A0 Sub-course
(Nuclear Physics Theory)

Research Activities Highlights
(2012.4 — 2019.3)

Members

(Physics Department)

Kenji Fukushima (2013.10 —)

New Associate Professor (2020.4 —)

(External Members supervising grad. students)

Osamu Morimatsu (KEK)

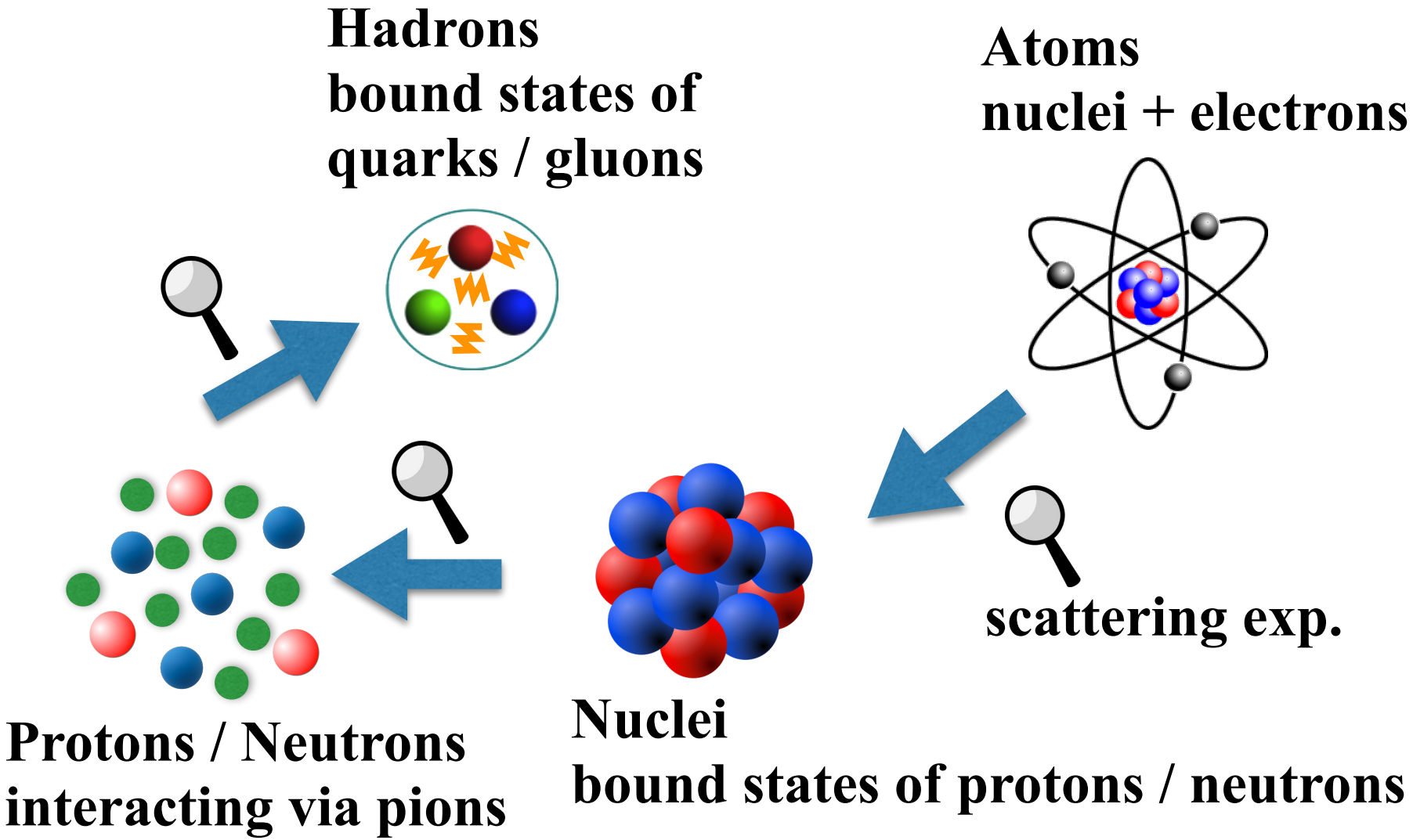
Haozhao Liang (RIKEN)

(Former Members leaving from Phys. Dept. after 2012.4)

Tetsuo Hatsuda (moved to RIKEN in 2015)

Takaharu Otsuka (retired in 2017)

Research Coverage



Research Coverage

Nucleons
Protons/Neutrons

Nuclei
~ Bound states
of nucleons

Hadrons
~ Bound states
of quarks

Partons
Quarks/Gluons

Resolution or
Energy Scale [MeV]

$\sim 10^1$ $\sim 10^2$ $\sim 10^3$

Research Coverage

Nucleons
Protons/Neutrons

Neutron Star

Partons
Quarks/Gluons

Hadrons
~ Bound states
of quarks

Nuclei
~ Bound states
of nucleons

QCD phase diagram

Exotic Hadrons with "strangeness"

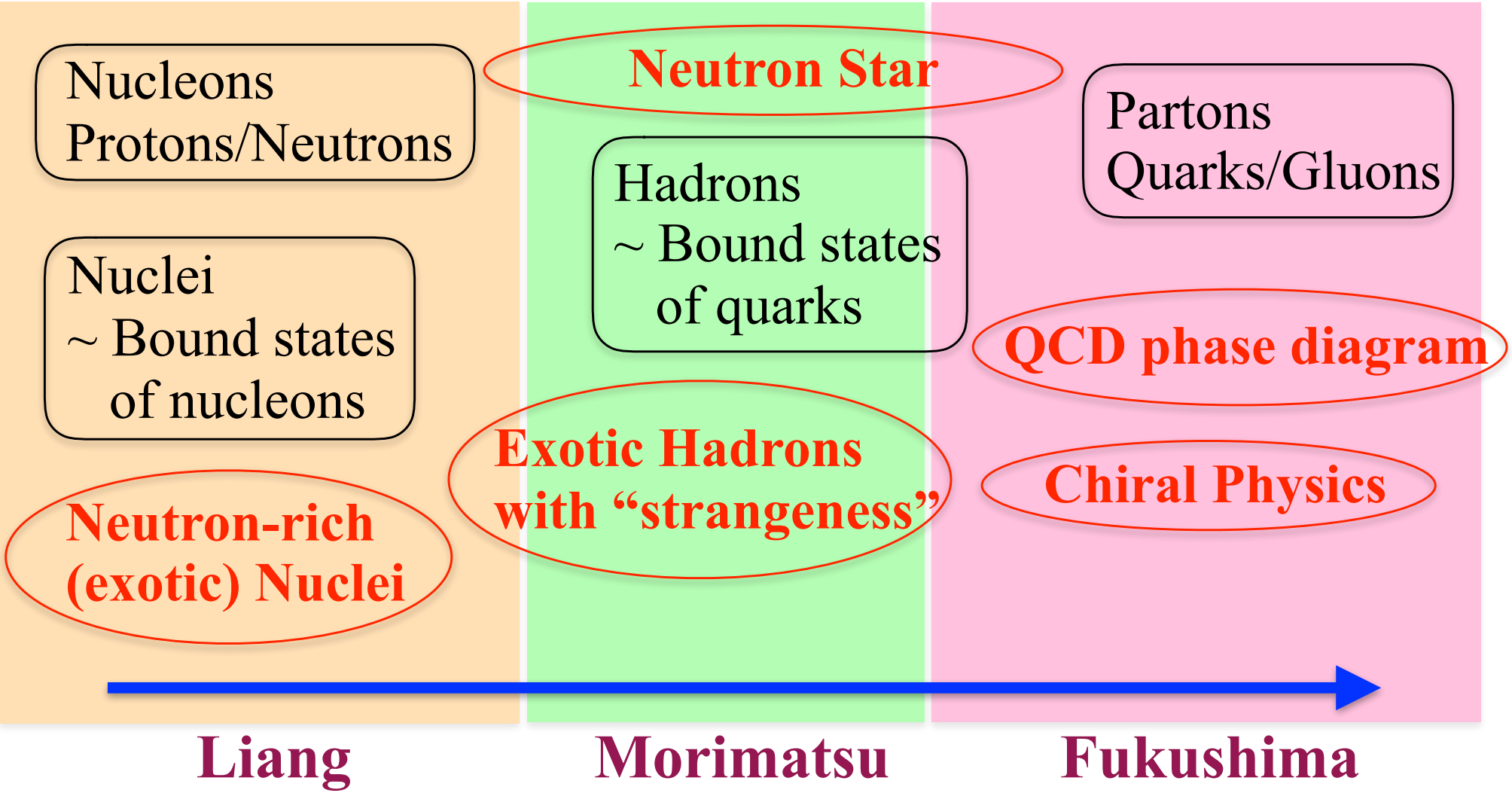
Chiral Physics

Neutron-rich (exotic) Nuclei

Resolution or Energy Scale [MeV]

$\sim 10^1$ $\sim 10^2$ $\sim 10^3$

Research Coverage



Ultimate Question in Nuclear Theory

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visible

What is the origin of matter ?

— how matter is formed ?
(bound state problems)

— how matter gets mass ?
("vacuum" structures)

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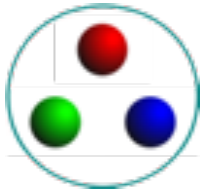


Quark/Gluon Confinement

— how matter gets mass ?
("vacuum" structures)

Chiral Symmetry Breaking

Ultimate Question in Nuclear Theory

Quantum Chromodynamics (QCD)

$$\mathcal{L} = -\frac{1}{2}\mathrm{tr}F_{\mu\nu}F^{\mu\nu} + \bar{\psi}[i\partial_\mu\gamma^\mu - m]\psi$$

More than 90% of matter constituents and masses can be "derived" from QCD… in principle…

Need to combine various probes to attack QCD

Examples of Approaches

- **Models (low-energy d.o.f. / symmetry)**
  - □ Shell model / Cluster model
  - □ Chiral Effective Theories (based on chiral sym.)
- **Phenomenology (constraints from exp. data)**
  - □ Neutron Star EoS
  - □ Nuclear Scattering Experiments
- **QCD-based Calc. with Hard Scales**
  - □ High-T / High-density / Strong-B / Fast rotations
- **Quantum Anomalies**
  - □ Chiral anomaly ~ non-perturbative consequences

Close contacts to cond-mat, elementary part., astrophysics

Kenji Fukushima (2012.4 — 2019.3)

43 Publications (individual)

PRL 8 / PRA 1 / PRB 1 / PRC 2 / PRD 16
PLB 4 / NPA 3 / AoP 2
JHEP 2
NJP 1
PTEP 2
AstroJ 1

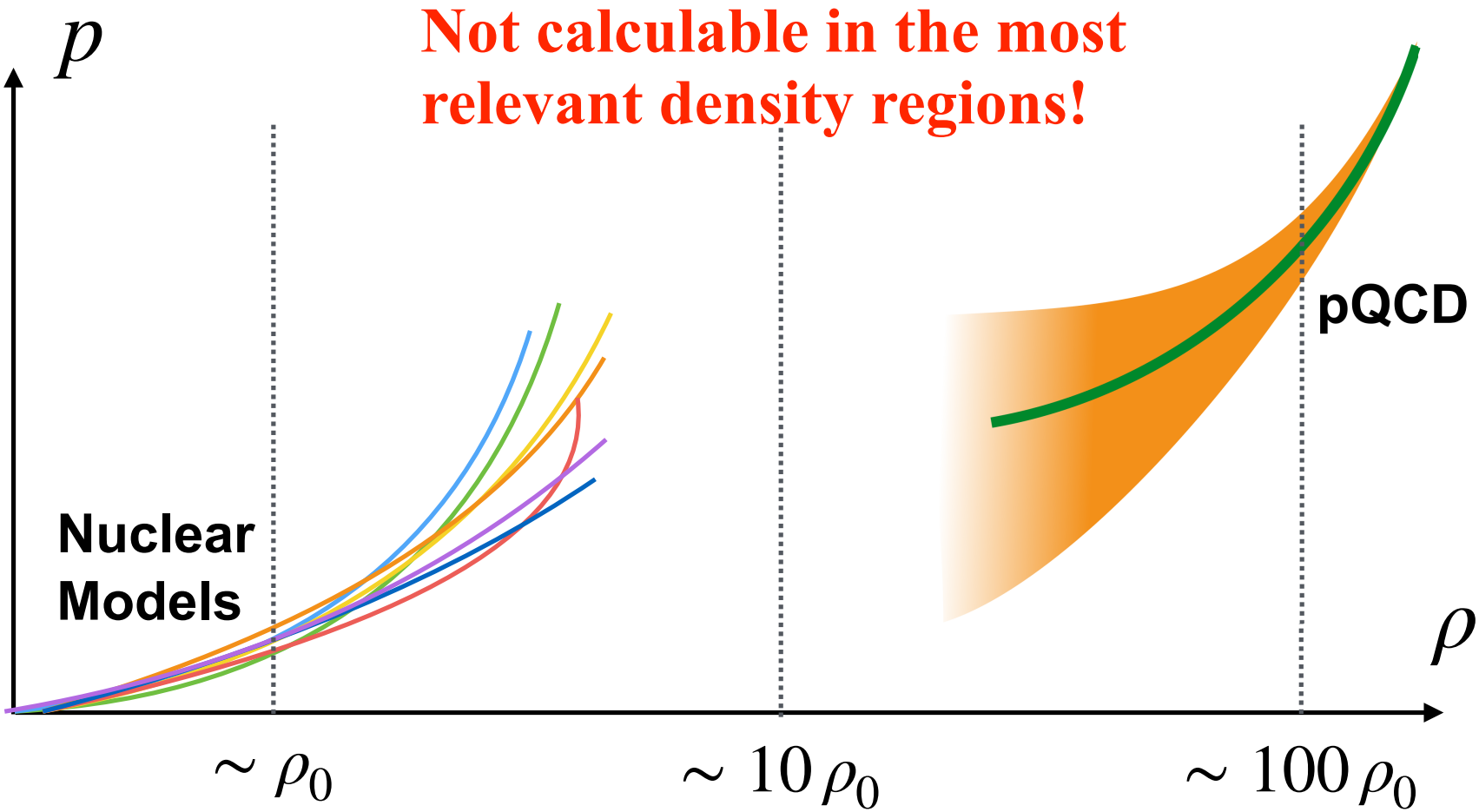
+ 5 invited review articles

+ group activities since 2014 (not coauthored with KF)

PRL 1 / PRA 1 / PRB 1 / PRC 3 / PRD 9
PLB 3 / NPA 1 / NPB 2
EPJ 1 / PTEP 5 / QG 1
A.Astro 1

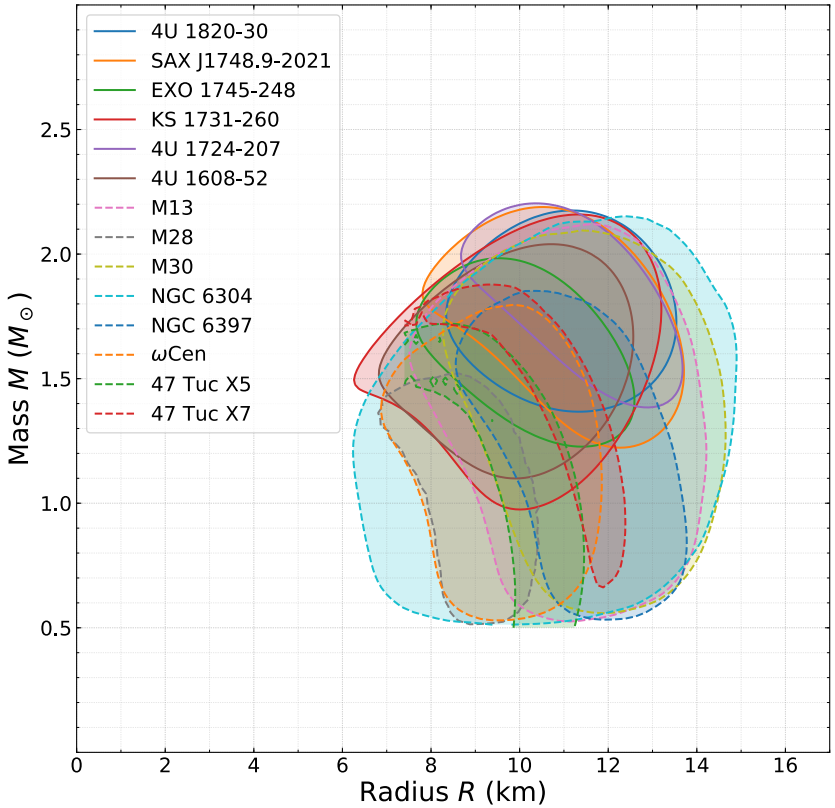
Neutron Star Physics

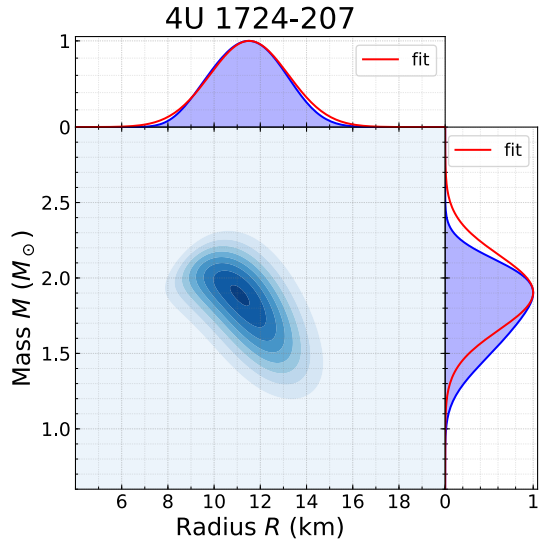
Equation of State is needed for the NS structures but…

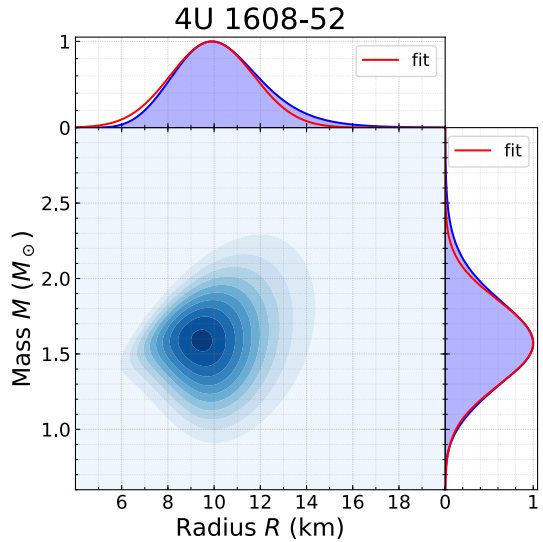


Neutron Star Physics

Neutron Star Observations
Mass ~ Radius Distributions





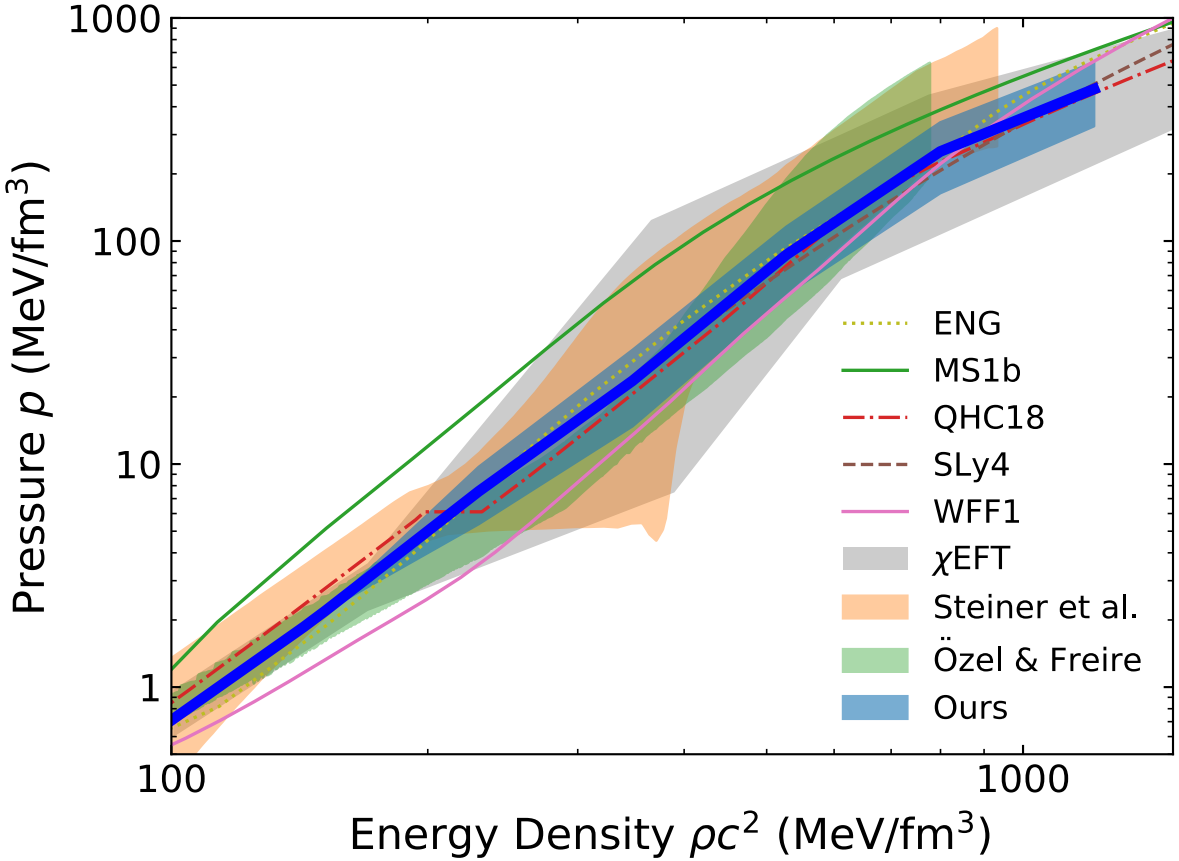


How to constrain EoS ?

Neutron Star Physics

Fujimoto-Fukushima-Murase (2019)

Solving the inversion problem with machine learning

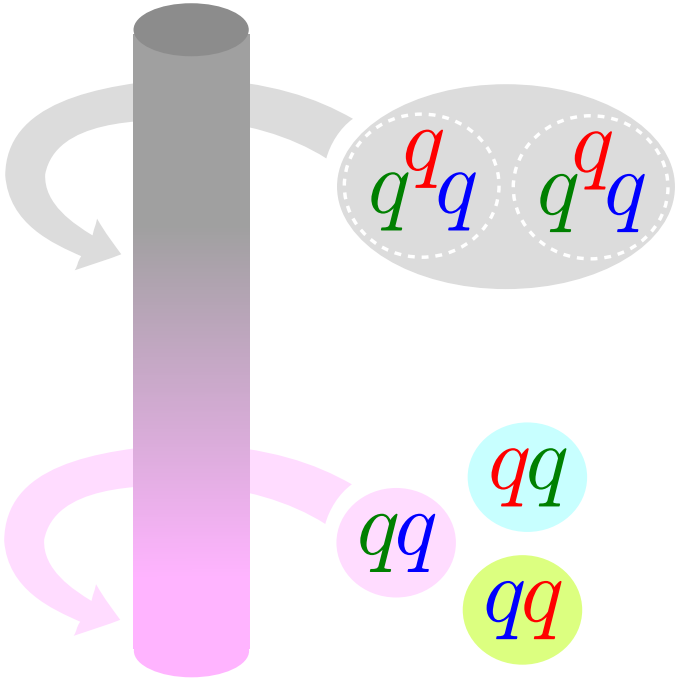


found a nonmonotonic structure in the speed of the sound
(a hint to quark matter)

Vortex in Continuous Transition

Neutron star cores ~ Superfluids ~ Vortices

Alford-Baym-Fukushima-
-Hatsuda-Tachibana (2018)



Hadronic Matter
(Nuclear Superfluid)

Could be continuously changed
(from the symmetry point of view)

Quark Matter
(Diquark Superfluid)

Vortex in Continuous Transition

Neutron star cores ~ Superfluids ~ Vortices

Alford-Baym-Fukushima-
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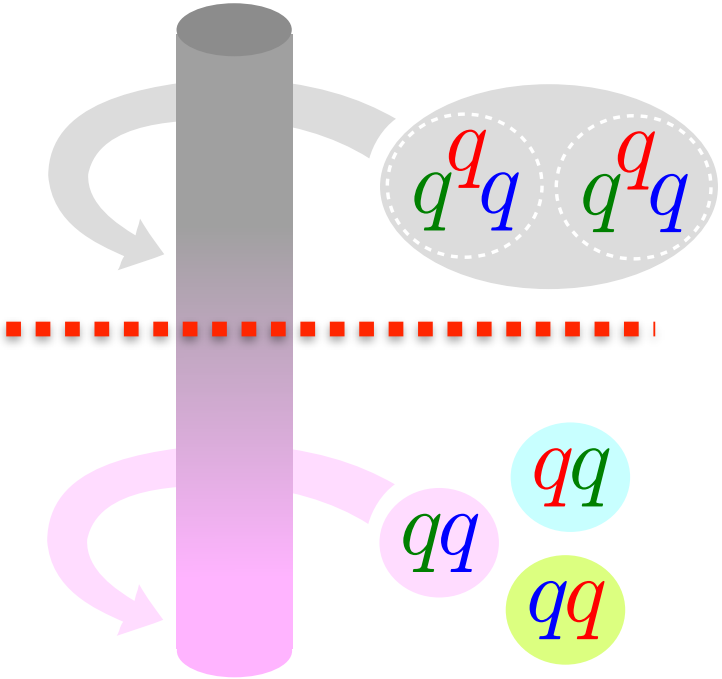

Topological phase transition?
Follow-ups using mathematical refinements (still controversial)

Internationalization

[Students / Postdocs]

China, USA, Chile, Croatia, Italy (coming soon)

→ Staff at USTC → Staff at U.of Zagreb

[Visitors]

G. Baym (Illinois), W. Weise (TUM), F. Gelis (Saclay)
J. Pawlowski (Heidelberg), J. Liao (Indiana), Y. Schroeder (Chile), etc

World-leading researchers have visited us constantly

[Long-term Visitings]

EMMI Professor at Heidelberg U. (1-2 months in 2016/2019)

Fudan Fellow at Fudan U. (1 month in 2018/2019)

Guest Visitor at Saclay (2 weeks in 2017) etc etc…

Expanding collaborations exchanging students / postdocs

Summary

Research Achievements

- □ Working on cutting-edge subjects
- □ One of the most productive groups in the world
- □ Individual activities by youngsters encouraged
- □ Interdisciplinary (in PRA/PRB/AstroJ…)

International Visibility

- □ Long-term visiting invitations
- □ International students / postdocs / visitors
- □ Organizing international conferences (LOC / IAC)
- □ Grant evaluations for various countries