Interaction between NTMs and non-local transport in HL-2A

X. Q. Ji [1]

On behalf of: Y. Xu[1], Yi Liu[1], O. Pan[1], Q. W. Yang[1], Z. B. Shi[1], B. B. Feng[1], W, Chen[1], C. Y. Chen[1], Z. X. Wang[2], L. Wei[2], M. Jiang[1], W. L. Zhong[1], Yuan Xu[1], T. F. Sun[1], Y. B. Dong[1], Y. Zhou[1], W. Deng[1], B. S. Yuan[1], X. R. Duan[1], Liu Yong[1] and the HL-2A team

[1] *Southwestern Institute of Physics, Chengdu 610041 China*

[2] *Dalian University of Technology, Dalian 116024 China*

Outline

- Motivation
- Non-local transport
  - Non-local transport in HL-2A
  - Enhanced avalanche characteristics during non-local transport
- NTM onset during non-local transport
  - Typical feature of NTM onset during non-local transport
  - Relation between NTM onset and non-local transport
- Impact of NTM on non-local transport
  - Damping effects of NTM on non-local transport
  - Reduction of avalanche feature with NTM in non-locality
- Summary

Motivation

♦ What is the mechanism of non-local transport ?

— **Non-local transport has been observed in many fusion devices.**

TEXT-U /TFTR /RTP /JET /TORE-SUPRA /HL-2A / LHD… *K W Gentle, PRL1995*

— **Non-local transport**: Long-distance-correlated events with reversed polarity.

— **Possible mechanisms:** *J. Callen, PPCF 1997, B173*

i) Empirical model, ii) marginal stability, iii) self-organized criticality (SOC)?

♦ What is the mechanism of NTM onset ?

— **NTM** effects → β limitation *or* major disruption

— **NTM** onset: Seeding process? Threshold? [dw/dt ~ $\Delta'(w)$, Δ'_{BS}, Δ'_{GGJ}, $\Delta'_{pol,}$ Δ'_{CD}]

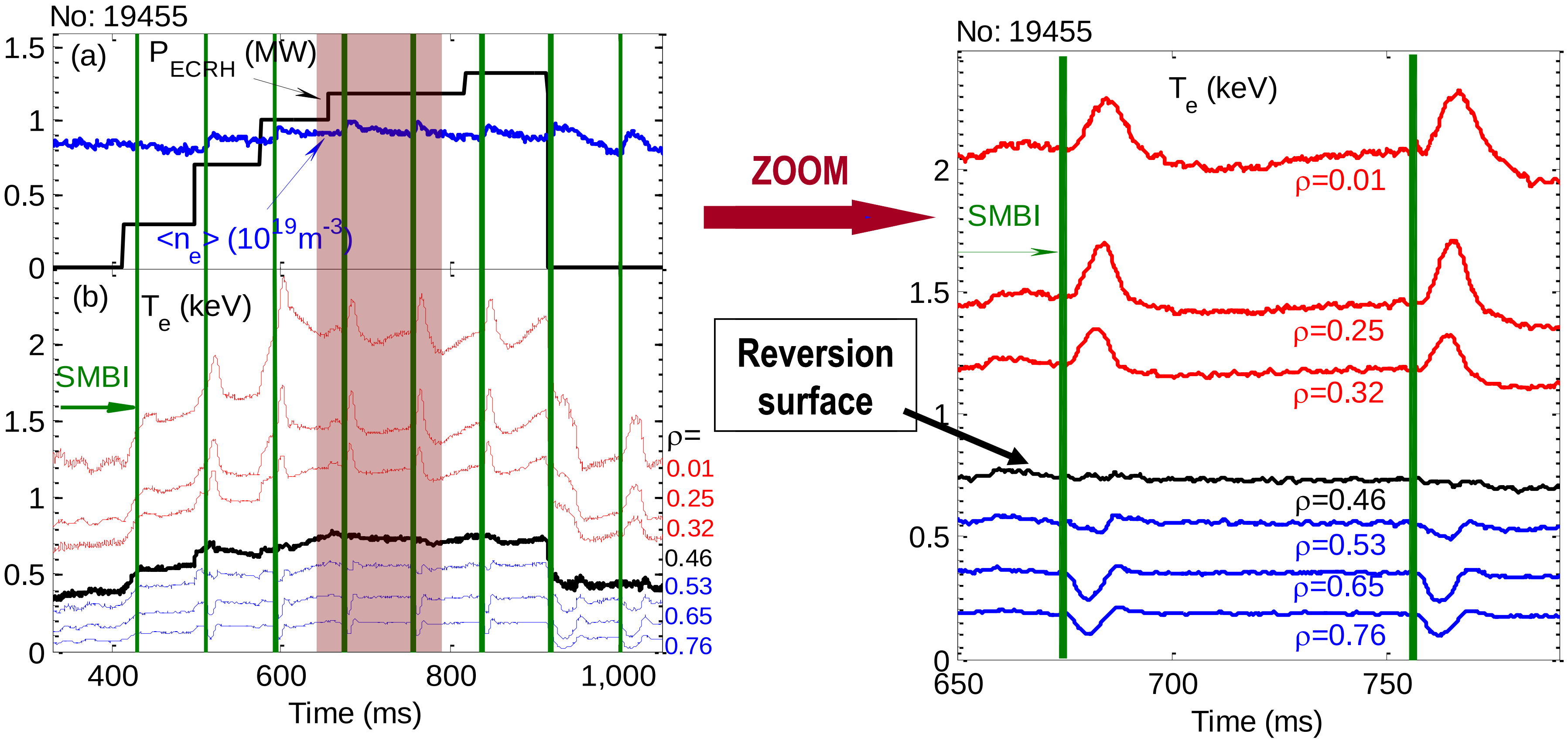
♦ What is the possible link between NTM and non-local transport ?

— In HL-2A, NTM onset during non-locality was observed for the first time.

Outline

- ❖ Motivation
- ❖ **Non-local transport**
  - ♦ Non-local transport in HL-2A
  - ♦ Enhanced avalanche characteristics during non-local transport
- ❖ **NTM onset during non-local transport**
  - ♦ Typical feature of NTM onset during non-local transport
  - ♦ Relation between NTM onset and non-local transport
- ❖ **Impact of NTM on non-local transport**
  - ♦ Damping effects of NTM on non-local transport
  - ♦ Reduction of avalanche feature with NTM in non-locality
- ❖ **Summary**

Non-local transport in HL-2A



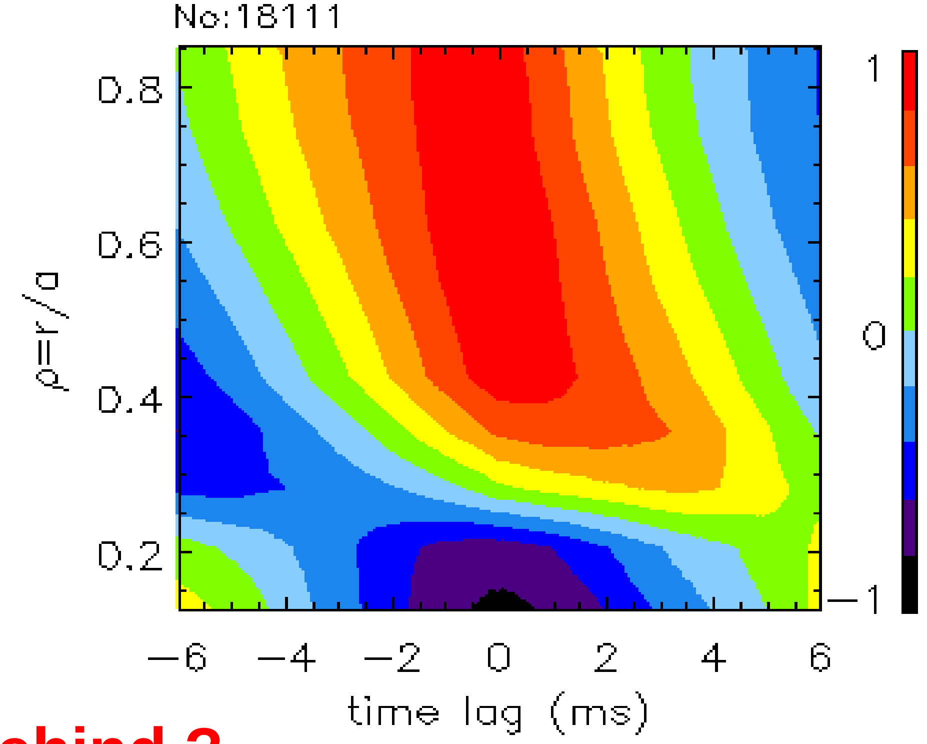
- After each SMBI (Supersonic Molecular Beam Injection), edge T_e reduces by cooling whereas the core T_e quickly rises over long-distance — non-local transport !
- This non-locality usually occurs (i) in low density ($<n_e> < 2.0 \times 10^{19} m^{-3}$) ohmic or ECRH heating plasmas; (ii) very transient process ~ (15-30) ms
- Reversion surface of T_e perturbation is normally outside q=1

Non-local transport: long-range radial propagation

Inward heat flux propagation observed in low-frequency range (**f ~ 200 Hz**) of T_e fluctuations

Edge

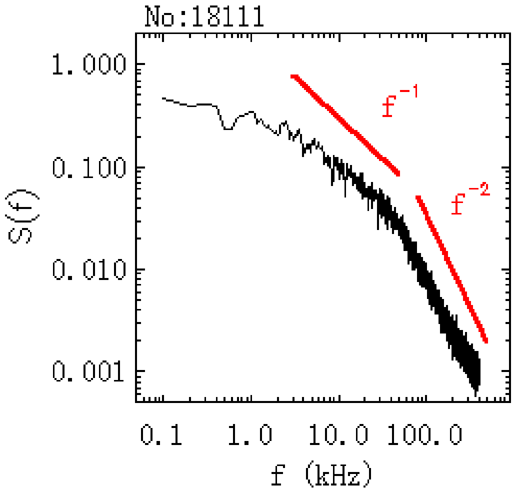
Core

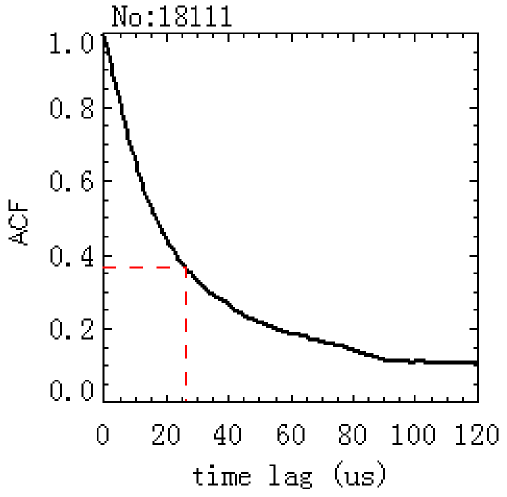


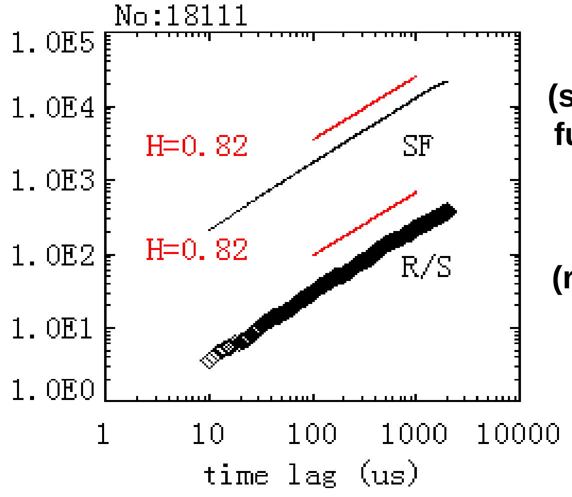
What are the mechanisms behind ?

- **Empirical model** (added diffusion/ heat coefficients)
- **Marginal stability** (propose critical parameters determining system states)
- **SOC** (avalanche, f^{-1} dependence, self-similarity /large Hurst exponent……)

Typical characteristics of SOC behavior



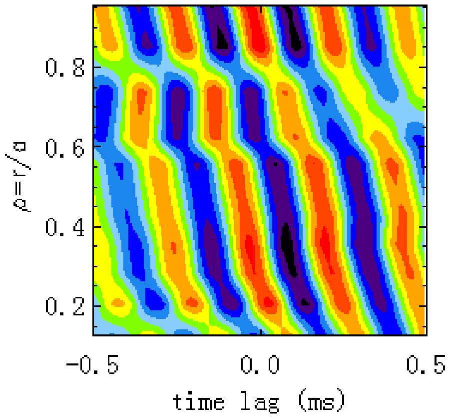


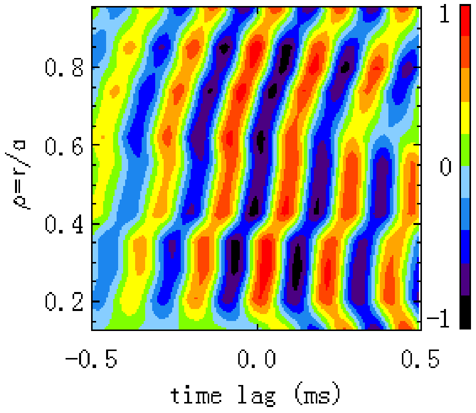


SF (structure function)

R/S (rescaled range)

Inward

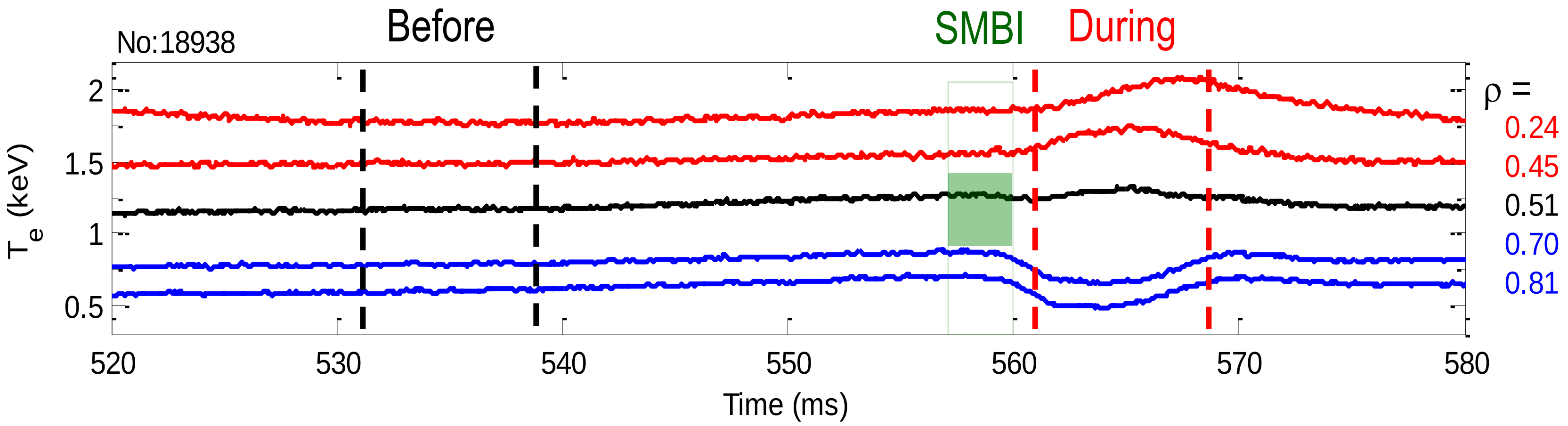


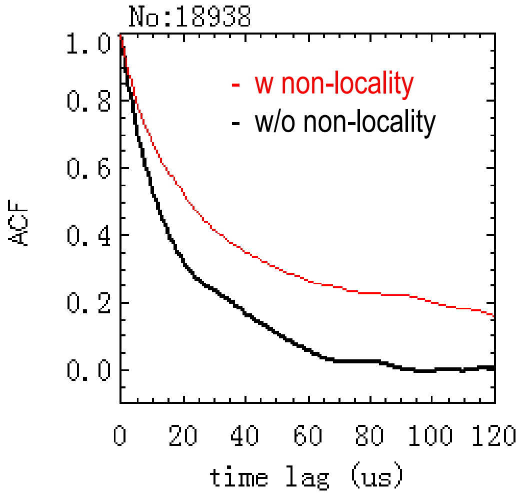


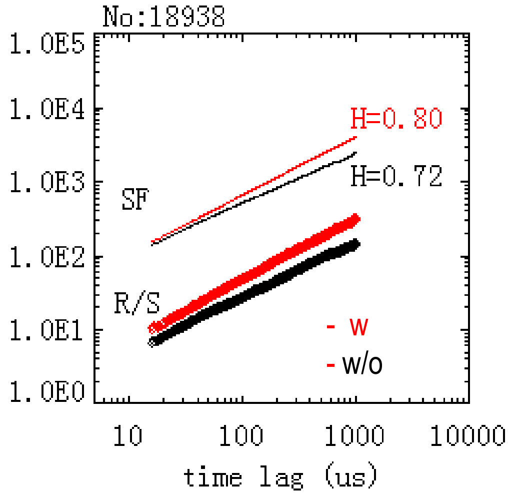
Outward

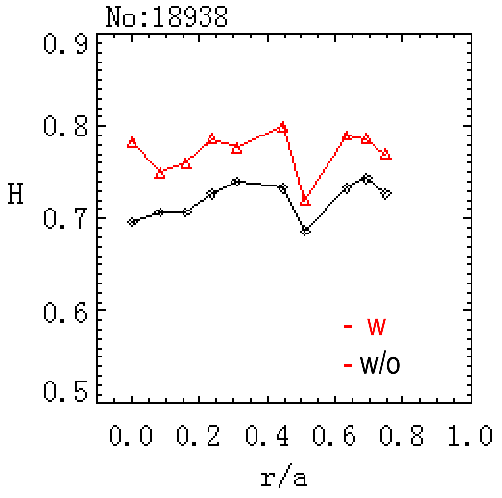
- f^{-1} dependence in Intermediate range (3-30 kHz) — overlapping of avalanche transport.
- long tail in autocorrelation function (ACF) — long time correlated events.
- Large value of Hurst parameter estimated by R/S and SF — indication of "self-similarity".
- Dual propagation of avalanche events — a signature of SOC system !

Enhanced avalanche characteristics during non-local transport (I)





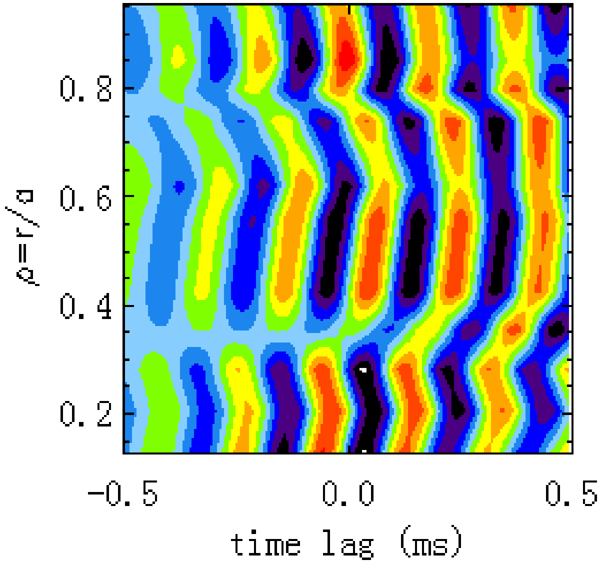




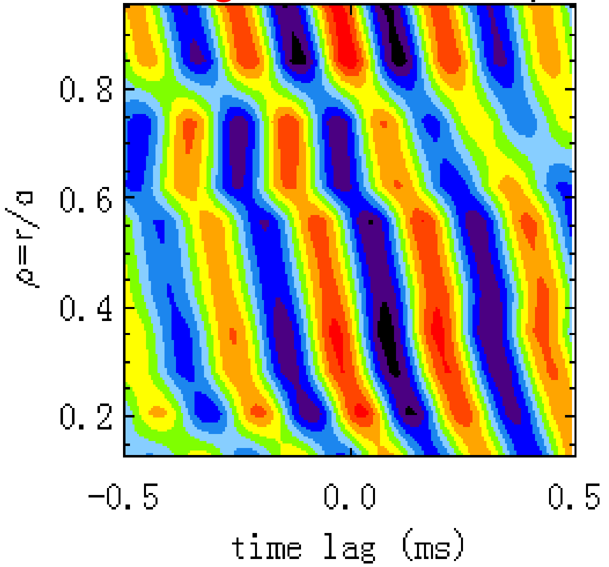
During non-local transport, the time lag in ACF and Hurst parameters are all larger than those before non-locality, revealing an enhanced avalanche behavior in the non-local transport.

Enhanced avalanche characteristics during non-local transport (II)

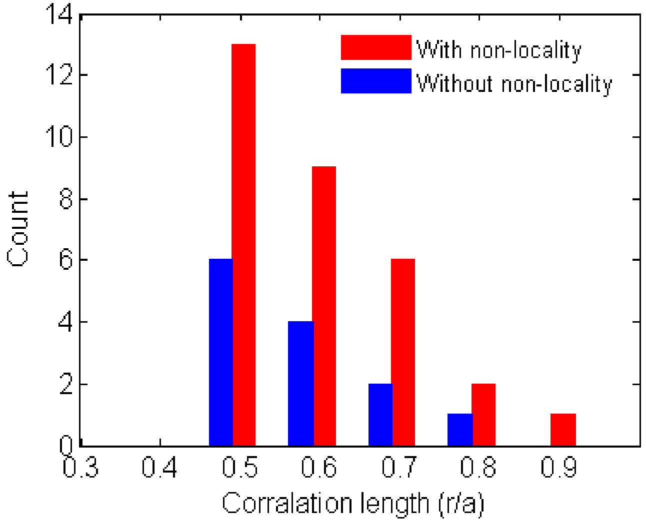
Before non-local transport



During non-local transport



Correlation length of radial propagation events ***mostly*** increase during non-locality.



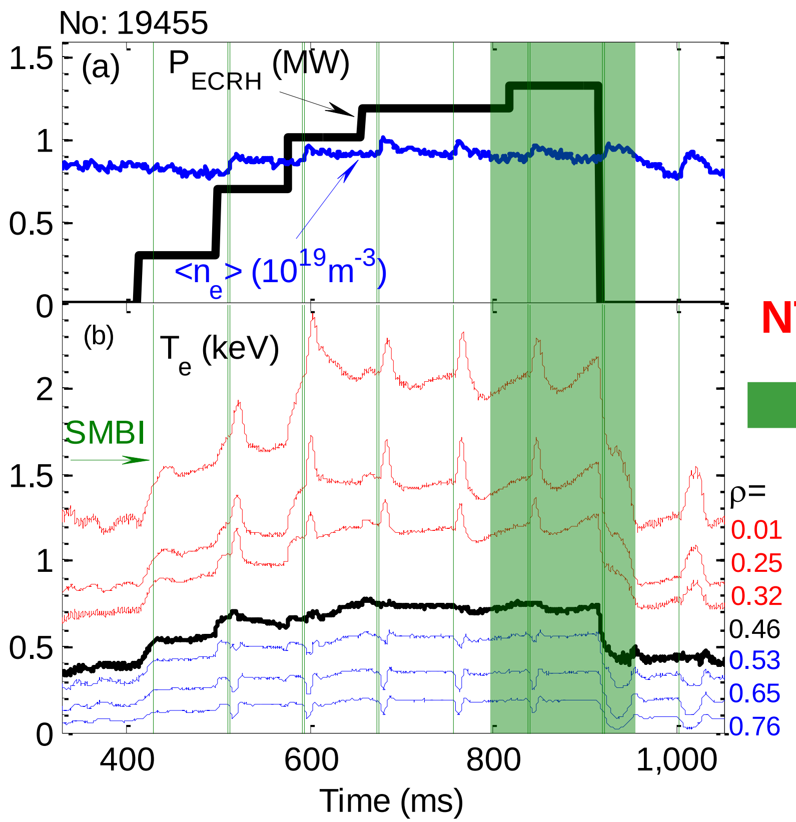
Count number of radial correlation length for avalanche propagation events with/without non-locality

It appears that the SOC regime could be responsible for the non-local transport at HL-2A

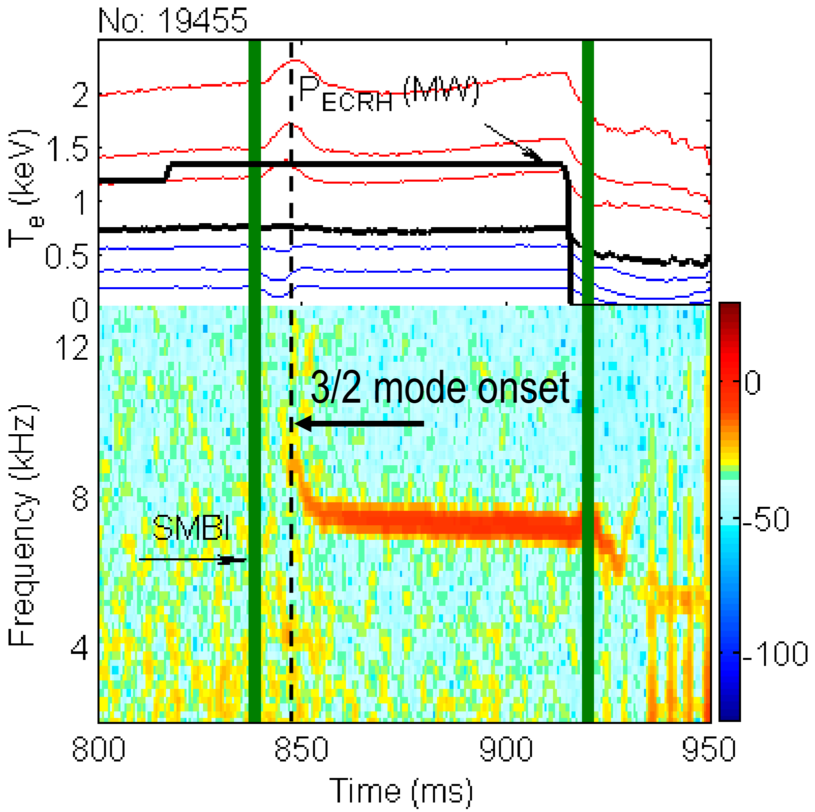
Outline

- Motivation
- Non-local transport
  - Non-local transport in HL-2A
  - Enhanced avalanche characteristics during non-local transport
- **NTM onset during non-local transport**
  - Typical feature of NTM onset during non-local transport
  - Relation between NTM onset and non-local transport
- **Impact of NTM on non-local transport**
  - Damping effects of NTM on non-local transport
  - Reduction of avalanche feature with NTM in non-locality
- **Summary**

Typical feature of NTM onset during non-local transport



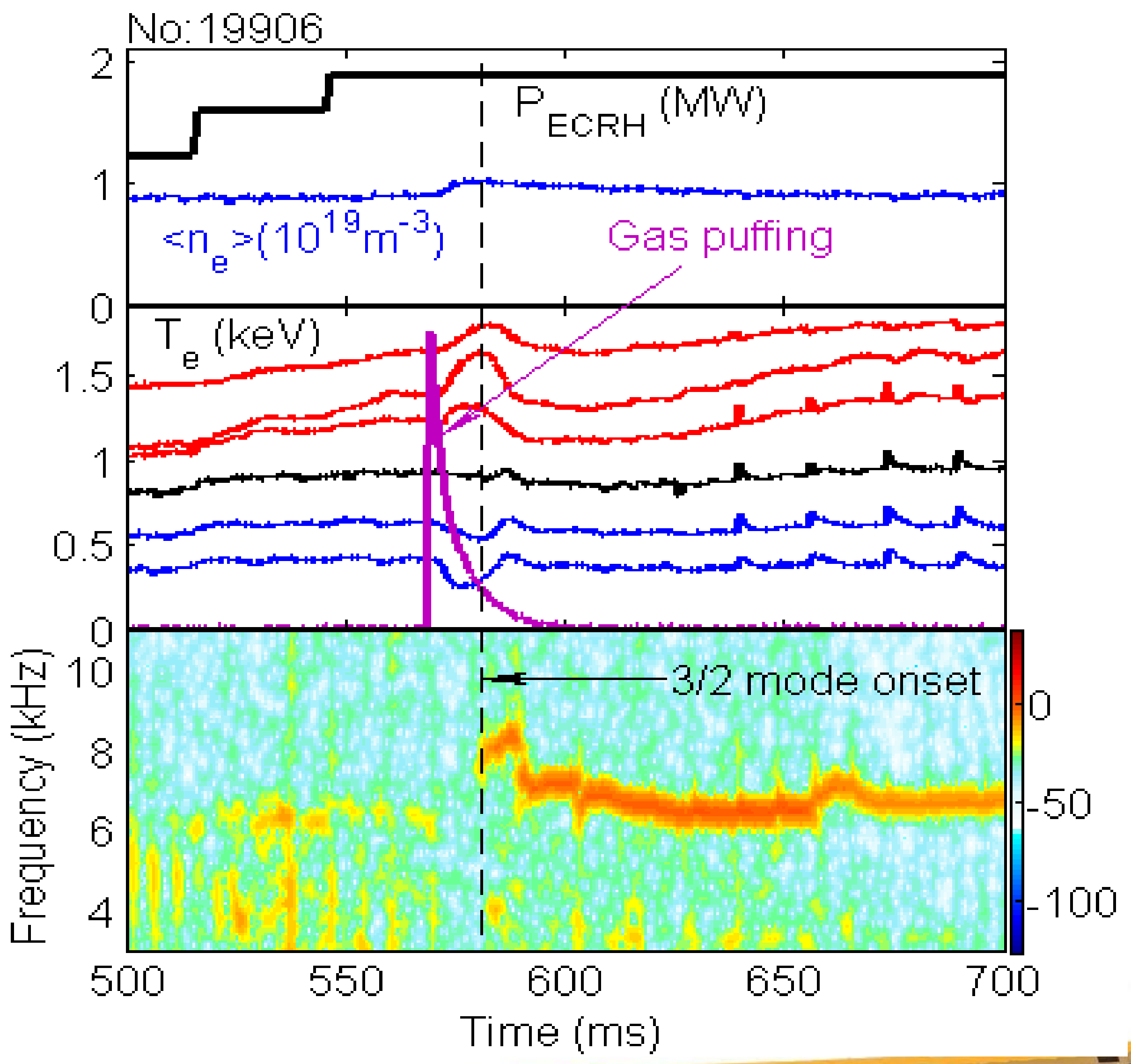
NTM onset



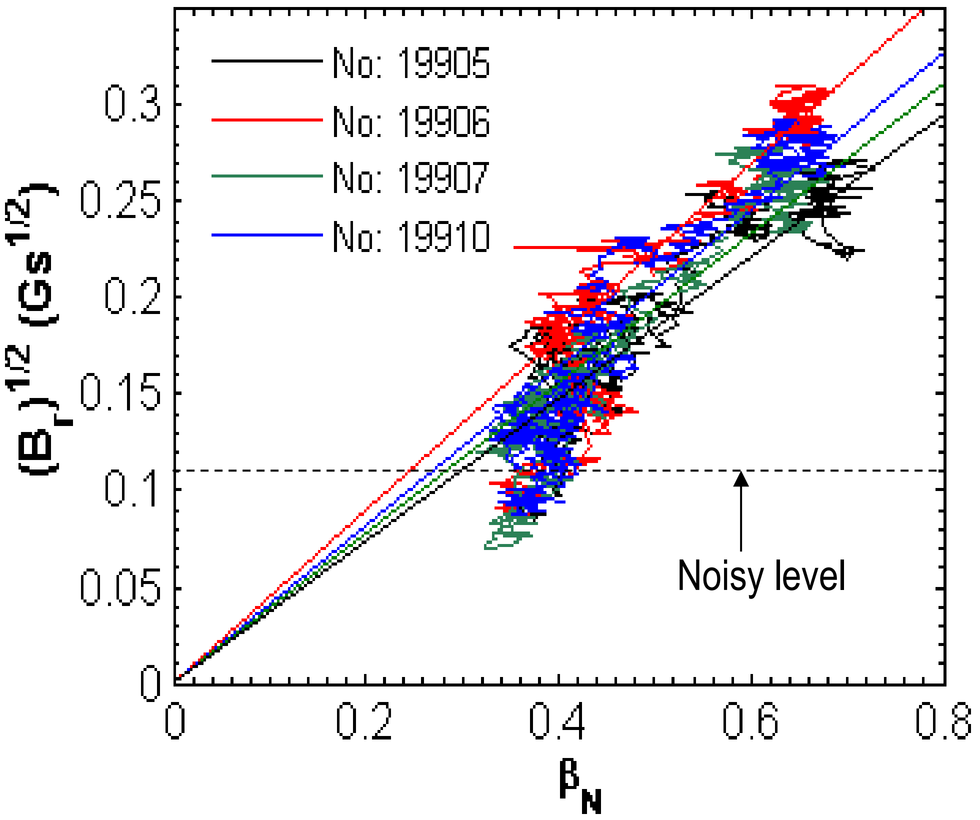
At high P_{ECRH}(high β), a 3/2 NTM mode is triggered during non-local transport

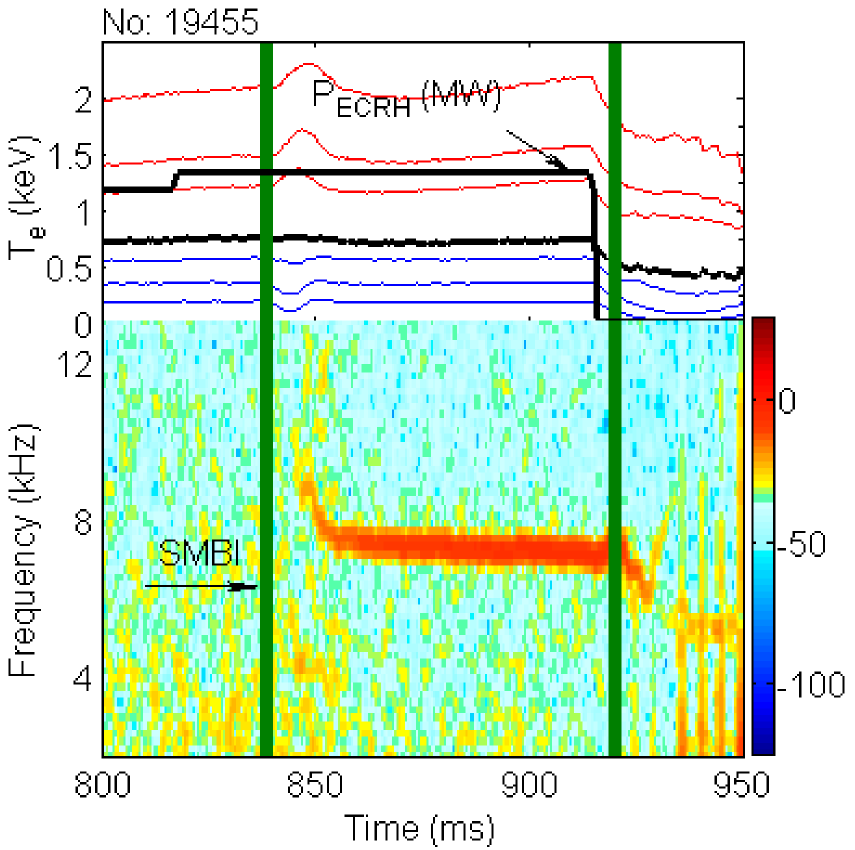
Note: NTM driven by the transient T_e perturbation during non-local transport is observed for the first time !

Another example of NTMs triggered by gas-puffing



Experimental evidence of NTM modes



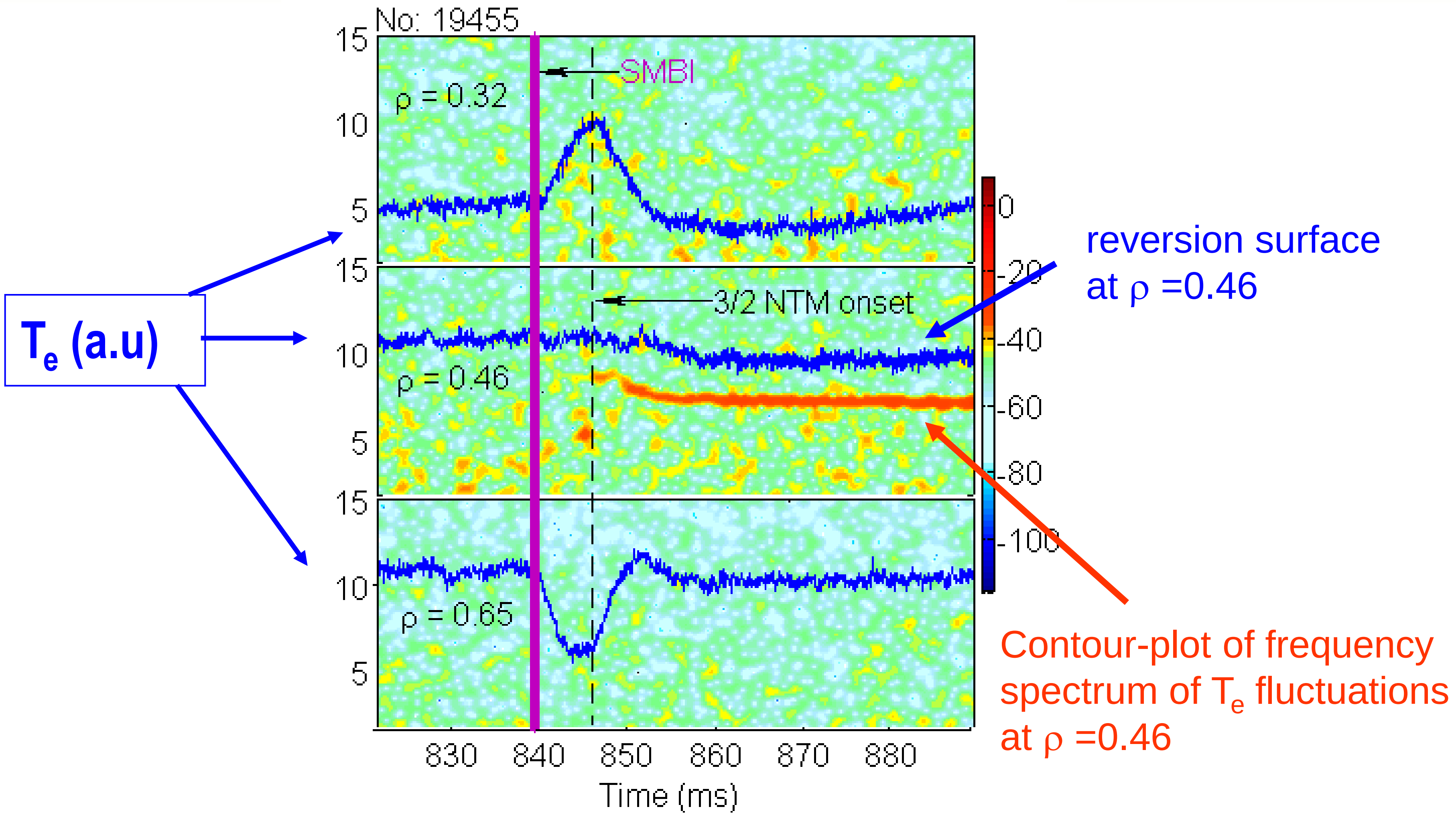


- **Island width $w \propto (B_r)^{1/2}$ displays linear dependence on β_N**
- **Saturated island width quickly drops on a time scale of ~10 ms after ECRH turn off**

Outline

- Motivation
- Non-local transport
  - Non-local transport in HL-2A
  - Enhanced avalanche characteristics during non-local transport
- NTM onset during non-local transport
  - Typical feature of NTM onset during non-local transport
  - Relation between NTM onset and non-local transport
- Impact of NTM on non-local transport
  - Damping effects of NTM on non-local transport
  - Reduction of avalanche feature with NTM in non-locality
- Summary

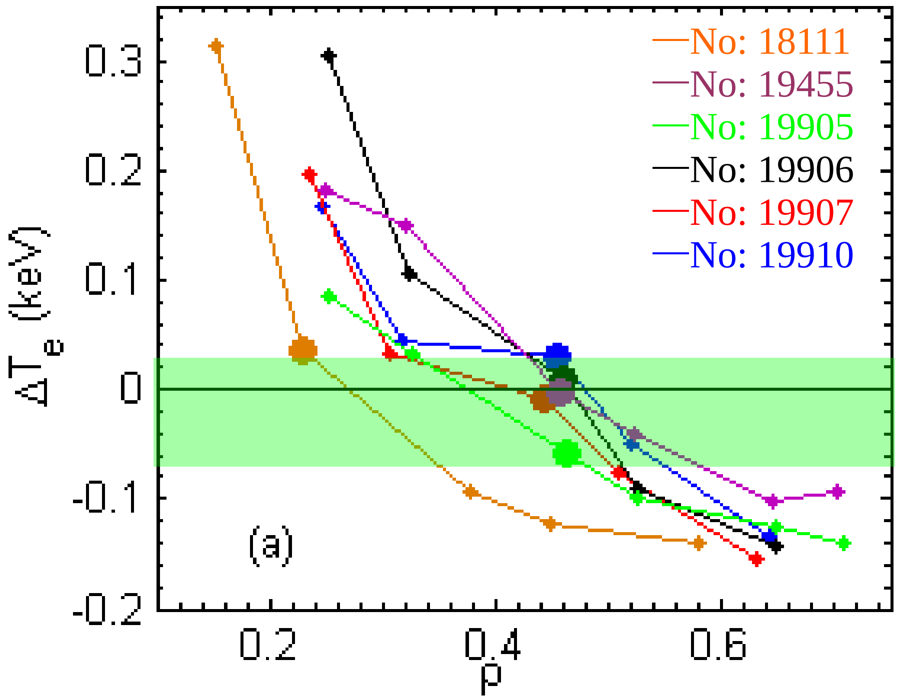
Relation between NTM onset and non-local transport

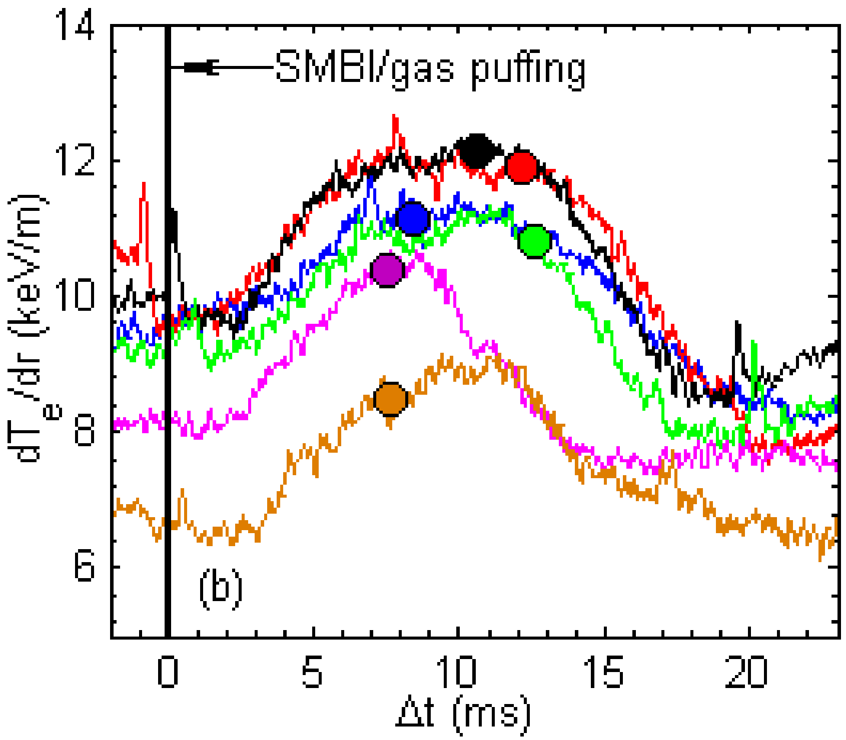


NTM onset location — at the reversion surface of non-locality

NTM onset time — at the maximum changes in T_e gradient

Relation between NTM onset and Non-local transport





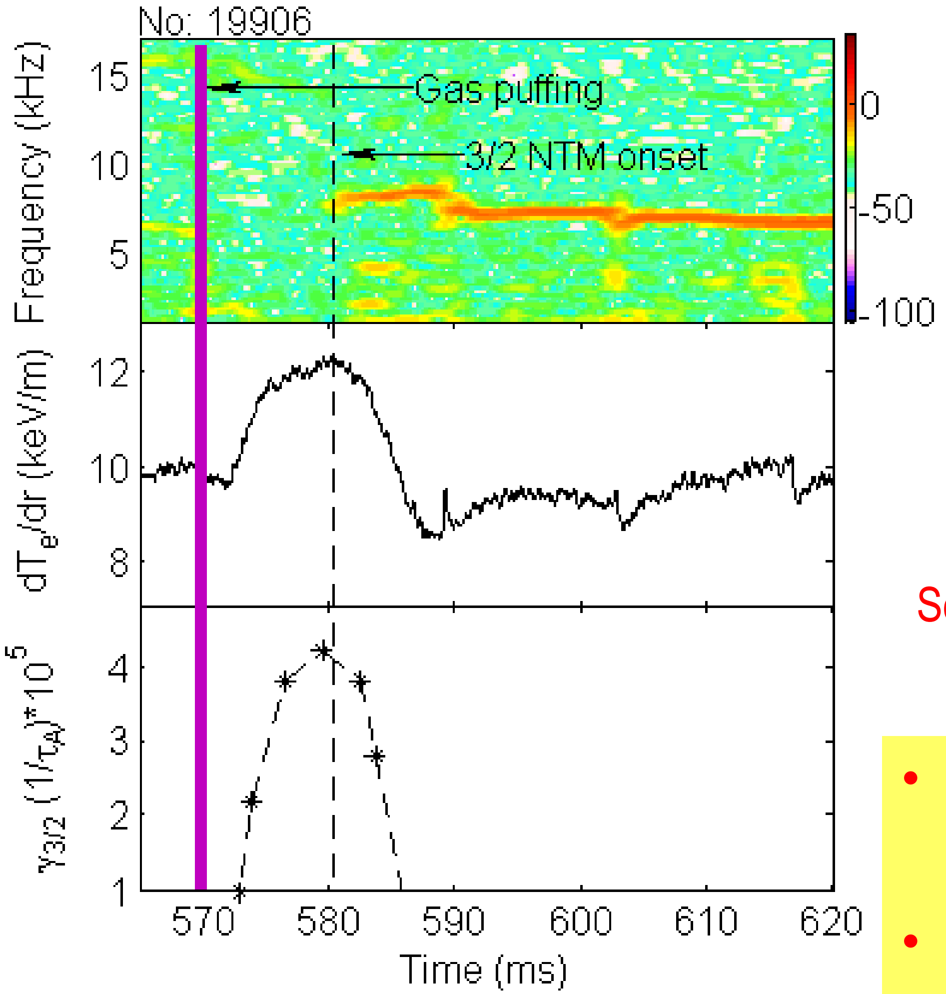
- $\Delta T_e = T_{e,3/2\ NTM} - T_{e,SMBI/gas\text{-}puffing}$
- Solid circles indicate location of q=3/2 surfaces

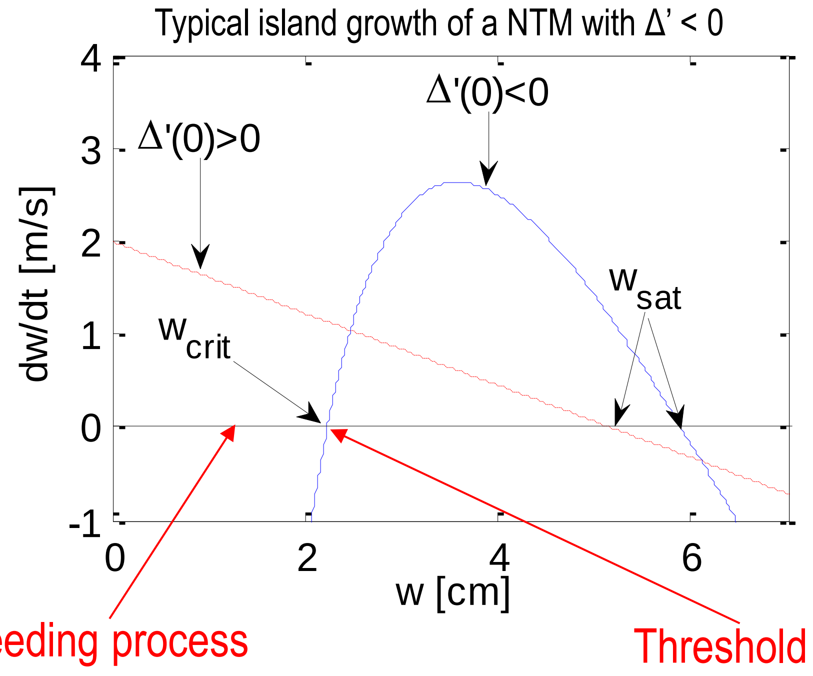
♦ The 3/2 NTMs are located near the inversion surface of electron temperature perturbation.

- dT_e/dr: T_e gradient of two radial loci around ρ_{inv}
- $\Delta t = t - t_{SMBI/gas\text{-}puffing}$
- Solid circles mark onset time of 3/2 NTM

♦ 3/2 NTMs onset when the local electron temperature gradient nearly reaches to the maximum value.

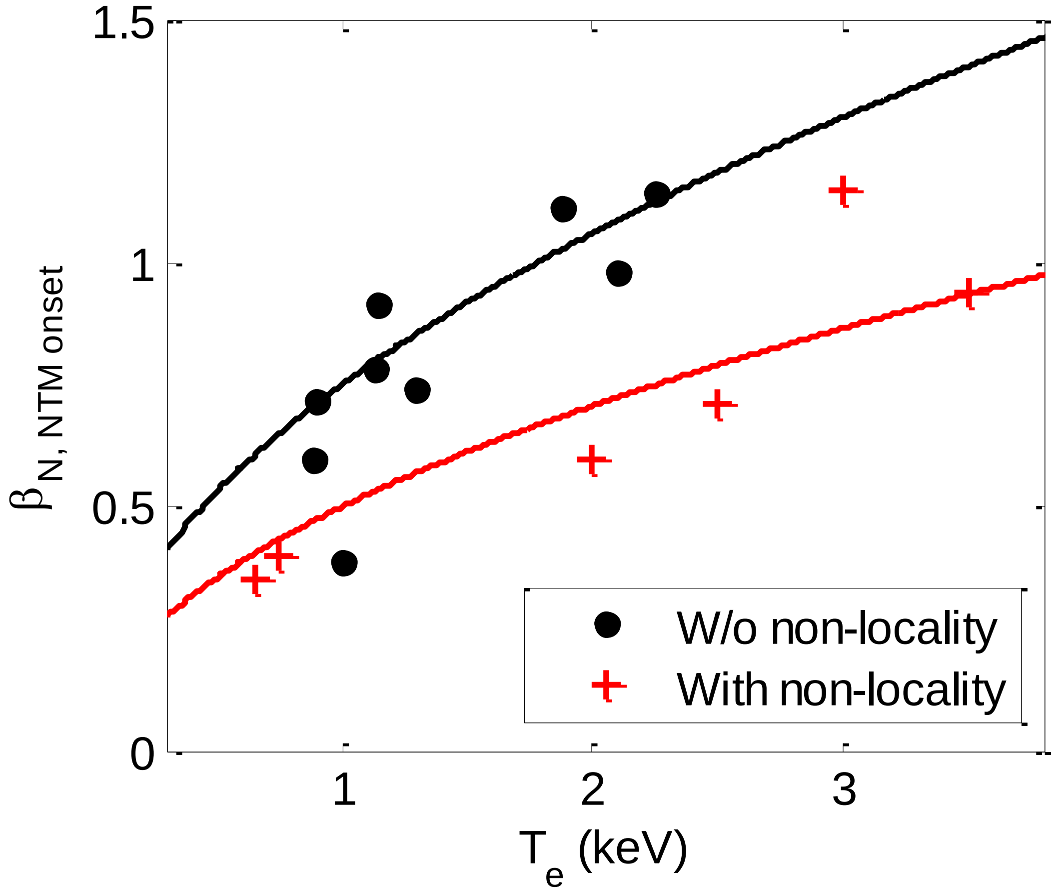
Spontaneous onset of NTMs during non-local transport





- Spontaneous NTM: no MHD activity was found as seeding island.
- ▽P grows strong enough (by non-locality) to linearly drive NTMs.

Critical value of β_N for NTM onset

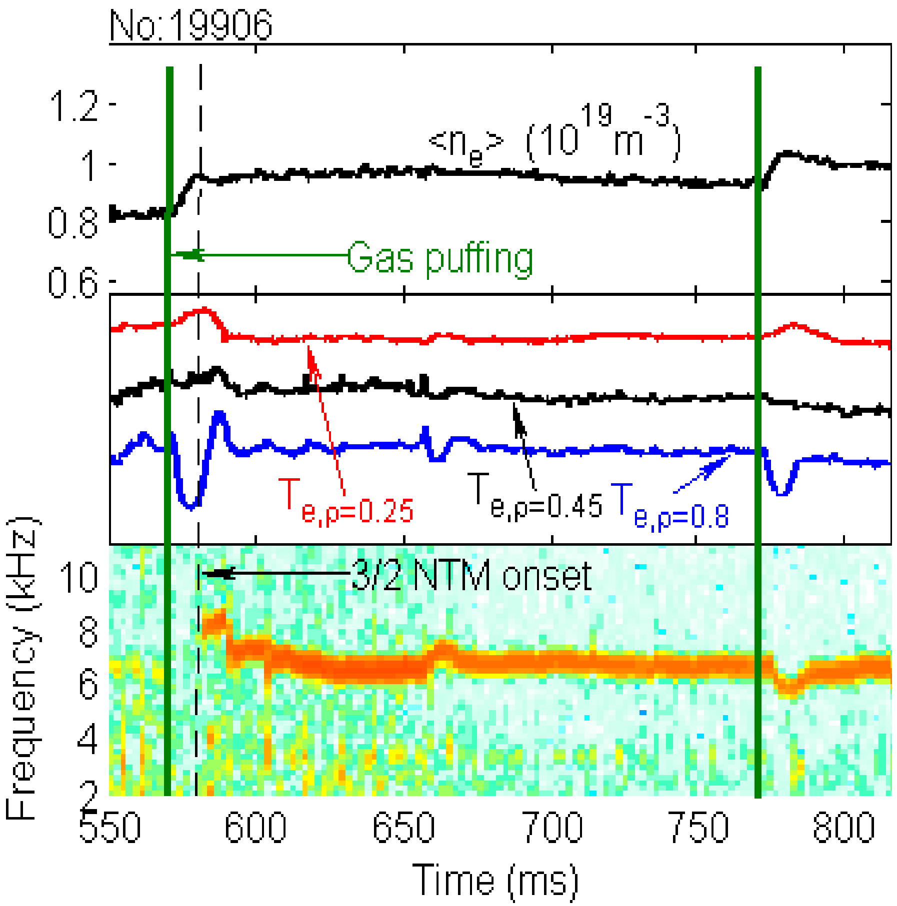


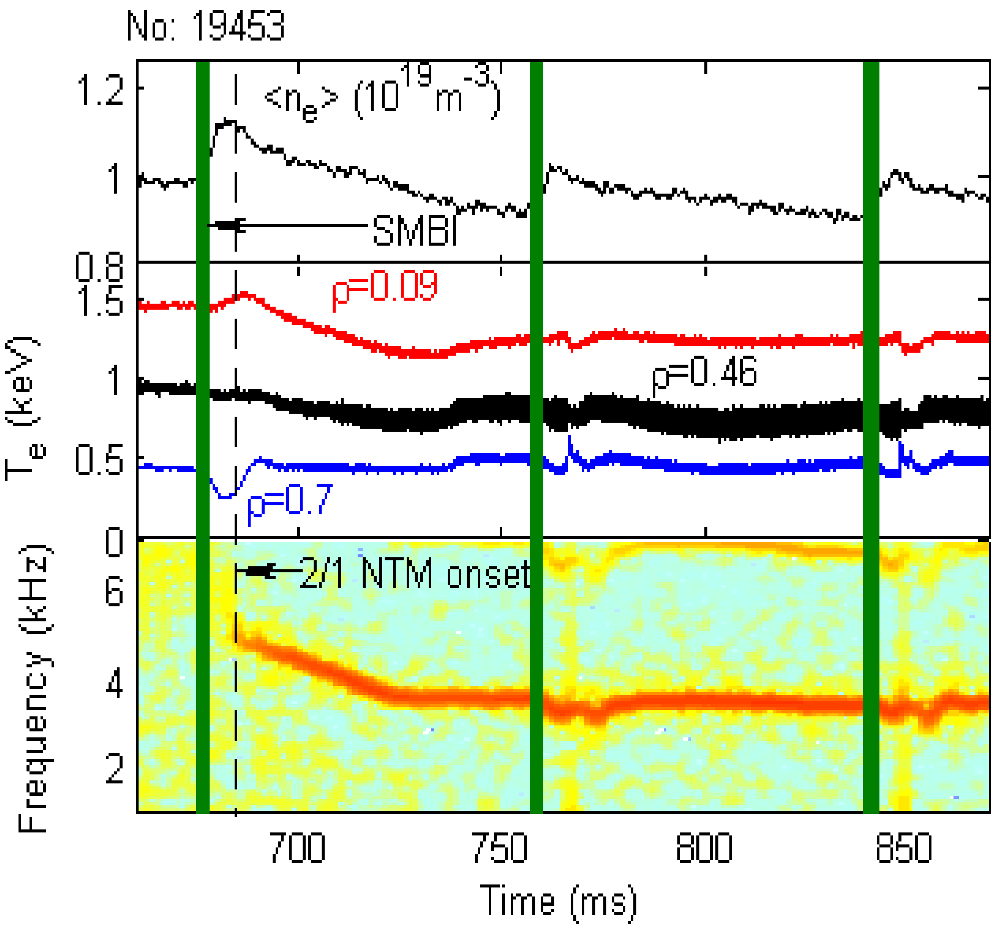
- With non-locality, the critical value of β_N for NTM onset is reduced.
- Possible mechanism for lower β_N in non-local transport to trigger the NTM is due to enhanced local ∇P (Δ'_{BS}) around the reversion surface.

Outline

- Motivation
- Non-local transport
  - Non-local transport in HL-2A
  - Enhanced avalanche characteristics during non-local transport
- NTM onset during non-local transport
  - Typical feature of NTM onset during non-local transport
  - Relation between NTM onset and non-local transport
- **Impact of NTM on non-local transport**
  - Damping effects of NTM on non-local transport
  - Reduction of avalanche feature with NTM in non-locality
- **Summary**

Damping effect of NTM on non-local transport

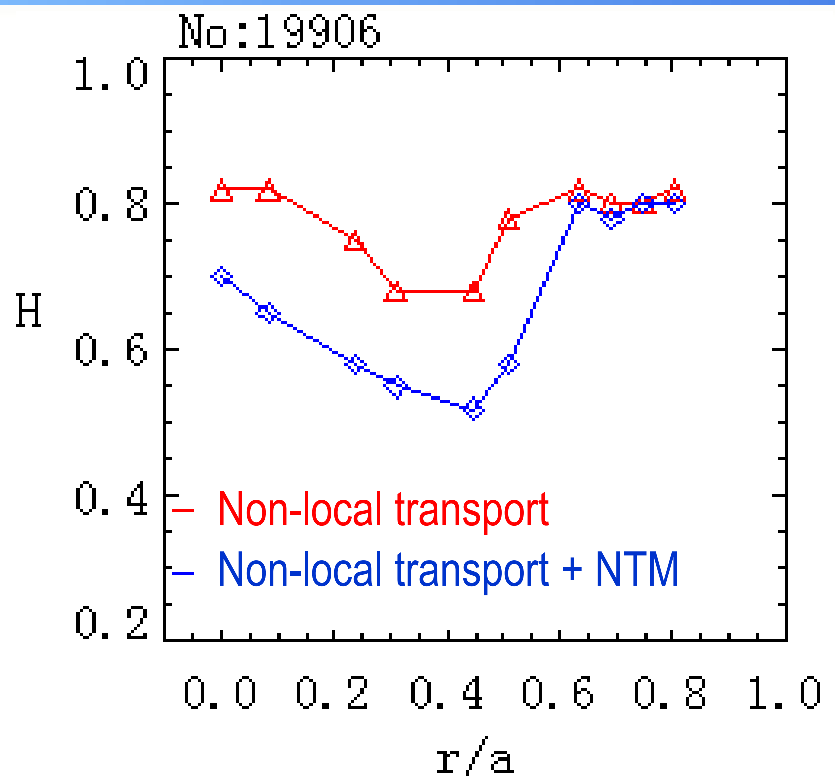




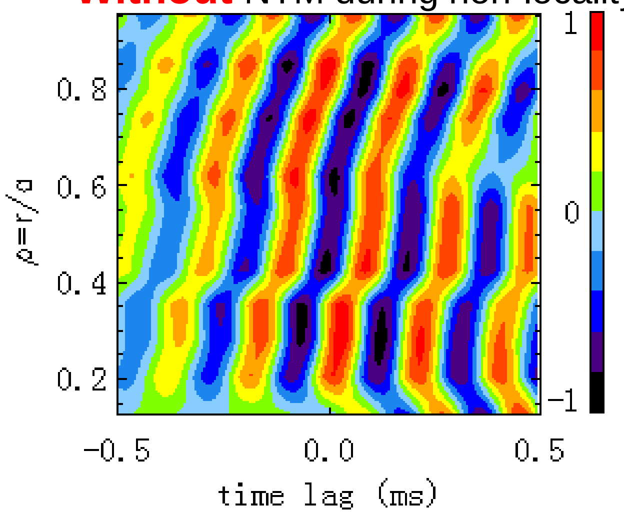
The NTMs impose damping effects on non-local transport.

Why ?

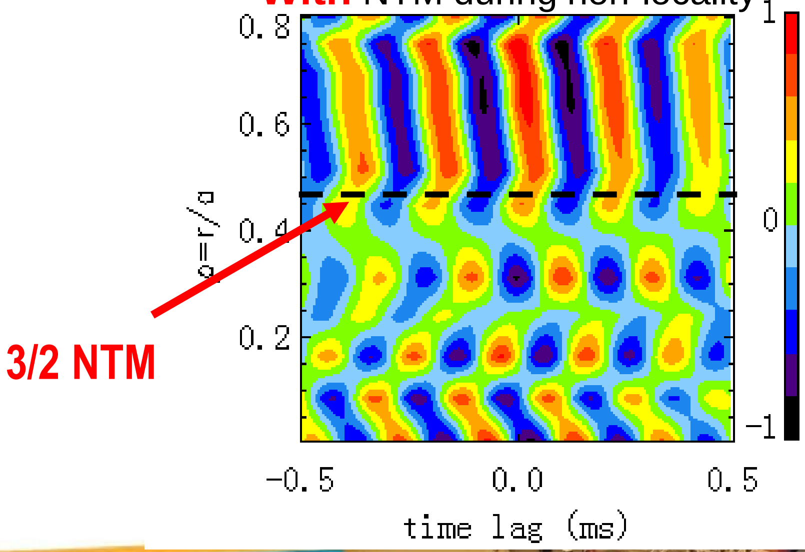
Reduction of avalanche feature with NTM in non-locality



Without NTM during non-locality



With NTM during non-locality



- ♦ **With NTMs, Hurst exponents decrease with weakened SOC dynamics in the core.**
- ♦ **Avalanche propagation is blocked near the NTM surface of island, where enhanced flow shear around rational surface may suppress avalanche**

Summary

- In HL-2A, we observed NTM onset during non-locality for the first time.

- During non-locality, avalanche characteristics are enhanced, suggesting that the SOC regime could be responsible for non-local transport in HL-2A.

- Possible link between non-locality and NTMs has been identified:

  (i) the local increase of ∇T_e nearby reversion surface of non-locality $\rightarrow$ enhanced ∇P (Δ'_{BS}) $\rightarrow$ onset of NTMs

  (ii) no seeding island was observed, indicating that ∇P grows strong enough (by non-locality) to linearly drive NTMs.

  (iii) Avalanche propagation is blocked nearby the NTM surface of island $\rightarrow$ SOC dynamics of non-locality are weakened $\rightarrow$ nonlocal transport is damped by NTM onset.

Thanks for your attention!

Modified Rutherford Equation

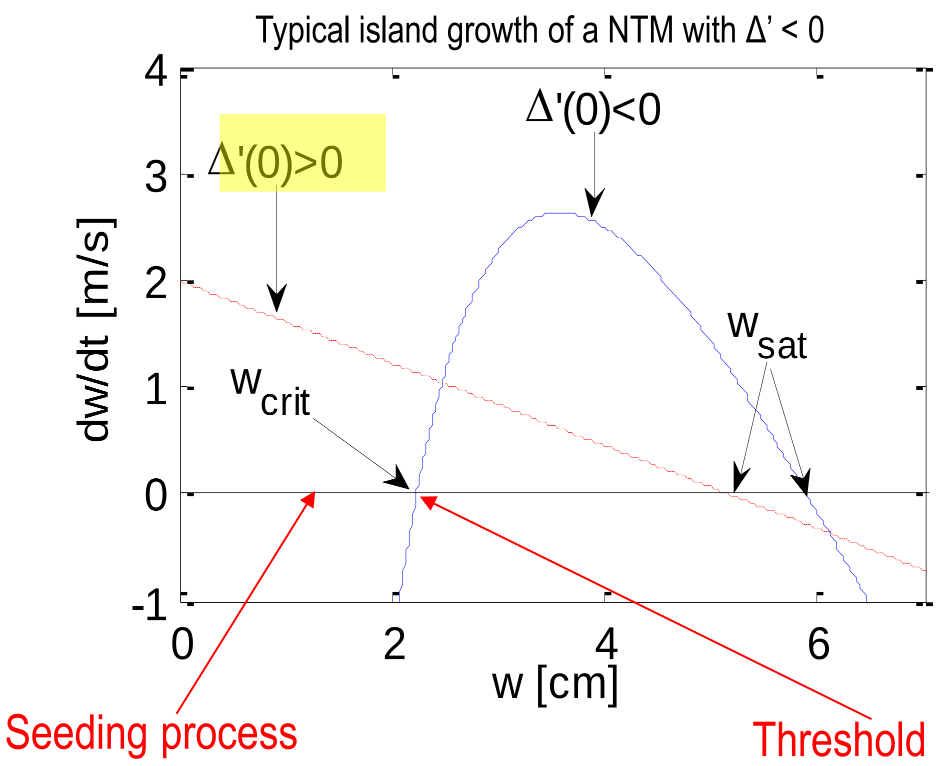
$$\frac{\tau_\mathrm{R}}{r_\mathrm{s}}\frac{\mathrm{d}W}{\mathrm{d}t} = r_\mathrm{s}\Delta'(W) + r_\mathrm{s}\beta_\mathrm{p}(\Delta'_\mathrm{BS} - \Delta'_\mathrm{GGJ} - \Delta'_\mathrm{pol}) + r_\mathrm{s}\Delta'_\mathrm{CD}$$

$$\Delta'_{BS} \propto \frac{w}{w^2 + w_d^2}$$

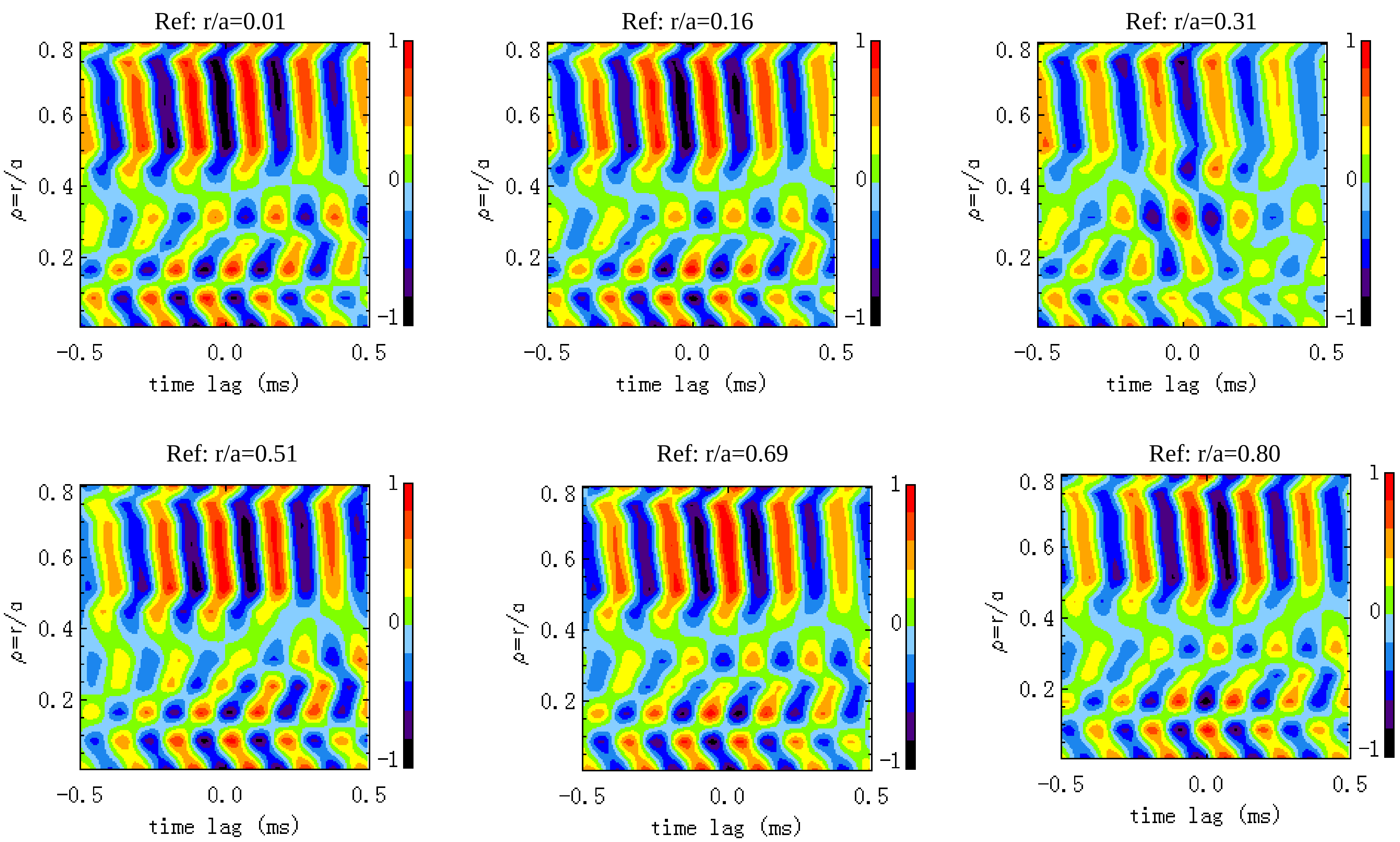
$$w_d = 1.8 r_s \sqrt{\frac{8R_0L_q}{r_s^2 n}}\left(\frac{\chi_\perp}{\chi_\parallel}\right)^{1/4}$$

$$\Delta'_{GGJ} \propto \frac{1}{w}$$

$$\Delta'_{pol} \propto \frac{1}{w^3}$$

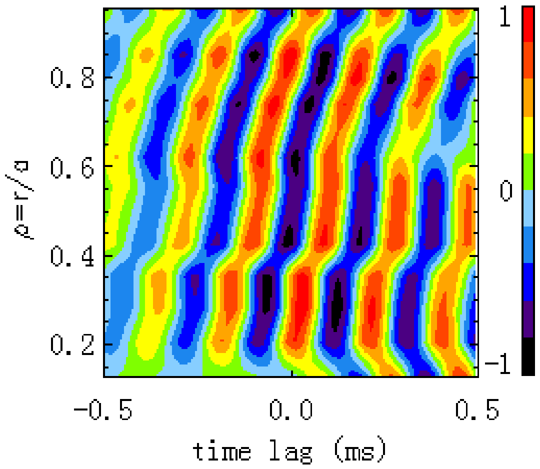


Different reference channels

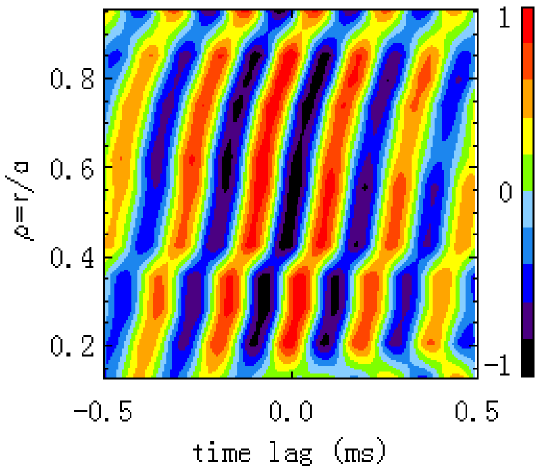


During non-local

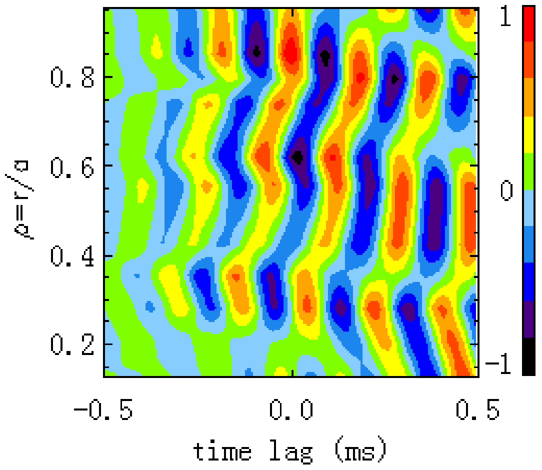
5-6kHz



5.2-5.8kHz



4.5-6.5kHz



Bicoherence of T_e and B