NIF Optics Inspection Systems

Observing and Quantifying Unresolved Objects

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NIF Optics Inspection Team

Imagine the scale of the task…500 trillion watts of optical power pulsed through 7500 optics, mirrors, and crystals…

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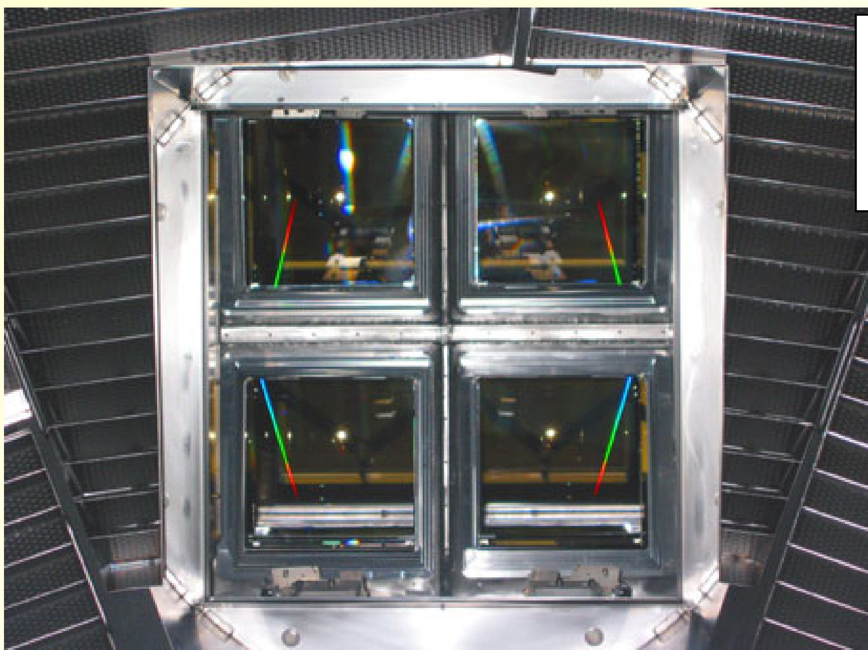
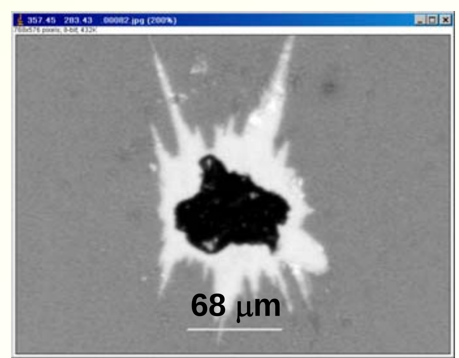
Now answer the question: Are the condition of these optics, mirrors and crystals adequate to pulse another 500 trillion watts of optical power through the system safely and without laser performance degradation?

This means locating debris, defects, and damage with diameters smaller than the thickness of human hair (less than 100 μm) across a thousand optics and crystals in the NIF… in only a few hours



This is the view you have for each beamline in the NIF as seen from the center of the target chamber

Where in the world is …



Micrograph of a damage site on a crystal

When damage does occur on an optic, NIF has a strategy to remove and recycle the optic

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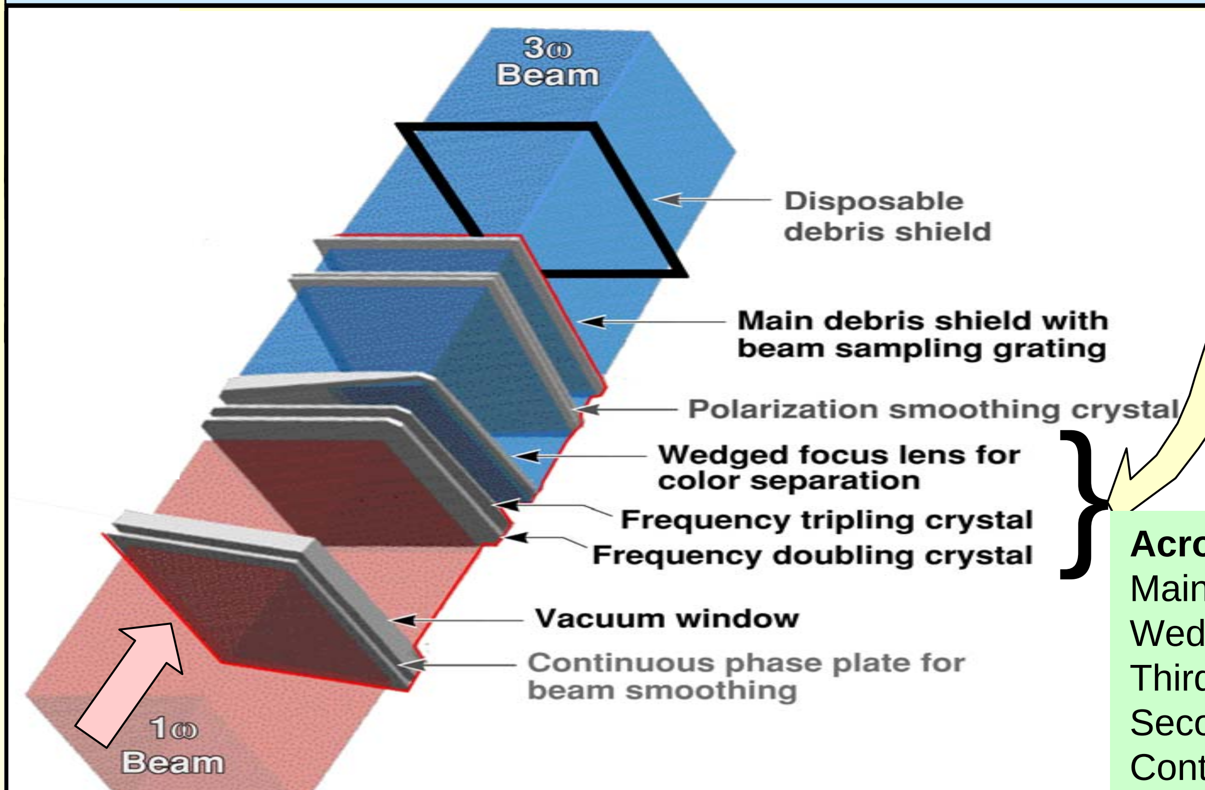
Optics in the Final Optic Section of the laser are the most vulnerable



Frequency conversion crystals and focus lens

Acronym Legend

Main Debris Shield – MDS
Wedged Focus Lens – WFL
Third Harmonic Generator – THG
Secodn Harmonic Generator – SHG
Continuous Phase Plate - CPP

The optic recycle strategy manages the impact of damage on these optics, extending the life of these optics on NIF while maintaining laser performance

Optics inspection is a key element in the recycle strategy, identifying damage while it's small is critical for success

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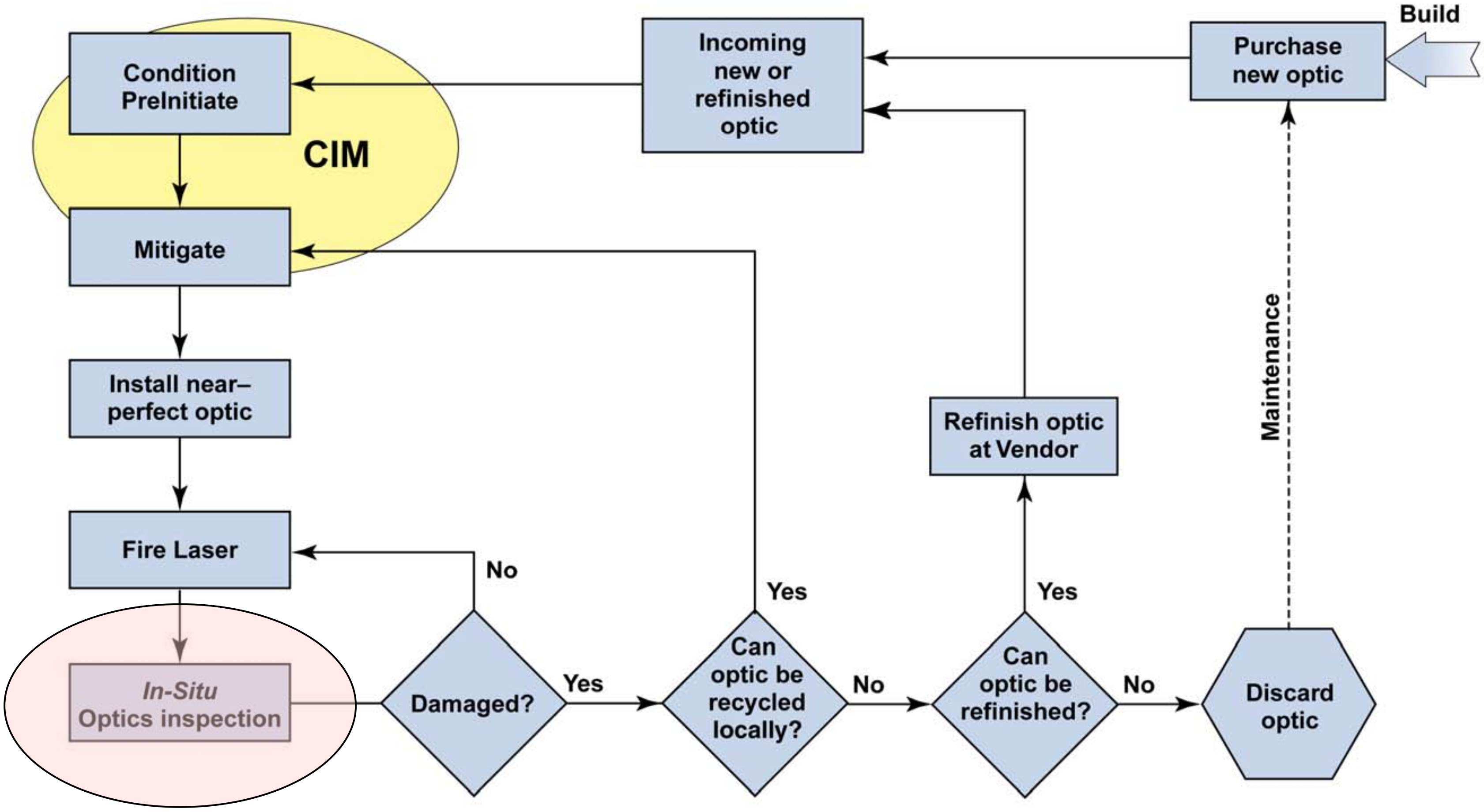

Optics inspection is the key element for this strategy

This is where size matters
(when we get it right, the loop works)

CoreStrategy-Loop-L4 [OP].ai
1/5MLS/cld

The inspection begins at the center of the NIF target chamber, the tool we developed for this purpose is the FODI telescope

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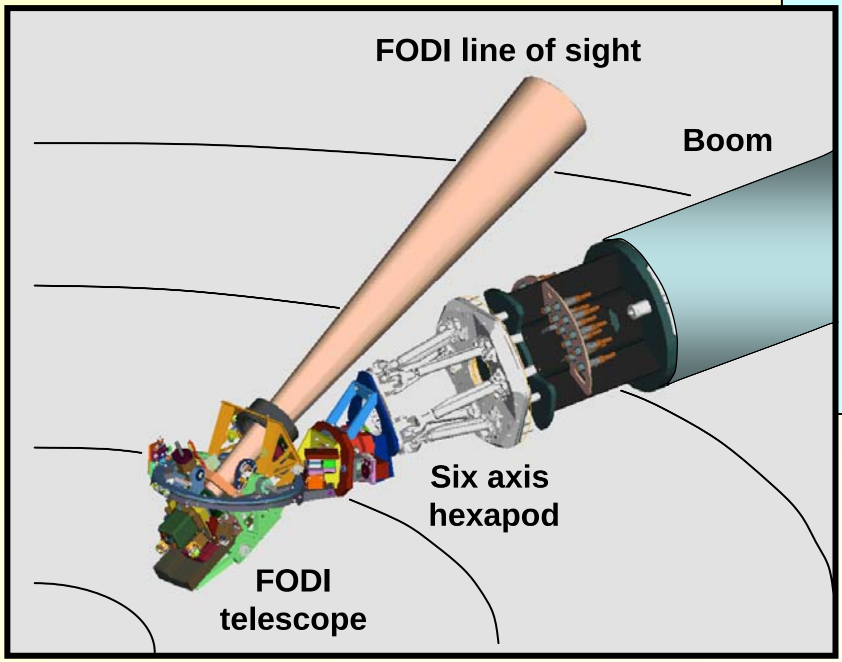
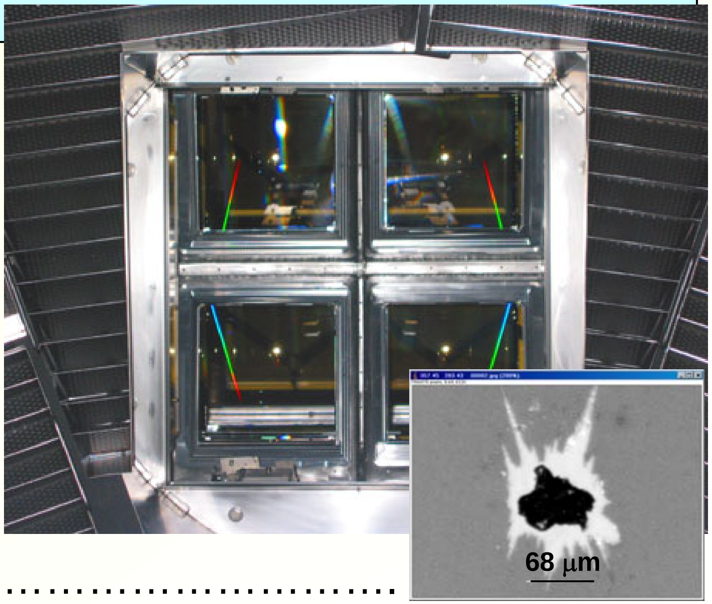
Final Optics Damage Inspection System



- **The FODI instrument is positioned at TCC using a 5 meter retractable boom**
- **The FODI hexapod accurately positions the telescope to the center of the chamber**
- **The FODI roll, pitch and yaw stages point FODI into each beamline**



Looking into the final optic section can be like looking into a hall of mirrors. We will need to overcome this and locate each optic plane.

The optics to be imaged are from 6 m to 70 m away……………………………

Operation in the NIF target chamber presents many challenges to overcome in the design of the FODI instrument

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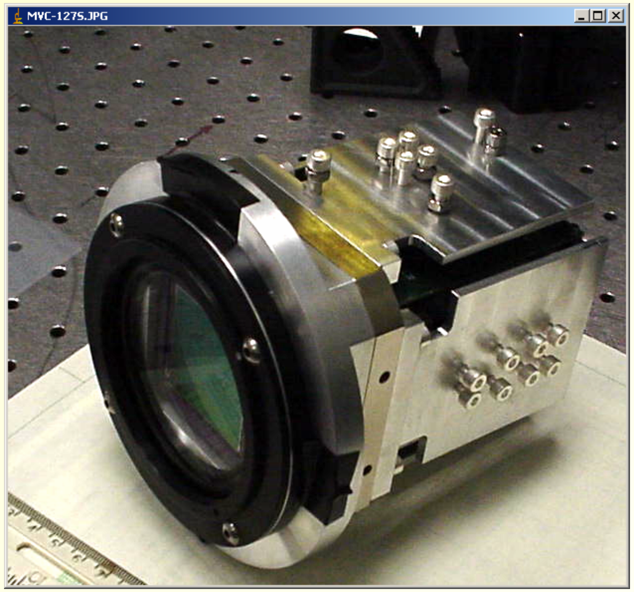
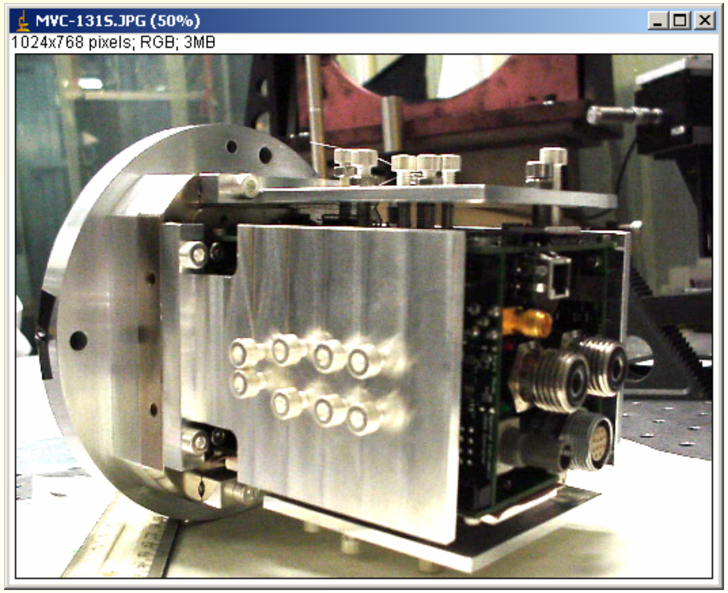
These challenges include: operation in vacuum, outgassing, Solgel coating compatibility, alignment, full field of view focus on tilted optics, high resolution and low noise, etc.

As an example, the CCD camera has been modified to be used in vacuum by exhausting heat through thermal conduction to water cooling lines, cleaning of components, elimination of any pressure sensitive components such as wet electrolytic capacitors, and repackaging.





Spectral Instruments 1000 camera modified for use in the FODI instrument

A high resolution CCD camera and optical telescope with motorized focus stage make up the FODI imaging system

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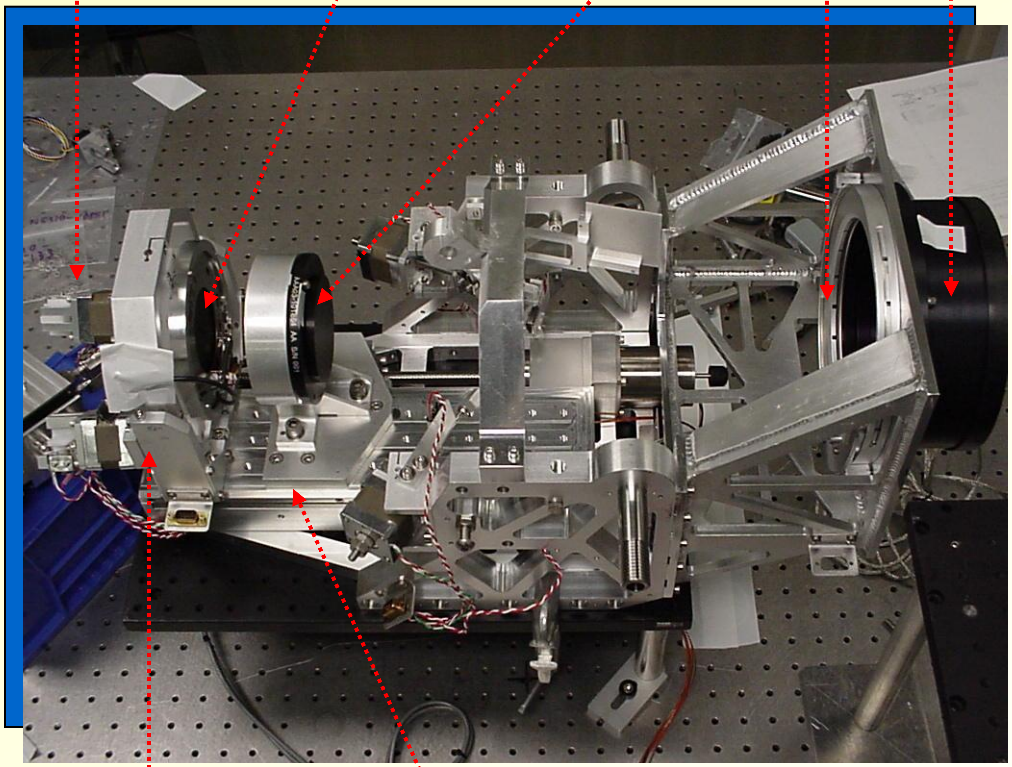

Working Distances

Final optics: 8 - 10 meters
Transport mirrors: 15 – 80 meters

FODI imaging system specifications

Lens focal length:	600mm
Lens F/# :	F3.6 to ~ ∞
Design wavelength:	1053nm & 808nm
CCD format:	4096 x 4096 pixels
Pixel size:	9 μm
Dynamic range:	72 dB
ADC format:	14-bits

The minimum pixel field of view at the shortest working distance is 100μm …

The FODI instrument is being assembled and tested off line to be ready for full system commissioning in FY07.

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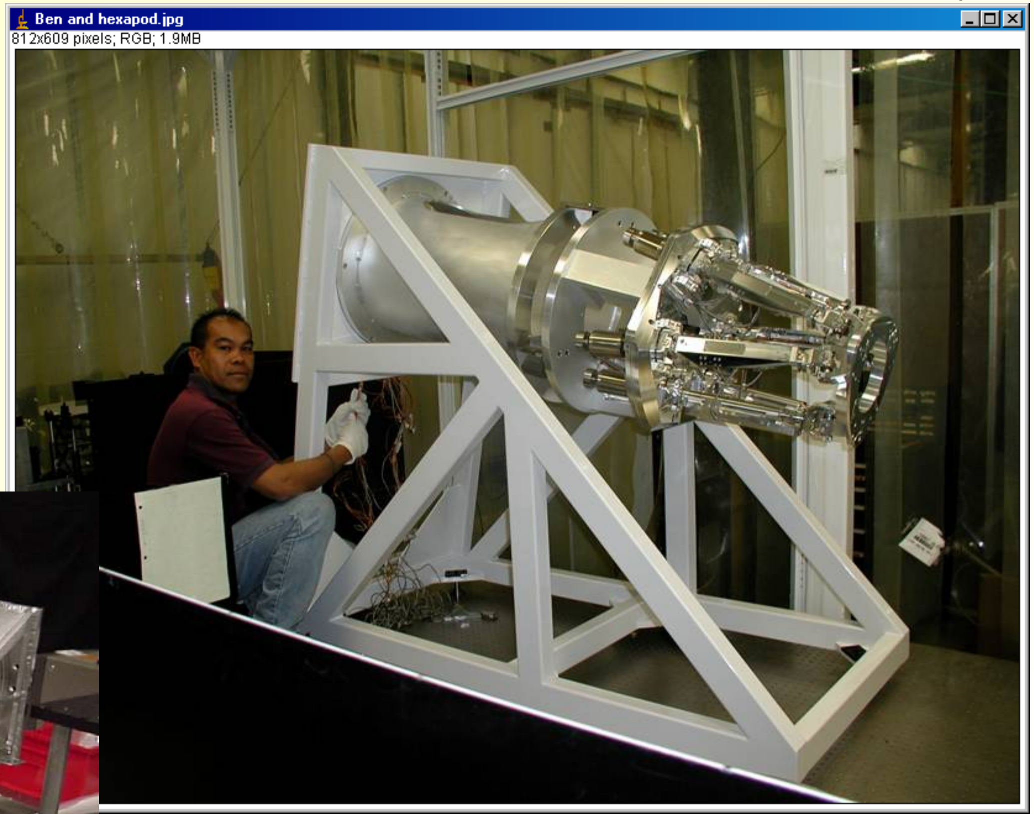

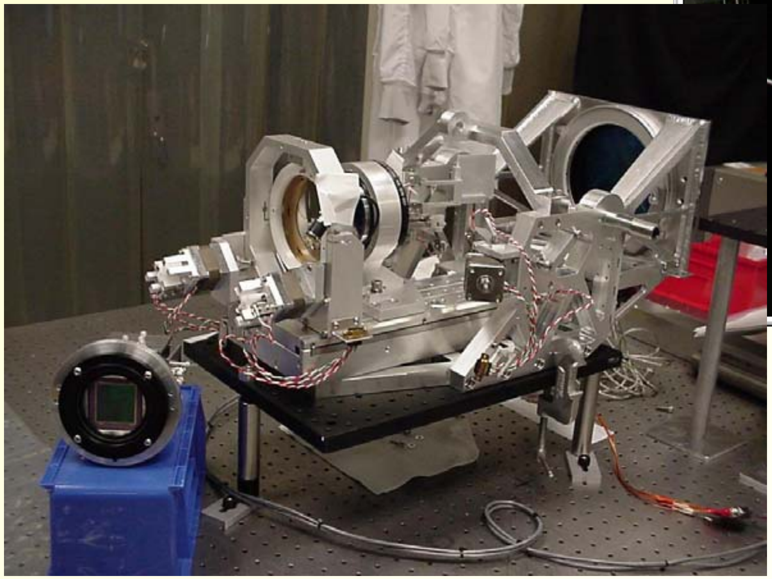

We have just finished characterizing the FODI optical performance in the laboratory and are ready for sub-system integration.

To enhance FODI's ability to image very small sites we have developed a unique system to illuminate these optics

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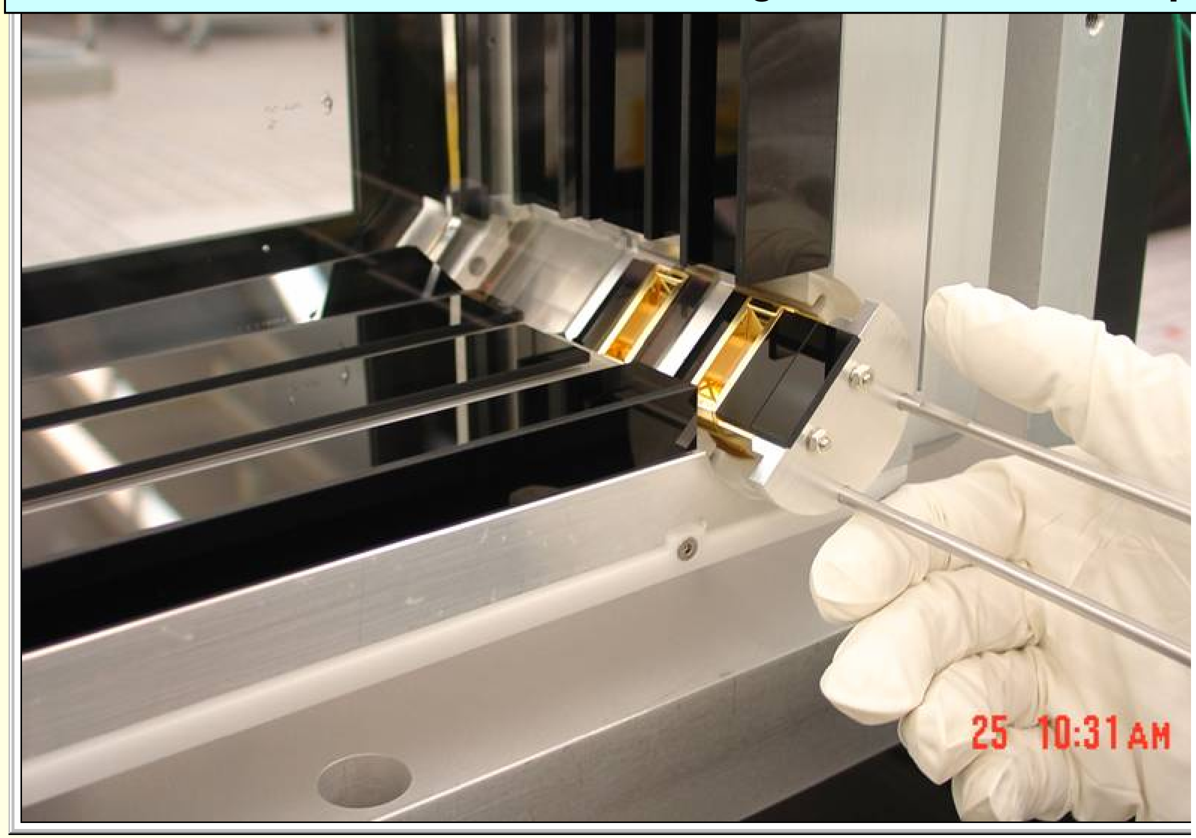
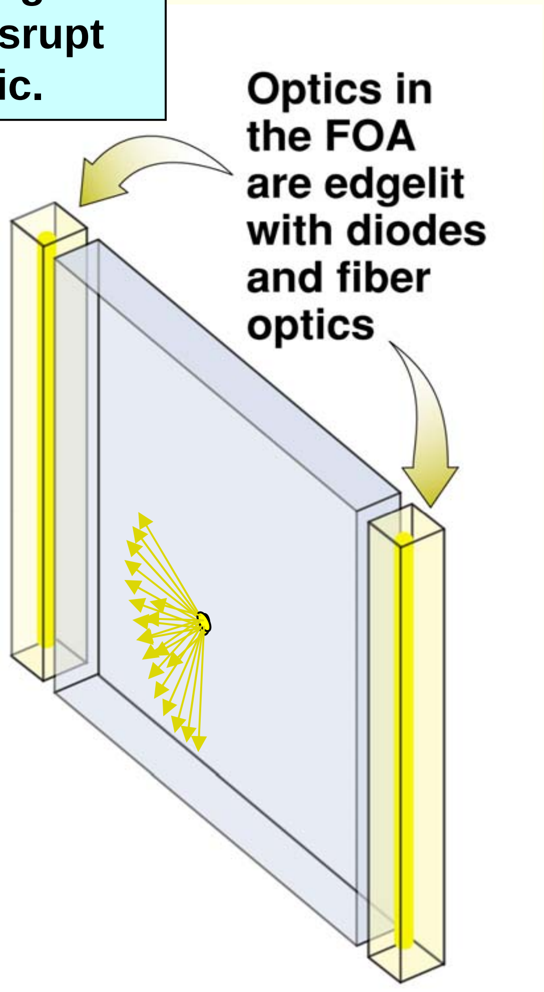
Light is launched into the optic and is mostly trapped through total internal reflection (TIR). Damage into the optic will disrupt the TIR conditions and scatter the light from out of the optic.



Corner illumination block being inserted into the final optics cell



Imagine an optical working distance of over 7 m (~23 ft), now detect and quantify the size of objects down to 20 μm or less

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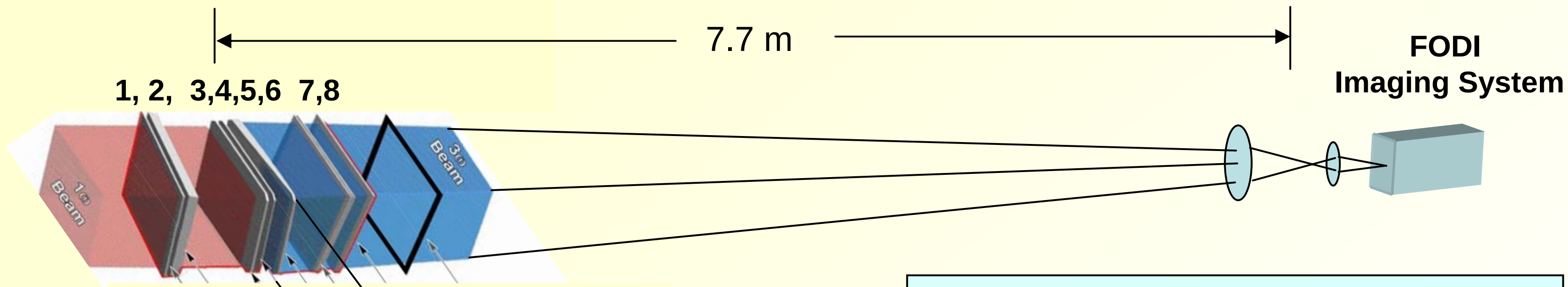
And no zoom capability is allowed … one image for each optic



Final Optics Section

1- 1ω Continuous Phase Plate
2- Vacuum Window
3- Second Harmonic (2ω) Crystal
4- 2ω Continuous Phase Plate
5- Third Harmonic (3ω) Crystal
6- Focus Lens
7- Main Debris Shield
8- Disposable Debris Shield

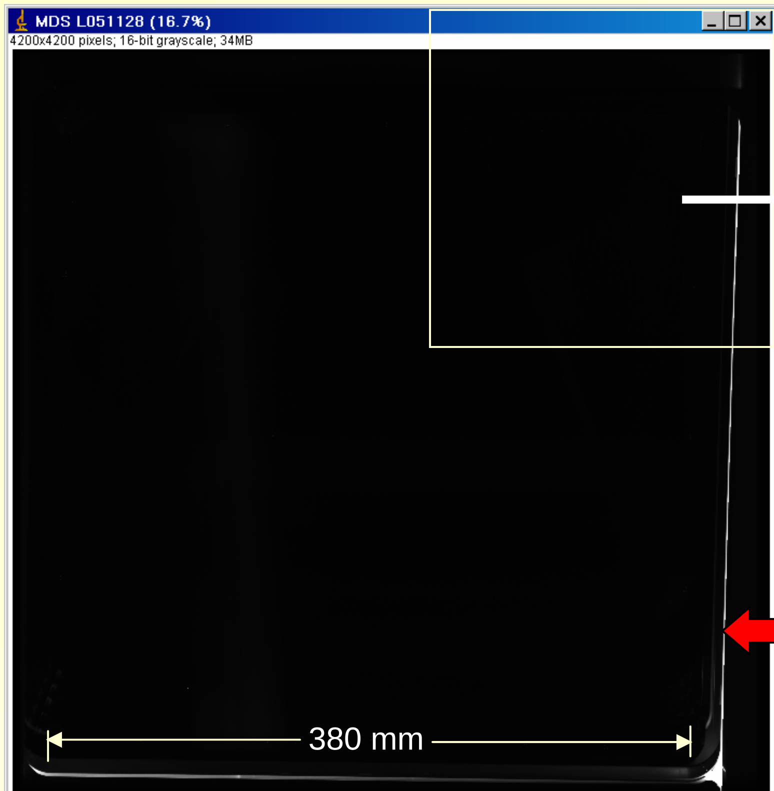
FODI imaging system specifications

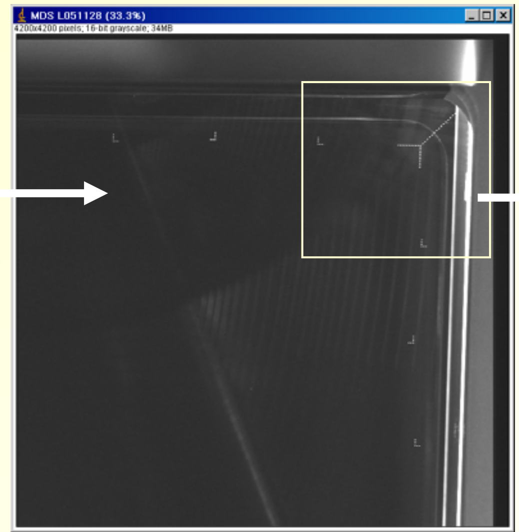
Lens focal length:	600mm
Lens F/# :	F4
Design wavelength:	1053nm & 808nm
CCD format:	4096 x 4096 pixels
Pixel size:	9 μm
Dynamic range:	72 dB
ADC format:	14-bits

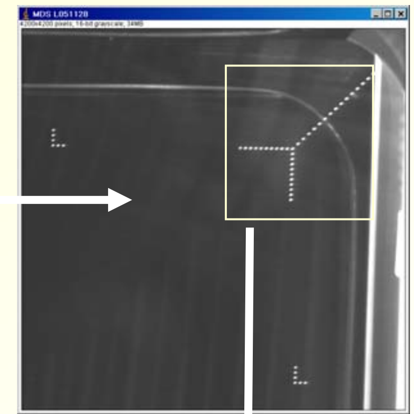
With a
Pixel field of view ~ 111 μm

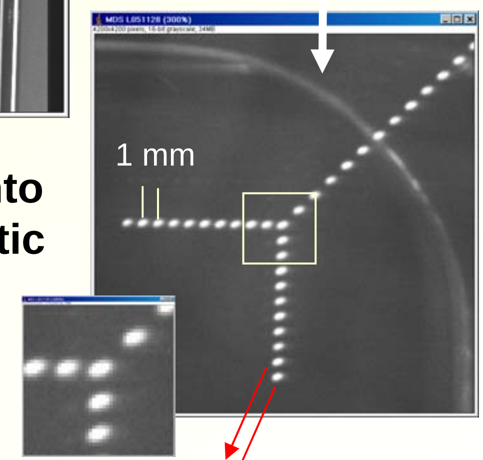
We can measure the effective diameter of sites with true diameters of less than 100μm to within ± 15% (at 1σ) !!

To help find focus (you need something to see), and to help locate and size damage sites, fiducials are added to some optics









Light is injected into the edge of the optic

Light is scattered at the surface of the optic

An image of the main debris shield as seen by PFODI during the FY06 NIF precision diagnostics campaign

Note the wide digital zoom capability

Precision diagnostics FODI = PFODI

To accurately estimate the effective diameter of damage sites we rely on calibration from a “truth” optic with measured sites

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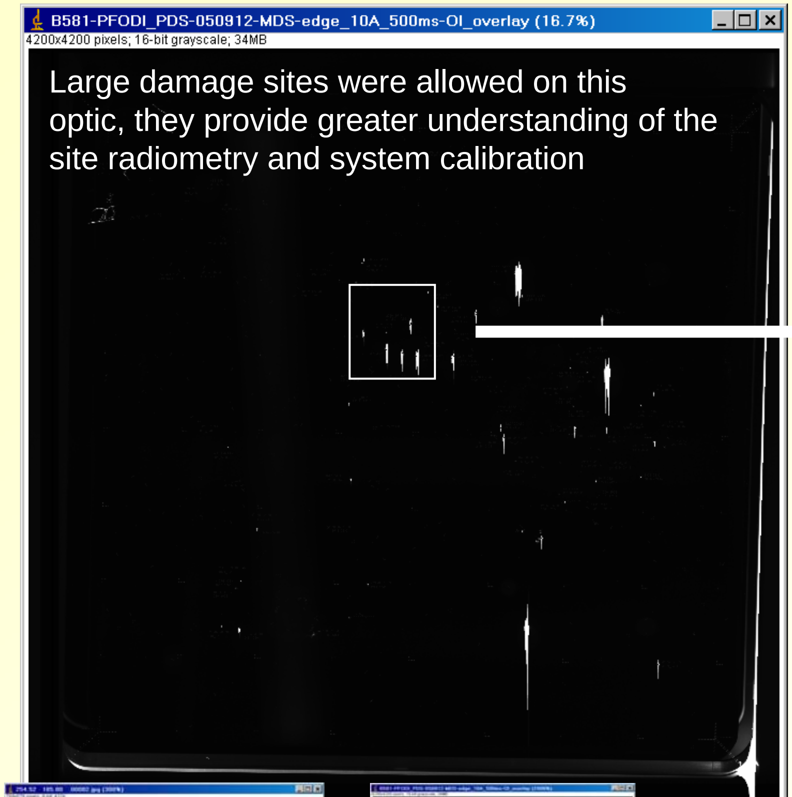
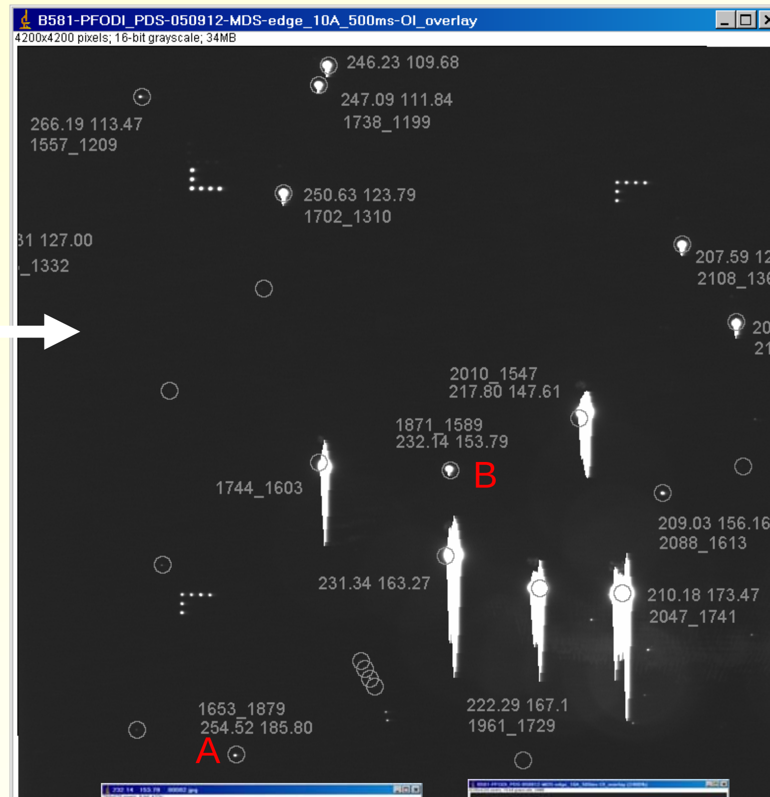
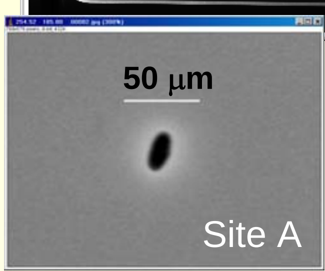
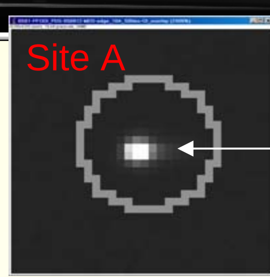




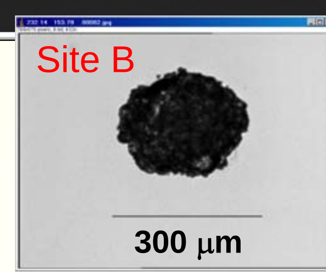


“Truth” micrograph

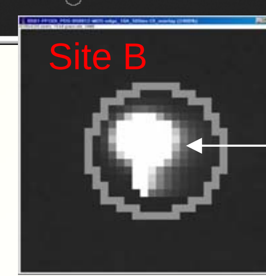


PFODI image

Sum the
total signal
“Sum Intensity”



“Truth” micrograph



PFODI image

Sum the
total signal
“Sum Intensity”

Plotting the “Sum Intensity” for each site against its effective diameter enables calibration coefficients to be derived

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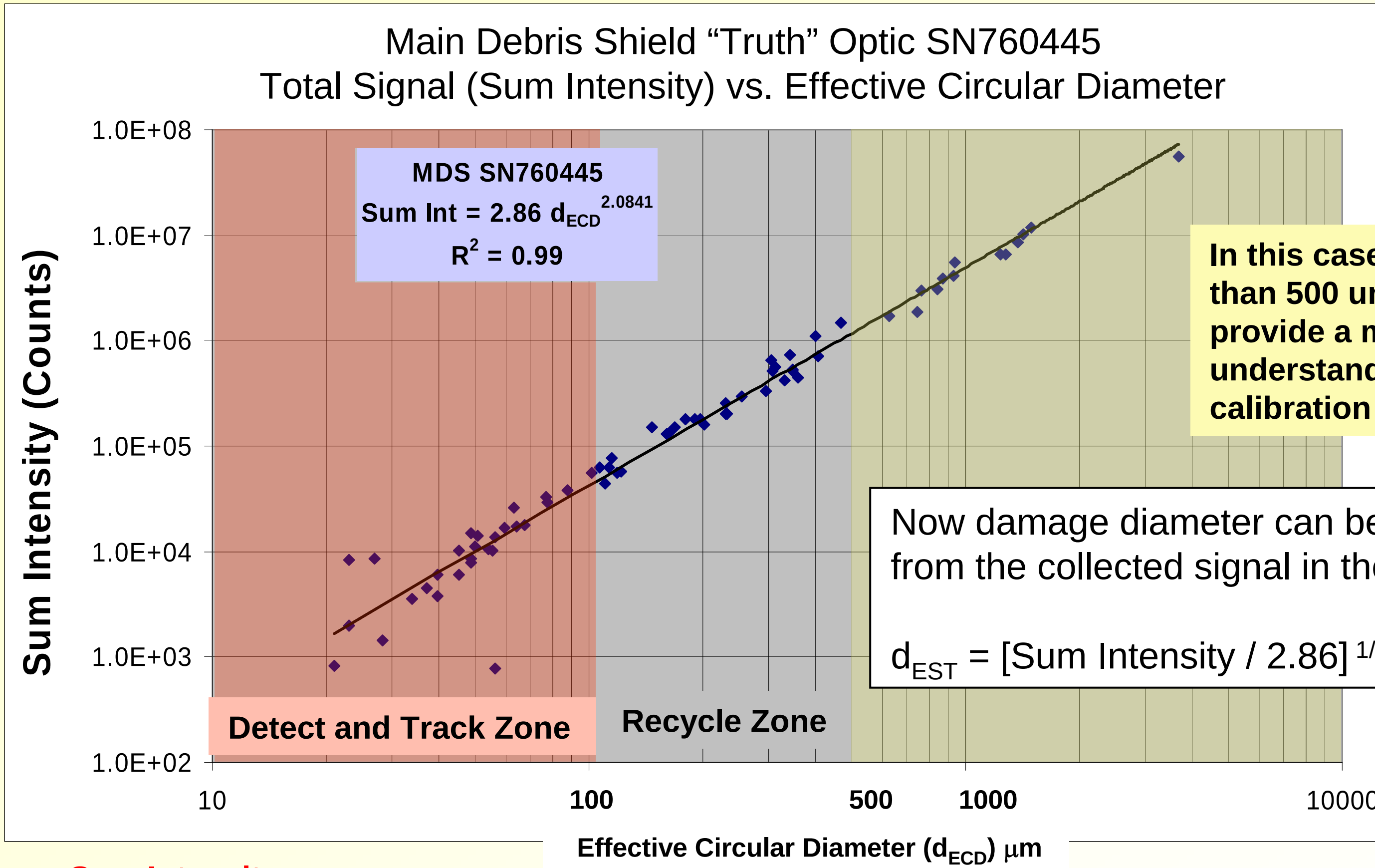


In this case, damage sites greater than 500 um were allowed, they provide a more complete understanding of the radiometric calibration

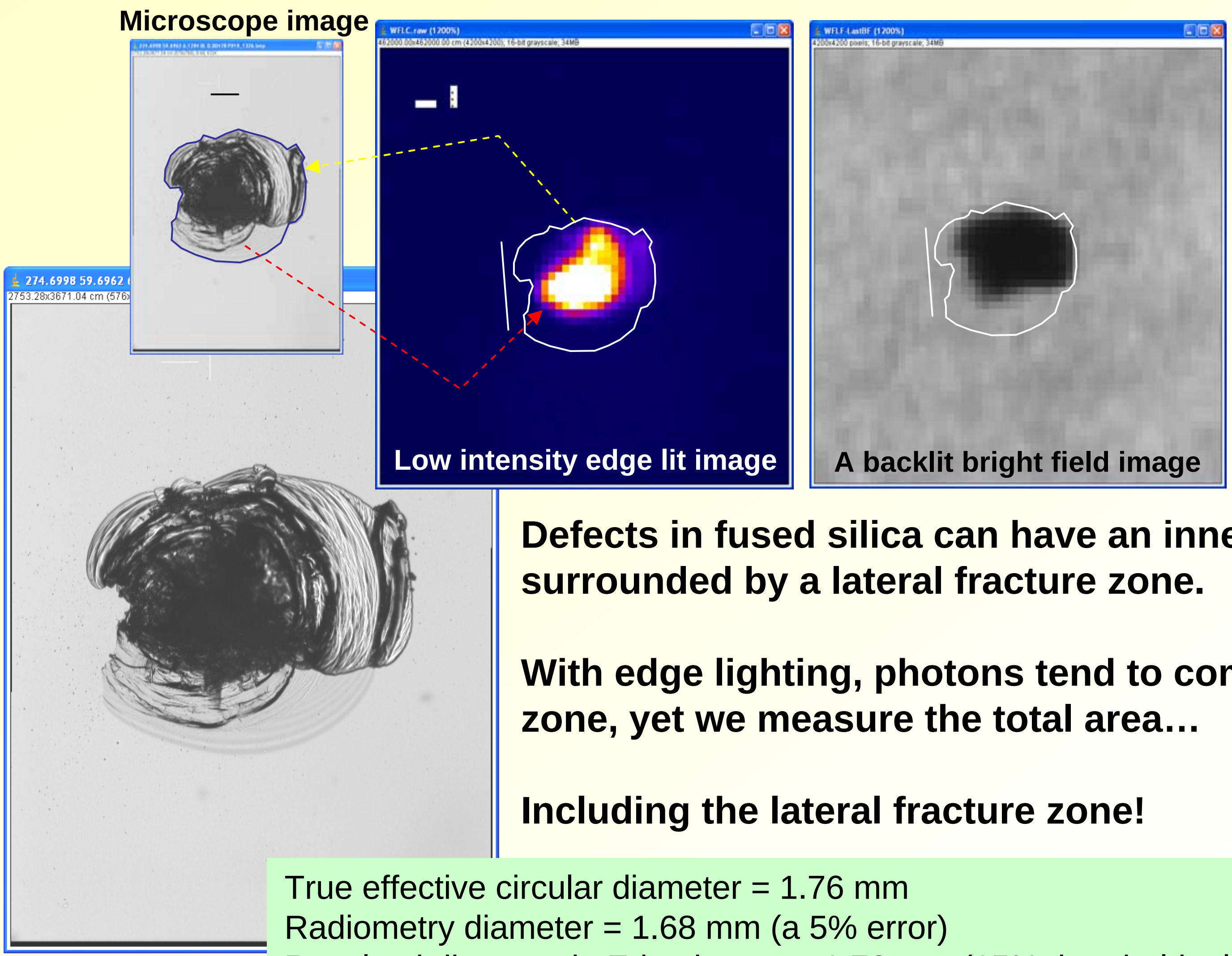
Now damage diameter can be estimated from the collected signal in the image

d_{EST} = [Sum Intensity / 2.86] $^{1/2.08}$ Estimated diameter

Sum Intensity =

$$\left[\frac{G_{Counts/electron}\ QE\ (\lambda)_{sensor}\ T_{exp}}{[2(f/\#)(m+1)]^2}\right]\left[P_{edge}\ \lambda\ \eta_{optic\ coupling}\ \beta_n(x,y,z)_{geometry}\right]\left[\frac{\pi\ d_{ECD}^{\ 2}\ \rho_{morphology}}{4\ \Omega_{object}}\right]\left[\frac{\pi\ T_r \cos^4\theta}{hc}\right]$$

Using radiometry to estimate the effective diameter of defects works well even for large sized defects …with some surprises



Defects in fused silica can have an inner crush zone surrounded by a lateral fracture zone.

With edge lighting, photons tend to come from the crush zone, yet we measure the total area…

Including the lateral fracture zone!

True effective circular diameter = 1.76 mm
Radiometry diameter = 1.68 mm (a 5% error)
Resolved diameter in Edge image = 1.76 mm (15% threshold – long axis)

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During the FY06 PDS campaign on NIF this technique was used to estimate the size of the observed sites with success

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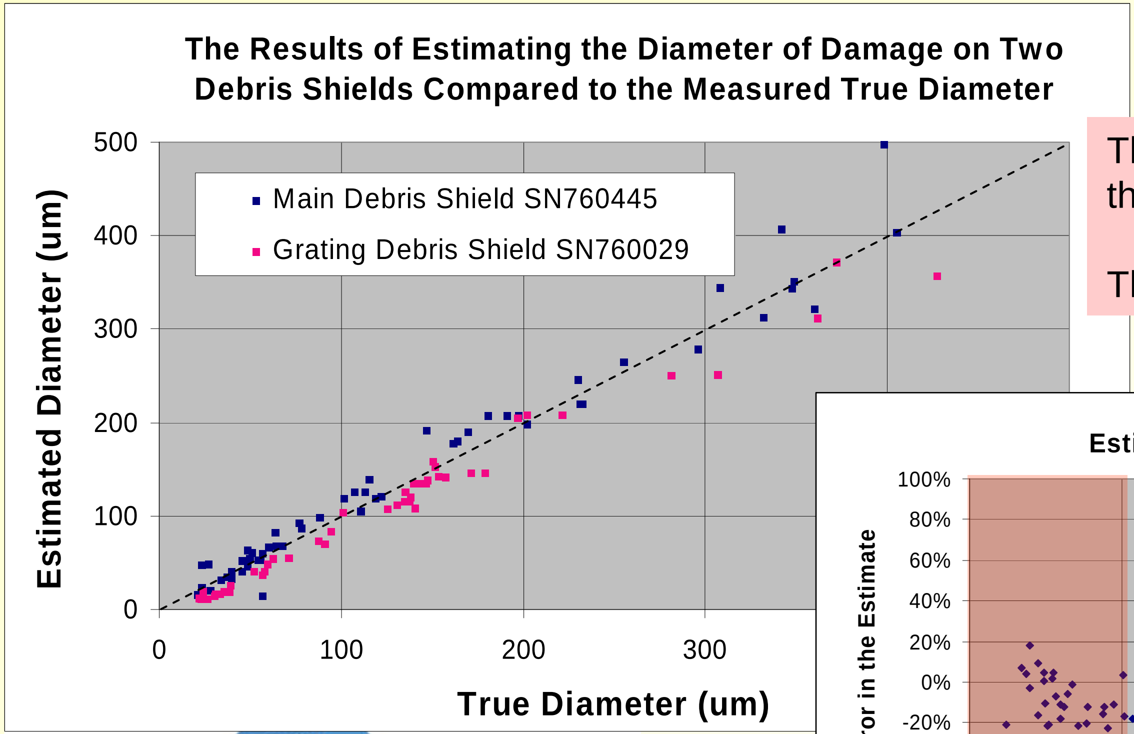
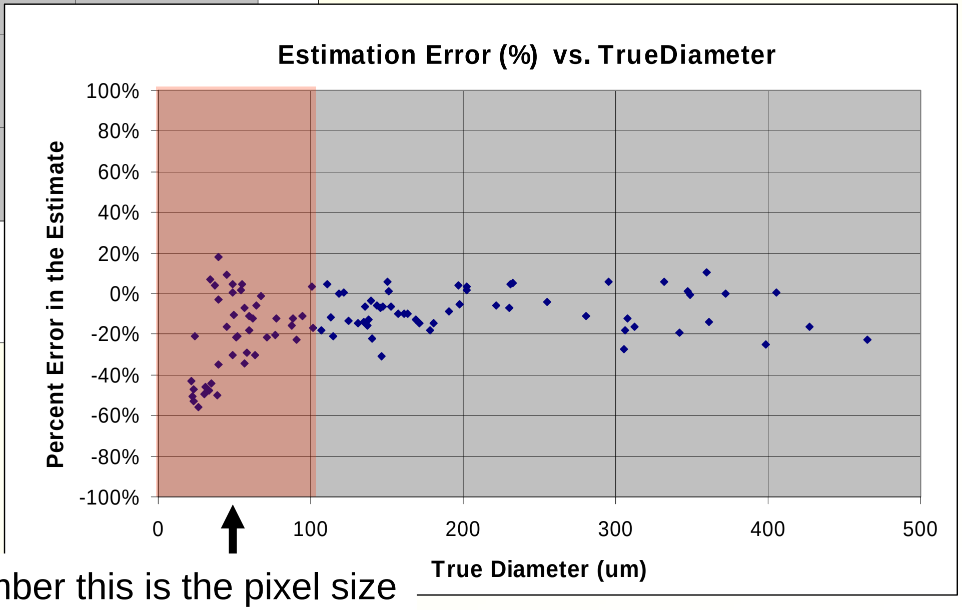
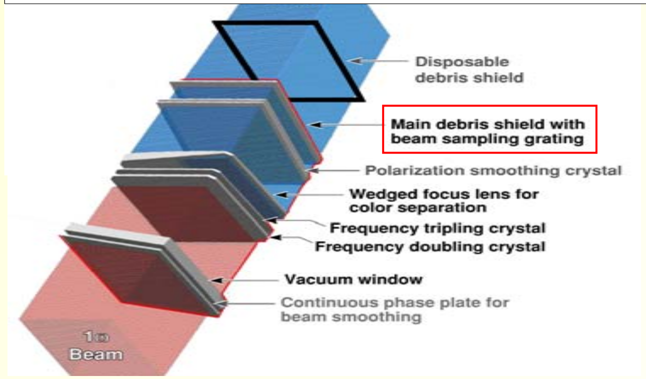


There was over six months between the two data sets

The calibration was very constant!!





Remember this is the pixel size projected at this optic

And we indeed did find the damage site at the third harmonic crystal… we estimated its size to within 2% of its actual size

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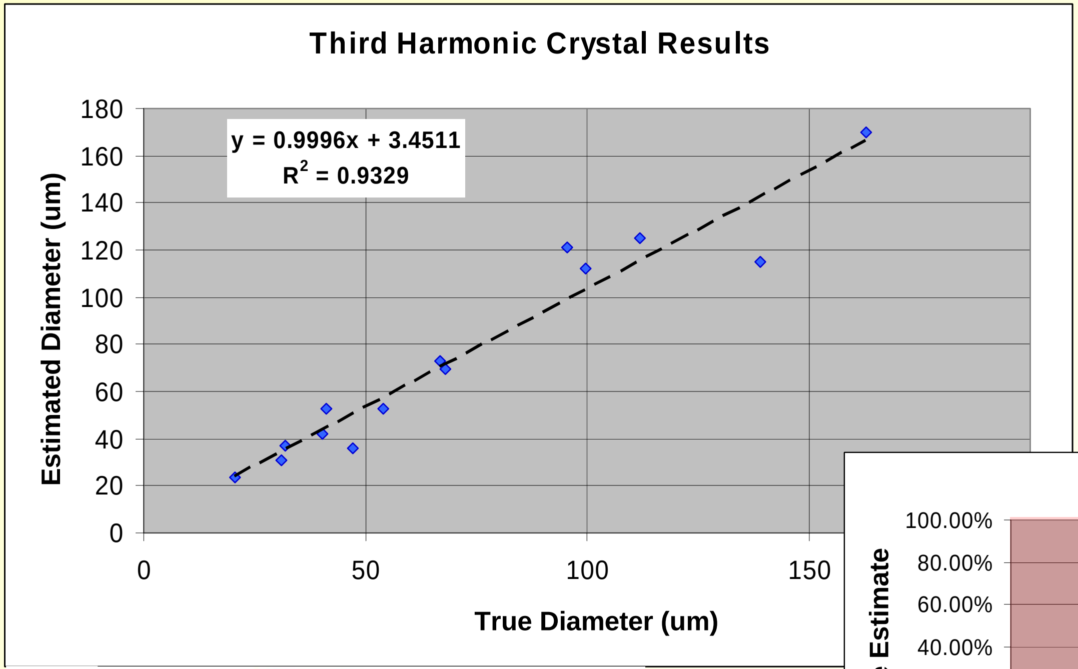

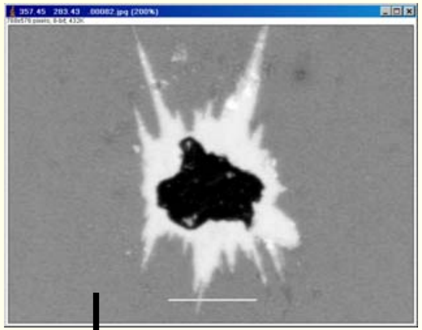

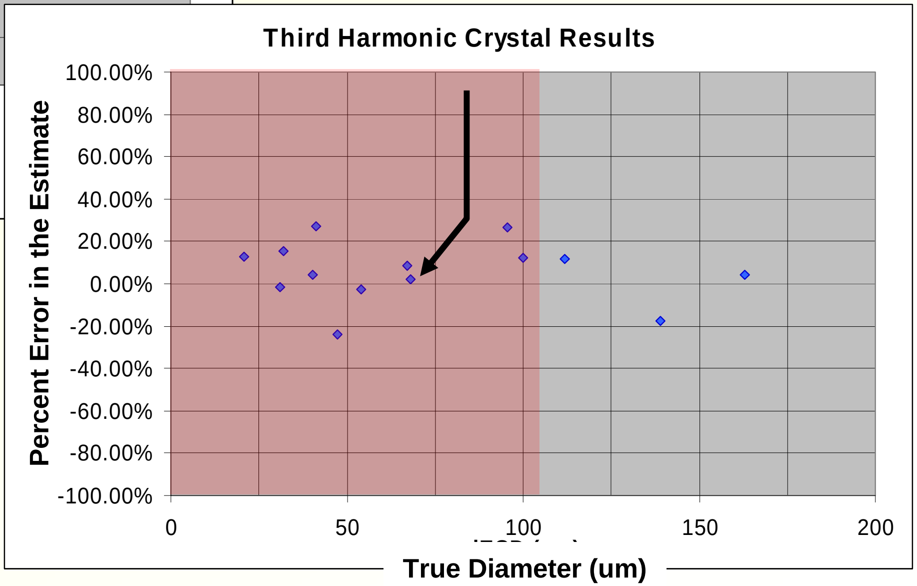

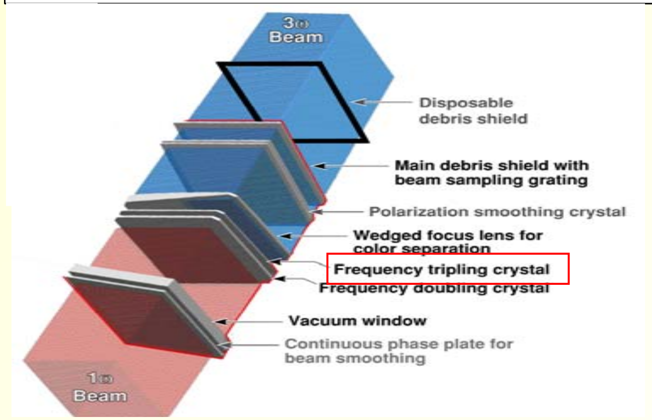

And finally a look at the results for estimating the diameter of damage on the wedged focus lens

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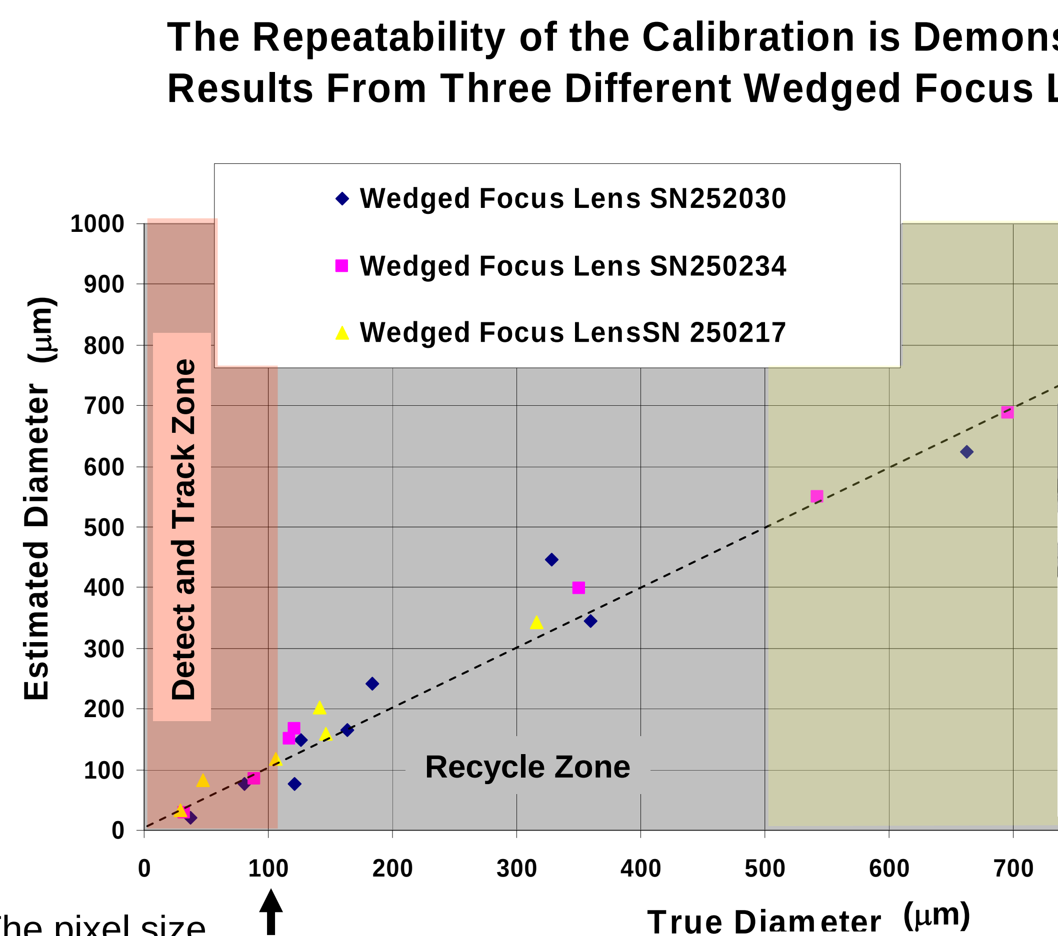

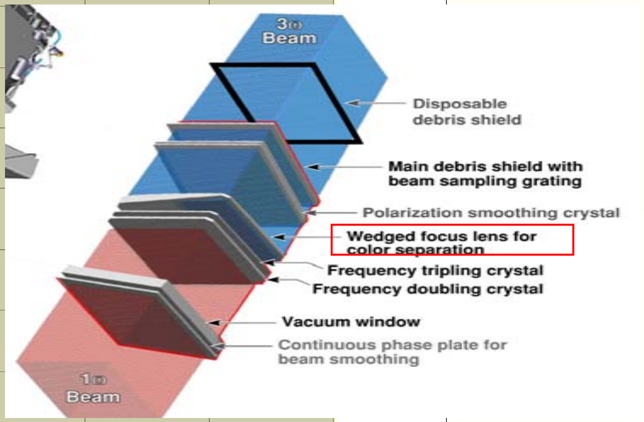

The pixel size projected at this optic

Damage larger than 500μm diameter was intentionally allowed on these optics, and provides a greater understanding of the use of radiometry to size damage sites

We have successfully demonstrated the ability to detect and size unresolved damage sites on optics within the NIF

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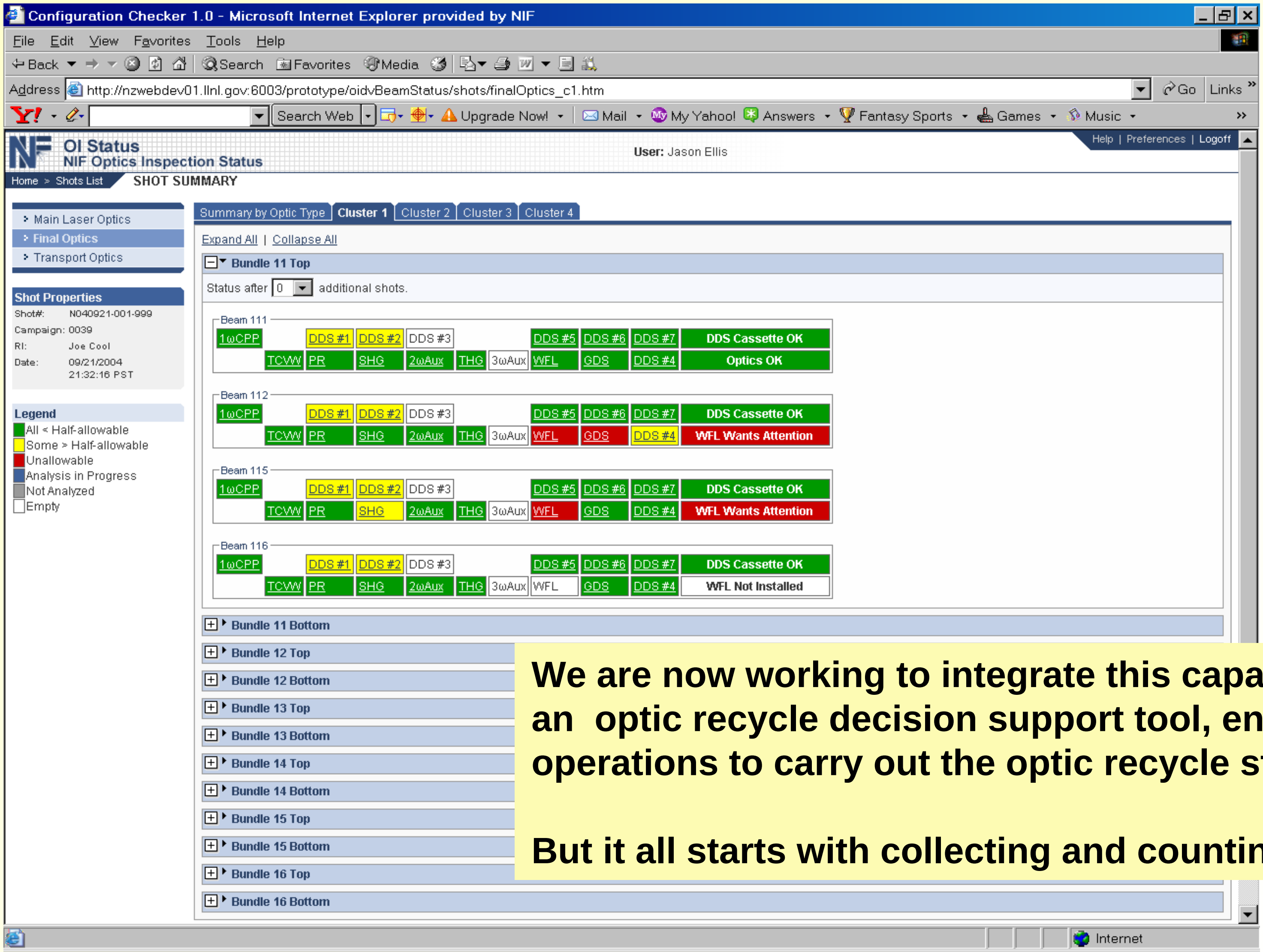

We are now working to integrate this capability into an optic recycle decision support tool, enabling NIF operations to carry out the optic recycle strategy

But it all starts with collecting and counting photons

THE END

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FODI is an optical telescope designed to image the final optics in each of NIF's 192 beamlines…looking for damage or debris.

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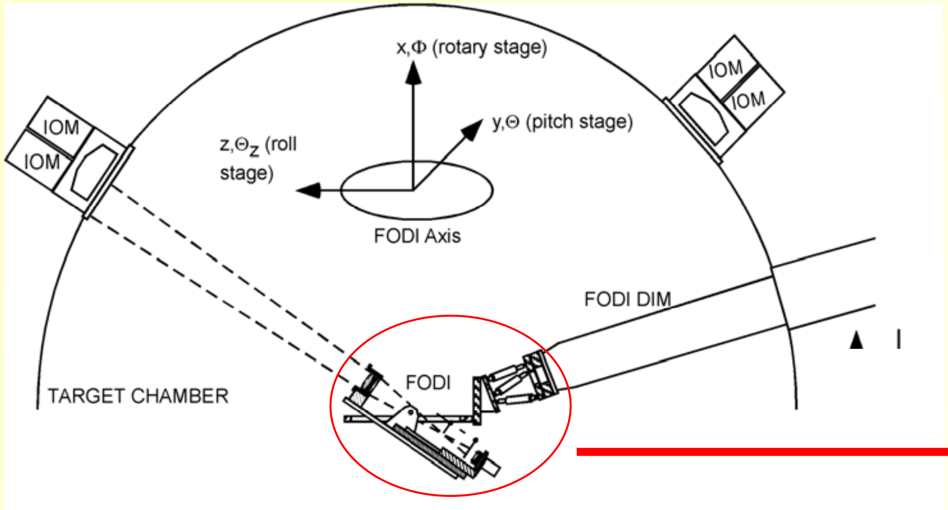

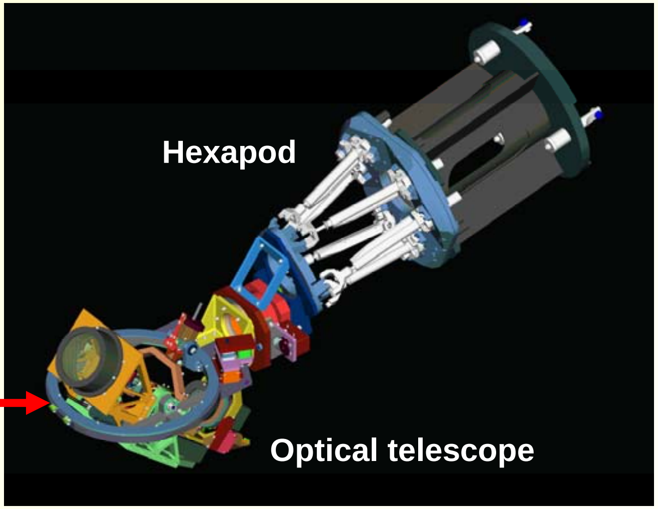

From target chamber center FODI can align to each beamline and image the final optic set.

That's over 1,300 optics!

A view looking inside the NIF target chamber