2D - IR Imaging Bolometer for NSTX

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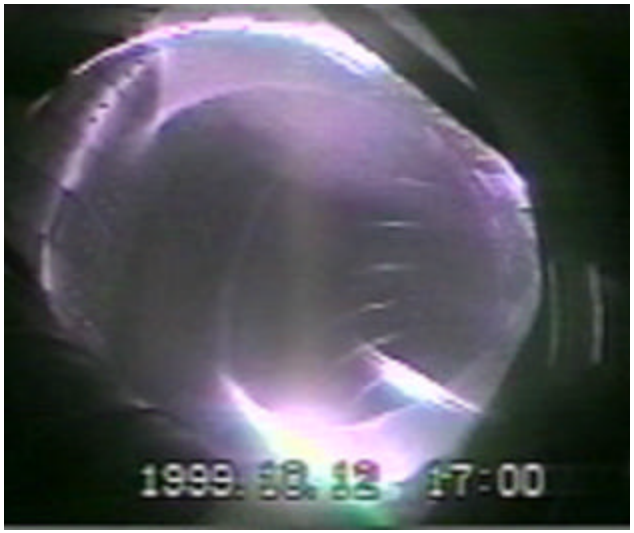
Jan. 17, 2001

NSTX Research Forum

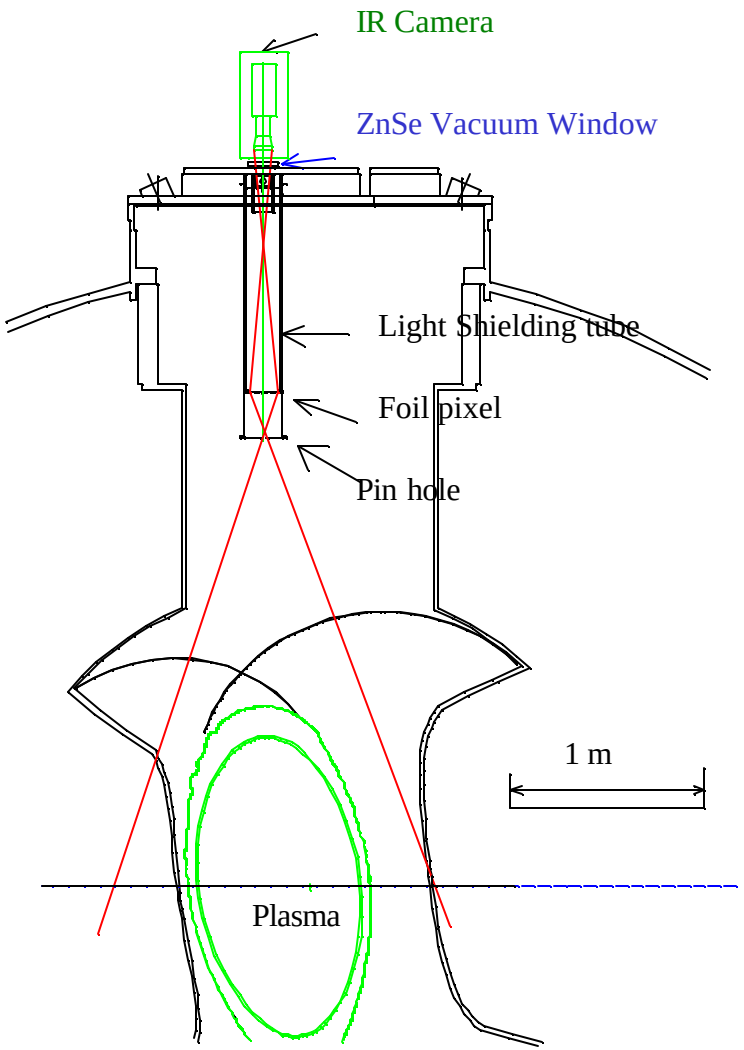
Introduction

Because of the complicated shape of a plasma, imaging techniques are needed for analysis. This poster will outline the development of a computer program that extracts data from an infrared (IR) image and uses the data to analyze the plasma radiation.



Imaging Bolometry

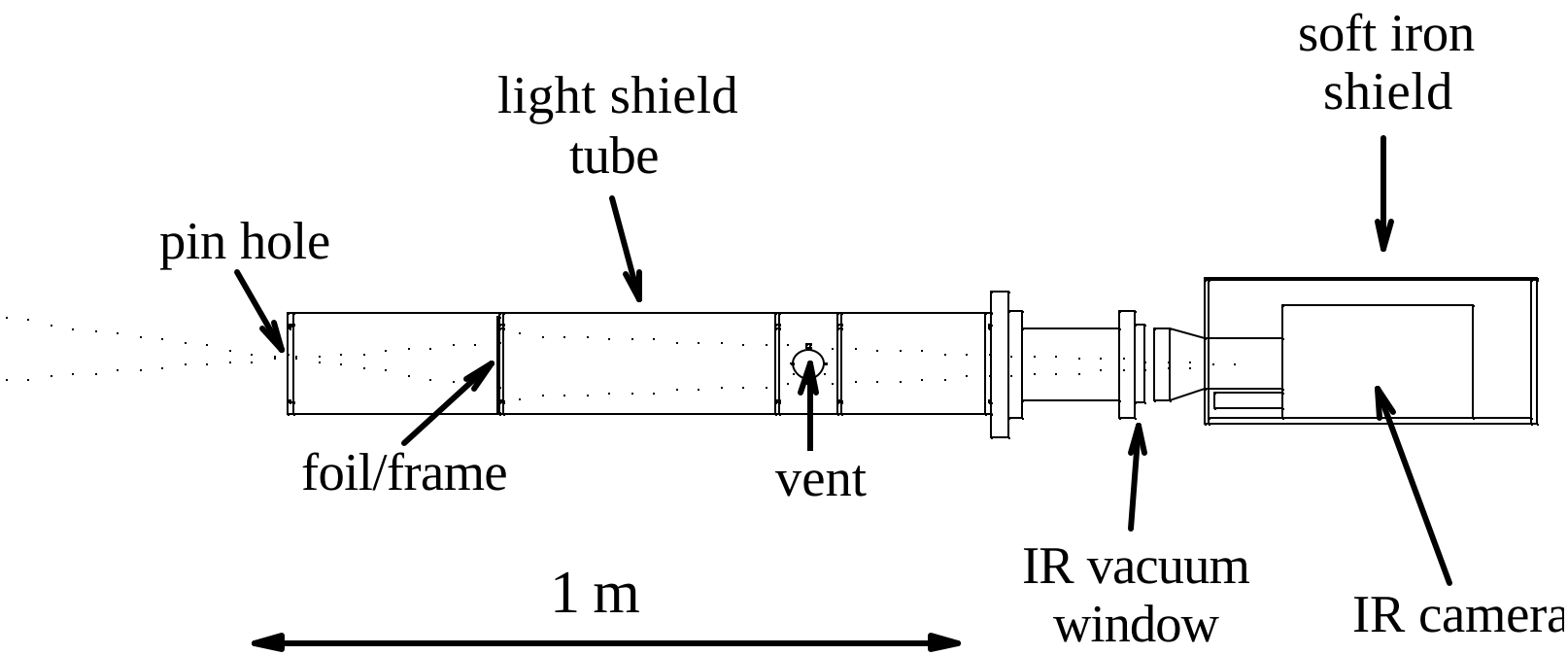
Foil Bolometry is a standard magnetic fusion plasma diagnostic, in which the energy of the plasma is measured through the heating of a thin (1 μm) metal foil. The scientists in the Magnetic Fusion Energy team at LANL and at the National Institute for Fusion Science in Japan are developing a new bolometric technique in which IR emission from the foil's back surface is observed by a high resolution IR camera.



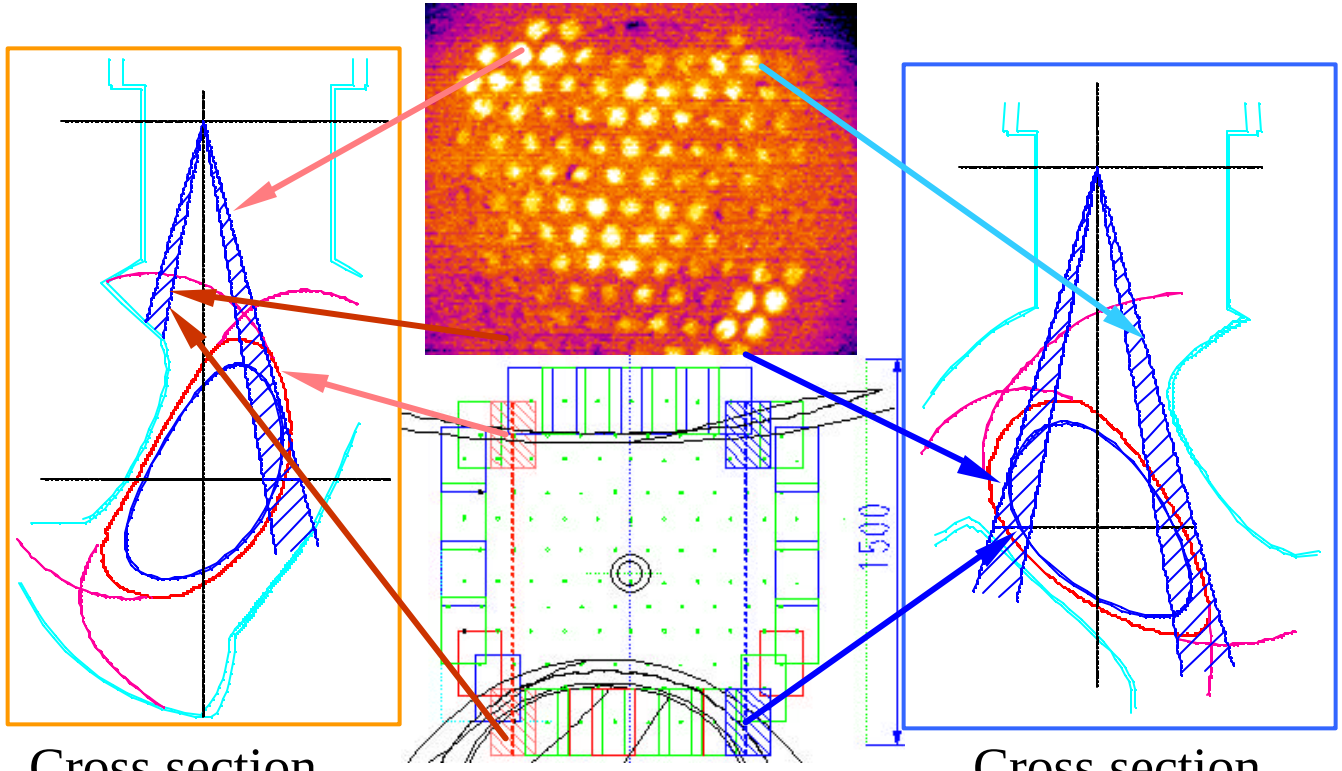
Segmented Matrix IR Imaging Bolometer (SIB)

- Thin aluminum or gold foil used.
- Foil supported by two oxygen-free copper masks.
- IR camera side of mask and foil blackened with graphite to increase emissivity
- No wires
- An IR window must be mounted on the vacuum vessel

LHD IR Imaging Bolometer Setup



LHD Top Port IR Image Sight Lines



Cross section

Top view of midplane

Cross section

Automated Analysis of Imaging Bolometry Data

• Image data is now available from two IR prototype systems on LHD (one top view, one tangential view), but we need to develop automated image analysis routines to handle the large amount of data, apply calibration factors, and extract useful waveforms.

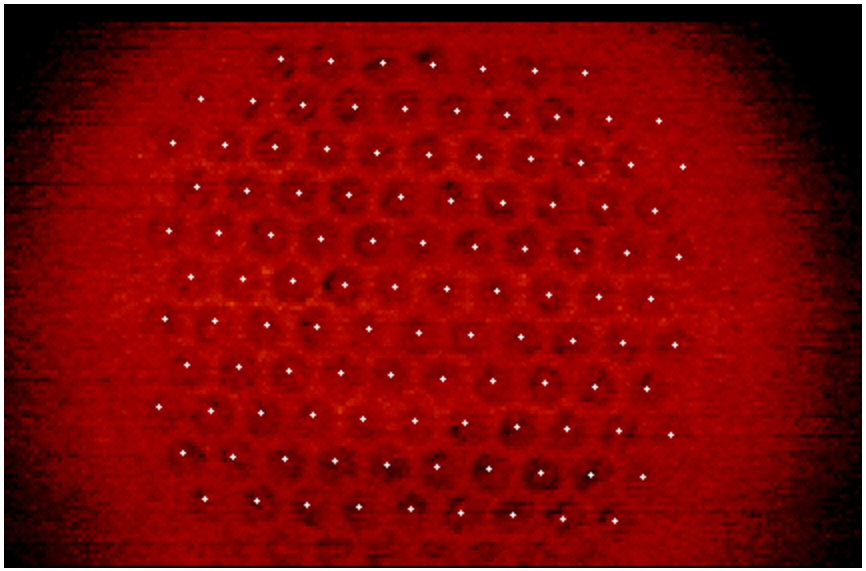
•Analysis done with IDL (Integrated Data Language) or PV-Wave

• “Pixels” selected from mask on IR images

• Plasma radiation calculated using IR images and calibration data matrices

Pixel Detection

Temperature data is extracted from pixels on IR images using edge detection and/or the geometry of the mask. The temperature is averaged over the size of the hole in the mask to determine the temperature of the pixel.

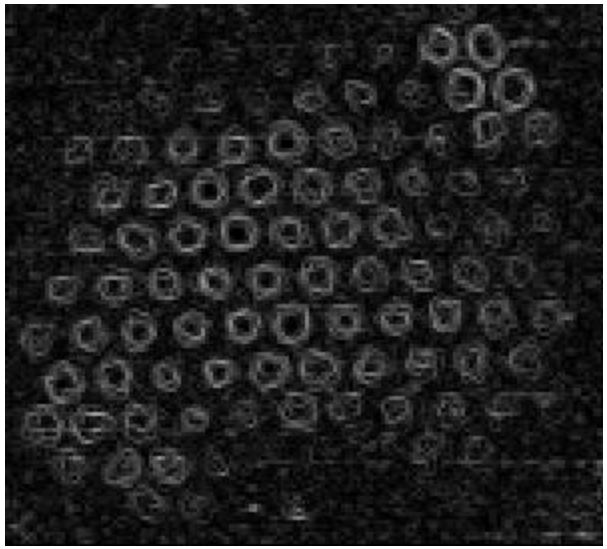


Edge Detection

- Roberts edge enhancement used:

$$G_{\Delta}(j,k) = |F_{j,k} - F_{j+1,k}| + |F_{j,k+1} - F_{j,k}|$$

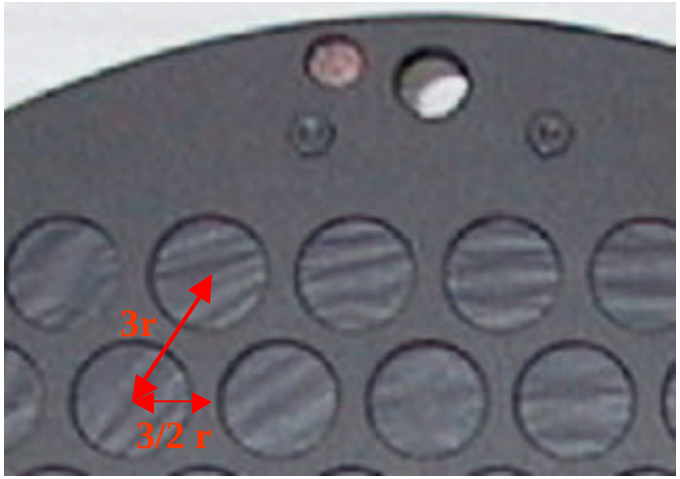
- Asymmetrical geometry of mask used to locate pixels without hard edges



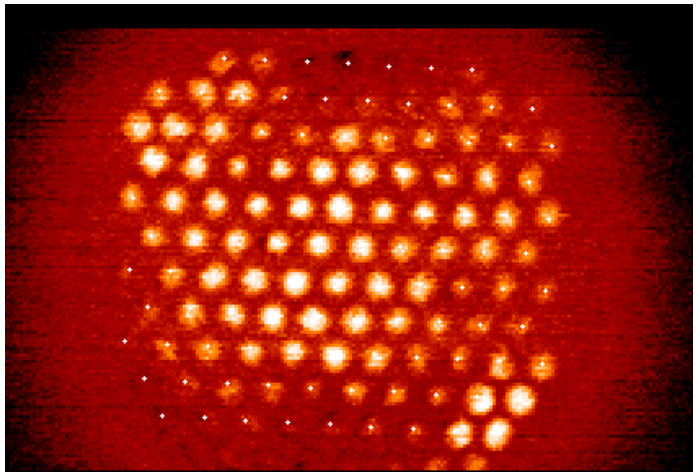
Edge enhanced IR image

Mask Geometry

- Asymmetric: top row with 8 pixels, bottom row with 7 pixels
- Spacing between pixels approximately equal to radius of pixel
- Rows offset by 3/2 radius of pixel
- Rows spaced by $(3\sqrt{3})/2$ radius
- With as few as two pixels located using edge detection or user input, the remaining pixels can be located based upon the geometry of the mask.



Sample Pixel Detection



Original Image

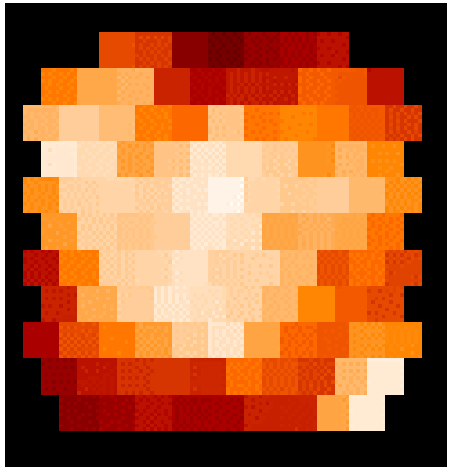
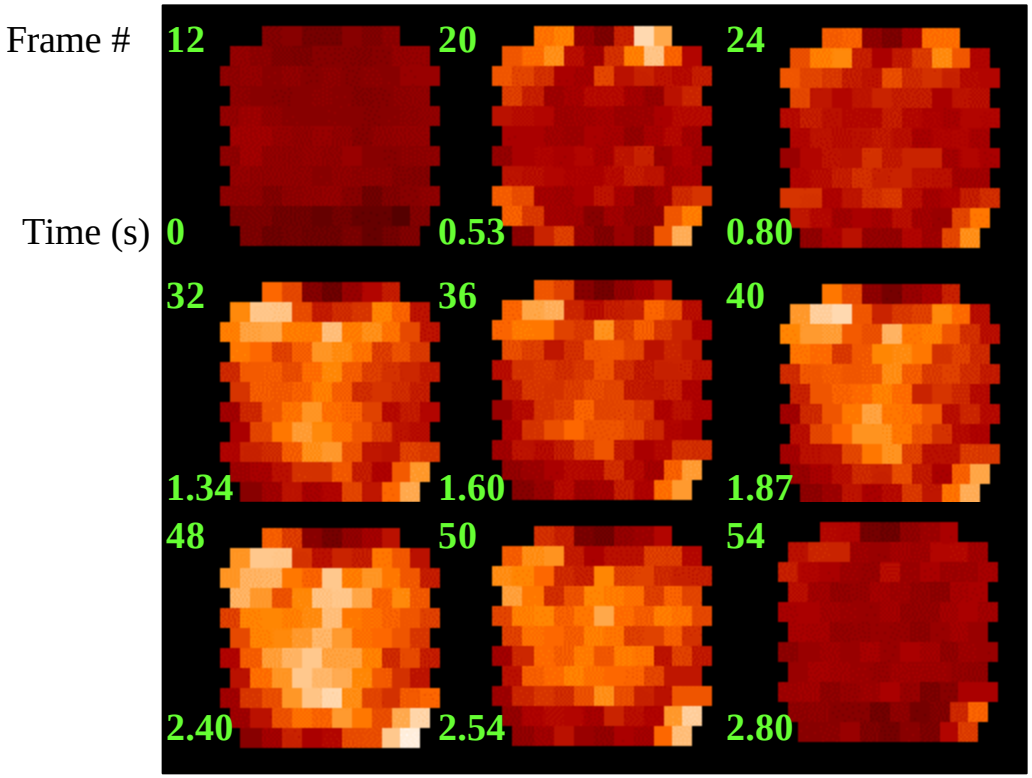
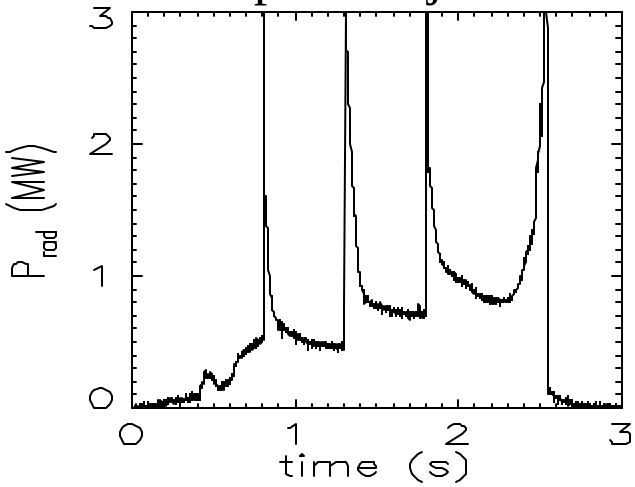


Image Pixels

Sample Data*



Plasma radiation power from resistive bolometer, with 4 pellet injection



* Data collected at the Large Helical Device (LHD) in Japan

Calculating Plasma Radiation

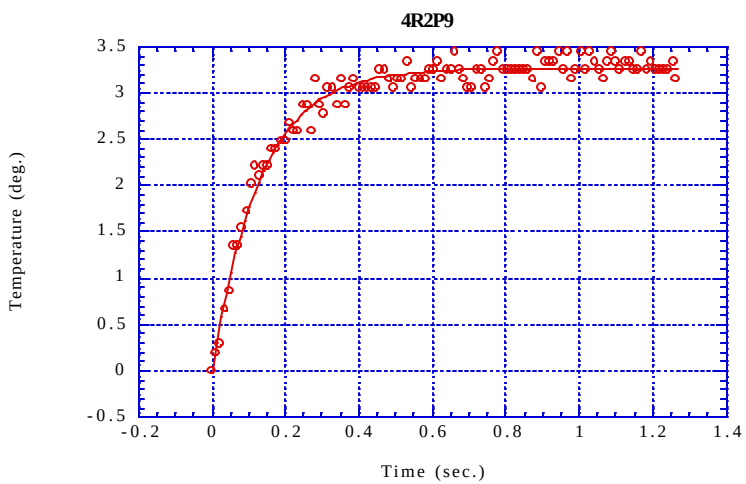
- Plasma radiation calculated using:

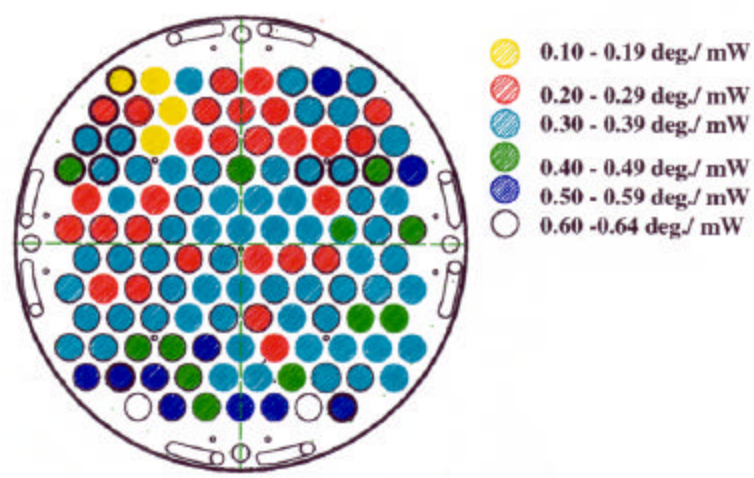
$$P_{rad} = \frac{1}{K}\left(\Delta T + t\,\frac{\partial \Delta T}{\partial t}\right)$$

- Calibration factor – κ
- Cooling decay time – τ

Calibration

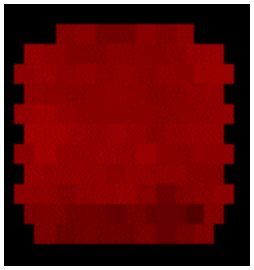
- A chopped He-Ne laser is used to determine κ and τ for each pixel
- Sample decay time is 0.13 sec. (this can be matched to the camera frame rate in use, ranging from 15 to 200 Hz).
- Average temperate rise (ΔT), by normalized incident laser power for each pixel is 0.80 deg/mW
- In the present implementatoin, some pixels show crosstalk, due to imperfect mask contact.





Background Temperature

- To calculate radiation, initial condition $\Delta T = 0$ is assumed
- Initial (background) temperature of foil and mask cause emission of IR radiation before heating by the plasma
- Background temperature determined by an average of pixels extracted from frames before heating begins.
- The background temperature is subtracted from the pixels of each frame to achieve initial temperature condition.



IR radiation before heating begins

Image Orientation

- Calibration matrices and IR image pixels must have same orientation (mask must be rotated at the same angle) for accurate calculation of plasma radiation
- Calibration matrices have fixed rotation
- Rotation of pixels determined by applying a mask at different rotations and calculating the sum of the resulting image.
- The angle at which the sum is minimum gives angle of rotation.
- Pixels are then rotated to match calibration matrices

Calculating Radiation from Images

$$P_{rad} = \frac{1}{K}\left(\Delta T + t\,\frac{\partial \Delta T}{\partial t}\right)$$

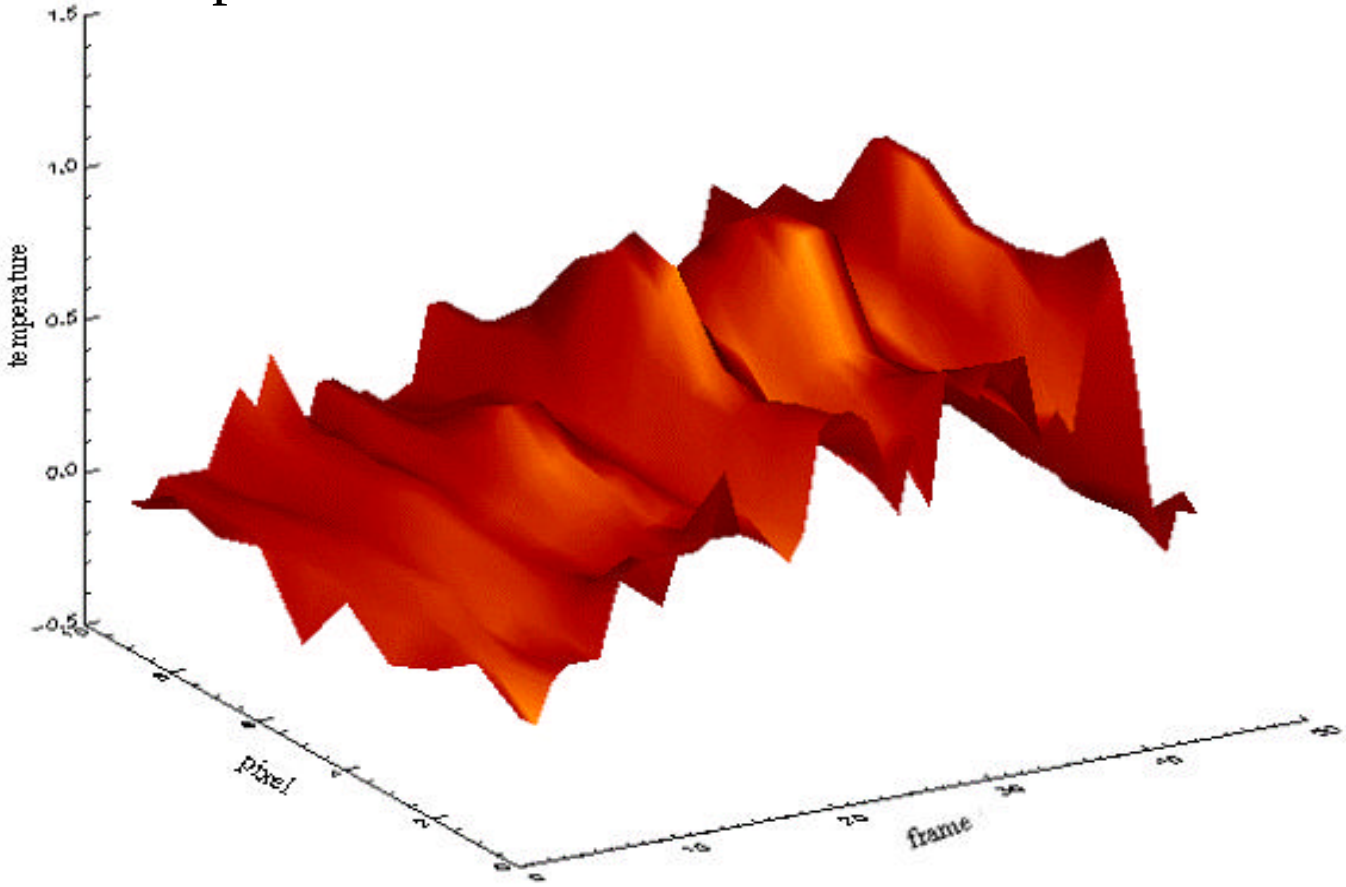
- LHD Agema IR Camera frame rate: 15 fps
  $\delta t = 0.0667$ sec.
- $\delta\Delta T$ determined by difference between first and second frames
- ΔT given by second frame temperature minus background temperature

Generating Radiation vs. Time Output

- Pixels located on frame with contrast between foil and mask (hard edges)
- Location of pixels saved and applied to other frames in the same shot.
- Radiation calculated using extracted temperature data.

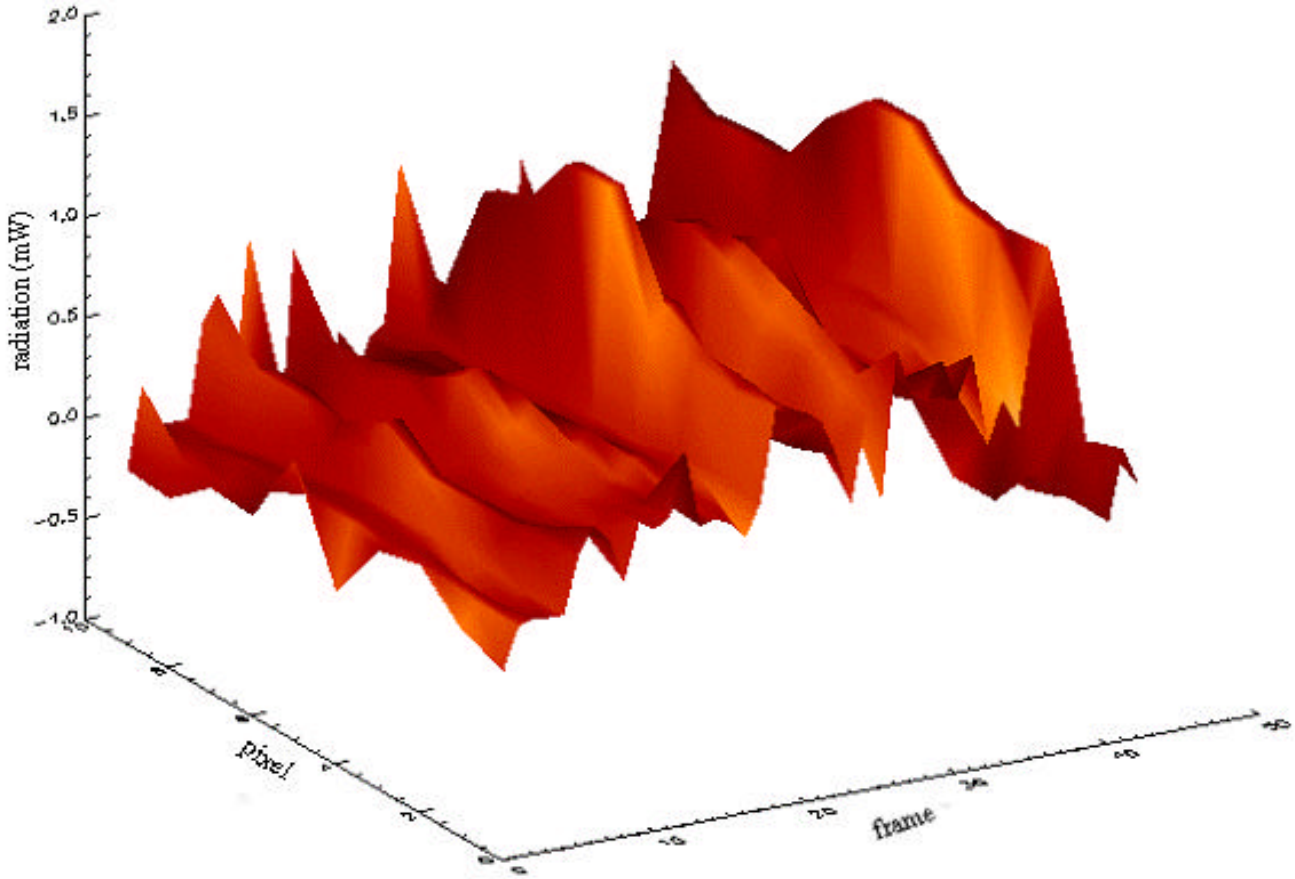
Sample Output - Temperature

Temperature of 4th Row Pixels vs. Frame Number



Sample Output - Radiation

Radiation of 4th Row Pixels vs. Frame Number



Summary

We have developed and tested both the idea, hardware, and software to prove the feasibility of such a bolometric imaging system.

Divertor and/or main plasma imaging on NSTX would be very feasible, and even economic for channels in excess of 100 sightlines, up to ~400-600 channels per “fan”.

The primary cost per “fan” is in the sensitive IR camera (~$95k), which replaces the electronics and data acquisition system of a conventional bolometer array.

We have generated automated IDL routines to extract temperature information from raw IR image data, and then use this data to produce time-scaled plasma radiation and temperature output.

LANL will write an FY02-05 NSTX proposal with a more detailed evaluation, including access constraints of the passive plates.

Acknowledgements

B. J. Peterson and G.A Wurden, “Development of imaging bolometers for long-pulse MFE experiments”, Rev. of Sci. Instrum, **70,** 255 (1999).

G.A. Wurden, B.J Peterson, and S. Sudo, “Design of an imaging bolometer system for the large helical device”, Rev. of Sci. Instrum, **68,** 766 (1997).

B. J. Peterson and G.A Wurden, in *Diagnostics for Experimental Thermonuclear Fusion Reactors 2*, edited by P. E. Scott *et al.* (Plenum Press, New York, 1998), pp. 399 – 408.

B.J. Peterson *et al.*, “Infrared Imaging Bolometers for LHD”, 13th Topical Conference on High Temperature Plasma Diagnostics, 5 June, 2000.

N. Ashikawa, B. J. Peterson collaborators at NIFS, Japan.