International Nuclear Physics Conference (INPC2016)
Sep. 11–16, 2016, Adelaide

Structure of Exotic Nuclei
--- a theoretical review ---

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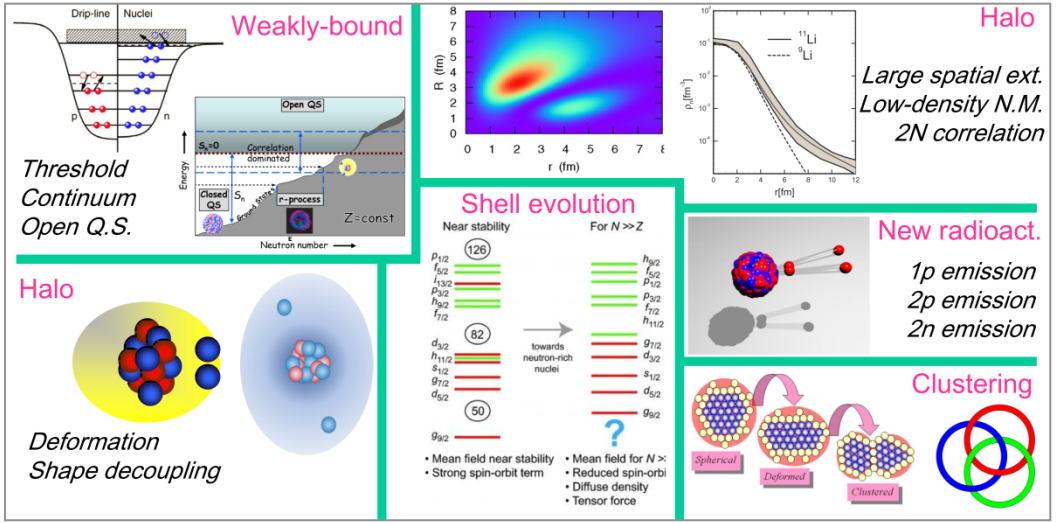
Synergetic Innovation Center for Quantum Effects and Application, Hunan Normal University, Changsha

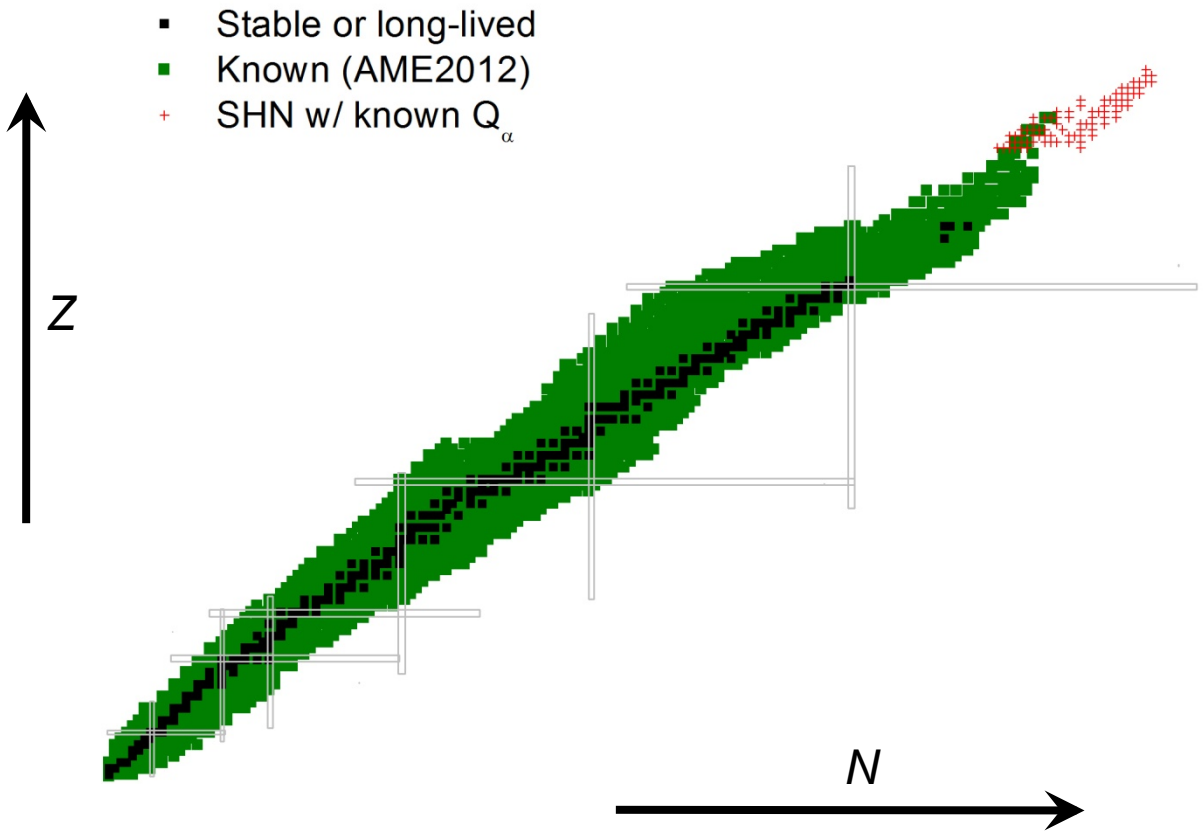
Supported by: NSFC & MOST
HPC Cluster of SKLTP/ITP-CAS
ScGrid of CNIC-CAS

Outline

- Introduction
- Physics of exotic nuclei
  - Weakly-bound features
  - Large spatial extension
  - Deformation effects
  - Shell evolution
  - New radioactivities
  - Clustering
- Perspectives

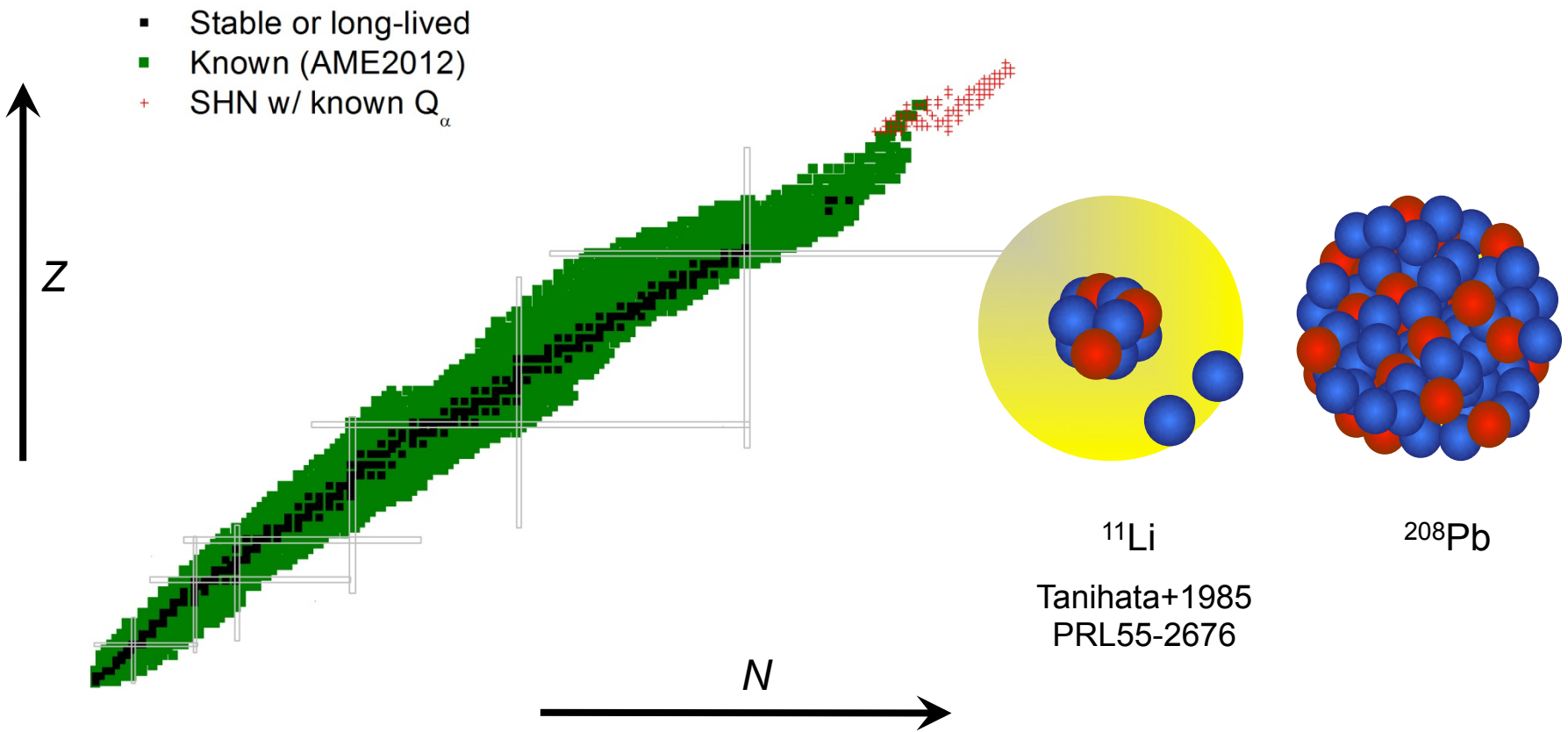


Extension of Nuclear Chart: Exotic Nuclei



Nuclear chart: courtesy of Ning Wang (王宁)

Extension of Nuclear Chart: Exotic Nuclei



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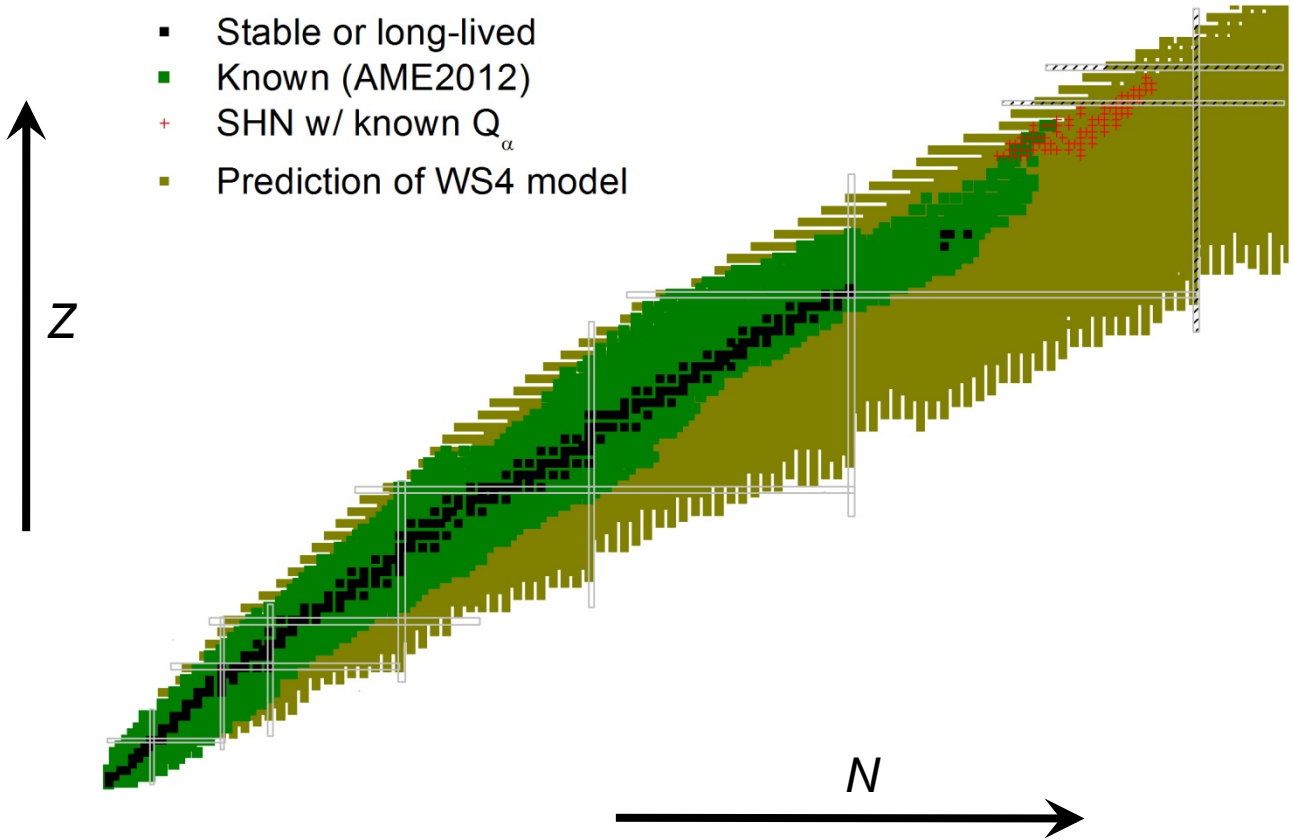
Extension of Nuclear Chart: Exotic Nuclei

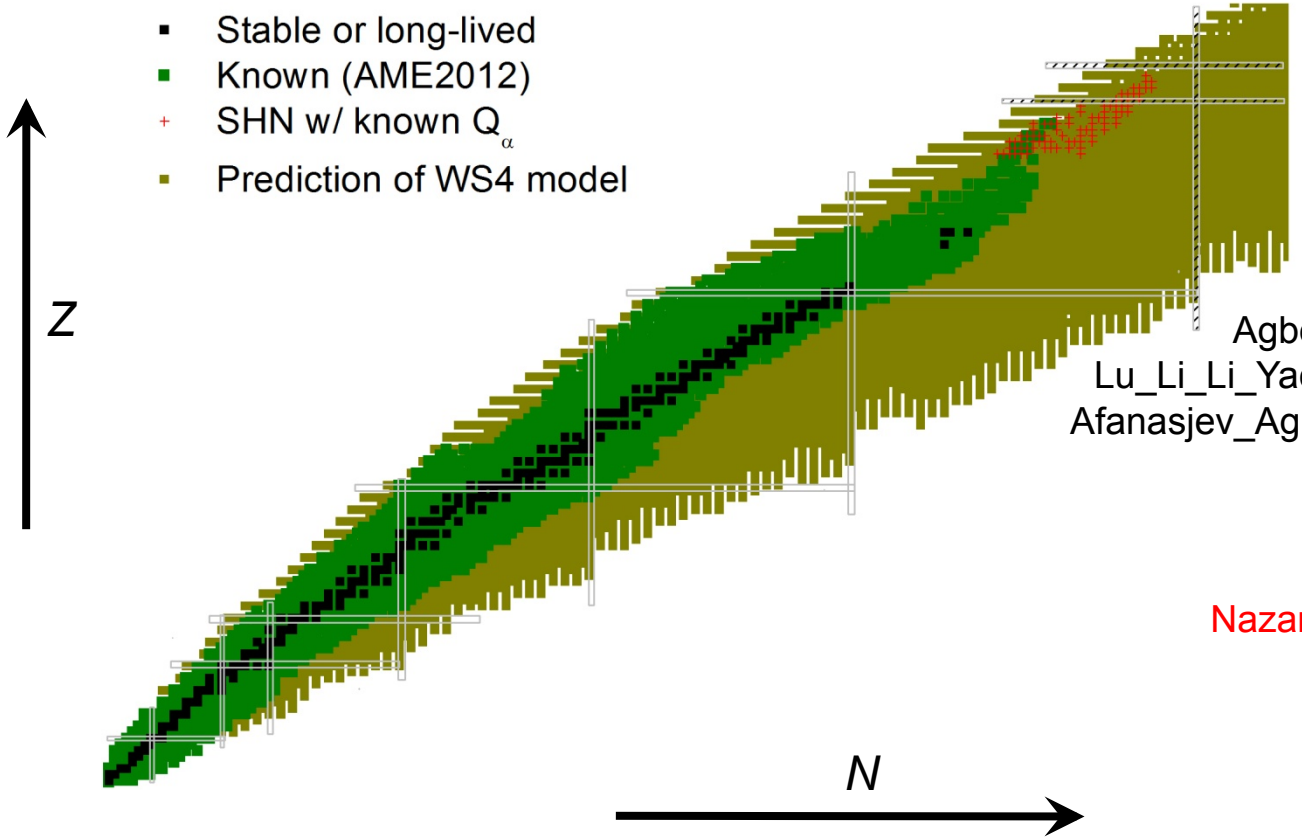


WS4: Wang_Liu_Wu_Meng 2014_PLB734-215

WS4: Weizsäcker-Skyrme mass model, Ver. 4

Nuclear chart: courtesy of Ning Wang (王宁)

Extension of Nuclear Chart: Exotic Nuclei



WS4: Wang_Liu_Wu_Meng 2014_PLB734-215

Erler+2012_Nature486-509

Agbemava+2014_PRC89-054320
Lu_Li_Li_Yao_Meng2015_PRC91-027304
Afanasjev_Agbemava2016_PRC93-054310

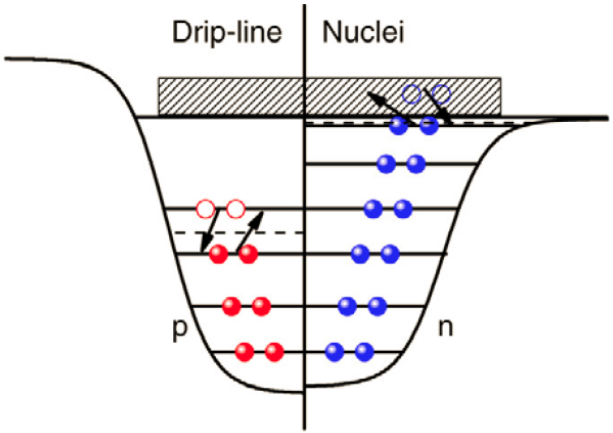
Nazarewicz's talk on PROSPECTS

WS4: Weizsäcker-Skyrme mass model, Ver. 4

Nuclear chart: courtesy of Ning Wang (王宁)

Exotic nuclei: Weakly bound

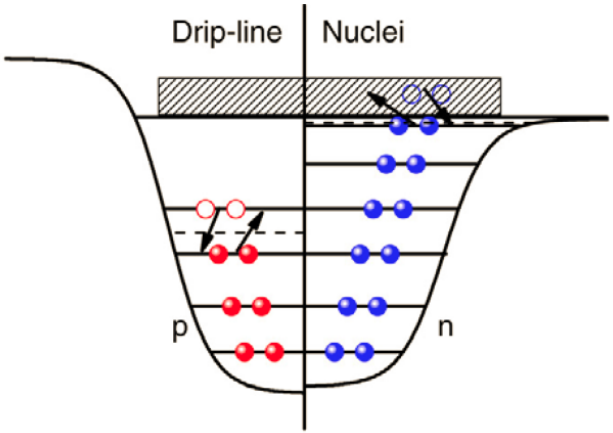
Threshold; Continuum & resonance; Open quantum systems



Meng+2006_PPNP57-470
Meng_SGZ2015_JPG42-093101

Exotic nuclei: Weakly bound

Threshold; Continuum & resonance; Open quantum systems



Meng+2006_PPNP57-470
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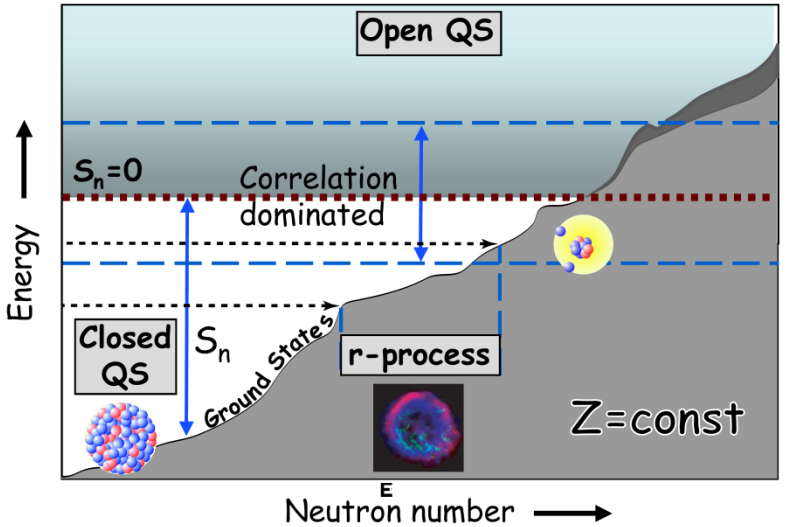
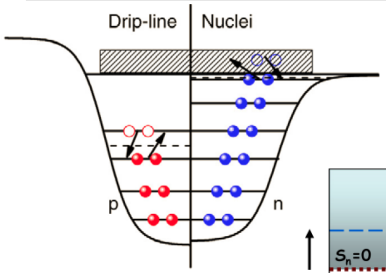


Dobaczewski+2007_PPNP59-432
Michel+2009_JPG36-013101

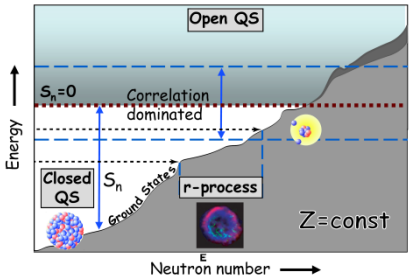
Bonaccorso & Larsen's talks
Lugaro & Surman's talks

Physics of exotic nuclei



Weakly-bound

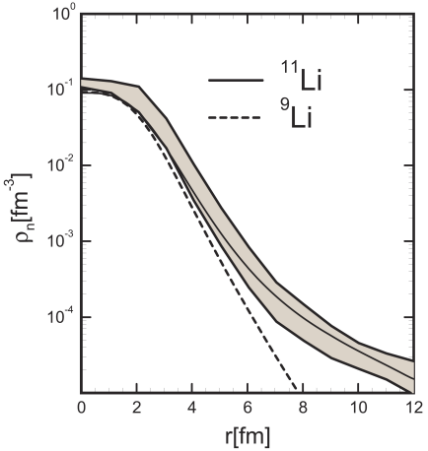
Threshold
Continuum
Open Q.S.



Halo: Large spatial extension

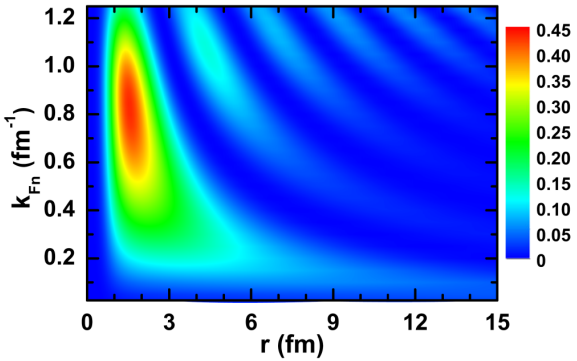
Low-density neutron matter; Di-neutron correlation; Soft dipole mode

Meng_Ring1996_PRL77-3963



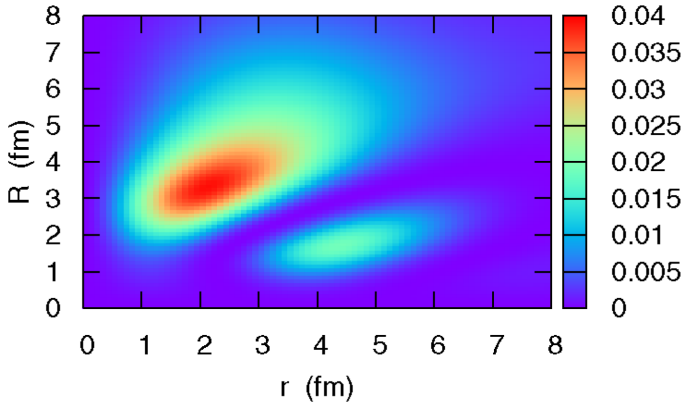
Vretenar2005_PR409-101
Meng+2006_PPNP57-470

Sun_Toki_Meng2010_PLB683-134



Matsuo2006_PRC73-044309
Sun_Sun_Meng2012_PRC86-014305

Hagino+2007_PRL99-022506

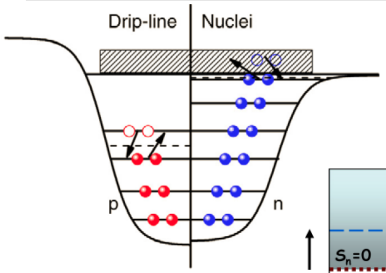


Sagawa_Hagino2015_EPJA51-102

^{11}Li: Nakamura+2006_PRL96-252502; …; Kanungo+2015_PRL114-192502

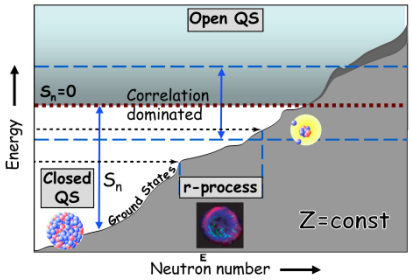
Tamii's talk

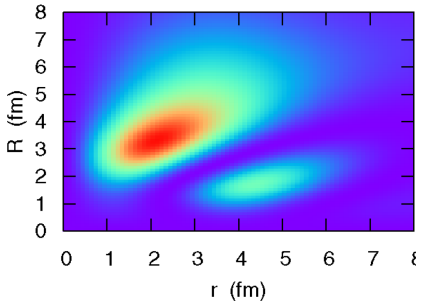
Physics of exotic nuclei

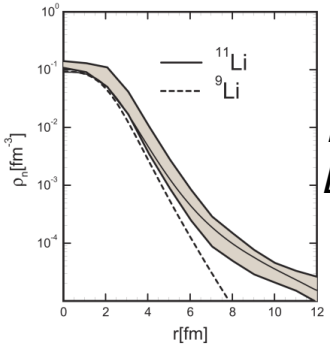


Weakly-bound

Threshold
Continuum
Open Q.S.







Halo

Large spatial ext.
Low-density N.M.
2N correlation

Halo: Deformation effects

$$R(\theta,\varphi) = R_0\left[1+\beta_{00}+\sum_{\lambda=1}^{\infty}\sum_{\mu=-\lambda}^{\lambda}\beta^*_{\lambda\mu}Y_{\lambda\mu}(\theta,\varphi)\right]$$

SGZ 2016_PhysScr 91- 063008

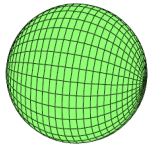
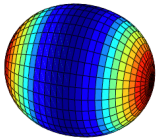
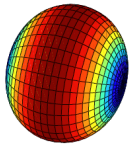
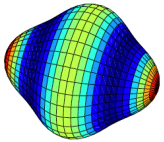
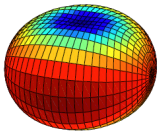
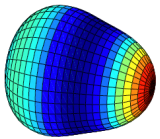
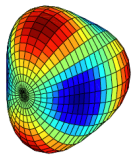
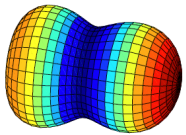
(a) $\beta_{\lambda\mu}=0$	(b) $\beta_{20}>0$	(c) $\beta_{20}<0$	(d) $\beta_{40}>0$
			
(e) $\beta_{22}\neq 0$	(f) $\beta_{30}\neq 0$	(g) $\beta_{32}\neq 0$	(h) $\beta_{20}\gg 0$
			

Figure courtesy of Bing-Nan Lu (吕炳楠)

Halo: Deformation effects

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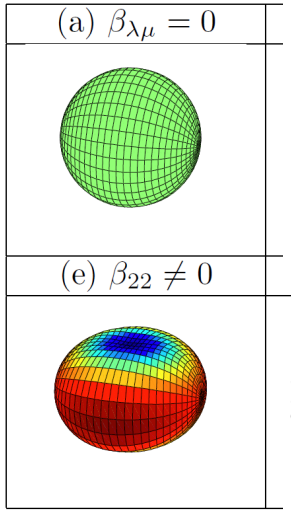
Nakamura+2014_PRL112-142501

PRL **112,** 142501 (2014) PHYSICAL REVIEW LETTERS week ending 11 APRIL 2014



Deformation-Driven *p*-Wave Halos at the Drip Line: ^{31}Ne

T. Nakamura,[1] N. Kobayashi,[1] Y. Kondo,[1] Y. Satou,[1,2] J. A. Tostevin,[3] Y. Utsuno,[4] N. Aoi,[5] H. Baba,[5] N. Fukuda,[5] J. Gibelin,[6] N. Inabe,[5] M. Ishihara,[5] D. Kameda,[5] T. Kubo,[5] T. Motobayashi,[5] T. Ohnishi,[5] N. A. Orr,[6] H. Otsu,[5] T. Otsuka,[7] H. Sakurai,[5] T. Sumikama,[8] H. Takeda,[5] E. Takeshita,[5] M. Takechi,[5] S. Takeuchi,[5] Y. Togano,[1,5] and K. Yoneda[5]

Kobayashi+2014_PRL112-242501

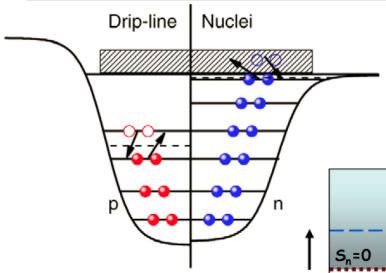
PRL **112,** 242501 (2014) PHYSICAL REVIEW LETTERS week ending 20 JUNE 2014

Observation of a *p*-Wave One-Neutron Halo Configuration in ^{37}Mg

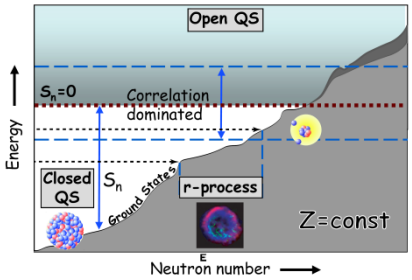
N. Kobayashi,[1,*] T. Nakamura,[1] Y. Kondo,[1] J. A. Tostevin,[2,1] Y. Utsuno,[3] N. Aoi,[4,†] H. Baba,[4] R. Barthelemy,[5] M. A. Famiano,[5] N. Fukuda,[4] N. Inabe,[4] M. Ishihara,[4] R. Kanungo,[6] S. Kim,[7] T. Kubo,[4] G. S. Lee,[1] H. S. Lee,[7] M. Matsushita,[4,‡] T. Motobayashi,[4] T. Ohnishi,[4] N. A. Orr,[8] H. Otsu,[4] T. Otsuka,[9] T. Sako,[1] H. Sakurai,[4] Y. Satou,[7] T. Sumikama,[10,§] H. Takeda,[4] S. Takeuchi,[4] R. Tanaka,[1] Y. Togano,[4,¶] and K. Yoneda[4]

Figure courtesy c

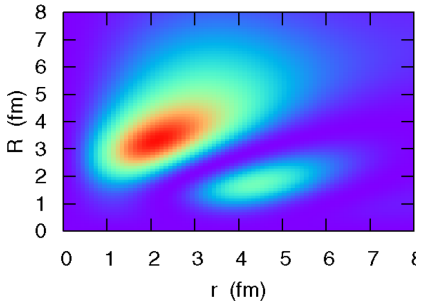
Physics of exotic nuclei

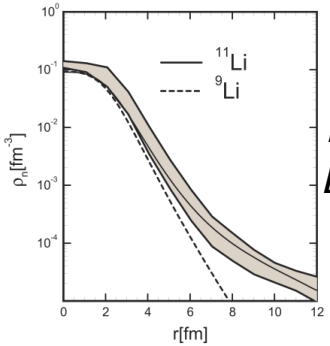


Weakly-bound



Threshold
Continuum
Open Q.S.

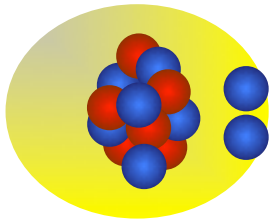


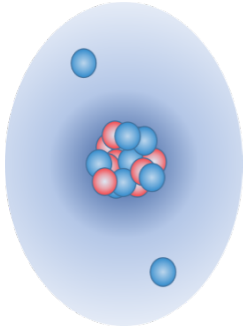


Halo

Large spatial ext.
Low-density N.M.
2N correlation

Halo

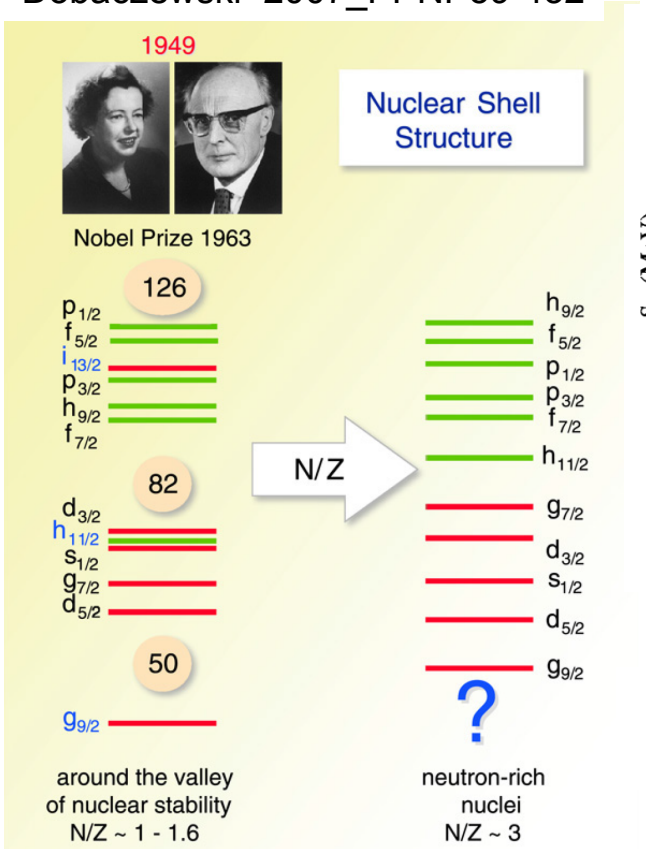




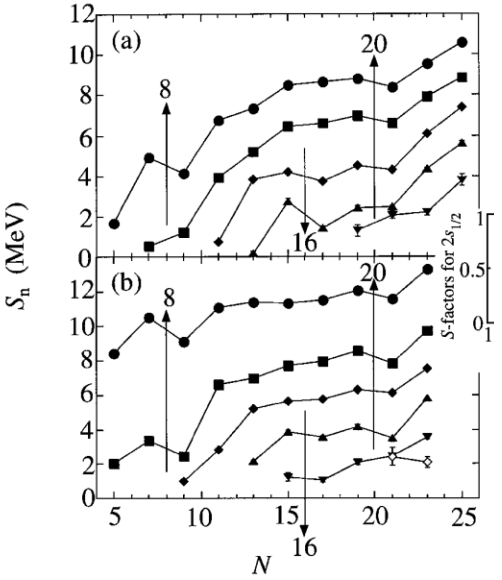
Deformation
Shape decoupling

Exotic Nuclei: Shell Evolution

Dobaczewski+2007_PPNP59-432

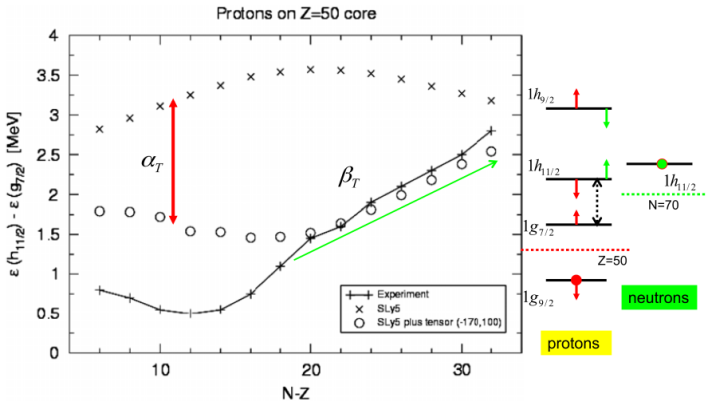


Ozawa+2000_PRL84-5493



Shape evolution
Shape coexistence

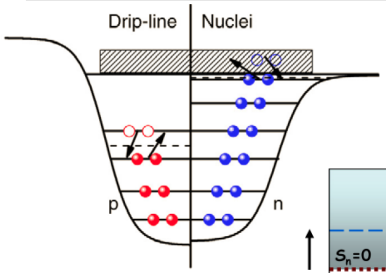
Colo+2007_PLB646-227
Sagawa_Colo2014_PPNP76-76



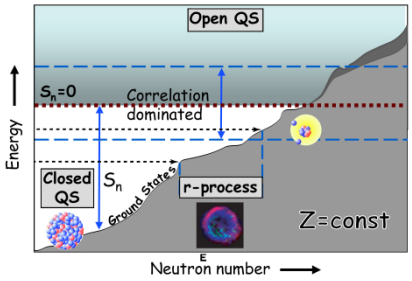
Peru_Girod_Berger2000_EPJA9-35
Otsuka+2005_PRL95-232502
Otsuka+2010_PRL104-012501
Otsuka+2010_PRL105-032501

Sorlin_Porquet2008_PPNP61-602

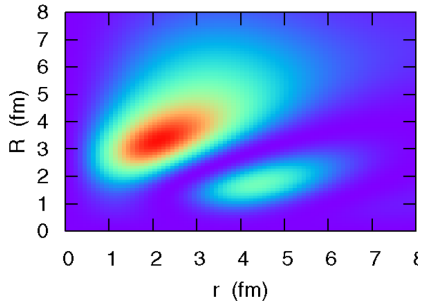
Physics of exotic nuclei

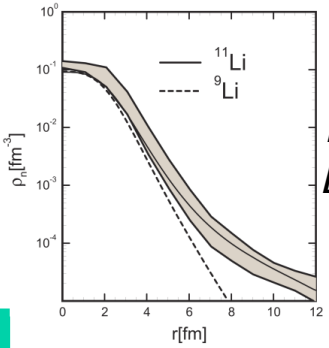


Weakly-bound



Threshold
Continuum
Open Q.S.

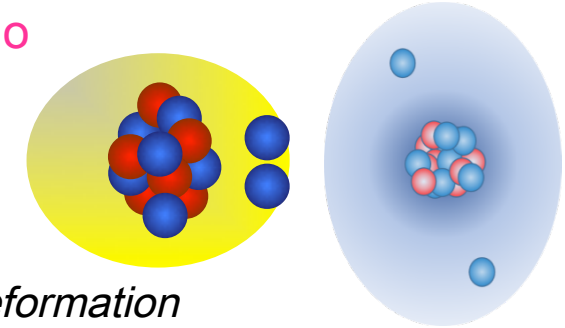




Halo

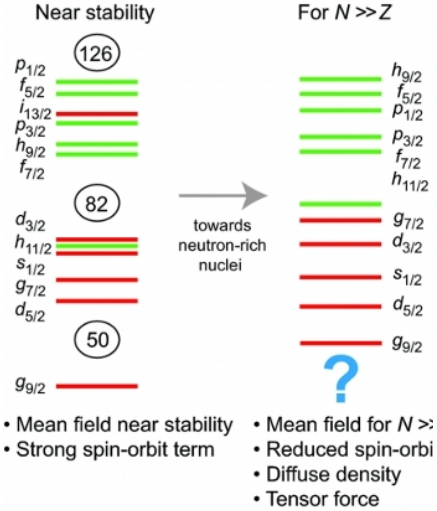
Large spatial ext.
Low-density N.M.
2N correlation

Halo



Deformation
Shape decoupling

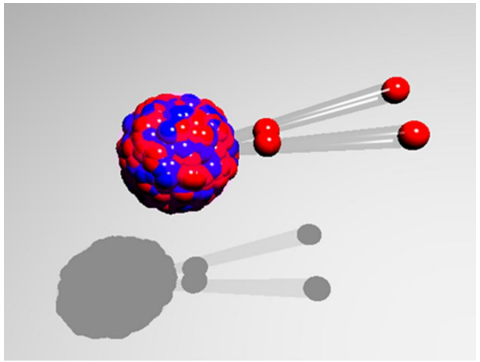
Shell evolution



Exotic Nuclei: New Radioactivities

Woods_Davids1997_ARNPS47-541
Thoennessen2004_RPP67-1187

Pfutzner+2012_RMP84-567



Lin+2011_SciChinaPMA54S1-73

SCIENCE CHINA
Physics, Mechanics & Astronomy

• Research Paper •
Radioactive Nuclear Beam Physics and Nuclear Astrophysics

August 2011 Vol.54 Suppl. 1: s73–s80
doi: 10.1007/s11433-011-4431-9

Experimental research into the two-proton emissions from ^{17,18}Ne, ^{28}P and ^{28,29}S

Ma+2015_PLB743-306

Physics Letters B 743 (2015) 306–309

Contents lists available at ScienceDirect

Physics Letters B

www.elsevier.com/locate/physletb

ELSEVIER

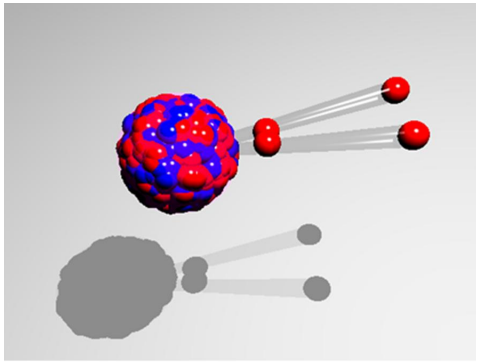
Different mechanism of two-proton emission from proton-rich nuclei ^{23}Al and ^{22}Mg

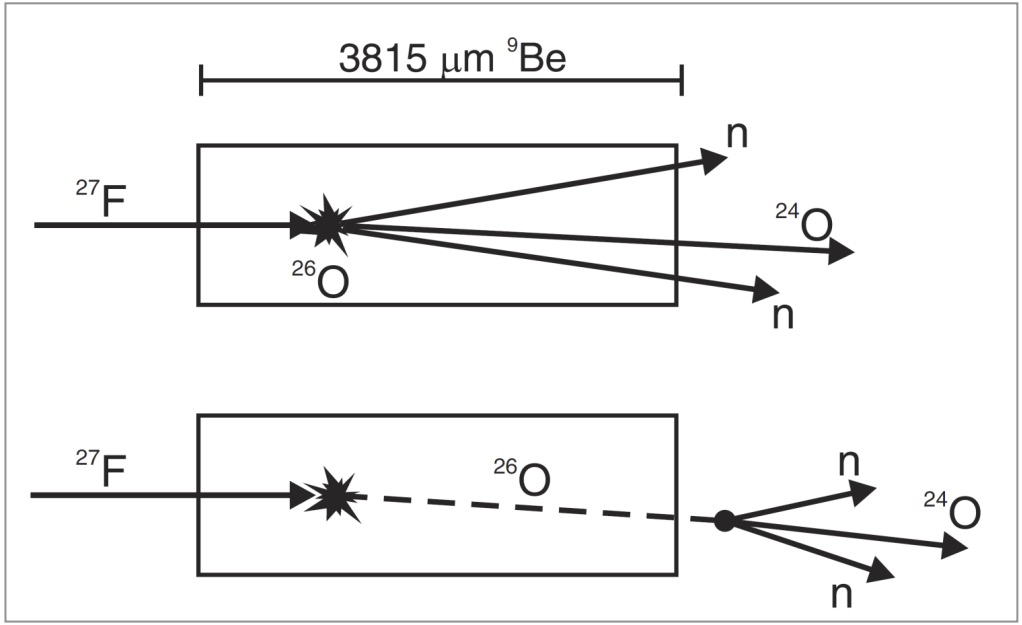
Exotic Nuclei: New Radioactivities

Woods_Davids1997_ARNPS47-541
Thoennessen2004_RPP67-1187

Pfutzner+2012_RMP84-567

Lunderberg+2012_PRL108-142503: E=150^{+50}_{-150} keV
Kohley+2013_PRL110-152501: $T_{1/2}$ (^{26}O) ~ 4.5 ps





Exotic Nuclei: New Radioactivities

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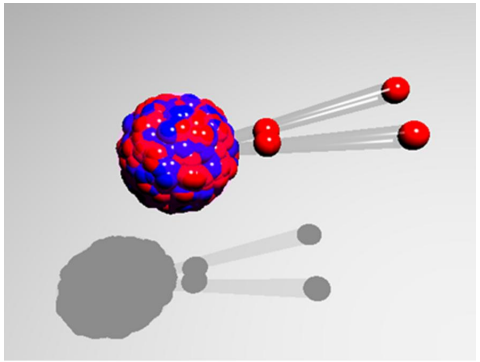
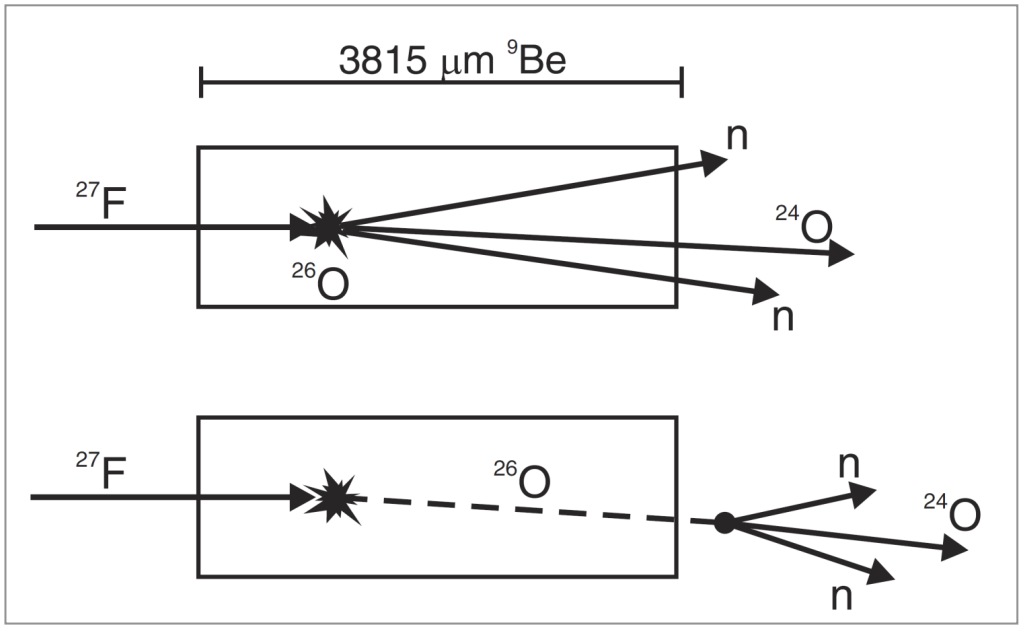
Thoennessen2004_RPP67-1187

Pfutzner+2012_RMP84-567



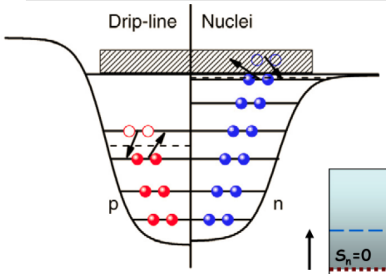
Lunderberg+2012_PRL108-142503: $E=150^{+50}_{-150}$ keV
Kohley+2013_PRL110-152501: $T_{1/2}$ (^{26}O) ~ 4.5 ps

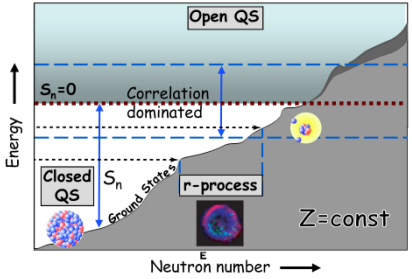


Kondo+2016_PRL116-102503: $T_{1/2}$ (^{26}O) ~ 10^{-17}-10^{-15} s

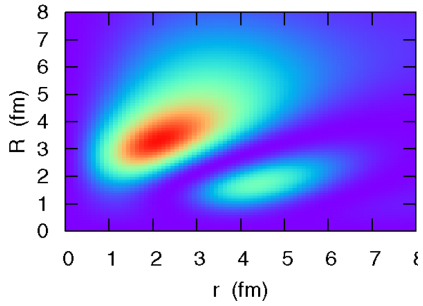
Physics of exotic nuclei

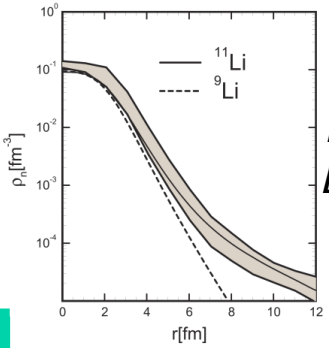
Weakly-bound





Threshold
Continuum
Open Q.S.

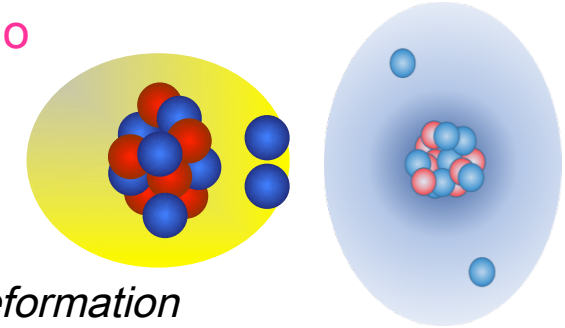




Halo

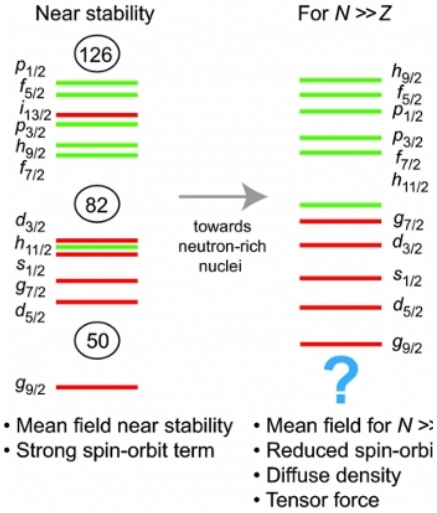
Large spatial ext.
Low-density N.M.
2N correlation

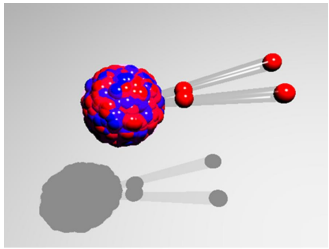
Halo



Deformation
Shape decoupling

Shell evolution



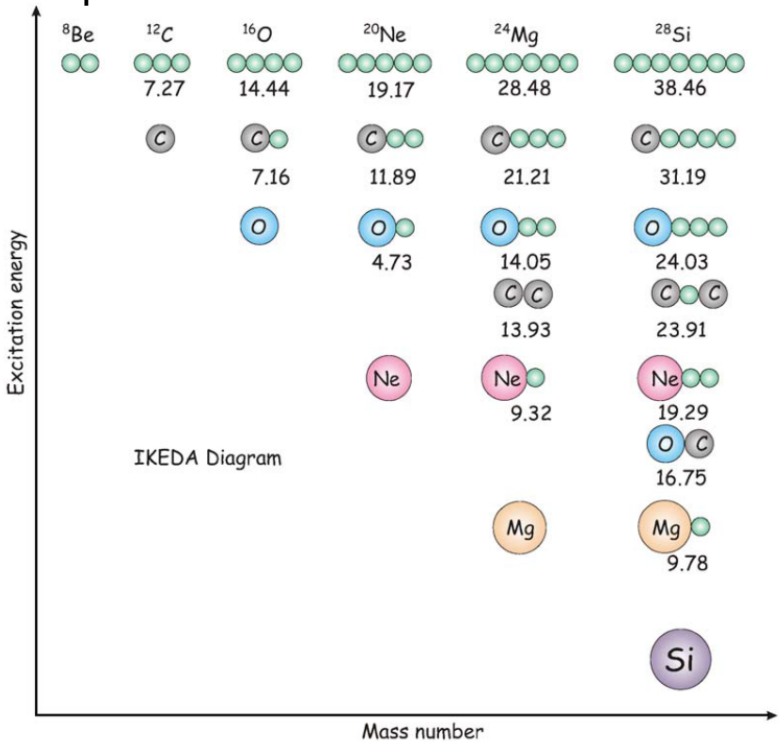


New radioact.

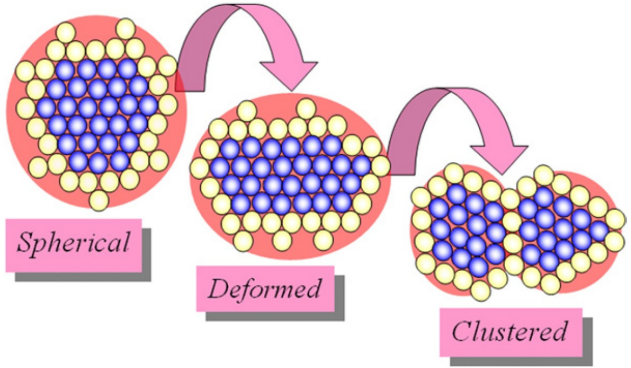
1p emission
2p emission
2n emission

Exotic Nuclei: Clustering

Alpha-nuclei: *N*=*Z*=even number



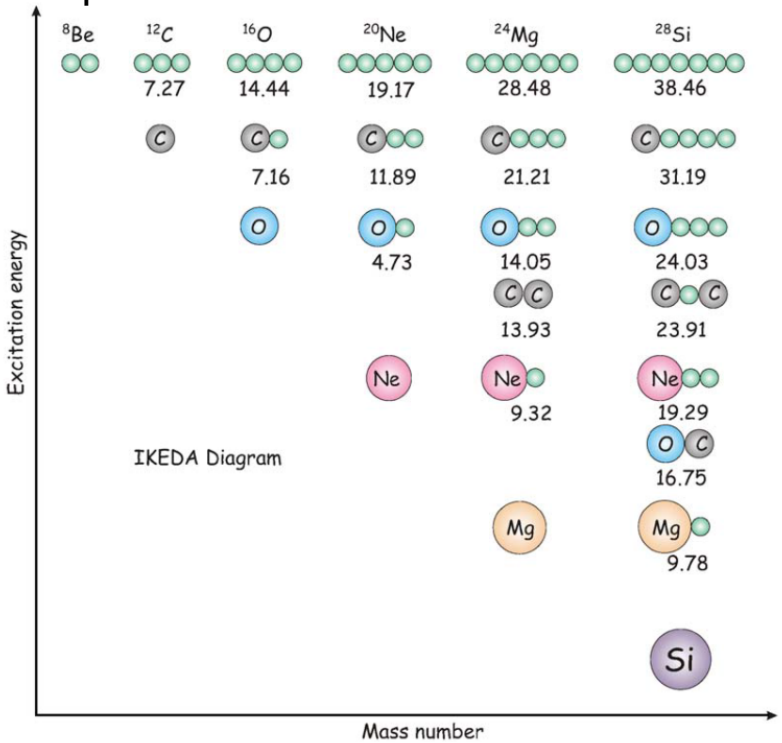
vonOertzen_Freer_Kanada-En'yo 2006_PR432-43



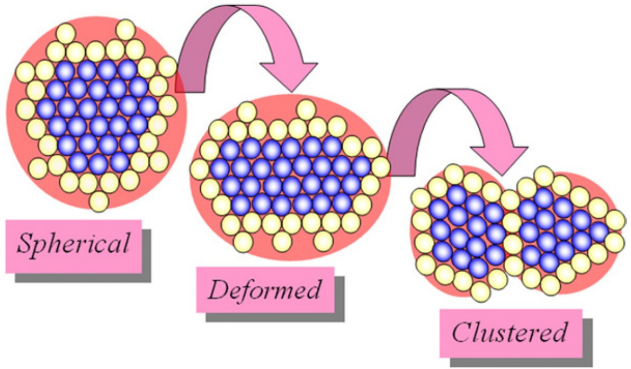
Freer2007_RPP70-2149

Exotic Nuclei: Clustering

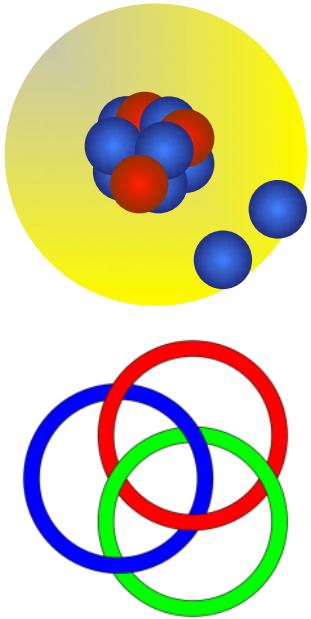
Alpha-nuclei: *N*=*Z*=even number



vonOertzen_Freer_Kanada-En'yo 2006_PR432-43



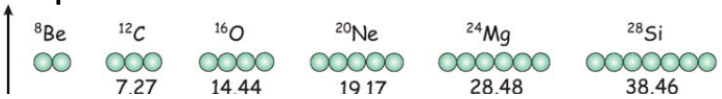
Freer2007_RPP70-2149



Borromean Ring

Exotic Nuclei: Clustering

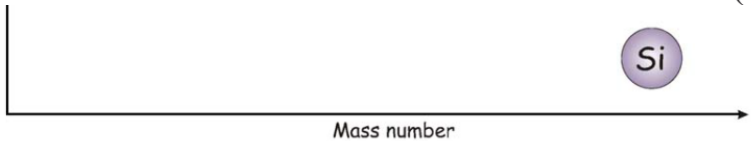
Alpha-nuclei: *N*=*Z*=even number



PRL **112,** 162501 (2014) PHYSICAL REVIEW LETTERS week ending 25 APRIL 2014

Observation of Enhanced Monopole Strength and Clustering in ^{12}Be

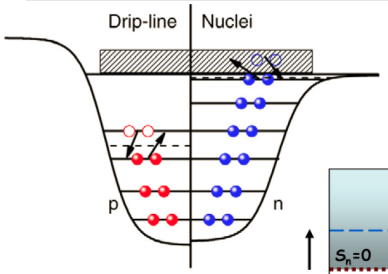
Z. H. Yang (杨再宏),[1] Y. L. Ye (叶沿林),[1,*] Z. H. Li (李智焕),[1] J. L. Lou (楼建玲),[1] J. S. Wang (王建松),[2] D. X. Jiang (江栋兴),[1] Y. C. Ge (葛愉成),[1] Q. T. Li (李奇特),[1] H. Hua (华辉),[1] X. Q. Li (李湘庆),[1] F. R. Xu (许甫荣),[1] J. C. Pei (裴俊琛),[1] R. Qiao (乔锐),[1] H. B. You (游海波),[1] H. Wang (王赫),[1,3] Z. Y. Tian (田正阳),[1] K. A. Li (李阔昂),[1] Y. L. Sun (孙叶磊),[1] H. N. Liu (刘红娜),[1,3] J. Chen (陈洁),[1] J. Wu (吴锦),[1,3] J. Li (李晶),[1] W. Jiang (蒋伟),[1] C. Wen (文超),[1,3] B. Yang (杨彪),[1] Y. Y. Yang (杨彦云),[2] P. Ma (马朋),[2] J. B. Ma (马军兵),[2] S. L. Jin (金仕纶),[2] J. L. Han (韩建龙),[2] and J. Lee (李晓菁)[3]

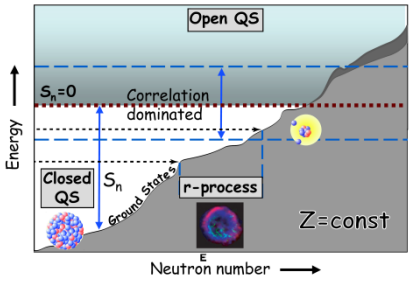


vonOertzen_Freer_Kanada-En'yo 2006_PR432-43

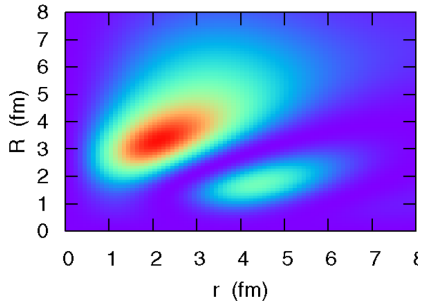
Physics of exotic nuclei

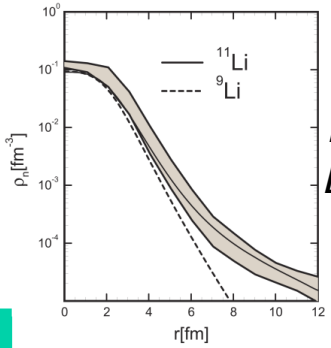
Weakly-bound





Threshold
Continuum
Open Q.S.

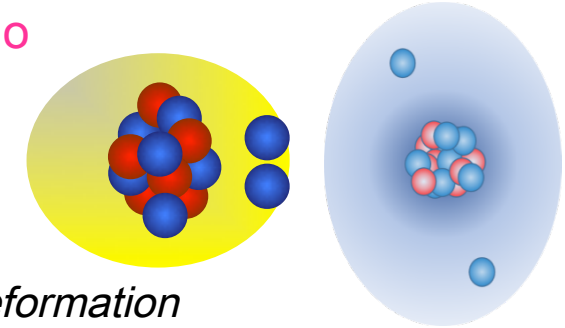




Halo

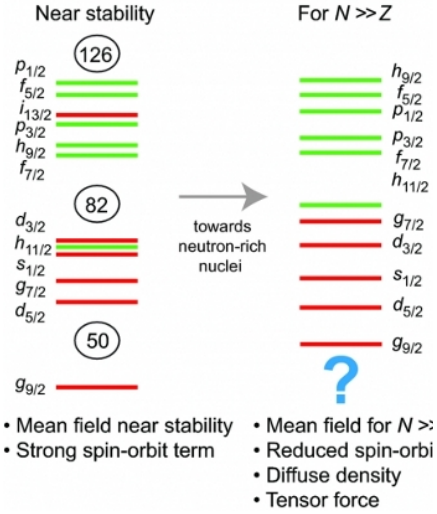
Large spatial ext.
Low-density N.M.
2N correlation

Halo

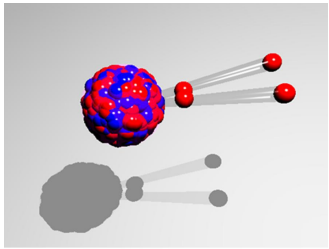


Deformation
Shape decoupling

Shell evolution

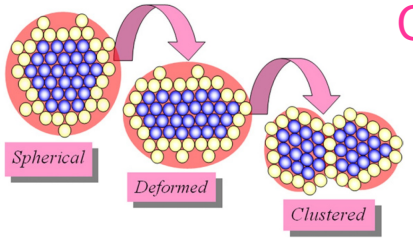


New radioact.



1p emission
2p emission
2n emission

Clustering



Weakly bound: Models dealing w/ Continuum

- Few-body approach
  - Two-particle Green's function or complex scaling methods
- Shell model
  - Berggren basis
- (Relativistic) Hartree(-Fock) + resonance BCS approach
- (Relativistic) Hartree(-Fock) Bogoliubov model
  - *R*-space or equivalent basis

Frederico+2012_PPNP67-939
Meng_SGZ2015_JPG42-093101
Sagawa_Hagino2015_EPJA51-102
Ji2016_IJMPE25-1641003

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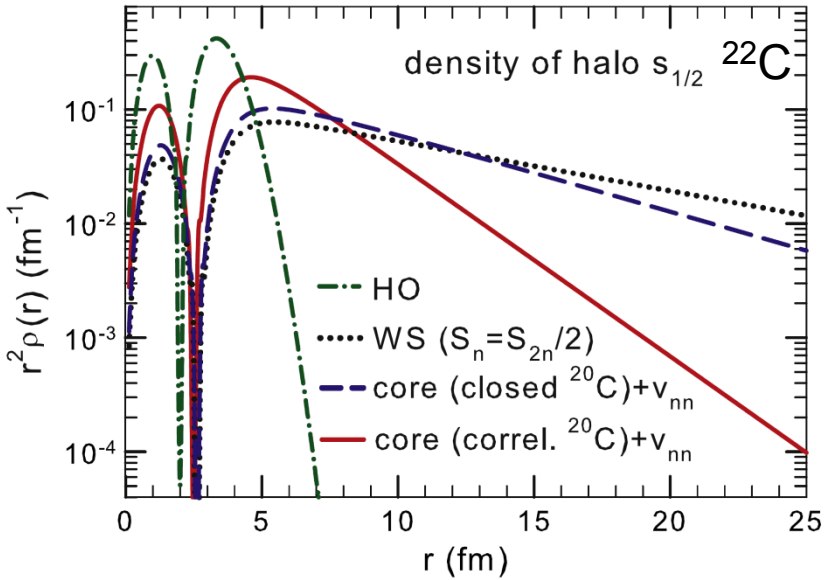
Frederico+2012_PPNP67-939
Meng_SGZ2015_JPG42-093101
Sagawa_Hagino2015_EPJA51-102
Ji2016_IJMPE25-1641003

Suzuki_Otsuka_Yuan_Navin2016_PLB753-199



Togano+2016_PLB761-412: r_m=3.44 ± 0.08 fm

Tanaka+2010_PRL104-062701: r_m=5.4±0.9 fm

Single Particle Resonances

- Scattering phase shift method
- Bound-state-like approaches — Efros+2007_JPG34-R459; Carbonell+2014_PPNP74-55
  - Analytical continuation of coupling constant (ACCC)

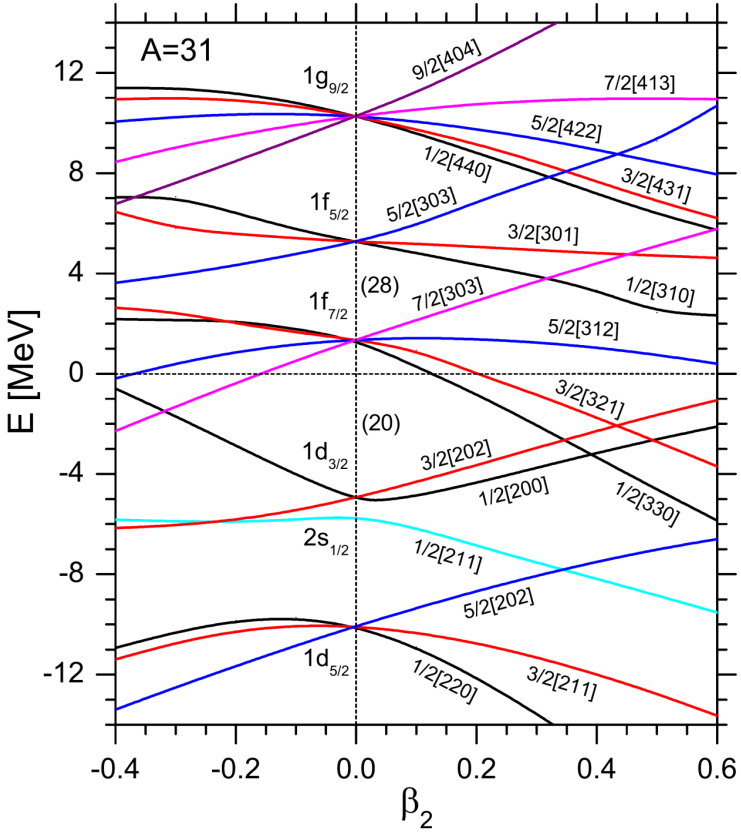
    Tanaka+1997_PRC56-562; Yang_Meng_SGZ2001_CPL8-196; Zhang+2004_PRC70-034308
    Guo_Fang2006_PRC74-024320; Zhang+2012_PRC86-032802; Xu+2015_PRC92-024324
  - Real stabilization method (RSM)

    Zhang+2008_PRC77-014312; Pei_Kruppa_Nazarewicz2011_PRC84-024311
  - Complex scaling method (CSM)

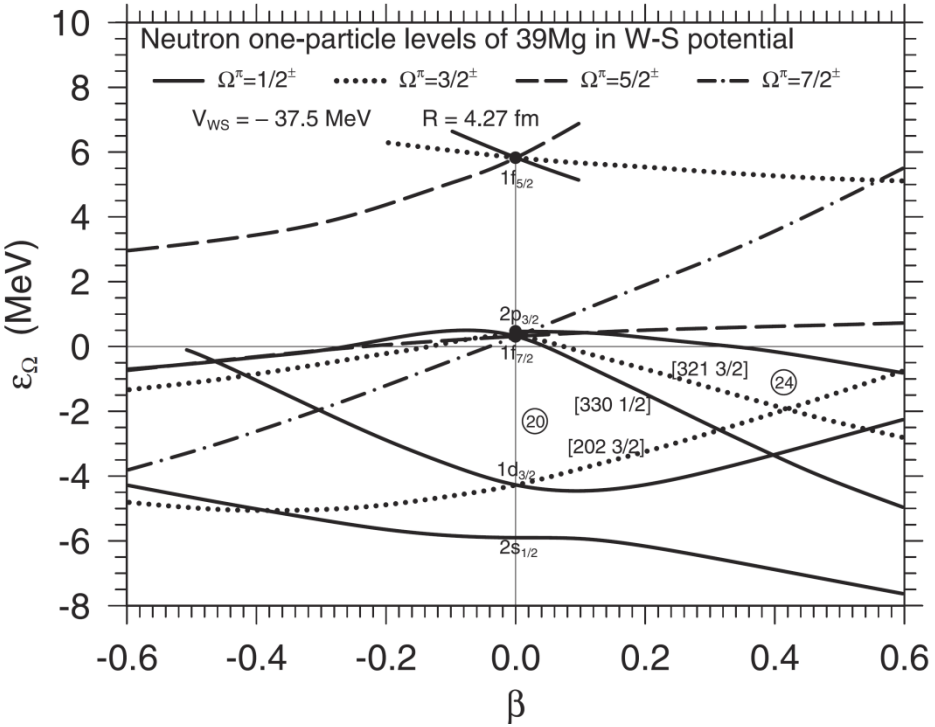
    ……; Myo+2014_PPNP79-1; Papadimitriou_Vary2015_PRC91-021001R
    Shi2015_PRC92-054313
- Jost function method — Lu_Zhao_SGZ2012_PRL109-072501; 2013_PRC88-024323
- Green's function method — Matsuo2001_NPA696-371; ……; Sun+2014_PRC90-054321
- Green's function + CSM — Shi+2015_PRC92-054313; Shi+2016_PRC94-024302
- Complex momentum representation — Li+2016_PRL117-062502; Liang's talk

Nilsson Diagram w/ Resonances

Shi_Liu_Niu_Guo2014_PRC90-034319

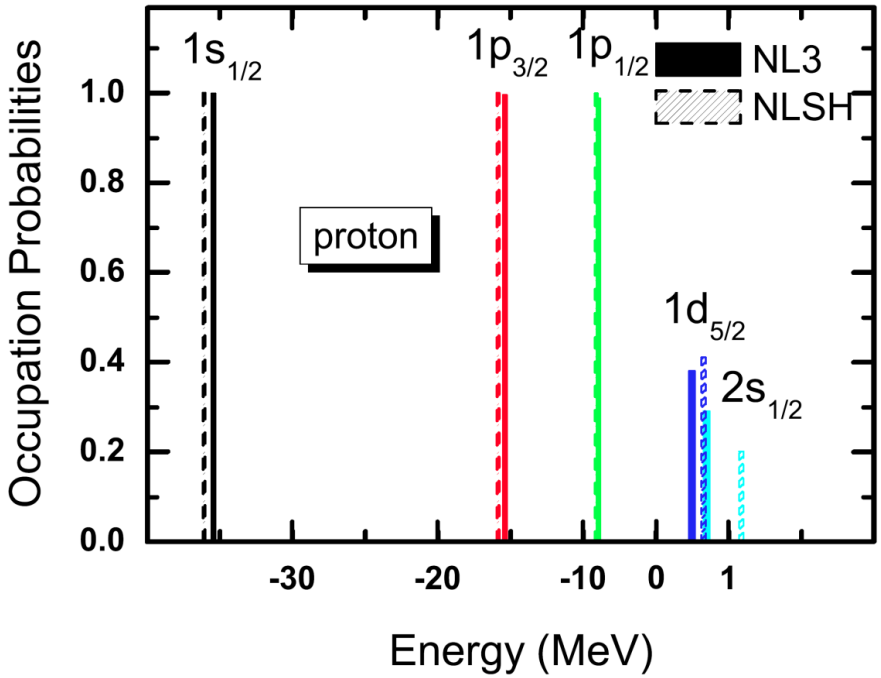


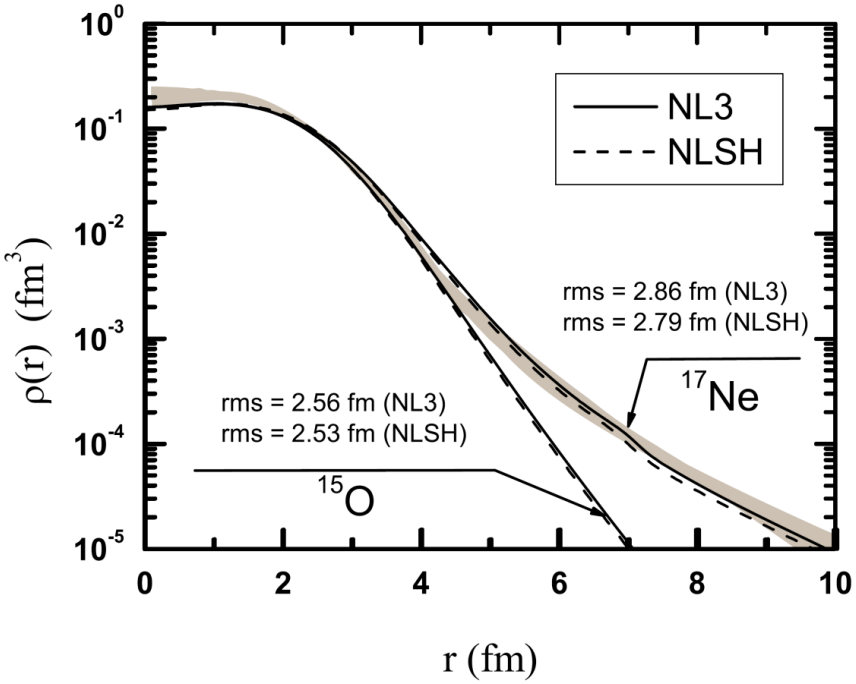
Hamamoto2016_PRC93-054328



^{17}Ne: RMF+ACCC+BCS

Zhang_Zhao_SGZ2013_EPJA49-77





rBCS: Sandulescu_Giai_Liotta2000_PRC61-061301R; Sandulescu+2003_PRC68-054323

Weakly bound: Continuum (R)HFB model

Contribution of continuum can be taken into account
by solving HFB equations in *r*-space

Bulgac1980 (nucl-th/9907088) ; Dobaczewski_Flocard_Treiner1984_NPA422-103

Weakly bound: Continuum (R)HFB model

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Bulgac1980 (nucl-th/9907088) ; Dobaczewski_Flocard_Treiner1984_NPA422-103

Skyrme or Gogny Hartree-Fock-Bogoliubov models

	Spherical Nuclei	Deformed Nuclei
Box Boundary	Dobaczewski_Flocard_Treiner1984_NPA422 Dobaczewski+1996_PRC53-2809 Schunck_Egido2008_PRC78-064305	Nakada2008_NPA808-47 Pei_Zhang_Xu2013_PRC87-051302R Pei+2014_PRC90-024317
Scattering Boundary	Zhang_Matsuo_Meng2011_PRC83-054301 Zhang_Matsuo_Meng2012_PRC86-054318	N/A

Weakly bound: Continuum (R)HFB model

Contribution of continuum can be taken into account
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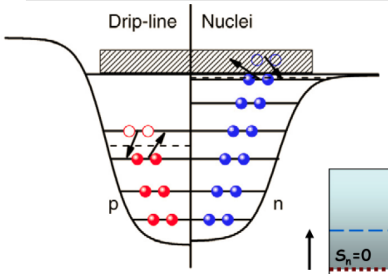
Bulgac1980 (nucl-th/9907088) ; Dobaczewski_Flocard_Treiner1984_NPA422-103

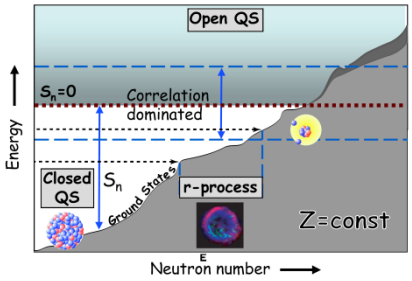
Relativistic Hartree(-Fock)-Bogoliubov models

	Spherical Nuclei	Deformed Nuclei
Box Boundary	Meng_Ring1996_PRL77-3963 Meng1998_NPA635-3 Poschl+1997_PRL79-3841 Long+2010_PRC81-024308	SGZ+2010_PRC82-011301R Li+2012_PRC85-024312 Li+2012_ChinPhysLett29-042101 Chen+2012_PRC85-067301
Scattering Boundary	N/A	N/A

Physics of exotic nuclei

Weakly-bound





Threshold
Continuum
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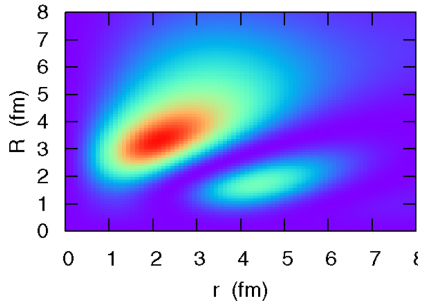

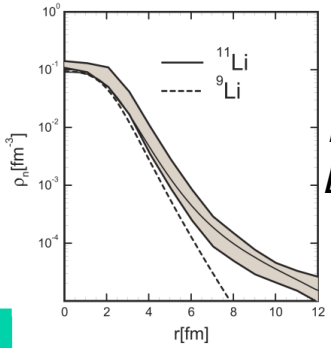

Halo

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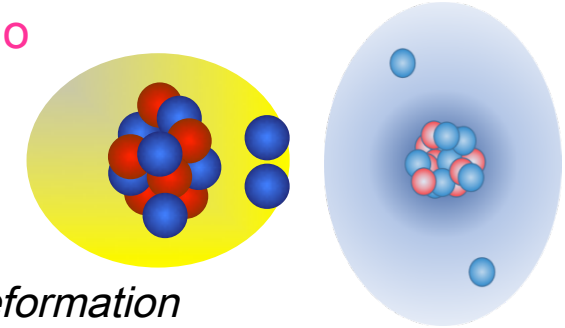

Deformation
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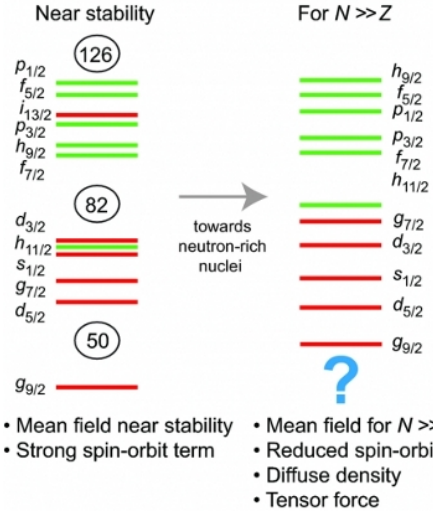
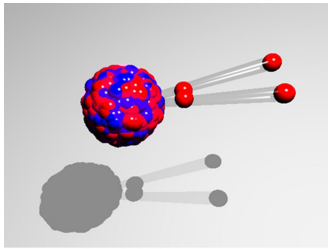
Shell evolution



New radioact.



1p emission
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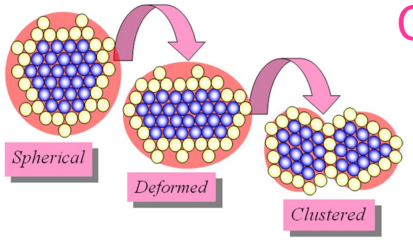
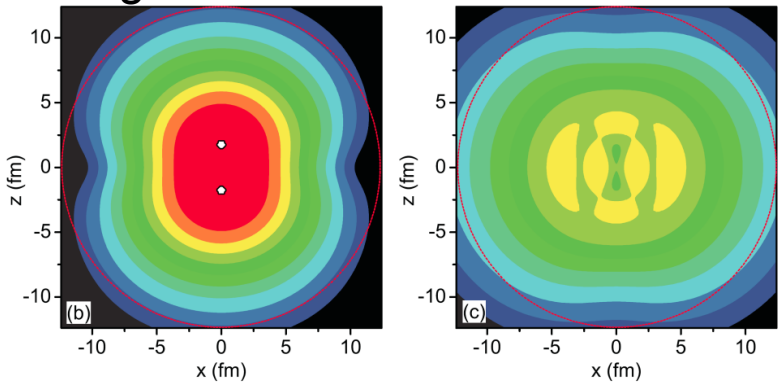
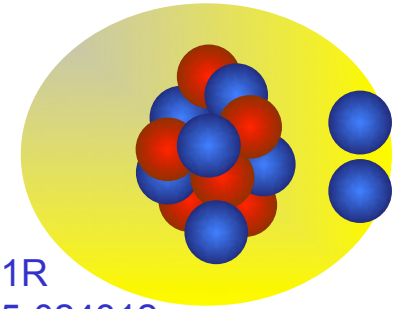


Shape Decoupling in Deformed Halo Nuclei

Relativistic HB model

^{44}Mg: Prolate Core + Oblate Halo





SGZ+2010
PRC82-011301R
Li+2012_PRC85-024312

Shape Decoupling in Deformed Halo Nuclei

Relativistic HB model

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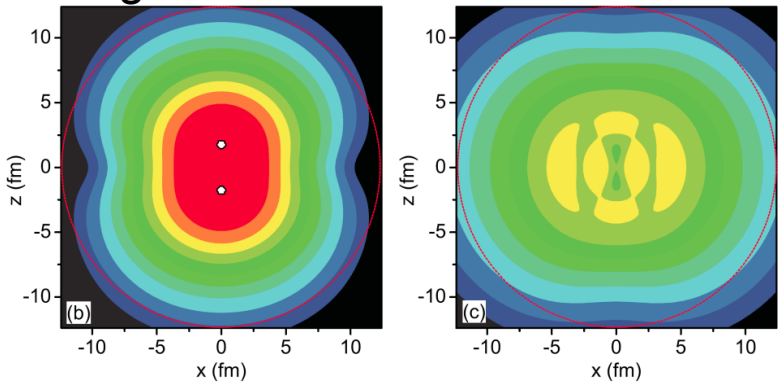
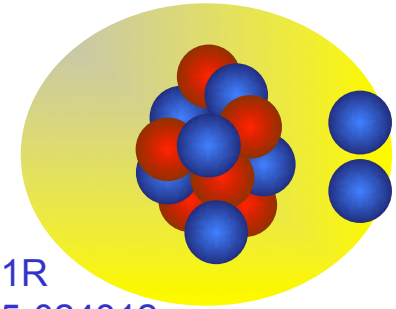
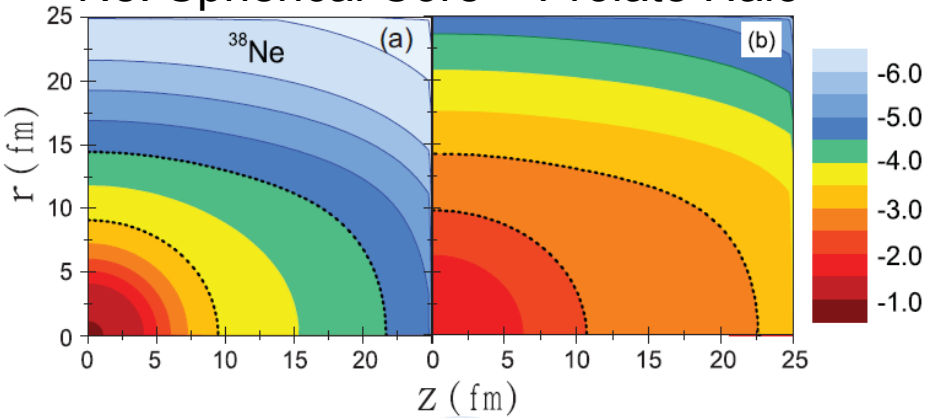


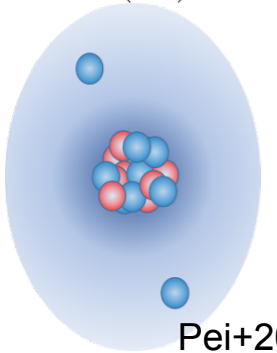


SGZ+2010
PRC82-011301R
Li+2012_PRC85-024312

Skyrme HFB model

^{38}Ne: Spherical Core + Prolate Halo



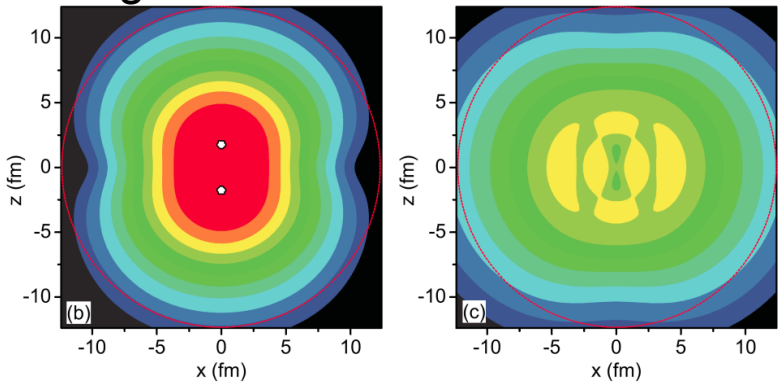


Pei_Zhang_Xu2013
PRC87-051302R
Pei+2014_PRC90-024317

Shape Decoupling in Deformed Halo Nuclei

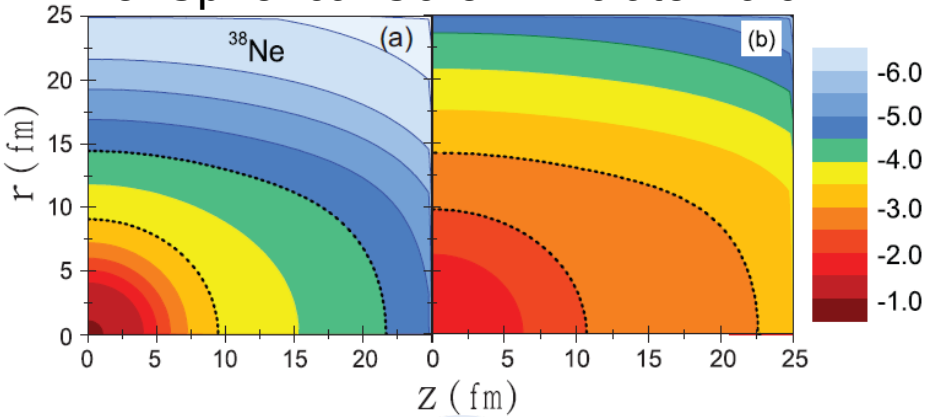
Relativistic HB model

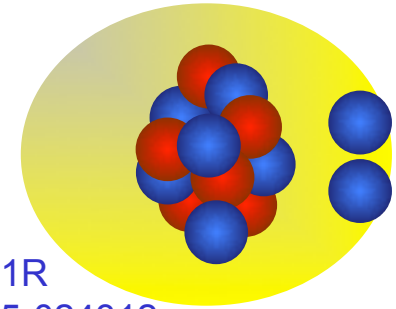
^{44}Mg: Prolate Core + Oblate Halo



Skyrme HFB model

^{38}Ne: Spherical Core + Prolate Halo

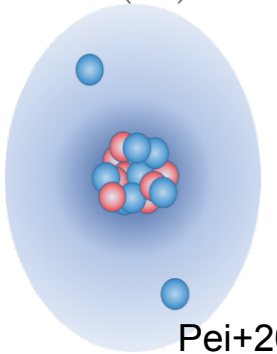




SGZ+2010
PRC82-011301R
Li+2012_PRC85-024312

Square well w/o ls

Misu_Nazarewicz_Aberg
1997_NPA614-44



Pei_Zhang_Xu2013
PRC87-051302R
Pei+2014_PRC90-024317

Shape Decoupling in Deformed Halo Nuclei

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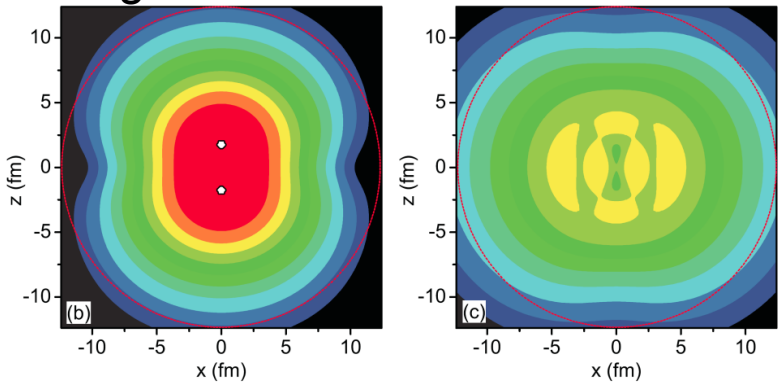

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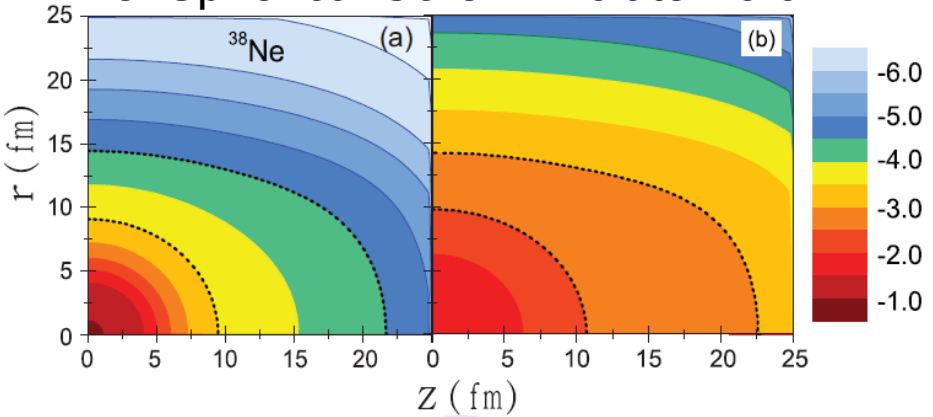
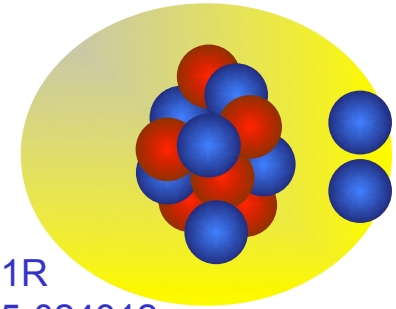
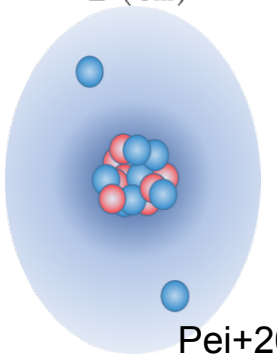




SGZ+2010
PRC82-011301R
Li+2012_PRC85-024312

How about rotation?

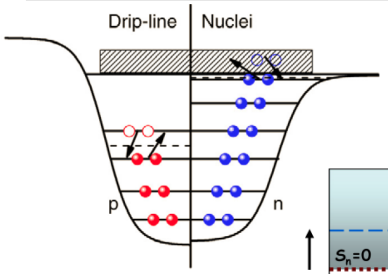
Fossez+2016_PRC93-011305R

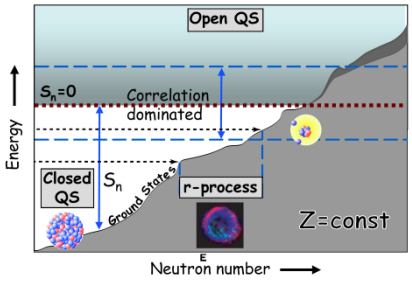


Pei_Zhang_Xu2013
PRC87-051302R
Pei+2014_PRC90-024317

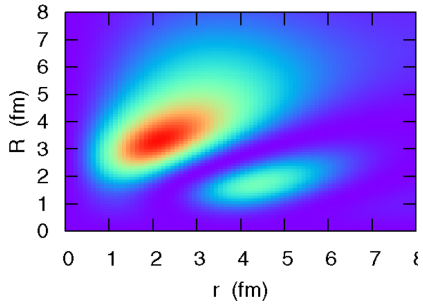
Physics of exotic nuclei

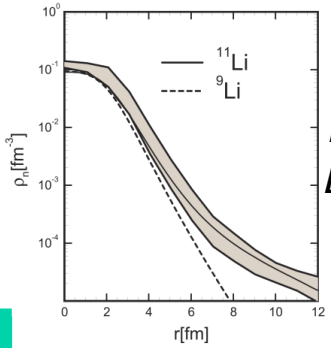
Weakly-bound





Threshold
Continuum
Open Q.S.

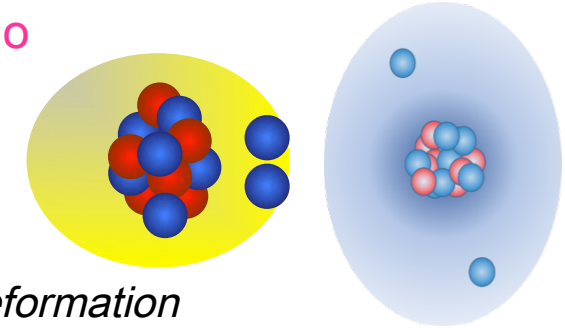




Halo

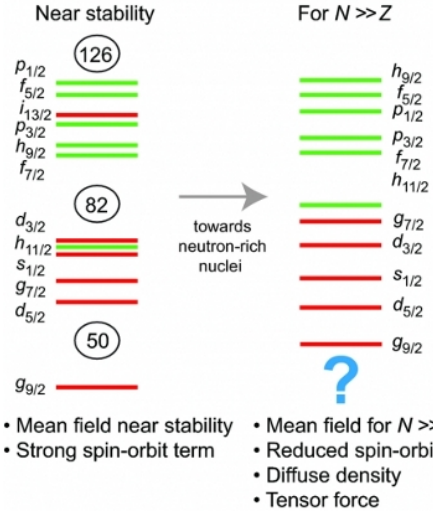
Large spatial ext.
Low-density N.M.
2N correlation

Halo

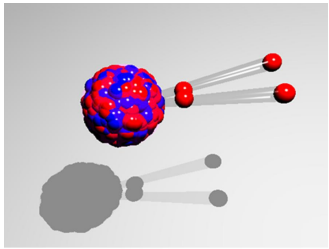


Deformation
Shape decoupling

Shell evolution

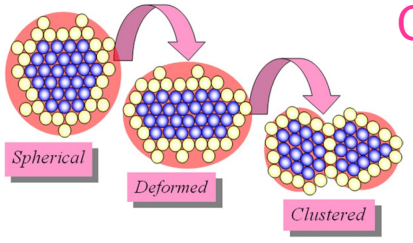


New radioact.



1p emission
2p emission
2n emission

Clustering



Di-nucleon correlations

- Asymptotic form of neutron Cooper pairs

  Zhang_Matsuo_Meng2014_PRC90-034313R

- Di-neutron corr.: ^{10}Be=^{8}Be+2n

  Kobayashi_Kanada-En'yo2016_PRC93-024310

- Di-proton corr.: ^{6}Be=^{4}He+2p

  Oishi_Hagino_Sagawa2014_PRC90-034303

- Neutron-proton corr.: ^{18}F=^{16}O+^{2}H

  Masui_Kimura2016_PTEP2016-053D01

Di-nucleon correlations

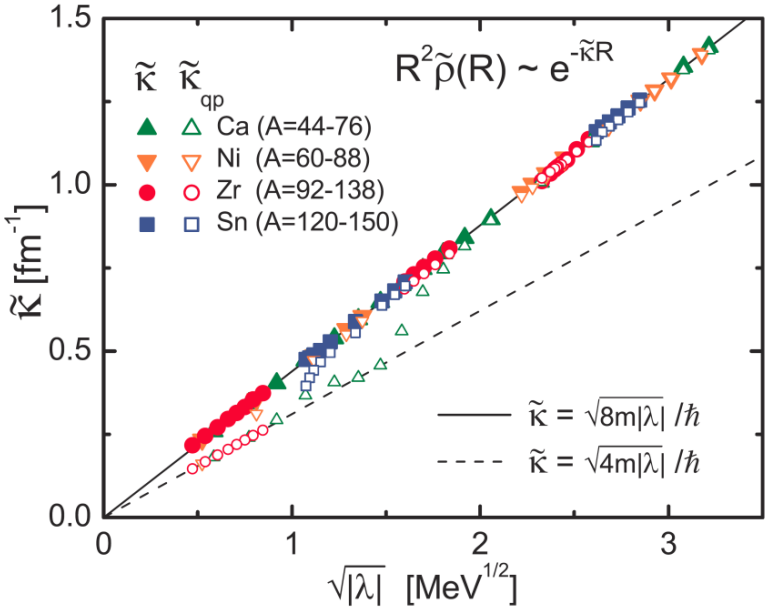
- Asymptotic form of neutron Cooper pairs

  Zhang_Matsuo_Meng2014_PRC90-034313R

Cooper pairs are spatially correlated in the asymptotic large distance limit, and the penetration length of the pair condensate is universally governed by the two-neutron separation energy

- Neutron-proton con...

  Masui_Kimura2016_PTEP2016-053D01



Soft dipole modes

Theo. Review: Paar_Vretenar_Colo2007_RPP70-691
Nakatsukasa_Matsuyanagi_Matsuo_Yabana2016_arXiv1606.04717 (RMP, in press)
Expt. Review: Savran_Aumann_Zilges2013_PPNP70-210

Ebata_Nakatsukasa_Inakura2014_PRC90-024303
Roca-Maza+2012_PRC85-024601
Vretenar+2012_PRC85-044317
Inakura+2014_PRC89-064316
Papakonstantinou_Hergert_Roth2015_PRC92-034311
Ma+2016_PRC93-014317
DeGregorio2016_PRC93-044314
Zheng2016_PRC94-014313

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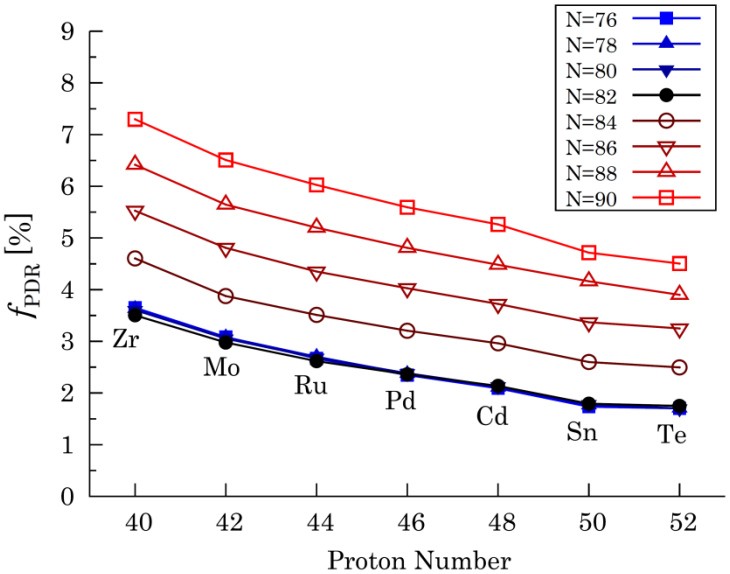
Expt. Review: Savran_Aumann_Zilges2013_PPNP70-210

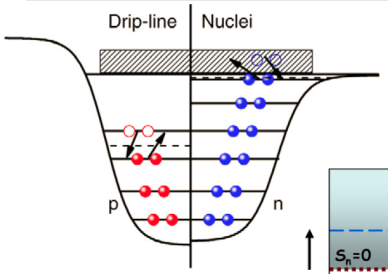
Ebata_Nakatsukasa_Inakura2014_PRC90-024303

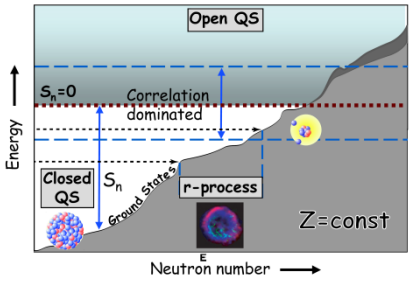
A systematic study with Cb-TDHFB reveals a number of characteristic features of the low-energy E1 modes, e.g., a universal behavior in the low-energy E1 modes for heavy neutron-rich isotopes, which suggests the emergence of decoupled E1 peaks beyond $N = 82$.



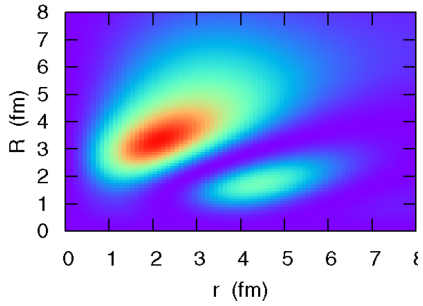
Physics of exotic nuclei

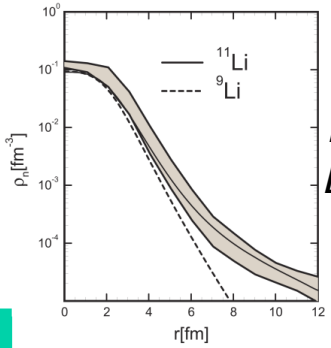
Weakly-bound





Threshold
Continuum
Open Q.S.

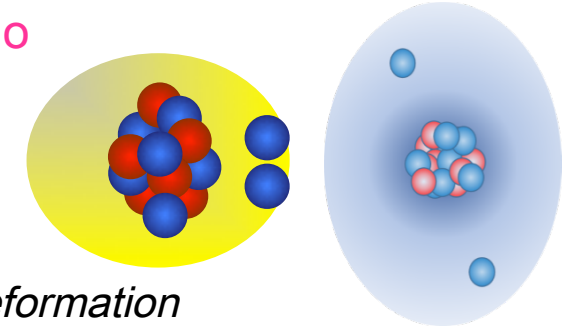




Halo

Large spatial ext.
Low-density N.M.
2N correlation

Halo



Deformation
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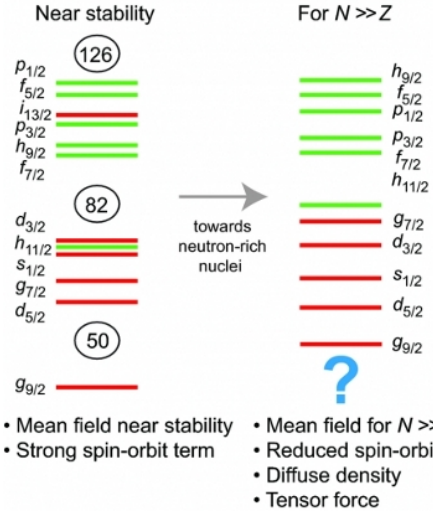
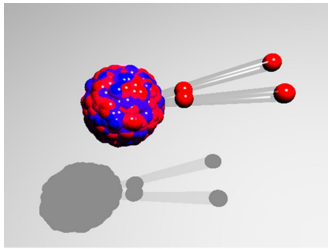
Shell evolution

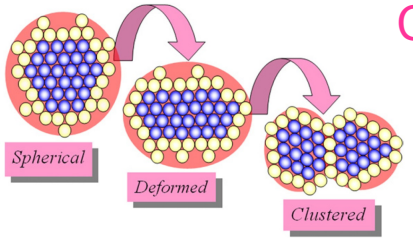


New radioact.



1p emission
2p emission
2n emission

Clustering



New doubly magic Ca isotopes?

Wienholtz+2013_Nature498-346

LETTER

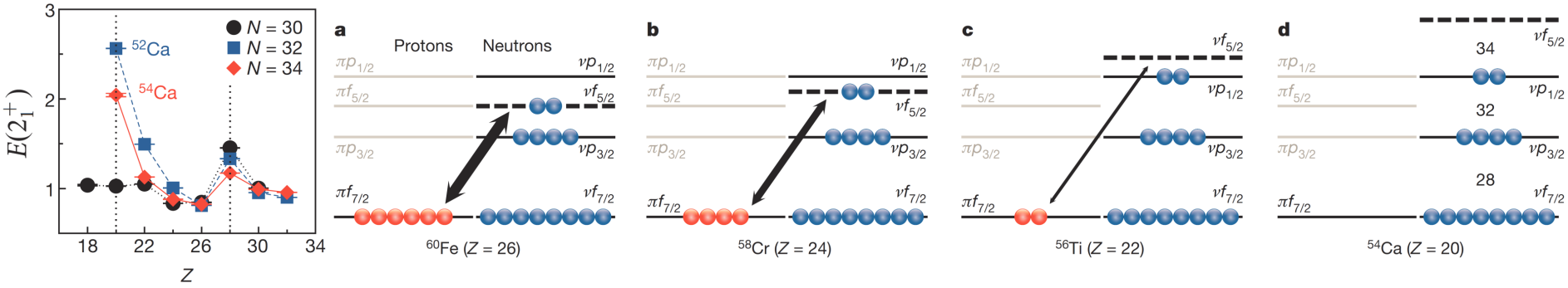
doi:10.1038/nature12226

Masses of exotic calcium isotopes pin down nuclear forces

F. Wienholtz[1], D. Beck[2], K. Blaum[3], Ch. Borgmann[3], M. Breitenfeldt[4], R. B. Cakirli[3,5], S. George[1], F. Herfurth[2], J. D. Holt[6,7], M. Kowalska[8], S. Kreim[3,8], D. Lunney[9], V. Manea[9], J. Menéndez[6,7], D. Neidherr[2], M. Rosenbusch[1], L. Schweikhard[1], A. Schwenk[7,6], J. Simonis[6,7], J. Stanja[10], R. N. Wolf[1] & K. Zuber[10]

New doubly magic Ca isotopes?

Steppenbeck+2013
Nature502-207



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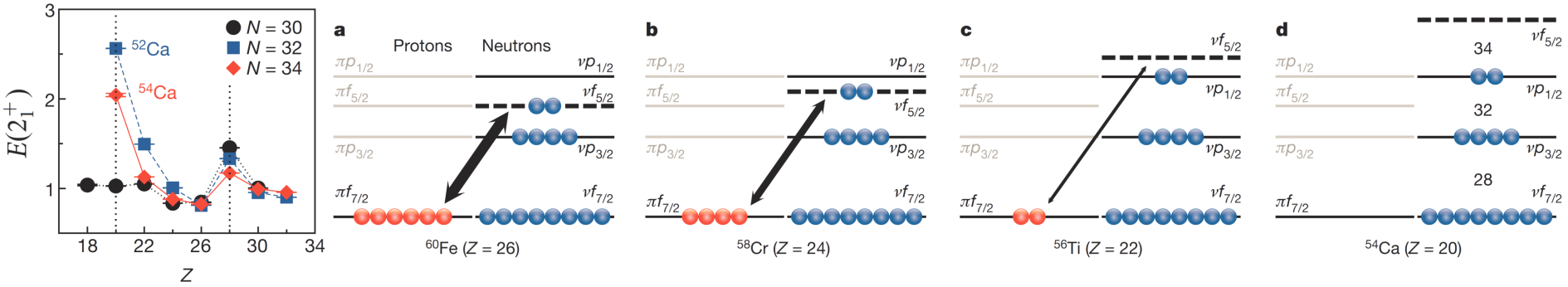
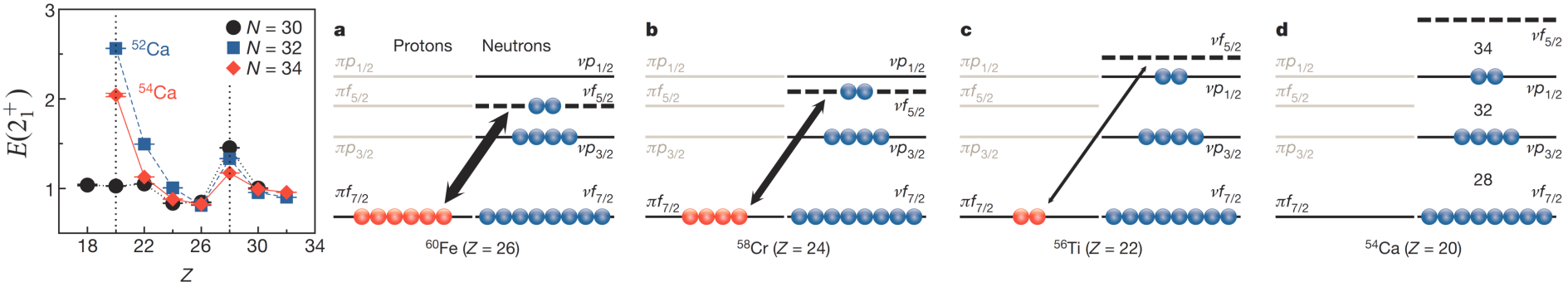


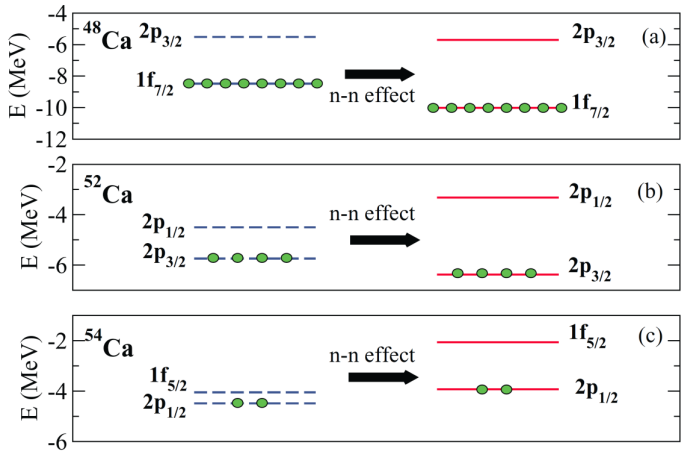
Grasso2014_PRC89-034316
Yueksel+2014_PRC89-064322
Wang_Dong2015_JPG42-125101

New doubly magic Ca isotopes?

Steppenbeck+2013
Nature502-207



Grasso2014_PRC89-034316



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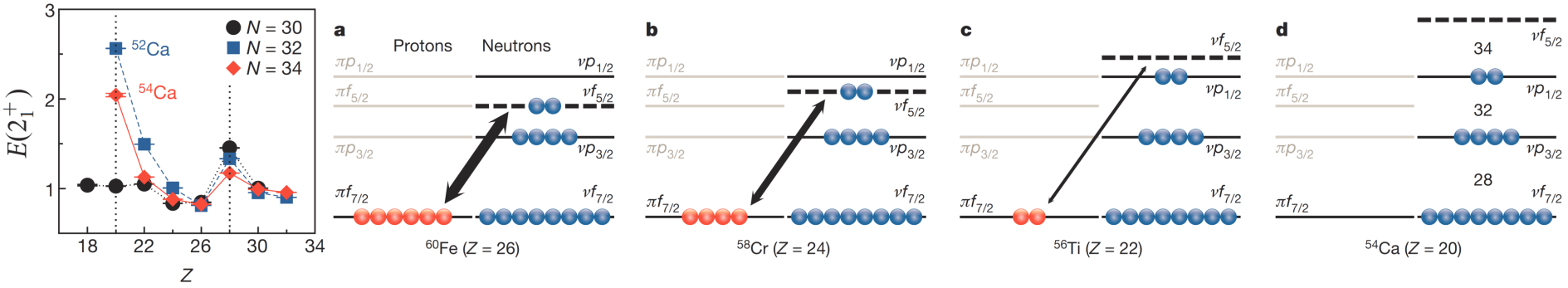
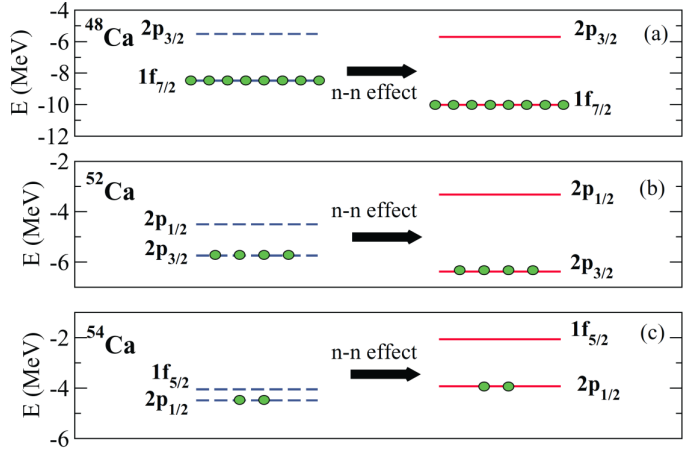
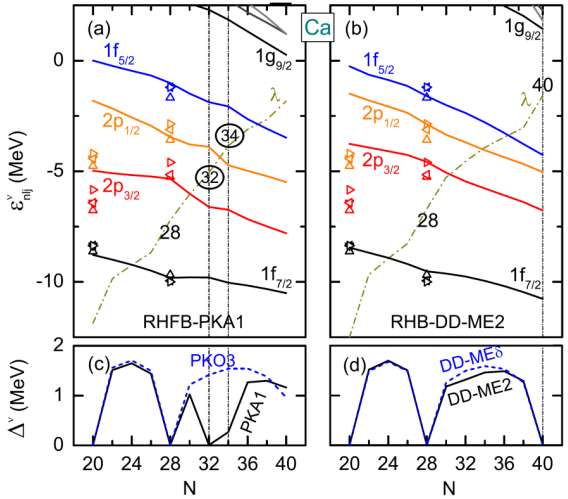


Grasso2014_PRC89-034316

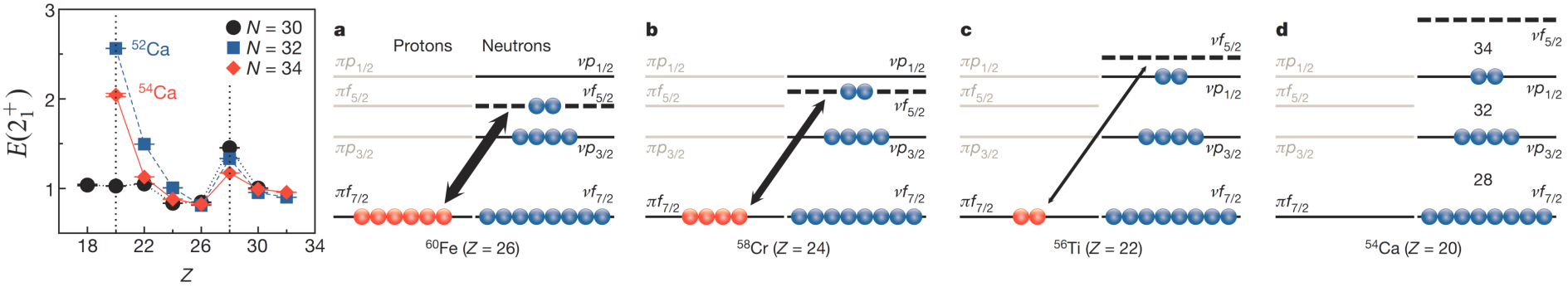


Li+2016_PLB753-97



New doubly magic Ca isotopes?

Steppenbeck+2013
Nature502-207



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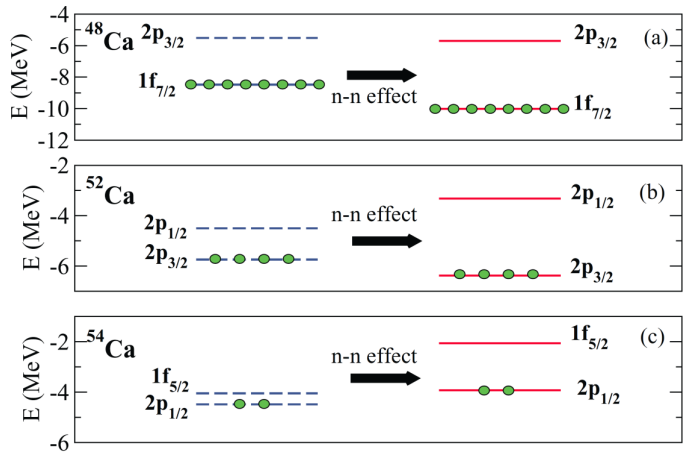
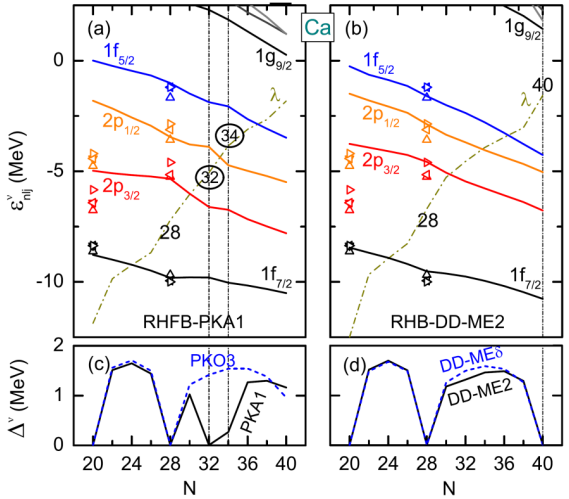
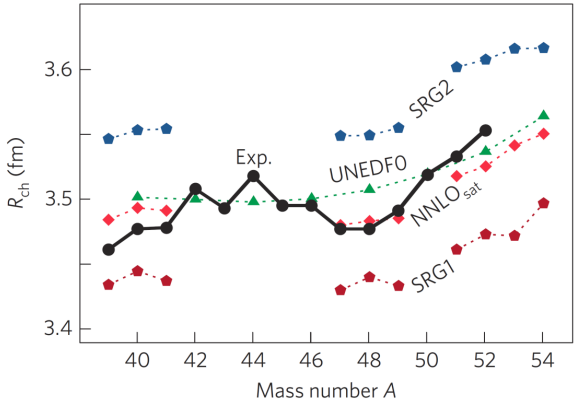


Li+2016_PLB753-97



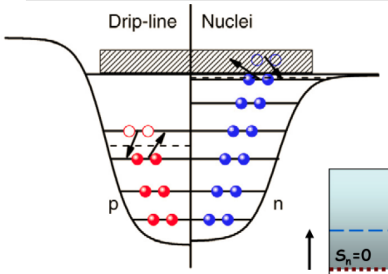
GarciaRuiz+2016NatPhys12-594

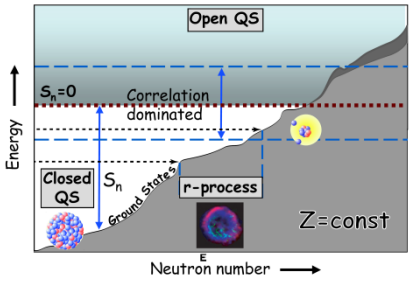


Nazarewicz & Eksröm's talks

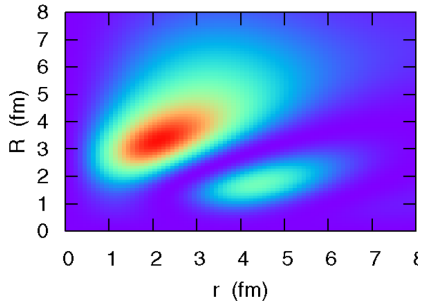
Physics of exotic nuclei

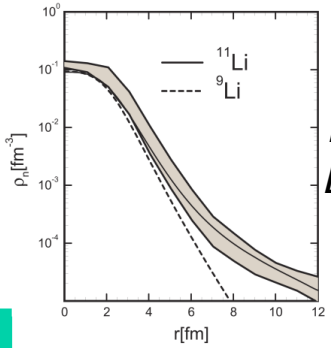
Weakly-bound





Threshold
Continuum
Open Q.S.





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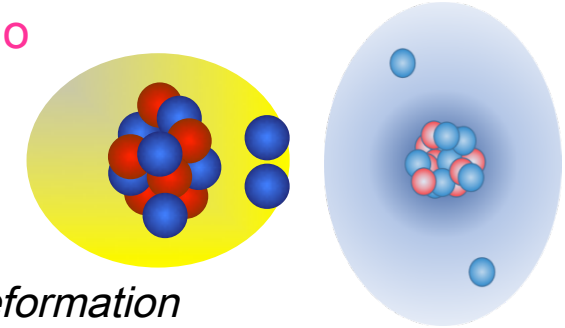
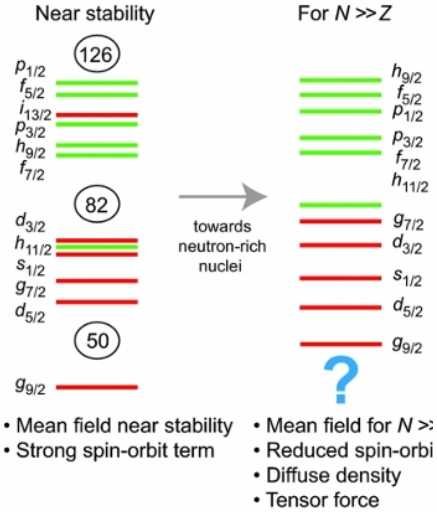


Deformation
Shape decoupling

Shell evolution



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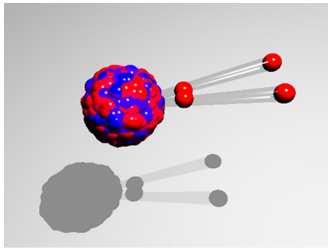
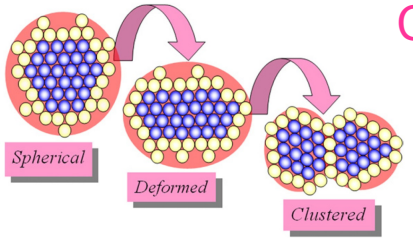


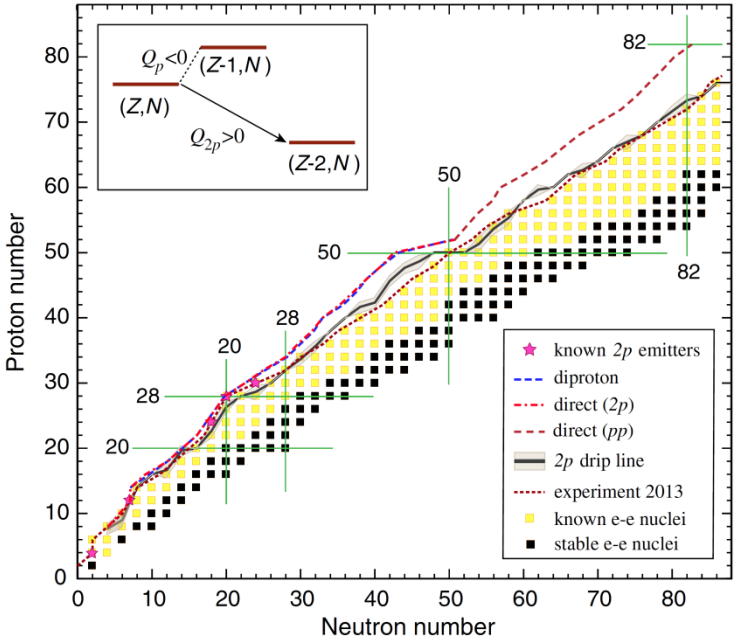
1p emission
2p emission
2n emission

Clustering



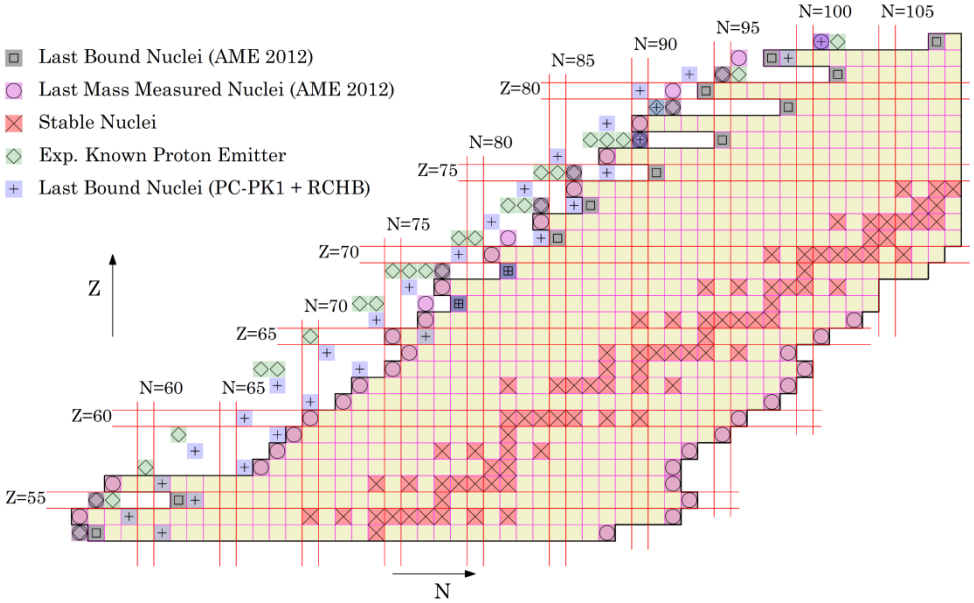
Study of 2p emitters with DFT

Hartree-Fock-Bogoliubov model



Olsen+2013_PRL110-222501
PRL111-139903E

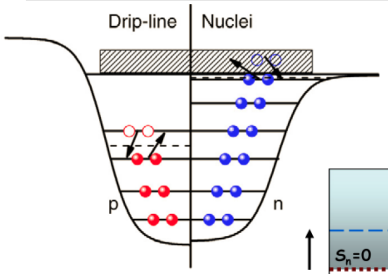
Relativistic cont. Hartree Bogoliubov model

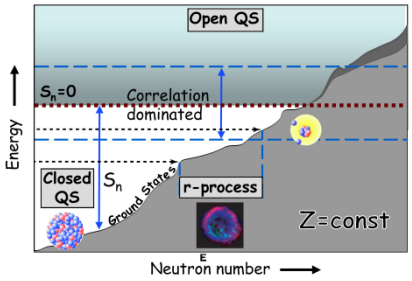


Lim_Xia_Kim2016_PRC93-014314

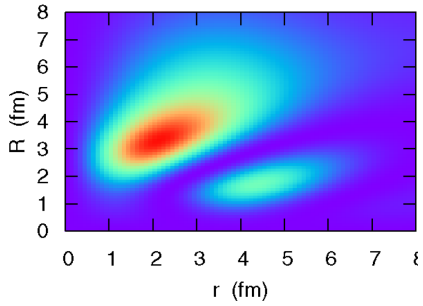
Physics of exotic nuclei

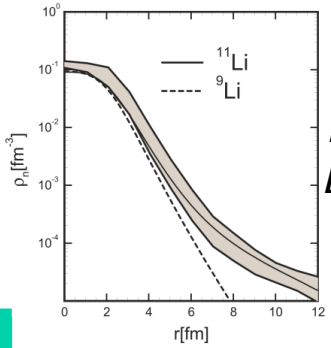
Weakly-bound





Threshold
Continuum
Open Q.S.

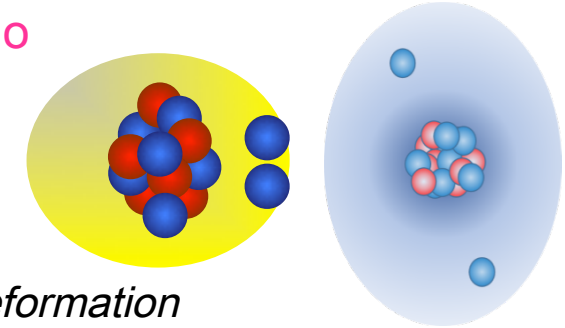




Halo

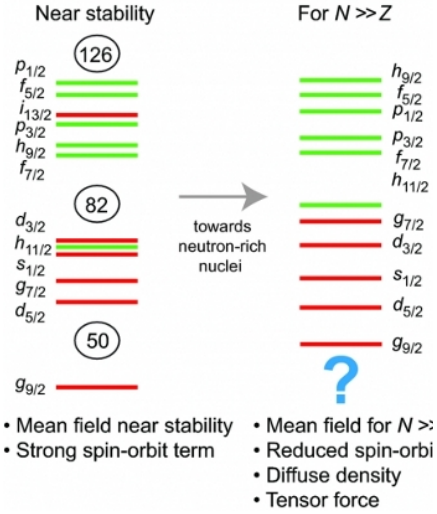
Large spatial ext.
Low-density N.M.
2N correlation

Halo

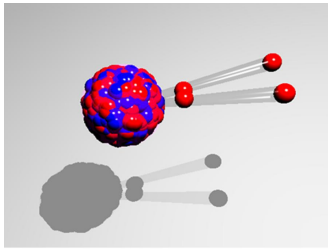


Deformation
Shape decoupling

Shell evolution

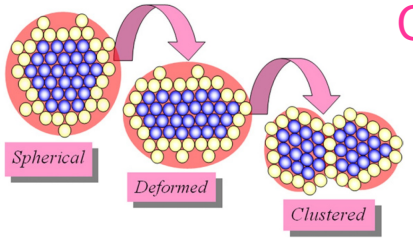


New radioact.



1p emission
2p emission
2n emission

Clustering



Clustering phenomena in nuclei

PRL **110,** 262501 (2013) PHYSICAL REVIEW LETTERS week ending 28 JUNE 2013

Zhou+2013_PRL111-103604

Nonlocalized Clustering: A New Concept in Nuclear Cluster Structure Physics

Bo Zhou,[1,2,3,*] Y. Funaki,[3,†] H. Horiuchi,[2,4] Zhongzhou Ren,[1,5,‡] G. Röpke,[6] P. Schuck,[7,8] A. Tohsaki,[2] Chang Xu,[1] and T. Yamada[9]

Cluster model
Container picture

PRL **113,** 032506 (2014) PHYSICAL REVIEW LETTERS week ending 18 JULY 2014

He2014_PRL113-032506

Giant Dipole Resonance as a Fingerprint of α Clustering Configurations in ^{12}C and ^{16}O

W. B. He (何万兵),[1,2] Y. G. Ma (马余刚),[1,3,*] X. G. Cao (曹喜光),[1,†] X. Z. Cai (蔡翔舟),[1] and G. Q. Zhang (张国强)[1]

QMD model
GDR connected to clusterring

PRL **115,** 022501 (2015) PHYSICAL REVIEW LETTERS week ending 10 JULY 2015

Zhao_Itagaki_Meng2015
PRL115-022501

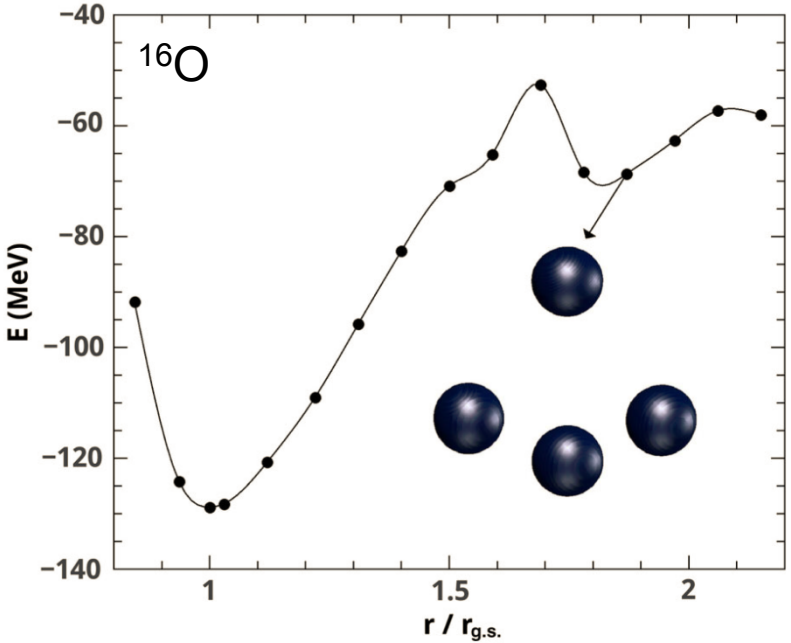
Rod-shaped Nuclei at Extreme Spin and Isospin

P. W. Zhao (赵鹏巍),[1,2,3] N. Itagaki (板垣直之),[1] and J. Meng (孟杰)[3,4,5,*]

Cranking RMF model
Clustering at extreme spin & isospin

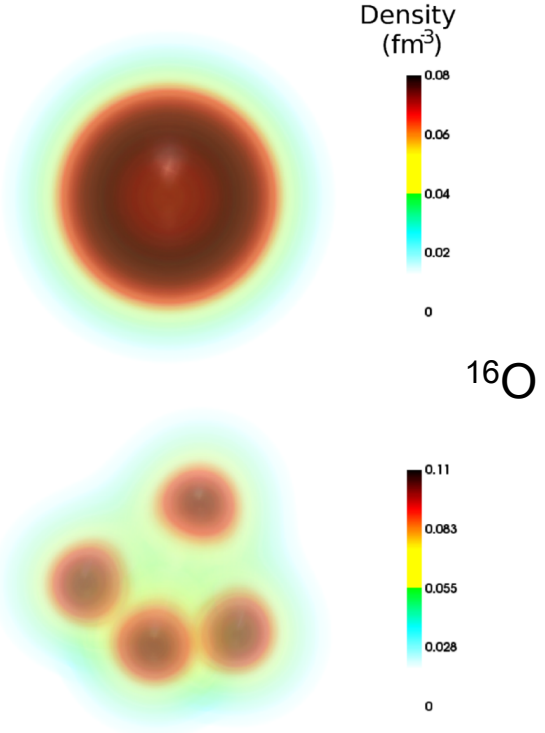
Constrained Cluster Structure

Hartree-Fock model



Girod_Schuck2013_PRL111-132503

Relativistic mean field model



Ebran_Khan_Niksic_Vretenar2012_Nature487-341
2014_PRC89-031303R

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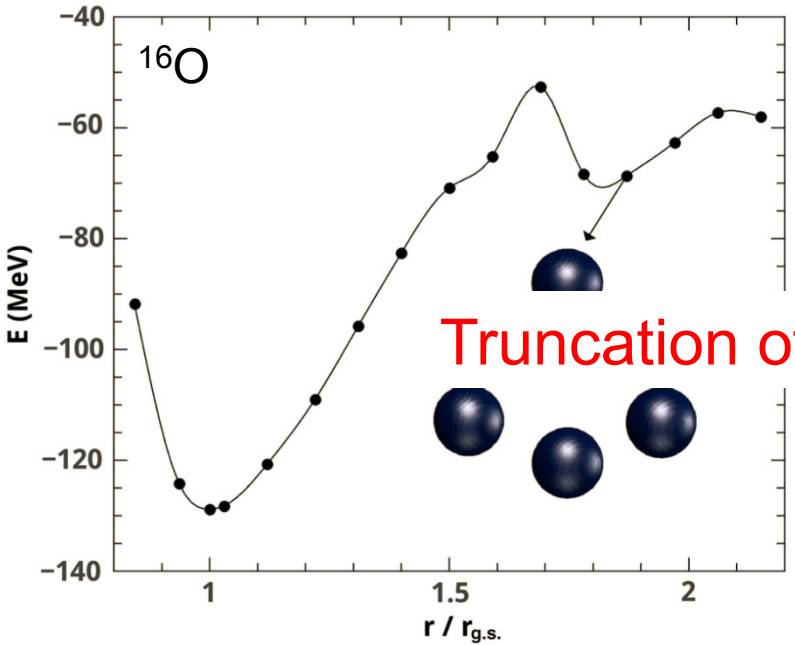

Girod_Schuck2013_PRL111-132503

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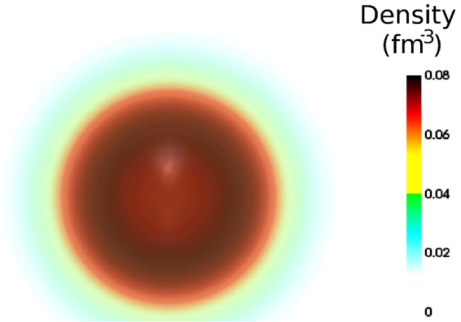
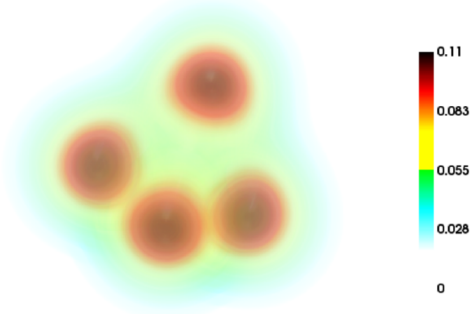


Truncation of basis & convergence

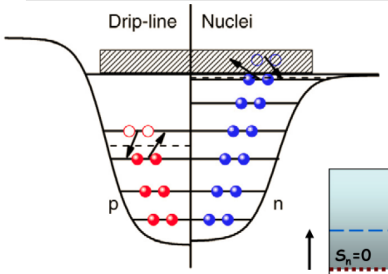
^{16}O

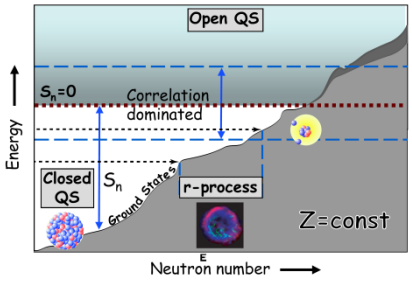


Ebran_Khan_Niksic_Vretenar2012_Nature487-341
2014_PRC89-031303R

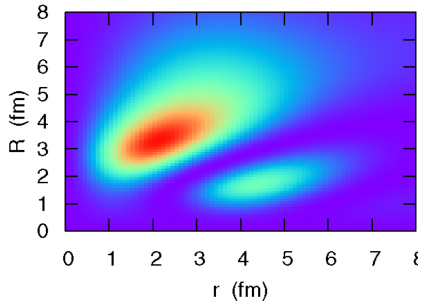
Physics of exotic nuclei

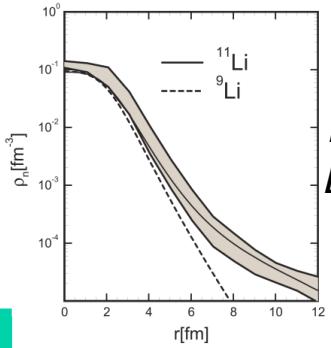
Weakly-bound





Threshold
Continuum
Open Q.S.





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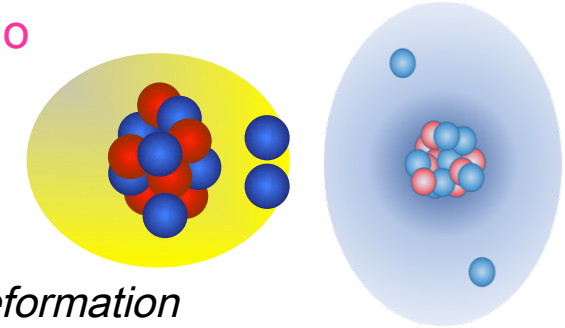

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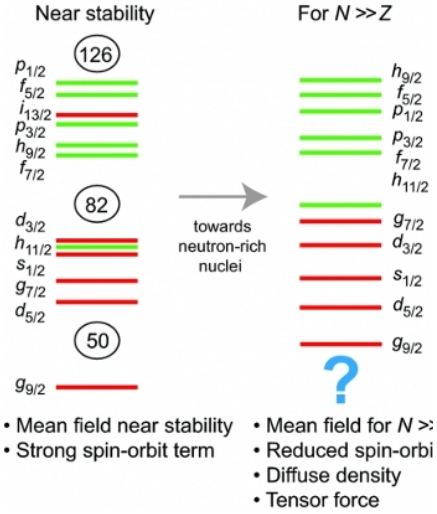

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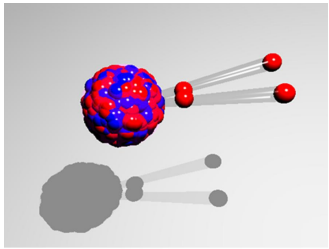

1p emission
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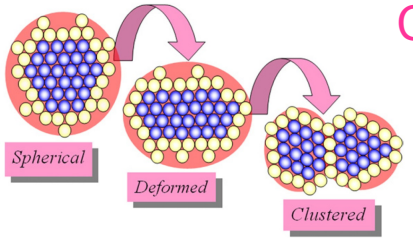

Model, models, models's, …

(INPC1995, Beijing)

Krishina Kumar:

We
not only
use different models to
describe different nuclei,
but also
use different models to
describe the same nucleus !

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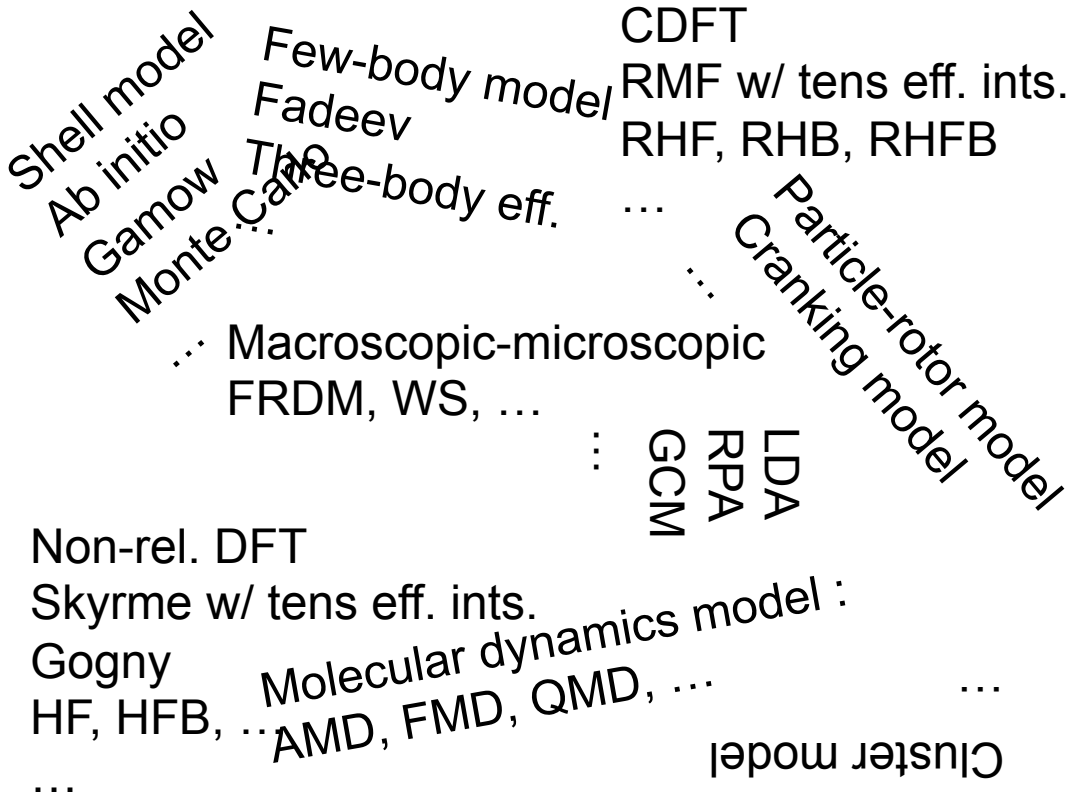

Efforts to unify models & work more together

- Ab initio — Ekström & Bacca's talks
- Density functional theories
  - Skyrme(-like): Ab initio derivation of model energy density functionals

    Dobaczewski et al., see, e.g., Dobaczewski2016_JPG43-04LT01
  - Covariant: Toward an ab initio covariant investigations of heavy nuclei

    Meng et al., see, e.g., Shen+2016_arXiv1609.01866; Liang's talk
- …

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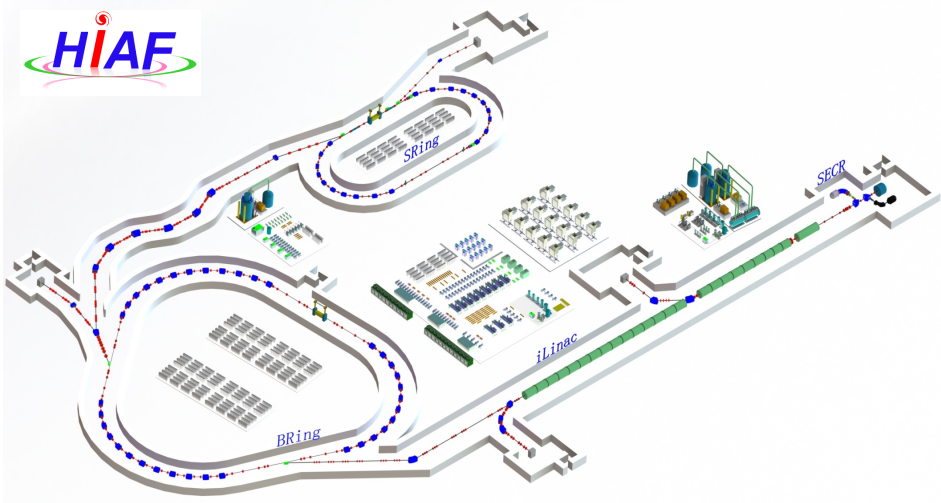
- …

- China-US Theory Inst. Phys. Exotic Nuclei (CUSTIPEN)
- DFG-NSFC Collaborative Research Centre (CRC110)
- …

Two future RIB facilities in China

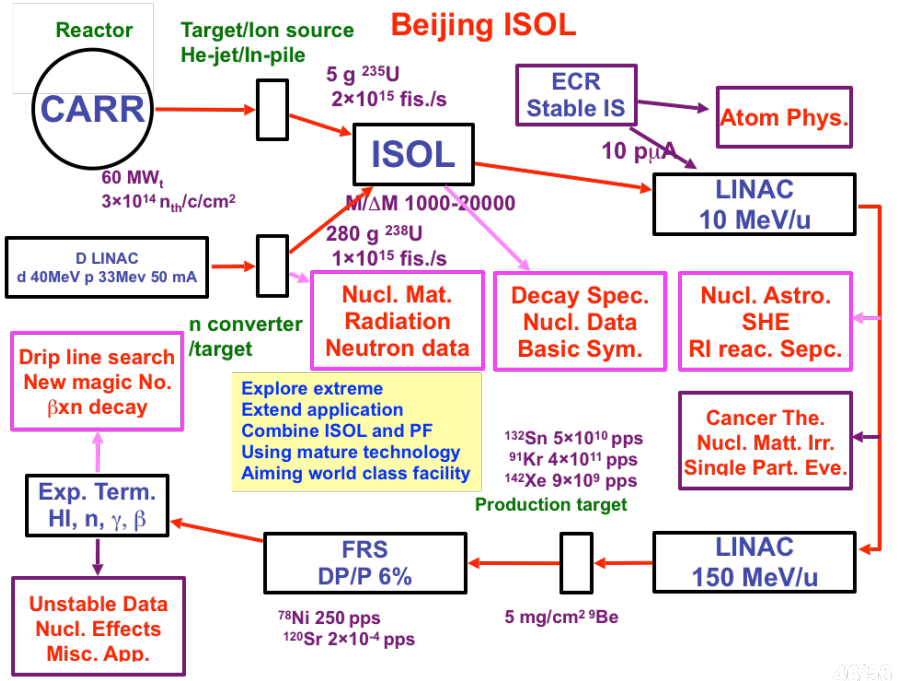
HIAF, Lanzhou-Huizhou
(High Intensity heavy-ion Accelerator Facility)



Phase 1: 2016-2023?

Courtesy of Xiao-Hong Zhou (周小红)

Beijing ISOL, CIAE-PKU
Proposed & successfully evaluated future facility

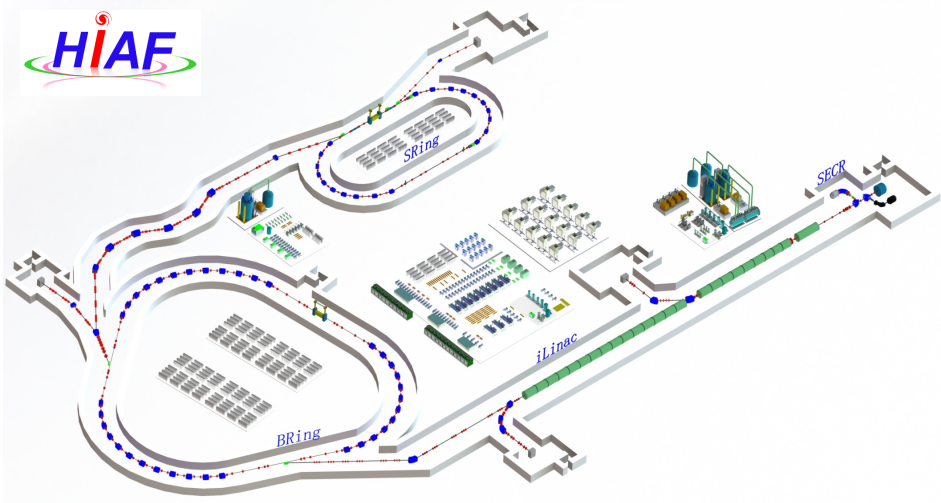


Courtesy of Wei-Ping Liu (柳卫平) & Yanlin Ye (叶沿林)

Two future RIB facilities in China

THANK YOU !

HIAF, Lanzhou-Huizhou
(High Intensity heavy-ion Accelerator Facility)



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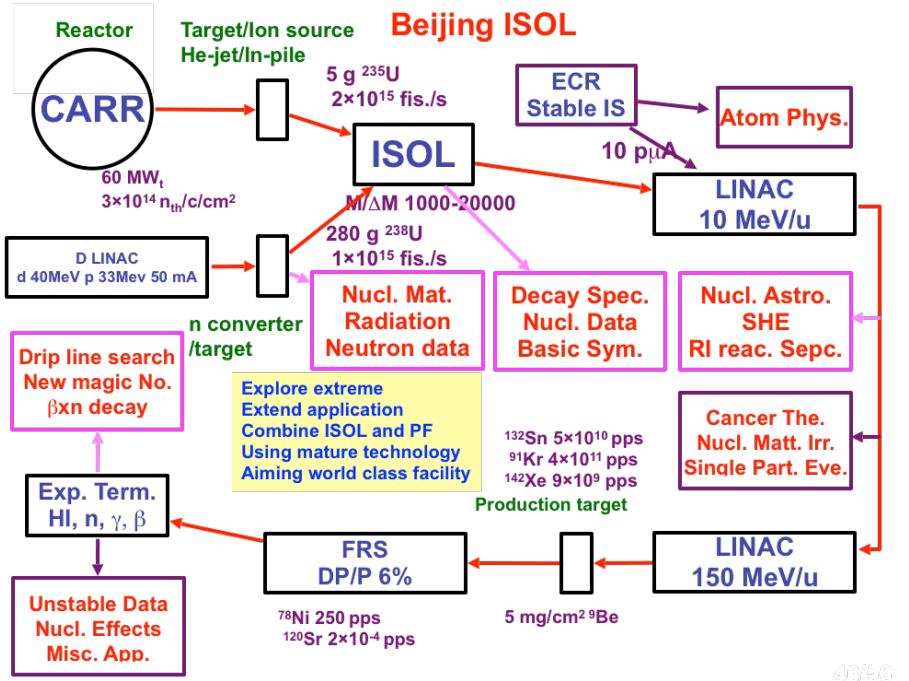
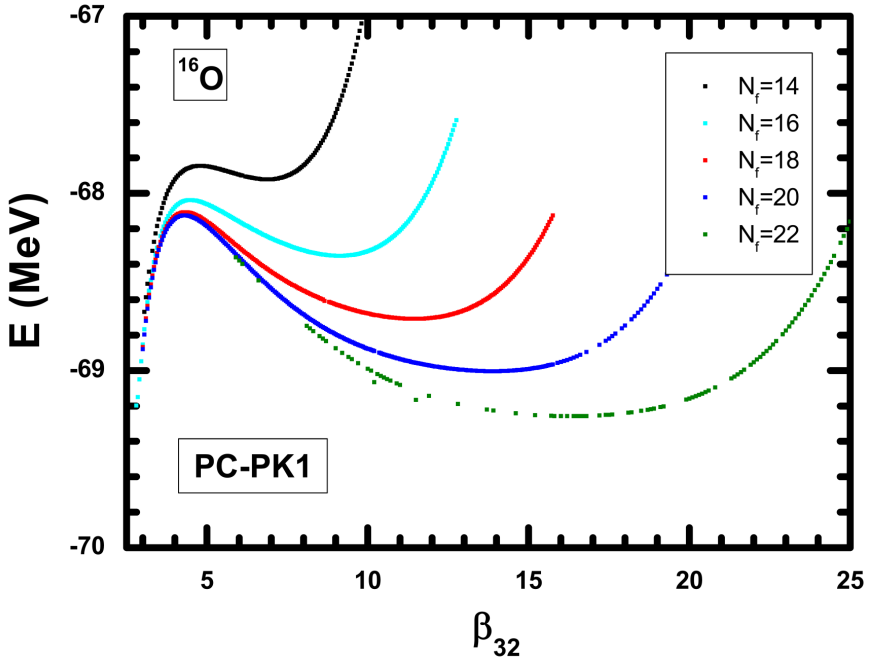
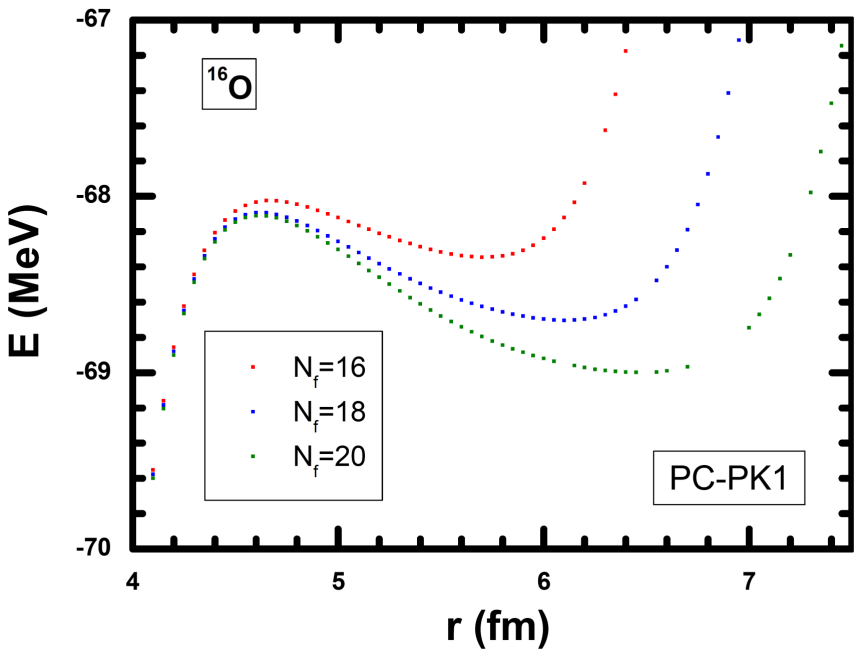


Courtesy of Wei-Ping Liu (柳卫平) & Yanlin Ye (叶沿林)

Constraint Cluster Structure: Convergence?

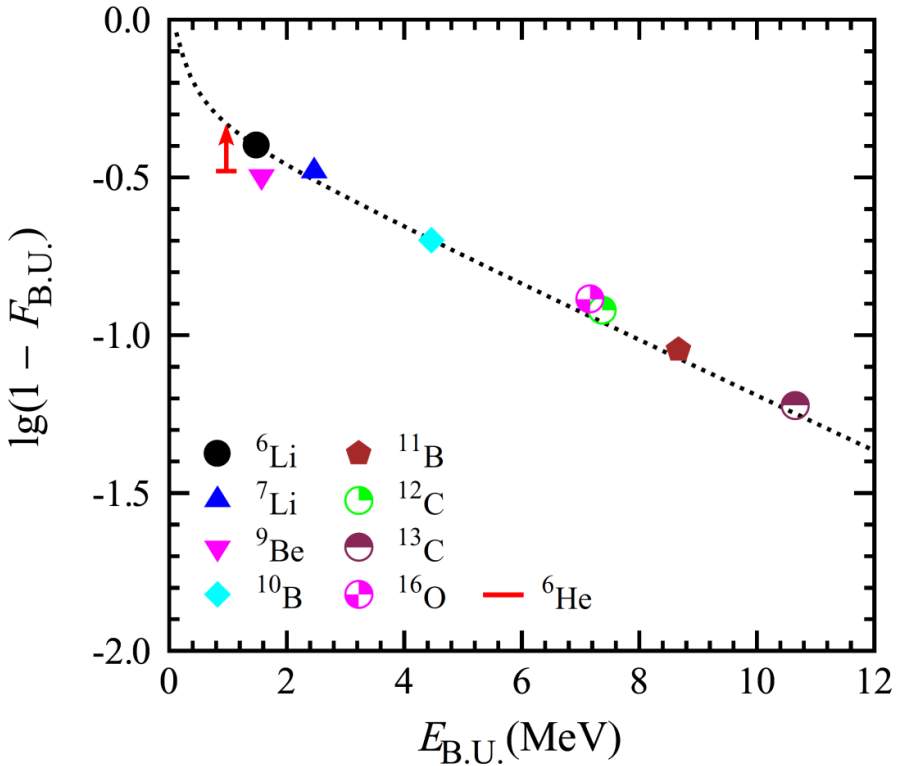
Calc. w/ multidimensionally-constrained covariant density functional (MDC-CDFT) theory





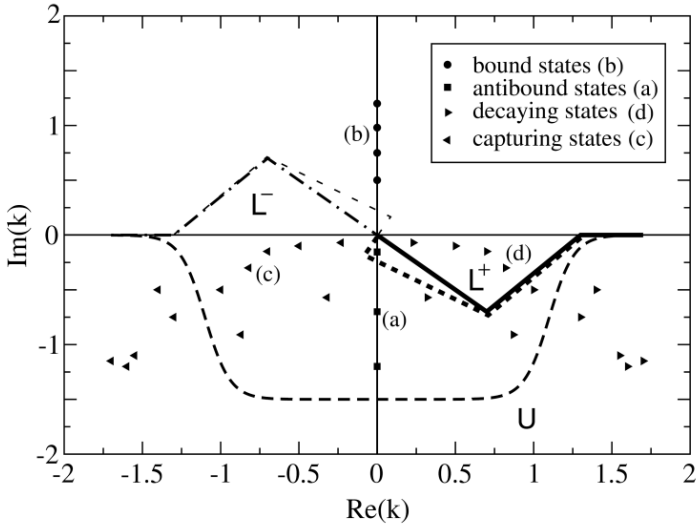
Jie Zhao et al., unpublished

Threshold effects: Breakup effects on CF



Wang_Zhao_Gomes_Zhao_SGZ2014_PRC90-034612
Wang_Zhao_Diaz-Torres_Zhao_SGZ2016_PRC93-014615

Weakly bound: Continuum Shell Model

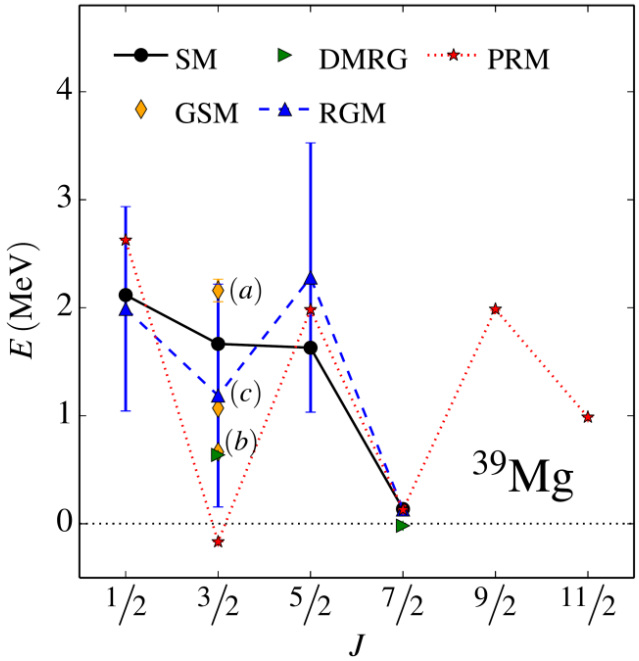


Berggren completeness relation

$$\sum_n u_n(E_n,r)u_n(E_n,r') + \int_L \mathrm{d}E u(E,r)u(E,r') = \delta(r-r'),$$

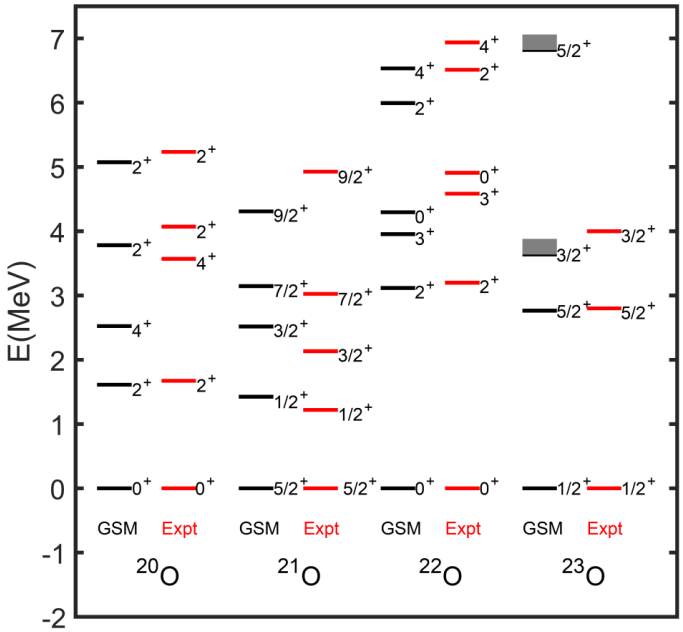
Okolowicz_Ploszajczak_Rotter2003_PR374-271
Michel+2009_JPG36-013101

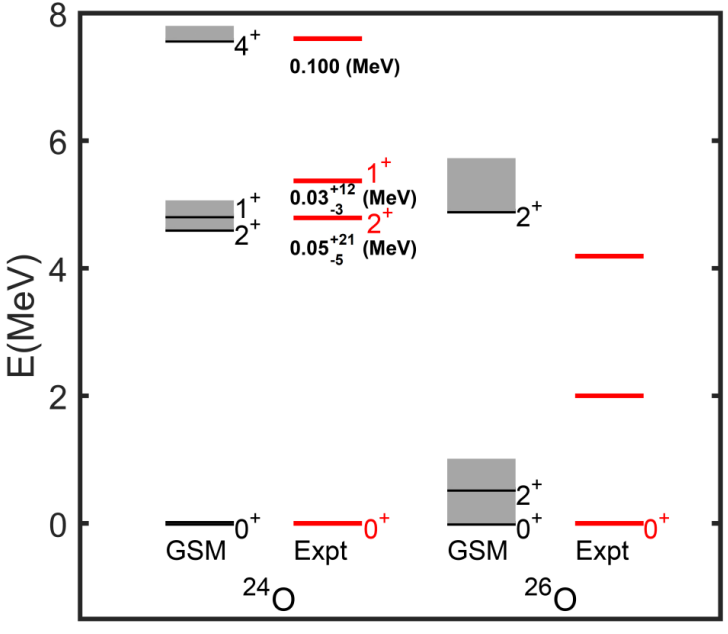
Fossez+2016_arXiv1607.08439



F. Xu et al.

Oxygen isotopes: Gamow Shell Model

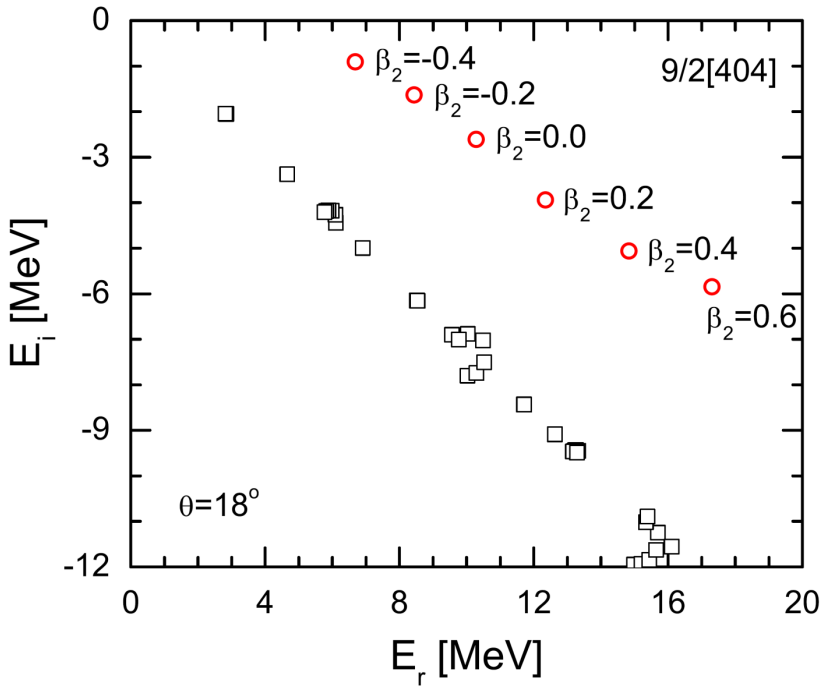


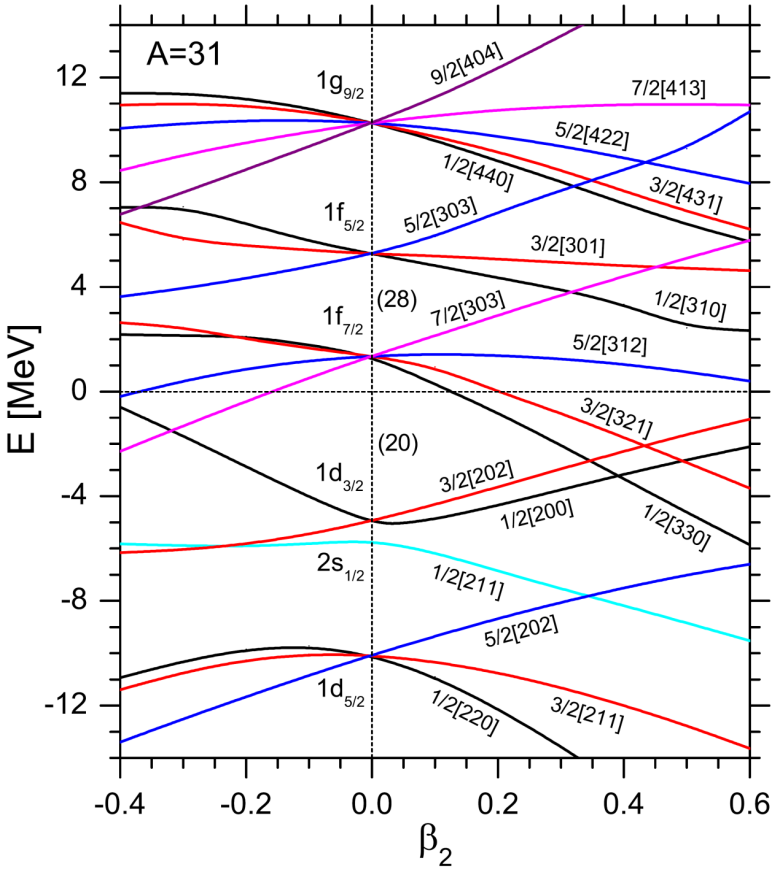


Zhong-Hao Sun, PhD Thesis

Nilsson Diagram w/ Resonances from CSM

Shi_Liu_Niu_Guo2014_PRC90-034319

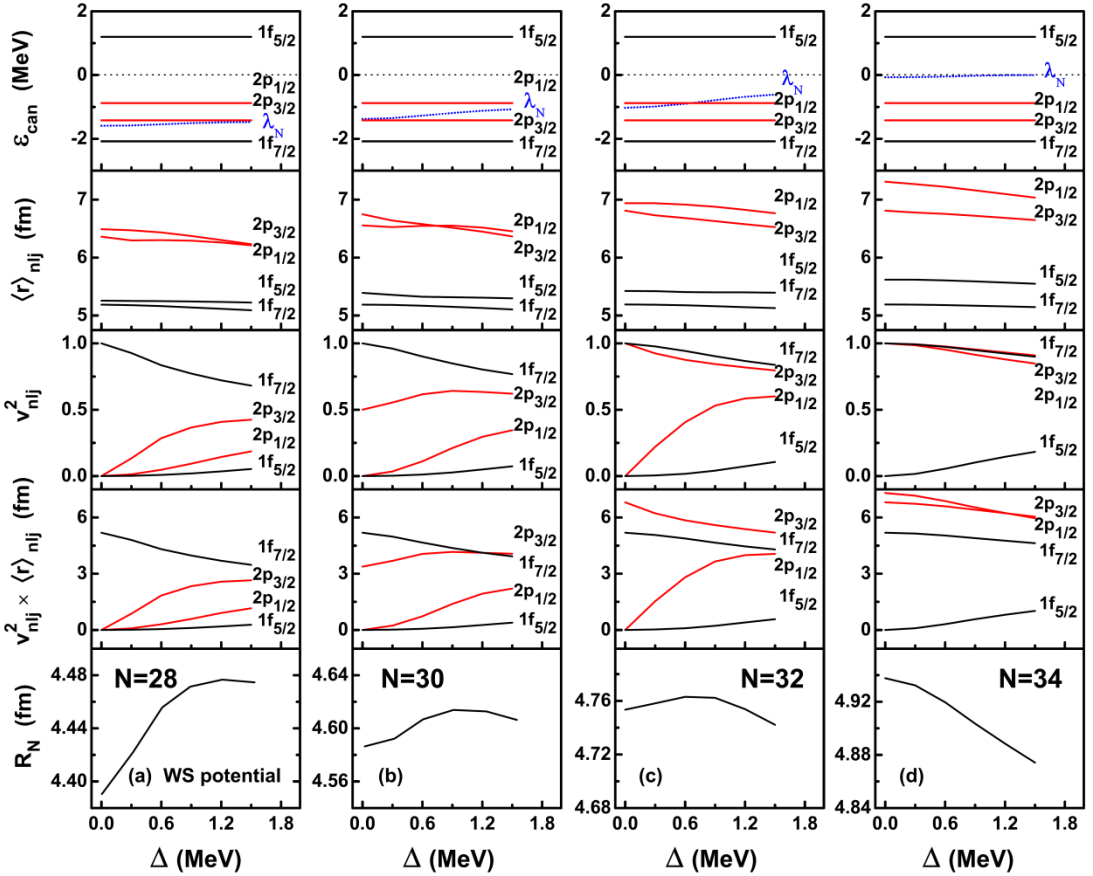




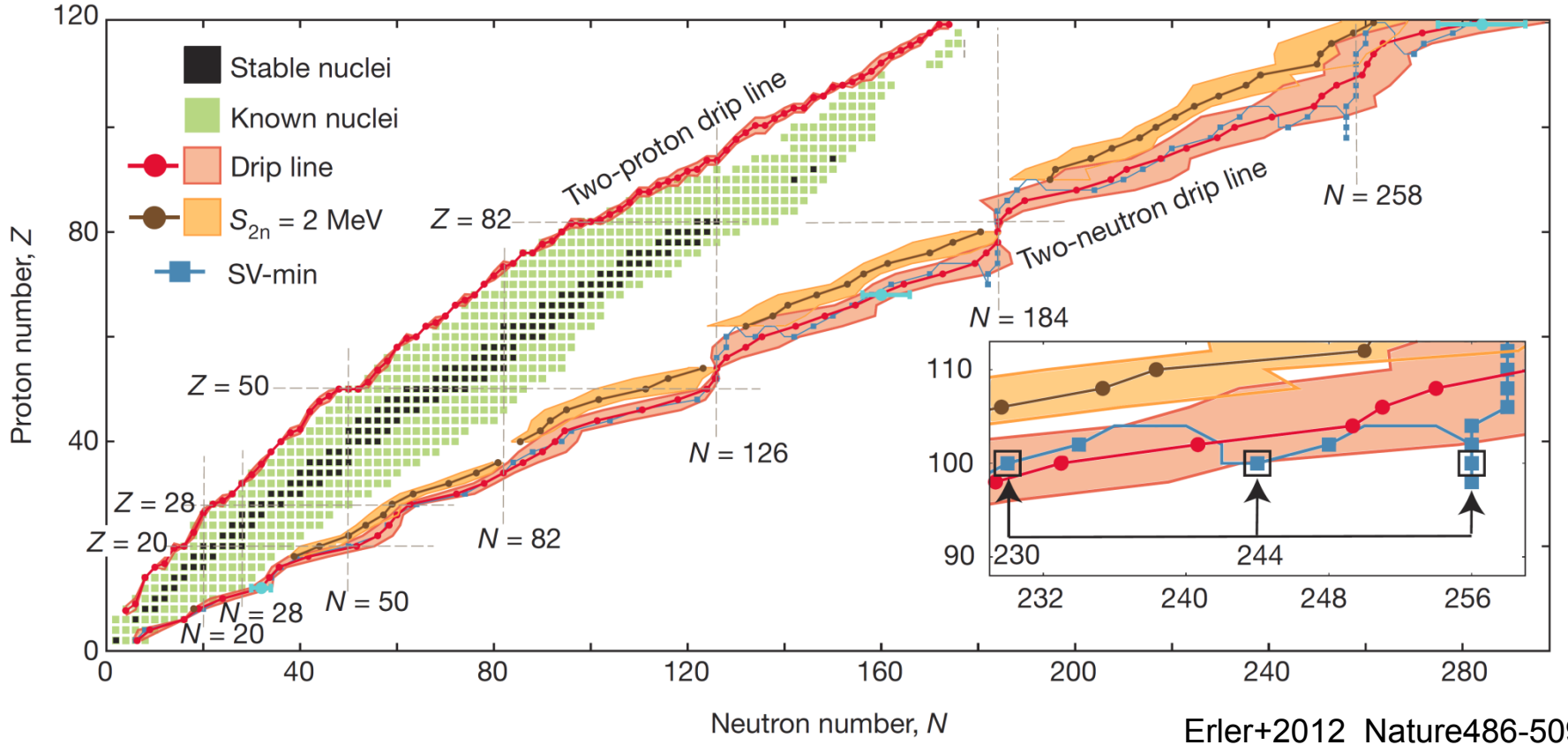
Pairing Anti-Halo Effect ?

Chen_Ring_Meng2014
PRC89-014312

Pairing correlations have a two-fold influence on the density distribution of the neutrons and therefore on the total nuclear size. First, they can change the root-mean-square radius of the individual weakly bound orbits and, second, they can change the occupation probabilities of these orbits in the nuclear system. Both effects are important, and finally the total radius is dominated by their competition.



Uncertainties in Predicted Drip Lines



Erler+2012_Nature486-509

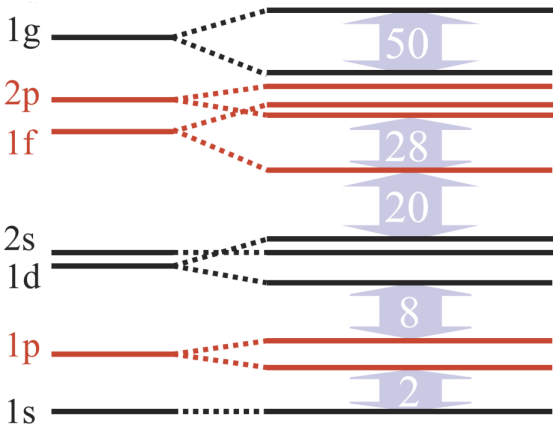
^{31}Ne

- Spherical models
  - Ren et al.: DDRMF Ren_Chen_Ma_Xu2001_CTP35-717
  - Zhang et al.: RMF+ACCC+BCS

    Zhang_Smith_Kang_Zhao2014_PLB730-30
- Deformed models
  - Qiu & Zhou: deformed Skyrme HF+BCS, tensor

    Qiu_Zhou2014_CTP61-101
- Experiment
  - Nakamura et al.: Deformation-driven p-wave halos at the drip-line: ^{31}Ne

    Nakamura … 2014_PRL112-142501



Liang_Meng_SGZ2015PhysRep

Tetraneutron state ? ! ?... !

Kisamori…2016_PRL116-052501

PRL 116, 052501 (2016)

Selected for a Viewpoint in *Physics*
PHYSICAL REVIEW LETTERS

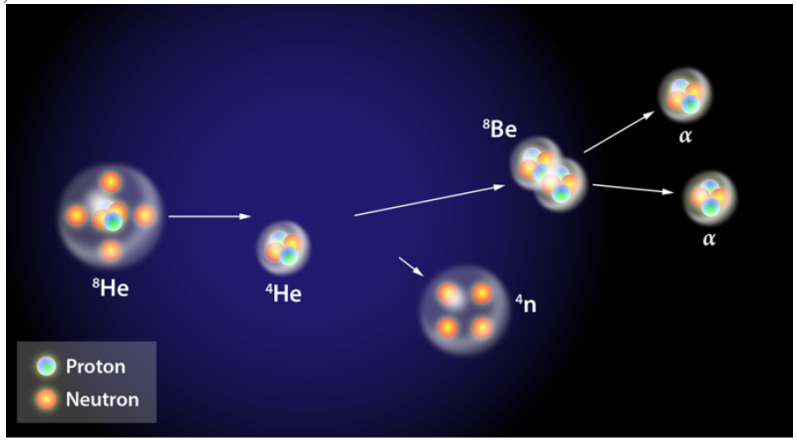
week ending
5 FEBRUARY 2016

Candidate Resonant Tetraneutron State Populated by the ^{4}He(^{8}He,^{8}Be) Reaction

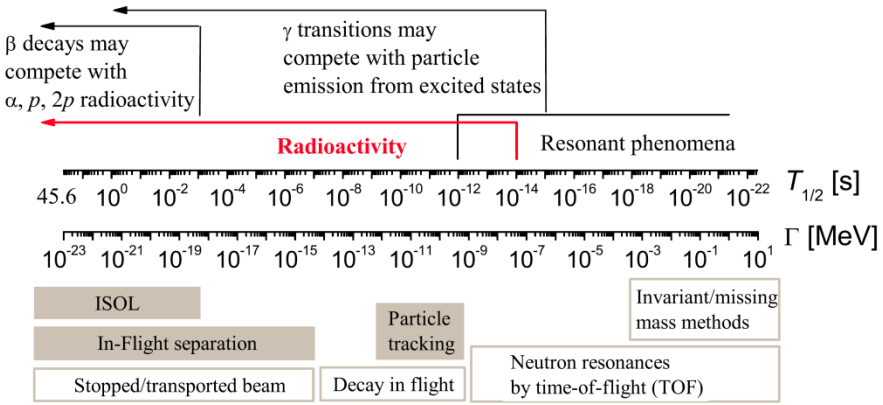
K. Kisamori,[1,2] S. Shimoura,[1] H. Miya,[1,2] S. Michimasa,[1] S. Ota,[1] M. Assie,[3] H. Baba,[2] T. Baba,[4] D. Beaumel,[2,3] M. Dozono,[2] T. Fujii,[1,2] N. Fukuda,[2] S. Go,[1,2] F. Hammache,[3] E. Ideguchi,[5] N. Inabe,[2] M. Itoh,[6] D. Kameda,[2] S. Kawase,[1] T. Kawabata,[4] M. Kobayashi,[1] Y. Kondo,[7,2] T. Kubo,[2] Y. Kubota,[1,2] M. Kurata-Nishimura,[2] C. S. Lee,[1,2] Y. Maeda,[8] H. Matsubara,[12] K. Miki,[5] T. Nishi,[9,2] S. Noji,[10] S. Sakaguchi,[11,2] H. Sakai,[2] Y. Sasamoto,[1] M. Sasano,[2] H. Sato,[2] Y. Shimizu,[2] A. Stolz,[10] H. Suzuki,[2] M. Takaki,[1] H. Takeda,[2] S. Takeuchi,[2] A. Tamii,[5] L. Tang,[1] H. Tokieda,[1] M. Tsumura,[4] T. Uesaka,[2] K. Yako,[1] Y. Yanagisawa,[2] R. Yokoyama,[1] and K. Yoshida[2]

Orr2016_Physics9-14

$E = 0.83 \pm 0.65(\text{stat.}) \pm 1.25(\text{syst.})$ MeV



Nuclear Radioactivities



Pfutzner_Karny_Grigorenko_Riisager 2012_RMP84-567

TABLE VI. Ground-state $2p$ emitters investigated experimentally. The indicated half-life corresponds to the partial value for the $2p$ decay.

^{N}Z	E (keV)	Γ or $T_{1/2}$	Reference
^{6}Be	1371(5)	92(6) keV	Whaling (1966)
^{12}O	1820(120)	400(250)[a] keV	KeKelis *et al.* (1978)
	1790(40)	580(200)[a] keV	Kryger *et al.* (1995)
	1800(400)	600(500)[a] keV	Suzuki *et al.* (2009)
^{16}Ne	1350(80)	200(100)[a] keV	KeKelis *et al.* (1978)
	1400(20)	110(40)[a] keV	Woodward, Tribble, and Tanner (1983)
	1350(80)	<200 keV	Mukha *et al.* (2008b)
^{19}Mg	750(50)	4.0(15) ps	Mukha *et al.* (2007)
^{45}Fe	1100(100)	$4.0^{+3.3}_{-1.8}$ ms	Pfützner *et al.* (2002)
	1140(50)	$8.5^{+6.4}_{-3.2}$ ms	Giovinazzo *et al.* (2002)
	1154(16)	$2.8^{+1.0}_{-0.7}$ ms	Dossat *et al.* (2005)
		$3.7^{+0.4}_{-0.4}$ ms	Miernik *et al.* (2007c)
^{48}Ni	1350(20)	$8.4^{+12.8}_{-7.0}$ ms[b]	Dossat *et al.* (2005)
		$3.0^{+2.2}_{-1.2}$ ms	Pomorski *et al.* (2011b)
^{54}Zn	1480(20)	$3.7^{+2.2}_{-1.0}$ ms	Blank *et al.* (2005)

[a]According to theoretical calculations, much smaller widths are expected (Barker, 1999; Barker, 2001; Grigorenko *et al.*, 2002).
[b]Only one decay event observed.