Pedestal Turbulence Dynamics in ELMing and ELM-free H-mode Plasmas

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Outline

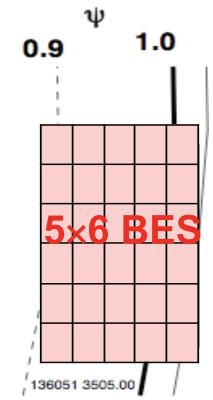
- **Dual-band long wavelength broadband density turbulence observed in ELMing H-mode plasmas**
  - Modulated with ELM cycle; modes propagating in opposite poloidal directions
  - Lower frequency band (50-150 kHz) dynamics correlate with pedestal electron pressure evolution
  - Lower frequency band exhibits KBM like features: propagating in the ion diamagnetic direction in the plasma frame; decorrelation rate exceeding E×B shearing rate

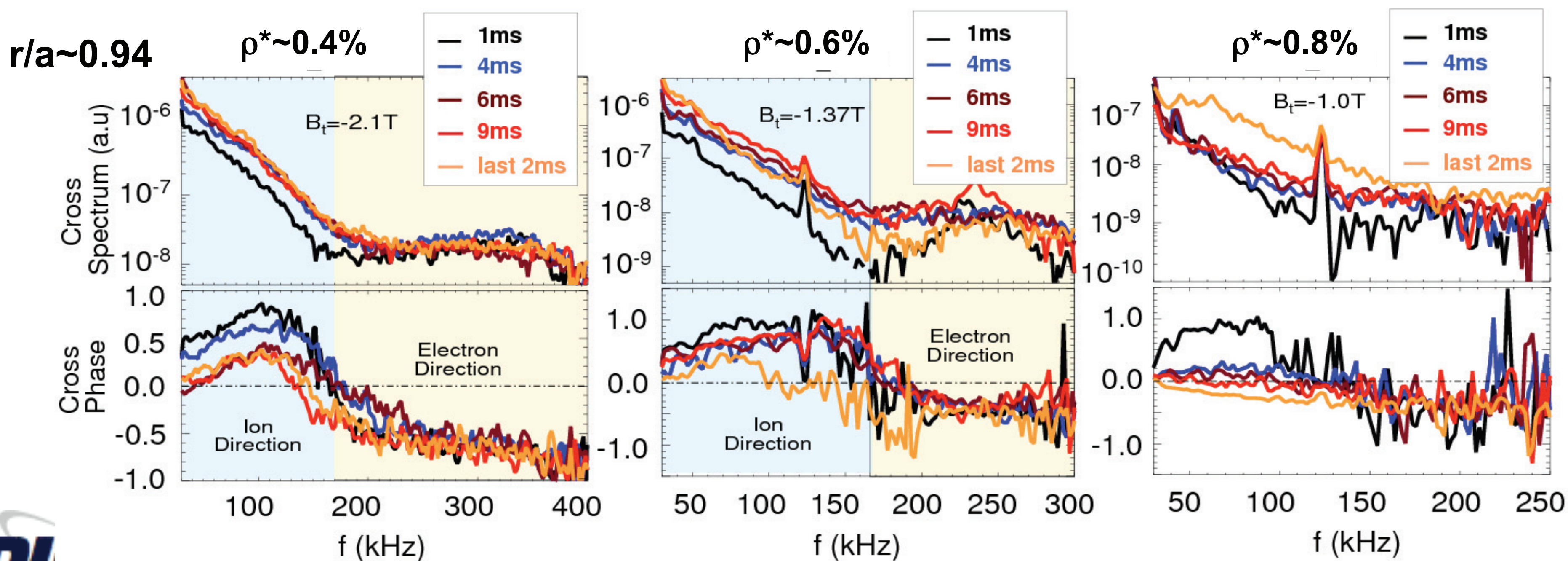
- **High Frequency Coherent Modes (HFC) are observed in ELM-free Quiescent H-mode (QH) plasma**
  - Mode localized to the pedestal region
  - KBM like features: mode frequency close to 0.2-0.3 ion diamagnetic frequency; propagating in ion diamagnetic direction in the plasma frame; mode decorrelation rate exceeding E×B shearing rate, medium-n structure (n=10-25)

- **Turbulence enhancement during RMP ELM-suppressed plasmas**
  - Turbulence enhancement varies radially with significant enhancement in core and modest response at pedestal
  - RMP-turbulence exhibits fast few ms temporal response to RMP modulation near r/a=0.8, and ~10 ms deeper in the core

Density Fluctuation Builds Up Quickly after ELM Crash at Low ρ* (0.4%) and Slower at High ρ*(0.8%) in ELMing H-mode Plasmas

- ρ* is scanned by a factor of 2 while keeping the other dimensional parameters at the pedestal top constant
- Two bands of fluctuations 1) 50-150 kHz, 2) 200-400 kHz propagate in different direction (i.e., e/i diamagnetic drift)
  - Different underlying instabilities?
- At ρ*~0.4% density fluctuation saturates in a few ms
- At ρ*~0.8% density fluctuation saturates >10 ms
- Higher frequency band fluctuation does not change significantly with time
- k_θ~0.3 cm^{-1} for 100 kHz at r/a~0.95 for ρ*~0.4%





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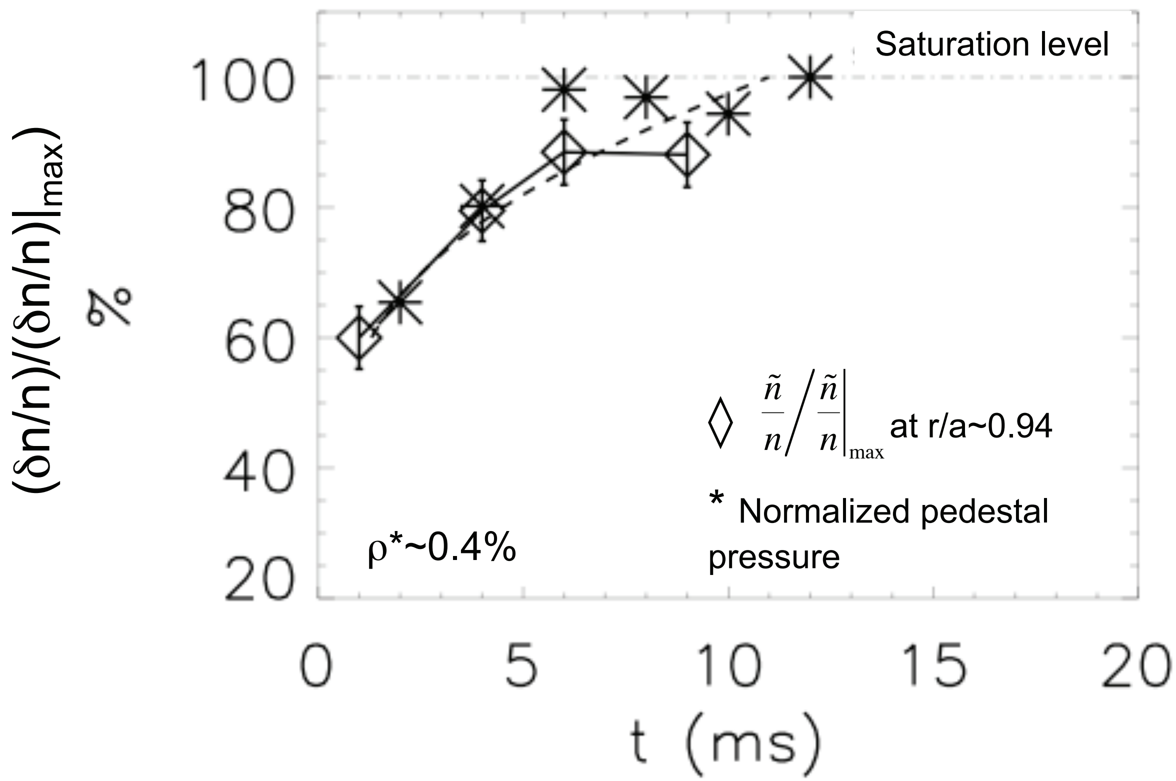
Note: Using test data in besmenu. Dc normalized

Low Frequency Band Turbulence Dynamics Consistent with Pedestal Electron Pressure Evolution

- **Pedestal electron pressure time evolution correlated with low frequency band (50-150 kHz) turbulence time evolution at ρ*~0.4%**



Average ELM free window is ~17ms

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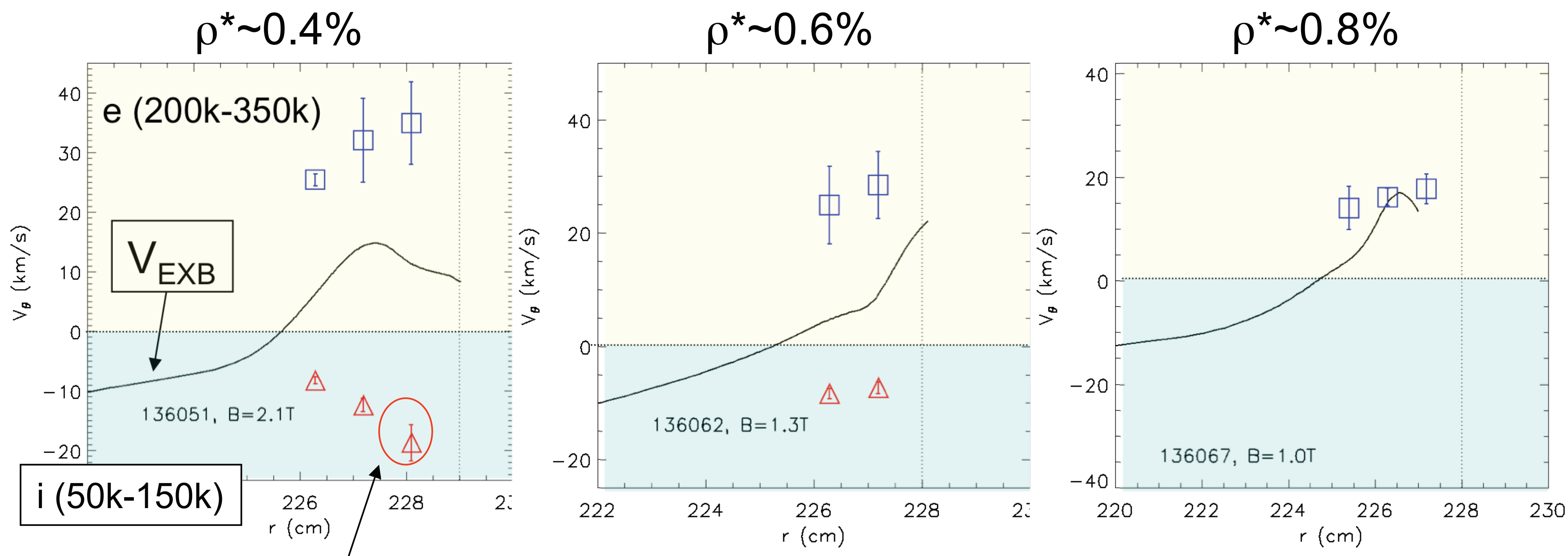
Two Modes Propagate in Different Directions in Plasma Frame

- Dual bands do not individually match ExB velocity
- Dual bands propagate in different direction in the plasma frame at fraction of diamagnetic velocity



Turbulence velocity V_θ measured by cross correlation time lag

$V_{\theta,turbulence}=V_{EXB}+V_{mode}$

$V_{mode} \sim V_D$

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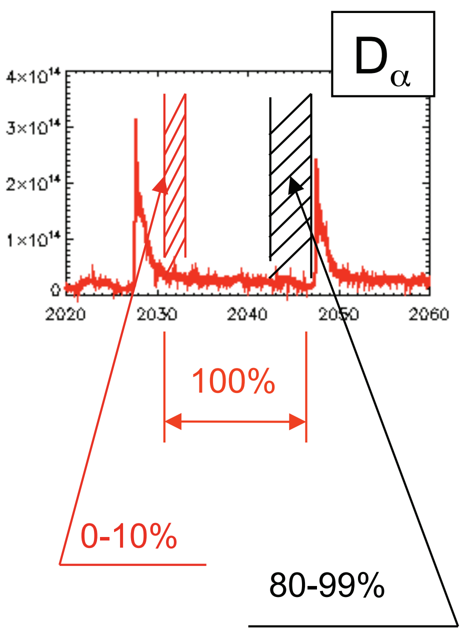
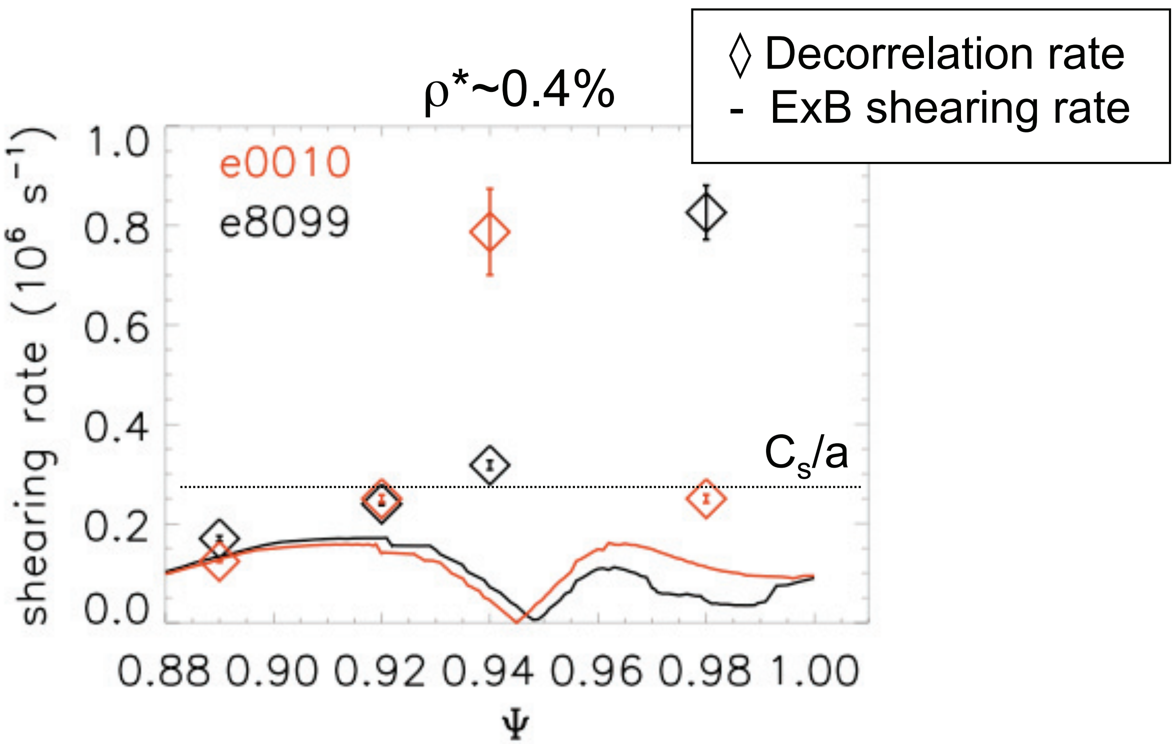
Decorrelation Rate Exceeds ExB Shearing Rate

- **Decorrelation rate decreases at later time in the ELM cycle**
  - Does this decrease in the growth rate suggest turbulence saturation mechanism other than equilibrium ExB shearing rate?
  - Need more sets of data and studies before drawing a conclusion

- **Similar regime predicted for KBM that the growth rate of KBM will exceed E×B shearing at high pressure gradient**

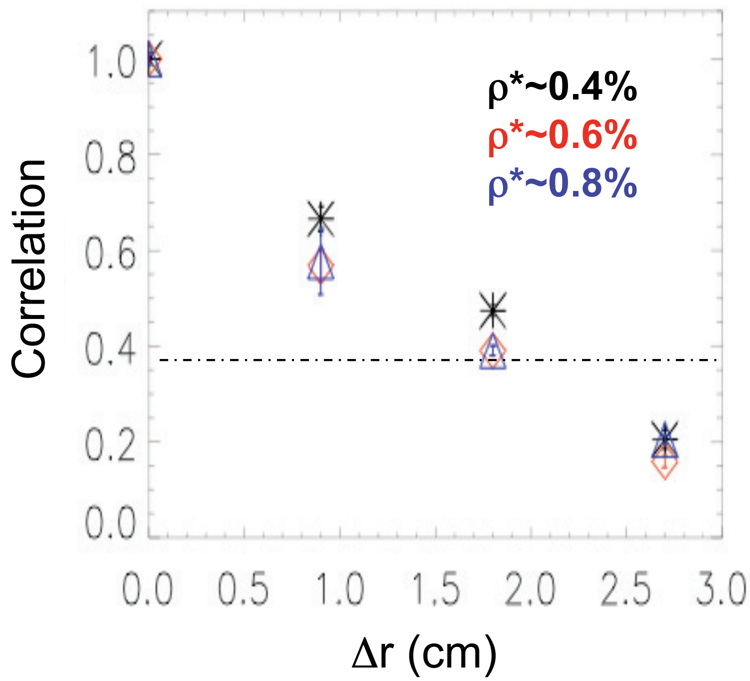




No Dependence of Radial Correlation Length on ρ*

- Radial correlation length for lower frequency band fluctuation (50-150 kHz) has no dependence on ρ*
- Poloidal correlation length has a little dependence on ρ*
- M.N.A Beurskens et al., showed that the pedestal width has no or weak dependence on ρ* [1]

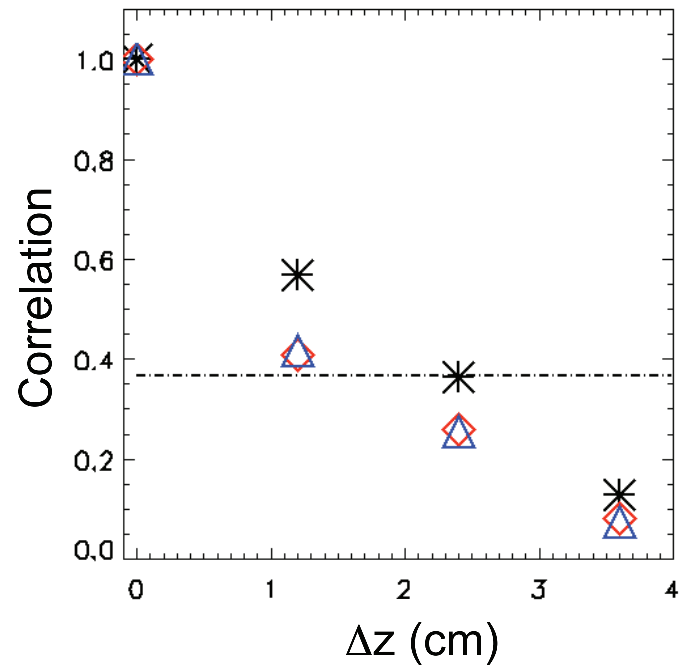
Radial correlation length



L_r~2 cm

r/a~0.94

Poloidal correlation length



ρ*~0.4% : L_θ~2 cm

ρ*~0.6%&0.8% : L_θ~1.5 cm

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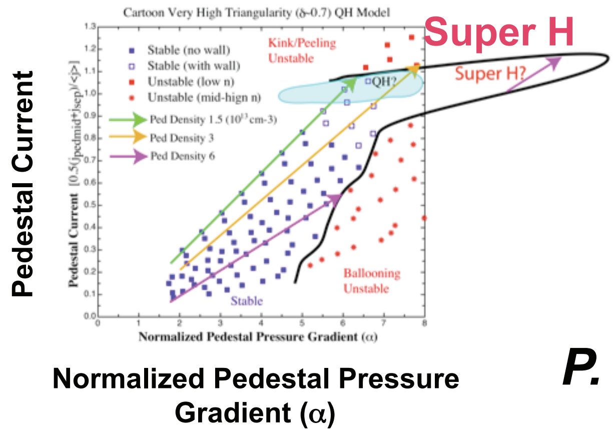
[1] M.N.A Beurskens, et al., PPCF, 51,124051, (2009)

High Pedestal Pressure Quiescent-H mode Discharges Exhibit High Frequency Coherent Modes

Pedestal Stability Diagram



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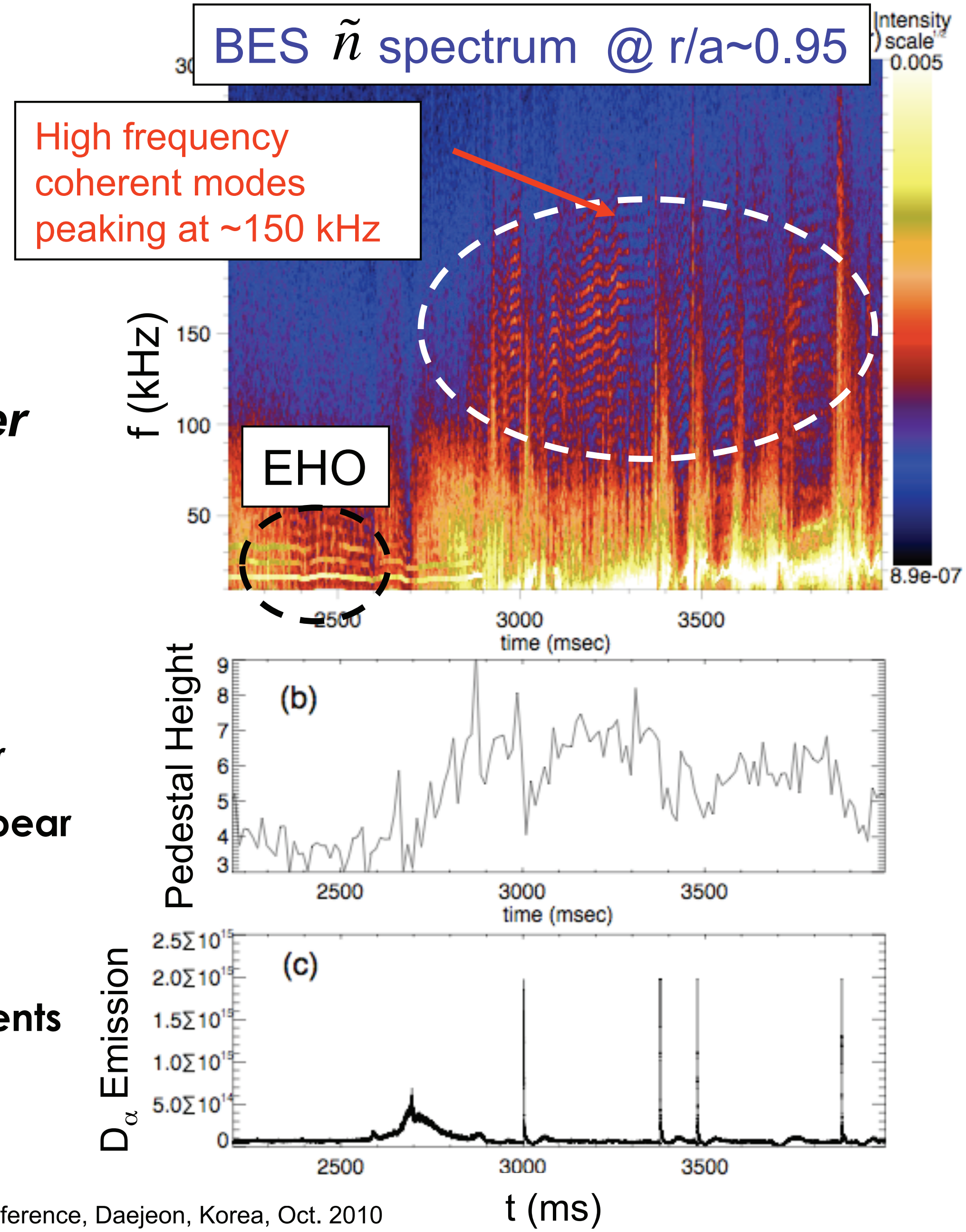

- **High frequency coherent (HFC) modes peaking ~150 kHz appear when EHO disappears**
- **Transition from EHO to HFC occurs as electron pedestal pressure increases**
- **Pedestal pressure saturates when modes appear**
- **HFC modes disappear at ELMs and rapidly reappear after**
- **EHO: n~1-3 — magnetics**
- **HFC mode: n~20 — (inferred from k_θ measurements and ELITE mode structure comparisons)**

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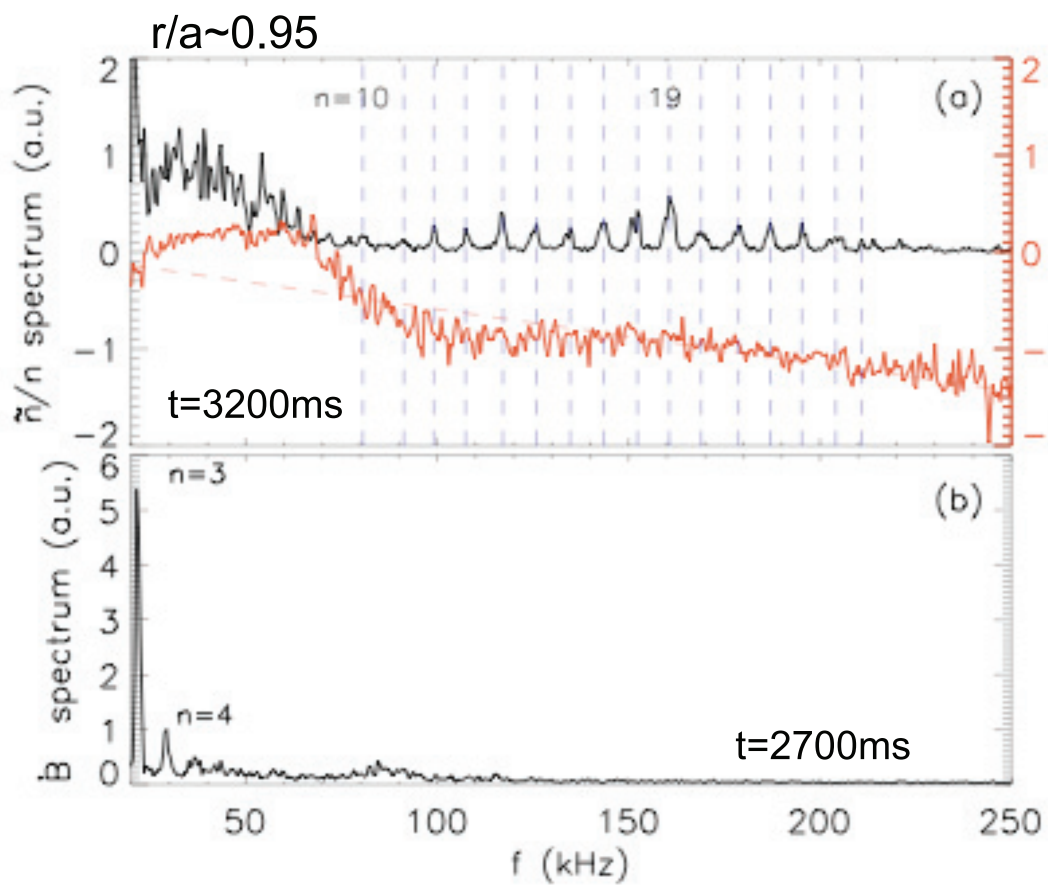
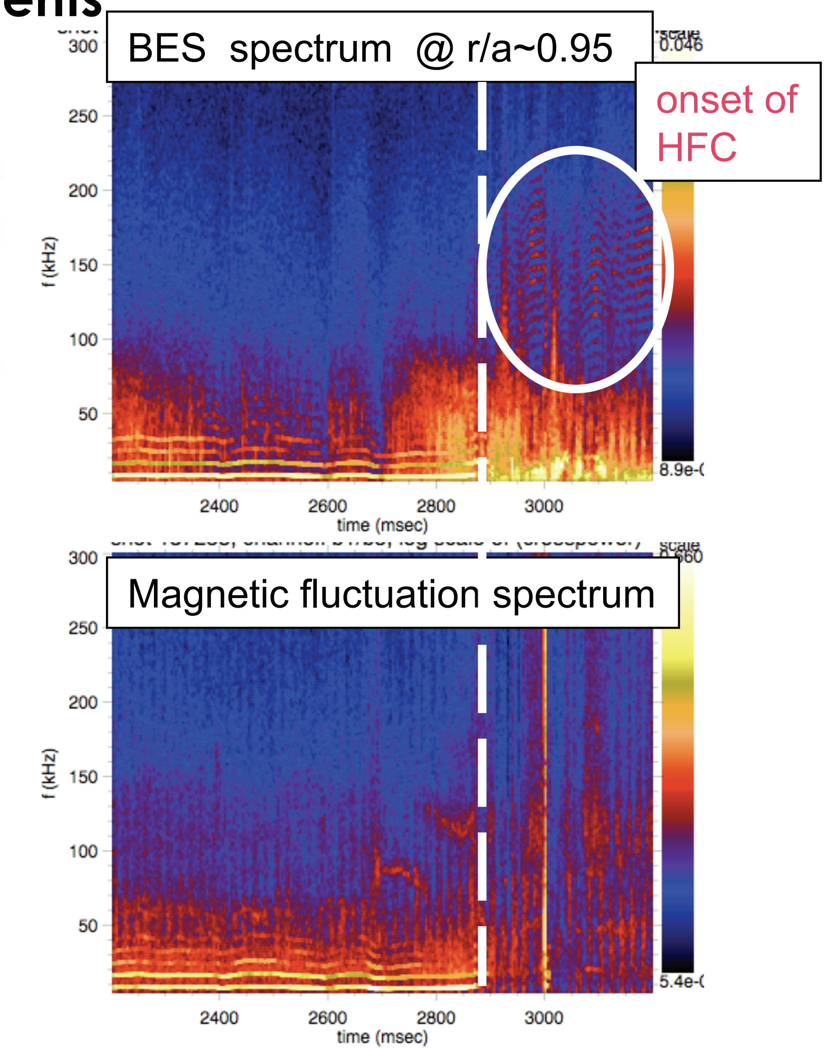
High Frequency Coherent Modes: k_θ~0.17-0.4 cm^{-1}

- k_θ~0.17-0.4 cm^{-1} , somewhat lower than ITG mode
- Dominant toroidal mode number n~19
- Not shown in the magnetic probe measurements





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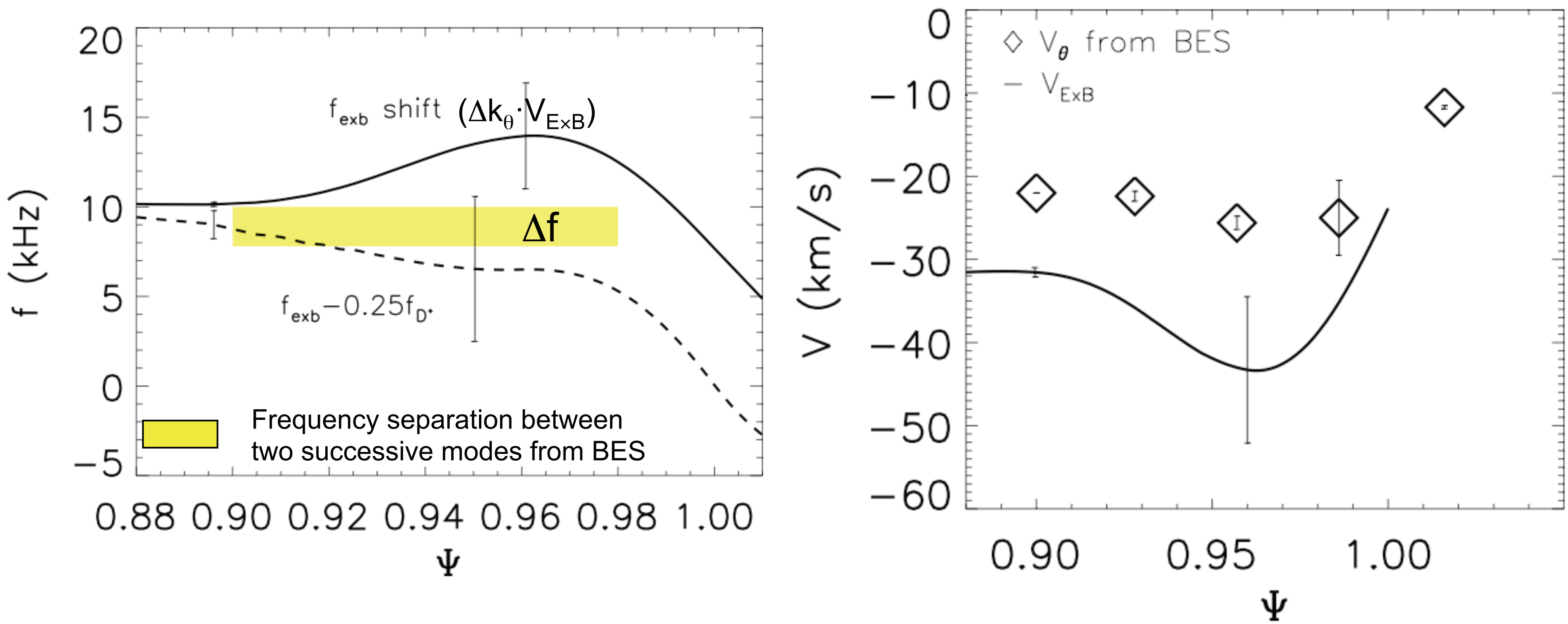
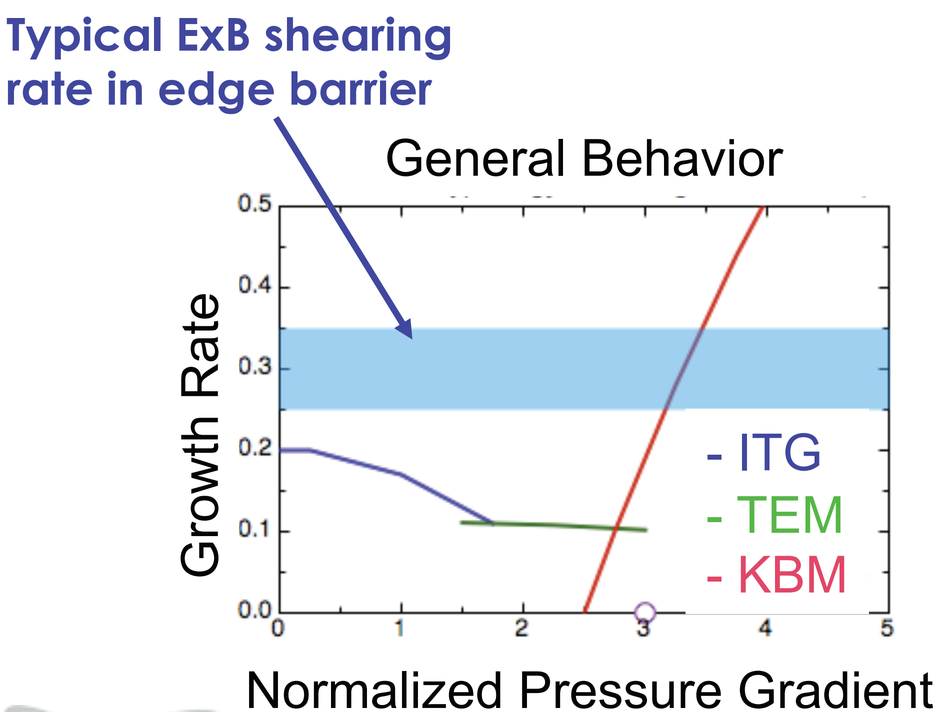
Mode Propagating in the Ion Diamagnetic Direction in the Plasma Frame

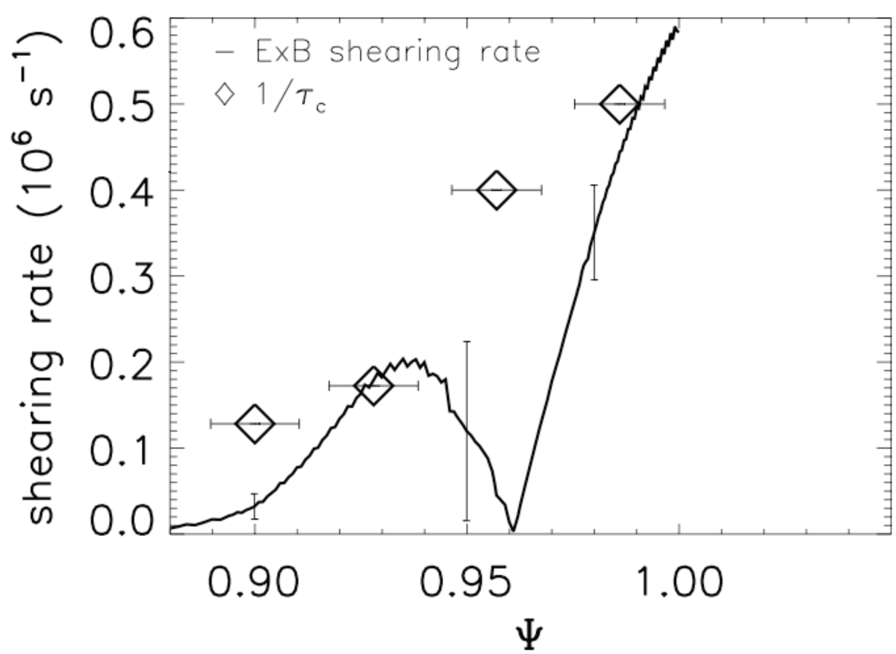
- **Mode frequency separation (Δn=1) compared with calculated separation**
- **Intrinsic mode frequency ~0.2-0.3 times ion diamagnetic frequency consistent with the KBM predicted frequency**



Mode Decorrelation Rate ($1/\tau_c$) Comparable to ExB Shearing Rate in the Edge Barrier

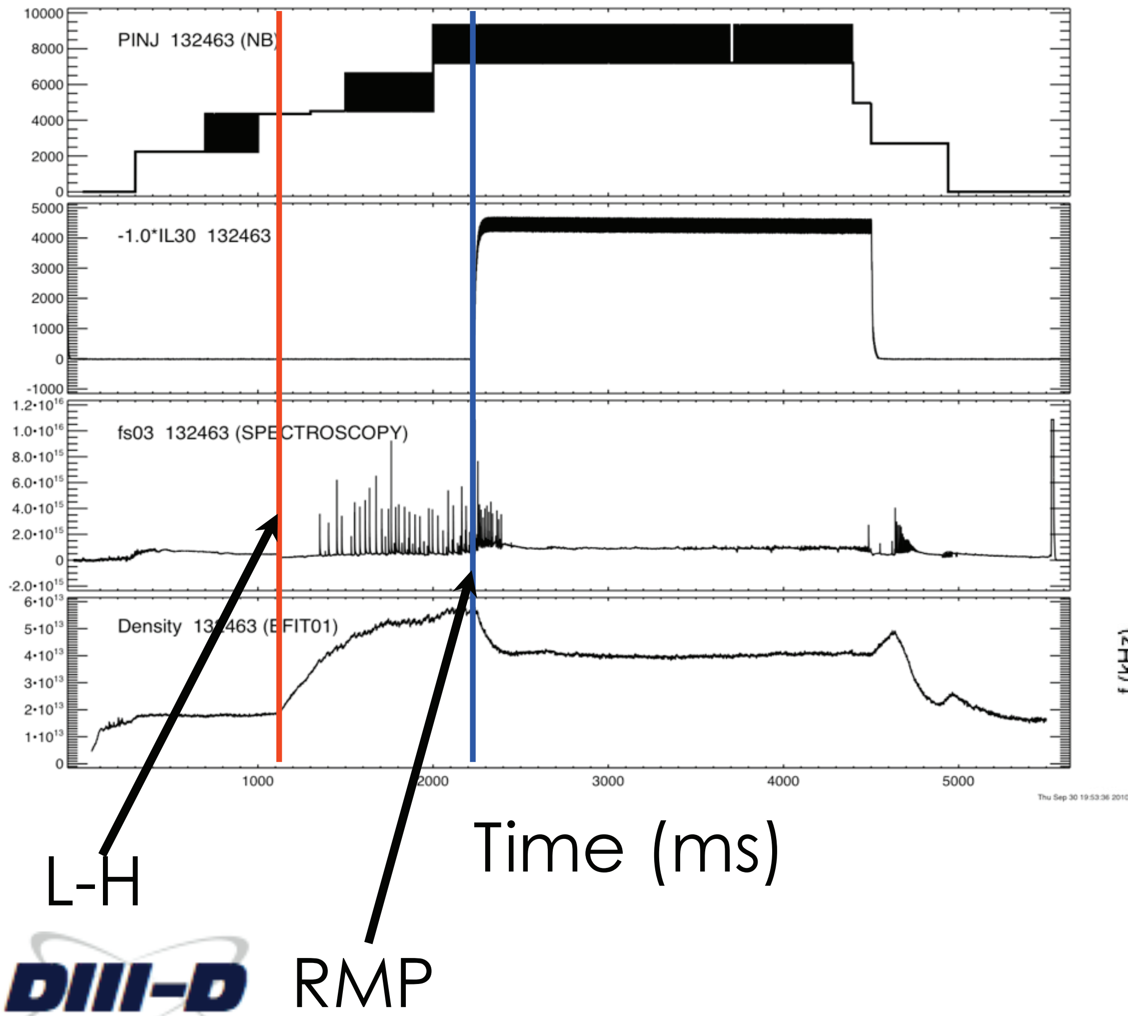
- **High ExB shearing rate expected to quench ITG, TEM**
- **At high pedestal pressure gradient KBM expected to be driven unstable**
- **HFC $1/\tau_c$ comparable to ExB shearing rate at the edge barrier**
  - Similar regime as KBM that the high growth rates can exceed ExB shear and potentially saturate pressure gradients



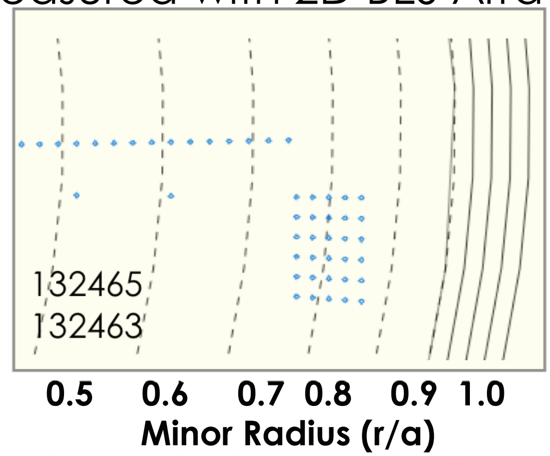


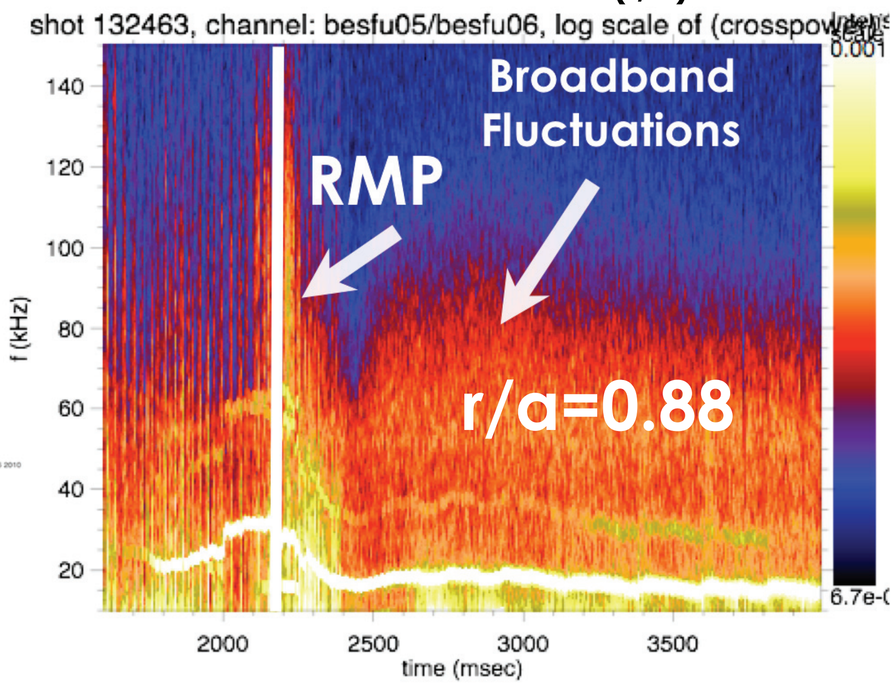
Broadband Turbulence Increases During ELM Suppression via Resonant Magnetic Perturbations (RMP)

Typical RMP ELM-Suppressed Discharge:
I_P=1.55 MA, B_T=1.9T, q_{95}=3.6, P_{INJ}=8 MW



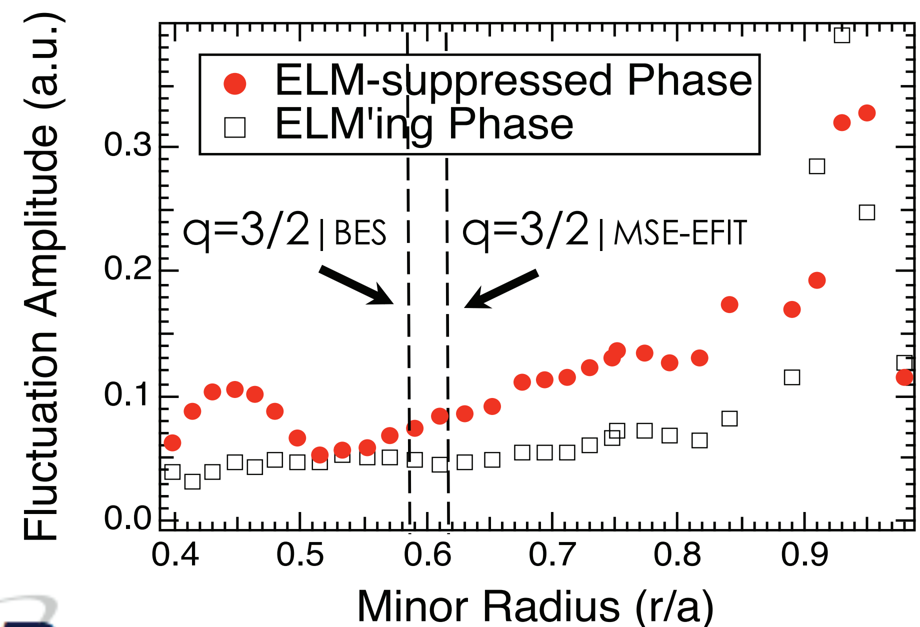
Long-Wavelength Fluctuations Measured with 2D BES Array

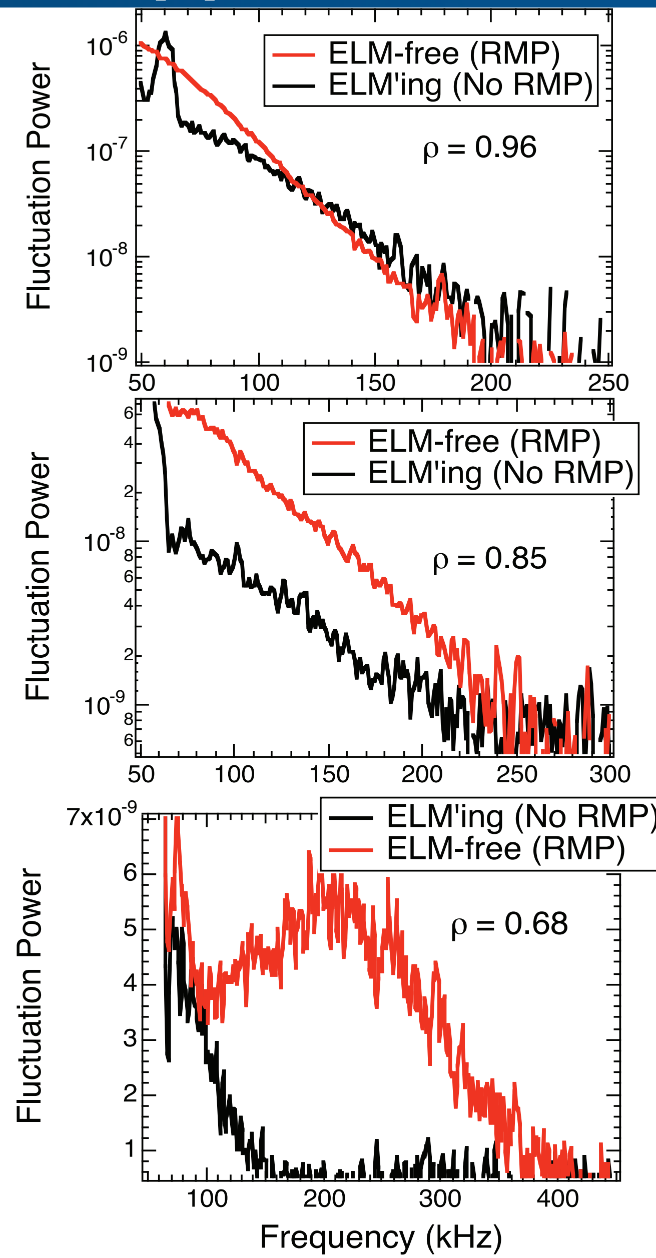




Broadband Fluctuation Amplitude Increase Most Pronounced at Outer Core When RMP Applied

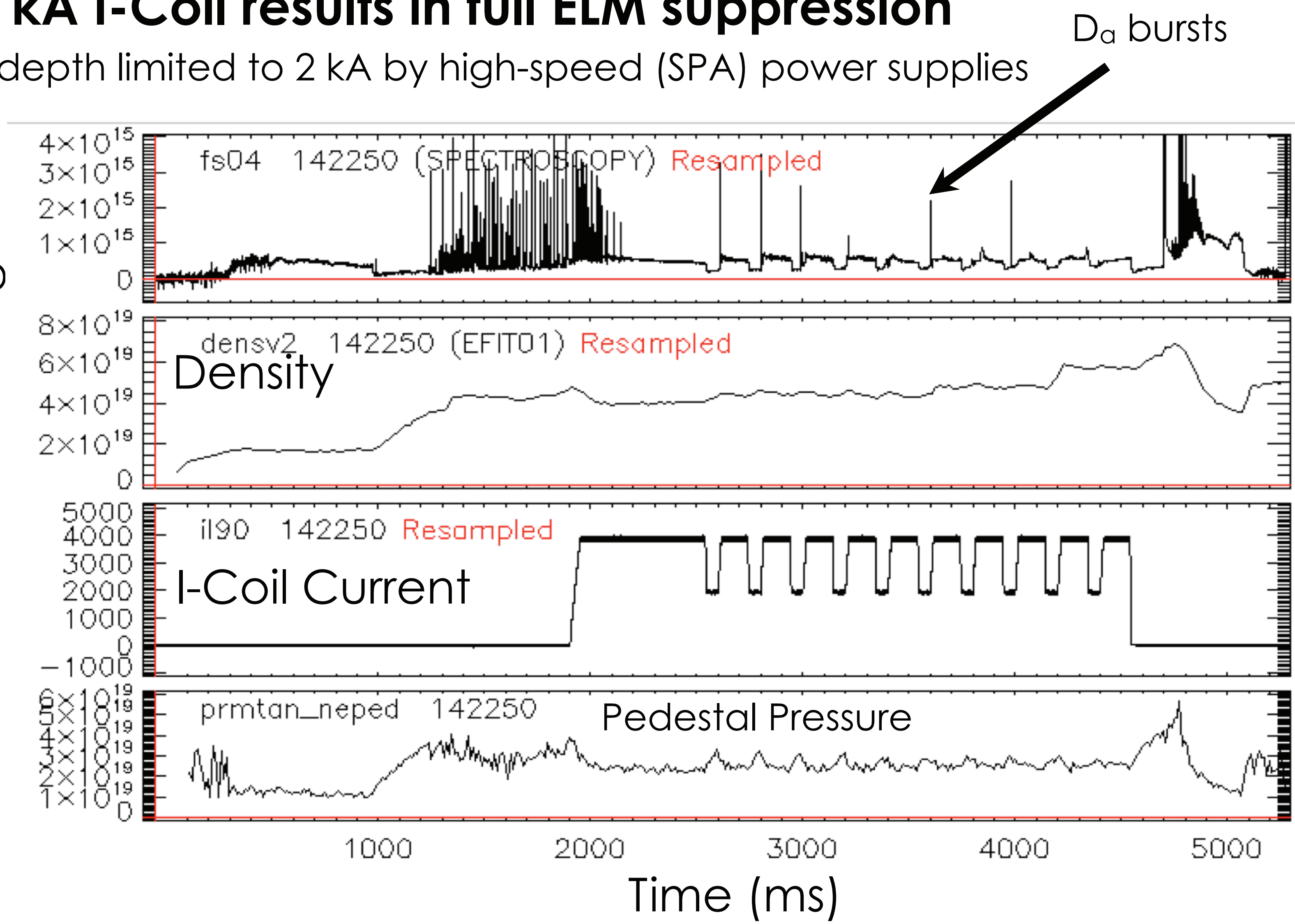
- **Pedestal region (0.9 < r/a < 1.0) exhibits modest increase in amplitude**
- **Core fluctuations (r/a<0.9) exhibit dramatic increase during RMP**
  - Spectral structure of turbulence also changes: fluctuations extend to high wavenumber
- **No change near q=3/2 surface, r/a≈0.6**





Modulated I-Coil Pulses Applied to Examine Turbulence and Density Profile Response

- **RMP from 4 kA I-Coil results in full ELM suppression**
  - Modulation depth limited to 2 kA by high-speed (SPA) power supplies
- **Affects**
  - Recycling D
  - Density
  - P_{ped}
  - Turbulence
  - τ_E



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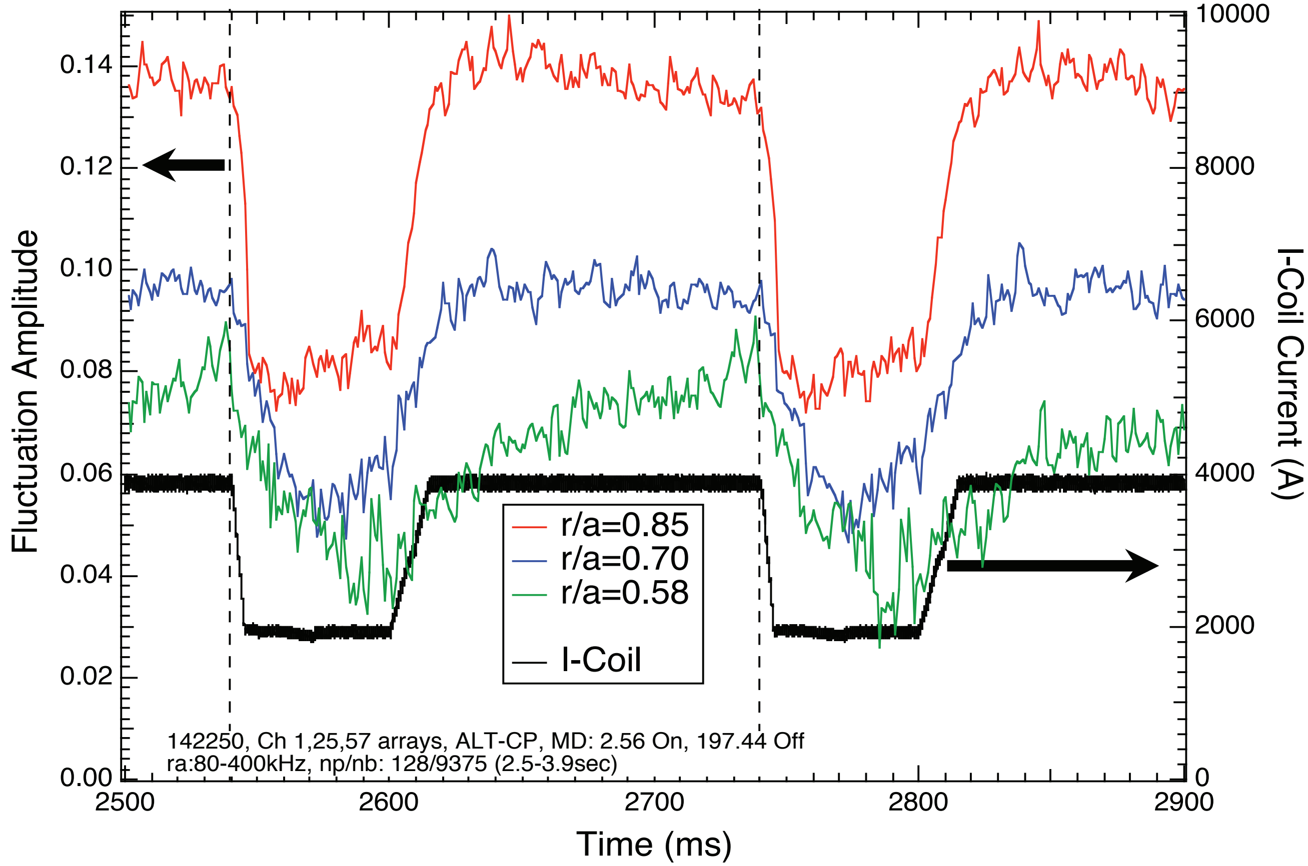
Turbulence Response Time to RMP Modulation Varies Radially

- **Integrated fluctuation amplitudes evaluated at high time resolution by phase-lock averaging over multiple cycles**



- **Near r/a=0.85, local turbulence responds within a few ms to RMP**
- **At smaller radii, turbulence response time to RMP increases**

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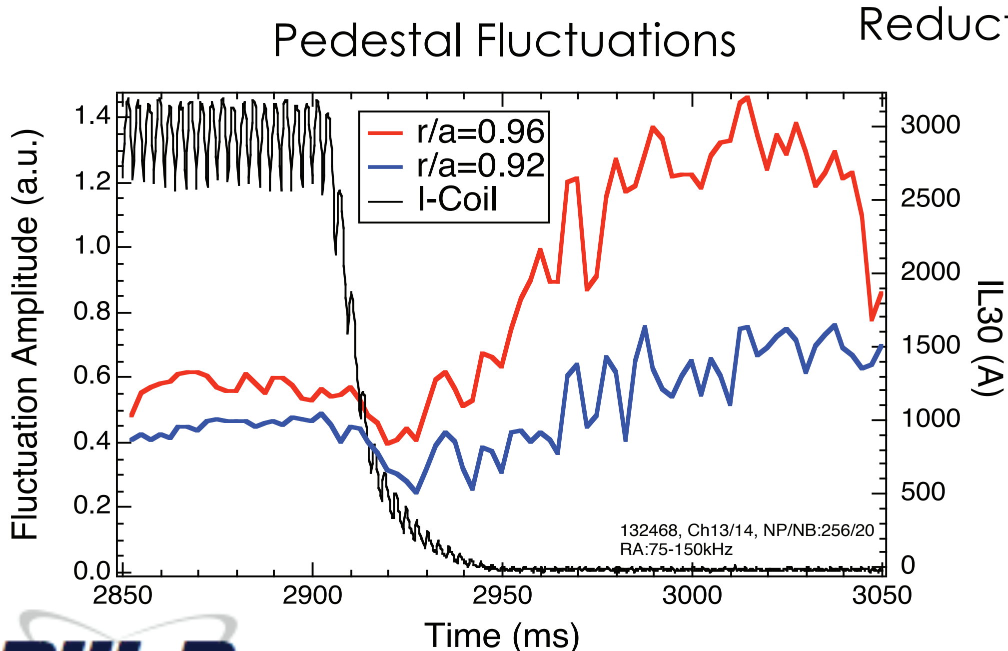
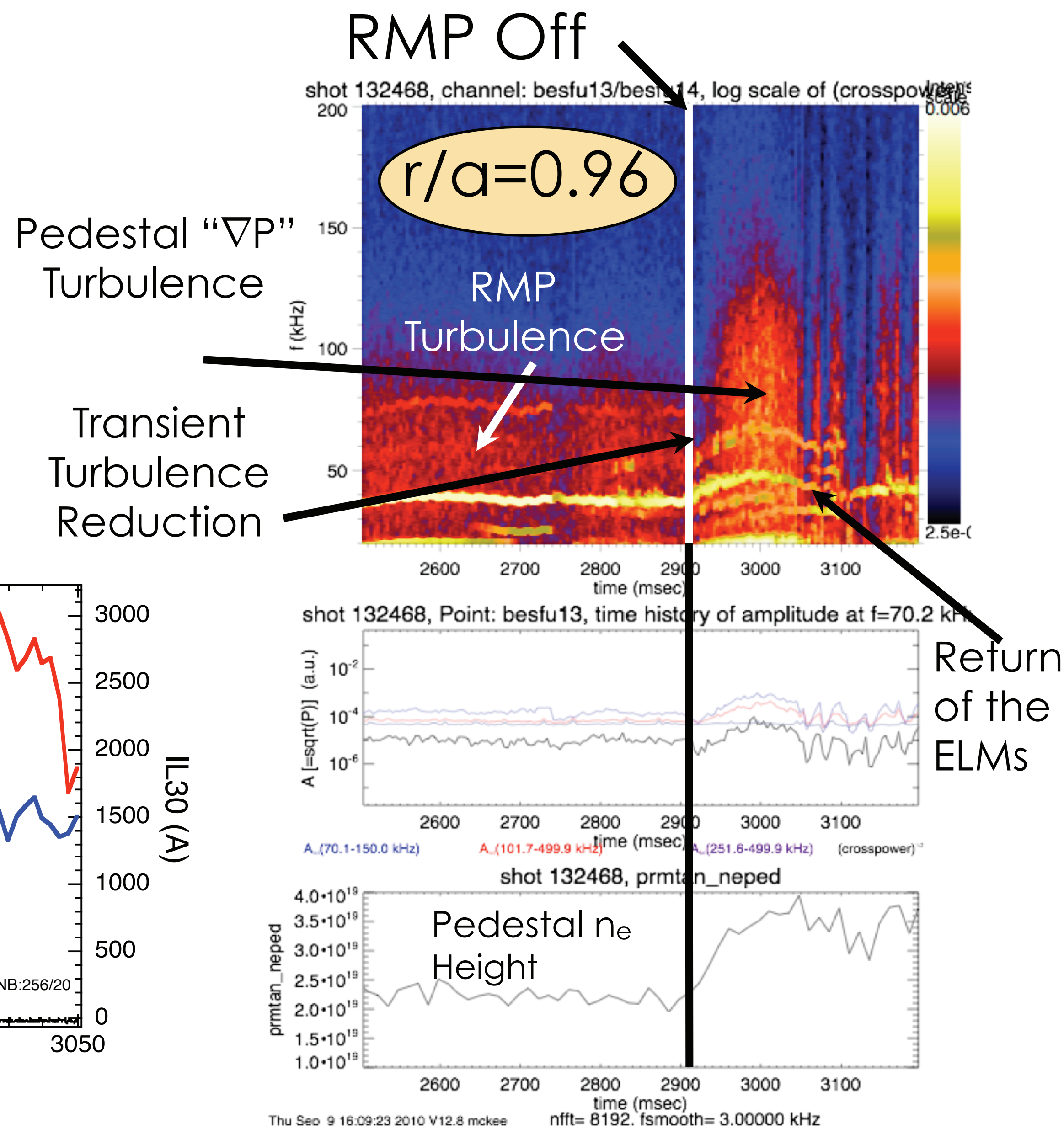
Pedestal Fluctuations Exhibit Complex Response to RMP

- **RMP turn-off allows for examination of pedestal fluctuations as pedestal pressure builds**
- **ELMs return ~120 ms after RMP turn-off**





Resonant Magnetic Perturbations Enhance Turbulence and Particle Transport

- **Turbulence and particle transport increase when RMP applied to H-mode discharges to suppress ELMs**
  - Significant enhancement to higher frequency fluctuations
- **Fluctuation enhancement varies radially**
  - Significant enhancement for $0.40 < r/a < 1.0$
  - "Null Radius" near r/a=0.5-0.55 (near q=3/2 surface) with little fluctuation change with RMP
  - Pedestal exhibits modest response, complicated by ∇P/ELM changes
- **RMP-turbulence exhibits fast temporal response (varies radially)**
  - Response time of few ms near r/a=0.8
  - ~10s ms deeper in core
  - *Not* driven by ExB Shear changes
- **Increase in turbulence at outer regions (r/a=0.8-1.0) consistent with *direct effect* of RMP on turbulence (causing transport?)**
  - Mechanism unidentified