Optimizing and validating the magnetic confinement approach to fusion

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Motivations

- Many challenges remain in the development of MFE
- Optimum magnetic configuration to address these challenges not yet known

- MFE step(s) beyond ITER may demand validated predictive capability

- Therein lie opportunities for “Exploratory Plasma Research” (EPR) in the U.S.

What is EPR?

- “EPR” a recently-coined term (formerly “ICC”)
- An important niche in the FES portfolio
- Includes experiments, computation, and theory
- Presently represents < 10% (est.) of non-ITER MFES funding
- Substantial contributor to workforce development (hands-on training)

- But breadth (and health) of program is diminishing

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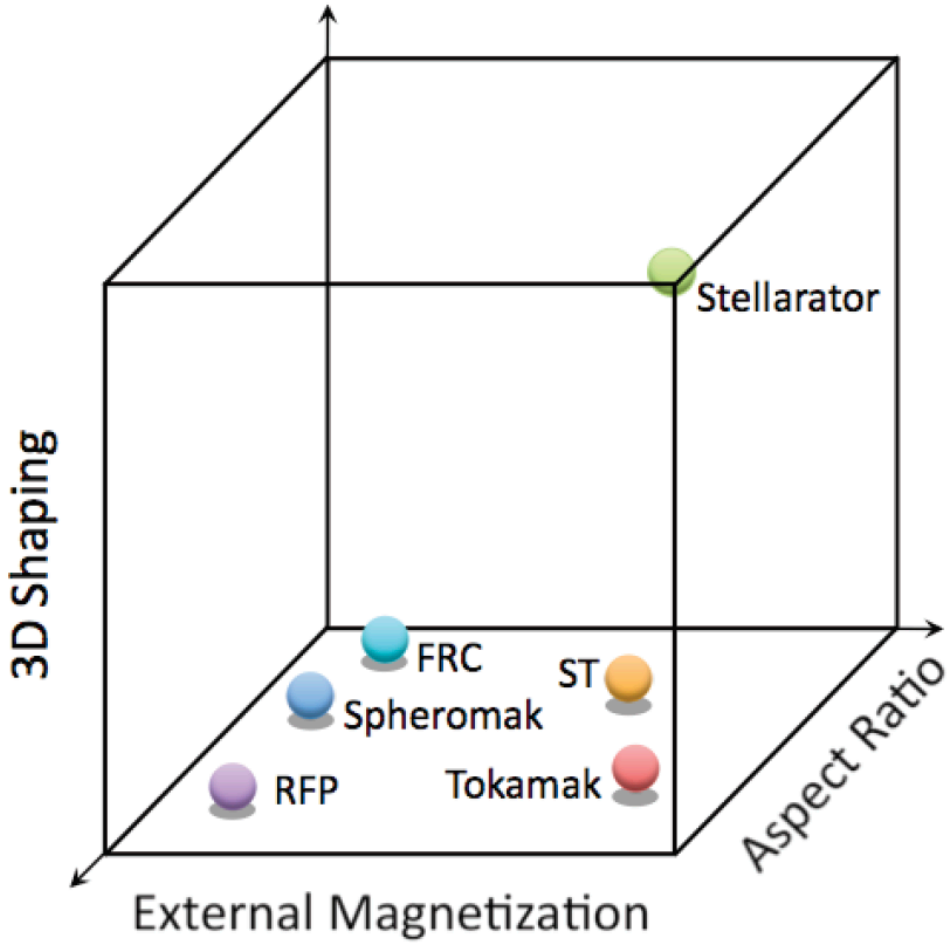
- I work on the MST RFP at UW-Madison
- I’m a member of the EPR Exec. Comm.

- Views here are my own, but draw on the views of others as well

Optimization

ReNeW Theme 5: Optimizing the magnetic configuration



Configuration space for toroidal magnetic confinement

- Each EPR configuration provides opportunities for optimization in unique ways
- Each also has challenges that reflect tradeoffs in physics and engineering
- Note that ReNeW did not include all EPR configurations

Optimizing the plasma-material interface

- Generic need in MFE for robust material at plasma boundary
- Generic need for material that does minimal harm to the fusing plasma

- Boundary is primitive in some (all?) of the less-well-developed configurations
- Due in part to limited resources

- Liquid metal (even flowing liquid metal) boundary might be route forward

Liquid metal boundary in EPR configurations?

- One route to improved performance in the RFP is changing $\mathbf{E}$ to increase edge $\mathbf{J}$
- Well-conditioned boundary critical, but recycling and impurity influx still occur
- A liquid boundary might substantially impact $\mathbf{J}$ via resistivity ($\mathbf{E} = \eta\mathbf{J}$)

- Similar benefit might accrue to other configurations (albeit due to different physics)
- Could help to accelerate EPR progress

- In the RFP case (for example) would like to better understand:
  - potential advantages/disadvantages for the RFP of a liquid boundary
  - potential advantages/disadvantages for a liquid boundary of the RFP
- Same questions should be asked for other configurations

Broadly inclusive program for liquid metal boundary

- Jaworski, Goldston *et al*. (white paper) proposes near-term program to more vigorously investigate viability of flowing liquid metal boundary
- Sounds exciting (and challenging) to me

- Ideally, such a program would encompass multiple configurations
  - varying strength and direction of B(a), varying plasma shape…
  - at least in modeling and small-scale experiment

- Broad effort would help configuration optimization
- *If* a liquid-metal boundary is the future, then configuration optimization with a solid boundary seems less relevant

Validation

"Validation" an important role for EPR - 1

- Viewed by OFES to be one of the primary missions for EPR

- There's validation
  - routine comparisons of experiment to theory and computation
  - widely practiced
  - in EPR, extending theory and computation to different magnetic configurations

- Then there's Validation
  - substantial extension of validation
  - quantitatively assess the degree to which a model accurately represents the real world
  - not widely practiced in MFE, as yet, but is in other fields (e.g., fluid dynamics)
  - ultimate goal is predictive capability
  - potential roles here for EPR

- NIF National Ignition Campaign struggling, apparently due to poor predictive capability

"Validation" an important role for EPR - 2

- Full predictive capability may or may not be attainable in MFE
- But validation/Validation may help to reduce uncertainty in extrapolations

- Including EPR, adjust the basic variables of magnetic confinement
- Maximize the range of our understanding

- With a broad approach, fusion science likely to be more reliable for prediction
- True even if the ultimate reactor configuration is similar to the present-day tokamak

What needs to be done in terms of prioritization?

- Continued *and strengthened* support for a broad EPR program
- A new initiative investigating liquid boundaries across configuration space

- Broad portfolio helps mitigate future risk (e.g., timeliness and economics of fusion)
- Also a sound scientific approach to MFE development