SAND2020-10819C

Sandia National Laboratories

Estimating electron density, electron temperature, and signal-to-noise ratio from laser-collision induced fluorescence data by treating the measurement as a stochastic process

Brian Z. Bentz[1], Zachary K. White[2], Ryan P. Gott[2], Kunning G. Xu[2], and Edward V. Barnat[3]

[1]Applied Science and Technology Maturation, Sandia National Laboratories
[2]Department of Mechanical and Aerospace Engineering, University of Alabama in Huntsville
[3]Applied Optical and Plasma Science, Sandia National Laboratories

I. Abstract

Diagnostic measurements are inherently stochastic. Using Gaussian statistics, we demonstrate estimation of electron density (n_e), temperature (T_e), and the signal-to-noise ratio (SNR) in 2-D in a cathodic arc (30 mTorr He) and the positive column of a DC discharge (500 mTorr He) using Laser-collision induced fluorescence (LCIF) data.

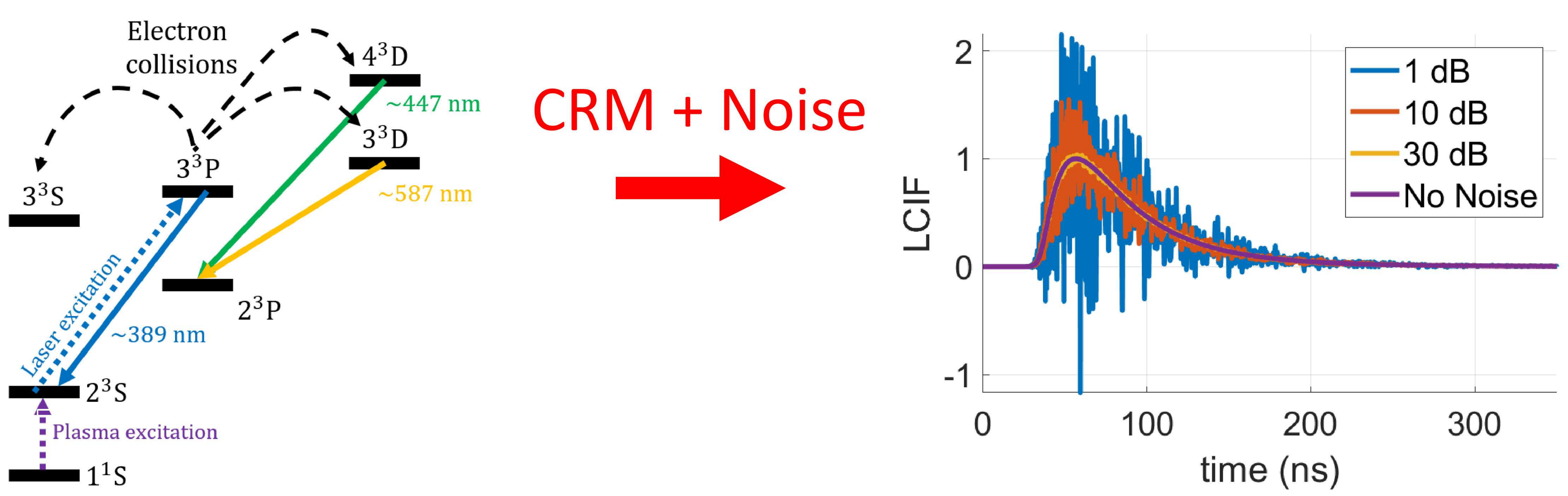
II. LCIF Diagnostic Measurement Model

- He atomic system described by collisional radiative model (CRM), $\boldsymbol{f}(n_e, T_e)$ [1]
- Shot noise for measured photodetector current, $\boldsymbol{y}$, is described by Gaussian statistics [2]

$$p(\boldsymbol{y}) = \frac{1}{[(2\pi)^P|\boldsymbol{\Upsilon}|]^{1/2}} \exp\left[-\frac{1}{2}\|\boldsymbol{y} - w\boldsymbol{f}(n_e, T_e)\|^2_{\Upsilon^{-1}}\right]$$

- Noisy measurements can be simulated from covariance, $\Upsilon_{ii} = \sigma^2$, and SNR

$$\boldsymbol{y} = \boldsymbol{y} + \sigma \mathrm{N}(0,1) \qquad \mathrm{SNR} = \frac{[f(n_e,T_e)]^2}{\sigma^2}$$



III. Parameter Estimation and Simulated Detection Limits

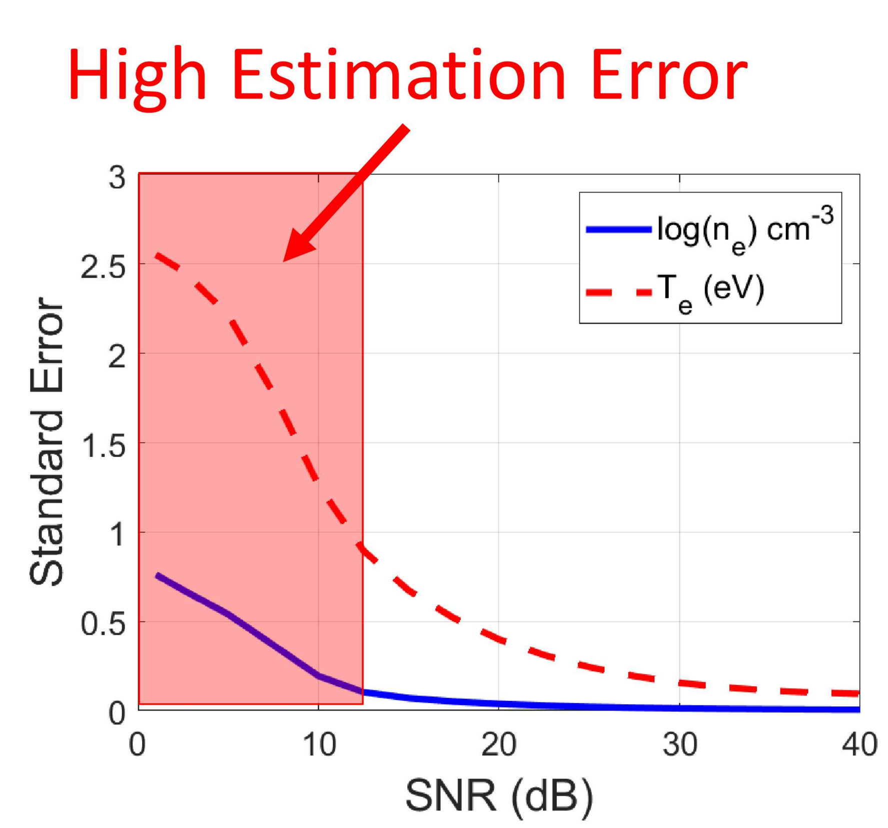
- Model enables estimation of $\mathbf{x} = [n_e, T_e]$ [3]

$$c(\boldsymbol{x}) = \|\boldsymbol{y} - \widetilde{w}\boldsymbol{f}(\boldsymbol{x})\|^2_{\Upsilon^{-1}} \qquad \widetilde{w} = \frac{\boldsymbol{f}^T(\boldsymbol{x})\boldsymbol{\Upsilon}^{-1}\boldsymbol{y}}{\boldsymbol{f}^T(\boldsymbol{x})\boldsymbol{\Upsilon}^{-1}\boldsymbol{f}(\boldsymbol{x})}$$

$$\widehat{\boldsymbol{x}} = \arg\min_{\boldsymbol{x}} c(\boldsymbol{x}) \qquad \widehat{w} = \widetilde{w}(\widehat{\boldsymbol{x}})$$

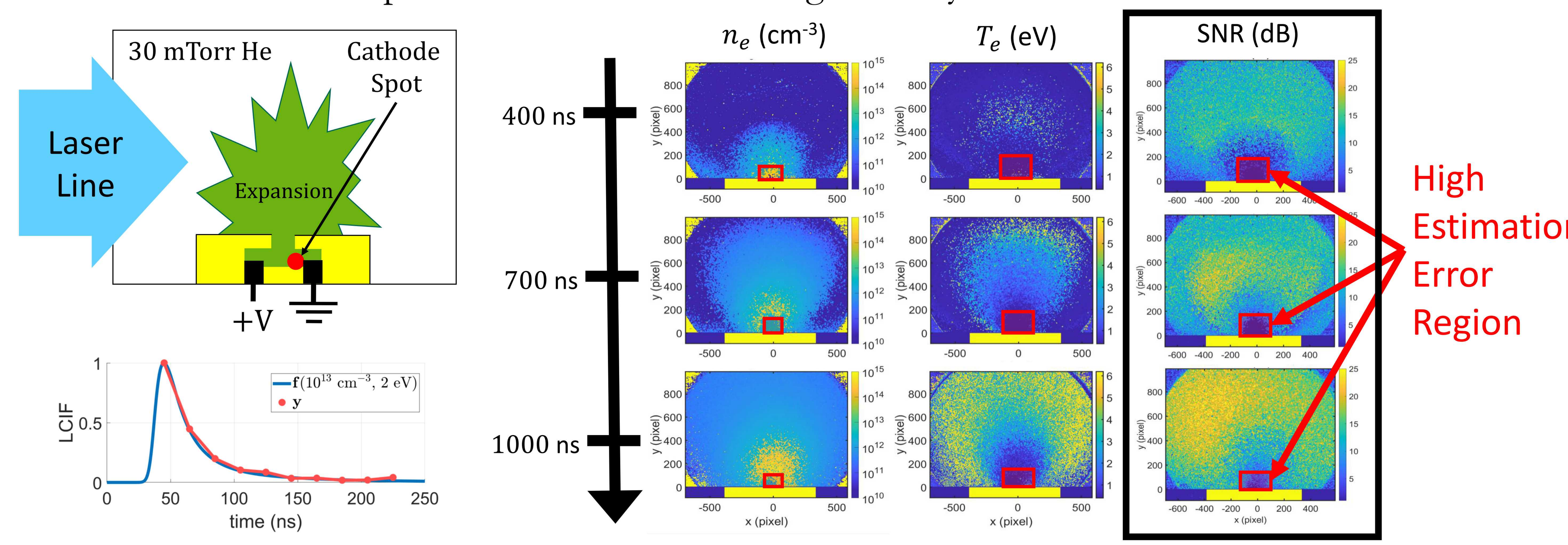
- SNR determined by estimating σ^2

$$\mathrm{SNR} = \frac{\boldsymbol{f}(\boldsymbol{x})}{\left[\frac{1}{N}\|\boldsymbol{y} - \widehat{w}\boldsymbol{f}(\widehat{\boldsymbol{x}})\|^2_{\widehat{\Upsilon}^{-1}}\right]}$$

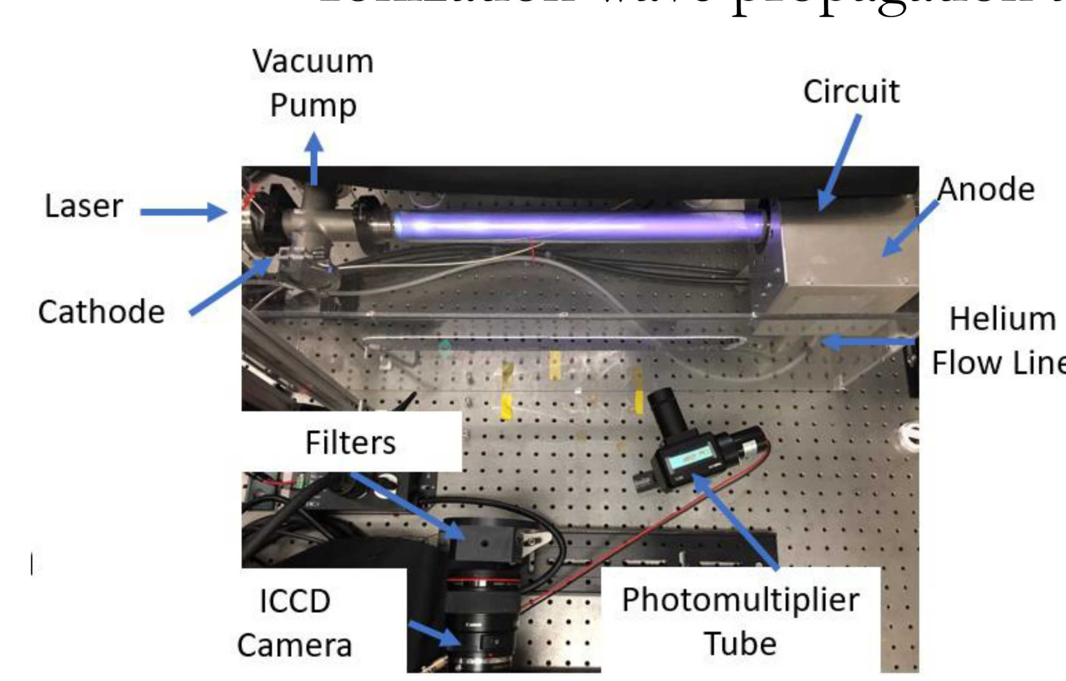


IV. Results

- Localized estimation of n_e and T_e in a cathodic arc expanding into 30 mTorr of He
- Fast electrons at expansion front and cooler high density core observed



- Estimation of n_e and T_e in the positive column of a DC discharge (500 mTorr He)
- Ionization wave propagation and radial expansion observed



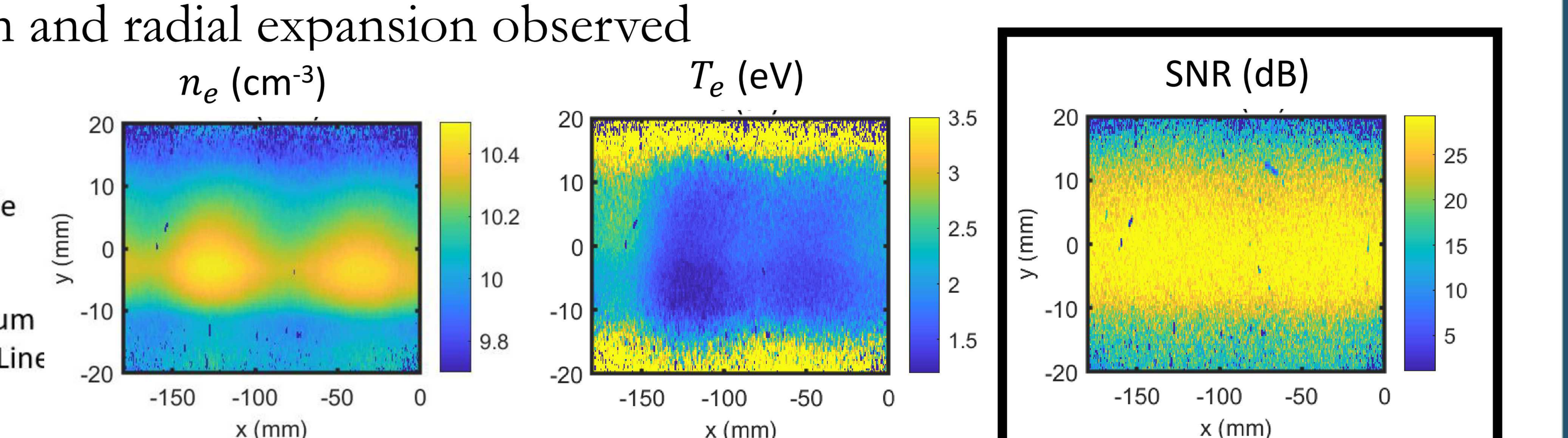
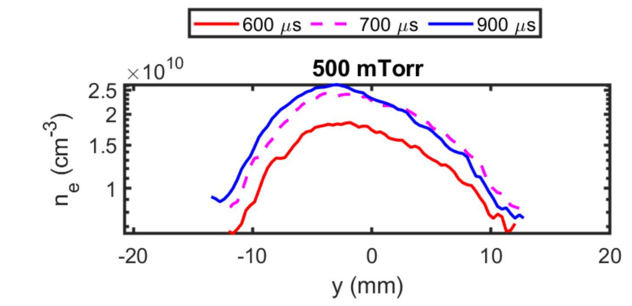
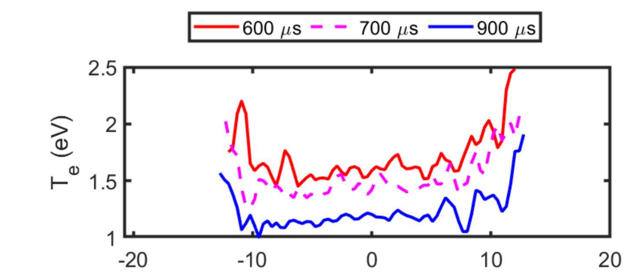


Table 1. Measured Wave Velocities

Pressure (Torr)	Group Velocity (m/s)	Phase Velocity (m/s)
1	277	-175
.75	514	-125
.5	1200	-125





V. Conclusions

Maximum likelihood estimation of n_e, T_e, and SNR in 2-D is possible using a CRM and Gaussian statistics. The SNR provides a useful metric for establishing regions of diagnostic validity.

References

[1] E. V. Barnat and K. Frederickson, *Plasma Sources Sci. Technol.* 19(5), 055015 (2010)
[2] J.-C. Ye, K. J. Webb, C. A. Bouman, and R. P. Millane, *J. Opt. Soc. Am. A* 16(10), 2400 (1999)
[3] B. Z. Bentz, D. Lin, and K. J. Webb, *Phys. Rev. Appl.* 10(3), 034021 (2018)

U.S. DEPARTMENT OF ENERGY
NNSA
Sandia National Laboratories is a multimission laboratory managed and operated by National Technology &Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.
SAND No. ____

Sandia National Laboratories