Characterization of ELMs and their Effects on NSTX using Multi-color Ultrasoft X-ray Imaging

K. Tritz, D. Stutman, L. Delgado-Aparicio, and M. Finkenthal

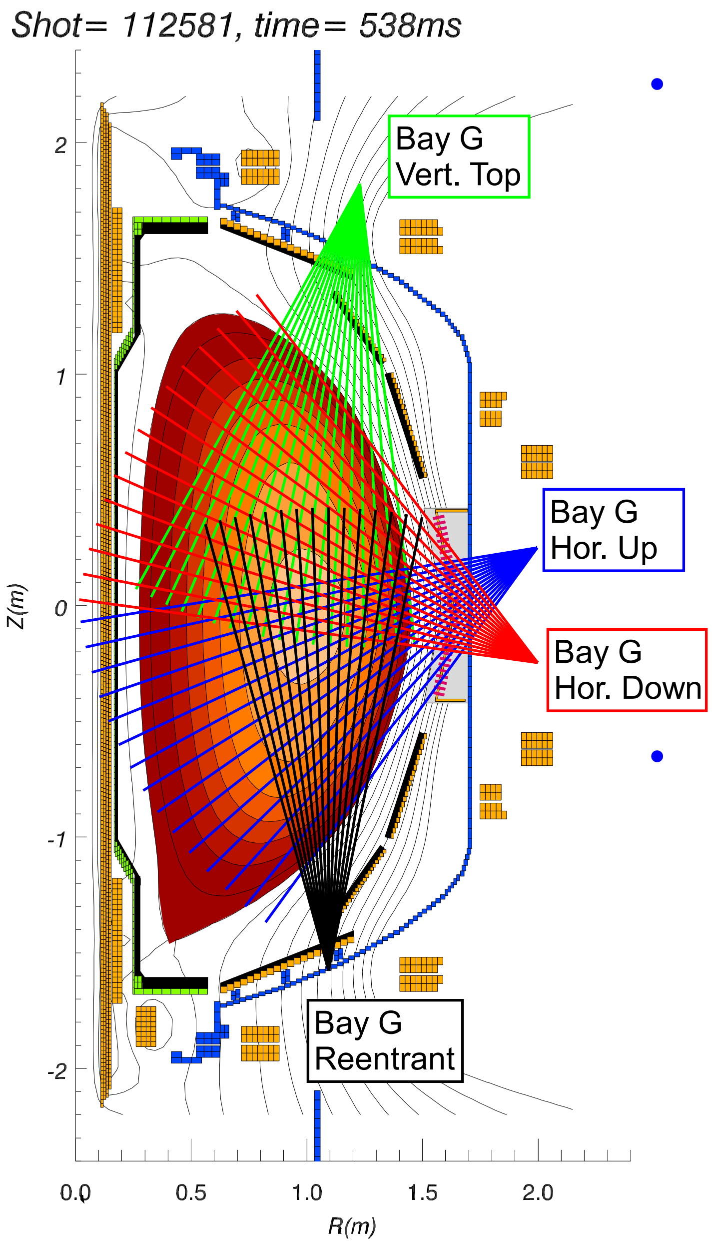
The Johns Hopkins University

R. Maingi (*ORNL*)

and the NSTX Team

NSTX Results Forum Sept. 19th-20th

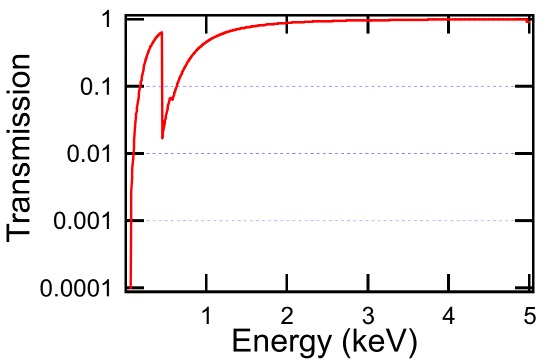
Upgraded Bay G USXR System Provides Improved Spatial Coverage

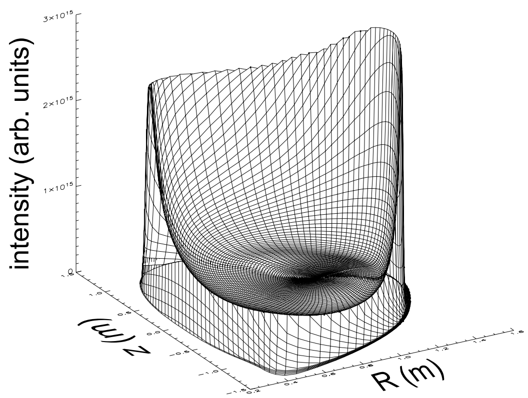


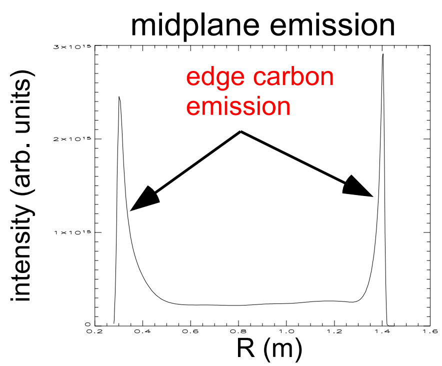
- Imaging and tomographic reconstruction used to analyze plasma activity
  - Oscillatory events (MHD modes, islands)
  - Intermittent events (sawteeth, ELMs, reconnections)
  - Slow phenomena (rotating/locked modes, RWMs)
- Arrays utilize variable filter settings to change plasma region focus
  - 0.3µm Ti filter views primarily edge C emission
  - 5µm Be filter passes X-rays from bulk plasma
  - 100µm Be filter focuses on core plasma emission

Comparison of Filtered X-ray Contribution

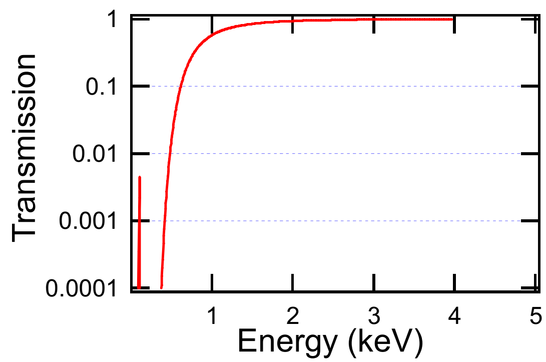
Ti 0.3μm

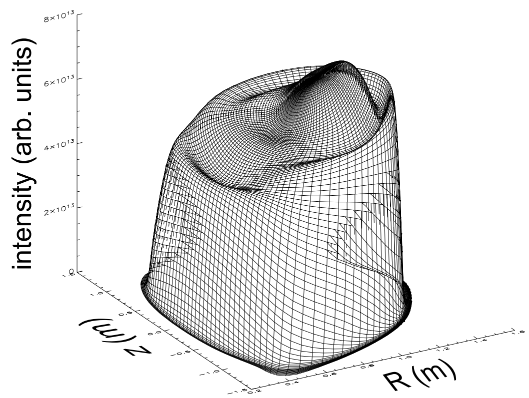


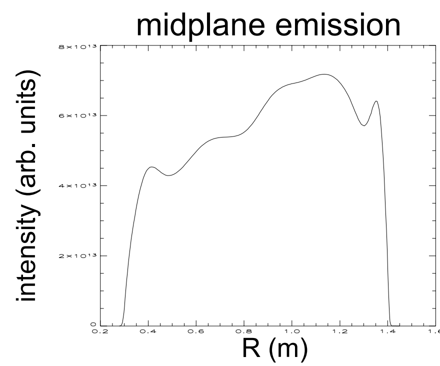




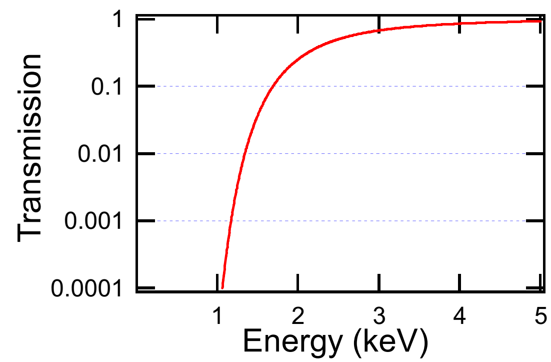
Be 5μm

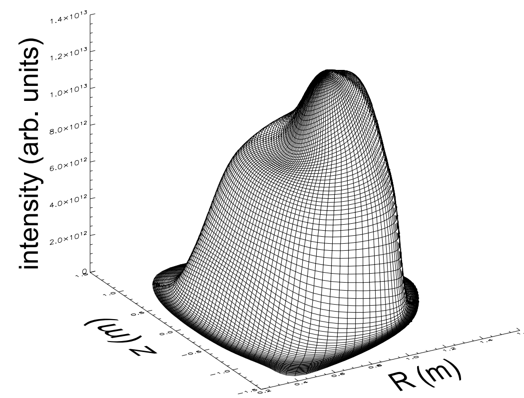


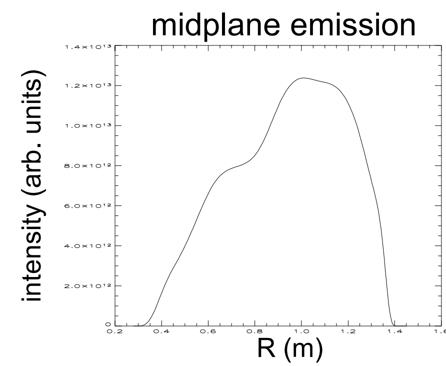




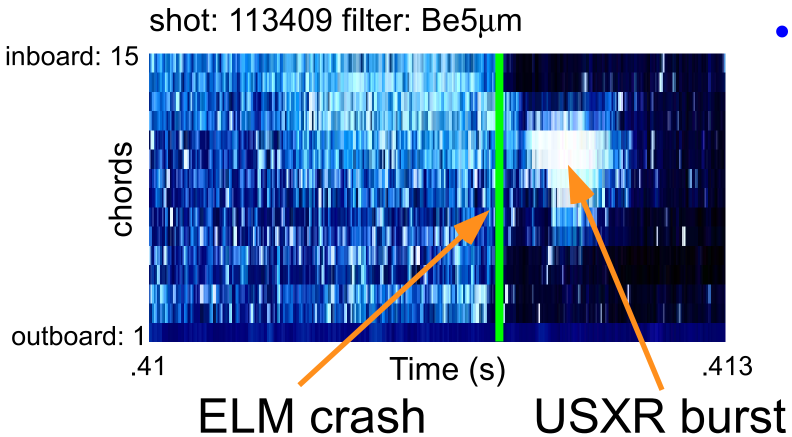
Be 100μm







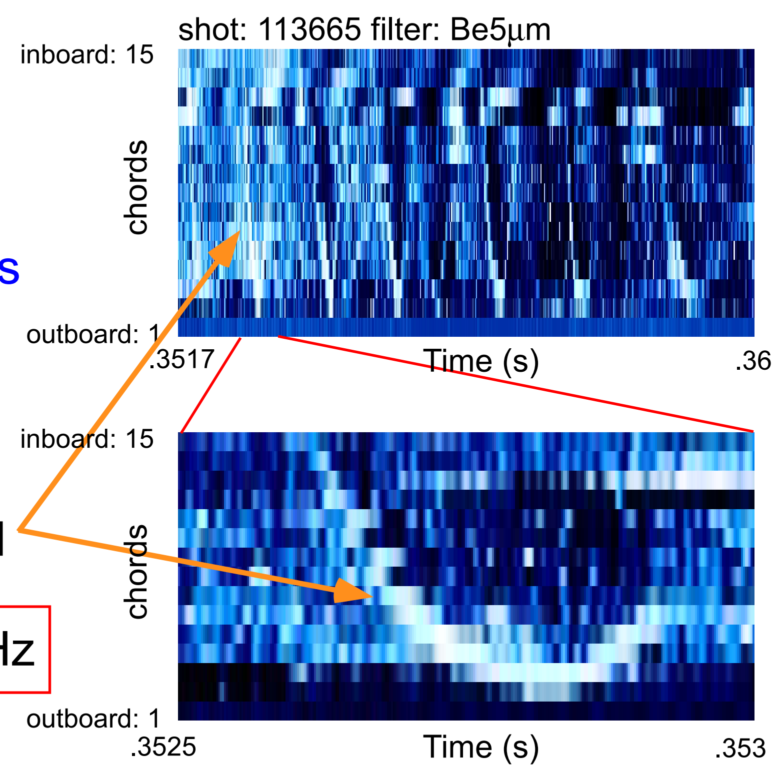
Addition of High-speed Reentrant Array Improves Imaging Capabilities



Localized USXR emission burst ~500μs after Type III ELM event

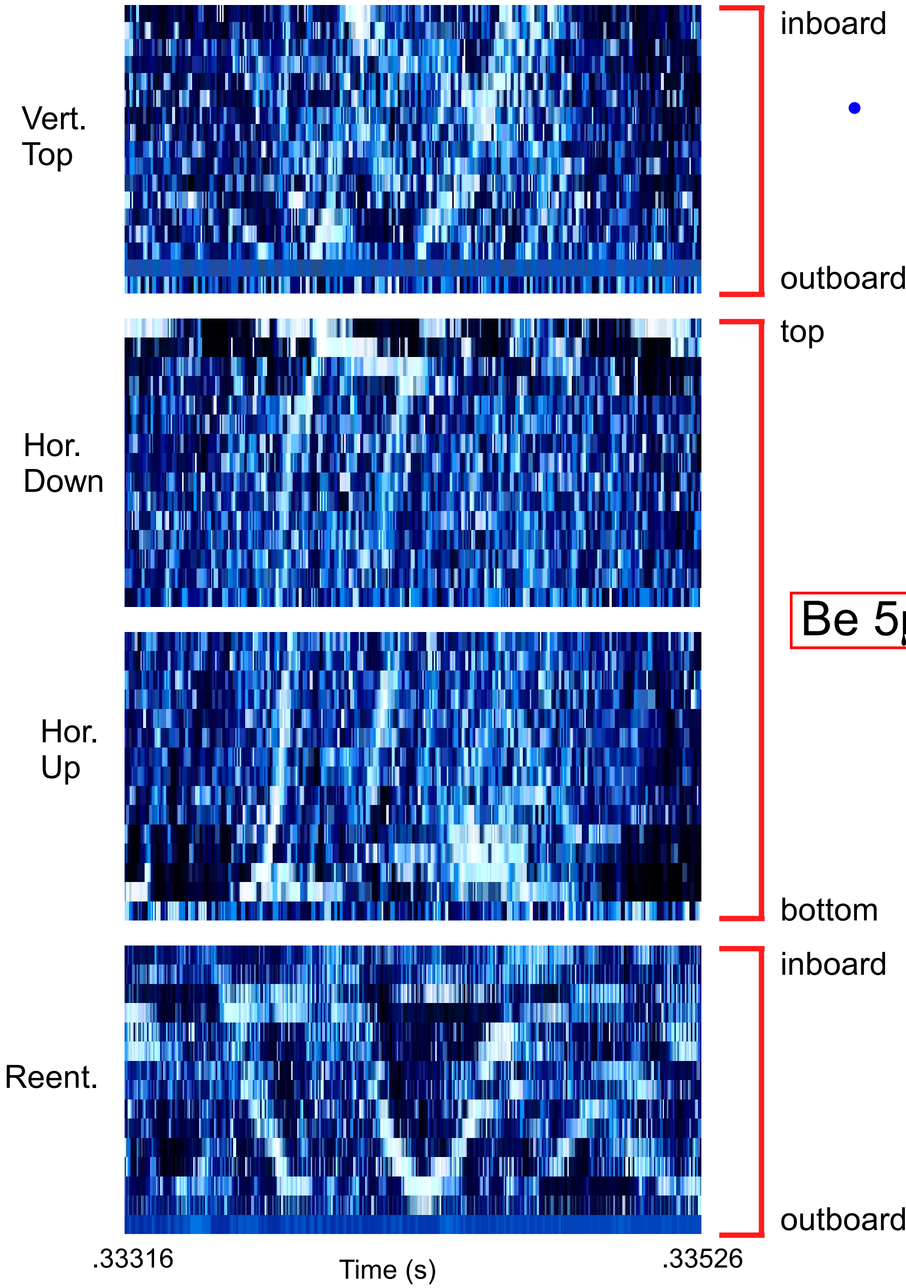
- Reentrant diode array uses AXUV-16 from IRD
  - Fast, low-noise amplifiers have ~300kHz bandwidth
  - High speed PCI digitizer board samples at 600kHz
  - Necessary to resolve outboard plasma edge

- Fast sampling improves imaging of Type V ELMs
  - Reentrant array helps pinpoint ELM origination
  - Improves measurement of event propagation



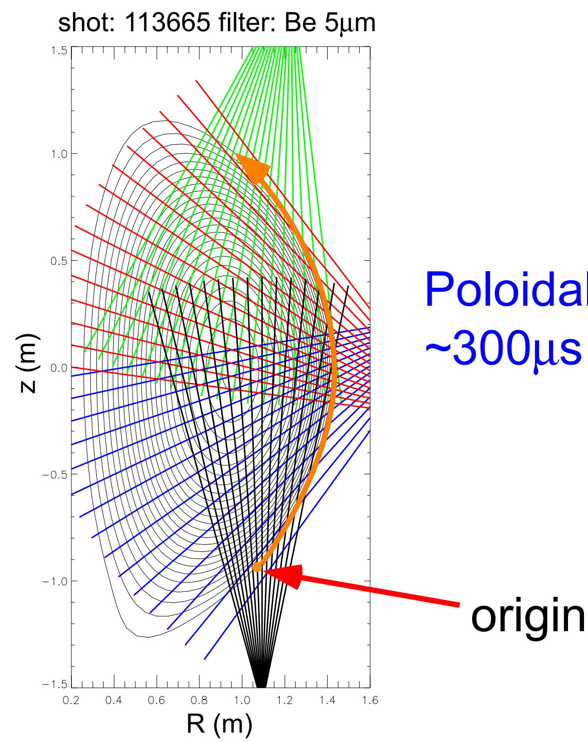
Reentrant array sampling at 600kHz

Imaging of Type V ELMs show Poloidal Propagation



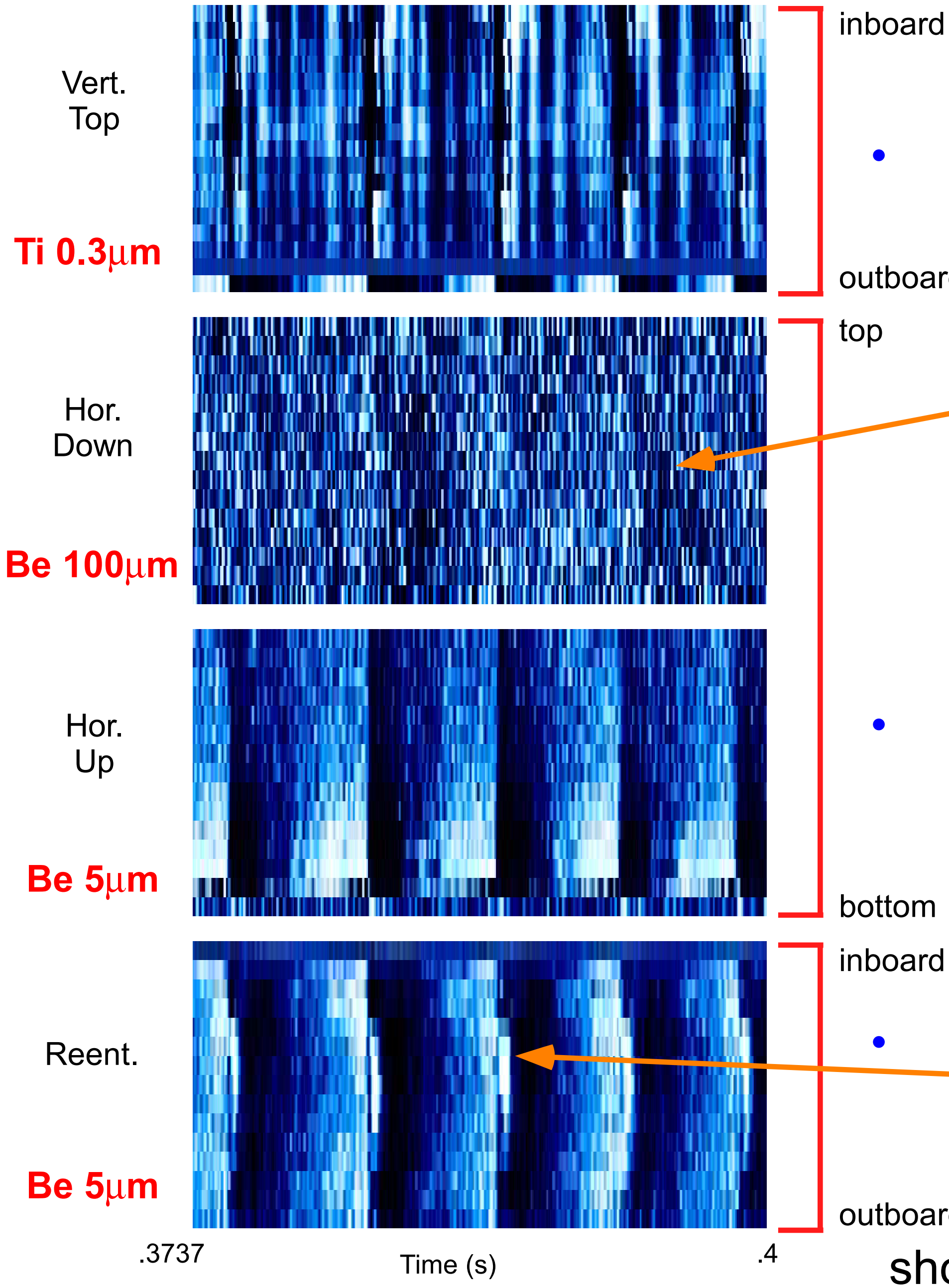
Be 5µm

- ELM characterized by small edge perturbation
  - ELMs originate typically in lower plasma region
  - Propagate counter-clockwise poloidally
  - Have negligible effect on bulk plasma (T_e, W, ...)
  - Regime often contains intermittent Type I events



Poloidal propagation ~300µs from bottom to top

Type III ELM Correlates with Edge n_e/Impurity Crash



- USXR data suggests ELM has negligible effect on bulk n_e, T_e
  - Neutron rate unaffected
  - High energy filter shows little/no evidence of ELM
- ELM frequency increases from ~100Hz to ~300Hz throughout shot (consistent with density increase)
- Localized USXR emission bloom robust, post-ELM feature

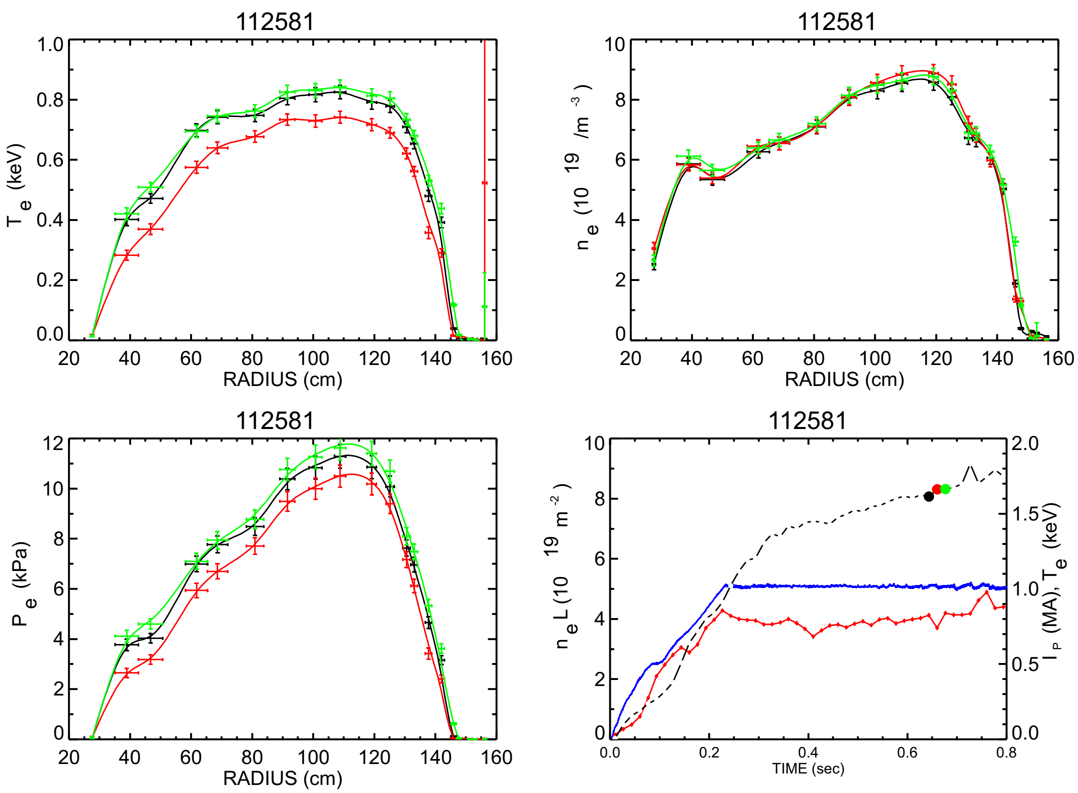
shot# 113406

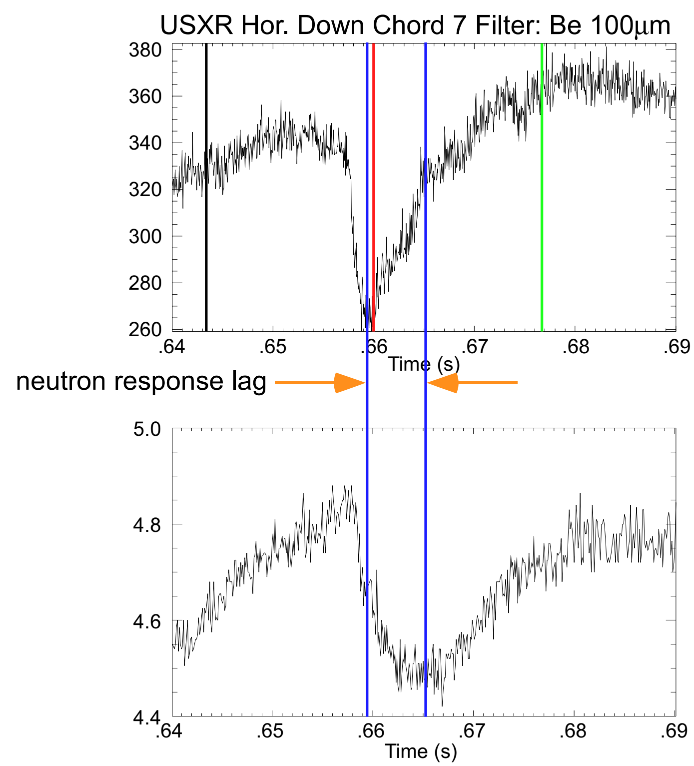
JOHNS HOPKINS
UNIVERSITY

NSTX

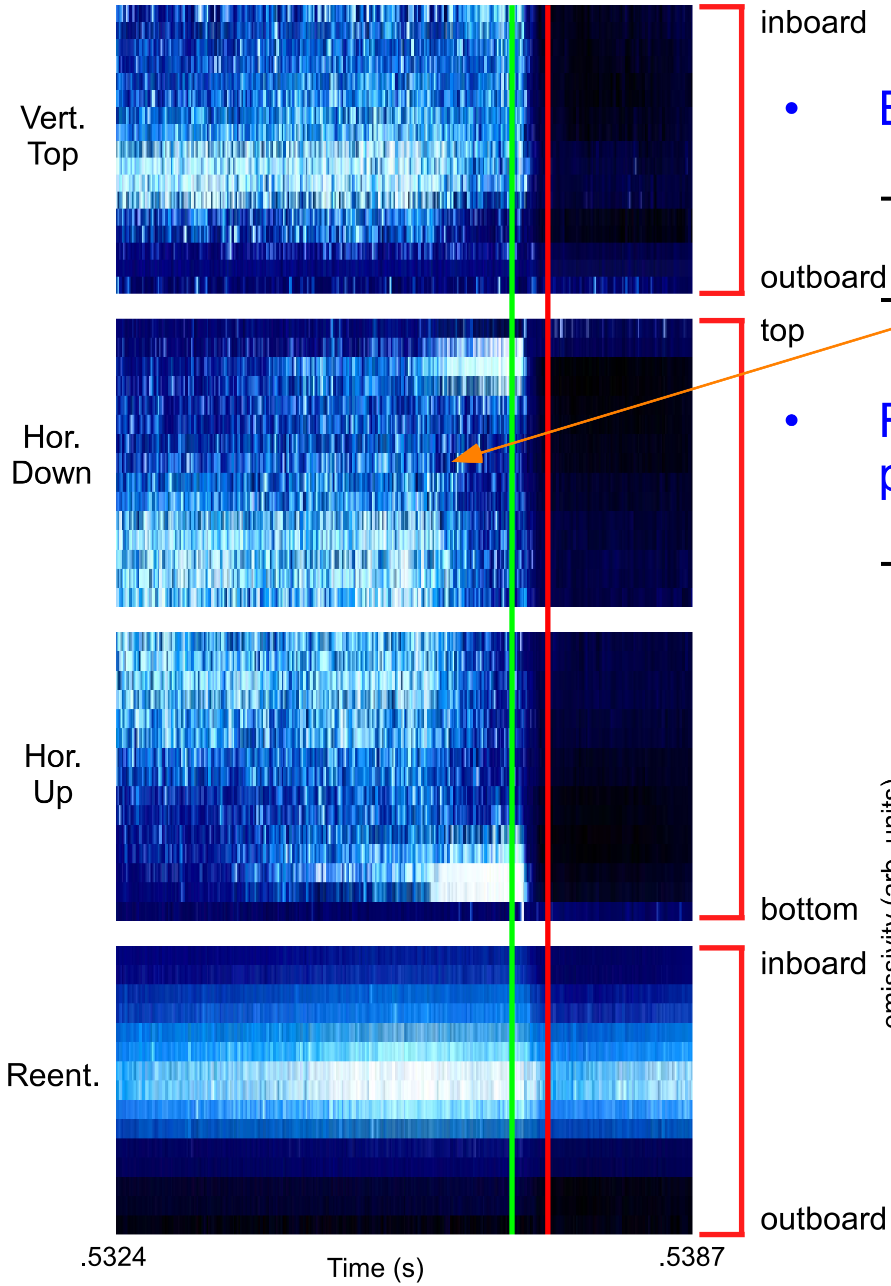
Type I ELM often Accompanied by Global T_e Perturbation

- Thompson measures drop in $T_e(r)$ on the order of 10-20% ($\Delta T_{core} \sim \Delta T_{edge}$)
  - n_e measured before, during, and after ELM shows little change (slight peaking?) pure conductive ELM? (i.e. $n\nabla T$ change only)
  - Neutron response lags T_e profile (decline by ~1ms, minimum by ~5ms)
  - Not all T_e perturbations reach core (e.g. shot 113665 @ 0.377s, 112581 @ 0.537s)

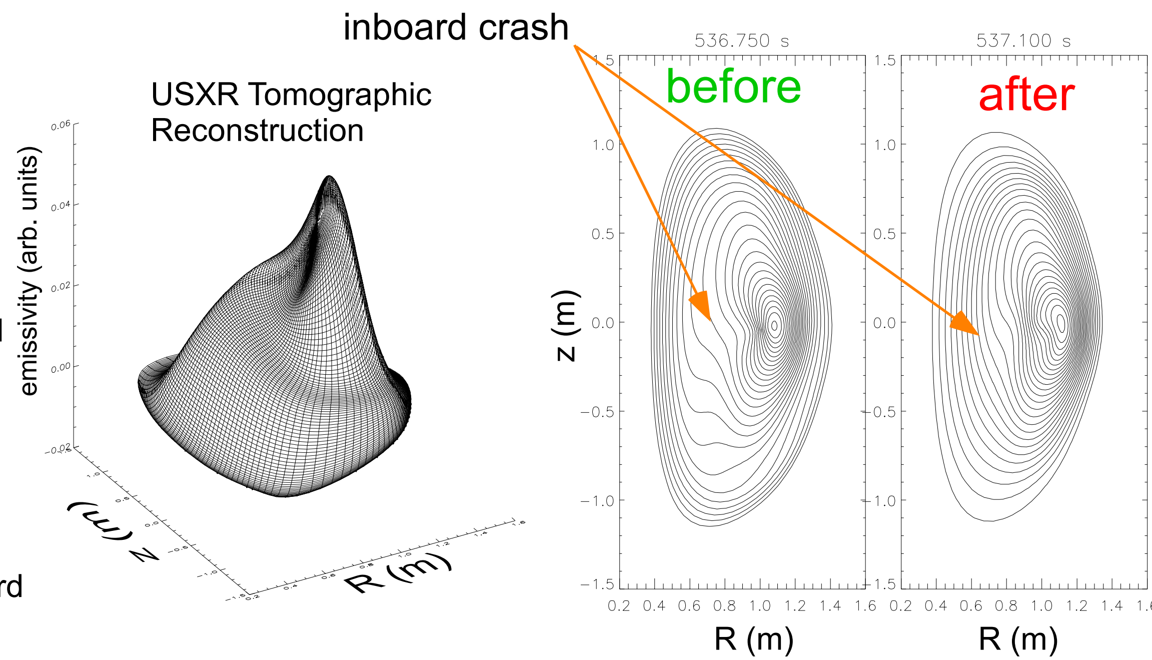




USXR Arrays Allow Tomographic Reconstruction of Type I ELM Perturbation

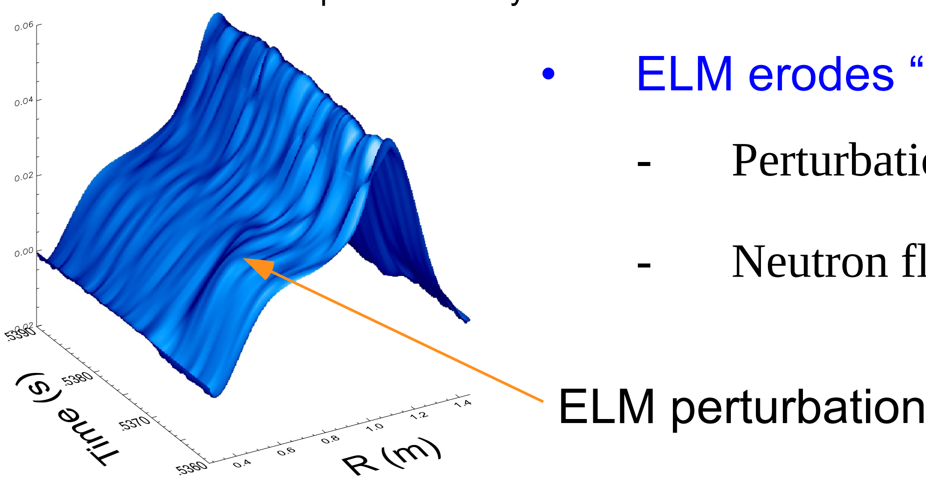


- Be 100μm filters focus on core emission
  - Reconstructed emissivity consistent with USXR model
  - Evidence of redistribution precursor (not always present)
- Reconstructions before and after ELM show main perturbation activity at inboard side of plasma
  - Two-color analysis necessary for T_e perturbation study



Preliminary Analysis Indicates Intensity Crash Begins at the Inboard of the Plasma Volume

Reconstructed midplane intensity

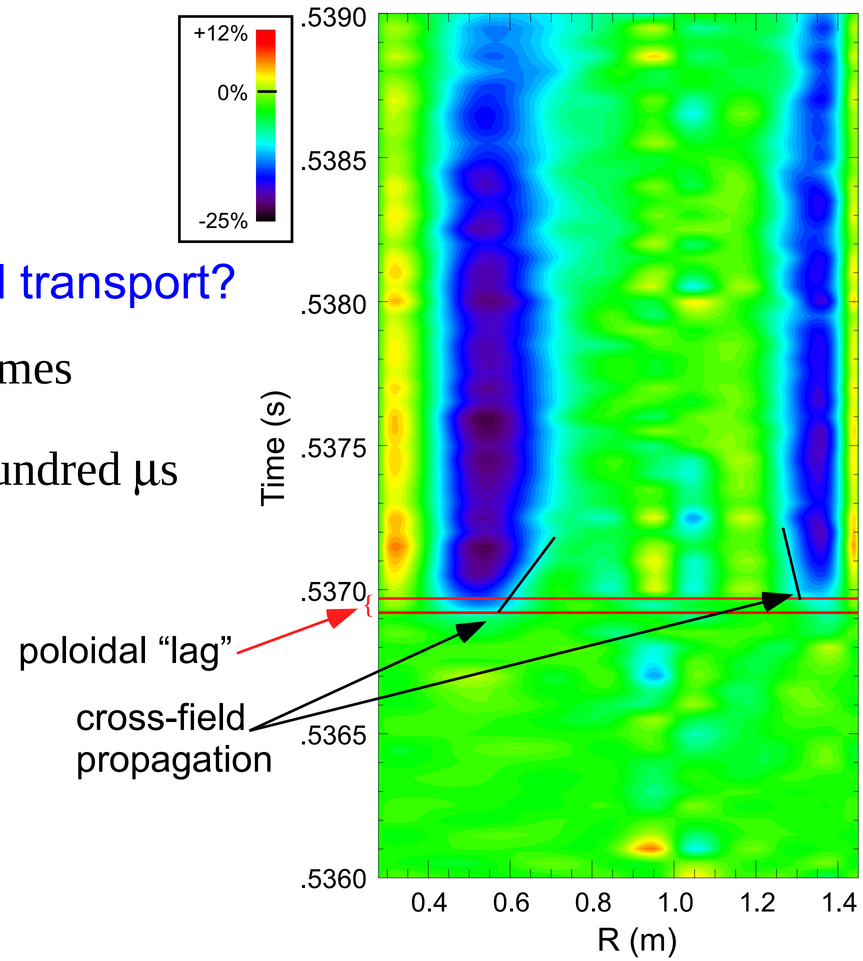


- ELM erodes “bump” at inboard of plasma
  - Perturbation reaches $\psi_N \sim 0.25$ (0.7m inboard, 1.27m outboard)
  - Neutron flux drops ~1-3%

- Delay of outboard crash indicates fast parallel transport?
  - ~50μs lag consistent with parallel transport times
  - Cross-field transport appears slower, ~ few hundred μs

- Caveat
  - Spatial resolution limited by spline knots
  - Time resolution limited by SNR (~50μs)
  - More events need to be analyzed

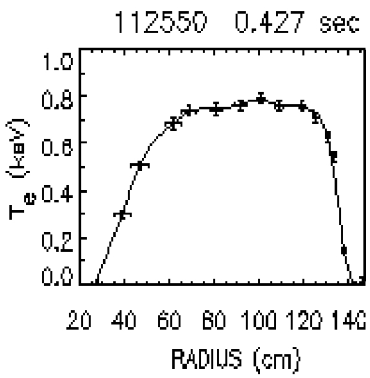
Relative midplane intensity change

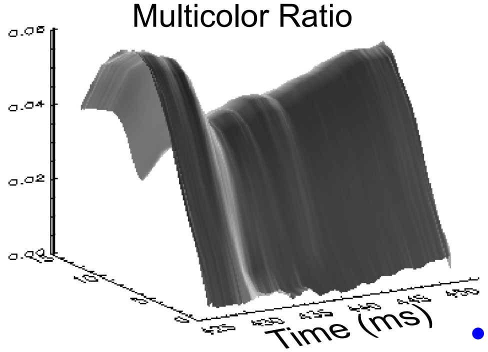


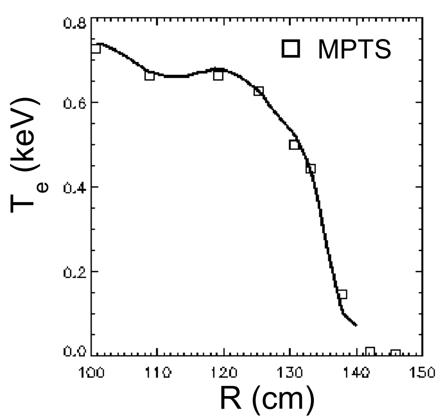
JOHNS HOPKINS UNIVERSITY

NSTX

MPTS T_e profile ‘propagated’ by 2-color USXR modeling







- Pre-ELM MPTS profiles used to fix n_e, n_z in USXR model
  - USXR profiles modeled using C, O and B coronal equilibrium radiative coefficients and magnetic surface mapping
- Ratio of Be 100μm/5μm filters sensitive function of T_e
  - 2-color modeling provides $T_e(R,t)$ with good temporal resolution
  - T_e crash in pedestal ~40-80%, core ~10-20% $\left(\frac{\Delta T}{T_{core}} \neq \frac{\Delta T}{T_{edge}}\right)$
  - Core perturbation consistent with ~20% reduction in neutron flux
- Propagated $T_e(R)$ matches well with subsequent MPTS profile
- Limitations of technique
  - Crossed arrays allow only 1-D modeling
  - Assumption of no asymmetric density shifts or plasma movement
  - Set of multi-color arrays would alleviate these limitations

Summary

- Upgraded USXR set provies good plasma coverage
    - High-speed reentrant array boosts fast imaging capabilities
    - Some portions of plasma volume still under-sampled
- Various ELM phenomena have been imaged using the USXR arrays
    - imaging of Type V ELMs show poloidal propagation
    - Type III ELMs correlate with edge n_e perturbation and subsequent localized USXR emission bloom
    - Type I ELMs often accompanied by a global T_e perturbation
- Preliminary tomographic reconstruction analysis suggests Type I ELM crash begins at inboard of plasma
- Multi-color USXR modeling is a powerful tool for fast T_e profile analysis