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Structure and structure-preserving algorithms for plasma physics[1]

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Conventional simulation studies of plasma physics are based on numerically solving the underpinning differential (or integro-differential) equations. Usual algorithms in general do not preserve known geometric structure of the physical systems, such as the local energy-momentum conservation law, Casimir invariants, and the symplectic structure (Poincaré invariants). As a consequence, numerical errors may accumulate coherently with time and long-term simulation results may be unreliable. Recently, a series of geometric algorithms that preserve the geometric structures resulting from the Hamiltonian and action principle (HAP) form of theoretical models in plasma physics have been developed by several authors. The superiority of these geometric algorithms has been demonstrated with many test cases. For example, symplectic integrators for guiding-center dynamics have been constructed to preserve the noncanonical symplectic structures and bound the energy-momentum errors for all simulation time-steps; variational and symplectic algorithms have been discovered and successfully applied to the Vlasov-Maxwell system, MHD, and other magnetofluid equations as well. Hamiltonian truncations of the full Vlasov-Maxwell system have opened the field of *discrete gyrokinetics* and led to the GEMPIC algorithm. The vision that future numerical capabilities in plasma physics should be based on structure-preserving geometric algorithms will be presented. It will be argued that the geometric consequences of HAP form and resulting geometric algorithms suitable for plasma physics studies cannot be adapted from existing mathematical literature but, rather, need to be discovered and worked out by theoretical plasma physicists. The talk will review existing HAP structures of plasma physics for a variety of models, and how they have been adapted for numerical implementation.

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