MARFE Structure and Dynamics in NSTX

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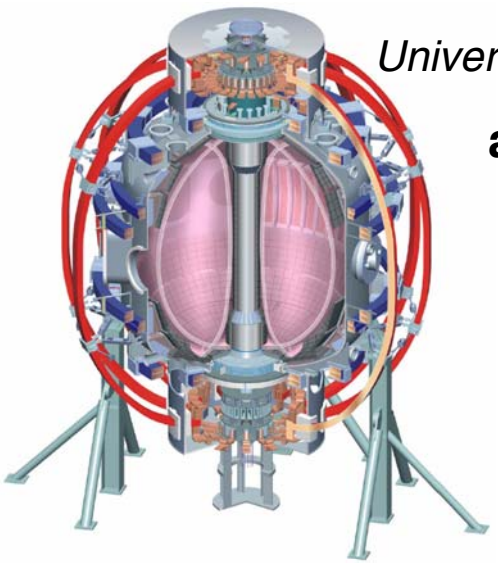

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Movie clips are hyperlinked to "camera" symbol.

NOVA PHOTONICS

NSTX

Complex MARFE and ELM interactions observed with fast camera in NSTX

- MARFES observed around center stack in Double-null discharges
- Whereas large ELMs can quench a MARFE, small ELMs result in temporary or partial quenching, followed by re-formation
- The MARFE is only roughly axisymmetric, with apparent rotation in emission profiles

Outline

- Basic MARFE physics review
- MARFE/ELM dynamics with fast, visible camera
- Temporal correlation of small ELM and MARFE cycles
- MARFE structure
- Summary

See Fred Kelly's poster **QP1.35**.

MARFE basics

Multifaceted **A**symmetric **R**adiation **F**rom the **E**dge

B. Lipschultz et al., Nucl. Fus. 1984

Conduction **Radiation**

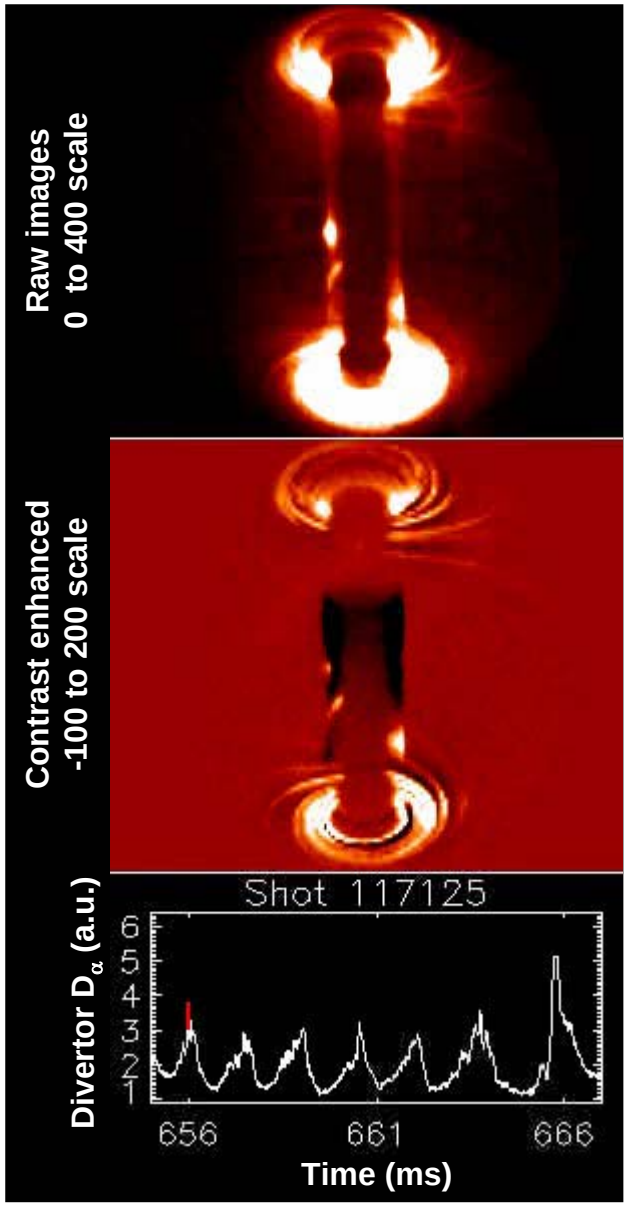
$$3\frac{\partial(nT)}{\partial t} = \frac{\partial}{\partial s}\left(K_{//}\frac{\partial T}{\partial s}\right) - \sum n_e n_z L_z(T) \pm \ldots$$

Thermal instability possible if *$dL_z/dT < 0$*, "radiation barrier".

Different models include additional terms, see Fred Kelly's poster **QP1.35**.

MARFE: Toroidal band of low temperature, high density, high radiation plasma surrounding the center column of the device.

MARFE dynamics (D_α)



- Toroidally symmetric MARFE moves downwards (ion ∇B-drift direction).
- ELM activity in divertor region coincides with burn through of most of MARFE.
- Toroidally localized MARFE remnants move upwards, following field line.
- Upward movement stagnates and MARFE precursor expands into a toroidally symmetric band.
- Type I ELM (at ~666 ms) burns through MARFE.

Clip: **D_α filter**
9 μs exposures

10 ms at 68000 frames/s
playback at 220 μs/s

~25 MB

800 kA
6.0 MW NBI
Double null

MARFE dynamics (Carbon emission)

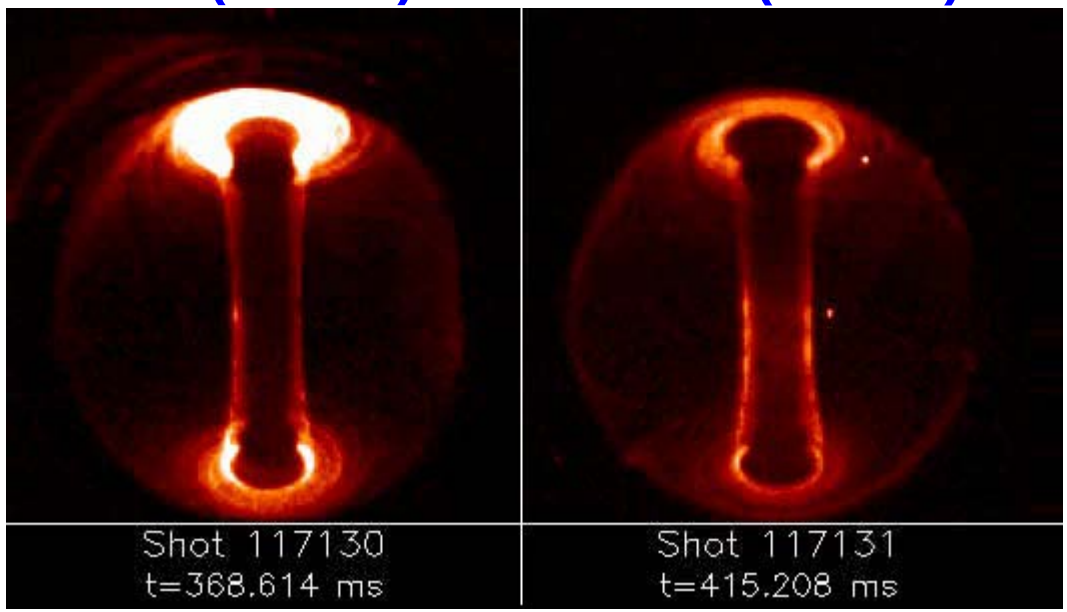
800 kA
6.0 MW NBI
Double null

~22 MB

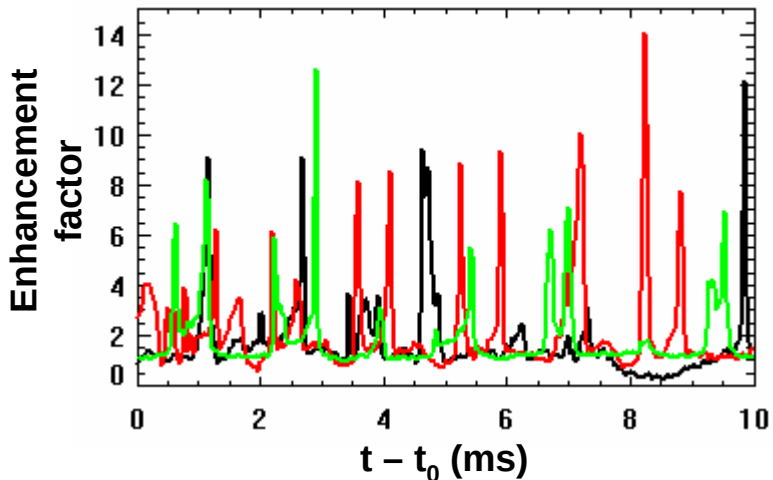
Clip: 26 μs exposures

10 ms at 30000 frames/s
playback at 250 μs/s

CII (6578 Å) CIII (4647 Å)



- **Dynamics similar** in CII and CIII compared to D_α.
- **Enhancement factors of 6-10** typical for <u>all</u> <u>three</u> CII, CIII and D_α.

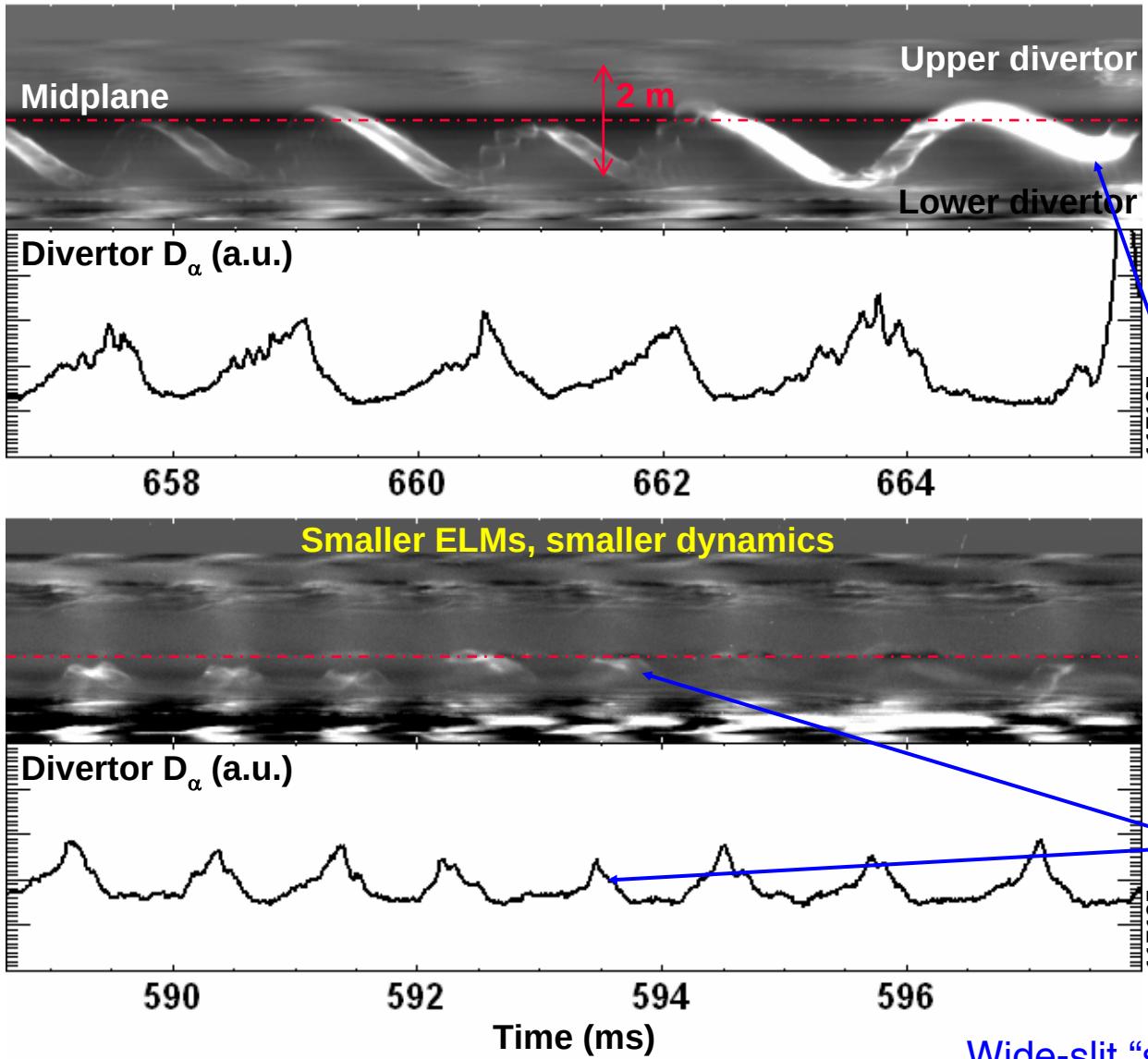


CII (t_0=368.6 ms)
Shot 117130

CIII (t_0=415.2 ms)
Shot 117131

D_α (t_0=384.4 ms)
Shot 117127

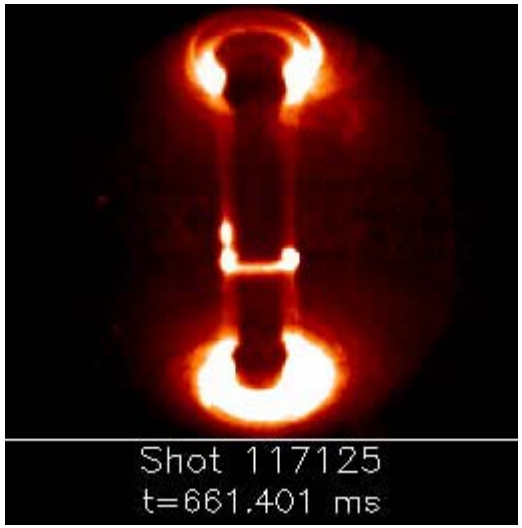
ELM cycle governs MARFE dynamics



- ELM cycle and MARFE cycle closely linked.
- Nevertheless, behavior and dimensions varies.
- Precursor of Type I ELM first reverses MARFE movement and then burns through MARFE.
- ELM character and size reflected on MARFE dynamics.

Wide-slit "streak" compositions, D_α light.

HFS ELM filament

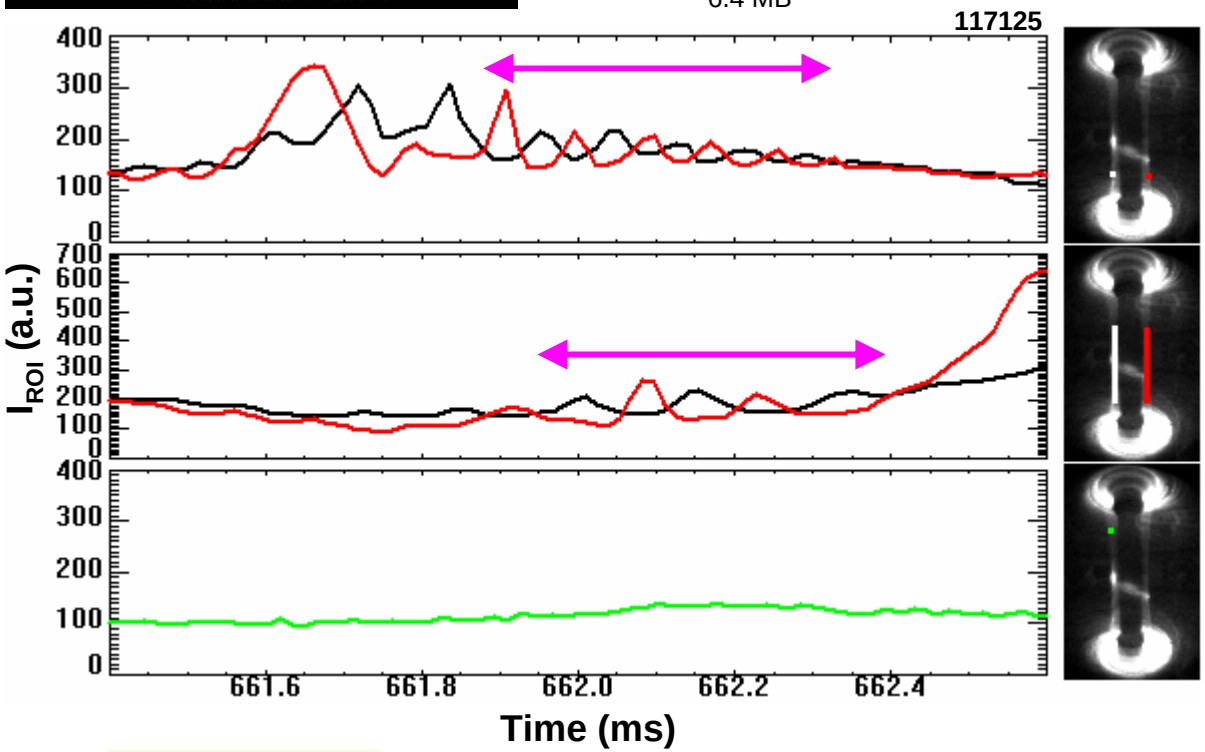


D_α filter
9 μs exposures

1.2 ms at 68000 frames/s
playback at 108 μs/s

~6.4 MB

MARFE precursor rotation frequency slower than HFS filament rotation.

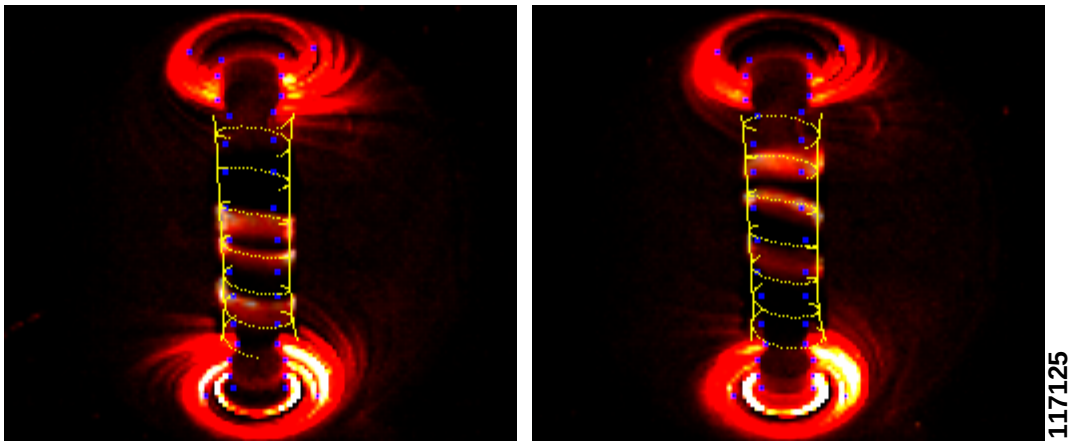


- Below MARFE, filament rotates at ~12 kHz (n=1), counter to I_p.
- MARFE precursor rotates at ~7 kHz, counter to I_p.
- No filament observed above MARFE.

MARFE Precursor trajectory

Upward movement of MARFE precursor

Multi-exposure composites, D_α light.



660.502 ms – 660.821 ms 661.937 ms – 662.285 ms

Field line at separatrix, ψ_N=1

LRDFIT, J. Menard, PPPL

MARFE pre-cursor almost field aligned near separatrix

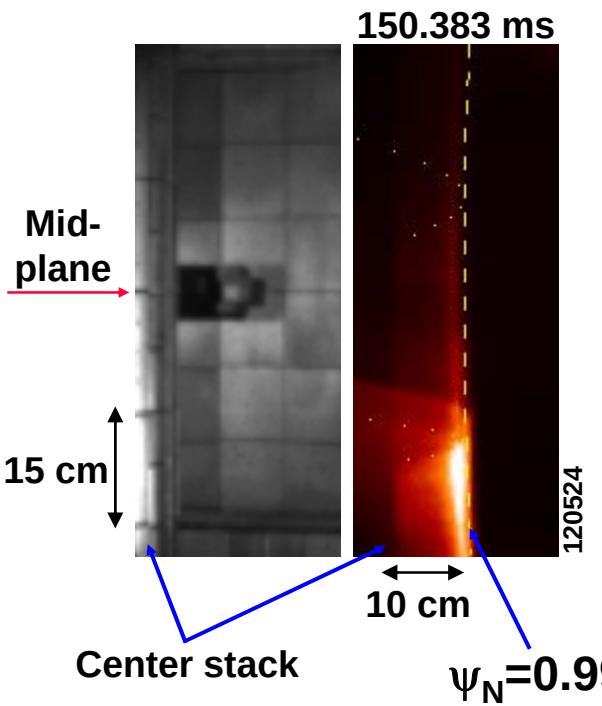
- Field line pitch decreases as vertical stagnation approached
- In lab frame v_{pl}=(14.0±2.0) km/s

(c_s ~ 4 eV for D^+)

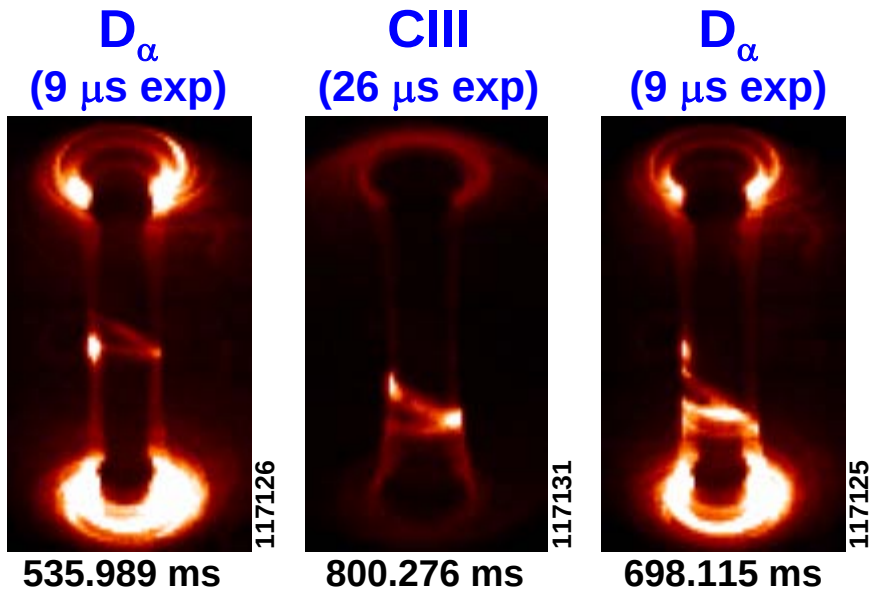
Parallel transport picture of MARFE movement

- Edges of precursor close to thermal stability.
- Extra heat upstream pulls lower edge out of unstable conditions.
- Particles now in warmer edge need to expand, both upstream and downstream.
- Particles moving downstream deepen instability condition on rest of plasmoid.
- Downstream edge grows and precursor “moves”.

MARFE structure



- MARFE structure extends within the separatrix.
- Typical poloidal extents of 5-15 cm.



- Bifurcated structure observed in ϕ, Z plane for the MARFE precursor.
- Moving precursor acts as seed for partial, short-lived toroidal MARFE.

Summary

- Coincident with the ELM cycle the MARFE moves up/down the center stack.
- The toroidally symmetric MARFE is, in some cases, born from a precursor resulting from partial burnthrough of the preceding MARFE in the cycle.
- HFS ELM filament rotates faster than MARFE precursor, and opposite to core plasma rotation.
- Pitch of precursor movement can be longer than pitch of B field.
- MARFE precursor presents a bifurcated structure in ϕ, Z plane, and MARFE extends within separatrix ($\psi_N < 1$).

Lots of questions, lots to model!

See Fred Kelly's poster **QP1.35**.

Backup

Wide-slit “streak” compositions