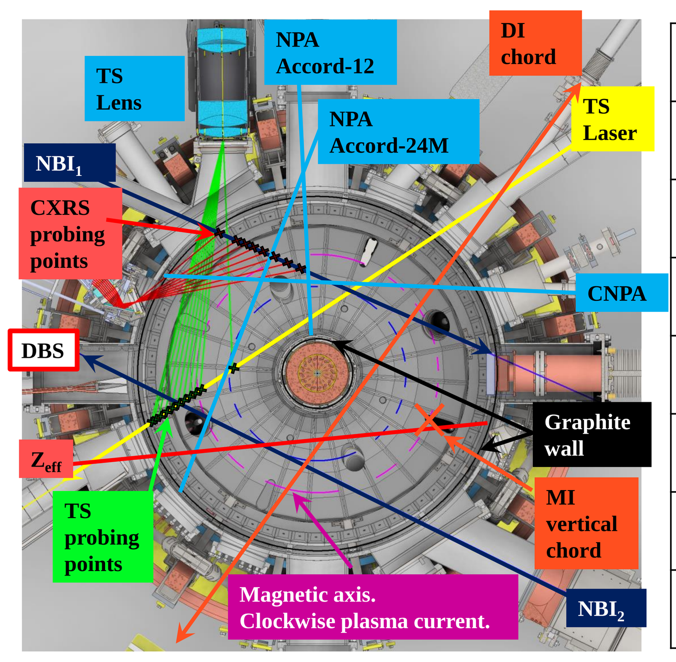
ID: 2681

THE STUDY OF ALFVÉN EIGENMODES ON THE SPHERICAL TOKAMAK GLOBUS-M2 USING DOPPLER BACKSCATTERING

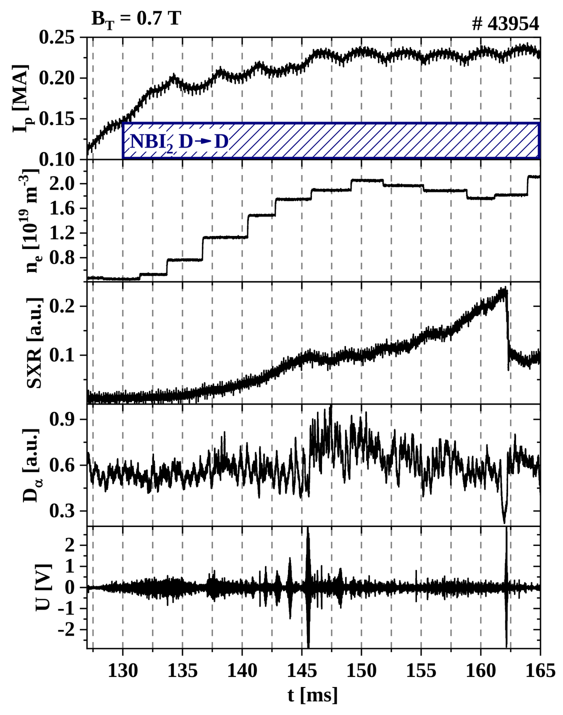
A.M. Ponomarenko, A.Y. Yashin, A.Y. Tokarev
Peter the Great Polytechnic University, St. Petersburg, Russian Federation
I.M. Balachenkov, N.N. Bakharev, V.K. Gusev, E.O. Kiselev, G.S. Kurskiev, V.B. Minaev, YU. V. Petrov, N.V. Sakharov, P.B. Shchegolev, O.M. Skrekel, E.E. Tkachenko, N.S. Zhiltsov
Ioffe Institute, St. Petersburg, Russian Federation
annap2000dreeonn@gmail.com

EXPERIMENTAL SETUP (AEs AND DBS ON GLOBUS-M2)

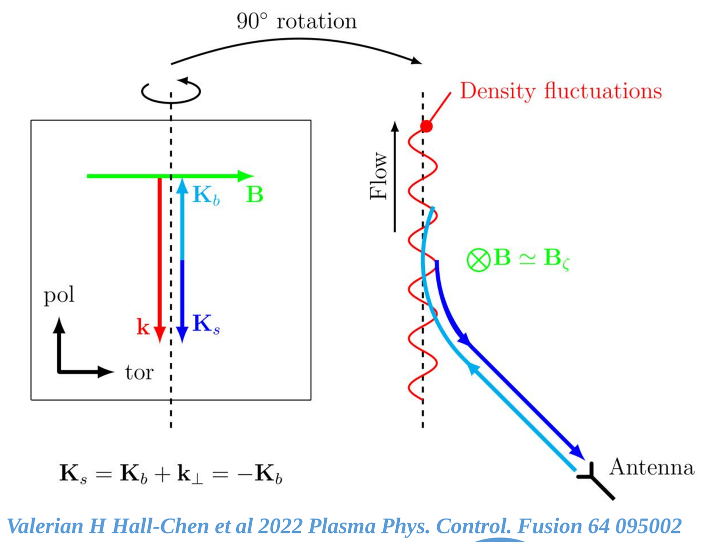
Various types of Alfvén eigenmodes (AEs) can be driven unstable by energetic particles when the resonance condition is satisfied. In a toroidal plasma, these modes lead to the ejection the high-energy particles from the plasma which in turn can cause significant loss of beam power (with degradation of plasma performance) and damage to the plasma facing components.



major radius R (m)	0.36
minor radius a (m)	0.24
aspect ratio	1.5
magnetic field B (T)	0.4 – 1
plasma current I_p (MA)	0.2 – 0.5
elongation κ	≤ 2.0
triangularity δ	≤ 0.4
t_{pulse} (s)	0.4



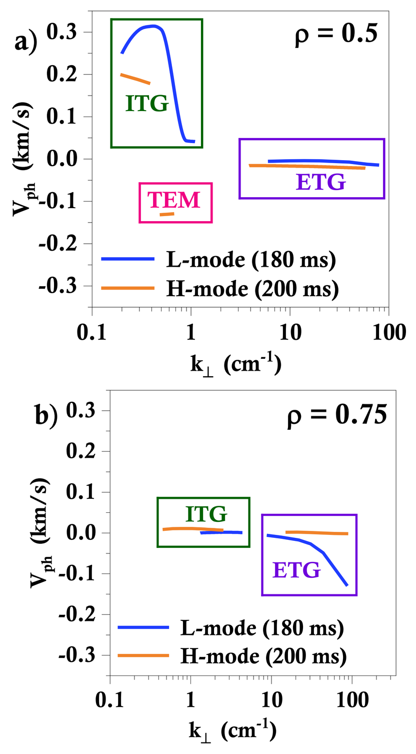
AEs have been a topic of research on the spherical tokamak Globus-M and now its modernised version Globus-M2 *[BAKHAREV N.N. OV]*. The increase of plasma parameters and upgrade of the neutral beam injection (NBI) system led to better fast particle confinement and changed the nature of the observed AEs with an expansion of their frequency spectrum.
Studies of AEs have been carried out using arrays of magnetic probes which allowed to determine their mode structure and amplitude.
TAE-induced losses of fast particles have been investigated using a neutron spectrometer and ACORD-24M neutral particle analyser (NPA) *[SKREKEL O.M. EX-W, P4]*.
This work presents the results of the AE study using **Doppler backscattering (DBS)** on Globus-M2 in a wide range of plasma parameters: I_p = 160-450 kA, B_T = 0.5-0.95 T, $n_e = 10^{19}$-10^{20} m^{-3}, E_{NBI} = 20-50 keV, P_{NBI} = 0.3-1.5 MW.

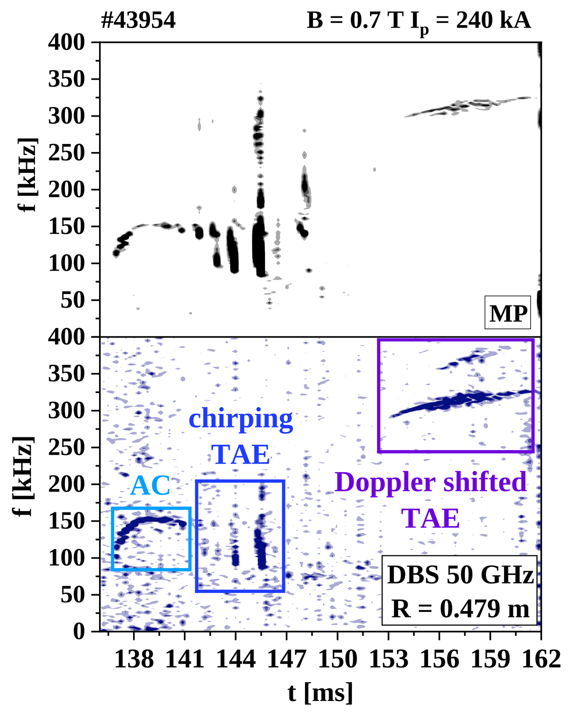


Valerian H Hall-Chen et al 2022 Plasma Phys. Control. Fusion 64 095002

$$\Delta\omega = \vec{v}\cdot\vec{k} = v_\parallel k_\parallel + v_\perp k_\perp + v_r k_r$$

$$\boxed{v_\perp = v_{E\times B} + v_{phase}}$$



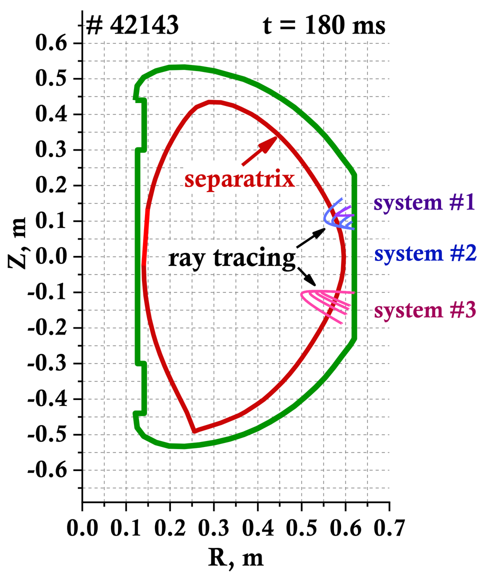


DBS is based on the detection of backscattered radiation near the cutoff of the probing microwave beam. Scattering takes place off density fluctuations with a wave vector $k_\perp$ which satisfies the Bragg's law of $k_\perp = 2k_i$ (k_i is the incident wave wavevector). A Doppler frequency shift $\Delta\omega_D$ is induced when the fluctuating plasma experiences movement in the direction of the electron or ion diamagnetic drift at a velocity of $V_\perp$ which can be determined using the formula $V_\perp = \Delta\omega_D/k_\perp$. The velocity $V_\perp$ can be described as the sum of the phase velocity of the density fluctuations V_{phase} and the E×B drift velocity $V_{E\times B}$. Gyrokinetic modelling using code GENE in a linear local approximation indicates that the V_{phase} does not exceed 0.3 km/s at ρ = 0.5 and 0.75 (significantly smaller than the typical measured $V_\perp$). In experiments under consideration, the main contribution to the measured $V_\perp$ comes from the ExB drift velocity $V_{E\times B}$.

Ponomarenko A. et al Sensors 2023, 23, 830 / A. Ponomarenko et al 2024 Nucl. Fusion 64 022001

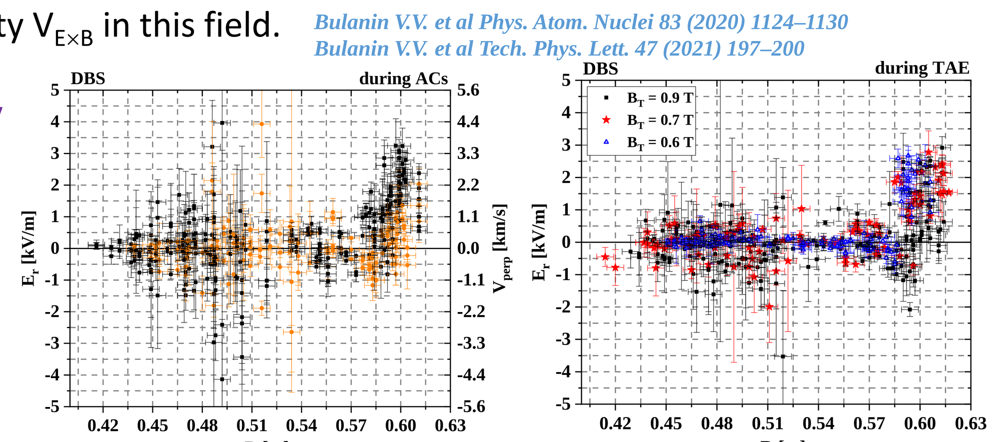
DBS provides characterization of turbulent density fluctuations and flows with non-invasive local measurements of the profile of rotation velocity of the plasma fluctuations. The field of application of DBS has expanded to include the study of coherent and magnetohydrodynamic (MHD) modes. *[YASHIN A.Y. EX-E, P4]*.
Oscillations at AE frequencies were detected in the Doppler frequency shift signals (corresponding to the plasma rotation velocity $V_\perp$) . These oscillations are observed simultaneously with bursts in the magnetic probe (MP) signal. The possibility of detecting AEs using DBS is due to the fact that the radial component of the electric field of the Alfvén wave causes fluctuations in the E×B drift velocity $V_{E\times B}$ in this field.

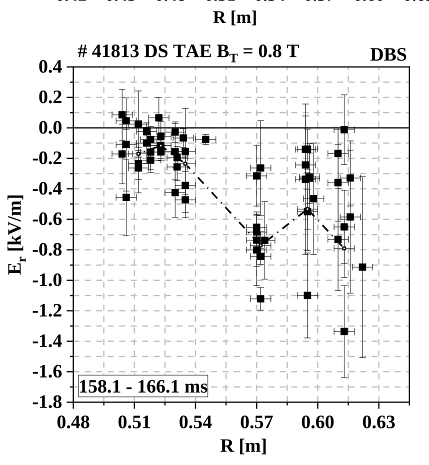
Bulanin V.V. et al Phys. Atom. Nuclei 83 (2020) 1124–1130
Bulanin V.V. et al Tech. Phys. Lett. 47 (2021) 197–200



System #1:
1 variable probing frequency
18-26 GHz
$k_\perp = 1.3 \div 1.9\ cm^{-1}$
$\rho = 0.9 \div 1.1$
System #2:
4 fixed probing frequencies
20, 29, 39, 48 GHz
$k_\perp = 1.1 \div 4.1\ cm^{-1}$
$\rho = 0.6 \div 1.1$
System #3:
6 fixed probing frequencies
50, 55, 60, 65, 70, 75 GHz
$k_\perp = 0.5 \div 8.0\ cm^{-1}$
$\rho = 0.2 \div 0.7$

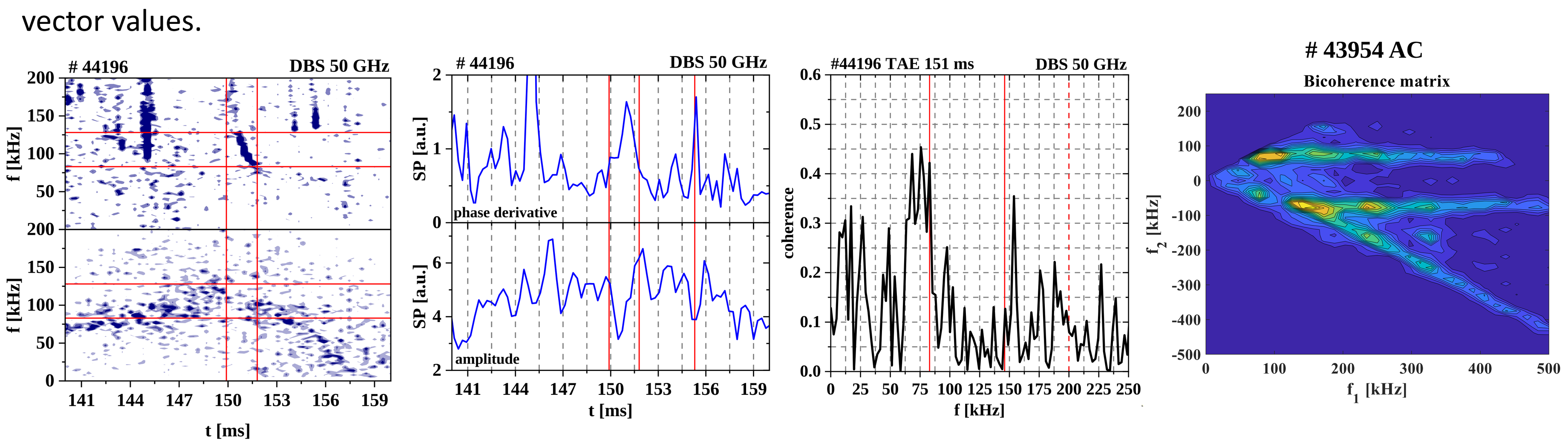
Yashin A.Y. et al JINST 17 (2022) C01023
Yashin A.Y. et al JINST 10 (2015) P10023





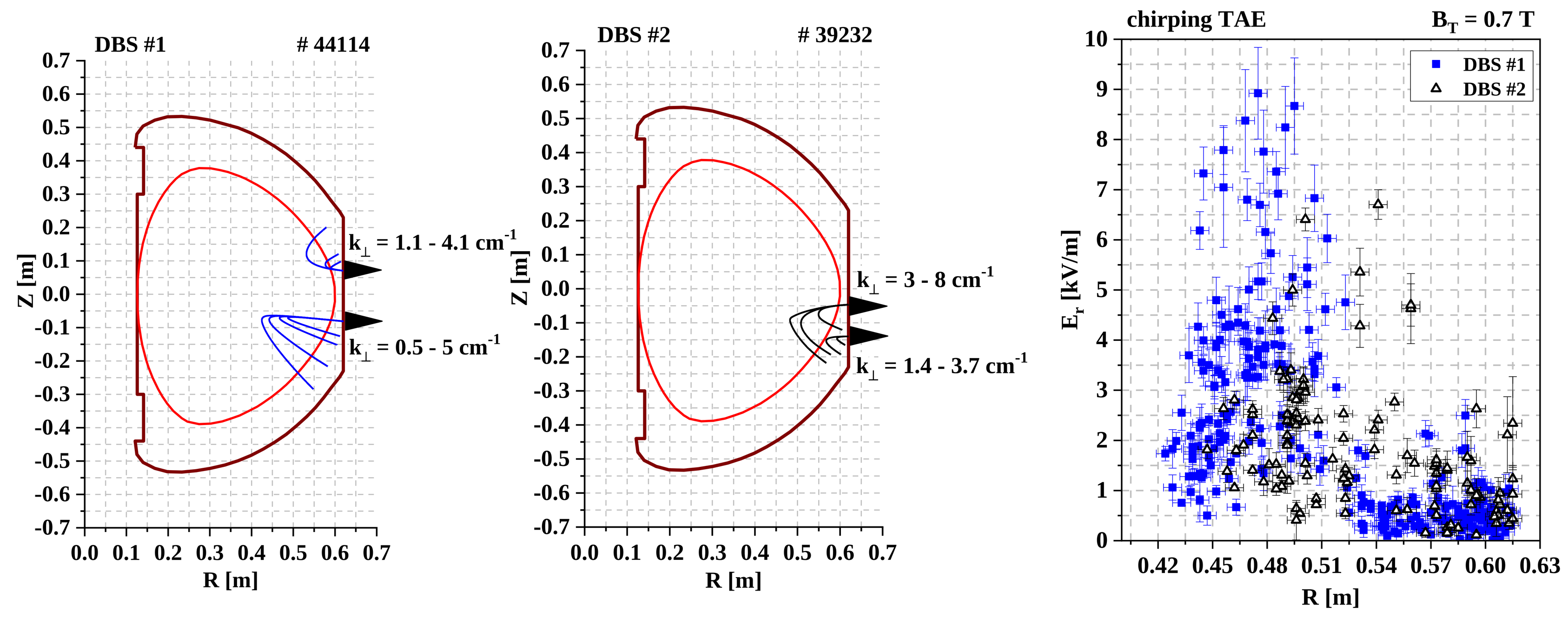
Multi frequency DBS was used to measure the velocity $V_\perp$ and corresponding radial electric field E_r profiles in regimes with various AE development. AE develop in L-mode plasmas at early stages of the discharge, so no strong rotation was observed.

Ray tracing with a 3D code in WKB approximation for the Globus-M2 tokamak geometry using Thomson scattering density measurements and magnetic configuration from the current coil filament method. Allows calculations of cut-off positions and wave vector values.

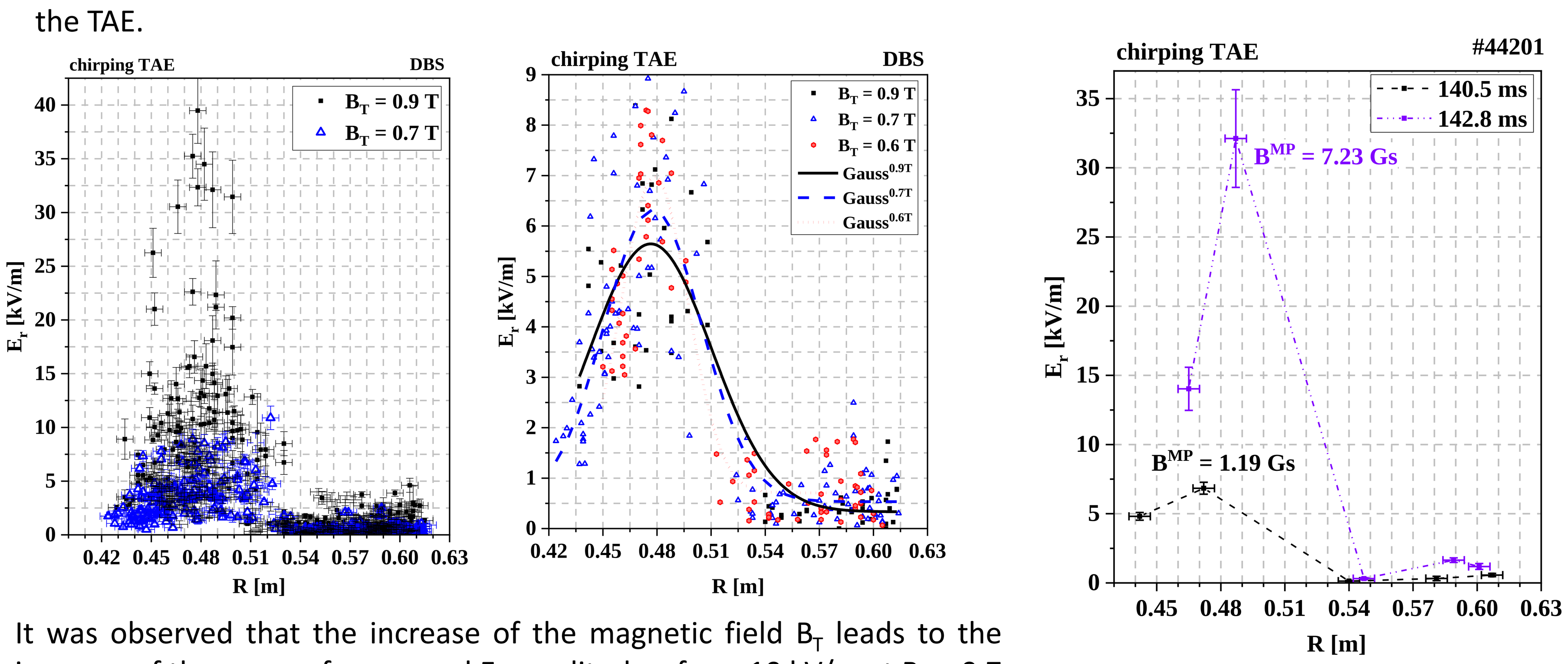


The turbulence level exhibits changes during AEs. For example, in the case of chirping TAE, it can be seen that there is a decrease in turbulence amplitude associated with each burst. Additionally, bispectral analysis was applied to the DBS signals to investigate the non-linear interaction between the plasma turbulence and AEs that may take place.

TOROIDAL ALFVÉN EIGENMODES



As DBS is sensitive to the wave vector $k_\perp$ of the density fluctuations off which the scattering takes place, experiments were conducted with different DBS geometries to investigate the effect on the observation of AEs. The results indicate that, despite different DBS geometries, the TAE E_r amplitudes are of the same order with DBS#1 profiles ranging from 0.5 kV/m to 9 kV/m and DBS#2 from 0.5 to 7 kV/m. Unfortunately, the compared discharges were not entirely identical: despite similar plasma parameters, different NBI sources were used (see NBI-1 (used in DBS#2 case) and NBI-2 (used in DBS#1 case)), which contributes to differences both in values and area of development of the TAE.

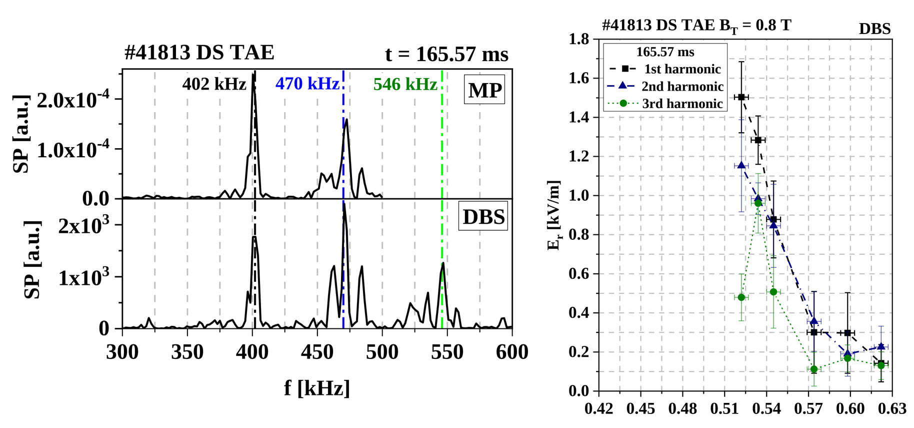


It was observed that the increase of the magnetic field B_T leads to the increase of the range of measured E_r amplitudes: from 10 kV/m at B_T = 0.7 to 40 kV/m at B_T = 0.9 T. For profiles with similar E_r amplitude values it was noted that the higher the B_T, the wider the profile around the local maximum of R = 0.48 m (see Gaussian fits). Additionally, in the case of lower B_T there is an increase of TAE E_r amplitudes at the edge at R = 0.55 – 0.62 m: for 0.9 T the E_r is about 0.5 kV/m, but for 0.6 T it reaches values up to 2 kV/m. This is in line with measurements of 3-4 kV/m at similar radii for discharges with even lower B_T = 0.5 T on Globus-M.

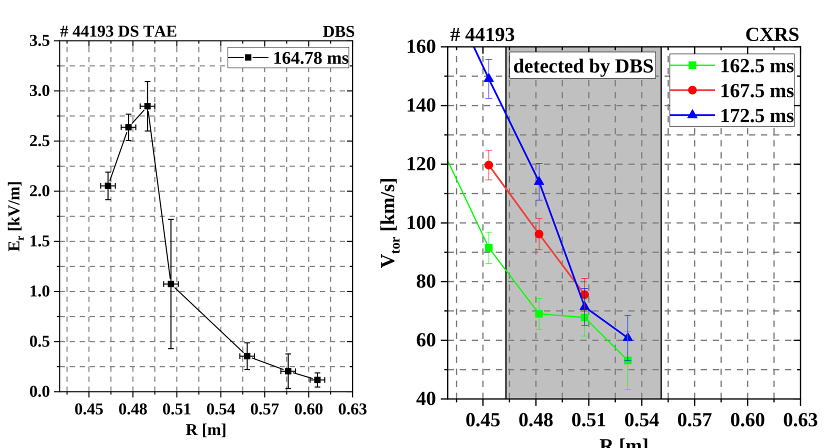
DBS measurements were compared with MP measurements of the TAE magnetic field amplitude B^{MP}. Results demonstrate that higher B^{MP} values correlate to higher E_r amplitudes.

In the assumption that oscillations in the Doppler shift are due to the drift velocity in the radial electric field of the Alfvén wave, then using this assumption, we can calculate the amplitude of oscillations of the poloidal magnetic field projection for the Alfvén electromagnetic wave by the formula $B_\theta = \frac{nE_r}{Rw}$, where n is the toroidal mode number and w is the TAE frequency. In the experiment, TAE frequencies were observed in the range from 100 to 250 kHz (depending on plasma parameters). Using magnetic probes, the poloidal and toroidal mode numbers m and n were determined: as a rule, the n = 1, m = 2, 3 modes are observed. For the presented case, it is estimated that the maximum B_θ measured using DBS is 33.5 Gs and 182.9 Gs. These values are much greater than those measured by MPs which might be explained by the fact that DBS provides local measurements in this region.

DOPPLER SHIFTED TAE



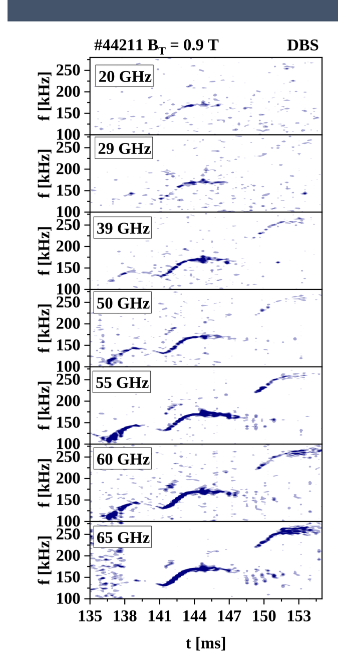
DBS was able to observe several harmonics of the DS TAE in the region of radii 0.45– 0.57 m. The first two harmonics extend deeper into the plasma (no decrease of amplitude detected using DBS), while the 3rd has a local maximum at around 0.53 m. These results are similar to observations on Globus-M where higher TAE harmonics developed closer to the separatrix.



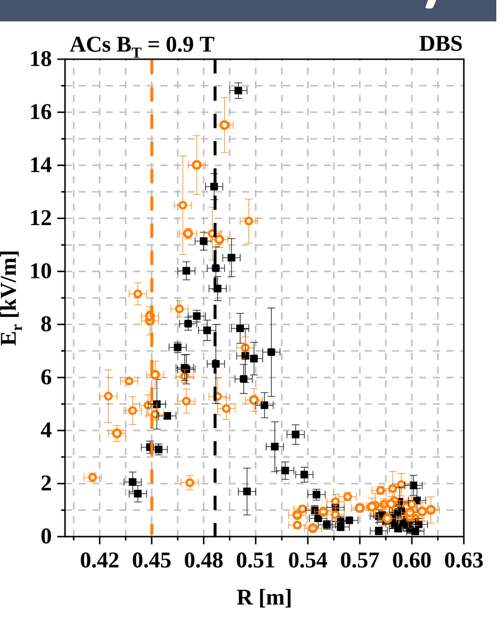
DBS and charge exchange recombination spectroscopy (CXRS) measurements indicate that the DS TAE location coincides with the region of the maximum gradient of the toroidal rotation velocity.

Balachenkov I.M. et al Plasma Phys. Rep. 50 (2024) 765–772

ALFVÉN CASCADES (REVERSED SHEAR ALFVÉN EIGENMODES)



ACs were detected in the range of radii R = 0.41- 0.54 m with E_r amplitudes from 1 to 17 kV/m. Some AC profiles are narrowly localised with a local maximum at about R = 0.48 m and others are deeper and seem to span even further into the plasma (in some cases the available probing frequencies do not allow to construct a full profile). As ACs develop in the region of the minimum of safety factor q_{min}, the differences in profiles seem to stem from differences in the safety factor profiles (there is an approximately 30% difference between safety factor values at the axis between the discharges). The DBS data regarding the region of AC localization makes it possible to estimate the radius with q_{min} and compare it with the calculations obtained using the ASTRA code.



Balachenkov I.M. et al Tech. Phys. Lett. 46 (2020) 1157–1161

ACKNOWLEDGEMENTS

This work was funded by the Ministry of science and higher education of the Russian Federation in the framework of the state contract in the field of science under project No. FSEG 2024 0005.