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THE AIR FORCE RESEARCH LABORATORY
LEAD | DISCOVER | DEVELOP | DELIVER

Neutral Gas Heating via Pulsed Optical Lattices

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Motivation

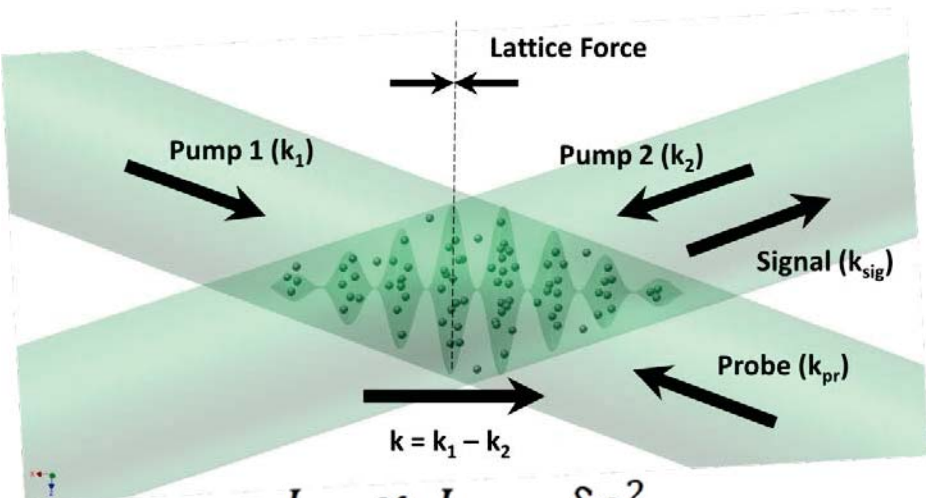
- **Desire for a source of high temperature gases (T > 2000K)**
  - Arbitrary
  - Highly tunable
  - Known chemical species
  - No ionization
- **Current techniques cannot accomplish these characteristics**
  - Pyrolysis, shock tubes, chemical reactions

Hypersonic Flows (One Example)

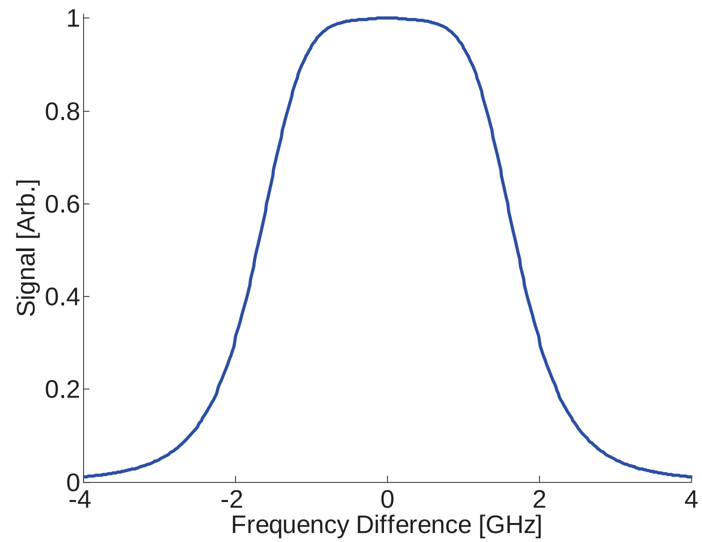
- **Re-entry flows are characterized by high temperature and enthalpy**
- **Flow is comprised of atmospheric constituents (N_2, O_2, N, O, CO_2, etc)**
- **Temperatures can exceed 2000 K**
- **Current Methodology:**
  - Arc discharge
    - Heats through Joule Heating
    - High ionization fraction
  - Combustion
    - Heats through chemical reaction
    - Unwanted species / Limited temperature
  - Laser pyrolysis
    - Heats through resonant roto-vibrational coupling
    - Limited applicability
  - Shock tubes
    - Limited test time (msec or less)
    - Unsteady flow behavior

Coherent Rayleigh-Brillouin Scattering

- **Optical lattice heating is a consequence of high intensity CRBS**
- **CRBS: Pulsed four-wave mixing scheme used for gas diagnostics**
- **Low intensity**
  - Perturbative regime (small perturbations)
  - Scattering spectra predicted by simplified gas dynamic model
- **High intensity**
  - Complex collision and forcing term
  - Cannot be predicted by simplified model (must be statistically simulated)
- **Experimentally prove gas heating via optical lattices**



$$I_{sig} \propto I_{probe}\delta\rho^2$$



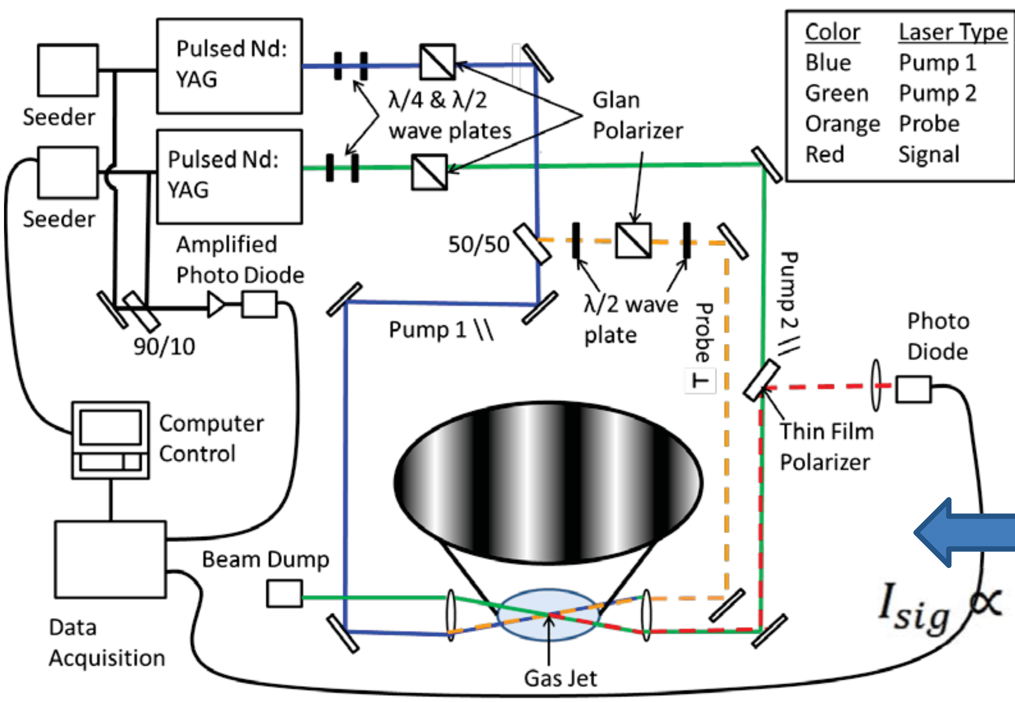
Experimental/Numerical Setup

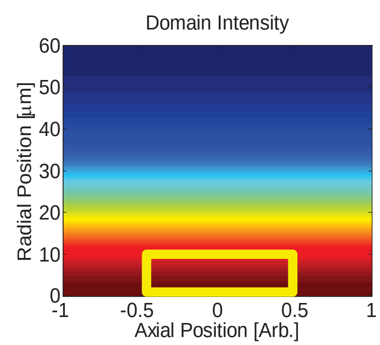
Experimental

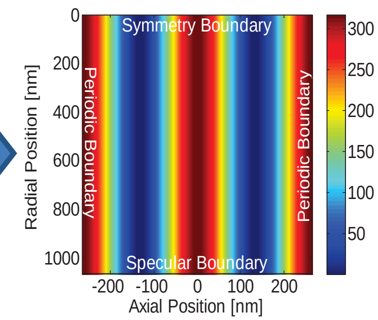
- Narrowband pump beams (~45 μm dia.)
- Frequency difference between pumps swept to vary lattice velocity
- Low speed gas jet placed at interaction region
- Signal magnitude measured on high speed oscilloscope

Numerical

- Modified version of a DSMC code SMILE used to simulate particles within optical lattice
- Parameters chosen for direct comparison with experiment
- Density perturbation found through non-linear least squares fit
- Domain represents centerline of laser pulse







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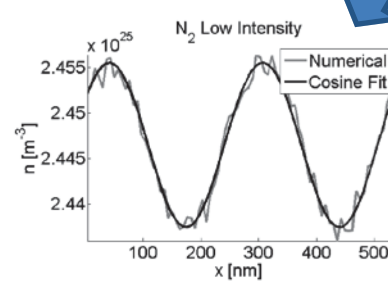
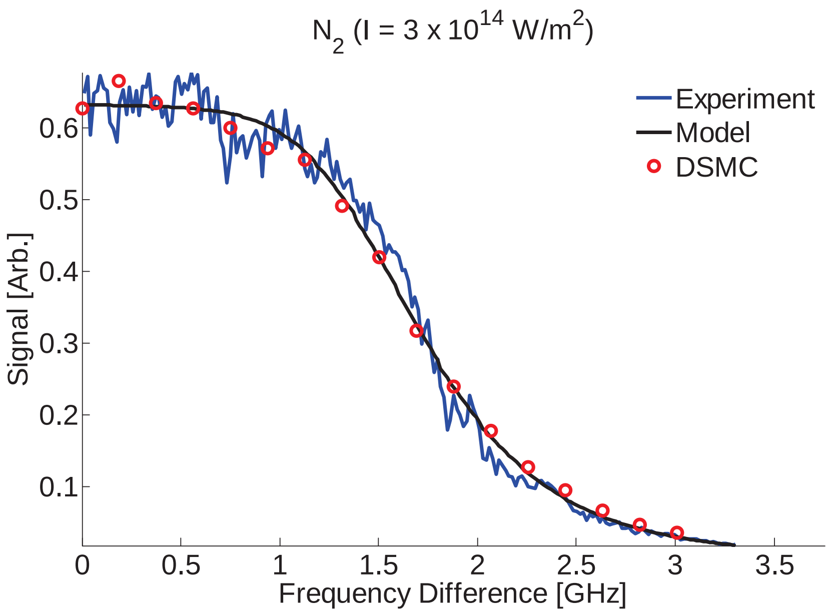
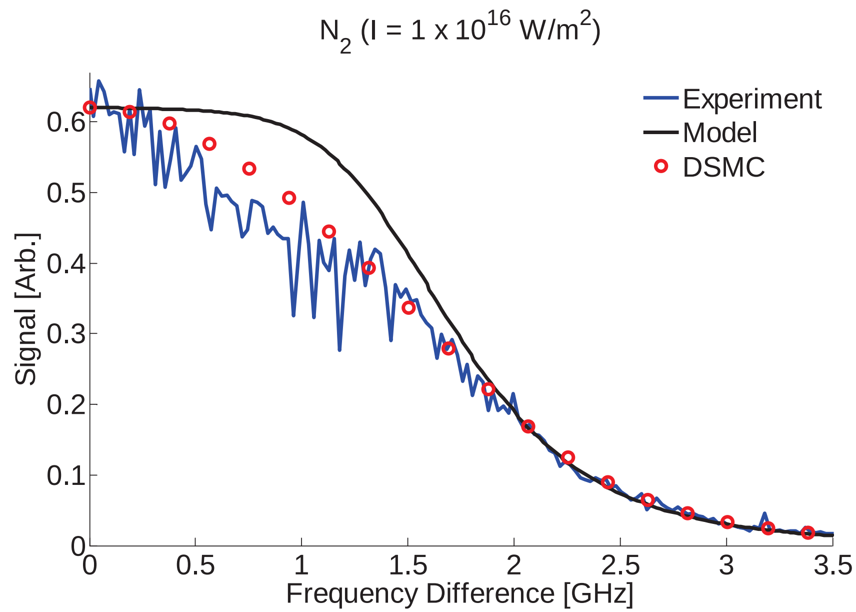


CRBS Results

Low Intensity

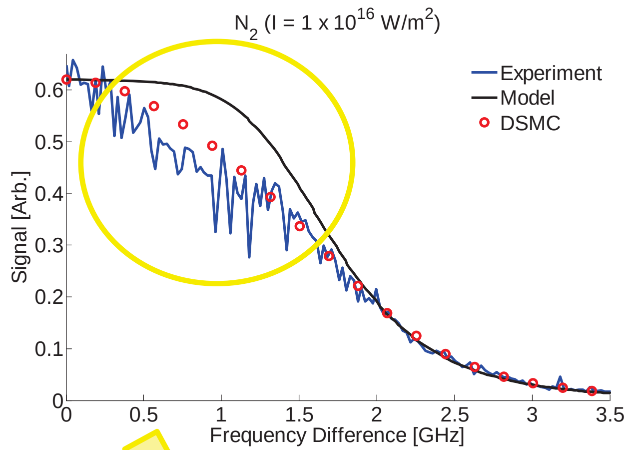


High Intensity

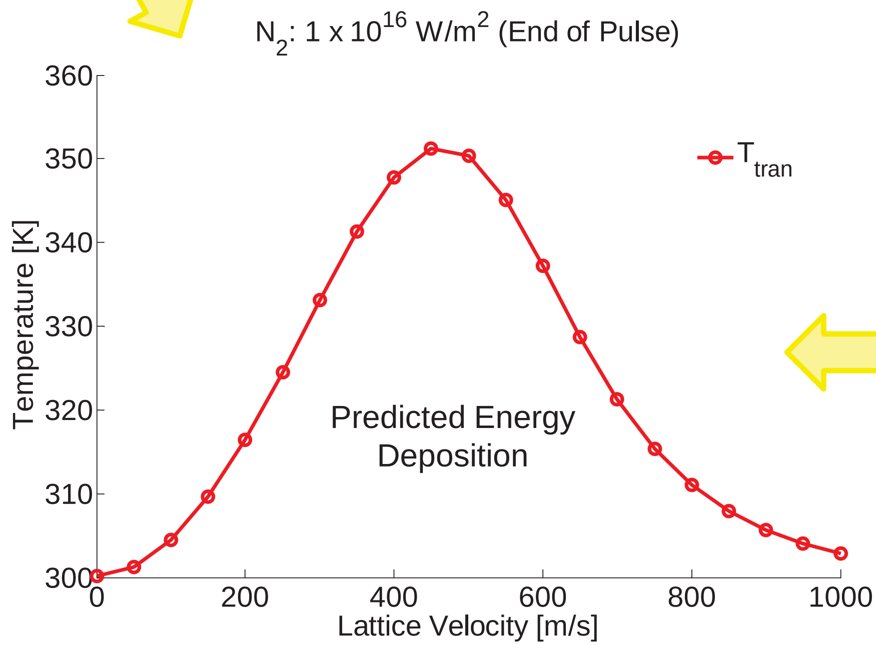


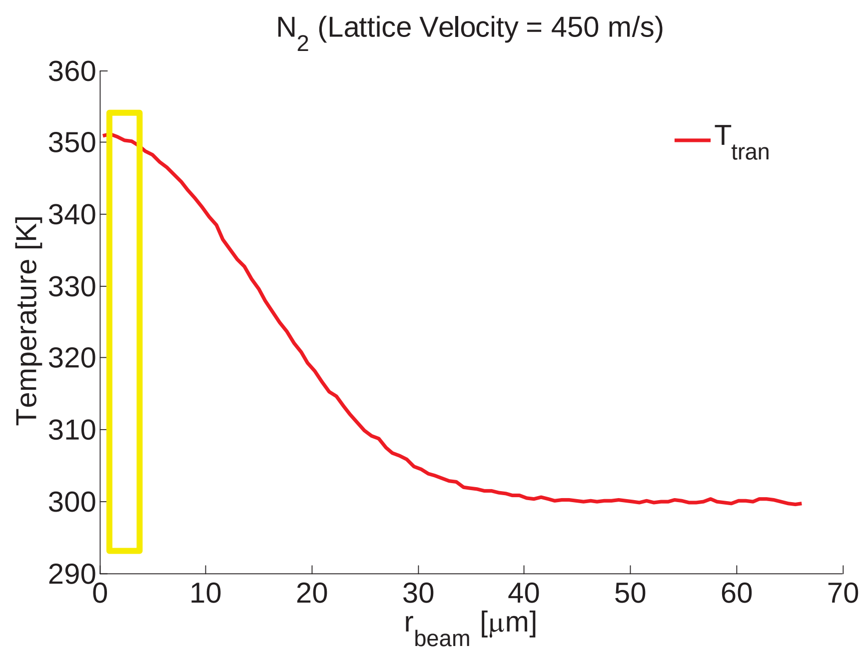
- **Experiment and DSMC show good agreement with six-moment model (s6) for low intensity**
  (X. Pan, "Coherent Rayleigh-Brillouin scattering," Princeton University (Ph.D. Thesis, 2003))
- **Possible causes of narrowing at higher intensities include:**
  - Partial ionization (not lattice velocity dependent)
  - Gas dissociation (not lattice velocity dependent)
  - **Gas heating** (lattice velocity dependent)

DSMC Heating Prediction

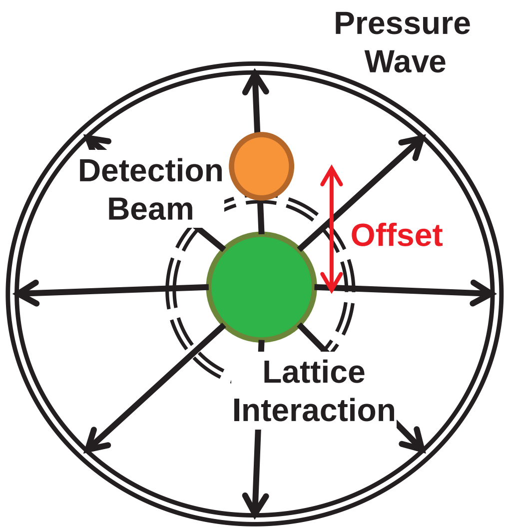


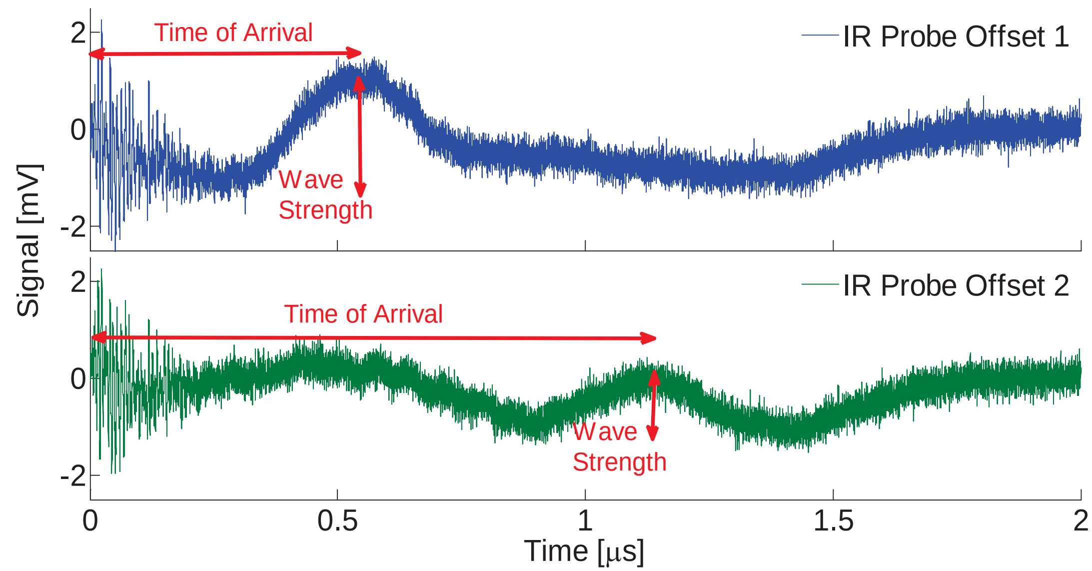
- **Peak centerline temperature increase of 51 K at lattice velocity = 450 m/s**
- **Temperature varies radially with I^2**
- **Average volume temperature (laser FWHM ~45 µm dia.) of 330 K**



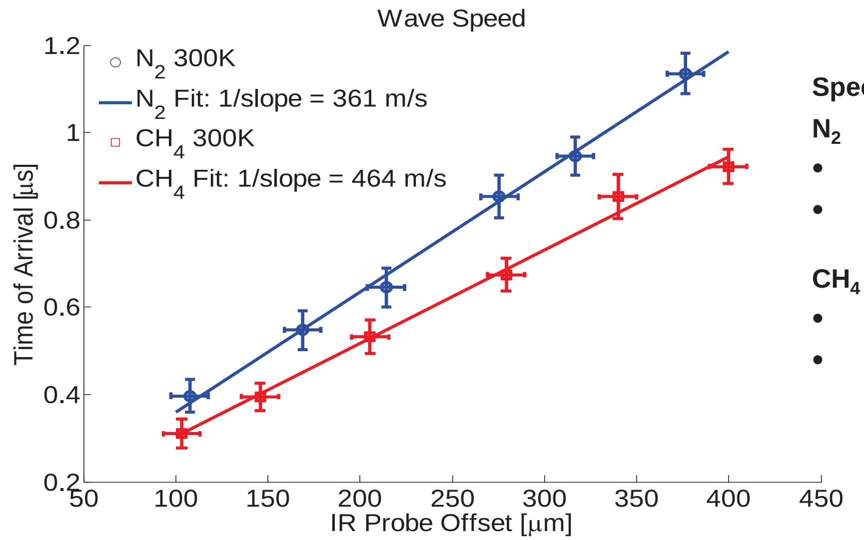


Experimental Energy Deposition





- Detects IR probe beam deflection due to refractive index change caused by pressure wave expansion
- Magnitude of photodiode signal proportional to strength of pressure wave
- Measurements taken vs. probe beam offset and lattice velocity



Speed of sound:

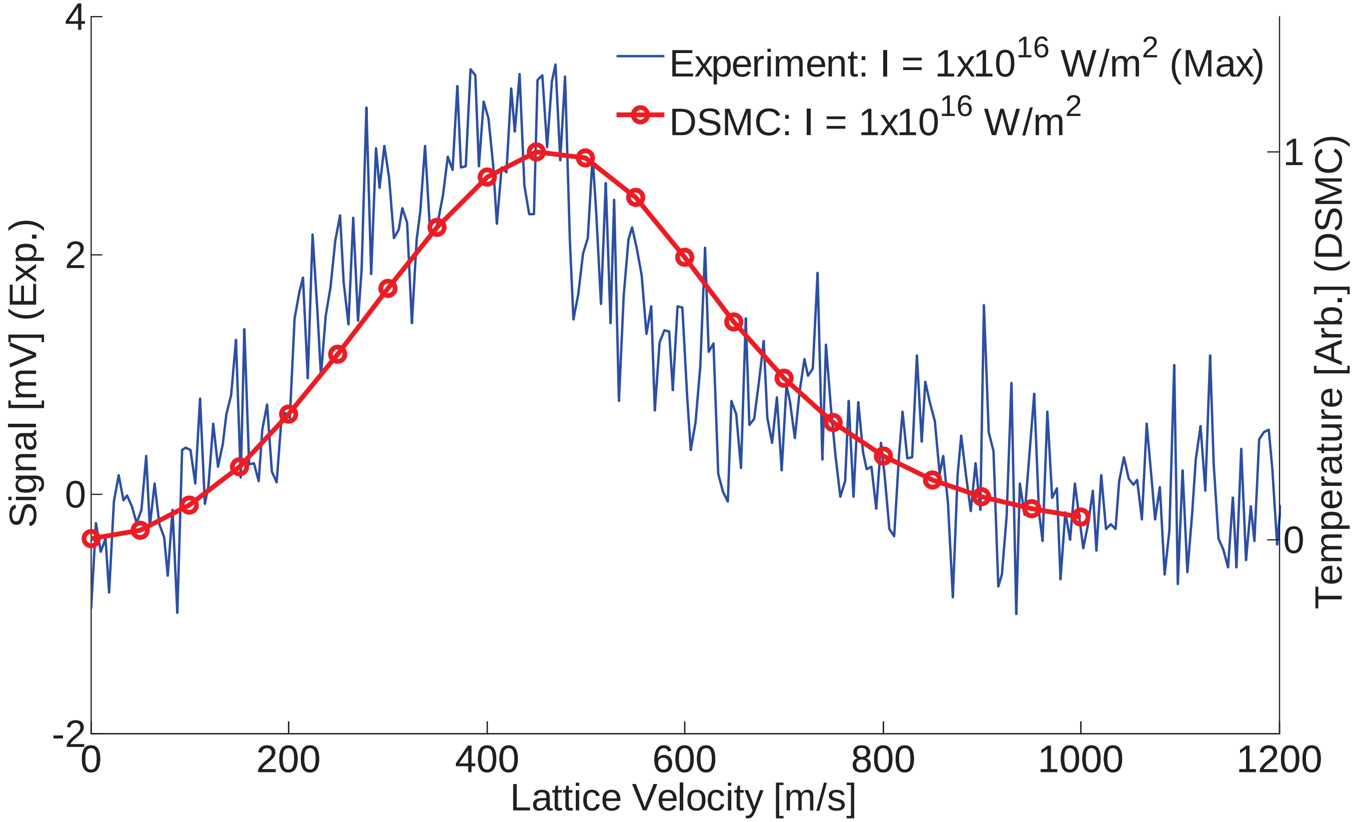
N_2

- **Calculated: a = 353 m/s**
- **Measured: a = 361 m/s (+2.3%)**

CH_4

- **Calculated: a = 450 m/s**
- **Measured: a = 464 m/s (+3.1%)**

IR Probe Results



- **Temperature profile normalized by maximum (trend only)**
- **Peak locations vary by ~40 m/s (~9%)**
  - DSMC assumes max intensity
  - Laser beam alignment
  - Pump timing

Summary

- **High Intensity CRBS effects:**
  - Partial ionization (Not lattice velocity dependent)
  - Gas dissociation (Not lattice velocity dependent)
  - **Gas heating** (Lattice velocity dependent)
- **Local gas heating shown in high intensity CRBS due to lattice interaction**
  - Numerically predicted
  - Experimentally verified by pressure wave detection with IR probe
  - Experiment and numerical simulations show good agreement