Back to Belgium Grants

Final Report

Name of the researcher	Clesse Sebastien
Selection Year	Back to Belgium Grants 2013
Host institution	Namur University
Supervisor	Prof. André Fuzfa
Period covered by this report	from 01/11/2013 to 30/09/2015
Title of the project	Backreactions from Cosmological Inhomogeneities during Inflation and Structure Formation

1. Objectives of the proposal

On large scales, the Universe is well described by a homogeneous and isotropic background dynamics around which perturbations evolve in the linear regime. However, on megaparsec scales, it has non-linear structures and voids. This has lead cosmologists to develop numerical and semi-numerical techniques, like N-body simulations, to study the formation of structures in the non-linear regime. However most of these methods assume a Newtonian dynamics and are thus not able to capture non-perturbative relativistic effects like the backreactions on the expansion. We also interpret observations (e.g. supernova spectra) as if light was propagating in a homogeneous-isotropic background. Before the time of structure formation, the linear theory of cosmological perturbations is usually assumed to be valid.

The main objective of the research project was to go beyond the linear theory or the Newtonian approximation, by developing codes of numerical relativity for cosmology, and by applying them to four specific situations where the Universe could have been highly inhomogeneous, with potentially important backreactions and possible observational consequences. The initial goal was to focus on (a) the initial conditions for inflation, (b) the tachyonic preheating, (c) eternal inflation, and (d) the clustering of structure formation, eventually in the presence a dark energy quintessence field or modifications of gravity.

With this project, our goal was to acquire a unique expertise in numerical relativity for cosmological applications. In the next years, characterising the backreactions from structure formation and from other periods of the Universe evolution will become necessary to measure with an increasing accuracy the cosmological parameters and to distinguish dark energy, dark matter, and even inflation models. This project was therefore offering interesting perspectives, for instance with the Euclid mission, in which Belgium and the group of cosmology in Namur are involved.

Developing such codes has been a big part of the research realized during the fellowship. In addition to that guideline, several opportunities have been seized to develop other numerical codes for timely research on directly related topics, especially in inflation, modified gravity. On the other hand, a theoretical work has been pursued to identify models leading to potentially large back-reactions, as it is for instance in a proposed model of primordial black holes involving backreactions from quantum field fluctuations during inflation as well as backreactions on the late-time expansion due to a large peak at small scales in the power spectrum of density fluctuations.

2. Methodology in a nutshell

As a methodology, we have followed those rough guidelines

1. Bibliographic work: to identify articles and research performed on similar topics, with a particular focus on the existing codes that have been used in the field. This work has been very useful to determine the formalisms we have then implemented in our codes.

2. Implementation phase: Development of the codes, using the formalisms decided in phase 1. Validation, using cross-checking between independent codes, as well as using theoretical arguments (e.g. checking the Hamiltonian constraint...).

3. Getting results: From simplest, toy-model cases, that can be cross-checked with the existing literature, up to more complicated and physically motivated cases.

4. Diffusion phase: writing scientific publications, diffusion in conferences, seminars, workshop.

This methodology was typically used for most of the projects that have been achieved during the fellowship.

3. Results

Backreactions from structure formation:

A first stage of the research project has consisted in studying in great details the existing scientific literature for each of the cosmological application mentioned above. The formalisms and methods of numerical relativity have been also the object of our attention. A first step has been to chose the methods to implement. The *Baumgarte-Shapiro-Shibata-Nakamura* (BSSM) formalism, that was developed for the study of the evolution of dense astrophysical object binaries, has been considered as the most appropriate to reach our objectives. The BSSM method is based on the *Arnowitt-Deser-Misner* (ADM) formalism but some variables are conveniently redefined to regularized solutions of the Einstein equations. Finally, we have drawn the guidelines for the implementation phase.

In collaboration with A. Füzfa and A. Roisin, an undergraduate student from Unamur we have supervised for a training course in research, we have implemented the core part of the code. Actually two different codes (one in fortran, one in C) have been developed and they are tested in parallel. This allows easy comparison and checks at each step of the development. The core part includes the tedious calculation of connections, of the Riemann, Ricci and extrinsic curvature tensors, Ricci scalar, etc. Our code works in 3+1 dimensions, but the cases of 1-dimensional and 2-dimensional inhomogeneities were first considered, in order to reach a higher spatial resolution with same computational resources. The codes have been tested successfully both for homogeneous and inhomogeneous configurations.

The evolution scheme has been also implemented, using a predictor/corrector method to gain in accuracy and stability compared to Eulerian methods used previously in the literature. It has been tested successfully for homogeneous configurations, and it already passed a series of tests for inhomogeneous cases. Various methods have been implemented for setting the initial conditions respecting Hamiltonian constraints with a good accuracy. Our results have illustrated that setting initial conditions in numerical relativity applied to cosmology is a very complex problem, requiring a very careful treatment.

We have considered the clustering of a dust matter field and its backreactions on the overall expansion dynamics, in two cases: i) a scale invariant power spectrum for primordial density fluctuations, as supported by the most recent CMB observations by the Planck satellite; ii) a peak on small scales, expected e.g. in some models of primordial black holes (see later).

The code has been called ICARUS, for *Inhomogeneous Cosmology And Relativistic Universe Simulations*, and will be released and made publicly available, with a proper documentation, in 2016. The work initiated during the BELSPO grant is actually pursued during my post-doc at RWTH-Aachen.

The ICARUS project should lead in 2016 to a bunch of publications related to backreactions during structure formation:

1. *Authors:* S.C., A. Roisin
Title: ***Cosmic Acceleration as a backreaction from large density fluctuations on small scales***

2. *Authors:* S.C., A. Füzfa, C. Joana Velasco, A. Roisin
Title: ***The ICARUS code 1: inhomogeneous cosmology and relativistic universe simulations***

3. *Authors:* S.C., A. Füzfa, A. Roisin
Title: ***The ICARUS code 2: level of backreactions during structure formation***

In addition, we have considered the light propagation into cosmic inhomogeneities such as collapsing clusters of galaxies, using exact Lemaitre Tolman Bondi solutions as well as numerical relativity methods implementing a dark energy quintescence field. This is still an ongoing project, which could lead at some point to an additional publication.

Inhomogeneous initial conditions for inflation and during eternal inflation

I have implemented in the ICARUS code the possibility of a multi-field scalar field dynamics. At the moment we only have studied the single-field dynamics for inhomogeneous initial conditions for inflation. The project is reaching its end, and publications will be released soon, on the fine-tuning problem of initial conditions for inflation. An interesting phenomenology has been identified, but cannot be described here, the paper not being yet released. This project is presently pursued at RWTH-Aachen in collaboration with C. Joana Velasco. Other personalities have been involved on this part of the project: C. Ringeval (UCLouvain), J. Martin (IAP, Paris), S. Colombi (IAP, Paris), V. Vennin (U. Portsmouth).

1. *Authors:* S.C., C. Joana Velasco, C. Ringeval, S. Colombi, J. Martin, V. Vennin.
Title: ***The ICARUS code 3: inhomogeneous initial conditions for inflation***

2. *Authors:* S.C., C. Joana Velasco
Title: ***The fine tuning of inhomogeneous initial conditions for Higgs inflation***

In parallel, I have developped a code based on the gradient expansion formalism, in collaboration with G. Rigopoulos (Heidelberg U.) who is an expert of such methods applied to inhomogeneous cosmological simulations. Our aim was to use this code for the study of backreactions during eternal inflation. Nevertheless, the proper treatment of the quantum fluctuations during inflation is a very complex problem and the code was fount to be inconsistent. This part of the project was therefore not fruitful. The question of backreactions during eternal inflation is thus still open.

__**Testing inflation with CMB spectral distortions**__

In parallel to the core research project, I had the opportunity during the first months of the period covered by the BELSPO return grant to achieve several projects started during my post-doc at TU-Munich, on directly related topics (inflation, modified gravity,...) The first one concerns spectral distortions of the cosmic microwave background produced by inflation and curvaton scenarios and has led to the publication of one article. This project had a very high interest in the context of possibly large backreactions since detectable models with CMB spectral distortion exhibit an enhancement of power on small scales for the distribution of density fluctuations, potentially able to lead to large backreactions during structure formation.

Authors: S.C., B. Garbrecht (TU-Munich), Y. (TU-Munich),
Title: ***Testing Inflation and Curvaton Scenarios with CMB distortions***
Abstract: Prior to recombination, Silk damping causes the dissipation of energy from acoustic waves into the monopole of the Cosmic Microwave Background (CMB), resulting in spectral distortions. These can be used to probe the primordial scalar power spectrum on smaller scales than it is possible with CMB anisotropies. An enhancement of power on these scales is nevertheless required for the resulting distortions to be detectable by future experiments like PIXIE. In this paper, we examine all 49 single-field inflation models listed by Martin et al. in the Encyclopaedia Inflationaris and find that only one of these may lead to a detectable level of distortions in a tuned region of its parameter space, namely the original hybrid model. Three effective multi-field scenarios are also studied: with softly and suddenly turning trajectories, and with a mild waterfall trajectory. Softly turning trajectories do not induce distortions at any detectable level, whereas a sudden turn in the field space or a mild waterfall trajectory predicts a peak (plus damped oscillations in the sudden turn case) in the scalar power spectrum, which can lead to an observable amount of CMB distortions. Finally, another scenario leading to potentially detectable distortions involves a curvaton whose blue spectrum is subdominant on CMB angular scales and overtakes the inflaton spectrum on smaller scales. In this case however, we show that the bounds from ultra compact minihaloes are not satisfied. Expectations for an ultimate PRISM-class experiment characterized by an improvement in sensitivity by a factor of ten are discussed for some models.

Dark Energy and modified Gravity:

Before to study the backreactions from non-linear effects during structure formation, it was important to fully understand the field dynamics of models of dark-energy/modified gravity, including the background dynamics, the linear perturbation dynamics, the non-linear and inhomogeneous static, including relativistic effects.

Several codes have been developed in various contexts. This tasks was achieved as a continuation of my work in that field and has lead to several publications. We have focus in particular:

1. on early modified gravity effects on the linear perturbation dynamics, for a general class of modified gravity/dark energy models
2. the background and linear dynamics of cosmological perturbations for the class of K-mouflage models
3. the inhomogeneous scalar field configurations in local environments for the K-mouflage model, and resulting constraints in the solar system.
4. the inhomogeneous scalar field configurations for chameleon models, and resulting constraints from atom-interferometry experiments

This has lead to four publications:

Authors: P. Brax (CEA, Saclay), C. van de Bruck (Sheffield U.), S.C., A.C. Davis (DAMTP, Cambridge U.), G. Sculthorpe (Sheffield U.),
Title: ***Early Modified Gravity: Implications for cosmology***

Abstract: We study the effects of modifications of gravity after Big Bang Nucleosynthesis (BBN) which would manifest themselves mainly before recombination. We consider their effects on the Cosmic Microwave Background (CMB) radiation and on the formation of large scale structure. The models that we introduce here represent all screened modifications of General Relativity (GR) which evade the local tests of gravity such as the violation of the strong equivalence principle as constrained by the Lunar Ranging experiment. We use the tomographic description of modified gravity which defines models with screening mechanisms of the chameleon or Damour-Polyakov types and allows one to relate the temporal evolution of the mass and the coupling to matter of a scalar field to its Lagrangian and also to cosmological perturbations. The models with early modifications of gravity all involve a coupling to matter which is stronger in the past leading to effects on perturbations before recombination while minimising deviations from Lambda-CDM structure formation at late times. We find that a new family of early transition models lead to discrepancies in the CMB spectrum which could reach a few percent and appear as both enhancements and reductions of power for different scales.

Authors: A. Barreira (U.Durham), P. Brax (CEA,Saclay), S.C., B. Li (U.Durham), P. Valageas (CEA,Saclay),
Title: ***Linear perturbations in K-mouflage cosmologies with massive neutrinos.***

Abstract: We present a comprehensive derivation of linear perturbation equations for different matter species, including photons, baryons, cold dark matter, scalar fields, massless and massive neutrinos, in the presence of a generic conformal coupling. Starting from the Lagrangians, we show how the conformal transformation affects the dynamics. In particular, we discuss how to incorporate consistently the scalar coupling in the equations of the Boltzmann hierarchy for massive neutrinos and the subsequent fluid approximations. We use the recently proposed K-mouflage model as an example to demonstrate the numerical implementation of our linear perturbation equations. K-mouflage is a new mechanism to suppress the fifth force between matter particles induced by the scalar coupling, but in the linear regime the fifth force is unsuppressed and can change the clustering of different matter species in different ways. We show how the CMB, lensing potential and matter power spectra are affected by the fifth force, and find ranges of K-mouflage parameters whose effects could be seen observationally. We also find that the scalar coupling can have the nontrivial effect of shifting the amplitude of the power spectra of the lensing potential and density fluctuations in opposite directions, although both probe the overall clustering of matter. This paper can serve as a reference for those who work on generic coupled scalar field cosmology, or those who are interested in the cosmological behaviour of the K-mouflage model.

Authors: A. Barreira (U.Durham), P. Brax (CEA,Saclay), S.C., B. Li (U.Durham), P. Valageas (CEA,Saclay),
Title: ***K-mouflage gravity models that pass Solar System and cosmological constraints***

Abstract: We show that Solar System tests can place very strong constraints on K-mouflage models of gravity, which are coupled scalar field models with nontrivial kinetic terms that screen the fifth force in regions of large gravitational acceleration. In particular, the bounds on the anomalous perihelion of the Moon imposes stringent restrictions on the K-mouflage Lagrangian density, which can be met when the contributions of higher-order operators in the static regime are sufficiently small. The bound on the rate of change of the gravitational strength in the Solar System constrains the coupling strength β to be smaller than 0.1. These two bounds impose tighter constraints than the results from the Cassini satellite and big bang nucleosynthesis. Despite the Solar System restrictions, we show that it is possible to construct viable models with interesting cosmological predictions. In particular, relative to ΛCDM, such models predict percent-level deviations for the clustering of matter and the number density of dark matter haloes. This makes these models predictive and testable by forthcoming observational missions.

Authors: Sandrine Schlogel (Unamur & UCLouvain), S.C., A. Füzfa (UNamur)
Title: ***Probing modified gravity with atom interferometry: a numerical approach***

Abstract: Refined constraints on chameleon theories are calculated for atom-interferometry experiments, using a numerical approach consisting in solving for a four-region model the static and spherically symmetric Klein-Gordon equation for the chameleon field. By modeling not only the test mass and the vacuum chamber but also its walls and the exterior environment, the method allows one to probe new effects on the scalar field profile and the induced acceleration of atoms. In the case of a weakly perturbing test mass, the effect of the wall is to enhance the field profile and to lower the acceleration inside the chamber by up to 1 order of magnitude. In the thin-shell regime, results are found to be in good agreement with the analytical estimations, when measurements are realized in the immediate vicinity of the test mass. Close to the vacuum chamber wall, the acceleration becomes negative and potentially measurable. This prediction could be used to discriminate between fifth-force effects and systematic experimental uncertainties, by doing the experiment at several key positions inside the vacuum chamber. For the chameleon potential $V(\phi)=\Lambda^4+\alpha/\phi^\alpha$ and a coupling function $A(\phi)=\exp(\phi/M)$, one finds $M\gtrsim 7\times 10^{16}$ GeV, independently of the power-law index. For $V(\phi)=\Lambda 4(1+\Lambda/\phi)$, one finds $M\gtrsim 10^{14}$ GeV. A sensitivity of $a\sim 10^{-11}$ m/s2 would probe the model up to the Planck scale. Finally, a proposal for a second experimental setup, in a vacuum room, is presented. In this case, Planckian values of M could be probed provided that $a\sim 10^{-10}$ m/s2, a limit reachable by future experiments. Our method can easily be extended to constrain other models with a screening mechanism, such as symmetron, dilaton and f(R) theories.

Hybrid inflation and tachyonic preheating:

In March 2014, the BICEP2 experiment measuring the B-mode polarization of the Cosmic Microwave Background has claimed the discovery of primordial gravitational waves, possibly produced during inflation. Such a discovery would have profound implications for inflation models, and since one aim of the present project is to study the backreactions from inhomogeneities for hybrid models of inflation (inhomogeneties that are present at the onset and during the final tachyonic preheating phase of hybrid inflation), it has been important to study first the implications of Planck results and of the BICEP2 *claim of discovery* (discovery was then discarded) for the hybrid model. This has been done in collaboration with J. Rekier and led to the publication of one article:

Authors: S.C., J. Rekier (U. Namur)
Title: ***Updated Constraints on Large Field Hybrid Inflation***

Abstract: We revisit the status of hybrid inflation in the light of Planck and recent BICEP2 results, taking care of possible transient violations of the slow-roll conditions as the field passes from the large field to the vacuum dominated phase. The usual regime where observable scales exit the Hubble radius in the vacuum dominated phase predicts a blue scalar spectrum, which is ruled out. But whereas assuming slow-roll one expects this regime to be generic, by solving the exact dynamics we identify the parameter space for which the small field phase is naturally avoided due to slow-roll violations at the end of the large field phase. When the number of e-folds generated at small field is negligible, the model predictions are degenerated with those of a quadratic potential. There exists also a transitory case for which the small field phase is sufficiently long to affect importantly the observable predictions. Interestingly, in this case the spectral index and the tensor to scalar ratio agree respectively with the best fit of Planck and BICEP2. This results in a $\Delta\chi2 \simeq 5.0$ in favor of hybrid inflation for Planck+BICEP2 ($\Delta\chi2 \simeq 0.9$ for Planck only). The last considered regime is when the critical point at which inflation ends is located in the large field phase. It is constrained to be lower than about ten times the reduced Planck mass. The analysis has been conducted with the use of Markov-chain-Monte-Carlo Bayesian method, in a reheating consistent way, and we present the posterior probability distributions for all the model parameters.

In addition, as mentioned in the project objectives, we have studied the phase of tachyonic preheating in the particular model of hybrid inflation with a mild waterfall phase. For this purpose, we have used and compare the HLATTICE and LATTICEEASY codes, the first one implementing relativistic corrections and backreactions from the metric inhomogeneities, the latter accounting only for the scalar field inhomogeneities without dealing with metric backreactions. This work is still in progress and should lead soon to a publication.

Authors: S.C., S. Orani (Basel U.)
Title: ***Tachyonic preheating after mild waterfall hybrid inflation***
in preparation.

<u>A cosmological model with primordial black holes and potentially important backreactions:</u>

I have studied the backreactions and development of inhomogeneities during the mild waterfall phase after hybrid inflation. The quantum fluctuations of the auxiliary field during this phase lead to an enhancement of density fluctuations, on smaller scales than the ones probed by CMB physics. Those density fluctuations can lead to the formation of primordial black holes, potentially accounting for dark matter, and that could also lead to important backreaction in the late-time expansion dynamics. Moreover, the quantum diffusion induce an inhomogeneous distribution of the primordial black holes, which cluster early in the Universe. The model was wound to have very interesting observational perspectives and is supported by the recent detection of gravitational waves by Advanced LIGO, due to the merging of massive black holes that could have a primordial origin.

Our work has lead to to publications, one during the BELSPO fellowship, one early 2016 (but part of the work was done during the BELSPO fellowship)

Authors: S.C., J. Garcia-Bellido (IFT, Madrid)
Title: ***Massive primordial black holes from hybrid inflation as dark matter and the seeds of galaxies***

Abstract: In this paper we present a new scenario where massive primordial black holes (PBHs) are produced from the collapse of large curvature perturbations generated during a mild-waterfall phase of hybrid inflation. We determine the values of the inflaton potential parameters leading to a PBH mass spectrum peaking on planetary-like masses at matter-radiation equality and producing abundances comparable to those of dark matter today, while the matter power spectrum on scales probed by cosmic microwave background (CMB) anisotropies agrees with Planck data. These PBHs could have acquired large stellar masses today, via merging, and the model passes both the constraints from CMB distortions and microlensing. This scenario is supported by Chandra observations of numerous BH candidates in the central region of Andromeda. Moreover, the tail of the PBH mass distribution could be responsible for the seeds of supermassive black holes at the center of galaxies, as well as for ultraluminous x-ray sources. We find that our effective hybrid potential can originate e.g. from D-term inflation with a Fayet-Iliopoulos term of the order of the Planck scale but sub-Planckian values of the inflaton field. Finally, we discuss the implications of quantum diffusion at the instability point of the potential, able to generate a Swiss-cheese-like structure of the Universe, eventually leading to apparent accelerated cosmic expansion.

Authors: S.C., J. Garcia-Bellido (IFT, Madrid)
Title: ***The clustering of massive primordial black holes as dark matter: measuring their mass distribution with Advanced-LIGO***

Abstract: The recent detection by Advanced LIGO of gravitational waves (GW) from the merging of a binary black hole system sets new limits on the merging rates of massive primordial black holes (PBH) that could be a significant fraction or even the totality of the dark matter in the Universe. aLIGO opens the way to the determination of the distribution and clustering of such massive PBH. If PBH clusters have a similar density to the one observed in ultra-faint dwarf galaxies, we find merging rates comparable to aLIGO expectations. Massive PBH dark matter predicts the existence of thousands of those dwarf galaxies where star formation is unlikely because of gas accretion onto PBH, which would possibly provide a solution to the missing satellite and too-big-to-fail problems. Finally, we study the possibility of using aLIGO and future GW antennas to measure the abundance and mass distribution of PBH in the range [5 - 200] Msun to 10% accuracy.

Contribution to a review on the standard cosmological model and its perspectives:

I had the opportunity to contribute to a review on the standard cosmological model and its observational perspectives, its possible theoretical extensions. I have contributed to the inflationary section, with D. Steel (APC, Paris) and F. Finelli (U. Bologna). This review has been published fall 2015.

Authors: P. Bull (Caltech & Oslo U.), Y. Akrami (Heidelberg & Oslo U.) + 39 authors
Title: ***Beyon Lambda-CDM: problems, solutions and the road ahead***

Abstract: Despite its continued observational successes, there is a persistent (and growing) interest in extending cosmology beyond the standard model, ΛCDM . This is motivated by a range of apparently serious theoretical issues, involving such questions as the cosmological constant problem, the particle nature of dark matter, the validity of general relativity on large scales, the existence of anomalies in the CMB and on small scales, and the predictivity and testability of the inflationary paradigm. In this paper, we summarize the current status of ΛCDM as a physical theory, and review investigations into possible alternatives along a number of different lines, with a particular focus on highlighting the most promising directions. While the fundamental problems are proving reluctant to yield, the study of alternative cosmologies has led to considerable progress, with much more to come if hopes about forthcoming high-precision observations and new theoretical ideas are fulfilled.

4. Valorisation/Diffusion (including Publications, Conferences, Seminars, Missions abroad...)

Publications in International Peer-review journals:

[1] The clustering of massive Primordial Black Holes as Dark Matter: measuring their mass distribution with Advanced LIGO
Sebastien Clesse (RWTH Aachen U.), Juan García-Bellido (Madrid, IFT). Mar 16, 2016. 7 pp.
e-Print: **arXiv:1603.05234** ***(submitted to Physical Review Letters)***

[2] BeyondΛCDM: Problems, solutions, and the road ahead
Philip Bull (Caltech & Oslo U.) *et al.*. Dec 16, 2015. 44 pp.
Published in **Phys.Dark Univ. 12 (2016) 56-99**
DOI: 10.1016/j.dark.2016.02.001
e-Print: **arXiv:1512.05356**

[3] Probing Modified Gravity with Atom-Interferometry: a Numerical Approach
Sandrine Schlögel (Namur U. & Louvain U., CP3), Sébastien Clesse (Aachen, Tech. Hochsch. & Namur U.), André Füzfa (Namur U. & Louvain U., CP3). Jul 11, 2015. 13 pp.
Published in **Phys.Rev. D93 (2016) no.10, 104036**
DOI: 10.1103/PhysRevD.93.104036
e-Print: **arXiv:1507.03081**

[4] K-mouflage gravity models that pass Solar System and cosmological constraints
Alexandre Barreira (Durham U. & Durham U., IPPP), Philippe Brax (IRFU, SPhN, Saclay), Sebastien Clesse (Namur U.), Baojiu Li (Durham U., ICC), Patrick Valageas (IRFU, SPhN, Saclay). Apr 7, 2015. 17 pp.
Published in **Phys.Rev. D91 (2015) no.12, 123522**
DOI: 10.1103/PhysRevD.91.123522
e-Print: **arXiv:1504.01493**

[5] Massive Primordial Black Holes from Hybrid Inflation as Dark Matter and the seeds of Galaxies
Sébastien Clesse (Namur U.), Juan García-Bellido (Madrid, IFT). Jan 29, 2015. 17 pp.
Published in **Phys.Rev. D92 (2015) no.2, 023524**
DOI: 10.1103/PhysRevD.92.023524
e-Print: **arXiv:1501.07565**

[6] Linear perturbations in K-mouflage cosmologies with massive neutrinos
Alexandre Barreira (Durham U., ICC & Durham U., IPPP), Philippe Brax (IPhT, Saclay), Sebastien Clesse (Namur U.), Baojiu Li (Durham U., ICC), Patrick Valageas (IPhT, Saclay). Nov 21, 2014. 20 pp.
Published in **Phys.Rev. D91 (2015) 063528**
DOI: 10.1103/PhysRevD.91.063528
e-Print: **arXiv:1411.5965**

[7] Updated Constraints on Large Field Hybrid Inflation
Sebastien Clesse, Jeremy Rekier (Namur U.). Jul 8, 2014. 13 pp.
Published in **Phys.Rev. D90 (2014) no.8, 083527**
DOI: 10.1103/PhysRevD.90.083527
e-Print: **arXiv:1407.1984**

[8] Testing Inflation and Curvaton Scenarios with CMB Distortions
Sebastien Clesse (Namur U.), Björn Garbrecht, Yi Zhu (Munich, Tech. U.). Feb 10, 2014. 32 pp.
Published in **JCAP 1410 (2014) no.10, 046**
TUM-HEP-931-14
DOI: 10.1088/1475-7516/2014/10/046
e-Print: **arXiv:1402.2257**

[9] Early Modified Gravity: Implications for Cosmology
Philippe Brax (IPhT, Saclay), Carsten van de Bruck (Sheffield U.), Sebastien Clesse (Namur U. & Munich, Tech. U.), Anne-Christine Davis (Cambridge U., DAMTP), Gregory Sculthorpe (Sheffield U.). Dec 11, 2013. 18 pp.
Published in **Phys.Rev. D89 (2014) no.12, 123507**
DOI: 10.1103/PhysRevD.89.123507 e-Print: **arXiv:1312.3361 [astro-ph.CO] |**

Conference Proceedings:

[1] ***An introduction to inflation after Planck: from theory to observations***
Sebastien Clesse (Namur U.). Jan 2, 2015. 39 pp.
Conference: C14-09-01.8 Proceedings
e-Print: **arXiv:1501.00460**

[2] ***Numerical forecasts for lab experiments constraining modified gravity: the chameleon model***
Sandrine Schlogel (Namur U.), Sebastien Clesse (Namur U. & Aachen, Tech. Hochsch.), Andre Fuzfa (Namur U.). Dec 24, 2015. 6 pp.
Conference: C15-07-12
e-Print: **arXiv:1512.07738**

Oral presentations in workshops and conferences:

1. *Slow-roll inflation in the era of Euclid*, Gravity at the largest scale conference, 2015-10, Heidelberg, **Germany**
2. *Massive Primordial Black Holes from Hybrid Inflation as Dark Matter and the Seeds of Galaxies*, COSMO-15 conference, 2015-09, Warsaw, **Poland**
3. *Massive Primordial Black Holes from Hybrid Inflation as Dark Matter and the Seeds of Galaxies*, 5th COSPA meeting, 2015-05, Mons University, Mons, **Belgium**
4. *Massive Primordial Black Holes from Inflation as Dark Matter and the Seeds of Galaxies*, 16th meeting of the FNRS contact group: Astronomie et Astrophysique, Brussels planetarium, Brussels, **Belgium**
5. Chairman with D. Steer and F. Finelli for the discussion session 5 on inflation, Beyond LCDM conference, 2015-01-14, Oslo, **Norway**
6. *Single-field inflation in the era of Euclid*, Euclid Theory Group meeting, 2015-01-11, Oslo, **Norway**
7. *Signatures of Modified Gravity on the 21cm Power Spectrum at Reionisation*, Dark Energy Interactions conference, 2014-10-01, NORDITA, Stockholm, **Sweden**
8. Series of Invited Lectures on Inflation and Planck-BICEP2 results, Xth Modave School of Mathematical Physics, 2014-09-01, Modave, **Belgium**
9. *Testing Inflation and Curvaton scenarios with CMB distortions*, COrE/PRISM workshop for a M4 ESA mission,, 2014-02-01, APC, Paris, **France**
10. *21-cm Cosmic Background: the cosmology of the future?*, 1st COSPA meeting, 2014-01-01, ULB, Brussels, **Belgium**

Participation to workshops and conferences (without oral contribution)

[1] July 2015, Solvay Colloquium: Cosmological Frontiers in Fundametal Physics, ULB, Brussels

[2] May 2015, Euclid consortium annual meeting, Lausanne.

[3] November 2014, 3rd COSPA meeting, University of Liège.

[4]June 2014, 2nd COSPA meeting, University of Ghent

[5] May 2014, Euclid Consortium annual meeting, Marseille, France.

Invited seminars:

[1] June 2014, Liege University, Belgium.

[2] January 2014, Mons University, Belgium

5. Future prospects for a permanent position in Belgium

1. I have applied for a FNRS *Chargé de Recherche* position in 2015 and 2016. Getting this grant would allow me to fill the gap between the BELSPO return grant and the eventual opening of a permanent positions in cosmology in a Belgian University, within the next few years.

2. In 2014-2015 I have applied for an Marie-Curie post-doctoral position at the University of Namur.

3. In 2015, I have applied successfully for a post-doctoral position at the RWTH-Aachen University. This position allowed me to pursue the project initiated by the BELSPO return grant. The close proximity of RWTH-Aachen with Belgium allows me to pursue an intense collaboration with the cosmology group at the University of Namur, as well as with other researchers in cosmology from other Belgian universities (e.g. Prof. C. Ringeval at CP3, UC Louvain). This should bring me in an ideal position for applying for a permanent position in Belgium, if some opening occurs in the next years.

4. In 2016, I have applied for a permanent academic position at the University of Namur. Unfortunately the selection committee decided that cosmology was not fitting the desired profile (in applied mathematics, oriented in the field of optimization) and my application was unsuccessful. Future calls may open, but not before 2019-20120, which therefore reinforce the importance of having a post-doctoral grant to cover this period.

5. From 2017-2018 I will applied for a FNRS permanent position.

6. Miscellaneous

Science outreach: In 2014 and 2015I have participated and organised several activities of science outreach:

- P*rintemps des Sciences* event: creation, organisation and presentation of several activities linked to cosmology for children/youth/families. Total of about 1000 participants
- Activities at the *Nuit des étoiles* event, Eurospace Center, Redu, Belgium
- Introduction lectures in Cosmology for secondary school classes.

Institutional responsabilities:

- Organisation of the internal Cosmology Seminars
- Management of the Cosmology Group website
- Jury Member for several Ms. Thesis, University of Namur. Jusy member for 1 PhD thesis (Dr. Jeremy Reckier).
- Representative member at the *Unité d'Appui à la Recherche*, University of Namur

Participation to space-missions: In 2014 I had the opportunity to become member of two cosmology dedicated space-missions:

- Euclid: member since 07/2014, Theory Work Package, Joint Cosmological Simulations-THeory Working Groups, Linear Spatial Dark Energy Perturbations and Initial Conditions subgroups.
- Since 03/2014: member of the COrE+ collaboration, inflation, CMB physics and CMB distortions working groups.