Chapter 5

Hydrodynamics

Reality continues to ruin my life.

Bill Watterson

Gas and fluid dynamics play an important role in many astrophysical processes. When addressing these physical phenomena, we refer to the collection of solvers by the generic term *hydrodynamics*. Gas dynamics forms the basis for our understanding of star and planet formation; it drives X-ray sources and accretion onto supermassive black holes; it dictates the appearance of galaxies. In AMUSE, hydrodynamics is addressed numerically using two quite distinct methods: the Lagrangian formalism with smoothed particles, and Eulerian grid-based finite volume formalisms. These approaches are complementary. Hybrid approaches that combine the advantages of both methods also exist, but are (currently) unavailable in AMUSE. Simulating hydrodynamics is an art, but one with a solid mathematical background.

5.1 In a Nutshell

Hydrodynamics deals with the motion of fluids driven by internal and external forces, for example due to pressure gradients and gravity. Although fluid dynamics is important for everyday life, we discuss it here in the context of astronomical phenomena. That means we will largely ignore many important fluid properties, such as viscosity and surface tension, that are critical to Earth-bound applications.

In AMUSE, we confine ourselves to a continuum description of the gas—we do not attempt to describe the microscopic behavior of its constituent particles. In doing so, we are assuming that we can sensibly define thermodynamic quantities, such as density and temperature, on the spatial scales of interest. In numerical simulations, the spatial variation of fluid properties may be represented in a variety of different ways—on a regular grid, or an irregular tessellation, or in terms of a collection of macroscopic particles that sample the fluid at different locations. In all cases, if the sampling scale is λ, the gas has number density n, and we are interested in a physical flow with characteristic length scale L, then we require $\lambda \ll L$ and $n\lambda^3 \gg 1$ (that is, a resolution element should contain many particles but still be much smaller than the length scales