Fluid & Plasmas I
IUCAA - NCRA Graduate School
5 January - 6 March 2026

Term Projects

January 8, 2026

1. Developing a Hydrodynamic Code

Develop a basic one-dimensional and two-dimensional Hydrodynamic Code that solves the three-dimensional compressible Euler equations (*ideal* fluid flow) given any initial conditions. The group will develop the code by writing a finite volume solver (here Riemann-type) for the Euler equation in both one and two dimensions. References/tutorials will be provided in the handout. It should be noted that only the "solver" (more in the handout sheet) will solve one-dimensional or two-dimensional fluxes, but the Euler equations will contain all three components of the fluid velocity. Specific tests of their code will be asked from the students, including, but not limited to :

i) The Sod Shock Tube Test for 1D and 2D. A density and pressure step function will be provided as an initial condition and the system should be allowed to evolve. The students will be asked to discuss the final results.

ii) The Sedov Blast Wave test must also be run, given the initial conditions for both 1D and 2D. For each case, the student will be expected to plot the density and pressure profiles at the end of the simulation run.

2. Developing a Smoothed Particle Hydrodynamics code

Develop a Smoothed Particle Hydrodynamics (SPH) code from first principles. Unlike grid-based methods, SPH is a fully Lagrangian, particle-based approach to solving the equations of hydrodynamics. The emphasis of this project is on understanding the numerical formulation of SPH, its strengths and limitations, and its application to problems involving smooth flows and shocks.

The project will proceed in a staged manner, with each stage building directly on the previous one:

i) The group will implement the fundamental components of SPH in 1D, including kernel interpolation, density estimation, neighbor search, and time integration of the equations of motion and internal energy. The implementation should be modular and tested on simple initial conditions.

ii) The SPH scheme will be extended to include artificial viscosity terms in order to handle converging flows and suppress numerical artifacts. The group will examine the effect of artificial viscosity on smooth-flow tests.

iii) The group will apply their SPH code to a standard shock problem, the Sod shock tube. The students will also simulate a 1D Sedov blastwave. This serves as the primary validation of the 1D SPH implementation.

iv) Finally, the group will extend their validated 1D SPH code to 2D and test their implementation using the 2D Sod shock problem.

Throughout the project, students are expected to validate their code using standard test problems, and explore the effect of numerical parameters such as the smoothing length and artificial viscosity. More details will provided in the handout.

3. Developing a Radiative Transfer code.

Develop a three-dimensional ray-tracer for a constant-temperature medium where each cell will have fixed opacity and temperature (source function). This will solve the basic absorption and emission through a homogeneous medium. Once this is done, the group must proceed to the following:

i) Add scattering to the medium. This will make the computational cost higher since for each cell, one needs to account for rays from all other cells that might have arrived at the current cell due to scattering. Details will provided in the handout.

ii) A high-intensity source at the center of the grid will be placed, along with an astrophysics-like disk that would follow a given density and emission profile.

iii) One would then produce a final 2D map of the emitted intensity, with bright edges, shadows and glows.