Plasma Characterization for Raman Amplification

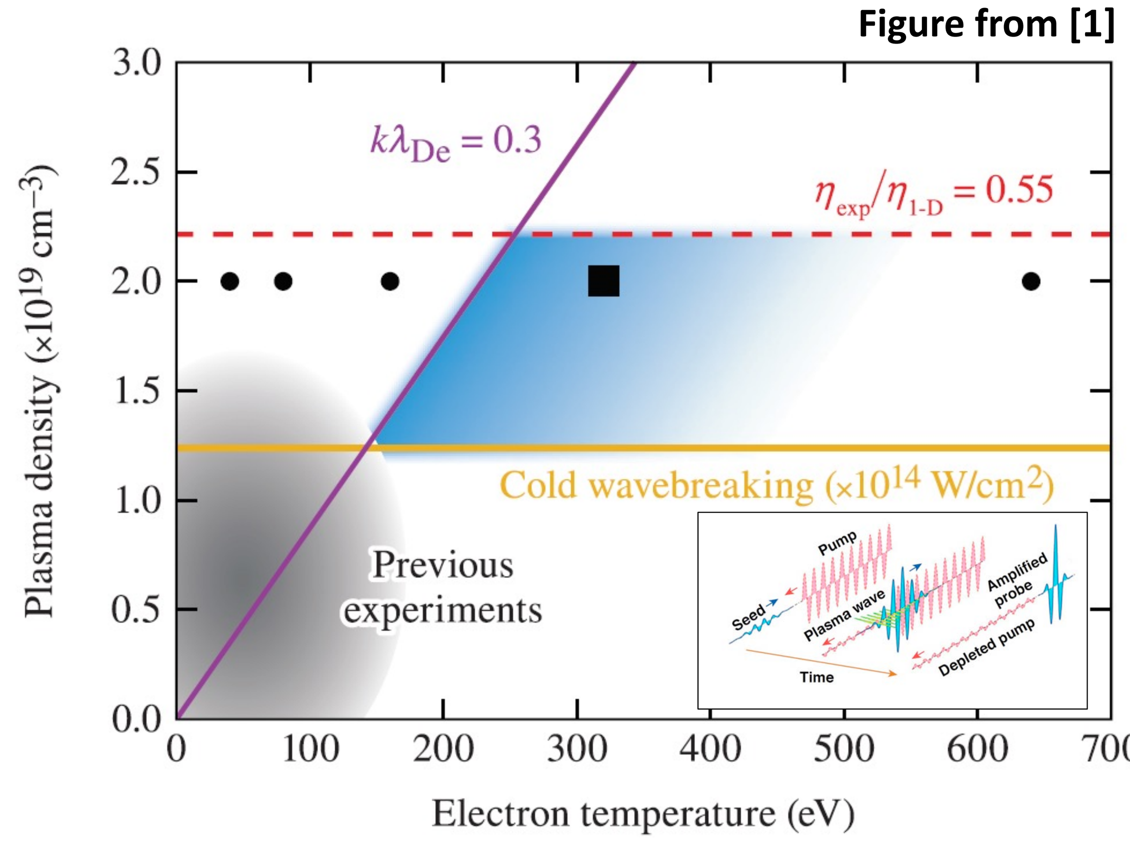
K. R. MCMILLEN, M. V. AMBAT, Z. BARFIELD, J. J. PIGEON, D. HABERBERGER, D. H. FROULA, and J. L. SHAW

University of Rochester, Laboratory for Laser Energetics

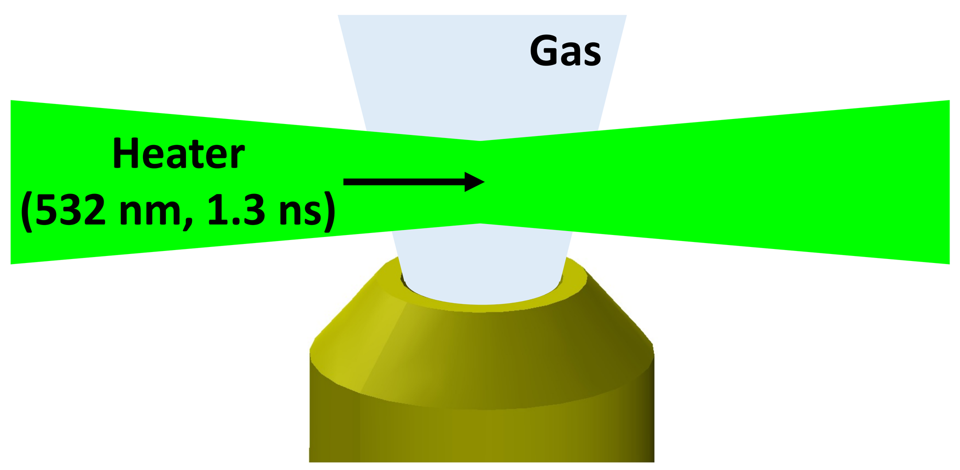
Raman Amplification

Simulations of our Raman amplification platform suggest plasma temperatures above 100 eV can mitigate ionization induced refraction (IIR), filamentation, and spontaneous Raman scattering from thermal noise, all of which lead to early or incomplete pump depletion. Moreover, plasma densities near 1×10^{19} cm^{-3} limit wave breaking while maximizing the transfer efficiency of energy to the seed [1]. This precise parameter space thereby demands the use of a separate heater beam for plasma creation. By adjusting the delay of the heater beam before the Raman Interaction, the plasma conditions for Raman amplification experiments can be finely adjusted.

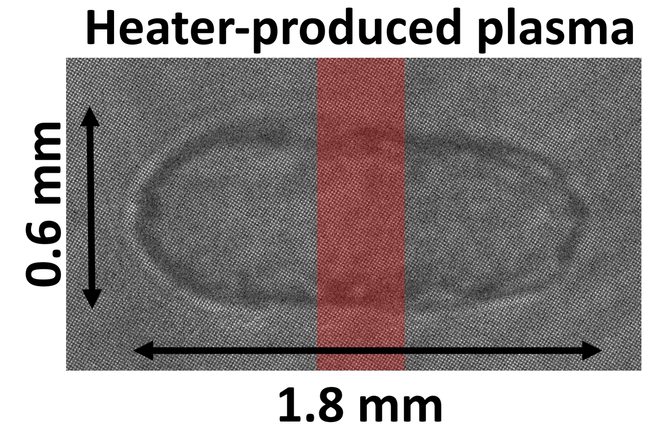
Figure from [1]



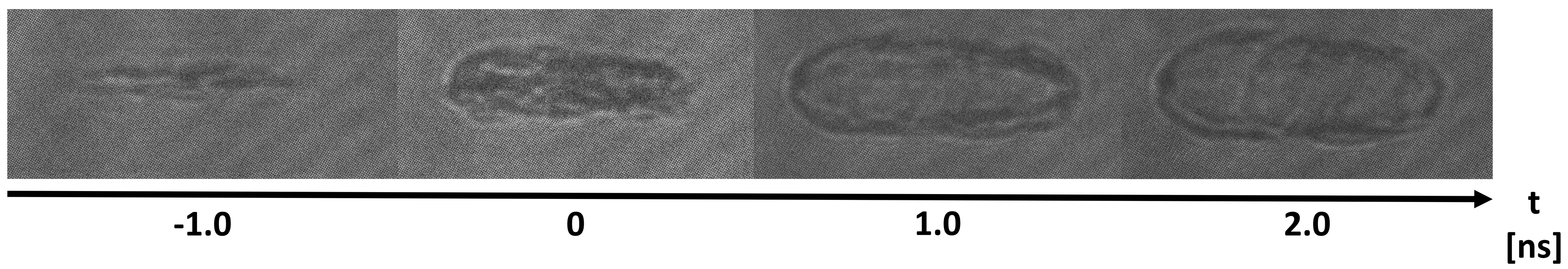
Experimental Setup & Methods



Heater-produced plasma



A SID4 (four-wave shearing interferometer device) measures plasma density and size at different delays after the heater beam. Measurements of plasma shape and density are averaged over the region indicated in red. It should be noted that this method is limited by the amount of light absorbed by the plasma as well as shot-to-shot phase modulations in the probe beam.



In the absence of Thomson-scattering diagnostics on our platform, plasma temperature is inferred from the shock-front velocities found from fitting radial shock-front positions over time to cylindrical blast-wave models [2].

Sedov–Taylor cylindrical blast wave:

$$r(t) = \left[\frac{4}{\pi}\frac{(\gamma+1)(\gamma-1)^2}{3\gamma-1}\right]\left(\frac{E_0}{\rho_0 l}\right)^{1/4} t^{1/2}$$

Cylindrical radiative shock:

$$r(t) = \left(\frac{18 E_0 r_0}{\pi \rho_0 l}\right)^{1/6} t^{1/3}$$

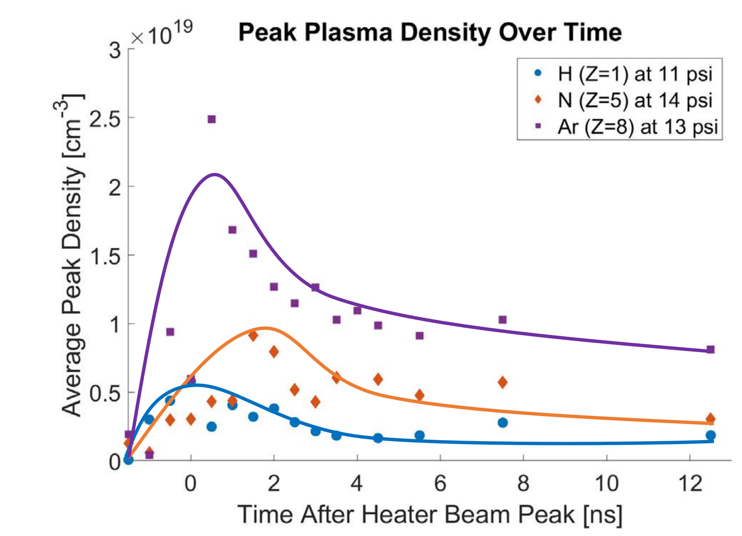
Radial plasma shock fronts propagate at the ion sound speed from which plasma temperature is found

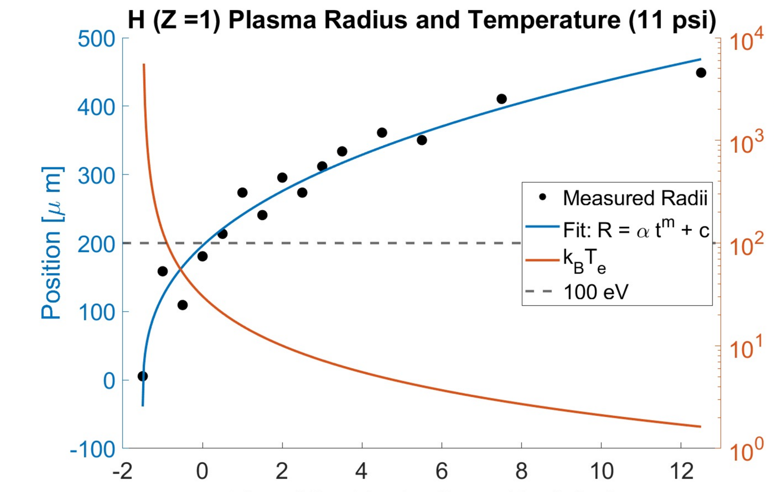
$$\frac{\mathrm{d}r}{\mathrm{d}t} = c_s = \sqrt{\frac{\gamma Z k_B T_e}{m_i}}$$

Results

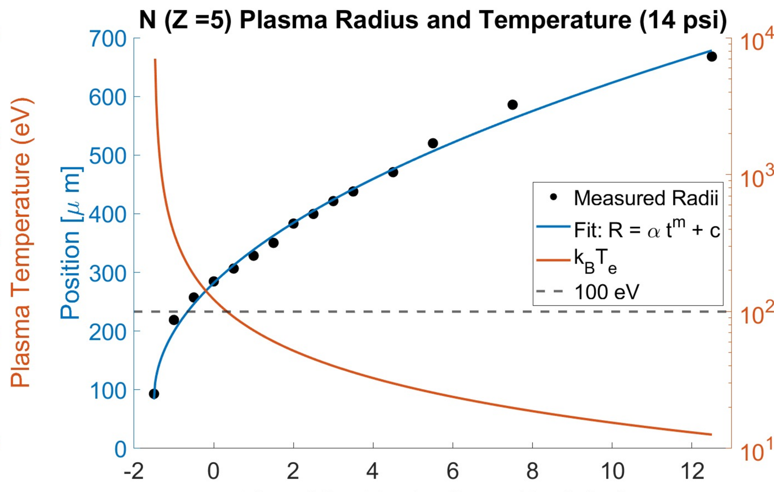
Density measurements, shown to the right, indicate an initial rise in plasma density, attributed to collisional ionization, followed by a smoother decrease in density as diffusive processes modify the plasma.

Results indicate higher-Z elements reach expansion velocities larger than that of lighter elements. This leads to sufficiently large temperatures above 100 eV necessary to mitigate IIR, filamentation, and spontaneous Raman scattering.

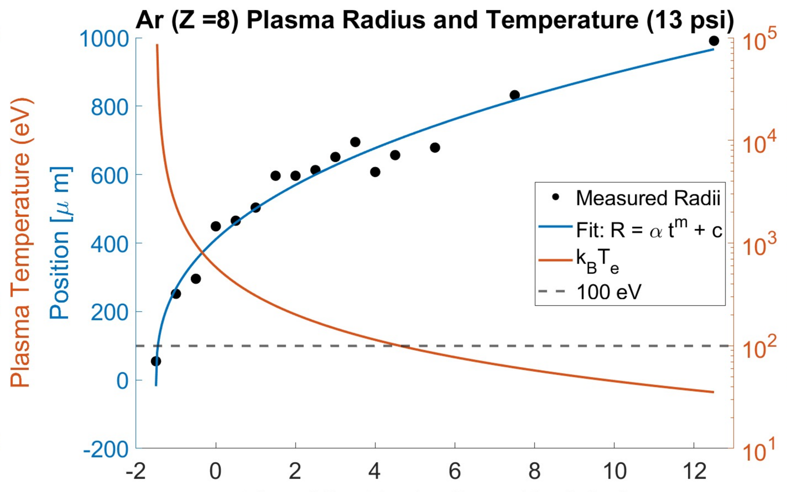




$\alpha = 204.3\ (105.7, 302.9)$
$m = 0.3446\ (0.2106, 0.4787)$
$c = -38.66\ (-133.7, 56.35)$



$\alpha = 162.6\ (133.3, 192.0)$
$m = 0.4912\ (0.4332, 0.5492)$
$c = 83.58\ (53.10, 114.1)$



$\alpha = 369.1\ (226.7, 511.6)$
$m = 0.3717\ (0.2603, 0.4831)$
$c = -18.18\ (-157.0, 120.6)$

[1] D. Haberberger, A. Davies, J. L. Shaw, R. K. Follett, J. P. Palastro, and D. H. Froula, Phys. Plasmas **28**, 062311 (2021).
[2] Y. B. Zel'dovich and Y. P. Raizer, *Physics of Shock Waves and High-Temperature Hydrodynamic Phenomena* (Courier Corporation, 2012).

Conclusion & Future Work

In order to prevent deleterious phenomena from depleting the pump beam, plasma temperatures above 100 eV and densities near 1×10^{19} cm^{-3} become necessary [1]. Temperature measurements based on blast-wave models indicate for sufficiently high temperatures to reach this regime the Raman interaction, in our current configuration, must take place between 1 to 4 ns after the heater beam, with heavier gases allowing for longer delays. Additionally, only these heavier gases like N_2 and Ar can reach the densities required near 1×10^{19} cm^{-3} in this amount of time.

Currently, density measurements are limited in their accuracy, so further analysis and optimization of this technique are needed. In response to these limitations, we are activating full-aperture backscatter spectrum (FABS) measurements as additional density diagnostics and working to remove phase modulations from the probe beam for the SID4. Future campaigns will seek to realize the optimal plasma conditions necessary for Raman amplification. Comparison between pump transmission and on-shot plasma characteristics will reveal the effectiveness of the hot Raman regime in suppressing IIR, filamentation, and spontaneous Raman scattering from thermal noise.

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