Research Proposal for DAAD PhD scholarship
The Gaseous Cosmic Web with AREPO

Sebastian Bustamante Jaramillo

A projection of the ILLUSTRIS simulation (http://www.illustris-project.org/)

Contents

1 General Information

Information of the Applicant

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

Information of the Project

Title	**The Gaseous Cosmic Web with AREPO**
Field	Cosmology, Astrophysics, Physical Sciences
Advisor 1	Volker Springel, PhD. Heidelberg Institute for Theoretical Studies (HITS) & University of Heidelberg, Germany
Advisor 2	Jaime Forero-Romero, PhD. Universidad de los Andes, Colombia
University	University of Heidelberg, IMPRS PhD program
Time Frame	3 years

2 Abstract

3 Introduction

Since the filamentary nature of the large-scale matter distribution of the observable cosmos (the so-called cosmic web) was evidenced by the first compiled galaxy surveys (Chincarini & Rood, 1975; Gregory & Thompson, 1978; Einasto et al., 1980a,b; Kirshner et al., 1981, 1987), it has been identified as one of the most striking features of the Megaparsec Universe and an increasing interest in studying its dynamical properties and environmental influences on a plethora of different astrophysical phenomena has become evident. At present, a tremendous amount of observational data supports the cosmic web scenario at the point that it has become an essential part of the current standard paradigm in cosmology. Last generation galaxy redshift surveys, such as the *two-degree-Field Galaxy Redshift Survey* (2dFGRS) and the *Sloan Digital Sky Survey* (SDSS), do evince the intricate and complex structure of the cosmic web at a level of detail never seen before. In addition, other valuable observational resources like X-ray emissions of hot intracluster gas embedded into large clusters of galaxies, Ly-α forest absorption lines in the spectra of shock-heated neutral hydrogen gas residing in filaments and clusters, and weak gravitational lensing and imprints in the CMB field produced by foreground structures, have also validated this picture undoubtedly.

On the theoretical side, early descriptions of the evolution of the large-scale Universe, based on gravitational instabilities in primordial stages and leaded by the seminal work of Zel'dovich (1970), are highly consistent with the cosmic web picture, where planar pancake-like regions of matter enclose enormous sub-dense voids and are bordered, in turn, by thin filaments and high-density clumpy knots (Bond et al., 1996). Since then, our understanding of the structure and dynamics of the cosmic web has been dramatically improved as new and more powerful theoretical and computational tools and more refined observational data become available. In particular, N-body simulations, fuelled by last generation computing systems and ever more efficient numerical algorithms, are acquiring an increasingly important role in fathoming the complexity of the large-scale Universe.

Due to the poorly interacting (and unknown) nature of the dark matter component of the cosmic inventory, observations have been devoted to establish the underlying structure of the cosmic web entirely based on detecting baryonic matter (with the exception of non-direct inferences based on gravitational lensing). On the other hand, the highly complex *gastrophysical* processes involved in baryonic dynamics, i.e. shock heating, photoionization, supernova feedback, stellar wind, radiative cooling, star formation and others, make extremely difficult to obtain a completely consistent and reliable scenario from numerical simulations as many of these processes are not fully understood yet. Accordingly, most of the related numerical research has been made based on dark matter-only N-body simulations, where the gas dynamics has been neglected. Although this duality between observations and simulations can be thought as a complementary situation, actually it also makes quite hard to splice both, observational data and numerical predictions.

In spite of most of the above-mentioned *gastrophysical* processes occurring in baryonic dynamics do represent a challenge for any endeavour for simulating the large-scale Universe, the merely hydrodynamic nature of the gas has been challenging enough even for the most simplified models. Traditionally, two different hydro-solvers has been used for astrophysical and cosmological applications, i.e. *Adaptive Mesh Refinement* (AMR) and *Smoothed Particle Hydrodynamics* (SPH).

4 Objectives

- ✓ Understanding, at the light of the last generation AREPO simulations, how is the dynamics of the baryonic matter component throughout the pipeline set up by the potential wells of the dark matter cosmic web.
- ✓ Quantifying gaseous environmental effects on galaxy formation and dynamics.
- ✓ Comparing our results with current (predicting new) observables and imprints of the gaseous cosmic web.

5 Methodology

The proposed project is subject to a PhD study and will cover the following aspects:

- ✓ *First, a set of simulations must be established for all succeeding steps. This may involve making new hydrodynamical simulations or adopting existing ones based on the AREPO code. This also includes a complete analysis of the simulations, i.e. characterization of physical fields (density, temperature, entropy), construction and analysis of catalogues of haloes, and others.*

As this project will be almost entirely based on numerical results, establishing a set of precise hydrodynamical simulations as a solid base for all our succeeding studies is, indeed, one of the key steps that must be fulfilled. The unprecedented accuracy and convergence achieved by the AREPO code, regarding other traditionally used schemes, will guarantee the needed precision.
In Heidelberg, the required computer facilities and the access to the private code AREPO (of which Prof. Volker Springel is the main author) is granted.

- ✓ *Second, an preliminary exploration of the dark matter cosmic web should be done. For this purpose, it is necessary an adaptation of some commonly used web-finding schemes (e.g. the V-web and the T-web) to the new Voronoi-based paradigm established by the AREPO code.*

A first exploration of the structures of the simulations should be done. For this purpose, many different schemes can be found in the literature, but taking into account the reported success of tensor-based web-finding schemes (e.g. the V-web and the T-web), in which prof. Jaime Forero-Romero has a wide research trajectory, it is quite interesting to quantify the dark matter cosmic web of last generation simulations at the light of them. Nevertheless, it is also necessary to adapt these schemes to the Voronoi-based paradigm leaded by AREPO as they was originally intended for traditionally used Cloud-in-Cell methods for computing the density field. It is also worth to mention previous research experiences in this topic of the applicant.

✓ *Third, once established the underlying dark matter cosmic web, it is necessary to quantify the through gas dynamics. To this aim, inward and outward gas fluxes through potential wells (set by non-linear structures such as clusters and filaments) and accretion rates of the gas component residing within dark matter halos at different redshifts should be computed. At this part, it is enabled to evaluate environmental influences on different astrophysical phenomena.*

In order to exploit the new accuracy provide by the AREPO code, a correct quantification of the gas dynamics should be done. The current cosmological paradigm predicts a complex pipeline set by the potential well of non-linear structures, generally corresponding to clusters and filaments, through which the gas is transported toward over-dense regions like dark matter haloes. This process yields to different environmental phenomena of great current interest. We list here the most relevant for this project: influence of filament-induced fluxes on star forming galaxies at high redshifts, acquisition of the spin of galaxies through exchanging of angular momentum with the gaseous cosmic web, and kinematical and dynamical effects of the host environment on Local Group-like systems.

✓ *Finally, a detailed comparison of our potential predictions (or restrictions) with currently available observational data should be done.*

6 Current State

7 Timetable

8 Bibliography

Bond J. R., Kofman L., Pogosyan D., 1996, Nature, 380, 603

Chincarini G., Rood H. J., 1975, Nature, 257, 294

Einasto J., Joeveer M., Saar E., 1980a, MNRAS, 193, 353

Einasto J., Joeveer M., Saar E., 1980b, Nature, 283, 47

Gregory S. A., Thompson L. A., 1978, ApJ, 222, 784

Kirshner R. P., Oemler Jr. A., Schechter P. L., Shectman S. A., 1981, ApJL, 248, L57

Kirshner R. P., Oemler Jr. A., Schechter P. L., Shectman S. A., 1987, ApJ, 314, 493

Zel'dovich Y. B., 1970, A&A, 5, 84