Dibaryon candidates with strangeness and effect from hidden-color channel

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Dai, Wang, Chen & Zhang, "The role of the hidden color channel in some interesting dibaryon candidates", Symmetry 15 (2023) 446

The exciting story in 2014

The COSY experiment [PRL112 (2014) 202301] found a peak in the $pn \to d\pi^0\pi^0$ fusion reaction that was associated to a $d^*(2380)$ state.

$\Downarrow$ nonstrange $(\Delta\Delta)_{ST=30}$

It corresponds to a nonstrange $\Delta\Delta$ dibaryon, its spin 3 and isospin 0, $(\Delta\Delta)_{ST=30}$, its experimental binding energy $84\ \mathrm{MeV}$, width $\simeq 70\ \mathrm{MeV}$, indicating a deeply bound state (dibaryon)

Before 2014, there were actually many theoretical works and the predicted binding energies ranged from about 10 to $390\ \mathrm{MeV}$.

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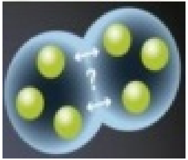
Wang, Ping, Wu, Teng, Goldman, PRC51 (1995) 3411;
H. Garcilazo, F. Fernández, Valcarce, Mota, PRC56 (1997) 84;
Gal, Garcilazo, PRL111 (2013) 172301;
Bashkanov, Brodsky, Clement, PLB727 (2013) 438;
Valcarce, Garcilazo, Mota, Fernandez, JPG27 (2001) L1;
Valcarce, Garcilazo, Fernandez, Gonzalez, Rept Prog Phys 68 (2005) 965;
. . . .
Yuan, Zhang, Yu, Shen, PRC60 (1999) 045203;
Dai, Chin Phys Lett 22 (2005) 2204

$\Downarrow$

Our predictions in the chiral SU(3) quark model and in the extended SU(3) quark model are in fairly consistent with the COSY experiment of 84 MeV binding energy.

Deuteron

♦ The first and the most famous state, deuteron, discovered in 1932. It is composed of proton-neutron (pn) system with S=1 and T=0.



Deuteron is a loosely bound state with a binding energy of only 2.2 MeV (molecular)

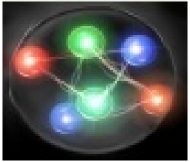
Weinberg first proposed to evaluate the molecular probability [S. Weinberg, Phys Rev 137, B672 (1965)]

Dibaryon

♦ no any other possible dibaryons were ever found in experiments for many years

$\Downarrow$ till 2014 [PRL112(2014)202301]

COSY experiment for the d^* structute



Actually, tracing back to 1964, first Gell-Mann [M. Gell-Mann, Phys Lett 8 (1964) 214] proposed the existence of dibaryons (not dynamical calculation).

Our predictions

- ♠ Our models

  In the chiral SU(3) quark model [Zhang, Yu, Shen, Dai, Faessler, Straub, NPA 625(1997)59] 153 cites

  In the extended chiral SU(3) quark model [Dai, Zhang, Yu, Wang, NPA 727 (2003) 321] 87 cites

- ♠ Resonating Group Method (RGM) Generating Coordinate Method (GCM)

- ♣ We consider the hidden-color channel (CC)

  We found that the CC channel plays an important role in the binding behavior of the d^* system.

  Yuan, Zhang, Yu, Shen, PRC60 (1999) 045203 (chiral model) 90 cites

  Dai, Chin Phys Lett 22 (2005) 2204 (extended chiral model)

Our **predictions** in the chiral and extended SU(3) quark models are in **fairly consistent** with the COSY experiment of 84 MeV binding energy

The chiral SU(3) quark model

Yu, Zhang, Shen, Dai, PRC52(1995)3393 48 cites
Zhang, Yu, Shen, Dai, Faessler, Straub, NPA625(1997)59 153 cites

SU(2) linear σ model	Chiral SU(3) quark model
$\Sigma = \sigma + i\sum_{a=1}^{3}\tau_a\pi_a$	$\Sigma = \sum_{a=0}^{8}\lambda_a\sigma_a + i\sum_{a=0}^{8}\lambda_a\pi_a$
$\mathcal{L}_I^{ch} = -g\left(\bar\psi_L\Sigma\psi_R + \bar\psi_R\Sigma^\dagger\psi_L\right) = -g\,\bar\psi\left(\sigma + i\gamma_5\sum_{a=1}^{3}\tau_a\pi_a\right)\psi$	$\mathcal{L}_I^{ch} = -g\left(\bar\psi_L\Sigma\psi_R + \bar\psi_R\Sigma^\dagger\psi_L\right) = -g\,\bar\psi\left(\sum_{a=0}^{8}\lambda_a\sigma_a + i\gamma_5\sum_{a=0}^{8}\lambda_a\pi_a\right)\psi$

More **generalized** chiral field terms are proposed to restore the chiral $SU(2)_L \times SU(2)_R$ symmetry of strong interaction [PRC52(1995)3393]

More **generalized** chiral field terms are proposed to restore the chiral $SU(3)_L \times SU(3)_R$ symmetry of strong interaction [NPA625(1997)59]

Hamiltonian of chiral SU(3) quark model

Total Hamiltonian for 6q systems:

$$H = \sum_{i=1}^{6}\left(m_i + \frac{\vec{P}_i^2}{2m_i}\right) - T_{cm} + \sum_{1=i<j}^{6}\left(V_{ij}^{\text{conf}} + V_{ij}^{\text{OGE}} + V_{ij}^{\text{ch}}\right)$$

Ch. SU(3) QM:

$$V_{ij}^{\text{ch}} = \sum_{a=0}^{8} V_{ij}^{\sigma_a} + \sum_{a=0}^{8} V_{ij}^{\pi_a}$$

In this chiral SU(3) quark model, the the nonet scalar meson exchanges and nonet pseudoscalar meson exchanges are considered in describing the medium and long range parts of the interactions, and the one gluon exchange (OGE) potential is still retained to contribute the short range repulsion [NPA625(1997)59].

We proposed the extended chiral SU(3) quark model

Some authors Stancu, Pepin, Glozman, PRC56 (1997) 2779; Shimisu, Glozman, PLB477 (2000) 59] studied short-range NN repulsion as stemming from the Goldstone boson (and rho-like) exchanges on the quark level and show that these interactions can substitute traditional OGE mechanism.

But whether OGE or vector meson exchange is the right mechanism for describing the short range part of the strong interactions, or both of them are important, is still a challenging problem.

$\Downarrow$ further include coupling between vector chiral field and quarks

We proposed the extended chiral SU(3) quark model

[Dai, Zhang, Yu, Wang, NPA 727 (2003) 321] 87cites

Hamiltonians

$$H=\sum_{i=1}^{6}\left(m_i+\frac{\vec{P}_i^2}{2m_i}\right)-T_{\mathrm{cm}}+\sum_{1=i<j}^{6}\left(V_{ij}^{\mathrm{conf}}+V_{ij}^{\mathrm{OGE}}+V_{ij}^{\mathrm{ch}}\right)$$

Ch. SU(3) QM:

$$V_{ij}^{\mathrm{ch}}=\sum_{a=0}^{8}V_{ij}^{\sigma_a}+\sum_{a=0}^{8}V_{ij}^{\pi_a}$$

Ext. Ch. SU(3) QM:

$$V_{ij}^{\mathrm{ch}}=\sum_{a=0}^{8}V_{ij}^{\sigma_a}+\sum_{a=0}^{8}V_{ij}^{\pi_a}+\sum_{a=0}^{8}V_{ij}^{\rho_a}$$

In the extended chiral SU(3) quark model, the strength of OGE interaction is greatly reduced.

The detailed differences between the chiral SU(3) quark model and the extended chiral SU(3) quark model are discussed in [Dai, Zhang, Yu, Wang, NPA727 (2003) 321].

Before the COSY experiment, our predictions for d^* structure

1) In the chiral SU(3) quark model

   Yuan, Zhang, Yu, Shen, Phys Rev C 60 (1999) 045203

2) In the extended chiral SU(3) quark model

   Dai, Chin Phys Lett 22 (2005) 2204

In both works, we consider the effect from hidden-color (CC) channel.

Determination of parameters and RGM study of ΔΔ-CC

[PRC60 (1999) 045203; CPL22 (2005) 2204]

Determination of parameters

- **Input:** $m_u = m_d = 313$ MeV,
  $b_u = 0.5$ fm (SU(3)) & 0.45 fm (ex. SU(3))
- **Coupling between quark & chiral fields:**

$$\frac{g_{ch}^2}{4\pi} = \left(\frac{3}{5}\right)^2 \frac{g_{NN\pi}^2}{4\pi}\frac{m_u^2}{m_N^2}, \qquad \frac{g_{NN\pi}^2}{4\pi} = 13.67$$

- **Mass of mesons:** experimental values except for m_σ
- **Coupling constant for OGE:** $g_u \propto m_\Delta - m_N$
- **Confinement strength & zero point energy:**

$$\frac{\partial m_N}{\partial b_u} = 0, \qquad m_N = 939 \text{ MeV}$$

RGM study of ΔΔ-CC

RGM wave functions for ΔΔ-CC system:

$$\psi_{6q} = \mathcal{A}\left[\hat{\phi}_\Delta^{\text{int}}(\vec{\xi}_1,\vec{\xi}_2)\,\hat{\phi}_\Delta^{\text{int}}(\vec{\xi}_4,\vec{\xi}_5)\,\eta_{\Delta\Delta}(\vec{r})\right]_{S=3,\,I=0,\,C=(00)} + \mathcal{A}\left[\hat{\phi}_C^{\text{int}}(\vec{\xi}_1,\vec{\xi}_2)\hat{\phi}_C^{\text{int}}(\vec{\xi}_4,\vec{\xi}_5)\,\eta_{CC}(\vec{r})\right]_{S=3,\,I=0,\,C=(00)}$$

$$\Delta: \quad (0S)^3[3]_{\text{orb}}, \quad S=\frac{3}{2}, \quad I=\frac{3}{2}, \quad C=(00)$$

$$C: \quad (0S)^3[3]_{\text{orb}}, \quad S=\frac{3}{2}, \quad I=\frac{1}{2}, \quad C=(11)$$

RGM equation for a bound state problem:

$$\langle \delta\psi_{6q} | H - E | \psi_{6q} \rangle = 0$$

Our predictions in the chiral and extended chiral SU(3) quark models [PRC60 (1999) 045203; CPL22 (2005) 2204]

The binding energy and corresponding root-mean-square (RMS) are defined:

$$\mathrm{B} = -[M_{AB} - (M_A + M_B)]\,, \quad \mathrm{RMS} = \sqrt{\frac{1}{6}\sum_{i=1}^{6}\langle(\boldsymbol{r}_i - \boldsymbol{R}_{c.m.})^2\rangle}\,.$$

without CC channel

	ΔΔ ($L=0,2$)		
	SU(3)	Ext. SU(3) (f/g=0)	Ext. SU(3) (f/g=2/3)
B (MeV)	28.96	62.28	47.90
RMS (fm)	0.96	0.80	0.84

with CC channel

ΔΔ – CC ($L=0,2$)		
SU(3)	Ext. SU(3) (f/g=0)	Ext. SU(3) (f/g=2/3)
47.27	83.95	70.25
0.88	0.76	0.78

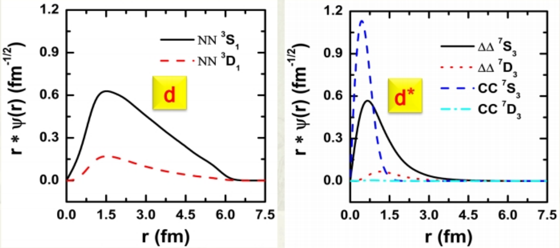
It is found that the CC channel plays an important role in the binding behavior of the d^* structure.

Our predictions are surprisingly in good agreement with the COSY experiment of 84 MeV binding energy.

Further analysis about the CC channel

Huang, Zhang, Shen, Wang, Chin Phys C 39 (2015) 071001

Relative wave function



Unlike deuteron, d* is rather narrowly distributed!

CC component

d* has a CC fraction of about 2/3

	$\Delta\Delta - \text{CC}$ $(L = 0, 2)$		
	SU(3)	Ext. SU(3) (f/g=0)	Ext. SU(3) (f/g=2/3)
B (MeV)	47.27	83.95	70.25
RMS (fm)	0.88	0.76	0.78
$(\Delta\Delta)_{L=0}$ (%)	33.11	31.22	32.51
$(\Delta\Delta)_{L=2}$ (%)	0.62	0.45	0.51
$(\text{CC})_{L=0}$ (%)	66.25	68.33	66.98
$(\text{CC})_{L=2}$ (%)	0.02	0.00	0.00

It is found that d^* has a CC fraction of about $2/3$. It is a hexaquark dominated exotic state.

Extension to dibaryon candidates with strangeness

Dai, Wang, Chen & Zhang , Symmetry 15 (2023) 446

In the chiral SU(3) quark model

Resonating Group Method (RGM)

Generating Coordinate Method (GCM)

Characterize the symmetry property

For the baryon-baryon state, the $\langle \mathcal{A}^{\mathrm{sfc}} \rangle$ is important to measure the action of the Pauli principle.

$$\langle \mathcal{A}^{\mathrm{sfc}} \rangle = \langle 1 - \sum_{i=1}^{3} \sum_{j=4}^{6} P_{ij}^{\mathrm{sfc}} \rangle = \langle 1 - 9 P_{36}^{\mathrm{sfc}} \rangle$$

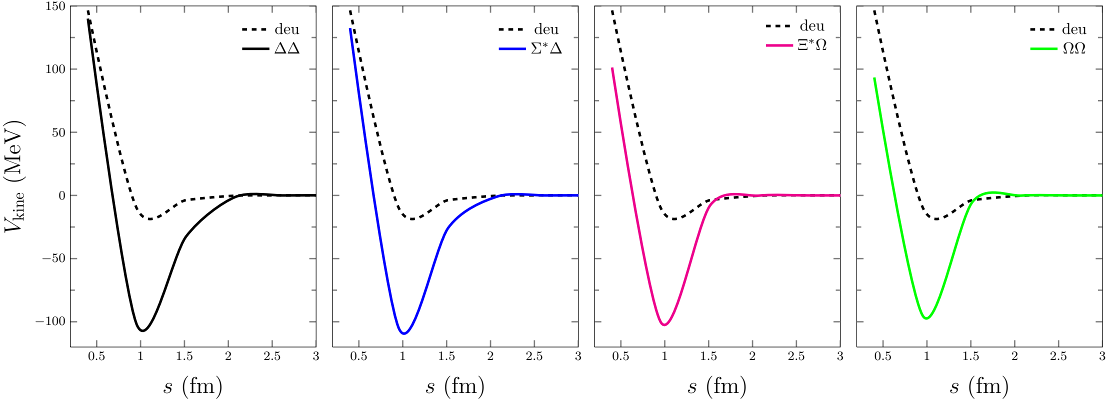
where sfc denotes the operator acts within the spin-flavor-color space, and quarks 1, 2, 3 are inside cluster A and quarks 4, 5, 6 are inside cluster B, thus P_{36}^{sfc} denotes the permutation operator representing the exchange operation between the 3-rd and 6-th quarks.

Characterize the symmetry property

		$\langle P_{36}^{\text{sfc}} \rangle$	$\langle \mathcal{A}^{\text{sfc}} \rangle$
deuteron	$(NN)_{ST=10}$	$-\frac{1}{81}$	$\frac{10}{9}$
	$(\Delta\Delta)_{ST=03}$	$-\frac{1}{9}$	2
d^*	$(\Delta\Delta)_{ST=30}$	$-\frac{1}{9}$	2
	$(\Sigma^*\Delta)_{ST=0\frac{5}{2}}$	$-\frac{1}{9}$	2
	$(\Sigma^*\Delta)_{ST=3\frac{1}{2}}$	$-\frac{1}{9}$	2
	$(\Xi^*\Omega)_{ST=0\frac{1}{2}}$	$-\frac{1}{9}$	2
	$(\Omega\Omega)_{ST=00}$	$-\frac{1}{9}$	2

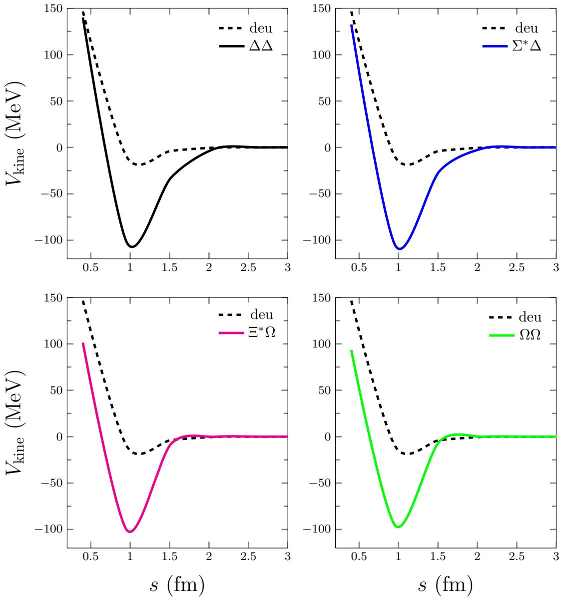
It is seen that six interesting candidates belong to $\langle \mathcal{A}^{\text{sfc}} \rangle = 2$. These systems would be enormously beneficial to form a state due to highly symmetric character of $[6]_O$ in orbital space.

kinetic energy part of the GCM matrix elements for deuteron and dibaryon candidates



generator coordinate *s*

(qualitatively describes the distance between A and B clusters)



The kinetic energy itself is spin-flavor-color independent, thus it is interesting to see the attraction arising from the quark exchange.

deuteron: the attraction is small in relatively long range part.

dibaryon candidates: It is seen the strong attraction in the short range part arising from the quark exchange.

⇓

which demonstrates clearly that the quantum mechanical effect alone has played a decisive role in binding the two clusters.

Construct the CC wave function

here we just show the $(\Delta\Delta)_{ST=03}$ case as an example

It is rather complicated to construct the CC wave function and evaluate the coefficients by using cfp method in group theory.

same as [PRC60 (1999) 045203 for d^* structure], CC wave function for $(\Delta\Delta)_{ST=03}$ can be written

$$|\mathrm{CC}\rangle_{ST=03} = a\,|\Delta\Delta\rangle_{ST=03} + b\,\mathcal{A}^{\mathrm{sfc}}|\Delta\Delta\rangle_{ST=03}$$

by utilizing the orthogonality

$$\langle\Delta\Delta|\mathrm{CC}\rangle = 0\,, \quad \langle\mathrm{CC}|\mathrm{CC}\rangle = 1$$

we obtain $a = -\frac{1}{2}$, $b = \frac{5}{2}$, thus

$$|\mathrm{CC}\rangle_{ST=03} = -\frac{1}{2}\,|\Delta\Delta\rangle_{ST=03} + \frac{5}{2}\,\mathcal{A}^{\mathrm{sfc}}|\Delta\Delta\rangle_{ST=03}$$

Then we compute all the matrix elements in spin-flavor-color (sfc) space for all the operators in the chiral SU(3) quark model.

for $(\Delta\Delta)_{ST=03}$, all the GCM matrix elements in sfc space

		$\Delta\Delta$	$\Delta\Delta$	CC		$\Delta\Delta$	$\Delta\Delta$	CC
		$\Delta\Delta$	CC	CC		$\Delta\Delta$	CC	CC
1		1	0	1				
P_{36}		$-\frac{1}{9}$	$-\frac{4}{9}$	$-\frac{7}{9}$				
$\lambda_i^c \cdot \lambda_j^c$	$\hat{O}_{12}$	$-\frac{8}{3}$	0	$-\frac{2}{3}$	$\hat{O}_{36}$	0	0	$-\frac{4}{3}$
	$\hat{O}_{12}P_{36}$	$\frac{8}{27}$	$\frac{32}{27}$	$\frac{2}{27}$	$\hat{O}_{36}P_{36}$	$-\frac{16}{27}$	$\frac{8}{27}$	$\frac{32}{27}$
	$\hat{O}_{13}P_{36}$	$\frac{8}{27}$	$\frac{32}{27}$	$\frac{20}{27}$	$\hat{O}_{16}P_{36}$	$\frac{8}{27}$	$-\frac{4}{27}$	$\frac{20}{27}$
	$\hat{O}_{14}P_{36}$	$-\frac{4}{27}$	$\frac{2}{27}$	$\frac{35}{27}$				

It is noted that the $\langle \mathrm{CC}|\lambda_1^c \cdot \lambda_2^c|\mathrm{CC}\rangle = -\frac{2}{3}$, verifying that the CC wave function is correct.

(continued) for $(\Delta\Delta)_{ST=03}$, all the GCM matrix elements in sfc space

		ΔΔ ΔΔ	ΔΔ CC	CC CC		ΔΔ ΔΔ	ΔΔ CC	CC CC
$\sigma_i \cdot \sigma_j \, \lambda_i^c \cdot \lambda_j^c$	$\hat{O}_{12}$	$-\frac{8}{3}$	0	$-\frac{10}{3}$	$\hat{O}_{36}$	0	$-\frac{16}{9}$	$-\frac{20}{9}$
	$\hat{O}_{12}P_{36}$	$\frac{8}{27}$	$\frac{32}{27}$	$\frac{74}{27}$	$\hat{O}_{36}P_{36}$	$\frac{112}{27}$	$-\frac{8}{27}$	$\frac{88}{27}$
	$\hat{O}_{13}P_{36}$	$\frac{8}{27}$	$\frac{32}{27}$	$\frac{68}{27}$	$\hat{O}_{16}P_{36}$	$\frac{8}{27}$	$\frac{44}{27}$	$\frac{68}{27}$
	$\hat{O}_{14}P_{36}$	$\frac{4}{9}$	$\frac{14}{9}$	$\frac{7}{3}$				
$\sigma_i \cdot \sigma_j \sum_{a=1}^{3} \lambda_a(i)\lambda_a(j)$	$\hat{O}_{12}$	1	0	-1	$\hat{O}_{36}$	$-\frac{5}{3}$	0	$-\frac{1}{3}$
	$\hat{O}_{12}P_{36}$	$-\frac{1}{9}$	$-\frac{4}{9}$	$\frac{11}{9}$	$\hat{O}_{36}P_{36}$	$\frac{7}{9}$	$\frac{4}{9}$	$\frac{1}{9}$
	$\hat{O}_{13}P_{36}$	$-\frac{1}{9}$	$-\frac{4}{9}$	$\frac{5}{9}$	$\hat{O}_{16}P_{36}$	$-\frac{1}{9}$	$\frac{8}{9}$	$\frac{5}{9}$
	$\hat{O}_{14}P_{36}$	$\frac{1}{3}$	$\frac{2}{3}$	0				
$\sigma_i \cdot \sigma_j \sum_{a=4}^{7} \lambda_a(i)\lambda_a(j)$	$\hat{O}_{12}$	0	0	0	$\hat{O}_{36}$	0	0	0
	$\hat{O}_{12}P_{36}$	0	0	0	$\hat{O}_{36}P_{36}$	0	0	0
	$\hat{O}_{13}P_{36}$	0	0	0	$\hat{O}_{16}P_{36}$	0	0	0
	$\hat{O}_{14}P_{36}$	0	0	0				

All central matrix elements in sfc space for $(\Sigma^*\Delta)_{ST=3\frac{1}{2}}$

		$\Sigma^*\Delta$ $\Sigma^*\Delta$	$\Sigma^*\Delta$ CC	CC CC		$\Sigma^*\Delta$ $\Sigma^*\Delta$	$\Sigma^*\Delta$ CC	CC CC
1		1	0	1				
P_{36}		$-\frac{1}{9}$	$-\frac{4}{9}$	$-\frac{7}{9}$				
$\lambda_i^c \cdot \lambda_j^c$	$\hat{O}_{12}$	$-\frac{8}{3}$	0	$-\frac{2}{3}$	$\hat{O}_{36}$	0	0	$-\frac{4}{3}$
	$\hat{O}_{12}P_{36}$	$\frac{8}{27}$	$\frac{32}{27}$	$\frac{2}{27}$	$\hat{O}_{36}P_{36}$	$-\frac{16}{27}$	$\frac{8}{27}$	$\frac{32}{27}$
	$\hat{O}_{13}P_{36}$	$\frac{8}{27}$	$\frac{32}{27}$	$\frac{20}{27}$	$\hat{O}_{16}P_{36}$	$\frac{8}{27}$	$-\frac{4}{27}$	$\frac{20}{27}$
	$\hat{O}_{14}P_{36}$	$-\frac{4}{27}$	$\frac{2}{27}$	$\frac{35}{27}$				
$\sigma_i \cdot \sigma_j \lambda_i^c \cdot \lambda_j^c$	$\hat{O}_{12}$	$-\frac{8}{3}$	0	$-\frac{2}{3}$	$\hat{O}_{36}$	0	0	$-\frac{4}{3}$
	$\hat{O}_{12}P_{36}$	$\frac{8}{27}$	$\frac{32}{27}$	$\frac{2}{27}$	$\hat{O}_{36}P_{36}$	$-\frac{16}{27}$	$\frac{8}{27}$	$\frac{32}{27}$
	$\hat{O}_{13}P_{36}$	$\frac{8}{27}$	$\frac{32}{27}$	$\frac{20}{27}$	$\hat{O}_{16}P_{36}$	$\frac{8}{27}$	$-\frac{4}{27}$	$\frac{20}{27}$
	$\hat{O}_{14}P_{36}$	$-\frac{4}{27}$	$\frac{2}{27}$	$\frac{35}{27}$				
$\sigma_i \cdot \sigma_j \sum_{a=1}^{3} \lambda_a(i)\lambda_a(j)$	$\hat{O}_{12}$	$\frac{2}{3}$	0	$-\frac{2}{3}$	$\hat{O}_{36}$	$-\frac{10}{9}$	0	$-\frac{2}{9}$
	$\hat{O}_{12}P_{36}$	$-\frac{2}{27}$	$-\frac{8}{27}$	$\frac{22}{27}$	$\hat{O}_{36}P_{36}$	$\frac{14}{27}$	$\frac{8}{27}$	$\frac{2}{27}$
	$\hat{O}_{13}P_{36}$	$-\frac{2}{27}$	$-\frac{8}{27}$	$\frac{10}{27}$	$\hat{O}_{16}P_{36}$	$-\frac{2}{27}$	$\frac{16}{27}$	$\frac{10}{27}$
	$\hat{O}_{14}P_{36}$	$\frac{2}{9}$	$\frac{4}{9}$	0				
$\sigma_i \cdot \sigma_j \sum_{a=4}^{7} \lambda_a(i)\lambda_a(j)$	$\hat{O}_{12}$	$\frac{2}{3}$	0	0	$\hat{O}_{36}$	$-\frac{2}{9}$	0	$\frac{2}{9}$
	$\hat{O}_{12}P_{36}$	$-\frac{2}{27}$	$-\frac{8}{27}$	$\frac{4}{27}$	$\hat{O}_{36}P_{36}$	$\frac{2}{9}$	0	$-\frac{2}{9}$
	$\hat{O}_{13}P_{36}$	$-\frac{2}{27}$	$-\frac{8}{27}$	$-\frac{2}{27}$	$\hat{O}_{16}P_{36}$	$-\frac{2}{27}$	$\frac{4}{27}$	$-\frac{2}{27}$
	$\hat{O}_{14}P_{36}$	$\frac{2}{27}$	$\frac{2}{27}$	$-\frac{2}{27}$				

It is noted that the $\langle CC|\lambda_1^c \cdot \lambda_2^c|CC\rangle = -\frac{2}{3}$, verifying that the CC wave function is correct.

All the matrix elements in sfc space **for $(\Sigma^*\Delta)_{ST=0\frac{5}{2}}$ case**

		$\Sigma^*\Delta$ $\Sigma^*\Delta$	$\Sigma^*\Delta$ CC	CC CC		$\Sigma^*\Delta$ $\Sigma^*\Delta$	$\Sigma^*\Delta$ CC	CC CC
1		1	0	1				
P_{36}		$-\frac{1}{9}$	$-\frac{4}{9}$	$-\frac{7}{9}$				
$\lambda_i^c \cdot \lambda_j^c$	$\hat{O}_{12}$	$-\frac{8}{3}$	0	$-\frac{2}{3}$	$\hat{O}_{36}$	0	0	$-\frac{4}{3}$
	$\hat{O}_{12}P_{36}$	$\frac{8}{27}$	$\frac{32}{27}$	$\frac{2}{27}$	$\hat{O}_{36}P_{36}$	$-\frac{16}{27}$	$\frac{8}{27}$	$\frac{32}{27}$
	$\hat{O}_{13}P_{36}$	$\frac{8}{27}$	$\frac{32}{27}$	$\frac{20}{27}$	$\hat{O}_{16}P_{36}$	$\frac{8}{27}$	$-\frac{4}{27}$	$\frac{20}{27}$
	$\hat{O}_{14}P_{36}$	$-\frac{4}{27}$	$\frac{2}{27}$	$\frac{35}{27}$				
$\sigma_i \cdot \sigma_j \, \lambda_i^c \lambda_j^c$	$\hat{O}_{12}$	$-\frac{8}{3}$	0	$-\frac{10}{3}$	$\hat{O}_{36}$	0	$-\frac{16}{9}$	$-\frac{20}{9}$
	$\hat{O}_{12}P_{36}$	$\frac{8}{27}$	$\frac{32}{27}$	$\frac{74}{27}$	$\hat{O}_{36}P_{36}$	$\frac{112}{27}$	$-\frac{8}{27}$	$\frac{88}{27}$
	$\hat{O}_{13}P_{36}$	$\frac{8}{27}$	$\frac{32}{27}$	$\frac{68}{27}$	$\hat{O}_{16}P_{36}$	$\frac{8}{27}$	$\frac{44}{27}$	$\frac{68}{27}$
	$\hat{O}_{14}P_{36}$	$\frac{4}{9}$	$\frac{14}{9}$	$\frac{7}{3}$				
$\sigma_i \cdot \sigma_j \sum_{a=1}^{3} \lambda_a(i)\lambda_a(j)$	$\hat{O}_{12}$	$\frac{2}{3}$	0	$-\frac{2}{3}$	$\hat{O}_{36}$	$-\frac{10}{9}$	0	$-\frac{2}{9}$
	$\hat{O}_{12}P_{36}$	$-\frac{2}{27}$	$-\frac{8}{27}$	$\frac{22}{27}$	$\hat{O}_{36}P_{36}$	$\frac{14}{27}$	$\frac{8}{27}$	$\frac{2}{27}$
	$\hat{O}_{13}P_{36}$	$-\frac{2}{27}$	$-\frac{8}{27}$	$\frac{10}{27}$	$\hat{O}_{16}P_{36}$	$-\frac{2}{27}$	$\frac{16}{27}$	$\frac{10}{27}$
	$\hat{O}_{14}P_{36}$	$\frac{2}{9}$	$\frac{4}{9}$	0				
$\sigma_i \cdot \sigma_j \sum_{a=4}^{7} \lambda_a(i)\lambda_a(j)$	$\hat{O}_{12}$	$\frac{2}{3}$	0	$-\frac{2}{3}$	$\hat{O}_{36}$	$-\frac{10}{9}$	0	$-\frac{2}{9}$
	$\hat{O}_{12}P_{36}$	$-\frac{2}{27}$	$-\frac{8}{27}$	$\frac{22}{27}$	$\hat{O}_{36}P_{36}$	$\frac{14}{27}$	$\frac{8}{27}$	$\frac{2}{27}$
	$\hat{O}_{13}P_{36}$	$-\frac{2}{27}$	$-\frac{8}{27}$	$\frac{10}{27}$	$\hat{O}_{16}P_{36}$	$-\frac{2}{27}$	$\frac{16}{27}$	$\frac{10}{27}$
	$\hat{O}_{14}P_{36}$	$\frac{2}{9}$	$\frac{4}{9}$	0				

It is noted that the $\langle CC|\lambda_1^c \cdot \lambda_2^c|CC\rangle = -\frac{2}{3}$, verifying that the CC wave function is correct.

All the matrix elements in sfc space **for $(\Xi^*\Omega)_{ST=0\frac{1}{2}}$ case**

		$\Xi^*\Omega$	$\Xi^*\Omega$	CC		$\Xi^*\Omega$	$\Xi^*\Omega$	CC
		$\Xi^*\Omega$	CC	CC		$\Xi^*\Omega$	CC	CC
1		1	0	1				
P_{36}		$-\frac{1}{9}$	$-\frac{4}{9}$	$-\frac{7}{9}$				
$\lambda_i^c \cdot \lambda_j^c$	$\hat{O}_{12}$	$-\frac{8}{3}$	0	$-\frac{2}{3}$	$\hat{O}_{36}$	0	0	$-\frac{4}{3}$
	$\hat{O}_{12}P_{36}$	$\frac{8}{27}$	$\frac{32}{27}$	$\frac{2}{27}$	$\hat{O}_{36}P_{36}$	$-\frac{16}{27}$	$\frac{8}{27}$	$\frac{32}{27}$
	$\hat{O}_{13}P_{36}$	$\frac{8}{27}$	$\frac{32}{27}$	$\frac{20}{27}$	$\hat{O}_{16}P_{36}$	$\frac{8}{27}$	$-\frac{4}{27}$	$\frac{20}{27}$
	$\hat{O}_{14}P_{36}$	$-\frac{4}{27}$	$\frac{2}{27}$	$\frac{35}{27}$				
$\sigma_i \cdot \sigma_j \, \lambda_i^c \cdot \lambda_j^c$	$\hat{O}_{12}$	$-\frac{8}{3}$	0	$-\frac{10}{3}$	$\hat{O}_{36}$	0	$-\frac{16}{9}$	$-\frac{20}{9}$
	$\hat{O}_{12}P_{36}$	$\frac{8}{27}$	$\frac{32}{27}$	$\frac{74}{27}$	$\hat{O}_{36}P_{36}$	$\frac{112}{27}$	$-\frac{8}{27}$	$\frac{88}{27}$
	$\hat{O}_{13}P_{36}$	$\frac{8}{27}$	$\frac{32}{27}$	$\frac{68}{27}$	$\hat{O}_{16}P_{36}$	$\frac{8}{27}$	$\frac{44}{27}$	$\frac{68}{27}$
	$\hat{O}_{14}P_{36}$	$\frac{4}{9}$	$\frac{4}{9}$	$\frac{7}{3}$				
$\sigma_i \cdot \sigma_j \sum_{a=1}^{3} \lambda_a(i)\lambda_a(j)$	$\hat{O}_{12}$	0	0	0	$\hat{O}_{36}$	0	0	0
	$\hat{O}_{12}P_{36}$	0	0	0	$\hat{O}_{36}P_{36}$	0	0	0
	$\hat{O}_{13}P_{36}$	0	0	0	$\hat{O}_{16}P_{36}$	0	0	0
	$\hat{O}_{14}P_{36}$	0	0	0				
$\sigma_i \cdot \sigma_j \sum_{a=4}^{7} \lambda_a(i)\lambda_a(j)$	$\hat{O}_{12}$	$\frac{2}{3}$	0	$-\frac{2}{3}$	$\hat{O}_{36}$	$-\frac{10}{9}$	0	$-\frac{2}{9}$
	$\hat{O}_{12}P_{36}$	$-\frac{2}{27}$	$-\frac{8}{27}$	$\frac{22}{27}$	$\hat{O}_{36}P_{36}$	$\frac{14}{27}$	$\frac{8}{27}$	$\frac{2}{27}$
	$\hat{O}_{13}P_{36}$	$-\frac{2}{27}$	$-\frac{8}{27}$	$\frac{10}{27}$	$\hat{O}_{16}P_{36}$	$-\frac{2}{27}$	$\frac{16}{27}$	$\frac{10}{27}$
	$\hat{O}_{14}P_{36}$	$\frac{2}{9}$	$\frac{4}{9}$	0				

It is noted that the $\langle CC|\lambda_1^c \cdot \lambda_2^c|CC\rangle = -\frac{2}{3}$, verifying that the CC wave function is correct.

All the matrix elements in sfc space **for $(\Omega\Omega)_{ST=00}$ case**

		$\Omega\Omega$	$\Omega\Omega$	CC		$\Omega\Omega$	$\Omega\Omega$	CC
		$\Omega\Omega$	CC	CC		$\Omega\Omega$	CC	CC
1		1	0	1				
P_{36}		$-\frac{1}{9}$	$-\frac{4}{9}$	$-\frac{7}{9}$				
$\lambda_i^c \cdot \lambda_j^c$	$\hat{O}_{12}$	$-\frac{8}{3}$	0	$-\frac{2}{3}$	$\hat{O}_{36}$	0	0	$-\frac{4}{3}$
	$\hat{O}_{12}P_{36}$	$\frac{8}{27}$	$\frac{32}{27}$	$\frac{2}{27}$	$\hat{O}_{36}P_{36}$	$-\frac{16}{27}$	$\frac{8}{27}$	$\frac{32}{27}$
	$\hat{O}_{13}P_{36}$	$\frac{8}{27}$	$\frac{32}{27}$	$\frac{20}{27}$	$\hat{O}_{16}P_{36}$	$\frac{8}{27}$	$-\frac{4}{27}$	$\frac{20}{27}$
	$\hat{O}_{14}P_{36}$	$-\frac{4}{27}$	$\frac{2}{27}$	$\frac{35}{27}$				
$\sigma_i \cdot \sigma_j \lambda_i^c \cdot \lambda_j^c$	$\hat{O}_{12}$	$-\frac{8}{3}$	0	$-\frac{10}{3}$	$\hat{O}_{36}$	0	$-\frac{16}{9}$	$-\frac{20}{9}$
	$\hat{O}_{12}P_{36}$	$\frac{8}{27}$	$\frac{32}{27}$	$\frac{74}{27}$	$\hat{O}_{36}P_{36}$	$\frac{112}{27}$	$-\frac{8}{27}$	$\frac{88}{27}$
	$\hat{O}_{13}P_{36}$	$\frac{8}{27}$	$\frac{32}{27}$	$\frac{68}{27}$	$\hat{O}_{16}P_{36}$	$\frac{8}{27}$	$\frac{44}{27}$	$\frac{68}{27}$
	$\hat{O}_{14}P_{36}$	$\frac{4}{9}$	$\frac{14}{9}$	$\frac{7}{3}$				
$\sigma_i \cdot \sigma_j \sum_{a=1}^{3} \lambda_a(i)\lambda_a(j)$	$\hat{O}_{12}$	0	0	0	$\hat{O}_{36}$	0	0	0
	$\hat{O}_{12}P_{36}$	0	0	0	$\hat{O}_{36}P_{36}$	0	0	0
	$\hat{O}_{13}P_{36}$	0	0	0	$\hat{O}_{16}P_{36}$	0	0	0
	$\hat{O}_{14}P_{36}$	0	0	0				
$\sigma_i \cdot \sigma_j \sum_{a=4}^{7} \lambda_a(i)\lambda_a(j)$	$\hat{O}_{12}$	0	0	0	$\hat{O}_{36}$	0	0	0
	$\hat{O}_{12}P_{36}$	0	0	0	$\hat{O}_{36}P_{36}$	0	0	0
	$\hat{O}_{13}P_{36}$	0	0	0	$\hat{O}_{16}P_{36}$	0	0	0
	$\hat{O}_{14}P_{36}$	0	0	0				

It is noted that the $\langle CC|\lambda_1^c \cdot \lambda_2^c|CC\rangle = -\frac{2}{3}$, verifying that the CC wave function is correct.

Predictions of dibaryon candidates with the CC channel

In the chiral SU(3) quark model

Dai, Wang, Chen & Zhang, Symmetry 15 (2023) 446

The baryon-baryon interactions by solving the RGM equation are dynamically investigated and ($\Delta\Delta$+CC), ($\Sigma^*\Delta$+CC), ($\Xi^*\Omega$+CC), or ($\Omega\Omega$+CC) will be considered, respectively.

The parameters are taken from [Dai, Zhang, Yu, Wang, NPA 727 (2003) 321]

The results for $(\Delta\Delta)_{ST=03}$ candidate

	$L=0$	
	$\Delta\Delta$	$\Delta\Delta$+CC
B (MeV)	22.6	31.6
RMS (fm)	1.03	0.97

The results for $(\Sigma^*\Delta)_{ST=0\frac{5}{2}}$ candidate

	$L=0$	
	$\Sigma^*\Delta$	$\Sigma^*\Delta$+CC
B (MeV)	32.3	41.5
RMS (fm)	0.94	0.90

The CC channel make an increment of **less than 10 MeV** to the corresponding binding energy.

The results for $(\Xi^*\Omega)_{ST=0\frac{1}{2}}$ candidate

	$L=0$	
	$\Xi^*\Omega$	$\Xi^*\Omega$+CC
B (MeV)	100.9	105.7
RMS (fm)	0.70	0.69

The results for $(\Omega\Omega)_{ST=00}$ candidate

	$L=0$	
	$\Omega\Omega$	$\Omega\Omega$+CC
B(MeV)	122.8	129.7
RMS (fm)	0.66	0.65

For S=0 candidate, the CC channel make an increment of **less than 10 MeV** to the corresponding binding energy.

The results for $(\Sigma^*\Delta)_{ST=3\frac{1}{2}}$ candidate

	$L=0$		$L=0+2$	
	$\Sigma^*\Delta$	$\Sigma^*\Delta$+CC	$\Sigma^*\Delta$	$\Sigma^*\Delta$+CC
B (MeV)	30.4	45.2	34.0	50.4
RMS (fm)	0.91	0.85	0.90	0.84

For S=3 candidate, further including tensor couplings from both OGE and pseudoscalar chiral fields exchanges, we see **an increment of about 20 MeV** to the binding energy.

Summary

The baryon-baryon interactions are dynamically investigated in the chiral and extended chiral SU(3)quark model.

1) Structure of d^* and effect from hidden-color (CC) channel

PRC60 (1999) 045203; CPL22 (2005) 2204; CPC39 (2015) 071001

Our predictions are surprisingly in good agreement with the COSY experiment.

It is found that the CC channel plays an important role in the binding behavior of the d^* structure, which has a CC fraction of about $\frac{2}{3}$, indicating a hexaquark dominated exotic state.

2) Extension to candidates with strangeness with CC channel

Symmetry15 (2023) 446

a) symmetry property

compared with deuteron, each dibaryon candidate has strong attraction in the short range part arising from the quark exchange, which has played a decisive role in binding the two clusters.

b) dynamically investigation

for ($\Delta\Delta$+CC), ($\Sigma^*\Delta$+CC), ($\Xi^*\Omega$+CC), ($\Omega\Omega$+CC) with different strangeness $0, -1, -5, -6$, respectively. We find that

1) for each S=0 dibaryon candidates, the CC channel has an **obvious effect.**

2) for S=3 candidate (due to further tensor coupling) the CC channel plays an **significant role** in forming its bound state.

- end -