Microstability analysis of pellet fuelled discharges in MAST

L. Garzotti

D. Dunai, A. Field, J. Figueiredo,
Y.-c. Ghim, G. Naylor, C. Roach,
M. Romanelli, R. Scannell, G. Szepesi, M. Valovič

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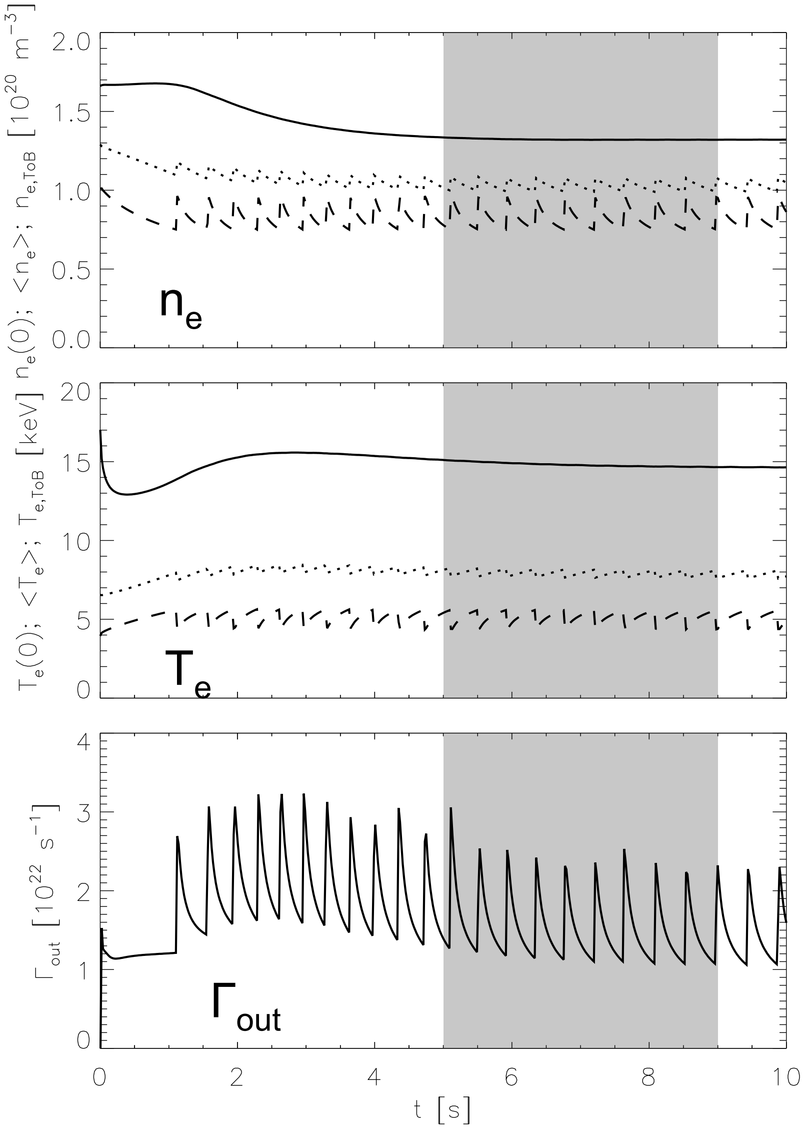
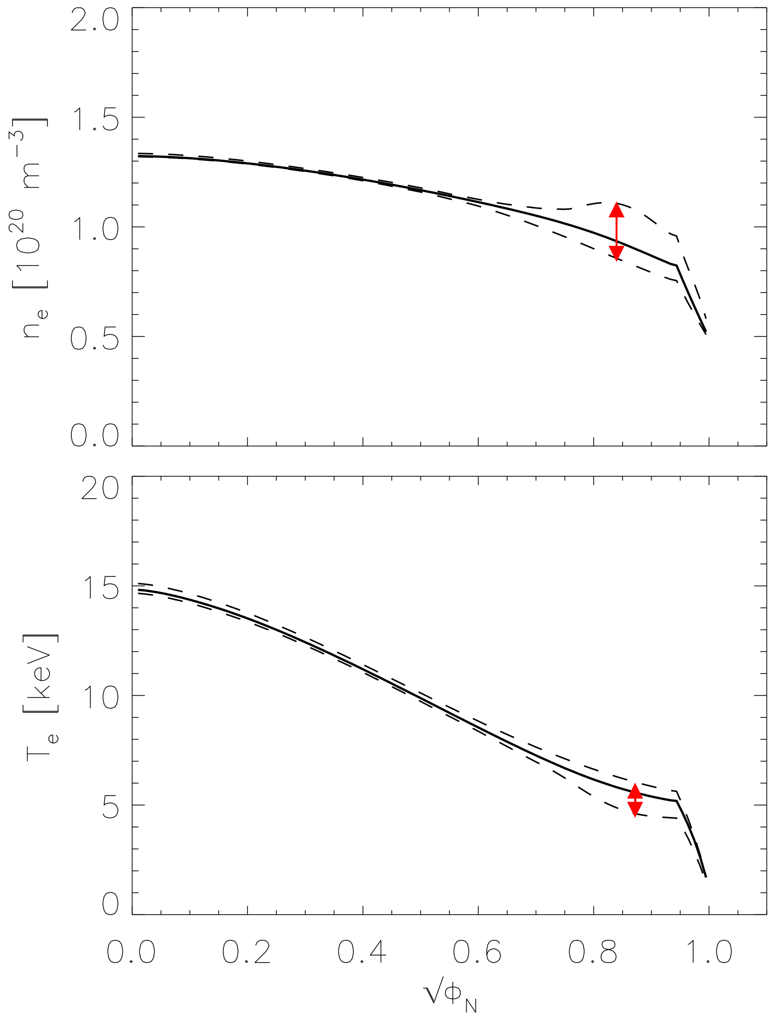
Introduction

- Reactor grade plasmas are likely to be fuelled by pellet injection.
- Steady-state fuelling scenario (e. g. gas puff): density and temperature profiles are stationary.
- Pellet fuelling: profiles undergo a periodic perturbation, (density becomes hollow, temperature gradient changes) before relaxing towards the pre-pellet profile.
- It is interesting to investigate the microstability of a pellet fuelled plasma to understand what confinement properties should be expected.
- Take advantage of diagnostic and modelling capabilities available on MAST to perform microstability analysis of H-mode, pellet fuelled, MAST plasmas.
- To our knowledge one of the first attempts to analyse the microstability of the transient following pellet injection using realistic (measured) profiles. Results very preliminary.

Example: ITER baseline scenario





JETTO simulation

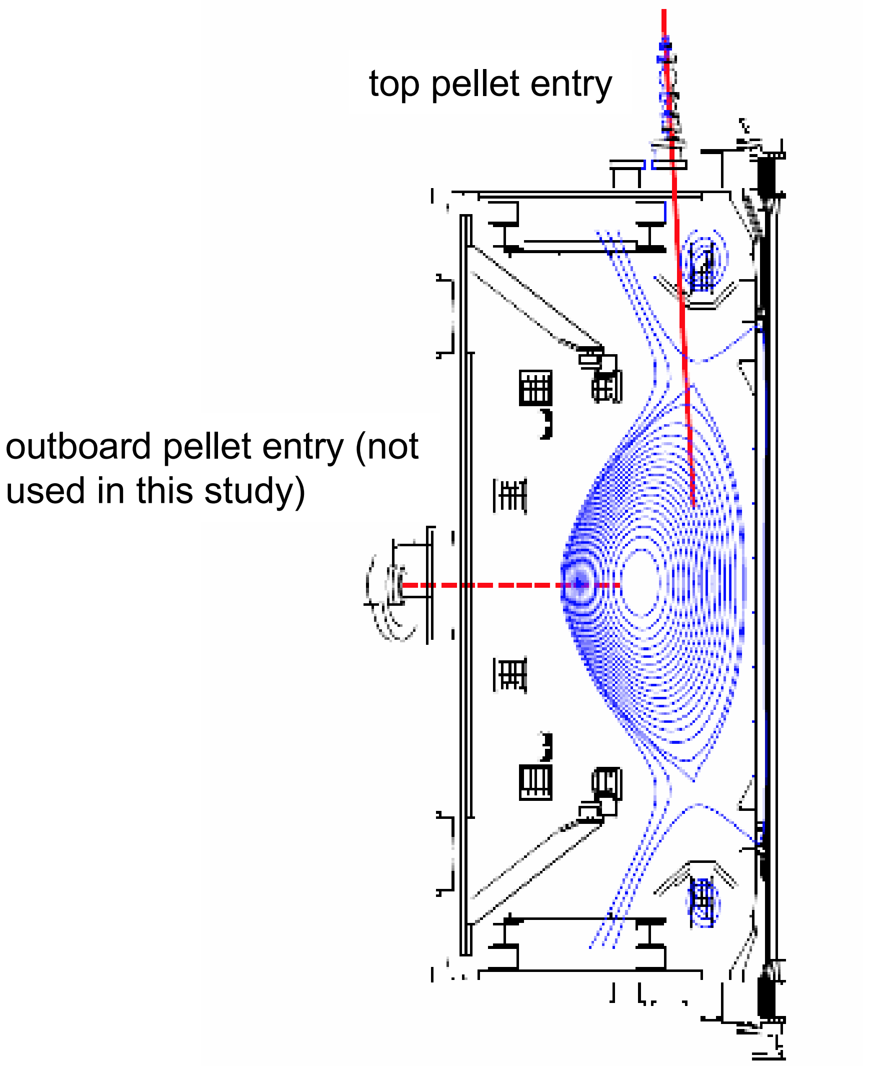
Garzotti et al., submitted to Nucl. Fusion

Overview

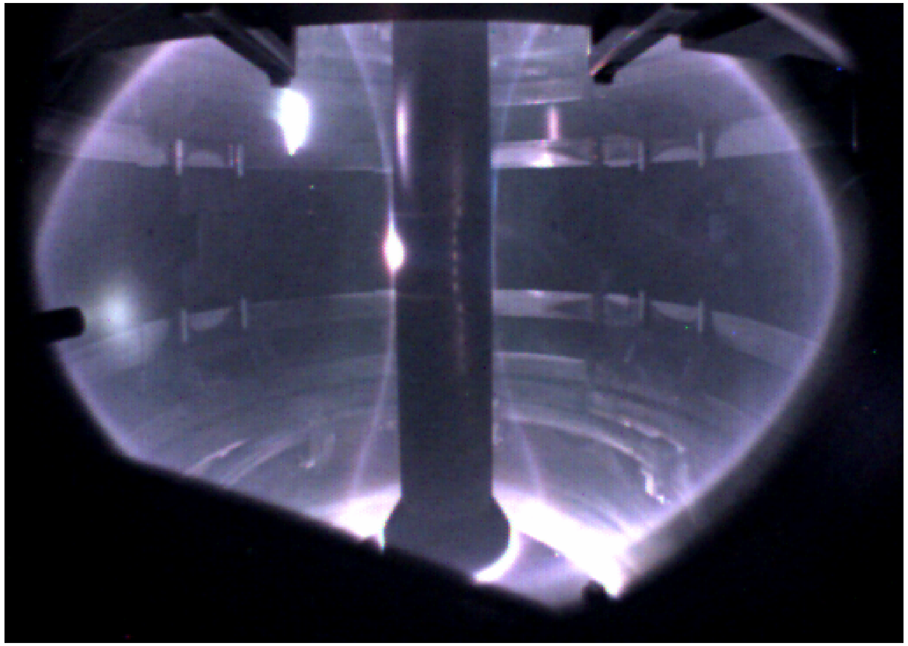
- Describe MAST pellet injector setup.
- Show Thomson scattering measurements synchronised with pellet injection.
- Describe GS2, GKW gyrokinetic stability analysis.
- Briefly mention the capabilities of the new beam emission spectroscopy (BES) diagnostic.
- Conclusions and final thoughts

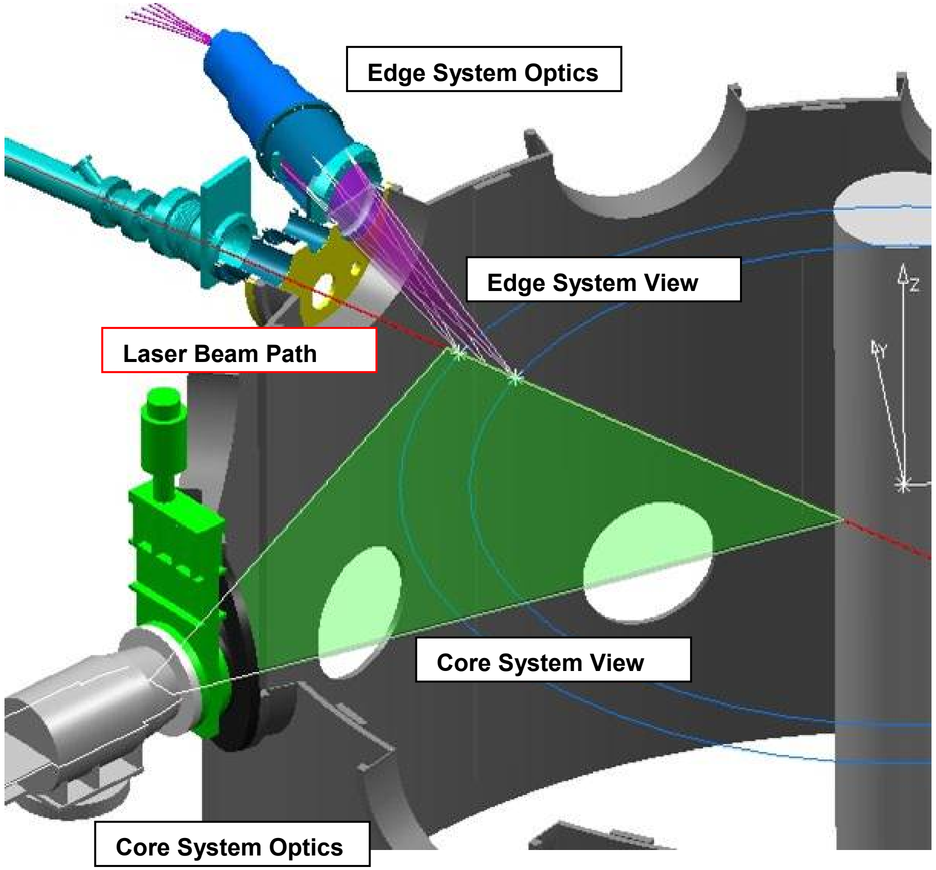
MAST pellet injection system

- On MAST deuterium pellets are injected vertically from the top of the machine into the high field side of the plasma.
  - Typical pellet speeds are between 250 and 400 m/s.
  - Nominal pellet masses are 0.6, 1.2 and 2.4 10^{20} atoms.
- Typical MAST target plasmas:
  - I_p=0.66-0.76 MA,
  - B=0.47-0.50 T,
  - $\langle n_e \rangle = 1.6\text{-}7.5 \cdot 10^{19}$ m^{-3},
  - T_{e0}=0.7-1.2 keV,
  - H-mode plasmas NBI heated (P_{NBI}=1.1-3.0 MW with neutral beams with energy 65-67 keV).
- ITER-like geometry (divertor and long launch track) but pellet too big.



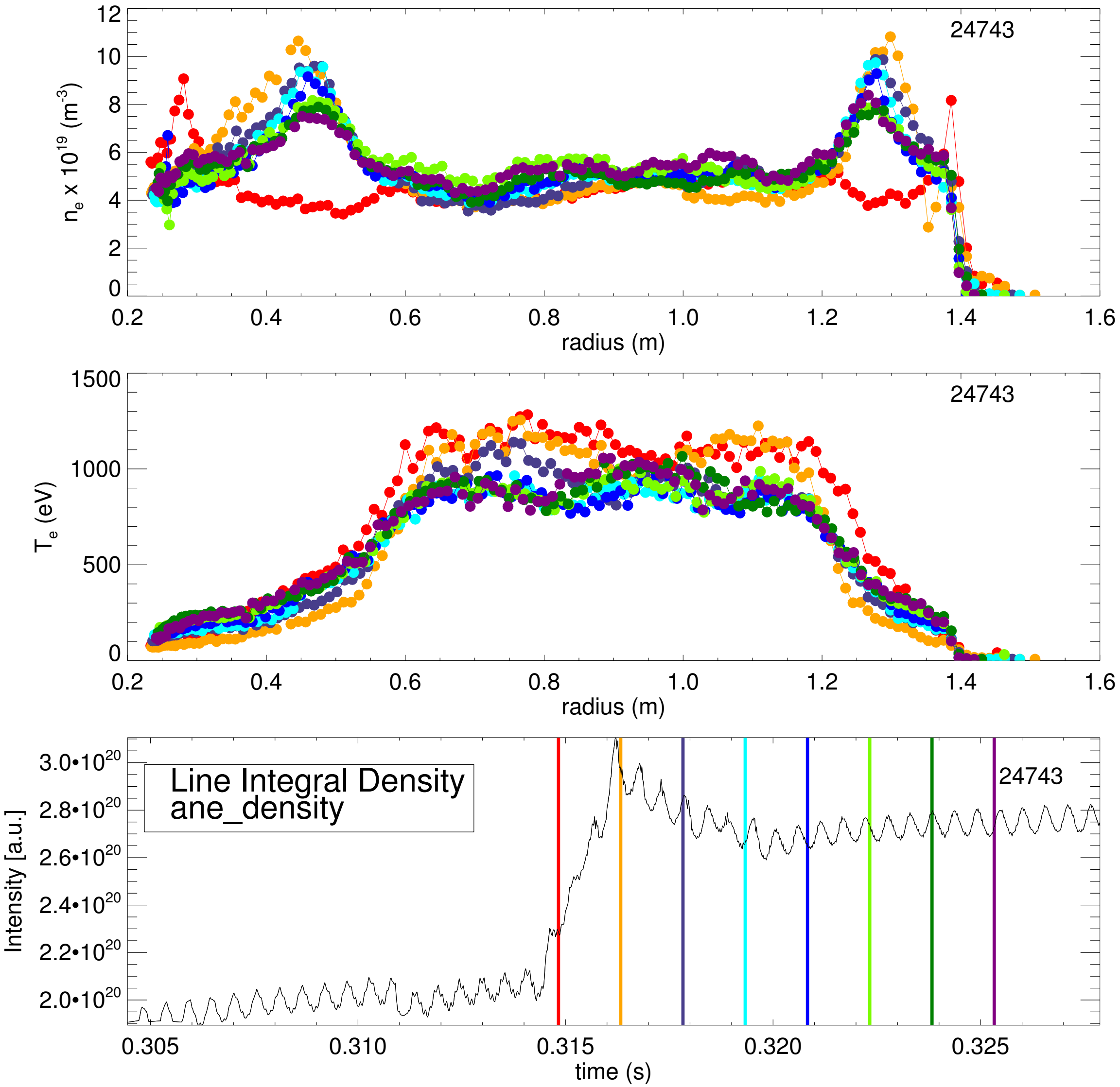
MAST TS Diagnostic





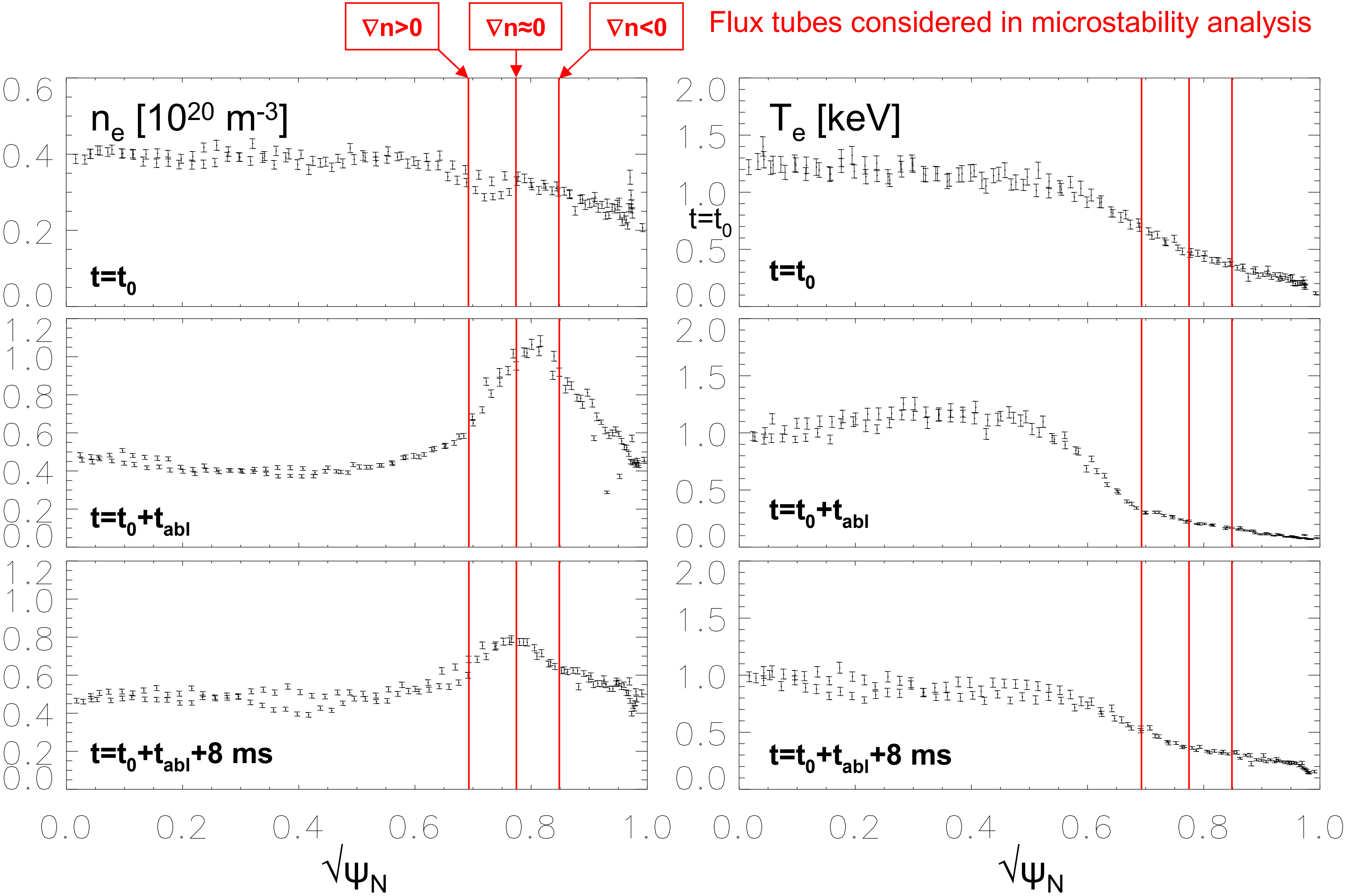
- High spatial resolution – 130 independent spatial points
- Eight Nd:YAG lasers used in burst mode provide profiles with arbitrary time resolution (bursts repeated every ~33ms).
- Bursts can be triggered when the pellet enters the plasma.

Thomson scattering measurements



Analysed profiles

Flux tubes considered in microstability analysis



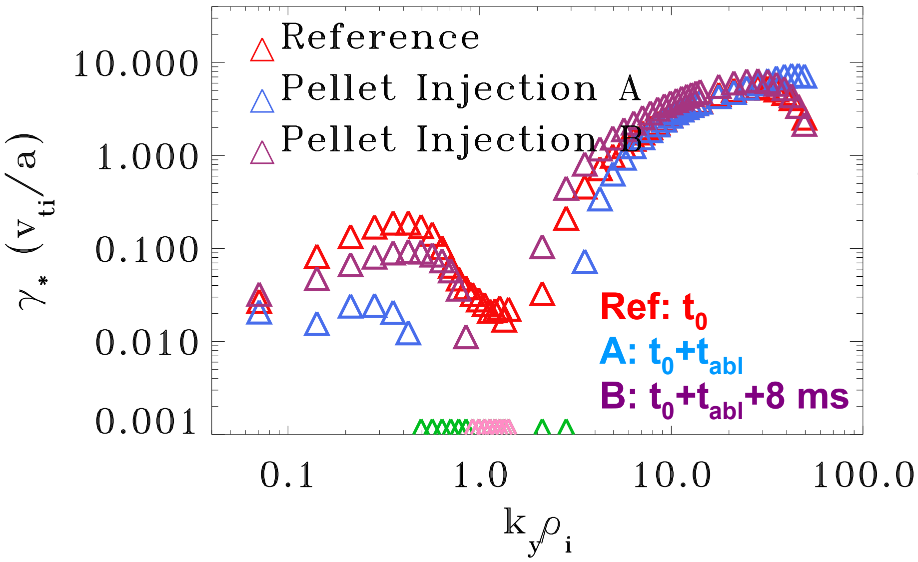
GS2 description

- GS2 code (US) solves linear/nonlinear GK equations in toroidal plasmas for arbitrary number of plasma species:
  - *Advanced physics*: includes full $\delta\mathbf{B}$.
  - *Geometry:* reduced volume “flux tube” aligned to follow equilibrium B field.
  - *Flux-tube:* handles general toroidal tokamak equilibrium geometry.
  - *Collisions:* energy and pitch angle scattering operator, only pitch angle scattering used here.
- Runs for pellet study:
  - Five species (electrons, D ions, H ions, fast D ions, C ions).
  - Linear, electromagnetic runs.
  - Equilibrium provided by TRANSP run.

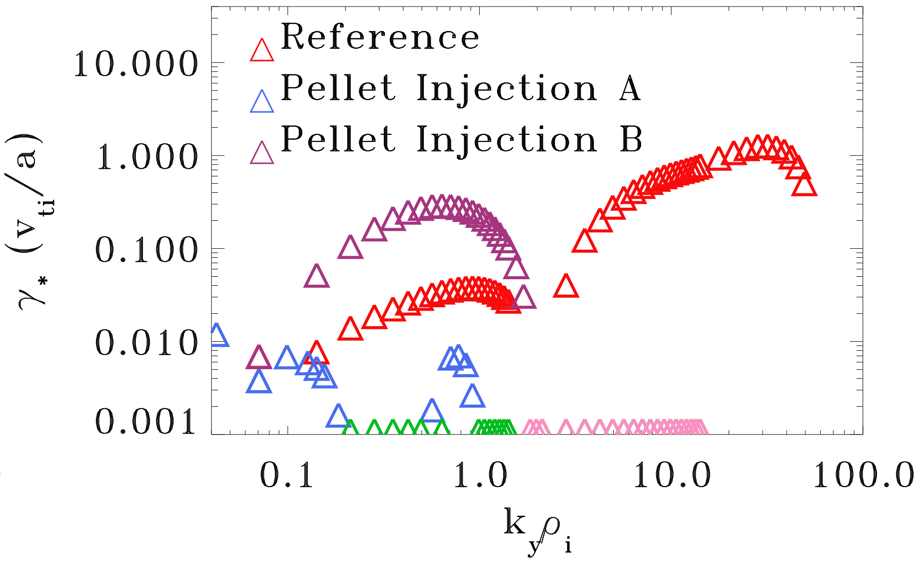
M. Kotschenreuther, G. Rewoldt, and W.M. Tang, Comp. Phys. Comm. 88, 128 (1995).
W. Dorland, F. Jenko, M. Kotschenreuther, and B.N. Rogers, Phys. Rev. Lett. 85, 5579 (2000).

GS2 results

$\sqrt{\psi_N} = 0.77$ ($\nabla n \approx 0$)



$\psi_N = \sqrt{0.85}$ ($\nabla n<0$)



- All k_ys are and remain stable for $\psi_N = \sqrt{0.69}$ ($\nabla n>0$).
- For $\psi_N = \sqrt{0.77}$ ($\nabla n \approx 0$), initial stabilisation of modes with $0.5<k_y\rho_i<2$.
- For $\psi_N = \sqrt{0.85}$ ($\nabla n<0$), initial stabilisation of modes with $0.2<k_y\rho_i<2$, subsequently:
  - modes with $k_y\rho_i<2$ are destabilised again with growth rates greater with respect to the reference profile,
  - modes with $k_y\rho_i>2$ remain stable.

GS2 tentative interpretation

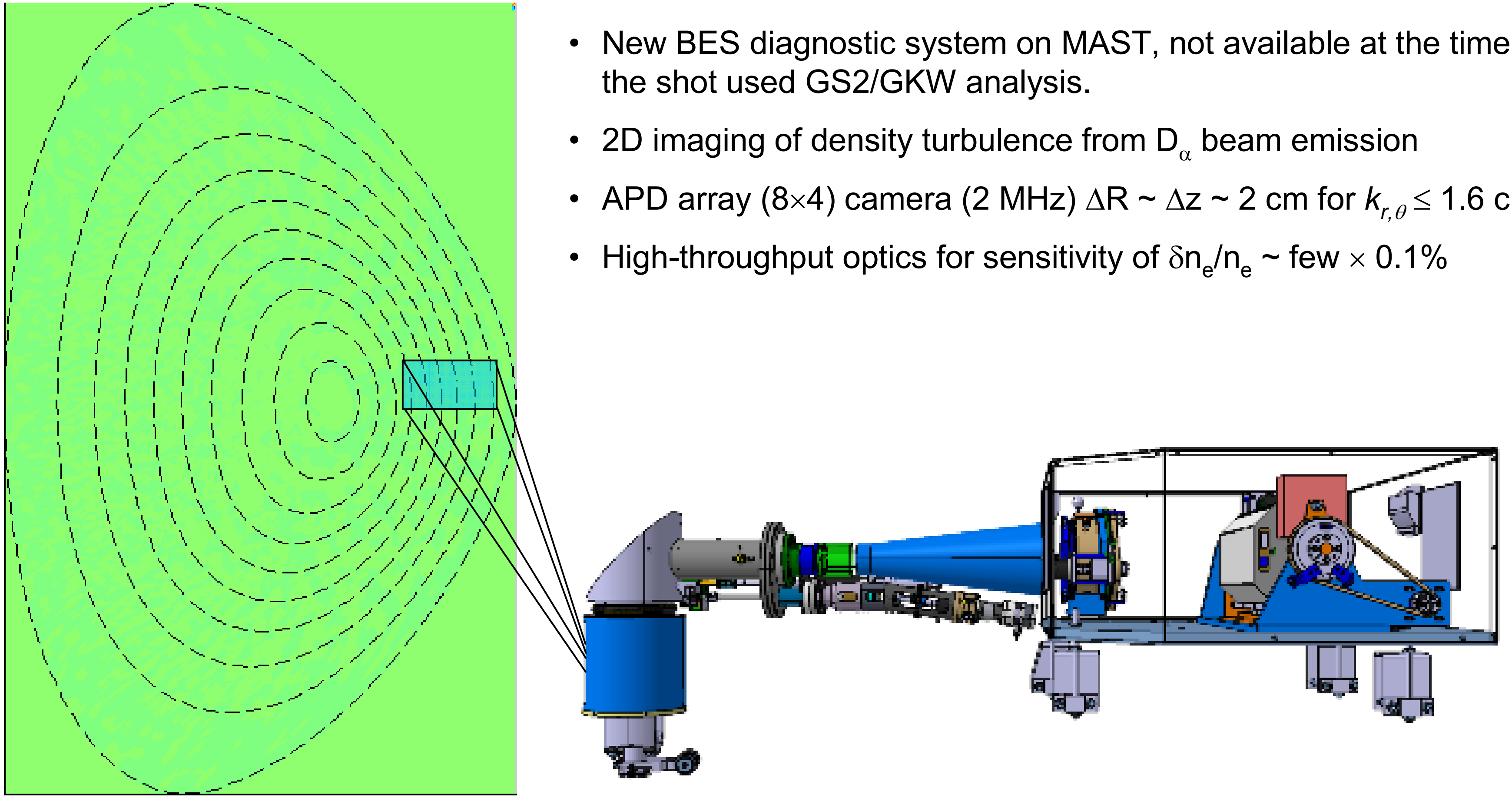
- Initial attempts to interpret GS2 results suggest that there is a competing effect between collisionality and gradients.
- Initial stabilisation is attributed to increased ν_e (lower T_e due to pellet cooling and higher density due to pellet fuelling).
  [Roach et al 2009 Plasma Phys. Control. Fusion 51 124020 doi:10.1088/0741-3335/51/12/124020]
- Subsequent destabilisation thought to be due to decreasing collisionality (T_e recovers) in presence of strong density gradients.
- The post pellet dynamics is different at different locations and further analysis is necessary to validate the points above and to clarify the dynamics of the pellet transient.
- The GKW gyrokinetic code was deployed to reproduce and corroborate these results.

GKW analysis

- GKW (EU): Local, flux tube, delta-f, initial value gyrokinetic code
  - *Physics*: fully electromagnetic (magnetic flutter and compression), sheared ExB flow (similar to GS2).
  - *Collisions:* Fokker-Planck collision operator with pitch angle scattering, energy scattering and friction terms (details of implementation differ from GS2).
  - *Geometry:* field aligned Hamada-coordinates, co-rotating reference frame, built-in circular and s-α equilibria (equilibria different from GS2).
- Runs for pellet studies
  - Microstability analysis as investigated with GS2.
  - Number of species reduced to three (deuterium, electron, carbon impurity), quasi-neutrality maintained by changing n_C.
  - Equilibrium calculated with CHEASE Grad-Shafranov solver [Lütjens et al., CPC 1996]
- So far GKW results are very different from GS2. Reasons for the discrepancy are under investigation.

A. Peeters *et al*, Computer Physics Communications 180 (2009) 2650–2672

MAST BES diagnostics

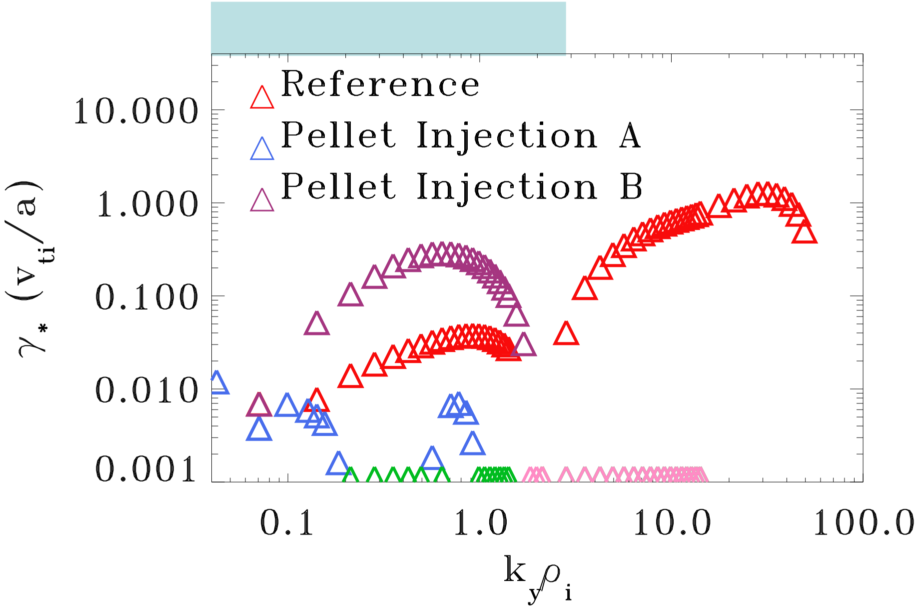


- New BES diagnostic system on MAST, not available at the time of the shot used GS2/GKW analysis.
- 2D imaging of density turbulence from D_α beam emission
- APD array (8×4) camera (2 MHz) $\Delta R \sim \Delta z \sim 2$ cm for $k_{r,\theta} \leq 1.6$ cm^{-1}
- High-throughput optics for sensitivity of $\delta n_e/n_e \sim$ few $\times$ 0.1%

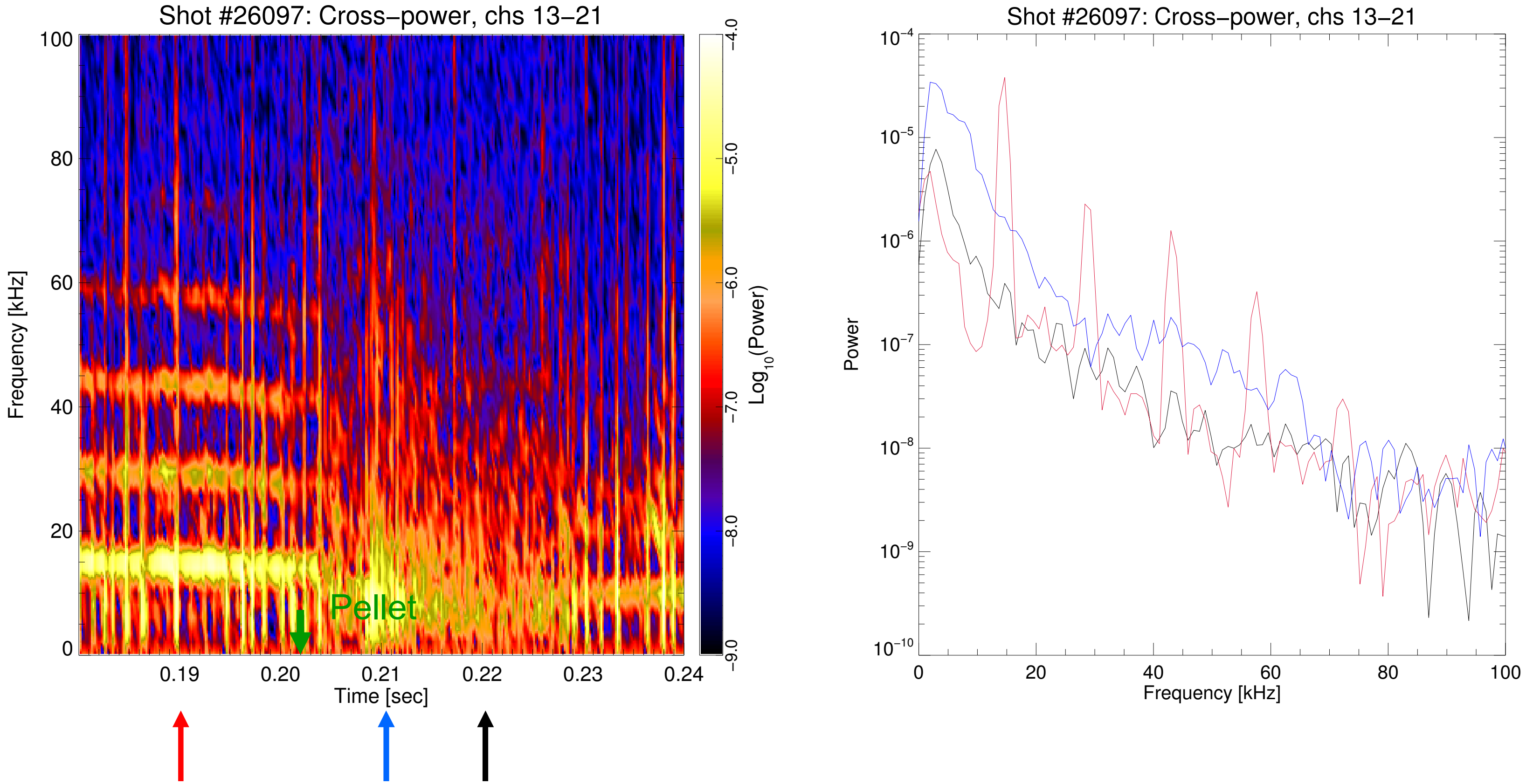
Future BES analysis

- Some data already collected in shots similar (but not identical) to the one analysed but interpretation complicated by presence of background MHD activity.
- More data are necessary.

Range of $k_y\rho_i$ measurable with MAST BES



BES data



- MHD activity present before pellet.
- Pellet induces temporary H-L transition.
- Difficult to compare directly with gyrokinetic simulations.
- Promising but more data needed.

Conclusions

- Detailed microstability analysis of pellet fuelled plasmas and associated transient on MAST (results are preliminary).
- State of the art diagnostics (Thomson scattering and BES) and gyrokinetic codes (GS2 and GKW) have been/are being/will be deployed in this study.
- Simulations suggest competition between time-dependent collisionality and gradients leading first to transient stabilisation of intermediate k modes and subsequently to destabilisation.
- GK simulations on analysed flux surfaces suggest:
  - competition between time-dependent collisionality and gradients leading to transient stabilisation and subsequent destabilisation at intermediate k on the surfaces at the peak deposition and outside.
  - microinstability asymmetric with respect to the pellet deposition peak (modes stable on chosen surface inside peak, and transient reduction of fluctuations outside the peak). Would slow penetration of pellet material towards plasma centre and preferential diffusion towards plasma edge (albeit at a lower rate with respect to steady state plasmas).
- BES data of pellet shot collected. Direct comparison with simulations not yet possible.

Final considerations/Future work

- Potentially interesting/relevant field (addresses the problem of pellet retention time) to which little effort has been devoted so far.
- Expand database on MAST.
- Perform stability studies in more detail (finer space resolution).
- Possibility to expand/pursue this kind of study (e. g. non linear gyrokinetics runs to infer fluxes).
- I would be interesting to extend the analysis on conventional tokamaks. Optimise diagnostic coverage for analysis/simulations of the transients.
- Create fuelling conditions as reactor relevant as possible (i.e. small, shallow pellets).