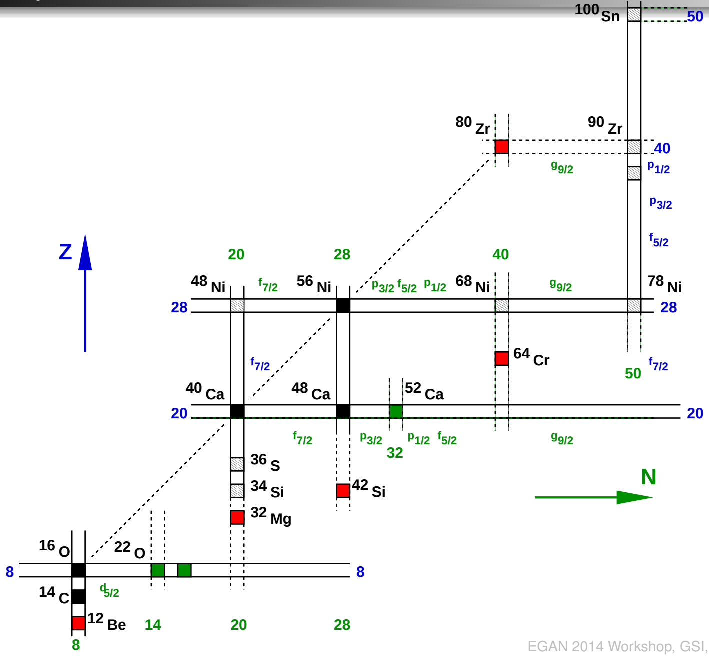
Correlations along the N=Z line

Frédéric Nowacki[1]

[1]Strasbourg-Madrid Shell-Model collaboration

Landscape of medium mass nuclei



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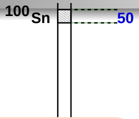
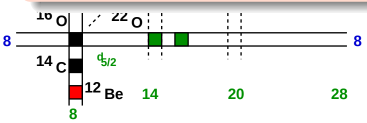


- New gaps: ^{24}O, ^{48}Ni, ^{54}Ca, ^{78}Ni, ^{100}Sn
- Vanishing of shell closure: ^{12}Be, ^{32}Mg, ^{42}Si, ^{64}Cr, ^{80}Zr ...
- Island of deformation around A$\sim$ 32, A$\sim$ 64
- Low-lying dipole excitations in Ne, Ni isotopes

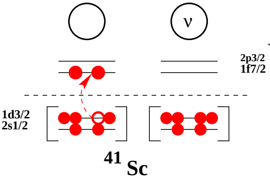
- Variety of phenomena dictated by shell structure
- Close connection between collective behaviour and underlying shell structure
- Interplay between
  - Monopole field (spherical mean field)
  - Multipole correlations (pairing, Q.Q, ...)

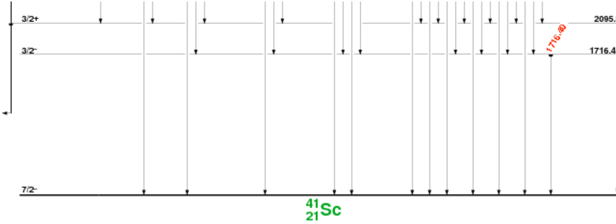
"Pairing plus Quadrupole propose, Monopole disposes"
A. Zuker, Coherent and Random Hamiltonians, CRN Preprint 1994



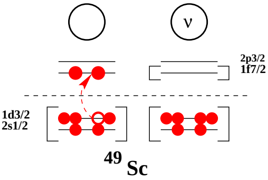
Stable Nuclei

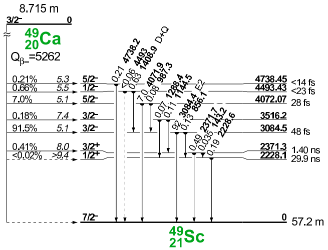
2BE(^{40}Ca)-BE(^{39}K)-BE(^{41}Sc) 7.2 MeV





2BE(^{48}Ca)-BE(^{47}K)-BE(^{49}Sc) 6.2 MeV





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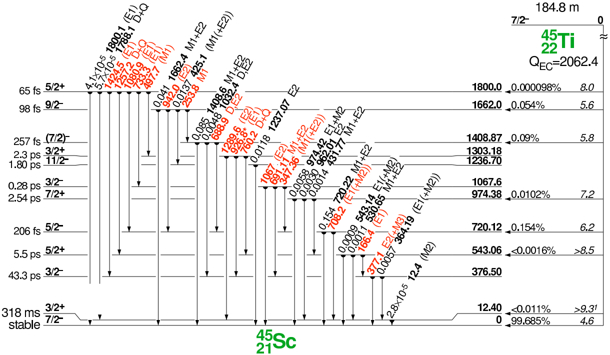
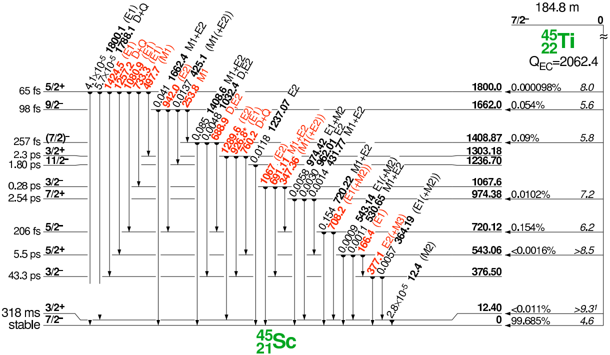


In ^{45}Sc, normal states and intruder states are degenerated!

But the proton shell gap remains more or less constant ...

Stable Nuclei



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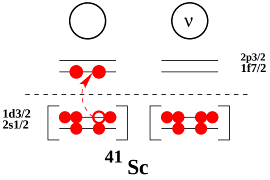
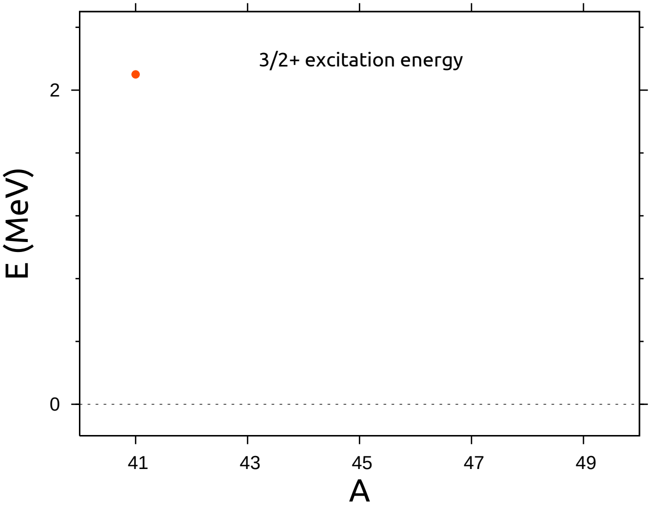
Almost Island of Inversion at Stability !!!

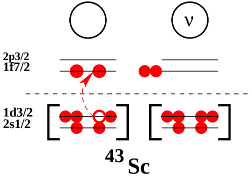
Intruders in Sc chain





N	20	22	24	26	28
pgap (MeV)	7.24	5.35	5.28	5.33	6.18

Stable Nuclei



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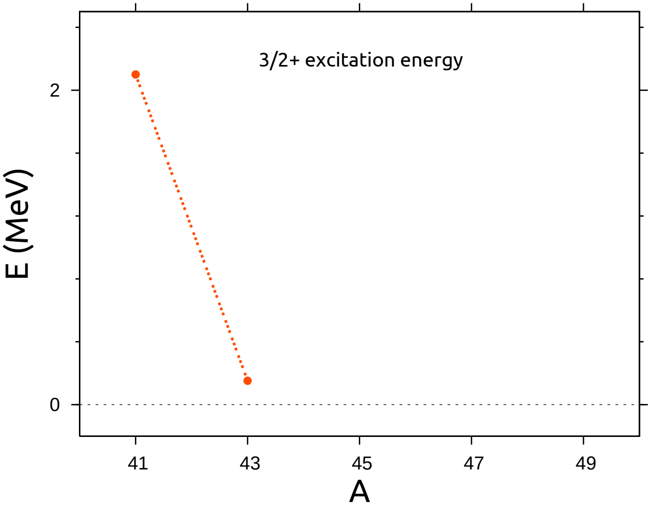

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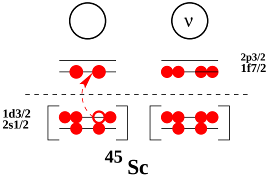

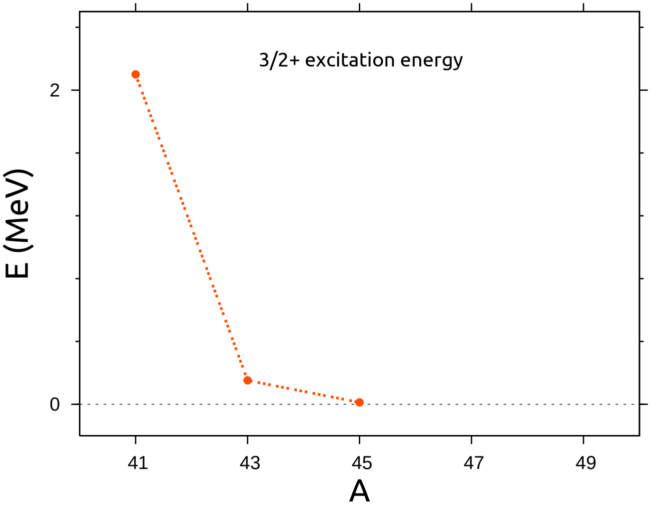

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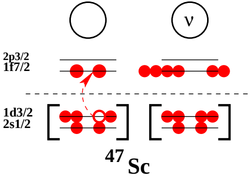

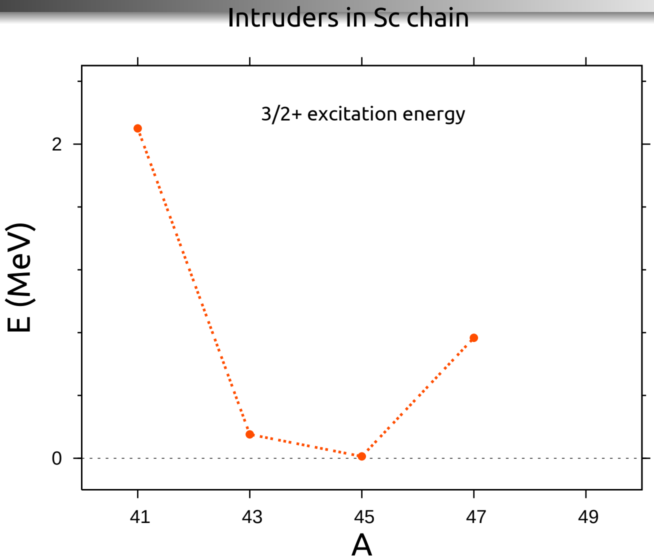

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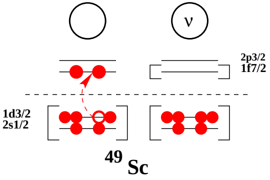

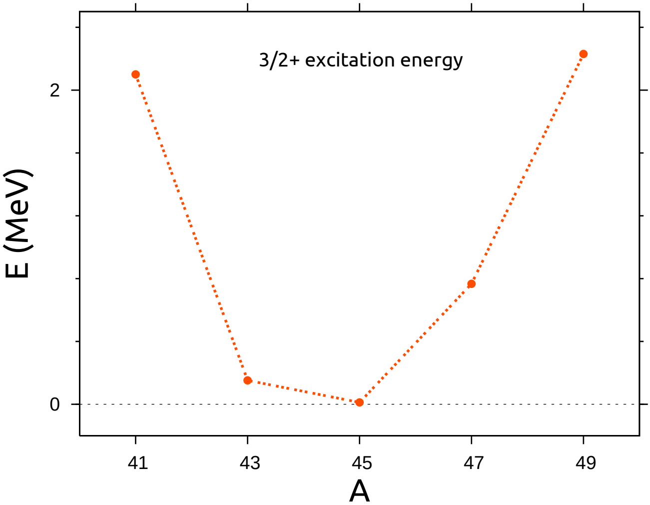

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Isotope shifts in Calcium isotopes

ELSEVIER

13 December 2001

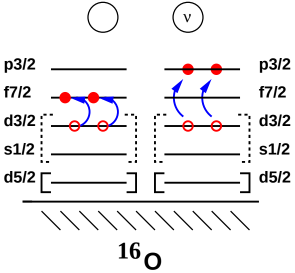
Physics Letters B 522 (2001) 240–244

PHYSICS LETTERS B

www.elsevier.com/locate/npe

Shell model description of isotope shifts in calcium

E. Caurier [a], K. Langanke [b], G. Martínez-Pinedo [b,c], F. Nowacki [d], P. Vogel [e]

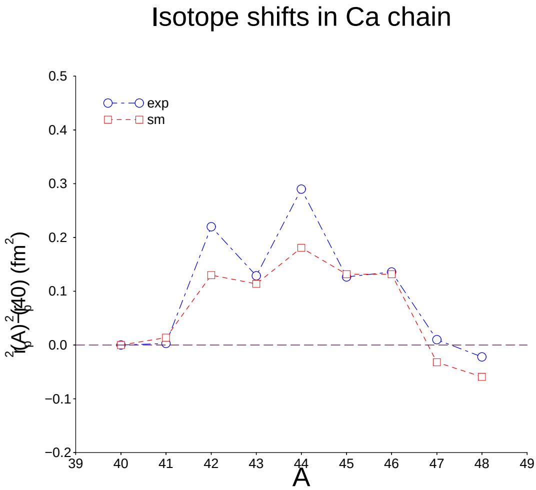


ZBM2 interaction:

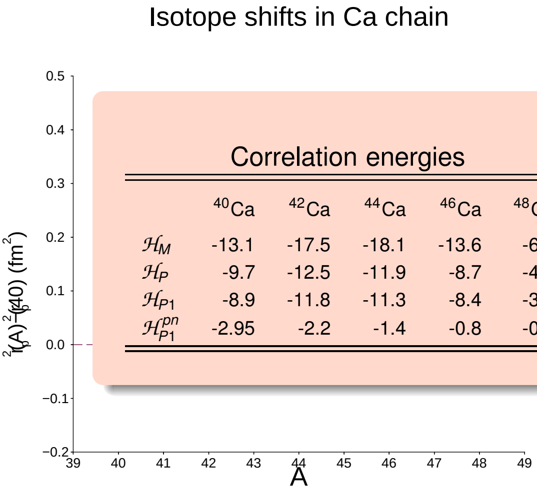
- based on realistic TBME
- monopole corrections to ensure ^{40}Ca and ^{48}Ca gaps
- full space calculations
- almost free of center of mass contamination

- provides very good spectroscopy at sd-pf interface

Isotope shifts in Calcium isotopes



$$\text{IS} = \frac{1}{Z} . n^{\pi}_{\text{fp}} . b^2$$



Correlation energies

	^{40}Ca	^{42}Ca	^{44}Ca	^{46}Ca	^{48}Ca
$\mathcal{H}_M$	-13.1	-17.5	-18.1	-13.6	-6.2
$\mathcal{H}_P$	-9.7	-12.5	-11.9	-8.7	-4.0
$\mathcal{H}_{P1}$	-8.9	-11.8	-11.3	-8.4	-3.9
$\mathcal{H}_{P1}^{pn}$	-2.95	-2.2	-1.4	-0.8	-0.2

$$\text{IS} = \frac{1}{Z}.n^{\pi}_{\text{fp}}.b^2$$

Proton-neutron pairing correlations in the self-conjugate nucleus ^{38}K probed via a direct measurement of the isomer shift

M. L. Bissell,[1,*] J. Papuga,[1] H. Naïdja,[2,3,4] K. Kreim,[5] K. Blaum,[5] M. De Rydt,[1] R. F. Garcia Ruiz,[1] H. Heylen,[1] M. Kowalska,[6] R. Neugart,[5,7] G. Neyens,[1] W. Nörtershäuser,[8,7] F. Nowacki,[2] M. M. Rajabali,[1] R. Sanchez,[3,9] K. Sieja,[2] and D. T. Yordanov[5]

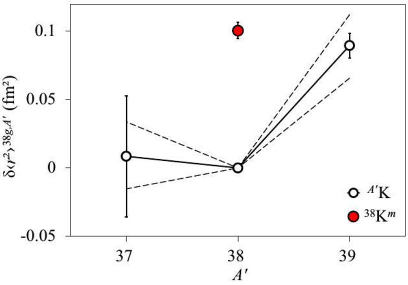


FIG. 2. Changes in mean square charge radius referenced to ^{38}K. The systematic uncertainty related to the atomic specific mass shift is represented by the two dotted lines. Datum for ^{37}K taken from [23].

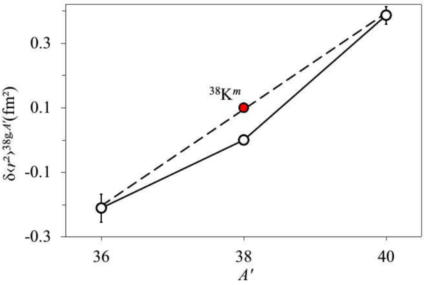


FIG. 3. Changes in mean square charge radii between the self-conjugate nuclei ^{36}Ar, ^{38}K and ^{40}Ca from this work and [29].

Isomer shift in ^{38}K

Pr

$$\mathcal{H}_m = \sum \varepsilon_i n_i + \sum a_{ij} n_i \cdot n_j + b_{ij}(T_i \cdot T_j - \frac{3}{4} n \delta_{ij})$$

Correction of the French-Bensal $b_{ij} = (V_{ij}^{T=1} - V_{ij}^{T=0})$ parameter for the $d_{3/2}$ orbital

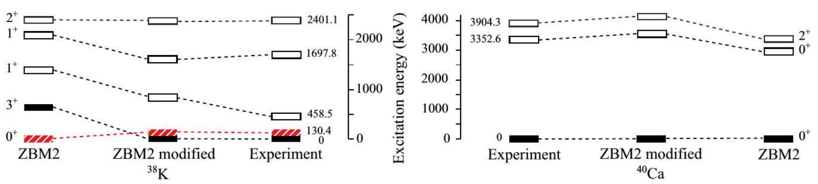


FIG. 4. Low energy excitation spectra of ^{38}K (left) and ^{40}Ca (right) calculated with the ZBM2 interaction before and after modification of the $V^{0,1}_{d_{3/2},d_{3/2}}$ centroids (see text for details.)

$\delta\langle r^2 \rangle^{38g,A'}$ (fm^2)

TABLE II. Proton occupancies of the $f_{7/2}p_{3/2}$ orbitals, and the difference in charge radii between 0^+ isomer and 3^+ ground state, calculated within the shell model. See text for details.

	$n^{\pi}_{fp}(38m)$	$n^{\pi}_{fp}(38g)$	$\delta\langle r_c^2 \rangle^{38g,38m}$ (fm^2)
ZBM2	0.86	0.50	0.075
ZBM2 modified	0.82	0.41	0.085
Experiment			0.100(6)

FIC
^{38}K
mas
^{37}K

Correlation energies

	3^+_{GS}	0^+_m
$\mathcal{H}_M$	-7.9	-13.2
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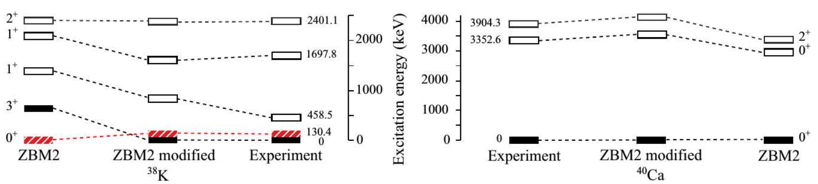

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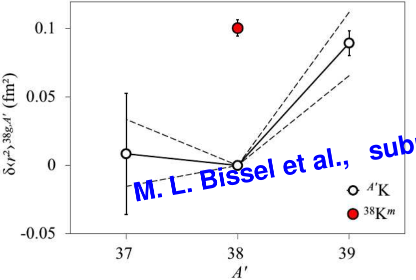

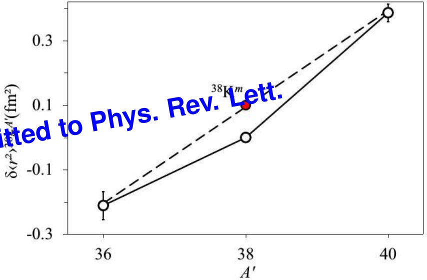

M. L. Bissel et al., submitted to Phys. Rev. Lett.

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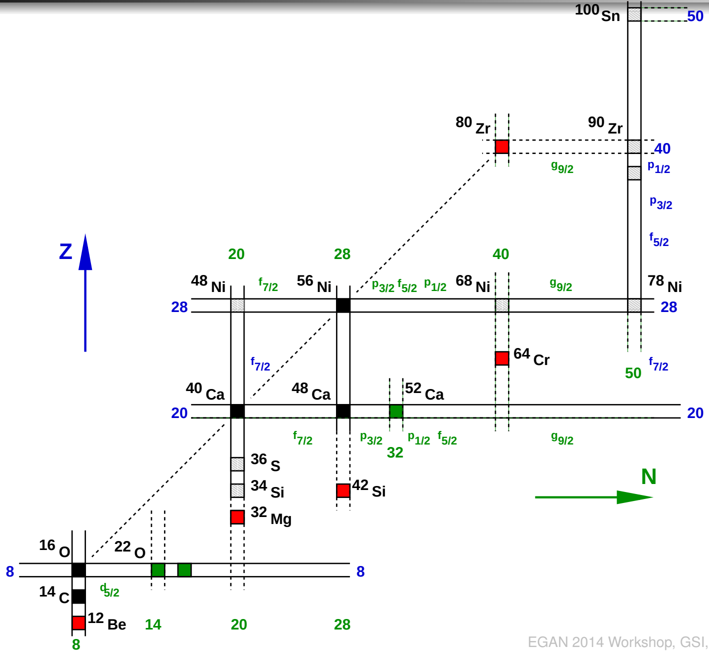
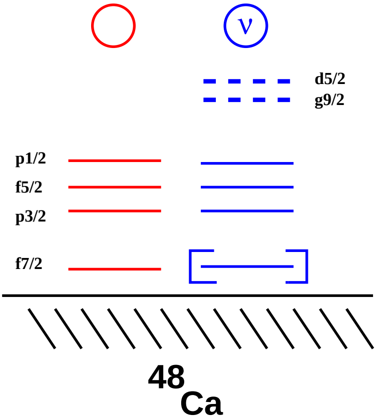


Island of Inversion around at N=40

PHYSICAL REVIEW C **82**, 054301 (2010)

Island of inversion around ^{64}Cr

S. M. Lenzi,[1] F. Nowacki,[2] A. Poves,[3] and K. Sieja[2,*]
[1]*Dipartimento di Fisica dell'Università and INFN, Sezione di Padova, I-35131 Padova, Italy*
[2]*IPHC, IN2P3-CNRS et Université de Strasbourg, F-67037 Strasbourg, France*
[3]*Departamento de Física Teórica e IFT-UAM/CSIC, Universidad Autónoma de Madrid, E-28049 Madrid, Spain*
(Received 10 September 2010; published 2 November 2010)



LNPS interaction:

- based on realistic TBME
- new fit of the pf shell (KB3GR, E. Caurier)
- monopole corrections
- $g_{9/2}$-$d_{5/2}$ gap now constrained to 2.5 MeV in ^{68}Ni

Calculations:

- Up to 14$\hbar\omega$ excitations across Z=28 and N=40 gaps
- Matrix diagonalizations up to 2.10^{10}
- m-scheme code ANTOINE (non public parallel version)

Triple coexistence in ^{68}Ni

- at first approximation, ^{68}Ni has a double closed shell structure for GS
- But low lying structure much more complex
- three coexisting 0^+ states appear between 0 and $\sim$ 2.5 MeV
- new location of 0_2^+ state ! Configuration mixing and relative transition rates between low-spin states in ^{68}Ni: F. Recchia et al. Phys. Rev. **C88**, 041302(R) (2013)
- prediction of very low-lying superdeformed band ($\beta_2 \sim 0.4$) of 6*p*6*h* nature!
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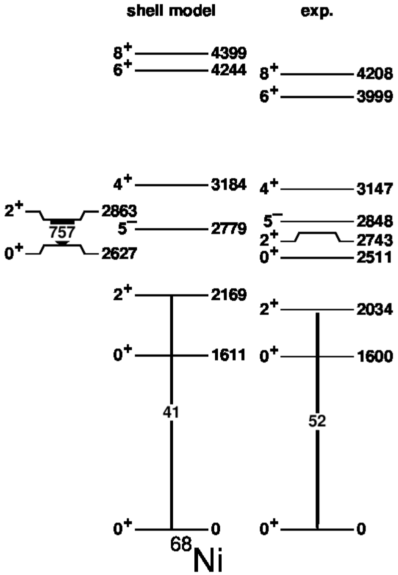

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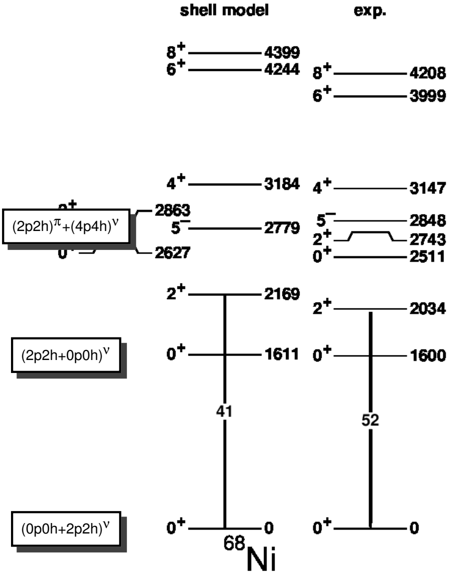

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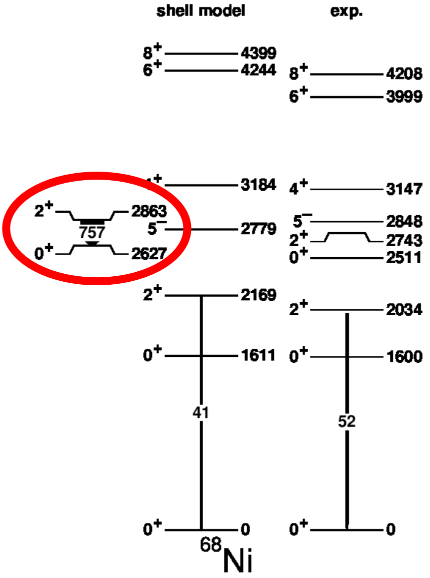
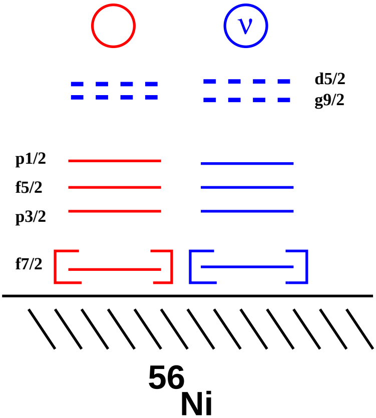


From Island of Inversion around N=40 to N=Z

PRL **112,** 142502 (2014) PHYSICAL REVIEW LETTERS week ending 11 APRIL 2014

Evolution of Collectivity in ^{72}Kr: Evidence for Rapid Shape Transition

H. Iwasaki,[1,2] A. Lemasson,[1] C. Morse,[1,2] A. Dewald,[3] T. Braunroth,[3] V. M. Bader,[1,2] T. Baugher,[1,2] D. Bazin,[1] J. S. Berryman,[1] C. M. Campbell,[4] A. Gade,[1,2] C. Langer,[1,5] I. Y. Lee,[4] C. Loelius,[1,2] E. Lunderberg,[1,2] F. Recchia,[1] D. Smalley,[1] S. R. Stroberg,[1,2] R. Wadsworth,[6] C. Walz,[1,7] D. Weisshaar,[1] A. Westerberg,[8] K. Whitmore,[1,2] and K. Wimmer[1,8]



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- $g_{9/2}$-$d_{5/2}$ gap now constrained to 2.5 Mev in ^{68}Ni
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Calculations:

- Up to 8$\hbar\omega$ excitations across Z=N=40 gaps
- Largest diagonalisation ever with Antoine

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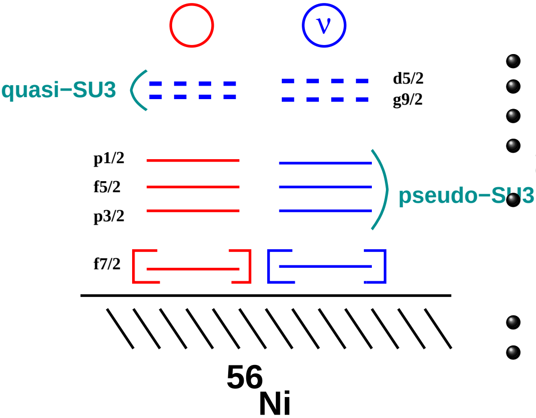

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PRL 112, 142502 (2014) PHYSICAL REVIEW LETTERS week ending 11 APRIL 2014

Evolution of Collectivity in ^{72}Kr: Evidence for Rapid Shape Transition

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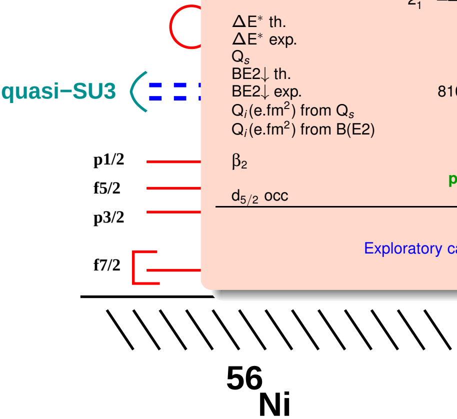
	^{72}Kr $2_1^+ \longrightarrow 0_1^+$	$2_2^+ \longrightarrow 0_2^+$
ΔE^* th.	0.405	-
ΔE^* exp.	0.710	-
Q_s	-61	+55
BE2↓ th.	1054	891
BE2↓ exp.	810(150)	-
Q_i(e.fm^2) from Q_s	212	192
Q_i(e.fm^2) from B(E2)	230	212
β_2	**0.33 prolate**	**-0.30 oblate**
$d_{5/2}$ occ	1.11	0.53

Exploratory calculations



IPS interaction:

BME

I (KB3GR, E. Caurier)

ns

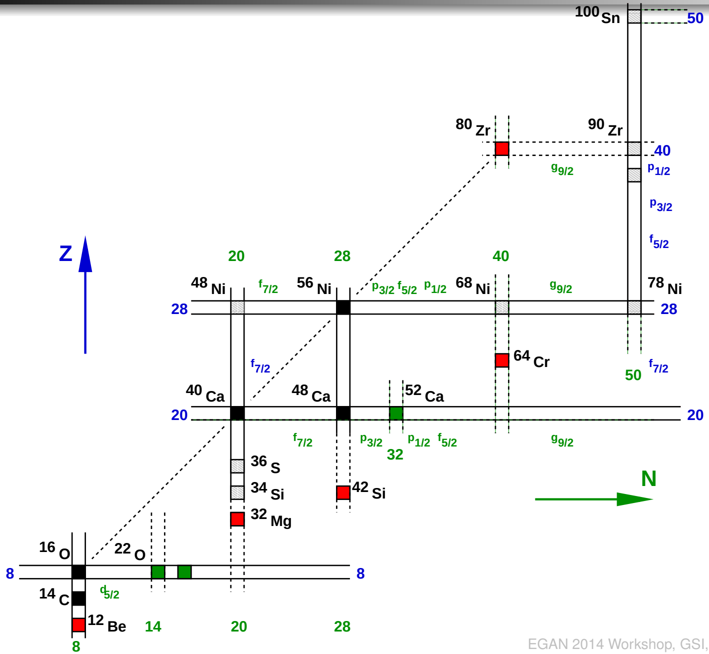
constrained to 2.5 Mev in

s deformation at N=Z

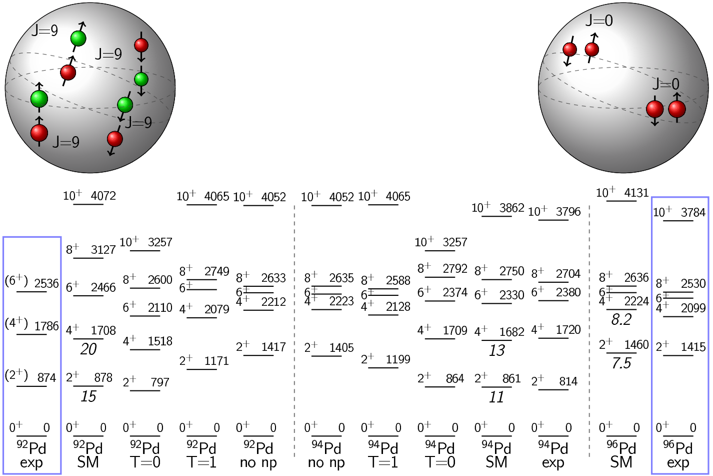
ations:

- Up to 8$\hbar\omega$ excitations across Z=N=40 gaps
- Largest diagonalisation ever with Antoine

Landscape of medium mass nuclei



New proton-neutron coupling scheme in ^{92}Pd ?

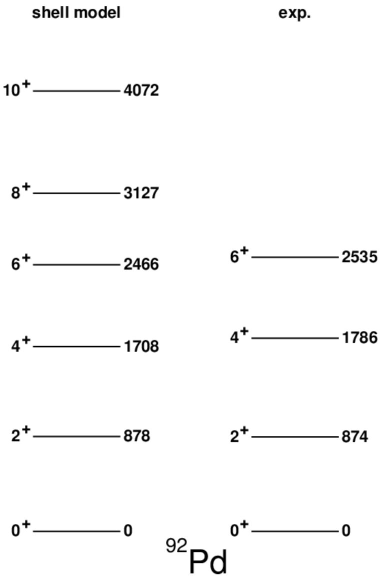


Claim for transition from Cooper pairs to aligned p-n pairs

New proton-neutron coupling scheme in ^{92}Pd ?

- In A=90-100 region, spin-orbit is at play : strong Z=50 shell closure and the $g_{\frac{9}{2}}$ orbital deeply bound with respect to the remaining *gds* orbitals
- level schemes of $A \sim 90$ nuclei to be described within $g_{\frac{9}{2}}$ orbital
- regular level spacing and constant BE2's
- wave function analysis lead to

  condensate of $(pn)^{J=9+}$ pairs

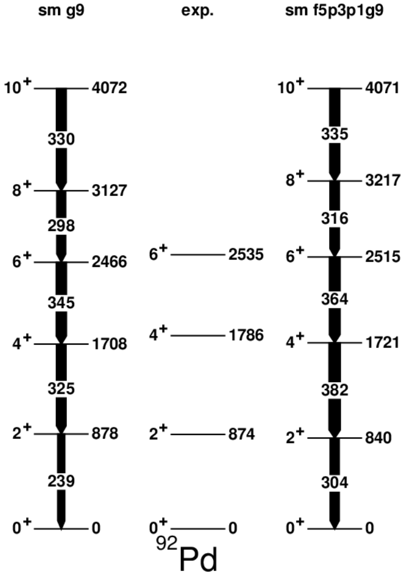


How to assess (pn) condensate regime

- 1) build $(j_p j_n)^N_{J=2j}$ objects
- 2) diagonalise $(J = 2j; T = 0)$ single matrix element for given system
- take the overlap with effective wave function
- take the expectation value of pair counting operator
- first two methods give $\sim$ results , and provide relative estimate
- counting pairs should provide absolute estimate

New proton-neutron coupling scheme in ^{92}Pd

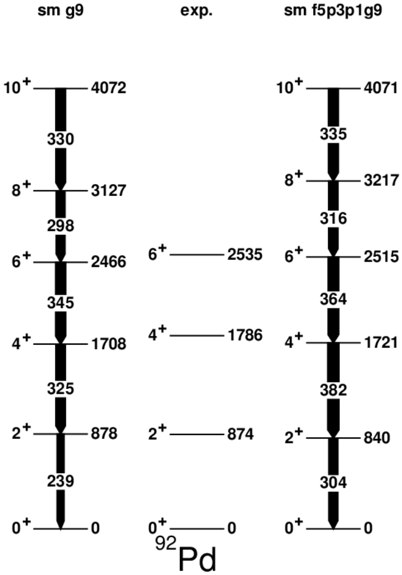
- calculations with effective $g_{\frac{9}{2}}$ (Chong et al.) and JUN45 (Otsuka et al.) interactions
- striking similarity of computed spectra
- regular level spacing and constant BE2's
- BUT quantitative differences between wave functions and underlying physics
- 29% of $(g_{\frac{9}{2}})^{12}$ configuration left in the full space calculation
- - vanishing Q's in *r3g*
  - large and constant in $g_{\frac{9}{2}}$



JT=90 pairs content

Table : correlated JT=90 pairs content in the yrast band of in ^{92}Pd.

J^π	$\langle cond \vert \Psi_{^{92}Pd} \rangle$ $g_{9/2}$	$\langle cond \vert \Psi_{^{92}Pd} \rangle$ r3g
0^+	0.83	0.45
2^+	0.87	0.48
4^+	0.91	0.58
6^+	0.87	0.62
6^+	0.73	0.57
8^+	0.86	0.69
10^+	0.35	0.34
⋮	⋮	⋮
24^+	1.00	0.99



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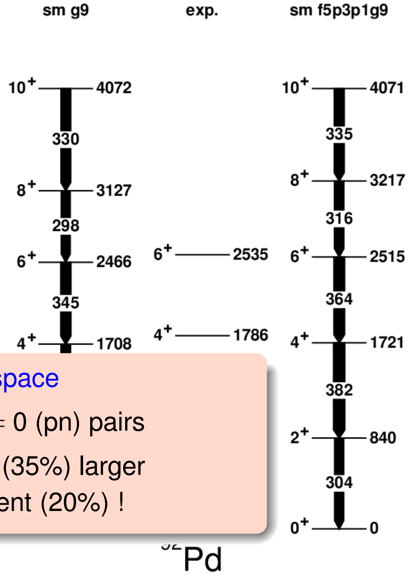
$\vdots$		
24^+		



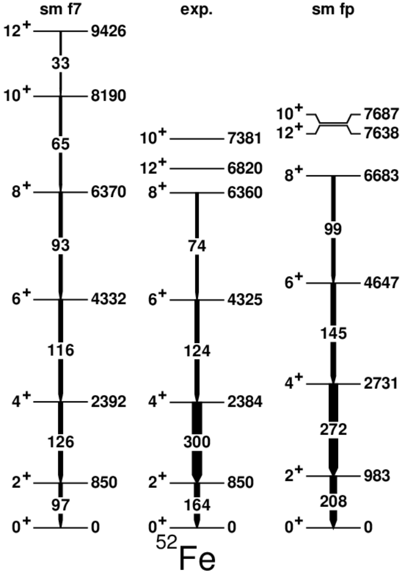
With JUN45 interation in *r3g* space

- weak content of $J = 9 T = 0$ (pn) pairs
- seniority zero component (35%) larger than condensate component (20%) !

Case of ^{52}Fe (mate of ^{96}Cd)

Table : correlated JT=70 pairs content in the yrast band of in ^{52}Fe.

J^{π}	$\langle cond \vert \Psi_{^{52}Fe} \rangle$ $f_{7/2}$	$\langle cond \vert \Psi_{^{52}Fe} \rangle$ fp
0^{+}	0.99	0.66
2^{+}	0.99	0.66
4^{+}	0.99	0.66
6^{+}	0.98	0.54
8^{+}	0.99	0.75
10^{+}	0.99	0.81
12^{+}	1.00	0.81

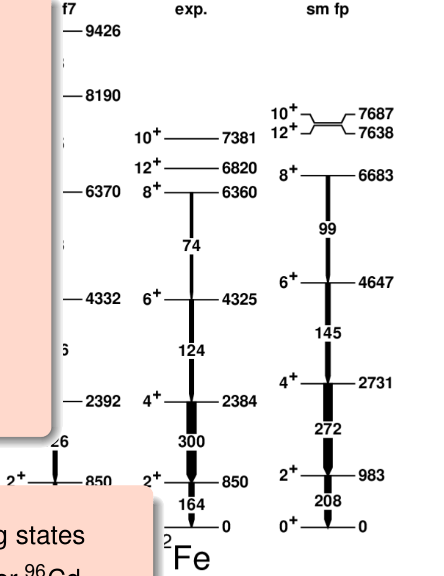


Case of ^{52}Fe (mate of ^{96}Cd)

Table : correlated J... in the yrast band of ...

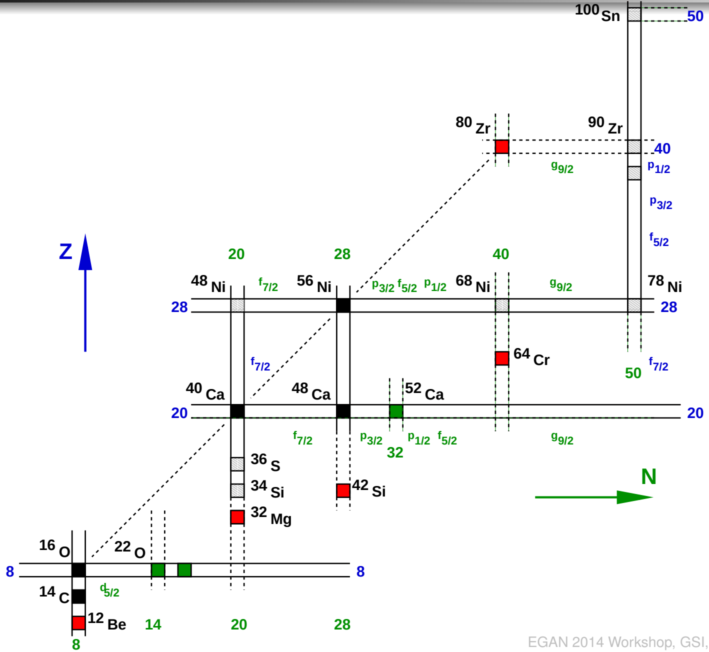
J^{π}	$\langle cond \vert \Psi_{^{52}Fe}$ ...	
	$f_{7/2}$	
0^+	0.99	
2^+	0.99	
4^+	0.99	
6^+	0.98	
8^+	0.99	
10^+	0.99	0.81
12^+	1.00	0.81

	^{52}Fe
$E^*(2_1^+)$ th.	0.98
Q_s	-29
BE2↓ th.	208
Q_i(e.fm^2) from Q_s	103
Q_i(e.fm^2) from B(E2)	102
β	0.25
$E^*(4_1^+)$	2.73
Q_s	-34
BE2↓ th.	272
Q_i(e.fm^2) from Q_s	93
Q_i(e.fm^2) from B(E2)	98
β	0.24
$E^*(6_1^+)$	2.73
Q_s	+3
BE2↓ th.	145
Q_i(e.fm^2) from Q_s	8
Q_i(e.fm^2) from B(E2)	68
β	-



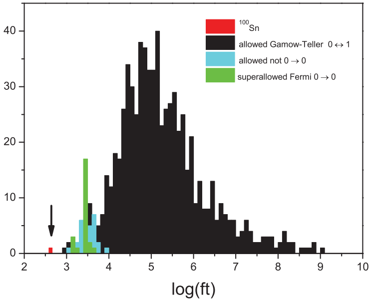
- Rotor regime for low-lying states
- Same conclusion holds for ^{96}Cd

Landscape of medium mass nuclei

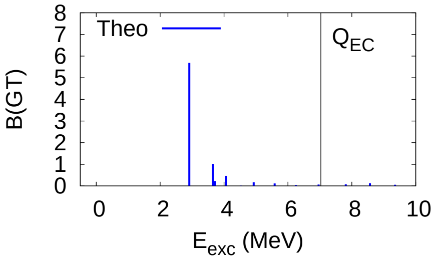


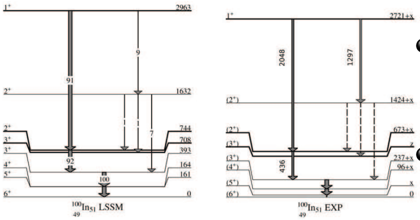
Exp: RISING, Theo: SM Strasbourg

nature *486, 341 (2012)*



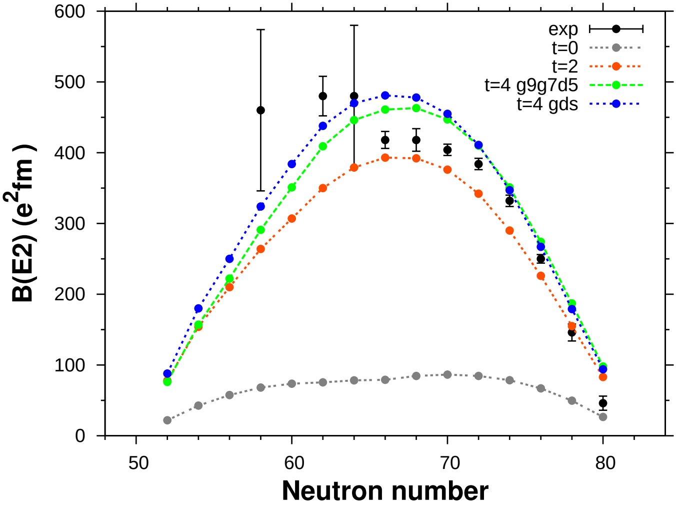
β decay of ^{100}Sn





- State-of-the art SM calculations in good agreement with experiment
- First information on the Z=50 proton gap (neutron gap inferred from our previous studies *PRL 107 (2011) 172502, PRC 84 (2011) 044311*)
- ^{100}Sn paradox: very stable with respect to strong force while very unstable with respect to weak force !

B(E2)'s in Tin isotopes



A. Banu et al.,

Phys. Rev. **C72**, 061305(R) (2005)

B(E2)'s in Tin isotopes

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Coulomb Excitation of ^{104}Sn and the Strength of the ^{100}Sn Shell Closure

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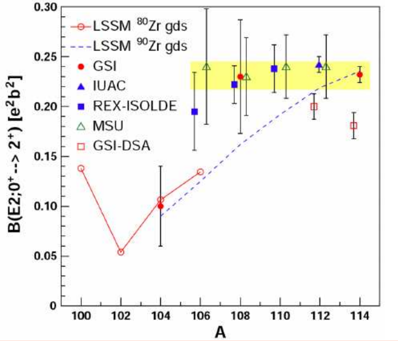

- overall agreement with recent experimental data
- strong sensitivity to (unknown) proton gap
- decrease of proton gap by 1 MeV increase B(E2) by 30% !!!

Summary

- Monopole drift develops in all regions but the Interplay between
  correlations (pairing + quadrupole)
  and spherical mean-field (monopole field) determines the physics.
  It can vary far from stability from
  - island of deformation at N=20 and N=40
  - deformation at Z=14, N=28 for ^{42}Si and shell weakening at Z=28, N=50 for ^{78}Ni

  but also along N=Z line
  - enhanced T=1 pairing correlations
  - enhanced Quadrupole correlations as in the case of extremely deformed rotors in the A$\sim$ 80 region

- Quadrupole energies can be huge and understood in terms of symmetries

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