Waves and Energetic Particle Research are Integral Component of US Fusion Program

- High power, externally launched radio-frequency waves (30 MHz to 110 GHz) heat plasmas and drive non-inductive toroidal current.
  - Only method for heating core of large burning plasma
  - Precision methods to control heating, current, and possibly plasma flow; crucial to innovations of “advanced tokamak” scenarios for ITER and beyond.

- Non-thermal particle distributions, e.g., fusion-produced α-particles in ITER, may destabilize Alfven wave modes of the plasma.
  - Possibility of reduced confinement and enhanced macroscopic instability in burning plasmas.

Variety of Wave Heating Schemes in Distinct Plasma Conditions in 3 US facilities

Missions: plasma heating, local current drive, instability control

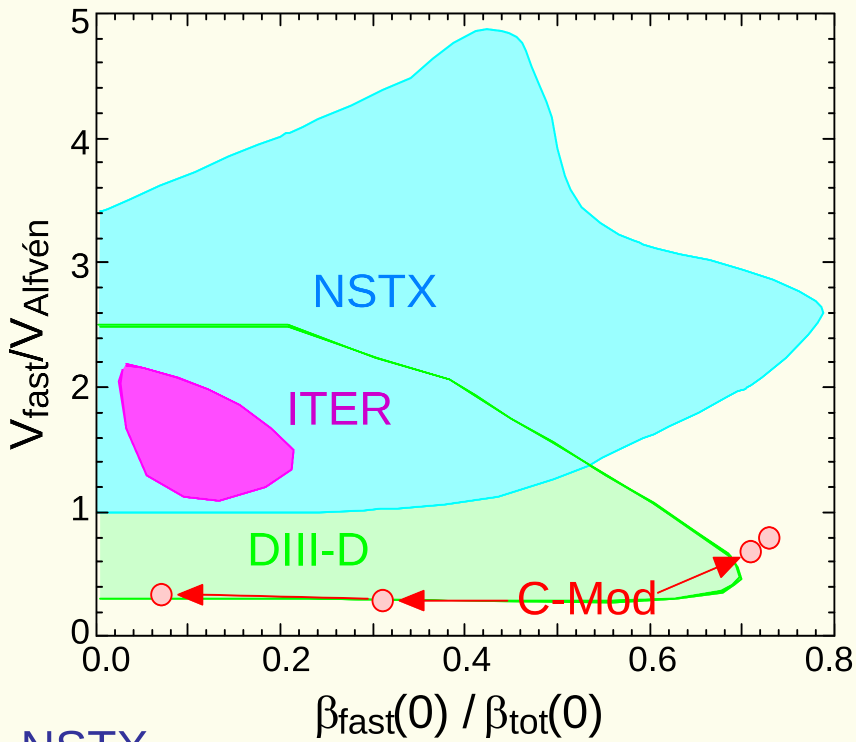
- DIII-D: Moderate field, moderate density advanced tokamak
  - Electron cyclotron waves for current drive (broader current profile, control of tearing instabilities); selected for ITER
  - Fast wave (ion cyclotron frequency range) for current replacement in core
- NSTX: Spherical tori address non-inductive current profile control in "overdense" plasmas for long-pulse operation.
  - Novel electron Bernstein wave current drive to be initiated for current drive.
  - Fast wave for core current drive.
  - Coaxial Helicity Injection for non-inductive start-up.
- C-Mod: Entirely radio-frequency wave-heated, high-density, high-field plasmas.
  - Ion cyclotron minority heating delivers flexible, controlled heating profile; selected for ITER.
  - Ion cyclotron mode conversion to supply local current drive and plasma flow
  - Lower hybrid current drive was recently implemented to access advanced tokamak schemes; this is a reserve option for ITER.

Strong Predictive Capability Developed in US Wave Research

- Wave heating research has long development path in US fusion program.
- Accurate comparisons of wave propagation and absorption measurements with comprehensive modeling of radio-frequency heating are hallmark of US program
  - Example: State-of-the-art full-wave calculation of ion cyclotron wave mode conversion is consistent with measurements of wave by versatile phase contrast imaging on C-Mod.
  - Similar capability for full-wave lower hybrid propagation and absorption on self-consistent fast electron population.
  - Ray tracing and absorption of electron cyclotron wave (DIII-D); electron Bernstein waves (NSTX).

Energetic Particle Studies on the Three Major US Facilities

- Energetic particle modes studied in all 3 US facilities for understanding of α particle-driven instabilities in ITER.
  - Neutral beam ions in NSTX, DIII-D
  - RF-driven ions in C-Mod



- In parameters relevant to energetic particle-driven modes, operating range of US facilities exceeds that for ITER.
  - V_{fast}/ V_{alfven} range extensive in DIII-D, NSTX
  - β_{fast} drive of fast particle instability high in all
  - ρ_{fast}/a > ITER value in all; best approached in C-Mod

U.S. Facilities Contribute Significantly to Energetic Particle Physics Research

- Since the shutdown of TFTR, experimental leadership in this area has belonged to the world's largest tokamaks, JET and JT-60U.
- U.S. facilities now provide key capabilities and strong physics program for world effort.
  - Plasma shaping and aspect ratio flexibility (DIII-D, NSTX)
  - Advanced diagnostics
  - Control of strength and anisotropy of fast particle distribution.
  - External antennae to excite Alfven eigenmodes to separate drive from damping (C-Mod)
  - Close interaction between experiment and modeling.

Assessment of Wave and Energetic Particle Physics

- U.S. facilities pursue non-duplicative methods of wave heating and current drive appropriate to diverse missions of
  - MHD instability suppression
  - Control of the radial profile of plasma current
  - Localized plasma heating

  in significantly different parameter ranges of the experiments.

- Studies performed in next five years will be important for ITER, and crucial for advanced tokamak/innovative concept development.

- U.S. facilities contribute significantly to vitally important understanding of threat of Alfven eigenmodes to burning plasma confinement.