^{7}Li in the no-core shell model with continuum framework with coupling of mass partitions

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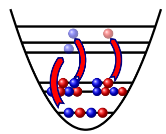
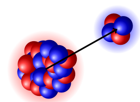
No-core shell model with continuum (NCSMC)

- Describes both bound and scattering states

- Wave function expanded in terms of NCSM eigenstates and NCSM/RGM binary-cluster states:

$$\Psi = \sum_{\lambda} c_{\lambda} \, |$$

$$\rangle + \sum_{\nu} \int dr \, u_{\nu}(r) \, |$$

$$\rangle$$

r ... parameter coordinate playing role of distance between clusters
$u_{\nu}(r)$ ... continuous amplitudes representing intercluster relative motion

- For scattering states asymptotic form of $u_{\nu}(r)$ determines scattering matrix $\rightarrow$ eigenphase shifts, properties of resonances, cross sections

- Distribution of nucleons between clusters is called "mass partition"

NCSMC calculations for ^{7}Li

- Motivation: nuclear astrophysics, primordial nucleosynthesis, ^{3}H for fusion energy generation via ^{6}Li(n,^{3}H)^{4}He

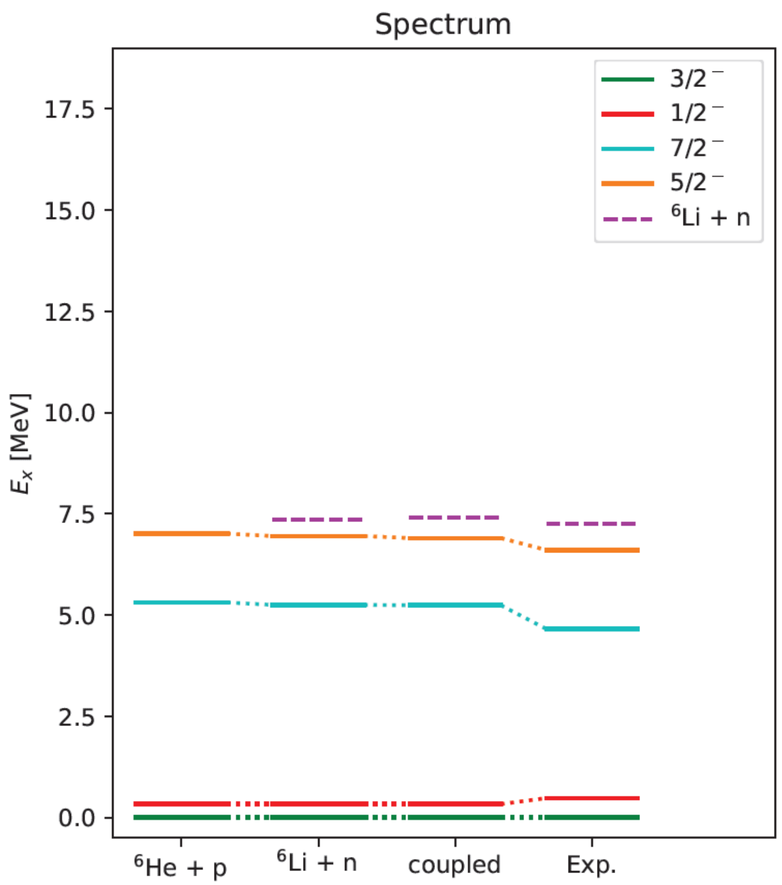
- We couple mass partitions ^{6}Li + n and ^{6}He + p

- Coupling of mass partitions allows for calculation of charge-exchange reaction ^{6}Li$(n, p)^6$He

- Chiral N^{3}LO nucleon-nucleon interaction used, 3-nucleon interaction neglected

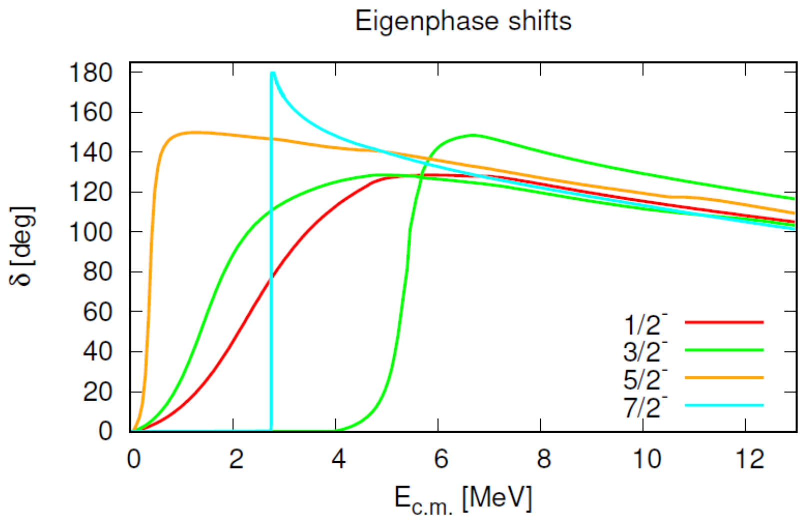
Bound-state energies for ^{7}Li

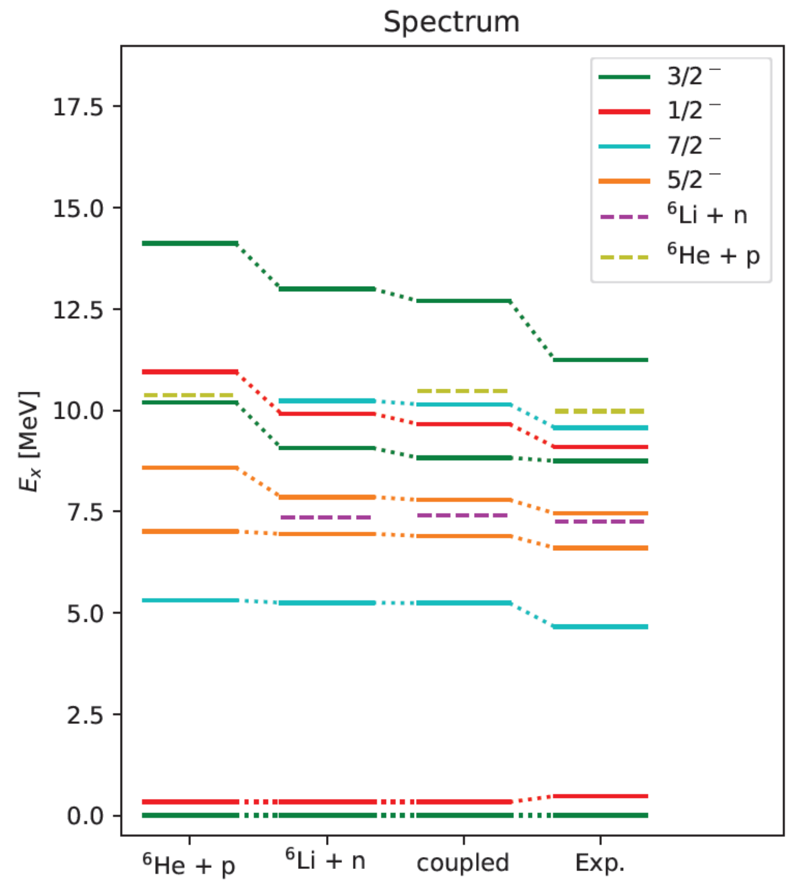
J^π	coupled E [MeV]	Exp. E [MeV]	^{6}Li + n E [MeV]	^{6}He + p E [MeV]
$3/2^-_1$	-38.14	-39.25	-38.11	-38.03
$1/2^-_1$	-37.81	-38.77	-37.78	-37.70
$7/2^-_1$	-32.90	-34.60	-32.86	-32.72
$5/2^-_1$	-31.24	-32.65	-31.16	-31.02



- Good agreement between calculated and experimental energies
- Results independent of mass partition - bound states well described by NCSM

Reproduced resonances in ^{7}Li

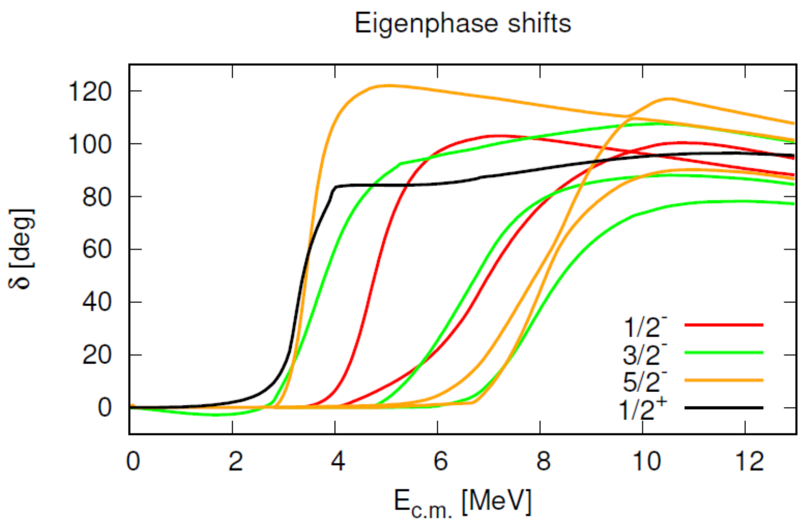


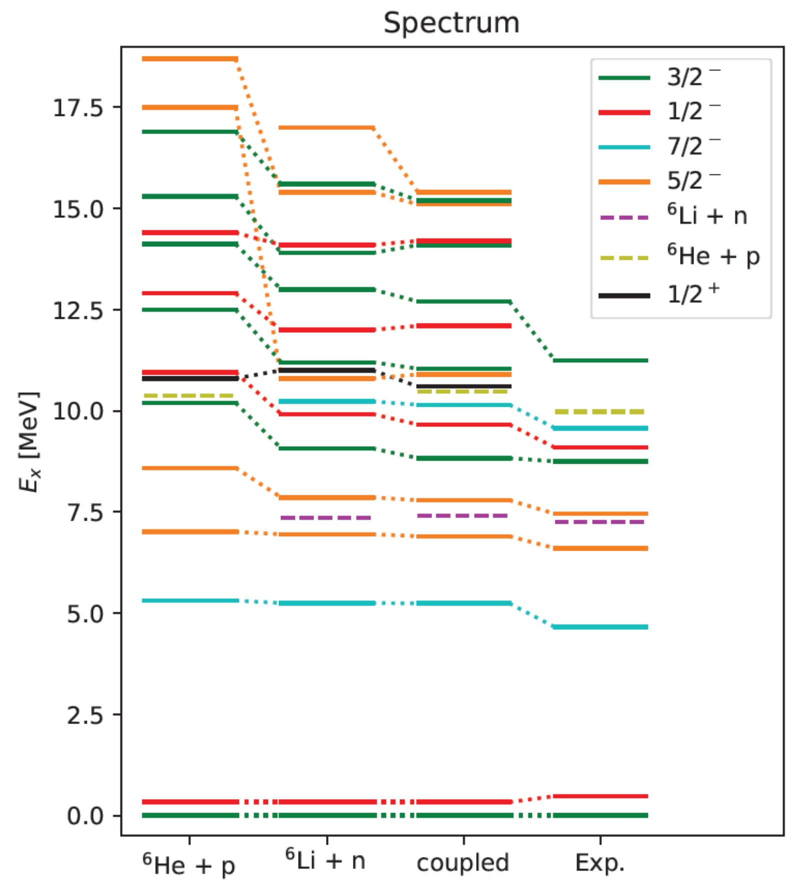


J^π	coupled Γ [MeV]	Exp. Γ [MeV]	^{6}Li + n Γ [MeV]
$5/2_2^-$	0.21	0.080	0.25
$3/2_2^-$	1.64	4.712	1.56
$1/2_2^-$	2.63	2.752	2.45
$7/2_2^-$	0.00008	0.427	0.02
$3/2_3^-$	1.6	0.26	4

- Experimentally observed resonances reproduced in correct order
- Results depend on mass partition
- Discrepancy between calculated and experimental widths (except $1/2_2^-$)

Predicted resonances in ^{7}Li

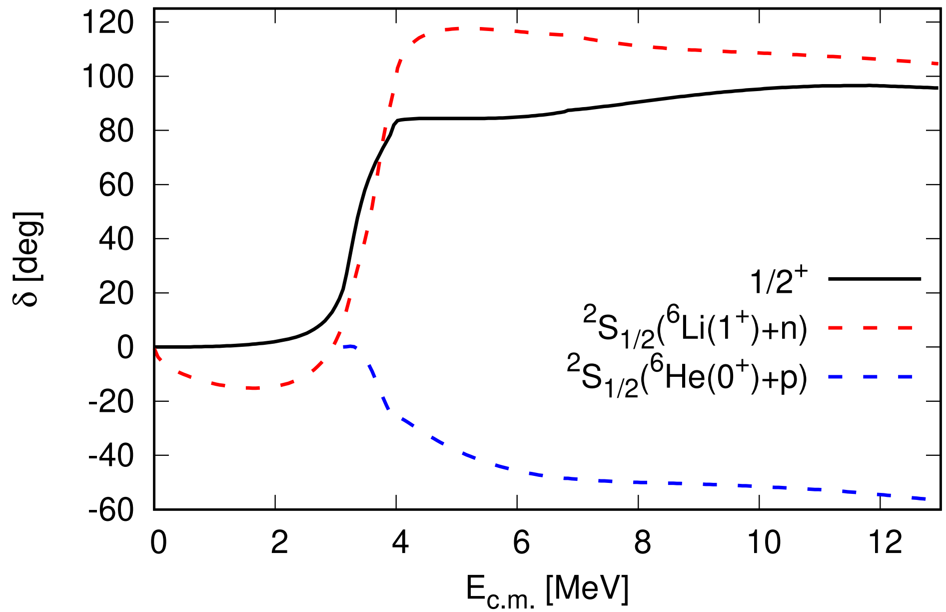




J^π	coupled Γ [MeV]	^{6}Li + n Γ [MeV]	^{6}He + p Γ [MeV]
$1/2^+_1$	1.0	1.2	0.32
$5/2^-_3$	0.7	0.8	6.8
$3/2^-_4$	2.0	2.6	0.3
$1/2^-_3$	1.4	1.3	0.2
$3/2^-_5$	3.4	3.5	5.7

- Two $1/2^-$, three $3/2^-$, three $5/2^-$ and one $1/2^+$ resonances predicted
- Results depend on mass partitions, effect of coupling

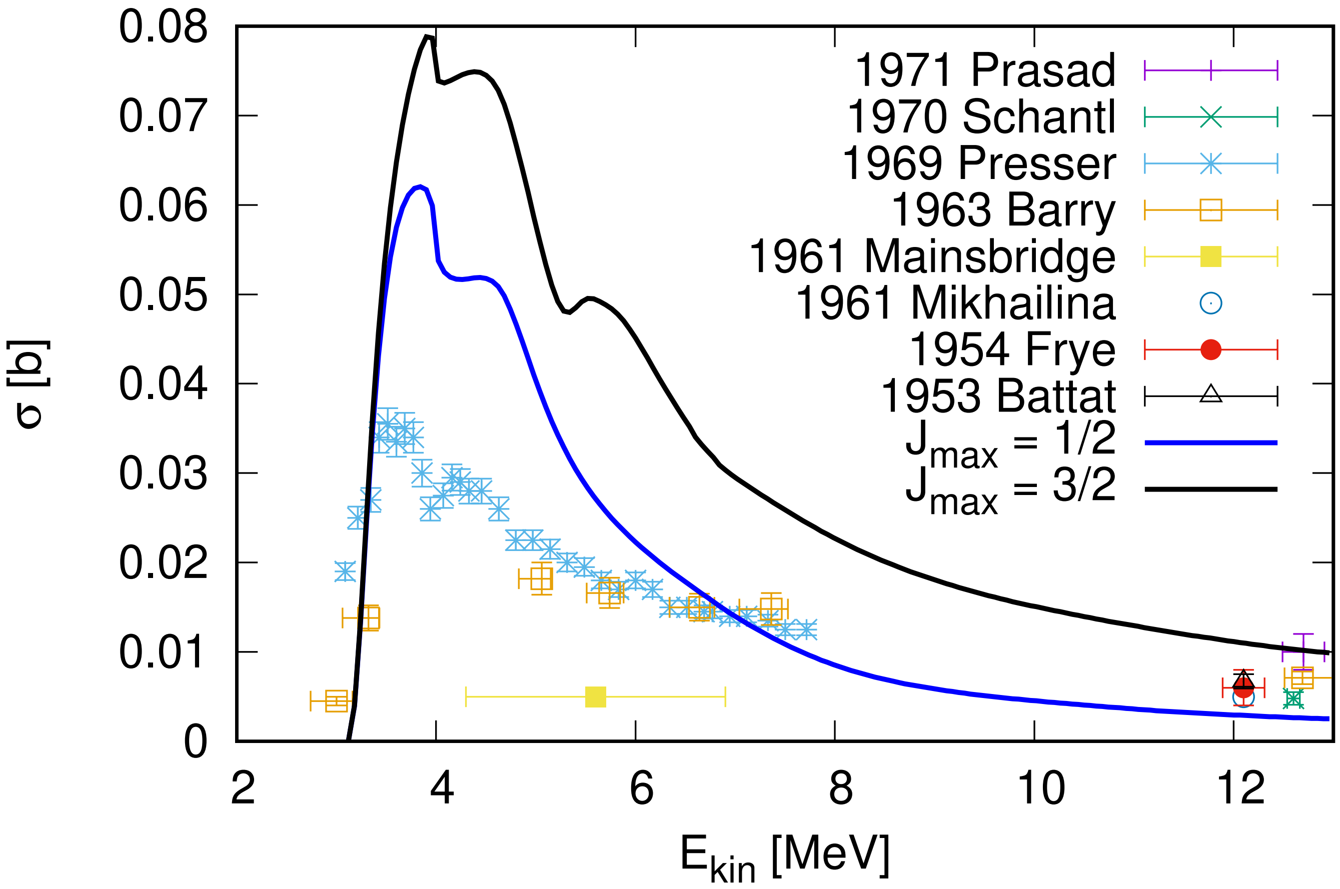
$1/2^+$ eigenphase shift and diagonal phase shifts



- Previous NCSMC calculations [1] neglecting coupling of mass partitions predict S-wave $1/2^+$ resonance in ^{6}He + p, but no such resonance was experimentally observed [2]
- The $1/2^+$ resonance is dominated by $^2S_{1/2}(^6\mathrm{Li}(1^+) + \mathrm{n})$ channel
- No $1/2^+$ resonance found in ^{6}He + p channels

[1] Vorabbi *et al.* Phys. Rev. C **100**, 024304 (2019)
[2] Dronchi *et al.* Phys. Rev. C **107**, L061303 (2023)

Cross section of ^{6}Li(n,p)^{6}He reaction



- Threshold and overall shape reproduced, values overestimated, missing channels

^{7}Li in the no-core shell model with continuum framework with coupling of mass partitions

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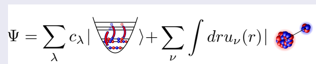
No-core shell model with continuum (NCSMC) [1]

- Describes both bound and scattering states
- System of nucleons described by intrinsic Hamiltonian

$$H = T_{\mathrm{rel}} + \sum_{i<j} V_{ij}$$

- Chiral N^{3}LO nucleon-nucleon interaction used
- Wave function expanded in terms of NCSM [2] eigenstates and NCSM/RGM [3,4] binary-cluster states:



$$\Psi = \sum_\lambda c_\lambda | \quad \rangle + \sum_\nu \int dr u_\nu(r) | \quad \rangle$$

r … parameter coordinate playing role of distance between clusters

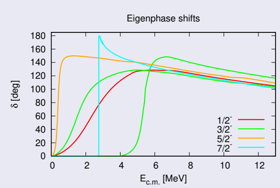
$u_\nu(r)$ … continuous amplitudes representing intercluster relative motion

- Distribution of nucleons between clusters is called "mass partition"
- Expansion coefficients c_λ and amplitudes $u_\nu(r)$ calculated by solving NCSMC equations on Lagrange mesh
- NCSMC equations can be solved for bound or scattering states by choosing asymptotic form of $u_\nu(r)$
- For scattering states asymptotic form of $u_\nu(r)$ determines scattering matrix → eigenphase shifts, properties of resonances, cross sections

Motivation

- Nuclear astrophysics, primordial nucleosynthesis, ^{3}H for fusion energy generation via ^{6}Li(n,^{3}H)^{4}He
- Previous work [5] taking into account relevant mass partitions separately predicts S-wave $1/2^+$ resonance in ^{6}He + p just above proton separation energy
- No such resonance was experimentally observed [6]
- We couple mass partitions ^{6}Li + n and ^{6}He + p
- We also predict S-wave $1/2^+$ resonance just above proton separation energy, but only in ^{6}Li + n channel
- Coupling of mass partitions allows for calculation of charge-exchange reaction ^{6}Li(n, p)^{6}He

Reproduced resonances

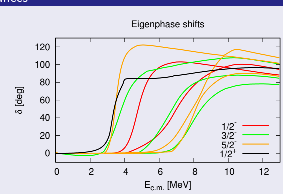


Widths

J^π	NCSMC Γ [MeV]	Exp. Γ [MeV]
$5/2^-_2$	0.21	0.080
$3/2^-_2$	1.64	4.712
$1/2^-_2$	2.63	2.752
$7/2^-_2$	0.00008	0.427
$3/2^-_3$	1.6	0.26

- Experimentally observed resonances reproduced in correct order
- Discrepancy between calculated and experimental widths

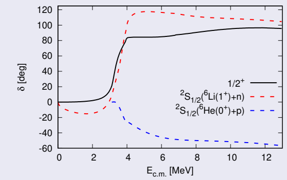
Predicted resonances



- Two $1/2^-$, three $3/2^-$, three $5/2^-$ and one $1/2^+$ resonances predicted

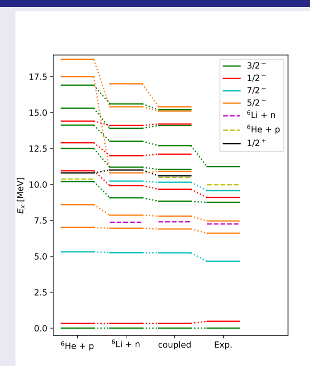
Predicted $1/2^+$ resonance

Eigenphase shift (solid line) and diagonal phase shifts (dashed lines):



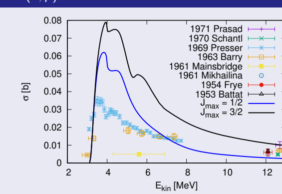
- The $1/2^+$ resonance is dominated by $^2S_{1/2}$(^{6}Li(1^+) + n) channel
- No $1/2^+$ resonance found in ^{6}He + p channels
- Discrepancy between previous NCSMC prediction and experiment explained

Spectrum



- Bound-state energies independent of mass partition - well described by NCSM
- Results for resonances depend on mass partition, effect of coupling

Cross section of ^{6}Li(n, p)^{6}He



- Threshold and overall shape reproduced, values overestimated, missing channels

References

[1] S. Baroni, P. Navrátil and S. Quaglioni, Phys. Rev. Lett. **110**, 022505 (2013)

[2] P. Navrátil, J. P. Vary and B. R. Barrett, Phys. Rev. Lett. **84**, 5728 (2000)

[3] S. Quaglioni and P. Navrátil, Phys. Rev. Lett. **101**, 092501 (2008)

[4] S. Quaglioni and P. Navrátil, Phys. Rev. C **79**, 044606 (2009)

[5] M. Vorabbi *et al.* Phys. Rev. C **100**, 024304 (2019)

[6] N. Dronchi *et al.* Phys. Rev. C **107**, L061303 (2023)