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Broadband microwave emission and electron losses associated with kinetic instabilities in ECR Plasmas

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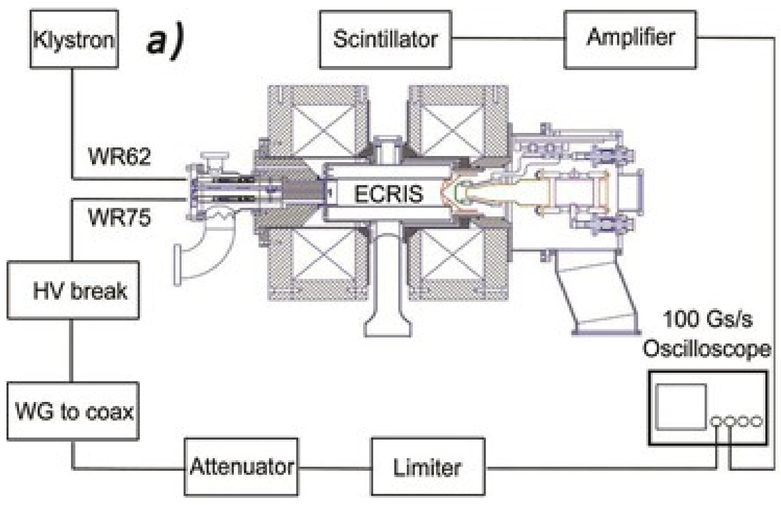
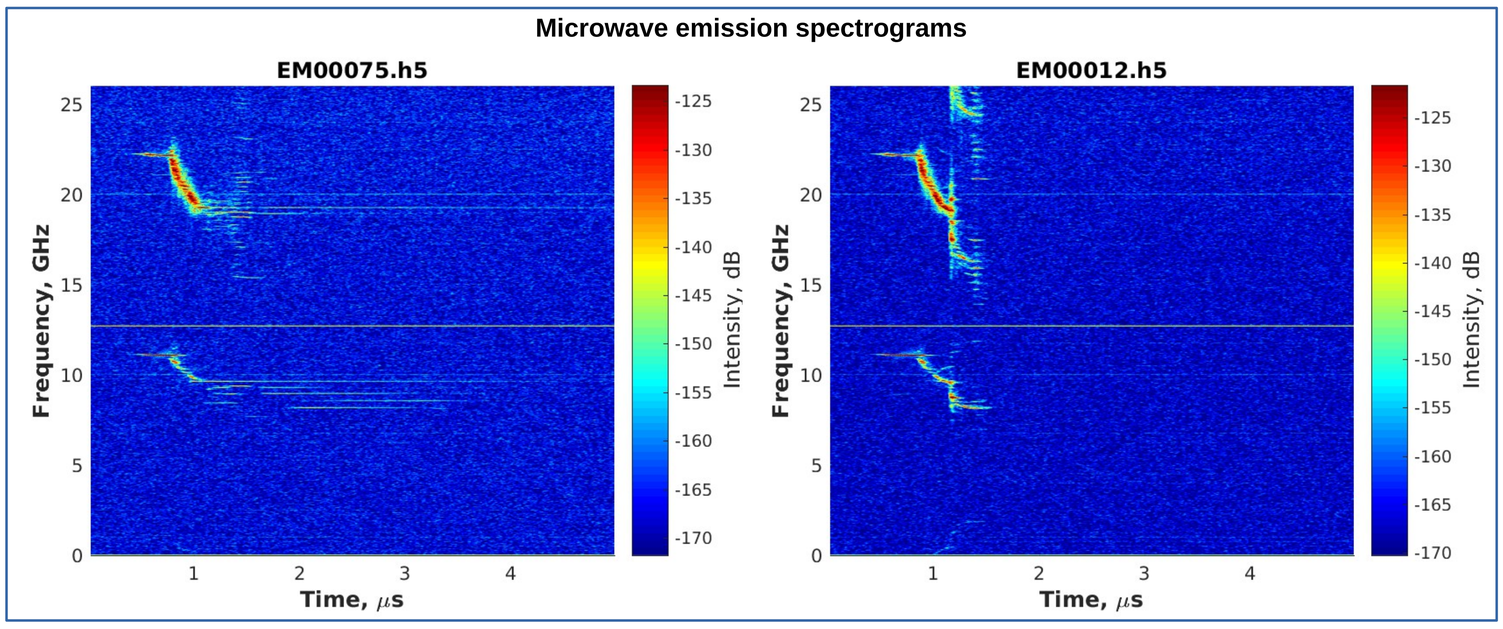
Electron cyclotron resonance ion sources (ECRIS) have been essential in the research and applications of nuclear physics over the past 40 years. They are extensively used in a wide range of large-scale accelerator facilities for the production of highly charged heavy ion beams of stable and radioactive elements. Plasmas of electron cyclotron resonance ion sources (ECRISs) are prone to kinetic instabilities due to the resonant heating mechanism resulting in anisotropic electron velocity distribution. Instabilities of cyclotron type are a proven cause of frequently observed periodic bursts of “hot” electrons and bremsstrahlung, accompanied with emission of microwave radiation, and followed by a well-known and frequently observed oscillations of extracted ion beam current in the case of high plasma heating power and/or strong magnetic field, leading to a notable reduction and temporal variation of highly charged ion production. Thus, investigations of such instabilities and techniques for their suppression have become important in ECRIS research. Data showing the presence of the microwave emission associated with the instabilities for different experimental facilities are presented. Detailed studies of the microwave radiation have been performed with a minimum-B 14 GHz ECRIS operating on helium, oxygen and argon plasmas. It is demonstrated that during the development of cyclotron instability “hot” electrons emit microwaves in sub-microsecond scale bursts at temporally descending frequencies in 6-25 GHz range and exhibit certain dominant frequencies regardless of ECRIS settings i.e. magnetic field strength, neutral gas pressure or species and microwave power. The possible energy range of the electron population amplifying the plasma waves is estimated and arguments on possible excited plasma wave modes are given.
An original method for direct measurement of the energy of electrons leaving the trap along a magnetic field using the 90 degree analyzing magnet as a spectrometer coupled to a secondary electron amplifier is developed. The measured electron energy spectra are presented and compared in stable and unstable regimes. A correlation is made between the energy of electrons leaving the trap during the development of the cyclotron instability and the spectrum of the electromagnetic radiation.

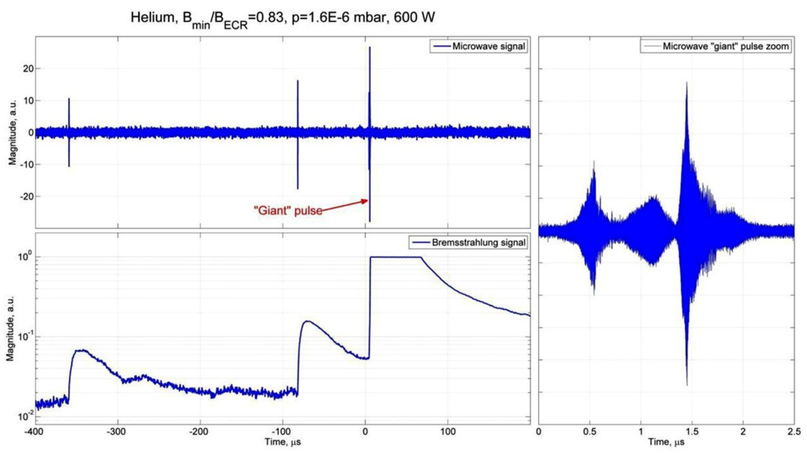
Experimental setup



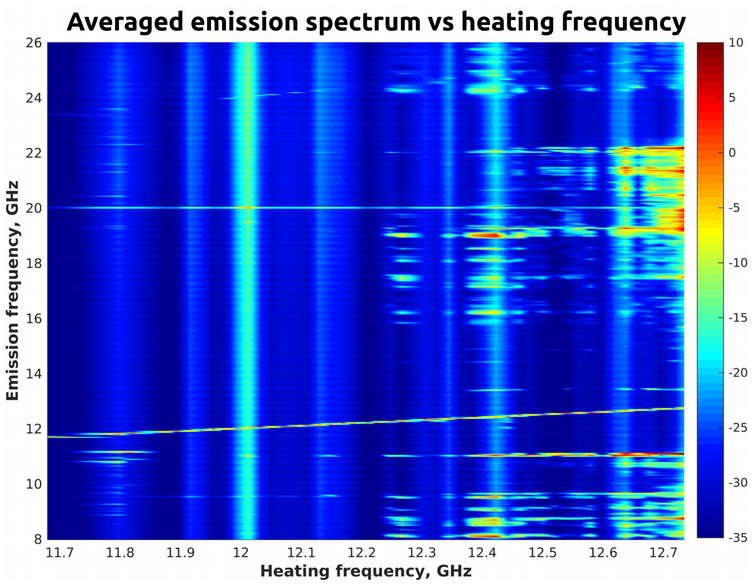
Microwave emission spectrograms



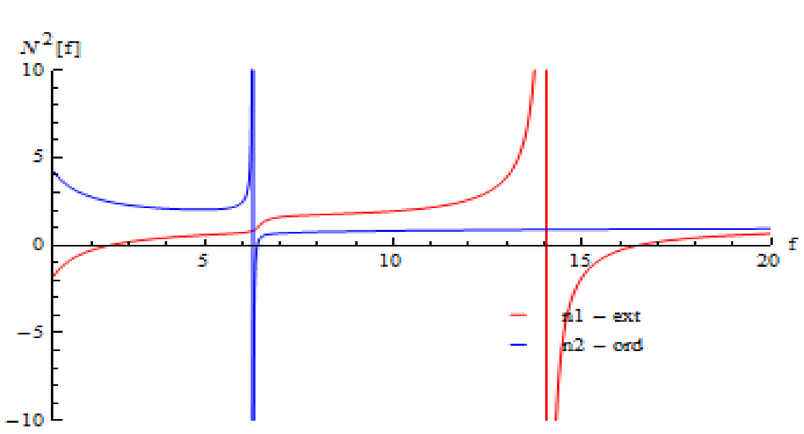
Example of x-ray and microwave bursts



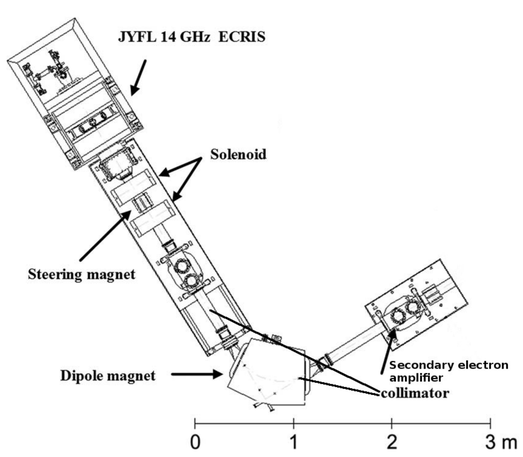
Averaged emission spectrum vs heating frequency



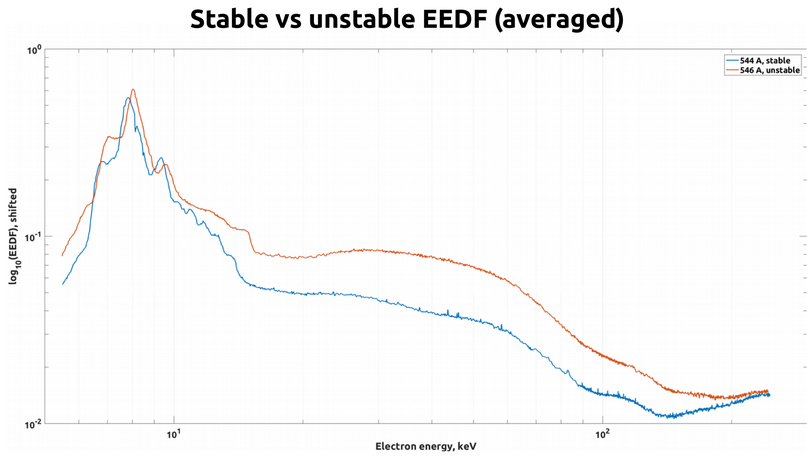
Slow extraordinary Z-mode propagating quasi-longitudinally with respect to the external magnetic field: emission frequency barely depends on plasma parameters.



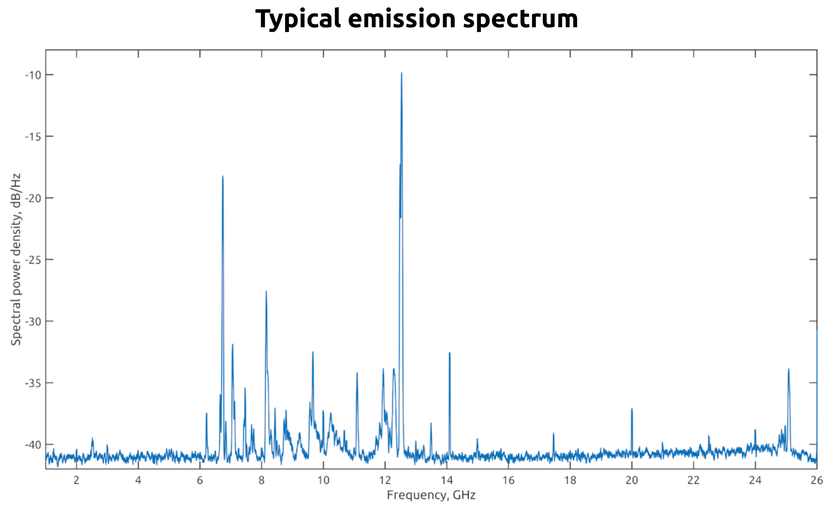
Electron energy measurement scheme



Stable vs unstable EEDF (averaged)



Typical emission spectrum



Distance between energy peaks correlates with distance between frequency peaks!