The current status of the Lithium beam diagnostic at ASDEX Upgrade

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Outline

Experimental setup

**Edge ion temperatures**
CX with He$^{2+}$
CX with D$^+$

**Edge ion densities**

**Edge electron densities**
ELM resolved profiles
LID evaluation with Bayes integrated concept
Wide Filters: high temporal resolution
Experimental setup

**Beam emission spectroscopy**

- Electron density measurement
- Li\(^0\) (2p-2s) @ 670.8 nm

**Li-beam**
- 30 – 80 keV, 2-4 mA
- ∅12 mm

**Charge exchange spectroscopy**

- Ion temperature measurement
- LIT
- M.Reich - Thesis

- Ion density measurement
- LIS
EM CCD improves availability of $T_i$ measurements.

- Signal/noise ratio much improved due to EM technology
- Same radial position
- Measured temperatures agree, $T_i = 370$ eV
- Temporal resolution: 10 channels (LOS) on one CCD with 4 ms continuously

PI Micromax CCD camera

PhotonMax EM CCD camera

Extended serial register: Electron multiplication via impact ionisation

active CCD area

frame transfer

‘traditional’ amplifier
1 MHz, 5 MHz

EM amplifier
5 MHz, 10 MHz
Edge ion temperature profiles

- Spatial resolution ~ 5 mm
- Temporal resolution not available: Signal must be integrated over 1-2 s.
- He concentration > 10%.
- L-mode o.k.
- H-mode: only for $f_{ELM} < 100$ Hz.
New: CX measurements also possible with D$^+$ ions.

Raw data: spectrum

- No ELMs or regular ELMs
- ELMs have to be cut out
- $\Delta t > 500$ ms integration time
- Fit difficult because centre is always dominated by photon statistics of passive line emission
- Inclusion of CXS_fit in progress
Edge ion densities, examples

#18055, \( t = 3-5 \) s

Core charge exchange Li-beam, ADAS Li-beam, no collisional mixing Li-beam, fully mixed

#20463, \( t = 3.9-5 \) s

Electrons, ions, electrons He^{2+}
Li^0 + plasma → Li(2p – 2s)@670.8nm

Lithium beam attenuation code:

\[ \frac{dN_i(z)}{dz} = [n_e(z) \cdot a_{ij}(T(z)) + b_{ij}] \cdot N_j(z) \]

- \( N_i \): relative occupation of state \( i \) (i=2s, 2p, …4f, Li^+)
- \( a_{ij} \): rate coefficients
- \( b_{ij} \): Einstein coefficients

\( a_{ij} \): Inelastic collisions with protons, electrons and impurities

\( b_{ij} \): radiative transitions

References:
Electron density measurements

Measured profile + errors

Produce fit to data

This relative profile $\text{Li}_{2p}(z)$ is directly related to occupation number of Li(2p).

$\alpha \text{Li}_{2p}(z) = N_{2p}(z)$, $\alpha = \text{const.}$

$\alpha$ is determined via 2 boundary conditions:

$N_i(z=0) = \delta_{1i}$

$N_1(z_{\text{end}}) = 0$

Use second equation of

$$\frac{dN_i(z)}{dz} = [n_e(z) \cdot a_{ij}(T(z)) + b_{ij}] \cdot N_j(z)$$

to get $n_e$.

Lithium beam attenuation code

Singularity near maximum of Li(2p) profile.
ELM resolved with int times ~ 1ms

Time interval extended to include Raus – scan:

- LID with 1 ms temp. resolution
- Shot: 12200 t1 = 3.400 t2 = 5.200
- Only data in window rel. to ELM: -3.5 ms to -1.5 ms

Electron density $[10^{19} \text{ m}^{-3}]$
Binning of raw signal relative to ELM yields density profiles across ELM.

- Choose time interval with regular ELMs
- Determine for every t in LIB signal:
  \( \Delta t \) to previous ELM
  \( \Delta t \) to next ELM
- Add all signals with same temporal distance to ELM
- Calculate density profile

Attention:
ELMs should have about same size.
ELM shotfile must be checked carefully: no missed or additional ELMs.
Lithium beam must be very stable: no sparks.
$n_e$ gradient in ETB region is recovered after 3 ms.
Rainer Fischer: integrated concept

Determine electron density profile given

Measured data of Li I (2p-2s) profile and their likelihoods

! accurate error determination!

Measurements of other diagnostics.

Description of profile:
13 knots using Hermite polynomials

Additional information:
$n_e$ profile monotonic

Lithium beam attenuation code

Li I (2p-2s) profile

$\chi^2$ fit to the data * factor $\alpha$

to determine 13 knots and $\alpha$. 
Electron density profile evaluation now beyond point of singularity.

Medium core density:
- Pedestal well determined.
- Temporal resolution: 1 ms
- So far LID density evaluation stops just before turn.
- New: high certainty of profile up to $\rho_{pol} = 0.93$

High core density:
- So far LID density evaluation stops in SOL.
- New: reliable profile up to $\rho_{pol} = 0.96$
Latest improvement: broader filters

- New filters: 2 nm FWHM, before 0.5 nm
- Easier to change to different beam velocity (no tilt adjustment necessary)
- Higher transmission (85%, before 50%)
- Signal ~ factor 10 larger
- Now 1.5 – 4 sec with 20 kHz (before 5 kHz)

#22287, 3-4s, t_exp = 4ms, LIA channel 4

![Graph showing emission lines and changes in signal strength and acquisition time]

Allows faster data acquisition:
1.5 – 4 sec with 20 kHz (before 5 kHz)
Summary

Ion temperature profiles
- No temporal resolution ($\Delta t > 500$ ms)
- Good spatial resolution (5 mm)
- C: concentration now too low (< 0.4 %)
- He: good data if concentration > 10%
- D: good data if plasma quiet, e.g. ohmic or L-mode

Ion density profiles
- Collisional mixing is important at the edge.

Electron density profiles (main business!)
- Excellent temporal resolution (~ 1 ms).
- Li-beam electron densities can resolve ELM, if several light profiles are binned relative to ELM.
- Integrated concept: edge pedestal densities can be determined up to $n_e^{\text{PED}} \sim 7 \times 10^{19}$ m$^{-3}$.
- New filters give more photons, more flexibility and allow faster data acquisition (20 kHz).