U.S. DEPARTMENT OF ENERGY | Office of Science

NSTX-U

Spectroscopic diagnostics for upper divertor and central stack on NSTX-U

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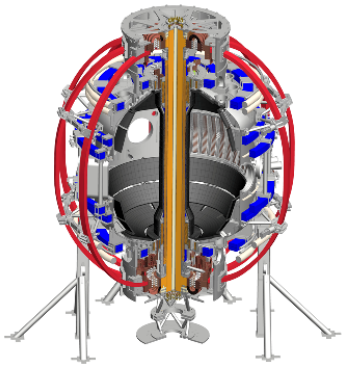
THE UNIVERSITY OF TENNESSEE KNOXVILLE

PPPL



Abstract

NSTX has demonstrated a number of discharge characteristics that improved with increasing lithium coatings, all with nominal thickness >> ion implantation depth. The asymmetries in the lithium coating and erosion and re-deposition of lithium in other regions possibly explain this phenomenon. In order to investigate the role of these mechanisms, new high resolution UV-VIS-NIR spectroscopic diagnostics are to be installed in NSTX-U to monitor the previously uncovered upper divertor and central stack region. The diagnostics consist of a high speed ProEM-HS 512 camera, an IsoPlane SCT320 spectrometer and 32 sightlines: 16 sightlines on the upper divertor and 16 sightlines on the central stack. The ratio of lithium emission to carbon emission as a function of pre-discharge lithium deposition will be measured in these two region to evaluate the hypothesis.

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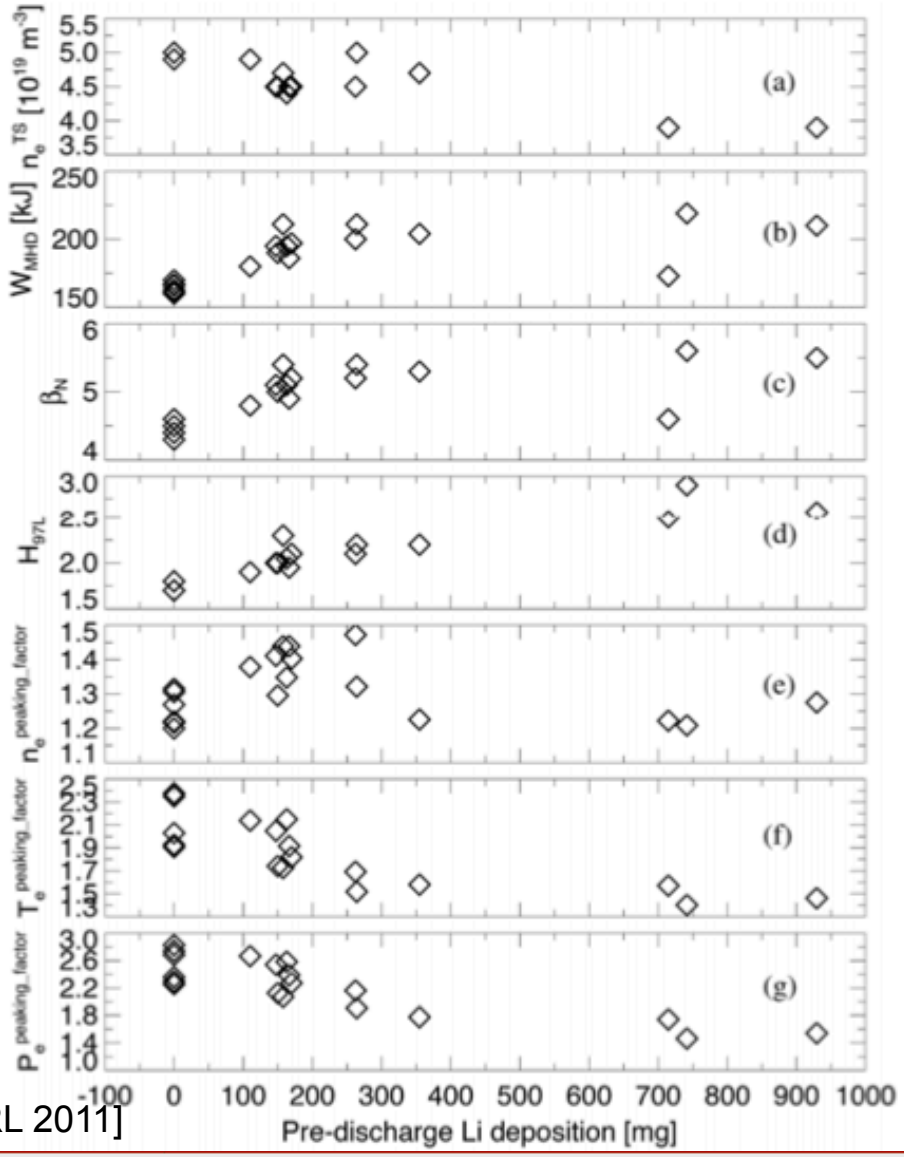
Valuable discussions with V. A. Soukhanovskii are gratefully acknowledged

Motivation: understanding Li coating effectiveness

- Open question:
  - Improvement increases linearly with pre-discharge evaporation
  - But... Nominal coating thickness >> ion implantation
  - What governs the effectiveness of Li deposition?

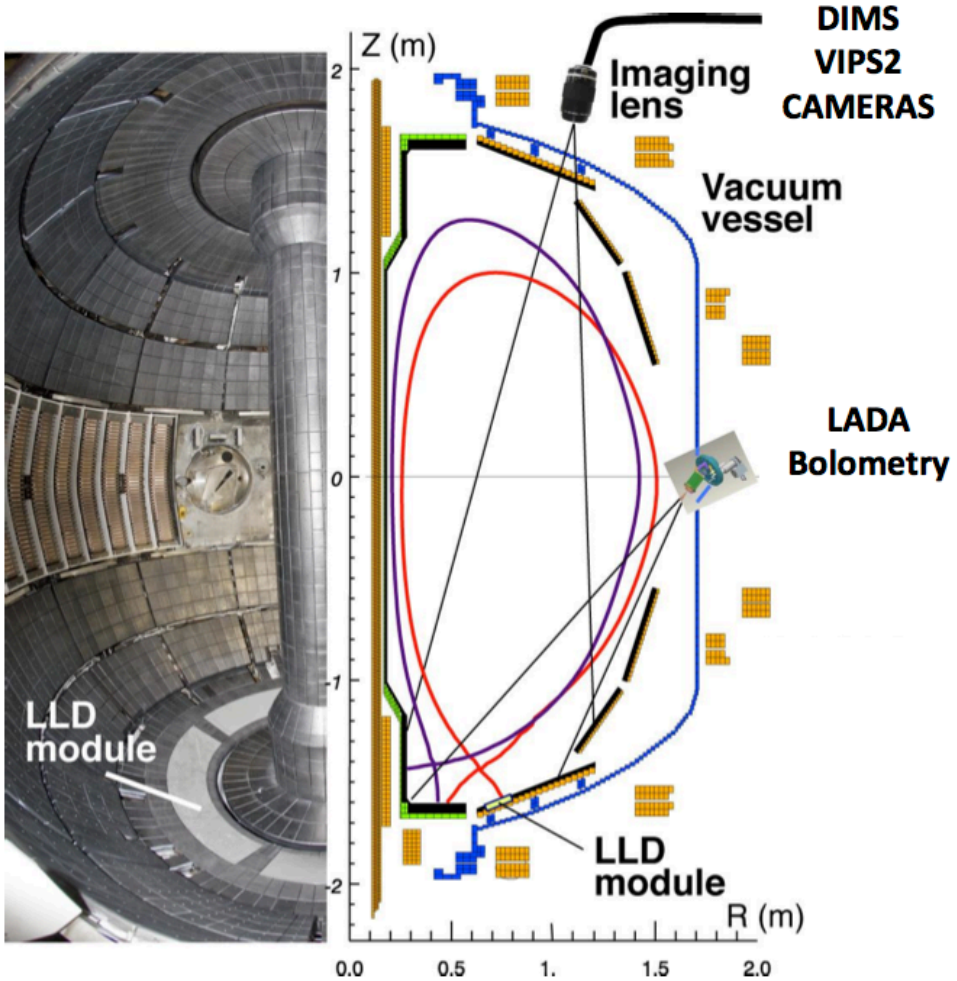
- Possible mechanism at play:
  - Role of regions low Li coverage
  - Erosion and re-deposition
  - Deposition of carbon-rich films during discharge
  - Lithium-Carbon chemistry

- Spatial distribution of Li coating is a key element



[R. Maingi, PRL 2011]

Lower divertor was well diagnosed on NSTX

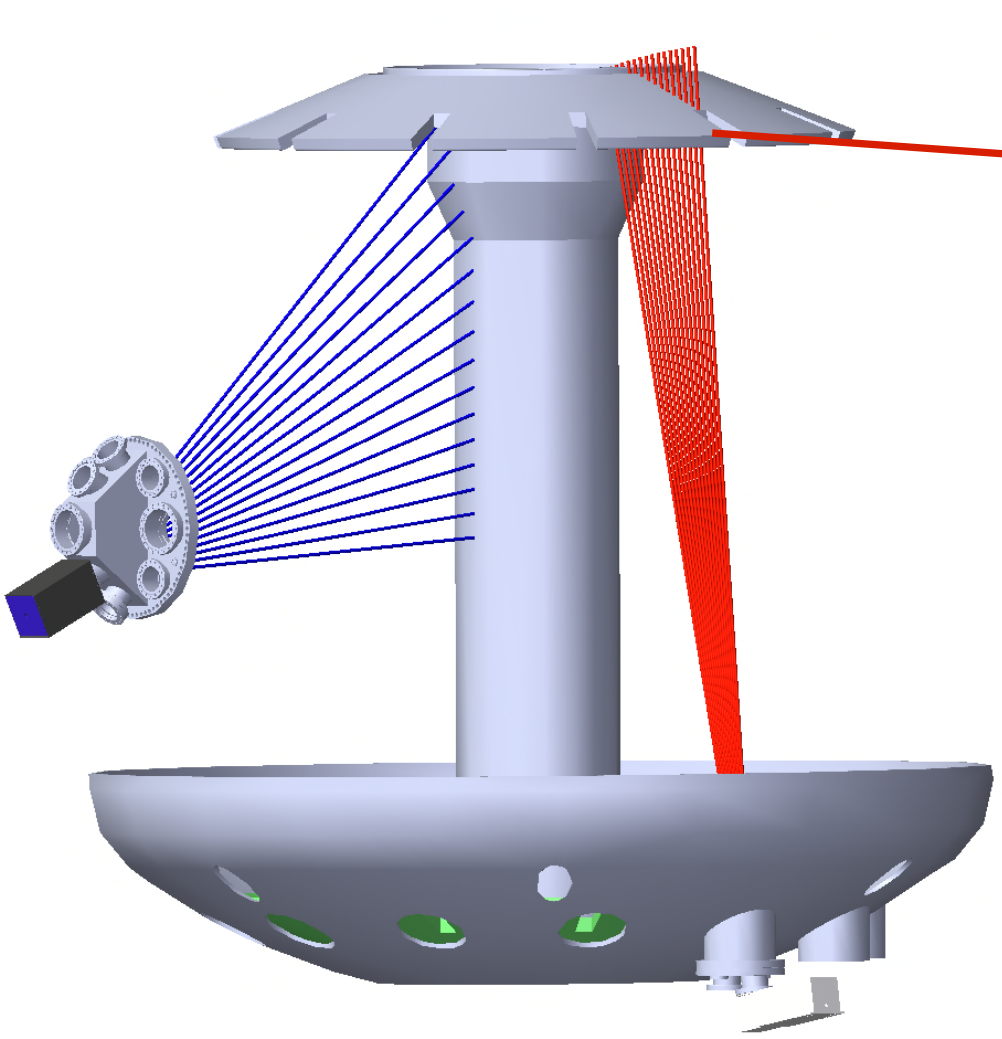


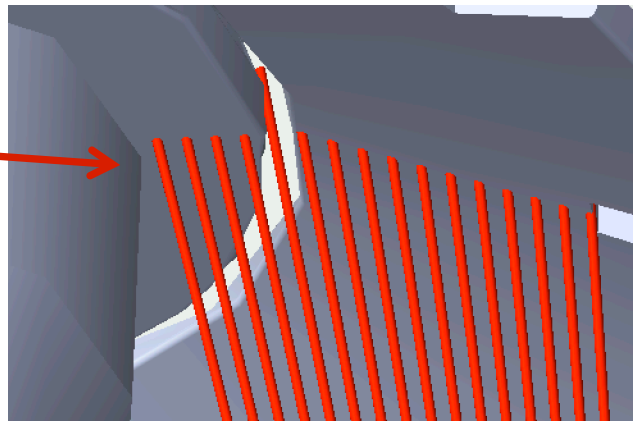
[V. A. Soukhanovskii, RSI 2010]

- Multi channel spectrometers (DIMS/VIPS2, LLNL/PPPL)
  - UV-VIS-NIR range, high resolution
  - 48 chords (30 simultaneously)
- Single channel spectrometers (ORNL)
  - 4X, VIS-UV, low resolution
- Diodes array (LADA/filter-scopes)
  - Lyα, Dα, C III, Li I
- Visible cameras (1D/2D)
  - Li I, Li II, C II, C III
- IR cameras (ORNL)
  - Fast dual band (L/MWIR, 1.6 kHz)
  - Wide angle (180° divertor coverage)

Poor coverage of the central stack and upper divertor

New spectroscopy Diagnostics port allocation

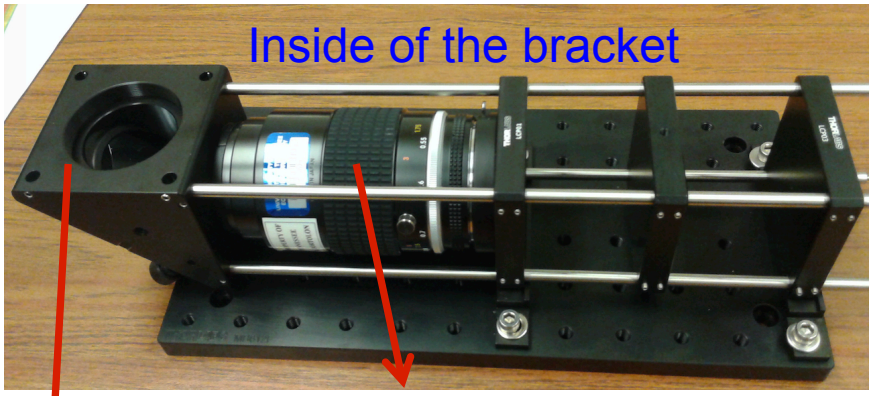




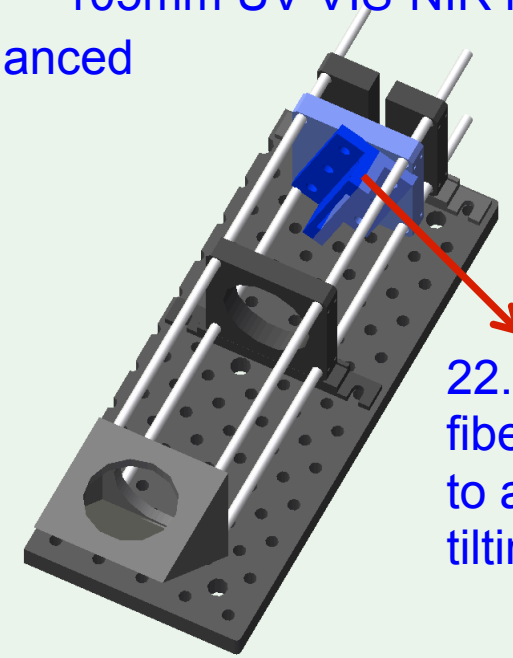
- Upper divertor spectroscopy
  - 16 sightlines
  - field of view: 8°
  - 4cm radial resolution, spots size 1.3cm
- Central stack spectroscopy
  - 16 sightlines
  - field of view: 40°
  - 10cm vertical resolution, spots size 1.3cm

The optomechanics for Upper divertor spectroscopy

Bracket for support optomechanics

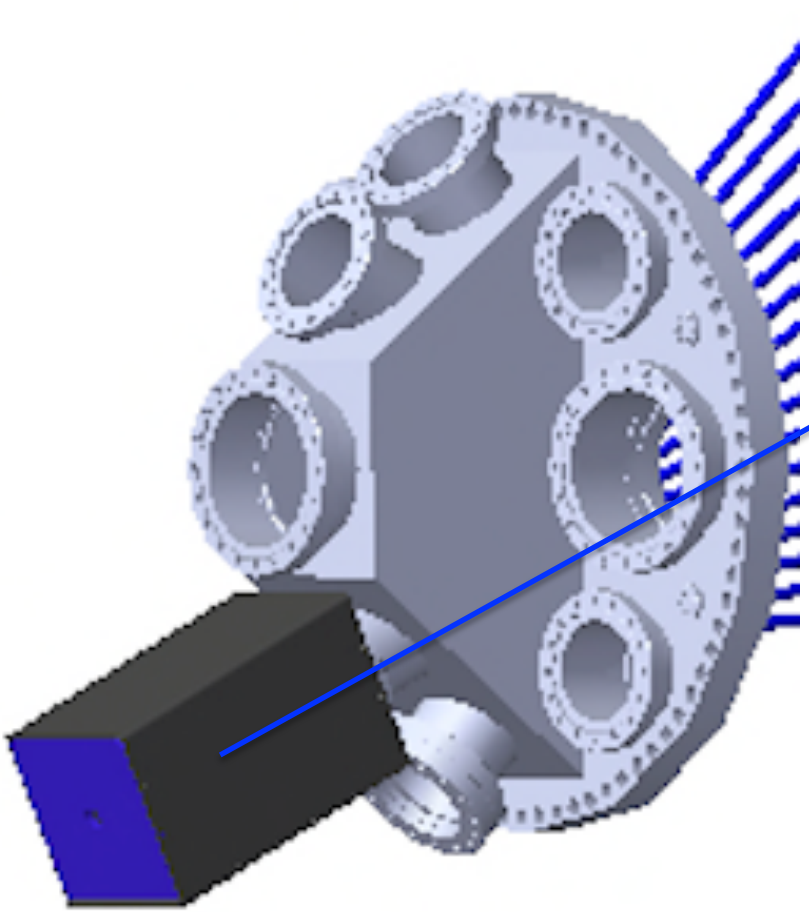


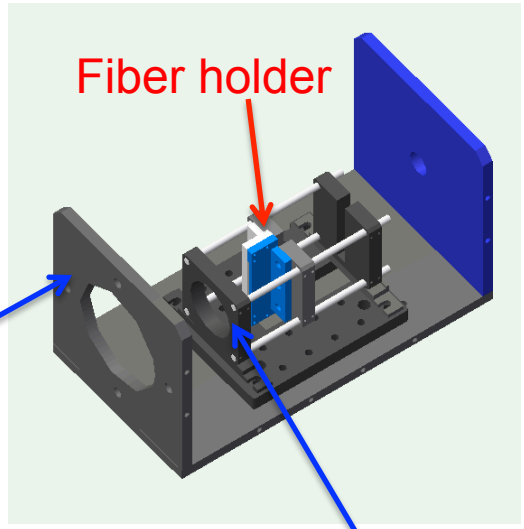
45° UV enhanced mirror

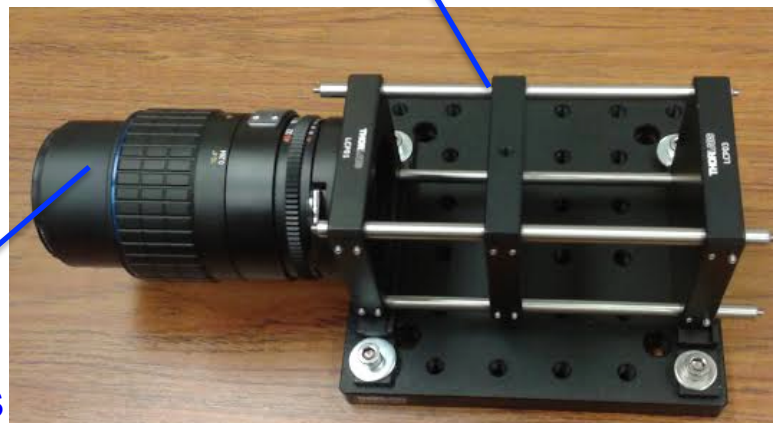


22.5° tilting fiber bundle to adjust the tilting bracket

The optomechanics for Central stack spectroscopy



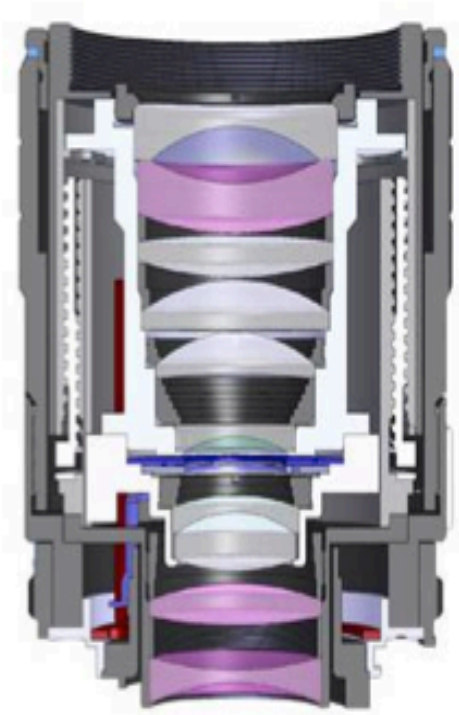




Jenoptik 60mm UV-VIS-NIR lens

Jenopitik 60mm lens

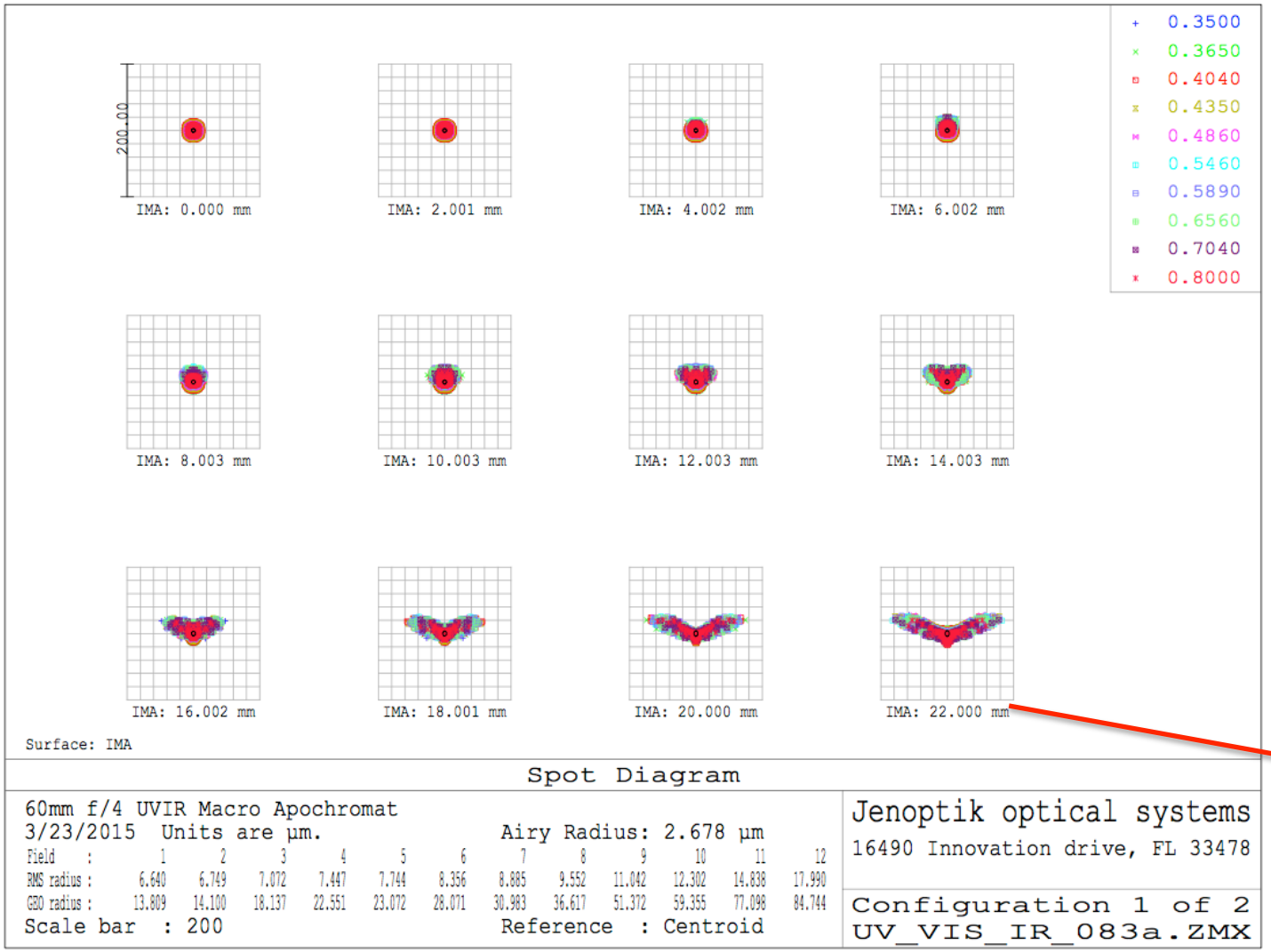
- No focus shift from UV thru IR
- Excellent UV transmission
- Flare and ghosting minimized across the UV–IR spectrum with advanced ultra broadband AR coatings
- Automatic diaphragm for maximum viewfinder brightness
- Precision manual focus with long life all-metal construction
- Advanced floating element design including five calcium fluoride elements ensures stunning performance in all conditions



Focal Length: 60mm
Aperture Range: f/4 - f/45
No. of Elements/Groups: 10/9
Maximum Format Size: 24 x 36mm
Transmission Waveband: 290 – 1500nm
Apochromatic Waveband: 315 – 1100nm
Focus Range: 264mm (10.4in) – Infinity
Maximum Magnification: 1:1.5
Mounting Flange: Nikon F Mount
Filter: 52mm thread (M 52 x 0.75)
Weight: 535g (1.18lb)
Length: 73.4mm (2.7in)

The height is 44mm for fiber array on the focal plane

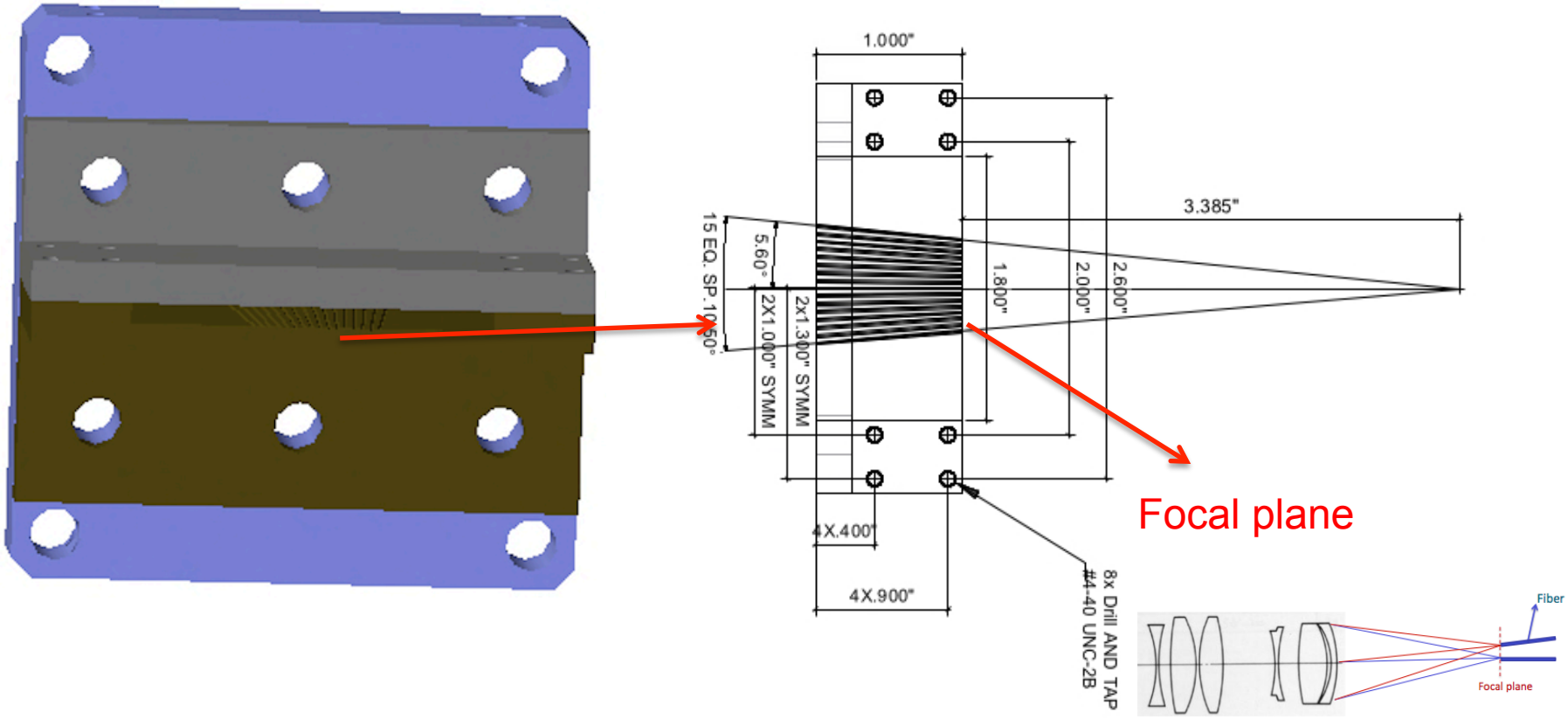
Spot diagram for 60mm Lens



20° incident angle

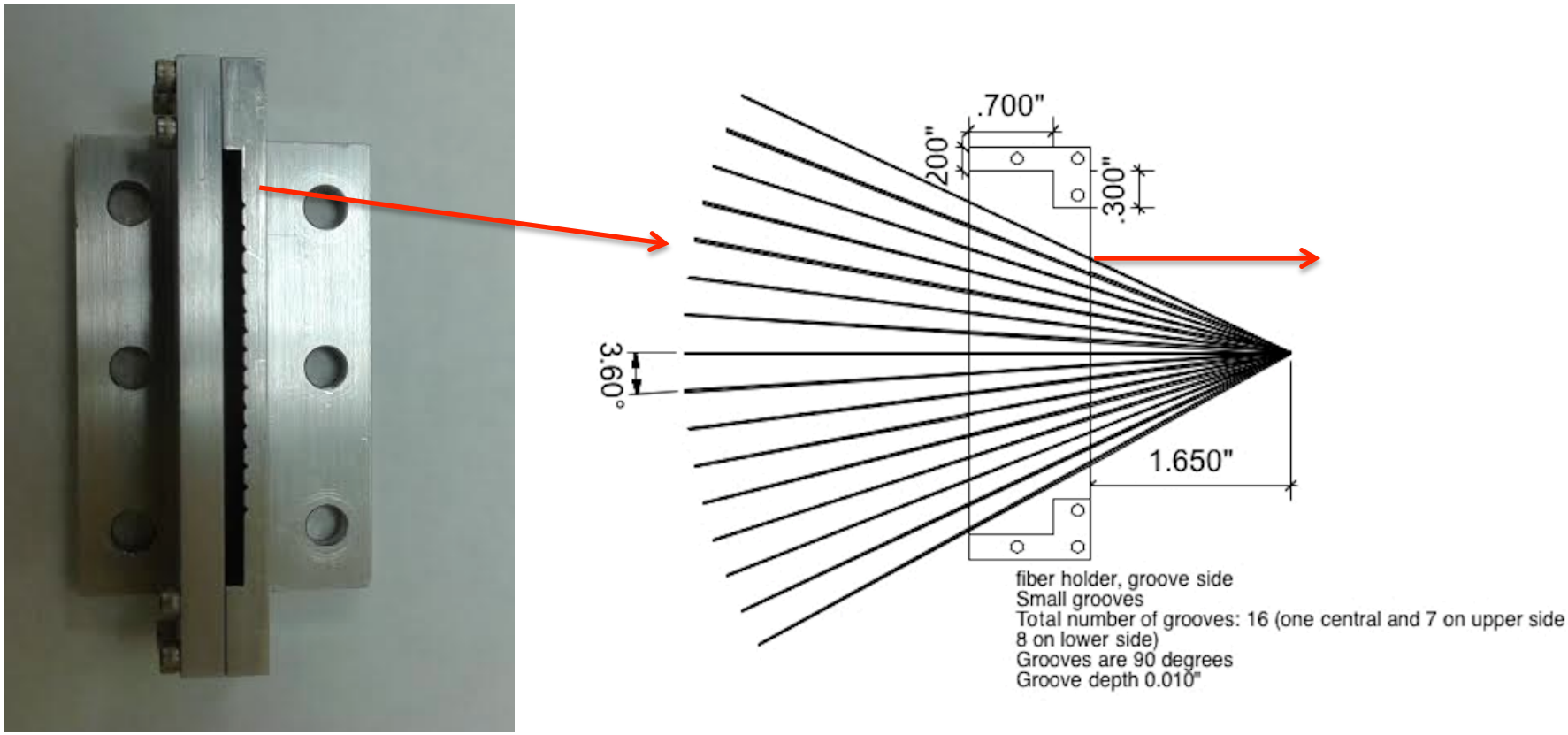
The image is good for 480nm fiber under 20° incident angle

Fiber holder design for upper divertor spectroscopy



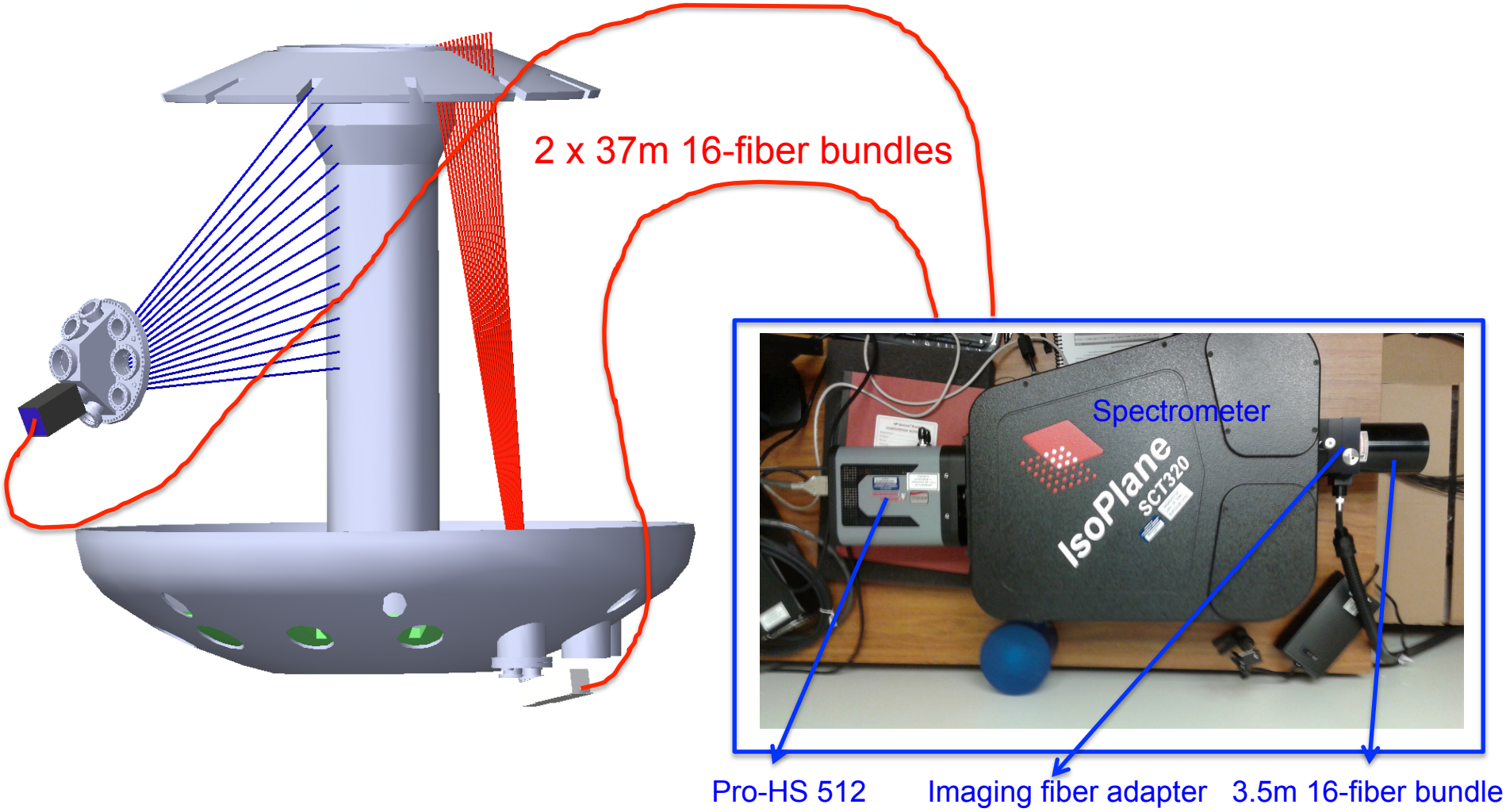
- Each fiber will tilt toward to the point which is 3.385” far away form the focal plane. The 3.385” is measured (to keep each fiber acquire the same intensity of signal.
- The 3.385” is the same distance between the focal plane and the lens

Fiber holder design for central stack spectroscopy



1.650” is the distance between the lens and the focal plane.

Camera and spectrometer will be in remote room shielded from radiation

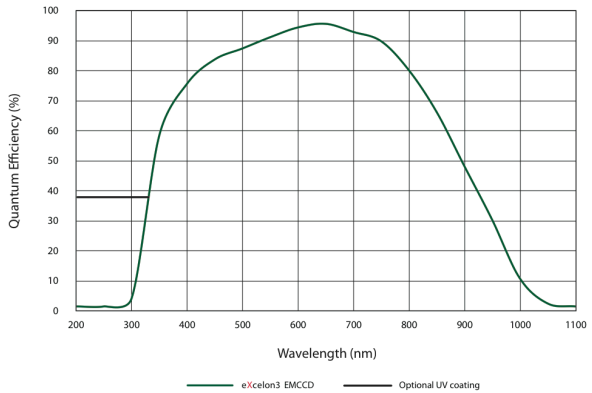


Princeton Instruments ProEM-HS:512B X 3

FEATURES	BENEFITS
Patented eXcelon®3 technology	Enhanced QE and fringe suppression versus standard back illuminated sensors.
20 MHz/16-bit readout	61 fps rate at full-frame resolution. Use ROI/binning for hundreds of frames per second.
All-metal, hermetic vacuum design	Lifetime vacuum guarantee and deep cooling. No epoxies used. Lowest dark current.
OptiCAL	Linear, absolute EM gain calibration using built in precision light source. EM and Non-EM modes for the lowest noise and the best linearity.
BASE	Baseline Active Stability Engine - stable reference for quantitative measurements.
High speed CCD readout	>1000 fps with reduced ROI size, >10,000 fps in spectroscopy mode.
100 kHz/16-bit readout	Noise performance of a slow scan camera for precise photometry applications.
Single optical window	Vacuum window is the only optical surface between incident light and the CCD surface; Advanced AR coatings for the highest throughput.
Built-in shutter	Conveniently capture dark reference frames and protect camera from dust when not in use.
Flexible lens mounts	C-mount (standard), Canon mount and adjustable C-to-Spectroscope mount - easily attaches to microscopes, standard lenses, telescopes or other optical instruments.
Gigabit Ethernet (GigE) interface	Industry standard for fast data transfer over long distances, up to 50m. Extenders available for even greater distance.
Optional: LightField® (for Windows 8/7, 64-bit) Or WinView/Spec (for Windows 8/7/XP, 32-bit)	Flexible software packages for data acquisition, display and analysis; LightField offers intuitive, cutting edge user interface, IntelliCal® and more.
PICAM (64-bit) / PVCAM (32-bit) software development kits (SDKs)	Compatible with Windows 8/7/XP, and Linux; Universal programming interfaces for easy custom programming.
LabVIEW®	Easy integration of camera into complex experiments.

Princeton Instruments ProEM-HS:512B X 3

	ProEM-HS: 512BX3	
Sensor	Back-illuminated 512 x 512 eXcelon3 EMCCD, 16 x 16 µm pixels, 8.2 x 8.2 mm imaging area	
Shutter	25 mm shutter included	
	EM mode	Normal CCD mode
Read noise	25 e^- rms @ 5 MHz 50 e^- rms @ 10 MHz 120 e^- rms @ 20 MHz *Read noise effectively reduced to <1 e^- rms with on-chip multiplication gain enabled*	3 e^- rms @ 100 kHz 4.9 e^- rms @ 1 MHz
Non-Linearity	<2%	<1%
Analog gain	12, 6, 3 e-/ADU	3.2, 1.6, 0.8 e-/ADU
Full well EM mode only EM and Normal CCD modes	 800 ke^- (output amplifier) 200 ke^- (single pixel)	
Deepest cooling temperature* (@ +20° C ambient; 10 MHz ADC)	-70° C +/- 0.05° C (guaranteed) Maximum Cooling: -80° C (air), -85° C (+20° C liquid), -90° C (+10° C liquid)	
Dark current	0.001 e-/p/sec (typical), 0.02 e-/p/sec (maximum)	
Clock induced charge (CIC) *Measured at 1000x EM Gain*	0.002 e-/pixel/frame	
Electron multiplication (EM) gain	1 to 1000x, controlled in linear, absolute steps	
Digitization	16 bits @ 20 MHz, 10 MHz, 5 MHz, 1 MHz and 100 kHz	
Vertical shift rate	300 nsec/row - 5 µsec/row (variable)	
Operating systems supported	Windows 8/7 (64-bit) and Linux (64-bit), Windows 8/7/XP (32-bit)	
I/O signals	Exposure, Readout, Trigger In, Image Shift, Waiting for Trigger	
Operating environment	0 to 30° C ambient, 0 to 80% relative humidity, non-condensing	
Certification	CE	
Dimensions / Weight	8.02 inches (20.37 cm) x 5.8 inches (14.73 cm) x 5.8 inches (14.73 cm) L x W x H Approximately 9.2 lbs (4.2 kg)	



Princeton Instruments ProEM-HS:512B X 3

Frame Rates (Standard Mode)

Binning	512 x 512	256 x 256	128 x 128	64 x 64	32 x 32
1 x 1	61	120	228	416	711
2 x 2	120	228	416	711	1099
4 x 4	228	416	711	1099	1506
8 x 8	416	711	1099	1506	1851

Frame Rates (High Speed CCD Readout Mode)

Binning	512 x 512	256 x 172	92 x 101	64 x 62	32 x 30
1 x 1	61	201.6	865	1529	3472
2 x 2	120	381	1557	2652	5617
4 x 4	228	682	2645	4132	7490
8 x 8	416	1131	3968	5899	9708

(High Speed Spectroscopy Readout Mode)

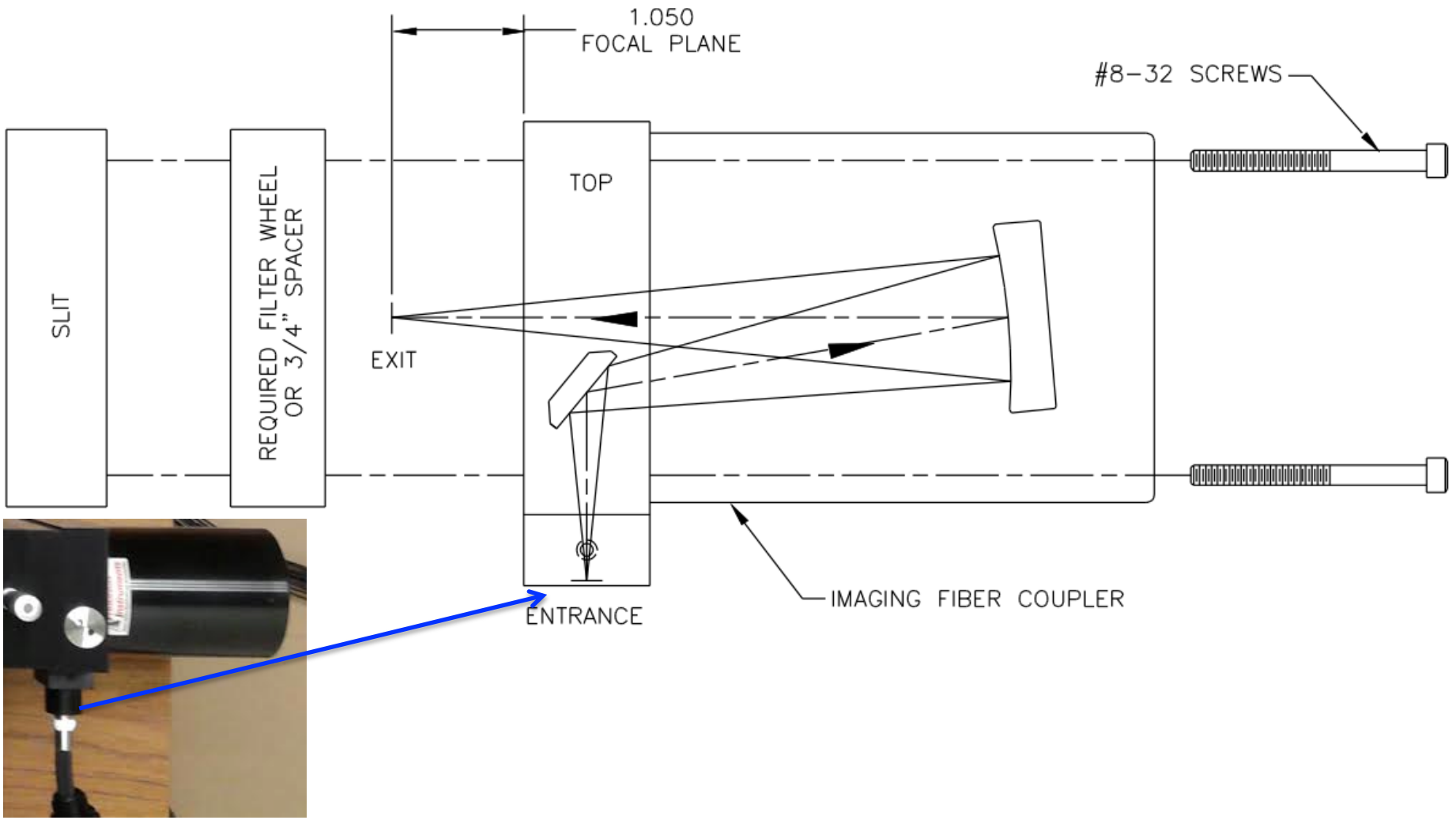
Binning	512 x 100	512 x 32	512 x 1
1 x 100	13850		
1 x 32		19305	
1 x 1			23529

IsoPlane SCT 320 spectrometer

	IsoPlane SCT 320
Focal length	320 mm
Aperture ratio	f/4.6
Scan range (with 1200 g/mm grating at 435 nm)	0 - 1400 nm
Linear dispersion	2.38 nm/mm
CCD resolution (20 µm pixel, 10 µm slit width)	0.08 nm
PMT resolution (10 µm slit, 4 mm high, 1200 g/mm grating at 435 nm)	0.05 nm
Wavelength coverage	64 nm
Grating size	68 x 68 mm
Grating mount	Interchangeable triple grating turret
Focal plane size	27 mm wide x 14 mm high *
Astigmatism	Zero (0)
Coma	Corrected at 500 nm with 1200 g/mm grating
Slits	Manual (10 µm to 3 mm) or optional motorized or kinematic entrance slits; Optional manual or motorized exit slits
Wavelength accuracy	± 0.2 nm
Repeatability	± 0.05 nm
Drive step size	0.005 nm
Size	20.4 in (518 mm) long 17.7 in (450 mm) wide 8.5 in (216 mm) high
Optical axis height	4.875 in (124 mm) with rubber feet 4.313 in (110 mm) without rubber feet
Weight	~ 60 lbs [27 kg]
Computer interface	USB and RS232

Two grating, 2400gr/mm and 3600gr/mm have been installed in this spectrometer

Imaging fiber adapter



Fiber bundles

2 X 37m 16-fibers bundles

1 X 3.5m 16-fiber bundle

- Fiber: Polymicro FBP400440480
- Diameter: 480nm
- full acceptance angle: 25.4^{o}
- Low Loss Broad Spectrum Fiber, 275-2100nm
- Recommended bend radius: 74.2mm
- Each fiber has been jacked with Hytrel
- The Fiber is the same as NSTX-U DIMS system

Summary

The fiber bundles, spectrometer and the camera have been prepared for the upper divertor and central stack spectroscopy. Once the fiber holder for upper divertor view and bracket for central stack view are completed, the new high resolution UV-VIS-NIR spectroscopic diagnostics can be installed for NSTX-U to monitor the previously uncovered upper divertor and central stack region.