Connecting ICC simulation tools to burning plasma physics

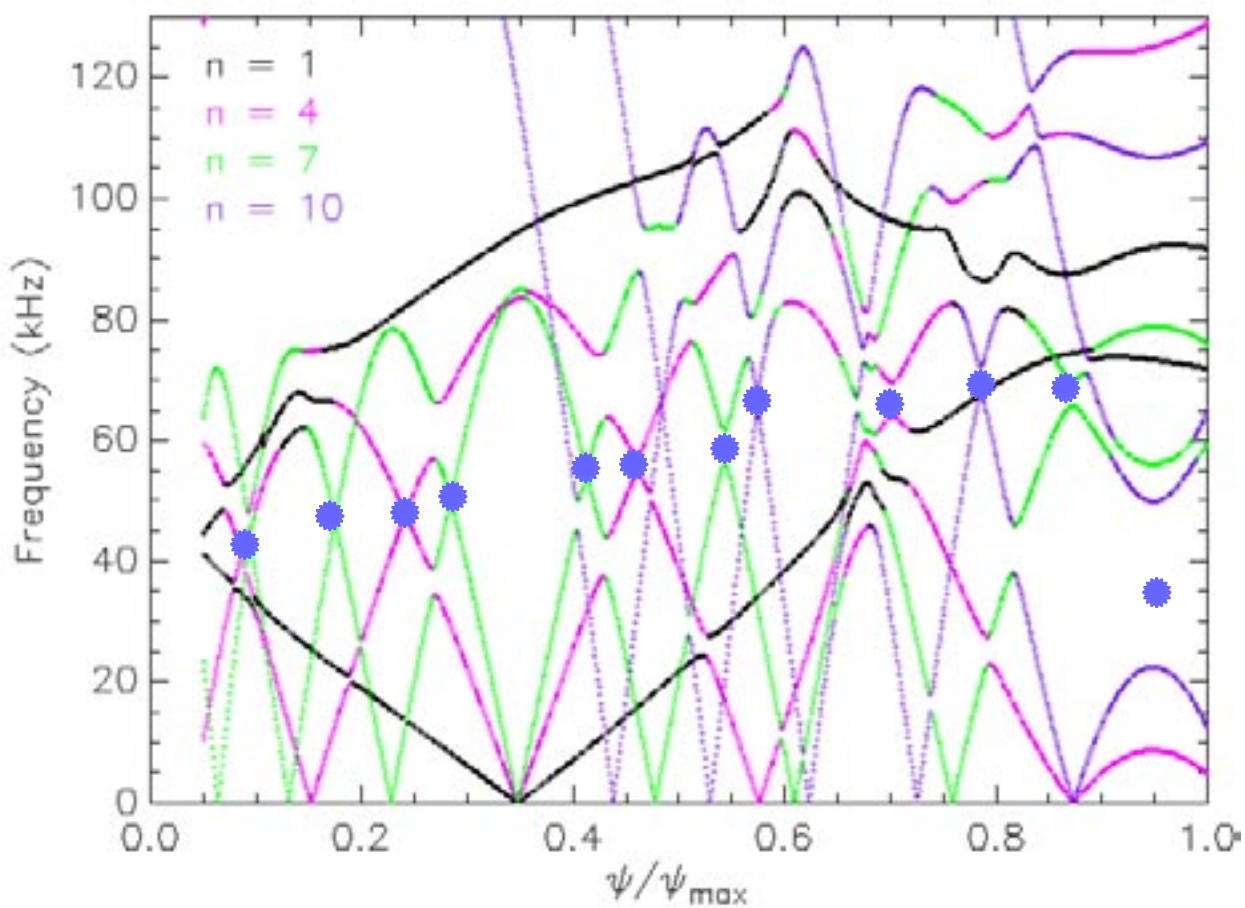
- Much of the knowledge obtained from a burning plasma experiment ultimately becomes encapsulated in simulation models
- As the BP step is expensive (> $1B), successful emerging innovative concepts need to take advantage of tokamak BP knowledge to either:
  - Minimize the expense of their BP step by a more focused approach
  - Take a more aggressive BP step
  - Or, to possibly leapfrog the BP step

For ICC's to accomplish this, enhanced modeling/simulation capabilities will be needed:

- Horizontally integrated simulation
  - encompasses multiple physics topics (MHD, transport, micro turbulence, heating, energetic particles, boundary physics, etc.)
  - has been a goal within the fusion program for some time (Numerical Tokamak, NTCC, ISOFS)
- Vertical integration across concepts has been more sporadic
  - tokamak->stellarator->spherical torus->spheromak->RFP->FRC, etc.
  - Examples: MHD simulations, stellarator codes can revert to tokamak limit, …

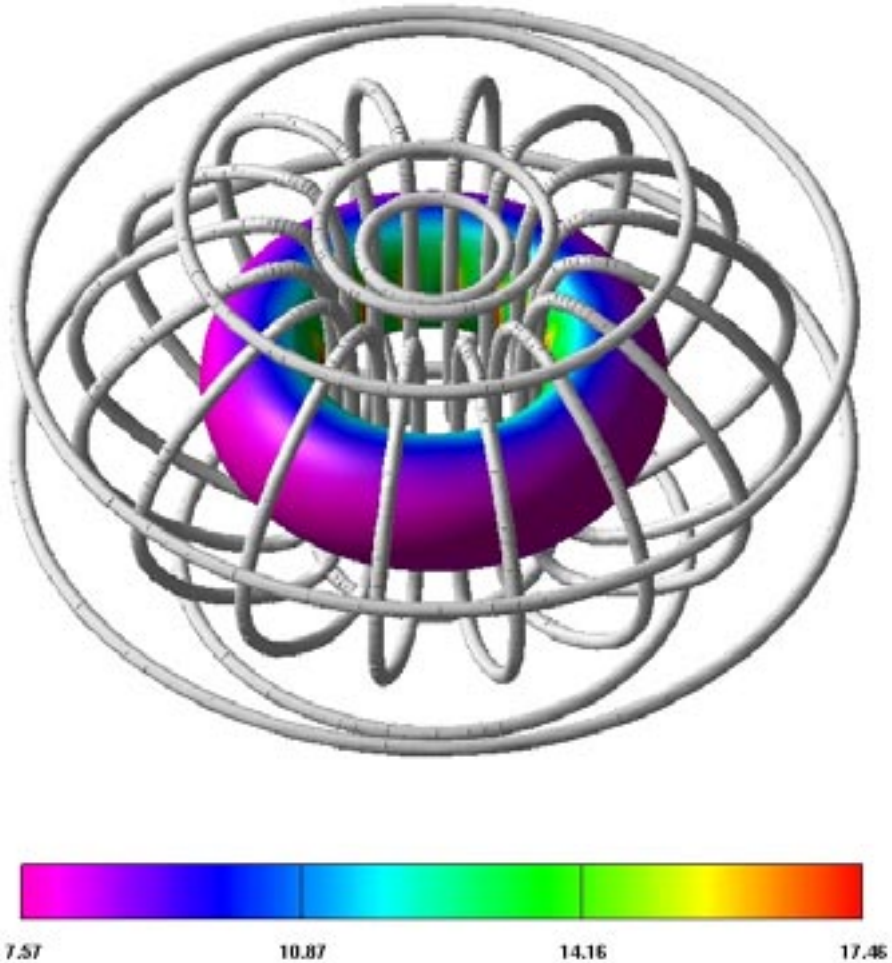
Compact Stellarators will have both toroidal Alfvén gaps (couple the same toroidal mode number, n) as well as helical Alfvén gaps (couple different n's) present.

- Alfvén continua shown here for the NCSX stellarator are color-coded based on the toroidal mode number
- For TAE gaps (indicated by blue dots) upper and lower curves have the same color
- For HAE gaps (all the other gaps) upper and lower curves change color as they pass through the gap location



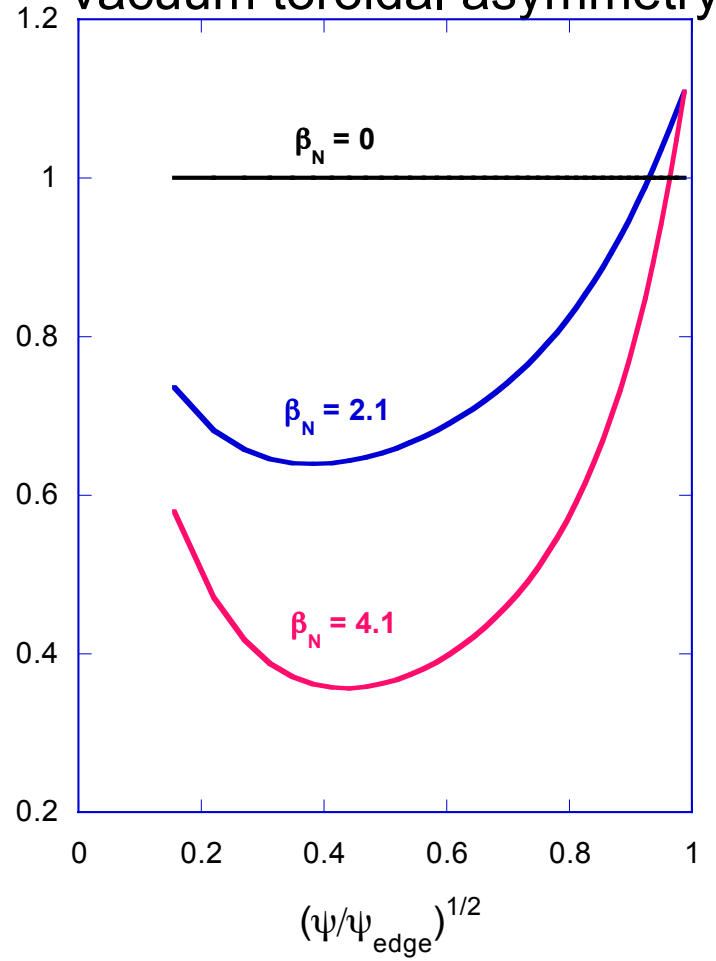
3D VMEC model of FIRE with toroidal field ripple: finite β can modify ripple in the plasma interior

FIRE outer flux surface (color contours show |B|) with filamentary toroidal (16) and poloidal coil systems



Magnetic field strength (Tesla)

Ratio of finite β toroidal asymmetry ($\sum_{n\neq 0} B_{mn}^2 \Big/ \sum_{n=0} B_{mn}^2$) to vacuum toroidal asymmetry



Challenges of vertically integrated simulation

- Introduces wider range of time/length scales
- Puts greater emphasis on first-principle models
- Requires larger team effort, open source code
- Sociological changes in how codes are developed and deployed
- Code validation must be done on a larger experimental database
- To really bypass the BP step, a much higher degree of simulation reliability is required than existing codes achieve