Nicolas Deparis | PhD student

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Research interests

- Cosmology - Reionization
- Galaxy formation and evolution
- Star formation and feedback
- High performance computing
- Data visualization

Education

Ph.D. in Astrophysics **2014–present**
Thesis title : Reionization of the local group *Strasbourg University*
Supervisor: Dominique Aubert

Master in Theoretical Physics **2009–2011**
Specialization : Astrophysics *Strasbourg University*

Experience

Fixed-term contract **2014**
6 months *Observatoire Astronomique de Strasbourg/CNRS*
Implementing stellar formation in a RHD cosmological code

Master Internship **2011**
3 months *Observatoire Astronomique de Strasbourg*
Study of the cosmological tidal field with N-body simulation.
Programming a multigrid algorithm to solve Poisson equation on GPU

Publications

N. Deparis, D. Aubert, P. Ocvirk, and N. Gillet, "Radiation and supernovae feedback during the epoch of reionization with emma," *Monthly Notices of the Royal Astronomical Society*, Submitted.

D. Aubert, N. Deparis, and P. Ocvirk, "EMMA: an adaptive mesh refinement cosmological simulation code with radiative transfer," *Monthly Notices of the Royal Astronomical Society*, vol. 454, pp. 1012–1037, Nov. 2015.

N. Deparis, D. Aubert, and P. Ocvirk, "Influence of reduced light speed approximation on reionization fronts speed in cosmological rhd simulations," *Monthly Notices of the Royal Astronomical Society*, In Prep.

D. Aubert, P. Ocvirk, and N. Deparis, "The reionization epoch of z=0 halos," *The Astrophysical Journal Letters*, In Prep.

N. Deparis, D. Aubert, and P. Ocvirk, "Stellar feedback during the reionization with EMMA," in *SF2A-2016: Proceedings of the Annual meeting of the French Society of Astronomy and Astrophysics* (C. Reylé, J. Richard, L. Cambrésy, M. Deleuil, E. Pécontal, L. Tresse, and I. Vauglin, eds.), pp. 399–402, Dec. 2016.

A. Schaaff, J. Berthier, J. Da Rocha, N. Deparis, S. Derriere, P. Gaultier, R. Houpin, J. Normand, and P. Ocvirk, "Immersive 3d Visualization of Astronomical Data," vol. 495, p. 125, Sept. 2015.

Computing skills

Languages: Python, C/C++, Fortran, Java

API: MPI,CUDA,OpenMP,HDF5,OpenGL

Tools: Git, Valgrind

Known HPC centers: PRACE TGCC Curie (Fance), PRACE CINES Occigen (France), OLCF Titan (USA)

Schools

11/2016: Parallel computing by David Brusson - Ecole Supérieure du professorat et de l'éducation, Strasbourg - France

06/2016: Gutenberg School on Astrophysics - Stars and Galaxy Formation - Observatoire de Strasbourg, France

05/2016: Galaxy formation and evolution in a cosmological context by Andrea Cattaneo - Institut d'Astrophysique de Paris, France

01/2016: From BioImage Processing to BioImage Informatics - Télécom Physique Strasbourg France

12/2015: Principle of imaging for membrane systems - Institut Charles Sadron, Cronenbourg, Strasbourg, France

03/2015: Numerical Simulations in Astrophysics - Observatoire de Strasbourg, France

Conferences

06/2016: Illuminating the Dark Ages: Quasars and Galaxies in the Reionization Epoch - MPIA Summer Conference 2016- Heidelberg, Germany

06/2016: Presentation at Journées de la SF2A - Lyon, France

04/2016: Presentation at 13th Potsdam/AIP Thinkshop "Near Field Cosmology" - Obergurgl, Tytol, Austria

10/2015: Presentation at meeting ORAGE - Roscoff, France

05/2015: Poster at The Olympian Symposium 2015 Cosmology and the Epoch of Reionization - Paralia Katerini's, Mount Olympus, Greece

05/2015: CLUES meeting 2015 - Copenhague, Danemark

Outreach

06/2015: Kids university - Strasbourg, France

Research Statement

Nicolas Deparis

1 Context

I am specially motivated by the field of numerical simulations of galaxy formation, particularly in the young universe, during the epoch of reionization (EoR).

Mainly two things happen during the EoR:

- The gravitational collapse of the gas creates regions with overdensities able to form the first stars of the universe.
- These first stars emit energetic light that change the chemical state of the whole universe.

So, to fully model the EoR, we have to confront star formation processes occurring in dense cold molecular cloud at sub parsec scales, to the global ionization state of the Universe needing volume of hundred mega parsec cube to get significant statistics. One major difficulty of cosmological simulations is to reproduce this wide range of length scale needed by the different processes in consideration. Furthermore, to accurately follows the ionization states of the universe, we need to follow the propagation of light through the gas. And as the light speed is orders of magnitude greater than typical speed of other processes, computing its propagation imply a significant increase in the cost in term of numerical resources.

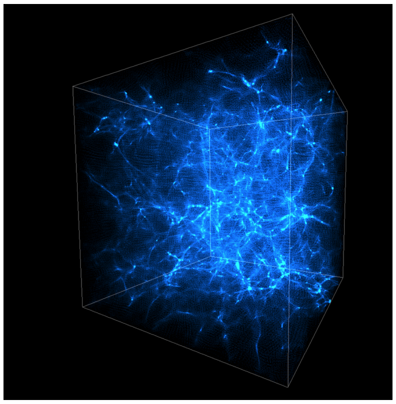
2 Numerical background

I am part of the development team of EMMA [1] , an adaptive mesh refinement (AMR) code with fully coupled radiative hydrodynamic (RHD) capability. To be able to follow the propagation of light on wide range of length scale, EMMA is designed to be massively parallel. Its three mains solvers (ie the N-body, the hydrodynamic at the radiation) has been ported on GPU architecture to take advantage of their acceleration capabilities.

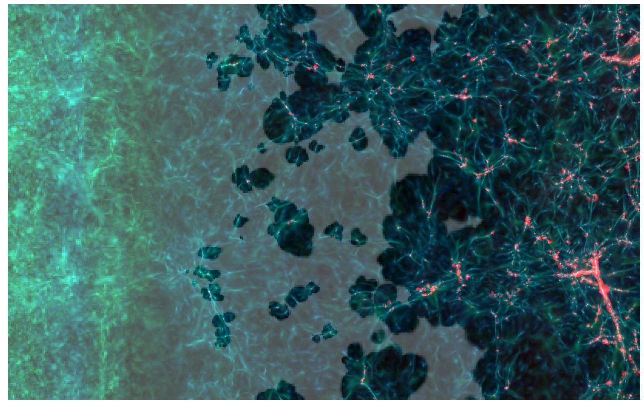
I have worked on different aspect of EMMA:

- During my first year Master trainee, I worked on its radiative transfer solver (CUDATON). My goal was to implement a multi-chromatic capability by considering different type of ionizing photons.
- During my second year Master trainee, I worked on its N-body solver. I implement a Poisson equation solver based on multigrid relaxation technique.
- During my Ph.D., I worked on its stellar model that I will briefly introduce in the next section. As stars have to deal with all physical solvers, it offer me a good global view of such a code. Also, as EMMA can generate a huge amount of data, an efficient data model is necessary. I implement a parallel HDF5 output mode who write the structured AMR data on hard disc in an efficient way.

I develop a python tool prosaically named pyEMMA to read, manage and transform EMMA output in an intuitive way.



(a) OpenGL particle viewer



(b) Light cone

Figure 1: (a) Visualization of a cosmological dark matter simulation made with my openGL particle viewer and (b) RGB composite image of a light cone of a simulation of reionization, a video of this run is available here.

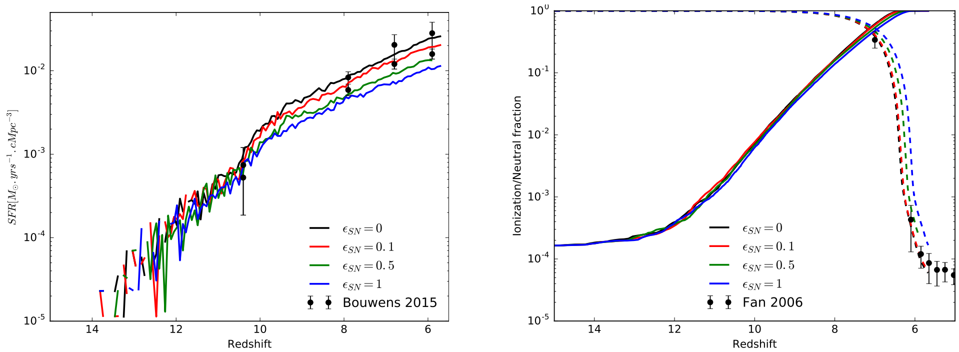
I am also motivated by the field of data visualization. Using Irrlicht, an open source game engine and the Oculus Rift DK, I develop a VR particle viewer in which one we can observe from the inside the evolution of dark matter or stellar particles. Irrlicht suffer of some performance limitations when rendering a high number of objects, so I start to develop an openGL/CUDA alternative, who is much more efficient but still a work in progress. I also use openseadragon and the CODA II simulation to made a zoomable baryon density map available here.

3 Stellar feedback and its influence on reionization

I have implemented in EMMA a model of star formation and evolution in accordance with our current resolution constraints to study the EoR (ie from several dozen of parsecs to several dozen of Megaparsecs). This model [2] is mainly separated in three parts:

- The star formation model aims to reproduce the observational Schmidt-Kennicut law, and consider a gas to star conversion rate function of a power law of the local gas density.
- During their lifetime, stars emit ionizing light. I calibrate their emissivity using a stellar population evolution model Starburst99. From this model we can obtain the evolution of radiative energy emitted by a parametrized population of stars.
- At the end of their life, a part of the stars of the population explode into supernovae, releasing energy in the surrounding gas. The problem of supernovae feedback is extensively studied from more than two decades, and there is still non consensus about a right way to deal with it. I develop an energy injection scheme taking into account the hundred parsec resolution, and the AMR oct tree structure of EMMA. This scheme is able to regulate cosmic star formation (Fig. 2a), and is efficient in term computational cost.

I run about a hundred simulations on the french Curie HPC center to explore the parameter space of this model. Starting from a fiducial simulation, I vary some free parameters to study their influence on



(a) SFH (b) Ionization

Figure 2: (a) Cosmic star formation histories and (b) volume weighted ionization (solid lines) and neutral (dashed lines) fraction as a function of redshift for different feedback efficiency. The star formation model is able to fit cosmic SFH constraint and the energy injection scheme is able to regulate the cosmic SFR. The more we inject energy, the more the star formation rate decrease. But, even with a strong regulation of the SFR, the reionization redshift does not depend of the quantity of energy injected.

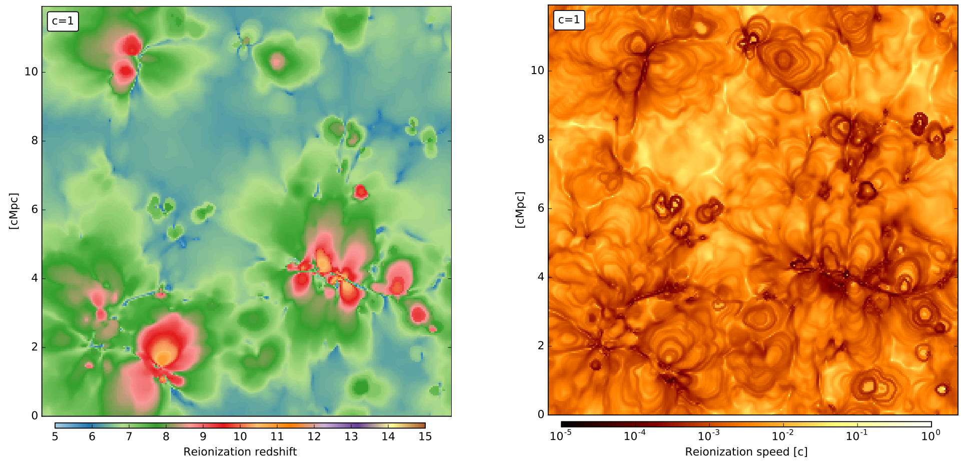
reionization histories. I found that even with a strong regulation of the SFR, and thus of the number of ionizing photons, the amount of injected energy only induce a very small change in the reionization redshift (Fig. 2b). I developed a tool to compute the radiative emissivity of halos at the virial radius and observe that the halo emissivity is not affected by feedback. Thus, I conclude that the supernovae feedback should increase the escape fraction of photon by a factor 3 to compensate the decreased number of emitted photon from stars. I also studied the influence of feedback on cosmic outflows. I observed that without feedback most halos are accumulating matter with a freefall tendency. But by introducing radiation, smaller halos (with masses under $10^9 M_{\odot}$) start to presents gas outflows. This is due to the effect of photo heating. I observe a similar effect with supernovae feedback, the more supernovae inject energy in the medium, the more massive halos start to get outflows.

4 Light propagation and ionization front speed

Due to the Courant condition, the high speed of light is one of the main limitation in RHD simulation. In the goal to reduce the cost of the radiative transfer computation, the reduced speed of light approximation (RSLA) was developed. In the goal to test the implication of this approximation, I developed a method to analyse the propagation of light in a simulated volume a posteriori. This method use the reionization redshift map and its gradient to derive the reionization front speed at any time.

With this method, I found that reionization fronts have an average velocity of about 1% of the speed of light. But when fronts reach the cosmic voids, at the end of the reionization, their speeds rises and can reach values as high as the speed of light. This can be a problem when using the RSLA as the front speed cannot be greater than the speed of light in the simulation, and thus the RSLA can limit the propagation of light in void.

Moreover, and as shown on Fig. 2b, the mains observational constrains of reionization are at the very end of it, at redshift z≈6. And as the RSLA could have significant influence at the end of the reionization, where the constrains are, it could significantly change our physical interpretation.



(a) (b)

Figure 3: (a) Reionization redshift map and (b) Ionization front speed map. From the redshift map, it's possible to derived the ionization front speed in all time.

5 Future work

In a general way, I would like to stay in the field of galaxies formation simulations and high performance computing. There is a lot to do with cosmological RHD simulations, but I'm not hermetic at extending my expertise to others field. Some ways I would like to explore are:

- I'm currently working with high redshift cosmological simulations where galaxies are numerous and came with a great diversity, but I would be curious to study higher resolution simulations going to redshift z=0.
- I would be interested into using observational techniques on numerical simulations in the goal to confront this two fields and try predict what futures generations of telescope will observe.
- It is known that the dark matter model suffers of some limitation. I would be interested by exploring some alternative, like for instance MOND or super-fluid dark matter.
- I'm also interested to AMR alternative methods like e.g. the moving-mesh technique.

References

[1] D. Aubert, N. Deparis, and P. Ocvirk, "EMMA: an adaptive mesh refinement cosmological simulation code with radiative transfer," *Monthly Notices of the Royal Astronomical Society*, vol. 454, pp. 1012–1037, Nov. 2015.

[2] N. Deparis, D. Aubert, P. Ocvirk, and N. Gillet, "Radiation and supernovae feedback during the epoch of reionization with emma," *Monthly Notices of the Royal Astronomical Society*, Submitted.