Rapport annuel d'avancement P2IO

Jean-Baptiste Durrive

Doctorant à l'Institut d'Astrophysique Spatiale, Orsay
Sujet : *Origine et évolution des champs magnétiques cosmologiques*

10 Septembre 2014

1 Project goals

The Universe is magnetized at all scales: magnetic fields are observed in stars, galaxies and galaxy clusters, at essentially every stage of their evolution. The origin of such fields is however still an open question, especially on cosmological scales. The current paradigm is based on the idea that they where first generated very early in the history of the Universe with very weak strengths. Only then were they amplified during the formation of large scale structures, essentially through turbulent motions, and thus reached the values we observe today. However the evolution of structures has been strongly non-linear, i.e. far too complex for us to recover, from present day measurements, any information on the strength and configuration of the fields at the time they were generated. But recent high energy gamma ray observations suggest that a substantial fraction, if not the whole, of the intergalactic space is magnetized too. This is extremely interesting since unlike within structures, the non-linearity in the intergalactic medium has been only mild at most. Therefore, intergalactic magnetic fields may have conserved signatures of their initial properties. Understanding present-day intergalactic magnetic fields could thus be the key to understanding the origin of cosmic magnetism.

My PhD thesis consists in, first through analytical modelling and then numerical simulations, studying the possible origins and evolution of these cosmological magnetic fields, and confronting to observations.

2 Description of work achieved

Numerous mechanisms to account for the existence of such fields have already been proposed. But none of them is satisfactory enough. The difficulty is to generate large enough strengths at large enough scales. Usually proposed mechanisms fail to comply with both requirements at the same time, or they need to invoke exotic physics in order to do so.
During this first year, I studied and improved a mechanism based on plasma-radiation interactions which occur during the so-called Epoch of Reionization of the Universe, the period during which the first stars and first galaxies formed. As these objects formed, they switched on and emitted ionizing radiation which photoionized the intergalactic neutral Hydrogen, thus generating currents and inducing magnetic fields.
I showed that previous studies overestimated the magnetic strengths and I also pointed out where and under which conditions precisely the fields may be generated around these sources. I also computed the precise geometrical configuration of the generated magnetic fields. Although weaker than previously claimed, the strengths of the fields photogenerated this way remain large enough to be of cosmological interest and to participate to the premagnetization of the whole Universe during its first billion years. Indeed, an appealing feature of this mechanism is that it easily premagnetizes large scales, which is the key in this cosmological context. More specifically, scales of the order of the mean free path of the ionizing photons, that is up to megaparsec scales in the case of quasars, may be significantly magnetized.
Note that this work will be of practical interest in a near future. Indeed, several radio telescopes, which are either taking data (LOFAR, MWA, and soon ASKAP, MeerKAT) or are on the verge of being constructed (SKA) and for which cosmic magnetism is one of their key science projects. They will for the first time probe precisely the cosmological Epoch I am modelling in my work, and confronting their data with models such as this one will be essential and very fruitful.
I have finished writing down the article relating these results. It will be submitted for publication before the end of the month. I also attended scientific conferences (*Semaine de l'Astrophysique Française : 2014*, Paris; *IAU Symposium 308: The Zel'dovich Universe: Genesis and Growth of the Cosmic Web*, Tallinn) where I presented posters on this work, and I will give a talk on it at the conference *Cosmic magnetic fields: current knowledge and the future ideas* in Kraków in October.

Tackling the question of the origin of cosmological magnetic fields is the first aspect of my study. Indeed, it is just as crucial to try and understand how, once generated, these fields evolved, in order to decode and interpret correctly the observations. For this reason, in parallel to my work on magnetogenesis, I am interested in their evolution and their amplification during the history of the Universe. As long as the very largest cosmological scales are concerned, the current approach is to consider the Universe as homogeneous and isotropic, and thus consider that magnetic fields are simply diluted by the expansion of space. This assumption is very well justified in the early stages of the evolution, but as structures form by gravitational collapse, magnetic fields are amplified and reorganized non-linearly.

More precisely, in our current understanding of the large scale structure of the Universe, we believe that it is mainly composed of an invisible matter sensitive to gravity only, called dark matter, distributed in a filamentary way, called the cosmic web. The usual matter we know and that stars and galaxies are made of is called baryonic matter. Because these two matter fields interact gravitationnally, to understand in detail the evolution of baryonic matter, and thus that of magnetic fields, one has to consider its interaction with the dark matter component. In that respect, I recently started a new project adopting two complementary approaches: one analytical and one numerical.
In the analytical approach I am modelling the evolution of a cosmic web filament as a cylindrical bi-fluid (dark and baryonic fluids). The aim is to assess the relative importance of all possible instabilities, gravitational, thermal or otherwise, susceptible to fragment the filament. Understanding the fragmentation of the baryonic gas within dark matter cosmic filaments is indeed essential if we want to understand both the accretion of matter onto galaxies and the non-linear evolution of the cosmic web.
For the numerical approach, I recently started a collaboration with a researcher in Strasbourg, Dominique Aubert, who developed a very powerful numerical code to simulate the Epoch of Reionization. This collaboration is at least threefold. First it is an opportunity for me to get familiar with numerical simulations, which is an essential tool in science nowadays. Second, since D. Aubert is simulating the structuration of the Universe, it will be a very fruitful and complementary approach to my analytical work. And third, his code includes in a self-consistent way the impact of radiation during the Epoch of Reionization, which is precisely the key ingredient of the magnetogenesis mechanism I studied earlier. It will be very fertile to compare and combine the two approaches.

Finally, in addition to my research activities, I have been teaching various topics at Paris-Sud University (biophysics, thermodynamics, special relativity, general physics) to various audiences (from 1st to 3rd grades). I also wrote two physics lecture notes for first grade students for a distance learning program and did some science outreach (a conference to general public in Lille and contributed to the P2IO *Zoom* exhibition in Orsay). I also participated to advanced sepcialized schools (*Galaxy Formation and Evolution in a Cosmological Context*, Marseille; *XXV Canary Islands Winter School of Astrophysics: Cosmic Magnetic Fields*, Spain) and attended post-doctoral lectures (on gravitational waves, APC, Paris).

3 Publications

- To be submitted: J-B. Durrive, M.Langer, *Intergalactic Magnetogenesis at Cosmic Dawn by photoionization* (2014)
- *Magnetogenesis at cosmic dawn*, J-B. Durrive, M.Langer, 2014, poster presented in Paris
- *Magnetogenesis at cosmic dawn*, J-B. Durrive, M.Langer, 2014, poster presented in Tallinn
- *L'univers magnétique: vers une cosmologie encore plus attractive*, contributed talk to the IAS PhD. Students Day, 2014
- *L'effet Doppler – point de vue de l'astrophysique* & *L'absorption dans*

l'atmosphère – point de vue de l'astrophysique, lecture notes for the distance learning of the IEP of Lille, 2013

4 Relevance of the project within P2IO

My project is at the heart of P2IO. It addresses the question of the Origins since I am studying notably the origin of magnetic fields in the period of the history of the Universe during which the very first stars and first galaxies formed. It is also obviously relevant to the 'infinitely large' part of the physics of P2IO as my project deals with a fundamental problem of Cosmology. And it also fits the P2IO philosophy of combining several scales and domains of physics, for the key ingredient of the Epoch of the history of the Universe I am considering is photoionization. Thus I am exploring plasma physics in a cosmological context, and I am looking at how, from the microphysics of the interaction between photons and matter, magnetic fields at the largest scales of the Universe emerge.