Implications of collisional physics for magnetically confined plasmas

ITER : Tungsten

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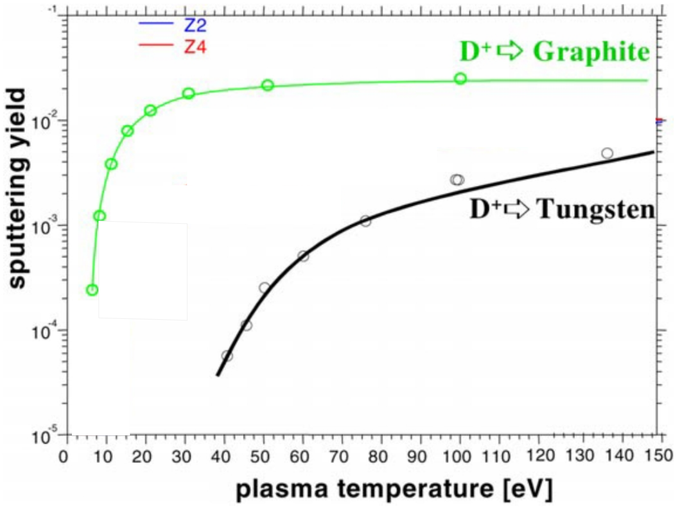
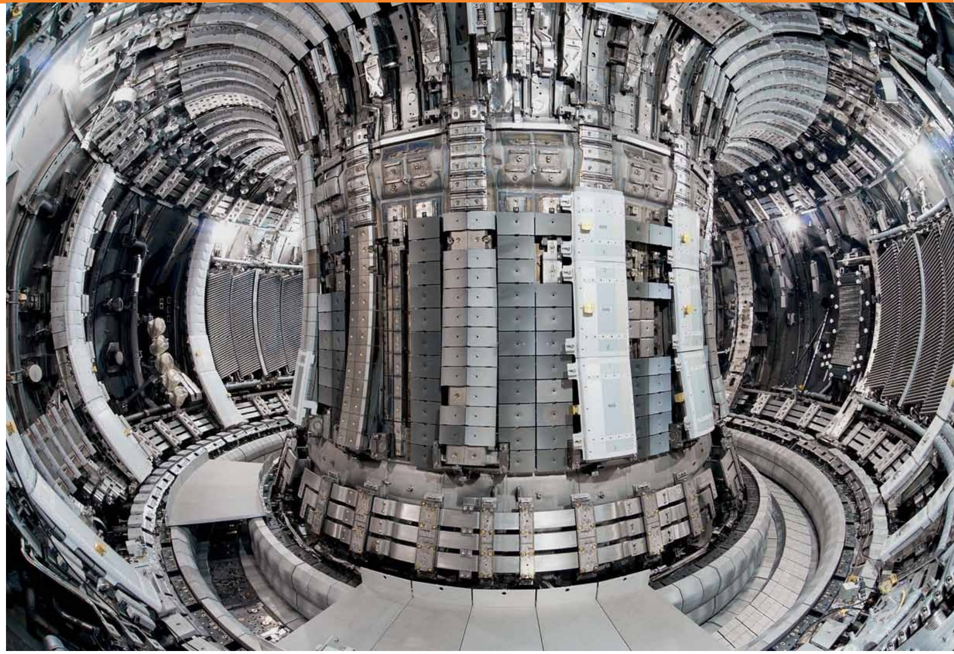
Motivation: High-Z materials are leading candidates for first wall materials in future fusion energy devices

- Reactor temperatures and heat flux will require new high-Z materials
    - High melting point and thermal conductivity
    - Reduced sputtering
    - Tritium retention is reduced
    - First wall lifetime is increased



- Tungsten (W) is a leading candidate for the divertor material for ITER

- Mo is presently being used on NSTX-U as the first wall material

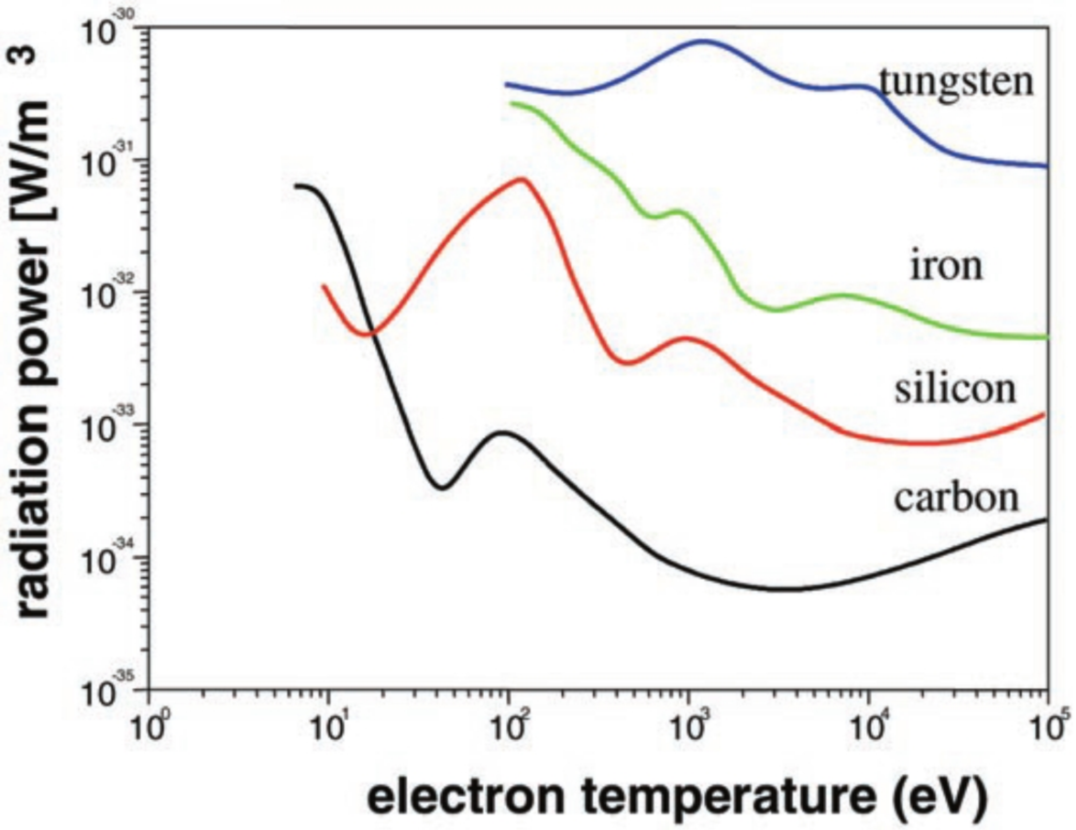


Inside of the JET tokamak W divertor, Be walls euro-fusion.org

"There is an urgent need in the fusion energy community to understand the rate of high-Z material erosion presently – DIII-D 5 year plan"

Motivation: High-Z materials are leading candidates for first wall materials in future fusion energy devices

- ***Allowable impurity concentration lower for high-Z materials***
  - High-Z materials radiate much more than previously used materials
  - Radiation significant enough to denigrate plasma performance
    - Concentration needs to be less than ~1E-4
  - Need to accurately quantify and minimize erosion of wall



V. Philipps

Quantifying wall erosion with passive spectroscopy

- The intensity of a spectral line can be related to its influx rate [Behringer PPCF 31 2059 (1989)]
- The number of ionizations per photon (S/XB) is directly proportional to the impurity influx

$$\Gamma = \int_0^\infty N_e N^z S^{z \to z+1} dx$$

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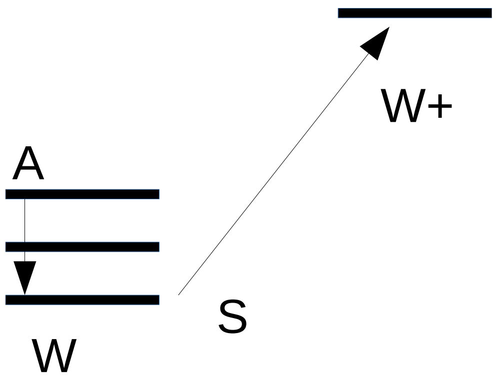

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$$= \int_0^\infty N_e SXB^z_{i\to j} \left(A_{i\to j}\frac{N_j}{N^z} \right) N^z dx$$

where $SXB^z_{i\to j} = \frac{S^{z\to z+1}(N_e, T_e)}{A_{i\to j}\frac{N_i}{N^z}(N_e, T_e)}$

Note electron temperature and density dependence

Atomic quantities of interest for fusion spectroscopy

- Non-invasive diagnostics depend on interpreting spectral lines
    - Atomic physics is key for accurate understanding:
        - Ionization fraction
        - Erosion rates (S/XB)
        - Expected line intensities (Photon emissivity coefficients {PEC})
        - Plasma temperature and density (ratio of PECs)

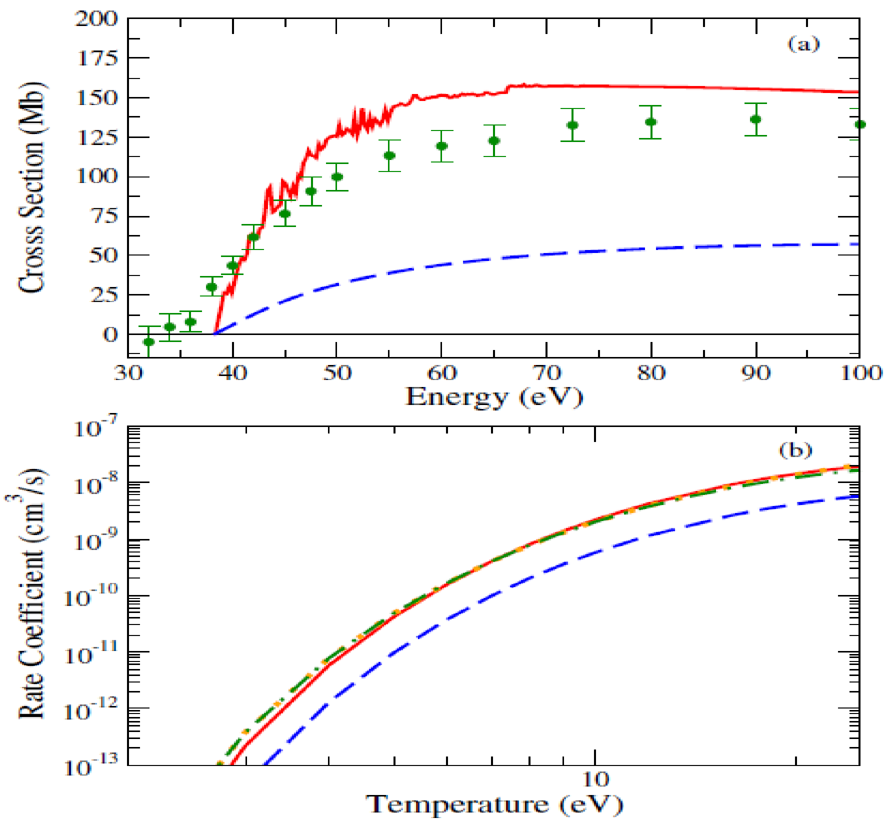
Plasma spectroscopic quantities are calculated with atomic physics models

- Large atomic physics calculations for near neutral systems (R-matrix) used to generate needed atomic data:
    - Ionization cross sections : ground & metastable (Michael Turkington)
    - Excitation cross sections (Ryan Smyth)
    - Modelling (Auburn, DIIID and QUB)

- Atomic Data and Analysis Structure (ADAS) provides the bridge between atomic calculations and these quantities
    - Database and suite of codes
        - Solves the system of generalized collisional radiative equations to return:
            - Line intensities for specified plasma conditions

This analysis has already been carried out for more highly charged states of Tungsten. Below, we have the total ionisation of W^3+ groundstate (5d^3)

Note for modelling we need ionisation from the other levels of the 5d^3



Direct ionisation may be dominated by large excitation-autoionisation to the total ionisation

Maxwellian averaged rates, both theoretical and experimental (Stenke et al)

1995 J. Phys. B: At. Mol. Opt. Phys. 28 2711

Simpler perturbative methods (ie distorted-wave) can overestimate the direct ionisation and excitation-autoionisation contributions

J. Phys. B: At. Mol. Opt. Phys. **46** (2013) 055202

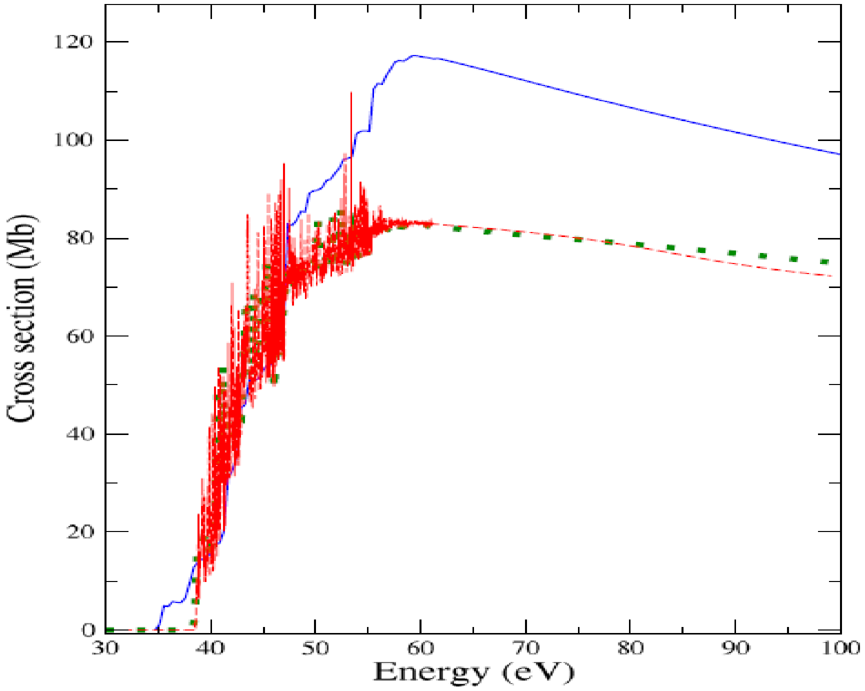


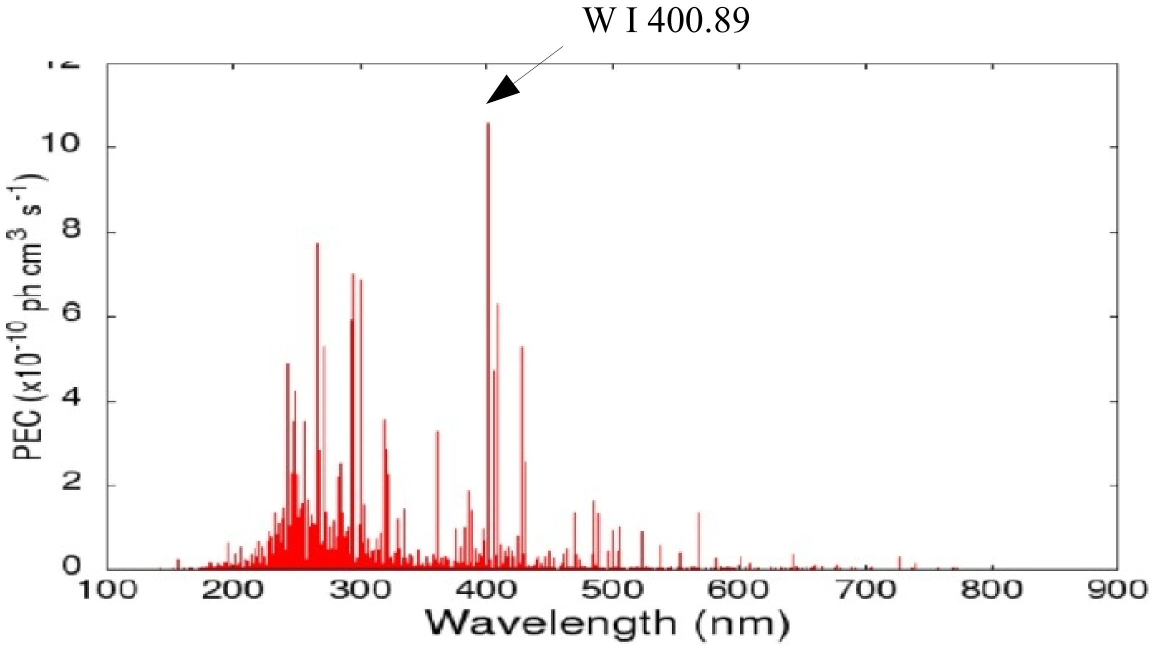
Figure 6. The 5p to 5d excitation-autoionization cross section from the $5p^6 5d^3\ ^4F_{3/2}$ ground level: *R*-matrix with coarse energy mesh—dotted curve (green); *R*-matrix with fine energy mesh—dashed curve (red); DW—solid curve (blue).

Up to 50% increase of DW over R-Matrix methods

5p^65d^3 → 5p^55d^4

ADAS predicts spectral emission of W I to be predominately at UV wavelengths

- Predicted lines in synthetic spectra should match real spectra
- ADAS predictions motivated installation of UV spectrometers
- Purpose was to find other strong W I lines as erosion diagnostics
- Presently the 400.89 W I lines solely used to diagnose W erosion
  - There are concerns about this line being blended with W II
  - Ideal erosion diagnostic lines would be isolated
- Other high-Z also predicted to be strong in the UV



Synthetic W I spectrum for t_e = 10 eV and N_e = 1x10 14 cm^{-3} .

super

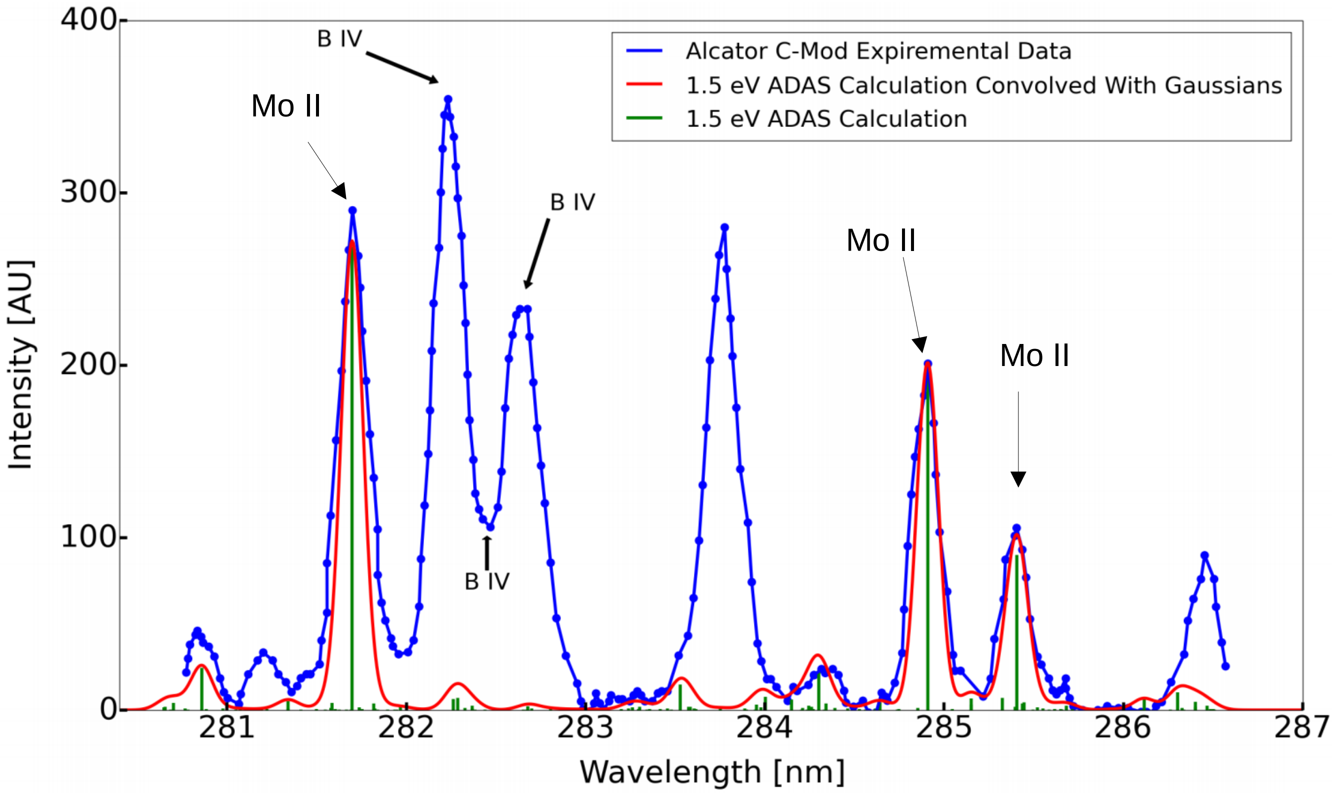
Talk Outline

- Background high-Z materials
- Erosion diagnostics
- ***Molybdenum spectroscopy work***
- Tungsten spectroscopy work
- Shifting ADAS energy level

Molybdenum calculations completed and benchmarked using C-Mod tokamak spectral measurements

- ADAS provides a good match with measured spectrum
- Relative line heights are not strongly density dependent
- Two lines were strongly temperature dependent
    - Two lines were strongly temperature dependent
    - Ratio of the two lines can be used for electron temperature diagnostic
- S/XB dependent on electron temperature
    - eliminates the need for independent temperature diagnostic

First identification of these Mo II lines in a tokamak



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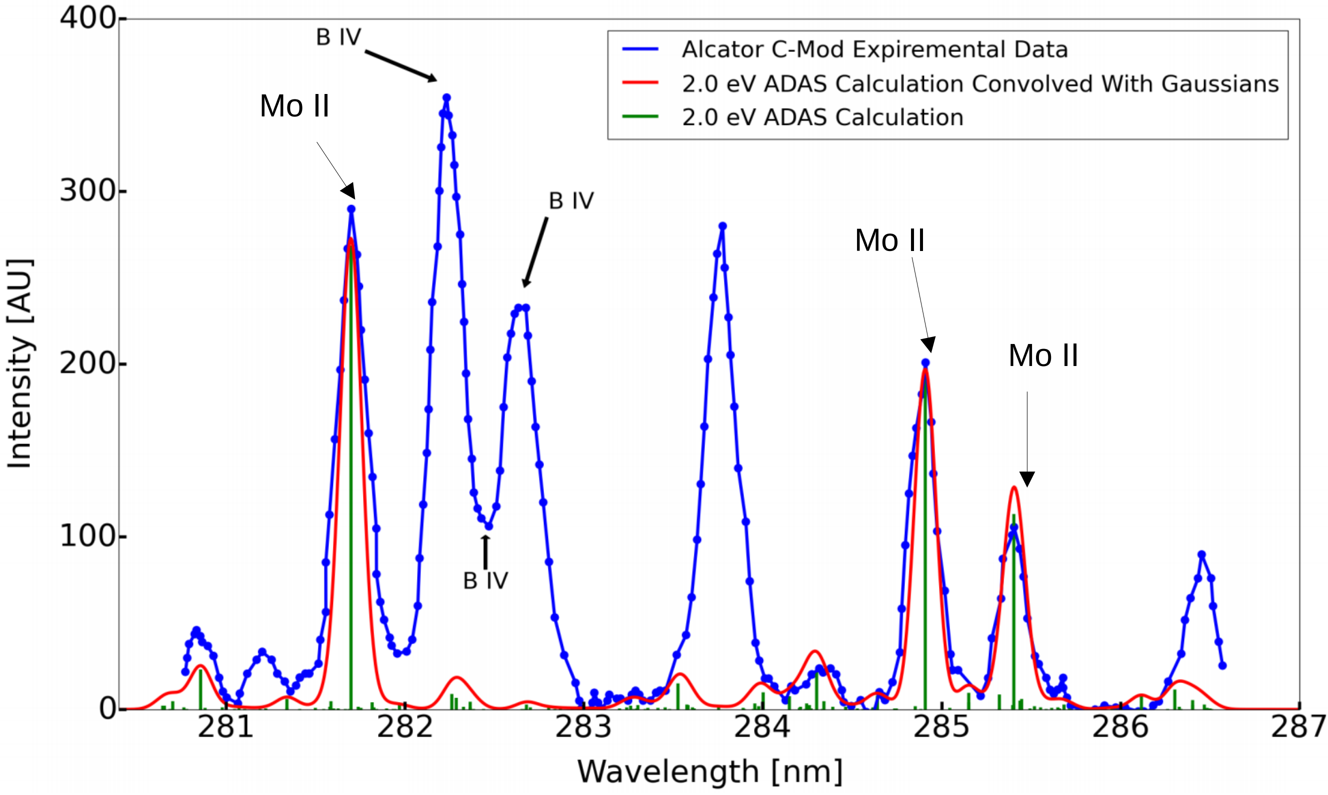

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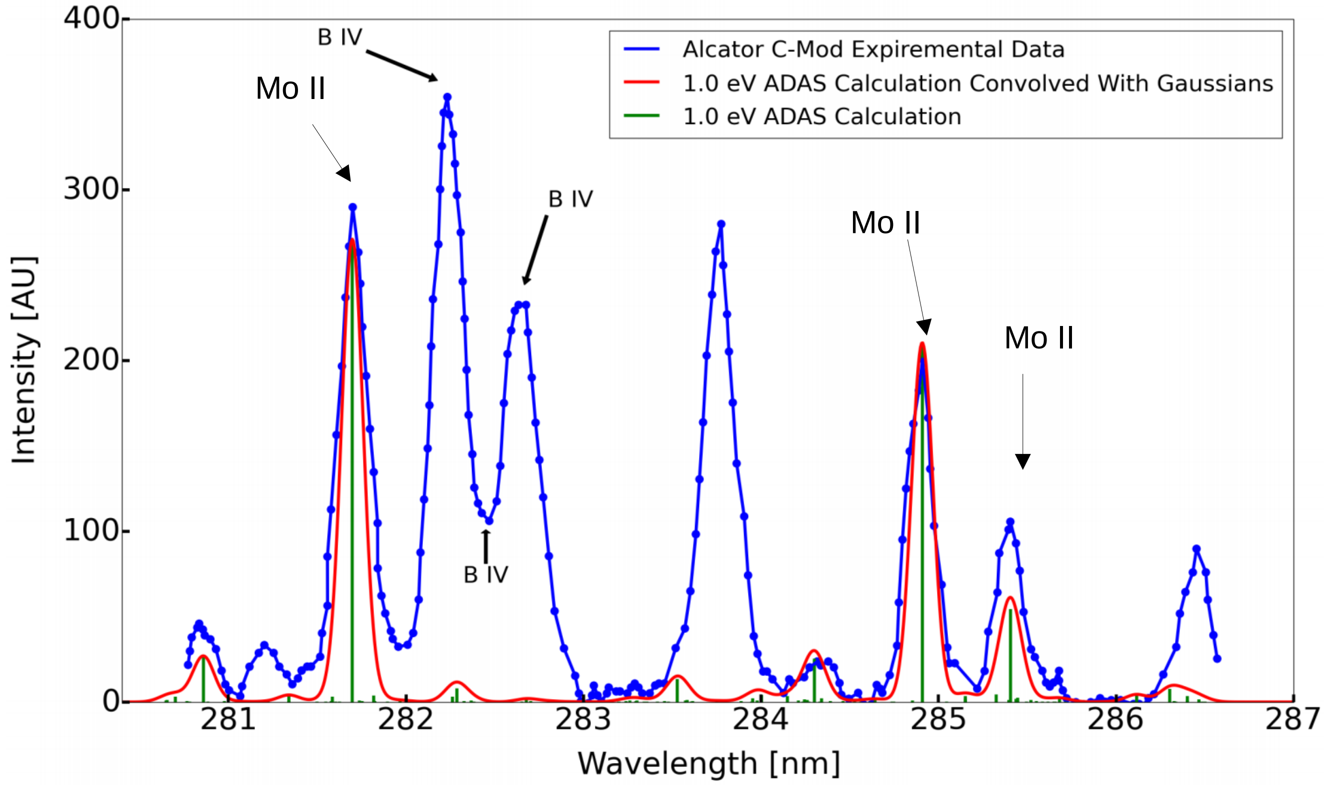

Molybdenum line ratios allow for plasma temperature in the edge to be calculated

- Ratio of Mo II 284.8 nm and Mo II 286.67 nm
- Ratio of lines not density dependent but strongly temperature dependent
- Predicts a reasonable electron temperature of 1.5 eV