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Astrophysics of Accretion onto Compact Objects[1]

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The most energetic phenomena in the universe are systems powered by gravity through accretion. For compact stars such as white dwarfs, neutron stars, and especially black holes, the energy released per unit mass accreted can significantly exceed that released by nuclear reactions. Over the last half century a growing body of observations has revealed a plethora of environments in which accretion plays a significant or even dominant role. Our theoretical understanding of accretion disk systems has not kept pace. Until recently theory has been based primarily on a one-dimensional time-steady model consisting of an optically thick, vertically-thin, Keplerian disk with an unknown, parameterized internal stress. While these analytic models have served us well to understand many properties of a wide variety of accretion systems, their limitations are now well-known, and the observation data demand moving beyond this standard. Space- and ground-based observations are providing increasingly detailed evidence that accretion systems are dynamic. For example, the spectral energy distribution and luminosity for sources such as X-ray binaries and AGN are strongly variable, often with substantial amplitudes. The timescales for variability are rapid, often comparable to the dynamical times associated with orbits near the central black hole. This variability must arise not from secular changes in the accretion rate (the only process accessible to time-stationary analytic disk models) but from processes that occur within the disk. Numerical simulations provide a way to investigate the dynamics of accretion flows directly with far fewer limitations compared to analytic models. Because magnetic fields are fundamentally important for jets and disks, and because we now know that magnetic turbulence accounts for the internal stress, the governing equations are those of compressible magnetohydrodynamics (MHD). Accretion disk dynamics can thus be investigated using three-dimensional MHD simulation codes that employ both global and local computational domains. Although it is not yet possible to do fully global time-dependent radiation transport in disk models, the observational implications of these simulations can be investigated using simple emission and absorption models coupled with relativistic ray tracing. The time and length-scales involved make such simulations challenging, but even the first results are intriguing. They have revealed details about time-dependent properties of disks, magnetic disk dynamos, jet launching mechanisms, and the dynamical properties of systems other than the standard thin disk. As the capabilities of computational hardware increase, and the development of advanced numerical codes continues, our theoretical understanding of accretion physics will substantially increase.

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