The heavy-light hadrons: Review and Outlook

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3.31-4.1 (2008)

Outline

1. Status of experiments and theories: Overview
2. Some interesting issues in heavy-light systems
3. Summary and outlook

With a special inner structure, the heavy-light hadron system can help us to gain more information about the non-perturbative behavior of quantum chromodynamics (QCD).

Heavy quark symmetry
Light quark chiral symmetry
SU(3) light-flavor symmetry

Heavy-light meson ($Q\bar{q}$): D, D_s, B, B_s

Heavy-light baryon (Qqq): $\Lambda_c, \Xi_c, \Sigma_c, \Xi_c', \Omega_c, \Lambda_b, \Xi_b, \Sigma_b, \Xi_b', \Omega_b$

(QQq): $\Xi_{cc}, \Omega_{cc}, \Xi_{bb}, \Omega_{bb}$, ……

Section one: Status of experiments and theories: Overview

For understanding the status of experiments and theories for heavy-light hadron system, one can consult the following references,

$D_{(s)}$ mesons	Averages of b-hadron, c-hadron, and τ-lepton properties as of summer 2016 HFLAV Collaboration (Y. Amhis (Orsay, LAL) *et al.*), Eur.Phys.J. C **77**, 895 (2017)
$Heavy-light$ baryons	Charmed baryons circa 2015 Hai-Yang Cheng, Front.Phys.**10**, 101406 (2015)
	Progress towards understanding baryon resonances V. Crede, W. Roberts, Rept.Prog.Phys. **76**, 076301 (2013)
	Baryon spectroscopy Eberhard Klempt, Jean-Marc Richard, Rev.Mod.Phys. **82**, 1095 (2010)
Comprehensive review	A review of the open charm and open bottom systems Hua-Xing Chen, Wei Chen, Xiang Liu, Yan-Rui Liu, Shi-Lin Zhu, Rept.Prog.Phys. **80**, 076201 (2017)

doublet	s_l^P	J^P	D($c\bar{q}$)	D_s($c\bar{s}$)	B($b\bar{q}$)	B_s($b\bar{s}$)	comment
H	$\frac{1}{2}^-$	0^-	$D(1869)$	$D_s(1968)$	$B(5279)$	$B_s(5366)$	****
		1^-	$D^*(2010)$	$D_s^*(2112)$	$B^*(5325)$	$B_s^*(5415)$	
H'	$\frac{1}{2}^-$	0^-	$D(2550)$				**
		1^-	$D^*(2600)$	$D_s^*(2700)$	$B_J(5840)$		
S	$\frac{1}{2}^+$	0^+	$D^*(2400)$	$D_{s0}^*(2317)$			*
		1^+	$D_1'(2430)$	$D_{s1}'(2460)$	$B_J^*(5832)$		
T	$\frac{3}{2}^+$	1^+	$D_1(2420)$	$D_{s1}(2536)$	$B_1(5721)$	$B_{s1}(5830)$	***
		2^+	$D_2^*(2460)$	$D_{s2}^*(2573)$	$B_2^*5747)$	$B_{s2}^*(5840)$	
X	$\frac{3}{2}^-$	1^-	$D_1^*(2760)$	$D_{s1}^*(2860)$			*
		2^-					
X'	$\frac{5}{2}^-$	2^-	$D_J(2740)$				*~***
		3^-	$D_3^*(2760)$	$D_{s3}^*(2860)$	$B_J(5960)$		
higher excitations			$D_J(3000)$	$D_{sJ}(3040)$			(*)
			$D_J^*(3000)$				
			$D_2^*(3000)$				

The λ mode excited heavy flavor baryons containing a "good" diquark

doublet	s_l^P	J^P	Λ_c (cud)	Ξ_c (csq)	Λ_b (bud)	Ξ_b (bsq)	comment
1S	0^+	$\frac{1}{2}^+$	$\Lambda_c(2286)$	$\Xi_c(2470)$	$\Lambda_b(5620)$	$\Xi_b(5795)$	****
2S	0^+	$\frac{1}{2}^+$	$\Lambda_c(2760)$	$\Xi_c(2980)$			*
1P	1^-	$\frac{1}{2}^-$	$\Lambda_c(2595)$	$\Xi_c(2790)$	$\Lambda_b(5912)$		***
		$\frac{3}{2}^-$	$\Lambda_c(2625)$	$\Xi_c(2815)$	$\Lambda_b(5920)$		
1D	2^+	$\frac{3}{2}^+$	$\Lambda_c(2860)$	$\Xi_c(3055)$			*~**
		$\frac{5}{2}^+$	$\Lambda_c(2880)$	$\Xi_c(3080)$			
2P	1^-	$\frac{1}{2}^-$					(*)
		$\frac{3}{2}^-$	$\Lambda_c(2940)$	$\Xi_c(3123)$			

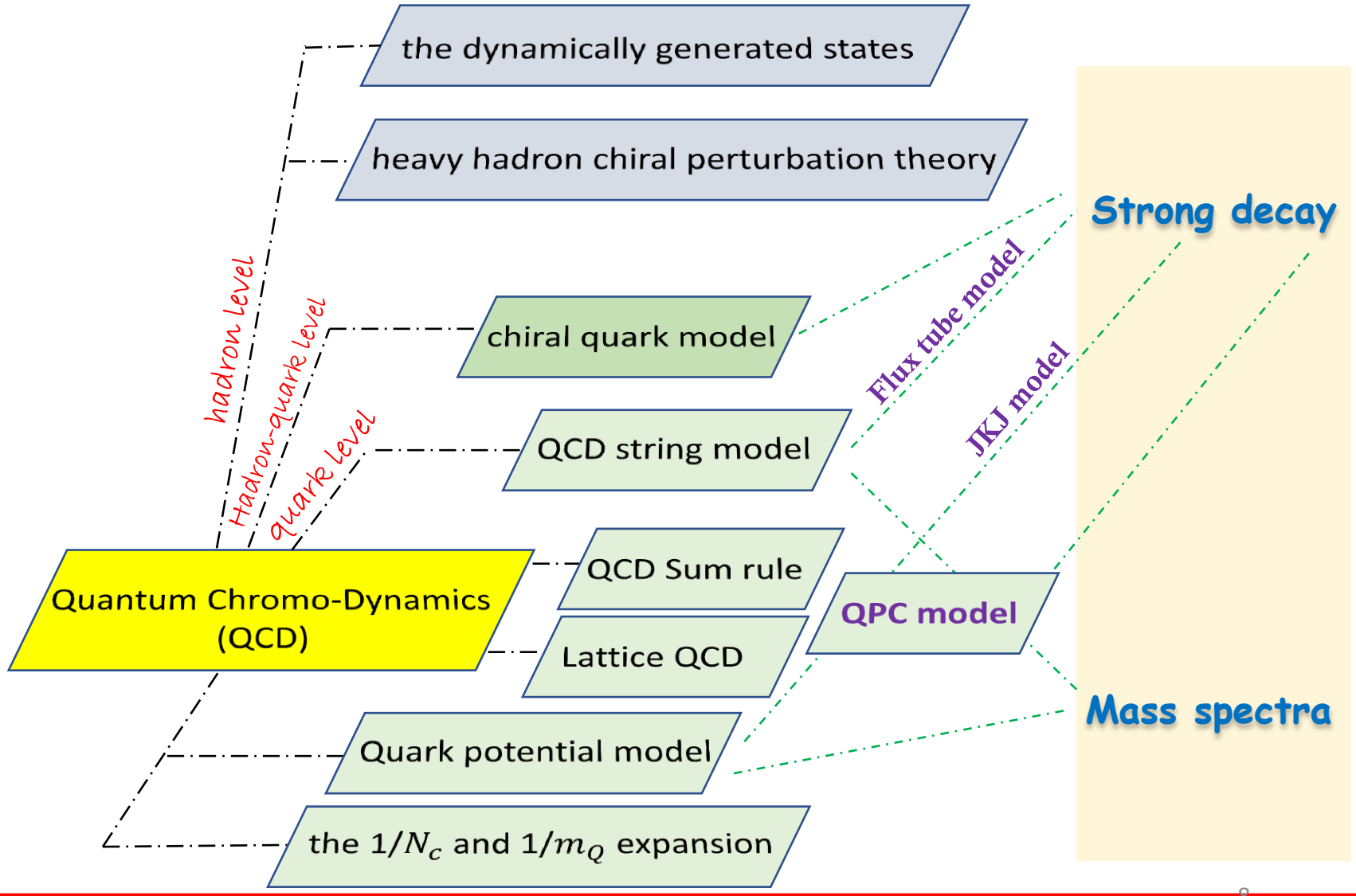
The λ mode excited heavy flavor baryons containing a “bad” diquark

	1S		1P					2S	
Σ_c	$\Sigma_c(2455)$	$\Sigma_c(2520)$			$\Sigma_c(2800)$				
Ξ_c'	$\Xi_c'(2570)$	$\Xi_c'(2645)$			$\Xi_c'(2930)$				
Ω_c	$\Omega_c(2700)$	$\Omega_c(2760)$	$\Omega_c(3000)$	$\Omega_c(3050)$	$\Omega_c(3066)$	$\Omega_c(3090)$	$\Omega_c(3119)$	$\Omega_c(3188)$	
Σ_b	$\Sigma_b(5815)$	$\Sigma_b(5835)$							
Ξ_b'	$\Xi_b'(5935)$	$\Xi_b'(5955)$							
Ω_b	$\Omega_b(6045)$								

D [14], D_s [10], B [7], B_s [4], 35

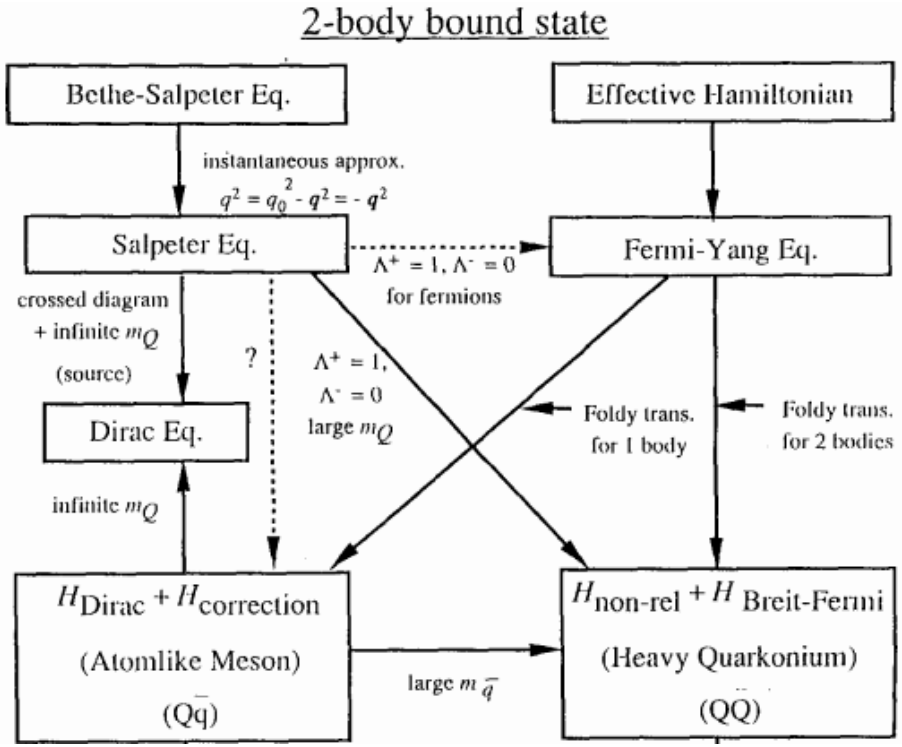
Λ_c [7], Ξ_c [7], Σ_c [3], Ξ_c' [3], Ω_c [8], Λ_b [3], Ξ_b [1], Σ_b [2], Ξ_b' [2], Ω_b [1], 37

Ξ_{cc}[1], Ω_{cc}, Ξ_{bb}, Ω_{bb}, …… 1


the dynamically generated states
heavy hadron chiral perturbation theory
chiral quark model
QCD string model
QCD Sum rule
Lattice QCD
Quark potential model
the $1/N_c$ and $1/m_Q$ expansion
Quantum Chromo-Dynamics (QCD)
Hadron Level
Hadron-quark Level
Quark Level
Flux tube model
JKJ model
QPC model
Strong decay
Mass spectra

Quark potential model

Different dynamics equation	Different type of potentials	Different methods for solution
A1. Schrödinger equation A2. Spinless Salpeter equation A3. Dirac equation A4. Bethe–Salpeter equation A5. Faddeev formalism	B1. Cornell potential B2. Logarithmic potential B3. power-law potential B4. modified Cornell potential with a screening potential … … + different kinds of spin-dependent interactions (one-gluon exchange or goldstone boson exchange)	C1. Variation Method C2. Perturbation Method C3. WKB approximation C4. Runge-Kutta Method … …



"Quark potential approach to baryons and mesons"
S.N. Mukherjee, et. al.,
Phys.Rept. 231 (1993) 201-292

Eichten et al. [17–19]	$V = -\frac{4}{3}\alpha_s/r + ar$
Celmaster et al. [20, 21]	$V = \frac{4}{3}\frac{6\pi}{33-2n_F}\frac{1}{r\ln(r/r_0)} - cr\exp(-r/d) + ar$
Bhanot and Rudaz [22]	$V = \begin{cases} -\frac{4}{3}\alpha_s/r & \text{for } r \le R_1 \\ c\ln(r/r_0) & \text{for } R_1 \le r \le R_2 \\ ar & \text{for } r \ge R_2 \end{cases}$ $r_0 = (4\alpha_s/3a)^{1/2}$, $c = er_0 a$, $\ln e = 1$ $R_1 = r_0/e$, $R_2 = er_0$
Lichtenberg et al. [23, 24]	$V = \frac{4}{3}\frac{6\pi}{33-2n_F}\frac{(1-r/r_0)^2}{r\ln(r/r_0)}$ $V_V = \frac{r_0}{r_0 - r}V$, $V_S = \frac{r}{r - r_0}V$
Richardson [25]	$V = -\frac{4}{3}\frac{48\pi^2}{33-2n_F}\frac{1}{(2\pi)^3}\int d^3k \frac{\exp(i\mathbf{k}\cdot\mathbf{r})}{k^2\ln(1+k^2/\Lambda^2)}$
Celmaster and Henyey [26], Levine and Tomozawa [27, 28], Buchmüller et al. [29, 30]	$V = -\frac{4}{3}\frac{1}{(2\pi)^3}\int d^3k \exp(i\mathbf{k}\cdot\mathbf{r})\frac{4\pi\alpha_s(k^2)}{k^2}$

"Bound states of quarks"
W. Lucha, F.F. Schoberl, and D. Gromes
Phys.Rept. 200 (1991) 127-240

II.A $1P_{1/2}(0^+, 1^+)$ heavy-light mesons

II.B $2S$ and $1D$ heavy-light mesons

II.C Higher heavy-light mesons

II.D $1P$ charmed baryons with a "bad" diquark

II.E $1D$ charmed baryons with a "good" diquark

II.A $1P_{1/2}(0^+, 1^+)$ heavy-light mesons

Properties of $1P_{1/2}(0^+, 1^+)$ charmed mesons measured by experiments

Resonance	J^P	Decay mode	Mass (MeV/c^2)	Width (MeV)	Measured by	References
$D_0^*(2400)^0$	0^+	$D^+\pi^-$	$2297 \pm 8 \pm 20$	$273 \pm 12 \pm 48$	BABAR	[1]
		$D^+\pi^-$	$2308 \pm 17 \pm 32$	$276 \pm 21 \pm 63$	Belle	[2]
		$D^+\pi^-$	$2407 \pm 21 \pm 35$	$240 \pm 55 \pm 59$	FOCUS	[3]
			2318.2 ± 16.9	267.4 ± 35.6	average	
$D_0^*(2400)^\pm$	0^+	$D^0\pi^+$	$2349 \pm 6 \pm 1 \pm 4$	$217 \pm 13 \pm 5 \pm 12$	LHCb	[4]
		$D^0\pi^+$	$2360 \pm 15 \pm 12 \pm 28$	$255 \pm 26 \pm 20 \pm 47$	LHCb	[5]
		$D^0\pi^+$	$2403 \pm 14 \pm 35$	$283 \pm 24 \pm 34$	FOCUS (m and Γ) + Belle(J^P)	[3,6]
			2350.6 ± 5.9	233.7 ± 15.5	average	
$D_1(2430)^0$	1^+	$D^{*+}\pi^-$	$2427 \pm 26 \pm 25$	$384^{+107}_{-75} \pm 74$	Belle	[2]

[1] Dalitz Plot Analysis of $B^- \to D^+\pi^-\pi^-$, BaBar Collaboration (Bernard Aubert (Annecy, LAPP) *et al.*), Phys.Rev. D **79** (2009) 112004
[2] Study of $B^- \to D^{**0}\pi^-(D^{**0} \to D^{(*)+}\pi^-)$ decays, Belle Collaboration (Kazuo Abe (KEK, Tsukuba) *et al.*), Phys.Rev. D **69** (2004) 112002
[3] Measurement of masses and widths of excited charm mesons D_2^* and evidence for broad states , FOCUS Collaboration (J.M. Link (UC, Davis) *et al.*), Phys.Lett. B **586** (2004) 11-20
[4] Dalitz plot analysis of $B^0 \to D^0\pi^+\pi^-$decays, LHCb Collaboration (Roel Aaij (NIKHEF, Amsterdam) *et al.*), Phys.Rev. D **92** (2015) 032002
[5] Amplitude analysis of $B^0 \to D^0K^+\pi^-$ decays, LHCb Collaboration (Roel Aaij (CERN) *et al.*)., Phys.Rev. D **92** (2015) no.1, 012012
[6] Study of $B^0 \to D^0\pi^+\pi^-$ decays, A. Kuzmin *et al.* (Belle Collaboration), Phys. Rev. D **76**, 012006

II.A $1P_{1/2}(0^+, 1^+)$ heavy-light mesons

Properties of $1P_{1/2}(0^+, 1^+)$ charmed-strange mesons measured by experiments

Observation of a narrow meson decaying to $D_s^+\pi^0$ at a mass of 2.32-GeV/c^2
BaBar Collaboration (B. Aubert (Annecy, LAPP) *et al.*). Apr 2003. 7 pp.
Published in **Phys.Rev.Lett. 90 (2003) 242001**
DOI: 10.1103/PhysRevLett.90.242001
e-Print: **hep-ex/0304021** | **PDF**
详细记录 - Cited by 812 records 500+

Resonance	J^P	Decay mode	Mass (MeV/c^2)	Width (MeV)	Measured by	References
$D_{s0}^*(2317)^\pm$	0^+	$D_s^+\pi^0$	$2319.6 \pm 0.2 \pm 1.4$	< 3.8	BABAR	[1]
		$D_s^+\pi^0$	$2317.3 \pm 0.4 \pm 0.8$		BABAR	[2]
$D_{s1}(2460)^\pm$	1^+	$D_s^{*+}\pi^0$, $D_s^+\pi^0\gamma$, $D_s^+\gamma$, $D_s^+\pi^+\pi^-$	$2460.1 \pm 0.2 \pm 0.8$	< 3.5	BABAR	[1]
		$D_s^+\pi^0\gamma$	$2458 \pm 1.0 \pm 1.0$		BABAR	[2]
		$D_{s1}(2460)^+ \to D_s^{*+}\pi^0$	$(56 \pm 13 \pm 9)\%$		BABAR	[3]
		$D_{s1}(2460)^+ \to D_s^{*+}\gamma$	$(16 \pm 4 \pm 3)\%$		BABAR	

[1] Study of the $D_{sJ}^*(2317)^+$ and $D_{sJ}(2460)^+$ mesons in inclusive $c\bar{c}$ production near s=10.6 GeV, B. Aubert *et al*. (BABAR Collaboration) Phys. Rev. D **74**, 032007 (2006)

[2] Observation of a narrow meson decaying to $D_s^+\pi^0\gamma$ at a mass of 2.458GeV/c2, B. Aubert *et al*. (BABAR Collaboration), Phys. Rev. D **69**, 031101(R) (2004)

[3] Study of B $\to D_{sJ}^{(*)+}\overline{D}^{(*)}$ decays and measurement of D_s^- and $D_{sJ}(2460)$ branching fractions, B. Aubert *et al*. (BABAR Collaboration) Phys. Rev. D **74**, 031103(R) (2006)

II.A $1P_{1/2}(0^+, 1^+)$ heavy-light mesons

Up to now, no experiments reported a meson state which could be suggested as a $1P_{1/2}(0^+, 1^+)$ B or B_s meson. Although much effort from both experimentalists and theorists have been given for these $1P_{1/2}(0^+, 1^+)$ heavy-light mesons,

(1) The masses and decay widths of D mesons should be measured with higher precision;
(2) The nature of $D_{s0}^*(2317)^+$ and $D_{s1}(2460)^+$ are still unclear.

(II.A.1) as the normal $c\bar{s}$ states

PHYSICAL REVIEW D **74,** 032007 (2006)

Study of the $D_{sJ}^*(2317)^+$ and $D_{sJ}(2460)^+$ mesons in inclusive $c\bar{c}$ production near $\sqrt{s} = 10.6$ GeV

(*BABAR* Collaboration)

Except, perhaps, for the mass, there is currently no conflict with the interpretation of the $D_{sJ}^*(2317)^+$ and $D_{sJ}(2460)^+$ mesons as the $J^P = 0^+$ and $J^P = 1^+$ p-wave $c\bar{s}$ states.

The predicted $1P_{1/2}(0^+, 1^+)$ D_s mesons by different methods:

D_s state	LS	LJM	LY	OSEF	GI	LNR	ZVR	EFG	DE	Lattice
0^+	2341	2344	2317	2383	2480	2455	2380	2509	2487	2417
1^+	2475	2488	2436	2570	2530	2502	2510	2536	2535	2537

II.A $1P_{1/2}(0^+, 1^+)$ heavy-light mesons

参考文献：

[**LS**] A Canonical $Ds(2317)$? Olga Lakhina, Eric S. Swanson, Phys.Lett. B **650** (2007) 159-165

[**LJM**] The newly observed open-charm states in quark model , De-Min Li, Peng-Fei Ji, Bing Ma, Eur.Phys.J. C **71** (2011) 1582

[**LY**] Spectrum of Higher excitations of B and D mesons in the relativistic potential model, Jing-Bin Liu, Mao-Zhi Yang, Phys.Rev. D **91** (2015) no.9, 094004

[**OSEF**] Molecular components in P-wave charmed-strange mesons, Pablo G. Ortega, Jorge Segovia, David R. Entem, Francisco Fernandez, Phys.Rev. D **94** (2016) no.7, 074037

[**GI**] Mesons in a Relativized Quark Model with Chromodynamics, S. Godfrey, Nathan Isgur, Phys.Rev. D **32** (1985) 189-231

[**LNR**] Spectra and M1 decay widths of heavy light mesons, T.A. Lahde, C.J. Nyfalt, D.O. Riska, Nucl.Phys. A **674** (2000) 141-167

[**ZVR**] Heavy mesons in a relativistic model, J. Zeng, J.W. Van Orden, W. Roberts, Phys.Rev. D **52** (1995) 5229-5241

[**EFG**] Heavy-light meson spectroscopy and Regge trajectories in the relativistic quark model, D. Ebert, R.N. Faustov, V.O. Galkin, Eur.Phys.J. C **66** (2010) 197-206

[**DE**] Excited heavy-light systems and hadronic transitions, Massimo Di Pierro, Estia Eichten, Phys.Rev. D **64** (2001) 114004

[**Latt.**] D and Ds meson spectroscopy, Daniel Mohler, R.M. Woloshyn, Phys.Rev. D **84** (2011) 054505

II.A $1P_{1/2}(0^+, 1^+)$ heavy-light mesons

(II.A.2) the questions of $D_{s0}^*(2317)^+$ and $D_{s1}(2460)^+$ as the conventional mesons

PHYSICAL REVIEW D **91,** 052002 (2015)

Dalitz plot analyses of $B^0 \to D^- D^0 K^+$ and $B^+ \to \bar{D}^0 D^0 K^+$ decays

(*BABAR* Collaboration)

The fit for $B^0 \to D^- D^0 K^+$ returns a mass and width of the scalar of 2412 ± 16 MeV/c^2 and 163 ± 64 MeV and for $B^+ \to \bar{D}^0 D^0 K^+$ of 2453 ± 20 MeV/c^2 and 283 ± 45 MeV, respectively (statistical uncertainties only). These two results are not incompatible ($\sim 1.5\sigma$ difference for both mass and width, where σ is the standard deviation), but the assumption of such a wide resonance at this mass would be speculative.

PHYSICAL REVIEW D **97,** 051103(R) (2018) Rapid Communications

Measurement of the absolute branching fraction of $D_{s0}^*(2317)^\pm \to \pi^0 D_s^\pm$

(BESIII Collaboration)

The absolute branching fraction of $D_{s0}^*(2317)^- \to \pi^0 D_s^-$ is measured for the first time to be $1.00^{+0.00}_{-0.14}(\text{stat})^{+0.00}_{-0.14}(\text{syst})$, …… The result shows that $D_{s0}^*(2317)^-$ tends to have a significantly smaller branching fraction to γD_s^{*-} than to $\pi^0 D_s^-$, and this differs from the expectation of the conventional $\bar{c}s$ hypothesis of $D_{s0}^*(2317)^-$ [13], which predicts that $D_{s0}^*(2317)^-$ should have a branching fraction of γD_s^{*-} at around 15% or even larger, but agrees well with the calculation in the molecule picture [14], which shows that the branching fraction of $\pi^0 D_s^-$ is in a range of 93–100%.

(II.A.3) Molecular scheme

Implications of a DK molecule at 2.32-GeV, T. Barnes, F.E. Close, H.J. Lipkin, Phys.Rev. D **68** (2003) 054006

Comprehensive Four-Quark Interpretation of Ds (2317), Ds(2457), and Ds(2632), Yu-Qi Chen, Xue-Qian Li, Phys.Rev.Lett. **93** (2004) 232001

II.A $1P_{1/2}(0^+, 1^+)$ heavy-light mesons

Strong and radiative decays of the $D_{s0}^*(2317)$ meson in the DK-molecule picture
Amand Faessler, Thomas Gutsche, Valery E. Lyubovitskij, Yong-Liang Ma,
Phys.Rev. D **76** (2007) 014005

Heavy-quark symmetry and the electromagnetic decays of excited charmed strange mesons
Thomas Mehen, Roxanne P. Springer,
Phys.Rev. D **70** (2004) 074014

Understanding the $D_{sJ}^*(2317)$ and $D_{sJ}(2460)$ with sum rules in HQET (*)
Yuan-Ben Dai, Chao-Shang Huang, Chun Liu, Shi-Lin Zhu,
Phys.Rev. D **68** (2003) 114011

(II.A.4) Tetraquark scheme

B decays as spectroscope for charmed four quark states
Hai-Yang Cheng, Wei-Shu Hou, Phys.Lett. B **566** (2003) 193-200

Ds(2317) as a four-quark state in QCD sum rules
Hungchong Kim, Yongseok Oh, Phys.Rev. D **72** (2005) 074012

II.A $1P_{1/2}(0^+, 1^+)$ heavy-light mesons

Disentangling two- and four-quark state pictures of the charmed scalar mesons
M.E. Bracco, A. Lozea, Ricardo D'Elia Matheus, F.S. Navarra, M. Nielsen,
Phys.Lett. B **624** (2005) 217-222

Revisiting $D_{s0}^*(2317)$ as a 0^+ tetraquark state from QCD sum rules
Jian-Rong Zhang, arXiv:1801.08725

Masses of tetraquarks with open charm and bottom
D. Ebert, R.N. Faustov, V.O. Galkin, Phys.Lett. B **696** (2011) 241-245

(a) where are the traditional $c\bar{s}$(0+, 1+) states in the quark model?
(b) where are those additional broad member states within the same multiplet?

New hadron states, Shi-Lin Zhu, Int.J.Mod.Phys. E **17**, 283 (2008)
Belle Collaboration, Phys.Rev. D **91**, 092011 (2015)

(II.A.5) methods including the coupled channel effect

The Coupled-channel analysis of the D and Ds mesons
Yu.A. Simonov, J.A. Tjon, Phys.Rev. D **70** (2004) 114013

II.A $1P_{1/2}(0^+, 1^+)$ heavy-light mesons

Hadronic-loop induced mass shifts in scalar heavy-light mesons
Feng-Kun Guo, Siegfried Krewald, Ulf-G. Meissner,
Phys.Lett. B **665** (2008) 157-163

Hadron loops effect on mass shifts of the charmed and charmed-strange spectra
Zhi-Yong Zhou, Zhiguang Xiao,
Phys.Rev. D **84** (2011) 034023

Masses of Scalar and Axial-Vector B Mesons Revisited
Hai-Yang Cheng, Fu-Sheng Yu,
Eur.Phys.J. C **77** (2017) no.10, 668

Molecular components in P-wave charmed-strange mesons
Pablo G. Ortega, Jorge Segovia, David R. Entem, Francisco Fernandez,
Phys.Rev. D **94** (2016) no.7, 074037

Mass of $D_{sJ}^*(2317)$ and coupled channel effect
Dae Sung Hwang, Do-Won Kim,
Phys.Lett. B **601** (2004) 137-143

II.A $1P_{1/2}(0^+, 1^+)$ heavy-light mesons

(II.A.6) the mixing angle for two 1^+ states

The mixing of $D_{s1}(2460)$ and $D_{s1}(2536)$
Xiao-Gang Wu, Qiang Zhao,
Phys.Rev. D **85** (2012) 034040

Properties of the charmed P-wave mesons
Stephen Godfrey,
Phys.Rev. D **72** (2005) 054029

$D_{s1}(2536)^+$ decays and the properties of P-wave charmed strange mesons
J. Segovia, A.M. Yasser, D.R. Entem, F. Fernandez,
Phys.Rev. D **80** (2009) 054017

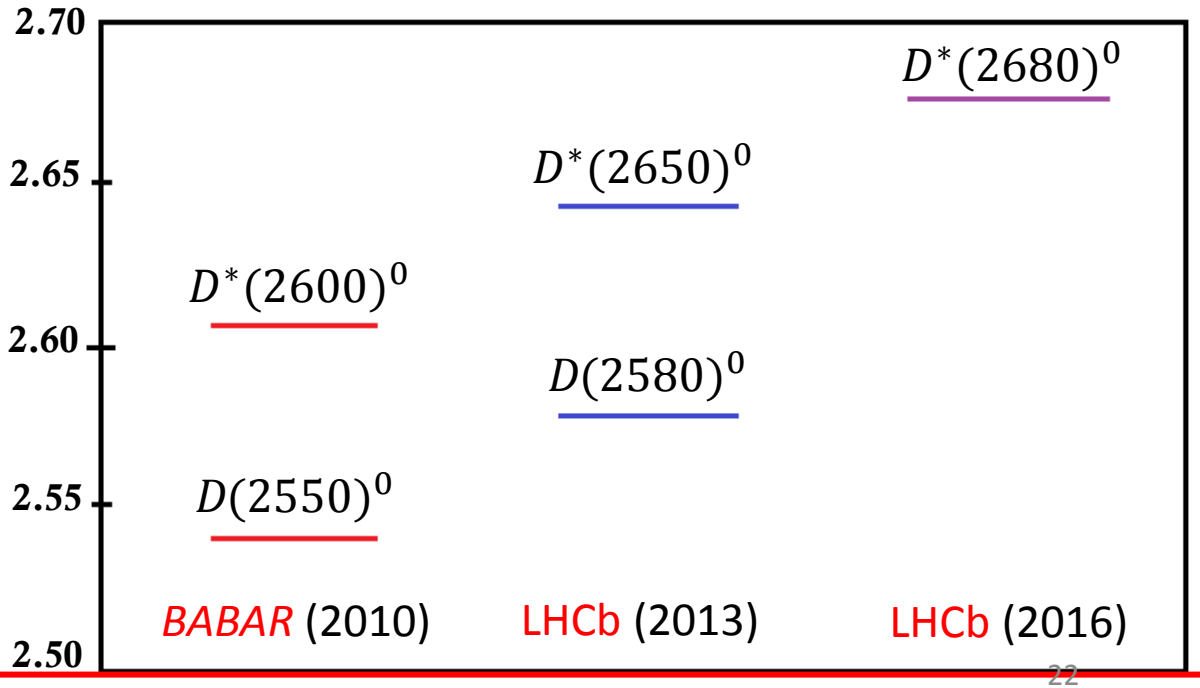
II.B $2S$ and $1D$ heavy-light mesons

State	Production	Observed decays	Mass (MeV)	Width (MeV)	J^P	Year	Collaboration
$D(2550)^0$	e^+e^-	$D^{*+}\pi^-$	$2539.4 \pm 4.5 \pm 6.8$	$130 \pm 12 \pm 13$	0^-	2010	*BABAR*
$D(2580)^0$	pp	$D^{*+}\pi^-$	$2579.5 \pm 3.4 \pm 5.5$	$117.5 \pm 17.8 \pm 46.0$		2013	LHCb
$D_1^*(2600)^\dagger$	e^+e^-	$D^+\pi^-$, $D^{*+}\pi^-$	$2608.7 \pm 2.4 \pm 2.5$	$93 \pm 6 \pm 13$		2010	*BABAR*
	pp	$D^{*+}\pi^-$	$2649.2 \pm 3.5 \pm 3.5$	$140.2 \pm 17.1 \pm 18.6$		2013	LHCb
	$B^- \to D_1^{*0}\pi^-$	$D^+\pi^-$	$2681.1 \pm 5.6 \pm 4.9 \pm 13.1$	$186.7 \pm 8.5 \pm 8.6 \pm 8.2$		2016	LHCb
$D_{s1}^*(2700)$	$B^+ \to \bar{D}^0 D_{s1}^{*+}$	D^0K^+	$2708 \pm 9^{+11}_{-10}$	$108 \pm 23^{+36}_{-31}$	1^-	2008	Belle
	$B^{+(0)} \to \bar{D}^0(D^-)D_{s1}^{*+}$	D^0K^+	2699^{+14}_{-7}	127^{+24}_{-19}	1^-	2015	*BABAR*
	e^+e^-	D^0K^+, $D^+K_S^0$	$2688 \pm 4 \pm 4$	$112 \pm 7 \pm 36$		2006	*BABAR*
	e^+e^-	$D^{(*)0}K^+$, $D^{(*)+}K_S^0$	$2710 \pm 2^{+12}_{-7}$	$149 \pm 7^{+39}_{-52}$		2009	*BABAR*
	pp	D^0K^+, $D^+K_S^0$	$2709.2 \pm 1.9 \pm 4.5$	$115.8 \pm 7.3 \pm 12.1$		2012	LHCb
$B_J(5840)^0$	pp	$B^+\pi^-$	$5862.9 \pm 5.0 \pm 6.7 \pm 0.2$	$127.4 \pm 16.7 \pm 34.2$		2015	LHCb

BABAR (2010) also measured

$$\frac{B(D^*(2600)^0 \to D^+\pi^-)}{B(D^*(2600)^0 \to D^{*+}\pi^-)} = 0.32 \pm 0.02 \pm 0.09;$$

$$\frac{B(D^*(2760)^0 \to D\pi)}{B(D(2750)^0 \to D^*\pi)} = 0.42 \pm 0.05 \pm 0.11.$$



II.B 1D heavy-light mesons

State	Production	Observed decays	Mass (MeV)	Width (MeV)	J^P	Year	Collaboration
$D_1^*(2760)$	$B^- \to D_1^{*0} K^-$	$D^+\pi^-$	$2781 \pm 18 \pm 11 \pm 6$	$177 \pm 32 \pm 20 \pm 7$	1^-	2015	LHCb
$D(2750)^\dagger$	e^+e^-	$D^{*+}\pi^-$	$2752.4 \pm 1.7 \pm 2.7$	$71 \pm 6 \pm 11$		2010	*BABAR*
	pp	$D^{*+}\pi^-$	$2737.0 \pm 3.5 \pm 11.2$	$73.2 \pm 13.4 \pm 25.0$		2013	LHCb
$D_3^*(2760)$	$B^0 \to D_3^{*-}\pi^+$	$\bar{D}^0\pi^-$	$2800 \pm 7 \pm 5 \pm 4$	$130 \pm 16 \pm 7 \pm 12$	3^-	2015	LHCb
	e^+e^-	$D^+\pi^-$, $D^{*+}\pi^-$	$2763.3 \pm 2.3 \pm 2.3$	$60.9 \pm 5.1 \pm 3.6$		2010	*BABAR*
	pp	$D^{*+}\pi^-$	$2760.1 \pm 1.1 \pm 3.7$	$74.4 \pm 3.4 \pm 19.1$		2013	LHCb
	$B^- \to D_3^{*0}\pi^-$	$D^+\pi^-$	$2775.5 \pm 4.5 \pm 4.5 \pm 4.7$	$95.3 \pm 9.6 \pm 7.9 \pm 33.1$		2016	LHCb
$D_{s1}^*(2860)$	$B_s^0 \to D_{s1}^{*-}\pi^+$	$\bar{D}^0K^-$	$2859 \pm 12 \pm 6 \pm 23$	$159 \pm 23 \pm 27 \pm 72$	1^-	2014	LHCb
$D_{s3}^*(2860)$	$B_s^0 \to D_{s3}^{*-}\pi^+$	$\bar{D}^0K^-$	$2860.5 \pm 2.6 \pm 2.5 \pm 6.0$	$53 \pm 7 \pm 4 \pm 6$	3^-	2014	LHCb
	e^+e^-	D^0K^+, $D^+K_s^0$	$2856.6 \pm 1.5 \pm 5.0$	$48 \pm 7 \pm 10$		2006	*BABAR*
	e^+e^-	$D^{(*)0}K^+$, $D^{(*)+}K_s^0$	$2862 \pm 2^{+5}_{-2}$	$48 \pm 3 \pm 6$		2009	*BABAR*
	pp	D^0K^+, $D^+K_s^0$	$2866.1 \pm 1.0 \pm 6.3$	$69.9 \pm 3.2 \pm 6.6$		2012	LHCb
$B(5970)$	$p\bar{p}$	$B^+\pi^-$	$5978 \pm 5 \pm 12$	$70^{+30}_{-20} \pm 30$		2014	CDF
	pp	$B^+\pi^-$	$5969.2 \pm 2.9 \pm 5.1 \pm 0.2$	$63.0 \pm 14.5 \pm 17.2$		2015	LHCb

BABAR (2009) also measured

$$\frac{B(D_{s1}^*(2700)\to D^*K)}{B(D_{s1}^*(2700)\to DK)} = 0.91 \pm 0.13 \pm 0.12;$$

$$\frac{B(D_{sJ}^*(2860) \to D^*K)}{B(D_{sJ}^*(2860) \to DK)} = 1.10 \pm 0.15 \pm 0.19.$$

II.B $2S$-$1D$ heavy-light mesons

Two 1^- $D_{(s)}$ states in the $2^3S_1 - 1^3D_1$ mixing scheme

Mode	Experiment	LJWYWC	LJM	SCLM	CLZ
θ_s	–	$8.7^{+3.9}_{-3.2}$	−(61–77)	6.8–11.2	−(4–16)
$\Gamma_{D_{s1}^*(2700)}$	117 ± 13	$100.8^{+3.1}_{-3.0}$	180–198	∼100	∼(210–220)
$R_K[D^*(2700)]$	0.91 ± 0.18	$0.91^{-0.18}_{+0.18}$	1.16–0.66	∼0.91	∼(1.35–0.69)
$\Gamma_{D_{s1}^*(2860)}$	159 ± 80	$108.8^{-1.1}_{+0.8}$	40–70	∼300	∼(120–150)
$R_K[D_{s1}^*(2860)]$	–	$0.62^{+0.22}_{-0.12}$	0.04–2.71	0.6–0.8	0.31–1.16

[LJWYWC] Study of the excited 1^- charm and charm-strange mesons
Qiang Li, Yue Jiang, Tianhong Wang, Han Yuan, Guo-Li Wang, Chao-Hsi Chang,
Eur.Phys.J. C **77** (2017) no.5, 297

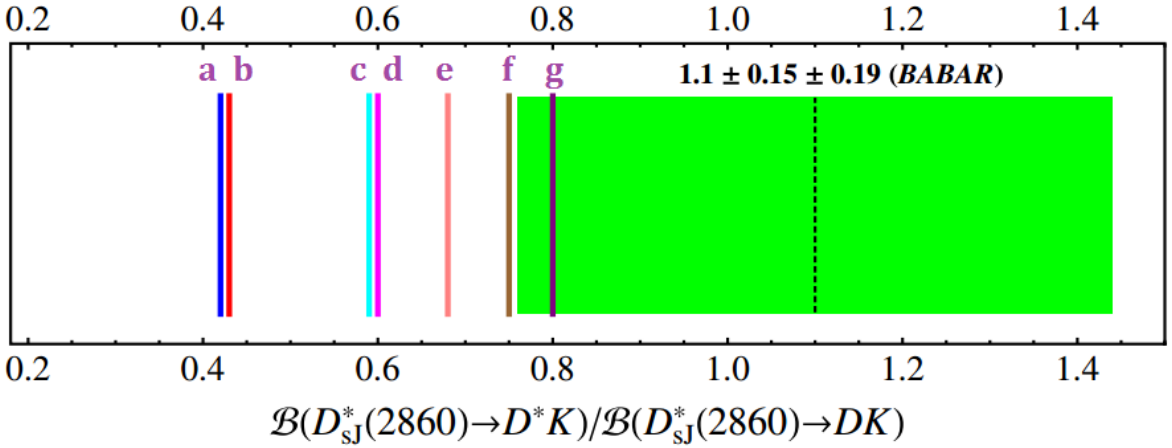
[LJM] The newly observed open-charm states in quark model
De-Min Li, Peng-Fei Ji, Bing Ma,
Eur.Phys.J. C **71** (2011) 1582

[SCLM] Charmed-strange mesons revisited: mass spectra and strong decays
Qin-Tao Song, Dian-Yong Chen, Xiang Liu, Takayuki Matsuki,
Phys.Rev. D **91** (2015) 054031

[CLZ] Combined study of 2S and 1D open-charm mesons with natural spin-parity
Bing Chen, Xiang Liu, Ailin Zhang,
Phys.Rev. D **92** (2015) no.3, 034005

II.B $2S$-$1D$ heavy-light mesons

Understanding of the the measured branching ratio for $D_{sJ}^*(2860)$



[a] S. Godfrey and I. T. Jardine, Nature of the $D_{s1}^*(2700)$ and $D_{sJ}^*(2860)$ mesons, Phys. Rev. D **89**, 074023 (2014).

[b] Bing Chen, Xiang Liu, Ailin Zhang, Combined study of $2S$ and $1D$ open-charm mesons with natural spin-parity, Phys.Rev. D **92** (2015) no.3, 034005

[c] B. Zhang, X. Liu, W. Z. Deng, and S. L. Zhu, $D_{sJ}(2860)$ and $D_{sJ}(2715)$, Eur. Phys. J. C **50**, 617 (2007).

[d] S. Godfrey and K. Moats, $D_{sJ}^*(2860)$ mesons as excited D-wave $c\bar{s}$ states, Phys. Rev. D **90**, 117501 (2014).

[e] J. Segovia, D. R. Entem, and F. Fernandez, Charmed-strange meson spectrum: Old and new problems, Phys. Rev. D **91**, 094020 (2015).

[f] D. M. Li and B. Ma, Implication of *BABAR*'s new data on the $D_{s1}^*(2700)$ and $D_{sJ}^*(2860)$, Phys. Rev. D **81**, 014021 (2010).

[g] Q. T. Song, D. Y. Chen, X. Liu, and T. Matsuki, Charmed-strange mesons revisited: Mass spectra and strong decays, Phys. Rev. D **91**, 054031 (2015).

II.B $2S$-$1D$ heavy-light mesons

State	$2S\,(0^-,\frac{1}{2})$	$2S\,(1^-,\frac{1}{2})$	$1D\,(1^-,\frac{3}{2})$	$1D\,(2^-,\frac{3}{2})$	$1D\,(2^-,\frac{5}{2})$	$1D\,(3^-,\frac{5}{2})$
SSCLZ		$B_J(5970)$				
XLM		$B_J(5970)$				
XZ						$B_J(5970)$
LL		$B_J(5970)$				
LPWWL	$B_J(5840)$					$B_J(5970)$
WWJJW						$B_J(5970)$
GU		$B_J(5970)$	$B_J(5840)$			

The assignments for $B_J(5840)$ and $B_J(5970)$

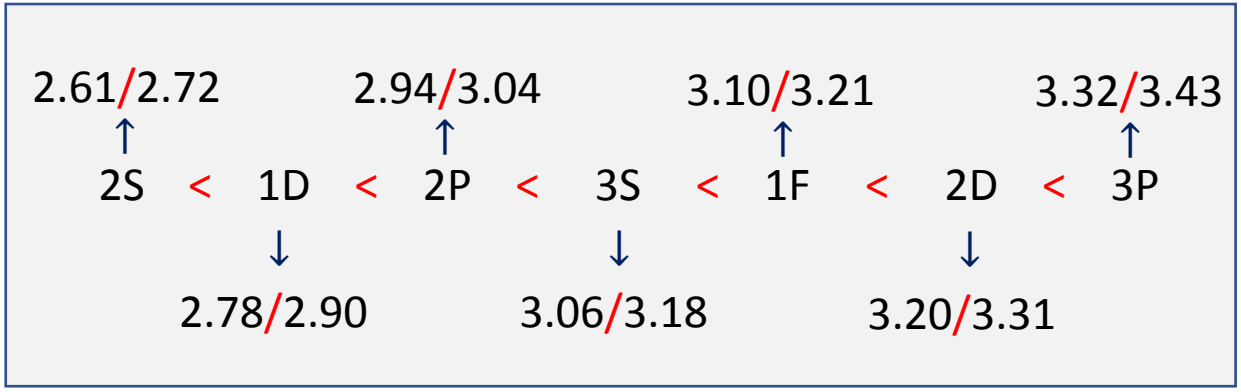
[SSCLZ] Yuan Sun, Qin-Tao Song, Dain-Yong Chen, Xiang Liu, Shi-Lin Zhu, Phys.Rev. D **89**, 054026 (2014)
[XLM] Hao Xu, Xiang Liu, Takayuki, Matsuki, Phys.Rev. D **89**, 097502 (2014)
[XZ] Li-Ye Xiao, Xian-Hui Zhong, Phys.Rev. D **90** (2014) no.7, 074029
[LL] Jing-Bin Liu, Cai-Dian Lu,Eur.Phys.J. C **77**, 312 (2017)
[LPWWL] Qi-Fang Lü, Ting-Ting Pan, Yan-Yan Wang, En Wang, De-Min Li,Phys.Rev. D **94**, 074012 (2016)
[WWJJW] Tianhong Wang, Zhi-Hui Wang, Yue Jiang, Libo Jiang, Guo-Li Wang,Eur.Phys.J. C **77**, 38 (2017)
[GU] P. Gupta, A. Upadhyay,arXiv:1803.03136

II.C Higher excited heavy-light mesons

II.C Higher excited heavy-light mesons

State	Production	Observed decays	Mass (MeV)	Width (MeV)	J^P	Year	Collaboration
$D_J(3000)^0$	pp	$D^{*+}\pi^-$	2971.8 ± 8.7	188.1 ± 44.8	UN	2013	LHCb
$D_J^*(3000)^0$		$D^+\pi^-$	3008.1 ± 4.0	110.5 ± 11.5	N		
$D_2^*(3000)^0$		$D^+\pi^-$	$3214 \pm 29 \pm 33 \pm 36$	$186 \pm 38 \pm 34 \pm 63$	$2^?$	2016	LHCb
$D_{sJ}(3040)^+$	e^+e^-	D^*K	$3044 \pm 8\,(^{+30}_{-5})$	$239 \pm 35\,(^{+46}_{-42})$		2009	*BABAR*

J^P assignments for these states



(predicted D/D_s masses in units of GeV)

II.C Higher excited heavy-light mesons

For $D_J(3000)$ and $D_J^*(3000)$ as the $2P$ states

Newly observed and $D_J(3000)^{+,0}$ and $D_J^*(3000)^0$ as $2P$ states in D meson family
Yuan Sun, Xiang Liu, Takayuki Matsuki,
Phys.Rev. D **88** (2013) no.9, 094020

Strong decays of higher excited heavy-light mesons in a chiral quark model
Li-Ye Xiao, Xian-Hui Zhong,
Phys.Rev. D **90** (2014) no.7, 074029

Systematic analysis of the $D_J(2580)$, $D_J^*(2650)$, $D_J(2740)$,$D_J^*(2760)$,$D_J(3000)$ and $D_J^*(3000)$ in D meson family
Guo-Liang Yu, Zhi-Gang Wang, Zhen-Yu Li, Gao-Qing Meng,
Chin.Phys. C **39** (2015) no.6, 063101

For $D_J(3000)$ and $D_J^*(3000)$ as the $3S$ and $1F$ states

Understanding the charmed states recently observed by the LHCb and BaBar Collaborations in the quark model
Qi-Fang Lü, De-Min Li,
Phys.Rev. D **90** (2014) no.5, 054024

II.D 1*P* charmed baryons with a "bad" diquark

II.D 1*P* charmed baryons with a "bad" diquark

Properties measured by experiments

State	Production	Observed decays	Mass (MeV)	Width (MeV)	J^P	Year	Collaboration
$\Sigma_c(2800)^0$	e^+e^-	$\Lambda_c^+\pi^-$	2806^{+5}_{-7}	72^{+22}_{-15}		2005	Belle
	$B^- \to \Sigma_c^{*0}\bar{p}$	$\Lambda_c^+\pi^-$	$2846 \pm 8 \pm 10$	86^{+33}_{-22}		2008	BaBar
$\Xi_c(2930)$	$B^- \to \Xi_c^{*0}\bar{\Lambda}_c^-$	$\Lambda_c^+K^-$	$2931 \pm 3 \pm 5$	$36 \pm 7 \pm 11$		2008	BaBar
			$2928.9 \pm 3.0^{+0.8}_{-12.0}$	$19.5 \pm 8.4^{+5.4}_{-7.9}$		2017	Belle
$\Xi_c(2980)^0$	e^+e^-	$\Xi_c'^0\pi^+, \Xi_c^0(2645)\pi^+$	$2970.8 \pm 0.7 \pm 0.2^{+0.3}_{-0.4}$	$30.3 \pm 2.3^{+1.0}_{-1.8}$		2016	Belle
$\Omega_c(3000)^0$	pp	$\Xi_c K$	$3000.4 \pm 0.2 \pm 0.1^{+0.3}_{-0.5}$	$4.5 \pm 0.6 \pm 0.3$		2017	LHCb
$\Omega_c(3050)^0$		$\Xi_c K$	$3050.2 \pm 0.1 \pm 0.1^{+0.3}_{-0.5}$	$0.8 \pm 0.2 \pm 0.1$			
$\Omega_c(3066)^0$		$\Xi_c K$, $\Xi_c' K$	$3065.6 \pm 0.1 \pm 0.3^{+0.3}_{-0.5}$	$3.5 \pm 0.4 \pm 0.2$			
$\Omega_c(3090)^0$		$\Xi_c K$, $\Xi_c' K$	$3090.2 \pm 0.3 \pm 0.5^{+0.3}_{-0.5}$	$8.7 \pm 1.0 \pm 0.8$			
$\Omega_c(3119)^0$		$\Xi_c K$, $\Xi_c' K$	$3119.1 \pm 0.3 \pm 0.9^{+0.3}_{-0.5}$	$1.1 \pm 0.8 \pm 0.4$			
$\Omega_c(3000)^0$	e^+e^-	$\Xi_c K$	$3000.7 \pm 1.0 \pm 0.2$			2018	Belle
$\Omega_c(3050)^0$		$\Xi_c K$	$3050.2 \pm 0.4 \pm 0.2$				
$\Omega_c(3066)^0$		$\Xi_c K$	$3064.9 \pm 0.6 \pm 0.2$				
$\Omega_c(3090)^0$		$\Xi_c K$	$3089.3 \pm 1.2 \pm 0.2$				
$\Omega_c(3119)^0$		$\Xi_c K$	—				

II.D $1P$ charmed baryons with a "bad" diquark

For $\Sigma_c(2800)$ as the $1P$ Σ_c state

(1) $\frac{1}{2}^-$, $\frac{3}{2}^-$

P-wave charmed baryons from QCD sum rules
Hua-Xing Chen, Wei Chen, Qiang Mao, Atsushi Hosaka, Xiang Liu, Shi-Lin Zhu,
Phys.Rev. D **91** (2015) no.5, 054034

Spectroscopy and Regge trajectories of heavy baryons in the relativistic quark-diquark picture
D. Ebert, R.N. Faustov, V.O. Galkin,
Phys.Rev. D **84** (2011) 014025

Faddeev study of heavy baryon spectroscopy
H. Garcilazo, J. Vijande, A. Valcarce,
J.Phys. G **34** (2007) 961-976

(2) $\frac{3}{2}^-$

Towards an understanding of heavy baryon spectroscopy
A. Valcarce, H. Garcilazo, J. Vijande,
Eur.Phys.J. A **37** (2008) 217-225

Strong Decays of Charmed Baryons in Heavy Hadron Chiral Perturbation Theory: An Update
Hai-Yang Cheng, Chun-Khiang Chua,
Phys.Rev. D **92** (2015) no.7, 074014

II.D $1P$ charmed baryons with a "bad" diquark

For $\Sigma_c(2800)$ as the $1P$ Σ_c state

(3) $\frac{3}{2}^-$, $\frac{5}{2}^-$

Strong and radiative decays of the low-lying S- and P-wave singly heavy baryons
Kai-Lei Wang, Ya-Xiong Yao, Xian-Hui Zhong, Qiang Zhao,
Phys.Rev. D **96** (2017) no.11, 116016

Low-lying charmed and charmed-strange baryon states
Bing Chen, Ke-Wei Wei, Xiang Liu, Takayuki Matsuki,
Eur.Phys.J. C **77** (2017) no.3, 154

(4) $\frac{5}{2}^-$

Charmed (70, 1^-) baryon multiplet
S.M. Gerasyuta, E.E. Matskevich,
Int.J.Mod.Phys. E **17** (2008) 585-610

II.D $1P$ charmed baryons with a "bad" diquark

For $\Sigma_c(2800)$ as a DN molecule state

S-wave $D^{(*)}N$ molecular states: $\Sigma_c(2800)$ and $\Lambda_c(2940)^+$?
Jian-Rong Zhang,
Phys.Rev. D **89** (2014) no.9, 096006

ND and NB systems in quark delocalization color screening model
Lifang Zhao, Hongxia Huang, Jialun Ping,
Eur.Phys.J. A **53** (2017) no.2, 28

Charmed baryon $\Sigma_c(2800)$ as a ND hadronic molecule
Yubing Dong, Amand Faessler, Thomas Gutsche, Valery E. Lyubovitskij,
Phys.Rev. D **81** (2010) 074011

Dynamically generated

Dynamically generated open charmed baryons beyond the zero range approximation
C.E. Jimenez-Tejero, A. Ramos, I. Vidana,
Phys.Rev. C **80** (2009) 055206

II.D $1P$ charmed baryons with a "bad" diquark

Phys.Rev. D 95, 116010 (2017)

State	AAS	CMCHLZ	KR	PM	CL	CC	Wang	ZYZ	AAS	HPW	WXZZ
$\Omega_c(3000)$		$1/2^-$	$1/2^-$ $(3/2^-)$	$1/2^-$	$1/2^-$	$1/2^-$	$1/2^-$	$1/2^+$ or $3/2^+$	$1/2^-$		$1/2^-$
$\Omega_c(3050)$		$1/2^-$	$1/2^-$ $(3/2^-)$	$1/2^-$	$5/2^-$	$3/2^-$	$1/2^-$	$5/2^+$ or $7/2^+$	$3/2^-$		$3/2^-$
$\Omega_c(3066)$	$1/2^+$	$1/2^+$ or $1/2^-$	$3/2^-$ $(5/2^-)$	$3/2^-$	$3/2^-$	$5/2^-$	$3/2^-$	$3/2^-$	$1/2^+$		$3/2^-$
$\Omega_c(3090)$			$3/2^-$ $(1/2^+)$	$3/2^-$	$1/2^-$	$1/2^+$	$3/2^-$	$5/2^-$	$1/2^+$		$5/2^-$
$\Omega_c(3119)$	$3/2^+$	$3/2^+$	$5/2^-$ $(3/2^+)$	$5/2^-$	$3/2^-$	$3/2^+$	$5/2^-$	$5/2^+$ or $7/2^+$	$3/2^+$	$1/2^-$	$1/2^+$ or $3/2^+$

① Five narrow Ω_c states as the $1P$ candidates

Quantum numbers of recently discovered Ω_c^0 baryons from Lattice QCD
M. Padmanath, N. Mathur, Phys.Rev.Lett. **119** (2017) no.4, 042001

Very narrow excited Ω_c baryons
Marek Karliner, Jonathan L. Rosner, Phys.Rev. D **95** (2017) no.11, 114012

Interpretation of the newly observed resonances
Wei Wang, Rui-Lin Zhu, Phys.Rev. D **96** (2017) no.1, 014024

New Ω_c^0 baryons discovered by LHCb as the members of $1P$ and $2S$ states
Bing Chen, Xiang Liu, Phys.Rev. D **96** (2017) no.9, 094015

II.D $1P$ charmed baryons with a "bad" diquark

② Some narrow Ω_c states as the $2S$ or higher excitations

Quantum numbers of Ω_c states and other charmed baryons
Hai-Yang Cheng, Cheng-Wei Chiang,
Phys.Rev. D **95** (2017) no.9, 094018

Understanding the newly observed Ω_c states through their decays
Kai-Lei Wang, Li-Ye Xiao, Xian-Hui Zhong, Qiang Zhao,
Phys.Rev. D 95, 116010 (2017)

Hadronic decay properties of newly observed Ω_c baryons
Ze Zhao, Dan-Dan Ye, Ailin Zhang,
Phys.Rev. D **95** (2017) no.11, 114024

Interpretation of the new Ω_c^0 states via their mass and width
S.S. Agaev, K. Azizi, H. Sundu,
Eur.Phys.J. C **77** (2017) no.6, 395

Revisit assignments of the new excited Ω_c states with QCD sum rules
Zhi-Gang Wang, Xing-Ning Wei, Ze-Hui Yan,
Eur.Phys.J. C **77** (2017) no.12, 832

II.D $1P$ charmed baryons with a "bad" diquark

③ Several narrow Ω_c states as the molecule or Pentaquarks systems

Investigating the excited Ω_c^0 states through $\Xi_c K$ and $\Xi_c' K$ decay channels
Hong xia Huang, Jialun Ping, Fan Wang,
Phys.Rev. D **97** (2018) no.3, 034027

A meson-baryon molecular interpretation for some Ω_c excited baryons
Glòria Montaña, Albert Feijoo, Àngels Ramos,
arXiv:1709.08737

Molecular Ω_c states generated from coupled meson-baryon channels
V.R. Debastiani, J.M. Dias, W.H. Liang, E. Oset,
arXiv:1710.04231

Searching for possible Ω_c-like molecular states from meson-baryon interaction
Rui Chen, Atsushi Hosaka, Xiang Liu
Phys.Rev. D **97** (2018) no.3, 036016

II.D $1P$ charmed baryons with a "bad" diquark

③ Several narrow Ω_c states as the molecule or Pentaquarks systems

Possibility of the existence of charmed exotica
Hyun-Chul Kim, Maxim V. Polyakov, Michał Praszałowicz,
Phys.Rev. D **96** (2017) no.1, 014009

Strong decays of exotic and nonexotic heavy baryons in the chiral quark-soliton model
Hyun-Chul Kim, Maxim V. Polyakov, Michal Praszalowicz, Ghil-Seok Yang,
Phys.Rev. D **96** (2017) no.9, 094021

Observed Ω_c^0 resonances as pentaquark states
C.S. An, H. Chen,
Phys.Rev. D **96** (2017) no.3, 034012

A new look at the Y tetraquarks and Ω_c baryons in the diquark model
A. Ali, L. Maiani, A. V. Borisov, I. Ahmed, M. J. Aslam, A. Ya. Parkhomenko, A. D. Polosa, A. Rehman,
Eur.Phys.J. C **78** (2018) no.1, 29

II.E 2*D* charmed baryons with a "good" diquark

II.E $2D$ charmed baryons with a "good" diquark

Properties of $\Lambda_c(2860)$, $\Lambda_c(2880)$, $\Xi_c(3055)$ and $\Xi_c(3080)$ measured by experiments

State	Production	Observed decays	Mass (MeV)	Width (MeV)	J^P	Year	Collaboration
$\Lambda_c(2880)^+$	e^+e^-	$\Sigma_c\pi, \Lambda_c^+\pi^+\pi^-$	$2282 \pm 1 \pm 2$	< 8		2001	CLEO
		D^0p	$2881.9 \pm 0.1 \pm 0.5$	$5.8 \pm 1.5 \pm 1.1$		2007	*BABAR*
		$\Sigma_c(2455)\pi, \Sigma_c(2520)\pi$	$2881.2 \pm 0.2 \pm 0.4$	$5.8 \pm 0.7 \pm 1.1$	$\frac{5}{2}$	2007	Belle
	pp	D^0p	$2881.75 \pm 0.29 \pm 0.07$	$5.43^{+0.77}_{-0.71} \pm 0.29$	$\frac{5}{2}$	2017	LHCb
$\Lambda_c(2860)^+$	pp	D^0p	$2856.1^{+2.0}_{-1.7} \pm 0.5$	$67.6^{+10.1}_{-8.1} \pm 1.4$	$3/2^+$	2017	LHCb
$\Xi_c(3080)$	e^+e^-	$\Lambda_c^+K^-\pi^+$	$3076.7 \pm 0.9 \pm 0.5$	$6.2 \pm 1.2 \pm 0.8$		2006	Belle
		$\Sigma_c(2455)K, \Sigma_c(2520)K$	$3077.0 \pm 0.4 \pm 0.2$	$5.5 \pm 1.3 \pm 0.6$		2008	*BABAR*
		$\Sigma_c(2455)K, \Sigma_c(2520)K$	$3077.9 \pm 0.4 \pm 0.7$	$3.2 \pm 1.3 \pm 1.3$		2014	Belle
		$\Lambda D^+, \Sigma_c^{++}K^-, \Sigma_c^{*++}K^-$	$3079.6 \pm 0.4 \pm 0.1$	< 6.3		2016	Belle
$\Xi_c(3055)$		$\Sigma_c(2455)K, \Sigma_c(2520)K$	$3054.2 \pm 1.2 \pm 0.5$	$17 \pm 6 \pm 11$		2008	*BABAR*
		$\Sigma_c(2455)K, \Sigma_c(2520)K$	$3058.1 \pm 1.0 \pm 2.1$	$9.7 \pm 3.4 \pm 3.3$		2014	Belle
		$\Lambda D^+, \Sigma_c^{++}K^-, \Sigma_c^{*++}K^-$	$3055.8 \pm 0.4 \pm 0.2$	$7.0 \pm 1.2 \pm 1.5$		2016	Belle

II.E $2D$ charmed baryons with a "good" diquark

Properties of $\Lambda_c(2860)$, $\Lambda_c(2880)$, $\Xi_c(3055)$ and $\Xi_c(3080)$ measured by experiments

$$\frac{B(\Lambda_c(2880)\to\Sigma_c(2520)\pi)}{B(\Lambda_c(2880)\to\Sigma_c(2455)\pi)} = 0.225 \pm 0.062 \pm 0.025;$$ Belle [2007]

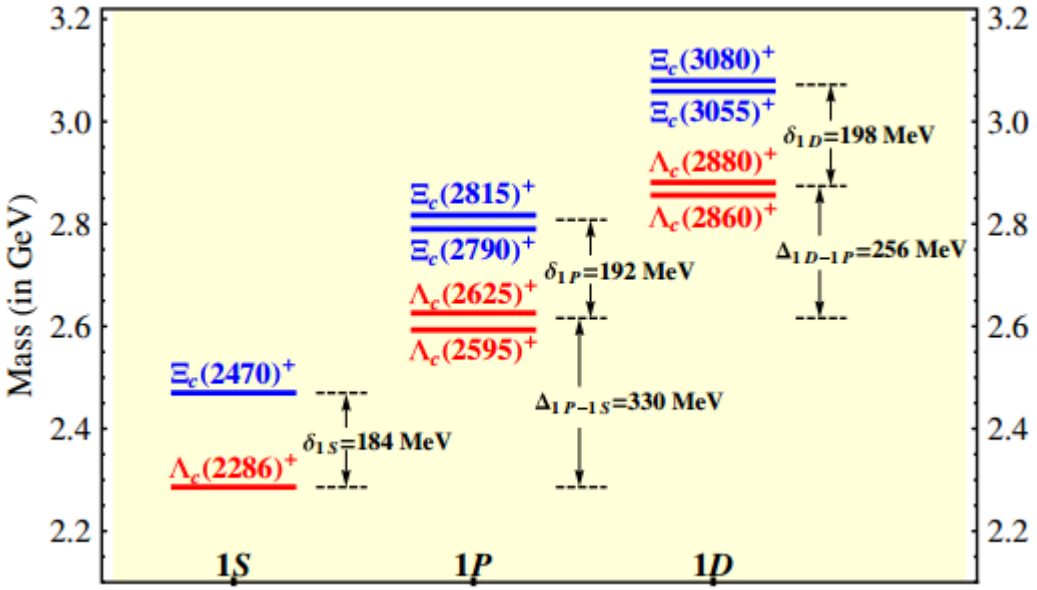
$$\frac{B(\Xi_c(3080)\to\Sigma_c(2520)K)}{B(\Xi_c(3080)\to\Sigma_c(2455)K)} = \frac{0.55\pm0.05\pm0.05}{0.45\pm0.05\pm0.05} = 0.82\sim1.86;$$ *BABAR* [2007]

$$\frac{B(\Xi_c(3080)\to\Sigma_c(2520)K)}{B(\Xi_c(3080)\to\Sigma_c(2455)K)} = 1.07 \pm 0.27 \pm 0.04;$$ Belle [2016]

$$\frac{B(\Xi_c(3080)\to\Lambda D\ )}{B(\Xi_c(3080)\to\Sigma_c(2455)K)} = 1.29 \pm 0.30 \pm 0.15;$$

$$\frac{B(\Xi_c(3055)\to\Lambda D\ )}{B(\Xi_c(3055)\to\Sigma_c(2455)K)} = 5.09 \pm 1.01 \pm 0.76;$$

II.E 2*D* charmed baryons with a "good" diquark



At present, most of predicted masses indicated that $\Lambda_c(2860)$, $\Lambda_c(2880)$, $\Xi_c(3055)$ and $\Xi_c(3080)$ are the *d*-wave charmed bayons.

Bing Chen, Xiang Liu, Phys.Rev. D 95, 074022 (2017)

States	Λ_c^+ baryons					Ξ_c baryons				
	PDG	CWLM	EFG	CWZ	CI	PDG [1]	CWLM	EFG	CWZ	RP
$\|1D, 3/2^+\rangle$		2843	2874	2857	2910	3054.2	3033	3059	3055	3012
$\|1D, 5/2^+\rangle$	2881.53	2851	2880	2879	2910	3079.9	3040	3076	3076	3004

II.E $2D$ charmed baryons with a "good" diquark

BWLM

Low-lying charmed and charmed-strange baryon states
Bing Chen, Ke-Wei Wei, Xiang Liu, Takayuki Matsuki,
Eur.Phys.J. C **77** (2017) no.3, 154

EFG

Spectroscopy and Regge trajectories of heavy baryons in the relativistic quark-diquark picture
D. Ebert, R.N. Faustov, V.O. Galkin,
Phys.Rev. D **84** (2011) 014025

CWZ

Assignments of Λ_Q and Ξ_Q baryons in the heavy quark-light diquark picture
Bing Chen, Ke-Wei Wei, Ailin Zhang, Eur.Phys.J. A **51** (2015) 82

CI

Baryons in a Relativized Quark Model with Chromodynamics
Simon Capstick, Nathan Isgur, Phys.Rev. D **34** (1986) 2809

RP

Heavy baryons in a quark model
W. Roberts, Muslema Pervin,
Int.J.Mod.Phys. A **23** (2008) 2817-2860

II.E $2D$ charmed baryons with a "good" diquark

Bing Chen, Xiang Liu, and Ailin Zhang, 95, 074022 (2017)

Decay modes	$\Lambda_c(2860)^+[1D(3/2^+)]$		$\Lambda_c(2880)^+[1D(5/2^+)]$	
	Γ_i	$\mathcal{B}_i$	Γ_i	$\mathcal{B}_i$
$\Sigma_c(2455)\pi$	2.2	3.0%	0.4	1.7%
$\Sigma_c^*(2520)\pi$	1.0	1.4%	3.7	15.4%
$\Sigma_c(2700)\pi$	0.0	0.0%	0.2	0.8%
D^0p	34.5	48.0%	10.8	44.8%
D^+n	34.2	47.6%	9.0	37.3%
Theory	71.9	100%	24.1	100%
Expt. [1]	$67.6^{+10.1}_{-8.1} \pm 1.4^{+5.9}_{-20.0}$		$5.43^{+0.77}_{-0.71} \pm 0.29^{+0.75}_{-0.00}$	

Decay modes	$\Xi_c(3055)[1D(3/2^+)]$		$\Xi_c(3080)[1D(5/2^+)]$	
	Γ_i	$\mathcal{B}_i$	Γ_i	$\mathcal{B}_i$
$\Sigma_c(2455)K$	4.2	27.3%	0.6	4.8%
$\Xi_c'(2580)\pi$	0.2	1.3%	0.1	0.8%
$\Sigma_c^*(2520)K$	0.7	4.5%	5.4	42.8%
$\Xi_c^*(2645)\pi$	0.3	2.0%	0.5	4.0%
$\Xi_c'(2840)\pi$	0.4	2.6%	0.7	5.5%
$D^+\Lambda$	9.6	62.3%	5.3	42.1%
Theory	15.4	100%	12.6	100%
Expt. [13]	$7.8 \pm 1.2 \pm 1.5$		$3.0 \pm 0.7 \pm 0.4$	

So far, all charmed baryon states which have been found by experiments could be explained as the λ-mode excited states. It means that degrees of freedom of two light quarks are frozen in these baryon states.

Section three: Summary and outlook

Heavy-light mesons

With the cooperative efforts from both experimentalists and theorists, many excited heavy-light meson states have been established. In the following years, we may pay attention to the following issues:

❶. More theories are needed for $D_{s0}(2317)$ and $D_{s1}(2460)$. The measurements of $B_{(s)0}$ and $B_{(s)1}$are required;
❷. More accurate measurements of $2S$ and $1D$ states should been carried;
❸. More decay channels should be measured for these higher excited heavy-light states;
❹. The spin-dependent interactions should be investigated in details;
❺. The coupled-channel effect and other final state interactions may be studied for a certain excited states.

Section three: Summary and outlook

Heavy-light baryons

With three confined quarks, the more complex dynamics of the baryon system could give us more information about the non-perturbative behavior of QCD. In the following years, we may pay attention to the following issues:

❶. The mechanism of confinement in the baryon system should be investigated deeply;
❷. The masses, hyperfine splitting, mixing angles, decays of p-wave heavy baryons with "bad" diquark should be studied in a three-body picture;
❸. Does the coupled-channel effect exist in some heavy baryon states, *e.g.* $\Lambda_c(2940)^+$;
❹. The heavy quark symmetry may play an important role in QQq baryons. How to incorporate it into the dynamics of these doubly heavy baryons?
❺. In principle, the degrees of freedom of two light quarks can also be excited. Theorists may give some useful clues to find them.

Thank you