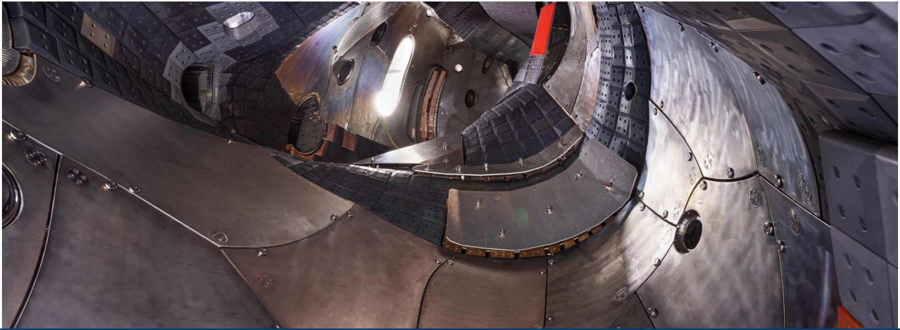


OBSERVATION AND CHARACTER-ISATION OF TRAPPED ELECTRON MODES IN WENDELSTEIN 7-X

July 22, 2024 | A. Krämer-Flecken | IFN-1

Member of the Helmholtz Association

JÜLICH Forschungszentrum

PAPER REHEARSAL

Observation and characterisation of trapped electron modes in Wendelstein 7-X

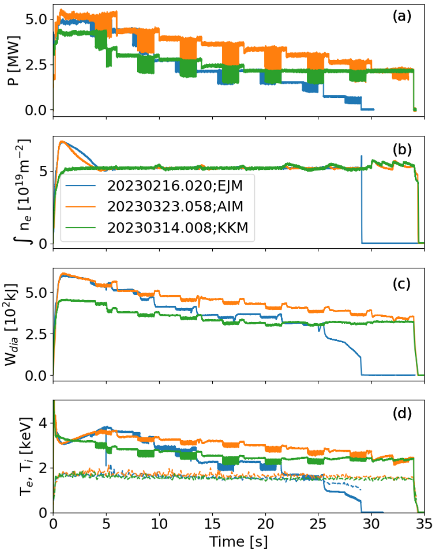
A. Krämer-Flecken, P. Costello, G. Fuchert, J. Geiger, S. Heuraux, A. Knieps, A. Langenberg, J.H.E. Proll, K. Rahbarnia, R. Sabot, L. Salazar, H.M. Smith, H. Thomsen, G. Weir, T. Windisch, H.M. Xiang and the W7-X-team

JÜLICH Forschungszentrum

ABSTRACT

This paper describes experiments, conducted at the Wendelstein 7-X stellarator (W7-X), which aim at detecting quasi coherent modes at low wave numbers. A Poloidal Correlation Reflectometer (PCR) installed at W7-X, is able to measure low wave numbers ($k_\perp \leq 3.5\,\mathrm{cm}^{-1}$). For medium line-averaged densities ($\int n_e \leq 6 \times 10^{19}\,\mathrm{m}^{-2}$) the plasma core is accessible for this diagnostic. For different magnetic configurations and plasma parameters, broad quasi-coherent structures are observed in the coherence spectra. From the analysis of the rotation and the poloidal structure, these quasi coherent (QC) modes show the properties of electron-temperature-gradient driven TEMs. It is the first observation of TEMs in W7-X. A linear relation between the mode velocity and the rotation frequency is found. The relation is uniform and confirms the nature of QC-mode observation as TEM in tokamaks, too.

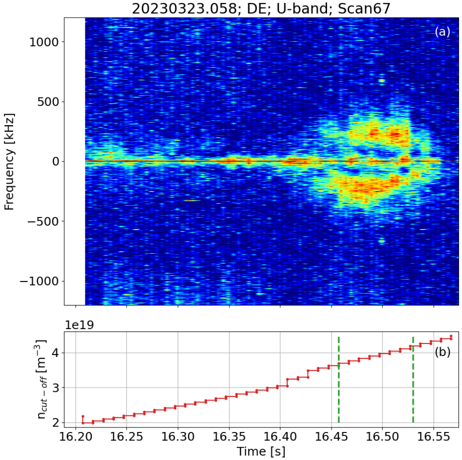
CONDUCTED PROGRAMS



- Low collisionallity plasma
- Constant density $\int n_e = 5 \times 10^{19}\,\text{m}^{-2}$
- Power step down 5 MW to 1 MW
- Decreasing W_{dia} with power
- Decreasing central T_e with power
- Nearly constant central T_i

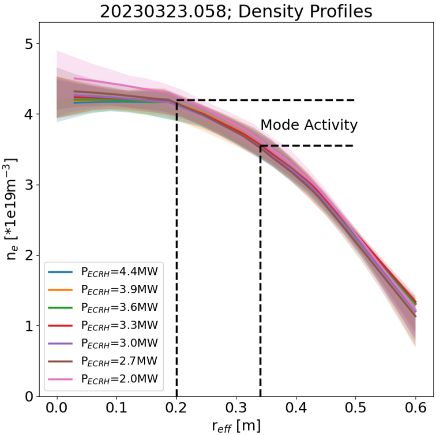
JÜLICH Forschungszentrum

QC-MODE IN PCR



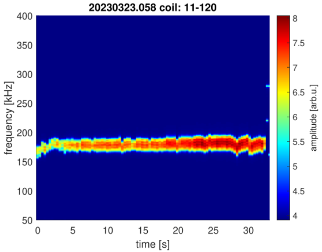
- Coherence spectrogam for $\Delta z = 17\,\mathrm{mm}$
- Broad band modes in the plasma core
- Density range: $3.7 \times 10^{19}\,\mathrm{m}^{-3}$ to $4.2 \times 10^{19}\,\mathrm{m}^{-3}$
- Observed for all scans and power steps

QC-MODE LOCALISATION

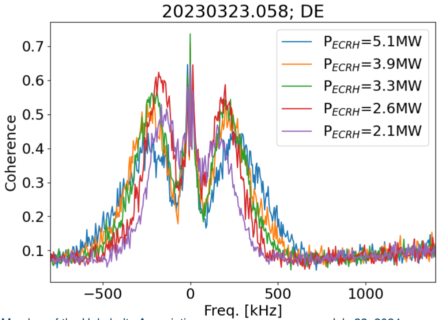


- Density Profiles from TS for different power steps
- No change in profiles as function of power
- QC-mode obtained for 0.2 m to 0.35 m
- QC-mode located in the plasma core

PROOF OF ELECTROSTATIC CHARACTER



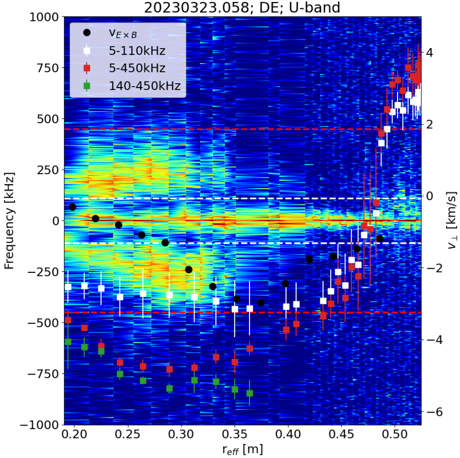
- No power dependence for Mirnov coils
- Center frequency: $f_c = 180\,\text{kHz}$
- Increasing amplitude towards lower power



- Clear power dependence observed
- Dependence of f_c from power yields: 170 kHz to 240 kHz
- Different frequency intervals for LF-turb. & QC-modes

JÜLICH Forschungszentrum

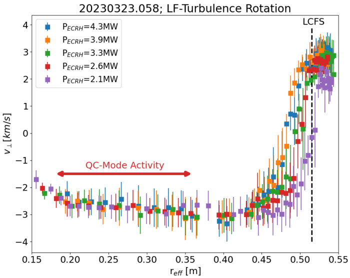
ESTIMATION OF VELOCITIES



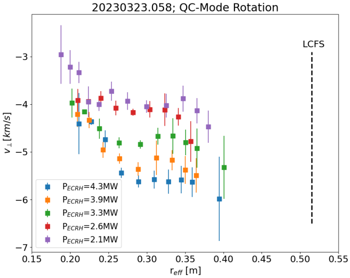
- Separation into different freq. ranges; LF-turb. & QC-modes
- Low frequency turbulence: $f \leq 110\,\mathrm{kHz}$
- QC-mode frequency: $140\,\mathrm{kHz} \leq f \leq 450\,\mathrm{kHz}$
- Full frequency range – red squares
- $E \times B$-velocity from NeoTransp
- Mode rotation in e^- diamagn. rotation

JÜLICH Forschungszentrum

VELOCITIES FOR POWER STEPS

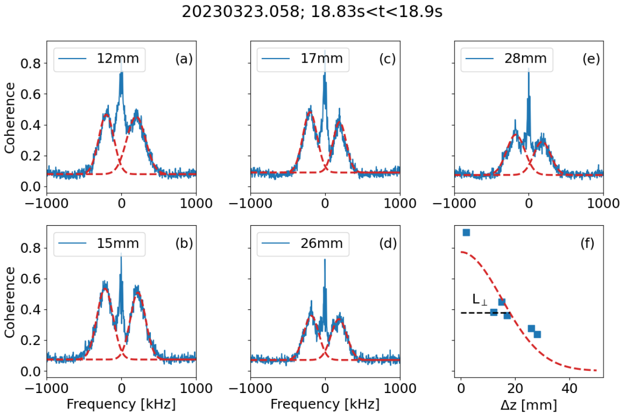


- Low frequency turbulence independent of power
- Low frequency covers $E \times B$-velocity
- Variation in the shear layer



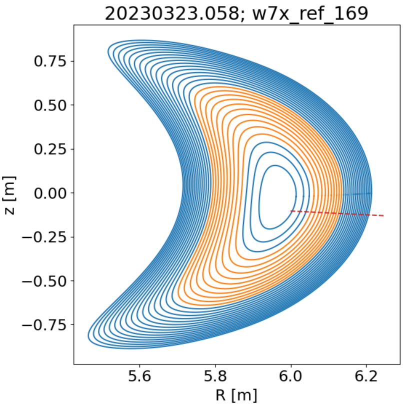
- Strong power dependence for QC-mode
- Ranges from $-5.6\,\mathrm{km\,s^{-1}} \leq v_\perp \leq -4\,\mathrm{km\,s^{-1}}$
- Indicates rotation in electron diamagnetic drift direction

SIZE OF QC-MODES



- Evolution of the coherence as function of poloidal distance
- Yields $L_\perp = 18\,\text{mm}$ and $k_\perp \approx 3\,\text{cm}^{-1}$; high poloidal mode number
- Calculated m-numbers from circumference of flux surfaces

SIZE OF QC-MODES



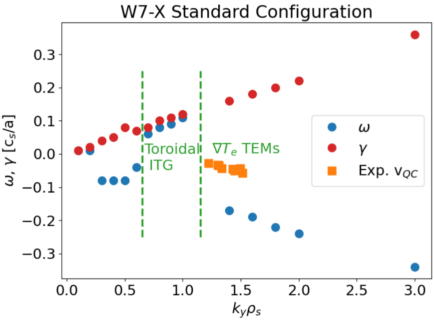
- Plasma cross-section for PCR position
- Highlighted region with QC-Mode activity

$$m = \frac{s\, f_{QC}}{v_\perp}$$

- Estimated mean mode number to $\overline{m} = 105 \pm 5$
- Poloidal mean mode size: $\overline{L_\perp} = 21\,\mathrm{mm} \pm 1\,\mathrm{mm}$
- Yields: $\overline{k_\perp} = 2.95\,\mathrm{cm}^{-1} \pm 0.15\,\mathrm{cm}^{-1}$

JÜLICH Forschungszentrum

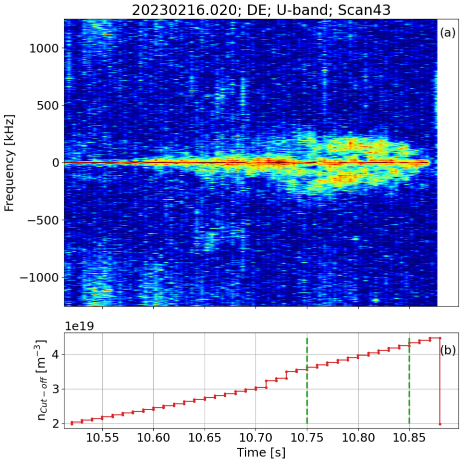
LINEAR GYROKINETIC SIMULATION



- Growth rate γ and ω as function of $k_\perp \rho_s$
- Simulation for the dominant modes show:
- Toroidal ITG-modes observed for $k_\perp \rho_s \leq 1.1$
- ∇T_e-modes for $k_\perp \rho_s \geq 1.1$
- Exp. conditions yield: $1.22 \leq k_\perp \rho_s \leq 1.55$

Evidence that the observed QC-modes are ∇T_e-TEMs

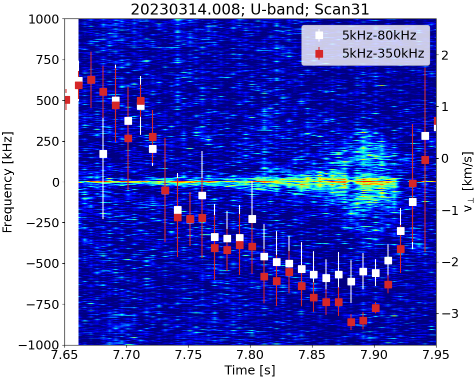
EFFECT OF MAGNETIC CONFIGURATION



- Low mirror configuration - 20230216.020
- Similar plasma parameters
- Observation of QC-modes in the core
- Smaller f_c of QC-mode
- Found similar power dependence
- Smaller QC-mode rotation for same power

JÜLICH Forschungszentrum

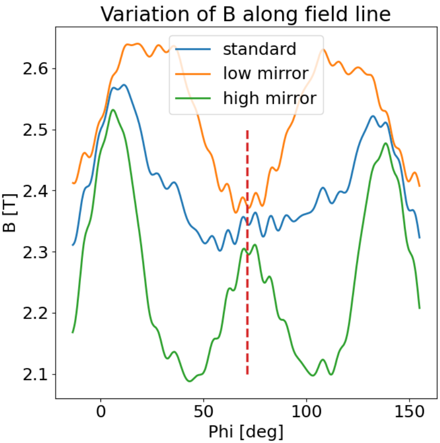
HIGH MIRROR CONFIGURATION - KKM



- Similar power scan as in other programs
- Very weak QC-mode in KKM
- Estimation of velocities for
  1. Low frequency turb. $f \leq 80\,\text{kHz}$
  2. Full range wit QC-mode: $f \leq 350\,\text{kHz}$
- Similar $v_\perp$ for both freq. intervals
- Only for QC-mode activity increased $v_\perp$

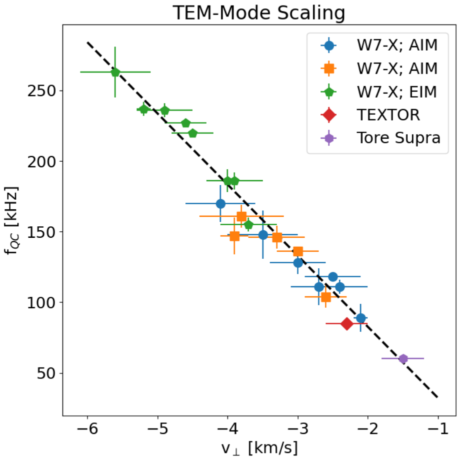
To understand the effect of magnetic configuration analyse $B(\phi)$

EFFECT OF TOROIDAL MAGNETIC FIELD



- Magnetic field line crossing the LoS of PCR
- Calculated for the radial range of QC-mode interval
- Position of PCR indicates by dashed line
- EJM and AIM: PCR in the minimum
- KKM in local maximum
- Explains the weak QC-mode in KKM

SCALING OF QC-MODES



- Found relation between mode frequency and velocity
- Linear increase of f_{QC} with $v_\perp$
- Slope depends on the size of mode
- Fits well for W7-X programs

Extrapolation to tokamaks

- Tore Supra-data with TEMs
- Used TEXTOR data
- Both data points follow the W7-X scaling

CONCLUSION

- Low collisionallity plasmas investigated in W7-X
- Found Quasi Coherent modes in the plasma core
- Mode frequency varies with the injected ECRH-power
- Absolute mode velocity exceeds $E \times B$-velocity
- Poloidal structure size 20 mm to 30 mm and $2\,\mathrm{cm}^{-1} \leq k_\perp \leq 3\,\mathrm{cm}^{-1}$
- QC-modes found for configs. where B_{min} coincides with LoS of PCR
- Observations in agreement ∇T_e-driven TEMs in W7-X
- Supported by linear gyrokinetic calculations
- Linear scaling between f_{QC} and $v_\perp$ found
- Data from tokamaks seems to follow the same scaling