



Multiple Impurity Monitoring System For The HSX Stellarator

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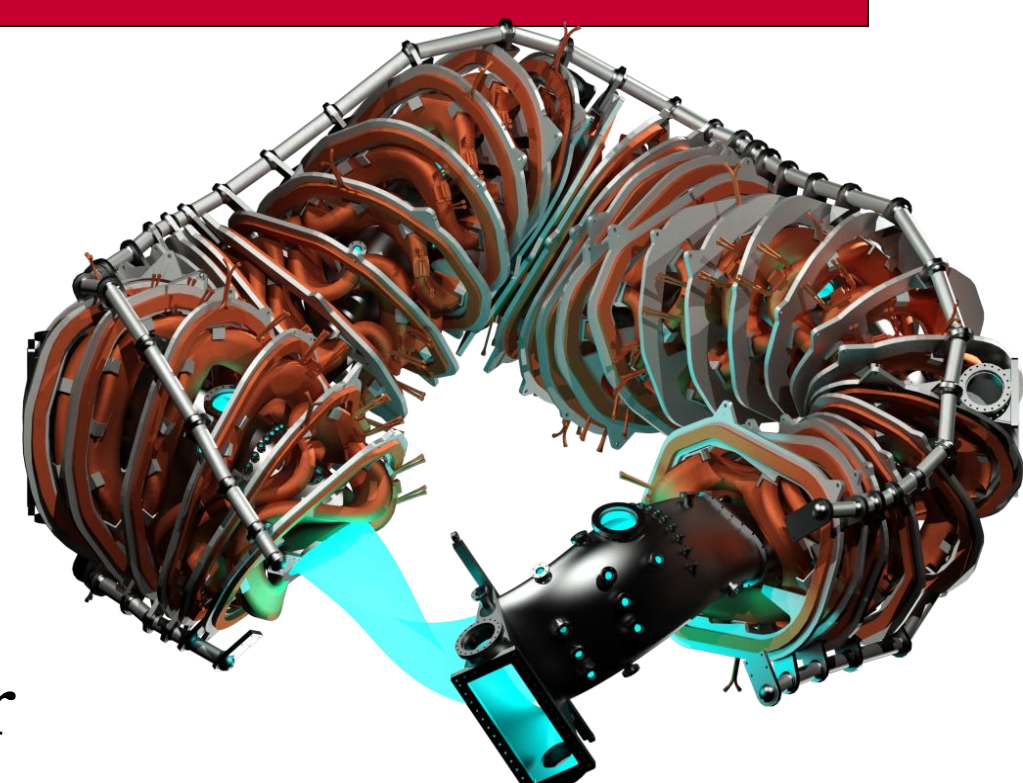
Motivation For Spectral Diagnostics

- Diagnose contamination events
- Experimental validation of atomic data
- Measurements of ion species densities which can affect:
 - Radiative power loss
 - Reduces temperature
 - Can determine density limits in stellarators
 - Can reduce peak heat loads on surfaces
 - Particle sourcing location
 - Turbulent and neoclassical transport

The HSX Stellarator

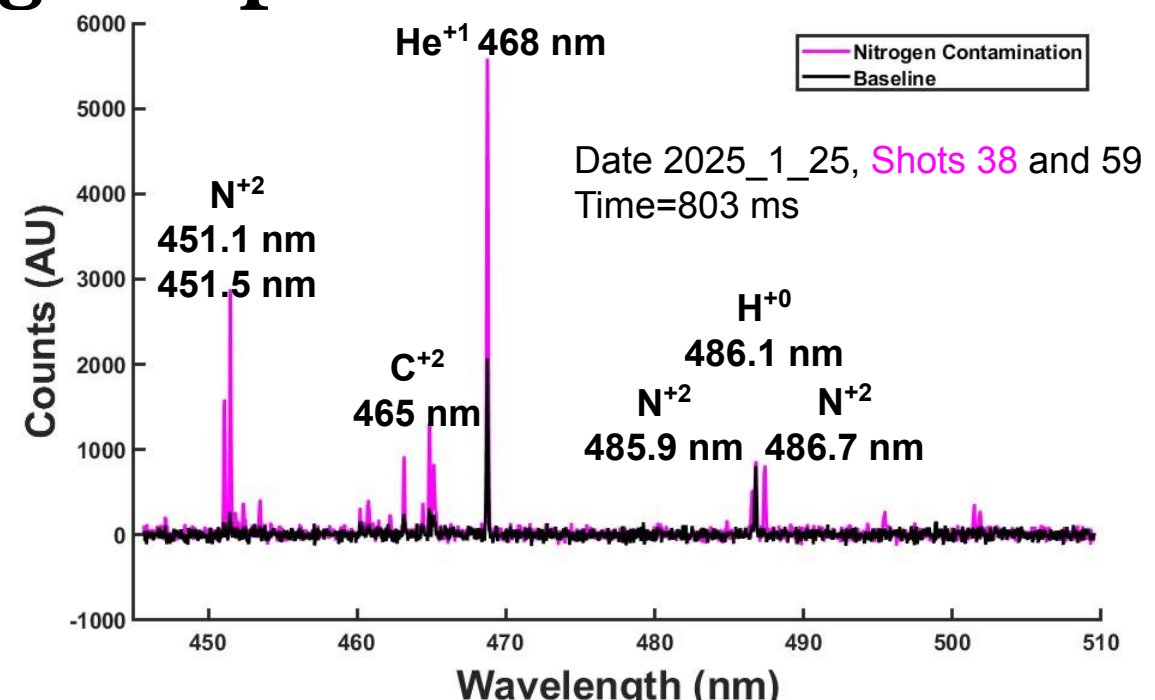
Operational parameters

- Major radius: 1.2 m
- Minor radius: 12 cm
- Main field: 1/2, 1 T
- 28 GHz ECRH
- ≤100 kW injected power

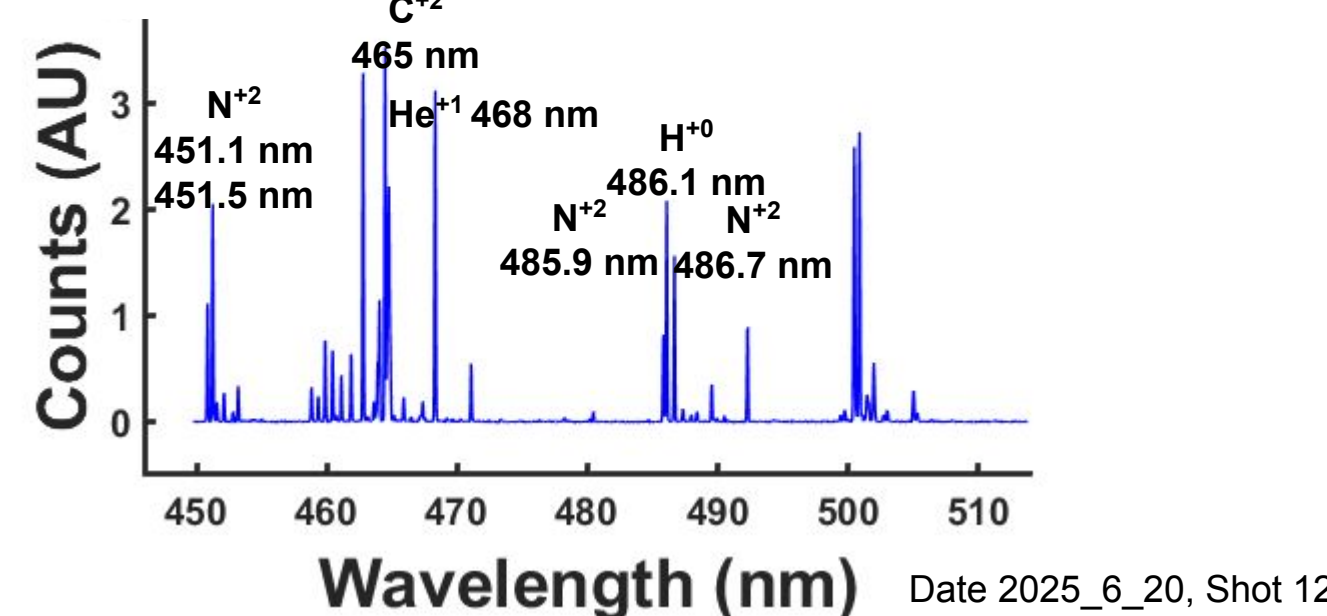


Impurity Identification

Nitrogen lines also observed after Raman Scattering was performed



Air contamination events show nitrogen and molecular lines



Multi Impurity Monitoring System (MIMS)

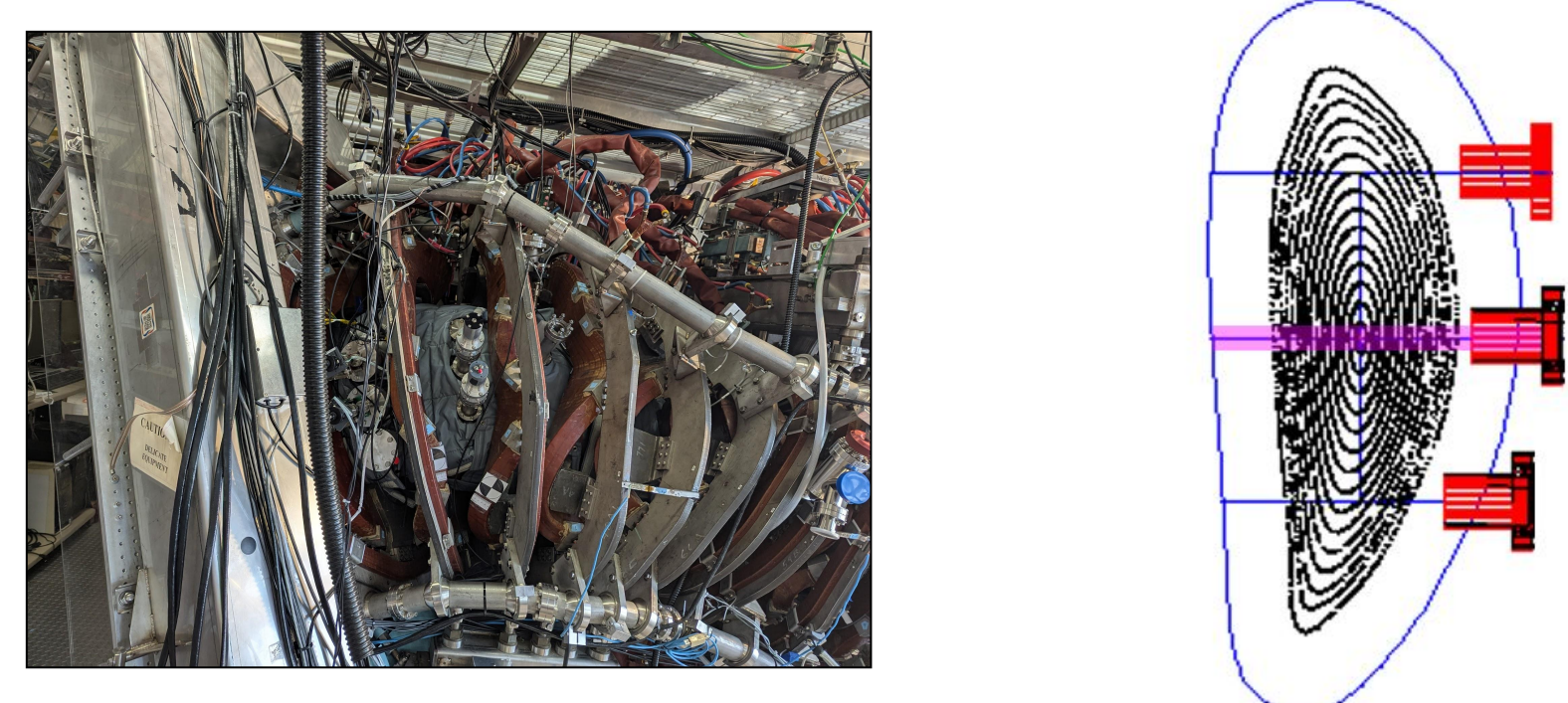
Survey spectrometer developed at HSX

- Input lens focal distance 300 mm f/4.5
 - Instrumental function of 0.2 nm
 - 100 pixels in the vertical direction
- Output lens focal distance 85 mm f/1.2
 - 40 nm spectral range,
 - Tunable across the visible spectrum
 - 0.03 nm/pixel dispersion
- S-CMOS camera Andor Sona Camera
 - 4.2 Megapixel back illuminated detector
 - 6.5 μm pixel size, 13.3 mm by 13.3 mm sensor
 - 5 ms integration time
- Round to linear fiber array
- 3D printed components

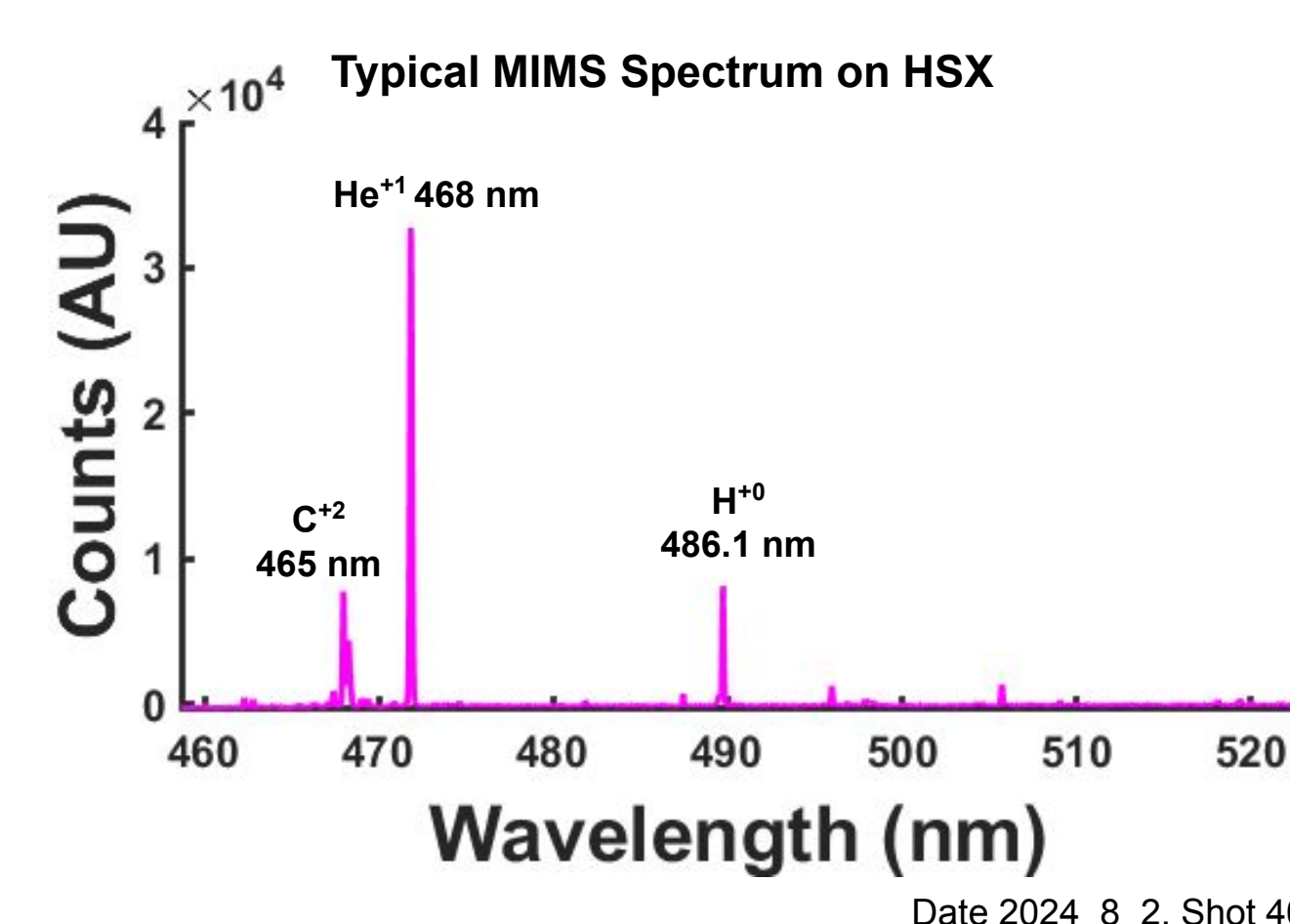


MIMS on HSX

- Currently deployed on a central view
- 1.5 inch diameter fused silica plano-convex collection lens



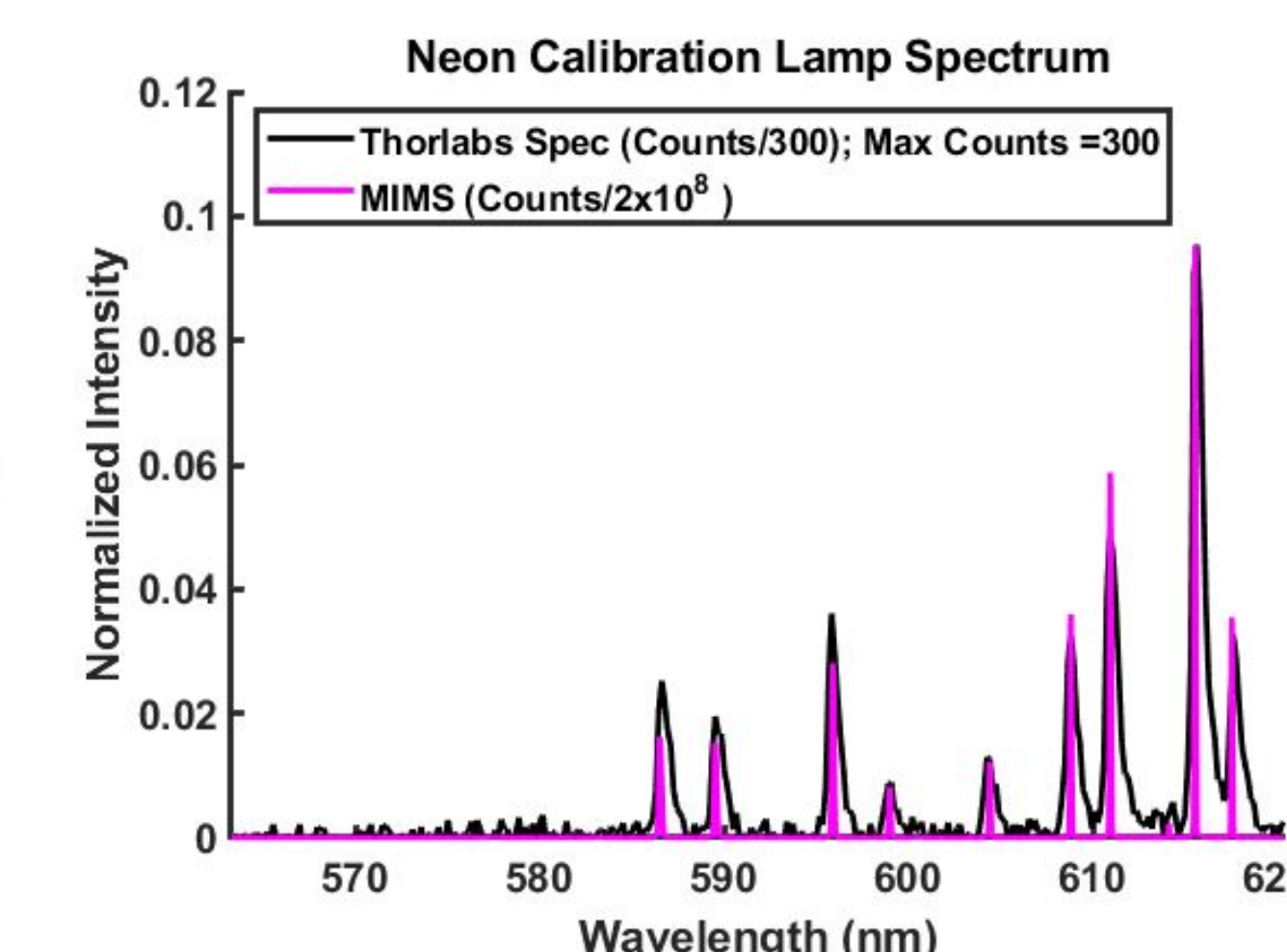
- Helium fueling
- Hydrogen and carbon are the primary minority species observed in the spectra



Comparison to Off the Shelf Spectrometer

The MIMS spectrometer has increased optical throughput, and narrower instrumental function, when compared to compact off-the shelf spectrometers

- Thorlabs CCS175 Compact Spectrometer used for comparison
 - 500-1000 nm range, 0.17 nm/pixel
 - Instrumental function=0.6 nm
 - Detector=linear array, 3648 pixels
 - Pixel size=8 μm x 200 μm



Ion Content Affects Electron Temperature Profile and Density Fluctuations

Higher T_e measured in discharges with higher carbon levels

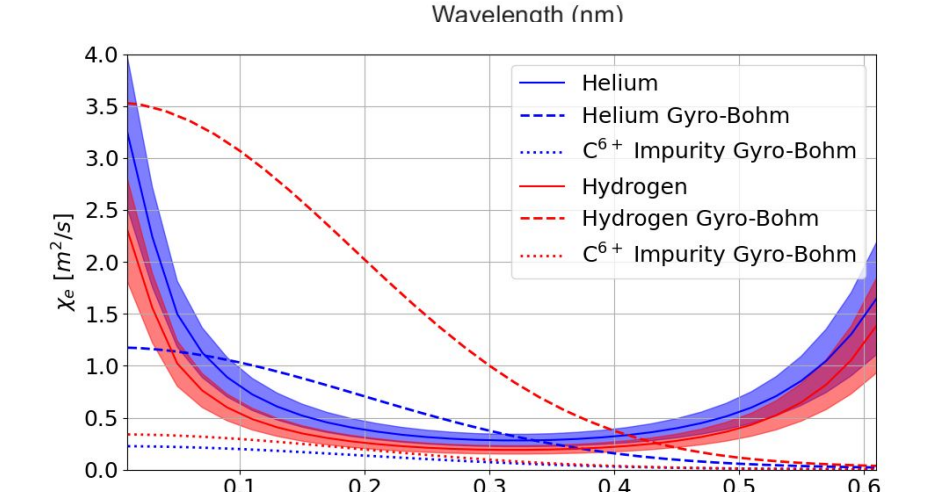
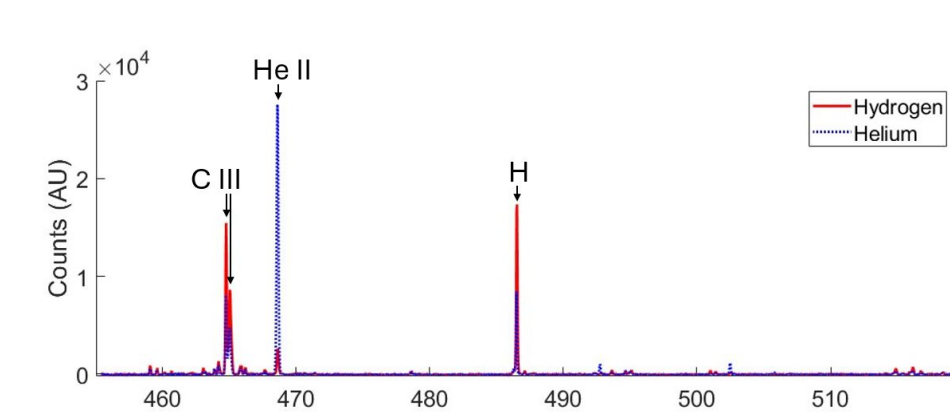
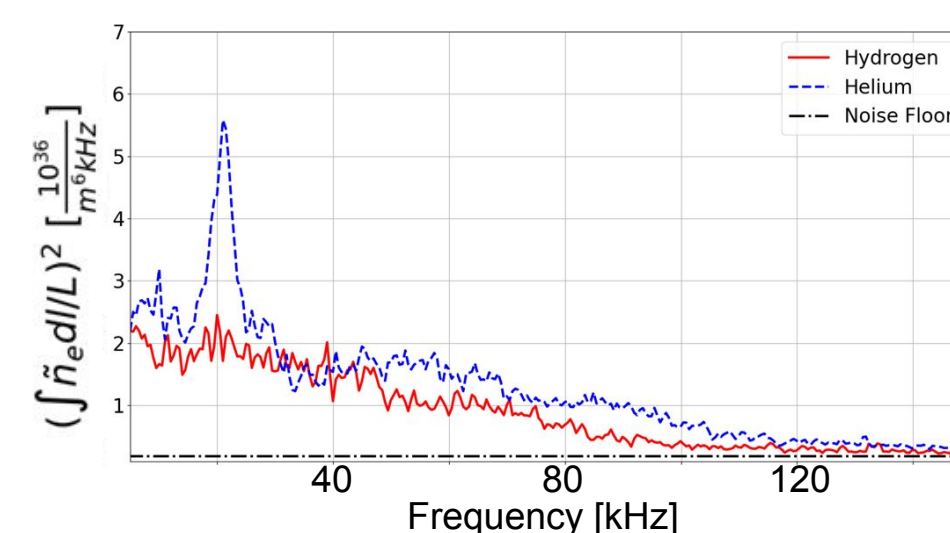
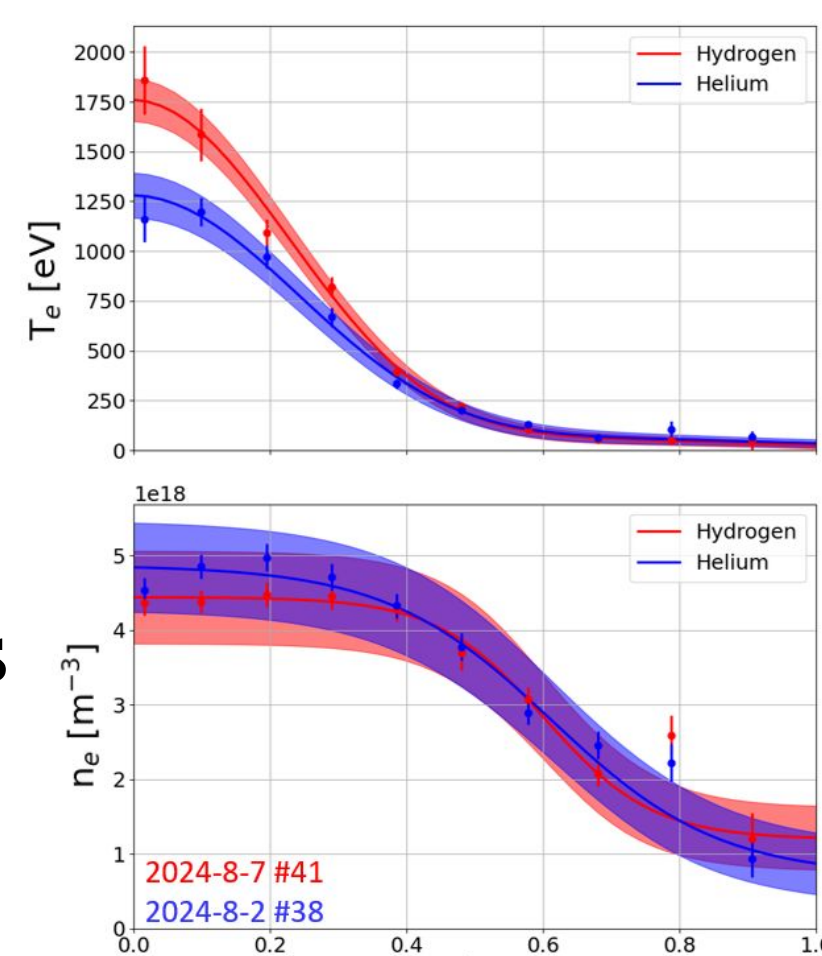
Hydrogen vs Helium fueled discharges

- H fueling leads to higher core T_e
- Lower broadband and coherent fluctuations observed in H
- Higher turbulence predicted for pure H vs He by Gyro-Bohm scaling
- C⁺⁶ predicted to have Much Lower turbulence

$$\chi_{GB} = \frac{m_i^{1/2} (eT_e)^{3/2}}{16Z_i^2 e^2 B a}$$

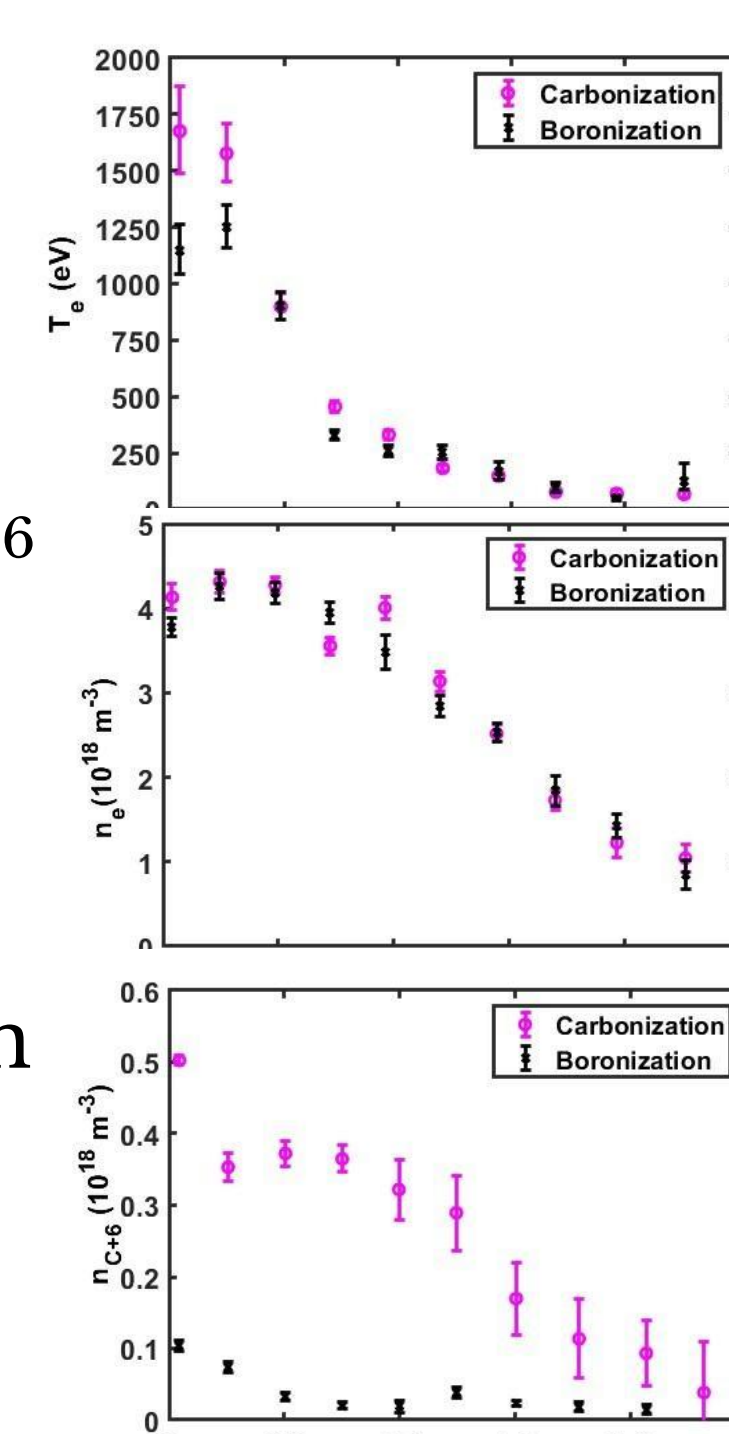
$$\chi_{GB H+1} = 2 \chi_{GB He+2}$$

$$\chi_{GB C+6} = 0.2 \chi_{GB He+2}$$



Carbonized walls vs Boronized walls

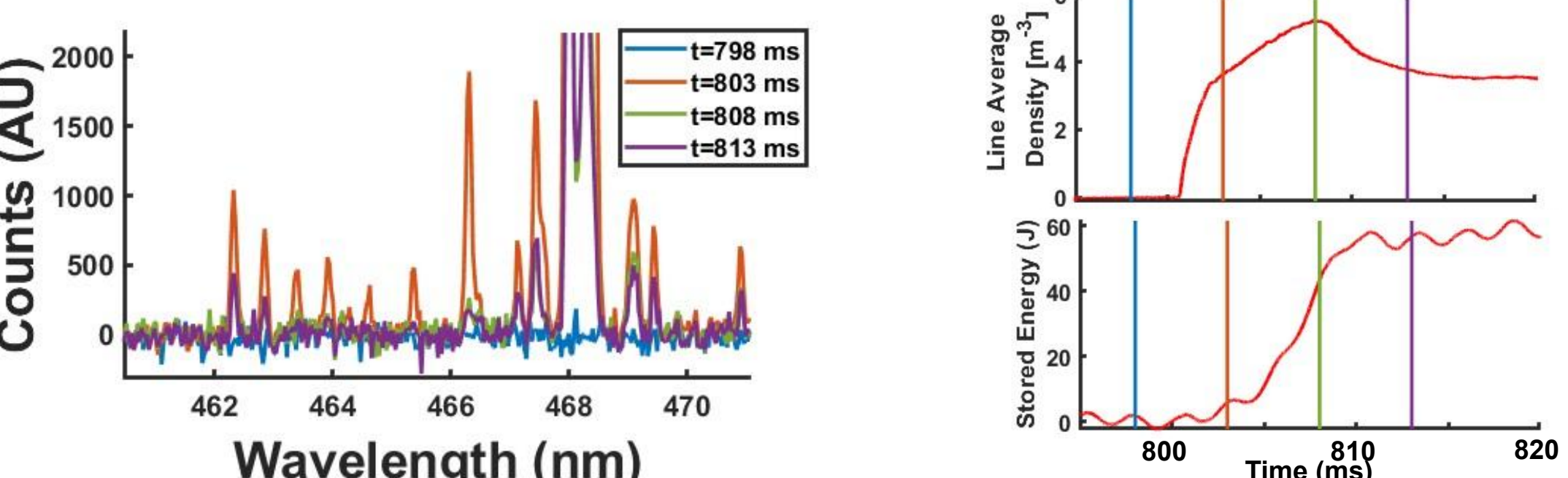
- When carbonization was used higher T_e was measured
- And higher C⁺⁶ content measured using charge exchange recombination spectroscopy



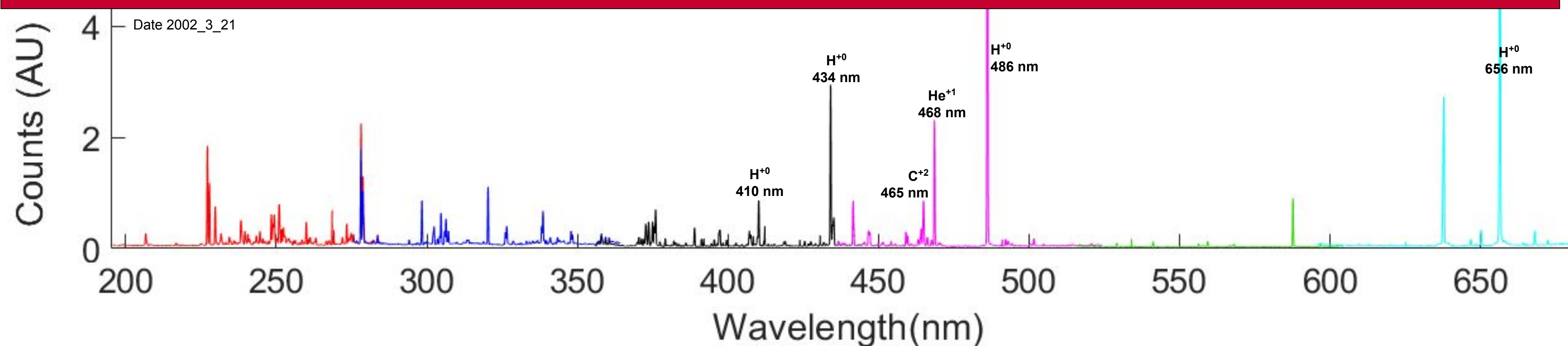
Molecular Emission Observed

Molecular emission observed during high density, low temperature startup phase

- Indicative of chemical erosion



Typical HSX Spectrum



Future Work

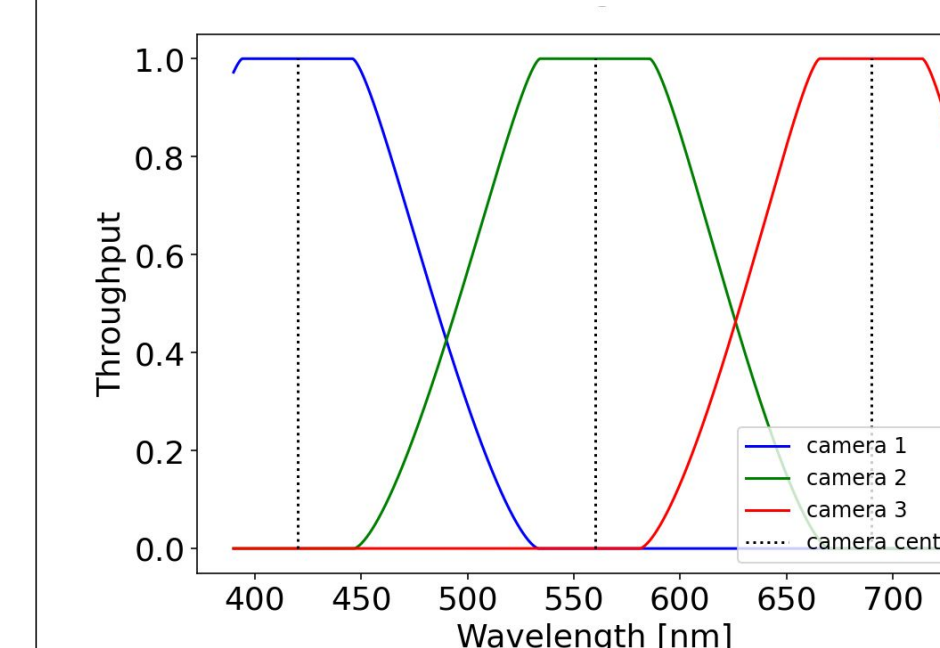
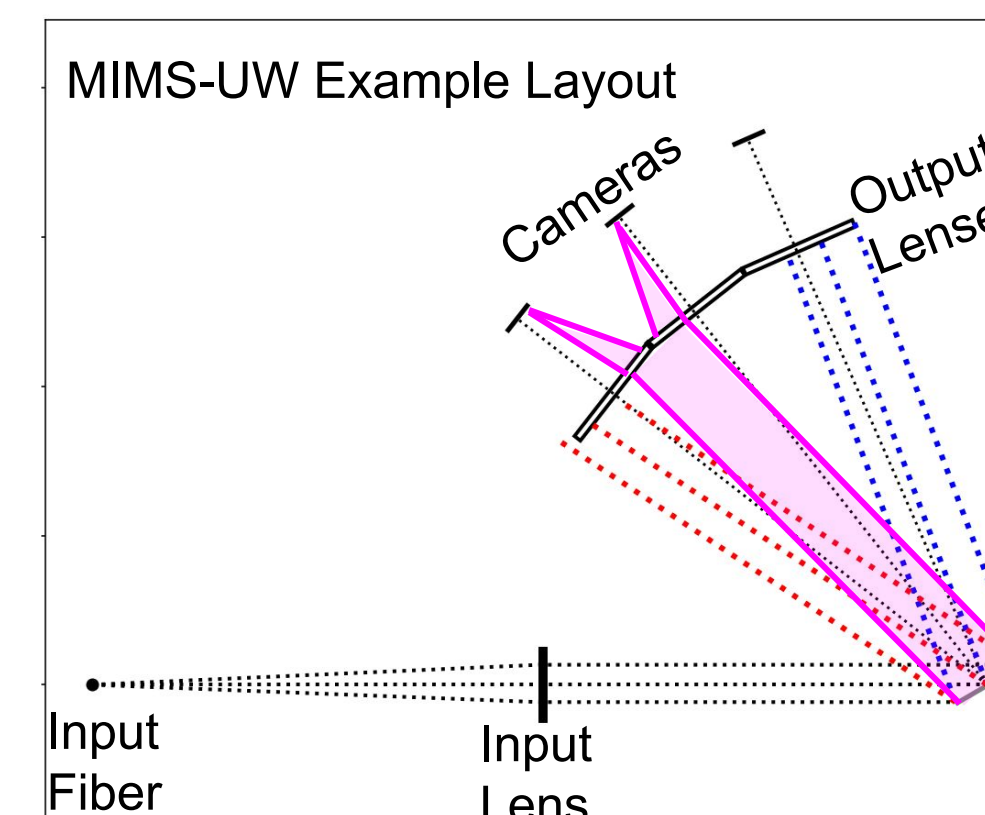
MIMS-2: Expanded spectral range achieved by adding a second camera

- Input lens 180 mm f/2.8
- Output lens:
 - 25 mm f/0.95
 - 50 mm f/0.95
- Compact Ximea cameras



MIMS-Ultra Wide: 3 cameras used to achieve full visible spectrum coverage

- Part of an INFUSE grant for Type-One Energy
- Light column can be divided to provide continuous and even overlapping wavelength coverage
- Overlapping ranges will have reduced throughput



Improved Analysis Under Development

- Bremsstrahlung fitting to measure Z_{effective}
- Helium line ratios to measure T_e and n_e
- Expanded line identification
 - Intentional impurity injection will be used