RF sustainment & CD for CT's

T.P. Intrator Los Alamos National Laboratory, P-24 Plasma Physics
R.P. Majeski, PPPL

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Radio frequency heating, CD

- radio frequency (RF) could drive and maintain the plasma currents that sustain Compact Tori (CT) configurations
- large plasma pressure or $\beta = nT/(B^2/2\mu_0)$
- Spheromaks: $\beta > 0.1$, $n \approx 10^{20} m^{-3}$, $B \approx 1$Tesla
- Field Reversed Configuration FRC, $\beta \approx 1$, $n \approx 10^{19} m^{-3}$, $B \approx 0.02$Tesla
- goal of RF sustainment of CT plasmas is to achieve efficient time-averaged current drive and heating

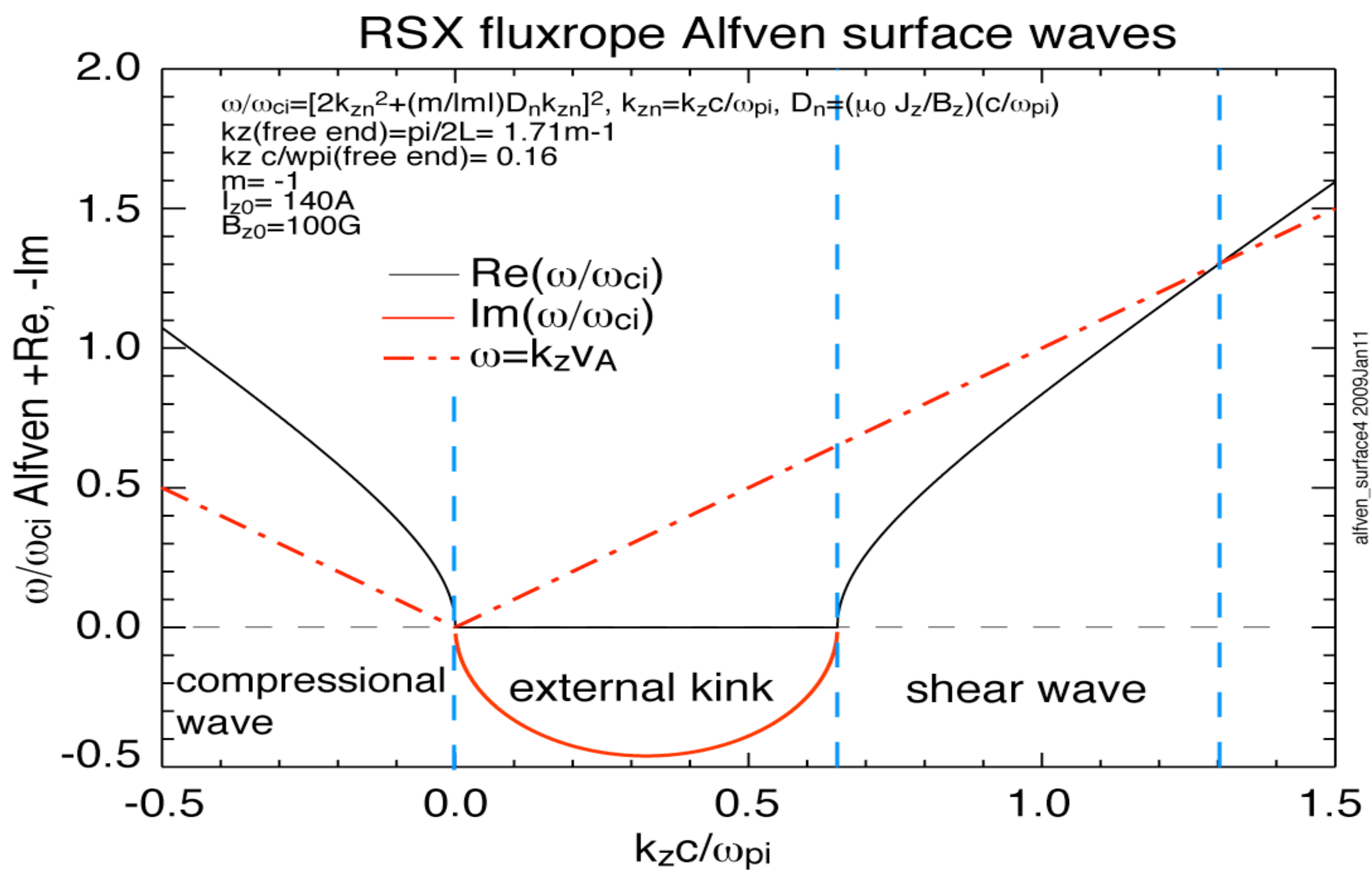
Wave access to a CT

- At large β, the plasma dielectric constant $\varepsilon = \omega_{pe}^2/\omega_{ce}^2 \approx 10\text{-}100$ is also large, compared with the typical tokamak value of $\varepsilon \approx 1$.
- In the ion cyclotron range of frequencies, fast magnetosonic wave accessibility to a plasma core is limited to low ion beta (β_i <10%).
- Lower Hybrid waves typically are cut off above a density limit that is frequently too low to be useful for CT plasmas

Other waves

- Other waves: accessibility + power absorbtion for large β
  - Electron Bernstein Waves (EBW) at harmonics $\omega \approx$ 1-2 ω_{ce}
  - High Harmonic Fast Waves (HHFW) between the ion cyclotron and lower hybrid ($\omega_{ci} < \omega < \omega_{LH}$) frequencies
  - Ion Bernstein Waves (IBW)
  - Alfven waves at low frequency $\omega < \omega_{ci}$
  - RMF at very low frequency $\omega << \omega_{ci}$
  - Alfven spectrum
    - surface wave
    - current driven kink and pressure driven ballooning modes
    - electrostatic waves driven by antenna voltages near separatrix.

External kink: compressional ⇔ shear Alfven



RF power required

- typically assumed that high RF heating power will be required for CT sustainment.
- However if confinement >100 msec, ohmic dissipation for a 30MA CT, P_{RF} <100MW

Status of RF in CT's

- There have not been any investigations of RF heating or sustainment for spheromaks.
- Rotating Magnetic Field (RMF) or rotomak current drive has been exploited in several FRC experiments.

Research gaps for RF in CT's

- antenna design
- launch access
- near and far field wave excitation
- Mode conversion
- power limits
- hardware limitations.
- Experiments, theoretical analysis, and computational modeling of wave effects are a research need

RMF drive in FRC

- like to apply rotomak current drive to large, reactor scale plasmas
- Excitation of near and far field (propagating), quasi mode, parasitic waves may alter the CD drive efficiency.
- Do phase assumptions hold for averaged fluctuating time & volume averaged δj, δE, δv, and δB ?

Antenna design

- Possible antenna design improvements
- FRC's have small vacuum vessels with dielectric walls, and could accommodate a variety of antenna geometries not tried on other devices,
  - antennas on air side of the vacuum vessel.
  - full 2π toroidal coverage,
    - resonant transmission line type traveling wave structures could facilitate highly selective and directional toroidal wave number.

Research thrusts

- virtually no evaluations of what Alfvenic RF waves would do in a high $\beta \approx 0.1$-1) plasma.
- Computer codes include
  - Cylinder r-z 2D mirror codes (some FLR, no mode conversion) ANTENA [McVey1984]
  - 1-D hot plasma higher order dispersion code CRF [Ignat1995]
  - Advanced full wave spectral codes: TORIC, AORSA
  - Possible surprises, dependence on plasma helicity, magnetic field structure in 2D or 3D.