F-I39 AAPPS-DPP2020
4th Asia-Pacific Conference on Plasma Physics, 26-31Oct, 2020, Remote e-conference

Hidden Symmetries and Fusion Energy

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The most compelling transformational use of magnetically confined, high-temperature plasma is to realize sustained fusion energy. The *tokamak*, which is the leading magnetic confinement concept in the world today, has the topology of a torus and continuous symmetry with respect to the toroidal angle, giving it good confinement properties. In the *stellarator*, which is the leading alternative to the tokamak, the confining magnetic field is mostly produced by external current-carrying coils. In contrast to the tokamak, stellarators *rely* on symmetry breaking to realize the magnetic field needed to confine particles.

Over the last few decades, a new concept has emerged in the design of stellarators, giving rise to a renaissance----the remarkable discovery that it is possible to design 3D magnetic confinement devices with *hidden symmetries* that can have the same virtues as tokamaks while overcoming some of the inherent drawbacks of the latter. An example of a hidden symmetry, known as “quasi-symmetry,” is that the magnitude B of the magnetic vector field $\mathbf{B}$ has an ignorable coordinate (in a special curvilinear coordinate system) even though $\mathbf{B}$ does not. The primary purpose of this collaboration, supported by the Simons Foundation, is to create and exploit an effective mathematical and computational framework for the design of stellarators with hidden symmetries.

Existing experiments show that stellarator design optimization holds the key to successful performance. Results from the Helically Symmetric Experiment (HSX) at the University of Wisconsin-Madison and the Wendelstein 7-X (W7-X) experiment at the Max Planck Institute of Plasma Physics in Greifswald (Germany), which started operation about three years ago, are very encouraging, compelling the design of the next generation stellarator.

The challenge of finding 3D optimum magnetic fields with hidden symmetries encompasses mathematical and computational problems of great subtlety, straddling optimization theory, plasma physics, dynamical systems, and the analysis of partial differential equations. We have, therefore, assembled a multi-disciplinary team of world experts in these disciplines, reflecting the breadth and importance of our challenge. Synthesizing the understanding developed through our research, our goals include a modern stellarator optimization code that can exploit the full power of petascale and exascale computers, and a few optimal designs of next-generation stellarator experiments.