γ-ray measurements

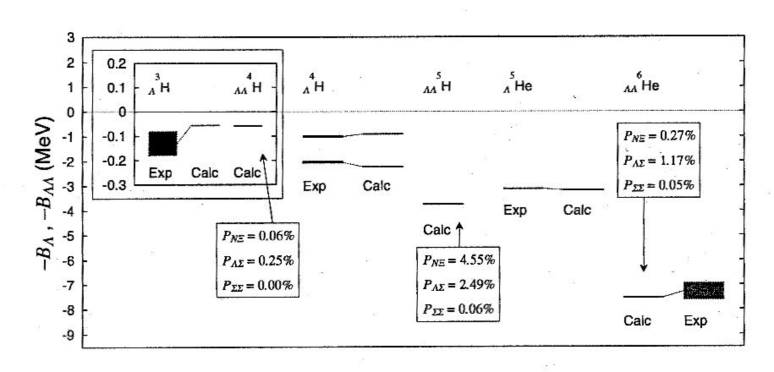
H. Tamura, Nucl. Phys. A 804 (2008) 73; 827 (2009) 153c [PANIC08]

$$V_{\Lambda N} = V_0(r) + V_\sigma(r)\, s_N \cdot s_\Lambda + V_{LS}(r)\, l_{N\Lambda} \cdot (s_\Lambda + s_N) + V_{ALS}(r)\, l_{N\Lambda} \cdot (s_\Lambda - s_N) + V_T(r)\, S_{12}$$

D.J. Millener, Nucl. Phys. A 804 (2008) 84

Λ *hypernuclei*

- s-shell Λ hypernuclei



Nemura et al, PRL 89 (2002) 142504 (including $\Lambda N \to \Sigma N$ and $\Lambda\Lambda \to \Xi N$ mixings)
variational approach

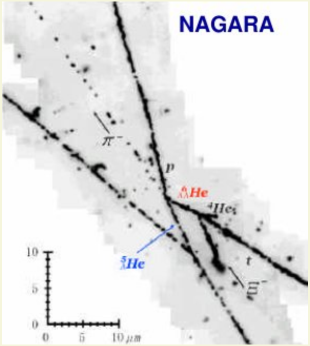
Hiyama et al, PRC 65 (2002) 011301(R) - Jacobi-coordinate Gaussian basis

Nogga et al, PRL 88 (2002) 172501 - Faddeev + Faddeev-Yakubovsky

ΛΛ *hypernuclei*

$$B_{\Lambda\Lambda}({}^{A}_{\Lambda\Lambda}Z) = B_{\Lambda}({}^{A}_{\Lambda\Lambda}Z) + B_{\Lambda}({}^{A-1}_{\Lambda}Z)$$
$$\Delta B_{\Lambda\Lambda}({}^{A}_{\Lambda\Lambda}Z) = B_{\Lambda}({}^{A}_{\Lambda\Lambda}Z) - B_{\Lambda}({}^{A-1}_{\Lambda}Z)$$

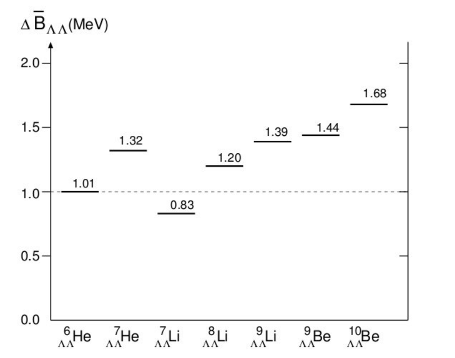
${}^{6}_{\Lambda\Lambda}$He (Prowse 66), ${}^{10}_{\Lambda\Lambda}$Be (Danysz 63), ${}^{13}_{\Lambda\Lambda}$B (KEK-E176 91) $\rightarrow \Delta B_{\Lambda\Lambda} \sim 4.3 - 4.8$ MeV



Takahashi et al, PRL 87 (2001) 212502

$$\Delta B_{\Lambda\Lambda}({}^{6}_{\Lambda\Lambda}\mathrm{He}) = B_{\Lambda\Lambda}({}^{6}_{\Lambda\Lambda}\mathrm{He}) - 2B_{\Lambda}({}^{5}_{\Lambda}\mathrm{He}) \approx 1 \text{ MeV}$$

ΛΛ *hypernuclei*

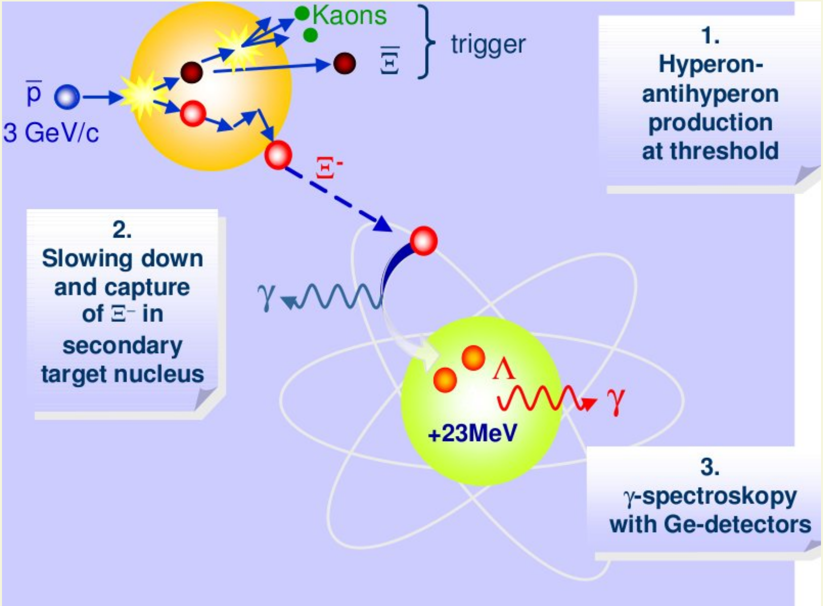


Hiyama, Kamimura, Motoba, Yamada, Yamamoto, NPA 754 (2005) 103c,

3- and 4-body cluster model calculations

Need to measure beyond $^{6}_{\Lambda\Lambda}$He $\rightarrow$ PANDA

ΛΛ *hypernuclei*



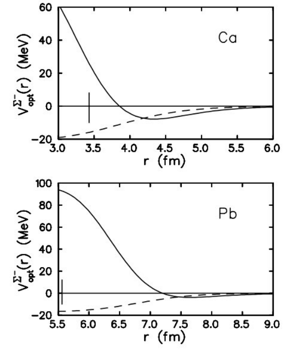
J. Pochodzalla

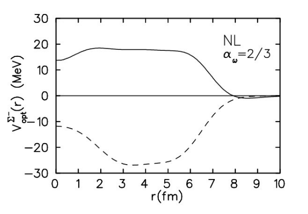
$\Lambda\Lambda$ *hypernuclei*

- Ξ^- conversion in 2 Λ: $\Xi^- + p \rightarrow \Lambda + \Lambda + 28.5$ MeV
- $p(K^-, K^+)\Xi^-$
  KEK - E176: 10^2 stopped Ξ per week
  KEK - E373: 10^3 stopped Ξ per week
  AGS - E885: 10^4 stopped Ξ per week
- $p + \bar{p} \rightarrow \Xi^- + \bar{\Xi}^+$
  antiproton storage ring HESR: few times 10^5 stopped Ξ per day !
  $\Rightarrow \gamma$-spectroscopy feasible

Σ *hypernuclei*

- Σ-nucleus interaction:
  (J.M., Friedman, Gal, Jennings, NPA 594 (1995) 311,
  E. Friedman, A. Gal, Phys. Rept. 452 (2007) 89)



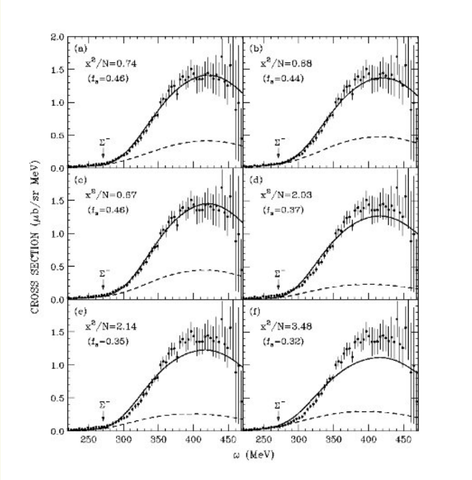


- Σ hyperons are not bound in nuclei except for $^{4}_{\Sigma}$He

- Sawafta et al, PRL 83 (1999) 25; Noumi et al, PRL 89 (2002) 072301

Σ *hypernuclei*

- DWIA calculations (Harada & Hirabayashi, NPA 759 (2005) 143)



^{28}Si(π^-, K^+) spectrum from KEK-E438, using 6 Σ-nucleus potentials,

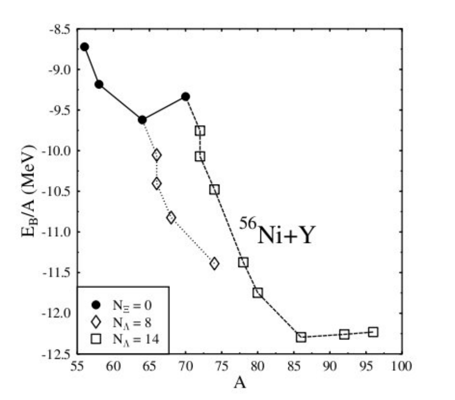
(a)-(c) with inner repulsion, (d)-(f) fully attractive

Ξ *hypernuclei*

- Ξ-nucleus interaction:

- no established yet QBS
- $^{12}\mathrm{C}(K^-, K^+)$ spectra (KEK -E224, BNL-E885) $\rightarrow$ $V_\Xi \approx 14\ \mathrm{MeV}$
- Calculations of light Ξ hypernuclei (Hiyama et al, PRC 78 (2008) 054316).
- Spectroscopic study of Ξ hypernucleus $^{12}_{\Xi}\mathrm{B}$ ... (T. Nagae), A 'Day-1' experiment E05 at J-Parc

Multi-strange baryonic systems

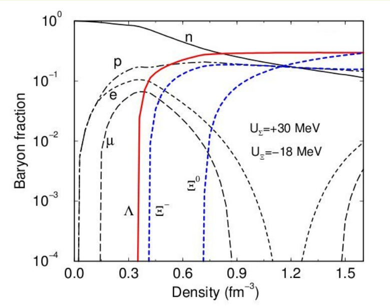


J. Schaffner, C.B. Dover, A. Gal, C. Greiner, H. Stöcker, PRL 71 (1993) 1328.

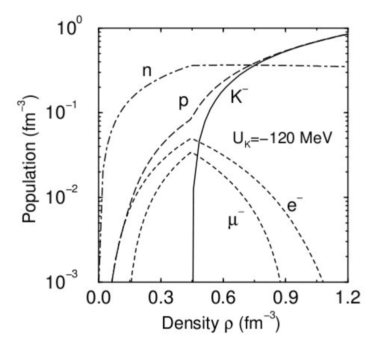
$\Xi N \rightarrow \Lambda\Lambda$ ($\approx$ 25 MeV in free space) is Pauli blocked

Strange hadronic matter

- neutron star structure



Schaffner-Bielich, NPA 804 (2008) 309



Glendenning, Schaffner-Bielich,

PRC 60 (1999) 025803

- kaon condensation could occur at $\rho \gtrsim 3\rho_0$, $l^- \rightarrow K^- + \nu_l$ ($\omega_{K^-} \leq 200$ MeV)

Kaonic nuclei

- $\bar{K}N$ interaction

  strongly attractive $\Leftarrow\ \exists\ \Lambda(1405)$ 27 MeV below K^-p threshold

- $\bar{K}$-nucleus interaction

  strongly attractive and absorptive $\Leftarrow$ kaonic atom level shifts and widths

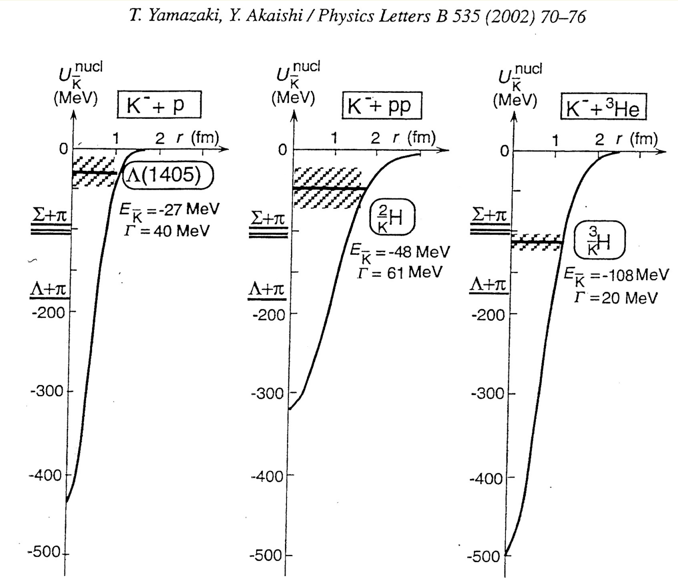
  ? optical potential depth:

  $\mathrm{Re}V_{opt} \simeq (\mathbf{150{-}200})$ MeV $\leftarrow$ phenomenological models
  $\mathrm{Re}V_{opt} \simeq (\mathbf{50{-}60})$ MeV $\leftarrow$ chiral models

  $\Rightarrow\ \exists$ of $\bar{K}$-nuclear states

  ? sufficiently narrow to allow identification by experiment

Kaonic nuclei



Status Quo

- K^- capture in Li and ^{12}C (FINUDA, PRL (2005)): $B = 115 \pm 6 \pm 4$ MeV, $\Gamma = 67 \pm 14 \pm 3$ MeV

vs.

- $K^- pN \rightarrow \Lambda N + FSI$ (Magas *et al.*, PRC (2006))

vs.

- K^- stopped in ^{6}Li $\rightarrow K^- ppn$ cluster, $B = 58 \pm 6$ MeV, $\Gamma \simeq 30$ MeV
  (FINUDA, PLB (2007) vs. Magas *et al.*, arXiv:0801.4504)

?

- $\bar{p}$ annihilation on ^{4}He (Obelix, LEAR) $\rightarrow K^- pp$: $B \simeq 160$ MeV, $\Gamma \simeq 24$ MeV
  $\rightarrow K^- ppn$: $B = 121 \pm 15$ MeV, $\Gamma < 60$ MeV
  (Bendiscioli *et al.*, NPA (2007))
- $pp \rightarrow K^+ \Lambda p$ (DISTO) $\rightarrow K^- pp$: $B = 105 \pm 118$ MeV
  (T. Yamazaki *et al* EXA08, arXiv: 0810.5182 [nucl-ex])

?

K^-pp quasibound state

- Coupled-channel calculations of a $\bar{K}NN - \pi\Sigma N$ system
  (Shevchenko, Gal, JM, PRL 98 (2007) 082301.)

- 3-body Faddeev equations (in AGS form):

$$\begin{aligned} U_{11} &= \quad\; + T_2\, G_0\, U_{21} + T_3\, G_0\, U_{31} \\ U_{21} &= G_0^{-1} + T_1\, G_0\, U_{11} + T_3\, G_0\, U_{31} \\ U_{31} &= G_0^{-1} + T_1\, G_0\, U_{11} + T_2\, G_0\, U_{21}, \end{aligned}$$

U_{ij} describe elastic and re-arrangement processes:

$$\begin{aligned} U_{11} &: \; 1 + (23) \to 1 + (23) \\ U_{21} &: \; 1 + (23) \to 2 + (31) \\ U_{31} &: \; 1 + (23) \to 3 + (12) \end{aligned}$$

- $\bar{K}N$ strongly coupled with $\pi\Sigma$ via $\Lambda(1405) \Rightarrow \pi\Sigma$ channel included

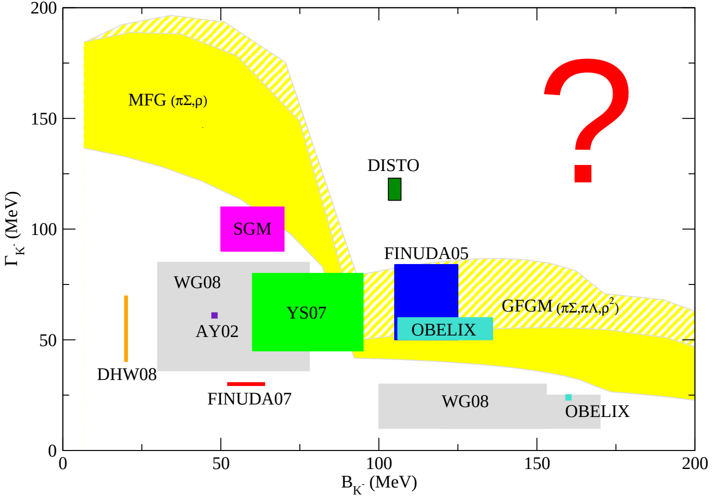
particle channels α:	$1 : (\bar{K}NN)$	$2 : (\pi\Sigma N)$	$3 : (\pi N\Sigma)$
$i = 1$	NN	ΣN	ΣN
$i = 2$	$\bar{K}N$	πN	$\pi\Sigma$
$i = 3$	$\bar{K}N$	$\pi\Sigma$	πN

K^-pp quasibound state

Table: Calculated K^-pp binding energies and widths (in MeV)

	single channel		coupled channel		
	AY	DHW	SGM	IS	WG
B	48	17-23	50-70	60 - 95	40-80
Γ	61	40-70	90-110	45-80	40-85

Status Quo



200
150
100
50
0
0
50
100
150
200
Γ_{K^-} (MeV)
B_{K^-} (MeV)
MFG (πΣ,ρ)
DISTO
?
SGM
FINUDA05
WG08
YS07
GFGM (πΣ,πΛ,ρ²)
AY02
OBELIX
DHW08
FINUDA07
WG08
OBELIX

RMF Methodology

- Larger K^--nuclear systems

Relativistic mean field model for a system of **nucleons** , K **mesons**, and **hyperons** interacting through the exchange of σ, σ^*, ω, ρ, ϕ and photon fields:

$$\mathscr{L} = \mathscr{L}_{RMF} + \mathscr{L}_K + \mathscr{L}_Y$$

where

$$\mathscr{L}_{RMF} = \text{standard relativistic mean field lagrangian density}$$

$$\mathscr{L}_K = (\mathcal{D}_\mu K)^\dagger (\mathcal{D}^\mu K) - m_K^2 K^\dagger K - g_{\sigma K} m_K \sigma K^\dagger K - g_{\sigma^* K} m_K \sigma^* K^\dagger K \ ,$$

$$\mathscr{L}_Y = \bar{\psi}_Y [\mathrm{i}\not{D} - (m_Y - g_{\sigma Y}\sigma - g_{\sigma^* Y}\sigma^*)]\psi_Y \ ,$$

with covariant derivative:

$$\mathcal{D}_\mu = \partial_\mu + \mathrm{i}\, g_{\omega K}\, \omega_\mu + \mathrm{i}\, g_{\rho K}\, \vec{I} \cdot \vec{\rho}_\mu + \mathrm{i}\, g_{\phi K}\, \phi_\mu + \mathrm{i}\, e\, (I_3 + \tfrac{1}{2} Y) A_\mu \ .$$

RMF Methodology

+ **antikaons**:

$$(-\nabla^2 - E_{K^-}^2 + m_K^2 + \Pi_{K^-})K^- = 0$$

$$\begin{aligned} \mathrm{Re}\,\Pi_{K^-} &= -\, g_{\sigma^* K}\, m_K\, \sigma^* - g_{\sigma K}\, m_K\, \sigma - 2\, E_{K^-}(g_{\omega K}\, \omega + g_{\rho K}\, \rho + g_{\phi K}\, \phi + e\, A) \\ &\quad - (g_{\omega K}\, \omega + g_{\rho K}\, \rho + g_{\phi K}\, \phi + e\, A)^2 \end{aligned}$$

$$\mathrm{Im}\,\Pi_{K^-} = (0.7\, f_{1\Sigma} + 0.1\, f_{1\Lambda}) W_0\, \rho_N(r) + 0.2\, f_{2\Sigma}\, W_0\, \rho_N^2(r)/\tilde{\rho}_0$$

f_{iY} kinematical suppression factors
(reduced phase space)

W_0 constrained by kaonic atom data

Absorption through:

- pionic conversion modes $\propto \rho_N(r)$

  $\bar{K}N \rightarrow \pi\Sigma$+90 MeV, $\pi\Lambda$+170 MeV (70%, 10%)

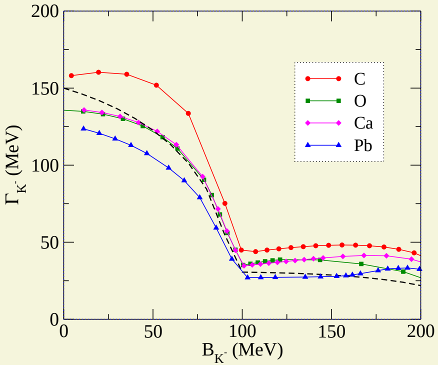
- nonmesonic modes $\propto \rho_N^2(r)$

  $\bar{K}NN \rightarrow YN$+240 MeV (20%)

Γ_{K-} width $\Leftarrow$ phase space suppression x density enhancement

Single-K^- nuclei

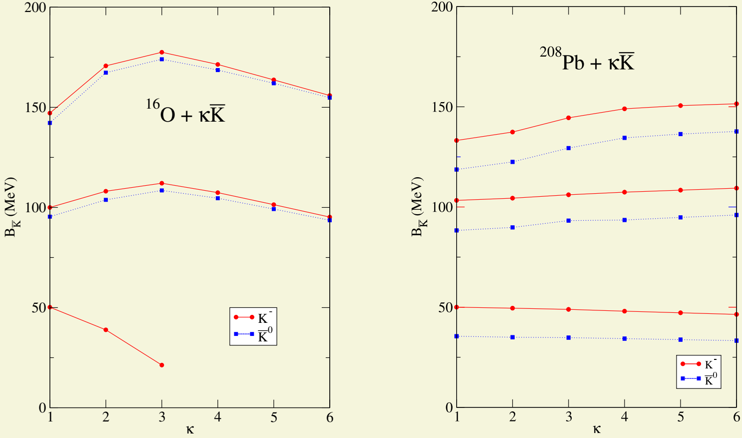
- Γ_{K^-} follows the dependence sf(B_{K^-})



The K^- decay widths Γ_{K^-} in $^{12}_{K^-}$C, $^{16}_{K^-}$O, $^{40}_{K^-}$Ca, and $^{208}_{K^-}$Pb as function of the K^- binding energy B_{K^-}.

The dashed line indicates a static nuclear matter calculation.

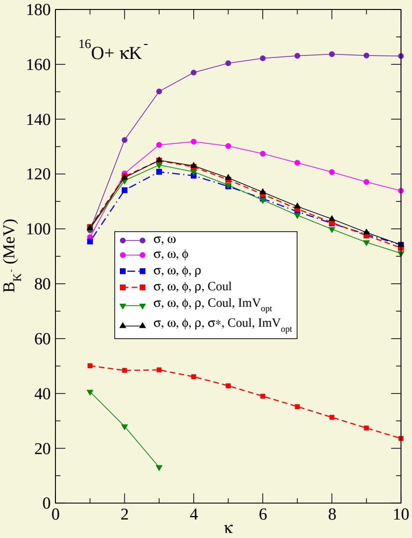
Multi-$\bar{K}$ nuclei



The $\bar{K}$ binding energies as functions of the number κ of antikaons.

- saturation observed across the periodic table
- $B_{\bar{K}} << m_K + m_N - m_\Lambda \gtrsim 320$ MeV, far away from kaon condensation

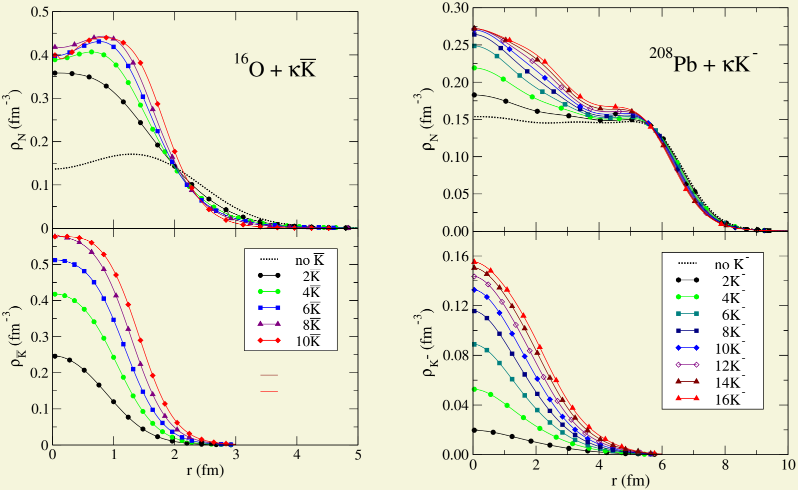
$Multi\text{-}\bar{K}$ nuclei



The K^- binding energy as a function of the number κ of antikaons.

- saturation occurs for any boson-field composition (when ω-field present $\Rightarrow$ repulsion)
- no saturation of $B_{\bar{K}}$ for a purely scalar interaction

Multi-$\bar{K}$ nuclei



Nuclear (ρ_N) and $\bar{K}$ ($\rho_{\bar{K}}$) density distributions for various numbers κ of antikaons.

Multi-$\bar{K}$ hypernuclei

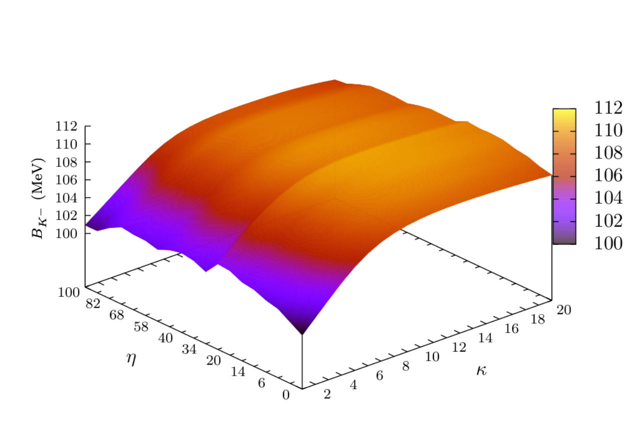
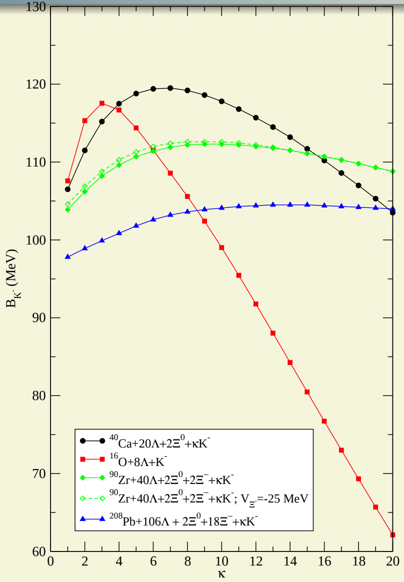


Fig. 17 The $\bar{K}$ binding energy $B_{\bar{K}}$ in ^{208}Pb as a function of the number κ of antikaons and η of Λ hyperons.

Multi-$\bar{K}$ hypernuclei



The $\bar{K}$ binding energy $B_{\bar{K}}$ in ${}^{A}\mathrm{Z} + \eta\Lambda + \mu_0\Xi^0 + \mu_-\Xi^- + \kappa K$ as a function of the number κ of antikaons.

Summary

- Λ hyperon bound by 28 MeV in nuclear matter, spin-orbit splitting $\rightarrow 0$
  Few-body Λ (and $\Lambda\Lambda$) hypernuclei - $\Sigma N \rightarrow \Lambda N$ important
  p-shell hypernuclei - effective ΛN interaction determined
  (exp. JLab, FINUDA, planned JParc, HypHI @ GSI (FAIR))

- more data on $\Lambda\Lambda$ hypernuclei needed $\rightarrow$ PANDA

- Σ hyperons are not bound in nuclei except for ${}^{4}_{\Sigma}$He

- Ξ hyperons perhaps bound by $\approx$ 14 MeV in nuclear matter
  (planned exp. JParc)

- $\bar{K}$ nuclei $\rightarrow$ the issue is far from being resolved
  (searches for $K^{-}pp$ are underway in GSI and JParc)

- kaon condensation is unlikely to occur in strong-interaction self-bound strange hadronic matter