

# Opening Remarks

--Clustering as a window on the hierarchical  
structure of quantum systems

中村隆司 (領域代表)

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Clusters & Hierarchies

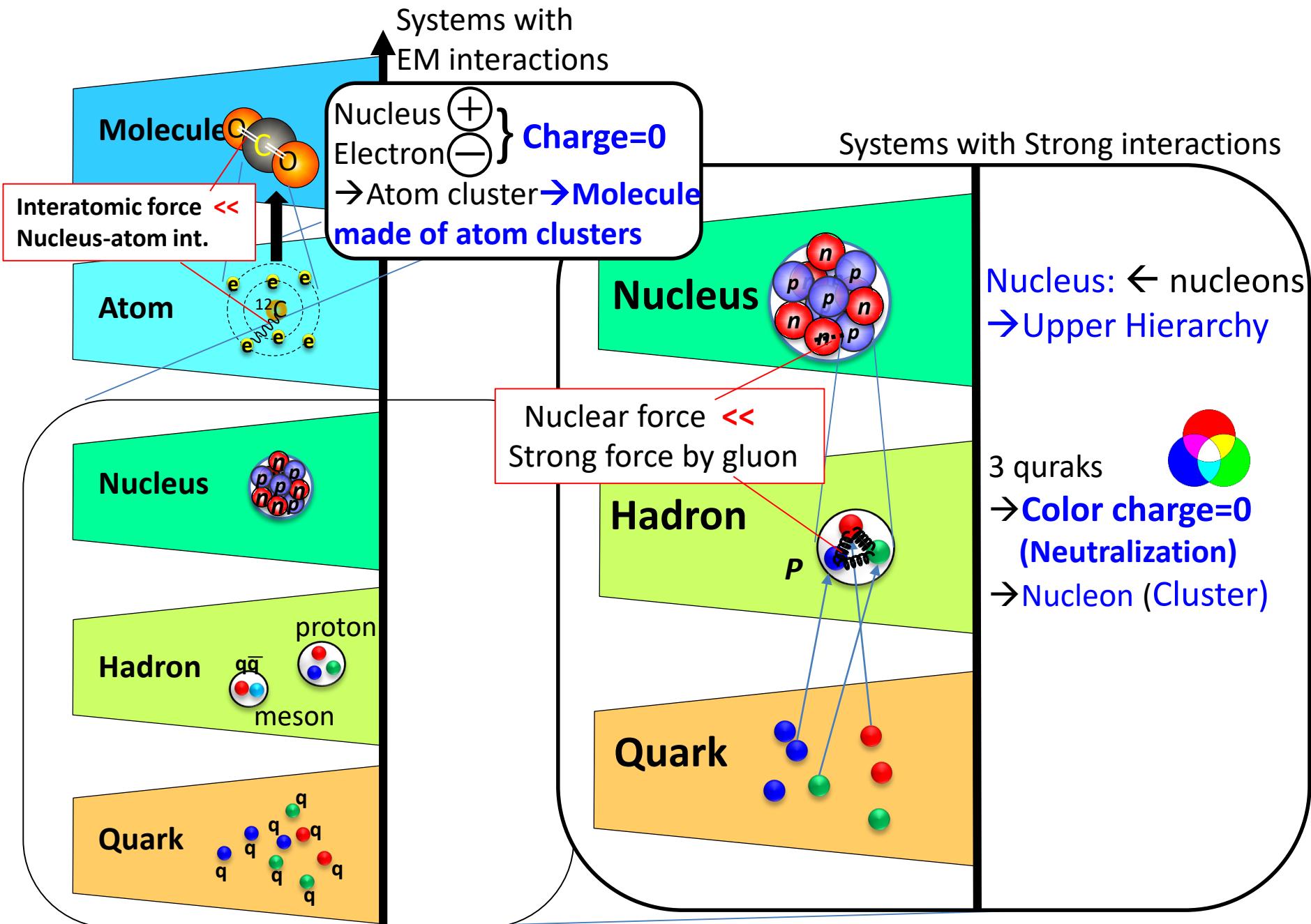
新学術領域「クラスター階層」第三回領域研究会

3<sup>rd</sup> Symposium on Clustering as a window on the hierarchical structure of quantum systems,

18 May, 2020

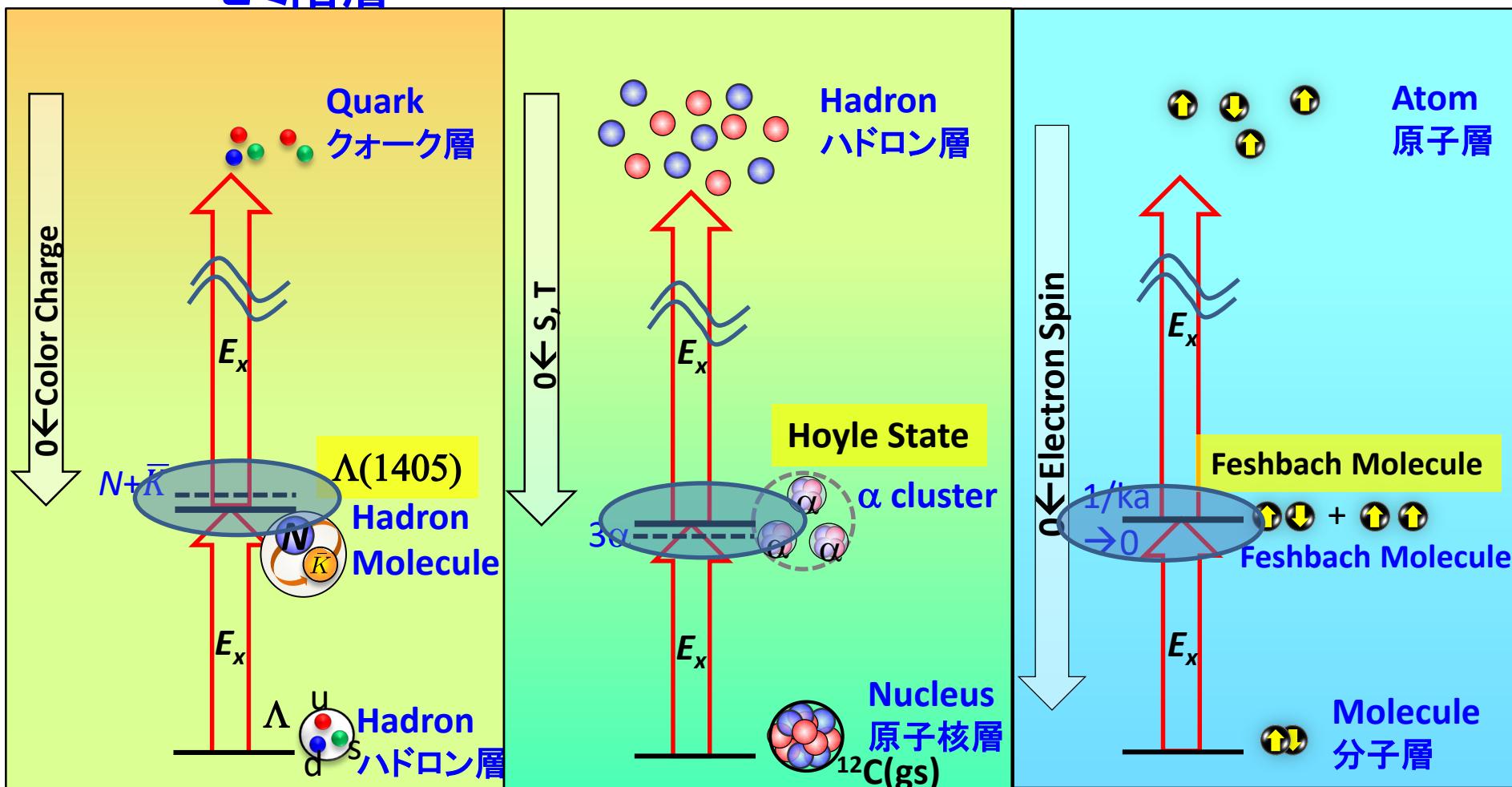
# Clustering: Key to understand **hierarchy** in quantum world?

2



# Semi-Hierarchy: Clustering and Hierarchy of Matter

セミ階層



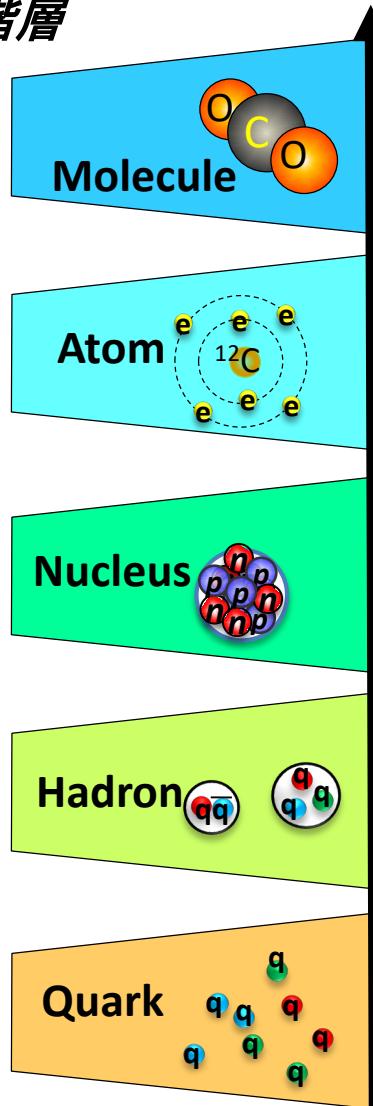
- ✓ Threshold: Clustering near Threshold → **Semi-Hierarchy**
- ✓ Degree of Freedom: Neutralization of Charge, Spin(S), Isospin(T)

# Clusters and Semi-Hierarchy

## *Conventional Hierarchy*

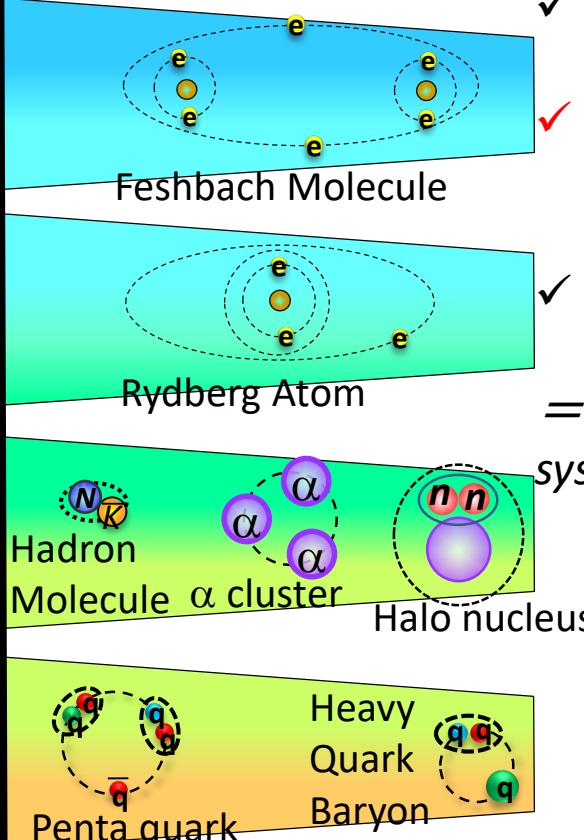
從來型階層

- ✓ Big Gap between Hierarchies
- ✓ **Strongly Bound** 強束縛
- ✓ Simple constituents: Nucleus= “nucleonic” system



## *Semi-Hierarchy*

セミ階層



- ✓ Smaller Gap between Hierarchies
- ✓ **Weakly Bound (Unbound)** 弱束縛(弱非束縛)
- ✓ Mixed constituents: Halo Nucleus = “nucleonic”+“dineutron” system

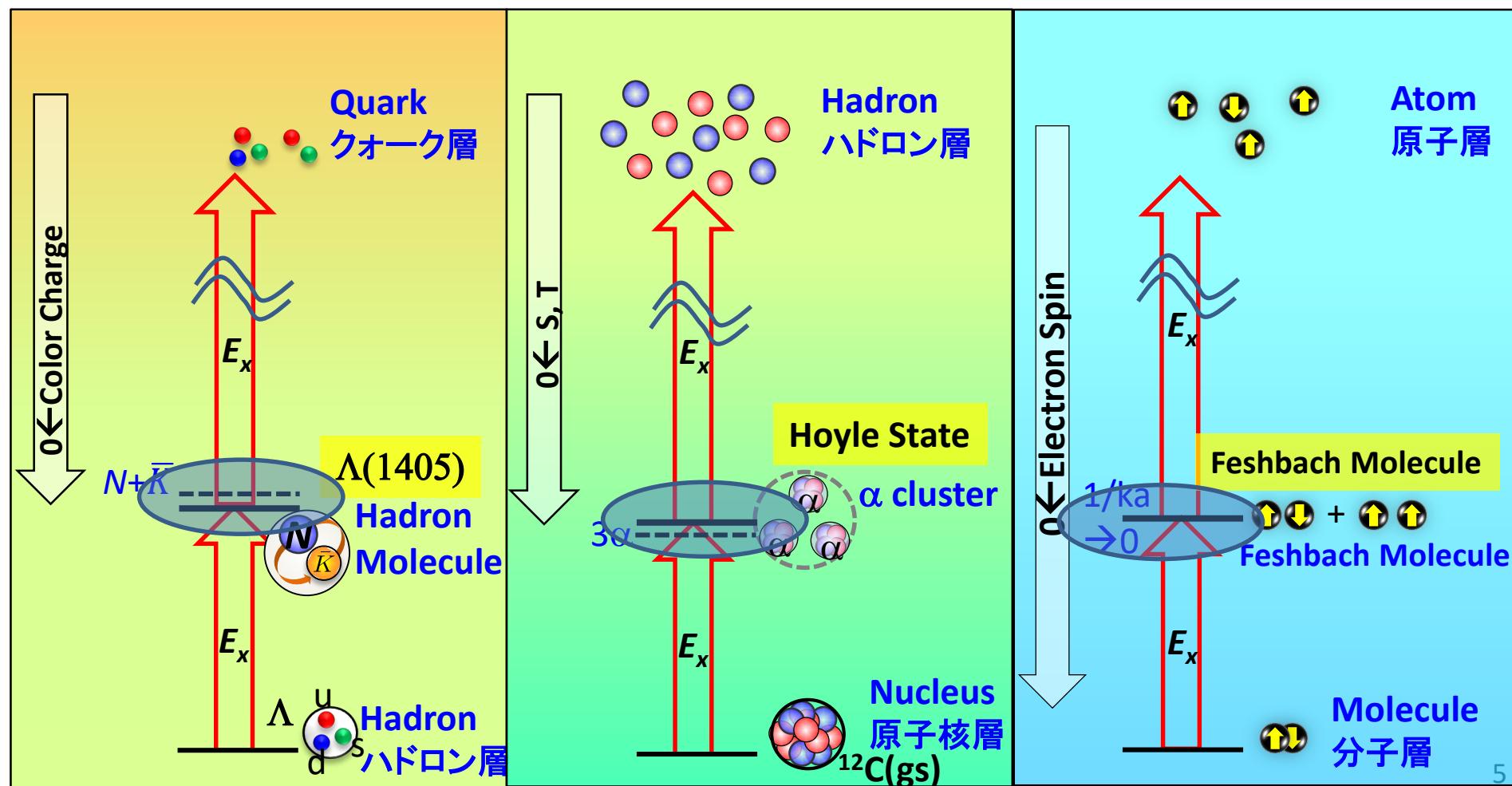


**Semi-Hierarchy:**  
Key Aspects to understand the hierarchical structure of matter

# This Research Area → "Three Key Indexes to Connect Hierarchies"

本領域研究→「階層間をつなぐ3つの指標」を確立

- ✓ Degree of Freedom 自由度 : Charge, Spin Isospin → Neutralization → Hierarchy
- ✓ Threshold Rule 閾値則 : Near Threshold → Cluster (Hierarchy)
- ✓ Degree of Separatin 分離度 : Quantify Separation by Purity of “Cluster state”



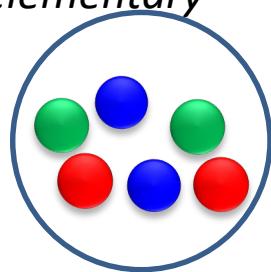
# Degree of Separation 分離度

Why deuteron is described as *two-nucleon system*, but not as *6q system*?

## Nuclei hierarchy vs. Hadron hierarchy

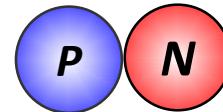
D.o. Separation: “**Compositeness : Z**  
(Field renormalization constant)

Hadron-like deuteron  
: *elementary*



$$Z \sim 1$$

Nuclear-like deuteron  
: *composite (cluster)*



$$Z \sim 0$$

S. Weinberg, PR 137, 672 (1965)  
T. Hyodo, IJMPA 28, 1330045 (2013)

$$|many\ body\ state\rangle = \sqrt{Z} |elementary\rangle + \sqrt{1-Z} |composite\rangle$$

Deuteron: Weakly bound limit ( $B=2.23$  MeV,  $a = 5.42$  fm,  $r_e = 1.74$  fm)

$$a = \frac{2(1-Z)}{2-Z} R + \sigma(m_\pi^{-1})$$

$$r_e = -\frac{Z}{1-Z} R + \sigma(m_\pi^{-1})$$

$$R = \frac{1}{\sqrt{2\mu B}} = 4.31 \text{ fm}$$

→  $Z \sim 0$

# Questions on D.o. Separation

- Compositeness:  
Valid for weakly bound 2-body system. How about deeply-bound system? 3-body or heavier system?
- Resonance?
- Compositeness vs. Spectroscopic factor

Goal: Establish “Universal Index” for the degree of Separation

One more Key Factor:

# Interactions → Clustering → Hierarchy

力「相互作用」

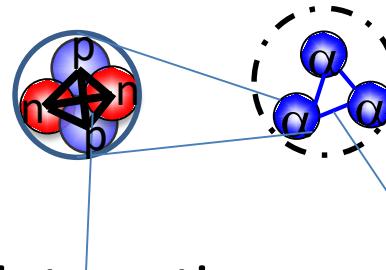
クラスター

階層構造

Key: Understand “the force”:

→ Clustering: Strong Inside, Weak Outside

中は強く、外は弱く



NN interaction >>  $\alpha\alpha$  interaction  
(Strong Inside)      (Weak Outside)

→(Semi)-Hierarchy

$\alpha$ -cluster nucleus: Fixed “ $a_{nn}$ ,  $a_{\alpha\alpha}$ ”

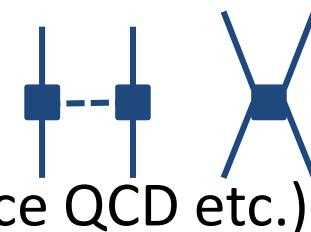
→ Ultracold atom: “ $a_s$ ” (散乱長, 相互作用の強さ) can be tuned

→ Exotic nuclei/Hyper nuclei very different “a”

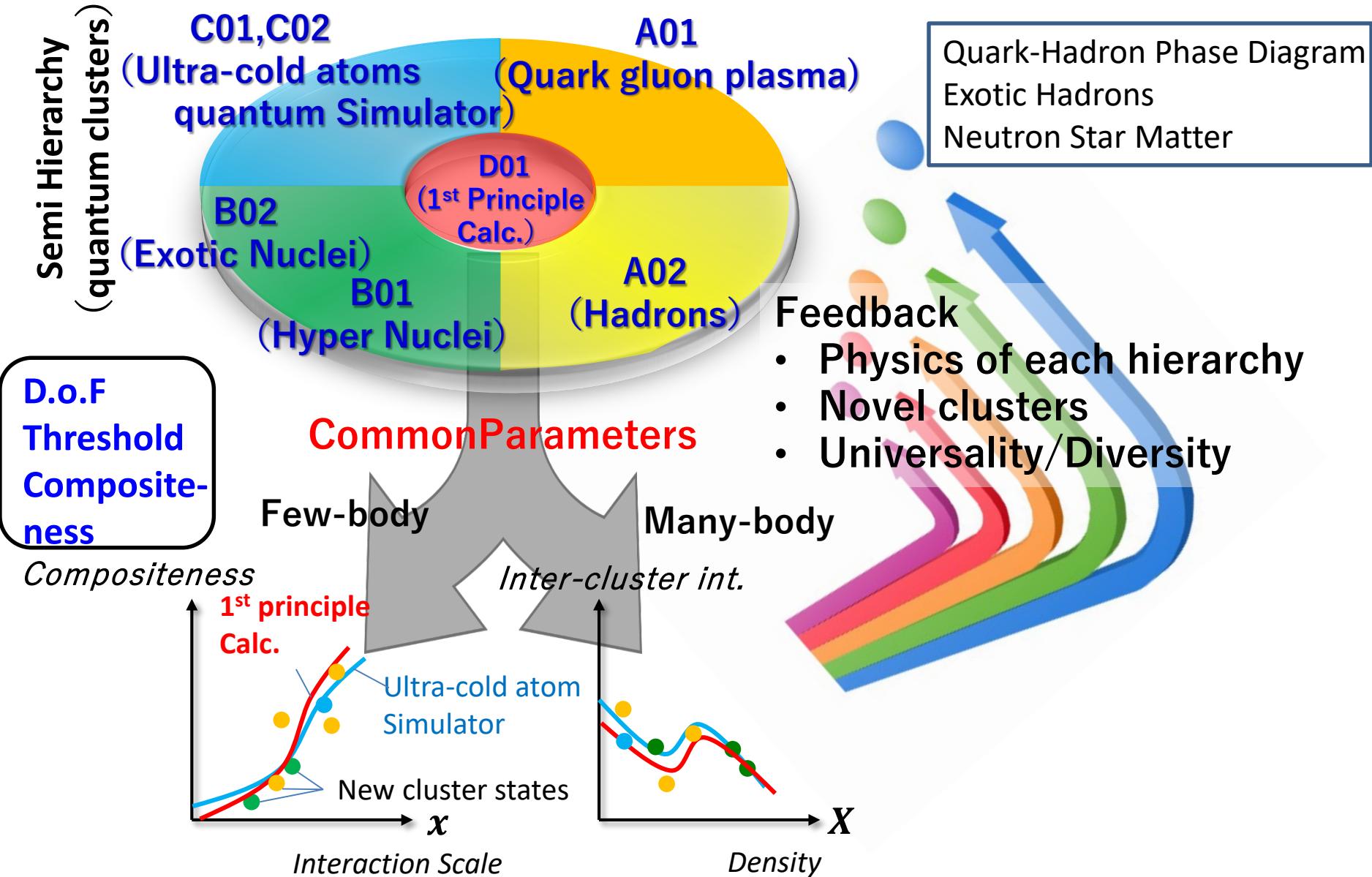
→ 3N force

→ Effective interactions (Medium effect)

→ Understand the force from fundamental level (Lattice QCD etc.)



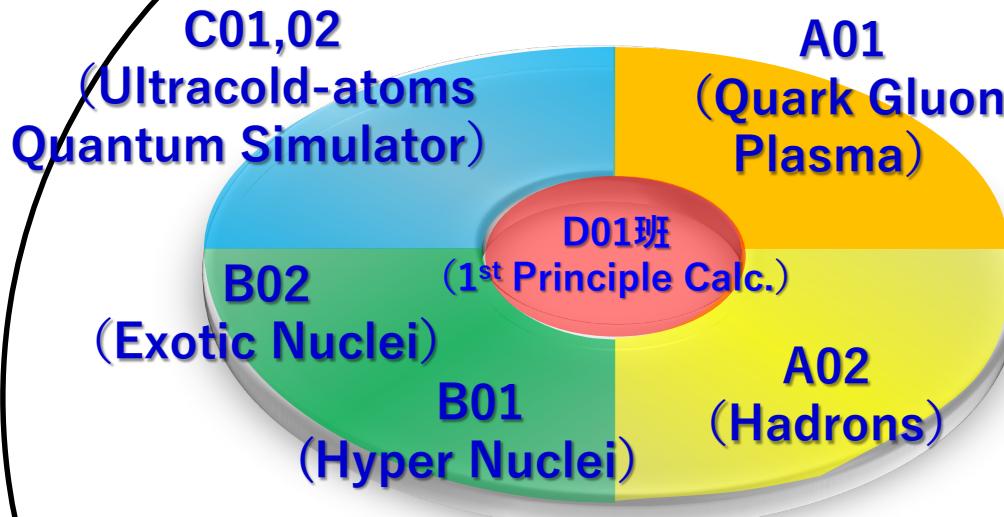
# Bridging Hierarchies



# 総括班の主要活動

Activities of Board of Directors

**AIM: Promote Strong Collaborations to bridge over different fields (hierarchies)**



- ✓ 国際レクチャーシリーズ  
(International Lecture Series)
- ✓ 物質階層を横断する会  
(Bridging Hierarchies: Topical WS)
- ✓ 検出器ワークショップ  
(Detector WS)

→Board meeting (総括班会議)、News Letters (領域ニュース)

Domestic/International Cross-field Symposium/Workshop (分野横断型研究会・ワークショップ)  
Promote International Activities (国際活動支援)

School/Promotion of Young Researchers/Students (スクール、若手プロモート)

Public Relations/Outreach Activities (広報・アウトリーチ)

**“Collaboration to overcome the gaps between hierarchies of matter”**

**「階層間の壁を超える連携研究」を本領域研究で実現！**



文部科学省 科学研究費補助金 新学術領域研究

# 量子クラスターで読み解く物質の階層構造

Clustering as a window on the hierarchical structure of quantum systems

## 領域ニュース

vol.6 2020/1/27 発行



**International Symposium on Clustering as a Window on the Hierarchical Structure of Quantum Systems (CLUSHIQ2020) を開催しました。**

2020年1月23日（木）－24日（金）、別府温泉、両筑別邸（大分県別府市）



## ポスター賞受賞者

Ms, Shiyo Enyo (Kyoto Univ.)

A large solid hydrogen target for ESPRI experiment

Mr. Yonghree Kim (Kyushu Univ.)

Spectrum of heavy baryons in a chiral diquark system

おめでとうございます。



(左) Yonghree Kim さん

(中央) Takashi Nakamura 領域代表

(右) Ms, Shiyo Enyo さん

# 新たなハイパー原子核「グザイ・テトラバリオン」

—グザイ粒子の振る舞いを精密計算で解き明かす—

論文 : E. Hiyama, K. Sasaki, T. Miyamoto, T. Doi, T. Hatsuda, Y. Yamamoto, Th. A.

Rijken, "Possible Light  $\Xi$  Hypernucleus with Modern  $\Xi N$  Interactions",  
Physical Review Letters, 124, 092501 (2020).

DOI: <https://doi.org/10.1103/PhysRevLett.124.092501>

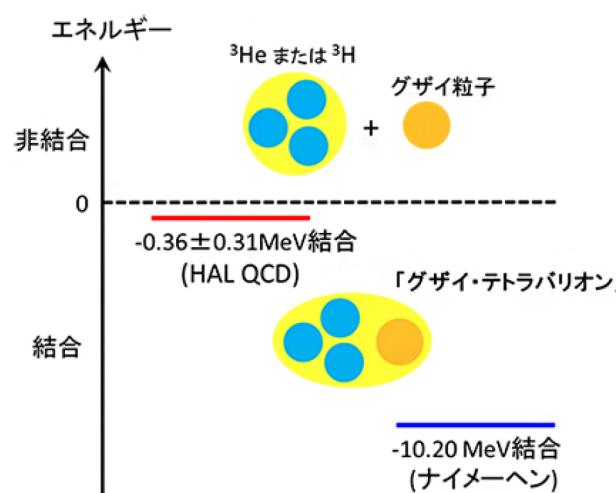
c.f. 領域ニュース Vol. 7

プレスリリース

新たなハイパー原子核「グザイ・テトラバリオン」

—グザイ粒子の振る舞いを精密計算で解き明かす—

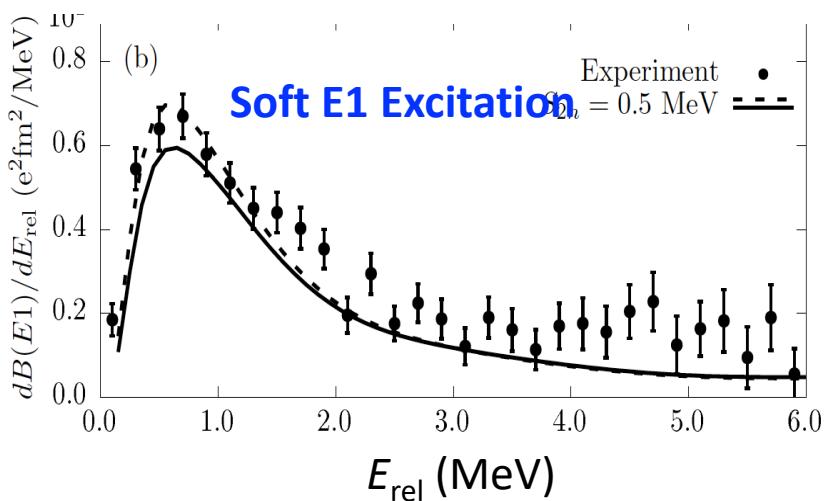
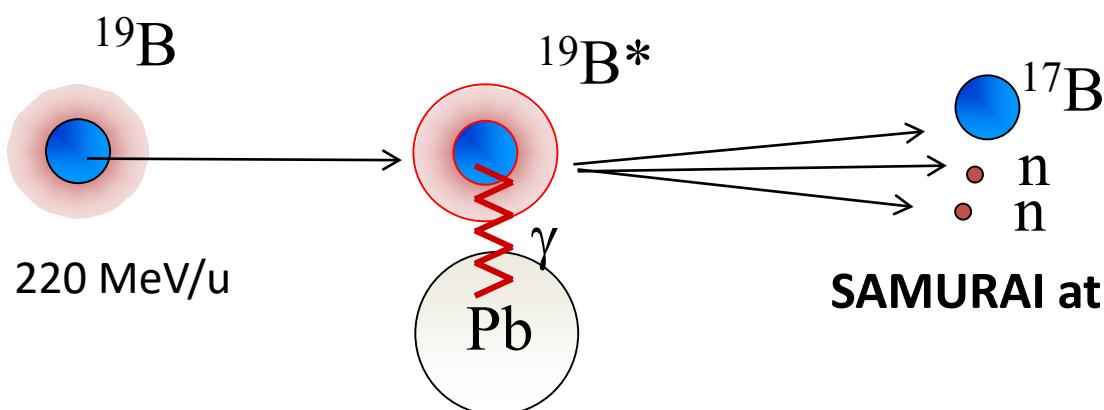
[https://www.riken.jp/press/2020/20200305\\_2/index.html](https://www.riken.jp/press/2020/20200305_2/index.html)



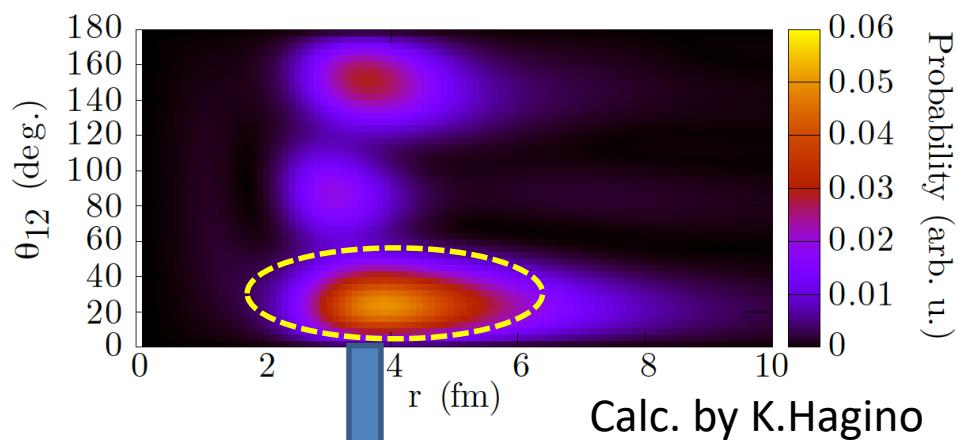
理論計算により示されたグザイ粒子 1 個と核子 3 個からなる系のエネルギー準位図。グザイ粒子と核子 3 個（ヘリウム 3 原子核あるいは水素 3 原子核）が束縛するしきい値を 0 としている。エネルギーが負の場合は、グザイ粒子が束縛したハイパー核を示し、エネルギーが低い程、グザイ粒子の結合が強いことに対応する。グザイ粒子と核子間の力として、格子 QCD 計算 (HAL-QCD) の結果を用いた場合（赤線）、現象論的に求められたもの（ナイマーへン）を用いた場合（青線）とも、ハイパー核「グザイ・テトラバリオン」の存在を予言している。

# Halo Structure of neutron drip-line nucleus $^{19}\text{B}$

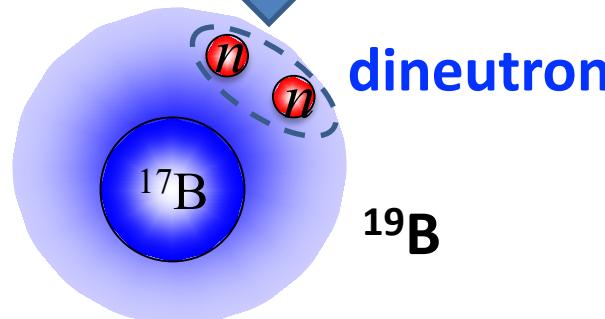
K.J. Cook, T.Nakamura et al.  
**Phys. Rev. Lett. In Press**  
Editor's Choice



SAMURAI at RIBF



$^{17}\text{B}-n \quad a < -50 \text{ fm}$   
 $n-n \quad a = -18.5 \text{ fm}$



c.f. E. Hiyama et al., "Modeling  $^{19}\text{B}$  as a  $^{17}\text{B}-n-n$  three-body system in the unitary limit"  
PRC100, 011603(R)(2019)

# まとめ 領域の目指すもの

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Summary: What we are aiming at?

Quantum Simulator

→Universality across hierarchies

C01,02

(Ultracold-atoms  
Quantum Simulator)

B02

(Exotic Nuclei)

B01  
(Hyper Nuclei)

D01班  
(1<sup>st</sup> Principle Calc.)

Hadron semi hierarchy  
→Clarify the properties of exotic hadrons

A01

(Quark Gluon  
Plasma)

A02

(Hadrons)

Nuclei semi-hierarchy

→Produce exotic nuclear clusters and clarify their properties

→First-principle Calculation  
Fundamental hierarchy  
→Upper hierarchy  
Clarify Key Factors

Understand “Semi-hierarchy/Clusters” “Force” →Universality/Diversity  
→Mechanism of Cluster formation/Hierarchy of Matter

Establish “Science of Matter-Hierarchy”