# OBSERVATIONS OF CORE HEATING AND CURRENT DRIVE BY HELICON WAVES AT DIII-D

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Experiments on DIII-D have shown clear evidence of heating and current drive due to fast waves in the lower hybrid range of frequencies, aka helicon waves. Results were obtained with a MW-level 476 MHz helicon system featuring a load-resilient comb-line traveling wave antenna. These are the first measurements of heating and current drive due to helicon waves in plasmas where the slow wave cannot propagate in the core. The experiments provide data on the viability and efficiency of the current drive scheme, and will provide a valuable benchmark to test our theoretical understanding.

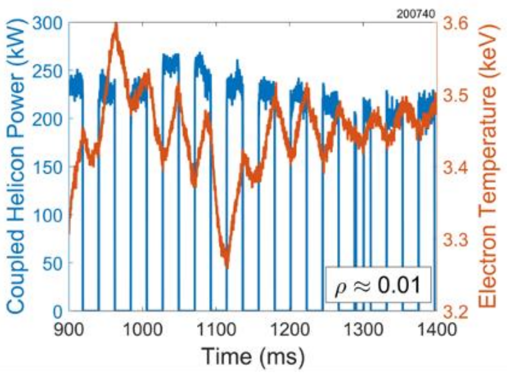


*Fig. 1: Response of the electron temperature to square wave modulated helicon power. The electron temperature shows the same modulation frequency with a 90° phase lag, as expected.*

Steady-state advanced tokamak reactors require non-inductive current drive in the mid-radius region, near $\rho \sim 0.6$. Helicon current drive has long been regarded as a promising tool for reactor grade plasmas [1-3]. In the helicon frequency range, fast waves have propagation characteristics similar to whistlers, i.e., the group velocity is directed mainly along the background magnetic field, slowly spiraling inwards from the edge. Helicon waves have been suggested for current drive in reactor plasmas, as they are thought to be able to propagate into the core without a density limit from which lower hybrid current drive suffers [4]. The weaker damping than lower hybrid waves also ensures helicon waves can reach deeper into the plasma and avoid full absorption at the plasma edge. Helicon current drive is therefore predicted to be effective at high densities and high electron temperatures envisioned for reactor plasmas, and has higher predicted efficiency than off-axis electron cylotron current drive.

Core heating was observed in both L- and H-mode plasmas. In experiments with modulated helicon power the local electron temperature in the plasma core was observed to have the same modulation with a 90° lag, as expected (Figure 1). Estimates of the absorbed power were compared to GENRAY modeling, and indicate that the observed heating agrees with the first-pass absorption predicted by GENRAY. In experiments with continuous helicon injection, the local electron heating was clearly seen as well, with in the best case a 0.7 keV jump in electron temperature with 0.4 MW of coupled helicon power. Electron temperature evolutions were compared to those in shots without helicon injection. The helicon power was also injected at different times during the discharge in successive shots to show the correlation of the heating with the applied helicon power.

Evidence of current drive was seen in L-mode plasmas. In experiments with continuous helicon injection, changes were observed on the motional Stark effect (MSE) diagnostic, measuring the pitch angle of the local magnetic field. This data was compared to data from DIII-D shots without helicon injection, and to data from shots with an equivalent amount of local heating power provided by electron cyclotron heating. Results show clear changes on MSE, and on the resulting q-profile, distinct from the MSE evolution due to local heating only (Figure 3). Changes in the onset and the character of sawteeth were observed, and correlate well with the helicon power.

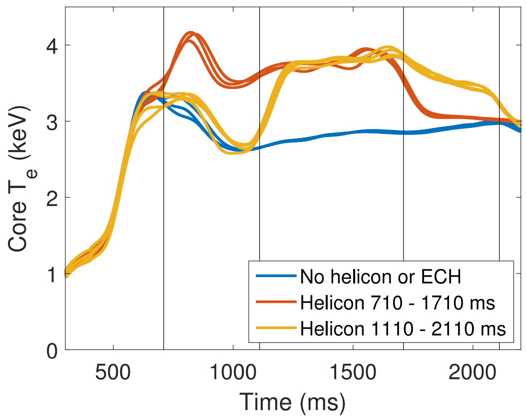


*Fig. 2: Response of core electron temperature to CW helicon power, for shots with different helicon injection times. An 0.3 keV difference is seen with ~0.25 MW of coupled power.*

Experiments are enabled by a 30-module comb-line traveling wave antenna [5] launching helicon power either in the co- or counter-current direction. Experiments at high power have demonstrated load-resiliency in ELMy plasmas [6], as predicted from RF modeling, as the input impedance is largely set by the mutual inductance between modules. Another important result is the absence of impurity influx during high-power operation, in contrast with operation of typical ICRF antennas. Multipactor effects and associated non-linear loss of RF power delivered to the antenna are an issue however. Data from scans of the helicon power clearly show the expected strong dependency on the applied power where klystron power levels in the range of 0.05-0.15 MW are most problematic. Direct excitation of the slow mode by the antenna was investigated by comparison of shots with good alignment between the Faraday screen (FS) and the magnetic field to shots with poor alignment. An order of magnitude increase in parametric decay activity measured by magnetic pickup coils at the wall was observed in plasmas with poor field alignment, indicative of effective screening of the slow mode by the FS with good field alignment.

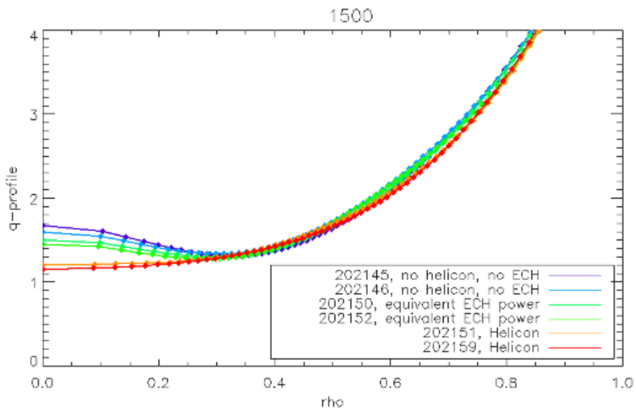


*Fig. 3: Differences in q-profile in plasmas with helicon power driving co-current, plasmas without helicon power and plasmas with an equivalent amount of heating power provided by ECH.*

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