Be Foil "Filter Knee Imaging" of NSTX Plasma with Fast Soft X-Ray Camera

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Overview

- Goal: implement fast soft x-ray camera for MHD studies on NSTX
- Fast soft x-ray camera installed in 2004 and operated during 2004 and 2005 NSTX campaigns
- Have acquired good plasma images at frame rates of 1-500 kHz
- Have observed a variety of MHD phenomena: internal reconnection events, disruptions, sawteeth, fishbones, tearing modes, etc.
- This poster presents Filter Knee Imaging and reconstruction of observations of an internal m/n=1/1 mode

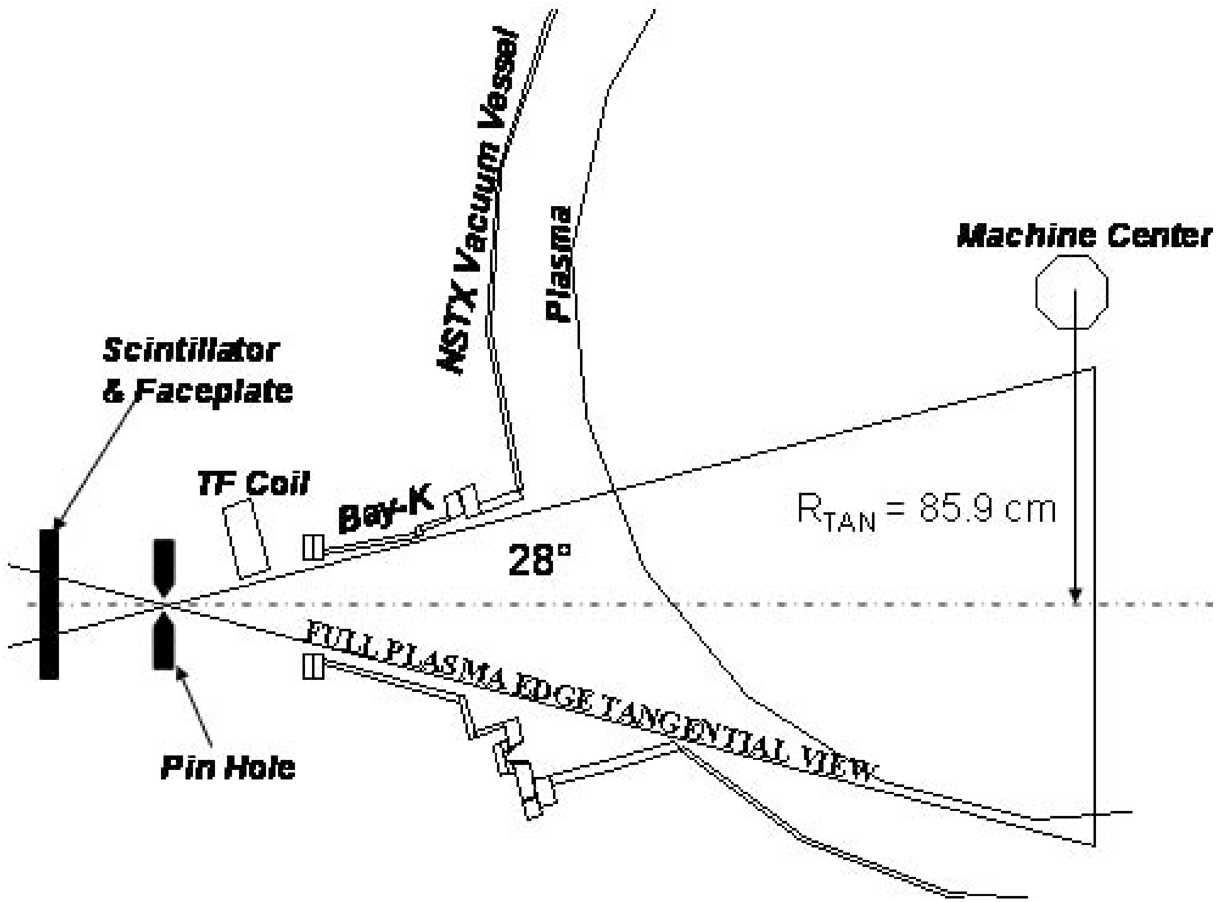
Fast Soft X-Ray Camera Instrumentation

- Pinhole camera with wide-angle tangential view of plasma [1,2]
- Based on Princeton Scientific Instruments PSI-5 CCD camera
  - 64 X 64 pixel image
  - Frame rates up to 500 kHz for 300 frames
- Soft x-rays (~1-5 keV) converted to visible light by fast P47 phosphor deposited on fiber-optic faceplate
- Electrostatic image intensifier and lenses demagnify image by 6:1 and couple light to CCD
- Remotely selectable pinholes (1-5 mm diameter) allow tradeoff of spatial resolution and signal level
- Remotely selectable beryllium foils allow low-energy cutoff to be varied

[1] S. von Goeler, *et al.,* Rev. Sci Instrum. **70** (1999) 599.

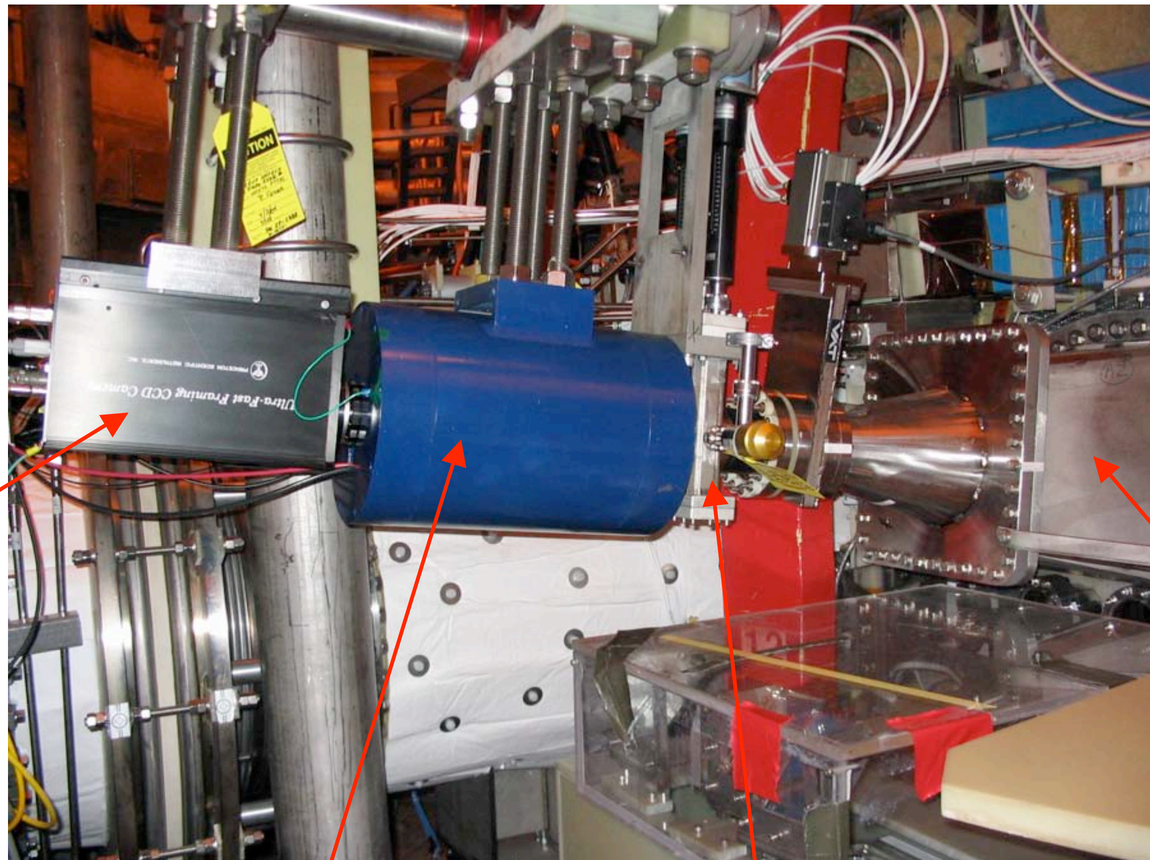
[2] B. C. Stratton, *et al.,* Rev. Sci Instrum. **75** (2004) 3959.

Horizontal Field-of-View of Camera



- Optical axis inclined at 9° downward angle with respect to midplane

System Installed on NSTX



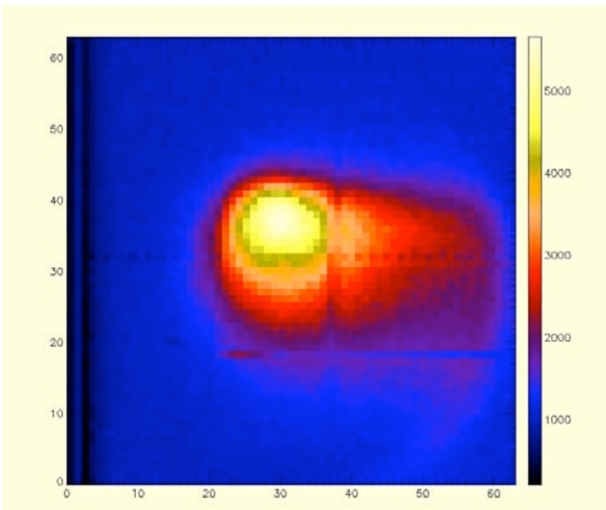
CCD camera

NSTX bay K port

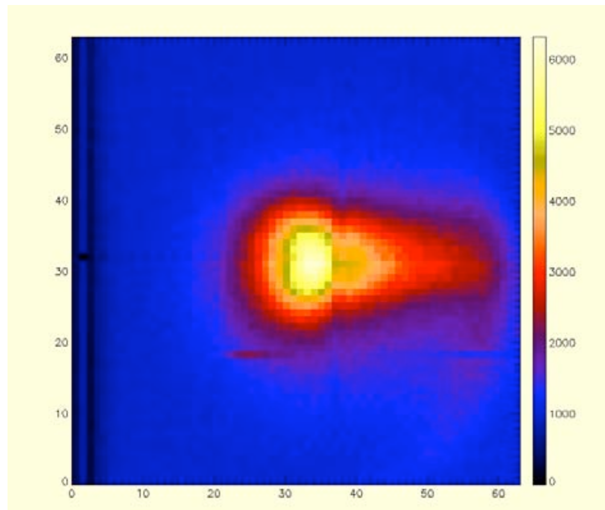
Image intensifier inside magnetic shield

Pinholes and Be foils

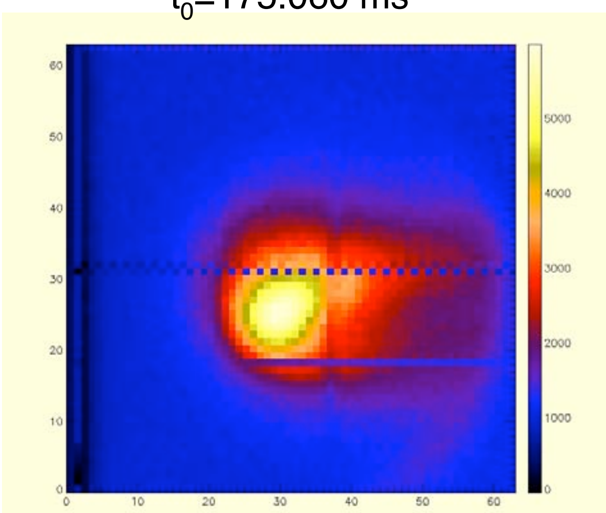
Example of SXR Images of m/n=1/1 Mode



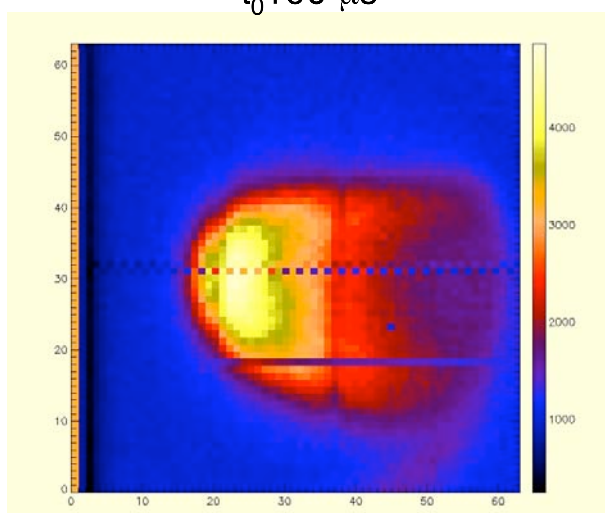
t_0=175.060 ms



t_0+90 μs



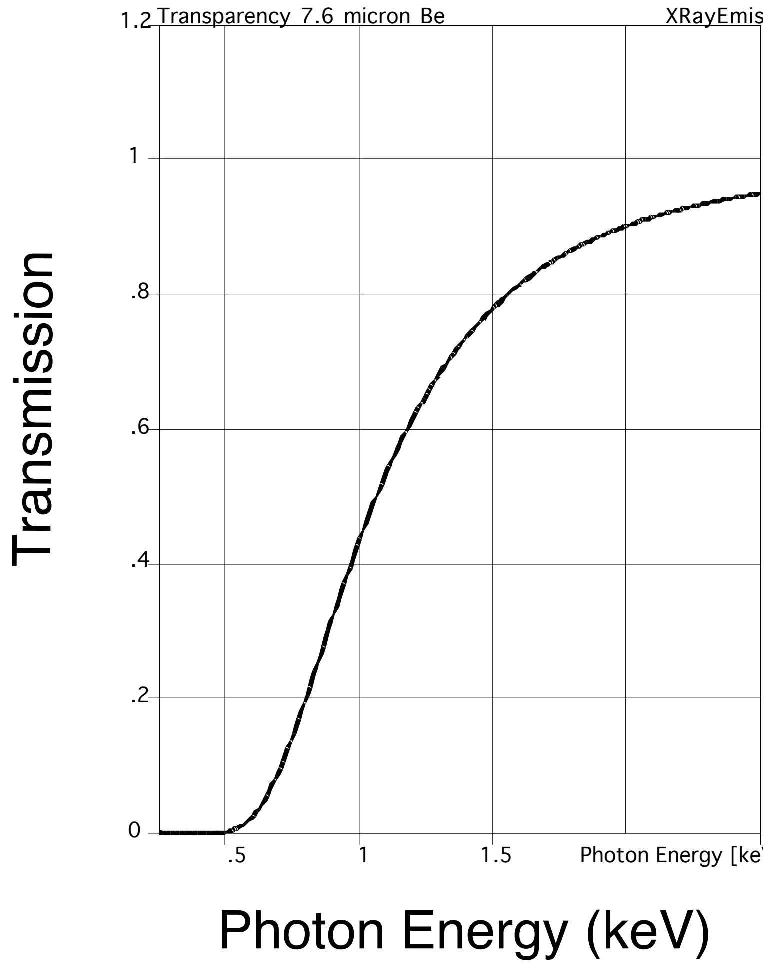
t_0+180 μs



t_0+270 μs

- Camera frame rate= 100 kHz
- Mode frequency: ~2.5 kHz
- Images show 4 times during one mode period
- m/n=1/1 mode character clearly seen
- Shot #113778

7.6 μm Be Foil Transmission Curve



- Knee in transmission F_{Be} in 0.5-1.5 keV photon energy range

Filter Knee Imaging Reconstruction of Images-1

- The signal S detected by one camera pixel is given by

$$S = \int_t^{t+\delta t} dt \int dh\nu \int_L F_{Be}(h\nu)\mathscr{E}_{h\nu}(T_e, Z_{eff}, n_e, \ldots)\frac{dV}{dL}dL \equiv \int_L \mathscr{E}(\ldots)\frac{dV}{dL}dL \qquad (1)$$

  where the time integration dt is performed over δt, the camera integration time, the second integration is over the photon energy $h\nu$, and the chord integration is weighted with the derivative dv/dL where L is the distance from the pinhole.

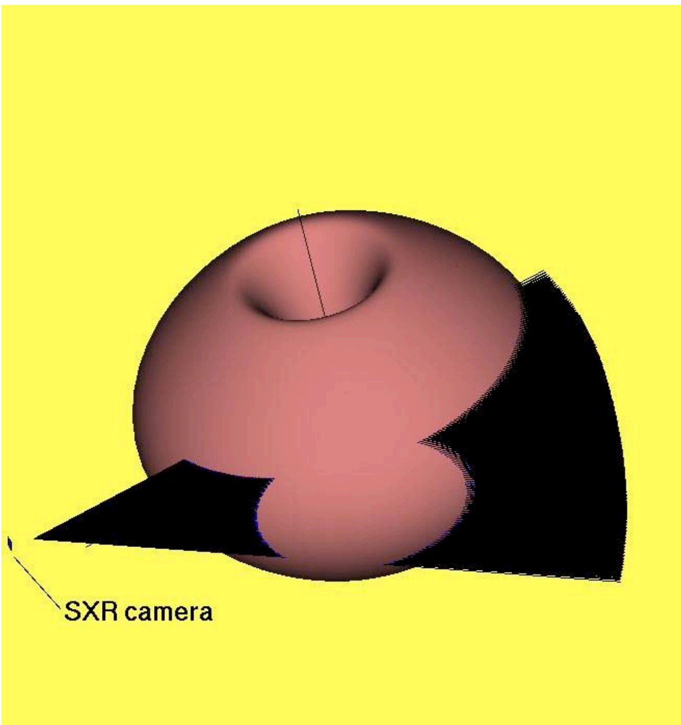
- The emissivity ε depends on local plasma parameters such as T_e, n_e, Z_{eff}, and the details of line, recombination, and bremsstrahlung emission.
- Reconstruction of plasma parameters from this equation is a complicated problem because it involves a) inversion of the integral equation for ε as a function of the spatial coordinates; and b) inversion of the ε function.
- A significant simplification of the problem is possible when T_e is below the filter knee. In this case, the camera sees only emission from the hot plasma core and the contrast in the image is significantly increased. We refer to this as “Filter Knee Imaging” or FKI.

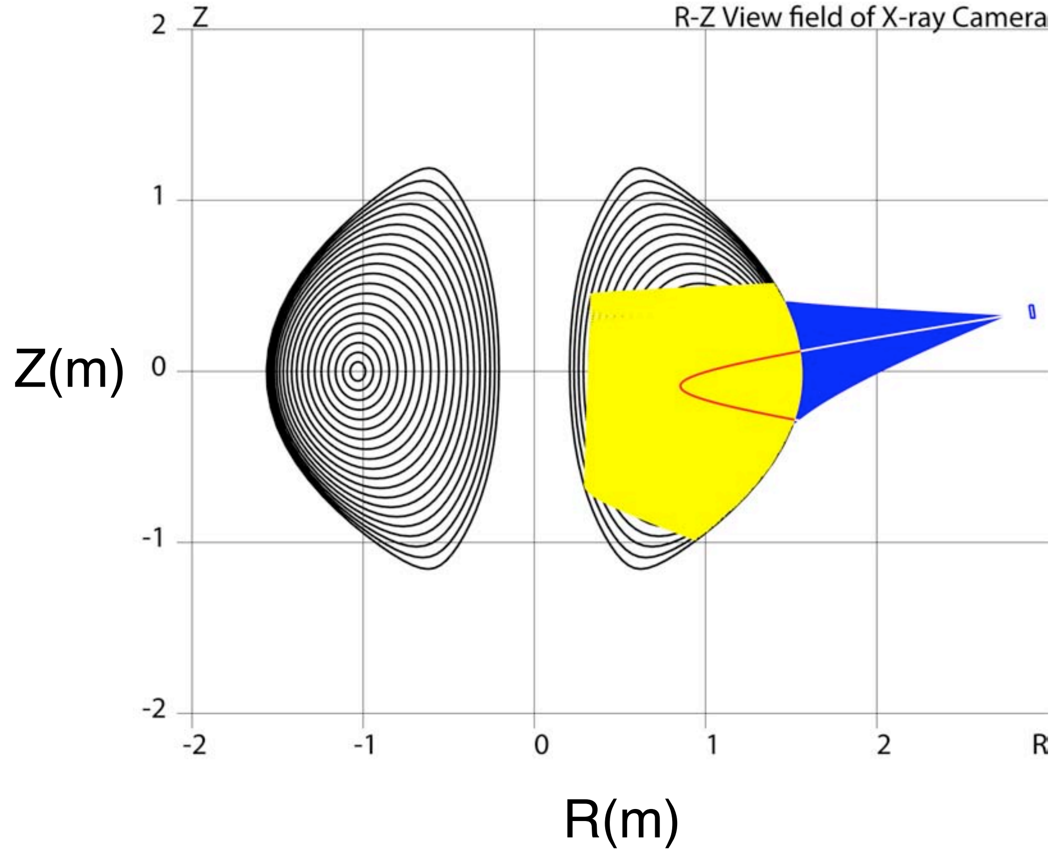
Filter Knee Imaging Reconstruction of Images-2

- A new code (Cbbst) was written to simulate the line integral (eq. 1) and to invert it assuming a simple spatial dependence of $\varepsilon = \varepsilon(a+\xi)$, where a is a flux surface label corresponding to the square root of the toroidal magnetic flux and $\xi(a,\theta,\varphi)$ is a perturbation that may include both ideal and tearing types of perturbations.
- Step-like m/n=1/1 perturbations were considered.
- The 21 radial values of the $\varepsilon(a_i)$ function and the amplitude and phase of the $\xi_{1/1}$ perturbation are reconstructed from the 64 X 64 data array S_{ij} using singular value decomposition and an iterative technique for solving the integral equation, which becomes non-linear in the presence of perturbations.
- The plasma equilibrium was generated by the Equilibrium and Stability Code [3] using a plasma boundary reconstructed by the EFIT code and TRANSP code simulations of plasma pressure and q profiles.

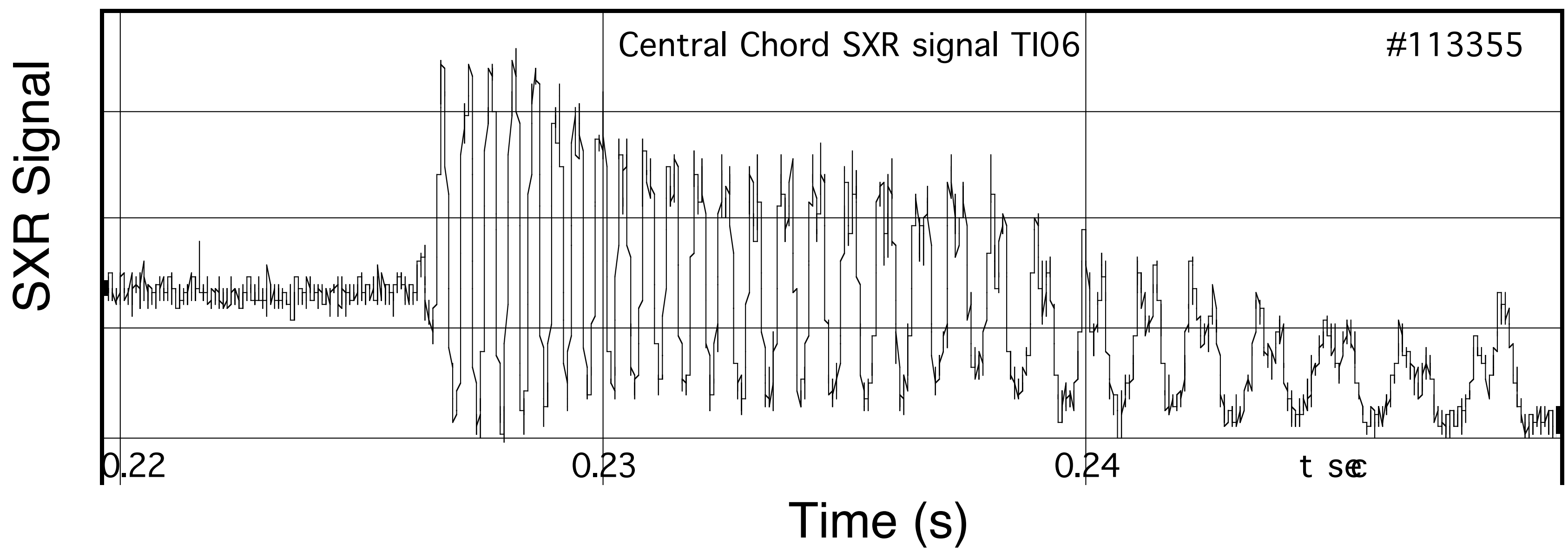
[3] L. E. Zakharov and A. Pletzer, Phys. Plasmas **6** (1999) 4693.

Field-of-View of the SXR Camera



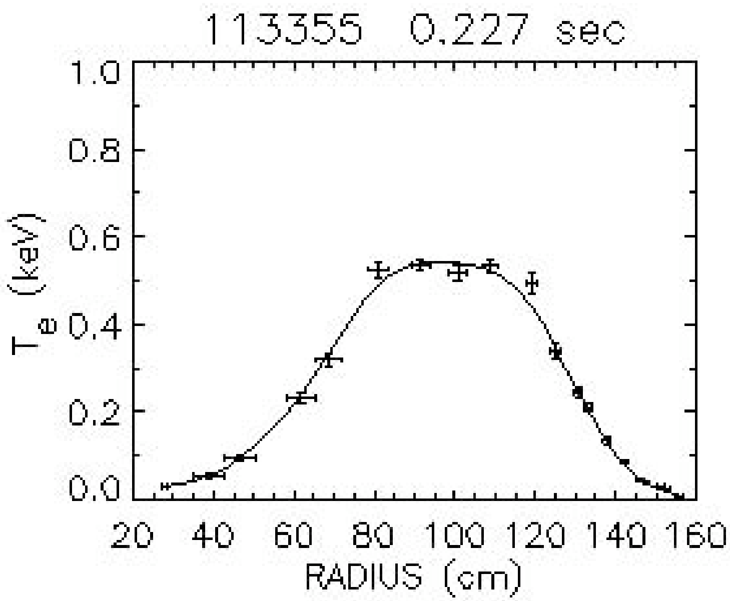


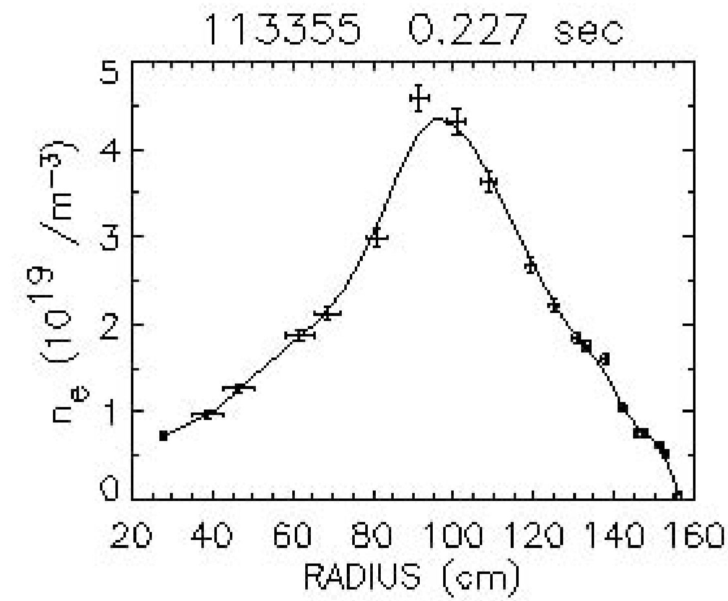
Time Evolution of m/n=1/1 Mode



- Signal from conventional soft x-ray diode with radial midplane view shows time evolution of m/n=1/1 mode (Shot 113355).
- As an example, will show of reconstruction of camera images late in the evolution of the mode (246.6 ms and 247.0 ms).

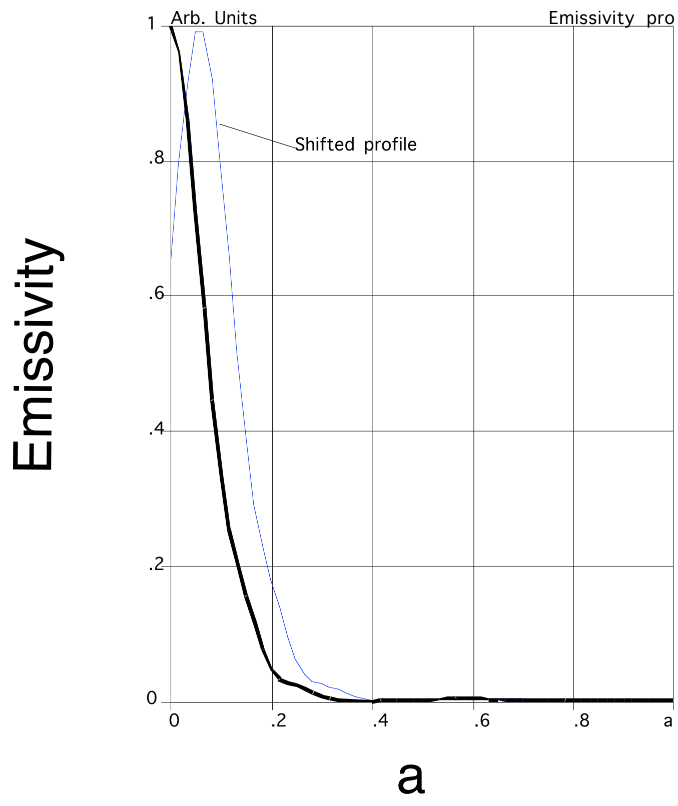
T_e and n_e Profiles During m/n=1/1 Mode

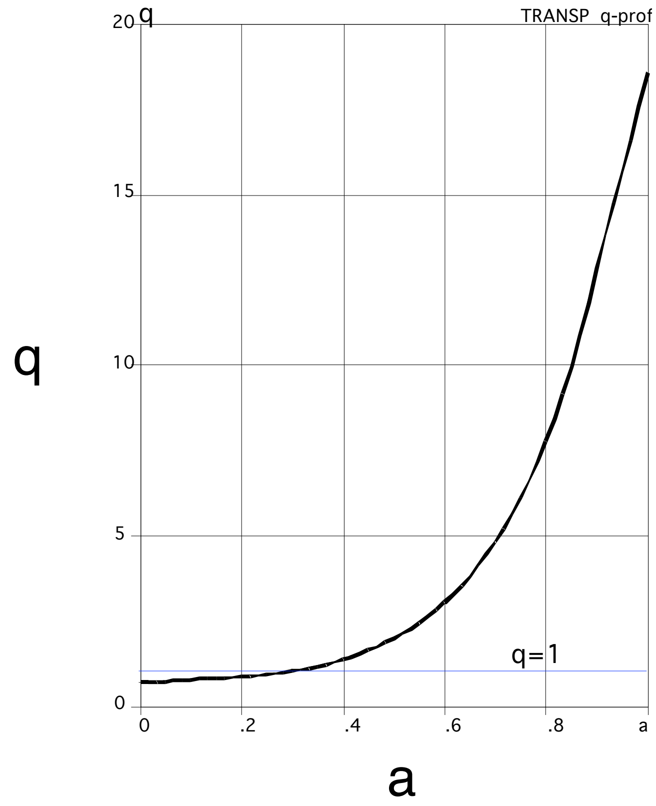




- Ohmically-heated helium discharge
- B_t=0.44 T and I_p=500 kA
- Camera parameters:
  - 3 mm pinhole and 7.6 μm Be foil
  - Frame rate=10 kHz to capture entire duration of mode

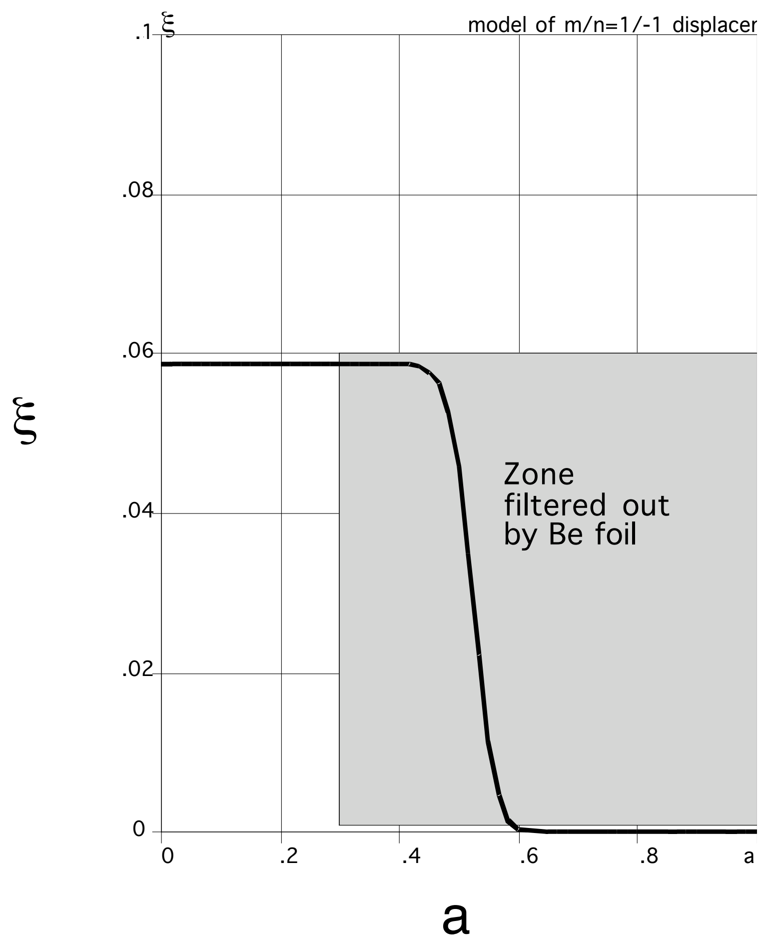
Emissivity and q profiles



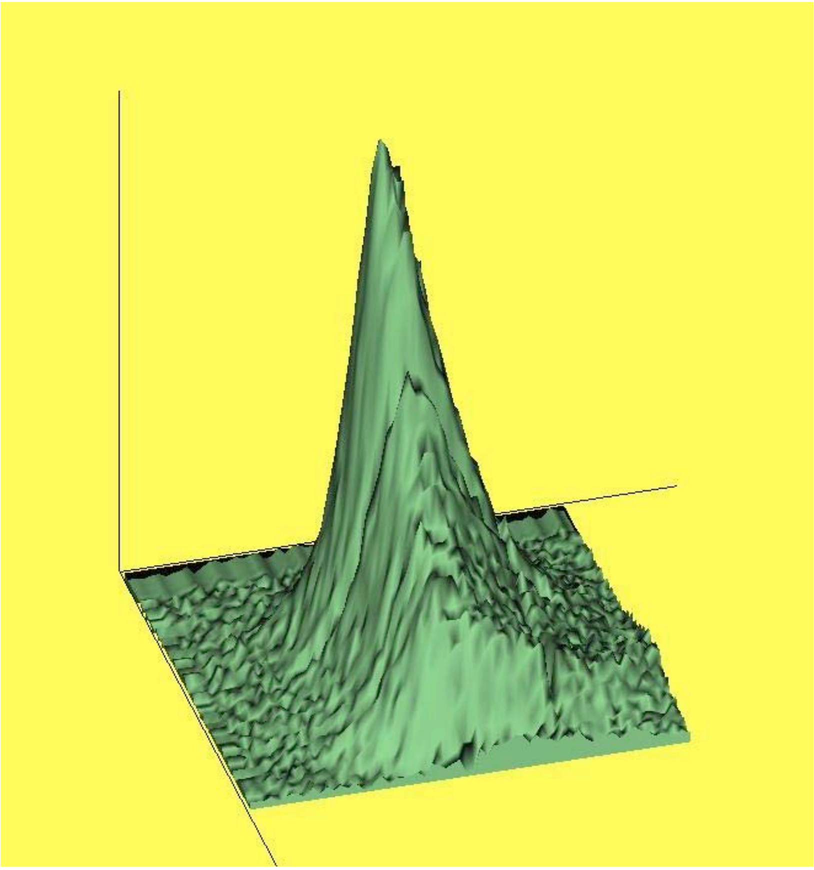


- Model emissivity profile includes perturbation due to m/n=1/1 mode.

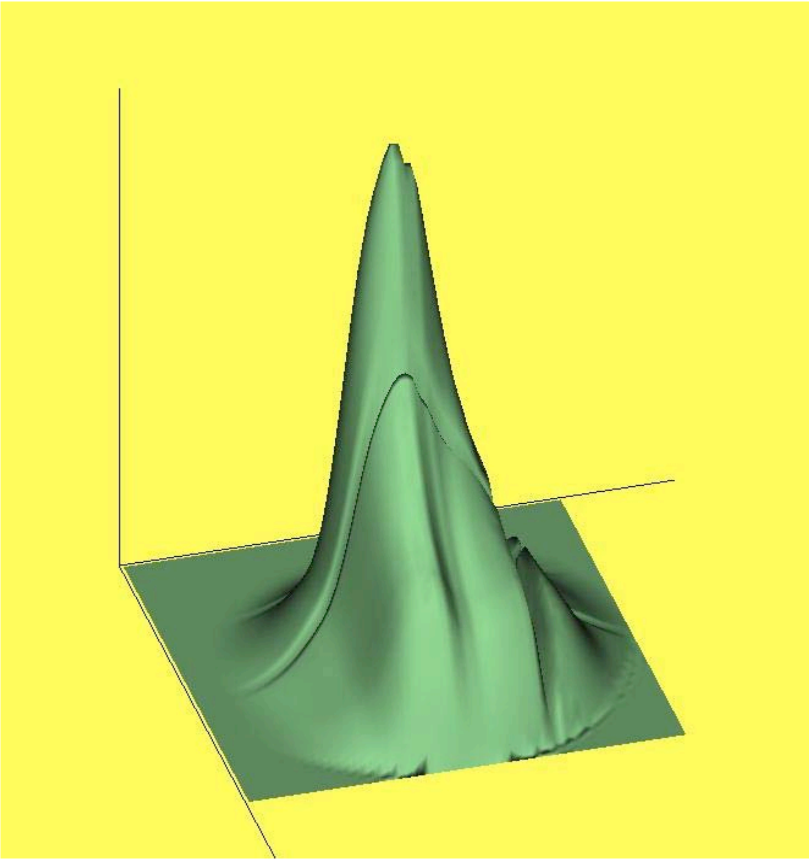
Assumed Structure of m/n=1/1 Mode Displacement



SXR Camera Image and Reconstruction at t=246.6 ms

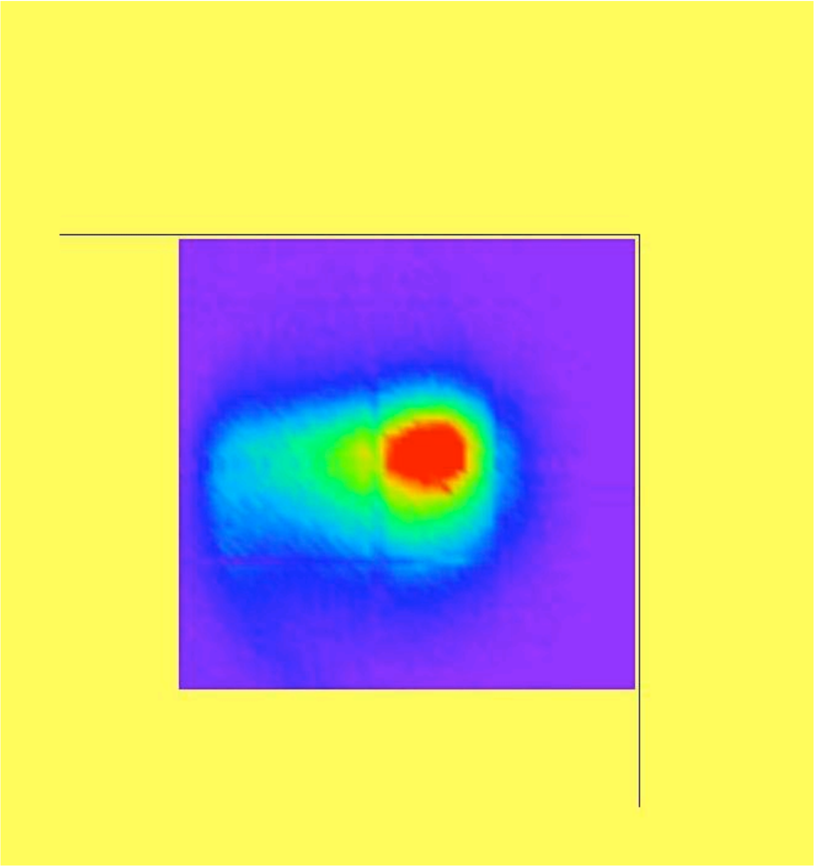


Camera Image

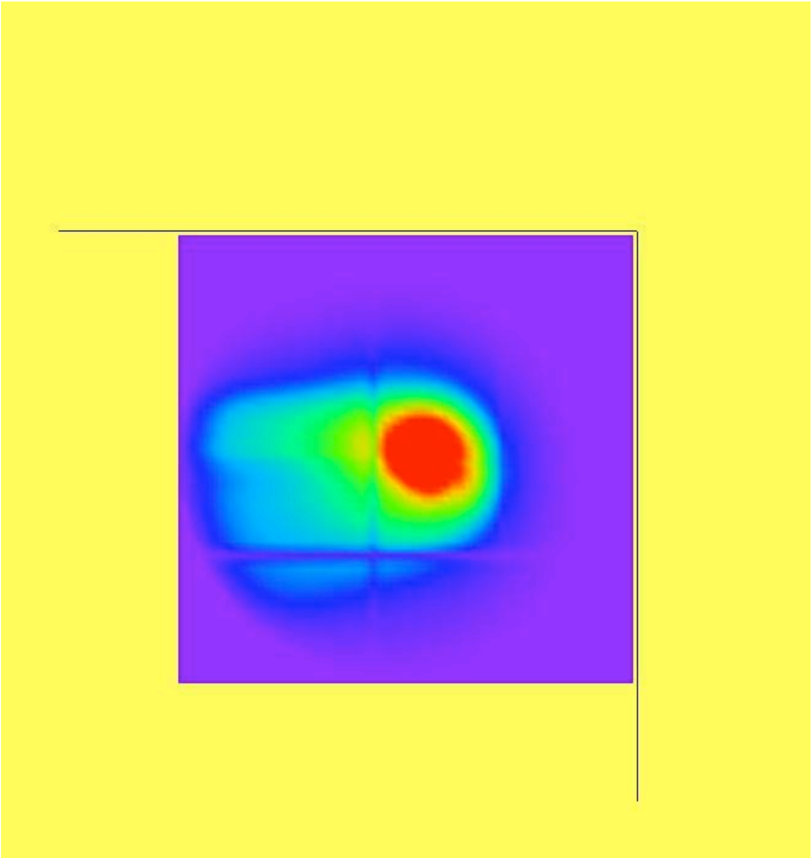


Reconstruction

SXR Camera Image and Reconstruction at t=246.6 ms

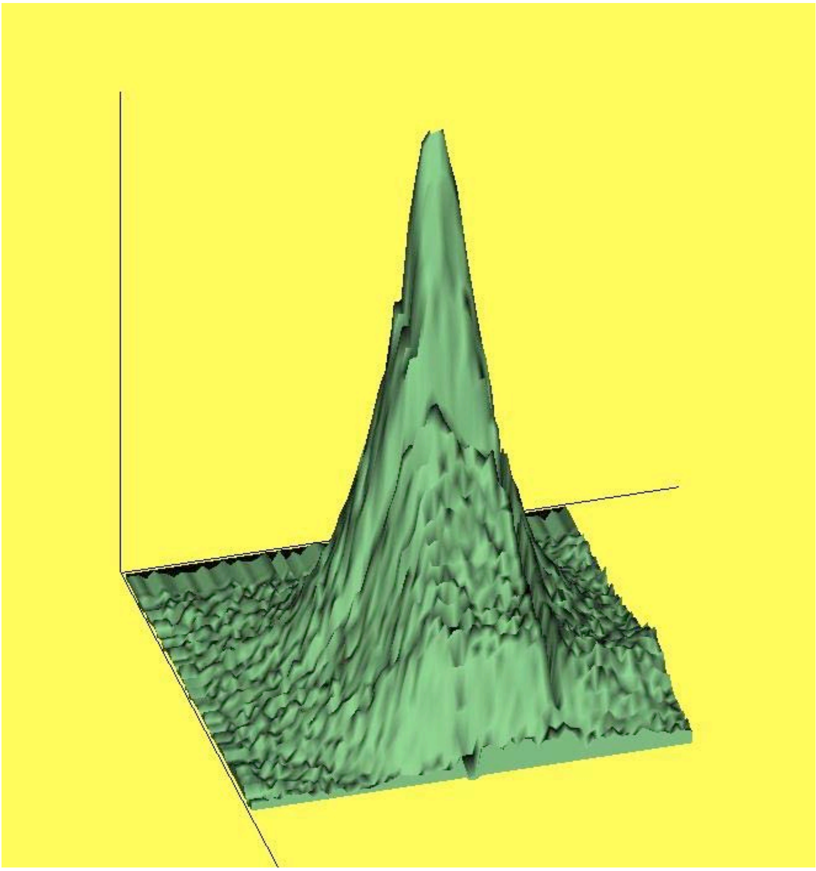


Camera Image

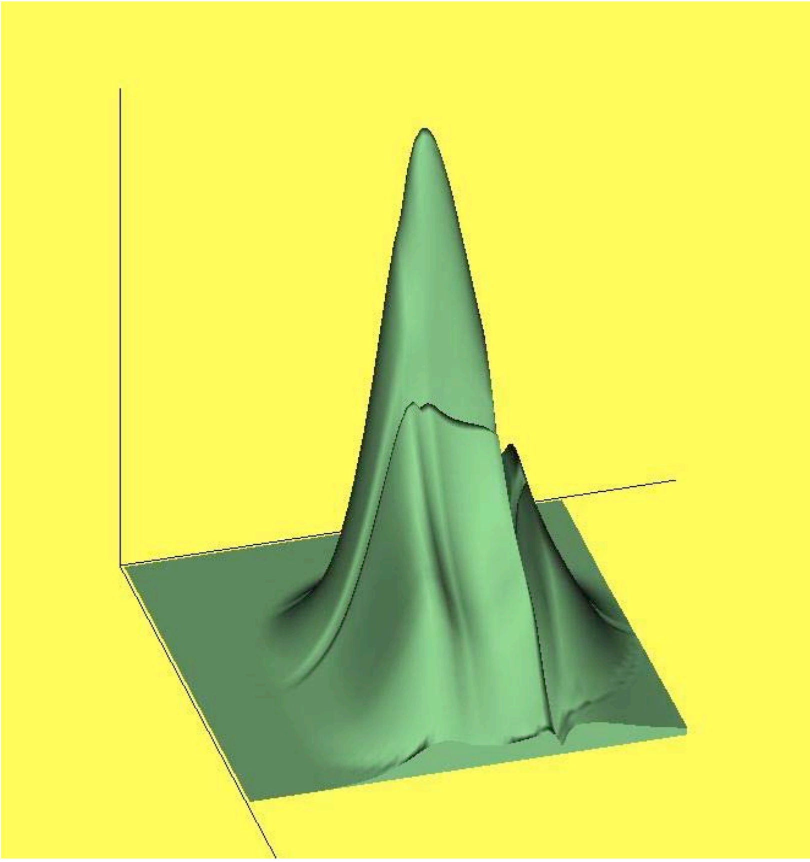


Reconstruction

SXR Camera Image and Reconstruction at t=247.0 ms

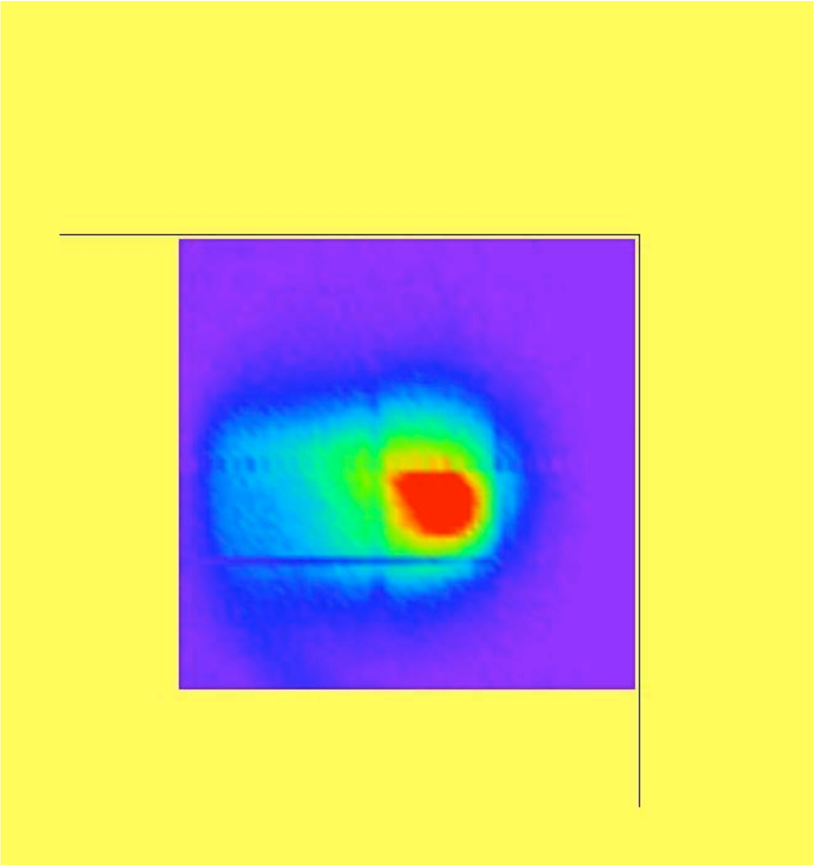


Camera Image

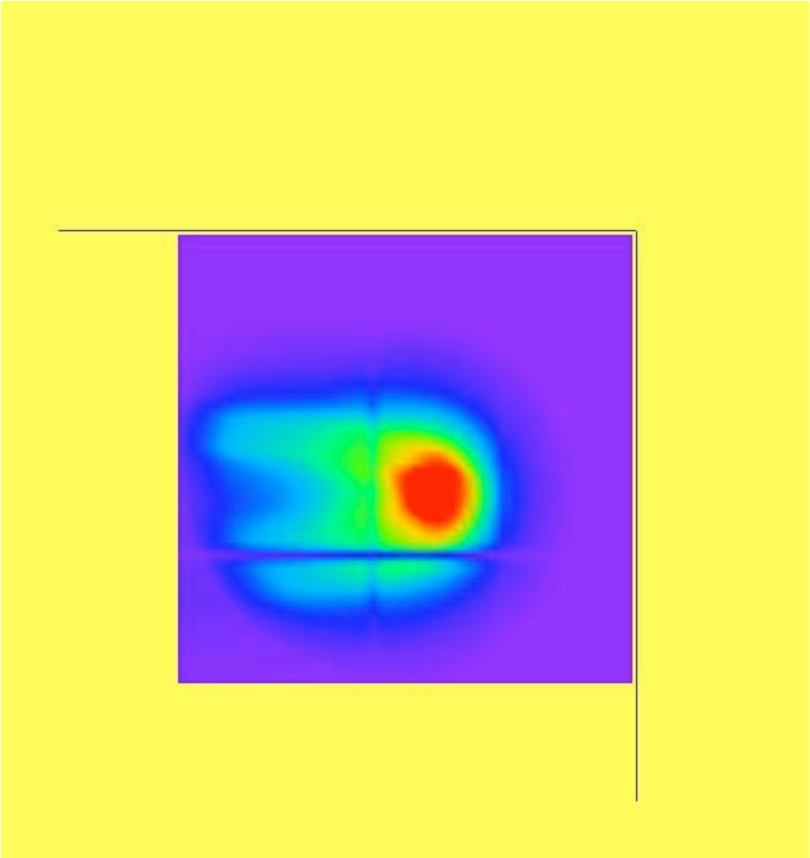


Reconstruction

SXR Camera Image and Reconstruction at t=247.0 ms



Camera Image



Reconstruction

Summary

- The Filter Knee Imaging technique allows reliable reconstruction of the phase and amplitude of core MHD perturbations in NSTX plasmas.
- We plan to use thicker Be foils to apply the FKI technique to hotter NSTX plasmas (T_e>1keV)
- We plan to study more complex MHD perturbations.
- Nonlinear resistive MHD modeling using the M3D code is planned.

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