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Diagnostics for lithium age on NSTX

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NSTX is implementing a staged approach to test lithium effects on plasma performance

- **Stage 1 - Lithium pellet injector**
- **Stage 2 - Lithium evaporator**
- **Stage 3 - Lithium divertor module**

- **CDX-U operation with Li and NSTX Li experiments demonstrated a preview of lithium age**

- **In this talk: Lithium age = liquid lithium divertor**

- **Diagnostic needs for lithium age on NSTX**
  - Impact on existing diagnostics
    - Secure existing diagnostics
    - Replace some diagnostics
  - Special diagnostics to study lithium effects

Measurements and their interpretation can be affected by lithium unless special care is taken

- Direct effect on measurements due to **lithium deposition**
  - Degradation of **window** transmission and **mirror** reflectivity
    - Impact on photometrically calibrated diagnostics (MPTS, CHERS, spectroscopic detectors and cameras)
  - Li coatings may be a problem for **exposed diagnostic parts**
    - Examples: flush-mounted Langmuir probes, SXR array foil filters, exposed detectors
  - **Change in measured parameter range** due to Li pumping
    - Examples: neutral pressure, density, recycling

- Effect due to wrong measurement **interpretation**
  - **Reflections** from liquid lithium surface or Li-coated surfaces complicate interpretation of some measurements
    - Examples: IR camera measures IR emissivity of carbon tile surface, filtered cameras measure edge emission

- **This list is not complete -** other effects on diagnostics, on plasma operations ?

Lithium pellet injector and lithium evaporator experiments demonstrated the benefit of addressing diagnostic issues in a timely manner

- **Just a few examples…**

- **Fast optical observations of Li and C pellets**
  - Purchased Li I and Li II filters for fast cameras to observe pellet propagation
  - Instrumented fast (~ 10 kHz) filtered visible detectors (EIES) with views of pellet trajectory

- **Spectroscopic measurements of recycling, lithium deposition and impurities**
  - Instrumented filtered (D_{α}, C II, CIII, Li I) cameras viewing divertors and CS
  - Testing Ly-alpha arrays (in collaboration with LTX)
  - XEUS impurity spectrometer

Particle and density control using lithium will be one of the main research thrusts on NSTX

- **Running NSTX with a liquid lithium divertor module means a new edge characterization**

- **From a Boundary Physics prospective:**
  - **Characterize particle balance, fueling and pumping**
    - Particle flux measurements - neutral and impurity sources and sinks
    - Particle balance using integrated edge and core modeling (e.g. DEGAS 2, UEDGE + TRANSP)

  - **Characterize impact on transport regimes**
    - Impurity and neutral profiles
    - Ion temperature and rotation profiles

  - **Characterize divertor performance**
    - Divertor heat flux handling
    - Divertor pumping, neutral pressures
    - MARFE formation
    - Role of molecular fluxes in fueling (D_2, hydrocarbons, dimers)

Success of LLD operation will depend in part on diagnostic measurements

- **Initial plan may include:**
  - Identify impact of LLD operation on
    1) NSTX diagnostics
    2) facility and plasma operations
  - Develop plan for required measurements and diagnostics to accomplish LLD mission and LLD-related milestones
    – Depends on LLD location
    – Need for vacuum vessel modification?
    – Depends on LLD goals, milestones,
    – …
  - CDX-U and LTX experience is valuable
- **Are NSTX diagnostic preparations a budgeted item ?**

Diagnostic	Impacted by LLD?
Bolometer – tangential array	
Bolometer – divertor	
CHERS – toroidal	?
CHERS – poloidal	?
Divertor fast camera	X
Dust detector	?
EBW radiometers	
Edge deposition monitors	
Edge pressure gauges	?
Edge rotation diagnostic	?
Fast ion D_alpha - FIDA	?
Fast lost ion probes - IFLIP	
Fast lost ion probes - SFLIP	
Filterscopes	X
FIReTIP	
Gas puff imaging	X
Hα camera - 1D	
High-k scattering	
Infrared cameras	X
Interferometer - 1 mm	
Langmuir probes - divertor	X
Langmuir probes – RF antenna	X
Magnetics – Diamagnetism	
Magnetics - Flux loops	
Magnetics - Locked modes	
Magnetics - Pickup coils	
Magnetics - Rogowski coils	
Magnetics - RWM sensors	
Mirnov coils – high frequency	
Mirnov coils – poloidal array	
Mirnov coils – toroidal array	
MSE	?
NPA – ExB scanning	
NPA – solid state	
Neutron measurements	
Plasma TV	X
Reciprocating probe	?
Reflectometer – 65GHz	
Reflectometer – correlation	
Reflectometer – FM/CW	
Reflectometer – fixed f	
Reflectometer – SOL	
RF edge probes	
Spectrometer – SPRED	
Spectrometer – VIPS	X
SWIFT – 2D flow	
Thomson scattering	X
Ultrasoft X-ray arrays	?
Ultrasoft X-ray arrays – bicolor	?
Ultrasoft X-rays – TG spectr.	
Visible bremsstrahlung det.	X
X-ray crystal spectrometer - H	
X-ray crystal spectrometer - V	
X-ray fast pinhole camera	

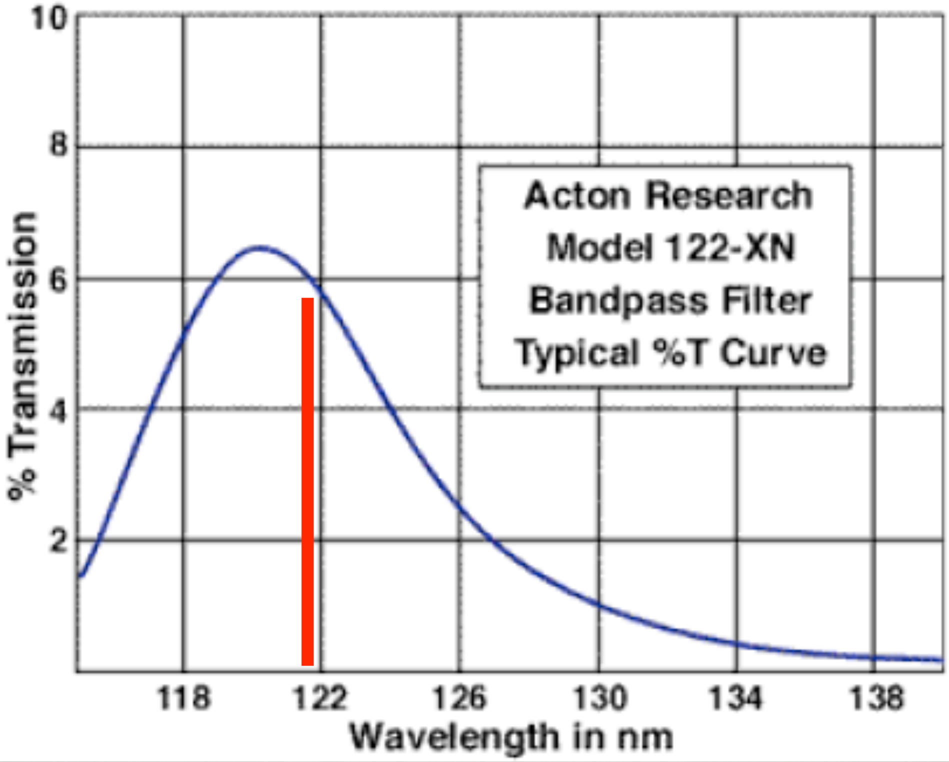
Diagnostic ideas for measurements important in Lithium age on NSTX (+ BP, T&T, ...)

- **Divertor particle flux (recycling) measurements in lithium environment** - Ly-alpha arrays
- **Divertor particle (atomic and molecular) fluxes, ion temperature, electron temperature and density** - imaging UV-VIS divertor spectrometer
- **Divertor heat flux measurements** - thermocouples, divertor tile fiber-based IR thermography, in-situ calibration techniques for IR cameras
- **Divertor physics** - multi-point divertor Thomson scattering system
- **Particle transport, confinement** - main plasma lithium density profile - soft X-ray arrays
- **Particle transport, confinement, fueling** - main plasma & pedestal neutral profile - laser-induced photoionization diagnostic

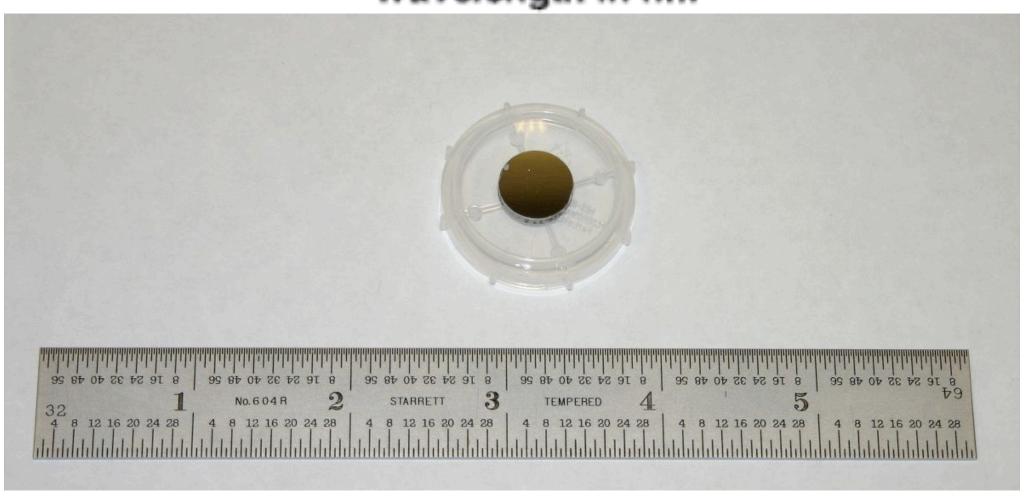
VUV measurements will be emphasized in lithium plasma environment

- Recycling is usually measured spectroscopically using atomic H (D) line emission
- Since recycling is localized to the surface plasma layer, line integrated measurements are usually not contaminated by main plasma emission
- However, **if the surface is reflecting, spectroscopic measurements in the visible range are hard to interpret**
- AXUV arrays developed by JHU Plasma Spectroscopy Group in collaboration with PPPL for CDX-U and NSTX spherical tori
  - CDX-U: RSI 72 (2001) 737; PPCF 44 (2002) 2339; RSI 72 (2001) 915
  - NSTX: RSI 70 (1999) 572
- **Filtered AXUV diodes can be used for recycling and lithium density measurements in the VUV range**

ARC (Acton Research Corp.) bandpass filter enables VUV Ly$_\alpha$ emission filtering



- Open-faced multilayer transmission filter mounted on MgF_2 substrate
- Bandpass is narrow enough to transmit only Ly$_\alpha$ light
- Practically no impurity (Li, C, O) emission lines within bandpass (e.g. Boivin et. al. RSI 72 (2001) 961



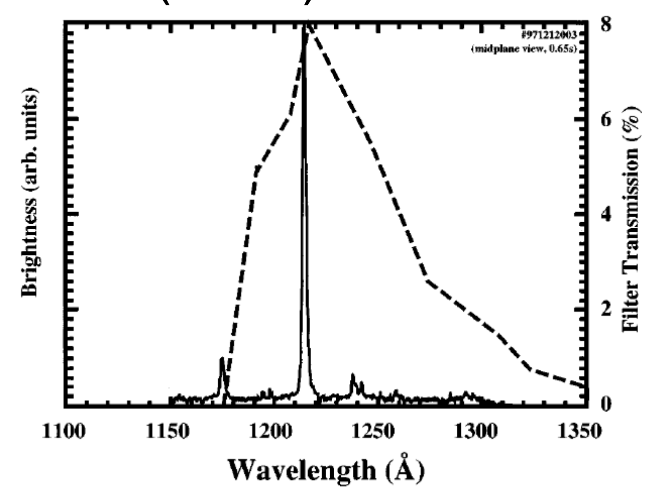
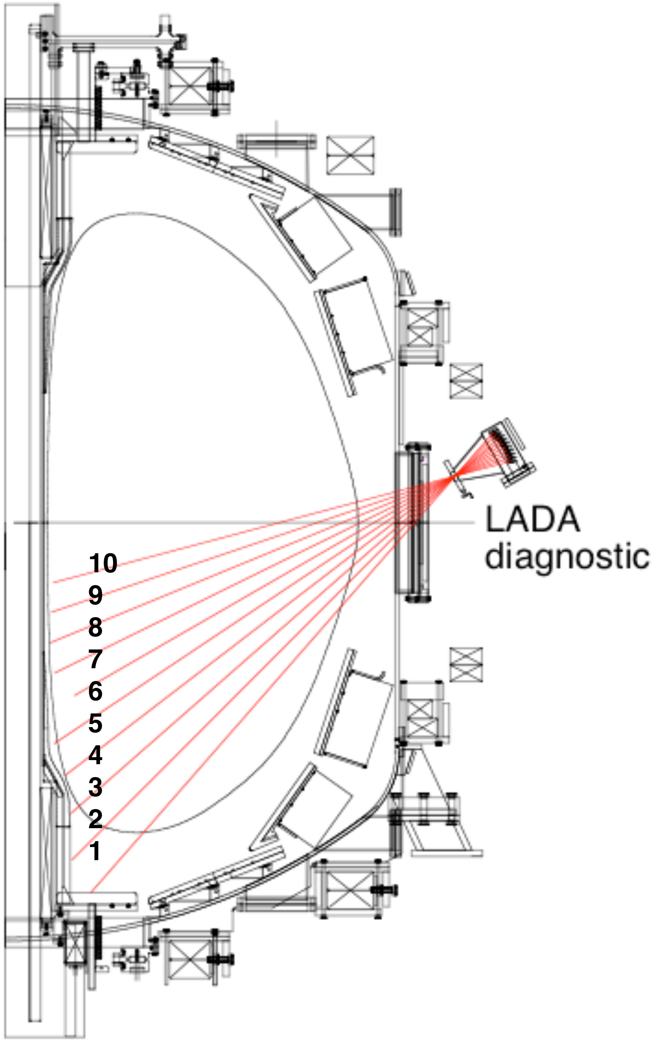


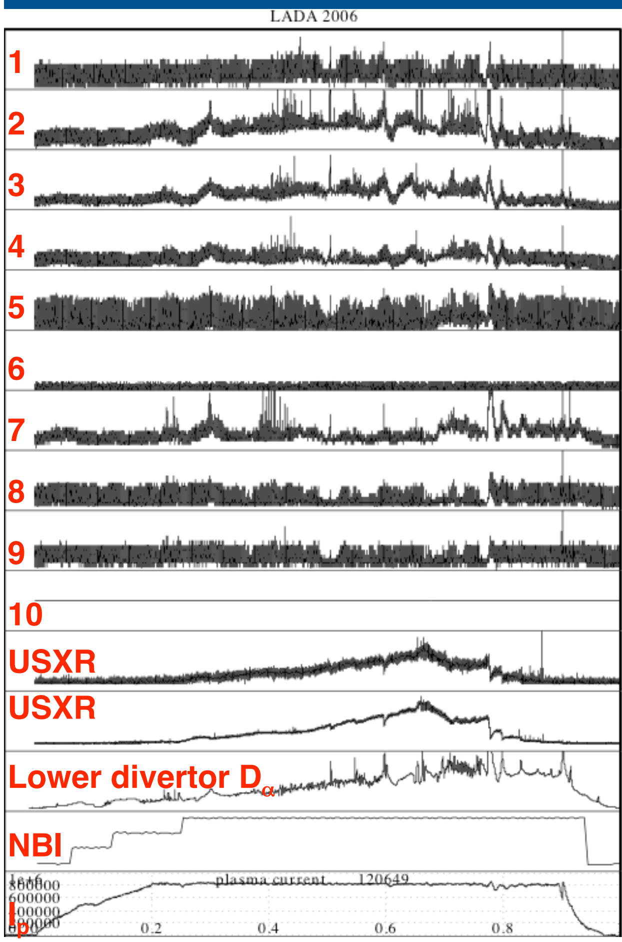
FIG. 3. Measured plasma emission in the UV region using a McPherson (VUV) spectrometer. Overlaid is the measured filter response.

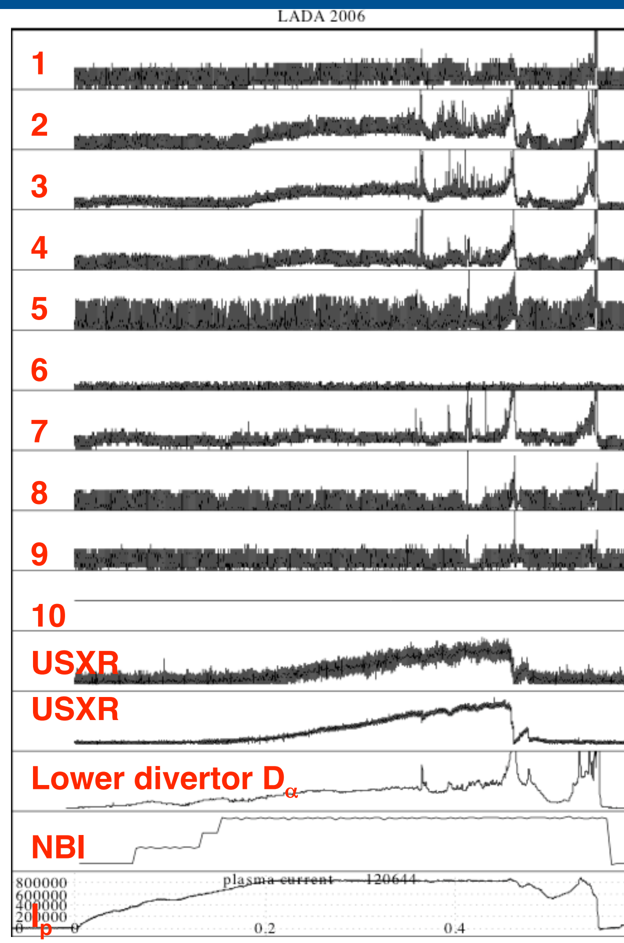
LADA diagnostic on NSTX monitoring recycling from lower inner wall and inner divertor regions

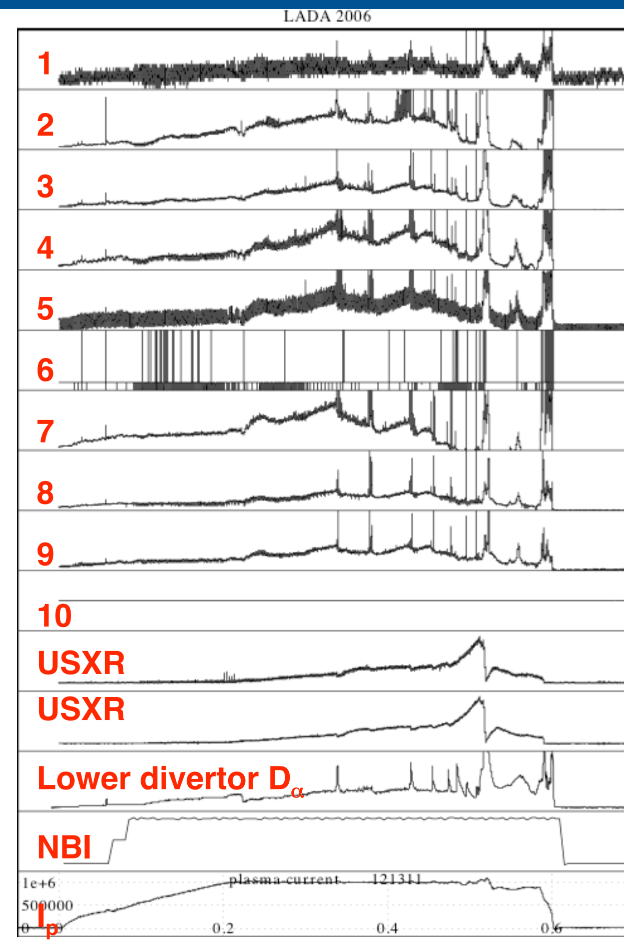


- **On-going collaboration with CDX-U / LTX**
- Installed on Bay J midplane port in mid-May 2006
- Operated for about one month in FY 2006 and throughout FY 2007 run
- Used ten channel PC-based DAQ system provided by JHU
- Channel 1 was vignetted by in-vessel hardware
- Otherwise collecting good data (examples on next page)

LADA diagnostic on NSTX operates in Ly$_\alpha$ and radiometer mode







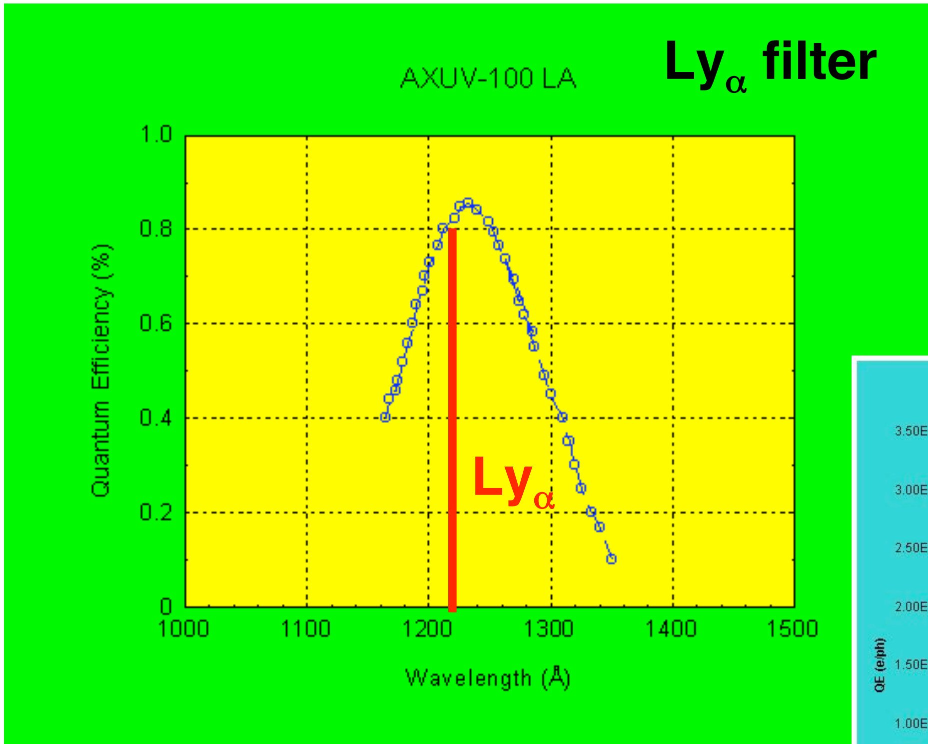
Ly$_\alpha$ filter mode

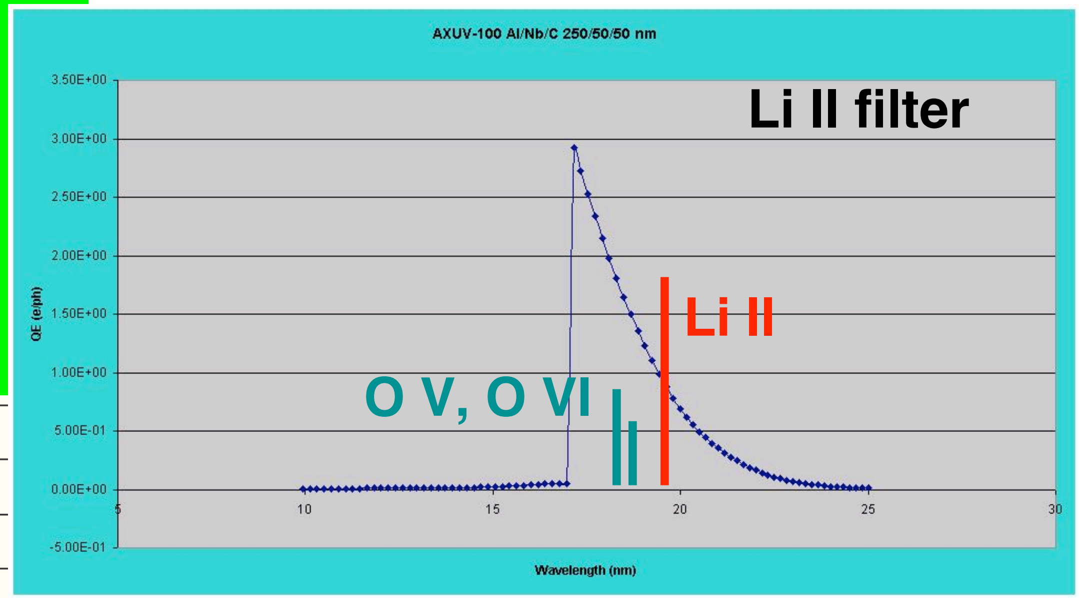
Ly$_\alpha$ filter mode

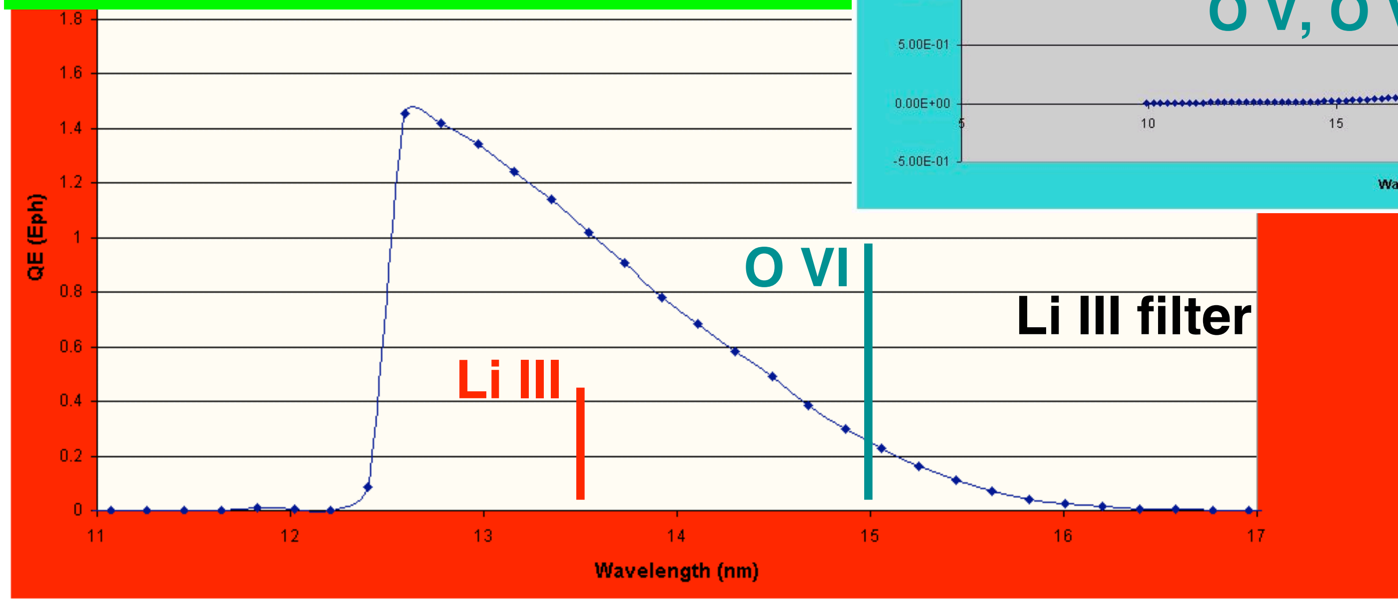
Radiometer mode (no filter)

Options for Ly$_\alpha$ and Li II, Li III AXUV diode arrays

Shown are transmission curves of foil filters optionally deposited on AXUV diode by IRD







Figures courtesy of IRD Inc.

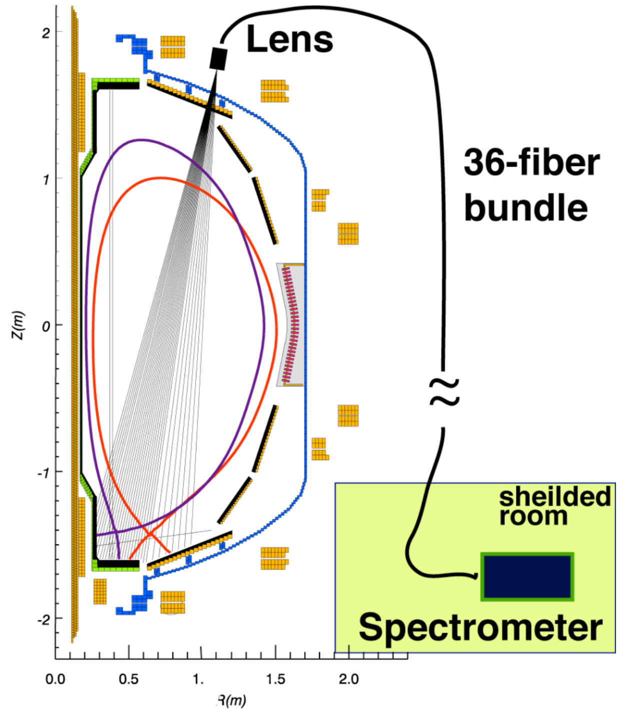
Imaging spectroscopy of divertor region for particle flux / divertor plasma measurements

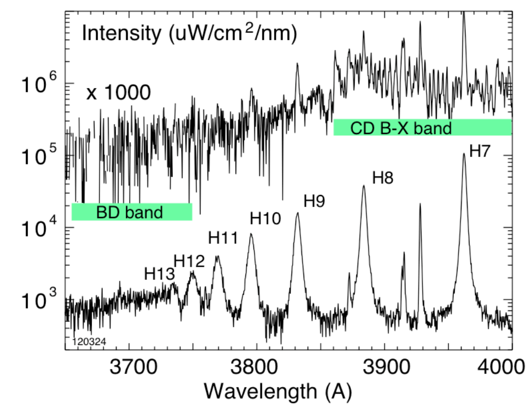
- **Imaging spectroscopy of divertor plasma - T_i, n_e, T_e, v, Γ_i**
  - Line and continuum profiles
  - Spectral line Doppler broadening for T_i profiles
  - Spectral line Doppler shift measurements for flow velocities
  - Balmer or Paschen series line broadening for n_e profiles, line intensities *for* T_e profiles in recombining divertor
  - Particle influx profiles - molecular, neutral, impurity ions

- **Fiber-optic array is already installed on NSTX**

- **Spectral analysis has been already developed** (Soukhanovskii et. al., RSI 77, 10F127 (2006))

- **Prototype of ITER divertor monitor**



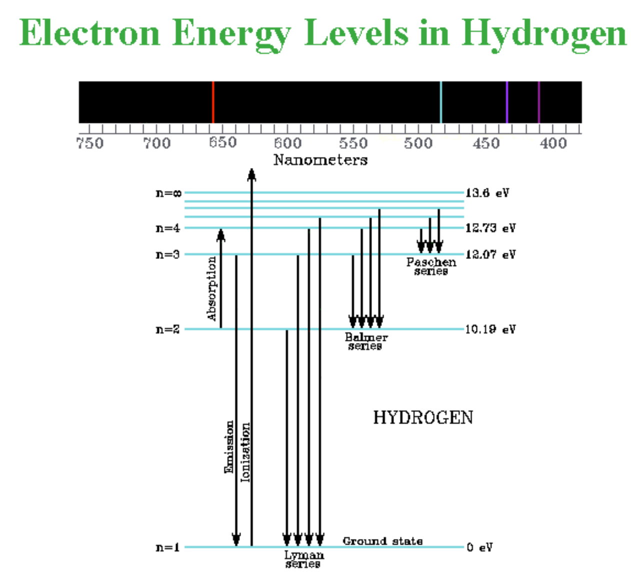


Presently based on 3-channel VIPS spectrometer measurements

Neutral density profile measurements for fueling, particle balance, NBI loss studies

Laser-induced ionization (LII) diagnostic for 1D core, pedestal and edge neutral profiles

- Developed at Ioffe Institute in the 90-s (Nuclear Fusion 35, 1385 (1995)
- Feasibility study for NSTX by Dr. S. Tolstyakov in 2001
- Based on optical measurements of neutral deuterium atom upper level populations using laser photoionization
- May be possible to use present MPTS laser, same APD detectors and electronics



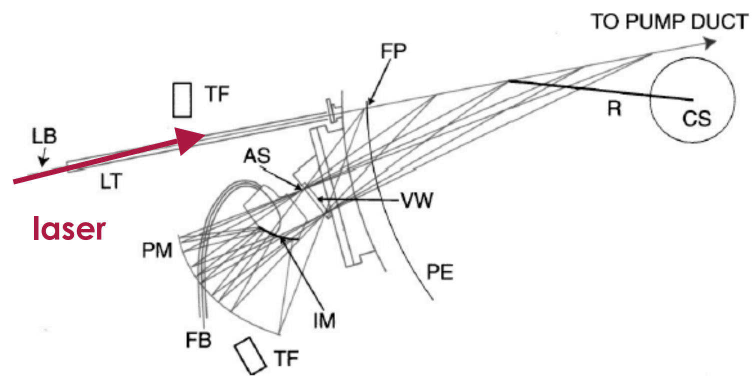


FIG. 2. Spherical mirror PM images laser path onto surface IM, where fiber bundle (FB) collects light. Only one out of 36 bundles is shown. Aperture stop (AS) is located next to the vacuum window (VW). Optics sees main plasma and scrape-off layer.

LeBlanc RSI 74, 1659 (2003)

Divertor heat flux measurements *not* based on direct detection of IR tile surface emissivity

Candidate heat flux measurements for lithium age on NSTX

- Thermocouples
- Tile-embeded fiber-based IR thermography
- For improved spatial resolution may require a new row of 1/4- 1/2 length tiles
- Thermocouples and/or fibers + cavities will be embedded in these short tiles
- Time resolution not as good as IR cameras