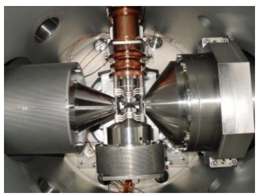
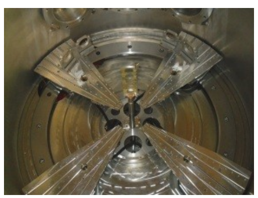


Introduction session physique nucléaire

Diego Gruyer

Normanie Université, ENSICAEN, UNICAEN, CNRS/IN2P3, LPC Caen, France
diego.gruyer@lpccaen.in2p3.fr

Nuclear physics, French geography and cakes

The atomic nuclei

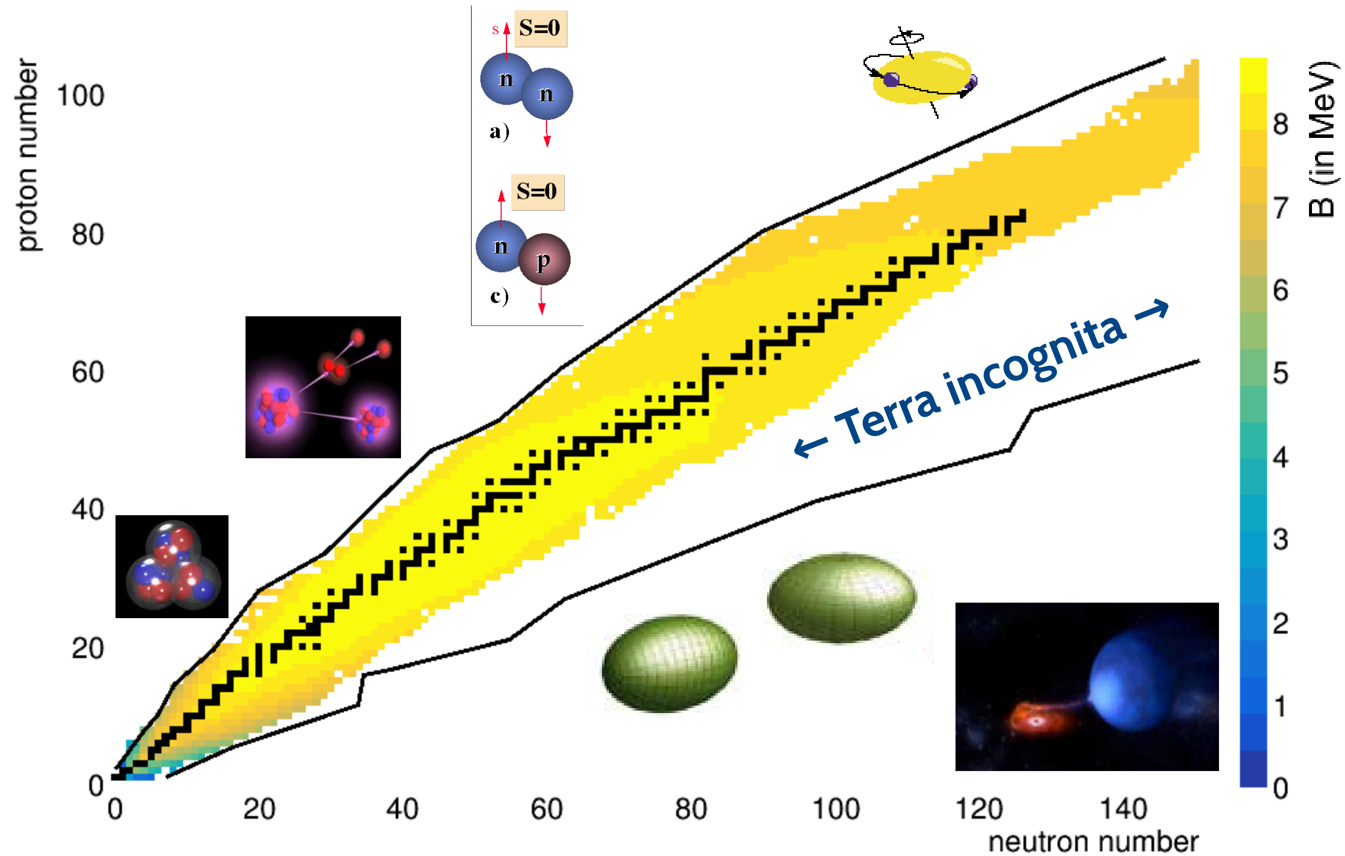
N-body quantum system
Protons and neutrons
Unknown residual interaction

Bound nuclei

~300 stable nuclei
~3000 experimentally known
~7000 predicted by theorists

Nuclear physicist's job

Characterize known regions
Explore new frontiers (driplines)
Extrapolate to unknown regions



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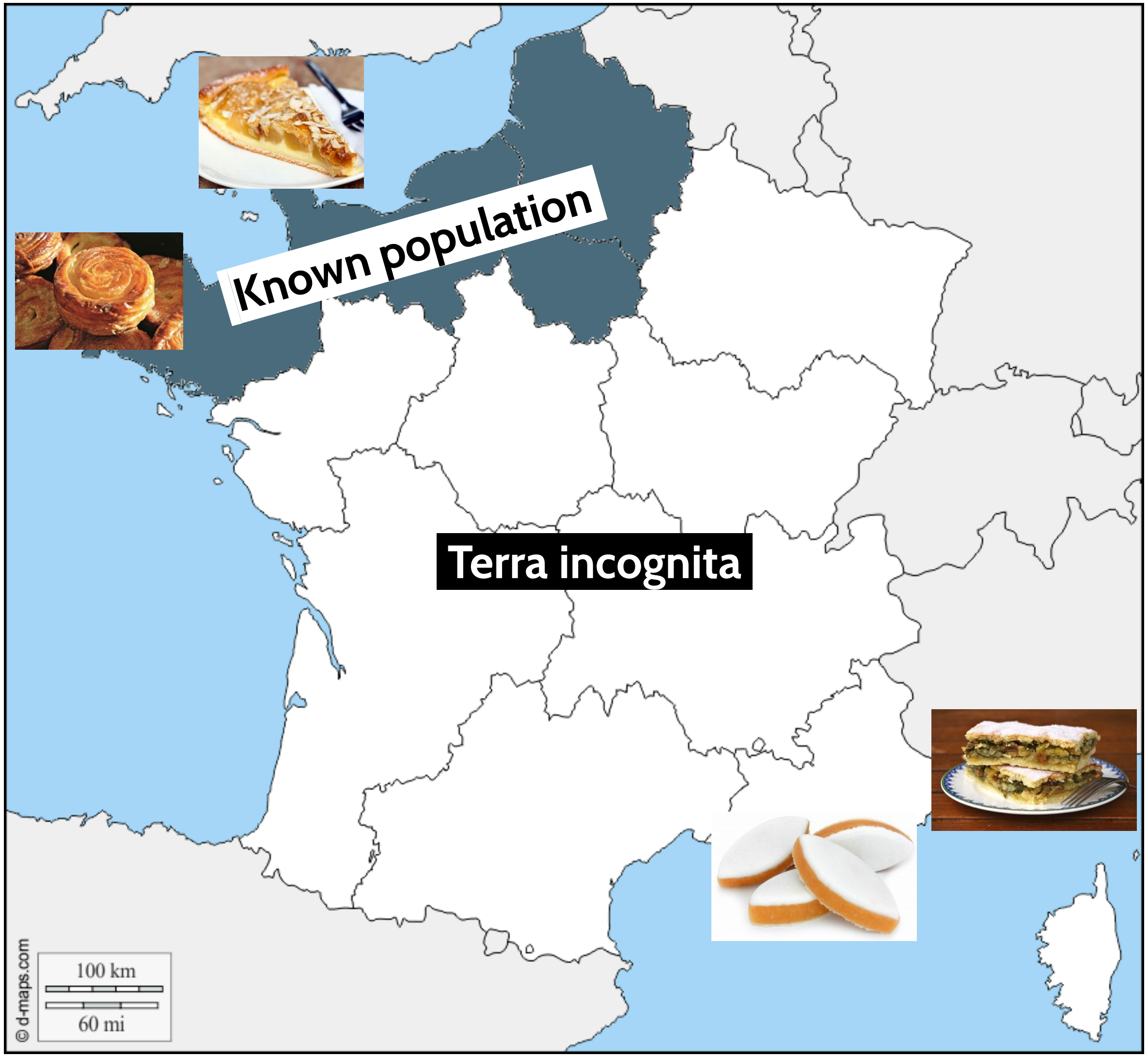
French population
25M known people/35M unknown
North West + Paris (4 regions)



Exercise
Knowing population properties (mass, deformation, groud state spin/parity, decay modes...)
Deduce Marseil people's behavior and predict the existence of Corsica

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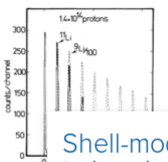

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SEPTEMBER 1, 1939 PHYSICAL REVIEW VOLUME 56

The Mechanism of Nuclear Fission

NIELS BOHR

University of Copenhagen, Copenhagen, Denmark, and The Institute for Advanced Study, Princeton, New Jersey

AND

JOHN ARCHIBALD WHEELER

Princeton University, Princeton, New Jersey

(Received June 28, 1939)

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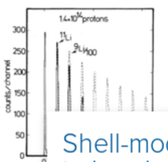

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The nuclear liquid-drop model

Gamow's idea

Protons and neutrons behave like molecules in a drop of liquid

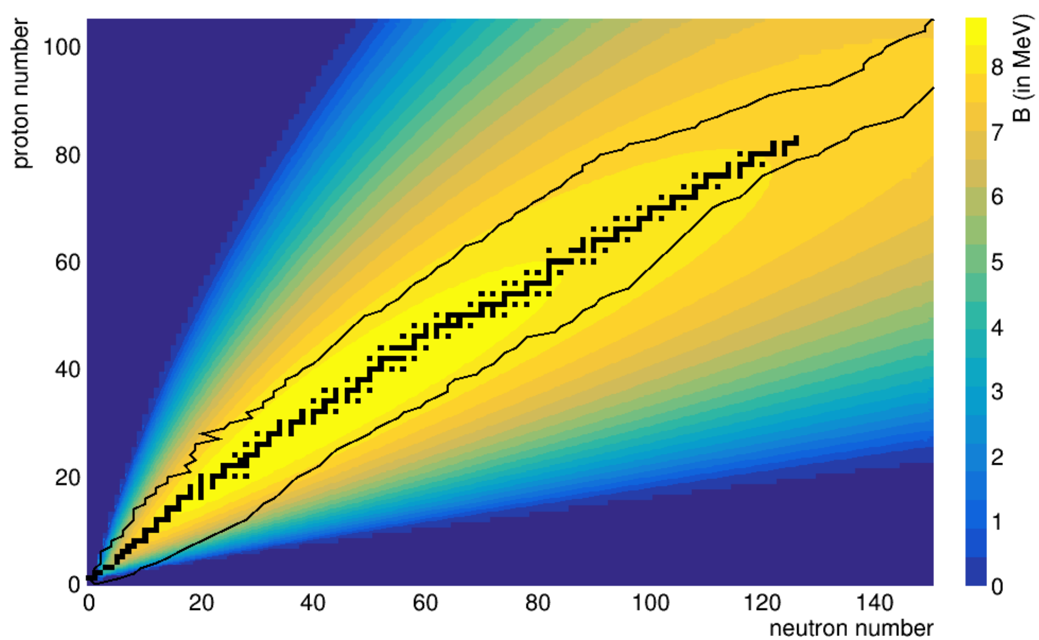
Weizsäcker's semi-empirical mass formula

Binding energy of spherical drops at constant density :

$$E_B = a_V A - a_S A^{2/3} - a_C \frac{Z(Z-1)}{A^{1/3}} - a_A \frac{(A-2Z)^2}{A} \pm \delta(A,Z)$$

Parameters fitted on experimentally measured masses

Allow to extrapolate not-observed nuclei/processes



Weizsäcker, Z. Physik **96** (1935) 431

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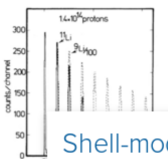

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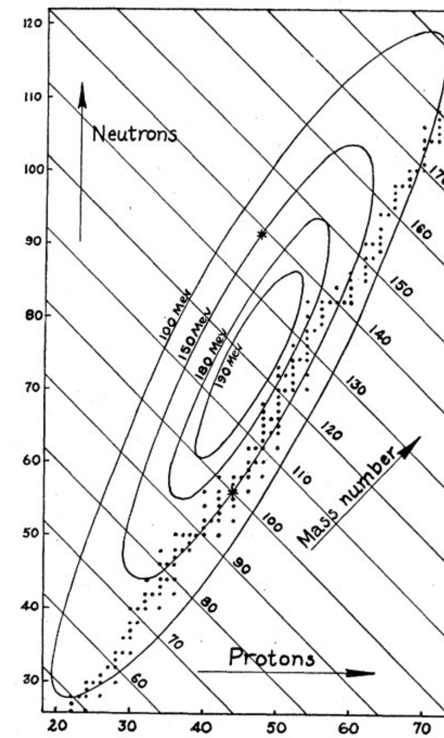
Fission

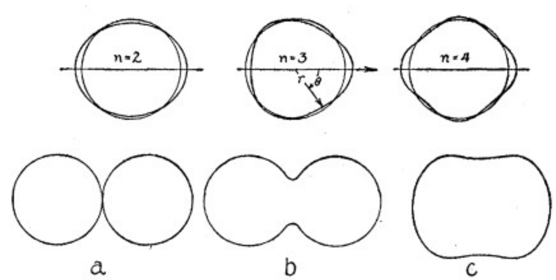
Energy release by $^{239}U \rightarrow {}^{100}Ru + {}^{139}Cd$

Production of neutron rich elements

Fission fragment beta decay

Estimation of the composite beta-spectrum



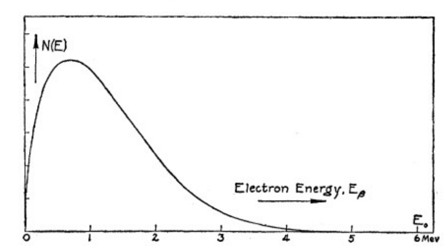


Deformation

Introduction of deformation modes

Fission as a constant-volume process

Stability as heavy elements agains fission



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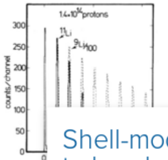

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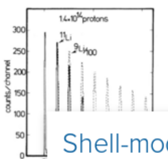

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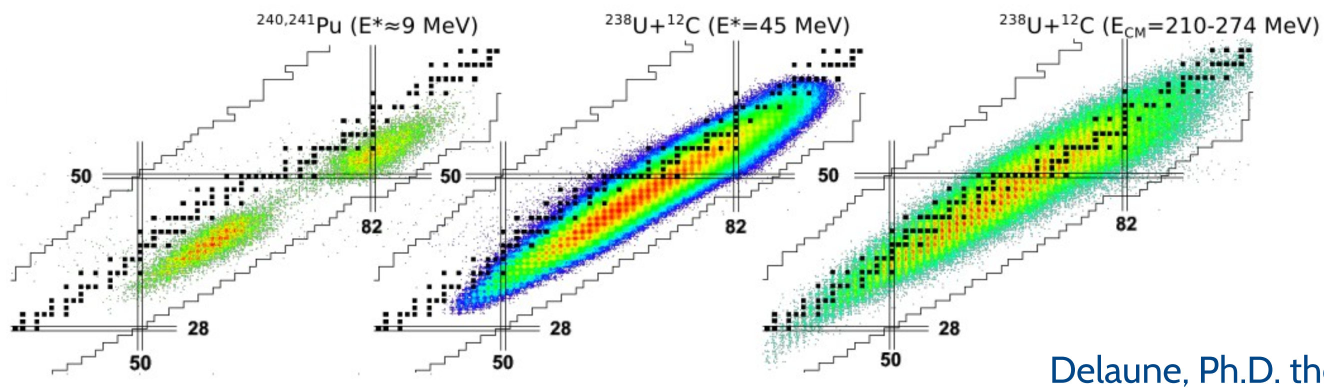
Modern nuclear fission studies

Fission experiments

Fission fragment mass/charge/energy measurement (GANIL, GSI)
Neutron, gamma and charged particle multiplicities
Used to produce exotic nuclei beams

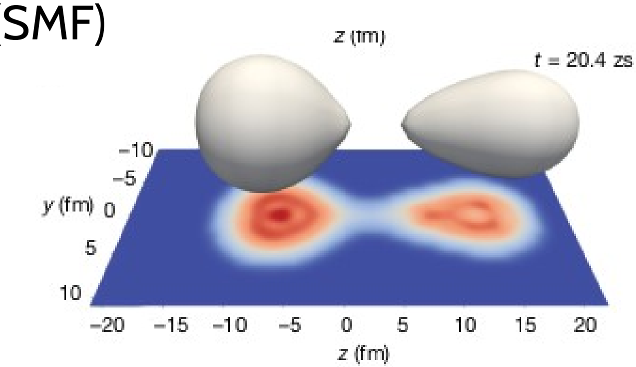


Delaune, Ph.D. thesis
Ramos, PRL **123** (2019) 092503

Fission models

Liquid-drop models + Langevin/Metropolis
Global coordinate methods (GCM)
Time-dependant stochastic mean field (SMF)

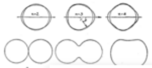
Scamps, Nature **564** (2018) 382



Recent highlights

Fission fragment internal properties
Impact of octupole shell closures

Shell closure ? Magic numbers ?



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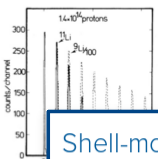

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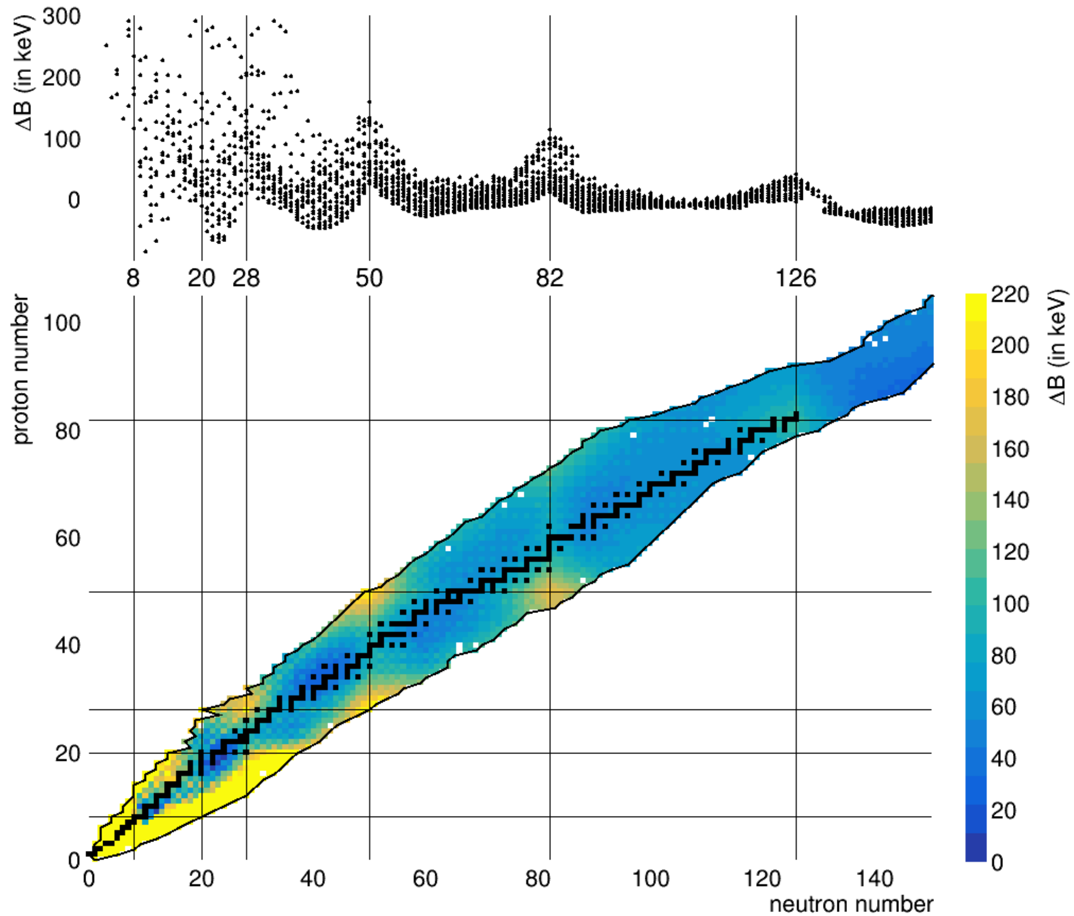

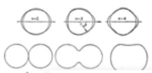

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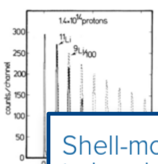

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The nuclear shell model

$H = T + V = (T + U) + (V - U) = H_0 + H_1$

T	:	kinetic part
V	:	nucleon-nucleon interaction part
U	:	external central potential
H_0	:	single particle energy
H_1	:	residual interaction

Spherical magic numbers

Harmonic potential → 2, 8, 20, ~~40~~, ~~70~~

Woods-Saxon or l^2 → l splitting

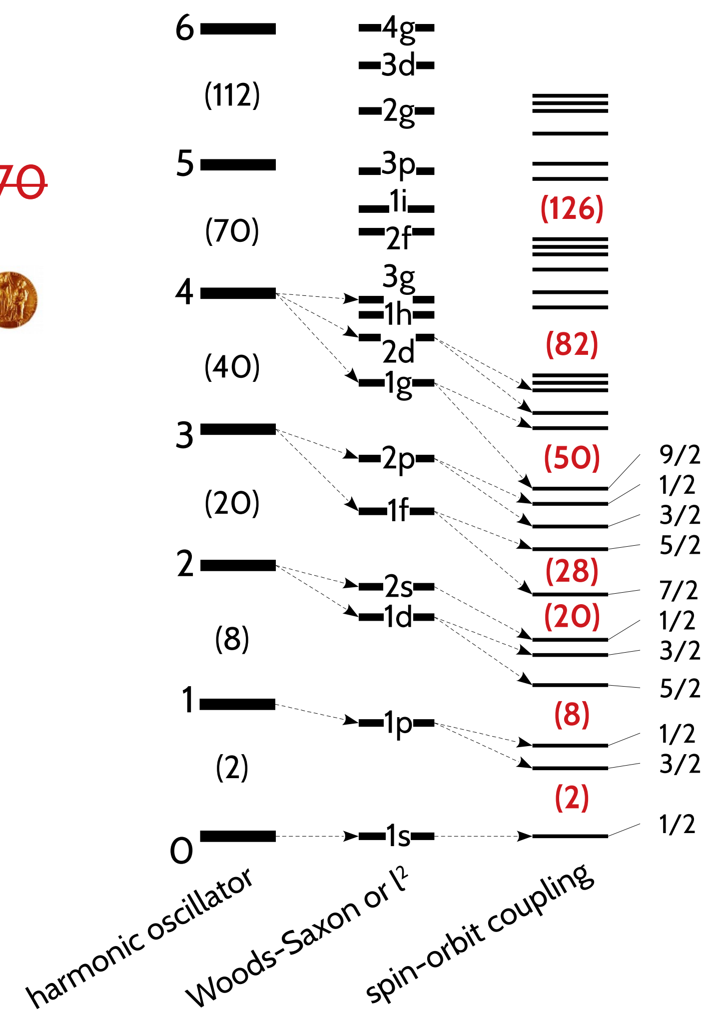
Spin-orbit coupling → Nobel price 

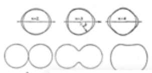
Single particle model

Magic numbers = shell gaps

Spin/parity of ground state

Excited states close to shell closure





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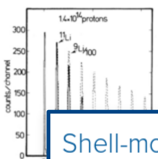

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PHYSICAL REVIEW C VOLUME 12, NUMBER 2 AUGUST 1975

Direct measurement of the masses of ^{11}Li and $^{26-32}$Na with an on-line mass spectrometer

C. Thibault, R. Klapisch, C. Rigaud, A. M. Poskanzer,* R. Prieels,† L. Lessard,‡ and W. Reisdorf§

Laboratoire René Bernas du Centre de Spectrométrie Nucléaire et de Spectrométrie de Masse, 91406 Orsay, France

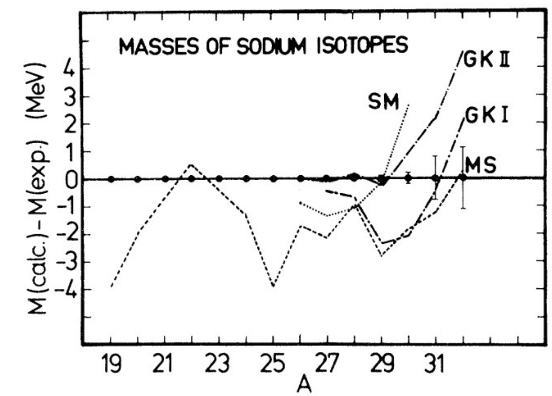
(Received 17 March 1975)

Deviation to Shell Model (SM)

Mass measurement of n-rich Na isotopes

Close to N=20 spherical magic number

Strong deviation to SM prediction



New magic numbers

Disapearence of magic number far from stability

Emergencence of new shell closure

Modern studies

Residual interaction

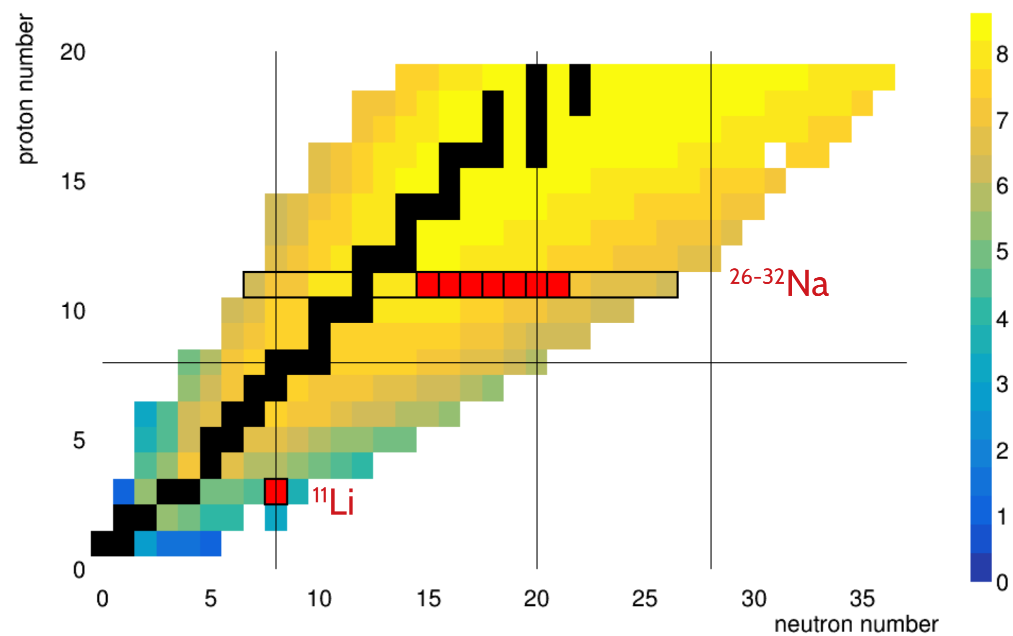
Spin-orbit splitting

Deformation

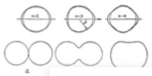
Shape coexistence

(...)

→ Armel's talk on ^{12}Be



Ahn, PRL **123** (2019) 212501



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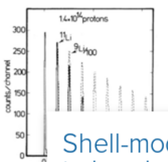

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The quest of super-heavy nuclei

Heaviest element

Liquid drop model : Z~104 (wrong)

Super-heavy only possible with shell closure

Many microscopic models predict an island of stability (Corsica ?)

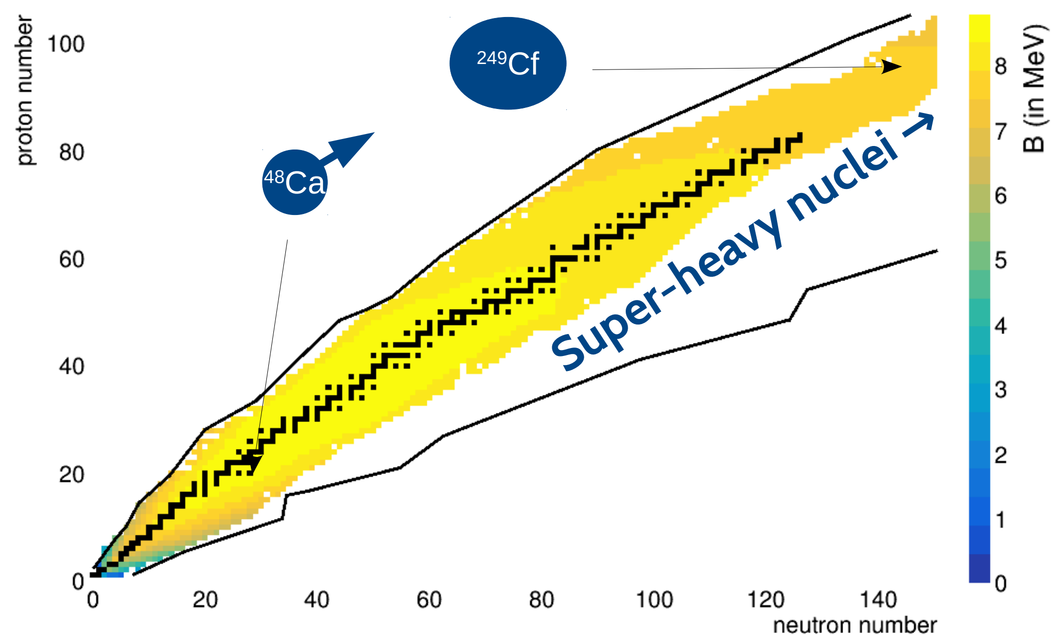
Experimental strategy

^{48}Ca beam (4.1 10^{19}) on heavy ^{249}Cf and ^{245}Cf target for Z=116,118

Energy close to the Coulomb barrier to maximize survival probability

No heavier target available → find the new golden projectile

Characterization of these nuclei → S^3@SPIRAL2 in GANIL



Oganessian, PRC **74** (2006) 044602

Nuclear physics in astro/particle physics

1939

Bethe predicts stellar nuclear reactions

Bethe shows that two types of helium-yielding nuclear reactions could power stars: the fusion of hydrogen and the so-called carbon-oxygen-nitrogen cycle. Nine years later, Bethe, Alpher, and Gamow propose an explanation for the abundance of the chemical elements using one of the first models of the post-big-bang Universe.

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1956

Parity violation is found in weak interaction

Mirror symmetry or, as physicists call it, parity symmetry, holds the status of a sacred principle until theorists Lee and Yang show that they can explain puzzling cosmic-ray data by assuming that the symmetry is violated in weak interactions. A year later, beta-decay experiments by Wu and her collaborators prove that parity is, in fact, violated.

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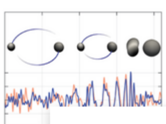

2016

LIGO reports observation of gravitational waves

The collaborations behind the Laser Interferometer Gravitational-Wave Observatory (LIGO) and the Virgo experiment report that LIGO's sensitive interferometers have picked up a gravitational-wave signal from the merger of two black holes—the first detection of the waves that Einstein had predicted in 1916. LIGO's success sets the stage for a new era of gravitational-wave astronomy, and it is soon followed by a joint detection with Virgo of a binary neutron star merger.

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Stellar fuel and nuclear abondances

Introduction of the C-N-O circle by Bethe
Prediction of nuclear abundances on cosmologic arguments by Gamow
Still a strong interplay between nuclear structure and astrophysics
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Fundamental symmetries

Lee and Yang's prescription : two experiment for parity violation test
Evidence of parity violation in ^{60}Co beta decay by Madame Wu's team
Triggered a lot of experiment looking for CP violation in beta decay
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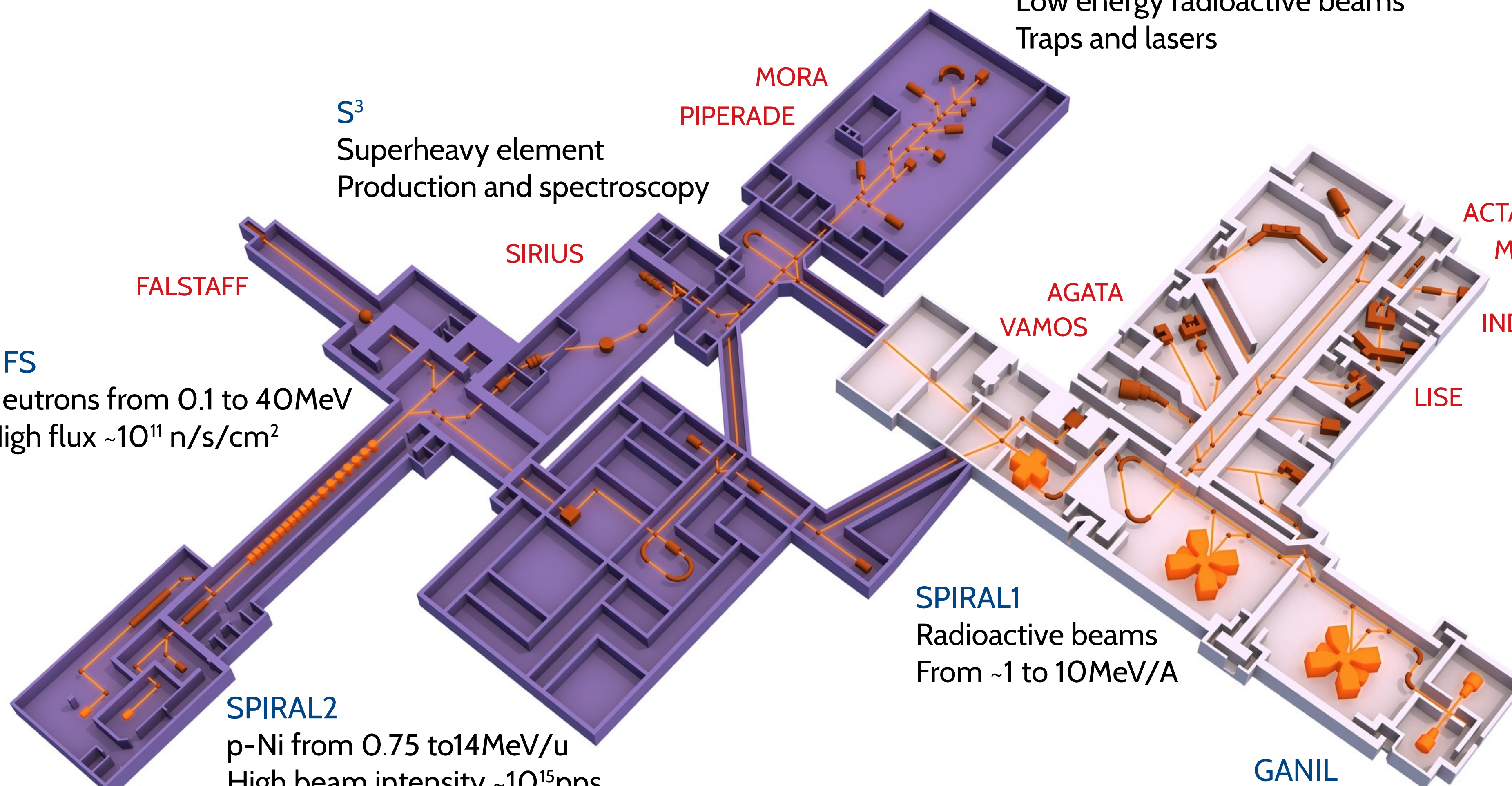
Nuclear equation of state

First BH-BH and NS-NS gravitational wave signal by LIGO/VIRGO
NS-NS merger electro-magnetic counterpart detected
New window on dense matter equation of state
Also accessible in violent heavy-ion collisions
→ See the Joël Quicray's talk

Quick overview of GANIL



La suite des hostilités

Armel 'the correlator' Kamenyero
Etude des corrélations neutron-neutron dans le noyau de ^{12}Be

Chloé 'cosmic' Fougères
Understanding cosmic abundance of ^{22}Na

Joël Quicray also known as 'jojoleBG'
Transport d'isospin dans les collisions nucléaires

Nishu 'Wu' Goyal
Detection of the decay of laser oriented radioactive isotopes

Nicolas Dray alias 'the activator'
Développement d'un module tout-en-un d'activation neutronique

Quentin 'PIXE' Mouchard
Hight energy PIXE : K-shell ionization cross section for Ti, Cu, and Ag atoms