Update on NSTX-U wall conditioning

NSTX-U Monday Physics Meeting

May 16, 2016

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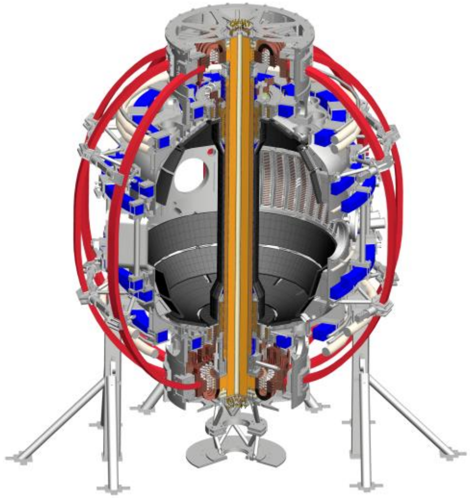
Fusion Energy Sciences

NSTX Upgrade



LLNL-PRES-XXXXXX

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PPPL

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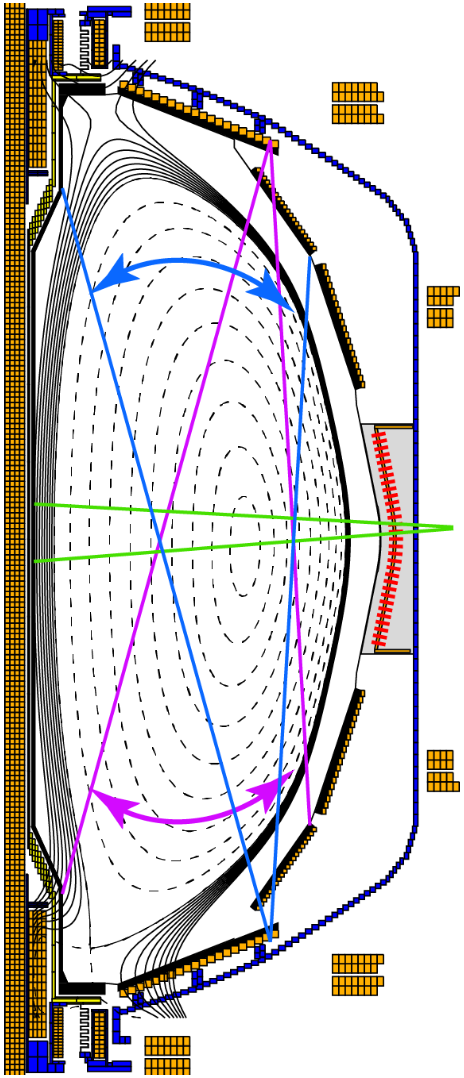
Outline/Conclusions

- Diagnostic overview
- Boronization trends in NSTX
- Oxygen evolution following boronization in NSTX-U
- H/D evolution following boronization in NSTX-U
- Tile asymmetries

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..



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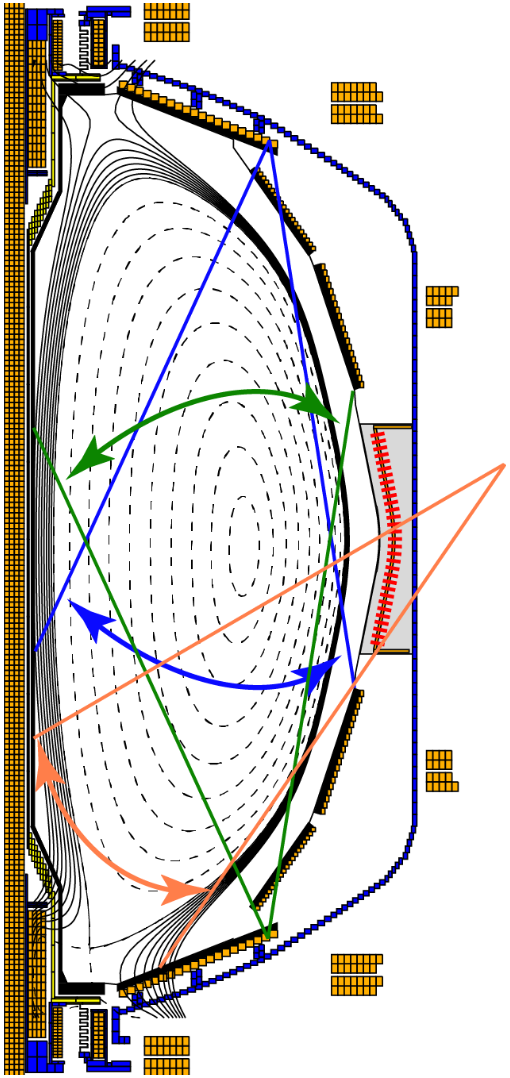
- Four 2D fast cameras [F. Scotti, RSI 2012]
  - C II, C III, D-α (Low. Div.), C II (Up. Div.)



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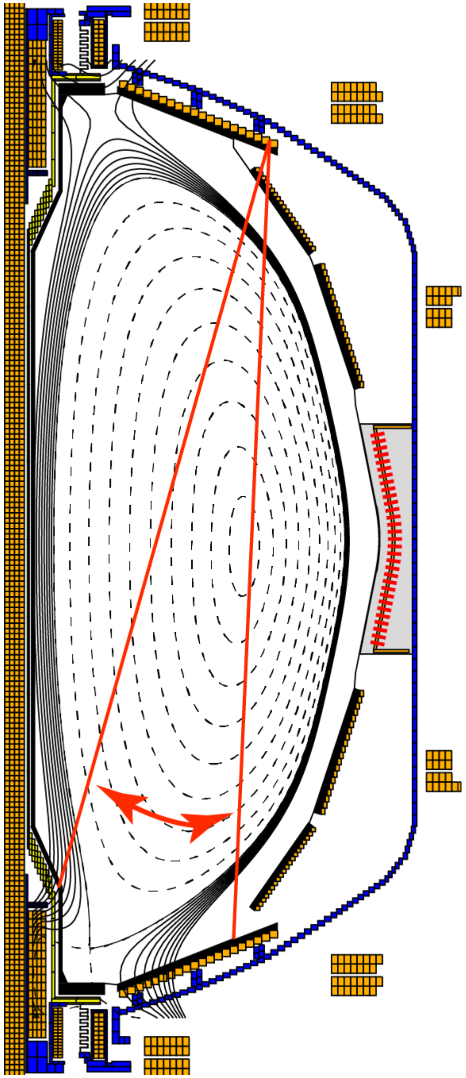
- Four 2D fast cameras [F. Scotti, RSI 2012]
  - C II, C III, D-α (Low. Div.), C II (Up. Div.)
- Two TWICE systems [F. Scotti, RSI 2015]
  - 2D two-color rad-hardened intensified CID cameras
  - TWICE-I on B II, O II
  - TWICE-II on Gerö band (CD), D-γ
- Overall simultaneous 2D imaging of lower divertor at 7 different wavelengths



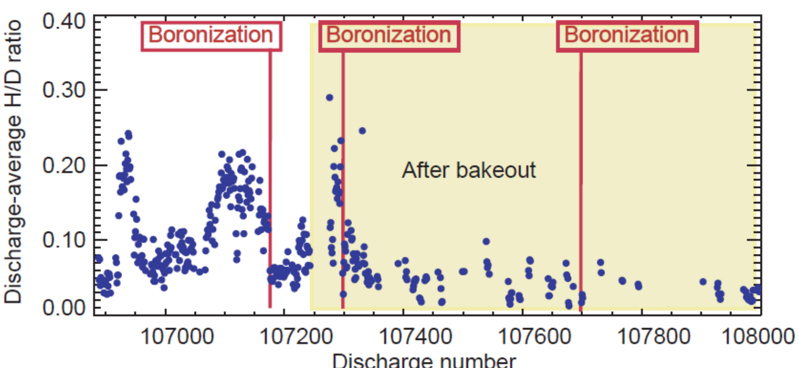
Boronizations with one D-TMB bottle/week for wall conditioning

- 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
  - 12+1/5 bottles used, 7+4/5 bottles left
  - Argon vent between 6^{th} and 7^{th} boronization
  - Starting from 11^{th} 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

Impurity emission evolution following boronization in 2002, 2007

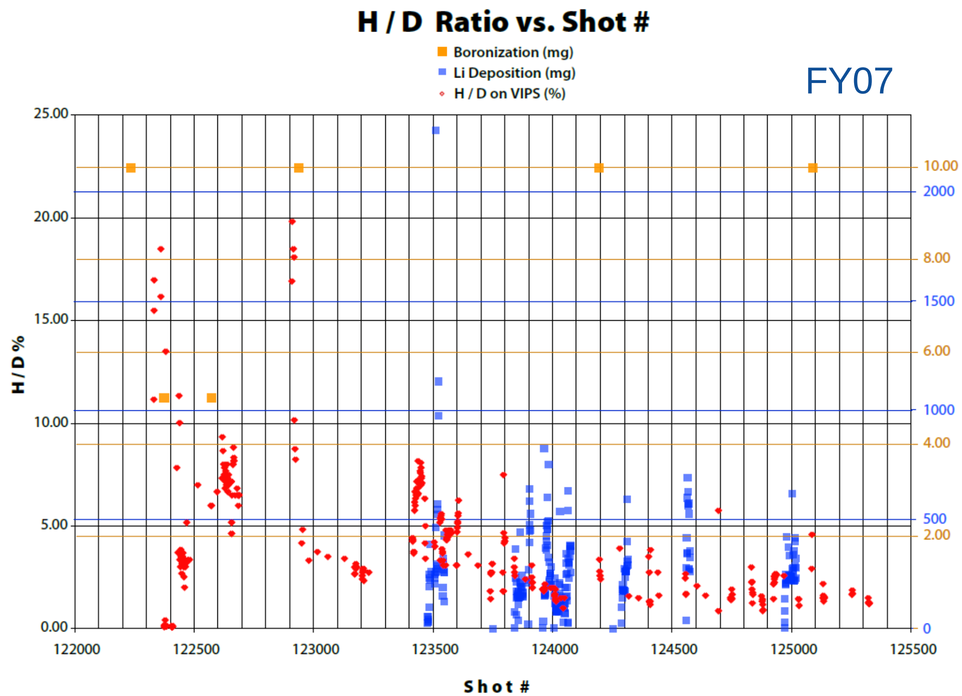
- NSTX experience on impurity evolution after boronizations
  - O II reduction by 14x after TMB in Ohmic discharges [Skinner, NF 2002]
  - H/D reduced below 5% after 350°C bake+D-TMB [Kugel, JNM 2003]
  - Progressive reduction in H/D to~2% with D-TMB and lithium in 2007 [Paul, 2007]

FY02



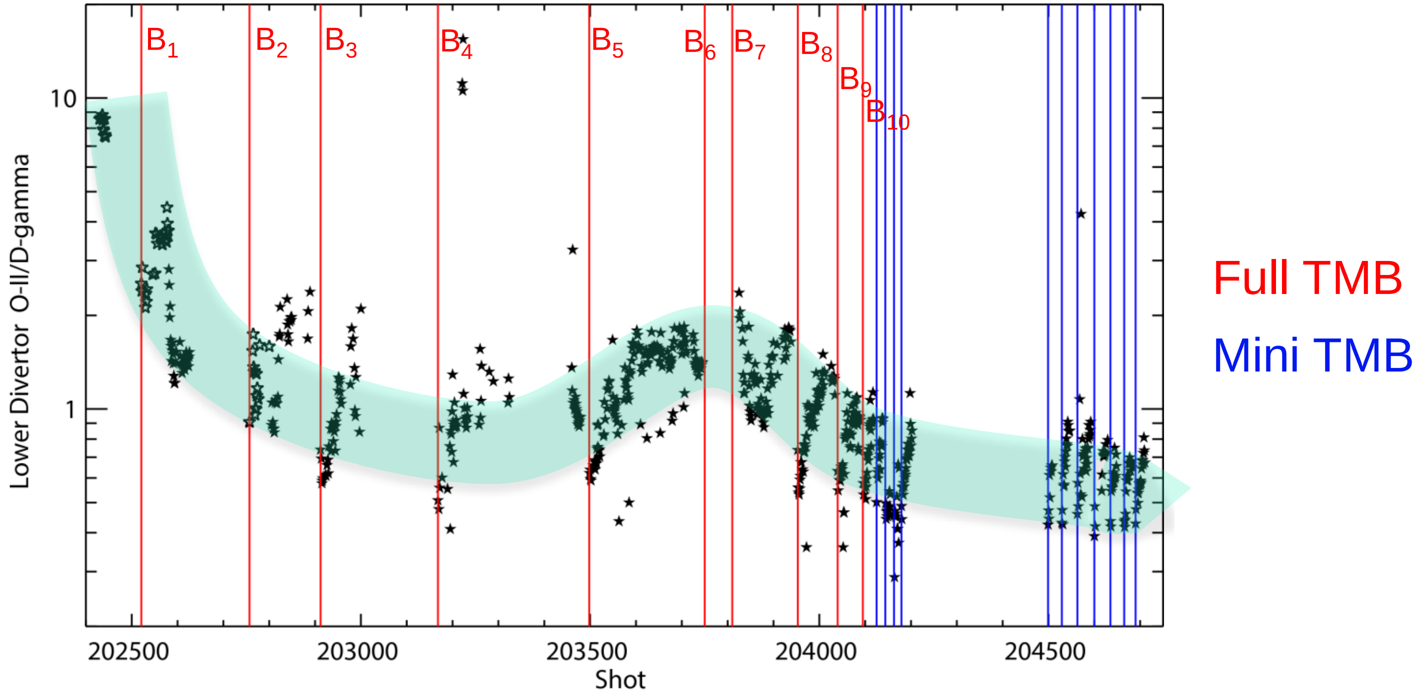
V.Soukhanovskii

FY07



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

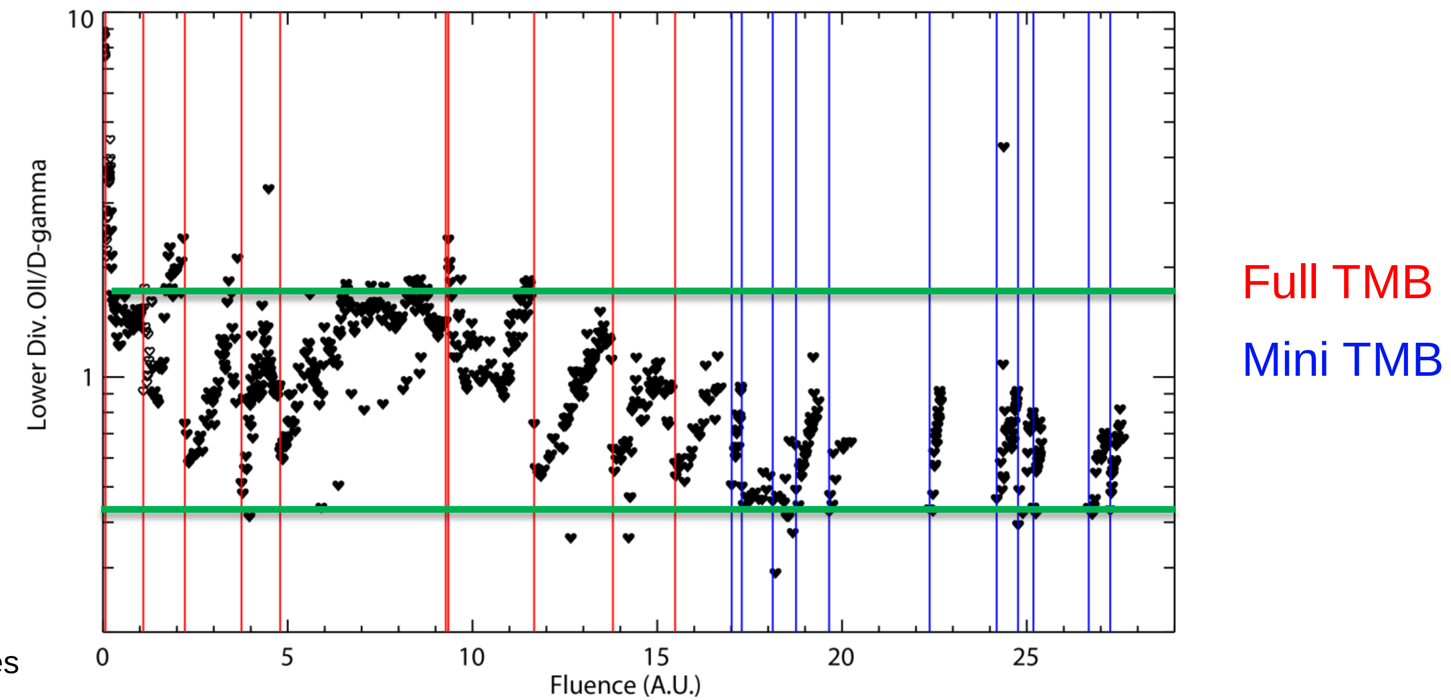
- Trying to identify a metric to schedule boronizations
- D-γ for particle flux, O II/D-γ ~representative of surface oxygen concentration
  - Oxygen levels drop ~3-4x after each boronization
  - No clear changes in other impurity emission (C, CD, etc…)
- TMB frequency increased as high power discharges started challenging PFCs



Oxygen evolution after boronizations covers constant fluence range, suggesting role of thin coating erosion

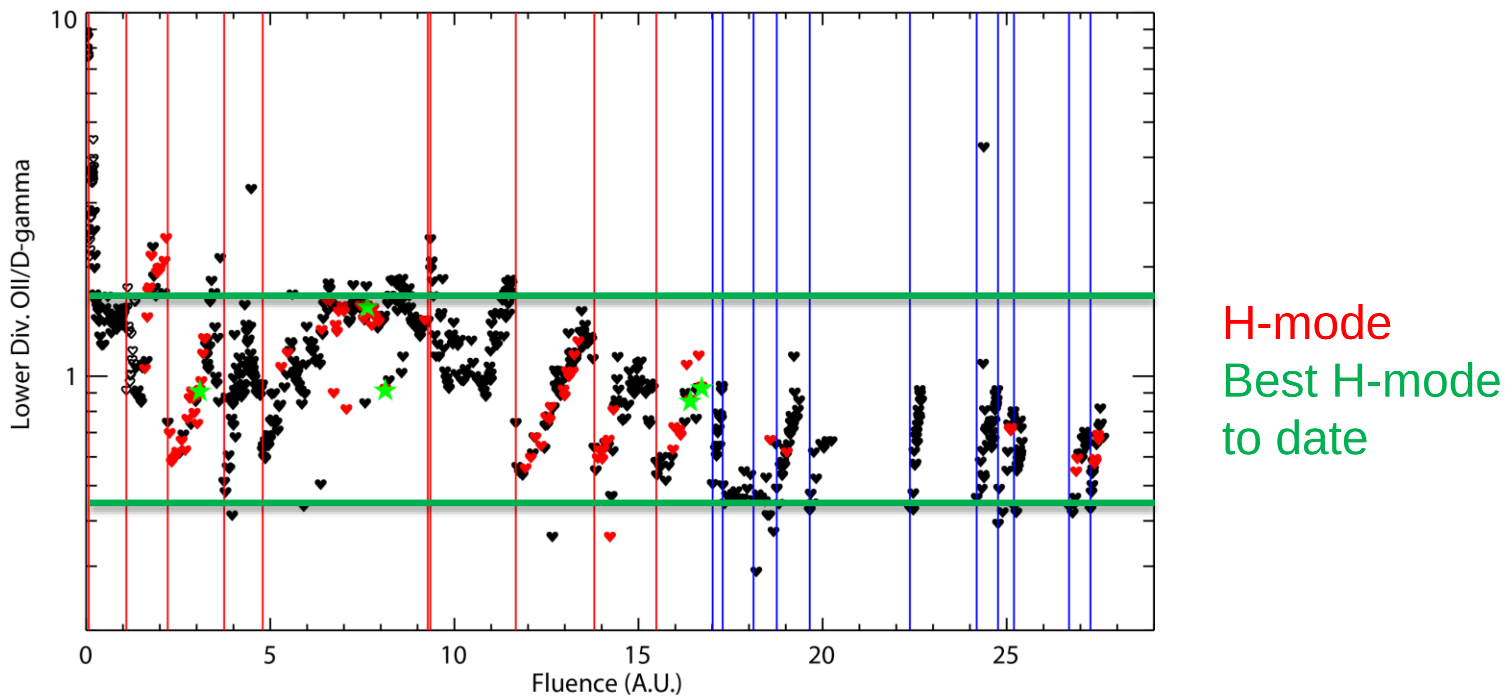
- Max/min of oxygen evolution range have been ~ constants over the latter part of the run
  - Representative of "bare tiles" and representative of thin boron coating
  - Increased TMB frequency likely prevented reaching the upper part of the range
- Oxygen evolution happens on same particle "fluence" scale after each boronization
- NBI-heated low-density L-mode fiducials on fresh coating don't seem to affect conditions

Empty-
D_2-prefill He discharges



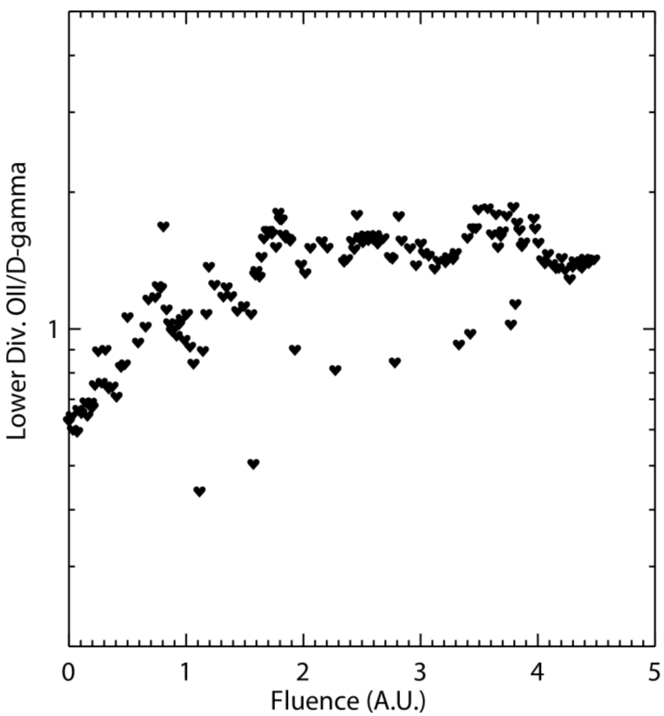
H-mode “quality” often observed to degrade with time after boronization

- Typically, quality of H-mode would degrade with consecutive discharges after boronization:
  - Change in ELM characteristics, fewer ELMs, ELM-free, and eventually harder to stay in H-mode
  - However, NSTX-U best H-modes have been in the high range of oxygen emission…
  - Other variables play more important role in H-mode access: NBI availability, control development, etc..
- Mini-boronizations meant to keep OII/D-γ metric daily in the range that provided most H-mode shots
  - Faster deconditioning could make phys. operator life harder



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

- Every boronization consistently following the same oxygen evolution trend
- Clean vent for BN shutter removal had no long term impact on wall conditions
- Mini boronizations span the same range of OII/D-γ over a narrower fluence range



B5

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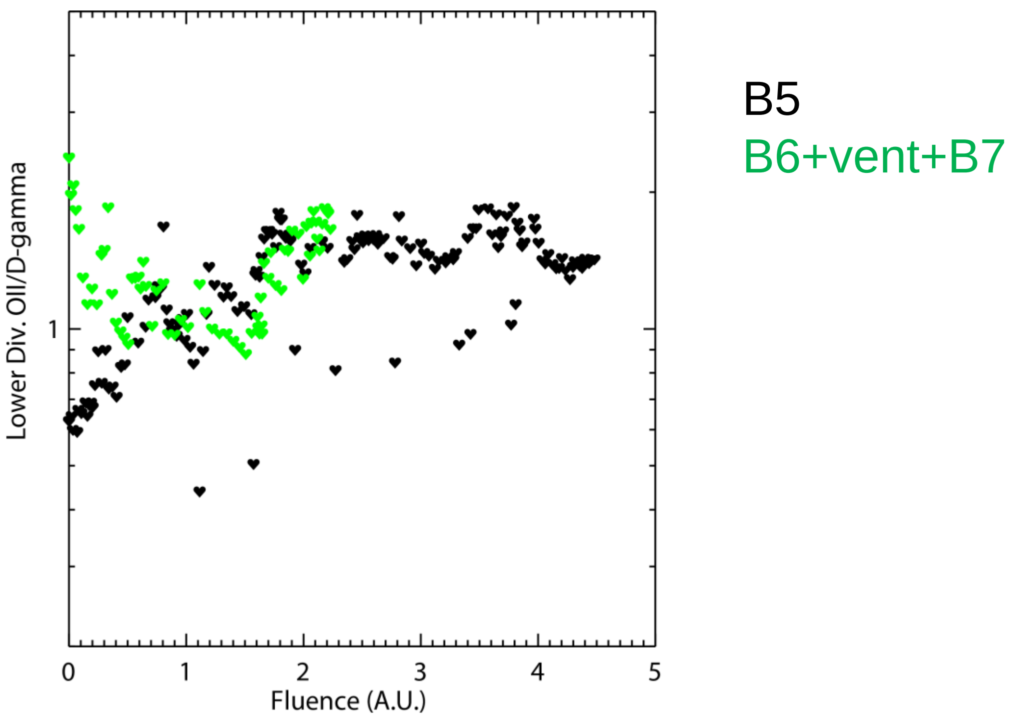

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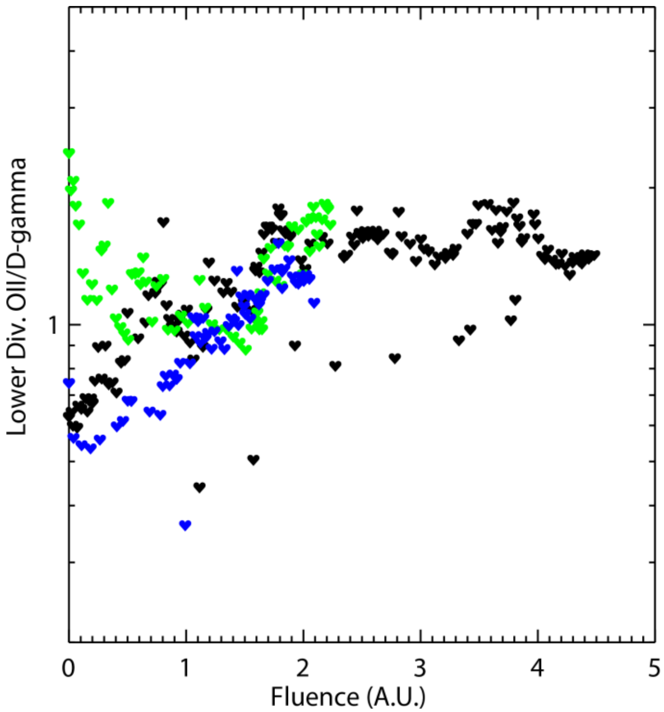

B5
B6+vent+B7
B8

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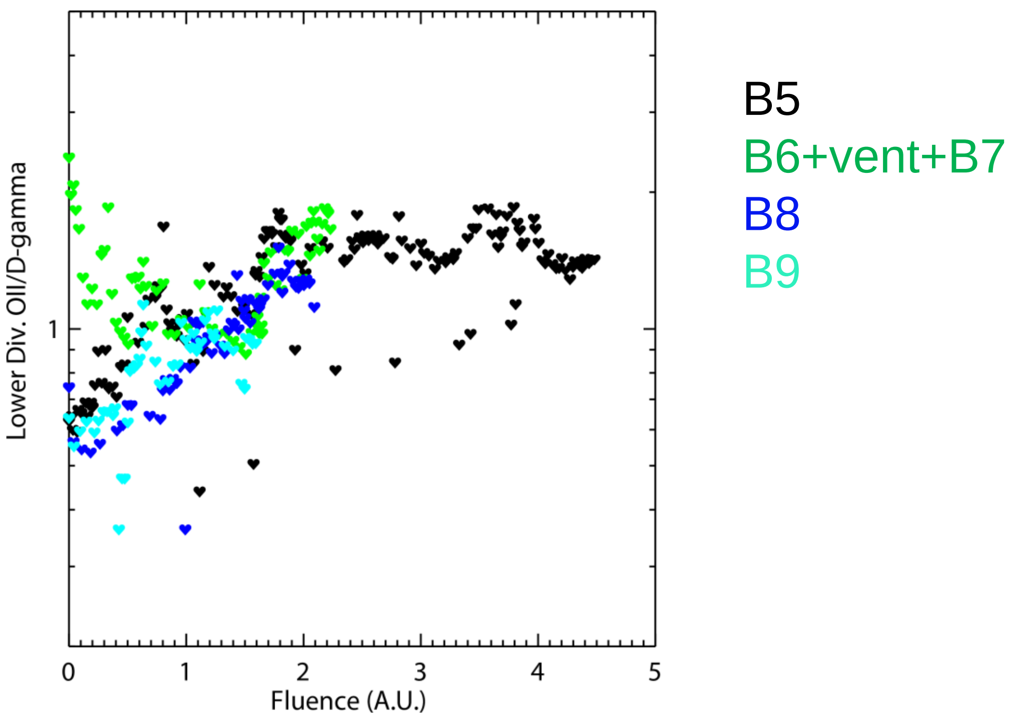

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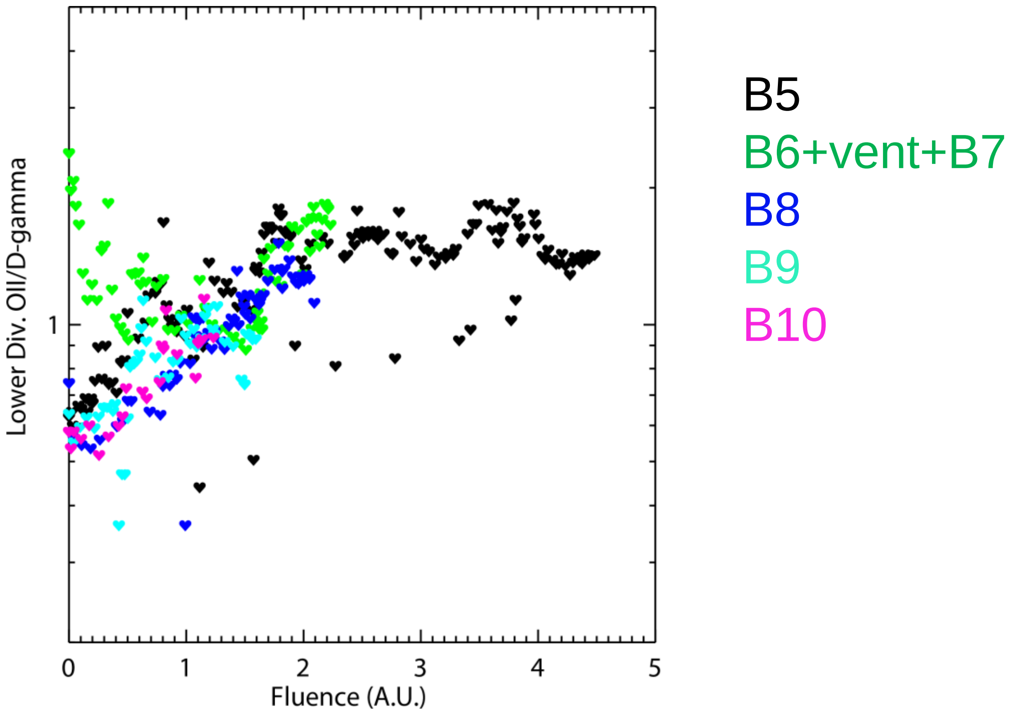

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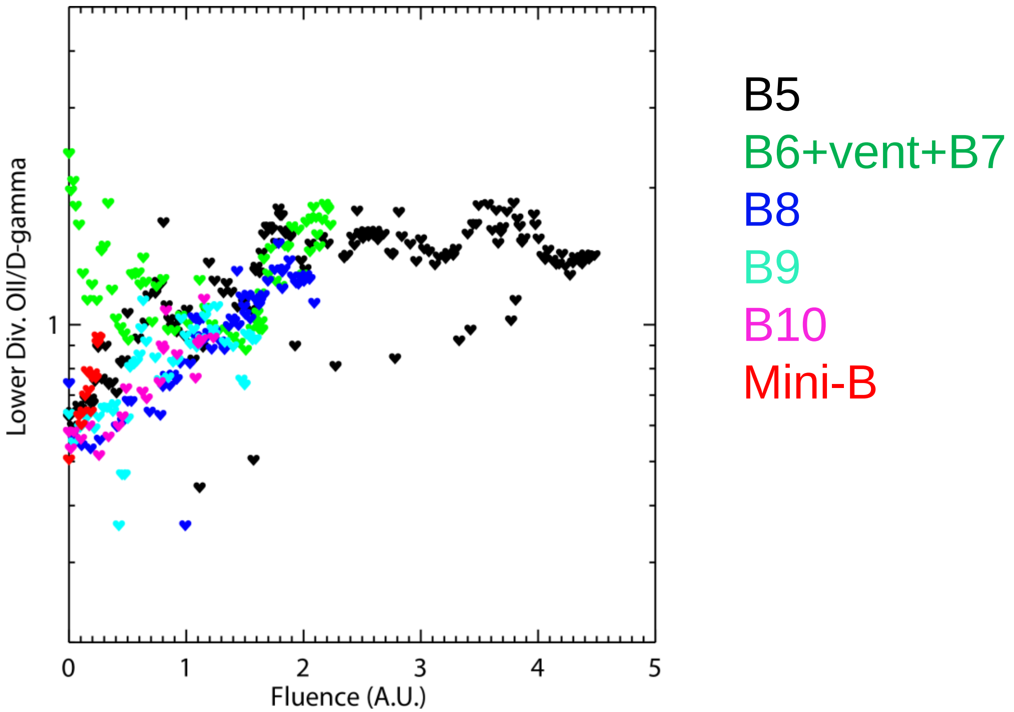

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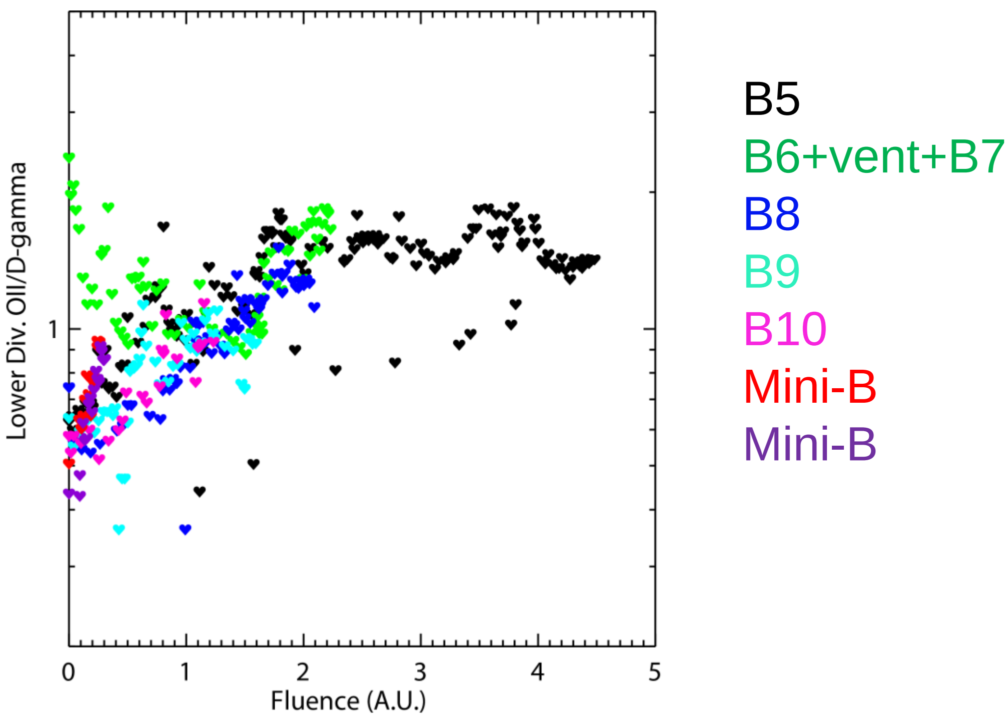
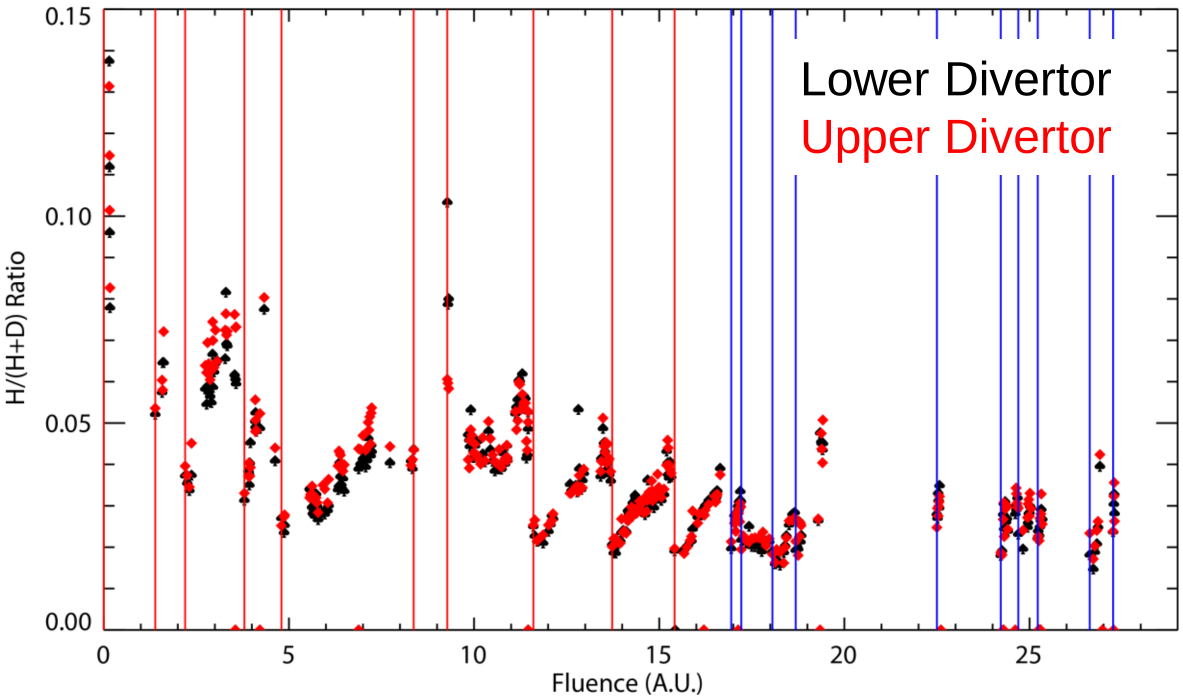
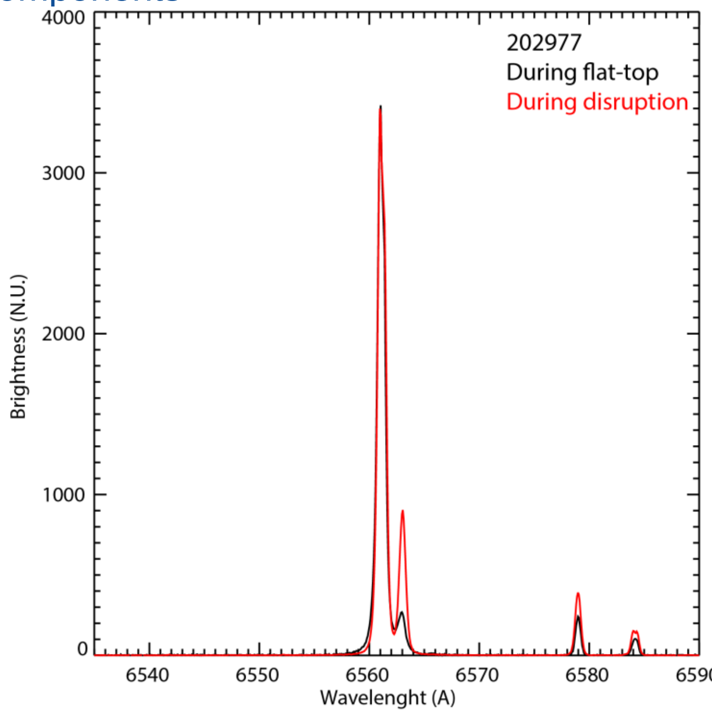


Evolution of H/D ratio closely follows evolution of O II emission

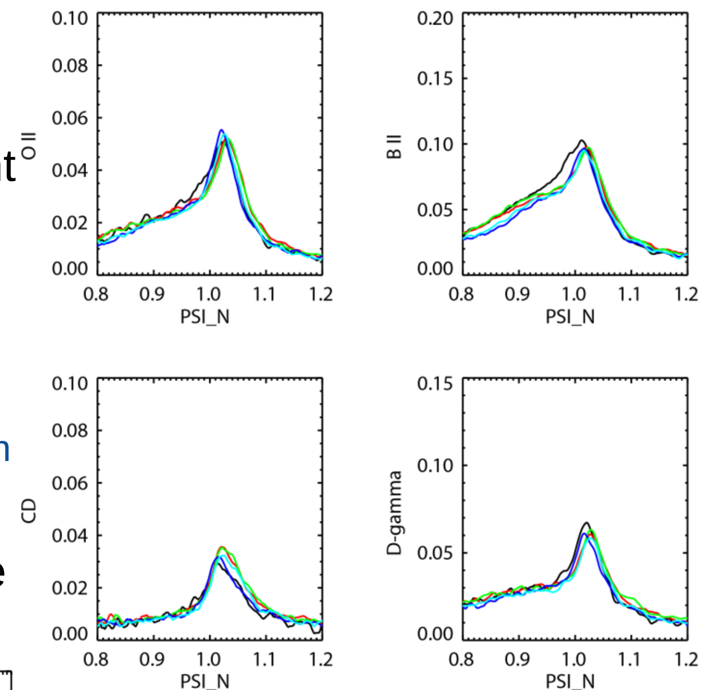
- H/(H+D) consistently drops to ~2-3% after boronization
  - D wall loading from D-TMB, water removal, thin coating covering graphite
- Back to 5% after ~few days
- H/(H+D) steady during discharge but jumps during disruptions
  - Possibly indicative of flash heating of insufficiently baked wall components

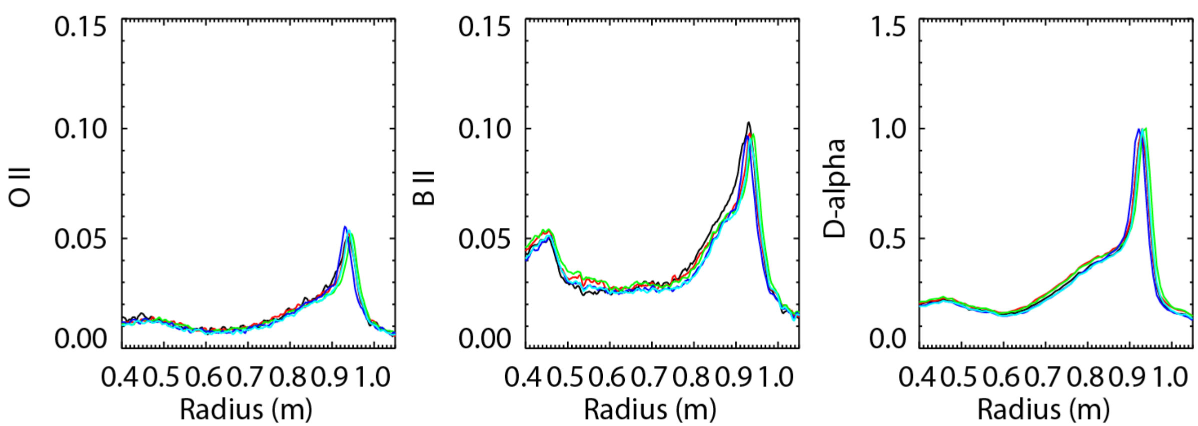




NBI-heated L-mode fiducials discharges don't seem to challenge PFCs

- Spatially resolved results from filtered cameras confirm trends from filterscopes
- All emission profiles strongly peaked at outer strike point
  - Particle flux ~1.5-3x10^{22} ions/m^2/s from D-α
- No changes in divertor impurity emission over 10 L-mode fiducials (P_{NBI}=1MW, nel~2.5x10^{15} cm^{-2})
  - Low power so not enough surface heating? Also, strike point on the best baked part of the divertor
- Boronization likely unnecessary if L-mode XP/XMPs are planned



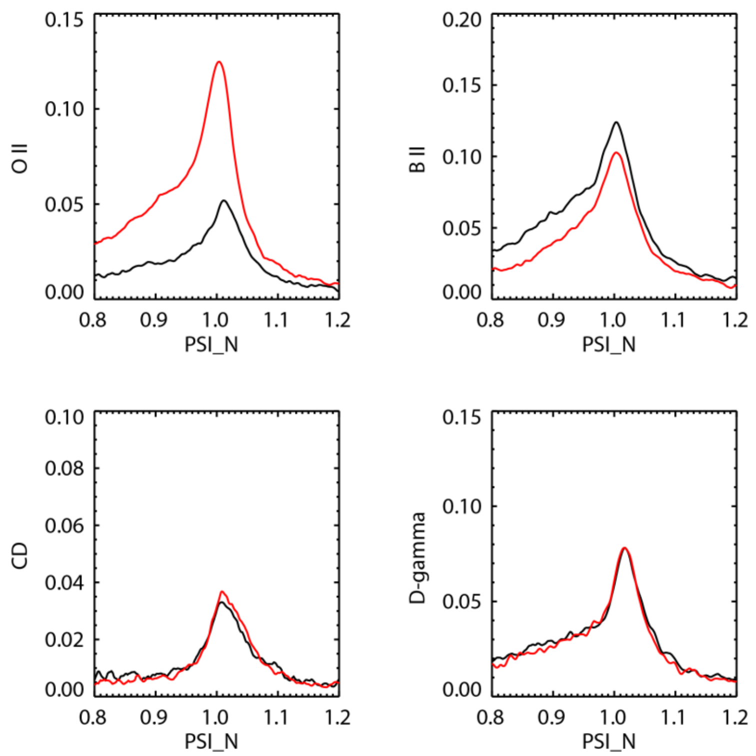


t=1.0s
204146
204149
204151
204153
204154

L-mode fiducials before/after high power H-mode discharges show increase in divertor O II emission

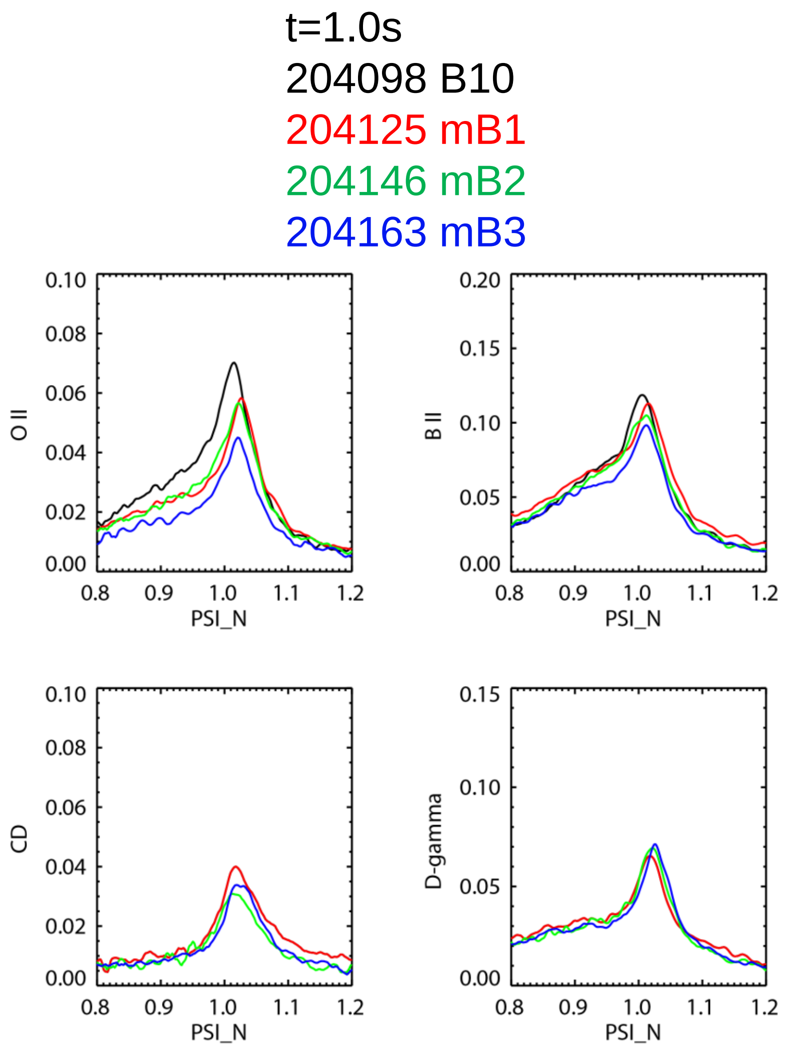
- L-mode fiducials before and after series of high power, high-δ discharges show:
  - Reduction in strike point boron emission
  - 2.5x increase in oxygen emission
  - Unchanged carbon emission

204179
204199



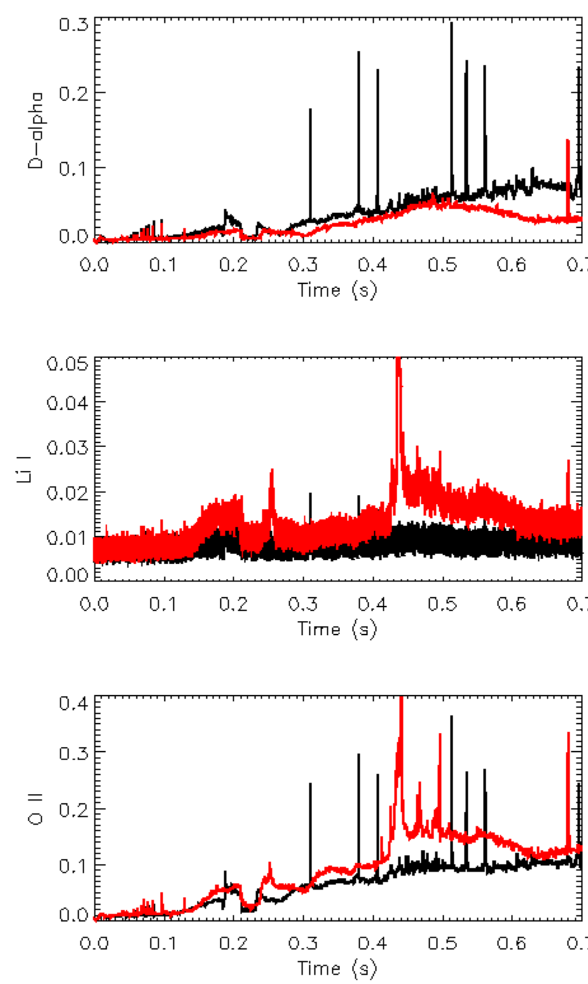
Comparable impurity emission in morning fiducials with full and mini boronizations

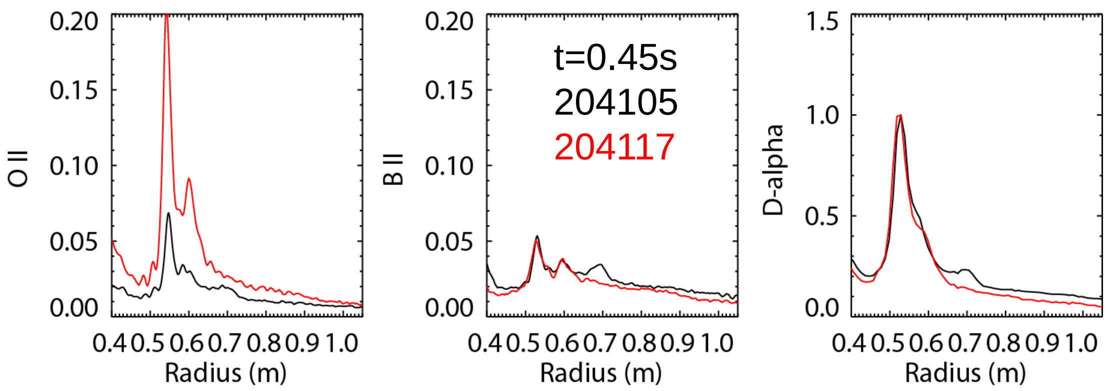
- Unchanged divertor impurity emission in fiducial discharges after full TMB bottle or ¼ TMB bottles
- ¼ bottle lasts ~¼ of the fluence indicating role of coatings erosion
- But QMB data show minimal deposition in the lower divertor with mini-boronizations
  - 7 Å at F bottom QMB compared to 30 Å E top [Skinner PSI 2016]



Ablation of lithium flakes observed to be accompanied by oxygen influxes

- Lithium flakes could be less innocuous than in NSTX
  - Larger oxygen influxes observed as lithium flakes ablate
  - Likely to be lithium carbonate formed over the outage
  - Frequency of flakes appears to have reduced during the run

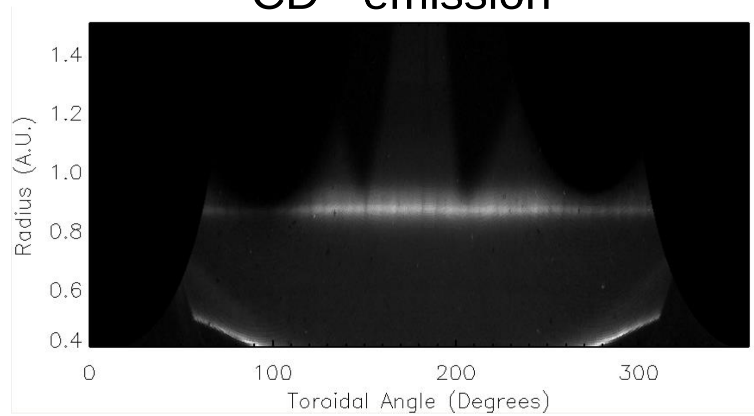




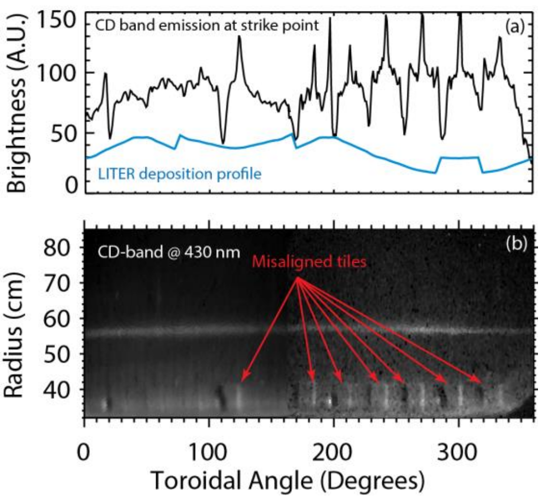
No leading edges observed so far in lower divertor tiles

- In NSTX, tile misalignments were evident both on row-1 of inboard divertor and BN (FY10) in outer divertor
- No clear tile edges observed except during disruptions

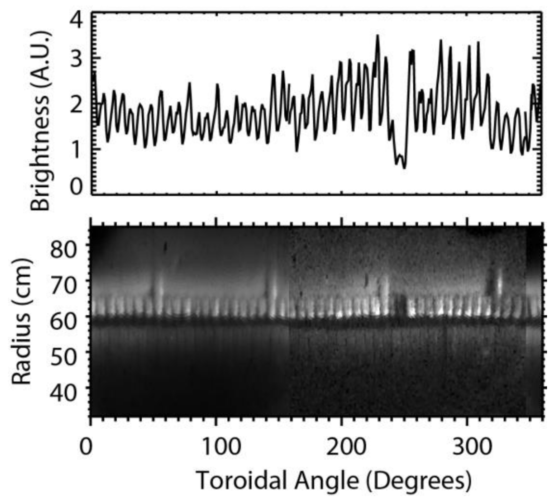
NSTX-U OD Row3 Tile
CD - emission



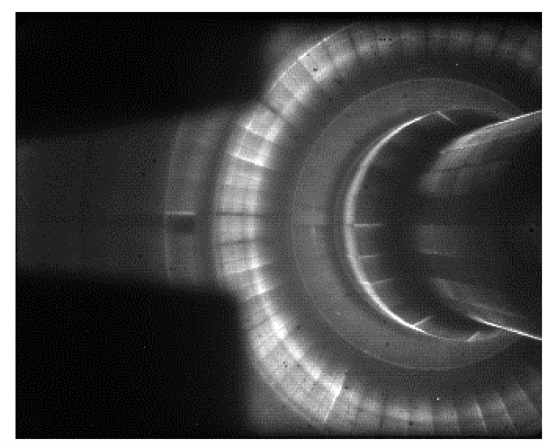
NSTX Row-1
CD



NSTX BN Tile
Li I

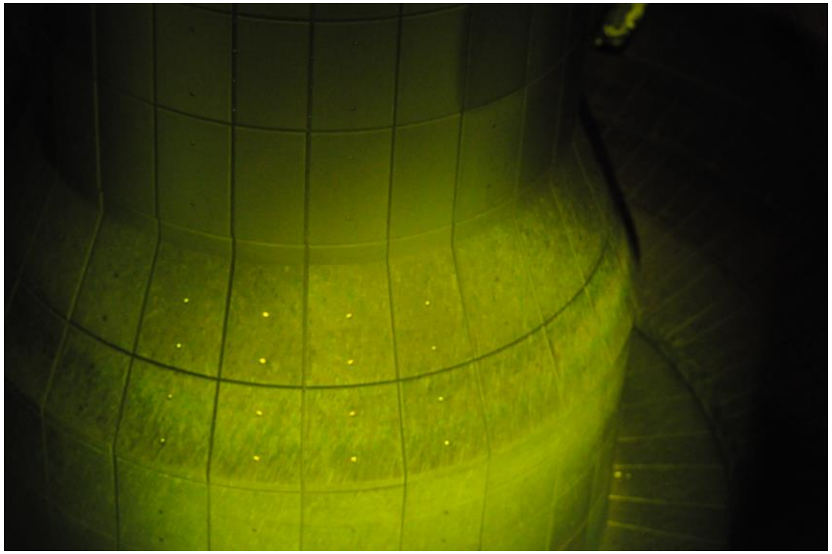


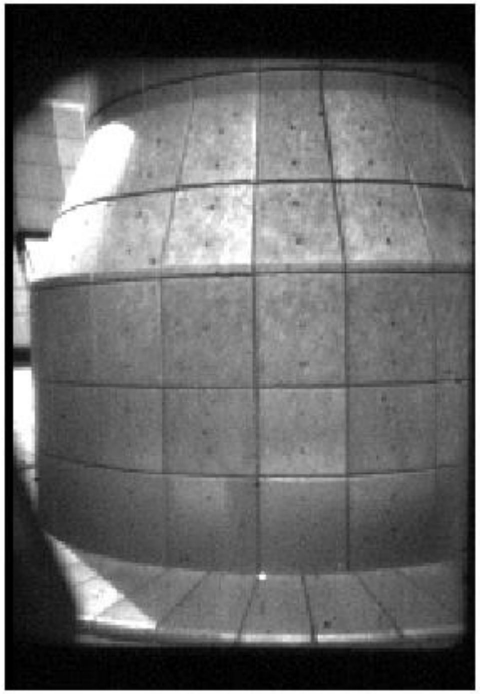
CD emission - Disruption

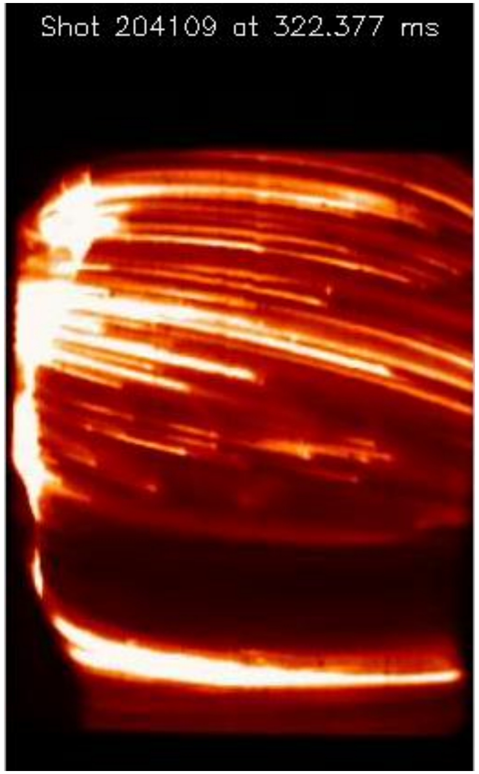


Arc tracks can be observed on lower center stack tilted tiles

- Arc tracks seen on the lower CS crown and vertical tiles
- Emission from hot spots (arcs?) routinely observed on lower CS tiles during disruptions





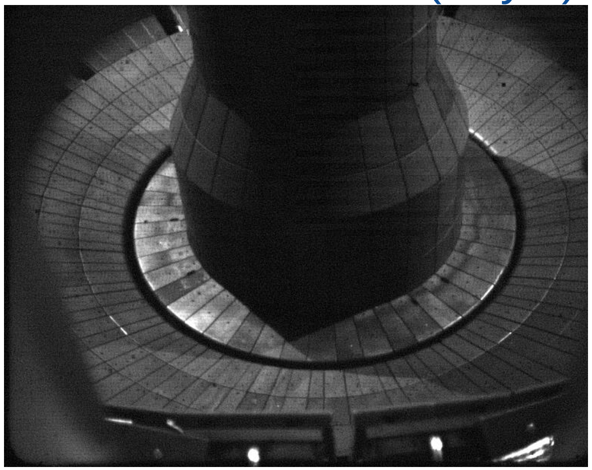


Backup

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

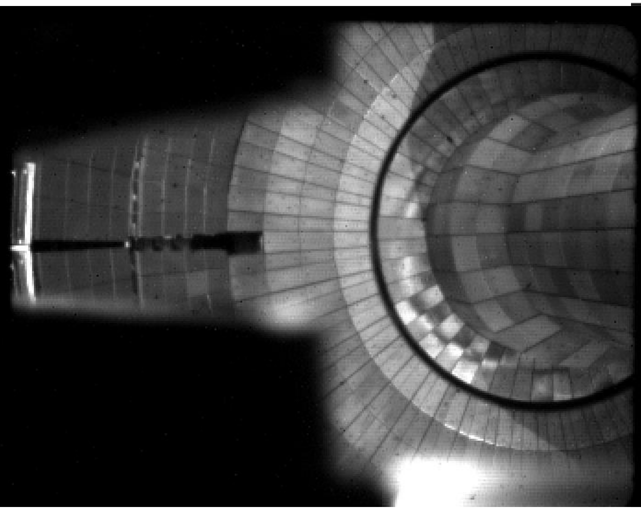
- Spatial resolution better than 1cm/pixel, framing 10-100kHz w/o cropping
- Fast optics, fast framing detectors and narrow bandpass filters allow studies of impurity emission, non-axisymmetric effects, turbulence
- Available filters: C I, C II, C III, C IV, B III, Li I, Li II, D-α, D-γ, Gero band (CD), O II on remotely controlled filter wheels

Lower divertor view (Bay J)



Upper divertor view (Bay H)

Lower divertor view (Bay E)



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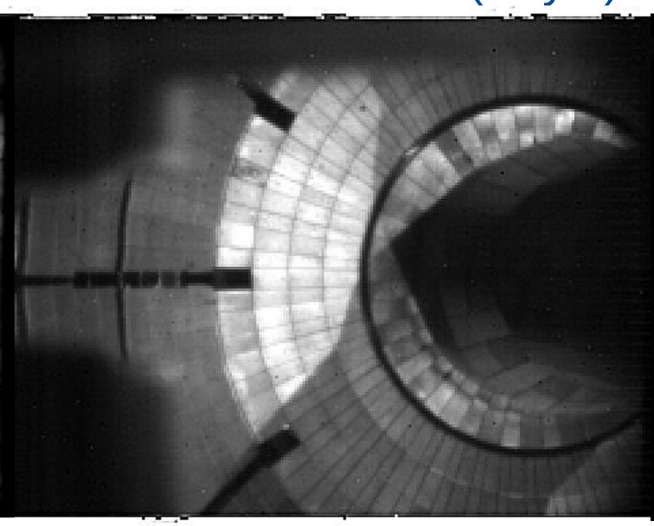
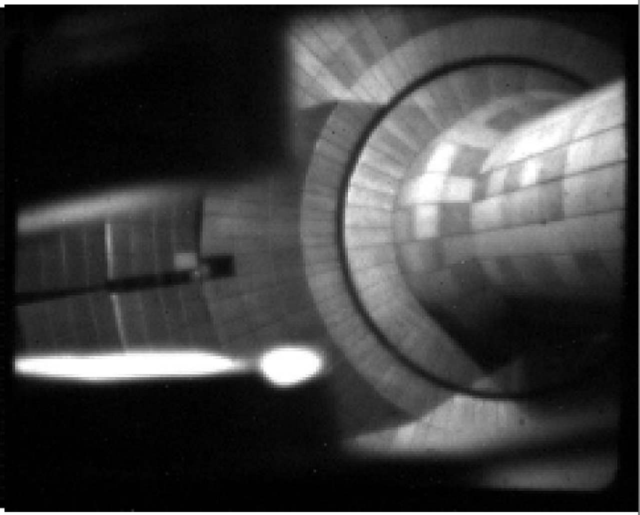
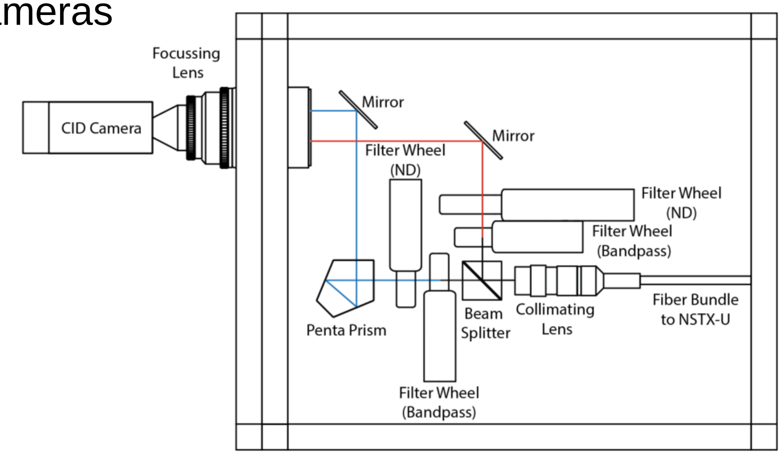


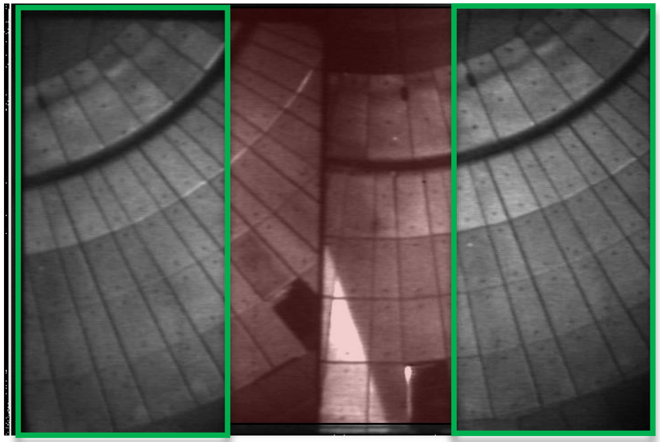


Two-color intensified systems (TWICE) for imaging of weaker emission lines

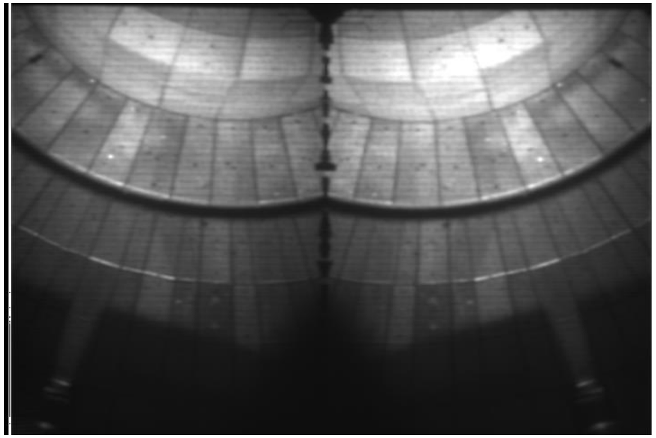
- Two-wavelength imaging with rad-hardened intensified cameras
  - ThermoScientific CIDTEC cameras CID8710, CID 3710
  - VGA resolution (720x480) – 8 bit, 30 Hz interlaced
- TWICE-I
  - Beam splitter for simultaneous 2-color imaging on same detector
  - Four filter wheels (2 for bandpass filters, 2 for neutral density filters)
  - B I, B II, Li I, D-γ, CD, O-II
- TWICE-II
  - 5x higher light throughput, 2 orders of magnitude higher intensifier
  - Fixed filters, currently dedicated to CD/D γ



TWICE-II (Bay I)



TWICE-I (Bay J)



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