Optical Emission and Cavity Ring-Down Spectroscopy Measurements in an Atmospheric Pressure Nitrogen Glow Discharge

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Motivation

- We are interested in efficiently producing large volume air plasmas with:
  - high electron number density ($n_e \sim 10^{13}/cm^3$)
  - low gas temperature (T_g<~2000K)
  - atmospheric pressure (P = 1 atm)

- Such plasmas are of interest as active sources for:
  - Decontamination / sterilization
  - Material processing
  - Remediation of toxic gases
  - Electromagnetic shielding

- Here we focus on the use of cavity ring-down spectroscopy (CRDS) and optical emission spectroscopy (OES) to characterize the plasmas.
  - CRDS allows ground state measurements, but is considerably more complex to implement.
  - OES is limited to excited state measurements, but is relatively easy to implement.

Atmospheric Pressure Nitrogen Glow Discharge

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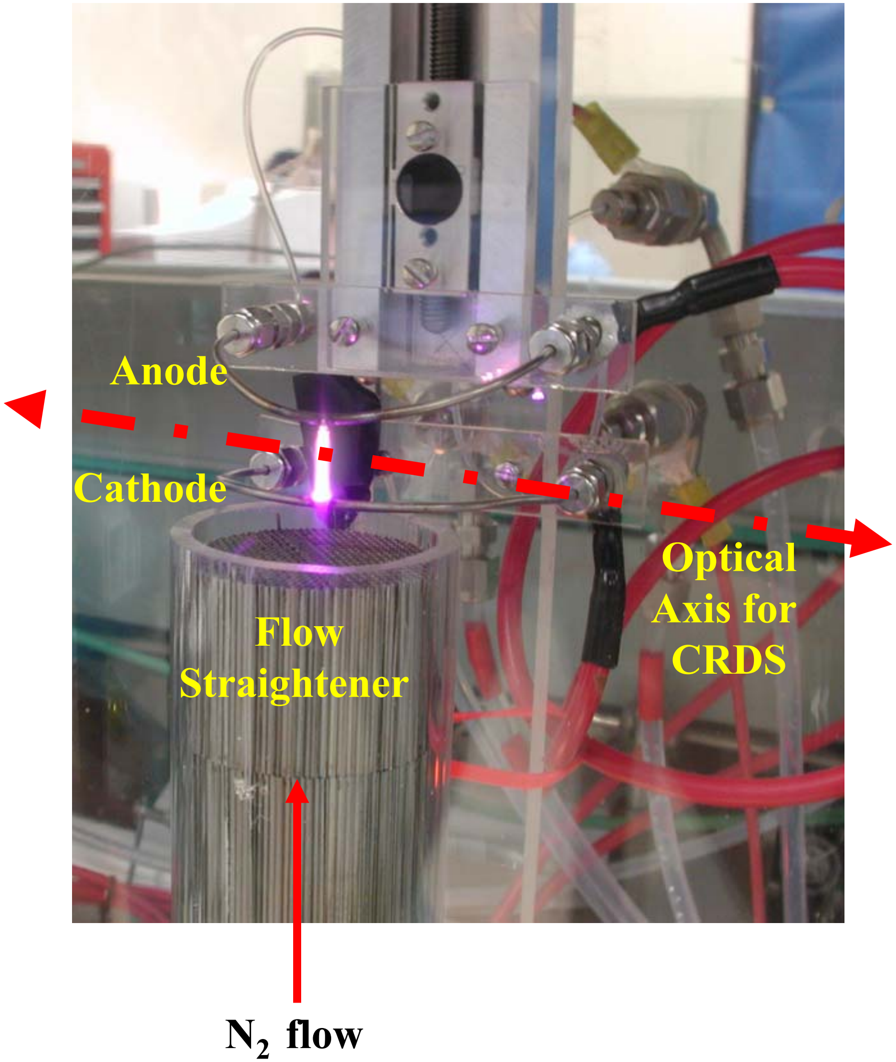
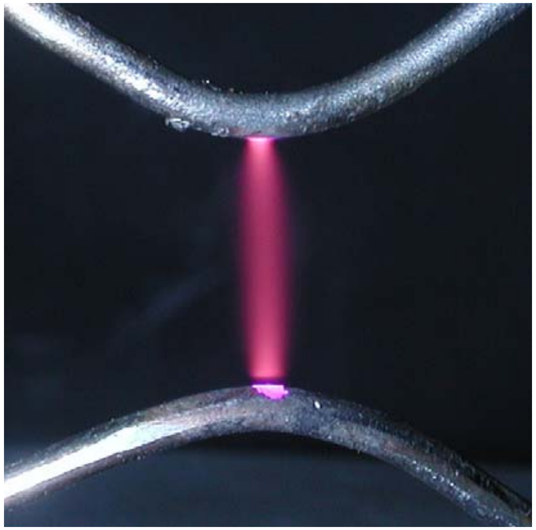


Typical DC parameters:

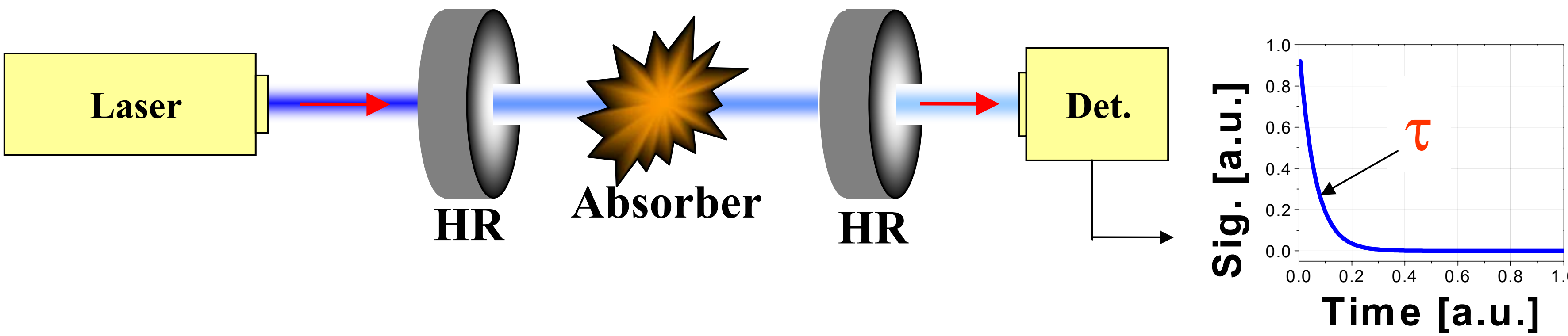
gas: N_2
Flow speed = 10-100 cm/s
i = 50-200 mA
V = 2.5 kV
R_b = 9 kΩ
electrode gap = 0-2 cm



Cavity Ring-Down Spectroscopy

Concept:

CRDS is an ultra-sensitive laser absorption method, in which the absorber is contained within a high-finesse optical cavity. The rate of decay of light within the cavity is measured, and high-sensitivity is achieved owing to the insensitivity to laser energy fluctuations, and the long effective path length.



$$Abs \sim (1\text{-}R)\ \Delta\tau/\tau$$

Optical Emission Spectroscopy

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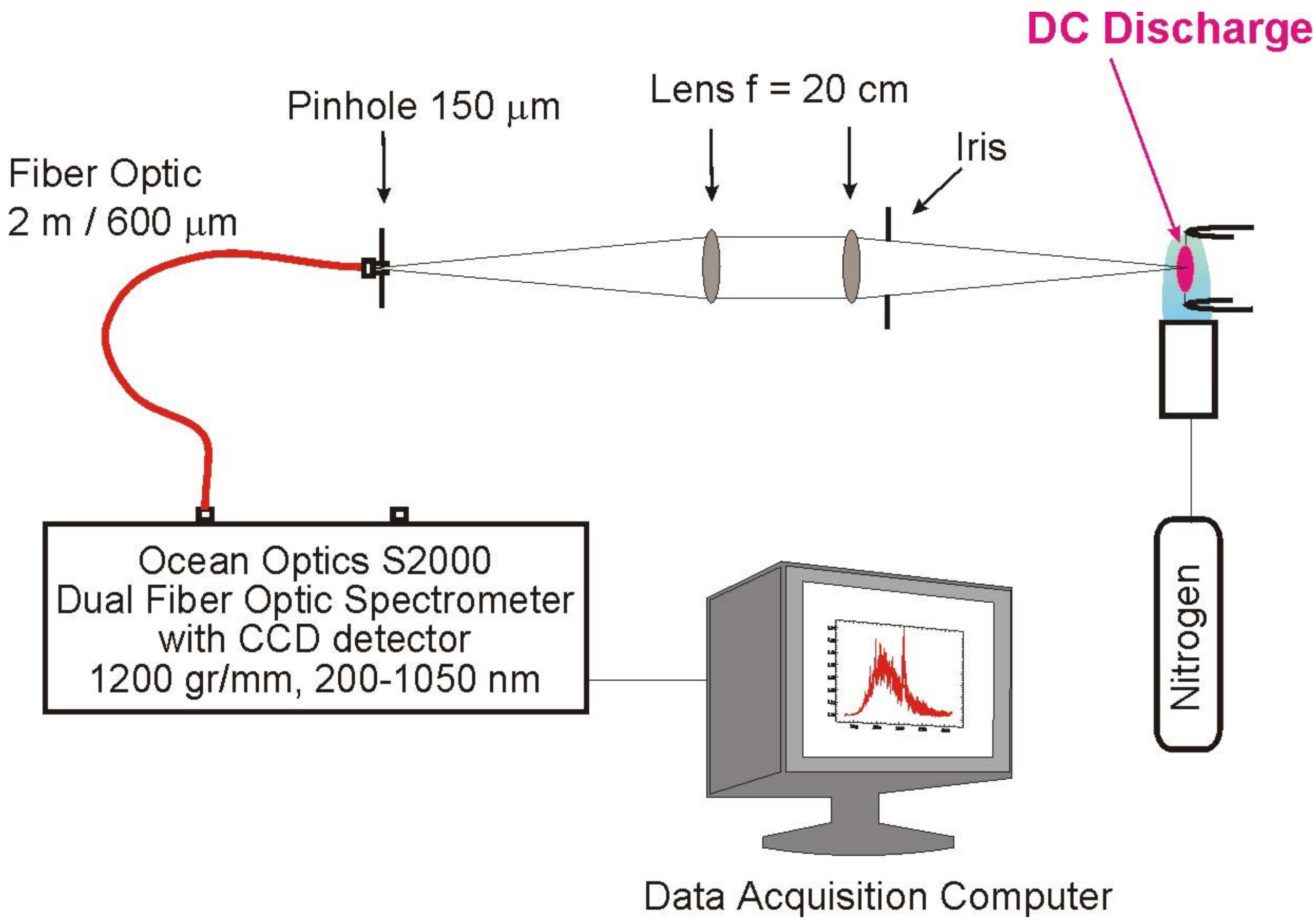

CRD Spectrum of N_2^+ in Nitrogen Plasma

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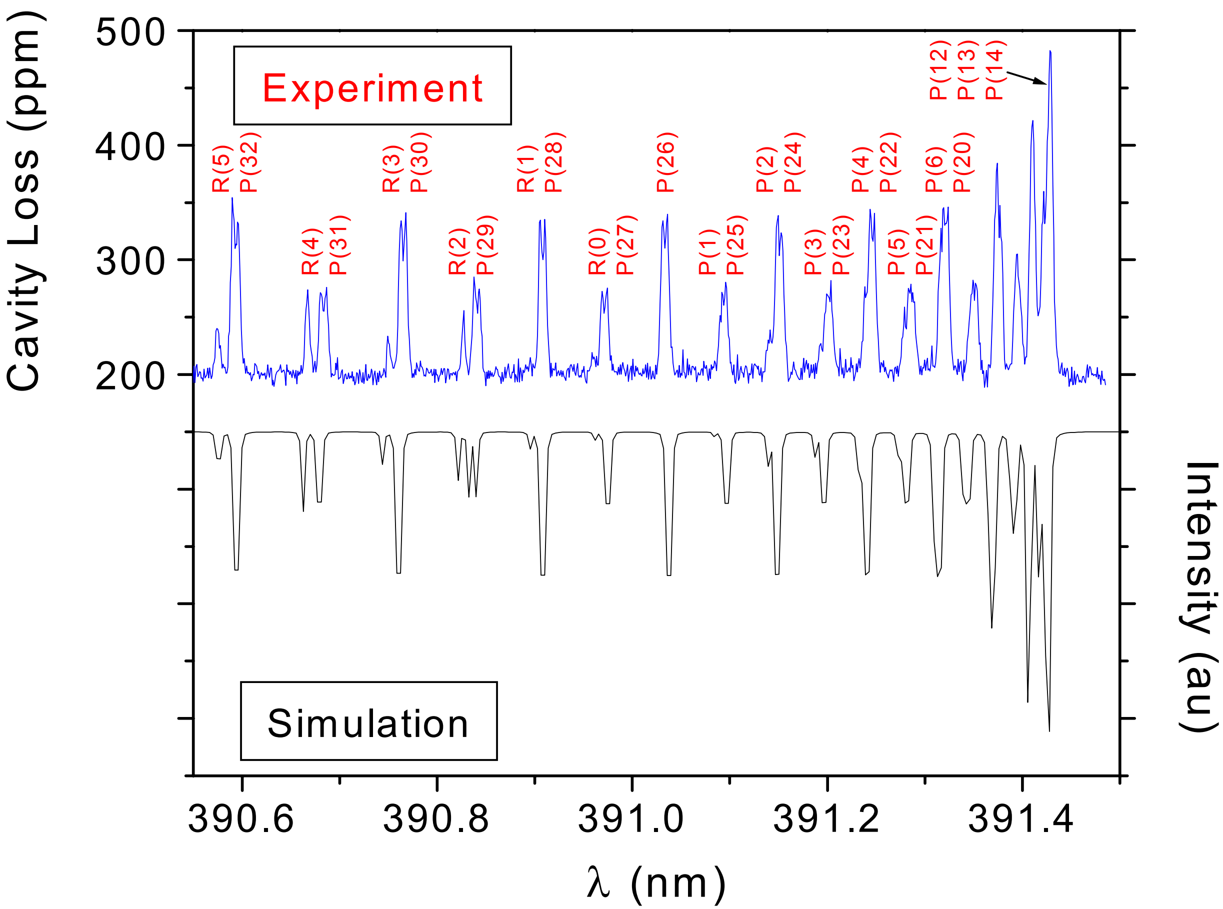
Position: on center-line ; i = 187 mA



Linewidths

Thermal: $\Delta\nu_D \sim 7$ GHz

Laser: $\Delta\nu_L \sim 4$ GHz

Resultant: $\Delta\nu_L \sim 9$ GHz

Baseline Reflectivity

Loss per pass ~ 200 ppm

R ~ 0.9998

OE Spectra of N_2 and N_2^+ DC Plasma

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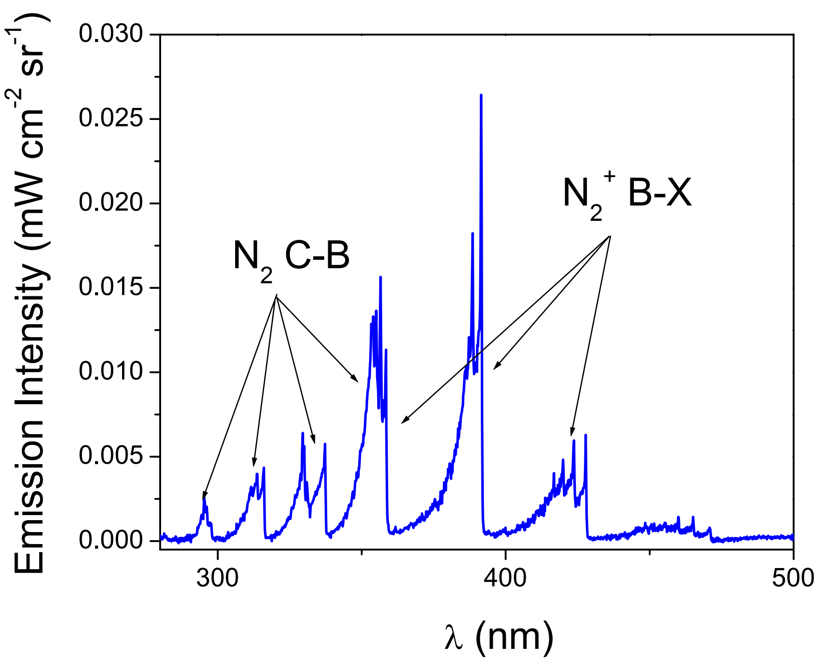
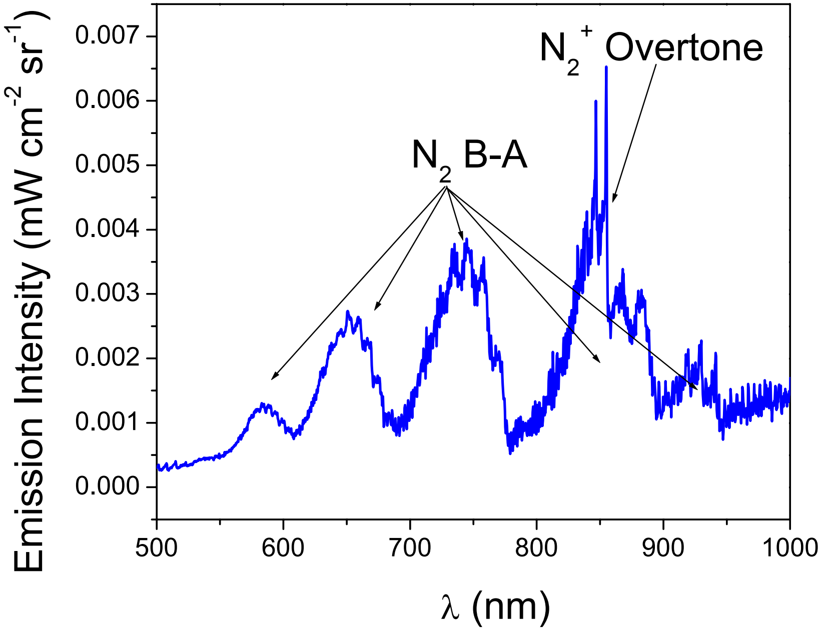
Position: on center-line ; i = 187 mA

UV Grating



Visible Grating



CRDS: N_2^+ Radial Profile

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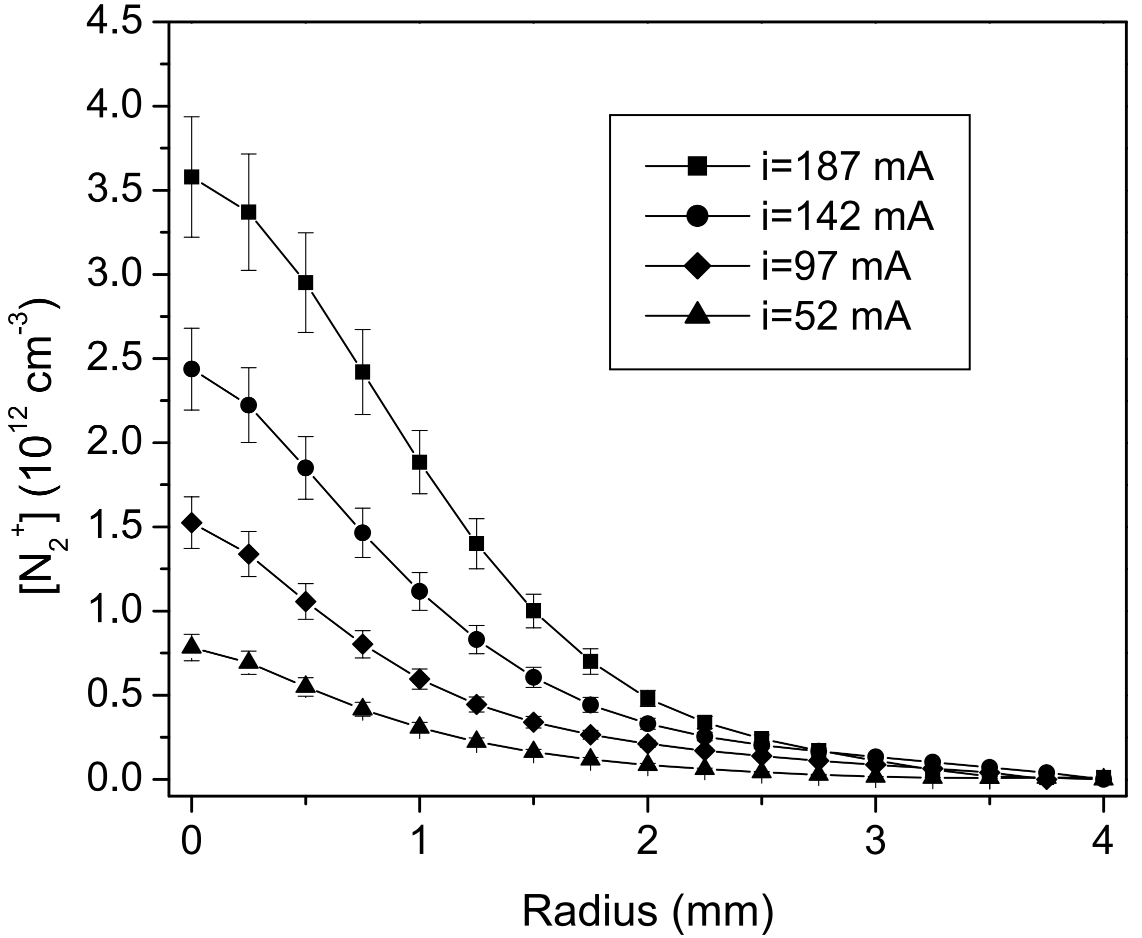
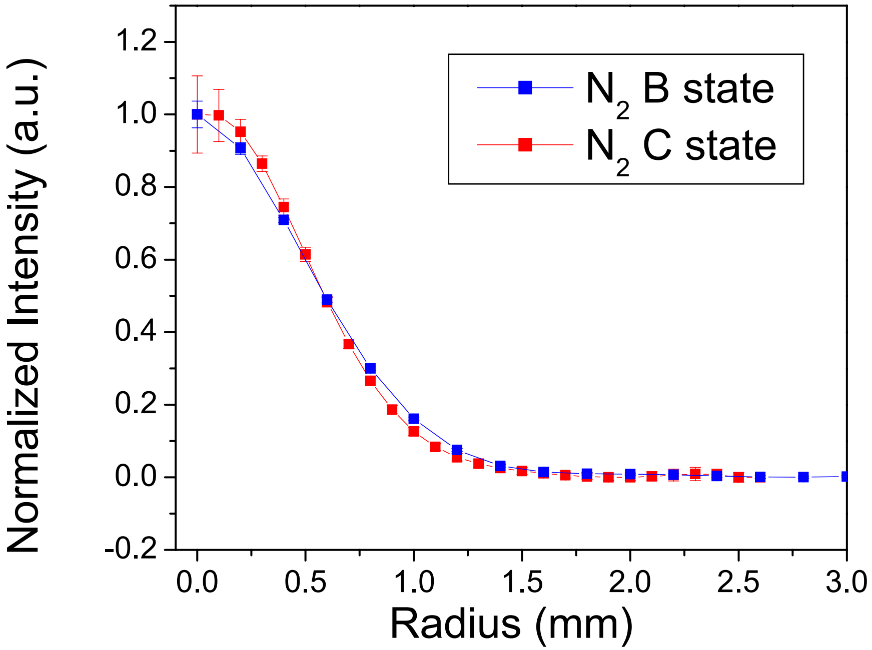
A collisional radiative (CR) model is used to relate the ground state population of N_2^+ (measured by CRDS) to the overall population.

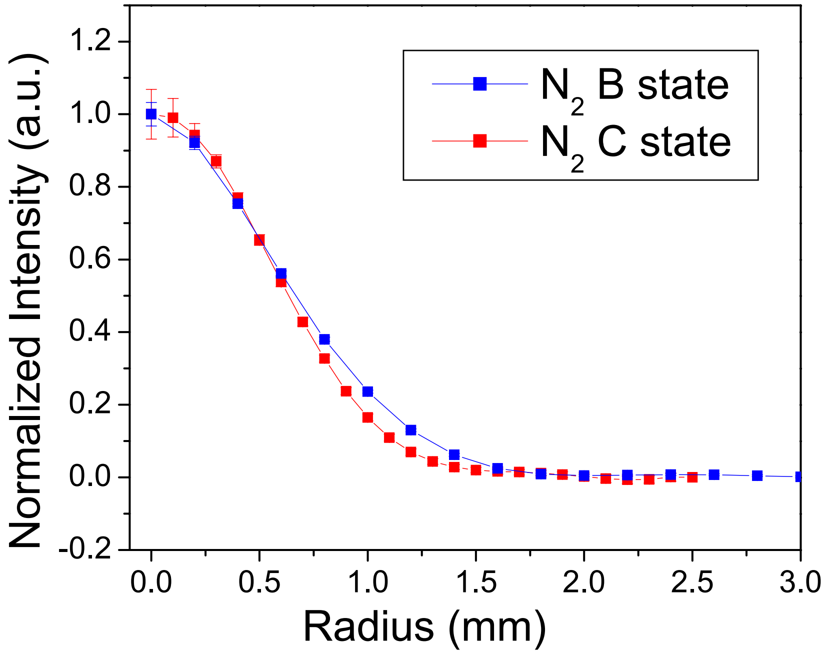


OES: N_2 Excited state profiles

i = 97 mA



i = 187 mA



OES: N_2^+ Excited states; CRDS: N_2^+ Ground states

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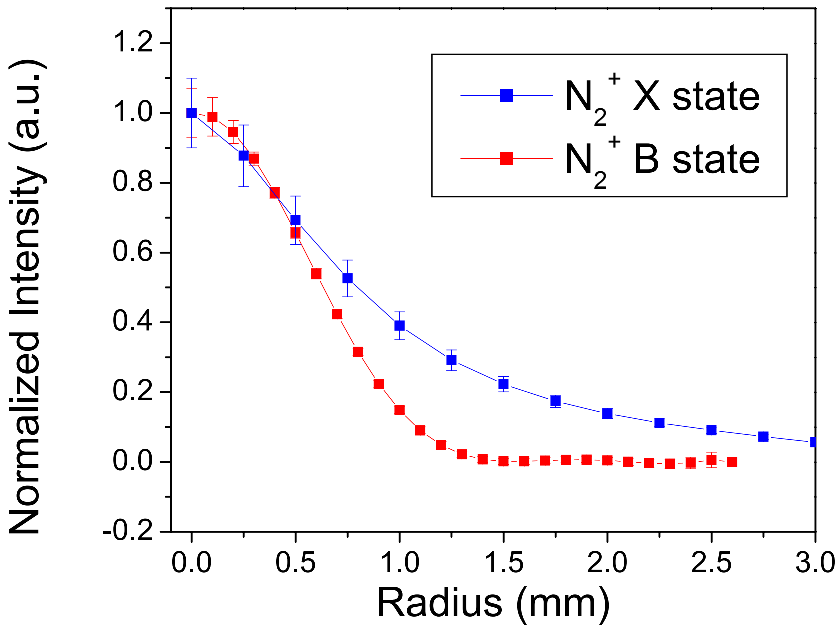
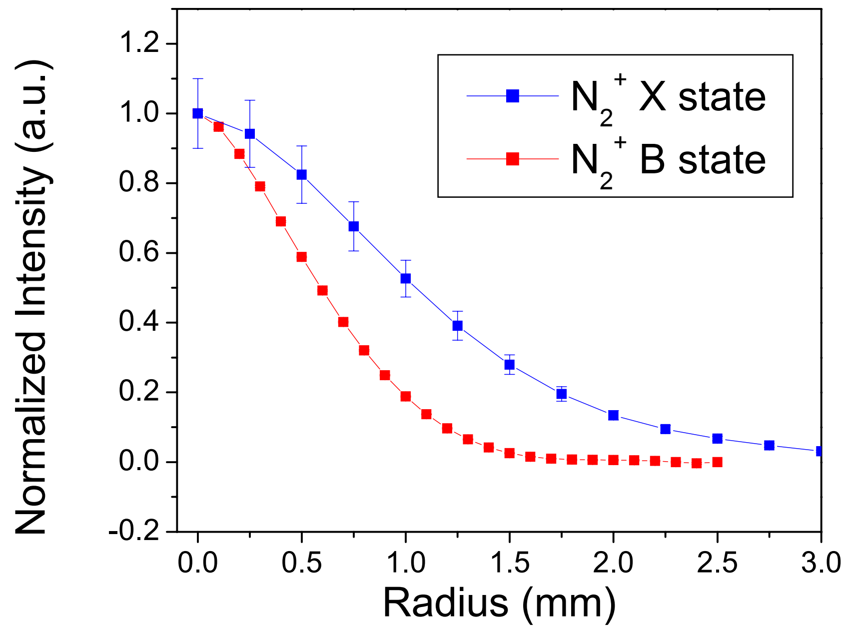
i = 97 mA



i = 187 mA



CRDS and OES Rotational Temperature Profiles

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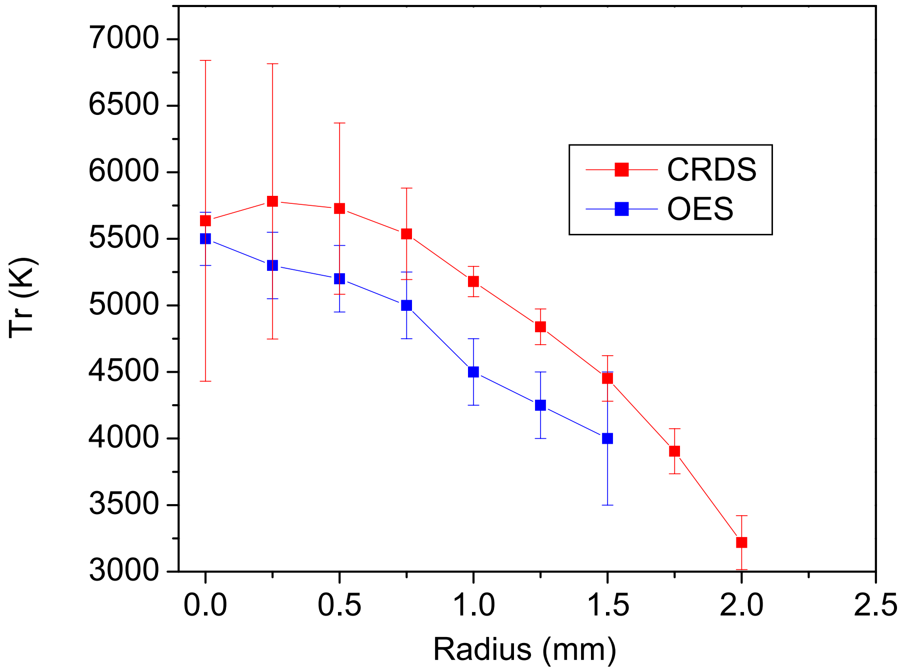
i = 187 mA



•CRDS Tr found from Boltzmann analysis of rotational lines.

•OES Tr found from shape of emission bands (not Abel inverted).

•Both CRDS and OES find Tv = 6100 +/- 600 K at center (r=0).

Discussion and Conclusions

- Good agreement of rotational temperatures gives confidence in CRDS and OES measurement techniques.

- Excited state profiles (from OES) tend to be narrower than the ground state profiles (from CRDS).

  As one moves away from discharge center:

  T_g ♍ ⇒ N ♊ ⇒ E/N ♍ ⇒ Excitation ♍

  In this type of plasma, the results of OES may not be used to infer ground state concentration profiles, and do not properly reflect the discharge dimension.

- Nonequilibrium plasmas may have different excited and ground state species concentration profiles. Combining CRDS and OES measurements enables a detailed characterization which is necessary to attain a fundamental understanding of the plasma.

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