Nuclei with Antikaons

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Outline

- Introduction and motivation
- Relativistic mean-field model for $\bar{K}$ nuclei
  - Single-$\bar{K}$ nuclei
  - Multi-$\bar{K}$ (hyper)nuclei
- Chiral approach for $\bar{K}$ nuclei
- Summary

Motivation

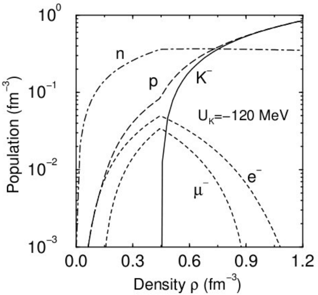
Study of $\bar{K}$ mesons in medium attracts considerable attention. Related topical questions include:

- Free-space and in-medium $\bar{K}N$ interaction:
  chiral model tests, nature of $\Lambda(1405)$
- Possible existence of (narrow) deeply bound $\bar{K}$–nuclear states
- Heavy ion collision:
  strangeness production, medium modifications
- Neutron stars:
  kaon condensation

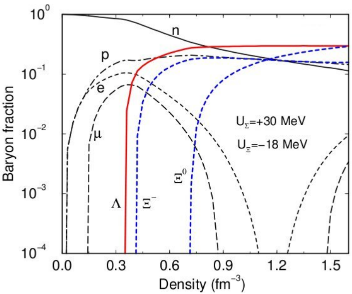
Motivation

Kaon condensation in neutron stars?

weak interaction operative, strangeness changing processes:
$e^- \rightarrow K^- \nu_e$ for $\mu_K = \mu_e \approx 200$ MeV



Glendenning, Schaffner-Bielich, PRC 60 (1999) 025803



Schaffner-Bielich, NPA 804 (2008) 309

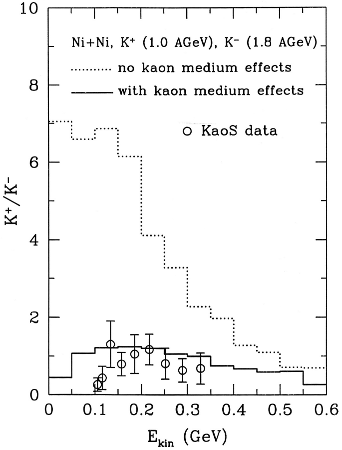
→ kaon condensation could occur at $\rho \gtrsim 3\rho_0$

Motivation

Heavy ion collisions – medium effects?

strong interaction operative

Li, Lee, Brown, NPA 625 (1997) 372



p+C, p+Au collisions

KaoS – Scheinast et al., PRL 96 (2006) 072301

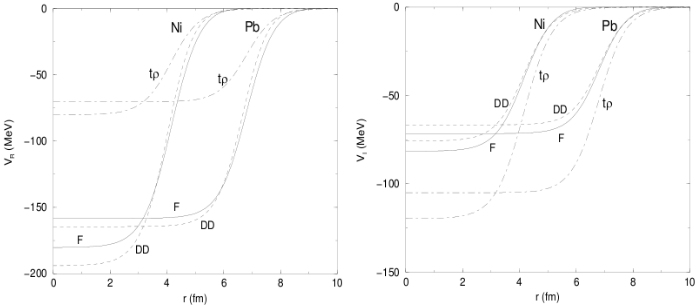
→ medium effects, $V_{K^-} \approx -80$ MeV

Motivation

Deeply bound and narrow $\bar{K}$–nuclear states?

phenomenological extrapolation from K^- atoms

(density-dependent optical potentials, RMF approach)



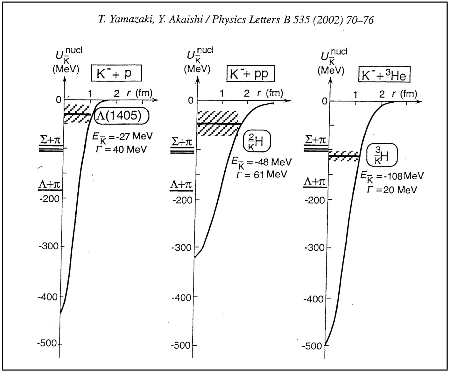
Mareš, Friedman, Gal, NPA 770 (2006) 84

$\rightarrow -\mathrm{Re}V_K \approx (180 - 200)$ MeV

Motivation

Deeply bound and narrow $\bar{K}$–nuclear states?

early calculations:



Motivation

Deeply bound and narrow K̄–nuclear states?

microscopic approaches based on chiral models
constrained by low-energy $\bar{K}N$ data (scattering, kaonic ^{1}H, branching ratios)

K̄N interaction

$\exists$ $\Lambda(1405)$ resonance $\Rightarrow$ χPT not applicable
$\rightarrow$ nonpertubartive approaches – L.–Sch./B.-S. equation
$\rightarrow$ importace of $\bar{K}N - \pi\Sigma$ coupled channel dynamics
well understood near $\bar{K}N$ threshold, **?** subtreshold extrapolations

$$\Downarrow$$

K̄–nucleus interaction

$\rightarrow$ strongly attractive and absorptive $\bar{K}$–nucleus interaction
$\rightarrow$ L.–Sch./B.-S. $T = T + VGT$, $V_K \propto T\rho$
$\rightarrow$ $-\mathrm{Re}V_K \approx 100 \pm 20$ MeV

Current status

Deeply bound and narrow $\bar{K}$–nuclear states?

Theory

- few-body systems
  - variational approaches, Akaishi, Yamazaki, Doté, ...:
    $\bar{K}NN$, $\bar{K}NNN$, ...: $B_K \gtrsim 100$ MeV, $\Gamma_K \approx 30$ MeV
  - Faddeev calculations, Shevchenko, Gal, Mareš:
    $K^- pp$: B=50–70 MeV, Γ=60–100 MeV
- heavier systems
  - phenomenology, RMF, K^- atom data analysis:
    $-\mathrm{Re}V_K \approx 150 - 200$ MeV
  - chiraly motivated approaches
    LO Tomozawa-Weinberg interaction: $-V_K = 3/(8\,f_\pi^2)\rho|_{\rho_0} \approx 55$ MeV
    coupled channel calculations, Weise, Härtle: $-\mathrm{Re}V_K \approx 100$ MeV
    $+\ \bar{K}$ selfenergies, Lutz, Ramos and Oset: $-\mathrm{Re}V_K \approx 50$ MeV

Current status

Deeply bound and narrow $\bar{K}$–nuclear states?

Experiment (candidate K^- bound states)

- ~~KEK-PS, E471, ^{4}He($K^-_{\rm stop}, p/n$)~~
- ~~BNL-AGS, parasite E930, ^{16}O(K^-, n)~~
- FINUDA, K^- capture in Li, C:
  PRL 2005, PRC 2006, NPA 2006, PLB 2007
  × Magas et al., Shevchenko et al., Ikeda & Sato
- OBELIX @ LEAR, $\bar{p}$ annihilation on ^{4}He
- DISTO @ SATURNE, pp collisions

none of them conclusive

dedicated experiments comming: J-PARC, GSI, Frascati, Jülich, ...

RMF model for K̄ nuclei

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

$$\mathscr{L} = \mathscr{L}_N + \mathscr{L}_Y + \mathscr{L}_K,$$

where

$$\begin{aligned}
\mathscr{L}_N = & \bar{\psi}(\mathrm{i}\not{D} - m_N)\,\psi + \frac{1}{2}\partial_\mu\,\sigma\partial^\mu\sigma - \frac{1}{2}m_\sigma^2\sigma^2 - \frac{1}{3}g_2\sigma^3 - \frac{1}{4}g_3\sigma^4 \\
& - \frac{1}{4}\Omega_{\mu\nu}\Omega^{\mu\nu} + \frac{1}{2}m_\omega^2\omega_\mu\omega^\mu + \frac{1}{4}\,d\,(\omega_\mu\omega^\mu)^2 \\
& - \frac{1}{4}\vec{P}_{\mu\nu}\cdot\vec{P}^{\mu\nu} + \frac{1}{2}m_\rho^2\,\rho_\mu\cdot\rho^\mu - \frac{1}{4}F_{\mu\nu}F^{\mu\nu} \\
\mathscr{L}_Y = & \bar{\psi}_Y[\mathrm{i}\not{D} - (m_Y - g_{\sigma Y}\sigma - g_{\sigma^* Y}\sigma^*)]\psi_Y \\
\mathscr{L}_K = & (D_\mu K)^\dagger\,(D^\mu K) - m_K^2 K^\dagger K - g_{\sigma K}m_K\,\sigma\,K^\dagger K - g_{\sigma^* K}m_K\,\sigma^*\,K^\dagger K,
\end{aligned}$$

with $\mathcal{D}_\mu$ given by:

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

baryons (nucleons, hyperons):

$$[-\mathrm{i}\alpha_j\nabla_j+(m_B-g_{\sigma B}\,\sigma-g_{\sigma^* B}\,\sigma^*)\beta+g_{\omega B}\,\omega+g_{\rho B}\,I_3\,\rho+g_{\phi B}\phi+e(I_3+\tfrac{1}{2}Y)A]\psi_B=\varepsilon\psi_B$$

mesons:

$$(-\nabla^2+m_\sigma^2)\sigma=g_{\sigma N}\rho_s+g_2\sigma^2-g_3\sigma^3+g_{\sigma K}\,m_K\,K^*K+g_{\sigma Y}\,\rho_{sY}$$
$$(-\nabla^2+m_\sigma^2)\sigma^*=g_{\sigma^* K}\,m_K\,K^*K+g_{\sigma^* Y}\,\rho_{sY}$$
$$(-\nabla^2+m_\omega^2)\omega=g_{\omega N}\rho_N-g_{\omega K}\,\rho_{K^-}+g_{\omega Y}\,\rho_Y$$
$$(-\nabla^2+m_\rho^2)\rho=g_{\rho N}\rho_3-g_{\rho K}\,\rho_{K^-}+g_{\rho N}\,\rho_{3Y}$$
$$(-\nabla^2+m_\phi^2)\phi=-g_{\phi K}\,\rho_{K^-}+g_{\phi Y}\,\rho_Y$$
$$-\nabla^2A=e\,\rho_p-e\,\rho_{K^-}+e\,\rho_{cY}$$

where $\rho_{K^-}=2(E_{K^-}+g_{\omega K}\,\omega+g_{\rho K}\,\rho+g_{\phi K}\,\phi+e\,A)K^*K$

+ **antikaons**:

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

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

$\mathbf{g_{VK}}$ ← SU(3) relations: $2g_{\omega K} = \sqrt{2}g_{\phi K} = 2g_{\rho K} = g_{\rho\pi} = 6.04$
$\mathbf{g_{\sigma K}}$ ← kaonic atom data / scaled

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

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

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%)

+ **antikaons**:

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

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

$\mathbf{g_{VK}} \leftarrow$ SU(3) relations: $2g_{\omega K} = \sqrt{2}g_{\phi K} = 2g_{\rho K} = g_{\rho\pi} = 6.04$
$\mathbf{g_{\sigma K}} \leftarrow$ kaonic atom data / scaled

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

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

W_0 constrained by kaonic atom data

Absorption through:

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  $\bar{K}N \to \pi\Sigma + 90$ MeV, $\pi\Lambda + 170$ MeV $(70\%, 10\%)$
- nonmesonic modes $\propto \rho_N^2(r)$
  $\bar{K}NN \to YN + 240$ MeV (20%)

Single-$\bar{K}$ nuclei

Aims:

- dynamical effects in nuclei due to the presence of $\bar{K}$
  - core nucleus polarization
  - $g_{\sigma K}$ scaled $\rightarrow$ wide range of B_K covered
- widths $\Gamma_K = \Gamma_K(B_K)$ of $\bar{K}$–nuclear states
  - states sufficiently narrow for large B_K?

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Single-$\bar{K}$ nuclei

Dynamical core polarization

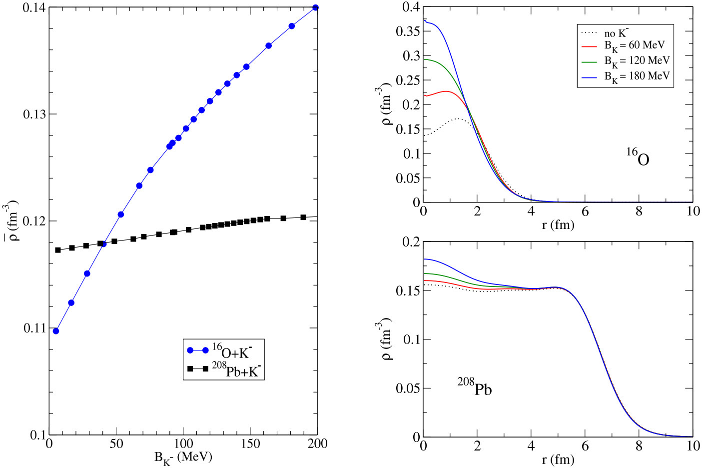

Fig. 1: Average nuclear density $\bar{\rho}$ (left) and nuclear density distribution $\rho(r)$ (right) for several values of $\bar{K}$ binding energy B_K.

Single-$\bar{K}$ nuclei

Widths of $\bar{K}$–nuclear states

Absorption through: $\bar{K}N \rightarrow \pi\Sigma$ (100%)

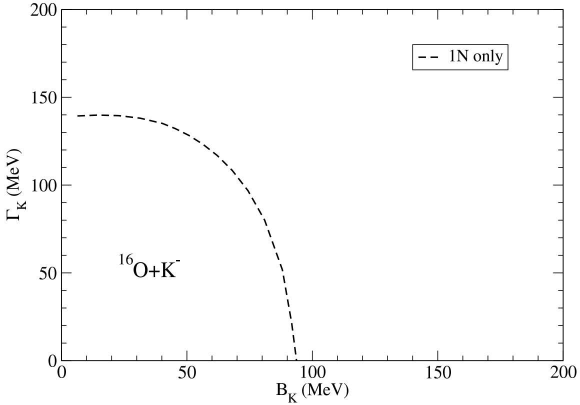

Fig. 2: Widths of $\bar{K}$–nuclear states as a function of $\bar{K}$ binding energy. .

Single-$\bar{K}$ nuclei

Widths of $\bar{K}$–nuclear states

Absorption through: $\bar{K}N \to \pi\Sigma$ (80%), $\bar{K}NN \to \Sigma N$ (20%) $\propto \rho$

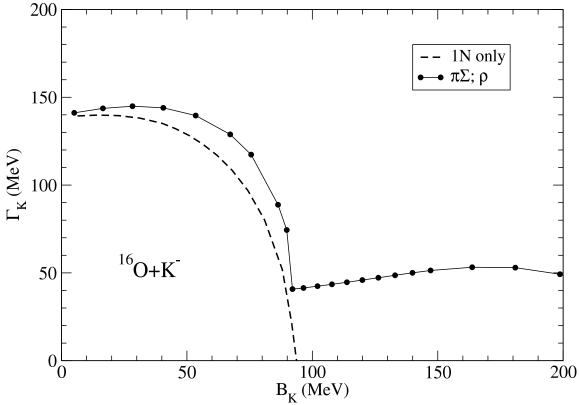

Fig. 3: Widths of $\bar{K}$–nuclear states as a function of $\bar{K}$ binding energy. .

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

Widths of $\bar{\text{K}}$–nuclear states

Absorption through: $\bar{K}N \rightarrow \pi\Sigma, \pi\Lambda$ (70%, 10%), $\bar{K}NN \rightarrow \Sigma N$ (20%) $\propto \rho$

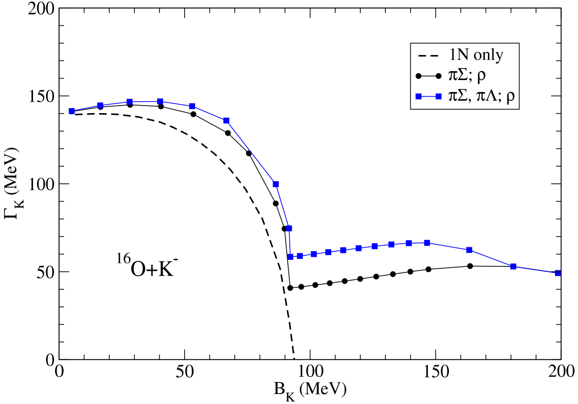

Fig. 4: Widths of $\bar{K}$–nuclear states as a function of $\bar{K}$ binding energy. .

Single-$\bar{K}$ nuclei

Widths of $\bar{K}$–nuclear states

Absorption through: $\bar{K}N \to \pi\Sigma, \pi\Lambda$ (70%, 10%), $\bar{K}NN \to \Sigma N$ (20%) $\propto \rho^2$

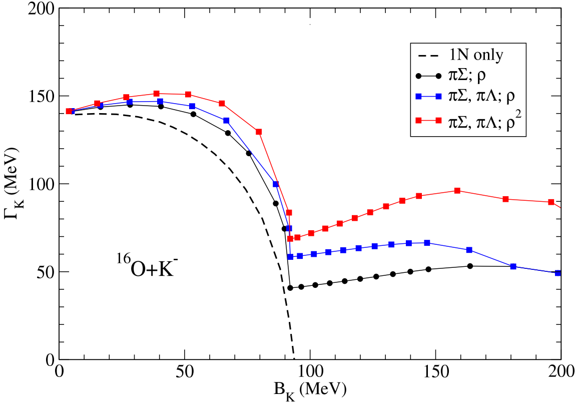

Fig. 5: Widths of $\bar{K}$–nuclear states as a function of $\bar{K}$ binding energy. .

Single-$\bar{K}$ nuclei

Widths of $\bar{K}$–nuclear states

Absorption through: $\bar{K}N \to \pi\Sigma, \pi\Lambda$ (70%, 10%), $\bar{K}NN \to \Sigma N$ (20%) $\propto \rho^2$

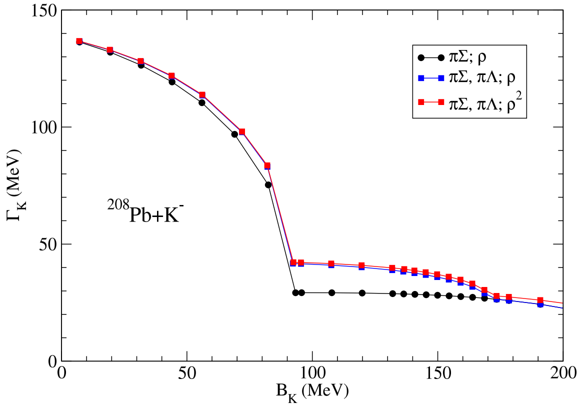

Fig. 6: Widths of $\bar{K}$–nuclear states as a function of $\bar{K}$ binding energy. .

Multi-$\bar{K}$ (hyper)nuclei

Aims:

- $\bar{K}$ "condensation" in finite self-bound nuclear systems
- behavior of $\bar{K}$ binding energies with increasing number of $\bar{K}$'s
  - $B_K \gtrsim 320$ MeV $\approx m_K + m_N - M_\Lambda$
    all $\bar{K}$ decay channels kinematicaly blocked
    $\bar{K}$ mesons relevant degrees of freedom
  - $B_K \gtrsim 240$ MeV $\approx m_K + m_N - M_\Sigma$
    decay widths $\sim$ fairly weak $\bar{K}NN \to \Lambda N$
- behavior of baryon densities with increasing number of $\bar{K}$'s
- "exotic" nuclear systems $\{n, \bar{K}^0\}$, $\{N, Y, K^-, K^+\}$

Phys. Rev. C 76 (2007) 055204, 77 (2008) 045206

Multi-$\bar{K}$ nuclei

$B_K = B_K(\# \text{ of } \bar{K}\text{'s})$

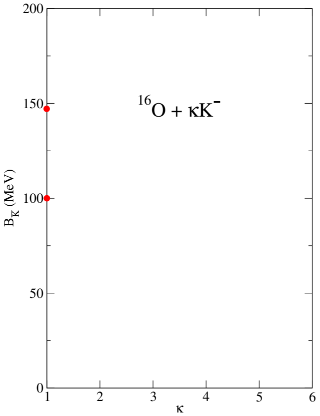

Fig. 7: $\bar{K}$ binding energies B_K as a function of the number κ of embedded antikaons.

Multi-$\bar{K}$ nuclei

$B_K = B_K(\#$ of $\bar{K}$'s$)$

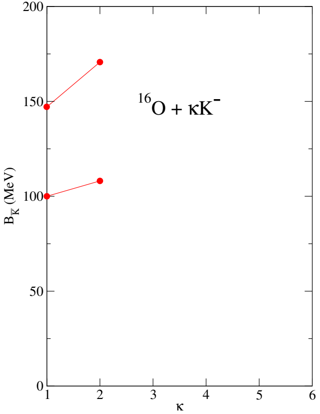

Fig. 8: $\bar{K}$ binding energies B_K as a function of the number κ of embedded antikaons.

Multi-$\bar{K}$ nuclei

$B_K = B_K(\# \text{ of } \bar{K}\text{'s})$

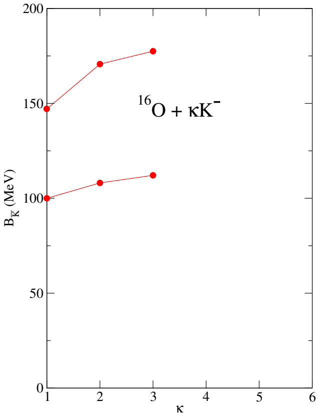

Fig. 9: $\bar{K}$ binding energies B_K as a function of the number κ of embedded antikaons.

Multi-K̄ nuclei

$B_K = B_K(\#\text{ of }\bar{K}\text{'s})$

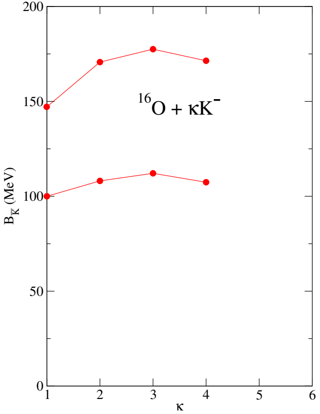

Fig. 10: $\bar{K}$ binding energies B_K as a function of the number κ of embedded antikaons.

Multi-$\bar{K}$ nuclei

$B_K = B_K(\#\text{ of }\bar{K}\text{'s})$

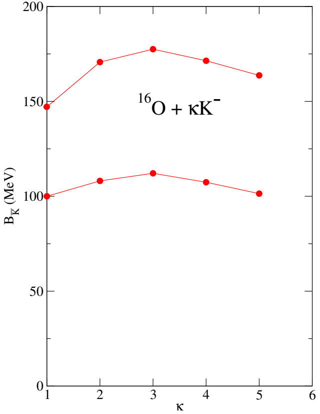

Fig. 11: $\bar{K}$ binding energies B_K as a function of the number κ of embedded antikaons.

Multi-K̄ nuclei

$B_K = B_K(\# \text{ of } \bar{K}\text{'s})$

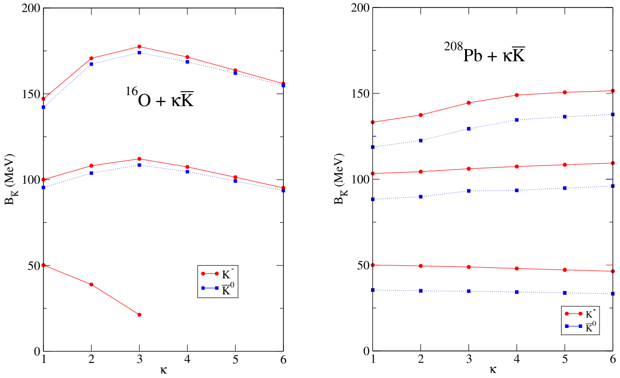

Fig. 12: $\bar{K}$ binding energies B_K as a function of the number κ of embedded antikaons.

Multi-K̄ nuclei

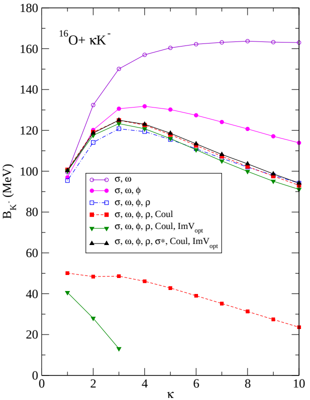

Fig. 13: $\bar{K}$ binding energies as a function of the number κ of antikaons for different mean field compositions.

- saturation observed for any field composition containing ω-meson
- no saturation for purely scalar interaction
- substantial effect of $\mathrm{Im}\Pi_{K^-}$ for $B_{K^-} \lesssim 100$ MeV

Multi-$\bar{K}$ nuclei

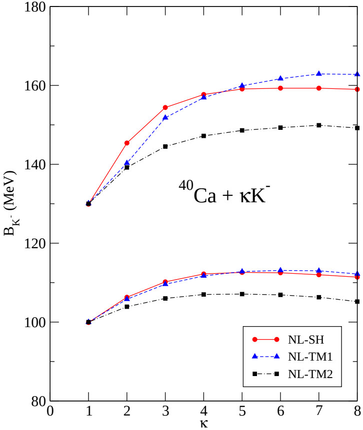

Fig. 14: $\bar{K}$ binding energies as a function of the number κ of antikaons for different RMF models.

- saturation qualitatively independent of RMF model used

Multi-$\bar{K}$ nuclei

Baryon and antikaon density distributions

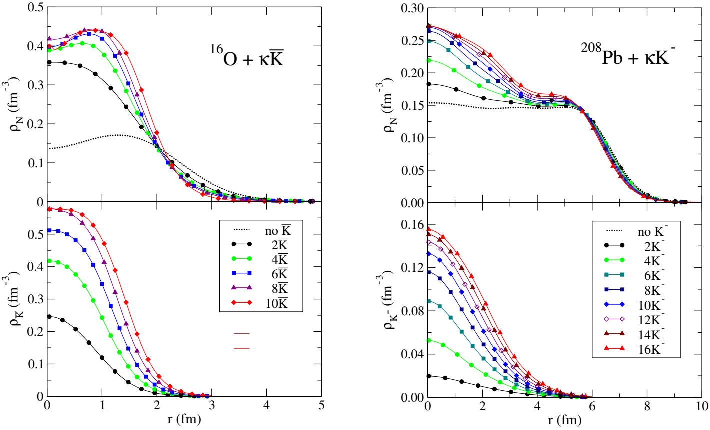

Fig. 15: Nucleon ρ_N and antikaon ρ_K density distributions in ^{16}O and ^{208}Pb.

Multi-$\bar{K}$ nuclei

instabilities of traditional nonlinear RMF models at high densities

↓

Dirac-Brueckner calculations of nuclear matter suggest $\mathbf{g_\phi = g_\phi(\rho)}$

$$g_\phi = g_\phi(\rho_0) a_\phi \frac{1 + b_\phi(\rho/\rho_0 + d_\phi)^2}{1 + c_\phi(\rho/\rho_0 + d_\phi)^2}, \ \phi = \sigma, \omega \qquad g_\rho = g_\rho(\rho_0) \mathrm{e}^{-a_\rho \rho/\rho_0}$$

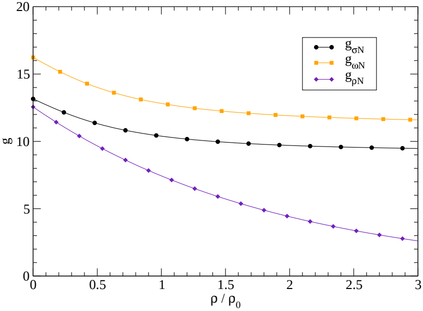

Fig. 16: Density dependence of the meson-nucleon coupling constants.

Multi-$\bar{K}$ nuclei

$B_K = B_K(\# \text{ of } \bar{K}\text{'s})$

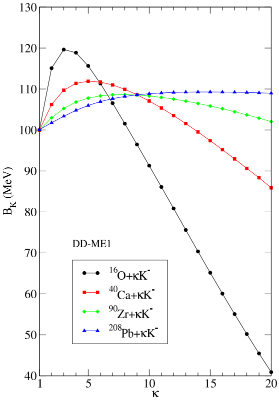

Fig. 17: $\bar{K}$ binding energies B_K as a function of the number κ of embedded antikaons for density dependent RMF model.

Multi-$\bar{K}$ "exotic" systems

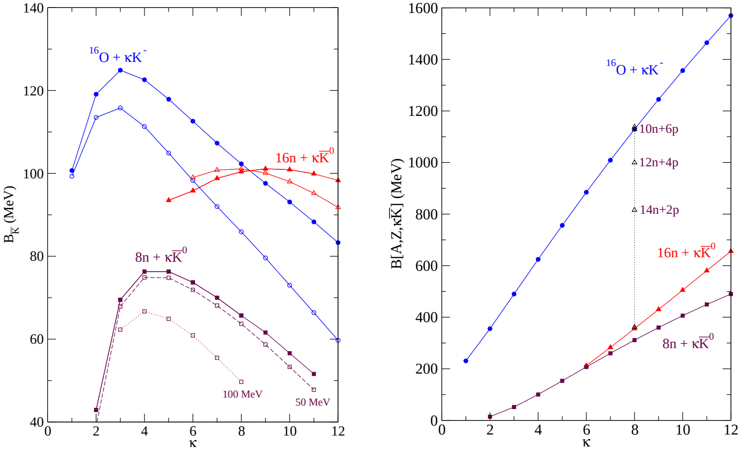

Fig. 18: $\bar{K}$ binding energies B_K (left) and total binding energies B (right) as functions of the number κ of embedded antikaons.

Multi-$\bar{K}$ hypernuclei

Adding hyperons

We considered self-bound systems consisting of SU(3) octet baryons $\{N, \Lambda, \Sigma, \Xi\}$. Only $\Xi^- p \to \Lambda\Lambda$ and $\Xi^0 n \to \Lambda\Lambda$ ($Q \approx 26$ MeV) can be overcome by binding effects $\to \{N, \Lambda, \Xi\}$ configurations.

- filling up Λ single-particle states up to the Λ Fermi level
- adding Ξ hyperons (Ξ^0, Ξ^-) as long as both reactions:
  $[AN, \eta\Lambda, \mu\Xi] \to [(A-1)N, \eta\Lambda, (\mu-1)\Xi] + 2\Lambda$
  $[AN, \eta\Lambda, \mu\Xi] \to [(A+1)N, (\eta-2)\Lambda, (\mu+1)\Xi]$
  are kinematically blocked

$\to$ particle-stable configurations with highest $|S|/B$ ratio for given core nucleus

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Multi-$\bar{K}$ nuclei

$B_K = B_K(\# \text{ of } \bar{K}\text{'s}, \# \text{ of } Y\text{'s})$

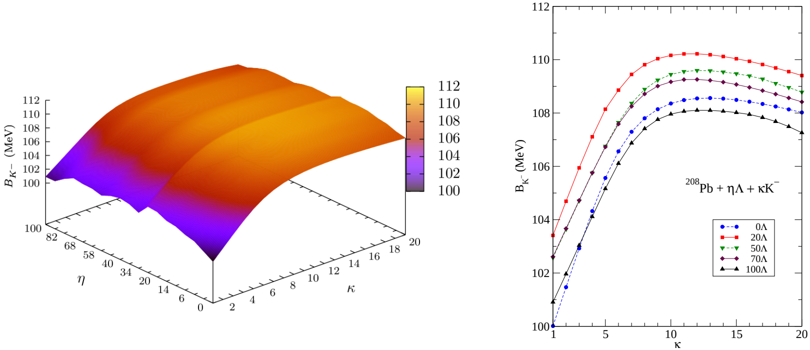

Fig. 19: $\bar{K}$ binding energy $B_{\bar{K}}$ in ^{208}Pb as a function of the number κ of antikaons and η of Λ hyperons.

Multi-$\bar{K}$ nuclei

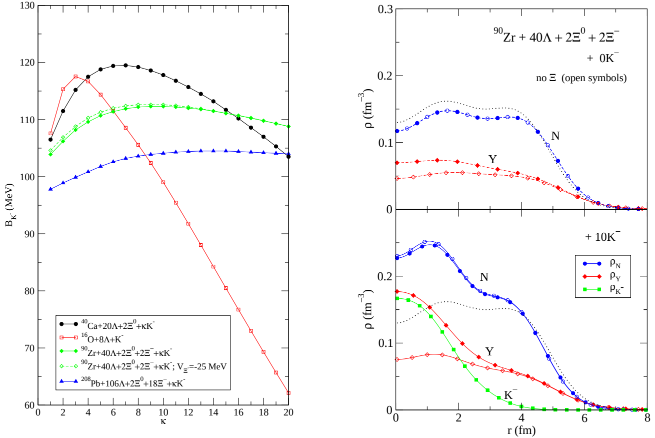

Fig. 20: $\bar{K}$ binding energies (left) and nuclear density distributions (right) in hypernuclear systems with maximal $|S|/B$ ratio.

Chiral approach for $\bar{\mathrm{K}}$ nuclei

$\bar{K}$–nuclear bound states studied by solving in-mediun K.–G. equation:

$$\left[\tilde{\omega}_K^2 + \vec{\nabla}^2 - m_K^2 - \Pi_K(\vec{p}_K, \omega_K, \rho)\right] \phi_K = 0$$

- complex energy $\tilde{\omega}_K = \omega_K - \mathrm{i}\Gamma_K/2 - V_C$
- selfenergy operator $\Pi_K(\vec{p}_K, \omega_K, \rho)$ constructed from chiral model

$$\frac{\Pi_K}{2\omega_K} = V_K = -\frac{2\pi}{\omega_k}\left(1 + \frac{\omega_K}{m_N}\right) F_{KN}(\sqrt{s}, \rho)\, \rho$$

ω_K = $\bar{K}$ energy in lab. frame
F_{KN} = $\bar{K}N$ scattering amplitude, $\sqrt{s}$ = $\bar{K}N$ energy in c.m. frame
ρ = nuclear density (RMF calculations)

- $\bar{K}N$ c.m. frame $\rightarrow$ $\bar{K}$–nucleus c.m. frame

$$\sqrt{s} \approx E_{th} - B_K - B_N - \frac{m_N}{m_K + m_N} T_N - \frac{m_K}{m_K + m_N} T_K$$

$$T_N = 23(\rho/\rho_0)^{2/3}\ \mathrm{MeV}, \quad T_K = -B_K - \mathrm{Re}\, V_K$$

- selfconsistent solution $\Pi_K = \Pi_K(\omega_K)$

Model

Chiral model for $\bar{K}N$ scattering amplitude

(A. Cieplý, J. Smejkal, Eur. Phys. J A 43 (2010) 191.)

- $SU(3)_L \times SU(3)_R$ chiral EFT for $\{\pi, K, \eta\} + \{N, \Lambda, \Sigma, \Xi\}$
- $\exists\ \Lambda(1405)$ resonance $\Rightarrow$ nonperturbative approach required
- **multichannel L.–Sch. equation**

$$T_{ij} = V_{ij} + V_{ik} G_{kl} T_{lj}$$

$$V_{ij} \text{ separable form, } G = \frac{1}{E - H_0 - \Pi(\sqrt{s}, \rho)}$$

$$\text{parameters of } V_{ij} \leftrightarrow \text{ parameters of } \mathcal{L}_\chi$$

meson(baryon) **selfenergies** $\Pi_{m(B)}$ in G_{ij} $\Leftrightarrow$ **selfconsistency** in V_K

Model

- **p-wave interaction**

$$\Pi_K^P = -4\pi \left(1 - \frac{\omega_K}{m_N}\right)^{-1} \vec{\nabla} C_{KN}(\sqrt{s})\rho \cdot \vec{\nabla}$$

C_{KN} p-wave amplitude parametrization of Weise and Härtle, NPA 804 (2008) 173

- **2N absorption modes**
nonmesonic $\bar{K}NN \to YN$ (20%) conversion modes from phenomenology:

$$\mathrm{Im}\,\Pi_K^{2N} = 0.2\, f_{2Y}\, W_0 \rho^2$$

f_{2Y} kinematical factor (phase space suppression)
W_0 constrained by kaonic atom data

- **dynamical core nucleus polarization**
selfconsistent RMF calculations $\to$ nuclear core polarized (compressed) by presence of $\bar{K}$ meson

Chiral approach for $\bar{\mathrm{K}}$–nuclear states

Aims:

- study in detail energy and density dependencies of $\bar{K}$–nuclear interaction
- calculate binding energies and widths of $\bar{K}$–nuclear states
- analyze kaonic atom data
  - deep phenomenological $\times$ shallow chiral potentials

Phys. Lett. B 702 (2011) 402, Phys. Rev. C 84 (2011) 045206, Nucl. Phys. A (2012)

Results

K̄N scattering amplitude

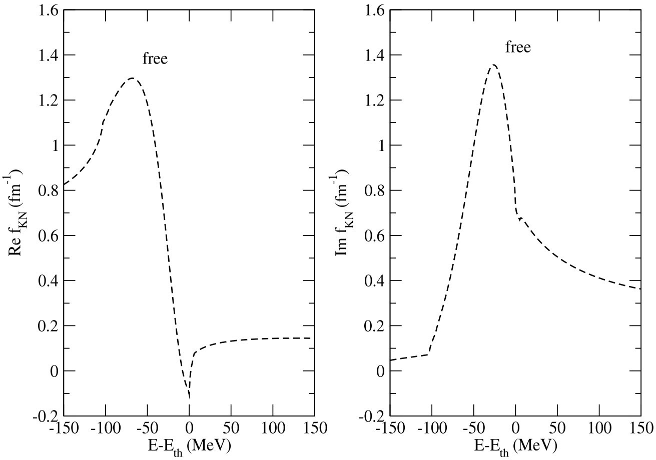

Fig. 21: Energy dependence of the effective $\bar{K}N$ scattering amplitude,

$f_{KN} = 1/2(f_{Kp} + f_{Kn})$, $E_{th} = m_K + m_N$.

Results

$\bar{K}N$ scattering amplitude

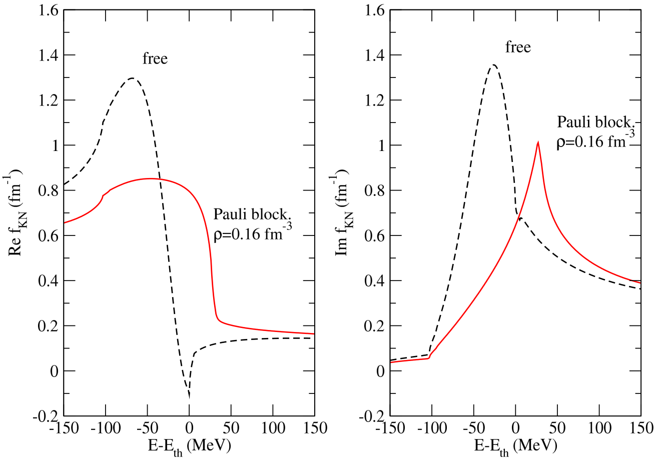

Fig. 22: Energy dependence of the effective $\bar{K}N$ scattering amplitude,

$f_{KN} = 1/2(f_{Kp} + f_{Kn})$, $E_{th} = m_K + m_N$.

Results

$\bar{K}N$ scattering amplitude

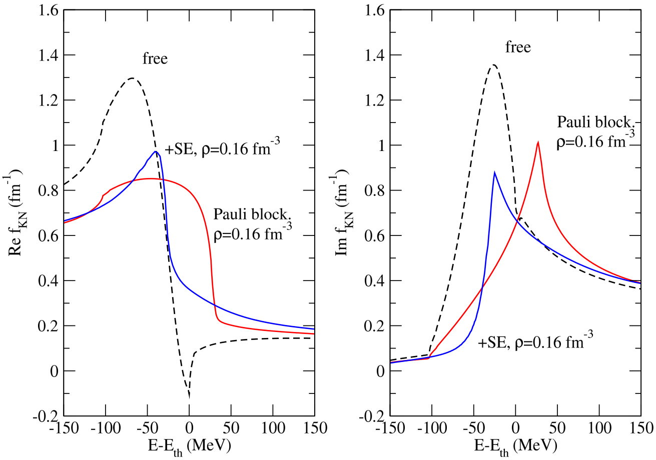

Fig. 23: Energy dependence of the effective $\bar{K}N$ scattering amplitude, $f_{KN} = 1/2(f_{Kp} + f_{Kn})$, $E_{th} = m_K + m_N$.

Results

K^-–nuclear potentials:

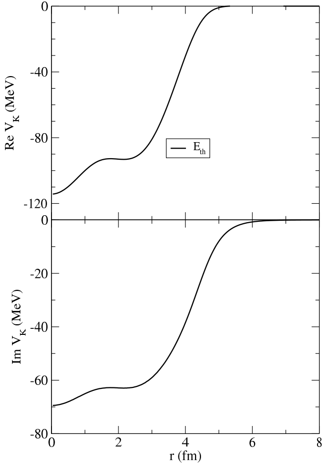

Fig. 24: K^-–nuclear potentials in ^{40}Ca.

amplitude at threshold:
$\sqrt{s}=E_{th}$

Table 1: K^- binding energies and widths of K^- states (in MeV).

	^{12}C	^{16}O	^{40}Ca	^{90}Zr	^{208}Pb
B_K	61.1	57.5	83.4	96.0	104.8
Γ_K	149.1	135.9	150.7	151.2	143.9

Results

K^-–nuclear potentials:

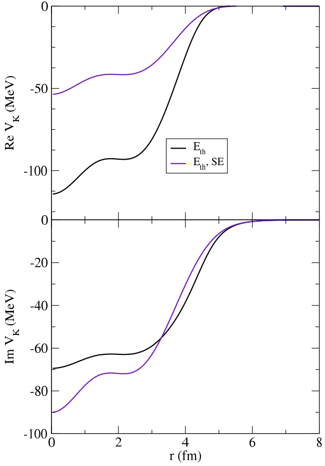

Fig. 25: K^-–nuclear potentials in ^{40}Ca.

amplitude at threshold:

$\sqrt{s} = E_{th}$

selfenergies in amplitude:

$F_{KN} = F_{KN}(\Pi_K)$

Table 2: K^- binding energies and widths of K^- states (in MeV).

	^{12}C	^{16}O	^{40}Ca	^{90}Zr	^{208}Pb
B_K	–	6.4	25.0	39.0	53.4
Γ_K	–	120.2	141.8	141.0	129.1

Results

K^-–nuclear potentials

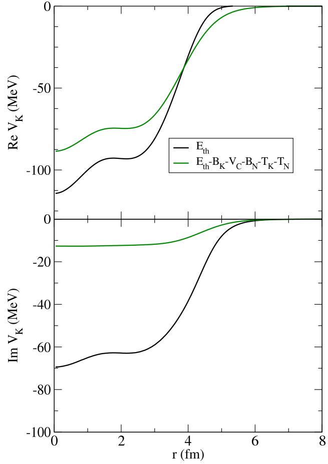

Fig. 26: K^-–nuclear potentials in ^{40}Ca.

amplitude below threshold:

$\sqrt{s} = E_{th} - B_K - V_C - B_N - T_K - T_N$

K.–G. eq. selfconsistent:

$\omega_K \Leftrightarrow V_K(\sqrt{s})$

Table 3: k^- binding energies and widths of K^- states (in MeV).

	^{12}C	^{16}O	^{40}Ca	^{90}Zr	^{208}Pb
B_K	40.9	42.4	58.5	69.5	77.6
Γ_K	29.4	30.8	23.6	22.4	22.0

Results

K^-–nuclear potentials

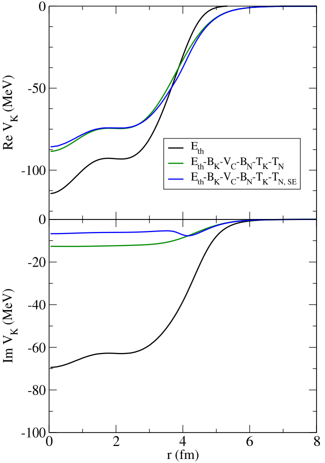

Fig. 27: K^-–nuclear potentials in ^{40}Ca.

amplitude below threshold:

$\sqrt{s} = E_{th} - B_K - V_C - B_N - T_K - T_N$

K.–G. eq. selfconsistent:

$\omega_K \Leftrightarrow V_K(\sqrt{s})$

selfenergies in amplitude:

$F_{KN} = F_{KN}(\Pi_K)$

Table 4: k^- binding energies and widths of K^- states (in MeV).

	^{12}C	^{16}O	^{40}Ca	^{90}Zr	^{208}Pb
B_K	42.4	44.9	58.8	68.9	76.3
Γ_K	16.5	16.2	12.0	11.5	11.3

Results

Binding energies and widths of $\bar{K}$–nuclear states

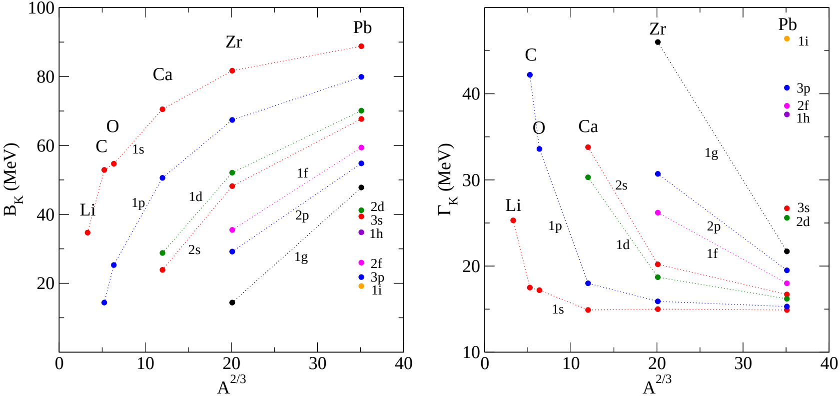

Fig. 28: Binding energies B_K (left) and widths Γ_K (right) of $\bar{K}$–nuclear states.

Results

Binding energies and widths of $\bar{K}$–nuclear states

Table 5: Binding energies B_K and widths Γ_K of $\bar{K}$–nuclear states in ^{40}Ca (in MeV).

		1s	1p	1d	2s
static calculation	B_K	70.5	50.6	28.8	23.9
	Γ_K	14.9	18.0	30.3	33.8
dynamical calculation	B_K	72.3	52.8	30.5	24.6
	Γ_K	14.8	17.7	29.2	30.9
p-wave interaction	B_K	73.0	53.1	32.1	26.3
	Γ_K	14.8	17.9	29.3	34.2
2N absorption	B_K	68.9	49.2	27.7	21.6
	Γ_K	**58.9**	**53.6**	**59.7**	**67.1**

Summary

Dynamical calculations of $\bar{K}$–nuclear states within RMF approach

- considerable core polarization for light nuclei
- substantial widths of $\bar{K}$–nuclear states even for $B_K \gtrsim \pi\Sigma$ threshold

(Hyper)nuclear systems containing several antikaons

- $\bar{K}$ binding energies and nuclear densities saturate with number of $\bar{K}$ mesons
- saturation occurs also in the presence of hyperons

Chiral approach for $\bar{K}$ nuclei

- chiral models results in relatively deeply bound $\bar{K}$–nuclear states
  $B_K \approx (50 - 100)$ MeV
- substantial absorption widths of $\bar{K}$–nuclear states for B_K near $\pi\Sigma$ threshold dominated by two-nucleon absorption
  $\Gamma_K \approx 10$ MeV $(\bar{K}N \rightarrow YN) + 40$ MeV $(\bar{K}NN \rightarrow YN)$