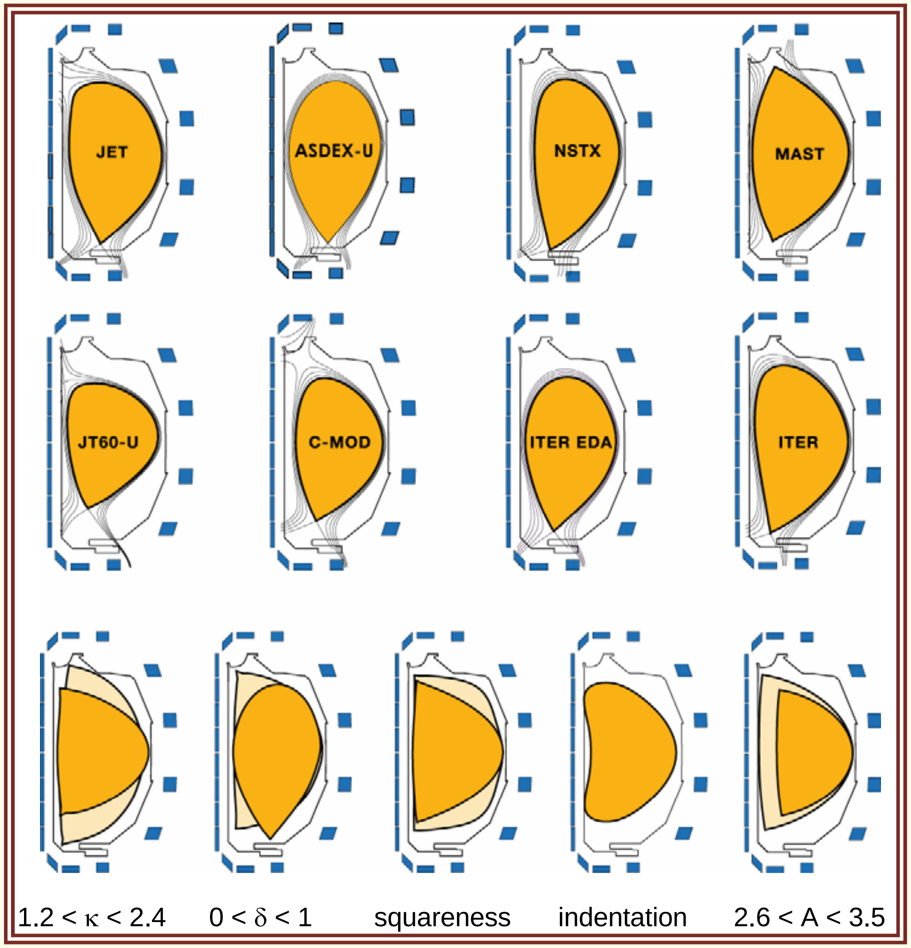
Macroscopic Plasma Physics

- Macroscopic plasma physics seeks to determine how to confine and sustain maximum plasma pressure efficiently in a magnetic field configuration.
  - Extremely important, since fusion energy production in a burning plasma facility (such as ITER) increases with the square of the plasma pressure
  - Useful dimensionless parameter β = plasma pressure / field pressure
- Key science topics addressed individually by first three topical questions (T1 – T3) defined in FESAC Program Priorities Report
  - Plasma Equilibrium and Magnetic Field Structure
  - Pressure-limiting Instabilities
  - External Control and Self-organization

Plasma shape can be altered to increase plasma pressure

DIII-D shaping flexibility



- All three facilities can match the ITER cross-sectional shape
- C-Mod: operates at, or above toroidal field of ITER (up to 8T)
  - Highest tokamak plasma pressure
- DIII-D: most flexible shaping
  - can produce a wide range of plasma shapes
  - can match the shapes of most machines
- NSTX: Low aspect ratio allows very high elongation, enabling very high β
  - world's only tokamak to study plasmas in the range of zero to unity (local) β

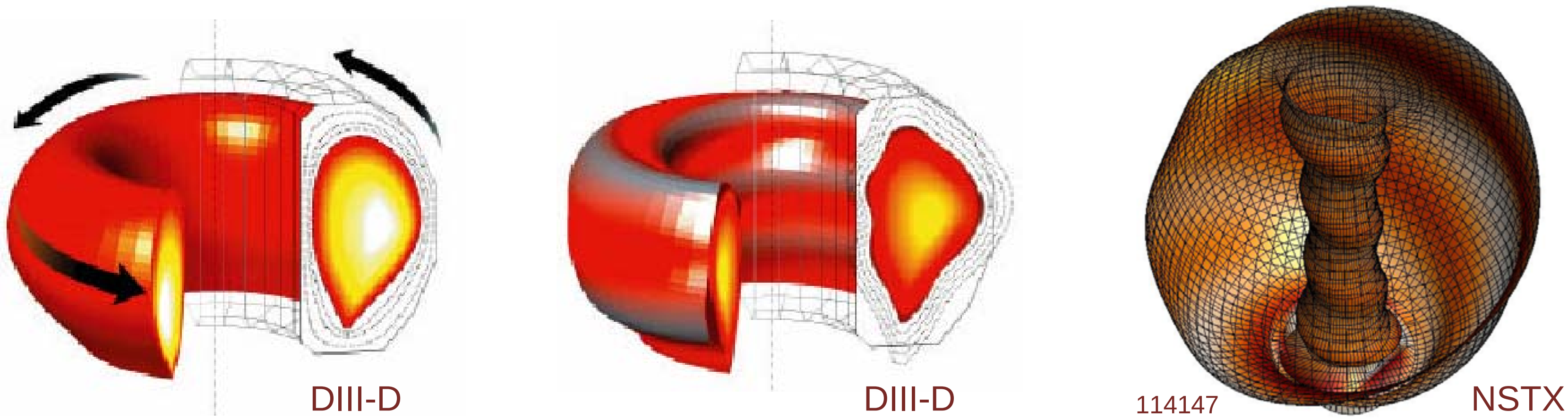
Instabilities can limit β in magnetically confined plasmas

- When plasma β exceeds an upper limit, large-scale unstable motions of the plasma can develop, leading to loss of confinement.
  - Kink/ballooning instability; edge localized mode (ELM)
  - Resistive wall mode (RWM)
  - Neoclassical tearing mode (NTM)

- Understanding the science of the stability limits set by these unstable modes is an essential goal of magnetic fusion research.
  - Plasma rotation can stabilize the kink/ballooning, and resistive wall modes.
  - Pressure, current, rotation profiles affect all modes including neoclassical tearing modes and ELMs
  - Modes and “error fields” can create drag that slows down the stabilizing plasma rotation.

Instabilities can cause rapid loss of plasma pressure and current

Rotationally stabilized | Unstable n = 1 RWM | Unstable n = 1-3 RWM



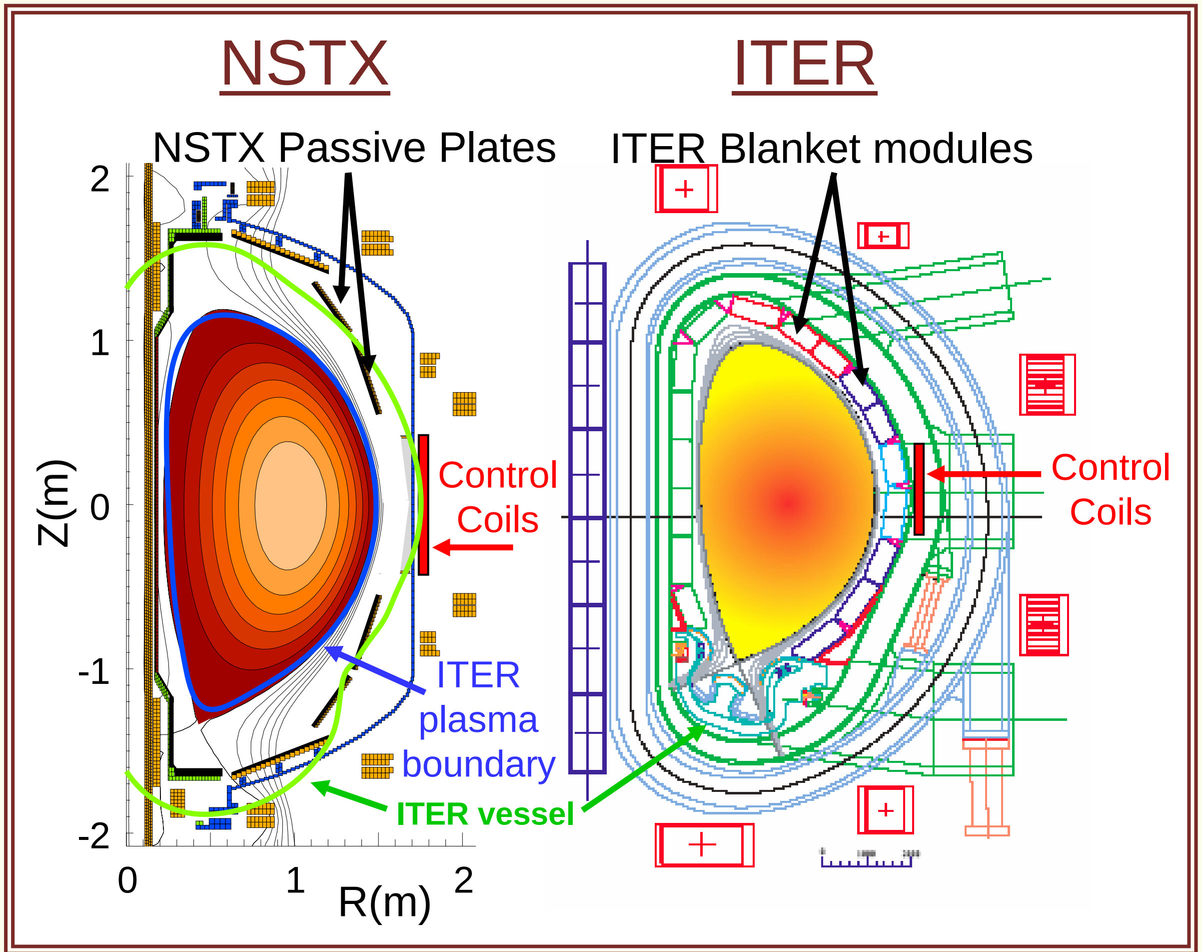
(surface distortions shown 10 times exaggerated)

- DIII–D, NSTX produce, and are diagnosed to study RWM, NTM, ELMs
- C-Mod, DIII-D can study
  - avoidance of rapid loss of pressure and current caused by instabilities (disruption)
  - mitigation of wall damage caused by disruptions

External Control and Self-organization

- Objective is to understand the fundamental science that will allow sustained, optimized fusion power production
  - All three national facilities are studying plasma self-organization and the proper balance between internal and external control.
- Plasma current is most efficiently sustained by "bootstrap" current that is self-generated by pressure gradients.
  - Large fractions of the total current—up to 85% in DIII-D, and 60% in NSTX
- Plasmas that are above instability limits can often be stabilized by external means, with a self-organizing plasma response.
  - DIII-D, NSTX can study external stabilization of the resistive wall mode.
  - DIII-D has demonstrated stabilization of neoclassical tearing modes using localized current drive from externally applied waves.
  - Within the next five years, C-Mod will address issues of bootstrap current generation and beta limits using lower hybrid current drive.

External control studies are providing validation for use in ITER



- Improvement of ITER design to include external control coils depends on studies of their effectiveness in DIII-D and NSTX.
- These coils are also being used for control and mitigation of edge localized modes.
  - ELM control and suppression critically important for ITER
- C-Mod plans to investigate lower hybrid current drive – an option for ITER.

The U.S. is a World Leader in Macroscopic Plasma Physics Research

- Scientific understanding of macroscopic plasma physics comes from a combination of experimental and theoretical investigation.

- Crucial experimental verification of theory requires facilities that can vary plasma conditions over an extended range.
  - The U.S. fusion program has a complementary set of three major experimental facilities that can access a very wide range of variations.

- The three major U.S. facilities contribute synergistically to this research.
  - *Combined* resources provide world leadership in scientific understanding
  - *Combined* resources provide physics validation for extrapolation to the burning plasma regime of ITER