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Observation of rapid frequency chirping driven by runaway electrons in DIII-D

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We report the first observation of chirping instabilities driven by runaway electrons (REs) in a tokamak. Energetic particles often drive instabilities through wave-particle resonances. The frequency of an instability can sweep gradually as background plasma parameters evolve or it can change rapidly (known as "frequency chirping") due to nonlinear evolution of the energetic-particle distribution function. Chirping instabilities driven by REs in two distinct frequency bands are observed for the first time in the DIII-D tokamak. In addition to their intrinsic interest, these observations could be of practical importance, as kinetic instabilities that modify the RE distribution function may mitigate damage by runaways in a tokamak reactor.

REs are often generated during tokamak disruptions due to large induced electric fields accelerating suprathermal electrons up to relativistic energies. In the present experiments the disruptions with generation of a hundreds kA RE beam are deliberately triggered by an injection of an argon pellet in DIII-D. The resultant post-disruption plasma is cold, dense, with a large fraction of the high-Z impurity. To extend the runaway stage and reduce the transformer flux required to run the current, argon is purged from the plasma by a secondary injection of deuterium gas. This provides access to a RE beam at low collisionality lasting more than a second and a large variability of an applied voltage.

The RE energy distribution function is constrained via hard x-ray bremsstrahlung measurements using the Gamma Ray Imager. It has a non-monotonic feature (bump) at about 5 MeV suggesting the presence of free energy to drive kinetic instabilities. The chirping instabilities driven by REs are observed when a negative (decelerating) loop voltage is applied.

The frequency chirping is detected in two distant frequency bands: 1-10 MHz and 45-75 MHz. The frequency typically changes by 0.5-1 MHz on a timescale of 1 ms. Modification of the RE distribution function is directly measured during the chirping in the low-frequency band. The low-frequency instability also correlates with an increase of an intermittent RE loss from the plasma. Distinct modes chirping upward and downward are observed during the high-frequency instabilities. The frequency of instabilities in both frequency bands increases nearly linearly when the toroidal magnetic field sensed by the RE beam increases. The instabilities are hypothesized to be compressional Alfven eigenmodes since their frequency lies between Alfven and ion cyclotron frequencies for given plasma parameters. They are supposedly driven by a non-monotonic RE distribution function, likely lead to a pitch-angle scattering of REs and increase RE radial transport. Similar frequency range instabilities are also observed shortly after the disruption without deuterium injection, opening the possibility of excitation of these modes at higher collisionality.

The observations of RE-driven frequency chirping provide a novel experimental platform for fundamental studies of nonlinear chirping. They also support a continued research effort to understand the RE loss driven by the instabilities and how to benefit for RE mitigation in ITER.

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