Direct reactions with SPES beams: Nuclear magicity at Z$\sim$50 and N$\sim$82 n-capture cross section via surrogate method

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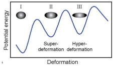
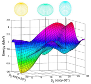
Outline

Nuclear Physics

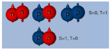
high angular momentum



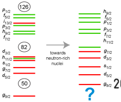
deformed nuclei

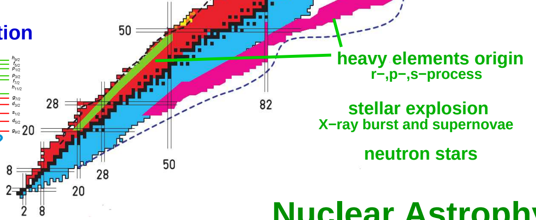


correlation (pairing)

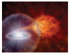


shell evolution





heavy elements origin
r−,p−,s−process



stellar explosion
X−ray burst and supernovae

neutron stars

Nuclear Astrophysics

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Nuclear Physics

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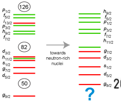

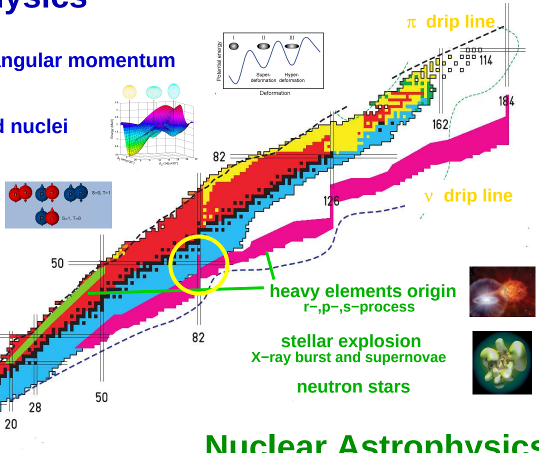

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Nuclear Astrophysics

Around doubly-magic ^{132}Sn

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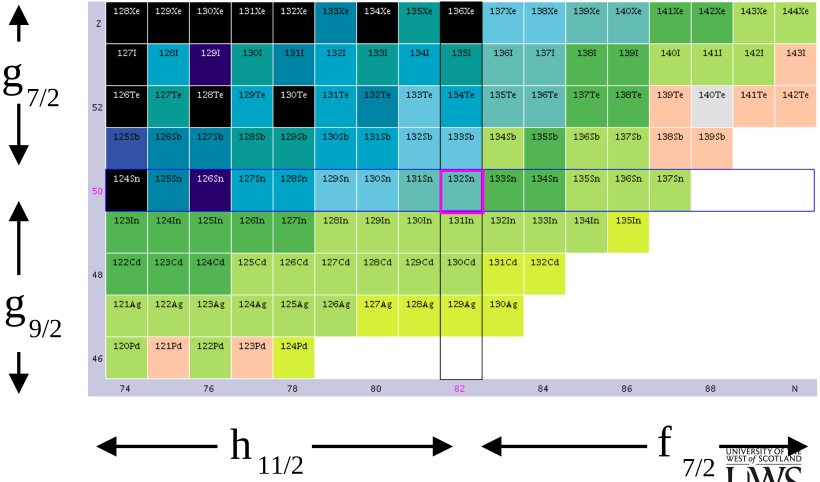
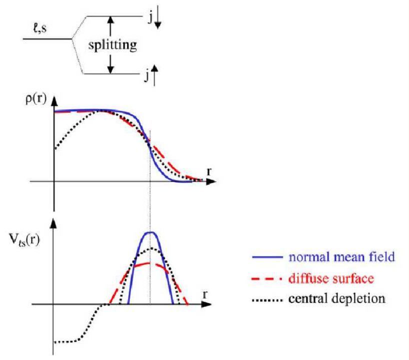
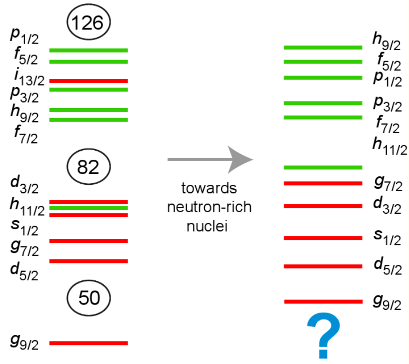


Around doubly-magic ^{132}Sn

SO term in exotic matter

SO-interaction scales with the derivative of the nucleon densities

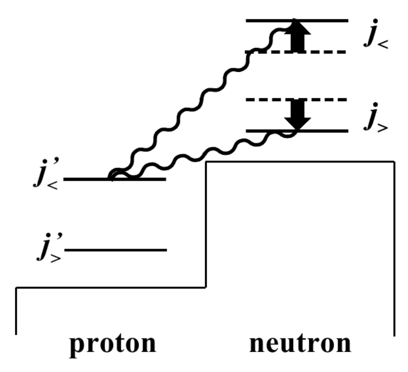


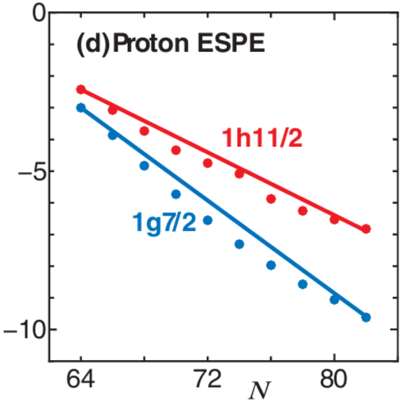


Shift of the proton single-particle energies

tensor interaction

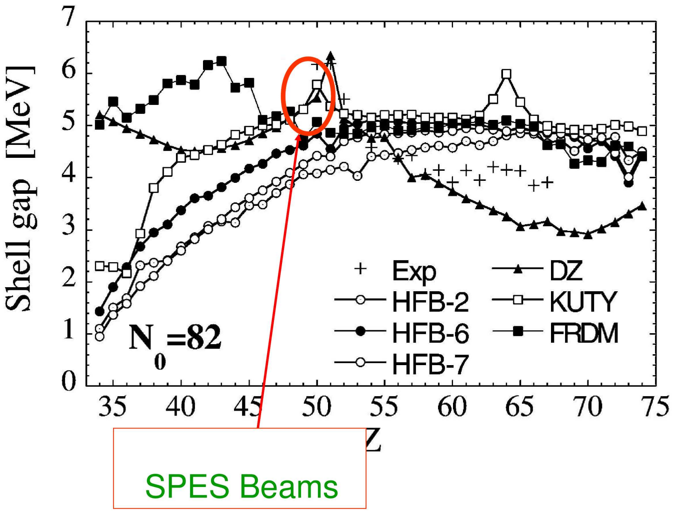
Attractive when spins of nucleons are antiparallel to their orbital angular momenta



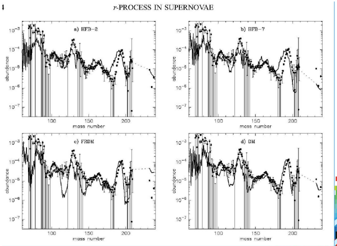


The N=82 shell closure

Single particle levels and spectroscopic factors in the ^{132}Sn region

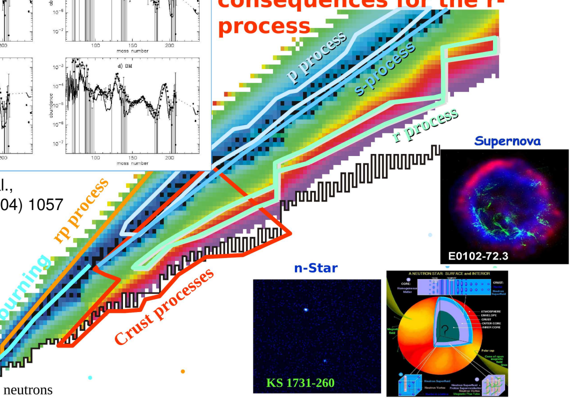


Implications on nuclear astrophysics



S. Wanajo et al., Astr. J 606 (2004) 1057

HFB and FRDM shell gaps have important consequences for the r-process



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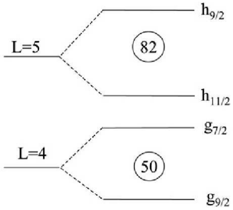
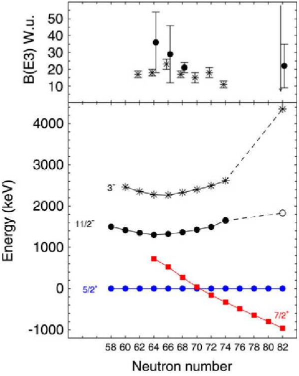
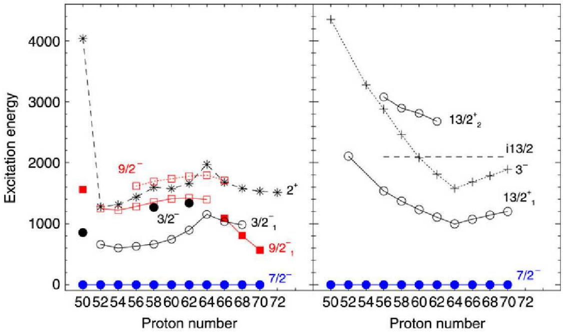
Proton orbit above Z=50





- magnifying effect of SO term
- fragmented or single particle levels?
- agreement with MF theory

Neutron orbit above N=82



- $3/2^-$: $f_{7/2} \otimes 2^+$
- $9/2^-$: $f_{7/2}, h_{9/2} \otimes 2^+$
- $13/2^+$: $f_{7/2} \otimes 3^-$

Proposed reactions at SPES

Expected SPES-beam intensity: $10^{5\div8}$ pps

Systematic measurements in the region

- **(d,p)** : ^{133}Sn, ^{134}Sn, ^{133}Sb, ^{131}In
- **(d,t)** : ^{131}Sn, ^{134}Sn, ^{131}In
- **(d,^{3}He)** : ^{131}Sn, ^{133}Sn, ^{131}In

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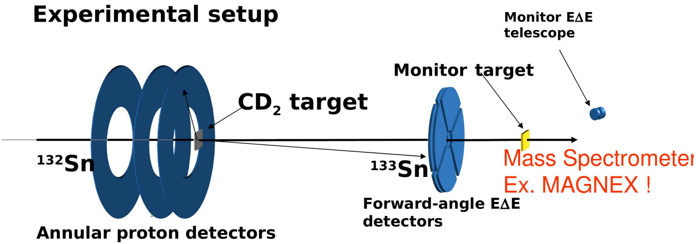
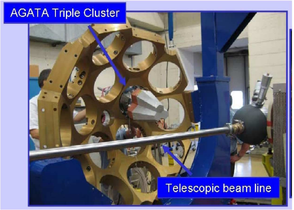
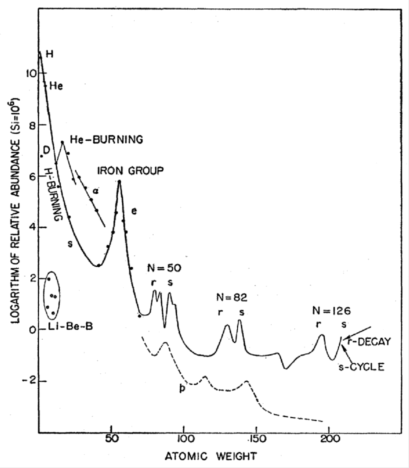
Inverse kinematics with short-lived beams

direct reactions: (d,p),(d,t),(d,^{3}He),...





Nucleosynthesis beyond Fe

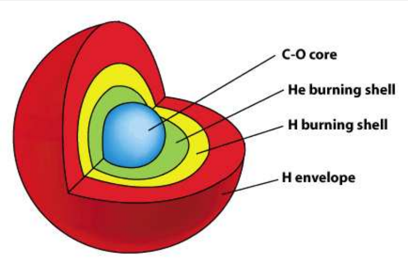


- Neutron captures are not hindered by coulomb repulsion
- Main mechanism: seed elements encounter an external neutron flux
- 2 primary contributions, r(rapid) and s(slow) processes identified
- Main difference: neutron density
- Additional p-process: proton capture, insignificant for high Z

Nuclear physics of the s process

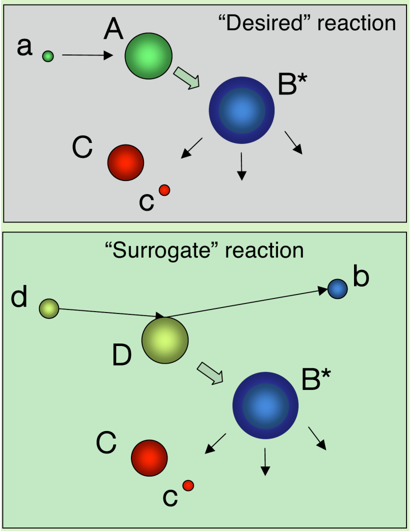
- s process: slow neutron capture, neutron captures much slower than beta decays
- 3 peaks (ls,hs,Pb) at magic N, local approximation in between
- Site: AGB stars
- Neutron sources: ^{13}C(α,n)^{16}O, ^{22}Ne(α,n)^{25}Mg
- Observations and results strongly linked to processes in the specific star

- the favoured neutron source predicts the AGB-star masses



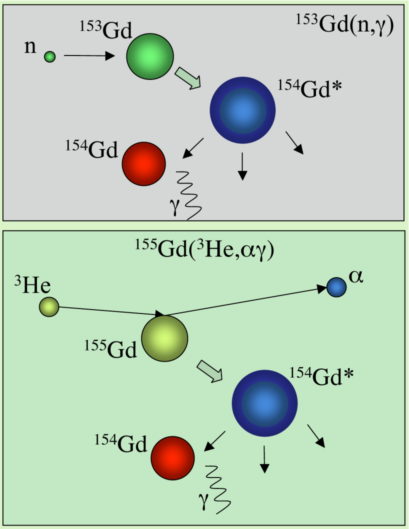
inert carbon-oxygen core, surrounded by two separate nuclear burning layers - an inner layer of Helium and an outer layer of Hydrogen

Indirect Determination of Cross Sections



The Surrogate Nuclear Reactions approach is an indirect method for determining XS of CN reactions difficult to measure directly.

(n,γ cross section



Various direct-reaction mechanisms can be employed to create the compound nucleus of interest.

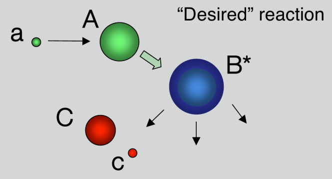
Theory

Hauser-Feshbach (HF) theory describes the "desired" CN reaction

$$\sigma_{\alpha\chi} = \Sigma_{J,\pi}\, \sigma_{\alpha}^{CN}(E,J,\pi) \cdot G^{CN}_{\chi}(E,J,\pi)$$

The issue:

- σ_{α}^{CN} can be calculated
- G^{CN}_{χ} are difficult to predict



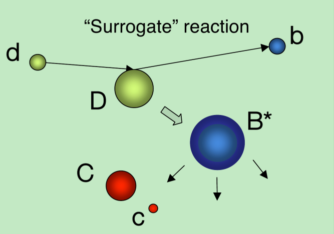
A Surrogate experiment gives

$$P_{\chi}(E) = \Sigma_{J,\pi}\, F_{\delta}^{CN}(E,J,\pi) \cdot G^{CN}_{\chi}(E,J,\pi)$$

I. Ideal procedure: calculate $F_{\delta}^{CN}(E,J,\pi)$, extract $G^{CN}_{\chi}(E,J,\pi)$, and insert into HF formula

II.Realistic: model CN decay, adjust parameters to reproduce measured $P_{\chi}(E)$, obtain G^{CN}_{χ}

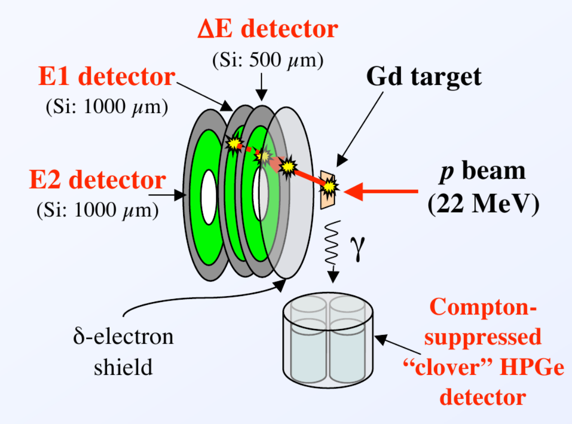
III. Most common approach - *approximations:* assume (J,π)-independent G^{CN} and employ simplified formulae ("Weisskopf-Ewing" and "Surrogate Ratio" approaches)



$P_{\chi} = N_{\delta\chi}/N_{\delta}$

CNR 2007, October 22-26, 2007* *J. Escher, LLNL*

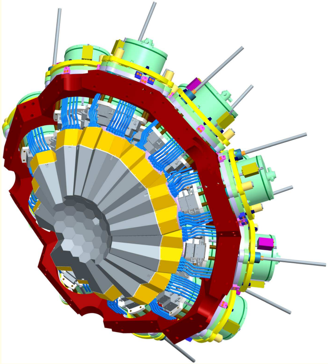
Possible SPES reaction: $^{123}Sn(d,p)^{124}Sn$



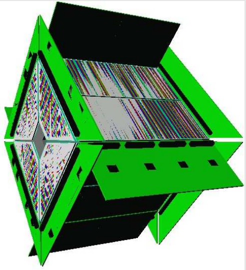
1. particle discrimination
2. γ coincidences
3. exit-channel prob
4. CN cross section

Experimental Setup

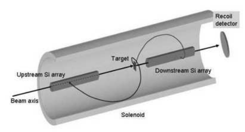
AGATA,GALILEO



TRACE



Solenoid



Summary and conclusions

- SPES RIB:
  10^{5-8} pps
- N∼82, Z∼51:
  Spectroscopic factor in Sb,Sn,In
- Detection Setup:
  AGATA, TRACE, SOLE