Summary of ET3 2001 discussions

Presented by David Swain for the NSTX HHFW and EBW groups

NSTX Research Forum

PPPL

January 15, 2001

Outline

- List of presentations
- High-harmonic fast wave (HHFW) plans for the rest of 2001
- Electron Bernstein wave (EBW) plans for the rest of 2001
- Status of EBW studies in 2000
- Status of HHFW studies in 2000

Conclusions

Extremely productive year for HHFW and EBW!

As usual when you have good people, there are more ideas than time and money to carry them out.

Plans for the rest of 2001 have some very interesting experiments in both fields

- Improved plasma diagnostics will be key to improved understanding.
- Increased capability of HHFW system (e.g., real-time phase control) will enable some interesting experiments *per se* and also in conjunction with beams.

Modeling work is becoming more attuned to challenging conditions in NSTX

- Earlier approximations that were valid for conventional tokamaks (but not for NSTX) are being replaced with more applicable models.
- Theoretical work appears strongly coupled to experimental results and needs.

Summary of presentations

- HHFW
  - Swain - HHFW coupling studies
  - (Wilson - XP-25 Early heating with HHFW)
  - LeBlanc - HHFW heating results
  - Ono - HHFW wave scattering
  - Mau - analysis of HHFW heating using CURRAY
  - Bonoli - full-wave simulations of HHFW using TORIC
  - Phillips - HHFW modeling using METS
  - Batchelor - HHFW modeling using AORSA
  - Rosenberg - ion absorption in NSTX: thesis plans
  - (Menard - Proposal for off-axis heating w. HHFW in NBI discharges)
- EBW
  - Taylor - EBW measurements and plans
  - Ram - EBW emission calculations
  - Pinsker - direct waveguide coupling to EBW in low-field devices

HHFW plans for the rest of 2001

Important issues (not prioritized):

- Better study of heating vs r,t (more Thomson scattering, start ion meas.) to get local power deposition
- CD phasing studies
- Closed-loop phase control
- RF H-mode studies
- Study early heating phenomenon (explain Menard's results)
- Test Ono's wave-scattering theory
  - reflectometery with finite bandwidth to look for sidebands
  - He vs D
  - trends (does heating behavior follow predictions of scattering theory?)
- Asymmetric loading studies and effects on CD
- Use rf as tool to make broader pressure profile for higher beta limits. (MHD group too).
- Effect of HHFW on beam-heated plasmas (fast ions, off-axis heating,…)

EBW plans for the rest of 2001

- Correlate measured gradients in n and T at upper hybrid resonance with emission levels (need reflectometer and Thomson scattering near edge)
- Add 8-12 GHz EBW radiometer in March to increase radial coverage (in addition to present 11-18 GHz)
- Use neon puffs to study EBW source localization and radial transport
- Modulate 18 GHz ORNL ECH during plasma, look at EBW emission with UCLA off mid-plane horn
- Include ray tracing weighted by antenna pattern in calculations
- Model expected EBW emission for actual NSTX plasmas we are studying
- Extend 18 GHz launcher horn nearer to plasma to improve coupling to EBW
- On CDX-U, continue EBW research with an in-vessel antenna/probe assembly

Status of NSTX EBW emission studies in 2000

- Measured mode-converted EBW with 11-18 GHz fast (<100μs) scanning radiometer
- Used dedicated re-entrant mid-plane port and ORNL dual ridged antenna
- During NBI-heated H-modes, with steep edge density profiles, emission increased ~ 300%
- Measured 10 - 20% mode conversion efficiency, consistent with theory
- Persistent multiple emission peaks observed during HHFW, so far not understood

Status of EBW modeling in 2000

NSTX

A. Ram

- Calculates necessary conditions for X-B and O-X-B mode conversion – analytic and computational models.
- Has full wave slab code with magnetic field shear, dens and temp profiles (perp. to B_0), kinetic model of waves: X, O and EBW.
- Finds
  - fraction of X-mode from outside changed to EBW is the same as fraction of EBW at center that is emitted by changing into X-mode
  - experiments on heating and current drive by EBW can be designed on the basis of emitted radiation.
- Need measurements of scale lengths near edge to compare theory with experiment.

Status of EBW modeling in 2000 (con't).

R. Pinsker

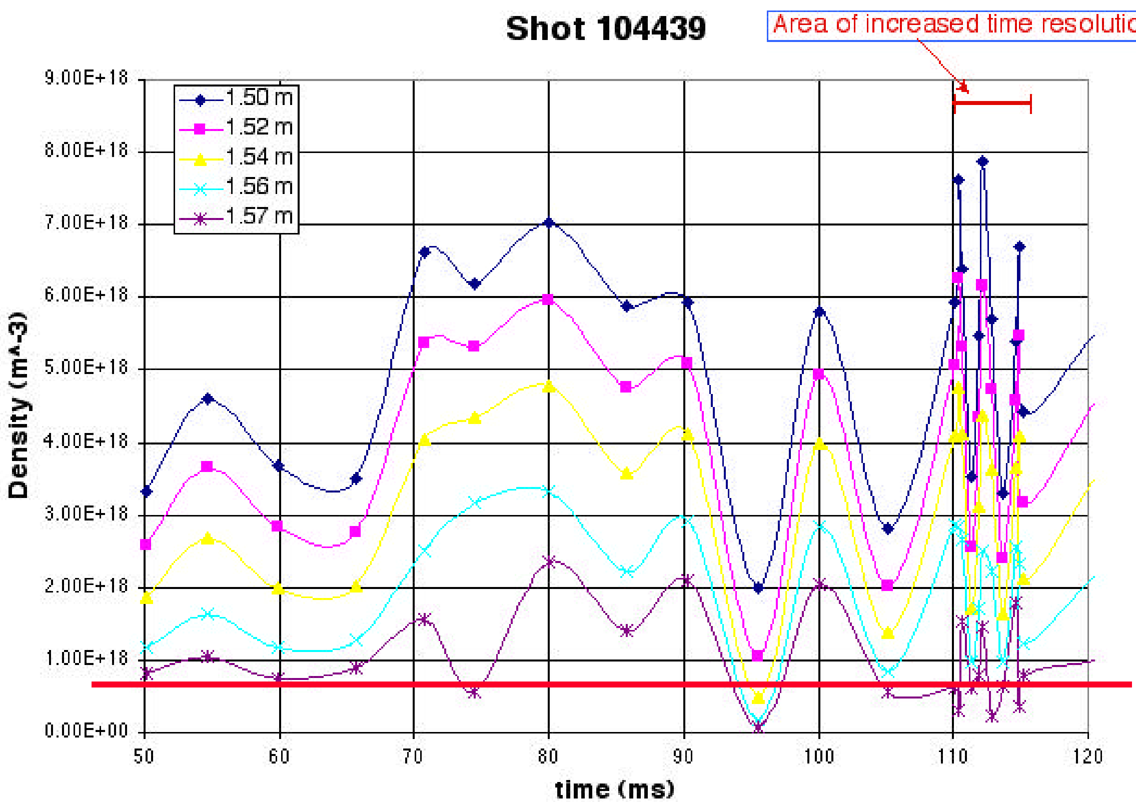
- Solves waveguide coupling into slab plasma, sees very little reflection with step function density profile within 1 cm of plasma (for $k_{||} = 0$).
- Can use GLOSI (M. Carter, ORNL) to do calculation with arbitrary density profile, which can then be used to calc. rho.
  - Should get good coupling to EBW if can get above UHL within ≈ 1 cm of launcher (moveable launcher?)
  - For larger gap, can get coaxial modes between launcher and plasma; these can "suck up all the power" if gap > vacuum wavelength.
- Would like to do experiments to test waveguide coupling, possibly on CDX-U, MST, Pegasus,…

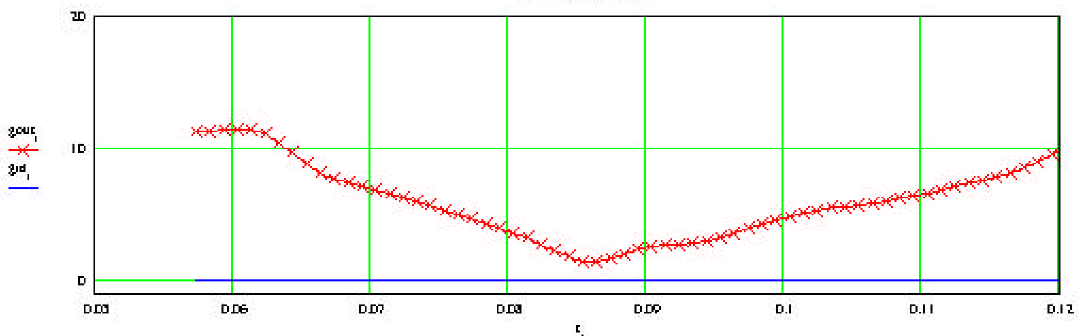
Status of HHFW in 2000

Swain

- Improved reflectometer data – lower density, better time resolution
  - Can measure lower density by using X-mode
  - Will enable dwell mode at one frequency to measure fast density fluctuations
  - Will observe 30 MHz coherent wave component (to meas. wave amplitude near antenna)
- Asymmetric loading appears to exist – seen theoretically and experimentally
- Loading is high, appears insensitive to gap
  - Understandable since distance to density where wave prop. begins is ≈ 1 cm
- Modeling of loading/circuit model interaction is becoming more sophisticated
  - RANT3D can now calculate 12-antenna impedance matrix
    - Allows computation of changes in effective loading and asymmetry as rf source amplitude and phase are varied
    - Can replace earlier assumptions in model

Reflectometer sees large fluctuations and “high” density near antenna





- Fluctuations ≥50% occurring in edge
- Fluctuation time faster than can be observed by present sweeping mode of reflectometer
- Propagation density for wave occurs within few cm of antenna surface

HHFW scattering from turbulence? - M. Ono's hypothesis

- Results of calculations indicate that HHFW could be subjected to low frequency fluctuation scattering. This could reduce the core heating for low $n_{||}$ modes.
  - Scattering increases with decreasing $n_{||}$.
  - Increasing temperature reduces scattering.
  - Increasing magnetic field also reduces scattering for the
  - fastest mode.

- How can we improve the situation, based on theory?
  - Clearly quieter edge is desirable. (Is the fluctuation level generally lower for helium compared to deuterium?)
  - Steeper density gradient is better. (Is the density gradient diverted discharge steeper than the limited discharge? How does the heating efficiency depends on the scrape-off length?)
  - Hotter edge is better. (H-mode?)
  - With scattering, there are considerable up and down shifts of wave spectra (broadening - more core heating?).

Possible HHFW turbulence XP's

Clearly we need to characterize the edge:

- Density and Temperature Profiles (MPTS, Reflectometry, CHERS, Edge Probe, etc.)
- Fluctuations (Reflectometry, Edge Probe, etc.)

Parametric dependence of interest:

- Helium vs. deuterium.
- Diverted vs. limited.
- Distance to the LCFS.
- Magnetic field scan (3 - 6 kG)
- L-mode vs. H-mode

Analysis opportunity:

- More precise geometry
- Input experimental measurements.
- Ray-tracing + scattering. ($n_{||}$ Up-shifts + downshifts)

HHFW modeling in 2000

Several groups worked to calculate HHFW heating and power deposition, using a variety of codes and approximations. All being guided by recent experimental results:

Bonoli-

- Has linked TORIC code to EFIT equilibria. Use of EFIT instead of moments method equilibrium broadens calculated deposition profiles in C-Mod and NSTX.

- Plans:
  - compute HHFW CD using CD module coupled to TORIC
  - examine convergence of poloidal mode expansion for HHFW (may need ≥ 60 modes instead of present 20 modes?)

BONOLI VG - CALC NSTX POWER DEPOSITION PROFILES

HHFW modeling in 2000 (con't.)

Mau -

- CURRAY code uses T_e profile similar to data. Finds peaked abs. during OH, off axis at r/a >0.6 during heating phase (agrees with meas.)
- Analyzed He discharges, sees peaked absorption profilewhen using meas T_e profiles; broader T_e profiles observed in D result in off-axis heating.
- He abs. weaker than D abs. For small H minority (5-10%) can get H abs. $\geq$ 40 % when $k_{||} \leq$ 10 m^-1. Alternative explanation for weaker $0\pi\pi0$ heating.
- Future work:
  - upgrade CURRAY to fully kinetic code, no expansions. Still trace rays, but uses full ion to calc. absorption.
  - more detailed analysis of HHFW as CHERS ion diagnostic comes on
  - develop approx. Maxwellian absorption analysis to use for shot-to-shot analysis
  - further code upgrades to get ready for 40% β, large f_{bs} operation in future.

HHFW modeling in 2000 (con't.)

Phillips -

- METS predicts weak but adequate damping for low target dens and temp. (T_0=300 eV, n_0=5x10^{13} m^{-3}).
- Substantial ion damping possible in D plasmas on H minority, particularly for lower $k_{||}$ modes (agreement w. Mau results).
- For He, get more abs. in electrons.

Batchelor -

- Uses AORSA full-wave all-orders code to calculate HHFW propagation, mode conversion to IBW, and absorption in NSTX plasma
- Sees addition of poloidal field spread power deposition profile, as observed in experiments.
- Can also calculate conversion to IBW at high harmonics.
- Requires large computational resources

Conclusions

Extremely productive year for HHFW and EBW!

As usual when you have good people, there are more ideas than time and money to carry them out.

Plans for the rest of 2001 have some very interesting experiments in both fields

- Improved plasma diagnostics will be key to improved understanding.
- Increased capability of HHFW system (e.g., real-time phase control) will enable some interesting experiments *per se* and also in conjunction with beams.

Modeling work is becoming more attuned to challenging conditions in NSTX

- Earlier approximations that were valid for conventional tokamaks (but not for NSTX) are being replaced with more applicable models.
- Theoretical work appears strongly coupled to experimental results and needs.