ECE and Reflectometry on HSX

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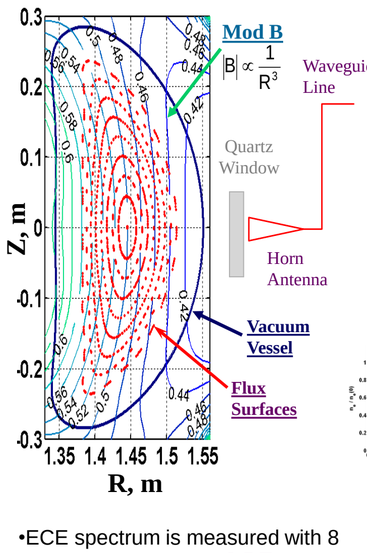
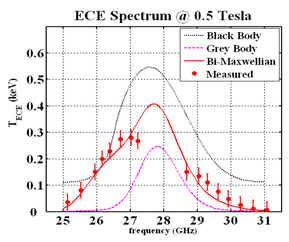
ECE Radiometer

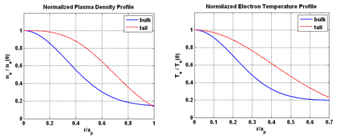
HSX Vertical Cut



Simple Model, ECE from Bi-Maxwellian Plasma Validates Measured Spectrum



N_e and T_e Broader for High Energy Electrons



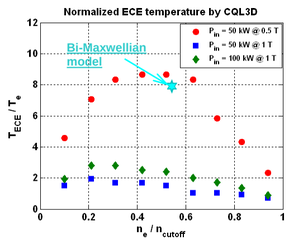
- Radiative transport equation is solved (1) in Bi-Maxwellian plasma:

$$T_{ECE} = \int_a^b ds(\alpha_{\omega,bulk}T_{bulk} + \alpha_{\omega,tail}T_{tail}) \exp[-\int_s^b (\alpha_{\omega,bulk} + \alpha_{\omega,tail})ds']$$

  (2) in quasi-linear case --- the electron distribution function from CQL3D code
- Thomson Scattering profiles are used to estimate the optical depth of the bulk plasma
- Bulk T_e = 0.6 keV ; N_e = $2.6 \cdot 10^{12}$ cm^{-3}
  Tail: T_e = 4.5 keV; N_e = $0.6 \cdot 10^{11}$ cm^{-3}
- Plasma stored energy measured by the flux loop (21 J) has two parts (1) 15 J in the bulk and (2) 6 J in the tail
- Broader tail N_e and T_e profiles give enhanced emission on both the low and high magnetic field sides

- ECE spectrum is measured with 8 channel radiometer at 0.5 Tesla
- Central region of the plasma is not accessible because the heating source frequency is within the emission band
- Radiometer has been calibrated against Thomson Scattering in plasma with off-axis heating when the plasma is thermal
- We replace the IF filters in order to cover the plasma radius within +/-0.6

CQL3D Fokker-Planck Code Calculates Non-Thermal ECE @ 0.5 T and Predicts Small Distortion in Momentum Space @ 1 T



- Distribution function is calculated by CQL3D
- Then it is used to find ECE spectrum
- Plasma density scan made at 0.6 keV (50 kW / 0.5 T), 1.2 keV (50 kW / 1 T) and 2 keV (100 kW / 1 T)

ECE Fluctuations

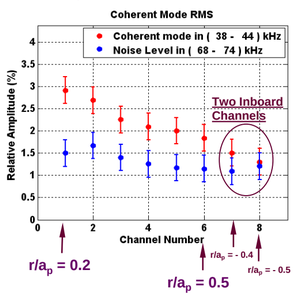
Coherent Mode is detected by ECE

- Plasma density fluctuations affect the ECE signals when the optical depth is low (< 1.7)
- HSX plasma at $1.5 \cdot 10^{12}$ cm^{-3} is optically thin ($\tau < 1$)
- Photon statistics noise in our case is about 1.5%
- RMS of the coherent mode is defined as follows

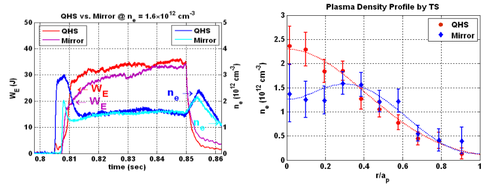
$$rms \equiv \sqrt{\int_{\Delta f} pdf} \Big/ A_{DC}$$

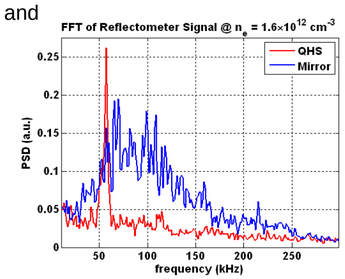
- Mode is well pronounced at the low magnetic field

Interferometer, Mirnov coils, Langmuir probes (r/a_p~0.6) see the mode as well



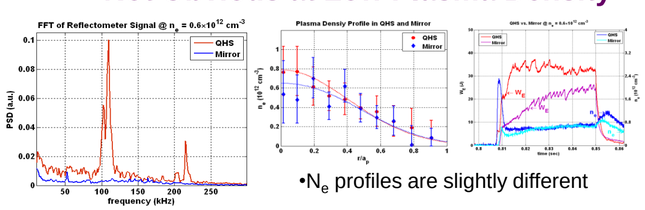
Broad Spectrum of Fluctuations in Mirror





- Stored energy and line average density are close
- QHS density profile is peaked while it is hollow in Mirror
- Probing beam frequency:
  19 GHz in both cases

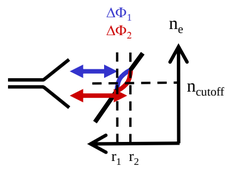
Not Obvious at Low Plasma Density

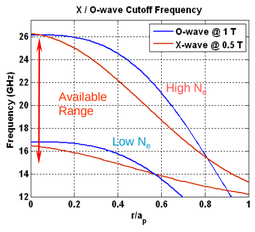


- N_e profiles are slightly different
- Probing beam frequency: 18 GHz in QHS and 19 GHz in Mirror, respectively

Reflectometer

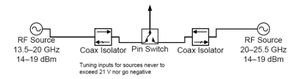
Principle of Diagnostic



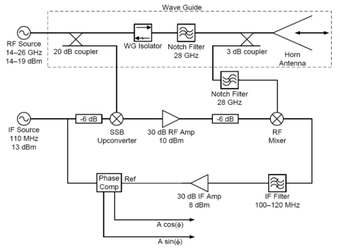


- Reflection of microwave beam from a cut-off plasma layer
- At a single frequency the measured time delay gives the distance to the reflection point (radar technique)
- With frequency sweep the inverted phase gives the plasma density profile
- Plasma density fluctuations introduce additional phase shift
- Range of the central density in HSX:
  1 - (0.5 – 4)·10^{12} cm^{-3} at 0.5 Tesla – X-wave;
  2 - (3.5 – 8)·10^{12} cm^{-3} at 1 Tesla – O-wave;
- Overlapping frequency band of two sources: (15 – 26) GHz

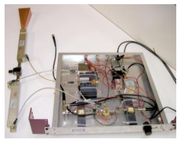
Two Sources Sweep Entire Plasma

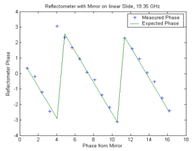


Heterodyne Detection



Bench Testing



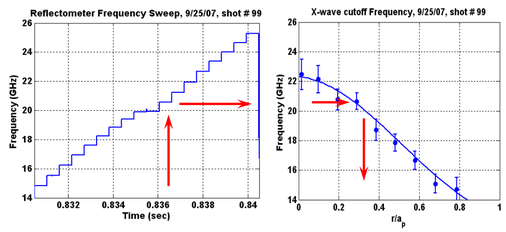


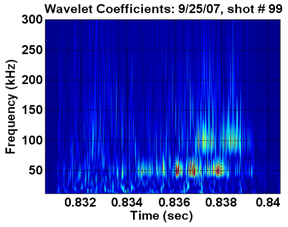
- Testing was made with a metal plate
- Good agreement between measured phase and calculations
- Slight shift is due to uncertainty in determining the distance between the antenna and the reflecting plate

Plasma Density Fluctuations

Coherent Mode Dominates in QHS Plasma Core

Sweep of Probing Beam Frequency

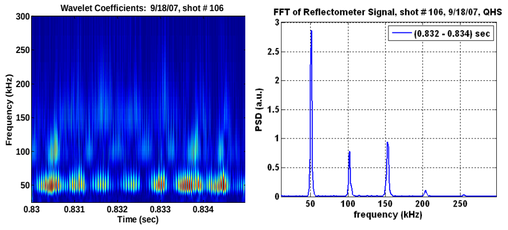




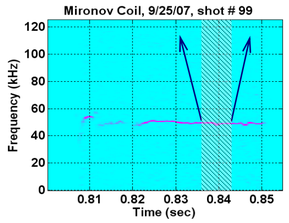
- A few sweep cycles during a plasma discharge
- Step function gives good frequency resolution
- Cut-off frequency is calculated based on TS profile

Bursty Mode and Higher Harmonics

Fixed Probing Beam Frequency



- Deep in plasma core (F_{beam} > 23 GHz) high harmonics are found
- Fast changes are on the order of e-e collision time (100 μsec)



The Mode is seen by Mirnov Coils During Full Sweep of Reflectometer

Future

- 16 channel ECE radiometer is ready. It has been tested on the bench
- 2-D modeling of wave propagation to be used to find a level of plasma fluctuations
- Measurements @ 1 Tesla

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