The Impact of Simulations in Cosmology and Galaxy Formation

A summary of the Workshop NOVICOSMO 2008.

*held in SISSA, Trieste, 20-23 October 2008.*

Résumé

In the study of the process of cosmic structure formation numerical simulations are crucial tools to interface observational data to theoretical models and to investigate issues otherwise unexplored. Enormous advances have been achieved in the last years thanks to the availability of sophisticated codes. The ever improving performances of large supercomputing facilities coupled with this efficiency of codes are now allowing to tackle the problem of cosmic structure formation and subsequent evolution by covering larger and larger dynamical ranges and to provide a progressively more realistic account of related complex astrophysical and cosmological processes. Moreover, computational cosmology is the ideal interpretative framework for the overwhelming amount of new data from extragalactic surveys and from large sample of individual objects. The Workshop Novicosmo 2008 “The Impact of Simulations in Cosmology and Galaxy Formation” held in SISSA was aimed at providing the state-of-the-art on the latest numerical simulations in Cosmology and in Galaxy Formation. Particular emphasis was given to the implementation of new physical processes in simulation codes, to the comparison between different codes and numerical schemes and how to use best supercomputing facilities of the next generation. Finally, the impact on our knowledge on the Physics of the Universe brought by this new channel of investigation has also been focused. The Workshop was divided in three sections corresponding (roughly) to three main areas of study: Reionization and Intergalactic medium; Dark and Luminous matter in galaxies; Clusters of galaxies and Large scale Structures. This paper will provide i) a short resume’ of the scientific results of the Workshop ii) the complete list of the talks and the instructions on how to retrieve the .pdf of the related (powerpoint) presentations iii) a brief presentation of the associated Exhibition “Space Art”

1 Highlights of the conference

It is evident that in different areas of Cosmology (N-Body, Hydrodynamical, SPH) simulations are a new privileged channel to acquire decisive knowledge.

1.1 Reionization

With the advent in the near future of radio telescopes as LOFAR, a new window on the high- redshift universe will be opened. In particular, it will be possible, for the first
time, to observe the 21cm signal from the diffuse Intergalactic Medium (IGM) prior to its reionization and thus probe the "dark ages". Simulations of IGM reionization are already considering its observability.

1.2 Lynam $\alpha$ forest

The Lyman-alpha forest is a tracer of intergalactic structures in the high redshift universe. Hydrodynamical simulations are used to interpret the high and low resolution quasar data sets available and the main physical ingredients that have been incorporated in the numerical codes to properly simulate the transmitted Lyman-alpha flux. The results of such simulations are related to cosmological parameters and synergy's with other large scale structure observables: they can measure the coldness of cold dark matter particles, non-gaussianities at high redshift and the intergalactic medium thermal state.

1.3 First Stars in the Universe

The formation of the first stars is thought to occur in very low mass sub-galactic units within the first Gyr of the cosmic history. The first stars are thought to be extremely luminous and reside in dark matter halos with masses of approximately a million solar masses. These metal-free (or virtually so) stars might have masses of more than $100 M_\odot$, and therefore are expected to end their life as pair-instability/core collapse supernovae. The energy and heavy element deposition by supernovae will affect the star formation rate within the first galaxies and the initial mass function of their stars, via a series of physical processes collectively known as "feedback". Numerical and radiation hydrodynamics simulations implement the relevant physics to follow in detail these early phases of cosmic evolution and their impact on high-redshift galaxy formation the ensuing chemical enrichment of the IGM and reionization. The HII regions created by the first stars are a few kiloparsecs in radius, which then overlap with each other and constitute a volume filling fraction of about a quarter at redshift 15.

1.4 Clusters

Clusters of galaxies have been proved to be ideal cosmological probes. They are the largest collapsed objects in the Universe and so are very sensitive to the structure formation process. Their cosmological simulations harbor enormous potential for the interpretation of observational data, though they are extremely challenging, as the structures in and around them span a very large dynamic range in scales. Furthermore, the complexity of the intra cluster medium revealed by multi-frequency observations demonstrates that a variety of physical processes are in action and must be included to produce accurate and realistic models. In detail, cosmological hydrodynamical simulations able also to follow turbulent flows and subgrid physics, study the thermal structure of the intra-cluster medium and its history of chemical enrichment. A particular focus is given on the effect that feedback from supernovae and AGN has on the observational properties of the hot diffuse cluster baryons, namely how does it affect the
profiles of entropy, temperature and metallicity and the scaling relations between X-ray observables.

1.5 Dark Matter Halos

N-body simulations of galactic dark matter halos remain a very hot topic. Ongoing programme has simulated a number of halos at different resolution, including one with 1.4 billion particles corresponding to a particle mass of less than 2000 $M_\odot$. Careful convergence studies validate the convergence for the structure of the main halo and its substructures (which number about 300000 in the largest simulation). The nature of the density profile of the main halo, its central cusp, the abundance and distribution of subhalos are being clarified. We are now able to accurately resimulate cosmological initial conditions, track dark matter subhalos in the central regions of parent halos, which is essential for understanding the assembly histories of dark matter halos and for running realistic semianalytic models of galaxy formation. Well defined predictions for the flux of the gamma-rays arising from the annihilation of supersymmetric cold dark matter in high density halos have been put forward.

1.6 Galaxy Structure and Formation

Galaxy formation is a laboratory for testing our knowledge of astrophysics as good as cosmology. Different kinds of simulations are set to reproduce the main properties of low- & high-redshift galaxies and Damped Lyman $\alpha$. That is the luminosity/mass functions, colors and metallicities, stellar content and molecular hydrogen in the process of establishing the validity of $\Lambda$ CDM scenario. The physics of how gas accretes into dark matter potential wells and gets converted into stars, is as crucial as complex. Feedback from stars and AGN and galactic outflows all regulate the complex multi-phase interstellar medium, in which magnetic fields, cosmic rays, molecules/dust play also a role. To reproduce all that is a huge computational challenge that requires to understand the physics at sub-grid level and also some detailed aspect of the occurring physical processes, e.g. the relation between the star formation and the distribution of molecular hydrogen. Simulations require a post-processing analysis in which great attention is given to checks for numerical artifacts and to pinpoint relevant physical processes. Important phenomenological constraints on the models can be obtained from matching the observed distributions of stellar masses and kinematics. Several long standing open issues such as the existence of bulgeless galaxies, the formation of disks with large angular momentum of the "missing satellites problem" has been tackled with a combination of increased numerical resolution and better models for star formation and the energy balance of the interstellar medium and detailed star formation histories.

1.7 Gas around Galaxies

High-resolution numerical simulations seconded by a large suite of cosmological gas-dynamical simulations that get repeated using different physical parameters probed the warm-hot gas halo that is predicted to surround normal disk galaxies in particular the gas accretion and outflows using simulations. The simulations predict a variety of
observational signatures, including X-ray emission and UV absorption/emission lines, and demonstrate that Lyα, OVI, and CIV spectral lines are important diagnostics of the strength of feedback in spirals.

1.8 AGNs-Coevolution of Black Holes and Galaxies

The interaction between active galactic nuclei (AGN) and the intracluster medium (ICM) is crucial in the formation of spheroids. Feedback by hot, underdense bubbles powered by AGN/QSO play a key role in structure formation. Hydrodynamical simulations investigate different physical processes claimed to be responsible for both BH accretion and bulge formation help discriminating among different theoretical models for the quasar lightcurve and for the dependence of the quasar lifetime on BH mass. These simulations are far from trivial requiring modeling of subgrid turbulence and a good understanding of Rayleigh-Taylor instabilities to pinpoint important implications such as the impact of AGN-driven clouds on the mixing of metals into the ICM.

2 Invited and contributed papers

Here follows the list of the invited and contributed papers of the Workshop Novicosmo 2008. All the .pdf files of the related (power-point) presentations given at the workshop can be downloaded at www.novicosmo.org, by clicking Proceedings.

Simulations of Galaxy Formation and Cosmological Reionization Renyue Cen
Feedback processes at Cosmic Dawn : Numerical Views Andrea Ferrara
Starting reionization with the first stars John Wise
Simulations of reionization Benedetta Ciardi
Simulating the formation of galaxies and the evolution of the intergalactic medium Joop Shaye
The interaction between galaxies and the intergalactic medium Tom Theuns
The chemical history of the universe Luca Tornatore
The high redshift intergalactic medium as a cosmological probe Matteo Viel
Simulating the Circumgalactic Medium Greg Bryan
Modeling molecular gas and star formation in high resolution Cosmol. simulations A. Kravtsov
Formation and Evolution of Giant Molecular Clouds in Disk Galaxies Elizabeth Tasker
Galaxy formation simulations in a CDM Universe Lucio Mayer
MUPPI A new star formation and feedback algorithm for numerical simulations G. Murante
DLAs in Galaxy Formation Simulations Andrew Pontzen
Chemodynamical models of dwarf spheroidal galaxies Pascale Jablonka
Simulations of Galaxy Formation Including Outflows Romeel Dave
Modeling Star Formation in Dark Matter Halos Oleg Gnedin
Galaxy kinematics : comparing observations and simulations Gianfranco Gentile
Galaxy Formation Simulations : successes and failures Kentaro Nagamine
Simulations of galactic disks including a dark baryonic component Yves Revaz
The effect of the TP AGB on the semianalytic modeling of galaxy formation Chiara Tonini
Dynamical Downsizing in Ellipticals : clues from Cosmol. Simulations R. Dominguez-Tenorio
Simulation of the AGN ICM interaction Marcus Brueggen
Feedback effects on the chemo and thermodynamics of the ICM Stefano Borgani
Magnetic fields, CRs and nonthermal emission in galaxy clusters Klaus Dolag
Modelling of turbulent flows applied to numerical simulations of galaxy clusters Luigi Iapichino
Coevolution of BHs and Galaxies : models for BH accretion and quasar light curve Silvia Bonoli
3 The Exhibition Space Art.

Simulations are "cosmology experiments" leading to important papers and scientific discoveries but, at the same time, they are beautiful images and thrilling movies. Once treated by an artist mind, they become unique moments of contemplation of the Cosmos, and of its mysteries and a reassessment of the role of each individual in the Grand Picture of Nature. As result, simulations (as astro-images from Large Telescopes) are a perfect mean to fill the gap between the curiosity of people and the difficulty of a scientific explanation. Here comes the Exhibition "Space Art", associated to the Workshop Novicosmo 2008, in which a number of simulations (many of which performed by participants of the workshop) are arranged by artists and experts of public outreach and presented to the general public. The Exhibition, that can be visited at Immaginario Scientifico until 11 January 2009, includes 4 different paths. That is 4 multivisions, displayed on 7 giant screens (3.5m x 2m), of length of 26', 13', 13' and 20' respectively. The trailer of the Exhibition is at www.youtube.com/watch?v=K0iKLHqTo, its brochure can be retrieved at www.novicosmo.org. Any information, including welcomed enquiries for showing it around during the Astronomy Year 2009, should be asked to spaceart08@libero.it.

Among the authors of the simulations : Borgani, Burkert, Coldberg, Dave', Dolag, Dubinsky, Frenk, Giacomazzo, Gnedin, Gritschneder, Heitsch, Kravtsov, Mayer, Moore, Naab, Nagamine, Rezzolla, Schaye, Springer, Theuns, Viel, Wise

Paolo Salucci, Stefano Borgani, Carlos Frenk, Lauro Moscardini, Matteo Viel