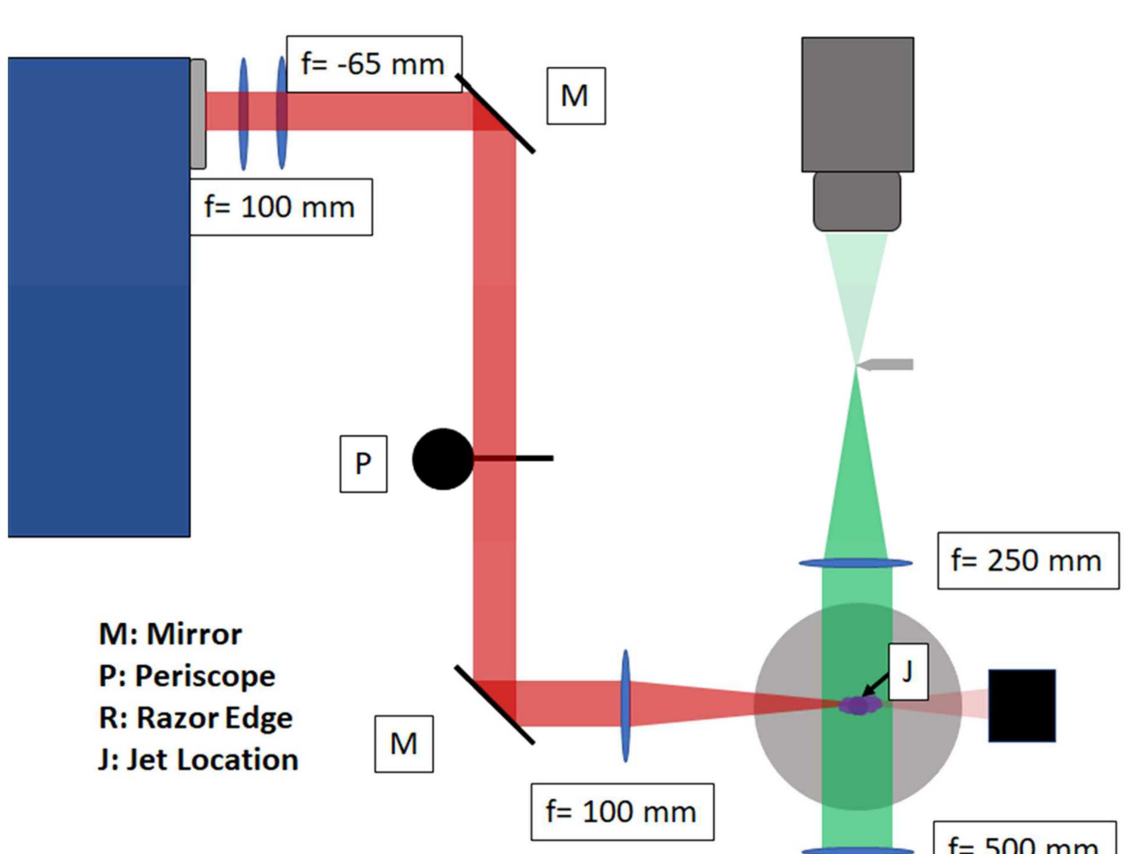
SAND2019-6697C

Interrogation of Burst-Mode Laser-Induced Plasma at 300-500 kHz Repetition Rate in an Overexpanded Jet via Advanced Spectroscopic and Imaging Diagnostics

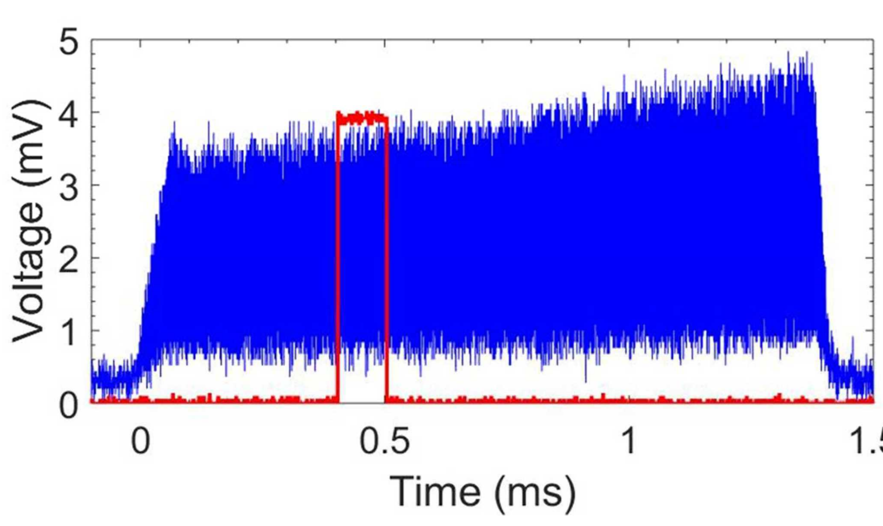
Caroline Winters and Justin Wagner

Laser-induced plasma formation occurs when a gas is ionized by focused electromagnetic radiation. While the ionization is localized to the region of energy deposition, the interaction effects from the plasma can extend far into the surrounding environment. High-bandwidth coupling between plasma gas dynamics and flow physics was observed when a pulse-burst laser-induced plasma operated at 300-500 kHz burst rate, was applied to an overexpanded jet. Ultra-fast (≈ 5 MHz) frame Schlieren imaging and optical emission spectroscopy (OES) was employed to freeze the plasma-induced blast wave and turbulent jet structure, as well as quantify shot-to-shot variation throughout the plasma burst. The jet provided crucial mechanisms for the stable generation and continuous sustainment of a laser-induced plasma, monitored via ultrafast N(II) emission imaging; concurrently, the plasma produced permanent modulation of the jet core flow and reduced stochasticity of turbulent structures. The active modulation of laser plasma location, energy, and repetition rate implies rapid adaptability for supersonic flow modification and plasma-ignition.

Experimental Set-up

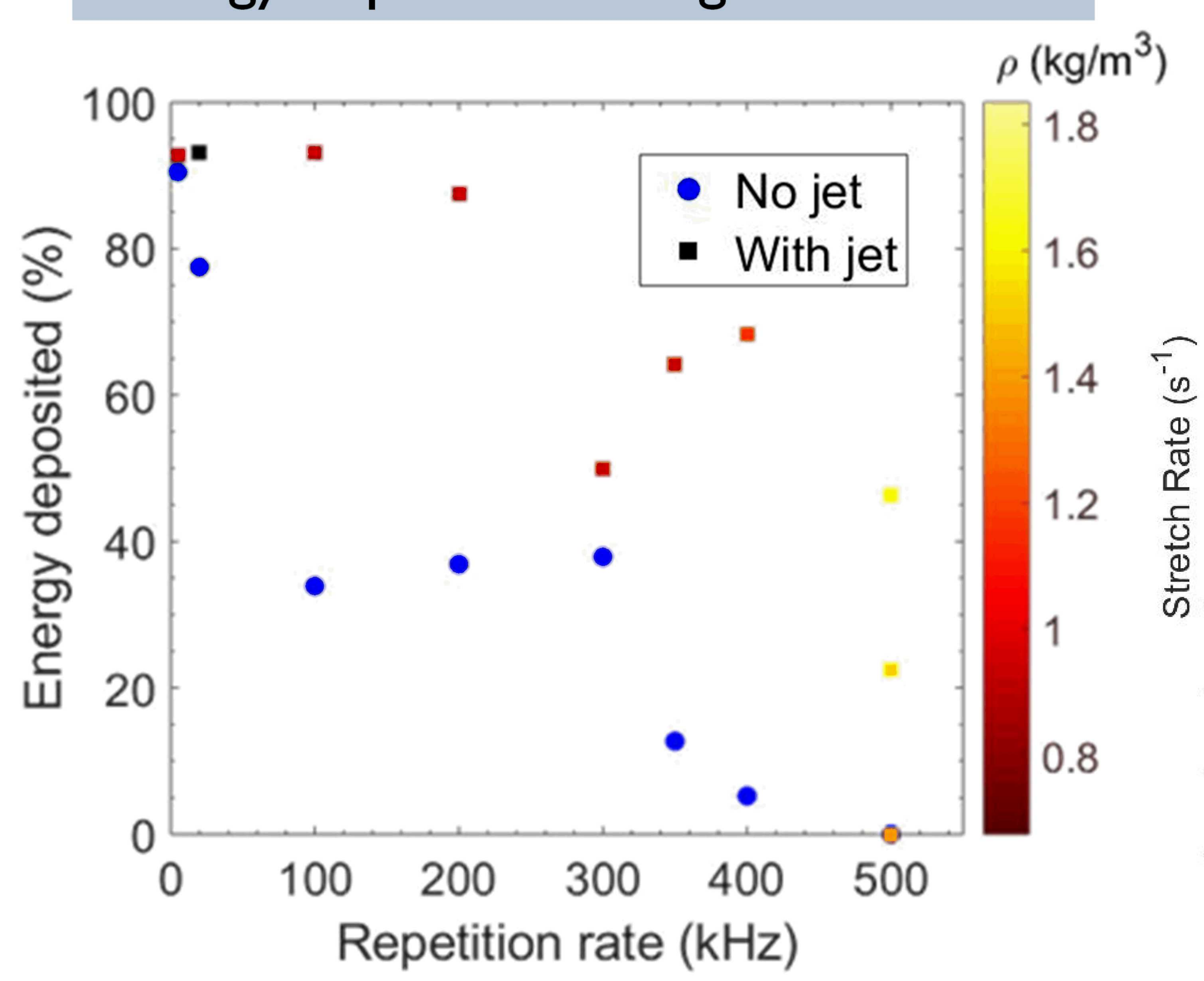


500 kHz pulse train



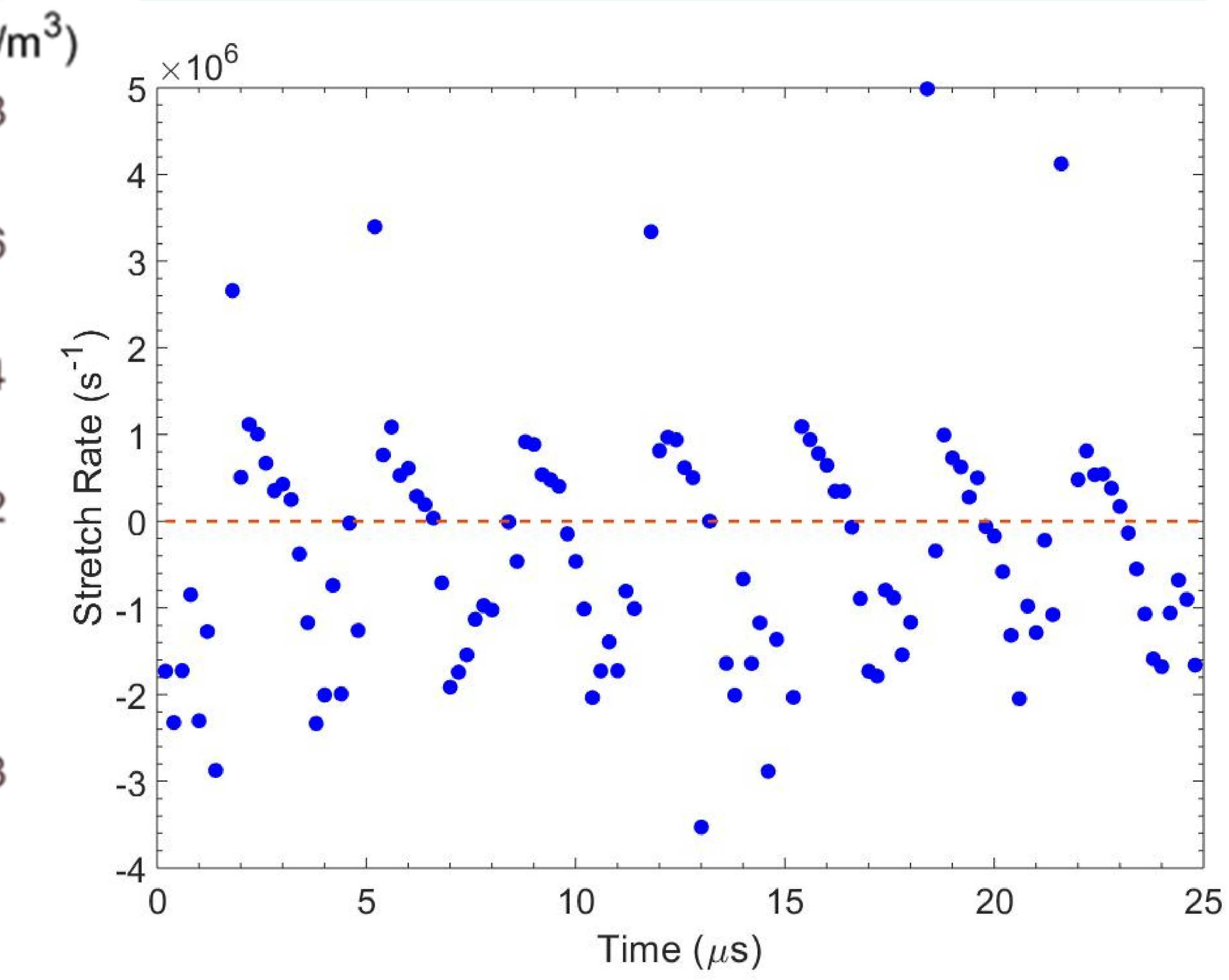
Burst duration: 1.5 ms
Total burst energy E ~ 15 J

Energy deposition at high-burst rates



- Breakdown stochasticity in quiescent air increases with burst rate
- Refresh rate sustains breakdown τ < 350 kHz
- Flow and elevated exit density is critical to sustaining breakdown at τ > 350 kHz

Flow dynamics of the plasma

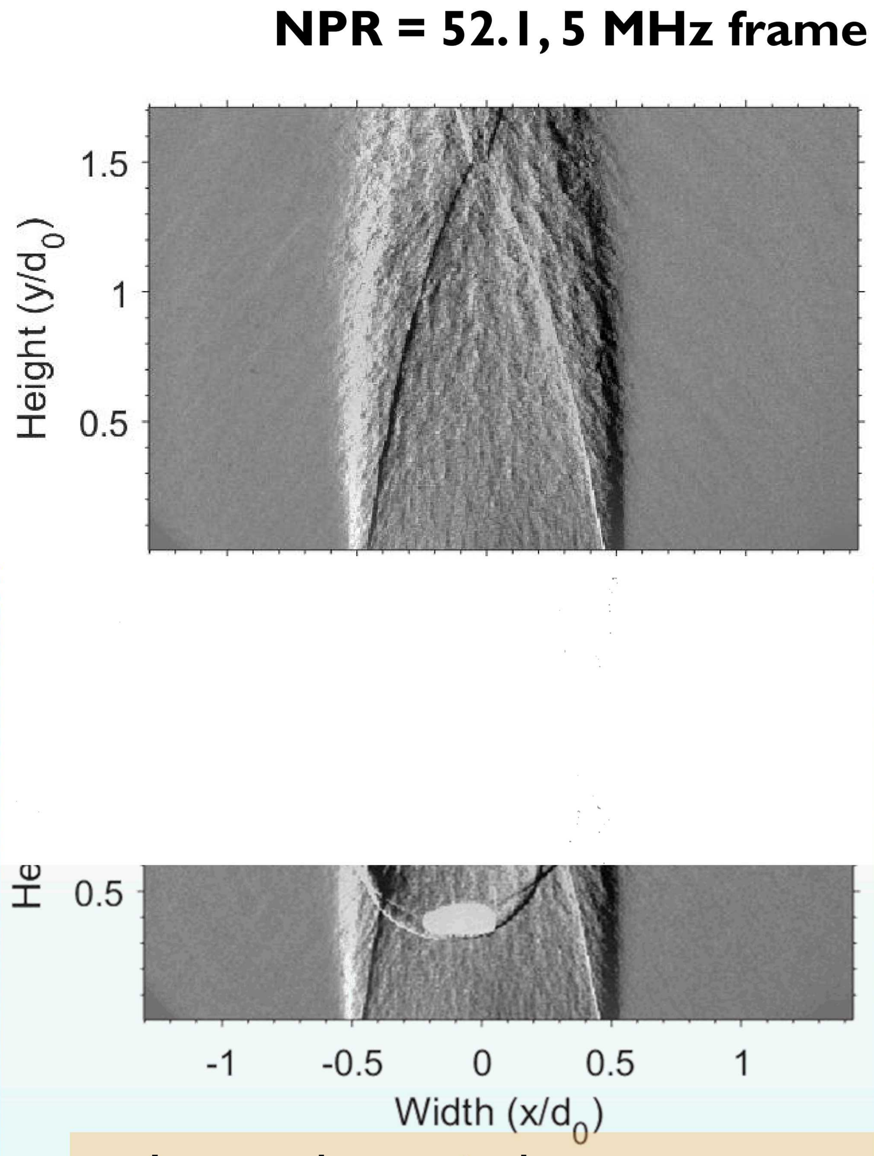


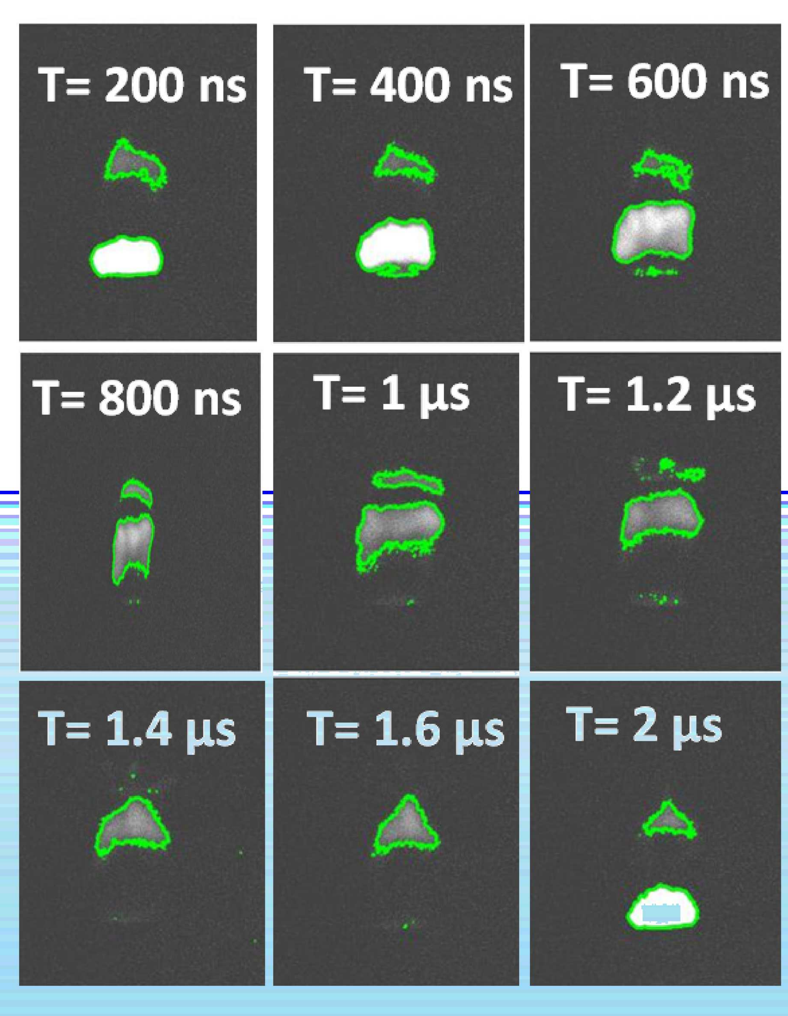
300 kHz burst rate
5 MHz frame rate, τ_{exp}= 100 ns

- Plasma surface area increases over 1.4 μs after each laser-plasma event
- Negative stretch rate caused by plasma species recombination and emission decay
- Laser-plasma generates local flow acceleration and convects repeatably

High-bandwidth plasma/flow interactions

NPR = 52.1, 5 MHz frame rate, τ_{Sch}= 10 ns, $\tau_{N(II)}$= 100 ns

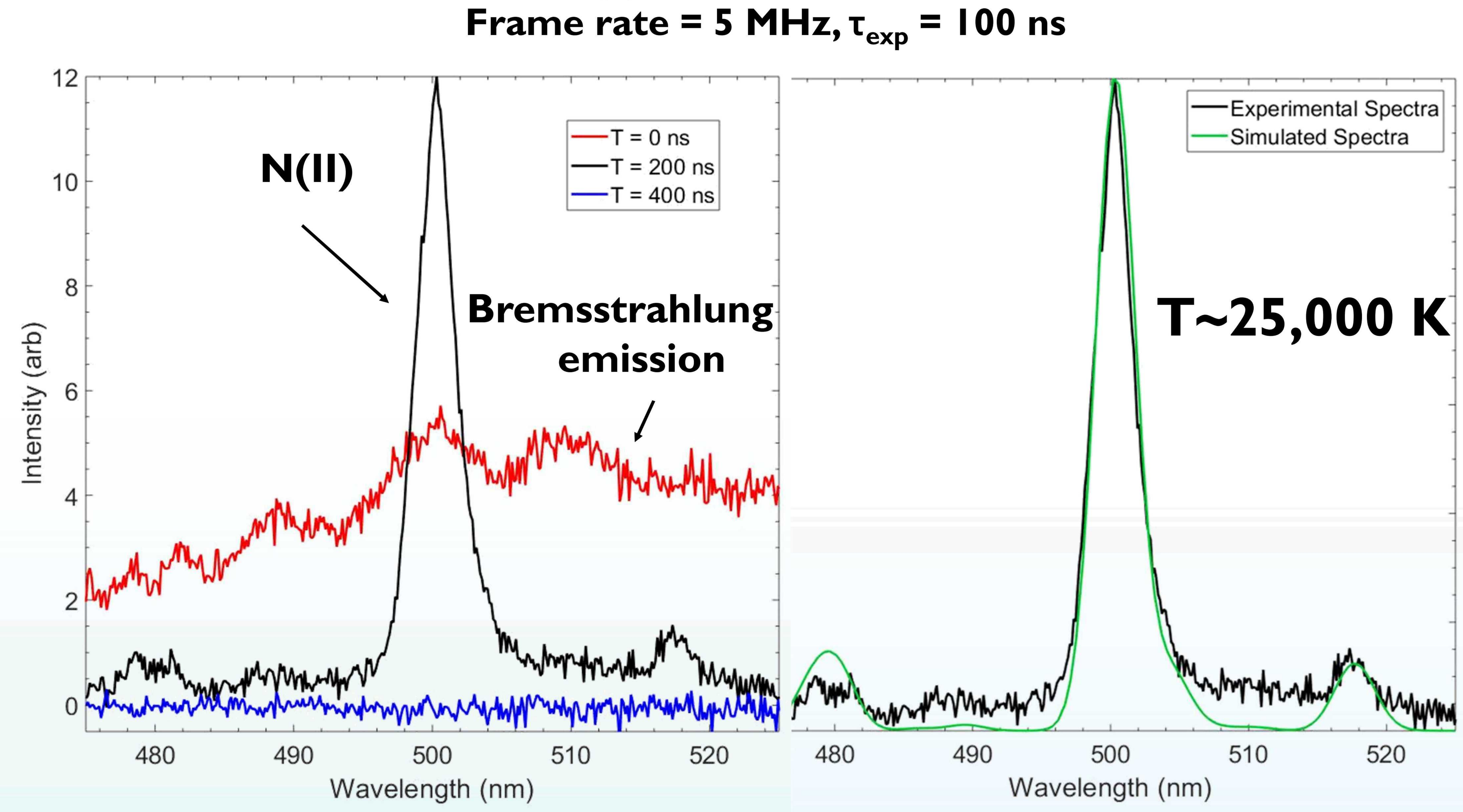




- Laser-plasma induces permanent disruption and standing blast-wave
- Perimeter of the plasma used for surface area analysis
- Non-trivial interaction between subsequent laser-plasma events

High-speed Temperature Inference

E= 17 mJ/pulse; Burst rate= 500 kHz;
Frame rate = 5 MHz, τ_{exp} = 100 ns



- Broadband emission plateau from electron-recombination processes
- Strong atomic features appear for τ < 500 ns
- 12 LIBS spectra was fit using NIST LIBS database

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. ____________