Applications of Electrostatic Waves to Burning Plasma Experiments

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Introduction and outline

This talk is concerned with rf heating and current drive in a burning plasma experimental device. In some of the regions of parameter space that are being considered for such a device, “conventional” rf H & CD scenarios become difficult. We will consider two such extremes:

1) high field (about 10 T or even higher), high density

2) low field, low aspect ratio, high beta, such as might be characteristic of an ST based device

In this context, we consider three varieties of electrostatic waves - the ion and electron Bernstein waves and the lower hybrid (slow) wave.

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Electrostatic waves in high field, high density devices: IBW

- Ion Bernstein Wave: advantages over fast waves and IBW in lower field devices include:

1) Simple waveguide launch, as in original IBW concept (Ono, '79)
2) Mode transformation from low frequency LH wave to IBW occurs well away from extreme edge of plasma, possibly in region with lower fluctuation levels and less scattering
3) Nonlinear effects (ponderomotive forces, PDI, etc.) are substantially reduced from lower field IBW situation due to very strong frequency dependence
4) Strong absorption at ion cyclotron harmonics leads to possibility of flow modification, controllable transport barrier, etc.

- IBW: disadvantages/uncertainties include:

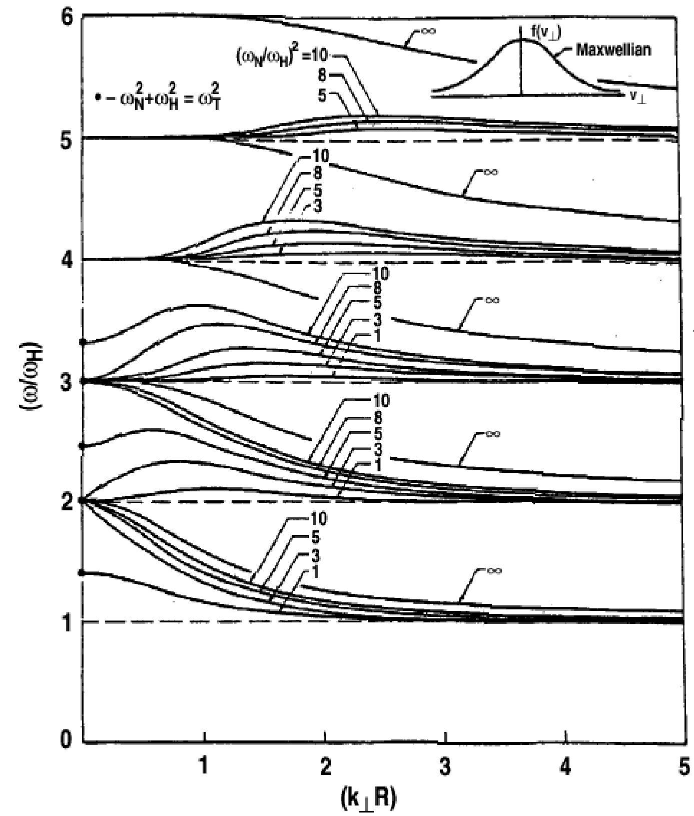
1) Difficult to test in anything less than full blown BPX (but see FTU results), so no really applicable database exists
2) May still be subject to strong scattering, due to very short cross-field wavelength

Electrostatic waves in high field, high density devices: LH waves

- Lower hybrid wave for electron heating - principal possible advantage for high field is that accessibility goes like density/B_T^2 - so if increase in density does not correspond to the square of the toroidal field, you win.
- Density limit for electron interaction roughly scales with f^2, so 10 GHz would allow electron heating at up to about 10^{21} m^{-3}
- Requires phase coherent sources, hence amplifiers, not oscillators like conventional gyrotrons. Consider massively parallel system of gyro-klystron amplifiers!
- Launcher is technically difficult, but relatively short pulse helps a great deal

Electrostatic waves in high field, high density devices: EBW

- Since EBW does not exist below fundamental, not clear that there is any particular advantage to the EBW over ‘conventional’ EC schemes for very high field - very high frequency sources are required in any case



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Electrostatic waves in low field, high density devices: IBW

- IBW probably not useful in this context, when compared with the high harmonic fast wave. This scheme has been tested in plasmas with similar values of toroidal field (at higher aspect ratio), and not found to work very reliably or predictably. This probably is a consequence of the very low density at the mode transformation layer, and the tendency of nonlinear effects to be very strong at the low frequencies necessary

- Not recommended!

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Electrostatic waves in low field, high density devices: LH

- Severe accessibility problems (due to high dielectric value), very low density limit. Conceivably of limited utility for modification of edge current density

Electrostatic waves in low field, high density devices: EBW

- This is probably the most useful of the electrostatic waves for high dielectric constant plasmas, IF the coupling of power to the EBW is reasonably efficient. Three schemes have been proposed and, to differing extents, studied:

1) O-X-B scheme, proposed many years ago, and demonstrated relatively recently at Garching

2) X-B, which was realized might be much more effective than originally thought due to the proximity of the high field side cutoff ("internal resonator"), analogous to ICRF case

3) direct Bernstein wave launch, which we may define as the situation in which the gap between the launcher and the system of cutoffs, UHR layer is much shorter than the vacuum wavelength, which for low harmonic EBW at low field and high density can easily be the case

Electrostatic waves in low field, high density devices: EBW, continued

- **Comments on EBW launching schemes:**

1) O-X-B scheme: requires precise control of the toroidal aiming of the microwave beam, the angle of which in principle depends on the density gradient at the O/X coalescence point. Hence, seems to be possibly quite difficult in a dynamic situation

2) X-B and direct launch cases both can launch waves with n-parallel of 0, but the mode conversion efficiency can be adjusted by the poloidal launch angle, the optimal value of which depends on the density gradient at the upper hybrid resonance layer - possibly requiring a poloidally steerable mirror

3) For the X-mode launch cases, one must consider the effect of multiple bounces between the wall and the UHR layer - like a beam bouncing between a somewhat lossy mirror (the UHR layer) and a perfectly conducting wall. Eventually all of the energy can be mode converted in such a situation. Unlike in ICRF, where sheath losses at the wall can compete with weak central absorption, seems likely that the wall can present a surface much closer to this ideal in the microwave region, as long as the "single pass" mode conversion is much larger than the ohmic losses in the walls.

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Conclusions

- For high field, high density situations, the two electrostatic modes that should be considered are directly (waveguide) launched Ion Bernstein Waves and X-band LH waves
- [In this case, most other requirements can be met with conventional fast waves and possibly with relatively conventional ECH, provided the rather high frequency sources can be developed (as described by Temkin)]

- For low field, high density (ST-like) situations, the Electron Bernstein Wave, excited either directly or via X-B with poloidal spectral control, should be considered
- [In the ST-like case, the High Harmonic Fast Wave should be quite useful, and 3rd harmonic EC may be useful under some circumstances, particularly for damping off-axis on the (relatively) high field side]

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