Image Plate Data Processing on the National Ignition Facility

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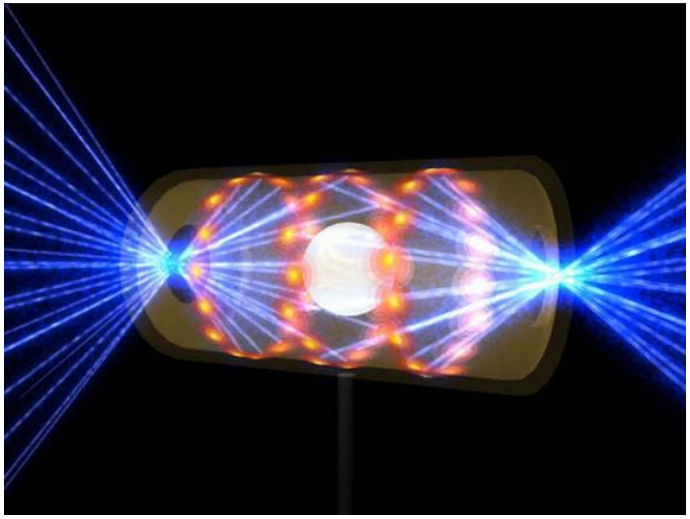
National Ignition Facility



National Ignition Facility – World's most energetic laser (1.8 MJ @ target)

Enables research in inertial confinement fusion and high-energy density science

Produces large amounts of radiation (neutrons, X-rays)

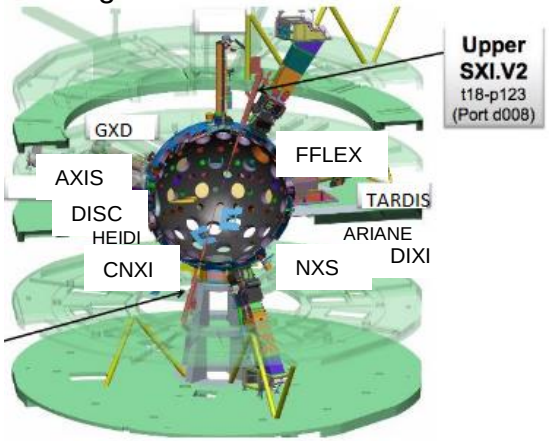
NIF Diagnostics

- **Numerous imaging diagnostics**
- **Hard radiation and conventional electronic imaging camera technologies (CCD, CMOS) do not work well together**

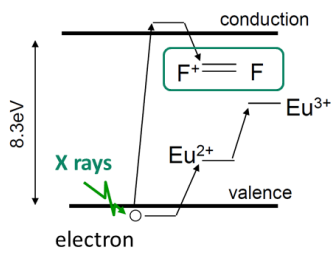
Image Plates

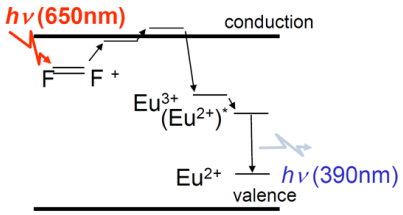
Image plates: Radiation detecting plates used for recording images

IP's used for various diagnostics in NIF chamber



Exposure & Readout Processes in Image Plates





Exposure: X-ray signal is stored in form of electrons that are "trapped" in color centers (metastable) in the band structure

Readout: Laser light in IP scanner (650 nm) excites these electrons into the conduction band from which they can radiatively decay into a stable state, thereby releasing a blue photon (390 nm). The amount of blue light (photodiode measurement in the IP scanner) is proportional to the number of released color centers.

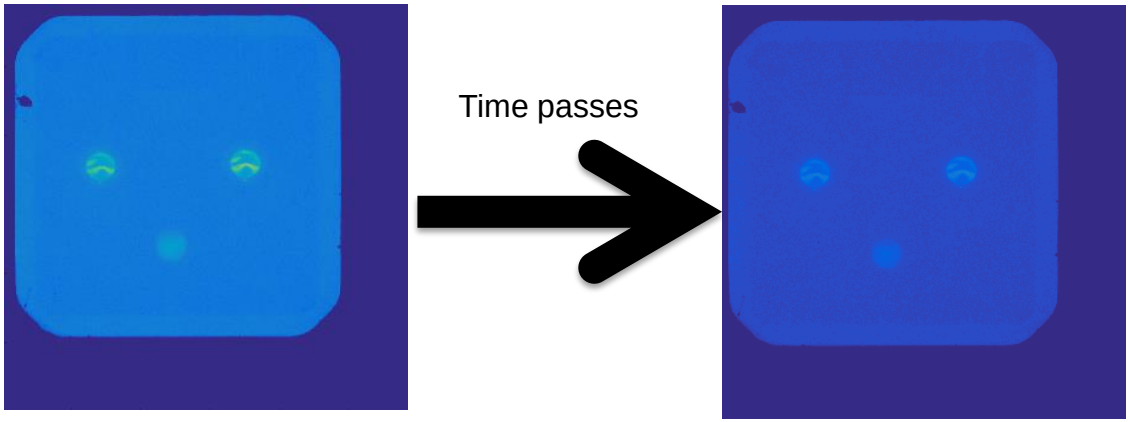
sketch of photostimulated luminescence adapted from N. Izumi et al. (ICOPS 2009, HTPD 2006); details can be found in Y. Iwabuchi et.al. Journal of Luminescence 48 & 49, 481 (1991).

Image plates are manually transported and scanned after shots; data is uploaded to NIF cluster

GE IP Scanner

Image Plate basic corrections

Image plate signal strength fades with time and with each readout—a correction is needed



$$FF(t) = 1 + \sum_{n=1}^{7} a_n \times \left[\log_{10}\left(\frac{t(\text{sec})}{1200} \right) \right]^n$$

a_n calibration coefficients are empirically determined for each plate

$$PSL_{@20\,\text{min}} = \frac{PSL}{FF(t)}$$

Convert to corrected physical units

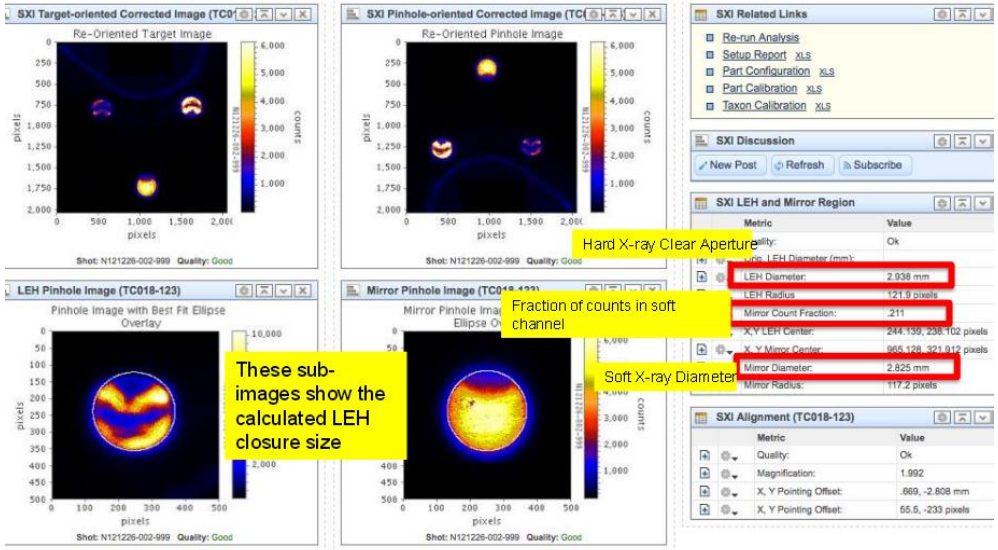
The pixels are not exactly square -> An anamorphic correction is applied to handle slight variances in the scanner readouts

Static X-ray Imager (SXI)

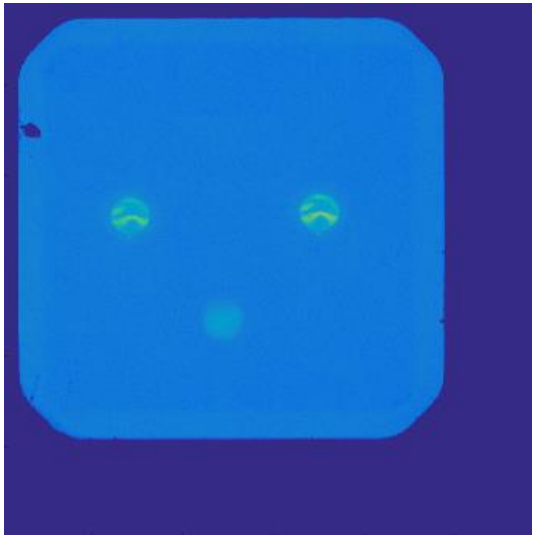
SXI is a pinhole camera that captures X-ray images of Hohlraum laser entrance hole

Uses CCD for most shots; needs image plate for high-yield DT shots

Algorithm already exists for CCD shots; uses Hough transform + template matching to find/analyze pinhole images



Needs to be adapted for image plates with neutron background



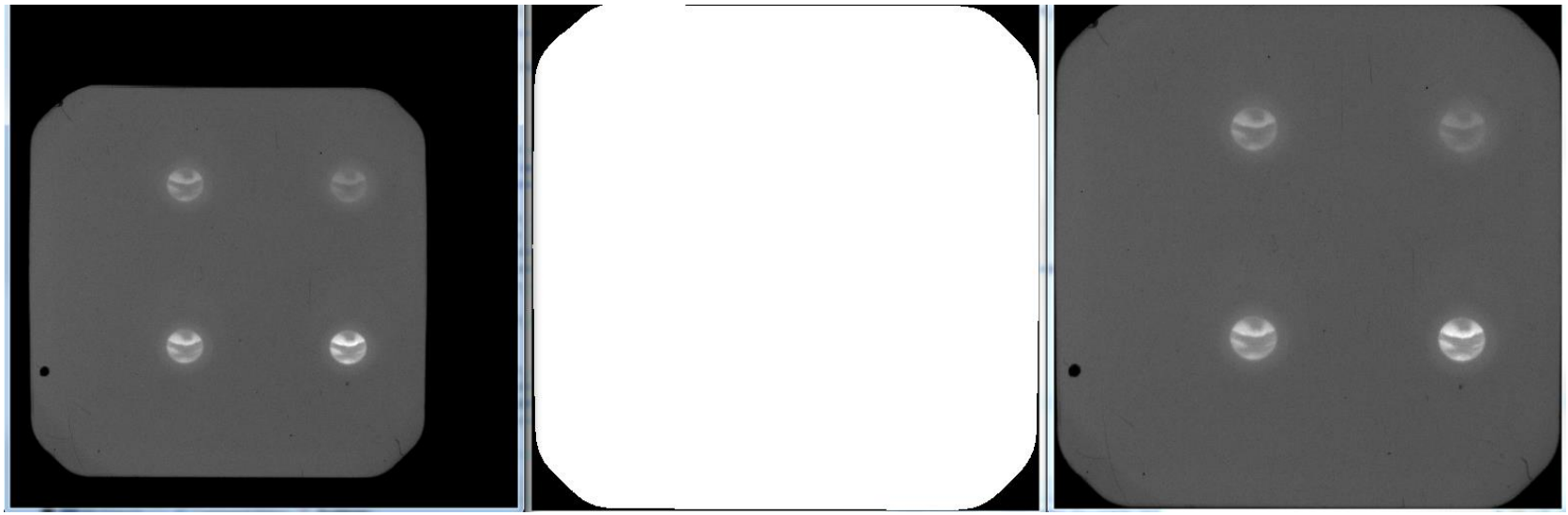
Static X-ray Imager (SXI) region extraction

1. Median blur (~99 pix kernel size) to eliminate noise/extraneous features
2. Generate binary mask--Run through adaptive Gaussian threshold
3. Find x & y region limits
4. Output cropped ROI mask and cropped data image

Starting image

ROI mask

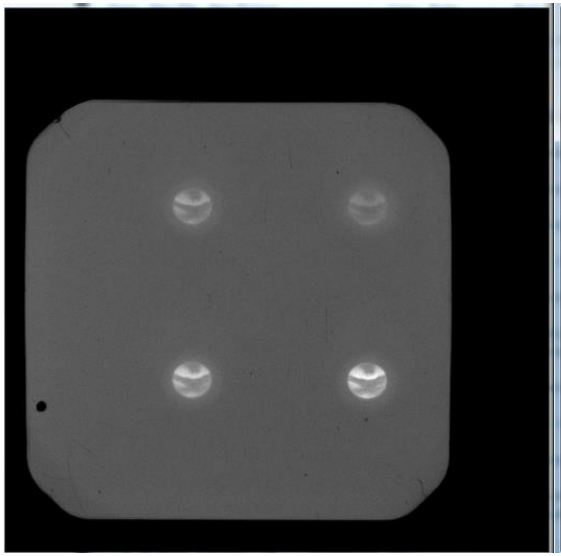
Image cropped to ROI



Fiducial finding

1. Median blur (~29 pix kernel size) to eliminate noise/extraneous features, but preserve fiducial
2. Run through adaptive Gaussian threshold
3. Floodfill region outside plate (everything white except fiducial)
4. Invert & compute fiducial centroid to single pixel level accuracy

Starting image



Step 5

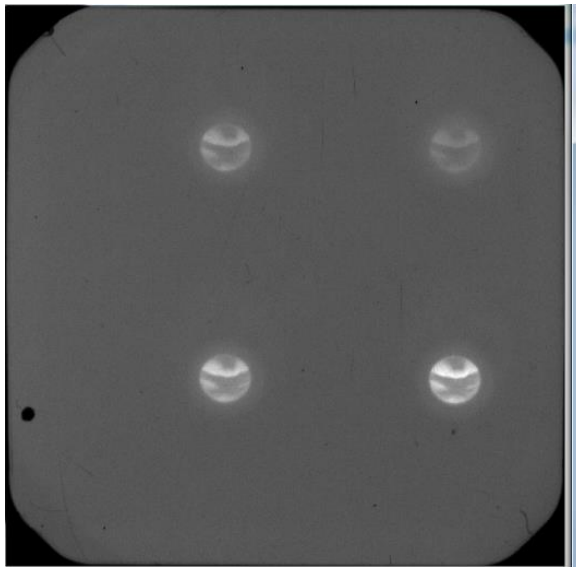
- Fiducial centroid found at **(196.6, 799.2)**

Coordinates can be output in cropped, uncropped, target and/or pinhole formats

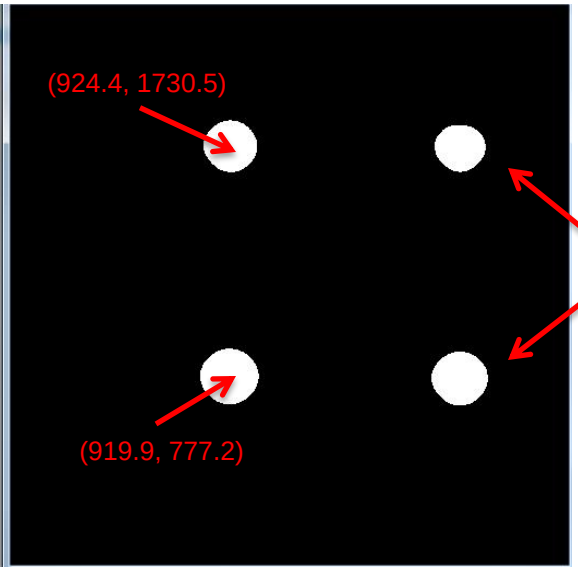
Pinhole region extraction

1. Compute histogram and find mode value for non-zero region (neutron background signal)
2. Subtract out background signal (clamp at 0)
3. Median blur and adaptive threshold
4. Separate out each image and compute centroid for each region
5. Output ROI mask & centroid coordinates

Starting image

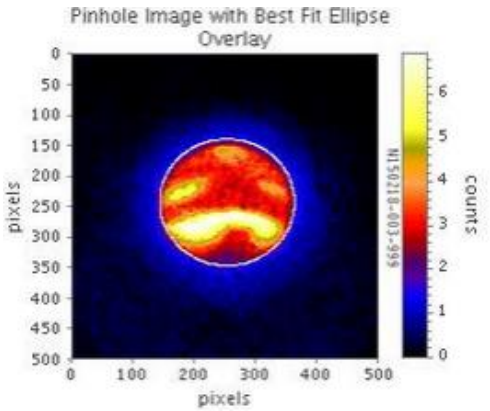


Pinhole ROI mask



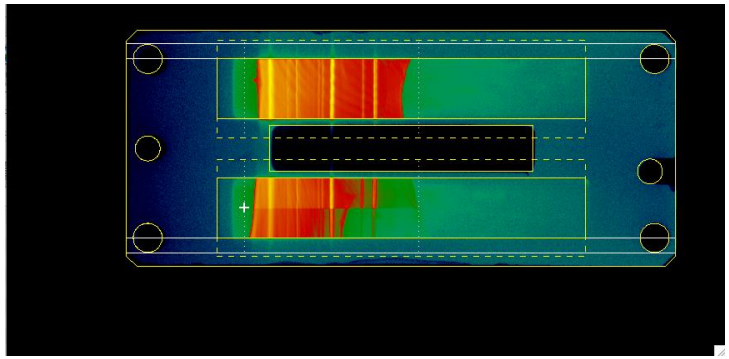
Centroid (x,y) output for each sub-image

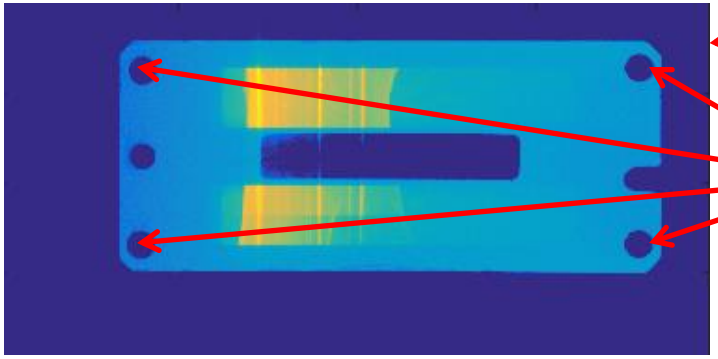
LEH size can be accurately estimated from background-subtracted image



NIF X-ray Spectrometer (NXS) image alignment

Scientists need properly aligned/rotated data segmented into regions of interest



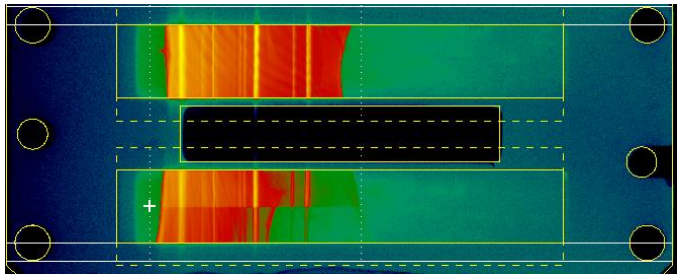


Convert to log-scale to enhance feature contrast

Find plate holes with Hough transform

These provide fiducials for transforming into a standard coordinate space

Apply 4-point perspective transform

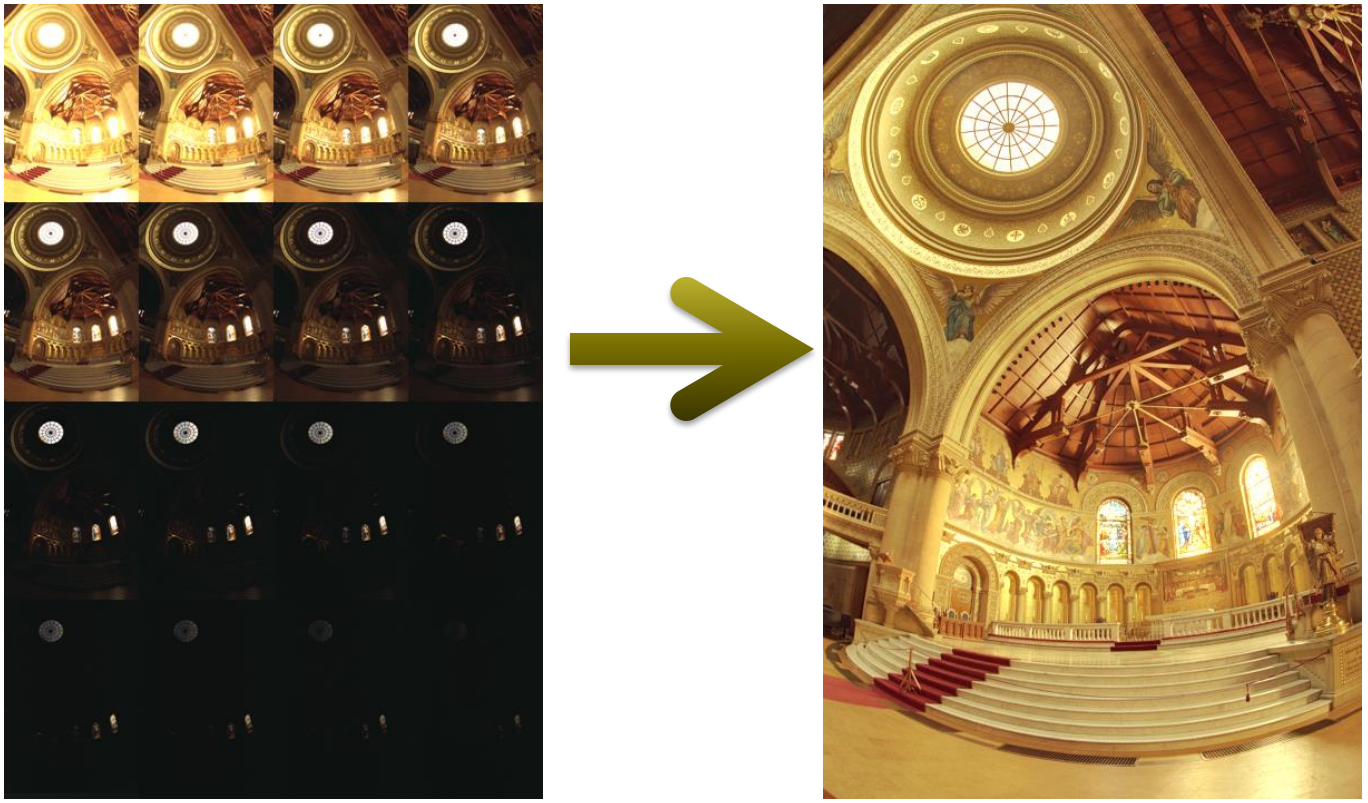


Now ROI's can be extracted using pre-determined coordinates

High Dynamic Range Imagery

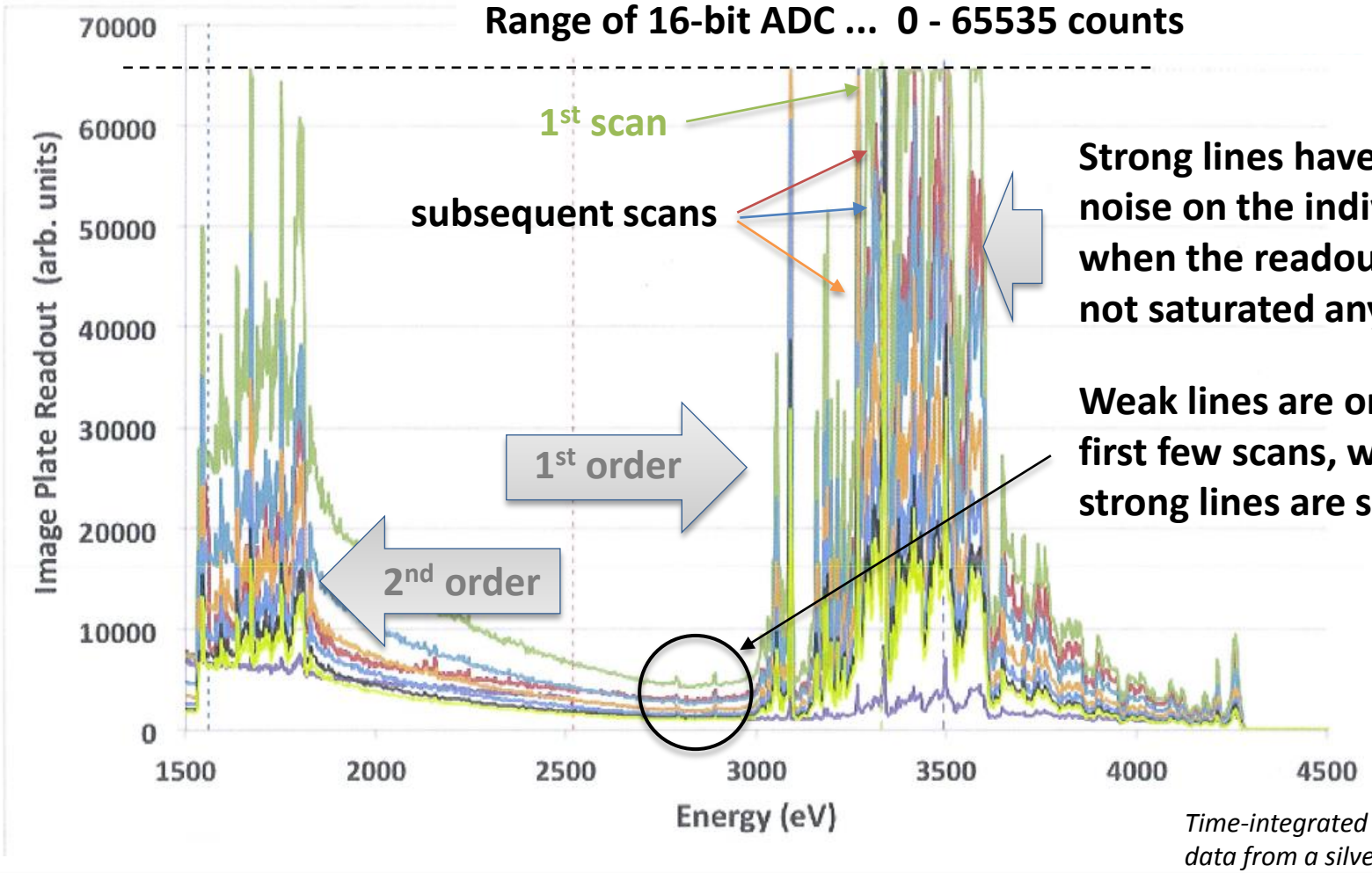
Concept: Take a series of images of static target from a limited dynamic range sensor (camera) while decreasing exposure

Use strongest unsaturated pixel values to compose values for output image with extended dynamic range



Images from
docs.opencv.org/3.1.0/d3/db7/tutorial_hdr_imaging.html

Comparison of Multiple Scans for a Single Image Plate



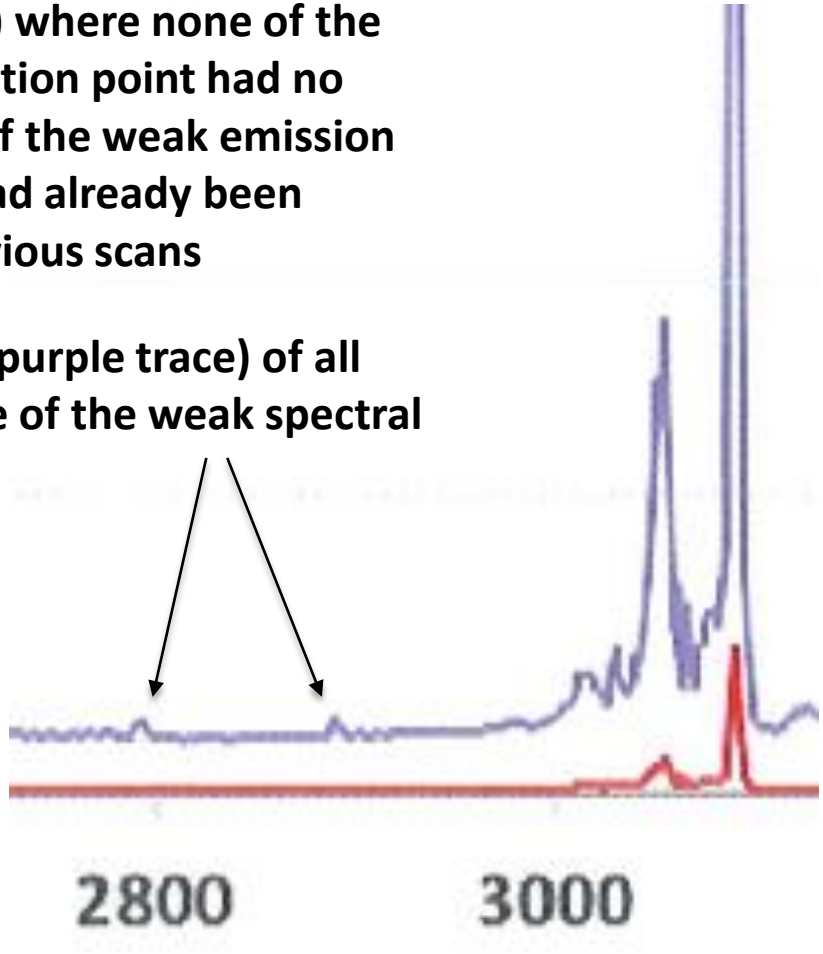
Strong lines have good signal-to-noise on the individual scan, when the readout for the line is not saturated anymore

Weak lines are only visible in the first few scans, when most of the strong lines are saturated

Time-integrated crystal spectrometer data from a silver target shot on NIF

Adding Lineouts from Multiple IP Scans Significantly Improves Signal-to-Noise Ratio for Weak Features

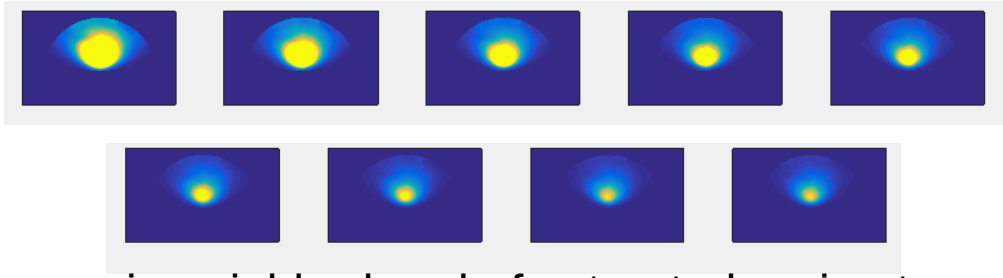
- **The individual IP scan (red trace) where none of the lines reached the readout saturation point had no more signal left in the location of the weak emission lines, i.e., all the color centers had already been activated (and depleted) by previous scans**
- **Simple addition of the lineouts (purple trace) of all scans clearly shows the presence of the weak spectral lines**



Data courtesy of Klaus Widmann, LLNL

Image Plate HDR Stitching Algorithm

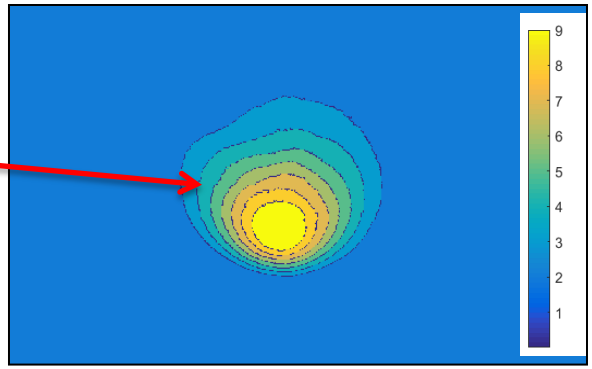
1. Stack images into a 3D array (third dimension is time-of-scan) for each plate



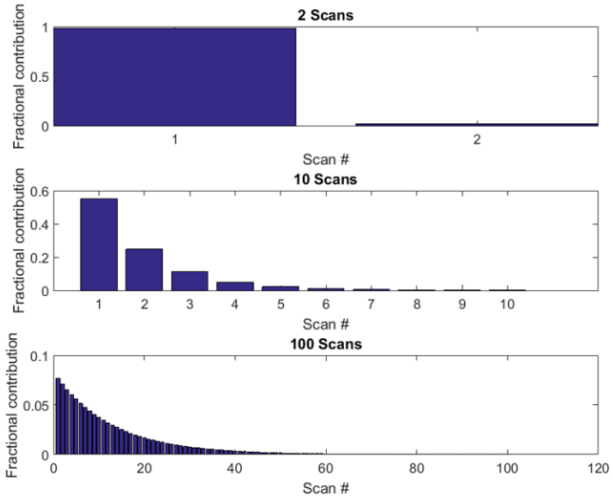
2. Analyze energy in neighborhood of saturated region transition contour
3. Normalize energies for each image scan to common (first scan) value
4. For each pixel in final image, compute a weighted sum over valid (non-saturated pixels) with preference towards earlier, stronger signal, scans

Image # for strongest unsaturated pixel value

Transition contours are used for adjacent image energy normalization

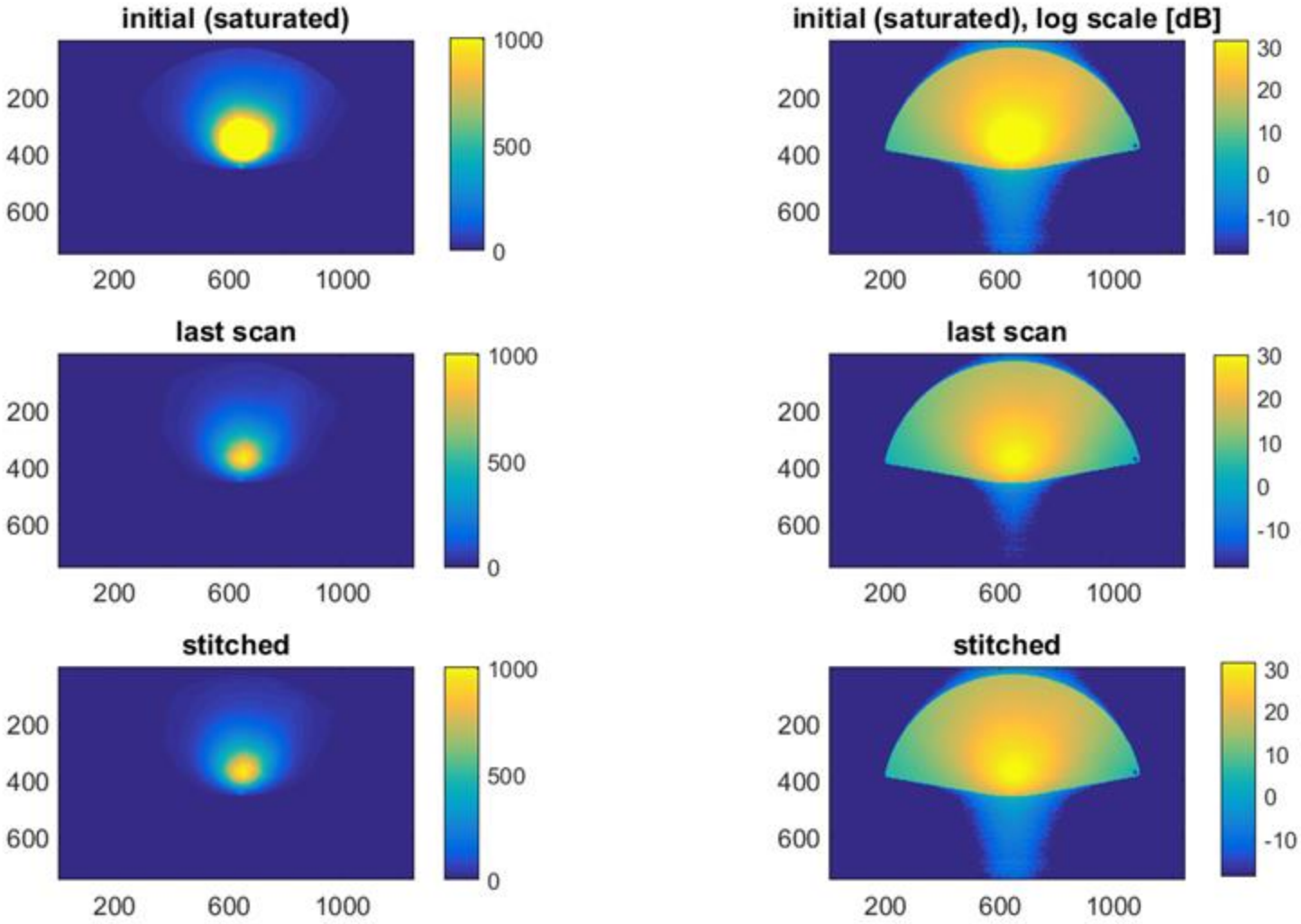


Exponential pixel weighting



TARDIS stitched image result

N150705-005-999 TARDIS



Summary

- Image plates allow for the robust capturing of 2D neutron and X-ray signals in the NIF chamber
- NIF scientists need robust automated codes to extract valuable data in the presence of noise, limited contrast, and shifts and rotations of input images
- Multiple techniques have been utilized and deployed in the SAVI system to robustly handle non-ideal shot data and find needed features
- By modifying already developed image processing algorithms, the dynamic range of the IP scanner can be extended enabling investigation of weaker features

Acknowledgements

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Thank you!