In the usual laboratory plasmas, thermal disequilibrium can be achieved in each species (Maxwellian distribution function), and NOT between them.

Thermal disequilibrium between species is a common feature.
Laser Thomson Scattering for very low Te plasmas

Precise comparison of Arc source with Discharge Cathode disk (LaB6 OES (He, 64V, 30A))

\[ T_e (\text{LTS}) \text{ monotonically decreased down to 0.065 eV, which agrees well with those obtained from the Boltzmann plot (BP) method (0.068 eV) for the Rydberg series and from CR model (high-}\text{n).} \]

Deviation around the brightest point is attributable to the integration effect:

\[ \text{LTS} \rightarrow T_e \text{ at the tip Spec. } \rightarrow \text{T}_e \text{ in the bright cone.} \]

**Conclusion #1**

\[ T_e (\text{high-}\text{n, BP and CR}) \sim 0.06-0.07 \text{ eV} \text{ -- confirmed by LTS} \]

Laser Thomson Scattering (LTS) - Principally, a direct observation of EEDF -

Corona (Thomson scattering) can be observed in the solar eclipse when incident component (sun) is shielded by the moon.

**LTS vs Spectroscopy (high -n) at EIR front**

**cf. LTS spectra**

**Difficulty and the Solution to \( T(p) \) Diagnostics**

He line broadening:
- Instrumental function: with aberration
- Doppler (temperature): \( W_0 \) Gaussian
- Stark (density): \( W_0 \) Lorentzian

\[ n_0 > 10^{15} \text{ cm}^{-3}, \text{ principal quantum number } n \geq 6 \]

Practically, however, it is difficult to determine \( W_0 \) and \( W_0 \) at the same time (freedoms for both could be compensated for each other).

Therefore, we have proposed measuring line profile of several spectra, in which the contribution balance of Gaussian and Lorentzian is different:
- low-\( n \) state: More Doppler \( \rightarrow \) Atomic temperature
- high-\( n \) state: Doppler and Stark \( \rightarrow \) Temperature and electron density

**Equilibrium Feature**

**Doppler-Stark Spectroscopy for He I line broadening**

\[ W_0 (3P) = W_0 (3P) = W_0 (1S) (\text{He}) \]

\[ \rightarrow \text{ Atomic Temperature} \]

\[ W_0 (3P) = W_0 (3P) + W_0 (1S) (\text{He}) \]

\[ \rightarrow \text{ Electron Density} \]

\[ W_0 (1S) = W_0 (1S) + W_0 (1S) (\text{He}) \]

\[ \rightarrow \text{ ion Temperature} \]

(in recombinating plasmas)
Disequilibrium Feature

Fitting was performed in the region free from the coma aberration (blue wing in UV region).

Achieving Thermal Equilibrium in Recombining Plasma

1/2 difference $\rightarrow$ integration effect

Values from Stark are plausible.

Using $n(TP)$ to determine $T(7^D)$ from Voigt profile can be reasonable.

Conclusion #2

In the recombining regime, $3P(\text{atom})$, $7^D(\text{ion})$ and electron are achieving thermal equilibrium among them.

In addition, thermal disequilibrium feature has been recognized in ionizing plasma.

Thermal Disequilibrium Feature in the Excited Atoms

Consideration of the equilibrium feature of the excited state is important because observed line emission reflects the excited state thermal.

Also, since we have observed that the atoms and ions are not in the thermal equilibrium state in the ionizing plasma ($T(p) \neq T(\text{ion})$), next we'd like to know if we need to pay attention to the excited level to be measured or not.

Thus, rigorous explanation to the observed disequilibrium feature in the ionizing plasma might be a hint to clarifying the underlying physics, and also might address requirements for the A&M data.

Ionizing Plasma: Possible heating mechanisms (hypothesis)

(hypothesis) atoms are heated while the bounded electron is excited. Plus, the D state more reflects the heated components. -- because the lifetime of each excited state is too short for the verification $\Rightarrow$ whole excited states are heated 2) ratio of the ex-heated to normal-heated components in the emission.

1) heating of the excited states.

2) Contribution to the observed emission lines

Average resident ratio of excitation before emission:

$\alpha(p) = \frac{n_pR_p(\text{ionizing})}{n_pR_p(\text{CX})}$

elastically by electrons and ions $\Rightarrow$ too small during the lifetime

$n^{\prime}$ principal quantum number.

Griem boundary $\sum n^{\prime} \Sigma_{n^{\prime}} e^{\text{ionizing}} \gg \sum n^{\prime} \Sigma_{n^{\prime}} e^{\text{CX}}$

elastic collision by electrons and ions

$\alpha(p) = \frac{n_pR_p(\text{ionizing})}{n_pR_p(\text{CX})}$

$n_0$, $n_0$ Raman (CX)

3) Contribution to the observed emission lines

Average resident ratio of excitation before emission:

$\alpha(p) = \frac{n_pR_p(\text{ionizing})}{n_pR_p(\text{CX})}$

elastically by electrons and ions

$n^{\prime}$ principal quantum number.

Griem boundary $\sum n^{\prime} \Sigma_{n^{\prime}} e^{\text{ionizing}} \gg \sum n^{\prime} \Sigma_{n^{\prime}} e^{\text{CX}}$

elastic collision by electrons and ions

$\alpha(p) = \frac{n_pR_p(\text{ionizing})}{n_pR_p(\text{CX})}$

$n_0$, $n_0$ Raman (CX)

Heating Mechanism of the Excited State by CX

Resident time $\approx$ average loss from $p > p^\prime$

Charge exchange

More accurate data would be helpful

Conclusion #3

CX "latter" heat the high-$n$ states during the characteristic (resident) time.
Contribution to the Observed Emission

Average resident ratio of excitation before emission:

- Above Griem: HOT
- Below Griem: COLD

\[ \alpha_{\text{ex}}(p) = \text{influx from above Griem} \]
\[ = \text{influx from below Griem} \]

\[ \alpha_{\text{ex}} \text{ is larger in high-}\text{n states.} \]
\[ \alpha_{\text{ex}} \text{ is larger for high electron density.} \]
\[ \text{Fine-structure dependence among same n.} \]

Review: experiments

- Low-\text{n}\text{e}: heating was not sufficient to be detected.
- Mid-\text{n}\text{e} and high-\text{n}\text{e}: only \text{T(D, }^3\text{D)} \text{ exhibits excess increase with } \text{n.}
- \text{ }^3\text{P cannot be observed (short wavelength).}

It seems a good agreement with the experiments.

Note: low-\text{ne}, heating was not sufficient to be detected.

Conclusions

Usually, plasma is in the thermal equilibrium states only for each species --- Boltzmann distributions with different temperatures.

This is due to the existent of the energy flow.

Equilibrium

Electrons: Thermal equilibrium is achieved in very low temperature below 0.1 eV for the recombining plasmas.

Thermal equilibrium between electron, ion and neutral is achieved in the recombining plasma.

Dis-equilibrium:

Plausible origin of the dis-equilibrium feature observed among the excited states in high density ionizing plasma was revealed to be the heating of atoms during the lifetime above Griem boundary (ladder-like travels within the excited states) via CX processes.

State-selective CX rates are demanded.

MAP-II in the future in Tsukuba-Univ.

- MAP-II has carried into Tsukuba-Univ. on 11/Sep/2014 AM
- no discharge planned in 2014

Plans for 2015 (Tsukuba-Univ.)

- Power cable connection
- Cooling water supply
- Evacuation test

Then, restating plasma discharge (hopefully).