Initial PMI measurements with boronization in NSTX-U

NSTX-U Results & Review 2016

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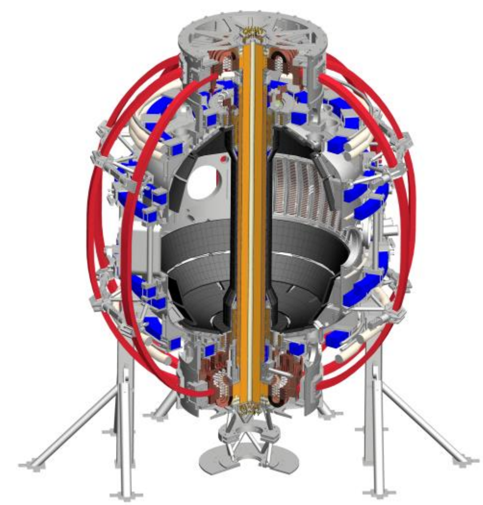
Fusion Energy Sciences

NSTX Upgrade



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PPPL

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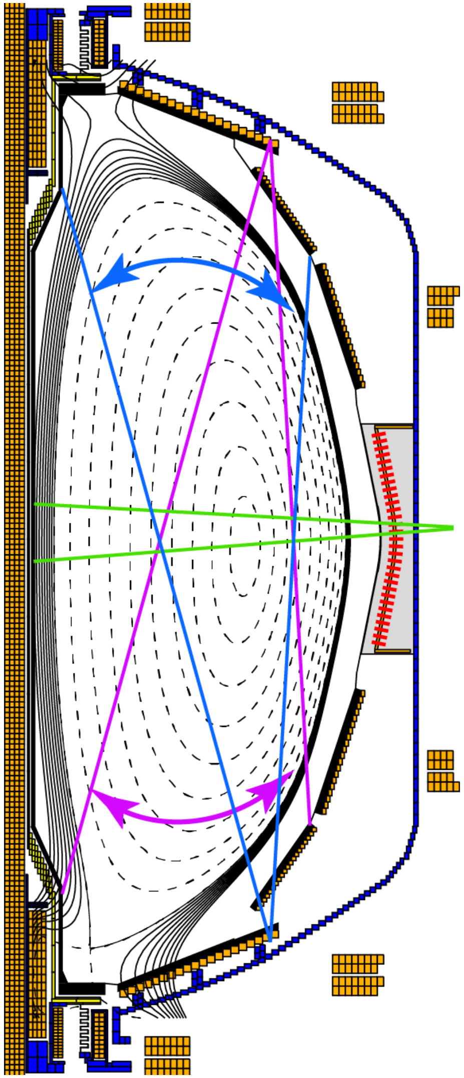
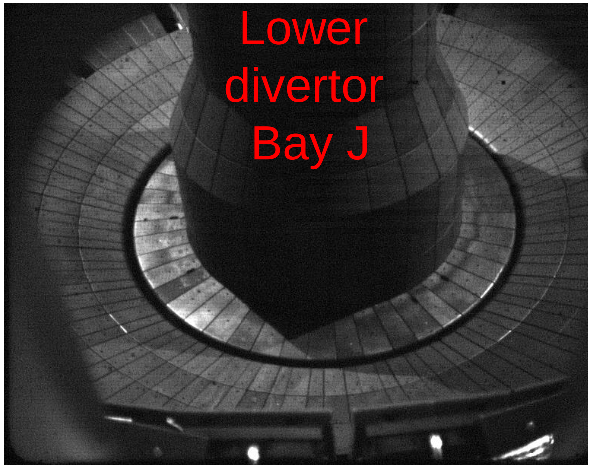
Volume-integrated and spatially-resolved spectroscopic diagnostics to monitor edge recycling, impurity evolution

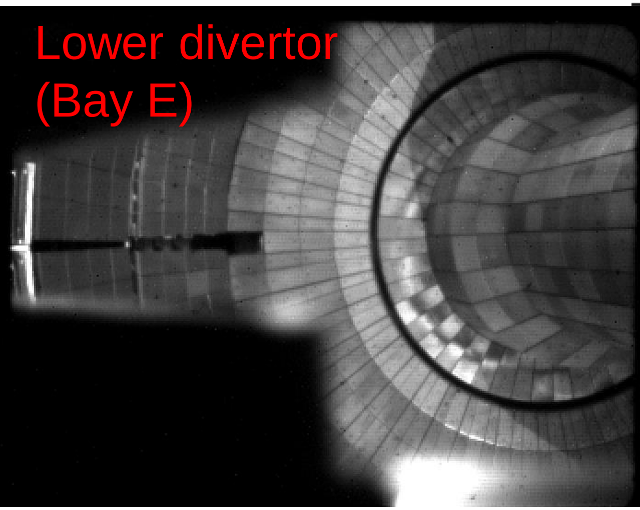
- New 32 channel EIES (filterscopes) system
  - Center stack, upper and lower divertor views
  - D-α, D-γ, C II, C III, B II, Li I, O II, He II
- VIPS2 survey spectrometer
  - Center stack, upper and lower divertor views
  - Survey spectroscopy, H/D ratios, etc..
- Four 2D fast cameras (operational since Dec.)
  - C II, C III, D-α (Low. Div.), C II (Up. Div.)
- Two TWICE systems (operational since Jan., Feb.)
  - 2D two-color rad-hardened intensified CID cameras
  - TWICE-I on B II, O II
  - TWICE-II on Gerö band (CD), D-γ
- Overall simultaneous 2D imaging of lower divertor at 7 different wavelengths

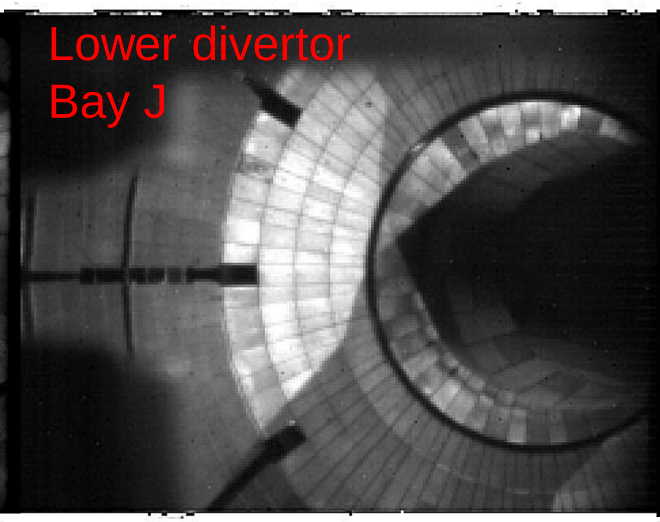


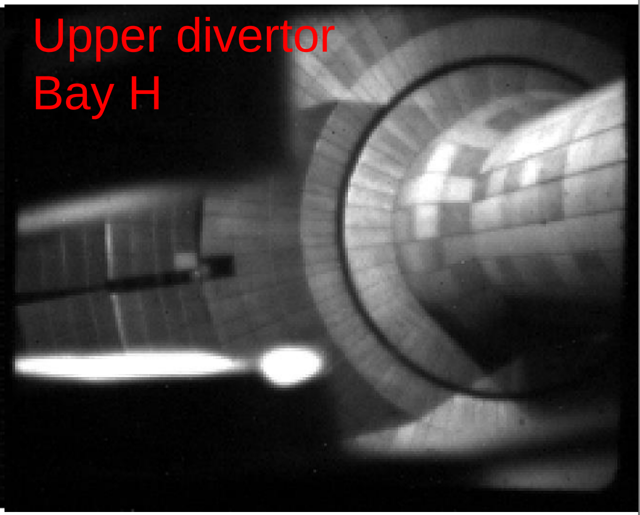
Photometrically-calibrated, fast cameras with wide angle view provide full toroidal divertor imaging

- Spatial resolution <1cm/pixel, up to 100kHz
- Fast optics, fast framing detectors for studies of impurity emission, non-axisymmetric effects, turbulence
- Narrow bandpass filters: C I, C II, C III, C IV, B III, Li I, Li II, D-α, D-γ, Gerö band (CD), O II on remotely controlled filter wheels



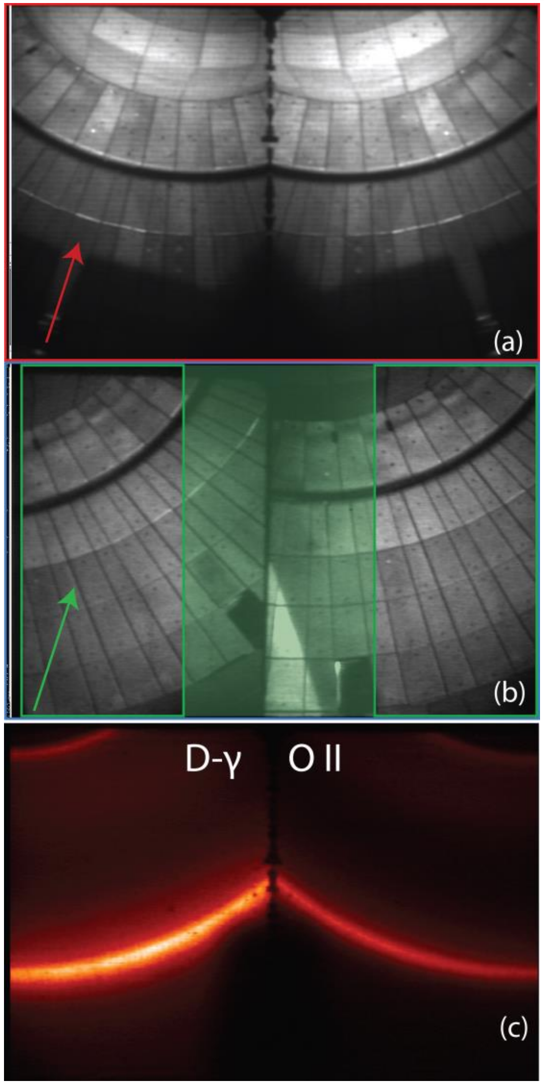






Two-color intensified systems (TWICE) for imaging of weaker emission lines

- Two-wavelength imaging with rad-hardened intensified cameras
  - ThermoScientific CIDTEC cameras 720x480
  - 8 bit, 30 Hz interlaced
- TWICE-I (Bay J)
  - Beam splitter for simultaneous 2-color imaging on same detector
  - Four filter wheels (2 for bandpass filters, 2 for neutral density filters)
  - B I, B II, Li I, D- γ, CD, O-II
- TWICE-II (Bay I)
  - 2.5x higher light throughput, 2 orders of magnitude higher intensifier
  - Fixed filters, dedicated to CD/D γ

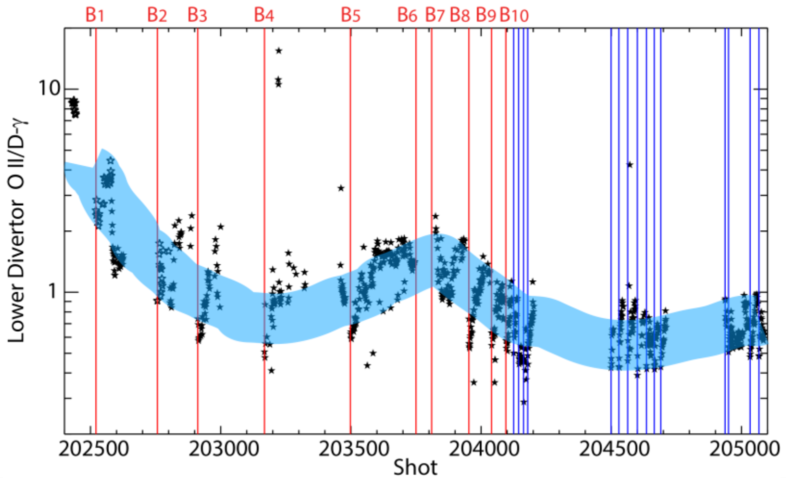


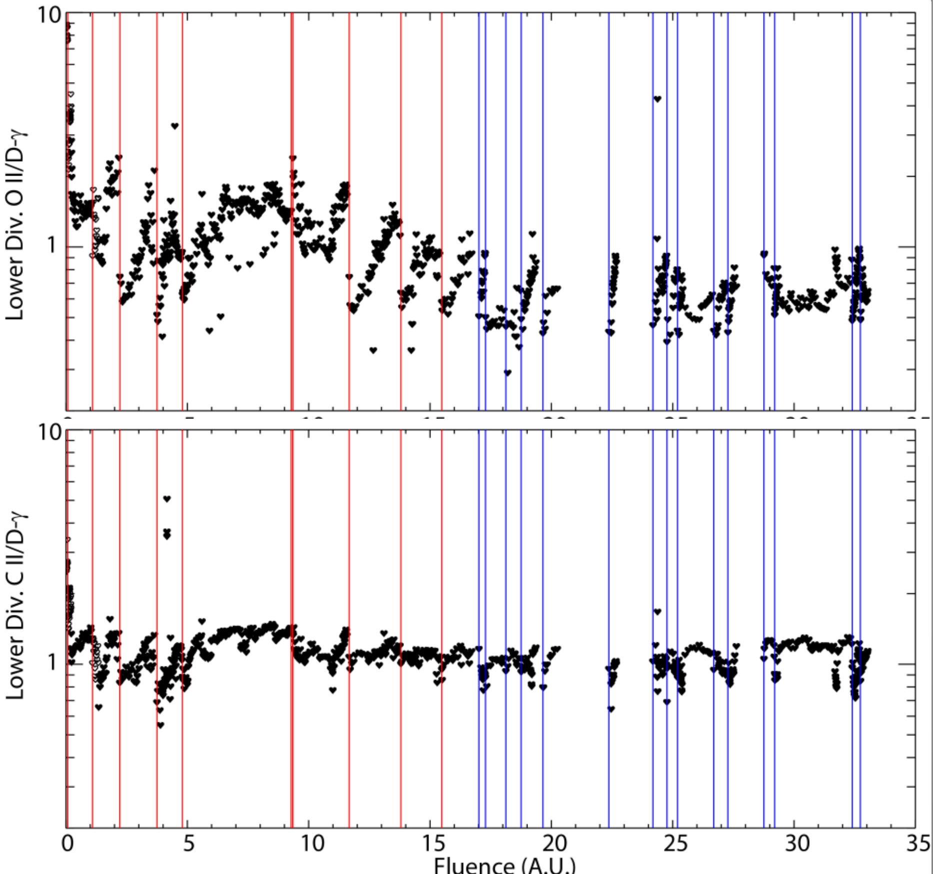
Boronizations with one D-TMB bottle/week for wall conditioning

- Mini center stack bake pre-CD-4
  - Followed by nitrogen vent for diagnostic installation
- ~3 weeks bake + D_2 and He-GDC:
  - Center stack and outboard divertor at ~350°C
  - Inboard horizontal tiles at ~230°C
  - End of bake based on vessel base pressure decay at full temperature extrapolated from NSTX experience
- One D-TMB bottle/week ($B(CD_3)_3$, 9g) followed by 2h He-GDC
  - 13 bottles used
  - Argon vent between 6th and 7th boronization
  - Starting from 11th bottle, mini-boronizations (1/4-1/5 bottle nightly followed by 30min/1h He-GDC) replaced full-bottle weekly boronization
  - 8 min He-GDC between shots

Wall conditions improved over the run, dynamic oxygen evolution between boronizations

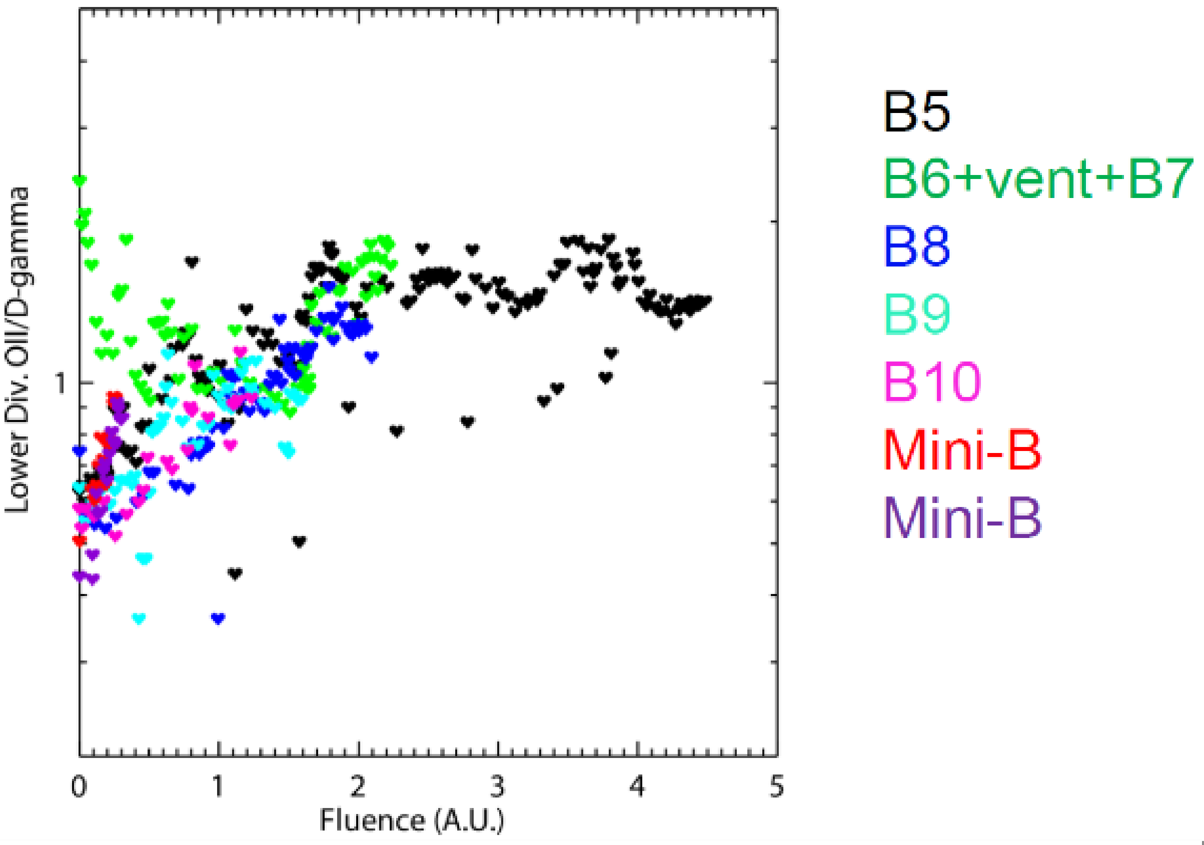
- O II/D-γ ~representative of <u>surface oxygen concentration</u>
  - Oxygen levels drop ~3-4x after full TMB; no changes in C, CD, weak B emission
- TMB frequency increased as higher power discharges challenged PFCs
- Mini-TMB to keep daily OII/D-γ low
  - W/o P_{rad} and core impurity emission, O II/D-γ, H/D used to guide TMB
- Less success in early H-mode access with mini-TMB
  - Non-linear divertor deposition observed
  - Full TMB planned before run interruption





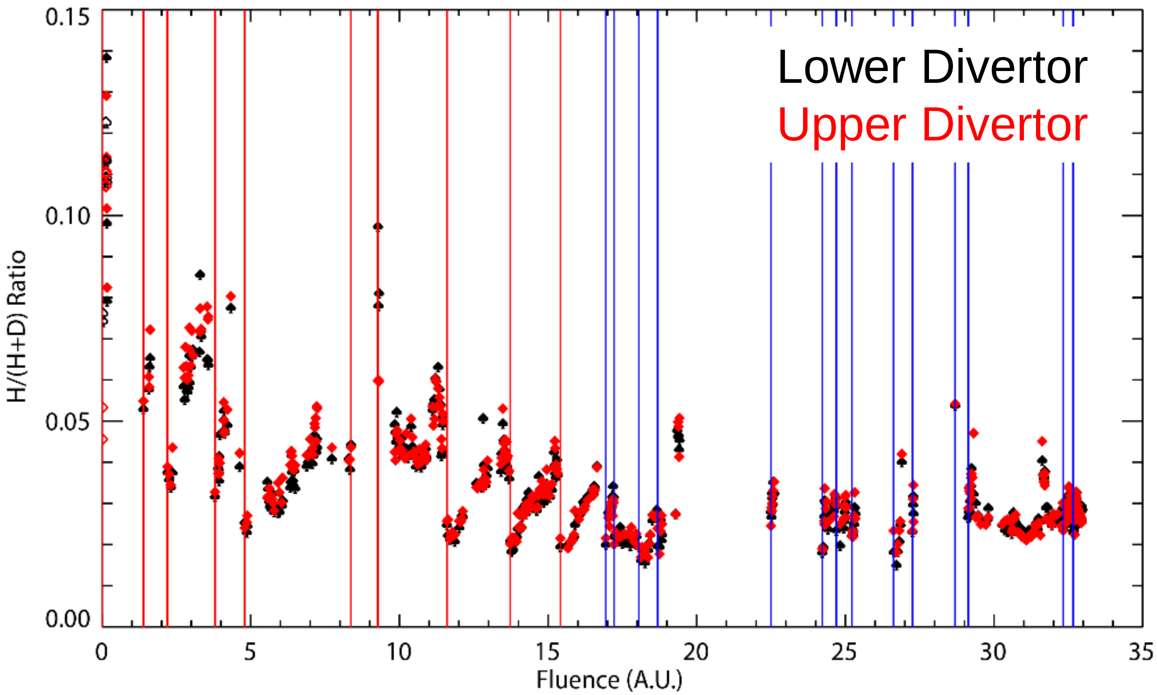
Mini-boronizations show the same range of oxygen evolution over a smaller fluence range

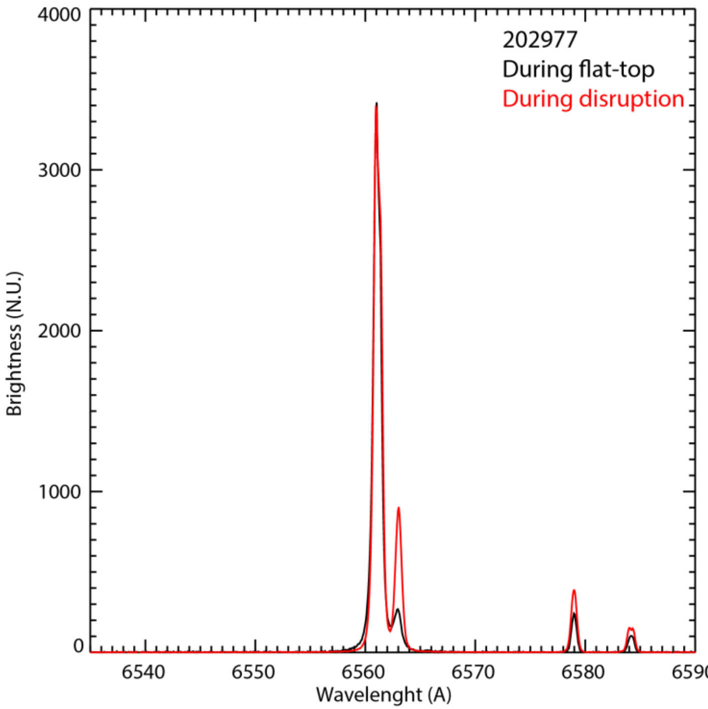
- Every boronization consistently following same oxygen evolution trend
- Max/min of oxygen evolution range constant over latter part of the run
- Clean vent for BN shutter removal had no long term impact on wall conditions
- Mini-boronizations span same range of OII/D-γ over a narrower fluence range
  - Suggests role of thin coating erosion
  - Even more dynamic wall conditions



H/D ratio closely follows O II evolution, correlation with other diagnostics underway

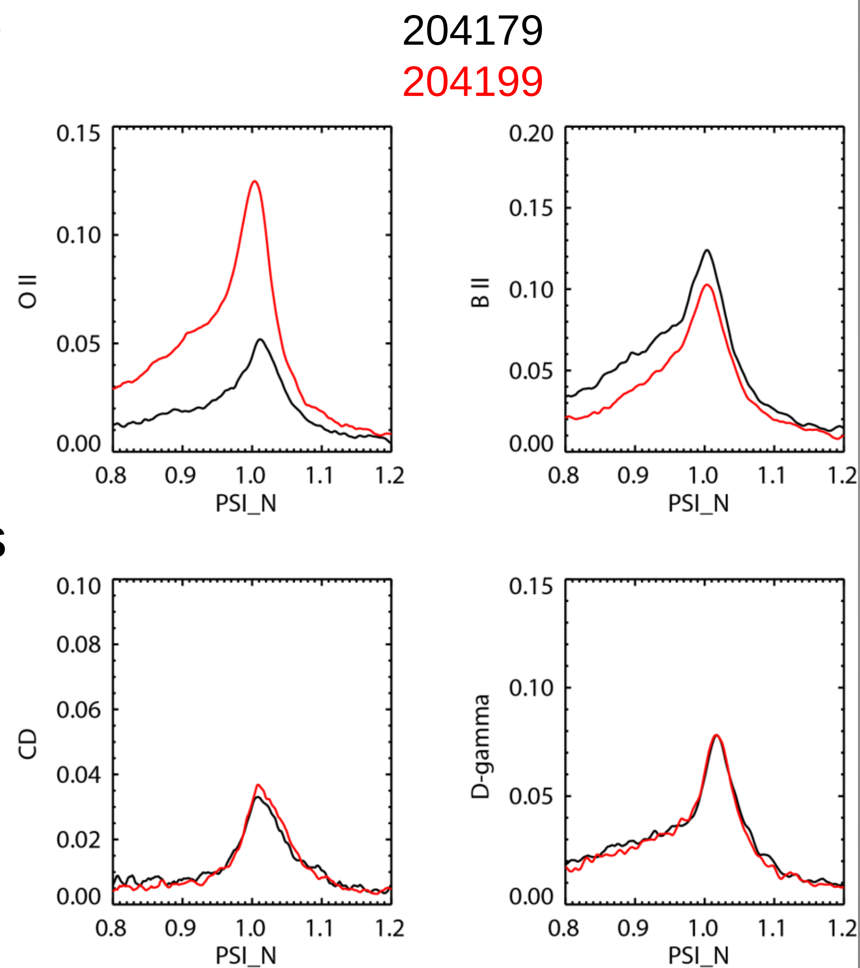
- H/(H+D) dropped to ~2-3% after boronization and recovered to ~5% after ~ days
  - D wall loading from D-TMB, water removal, thin coating covering graphite
- H/(H+D) steady during discharge but jumps during disruptions
  - Possibly indicative of flash heating of insufficiently baked wall components
- Correlation of H/D with RGA and core EUV spectroscopy started (D. Caron, SULI)
  - Dataset limited to mini-boronizations





Spatially-resolved diagnostics confirm EIES trends, absence of Langmuir probes prevents quantitative analysis

- Spatially resolved absolutely-calibrated CD, C II, C III, Dα, Dγ, B II, O II simultaneously available for mini and full boronizations
- Trends observed from filterscopes confirmed by spatially resolved diagnostics
- E.g., L-mode fiducials before and after series of high power, high-δ discharges show:
  - Reduction in strike point boron emission
  - 2.5x increase in oxygen emission
  - Unchanged carbon emission
- Absence of Langmuir probes precludes quantitative analysis of impurity sources/sputtering



Initial in-vessel inspections

- Lower divertor in good conditions, no evidence of leading edge erosion
- Cracked row 2 tile in upper divertor and some evidence of possible leading edges