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Unstable beta-induced ion temperature gradient (BTG) eigenmodes in JET plasmas with ITBs and elevated monotonic q-profiles.

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Abstract:
JET deuterium experiments in an advanced tokamak scenario with an internal transport barrier (ITB) exhibit unstable electromagnetic (EM) perturbations in the sub-TAE frequency range. In JET pulse number (JPN) 92054, a high-beta plasma ($\beta_N = \beta_T B_T a / I_P \sim 4.38[\% Tm/MA]$) with high power neutral beam injection (NBI), $P_{NBI} = 25.1MW$, contained EM perturbations identified as beta-induced ion temperature gradient (BTG) eigenmodes and not beta-induced Alfvén eigenmodes (BAE) nor beta-induced Alfvén acoustic eigenmodes (BAAE) which are often destabilised in similar plasma conditions. The EM perturbations are localised near the $q = 2$ magnetic surface related to the ITB, and their frequency correlates well with the BTG characteristic frequency (ion diamagnetic frequency, ω_i^*) and the thermal ion temperature gradient (∇T_i). BTG modes are the most unstable modes due to the high thermal ion temperature gradient in the ITB, high thermal ion temperature compared to thermal electron temperature ($T_i/T_e > 1$), and a high ion beta. Three well-defined conditions for BTG modes to exist, defined by BTG analytical theory [1], are fulfilled in JPN 92054: (1) a positive relative ion temperature gradient, (2) ion beta higher than a critical value, and (3) a low magnetic shear. BTG theory also predicts a mode location in the vicinity of a rational magnetic surface, a frequency scaling with ω_i^*, and a coupling between Alfvén and drift waves. We have performed linear gyrokinetic simulations with validated plasma profiles and equilibrium, and find a mode with features resembling those of the experimental and theoretical BTG modes; specifically the mode is kinetically driven by thermal ions, is localised near the $q = 2$ magnetic surface, has a dominant Alfvénic polarisation, and its frequency scales with ω_i^* dependent on the toroidal mode number (n). Parts of this work have been reported in [2].

BTG modes are also observed in more recent JET plasmas during energetic particle scenario experiments aimed at studying alpha-particle driven AEs, performed in JET 2019/2020 deuterium campaigns. Reflectometer diagnostic data confirm that the mode location is around the $q = 2$ magnetic surface. We also present evidence for a systematic correlation between the BTG mode stability and the neutron rate roll-over (i.e. $d(R_{NT})/dt$ transiting from positive to negative).

References:
[1] A. B. Mikhailovskii and S. E. Sharapov. Beta-induced Temperature-gradient Eigenmodes in Tokamaks. Kinetic Theory. JET Joint Undertaking Reports, JET–P(98)12:1–16, 1998.
[2] N. Fil, et al. Interpretation of electromagnetic modes in the sub-TAE frequency range in JET plasmas with elevated monotonic q-profiles. Physics of Plasmas, Accepted, 2021.

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