The Grand Challenge of Quantitatively Predicting the Behavior of Plasmas with Lundquist Number Less than 1000

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Panel: Plasma self-organization. Topic: Theory and Computation.

Developing computational predictability for plasmas of Lundquist number (S) less than 1000 is a very exciting area of research because state of the art codes and computers have now reached the capabilities to make quantitative validations of codes modeling of this class of experiments possible. A center is needed to provide the resources for the required attention to details in experimental data, and in code development to make this happen. We should concentrate on these low-S experiments for two reasons. First, unlike the mainline fusion concept experiments, many smaller experiments have as their primary effect phenomena that are secondary in larger, hotter machines. For example, the Hall effect is very important in imposed dynamo current drive experiments. Self-organization is essential in spheromak formation and helicity injection ST startup experiments. Flow is dominant in flow stabilized Z-pinches. Charge exchange and other neutral particle effects can dominate small experiments. Using physically accurate boundary conditions is essential for steady-inductive-helicity-injection experiments. Second, the cooler smaller experiments have smaller Lundquist numbers (S) making it practical to run fluid-based codes at actual experimental values for quantitative validation.

To do this validation metrics and uncertainty quantification need to be developed. The PSI-Center is using biorthogonal decomposition (BD)[1] as an impartial validation[2,3] assessment tool. The value of the method is that the dominant spatial and temporal structures of global data sets are found mathematically. This greatly facilitates a quantitative validation assessment with uncertainties also quantified. The method is an efficient, simple way to include large amounts of data by maximizing the benefit of high speed computing. We have begun developing methodologies and metrics based on BDs, and are developing error propagation for uncertainty quantification.[4,5]

Achieving the grand challenge of quantitative predicting the behavior of plasmas with Lundquist number less than 1000 will make it possible to develop engineering design tools for this class of plasma. One goal is to be able to design plasma producing equipment that reliably meets the design goal. The main practical value of science is quantitative predictability which provides the bases of technological development. This predictability may lead to a plasma technological revolution of great value to humanity. Examples of areas that plasmas are being studied for use today are plasma processing, sterilization of equipment, drag reduction and many more. Progress would be more rapid and more areas developed if we had quantitative predictability.

Figure 1 shows our long-term vision of using computational predictability to lead to improved parameters for the low-S experiments. The goal is to develop predictability of the whole experiment for a good fraction of the time of the discharge for many present experiments. The codes need to be user friendly enough to be used as engineering design tools so that detailed designs of future experiments can be computationally tested before they are built. This is a

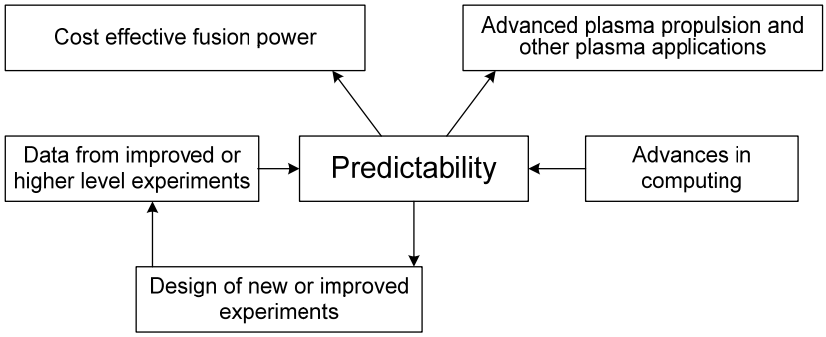

Figure 1: ***Schematic illustrating the contribution of predictability towards the goal of cost effective fusion power.***

difficult long term goal that needs a significant level of effort. The first step is accurately predicting low-S experiments from breakdown to well beyond the best performing part of the discharge. The second step will be using the predictability to design modifications for present experiments that raise S. Finally, when the confidence is sufficient the next level experiments will be designed and computationally "ran" as they are being designed. Data from the new experiments, after they are built, will then be used to improve the physics for better predictability at the improved parameters, making them ready to be used in designing the next advancement at higher S. All the while, advances in computer hardware and algorithms will make the codes faster, more accurate, and more user-friendly. In this way a center will help all of the collaborating experiments achieve their goals, as low-S research evolves, while developing computational predictability that will be valuable to the entire plasma physics community.

This knowledge-led approach supported by the rapid advances in computing technology, and the tokamak plasma and technology knowledge base, may lead to a very cost effective configuration optimization. The first step in this process is quantitative predicting the behavior of plasmas with Lundquist number less than 1000.

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[5] C. Hansen *et al*., "Numerical studies and metric development for validation of magnetohydrodynamic models on the HIT-SI experiment", Phys. Plasmas 22, 056105, 2015.