Recent advances….and puzzles!….
in full wave modeling
of wave-plasma interactions in tokamaks

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in collaboration with

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(for TORIC code)

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Fast ions excite a variety of modes in fusion plasmas: *Can full-wave TORIC code offer any insights?*

TORIC retains effects neglected in the linear and nonlinear MHD / hybrid codes, including:

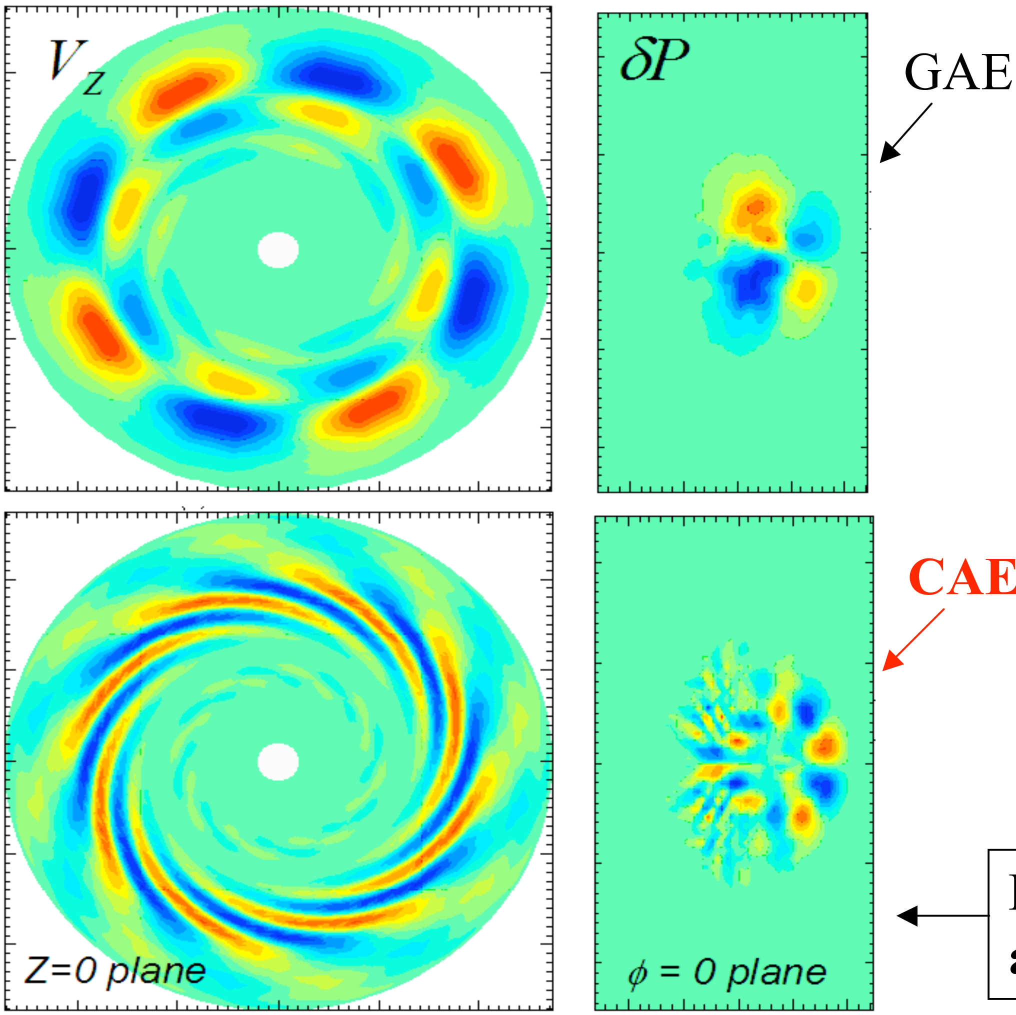
- **FLR effects, finite ω/ω_c effects, cyclotron resonances**
- **full toroidal geometry, fast ion distributions**

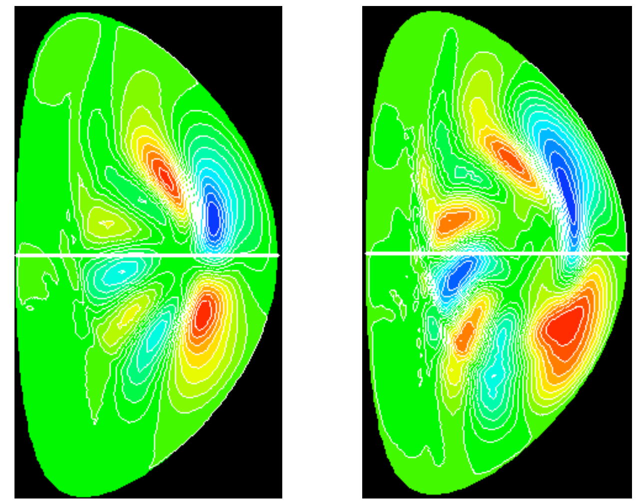
In addition, TORIC can attain much higher spatial resolution of modes, but in a linear (or eventually) quasilinear treatment

$\Rightarrow$**Approach >>>** ***Utilize TORIC to study dynamics of driven modes in the linear regime***

- **begin in the $\omega \sim \omega_c$ regime (CAE, GAE modes)**
- **modify code as needed for $\omega << \omega_c$ regime (TAE,EPM, etc)**
- **validate code with results from driven mode experiments**

Predicted structure of fast particle modes is commensurate with TORIC resolution capabilities





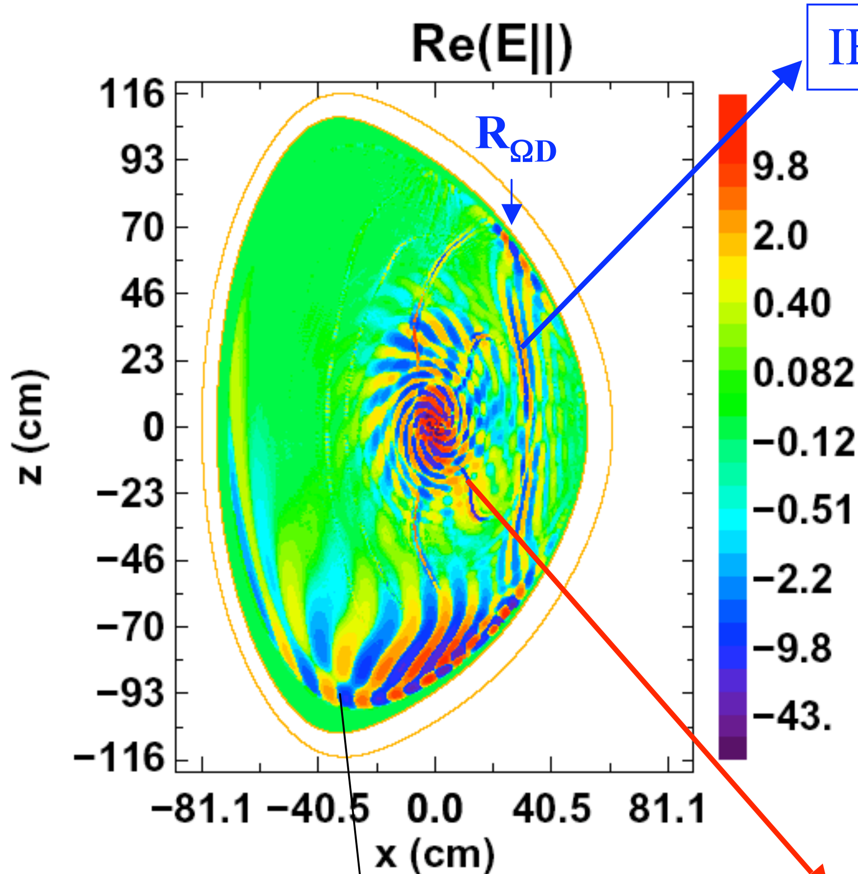
M3D nonlinear hybrid simulations of beam-driven TAE modes in NSTX (Fu)

[M3D has ≤ 200 radial nodes]

HYM code simulations of GAE and CAE in NSTX (Belova)

CAE's were first predicted by the HYM code and then observed in NSTX

TORIC finds three modes in addition to the fast wave in NSTX with $f_0 \sim f_{CD}$



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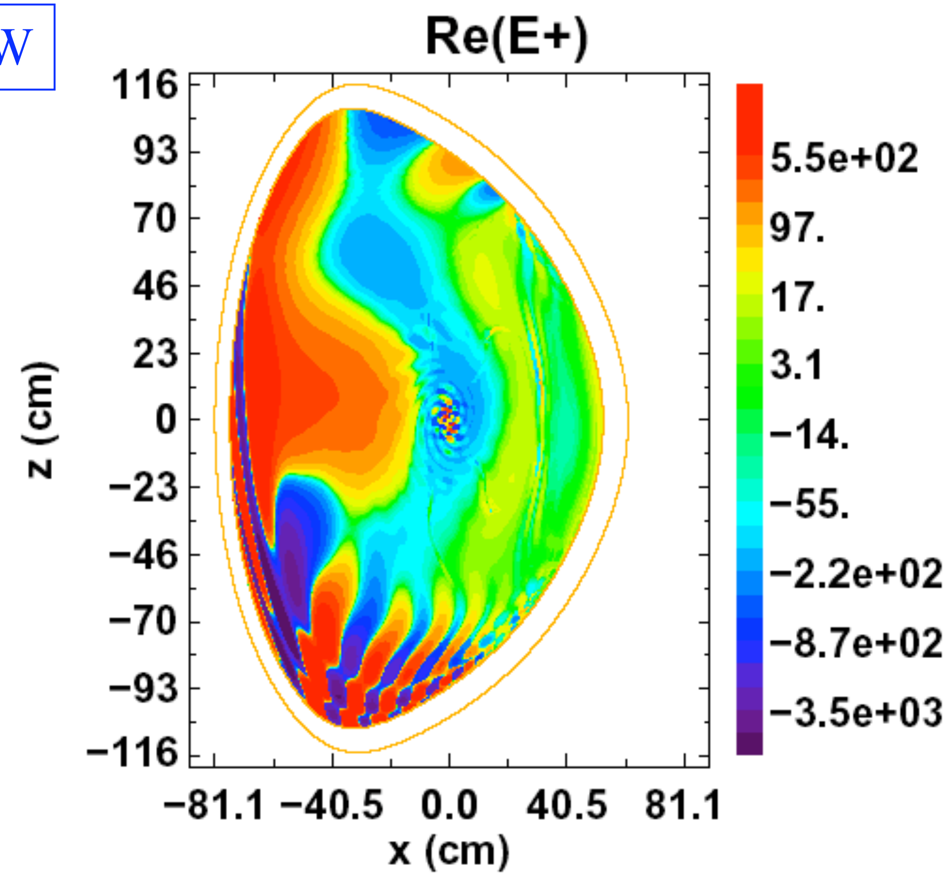
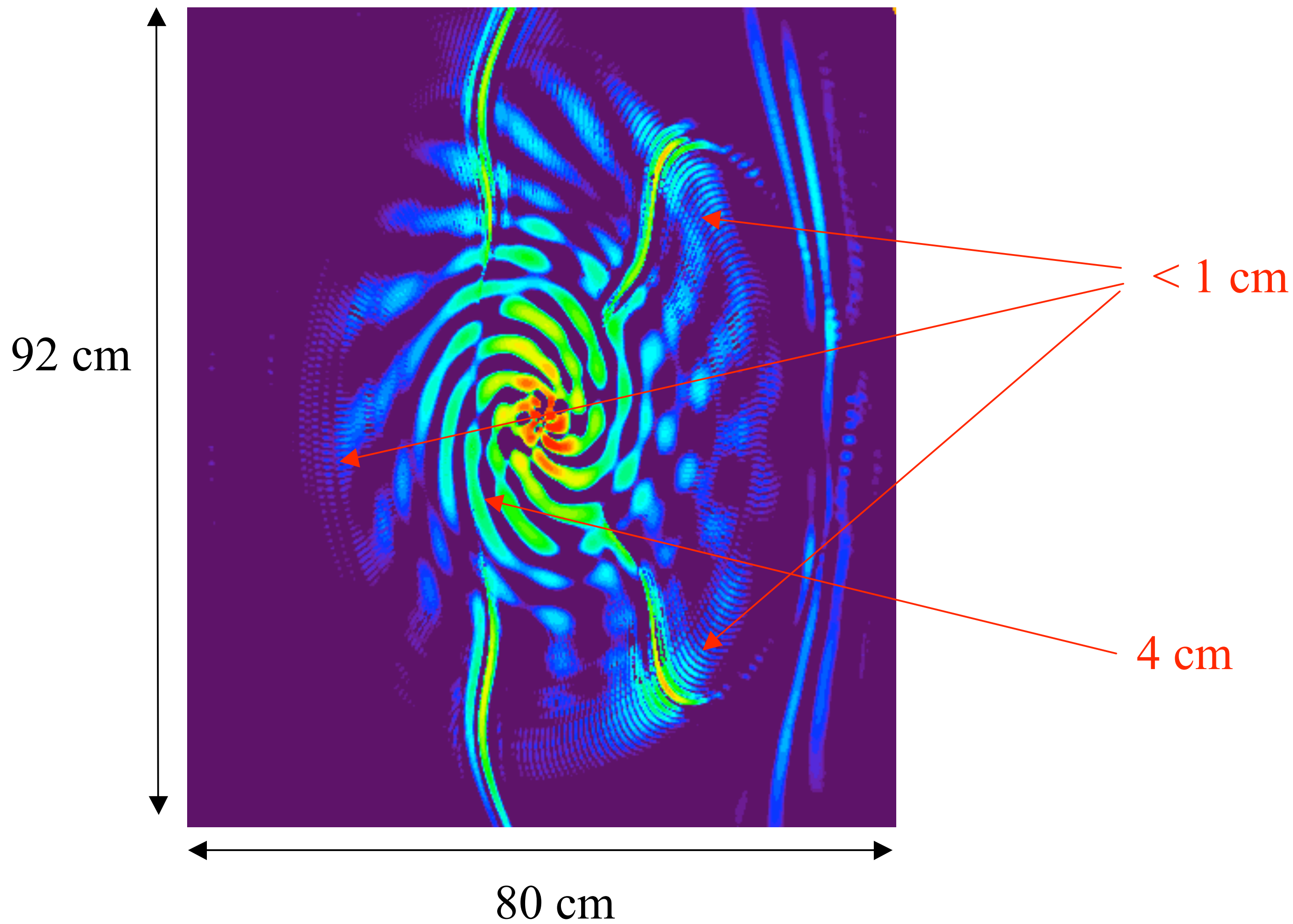


CAE / GAE? Simple dispersion relations indicate 'slow wave' can propagate in the core

ion cyclotron wave?

Dominant wavelength in the core mode is larger than simple estimates



dominant wavelength ~ 4 cm but some shorter structure ~ 1 cm is evident in the electron damping contours (and in $E_{//}$ contours) for the core mode (resolution?)

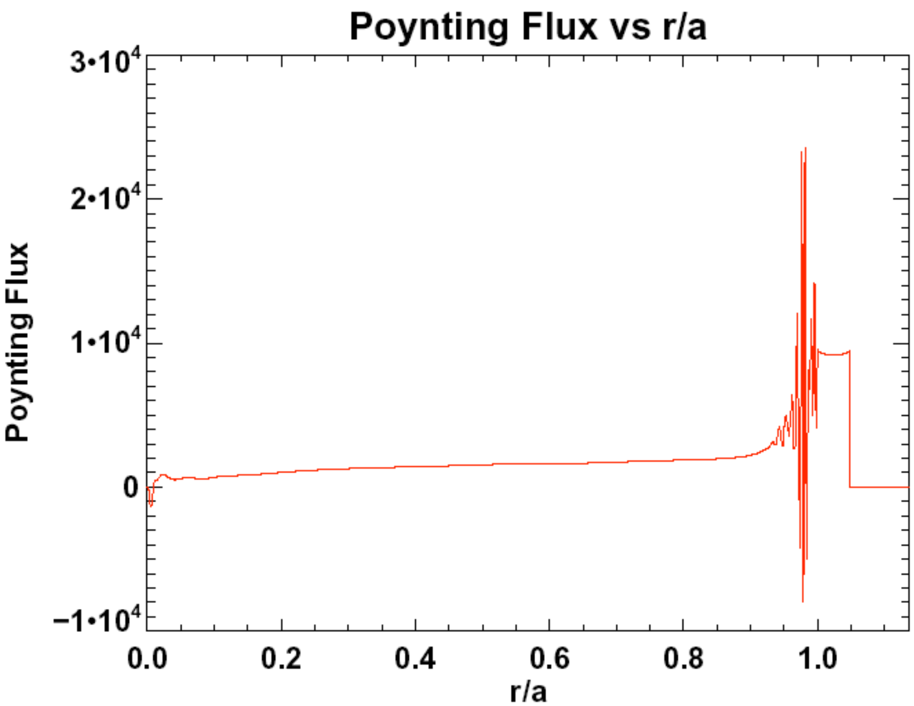
Further work is needed to simulate driven eigenmodes with TORIC

Power balance needs improvement:

- code has difficulty with Poynting flux in the edge regions
- >due to neglect of kinetic flux?

Benchmark against other codes (PENN; NOVA-K, etc.) and NSTX data

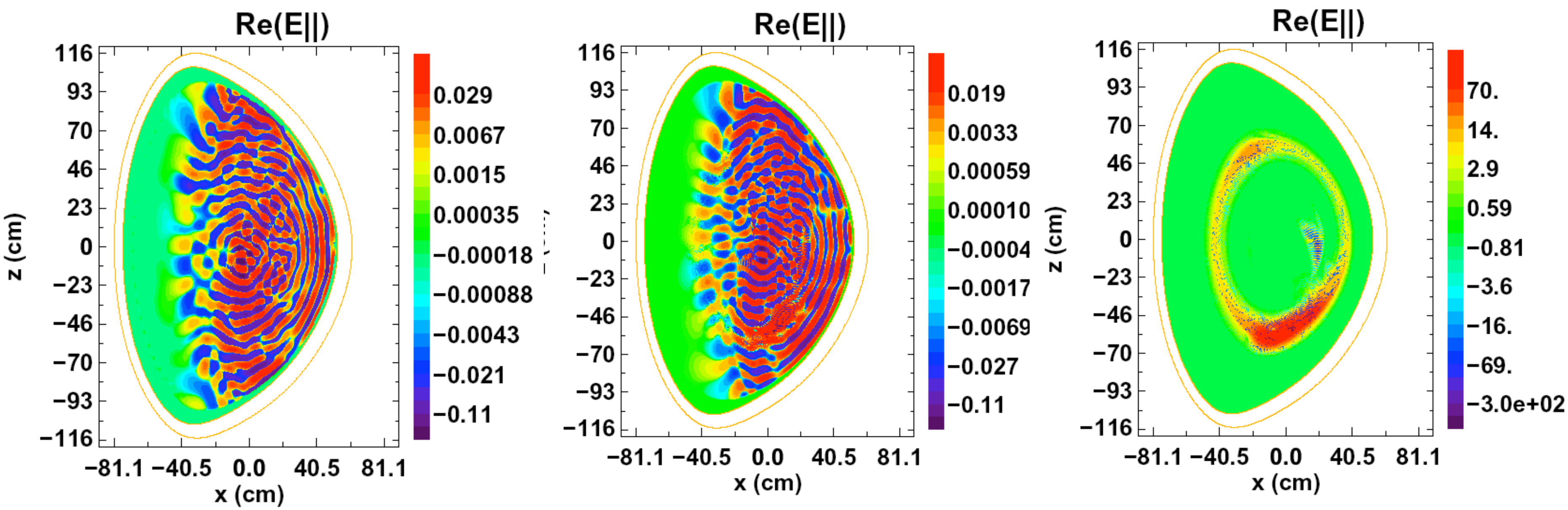
- > new scattering diagnostic can see structures ~ 1 cm (Smith, Mazzucatto, Park)



Brambilla notes that numerical algorithm may have trouble for $\omega << \Omega_{ci}$

- > initial runs with fundamental Ω_{ci} layer out of plasma had poor power balance
- > may need new numerical algorithm

Is the "slow wave" present in the HHFW regime on NSTX?



nelm=240 nmod=127 | nelm=483 nmod=255 | nelm=720 nmod=255

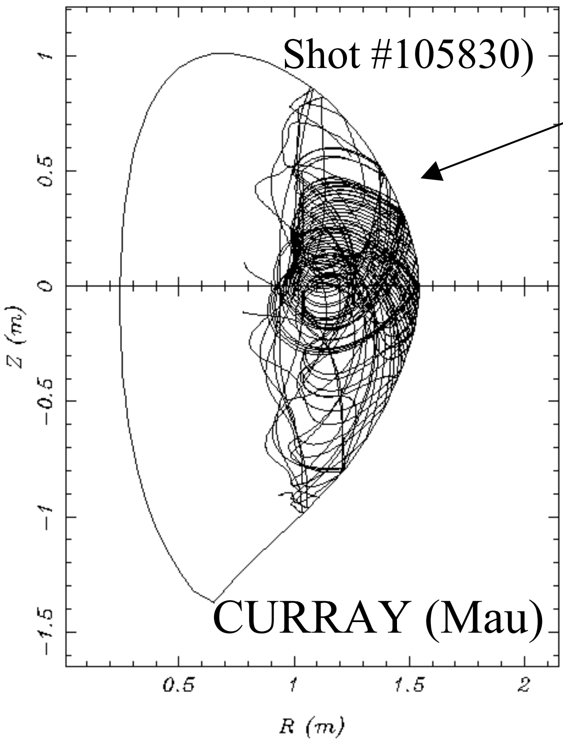
Pabs = 2.71 / Prad = 2.42 | Pabs = 1.83 / Prad = 1.82 | Pabs = 1.15e5 / Prad = 1.68

Slow wave appears as resolution is increased - but power balance degrades

For sufficiently high $k_{//}$ and electron temperature, simple dispersion relations indicate slow wave may propagate in the HHFW regime.

Are these high $k_{//}$'s excited as the HHFW propagate?

Simulations must include enough poloidal harmonics to resolve the high harmonic fast wave



Note that the HHFW rays spiral in towards the core

To resolve HHFW in poloidal direction,

with $\omega \sim k_\perp V_A \Rightarrow k_\perp \sim 125\ m^{-1}$ $(\lambda \sim 5\ cm)$

require $\frac{m}{r} \sim \frac{m}{0.3} \sim k_\perp \sim 125 \Rightarrow m \geq 40$

TORIC uses $-M_{max}$ to $+M_{max}$ poloidal modes, so require at least nmod ~ 81

>> **must use nmod = 127, 255, or higher in simulations**

(nmod ~ $2^N/2 + 1$ for FFT efficiency)

These higher poloidal modes may give rise to "slow waves" that may propagate.

Further studies are needed to determine if slow wave excitation is occurring and affecting power absorption

Are 'slow waves' excited by the HHFW or are the predicted fields just numerical artifacts?

➞ Is the mode an electrostatic ion cyclotron mode or a kinetic Alfven wave?

➞Is the mode detectable with reflectometry or the new high k scattering diagnostic?

➞Is the mode adequately resolved in the TORIC simulations?

➞Is the mode treated correctly in the high harmonic version of TORIC?

➞Is the mode reproducible in 1D kinetic full wave codes? (e.g. METS)

➞***How is power absorption modified if this mode is real and present?***