The photoresponse of heavy nuclei – some implications on nucleosynthesis

• Nuclear physics and the p-process
• Photoresponse of atomic nuclei
• Structure of the Pygmy Dipole Resonance
• Outlook
The p-process of nucleosynthesis
Nuclear reactions and decays during p-process

In addition (n,γ) and (p,γ) reactions and the νp-process may become important.
Nuclear physics in the p-process network

- Ground state masses
- Properties of excited states
- Nuclear level densities
- Photoresponse ($\gamma,\gamma'$), ($\gamma,n$), ($\gamma,\alpha$), ($\gamma,p$)
- Optical potentials
The photoresponse of atomic nuclei – E1 strength

- **Two Phonon Excitation:** $E_x \sim 3\ \text{MeV}$, $B(E1) \sim 10^{-2}\ \text{W.u.}$
- **Giant Dipole Resonance:** $E_x \sim 18\ \text{MeV}$, $B(E1) \sim 10\ \text{W.u.}$
- **Pygmy Dipole Resonance?**
  - F. Iachello, PLB 160 (1985) 1
  - G. Colò et al., PLB 485 (2000) 362
  - D. Vretenar et al., PLB 487 (2000) 334
Experimental tools

- Photon scattering ($\gamma, \gamma'$)
- Photodissociation ($\gamma, n), (\gamma, p), \ldots$

Real and virtual photons can be used for excitation!

Talks by A. Junghans and K. Sonnabend
E1 strength above threshold in exotic nuclei

P. Adrich et al.,
(Coulex in inverse kinematics)

(Results on $^{18,20}$O: E. Tryggestad et al., PRC 67 (2003) 064309)
Photoresponse below threshold of stable nuclei: Real photon scattering - NRF

Photon scattering off $^{138}\text{Ba}$

$^{138}\text{Ba}$
$E_{\text{max}}=9.2$ MeV

Photon scattering using bremsstrahlung

- Excitation with „white“ photon spectrum
- \( \gamma \) decay from bound states measured with very high energy resolution

→ Complete photoresponse below the particle threshold, i.e. \( B(E1), B(M1), B(E2) \) strength

+ Model independent
+ One experiment covers wide energy range
- Increasing background at small energies
- Studies of radioactive nuclei impossible
- Limited information about nuclear structure
E1 strength below threshold in N=82 nuclei

\[ B(E1) \times 10^{-3} \text{ e}^2 \text{fm}^2 \]

PRELIMINARY
E1 strength below 9 MeV in N=82 nuclei

Substructure within the PDR?

![Graph showing binding energy for different isotopes with width parameter Γ = 500 keV].

F. Iachello
Investigating the PDR with $\alpha$-particles

This setup combines isospin selectivity and skin sensitivity of $\alpha$-particles with spin selectivity and energy resolution of $\gamma$-spectroscopy.

D. Savran et al, submitted to NIM A
The new ISOSPIN setup at KVI

Total photopeak efficiency: ~0.1% at 9 MeV
2D-energy matrix: $(\alpha,\alpha'\gamma)$ on $^{140}\text{Ce}$

$$|E_X - E_\gamma| \leq 300\text{keV}$$

$$E_X - E_\gamma - E_{2^+_1} \leq 300\text{keV}$$
E1 strength in $^{140}$Ce: $(\alpha,\alpha'\gamma)$ vs. $(\gamma,\gamma')$
Summary

• An E1 resonance exhausting up to 1% of the EWSR is observed in all examined stable nuclei around about 7 MeV

• The strength seems to split up into two parts with different underlying isospin structure and/or different nuclear surface content

• More resonance like strength is found above the particle threshold in n-rich systems

• We do not understand the connection between the strength below and above the threshold and between the strength in stable and exotic nuclei
Connection to E1 strength above the threshold in stable nuclei

Low Energy Photon Tagger @ S-DALINAC
NiederEnergiePhotonenTagger

High resolution measurement (<0.25 %) of photon induced reaction rates in the energy range $8 \text{ MeV} < E_\gamma < 20 \text{ MeV}$
NEPTUN at S-DALINAC

Clam Shell Magnet
$B_{\text{Peak}} = 0.3$ T

$E_0 = 31$ MeV

$\gamma$

$radiator$

$\sim 1$ mm

$1$ MeV $\approx 5$ cm

$220$ MeV

$18$ MeV $20$ MeV $19$ MeV $21$ MeV
The photoresponse of heavy nuclei – some implications on nucleosynthesis

- Complete photoresponse ($\gamma,\gamma'$), ($\gamma,n$), ($\gamma,\alpha$), ($\gamma,p$) can be measured in stable nuclei at S-DALINAC
- Additional information about structure from ($\alpha,\alpha'\gamma$) and ($e,e'$) experiments
The photoresponse of heavy nuclei – some implications on nucleosynthesis


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More information and references: www.zilges.de