Spectroscopic Diagnosis of Hydrogen Helicon Plasma Discharge

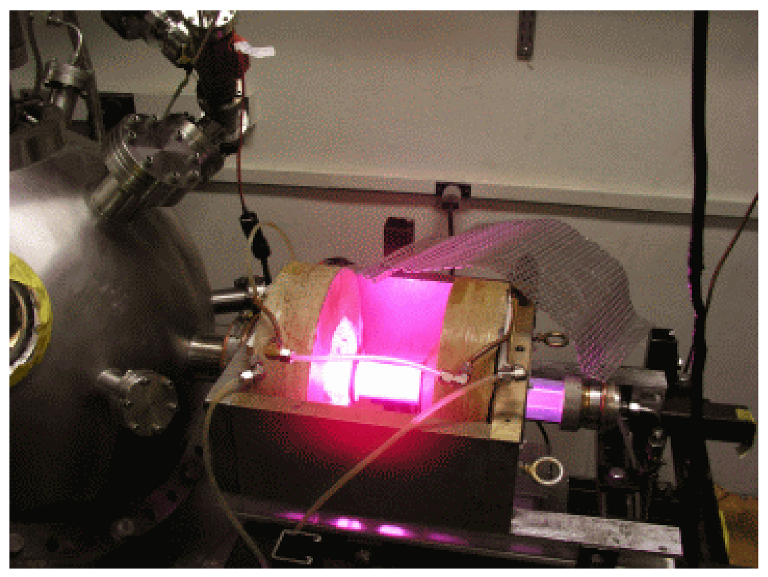
E.C. Alderson, G.L. Kulcinski, J.F. Santarius, D.R. Boris, S.J. Zenobia, G.R. Piefer
University of Wisconsin-Madison Fusion Technology Institute
J. Khachan
University of Sydney Australia

THE UNIVERSITY of WISCONSIN MADISON

Abstract

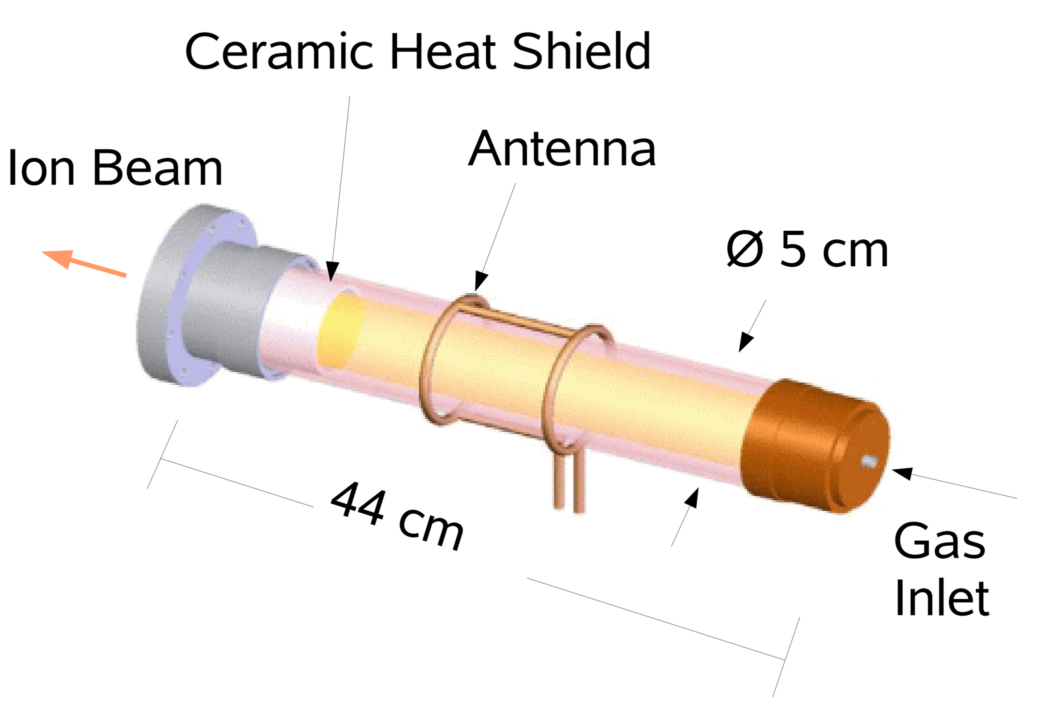
A hydrogen discharge in a helicon source has been studied by coupling spectroscopic measurements with a Collisional Radiative model to produce a series of measurements of the plasma. This plasma diagnosis yielded an electron temperature on the order of 5 eV and electron density in the high 10^{11} cm^{-3} range. The hydrogen gas atomic to molecular ratio was measured between 10 and 27, and the gas temperature was measured by analyzing molecular line emission and found to be on the order of 500K. These results will be useful both in comparing the studied helicon with contemporary helicon sources, and optimizing ion current extraction for use in an Inertial Electrical Confinement fusion device.

The Helicon Source



Applied RF Power: upto **2 kW**
Applied Magnetic Field: up to **0.15 T**

Maximum deuterium current extracted from this device: **30 mA**



Helicon utilized as deuterium and helium-3 ion source for Inertial Electrostatic Confinement fusion application

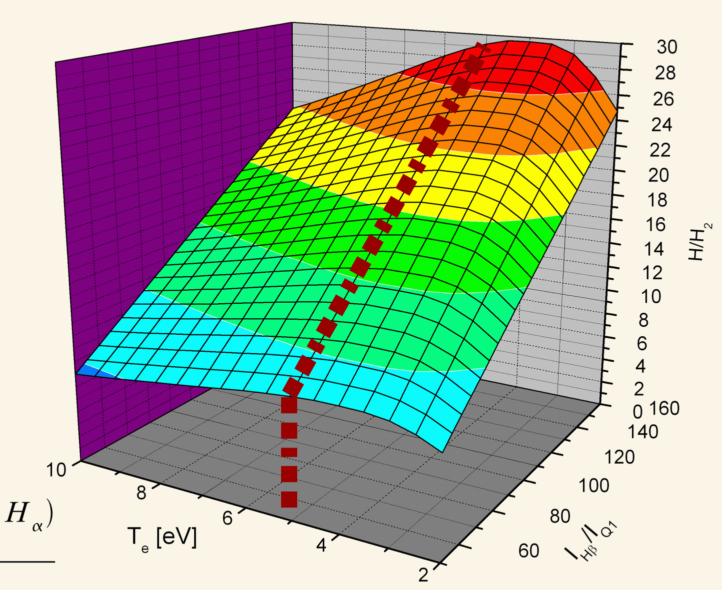
Direct measurement of helicon plasma can be problematic:

- the plasma can be detrimental to physical probes via sputtering and melting
- magnetic fields can introduce electron streaming, perturbing measurements
- applied RF requires special techniques to obtain correct probe reading

Determining the plasma state in a helicon is a challenging problem.

H/H_2 Ratio can be Determined from Spectra Correlation with Collisional Radiative Model.

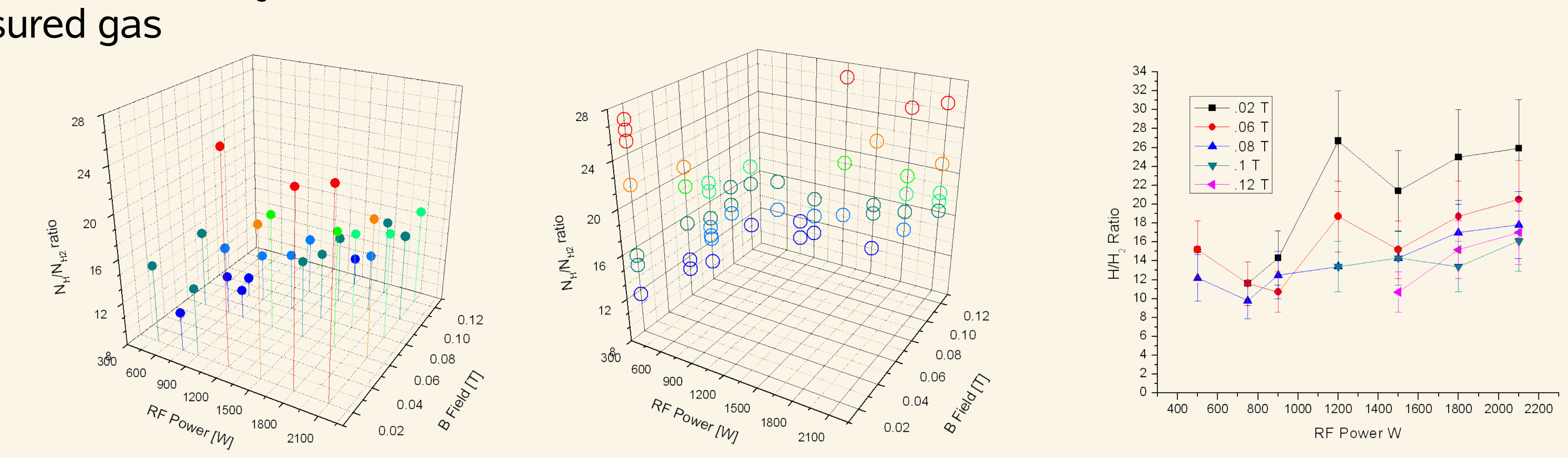
Utilizing work from Lavrov [2], the H/H_2 ratio can be determined from tabulated, electron temperature dependent, transition coefficients, and observed intensity ratios, as described by this equation:



$$\frac{H}{H_2}=\frac{\left(\frac{I_{H\alpha}}{I_{Q1}}\right)\eta(T_{gas})A_{a21}^{d\text{-}21}\tau_{d-21}K_{mol}^{ex}(T_e^{eff}|Q1)-K_{dis}^{em}(T_e|H_\alpha)}{K_{dir}^{em}(T_e|H_\alpha)}$$

T_e is not at this point known in the diagnosis, but a value can be assumed, and checked against later determination for agreement, iterating the value if necessary. The $\eta(T_{gas})$ determined from the measured gas temperature.

[2] B. P. Lavrov, A. V. Pipa, and J. Ropcke, "On determination of the degree of dissociation of hydrogen in non-equilibrium plasmas by means of emission spectroscopy: I. The collision-radiative model and numerical experiments," Plasma Sources Science & Technology 15.1 (2006): 135-46.



Using the produced plot and observed ratios, the H/H_2 ratio was found to be between 10 and 27. The H/H_2 ratio was observed to increase with B-field.

Gas Temperature and Density can be Determined from Molecular Lines.

Gas temperature determined using molecular line properties, tabulated by Astashkevich [1]. The intensity of these lines are governed by:

$$I_{n'',v'',N''}^{n',v',N'}\propto N_{n',v',N'}A_{n'',v'',N''}^{n',v',N'}h\nu$$

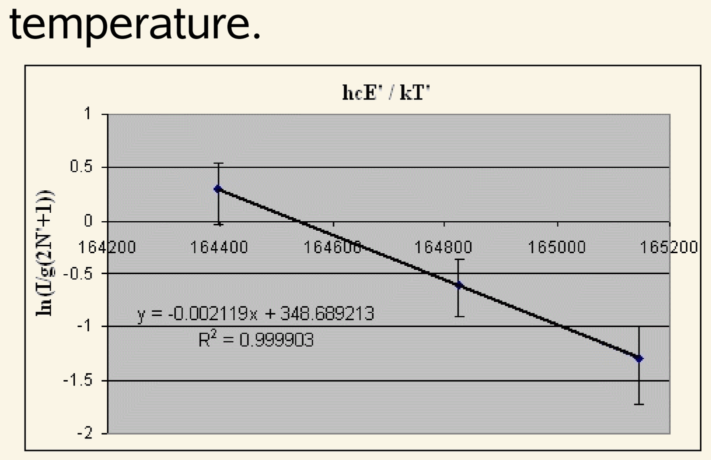
where N is governed by:

$$N_{n',v',N'}\propto c_{n',v'}g_{a,s}(2N'+1)\exp\left(\frac{-hcE_{n',v',N'}}{kT_{rotational}(n',v')}\right)$$

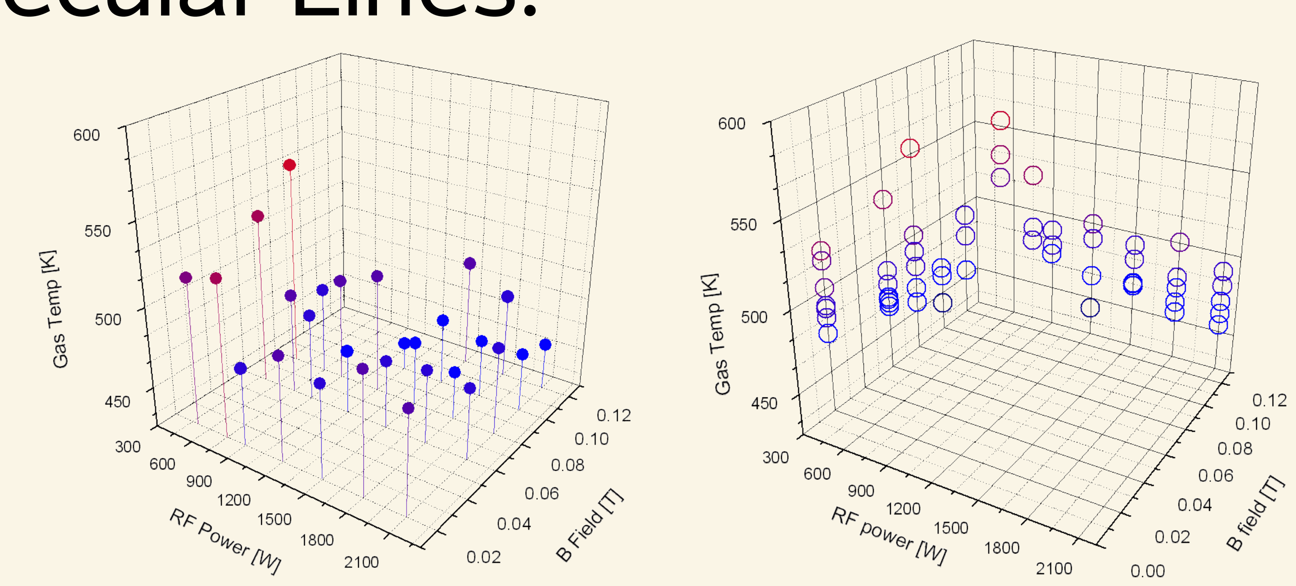
so that the intensity equation is recast:

$$\ln\left(\frac{I_{n'',v'',N''}^{n',v',N'}}{A_{n'',v'',N''}^{n',v',N'}g_{a,s}(2N'+1)}\right)=\ln(C_{onst})-\frac{hcE_{n',v',N'}}{kT_{rotational}(n',v')}$$

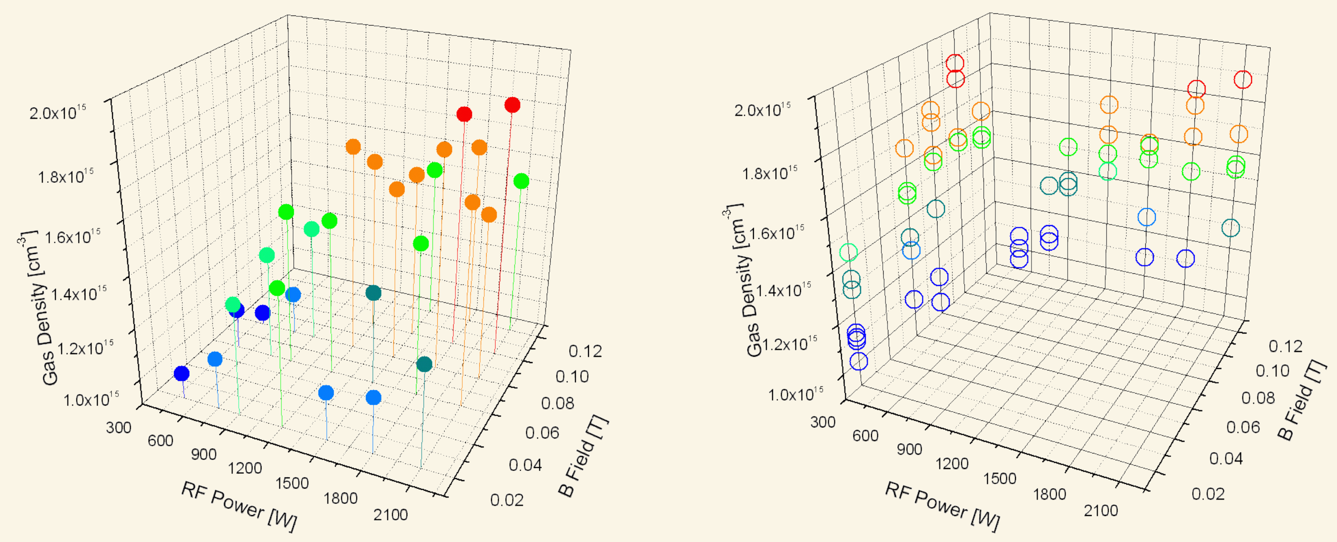
The points may then be graphed, to produce a line where the slope is proportional to the gas temperature.



[1]SA Astashkevich, et al, "Radiative characteristics of 3p Sigma, Pi; 3d Pi-, Delta-states of H2 and determination of gas temperature of low pressure hydrogen containing plasmas," Journal of Quantitative Spectroscopy and Radiative Transfer 56.5 (1996): 725-51.



Gas Temperature determined from molecular line assessment, in helicon operation space, found to be on the order of 500 K.



Gas density determination in helicon operation space, via gas conductance theory, found to be on the order of 10^{15} cm^{-3}.

Electron Population Characteristics can be Determined from Spectra Correlation with Collisional Radiative Model.

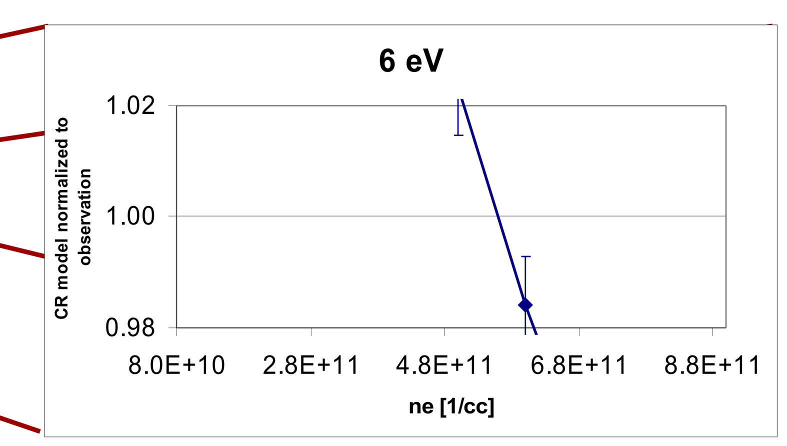
n_e/T_e	5.0E+11	6.0E+11	7.0E+11
4	0.259	0.248	0.239
5	0.262	0.250	0.241
6	0.263	0.252	0.242

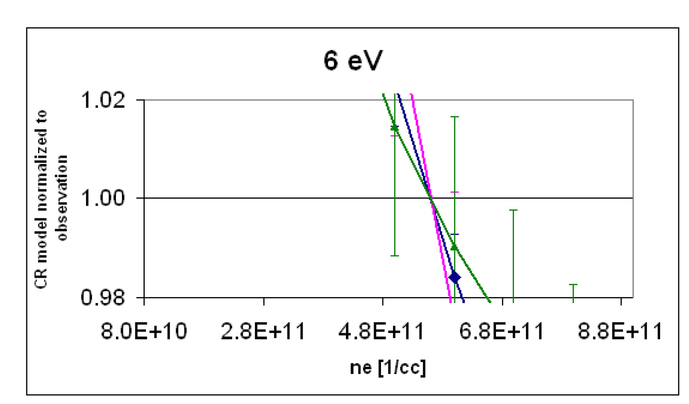
→

n_e/T_e	5.0E+11	6.0E+11	7.0E+11
4	1.017	0.974	0.938
5	1.029	0.982	0.946
6	1.033	0.989	0.950

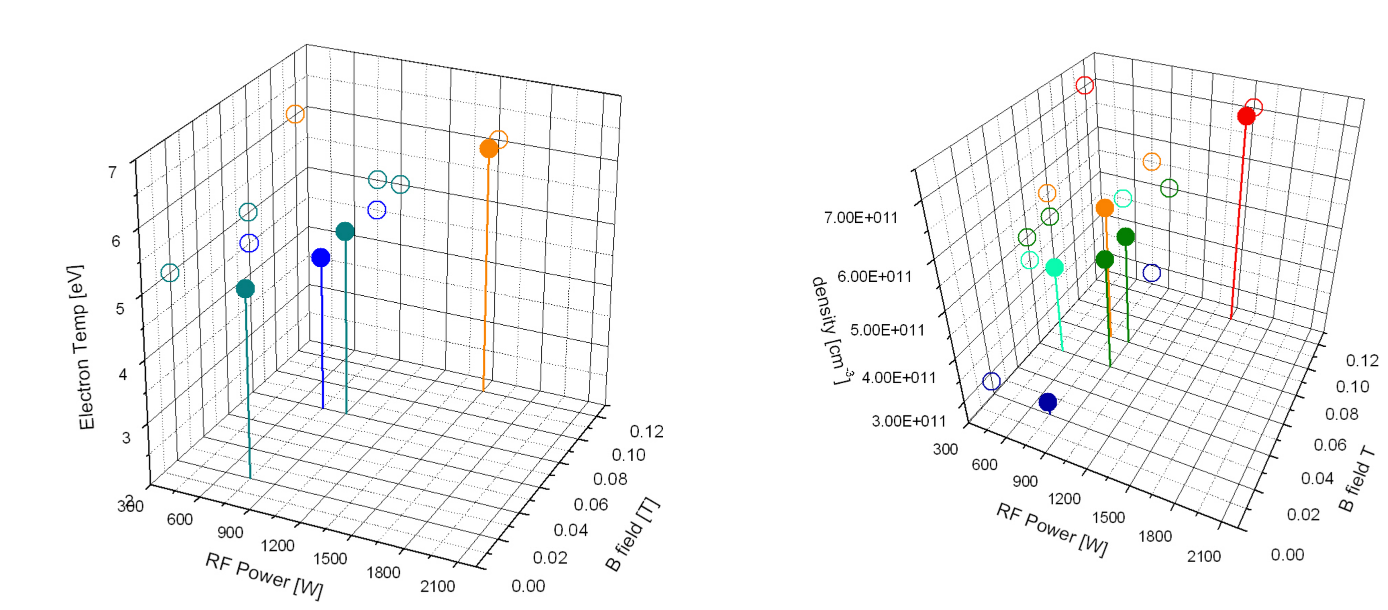
A CR model produced by Sawada [3] is used to predict Balmer series intensity ratios, based on T_e and n_e

The predicted ratios are normalized against the observed ratios to find agreement between model and observation





The election population is determined by the point where multiple intensity ratios agree with the CR model.



[3] Sawada, K. Eriguchi, and T. Fujimoto, "Hydrogen atom spectroscopy of the ionizing plasma containing molecular hydrogen: Line intensities and ionization rate," Journal of Applied Physics 73 (1993): 8122.

The electron density was found to be near 5 eV, and density around 10^{11} cm^{-3}.
From this data we can project that the extracted ion current could be much higher with optimized ion optics.