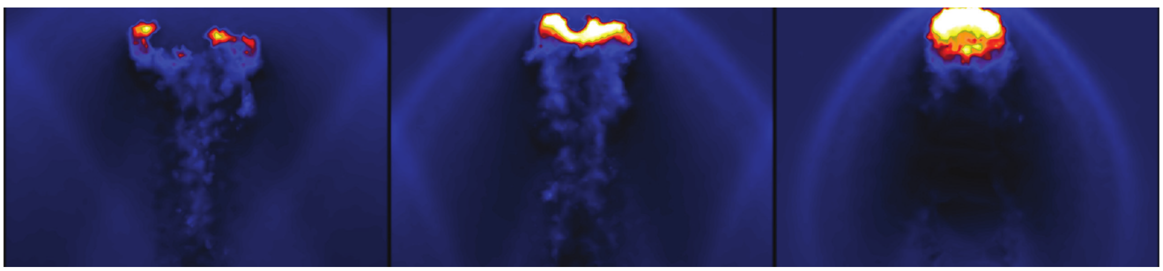
Research Proposal for a Master Thesis in Physics
Verifying the VPH scheme in Galaxy Formation

Sebastian Bustamante Jaramillo



Time evolution of a gas cloud in a supersonic wind using a VPH scheme. Taken from (Heß & Springel, 2010)

Contents

1 General Information

Information of the Student

Name	Sebastian Bustamante Jaramillo
Degree	B.Sc. in Physics, Universidad de Antioquia (2013)
E-mail 1	macsebas33 *at* gmail.com (personal)
E-mail 2	sebastian.bustamante *at* udea.edu.co (academic)

More detailed information of the applicant can be found here `http://goo.gl/BPZGzK`

Information of the Project

Title	**Verifying the VPH scheme in Galaxy Formation**
Field	Cosmology, Astrophysics, Physical Sciences
Advisor 1	Professor Juan Carlos Munoz-Cuartas. Universidad de Antioquia, Colombia.
University	Universidad de Antioquia, Master of Physics program
Time Frame	2 years

2 Abstract

3 Introduction

As we understand more deeply the physical processes involved in astrophysical phenomena, it becomes necessary to compute complex interactions of a ever increasing number of single components. Some prominent examples include the large-scale Universe, galaxy evolution, stellar interior, star formation and protoplanetary disk dynamics. A common aspect of these examples is that all of them can be regarded basically as a fluid mechanic problem.

Although the development of analytical approaches has demonstrated to be a valuable resource for studying these processes, their increasing complexity makes necessary to invoke numerical solutions as a more viable alternative. For this purpose, two different families of hydrodynamics solvers has been explored and widely used by the astrophysical community. First, a family of moving-mesh-based techniques (e.g. *Smoothed Particle Hydrodynamics* `SPH` (Monaghan, 1992), *Voronoi Particle Hydrodynamics* `VPH` (Heß & Springel, 2010)), and a second family of fixed-mesh-based techniques (e.g. *Adaptive Mesh Refinement* `AMR` (Berger & Colella, 1989)).

Due to the Lagrangian character of moving-mesh methods, techniques like `SPH` are easily implemented on a computer. Furthermore, as the physical system evolves, the mass particles naturally move into higher density regions, providing a self-adjusting spatial resolution. Nevertheless, `SPH` has been shown to produce spurious suppression of fluid instabilities due to its kernel-based density estimator, making it unsuitable to model some of the dynamics accurately. On the other hand, fixed-mesh methods like `AMR` are more efficient for capturing shock dynamics. However, due to the conservative nature of the hydrodynamical equations, a fixed mesh causes a lack of Galilean invariance. Furthermore, the sampling of physical properties over the grid introduces spurious vorticity to the fluid, making this technique poor suitable for studying turbulent flows.

A completely new approach to solve hydrodynamical problems was introduced by Springel (2010) and implemented into the `AREPO` code. It combines the strengths of `AMR` and `SPH` but overcomes many of their weaknesses, hence it can be though as a mixed technique. `AREPO` uses a moving mesh based on a Voronoi tessellation defined over a set of particles that represents the fluid. The geometry of the mesh resembles very closely that of the point distribution, retaining the self-adaptivity inherent of `SPH` and also keeping a grid to capture shocks like `AMR` does. These features make `AREPO` highly accurate for simulating a wide range of hydrodynamical problems. Nevertheless, there is a price to pay for this accuracy, `AREPO` demands a huge computing time as compared with `SPH` and even `AMR`.

A very interesting alternative was introduced by Heß & Springel (2010), i.e. the *Voronoi Particle Hydrodynamics* `VPH` technique. This approach consists of an implementation of `SPH` with a modified density estimator based on the *Voronoi Tessellation Field Estimator* `VTFE`. The new estimator has demonstrated to improve substantially the spurious suppression of fluid instabilities as well as retaining the computational efficiency of the original formulation.

Finally, galaxy evolution and large-scale structure formation are very rich astrophysical phenomena where a plethora of hydrodynamical processes can be found and studied. In this fashion, cosmological simulations are a quite suitable scenario for performing detailed physical and computational comparisons of all above-mentioned techniques. It is especially interesting to quantify the computational performance of the `VPH` technique in terms of its physical accuracy as compared with the classical approaches and `AREPO`.

4 Objectives

General Objective

Quantifying the computational performance of the `VPH` technique in terms of its physical accuracy for a cosmological setup.

Specific Objectives

- Evaluating the physical accuracy provided by `VPH` for a cosmological setup as compared with `AMR`, `SPH` and `AREPO`.
- Exploring and quantifying the differences between `VPH` and `AMR` for describing shock dynamics in specific hydrodynamical instabilities.
- Exploring and quantifying the differences of `VPH` and `SPH` for describing turbulent flows.
- Measuring the computational performance of `VPH` as compared with `AREPO`.

5 Theoretical Framework

6 Methodology

The proposed project is subject to a M.Sc. study and will cover the following steps:

✓ *First, a bibliographic review of the original papers where were formulated each of the discussed methods should be done. Also a review of previous comparison projects.*

7 Expected Results

At the end of the stipulated development time for this project, we hope to have obtained the following results:

- A toolbox of codes to study the performance of hydro-solvers over cosmological setups and over standard benchmark problems in fluid mechanics.
- A M.Sc. thesis.
- Submitting a first-author paper to an international journal.
- Participating with a poster or an oral presentation in an international event.

8 Scientific Impact

9 Schedule

Semester	**Goals**
First	• Identifying a set of existing `AREPO` simulations suitable for our succeeding studies. • Applying web finding schemes (T-web and V-web) to the simulations for quantifying structures in the gaseous cosmic web, i.e. voids, walls, filaments and clusters. • Evaluating properties of found structures at different redshifts.
Second	• Studying by mean of high resolution simulations the impact of the gaseous cosmic web on specific galaxy evolution processes.

8 Bibliography

Berger M. J., Colella P., 1989, Journal of Computational Physics, 82, 64

Heß S., Springel V., 2010, MNRAS, 406, 2289

Monaghan J. J., 1992, ARA&A, 30, 543

Springel V., 2010, MNRAS, 401, 791