Nuclear matter properties from energies of giant resonances

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The development of a modern and more realistic nuclear energy density functional (EDF) for accurate predictions of properties of nuclei is the subject of enhanced activity, since it is very important for the study of properties of rare nuclei with unusual neutron-to-proton ratios that are difficult to produce experimentally and likely to exhibit interesting new phenomena associated with isospin, clusterization and the continuum. Adopting the standard parametrization of the Skyrme type interactions, it is common to determine the parameters of the EDF within the Hartree-Fock (HF) mean-field approximation by carrying out a fit to an extensive set of data on; (i) binding energies, (ii) single-particle energies, and (iii) charge root-mean-square (rms) radii. This approach has resulted with over 200 EDFs associated with the Skyrme type effective nucleon-nucleon interaction.

To better determine the values of the Skyrme parameters, we investigate the sensitivities of the centroid energies E_{CEN} of the isoscalar and isovector giant resonances of multipolarities $L = 0 - 3$ in ^{40}Ca and ^{48}Ca. For this purpose, we have carried out fully self-consistent Hartree-Fock (HF) based RPA calculations of the isoscalar ($T = 0$) giant monopole resonance (ISGMR), dipole (ISGDR), quadrupole (ISGQR), and the octopole (ISGOR) strength functions, and for the isovector ($T = 1$) giant monopole resonance (IVGMR), dipole (IVGDR), quadrupole (IVGQR) and octopole (IVGOR) strength functions, for ^{40}Ca and for ^{48}Ca, using a wide range of over 15 commonly employed Skyrme type interaction. These interactions, which were fitted to ground state properties of nuclei are associated with a wide range of nuclear matter properties such as incompressibility coefficient K_{NM} = 200 - 255 MeV, symmetry energy J = 27 - 37 MeV and effective mass m* = 0.6 - 1.0. We investigate the sensitivities of E_{CEN} and of the isotopic differences $\Delta E_{CEN} = E_{CEN}(^{48}\mathrm{Ca}) - E_{CEN}(^{40}\mathrm{Ca})$ to physical quantities of nuclear matter (NM), such as the effective mass m*; the incompressibility coefficient $K_{NM} = -9\rho_0^2 \frac{d^2(E/A)}{d\rho^2}\Big|_{\rho_0}$; the symmetry energy coefficient $J = E_{sym}(\rho_0)$; the symmetry energy at 0.1 fm^{-3}, $J(0.1) = E_{sym}(0.1)$ the coefficient proportional to the slope, $L = 3\rho_0 \frac{d(E_{sym})}{d\rho}\Big|_{\rho_0}$, and the curvature $K_{sym} = 9\rho_0^2 \frac{d^2(E_{sym})}{d\rho^2}\Big|_{\rho_0}$ of the density dependence of the symmetry energy, respectively, κ , the enhancement factor of the energy weighted sum rule for the IVGDR, and the strength of the spin-orbit interaction W_0.

In Table I and II we present the Pearson Correlation Coefficients between the values of E_{CEN} and ΔE_{CEN} of the isoscalar and isovector giant resonances, respectively, and the properties of NM. It is seen from the Tables that strong correlations were found between the energies of compression modes (ISGMR and ISGDR) and K_{NM}, and between the energies of the ISGQR (and ISGOR) and m*. However, weak correlations were found between IVGDR in ^{40}Ca and ^{48}Ca and the values of J, L, or $K_{sym.}$

Table I. Pearson's correlation coefficient between the energies of Isoscalar (T=0) giant multipole (L=0-3) resonances and NM properties

				m*/m	K_{NM}	J	J(0.1)	L	K_{sym}	J(0.1)/J	κ	$W_0(X_W=1)$
L0	T0	Ca 40	E_{CEN}	-0.71	0.95	0.39	-0.29	0.76	0.86	-0.65	-0.02	0.02
L0	T0	Ca 48	E_{CEN}	-0.85	0.85	0.29	-0.41	0.73	0.87	-0.66	0.16	0.30
L0	T0		ΔE_{CEN}	-0.59	0.13	-0.07	-0.40	0.21	0.36	-0.29	0.41	0.69
L1	T0	Ca 40	E_{CEN}	-0.86	0.88	0.35	-0.38	0.77	0.92	-0.69	0.05	0.23
L1	T0	Ca 48	E_{CEN}	-0.94	0.82	0.25	-0.26	0.58	0.82	-0.50	0.03	0.43
L1	T0		ΔE_{CEN}	-0.71	0.32	-0.07	0.12	-0.10	0.24	0.16	-0.02	0.53
L2	T0	Ca 40	E_{CEN}	-0.96	0.76	0.29	-0.25	0.61	0.85	-0.53	-0.04	0.50
L2	T0	Ca 48	E_{CEN}	-0.98	0.68	0.25	-0.25	0.54	0.80	-0.48	0.03	0.57
L2	T0		ΔE_{CEN}	-0.56	-0.04	-0.10	-0.14	-0.03	0.18	-0.02	0.32	0.48
L3	T0	Ca 40	E_{CEN}	-0.96	0.77	0.30	-0.19	0.58	0.83	-0.49	-0.03	0.41
L3	T0	Ca 48	E_{CEN}	-0.98	0.68	0.20	-0.27	0.51	0.79	-0.45	0.06	0.59
L3	T0		ΔE_{CEN}	-0.25	-0.17	-0.32	-0.33	-0.13	0.01	0.03	0.35	0.56

Table II. Pearson's correlation coefficient between the energies of Isovector (T=1) giant multipole (L=0-3) resonances and NM properties

				m*/m	K_{NM}	J	J(0.1)	L	K_{sym}	J(0.1)/J	κ	$W_0(X_W=1)$
L0	T1	Ca 40	E_{CEN}	-0.43	0.69	0.09	-0.41	0.48	0.48	-0.43	0.43	0.01
L0	T1	Ca 48	E_{CEN}	-0.56	0.58	-0.03	-0.60	0.46	0.52	-0.48	0.63	0.36
L0	T1		ΔE_{CEN}	-0.36	-0.06	-0.21	-0.47	0.09	0.20	-0.21	0.51	0.70
L1	T1	Ca 40	E_{CEN}	-0.03	0.08	-0.27	0.03	-0.30	-0.32	0.32	0.58	-0.01
L1	T1	Ca 48	E_{CEN}	-0.17	0.07	-0.32	-0.15	-0.24	-0.21	0.21	0.70	0.25
L1	T1		ΔE_{CEN}	-0.42	0.00	-0.20	-0.49	0.11	0.24	-0.24	0.47	0.68
L2	T1	Ca 40	E_{CEN}	-0.68	0.51	-0.01	-0.19	0.20	0.33	-0.15	0.60	0.43
L2	T1	Ca 48	E_{CEN}	-0.70	0.39	-0.14	-0.32	0.14	0.31	-0.13	0.64	0.66
L2	T1		ΔE_{CEN}	-0.47	-0.03	-0.37	-0.47	-0.06	0.14	-0.04	0.47	0.71
L3	T1	Ca 40	E_{CEN}	-0.71	0.58	0.13	-0.21	0.38	0.53	-0.30	0.40	0.37
L3	T1	Ca 48	E_{CEN}	-0.73	0.53	0.01	-0.22	0.26	0.43	-0.19	0.48	0.42
L3	T1		ΔE_{CEN}	0.30	-0.38	-0.33	0.06	-0.45	-0.45	0.39	-0.02	-0.11

[1] M.R. Anders *et al.*, in preparation.