Impact of stellar triple alpha reaction enhancement on the r-process

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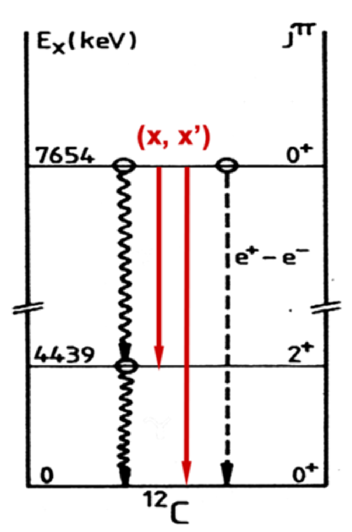
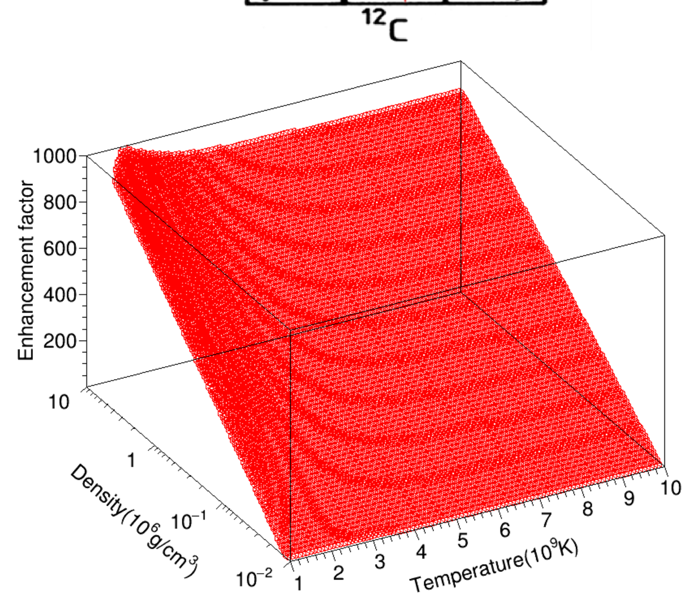
Motivation

The rapid neutron capture process is responsible for the synthesis of approximately half the nuclides heavier than iron[1]. As temperatures and densities decrease and nuclear statistical equilibrium break down the r-process begins with the build up of ^{12}C and heavier seed nuclei from neutrons and alpha-particles. It was recently pointed out that one of the pathways to produce ^{12}C r-process seeds, the triple alpha reaction, may be significantly enhanced at extreme stellar conditions compared to standard predictions[2].

Rate enhancement

- triple alpha reaction rate is proportional to the Hoyle state width
- neutron proton and α inelastic scattering induced de-excitation of the Hoyle state result in the enhancement
- in stellar condition such as neutrino driven wind with high neutron density and temperature the rate can enhanced up to 10^3
- lower the neutron to seed ratio and the robust of r-process





Sensitivity study

- gauge the response of varying nuclear astrophysical parameter to figure out which one play more important role
- Methodology:

❖ use SkyNet: a nucleosynthesis network calculation[3] include:7841 nuclides 95465 reactions

❖ use temperature and density parametrization three trajectories:

(1) $\rho=\begin{cases}\rho_0 e^{-t/\tau}, & x<3\tau\\ \rho_0\left(\frac{3*\tau}{e*t}\right)^3, & x\geq 3\tau\end{cases}$

(2) neutrino driven wind from young hot neutron stars[4]

(3) neutrino driven wind based on hydrodynamic simulations[5]

❖ use range of parameters spanning typical conditions in neutrino driven winds and neutron star mergers:

entropy (S) ~T^3/ρ

expansion time(tau): time of density fall to 1/e of peak

Ye: the electron to neutron ratio, 0.45

❖ compare abundances of enhanced with no enhanced 3 α rate

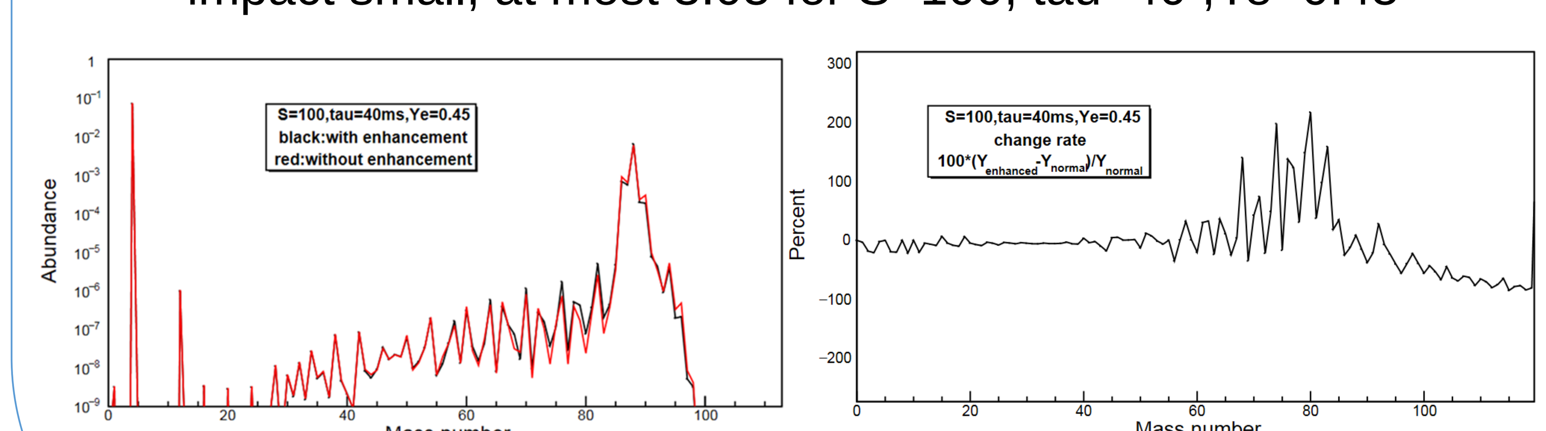
Result

p	tau=20	tau=7.1	tau=3.5	tau=1.8	tau=0.9	tau=0.5	tau=0.2
S=200	0.55	0.35	0.43	0.38	0.17	0.09	0.03
S=150	0.86	0.55	0.44	0.56	0.43	0.24	0.08
S=100	1.54	0.83	0.52	0.33	0.20	0.11	0.04
S=50	0.85	0.45	0.24	0.13	0.06	0.03	0.01

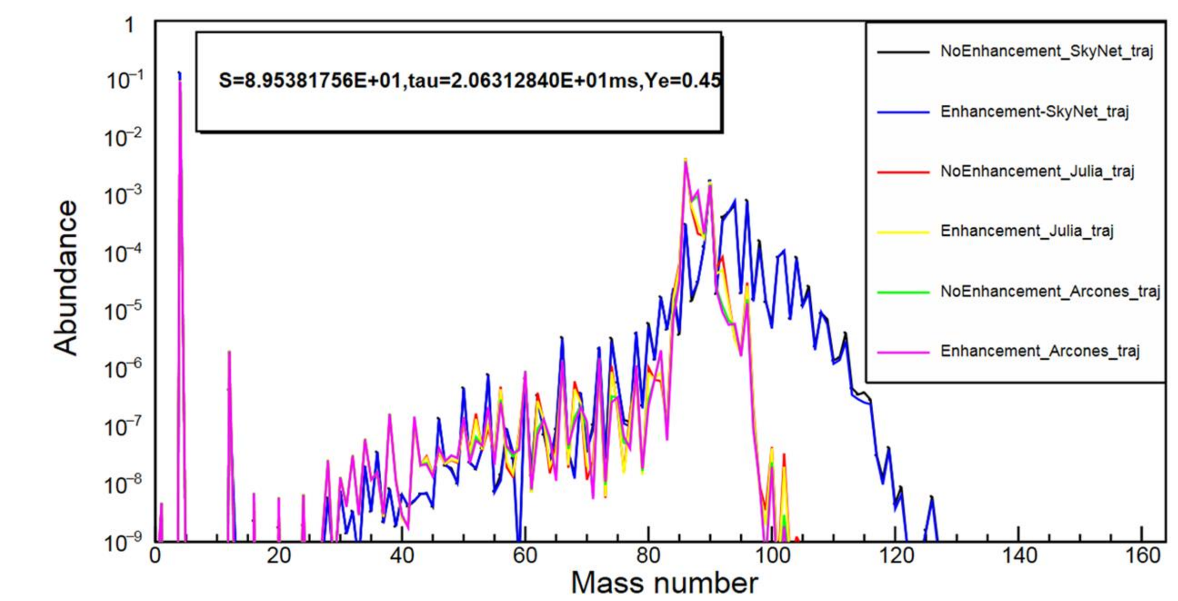
- p: accumulated rate of change to reflect the impact

$$p=\sum_k \left(\frac{Y_{enhanced}-Y_{normal}}{Y_{normal}}\times 100\right)^k * \frac{Y_{normal}^{\,k}}{\sum_i Y_{normal}^{\,i}}$$

- 28 parametric combinations by using trajectory (1)
- impact small, at most 3.05 for S=100, tau=40 ,Ye=0.45



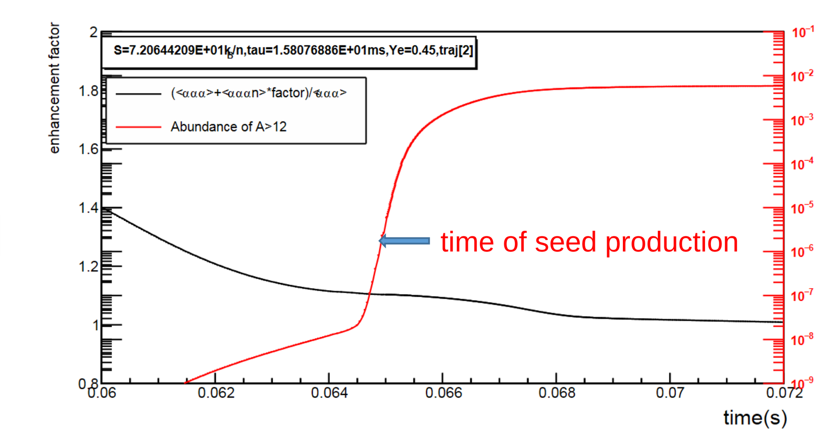
The abundance and the rate of change at most impact point

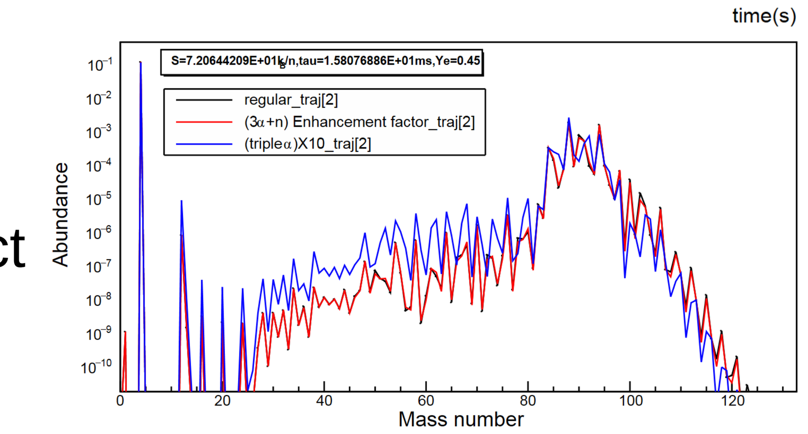


- the trajectory has a more significant impact on the abundances than the rate enhancement

Discussion

- predicted enhancement is small at time of seed production
- a factor of 10 larger enhancement of 3α has a apparent impact to abundance





Conclusion

- with current prediction and the specific scenarios investigated the effect is small
- a factor of 10 larger enhancement would have a strong effect
- need better prediction of enhancement

We acknowledge J. Bliss for providing trajectories of NWD model [4].

Reference

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