Recent JET Experiments on Alfvén Eigenmodes with Intermediate Toroidal Mode Numbers: Measurements and Modelling

D.Testa[1], N.Mellet[1,2], T.Panis[1], S.E.Sharapov[3], D.Spong[4], P.Blanchard[1,5], H.Carfantan[6], A.Fasoli[1], A.Goodyear[3], JET EFDA contributors*

JET-EFDA, Culham Science Centre, Abingdon, OX14 3DB, UK

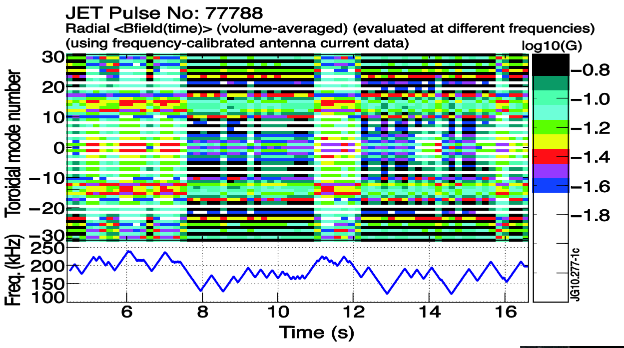
[1] Ecole Polytechnique Fédérale de Lausanne (EPFL), Centre de Recherches en Physique des Plasmas (CRPP), Association EURATOM – Confédération Suisse, Lausanne, CH
[2] Association Euratom – CEA, Cadarache, Saint-Paul-lez-Durance, FR
[3] Culham Centre for Fusion Energy, Culham Science Centre, Abingdon, UK
[4] Oak Ridge National Laboratory, Fusion Energy Theory Group, Oak Ridge, USA
[5] EFDA-CSU, Culham Science Centre, Abingdon, UK
[6] Laboratoire d'Astrophysique de Toulouse – Tarbes, Université de Toulouse – CNRS, FR
[*See Appendix of F. Romanelli, 23rd IAEA Fusion Energy Conference, paper OV1/3, this conference]

ABSTRACT

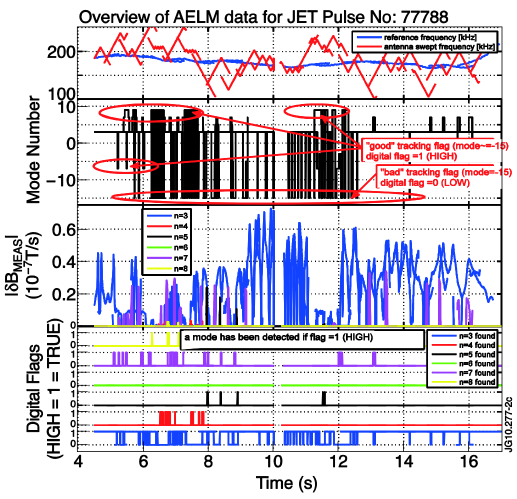
- reporting recent experiments performed on the JET tokamak on Alfvén Eigenmodes (AEs) with toroidal mode number (n) in the range |n|<15
- development of a new algorithm for mode detection and discrimination using the **Sparse Signal Representation** theory and the **SparSpec** code: the speed and accuracy of this algorithm has made it possible to deploy it in our plant control software, allowing real-time tracking of individual modes during the evolution of the plasma background on a 1ms time scale
- first quantitative analysis of the measurements of the damping rate (γ/ω) for stable n=3 and n=7 Toroidal AEs (TAEs) as function of the edge plasma elongation (κ_{95})
- initial theoretical analysis of these data performed with the LEMan, CASTOR and TAEFL codes
- measurement of the effective plasma isotope ratio A_{EFF} during gas change-over experiments
- poster and (proceedings) paper available on: http://crpp.epfl.ch/iaea2010/

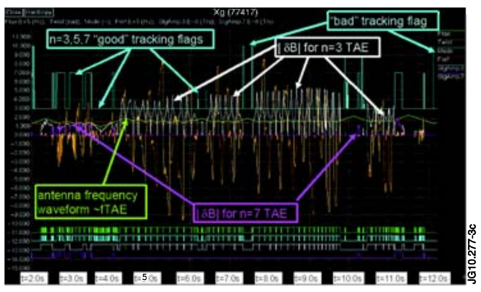
THE NEW JET ALFVEN EIGENMODE DIAGNOSTIC

- 2 groups of 4 closely spaced antennas, at toroidally opposite locations, same poloidal position
- 5kW class-AB amplifier: max(I_{ANT})~10A-peak, max(V_{ANT})~1kV-peak, frequency: 10kHz→500kHz
- multi-components, frequency-degenerate magnetic field driven by the antennas, components up to |n|~30 have a sufficiently high amplitude $|\delta B_{DRIVEN}|$>5mG at the plasma edge
- 48 synchronous detection channels: engineering signals, magnetics, ECE and reflectometry
- real-time acquisition, interface with global JET real-time controller, 1kHz clock rate
- real-time mode detection, n-number discrimination and tracking using the SparSpec algorithm



Calculated antenna-driven, volume-averaged, radial magnetic field $\langle B_{RAD}(n,t)\rangle$ for the JET shot #77788: note the ~2 order of magnitude variation in B_{RAD} between the different n-components as the plasma background evolves and the antenna frequency is swept around the TAE frequency.

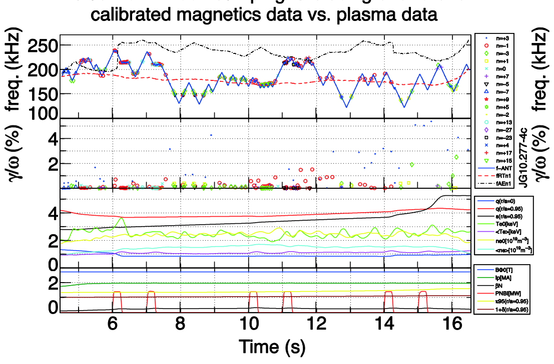


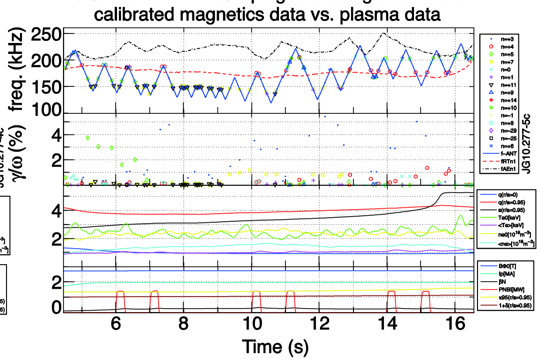


Real-time discrimination (for the JET shot #77417 (top) and #77788 (left)) between the different toroidal components in the frequency-degenerated spectrum driven by the new AE antennas, performed using the SparSpec code within a CPU-time of <600μs for each 1ms AELM clock cycle.

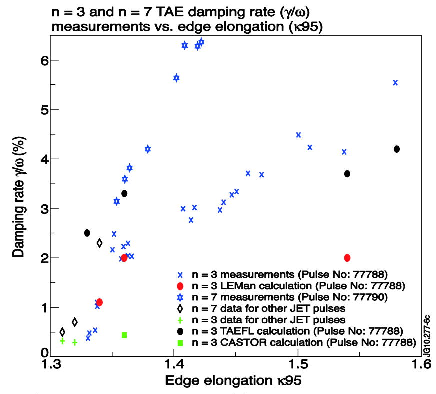
MEASUREMENT AND MODELLING OF THE DAMPING RATE FOR MEDIUM-N AEs IN JET AS FUNCTION OF THE EDGE ELONGATION

- damping rates of modes up to |n|~12 now routinely and reliably measured in JET with the new antennas and real-time (and post-pulse) detection/discrimination of the individual n-components
- damping rate for n=3 and n=7 TAEs linearly increases with edge elongation, as for low-n modes
- various model calculations (LEMan, TAEFL, CASTOR) are found to be in sufficiently good agreement with the measurements when:
  - a large number of poloidal harmonics is used
  - the up/down asymmetry of the plasma poloidal cross-section is explicitly considered
  - continuum damping is not the sole damping mechanisms



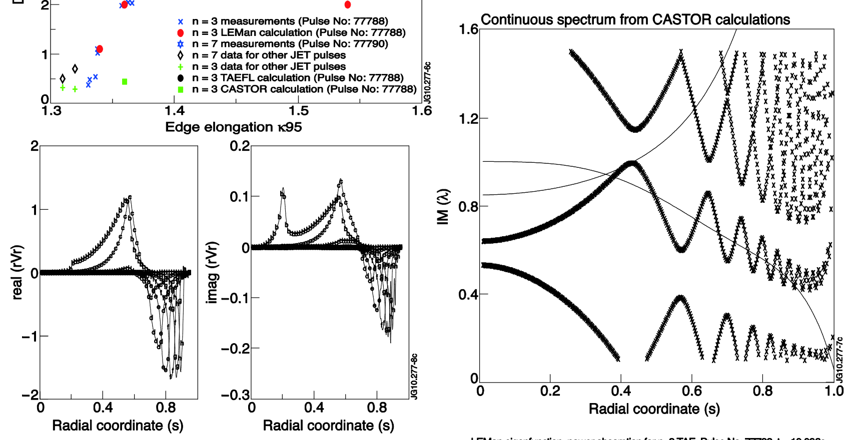


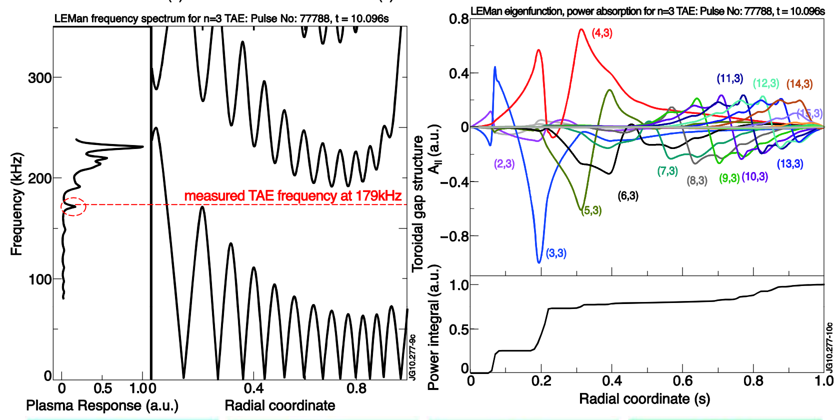
Measurement of the damping rate for individual toroidal mode numbers for the JET shot #77788 (left: odd |n|=3-7 max. antenna drive) and #77790 (right: odd |n|=5-11 max. antenna drive) as function of the evolution of the plasma background parameters.



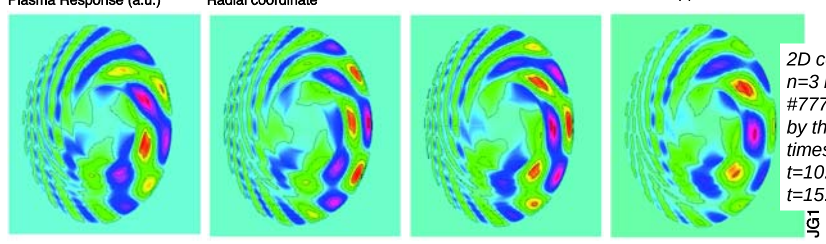
Damping rate data for the n=3 and n=7 TAEs as function of κ_{95}, showing a linear dependence $\gamma/\omega=f(\kappa_{95})$, compared with the results of the LEMan, TAEFL and CASTOR simulations (all codes are using the same input density, temperature and q-profiles).

Eigenfunction rV_r and shear Alfvén continuum as calculated by the CASTOR code for the n=3 TAE in #77788 at time =10.100s.





Antenna loading, shear Alfvén continuum, Eigenfunction and power absorption as calculated by the LEMan code for the n=3 TAE in #77788 at t=10.096s.



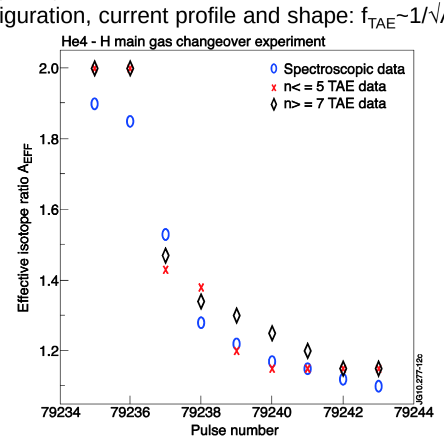
2D contour plot of the n=3 Eigenmode in #77788 as calculated by the TAEFL code at times t=6.265s, t=10.157s, t=10.248s, t=15.835s.

DIAGNOSTIC USE OF MEDIUM-N AEs: PLASMA ISOTOPE RATIO A_{EFF}

- usual spectroscopic, gas-balance and neutral particle analyser measurements are not very fast
- AE measurement of A_{EFF} from comparing frequency of modes with the same toroidal mode number in plasmas with the same magnetic configuration, current profile and shape: $f_{TAE}\sim 1/\sqrt{A_{EFF}}$

$$F_{ALFVEN}=\frac{V_{ALFVEN}}{4\pi qR}\propto\frac{1}{\sqrt{A_{EFF}}}$$

$$A_{EFF}=\frac{\sum_i n_i\left(m_i/m_p\right)}{\sum_i n_i}\approx\frac{1}{n_e/Z_{EFF}}\sum_i n_iA_i$$



Measurement of the plasma effective isotope ratio A_{EFF} during the gas change-over experiments in JET; the minor but clear difference in $A_{EFF}(n)$ for different modes is suggestive of a radial dependence in $A_{EFF}(r)$.

CONCLUSIONS

- damping rate of medium-n AEs increases with edge elongation as for low-n AEs ➔ this can be used as a real-time actuator to control the AE stability in ITER
- model calculation can reproduce measurements of damping rate if including kinetic effect and actual up/down asymmetric plasma poloidal cross-section
- diagnostic potential of medium–n AEs for A_{EFF} open further perspectives for ITER AE diagnostic

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