Inhomogeneous Cosmologies 2017

Abstracts

http://cosmo.torun.pl/CosmoTorun17

Contents

1 SageManifolds — a free and open-source differential geometry and symbolic tensor calculus toolkit

Michał Bejger
CAMK

I will present the SageManifolds package, an extension of a free and open-source modern computer algebra system SageMath towards differential geometry and symbolic tensor calculus. SageManifolds deals with differentiable manifolds of arbitrary dimension. Various coordinate charts and vector frames can be introduced on the manifold, which does not need to be parallelizable. A given tensor field is then described by its representations (sets of components) in each vector frame. Generic pseudo-Riemannian manifolds can be considered, among which Riemannian manifolds and Lorentzian manifolds, with applications to General Relativity. In particular, the computation of the Riemann curvature tensor and associated objects (Ricci, Weyl, Schouten and Cotton tensors) is implemented. SageManifolds can also deal with generic affine connections, not necessarily Levi-Civita ones.

2 Dynamics and evolution of silent universes

Krzysztof Bolejko
The University of Sydney

Irrotational silent universes belong to a class of systems where each worldline evolves independently of other worldlines - there is no communication between the worldlines, i.e. no pressure gradients, no energy flux, no gravitational radiation. In my talk I will discuss properties and evolution of the irrotational silent universe.

3 Weak field and full GR cosmological simulations

Marco Bruni
ICG (Portsmouth, UK)

In this talk I will describe progresses in considering GR effects in the dynamics of structure formation. First I will present results of a nonlinear post-Friedman approximation, a kind of post-Newtonian formalism. Then I will focus on recent fully nonlinear numerical relativity simulations. Numerical relativity is a fundamental tool in the modelling of gravitational waves sources, but its application to cosmology is in its infancy. As more interdisciplinary work between the gravitational waves and the cosmology communities will develop, in the next few years numerical relativity may become a fundamental tool for understanding the extent to which we can trust standard newtonian N-body simulations on the largest scales. First results of simulations representing the full GR nonlinear evolution of initial perturbations in a Einstein de Sitter background are: 1) back-reaction effects on the overall expansion of the model are very small; 2) voids expansion rate is significantly higher than that of the background; 3) over-densities can reach turn-around much earlier than predicted by the standard top-hat model. To establish the significance of these results is the goal of future work.

4 Opening Talk

Thomas Buchert
CRAL

I will put the different topics addressed in this workshop into perspective, and localize corresponding challenges that we face.

5 The Roles of Structure Formation and Lambda in Black Hole Universes.

Jessie Durk
Queen Mary University of London

Small-scale inhomogeneities may play a role in the large-scale evolution of the Universe, a phenomenon known as backreaction. These inhomogeneities are otherwise overlooked in the standard model of cosmology, which assumes a fluid description, and in turn may further affect cosmological observables. It is therefore theoretically and observationally important to relax the homogeneity and isotropy assumptions. We do this by generalising existing black hole lattice universes, consisting of regularly arranged Schwarzschild masses, in two ways. The first is to split each mass up into a number of further masses and move these along parameterised trajectories, allowing the effect of clustering to be investigated. The second is to include the cosmological constant, Λ. Both types of model are exact solutions of the Einstein field equations. After finding the relevant horizons and masses of each of the black holes for both types of model, we compare them to the corresponding FLRW universes. We find that as the number of black holes is increased, the large-scale expansion of space approaches that of an FLRW model filled with dust (and Λ). During clustering, an extra apparent horizon appears, whereby the scales of the lattice universes decrease to $\sim 50\%$ of that of the corresponding FLRW universes.

6 Non-Gaussianity in CMB sky maps

Martin J France
CRAL

The CMB non-Gaussianity of Planck 2015 and of a related ΛCDM map sample is analyzed with four statistical descriptors. We compare and discuss model-dependent and model-independent results of non-Gaussianity, emphasizing anomalies when applying perturbation theory to the data that do not occur in the model-independent method. For all statistical descriptors, a few percent of one hundred thousand ΛCDM maps with U73 mask diverge from Gaussianity at levels of more than 5σ .

7 Symmetry in Szekeres Models

Ira Georg
University of Cape Town

Szekeres space–times in general have no Killing vectors, although they consist of highly symmetric submanifolds. The conditions for a model with full symmetry and one with no symmetry are known. However, the symmetric special models with a single Killing vector have not been explored despite the fact that many applications necessitate a spatially axi-symmetric model. We look for all Szekeres models with one single Killing vector and find the conditions on the free functions. For quasi hyperboloidal ($\epsilon = -1$) models, we find that translational symmetries are possible, but only in metrics that have shell crossings somewhere, while metrics that can be made free of shell crossings only permit rotations. The quasi planar metrics ($\epsilon = 0$) either have no Killing vectors or they admit full planar symmetry. Single symmetries in quasi spherical metrics ($\epsilon = +1$) are all rotations.

8 Averaging of disturbed Friedmann–Lemaitre cosmological model

Krzysztof Głód
Jagiellonian University

We examine a naive perturbative generalization of the Friedmann–Lemaitre cosmological model. We introduce at the metric level parameters which control basic properties of inhomogeneities, their profile, growth rate and density contrast. We give conditions under which the model can be considered reasonable and comment limitations of this approach. Finally, we perform an averaging procedure of the model using the notion of weak limit and propose a method to construct its background model.

9 Supernovae analysis of the timescape model

Asta Heinesen
University of Canterbury

We compare the timescape model and the spatially flat ΛCDM model using the JLA dataset and the likelihood construction of Nielsen, Guffanti, and Sarkar. We uncover a number of model dependent assumptions in data reduction relevant for any inhomogeneous cosmological model. We see hints of a statistical homogeneity scale at $\sim 100/h$ Mpc. It changes best fit light curve parameters considerably when data below this scale are excluded. The spatially flat ΛCDM model and the timescape model are statistically indistinguishable by Bayesian comparison. Irrespective of which model ultimately fits better, the use of a non-FLRW expansion history can be an important diagnostic tool for empirical light curve fitting.

10 Observable Matter Flows In Szekeres Spacetimes

Charles Hellaby
University of Cape Town

We consider an arbitrarily placed observer, in a given inhomogeneous metric, and set up a general framework for calculating a number of cosmological observables, and their variation down the past null cone. Of particular interest are observables that are zero in the spherically symmetric case, such as proper motions on the sky. The method is tailored for practical calculation. The approach is applied to the Szekeres spacetime, a numerical code is created, and it is succesfully validated against a set of special cases. Graphical results are presented for a selection of Szekeres toy models.

11 Fully nonlinear and exact cosmological perturbation theory (by Jai-chan Hwang and Hyerim Noh)

Jai-chan Hwang
Kyungpook National University

We present fully nonlinear and exact cosmological perturbation formulations now including all three-types of perturbations. The equations are presented without taking the temporal gauge condition in the Friedmann background with general curvature and the cosmological constant. As a limiting case we present the special relativistic hydrodynamics in the presence of weak gravity.

12 Drift effects in inhomogeneous cosmology

Mikołaj Korzyński
CFT PAN

I will present the general theory of drift effects in inhomogeneous cosmologies, applicable to numerical research and to exact solutions

13 A possible connection of blueshifts in the Lemaitre - Tolman and Szekeres models with the gamma-ray bursts

Andrzej Krasiński
N. Copernicus Astronomical Center, Warsaw, Poland

As known since 1980, some light rays emitted from the Big Bang (BB) in a Lemaitre - Tolman (L-T) model reach all observers with an infinite blueshift. This happens when at the emission point the BB instant is, in comoving coordinates, nonconstant and the rays propagate radially. Some authors portrayed the existence of blueshifts as a disaster disqualifying

the L-T models. This author recently proposed that blueshifted rays are actually observed as gamma-ray bursts (GRBs). Two papers were published. In the first one, it was shown that L-T based models of GRB sources successfully account for the energies of the GRBs, the large distances to them, their multitude, and for the existence of the afterglows. However, these models did not account for the durations of the GRBs and of the afterglows and for their (hypothetical) collimation into narrow jets. In the second paper, the existence and properties of blueshifts were investigated in exemplary Szekeres models. In them, infinite blueshifts may arise only along two opposite directions, so the collimation is accounted for. The third paper, now being prepared, aims at constructing realistic Szekeres-based models of GRBs and showing how they improve upon the L-T based models.

14 The Lagrangian perturbation theory in relativistic universe with perfect fluid sources

Yongzhuang Li
University of Canterbury

We are focusing on the generalization of Lagrangian perturbation theory in a relativistic universe with perfect fluid sources. As expected the appearance of pressure gradient will affect the evolution of perturbations.

15 “Big Rip” in an inhomogeneous universe

Colin MacLaurin
University of Queensland

16 Inhomogeneous cosmology with numerical relativity

Hayley Macpherson
Monash University

Upcoming cosmological surveys will reach a precision at which nonlinear general relativistic effects could become important. I will present our 3-dimensional simulations of cosmological structure formation with numerical relativity, with a view towards quantifying the effect of nonlinear structures on our observations.

17 Light propagation in perturbed ΛLTB models

Sven Meyer
ITA Heidelberg

We study the evolution of gauge-invariant linear perturbations in Λ-Lemaître-Tolman-Bondi models and their effects on light propagation for a central observer in the Born approximation. Since gauge invariant quantities in ΛLTB models are abstract mathematical objects (as derived in Clarkson, Clifton, February (2009)), light propagation is also an essential tool to map these quantities to the cosmic shear field as possible observable. I will present results on the numerical evolution of gauge-invariant perturbations in ΛLTB models and outline the formalism to project the results onto lightcone observables like the cosmic shear field for a central ΛLTB observer.

18 Averaging general inhomogeneous fluids on arbitrary spatial foliations in Relativistic Cosmology

Pierre Mourier
CRAL

The non-commutation of time evolution and regional spatial averaging for inhomogeneous scalars leads to extra ('backreaction') terms in the effective averaged cosmological equations for an inhomogeneous universe. Initially derived for irrotational perfect fluids within fluid-orthogonal hypersurfaces, these effective equations have been extended to general fluids in arbitrary foliations through several approaches. I shall put these various results from the literature into perspective, focusing on the consequences of the possible choices of propagation for the averaging domain. I will then present a new averaging formalism, intrinsic to the fluid, that allows the derivation of simpler and more transparent effective equations while preserving their high level of generality.

19 Fully nonlinear and exact cosmological perturbation theory

Hyerim Noh
Korea Astronomy and Space Science Institute

I am the co-author of "Fully nonlinear and exact cosmological perturbation theory" and Dr. Jai-chan Hwang will have a presentation with this title.

20 Persistent Holes in the Universe

Pratyush Pranav
Technion

Due to computational advances in the last couple of decades, algebraic topology, specifically homology, has transformed from a purely theoretical subject to one with strong aspects of applicability. A manifold in d-dimensions can be analyzed in terms of the ambient holes of dimension k (k = 0,...,d). While general in nature, these holes have an intuitive physical interpretation in spatial dimensions. The number of independent holes in the different dimensions, measured by the Betti numbers, has interesting connections with the cosmologically familiar Euler characteristic or genus. The Euler-Poincaré formula states that the Euler characteristic is an alternating sum of Betti numbers. This implies that two manifolds with different Betti characteristics may turn out to be the same when studied through the Euler characteristic. This has important repercussions when model discrimination is the primary focus. As homology is the mathematical language of formalizing holes of a manifold, so is persistence homology its hierachical extension, and adds another level of refinement to the available topological information. This is especially relevant when it comes to robustly measure hierarchically nested structures while roughening their geometry. In my talk, I shall provide an intuitive understanding of the concepts of homology and persistence, and towards the end present some examples of relevance in the cosmological setting.

21 Ways to settle the backreaction conjecture

Syksy Räsänen
University of Helsinki

I will present a review of the situation of the backreaction conjecture and discuss ways to prove it one way or another.

22 Computational Challenges in Relativistic Cosmology

Vincent Reverdy
University of Illinois at Urbana–Champaign

We have been told that fully relativistic cosmological simulations were out of reach because of their intrinsic computational complexity. However, the reality is more subtle. Very few code are currently able to make the most of petascale supercomputers, and exascale supercomputers are likely to be available within the next five years. In this talk, I will discuss how the main bottleneck of numerical relativistic cosmology may not be the pure computational power, but the lack of libraries to exploit this power. I will explore the question of numerical relativistic cosmology from the standpoint of computer science, high performance computing and computer engineering. In particular, I will highlight the importance of achieving genericity, performance and ease-of-use in numerical libraries and I will review how recent developments in the domain of programming languages can help us to pave the way toward relativistic cosmology. The talk will be illustrated with lessons coming from the Tree Building Blocks project currently in development at the University of Illinois at Urbana-Champaign. The conclusion will focus on interdisciplinary approaches in between astrophysics and computer science to make fully relativistic cosmological simulations possible.

23 Scalar-averaged N-body simulations

Boud Roukema
TCfA NCU

In the standard N-body approach to modelling cosmological structure formation, the formation of galaxies, filaments and voids is assumed to follow Newtonian gravity and to be decoupled from Einsteinian gravity operating at cosmological scales. The method and preliminary results of applying scalar averaging to set general-relativistic constraints on N-body simulations will be presented, including calibration using the Relativistic Zel'dovich Approximation. The aim is to develop a self-consistent general-relativistic simulation code using front-end software and libraries that are verifiable, modifiable, and redistributable by the community under free-software licences.

24 Backreaction for perfect fluid spheres

Mieszko Rutkowski
Jagiellonian University

(Draft:) During my talk I will discuss backreaction effect for spherically symmetric solutions to Einstein equations with perfect fluid source.

25 Example of an inhomogeneous cosmological model inspired by the perturbation theory

Szymon Sikora
Jagiellonian University

I present the cosmological model which approximates the periodically distributed dust overdensities on the Einstein-de Sitter background. The model construction enables application of the Green-Wald averaging scheme and the Buchert averaging technique simultaneously. The comparison of the angular diameter distance obtained within the presented model and the angular diameter distances for the respective average space-times is given.

26 A non-perturbative approach to inhomogeneous cosmology

Harald Skarke
TU Wien

The mass-weighted average has the property that averaging and taking time derivatives commute. This fact gives it a technical advantage over the more commonly used volume average and affords numerical computations of a non-perturbative nature. Applying the resulting framework to a universe with the standard initial conditions (almost perfect homogeneity with only small Gaussian fluctuations) we find that volume evolution in such a universe is not modified significantly by the inhomogeneities, but that light propagation gets modified in such a way that the observed redshift-distance relations may be explained without invoking a cosmological constant.

27 Szekeres models as a powerful theoretical tool in inhomogeneous cosmology

Roberto A Sussman
ICN-UNAM (Mexico)

I examine Szkeres models of class I by means of covariant variables related to weighted averages and their fluctuations. These variables allow for a description of the evolution of non-trivial multiple networks of over densities and voids whose spatial position can be prescribed through initial conditions. The exact density and velocity fluctuations reproduce and contain cosmological perturbations at all orders, providing also an exact and fully relativistic realisation of the Zeldovich approximation. I discuss various possible applications of the models to open problems in theoretical and observational cosmology.

28 Backreaction for Einstein–Rosen waves coupled to a massless scalar field

Sebastian Szybka
Jagiellonian University

I will present an exact solution to Einstein's equations for which the backreaction may be studied explicitly.

29 Game dynamics of 3-geometries in an inhomogeneous universe

Nezihe Uzun
Charles University, Prague

In this talk, we investigate the statistical evolution of 3-dimensional spatial subregions of a domain by using the formalism of game theory. It will be shown that the statistical evolution of those subregions corresponds to a Darwinistic game in which each subclass tries to increase its payoff/fitness until the (Nash) equilibrium is reached. We introduce a new, geometric definition of statistical homogeneity in cosmology which corresponds to our equilibrium state and we discuss the maximization of the relative information entropy. A quantum mechanical interpretation and the corresponding group representation will also be provided.

30 Timescape cosmology

David L Wiltshire
University of Canterbury, NZ

General relativity leaves many important questions unanswered that are directly relevant to the fitting problem for inhomogeneous cosmology, including the nature of gravitational energy. The timescape cosmology is a phenomenological model (without dark energy) which returns to first principles to address such questions, and to derive observables for the Buchert averaging formalism. It is successful in as far as it can be tested, and it offers falsifiable predictions. To make more precise predictions, we need to develop a deeper understanding of the geometrical nature of the Universe on large scales, in as far as light propagation is concerned, given that the Einstein equations are no longer assumed to apply for averages on arbitrarily large scales. In this talk I will outline the current status of the timescape model, and directions for future work.