

**Annual Report of the RCNP Collaboration Research Network (RCNP-CORENet)**

1 Title of research:  
“Study of the chiral tensor dynamics in the heavy exotic hadrons”

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3 Period of research:  
July 2019 – March 2020

4 Main location of collaboration implementation:  
RCNP, Osaka University and Nishina Center, RIKEN.

## 5 Publication list

(1) Y. Yamaguchi, A. Hosaka, S. Takeuchi and M. Takizawa, “Heavy hadronic molecules with pion exchange and quark core couplings: a guide for practitioners”, Topical Review, *J. Phys. G: Nucl. Part. Phys.* **47** (2020) 053001, 1-67, <https://doi.org/10.1088/1361-6471/ab72b0>

(2) Y. Yamaguchi, H. G.-Tecocoatzi, A. Giacino, A. Hosaka, E. Santopinto, S. Takeuchi and M. Takizawa, “ $P_c$  pentaquarks with chiral tensor and quark dynamics”, accepted for publication in *Phys. Rev. D* (RC).

### Talk list

(1) Y. Yamaguchi, “One pion exchange potential and Hadronic molecules”, Workshop on Exotic hadrons from the quark model and new aspect of QCD, RIKEN, Saitama, Japan 6 July 2019

(2) S. Takeuchi, “Role of the color-octet configurations in the exotic hadrons”, Workshop on Exotic hadrons from the quark model and new aspect of QCD, RIKEN, Saitama, Japan 6 July 2019

(3) A. Hosaka, “Heavy quark baryons — Hadronic molecules as exotic candidates —  $P_c$ ”, HISS/DIAS-TH international school, JINR, Dubna, July 21-30, 2019

(4) Y. Yamaguchi, “Role of the tensor force in the heavy hadronic molecules”, The 18th International Conference on Hadron Spectroscopy and Structure (HADRON2019), Guilin, China 16-21 Aug. 2019

(5) S. Takeuchi, “Flavor-singlet strange pentaquarks with hidden heavy quark pairs  $[udsQ\bar{Q}]$ ”, The 18th International Conference on Hadron Spectroscopy and Structure (HADRON2019), Guilin, China 16-21 Aug. 2019

(6) Y. Yamaguchi, “Tensor force in heavy hadronic molecules”, Workshop on Chiral and heavy quark symmetries in quark-hadron physics, Osaka University, Osaka, Japan 25 Aug. 2019

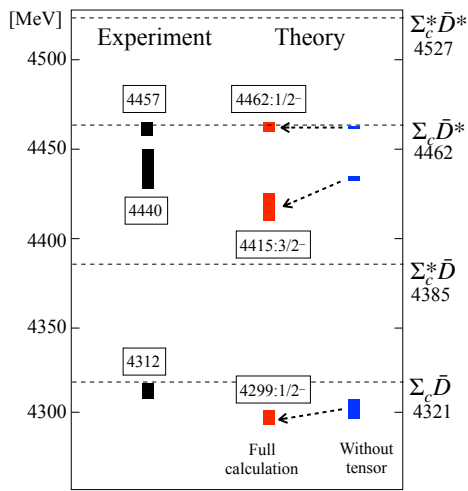
- (7) Y. Yamaguchi, “Hadronic molecules of heavy hadrons with tensor force”, The 24th European conference on few-body problems in physics (EFB24), University of Surrey, Guirford, UK 2-6 Sep 2019
- (8) M. Takizawa, “Study of the hidden-charm pentaquarks in the heavy-quark effective model with coupling to 5-quark states”, JPS Autumn meeting, Yamagata Univ., Yamagata, Japan 17 Sept. 2019
- (9) S. Takeuchi, “Hidden charm and bottom pentaquarks with strangeness”, JPS Autumn meeting, Yamagata Univ., Yamagata, Japan 17 Sept. 2019
- (10) A. Hosaka, “Pentaquark  $P_c$  as heavy hadronic molecules with pion exchange force”, Perspectives in Hadron Physics, ICISE, Quy Nhon, Vietnam, September 22-28, 2019
- (11) M. Takizawa, “Heavy Quark Spin Symmetry with Chiral Tensor Dynamics in the Light of the Recent LHCb Pentaquarks”, Diquark correlations in Hadron Physics: Origin, Impact and Evidence, ECT\*, Trento, 26 Sept. 2019
- (12) A. Hosaka, “Chiral tensor dynamics for heavy baryons  $P_c$ ”, Universal physics in Many-Body Quantum Systems – From Atoms to Quarks, ECT\*, Trento, Oct. 7-11, 2019
- (13) A. Hosaka, “Heavy Hadrons — Where and How —”, Flavor Physics Workshop 2019, Osaka, Japan Nov. 19-21, 2019
- (14) A. Hosaka, “Heavy Hadrons — Where and How —”, Quarks to Universe in Computational Science 2019, YITP, Kyoto Univ. Kyoto, Japan, Dec. 16 - 19, 2019
- (15) S. Takeuchi, “ $X(3872)$  by a quark-hadron hybrid model with the OPEP S-D-wave coupling”, Workshop on “Physics of heavy-quark and exotic hadrons”, KEK Tokai Campus, Ibaraki, Japan, 28 Jan. 2020
- (16) Y. Yamaguchi, “Heavy hadronic molecules: pion exchange and coupling to multi-quark states”, Workshop on “Physics of heavy-quark and exotic hadrons”, KEK Tokai Campus, Ibaraki, Japan, 29 Jan. 2020

(17) Y. Yamaguchi, “Tensor force in the heavy hadronic molecules”, REIMEI Workshop on Universal Features of Quantum Flows with Spin, Orbital and Tensor Correlations, Ibaraki Quantum Beam Research Center, Tokai, Ibaraki 17-19 Feb. 2020

(18) S. Takeuchi, “Study of the color-octet resonances in the baryon-meson scattering”, JPS spring meeting 2020, Mar. 2020

## 6 Description of the outputs

(1) “Chiral tensor and quark dynamics explains the pentaquarks discovered by the LHCb experiment”.



Using an effective theory for open charm meson-baryons with a compact quark core we have explained the masses and decay widths of the three new pentaquark states observed at LHCb. Pentaquarks are considered to have exotic and entirely different nature from the standard ones such as protons and neutrons. The theory is based on the symmetries of QCD; the heavy quark and chiral symmetries. The chiral symmetry necessitates one pion exchange between mesons and

baryons. Both the masses and widths of these three states are in reasonable agreement with the experimental results as shown in the figure. In addition to these three states, we have predicted four more states, waiting for further experiments. We find that the short-range interaction by the coupling to the quark core plays a major role for the ordering of these states, while the long-range force of the pion tensor term does for the decay widths. The interplay of the chiral tensor and quark dynamics turns out to be a universal feature for heavy hadron systems. We reported present results in Physical Review D (Rapid Communications) and will be appeared soon.

(2) “We write up the review article on heavy hadronic molecules with chiral tensor and quark dynamics”

In this review article, we discuss selected and important features of hadronic molecules as one of several promising forms of exotic hadrons near thresholds. Using examples of  $D \bar{D}^*$  systems such as X(3872) and  $Z_c$ , emphasis is put on the roles of the

one pion exchange interaction between them and their coupling to intrinsic quark states. Thus, hadronic molecules emerge as admixtures of the dominant long-range hadron structure and short-range quark structure. For the pion exchange interaction, properties of the tensor force are analyzed in detail. More coupled channels supply more attractions, and heavier constituents suppress kinetic energies, providing more chances to form hadronic molecules of heavy hadrons. The review article was published in topical review section, *J. Phys. G: Nucl. Part. Phys.* **47** (2020) 053001, 1-67, <https://doi.org/10.1088/1361-6471/ab72b0>

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