Reactivity Computation in Non-Maxwellian Plasmas: Concepts and Proposals

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Formulas for Reactivity Computation

Reactivity is a crucial quantity for thermonuclear fusion reaction rate computation and is defined as

$$\langle \sigma v \rangle = \int_0^\infty \sigma(v) v f(v)\,\mathrm{d}v. \tag{1}$$

If Maxwellian distribution of particles is supposed, the following expresion could be used:

$$\langle \sigma v \rangle = \frac{4\pi}{(2\pi m_r)^{1/2}} \frac{1}{(k_B T)^{3/2}} \int_0^\infty \sigma(\varepsilon)\varepsilon \exp\left(-\frac{\varepsilon}{k_B T}\right) \mathrm{d}\varepsilon. \tag{2}$$

Moreover, there are many different parametrizations of Maxwellian reactivity in dependence on the plasma's temperature. There is introduced the Bosch&Hale parametrization:

$$\langle \sigma v \rangle = C_1 \theta \sqrt{\frac{\xi}{m_r c^2 T^3}} \exp(-3\xi), \tag{3}$$

$$\theta = T / \left(1 - \frac{T(C_2 + T(C_4 + TC_6))}{1 + T(C_3 + T(C_5 + TC_7))}\right), \tag{4}$$

$$\xi = \sqrt[3]{\frac{\varepsilon G}{4\theta}}. \tag{5}$$

This project investigates thermonuclear fusion reaction rate in dependence on temperature for reactions D(d,n)^{3}He, D(d,p)T, T(d,n)α, ^{3}He(d,p)α, ^{11}B(p,α)2α and ^{14}N(p,γ)^{15}O. Possible modifications of nuclear processes so as to increase the reaction rate are discused for reactions D(d,n)^{3}He and carbon burning.

Set of non-Maxwellian Distributions

Maxwell distribution

$g(v;T) = 4\pi\left(\frac{m}{2\pi k_B T}\right)^{3/2} v^2 \exp\left(-\frac{mv^2}{2k_B T}\right)$

Two-temperature distribution - top right

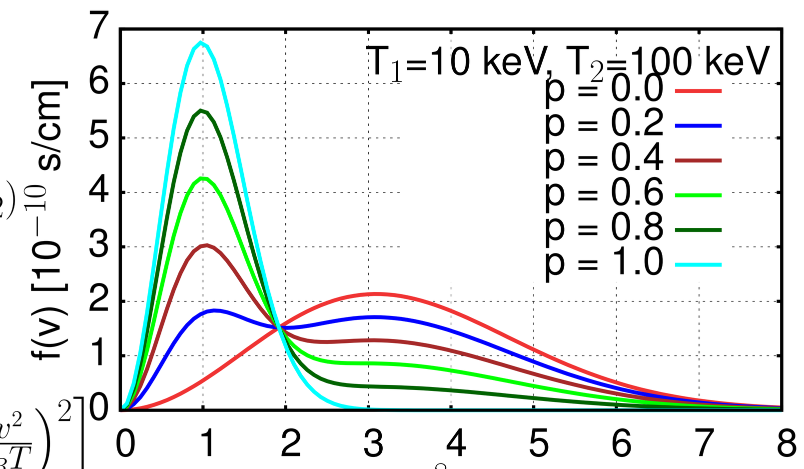
$g_{2T}(v;p,T_1,T_2) = pg(v,T_1) + (1-p)g(v,T_2)$

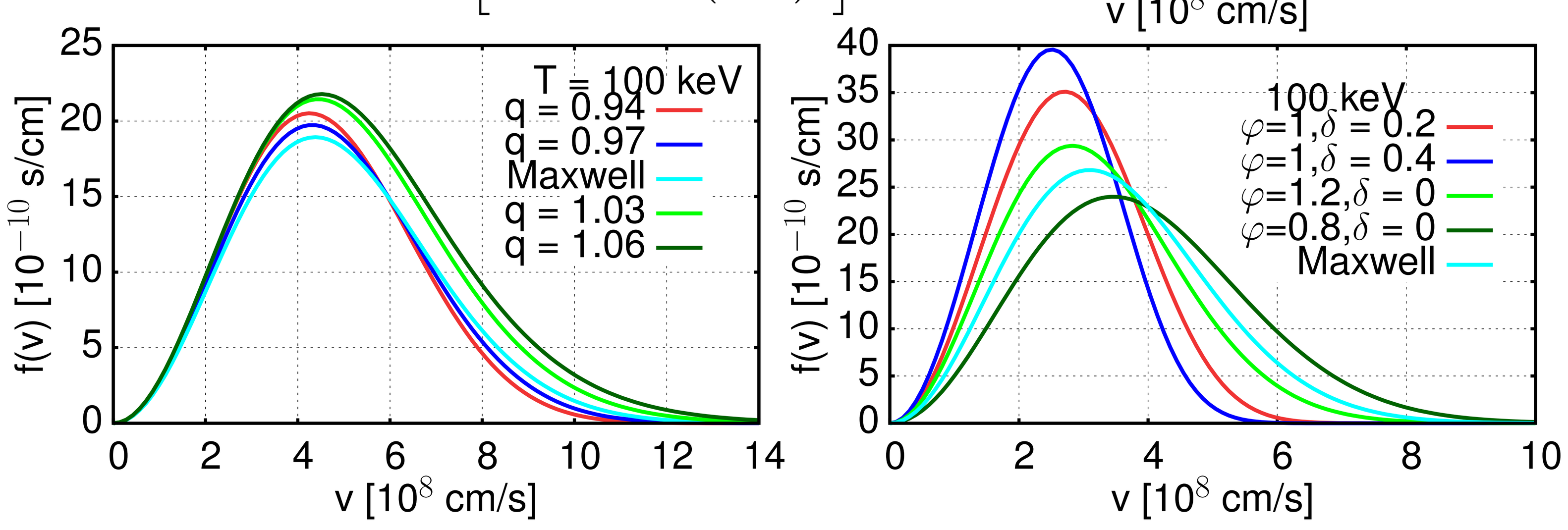
Tsallis's distribution - bottom left

$g_{Ts}(v;T,q) = \frac{1}{A}v^2\left[1+(q-1)\frac{mv^2}{2k_BT}\right]^{\frac{1}{1-q}}$

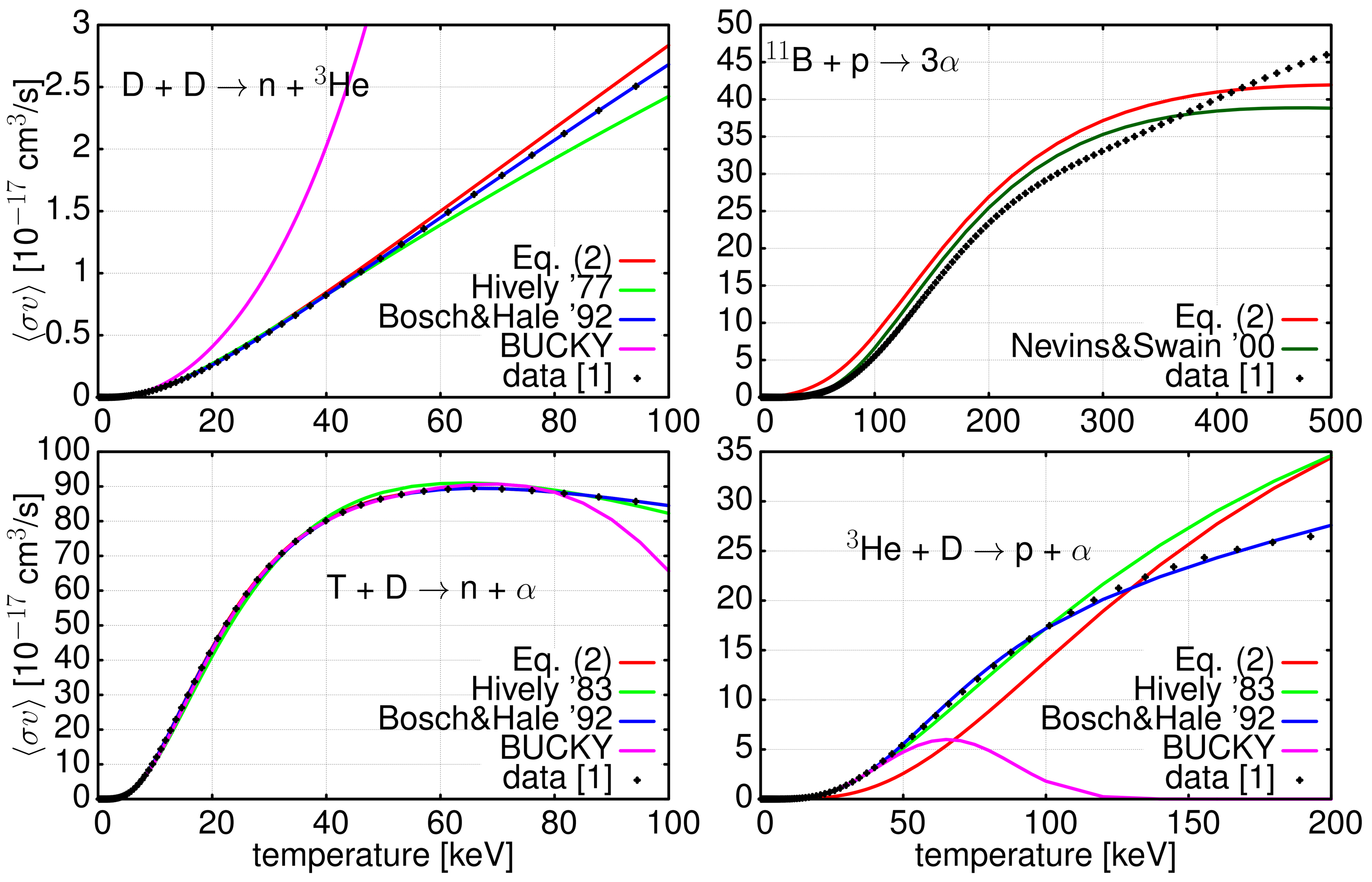
Druyvenstein's distribution - bottom right

$g_{Dr}(v;T,\varphi,\delta) = \frac{1}{B}v^2\exp\left[-\varphi\frac{mv^2}{2k_BT} - \delta\left(\frac{mv^2}{2k_BT}\right)^2\right]$

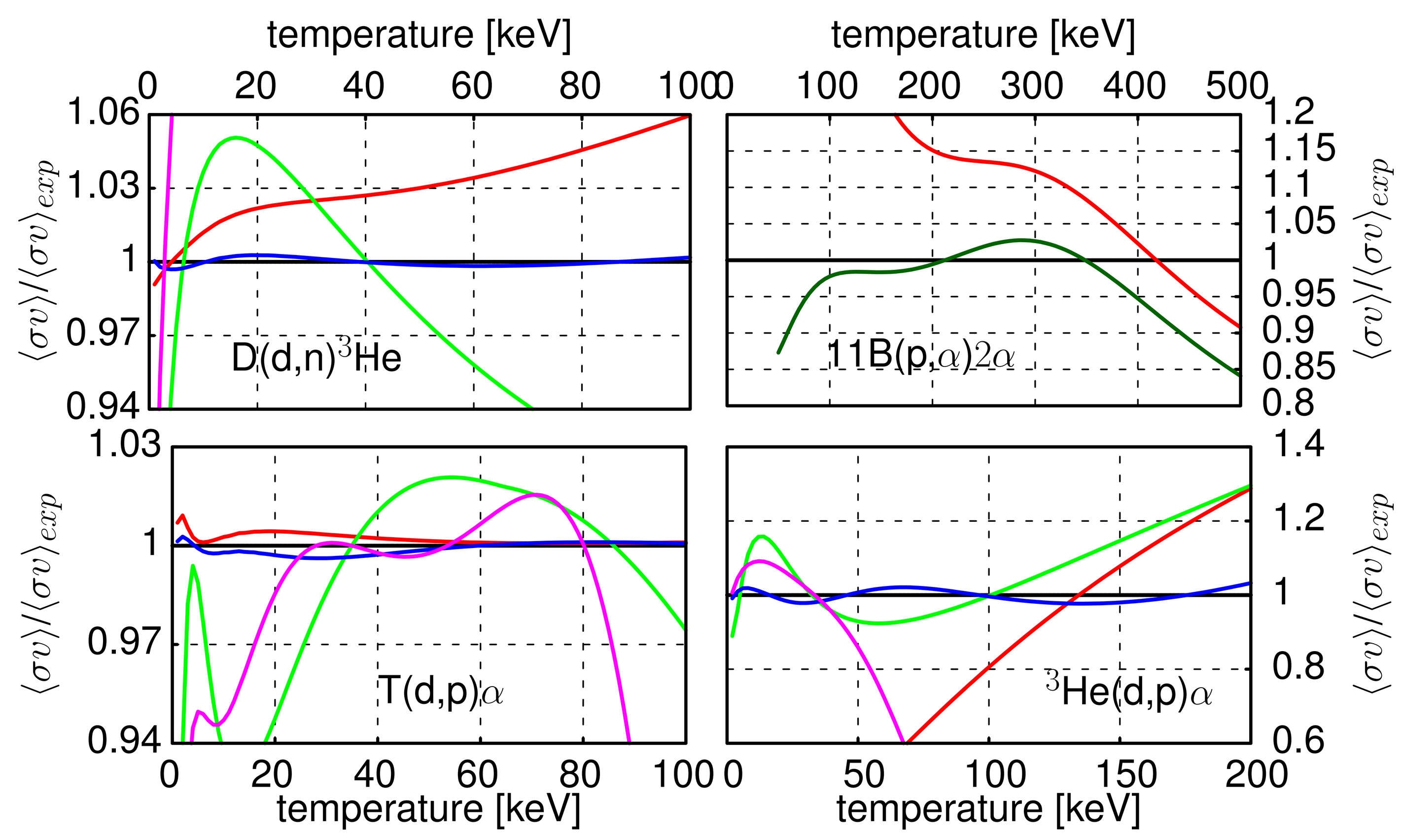




Reactivity Computation in Plasmas with Maxwellian Particles's Velocity Distribution

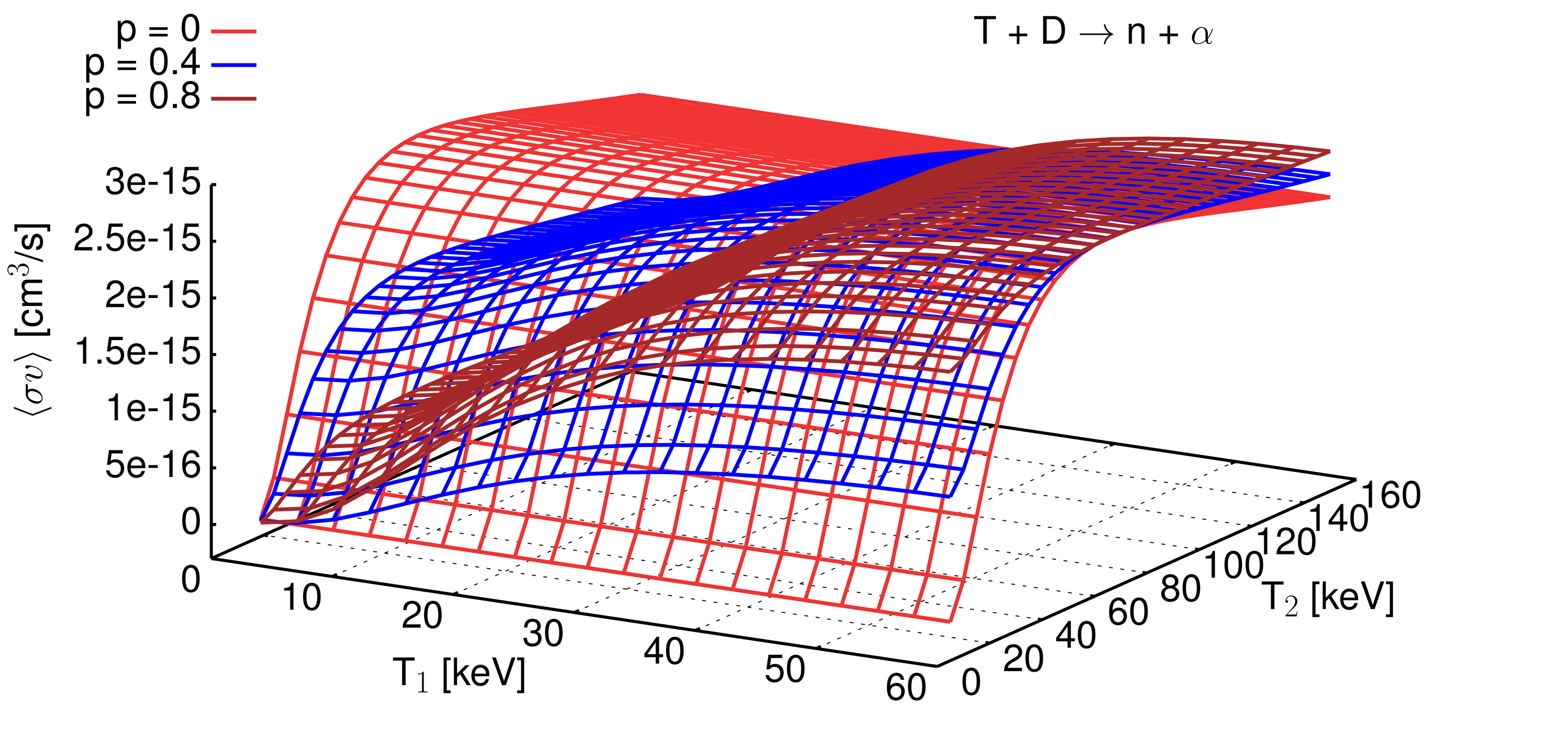


Maxwellian Distribution: Comparison between Formulas and Data Spline



The positions of graphs and colours of lines agree with the figure on the left side. The most precise seems to be to compute reactivity by Bosch&Hale parametrization formula for light nuclei reaction. Nevins&Swain formula satisfies the ^{11}Bp reactivity data sufficiently.

Two-Temperature Distribution



The most effective is to run DT reaction at tempetrature 64 keV.

Tsallis's Distribution

Relevancy

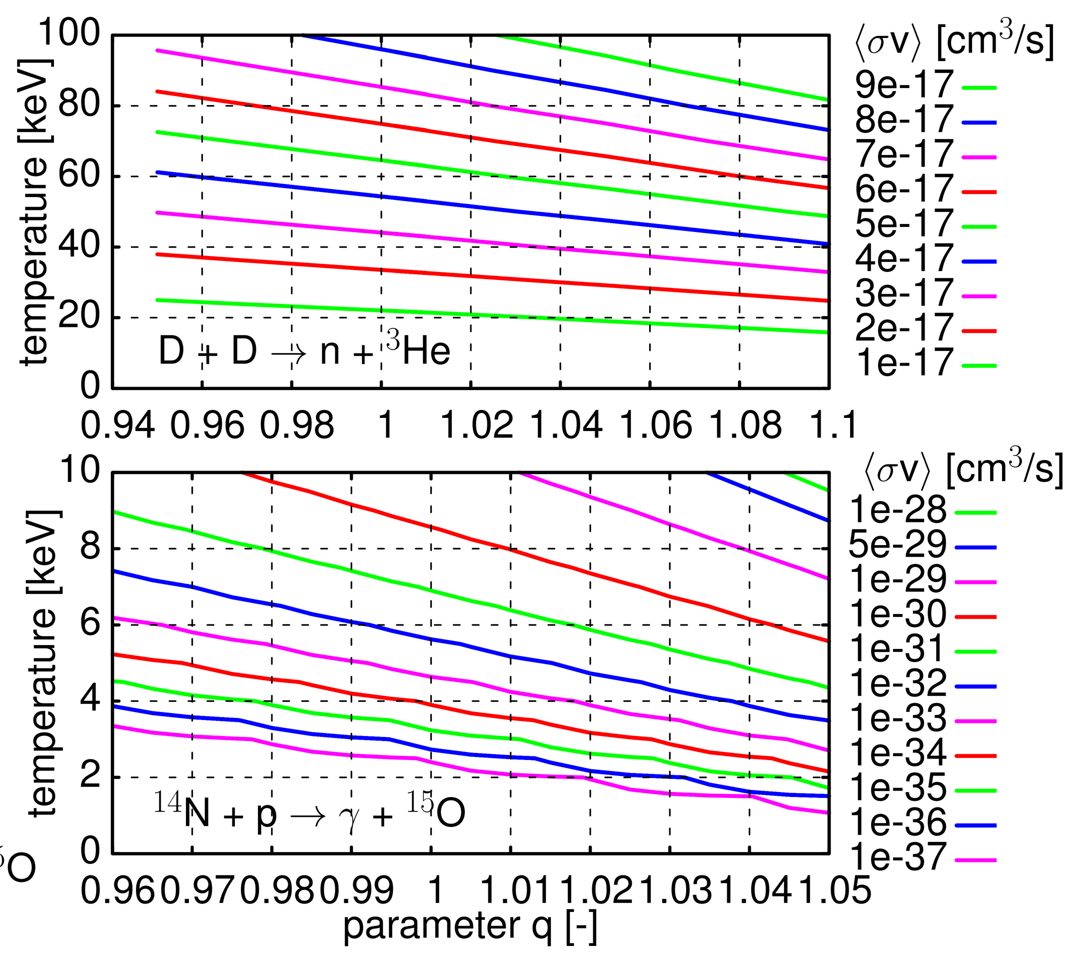
- Fokker-Planck equation solution
- Tsallis's formulation of statistical mechanics
- Maxwellian distribution is a limit case for $q \to 1$

Usage

- Reaction rate computation in the stellar plasmas
- Possible explanation of small discrepancies

Observation

- When $q > 1$, inrease of rate, otherwise decrease
- Observable deviation when $|q-1| > 0.002$
- Huge increase for ^{14}N(p,γ)^{15}O reaction of CNO cycle



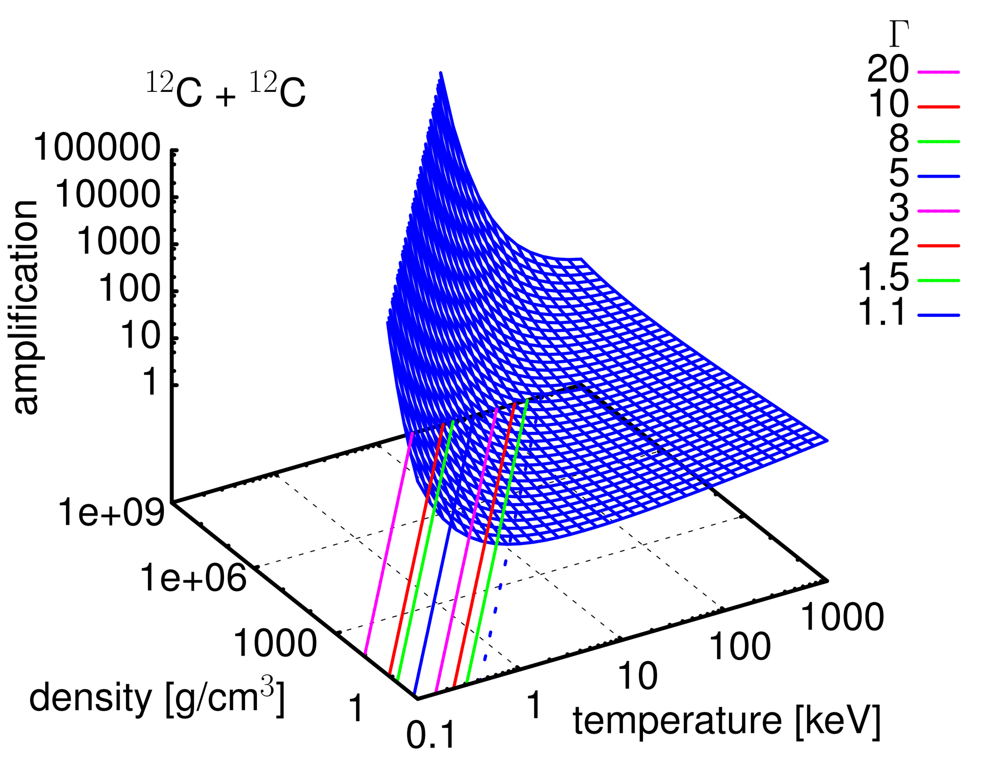
Reacion Rate Amplification in Plasma with Strong Screening

Cold and dense plasma

- ions as strongly coupled classical Coulomb system
- main contribution to rate from ions with $E \approx E_{Gp}$

Carbon burning

- White dwarfs $\rho \approx 10^9$ cm^3/s, $T \approx (10-60)$ keV
- Massive increse of reaction rate in comparison with pure termonuclear regime



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References

[1] Nuclear Astrophysics Data. Los Alamos National Laboratory, June 2011. http://t2.lanl.gov/data/astro/astro.html

[2] Atzeni, S.; ter Vehn, J. M.: *The physics of inertial fusion: beam plasma interaction, hydrodynamics, hot dense matter.* International series of monographs on physics, Oxford University Press, 2004, ISBN 9780198562641.

[3] Belyaev, V.; Vinogradov, V.; Matafonov, A.; aj.: Excitation of promising nuclear fusion reactions in picosecond laser plasmas. *Physics of Atomic Nuclei*, Volume 72, No. 7, 2009: s. 1077–1098, ISSN 1063-7788.

[4] Bosch, H.-S.; Hale, G.: Improved formulas for fusion cross-sections and thermal reactivities. *Nuclear Fusion*, Volume 32, No. 4, 1992: site 611. http://stacks.iop.org/0029-5515/32/i=4/a=I07

[5] Gasques, L.; Afanasjev, A.; Aguilera, E.; aj.: Nuclear fusion in dense matter: Reaction rate and carbon burning. *Physical Review C*, Volume 72, No. 2, 2005: site 025806.

[6] Kaniadakis, G.; Lavagno, M.; Lissia, M.; aj.: Thermal distributions in stellar plasmas, nuclear reactions and solar neutrinos. *Brazilian Journal of Physics*, ISSN 0103-9733.