U.S. DEPARTMENT OF ENERGY | Office of Science

NSTX-U

Comments on partial row program

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To high-Z or Not to High-Z
PPPL
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Lawrence Livermore National Laboratory

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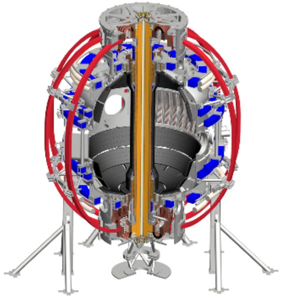

DivSOL TSG is planning extensive experimental program for FY2017-2018 run

- Tier I experiments from FY2015 Research Forum
  - SOL transport and turbulence (SOL width)
  - Radiative divertor
  - Divertor profiles w/ 3D fields
  - Snowflake divertor physics
  - B2Li transition studies

High-δ or low-δ ?
Milestones ?

- Lower divertor / SOL diagnostics readiness (partial list as of 08/2016)
  - IR cameras – took first data in FY2016
  - Divertor Langmuir probes – took first data in FY2016
  - Divertor bolometry – not installed in FY2016 (LADA operational in FY2016)
  - Filtered cameras – all operational in FY2016
  - Lower divertor spectrometers (VIPS, DIMS) – operational in FY2016
  - GPI – passively operational in FY2016 (no gas injector)

DivSOL TSG likely not to be impacted by the absence of high-Z tiles

Disadvantages / advantages of partial row

- Plasma operations
  - Con: no experience with high-Z/graphite tile environment, always some risk
  - Pro: somewhat reduced risk with few high-Z tiles
  - Pro: total gross / net erosion source scaled down
  - Pro: larger operational window? (radial OSP sweeping over few high-Z tiles allowed?)
- Experimental program
  - Con: range of scientific topics severely limited
    - Gross eroson due to low-Z impurities not characteristic of full row / full high-Z divertor
    - Leading-edge melting / erosion not characteristic of full row / full high-Z divertor
    - Studies of lithium on high-Z complicated
    - Small high-Z source for meaningful studies
  - Con: Select torioidal location(s) imply select diagnostics (likely fewer)
  - Pro: High-Z spectroscopy commissioning and new development
  - Pro: Basic studies possible (e.g., erosion gross / net fluxes, yields, leading-edge, "heat pathways")
- Research program
  - Con: certain groups / researchers impacted to a large extent (e.g., LLNL collaboration)
  - Pro: resources may be freed for base DivSOL Program and existing diagnostics

LLNL Collaboration Research Focus Areas support NSTX-U priorities in FY2016-2018 (high-Z related in bold)

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1. Scrape-off Layer and Divertor physics
   - Snowflake divertor transport, turbulence and radiation
   - Radiative (detached) divertor and detachment front control
   - Experiment support for cryo-pump design
2. **Plasma-surface interactions and material migration**
   - Divertor and wall recycling with lithium
   - Divertor and wall material erosion and migration
   - Mixed-material interactions (Li, B, C, O, Mo, W)
3. **Core impurity studies**
   - Low and high-Z impurity transport
   - Laser blow-off impurity injector for impurity transport experiments
   - Impurity spectroscopy and Atomic physics
4. Coaxial helicity injection (CHI) modeling
   - NIMROD modeling of MHD effects on CHI

High-Z erosion and transport studies is one of major elements of LLNL collaboration research

- High-Z spectroscopy ready in FY2016 (summarized in three RSI papers – Scotti, Weller, Soukhanovskii)
  - **Core:** XEUS, LoWEUS, MonaLisa – Mo XIII- Mo XXXII and W XXVIII - W XLIV
  - **Divertor:** divertor SPRED (finish in FY2017) – Mo III-Mo XIV in divertor leg
  - **Divertor PSI:** TWICE-1, TWICE-2, Phantom cameras, DIMS, VIPS – Mo I-Mo III, W I-W III, low-Z near PFC
- Modeling
  - Collaboration with Auburn U. on Mo I-II and W I-II atomic physics (SXBs) for gross and net erosion measurements
  - Mo and W atomic data for STRAHL and MIST core impurity transport

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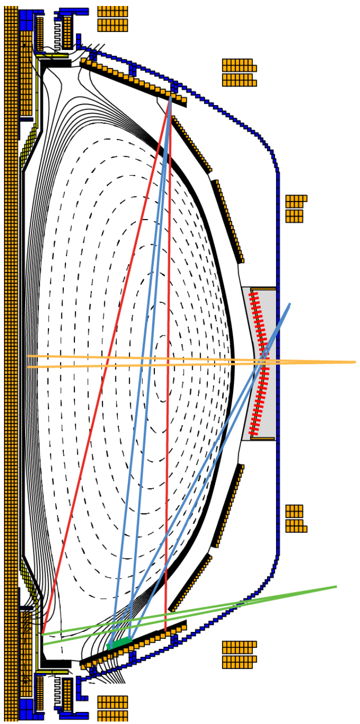


Backup slides

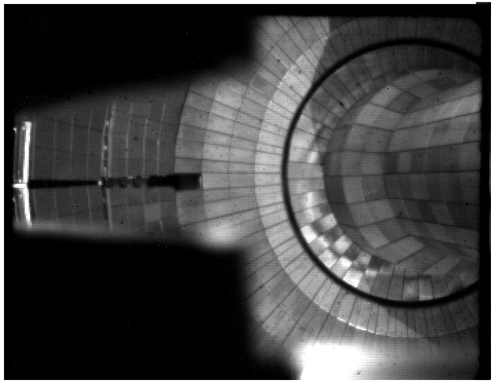
LLNL diagnostics and plans summarized at

http://nstx.pppl.gov/DragNDrop/Program_PAC/Collaborator_research_plans/FY2016_2018_diagnostics/Meeting_1/Soukhanovskii-LLNL-diagnostics-FY16-18.pdf

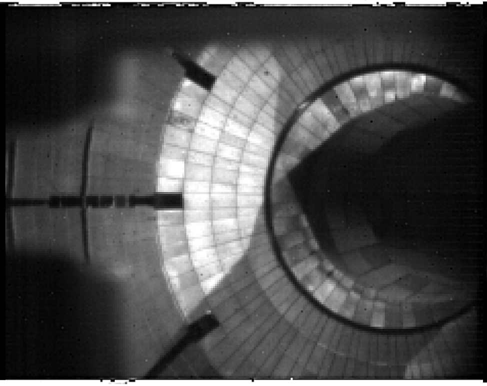
Photometrically-calibrated, fast cameras with wide angle view provide full toroidal divertor imaging

- Described in F. Scotti, RSI 83, 10E532 (2012)
- Cameras Phantom v710, Phantom v7.3, Miro 4
- Spatial resolution better than 1cm/pixel, framing 10-100kHz w/o cropping
- Fast optics 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

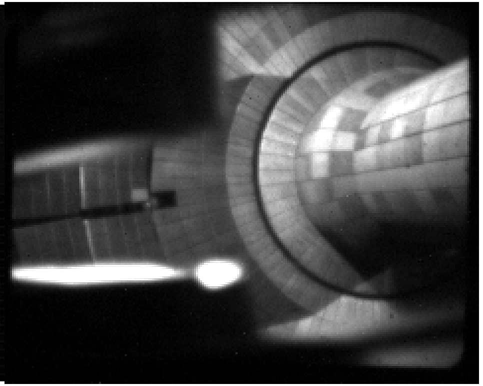
Lower divertor view (Bay E)



Lower divertor view (Bay J)



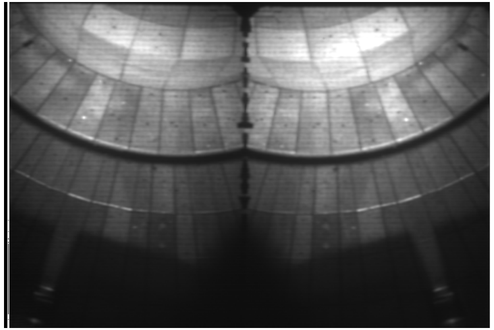
Upper divertor view (Bay H)

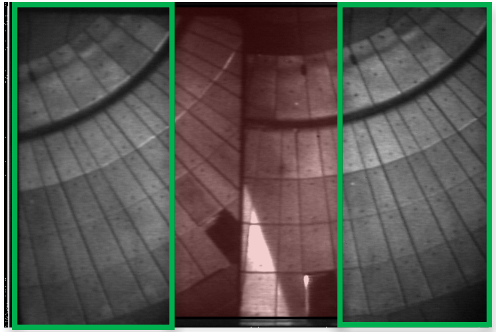


Duo-chromatic intensified camera systems (TWICE-1,2) for mixed material plasma surface interaction studies

- Described in F. Scotti, RSI 86, 123103 (2015);
  - Single filtered cameras described in
    - M. E. Fenstermacher,W. H. Meyer, R. D.Wood, D. G. Nilson, R. Ellis, and N. H. Brooks, Rev. Sci. Instrum. 68, 974 (1997)
    - A. James et.al.,, Plasma Phys. Control. Fusion 55, 125010 (2013)
- Duo-chromatic 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
  - 2.5x higher light throughput, 2 orders of magnitude higher intensifier
  - Fixed filters, currently dedicated to CD/D γ

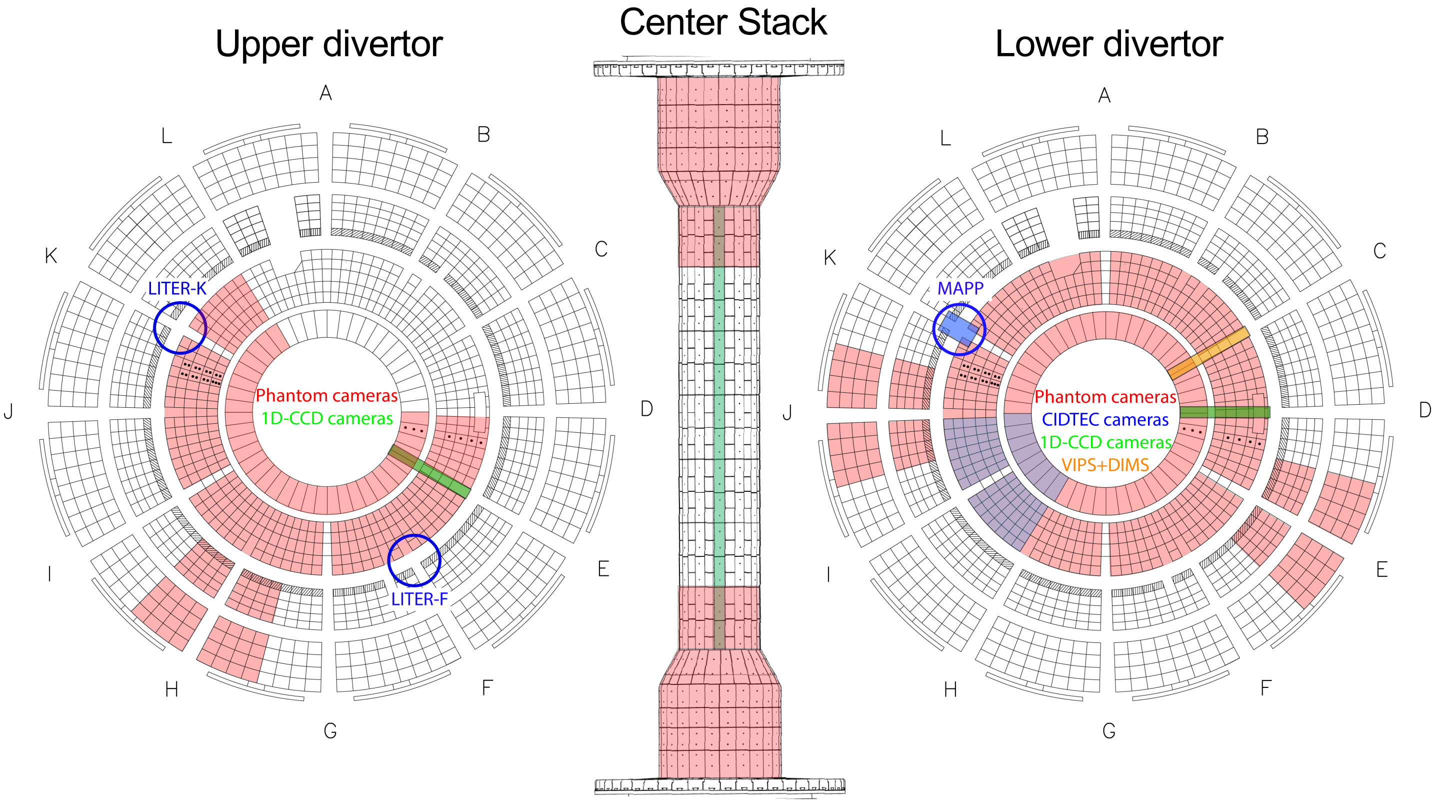
TWICE-I (Bay J)





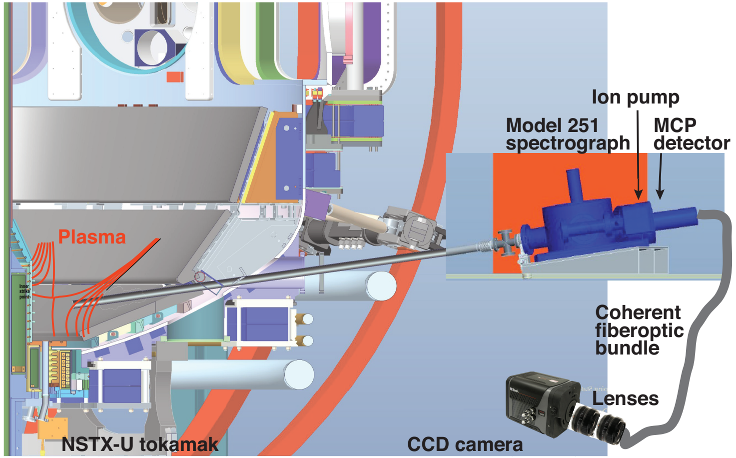
TWICE-II (Bay I)

LLNL diagnostics provide full poloidal and toroidal coverage of SOL and divertor impurity emission at multiple wavelengths



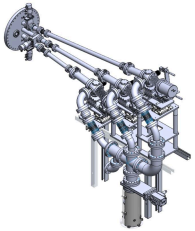
Divertor SPRED spectrometer has broad applications for NSTX-U program

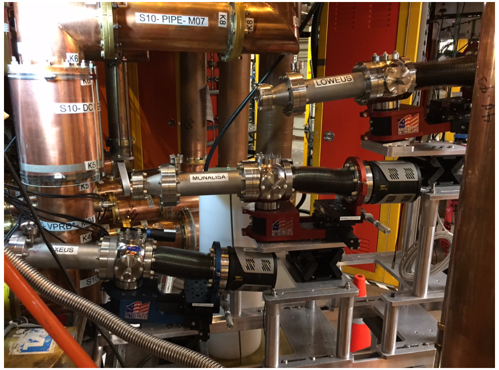
- Support plasma-facing component program
  - Steady-state and transient divertor impurity measurements
    - edge / divertor Mo III-XIV line emission
    - SOL / divertor Li II, Li III, C II, C III, C IV line emission
- Support divertor program
  - Divertor carbon ionization balance (steady-state and during ELMs)
  - Divertor T_e estimates from C II, C III, C IV line ratio (LR) measurements
    - Deviation from Maxwellian EEDF might be detected from these LR's
  - Improved divertor P_{rad} analysis
    - Most P_{rad} is due to several strong C III - C IV emission lines in the VUV
  - Radiative divertor impurity radiation (CD_4, N_2, Ne, Ar)
  - Detached divertor Lyman series for recombination rate, T_e, opacity



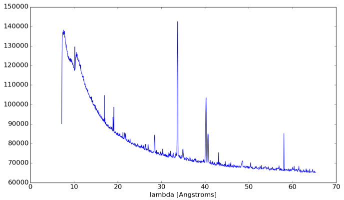
Three EUV spectrometers provide simultaneous measurements of all low Z, medium-Z, and high-Z impurities

- Described in
  - J. K. Lepson, J. Phys. B: At. Mol. Opt. Phys. 43, 144018 (2010)
  - J. Clementson, RSI 81, 10E326 (2010)
  - J. K. Lepson, RSI 83, 10D520 (2012)
  - M. Weller, RSI 2016
- Midplane sightlines
- Two upgraded NSTX spectrometers
  - XEUS, 5 to 60 Å region, 2400 gr/mm grating
  - LoWEUS, 200 to 400 Å region, 1200 l/mm grating
  - Princeton Instruments PIXIS XO 100B CCD detector
- New MonaLisa (Metal Monitor and Lithium Spectrometer Assembly) spectrometer, 60 to 220 Å
  - 0.23 m, 1200 l/mm grating
  - Princeton Instruments PIXIS XO 100B CCD detector



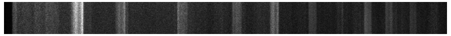


LLNL EUV Spectrometers Mounted on NSTX-U



First Xeus spectrum

First Loweus spectrum



First MonaLisa spectrum