



U.S. DEPARTMENT OF
ENERGY

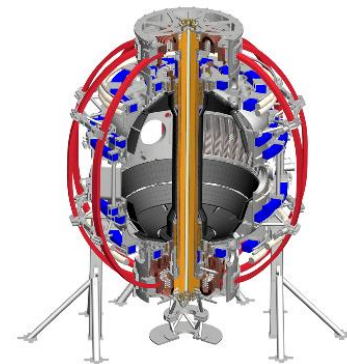
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First Results from Three EUV Spectrometers for Impurity Monitoring

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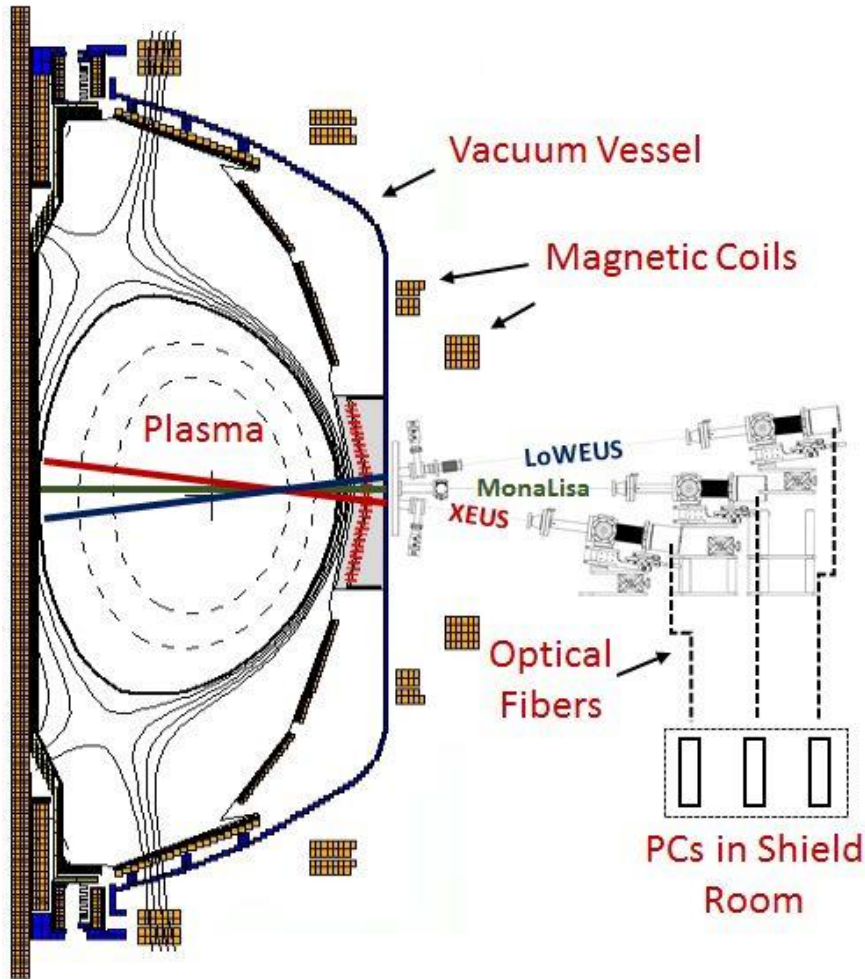
NSTX-U Results Review
September 21-22, 2016



Summary of Data Collected

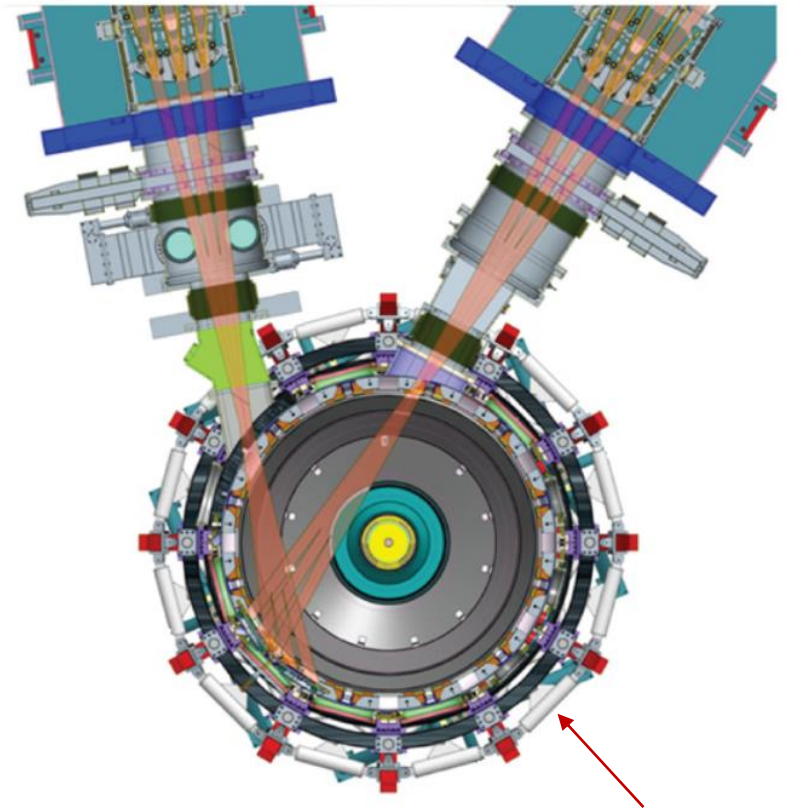
- First data collected on May 9th, starting from NSTX-U shot 204563
- Operated during a total of approximately 240 plasma shots over 12 run days
- Total wavelength coverage approximately 8 – 440 Å
 - X-ray and Extreme Ultraviolet Spectrometer (XEUS): 8 – 70 Å, 0.1 Å FWHM
 - Metal Monitor and Lithium Spectrometer Assembly (MonaLisa): 50 – 220 Å, 0.3 Å FWHM (not fully focused yet)
 - Long-Wavelength Extreme Ultraviolet Spectrometer (LoWEUS): 190 – 440 Å, 0.3 Å FWHM
- Temporal Resolution
 - Full Frame (for calibration, good signal to noise): 70 ms
 - Full Bin (for fast readout times, problems with x-ray and neutron noise): 3 – 5 ms
 - Region of Interest (medium readout time, medium signal to noise): 8 – 13 ms
- Confirmed Elements measured on EUV Spectrometers:
 - He, Li, B, C, O, Cr, Fe, and Ni
- Published first data in RSI (M.E. Weller *et al.*, RSI **87**, 11E324, 2016)

Spectrometer Locations



New 2nd NBI
($R_{TAN}=110, 120, 130\text{cm}$)

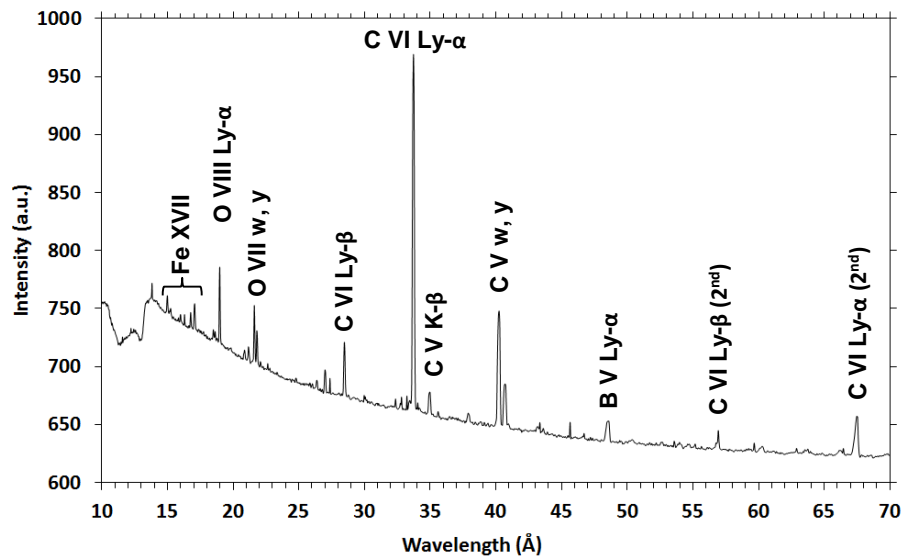
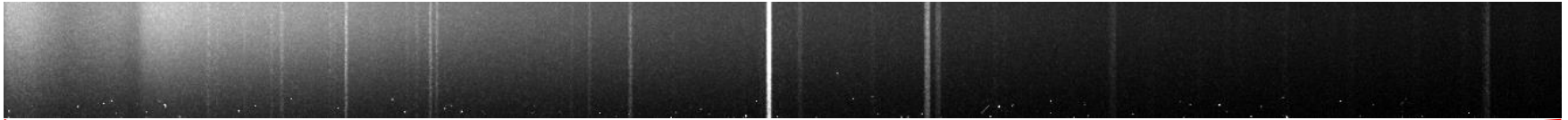
Present NBI
($R_{TAN} = 50, 60, 70\text{cm}$)



Location of EUV Spectrometers (Bay E)

Example of Experimental Results for XEUS

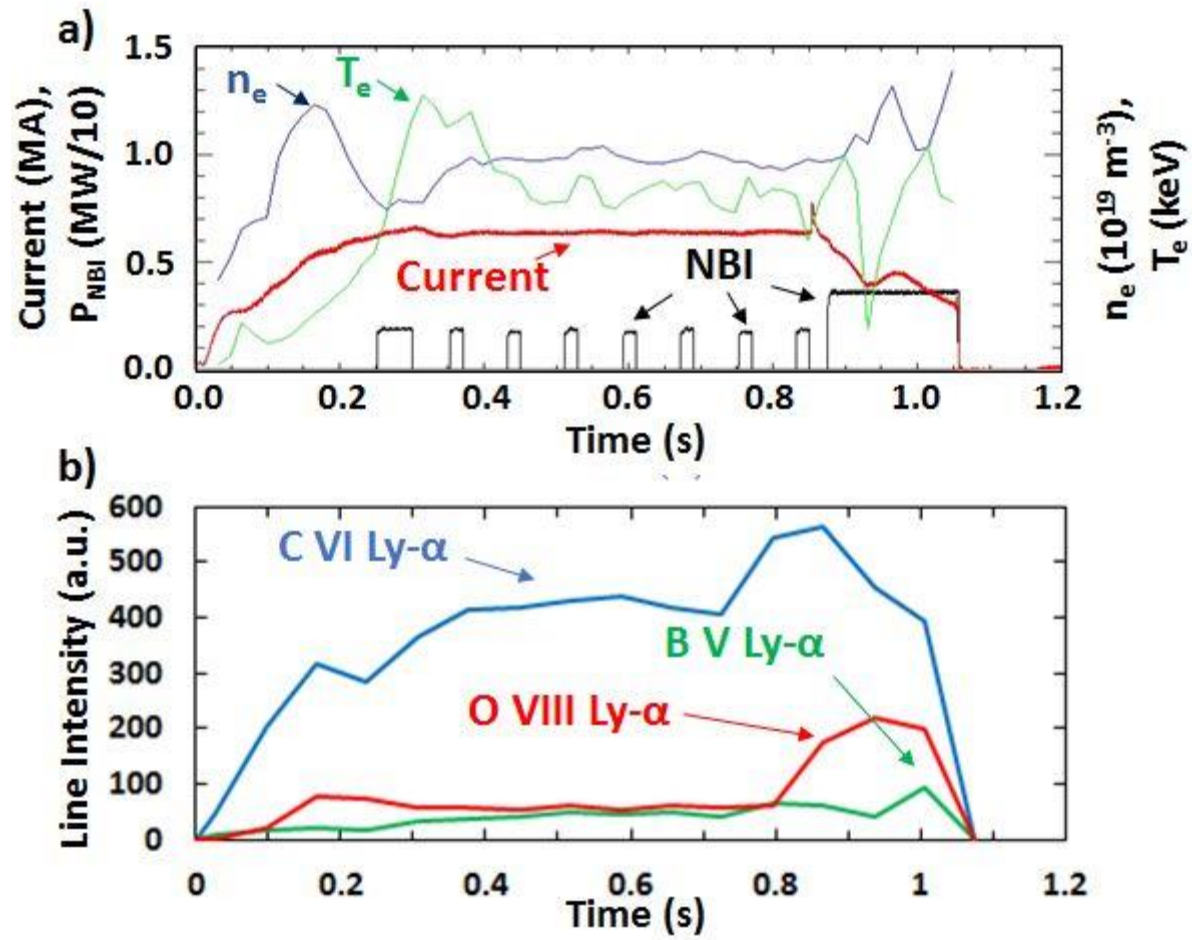
NSTX-U 205079, 170 ms



C, O, B, and Fe lines identified for first results from XEUS. L-shell Fe lines radiate from various stainless steel components.

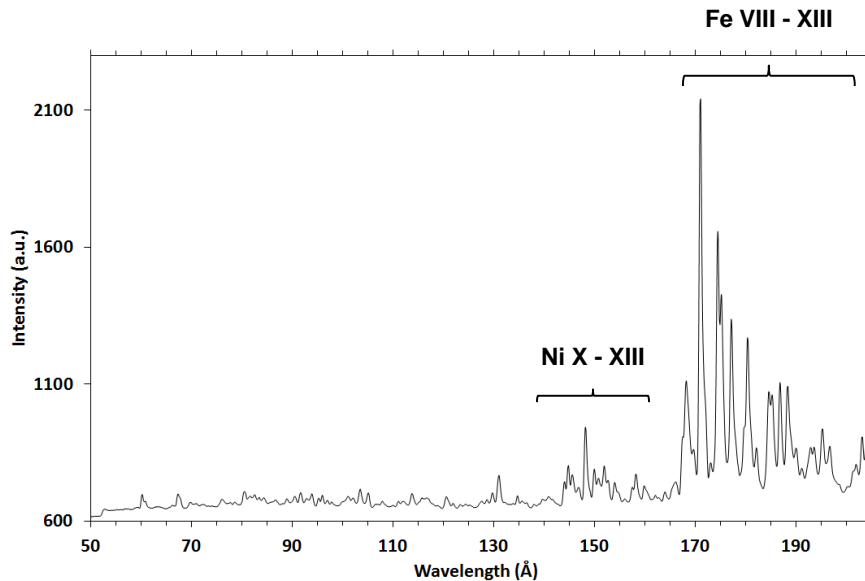
Lines	Transition	λ (Å)
O VIII Ly- α	$2p \ ^2P_{1/2,3/2} \rightarrow 1s \ ^2S_{1/2}$	18.97
O VII w	$1s2p \ ^1P_1 \rightarrow 1s^2 \ ^1S_0$	21.60
O VII y	$1s2p \ ^3P_1 \rightarrow 1s^2 \ ^1S_0$	21.80
C VI Ly- β	$3p \ ^2P_{1/2,3/2} \rightarrow 1s \ ^2S_{1/2}$	28.46
C VI Ly- α	$2p \ ^2P_{1/2,3/2} \rightarrow 1s \ ^2S_{1/2}$	33.73
C V w	$1s2p \ ^1P_1 \rightarrow 1s^2 \ ^1S_0$	40.26
C V y	$1s2p \ ^3P_1 \rightarrow 1s^2 \ ^1S_0$	40.72
B V Ly- α	$2p \ ^2P_{1/2,3/2} \rightarrow 1s \ ^2S_{1/2}$	48.58
Fe XVII 3C	$2p^5 3d \ ^1P_1 \rightarrow 2p^6 \ ^1S_0$	15.02
Fe XVII 3D	$2p^5 3d \ ^3D_1 \rightarrow 2p^6 \ ^1S_0$	15.28
Fe XVII 3F	$2p^5 3s \ ^1P_1 \rightarrow 2p^6 \ ^1S_0$	16.81
Fe XVII 3G	$2p^5 3s \ ^3P_1 \rightarrow 2p^6 \ ^1S_0$	17.08

Line Ratios of Ly- α Lines



Example of Experimental Results on MonaLisa

NSTX-U 205079, 30 ms

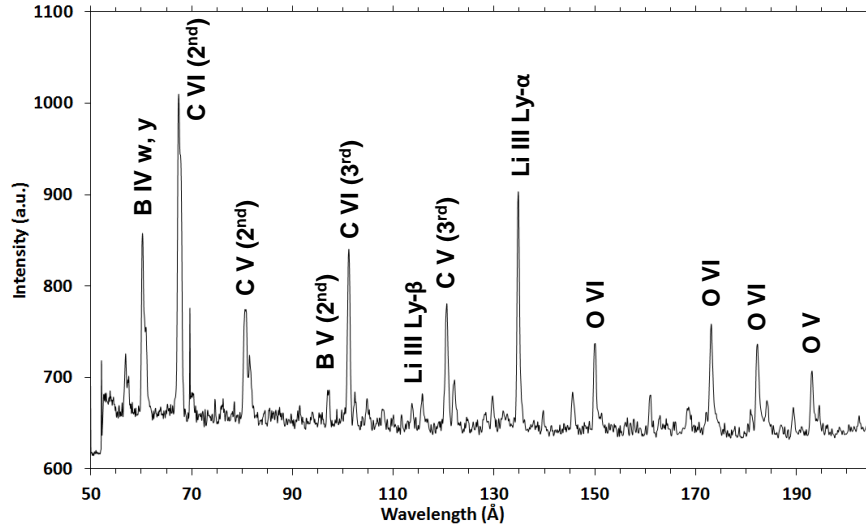
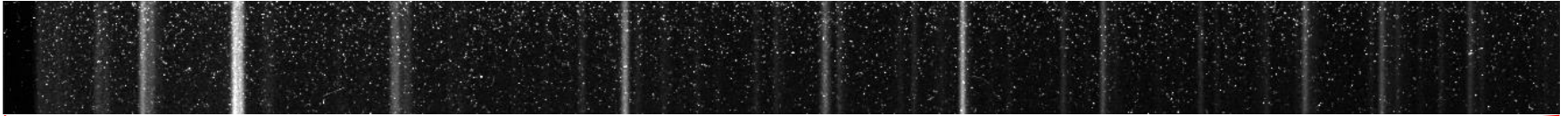


During early time on NSTX-U, the spectrum is dominated by M-shell lines of Fe and Ni, which come from stainless steel.

Lines	Transition	λ (Å)
Fe VIII	$3p^5 3d^2 \ ^2D_{5/2} \rightarrow 3d \ ^2D_{5/2}$	168.2
Fe IX	$3p^5 3d \ ^1P_1 \rightarrow 3p^6 \ ^1S_0$	171.1
Fe X	$3p^4 3d \ ^2D_{5/2} \rightarrow 3p^5 \ ^2P_{3/2}$	174.5
Fe X	$3p^4 3d \ ^2P_{3/2} \rightarrow 3p^5 \ ^2P_{3/2}$	177.2
Fe X	$3p^4 3d \ ^2P_{1/2} \rightarrow 3p^5 \ ^2P_{1/2}$	180.4
Fe X	$3p^4 3d \ ^2S_{1/2} \rightarrow 3p^5 \ ^2P_{3/2}$	184.5
Fe XI	$3p^3 3d \ ^3D_3 \rightarrow 3p^4 \ ^3P_2$	180.4
Fe XI	$3p^3 3d \ ^3P_2 \rightarrow 3p^4 \ ^3P_2$	188.2
Fe XII	$3p^2 3d \ ^2D_{3/2} \rightarrow 3p^3 \ ^2P_{1/2}$	188.2
Fe XII	$3p^2 3d \ ^4P_{5/2} \rightarrow 3p^3 \ ^4S_{3/2}$	195.1
Fe XIII	$3p 3d \ ^1F_3 \rightarrow 3p^2 \ ^1D_2$	196.5
Ni XI	$3p^5 3d \ ^1P_1 \rightarrow 3p^6 \ ^1S_0$	148.4

Example of Experimental Results on MonaLisa

NSTX-U 205079, 730 ms

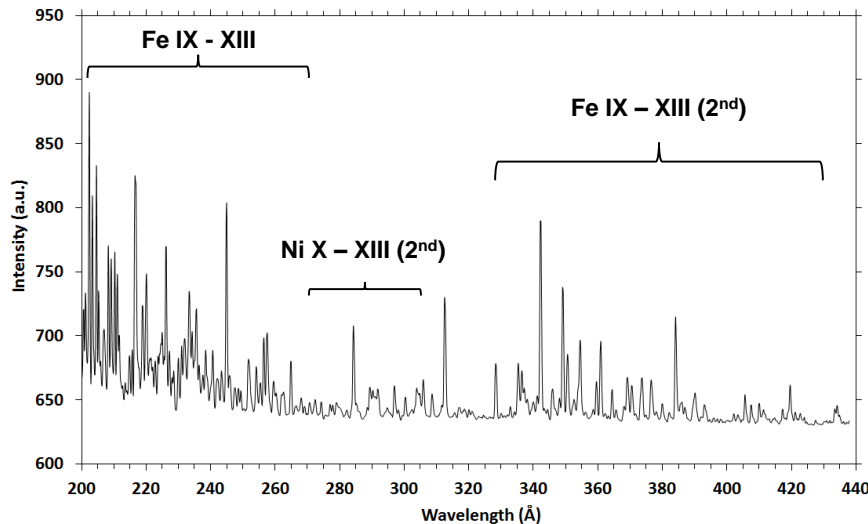
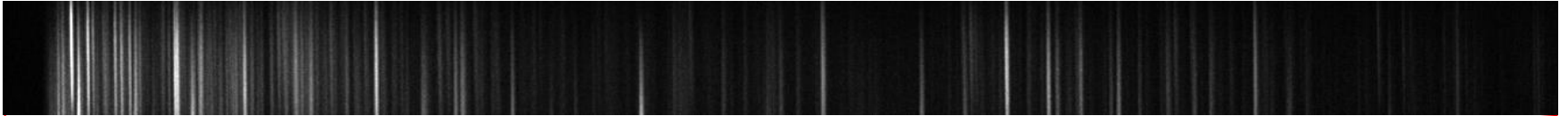


Lines	Transition	λ (Å)
Li III Ly- β	$3p \ ^2P_{1/2,3/2} \rightarrow 1s \ ^2S_{1/2}$	113.9
Li III Ly- α	$2p \ ^2P_{1/2,3/2} \rightarrow 1s \ ^2S_{1/2}$	134.9
O VI	$3p \ ^2P_{1/2,3/2} \rightarrow 2s \ ^2S_{1/2}$	150.1
O VI	$3d \ ^2D_{3/2,5/2} \rightarrow 2p \ ^2P_{1/2,3/2}$	173.1
O VI	$3s \ ^2S_{1/2} \rightarrow 2p \ ^2P_{1/2,3/2}$	184.1
O V	$2s3d \ ^3D_1 \rightarrow 2s2p \ ^3P_1$	184.1

After a few hundred ms, usually after NBI's are turned on, the spectrum is dominated by Li, B, C, and O lines.

Example of Experimental Results on LoWEUS

NSTX-U 205079, 30 ms

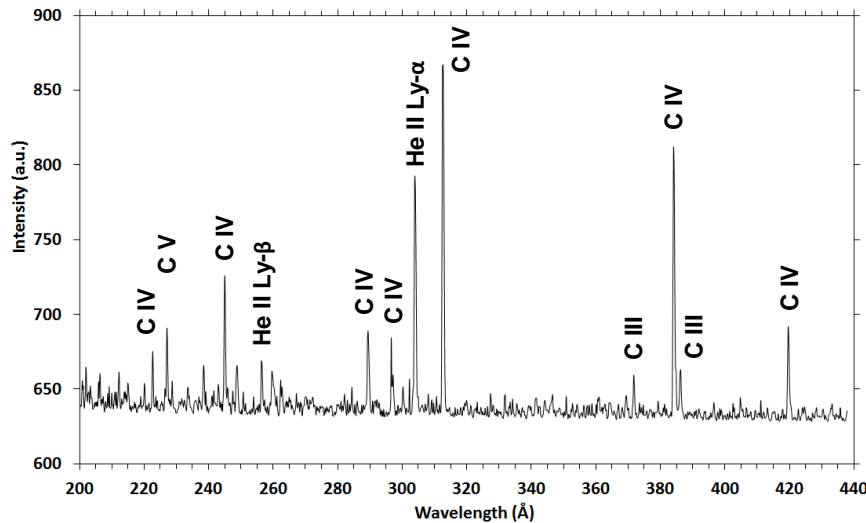
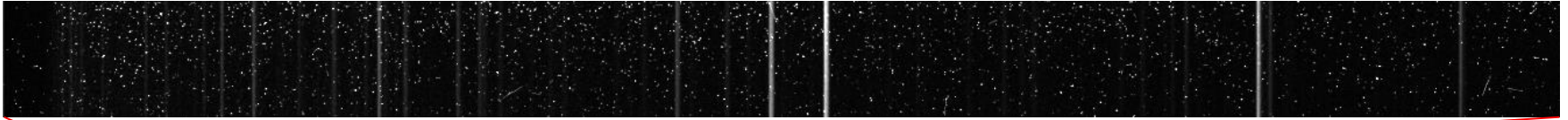


During early time on NSTX-U, the spectrum is dominated by M-shell lines of Fe, Ni, and Cr which come from stainless steel.

Lines	Transition	λ (Å)
Fe XIII	$3p3d \ ^3D_3 \rightarrow 3p^2 \ ^3P_2$	203.8
Fe XIV	$3d \ ^2D_{5/2} \rightarrow 3p \ ^3P_{3/2}$	219.1
Fe XV	$3s3p \ ^1P_1 \rightarrow 3s^2 \ ^1S_0$	284.2
Fe XVI	$3p \ ^2P_{3/2} \rightarrow 3s \ ^2S_{1/2}$	335.4
Fe XVI	$3p \ ^2P_{1/2} \rightarrow 3s \ ^2S_{1/2}$	360.8
Ni XVII	$3s3p \ ^1P_1 \rightarrow 3s^2 \ ^1S_0$	249.2
Ni XVIII	$3p \ ^2P_{3/2} \rightarrow 3s \ ^2S_{1/2}$	292.0
Ni XVIII	$3p \ ^2P_{1/2} \rightarrow 3s \ ^2S_{1/2}$	320.6
Cr XIII	$3s3p \ ^1P_1 \rightarrow 3s^2 \ ^1S_0$	328.3
Cr XIV	$3p \ ^2P_{3/2} \rightarrow 3s \ ^2S_{1/2}$	389.9
Cr XIV	$3p \ ^2P_{1/2} \rightarrow 3s \ ^2S_{1/2}$	412.1

Example of Experimental Results on LoWEUS

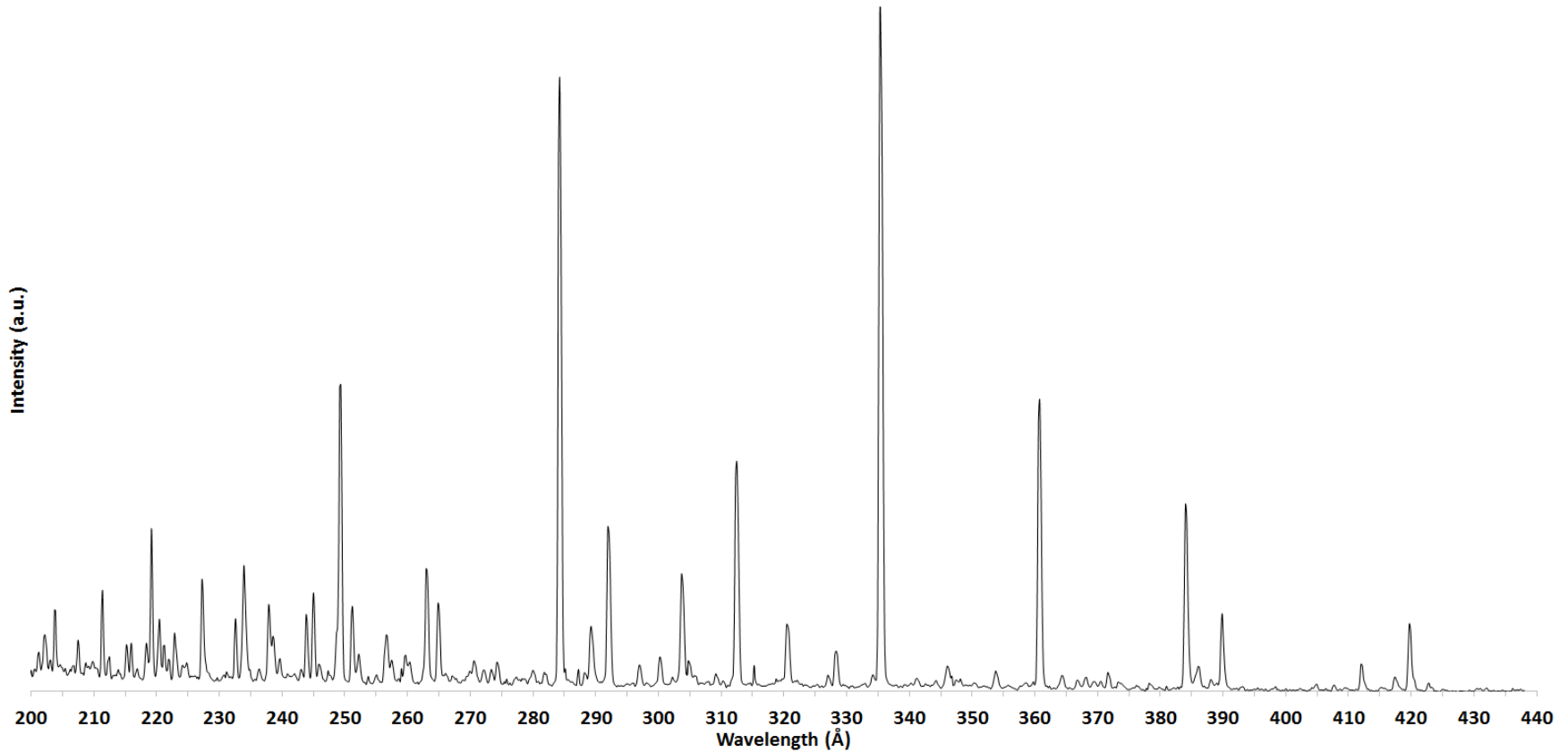
NSTX-U 205079, 730 ms



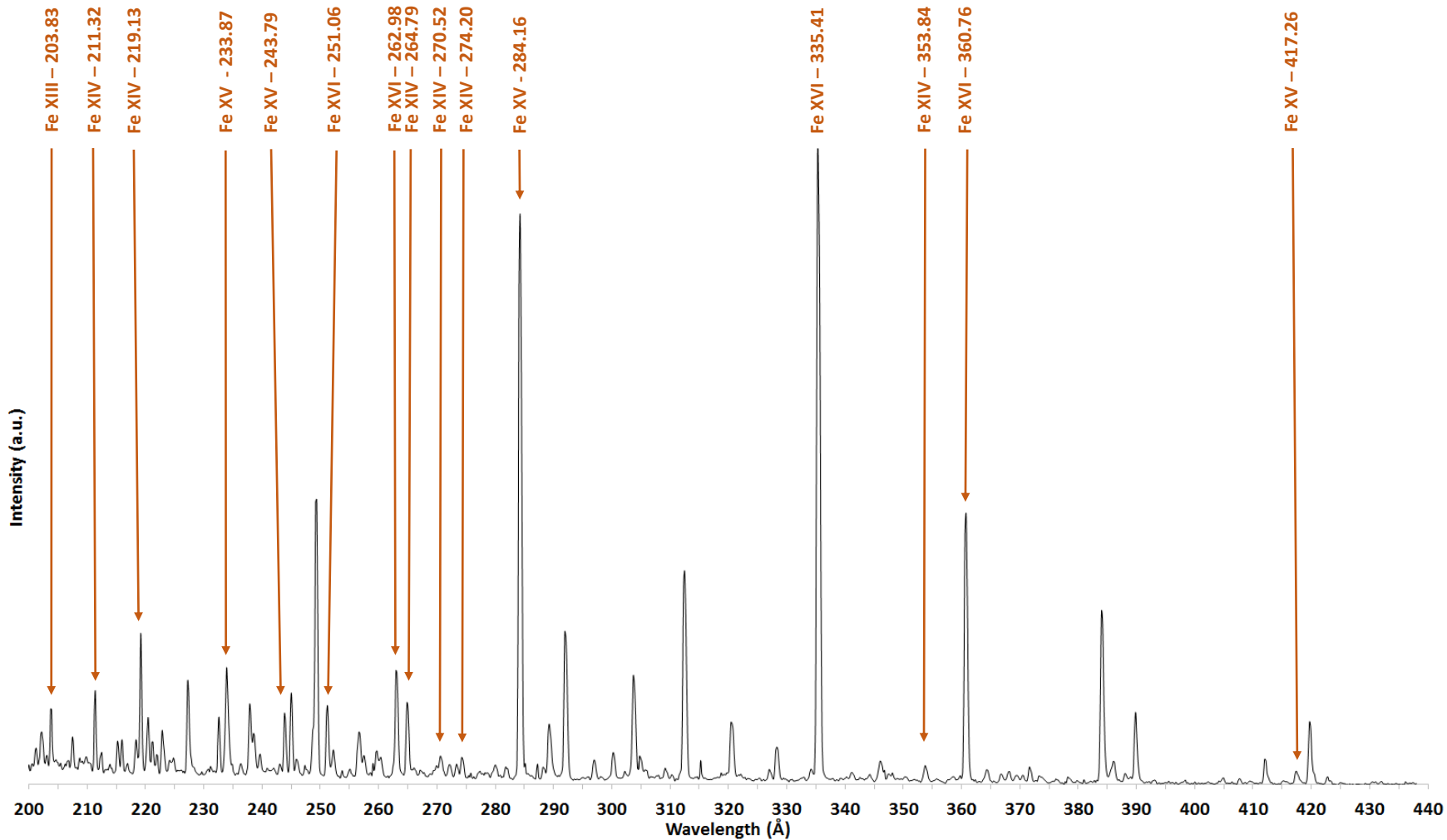
After a few hundred ms, usually after NBI's are turned on, the spectrum is dominated by He, C, and O lines.

Lines	Transition	λ (Å)
He II Ly- β	$3p \ ^2P_{1/2,3/2} \rightarrow 1s \ ^2S_{1/2}$	256.3
He II Ly- α	$2p \ ^2P_{1/2,3/2} \rightarrow 1s \ ^2S_{1/2}$	303.8
C IV	$5p \ ^2P_{3/2} \rightarrow 2s \ ^2S_{1/2}$	222.8
C IV	$4p \ ^2P_{3/2} \rightarrow 2s \ ^2S_{1/2}$	244.9
C IV	$4d \ ^2D_{5/2} \rightarrow 2p \ ^2P_{3/2}$	289.2
C IV	$3p \ ^2P_{3/2} \rightarrow 2s \ ^2S_{1/2}$	312.4
C IV	$3d \ ^2D_{5/2} \rightarrow 2p \ ^2P_{3/2}$	384.2
C IV	$3s \ ^2S_{1/2} \rightarrow 2p \ ^2P_{3/2}$	419.7
C V	$3p \ ^3P_2 \rightarrow 2s \ ^3S_1$	227.2

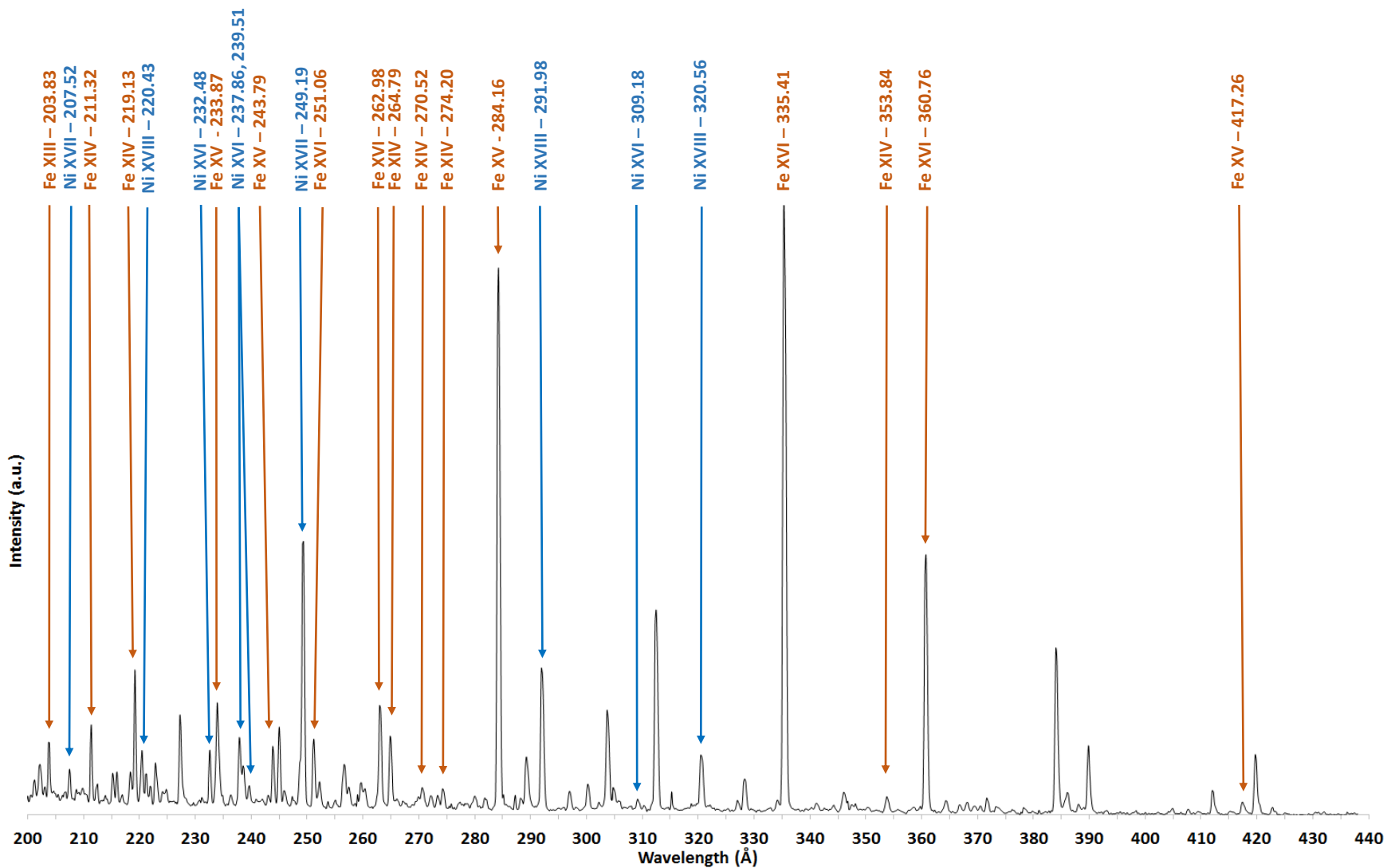
LoWEUS Spectra from NSTX-U 205079 at 0.166 s



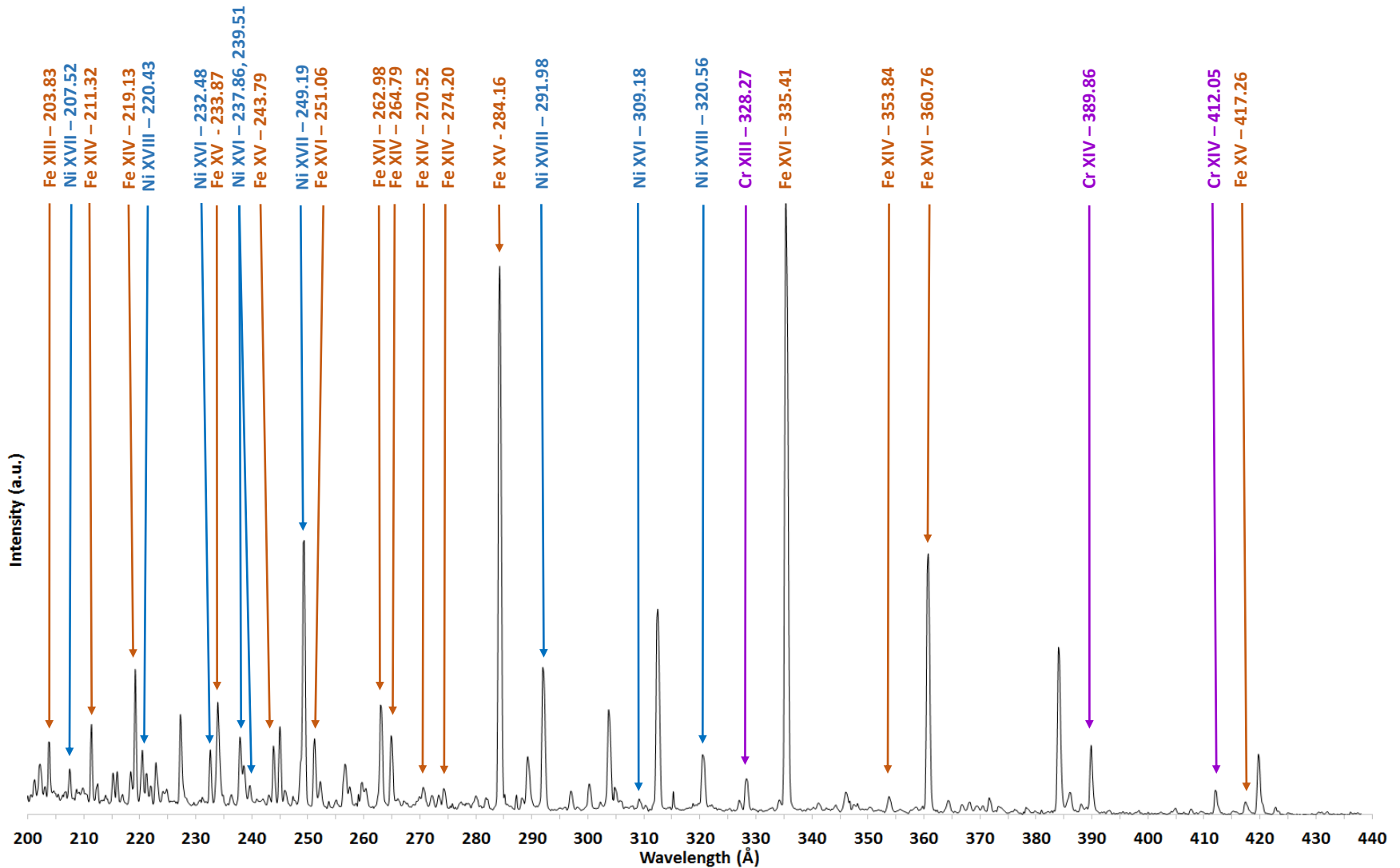
Fe Lines Identified



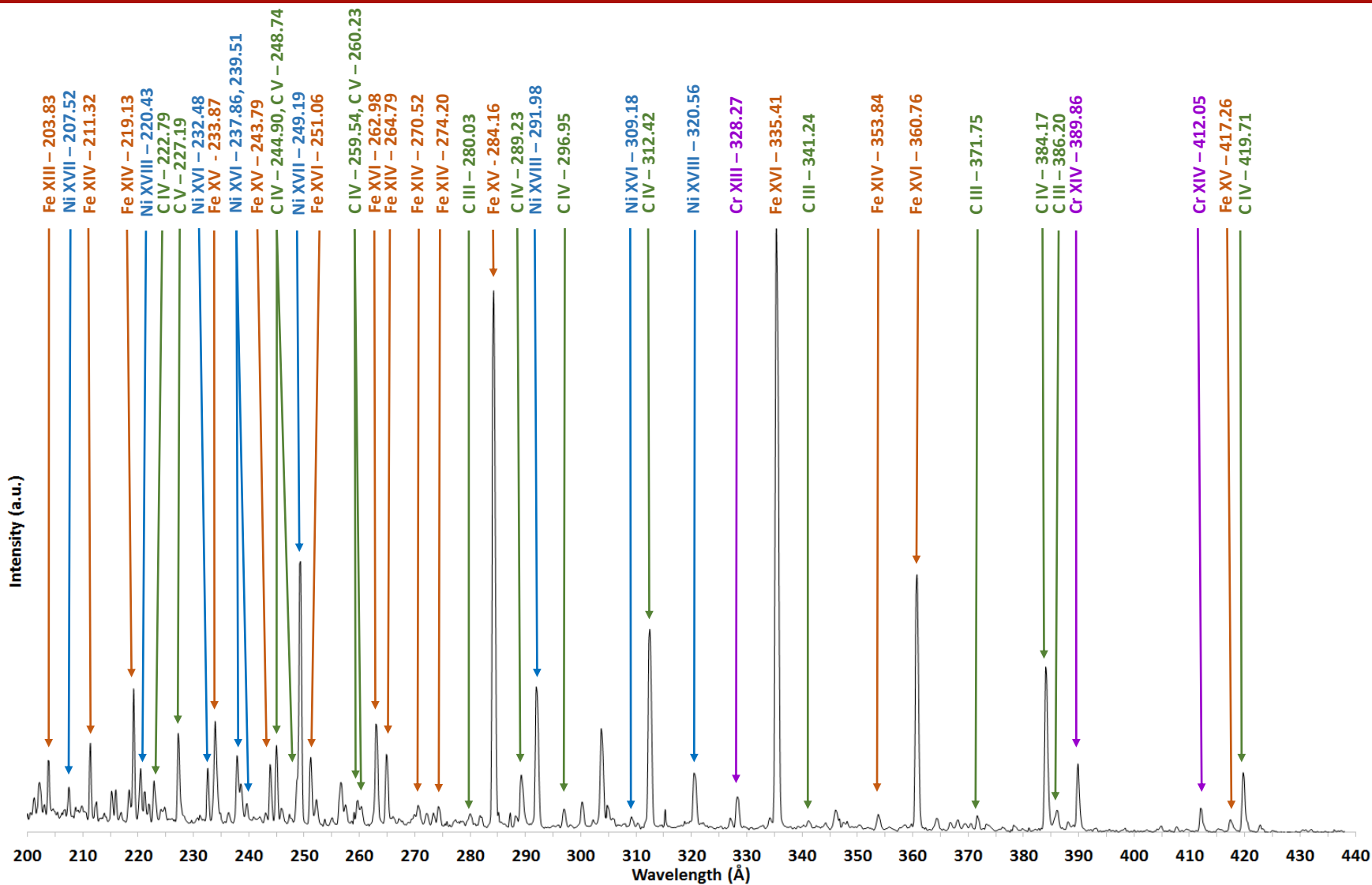
Ni Lines Identified



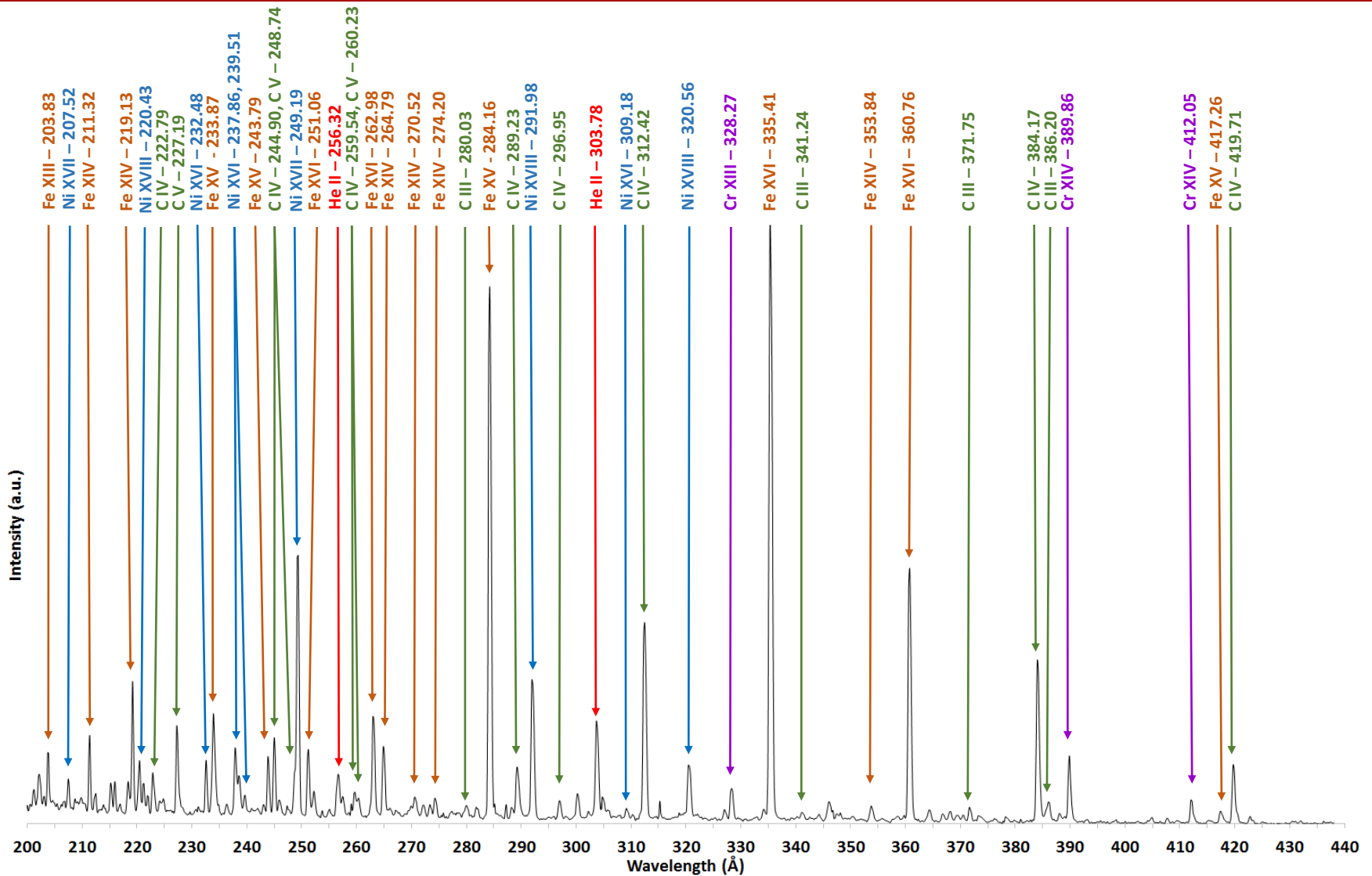
Cr Lines Identified



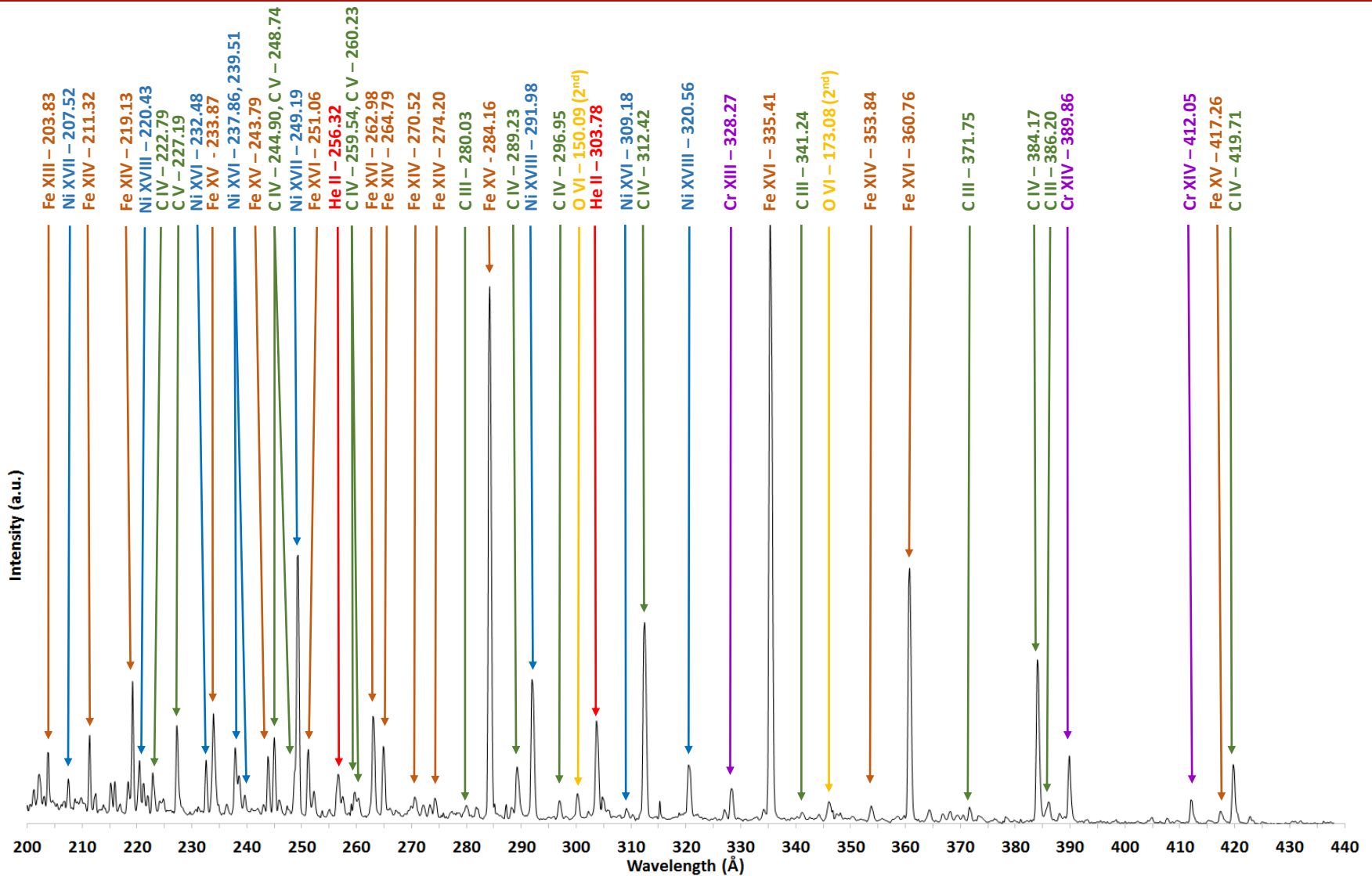
C Lines Identified



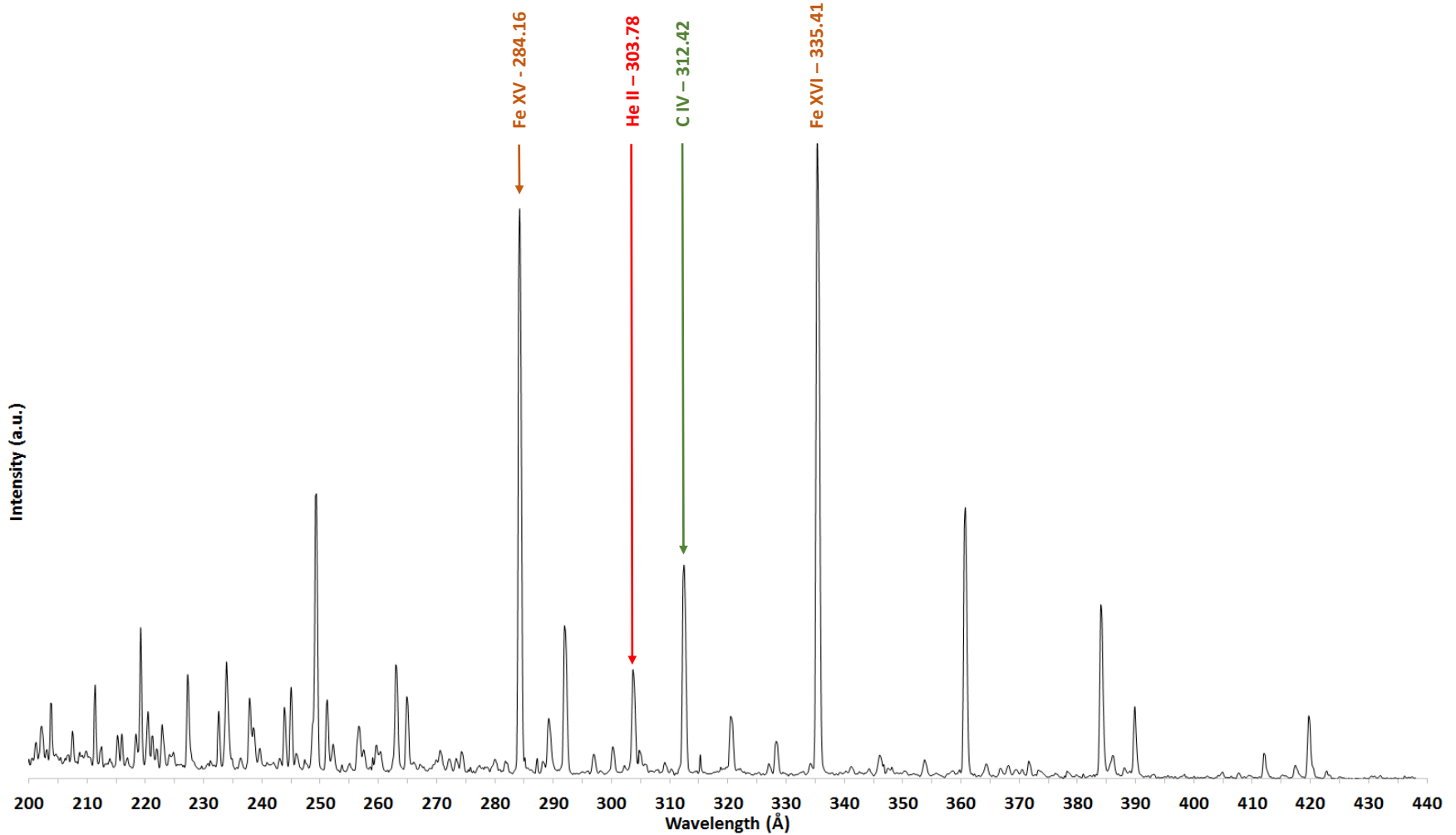
He Lines Identified



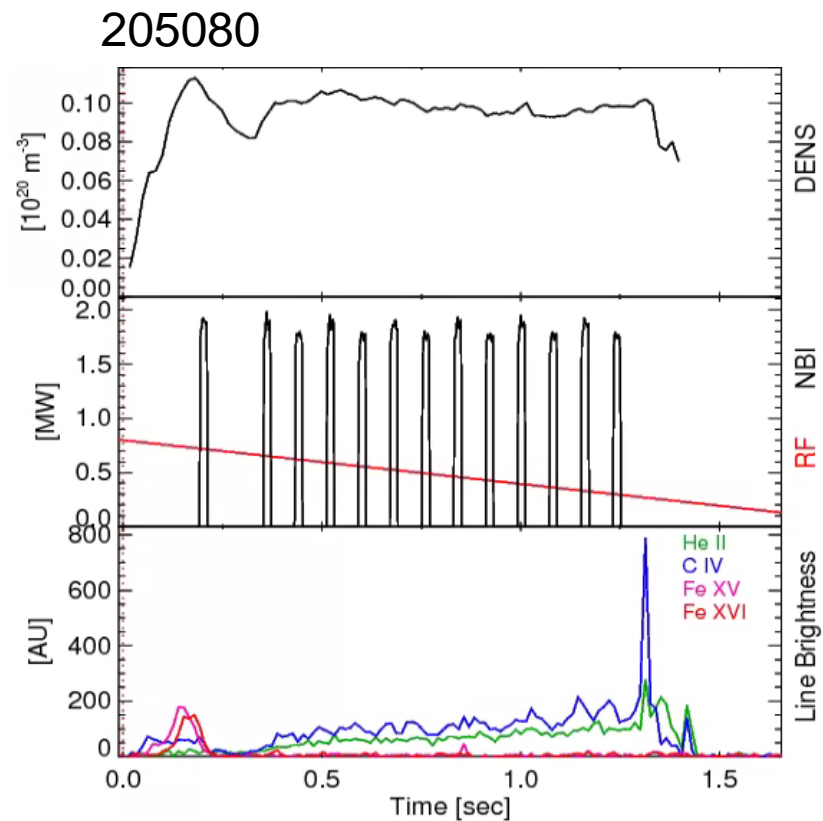
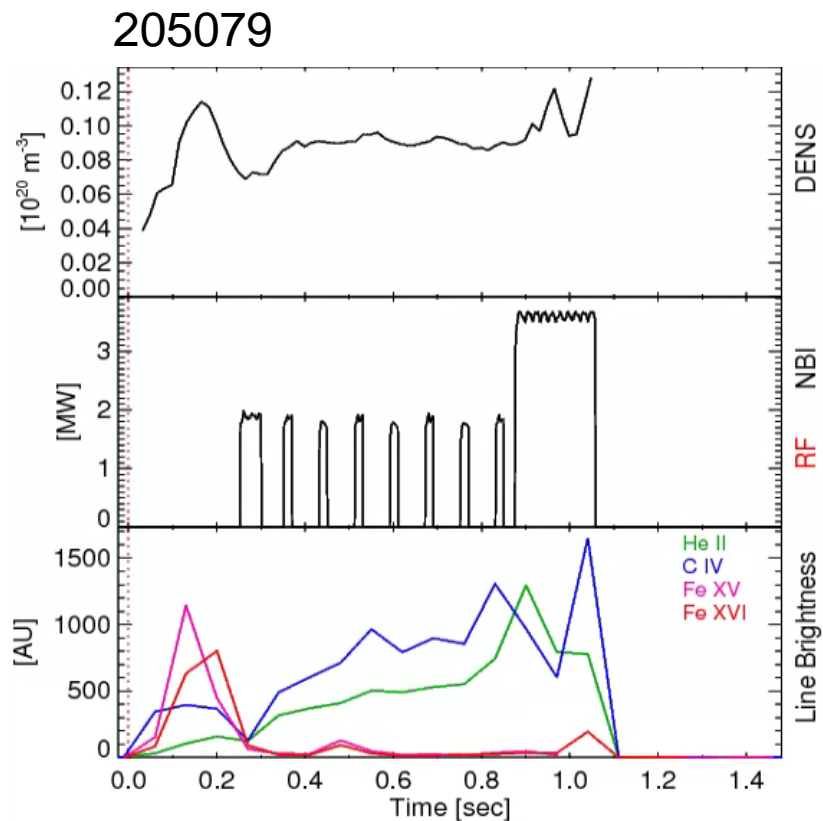
O Lines Identified



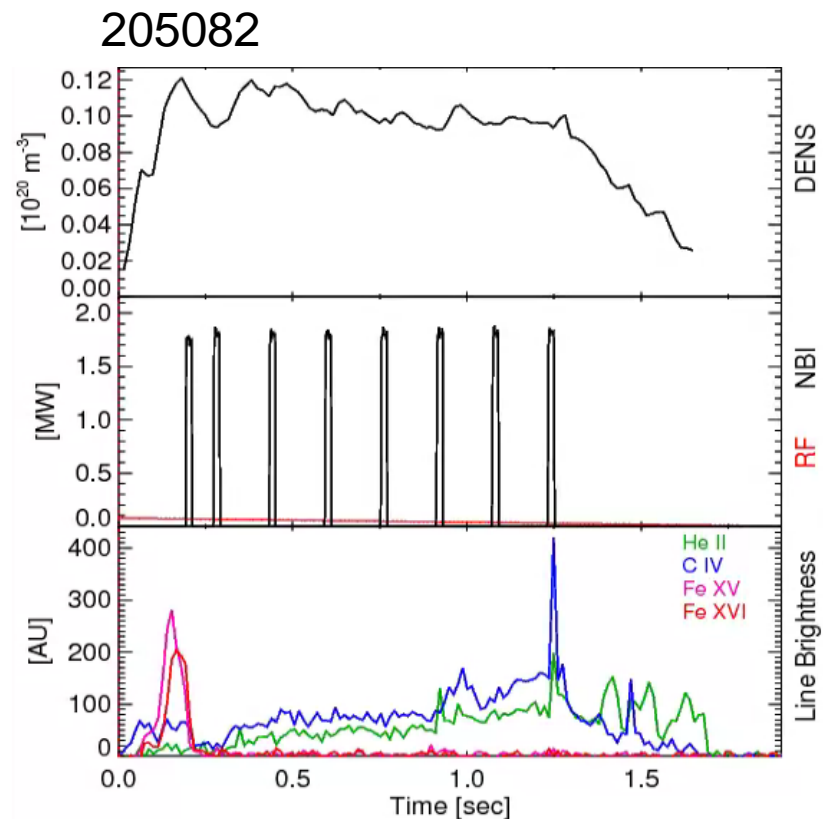
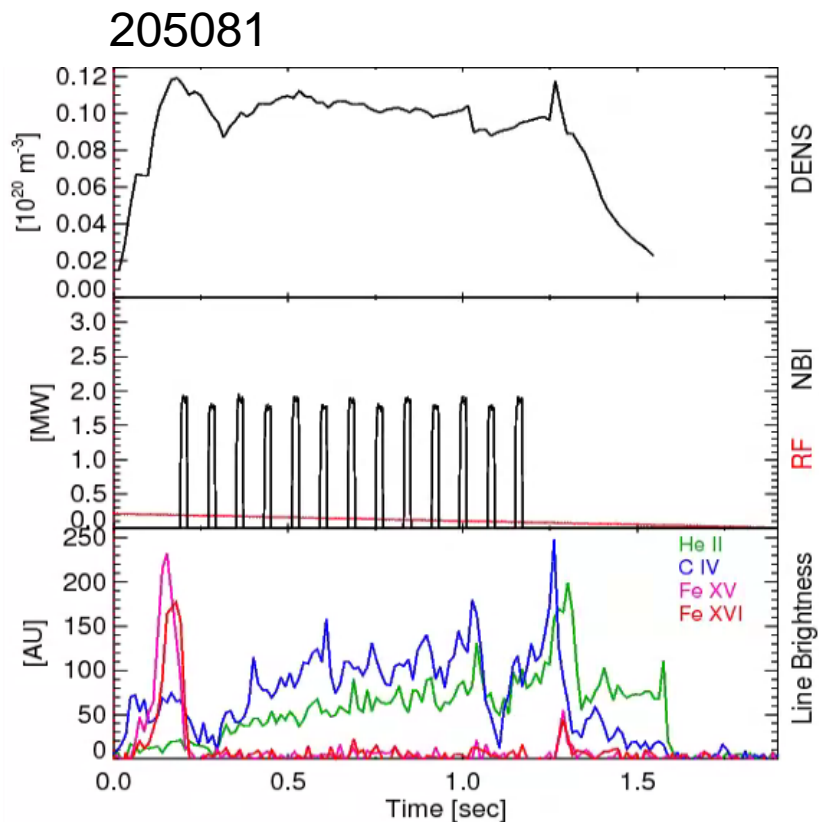
Potentially Diagnostically Important Lines for LoWEUS



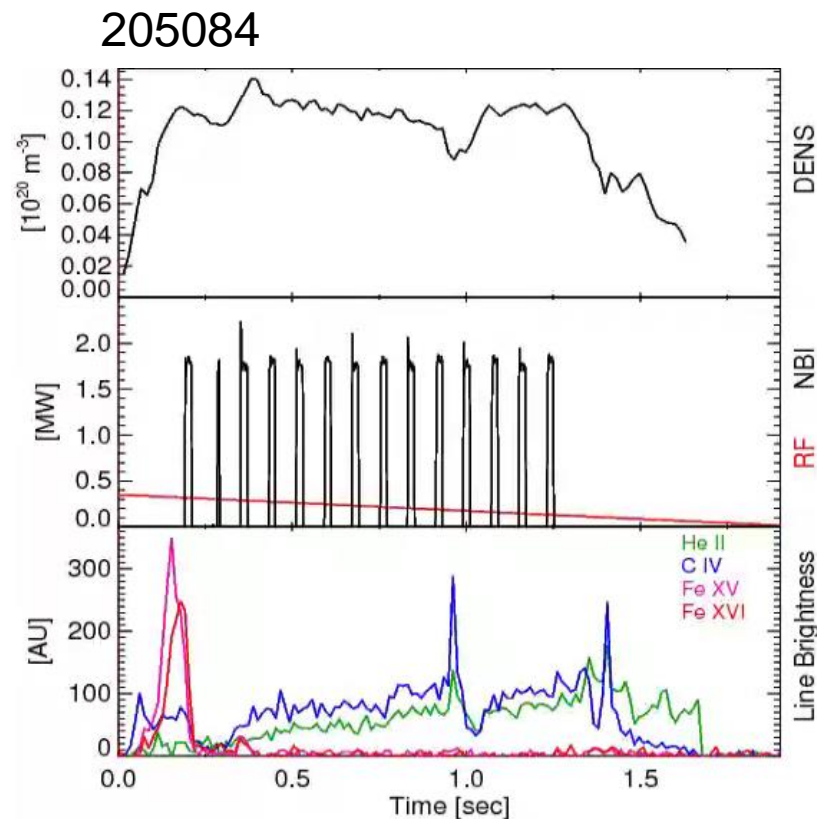
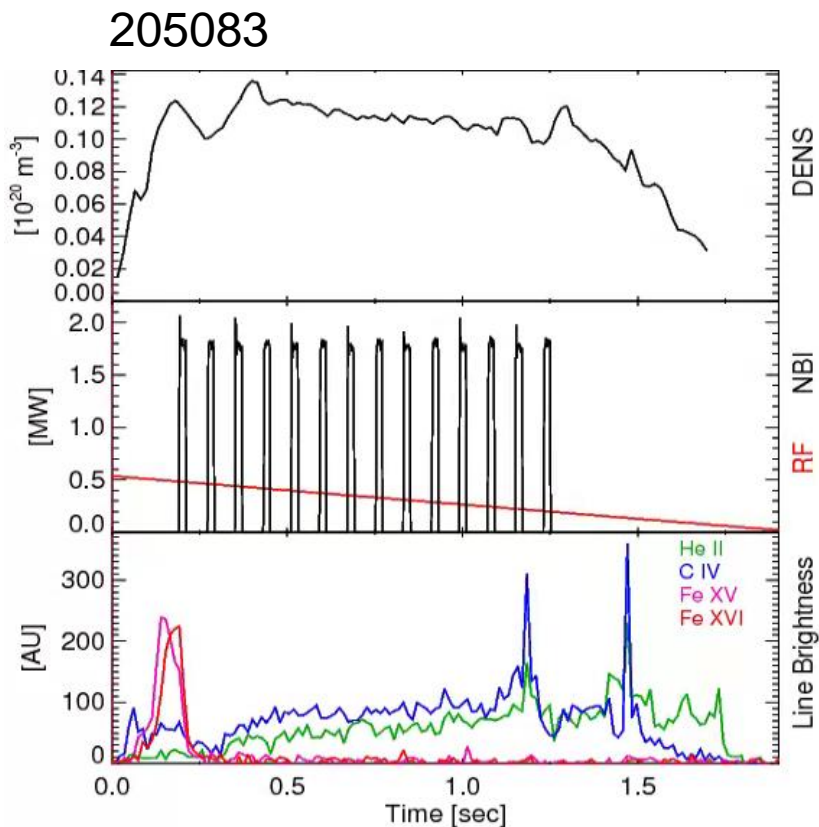
Time Histories of He, C, and Fe on LoWEUS



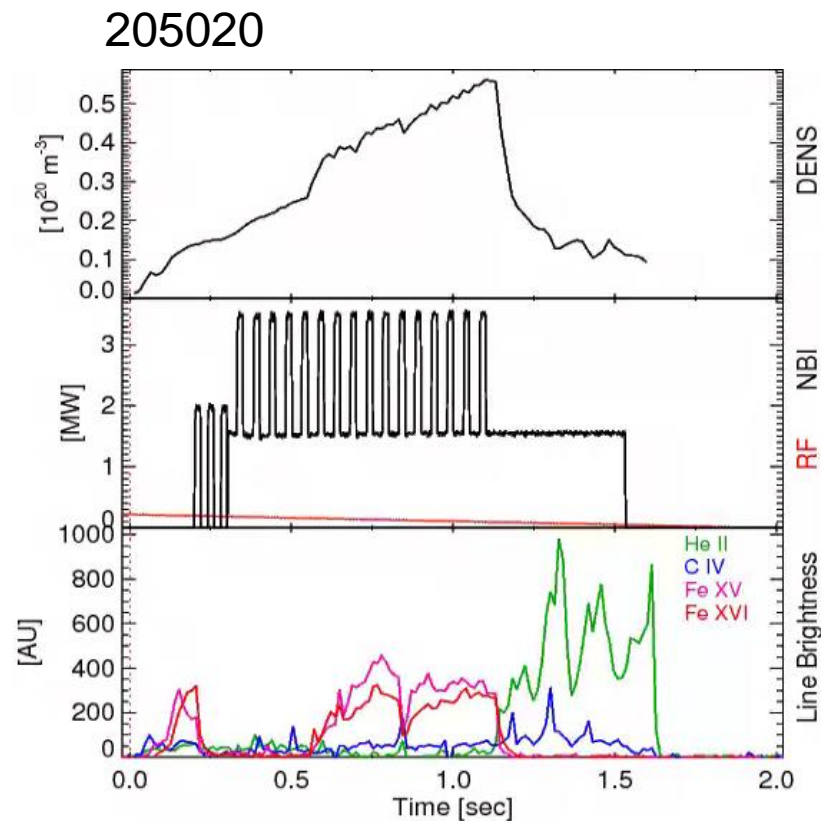
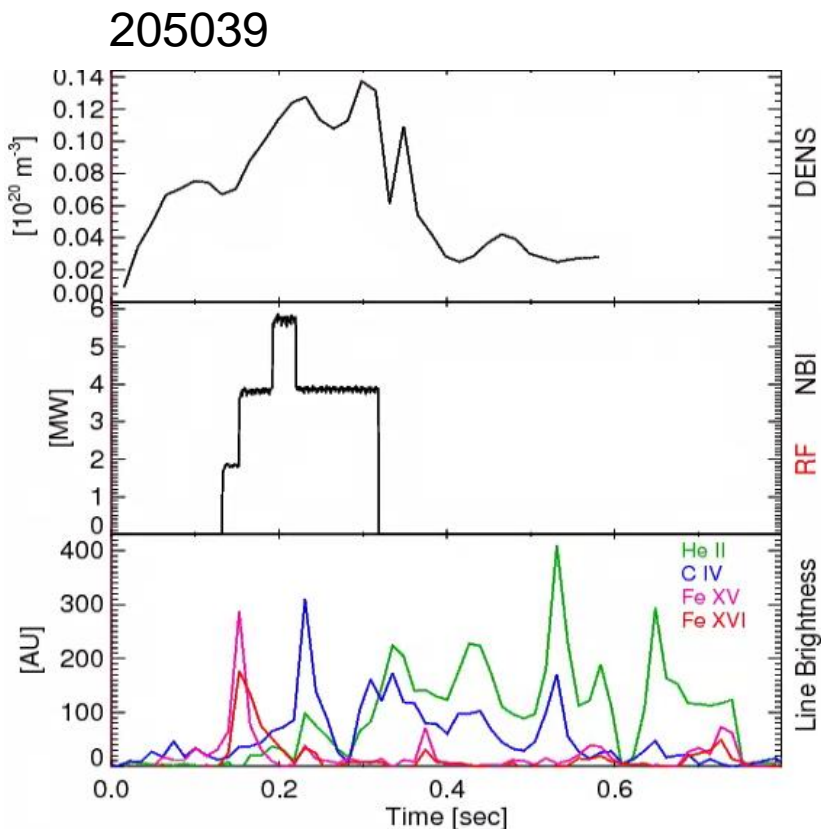
Time Histories of He, C, and Fe on LoWEUS



Time Histories of He, C, and Fe on LoWEUS



Time Histories of He, C, and Fe on LoWEUS



Conclusions

- NSTX-U results of EUV spectra covering the spectral range of 8-440 Å have been shown for the first time
 - Over 240 plasma shots covering 12 run days
- Hundreds of lines identified with confirmed elements:
 - He, Li, B, C, O, Cr, Fe, Ni
- In particular data from LoWEUS covered the spectral range > 250 Å, identifying many new lines on NSTX-U to study
- Radiation dominated by M-shell Fe, Ni, and Cr lines and then dominated by C, followed by He, Li, O, and B
- Can possibly use Fe XV (284.2 Å) and Fe XVI (335.4 Å) lines as warning signals