

Pegasus-III Experiment

Effects of Impurity Transport in Tokamak Startup Using LHI on the Pegasus-III Experiment

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65th Annual Meeting of the APS Division of Plasma Physics
Denver, CO, Presentation BO08.00006
October 30, 2023
Work Supported by US DOE Grant DE-SC0019008



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Predicting LHI Performance Needs Impurity Assessment

- Pegasus-III is a major upgrade to the Pegasus ST
  - **Mission:** compare, contrast and combine startup techniques
  - New high power LHI system

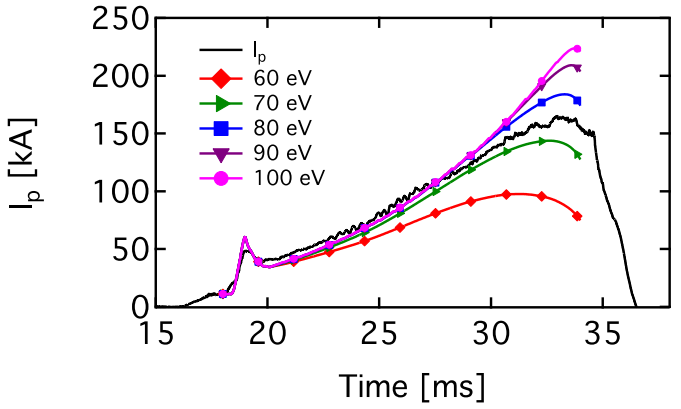
- Helicity input balanced by resistive dissipation

$$\dot{K}_{dis} \approx \frac{4\pi R_0}{A_p}\langle\eta\rangle I_p \Psi \qquad \eta \propto Z_{eff} T_e^{-3/2}$$

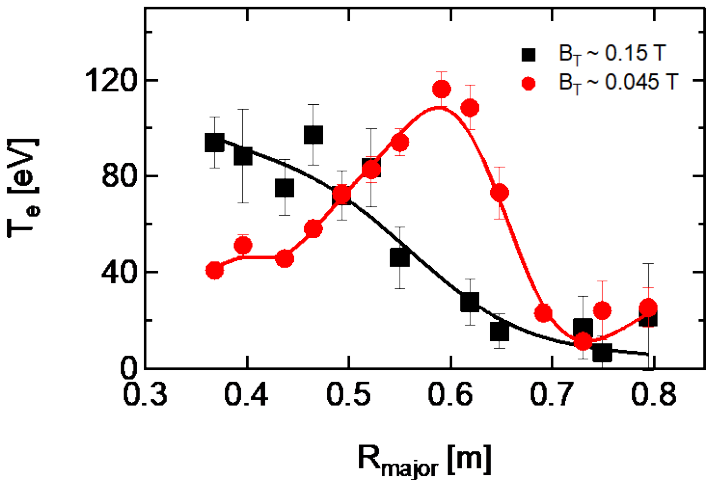
- Impurity concentration directly affects resistivity
  - Increased Z_{eff}
  - Plasma cooling

- LHI is useful **if** its target can couple to other CD
  - Acceptably low Z_{eff}
  - Power losses do not significantly impact the power balance

Projected $I_p(t)$ at different T_e[1]



T_e profiles at different B_T levels[2]



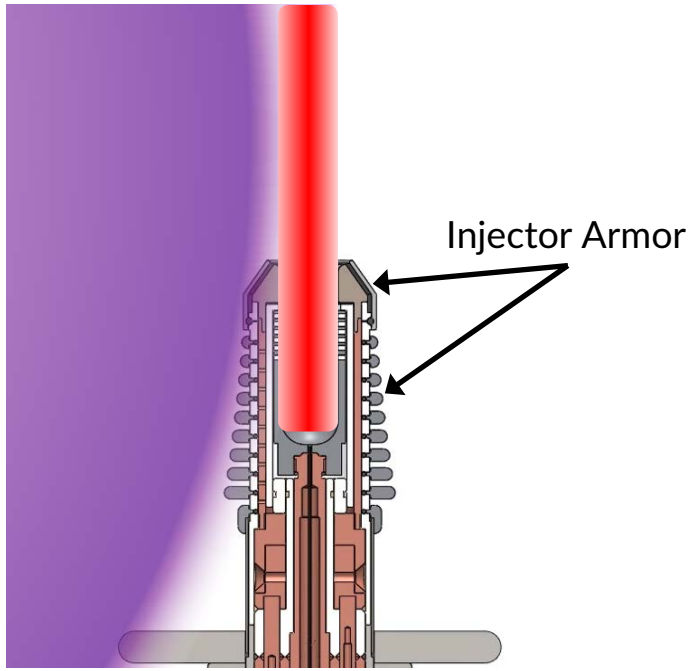
[1] J.L. Barr et al., Nuclear Fusion **58**, (2018).
[2] G.M. Bodner et al., Physics of Plasmas **28**, 102504 (2021).

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MW Class LHI System Could be a Source of Impurities

Injector structures

- Erosion of injector limiter and/or armor

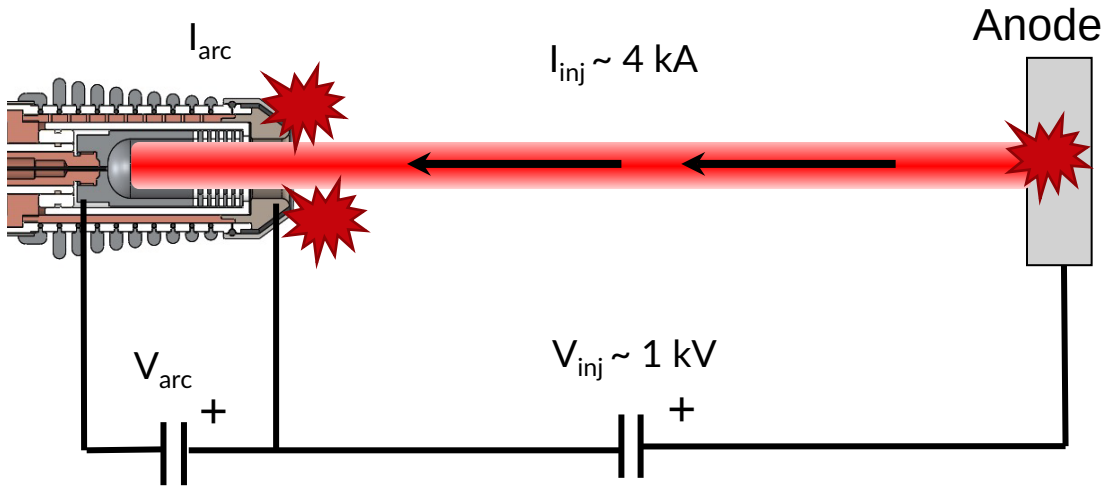


Cathode spots

- Trigger at high V_{inj}
- Erosion of adjacent surfaces

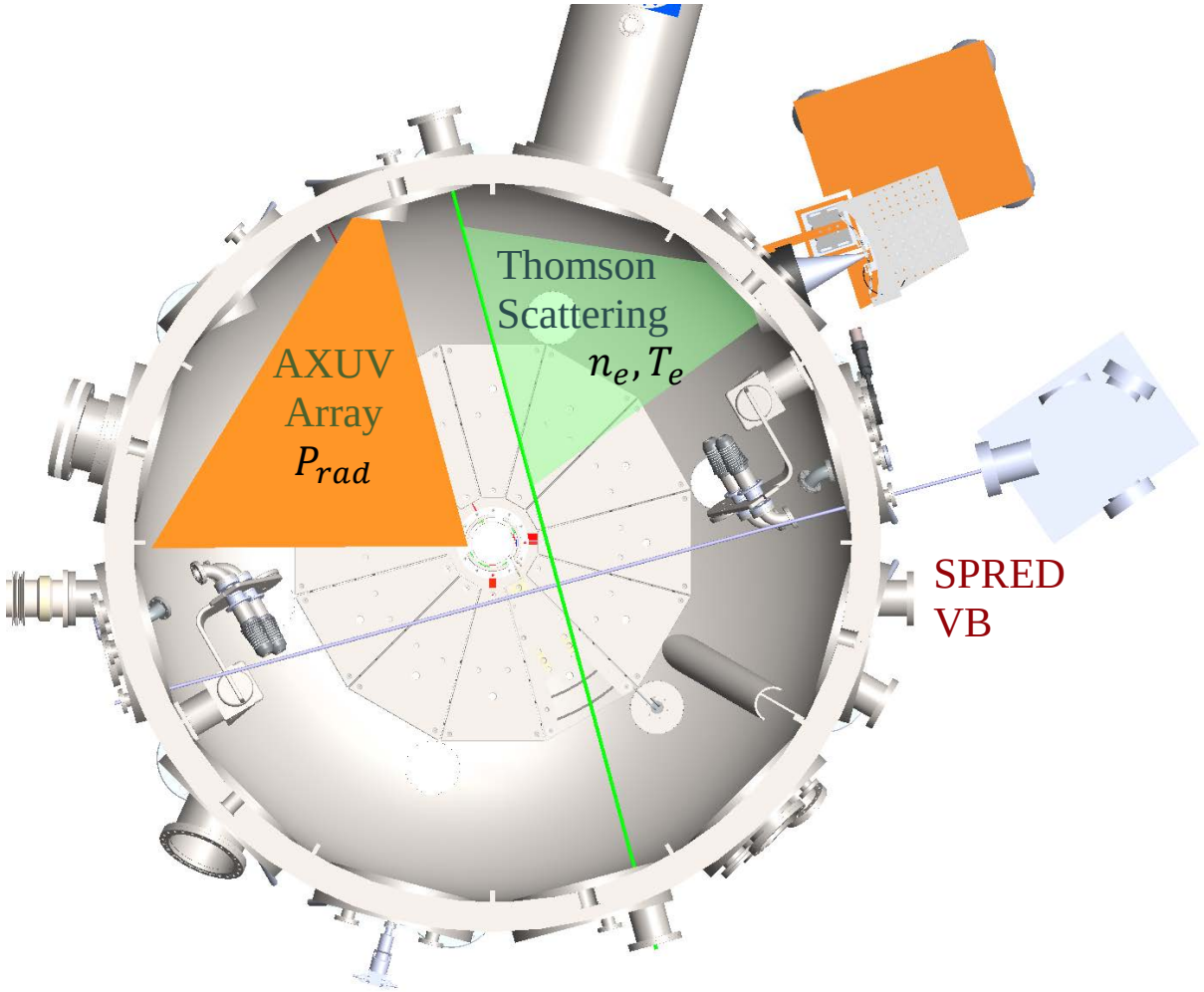
Electron beam

- Desorption of trapped gases
- Ablation



Impurity Studies will Utilize Multiple Diagnostics and Tools

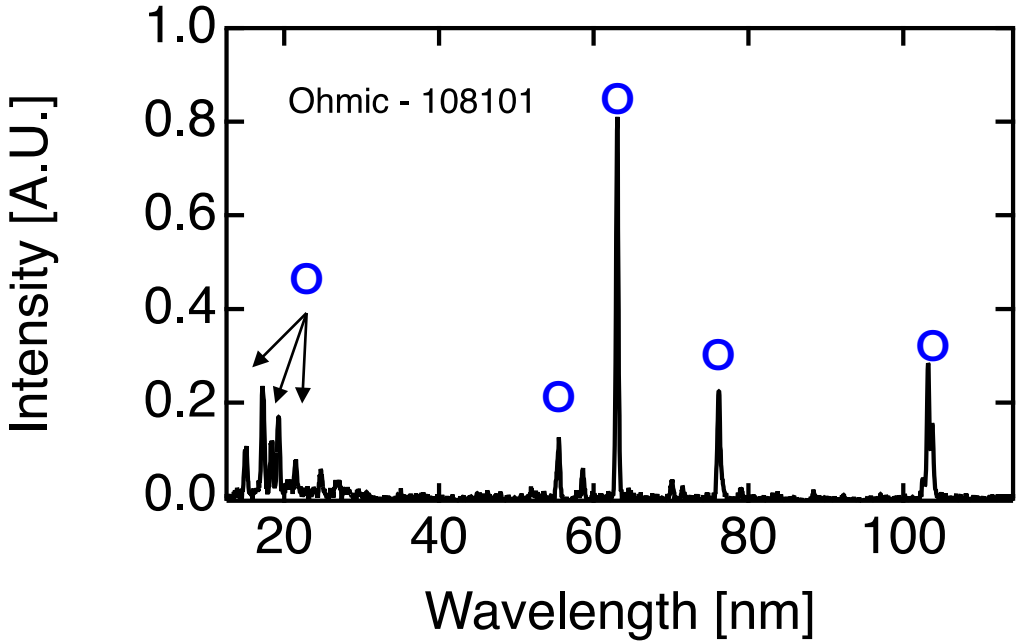
- Species Identification using VUV Spectroscopy
  - SPRED Spectrometer
- AXUV radiometry for P_{rad}
- Z_{eff} measurements with Visual Bremsstrahlung (VB)
  - Needs n_e and T_e from Thomson Scattering
- Impurity transport modeling with STRAHL



SPRED Spectra Shows That LHI Can Increase Impurity Influx

• Ohmic Solenoid Discharge

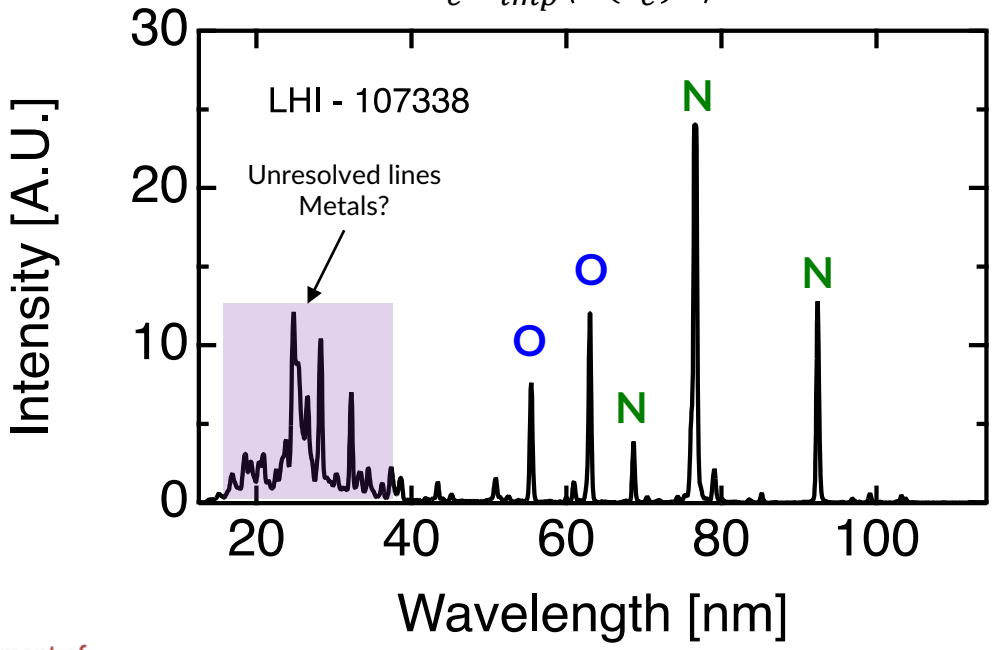
- Oxygen dominated
- Relative low intensity



• Pegasus LHI Discharge

- Nitrogen and oxygen Identified
  - Possible sources are plasma material interaction
- Intensity is higher than Ohmic
  - At similar n_e and T_e, this suggest higher n_{imp}

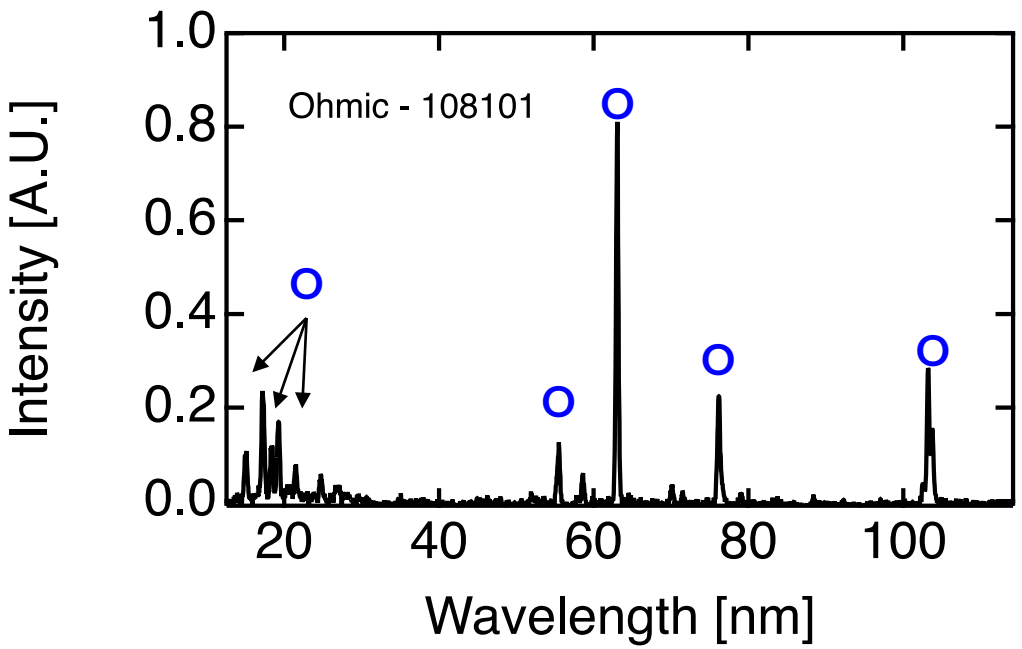
$$\epsilon \propto n_e \, n_{imp} \langle \sigma(T_e) v \rangle$$



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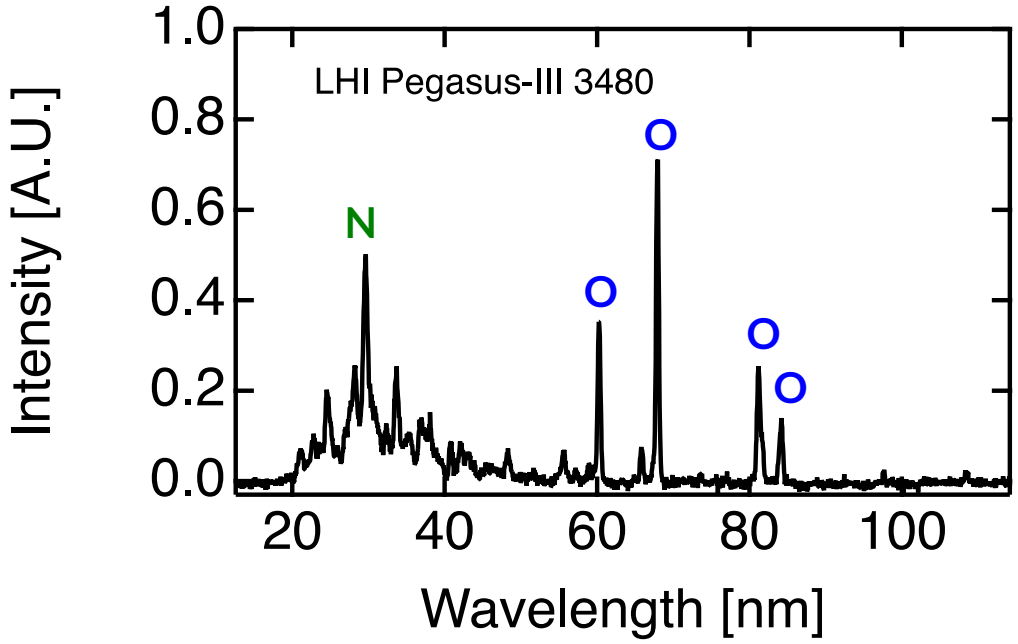
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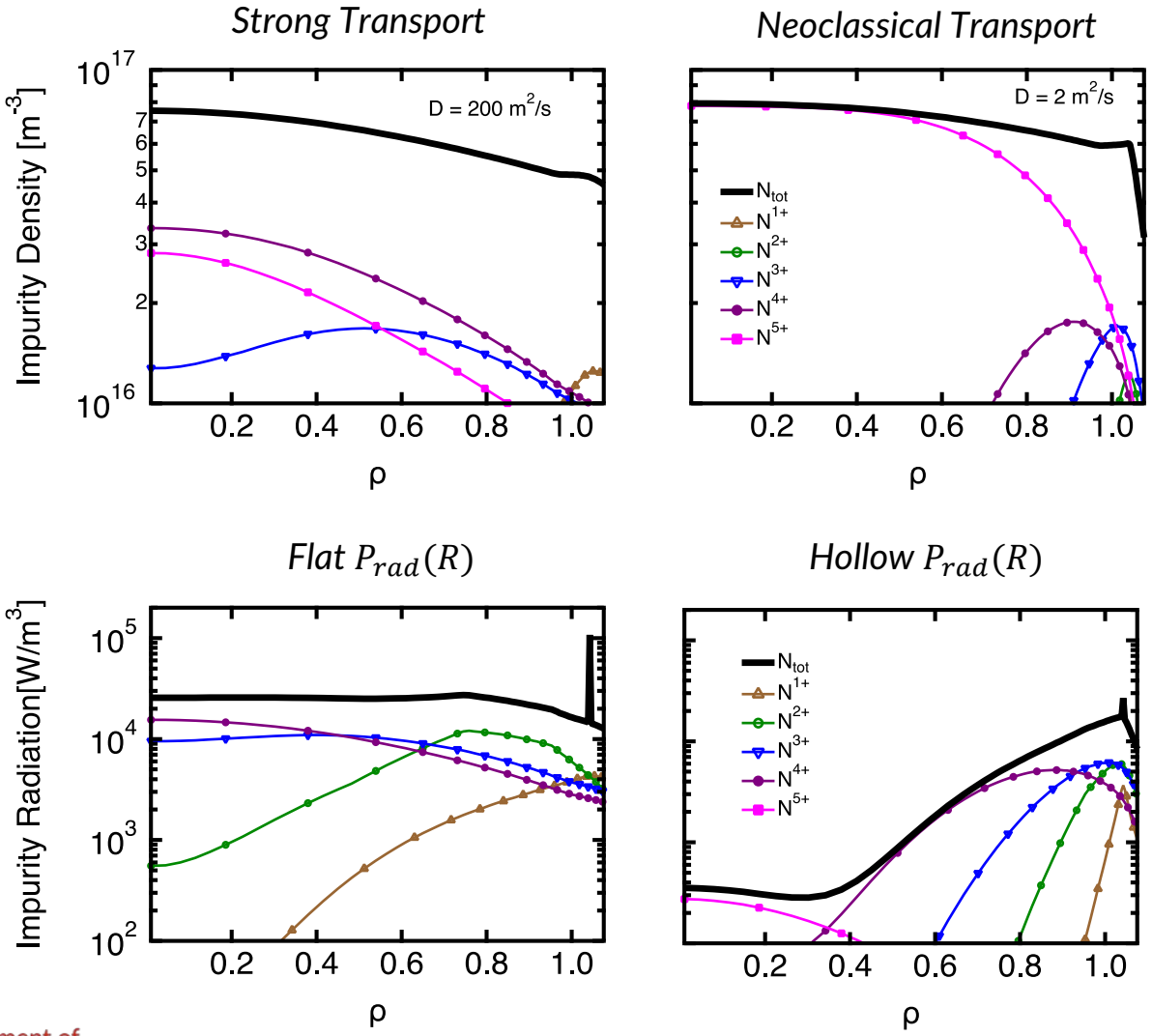
• Pegasus-III LHI Discharge

- Spectrum looks more Ohmic-like



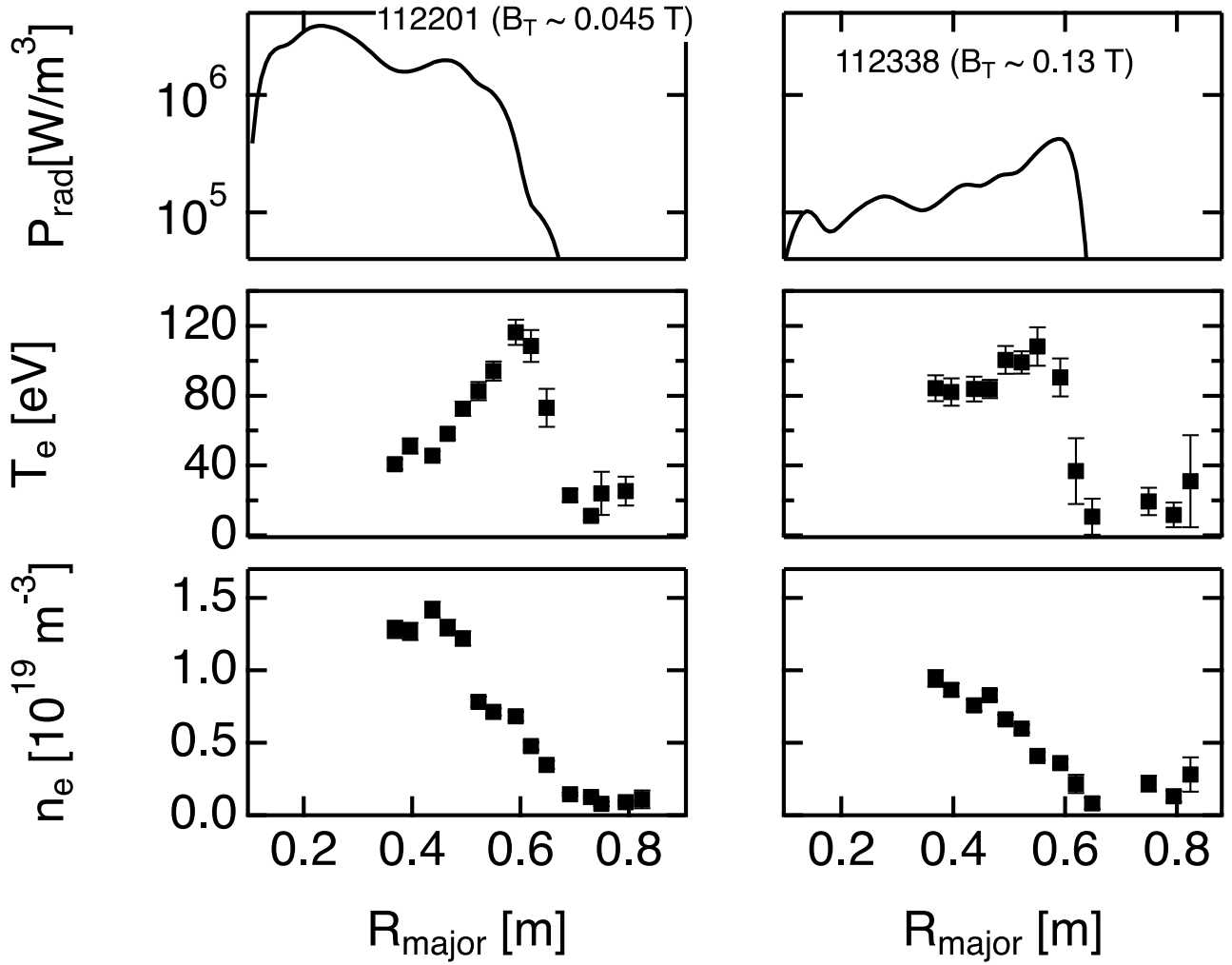
STRAHL Simulations Show That Transport Affects $P_{rad}(R)$

- STRAHL: Impurity transport code
  - Solves the continuity equation
  - Output impurity densities and emission
- Charge-state balance determined by transport
  - In both cases, low impurity concentration
    - Nitrogen fraction ~ 2 %
  - Strong transport leads to high core radiation
    - Low, highly radiative charge states can exist in the core
    - Flat radiation profile
    - $P_{rad,0} > \eta J_0^2$ → Hollow $T_e(R)$
  - Reduced impurity transport
    - Low charge states reside only at the edge
    - Hollow $P_{rad}(R)$



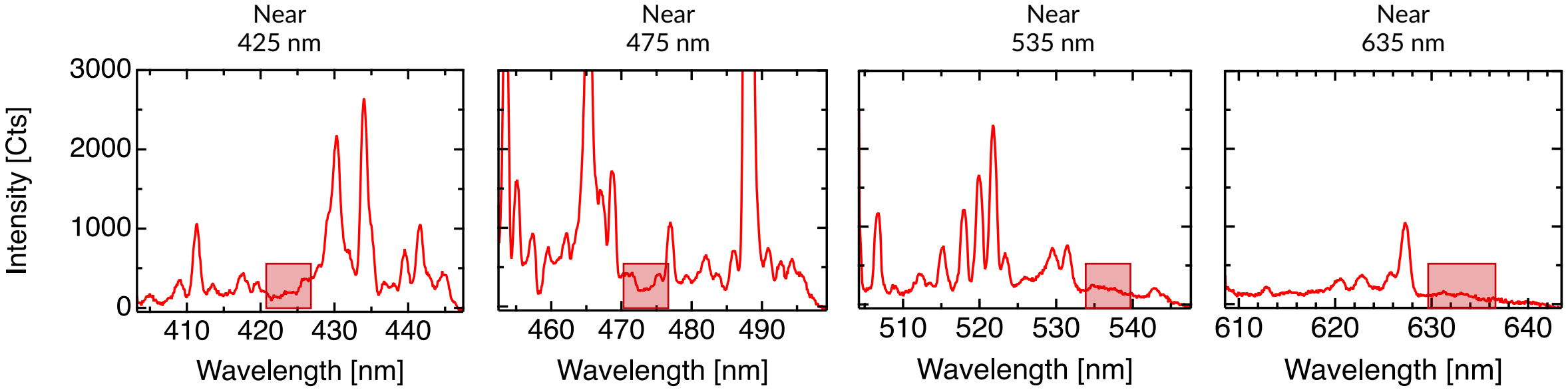
AXUV $P_{rad}(R)$ Profiles are Similar to Simulation Results

- Low toroidal field exhibits high P_{rad} and hollow T_e
- At increased B_T , lower radiation and flatter T_e
- Transport expected to decrease at higher field
  - Pegasus-III upgraded TF coils to deliver up to 0.6 T on axis



Spectral Regions Free of Line Emission Identified for Possible Measurements of Z_{eff}

- Exploring viability of measuring Z_{eff} in startup plasmas via Bremsstrahlung continuum
  - Bremsstrahlung emission $\propto Z_{eff} n_e^2 T_e^{1/2}$
  - Survey spectrometer employed to identify region free of line emission
  - Other sources of emission can pollute the continuum



Influence of Impurities on LHI Tokamak Startup is Being Studied in Pegasus-III

- Impurity studies are needed for better LHI projections
  - Impurities affect helicity dissipation through changes in resistivity
    - Increase in mean ionic charge and cooling
  - Accurate $I_p(t)$ projections require a model to scale helicity dissipation

- Pegasus-III new capabilities will enable impurity studies under different conditions
  - Upgraded LHI systems
  - New TF magnets

- A suite of diagnostics and tools will be used to do an impurity assessment
  - Species identification with SPRED
  - AXUV radiometry for P_{rad}
  - VB spectroscopy for Z_{eff}
  - Impurity Transport modeling with STRAHL