Spectroscopy of light nuclei through χEFT-based PGCM calculations

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Motivations

- Progress in *ab initio* description of atomic nuclei
  - Development of new methods but also revisiting old ones
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  Egido, Physica Scripta 91, 073003 (2016)

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- Many advantages
  - Efficient at capturing static correlations (e.g. deformation)
  - Respects the symmetries of H
  - Access to excited states and various observables
  - Gentle scaling: mean field $\times$ large prefactor

PGCM: main principles

- Approximate wave function

$$|\Psi^{\sigma}_{\epsilon}\rangle = \sum_i f^{\sigma}_{\epsilon,i} P^{\sigma} |\Phi_i\rangle \quad \text{where} \quad \sigma \equiv Z, N, J, M, K, \pi$$

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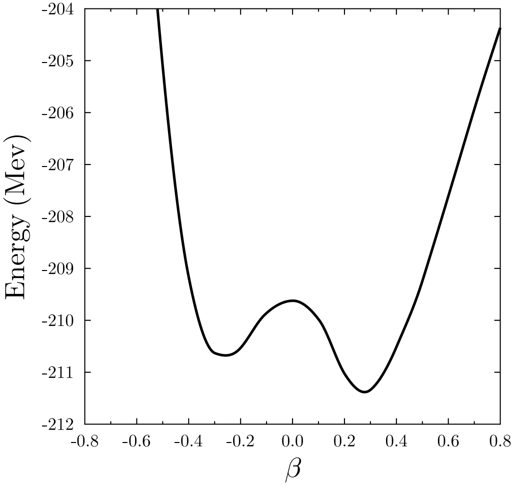
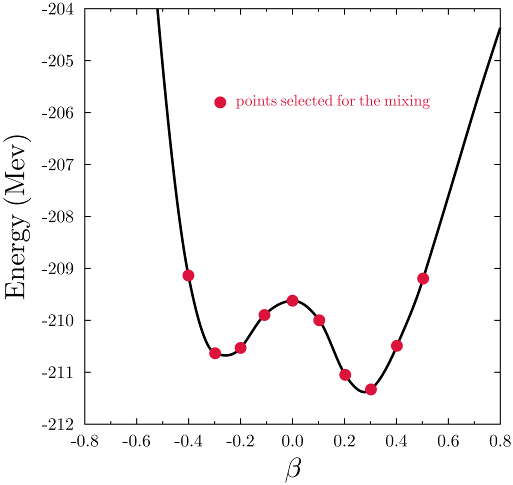
PGCM: schematic example



PGCM: schematic example



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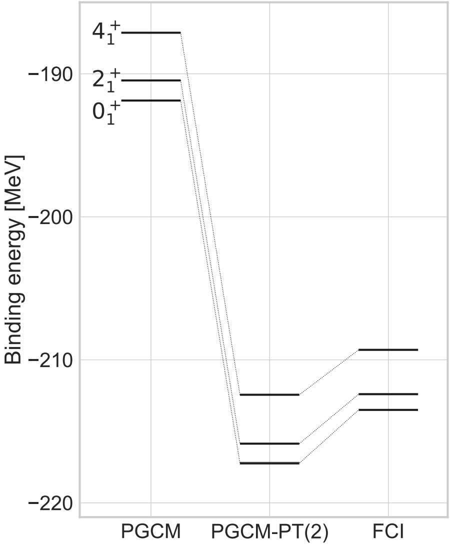
- New formalism: PGCM - Perturbation Theory (PGCM-PT)

  Frosini, EPJA 58, 62 (2022); Frosini, EPJA 58, 63 (2022); Frosini, EPJA 58, 64 (2022)

  - Multi-reference perturbation theory on top of a PGCM reference state
  - Includes missing dynamical correlations

PGCM-PT: example of ^{20}Ne



Spectroscopy of ^{20}O and ^{16}C (preliminary)

- ^{20}O: Recent experimental results compared with *ab initio* calculations
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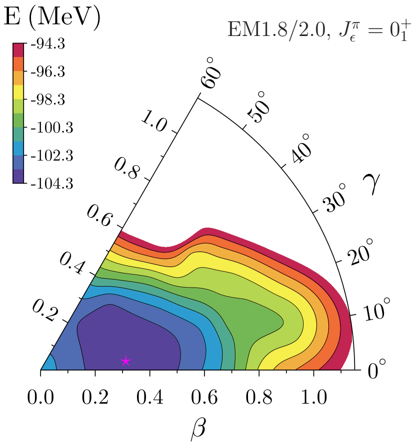
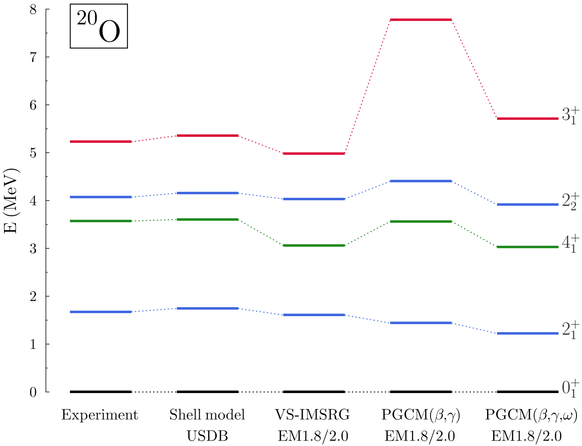
- Details of the calculation
  - Hamiltonians: EM1.8/2.0, Hüther N3LO
    Hebeler, PRC 83, 031301 (2011); Hüther, PLB 808, 135651 (2020)
  - Rank-reduction of 3N to an effective 2N
    Frosini, EPJA 57, 151 (2021)
  - $e_{max} = 6$ (7 HO shells), $e_{3max} = 18$, $\hbar\omega = 12$
  - Collective coordinates: triaxial deformations (β, γ), cranking (ω)

Spectroscopy of ^{20}O (preliminary)



- Minimum only slightly triaxial: $\beta \approx 0.31$, $\gamma \approx 6^{\circ}$

Spectroscopy of ^{20}O (preliminary)



[Data partly taken from Zanon, PRL 131, 262501 (2023)]

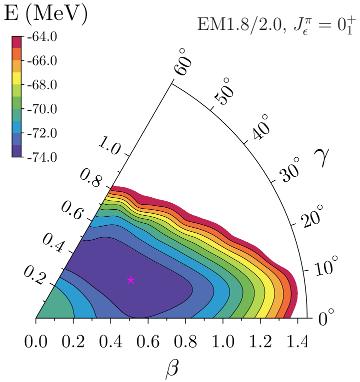
- PGCM(β, γ, ω) consistent with VS-IMSRG calculations

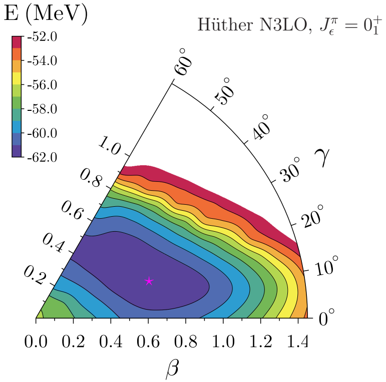
Spectroscopy of ^{20}O (preliminary)

$B(E2)$ ($e^2 fm^4$)	Experiment	Shell model USDB	VS-IMSRG EM1.8/2.0	PGCM(β,γ) EM1.8/2.0	PGCM(β,γ,ω) EM1.8/2.0
$2_1^+ \to 0_1^+$	5.9(2)	3.25	0.89	1.59	1.33
$2_2^+ \to 0_1^+$	1.3(2)	0.77	0.20	0.45	0.45
$2_2^+ \to 2_1^+$	4(2)	0.0005	0.07	0.01	0.006
$3_1^+ \to 2_1^+$	0.32(7)	0.57	0.17	1.13	0.34

- Theory does not reproduce experimental data
  (not shown here but works slightly better for $B(M1)$)
- Cranking does not change much the transition probabilities
  $\to$ but better for 3_1^+

Spectroscopy of ^{16}C (preliminary)





- Similar energy surfaces but EM1.8/2.0 more rigid
- Triaxial minima: 0.55, 22° (EM1.8/2.0) and 0.63, 18° (Hüther N3LO)

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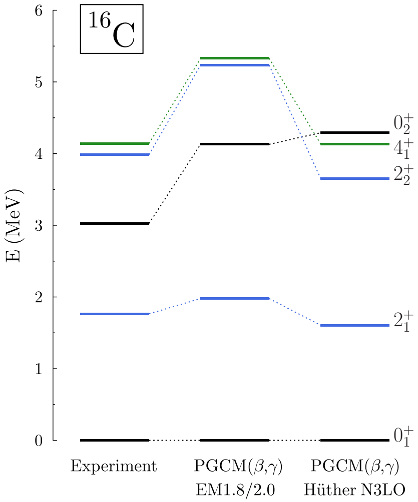

- Preliminary predictions, e.g. need to add cranking

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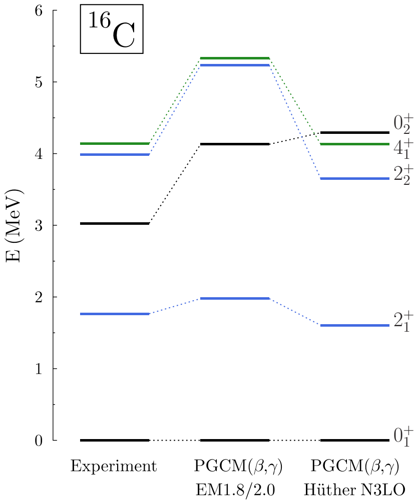

Quantity	EM1.8/2.0	Hüther N3LO
$\mu(2_1^+)$	+0.11	+0.19
$\mu(2_2^+)$	+0.54	+0.94
$\mu(4_1^+)$	-0.30	-0.03
$Q_s(2_1^+)$	-3.4	-4.0
$Q_s(2_2^+)$	+4.0	+4.4
$Q_s(4_1^+)$	-5.5	-8.1
$B(E2 : 2_1^+ \to 0_1^+)$	3.2	5.3
$B(E2 : 4_1^+ \to 2_1^+)$	2.2	3.0
$B(E2 : 2_2^+ \to 2_1^+)$	3.6	7.3
$B(E2 : 0_2^+ \to 2_1^+)$	2.3	4.1

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Conclusions

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  - Use of χEFT-based Hamiltonians
  - Formulation of PGCM-PT
  - Work remains to make the whole scheme more systematic/controllable

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- Useful tool to describe low-energy spectroscopy
  - Captures important collective correlations
  - Conserves symmetries and associated selection rules for transitions
  - Access to various observables of interest (J^π, E_{exc}, Q_s, μ, $B(T\lambda)$, ...)

- Good descripton of ^{20}O and ^{16}C spectra

Collaborators

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