Ioffe Physico-Technical Institute

GAM EVOLUTION AND LH-TRANSITION IN THE TUMAN-3M TOKAMAK

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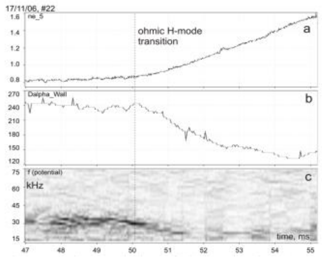
- Geodesic acoustic mode (GAM) is a specific mode of low-frequency radial electric field and density oscillations. GAM do not participate in radial transport directly, although create strong inhomogeneity of radial electric field (shear) and transverse rotation velocity, and thus affect anomalous transport through control of turbulence level. GAM-induced shear of E_r is not constant in time, therefore possibility of LH-transition initiation in this case is to be studied.
- The following situation was observed in TUMAN-3M tokamak: GAM oscillations were detected before LH-transition by means of HIBP and Doppler reflectometry; no oscillations were detected after transition [1,2].

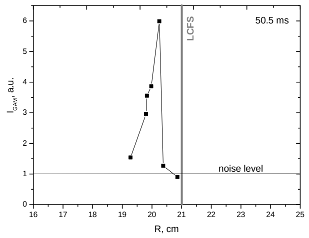
Can GAM be a trigger, initiating LH-transition?

- Simulation of density profile evolution with E_r-shear-dependent diffusion coefficient shows possibility of LH-transition, initiated by a space- and time-localized GAM burst, if GAM parameters are within certain limits. Those limits are related with each other and also depend on plasma parameters, primarily ion temperature; experimental GAM amplitude was found to be in range of transition initiation possibility

GAM observation on TUMAN-3M

- GAM were detected by means of HIBP [1] and Doppler reflectometry [2]





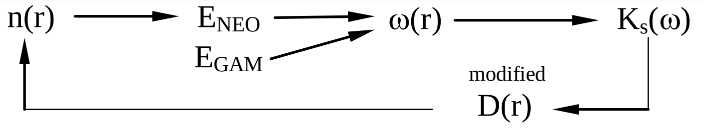
Model

- Spatial and temporal evolution of density profile was simulated (for TUMAN-3M geometry and basic plasma parameters) [3]

$$\frac{\partial n(r,t)}{\partial t}-\frac{1}{r}\frac{\partial}{\partial r}r\cdot\left(D(r,t)\cdot\frac{\partial n(r,t)}{\partial r}-v(r)\cdot n(r,t)\right)=S(r)$$

- Initial profile $n_0(r)$ was derived from experiments; using $n_0(r)$ there were obtained $D_0(r)$, $v(r)$ and $S(r)$
- Diffusion coefficient depends on electric field shear value $\omega(r)$:

$$D(r,t)=K_s(\omega)\cdot D_0(r)$$



$$\begin{tikzcd}
n(r) \arrow[r] & E_{NEO} \arrow[r] & \omega(r) \arrow[r] & K_s(\omega) \arrow[d] \\
 & E_{GAM} \arrow[ru] & & \text{modified } D(r) \arrow[lllu, bend left]
\end{tikzcd}$$

Electric field representation

- Total radial electric field $E_r=E_{NEO}+E_{GAM}$

$$E_{NEO}=\frac{T_i}{e}\left[\frac{\partial\ln n}{\partial r}+k_T\frac{\partial\ln T_i}{\partial r}\right]\approx 2\frac{T_i}{e}\frac{d}{dr}\ln(n(r,t)) \qquad E_{GAM}(r,t)=E_{GAM}\cdot\cos(2\pi\cdot f\cdot t-\frac{2\pi}{\lambda}\cdot r)\cdot\exp\left(-\frac{(r-r_0)^2}{w^2}\right)\cdot\mathrm{rect}(t_0,T)$$

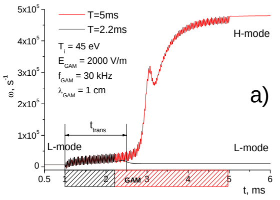
- **E_{NEO}**: it is considered that $T_i(r)$ profile is the same as $n(r)$; E_{NEO} values for peripheral $T_i \approx 40$ eV are close to experimental
- **E_{GAM}**: time- and space-localized traveling wave, propagating radially outwards in a rectangular time window T;
  - frequency (f = 15–45 kHz) and localization area (r_0 = 20 см, $w = \Delta r_{GAM}/4 = 0.3$ cm) are close to experimental [1,2];
  - «free parameters»: wavelength ($\lambda_{GAM} \approx (0.3\text{-}2)\Delta r_{GAM} = 0.4$–$2.5$ cm) and amplitude (E_{GAM} = 200–7000 V/m) are related with each others via amplitude of central plasma potential oscillations

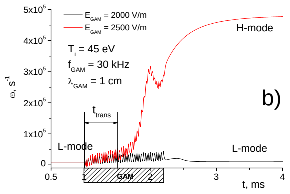
Diffusion suppression

- Analytical dependence $K_s(\omega)=1/(1+(\omega/\gamma)^2) + K_{NEO}$ [4]
  - K_{NEO}=0.05 describes fully suppressed anomalous transport
  - for the present modeling TEM mode with $\gamma = 0.7\cdot10^5$ s^{-1} was used
- Oscillating field shear has weaker effect on turbulence suppression [5]
  - effective shear value for oscillating electric field component should be used: $\omega_{eff} = \omega\cdot F(2\pi f_{GAM}/\gamma)$, $F\to 0$ if $2\pi f_{GAM} >> \gamma$

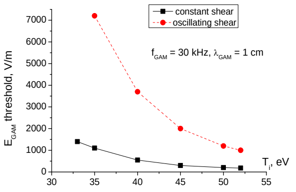
Modeling results

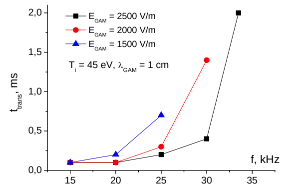
- For specific combinations of GAM and plasma parameters, GAM-initiated transport barrier becomes self-sustaining and exists after GAM switching-off
- If GAM burst duration (a) and amplitude (b) overcome certain threshold values, plasma goes into H-mode; GAM parameters (amplitude, frequency, wavelength) and T_i define t_{trans} - minimal time of GAM existence required for transition initiation





- There are LH-transition initiation threshold values for different GAM parameters e.g.:
  - threshold electric field decreases rapidly with ion temperature
  - GAM frequency decrease facilitates initiation of LH-transition





Comparison with experiment

- Parameters of typical TUMAN-3M discharge with GAM activity:

$$B_T < 1\ \mathrm{T},\ I_p < 180\ \mathrm{kA},\ q_{cyl} = 2.5\text{–}3.3,\ n_L \sim 0.8\text{–}0.9\cdot10^{19}\ \mathrm{m}^{-3}$$

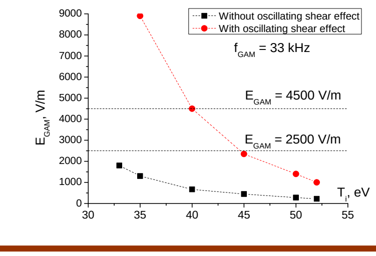
- GAM were detected before LH-transition; single burst duration ~ 0.1 ms
- HIBP measured potential oscillations $\Delta\Phi \approx$ 10-15 V in central plasma ($r_{HIBP} \approx 6$ cm) [1]
- GAM frequency f_{GAM} = 33 kHz and localization area $\Delta r_{GAM}=4w=1.2$ cm were obtained from Doppler reflectometry measurements [2]
- Combination of E_{GAM} and λ_{GAM} define central potential oscillations amplitude $\Delta\Phi$:

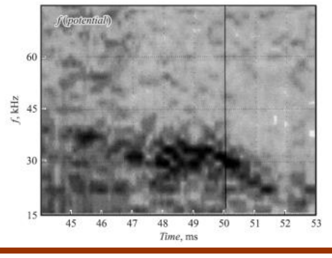
$$\Delta\Phi=\int_a^{r_{HIBP}}E_{GAM}(r,t)dr\approx 10\mathrm{V}$$

- GAM wavelength value was not obtained from experiments; two characteristic “limiting” cases were chosen:

λ_{GAM} = 1 cm, E_{GAM} = 4.5 kV/m ($\lambda_{GAM} < 2\Delta r_{GAM}$); λ_{GAM} = 2 cm, E_{GAM} = 2.5 kV/m ($\lambda_{GAM} \approx 2\Delta r_{GAM}$)

- Conditions on radial wavelength are chosen corresponding to the fact that GAM with short wavelength (compared to localization area, i.e. $\lambda_{GAM} << \Delta r_{GAM}$) could not be detected by means of central HIBP measurements
- Experimental GAM amplitude for different λ_{GAM} is higher than threshold in a certain range of T_i values
- GAM frequency decrease before and during the transition may be one of causes of LH-transition initiation





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