Antikaon condensed dense matter in neutron star with SU(3) flavour symmetry

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Aim

To determine SU(3) antikaon couplings, study their impact on dense neutron star matter, and investigate the resulting astrophysical observables.

- Calculate the hadron couplings in the meson sector to study antikaon condensation in the dense nuclear matter.
- We estimate antikaon couplings based on SU(3) symmetry in flavor space.
- The couplings are determined using Clebsch-Gordan coefficients, with only one free parameter.
- The star structure and other astrophysical observables are derived from the resulting EOS.

Vector Meson interaction and SU(3) flavour symmetry

- ➔ The invariant Yukawa Lagrangian can be constructed with interacting octet mesons and mediator nonet mesons.

$$\mathcal{L}_{\text{int}} = -g\bar{N}NM$$

- ➔ There are three parameters in the flavor SU(3) symmetry: the weight factor α_v, the ratio $z = g_8/g_1$, and the mixing angle θ_v.

- ➔ Coupling constant expressions are obtained from the Clebsch-Gordan coefficients in terms of these three parameters.

Results

➔ Expressions for the couplings using CG coefficients:

$$g_{\omega_8 K} = \frac{1}{3} g_8 \sqrt{3}(4\alpha_v - 1)$$
$$g_{\omega_8 \bar{K}} = -\tfrac{1}{3} g_8 \sqrt{3}(1 + 2\alpha_v)$$
$$g_{\omega_8 \pi} = \frac{2}{3} g_8 \sqrt{3}(1 - \alpha_v)$$
$$g_{\omega_8 \eta} = -\frac{2}{3} g_8 \sqrt{3}(1 - \alpha_v)$$

$$g_{\rho K} = g_8$$
$$g_{\rho \bar{K}} = -g_8(1 - 2\alpha_v)$$
$$g_{\rho \pi} = 2 g_8 \alpha_v$$
$$g_{\rho \eta} = 0$$

➔ In nature, the physical realization of the isospin singlet vector mesons are ω and ϕ mesons are done by the mixing of theoretical ω_8 and ϕ_1 states.

$$\omega = \cos\theta_v \left|\phi_1\right\rangle + \sin\theta_v \left|\omega_8\right\rangle$$
$$\phi = -\sin\theta_v \left|\phi_1\right\rangle + \cos\theta_v \left|\omega_8\right\rangle ,$$

- Thus the expressions for the couplings in the mesonic sector are:

$$
\begin{aligned}
g_{\omega K} &= g_1 \cos\theta_v + g_8 \sin\theta_v \frac{1}{\sqrt{3}}(4\alpha_v - 1) \\
g_{\omega \bar{K}} &= g_1 \cos\theta_v - g_8 \sin\theta_v \frac{1}{\sqrt{3}}(1 + 2\alpha_v) \\
g_{\omega \pi} &= g_1 \cos\theta_v + g_8 \sin\theta_v \frac{2}{\sqrt{3}}(1 - \alpha_v) \\
g_{\omega \eta} &= g_1 \cos\theta_v - g_8 \sin\theta_v \frac{2}{\sqrt{3}}(1 - \alpha_v).
\end{aligned}
$$

- Couplings with ϕ obtained by substituting $\sin\theta_v$ and $\cos\theta_v$ by $\cos\theta_v$ and $-\sin\theta_v$ respectively.

$$
\begin{aligned}
g_{\rho K} &= g_8 \\
g_{\rho \bar{K}} &= -g_8(1 - 2\alpha_v) \\
g_{\rho \pi} &= 2 g_8 \alpha_v \\
g_{\rho \eta} &= 0
\end{aligned}
$$

Constraining the Parameters

The ``ideal mixing" for the ω_8 and ϕ_1 meson

$$\tan\theta_v = \frac{1}{\sqrt{2}}$$

Ideal mixing angle ($\theta v \approx 35.3^\circ$) ≈ ($\theta v \approx 40^\circ$) (quadratic mass formula for the mesons)

Range of α_v is from $0 \leq \alpha_v \leq 1$.

$$\frac{g_{\omega\bar{K}}}{g_{\omega N}} = \frac{\sqrt{6} - z_m(1+2\alpha_m)}{\sqrt{6} + z_b(4\alpha_b - 1)}$$

- Mesonic and baryonic octets originate from distinct SU(3) representations.
- No inherent correlation exists.
- Corresponding couplings introduced independently.

The couplings for kaons are attractive. Hence, $\frac{g_{\omega\bar{K}}}{g_{\omega N}} \geq 0$

This requires the range of z_m to be $\boxed{0 \leq z_m \leq 2/\sqrt{6}}$ as we have the constraint $\boxed{0 \leq \alpha_v \leq 1.}$

SU(6) Symmetry

Requirement of spin-independence for the qqω and qqϕ couplings within the identically flavoured K and K^- gives $g_{K\omega} - g_{\bar{K}\omega} = 0 \rightarrow g_8 \sin\theta_v \frac{1}{\sqrt{3}} 6\alpha_v = 0 \longrightarrow \boxed{\alpha_v = 0}$

Here, we fix $\alpha_v = 0$ as g_8 and θ_v can not be zero.

From the constraint in SU(6), $g_{\pi\phi} = 0$ we get

$$\rightarrow \frac{g_1}{g_8} \tan\theta_v = \frac{2}{\sqrt{3}} \longrightarrow \boxed{z = \frac{\sqrt{3}}{2\sqrt{2}}}$$

Fixing the z_m value

We fix z_v value to SU(6) $\longrightarrow$ $\boxed{z = \frac{\sqrt{3}}{2\sqrt{2}}}$
vary the parameter α_m within its allowed range.

1.) $\alpha_b = \alpha_m$ 2.) $\alpha_b = 2\alpha_m$ 3.) $\alpha_b = \alpha_m/2$

Fixing the α_m value

We then fix α_m to a representative value, $\alpha_v = 0.6$, and vary the parameter z_m within its allowed range.

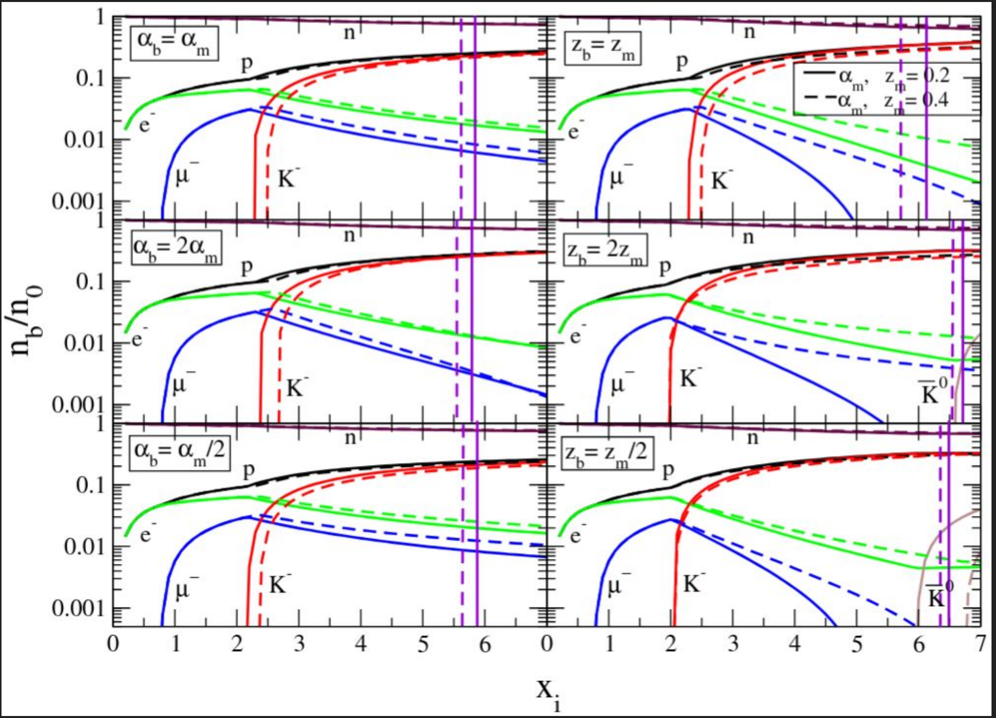
1.) $z_b = z_m$

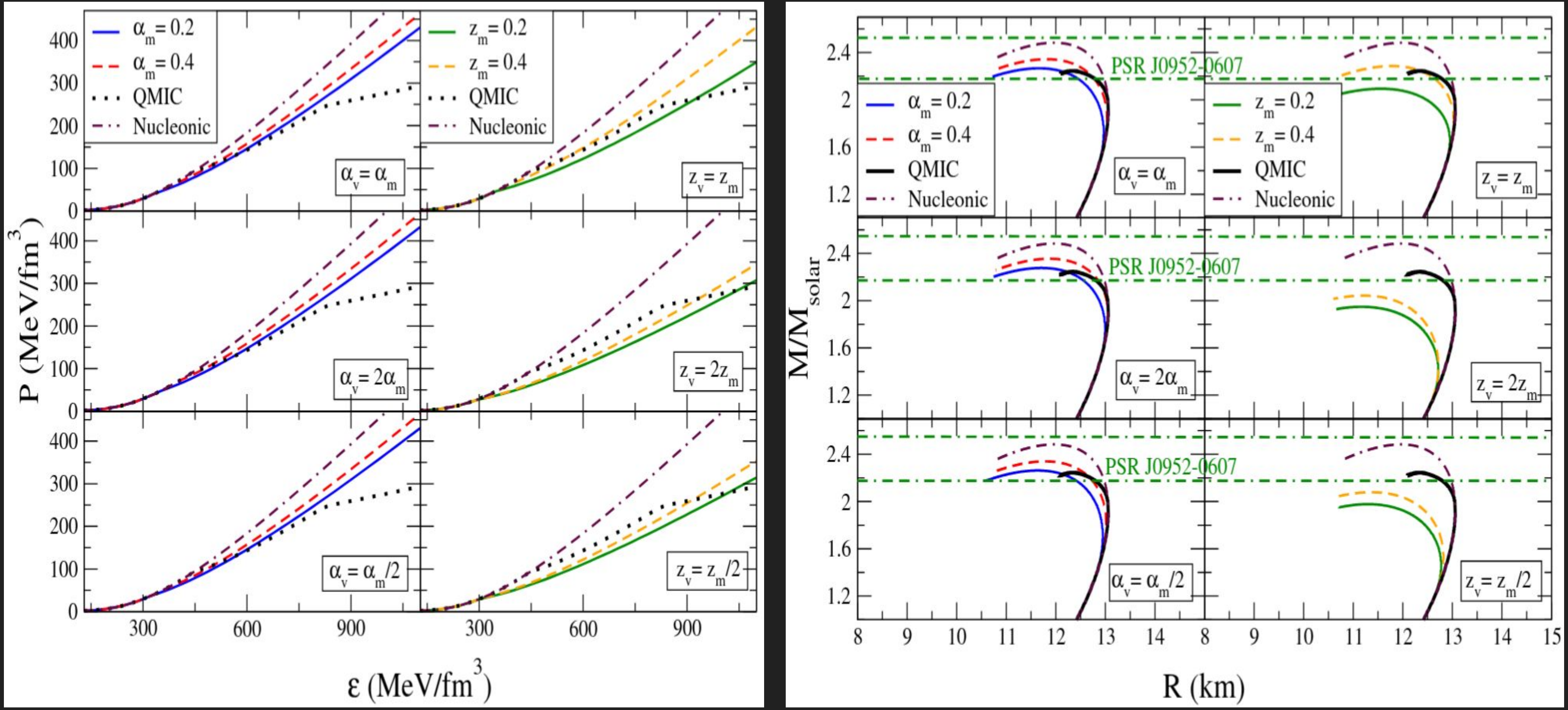
From SU(6) symmetry $\longrightarrow$ $\boxed{\alpha_v = 0}$

2.) $z_b = 2z_m$ 3.) $z_b = z_m/2$

Matter Properties

- The relative abundances of different particle species for α_m = 0.2 and 0.4 are shown in left panel and those for z_m = 0.2 and 0.4 are shown in right panel, for the optical potential value of U_{K^-} = −130 MeV.
- Threshold density for K^- condensation increases with increasing α_m in the case of the varying α_m scenario.
- K^0 does not appear within the stable dense matter in most of the EOSs considering SU(3) couplings.





$\alpha_m = 0.2$
$\alpha_m = 0.4$
QMIC
Nucleonic
$z_m = 0.2$
$z_m = 0.4$
$\alpha_v = \alpha_m$
$z_v = z_m$
$\alpha_v = 2\alpha_m$
$z_v = 2z_m$
$\alpha_v = \alpha_m/2$
$z_v = z_m/2$
P (MeV/fm^3)
ε (MeV/fm^3)
PSR J0952-0607
M/M$_{solar}$
R (km)

Table showing maximum mass, M_{max} (in units of $M_\odot$), corresponding central density, and threshold densities for antikaon condensation for the value of optical potential depth $U_{K^-} = -130$ MeV at $n_0 = 0.152$ fm^{-3} for the case of varying α_m (left panel) and varying z_m (right panel).

	α_m varying						z_m varying				
	α_m	$x_{th}^{K^-}$	$x_{th}^{\bar{K}^0}$	$M_{\max}$	x_{central}		z_m	$x_{th}^{K^-}$	$x_{th}^{\bar{K}^0}$	$M_{\max}$	x_{central}
$\alpha_b = \alpha_m$	0.2	2.30	–	2.26	5.84	$z_b = z_m$	0.2	2.30	–	2.09	6.13
	0.4	2.50	–	2.34	5.61		0.4	2.50	–	2.28	5.71
	1.0	3.50	–	2.42	5.31		0.8	3.10	–	2.45	5.37
$\alpha_b = 2\alpha_m$	0.2	2.40	–	2.27	5.79	$z_b = 2z_m$	0.2	2.00	6.60	1.94	6.72
	0.4	2.70	–	2.35	5.55		0.4	2.00	–	2.04	6.56
	0.5	2.80	–	2.38	5.47		–	–	–	–	–
$\alpha_b = \alpha_m/2$	0.2	2.20	–	2.26	5.87	$z_b = z_m/2$	0.2	2.10	5.60	1.97	6.54
	0.4	2.40	–	2.33	5.64		0.4	2.10	6.80	2.07	6.35
	1.0	3.40	–	2.46	5.35		0.8	2.20	–	2.25	5.92
QMIC	–	2.90	4.70	2.24	5.35	QMIC	–	2.90	4.70	2.24	5.35
Nucleonic Case	–	–	–	2.48	5.34	Nucleonic Case	–	–	–	2.48	5.34

References

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