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United States Department of Energy

Johns Hopkins University

NSTX

An assessment of electron thermal transport dynamics and its origins on NSTX

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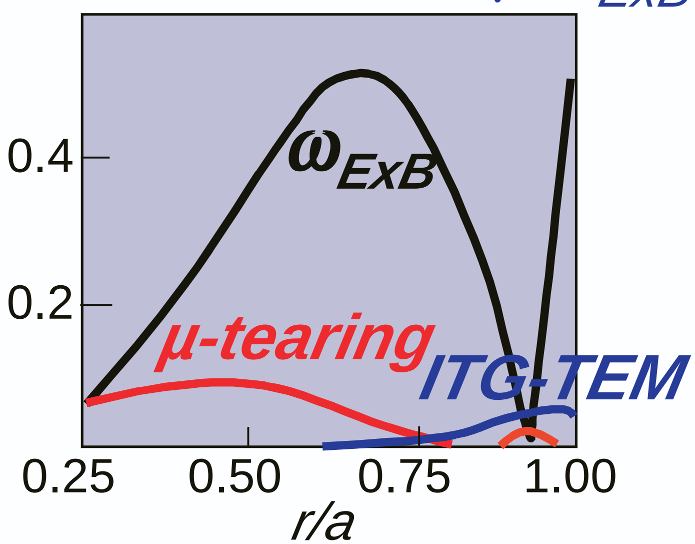
NSTX operates at parameters different from conventional aspect-ratio tokamak

- Low R/a (1.5) → more 'good curvature'
- High β (up to 35%) → E-M effects important
- Low B_T (down to 3 kG) → large ω_{ExB} (E/B)

GS2 normalized γ, ω_{ExB}



Kotschenreuther 2000

- $\omega_{ExB} > \gamma_{ITG\text{-}TEM}$ →
  neoclassical ion transport
- Strong μ-tearing ($k_\theta \rho_i$ >1) →
  rapid electron transport
  ↓
  Flat core T_i , T_e

Electron transport studied in two regimes

I) High density NB-heated H-Modes:

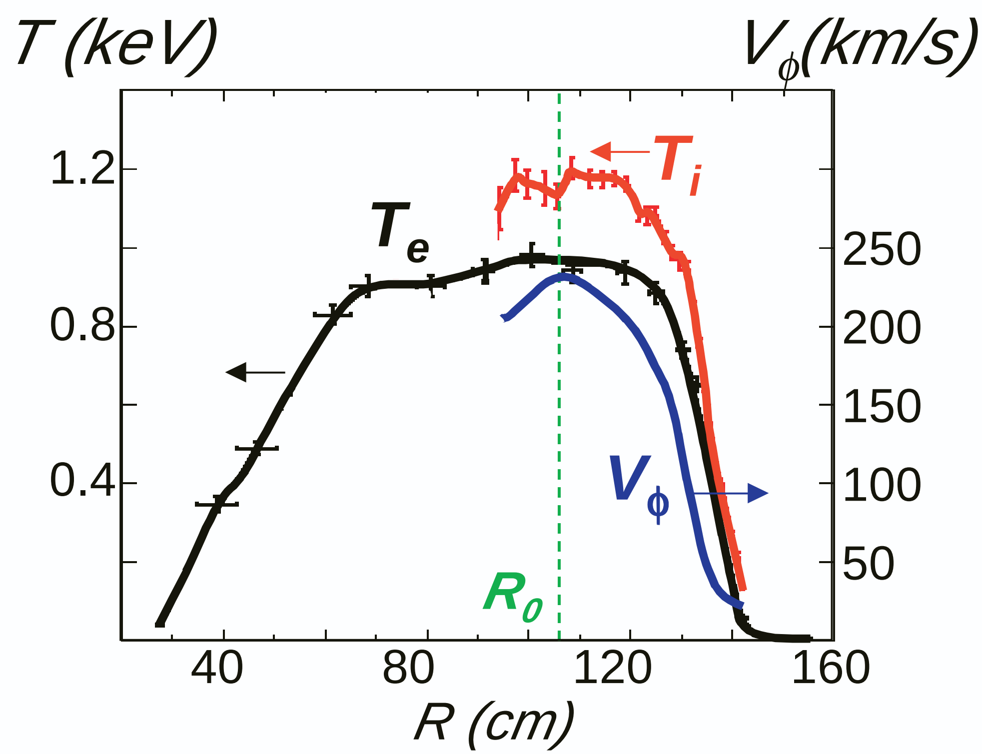
Experiment	• Flat T_e,T_i, • neoclassical ion, rapid electron transport
Linear GS2 assessment	• strong μ-tearing, ETG drive in ∇T_e region

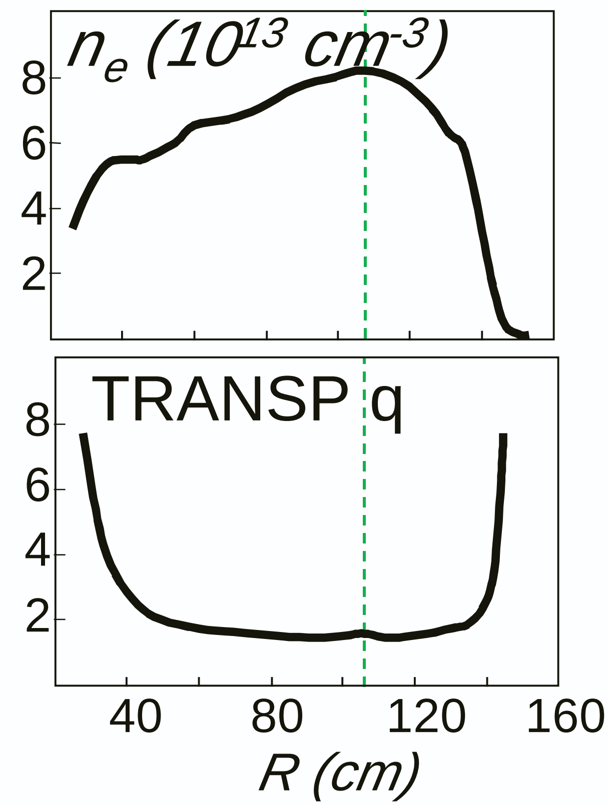
II) Low density NB-heated L-Modes:

Experiment	• vary magnetic shear *s*, through I_p ramp, t_{beam} • eITB and iITB when $s < 0$ inferred
Linear GS2 assessment	• Reduced instability drive when $s < 0$

High $n_{e,}$ β_t H-mode has flat T_i, T_e as predicted

7 MW H-Mode ($\beta_t \approx 25\%$, $\tau_E \approx \tau_{E,98y2}$)

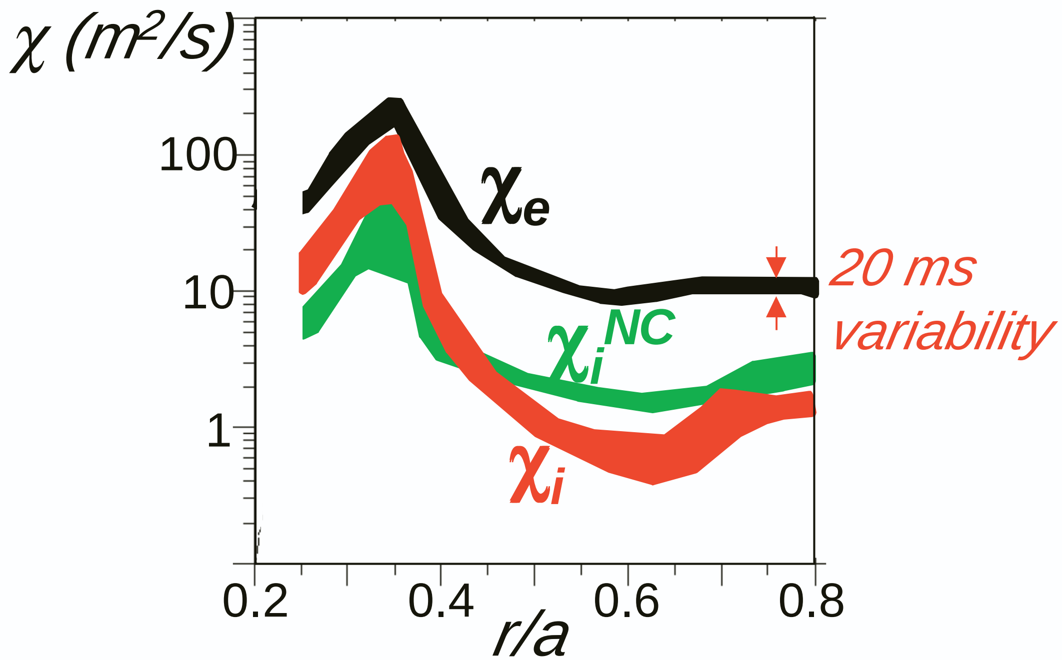




- No strong core MHD activity, Type-I ELMs at ≈ 50 Hz
- T_i > T_e although beams predominantly heat electrons

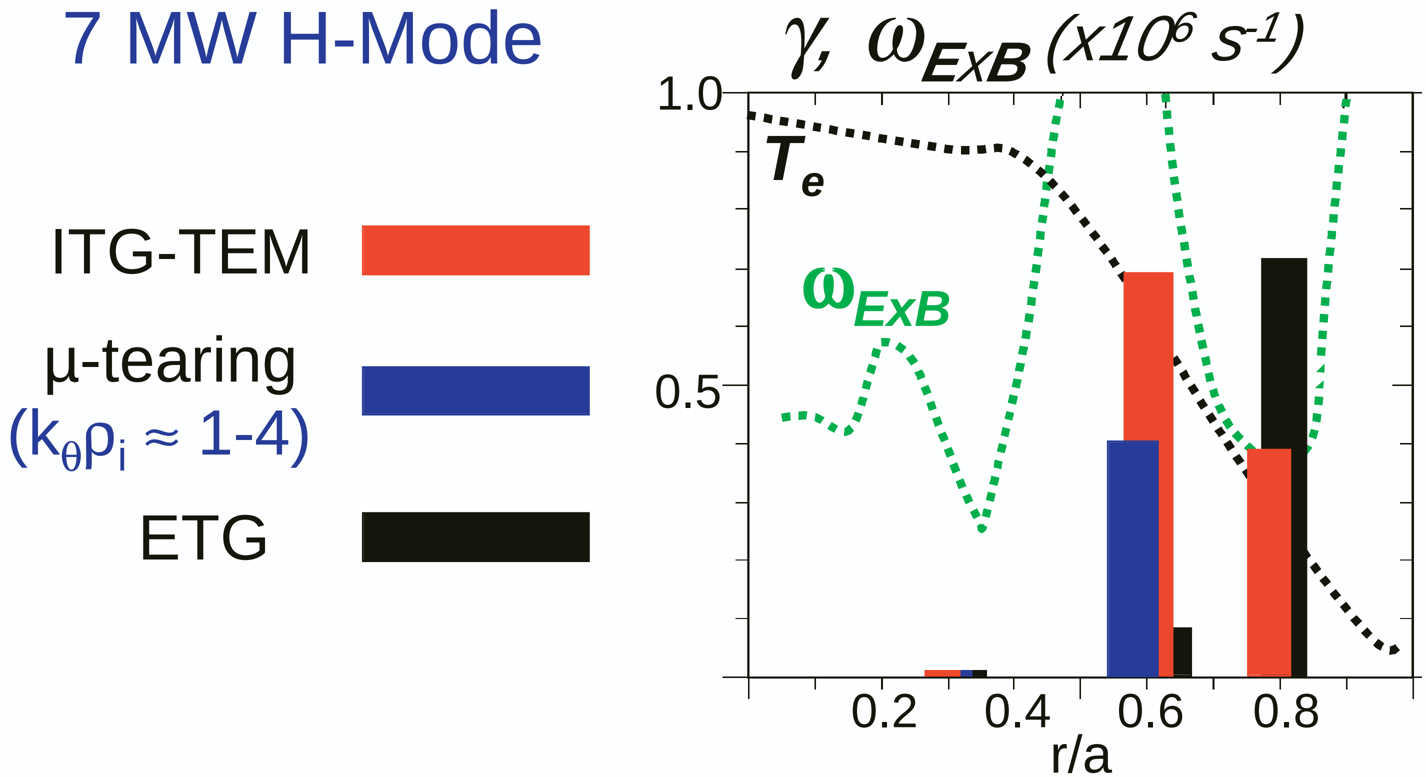
Ion transport near neoclassical over broad region, electron transport rapid

7 MW NB H-Mode



Linear GS2 calculations predict instabilities in the gradient region

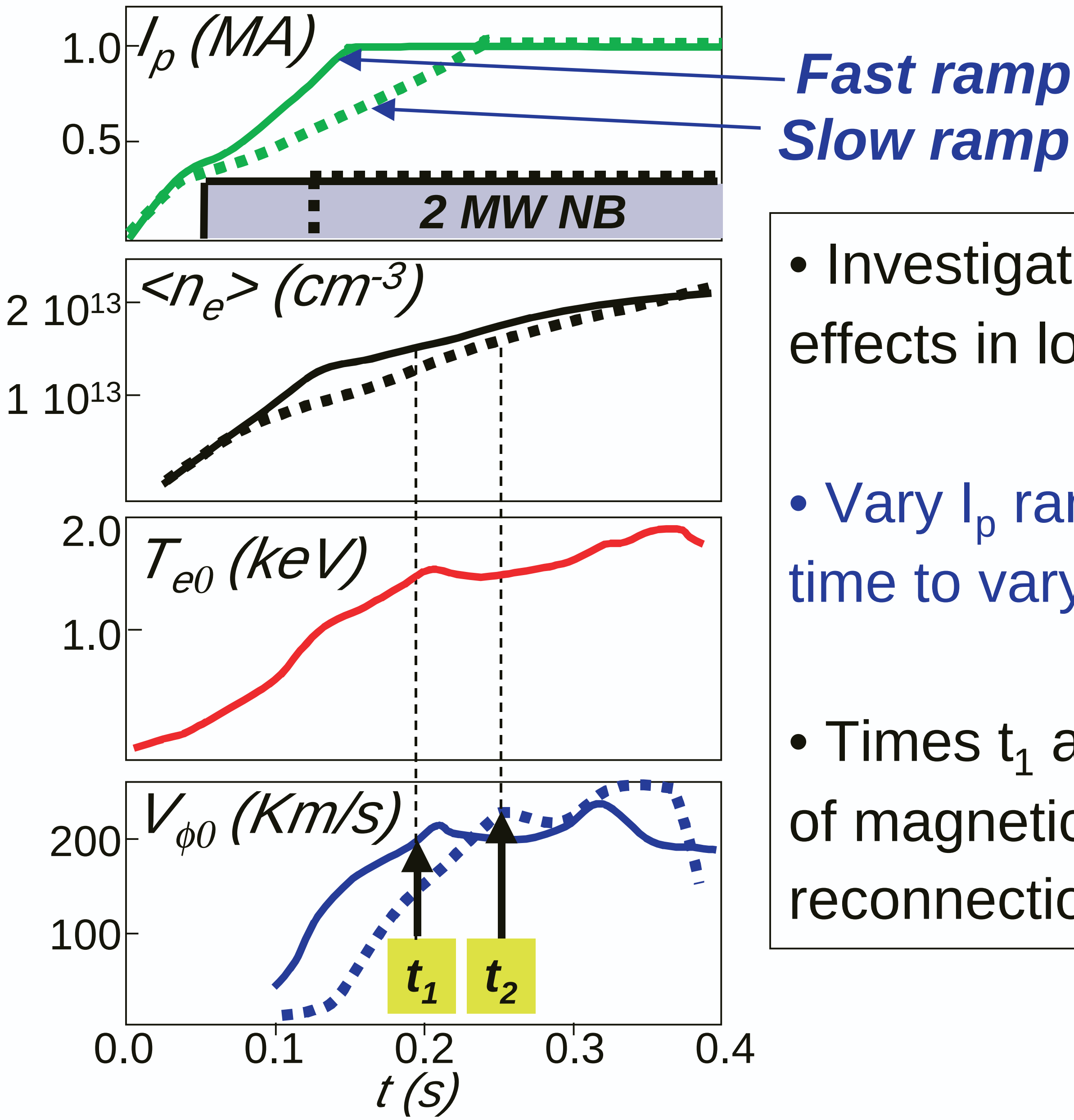
7 MW H-Mode



Redi, JP1.021

- Non-linear GS2 $\chi_e^{ETG} \approx$ experimental χ_e at r/a=0.8 *(preliminary)*
- Linear calculations do not explain electron transport at r/a $\leq$ 0.4

Electron transport can be reduced in NSTX

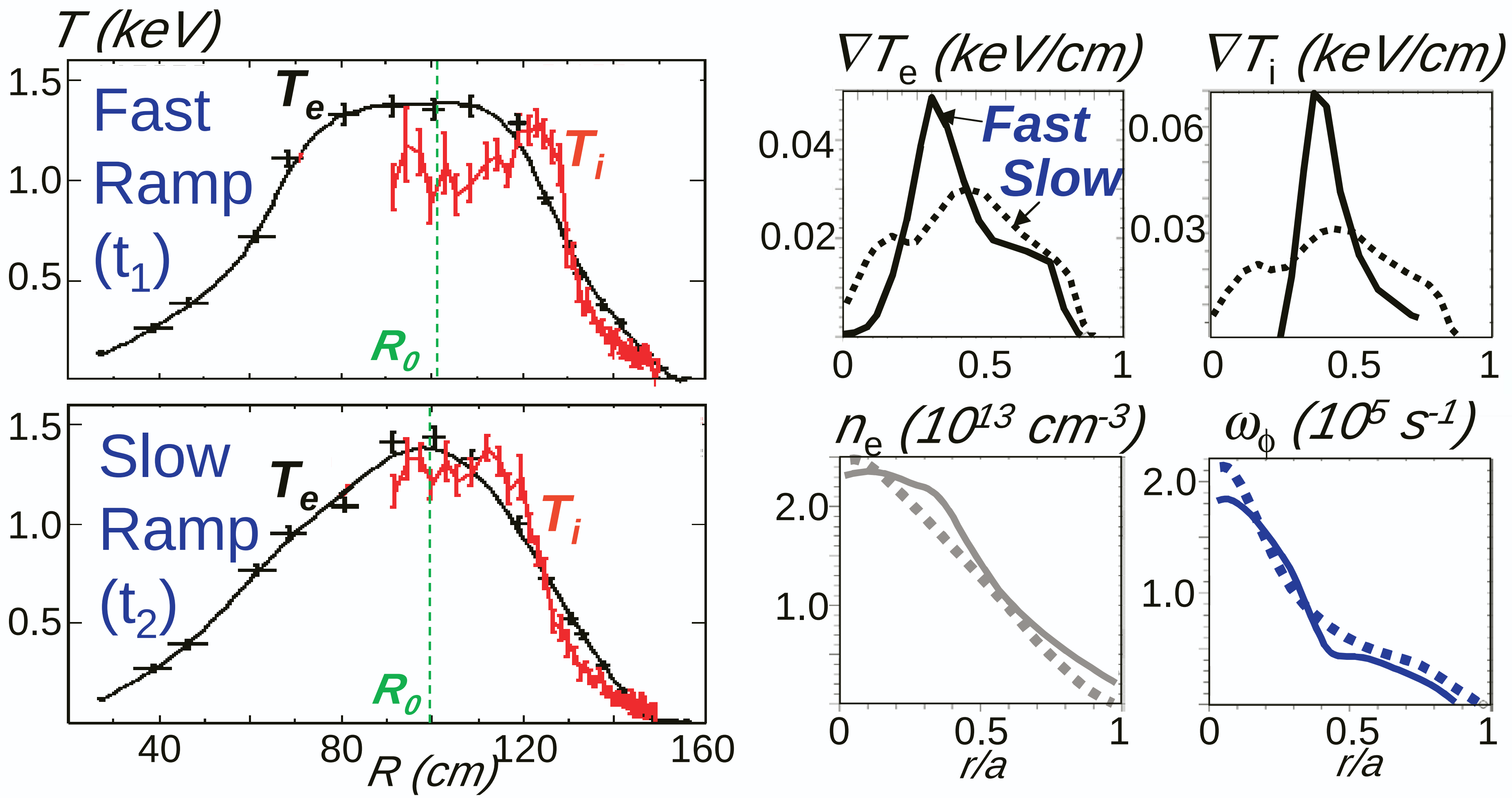


- Investigate magnetic shear effects in low n_e, high T_e L-Modes

- Vary I_p ramp rate, beam onset time to vary magnetic shear

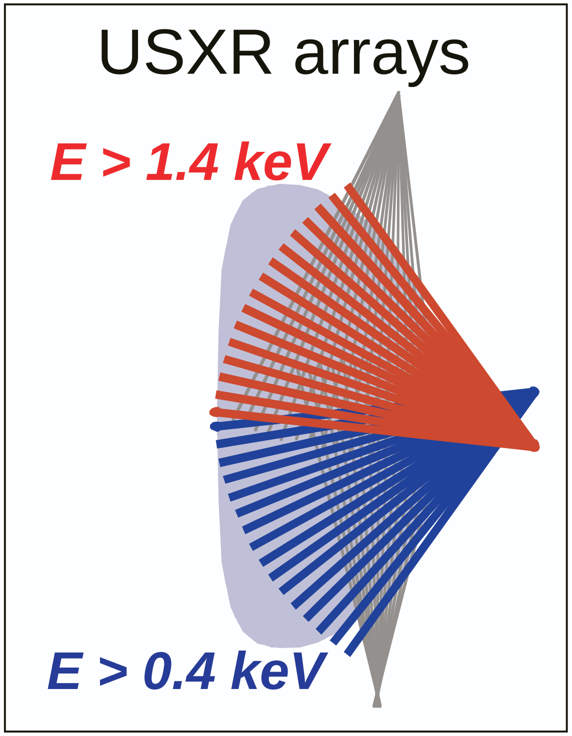
- Times t_1 and t_2 for comparison of magnetic shear effects (no reconnections, $n_{e1} \approx n_{e2}$, $V_{\phi 1} \approx V_{\phi 2}$)

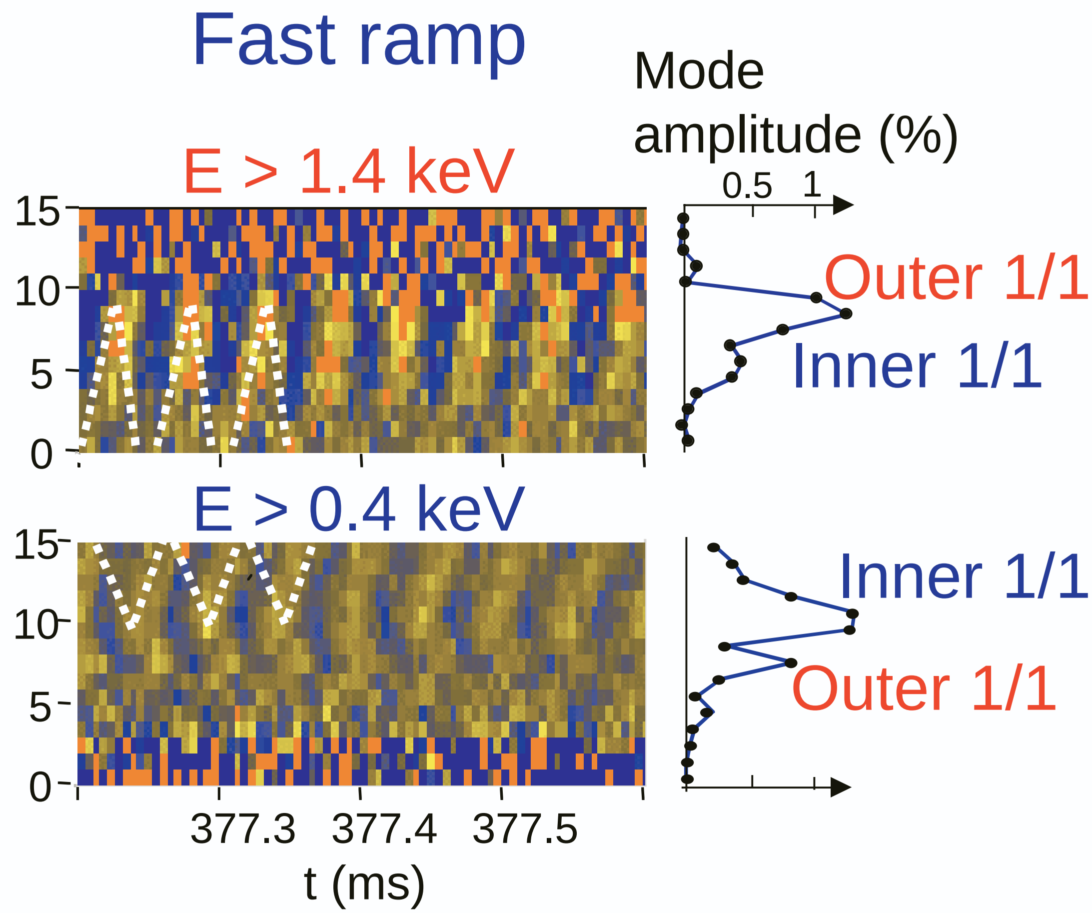
Steep $T_{e,}T_i$ gradients develop in fast ramp case



- Comparable ω_ϕ, T_i/T_e, collisionality and β (≈8%)

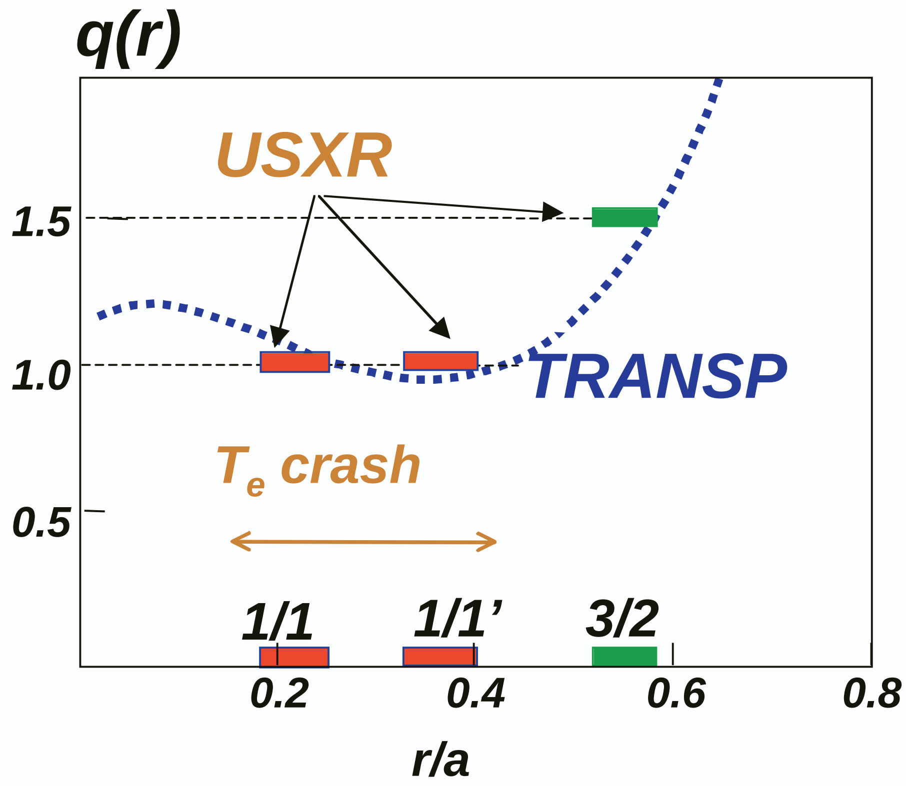
USXR data points to q-reversal in fast ramp case





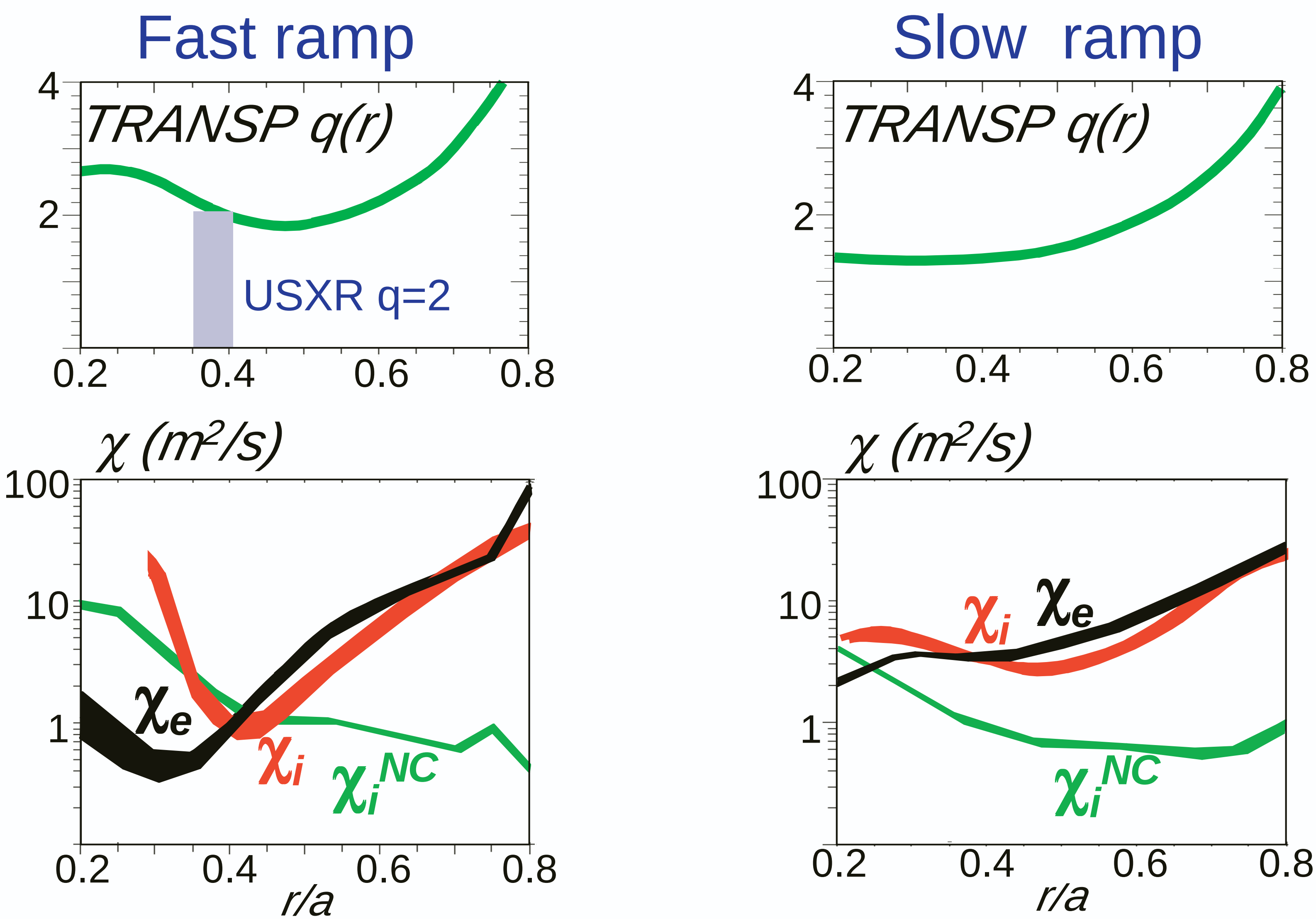
TRANSPC computed q(r) also indicates magnetic shear reversal

Fast ramp 108918



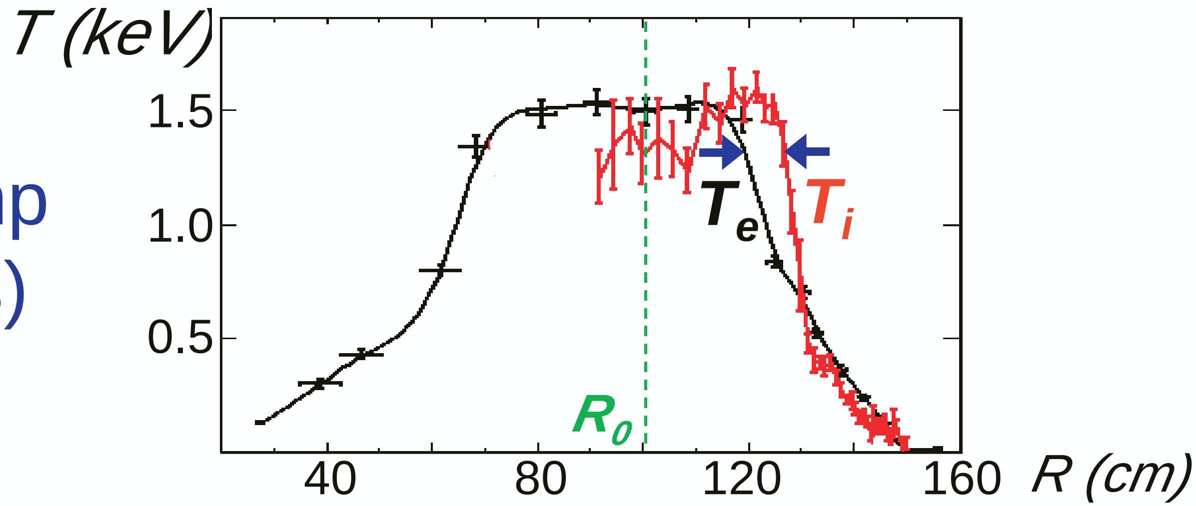
- No indications of strong q-reversal with slow ramp

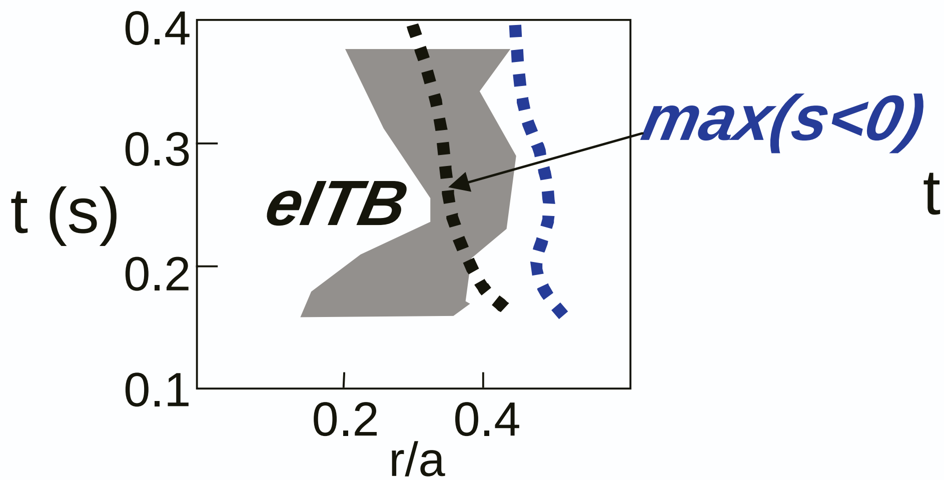
Electron, ion transport vary with magnetic shear

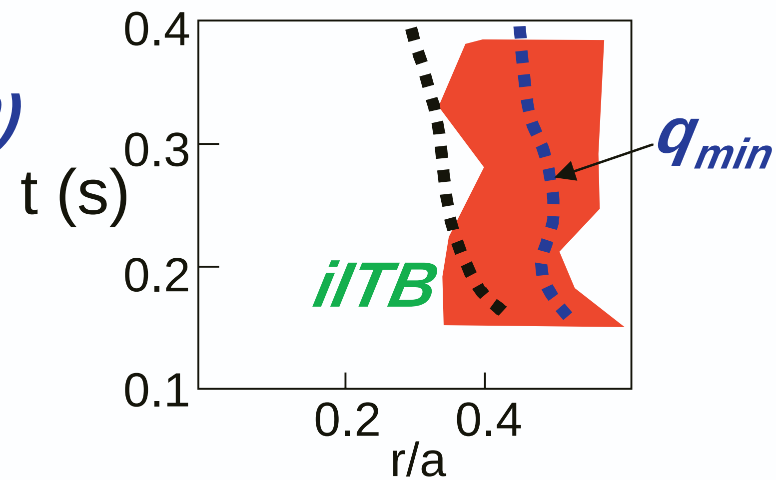


Electron and ion barriers are at different radii

Fast ramp
(t≈0.21 s)

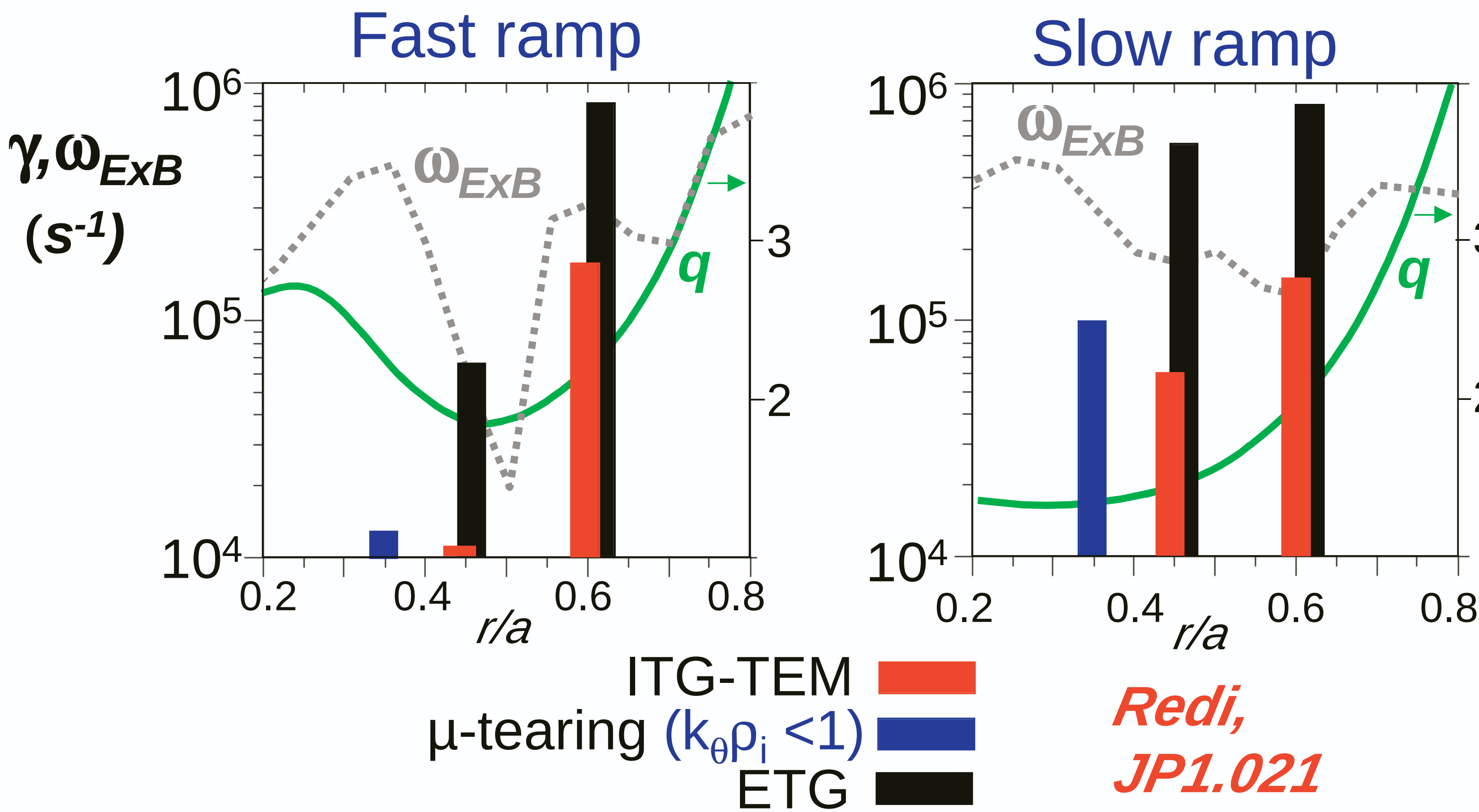






- Electron ITB in region of large negative shear
- Ion ITB in region of low magnetic shear (near q_{min})

Reduced instability drive in regions of $s < 0$

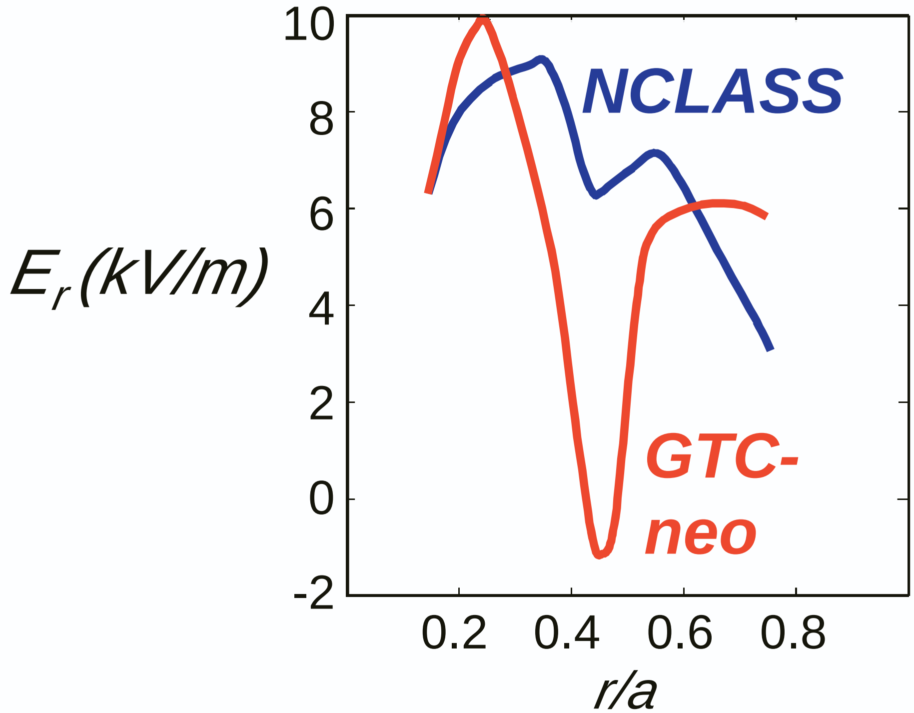


Redi, JP1.021

- ITG-TEM reduced in iITB region ($s \approx -0.6$)
- μ-tearing reduced in eITB region ($s \approx -1.7$) - *preliminary*
- ETG reduced or stable in regions of $s < 0$, $s \approx 0$

Effects of ExB shear under assessment

Fast ramp

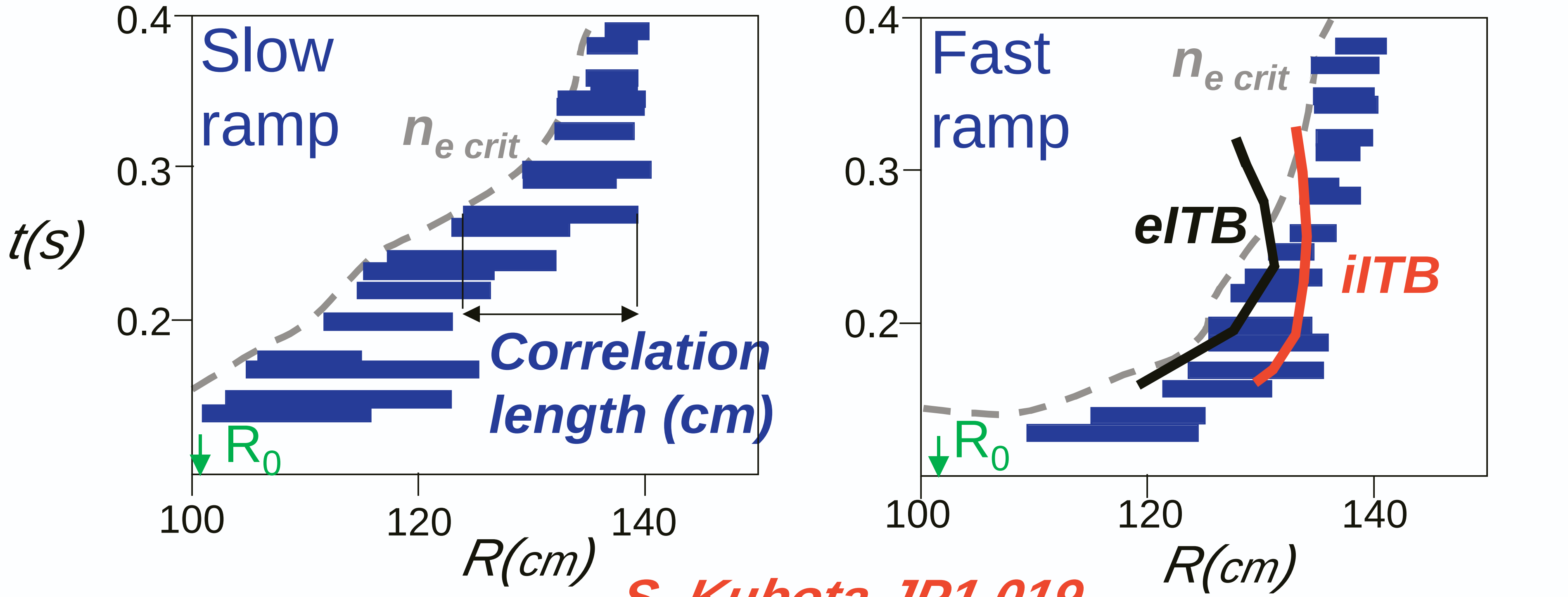


Large difference in E_r from different neoclassical calculations

• GTC-neo: global code, large, non-standard orbits, shaped geometry

W. Wang, G. Rewoldt, W. Tang, J. Manickam, F. Hinton

Density fluctuation correlation lengths measured by microwave reflectometry



S. Kubota JP1.019

- Large lengths in slow ramp case, reduced in fast case
- Correlation lengths scale with ρ_s
- Fluctuations cross ion ITB in fast ramp case
- Density and $\dot{B}$ fluctuations broadly correlated

Conclusions

H-Modes

- Flat T_e, T_i profiles, neoclassical ion transport, rapid electron transport in high density, NB heated NSTX H-Modes
- Consistent with linear GS2 predictions for $r/a \geq 0.6$
    - μ-tearing, ETG good candidates for electron transport
- GS2 cannot explain electron transport levels in the core

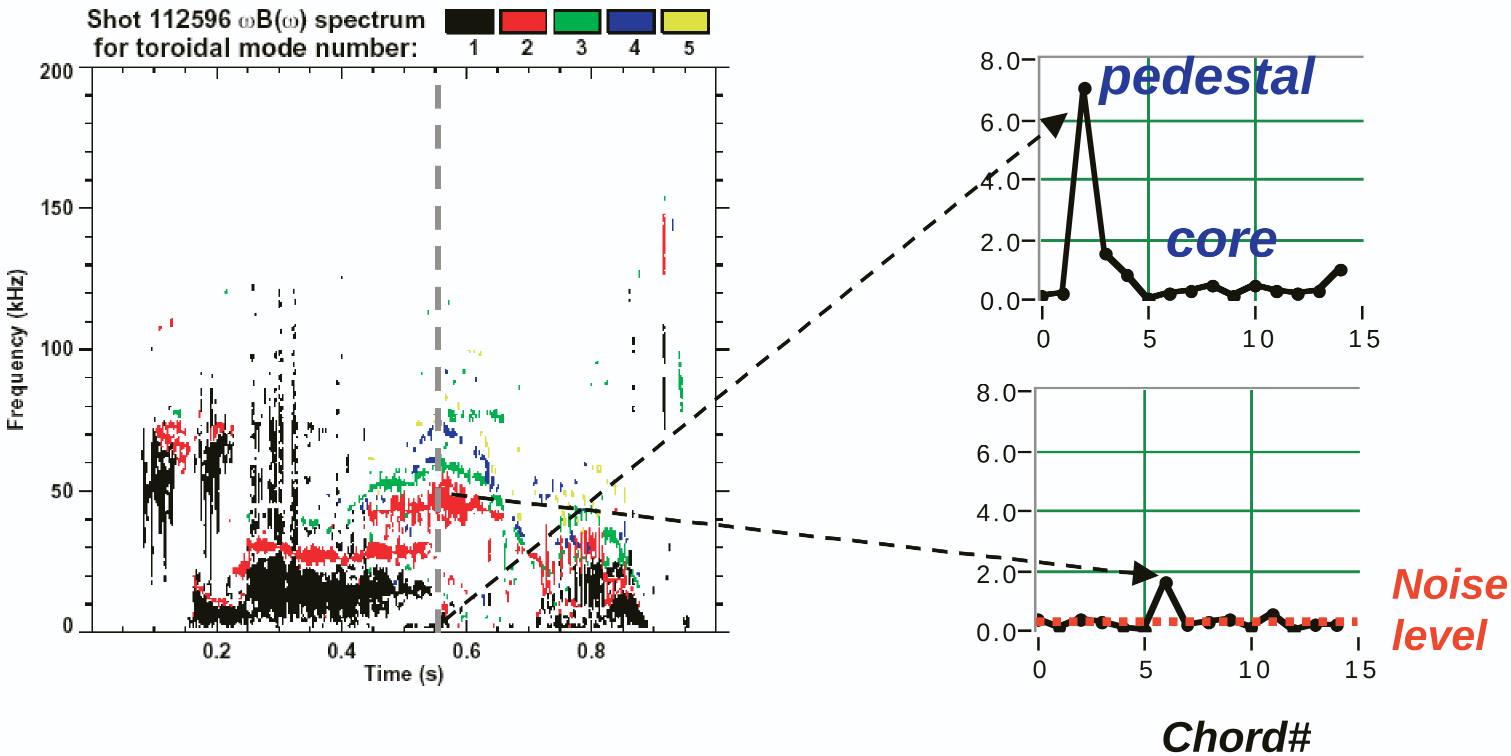
L-Modes

- Electron, ion transport much reduced when negative magnetic shear inferred at low n_e (rapid e^- transport ***not*** ST intrinsic)
- GS2 calculations indicate negative shear influences stability
    - reduced ITG-TEM near ion ITB ($s \lesssim 0$)
    - μ-tearing reduced at eITB ($s < 0$)
    - ETG stable in regions of $s < 0$, $s \approx 0$
- Density and magnetic fluctuations broadly correlated
    - possible relation to transport being assessed

Flat H-mode T_e profiles not due to MHD activity

7 MW NBI H-mode

Magnetic fluctuations — **USXR mode amplitude (0.545-0.555 s)**

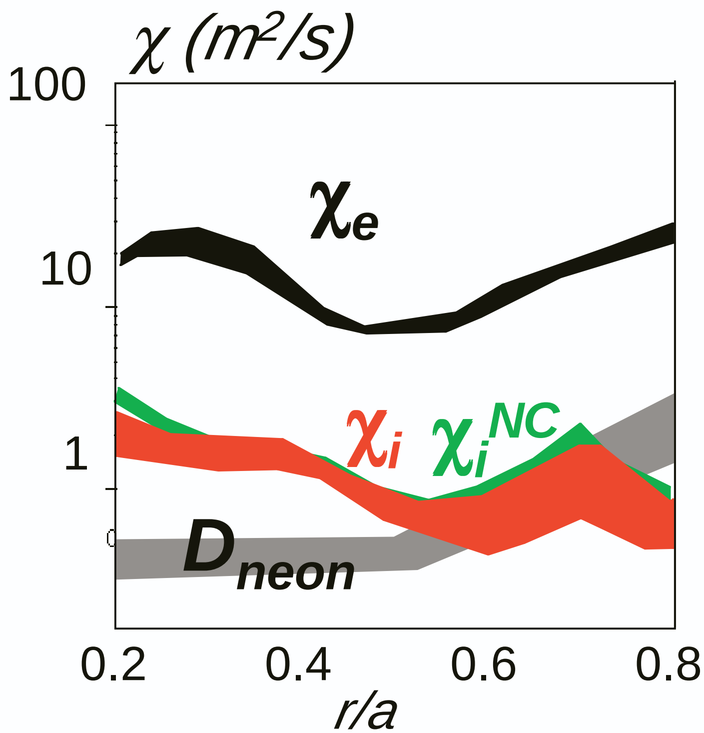


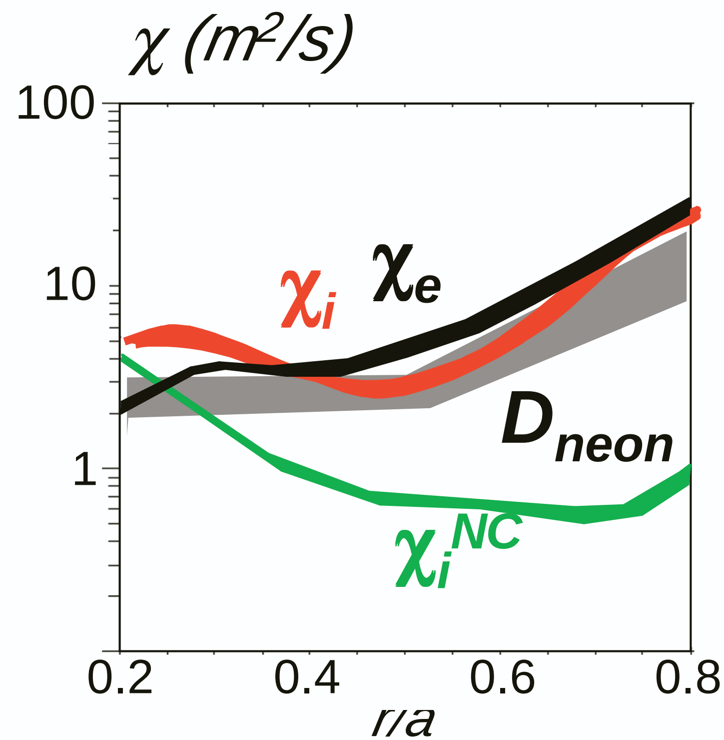
- ***Magnetic and USXR data shows only peripheral, or weak and localized core MHD modes in the 0-200 KHz range***

Intermediate density and low density L-modes have different transport situations

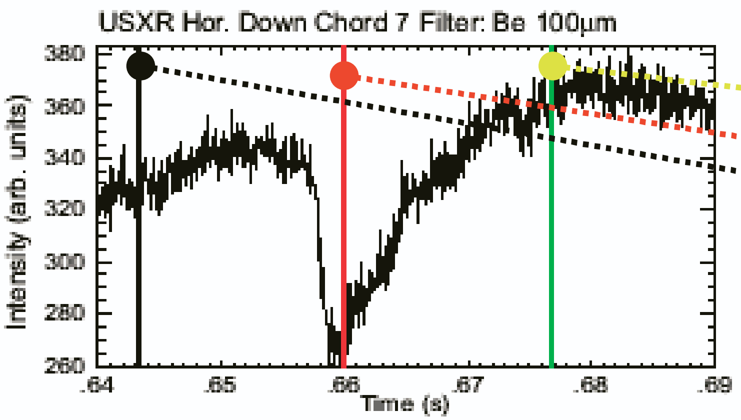
1.6 MW L-Mode
$\langle n_e \rangle \approx 4\ 10^{13}\ cm^{-3}$

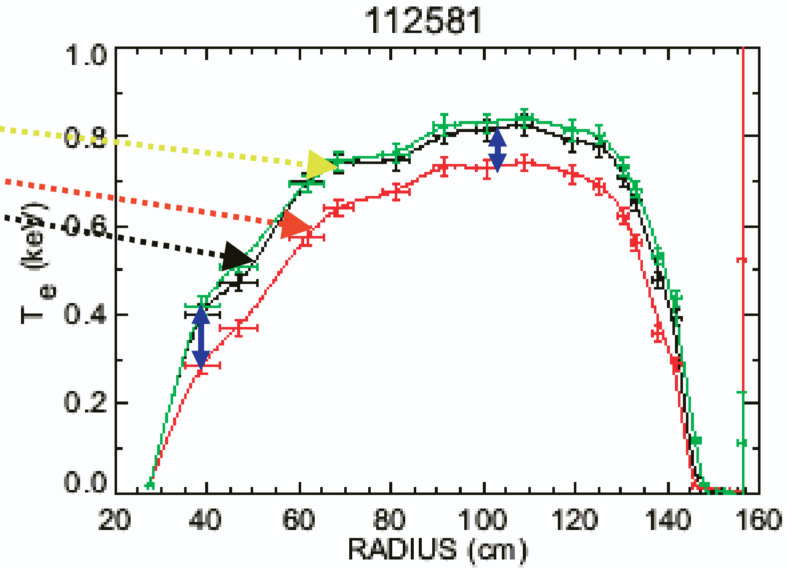
2 MW L-Mode
$\langle n_e \rangle \approx 2\ 10^{13}\ cm^{-3}$
('Slow ramp')



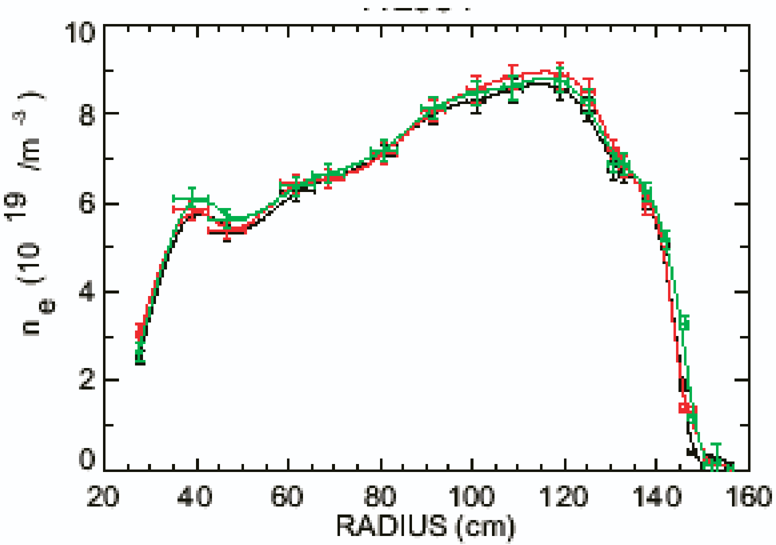


Type-I ELM perturbation probes electron transport

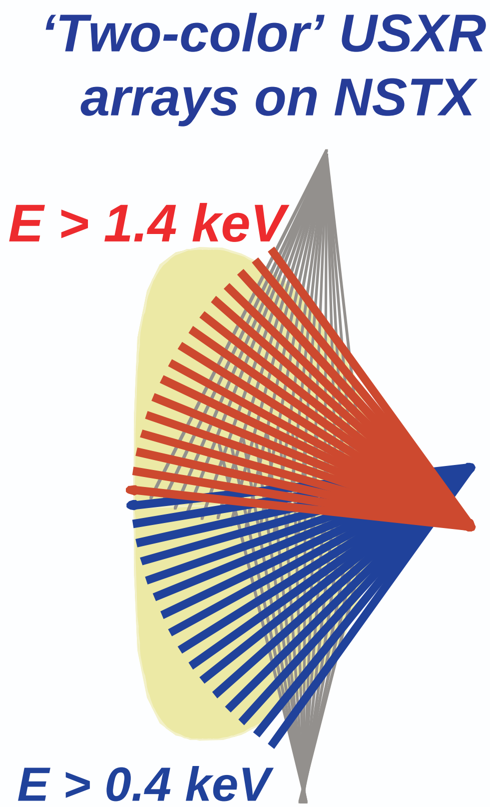


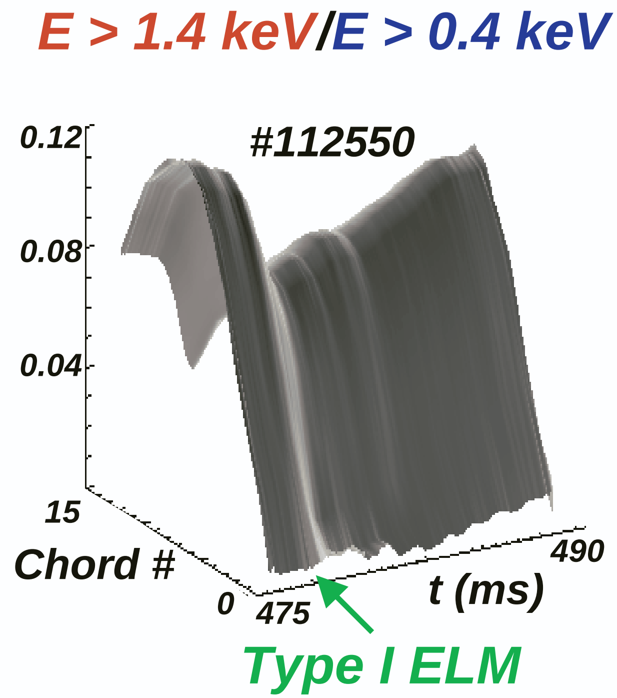


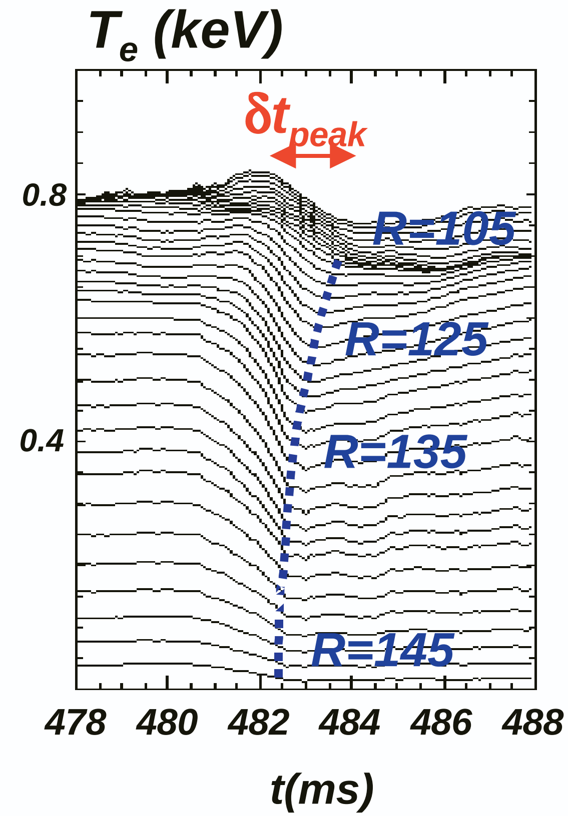
- ***USXR emission used to track T_e perturbation by Type-I ELM***
- ***δT_e >10% in the core, $\delta n_e \leq 3$ %***
- ***T_e changes such as to keep $\nabla Te \approx$ constant***
- ***'Two-color' USXR used to assess 'cold pulse' propagation***



USXR measurement confirms fast core transport



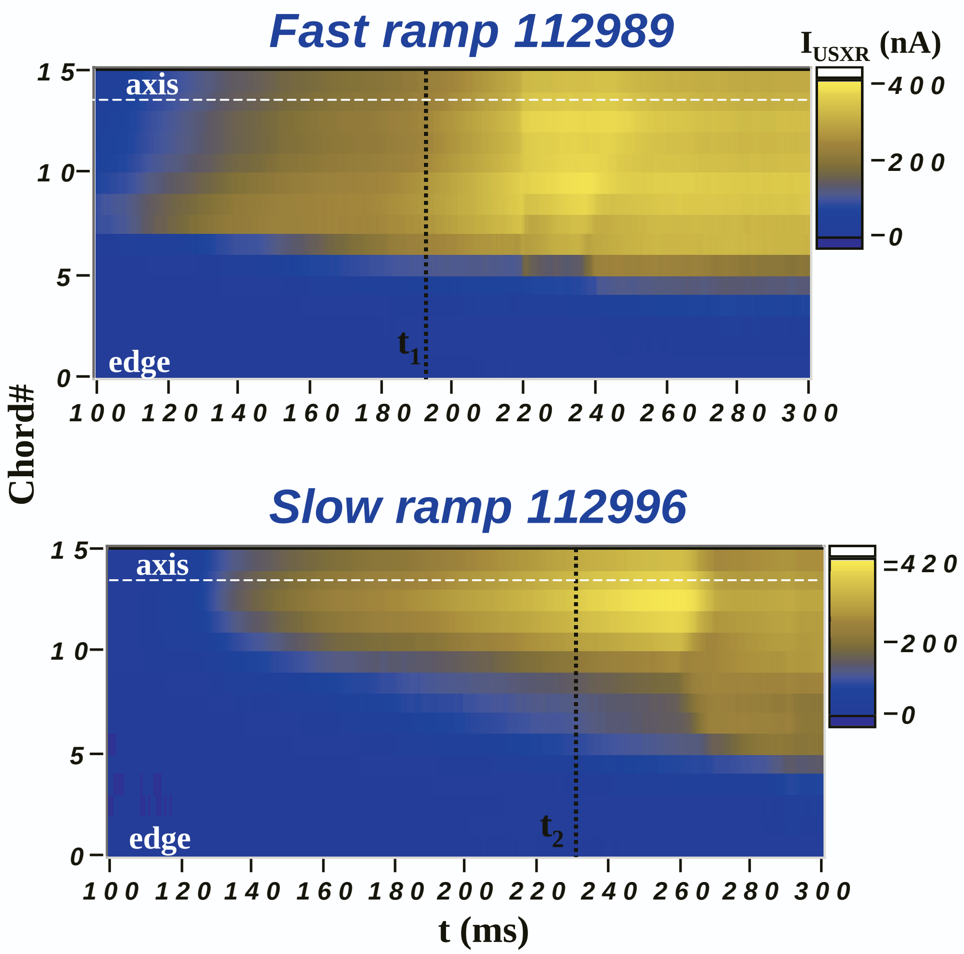




- 'Two-color' ratio modeled for fast T_e perturbation ($n_e \times n_Z \approx$ factors out)
- Perturbative electron transport also very rapid ($a/\delta t_{peak} \approx 75\text{-}100\ m^2/s$)
- 'Cold pulse' slows down where T_e flattens

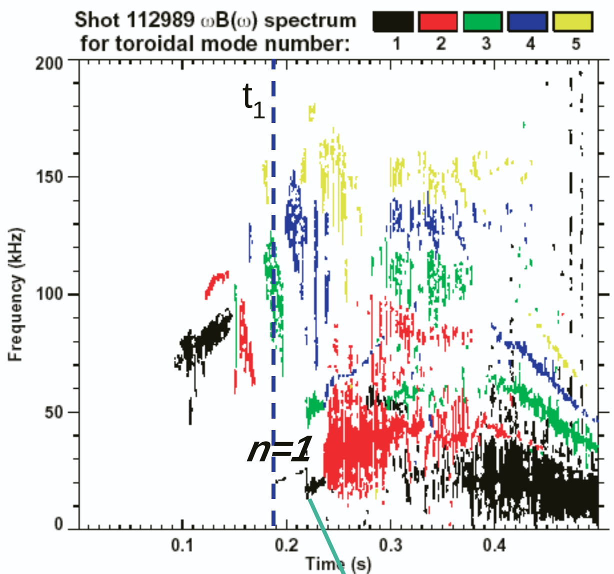
USXR shows no reconnections or MHD modes till t_1 and t_2

USXR profiles (E > 0.4 keV)

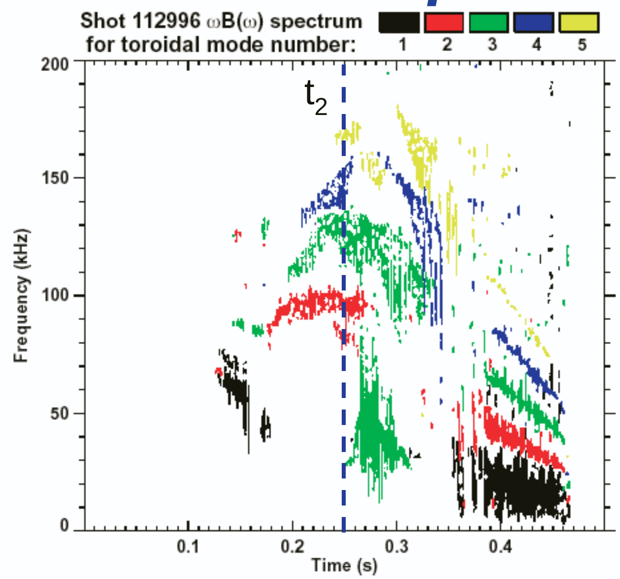


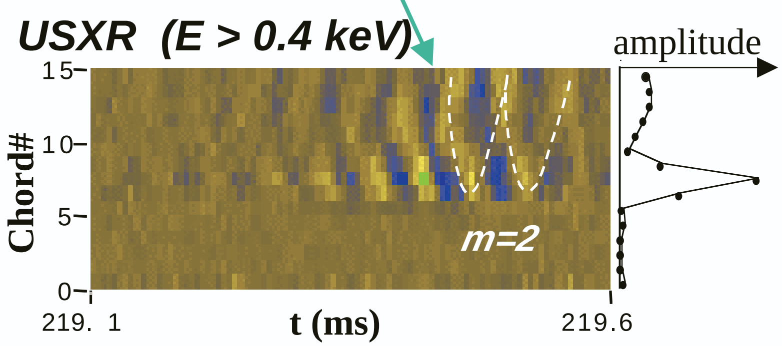
Magnetic data shows no low-n activity in either case

fast ramp



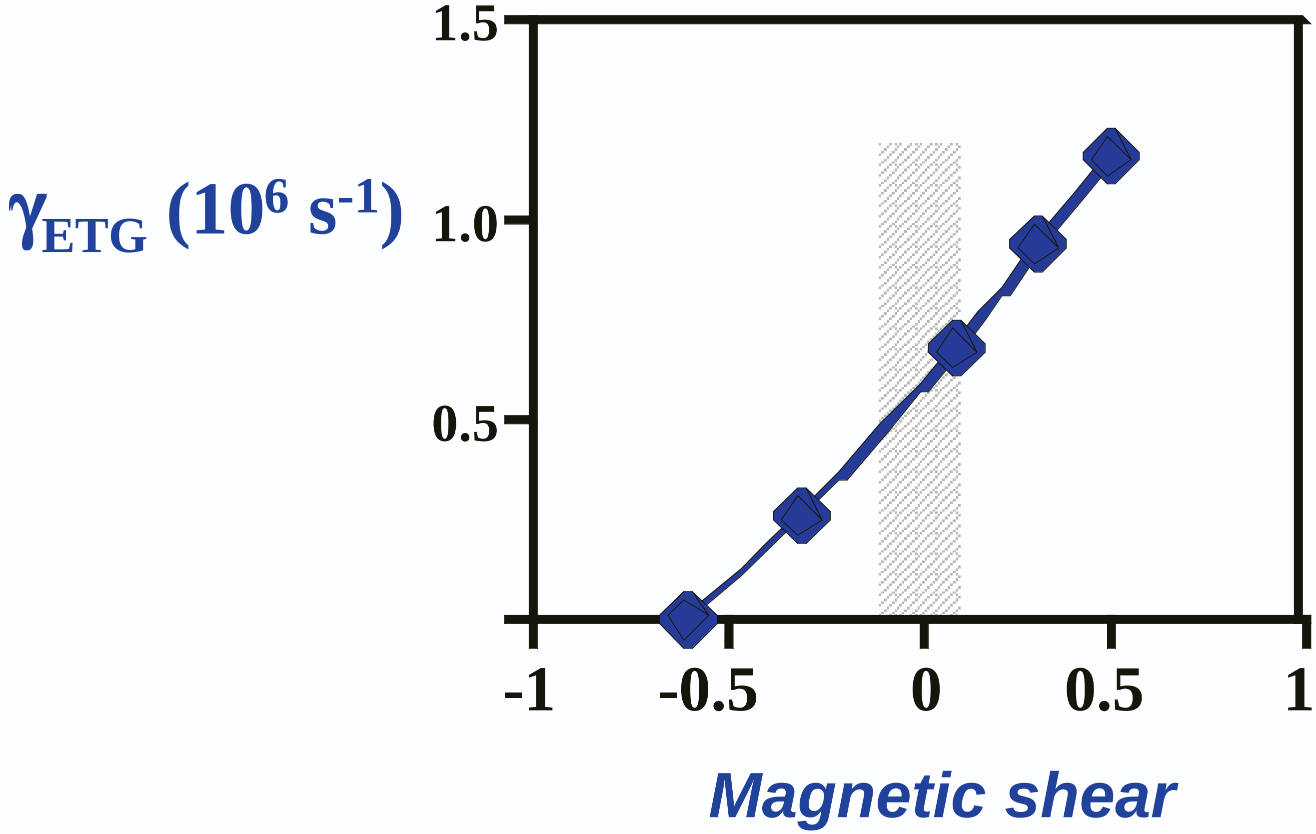
slow ramp





- *In fast ramp shot 112989 a ≈ 20 kHz, n=1 mode briefly appears and locks in the magnetic spectrum around t ≈ 0.22 s (likely causing the V_t 'plateau' below)*
- *USXR data indicates it is a 2/1 mode located in the core (r/a ≈ 0.4)*
- *Mode located around TRANSP predicted q=2 radius*

GS2 shear scan at experimental dT_e/dr



2 MW L-Mode

$\langle n_e \rangle \approx 2\ 10^{13}\ cm^{-3}$

('Slow ramp')