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Recycling measurements using hydrogen (deuterium) Lyman Alpha line and AXUV diodes

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Acknowledgements:

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LTX Meeting
Princeton, NJ
15 August 2006

Recycling measurements background

- Recycling is the dominant (*) source of fueling in present day plasma fusion devices (* with some exceptions)

- Recycling is usually measured spectroscopically using atomic H (D) line emission

- Simple measurements - can be done with
  - spectrometers
  - detectors with narrow bandpass interference filters

- 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, measurements are hard to interpret**

Spectroscopic background

- Balmer alpha line H_α (D_α) (3-2) is most commonly used
  - λ=656.3 nm (656.1 nm) - it's in the visible range
  - …where many optical detectors (CCDs, PMTs, silicon diodes, APDs, …) have high efficiency
  - However, PFC surface reflections are a problem (very high!)

- Balmer beta line H_β (D_β) (4-2) is a good choice
  - λ=486.1 nm (486.0 nm) - it's also in the visible range
  - …where many optical detectors have *fairly high* efficiency
  - but: about x10 less intensity than H_α (D_α) intensity
  - and PFC reflections are still (but less of) a problem

- Higher level transitions (5-2, 4-3) are weak but can be considered

- Lyman alpha line Ly_α $(2\text{–}1)$ is also a good choice
  - λ=121.6 nm - in the Vacuum Ultraviolet (VUV) wavelength region
  - very bright - resonant transition!
  - but: need special VUV detectors , filters and windows
  - normal reflections are weak from common PFC materials (graphite, CFC, blackened SS, etc)

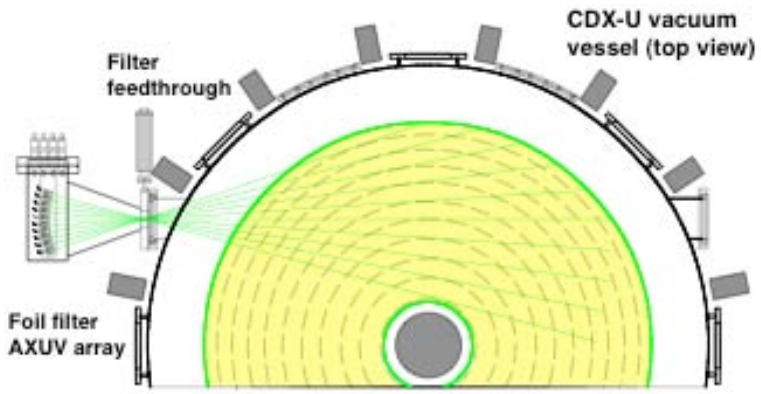
AXUV diode array diagnostic on CDX-U

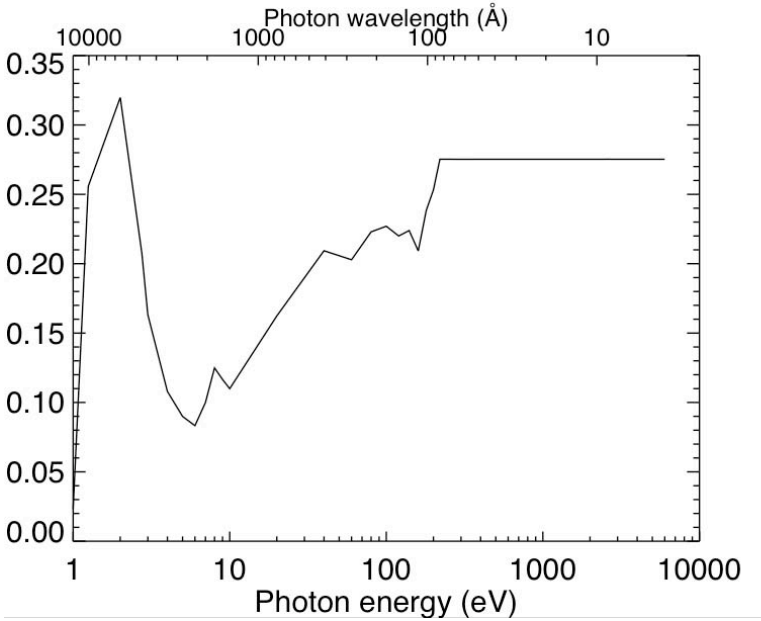
- AXUV diode is an ***absolute*** radiometric reference if properly used. Manufactured by International Radiation Detectors http://www.ird-inc.com/

- 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

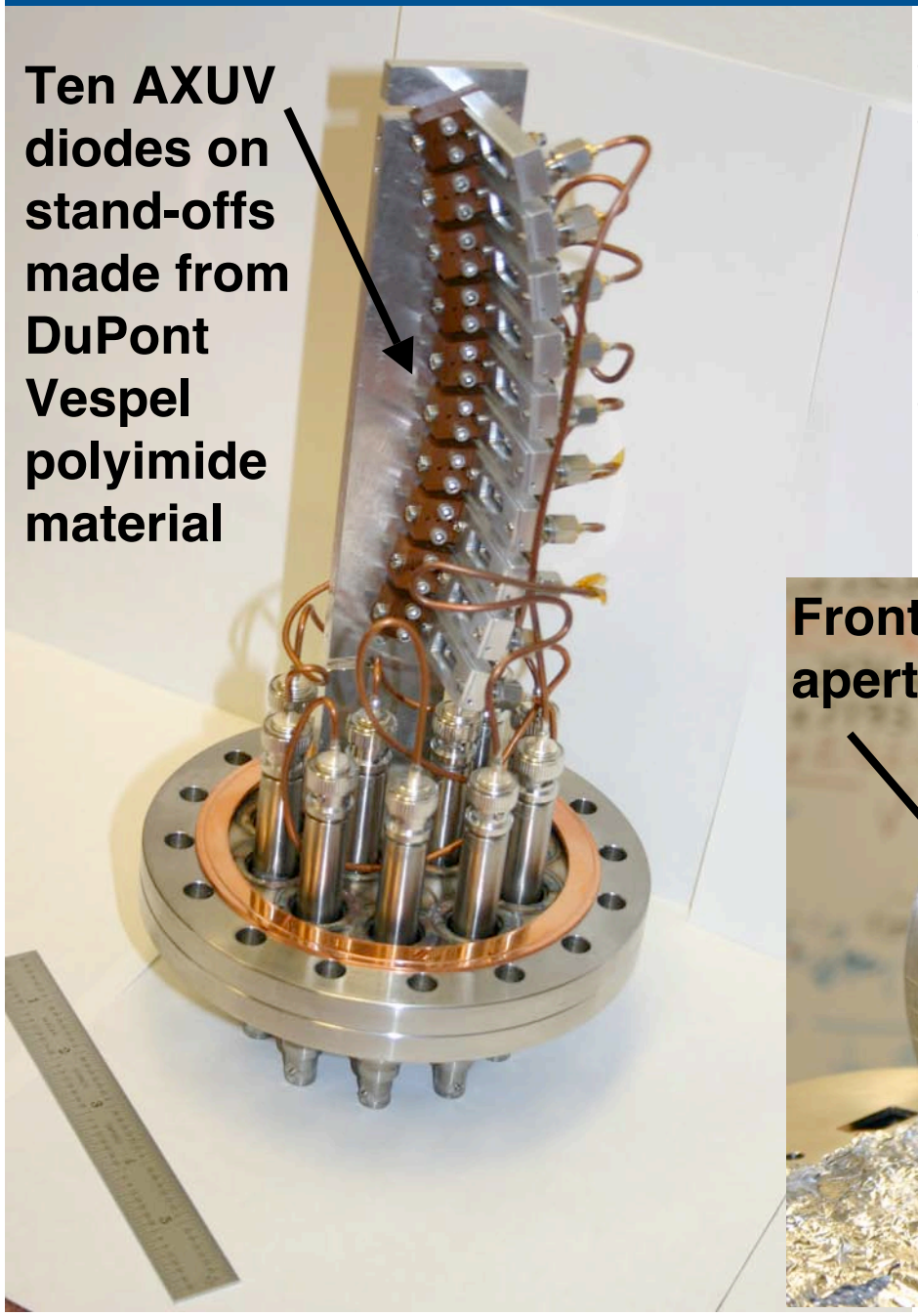
- AXUV radiometer array operated on CDX-U from 1999 to 2006
  - Used for radiated power measurements
  - Used for plasma position and equilibrium estimates
  - Used for midplane impurity profile measurements in 1999-2000 with NSTX amplifiers and Ti / Be filters

- Many other plasma devices have built and used AXUV diode arrays (Alcator C-Mod, DIII-D, TCV, CHS, T-10, T-11M, LHD - ask me for the references)

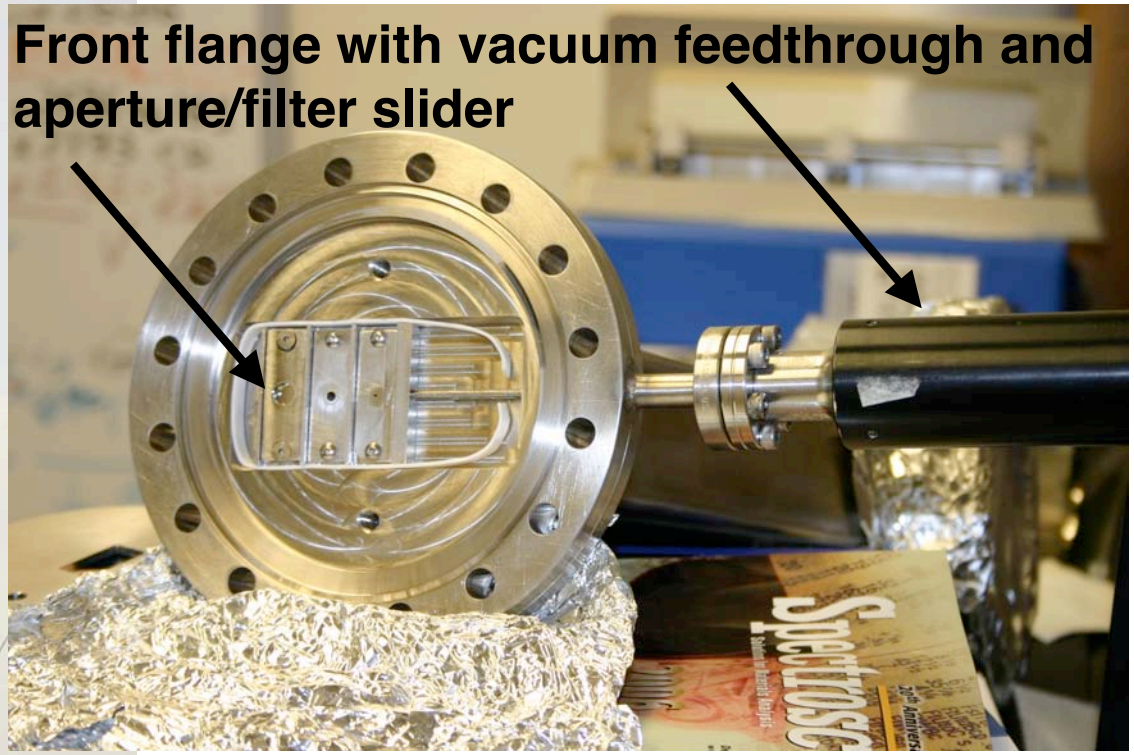




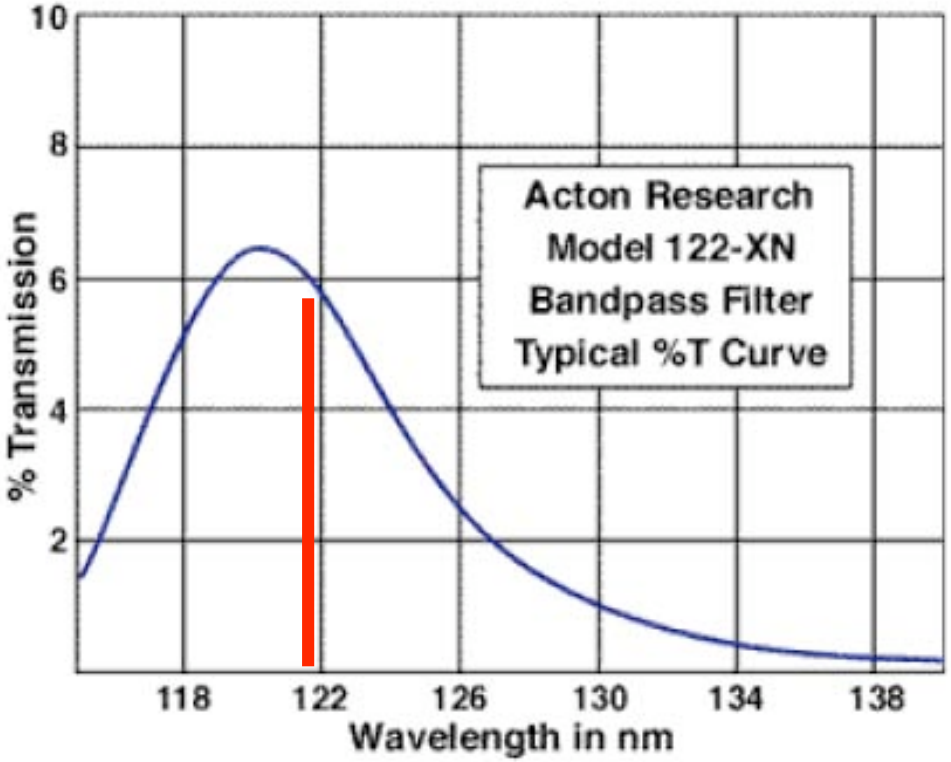
LADA diagnostic used on NSTX in 2006

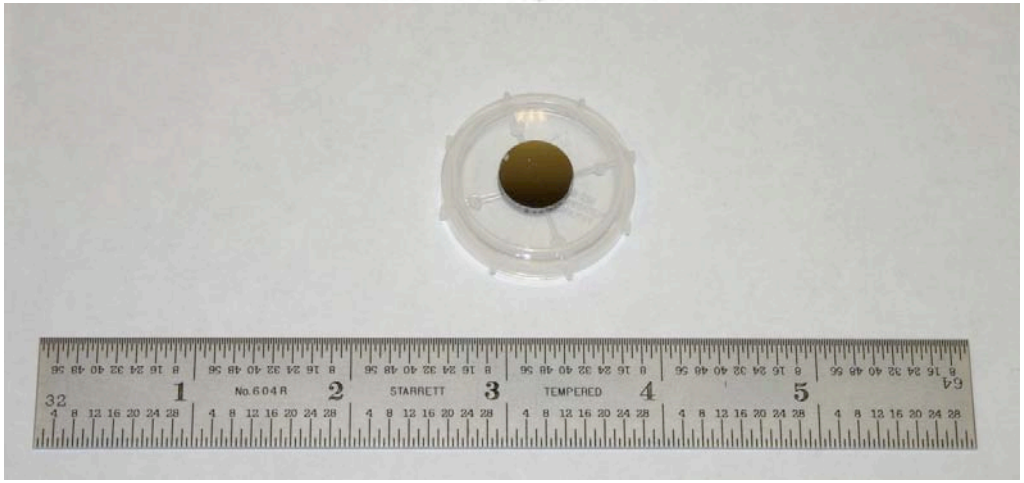


- LADA means Lyman Alpha Diode Array
- Upgraded CDX-U AXUV array to all UHV-compatible materials
- Replaced pinhole apertures
- Mounted ARC Ly_α 1/2" diameter filter purchased by LLNL
- Three apertures: one small and one large for radiometry, Ly_α filter for recycling measurements



ARC (Acton Research Corp.) bandpass filter enables VUV Ly_α emission filtering





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

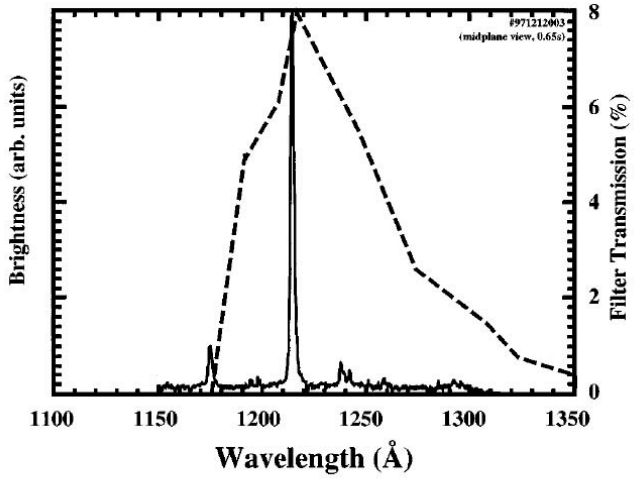
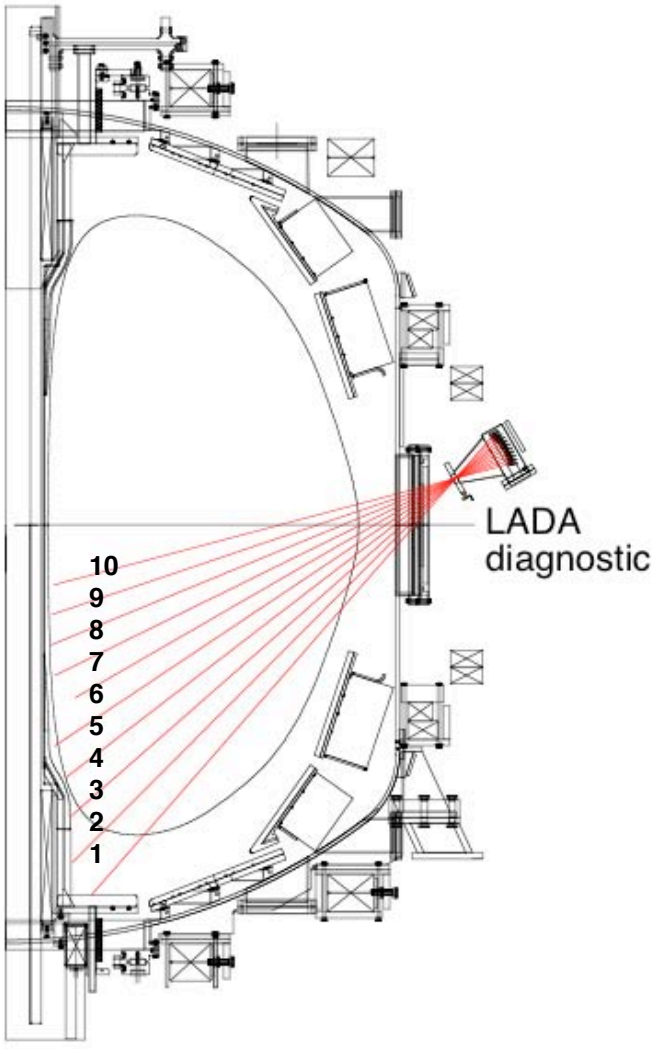


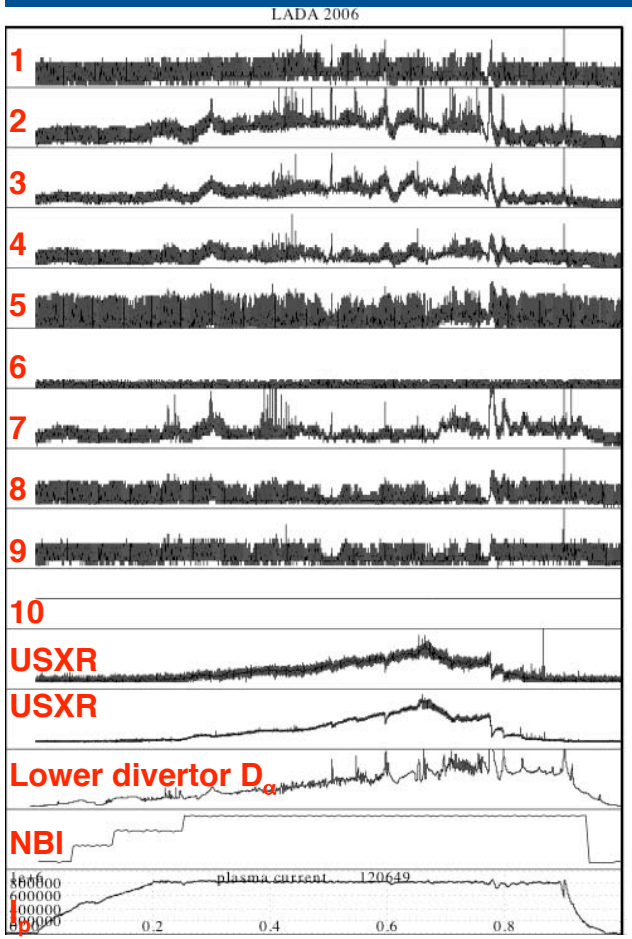
FIG. 3. Measured plasma emission in the UV region using a McPherson (VUV) spectrometer. Overlaid is the measured filter response.

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

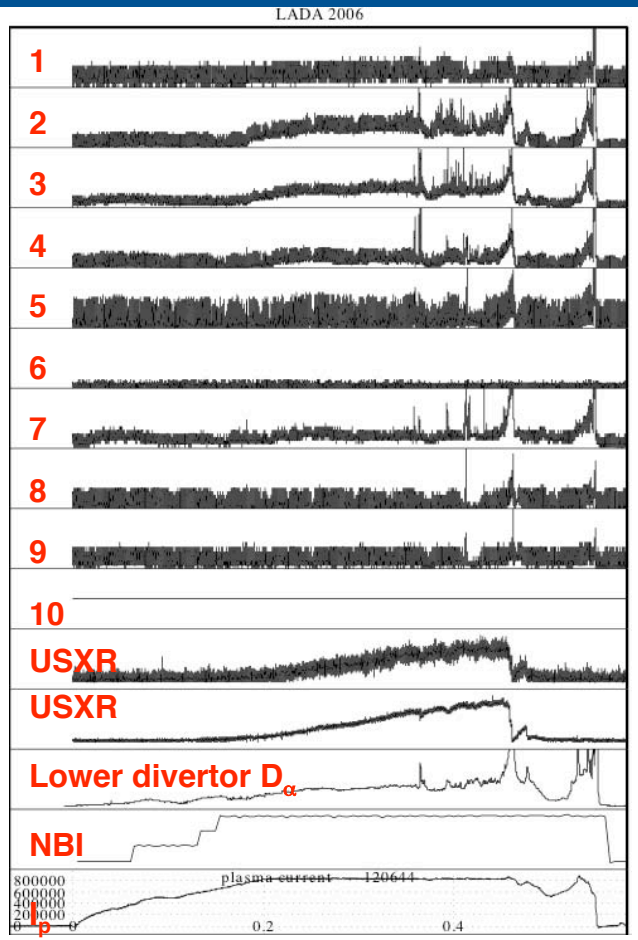


- Installed on Bay J midplane port in mid-May 2006
- Operated for about one month
- Used ten CAMAC differential amplifiers provided by CDX-U
- Used ten channel PC-based DAQ system provided by JHU
- Channel 1 was vigneted by in-vessel hardware
- Otherwise collected good data (examples on next page)

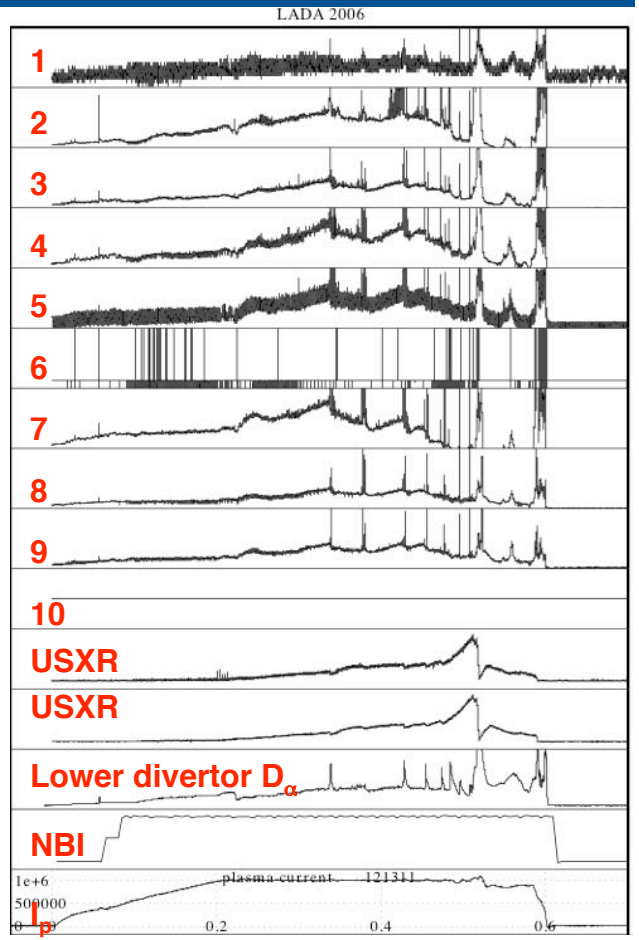
LADA diagnostic on NSTX operated in Ly_α and radiometer mode



Ly_α filter mode



Ly_α filter mode



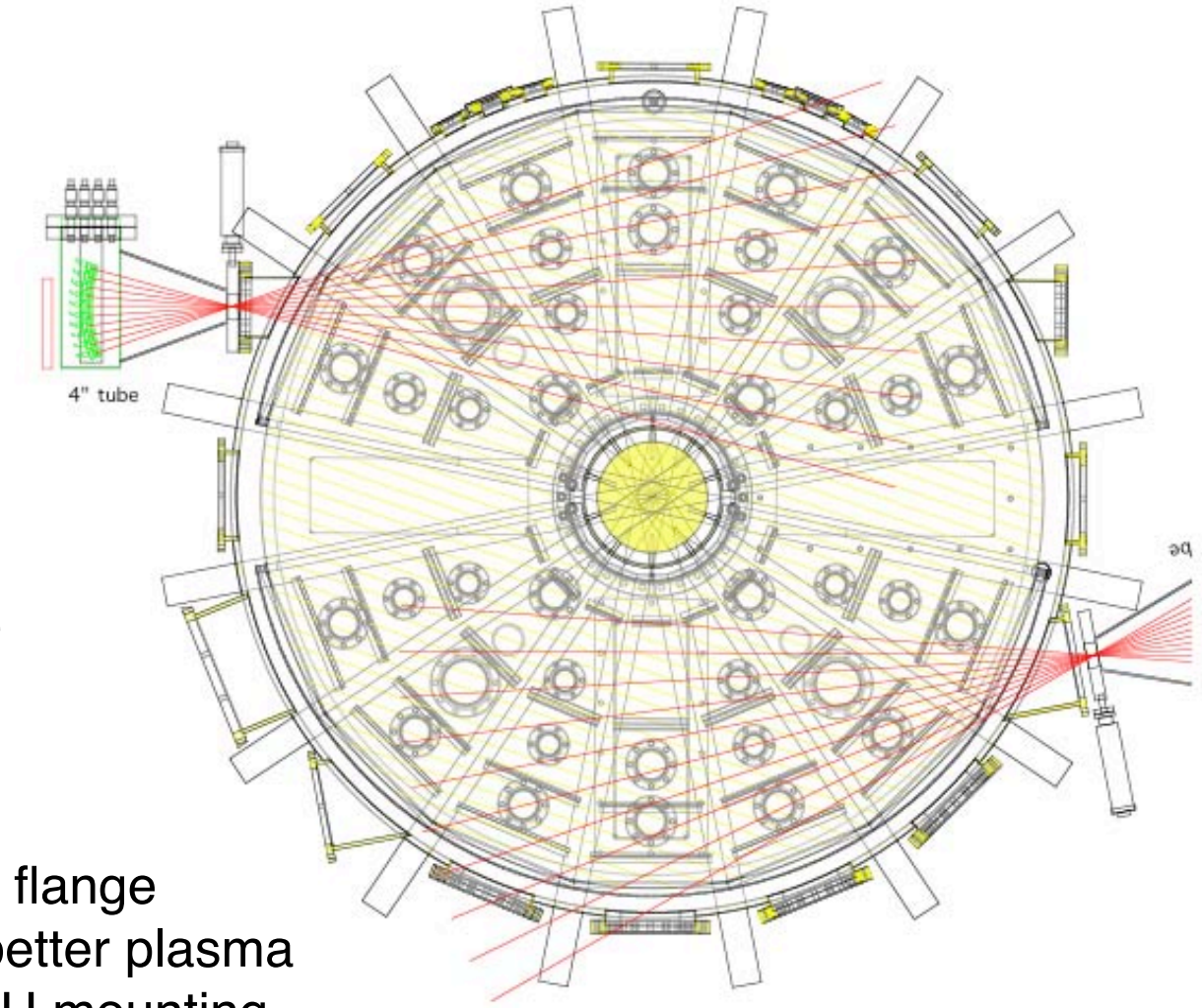
Radiometer mode (no filter)

LARDA diagnostic for LTX

- LARDA now means Lyman Alpha and *Radiometer* Diode Array

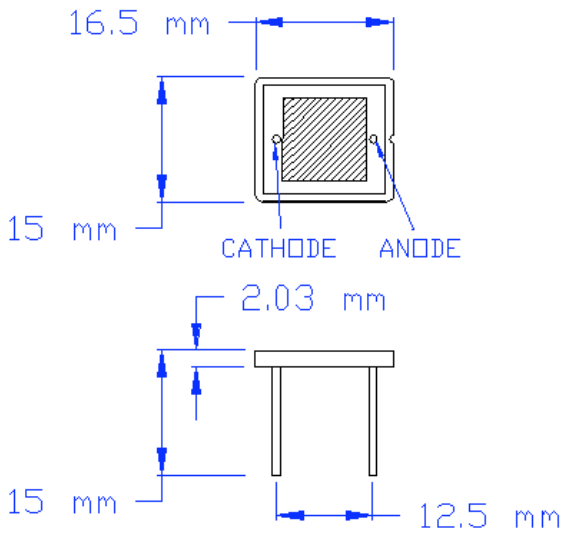
- Three positions in the filter slider: one for radiometer aperture, one for 1/2" Ly_α filter, one vacant (can use for other filter or different size radiometer aperture)

- The horizontal rectangular flange mounting provides much better plasma coverage in LTX (vs CDX-U mounting on 4" midplane flange)



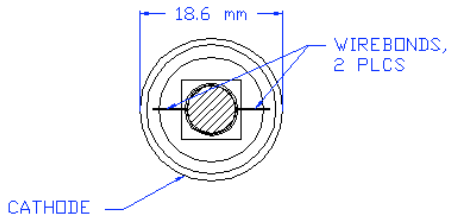
Options for single AXUV diode channel

- AXUV diodes come in various packaging:
  - No package - need to design own mount
  - BNC package - can be conveniently mounted in-vacuum on a BNC feedthrough

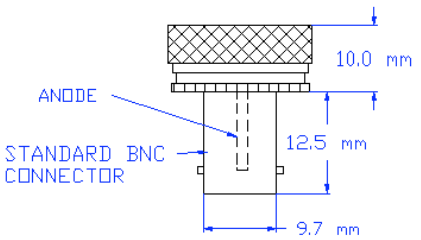


- AXUV diodes can be coated with multilayer transmission filters by IRD (see next page):
  - Ly_α filter available
  - Li III filter for λ = 13.5 nm
  - Li II filter for λ =19.9 nm

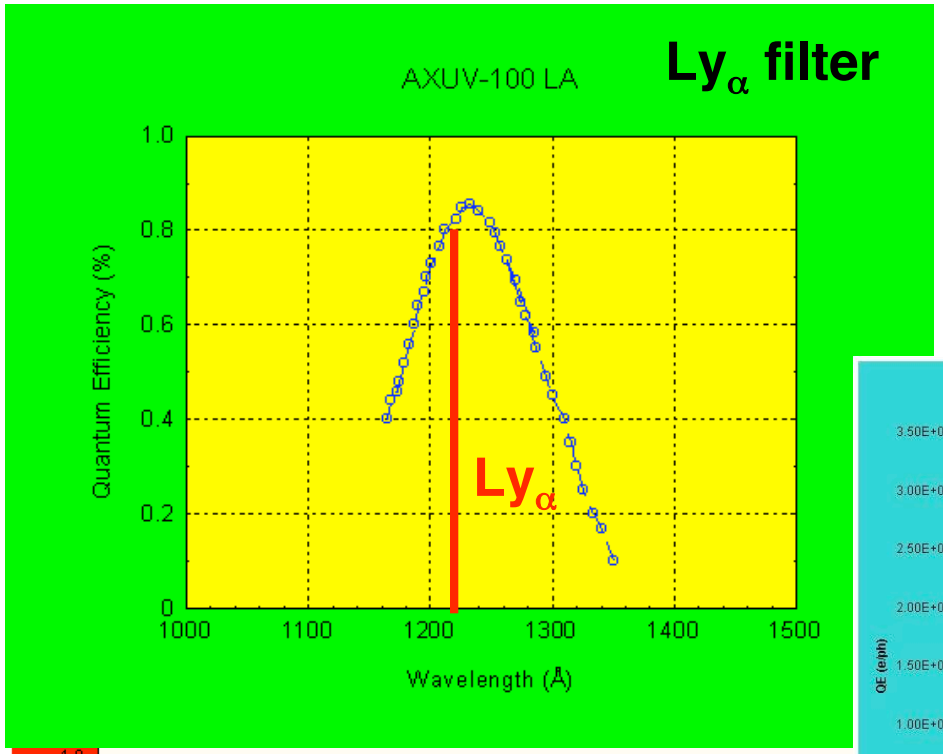
- Another option is to go with ARC transmission filter as on NSTX LADA for Ly_α measurements



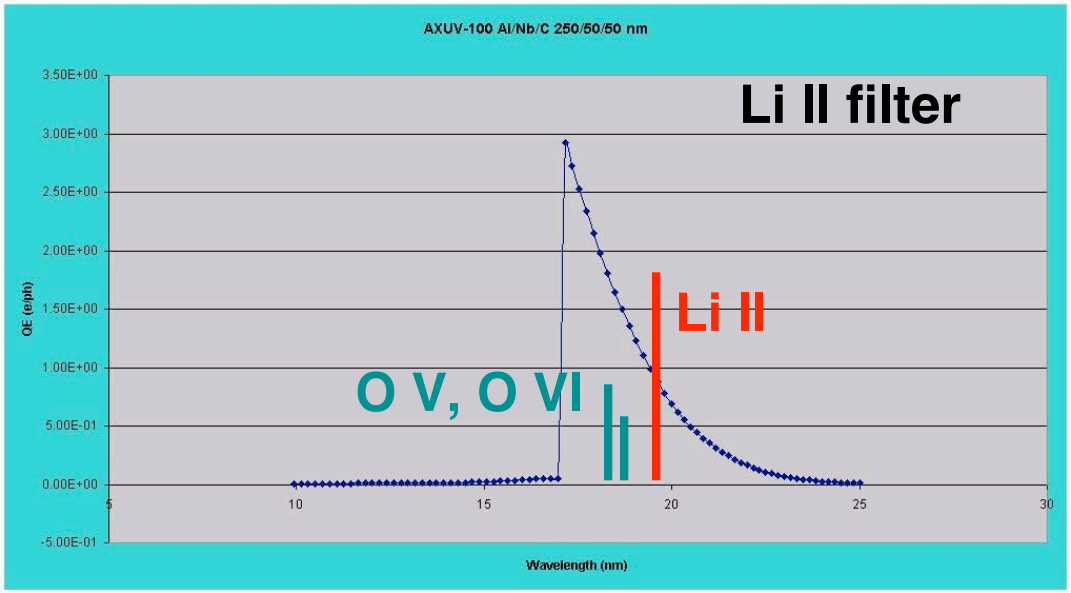
- IRD also sells trans-impedance variable gain amplifiers for AXUV diodes

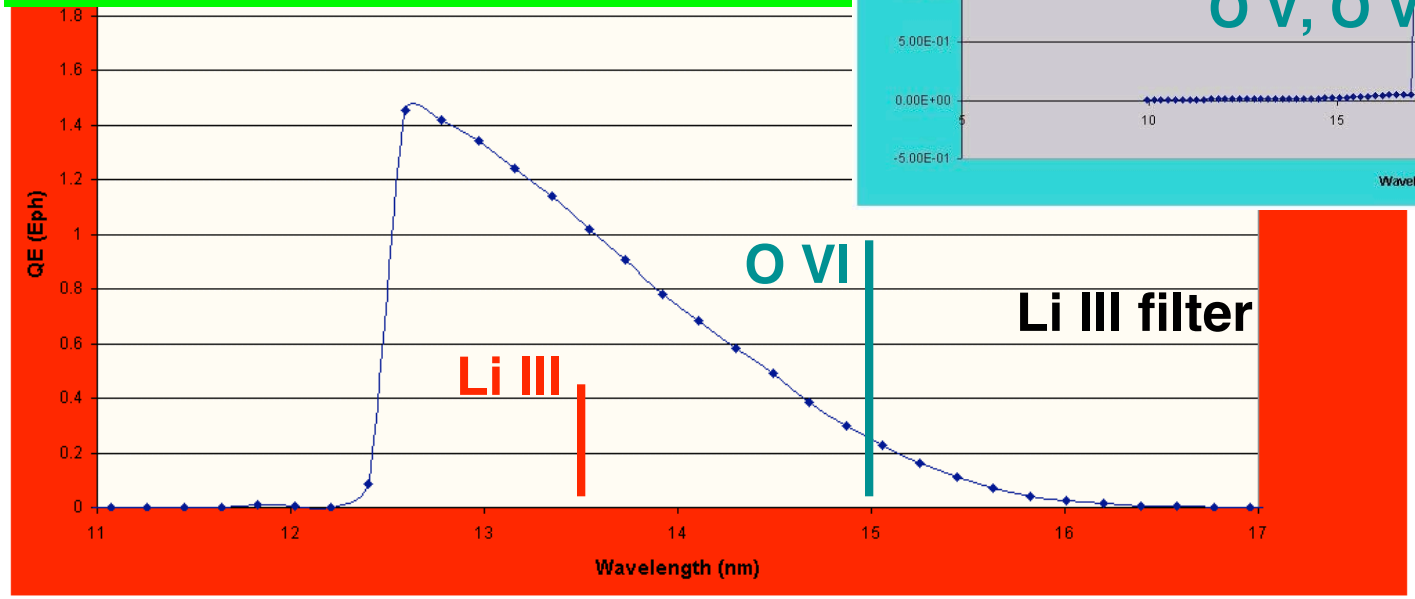


Options for LTX single AXUV diode channel



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





Figures courtesy of IRD Inc.

Summary

- LADA diagnostic worked well on NSTX in 2006
- In radiometric mode collected good data on ELM propagation along inner wall
- In filtered Ly_{α} mode the LADA diagnostic could only detect very bright emission from the inner detached divertor leg region (aperture was too small)
- LADA array is a good candidate for recycling measurements on LTX providing
  - Aperture sizes and mounting geometry properly arranged
  - We understand VUV light reflection from lithium-coated metal surfaces
- Useful links
  - International Radiation Detectors: www.ird-inc.com
  - Acton Research Corporation: www.acton-research.com