Practical hands-on session, Karpacz winter school
Daniel Bemmerer: "Nucleosynthesis in the stars and the big bang - the seeds for the r process"

Thermonuclear reaction rate:

- Find and download a copy of the 2018 Physical Review Letters paper by Ferraro and Takács . (There is at least one free of charge version on the internet.)

- Using the equations from the lecture, compute the thermonuclear reaction rate for the resonances at 156, 189, and 256 keV (sum of all of them) and for "bare" colliding nuclei, i.e. without electron screening enhancement. If you have a computer, plot the rate (GNUPLOT or ROOT) for the range T_9 = 0.01-1, and extract the values at 0.1 and 0.2. If you do not have a computer, compute the rate at T_9 = 0.1 and T_9 = 0.2.

- Using figure 4 and the equations from the lecture, estimate the non-resonant thermonuclear reaction rate at T_9 = 0.1. Which approximations do you need to make? Estimate the resultant uncertainty, and quantify the effect this uncertainty has on the total reaction rate.

- There is a reported 0.7 keV uncertainty on the resonance energy of the 156.2 keV resonance. What is the resultant uncertainty on the thermonuclear reaction rate at T_9 = 0.1 and T_9 = 0.2, respectively?

- The Q value of a nuclear reaction is known with 10 keV uncertainty. What is the resultant relative uncertainty of the thermonuclear reaction rate at T_9 = 0.1, 0.3, 1.0? If you have a computer, plot this relative uncertainty as a function of T_9 from 0.01-10.

- Assume that you are interested in an astrophysical scenario at T_9 = 0.5. What is the relevant center of mass energy for an experimental study? What proton or Ne-22 beam energy do you need?
  The total thermonuclear reaction rate is 9.6 $cm^3\ s^{-1}$ at this temperature. We are looking for a resonance that contributes 10% of the total rate and is situated exactly at the relevant energy; what is the strength of this resonance in eV?
  If the non-resonant contribution is another 10% of the total rate and the S-factor does not depend on energy, what is the S-factor in keV barn?

Relevant energy range and literature:

- Select one of the following reactions and temperature ranges:
  $^{2}H(p,\gamma)^{3}He$ T_9=0.1-0.5 (BBN)
  $^{14}N(p,\gamma)^{15}O$ T_9=0.01-0.1 (Hydrostatic hydrogen burning)
  $^{12}C(\alpha,\gamma)^{16}O$ T_9=0.1-0.35 (Hydrostatic helium burning)

- For the selected reaction and temperature range, compute the relevant center-of-mass energy range.

- Select one of the following evaluations or data bases and find it on the web:
  NACRE (1999, Angulo et al.)
  NACRE-II (2013, Xu et al.)
  EXFOR (IAEA)

- For the selected reaction, energy range, and data base, write down the experimental works addressing this case.

- (Bonus:) Plot the relevant experimental data. (Hint: EXFOR quick-plot functionality.)