Ab initio approach for Exotic Nuclei : Ne isotopes

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  - NCSM : No-core Shell Model
  - Daejeon16 interaction
- Ne isotopes
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No core Shell Model

- No-core shell model / full configuration

  - All nucleons are treated as active degrees of freedom equally
  - We need more huge computing resources as mass number and matrix dimensions grow

A-nucleon Schrodinger equation

$$\hat{H}\,\Psi(r_1,\cdots,r_A) = E\,\Psi(r_1,\cdots,r_A)$$

Hamiltonian with *NN* (+*NNN*) interactions

$$\hat{H} = \frac{1}{A}\sum_{i<j}\frac{(\vec{p_i}-\vec{p_j})^2}{2m} + \sum_{i<j}V_{ij} + \sum_{i<j<k}V_{ijk} + \cdots$$

No core Shell Model

❖ No-core shell model / full configuration

Diagonalize Hamiltonian matrix

$$H_{ij} \equiv \langle \Phi_i | \hat{H} | \Phi_j \rangle$$

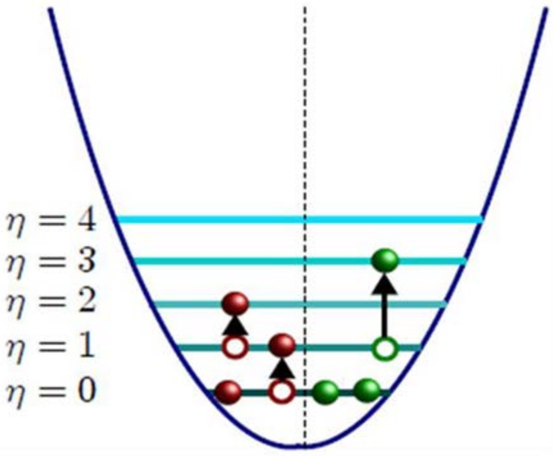
BUT infinite model space is impossible

=> Truncation is needed !

$$\sum_{k=1}^{A} (2\, n_{ik} + l_{ik}) \;\leq\; N_0 + N_{\text{max}}$$

The results of NCSM show N_{max} and **hΩ** dependence

$4\hbar\Omega$



Daejeon16

the flow parameter λ =1.5 fm^{-1}

Idaho N3LO χEFT *NN* interaction (EM)

N3LO interaction

SRG
(similarity renormalization group)

SRG-evolved N3LO

PET
(phase equivalent transformation)

Daejeon16

https://lib.dr.iastate.edu/energy_datasets/1/

Simplest PETs with continuous parameters are used to fit the B.E. of several light nuclei in NCSM calculations.

[A.M.Shirokov, I.J.Shin, Y.Kim, M.Sosonkina, P.Maris and J.P.Vary, "N3LO NN interaction adjusted to light nuclei in *ab exitu* approach," Phys. Lett. B **761**, 87 (2016)]

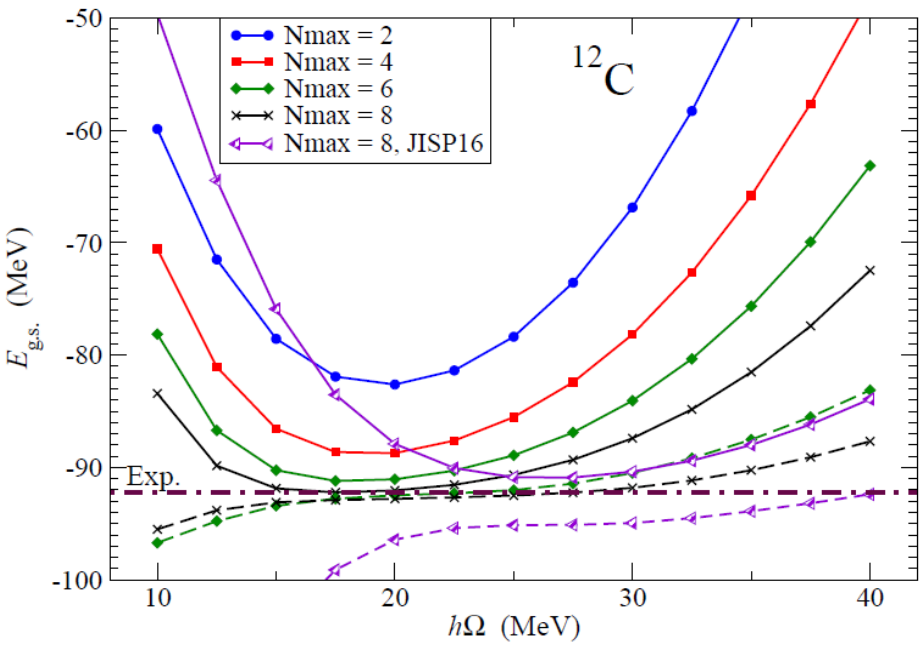
How to fit :

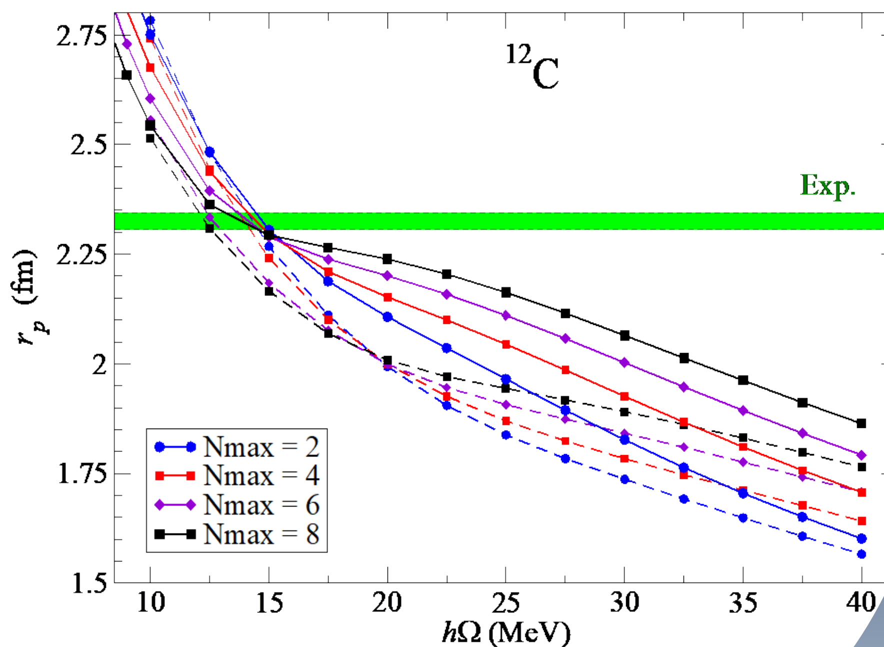
- ✓ using PETSc (TAO)
- ✓ ^{3}H, ^{4}He, ^{6}Li(+2ex), ^{10}B, ^{12}C(+1ex), ^{16}O and ^{8}He
- ✓ target values are estimated from comparison between the results of NCSM calculation and experimental values

Wave	$^1s_0$	$^3sd_1$	$^1p_1$	$^3p_0$	$^3p_1$	$^3pf_2$	$^3d_2$
Angle	-2.997	4.461	5.507	1.785	4.299	-2.031	7.833

Daejeon16

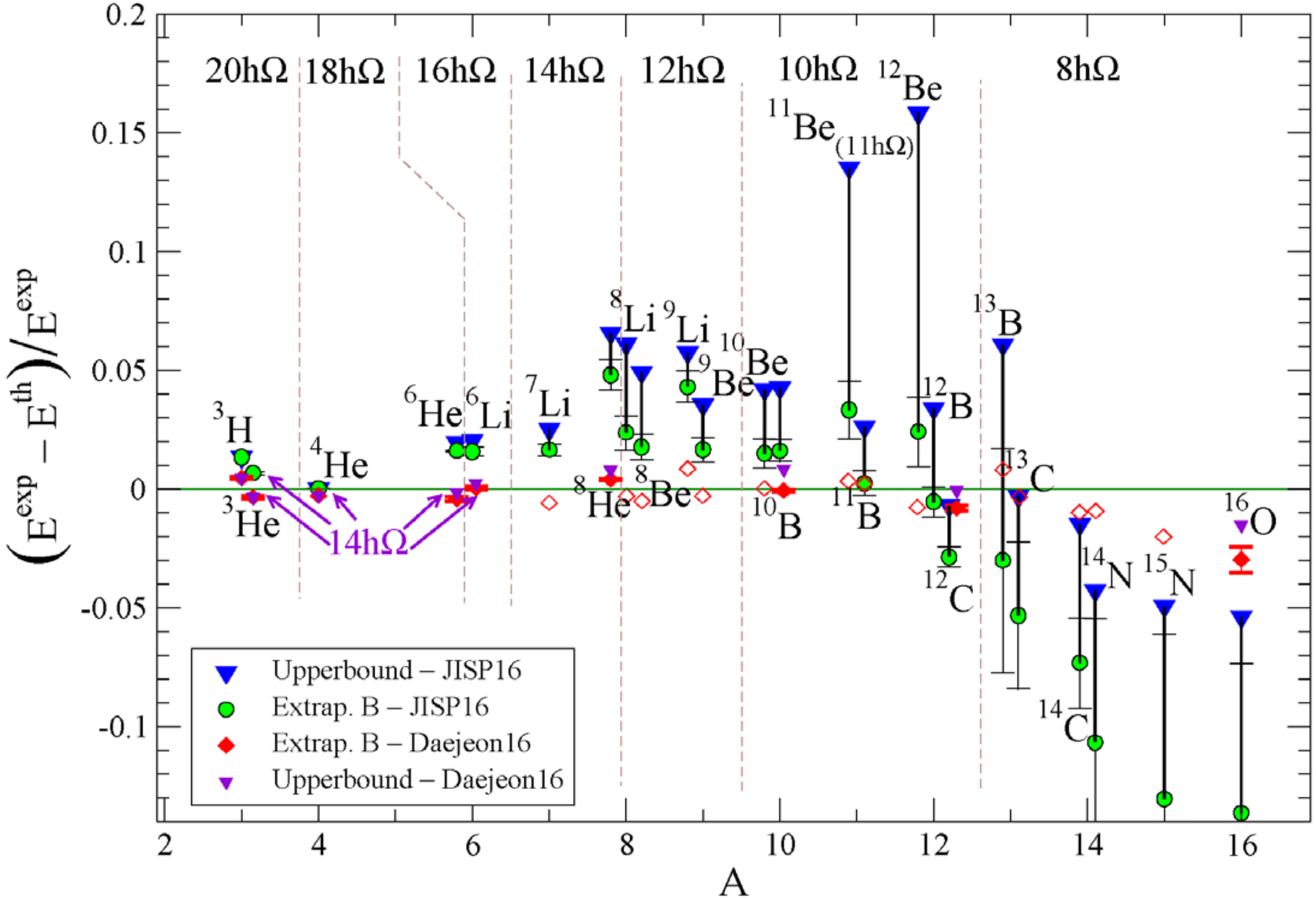
- Good convergence of NCSM calculations
- Good descriptions of binding energies and spectra
- Improved description of other observables, e.g., rms radii





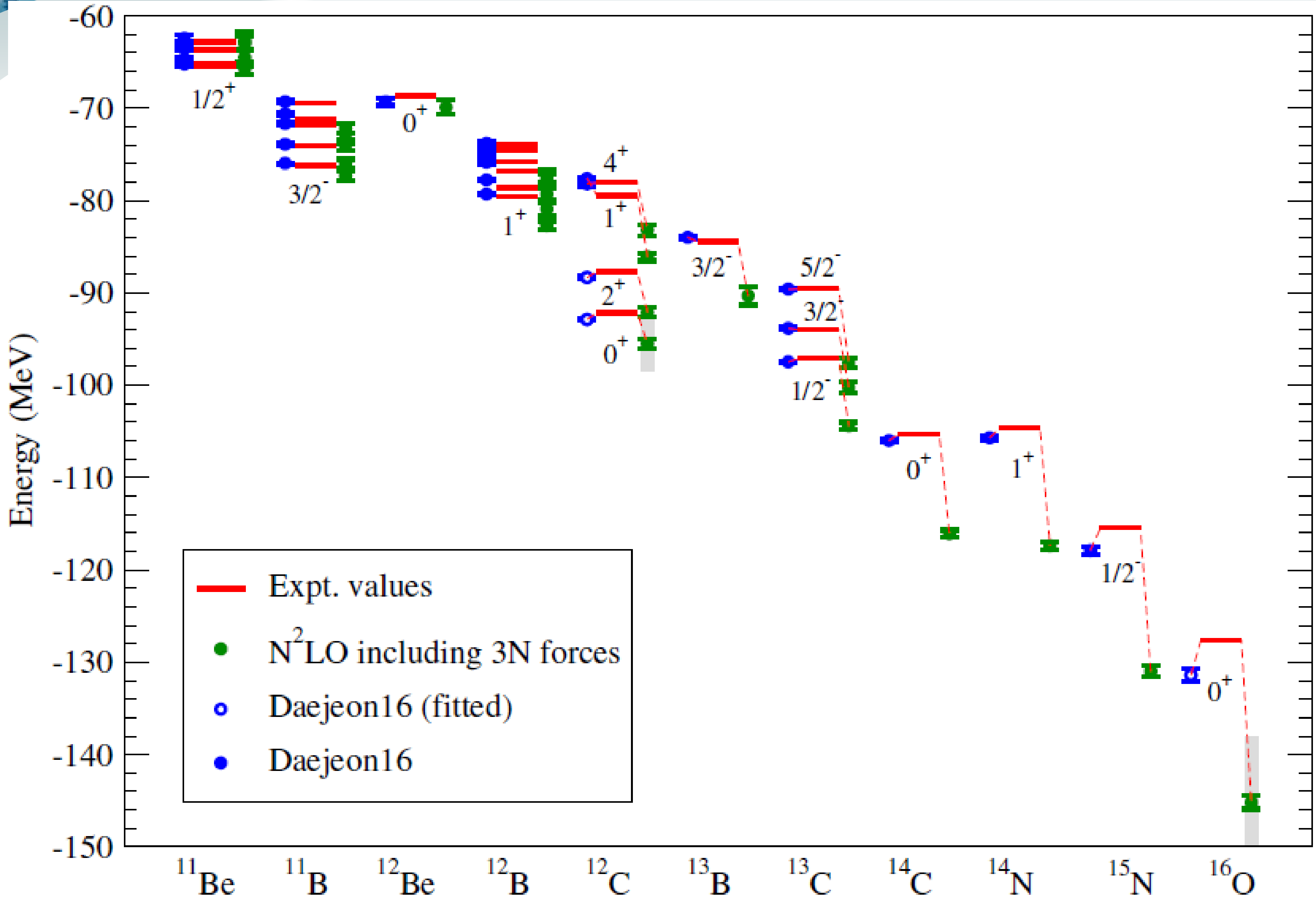
[A.M.Shirokov, *et al.*, Phys. Lett. B **761**, 87 (2016)]

Daejeon16



20hΩ
18hΩ
16hΩ
14hΩ
12hΩ
10hΩ
8hΩ
14hΩ
(11hΩ)
0.2
0.15
0.1
0.05
0
-0.05
-0.1
2
4
6
8
10
12
14
16
A
(E^exp – E^th)/E^exp
Upperbound – JISP16
Extrap. B – JISP16
Extrap. B – Daejeon16
Upperbound – Daejeon16

Daejeon16



Energy (MeV)
-60
-70
-80
-90
-100
-110
-120
-130
-140
-150
1/2+
3/2-
0+
1+
4+
1+
2+
0+
3/2-
5/2-
3/2-
1/2-
0+
1+
1/2-
0+
Expt. values
N2LO including 3N forces
Daejeon16 (fitted)
Daejeon16
11Be
11B
12Be
12B
12C
13B
13C
14C
14N
15N
16O

Exotic nuclei

❖ ^{14}F

^{14}F : Z=9 and N=5
even though including *sd*-shell,
it seems to be reasonable

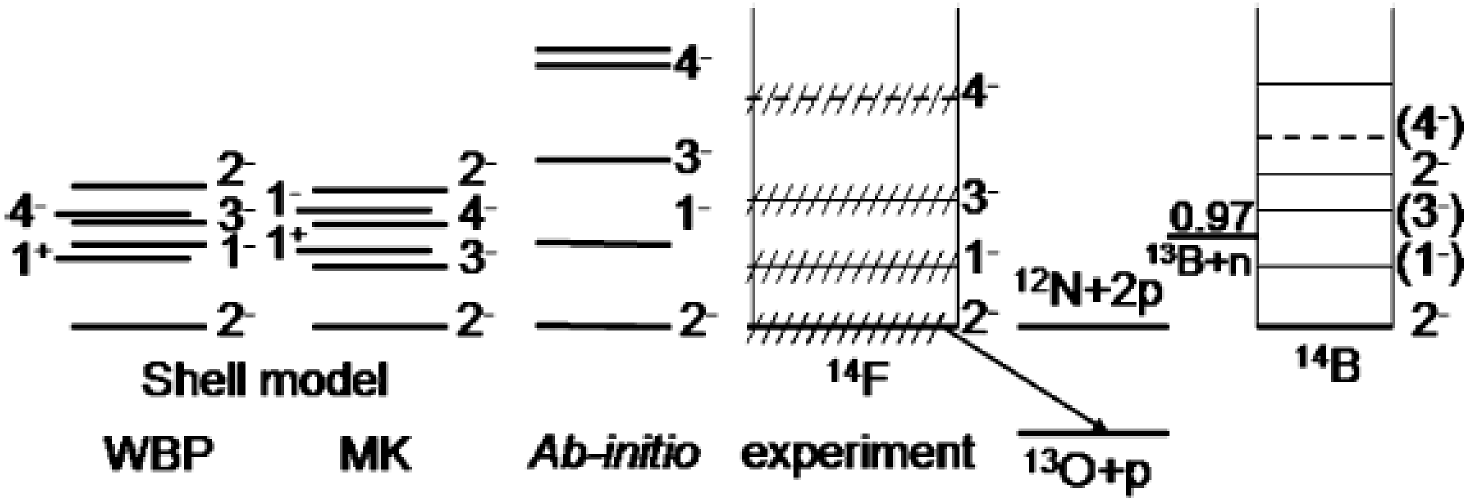
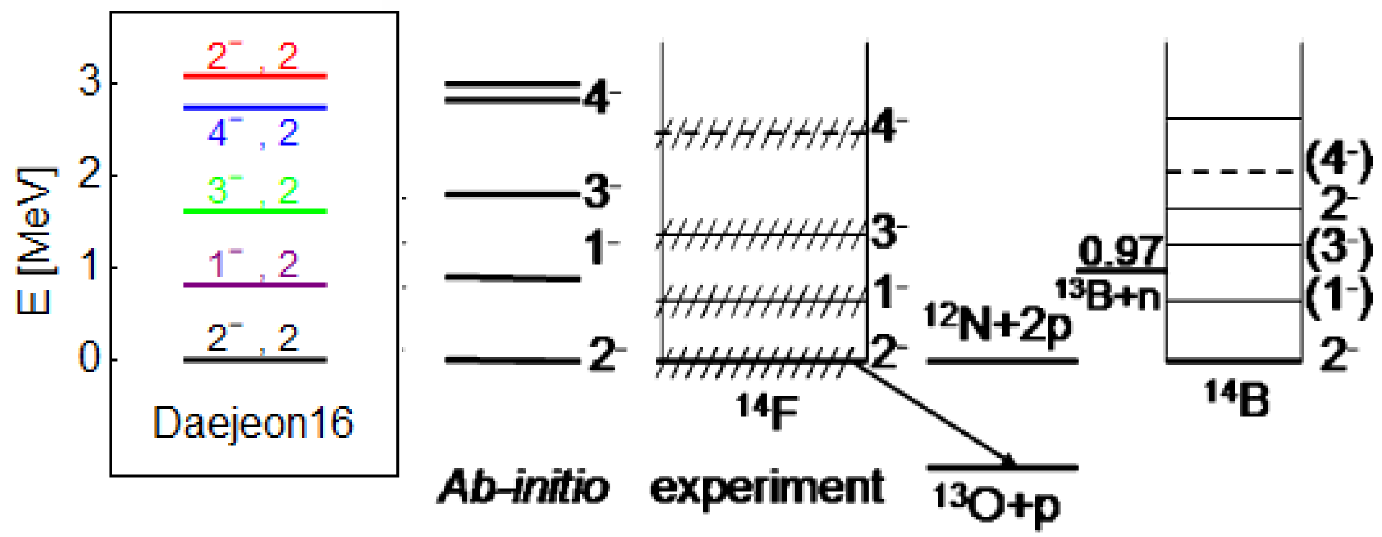


Fig. 6. ^{14}F level scheme from this work compared with shell-model calculations, *ab-initio* calculations [3] and the ^{14}B level scheme [16]. The shell model calculations were performed with the WBP [21] and MK [22] residual interactions using the code COSMO [23].

[V.G.Goldberg, *et al.*, Phys. Lett. B **692**, 307 (2010)]

Exotic nuclei

- ^{14}F



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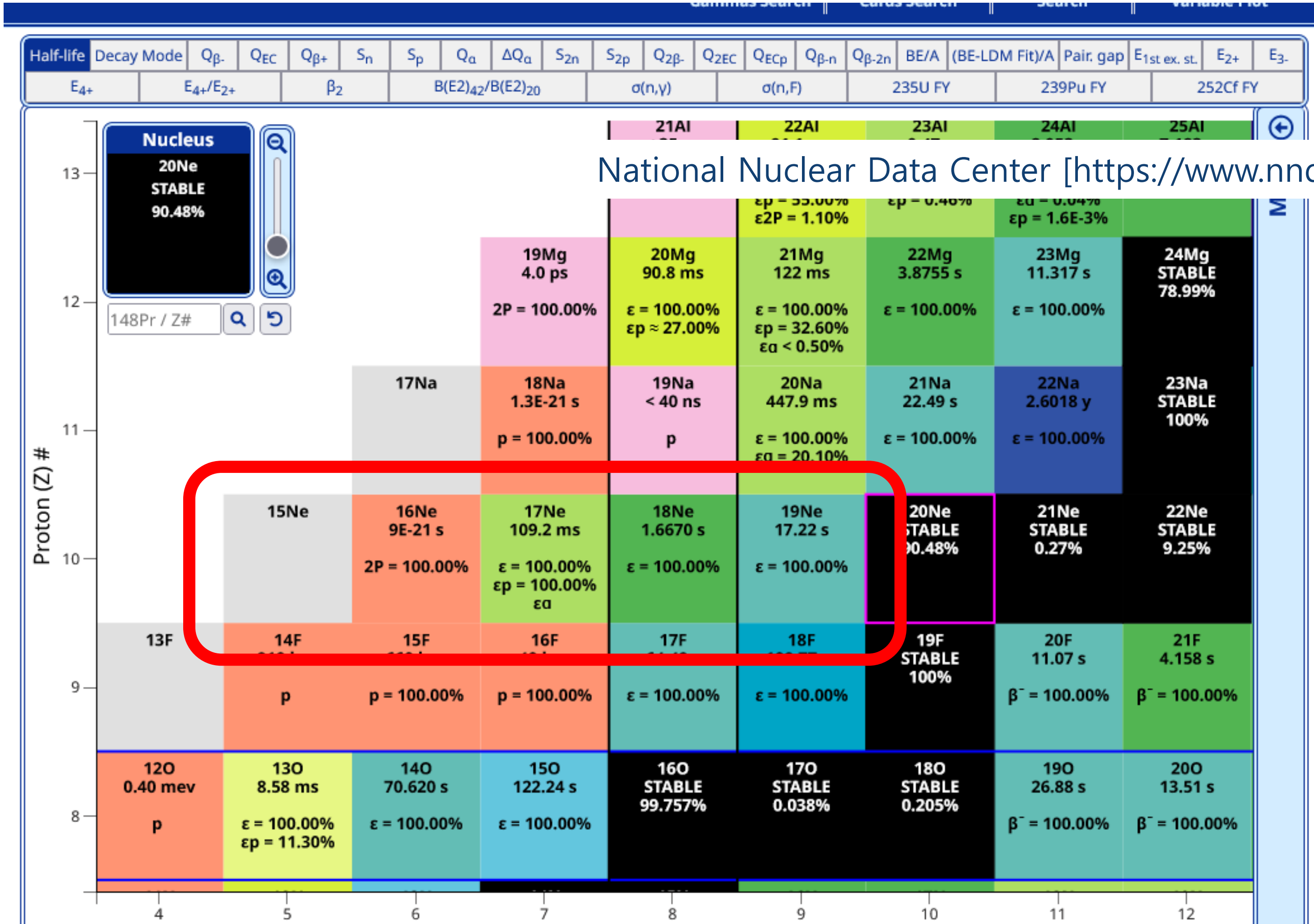
Ne isotopes

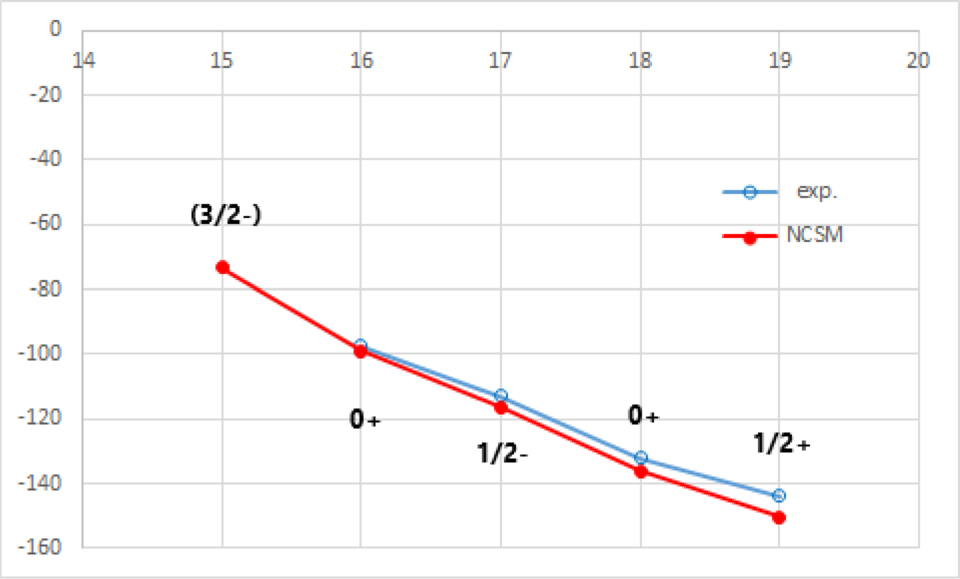
- Ne isotopes



National Nuclear Data Center [https://www.nndc.bnl.gov/]

Ne isotopes

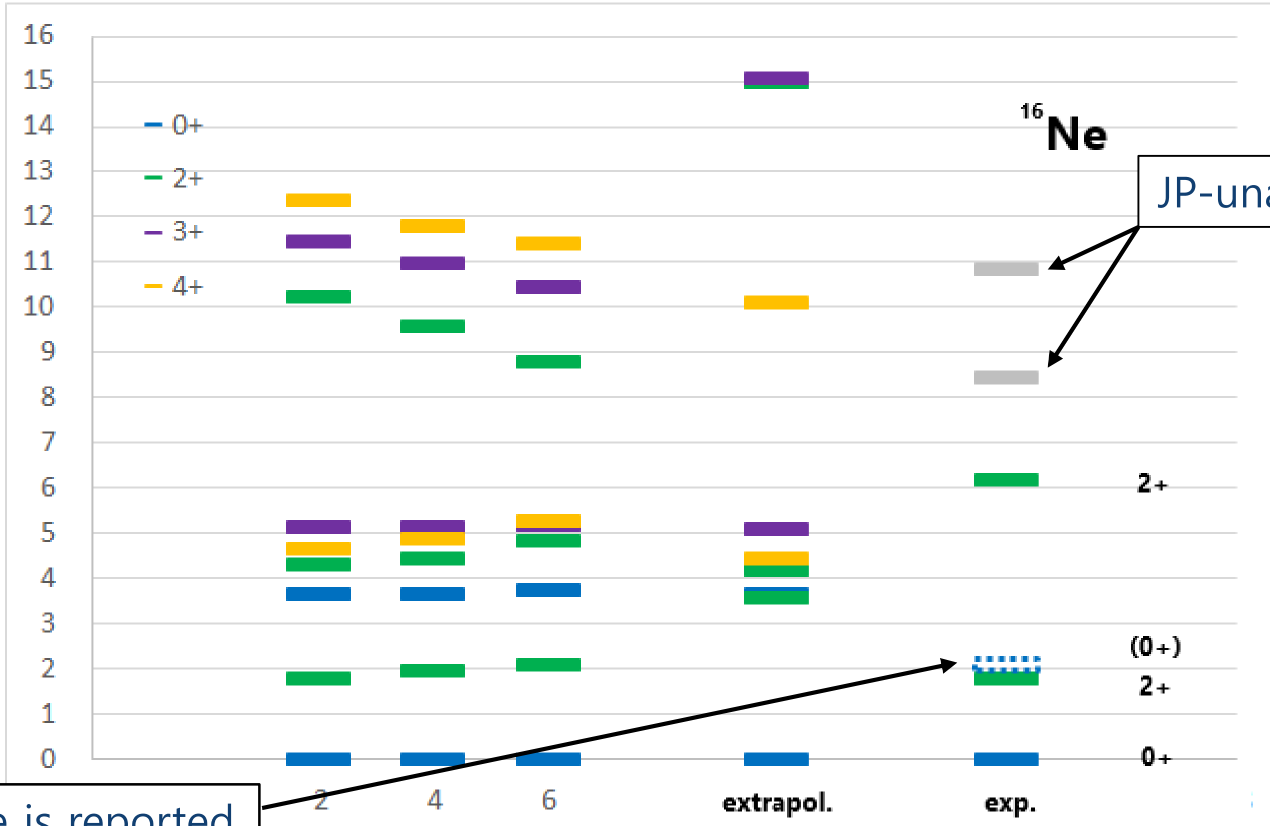
❖ Ground state energies



For ground state energies, NCSM calculations of ^{15}Ne~^{19}Ne are within 5% of the experimental values.

Ne isotopes

❖ ^{16}Ne

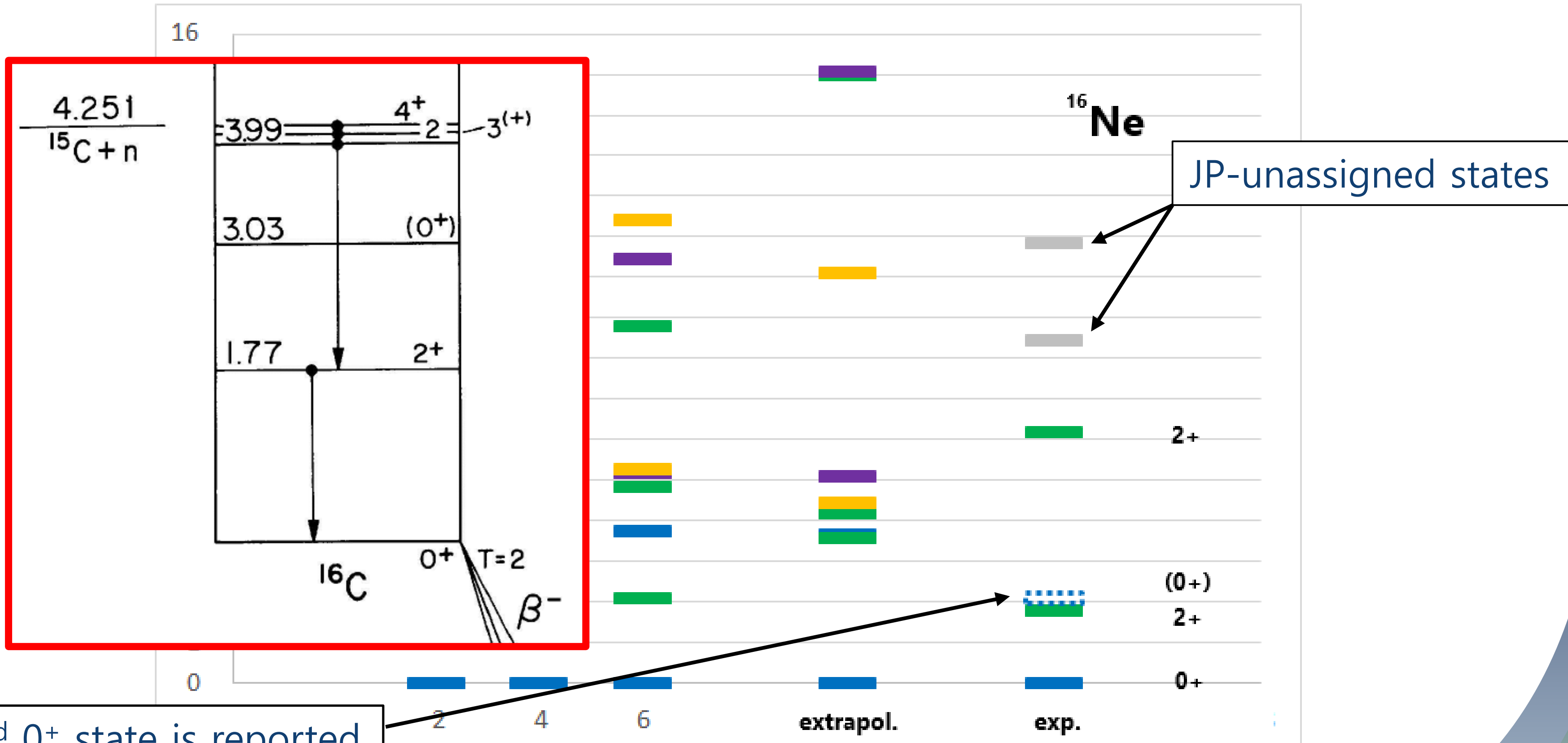


JP-unassigned states

2nd 0+ state is reported in several references.

Ne isotopes

❖ ^{16}Ne



2nd 0+ state is reported in several references.

Ne isotopes

❖ ^{16}Ne

^{16}Ne -> ^{14}O + *p* + *p*

: two-proton emitter

PHYSICAL REVIEW C **82**, 054315 (2010)

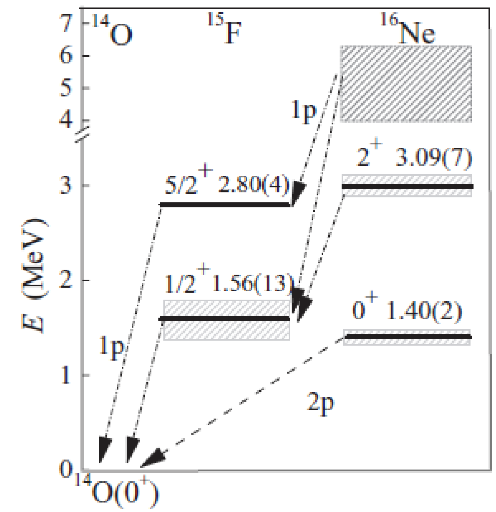
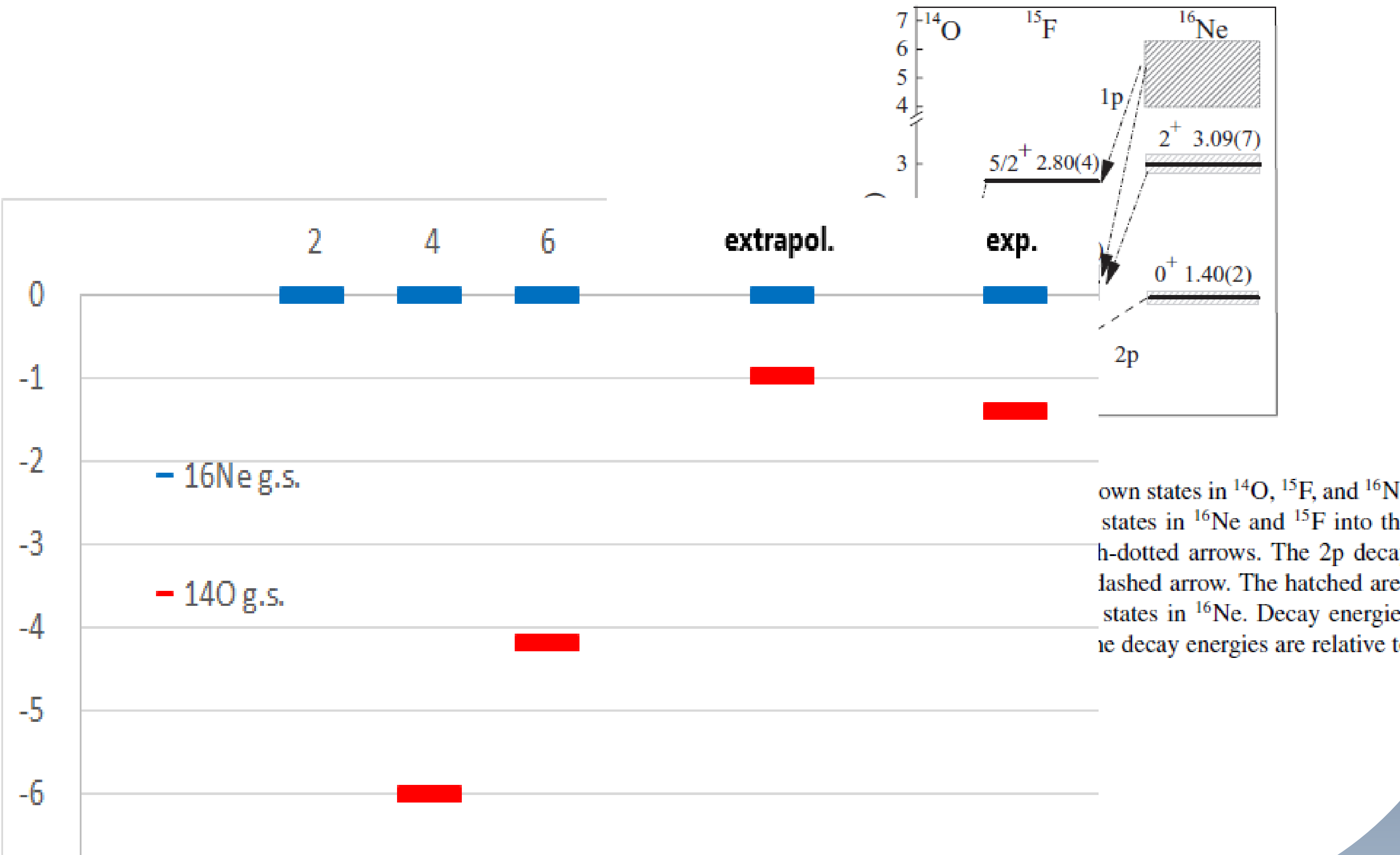


FIG. 12. The level schemes of known states in ^{14}O, ^{15}F, and ^{16}Ne (Refs. [12–14,31,32]). 1p decays of states in ^{16}Ne and ^{15}F into the g.s. of ^{14}O are indicated by the dash-dotted arrows. The 2p decay of the ^{16}Ne g.s. is illustrated by the dashed arrow. The hatched area indicates the unspecified continuum states in ^{16}Ne. Decay energies and level widths are given in MeV; the decay energies are relative to the respective 1p and 2p thresholds.

Ne isotopes

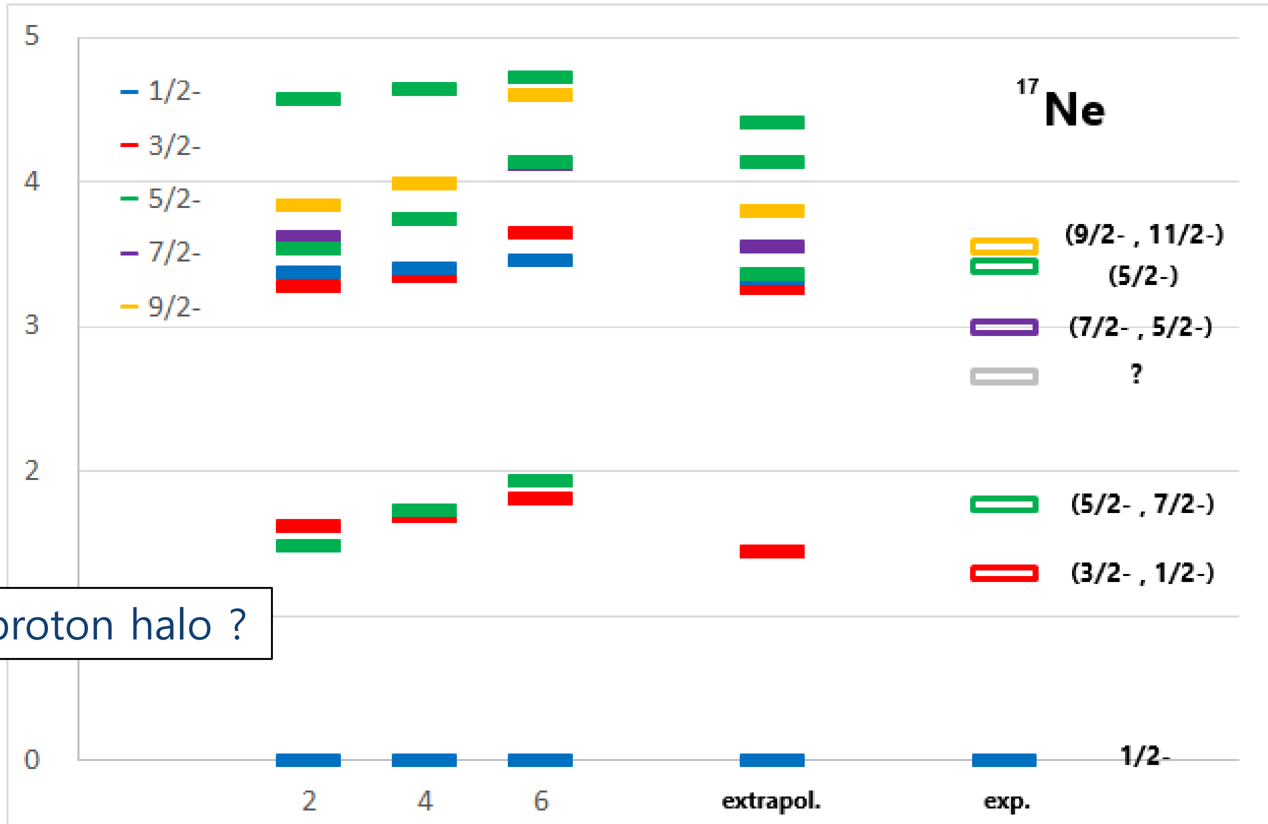
❖ ^{16}Ne

PHYSICAL REVIEW C 82, 054315 (2010)



Ne isotopes

- ^{17}Ne



^{17}Ne : two-proton halo ?

Ne isotopes

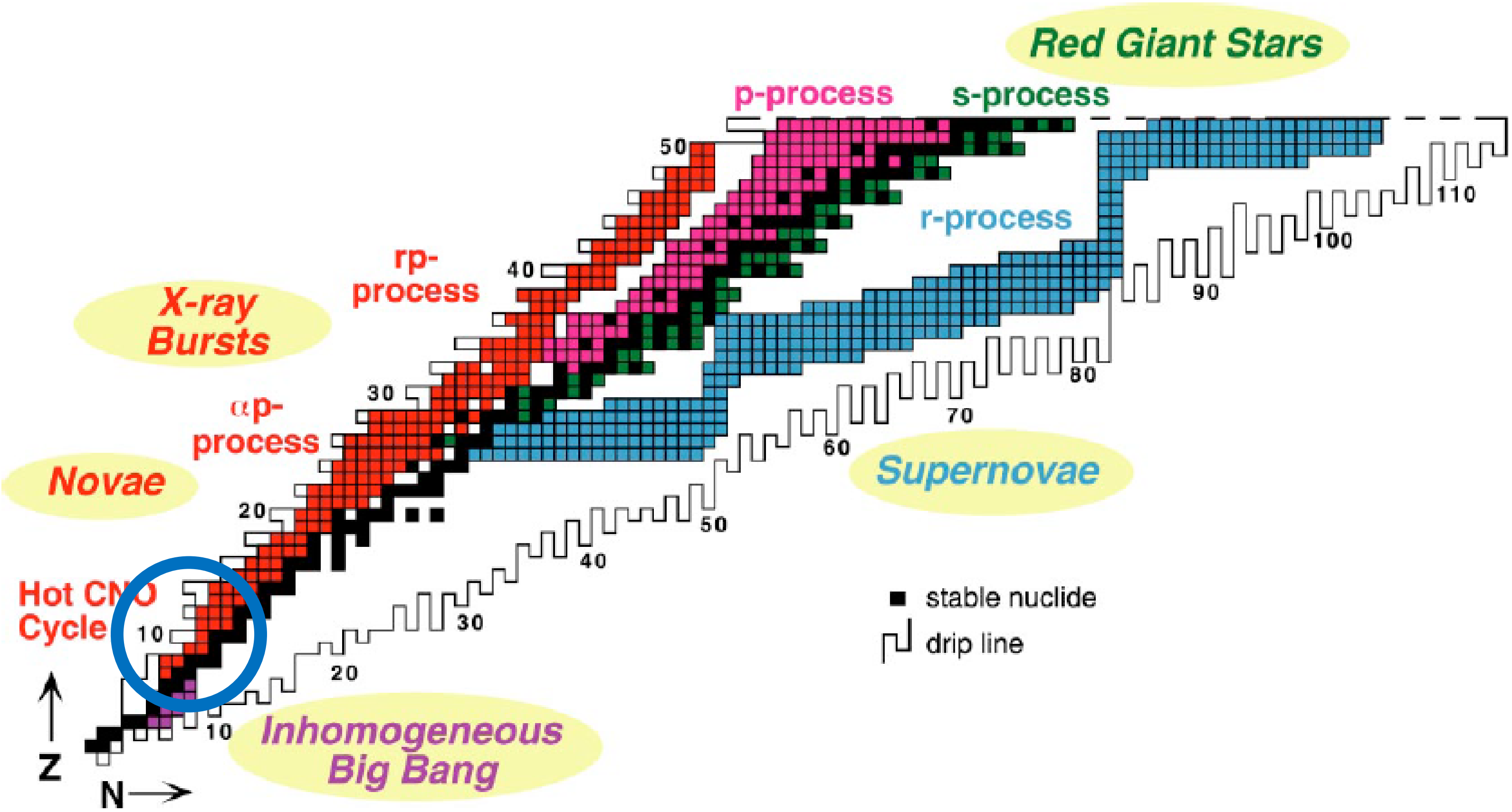


Figure 1 Importance of radioactive nuclei in astrophysics. Nuclides involved in nucleosynthesis processes (e.g., the *rp*-process and *r*-process) are shown along with stable nuclides and the particle driplines. Representative astrophysical environments for the processes are also indicated.

M. S. Smith and K. E. Rehm, Annu.Rev.Nucl.Part.Sci. **51**, 91 (2001)

Ne isotopes

❖ ^{18}Ne

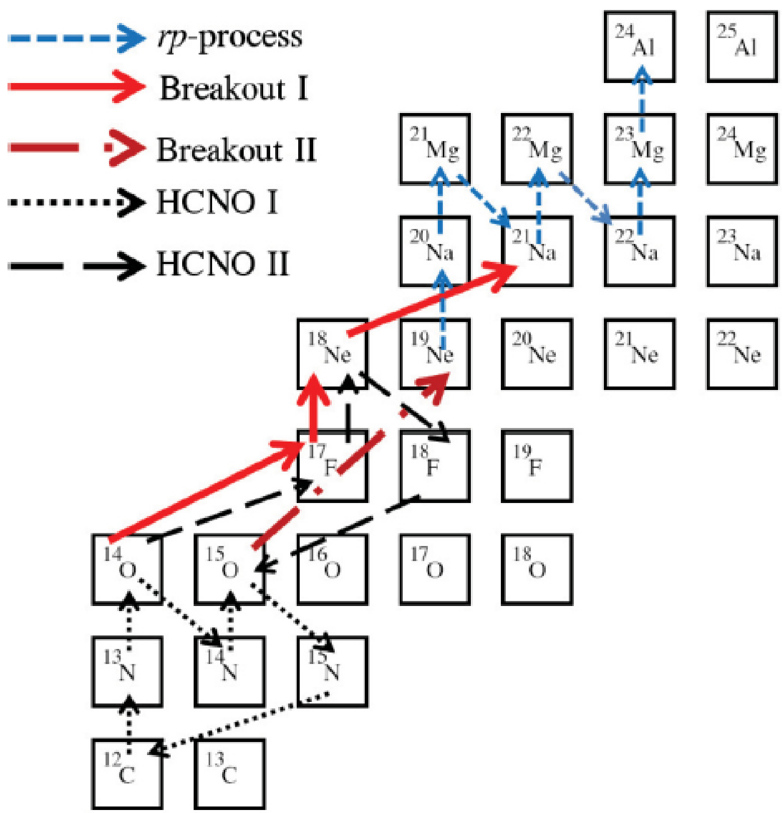
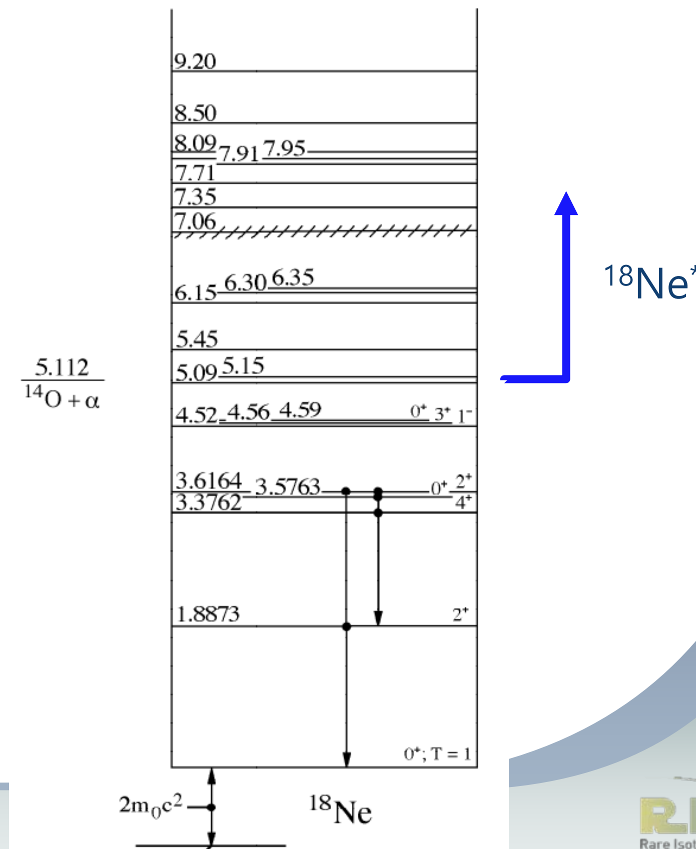


FIG. 1. (Color) Hot CNO cycles and their breakout paths towards the *rp* process. In the present work we explore the $^{14}O(\alpha,p)^{17}F$ reaction along the path labeled as Breakout I.

S. Almaraz-Calderon, *et al.*, Phys.Rev.C 86, 025801 (2012)

$^{14}O(\alpha,p)^{17}F$:

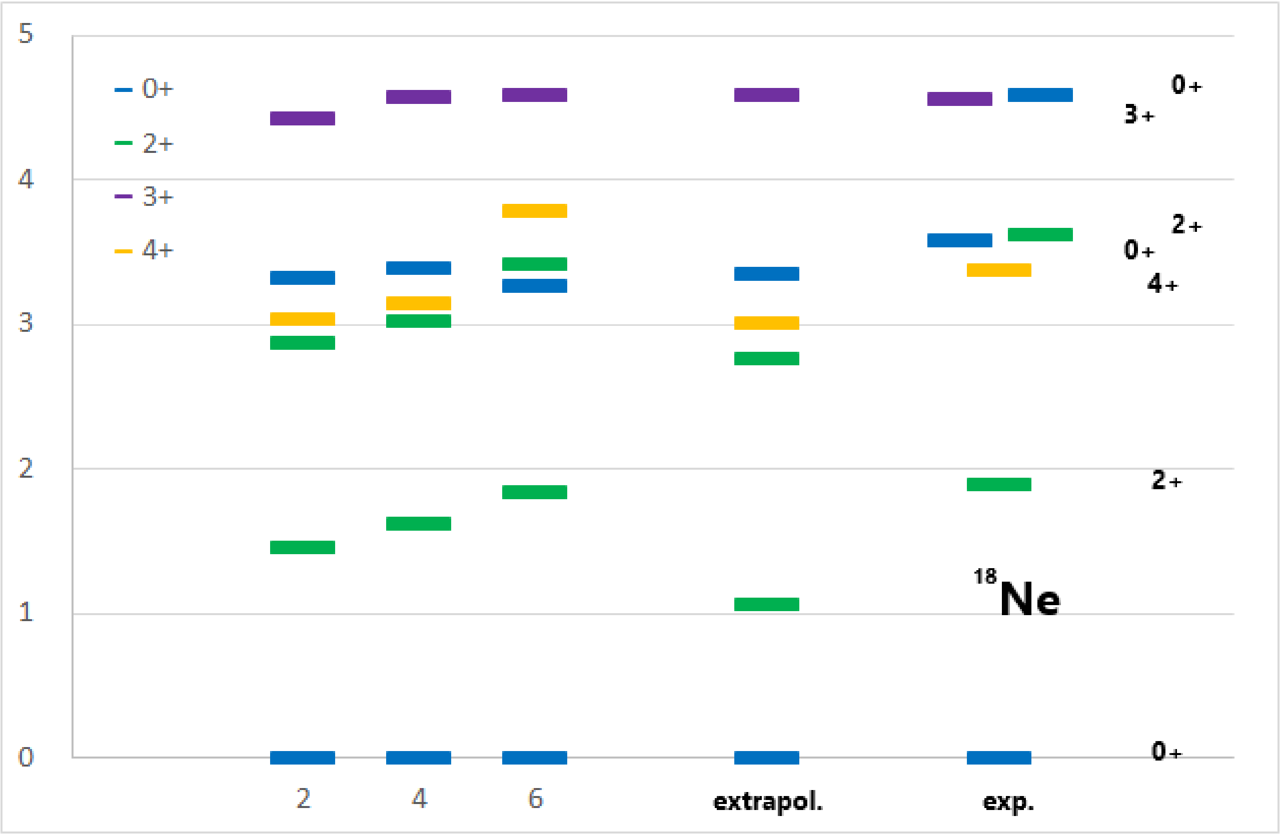
The key reactions that are responsible for breaking out from the HCNO cycle to the *rp*-process



Ne isotopes

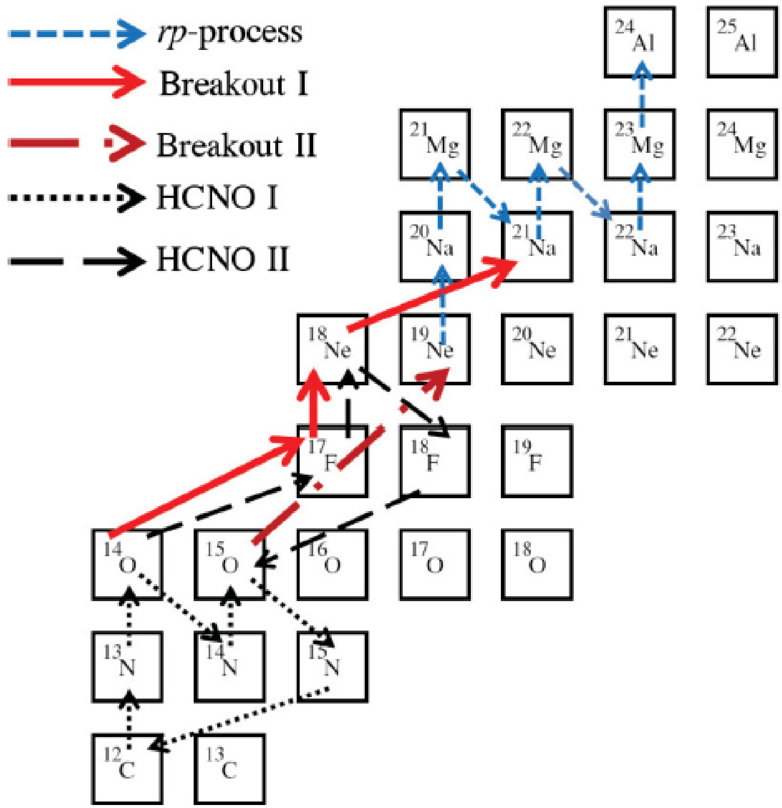
- ^{18}Ne

Above E_x=5 MeV, the convergence is poor, and the states are dense…



Ne isotopes

❖ ^{19}Ne



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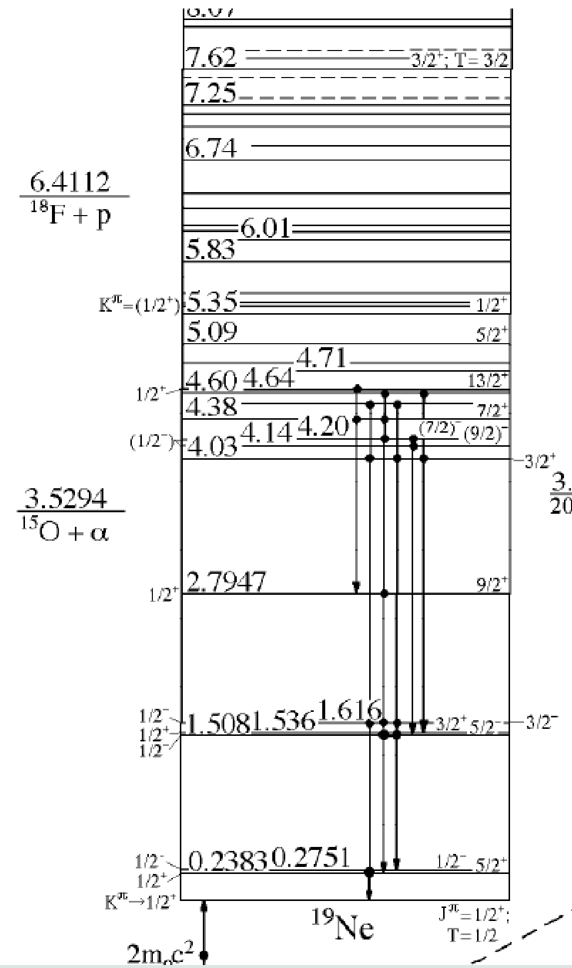
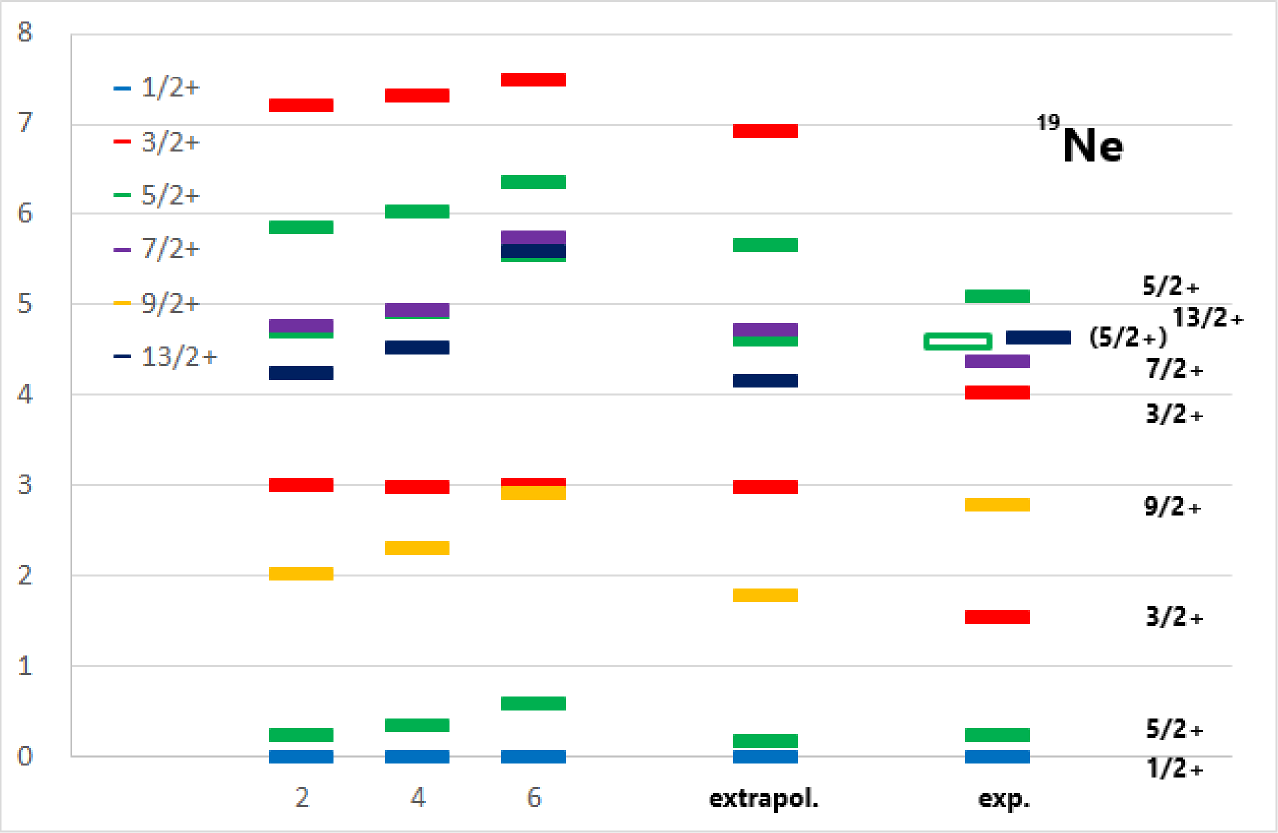
$^{18}F(p,\alpha)^{15}O$



Ne isotopes

❖ ^{19}Ne



Summary and outlook

- ✓ *Ab initio* approaches including no core shell model are attractive, and Daejeon16 is appropriate for *p*-shell nuclei, especially including exotic neutron/proton rich isotopes

- ✓ However, the application for Ne isotopes with A ~ 20 still needs more efforts: method, interaction, comparison with SM, etc.

- ✓ Toward more heavy and exotic nuclei which will be available on RAON !!


THANK YOU !