Upgraded SXR/EUV Spectroscopy Capabilities for Alcator C-Mod

M.A. Chilenski,[a*] T. Christensen,[a] M. Greenwald,[a] M.L. Reinke,[a] J. Terry,[a] A.E. White,[a] P. Beiersdorfer,[b] E. Magee[b]

[a]Massachusetts Institute of Technology Plasma Science and Fusion Center [b]Lawrence Livermore National Laboratory *Contact: markchil@mit.edu

Abstract

Alcator C-Mod is equipped with several spectrometers for the SXR/EUV range. These instruments provide a survey of the impurity content of the plasma, particularly K-shell emission from low-Z elements (B to Ne), L-shell emission from mid-Z elements (Ar to Fe) and M-shell emission from intrinsic Mo. Diagnosis of these lines is important for understanding impurity transport and main ion dilution in C-Mod. The X-ray and Extreme Ultraviolet Spectrometer (1–7 nm, 2400 l/mm grating) has been calibrated using an electron impact x-ray source with a variety of anodes to give lines from 6.76 nm (B Kα) to 1.19 nm (Na Kα). The Long Wavelength and Extreme Ultraviolet Spectrometer (2–40 nm, 1200 l/mm grating) is being commissioned for use on C-Mod, with the intent of replacing an aging 2.2 m Rowland circle spectrometer presently used to survey the longer EUV wavelengths (9 nm $< \lambda <$ 100 nm) and monitor M-shell Mo emission. The new instrument is both more compact and should provide significantly better spectroscopic data.

Monitoring 1–7 nm Plasma Emission

A Flat-Field Grating Spectrometer Covers the 1–7 nm Spectral Region

- Designed at the LLNL EBIT lab, equivalent to the XEUS instrument on NSTX [1].
- Concave, variable line spacing (2400 l/mm average) grating mounted at grazing incidence with flat focal field.
- Princeton Instruments PIXIS-XO 100B camera:
  - back-illuminated 1340 × 100 CCD, 20 μm pixels
  - operated with as fine as 5 ms time resolution
- Spectral range: 1–7 nm (180–1200 eV).

Monitoring 2–40 nm Plasma Emission

A Rowland Circle Spectrometer Presently Covers the 9–100 nm Spectral Region

- 600 l/mm grating, 2.2 m
- Can only observe a 4–10 nm range at once.
- MCP fiber-coupled to 1024 channel Reticon array.
- Time resolution as fine as 4 ms.
- Aging instrument: difficult to upgrade, bulky.

A Second Flat-Field Grating Spectrometer to Cover the 2–40 nm Range is Being Installed

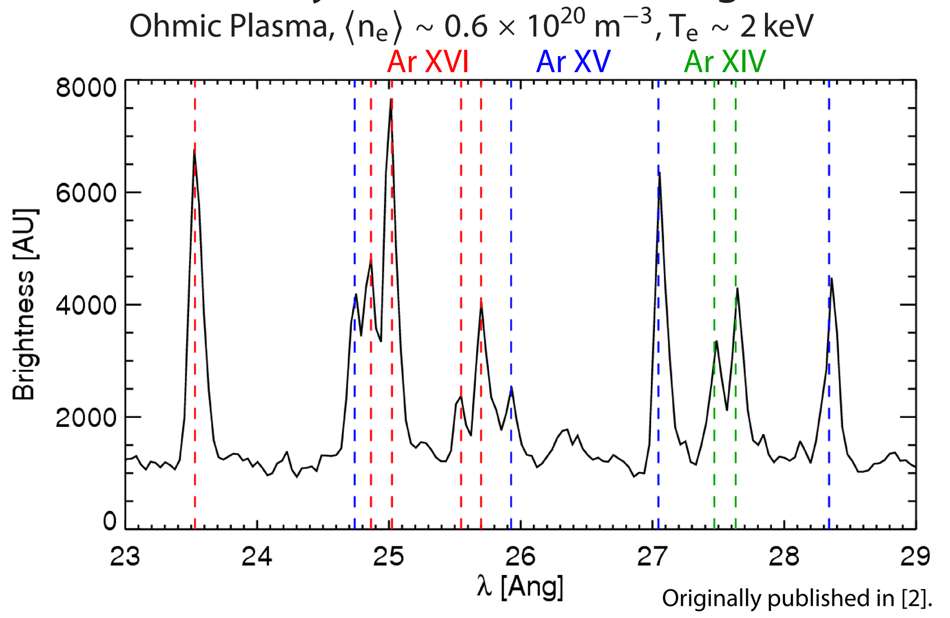
- Same LLNL design as the 1–7 nm flat-field spectrometer, equivalent to the LoWEUS instrument on NSTX [1].
- Same camera as on 1–7 nm flat-field spectrometer.
- Variable line spacing grating, 1200 l/mm average.
- Spectral range: 2–40 nm (30–620 eV), ~16 nm at once.
- Will perform the main functions of the Rowland circle spectrometer in a much smaller package with a better interface.
- Retiring the Rowland circle spectrometer will streamline operations and open up valuable port space.

Motivation and Applications[2]

These SXR/EUV instruments provide time-resolved surveys of many important impurities.

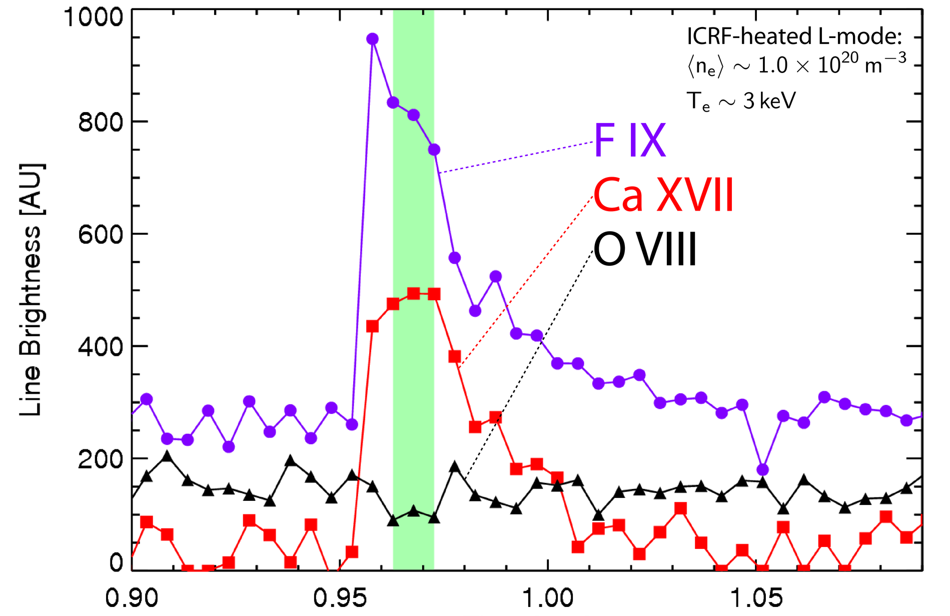
The 1–7 nm Range Includes Multiple Impurities of Operational and Scientific Interest

Ar is routinely seeded for other diagnostics



Originally published in [2].

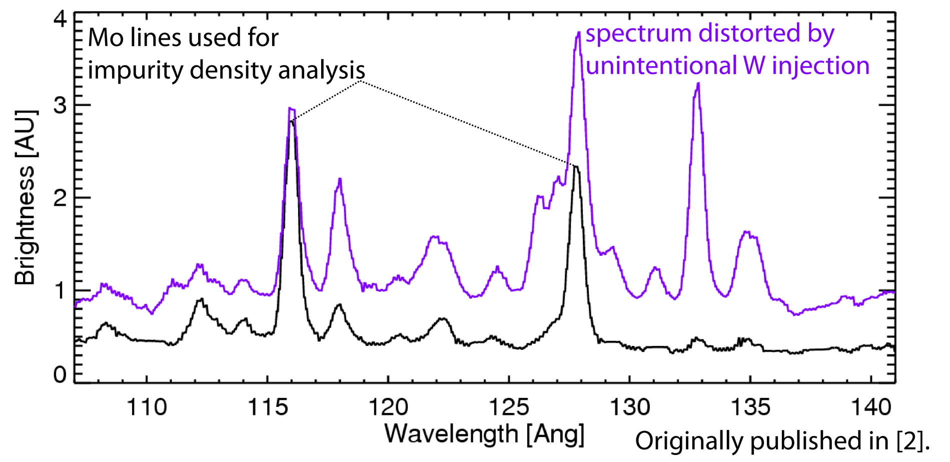
Transport is studied with laser blow-off injection of CaF_2



Originally published in [2].

The 2–40 nm Range Includes Many Impurities from Plasma-Facing Components

Mo from wall tiles, W from row of tiles in divertor



Originally published in [2].

This range also includes emission from:

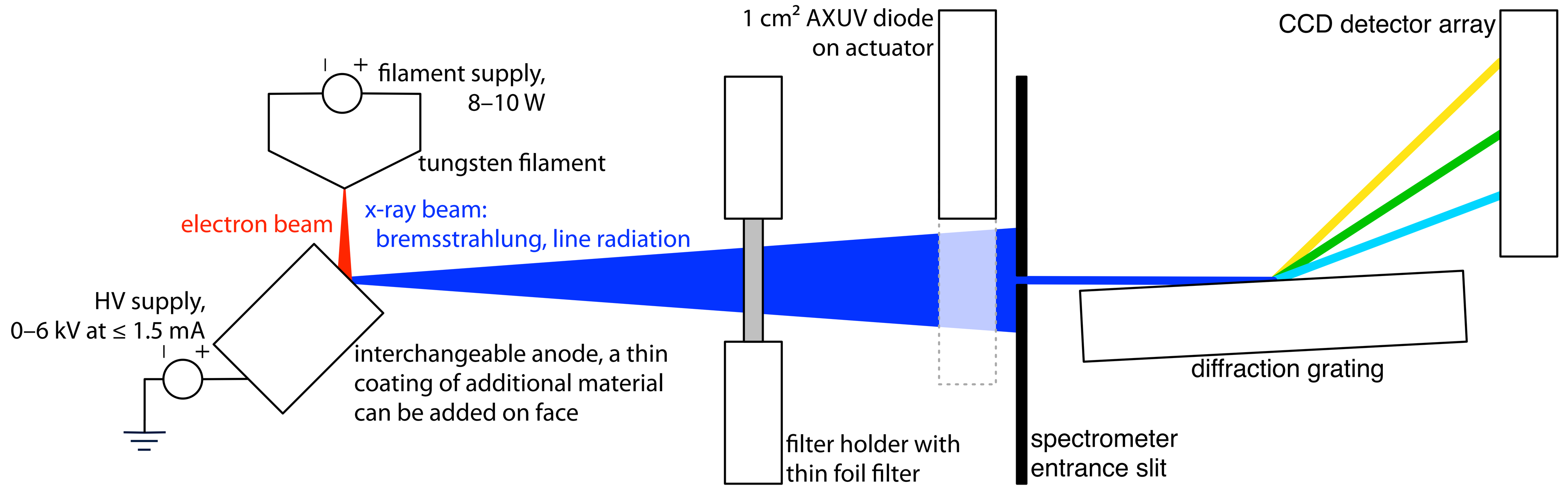
- Fe (various steel components)
- Ni (Inconel 625 ICRF antenna components)
- Cu (antenna strap plating)
- Ti (antenna Faraday screen plating)

Will be important for assessing impurities injected when operating the new rotated 4-strap ICRF antenna.

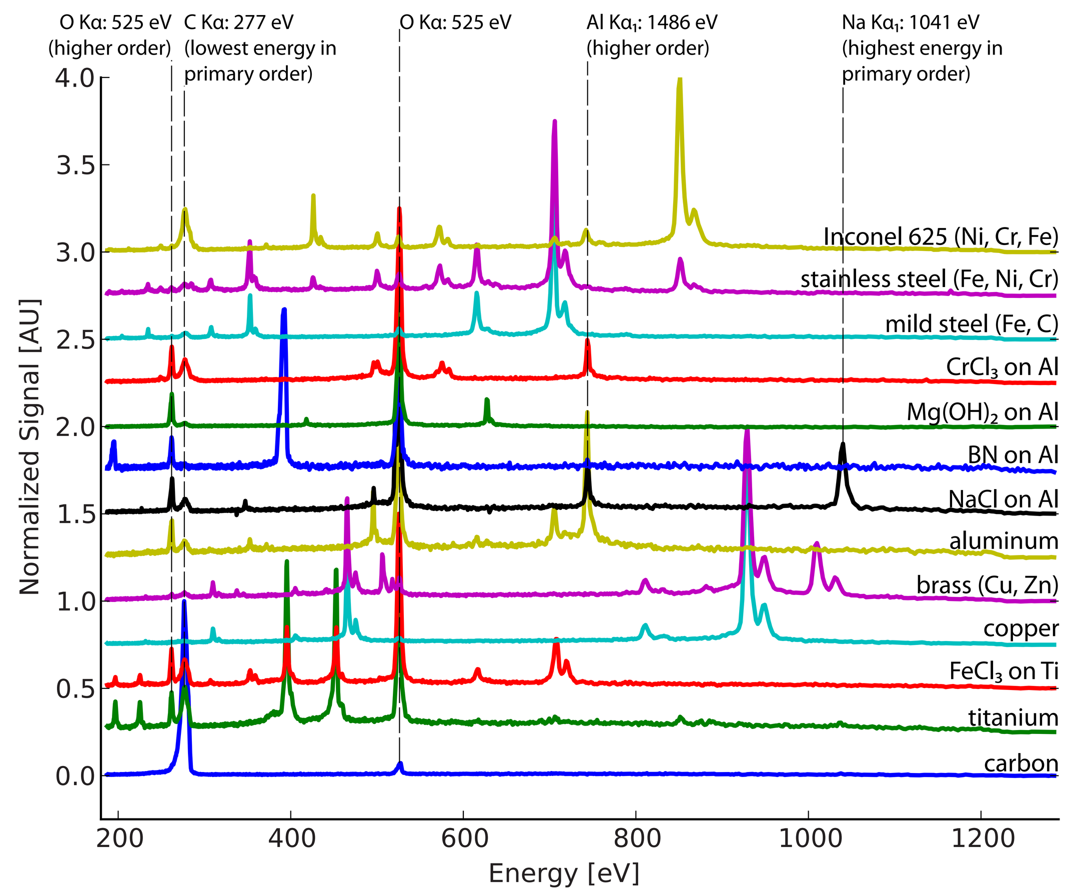
Calibration Using an Electron Impact X-Ray Source Has Proven to be Nontrivial

An Electron Impact X-Ray Source Provides Lines up to 1.5 keV

Simplified Schematic of Manson Mini-Focus Model 1 Electron Impact X-Ray Source With Flat-Field Spectrometer

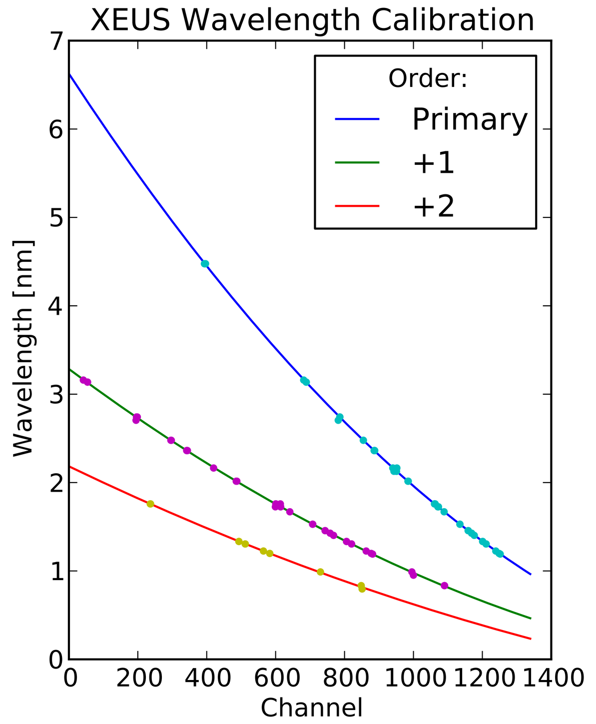


A Variety of Anodes/Coatings Provides a Wide Assortment of Lines



- Each spectrum normalized to brightest line.
- Each spectrum vertically offset by 0.25 units.
- Line energies and other spectral data are from [3, 4].
- Anodes can be made from nearly any conductive material.
- Anodes can be coated with a variety of materials; the coating is typically destroyed after each run.

These Simple Spectra Allow for Calibration of the Wavelength Axis



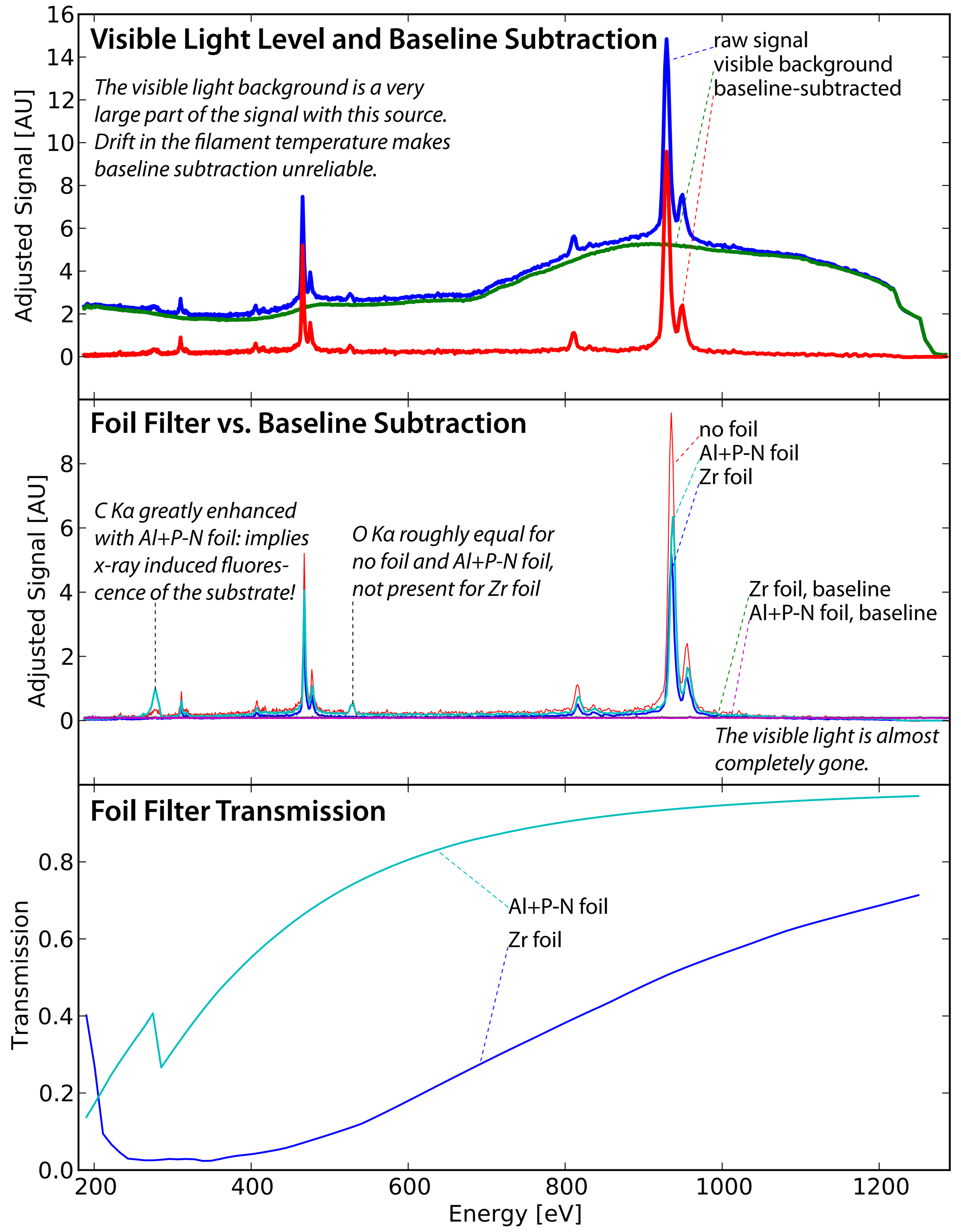
- Well-fit by parabolas, as would be expected from the grating equation and [5]: *the dispersion is non-linear.*
- The primary and two higher orders have been calibrated.
- Having these unambiguous bench calibrations will assist in interpreting the more complex plasma data.

A More Refined Light Source is Needed to Calibrate the Intensity Axis

- Objective is to calibrate spectrometer signal against a detector with known responsivity.
- Even with visible light removed by the foil, continuum background is unacceptably large.
- Accounting for the higher diffraction orders is trivial with discrete lines but unconstrained with a continuum.
- Light source with minimal continuum is required.
- A reflection-mode fluorescence setup was tested but no signal was observed.

Visible Light From the X-Ray Source Necessitates Use of a Foil Filter

Copper Anode at 4 kV



- Spectra were taken with different exposures t and currents I.
- Signals have been scaled by $(900\,\mathrm{A\,s})/(tI)$.
- Transmission data from [6].
- Both 0.1 μm Al on a 0.1 μm Parylene N substrate and 0.2 μm Zr were tested.
- Both materials are nearly opaque in the visible: a small signal attributable to visible light is seen on the AXUV diode, but it is ~5 times smaller than the signal from x-rays.
- A higher-order aluminum fluorescence line was seen from the Al/Parylene N foil at higher voltage, but was not nearly as strong as the carbon fluorescence.

Future Work

- First light for the new 2–40 nm spectrometer on C-Mod.
- Create software tools to automate processing of spectral data from the spectrometers.
- Identify a better light source for the intensity calibration.
- Work is underway to add imaging capability to the 1–7 nm flat-field spectrometer.

References

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