Unit 2. Partial differential equations (PDEs) in physics

Lecture 201

Reference book:

"Introduction to Computational Astrophysical Hydrodynamics" by Zingale.

W. Banda-Barragán, 2022

What is a physics simulation?

Simulation enables us to build a model of a system and allows us to do virtual experiments to understand how this system reacts to a range of conditions and assumptions.
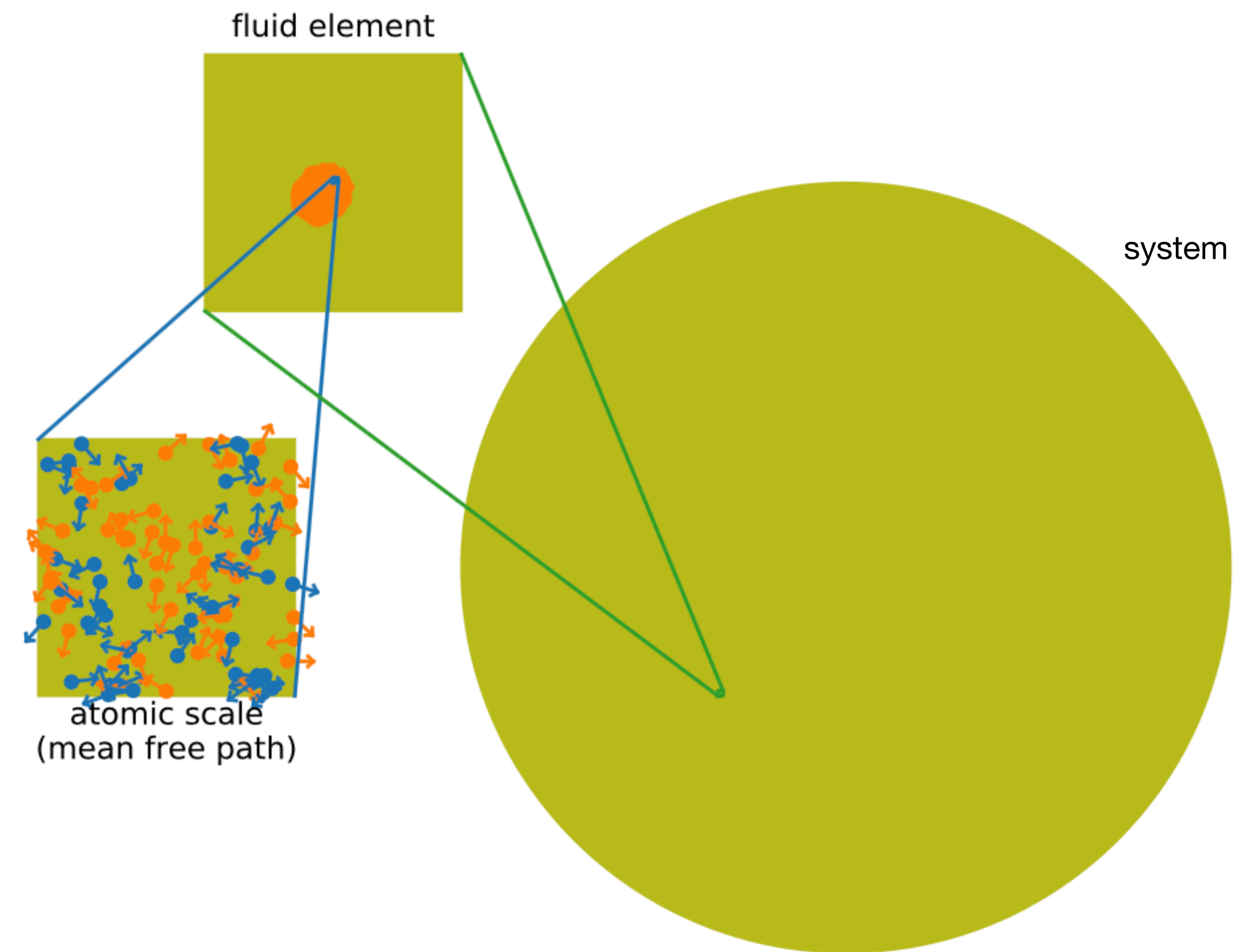
It's tempting to think that one can download a simulation code, set a few parameters, maybe edit some initial conditions, run, and then have a virtual realisation of some physical system that you are interested in. Just like that. In practice, it is not this simple.

What is a physics simulation?

All simulation codes make approximations—
these start even before one turns to the computer,
simply by making a choice of what equations are
to be solved.

The main approximation that we will follow
here, is the *fluid approximation*.

fluid element

system

atomic scale
(mean free path)

What is a physics simulation?

We don't want to focus on the motions of the individual atoms, nuclei, electrons, and photons in our system, so we work on a scale that is much larger than the mean free path of the system.

This allows us to describe the bulk properties of a fluid element, which in turn is small compared to the system of interest.

Within the fluid approximation, additional approximations are made, both in terms of the physics included and how we represent a continuous fluid in the finite-memory of a computer (the *discretisation* process).

What is a physics simulation?

Typically, we have a system of PDEs, and we need to convert the continuous functional form of our system into a discrete form that can be represented in the finite memory of a computer. This introduces yet more approximation.

Blindly trusting the numbers that come out of the code is a recipe for disaster. You don't stop being a physicist the moment you execute the code—your job as a computational scientist is to make sure that the code is producing reasonable results, by testing it against known problems and your physical intuition.

What is a physics simulation?

Because the systems we solve are so nonlinear, small changes in the code or the programming environment (compilers, optimisation, etc.) can produce large differences in the numbers coming out of the code.That's not a reason to panic.

As such it is best not to obsess about precise numbers, but rather the trends our simulations reveal. To really understand the limits of your simulations, you should do parameter and convergence studies.

Every algorithm begins with approximations and has limitations. Comparisons between different codes are important and common, and build confidence in the results that we are on the right track.

What is a physics simulation?

To really understand your simulations, you need to know what the code your are using is doing under the hood. This means understanding the core methods used in physics.

The best way to learn is to code up these methods for yourself.