Light clusters in hot nuclear matter: calibrating the interaction with heavy-ion collisions

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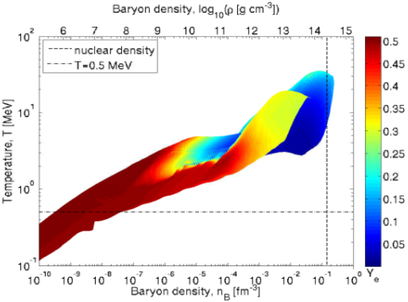
Motivation

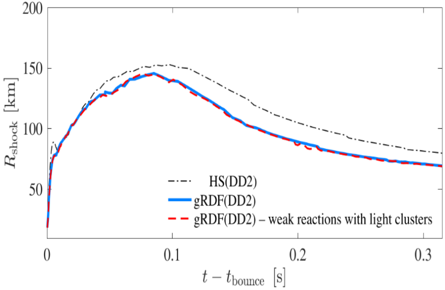
- Light nuclei might be present in both Core-Collapse Supernova and Binary Neutron Star Mergers

- Their presence influences the dynamics of these astrophysical events

- Accounting for in-medium modifications to the light clusters is essential to determine their correct abundances



[Fischer et al. (2014)]



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Relativistic Nuclear Field Theory

• In Relativistic Mean-Field Theory, the interactions are mediated via the exchange of virtual mesons:

$$\sigma, \omega, \rho \tag{1}$$

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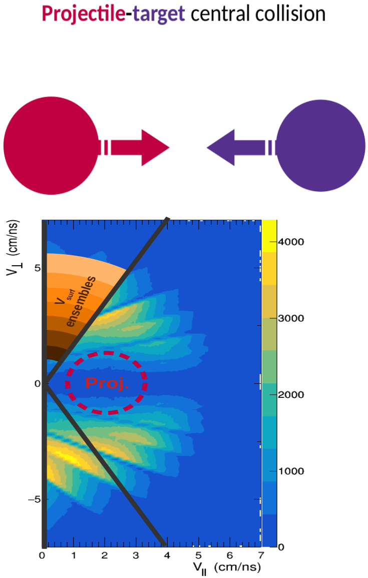
• $x_s(\rho, T)$ is a way of accounting for in-medium modification of the clusters self-energies

INDRA Heavy-Ion Collisions

$^{136,124}Xe + ^{124,112}Sn$ (32MeV/nucleon)

- v_{surf} is the velocity of the emerging particle at the nuclear surface, prior to Coulomb acceleration



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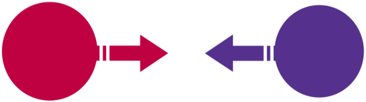
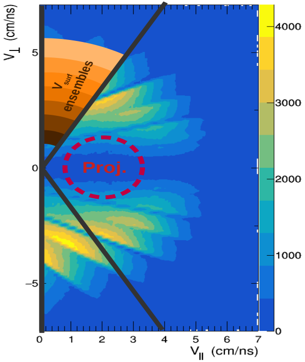
Projectile-target central collision





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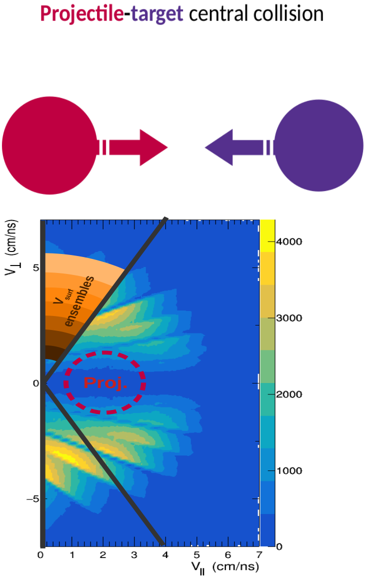
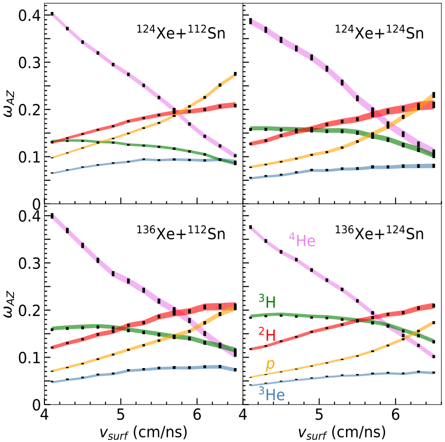


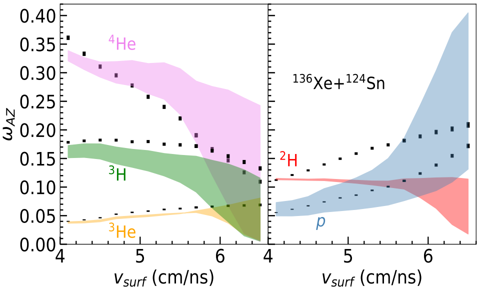
- v_{surf} is the velocity of the emerging particle at the nuclear surface, prior to Coulomb acceleration
- Associate a statistical ensemble to each v_{surf} with corresponding particle mass fractions (nucleons and light clusters)
- Perform a Bayesian inference of ρ, T, x_s using experimentally measured mass fractions

Mass Fractions

Present Study



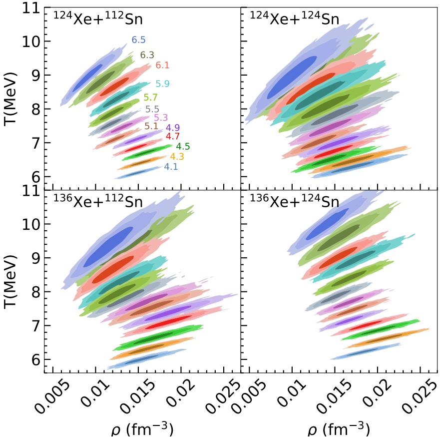
Modified Ideal Gas

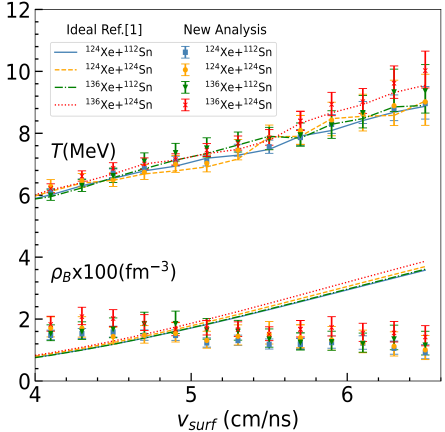


[Pais et al. (2020)]

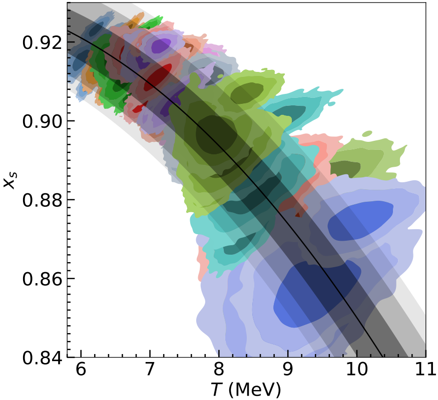
Calibrated Temperatures and Densities

- Temperature evolution similar to the ideal gas estimation
- Results compatible with a single density ~0.015 fm^{-3}: chemical freeze-out density at the surface of the emitting source (?)





Calibrated $x_s(T)$

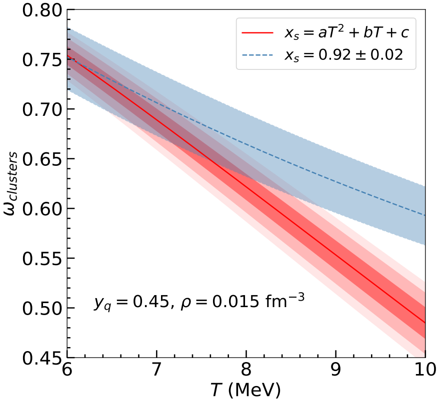


- x_s is temperature dependent
- Interaction weakens with T
- $x_s(T)$ compatible for all four entrance channels
- Limited ρ range cannot provide information on possible x_s dependence on ρ

Parameter	Unit	Median	1σ	2σ
a	MeV^{-2}	-0.00203	± 0.00003	± 0.00006
b	MeV^{-1}	0.01477	± 0.00047	± 0.00093
c		0.90560	± 0.0018	± 0.00355

Table: Parameter estimates a, b, c with 1, 2σ uncertainties for the quadratic fit $x_s = aT^2 + bT + c$

Consequences of $x_s(T)$ for light cluster abundances



- Above $T \sim 8$ MeV abundances are systematically lower than the predictions of modified ideal gas
- Smaller x_s corresponds to weaker cluster-σ coupling, resulting in less bound clusters and, consequently, smaller abundances

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- In this work, a Bayesian inference was performed with a RMF model using mass fractions to determine temperature, density and cluster couplings

- T shows same increasing behaviour as before but the density turned out to be constant: chemical freeze-out (?)

- x_s shows a dependence on T, weakening the clusters binding and abundances