Study of Impurities in the Pegasus Toroidal Experiment

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PEGASUS Toroidal Experiment

Abstract

- Levels and roles of impurities are currently under study in three distinct operating regimes:
  1. Ohmic heating
  2. Helicity injection for local arc guns in the plasma edge
  3. Non-solenoidal startup followed by ohmic drive

- Plasma impurities are monitored by:
  1. 32 channel AXUV bolometer diode array to determine P_{RAD}
  2. Visible bremsstrahlung spectrometer to determine Z_{eff}
  3. SPRED VUV spectrometer to identify the impurity species

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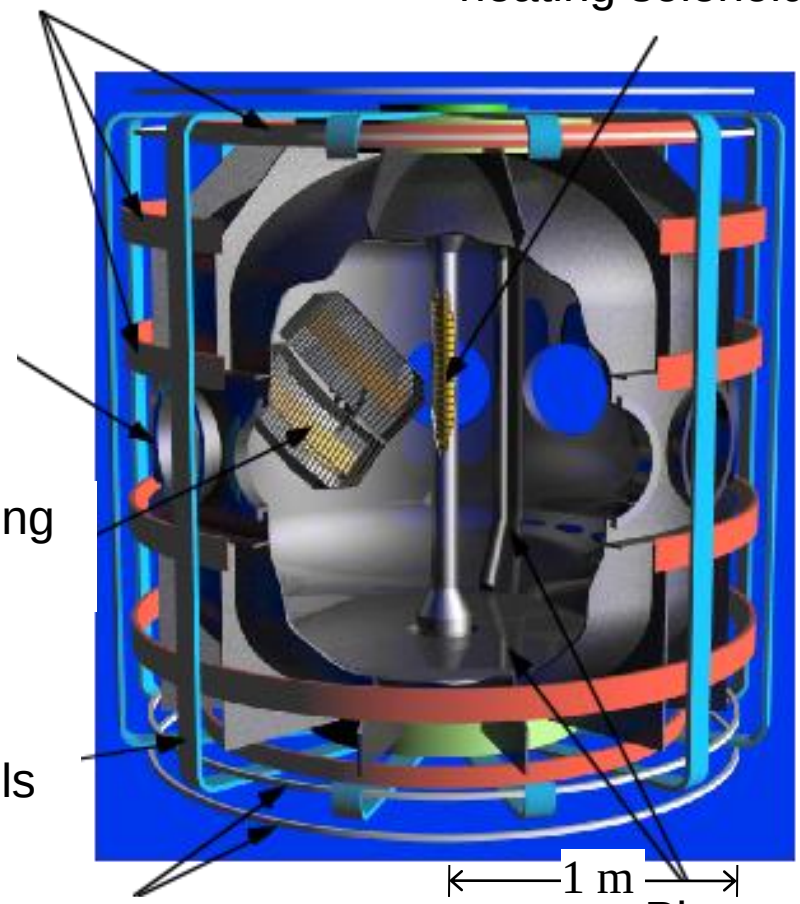
Motivation for Study

- The levels and roles of impurities are significant for each of the three operating regimes
- Ohmically-driven plasmas show very low radiated power, with VUV spectra dominated by O emission
- Impurity levels in helicity-driven plasmas are important due to the presence of local plasma gun injectors in the scrape-off region
  - Helicity driven plasmas show strong N and O emissions, which presumably arise from interaction with the guns' BN shields
- Non-solenoidal startup plasmas during the ohmic phase do not suggest radiative collapse

Outline

- Diagnostics
- Preliminary ohmic impurity results
- Preliminary impurity results in non-solenoidal startup and post non-solenoidal startup ohmic-drive phase
- Future work and conclusions

Pegasus is a Compact Ultralow-A ST



Experimental Parameters

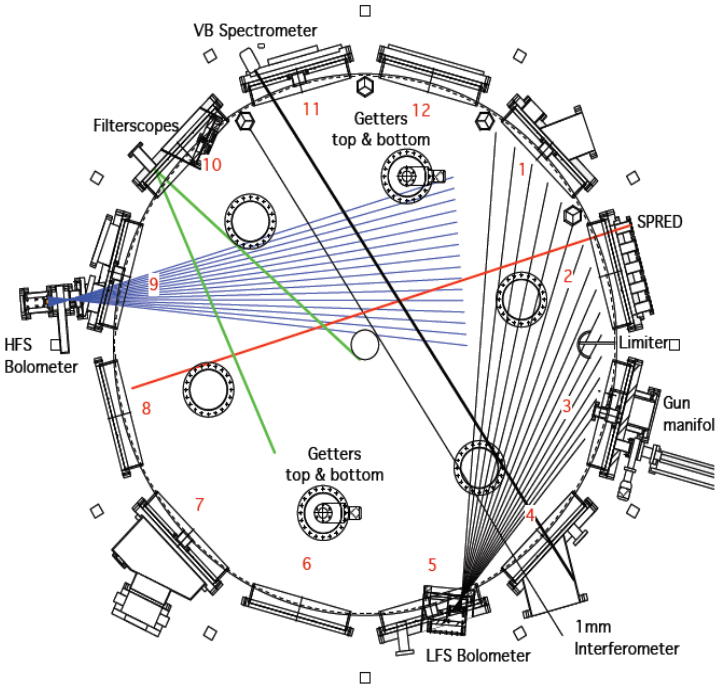
Parameter	To Date
A	1.15 – 1.3
R(m)	0.2 – 0.45
I_p (MA)	≤ .22
I_N (MA/m-T)	6 – 12
l_i	0.2 – 0.5
κ	1.4 – 3.0
τ_{shot} (s)	≤ 0.025
β_t (%)	≤ 25
P_{HHFW} (MW)	0.2



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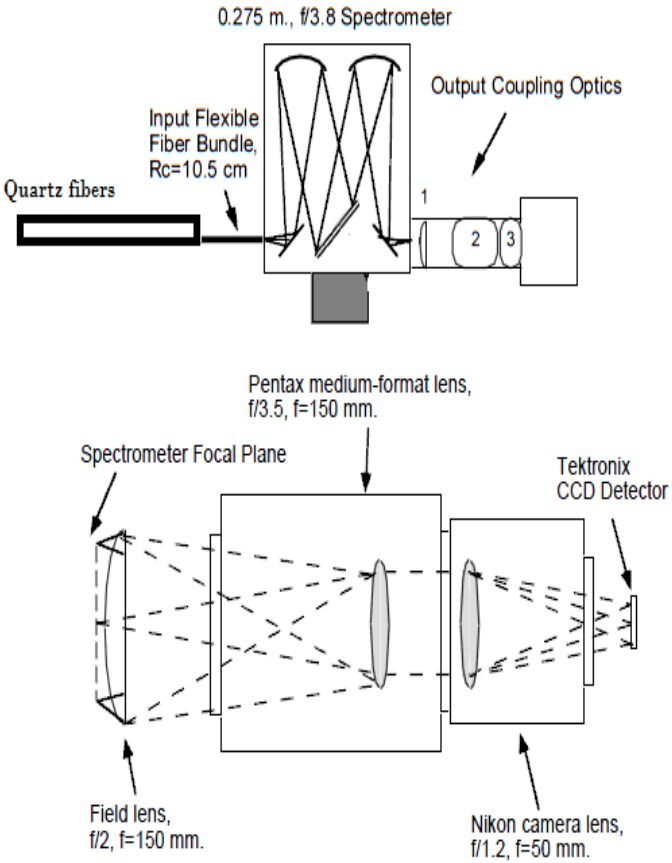
There are four available impurity diagnostics

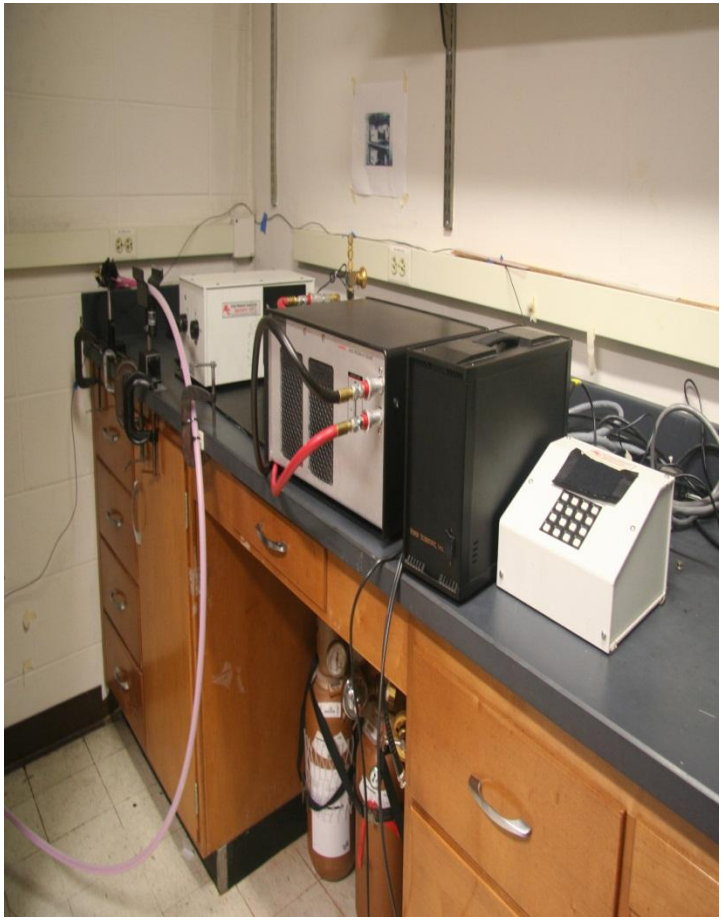
- SPRED VUV spectrometer
  - 10-110 nm spectrometer, 200 μs resolution
  - Not absolutely calibrated
- 2-16 channel AXUV bolometer diode arrays
  - One inboard array, one outboard array
  - Only sensitive to photons, 0.4 ms resolution
- Visible bremsstrahlung filterscope
  - Near radial view, uncalibrated single view
  - 3 μs resolution, takes measurements at 523.5 nm with a spectral range of 1 nm
- Visible bremsstrahlung spectrometer
  - Scanning survey spectrometer to find a line-free spectral region
  - 400-800 nm, currently 2 ms resolution
  - Not absolutely calibrated (will be in future)



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VB Spectrometer is new addition to Pegasus impurity diagnostics





See G. McKee, CONFINED NONTHERMAL ALPHA DISTRIBUTION AND TRANSPORT MEASUREMENTS IN D-T PLASMAS ON TFTR, UW-Madison NEEP (1995).

Pegasus has 3 distinct operating regimes

1) Ohmically driven plasmas

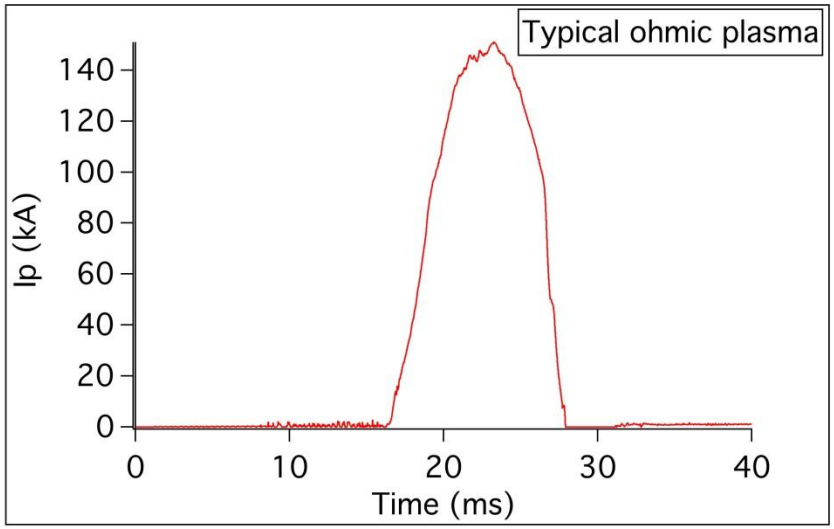
- $n_e \sim 2 \times 10^{19}\ m^{-3}$
- $I_p \sim 100\text{-}175$ kA

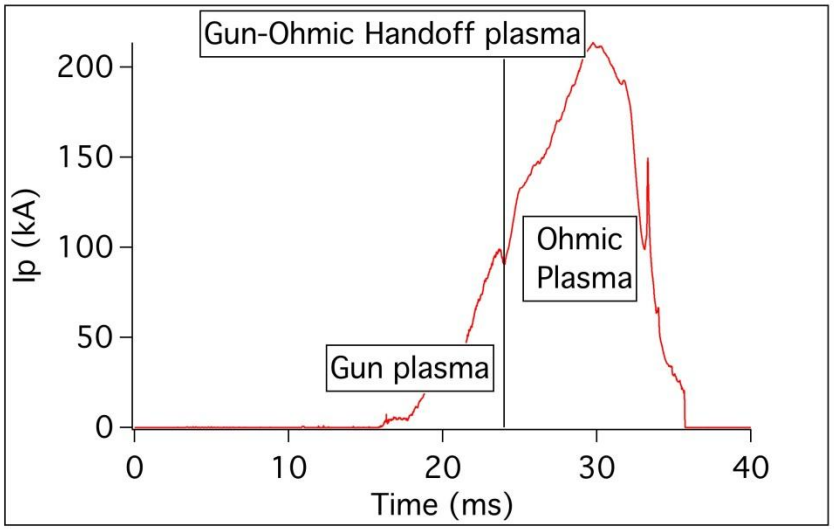
2) Non-solenoidal startup

- $n_e \sim 5 \times 10^{18}\ m^{-3}$
- $I_p \sim 100\text{-}175$ kA

3) Ohmic-drive phase after non-solenoidal startup

- $n_e \sim 2 \times 10^{19}\ m^{-3}$
- $I_p \sim 150\text{-}200+$ kA

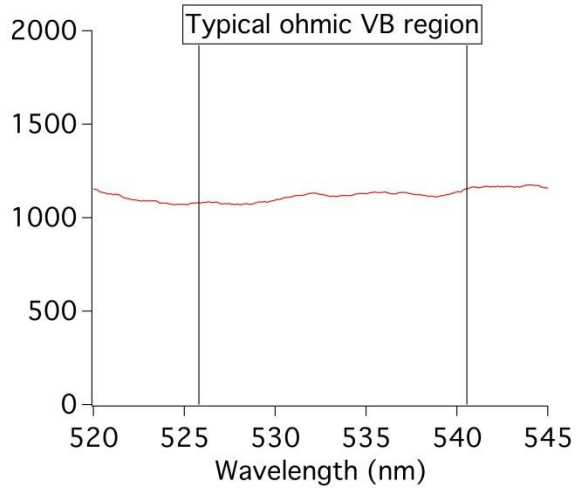




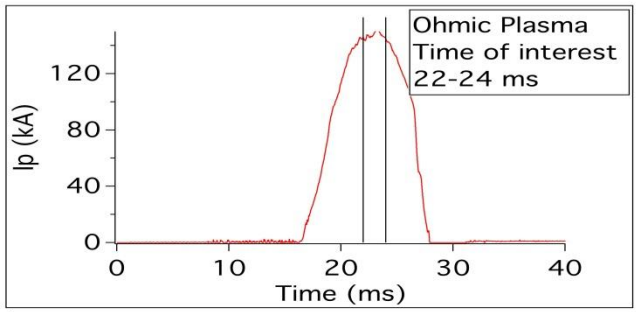
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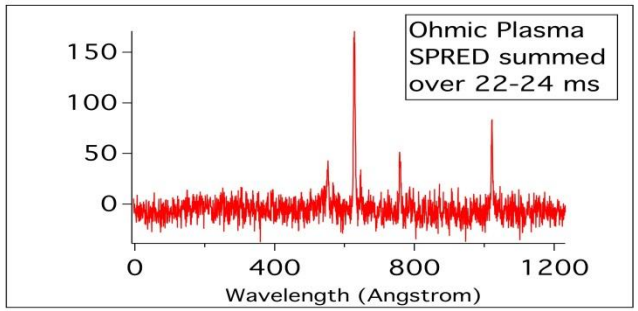
Ohmic Results: SPRED shows low signals, VB filterscope and spectrometer agree in time

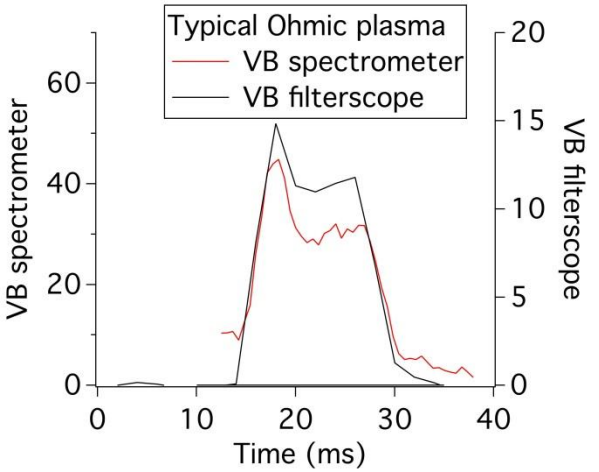
- SPRED shows O and D lines
- VB typically measured in 523-536 nm range
  - No spectral lines evident in this region during ohmic discharge



- VB signal from filterscope and spectrometer show similar time evolution



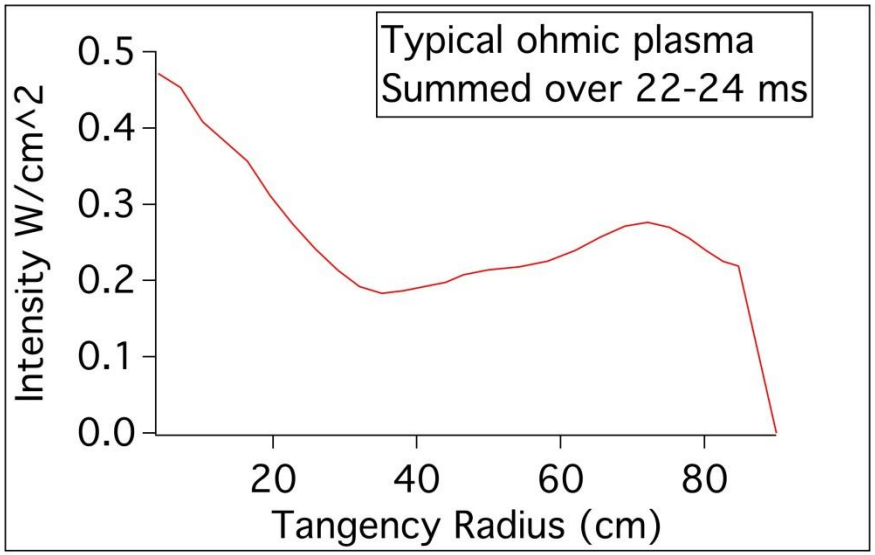


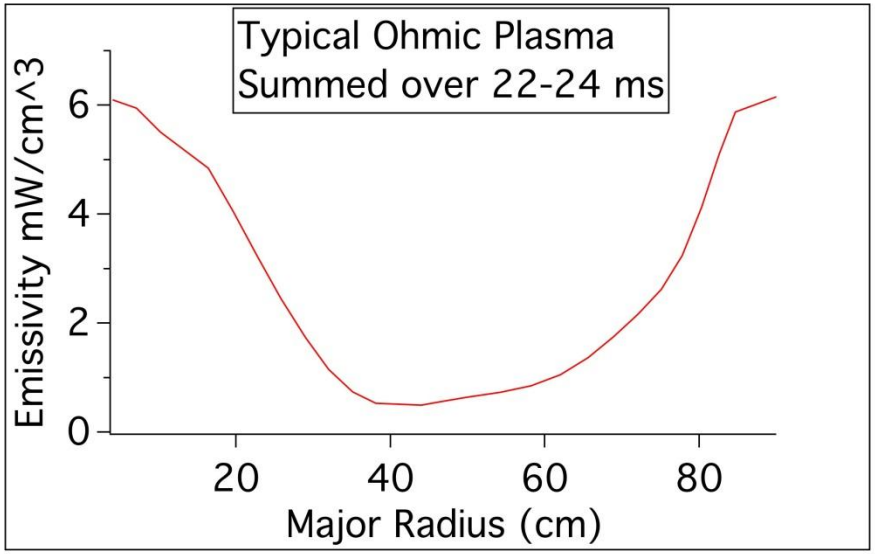


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Ohmic results: Bolometer shows very low P_{RAD}

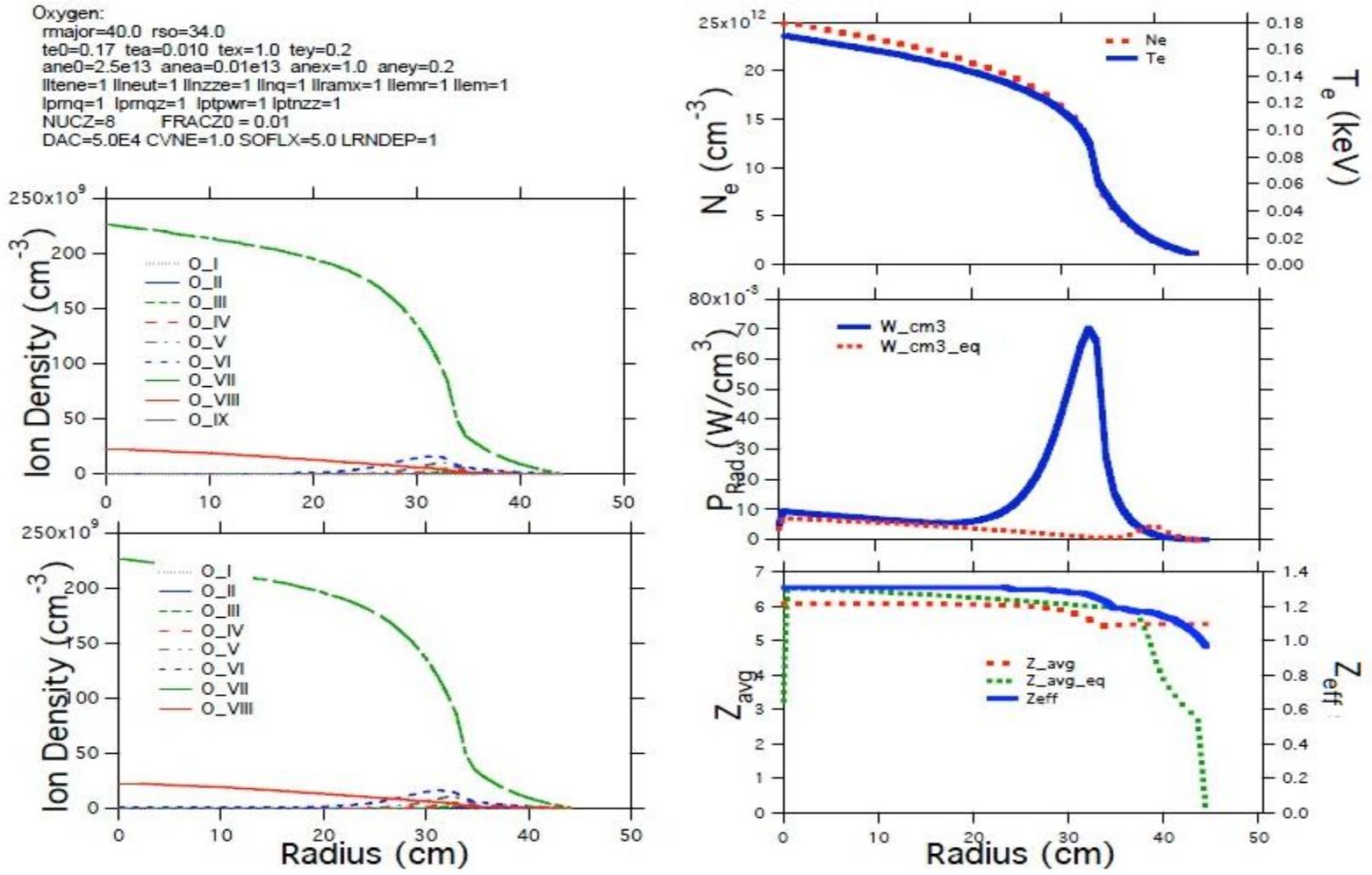
- Generally, obtaining coarse estimates of core radiation
  - Assume cylindrical symmetry
  - Let signal go to 0 at 90 cm; somewhat arbitrary
  - Maximum emissivity is 5-6 mW/cm^3 at edge
    - Profile is strongly hollow
  - Wall and centerstack reflection not taken into account (could possibly account for large portion of signal)





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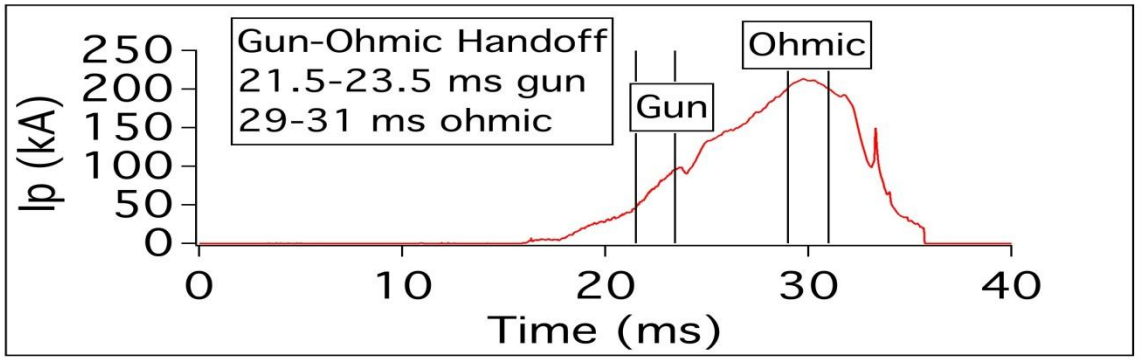
Ohmic MIST calculations suggest Z_{eff}~1.2

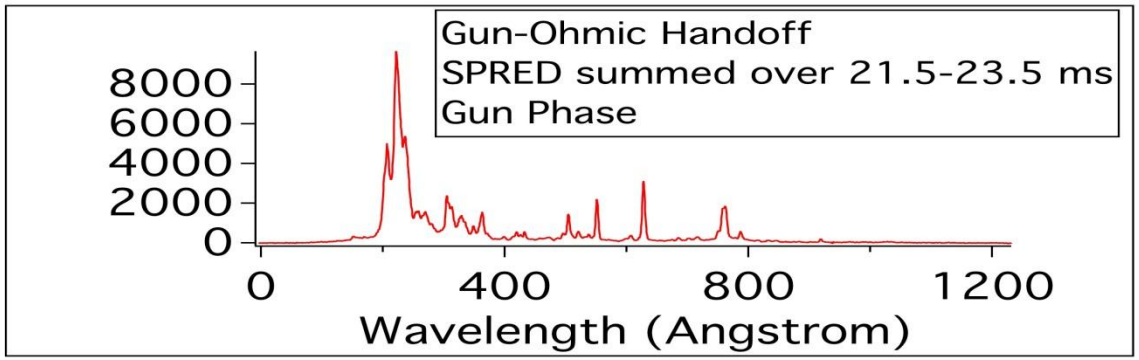


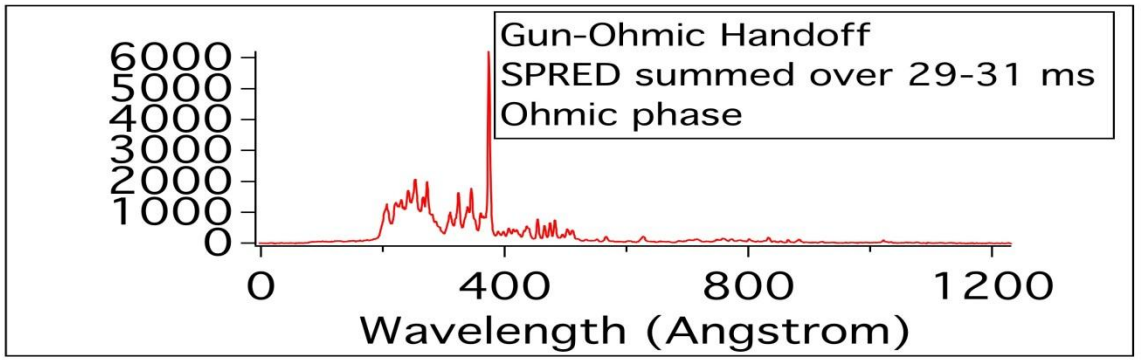
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Gun-Ohmic Handoff Results: Plasmas dominated by N during gun phase and Ti during ohmic phase

- Gun phase is dominated by N and O
- Ohmic-drive phase after non-solenoidal startup recently dominated by Ti
  - New upper limiter geometry
  - Previously it was dominated by O



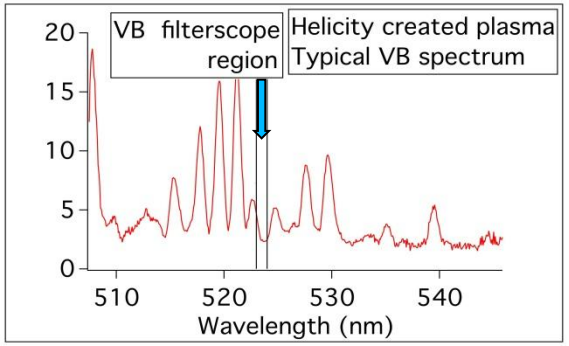


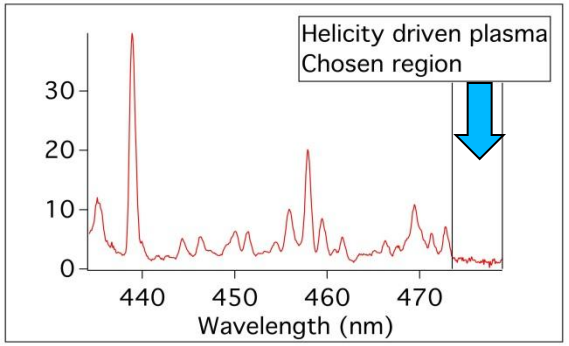


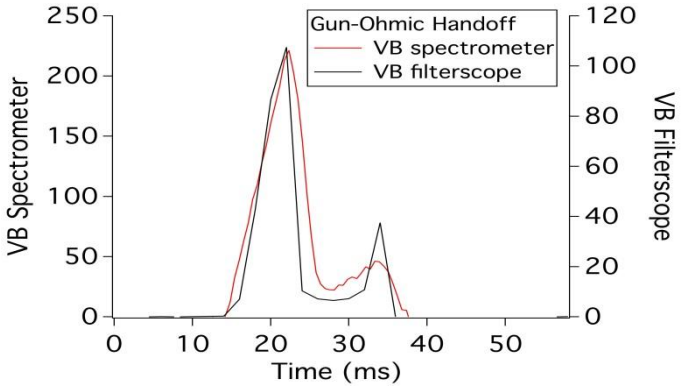
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Gun-Ohmic Handoff Results: VB signal order of magnitude larger during gun phase than ohmic-drive phase and ohmic-only plasmas

- Typical spectrum used in VB measurements is 523-536 nm but many spectral lines were present in this region in gun discharges
  - Filterscope takes measurements at 523.5 nm with a spectral width of 1 nm
- A region of line-free spectrum was found from 473.5 to 479.0 nm
  - VB measurements were taken with the spectrometer in this region
  - VB spectrometer level was approximately 7 times in the gun phase that of the ohmic levels only
  - VB spectrometer levels in ohmic drive after non-solenoidal startup was similar to that in ohmic-only plasmas



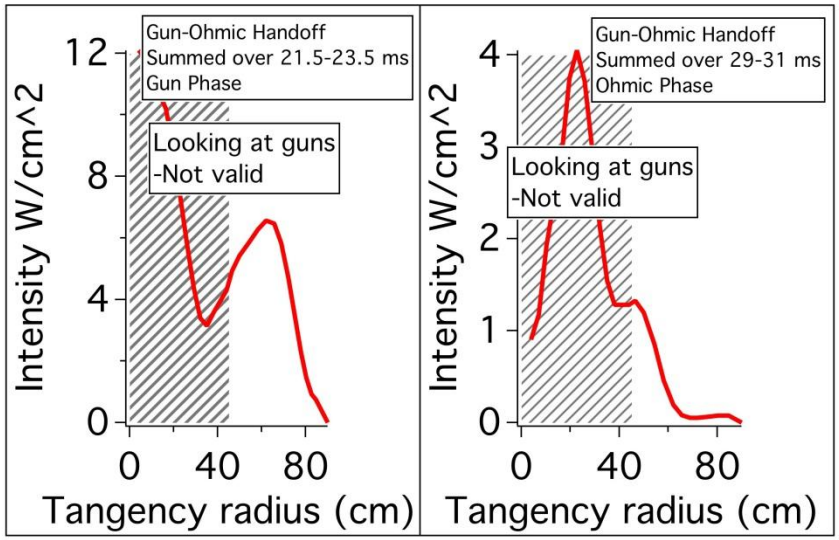


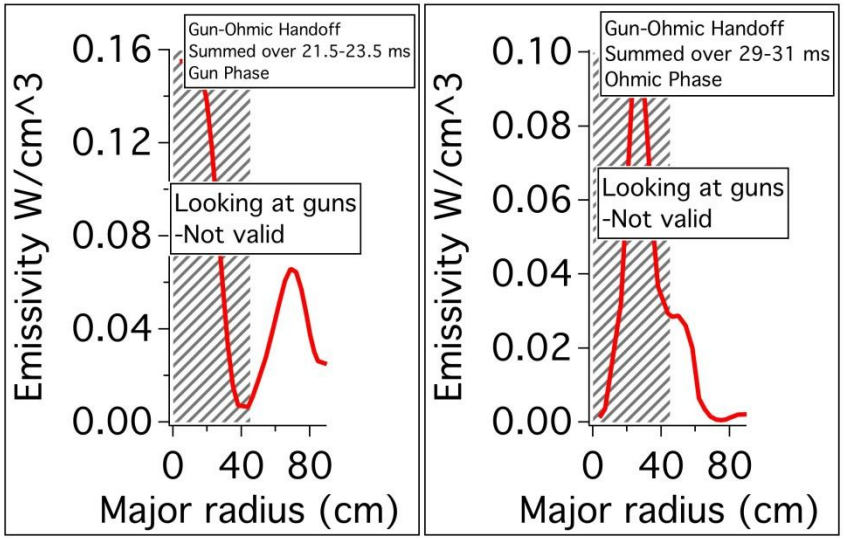


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Gun-Ohmic Handoff Results: P_{RAD} order of magnitude higher during gun phase than ohmic-drive phase and ohmic-only plasma

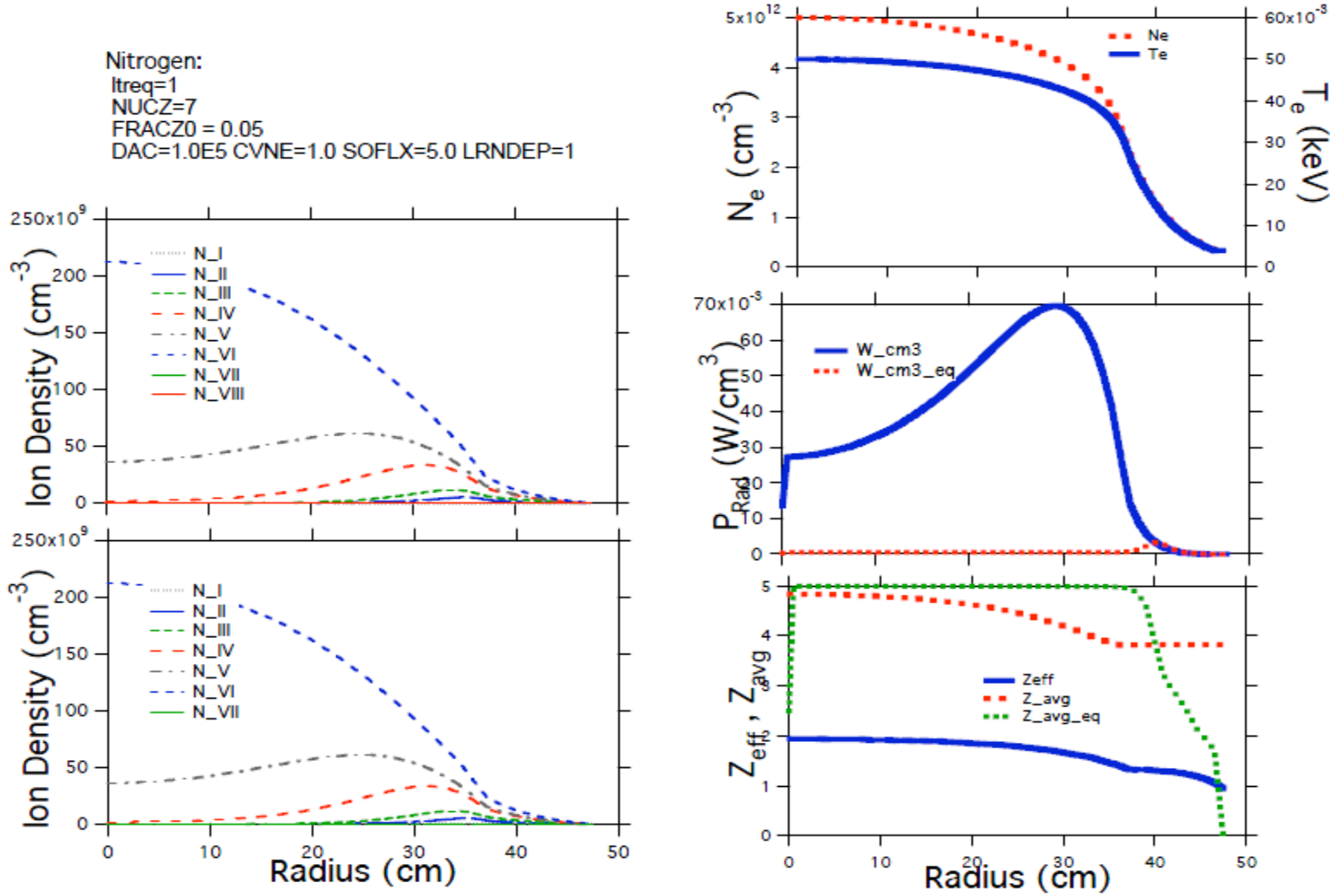
- Inboard array is looking at plasma guns
  - Data from 0 to ~ 45 cm not valid
- Generally more radiation is present during gun drive than ohmic drive
  - Emissivity during gun phase approximately 10 times higher than ohmic only
  - Emissivity during ohmic phase after gun startup is at least 5 times higher than ohmic only drive





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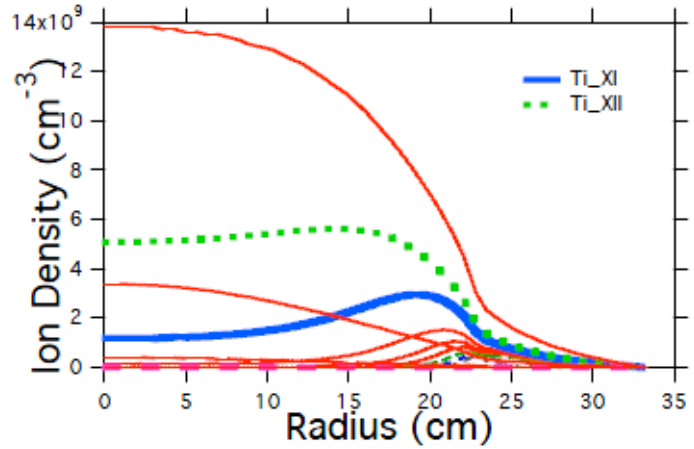
Gun-Ohmic Handoff: Gun phase MIST calculations suggest a $1.5<Z_{eff}<3$, most likely $Z_{eff}\sim2.2$

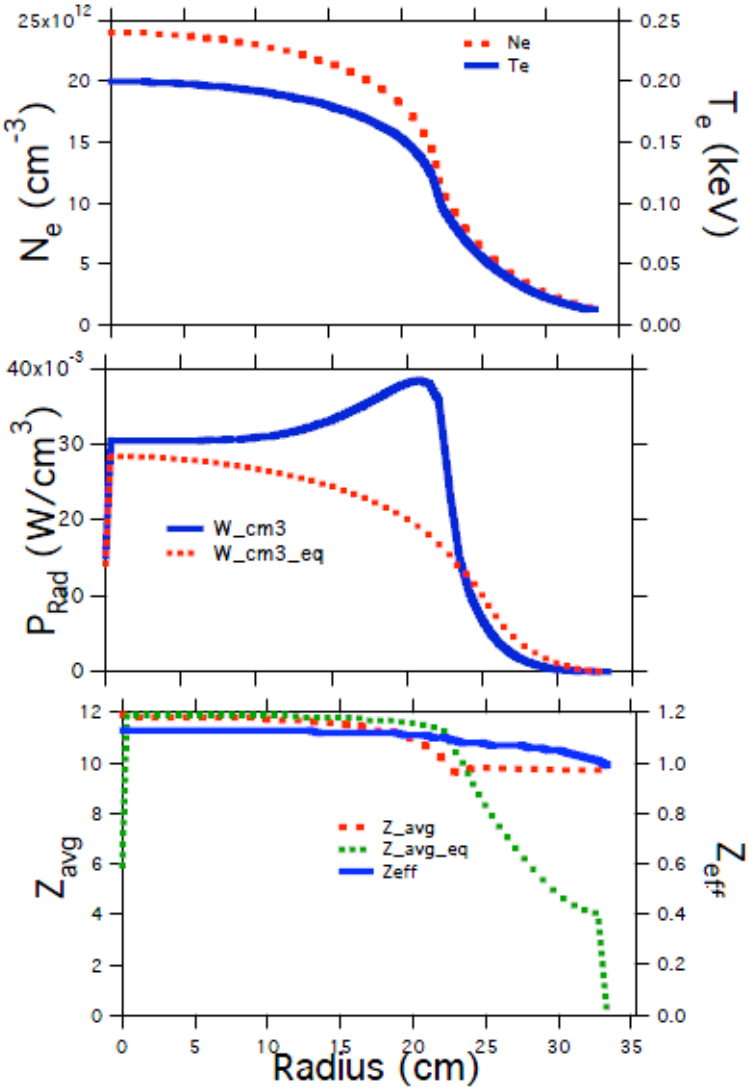


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Gun-Ohmic Handoff: Ohmic phase MIST calculations suggest a Z_{eff}~1.2

Titanium:
rmajor=28.0 rso=23.0
te0=0.20 tea=0.010 tex=2 tey=0.2
ane0=2.4e13 anea=0.01e13 anex=2 aney=0.2
lltene=1 llneut=1 llnzze=1 llnq=1 llramx=1 llemr=1 llem=1
lprnq=1 lprnqz=1 lptpwr=1 lptnzz=1
ltreq=1 NUCZ=22 FRACZ0 = 0.001
DAC=2.0E4 CVNE=1.0 SOFLX=5.0 LRNDEP=1





K. E. Thome

Future work will provide quantitative measurements

- Major port rearrangement planned
  - Bolometers will be moved to not have plasma gun or gas puffs in field of view
- Upgrade bolometer electronic circuit, eliminate power supply switching noise
- Absolutely calibrate VB spectrometer to accurately measure Z_{eff}
  - Upgrade VB filterscopes to clean spectral range for shot-shot VB measurements, and eventually radially profile
  - Viewing dump is needed
- Possibly also absolute calibrate SPRED VUV spectrometer

Conclusions

- Impurity content in plasmas with helicity injection is a point of concern

- Initial observations are based on bolometers, relative visible bremsstrahlung, and impurity signals
  - These initial measurements illustrate trends and provide some estimates of impurity content
  - Ohmic-only plasmas are dominated by O, very low signal level, Z_{eff}~1.2
  - Gun drive plasmas are dominated by N (from BN gun assembly), Z_{eff}~2.2
  - Post non-solenoidal startup ohmic-drive phase dominated by O or Ti (depends on operating conditions), relatively low signal levels, Z_{eff}~1.2