Analysis of $X(3872)$

Yan-Mei Kong* and Ailin Zhang†

Department of Physics, Shanghai University, Shanghai, 200444, China

Properties of Regge trajectories for charmonium are studied. Possible interpretations and their implications to newly observed $X(3872)$ are examined. It seems that $X(3872)$ is impossible to be the $2^{++} 2D_2$ charmonium or the $2^{++}$ tetraquark state.


I. INTRODUCTION

Recently some new charmonium or charmonium-like states, such as $X(3872)$[1, 2, 3, 4, 5], $Y(3940)[6]$, $X(3940)[7]$, $Y(4260)[8, 9]$ and $Z(3930)[10]$ were observed. $Z(3930)$ was pinned down as the $\chi_{c2}(2p)$ in 2006 PDG[11], while others have not been identified. Among these new states, $X(3872)$ has drawn people’s great interest for its peculiar decay properties. $X(3872)$ was first observed by Belle[1] in exclusive B decays,

$$B^\pm \to K^\pm X(3872), X(3872) \to \pi^+ \pi^- J/\psi.$$ (1)

Subsequently it was confirmed by CDF[2, 3], D0[4] and BaBar[5]. The mass of this state is $M = 3871.2 \pm 0.5$ MeV and the width $\Gamma < 2.3$ MeV(0.9 C.L.). The mass is within errors at the $D^0\bar{D}^{*0}$ threshold, but the width is small.

To accommodate $X(3872)$ in hadron spectroscopy, considerable speculations and plenty of interpretations were proposed. There are conventional $c\bar{c}$ charmonium assignments[12, 13, 14, 15, 16, 17, 18, 19, 20, 21], molecule state interpretations[12, 22, 23, 24, 25], tetraquark state interpretations[26], hybrid interpretations[12, 27] or mixing states interpretations among them[24, 28, 29].

Due to its decay final states, $X(3872)$ is naturally expected to be a charmonium state. However, $X(3872)$ has a lower mass, a narrower width and puzzling decay properties. An upper limit for the radiative transition $X(3872) \to \gamma \chi_{c1}$ has been set[1], which makes it difficult to identify $X(3872)$ with any charmonium state. The decay $X(3872) \to J/\psi \phi[24, 25]$ and the decay $X(3872) \to J/\psi \omega[30, 31]$ were both observed by Belle. The simultaneous decay to $J/\psi\rho$ and $J/\psi\omega$ with roughly equal branching ratios is a strong implication of the "molecule" state assignment for $X(3872)$. Therefore, $X(3872)$ which seems not match any predicted charmonium state was interpreted as a "molecule" or tetraquark state.

Things are not over and get more complicated since the observation of $X(3872) \to \gamma J/\psi$ by Belle[31] and BaBar[32], in which the observed branching fraction is much smaller than theoretically predicted one for molecule states. In particular, $B \to D^0\bar{D}^{*0}\pi K$ was recently observed by Belle[33]. If this near-threshold enhancement is due to $X(3872)$, it has a branching ratio $9.4^{+3.6}_{-4.3}$ times larger than $B(B^+ \to X(3872)K^+) \times B(X(3872) \to J/\psi\pi^+\pi^-)$. This branching ratio is much larger than the predicted one in the molecule model.

Both charmonium state interpretation and four-quark state interpretation have difficulties. So far, there is no compelling evidence to confirm one interpretation or to exclude one interpretation.

One better way to understand $X(3872)$ is identifying its $J^{PC}$. The observation of $X(3872) \to \gamma J/\psi$ indicates that its $C = +$. Though some analyses favor $J^{PC} = 1^{++}$[34, 35], the analysis of the angular distribution of the decay and the analysis of the $\pi\pi$ invariant mass distribution suggest that both $1^{++}$ and $2^{++}$ are possible[3, 24]. This assignment is supported by a most recent analysis[35].

Though the hadron dynamics was mainly exhibited through its production and decay properties, much hadron dynamics could also be detected from its mass (e.g., the relation between the spectrum and its quantum numbers). In this way, $X(3872)$ has recently been studied in terms of Regge trajectory theory[35, 37].

No matter what $X(3872)$ is and no matter what quantum number it really has, the charmonium possibility of $X(3872)$ and its implication may be detected through the study of some relations on its mass within charmonium states.

II. REGGE TRAJECTORY AND HYPERFINE SPLITTING OF CHARMONIUM

Regge trajectory[38, 39] is an important phenomenological way to describe the masses relations among different hadrons. There is resurgent interest in Regge theory for much more experimental data accumulated lately. Furthermore, some quark models need more complete experimental fits for testing[40]. Regge trajectories are some graphs of the total quantum numbers $J$ versus mass squared $M^2$ over a set of particles which have fixed principle quantum number $n$, isospin $I$, dimensionality of the symmetry group $D$ and flavors. A Chew-Frautschi Regge trajectory is a line:

$$J(M^2) = \alpha(0) + \alpha'M^2,$$ (2)
where intercept $\alpha(0)$ and slope $\alpha'$ depend weakly on the flavor content of the states lying on corresponding trajectory. For light quark mesons, $\alpha' \approx 0.9 \text{ GeV}^{-2}$. Different Regge trajectories are approximately parallel.

It is found that the linearity and parallelism of Regge trajectories with neighborhood mesons stepped by 1 in $J$ with opposite $PC$ holds not well [11, 42, 43]. The intrinsic quark-gluon dynamics may result in large non-linearity and non-parallelism of such Regge trajectories. However, the linearity and parallelism of Regge trajectories with neighborhood mesons stepped by 2 in $J$ with the same $PC$ is found to hold well [44].

In addition to these properties of the Regge trajectories with the same principal quantum number $n$, another relation for Regge trajectories with different $n$ was assumed. It was argued that the parallelism of Regge trajectories with different $n$ (others are identical) may hold for similar dynamics [40]. Whether this parallelism property of Regge trajectory holds or not has not been tested for the lack of data.

For radial excited light $q\bar{q}$ mesons, there exist relations between their masses and principle quantum numbers $n$. These mesons consist of another kind of trajectory on $(n, M^2)$-plots [14].

$$M^2 = M_0^2 + (n-1)\mu^2,$$

where $\mu^2$ is the slope parameter (approximately the same for all trajectories).

Hyperfine (spin-triplet and spin-singlet) splitting is another important mass relation among hadrons. In many potential models [45, 46, 47], the S-wave hyperfine (spin-triplet and spin-singlet) splitting, $\Delta M_{hf}(nS) = M(n^3S_1) - M(n^1S_0)$, is predicted to be finite, while other hyperfine splitting of P-wave or higher L-state is expected to be zero:

$$\Delta M_{hf}(1P) = <M(1^3P_J) > - M(1^1P_J) \approx 0, \quad \Delta M_{hf}(1D) = <M(1^3D_J) > - M(1^1D_J) \approx 0,$$

where the deviation from zero is no more than a few MeV. Though these predictions are model dependent, the masses relation of the 1P charmonium multiplet has been proved to hold in a high degree accuracy [11]. This hyperfine splitting relations of the 1P, 1D and 2D multiplets will be used as facts (or assumptions).

The paper is organized as follows. In section III, in terms of the experimental data accumulated lately, all the properties of possible Regge trajectories for the charmonium are studied, and an updated phenomenological analysis is made to the new data. Secondly the linearity and parallelism of Regge trajectories with neighborhood mesons stepped by 2 in $J$ is combined with the hyperfine splitting relations of D-wave multiplets to examine some possible charmonium arrangements to $X(3872)$. Finally, we analyze $X(3872)$ through the observed trajectory property in $(n, M^2)$-plots. In section IV, the tetraquark state possibility of $X(3872)$ is briefly analyzed. Some conclusions and discussions are given in the last section.

### TABLE I: Spectrum of charmonium.

<table>
<thead>
<tr>
<th>States</th>
<th>$J^{PC}$</th>
<th>$n^{2S+1}L_J$</th>
<th>Mass(MeV)</th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\eta(1S)$</td>
<td>$0^{-+}$</td>
<td>$1^1S_0$</td>
<td>2980.4</td>
<td>PDG</td>
</tr>
<tr>
<td>$\eta(2S)$</td>
<td>$0^{-+}$</td>
<td>$2^1S_1$</td>
<td>3638 ± 4</td>
<td>PDG</td>
</tr>
<tr>
<td>$\eta(3S)$</td>
<td>$0^{-+}$</td>
<td>$3^1S_0$</td>
<td>?</td>
<td>?</td>
</tr>
<tr>
<td>$J/\psi(1S)$</td>
<td>$1^{++}$</td>
<td>$1^3S_1$</td>
<td>3096.9</td>
<td>PDG</td>
</tr>
<tr>
<td>$\psi(2S)$</td>
<td>$1^{--}$</td>
<td>$2^3S_1$</td>
<td>3686.1</td>
<td>PDG</td>
</tr>
<tr>
<td>$\psi(2P)$</td>
<td>$1^{++}$</td>
<td>$2^1P_1$</td>
<td>4039 ± 1</td>
<td>PDG</td>
</tr>
<tr>
<td>$\psi(4415)$</td>
<td>$1^{--}$</td>
<td>$2^3S_1$</td>
<td>4421 ± 4</td>
<td>PDG</td>
</tr>
<tr>
<td>$\chi_{c0}(1P)$</td>
<td>$0^{++}$</td>
<td>$1^3P_0$</td>
<td>3414.8</td>
<td>PDG</td>
</tr>
<tr>
<td>$\chi_{c0}(2P)$</td>
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<td>$2^3P_0$</td>
<td>?</td>
<td>?</td>
</tr>
<tr>
<td>$\chi_{c1}(1P)$</td>
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<td>$1^3P_1$</td>
<td>3510.7</td>
<td>PDG</td>
</tr>
<tr>
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<td>$1^{++}$</td>
<td>$2^3P_1$</td>
<td>?</td>
<td>?</td>
</tr>
<tr>
<td>$\chi_{c2}(1P)$</td>
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<td>$1^3P_2$</td>
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<td>PDG</td>
</tr>
<tr>
<td>$\chi_{c2}(2P)$</td>
<td>$2^{++}$</td>
<td>$2^3P_2$</td>
<td>3929 ± 5</td>
<td>PDG</td>
</tr>
<tr>
<td>$\psi(3770)$</td>
<td>$1^{--}$</td>
<td>$1^3D_1$</td>
<td>3771.1</td>
<td>PDG</td>
</tr>
<tr>
<td>$\psi(4160)$</td>
<td>$1^{--}$</td>
<td>$2^3D_1$</td>
<td>4153 ± 3</td>
<td>PDG</td>
</tr>
<tr>
<td>$\chi_{c2}(3P)$</td>
<td>$2^{++}$</td>
<td>$3^3D_1$</td>
<td>?</td>
<td>?</td>
</tr>
<tr>
<td>$\chi_{c3}(1P)$</td>
<td>$2^{++}$</td>
<td>$1^3D_2$</td>
<td>?</td>
<td>?</td>
</tr>
<tr>
<td>$\chi_{c3}(2P)$</td>
<td>$2^{++}$</td>
<td>$2^3D_2$</td>
<td>?</td>
<td>?</td>
</tr>
<tr>
<td>$\chi_{c4}(1P)$</td>
<td>$3^{++}$</td>
<td>$1^3D_3$</td>
<td>?</td>
<td>?</td>
</tr>
<tr>
<td>$\chi_{c4}(2P)$</td>
<td>$3^{++}$</td>
<td>$2^3D_3$</td>
<td>?</td>
<td>?</td>
</tr>
</tbody>
</table>

### III. c\bar{c} POSSIBILITY OF $X(3872)$

In constituent quark model, $q\bar{q}$ mesons could be marked by their quantum numbers, $n^{2S+1}L_J$, and the quantum numbers $PC$ of quarkonia are determined by $P = (-1)^{L+1}$ and $C = (-1)^{L+S}$. With most new data for charmonium mesons [11], we get table [11]. In this table, the observed states are listed in the first volume, experimentally confirmed or favorable theoretical assignment of $J^{PC} = n^{2S+1}L_J$ and masses to these states are put in the sequential three volumes. Entries in the last volume are information from PDG, and the states marked with a "?" are those not confirmed or omitted from the summary table.

With this table in hand, we can construct different possible Regge trajectories, study their properties, and proceed with our analysis of $X(3872)$.

As we know, confirmed states in each group below construct a trajectory

$$0^{-+}(1^1S_0), \quad 1^{++}(1^1P_1)$$

$$0^{++}(1^3P_0), \quad 1^{--}(1^3D_1),$$

respectively. This two trajectories are shown in Fig.1. In the fig-
FIG. 1: Existed trajectories of charmonium singlet and triplet with $n = 1$.

FIG. 2: Existed trajectories of Charmonium triplets with $n = 1$ and $n = 2$.

ure, the slope of line 1 is 2.558 GeV$^2$, the slope of line 2 is 3.552 GeV$^2$. It’s obvious that the two trajectories are not parallel. Once the parallelism of this two trajectories is assumed, a large deviation (e.g., $\psi(3770)$ has 0.130 GeV deviation from the “ideal” $1^{+-}(1^1 P_1)$ state) would appear.

Another two trajectories with different $n$ are constructed by $J/\psi(1S)$, $\chi_{c2}(1P)$ and radial excited $\psi(2S)$, $\chi_{c2}(2P)$, respectively,

$$1^{+-} 1^3 S_1, \quad 2^{++} 1^3 P_2$$

$$1^{--} 2^1 S_1, \quad 2^{+-} 2^1 P_2.$$ 

This two trajectories are shown in Fig. 2. In Fig. 2, the slope of 1 is 1.850 GeV$^2$, the slope of 2 is 3.054 GeV$^2$. The discrimination of this two slopes is obvious, two trajectories are not parallel. The deviation of $\chi_{c2}(2P)$ from the "ideal" $2^{++} 2^3 P_2$ is about 0.150 GeV$^2$. Obviously, the assumption in Ref. [10] that the parallelism of Regge trajectories with different $n$ may hold does not work in charmonium. In fact, even though the dynamics in hadrons with different $n$ is similar, the parallelism cannot be deduced directly.

Indeed, trajectories of charmonium in $(M^2, J)$-plots with neighborhood mesons stepped by 1 in $J$ are not parallel, and they "fan in"[10]. Therefore, the use of the parallelism of these trajectories to predict new states is not reliable if the deviations are unknown to us.

For mesons, there are other Regge trajectories with neighborhood charmonium stepped by 2 in $J$. According to Ref. [10], the linearity and parallelism of this kinds of Regge trajectories is found to hold well. Once this property for Regge trajectories is combined with the hyperfine splitting relation in a multiplet, some interesting predictions could be derived. Especially, the $2^{--}$ ($1^3 D_2$ or $2^1 D_2$) charmonium possibility of $X(3872)$ could be examined.

Firstly, let us examine the $2^{--}$ $1^3 D_2$ possibility of $X(3872)$. It is known that states below construct two Regge trajectories

$$0^{+-} 1^1 S_0, \quad 2^{+-} 1^1 D_2,$$

$$1^{--} 1^3 S_1, \quad 3^{--} 1^3 D_3.$$ 

In this two trajectories, the $0^{+-} 1^1 S_0$ and the $1^{--} 1^3 S_1$ are confirmed states, while the $2^{+-} 1^1 D_2$ and the $3^{--} 1^3 D_3$ have not been fixed on. If $X(3872)$ is the $2^{+-} 1^1 D_2$ state, the mass of the $3^{--} 1^3 D_3 (M)$ can be derived in terms of the approximate parallelism relation

$$3.871^2 - 2.980^2 = M^2 - 3.097^2$$ (5)

with $M = 3.962$ GeV. In the meantime, the mass of the $2^{+-} 1^3 D_2$ can be obtained due to zero of hyperfine splitting of the $1D$ charmonium multiplet. The mass of the $2^{+-} 1^3 D_2 (M_2)$ is determined by

$$3.871 = \frac{3 \times 3.771 + 5M_2 + 7 \times 3.962}{15}$$ (6)

with $M_2 = 3.804$ GeV, where the spin average is implied.

The $1D$ multiplet is therefore pitched down as follows

$$1^3 D_1, \quad 1^3 D_2, \quad 1^1 D_2, \quad 1^3 D_3$$

$$3.771, \quad 3.804, \quad 3.871, \quad 3.962 \text{ GeV}.$$ 

The mass of $1D$ spin triplets increases with the increase of $J$, and the whole mass sequence is reasonable. This
analysis implies that the $2^+ 1^3D_2$ charmonium arrangement of $X(3872)$ is compatible with the ordinary mass relation in a multiplet. Furthermore, the analysis indicates that the $1^3D_2$ is located around $3.804$ GeV and the $1^3D_0$ is located around $3.962$ GeV.

The $2^+ 2^1D_2$ assignments of $X(3872)$ could be analyzed in a similar way. In this case, two trajectories are consisted of

$$ 0^+ 2^1S_0, \quad 2^+ 2^1D_2, \quad 1^- 2^3S_1, \quad 3^- 2^3D_3, $$

respectively. In this two trajectories, the $0^+ 2^1S_0$ and the $1^- 2^3S_1$ are confirmed states, while the $2^+ 2^1D_2$ and the $3^- 2^3D_3$ have not been fixed on. If $X(3872)$ is the $2^+ 2^1D_2$ state, the mass of $3^- 2^3D_3 (M)$ is determined accordingly


(7)

with $M = 3.916$ GeV. Once the mass of the $3^- 2^3D_3$ is known, the mass of the $2^+ 2^1D_2 (M_1)$ is obtained due to zero of hyperfine splitting of the $2D$ charmonium

$$ 3.871 = \frac{3 \times 4.153 + 5M_1 + 7 \times 3.916}{15} $$

(8)

with $M_1 = 3.639$ GeV.

The $2D$ spectrum are therefore determined as follows

$$ 2^3D_1, \quad 2^3D_2, \quad 2^3D_3, \quad 2^3D_4, \quad 3.639, \quad 3.871, \quad 3.916. $$

Obviously, the spectrum is exotic ($M(2^3D_1) > M(2^3D_3)$). That's to say, the $2^+ 2^1D_2$ charmonium arrangement of $X(3872)$ seems impossible.

Now, let us study the parallelism property of $(M^2, n)$-plots for charmonium. From table I, states in each group below construct a trajectory in $(M^2, n)$-plots,

$$ 1^3S_1, \quad 2^3S_1, \quad 3^3S_1, \quad 4^3S_1, \quad 1^3P_2, \quad 2^3P_2, \quad 1^3D_1, \quad 2^3D_1, $$

respectively.

This three Regge trajectories in $(M^2, n)$-plots are displayed in Fig. 3. In the figure, the slope of 1 is 3.259 GeV$^2$, the slope of 2 is 2.792 GeV$^2$, the slope of 3 is 3.027 GeV$^2$, the slope of 4 is 2.665 GeV$^2$, and the slope of 5 is 3.861 GeV$^2$. In this figure, it is easy to observe that the trajectory 5 (with $Y(3940)$ involved) intersects with trajectories 2 and 4, while the trajectory 4 (with $X(3872)$ involved) approximately parallels trajectories 1, 2 and 3. From this observation, we may conclude that the $1^{++} 2^3P_1$ charmonium suggestion of $X(3872)$ does not contradict with possible mass relations in charmonium. As a byproduct, the $2^3P_0$ charmonium assignment of $Y(3940)$ seems impossible.

### IV. Tetraquark State Possibility of $X(3872)$

Four-quark states have been extensively studied for a long time. Unfortunately, their properties especially their decay properties are still unfamiliar to us. So far, many states...
such as $f_{0}(600)$ (or $\sigma$), $f_{0}(980)$, $a_{0}(980)$, the unconfirmed $\kappa(800)$, $D_{sJ}^{*}(2317)^{\pm}$, $X(3872)$, $Y(4260)$, $X(1835)$ and $X(1812)$ have once been interpreted as four-quark state.

As well known, a four-quark state may be composed of a $[q\bar{q}][\bar{q}\bar{q}]$ diquark anti-diquark configuration (tетraquark state) or a $[q\bar{q}][q\bar{q}]$ configuration. The $[q\bar{q}][\bar{q}\bar{q}]$ is sometimes denoted as "baryonium" for its strong coupling to baryon-antibaryon channels and weak coupling to meson channels. It was once argued that the light (orbital angular momentum between the diquark and the anti-diquark $L = 0$) $[q\bar{q}][\bar{q}\bar{q}]$ states may decay mainly into meson-meson channels, while the heavier ones ($L \geq 1$) decay mainly into baryon-antibaryon channels.

For the $[q\bar{q}][\bar{q}\bar{q}]$ configuration, there are two different intrinsic structures. One is composed of two color octet $q\bar{q}$ clusters and another (denoted often as "molecule") is composed of two lightly bounded color singlet $q\bar{q}$ mesons which attract each other.

The quark dynamics in normal hadron is described well though there are many unresolved problems. The quark dynamics in four-quark state has been studied for a long time. Its feature is still completely unclear. Most recently, the dynamics in four-quark state was studied and a fall-apart decay mechanism was proposed and applied to multiquark phenomena including tetra, penta and molecule.

In last section, the $1^{++}$ $2^{3}P_{1}$ and the $2^{−} 1^{1}D_{2}$ charmonium assignments of $X(3872)$ are found to be compatible with possible spectrum relations of charmonium. On the other hand, it is possible that $X(3872)$ is a four-quark state for its special decay properties.

In the following, the $[c\bar{q}][\bar{c}\bar{q}]$ tetraquark state possibility of $X(3872)$ and its implications will be concentrated on. If it is a tetraquark state, its composite configuration is most likely to be $1/\sqrt{2}(c\bar{q}+\bar{c}q)$ for its positive C-parity and 0-isospin property. In this configuration, the $[c\bar{q}]$ and the $[\bar{c}\bar{q}]$ are the 0$^{+}$ "good" diquark and anti-diquark ($S = 0$), the P-parity and the C-parity of this kind of tetraquark state are the same $(-1)^{L}$, where $L$ is the orbital angular momentum between the diquark and the anti-diquark. Therefore, possible $J^{PC}$ of this tetraquark state is $0^{++} (L = 0)$, $1^{−} (L = 1)$, $2^{++} (L = 2)$, \ldots. If the heavy quark symmetry holds in the $[c\bar{q}]$ and $[\bar{c}\bar{q}]$ ("bad" diquark), the spin of the $[c\bar{q}]$ and the $[\bar{c}\bar{q}]$ may be one. The P-parity and the C-parity of this kind of tetraquark state are also the same $(-1)^{L+S}$. Correspondingly, possible $J^{PC}$ of this tetraquark state is $0^{−−} (L = 0)$, $1^{++} (L = 1)$, $2^{−−} (L = 2)$, \ldots.

From this simple analysis, it is found that $X(3872)$ is very unlikely to be the $2^{−} 1^{1}D_{2}$ tetraquark state. If the $J^{PC}$ of this tetraquark $X(3872)$ is pinned down as $1^{++}$, it may be the tetraquark state composed of "bad" diquark and anti-diquark. From the decay properties of $X(3872)$, a lower exotic $0^{−−} (L = 0)$ tetraquark state which decays mainly into mesons is possible to exist. The existence of this new state will be an obvious signal for the tetraquark state.

V. CONCLUSIONS AND DISCUSSIONS

The nature of $X(3872)$ is still unclear. In addition to its $J^{PC}(1^{++} \text{ or } 2^{−−})$, whether it is a charmonium state or an exotic state is still uncertain, more experiments and analyses are required. In this paper, properties of possible Regge trajectories for charmonium are studied. Some assignments of $X(3872)$ are examined. With this phenomenological analysis, some interesting results have been obtained.

If $X(3872)$ is a $2^{−} 1^{1}D_{2}$ charmonium state while is unlikely to be the $2^{−} 2^{3}D_{1}$ charmonium state. If it is really the $2^{−} 1^{1}D_{2}$ charmonium state, the whole 1D multiplet is pitched down with the $1^{3}D_{2}$ located around 3.804 GeV and the $1^{3}D_{3}$ located around 3.962 GeV.

If $X(3872)$ is a $1^{++}$ state, it may be the $1^{++} 2^{3}P_{1}$ charmonium. As a byproduct, it is found that $Y(3940)$ is unlikely to be the $0^{++} 2^{3}P_{0}$ charmonium.

If $X(3872)$ is a tetraquark state, according to phenomenological arguments, it seems impossible to be the $2^{−} 2^{−}$ tetraquark state. It may be the $1^{++}$ tetraquark state, in which case a lower exotic $0^{−−} (L = 0)$ tetraquark state decaying mainly into mesons may exist.

So far, the study of four-quark state and the study of meson near thresholds are not satisfactory. Four-quark state is usually invoked to explain the special decay properties of newly observed states, which in fact may be explained also without four-quark state. Only when

![Diagram](image-url)
the properties of four-quark state are definitely clear, the four-quark state explanation of newly observed state will be satisfactory.

Of course, some properties in our analysis may not have firm foundation. For example, the linearity and parallelism of Regge trajectories with neighborhood mesons stepped by 2 in $J$ and the decay properties of tetraquark state may be questionable, which require more investigation. These properties should be tested true or false with more data from forthcoming experiments.

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[34] K. Abe, et al., Belle collaboration, hep-ex/0505038.