Radiation of nonequilibrium recombining plasma flows

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Radiation of Nonequilibrium Recombining Plasma Flows

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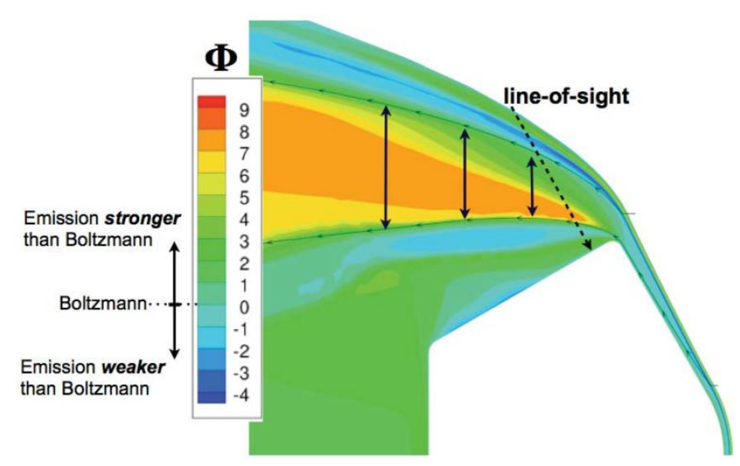
1. Motivation

- There are large uncertainties (~200%) on the prediction of radiative fluxes on afterbody surfaces
- The radiative heat flux to an afterbody surface is governed by recombining plasma dynamics

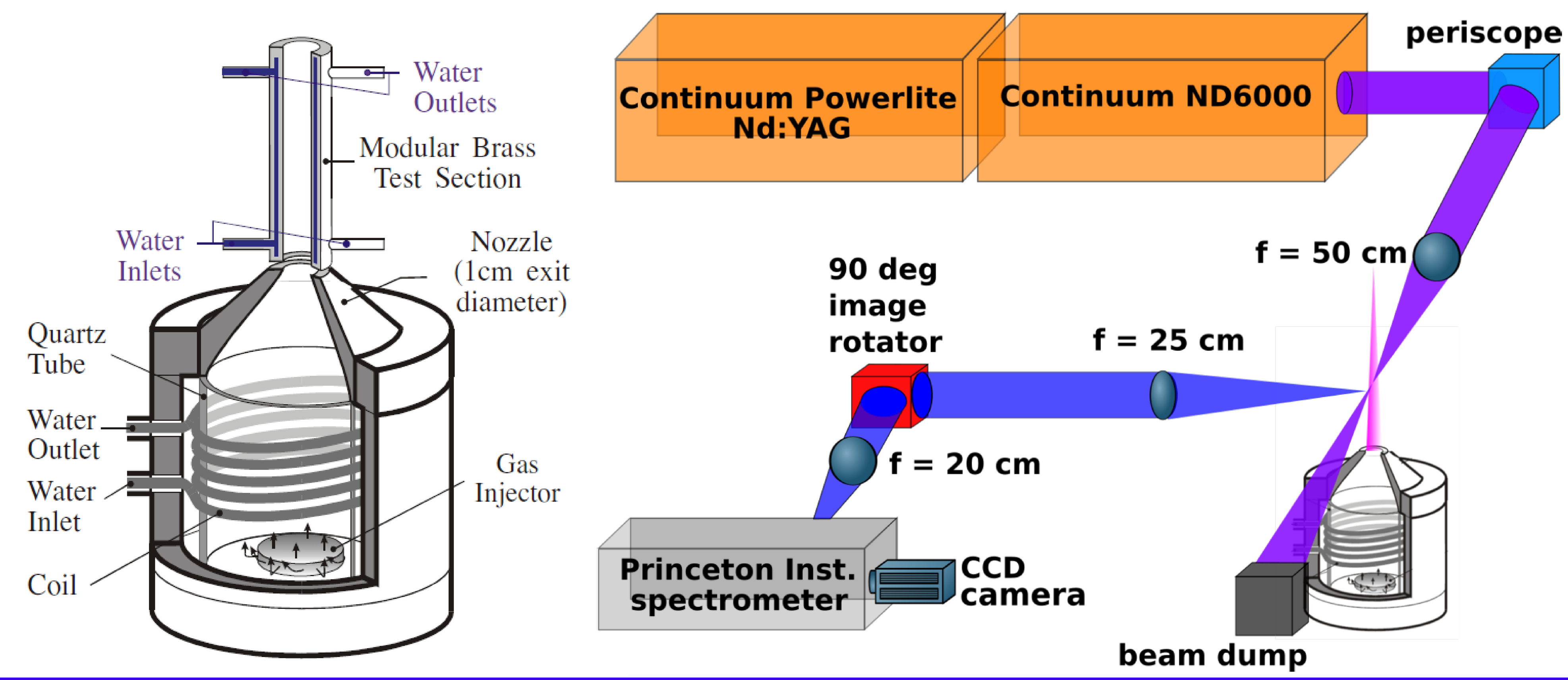
Radiation enhancement factor around Stardust (Johnston [1])



➡ **Experimental data are needed to validate radiation models in recombining flows**

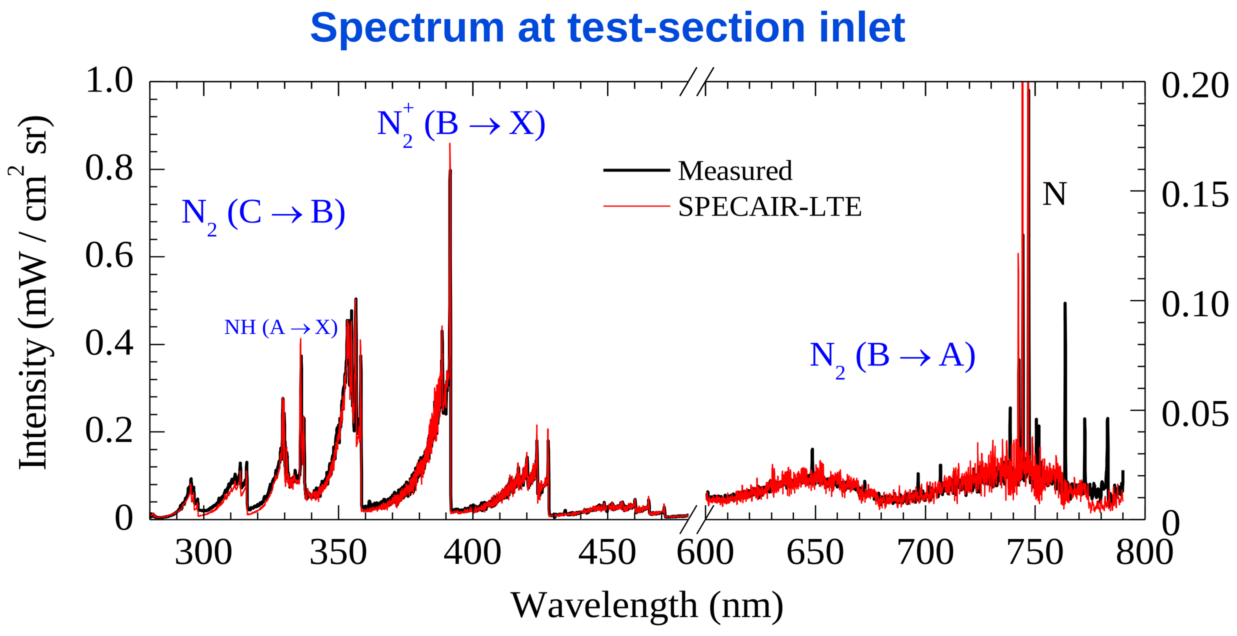
2. Experimental Setup

- 50 kW ICP Plasma Torch (1 atm)
- Recombining flow is produced in a modular water-cooled brass tube (from 0 to 65 cm)
- Emission and Raman scattering spectroscopy are used to measure temperature



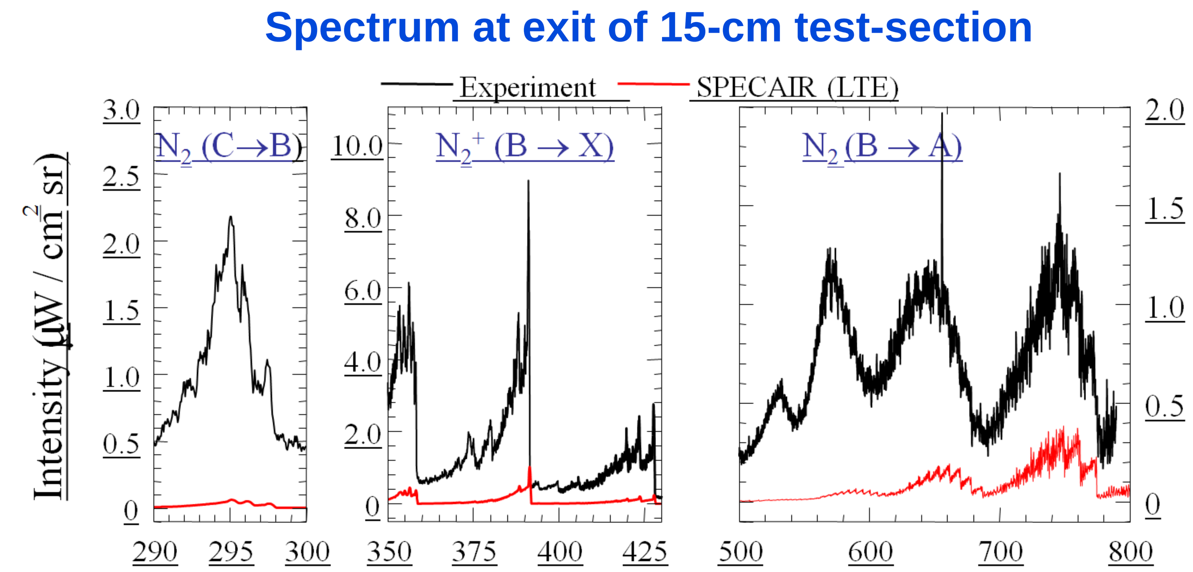
3. Previous measurements (Stanford 1997-2003, Laux et al [2])

Spectrum at test-section inlet



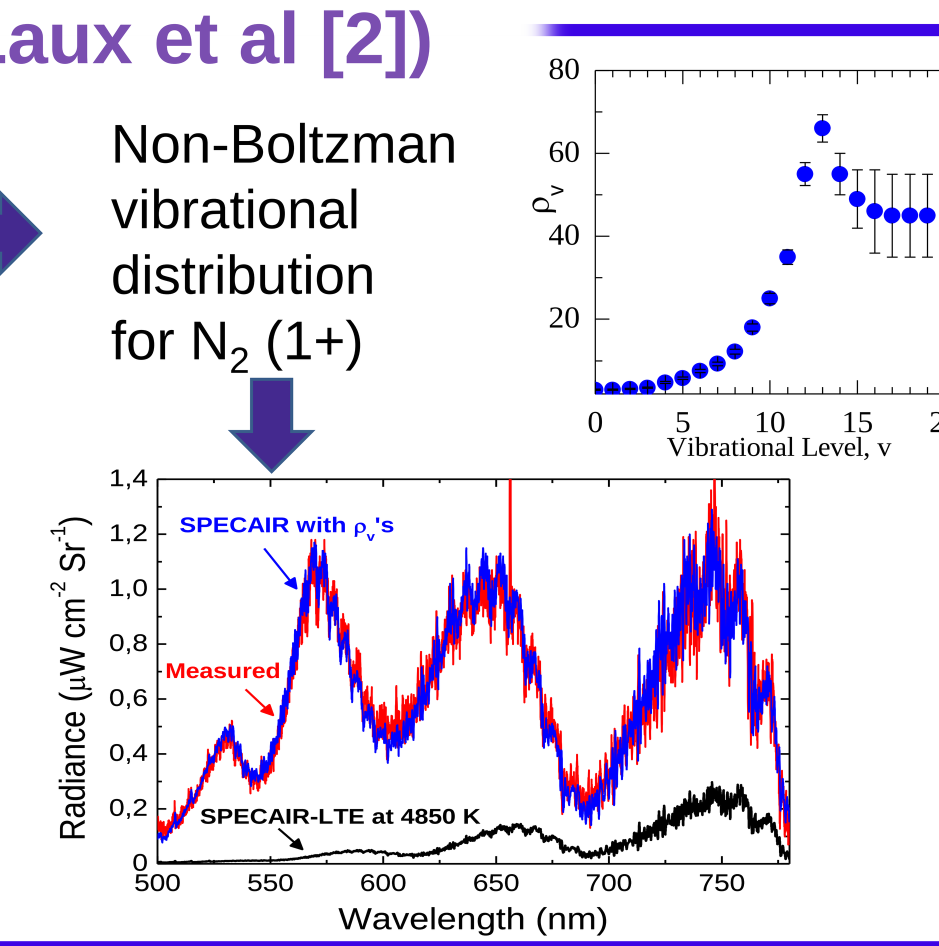
- LTE plasma at 7200 K

Spectrum at exit of 15-cm test-section

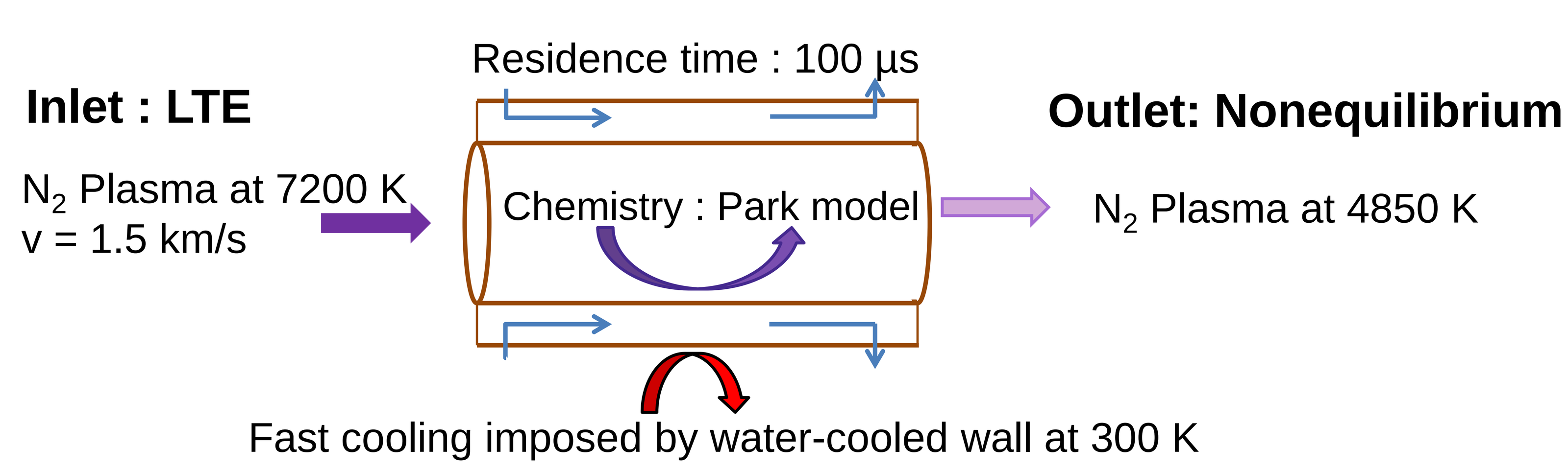


- Nonequilibrium plasma at 4850 K
- Radiation is higher than LTE: x6 for N_2 (1+), x30 for N_2 (2+), x10 for N_2^+ (1-)

Non-Boltzman vibrational distribution for N_2 (1+)

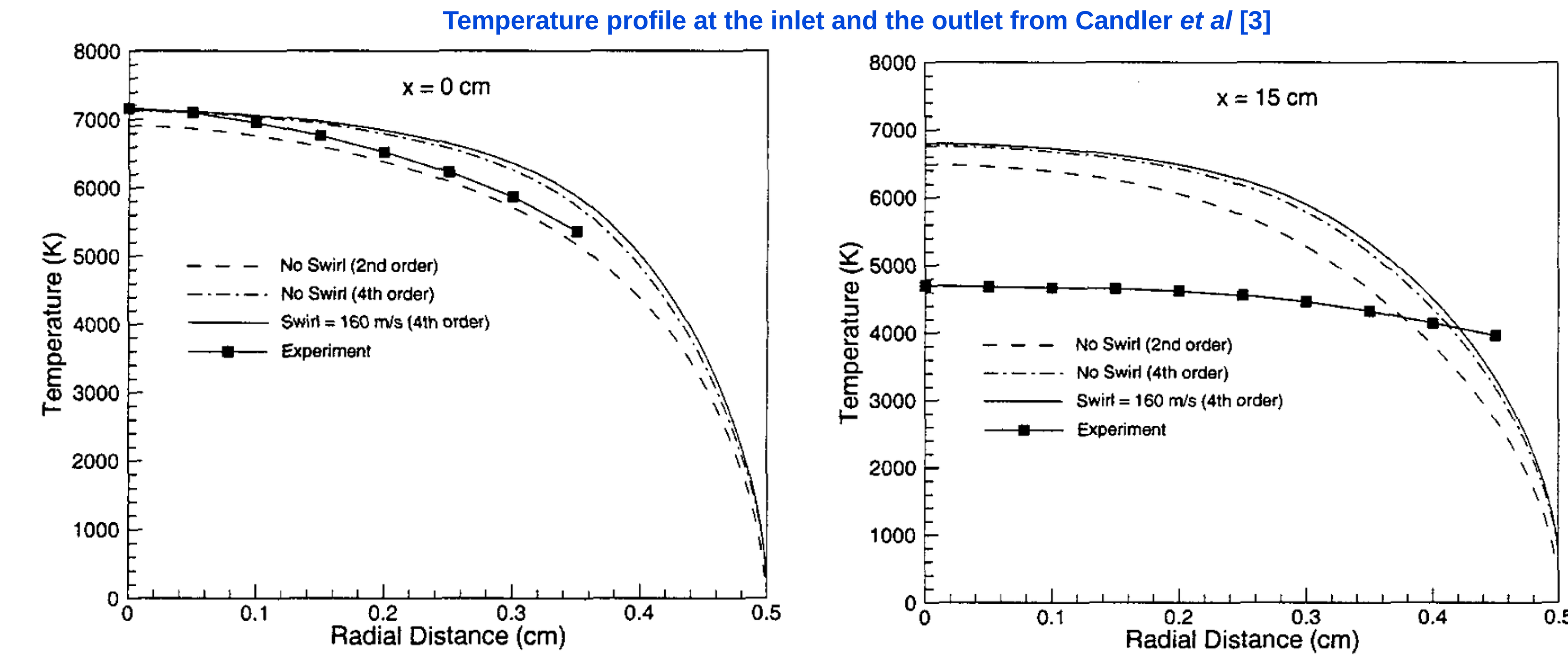


4. Simulations (Candler, 2000)



- Large discrepancy at 15 cm exit between simulations and experiments [3]
- Same discrepancy with Eilmer3 (CFD code from UQ [4])

Temperature profile at the inlet and the outlet from Candler *et al* [3]

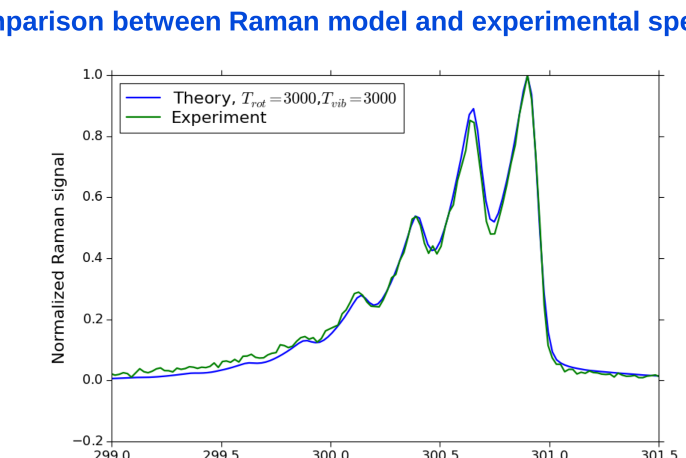


5. Reasons for discrepancy

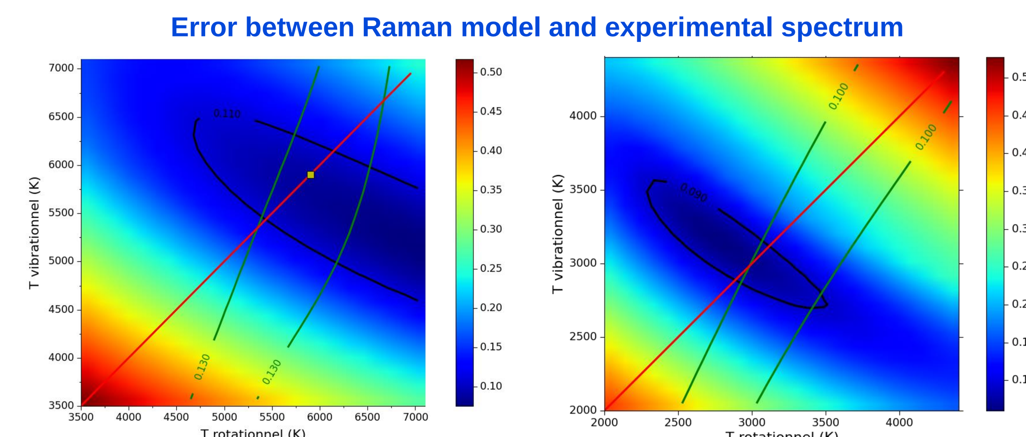
- Recombination of N into rovibrationally excited N_2 is less exothermic than into ground state N_2. Therefore, the temperature may decrease more than predicted using the simple kinetic rate
- Radiant conductivity may increase radial diffusion
- Temperature measured with emission spectroscopy of N_2^+ rotational lines may differ from gas temperature: an independent measurement of temperature is needed.

6. Raman scattering temperature measurements

Comparison between Raman model and experimental spectrum



Error between Raman model and experimental spectrum



Test-section inlet   Exit of 15 cm test-section

- Raman measurements at test-section inlet: $T_{rot} = T_{vib} = 6500 \pm 400K$ close to temperature measured with emission spectroscopy
- At exit of 15 cm test-section: $T_{rot} = T_{vib} = 3100 \pm 250K$ much lower than temperature measured with emission spectroscopy

Future work:

- Measurements at known gas temperature condition for validation of Raman model
- Measurements for various values of $\frac{\tau_{residence}}{\tau_{chemistry}}$, ranging from equilibrium to nonequilibrium conditions

7. References

[1] C.O. Johnston and A. M. Brandis. Features of afterbody radiative heating for earth entry. *Journal of Spacecraft and Rockets*, 52(1):105–119, 2014

[2] C. O. Laux, L. Pierrot, R. J. Gessman. *State-to-state modeling of a recombining nitrogen plasma experiment. Chemical Physics*

[3] G. V. Candler *et al.* Numerical Simulation of Nonequilibrium Nitrogen and Air Plasma Experiments. 29TH AIAA, *Plasmadynamics and lasers conference*

[4] P. A. Jacobs *et al.* Eilmer's Theory Book: Basic Models for Gas Dynamics and Thermochemistry. *Mechanical Engineering Report 2010/09*