Contributions to Captures

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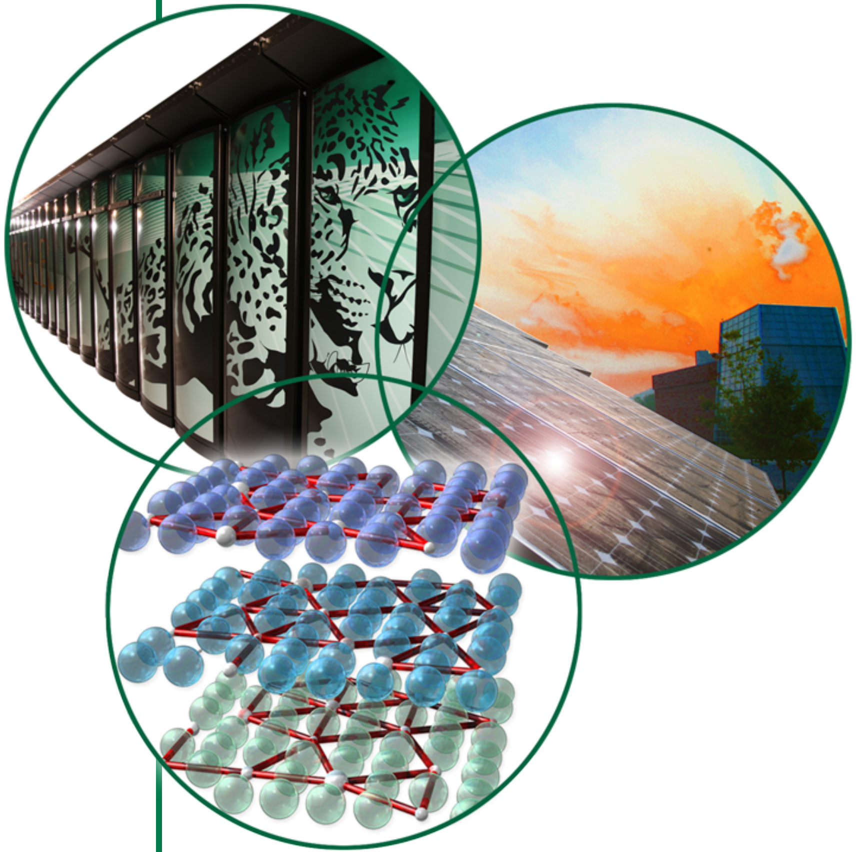

Year 1 Review
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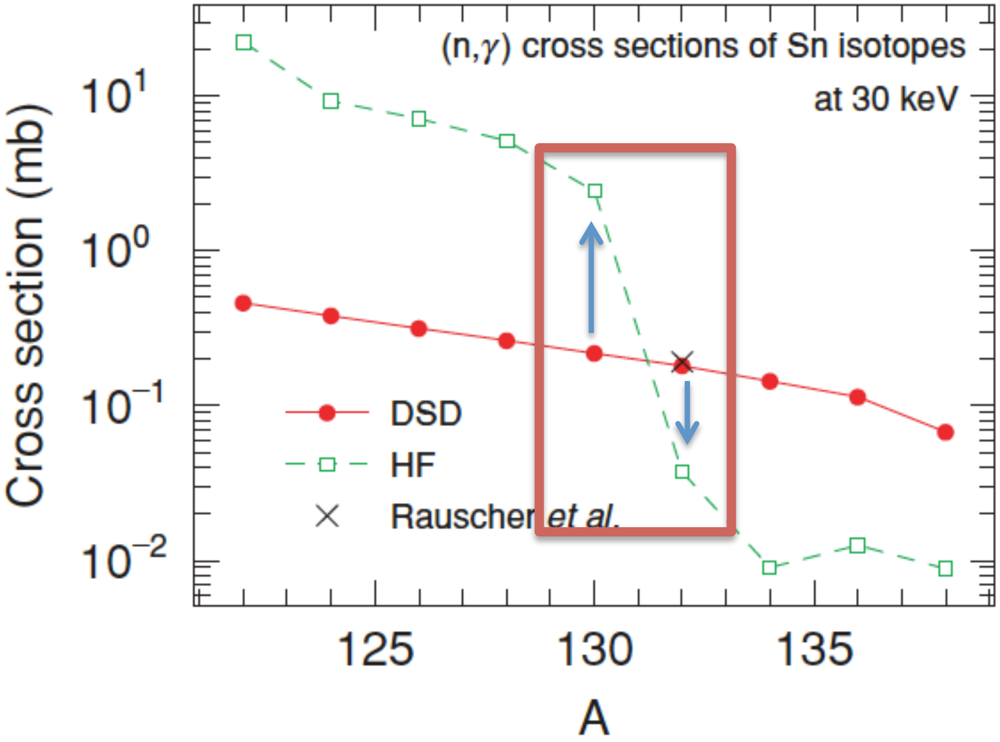
Main Contributions to captures

- Direct capture (D) (i.e. one-step)
  - Important at low energies on light, or neutron rich nuclei
  - Potential model needs ANC from a (d,p) reaction
- Semidirect (SD) capture (i.e. two-step)
  - Via GDR, GQR or other doorway states
  - Dominates at, and around, $E_b + E_{GDR}$
  - D + SD contributions interfere; their amplitudes add
- Compound capture (i.e. many-step)
  - Via (complex) compound nuclear states
  - Competes with the above at all energies, and dominates for low-energy gammas

^{130}Sn(n,g) important for nucleosynthesis

- Relative contribution of DSD vs. compound capture varies
  - Hauser-Feshbach models indicate DSD >> compound above shell closure



S. Chiba et al. Phys. Rev. C 77, 015809 (2008)

Integrating Direct and Compound-Nucleus Reactions

- Implemented E1 DSD capture via GDR into *bound* states (yr 1)
  - These processes are unaffected by compound resonances
  - Compute for a few select targets
  - Extend to other doorway states, like pygmy resonances and isobar analogue states in Year 2
- Implement E1 DSD capture via GDR into *continuum* (years 3-5)

Implementation Strategy

- Compare Fresco and Cupido DSD results
- Cupido:
  - 1st order perturbation DSD capture code (F. Dietrich, LLNL)
  - Uses one pole approximation for inelastic neutron Green's function
- Fresco:
  - Coupled channels code
  - DWBA implementation of DSD for comparison with Cupido
  - Should be more accurate away from GDR peaks.
- Two test cases (so far):
  - $^{60}Ni(n,g)^{61}Ni_{g.s.}$
  - $^{130}Sn(n,g)^{131}Sn$
  - Agreement near GDR peaks, but different treatment of Green's function leads to some differences away from peaks

DWBA Implementation of DSD

$$T_{\mathrm{if}}^{(\lambda)} = \langle \Psi_{\mathrm{i}} | O_\lambda | u_{\mathrm{f}} \psi_0 \rangle \qquad H = H_0 + H_n + V_{\mathrm{coll}}$$

$$|\Psi_{\mathrm{i}}\rangle = |\chi_{\mathrm{i}} \psi_0\rangle + \frac{1}{E - H_0 - H_n} V_{\mathrm{coll}} |\chi_{\mathrm{i}} \psi_0\rangle$$

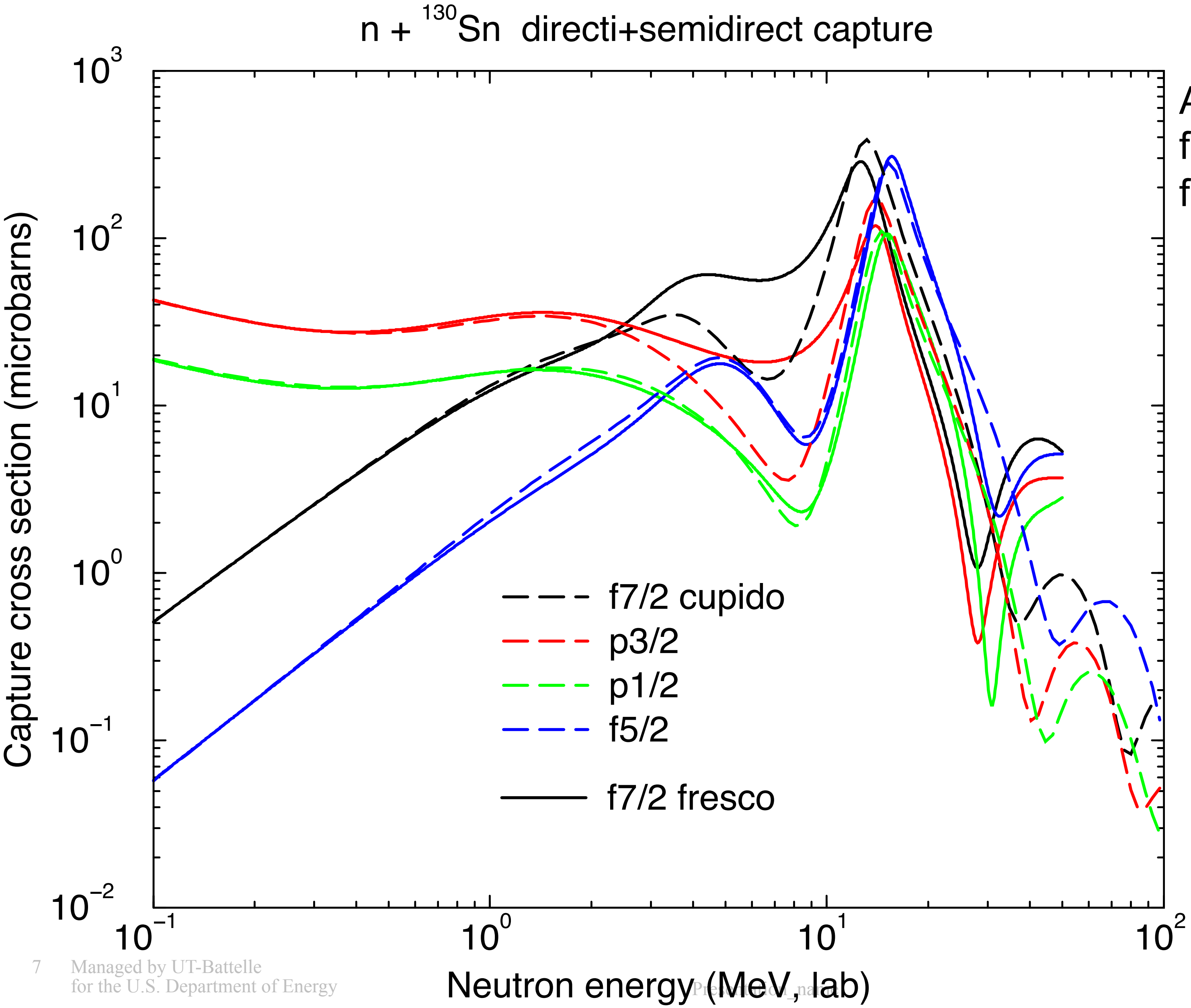
$$T_{\mathrm{if}}^{(\lambda)} = T_{\mathrm{D}} + T_{\mathrm{SD}}$$

$$T_{\mathrm{D}} = \langle \chi_{\mathrm{i}} | O_\lambda | u_{\mathrm{f}} \rangle$$

$$T_{\mathrm{SD}} = \langle \chi_{\mathrm{i}} \psi_0 | V_{\mathrm{coll}} \frac{1}{E - H_0 - H_n} O_\lambda | u_{\mathrm{f}} \psi_0 \rangle$$

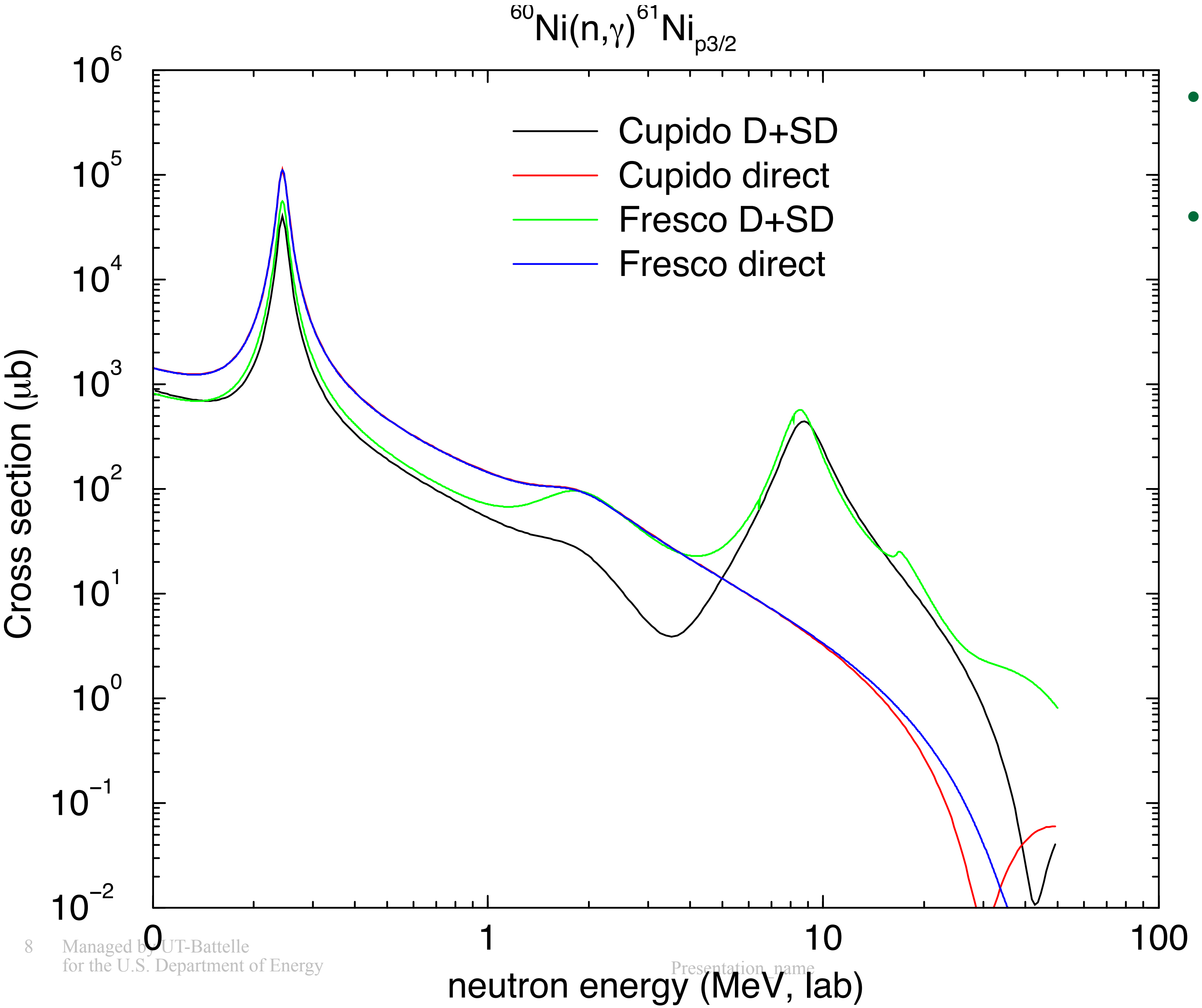
Fresco: $$T_{\mathrm{SD}} = \langle \chi_{\mathrm{i}} \psi_0 | V_{\mathrm{coll}} | \psi_{\mathrm{D}} \rangle \frac{1}{E - E_{\mathrm{D}} - H_{\mathrm{n}}} \langle \psi_{\mathrm{D}} | O_\lambda | u_{\mathrm{f}} \psi_0 \rangle$$

Cupido: $$T_{\mathrm{SD}} = \langle \chi_{\mathrm{i}} \psi_0 | V_{\mathrm{coll}} | u_{\mathrm{f}} \psi_{\mathrm{D}} \rangle \frac{1}{E - E_{\mathrm{D}} - E_{\mathrm{b}}} \langle u_{\mathrm{f}} \psi_{\mathrm{D}} | O_\lambda | u_{\mathrm{f}} \psi_0 \rangle$$



At several MeV's
f5/2, p1/2 discrepant
f7/2, p3/2 consistent

Test Case 2: ^{60}Ni(n,g) ^{61}Ni$_{\mathrm{G.S.(3p3/2)}}$



- **Large SD effect at low E**
- **Different shapes around 1-6 MeV**

Outlook

- Further investigation of GDR Green's functions and coupling form factors to understand all differences
- Future versions will include coupled channels effects beyond 2nd order DWBA
- Selected set of nuclides will provide a systematic study, in addition to nuclei of current experimental interest

Direct-Semidirect Capture in Coupled Ch.

- **T-matrix: a coherent sum of *direct* and *semidirect* parts**

$$T_{\mathrm{fi}}(E,E_\gamma)=\langle\Psi_{\mathrm{f}}(E,E_\gamma)|O_\lambda^{\mathrm{n}}+O_\lambda^{\mathrm{c}}|\Psi_{\mathrm{i}}(E)\rangle$$

- **Incoming and outgoing wave functions**

$$\begin{aligned}\Psi_{\mathrm{i}}(E) &= \chi_{\mathrm{n}}^{E}(r_{\mathrm{n}})\phi_{\mathrm{gs}}(\xi)+\chi_{\mathrm{d}}^{E-E_{\mathrm{d}}}(r_{\mathrm{n}})\phi_{\mathrm{d}}(\xi)\\ \Psi_{\mathrm{f}}(E,E_\gamma) &= [\chi_{\mathrm{b}}^{E-E_\gamma}(r_{\mathrm{n}})\phi_{\mathrm{gs}}(\xi)+\chi_{\mathrm{e}}^{E-E_{\mathrm{d}}-E_\gamma}(r_{\mathrm{n}})\phi_{\mathrm{d}}(\xi)]\zeta_\gamma(r_\gamma)\end{aligned}$$

- **Inserting yields four terms**

$$T_{\mathrm{fi}}=\boxed{\langle\chi_{\mathrm{b}}|O_\lambda^{\mathrm{n}}|\chi_{\mathrm{n}}\rangle}+\langle\chi_{\mathrm{e}}|O_\lambda^{\mathrm{n}}|\chi_{\mathrm{d}}\rangle+\boxed{\langle\chi_{\mathrm{b}}|\chi_{\mathrm{d}}\rangle\langle\phi_{\mathrm{gs}}|O_\lambda^{\mathrm{c}}|\phi_{\mathrm{d}}\rangle}+\langle\chi_{\mathrm{e}}|\chi_{\mathrm{n}}\rangle\langle\phi_{\mathrm{d}}|O_\lambda^{\mathrm{c}}|\phi_{\mathrm{gs}}\rangle$$

Dominant terms