格子QCDによる バリオン間相互作用の計算

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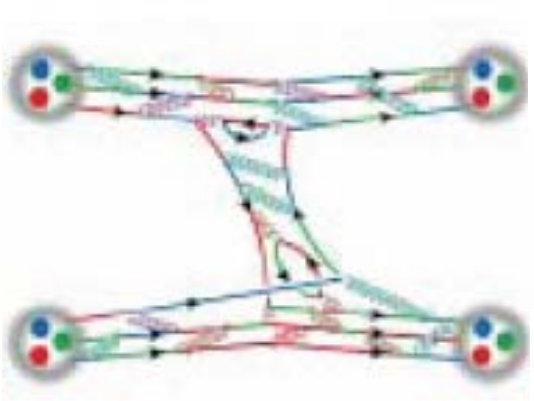
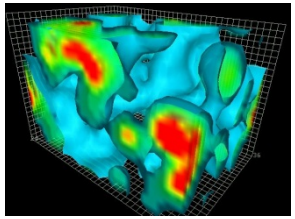
- Introduction
- Recent achievements
- The “First Light” at the physical point
- Prospects



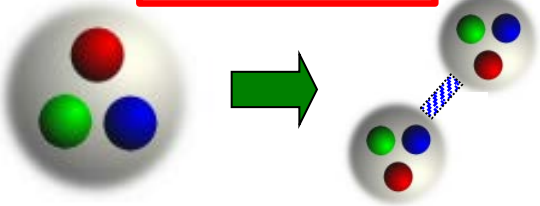
Motivation:

Nuclear Physics and Astrophysics from Lat QCD



QCD Vacuum

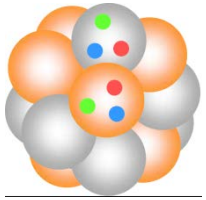
分野5課題1



Baryon

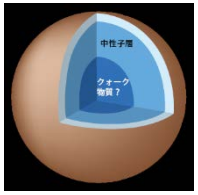
Few-Body

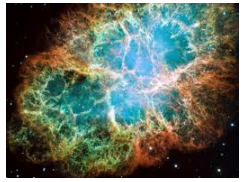
分野5課題2



Nuclei

分野5課題3





Neutron Star / Supernova

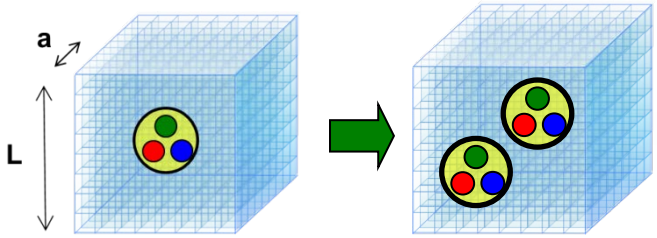
Standard Model

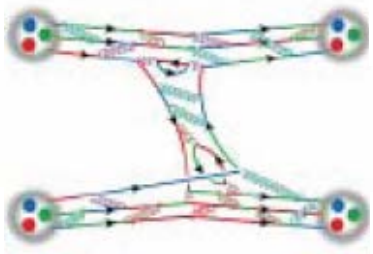
Vacuum Generation
➔ Ukita's talk

1st-principle lat calc.

Baryon Forces

ab-initio nuclear calc.



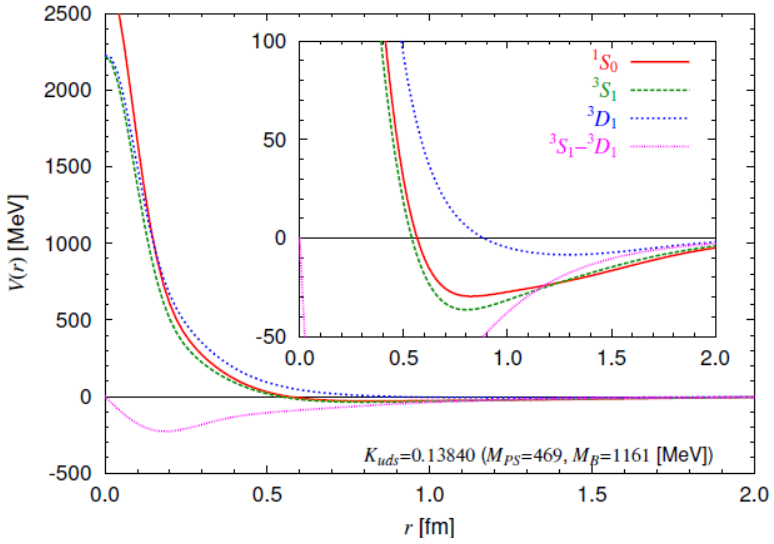


Lattice QCD predictions play a crucial role

(Another approach: Yamazaki's talk)

From LQCD to Nuclei / Neutron Star

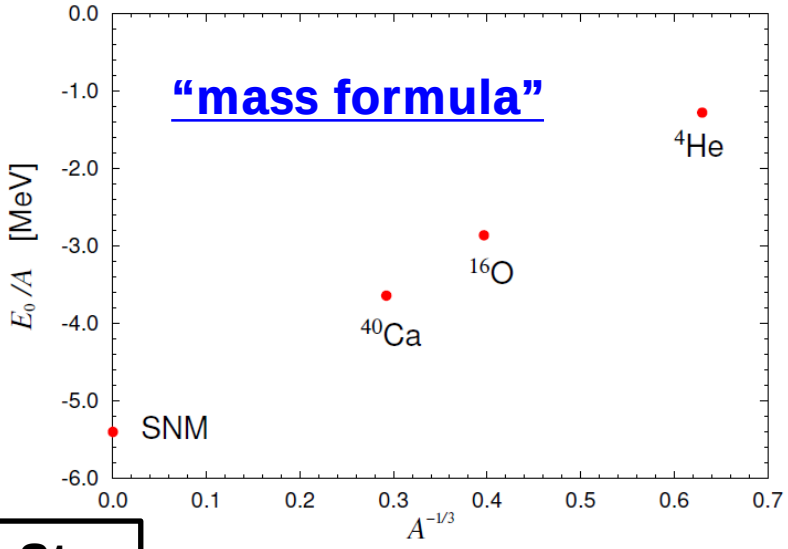
Lat NN forces



(SU(3), m(PS)=0.47GeV)

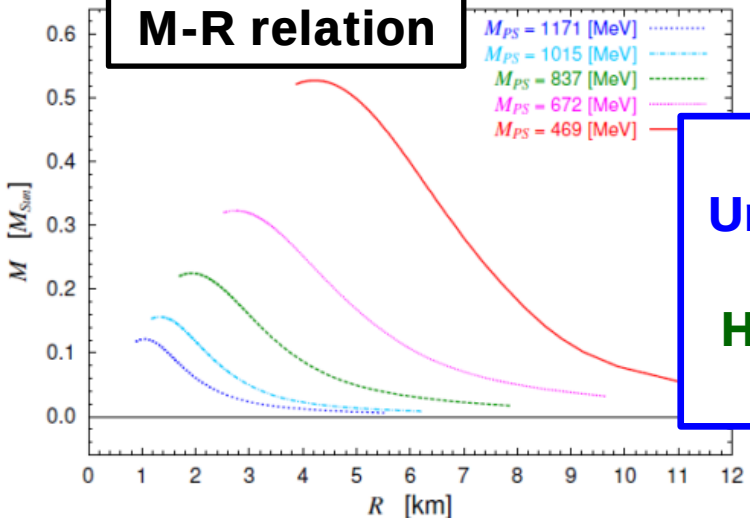
BHF

B.E. of medium-heavy nuclei



BHF & TOV

Neutron Star M-R relation

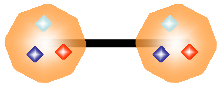


[LQCD]
Unphysical mass
[Missing]
Hyperon Forces
(& 3NF/3BF)

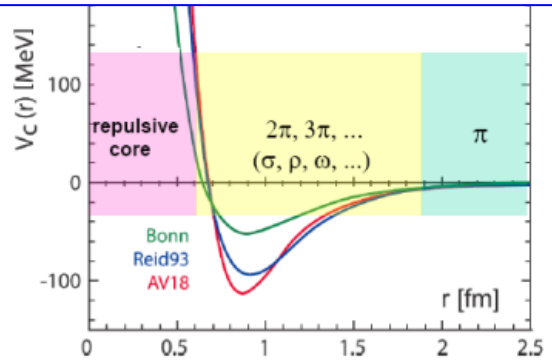
T.Inoue et al. (HAL Coll.) PRL111(2013)112503

T.Inoue et al. (HAL Coll.), PRC91(2015)011001

LQCD prediction for Hyperon Forces highly awaited

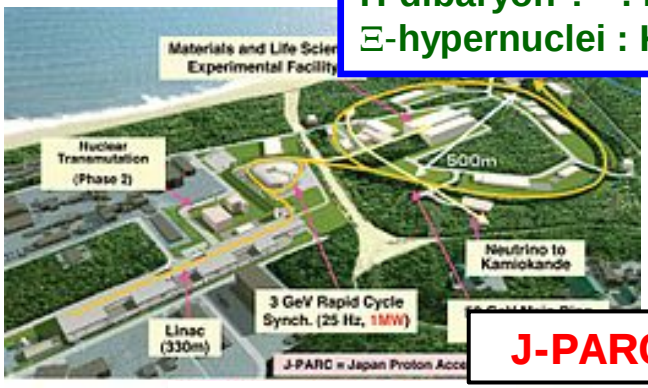


Nuclear Forces
➔ **Foundation of Nuclear Physics**



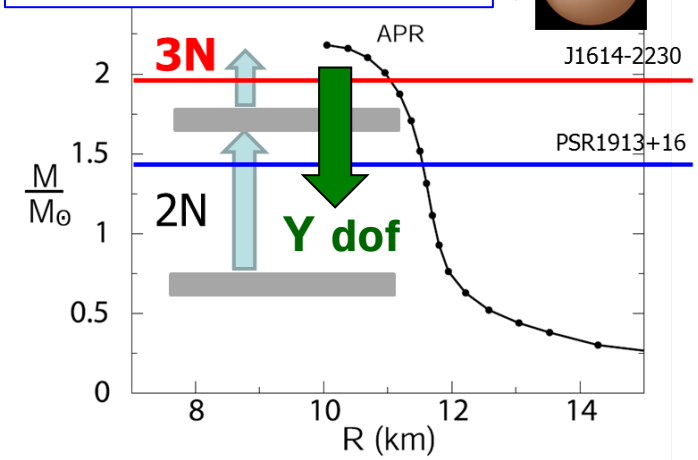
Hyperon Forces
➔ **Universal Picture for Baryon Forces**

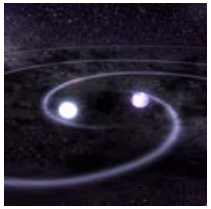
H-dibaryon ? : NAGARA-event (2001)
Ξ-hypernuclei : KISO-event (2014)



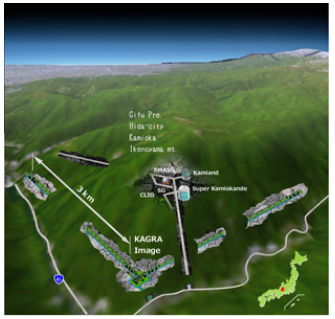
J-PARC (coming back !)

EoS of Dense Matter
➔ **Neutron Star**





ASTRO-H
(FY2015-)



KAGRA
(2018-)

Recent "Exponential" Improvements

- **Time-dependent HAL method** N.Ishii et al. (HAL QCD Coll.) PLB712(2012)437
  - Traditional Lat calc ➔ Ground State saturation is necessary
  - S/N gets worse for larger mass number A & light quark mass & $t \to \infty$

$$S/N \sim \exp[-\mathbf{A} \times (\mathbf{m_N} - \mathbf{3/2 m_\pi}) \times \mathbf{t}]$$

$$S/N \sim 10^{-42} \ !?$$

  - ➔ Extract the signal from excited states w/o G.S. saturation

- **Unified Contraction Algorithm (UCA)** TD, M.Endres, CPC184(2013)117
  - Enormous comput. cost by
    - Wick contraction (permutations) $\sim [(\frac{3}{2}A)!]^2$
    - color/spinor contractions $\sim 6^A \cdot 4^A$ or $6^A \cdot 2^A$
  - ➔ A novel method which unifies two contractions ➔ drastic speedup

$\times 192$ for ^{3}H/^{3}He, $\times 20736$ for ^{4}He, $\times 10^{11}$ for ^{8}Be

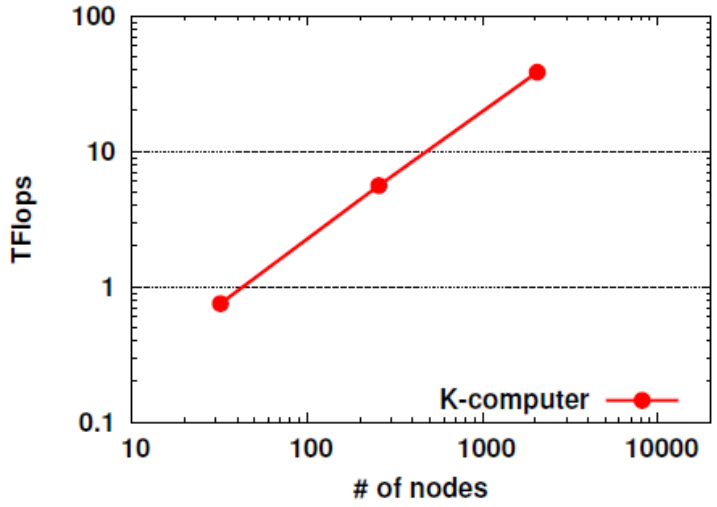
Simulation Code

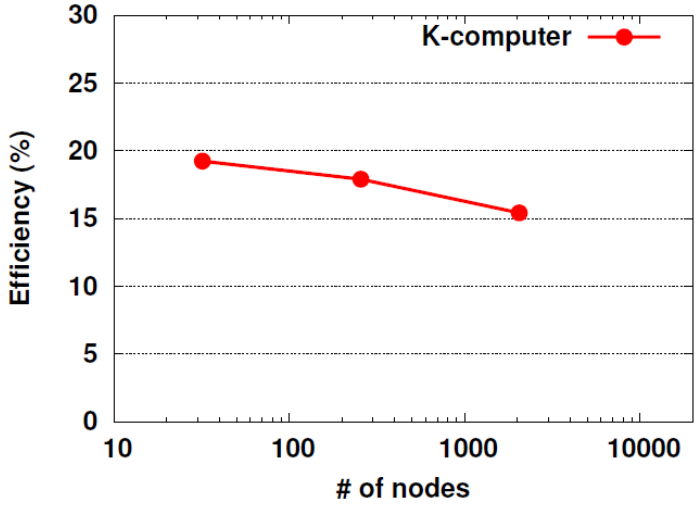
- **Major upgrade of Hadron-Force code (HF-code) in FY2013**
  - All 2-baryon-forces (octet-octet) in P=(+) channel calculated
    - Coupled channel, ~50 baryon-pairs in total, FFT calc included
  - Unified Contraction Algorithm, Better MPI/OMP, Cache tuning, FFT tuning, …

➔ O(10-100) speedup

- **Performance: K @ 2048 node : ~15%**
  - Solver (Ishikawa): ~25%
  - HF-code (w/o IO): ~15% (hot spot: 25-35%)

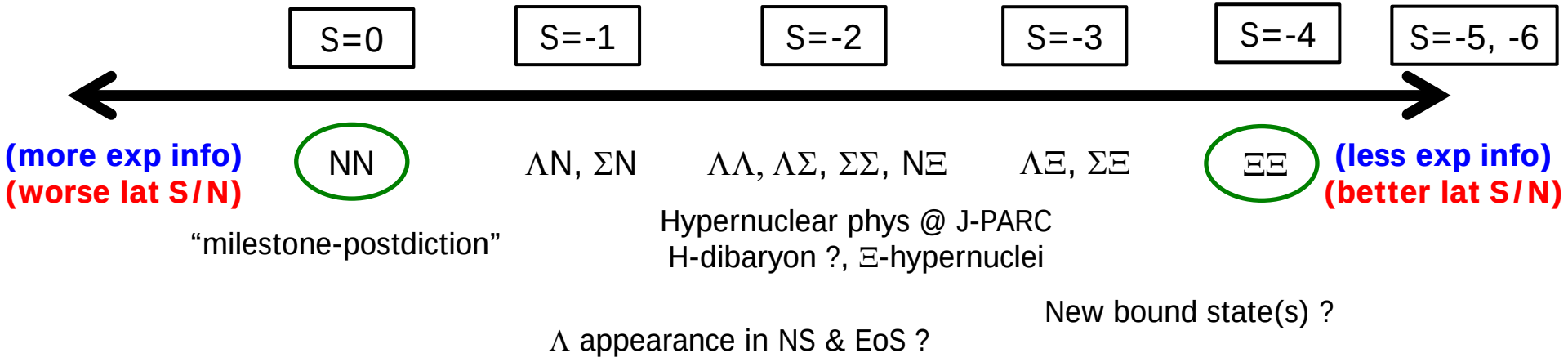
Weak scaling (total of HF-code, w/o IO)





Strategy at phys point w/ K-computer

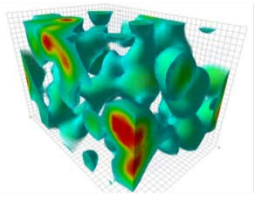
- Baryon-baryon interactions at (almost) physical point
  - Notoriously noisy on the lattice
  - Focus on the most important forces: central/tensor forces in P=(+) for all NN/YN/YY
    - Forces in P=(-) channel, LS/ALS, 3-body-forces ➔ future works

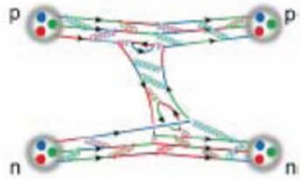


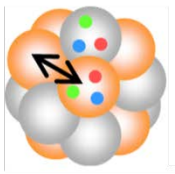
- ΞΞ interaction
  - $^1S_0$ ～ 27-plet : NN($^1S_0$) + SU(3) breaking
    - Bound or Unbound ?
    - Phen. Pot (Nijmegen), EFT (Haidenbauer et al.), etc.
    - HIC experiment ?
  - $^3S_1$-$^3D_1$ ～ 10-plet : Unique w/ hyperon DoF
    - Σ^- in neutron star : to be or not to be

Preliminary

Summary







- Baryon Interactions by 1st principle Lat calc
  - Bridging different worlds:
    Particle Physics / Nuclear Physics / Astrophysics
- Intriguing physics even at heavy quark masses
- The “First Light” results at the (almost) physical point
  - Promising in particular for hyperon forces
- On the K computer (& others)
  - “Massive calc” w/ “physically massive” quarks in FY2015