Inhomogeneous Cosmologies 2019

Abstracts

https://cosmo.torun.pl/CosmoTorun19

Contents

KUJAWY POMORZE

1 GRAMSES

Cristian Barrera-Hinojosa
PhD Student, Institute for Computational Cosmology, Durham University

The implementation of General Relativistic cosmological simulations has received increasing attention in the last few years, not only as a counterpart to Newtonian simulations in the era of precision cosmology, but also as a natural framework to study phenomena such as the back-reaction of structure formation on the expansion rate of the Universe. In this talk I will give an overview of our recently implemented code GRAMSES, an N-body code for nonlinear, general relativistic simulations in cosmology based on RAMSES. I will discuss its foundations and main aspects of its implementation such as the Fully Constrained Formulation of General Relativity, which maximises the number of elliptic equations by solving the constraints equations at each time-step and appropiate gauge conditions. Furthemore, I will discuss some first results for cosmological simulations in a LCDM universe and how these compare with Newtonian counterparts, as well as some aspects on the generation of initial conditions in terms of particle data for N-body simulations.

2 Gevolution: general simulations and void science

Justyna Borkowska
Toruń Centre for Astronomy, Poland

Gevolution 1.2 is a relativistic particle-mesh N-body code that, while remaining relatively simple, goes a step further towards a fully GR treatment of the evolution of the Universe. As a result, it can serve as a bridge between initial conditions generators, such as mpgrafic, S-GenIC, and CLASS, and other codes that can take the numerical metrics as an input and analyze them.

In my talk I will present what gevolution can and cannot do, and what are the possible directions for the further development, modification and/or usage of the code. As an example, I will mention how gevolution may contribute to the field of cosmology that is more commonly known as "void science" — that is, how gevolution simulations can be used to understand and extract valuable information from cosmic voids.

3 How does torsion affect light propagation?

Matteo Cinus
Toruń Centre for Astronomy, Nicolaus Copernicus University

Einstein's theory of gravity (general relativity, GR) is based on Riemannian geometry. Modified theories of gravity such as $f(R)$ theories are also based on Riemann spaces and so are intrinsically limited. In order to better understand the nature of gravity it is worth going further, beyond Riemannian geometry. The simplest extensions of Riemannian geometry are based on non-null non-metricity tensors and non-symmetric connections. I will briefly discuss these extensions and focus on models with a totally antisymmetric torsion tensor, i.e. with a null non-metricity tensor. I will show how the presence of torsion affects light propagation and I will discuss how to use cosmological observations to test some of these non-Riemannian extensions of the geometry of our Universe.

4 The dynamics of General Relativity in the Geodesic Light-Cone coordinates

Giuseppe Fanizza
INFN - Pisa

Geodesic Light-Cone (GLC) gauge consists of coordinate system exactly adapted to the description of the inhomogeneous observer's past light-cone, where the metric tensor is not required to have any simmetry. Thanks to its geometrical properties, cosmological observables can be written fully non linearly in this coordinate system. In this talk, I will discuss the description of the Einstein's equations in GLC in analogy with the ADM formalism. Whereas the latter consistes of 1+3 foliation of spacetime, GLC coordinates can be interpreted as a 1+1+2 foliation of the spacetime itself. This leads to a straightforward way to write down the exact Einstein's equations on the observer's past light-cone.

5 CMB anomalies in an inhomogeneous universe

Martin Jacques France
CRALyon

Origins of the anomalies on the CMB are unknown. No universe model provides a CMB map morphologically conform to the Planck map. But statistical CMB properties of quasi homogeneity, isotropy, weak non-Gaussianity and nearly zero mean, satisfy to the predictions of the LambdaCDM model with slow-roll inflation. The CMB is almost entirely defined by its power spectrum. These quasi, nearly, almost leave room to the CMB sky features that are usually referred to as anomalies. Of which, the vanishing 2-point angular correlation function above 60 degrees of the CMB sky appears also in the simulation maps of several multi-connected topological manifolds while totally absent in the LambdaCDM CMB maps. I shall discuss the work aiming at probing CMB anomalies and the multi-connected nature of the universe with other CMB observables.

6 Covariant formalism for light propagation in cosmological models

Krzysztof Głód
Astronomical Observatory of the Jagiellonian University

We present a covariant approach to the classic problem of light beam propagation in cosmological models. Using the concept of screen surface, we introduce covariant definitions for Sachs and Jacobi fields and for the area distance. Then we derive relationships between them and their propagation equations and initial conditions for these equations. Ultimately, for practical use, we transform the resulting formulas into a redshift dependent form.

7 Ray tracing, parallax, position and redshift drift in numerical relativity

Michele Grasso
Center for Theoretical Physics Polish Academy of Sciences

In the recent years, the unprecedented accuracy reached by the experimental apparatus has opened a new era of cosmological observations, referred to as the "real-time cosmology", concerned with measuring small temporal changes of positions, redshift and distances of objects at cosmological scales. The time variations of such quantities are known as optical drift effects and their estimation can provide a direct and model-independent measurements of the large scale structure and of the expansion history of the Universe. I will present a numerical approach to the problem of evaluating the parallax, position drift (proper motion) and redshift drift (secular change of the redshift) of faraway sources in numerical relativity. The mathematical machinery is based on the covariant formulation of the geometric optics using the bilocal geodesic operators (BGO) and their relation to the geodesic deviation equation and curvature [1]. The analysis of the optical properties of complicated spacetimes using the BGO formalism constitutes an efficient approach to probe the dynamics of the inhomogeneities on the large scale.

References: [1] Grasso, M., Korzyński, M., Serbenta, J. (2019). "Geometric optics in general relativity using bilocal operators". Physical Review D, 99(6), 064038.

8 Evolution of two non-comoving cosmological dust components

Carlos Hidalgo
UNAM (Mexico)

We present the relevant system of equations to evolve two non-comoving inhomogeneous components of pressureless matter in spherical symmetry. Through its numerical evolution we provide the fully relativistic evolution of cosmic voids constituted by baryons and cold dark matter (CDM), represented by two non-comoving dust sources in an asymptotic ΛCDM background. Through this simple example we explore the frame-dependence of the local expansion and the Hubble flow for each observer. We find that the relative velocity between components yields a significantly different evolution in comparison with that of the two sources in a common 4-velocity (which reduces to a Lemaître-Tolman-Bondi model). In particular, significant modifications arise for the density contrast depth and void size, as well as in the amplitude of the surrounding over-densities.

9 Backreaction in Swiss-cheese models

Sofie Marie Koksbang
University of Helsinki and HIP

Locally inhomogeneous but statistically homogeneous and isotropic cosmological models can be constructed as exact solutions to the Einstein equations as Swiss-cheese models. Swiss-cheese models have e.g. been used to study the affects of inhomogeneities on light propagation and hence observations. One major shortcoming of Swiss-cheese models is that it is very difficult to construct them in such a way that significant cosmic backreaction appears. I will present a method that at least in principle enables the construction of perfect fluid Swiss-cheese models with significant backreaction and comment on why the construction of such exact solutions to the Einstein equations are important in relation to the backreaction debate.

10 Weighing the spacetime along the line of sight

Mikołaj Korzyński
CFT PAN Warsaw

I will present a method of determining the amount of matter along the line of sight by comparing the angular diameter distance or the luminosity distance of an object to its parallax distance. The method is insensitive to perturbations due to peculiar motions and can be used to probe the isotropy of matter distribution.

11 Utilizing cosmological post-Newtonian approximation for the PPN formalism

Masaaki Morita
Okinawa National College of Technology

We propose a new scheme of the parametrized post-Newtonian (PPN) formalism for modified gravity theories involving higher curvature. In higher-curvature gravity theories, higher-order spatial derivatives of metric perturbations would appear in the PPN limit of the field equations, whose effect could be significant in local-scale high-density regions. We employ a cosmological post-Newtonian approximation, in which two small parameters, $epsilon := v/c$ (peculiar velocity divided by the speed of light) and $kappa := ell/ell_H$ (scale of cosmic inhomogeneities divided by the Hubble horizon scale) are introduced. This approximation enables us to analyze gravitational screening mechanism, such as the chameleon mechanism in f(R) gravity. We present an illustrative example of the formalism with chameleon f(R) gravity.

12 A full pipeline for modelling low surface brightness

Marius Peper
Nicolaus Copernicus University

Low surface brightness galaxies (LSBGs) appear to provide a challenge to the cosmological standard model. Their formation is not yet completely understood. I will present a full pipeline of numerical treatment of LSBGs and their resulting key parameters (including metallicity, mass, spin). I will show the fully simulated dark matter distributions and their followup analysis. The simulations and the analysis are all performed on a single computer, starting with initial conditions generated by Mpgrafic. The N-body simulation is based on the adaptive mesh code Ramses that reads in the initial conditions, structures are analyzed with Vide and Rockstar, and finally I use the semi-analytical galaxy evolution code SAGE to enrich the simulation with galaxies. All the characteristics of LSBGs can thus be studied in a new way in which every single step can be controlled. We aim to compare the characteristics of the simulated LSBGs, e.g. their contribution to the very faint end of the galaxy luminosity function, to observational estimates in order to see whether or not LSBG statistical properties are consistent with the standard cosmological model.

13 Algebraic topology of data sets

Pratyush Pranav
CRALyon

In the last couple of decades, algebraic topology has matured from a purely theoretical field to one with strong applicability in various research domains. Combining Morse theory, Homology and Persistent Homology, this has enabled a new branch in data analysis called topological data analysis (TDA). The central tenet is based on the identification of topological changes that occur in a manifold as a function of the excursion sets of the field. The topological changes are accounted for by tracking the creation and destruction of p-dimensional topological holes in a d-dimensional manifold ($p = 0...d$). Intuitively, in three spatial dimensions, these changes correspond to creation and destruction of connected components, loops/tunnels and voids. Towards the end, I will present an example of application of the formalism to datasets arising in Cosmology: the Cosmic Microwave Background

(CMB) radiation. The CMB is the earliest visible light in the Universe, and studying its properties has the potential to reveal information about the physical processes occurring in the nascent stages of the Universe. The accepted model for the CMB is a homogeneous, isotropic Gaussian random field. We find that the observations depart significantly from the theoretical model.

14 Does spatial flatness forbid the turnaround epoch of collapsing structures?

Boudewijn F. Roukema
TCfA NCU

A non-perturbative background-free argument for an expanding dust universe with a flow-orthogonal foliation and an irrotational fluid shows that reaching the turnaround epoch for gravitational collapse requires positive spatial curvature pointwise. In the average sense on a domain, flatness in at least one special plane-symmetric case fundamentally distinguishes the Newtonian from the general-relativistic case: the growing mode is absent in the latter case, preventing pancake collapse. The more general plane-symmetric case yields critical values of the Ω parameters at turnaround. Numerical simulations show values broadly consistent with these special values, for both Einstein–de Sitter and Λ-cold-dark-matter reference models. No realisations allowed turnaround to occur with zero or negative spatial curvature.

15 Positivity and monotonicity of the Hawking energy on the past light cone

Dennis Stock
ZARM, University of Bremen

The past light cone of a point in a globally hyperbolic spacetime can be sliced by a family of Cauchy surfaces. Imposing some further conditions, the Hawking energy can be shown to be positive and monotonously increasing along the family of intersections down the past light cone.

16 A relativistic, geometric and covariant interpretation of Milgrom's acceleration

Roberto Sussman
ICN-UNAM

The quantity $a_0 = 10^{-8}\text{cm/sec}^2$ is known as Milgrom's acceleration. It is an empiric quantity that marks the departure from Newtonian gravity into a Modified Newtonian Gravity

(MOND) regime that fits galactic rotation curves without assuming the presence of dark matter. In the present work we provide a relativistic, geometric and covariant (but frame dependent) interpretation for a_0 in terms of the product of the Kretschmann scalar times the surface area of 2-spheres of characteristic length scales for local (solar system) and cosmic (close to the Hubble horizon but still sub horizon) regimes that fulfil observational data. This interpretation explains the empiric relation $a_0 \approx cH_0$ and is not tied to the MOND paradigm, as it can also be useful to understand and place bounds on dark matter models.

17 Einstein clusters as models of inhomogeneous spacetimes

Sebastian Szybka
Jagiellonian University

We show that an exact solution 'Einstein cluster' may be used to construct a simple toy-model for studies of the effect of small-scale inhomogeneities in general relativity.

18 Towards precision tests of the cosmological principle

David L Wiltshire
University of Canterbury, NZ

Upcoming missions such as the Euclid satellite will have the power to test the Friedmann equation via the Clarkson-Bassett-Lu test and similar tests, potentially falsifying a core assumption of the standard cosmology. However, to achieve the necessary precision also requires dealing with the fact that the standard cosmology is very often implicitly assumed in the data reduction process. We consider both type Ia supernovae data and baryon acoustic data, by new methods which are as model-independent as possible. We compare the Lambda CDM to the timescape cosmology (a model with backreaction). Both models fit well with current data. However, in the case of supernovae we uncover systematic errors related to the emergence of a scale of statistical homogeneity, irrespective of the cosmological model. Regardless of which model is correct, such issues need to be confronted to achieve per cent level precision.