第2回実証的原子核物理学研究会 2012.2.22-23 at RCNP

非共鳴3α融合反応率の実験的決定

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Theoretical Support

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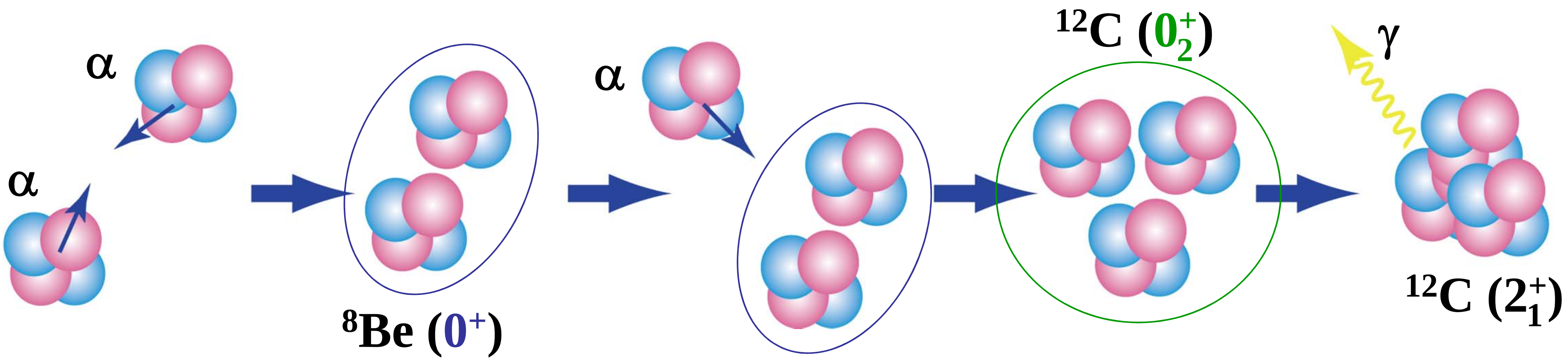
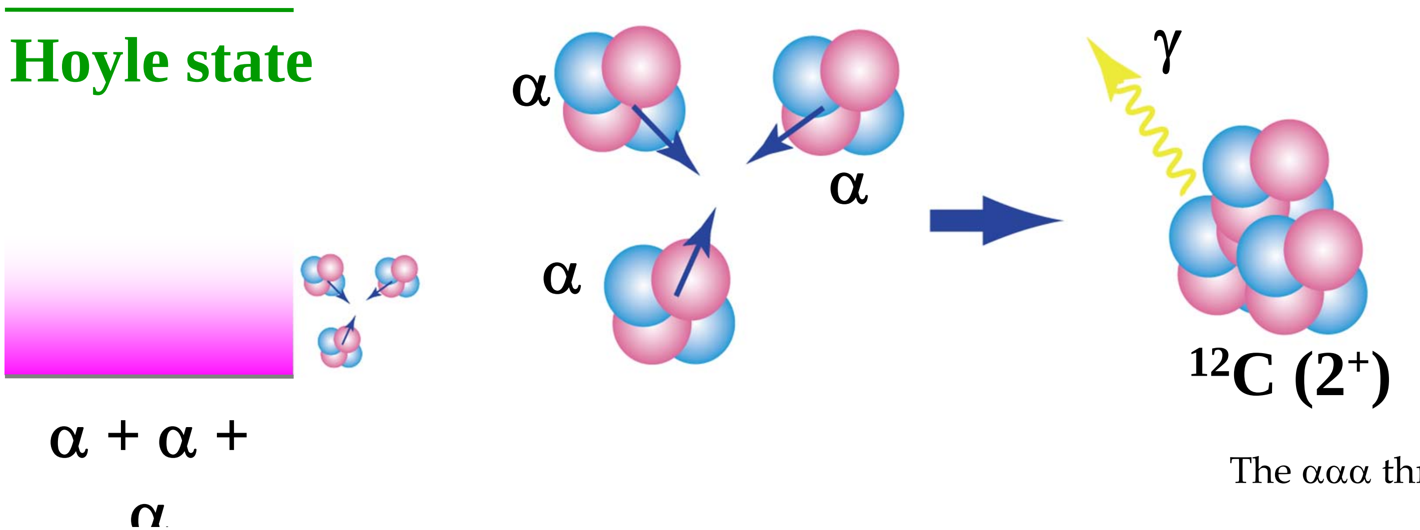
M. Kamimura	RIKEN, Japan	Research Fellow

The Resonant and Nonresonant Triple-α processes

- T > a few 10^8 K: **resonant** capture

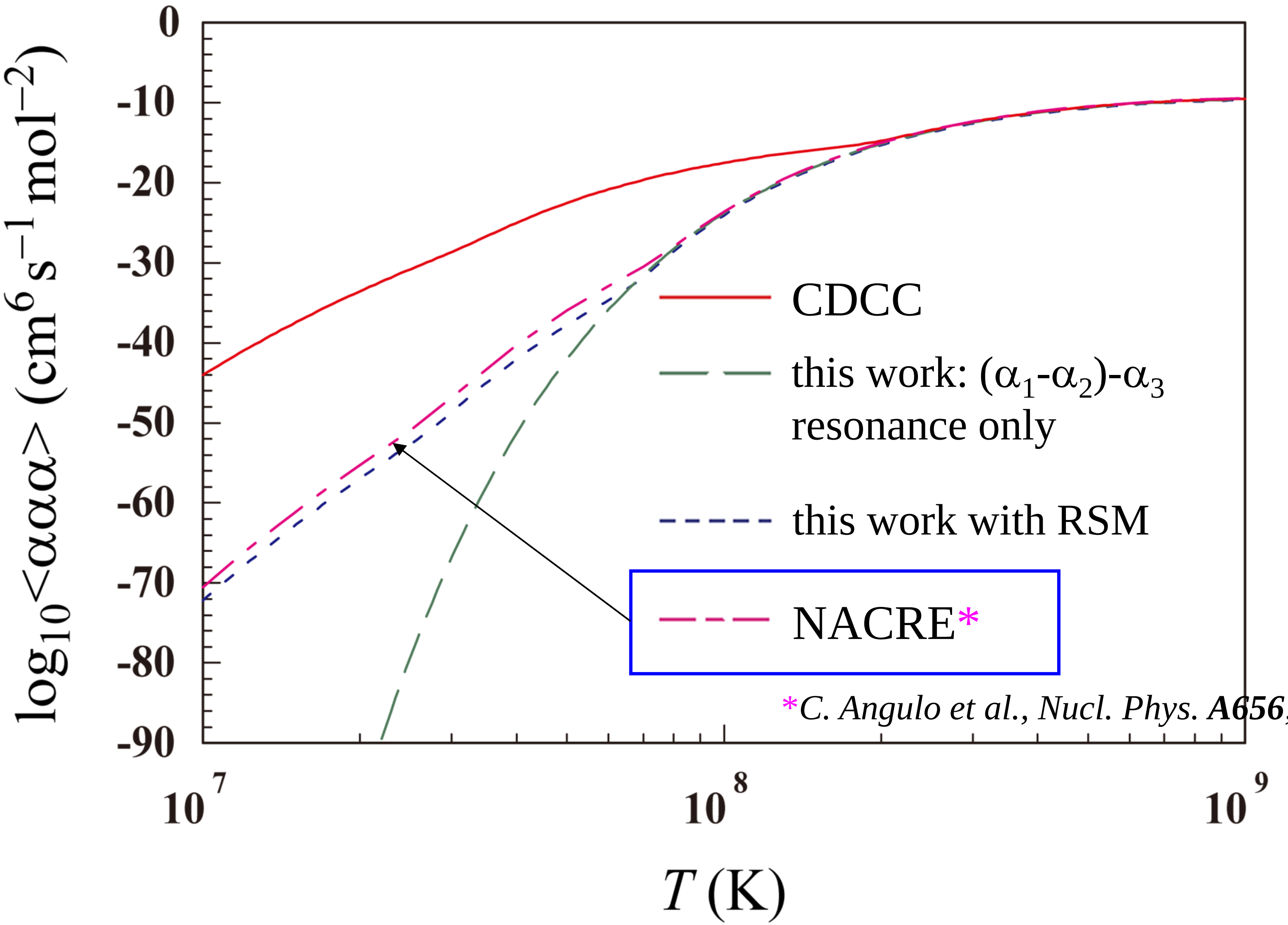


- $T < 10^8$ K: **nonresonant** capture (**T**ernary **F**usion **P**rocess)



The ααα threshold is at 7.275 MeV.

The Triple-α Reaction Rate

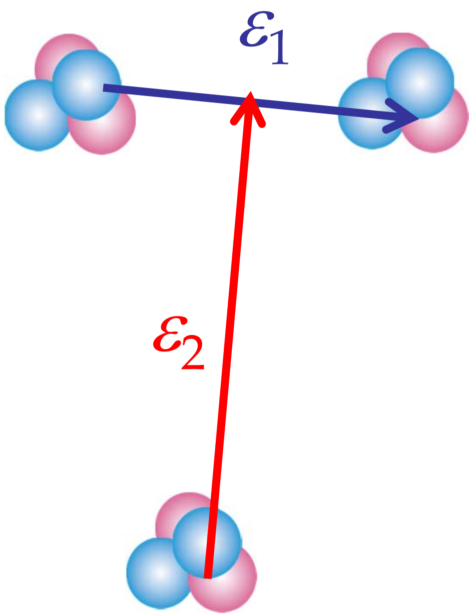


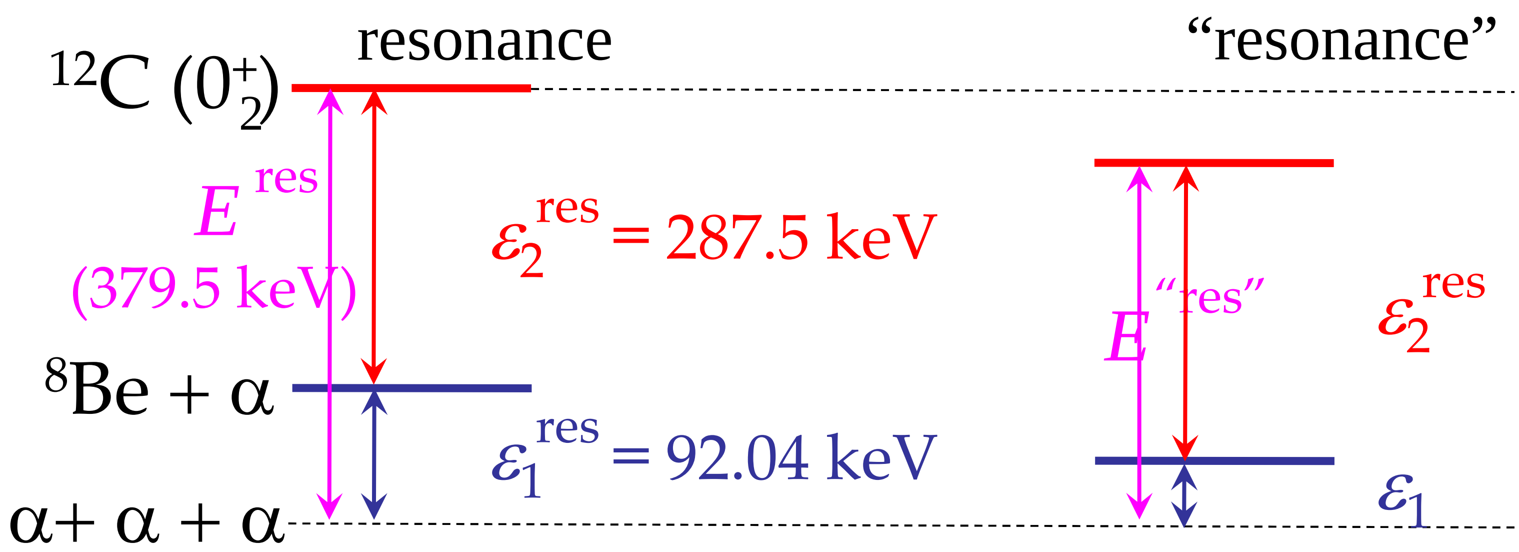
*C. Angulo et al., Nucl. Phys. **A656**, 3 (1999).

from K.Ogata, M. Kan, and M. Kamimura, Prog. Theor. Phys. ***122****, 1055 (2009);*

Resonance Shift Method (RSM)

—— *K. Nomoto, Astrophys. J. 253, 798 (1982).*

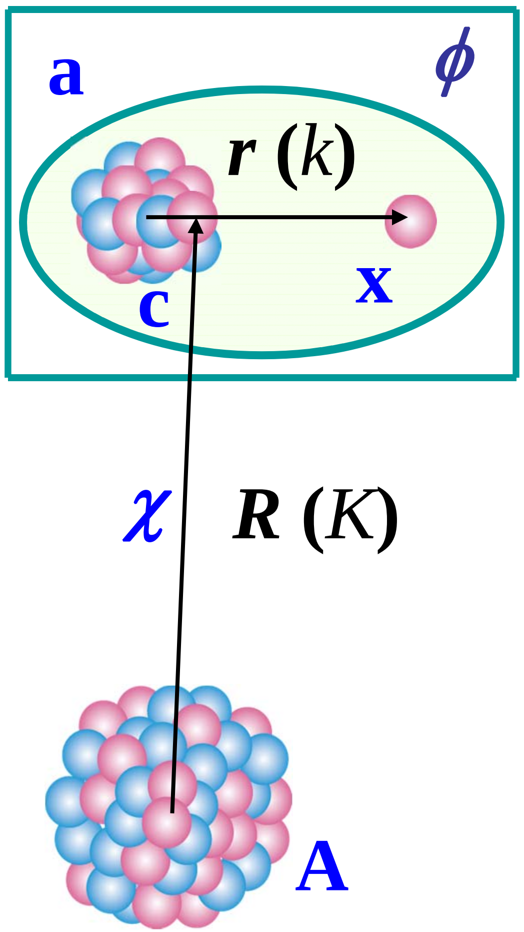


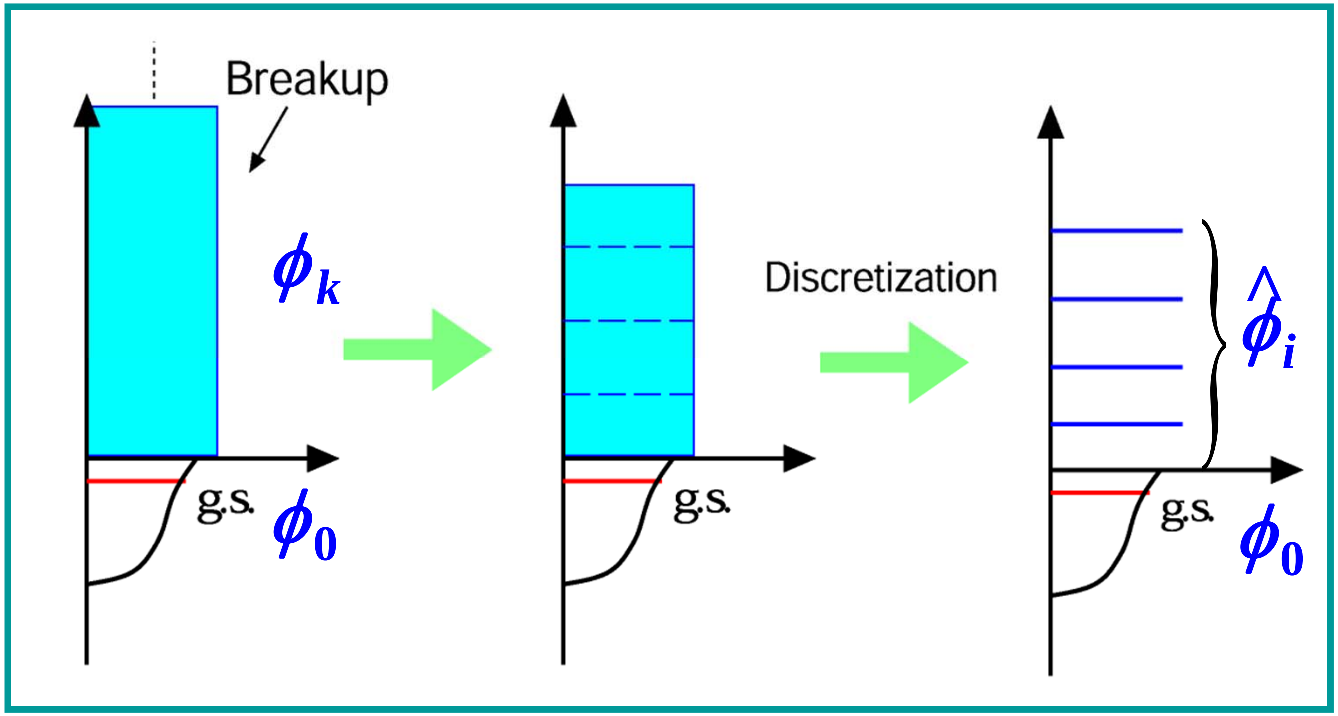


No clear physical background on the assumption of the RSM calculation.

The Continuum-Discretized Coupled-Channels method: CDCC (conventional CDCC)

—— *M. Kamimura, Yahiro, Iseri, Sakuragi, Kameyama and Kawai, PTP Suppl.* ***89****, 1 (1986);*
N. Austern, Iseri, Kamimura, Kawai, Rawitscher and Yahiro, Phys. Rep. ***154*** *(1987) 126.*

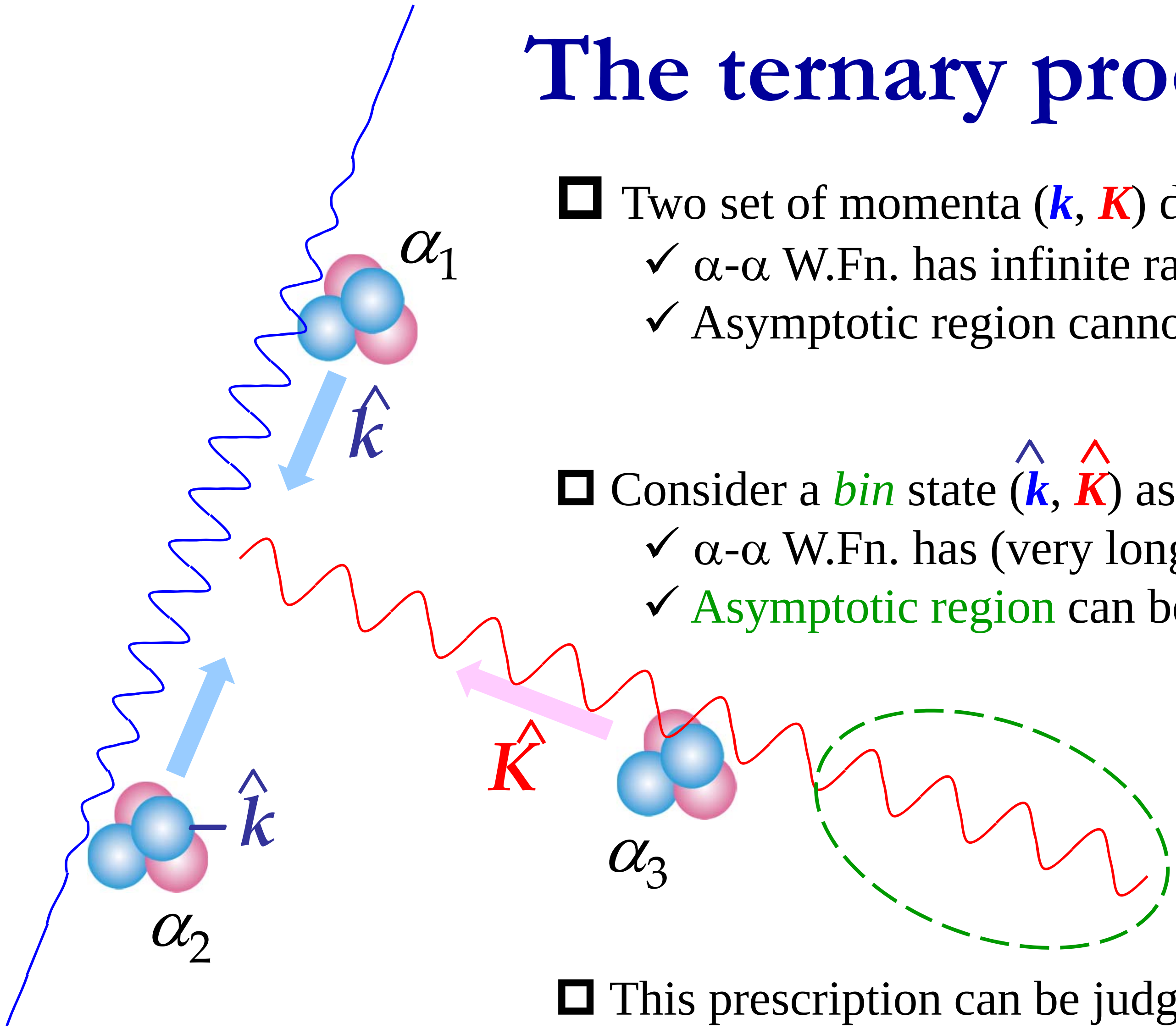




$$\psi = \phi_0 \chi_0 + \int_0^\infty \phi_k \chi_k dk \;\Rightarrow\; \psi^{\mathrm{CDCC}} = \sum_i^{i_{\max}} \hat{\phi}_i \hat{\chi}_i$$

c.f. N. Austern, M. Yahiro, and M. Kawai, Phys. Rev. Lett. ***63****, 2649 (1989);*
*N. Austern, M. Kawai, and M. Yahiro, Phys. Rev. C****53****, 314 (1996).*

The ternary process



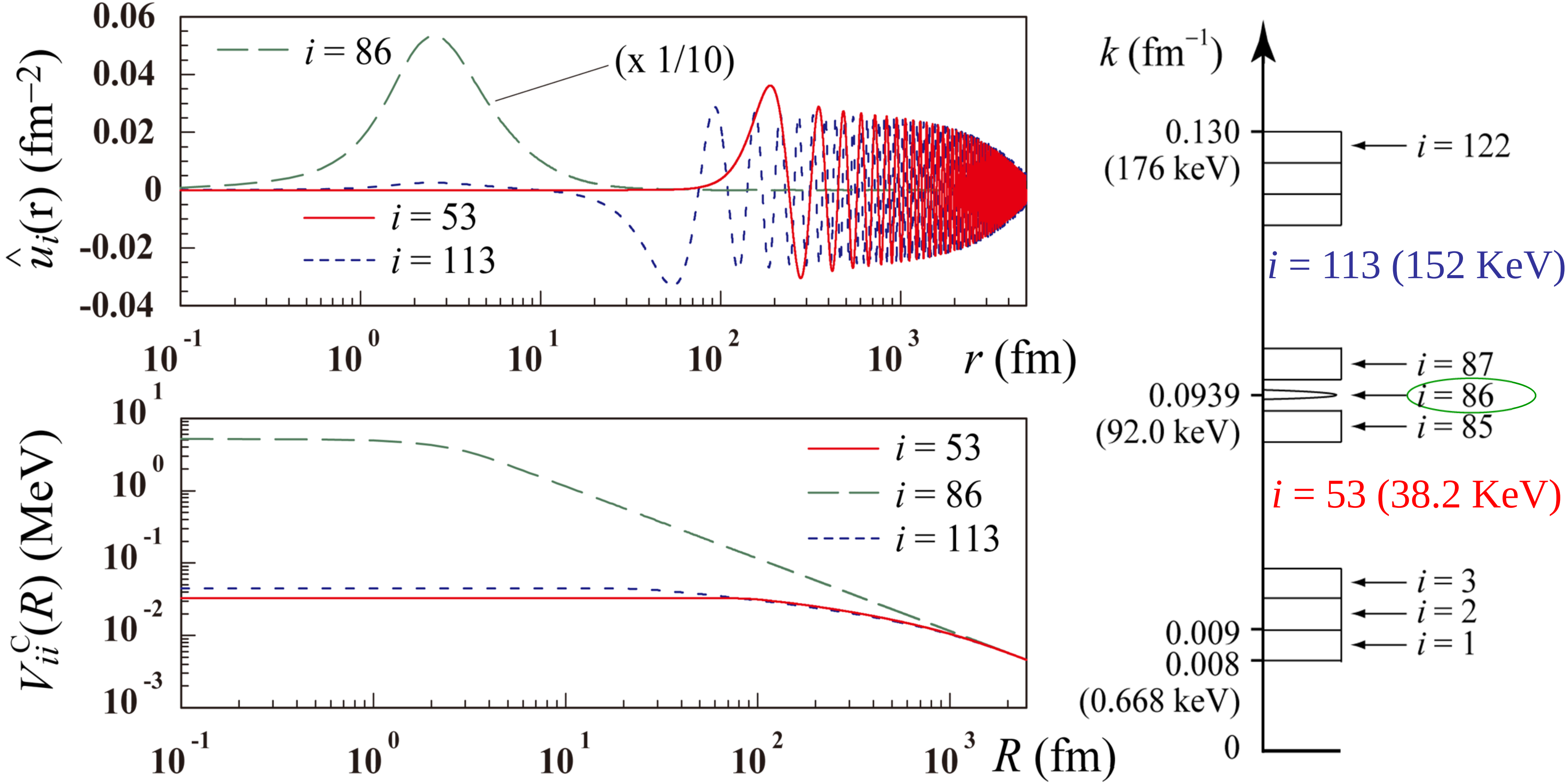
- Two set of momenta ($\boldsymbol{k}$, $\boldsymbol{K}$) define the incident channel.
  - ✓ α-α W.Fn. has infinite range.
  - ✓ Asymptotic region cannot be defined.

- Consider a *bin* state ($\hat{\boldsymbol{k}}$, $\hat{\boldsymbol{K}}$) as an incident channel.
  - ✓ α-α W.Fn. has (very long but) finite range.
  - ✓ Asymptotic region can be defined.

- This prescription can be judged whether the resulting reaction rate converges or not.

c.f. N. Austern, Yahiro, and Kawai, PRL ***63****, 2649 (1989);*
N. Austern, Kawai, and Yahiro, PRC ***53****, 314 (1996);*
R. A. D. Piyadasa, Kawai, Kamimura, and Yahiro, PRC ***60****, 044611 (1999).*

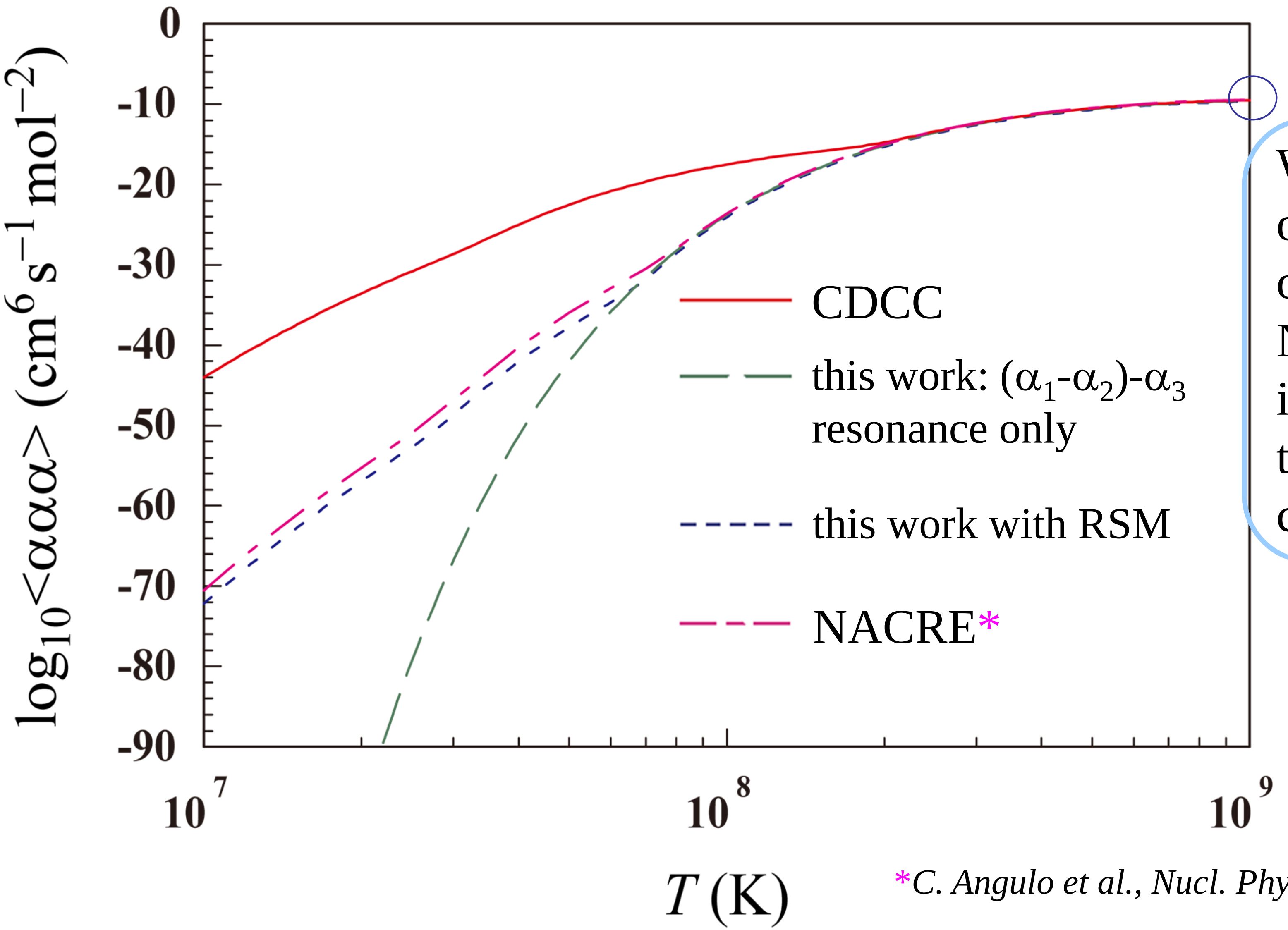
α_1-α_2 W.Fn. and (α_1-α_2)-α_3 Coulomb pot.



Resonant and nonresonant Coulomb potentials are completely different.
The RSM neglects this difference and is a very crude approximation.

The Triple-α Reaction Rate

—— *K.Ogata, M. Kan, and M. Kamimura, Prog. Theor. Phys.* ***122****, 1055 (2009); arXiv:0905.0007 [astro-ph.SR].*



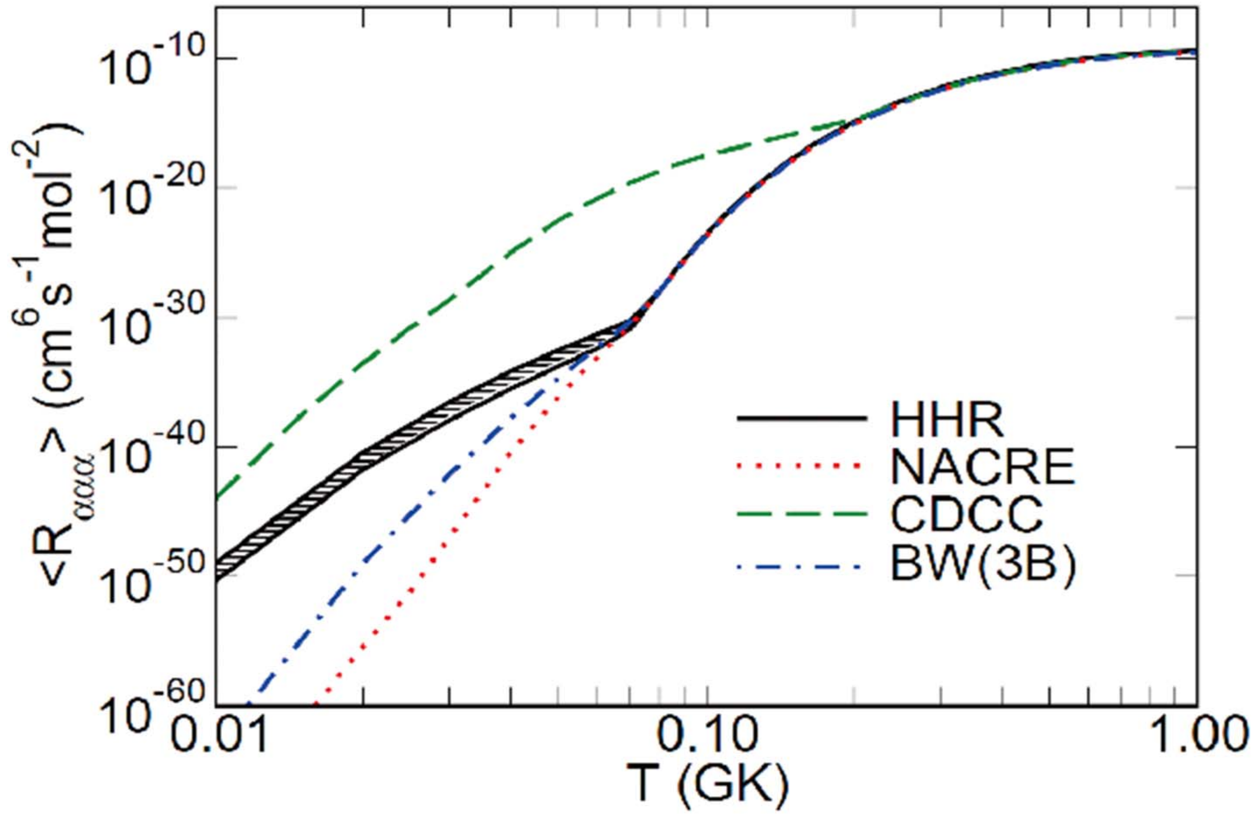
We have normalized our results to the rate of NACRE at 10^9 K. Normalization factor is 1.5 that indicates the uncertainty of our calculation.

C. Angulo et al., Nucl. Phys. ***A656****, 3 (1999).*

BIG Impact on Nuclear-Astrophysics

Stellar models	Conclusions
• **Evolutional track of stars**: Dotter and Paxton Shortening or **disappearance of the Red-Giant phase**	**Negative**
• **Suppression of He-shell flashes** on AGB phase: T. Suda	**Negative**
• Ignition of accreting helium on C-O white dwarfs: Saruwatari *et al*. Carbon deflagration for slow accretion rates disappears	**Negative?**
• Helium ignition on accreting neutron stars: Peng and Ott Significant lower ignition column density Too low burst energy for ultra-compact X-ray binaries	**Negative**
• Helium flash on accreting neutron star: Matsuo **Better describe the X-ray burst**	**Positive**
• Evolutional tracks of Cepheid models: Morel *et al* The first dredge-up does not occur	**Negative**
A **long-lasting problem on theoretical mass may be solved**.	**Positive**
Temporal derivative of the period keeps a positive sign → can be recovered with a few percent modification of the rate	**Marginal**

Predictions of Other Theoretical Models



CDCC: Continuum Discretized Coupled-Channel Method, K. Ogata et al., PTP122,1055(2009)
HHR: Faddeev Hyperspherical Harmonics with R-Matrix Expansion, N.B. Nguyen et al., arXiv:1112.2136v1
BW(EB): Phenomenological Parametrization of Photodissociation using Three-Body Breigt-Wigner Form, E. Garrido et al., EPJA47, 102(2011)
NACRE: NACRE compilation, C. Angulo et al., NPA656,3(1999), Resonance Shift Method

More recent works exist by the groups of S. Ishikawa, K. Yabana, and ...

Conclusion must be drawn in the field of nuclear physics.

Experimental data is quite important.

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