

# Visible imaging of divertor turbulence in NSTX and NSTX-U L-mode discharges

NSTX-U Results Review 2016

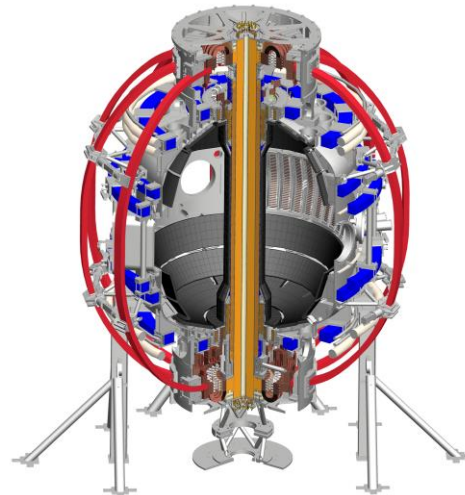
September 20, 2016

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 Lawrence Livermore  
National Laboratory



 NSTX Upgrade



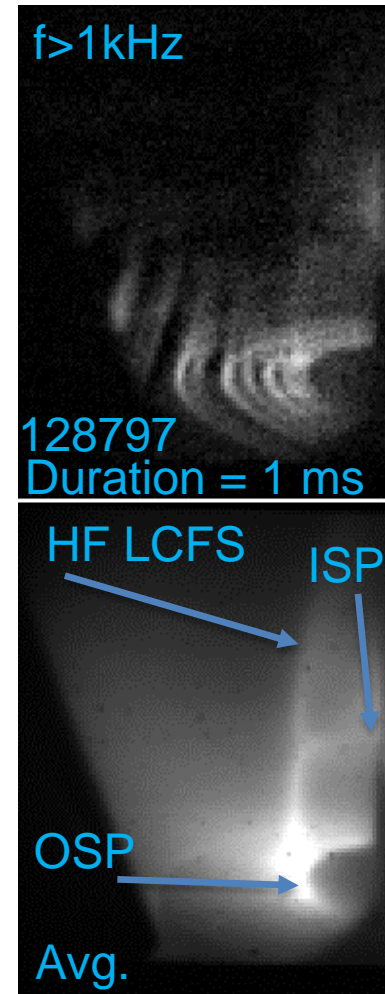
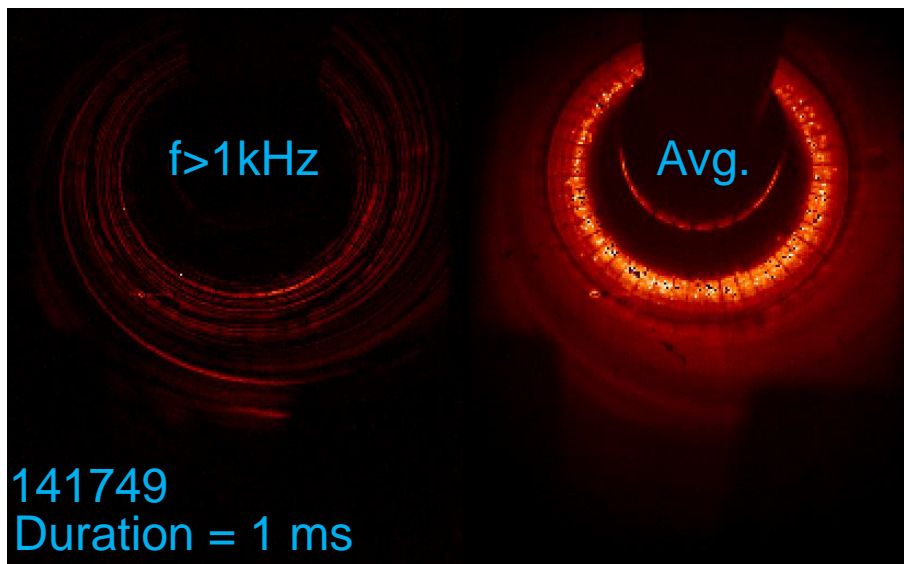
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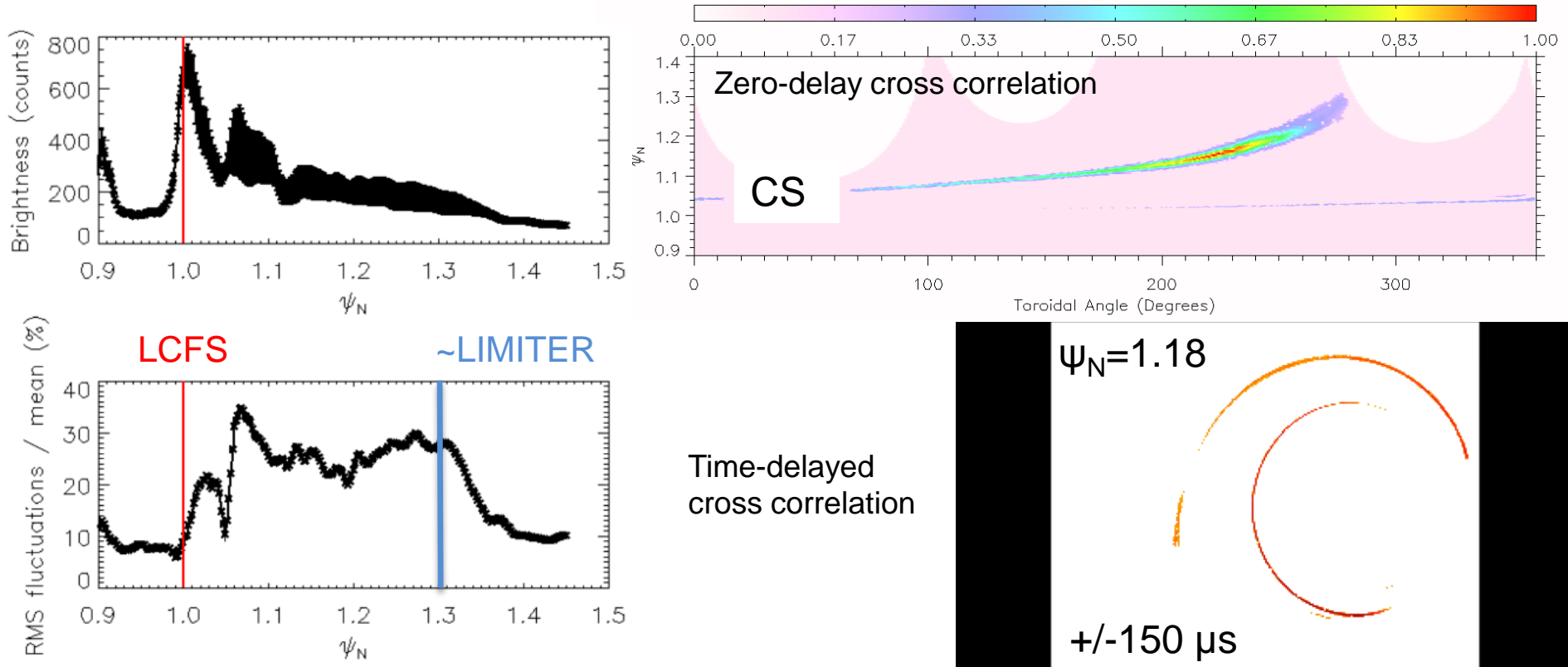
# Divertor intermittent filaments routinely observed in NSTX L-mode and H-mode discharges

- Understanding divertor turbulence is important to assess its role in setting divertor heat and particle flux magnitude and width
- Divertor intermittent filaments have been studied in NSTX L-mode (Scotti APS 2016) and H-mode discharges (Maqueda NF 2010)
- Most easily studied via neutral lithium imaging of filament footprint
  - Brightest line in NSTX (with Li), atomic physics provides surface localization
  - Brightness fluctuations can be understood as being  $\sim \tilde{n}_e$
  - Tangential  $D\alpha$  imaging can complement with poloidal filament structure



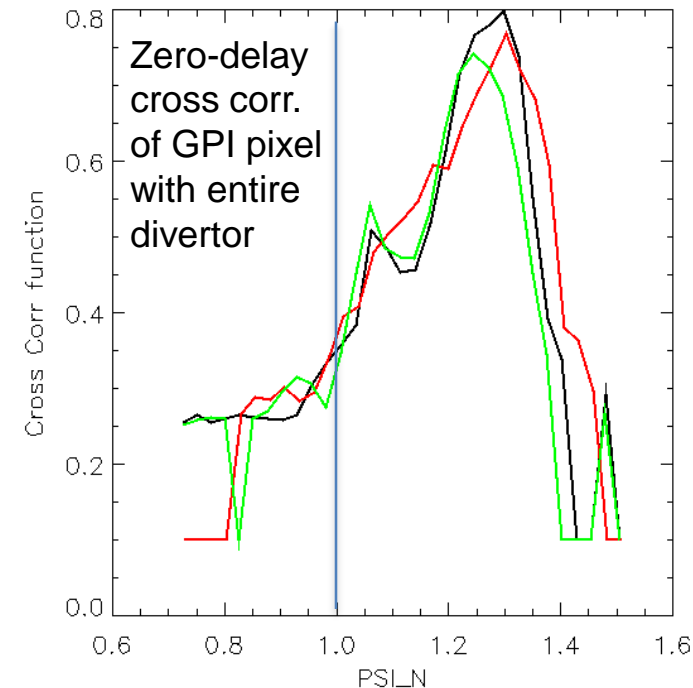
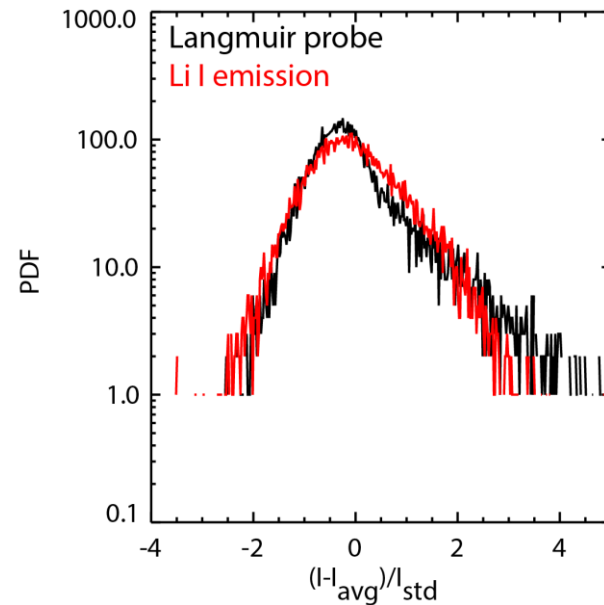
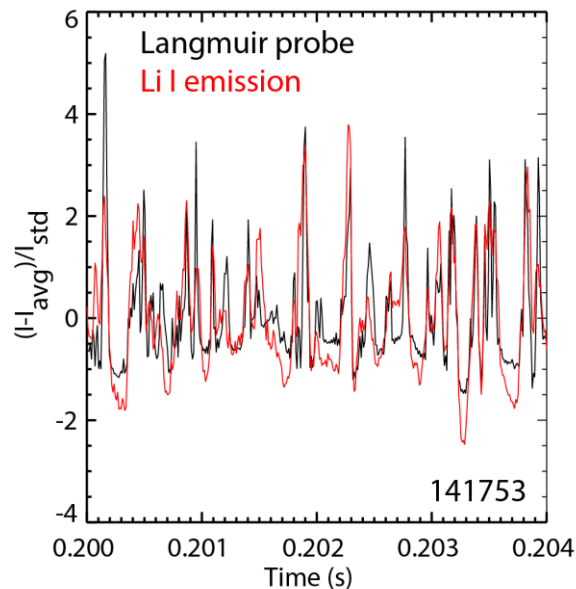
# In diverted L-modes from NSTX, fluctuations up to 30-50%, time delayed cross correlation consistent with upstream radial motion

- Diverted NSTX Ohmic L-mode discharges from 2010: Li I @ 100kHz, 8 $\mu$ s exposure
  - Fluctuations up to 30-50%, autocorrelation  $\sim$ 50-100 $\mu$ s, statistical moments follow expectations for Gamma distribution
  - Cross correlation of single pixel with rest of image shows helical correlation regions
  - Spiral motion consistent with upstream radial and poloidal motion, toroidal number  $\sim$ 10



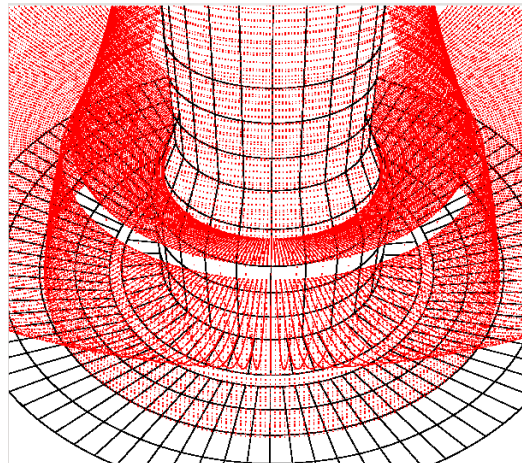
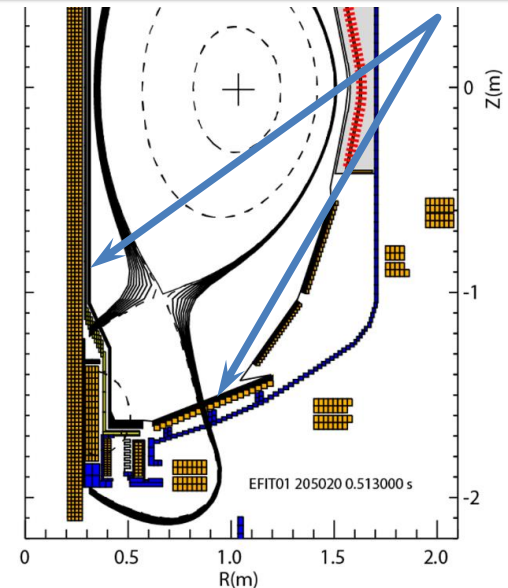
# Filament footprint in Li I emission correlates with probe $J_{\text{sat}}$ at target and GPI upstream

- Cross correlation with probe ion saturation current at same  $(r, \phi)$  up to 0.7-0.8, peaked at zero delay
- Cross correlation with GPI up to 0.7-0.8 in far SOL in region magnetically connected to GPI field of view
  - Peaked at zero delay, as also observed in [Maqueda NF 2010]
  - No features observed at ion transit time scales
  - Progressive decrease of correlation towards LCFS

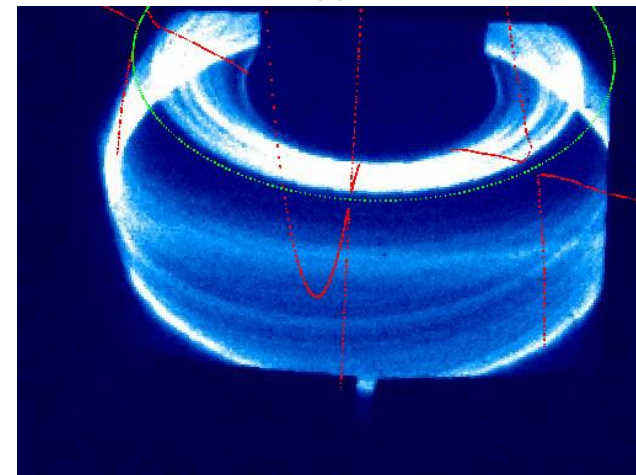
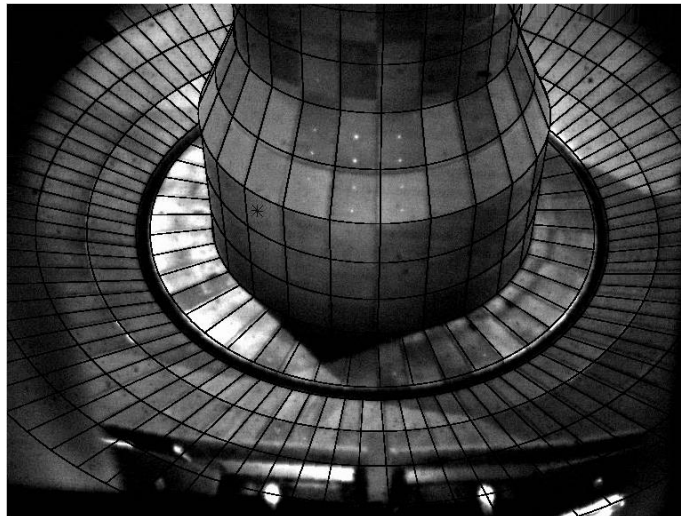


# Throughput-optimized camera and high-X-point L-modes enabled near-separatrix turbulence imaging in NSTX-U

- Divertor turbulence imaging through different species/charge states provides information at different spatial locations
- Throughput-optimized setup enabled turbulence imaging via C III (up to 140kHz)
  - Filaments along divertor legs (vs. filament footprint on floor via Li I or D $\alpha$ )

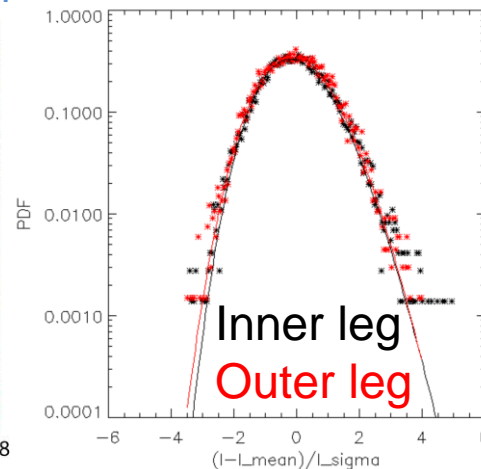
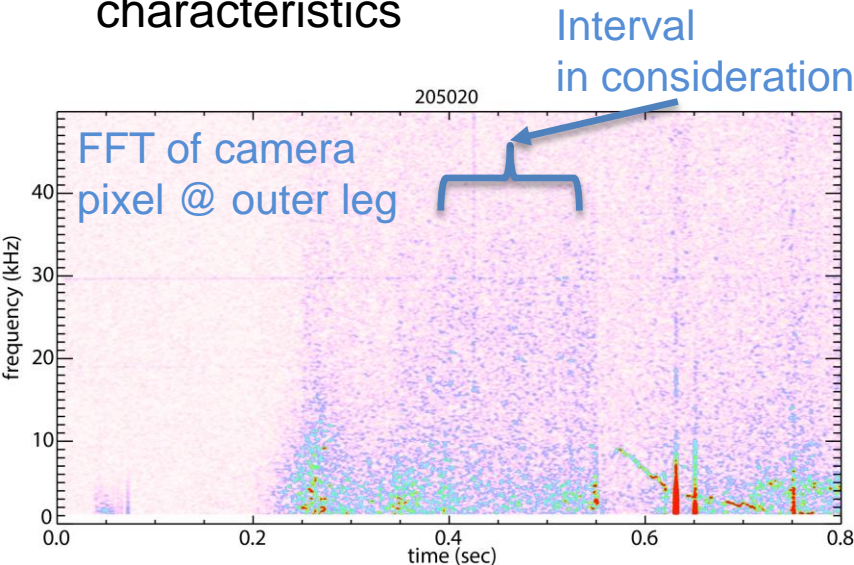
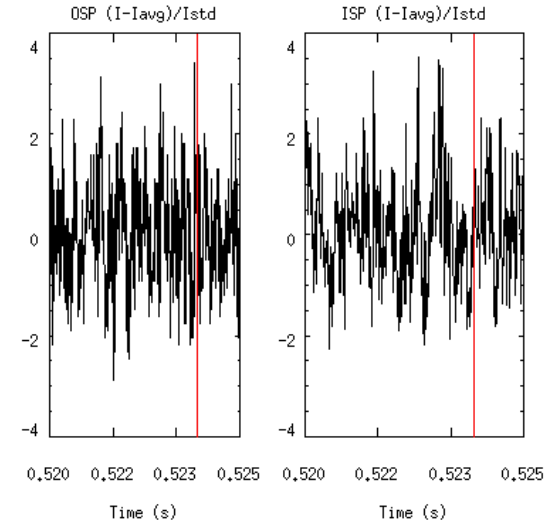


Reconstructed view + separatrix

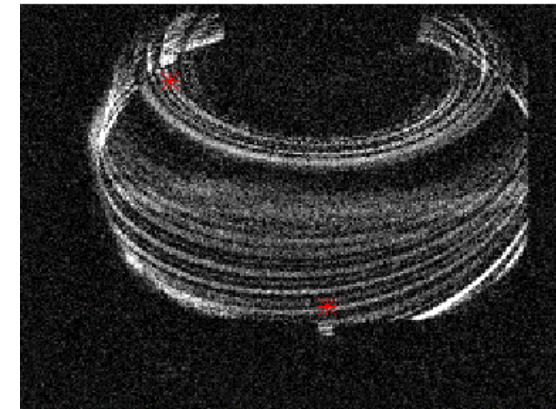


# Intermittent field-aligned filaments observed in inner and outer divertor legs

- NBI-heated downward biased L-mode discharges
- Intermittent filaments observed on both inner and outer divertor legs (as recently observed in MAST and C-Mod)
- FFT amplitude shows broadband fluctuations
- $\delta I/I \sim 10\text{-}20\%$
- PDF of inner and outer leg filaments show similar characteristics

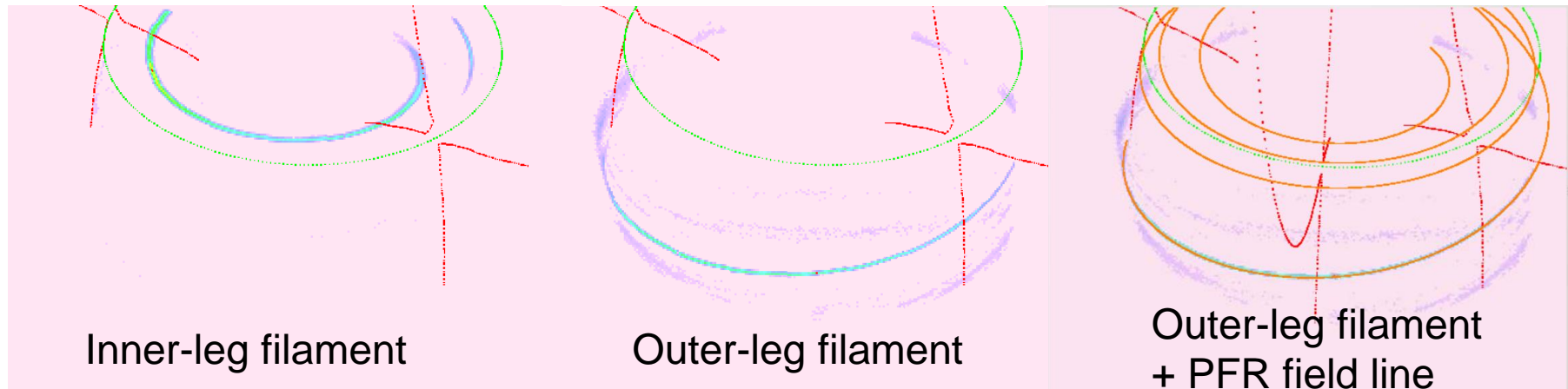
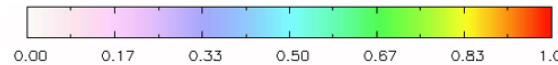
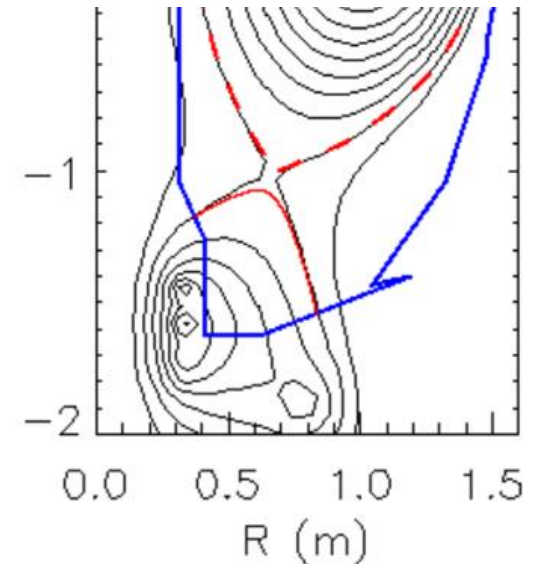


High-pass filter 1kHz



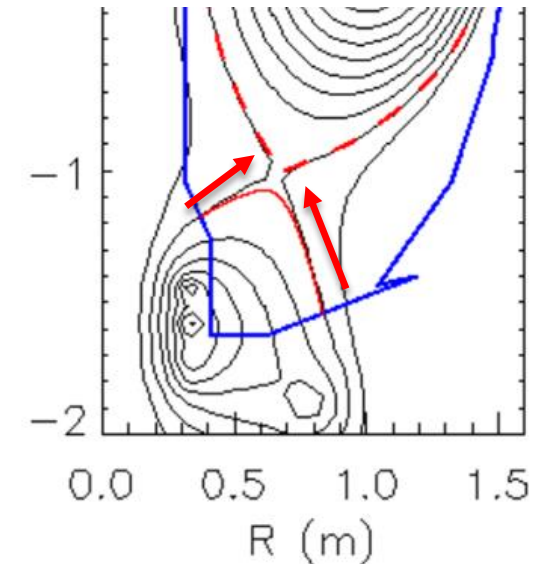
# No correlation observed between inner and outer leg filaments

- Zero-delay cross correlation of single pixel with rest of image performed for both inner and outer leg filaments over 10ms
- Filaments are field aligned, radial localization around the leg
  - Impossible to determine whether inside, at or outside separatrix
- Correlation  $>$  toroidal turn on inner leg,  $<$ toroidal turn in outer leg
  - Can be affected by lower signal to noise due to C III shell localization
- Inner and outer leg filaments are uncorrelated (despite being magnetically connected)
- Auto-correlation  $\sim 10$ s microsec

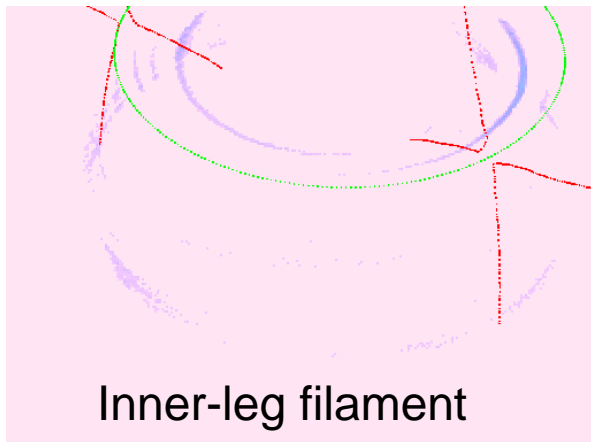


# Time delayed cross correlation shows opposite toroidal rotation for inner/outer leg filaments

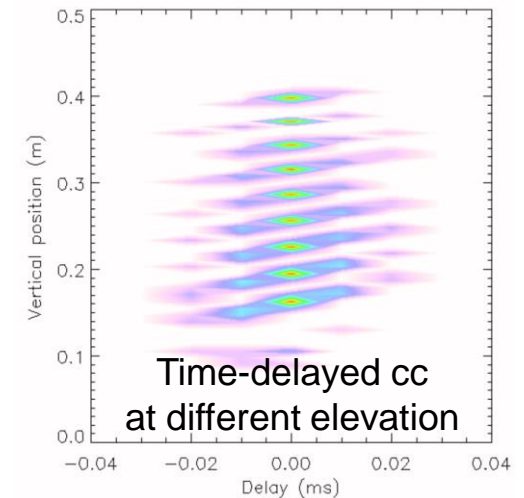
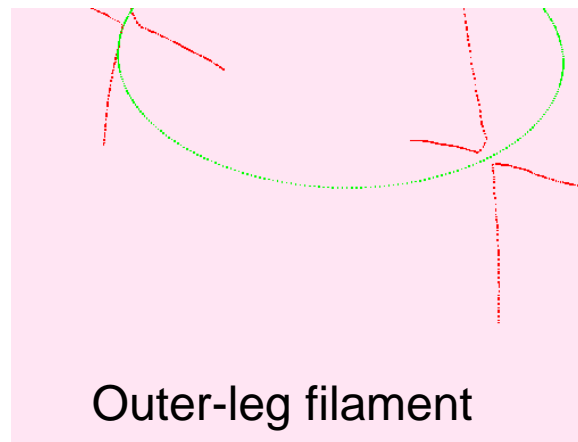
- Time-delayed cross correlation of single pixel with rest of image to show average filament propagation
- Apparent poloidal motion for both inner and outer leg filaments towards X-point
  - Or equivalently opposite toroidal directions
  - Inconsistent with flux tube rigid rotation (also in C-Mod, J. Terry JNME 2016)
- Poloidal velocity  $\sim 1\text{km/s}$



Delay  $[-30, +40]\mu\text{s}$



Delay  $[-40, +40]\mu\text{s}$



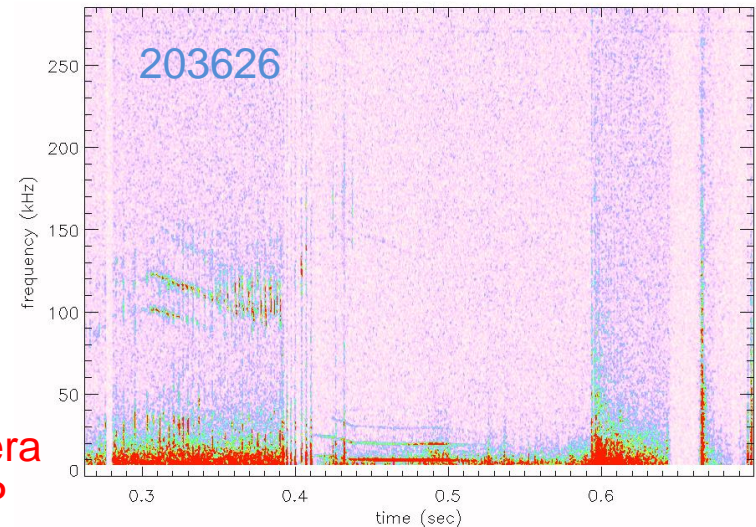


# Summary and future work

- Data to analyze from the 2010 divertor high speed database + high quality GPI
- Expand work on near-separatrix filaments:
  - Correlation with GPI not observed so far
  - Filaments characterization for
    - Different collisionality regimes, magnetic geometry
    - During detachment (inner SOL filaments observed)
  - Apply existing models (e.g., stochastic model) or codes (XGC, BOUT++)
- Would have been useful to have Langmuir probes and IR camera data during FY16 campaign to understand impact on divertor particle and heat fluxes
- Analyze impact of MHD modes on divertor profiles and turbulence

FFT of camera pixel @ OSP

NSTX-Upgrade
Along inner leg, outer leg, inboard SOL
Apparent motion: upward along legs
Size ~1 cm
>One transit in inner leg, < one transit in outer leg
Life time ~10s microseconds
Fluctuation level ~10-20 %
Speed ~1km/s



# Update on new ENDD status

- ENDD has a new setup in NSTX-U
  - Relocated from Bay I to Bay G to accommodate JHU diagnostics
  - Looking toroidally in front of NBI dump tiles
  - Re-entrant viewport with imaging bundle and in-vessel mirror
  - $D\alpha$  instead of  $D\beta$
- Main concerns with new view is toroidal asymmetry in neutral density due to proximity of beam dump
- ENDD operational for most of the year
  - In-vessel mirror alignment finalized in March
- Absolute calibration of GPI ( $180^\circ$  from ENDD) to check toroidal variation in neutral density, validate ENDD view

