Stellarator / Heliotron Complementary Path to Fusion

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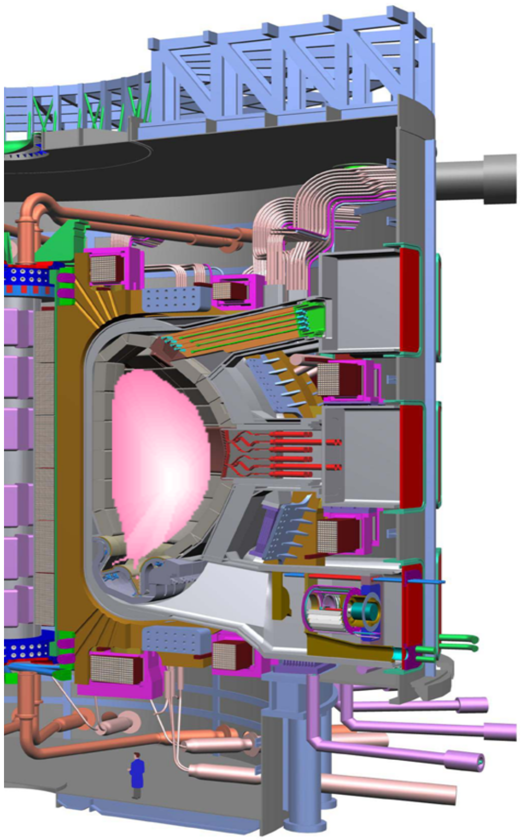
Innovations Needed Beyond ITER

Need

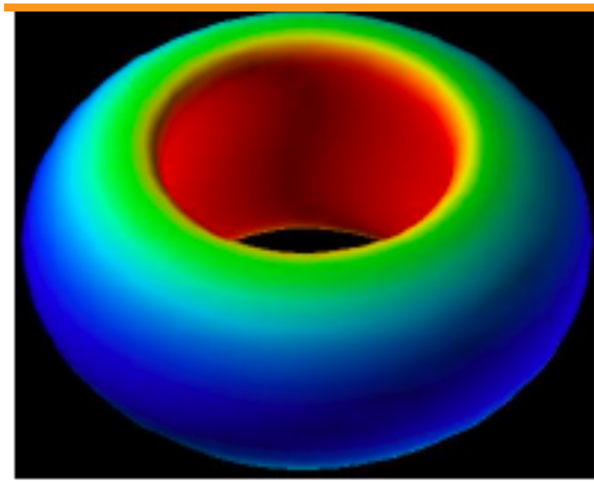
- Higher fusion performance at ~same size
  - higher Q, $Q_{engineering}$ for net energy
  - higher power density P_{fusion}
  - ➔ higher pressure (β)
- Steady state with less current drive
- Disruption free, reliable confinement
- Robust divertor & structure
- Breeding blankets producing tritium



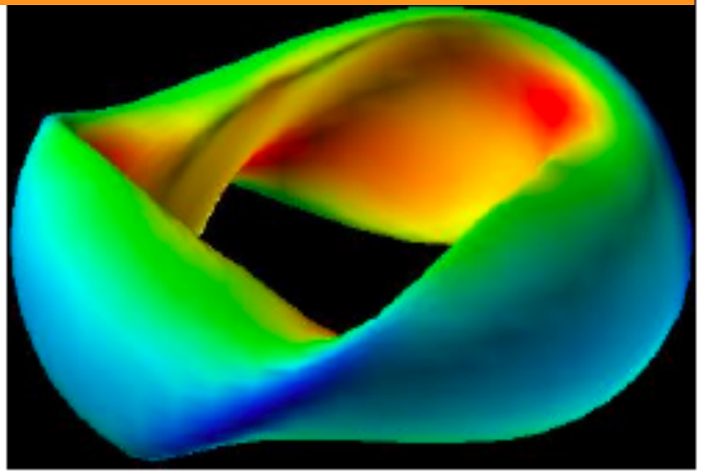
ITER

And: must be simpler, more cost effective.

3D Shaping Gives Steady-State, Increased Reliability



For plasma confinement
Need:
- Toroidal geometry
- Helical magnetic field



Tokamak

Strong plasma current
- External current drive power
- Maybe pulsed to be economical

Current drives instabilities
- Requires feedback stabilization

Stellarator / Heliotron

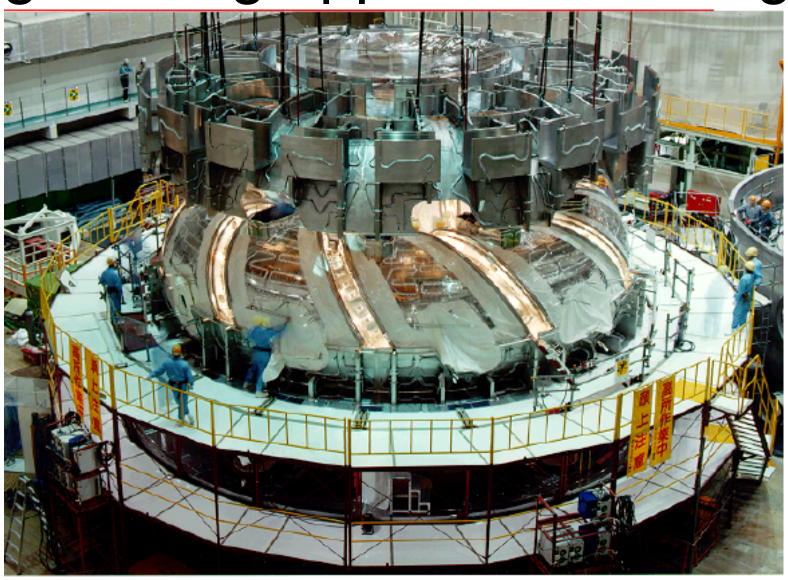
3D Magnetic field from coils
- No driven current.
- Steady state

Passive stability at high pressure (β)

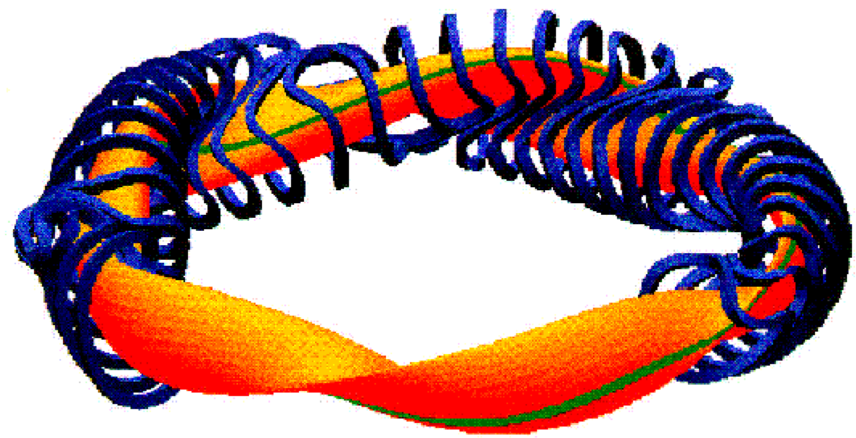
- Shared understanding of basic physics
- Will be informed by ITER

Evolution of Stellarators / Heliotrons

- Invented by L. Spitzer in 1951
- Broadly studied after 1958 declassification
- 1970s & 80's: importance of optimizing 3D shape for confinement
- Many experiments of different designs, improving understanding
- Engineering approaches to high B, large scale



Large Helical Device (NIFS)
a=0.55 m, R=3.9 m,   B=3T,
superconducting



Wendelstein 7-X (IPP, 2014)
a=0.5 m, R=5.4 m,   B=3T
superconducting

3D Shaping Gives New Options for Improved Plasma Confinement

- Quasi-isodynamic
  - Design to cancel 3D & toroidal effects
  - Can eliminate some types of turbulence
  - W7-AS, LHD (partially optimized), W7-X (fully optimized)

- Quasi-symmetric
  - |B| approximately symmetric in magnetic coordinates quasi-axially (QA), quasi-helically (QH)
  - Tokamak like confinement properties
  - QA turbulence predicted to be like advanced tokamaks (very low)
  - Can be compact (aspect ratio as low as ~2.5) similar to tokamaks
  - HSX (small scale, Univ. of Wisconsin, quasi-helical)

Stellarators Already Provide Advanced Characteristics

Steady-state with

✓No disruptions. ⇒ Reduce forces on first wall, blankets, structures
Reduced power exhaust loads on boundary

✓No current drive ⇒ Low recirculating power
intrinsically high Q, higher reliability

✓Quiescent high-beta up to 5%, with confinement similar to tokamaks.

✓Very high density limit ⇒ higher fusion reactivity
easier plasma solutions for divertor
reduced fast-ion instability, fast ion loss to walls

✓No need for feedback stabilization ⇒ simplify plasma control,
strongly reduce diagnostics, actuators needed for reactor

✓Stable detached divertor configs. ⇒ ~90% radiated in edge (W7AS,LHD)

Greatly simplifies design of Fusion Power systems.

Eliminating Current Drive Has Important Engineering Consequences

Strongly reduces recirculating power

- Provides design margin on operating performance, constraints
  - power production at lower plasma performance (e.g. L-mode)
  - power producing pilot plants at reduced size (conceptual)
- Reduces sensitivity to thermal conversion efficiency
  - can use lower temperature blanket with water cooling
  - reduce engineering challenges

- Minimizes wall penetrations, blocking of breeding blankets

  Increases Tritium Breeding efficiency

Summary

- Stellarators provide simpler solutions for Fusion Energy
  - No disruptions, no current-drive. Higher stable pressure.
  - No feedback stabilization. No nearby conducting walls.
  - Optimized configurations for improved confinement
  - Relatively small steps needed from achieved stellarator characteristics

- Need to validate understanding at large scale, with reactor-like plasmas (high temperature, low collisionality)
- Need to integrate with fusion technology development (metalic PFCs, remote maintenance, breeding blankets).