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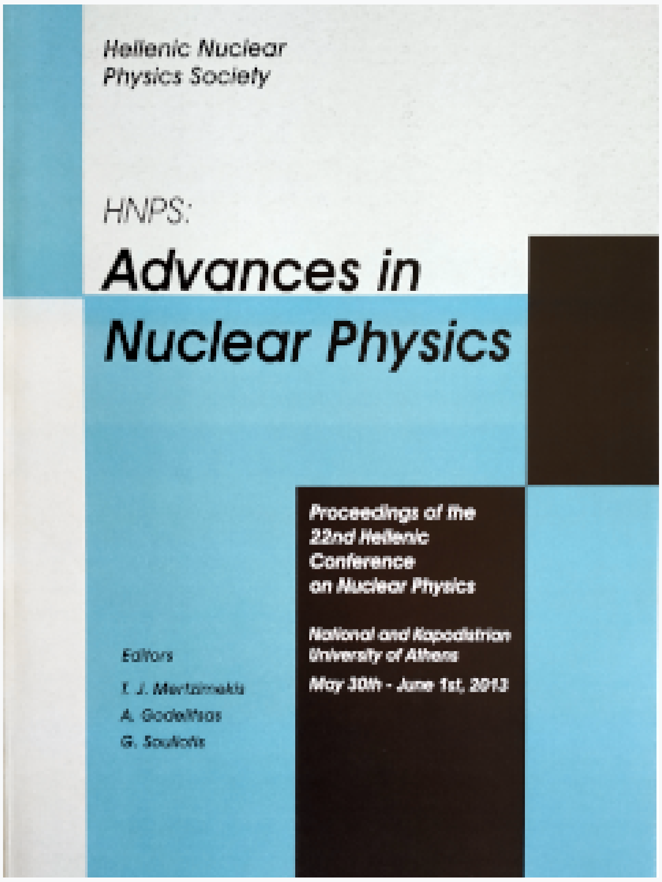

Exotic structure and decay of medium mass nuclei near the drip lines

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Exotic structure and decay of medium mass nuclei near the drip lines

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Abstract

Properties of medium mass nuclei near the drip lines are not only relevant for nuclear structure, but are of high interest in nuclear astrophysics and in several applications, in particular nuclear technology. Shape coexistence effects play an essential role in the structure and dynamics of proton-rich A∼70 nuclei and neutron-rich A∼100 nuclei. Results concerning a self-consistent description of exotic phenomena including Gamow-Teller β-decay of proton-rich nuclei, triple shape coexistence and shape evolution in the N=58 Sr and Zr isotopes as well as Gamow-Teller β-decay strength distributions and structure properties of neutron-rich nuclei relevant for reactor decay heat obtained in the frame of the *complex* Excited Vampir model using realistic effective interactions in large model spaces will be presented.

Keywords: proton-rich nuclei, neutron-rich nuclei, shape coexistence, beta decay, beyond-mean-field Excited Vampir model

1. Introduction

Nuclear shape coexistence dominates the properties of proton-rich nuclei in the A∼70 region that are important for the rp-process and the understanding of the nucleosynthesis. The isotopic chain of neutron-rich strontium and zirconium nuclei present rapid transition from spherical to deformed shape with a possible identification of the sudden onset of quadrupole deformation between N=58 and 60. The β-decay properties of neutron-rich nuclei in the A∼100 mass region are relevant for the astrophysical r-process and specific nuclei are important contributors to the reactor decay heat. Different theoretical investigations revealed the difficulty of describing in a unitary way the experimental data at low and high spins as well as the Gamow-Teller (GT) β-decay properties of these nuclei. The realistic description of shape coexistence phenomena in proton-rich A∼70 nuclei and neutron-rich A∼100 nuclei requires beyond-mean-field approaches.

We investigated the coexistence phenomena dominating the structure and dynamics of medium mass nuclei near the drip lines within the *complex* Excited Vampir approach. This approach uses Hartree-Fock-Bogoliubov (HFB) vacua as basic building blocks, which are only restricted by time-reversal and axial symmetry. The underlying HFB transformations are essentially *complex* and do mix proton- with neutron-states as well as states of different parity and angular momentum. The broken symmetries of these vacua (nucleon numbers, parity, total angular momentum) are restored by projection techniques and the resulting symmetry-projected configurations are used as test wave functions in chains of successive variational calculations to determine the underlying HFB transformations as well as the configuration mixing. The HFB vacua of the above type account for arbitrary two-nucleon correlations and thus simultaneously describe like-nucleon as well as isovector and isoscalar proton-neutron pairing. Furthermore the *complex* Excited Vampir model (EXVAM) allows the use of rather large model spaces and realistic effective interactions. For nuclei in the A∼100 mass region is used a rather large model space above the ^{40}Ca core built out of $1p_{1/2}$, $1p_{3/2}$, $0f_{5/2}$, $0f_{7/2}$, $2s_{1/2}$, $1d_{3/2}$, $1d_{5/2}$, $0g_{7/2}$, $0g_{9/2}$, and $0h_{11/2}$ oscillator orbits for both protons and neutrons in the valence space [1, 2]. The corresponding single-particle energies had been adjusted in *complex* Monster (Vampir) calculations for odd mass nuclei in the A∼100 mass region [1, 2]. This rather large model space allows the realistic description of the Gamow-Teller β-decay properties of neutron-rich nuclei in the A∼100 region as well as the proton-rich nuclei in the A∼70 region. The effective two-body interaction is constructed

from a nuclear matter G-matrix based on the Bonn A potential. In order to enhance the pairing properties the G-matrix was modified by three short-range (0.707 fm) Gaussians for the isospin T = 1 proton-proton, neutron-neutron, and neutron-proton matrix elements. The isoscalar spin 0 and 1 particle-particle matrix elements are enhanced by an additional Gaussian. In addition, the isoscalar interaction was modified by monopole shifts including all T = 0 matrix elements of the form $\langle 0g_{9/2}0f; IT = 0|\hat{G}|0g_{9/2}0f; IT = 0\rangle$ involving protons and neutrons occupying the $0f_{5/2}$ and the $0f_{7/2}$ orbitals. The Coulomb interaction between the valence protons was added.
In the following sections we shall present the *complex* Excited Vampir results on the structure and Gamow-Teller β decay of the rp-process waiting point nucleus ^{72}Kr, triple shape coexistence and shape evolution in the N=58 Sr and Zr isotopes as well as β-decay properties of the neutron-rich ^{102}Tc and ^{104}Tc nuclei relevant for nuclear technology.

2. rp-process waiting point nucleus ^{72}Kr

We present the results of the first attempt at a completely self-consistent calculation of the Gamow-Teller β decay of the ground state of ^{72}Kr to ^{72}Br using the *complex* Excited Vampir approach in the large model space presented above compared to the results obtained in a smaller model space [3]. In the experiments at CERN/ISOLDE the GT strength distribution for the ^{72}Kr beta decay could only be established up to 2 MeV excitation energy in ^{72}Br while the whole beta window amounts to Q_{EC} = 5.040(375) MeV [4]. The structure of the wave functions for parent and daughter states indicate variable, in some cases strong oblate-prolate shape mixing. In Figure 1 we present the accumulated Gamow-Teller strength for the decay of the ground state of ^{72}Kr and compare it to the available data [4]. The investigations are currently extended to the decay of the low-lying isomeric 0^+ state in ^{72}Kr.

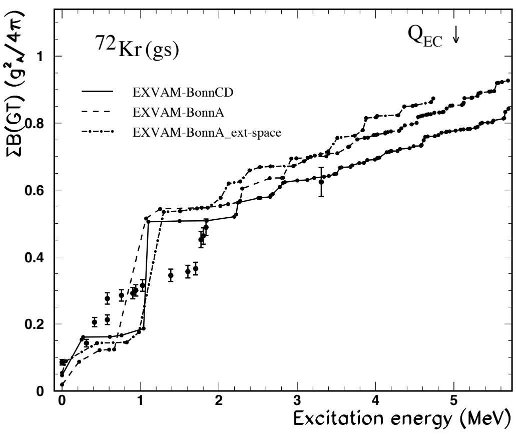

Figure 1: The accumulated Gamow-Teller strength for the decay of ^{72}Kr obtained within the *complex* Excited Vampir model using Bonn A (Bonn CD) potential and different model spaces compared to data [4].

3. Coexistence phenomena in neutron-rich A∼100 nuclei

3.1. Sape coexistence and shape evolution in neutron-rich A∼100 nuclei

For neutron-rich nuclei in the region the N=58 is considered a critical number of neutrons. We investigated the structural changes and the evolution of deformation with increasing spin aiming at a unitary description of the lowest few 0^+ states and the low, intermediate, and high spins in ^{96}Sr and ^{98}Zr. We studied the properties of the positive parity states up to spin 20^+ in the frame of the *complex* Excited Vampir model including in the many-nucleon bases up to 12 EXVAM configurations [2]. The theoretical lowest bands of ^{96}Sr and ^{98}Zr are compared to the experimental spectra in Figure 2. The labels of the bands indicate the prolate (p) or oblate (o) intrinsic quadrupole deformation for the dominant projected EXVAM configurations underlying the states of the corresponding bands. The states building the *po*(*p*)-band in each

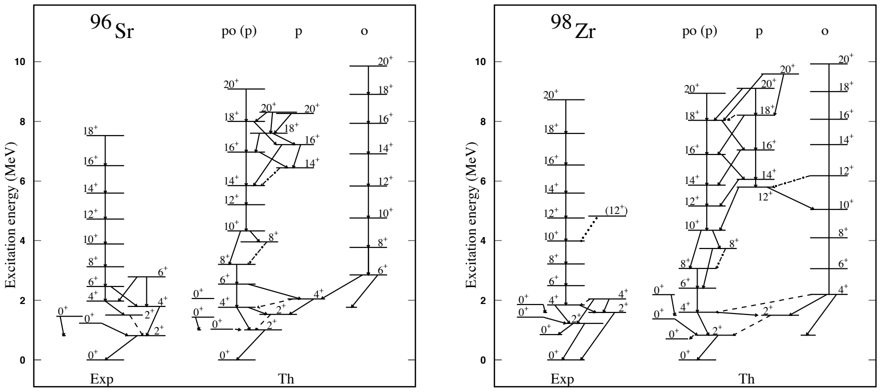

Figure 2: The EXVAM spectrum of ^{96}Sr (left) and ^{98}Zr (right) compared to data [6–8].

nucleus are characterized by strong prolate-oblate mixing at low spins and variable prolate mixing at intermediate and high spins. The almost pure oblate states belonging to the most right band in the theoretical spectrum are feeding the second 4^+ (2^+) state in ^{96}Sr (^{98}Zr) that manifests maximum o-p mixing.

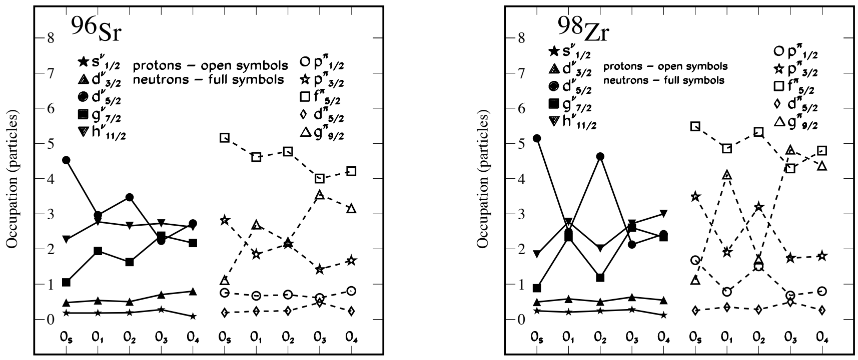

Figure 3: Occupation of valence spherical orbitals for 0^+ states in ^{96}Sr (left) and ^{98}Zr (right).

A particular situation is found for the 0^+ states: the lowest projected EXVAM configuration is spherical in both nuclei (the quadrupole deformation parameter amounts to $\beta_2 \simeq 0.03$). In ^{96}Sr the second 0^+ configuration is oblate deformed in the intrinsic system (β_2 = -0.32), the third one is prolate (β_2 = 0.37) and all three orthogonal configurations are situated in an energy interval of 375 keV. In ^{98}Zr the second configuration is prolate (β_2 = 0.37), the third is oblate (β_2 = -0.30) and the separation energy between the spherical one and the third one is 323 keV. The occupation of the relevant valence single-particle orbitals for the spherical 0^+ EXVAM configuration (the first state in the row for each nucleus) and for the lowest four 0^+ states in ^{96}Sr and ^{98}Zr are presented in Figure 3.

3.2. Gamow-Teller β-decay of neutron-rich A∼100 nuclei

Aiming at a unitary description of the structure and dynamics of neutron-rich nuclei in the A∼100 mass region we extended our investigations to the Gamow-Teller β-decay of the even-even and odd-odd isotopes studying the strength distributions, β-decay half-lives, and β-delayed neutron emission probabilities [5, 10]. We shall present some results on the Gamow-Teller β-decay properties of ^{102}Tc to ^{102}Ru and of ^{104}Tc to ^{104}Ru within the *complex* Excited Vampir model compared to recent results of the total absorption gamma spectrometer (TAGS) measurements [9, 10].
We calculated the lowest 1^+ states in ^{102}Tc and the positive-parity states up to spin 4^+ in ^{102}Ru. The obtained results indicate that the structure of the wave function for the lowest 1^+ state of ^{102}Tc manifests a

strong mixing of differently deformed prolate and oblate configurations in the intrinsic system. In ^{104}Tc the results indicate completely different structure properties. The 3^+ parent state is dominated by one prolate component which represents more than 99% of the total amplitude. The daughter states in ^{102}Ru and ^{104}Ru manifest variable prolate-oblate mixing.

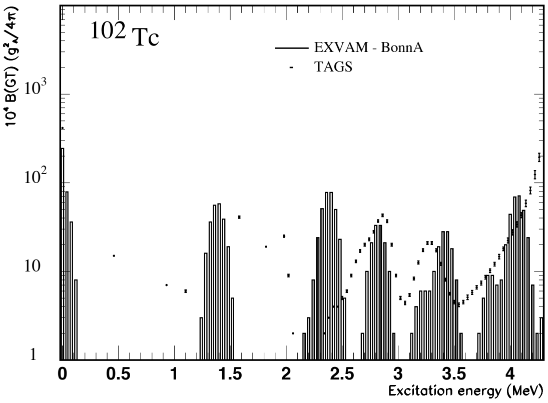

Figure 4: The Gamow-Teller strength distribution for the decay of ^{102}Tc obtained within the *complex* Excited Vampir model compared to TAGS data [9, 10].

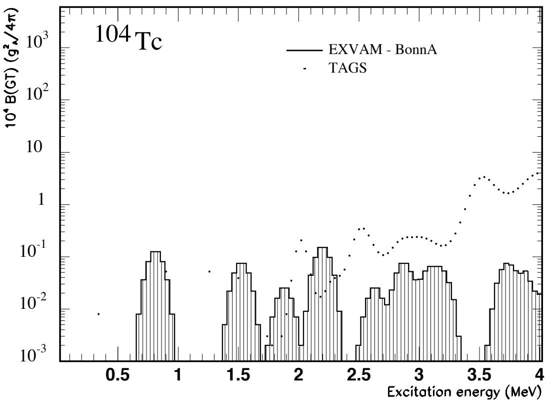

Figure 5: The Gamow-Teller strength distribution for the decay of ^{104}Tc obtained within the *complex* Excited Vampir model compared to TAGS data [9, 10].

The Gamow-Teller strength distribution for the decay of the 1^+ parent state in ^{102}Tc to the calculated 0^+ and 2^+ daughter states in ^{102}Ru is compared to TAGS results in Figure 4. The Gamow-Teller strength distribution for the decay of the 3^+ parent state in ^{104}Tc to the calculated 2^+ and 4^+ daughter states in ^{104}Ru is compared to TAGS results in Figure 5. The specific mixing of prolate and oblate projected configurations in the structure of the parent state as well as the daughter states is responsible for the significant difference in the Gamow-Teller β-decay properties of ^{102}Tc and ^{104}Tc found experimentally [10].

4. Conclusion

In the present paper we presented results obtained within the *complex* Excited Vampir variational approach using realistic effective interactions and a large model space on the structure and dynamics of medium mass nuclei near the drip lines. This approach going beyond-mean-field approximation allows to describe self-consistently the coexistence phenomena characteristic for proton-rich nuclei in the A∼70 mass region as well as neutron-rich nuclei in the A∼100 region.

5. Acknowledgments

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