Comparison between measured and predicted turbulence frequency spectra in ITG and TEM regimes

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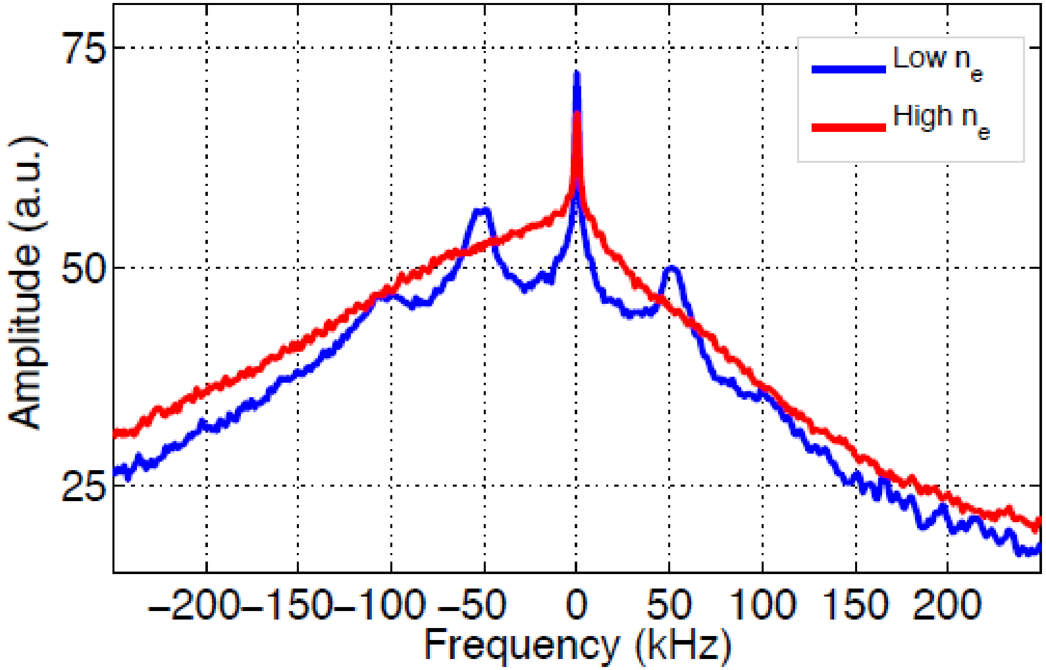
Reproduction of distinct reflectometry features in Tore-Supra discharge by GK modelling

Reflectometery spectrum, TS shot #48102 at r/a~0.15-0.2



Ohmic discharges with current (density) ramp and distinct phases

SOC – broad spectrum

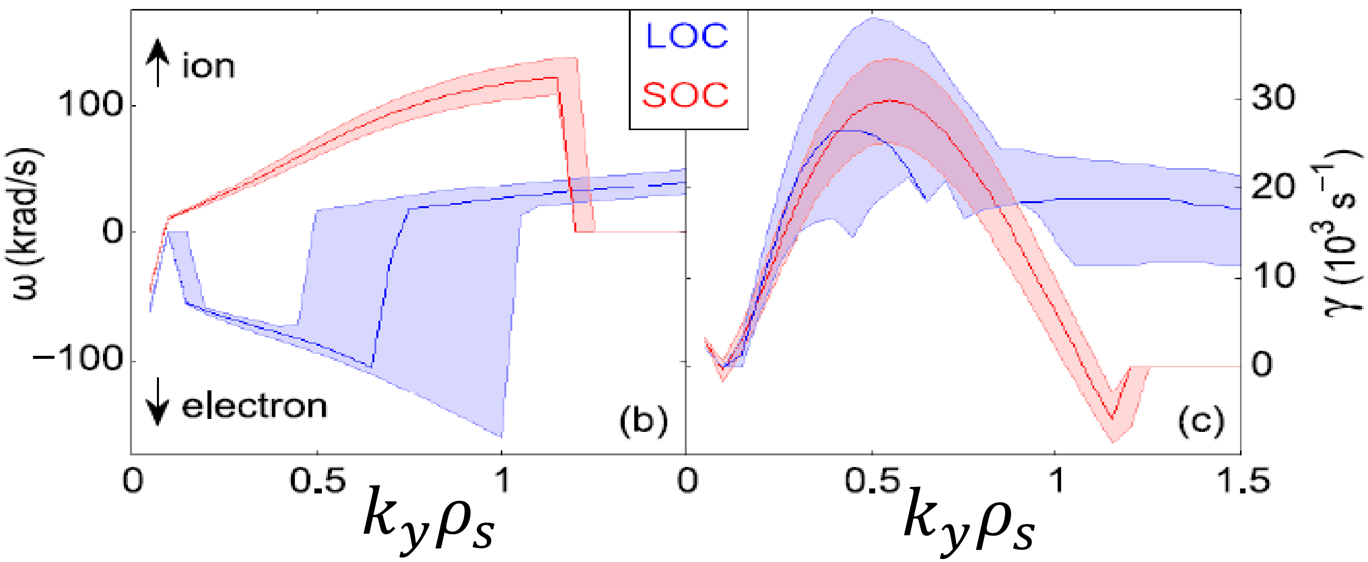
LOC – "quasicoherent" modes

- 'Quasicoherent modes' observed in LOC phase of a LOC-SOC transition Tore-Supra discharge. Similar observations in many machines and regimes [H. Arnichand, et al., NF Lett 2014, NF 2015, PPCF 2016]
- Can nonlinear gyrokinetic simulations shed light on source of feature?
- This work was in support of Hugo Arnichand PhD (CEA Cadarache)

Linear gyrokinetics shows ITG in SOC phase, and TEM in LOC phase

Linear-GENE input (from a CRONOS interpretative simulation).
Studied at $\rho = 0.37$ due to poor T_i diagnostics in inner core.

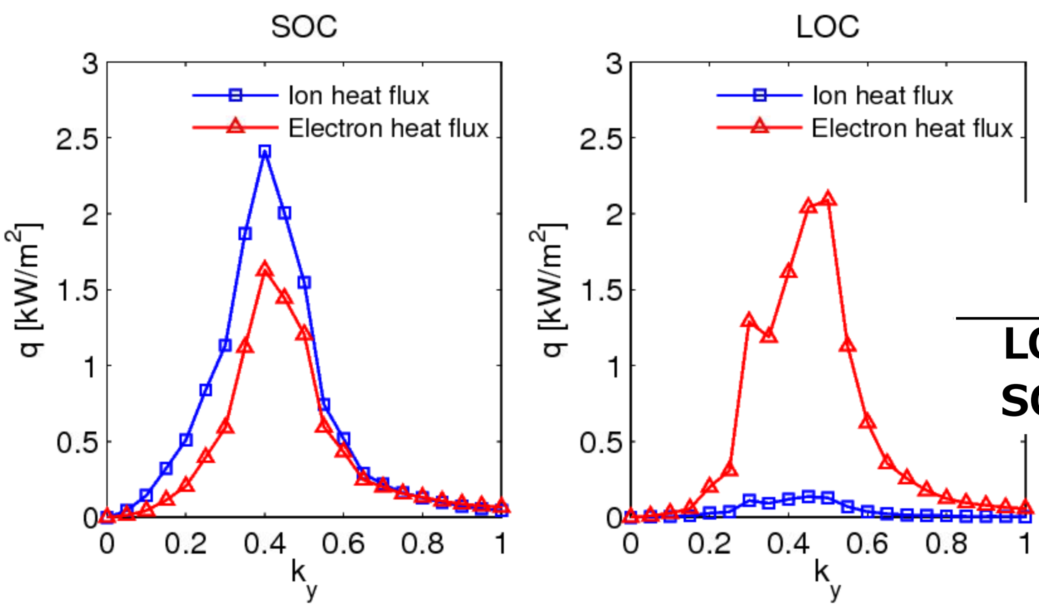
Phase	R/L_{Ti}	R/L_{Te}	R/L_{ne}	T_e/T_i	β_e [%]	$\hat{s}$	q	ν^*	Z_{eff}
LOC (t=3.8-3.4 s)	4.7±0.5	9.2±0.35	2.8±0.1	1.8±0.1	0.13	0.7	1.3	0.012	3.0±0.1
SOC (t=5.8-6.4 s)	5.0±0.4	8.9±0.25	1.8±0.1	1.6±0.1	0.14	0.75	1.25	0.029	1.4±0.1



Uncertainties in linear results from propagation of logarithmic gradient uncertainties

- LOC→SOC transition here associated with TEM→ITG transition
- Lower Z_{eff} and lower R/Ln more responsible for TEM→ITG transition than increase in ν^*
- LOC regime ion mode at higher ky is a carbon-ITG. Stabilized with a 30% reduction in R/L_{TC}

Nonlinear GENE simulations of each case: flux spectra and power balance matching



Comparison of simulated and exp fluxes.
All values in kW/m^2

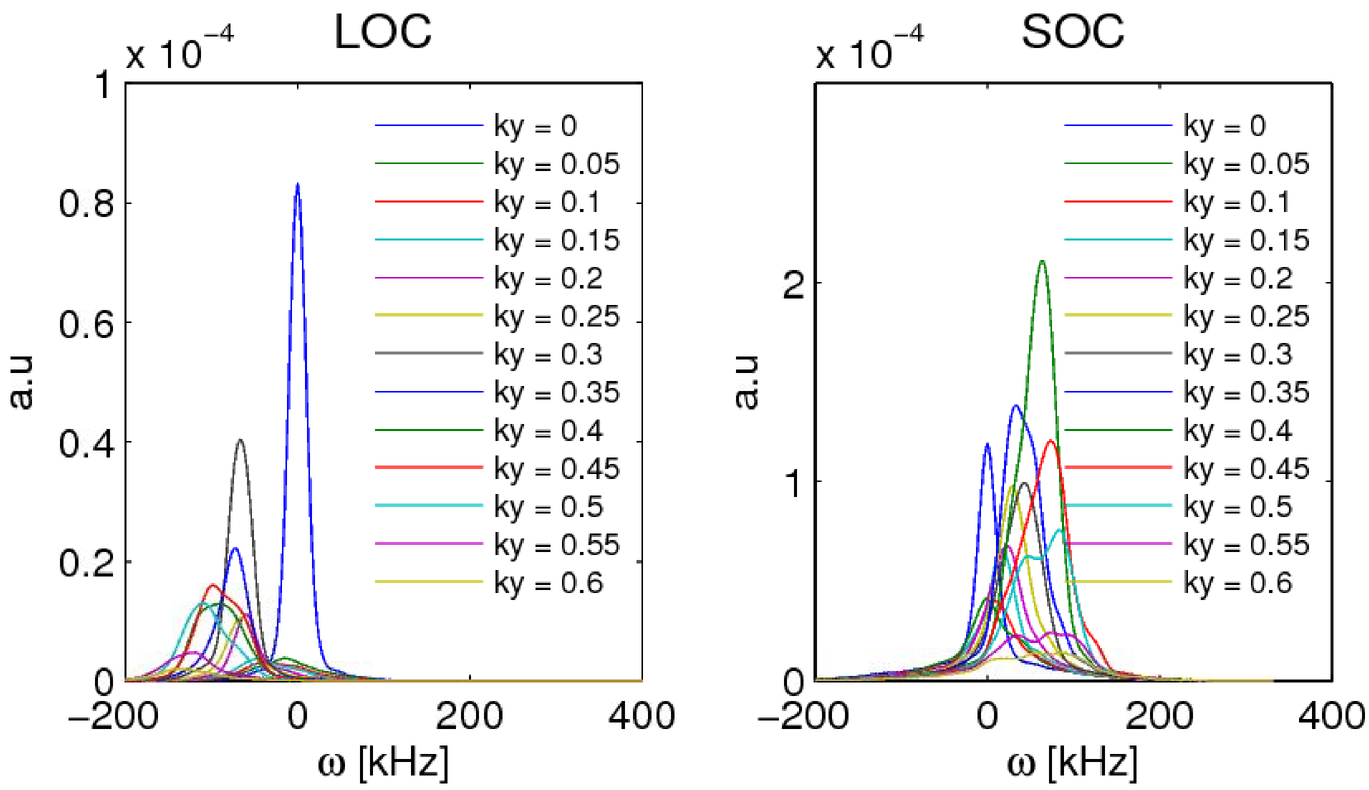
	Power balance		GENE	
	q_i	q_e	q_i	q_e
LOC	4.5 ± 1	6.7 ± 1	1 ± 1	12 ± 3
SOC	14 ± 3	-1 ± 3	14 ± 2	9 ± 2

- Power balance uncertainties from propagation of T_i and T_e errors in collisional heat transfer
- GENE error bars underpredicted since they don't include propagation of input parameter statistical and systematic errors (see Ian's talk tomorrow)
- From additional simulations with sensitivity studies, easy to get power balance agreement for all cases apart from apart from SOC q_e. Systematic experimental Ti error?

Correspondence deemed close enough to justify qualitative comparison of spectra

Nonlinear simulations show sharper drift-wave TEM peaks compared to ITG

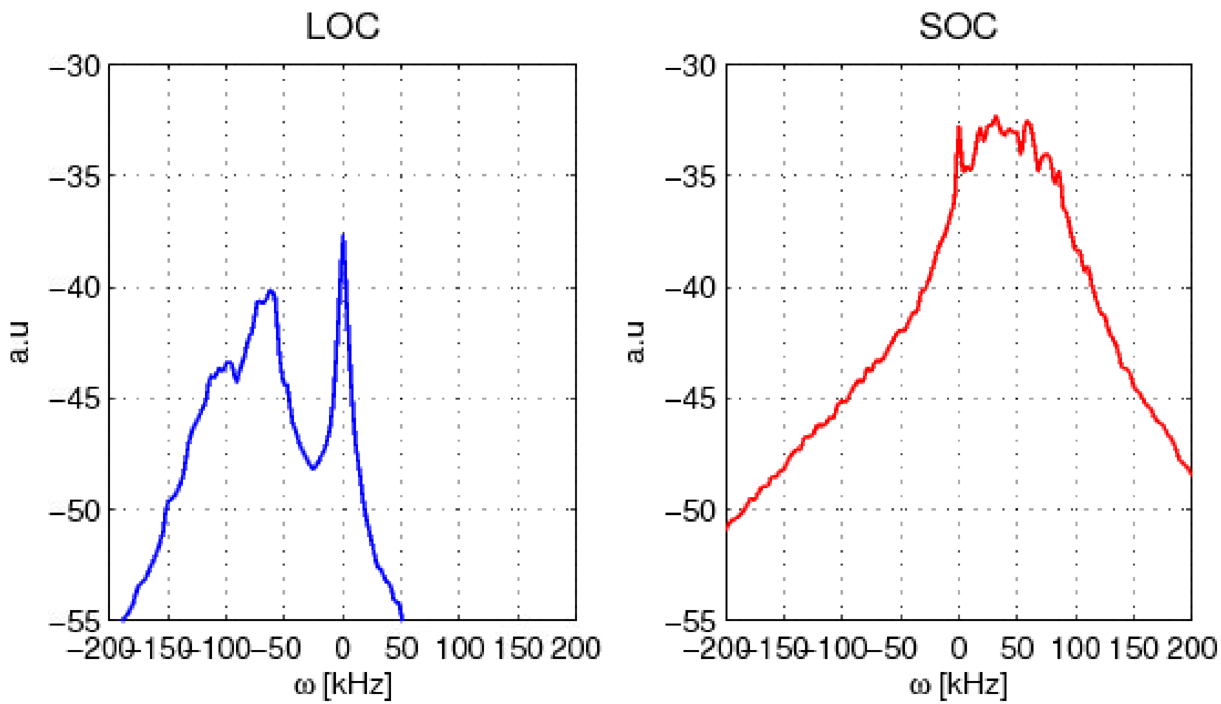
Comparison of kx-averaged frequency spectrum per toroidal wavenumber



- Difference in broadening and nonlinear spectrum has major ramifications
- LOC narrow broadening and “condensation” to fewer drift waves leads to emergence of TEM modes in nonlinear spectrum
- SOC modes all overlap and smear out the frequency spectrum

Summed frequency spectrum shows gap for TEM (LOC) spectrum compared to ITG (SOC)

Summed frequency spectra (logy scale, as in diagnostic)



Summed spectra qualitatively show same characteristics as the reflectometry measurements – a separated peak in drift-wave frequencies for TEM (LOC) vs broad band for ITG (SOC)

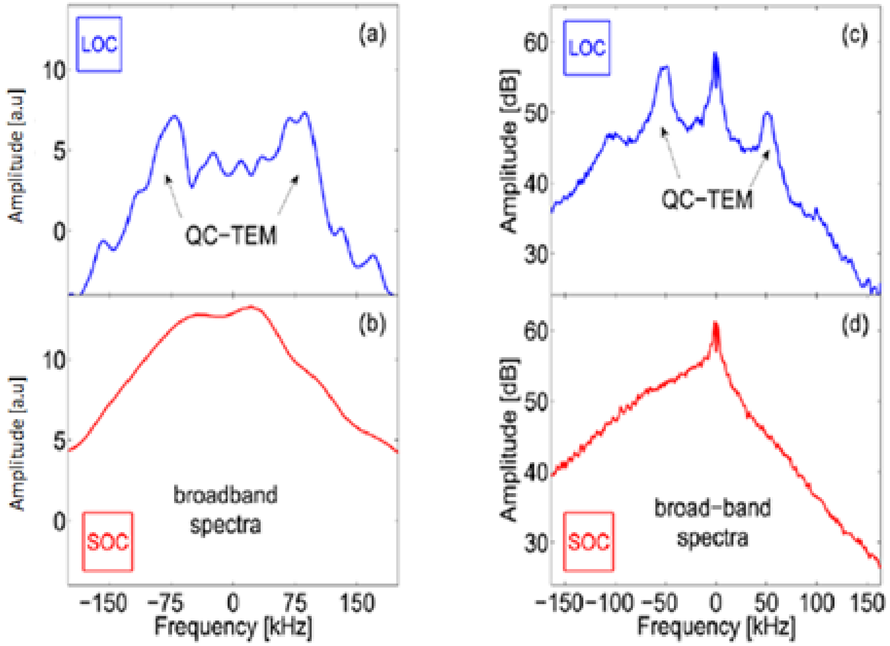
Note: reflectometry will not observe the $\omega = 0$ peak

Experimental QCM feature recovered with synthetic reflectometry diagnostic

GENE fluctuations used in synthetic reflectometry diagnostic (S. Hacquin submitted to PPCF). Quantitatively recovers measured spectrum

$V = V_{phase} + V_{ExB}$: ExB velocity estimated from E_r maintaining ambipolarity in ripple dominated regime [Trier NF 2008]

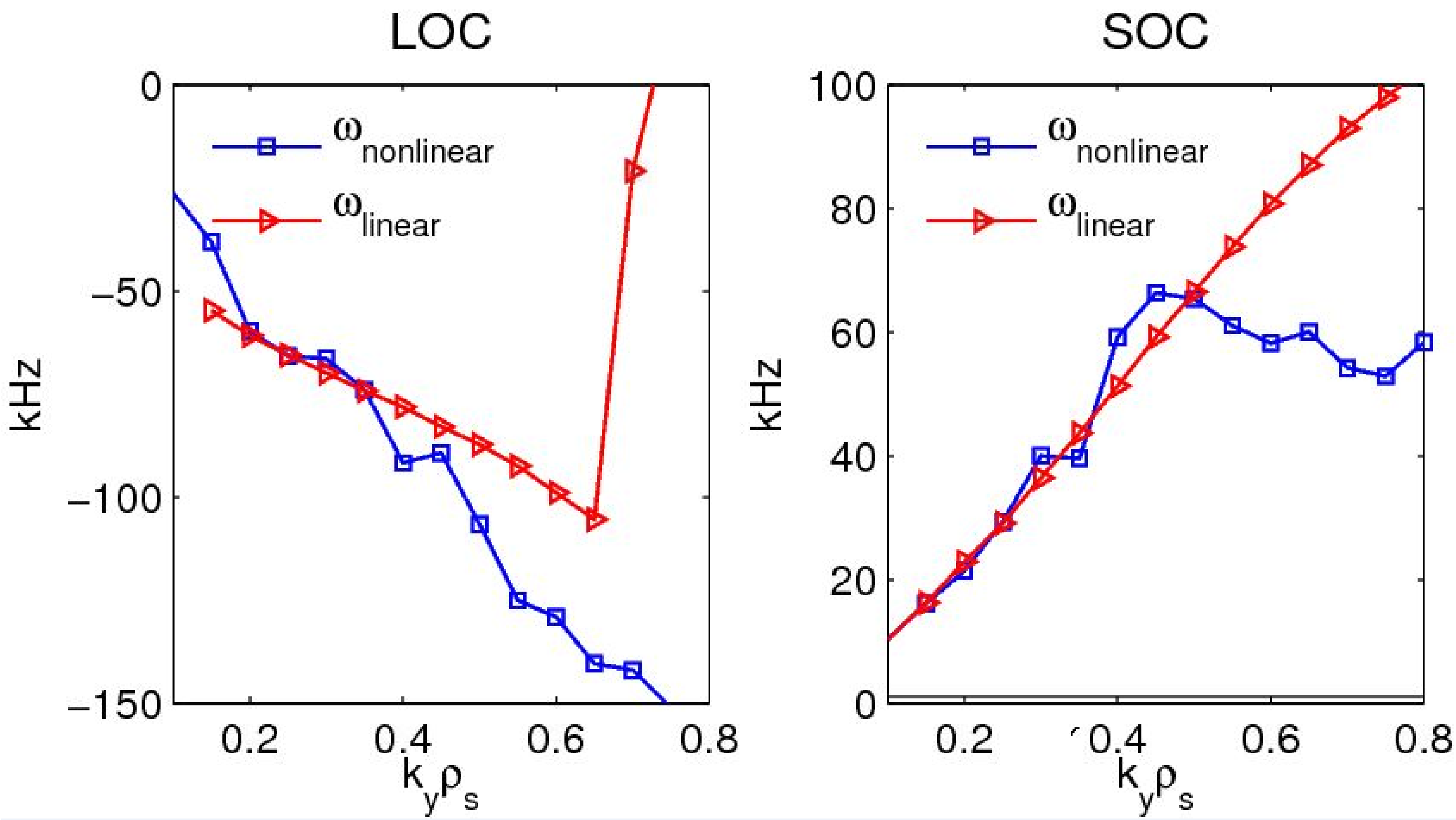
SYNTHETIC REFLECTOMETER (a-b) at r/a≈0.37 and REFLECTOMETRY MEASUREMENTS (c-d) at r/a≈0.18



S. Hacquin et al., submitted to Plasma Phys. Control. Fusion

Adds to fundamental validation of underlying turbulence model

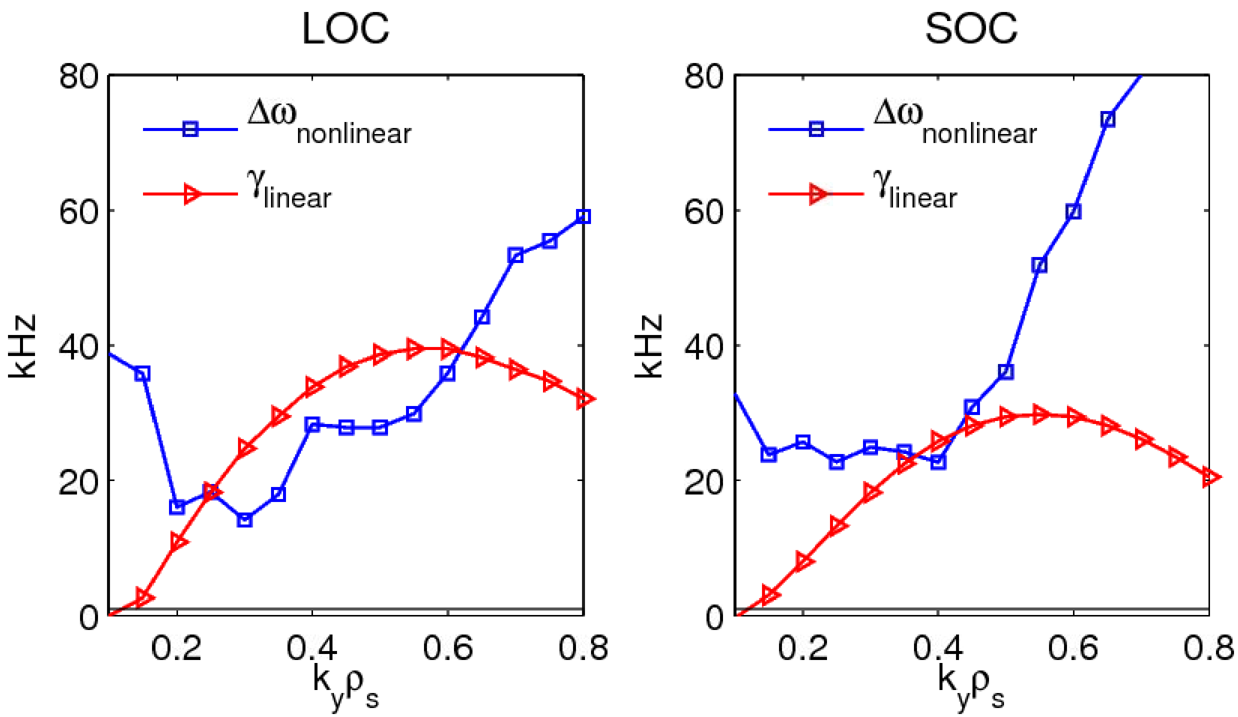
Comparison of linear and nonlinear frequency spectra



ω_{nl} comparable to ω_{lin} where linear drive is strong

Comparison of linear and nonlinear frequency spectra

Nonlinear frequency spectra
at each individual spatial scale



- $\Delta\omega_{nl}$ comparable to γ_{lin} where linear drive is strong: validates quasilinear assumptions
- LOC nonlinear broadening less than SOC
- Speculation: related to nonlinear saturation mechanisms?
  $\eta_e > 1$ TEM saturation mechanism not related to ZF (Merz, Jenko PRL 2008)

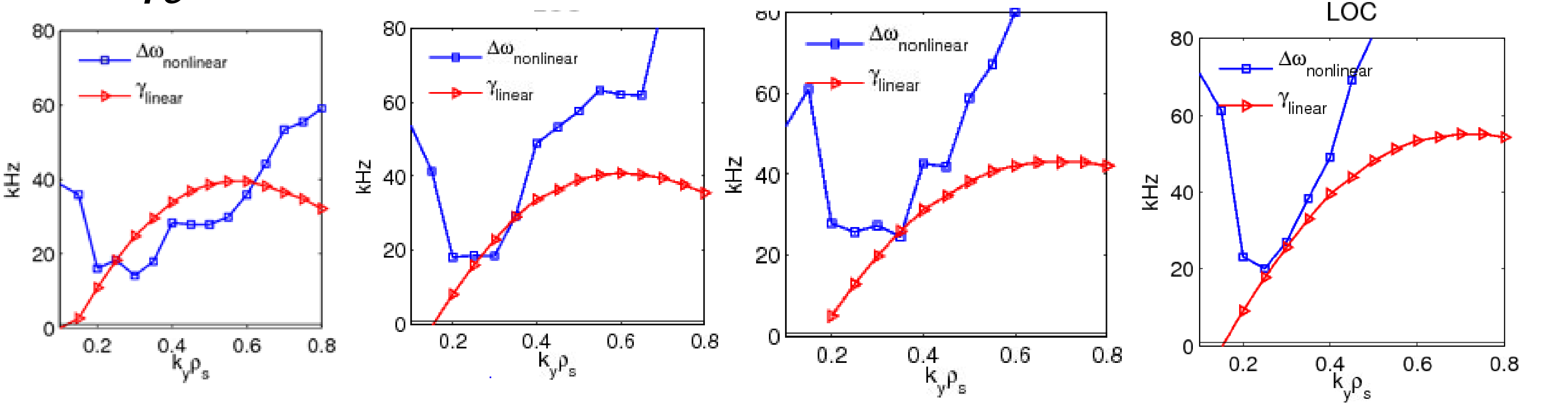
TEM frequency broadening converges to similar behaviour as ITG for $\eta_e < 1$

η_e (L_{ne}/L_{Te}) scan. (Nominal η_e was 3.3)

Motivation: TEM saturation physics depends on η_e. For $\eta_e > 1$ does not depend of ZF coupling (Merz, Jenko, Ernst)

Frequency broadening comparison

η_e=3.3 η_e=1.6 η_e=1 η_e=0.3



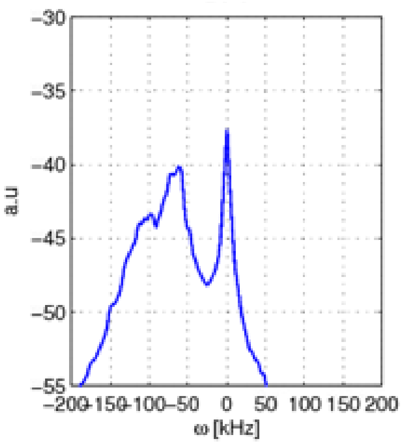
Trend for increased frequency broadening as $\eta_e \leq 1$

Note: R/Lte and R/Lne parameters were tweaked (while maintaining each η_e) such that all cases have similar fluxes agreeing with q_e power balance (within 20%)

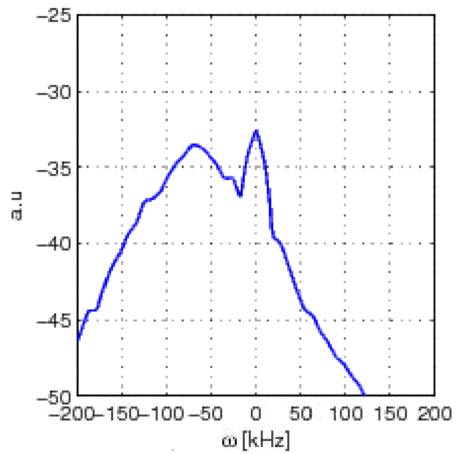
Quasicoherent mode signature predicted to reduce as $\eta_e < 1$

Summed frequency spectra comparison

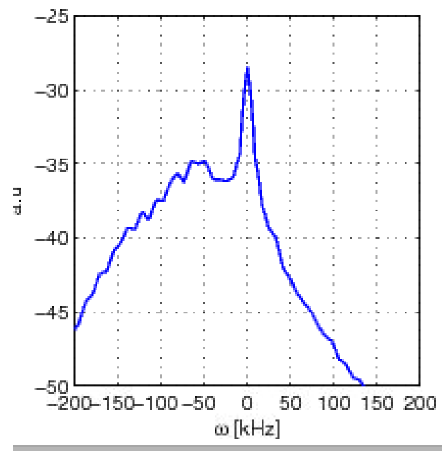
η_e=3.3



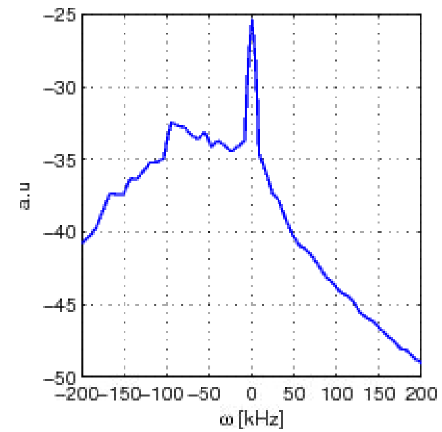
η_e=1.6



η_e=1



η_e=0.3



Drift-wave gap is filled in at lower η_e.

Prediction that quasicoherent modes should disappear for density gradient dominated TEM regime?

Nonlinear simulations show narrower frequency broadening of TEM modes

- "quasi-coherent" modes measured in LOC phase and disappear in SOC phase, in multiple regimes. We have focused on one Tore-Supra example. Linear GENE simulations relate LOC→SOC to TEM→ITG

- Non-linear simulations show that TEM nonlinear frequency broadening is narrower than the ITG case

- TEM frequency spectra thus shows a distinct peak in the drift-wave frequencies. ITG is broadband.

- Synthetic diagnostic shows quantitative agreement with experiment

- Open question: reduced TEM nonlinear frequency broadening related to different nonlinear saturation mechanism? Effect seems to be reduced when $\eta_e < 1$ (similar saturation mechanism to ITG)

- QC-modes an experimental signature of $\eta_e > 1$ TEM?