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Limitations of Helium as a Surrogate for Deuterium in LPI Studies

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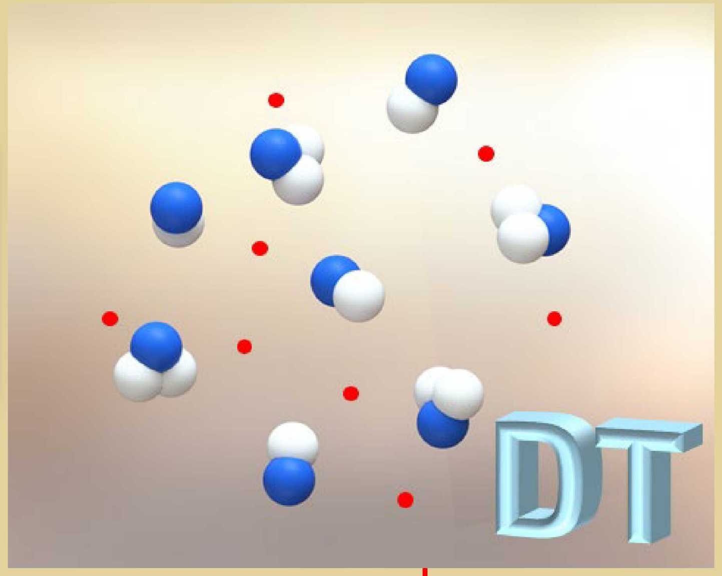
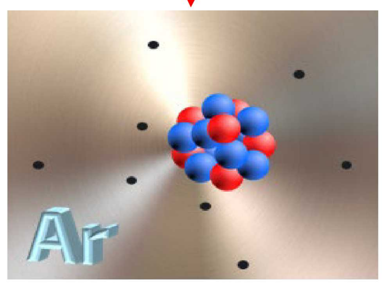
Why don't we all use DT for fusion and laser-plasma instability (LPI) studies?

Assumption:
Need to match electron density for DT scenario

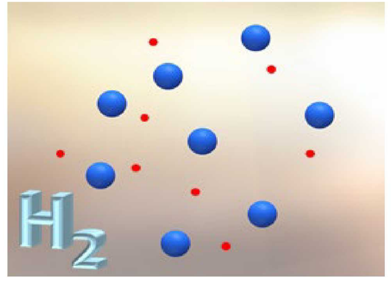


flammable,
high pressure,
radioactive

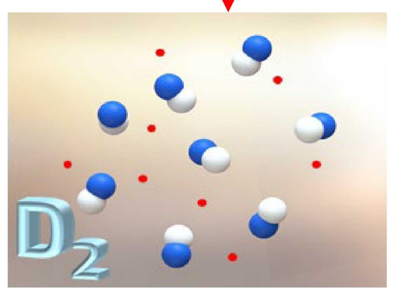
non-flammable, low pressure, stable, diagnosable



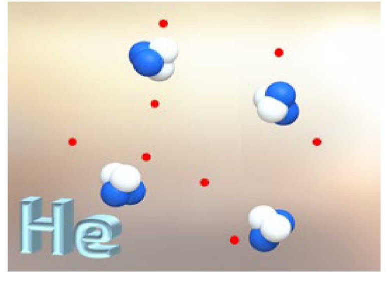
stable



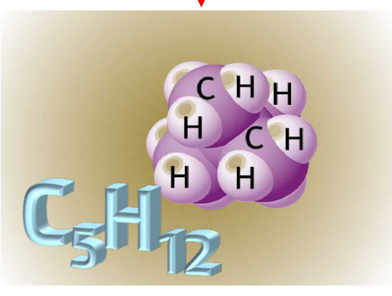
stable



non-flammable, stable



stable, low pressure



Element	Benefit	Ion species	Molecular mass	Mean ionic mass	Mean nucl. charge
Argon	Diagnosable, non-fl., dense	Unique	40 u	40 u	18 (bad!)
Hydrogen	Cosmic abundance	Unique	2 u	1 u	1
DT	Ideal fusion fuel	2-component	5 u	2.5 u	1
Deuterium	Non-radioactive fusion fuel	Unique	4 u	2 u	1
Helium	Non-flammable, rel. low Z	Unique	4 u	4 u	2
Neopentane	High density, rel. low Z	2-component	72 u	4.24 u	2.47

Radiation losses: $\frac{dE}{dt} \propto Z_i^2$

Ion Diversity:

- Potential isotope separation can effect LPI in general.
- Multiple co-existing ion-acoustic wave modes can effect stimulated Brillouin scattering.

Initial conditions:

Thickness and deformation of the laser-gas barrier are determined by the initial pressure, which depends on the molecular mass.

Dominant effects:

- Density of barrier plasma
- Spatial distribution of plasma interfaces
- Laser absorption losses in barrier

Thermal rarefaction:

Plasmas can expand at significantly different rates based on ion weight. Example: highly collisional plasma of ~ 1 kev temperature.

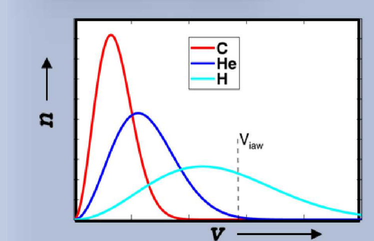
V_{carbon} = 90 µm/ns
V_{helium} = 150 µm/ns
$V_{deuterium}$ = 220 µm/ns
$V_{hydrogen}$ = 310 µm/ns

(carbon, hydrogen: Neopentane!)

Strong effects if plasma is not confined or if it is filamented. Isotope separation?

Landau damping:

Strong for ions near the phase velocity of an ion-acoustic wave.



SBS ⇅ m_i

Stimulated Brillouin Scatter:

(Weakly) dependent on the ion charge state.

Sensitive to charge over mass, particularly with partial ionization!

$$\gamma_0 \propto \sqrt{\frac{m_e n_e Z_i}{m_i}}$$

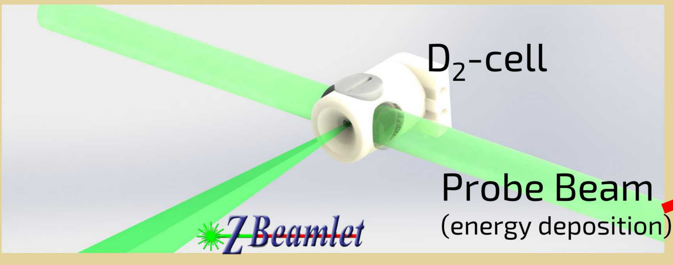
SBS ⇅ Z_i

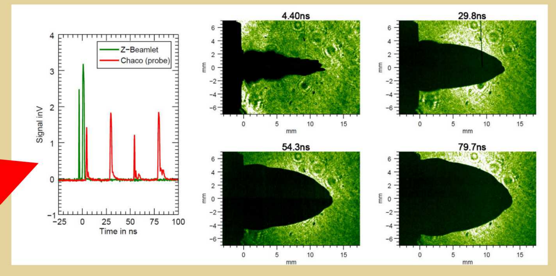
The bremstrahlung-absorption coefficient:

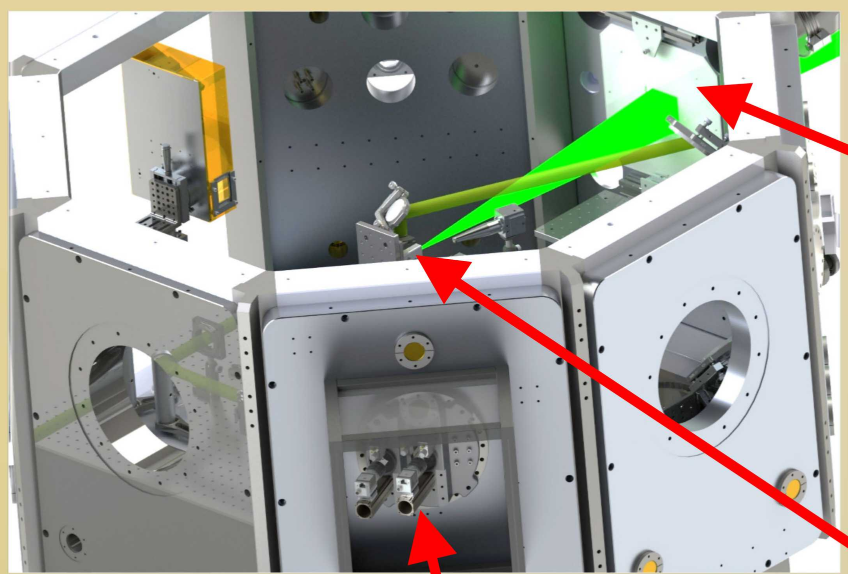
$$K \propto \frac{n_e^2 Z_i}{\sqrt{1 - ne/n_c}}$$

- proportional to the charge state
- compensated with initial gas/electron density (?)

Example: Pre-Heat studies for magnetized Liner Inertial Fusion with the Z-Beamlet laser at Sandia





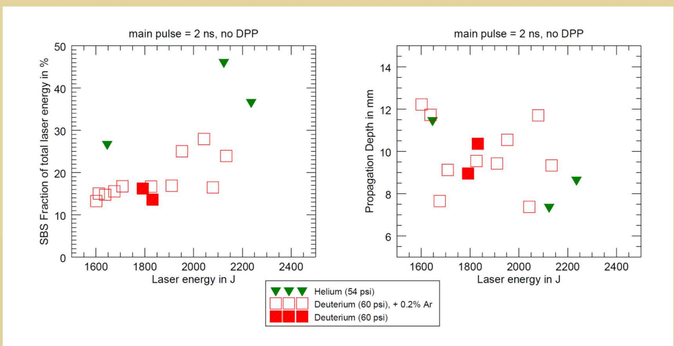


Backscatter screen

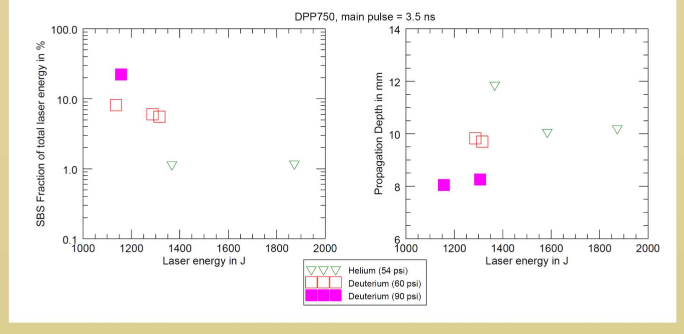
Target (D_2-cell)

SBS and SRS cameras, SBS diode,
SRS diode > 610 nm, SRS diode > 715 nm

SBS Generation and laser propagation depth with and without Distributed Phase Plate (DPP, 750 µm diameter) for focus conditioning.

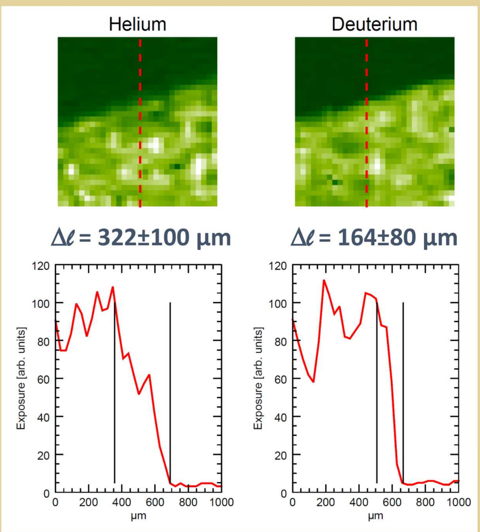


No DPP: High LPI-case with decreased SBS for deuterium, likely due to Landa damping. Absorption/ length matched by pressure variation..



750µm DPP: Low LPI-case with decreased SBS for helium most likely due to lower pressure.

Blast wave edge is sharper for D_2, possibly because of different ionic mean free paths.



Summary:
Even the seemingly very similar gases He and D_2 vary appreciatively, and the differences depend on the LPI regime the laser encounters!

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