

# Effective Rate Coefficients for Charge Exchange Recombination Spectroscopy (CXRS) with fully Ionized Helium and Argon

23. Januar 2012

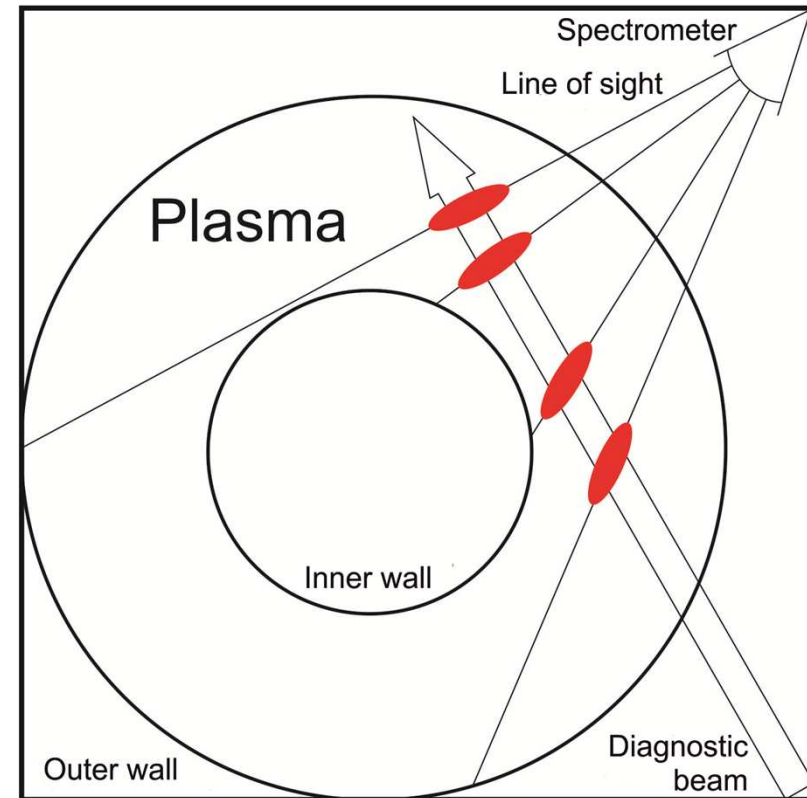
T. Schlummer<sup>1</sup>, O. Marchuk<sup>1</sup>, W. Biel<sup>1</sup>, Yu. Ralchenko<sup>2</sup>, D.R. Schultz<sup>3</sup>, G. Bertschinger<sup>1</sup>, D. Reiter<sup>1</sup>

1. Institut f. Energie- und Klimaforschung, Plasmaphysik, Forschungszentrum Jülich GmbH, Association EURATOM – FZJ, Partner im Trilateralen Euregio Cluster, Jülich, Deutschland
2. National Institute of Standards and Technology, Gaithersburg, MD 20899-8422, USA
3. Physics Division, Oak Ridge National Laboratory, Oak Ridge, TN 37831, USA

# Part 1 – CXRS

## Charge Exchange Recombination Spectroscopy (CXRS)

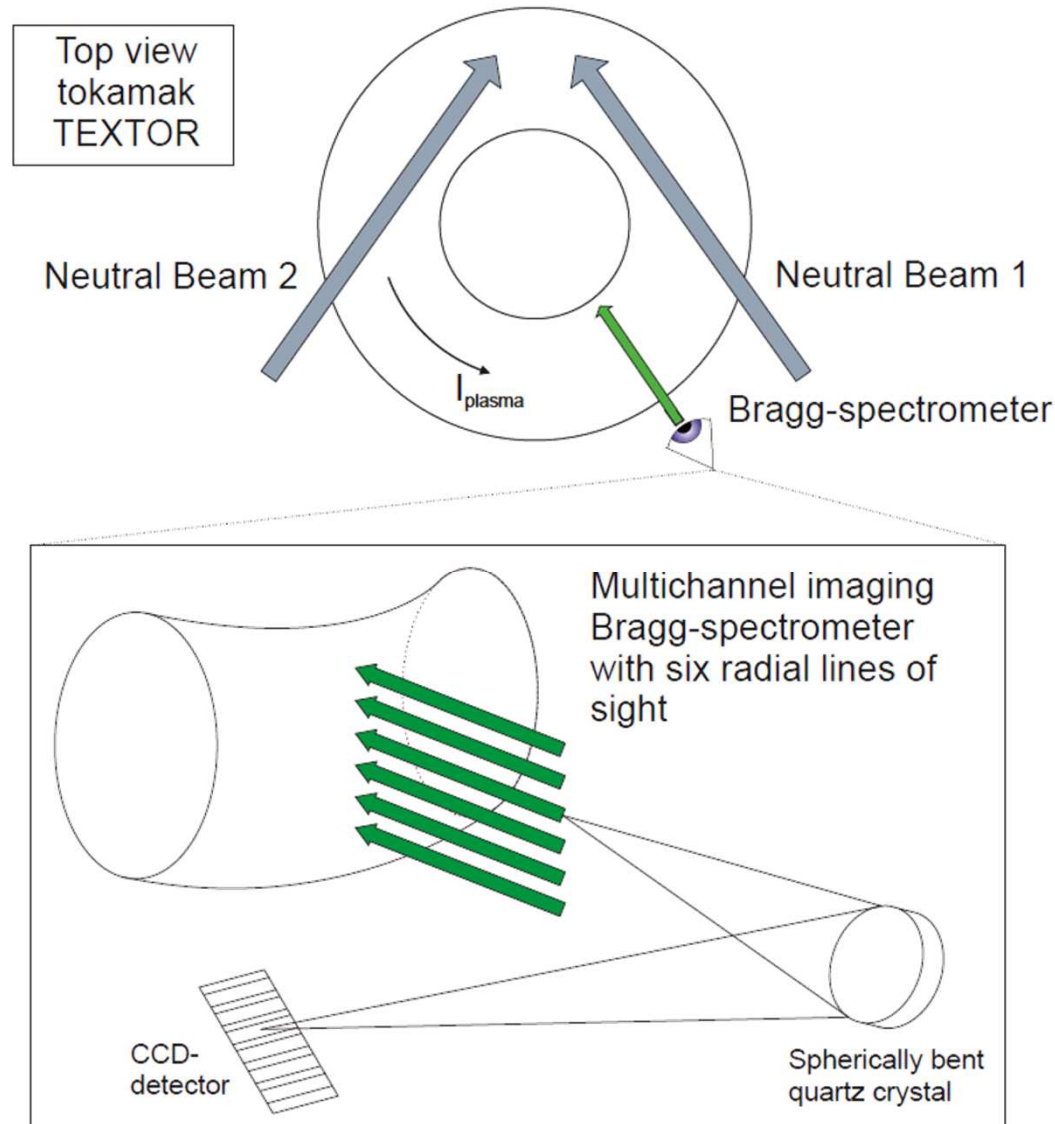
- Active plasma diagnostic for:
  - ion temperature
  - Plasma velocity
  - Absolute impurity densities (e.g. helium, carbon, neon or argon)
  
- Based on neutral beam injection:
  - H-atoms @ 100keV (ITER)
  
- The produced line intensities are proportional to the absolute density of the impurity ions
  - $I \sim Q_{\text{eff}} \cdot N_{\text{imp}} \cdot N_{\text{beam}}$



# Part 1 – Effective rate coefficient $Q_{\text{eff}}$

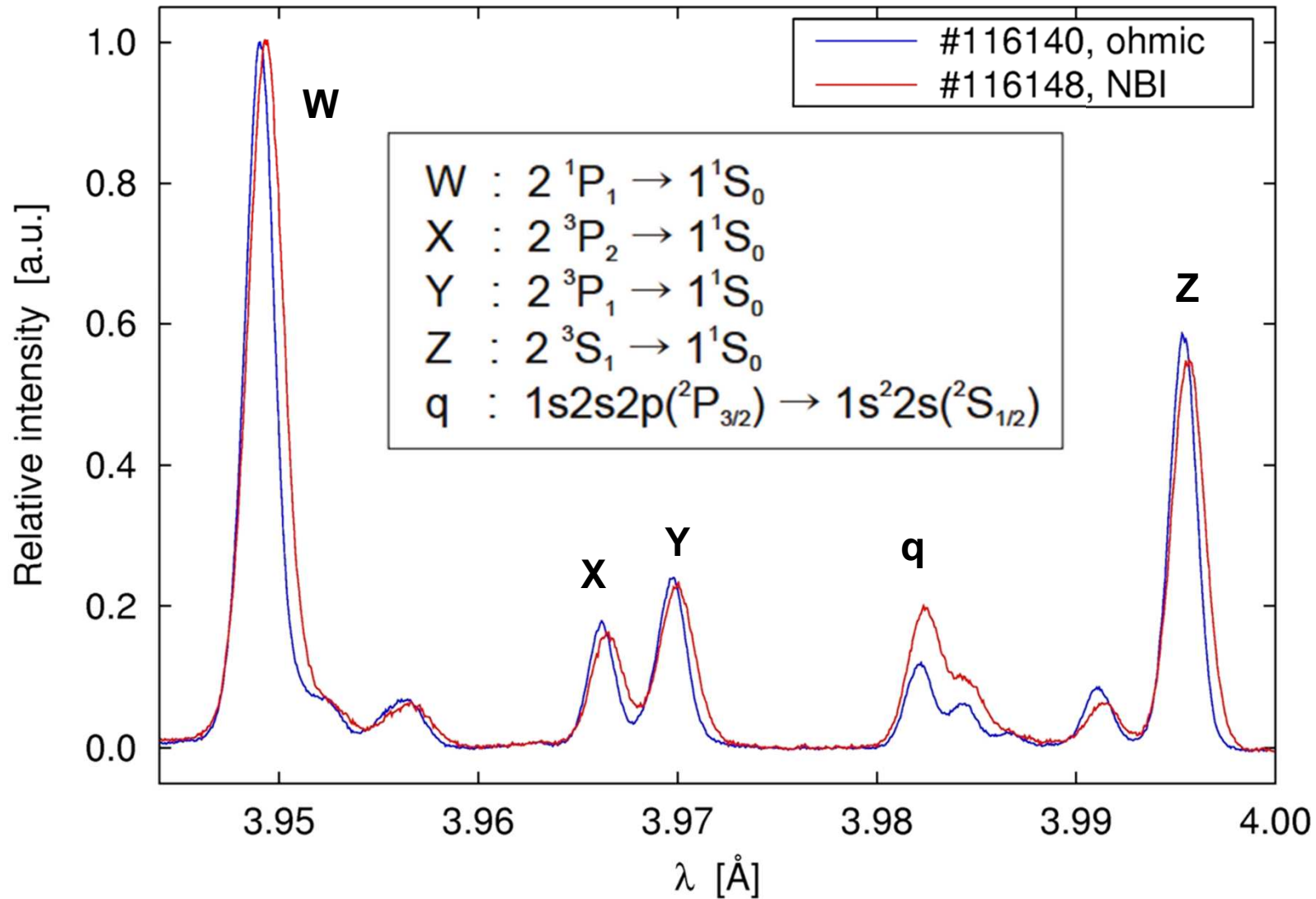
- The effective rate coefficient  $Q_{\text{eff}}$  contains all atomic data involved in light emission.
- Verification of existing  $Q_{\text{eff}}$  – data (**ADAS**, [www.adas.ac.uk](http://www.adas.ac.uk))
- Calculation of  $Q_{\text{eff}}$  based on the collisional radiative model **NOMAD** (Y. Ralchenko)
- **Results:**
  - Up to **80% higher** than the reference data
  - Partly qualitative differences in parameter dependencies ( $n_e$ ,  $T$ ,  $Z_{\text{eff}}$ )

# Part 2 – Argon ion ratios in TEXTOR



- New 6 channel imaging **Bragg-spectrometer** for future use at W7-X
- Optimized for **K-alpha spectrum of He-like argon**
- **Radial profiles of:**
  - Ion temperature
  - Electron temperature
  - **Argon ion ratios**
    - **H-like**
    - **He-like**
    - **Li-like**

# Part 2 – Argon ion ratios in TEXTOR



# Thank you for your attention !

## Effective Rate Coefficients for Charge Exchange Recombination Spectroscopy (CXRS) with fully Ionized Helium and Argon

T. Schlummer<sup>1)</sup>, O. Marchuk<sup>1)</sup>, G. Bertschinger<sup>1)</sup>, Yu. Raichenko<sup>2)</sup>, D.R. Schultz<sup>3)</sup>, W. Biel<sup>1)</sup>, D. Reiter<sup>1)</sup> and the TEXTOR Team<sup>1)</sup>

1) Institute of Energy and Climate Research - Plasma Physics, Forschungszentrum Jülich GmbH, Association EURATOM-FZJ, Partner in the Trilateral Euregio Cluster, Jülich, Germany  
2) Atomic Physics Division, National Institute of Standards and Technology, Gaithersburg, MD 20899-8422, USA  
3) Controlled Fusion Atomic Data Center Oak Ridge, National Laboratory Oak Ridge, Tennessee 37831-6373, USA

---

### Charge Exchange Recombination Spectroscopy (CXRS) for absolute impurity density measurements at ITER

#### Principles of CXRS

- CXRS is an active diagnostic for fusion plasmas using a highly energetic (100keV) neutral beam of H-atoms to induce line emission radiation.
- Charge exchange (CX) collisions between the beam atoms and the fully ionized impurity ions produce highly excited H-like impurity ions, followed by line emission radiation.
- $A^{Z+1} + H^0 \rightarrow A^Z + H^+ \rightarrow A^Z + H^{\alpha} + h\nu$
- CXRS is an established and powerful method for measurements of:
  - plasma temperature (Doppler broadening)
  - plasma velocity (Doppler shift)
  - absolute impurity densities (line intensities)

#### Impurity density measurements

- The absolute impurity densities  $N_{i,j}$  are proportional to the line intensities  $I_{i,j}$ .
- $I_{i,j}(n_i \rightarrow n_j) \propto Q_{eff}(n_i \rightarrow n_j) \cdot N_i \cdot N_{i,j}$
- $Q_{eff}$  is the effective rate coefficient, containing all atomic data involved in the process of line emission radiation.
- Common source for  $Q_{eff}$  data is the ADAS data base<sup>1)</sup>.
- To approach the ambitious aim of 10% accuracy in impurity density measurements (ITER request), the quality of  $Q_{eff}$  needs verification.

#### The effective rate coefficient for charge exchange $Q_{eff}$

- For the transition from upper level  $n_i$  to lower level  $n_j$ ,  $Q_{eff}$  is the product of transition probability  $A_{i,j}$  and population density  $N_i$ .
- $Q_{eff}(n_i \rightarrow n_j) \propto \sum_k A_{k,i \rightarrow n_j} \cdot N_{k,i}$
- The population densities  $N_i$  have been calculated via the collisional radiative model NOMAD<sup>2)</sup> allowing for:
  - The bare nucleus and the H-like ionization stage
  - nl-resolved CX cross sections<sup>3)</sup>
  - up to  $n=20$  (Helium)
  - up to  $n=30$  (Argon)
  - Collisional processes with electrons and protons (deexcitation, ionization)

---

### Results for the theoretical effective rate coefficient for charge exchange ( $Q_{eff}$ )

#### $Q_{eff}$ as a function of electron density $n_e$

- The behavior of  $Q_{eff}(n_e)$  is due to the collisional redistribution ( $\Delta n \neq 0$ ) of the population densities  $N_i$ .
- At fusion relevant densities ( $n_e = 10^{21} \text{ cm}^{-3}$ ) population density distribution can neither be characterized by corona limit or LTE approximation.
- This shows the necessity of collisional radiative modeling.

#### Impact of cascade contributions on $Q_{eff}$

- $Q_{eff}$  has been calculated as a function of the maximal principal quantum number  $n_{max}$  for which direct CX influx is taken into account.
- When allowing for all available CX cross sections, the cascade contributions hold about 30% for Helium and about 50% for Argon of the total value.
- Contributions from higher  $n$  quantum numbers are not expected to be relevant.

#### Comparison to ADAS data

**Absolute values:**

- Corona limit: 30% higher (Helium), 80% higher (Argon)
- ITER relevant density ( $n_e = 10^{21} \text{ cm}^{-3}$ ): 15% ± (Helium), 30% - 40% higher (Argon)

**Parameter dependencies:** ( $E_i, n_e, Z_i$  and  $T$ )

- Our results do not show a separation of the parameter dependencies as in ADAS data.
- The two sets of  $Q_{eff}$  data partly show qualitative differences.

---

### Measurements of argon ionization balance influenced by charge exchange in TEXTOR

#### Experimental Setup

#### Radially resolved X-ray spectra

#### Argon ion ratio

Member of the Helmholtz Association

Forschungszentrum Jülich | Institute of Energy Research - Plasma Physics | Association EURATOM - FZJ