NUCLEAR STRUCTURE (PART II--lectures):
viewed from afar (from stability)

The foundational models of the nucleus were developed based on structure studies of stable and near-stable nuclei

Far-from-stability studies of nuclear structure can test these models in regions of proton/neutron number far away from their point of origin

Reference: “Shape coexistence in atomic nuclei”,
Kris Heyde and John L. Wood, Rev. Mod. Phys. 83 1467 (2011)

LECTURE 1: The saga of the "island of inversion"

--breakdown of the shell model vs. shape coexistence @ N =20

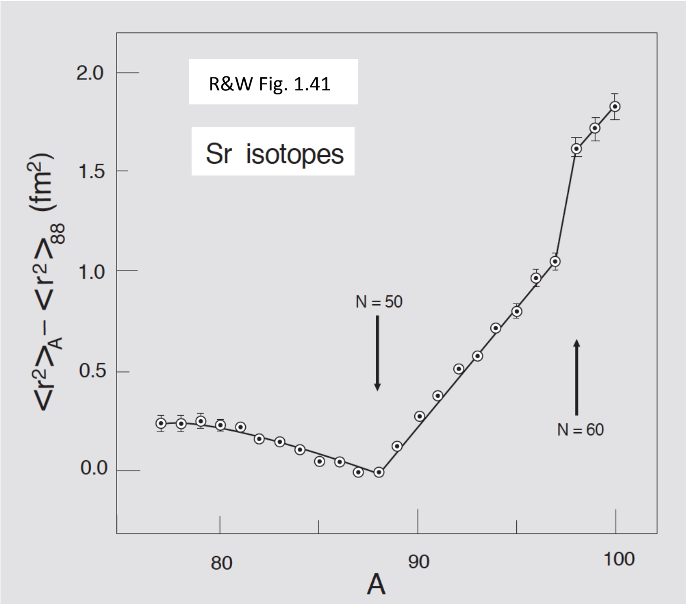
- Illustration of the "first signatures" of interesting structure—

  masses and mean-square charge radii of nuclear ground states

  energies of 2_1^+ states of even-even nuclei

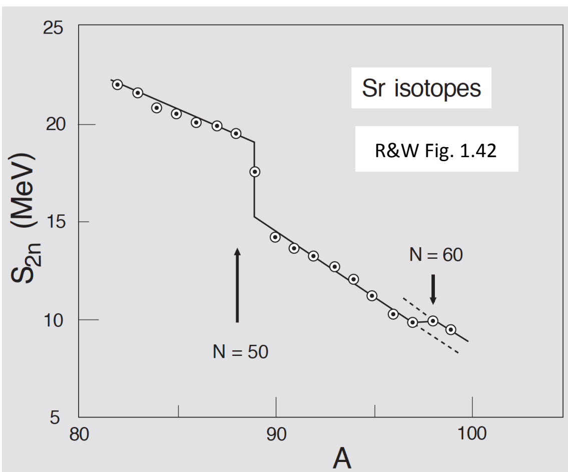
- Illustration of the time frame for elucidation of underlying structure by detailed spectroscopy

Ground-state properties are a direct signature of shell and deformation structures



Differences in mean-square charge radii (isotope shifts) determined by:

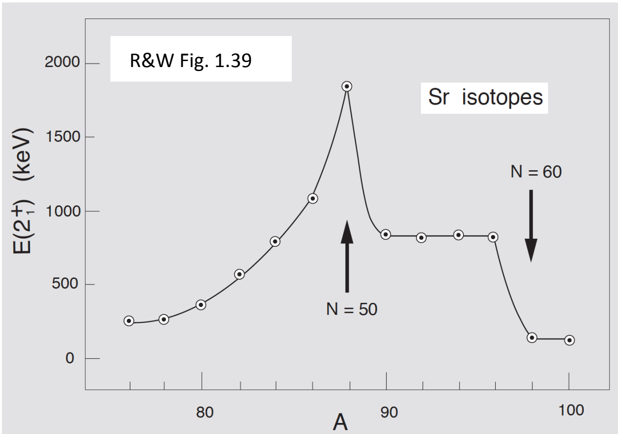
optical hyperfine spectroscopy using lasers



Two-neutron separation energies deduced from nuclear masses determined by:

direct mass measurements

2_1^+ state properties are a strong signature of shell and deformed structures

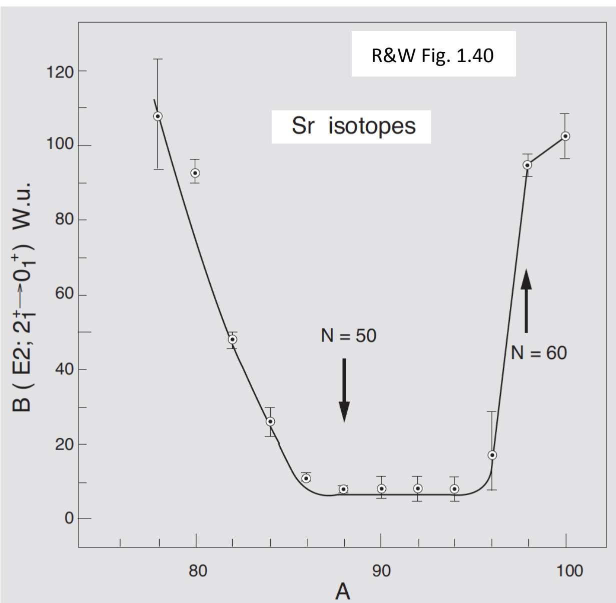


Energies of 2_1^+ states determined by:

gamma-ray spectroscopy following β decay

problem—β-decaying parent is further from stability and yield will be (much) lower than nucleus of interest

gamma-ray spectroscopy following Coulomb excitation



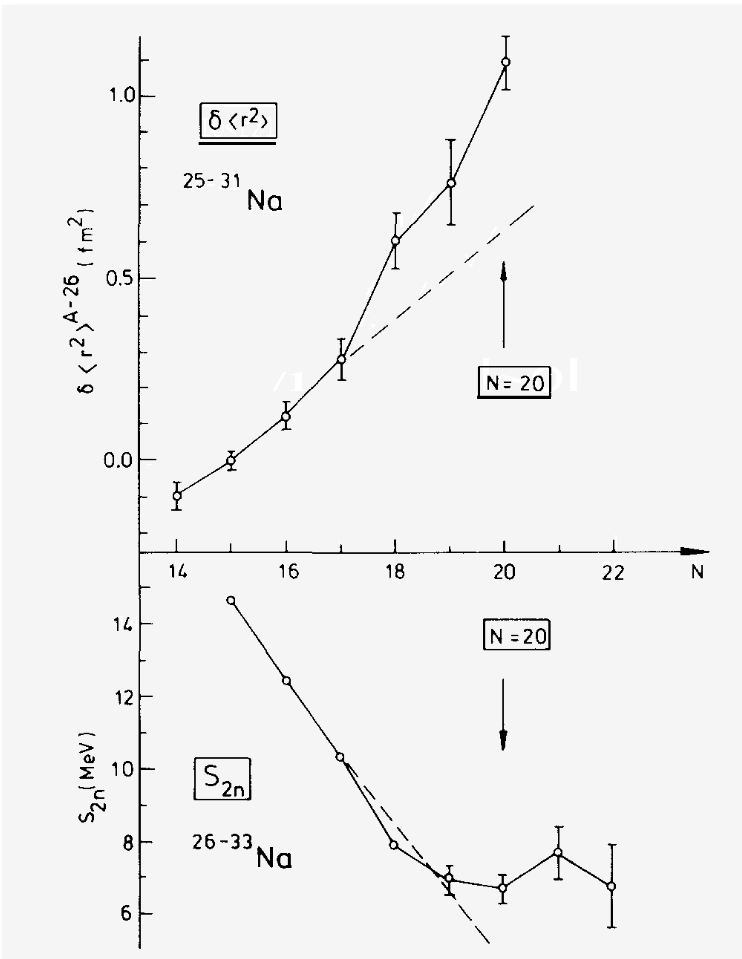
Reduced E2 transition rates, B(E2) from 2_1^+ states determined by:

lifetime measurements using fast β-γ timing following β decay

problem--see above

gamma-ray yields following Coulomb excitation

N=20: sudden onset of deformation in the Na isotopes revealed by ground-state isotope shift and mass data



Na isotope-shifts determined by:

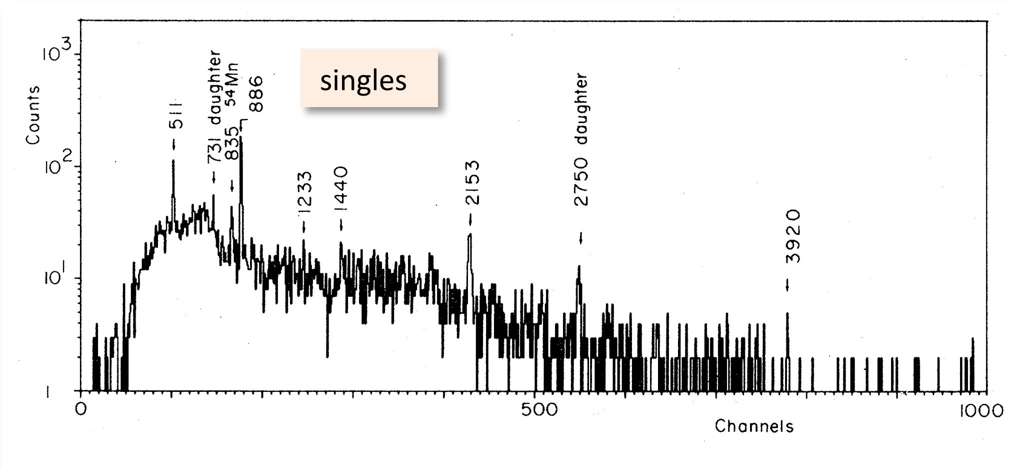
G. Huber et al., PRL 34, 1209 (1975); PR C18, 2342 (1978)

BUT: N = 20 is supposed to be a closed shell!

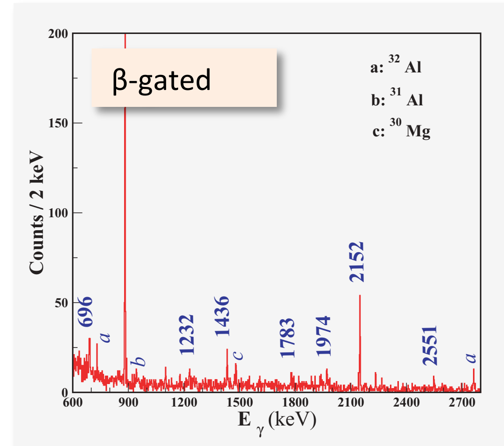
Na two-neutron separation energies deduced from masses determined by:

C. Thibault et al., PR C12, 644 (1975)

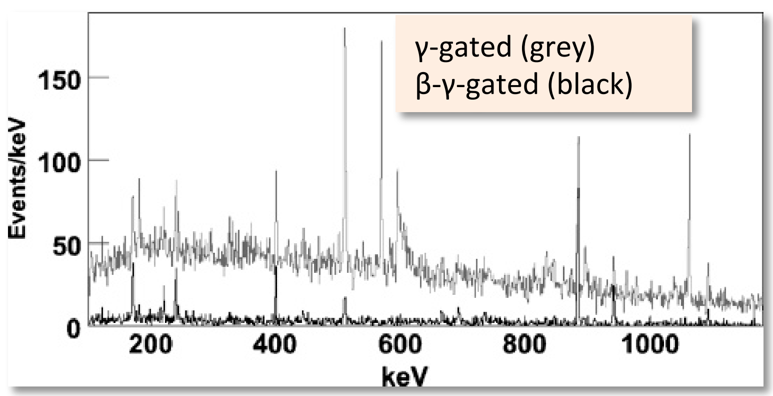
Studies of ^{32}Na → ^{32}Mg: 1979-2008



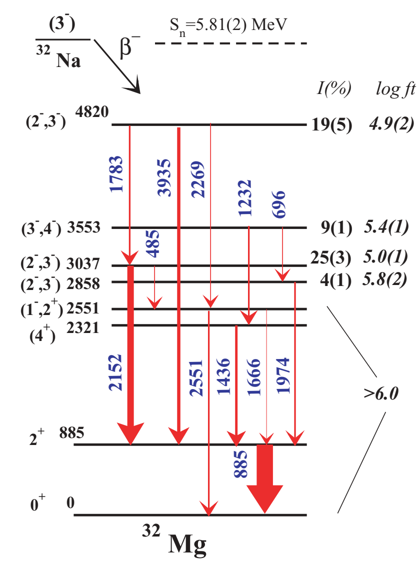
C. Detraz et al., PR C19, 164 (1979) [ISOLDE-I]



V. Tripathi et al., PR C77, 034310 (2008)[NSCL]



C.M. Mattoon et al., PR C75, 017302 (2007) [TRIUMF-ISAC]



$E(2_1^+)$ systematic: a simple view of nuclear structure

Figure from Heyde & Wood

Z \ N		18	20	22	24	26	28	30	32	34	36
Cr	24			892	752	783	1434	835	1007	881	646
Ti	22		1556	1083	889	983	1554	1050	1495	1129	
Ca	20	2213	3904	1525	1157	1346	3832	1026	2563		
Ar	18	1970	2168	1461	1208	1158	1577	1037			
S	16	2127	3291	1292	904	890	1330	952			
Si	14	1941	3328	1399	1084	986	770				
Mg	12	1483	886	660	660						
Ne	10	1320	792	722							

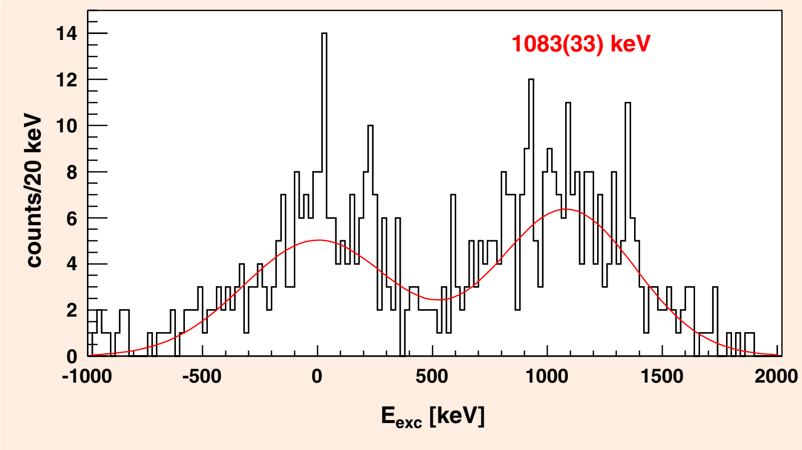
$B_n \sim 0$

$E(2_1^+)$

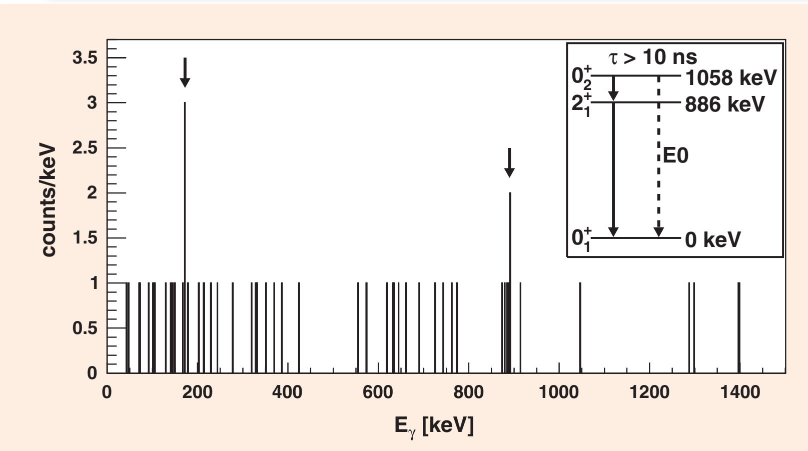
Has the shell structure @ N=20 "collapsed" or "melted" for Z ≤ 12?

And @ N=28 for Z ≤ 14?

^{32}Mg: 0_2^+ state observed by (t,p) via inverse kinematics with a ^{30}Mg beam



K. Wimmer et al., PRL 105, 252501 (2010) [REX-ISOLDE]



N=20 systematic showing the ν(2p-2h) 0^+ bands @ Z=14-18

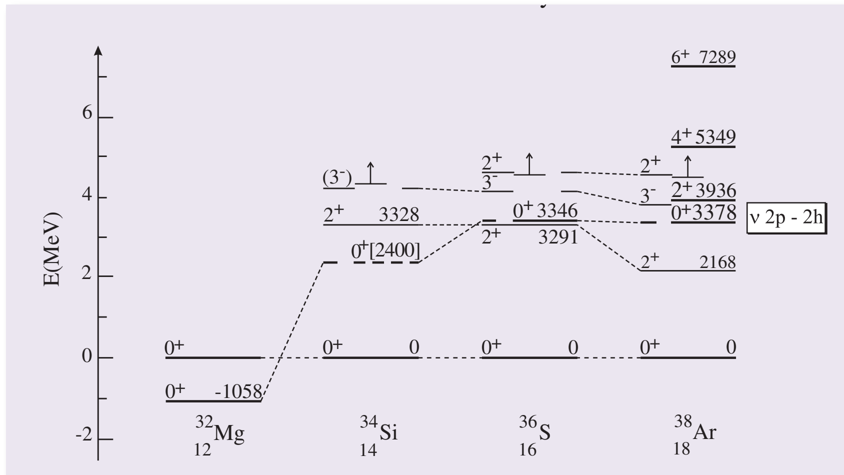
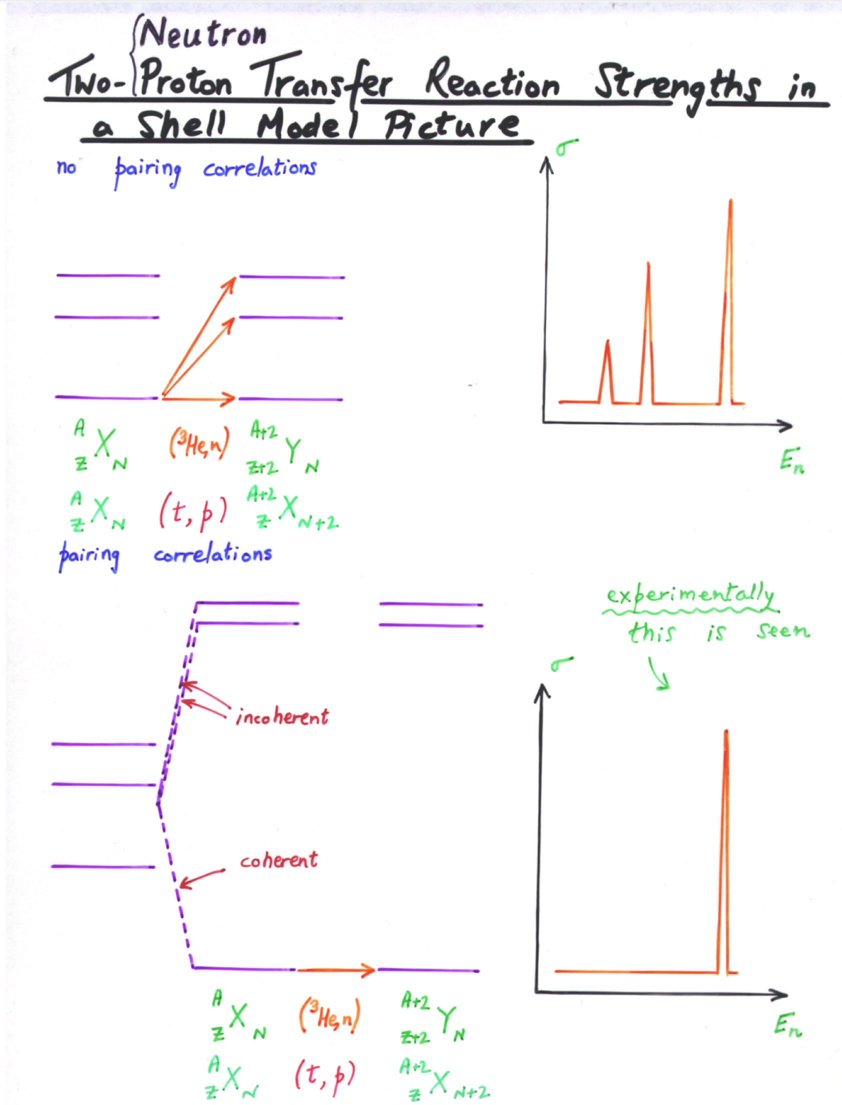


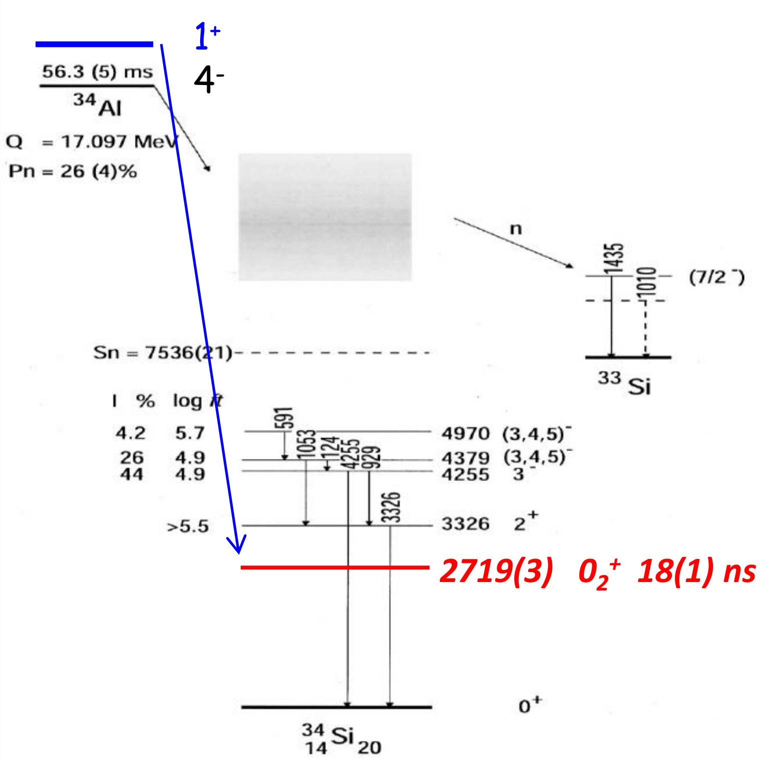
Figure from Heyde & Wood

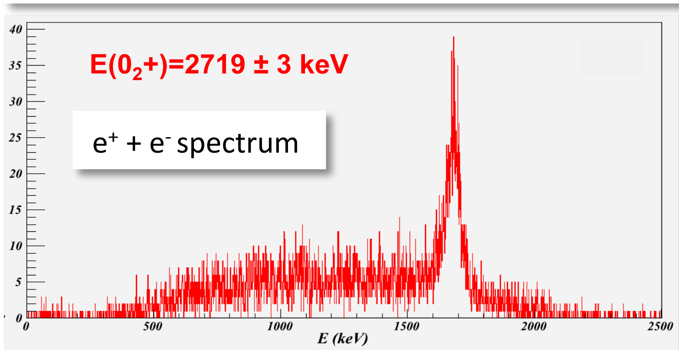
Not a collapse or melting of the shell structure, but an "intrusion" of configurations from above the shell gap, sometimes called an "inversion" or "island of inversion"

The anatomy of pairing in finite many-body quantum systems: effect on two-nucleon transfer reactions



^{34}Si: 0_2^+ state observed by internal-pair (electron) spectroscopy via β decay of ^{34m}Al





S. Grévy et al., invited talk, ARIS 2011 (Leuven, Belgium);
F. Rotaru et al. PRL 109 092503 (2012) [GANIL-LISE3]

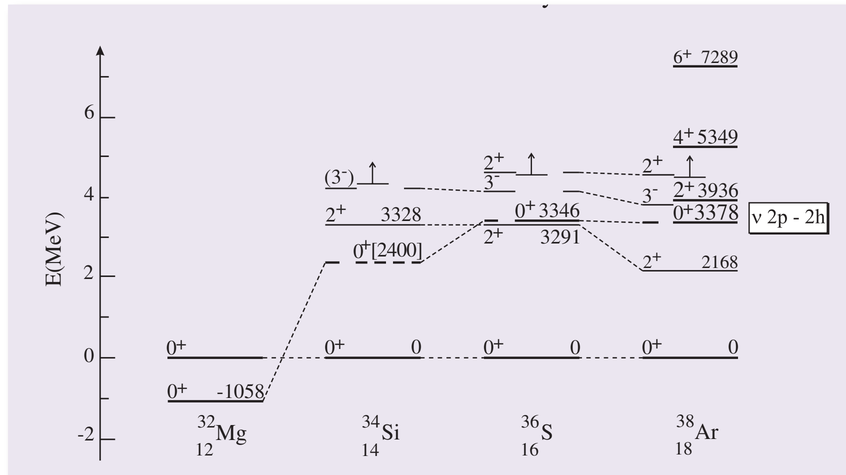
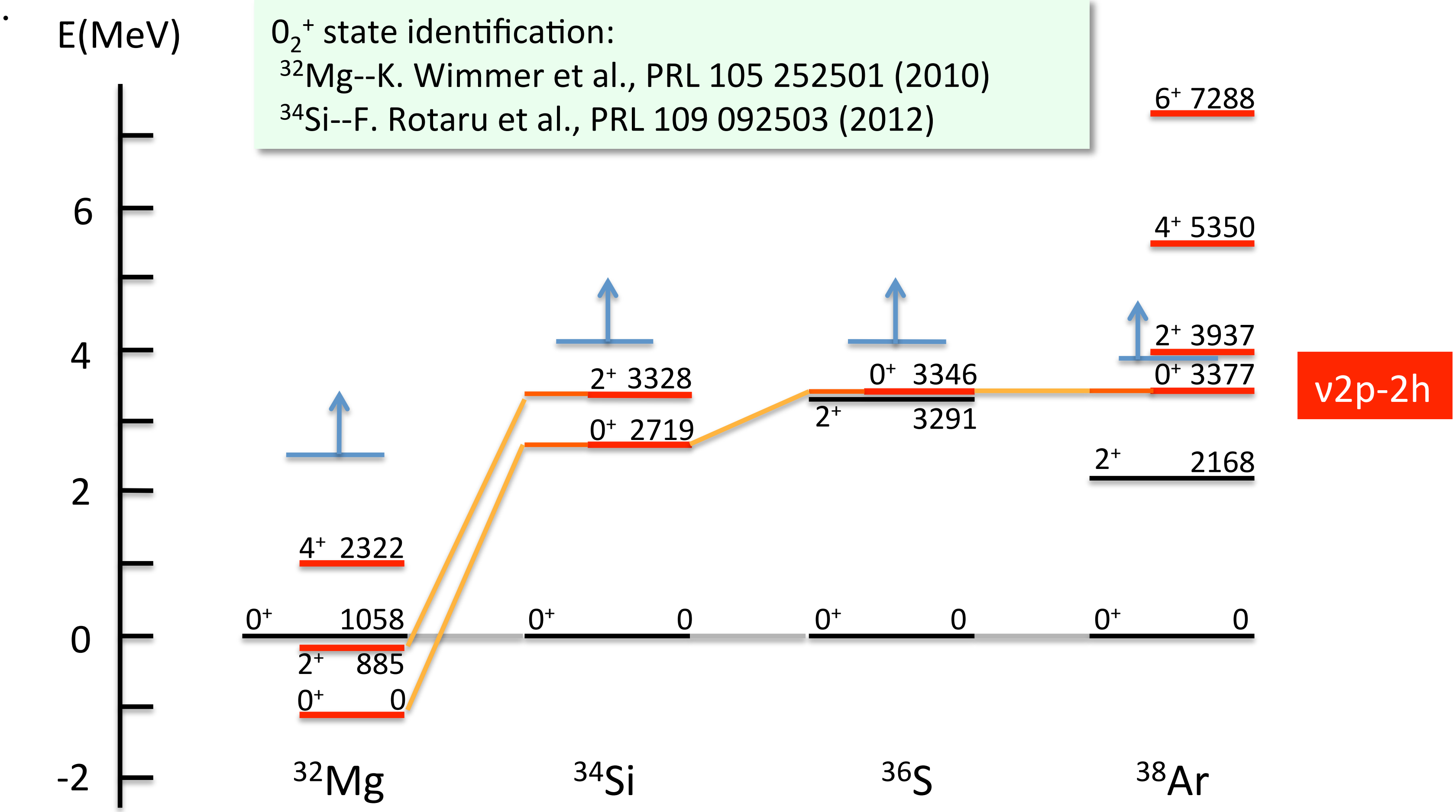


Figure from Heyde & Wood

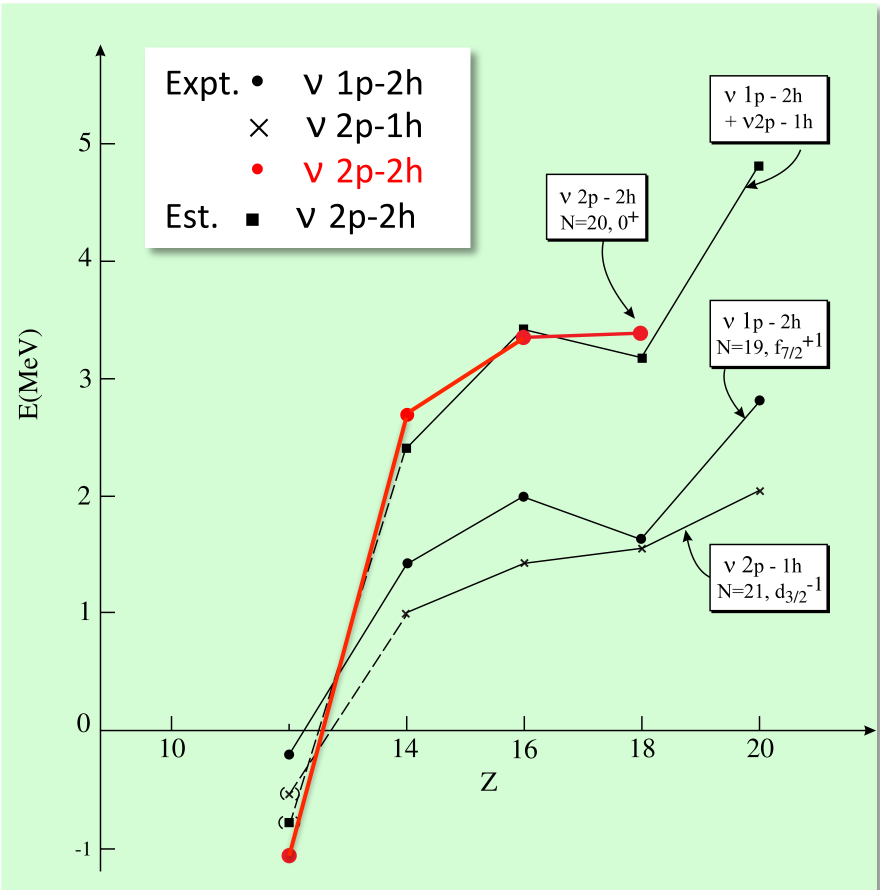
Intruder states or the “island of inversion” @ N=20

0_2^+ state identification:
^{32}Mg--K. Wimmer et al., PRL 105 252501 (2010)
^{34}Si--F. Rotaru et al., PRL 109 092503 (2012)



0+ ν(2p-2h) intruder state energies @ N=20: estimates from ν (1p-2h) + ν (2p-1h) energies

Figure adapted from Heyde & Wood



Intruder state energies @ N = 20 have contributions from multiple sources which are not limited to the pure* shell model

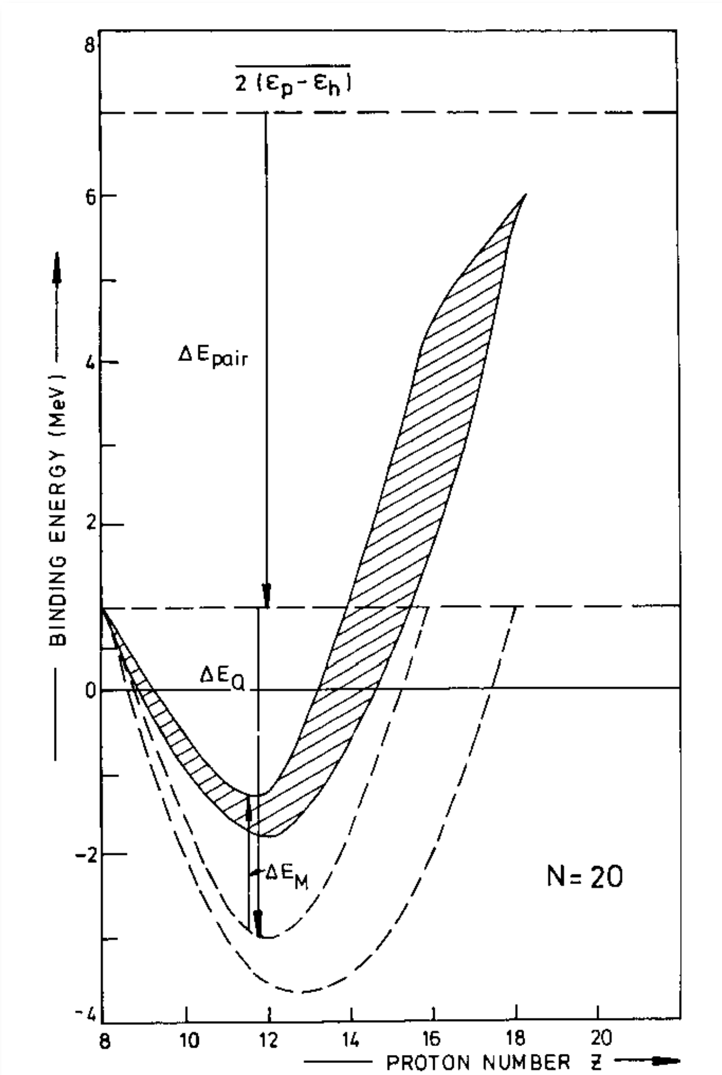


Figure from K. Heyde and J.L. Wood, J. Phys. G17, 135 (1991).

*the pure shell model is an independent-particle model: intruder state energies have very large contributions from many-body *correlations*—pairing, monopole, and quadrupole interactions.