

The Role of Theory and Computation in Advancement of the Stellarator Concept

Theory and computation has played a pivotal and pioneering role in the resurgence of the stellarator as a potentially viable candidate for fusion energy. With inherent steady-state operation, no disruptions in low-current manifestations, flexibility in plasma density, and no need for current drive, stellarators avoid many of the complicated systems and conflicting design requirements being addressed within the tokamak program. Historically however, stellarators faced a supreme challenge with low collisionality neoclassical transport inconsistent with reactor conditions. Theory and computation showed the concept of quasisymmetry, and its relative quasi-omnigeneity, could remove this roadblock. Stellarators needed optimization, within a largely expanded parameter space (compared to 2D systems), to succeed. Quasisymmetry was experimentally tested successfully in HSX, which showed greatly improved low-collisionality electron transport, and quasi-omnigeneity formed the basis for the W7-X design and its resulting construction.

Theory and computation need to lead the way for the next advancements in the stellarator concept, and there is significant work to be done, with many exciting opportunities. Optimization must continue, with some of the targets and tools in place and needing attention, and other targets and even basic tenets needing to be developed. With increasingly limited resources and increased costs for experiments, theory and computation must play a critical role in guiding our course and choices. One particularly intriguing question is can we optimize turbulent transport? Modern gyrokinetic tools are now in place to permit addressing this question. Impurity accumulation is critical to any reactor concept. This is perhaps the most critical issue for stellarators because the ion root in neoclassical theory suggests impurity accumulation in a reactor. Experiment shows, however, that under certain conditions, impurities are expelled from the core (W7-AS HDH mode and LHD ‘impurity-hole’)! There is at present no theoretical understanding of these results. Another critical issue for stellarators is improved alpha particle confinement. Optimization for neoclassical thermal confinement does not necessarily ensure good confinement of energetic ions. Divertors in 3D are also a key issue needing attention, with scaling of the island divertor concept to reactors being an open issue. Metrics for divertor design in stellarators for optimization are unknown. Equilibrium tools need improvement to be able to deal with magnetic islands and plasma flow. Flows and their damping are critical and often ignored, and may make important differences to anomalous transport and choice of magnetic configuration.

There are tremendous opportunities and needs for theory and computation within the stellarator arena, and in 3D configurations, and a chance to make game changing impacts to the future of fusion.