Laser Thomson Scattering Diagnostics for Low Temperature Recombining Plasmas in Divertor Simulator MAP-II

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Abstract

Electron temperature and density measurements of Helium recombining plasmas are performed in the divertor/edge plasma simulator MAP-II, by means of Laser Thomson Scattering (using a ND:YAG Laser, a double monochromator and an ICCD detector) and optical emission spectroscopy (using a spectrometer and a CCD detector).
The recent upgrades of our LTS system (reduction of the level of stray light and reduction of the passband of the notch filter) allowed us to measure temperatures as low as 0.1 eV and to investigate Electron Ion Recombination (EIR) processes in He plasma.
Spatial profiles of electron temperature and density along the plasma column have been taken moving the plasma "recombination front" across the measurement point by controlling the gas pressure from 80 to about 145 mtorr.
A comparison between LTS results and spectroscopic analysis based on a He I CR model including radiation trapping will be shown in order to confirm the consistency of the diagnostics.

Outline

Background and Purpose

Experimental Considerations:

- MAP-II
- Laser Thomson Scattering System for Low Temperature Plasmas
- He I CR Model
- Helium Recombining Plasmas in MAP-II

Experimental Results:

- T_e and n_e profiles towards the “Recombining Front”
- Comparison between results from LTS and He I CR Model

Summary

Background and Purpose

<u>Heat flux</u> onto the divertor plate will be an operational limit for fusion reactors

<u>Volumetric recombination</u> process is regarded as important to achieve divertor detachment, capable of reducing the heat flux onto the divertor plate

Electron Ion Recombination EIR (<1 eV)

$A^+ + e + e \rightarrow A + e$ 3-body recombination

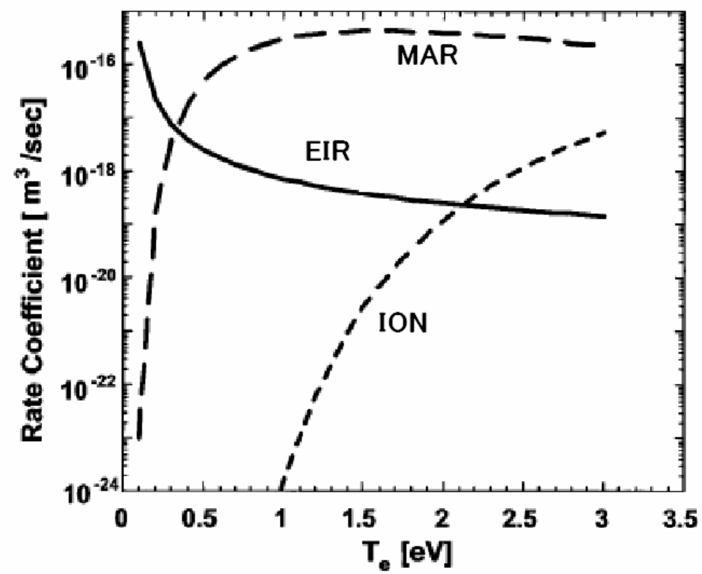
$A^+ + e \rightarrow A + h\nu$ radiative recombination

Molecular Assisted Recombination MAR (2-3 eV)

$$H_2(v) \rightarrow \begin{cases} H^- \leftarrow A^+ & \text{mutual neutralization} \\ H_2^+ \leftarrow e & \text{dissociative recombination} \end{cases}$$

Need for reliable diagnostics in these regimes

Spectroscopy always reflects the brightest point and in recombining plasmas electric probe characteristic exhibits an anomaly

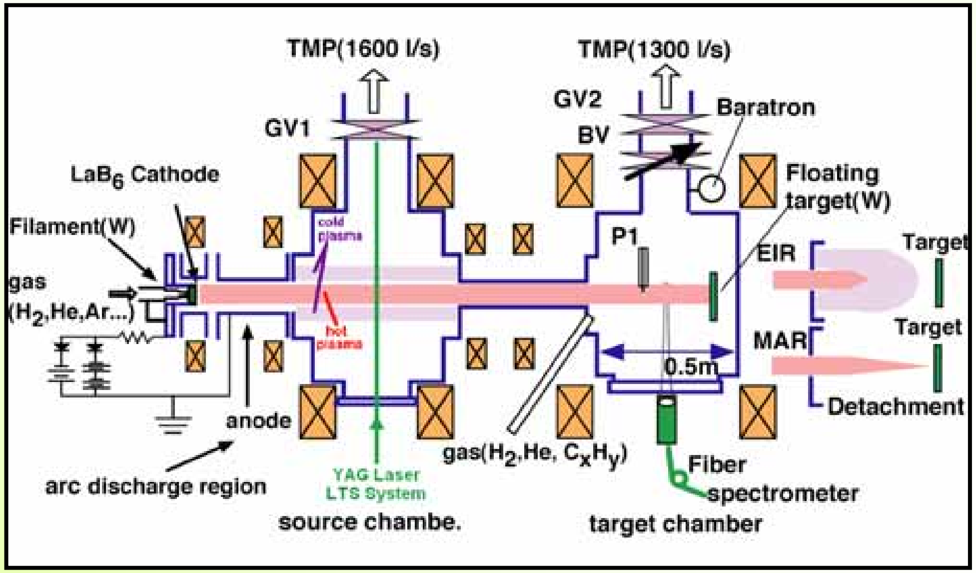


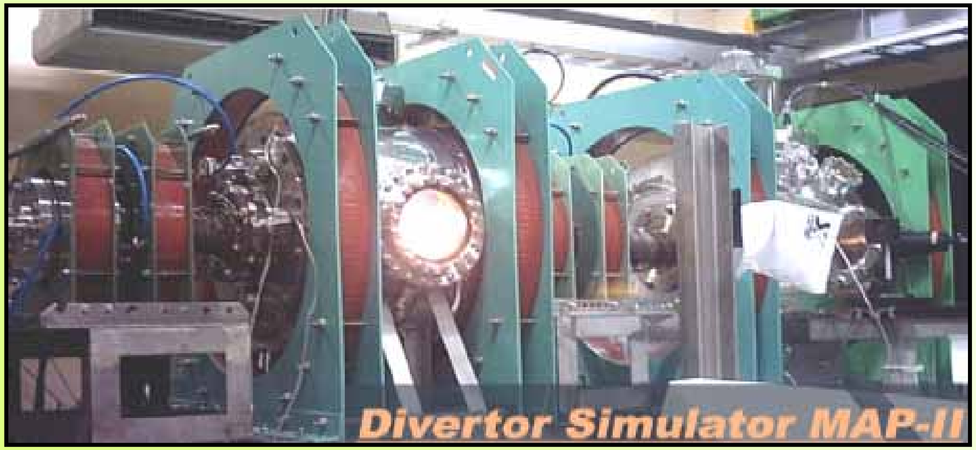
A.Pigarov and S.Krasheninnikov, *Phys.Lett.A* 222(1996)251

<u>Laser Thomson Scattering</u> can be a solution as a diagnostic tool both to measure plasma parameters and to verify results from other diagnostic techniques, such as spectroscopy with a model for the excited state population

The present upgrades are intended for the application of LTS to EIR plasmas

MAP-II Divertor/Edge Simulator





MAP-II: Divertor/Edge Plasma Simulator

Discharge gas: H_2, He, Ar

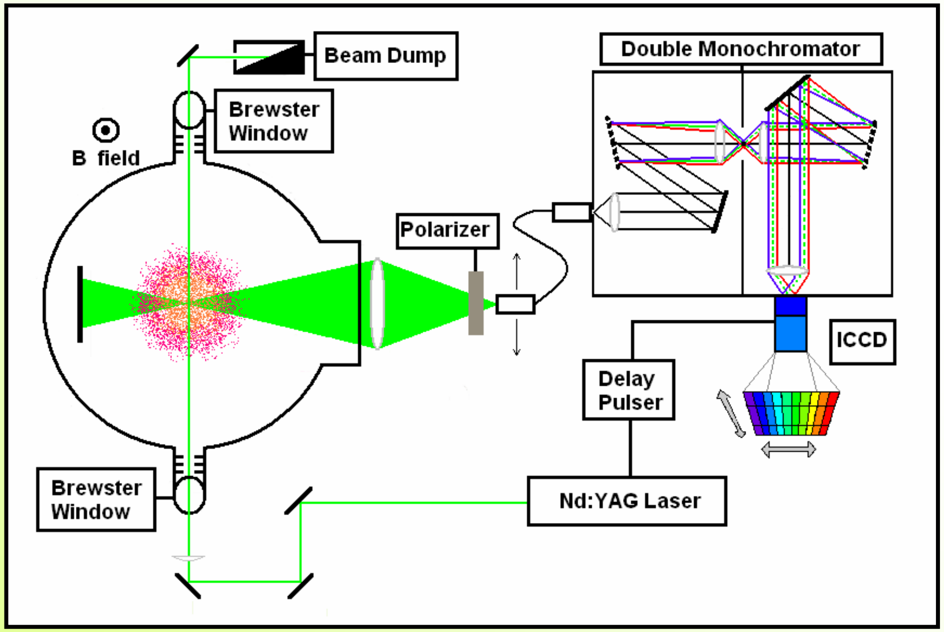
Magnetic field: 200-300 Gauss

Electron Temperature:
less than 10 eV (for He plasma)

Electron Density (1st chamber):
less than several 10^{13} cm^{-3}

S. Kado *et al.*, *J. Plasma Fusion Res.* **81**, 810 (2005) http://www.jspf.or.jp/Journal/2005.html

MAP-II LTS System



A. Okamoto, S. Kado, S. Kajita, and S. Tanaka, *Rev. Sci. Instrum.* **76** (2005) 116106

Frequency-doubled Nd:YAG Laser (500 mJ, 532 nm, 7 ns, 10 Hz)

Accumulation of ~6-8 kJ total Laser input energy (30-40 minutes)

Collecting lens (f=150mm, F/1.4)

Spatial resolution 4.5 mm

Measurable T_e range: **~0.3eV-~20eV**
(0.1eV in the upgrade)

Measurable n_e range: **>~10^{11} cm^{-3}**

Stray light suppression: baffles, Brewster windows, polarizer, beam dump, viewing dump, double monochromator

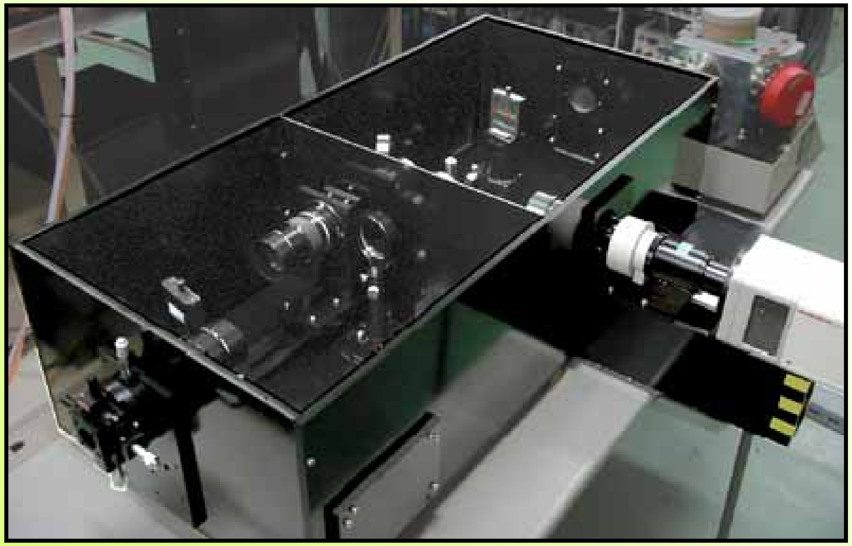
Double Monochromator

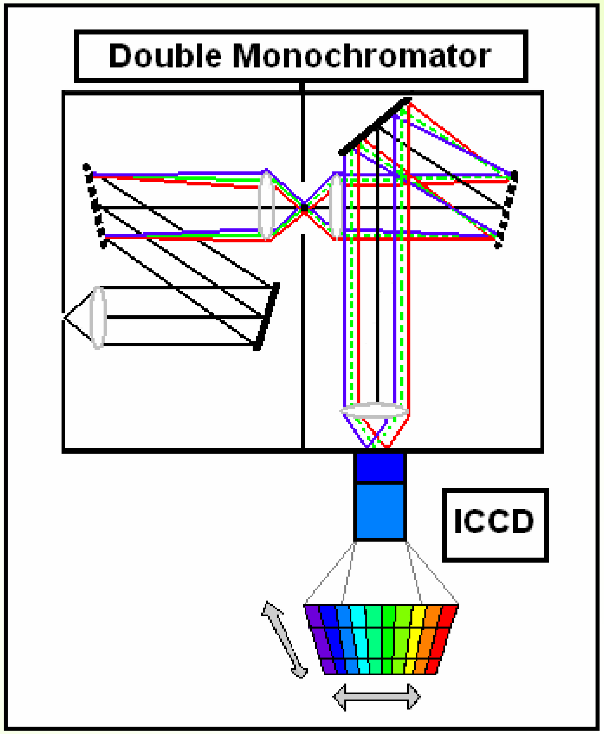
Camera lenses (*f* =135 mm, *F*/2.8) to reduce spherical and achromatic aberrations

Holographic gratings: 50 mm X 50 mm, 1800 lines/mm

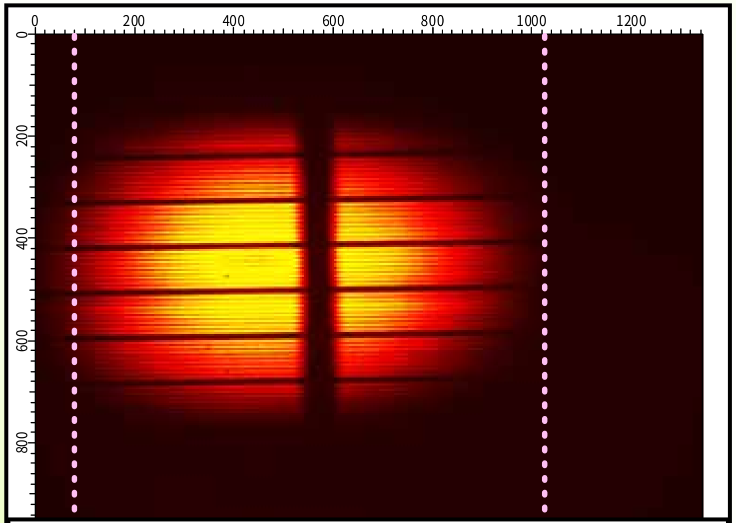
Rayleigh Block: Carbon rod Ø=0.35mm (recently upgraded), determining the lowest measurable temperature

Wavelength Resolution: 0.15 nm (FWHM)
Reciprocal Linear Dispersion: 0.02 nm/PIXEL

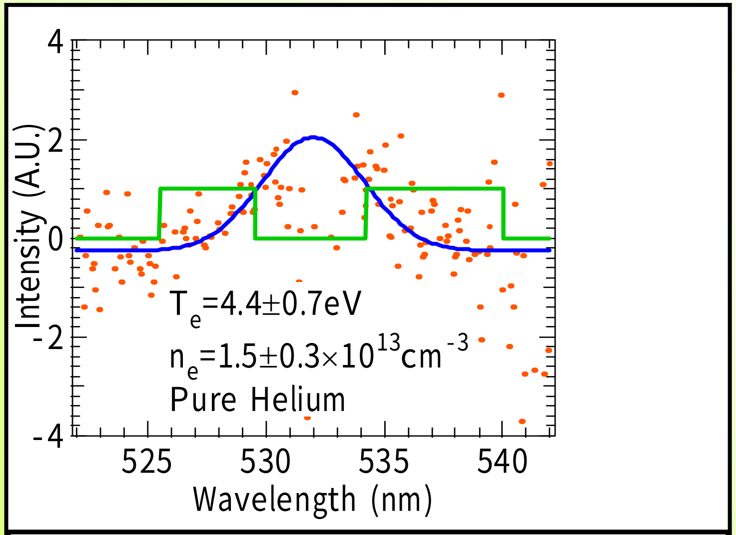




Upgrades of MAP-II LTS System



Block profile @ CCD vs. continuous light



Thomson spectrum

Upgrades of LTS System allowing the investigation of EIR processes :

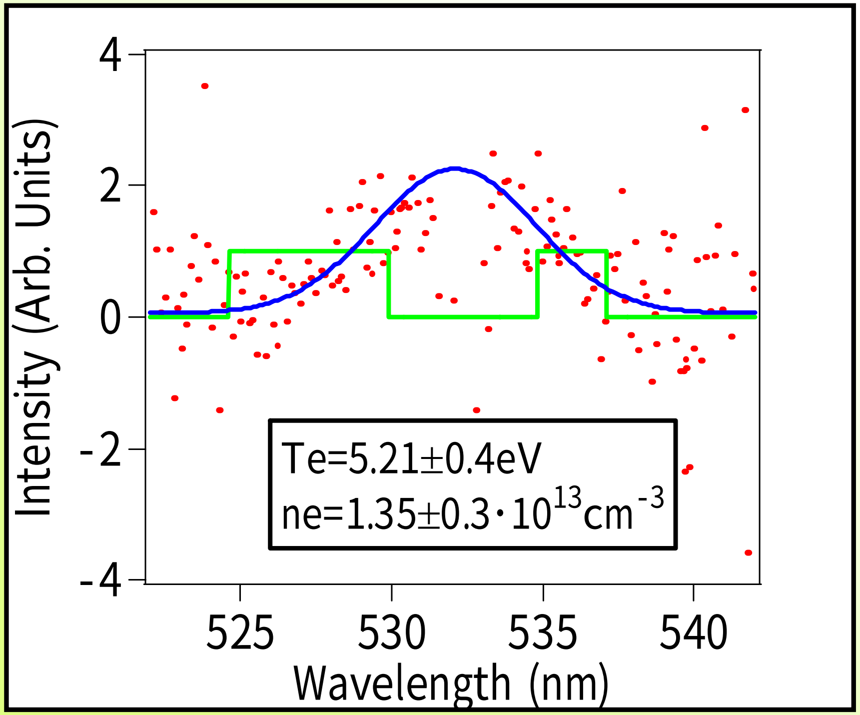
Reduction of the pass band of the notch filter (carbon rod Ø=0.35mm ->copper wire, Ø<0.2mm) reducing the lowest measurable temperature to 0.1 eV

Trade off between lowest measurable T_e and stray light rejection

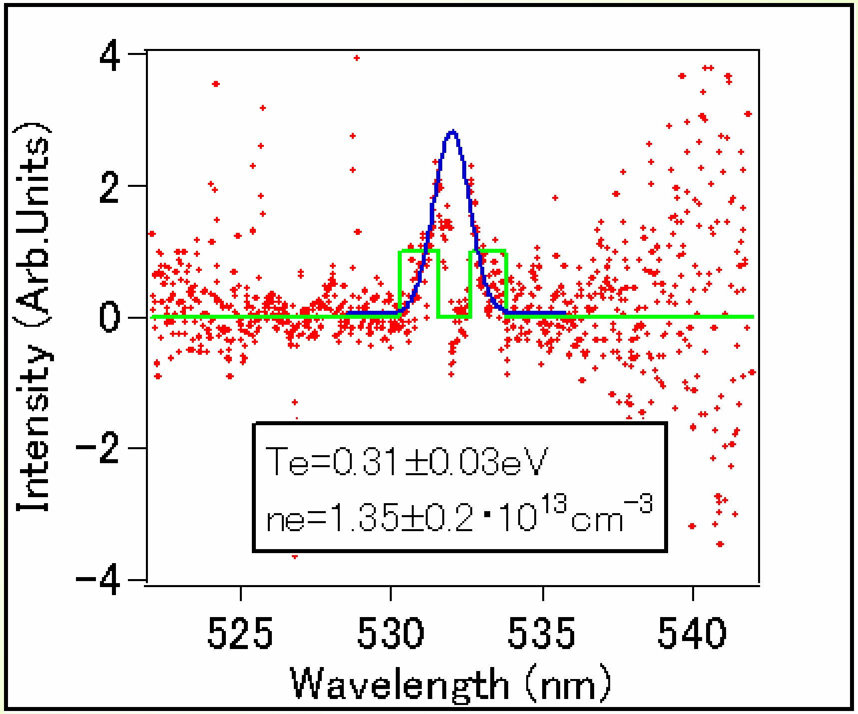
Reduction of the level of stray light from about 10 torr of equivalent N_2 Rayleigh scattered light to about 1-2 torr

Helium Recombining Plasma in MAP-II

Doppler broadened Thomson scattered spectrum in He Plasma in Ionization regime before the latest upgrade



Doppler broadened Thomson scattered spectrum in He Plasma in Recombining regime after the notch filter upgrade



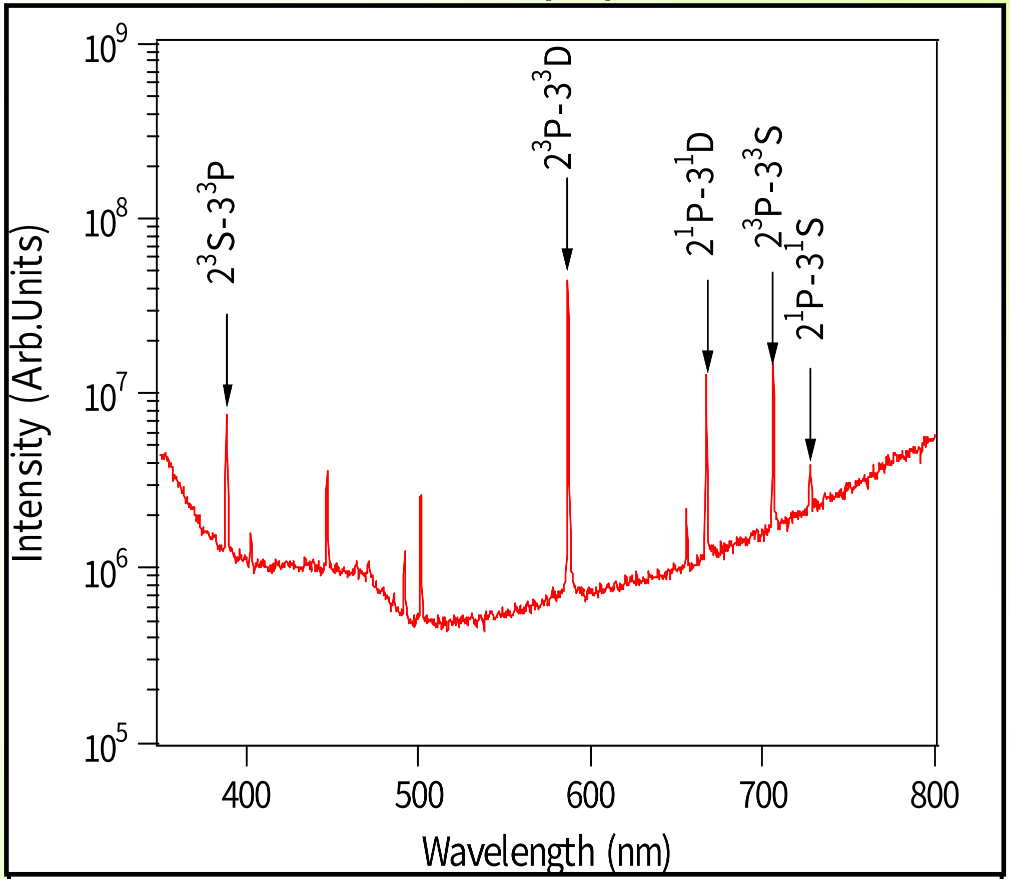
He I CR Model

Spectroscopic data were acquired, using the same optics of LTS, by means of a simple spectrometer equipped with a CCD camera

A Collisional Radiative model, developed by Prof. T. Fujimoto, and Dr. M. Goto was used in order to reproduce the He I excited state population

Radiation trapping was taken into account by means of an optical escape factor in Otsuka's formulation with an effective plasma radius of 2.5 cm (Y.Iida in 2005 for MAP-II plasma)

The fitting to the experimental lines was done using transitions from the level n=3 that resulted more sensitive to electron temperature and density in these regimes: 388.9nm (2^3S-3^3P), 587nm (2^3P-3^3D), 667nm (2^1P-3^1D) , 706nm (2^3P-3^3S), 728nm (2^1P-3^1S)

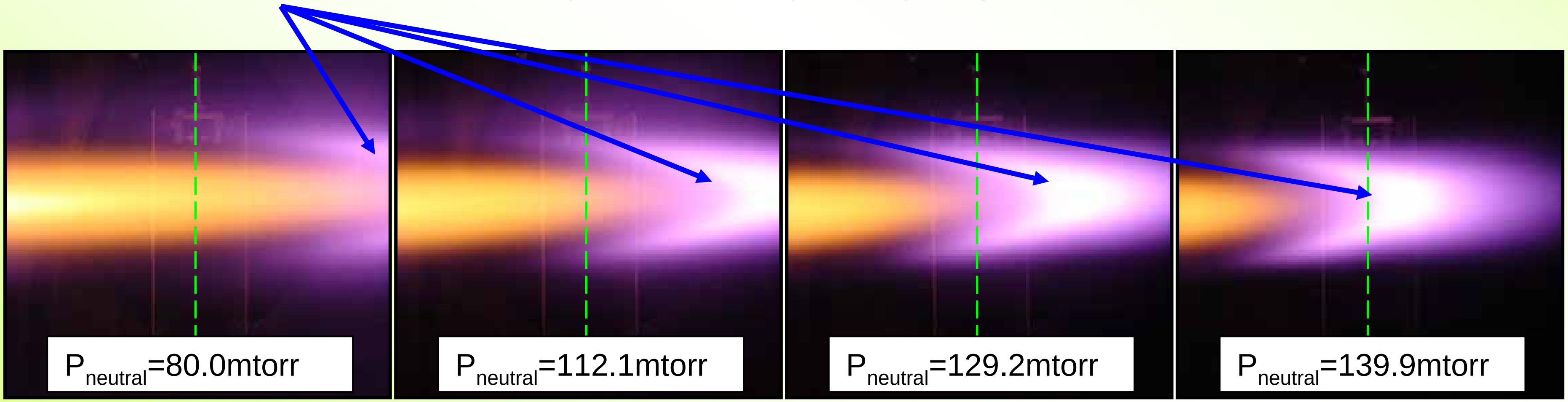


Example of Spectroscopic Data in He Ionizing Regime

Helium Recombining Plasma in MAP-II

He Recombination is induced in the 1st chamber by increasing He puffing from the 2nd chamber, without changing the discharge conditions

Since the position of the laser is fixed, in order to measure a spatial profile of the recombining plasma along the plasma column, we moved the "recombination front" by controlling the gas pressure



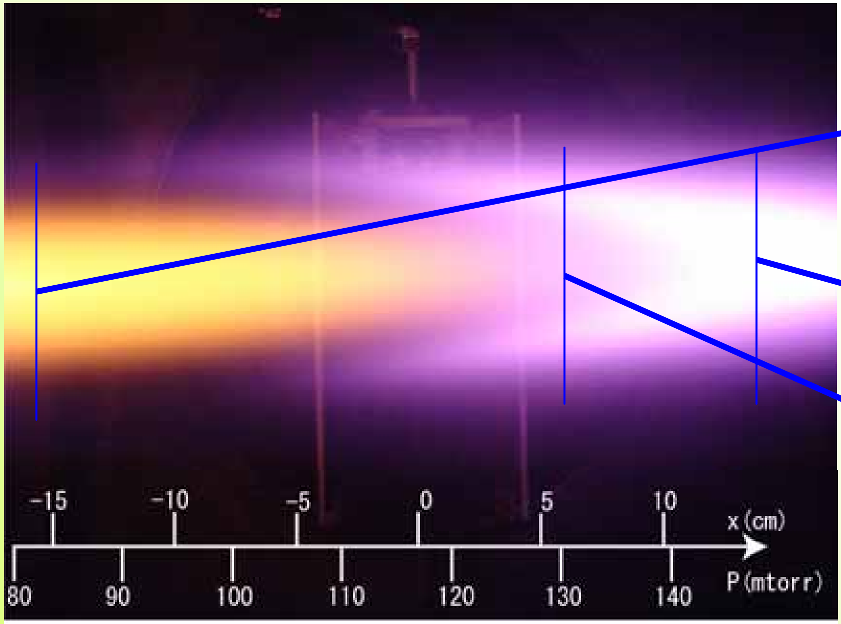
Discharge conditions: V=65 V, I=30 A, changing neutral pressure from 80 to 145 mtorr by changing the gas flow

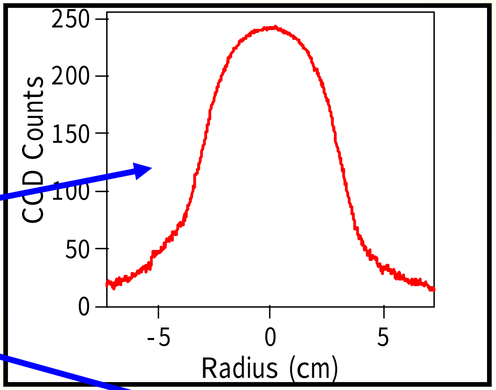
Helium Recombining Plasma in MAP-II

Electron collisions were dominated by elastic collisions with neutrals and ions with a mean free path decreasing from about 1 mm to about 0.1 mm

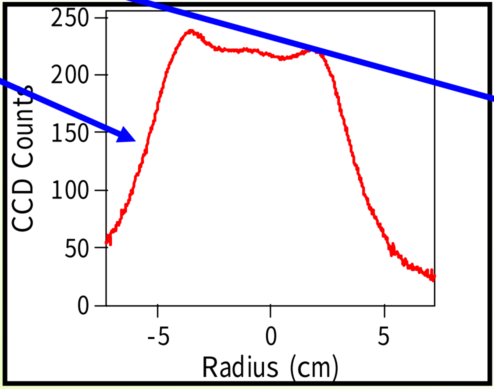
The energy relaxation length, due to elastic collisions, results of the order of 10 cm, comparable with the characteristic length in the plasma column

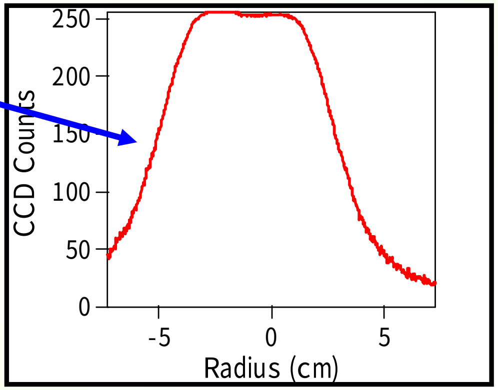
The responsibility for the decrease in electron temperature goes to the elastic collisions with neutrals and ions





Local measurement (LTS)
vs.
averaging over the line of sight (spectroscopy)





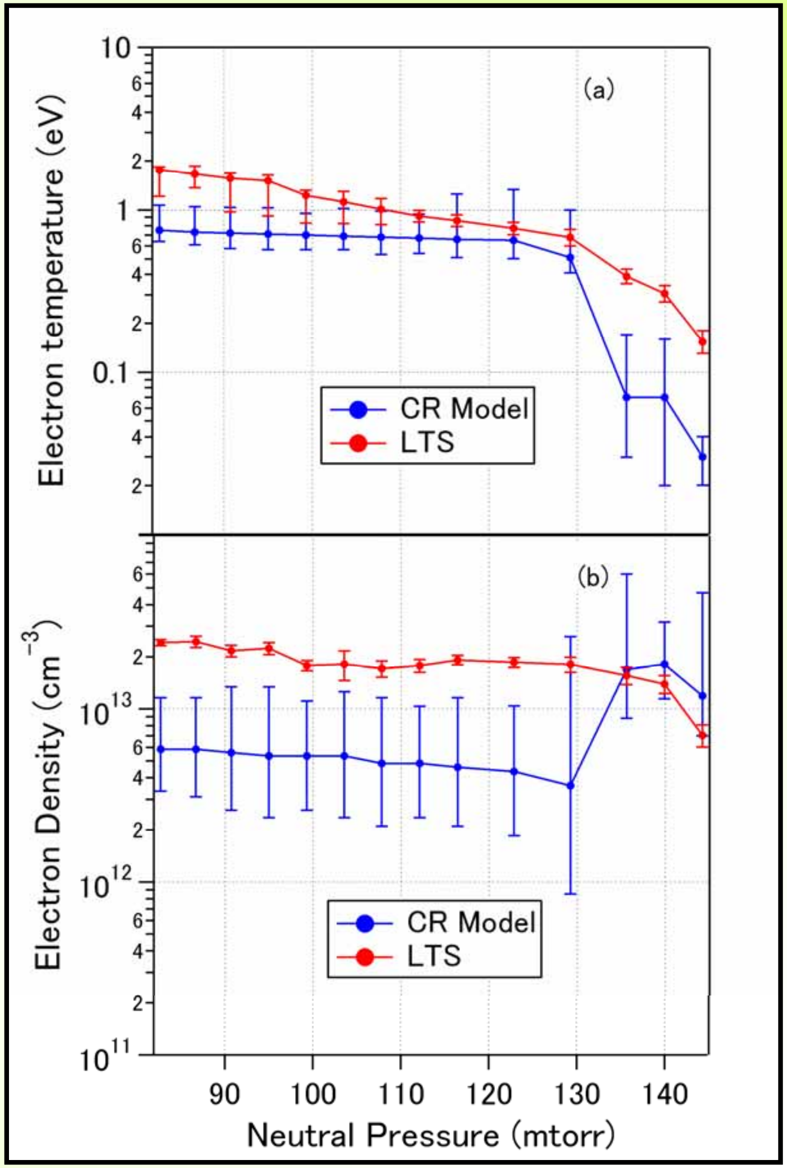
LTS vs. He I CR Model results

According to LTS results, T_e monotonically decreased as increasing the P_{neutr} with the lowest measured T_e (0.15 eV) close to the lower limit of our system

The steeper slope in T_e and the beginning of the decrease in n_e after the neutral pressure of 130 mtorr suggest the beginning of EIR

For what concerns CR Model results, the fitting in the recombining region results consistent with LTS

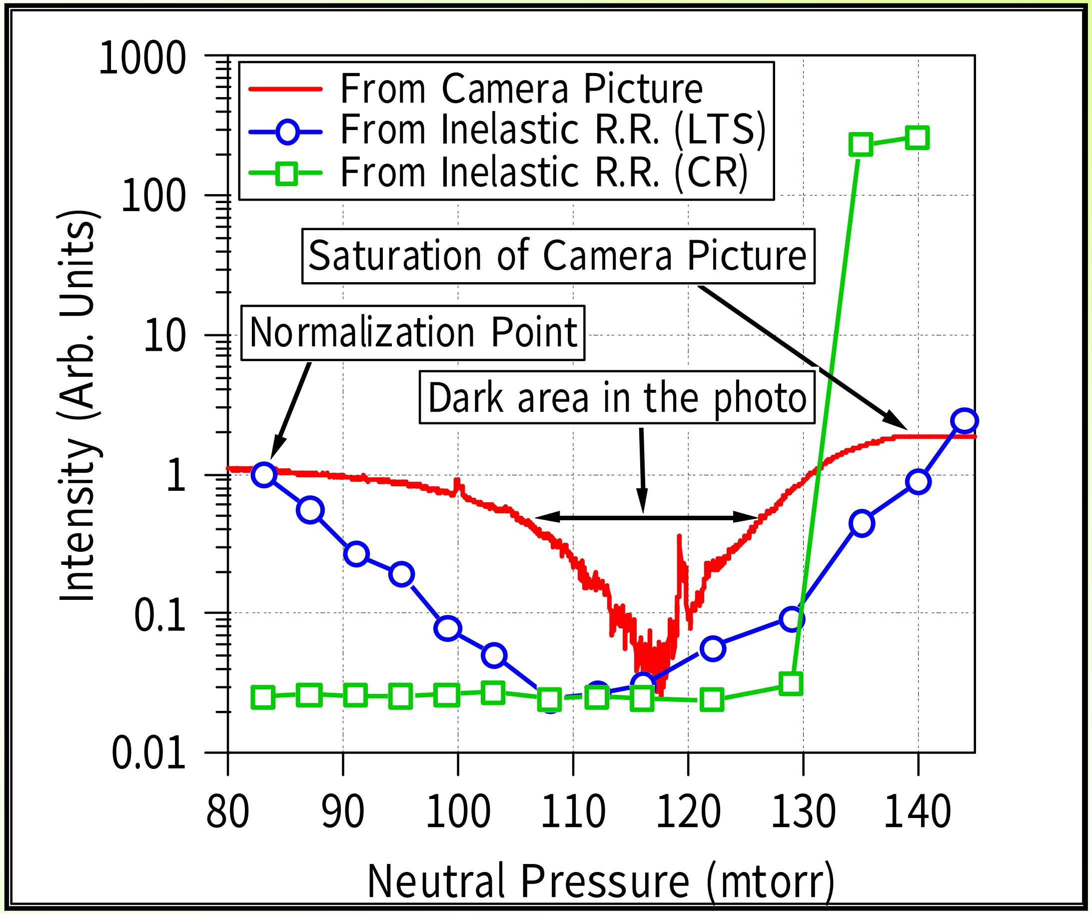
The ionizing region results deviated especially in the density profile by means of a factor of 3-4, that cannot be explained only by the averaging over the line of sight



LTS vs. He I CR Model results

The inelastic reaction frequency can be put qualitatively in correspondence with the light emitted from the plasma

We can compare the relative light intensity from digital camera picture with the profile of the inelastic reaction frequencies obtained using as plasma parameters the result from LTS and CR Model



The decrease of the inelastic reaction frequency, evaluated using LTS results, in the central region of the plasma column results consistent with the darkest region observed in camera pictures

Summary

Summary

•LTS measurements are performed in low temperature recombining plasmas

•LTS upgrades for application to He EIR plasmas have been presented

•Measurements of T_e and n_e spatial profiles in EIR plasmas have been carried out in MAP-II

•A comparison with He I CR Model including radiation transport has been shown

•As expected, the results of CR Model agreed with LTS results in the recombining region

•Deviations between the two diagnostics, in particular in the absolute value of the electron density, can be found in the ionizing region