Magnetic Cycles and Flux Emergence in Solar and Stellar Dynamos

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The 11-year solar sunspot cycle is arguably the most well-known and well-studied manifestation of an astrophysical dynamo. Yet, the underlying physics is surprisingly subtle and far from settled. In addition to the challenge of deciphering the fundamental mechanisms that determine the cycle period and amplitude, one must account for the presence of the sunspots themselves, which are both touchstones for cyclic magnetic activity and conduits for the transport of magnetic flux, energy, and helicity from the solar interior to the solar atmosphere. It is still unclear how closely these two fundamental mysteries (magnetic cycles and sunspots) are linked; is the emergence of magnetic flux through the solar surface that produces sunspots and related active regions essential to the operation of the cyclic solar dynamo or is it merely a superficial by-product of deeper-seated dynamics? How does such striking regularity emerge from the highly turbulent conditions of the solar convection zone? What do observations of cyclic magnetic activity in other stars reveal about the underlying dynamo mechanisms? I will address these questions and more based on a suite of modern, 3D MHD simulations of solar and stellar dynamos that are beginning to capture some of the essential dynamo ingredients with increasing fidelity. Highlights include magnetic self-organization by turbulent convection yielding magnetic wreathes and cycles, the first self-consistent generation of buoyant magnetic flux tubes in a convective dynamo simulation, and the first 3D solar dynamo model that explicitly includes sunspots (and even relies on them for the dynamo to operate).