Get out of my walls! : Impurity ions in MST

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UW Fusion Experiment Workshop: Managing Neutrals and Impurities
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WiPPL

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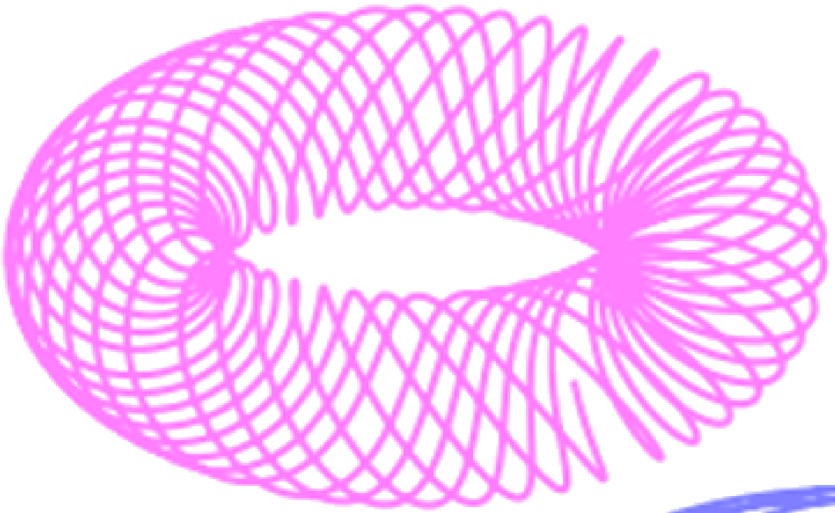
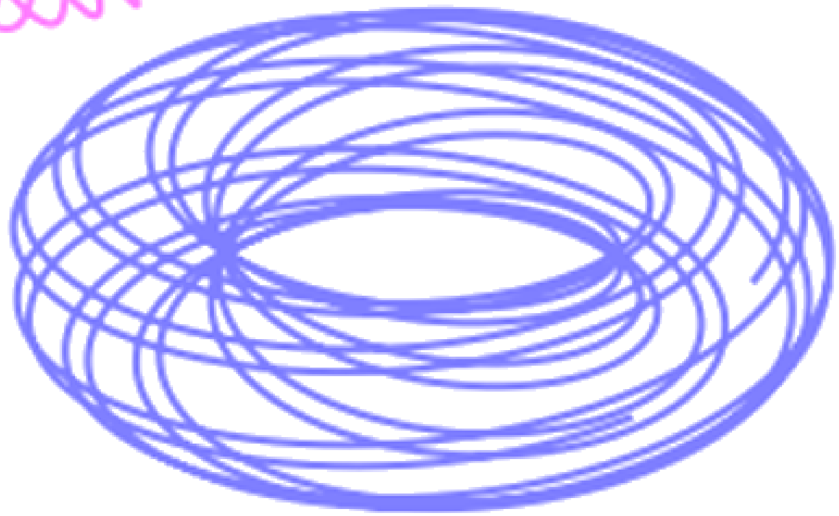
MST Operates in Many Regimes

- Two power supplies
  - Legacy: timed pulse forming network
  - Programmable power supply (PPS): feedback driven, high voltage
- Variable field configurations
  - Reversed Field Pinch (RFP)
  - Tokamak
  - Ultra-low q (Ulq)





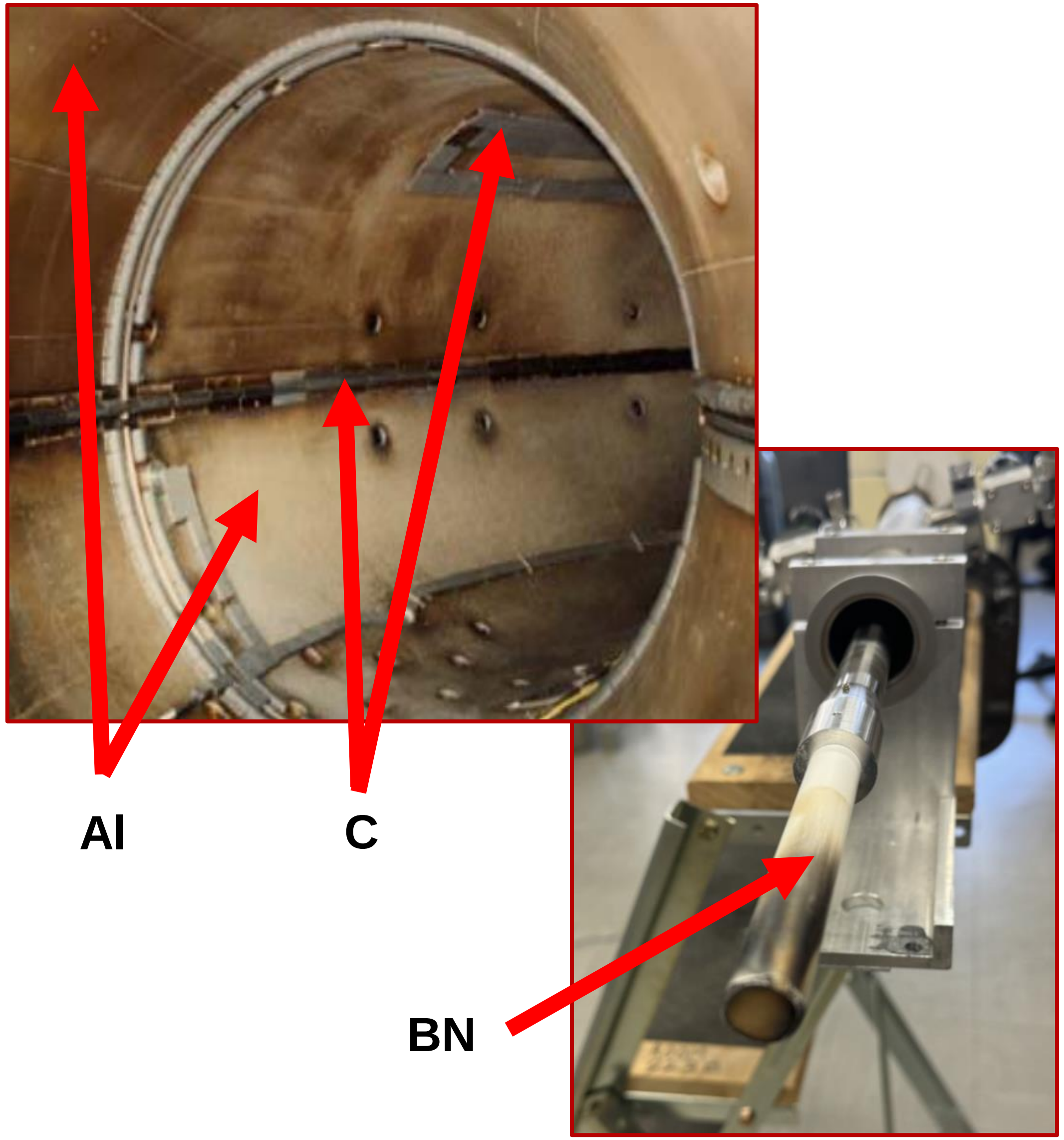
Configuration	RFP	Tokamak	Ulq
Density n_e	0.2 – 10 x 10^{19} m^{-3}	0.05 – 9 x 10^{19} m^{-3}	0.1 – 1 x 10^{19} m^{-3}
Temperature T_e	200 eV – 2 keV	50 – 100 eV	50 – 100 eV ?
Loop voltage V_{pg}	~ 20 V	2-3 V	20 – 40 V

Talk Outline

- **Overview of impurity species in MST**
- Impurity identification and diagnostics
- Effects of high impurity content
- Methods to remove impurities from MST
- Adding impurities

Dominant Impurity Species

- <u>Endemic</u> – occur as a natural part of machine construction and operation
  - Aluminum – wall
  - Carbon – tiles and limiters
  - Boron – probes, boronization (formerly)
  - Nitrogen – probes
  - Helium – cleaning cycle fueling
- <u>External</u> – introduced inside the machine inadvertently
  - Oxygen – air leak
    - Water
  - Argon – air (or doping)



Talk Outline

- Overview of impurity species in MST
- **Impurity identification and diagnostics**
  - Doppler spectroscopy
  - Monochromators
  - Broad-range spectrometer
- Effects of high impurity content
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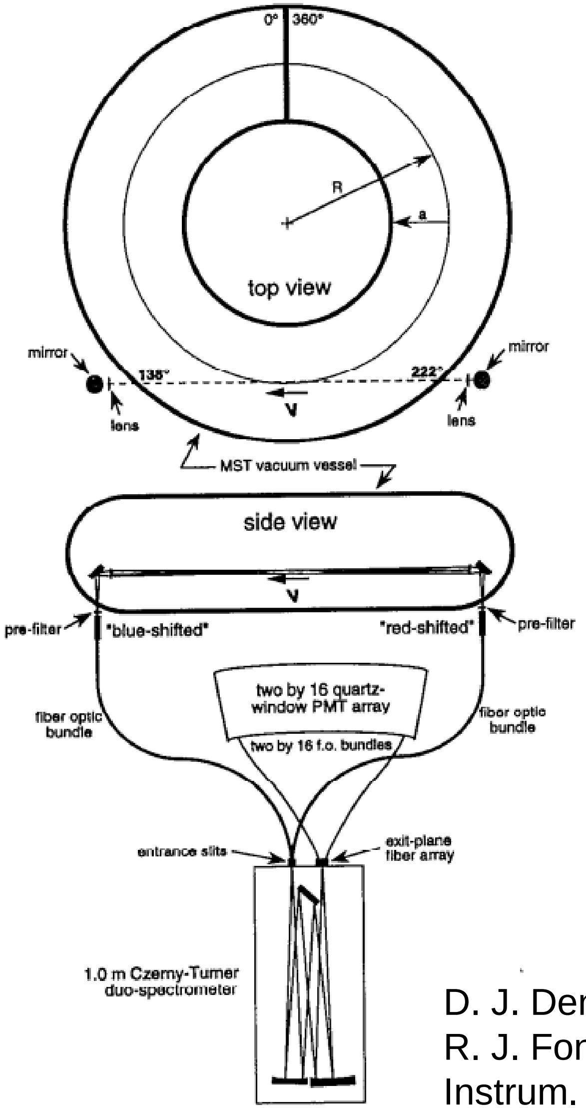
Ion Doppler Spectrometer (IDS)

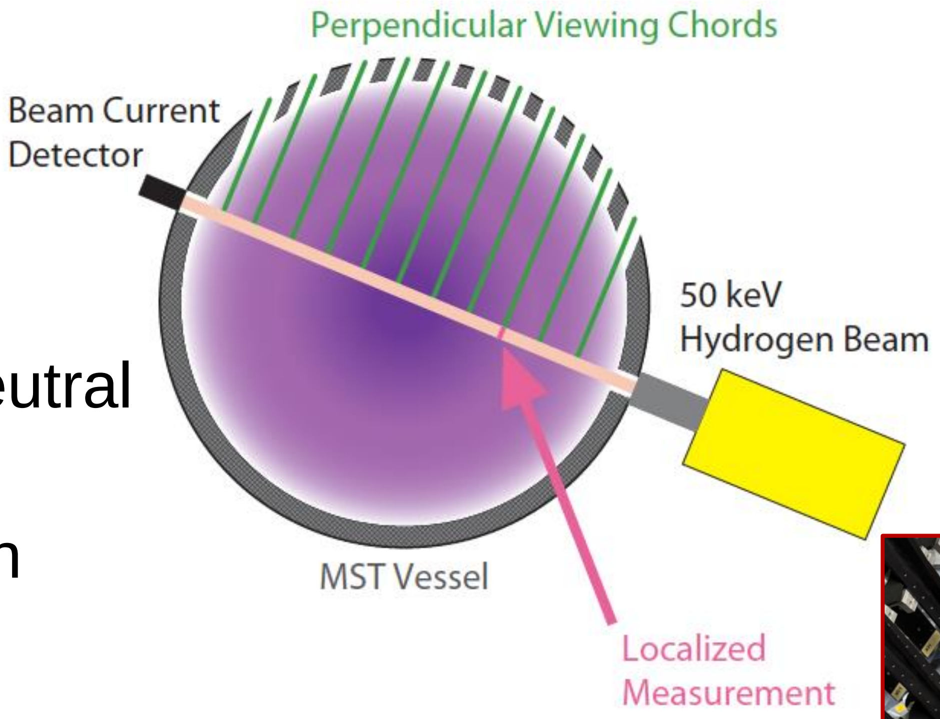
- First version (IDS I) installed 1994, second (IDS II) in 2007
- Measures impurity line radiation
  - High resolution over narrow range
  - Tunable to desired wavelength
- Used to study dynamics of impurity species
  - Doppler shift → flow speed
  - Doppler broadening → thermal speed
  - Total radiation → ion density
- Integrated along two sightlines
  - 11 radial chords, 2 toroidal views

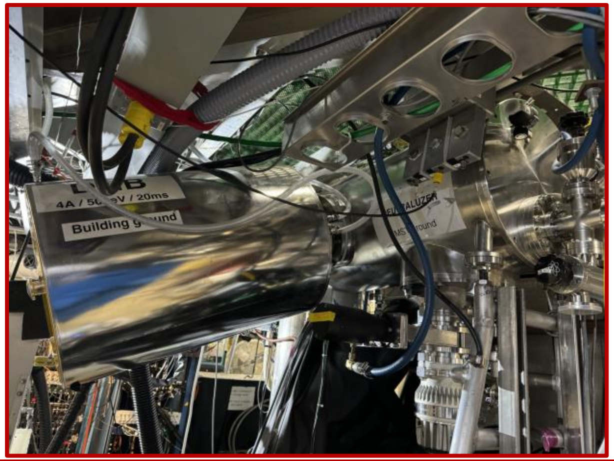


D. J. Den Hartog and R. J. Fonck, Rev. Sci. Instrum. 65, 3238 (1994)

Charge Exchange Recombination Spectroscopy (CHERS)

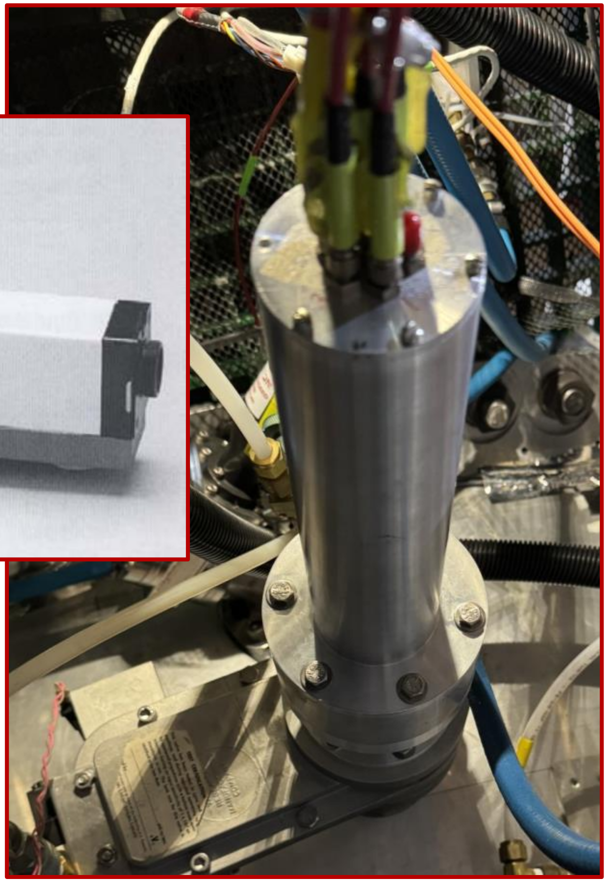
- Diagnostic neutral beam (DNB) perpendicular to IDS sightlines
- Charge exchange produces radiation
  - Ionized impurity receives electron from neutral Hydrogen
  - Decay from excited state produces photon
- Allows localized measurements
  - Sightlines placed on and off DNB path
- Chosen impurity depends on type of shot
  - Carbon V in the core for RFPs (< 2 keV)
  - Boron IV for tokamaks (< 0.1 keV)
  - Carbon III for colder tokamaks (< 0.05 keV)





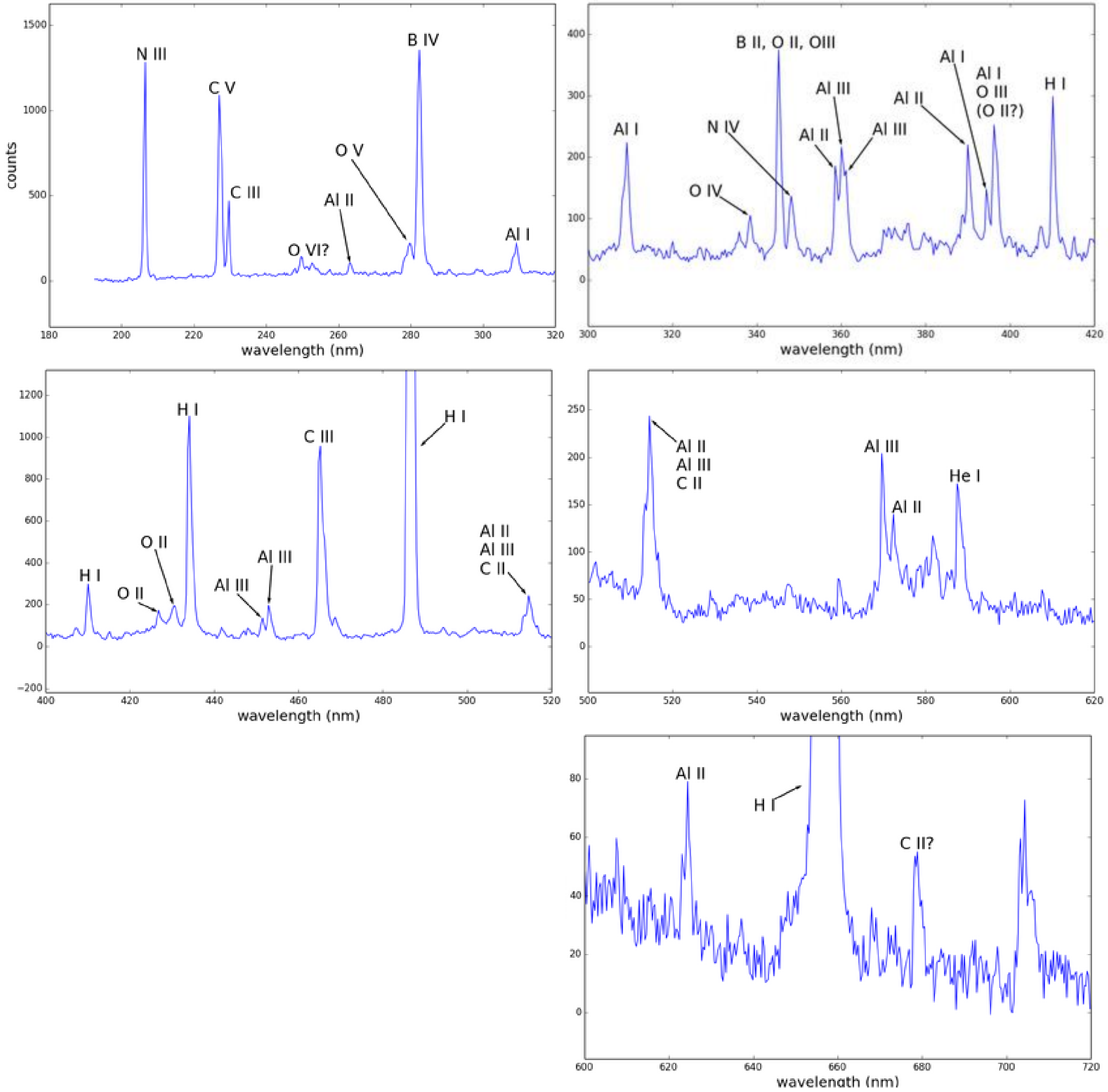
Impurity Monochromator Array (IMA)

- Most recent in series of line radiation diagnostics, 0.01 ms time res
- Monitors 5 impurity lines common in MST
  - Carbon III (229.69 nm) in extreme edge
  - Carbon V (227.09 nm) in the core
  - Boron IV (282.17 nm) in the midradius
  - Oxygen IV (338.55 nm) in edge
  - ~~Aluminum III (360.19 nm) in edge~~
  - Nitrogen IV (347.87 nm)
- Radiation provides information about impurity density
- Functions as approximate temperature diagnostic



Compact Spectrometer

- Broad range spectrometer
  - Records 193-893 nm
- Wavelength resolution ~1nm
- Integrated over 30ms during shot
- Can see many impurity lines simultaneously, find dominant radiation effects



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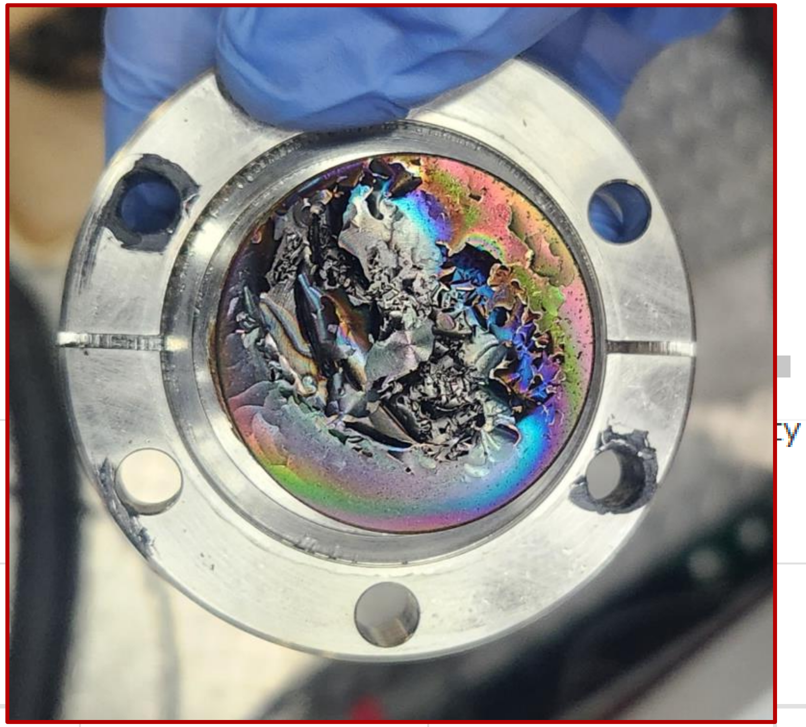
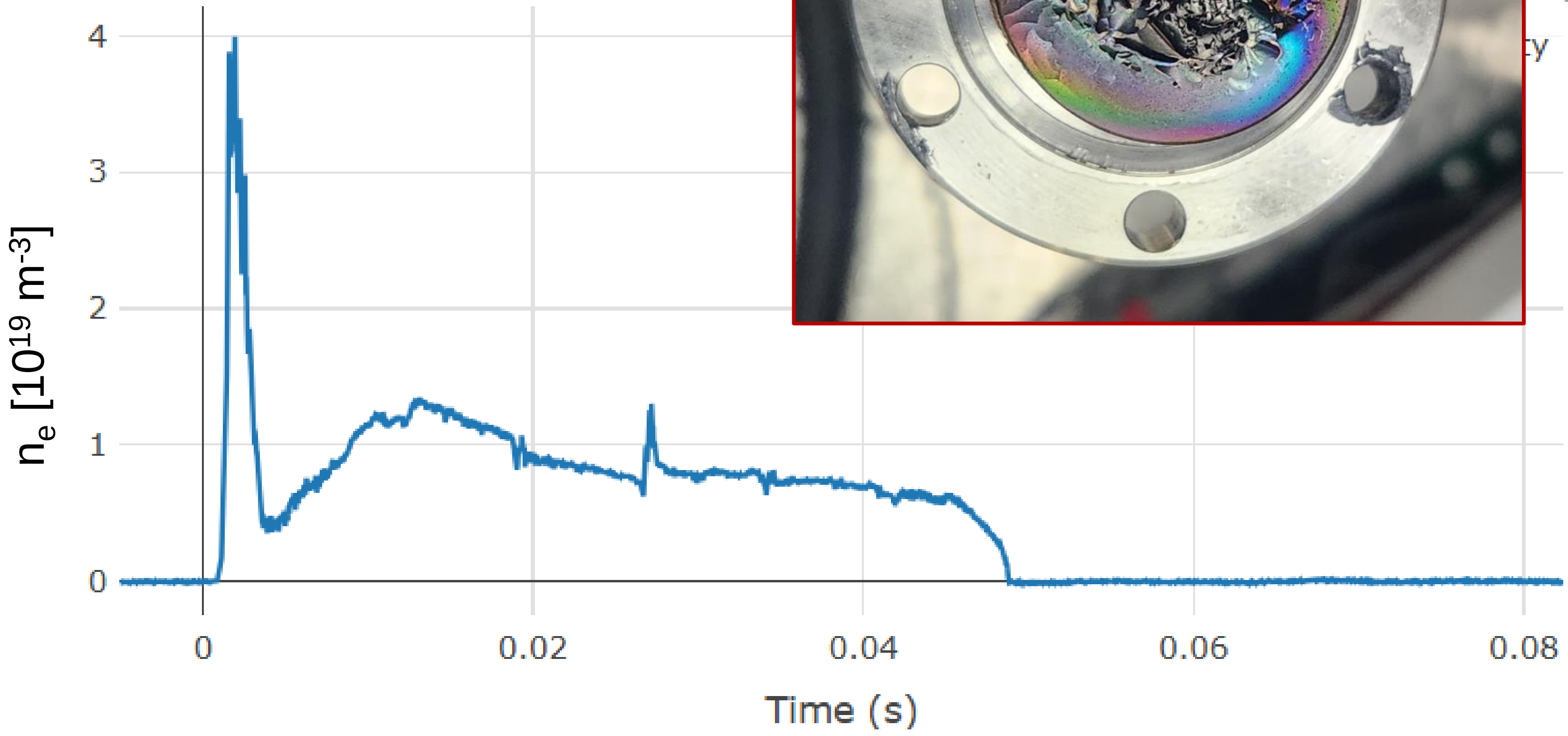
Effects of High Impurity Content

- High loop voltage
  - RFP: 20V in good conditions, up to 100V in bad
  - Tokamak: 2-3 V in good conditions, 10-20 in bad
- Poor sustainment
- Flux consumption
- Density excursions





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Pulsed Discharge Cleaning (PDC)

- High repetition rate (0.2 Hz) Ulq Helium plasma
- Current of 100kA for 3ms
- Removes outermost layers of loose impurities
- Variation on Taylor discharge cleaning
- Automated to run without operators
- PDC is run:
  - Nightly by default
  - Over weekends as needed
  - During run days if conditions are poor

RFP Conditioning

- Procedural run of RFP shots with increasing current
- High temperature RFPs deliver energy to the walls
  - Sawtooth cycle generates particle flux
  - UV radiation
- Conditioning is done:
  - After vents
  - After long periods of idle time
  - When impurities have been introduced
  - When experiments require particularly good conditions

How to Condition MST

- Protocol divided into 3 phases

1. Consistent reversal, stable density, short pulses up to 200kA
   - Density can increase between shots, increases resistivity
   - PDC used intermittently to regain control
   - Often will not need gas puffing
2. Always reversed, stable density, short pulses up to 500 kA
   - Higher current $\rightarrow$ more density excursions
   - Need to work up slowly to avoid current excursions on transformer primary
   - Must be clean enough to require gas puffing
3. Longer pulses up to 500kA
   - Build up from low current with full legacy PFN
   - Remain here until satisfied with conditions

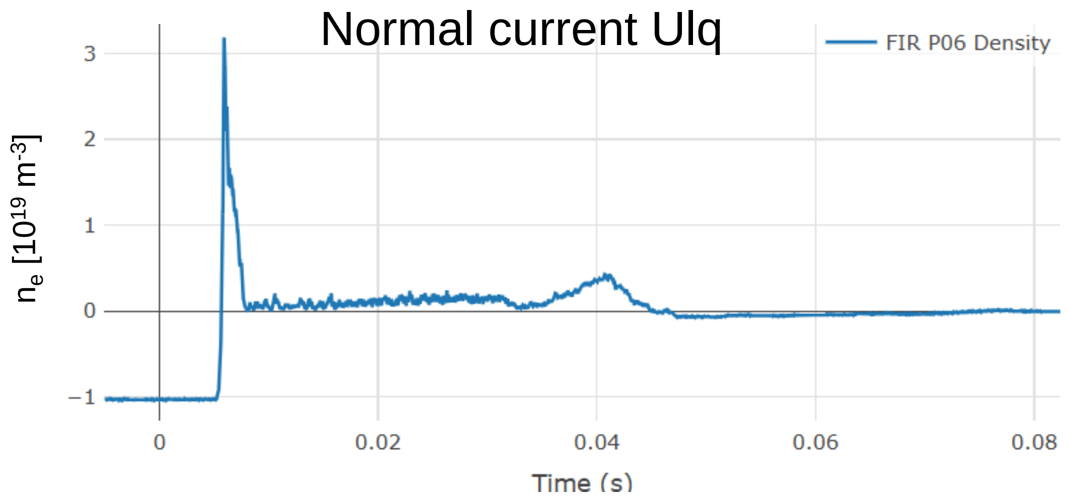
PPS Conditioning

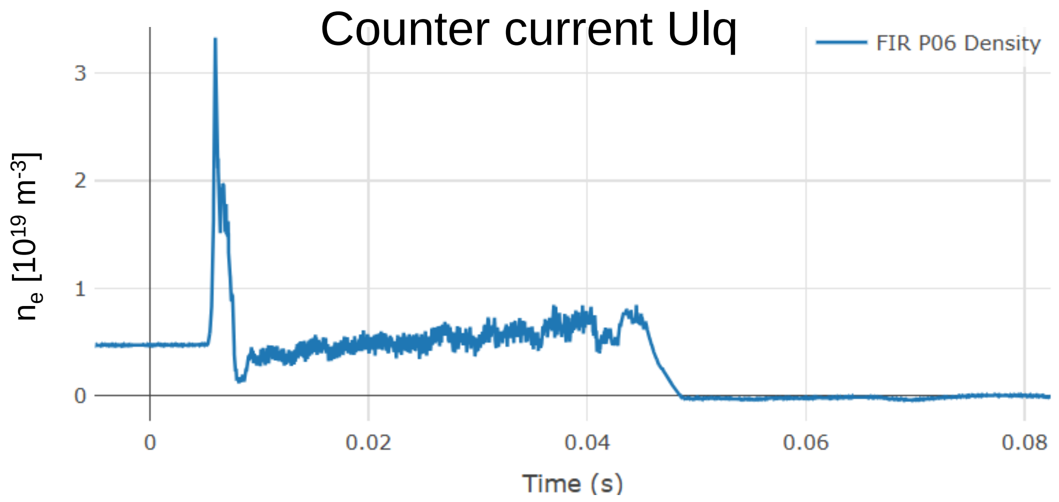
- Less regimented than legacy conditioning
- Decreased risk of primary current excursions
- Finer control over plasma current and duration
- Easier to ensure reversal at edge
  - BT can be controlled

- General procedure:
  - Start from 100kA RFPs
  - Increase current when loop voltage ~ 20 V
  - Extend duration at high current

Specialized Conditioning

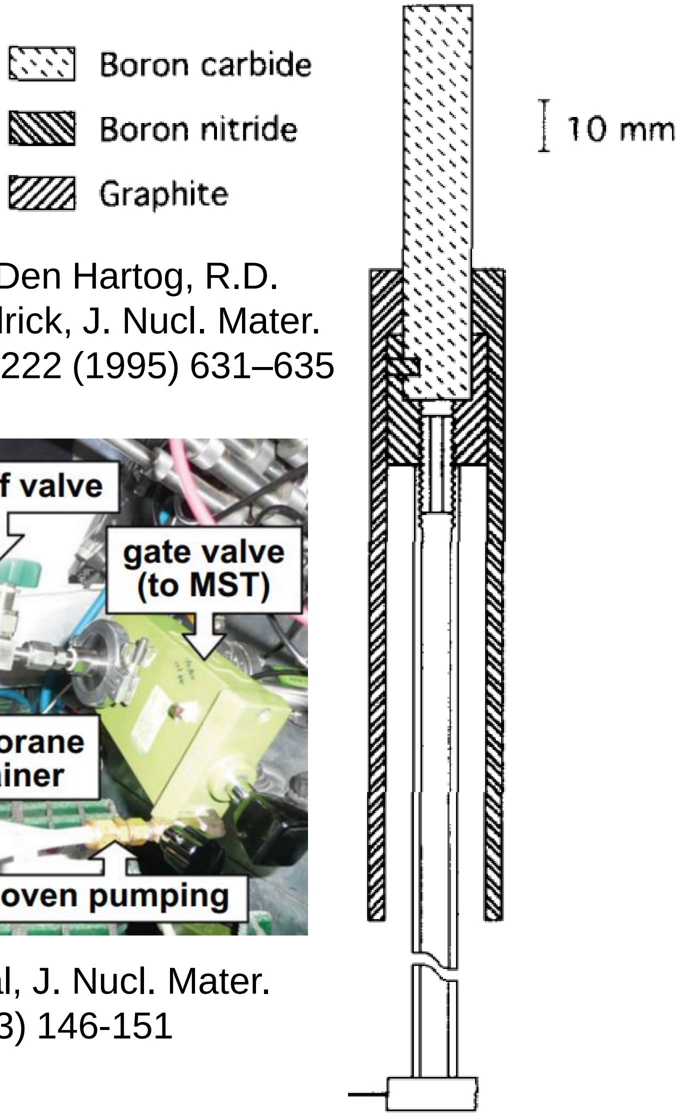
- Specific operation types require conditioning using those plasmas
  - Different limiters, areas of wall affected
  - Asymmetry involved in sawtooth cycle
- Not always RFPs
- Resonant magnetic perturbation (RMP)
  - Changes shape of modes
  - Condition with the planned perturbation
- Change of current direction
- Newly inserted probes
  - Need limit for safe temperature



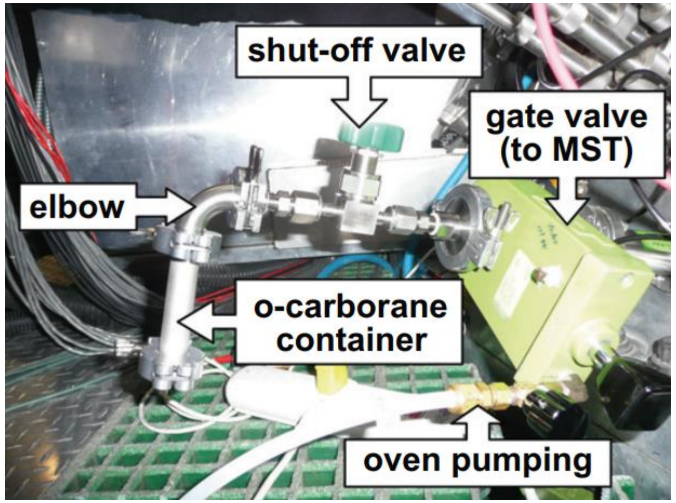


Boronization

- No longer a regular procedure on MST
  - Last boronization occurred 2015
- Solid target boronization
  - Stick of boron carbide (B_4C) inserted into machine
  - Could be left in for RFP operation or PDC
  - Biased for higher energy transfer in PDC
- Gaseous boronization
  - O-Carborane sublimated into MST by ovens
  - Run with rapid PDC (10kA, 1Hz)
  - Coating thickness 50-300 nm
- Both resulted in decreased impurity radiation



D.J. Den Hartog, R.D. Kendrick, J. Nucl. Mater. 220–222 (1995) 631–635



J. Ko et al, J. Nucl. Mater. 432 (2013) 146-151

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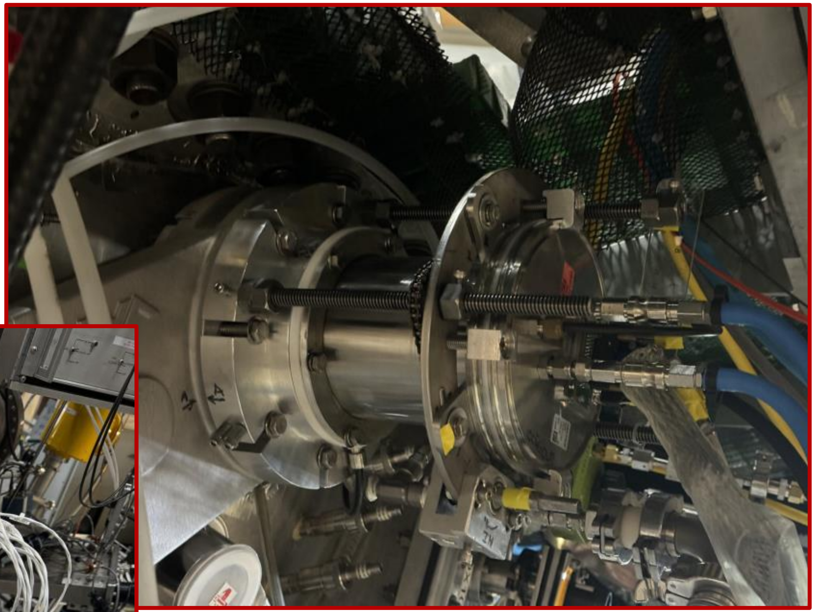
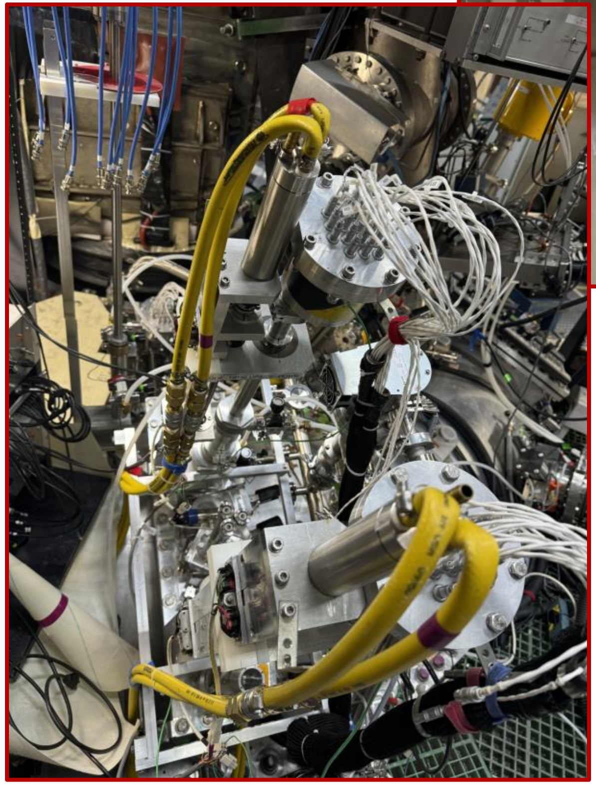
Doping

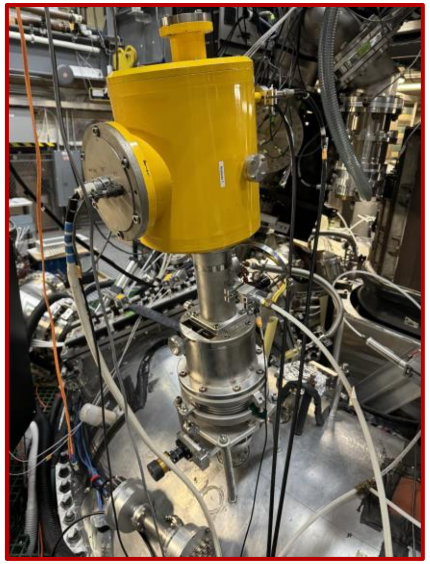
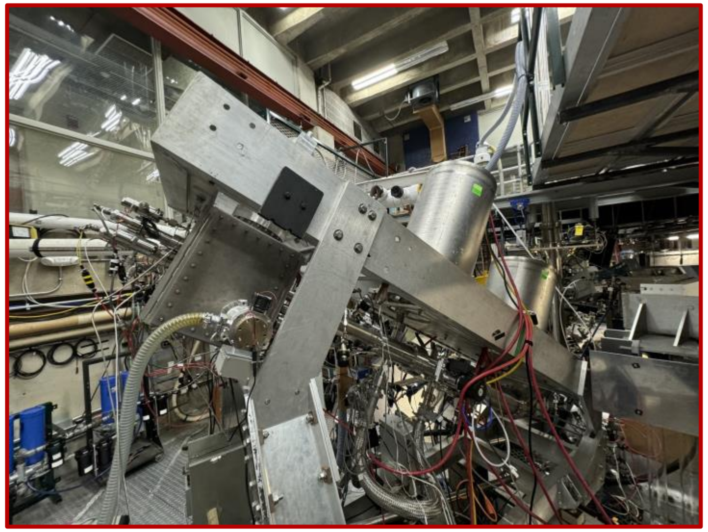
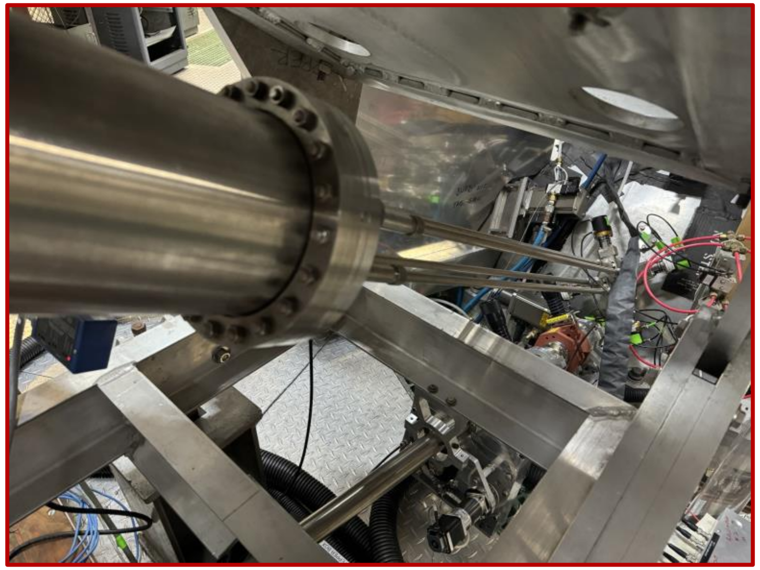
- Operated with programmable puffing, same as Deuterium
  - Dopant or working gas
- Interchangeable gas
  - Helium, Methane (CH_4), Argon
- Used to study:
  - Impurity transport in PPCD
    - SXR tomography
    - Multi-energy soft x-ray camera (ME-SXR)
  - Induced tokamak disruptions
  - Density snake formation and stability





Diagnostic Impurities

- Beam injection
  - Rutherford scattering with Argon
  - Possible with neutral beam injector
- Pellet injection
  - Methane pellets fueling PPCD RFP core used to study Carbon transport
- IDS line stimulation
  - Boron IV
  - Argon

Takeaways

- MST impurities are mostly low- and mid-Z
  - Aluminum wall is the biggest source
- Range of diagnostics allows monitoring of impurity content
  - Combination of resolution and range
- Plasma can clean your plasma experiment
  - Heat flux to the walls liberates impurities
  - Surface cleaning done by lower energy discharges