Determination of the reaction rate for $^{13}\mathrm{C}(\alpha,n)^{16}\mathrm{O}$ by means of CDCC analysis of sub barrier α transfer reaction

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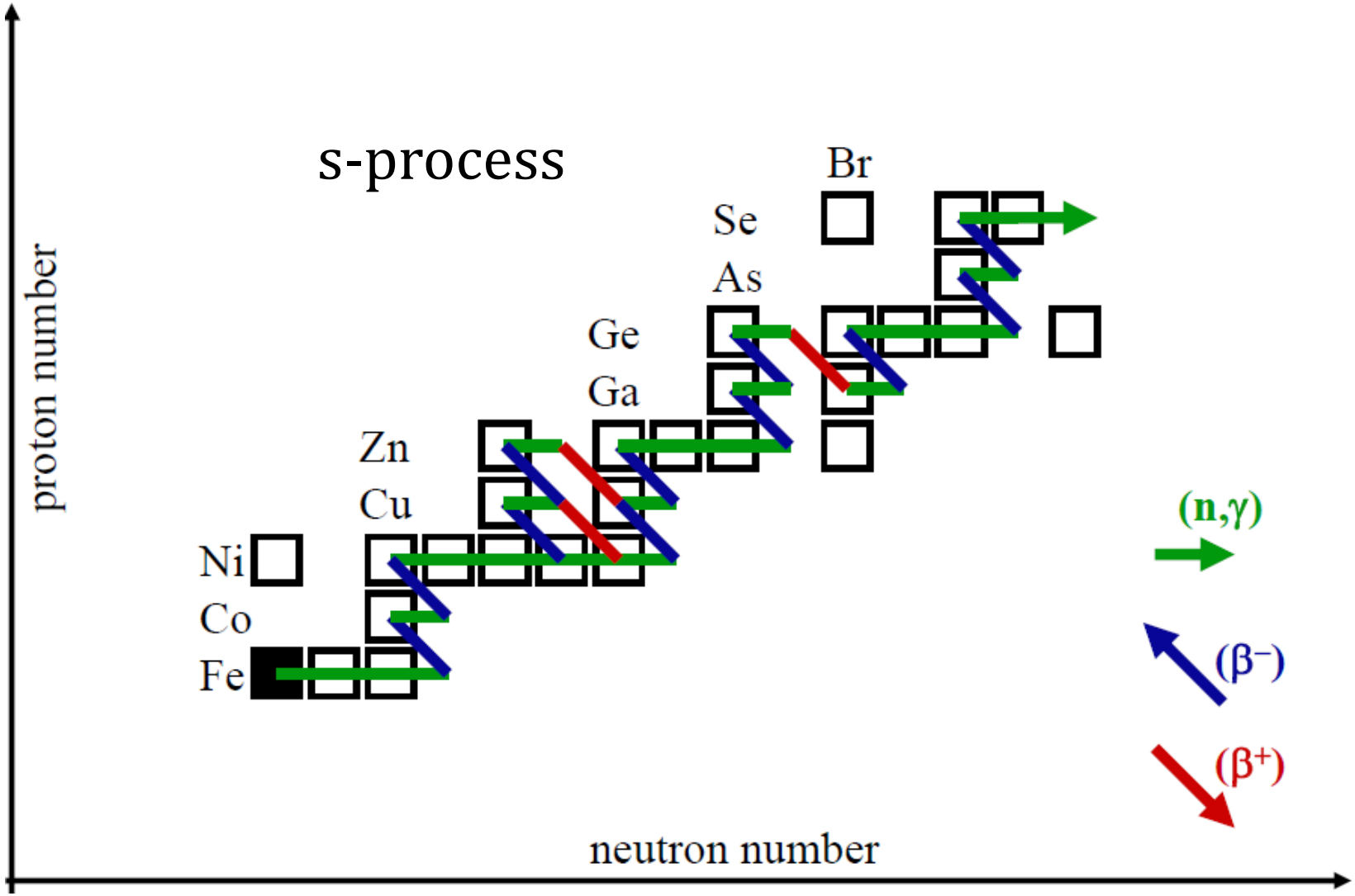
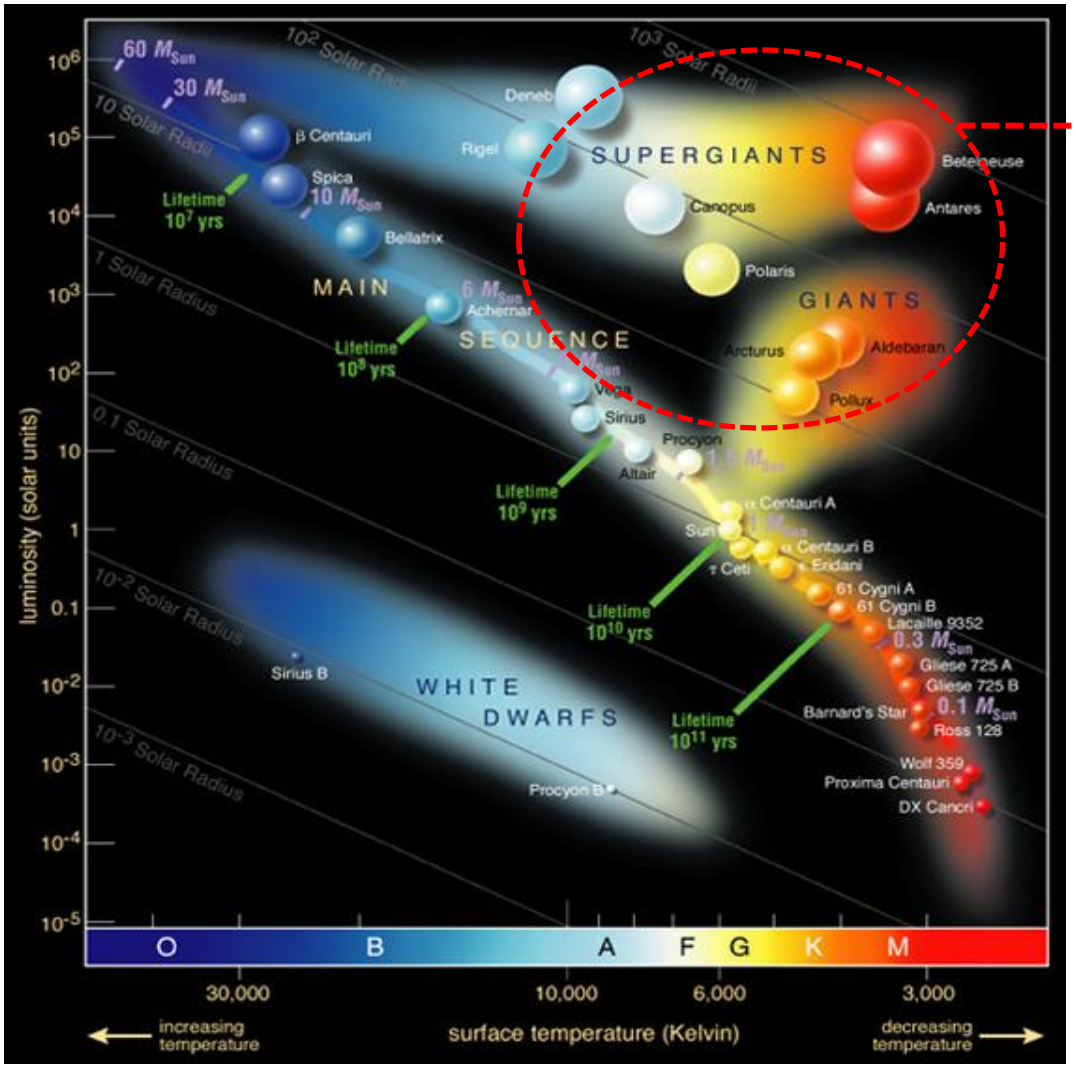

s-process
proton number
neutron number
Fe
Co
Ni
Cu
Zn
Ga
Ge
As
Se
Br
(n,γ)
(β⁻)
(β⁺)

Introduction

AGB(Asymptotic Giant Branch)stars

H-R diagram



http://www.bramboroson.com/astro/apr1.html

AGB stars

$^{13}C(\alpha,n)^{16}O$

the main source of neutron for the s-process in AGB

$^{13}C(\alpha,n)^{16}O$

$\alpha + {}^{13}C \rightarrow {}^{17}O$ (virtual synthesis)

unknown

${}^{17}O \rightarrow {}^{16}O + n$ (virtual decay)

known(R-matrix theory)

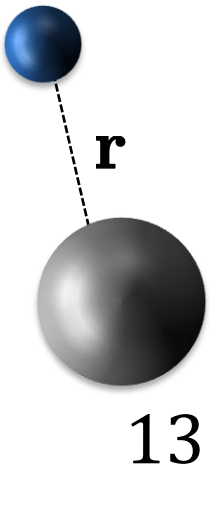
Formulation　ANC(Asymptotic Normalization Coefficient) method

$\alpha + {}^{13}\mathrm{C} \rightarrow {}^{17}\mathrm{O}$　(virtual synthesis)

$$\langle \phi_{17}(\mathbf{r}) | \phi_\alpha(\xi_\alpha)\phi_{13}(\xi_{13})\psi_{\alpha-13}(\mathbf{r}) \rangle$$

$$= \langle I(\mathbf{r}) | \psi_{\alpha-13}(\mathbf{r}) \rangle$$

$$= \begin{cases} 0 & (\mathbf{r} \le \mathbf{r}_N) \\ \langle CW(\mathbf{r}) | \psi_{\alpha-13}(\mathbf{r}) \rangle & (\mathbf{r} \gg \mathbf{r}_N) \end{cases}$$



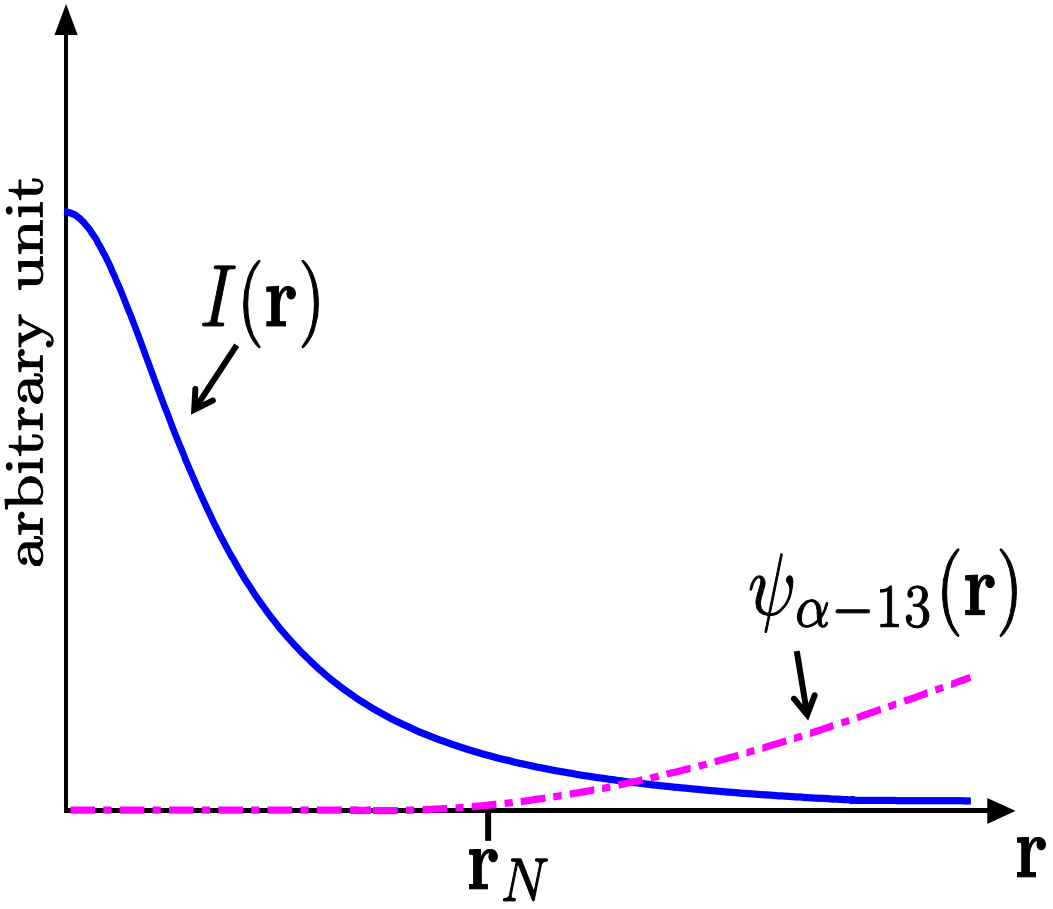
$$I(\mathbf{r}) \equiv \langle \phi_{17}(\mathbf{r}) | \phi_\alpha(\xi_\alpha)\phi_{13}(\xi_{13}) \rangle$$

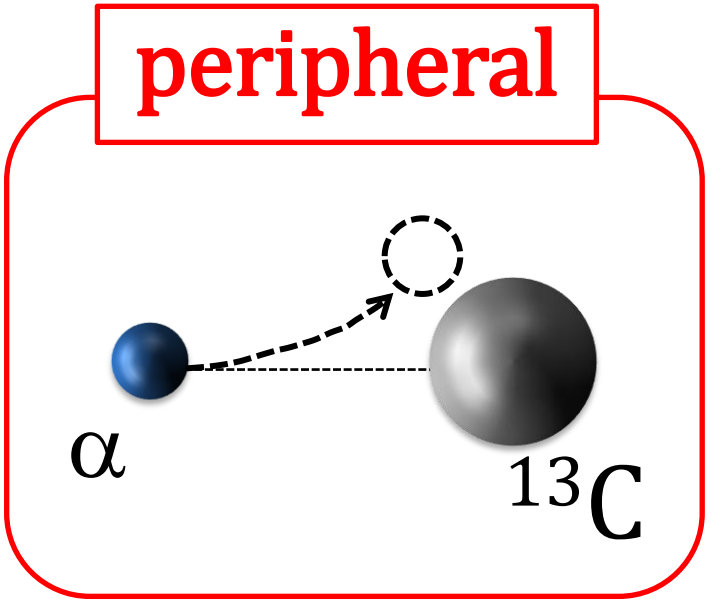
$$\xrightarrow{\mathbf{r} \gg \mathbf{r}_N} CW(\mathbf{r})$$

→ **ANC(const.)**

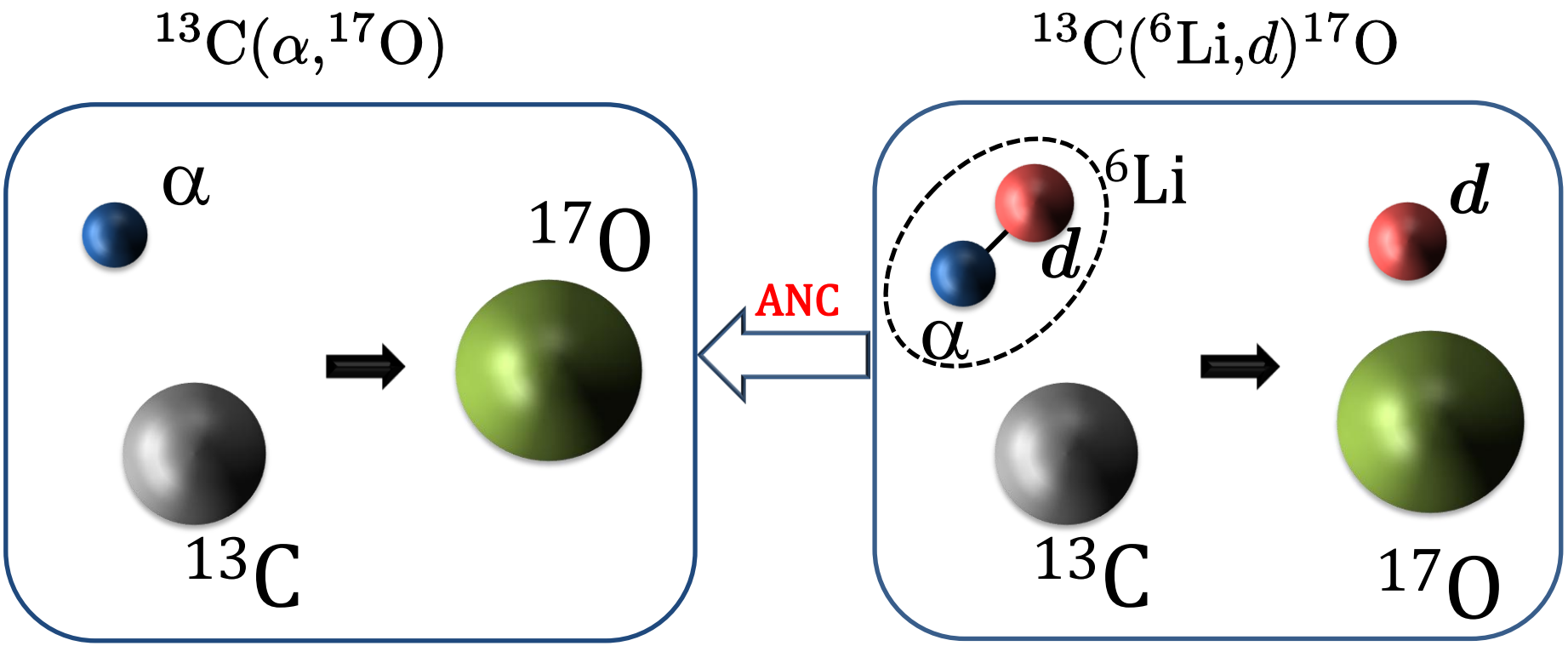
Formulation ANC(Asymptotic Normalization Coefficient) method

$$\langle I(\mathbf{r})|\psi_{\alpha-13}(\mathbf{r})\rangle \xrightarrow{\mathbf{r}\gg\mathbf{r}_N} \langle CW(\mathbf{r})|\psi_{\alpha-13}(\mathbf{r})\rangle$$





Formulation ANC(Asymptotic Normalization Coefficient) method



$$T = \langle \phi_{17}\phi_d\chi_{d-17}|V|\phi_\alpha\phi_d\phi_{13}\varphi_{\alpha-d}\chi_{\mathrm{Li}-13}\rangle$$

$$= \langle I\ \chi_{d-17}|V|\varphi_{\alpha-d}\chi_{\mathrm{Li}-13}\rangle$$

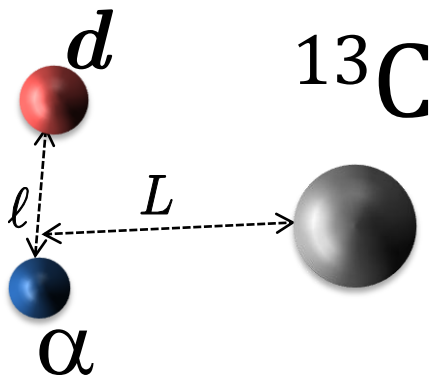
$$I = \langle \phi_{17}|\phi_\alpha\phi_{13}\rangle \xrightarrow{\mathbf{r}\gg\mathbf{r}_N} CW$$

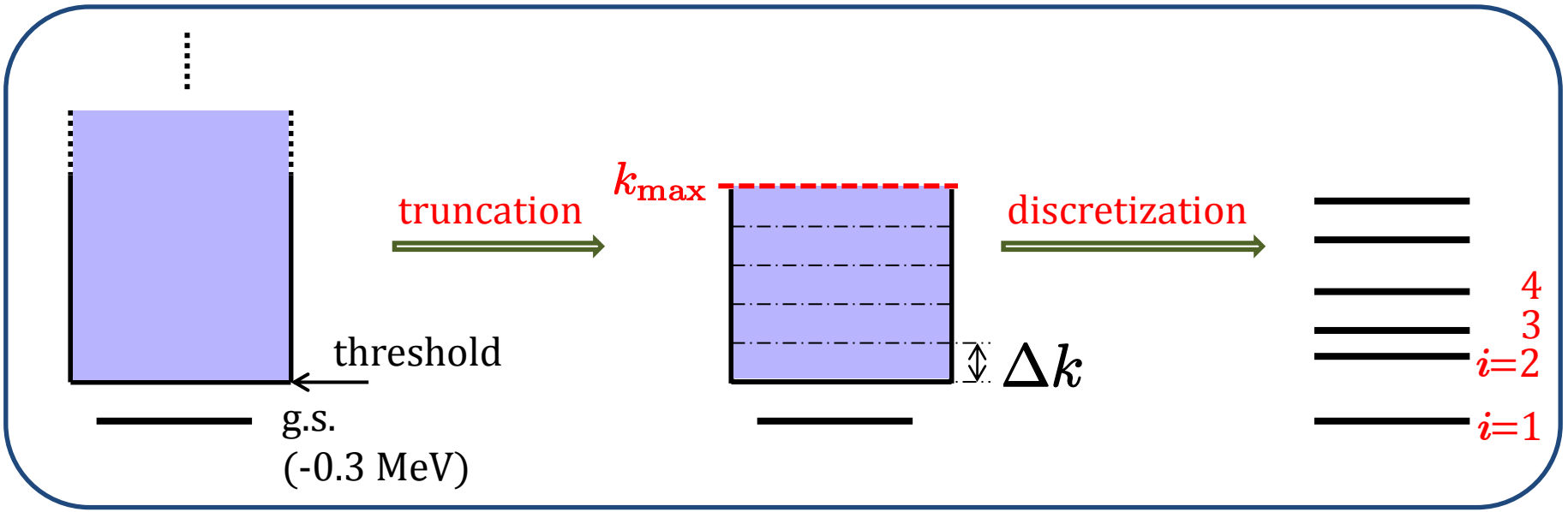
Formulation CDCC (Continuum Discretized Coupled Channels) method

$$\psi_{\alpha d} = \sum_{\ell=0}^{\infty} \sum_{|J-\ell|<L<|J+\ell|} \int_0^{\infty} dk [\varphi^{\ell}_{\alpha-d} \otimes \chi^{\ell L}_{\mathrm{Li}-13}]_{JM}$$

$$\approx \sum_{\ell=0}^{\ell_{\max}} \sum_{|J-\ell|<L<|J+\ell|} \int_0^{k_{\max}} dk [\varphi^{\ell}_{\alpha-d} \otimes \chi^{\ell L}_{\mathrm{Li}-13}]_{JM}$$

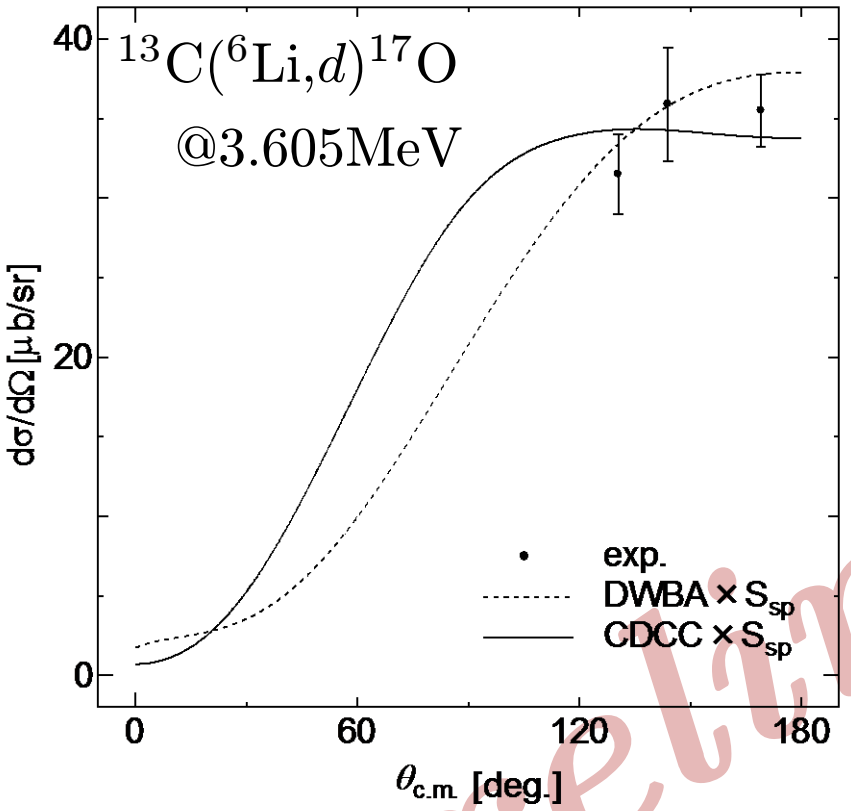
$$\approx \sum_{\ell=0}^{\ell_{\max}} \sum_{|J-\ell|<L<|J+\ell|} \sum_{i} [\hat{\varphi}^{\ell}_{i} \otimes \hat{\chi}^{\ell L}_{i}]_{JM}$$

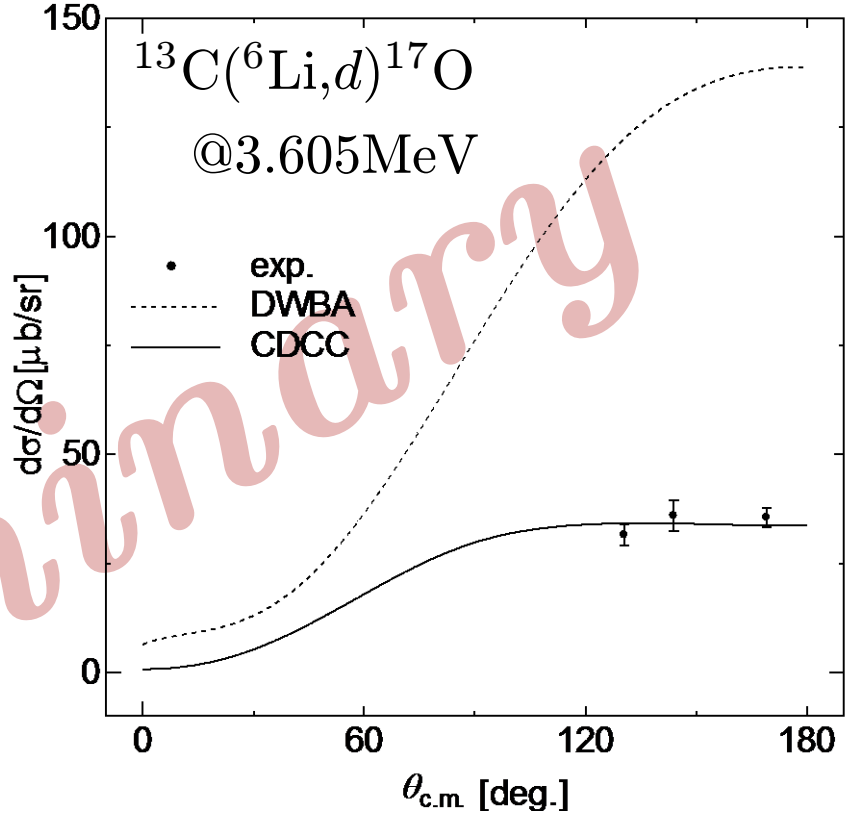




Result

cross section & ANC





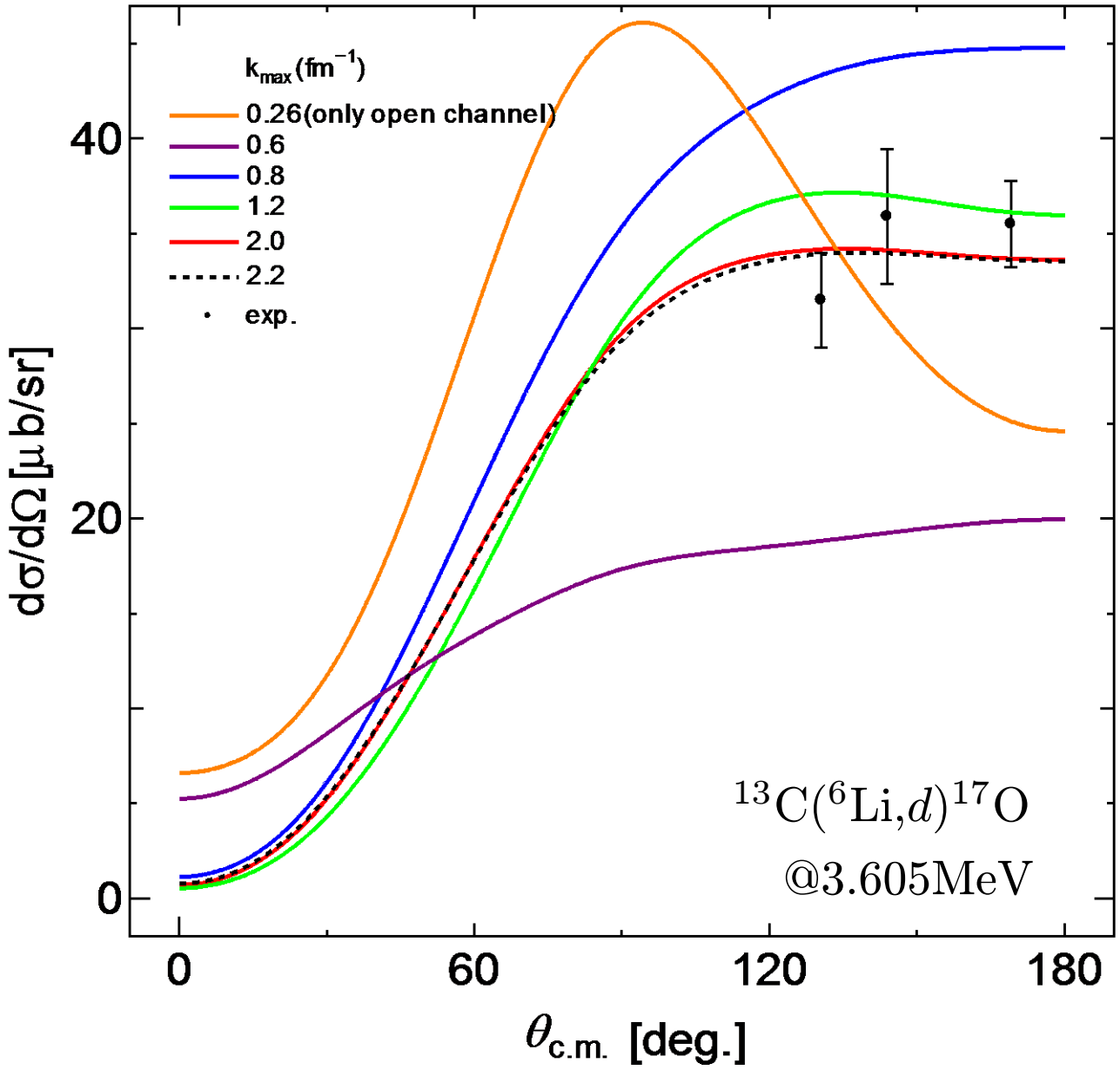
	DWBA	CDCC
S_{sp}	0.273	1.004
$(C^{^{17}\mathrm{O}}_{\alpha^{13}\mathrm{C}})^2$	0.89 ± 0.23 fm^{-1}	$2.91^{+0.30}_{-0.47}$ fm^{-1}

$$C^{^{17}\mathrm{O}}_{\alpha^{13}\mathrm{C}} = \sqrt{S_{sp}}a$$

$$a = 1.7022(const.)$$

Result

convergency



Summary

- CDCC's result(ANC) is different from DWBA's by about factor of 3!!

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  It doesn't provide precise result that
  analysis with DWBA for the low energy transfer reaction.

- It's not easy to obtain convergent results.

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  It requires a huge model space,
  when we calculate the low energy transfer reaction.