

NIF



NIF Target Diagnostic Automated Analysis: Transitioning to a User Facility

**Presentation to
CASIS**

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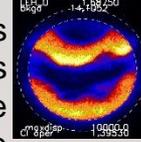
This work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344

Automated diagnostic analysis is used to estimate NIF experimental key performance metrics and enable facility optimization

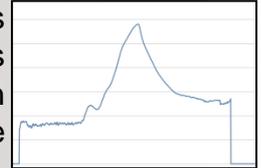
Key performance metrics

- **Temperature:**
 - Hot spot temperature
 - Hohlraum radiation temperature
- **Density** – areal density of hot spot
- **Yield** of fusion reaction– total production of neutrons or gammas
- **Velocity** – measure of capsule radius over time
- **Shape** – symmetry of the implosion
- **Timing**
 - Shock timing
 - Bang time – time of peak fusion reaction
- **Preheat** of the ablator

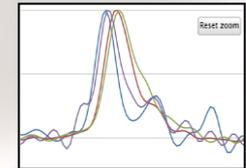
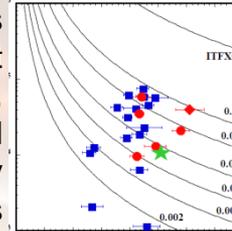
SXI analysis estimates Laser Entrance Hole Closure



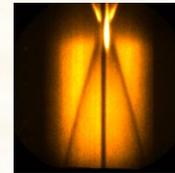
Dante analysis estimates radiation temperature



nTOF analysis reports hot spot temp, neutron yield and density metrics

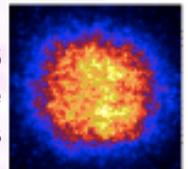


Gamma yield depends on **GRH** analysis

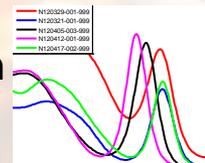
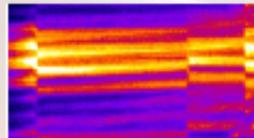


DISC uses camera corrected images

Shape metrics rely on **GXD, Ariane, NIS** timing and image analyses

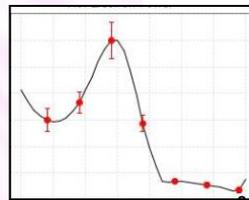


VISAR interferometry analysis enables shock timing

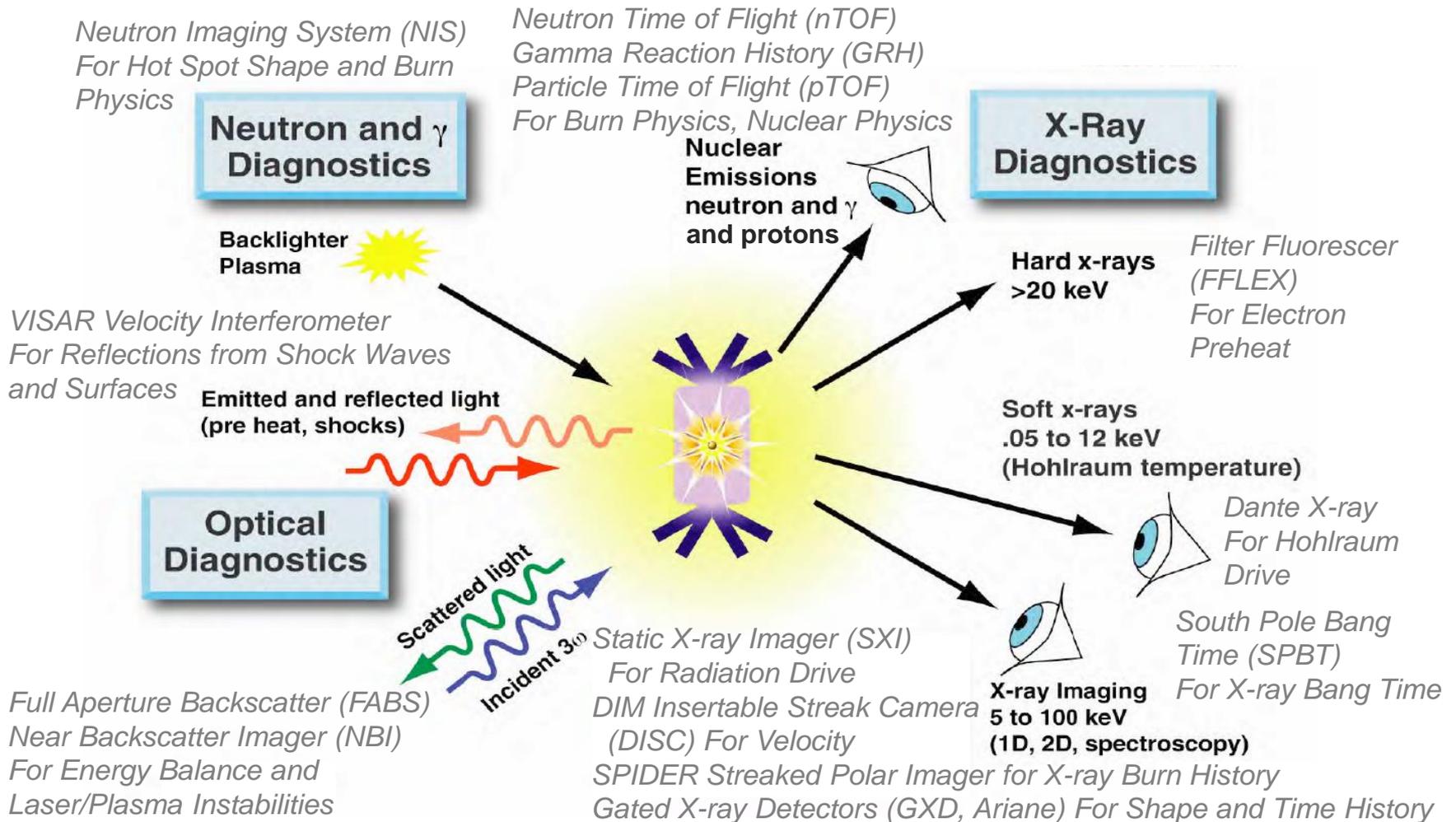


SPBT & GRH analyses report bang time

FFLEX analysis reports hot electrons & preheat



After a NIF laser shot, analysis is automatically run on data from more than 20 target diagnostic systems



Overview from study on shifts needed for diagnostic scientists, setup, and analysis to support the NIF user facility

- **Full automation of diagnostics is feasible with minimum loss of data quality**
 - **Deliver defined standard analysis results within stated errors**
 - **Stretch analysis goals may be compromised (e.g. NTOF velocity)**

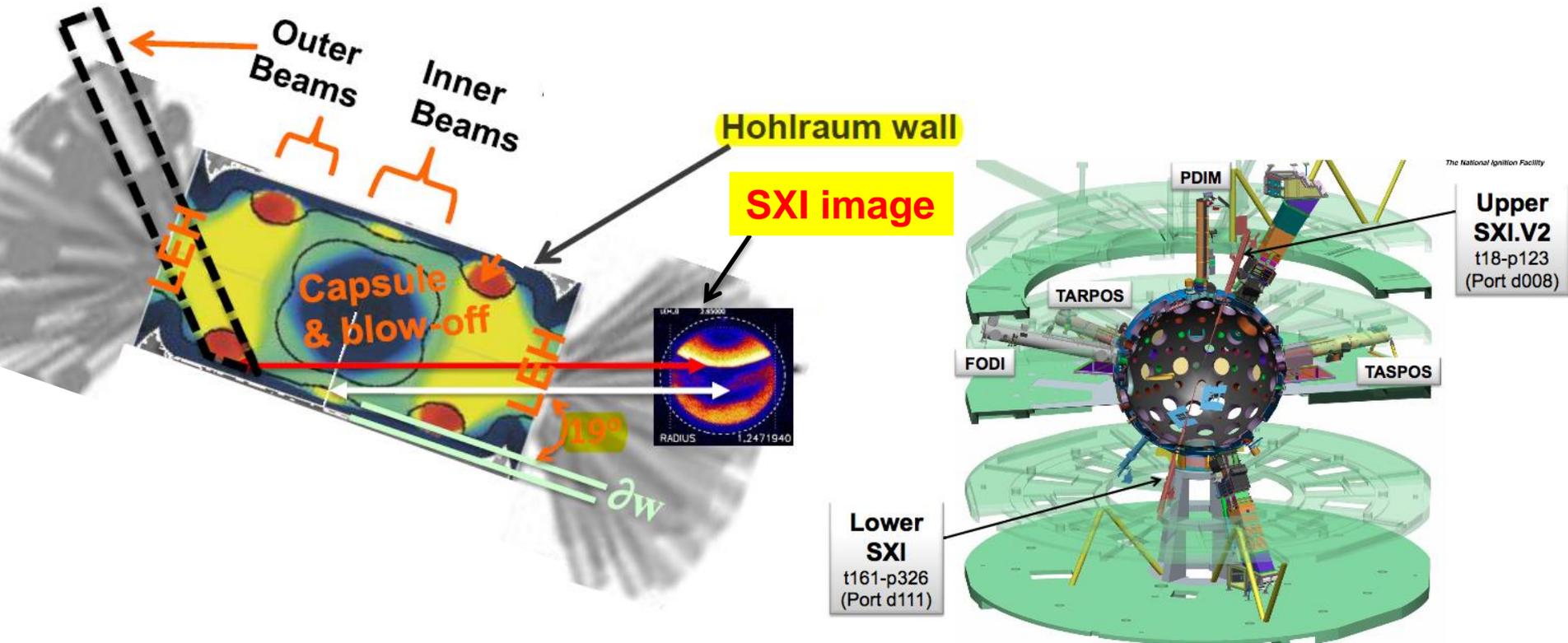
- **Templates can be used to set up diagnostics with little risk to equipment**
 - **Restrict use of some templates based on set up values such as laser energy or neutron yield**

- **All diagnostics require some scientist support to achieve automation**
 - **Implement templates and automated approval**
 - **Analysis requirements updates**
 - **Update calibrations used for automated analysis**
 - **Guidelines and estimators for diagnostic set up**

- **Implementation will require a cultural change**
 - **Program not blame diagnostic scientist for operations failure**
 - **Diagnostic scientist accept operations failure due to incorrect set up**
 - **Diagnostic scientists fully adopt automated processing instead of rerunning manual analysis**

User facility analysis example: Static x-ray imager (SXI)

- SXI uses hohlraum wall to back light the laser entrance hole (LEH) closure
- Two SXI instruments are positioned almost opposite each other within NIF

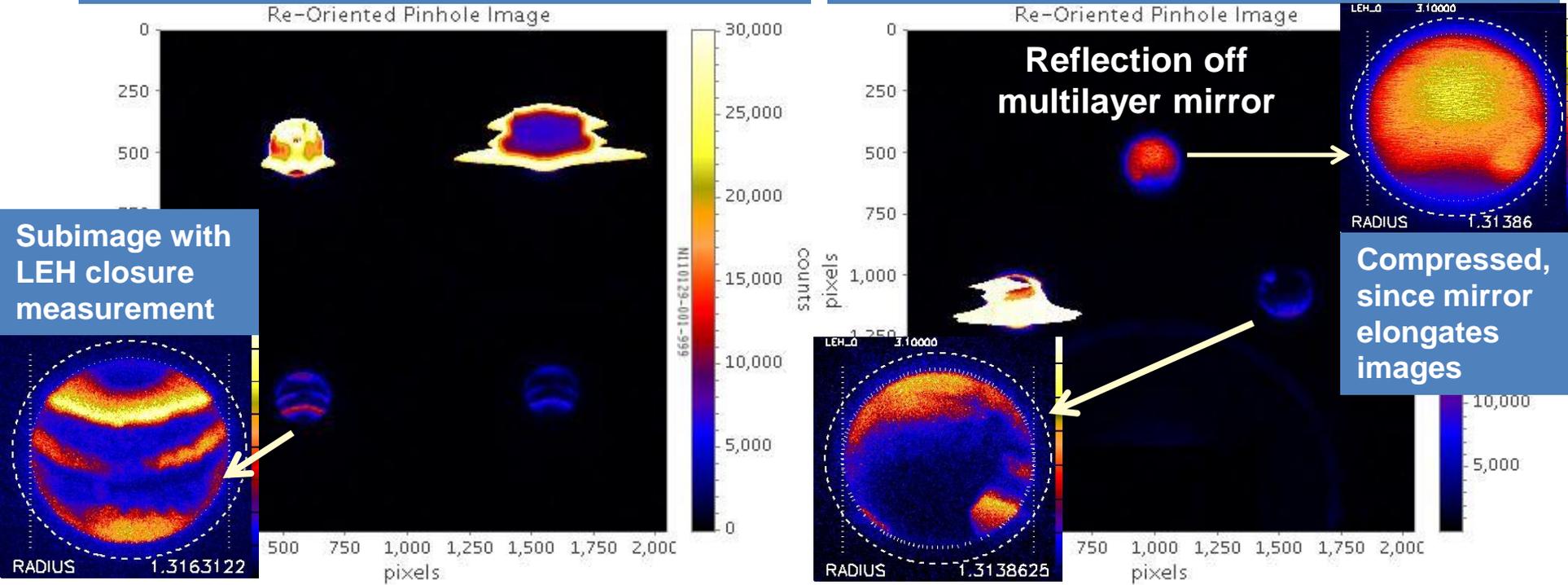


SXI LEH closure size, with Dante, are important for quantifying the energetics aspects of ignition hohlraums and producing radiation Temperature

Introduction to SXI data: SXI-Lower has four hard images, SXI-Upper has two hard and one soft (mirror channel) image

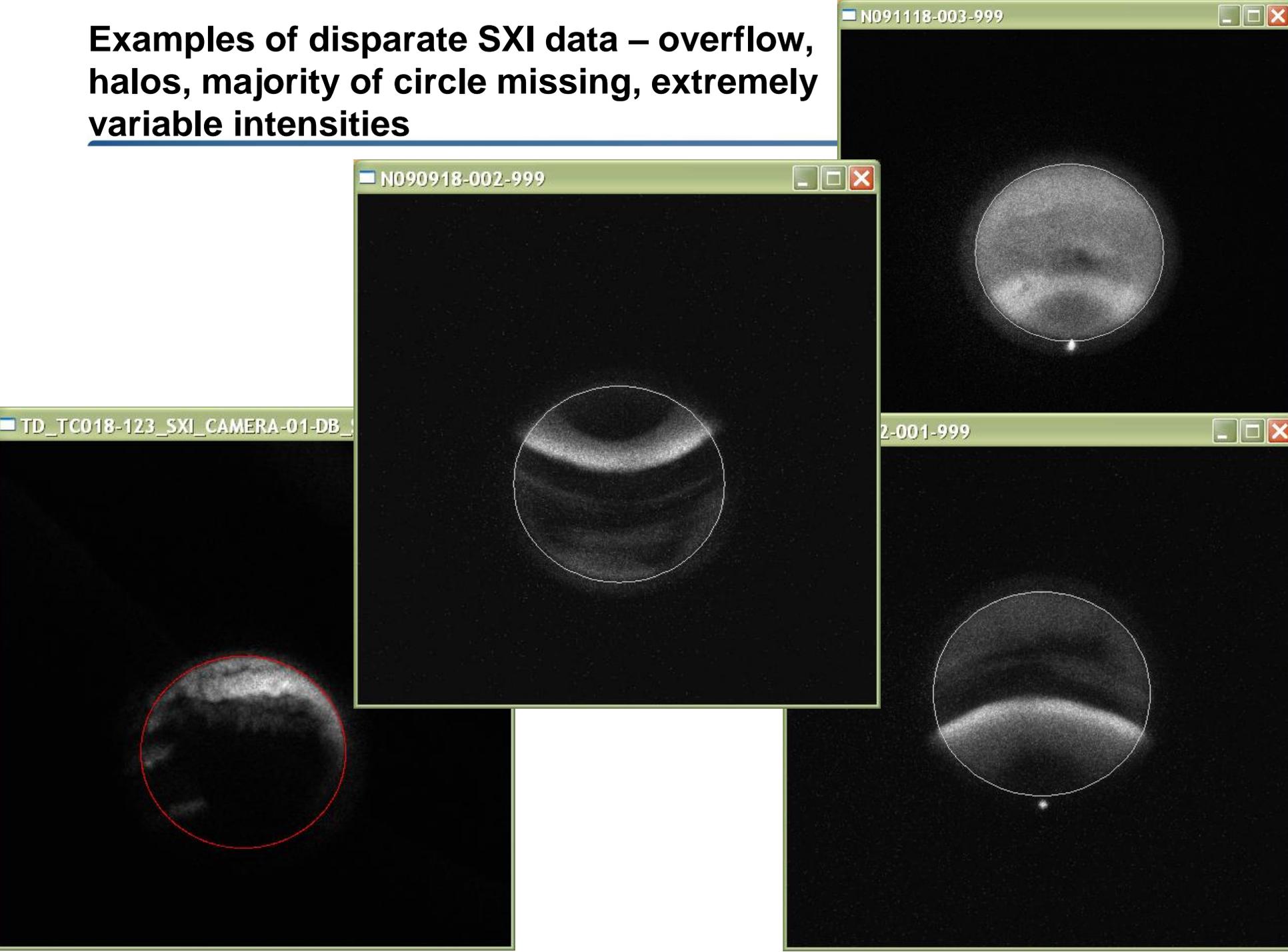
SXI-Lower Pinhole image (used for pointing)

SXI-Upper Pinhole image (used for pointing)



- Key Goals for Analysis Measurements:
1. Size of Clear Aperture in SXI-Lower
 2. Size of Clear Aperture in SXI-Upper hard image
 3. Fraction of counts in SXI-Upper soft image within Clear Aperture of SXI-Upper hard channel
 4. Pointing and magnification of SXI instrument, identified by centroiding all pinhole images
 5. Brightness of beam spots (currently requires manual analysis)

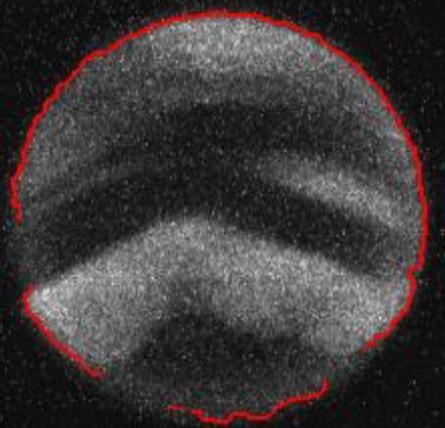
Examples of disparate SXI data – overflow, halos, majority of circle missing, extremely variable intensities



Accurate segmentation is achieved using Isodata & minimum perimeter threshold, adaptive threshold removes outer pixels in areas of low standard deviation

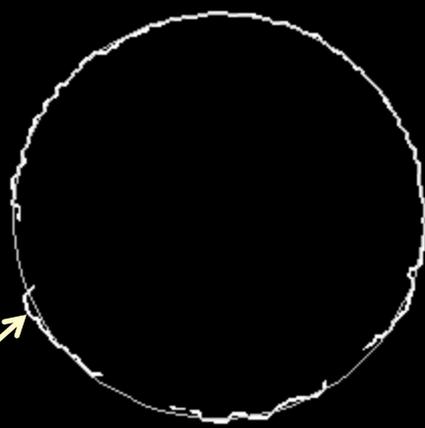
IDL 0

After segmentation, adaptive & morphological filtering, edge finding, and preserving only outermost pixels:



IDL 36

Find top 10% of best fit circles using Hough Circles, evaluate based on ave 'gap density' and 'gap density' stddev around circle to choose best candidate:

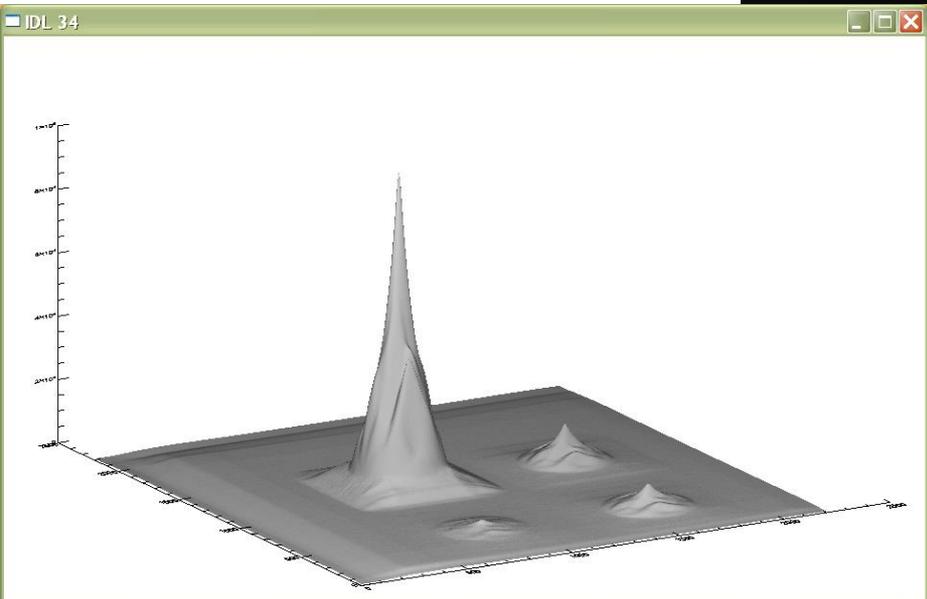
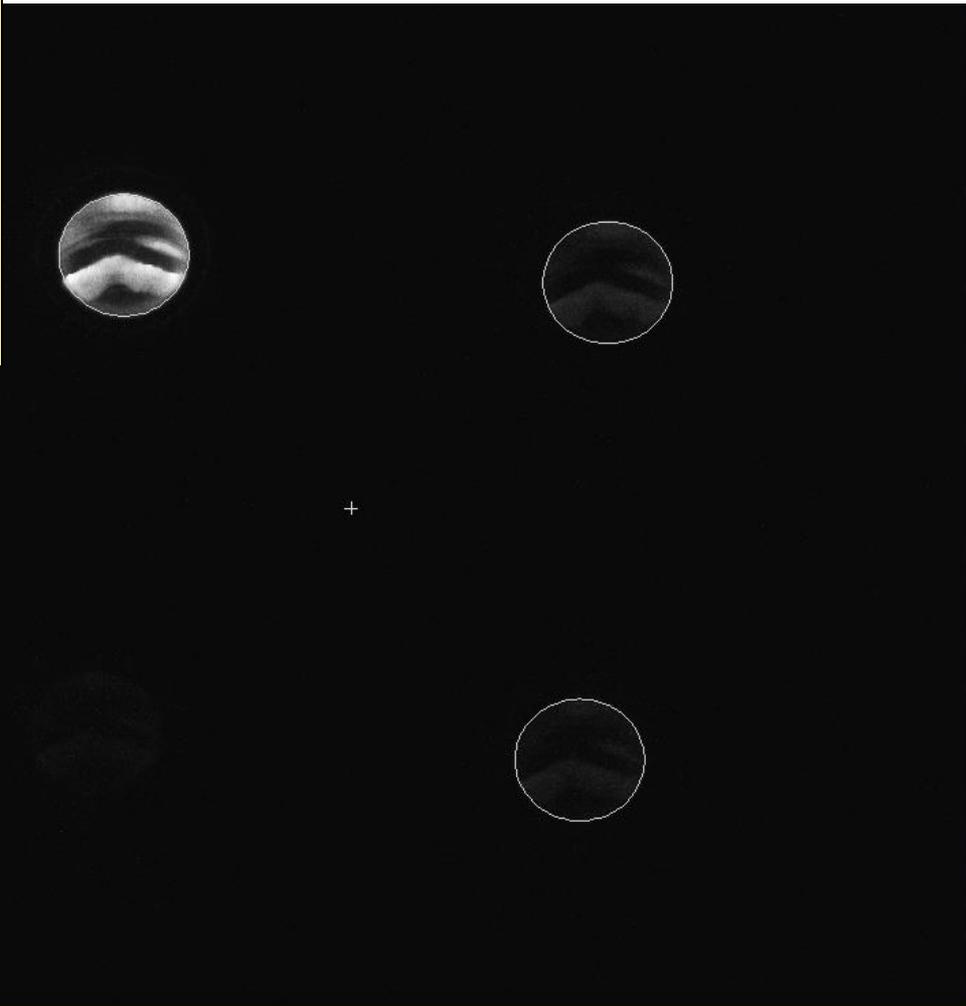


Gaps are the distance between data perimeter and circle candidate

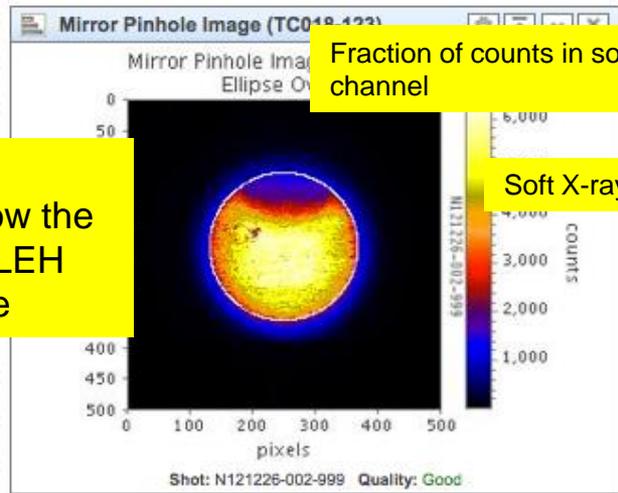
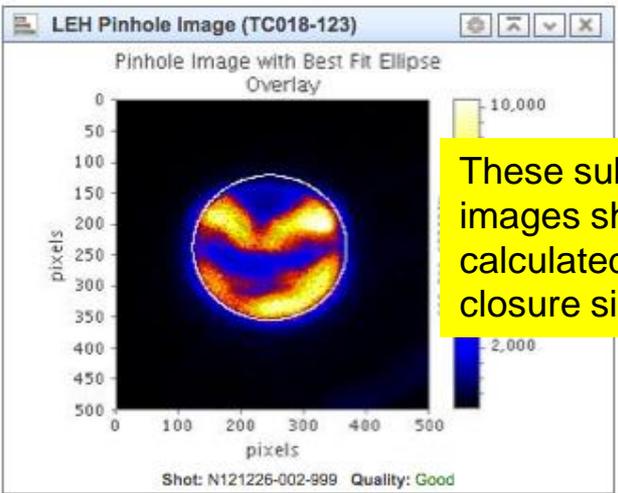
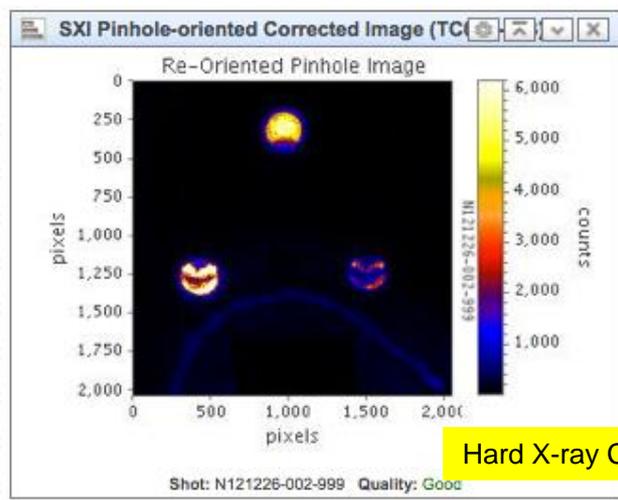
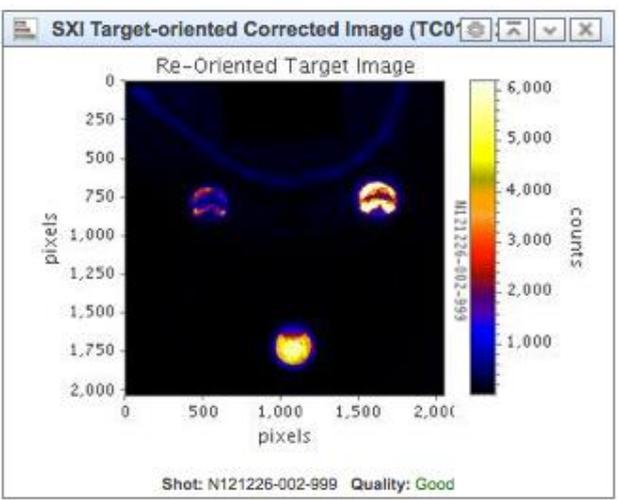
SXI pointing & magnification calculations require accurate centroiding of all pinhole sub-images

Match filtering is used to identify all candidate pinholes. Compare autocorrelation metrics with candidate peaks to identify pinholes:

- Pedestal: Number of pixels in the top 80%
- Formfactor (shape evaluation)
- Expected vertical & horizontal pairings



SXI-Upper automated analysis results dashboard



These sub-images show the calculated LEH closure size

Hard X-ray Clear Aperture

Fraction of counts in soft channel

Soft X-ray Diameter

SXI Related Links

- [Re-run Analysis](#)
- [Setup Report XLS](#)
- [Part Configuration XLS](#)
- [Part Calibration XLS](#)
- [Taxon Calibration XLS](#)

SXI Discussion

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SXI LEH and Mirror Region

Metric	Value
Quality:	Ok
Orig. LEH Diameter (mm):	
LEH Diameter:	2.938 mm
LEH Radius:	121.9 pixels
Mirror Count Fraction:	.211
X, Y LEH Center:	244.139, 238.102 pixels
X, Y Mirror Center:	965.128, 321.912 pixels
Mirror Diameter:	2.825 mm
Mirror Radius:	117.2 pixels

SXI Alignment (TC018-123)

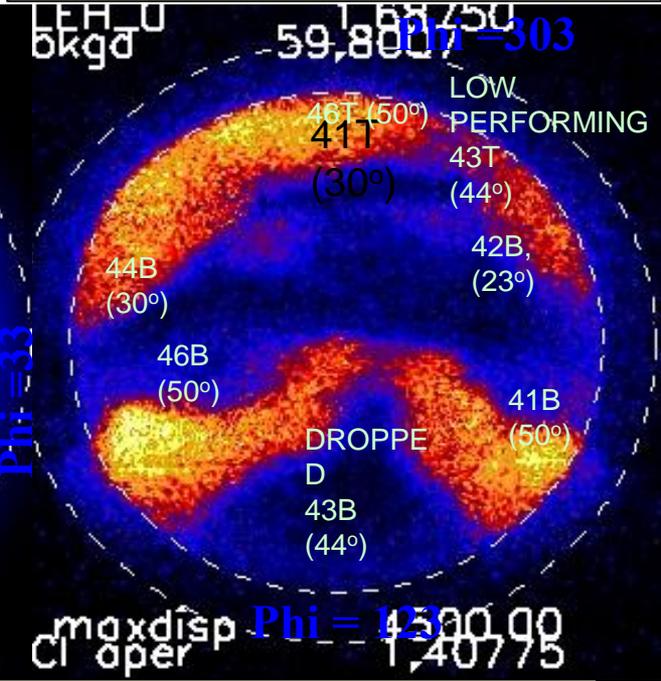
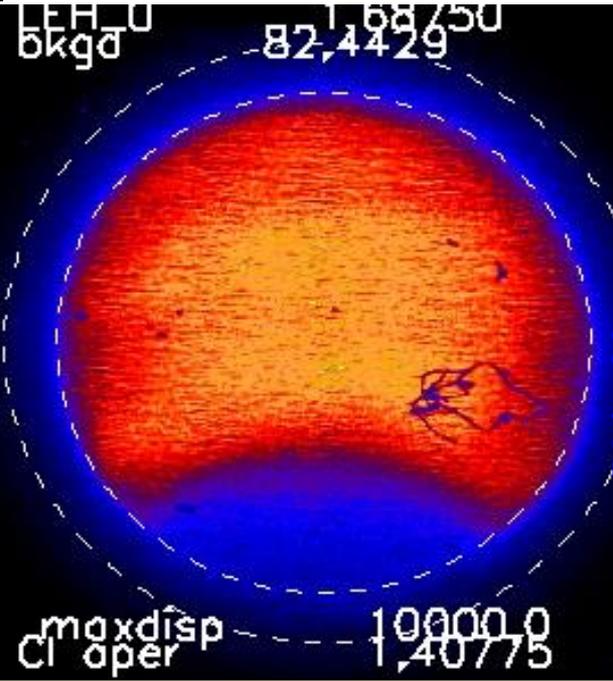
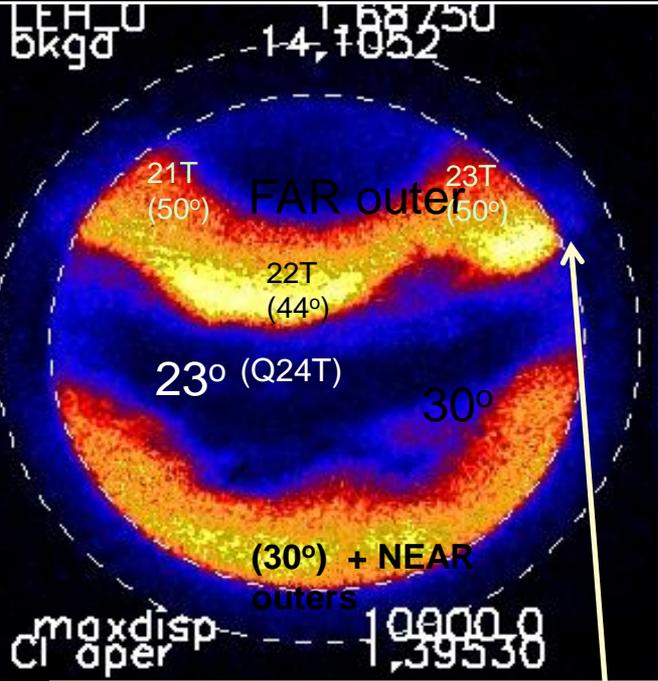
Metric	Value
Quality:	Ok
Magnification:	1.992
X, Y Pointing Offset:	.669, -2.808 mm
X, Y Pointing Offset:	55.5, -233 pixels

Example of the diagnostic scientist's analysis results report

SXI-Lower 50 μ m Ti + 75 μ m Be (different snout)
CLEAR Aperture: 2.79 mm

SXI-Upper 870 eV image
88.0 % is within SXI-U clear aperture 40 μ m PH

SXI-Upper 50 μ m Ti + 2 μ m Cu + 1 μ m polyimide
CLEAR Aperture: 2.81 mm



- MEASURED:
1. Size of Clear Aperture in SXI-Lower (calculated with independent algorithm)
 2. Size of Clear Aperture in SXI-Upper hard image (calculated with independent algorithm)
 3. Fraction of counts in SXI-Upper soft image within Clear Aperture of SXI-Upper hard channel
 4. Brightness of beam spots (based on scientist inspection)

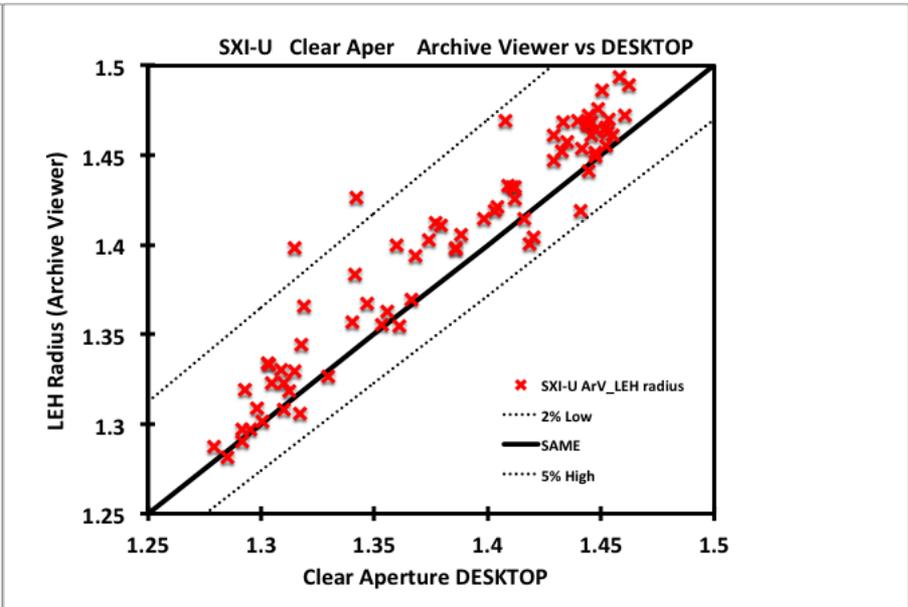
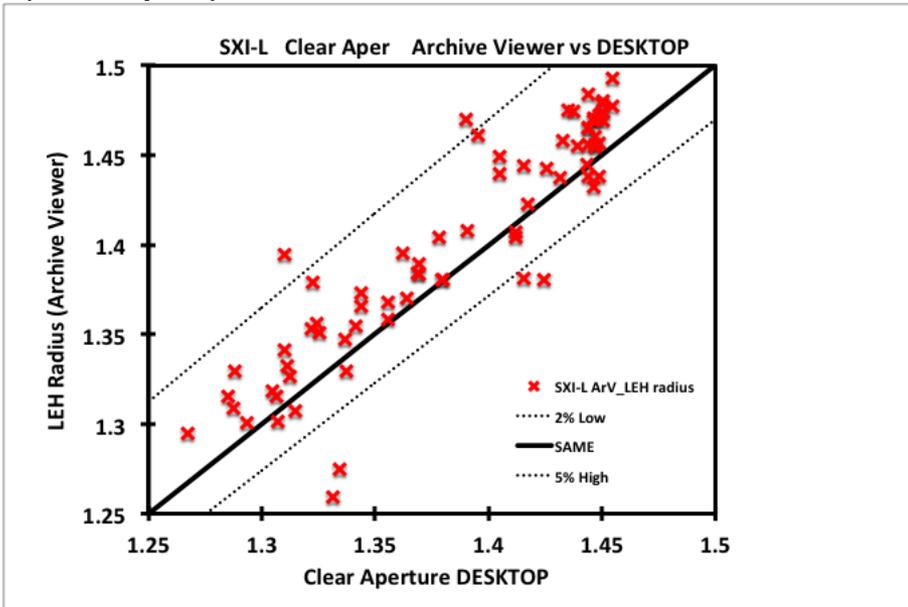
Comparison of scientist manual analysis of clear aperture to automated analysis

SXI-L Clear Aperture

Automated analysis tends to be ~ 2% high (~ 30 μm)

SXI-U Clear Aperture (3-5 keV)

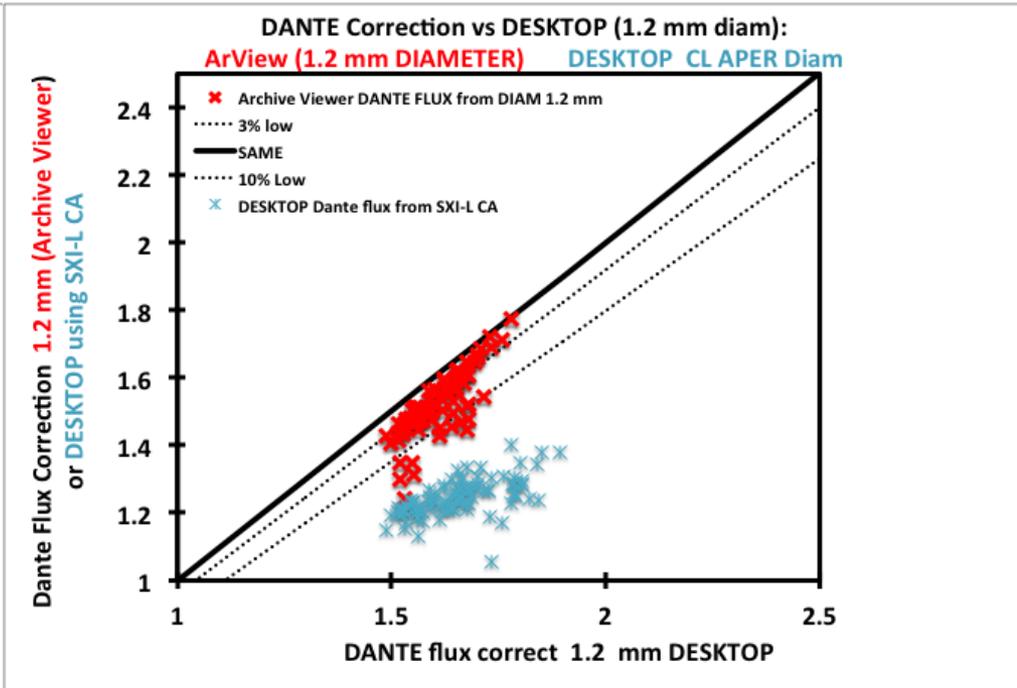
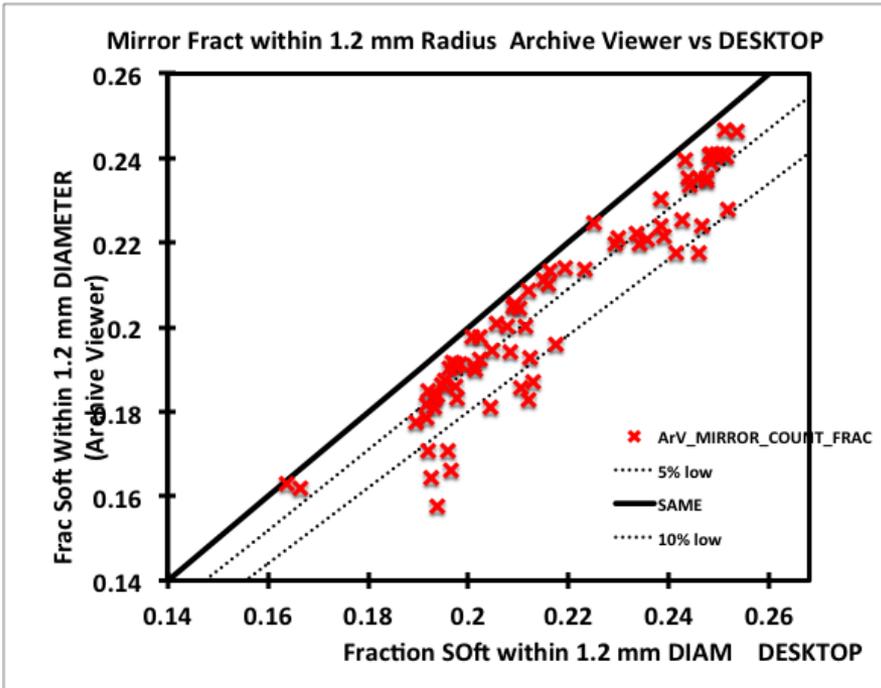
Automated analysis tends to be ~ 2% high



Comparison of scientist analysis to automated for ultimate goal, DANTE flux correction

Fraction of Soft image counts within 1.2 mm diameter
Automated analysis is ~ 4% lower

DANTE Correction
 $(\text{frac} * (\text{Orig_LEH} / \text{diam})^2)$
 Automated analysis about 3-5% lower on average



- Scientists requested update to diameter used to calculate fraction

Review how SXI automated analysis will meet diagnostic shift towards NIF user facility

- **Full automation of diagnostics is feasible with minimum loss of data quality**
 - Deliver defined standard analysis results within stated errors
 - **Stretch analysis goals may be compromised (e.g. SXI beam spot analysis)**
- Templates can be used to set up diagnostics with little risk to equipment
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- **All diagnostics require some scientist support to implement automation**
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 - **Analysis requirements updates**
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NIF

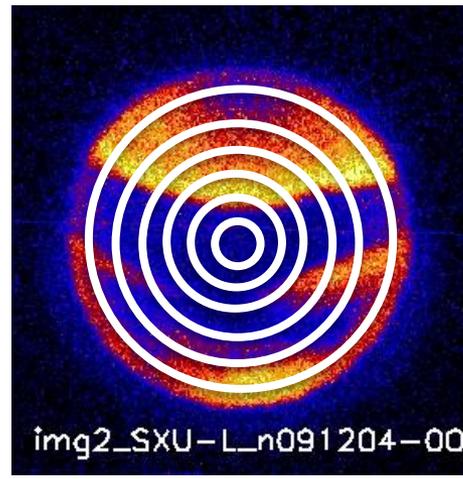
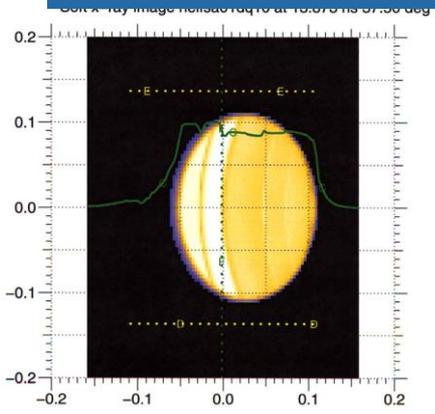
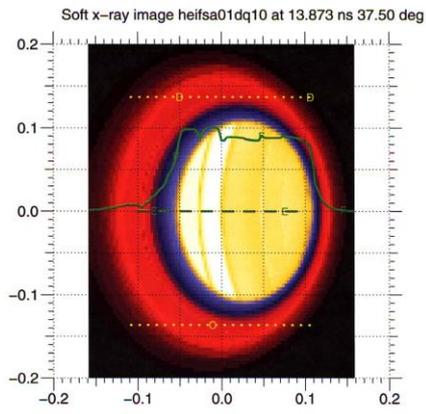


To calculate fraction of counts inside certain Diameter vs Diameter in Soft image, stretch image & calculate radial distribution function

Simulation of DANTE view of LEH: notice flux

The flux inside the "clear aperture" is used to calculate flux onto capsule

IMAGE stretched vertically by $1/\cos(19^\circ)$ to be circular



Calculate radial distribution function (RDF)
Then fract counts within each diameter vs diameter

Find LEH diameter – outline of LEH size estimation algorithm

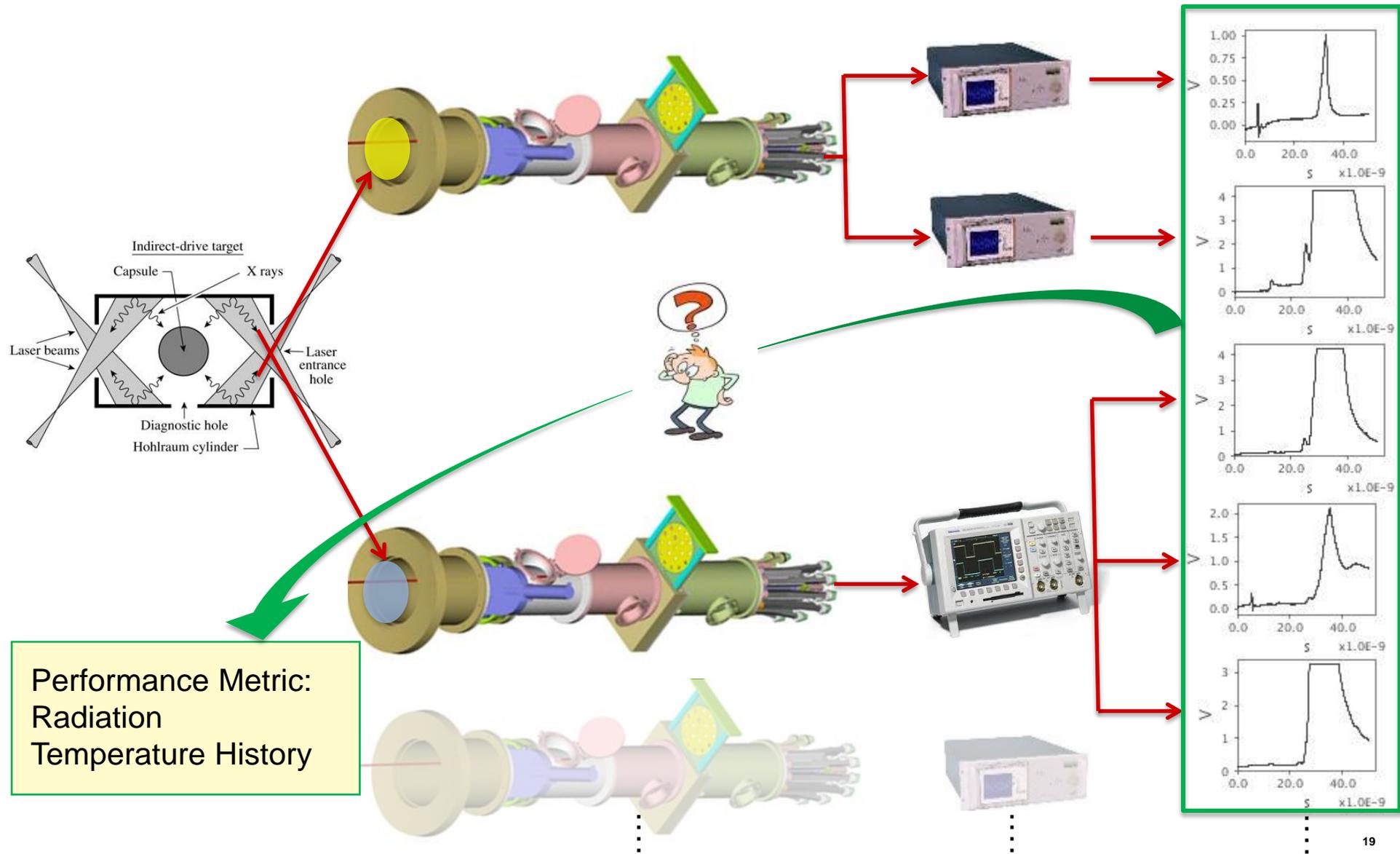


- Set expected width of pinhole subimage (500x500 pixels), border size (100 pix), approx radius (100 pix)
- Run `td_identify_2d_region` – finds general regions using isodata threshold (or if that fails uses simple % threshold) & ignoring border. Smooths and dilates to connect neighboring regions, still pinholes are often broken up.
- Find second brightest pinhole: chose region with second greatest median (correctly orders regions if there is a very bright spot in one).
- Stretch in the x direction to make circular from oval: use `congrid`
- Main segmentation:
 - `new_min_perimeter_thresh` searches for threshold that creates the minimum perimeter. Need to input the minimum area accepted and the amount of dilation/erosion to use.
 - Also find the isodata threshold, apply the average of the min perimeter and isodata thresholds
 - Remove extra particles with a morphological opening
 - If the threshold resulted in less than half of the expected circle size, use a morphological closing to fill in any gaps.
 - Apply a new adaptive thresholding routine. This routine checks the local `stddev` and greyscale values around each edge pixel. If the edge pixel is less than 25% above the min value in that local region, it is removed. If the local `stddev` is very low, that edge pixel is removed (edge is currently on a plateau). Basically we are trying to remove pixels that are not actually on the edge. This routine goes through 10 iterations, optionally removing one pixel deep around the outside of the mask each time.
 - Remove small holes and indents with morphological closing
- Remove the small dot that is outside of the circle – look for a small separate region that is at the max or min y, and either has a high median value or is very small compared to the biggest three region sizes. This dot was confusing the estimated radius and circle finding algorithms.
- Find the edges of the mask, use correct morphological filter to not double count diagonal pixels
- Remove the middle points of the circle (sometimes these were very close to the outside edge and confused the algorithm). To do this first find the approximate center of the circle using the min x, max x, min y, max y. Check to make sure the min y and max y are available at ~ the correct x location. The top or bottom is often missing, if so use the available one and the radius from the x dir. Once you have the center, find the distances and angles from all points to the center. Remove all points with the same angle except the one with the maximum distance from the center.
- Create a big range for possible radii centered on $\max(\max x - \min x, \max y - \min y)$
- Find all circles that fit the edges (to 90% of best fit) using `hough_circles` routine: `circlehoughlink`, pass in radii array.
- Find the max gap size, average gap density and `stddev` gap density for all circle candidates. These are based on the distances between overlapped pixels of the circle candidate and the outlined edge, each such distance is called a gap. The ideal candidate would have a max gap size of 0. The gap density is the number of overlaps over the total number of pixels in the nearest 1/6th of the circle. This is implemented with a smooth operation. The ave gap density should be high for a good match and the `stddev` of the gap density should be low – we want the best fit circle to fit equally well all the way around the edge contour.
- Choose the final circle: choose the best hough circle if it has a good enough `stddev` gap density and there isn't a candidate with both better `stddev` and ave gap densities. Otherwise look for circles with good `stddev` and ave gap densities and choose the one with the best ave. If there aren't any of these, go with the circle with the minimum `stddev` gap density, however if that one has an extremely low ave density go with the first hough circle

Outline of Pointing/Magnification estimation

- Find the rest of the pinholes by template matching with the one we located exactly.
 - Compute metrics about the autocorrelation peaks to compare with candidate peaks:
 - Pedestal: Number of pixels in the top 80%
 - Normalized autocorrelation region
 - Formfactor (indicates shape)
 - Compute evaluation tests on each subsequent template match peak:
 - Ratio between the auto pedestal and this peaks' pedestal (should be between 1 and 10)
 - Mean squared error between the normalized region and the auto normalized region (should be low, $<.3$)
 - Ratio between the auto formfactor and this peak's formfactor (should be close to 1)
- Identify the distances between pinholes & find magnification
 - Search through all pairs of points, identify vertical pairs and horizontal pairs. If a point doesn't have a pair then that pinhole location is invalid
 - Identify exactly which point in the square each pinhole location is. A third point in the middle will not be considered.
 - Ave distances between all valid pairs and use that to calculate the magnification.
- Identify the center point of the pinholes and find pointing
 - If you have two corner points use those to compute the center
 - Otherwise, use trigonometry and the two side points to compute the center. Assume the length of the missing direction equals the distance between the two points.
 - Pointing offset will be difference between this center and the center of the original image (this image will have the active region cut out).

Novel signal & image processing is needed to turn raw diagnostic data into the key performance metrics

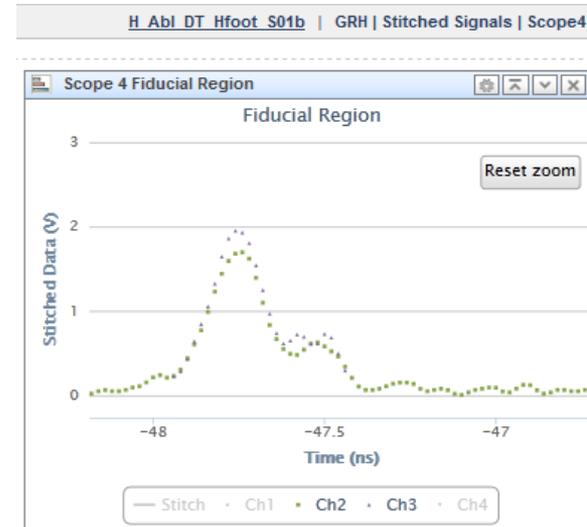


Performance Metric:
Radiation
Temperature History

Two critical components of automated analysis are supporting NIF operations and maintaining calibration data

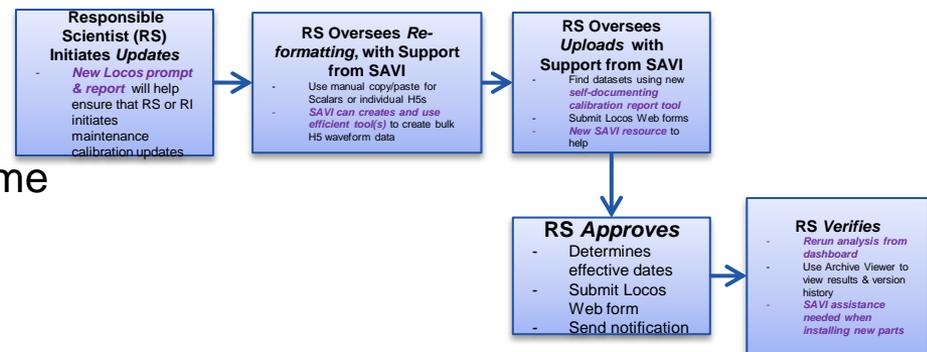
- **Handling operational off-normal data**

- Diagnostic raw data may be different than expected due to hardware redesigns, detector malfunctions, abnormal shot types, noise, etc.
- Review one example: Gamma Reaction History (GRH) peak suppression discrepancies between channels.

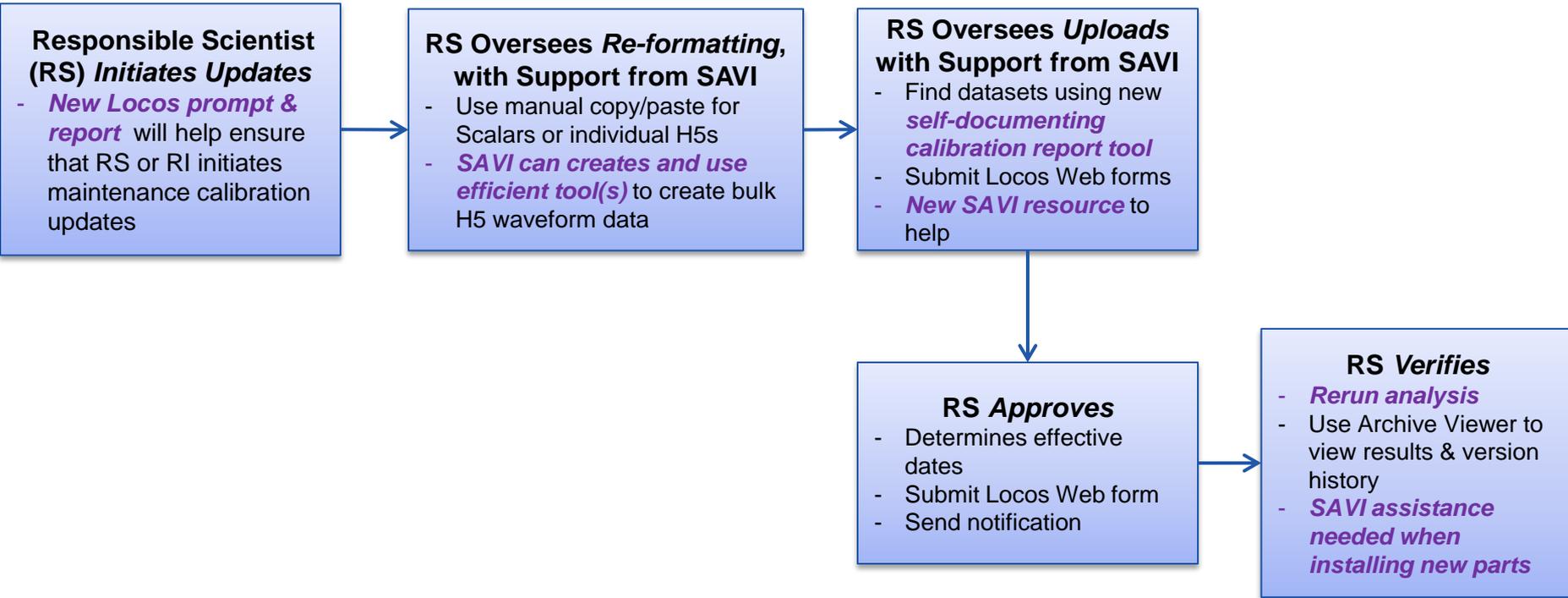


- **Calibration maintenance design**

- Analysis relies on a gargantuan amount of calibration data
- Review example of oscilloscope time base calibration for DANTE
- Review scope of the maintenance feat



Partnering with scientific diagnostic teams to define calibration maintenance flow and design tools



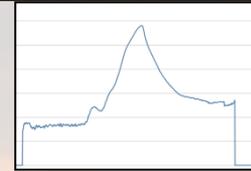
Analysis (SAVI) team is instrumental in the process of maintaining calibration data and thereby ensuring the success of target diagnostic algorithm automation and robust accurate results.

Supporting operations, calibration, quality assurance and new analysis automation are the foundation for successful automated target diagnostic analysis

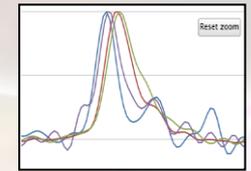
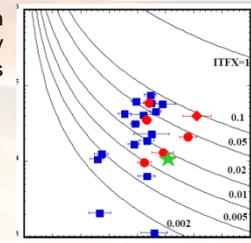
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- **Shape** – symmetry of the implosion
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- **Preheat** of the ablator

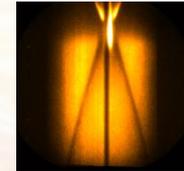
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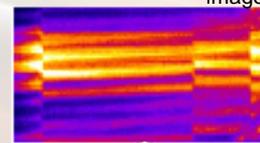
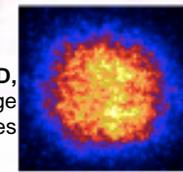


Gamma yield depends on GRH analysis

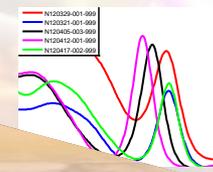


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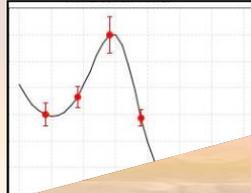


VISAR interferometry analysis enables shock timing



SPBT & GRH analyses report bang time

FFLEX analysis reports hot electrons & preheat



Operations Support
for changes & off-normal shot data

Calibrations Support
Creation design & maintenance tools

Quality Assurance
Unit and integrated testing

New Analysis & Automation
Automating new diagnostics and furthering existing