Groupe THEORIE

Journée M2PSA du 7 octobre 2016

Kamila SIEJA, pour le Groupe THEORIE

IPHC/DRS et Université de Strasbourg

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Le Groupe THEORIE en quelques mots...

Coordinateur

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Localisation au sein de l'IPHC

Bâtiment 27, premier et deuxième étage

Membres permanents

6 enseignants-chercheurs

- M. Johann BARTEL, Maître de Conférences
- M. Jerzy DUDEK, Professeur Emerite
- Mme Marianne DUFOUR, Maître de Conférences
- M. Hervé MOLIQUE, Maître de Conférences
- M. Janos POLONYI, Professeur
- M. Michel RAUSCH de TRAUBENBERG, Professeur

4 chercheurs CNRS

- M. Etienne CAURIER, Directeur de Recherches Emérite
- M. Rimantas LAZAUSKAS, Chargé de Recherches
- M. Frédéric NOWACKI, Directeur de Recherches
- Mme Kamila SIEJA, Chargée de Recherches

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Membres non-permanents

USIAS Fellow

- Prof. Alfredo POVES (UAM Madrid), 3 mois par an

Etudiants en thèse

- Mme Irene DEDES (J. Dudek et H. Molique)
- M. Damien TANT (M. Rausch de Traubenberg)
- M. Mateo VALDES DUPUY (M. Dufour et R. Lazauskas)

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ACTIVITES DE RECHERCHE

Physique théorique des hautes energies

J. Polonyi, M. Rausch de Traubenberg

- Théories de jauges (non)commutatives
- Condensat de Bose-Einstein
- Effets non perturbatifs
- Groupe de renormalisation
- Décohérence
- Causalité et relativité générale
- Etude formelle et mathématique de la supersymétrie

Structure nucléaire et réactions

J. Bartel, E. Caurier, J. Dudek, M. Dufour, R. Lazauskas, H. Molique, F. Nowacki, K. Sieja

- Systèmes "few-body"
- Noyaux exotiques
- Evolution des couches loin de la stabilité
- Fusion-fission
- Réactions d'intérêt astrophysique
- Equation Faddeev-Yakubovsky
- Modèles en amas
- Modèle en couches
- Modèle de champ moyen auto-cohérent
- Recherches pluridisciplinaires (BETASHAPE)

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Sujet de master proposé:
Study of unique first-forbidden β-decays in the ^{78}Ni region

Proposition de sujet de stage M2 (2016) à l'Institut de Pluridisciplinaire Hubert Curien (IPHC)

Study of unique first-forbidden β-decays in the ^{78}Ni region.

The allowed Gamow-Teller transitions are the most common nuclear weak-processes which play a key role in astrophysical processes, ike supernovea explosions and nuclear synthesis. However, in neutron-rich nuclei, where valence protons and neutrons occupy orbitals of different parities, the first-forbidden transitions become of importance and can not be omitted in the evaluation of beta-decay half-lives, crucial ingredients of e.g. r-process nucleosynthesis simulations.

In the present Master training we will focus on particular type of first-forbidden transitions, i.e. unique first-forbidden ones (change of spin between parent/daughter nucleus by 2 units). After getting familiar with the elements of the beta-decay theory and the large-scale shell model approach, which will be our tool for computing the nuclear states, the candidate will perform numerical applications in the region of ^{78}Ni nucleus. ^{78}Ni is a hot topic in nuclear structure : this possibly dubly magic nucleus is a key for the nuclear structure models and the comprehension of shell evolution far from stability. However, only its half-life is so far known experimentally. A wealth of experimental data of nuclei around it, including those from beta-decays, has been accumulated. A proper theoretical interpretation of those could help to discover the shell structure of ^{78}Ni and the mechanisms governing the shell evolution in neutron-rich nuclei.

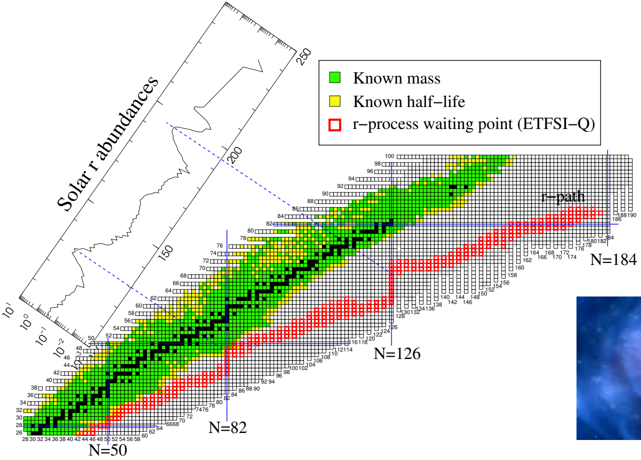
The student is expected to learn the beta-decay theory and get familiar with the Strasbourg shell model codes (knowledge of fortran required). The master thesis can be followed by a PhD thesis, enlarging the present subject to the studies of non-unique forbidden transitions as well as other nuclear observables of importance for stellar evolution models and nucleosynthesis.

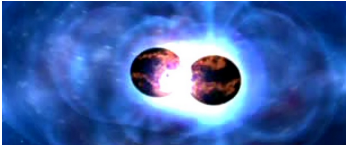
References:

[1] H. Behrens and W. Buhring, "Nuclear beta decay", Nuc. Phys. A162 (1971) 111-144.
[2] E. K. Warburton et al., "First-forbidden beta decay near A=40", Annals of Physics 187 (1988) 471-501.
[3] Q. Zhi et al., "Shell model half-lives including first-forbidden contributions for r-process wating point nculei", Phys. Rev. C87 (2013) 025803.
[4] E. Caurier et al., "Shell model as unified view of nuclear structure", Rev. Mod. Phys. 77 (2005) 427.

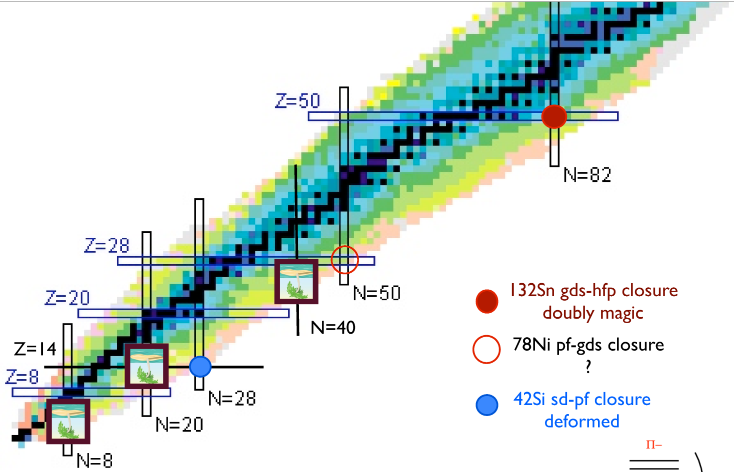
Making gold in nature: r-process nucleosynthesis

☞Nuclear models are needed to provide input for r-process simulations: *masses*, *level densities*, β *half-lives*, γ*-SF*, fission barriers...
☞Half-lives are particularily important at the r-process waiting points N=50, 82, 126 where abundances peak.





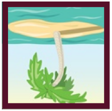
Mysterious ^{78}Ni



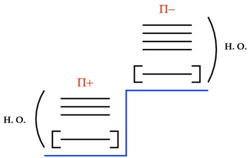
132Sn gds-hfp closure
doubly magic

78Ni pf-gds closure
?

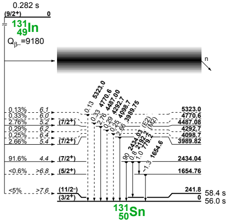
42Si sd-pf closure
deformed



Island of inversion=region of sudden deformation in nuclei with a h.o. neutron shell closure



β-decay in exotic nuclei

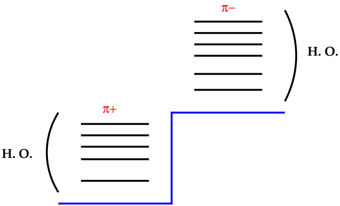


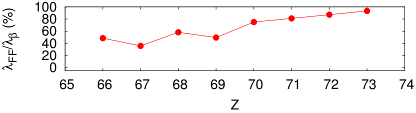
$$\lambda = \frac{\ln 2}{T_{1/2}} = \sum_f \lambda_f$$

☞To calculate beta decay between two states one needs:

- accurate value of the decay energy ($T_{1/2} \sim \Delta E^{-5}$)
- matrix elements of Gamow-Teller ($\Delta J^\pi = 0^+, 1^+$) first forbidden ($\Delta J^\pi = 0^-, 1^-, \mathbf{2}^-$) transition operators

☞When protons and neutrons occupy orbitals with different parities, first forbidden transitions play a role

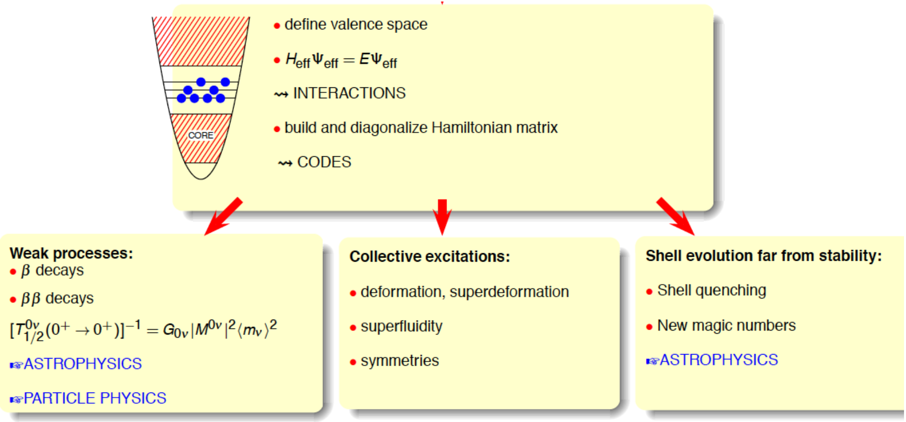




N=126 isotones

PRC87, 025803 (2013)

Large Scale Shell Model



- known as well as Configuration Interaction in chemistry and solid state physics
- variational method of solving many-body Schrödinger equation

Shell Model: giant computations

- Problem dimension in the m-scheme:

$$D \sim \binom{d_\pi}{p} \cdot \binom{d_\nu}{n}$$

In the *pf*-shell ($1f_{7/2}$, $2p_{3/2}$, $1f_{5/2}$, $2p_{1/2}$):

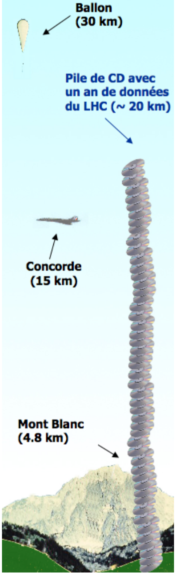
^{48}Cr	1,963,461
^{56}Ni	1,087,455,228

- Current diagonalization limit in m-scheme 10^{10}

- The largest SM diagonalization up to date has been achieved by the Strasbourg group (using very modest computing resources):
Phys. Rev. C82 (2010) 054301, ibidem 064304

  - m scheme CODE ANTOINE
  - coupled scheme CODE NATHAN

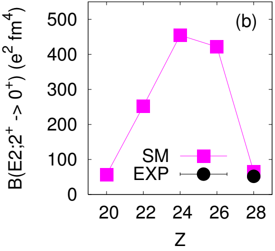
E. Caurier et al., Rev. Mod. Phys. 77 (2005) 427; ANTOINE website



Largest SM matrices we treat contain $\sim 10^{14}$ non-zero matrix elements. They can not be stored on a hard drive. It would take 100.000 DVDs to store one matrix!

Shell Model: link with experiment

PRC82, 054301 (2010)



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PRL **106**, 022502 (2011) PHYSICAL REVIEW LETTERS week ending 14 JANUARY 2011

Enhanced Quadrupole Collectivity at $N = 40$: The Case of Neutron-Rich Fe Isotopes

W. Rother,[1] A. Dewald,[1] H. Iwasaki,[2,3] S. M. Lenzi,[4] K. Starosta,[5] D. Bazin,[2] T. Baugher,[2,3] B. A. Brown,[2,3]

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RAPID COMMUNICATIONS

PHYSICAL REVIEW C **86**, 011305(R) (2012)

Intermediate-energy Coulomb excitation of ^{58,60,62}Cr: The onset of collectivity toward $N = 40$

T. Baugher,[1,2,*] A. Gade,[1,2] R. V. F. Janssens,[3] S. M. Lenzi,[4] D. Bazin,[1] B. A. Brown,[1,2] M. P. Carpenter,[3] A. N. Deacon,[5]

GANIL

RAPID COMMUNICATIONS

PHYSICAL REVIEW C **81**, 061301(R) (2010)

Onset of collectivity in neutron-rich Fe isotopes: Toward a new island of inversion?

J. Ljungvall,[1,2,3] A. Görgen,[1] A. Obertelli,[1] W. Korten,[1] E. Clément,[2] G. de France,[2] A. Bürger,[4] J.-P. Delaroche,[5] A. Dewald,[6]

Legnaro

PHYSICAL REVIEW C **85**, 064305 (2012)

Spectroscopy of odd-mass cobalt isotopes toward the $N = 40$ subshell closure and shell-model description of spherical and deformed states

F. Recchia,[1,2] S. M. Lenzi,[1,2] S. Lunardi,[1,2] E. Farnea,[2] A. Gadea,[3,4] N. Mărginean,[4,5] D. R. Napoli,[4] F. Nowacki,[6] A. Poves,[7]

- most precise method in nuclear structure physics for studies of spectroscopic properties
- the model of choice for interpretation of data from experiments with RIB ☞collaborations with experimental groups worldwide

Quelques remarques

- Les compétences acquises:
  - structure nucléaire: evolution des couches loin de la stabilité,
  - interactions faibles et fortes,
  - astrophysique nucléaire,
  - méthodes des mélanges de configurations, modèle en couches à grande échelle,
  - prise en main des codes SM.
- Les compétences requises:
  - connaissances de fortran (ou autre langage de programmation), systémes unix, linux,
  - bonne connaissance de l'anglais.

☞Les résultats obtenus feront l'objet d'une publication.

☞Le sujet de ce stage consititue la base d'un projet de thèse qui sera proposé l'an prochain (*Nuclear observables for nucleosynthesis models).*

Informations pratiques

Encadrante du stage

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Localisation au sein de l'IPHC

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