Fusion reactions in dense matter: effects of plasma screening

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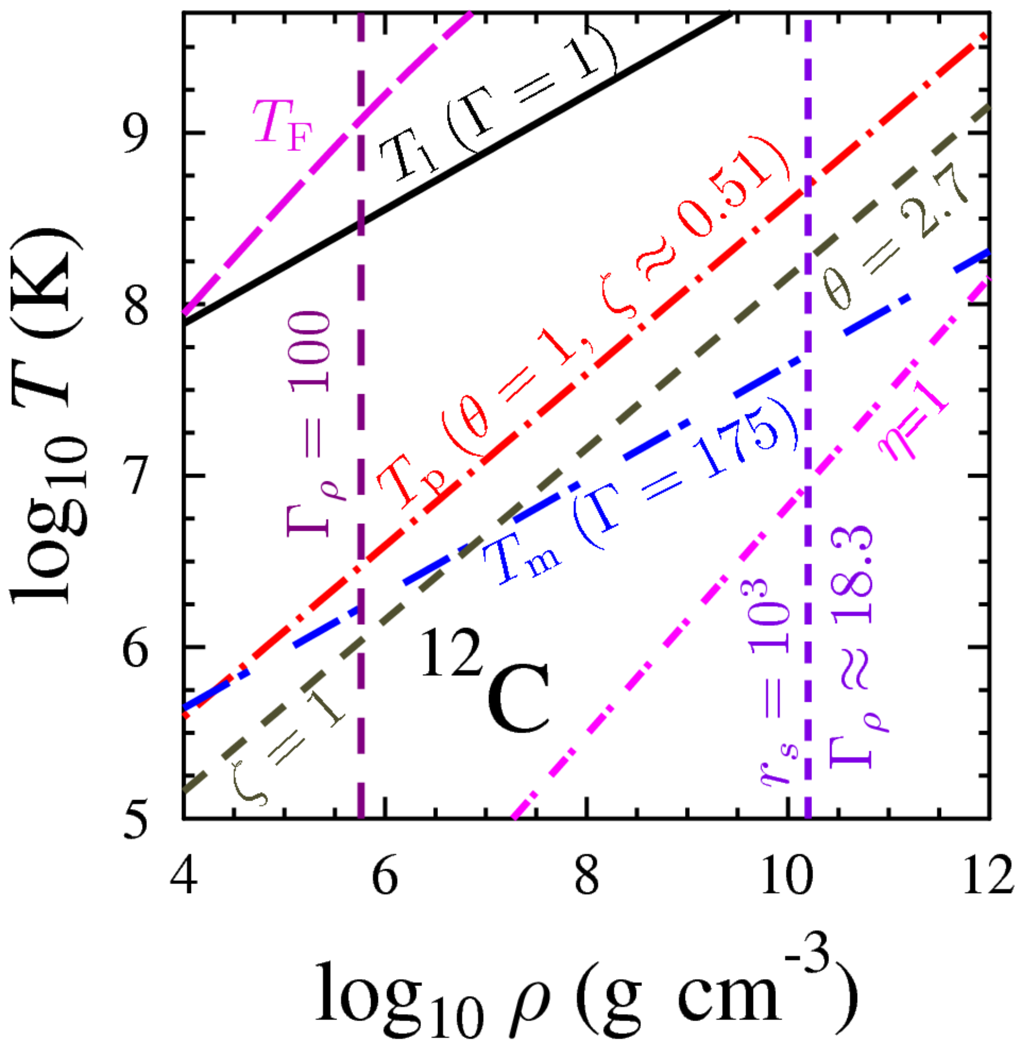
Talk Map

1. Parameters of matter
2. One component plasma
3. Binary mixtures
4. Conclusions

Parameters of matter



$$\Gamma = \frac{Z^2 e^2}{a k_\mathrm{B} T} \approx \frac{22.75 Z^2}{T_6} \left(\frac{\rho_6}{A}\right)^{1/3}$$

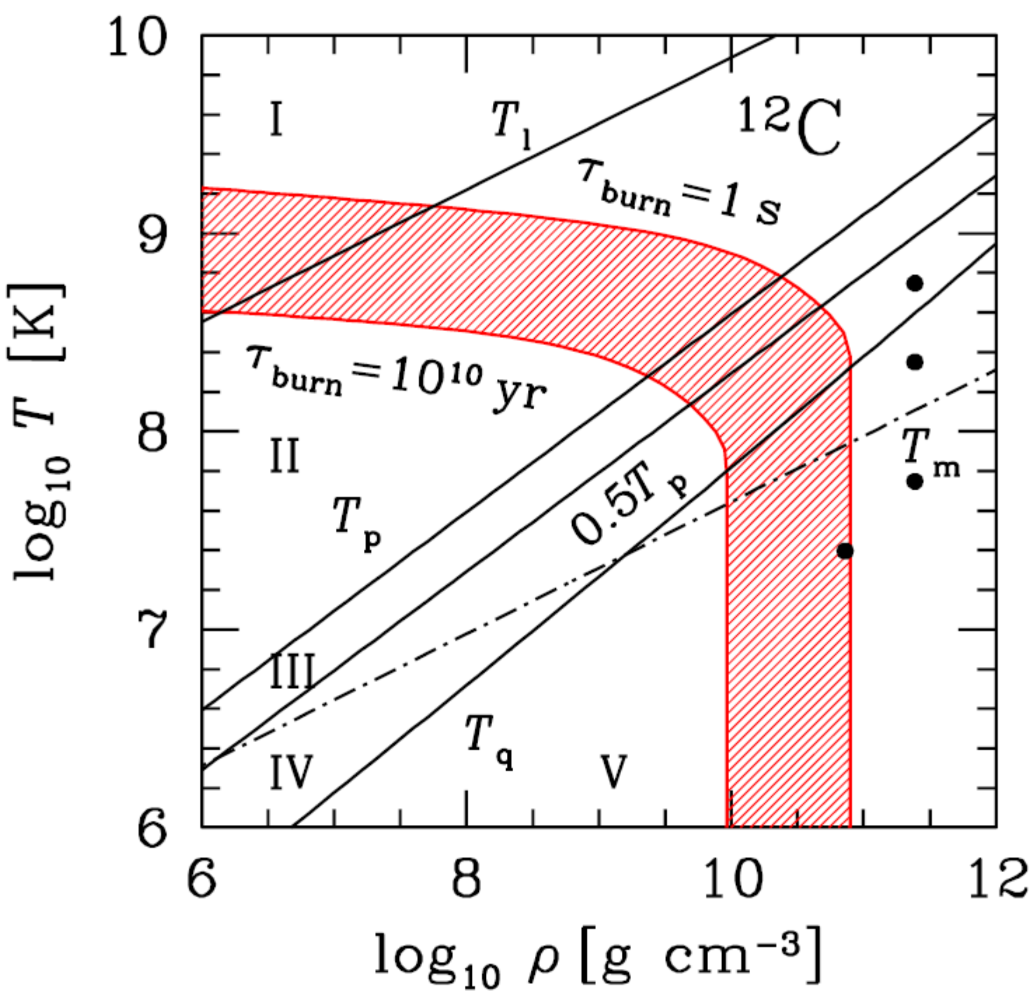
$$a = \left(\frac{3}{4\pi n_\mathrm{i}}\right)^{1/3}$$

$$T_\mathrm{p} = \frac{\hbar \omega_\mathrm{p}}{k_\mathrm{B}} \approx 7.832 \cdot 10^6 \left(\frac{Z}{A}\right) \rho_6^{1/2}\ \mathrm{K}$$

$$\omega_\mathrm{p} = \sqrt{\frac{4\pi Z^2 e^2 n_\mathrm{i}}{m_\mathrm{i}}}$$

$$r_s = \frac{a}{a_\mathrm{B}} \qquad \eta = \frac{\Gamma}{r_s} \qquad a_\mathrm{B} = \frac{\hbar^2}{Z^2 e^2 m_\mathrm{i}}$$

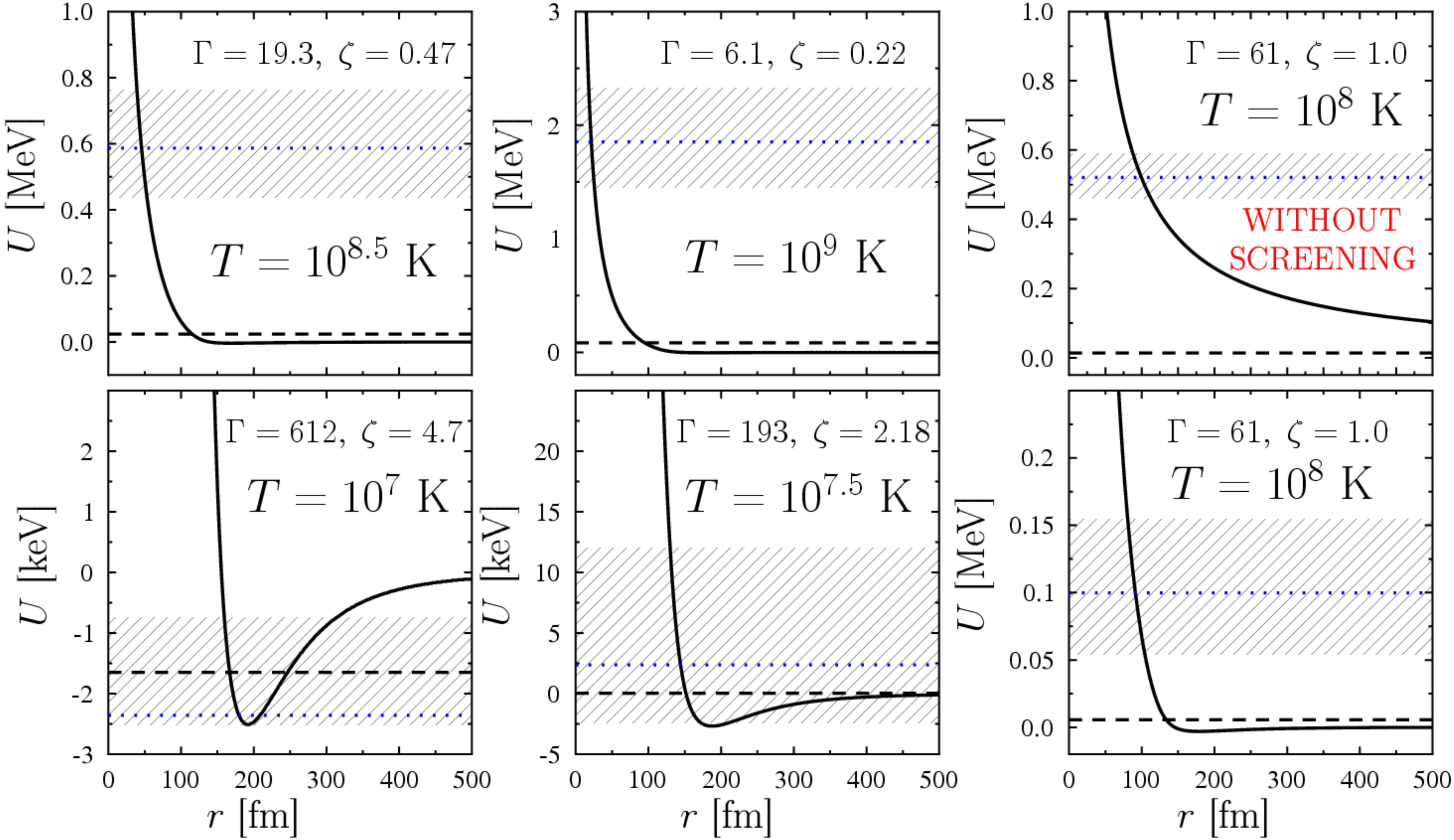
One component plasma: Nuclear burning regimes



№	Regime	Domain
I	Thermonuclear with weak screening	$T \gg T_l$
II	Thermonuclear with strong screening	$T_p \lesssim T \lesssim T_l$
III	Thermo-pycnonuclear	$0.5T_p \lesssim T \lesssim T_p$
IV	Thermally enhanced pycnonuclear	$T_q \lesssim T \lesssim 0.5T_p$
V	Zero temperature pycnonuclear	$T \lesssim T_q$

«Gamow peak» ions

$$C^{12}, \quad \rho = 5 \times 10^9 \text{ g cm}^{-3}$$



Mean field model

Mean field potential $H(r) = \frac{Z^2e^2}{r} - U(r)$: $g_{\rm class} = \exp\left\{-\frac{1}{T}\left[\frac{Z^2e^2}{r} - H(r)\right]\right\}$

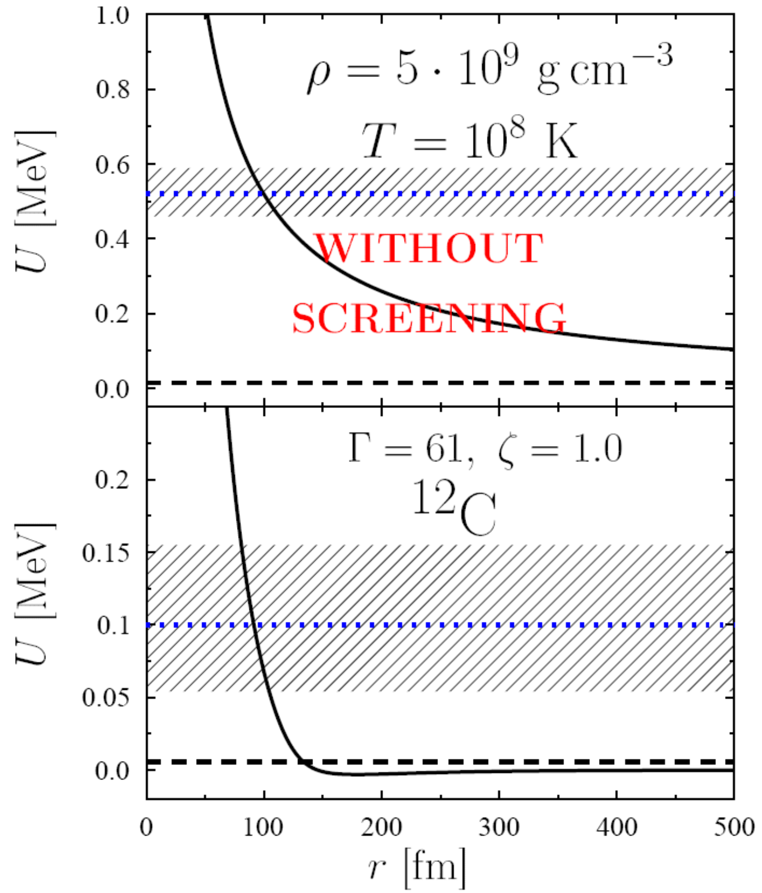
Classical Monte Carlo calculation $\Longrightarrow$ We determine

Mean field approximation:

$$F = I\{H\}/I\{0\}$$

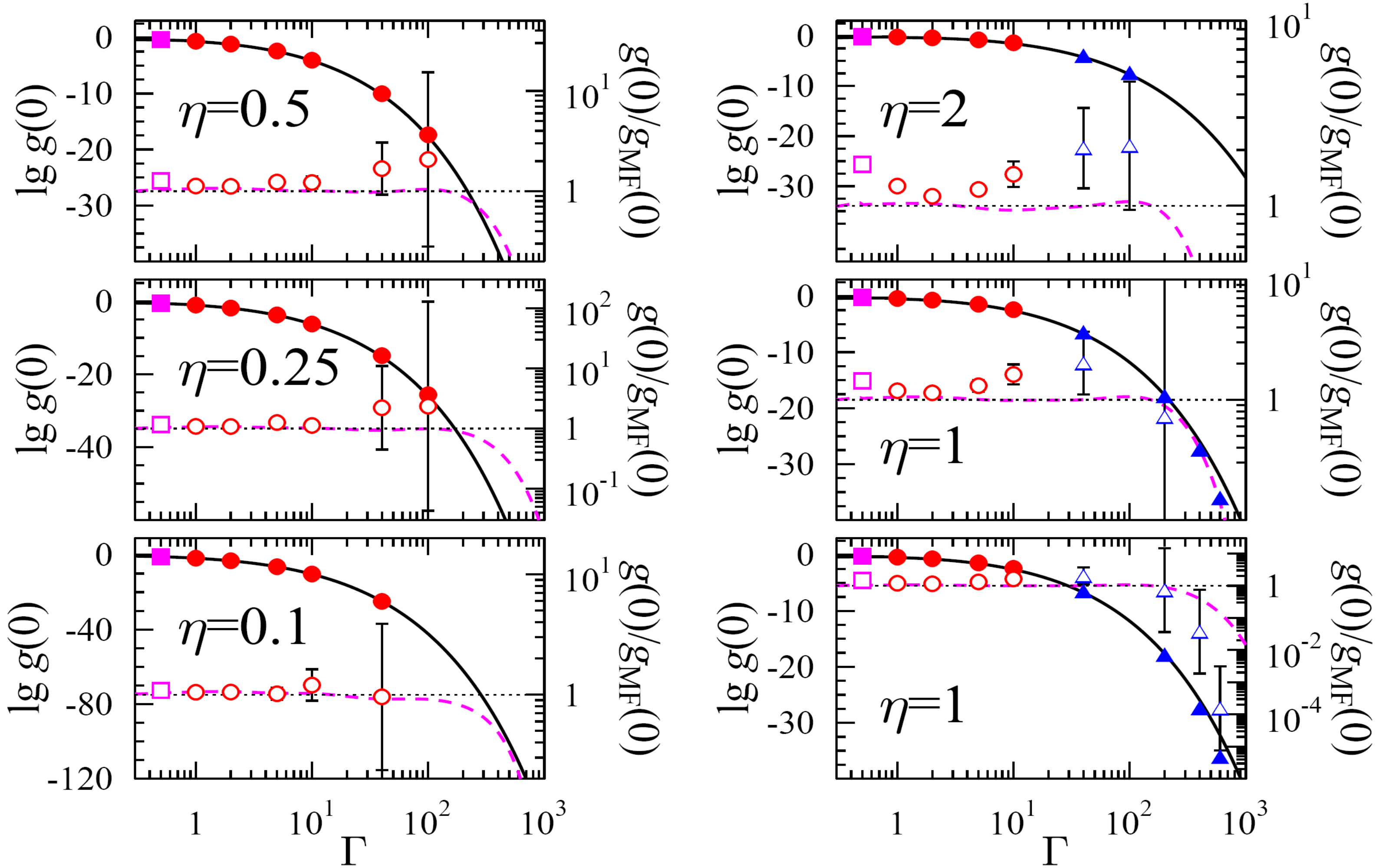
$$I\{H\} = \int_{E_{\rm min}}^{\infty} {\rm d}E \, \exp\left(-\frac{E}{k_BT} - P(E)\right)$$

$$P(E) = \frac{2\sqrt{m}}{\hbar}\int_{r_n}^{r_t} {\rm d}r \sqrt{\frac{Z^2e^2}{r} - H(r) - E}$$



Comparison with Path Integral Monte Carlo

B. Militzer, E. L. Pollock, Phys. Rev. B 71(2005), 134303



$$R = \frac{n_{\rm i}^2}{\pi} \frac{a_{\rm B}}{\hbar} S(E_{\rm pk})\, g(0)$$

Binary mixtures

129 Monte Carlo calculations (Z_1, Z_2, N_1, N_2, Γ_e)

$$\frac{1}{3} \lesssim \Gamma_e \lesssim 200$$

$$1 \leq Z_2/Z_1 \leq 8$$

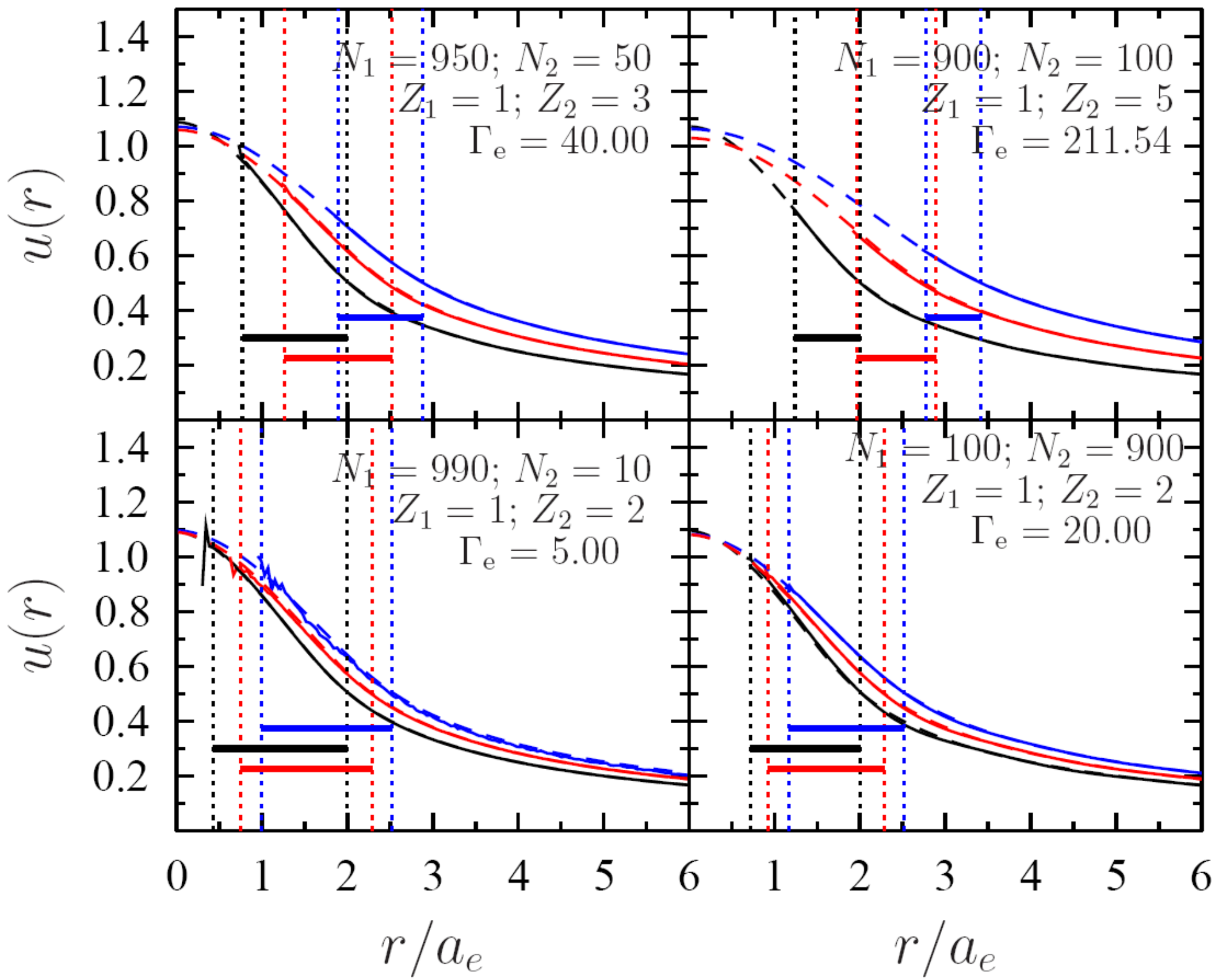
$$0.01 \lesssim \frac{N_1}{N_2} \lesssim 1$$

$$u_{11} = u(\Gamma_1, r/a_1)$$

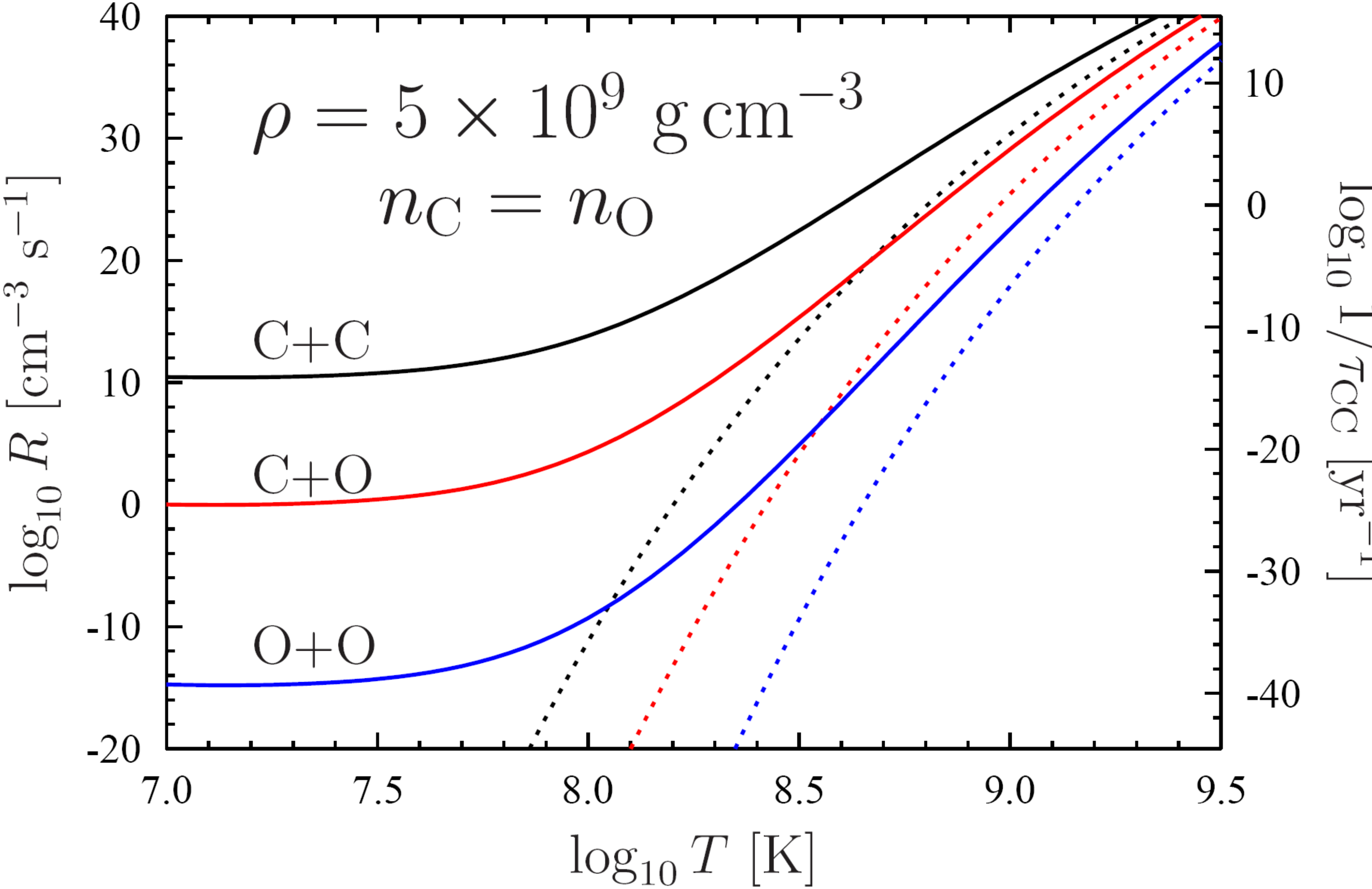
$$u_{22} = u(\Gamma_2, r/a_2)$$

$$a_1 = Z_1^{1/3} a_e$$

$$a_2 = Z_2^{1/3} a_e$$



Reaction rates



Results and Conclusions

- The reasults of Path Integral Monte Carlo are in good agreement with Mean Field calculations in a wide parameter range.
- Many Mean Field potentials in binary mixtures are analyzed and approximated by analytic expressions.
- The plasma screening enhancement factors in nuclear reactions in one and two component ion plasmas are calculated and approximated by analytic expressions.

OCP: A.I.C., H.E. DeWitt, D.G. Yakovlev, Phys. Rev. D **76** (2007),025028

BIM: A.I.C., H.E. DeWitt, D.G. Yakovlev, in preparation