COMPASS INSTITUTE OF PLASMA PHYSICS ASCR

42nd European Physical Society Conference on Plasma Physics

Alfvén-wave character oscillations in tokamak COMPASS plasma

T. Markovič[1,2,*], J. Seidl[1], A. Melnikov[3,4], P. Háček[1,2], J. Havlicek[1,2], A. Havránek[1,5], M. Hron[1], O. Hronova[1], M. Imríšek[1,2], F. Janky[1,2], K. Kovařík[1,2], O. Mikulín[1], R. Pánek[1], R. Papřok[1,2], J. Pipek[1], P. Vondráček[1,2], V. Weinzettl[1]

[1] Institute of Plasma Physics CAS, Prague, Czech Republic
[2] Charles University in Prague, Faculty of Mathematics and Physics, Prague, Czech Republic
[3] National Research Centre 'Kurchatov Institute', Moscow, Russian Federation
[4] National Research Nuclear University MEPhI, Moscow, Russian Federation
[5] Czech Technical University in Prague, Faculty of Electrical Engineering, Prague, Czech Republic

* E-mail address: markovic@ipp.cas.cz

1. Introduction and motivation

- Auxiliary heating or fusion products → suprathermal particles that drive the Alfvén modes unstable [1,2] → degradation in high-energy particle confinement
- Toroidal Alfvén Eigenmodes (TAE):
  - Gap mode oscillations – interference between 2 poloidal harmonics
  - Low damping rate (in comparison to Aflvén continuum)
- Currently open questions [2]:
  - Non-linear behavior of Alfvén Eigenmodes (AE) in toroidal devices
  - Effect of Resonant Magnetic Perturbations (RMP) and AE instabilities on fast particle confinement
- Tokamak COMPASS → flexible RMP configuration + recent observation of Alfven-like oscillations with unclear driving mechanism

2. Experimental arrangement on the COMPASS tokamak

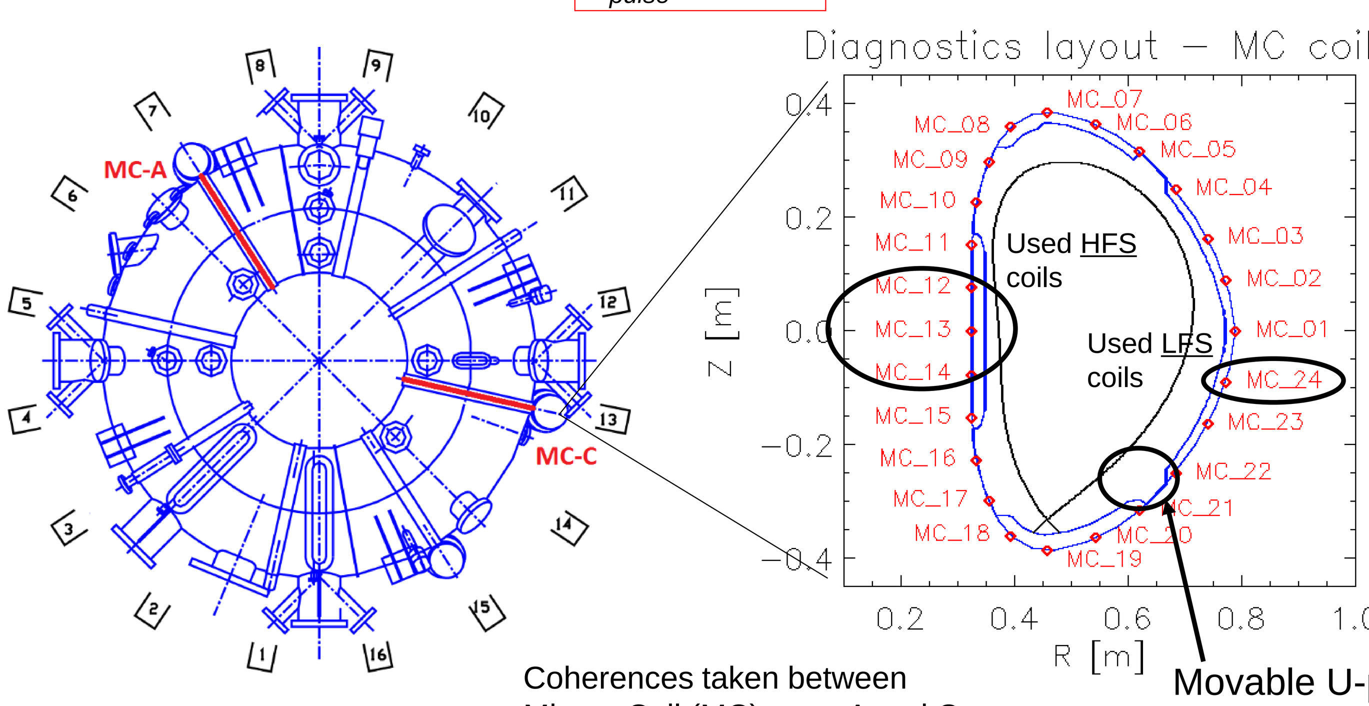
- Small tokamak → flexible operation
- ITER-like geometry.
- H-mode discharges:
  - Fully ohmic H-modes.
  - NBI-assisted H-modes.
- Equipped with RMP coils.

Parameters:
R_0 = 0.56 m
a = 0.2 m
I_p < 0.4 MA
B_0 < 2.1 T
T_{pulse} < 1s

- Good coverage with magnetic diagnostics.
- Oscillations detectable as coherence between detection coils:

$$\mathrm{Coh}_{xy} = \frac{S_{xy}^2}{S_{xx} S_{yy}}$$

S_{xy} – Cross-spectral density of signal *x* to *y*; S_{xx}, S_{yy} – Auto-spectral density of signal *y*



Oscillations = fluctuations of magnetic field

Detected by small coils

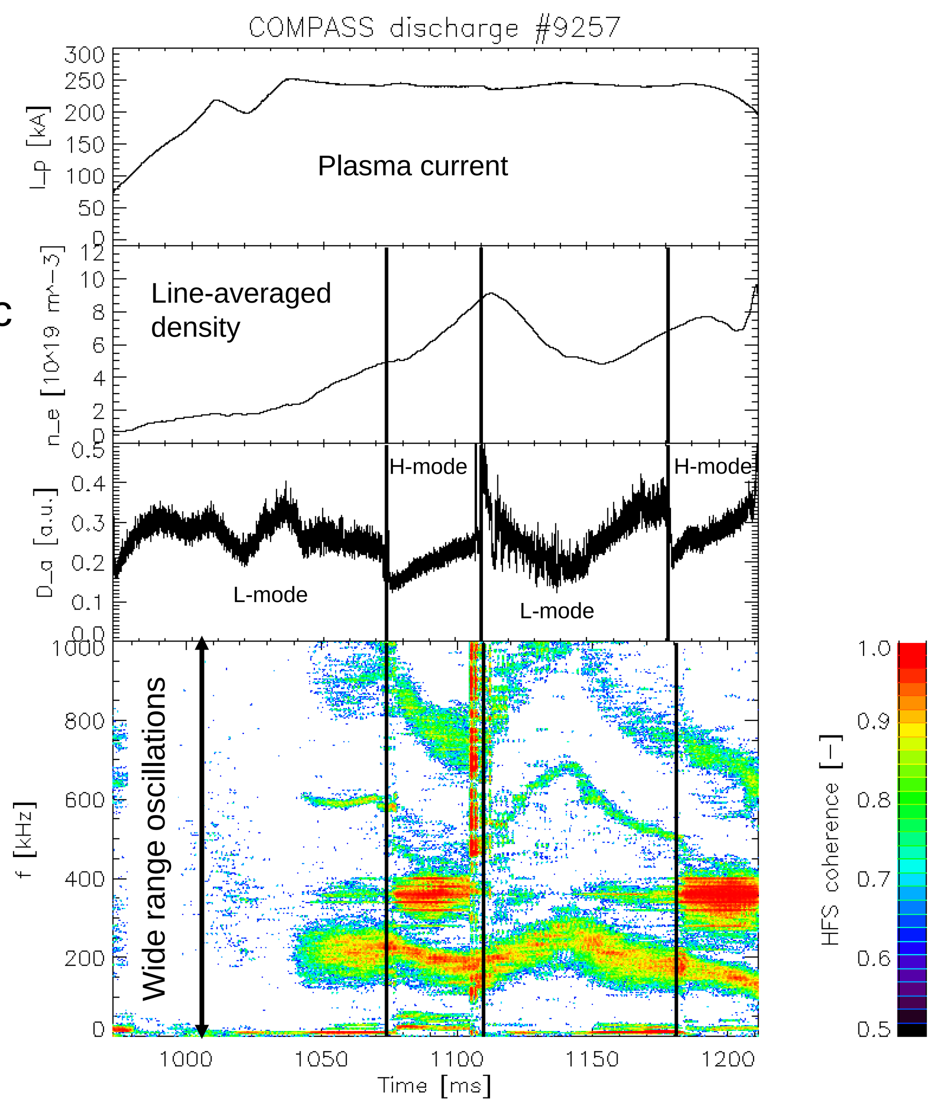
MC coils – good responsivity to high frequency signals (up to 1 MHz)

Coherences taken between Mirnov Coil (MC) array A and C

Movable U-probe [4] manipulator with coils capable of detection of 2.5 MHz oscillations

3. COMPASS plasma eigenmode oscillations

- Oscillations of 50-250 kHz spectral range reported during COMPASS ELM-free H-modes [3].
- Observations – analogue-integrated magnetic sensors → low-pass filter of *f* < 300 kHz.
- Present in both NBI-heated and ohmic H-modes:
  - Eigenmode oscillations on HFS identified as TAE [3].
  - Eigenmode oscillations on LFS identified as BAE [3].
- LFS oscillations also observed by electrostatic reciprocating probes.
- Recently – measurements by non-integrated sensors:
  - Mirnov coils of $f_{Nyquist}$ < 1.0 MHz.
  - U-probe [4] coils of $f_{Nyquist}$ < 2.5 MHz.
- High-frequency oscillations detected on HFS.
  - In both H-mode and L-mode plasmas.
  - Continuous across L-H and H-L transitions.



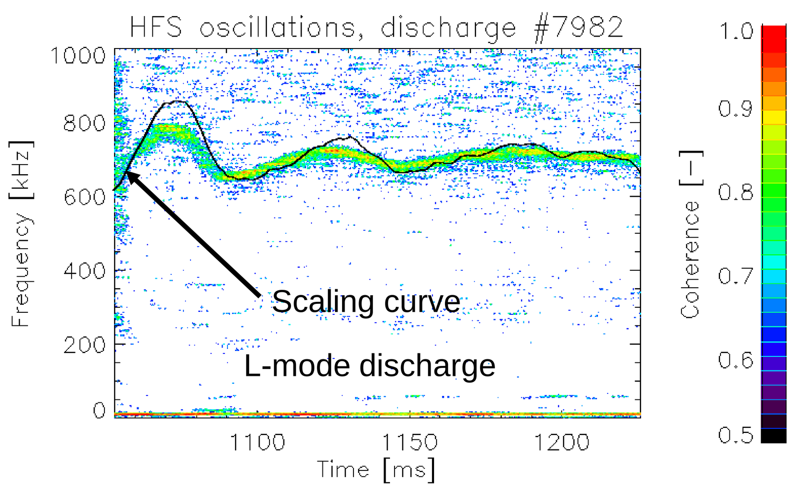
4. TAE-like parametric scaling

- Frequency of observed oscillations – variable in time with discharge params.
- Frequency of TAE oscillations expected to scale as [1]:

$$f_A = \frac{B_0}{4\pi q R \sqrt{\mu_0 \sum m_i n_i}}$$

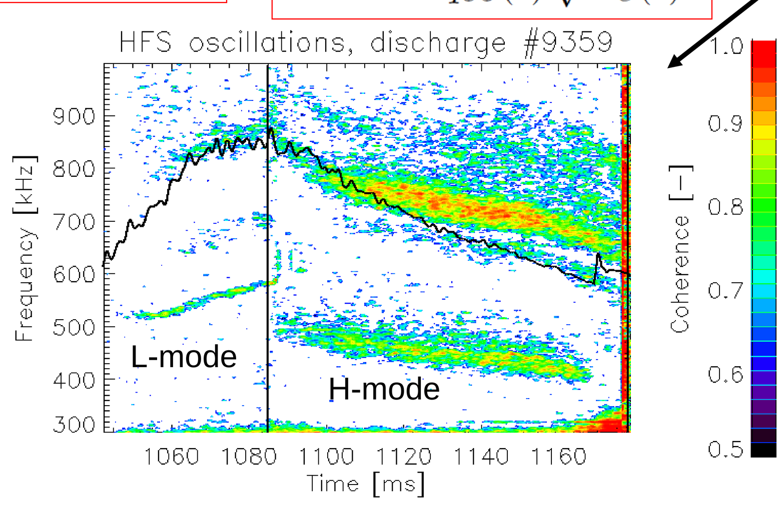
- This study – scaling approximation of:

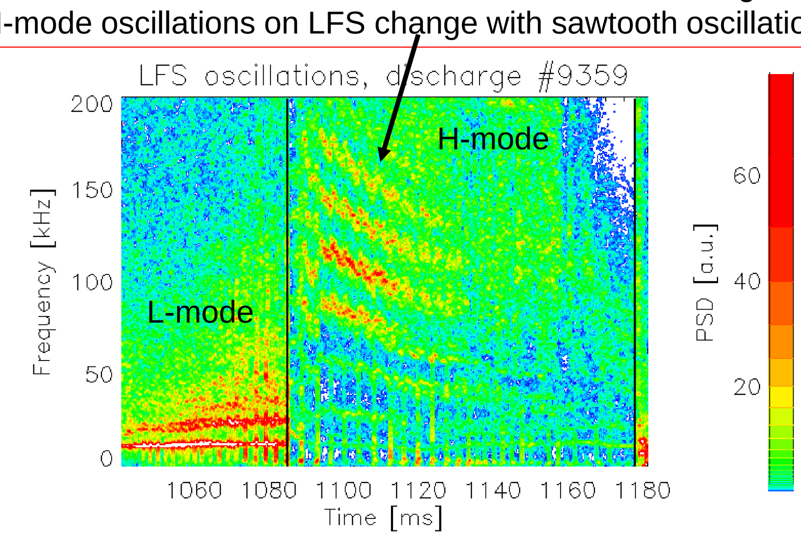
$$f_A(t) \sim \frac{B_0}{q_{95}(t)\sqrt{n_e(t)}}$$



L-mode oscillations scale as TAE.

H-mode oscillations on HFS seem to follow TAE scaling
H-mode oscillations on LFS change with sawtooth oscillations



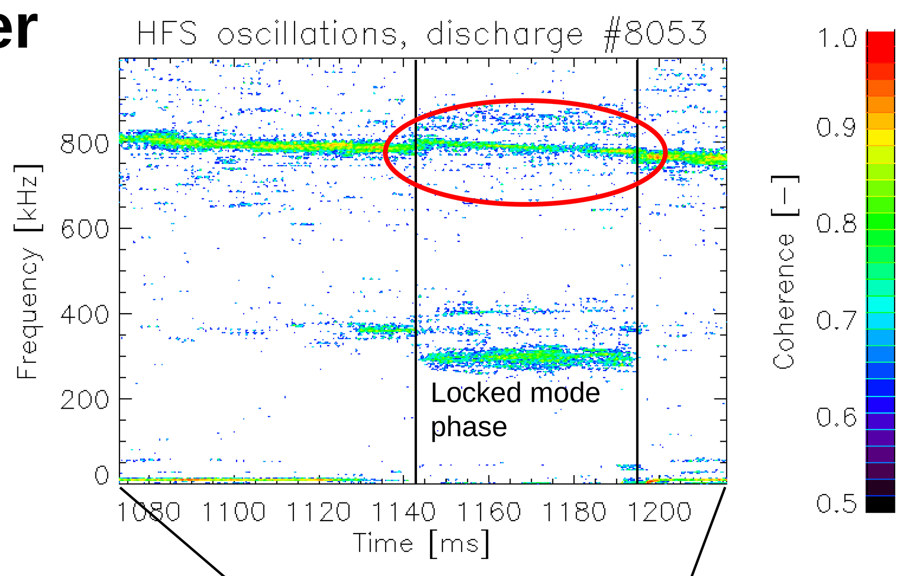


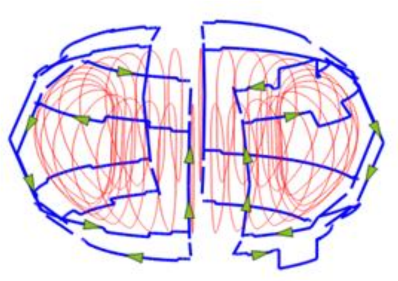
5. Travelling-wave character

- Alfvén-wave oscillations – travelling along magnetic field-lines + Doppler shifted by plasma rotation [5]:

$$f_{\mathrm{tot}} = f_A + n \cdot f_{\mathrm{plasma}}$$

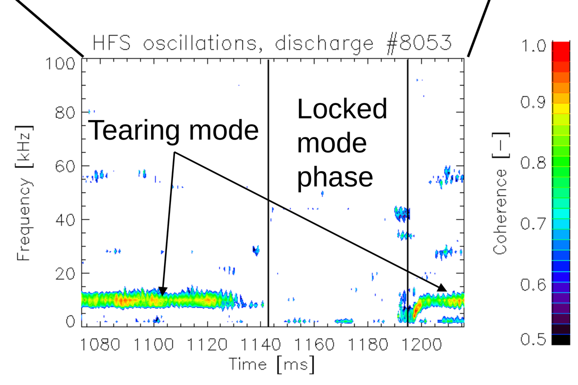
- Typical MHD oscillations – rotating with bulk plasma.
- COMPASS equipped with stationary RMP field circuit.
- Interaction of tearing mode with RMP field → generation of locked mode → localized braking of plasma rotation.





COMPASS RMP field generation circuit

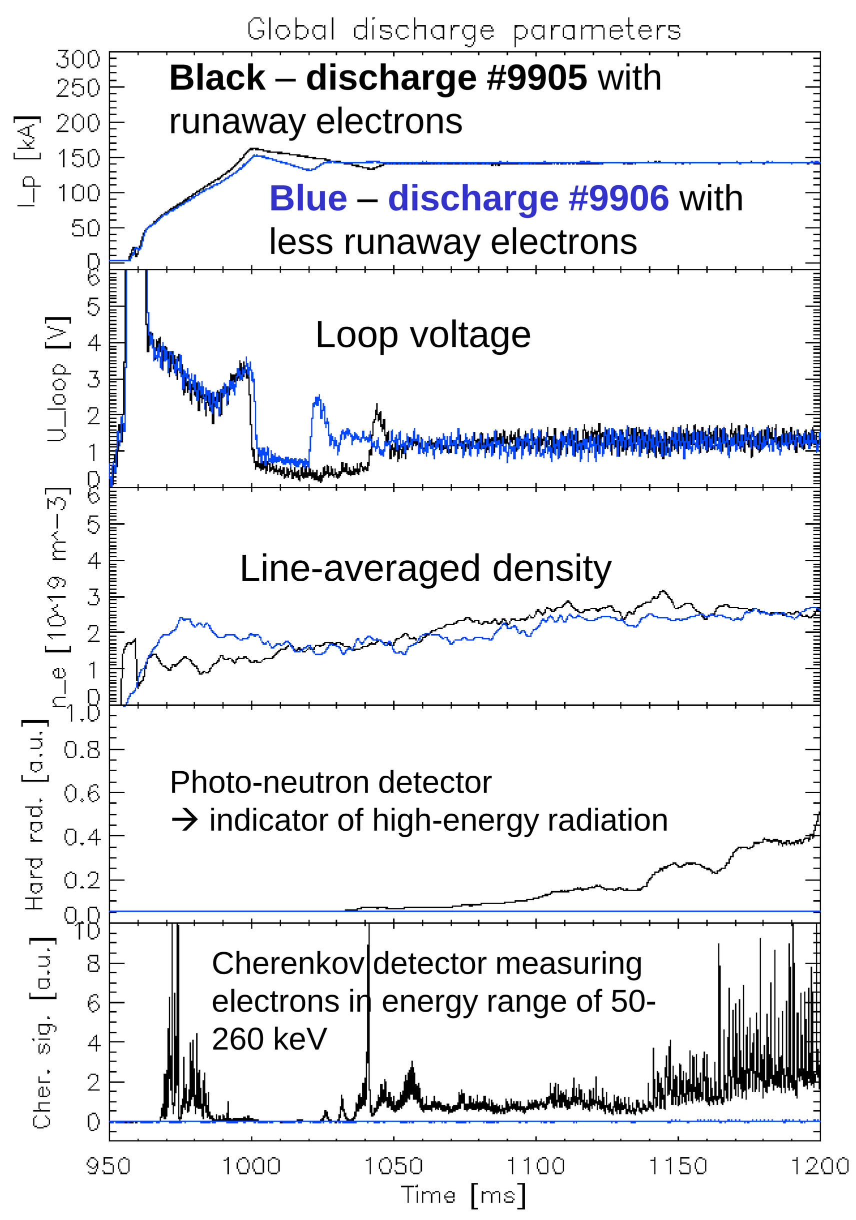
Persistence of high-frequency oscillations during locked mode phase indicates their travelling-wave character

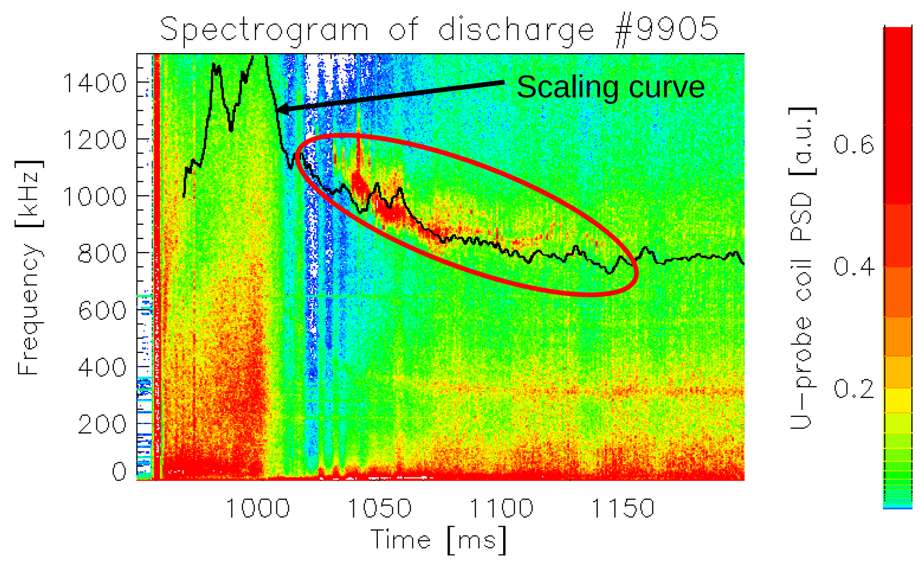


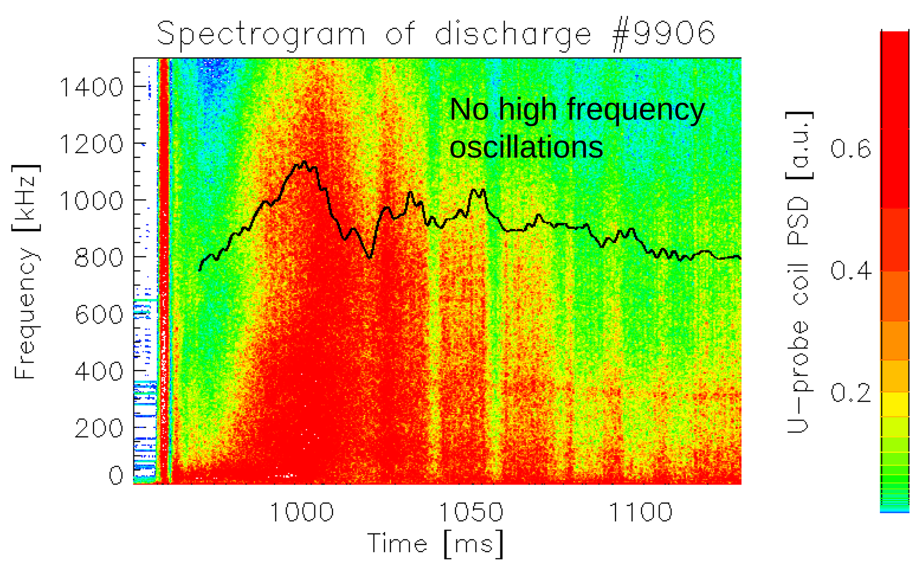
Detail of low-frequency oscillations showing braking of tearing mode

6. Mode correlated with runaway electrons

- Low density discharges → generation of runaway electron beam.
- Under these conditions – observation of oscillations in the spectral range *f* = 0.7 - 2.5 MHz.
- Oscillation frequency follows TAE parametric scaling.
- Dedicated experiment – increase gas puff during current ramp-up phase in order to mitigate the runaway beam → chirped oscillations no longer present.







7. Conclusions

- Recent measurements using non-integrated magnetic coils → observation of wide range of high-frequency oscillations in COMPASS plasma.
- It was found that these oscillations:
  - Are present in bot L-mode and H-mode plasmas (unlike those previously reported in [3]).
  - Show TAE-like frequency scaling with discharge parameters.
  - Suggest travelling-wave character.
- Highest-frequency oscillations → data suggest their driving mechanism includes runaway electron beam.
- Driving mechanism of the rest of oscillations still unknown → MHD modelling necessary.

Acknowledgements

This work was supported by projects GACR P205/12/2327, GACR 15-10723S, GA14-35260S and by grant RSF 14-22-00193.

References

[1] W.W. Heidbrink, Physics of Plasmas **15**, 055501 (2008).
[2] N.N. Gorelenkov, S.D. Pinches, K. Toi, Nucl. Fusion **54**, 125001 (2014).
[3] A.V. Melnikov, T. Markovic, L.G. Eliseev, et al., Plasma Physics and Controlled Fusion **57**, 065006 (2015).
[4] K. Kovařík, et al., 41st EPS Conference Proceedings, P5.025 (2014).
[5] S.E. Sharapov, 11th CMSS on Plasma and Fusion Energy Physics proceedings (2013).