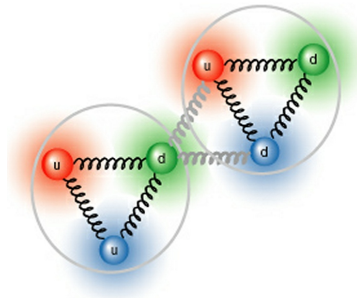
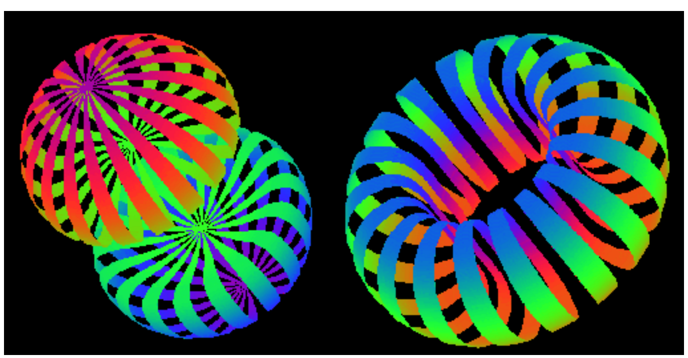


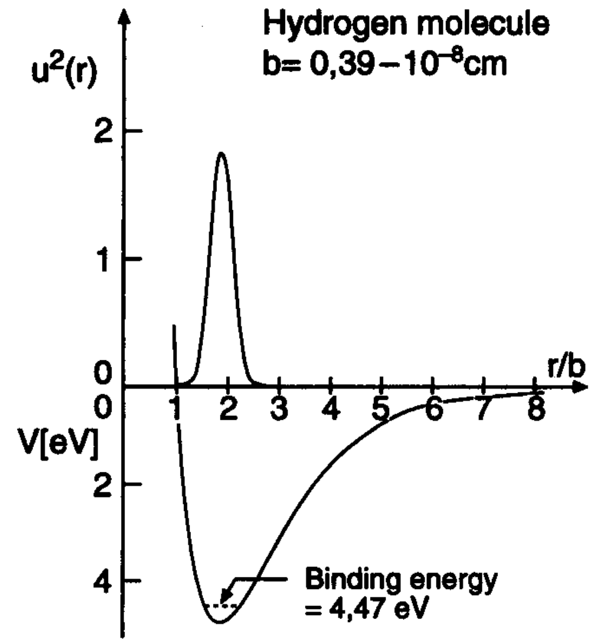
Deuteron

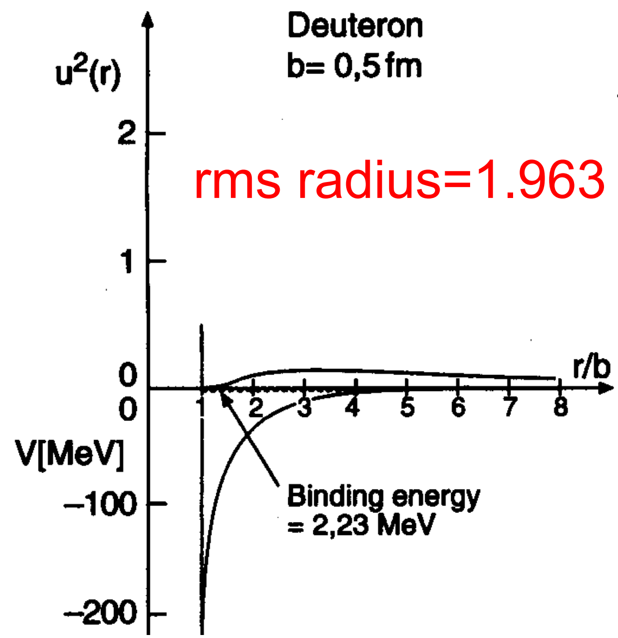
Binding energy	2.225 MeV
Spin, parity	1^+
Isospin	0
Magnetic moment	$\mu=0.857\ \mu_N$
Electric quadrupole moment	$Q=0.282\ e\ \mathrm{fm}^2$

$$|\psi_d\rangle = 0.98\,|{}^3S_1\rangle + 0.20\,|{}^3D_1\rangle$$

D-wave produced by tensor force!

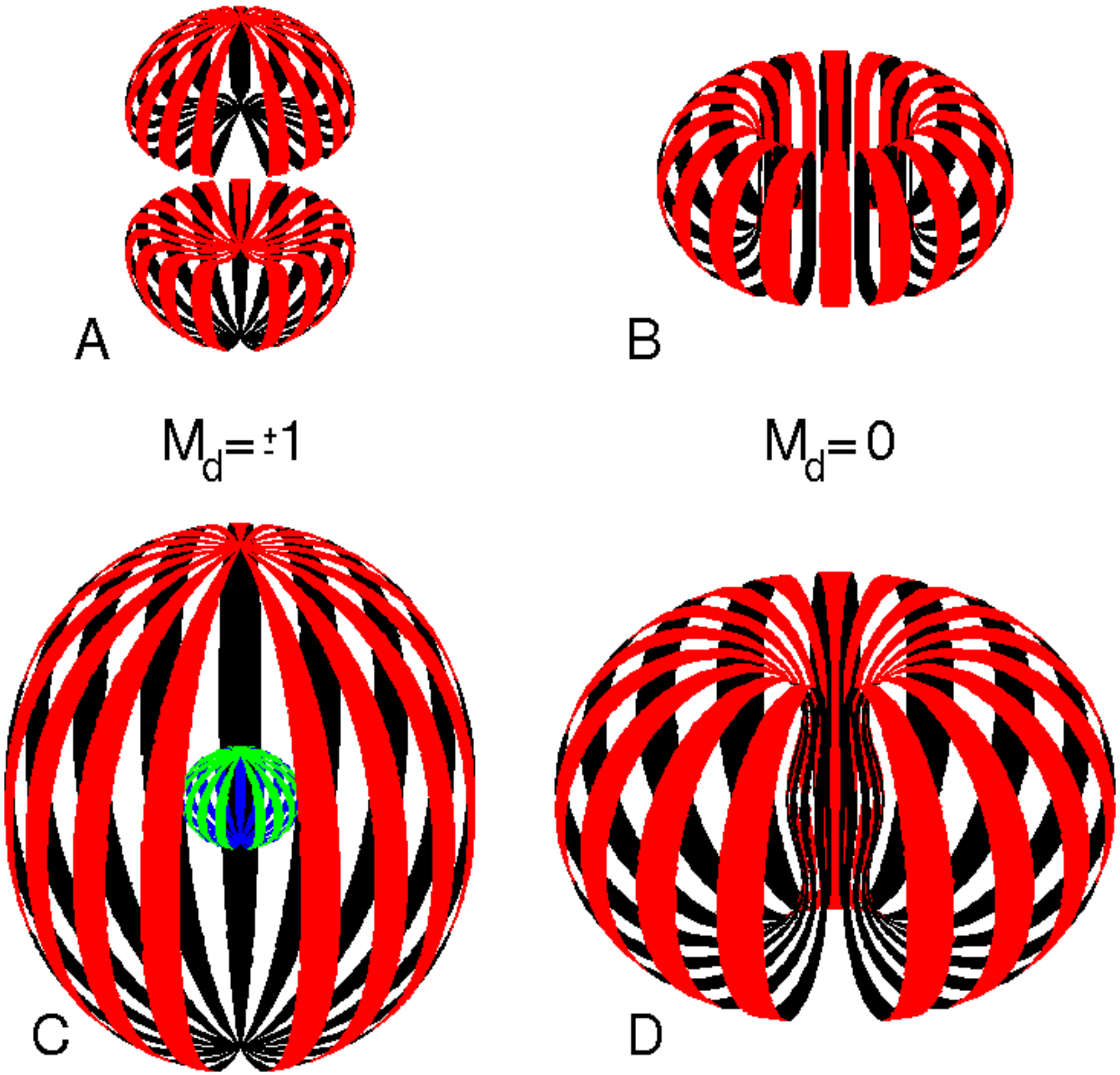




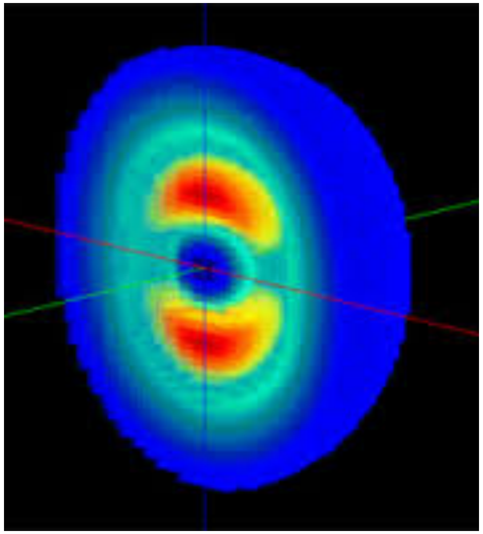


rms radius=1.963 fm

Deuteron Shapes with V_{18}

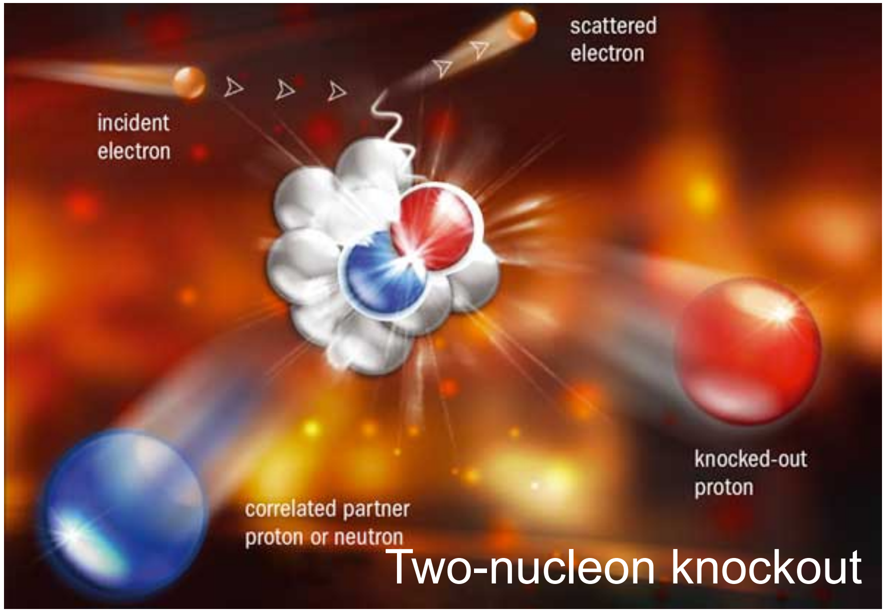


Jlab data



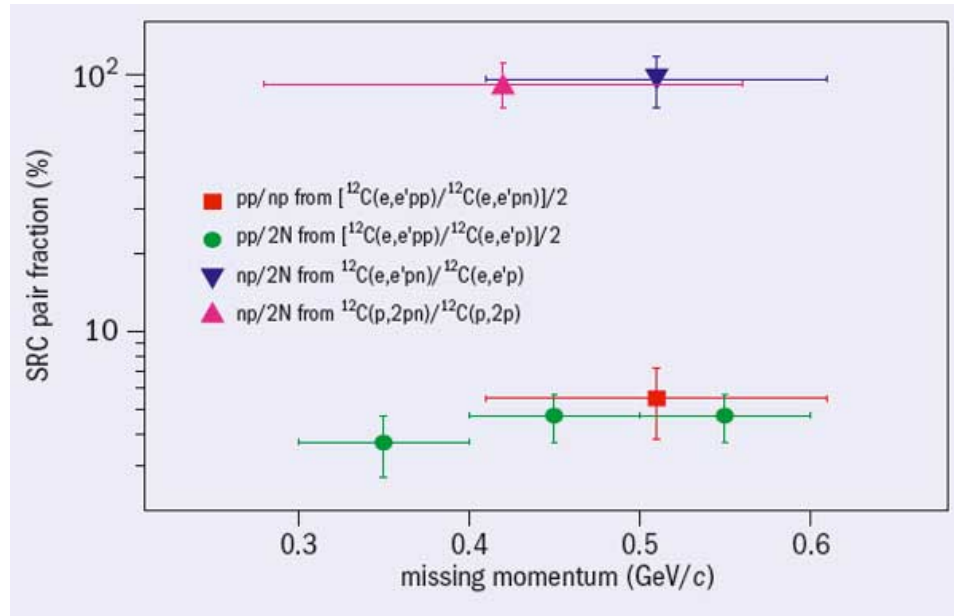
http://www.phy.anl.gov/theory/movie-run.html

Short Range Correlations and Tensor Force

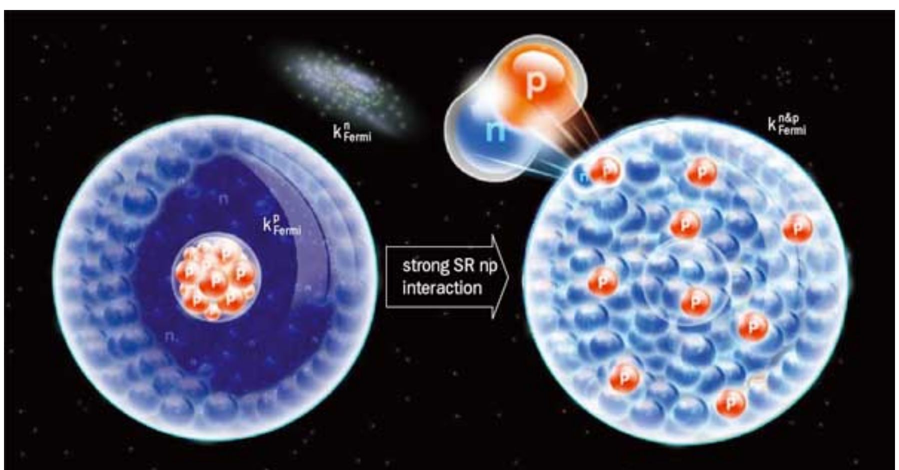


Dominance of proton–neutron pairs at intermediate range (c.o.m. momenta around 400 MeV/c)

Science 320, 1475 (2008)



http://cerncourier.com/cws/article/cern/34919
http://cerncourier.com/cws/article/cern/37330



Theory explains the pn pair dominance in terms of the tensor force:

Phys. Rev. Lett. 98, 132501 (2007)

Happy the man who has been able to discern the cause of things

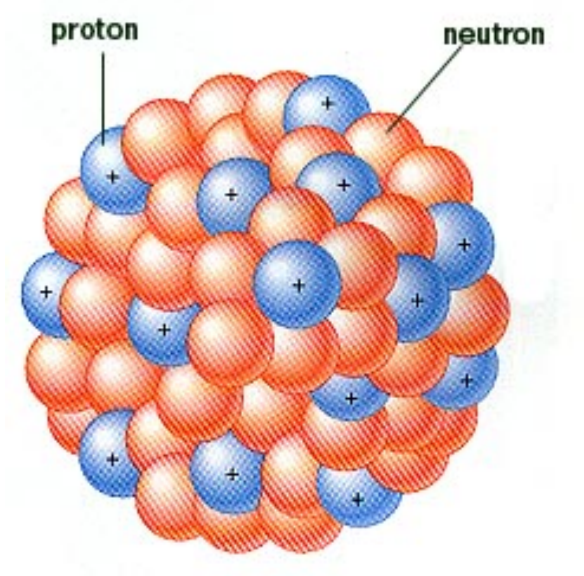
Virgil, Georgica

Theories
Models

- A first rate theory predicts
- A second rate theory forbids
- A third rate theory explains after the facts

Alexander I. Kitaigorodskii

Modeling the Atomic Nucleus



Theoretical bag of tricks…

The Nuclear Many-Body Problem

$$\hat{H}\Psi = E\Psi$$

$$\hat{H} = \hat{T} + \hat{V}$$

$$\hat{T} = \sum_{i=1}^{A} \frac{\hat{p}_i^2}{2m_i},$$

one-body

Kinetic energy

$$\hat{V} = \sum_{i<i} \hat{V}_{2b}(i,j) + \sum_{i<i<k} \hat{V}_{3b}(i,j,k)$$

two-body three-body

Potential energy

$$\Psi = \Psi\left(\vec{r}_1, \vec{r}_2, \ldots, \vec{r}_A; s_1, s_2, \ldots, s_A; t_1, t_2, \ldots, t_A\right)$$

3A nucleon coordinates in r-space

nucleon spins: ±1/2

nucleon isospins (p or n): ±1/2

Eigenstate of angular momentum, parity, and ~isospin

Bottom line:

$$2^A \times \frac{A!}{N!Z!}$$

coupled integro-differential equations in 3A dimensions

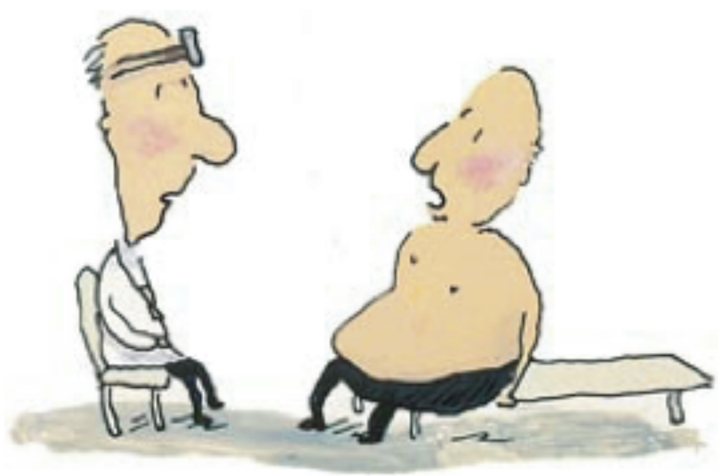
Weinberg's Laws of Progress in Theoretical Physics

From: "Asymptotic Realms of Physics" (ed. by Guth, Huang, Jaffe, MIT Press, 1983)

First Law: "The conservation of Information" (*You will get nowhere by churning equations*)

Second Law: "Do not trust arguments based on the lowest order of perturbation theory"

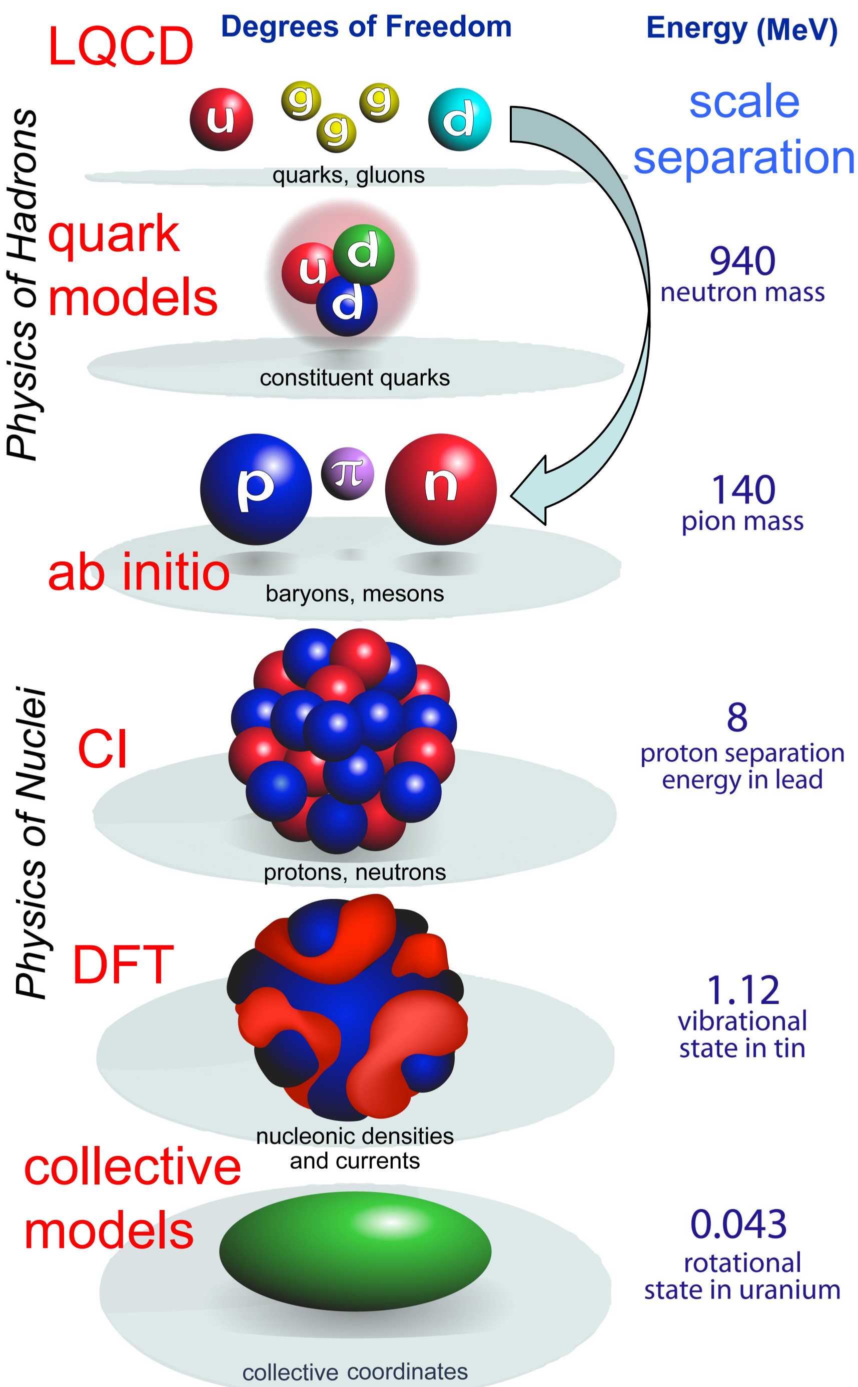
Third Law: "You may use any degrees of freedom you like to describe a physical system, but if you use the wrong ones, you'll be sorry!"



Patient: Doctor, doctor, it hurts when I do this!
Doctor: Then don't do that.

How are nuclei made?

Origin of elements, isotopes



Resolution

Hot and dense quark-gluon matter

Hadron structure

Hadron-Nuclear interface

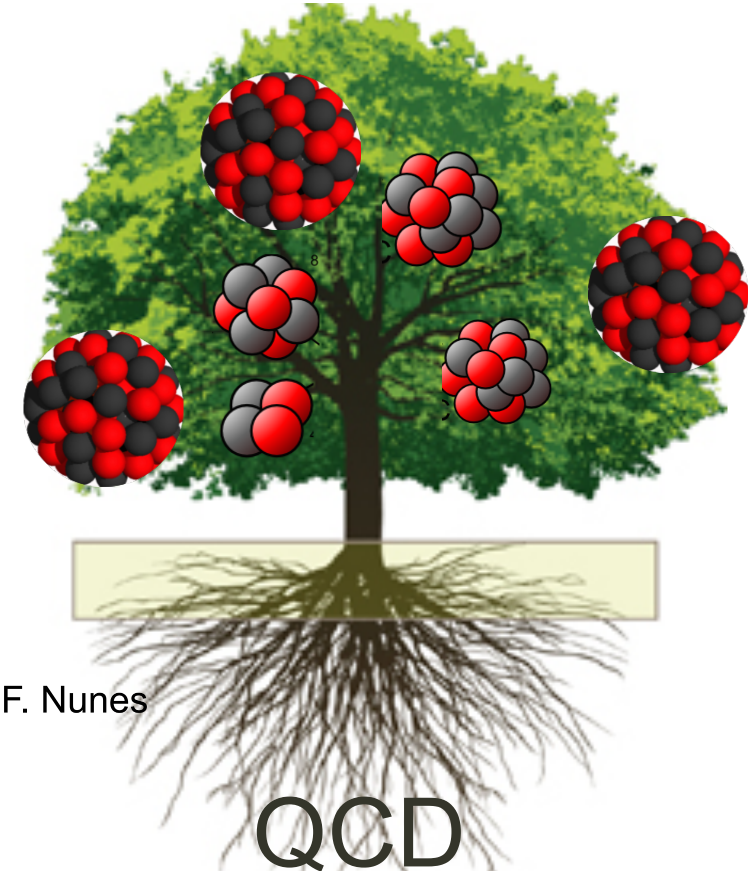
Effective Field Theory

Nuclear structure
Nuclear reactions
New standard model

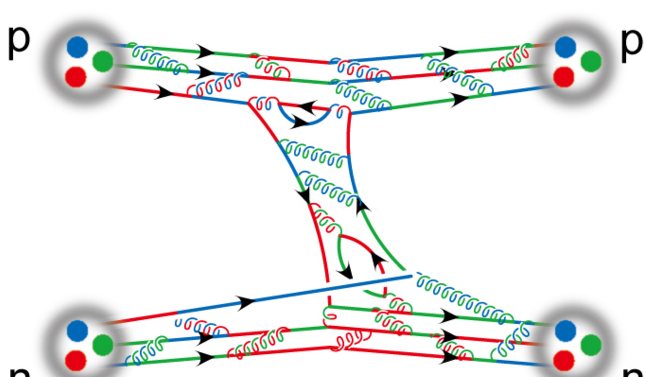
Applications of nuclear science

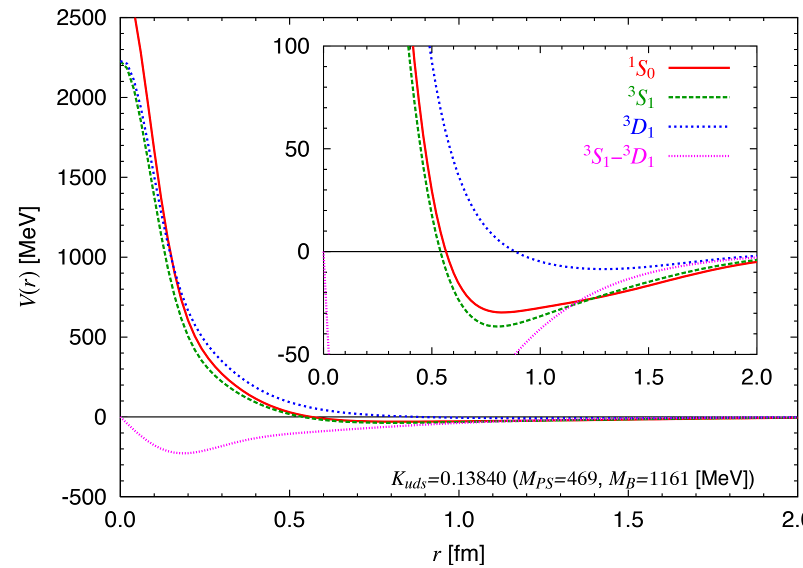
To explain, predict, use…

Rooting nuclei in QCD



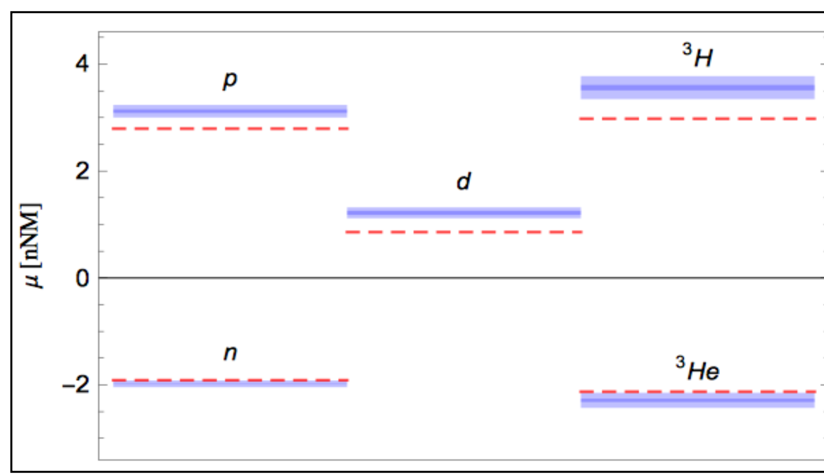
F. Nunes





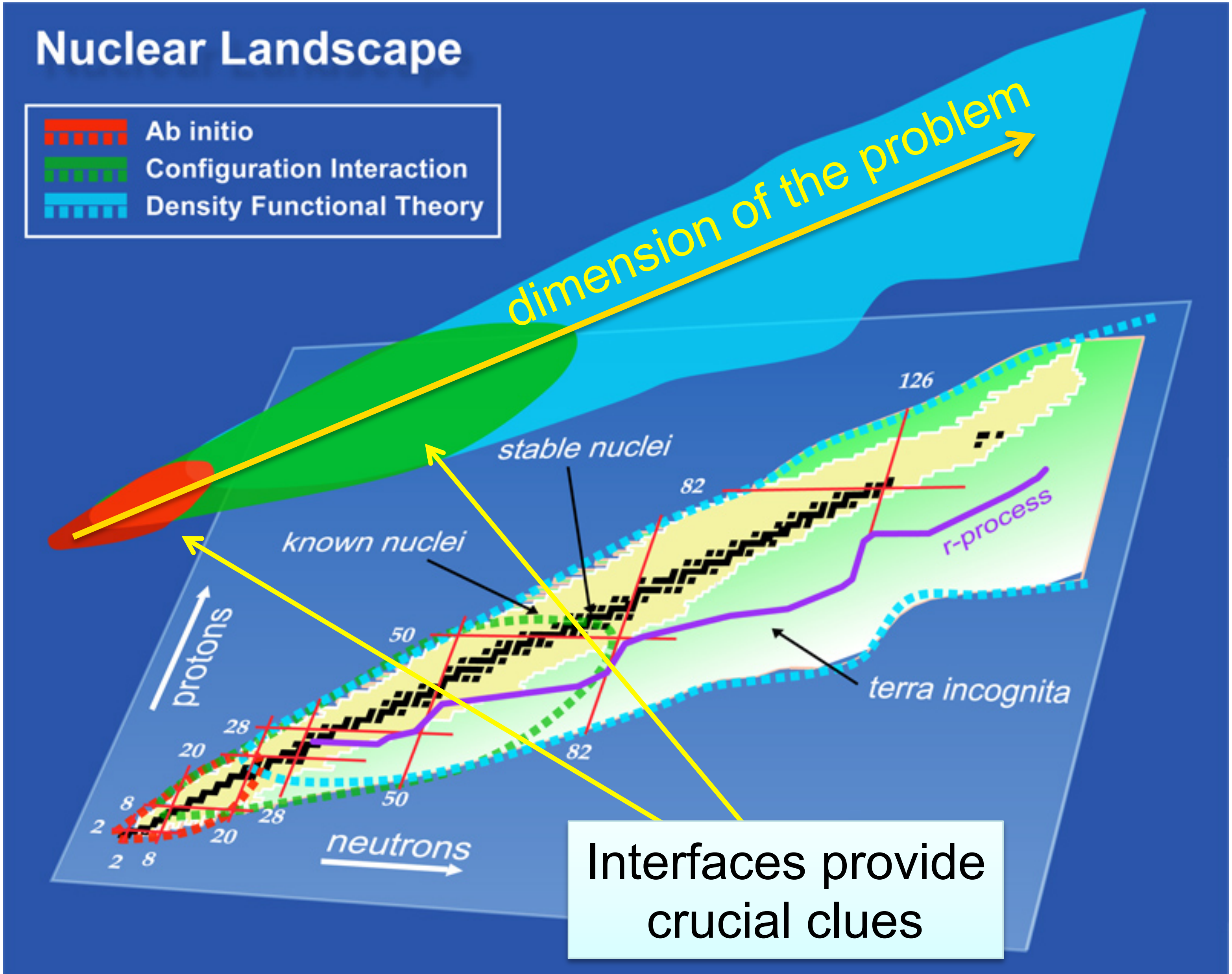
Nuclear Force from Lattice QCD

Inoue et al. PRL 111, 112503 (2013); HALQCD/HPCI



LQCD predictions for magnetic moments A<4

Beane et al., PRL113, 252001 (2014); NPLQCD



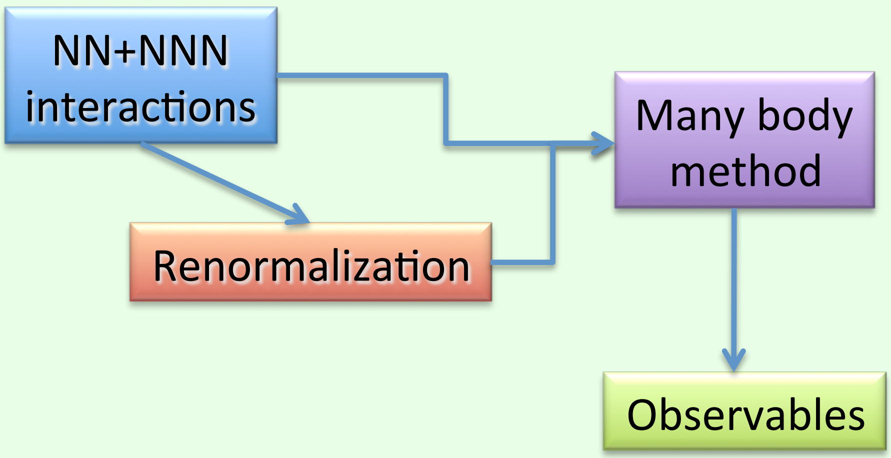
number of nuclei < number of processors!

Ab initio theory for light nuclei and nuclear matter

Ab initio: QMC, NCSM, CCM,…

(nuclei, neutron droplets, nuclear matter)

Ab initio input

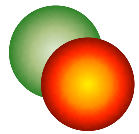


- Direct comparison with experiment
- Pseudo-data to inform theory

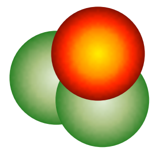
Input:

- Excellent forces based on the phase shift analysis and few-body data
- EFT based nonlocal chiral NN and NNN potentials
- SRG-softened potentials based on bare NN+NNN interactions

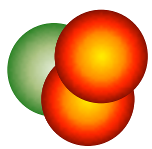
Few-nucleon systems



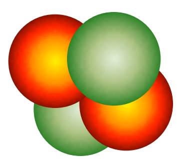
A=2: many years ago…



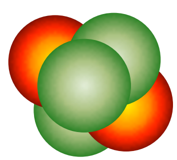
^{3}H: 1984 (1% accuracy)



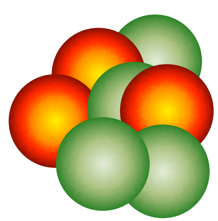
^{3}He: 1987



^{4}He: 1987



^{5}He: 1994 (n-α resonance)



A=6,7,..12: 1995-2011