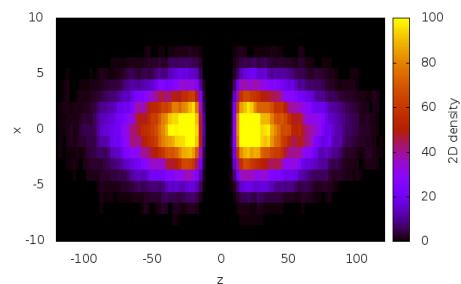
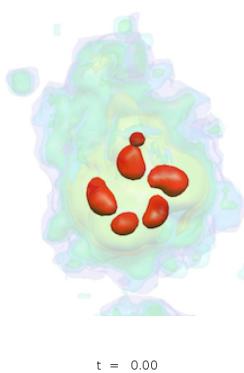
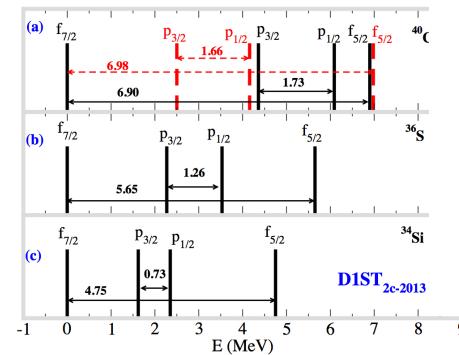
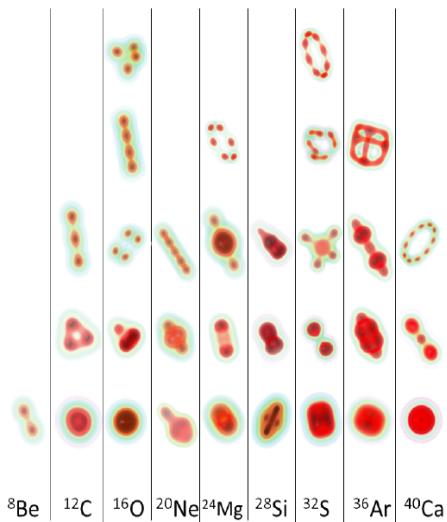
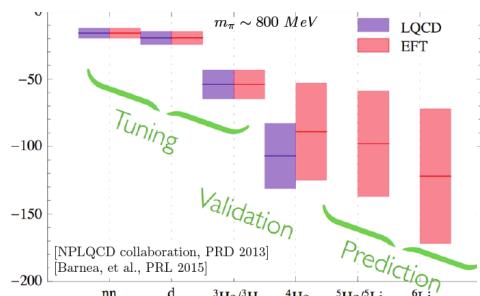


12 June 2017

Highlights of the theory group (low energy nuclear physics branch)

Denis Lacroix (IPN Orsay)



Low energy branch of IPN Theory group

Some general information

Members of the (sub)-group

8 permanent CNRS

J. Carbonell (CNRS-01)
M. Grasso (CNRS-01)
G. Hupin (CNRS-01, sept 2017)
D. Lacroix (CNRS-01)
M. Lassaut (CNRS-02)
P. Napolitani (CNRS-01)
M. Urban (CNRS-02)
U. van Kolck (CNRS-01)

1 permanent University

Elias Khan (Univ.)

3 Emeritus

N. Rowley (CNRS-01)
P. Schuck (CNRS-02)
N. Van Giai (CNRS-02)

4 postdoc

J. Bonnard
D. Regnier
N. Yamanaka
J. Yang

6 PhD

A. Boulet
B. R. Lasseri
P. Marevic
J. Ripoche
M. Sanchez
O. Vasseur

General Introduction

From quark and hadrons to nuclei

Degrees of Freedom



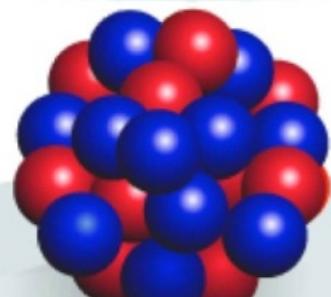
quarks, gluons



constituent quarks



baryons, mesons



protons, neutrons

From quarks to hadrons/mesons

From hadrons to nucleons

From nucleons to nuclei

- Chiral EFT
- Effective nucleon-nucleon interaction
- Nuclear structure and reactions
- Interdisciplinary: theory of complex interacting systems
- Interdisciplinary test of Fundamental symmetries
- Interdisciplinary research in astrophysics

Physics beyond the standard model at the nuclei scales

Matter-antimatter asymmetry → T violation beyond Standard Model

Standard Model + Beyond SM

dimension-4
interactionsmostly dimension-6
interactions

- CKM phase
- QCD vacuum angle
- quark electric dipole moments
- quark color-EDMs
- gluon color-EDM
- 4-quark contact interactions

e.g. quark color-EDMs: $d_h + d_t \simeq 2d_d \gg d_n \sim d_p$

Engel, Ramsey-Musolf + van Kolck '13; Mereghetti + van Kolck '15 helion triton deuteron neutron proton



T-violating dynamics of nucleons and pions leads to nucleon and light-nuclear Elec. Dip. Moments

proposed program for storage-ring measurements (KAIST, COSY)
could identify dominant source(s) of T violation in quark/gluon sector

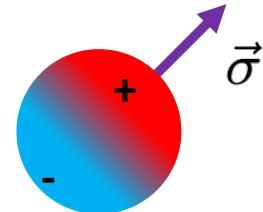
EDM: $\langle \vec{d} \rangle = \langle \psi | e \vec{r} | \psi \rangle$

EDM is a sensitive probe of BSM CP violation,
required to explain matter abundance of the Universe

Use Gaussian expansion method to solve few-body problem

⇒ Evaluation of EDM of 2H, 3H, 3He, 6Li, 7Li, 9Be, 13C completed

N. Yamanaka, "Review of the electric dipole moment of light nuclei", Int.J.Mod.Phys. E26 (2017) 1730002.



$$\mathcal{L}_{\text{QCD}} \rightarrow \mathcal{L}_{\text{EFT}}$$

Goal

QCD → Nuclear EFT → “*ab initio*” methods → nuclear properties

For now

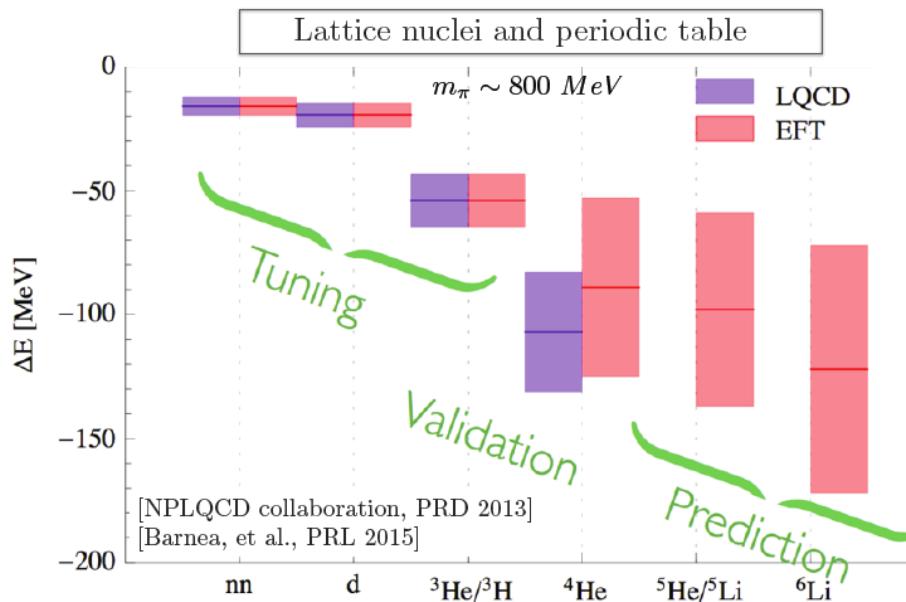
Lattice QCD at unphysical quark masses

Pionless EFT at LO

- Effective-Interaction Hyperspherical Harmonics
- Refined Resonating Group
- Auxiliary Field Diffusion MC

- nucleon-deuteron scattering
- p-shell medium mass binding energies

Example

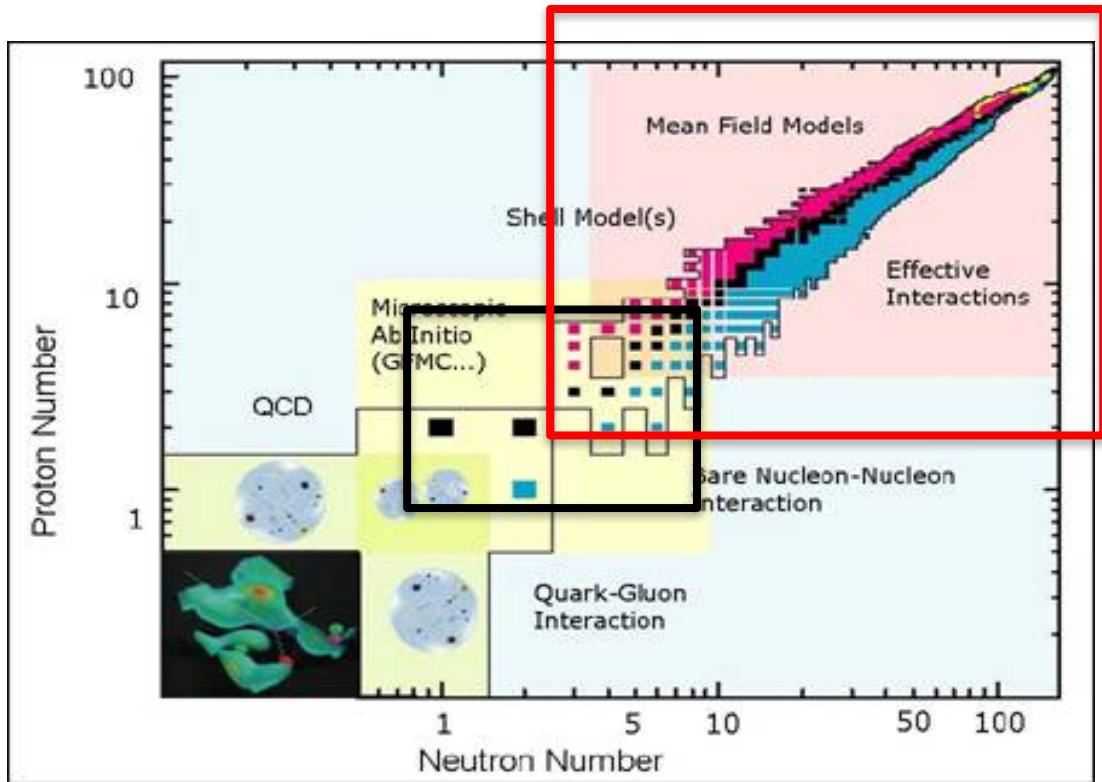


Barnea, Contessi, Gazit, Pederiva + v.K. '15
 Kirscher, Barnea, Gazit, Pederiva + v.K. '15
 Contessi, Kirscher, Lovato, Pederiva, Roggero + v.K.'17

U. van Kolck, B. Bazak
 M. Sanchez

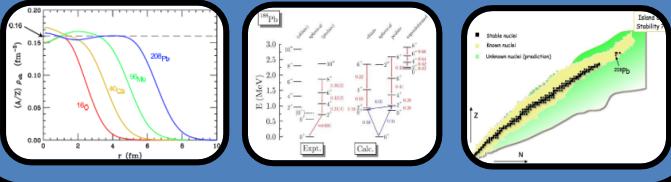
From Hadrons to nuclei: Energy Density Functional

Unifying nuclear structure and dynamics

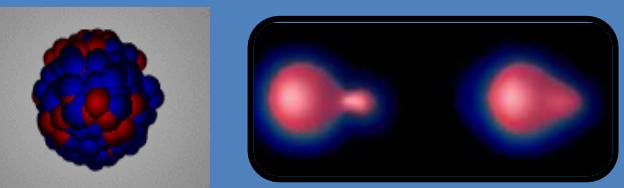


EDF sector

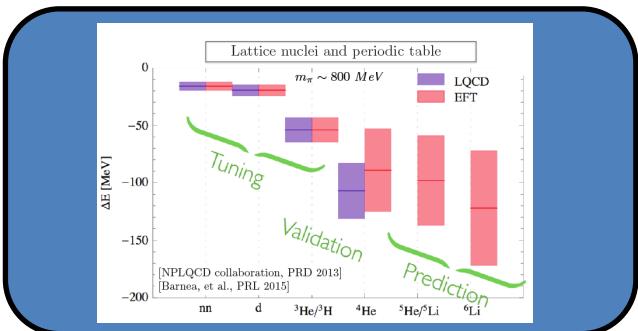
GROUND STATE-STRUCTURE OF THE ATOMIC NUCLEUS



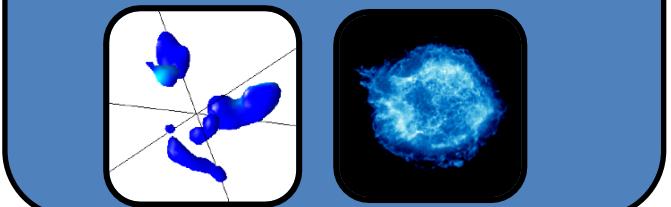
SMALL AND LARGE AMPLITUDE DYNAMICS



EFT sector

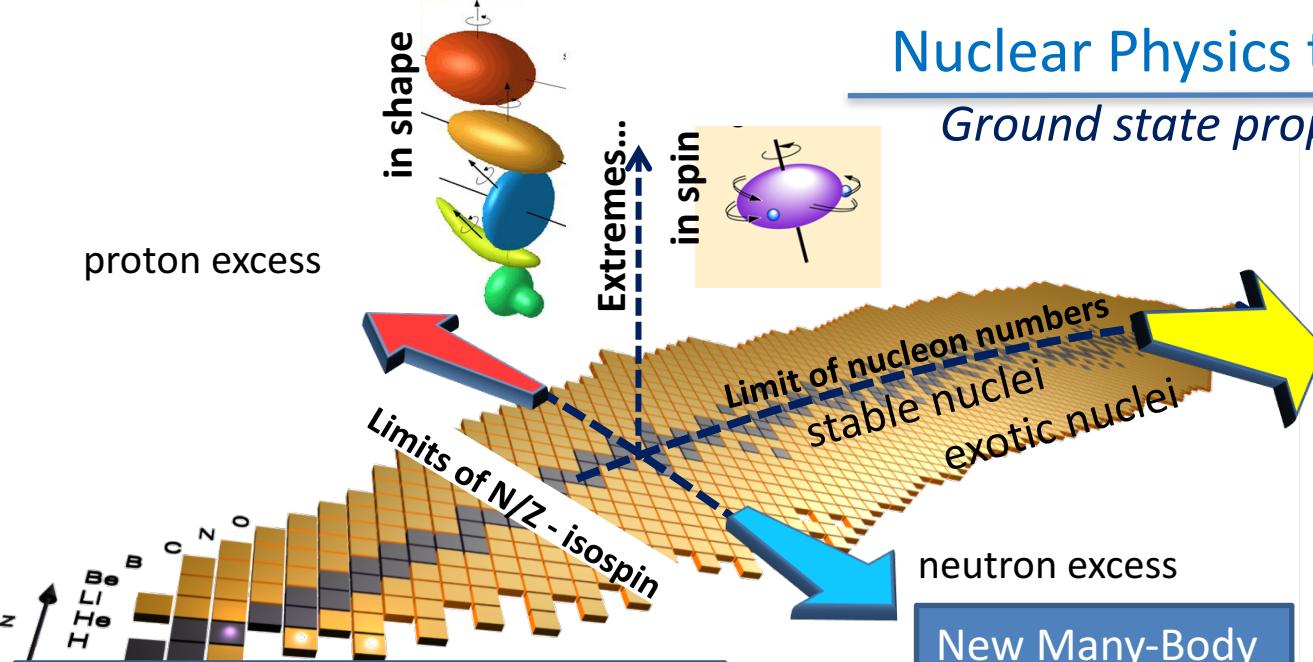


Nuclear Thermodynamic
(from finite or infinite systems)



Nuclear Physics today

Ground state properties

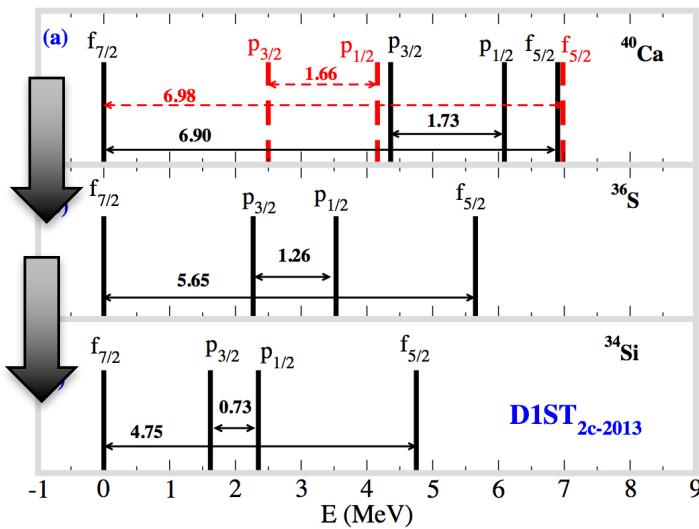


New properties of N-N interaction
And shell effects

Tensor/spin-orbit part of
N-N interaction, 3-body int...

Tensor induced
Neutron gap

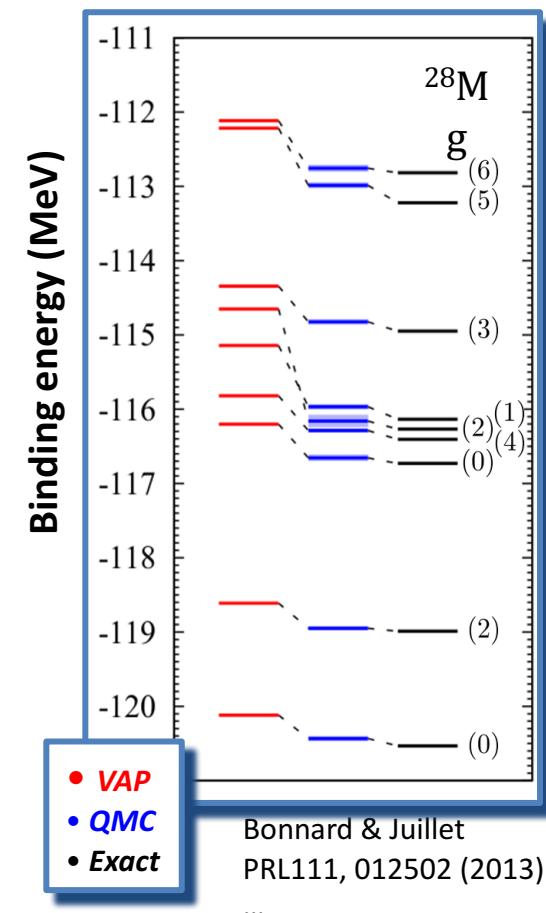
Spin-orbit
induced
Neutron gap



New Many-Body
techniques

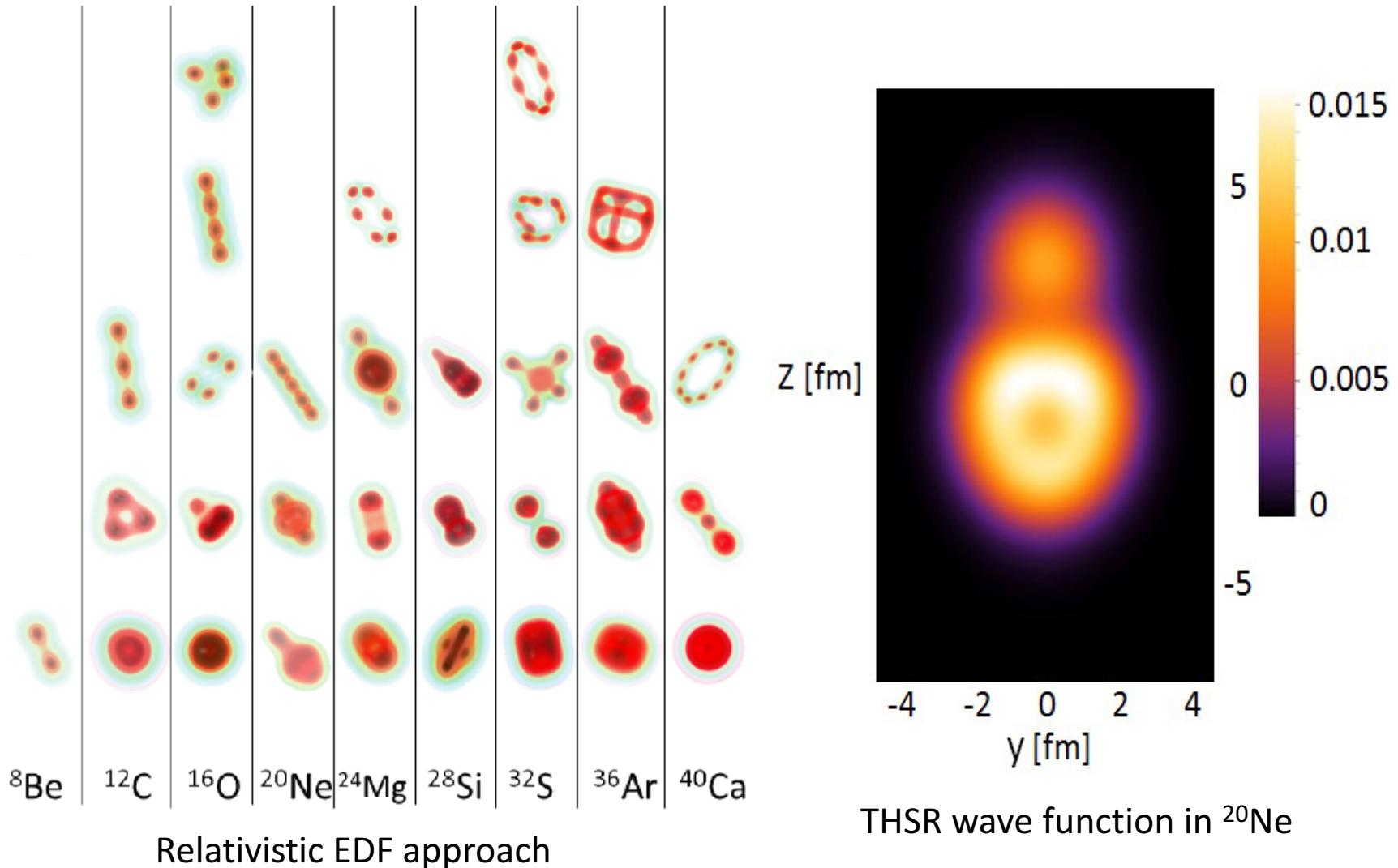
Monte-Carlo methods,
Extension of RPA,
Projection techniques

Nuclear density
profiles and shapes
New magic numbers



Excited states: new views on clusterisation

In relativistic and non-relativistic methods(E. Khan, P. Schuck,R. Lasseri, P. Marevic)

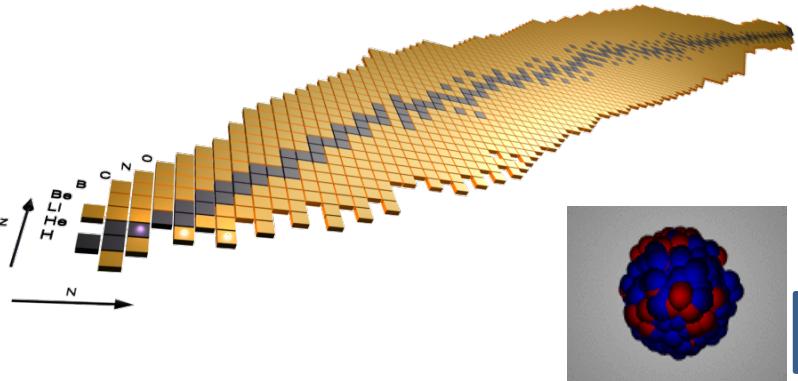


J.-P. Ebran, E. Khan, T. Niksic, D. Vretenar, Nature 487 (2012) 341, Phys. Rev. C 87 (2013) 044307, Phys. Rev. C 89 (2014) 031303(R), Phys. Rev. C 90 (2014) 054329.

Bo Zhou et al., Phys. Rev. C 89(2014)034319.

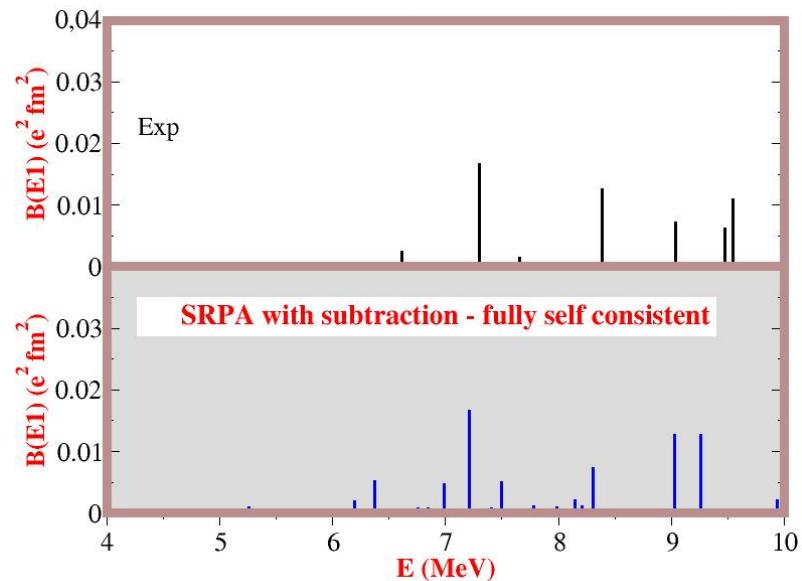
Chang Xu et al, Phys. Rev. C in preparation

From static to small amplitude dynamics



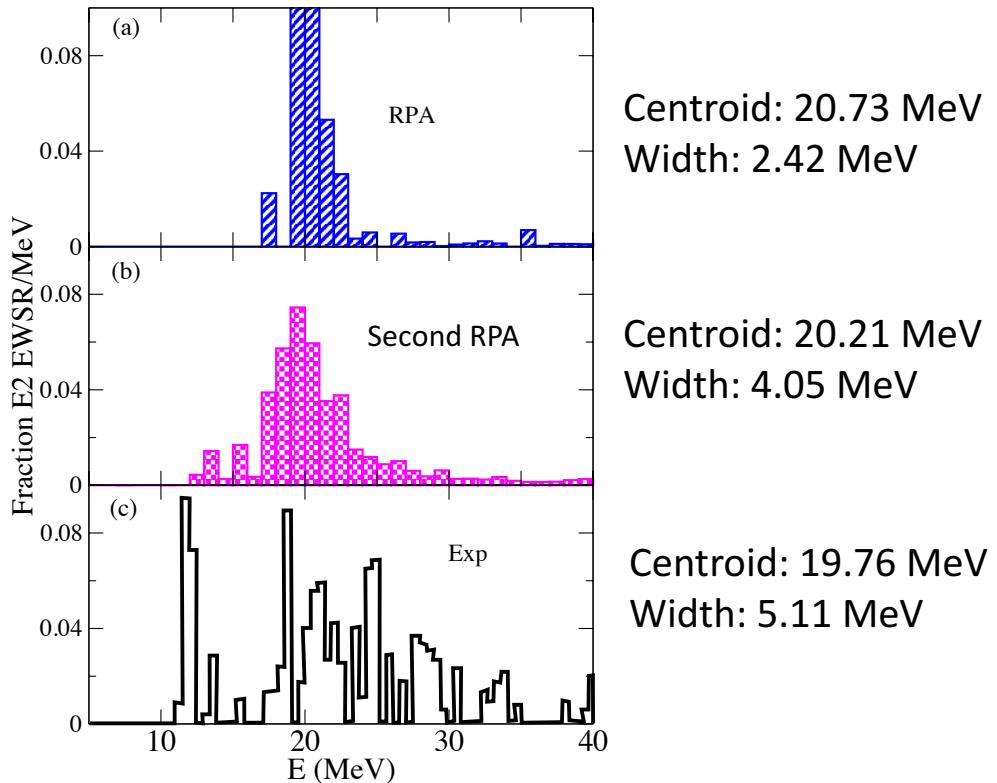
Nuclear response function beyond the RPA

Low-lying modes



Gambacurta, Grasso (2017)

Collective high-lying modes

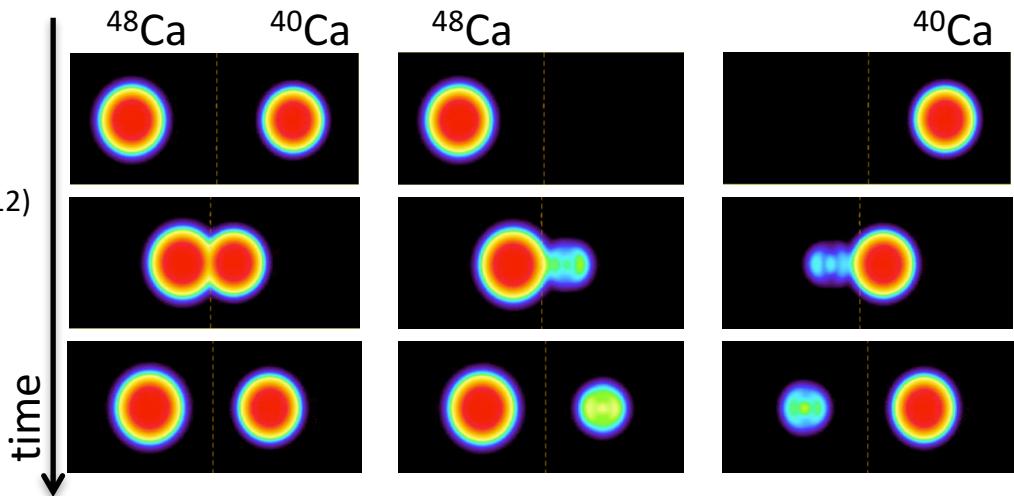


Gambacurta, Grasso, Engel, PRC 92, 034303 (2015)
Vasseur et al (2017)

Transfer Reaction with pairing

Scamps, Lacroix, Phys. Rev. C 87, 014605 (2013)

Scamps, Lacroix, Bertsch, Washiyama, Phys. Rev. C 85 (2012)



Microscopic description of the fission of superfluid nuclei

Time (fm/c)

1000

2000

3000

4000

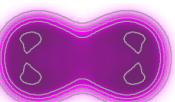
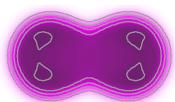
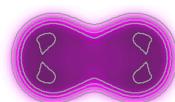
5000

Fast fission

5300

5500

5600



Extremely slow pairing/dissipation dominated motion

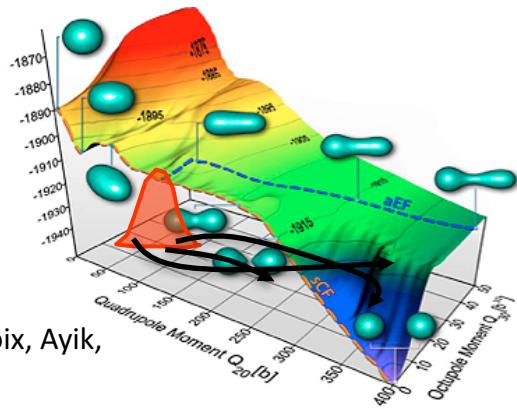
Coulomb boost

Scamps Simenel, Lacroix, PRC 92 (2015)

Tanimura, Lacroix, Scamps, PRC 92 (2015)

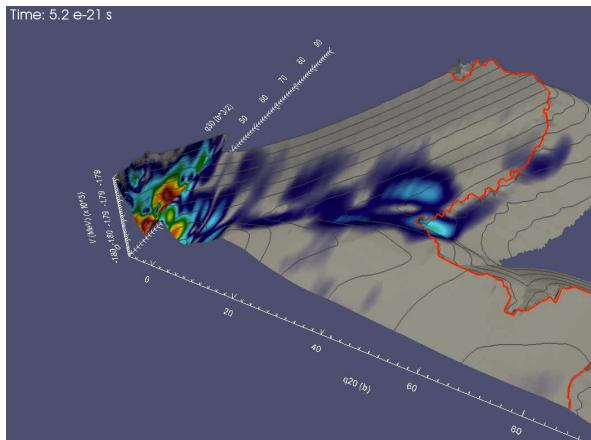
Quantum approaches

Phase-space methods



Tanimura, Lacroix, Ayik,
PRL (2017)

Quantum mechanical approach



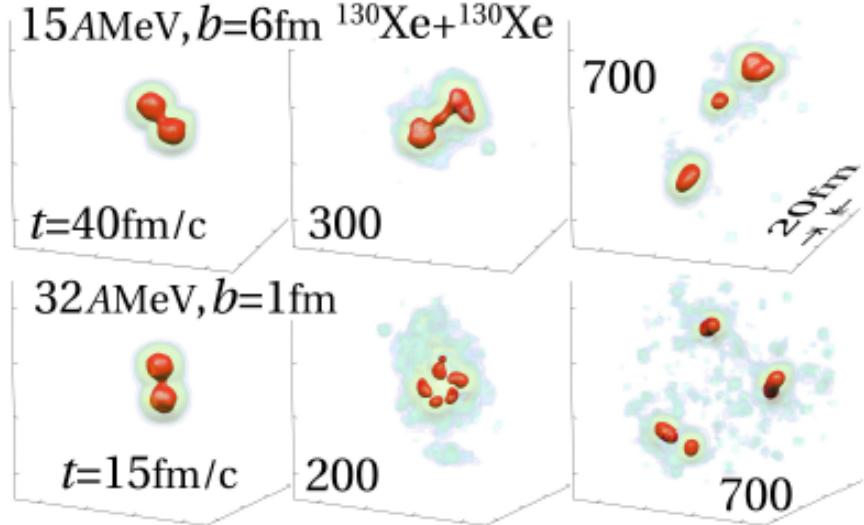
D. Regnier, et al , PRC93, 054611 (2016)

Semi-classical approaches

Strong fluctuations at Fermi energy

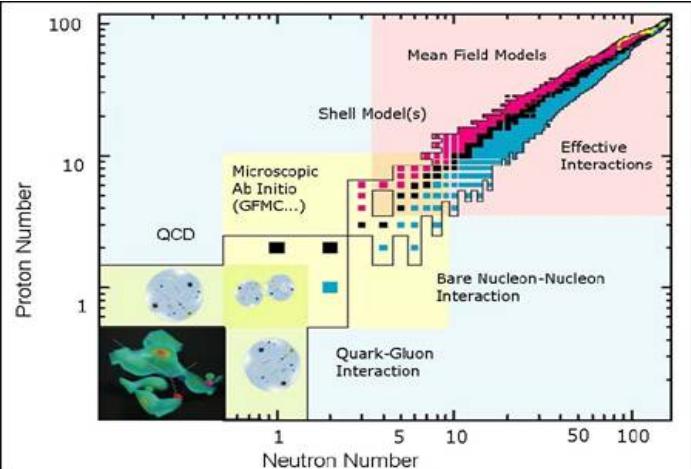
- driven by **violent perturbations** in *HI dissipative collisions*
→ mechanical instability + mean-field resilience competing:

15AMeV, $b=6\text{fm}$ $^{130}\text{Xe}+^{130}\text{Xe}$



BLOB model: from Neck to spinodal
P.NAPOLITANI AND M.COLONNA, PLB726 (2013) 382

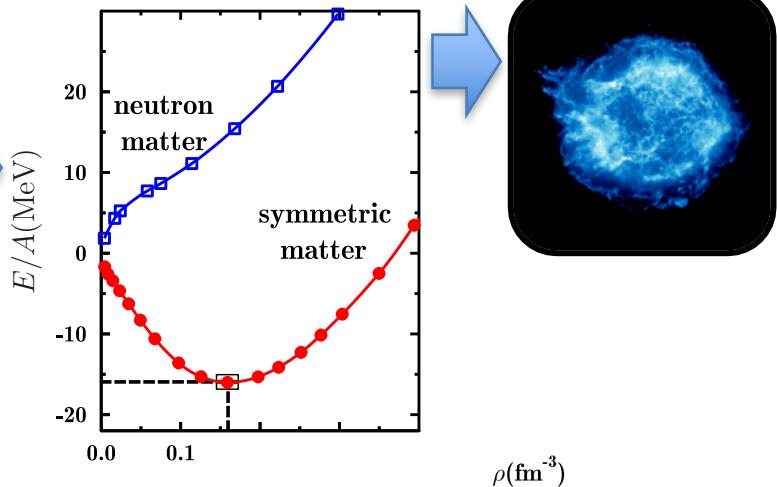
From finite to infinite systems towards nuclear astrophysics



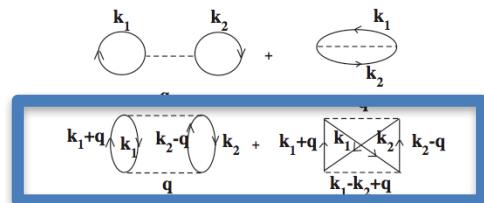
Toward global non-empirical approach to the
Equation of state of neutron and nuclear matter

NN
interaction

Empirical Energy Density Functional



Many-body strategy with contact interaction
(low density guided)



Regularization,
Renormalizability,
Power-counting, ...

FIG. 1. First- and second-order diagrams for the total energy in uniform matter. Labels refer to momentum states.

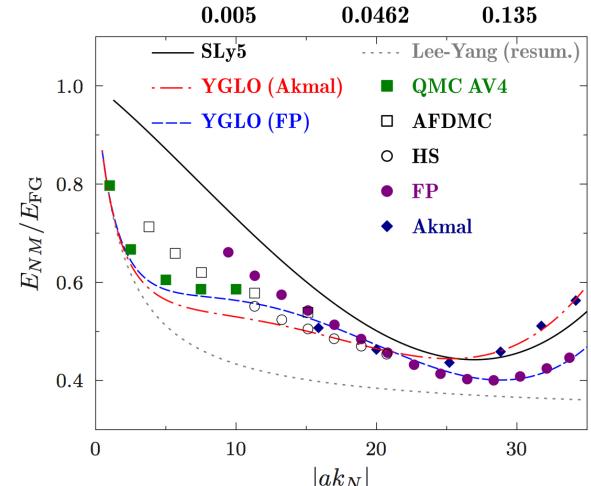
Yang, Grasso, et al, PRC 94, (2016)

Yang, Grasso, van Kolck et al, PRC 95 (2017)

New generation of functional theory
Beyond mean-field

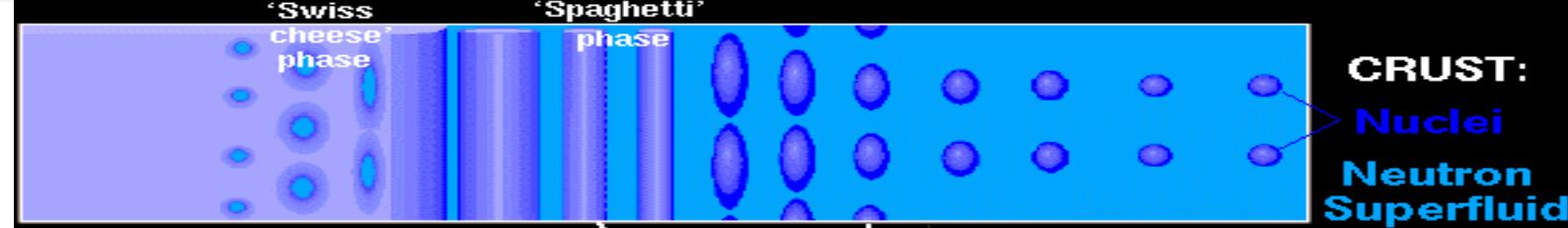
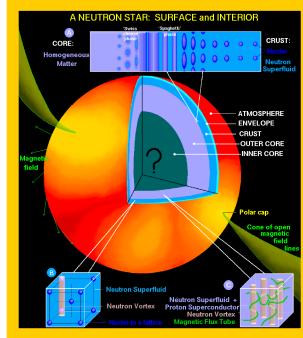


Contact with low
energy constant
by resuming diagram



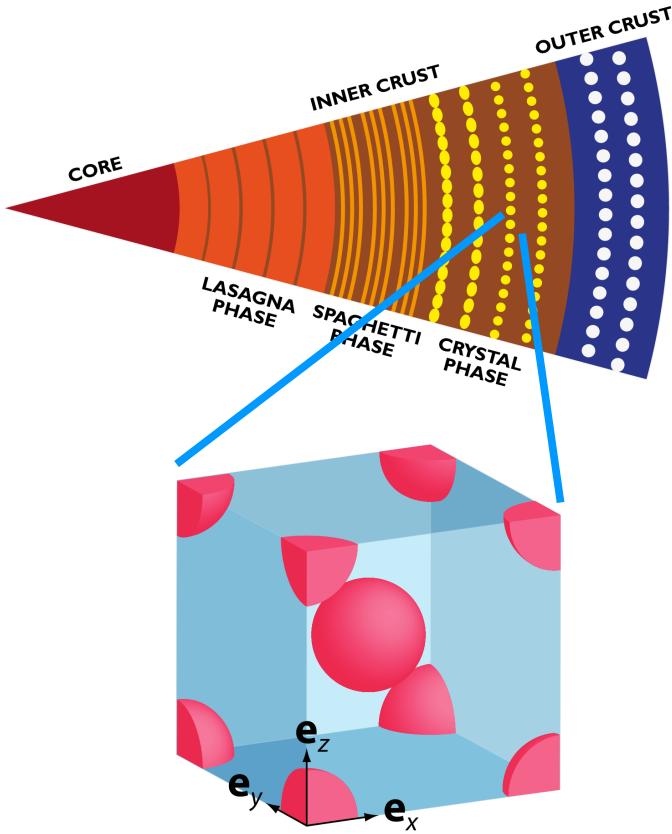
Yang, Grasso, Lacroix, Boulet, PRC
(2016), PRA(2016), PRC(2017)

Study of static and dynamical properties in neutrons stars



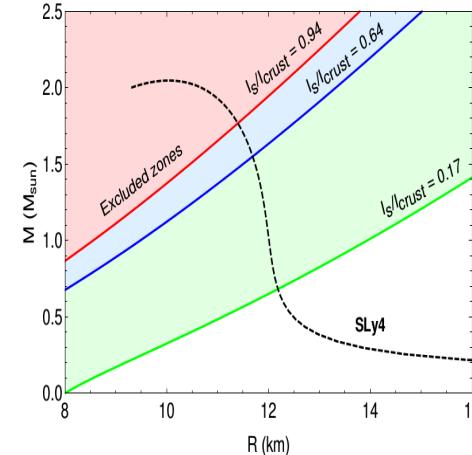
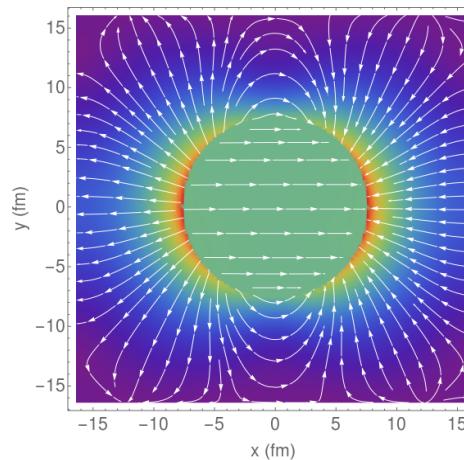
Formation of clusters in the crust of NS

J.-P. Ebran, Khan, et al Nature (2012)



Superfluid hydrodynamics in the neutron star crust

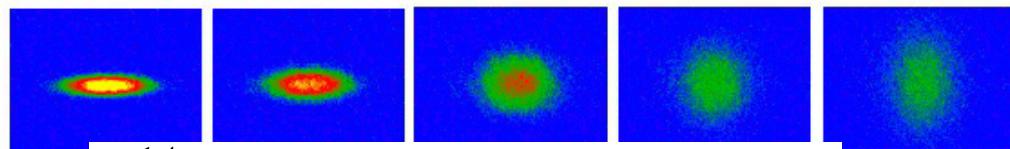
- + interplay between astrophysics and nuclear physics:
 - + equation of state, pairing (superfluidity)
 - + inner crust: crystal lattice of 'nuclei' (clusters)
 - + in a superfluid gas of unbound neutrons
 - + study relative motion between gas and clusters within superfluid hydrodynamics
 - + superfluid density higher than thought previously
 - + → can explain observed glitches of Vela pulsar



Solution of the Boltzmann equation for ultracold atoms

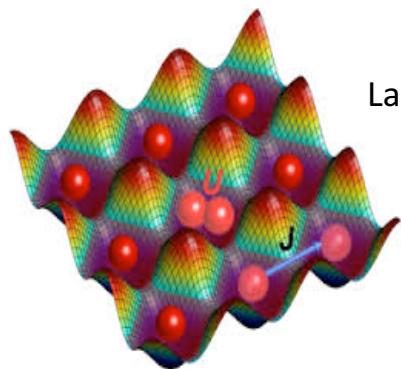
- expansion of from an anisotropic trap

Urban et al, PRA (2015)

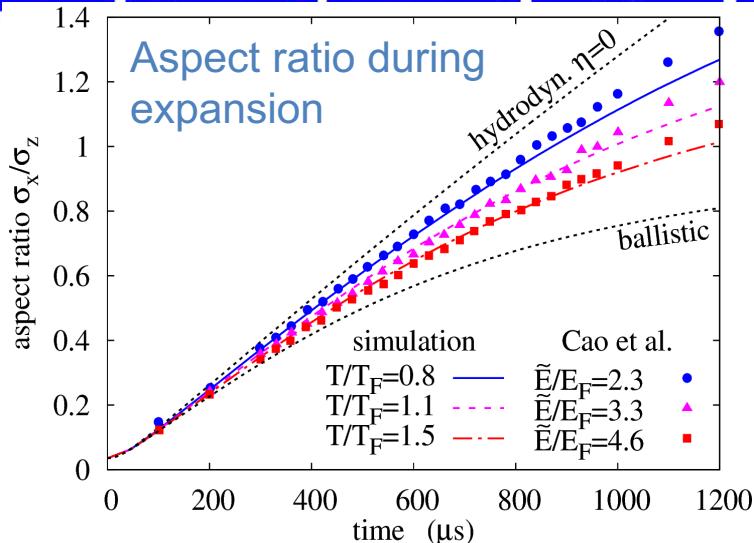


Fast quantum dynamics after a quench

Electron dyn. on Lattices



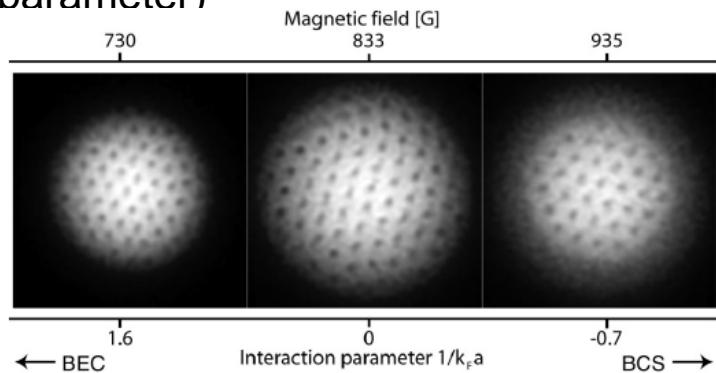
Lacroix et al, PRB90 (2014)



→ excellent agreement with data (no free parameter)

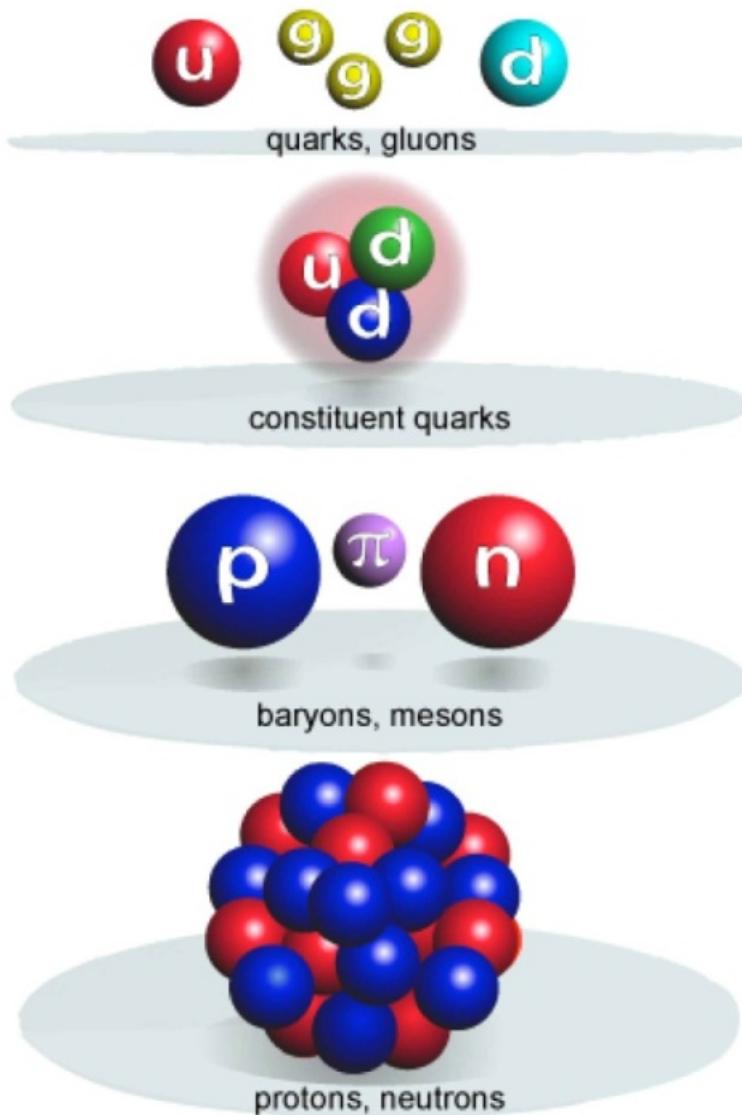
Properties of superfluid systems: from BEC to BCS

Schuck, Urban et al, PRB90 (2014)



The BCS-BEC crossover: From ultra-cold Fermi gases to nuclear systems

Degrees of Freedom



From quarks to hadrons/mesons

From hadrons to nucleons

From nucleons to nuclei

From quarks hadrons and nuclei to other strongly interacting systems