STATISTICAL CHALLENGES in 21st CENTURY COSMOLOGY

IAU Symposium 306

Lisbon, Portugal, 25-29 May, 2014

Book of Abstracts

Contents

Foreword

Full exploitation of the very large surveys of the Cosmic Microwave Background, Large-Scale Structure, weak gravitational lensing and future 21cm surveys will require use of the best statistical techniques to answer the major cosmological questions of the 21st century, such as the nature of Dark Energy and gravity.

Thus it is timely to emphasise the importance of inference in cosmology, and to promote dialogue between astronomers and statisticians. This has been recognized by the creation of the IAU Working Group in Astrostatistics and Astroinformatics in 2012.

IAU Symposium 306 – Statistical Challenges in 21st Century Cosmology is devoted to problems of inference in cosmology, from data processing to methods and model selection, and will have an important element of cross-disciplinary involvement.

Keynote speakers

David van Dyk (UK) on Bayesian methods

Aurore Delaigle (Australia) on Errors and nonparametric estimation

Graca Rocha (USA) on Cosmic Microwave Background

Ben Wandelt (France) on Massive parameter estimation

Masahiro Takada (Japan) on Weak Gravitational Lensing

Licia Verde (Spain) on Large-scale structure

Sabino Matarrese (Italy) on Statistics of fields

Alex Szalay (USA) on Overwhelmingly large datasets

Jalal Fadili (France) on Sparsity

Mario Santos (South Africa / Portugal) on 21cm cosmology

Anais Rassat (Switzerland) on Combining probes

Invited speakers

Denis Barkats for BICEP2 (ESO) on B-mode polarization

Hiranya Peiris (UK) on Anomalies

Narciso Benítez (Spain) on Statistical aspects of photo-z

Mike Hobson (UK) on Machine-learning in Astronomy

Jérôme Bobin (France) on Sparsity based CMB reconstruction

Mario Hamuy (Chile) on Supernovae Cosmology

Joseph Hilbe (USA), for closing remarks from a statistician

Andrew Jaffe (UK) for closing remarks from a cosmologist

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Bruce Bassett (South Africa)

Joseph Hilbe (USA)

Vicent Martinez (Spain)

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Qingjuan Yu (China)

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IAUS306–SCCC21 is supported by

Internationa Astronomical Union
http://www.iau.org

European Research Council
http://erc.europa.eu

http://astro.ic.ac.uk/research/imperial-centre-inference-and-cosmology-icic

Commissariat à l'énergie atomique et aux énergies alternatives
http://www-centre-saclay.cea.fr

Laboratoy for Systems, Instrumentation and Modelling
http://www.sim.ul.pt

http://www2.acad-ciencias.pt

http://wuala.com

http://www.cienciaviva.pt/home/

General information

Moving around

The *Tutorial sessions* and the *Symposium sessions* will take place at the auditorium of the *Pavilhão do Conhecimento* science museum, near the Oriente metro station (10 minutes walking slowly from the station). There is a map in the next page showing the surroundings of the venue.

The *Welcome cocktail* and the *Public lecture* will take place at the *Academia das Ciências de Lisboa*. If you walk from the metro stop Baixa–Chiado, you will need less than 20 minutes to arrive there walking slowly. Make sure you leave at the metro at the Chiado exit (there are several escalators to take). You can find a map indicating the path to follow from the Chiado exit in two pages.

The *Conference dinner* will take place at the Zambeze restaurant. You can find a map to arrive there from the Baixa–Chiado metro station (10 minutes walking) in three pages. To enter the restaurant, bring your conference badge!

Finally, four pages from now, you can find a map of Lisbon's metro. Alternatively, you can find interactive maps in the following links:

Pavilhão do Conhecimento: http://bit.ly/1vnJvgU

Academia das Ciências de Lisboa: http://bit.ly/1jrznjo

Zambeze restaurant: http://bit.ly/1lBHOFQ

Metro lines: http://www.metrolisboa.pt/eng/

Internet

Free and open internet connection is available at the Symposium venue. You can use any of the following two wifi networks to connect:

`cv_public`

`cv_auditorio`

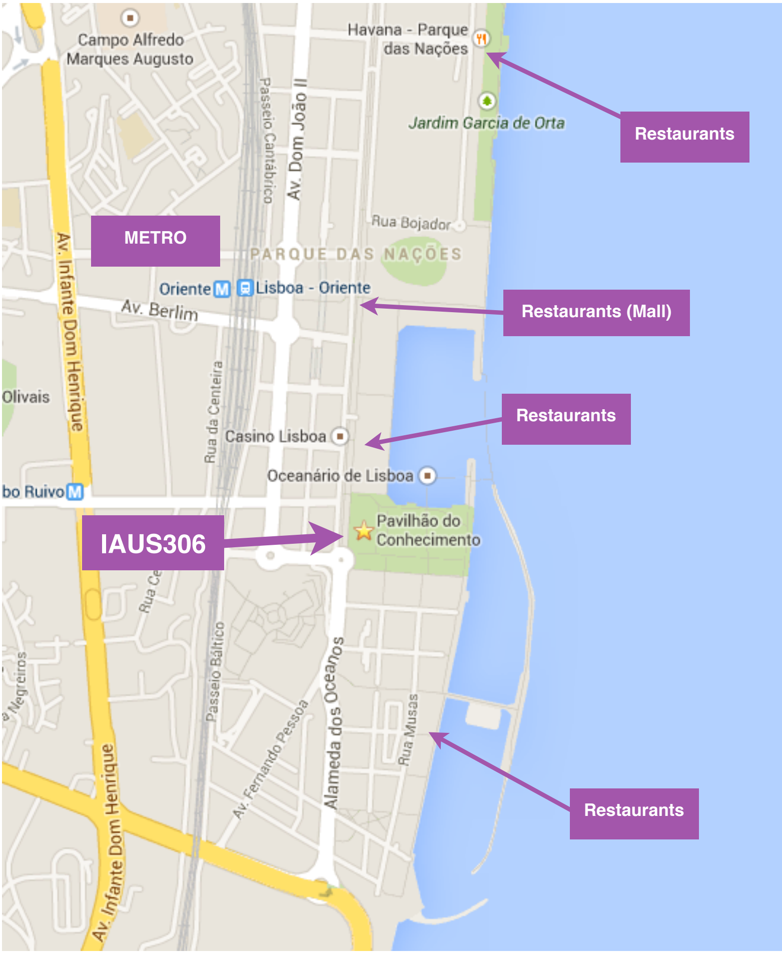
Lunch

There are several restaurants around the Symposium venue. For those in a hurry, there are also fast food options almost at the door. The map indicates some regions where you can find restaurants for your lunch.

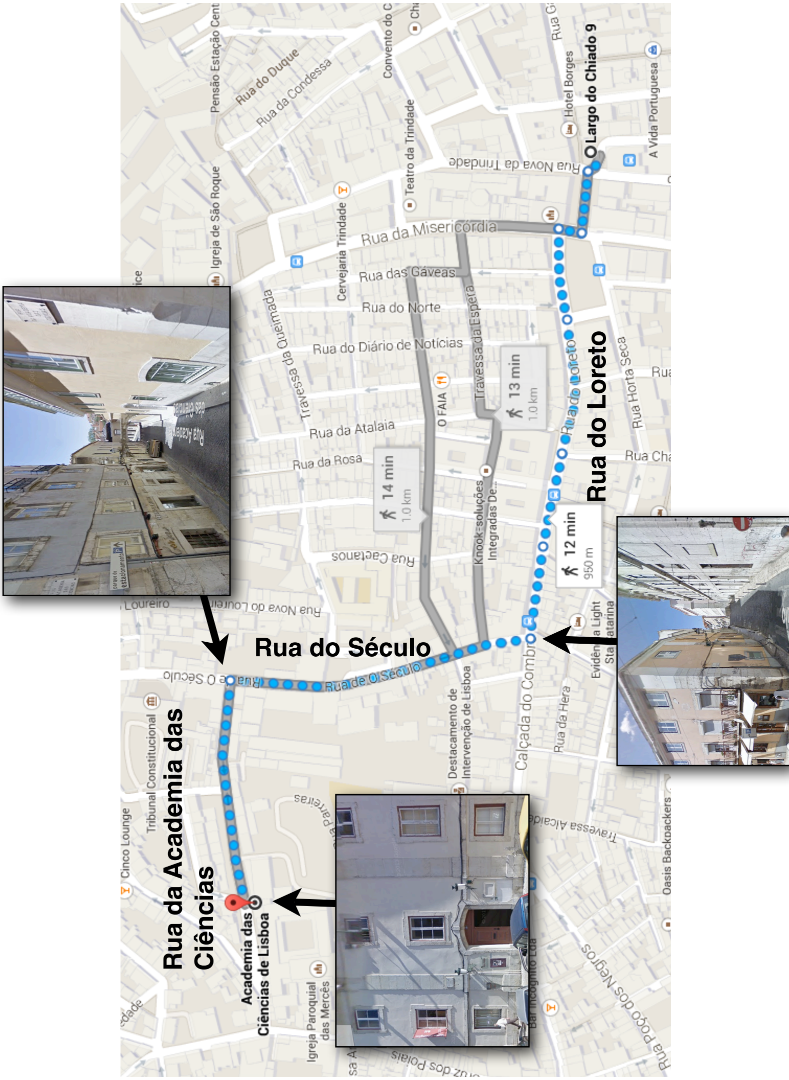
Secretary desk

The secretary desk is located at the entrance of the Symposium venue. It will be open during the whole conference. You can also contact it at `sccc21@sim.ul.pt`. If you need any kind of assistance (ex. taxi, hospital, language), do not hesitate in contacting us.

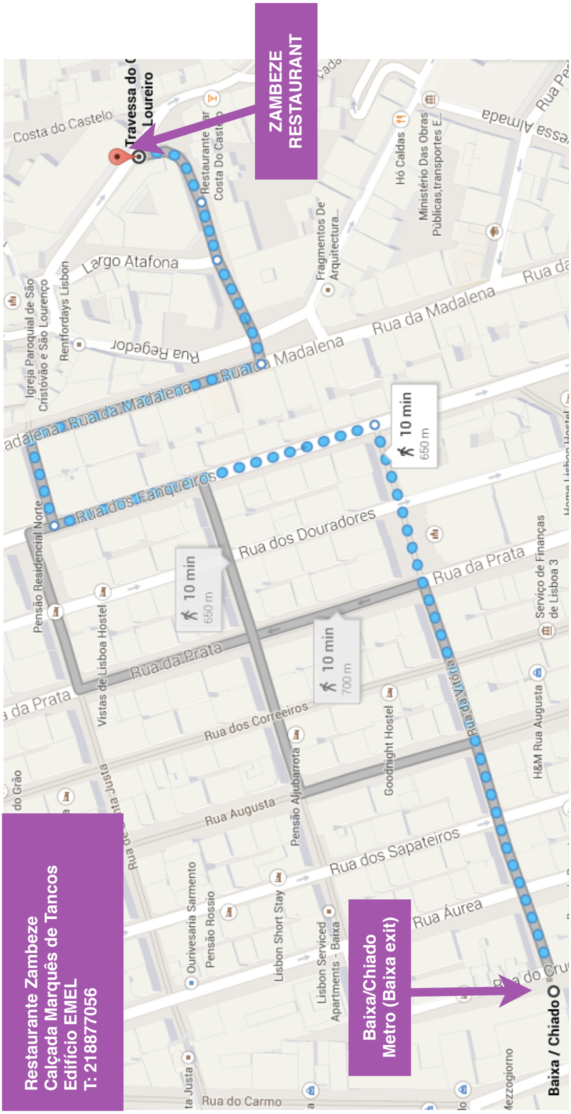
Map: Pavilhão do Conhecimento



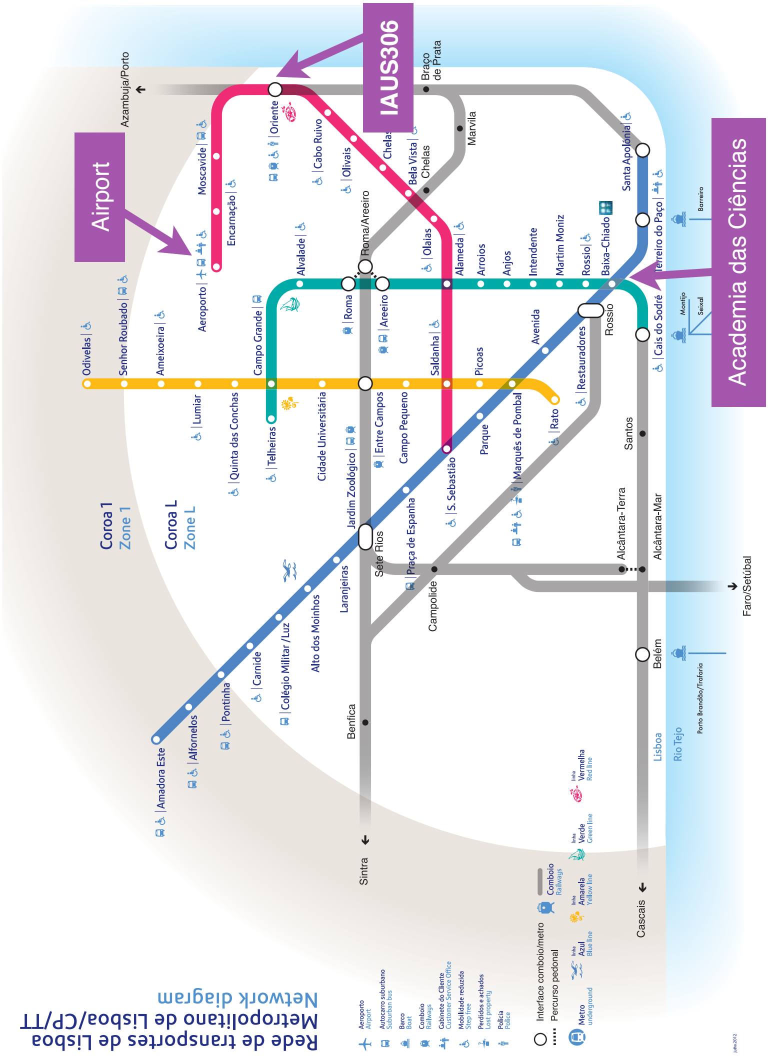
Map: Academia das Ciências



Map: Conference dinner



Map: Lisbon metro network



Useful contacts

Emergencies (police and medical)

The European Emergency Number is: **112**

This number can be called from any phone, including mobile phones without a SIM card. Calls are answered within 6 seconds.

Taxi services

Taxis in Lisbon are relatively cheap compared to other cities in Europe. A trip from the Airport to the city center (or vice-versa, as it should be a bijection, and thus invertible!) should cost you between 8 and 13 euros, depending on where you are heading to.[1]

Teletaxis: +351–218 111 111

Hospitals

Hospital da Luz (http://www.hospitaldaluz.pt/en/): +351–217 104 400

British Hospital: +351–217 213 410 / 1

Hospital St. Maria: +351–217 805 000 / +351–217 805 111

Copy and print services

PrintWork (printwork@printwork.pt): +351–218 967 185

Printpoint (expo@printpoint.pt): +351–218 951 122

Conference dinner restaurant

Zambeze restaurant: +351–218 877 056

In case of emergencies: If you are in a **real emergency situation (e.g life threatening)**, you can contact the LOC chair directly at: +351–916 185 386.

[1] A trip between the airport and the Expo region, where the Symposium venue is located, should cost from 8 to 10 euros. But note that you can easily arrive at Expo from the airport using the metro as well – just make sure you leave at the Oriente station.

Conference Programme

In a nutshell

The *Symposium sessions* will take place at *Pavilhão do Conhecimento*. It will open the doors all days at 8h30, except on the Sunday, when it will open at 10h00. Note that the *Welcome cocktail* and the *Public lecture* will take place at *Academia das Ciências de Lisboa*.

Sunday

10h00 :: Registration starts
10h20 – 17h00 :: Tutorials
18h00 – 20h00 :: Welcome cocktail

Monday

9h00 – 18h10 :: Symposium sessions: Bayes & CMB
18h10 – 18h40 :: IAA Cosmostatistics Working Group meeting

Tuesday

9h00 – 18h10 :: Symposium sessions: Bayes, Weak-Lensing & Large Scale Structure
19h30 – 20h15 :: Public lecture

Wednesday

9h00 – 18h10 :: Symposium sessions: Data, Sparsity & Statistics
18h10 – 18h40 :: Poster session
20h00 :: Conference dinner

Thursday

9h00 – 17h10 :: Symposium sessions: Radio, Supernovae & Joint probes
17h10 :: Symposium closes

Sunday, 25th May

This is the first day of IAUS306-SCCC21! Note that everyone is welcome to register in the symposium at the secretary desk at any moment during the Sunday, but in order to participate in the tutorials you must have registered.

10h00	The venue opens for participants

10h00	Registration opens	
10h30	Statistical Methodology and R	Eric Feigelson
	Sparsity 1: Blind Source Separation	Jérôme Bobin
12h00	Lunch	
13h00	Statistical Methodology and R	Eric Feigelson
	Sparsity 2: Sparse regularization of inverse problems	François Lanusse
	Bayesian Cosmology	Daniel Mortlock & Andrew Jaffe
17h00	Session ends	

17h30	The venue closes for participants

18h00 – 20h00	Welcome cocktail at Academia das Ciências

Monday, 26th May

This is the second day of IAUS306-SCCC21! If you did not registered on the Sunday, you can register at any moment during the entire week. Nevertheless, note that you will not be allowed to enter the Symposium before the registration, so please arrive early. The doors are open from 8h30, so you can register before the Symposium starts.

On Monday you also have a free night, so you can enjoy the city as you please! If you need any help, let the LOC know.

8h30	The venue opens for participants

9h00	Welcome messages	
Session: Bayes		
9h20	The Advantages of "Shrinkage Estimates" in Astronomy	David van Dyk
10h05	Bayesian model comparison in cosmology	Daniel Mortlock
10h25	Coffee break	
10h50	Nonparametric estimation and measurement errors	Aurore Delaigle
11h35	Phase-space reconstruction of the cosmological large scale structure	Francisco-Shu Kitaura
11h55	What we talk about when we talk about fields	Ewan Cameron
12h15	Lunch	
Session: CMB		
14h00	Cosmic Microwave Background	Graça Rocha
14h45	Detection of B-mode polarization at at degree angular scales using BICEP2	Denis Barkats
15h25	Spin scale-discretised wavelets on the sphere for the analysis of CMB polarization	Jason McEwen
15h45	Coffee break	

Session: CMB		
16h15	Anomalies	Hiranya Peiris
16h50	Transforming Data into Science: Planck data and the CMB non-Gaussianity	Anna Mangilli
17h10	Applications of the Gaussian Kinematic Formula in Cosmology	Yabebal Fantaye
17h30	Detectability of multi-connected topologies	Ophélia Fabre
17h50	Cosmology with photometric quasars	Boris Leistedt
18h10	Session ends	

18h10 – 18h40	Meeting of the IAA Working Group on Cosmostatistics	Hosted by Rafael de Souza

18h50	The venue closes for participants

Tuesday, 27th May

In this third day of IAUS306-SCCC21, besides the Symposium sessions, you are also welcome to attend Alex Szalay's Public Lecture on *the Fourth Paradigm of Science* and learn about its impact *from Genes to Stars*!

8h30	The venue opens for participants

Session: Bayes		
9h00	Massive parameter estimation	Benjamin Wandelt
9h45	Bayesian Photometric Redshifts v2.0	Txitxo Benítez
10h20	Coffee break	
10h50	Statistical challenges in weak lensing cosmology	Masahiro Takada
11h35	The Potential of Likelihood-Free Inference of Cosmological Parameters with Weak Lensing Data	Michael Vespe
11h55	The probability distribution of ellipticity: implications for weak lensing measurement	Massimo Viola
12h15	Lunch	
Session: Large Scale Structure		
14h00	Precision cosmology, accuracy cosmology and statistical cosmology	Licia Verde
14h45	Errors on errors - estimating cosmological parameter covariance	Benjamin Joachimi
15h05	Bayesian large-scale structure inference: initial conditions and cosmic voids	Florent Leclercq
15h25	Marked point processes for morpho-statistical characterization of the cosmic web	Radu Stoica
15h45	Coffee break	

16h10	Low/High Redshift Classification of Emission Line Galaxies in the HETDEX survey	Viviana Acquaviva
16h30	Distribution of maximal luminosity of galaxies in the Sloan Digital Sky Survey	Eniko Regos
16h50	Bootstrap: a valid alternative for clustering analyses?	Pablo Arnalte-Mur
17h10	Detection of a Supervoid Aligned with the Cold Spot of the Cosmic Microwave Background	András Kovács
17h30	Sufficient observables for galaxy surveys	Julien Carron
17h50	Improved distance measurements with reconstructed WiggleZ	Eyal Kazin

18h10	Session ends

18h30	The venue closes for participants

19h30	From Genes to Stars: the Fourth Paradigm of Science *Public lecture at Academia das Ciências de Lisboa*	Alex Szalay

Wednesday, 28th May

In this fourth day of IAUS306-SCCC21, besides the Symposium sessions, the poster session will also take place. Also, do not forget the conference dinner, and remember that you must bring your conference badge to have access to the restaurant.

8h30	The venue opens for participants

Session: Data		
9h00	Statistics of Fields	Sabino Matarrese
9h45	Machine-learning in astronomy	Mike Hobson
10h20	Coffee break	
10h50	Overwhelmingly large datasets	Alex Szalay
11h35	Machine Learning in Astronomy	Lise du Buisson
11h55	Euclid space mission: a cosmological challenge for the next 15 years	Roberto Scaramella
12h15	Lunch	
Session: Sparsity		
14h00	Sparsity	Jalal Fadili
14h45	Estimating the distribution of Galaxy Morphologies	Giuseppe Vinci
15h05	PURIFY: a new approach to radio-interferometric imaging	Yves Wiaux
15h25	PRISM: Sparse Recovery of the Primordial Power Spectrum	Paniez Paykari
15h45	Coffee break	
Session: Statistics		
16h15	Sparsity-based CMB reconstruction	Jérôme Bobin

16h50	Maximum-likelihood determination of the galaxy LF, evolution and selection function	Jonathan Loveday
17h10	Transformatively Taming Spatial Statistics	Mark Neyrinck
17h30	Clipping the Galaxy Power Spectrum in GAMA	Fergus Simpson
17h50	How accurate are measurements of primordial non-Gaussianity parameters from large-scale structure?	Nina Roth
18h10	Session ends	

18h10 – 18h40	Poster session

19h00	The venue closes for participants

20h00	Conference dinner at *Restaurante Zambeze*

Thursday, 29th May

Unfortunately, there is a last day in all Symposia! We planned this last day to be a bit shorter so you can catch your flights if you are leaving Lisbon. On the other hand, if you are staying a bit longer, and if you are willing to, you can try to get tickets for the Rolling Stones concert (also the last one?) or Beethoven's 9th Symphony (surely not the last one) concert!

8h30	The venue opens for participants

Session: Radio		
9h00	21cm Cosmology	Mario Santos
9h45	Beyond confusion: A Bayesian P(D) analysis of the Deepest Radio Survey	Jasper Wall
10h05	Bayesian Inference for Radio Observations (BIRO) – A new technique for simultaneously estimating instrumental errors and science parameters directly from radio visibility data	Michelle Knights
10h25	Coffee break	
Session: Supernovae		
11h00	Supernovae Cosmology	Mario Hamuy
11h35	Testing the consistency of different supernova surveys	Natallia Karpenka
11h55	Improved Kernel Principal Component Analysis for Supernova Photometric Classification	Emille Ishida

12h15	Lunch

Session: Joint probes		
14h00	Combining Probes	Anais Rassat
14h45	Cross Correlation between Astrophysical and Cosmological Datasets: Precision of Covariance Estimation and Impact on the Signal Detection Significance	Federico Bianchini

15h05	Information Gains from Cosmic Microwave Background Experiments	Sebastian Seehars
15h25	How well can the evolution of the scale factor be reconstructed by the current data?	Sandro Vitenti
15h45	Coffee break	
16h10	Cosmology with photometric surveys & an update on the Dark Energy Survey	Filipe Abdalla
16h30	Statistics and the Future of Astronomy	Joseph Hilbe
16h50	Closing remarks from a Cosmologist	Andrew Jaffe
17h10	IAUS306 – SCCC21 ends	

18h00	The venue closes for participants

Tutorials

The IAU Symposium 306 – Statistical Challenges in 21st Century Cosmology includes a full tutorial day, with the goal to present advanced statistical methods, and to demonstrate how one may use readily available codes, relevant for new and exciting applications in Cosmology and Astronomy!

These tutorials will take place on the Sunday, 25th May 2014, at the Pavilhão do Conhecimento.

For the most up to date information, please check:

`http://www.sccc21.ul.pt/tutorials.html`

Statistical Methodology and R

Eric Feigelson

Pennsylvania State University, USA

The fields of astronomy and statistics were, in past centuries, essentially merged but they diverged in the 20th century. The result today is that astronomers are poorly informed about the wealth of powerful methodologies developed by statisticians, and statisticians know little about contemporary challenges in modern astronomy. Statistics is needed for: understanding astronomical images, spectra and lightcurves; inference about underlying populations from limited samples; linking astronomical observations to astrophysical theories; and more. Fortunately, a very large, integrated and user friendly public domain software system has emerged in recent years to implement modern methods. R with its > 5000 add-on CRAN packages has $\sim 100,000$ statistical functionalities with extensive graphics, links to other languages, and more. Over 100 textbooks and extensive on-line support provide guidance for the sophisticated R user.

The tutorial will be in five segments:

- Introduction to astrostatistics and statistical computing (lecture)
- Basic data analysis with R
- Density estimation (data smoothing) with R and CRAN
- Multivariate clustering and classification with R and CRAN
- Spatial point processes with R and CRAN

Sparsity 1: Blind Source Separation

Jérôme Bobin

CEA – Commissariat à l'Énergie Atomique – Saclay, France

This tutorial will give essential insights into the use of blind source separation methods in astrophysics with a particular application in cosmology. Multichannel or multiwavelengths data are more than common in the field of astronomy and astrophysics. Analyzing this particular multidimensional data requires specific tools; these data are commonly modeled as the superposition of elementary components or sources which generally do not contribute similarly in each observation channel. The aim of blind source separation is to estimate simultaneously the sources and their contribution weight in each of these channels. Think for instance of a symphonic concert recorded with different microphones (i.e. the observation channels) and imagine the problem of separating out the contribution of each individual instrument from this cacophony. This tutorial will review the basics of blind source separation as well as more recently introduced sparsity-based techniques. An application to WMAP data will also be at the menu.

Sparsity 2: Sparse regularization of inverse problems

François Lanusse

CEA – Commissariat à l'Énergie Atomique – Saclay, France

In this tutorial we will introduce powerful sparse regularization techniques to address ill-posed linear inverse problems. For such problems, the inverse operator is potentially unbounded and there is no unique solution in the absence of prior. As an example of this class of problems we will be introducing the specific case of deconvolution which is a recurring problem in signal processing and has been extensively covered for the past 30 years.

The aim of this tutorial is to have a hands on experience with sparse regularization techniques and with the selection of appropriate dictionaries to address the deconvolution problem. Several practical problems will be proposed illustrating the strength of the sparsity prior.

Bayesian Cosmology

Daniel Mortlock & Andrew Jaffe

Imperial College London, United Kingdom

Most researchers will at some point be required to perform some form of data analysis. This may be anything from simple line-fitting, through parameter estimation, to complex and computationally-demanding sampling for model selection on large datasets. Bayesian inference is a practical methodology for solving such problems that is built up from the fundamentals of probability theory.

The purpose of this short course is to provide understanding of Bayesian data analysis, especially in a cosmological context, concentrating on the underpinnings of probability theory, Bayes' theorem itself, and its application to the estimation of parameters. To apply these ideas, the tutorial will include discussion problems and a hands-on workshop implementing Monte Carlo Markov Chain (MCMC) samplers.

Keynote talks

The Advantages of "Shrinkage Estimates" in Astronomy

David van Dyk
Imperial College London, United Kingdom

Astronomical studies often involve samples or populations of exchangeable sources. The parameters describing such sources can either be fit to each source in a separate analysis, or all be fit in a single unified analysis. The latter strategy allows us to incorporate the population distribution into a coherent statistical model and exhibits district statistical advantages. In particular, objects with smaller error bars and well-constrained parameters allow us to estimate the population distribution, which in turn can be used to better estimate the weakly-constrained parameters associated with objects with larger error bars. The fitted values of such weakly-constrained parameters will "shrink towards" the population mean, and are thus called "shrinkage estimates". This talk describes both frequentist and Bayesian advantages of shrinkage estimates and illustrates how they can be used in astronomy. In the first of two examples we estimate the absolute magnitudes of a SDSS sample of 288 Type Ia Supernovae using shrinkage estimates and illustrate how they differ from naive estimates. In the second example, we use photometric magnitudes of three galactic halo white dwarf stars to simultaneously obtain shrinkage estimates of the stellar ages and an estimate the age of the halo.

Nonparametric estimation and measurement errors

Aurore Delaigle
University of Melbourne, Autralia

In this talk I will introduce nonparametric methods for estimating curves (density, regression) nonparametrically, that is, without making parametric assumptions about the shape of the curves. Popular nonparametric methods include kernel smoothing approaches and spline techniques.

In many cases, the data that are available can only be observed with measurement errors, and techniques have to be developed that take this noise into account. I will introduce nonparametric methods to this problem, in cases where the error distribution is either known or unknown. In the statistics literature, this inverse problem is often refereed to as as a deconvolution problem.

If time permits I will also introduce methods which mix parametric and nonparametric approaches, and nonparametric methods which enable one to incorporate some a priori knowledge about the curve, such as for example monotonicity of the curve.

Cosmic Microwave Background

Graça Rocha

Jet Propulsion Laboratory, California Institute of Technology, USA

In this talk I will give an overview of the progress made in Cosmology and in our understanding of the Universe by observing and analyzing the anisotropies in the Cosmic Microwave Background (CMB) radiation. The increase of the CMB data volume required the application and development of sophisticated statistical approaches as well as optimized computational implementations of data analysis and parameter inference.

These techniques and algorithms enabled an optimal scientific exploitation of the CMB data resulting in major scientific breakthroughs. In this talk I will give an overview of these scientific advances along with the corresponding statistical and algorithmic developments that made it possible.

Special mention will be given to the statistical and algorithmic implementation challenges encountered when analyzing Planck data and resulting major scientific findings. An overview of other experiments and recent cosmological results will be also given including the recent BICEP2 results.

Massive parameter estimation

Benjamin Wandelt

Institut d'Astrophysique de Paris, France

Institut Lagrange de Paris, France

University of Illinois at Urbana-Champaign, USA

The goal of cosmostatistics is to derive quantitative insights into the outstanding puzzles of cosmological physics from astronomical data sets. How did the Universe begin? What are the properties of dark energy? How did the largest structures in the Universe form? In many cases these inferences involve non-Gaussian and/or non-linear data models, and involve tens of millions of parameters. I will describe two solution approaches to analysis of galaxy surveys: one based on Bayesian forward modeling, and the other using computational geometry methods that extract features from the observed galaxy distribution. These approaches have led to the first quantitative reconstructions of the cosmological initial conditions from galaxy surveys, the discovery of a universal profile for cosmic voids, the development of new cosmological tests, and an exceptionally detailed characterization the cosmic web underlying the observed galaxy distribution.

Statistical challenges in weak lensing cosmology

Masahiro Takada

Kavli Institute for the Physics and Mathematics of the Universe (IPMU)
Todai Institutes for Advanced Study (TODIAS) – University of Tokyo, Japan

There are various ongoing and upcoming wide-area galaxy surveys aimed at achieving a high-precision measurement of weak gravitational lensing due to large-scale structure in the Universe. Even though the initial density field is nearly Gaussian, the nonlinear gravitational clustering in structure formation induces substantial non-Gaussian features in the weak lensing field. Hence, the most conventionally used two-point correlation function or the Fourier counterpart, the power spectrum, can no longer extract the full information. Thus, which statistical method to extract the full information, more generally from large-scale structure probes, is still an open question. In this talk, I review the statistical challenges in the weak lensing cosmology, and discuss whether or not we can recover (or perhaps cannot recover?) the information content of the original Gaussian field, by combining different statistical observables we can obtain from galaxy surveys. Hope this talk will raise some open issues/questions, then followed by discussion during the conference.

Precision cosmology, accuracy cosmology and statistical cosmology

Licia Verde

Universidad de Barcelona, Spain & University of Oslo, Norway

The avalanche of data over the past 10-20 years has propelled cosmology in the “precision era”. The next challenge cosmology has to meet is to enter the era of accuracy. Because of the intrinsic nature of studying the Cosmos and for the sheer amount of data both available and coming soon, the only way to meet these challenges is by developing suitable and specific statistical techniques. I will outline some open challenges and discuss some specific examples.

Statistics of Fields

Sabino Matarrese

Università degli Studi di Padova, Italy

I will review both general problem of the statistics of the primordial curvature perturbation field in cosmology. The search for non-Gaussian signatures in cosmological perturbations, originated from inflation in the early Universe will be discussed both from the theoretical point of view and in connection with constraints coming from recent observations and future prospects for observing/constraining them.

Overwhelmingly large datasets

Alex Szalay

The Johns Hopkins University, USA

Astronomy surveys are collecting data from hundreds of millions to billions of celestial objects. These data are accessible through large public databases. These surveys are taken at different wavelengths, and one needs to perform statistical cross-matches to associate the detections with real physical objects. During the statistical analyses of the data astronomers are realizing that with billions of objects statistical noise is less of a problem, but systematic errors are becoming more important. We will discuss various ways, like optimal subspace filtering, of how the known systematic errors can be removed. We also explore the scaling behavior of different algorithms, and conclude that we need increasingly use streaming versions of the different statistics. Finally, as the amount of data collected is going to explode further, it is timely to consider how we could collect less, by focusing on parts of the data with the highest information content. The talk will present examples of these challenges.

A Sparsity Tour of Inverse Problems and Applications

Jalal Fadili

Ecole Nationale Supérieure d'Ingénieurs de Caen, France

In the last decade sparsity has emerged as one of the leading concepts in a wide range of data processing applications (restoration, inverse problems, feature extraction, source separation, compression, to name only a few). Sparsity-based methods also enjoy solid theoretical guarantees. Its domains of application are incredibly wide, including imaging and signal processing in astronomy, physics and the natural sciences etc. In this talk, I'll explore several classical inverse problems for which sparsity offers a unified and grounded framework to analyze and solve. Both theoretical and practical issues will be discussed and exemplified.

21cm Cosmology

Mario Santos

University of the Western Cape, South Africa

The "21 cm" line from neutral hydrogen provides an effective way to trace the matter content of the Universe, mapping its large scale structure in three dimensions and allowing exquisite constraints on cosmology. This can be done using the line to detect large numbers of galaxies or by using the novel technique of "HI intensity mapping" which relies on measuring the intensity of the redshifted 21cm line over the sky and a range of redshifts without the requirement to resolve individual galaxies. HI IM surveys can provide powerful tests of dark energy models and modifications to General Relativity as well as probe physics on ultra-large scales. I will describe the basics of the HI cosmological signal and what can be achieved with future surveys and then address the statistical challenges that we will need to face with these huge datasets, in particular the foreground cleaning methods and the calibration issues involving measurements with radio telescopes.

Combining Probes

Anais Rassat

EPFL - École Polytechnique Fédérale de Lausanne, Switzerland

With the advent of wide-field surveys, cosmology has entered a new golden age of data where our cosmological model and the nature of dark universe will be tested with unprecedented accuracy, so that we can strive for high precision cosmology. Observational probes like weak lensing, galaxy surveys and the cosmic microwave background as well as other observations will all contribute to these advances. These different probes trace the underlying expansion history and growth of structure in complementary ways and can be combined in order to extract cosmological parameters as best as possible.

With future wide-field surveys, observational overlap means these will trace the same physical underlying dark matter distribution, and extra care must be taken when combining information from different probes. Consideration of probe combination is a fundamental aspect of cosmostatistics and important to ensure optimal use of future wide-field surveys.

Invited talks

Detection of B-mode polarization at degree angular scales using BICEP2

Denis Barkats[1] on behalf of the BICEP2 collaboration
1. ALMA - ESO, European Southern Observatory

BICEP2 recently reported a detection of B-modes in the CMB polarization at degree angular scales. This B-mode pattern is widely interpreted as the likely signature from primordial gravitational waves, consistent with those predicted to arise in the first $10^{-}34$ seconds of the history of the universe, stretched from quantum to classical scales by the exponential expansion of cosmic inflation. BICEP2 is a CMB polarimeter that was specifically designed to search for the elusive signal from inflationary gravitational waves in the B-mode power spectra around $l = 80$. BICEP2 has accumulated 3 years of data from the South Pole from 2010 to 2012, integrating continuously on a low-foreground region of effective size 1% of the whole sky. I will describe the experimental strategy, tests for foreground or systematics contamination, and results in the map and power spectra. The reported B-mode spectrum is well fit by a lensed-LCDM plus tensor theoretical model with tensor/scalar ratio $r = 0.20 + 0.07 - 0.05$ with $r = 0$ is strongly disfavored.

Anomalies

Hiranya Peiris
University College London, United Kingdom

Anomaly detection drives scientific discovery - it is correlated with the cutting edge of the research frontier, and thus inevitably involves small signal-to-noise. In astronomy, the prevalence of systematics – both “known unknowns” and “unknown unknowns” – combined with increasingly large datasets, the prevalence of ad hoc estimators for anomaly detection, and the “look elsewhere” effect, can lead to spurious false detections. I will argue that anomaly detection leading to discoveries of new (astro)physics needs a combination of physical understanding, careful experimental design to avoid confirmation bias, and self-consistent statistical methods. I will illustrate these points with several concrete examples from cosmology.

Bayesian Photometric Redshifts v2.0

Txitxo Benítez

Instituto de Astrofísica de Andalucía – CSIC, Spain

Photometric Redshifts have become crucial for large field (> 5000 sq.deg) Astrophysical Surveys, whether as their main technique or as a preliminary target selection step. The application of a rigorous Bayesian approach to photometric redshift estimation helps to solve many of the practical problems arising in the design and implementation of such surveys. Using a properly calibrated redshift/magnitude prior is essential to produce posteriors $p(z)$ for individual galaxies which not only are more compact, but also describe accurately the full sample redshift distribution $n(z)$. In addition, a Bayesian framework enables an easy characterisation of the spread of $p(z)$ via quality indicators as the odds ratio. This feature is key to design filter systems which maximise photo-z depth and precision, an overlooked issue since traditional broad-band, contiguous filter systems are far from optimal for redshift estimation. These photo-z quality indicators can be employed to efficiently extract subsamples with very high precision and purity from lower average quality datasets. This is essential for problems like radial BAO measurements, which require $dz/(1+z) < 0.3\%$. I present the latest version of the BPZ code, which includes new priors and a empirically calibrated template library.

Machine-learning in astronomy

Mike Hobson

University of Cambridge, United Kingdom

In modern astronomy, one is increasingly faced with the problem of analysing large, complicated and multidimensional data sets. Such analyses typically include tasks such as: data description and interpretation, inference, pattern recognition, prediction, classification, compression, and many more. One way of performing such tasks is through the use of machine learning methods. An intuitive and well-established approach to machine learning, both supervised and unsupervised, is based on the use of artificial neural networks (NNs), which consist of a group of interconnected nodes, each of which processes information that it receives and then passes this product on to other nodes via weighted connections. In particular, I discuss the first public release of the generic neural network training algorithm, called SkyNet, and demonstrate its application to a number of toy problems, and to astronomical problems focusing on the recov-

ery of structure from blurred and noisy images, the identification of gamma-ray bursters, and the compression and denoising of galaxy images. The SkyNet software, which is implemented in standard ANSI C and fully parallelised using MPI, is available at http://www.mrao.cam.ac.uk/software/skynet/.

Sparsity-based CMB reconstruction

Jérôme Bobin, Florent Sureau & Jean-Luc Starck
CEA – Commissariat à l'Énergie Atomique – Saclay, France

The reconstruction of an accurate map of the Cosmological Microwave Background radiation (CMB) from multi-wavelength surveys such as Planck is crucial for cosmology. However, this turns to be a challenging statistical problem as the CMB can hardly be measured directly and has to be disentangled from various sources of foreground emissions using so-called component separation methods. We will present a radically new component separation methods which makes profit of the natural sparsity of astrophysical components in the wavelet domain. In contrast to state-of-the-art methods proposed so far in astrophysics, the use of sparsity allows for a much better modeling of complex inhomogeneous components that mainly originate from galactic emissions. This sparsity-based method, coined LGMCA, has recently provided a very clean full-sky estimate of the CMB map with particularly low foreground contamination and without detectable remainings of thermal Sunyaev-Zel'Dovich effect.

Supernovae Cosmology

Mario Hamuy
Universidad de Chile, Chile

Type Ia Supernovae have played a central role in the measurement of the expansion history of the Universe and the determination of fundamental cosmological parameters, since the discovery of acceleration and dark energy in 1998 (Nobel Prize in Physics 2011). However, the nature of dark energy remains a mystery and understanding its origin is to be of paramount importance, as it offers the promise of revealing new physics. The answer to this question will arise in part from the analysis of large volumes of data emanating from massive wide-field surveys, through different complementary techniques such as weak lensing, large scale structure, galaxy clusters, and Type Ia supernovae themselves. The supernova method will require the measurement of precise and accurate distances over a wide range in redshifts. Achieving such goal will require careful analysis of large statistical samples of supernova light curves and a thorough understanding of the systematic errors that could bias our conclusions. Here I summarize the main challenges that need to be addressed in order to measure reliable distances derived from Type Ia supernovae and I will discuss the prospects for the use of Type II supernovae as independent cosmological probes in the effort to understand dark energy.

Statistics and the Future of Astronomy

Joseph M. Hilbe

Arizona State University & Jet Propulsion Laboratory, USA

Given the generic definition of statistics, it is clear that astronomers have engaged in statistical analysis of some variety since astronomy first emerged as a science. However, from the early nineteenth century until the beginning of the twenty-first the two disciplines have been somewhat estranged – there has been no formal relationship between the two. This has now changed, as is evidenced by this symposium. The challenge for us to come is in establishing how statisticians and astronomers relate in developing the discipline of astrostatistics. Astronomers currently recognize that statistics is driving many areas of cosmology and astrophysics, and will likely play an important, if not leading, role in our future understanding of the structure and foremost features of our universe. I shall propose a direction for how the discipline can progress in both the short term as well as for future generations of astrostatisticians.

Contributed talks

Bayesian model comparison in cosmology

Daniel Mortlock & Alex Khanin

Imperial College London, United Kingdom

Bayesian inference provides a self-consistent method of model comparison, provided that i) there are at least two models under consideration and ii) all the models in question have fully-specified and proper parameter priors. Unfortunately, these requirements are not always satisfied in astronomy and cosmology: despite the existence of exquisitely-characterised measurements and quantitative physical models (i.e., sufficient to compute a believable likelihood), these models generally have parameters without well-motivated priors, making completely rigorous model comparison a formal impossibility. Still, huge advances have been made in cosmology, in particular, in the last few decades, implying that model comparison (and testing) is possible in practice even without fully specified priors. I will describe a method for Bayesian model comparison that can be used when prior information on parameters is weak, showing its application to the problem of ultra-high energy cosmic ray origins.

Phase-space reconstruction of the cosmological large scale structure

Francisco-Shu Kitaura

Leibniz-Institut für Astrophysik Potsdam (AIP), Germany

I present an approach to recover the phase-space distribution from galaxy redshift surveys. This method is based on a Bayesian approach and includes an improved perturbation theory approach to model structure formation including nonlinear and stochastic galaxy biasing. I present the analysis of the 2-point, 3-point statistics and the bispectrum and quadrupole in redshift space showing that the method is accurate down to a few Mpc.

What we talk about when we talk about fields

Ewan Cameron

University of Oxford, Department of Zoology, United Kingdom

It often occurs in application of the physical sciences that we wish to make statistical inferences as to the nature of some unknown signals over continuous space (i.e. "fields") given a limited set of observational data. Examples include: mapping the large-scale distribution of mass in the local universe and inferring its power spectrum based the observed distribution of bright galaxies; or predicting the volume of exploitable minerals within a particular region given a series of drill core measurements at irregularly spaced test sites. In this talk I will review the Bayesian approach to this problem on both the discrete (finite pixel grid) and continuous (infinite dimensional signal) problem spaces in which our inference challenge may be defined, and I will describe a number of important mathematical subtleties key to a robust treatment of this dichotomy (i.e., Kolmogorov's extension theorem, convergence in distribution vs convergence in mean, Prokhorov's theorem, and the nature of stochastic process priors). I will then give a brief overview of various contemporary Bayesian techniques for exploring the field space posterior (i.e., Hamiltonian MCMC, and the Integrated Nested Laplace Approximation) and I will discuss a number of technical difficulties for implementation of these methods (e.g. the problem of joint simulation for gauging large scale uncertainty in the case of high resolution spatial grids).

This work will draw on my diverse, cross-disciplinary experience in astronomy, statistics, and epidemiology/zoology.

Spin scale-discretised wavelets on the sphere for the analysis of CMB polarization

Jason D. McEwen[1], Martin Buettner[1], Boris Leistedt[1], Hiranya V. Peiris[1], Pierre Vandergheynst[2] & Yves Wiaux[3]

1. University College London, United Kingdom

2. EPFL - École Polytechnique Fédérale de Lausanne, Switzerland

3. Heriot-Watt University, United Kingdom

We construct a new spin scale-discretized wavelet transform on the sphere that supports a directional and steerable wavelet analysis of spin signals. Scale-discretized wavelets allow in practice the exact synthesis of a signal from its wavelet coefficients. We present new exact and efficient algorithms to compute the spin scale-discretized wavelet transform of band-limited signals on the sphere up to high band-limits. Finally, we highlight the application of spin scale-discretized wavelets to analysis polarized CMB data, which is a spin-2 signal on the sphere.

Transforming Data into Science: Planck data and the CMB non-Gaussianity

Anna Mangilli[1] on behalf of the Planck Collaboration

1. Institut d'Astrophysique de Paris, France

Studying the non-Gaussianity (NG) of the Cosmic Microwave Background (CMB) is an extremely powerful tool to investigate the properties of the very early Universe, complementary e.g. to the search of B-modes in the CMB polarization. The Planck nominal mission CMB maps yielded unprecedented constraints on primordial non-Gaussianity. Thanks to Planck's high sensitivity, we also got the first evidence of the "late-time" non-Gaussianity arising from the Lensing-Integrated Sachs Wolfe (ISW) cross correlation. In this talk I will give details on the Planck data analysis and I will discuss the theoretical implications of the results.

Applications of the Gaussian Kinematic Formula in Cosmology

Yabebal Fantaye

Università degli Studi di Roma Tor Vergata, Italy

Minkowski Functionals (MFs) have been used extensively in Cosmology, for instance to test for Gaussianity and Isotropy of the Cosmic Microwave Background maps. Although some analytical predictions of MFs for a Gaussian and mild non-Gaussian fields are known in the astrophysical community, much more refined results can be provided exploiting recent advances in the mathematical literature. In this work, we exploit the so-called Gaussian kinematic formula by J.Taylor and R.Adler to provide exact analytic expressions for the expected values of MFs in multipole and needlet space. Our results cover Gaussian fields and their power transformations, for instance quadratic and cubic polynomials; the latter can be used to obtain local estimates of the angular power spectrum, local estimates of nonGaussianity, tests for anisotropies and asymmetries and many other applications. We also show how to derive exact and efficient analytical predictions on the expected values of MFs for spherical random fields on a cut sky, such as those arising from WMAP and Planck masks. All our theoretical results are found to be in extremely good agreement with CMB simulations under realistic experimental conditions.

Detectability of multi-connected topologies

Ophélia Fabre, Simon Prunet & Jean-Philippe Uzan
Institut d'Astrophysique de Paris, France

The global shape, or topology, of the universe is not constrained by the equations of General Relativity, which only describe the local universe. As a consequence, the boundaries of space are not fixed and topologies different from the trivial infinite Euclidean space are possible. The cosmic microwave background (CMB) is the most efficient tool to study topology and test alternative models. Multi-connected topologies, such as the 3-torus, are of great interest because they are anisotropic and allow us to test a possible violation of isotropy in CMB data.

In this presentation, the signature of a multi-connected topology on the properties of the CMB anisotropies is revisited. We show that the correlation function of the coefficients of the expansion of the temperature and polarization anisotropies in spherical harmonics encodes a topological signature. This signature can be used to distinguish an infinite space from a multi-connected space on sizes larger than the diameter of the last scattering surface.

With the help of the Kullback-Leiber divergence, we set the size of the edge of the biggest distinguishable torus with CMB temperature fluctuations and E-modes of polarization to 1.15 times the diameter of the last scattering surface. We also notice that CMB temperature fluctuations allow us to detect universes bigger than the observable universe, whereas E-modes are more efficient that temperature fluctuations to detect universes smaller than the observable universe.

Cosmology with photometric quasars

Boris Leistedt & Hiranya Peiris
University College London, United Kingdom

Quasars are highly biased tracers of the large-scale structure and therefore powerful probes of the initial conditions and the evolution of the universe.

However, current spectroscopic catalogues are too small for studying the clustering of quasars on large-scales and over extended redshift ranges. Hence one must resort to photometric catalogues, which include large numbers of quasars identified using imaging data but suffer from significant stellar contamination and systematic uncertainties. We will present a detailed analysis of the clustering of photometric quasars from the Sloan Digital Sky Survey, and demonstrate that the effects of observational systematics can be robustly eliminated with appropriate techniques. In particular, we will show how to mitigate the impact of spatially varying systematics, such as calibration and observing conditions, using an extended mode projection approach when correlating the quasar samples. We will finally present constraints on the quasar bias in the range $0.5 < z < 3.5$ derived using an optimal estimator that exploits both the clustering of the quasar samples and their cross-correlation with CMB lensing.

The Potential of Likelihood-Free Inference of Cosmological Parameters with Weak Lensing Data

Michael Vespe

Carnegie Mellon University, USA

In the statistical framework of likelihood-free inference, the posterior distribution of model parameters is explored via simulation rather than direct evaluation, permitting inference on models where the likelihood function is analytically intractable. We consider the problem of estimating cosmological parameters using measurements of the weak gravitational lensing of galaxies; specifically, we use a likelihood-free approach to investigate the posterior distribution of some parameters in the ΛCDM model upon observing a large number of sheared galaxies. As the choice of summary statistic used in comparison of observed data and candidate data in the likelihood-free inference framework is critical, we work toward a principled method of choosing the summary statistic, aiming for dimension reduction while seeking a statistic that is as close as possible to being sufficient for the parameters. Using simulated data, we evaluate the resulting statistic, as compared with others used in existing work, according to their ability to constrain the model parameters. This work is in collaboration with Peter Freeman, Rachel Mandelbaum, and Chad Schafer.

The probability distribution of ellipticity: implications for weak lensing measurement

Massimo Viola

Leiden Observatory, Netherlands

The weak lensing effect generates spin-2 distortions, referred to as 'shear', on the observable shape of distant galaxies induced by some intervening gravitational tidal field. Traditionally the spin-2 distortion in the light distribution of distant galaxies is measured in terms of a galaxy "ellipticity". This is a very good unbiased estimator of the shear field in the limit that a galaxy is measured at infinite signal-to-noise. However the ellipticity is always defined as a ratio of two quantities (the polarisation and a measurements of the galaxy size, or the semi-major and semi-minor axis of the galaxy to mention just two possibilities) and therefore requires some non-linear combination of the image pixels. This leads to biases in the measurement of the shear (and hence in the cosmological parameters) in any realistic case, where noise is present in the image. I will describe how this type of bias can be understood from the particular shape of the 2D probability distribution of the ellipticity of an object measured from data. Moreover I will discuss how this probability distribution can be used to explore strategies for calibration of noise biases in present and future weak lensing surveys(KiDS, DES, Euclid...).

Errors on errors - estimating cosmological parameter covariance

Benjamin Joachimi[1] & Andy Taylor[2]

1. University College London, United Kingdom

2. University of Edinburgh, United Kingdom

Current and forthcoming cosmological data analyses share the challenge of huge datasets alongside increasingly tight requirements on the precision and accuracy of extracted cosmological parameters. The community is becoming increasingly aware that these requirements not only apply to the central values of parameters but, equally important, also to the error bars. Due to non-linear effects in the astrophysics, the instrument, and the analysis pipeline, data covariance matrices are usually not well known a priori and need to be estimated from the data itself, or from suites of large simulations. In either case, the finite number of realisations available to determine data covariances

introduces significant biases and additional variance in the errors on cosmological parameters in a standard likelihood analysis. I am going to review recent work on quantifying these biases and additional variances, including the new results presented in Taylor & Joachimi (2014, astro-ph/1402.6983). I will discuss approaches to remedy these effects and the resulting requirements on the analysis and simulation effort of cosmological surveys.

Bayesian large-scale structure inference: initial conditions and cosmic voids

Florent Leclercq[1,2,3], Jens Jasche[1,2], Paul M. Sutter[1,2,4], Nico Hamaus[1,2,5] & Benjamin D. Wandelt[1,2,5]

1. Institut d'Astrophysique de Paris, France

2. Institut Lagrange de Paris, France

3. École Polytechnique ParisTech, France

4. Ohio State University, USA

5. University of Illinois, USA

Establishing a link between cosmological observations and theories describing the early Universe is important because it can further our knowledge of fundamental physics on a wide range of energy and distance scales. In this talk, I will describe recently proposed statistical data analysis methods designed to study the primordial large-scale structure via physical inference of the initial conditions in a fully Bayesian framework, and demonstrate its application to the Sloan Digital Sky Survey data release 7. Our algorithm explores the joint posterior distribution of all parameters involved via efficient Hamiltonian Markov Chain Monte Carlo sampling.

Building upon these results, I will show how to generate a set of data-constrained reconstructions of the present large-scale dark matter distribution. As a physical illustration, we apply a void identification algorithm to them. In this fashion, we access voids defined by the inferred dark matter field, not by galaxies, greatly alleviating the bias problem. In addition, the use of full-scale physical density fields yields a drastic reduction of statistical uncertainty in void catalogs. This new catalog is an enhanced data set for cross-correlation with other cosmological surveys.

Finally, as three-dimensional large-scale structure surveys contain a wealth of information which cannot be trivially extracted due to the non-linear dynamical evolution of the density field, I will discuss methods designed to improve upon previous approaches by including the salient features of the non-linear regime.

Marked point processes for morpho-statistical characterization of the cosmic web

Radu S. Stoica

Université Lille 1, Laboratoire Paul Painlevé, France &

Institut de Mécanique Céleste et Calcul d'Ephémérides, Observatoire de Paris, France

The cosmic web is the intricate network of filaments outlined by the galaxy distribution in our Universe. One possible manner to break the complexity of such an elaborate geometrical structure is to assume it made of simple interacting objects. Under this hypothesis, the filamentary network can be considered as the realization of a marked point process.

Marked point process are probabilistic models dealing with configurations of random points having random characteristics or marks. If the marks represent properties of some geometrical object, the marked point process is also called an object point process. Here, the filamentary network is considered as the realization of such a random process, with the objects being cylinders that align and connect in order to form the network.

The aim of this talk is to present the use of marked point processes to the detection and to the morpho-statistical characterization of the galactic filaments. The talk follows the standard steps of a probability and statistics based methodology : exploratory statistics, marked point processes modelling, Monte Carlo simulation and statistical inference. In the conclusion and perspective part, we will discuss how this methodology can be applied to other problems coming from astronomy.

Low/High Redshift Classification of Emission Line Galaxies in the HETDEX survey

Viviana Acquaviva[1], Eric Gawiser[2], Andrew Leung[2] & Mario R. Martin[1]

1. CUNY New York City College of Technology, USA

2. Rutgers University, USA

We discuss different methods to separate high- from low-redshift galaxies based on a combination of spectroscopic and photometric observations. Our baseline scenario is the Hobby-Eberly Telescope Dark Energy eXperiment (HETDEX) survey, which will observe several hundred thousand Lyman Alpha Emitting (LAE) galaxies at $1.9 < z < 3.5$, and for which the main source of contamination is [OII] emitters at $z < 0.5$. Additional information useful for the separation comes from empirical knowledge of LAE and [OII] luminosity functions and equivalent width distributions as a function of redshift. We consider three separation techniques: a simple horizontal cut in equivalent width, a Bayesian separation method, and machine learning algorithms, including support vector machines. We show how the latter two can be easily applied to other surveys and used on simulated data in the framework of survey planning.

Distribution of maximal luminosity of galaxies in the Sloan Digital Sky Survey

Eniko Regos[1], Manu Taghizadeh-Popp[2], Katalin Ozogány[1], Zoltán Rácz[1] & Alex S. Szalay[2]

1. Eötvös Loránd Tudományegyetem (Eotvos University), Hungary

2. The Johns Hopkins University, USA

Extreme value statistics is applied to the distribution of galaxy luminosities in the Sloan Digital Sky Survey. We analyze the DR8 Main Galaxy Sample (MGS), as well as the luminous red galaxies (LRGs). Maximal luminosities are sampled from batches consisting of elongated pencil beams in the radial direction of sight. For the MGS, results suggest a small and positive tail index ξ, effectively ruling out the possibility of having a finite maximum cutoff luminosity, and implying that the luminosity distribution function may decay as a power law at the high-luminosity end. Assuming, however, $\xi = 0$, a non-parametric comparison of the maximal luminosities with the Fisher-Tippett-Gumbel distribution (limit distribution for variables distributed by the Schechter fit) indicates a good agreement provided that uncertainties arising from both the finite batch size and the batch-size distribution are accounted for. For a volume-limited sample of LRGs, results show that they can be described as being the extremes of a luminosity distribution with an exponentially decaying tail, provided that the uncertainties related to batch-size distribution are taken care of.

Bootstrap: a valid alternative for clustering analyses?

Pablo Arnalte-Mur & Peder Norberg

Durham University, United Kingdom

Modern surveys are measuring the two-point correlation function of the galaxy

distribution to unprecedented precision, a trend that will continue with ongoing and planned projects. In order to make use of these data to obtain cosmological information, it is essential to accurately estimate the covariance matrix of the measurements. Recent works have based this estimation on the use of a large number of simulated mock catalogues, taken as independent realisations of the data. However, the needed number of simulated realisations makes this a very computationally intensive method. An alternative is to use internal variance estimators such as jackknife and block bootstrap, based on re-sampling sub-regions of the original data. These are much cheaper computationally, and do not depend on the accuracy of external simulations. The bootstrap method has the advantage of providing a nearly unlimited number of data realisations. However, in the standard bootstrap method, these realisations cover only a fraction of the total volume and thus the variance is over-estimated. We developed a new bootstrap method that avoids this problem by assigning continuous weights to the different sub-regions of the data. It thus provides a more accurate estimation of the covariance matrix. In this talk, we will present this new method and compare the performance of the different internal error estimations. Using a set of mock galaxy surveys, we will assess the applicability of these methods in a cosmological context.

Detection of a Supervoid Aligned with the Cold Spot of the Cosmic Microwave Background

István Szapudi[1], András Kovács[2], Benjamin R. Granett[3], Zsolt Frei[1], Joseph Silk[4], Will Burgett[1], Shaun Cole[5], Peter W. Draper[5], Daniel J. Farrow[5], Nicholas Kaiser[1], Eugene A. Magnier[1], Nigel Metcalfe[5], Jeffrey S. Morgan[1], Paul Price[6], John Tonry[1] & Richard Wainscoat[1]

1. University of Hawaii, USA

2. Eötvös Loránd Tudományegyetem (Eotvos University), Hungary

3. Istituto Nazionale di Astrofisica Brera, Italy

4. The Johns Hopkins University, USA

5. Durham University, United Kingdom

6. Princeton University, USA

We use the WISE-2MASS infrared galaxy catalog matched with Pan-STARRS1 (PS1) galaxies to search for a super-void in the direction the Cosmic Microwave Background Cold Spot. Our imaging catalog has median redshift $z \simeq 0.14$, and we obtain photometric redshifts from PS1 optical colours to create a tomographic map of the galaxy distribution. The radial profile centred on the

Cold Spot shows a large low density region, extending over 10's of degrees. Motivated by previous Cosmic Microwave Background results, we test for underdensity at two angular radii, 5°, and 15°. The counts in photometric redshift bins show significantly low densities at high significance, $\gtrsim 5\sigma$ and $\gtrsim 6\sigma$, respectively, for the two fiducial radii. The line-of-sight position of the deepest region of the void is $z \simeq 0.15 - 0.25$. Our data, combined with an earlier measurement by Granett et al. (2010), are consistent with a large $R_{void} = (192 \pm 15)\mathrm{h}^{-1}\mathrm{Mpc}$ (2σ) supervoid with $\delta \simeq 0.12$. Such a super-void, constituting a $\simeq 3.5 - 5\sigma$ fluctuation in a Gaussian distribution in the ΛCDM model, is large enough to affect the Cosmic Microwave Background through the integrated Sachs-Wolfe effect.

Sufficient observables for galaxy surveys

Julien Carron

Institute for Astronomy, University of Hawaii, USA

Statistical inference on cosmology from galaxy surveys requires a thorough understanding of the statistical properties of the cosmological matter density field. The non-linear nature of gravity distorts the Gaussianity of the primordial fluctuation field, making the efficient extraction of useful information on cosmological models a difficult challenge. Using simplified yet sufficiently realistic statistical models, this talk will describe the 'sufficient statistics' of the matter field, observables designed to capture its entire information content, just like the power spectrum does for Gaussian fields. This talk will also discuss consequences for inference on parameters from traditional cosmological observables such as the two-point function, or power spectrum, and tight connections to the log-density field.

Improved distance measurements with reconstructed WiggleZ

Eyal Kazin[1], Jun Koda[1], Chris Blake[1], Nikhil Padmanabhan[2] & the WiggleZ Dark Energy Survey

1. Swinburne University of Technology, Australia

2. Yale University, USA

The baryonic acoustic oscillations in galaxy maps has been shown to be a central tool in constraining cosmology. However, due to the growth of structure, which causes ~ 5 Mpc shifts in galaxy positions, this 150 Mpc feature in the two-point correlation function becomes slightly blurred causing a degradation of its ability to constrain distances. In this talk I present the reconstruction technique which, by restoring information encoded in the matter density field, sharpens this standard ruler, and by so enhances its constraining power. We have recently applied this technique on the galaxy maps of the WiggleZ Dark Energy Survey ($0.2 < z < 1$), and find the method successful, significantly improving distance measurements.

Machine Learning in Astronomy

Lise du Buisson[1,2], Bruce A. Bassett[1,2,3] & Navin Sivanandam[2]

1. University of Cape Town, South Africa

2. African Institute for Mathematical Sciences, South Africa

3. South African Astronomical Observatory, South Africa

The use of machine learning techniques in the field of astronomy has gained impetus in the last few years, as the sheer amount of data produced by astronomical surveys are putting an increasing amount of strain on human and other resources in their efforts to classify and sort data in such a way as to be able to gain insight and extract valuable results from it. Some examples of problems where the use of machine learning is employed for astronomical data analysis include the classification of stars, galaxies and AGNs, the identification and selection of possible quasars from surveys and the finding or classification of supernovae (SNe).

The next generation of surveys and telescopes, such as the Dark Energy Survey (DES) and the Large Synoptic Survey Telescope (LSST), will produce a vast amount of photometric data. Selecting SNe for spectroscopic follow-up from such data sets can be a very time-consuming task, one that can be more easily addressed using machine learning techniques in order to arrive at an automated and accurate selection/classification process.

For this investigation, photometric difference images obtained from Year II and III of the Sloan Digital Sky Survey (SDSS) are used to investigate which machine learning algorithms are best suited for classifying SNe from other objects in photometric data sets. Feature extraction techniques, including principal component analysis (PCA) and linear discriminant analysis (LDA), are used in combination with different machine learning algorithms, such as a naïve Bayes classifier, an artificial neural network (ANN), a support vector machine (SVM), a k-nearest neighbour algorithm and a self-organising map in order to find the most effective and accurate technique. This technique will then either be applied to similar SNe classification problems (e.g. classifying SNe using data from DES) or to other slightly different photometric classification problems.

Euclid space mission: a cosmological challenge for the next 15 years

Roberto Scaramella[1] on behalf of Euclid Consortium

1. Osservatorio Astronomico di Roma, Italy

Euclid is the next ESA mission devoted to cosmology. It aims at covering most of the extragalactic sky, studying both gravitational lensing and clustering over 15000 square degrees. The mission is expected to be launched in year 2020 and to last six years.

The sheer amount of data of different kinds, the variety of (un)known systematic effects and the complexity of measures require large efforts both in sophisticated simulations and techniques of data analysis. We will review the mission main characteristic, focus on the survey aspects and highlight some of the areas of interest to this meeting.

Estimating the distribution of Galaxy Morphologies

Giuseppe Vinci[1], Peter Freeman[1], Christopher Genovese[1], Jeffrey A. Newman[2] & Larry Wasserman[1]

1. Carnegie Mellon University, USA

2. University of Pittsburgh, USA

Estimating the distribution of galaxy morphologies is one means to test theories of the formation and evolution of the Universe. Galaxy images are intrinsically high-dimensional data. Thus, statistical methods based on a lower-dimensional representation of the images of galaxies are required. Summary statistics based on the ”persistent homology” of the density of the lfight intensity distribution produced by the galaxies can be helpful to classify mergers and non-mergers. However, crude 0-1 classifications are not enough to describe the complexity of the galaxies. ”Dictionary learning” and ”sparse coding” allow us to reduce the high dimensional space of shapes into a manageable low dimensional continuous vector space of coefficients. The corresponding estimated continuous probability distribution can be used to identify clusters of shapes in an

unsupervised way, and to compare the population of real galaxy shapes with that of simulated ones.

Spin scale-discretised wavelets on the sphere for the analysis of CMB polarization

Jason D. McEwen[1], Martin Buettner[1], Boris Leistedt[1], Hiranya V. Peiris[1], Pierre Vandergheynst[2] & Yves Wiaux[3]

1. University College London, United Kingdom

2. EPFL - École Polytechnique Fédérale de Lausanne, Switzerland

3. Heriot-Watt University, United Kingdom

We construct a new spin scale-discretized wavelet transform on the sphere that supports a directional and steerable wavelet analysis of spin signals. Scale-discretized wavelets allow in practice the exact synthesis of a signal from its wavelet coefficients. We present new exact and efficient algorithms to compute the spin scale-discretized wavelet transform of band-limited signals on the sphere up to high band-limits. Finally, we highlight the application of spin scale-discretized wavelets to analysis polarized CMB data, which is a spin-2 signal on the sphere.

PRISM: Sparse Recovery of the Primordial Power Spectrum

Paniez Paykari, François Lanusse, Jean-Luc Starck, Florent Sureau & Jérôme Bobin

CEA – Commissariat à l'Énergie Atomique – Saclay, France

The primordial power spectrum describes the initial perturbations in the Universe which eventually grew into the large-scale structure we observe today, and thereby provides an indirect probe of inflation or other structure-formation mechanisms. Here, we introduce a new method to estimate this spectrum from the empirical power spectrum of cosmic microwave background (CMB) maps. A sparsity-based linear inversion method, coined PRISM, is presented. This technique leverages a sparsity prior on features in the primordial power spectrum in a wavelet basis to regularise the inverse problem. This non-parametric approach does not assume a strong prior on the shape of the primordial power spectrum, yet is able to correctly reconstruct its global shape as well as localised features. These advantages make this method robust for detecting

deviations from the currently favoured scale-invariant spectrum. We investigate the strength of this method on a set of WMAP 9-year simulated data for three types of primordial power spectra: a nearly scale-invariant spectrum, a spectrum with a small running of the spectral index, and a spectrum with a localised feature. This technique proves to easily detect deviations from a pure scale-invariant power spectrum and is suitable for distinguishing between simple models of the inflation. We process the WMAP 9-year data and find no significant departure from a nearly scale-invariant power spectrum with the spectral index $n_s = 0.972$. A high resolution primordial power spectrum can be reconstructed with this technique, where any strong local deviations or small global deviations from a pure scale-invariant spectrum can easily be detected.

Maximum-likelihood determination of the galaxy LF, evolution and selection function

Jonathan Loveday

University of Sussex, United Kingdom

With the creation of larger and larger galaxy redshift surveys, it is becoming more and more important to minimise systematic errors so that they do not dominate over the rapidly-shrinking random errors. One common source of systematic error in clustering analyses comes from inaccurate modelling of the radial selection function, which is required in order to generate random catalogues to correct for survey sampling effects.

In this contribution, I will describe modifications made to the joint stepwise maximum likelihood method of Cole (2011) in order to simultaneously fit the galaxy luminosity function (LF), corrected for radial density variations, and its evolution with redshift. I will present the r-band LF and evolution parameters for galaxy subsamples drawn from the Galaxy and Mass Assembly (GAMA) survey, and show how this allows random catalogues with accurate radial number densities to be produced. Finally, I will present type-dependent clustering results from GAMA.

Transformatively Taming Spatial Statistics

Mark Neyrinck

The Johns Hopkins University, USA

Cosmological spatial statistics typically start (and sometimes end) with two-

point correlation functions, or power spectra. I will show some advantages of an approach that is nearly as simple, but much more statistically powerful: splitting the information in a field into the 1-point PDF, and the spatial statistics of the Gaussianized field (i.e. the field subjected to a function, such as a logarithm, that turns its 1-point PDF more Gaussian). In the matter density field, such an operation makes features more localized in the initial power spectrum, and greatly decreases small-scale cosmic variance. In more-observable, tracer fields, on scales large enough to have small discreteness noise, this operation splits the information into the 'biasing' part (encoded in the PDF), and the essential clustering of the matter (encoded in the Gaussianized-field statistics).

Clipping the Galaxy Power Spectrum in GAMA

Fergus Simpson[1], GAMA Collaboration

Universitat de Barcelona, Spain

I will present preliminary results from a new analysis of redshift space distortions in the GAMA survey. By down-weighting the highest density regions of the galaxy field, contributions to the power spectrum from nonlinear structure are suppressed. This extends the range of scales over which perturbation theory remains valid, allowing the extraction of more cosmological information, such as the growth of structure.

How accurate are measurements of primordial non-Gaussianity parameters from large-scale structure?

Nina Roth[1] & Cristiano Porciani[2]

1. University College London, United Kingdom

2. Argelander-Institut für Astronomie, Universität Bonn, Germany

The scale-dependent galaxy bias generated by primordial non-Gaussianity (PNG) can be used to detect and constrain deviations from standard single-field inflation. The strongest signal is expected in the local model for PNG, where the amplitude of non-Gaussianity can be expressed by a set of parameters (f_{nl}, g_{nl}, ...). Current observational constraints from galaxy clustering on f_{nl} and g_{nl} assume that the others PNG parameters are vanishing. Using two sets of cosmological N-body simulations where both f_{nl} and g_{nl} are non-zero, we show that this strong assumption generally leads to biased estimates and

spurious redshift dependencies of the parameters. Additionally, if the signs of f_{nl} and g_{nl} are opposite, the amplitude of the scale-dependent bias is reduced, possibly leading to a false null detection. Finally, we show that model selection techniques like the Bayesian evidence can (and should) be used to determine if more than one PNG parameter is required by the data. This is particularly interesting in light of the next generation of galaxy and cluster surveys like eROSITA, Euclid or LSST which are expected to significantly reduce the error bars of the PNG parameters measured from galaxy clustering.

Beyond confusion: A Bayesian P(D) analysis of the Deepest Radio Survey

Jasper Wall, Tessa Vernstrom & Douglas Scott

University of British Columbia, Canada

We present a Bayesian method to estimate the count of faint radio sources from P(D) (probability of deflection) data obtained in the deepest radio survey yet. The deep count is critical in establishing the nature of faint radio sources and their role in galaxy formation. The method makes minimal assumptions on the form of the count and uses MCMC chains to perform accurate error analysis. Full large-scale simulations included clustering and resolution effects, and showed that the method is accurate and robust. We find that the source count can be constrained by P(D) data to a factor of 20 below the conventionally-defined confusion limit. With our 3-GHz deep JVLA data, this translates to a level of 50 nano-Jansky. The count obtained implies modification of current estimates of evolution of faint-source populations, and sets a hard upper limit to the sky surface-brightness contribution from faint radio sources.

Bayesian Inference for Radio Observations (BIRO) – A new technique for simultaneously estimating instrumental errors and science parameters directly from radio visibility data

Michelle Knights[1,2], Bruce Bassett[2,1,3], Oleg Smirnov[4,5], Jon Zwart[6], Iniyan Natarajan[1] & Martin Kunz[7,2]

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2. African Institute for Mathematical Sciences, South Africa

3. South African Astronomical Observatory, South Africa

4. SKA Africa, South Africa
5. Rhodes University, South Africa
6. University of the Western Cape, South Africa
7. Université de Genève, Switzerland

When creating a radio image from an interferometer, certain assumptions about instrumental errors must be made. The science extracted from the resulting image could be seriously affected by these parameters if the estimates are wrong. Additionally, accurately estimating the uncertainties on these instrumental parameters is challenging. We propose Bayesian Inference for Radio Observations (BIRO): a new technique for simultaneously estimating the instrumental and science parameters, as well as the error on these parameters, directly from the visibility data.

A popular method in radio astronomy, a standard least squares approach, is only able to obtain the best fitting parameters. However, with a Bayesian approach we can obtain the full posterior probability distribution. This means we can determine the uncertainties for all parameters and the correlations between parameters. In this talk, I will give an overview of BIRO and show a specific application for the case of estimating the pointing errors, beam parameters and fluxes of a set of sources with known positions. Even in this simple case, important correlations between the parameters arise. These correlations, if not taken into account in the uncertainty estimates, could produce biased estimates of the science parameters, such as the fluxes. I will also briefly touch on other applications of BIRO and it's feasibility for use with SKA data.

Testing the consistency of different supernova surveys

Natallia Karpenka[1], Farhan Feroz[2] & Mike Hobson[2]
1. Stockholms universitet (Stockholm University), Sweden
2. University of Cambridge, United Kingdom

SNe catalogues typically contain data from a number of different surveys. In constraining cosmological parameters, most studies perform an analysis of the full SNe catalogue. The key assumption underlying such analyses is that the different SN data-sets comprising the catalogue are mutually consistent. It is possible, however, to have some unaccounted for systematics in SN data-sets, so it is extremely important to establish whether these data-sets are mutually consistent before performing a coherent joint analysis. It is even more important for the set to be consistent if one is attempting to find "new" signatures, such as anisotropy of the cosmological expansion. I apply robust statistical tests to determine whether different SNe data-sets are mutually consistent. My preliminary studies indicate that some inconsistencies do arise in terms of the model parameter constraints derived from them.

Improved Kernel Principal Component Analysis for Supernova Photometric Classification

Emille E. O. Ishida[1] & Filipe Abdalla[2]

1. Max-Planck-Institut für Astrophysik, Germany

2. University College London, United Kingdom

The problem of supernova photometric identification will be extremely important for large surveys in the next decade. In a previous investigation (Ishida & de Souza, 2013, presented in the XXVIII IAU General Assembly under special section: Data Intensive Astronomy), we showed how the use of Kernel Principal Component Analysis (kPCA) and Nearst Neighbour algorithms were capable of photometricaly classifying supernovae with a high rate of success. In the present work, we demonstrate that the introduction of Gaussian Process Regression (GPR) in determining each light curve highly improves the efficiency and purity rates of our previous results. This is due to two crucial GPR features: (1) it provides not only a best-fit functional form but also an uncertainty over each point in the new function and (2) it allows for extrapolation beyond the domain covered by the data. Given an uncertainty around each light curve, we were able to address, to each supernova, the probability of being an Ia. Beyond that, the possibility to extrapolate the measured light curve prevents us from neglecting to classify many objects which do not have a proper epoch coverage. Consequently, the classification process was highly simplified and results were significantly improved. We present detailed comparison with our previous results and those reported in the literature, based on simulations as well as real data. The method proved to be satisfactorily efficient, providing extremely high purity rates when compared with standard algorithms, without needing any information on astrophysical properties of the local environment, host galaxy or redshift.

Cross Correlation between Astrophysical and Cosmological Datasets: Precision of Covariance Estimation and Impact on the Signal Detection Significance

Federico Bianchini

SISSA – Scuola Internazionale Superiore di Studi Avanzati, Italy

We study the statistical properties of estimators of cross-correlation between astrophysical and cosmological datasets, focusing on the case of gravitational lensing of the Cosmic Microwave Background anisotropies from Large Scale Structure. We study the impact that signal modeling and covariance estimation may have onto the signal measurement in the perspective of estimating astrophysical and cosmological parameters out of cross-correlation studies.

Information Gains from Cosmic Microwave Background Experiments

Sebastian Seehars, Adam Amara, Alexandre Refregier,
Aseem Paranjape & Joel Akeret

ETH Zurich – Eidgenössische Technische Hochschule Zürich, Switzerland

To shed light on dark energy and dark matter, a large number of experiments have been performed and combined to constrain cosmological models. Comparing these parameter constraints is crucial for finding ways to challenge existing models with observations. We present the Kullback-Leibler divergence as a measure for the differences between the posterior distributions of the model parameters from a pair of experiments. We distinguish contributions from the reduction of statistical errors and the 'surprise' corresponding to a significant shift of the parameters' central values. Applying it to a historical sequence of CMB experiments, we discuss how this technique provides a useful tool for both quantifying the constraining power of data from cosmological probes and detecting tensions between experiments.

How well can the evolution of the scale factor be reconstructed by the current data?

Sandro Vitenti[1] & Mariana Penna-Lima[2]

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2. Instituto Nacional de Pesquisas Espaciais, Brazil

Distance measurements are currently the most powerful tool to study the expansion history of the universe without assuming its matter content nor any theory of gravitation. In general, the reconstruction of the scale factor derivatives, such as the deceleration parameter $q(z)$, are computed using two different methods: fixing the functional form of $q(z)$, which yields biased estimates, or approximating $q(z)$ by a piecewise nth-order polynomial function, whose variance is large. In this presentation, we address these two methods reconstructing $q(z)$ in the redshift interval $[0.01, 1.4]$, using the Supernova Legacy Survey 3-year (SNLS3) sample and assuming only an isotropic and homogeneous universe. For this, we approximate $q(z)$ by a piecewise cubic spline function, considering 8 knots in z. The cubic spline has its third derivative discontinuous at its knots, thus, we add a Gaussian prior, with scatter given by σ, on the third derivative of $q(z)$ with respect to z for each knot. This prior allows us to vary continuously between the full 8 knots spline, $\sigma \to \infty$, and a single cubic polynomial, $\sigma \to 0$. The $q(z)$ reconstruction is overfitting dominated for large σ. On the other hand, for small σ, $q(z)$ is better constrained but biased. We estimate the coefficients of $q(z)$ using the Monte Carlo approach, where the realizations are generated considering ΛCDM as a fiducial model. We perform this analysis for different values of σ to find the best balance between variance and bias. We also compute the significance of the decelerated to accelerated expansion of the universe fitting simultaneously $q(z)$ with three nuisance parameters of the supernovae, namely, the magnitude $\mathscr{M}_B$ and the light curve parameters α and β. In this case, we use a combined likelihood of SNLS3, baryonic acoustic oscillations and Hubble function measurements, where now $z \in [0, 2.3]$.

Cosmology with photometric surveys & an update on the Dark Energy Survey

Filipe B. Abdalla

University College London, United Kingdom

I will discuss the potential cosmology we can learn from photometric redshift surveys and how these studies it will lead the way in the next few years in terms of cosmological measurements. I will give an update on the status of the Dark Energy Survey, present some preliminary results on the data and data quality taken in science verification and the status of the first year data.

Posters

Bayesian CMB foreground separation with a correlated log-normal model

Niels Oppermann[1] & Torsten A. Enßlin[2]

1. Canadian Institute for Theoretical Astrophysics, Canada

2. Max-Planck-Institut für Astrophysik, Germany

The extraction of foreground and CMB maps from multi-frequency observations relies mostly on the different frequency behavior of the different components. Existing Bayesian methods additionally make use of a Gaussian prior for the CMB whose correlation structure is described by an unknown angular power spectrum. We argue for the natural extension of this by using non-trivial priors also for the foreground components. Focusing on diffuse Galactic foregrounds, we propose a log-normal model including unknown spatial correlations within each component and cross-correlations between the different foreground components. We present case studies at low resolution that demonstrate the superior performance of this model when compared to an analysis with flat priors for all components.

A high-dimensional look at VIPERS galaxies

Ben Granett[1] & the VIPERS team

1. Istituto Nazionale di Astrofisica Brera, Italy

The VIMOS Public Extragalactic Redshift Survey (VIPERS) is targeting 100k galaxies with spectroscopy at redshifts z=0.5 to 1.2. With complementary photometric coverage from UV to IR and morphological measures from CFHTLS, this unique dataset is providing unprecedented detail on the properties of galaxies and the formation of structure at intermediate redshifts.

We investigate how galaxies in VIPERS inhabit the cosmological density field by examining the correlations across the observable parameter space of galaxy properties, local density and clustering strength. The high-dimensional analysis is made manageable by the use of group-finding and regression tools. We find that the major trends in galaxy properties can be explained by a single parameter related to stellar mass. After subtracting this trend, residual correlations remain between galaxy properties and the local environment pointing to complex formation dependencies. As a specific application of this work we build subsamples of galaxies with specific clustering properties for use in cosmological tests.

Detecting filamentary pattern in the cosmic web: method and applications

Elmo Tempel[1], Radu S. Stoica[2] & Enn Saar[1]

1. Tartu Observatoorium (Tartu Observatory), Estonia

2. Université Lille 1, France

The main feature of the spatial large-scale galaxy distribution is its intricate network of galaxy filaments. This network is spanned by the galaxy locations that can be interpreted as a three-dimensional point distribution. In my talk I give an overview about an object point process with interactions (the Bisous model) to trace and extract the filamentary network. This method works directly on the galaxy distribution and does not require any additional smoothing, it only requires fixing the scale of structures. The main advantage of our method is in its probabilistic nature. I give an example, how single realisations of the model are sensitive to noise (observational uncertainties and small number densities of galaxies). Still, averaging many realisations reduces the noise influence, and allows computation of robust statistical quantities.

Our filament finder (the Bisous model) is probabilistic in the sense that it gives us the filament detection probability field together with the filament orientation field. Using these two fields, we define the spines of the filaments and extract single filaments from the data. To trace and extract the filamentary network, we applied our model to the presently largest galaxy redshift survey, the Sloan Digital Sky Survey (SDSS). We divided the detected network into single filaments and constructed a catalogue of filaments. In my talk, I give an overview about the detected filaments in the SDSS and present some basic properties (e.g. length distribution, radial profiles) of filaments.

Using the SDSS filaments, we have studied the correlation between galaxy spin axes and filament spines. I give an brief overview, how filaments affect the orientation of galaxy spin axes.

Line-of-sight density field analysis for the WHIM search

Lauri Juhan Liivamagi

Tartu Observatoorium (Tartu Observatory), Estonia

The whereabouts of up to half of the baryons is unknown in the low-ledshift ($z<2$) universe. These are thought to be in the form of the so-called WHIM (warm-hot intragalactic matter). This gas would be slightly enriched with metals and would reside in low-density environment of the large-scale structures, such as filaments and outskirts of superclusters. It's temperature is $10^5 \ldots 10^7$ K and density $10^{-6} \ldots 10^{-4}$ cm^{-3}, making it both too ionized to effectively absorb radiation and too cool and sparse to observe the emission. So far, only a few tentative detections have been made, observing OVII absorbtion in X-ray spectra of background blazars.

Using various simulations, we have determined a rough relation between the column density of the WHIM and luminosity density of observed large-scale structures of galaxies. We analyse the line-of-sight density field profiles derived from large galaxy redshift surveys (SDSS, 2dF, 2MASS) and attempt to delineate areas where detecting the X-ray absorption in spectre of bright background objects is most probable. We also study the plausibility of using gamma-ray burst afterglows as background X-ray sources.

Learning the Gravitational Mass Density of Real Galaxies in the Absence of Training Data

Dalia Chakrabarty

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Department of Statistics, University of Warwick, United Kingdom

Learning the gravitational mass density function of a galaxy given (missing) data on some of the phase space coordinates of one or more samples of tracers in the system, is fundamentally an inverse problem. However, it is an inverse problem that is unusually difficult since it is characterised by our ignorance about the functional relation between the measurable and the sought model function. While this unknown functional relation can in principle be trained using training data, no reliable training data set may exist for an observed galaxy. In lieu of such training sets, one resorts to learning a discretised version of the gravitational mass density function, i.e. values of the function–treated as *iid*, albeit distribution-free parameters–at N chosen points in its support $\mathbf{X} \in \mathbb{R}^3$. Thus the problem is reduced to the learning of the unknown gravitational mass density vector ρ, the i-th component of which is the value of the function at the i-th chosen value of $\mathbf{X}$, namely $\mathbf{x}_i$, $i = 1, \ldots, N$. Within this paradigm, ρ is learnt by embedding it within the definition of the support of the phase space density, where the latter is invoked to write the likelihood. The phase space density is modelled as an anisotropic function of the phase space coordinates. Priors motivated by literature are used to define the posterior of the unknown distribution-free parameters, given the data. Posterior samples are taken with an adaptive Metropolis-Hastings scheme. Application to the real galaxy NGC3379 are included.

A new photometric typing technique for normal and peculiar type Ia supernovae

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2. Universidad de Chile, Chile

Although type Ia supernovae (SNe Ia) are powerful distance indicators, only a subset of them, ”normal SNe Ia”, are suitable for precise cosmology. Current and future transient surveys will routinely discover hundreds to thousands of supernovae at various redshift ranges. As their spectroscopic follow-up becomes expensive, new photometric classifiers capable of identifying peculiar objects becomes imperative. We present a new photometric classification technique capable of identifying several peculiar subsets of SNe Ia such as subluminous SNe Ia, SNe Iax and super-Chandrasekhar SNe Ia. We show that these objects present remarkably similar light-curve properties such as later maxima in all photometric filters and the absence of a secondary peak in redder filters. By performing different light-curve fits, we demonstrate that our classification methodology is a powerful technique to identify such harmful outliers and to obtain pure normal SN Ia sample for cosmological studies.

Simulation of the analysis of interferometric microwave background polarization data

Emory F. Bunn[1], Ata Karakci[2], Paul M. Sutter[3,4], Le Zhang[5], Gregory S. Tucker[2], Peter Timbie[5] & Benjamin D. Wandelt[4]

1. University of Richmond, USA

2. Brown University, USA

3. Ohio State University, USA

4. Institut d’Astrophysique de Paris, France

5. University of Wisconsin - Madison, USA

We present results from an end-to-end simulation pipeline interferometric observations of cosmic microwave background polarization. We use both maximum-likelihood and Gibbs sampling techniques to estimate the power

spectrum. In addition, we use Gibbs sampling for image reconstruction from interferometric visibilities. The results indicate the level to which various systematic errors (e.g., pointing errors, gain errors, beam shape errors, cross-polarization) must be controlled in order to successfully detect and characterize primordial B modes as well as other scientific goals.

PCA of type II SNe light-curves

Lluís Galbany[1] & and collaborators

1. Departamento de Astronomía, Universidad de Chile, Chile

We present a Principal Component Analysis (PCA) of the light-curves of a sample of more than 200 Core-collapse supernovae (SNe) from several sources, and most of them previously unpublished. We used different reference epochs in order to extract the common properties of these light-curves and searched for correlations to some physical parameters such as the burning of Ni56, amount of Hydrogen, and morphological parameters such as the length of the plateau, the stretch or the light-curve, and the decrements in brightness after maximum and after the plateau. We also used these similarities to produce SNe II light-curve templates that will be used in the future for standardize these objects and determine cosmological distances.

Cosmological Constraints from the Anisotropic Clustering Analysis using BOSS DR9

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Our observations of the Universe are fundamentally anisotropic, with data from galaxies separated transverse to the line of sight coming from the same epoch while that from galaxies separated parallel to the line of sight coming from different times. Moreover, galaxy velocities along the line of sight change their redshift, giving redshift space distortions. We perform a full two-dimensional anisotropy analysis of galaxy clustering data, fitting in a substantially model

independent manner the angular diameter distance DA, Hubble parameter H, and growth rate dδ/dlna without assuming a dark energy model. The results demonstrate consistency with ΛCDM expansion and growth, hence also testing general relativity. We also point out the interpretation dependence of the effective redshift z_{eff} , and its cosmological impact for next generation surveys.

Precision growth index using the clustering of cosmic structures

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3. Aristotle University of Thessaloniki, Greece

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5. National Observatory of Athens, Greece

In order to test the validity of General Relativity (GR) on cosmological scales, it has been proposed that measuring the so called growth index, γ, could provide an efficient way to discriminate between scalar field dark energy models which admit to general relativity and modified gravity models. Using the clustering properties of the Luminous Red Galaxies and galaxy clusters we attempt to place tight constraints on the growth index γ and thus testing possible departures from GR.

Compressed Convolution

Franz Elsner[1] & Benjamin D. Wandelt[2]

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2. Institute d'Astrophysique de Paris, France

I present the concept of compressed convolution, a technique to convolve a given data set with a large number of non-orthogonal kernels. In typical applications the method drastically reduces the effective number of computations. It is based on linear compression of the collection of kernels into a small number of coefficients in an optimal eigenbasis. The final result can then be decompressed in constant time for each desired convolved output.

The algorithm is fully general, applicable to convolutions with symmetric and asymmetric kernels, and can be easily controlled for an optimal tradeoff between speed and accuracy. I give explicit examples in the context of simulation challenges for upcoming multi-kilo-detector cosmic microwave background (CMB) missions. For a CMB experiment with O(10,000) detectors with similar beam properties, I demonstrate that the algorithm can decrease the costs of beam convolution by two to three orders of magnitude with negligible loss of accuracy.

Cross-correlating photometric and spectroscopic surveys

Martin B. Eriksen

Universiteit Leiden, Netherlands

This talk discuss how to constrain cosmological models with the combination of spectroscopic and photometric galaxy surveys. On one hand, the photometric survey measures 2D Weak Lensing (WL) information from galaxy shape distortions and 2D clustering information from galaxy number density counts, including magnification. On the other hand, the higher redshift precision of an spectroscopic survey allows measurements of redshift space distortions (RSD) from 3D galaxy clustering counts. Here the theoretical constraints that could be obtained from a complete tomographic analysis of 2D cross-correlations in narrow ($\delta z \simeq 0.01$) redshift bins, including the exact contributions (of RSD, BAO, WL shear and magnification) for combining 2D photometric and 3D spectroscopic galaxy populations including all error covariances. In this talk we first study the effect of the Limber approximation, RSD and Baryon Acustic Oscillations in narrow redshift bins. Second we present forecast of combined photometric and spectroscopic samples, focusing on the benefit of overlapping surveys. Last, we comment on the sensitivity to the galaxy bias.

Understanding Cosmological Measurements with a Large Number of Galaxy Mock Catalogues.

Marc Manera[1] & collaborators of the BOSS galaxy working group

1. University College London, United Kingdom

Mock galaxy catalogues are essential to the analysis of cosmological measurements from big galaxy surveys covering thousands of degrees of the sky, like BOSS, WiggleZ, DES or Euclid. In my talk I will introduce the 1600 mock galaxy catalogues created for the analysis of BOSS survey data. I will explain how we have used them for producing covariance matrices, characterising the different galaxy clustering estimators,and understanding and correcting for systematic errors. I will also comment on the error budget and error propagation when using likelihood analysis from mocks. Finally, I will present some of the challenges that the new and ongoing surveys like DES bring in terms data analysis and management.

For further information see papers from BOSS collaboration,specially, Manera et al. 2013&2014, Percival et al. 2013, and Anderson et al. 2014.

Searching for non-Gaussianity in the Planck data

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2. Observatorio Nacional, Brazil

The statistical properties of the temperature and polarization anisotropies of cosmic microwave background (CMB) radiation and of the large-scale structure of the Universe offer a powerful probe of the physics of the early universe. It is conceivable that no single statistical estimator can be sensitive to all forms and levels of non-Gaussianity that may be present in observed CMB data. In recent works a statistical procedure based upon the calculation of the skewness (S) and kurtosis (K) of the patches of CMB sky-sphere has been proposed and used and use to examine the large-angle deviation from Gaussianity WMAP maps [PRD 79, 063528 (2009); PRD 81, 063533 (2010); PRD 85, 023522 (2012)]. We address the question as to how the our analysis of Gaussianity of WMAP maps is modified if the foreground-cleaned Planck maps are used. As the foreground is cleaned through different component separation procedures, each of the resulting Planck maps is tested for Gaussianity. We determine quantitatively the effects for Gaussianity of masking the foreground-cleaned Planck maps with the INPMASK, VALMASK and U73 Planck masks. We show that although the foreground-cleaned Planck maps present significant deviation from Gaussianity of different degrees when the less severe INPMASK and VALMAKS are used, they become consistent with Gaussianity as detected by one of our indicator, S, when masked with the union mask U73. A slightly smaller consistency with Gaussianity is found when the K indicator is employed, which seems to be associated with large-angle anomalies reported the Planck team. The results of our analyses provide important information about the suitability of the foreground-cleaned Planck maps as Gaussian reconstructions of the CMB sky.

The impact of superstructures in the Cosmic Microwave Background

Stéphane Ilic[1], Mathieu Langer[2] & Marian Douspis[2]

1. IRAP – Institut de Recherche en Astrophysique et Planétologie, Toulouse, France

2. IAS – Institut d'Astrophysique Spatiale, Orsay, France

In 2008, Granett et al. claimed a direct detection of the integrated Sachs-Wolfe (iSW) effect by a stacking approach of patches of the CMB at the positions of identified superstructures. However, the high measured amplitude of the effect seems to be at odds with predictions from the standard model of cosmology. The limited number of structures used might also raise concerns over the statistics of such extreme objects. I first revisited this study with a new protocol, completed and associated with a thorough variety of statistical tests to check the significance of these results – particularly difficult to assess and subject to possible selection bias. After extending the study to other, larger catalogues of structures, my new results suggest there the presence of a signal more consistent with theory, albeit with moderate significance. Multiple questions arise from these results and their expected value : this led me to propose an original theoretical prediction of the iSW effect produced by such superstructures. I use simulations based on GR and the LTB metric to reproduce cosmic structures and predict their exact full theoretical iSW effect. Expected amplitudes are consistent with the measured signal ; however the latter shows non-reproducible features that are hardly compatible with LCDM predictions.

Combining cluster counts and galaxy angular correlation functions : forecasts for the Dark Energy Survey

Fabien Lacasa & Rogerio Rosenfeld

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In the course of its 5-year observation of the southern sky, the Dark Energy Survey (DES) is forecast to detect ~ 300 millions galaxies and thousands clusters up to redshift ~ 1.3, with photometric redshift determinations. This will enable unprecedented studies of galaxy clustering and cluster constraints on cosmology. I will show ongoing work to combine these two probes to reach tighter cosmological constraints. The halo model can be used to model

the cross covariance between cluster counts and galaxy power spectrum (or real-space correlation function), and I will introduce a diagrammatic method to compute easily the different terms implied and have a simple representation. Furthermore I will show how the Gram-Charlier series can be used to compute the joint likelihood of cluster counts and galaxy power spectrum, a likelihood which is highly non-Gaussian due to the Poissonian character of cluster counts. I will conclude with forecasts of cosmological constraints achievable by DES with this method.

Data Rich Astronomy: Mining Sky Surveys

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1. INAF-Astronomical Observatory of Capodimonte, Italy

2. Department of Physical Sciences, University Federico II, Italy

In the last decade a new generation of telescopes and sensors has allowed the production of a very large amount of data and astronomy has become a data-rich science. New automatic methods largely based on machine learning are needed to cope with such data tsunami. We present some results in the fields of photometric redshifts and galaxy classification obtained using the MLPQNA algorithm available in the DAMEWARE (Dat Mining and Web Application Resource) for the SDSS galaxies (DR9 and DR10) paying special attention to the so called “catastrophic outliers”.

Adapting Predictive Models For Cepheid Variable Star Classification Using Linear Regression And Maximum Likelihood

Ricardo Vilalta[1], Vicken Asadourian[1], Kinjal Dhar Gupta[1] & Lucas Macri[2]

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2. Texas A&M University, USA

We describe an approach to automate the classification of Cepheid variable stars into two subtypes according to their pulsation mode. Automating such classification is relevant to obtain a precise determination of distances to nearby galaxies, which in addition helps reduce the uncertainty in the current expansion of the universe. One main difficulty lies in the compatibility of models trained using different galaxy datasets; a model trained using a training dataset may be ineffectual on a testing set. A solution to such difficulty is to

adapt predictive models across domains; this is necessary when the training and testing sets do not follow the same distribution. Automatically classifying variable stars is a prime example of such a scenario, because switching from one galaxy dataset to another inevitably carries a sample bias due to our limitation to observe faint stars; as the distance to a galaxy increases, our star sample will inevitably concentrate on higher-luminosity stars. Additionally, a noticeable displacement across datasets is to be expected along Apparent Mean Magnitude.

The gist of our methodology is to train a predictive model on a nearby galaxy (e.g., Large Magellanic Cloud), followed by a model-adaptation step to make the model operable on other nearby galaxies. We follow a parametric approach to density estimation by modeling the training data (anchor galaxy) using a mixture of linear models. We then use maximum likelihood to compute the right amount of variable displacement, until the testing data closely overlaps the training data. At that point, the model can be directly used in the testing data (target galaxy). Our approach differs from previous work in the probabilistic model used to characterize the Cepheid variable star population; we favor a linear model that more closely resembles the distribution of Cepheid variable stars. Experimental results with several galaxy datasets show the effectiveness of our approach.

Semi-analytical Study on the Generic Degeneracy for Galaxy Clustering Measurements

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Future galaxy surveys will provide new opportunities to verify the current standard cosmological model, and also to constrain modified gravity theories invoked to explain the present accelerated expansion of the universe. From the galaxy power spectrum in redshift space, we derive semi-analytical results on the generic degeneracy of galaxy clustering measurements. Defining the observables $\bar{A} = Gb\delta_{\mathrm{m},0}$ and $R = Gf\delta_{\mathrm{m},0}$, (being G the growth function, b the bias, f the growth rate, and δ_m the dark matter density contrast today), we perform a Fisher matrix formalism to forecast the expected precision of these quantities for a Euclid-like survey. Among the results we found that galaxy surveys have generically a slightly negative correlation between $\bar{A}$ and $\bar{R}$, and they can always measure $\bar{R}$ about 3.5 to 4.5 times better than $\bar{A}$. Finally, we briefly present results on the precision in which galaxy surveys can measure the anisotropic stress η, based on a model-independent analysis.

Cosmography with high-redshift probes

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Cosmography is the tool that makes possible to untie the interpretation of cosmological observations from the definition of any dynamical prior. We review the constraints on the cosmographic parameter obtained using the most thorough data set ensemble available. We focus on some specific topics about the statistically based selection of the most stringent fitting expansion.

Darth Fader: Analysing galaxy spectra at low signal to noise

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Spectroscopic redshift surveys are an incredibly valuable tool in cosmology, allowing us to trace the distribution of galaxies as a function of distance and, thus, trace the evolution of structure formation in the Universe. However, estimating the redshifts from spectra with low signal-to-noise is difficult, and such data are often either discarded or require human classification of spectral lines to obtain the galaxy redshift. Darth Fader offers an automated method for estimating the redshifts of galaxies in the low signal-to-noise regime. Using a sophisticated, wavelet-based technique, galaxy spectra can be separated into continuum, line and noise components, and the lines can then be cross-correlated with template spectra in order to estimate the redshifts. Cross-matching of the identified lines then allows for a cleaning of the resulting catalogue, effectively removing the vast majority of erroneous redshift estimates and resulting in a highly pure, highly accurate redshift catalogue. Darth Fader allows us to effectively use low signal-to-noise galaxy spectra, and dramatically reduces the number of human hours required to do this, allowing spectroscopic surveys to probe deeper into the formation history of the Universe.

Biased cosmological parameter estimation with galaxy cluster counts in the presence of primordial non-Gaussianities.

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The redshift dependence of the abundance of galaxy clusters is very sensitive to the statistical properties of primordial density perturbations. It can thus be used to probe small deviations from Gaussian initial conditions. Such deviations constitute a very important signature of many inflationary scenarios, and are thus expected to provide crucial information on physical processes which took place in the very early Universe. We have determined the biases which may be introduced in the estimation of cosmological parameters by wrongly assuming the absence of primordial non-Gaussianities. Although we find that the estimation of the present-day dark energy density using cluster counts is not very sensitive to the non-Gaussian properties of the density field, we show that the biases can be considerably larger in the estimation of the dark energy equation of state parameter w and of the amplitude of the primordial density perturbations. Our results suggest that a significant level of non-Gaussianity at cluster scales may be able to reconcile the constraint on the amplitude of the primordial perturbations obtained using galaxy cluster number counts from the Planck Sunyaev-Zeldovich Catalog with that obtained from the primary Cosmic Microwave Background anisotropies measured by the Planck satellite.

Photometric classification of Supernovae from the SUDARE survey

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I will present first results from the algorithm we developed to photometrically classify the supernovae discovered by the Supernova Diversity and Rate Evolution (SUDARE). The classification outcome is compared with other methods reported in literature.

Search for bias and correlations within a Bayesian framework

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A range of Bayesian tools has become widely used for the treatment of cosmological data and parameter inference. With bigger data sets and increasing precision, tools that enable us to further enhance the accuracy of our measurements will gain importance. Here we present a Bayesian how-to for the identification of biased subsets of data as well as the search for hidden correlations in a model-independent way using as an example SN Ia data. We discuss different approaches for the identification of hidden biases and correlations and present our results on SN Ia data used for cosmological parameter estimates.

OCAAT: automated analysis of star cluster colour-magnitude diagrams for gauging the local distance scale

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Star clusters are among the fundamental astrophysical objects used in setting the local distance scale. Despite its fundamental importance, the accurate determination of the distances to the Magellanic Clouds (SMC/LMC) remains a fuzzy step in the cosmological distance ladder. The exquisite astrometry of the recently launched ESA Gaia mission is expected to deliver extremely accurate statistical parallaxes, and thus distances, to the SMC/LMC. However, an independent SMC/LMC distance determination via main sequence fitting of star clusters provides an important validation check point for the Gaia distances. This has been a valuable lesson learnt from the famous Hipparcos Pleiades distance discrepancy problem. Current observations will allow hundreds of LMC/SMC clusters to be analysed in this light.

Today, the most common approach for star cluster main sequence fitting is still by eye. The process is intrinsically subjective and affected by large uncertainties, especially when applied to poorly populated clusters. It is also, clearly, not an efficient route for addressing the analysis of hundreds, or thousands, of star clusters. These concerns, together with a new attitude towards advanced statistical techniques in astronomy and the availability of powerful computers, have led to the emergence of software packages designed for analysing star cluster photometry. With a few rare exceptions, those packages are not publicly available.

Here we present OCAAT, a suite of publicly available open source tools that fully automatises cluster isochrone fitting. The code will be applied to a large set of hundreds of open clusters observed in the Washington system, located in the Milky Way and the Magellanic Clouds. This will allow us to generate an objective and homogeneous catalogue of distances up to $\sim$60 kpc along with its associated reddening, ages and metallicities and uncertainty estimates.

Quantifying correlations between galaxy emission lines and stellar continua using a PCA-based technique

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We analyse the correlations between continuum properties and emission line equivalent widths of star-forming and narrow-line active galaxies from SDSS. We show that emission line strengths can be predicted reasonably well from the PCA coefficients of the stellar continuum using the “local multiple linear regression” method. Since upcoming large sky surveys will make broadband observations only, theoretical modelling of spectra will be essential to estimate physical properties of galaxies. Combined with stellar population synthesis models, our technique will help generate more accurate model spectra and mock catalogues of galaxies to be used to fit data of the new surveys. The more accurate modelling of emission lines is also expected to improve template-based photometric redshift estimation techniques. We also show that, by combining PCA coefficients from the pure continuum and the emission lines, a plausible distinction can be made between weak AGNs and quiescent star-forming galaxies. The method makes use of a support vector machine, and allows a more refined separation of active and star-forming galaxies than the empirical curve of Kewley et al.

The Stochastic gravitational wave background generated by cosmic string networks

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Cosmic string interactions often result in the formation of cosmic string loops that detach from the long string network, and radiate their energy in the form of gravitational waves. Loop production occurs copiously throughout the cosmological evolution of a cosmic string network and the superimposition of their emissions gives rise to a stochastic gravitational wave background with a characteristic shape. Computations of the this background are often based on the assumption that cosmic string networks experience scale-invariant evolution throughout their evolution. Here, we relax this assumption and demonstrate that it leads to an underestimation of the amplitude and broadness of the characteristic peak of the spectrum, that may consequently lead to inaccurate observational constraints on the cosmic string tension.

Cluster strong lensing: a new strategy for testing cosmology with simulations

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Comparisons between observed and predicted strong lensing properties of galaxy clusters have been used to claim either tension or consistency with LCDM cosmology. However, standard approaches to such cosmological tests are unable to quantify the preference for one cosmology over another. We advocate a Bayesian approach whereby the parameters defining the scaling relation between Einstein radii and cluster mass are treated as the observables. We demonstrate a method of estimating the likelihood for observing slope and intercept of this relation under the LCDM framework, using the X-ray selected $z > 0.5$ MACS clusters as a case in point and employing both N-body and hydrodynamic simulations of clusters. Besides non-radiative hydrodynamics, these simulations have been also carried out by including star formation, chemical evolution, supernovae and AGN feedback, so as to produce a realistic population of galaxy clusters. We account for the large (mock) sample-to-sample variation due to cluster lens triaxiality, within the modelling of the likelihood function. Cluster selection criteria and characterisation of the

Einstein radius are found to play as important a role as the uncertainty related to the description of star formation and feedback. The relation between triaxial cluster masses at various overdensities provide a possible alternative to the strong lensing test.

Using neural networks to estimate redshift distributions, applied to CFHTLenS and the Dark Energy Survey

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We present a novel way of using neural networks (NN) to estimate the redshift distribution of a galaxy sample. We are able to obtain a probability density function (PDF) for each galaxy using a classification neural network. The method is applied to 58714 galaxies in CFHTLenS that have spectroscopic redshifts from DEEP2, VVDS and VIPERS. Using this data we show that the stacked PDF's give an excellent representation of the true N(z) using information from 5, 4 or 3 photometric bands. Finally a brief overview of the photometric redshift in the Dark Energy survey obtained by several state of the art methods will be presented.

Hierarchical probabilistic inference of cosmic shear

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Point estimators for the gravitational lensing induced shearing of galaxy images are complicated by the presence of noise, pixelization, and model uncertainties. We present a probabilistic forward modeling approach to gravitational lensing inference that has the potential to avoid the biased inferences in most common point estimators and is practical for upcoming lensing surveys. The first part of our statistical framework requires specification of a likelihood function for the pixel data in an imaging survey given parameterized models for the

galaxies in the images. We derive the lensing shear posterior by marginalizing over all intrinsic galaxy properties that contribute to the pixel data (i.e., not limited to galaxy ellipticities) and learn the distributions for the intrinsic galaxy properties via hierarchical inference with a suitably flexible intermediate probability distribution specification. We use importance sampling to separate the modeling of small imaging areas from the global shear inference, thereby rendering our algorithm computationally tractable for large surveys. With a simple numerical example, we demonstrate the importance of the prior specification for the intrinsic galaxy properties when the data are generated from an unknown number of distinct galaxy populations with different morphological characteristics.

High cadence supernova survey with DECam

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We report the results of a novel high cadence transient survey with DECam. We have observed 90 deg2 with a cadence of two hours during 5 nights, transferred the data to the Center for Mathematical Modelling (CMM) and processed it in real time using a new pipeline we have specially developed for this purpose. Candidates were generated three minutes after each observation, allowing us to change the observational schedule in real time. We found a dozen very young SNe events, some of them spectroscopically confimed using NTT and VLT. We have collected some of the earliest light curves known of both core collapse and Type Ia supernovae, as well as a plethora of transient objets. I will discuss some progenitor constraints that can be derived from this unique data set and implications for future large field of view surveys looking for very young supernovae and shock breakout events.

Euclid Space Mission: the current sky survey

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We show the current implementation of the Sky Survey for the Euclid ESA Mission. This is a core deliverable that incorporates scientific goals and technical specifications. It demonstrates the feasibility of the mission to cover the required area within the time span of operations.

Euclid space mission: building the sky survey

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The Euclid space mission will survey 15000 sq.deg of the extragalactic sky during 6 years, with a step-stare technique. The scheduling of optimized observation sequences is constrained by the primary scientific objectives, spacecraft operations, calibration requirements and sky background. We present technical aspects of on-going work on the implementation of various survey scenarios.

How isotropic is the Universe really?

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The Copernican principle along with General Relativity leads to the Friedmann-Lemaître-Robertson-Walker metric has been incredibly successful at describing the large scale structure of our universe. Though like any hypothesis, the Copernican principle should and can be rigorously tested. On the largest scales (up to $\ell \sim 64$) there are hints that the temperature power is dipole modulated, while the significance of this signal is marginal and not without debate, if true it would imply that our universe has some preferred direction. Recent tests suggest that while the dipole modulation goes away for $\ell \geq 64$ the power still shows an asymmetry that picks the same direction of the dipole asymmetry up to $\ell \leq 600$. The significance of such claims lie at the 3σ level and are unlikely to change using only temperature data.

Statistical assesement of the relation between the inferred morphological type and the emission-line activity type of a large sample of galaxies.

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There is anecdotical evidence of galaxies with different morphologies having different dominant emission-line activity types. We present here statistical evidence of the relation between these two characteristics of galaxies for a large sample of $\sim 800,000$ galaxies from the SDSS-DR7, in the form of confidence intervals for the differences in the mean morphological type between galaxies with different activity types.

Using a standard diagnostic diagram based on emission-line ratios, we classified our large sample of galaxies according to their dominant activity type. We used the STARLIGHT code to measure the emission-line flux of all the lines seen in the spectra of the entire sample of galaxies. For our analysis, we only considered galaxies with the lines relevant to the diagnostic diagram with S/N > 3.

Also, using known relations between the broad-band colours and a concentration index of their brightness profile of subsamples of these galaxies and

their morphology classified by eye, we inferred the morphological type of the aforementioned $\sim 800,000$ galaxies.

Using the R suite of statistical analysis, we then compared the distribution of the inferred morphologies of galaxies of different dominant activity types, showing the significance of the difference in the median morphological type between the activity-type samples. We also tested the significance of the difference in the mean morphological type between all the activity-type samples using an ANOVA model with a modified Tukey test that takes into account heteroscedasticity and the unequal sample sizes. We show this test in the form of simultaneous confidence intervals for all pairwise comparisons of the mean morphological types of the samples.

VEJA - Visual Exploration Just Anywhere

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Visual data exploration is essential to the scientific process. It can provide scientific insight that blind statistical analysis cannot. Often, this visual insight is the starting point and even the guiding reference for scientific thought.

The extremely large archives produced by today's astronomical surveys and observatories, together with the Virtual Observatory standards for data interexchange and application messaging are producing a paradigm shift in the way data is explored. The tendency is becoming not to download the data to the user's workstation and explore it locally, but instead to use on-line services for querying and exploring those archives. Thus, it also becomes natural to address modern visual data exploration with on-line services. Indeed, this is becoming a reality and recent services such as *rapidgraph* and *plotly* are receiving attention from the astronomical community.

Here we present VEJA , a package for implementing an interactive visual exploration web service. VEJA is being developed as part of a course work in the Bioinformatics master at the University of Lisbon and is the result of collaboration between astronomy (SIM) and informatics (LASIGE) Centres. Although conceived for the needs of astronomers, it can be used with any kind of tabular point data. VEJA supports multiple panels with linked views for easing the exploration of multi-dimensional data sets. It currently accesses any table made available by CDS-Vizier. The plots can be annotated and published on social networks, providing a collaborative data exploration facility. Because VEJA is web based, no software besides a browser is required on the client side, thus enabling data exploration and collaboration also on mobile phones and tablets.

Pulsar data interpolation via curvlet transform and Radon transform based dedispersion

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Curvelet is a multiresolution and multidirection transform, which belong to a family, including redgelet, shearlet, physical wavelet. They all come from wavelet, adding a direction information. The algrithm of curvelet is first transform the original image into frequency doman, then use a wedge like window to split the whole frequency plane, at last take a inverse fourier transform for every window. Curvelet is proven to be the optimal sparse representation for 2-order continuous curve. We assume that pulsar data has missing data of some frequencies for filterbank. A simultaneous denoise and interpolation method is taken. A simple idea of compressive sensing is to transform the objective function to a proximate operator and solve a more simple problem. Then the non-differential l1 term can be split into two differential term. We take iterative threshold/shrinkage method to solve this problem in this work. Radon tranform is another sparse transform for pulsar data. Different from curvlet tranform, it is not multiscale or multidirection, but it is not necessary for pulsar data. The interpolation result with radon transform shows bad performance. Thus we know, radon transform is used for dectetion, not for processing, except special designed radon transform. Radon transform is an idea, or a theory frame. We can construct radon transform for integration on any continuous curve and a fast radon transform accompanied. We know that in theory pulse arrive time has a hyperbolic relationship with frequency. So we can construct a hyperbolic radon transform for pulsar data. A parabolic in original is transformed into a point in radon domain. One axis coresponding to time and another to curve bending degree, which is related to DM. So this method is a fast algrithm to find the right DM value. Once the DM is found, we can use incoorelated method to continue dedispersion.

The first analytical expression to estimate photometric redshifts suggested by a machine

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Symbolic regression is a novel methodology that was recently proposed to automatically search for underlying analytical laws in data (Schmidt, 2009). Its importance has been highlighted into astronomy by Graham et al., (2013), and this work is the first attempt to use it in a cosmological context. To demonstrate the potential of machine proposed analytical relations in providing simple and reliable photo-z estimates, we applied the aforementioned method to derive an analytic expression for photometric redshift (photo-z) determination from Sloan Digital Sky Survey 10th data release (SDSS-DR10, Ahn et al., 2013).

We report the first analytical expression purely constructed by a machine to determine photometric redshifts ($z_{\rm phot}$) of galaxies. A simple and reliable functional form is derived using $41,214$ galaxies from the SDSS-DR10 spectroscopic sample. The method automatically dropped the u and z bands, relying only on g, r and i for the final solution. Applying this expression to other $1,417,181$ SDSS-DR10 galaxies, with measured spectroscopic redshifts ($z_{\rm spec}$), we achieved a mean $\langle (z_{\rm phot} - z_{\rm spec})/(1+z_{\rm spec})\rangle \lesssim 0.0086$ and a scatter $\sigma_{(z_{\rm phot}-z_{\rm spec})/(1+z_{\rm spec})} \lesssim 0.045$ when averaged up to $z \lesssim 1.0$. This is the first use of symbolic regression in cosmology, representing a leap forward in astronomy-data-mining connection.

Entropy in universes evolving from initial to final de Sitter eras.

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This work studies the behavior of entropy in recent models of cosmic evolution that start with an initial de Sitter expansion phase, go through the conventional radiation and matter dominated eras to be followed by a final and everlasting de Sitter expansion. In spite of their seemingly similarities (from the observational viewpoint they are arbitrary close to the conventional Lambda-CDM model), different models deeply differ in their underlying physics. Our study reveals that thermodynamic equilibrium is approached in the last de Sitter era. This happens in the sense that the entropy of the apparent horizon plus that of matter and radiation inside it increases and is concave. Accordingly, this class of models is thermodynamically correct. Cosmological models that do not approach equilibrium at the last phase of their evolution appear in conflict with the second law of thermodynamics. [Based on the Ref: Phys.Rev. D87 (2013) 047302]

A Lemaitre-Tolman-Bondi Void Imprinting the Cosmic Microwave Background Cold Spot

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The Cold Spot, one of the most significant of anomalies in the Cosmic Microwave Background, could be of primordial origin or caused by a foreground structure. The recently constructed WISE-2MASS all-sky infrared catalogue has an underdensity in the direction of the Cold Spot with an angular size 10's of degrees, and as deep as $\delta \simeq -0.16$ in the center. We show that a spherical Lemaitre-Tolman-Bondi (LTB) void model with a novel profile can simultaneously fit the underdensity in the WISE-2MASS catalogue and the Cold Spot as observed by the Wilkinson Anisotropy Probe and *Planck* satellites. Thus an LTB supervoid is a prime candidate for an explanation of this anomaly, while a texture model gives a poor fit of the Cosmic Microwave Background profile. When the galaxy bias measured from the large scale angular power spectrum is taken into account, a simultaneous three parameter fit for the void model and the temperature profile gives $z = 0.21$ for the redshift of the supervoid, $r_0 = 235h^{-1}Mpc$ for the size of the void, and $\delta_0 = -0.11$ for the depth of the void. These parameters fit from the projected data alone are in excellent agreement with the results of Szapudi et al. 2014, who used photometric redshifts from Pan-STARRS1 for direct tomographic imaging of the void.

Sparse Inpainting and Isotropy

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Sparse inpainting techniques are gaining popularity as a tool for cosmological data analysis, in particular for handling data with masked regions or missing observations. We investigate here the relationship between sparse inpainting techniques using the spherical harmonic basis as a dictionary and the isotropy properties of cosmological maps, as for instance those arising from cosmic microwave background (CMB) experiments. In particular, we investigate the possibility that inpainted maps may exhibit anisotropies in the behaviour of higher-order angular polyspectra. We provide analytic computations and simulations of inpainted maps for a Gaussian isotropic model of CMB data, suggesting that the resulting angular trispectrum may exhibit small but non-negligible deviations from isotropy.

The halo mass of GAMA galaxy groups from maximum-likelihood weak lensing

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We present a maximum-likelihood weak lensing analysis of the mass distribution in optically selected Galaxy Groups (G3Cv1) in the Galaxy And Mass

Assembly (GAMA) survey, using background SDSS galaxies. The scaling of halo mass, Mh, with various group observables is investigated. Our main results are: 1) the measured relations of halo mass with group luminosity, virial volume and central galaxy stellar mass, $M_\star$, agree very well with predictions from mock group catalogues constructed from a GALFORM semi-analytical galaxy formation model; 2) the measured relations of halo mass with velocity dispersion and projected half-abundance radius show weak tension with mock predictions, hinting at problems in the mock galaxy dynamics and their small scale distributions; 3) the median $Mh|M_\star$, which can be measured using weak lensing, depends more sensitively on the dispersion in $M_\star$ at fixed Mh than it does on the median $M_\star|Mh$. Our measurement suggests an intrinsic dispersion of $\sigma log(M_\star) \sim 0.15$; 4) Comparing our mass estimates with those in the catalogue, we find that the G3Cv1 mass can give biased results when used to select subsets of the group sample. Of the various new halo mass estimators that we calibrate using our weak lensing measurements, group luminosity is the best single-proxy estimator of group mass.

Sizes and Magnitudes in Weak Gravitational Lensing

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Light from distant galaxies is continuously deflected by the gravitational field of intervening large-scale density inhomogeneities in the Universe on its way to Earth. This weak gravitational lensing results in distortions in the projected images of galaxies on the sky, modifying their shapes (cosmic shear), sizes and magnitudes (through the convergence field) at the % level. The intrinsic shape, size or flux of an observed galaxy is not known a priori, so the lensing effect is detected statistically.

Traditionally, the statistic of choice has been cosmic shear. However, other effects such as the magnification of sizes and magnitudes can be used to add statistical power. Furthermore, each observable is subject to its own set of observational and theoretical systematic effects. This provides very strong motivation for developing a number of independent probes, each suffering from different systematic effects.

In this work we compute the additional information in sizes and magnitudes of individual sources in addition to galaxy shapes. This question neatly splits into two parts: firstly, we explore how well we can (statistically) determine the convergence field from sizes and magnitudes given their intrinsic distribution; we measure the joint distribution of galaxy sizes and magnitudes in CFHTLenS data and find that expect to recover the convergence with an effective dispersion of 0.7 per galaxy; secondly, we show that considerable gains may be possible from combining size and magnitude information with a cosmic shear analysis. Neglecting systematic errors, we find a 30% improvement in the Dark Energy Figure of Merit. In a more optimistic scenario, including intrinsic alignments for shear (but neglecting intrinsic size-magnitude correlations) the FoM is increased by as much as 80%, from the same data.

The Gaia archive: delivering the promise of Gaia

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5. European Space Agency – ESTEC

ESA's Gaia mission is the next European breakthrough in Astronomy, a cornerstone mission launched in december 2013 aimed at producing the most accurate 3D map of the Milky Way. The resulting census of our Galaxy will represent a giant leap in astrometric accuracy, complemented by the only full sky homogeneous photometric survey with angular resolution comparable to the Hubble Space Telescope, as well as the largest spectroscopic survey ever undertaken. Its scientific bounty will be immense, not only unravelling the formation history and evolution of our Galaxy, but also providing precise and accurate calibrations of the cosmic distance ladder, revealing and classifying thousands of extra-solar planetary systems, minor bodies within our solar system and millions of extragalactic objects - including about a million quasars.

In this context, to support the main goals of Gaia the archive must be able to answer complex questions involving the analysis of more than one billion sources that will comprise one petabyte at the end of the mission. But what makes this archive unique is that beyond its size it will also be intricately interrelated: no other survey exists or is planned which delivers all sky astrometry, photometry and spectroscopy.

The Gaia archive is being designed largely through science requirements gathered from the astronomical community. Accordingly, its structure covers from detailed documentation to visualization, passing through management, the actual architecture and development, data validation, operation and services, education and outreach and science enabling applications.

In this poster we will present an overview of the planned Gaia data releases and the near term archive structure with its functionalities, specially emphasizing the first two data releases planned for end-2015 and mid-2016. Finally, we will also present a glimpse of what might be available in the archive by the time the final catalogue is ready, seven years from now.

1-point Statistics of Reionization

Catherine A. Watkinson & Jonathan R. Pritchard

Imperial College London, United Kingdom

Much attention to date has been focussed on the power spectrum of the 21-cm brightness temperature during reionization; I will discuss several potentially useful signatures exhibited by the simpler and more easily measured 1-point statistics. To do so I shall consider a selection of semi-analytical simulations that each model different physical processes that may have occurred during reionization such as, [1] the clumping of LLS and residual neutral hydrogen that we expect to see embedded in large-scale ionized bubbles forged by the collective radiation of galaxy clustering, and [2] spin-temperature fluctuations resulting from the inhomogeneous heating of the IGM. We will see how even the current generation of radio telescope should be able to provide insight into the nature and timing of reionization using 1-point statistics.

Weak Gravitational Lensing with Future Radio Surveys

Prina Patel

University of the Western Cape, South Africa

Weak gravitational lensing is a promising cosmological probe with future radio surveys with upcoming radio facilities such as eMERLIN, LOFAR and eventually the SKA. Since weak lensing has up till now primarily been in the optical domain, exploration of it's feasibility through simulations has recently begun. In this talk I highlight the reasons why radio weak lensing is

an attractive cosmological prospect and also why it has several advantages over it's optical counterpart. I shall also describe a weak lensing simulation pipeline that we have begun to develop and how we have used it to begin exploring the problem of shape measurement with radio interferometric data. In light of the vastly improved data rate capabilities of future radio interferometers I also describe potential issues that need to be considered for the future radio surveys.

Extreme-Value Statistics for Testing Dark Energy

Simone Aiola

University of Pittsburgh, USA

The accelerated expansion of the universe leaves an imprint in the cosmic microwave background temperature fluctuations on large angular scales, known as the late-time integrated Sachs-Wolfe Effect. A detection of this signal has been claimed at 4.4-sigma significance by stacking temperature patches aligned with superstructures identified in the Sloan Digital Sky Survey. Recently, several authors have argued that this strong detection is in tension with the standard Lambda-CDM model at more than a 3-sigma level. I will present estimates of the expected signal by computing extreme-value statistics on Gaussian random realizations of the microwave sky temperature fluctuations. Such simulations include the effect of anisotropies on small angular scales as well as the correlations between various temperature components, and are simpler to construct and interpret than models of the signal based on large-scale structure simulations. I will also discuss prospects for using extreme-value statistics with weak lensing of the microwave background, and for constraining properties of dark energy.

The Needlet CMB Trispectrum

Antonino Troja[1], Domenico Marinucci[2], Simona Donzelli[3] & Davide Maino[1]

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The Inflationary models describe the dynamics of the first instants of the Universe. Each model introduces a characteristic track of non-Gaussianity into the anisotropy distribution of the Cosmic Microwave Background (CMB)

radiation. The amount of non-Gaussianity is parametrized by the constants f_{NL} and g_{NL}. Constrain f_{NL} and g_{NL} then means constrain the inflationary models. f_{NL} and g_{NL} parametrize also the amplitude of the bispectrum and trispectrum of the anisotropy distribution, that are the harmonic counterpart of the 3-point and 4-point correlation function. Although there exist several optimal bispectrum estimators that allowed to evaluate f_{NL} with high confidence, the lack of an optimal trispectrum estimator prevented the evaluation of strong contraints on g_{NL}. I derived for the first time an optimal estimator for the trispectrum based on the Fourier transform on the sphere, using in particular the Spherical Needlets system. Spherical Needlets are a wavelet system on the sphere whose property make them the closest system to the Spherical Harmonics, i.e. the orthonormal basis of the functions defined on the sphere, and improve the statistics in presence of incomplete maps with respect to the Spherical Harmonics. Moreover, I implemented a software able to calculate the trispectrum on CMB data. The software will be applied on Planck data. It should allow to compute the amplitude of g_{NL} with a statistical precision never achieved before in order to put strongest constraints on the inflationary scenarios.

Evidence for a Lower Value for H_0 from Cosmic Chronometers Data

Vinicius C. Busti[1], Chris Clarkson[1] & Marina Seikel[2,1]

1. University of Cape Town, South Africa

2. University of Western Cape, South Africa

An intriguing discrepancy emerging in the concordance model of cosmology is the tension between the locally measured value of the Hubble rate, and the global value inferred from the cosmic microwave background (CMB). This could be due to systematic uncertainties when measuring H_0 locally, or it could be that we live in a highly unlikely Hubble bubble, or other exotic scenarios. We point out that H_0 can be found by extrapolating $H(z)$ data points at high-z down to $z = 0$. By doing this in a Bayesian non-parametric way we can find a model-independent value for H_0. We apply this to 19 measurements based on differential age of passively evolving galaxies as cosmic chronometers. We find $H_0 = 64.9 \pm 4.2$ km s^{-1} Mpc^{-1} (1σ), in agreement with the CMB value, but reinforcing the tension with the local value. An analysis of possible sources of systematic errors shows that the stellar population synthesis model adopted may change the results significantly, being the main concern for subsequent

studies. Forecasts for future data show that distant $H(z)$ measurements can be a robust method to determine H_0, where a focus in precision and a careful assessment of systematic errors are required.

Cosmic Infrared Background (CIB) anisotropies with Planck and their correlation with Large Scale Structures

Paolo Serra[1] on behalf of Planck Collaboration

1. Institut d'Astrophysique Spatiale, Orsay, France

The power spectrum of Cosmic Infrared Background (CIB) anisotropies is sensitive to the link between star formation and dark matter halos over the entire cosmic star formation history. We present a model that associates star-forming galaxies with dark matter halos and their sub-halos and that has been used by the Planck collaboration to interpret the latest (2013) accurate measurements of the CIB power spectra at all scales. We discuss constraints on the cosmic star formation history, cosmic dust evolution and dark matter - galaxy bias. We finally present results from the cross-correlation of CIB sources with other tracers of the dark matter field.

Methods of Cosmological Models Selection

Wlodzimierz Godłowski[1], Marek Biesiada[2] & Zong-Hong Zhu[3]

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2. Department of Astrophysics and Cosmology, Institute of Physics, University of Silesia, Poland

3. Department of Astronomy, Beijing Normal University, China

One of the crucial problem of modern observational cosmology is the problem of discrimination between different cosmological models. This difficulty, called as the degeneracy problem is that many different scenarios are compatible with the present day observations. To solved this problem we use the combined analysis of astronomical data like supernovae type Ia (SNIa) data, Fanaroff-Riley type IIb (FRIIb), Radio Galaxy (RG) data, baryon oscillation peak and cosmic microwave background radiation (CMBR) We use the Akaike and Bayesian information criteria of model selection as well as evidence and information entropy to overcome this degeneracy and to determine a model with such a set of parameters which gives the most preferred fit to the data. Moreover we show that different cosmological models give different predic-

tions for value of parameters like for example $\Omega_{m,0}$. These value could be compared with independent astrophysical measurements and as results they also could be used for discrimination between models.

X-ray cross-correlation analysis of low-mass X-ray binary 4U 1636-53

Yajuan Lei

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With Rossi X-ray Timing Explorer data, we analyze the cross-correlations of the soft and hard X-rays of the atoll source 4U 1636-53. The results show that the cross-correlations evolve along the different branches of the color–color diagram. The cross-correlations of two atoll sources 4U 1735-44 and 4U 1608-52 have been studied in previous work. We compare the results of 4U 1636-53 with those of 4U 1735-44 and 4U 1608-52.

Shape estimation for Košice, Almahata Sitta and Bassikounou meteorites

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3. Lomonosov Moscow State University, Institute of Mechanics, Russia

Each meteorite sample can provide data on chemical and physical properties of interplanetary matter. The set of recovered fragments can give additional insights into the history of the parent asteroid. A reliably estimated meteoroid shape is a valuable input parameter for for the atmospheric entry scenario, since the pre-entry mass, terminal meteorite mass, and fireball luminosity are proportional to the pre-entry shape factor of the meteoroid to the power of 3 [1]. We present a statistical approach to the estimation of meteoroid pre-entry shape [2], based on the detailed data on surviving meteorite fragments recovered on the ground. This is a continuation of our recent study on the fragment mass distribution functions for the Košice meteorite fall [3]. It is known that the brittle shattering has fractal properties similar to many other natural phenomena [4]. This self-similarity for scaling mass sequences is described by power law statistical expressions [5]. We apply the technique of scaling analysis of shapes to statistically abundant empirical data on the mass distributions for Košice, Almahata Sitta and Bassikounou meteorites.

Based on: [1] Gritsevich M. and Koschny D. 2011. Constraining the luminous efficiency of meteors. Icarus, 212(2): 877-884. [2] Oddershede L., Meibom A. and Bohr J. 1998. Scaling analysis of meteorite shower mass distributions. Europhys. Lett, 43(5): 598-604. [3] Gritsevich M., Vinnikov V., Kohout T., T'oth J., Peltoniemi J., Turchak L., and Virtanen J. 2014. A comprehensive study of distribution laws for the fragments of Košice meteorite. Meteorit. Planet. Sci. 49: 1-19, in print. [4] Lang B. and Franaszczuk K. 1986. Fractal Viewpoint of Fragmentation of the Lowicz Meteorite. Meteoritics, 21:428 [5] Oddershede L, Dimon P and Bohr J. 1993. Self-organized criticality in fragmenting. Phys Rev Lett. 71(19):3107-3110.

Insights into physical properties of meteoroids from empirical distributions of meteorite fragments

Maria Gritsevich[1,2], Vladimir Vinnikov[2], Tomáš Kohout[3,4], Juraj Tóth[5], Jouni Peltoniemi[3,1], Leonid Turchak[2] & Jenni Virtanen[1]

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5. Comenius University, Finland

This study focuses on evaluating pre-atmospheric meteoroid mass and its other properties based on the recovered meteorite fragments and observed atmospheric trajectory. Meteorite studies represent a low-cost possibility to probe cosmic matter reaching planetary surface and it complements results of sample-return missions bringing back pristine samples of the materials. As example, we study the details of the Košice meteorite fall (February 28, 2010) and derive a reliable law describing the mass distribution among the recovered fragments (Gritsevich et al. 2014). Bimodal Weibull, bimodal Grady and bimodal lognormal distributions are found to be the most appropriate for describing the Košice fragmentation process. Based on the assumption of bimodal lognormal, bimodal Grady, bimodal sequential and bimodal Weibull fragmentation distributions, we suggest that, prior to further extensive fragmentation in the lower atmosphere, the Košice meteoroid was initially represented by two independent pieces with cumulative residual masses of approximately 2 kg and 9 kg respectively. The smaller piece produced about 2 kg of multiple lightweight meteorite fragments with the mean around 12 g. The larger one resulted in 9 kg of meteorite fragments, recovered on the ground, including the two heaviest pieces of 2.374 kg and 2.167 kg with the mean around 140 g. Based on our investigations, we conclude that two to three larger Košice meteorite fragments of 500-1000g each should exist, but were either not recovered or not reported by illegal meteorite hunters. The proposed approach helps to summarize the data on existing terrestrial impacts and to formulate recommendations for further studies valuable for planetary defense.

Statistical analysis of cross-correlation samples of 3XMM-DR4 with SDSS-DR10 and UKIDSS-DR10

Yanxia Zhang[1], Yongheng Zhao[1], Xue-Bing Wu[2] & Haijun Tian[1]

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We match the XMM-Newton 3XMMi-DR4 catalog with the Sloan Digital Sky Survey (SDSS) Data Release 10. Based on this the X-ray/optical catalog, we probe the distribution of various types of X-ray emitters in the multidimensional photometric parameter space. It is found that quasars, galaxies and stars have some kind distribution rule, especially for stars. Then we cross-correlate this X-ray/optical catalog with United Kingdom Infrared Deep Sky Survey (UKIDSS) Data Release 10, obtain a X-ray/optical/near-infrared catalog. The result shows that the dominant soft-X-ray-source population is relatively nearby coronally-active stars while the hard-X-ray-source population remains uncertain considering the known classes of accreting and non-accreting systems.

Data-mining based expert platform for the spectra inspecting

Haijun Tian, Yang Tu, Yanxia Zhang, Yongheng Zhao & Xuelei Chen

National Astronomical Observatory, China

With the surveys ongoing, such as LAMOST, Pan-STARRS1, etc., more and more spectra are collected, which are critically important for the scientific research. However, except the good qualified data, there still exist many “unknown” spectra. Usually most of these spectra are normal objects with low SNR, which can not be classified by the automated pipeline. These parts of data should be integrated of the survey. Moreover, some important new discoveries are probably hided in these data. Therefore, we should not give up

these seemingly discarded data. How to handle these data is one of the biggest challenges to the modern statistics and data mining techniques. If the SNR of spectra are too low to be processed automatedly, we must motivate experts to inspect them by eye. Due to a large amount of such spectra generated continuously by the survey, it will take much time and efforts to check these spectra one by one.

We propose a scheme aiming to set up a platform to efficiently manage these datasets and assist the experts to inspect the spectra. The platform is a three-tier structure, including the database layer, data mining layer and expert layer. The key part is the data mining. Before the inspecting, the dataset will be preprocessed with various statistical and data-mining techniques. For instance, the dataset can be classified roughly according to the limited information, the best-fit templates could be found by the chi-square technique, the redshift could be estimated through dividing the spectra into multiple photometric filters, etc. All of the results from the data-ming could efficiently assist the experts. The expert layer provides an interface by which experts with different weight levels may check the spectra and give the results. Finally the system gives a more reliable result according to the experts'. The VO-enalbed client will be of diverse forms, such as Matlab-GUI, Java-application, Java-applet, etc.

Markov Chain Monte Carlo Constraints on the Evolution of the Far-IR Luminosity Function

Noah Kurinsky
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We have developed a novel Markov Chain Monte Carlo fitting software package which enables a user to combine multi-wavelength, high redshift galaxy observations with SED templates to constrain the evolutionary properties of a generic luminosity function. This is achieved through Monte Carlo simulation of galaxy populations, observed through band passes with user-defined properties. I will demonstrate the application of this program to far-infrared galaxies, particularly those observed with Herschel, and discuss how it may easily be adapted to other regimes, or used to simulate surveys conducted with future instruments, given assumed luminosity functions and SED models. The MCMC functionality and simulation aspect of this package has been written entirely in C++ and should be highly portable to other programs, and the class-based approach allows various aspects of the simulation to be modified without

interfering with the main functionality. We have also created an interactive widget written for IDL, which may also be used to modify inputs and plot outputs and run simulations through simple point and click functionality. Our hope is to share this new program with the astrostatistics community such that others with similar analyses may find use for it in their own research.

The new method of the analysis on the orientation of galaxies in structures

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2. Institute of Physics, Jan Kochanowski University, Poland

Problem of large structure formation is one of the most important problems in modern cosmology and extragalactic astronomy. Investigating the orientation of galaxies is a standard test for scenarios of galaxy formation since different theories of galaxy formation make various predictions regarding the angular momentum of galaxies. A new method of analyzing galaxy alignments in clusters proposed by Godłowski 2012 now is improved The distribution of position angles for galaxy major axes was analyzed, as well as the distribution of the two angles describing the spatial orientation of the galaxy plane, both of which provide information about galaxy angular momenta. The orientation of galaxies in groups and clusters of galaxies is discussed, and the results illustrate the dependence of alignment with respect to cluster richness. The implications for theories of galaxy formation are also discussed.

Exploring the total Galactic extinction with SDSS BHB stars

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National Astronomical Observatory, China

Aims: We use 12,530 photometrically-selected BHB stars from Sloan Digital Sky Survey to estimate, the total extinction of the Milky Way in high Galactic latitude, RV and AV in each line of sight.

Methods: A Bayesian method is developed to estimate the reddening values in the given lines of sight. Based on the most likely values of reddening in multiple colors, we are able to derive the values of RV and AV .

Results: We select 94 zero-reddened BHB stars from 7 globular cluster as the template. The reddening in the 4 SDSS colors for the northern Galactic cap are estimated by comparing the field BHB stars with the template stars. The accuracy of this estimation is around 0.01mag for the most line of sights. We also obtain $<$RV$>$ to be around 2.40 ± 1.05 and AV map with in uncertainty of 0.1mag. The results, including reddening values in the 4 SDSS colors, AV , and RV in each line of sight, are released on line. In this work, we employ an up-to-date parallel technique on GPU card to overcome the time-consuming computation. We plan to release online the C++ CUDA code used for this analysis.

Conclusions: The extinction map derived from BHB stars is highly consistent with that from Schlegel, Finkbeiner & Davis (1998). The derived RV is around 2.40 ± 1.05. The contamination probably makes the RV tend to be larger.

Automatic stellar spectral parametrization pipeline for LAMOST survey

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The LAMOST project is performing the 2nd year of its general survey. It finished its pilot survey and the 1st year generally survey with First Data Release (DR1) of more than 2.2 million medium resolution spectra as an output. One of the two main components of the project is the LAMOST Experiment for Galactic Understanding and Exploration (LEGUE) which is focusing on the formation and evolution of the Milky Way. To automated and credibly derive the intrinsic physical properties of the Galactic member stars plays a significant role between the large survey database and the good science outcomes. Thus, we developed and implemented the LAMOST stellar parameter pipeline (LASP) which is an automatic parameterization for the fundamental stellar atmospheric parameters (effective temperature, surface gravity, metallicity and radial velocity) for AFGK-type stars observed during the LEGUE survey. Based on the algorithms CFI and ULySS, by fitting the spectra, LASP executed in two stages. First we exploit CFI to quickly get a set of coarse estimations, second by using CFI results as an initial guesses, we adopt ULySS to obtain the final determined credible measurements. With using some external data set, we tested the performance of the LASP through various comparisons and validations in a serials of previous work. LASP was integrated into the LAMOST Spectra Analysis Pipeline which was combined with three modular, 2D pipeline (raw data reduction), 1D pipeline (classification) and LASP. With the LAMOST DR1, a stellar atmospheric parameters catalogue, which contains 1,085,404 stars was simultaneous released, till now this product was characterized as the largest one in the world. Considering of five years operation, further LAMOST survey will yield more than 10 million objects covering in a wider sky area and depth, this will broaden the expected Science especially for the characterization of the Galaxy with various evolutionary stages of the stars collected.

Effects of primordial magnetic fields on CMB

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The origin of large-scale magnetic field is an unsolved problem in modern cosmology. In order to overcome this problem, a possible scenario comes from the idea that these fields emerged from a small primordial field produced in the early universe. This field could lead to the observed large-scales magnetic fields but also, would have left an imprint on the CMB. In this work we summarize some statistical properties of this primordial magnetic fields on the FLRW background Universe. Then, we show the resulting magnetic field power spectrum using the gauge invariant approach in cosmological perturbation theory and we describe some effects of primordial magnetic fields on the CMB anisotropies.

ANNz2 - A new code for galaxy redshift estimation, using machine-learning methods.

Iftach Sadeh

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Large photometric galaxy surveys are increasingly becoming an important tool for exploring the large-scale structure of the universe. As such they allow the study of questions at the forefront of science, such as the nature of dark energy. The success of photometric surveys greatly depends on the ability to measure the photometric redshifts of objects (photo-zs) based on limited spectral data. A

new major version of the public photo-z estimation software, ANNz, has been developed. The new code incorporates several machine-learning methods, such as artificial neural networks, boosted decision trees and k-nearest neighbours, implemented in the TMVA software package. The different algorithms are used in concert in order to optimize the photo-z reconstruction performance, and to estimate the uncertainties of the photometric solutions. The uncertainties are further used to derive probability density functions (PDFs), in addition to the corresponding best-fit solutions. An alternative method is also used to calculate PDFs, in which the redshift region is divided into multiple bins; the PDFs are derived from the combined probabilities of an object occupying a given redshift-bin, estimated using machine-learning classification techniques. The new code is also adapted to provide solutions to general classification problems, where the different machine-learning methods are dynamically optimized and compared.

Biases on cosmological parameter estimators from galaxy cluster number counts

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The abundance of galaxy clusters is becoming a standard cosmological probe. In particular, Sunyaev-Zel'dovich (SZ) surveys are promising probes of the Dark Energy equation of state, given their ability to find distant clusters and provide estimates for their mass. However, current SZ catalogs contain tens to hundreds of objects. In this case, it is not guaranteed that maximum likelihood estimators of cosmological parameters are unbiased. In this presentation we show the study of estimators from cluster abundance for some cosmological parameters. We use the Monte Carlo approach to determine the presence of bias and its behavior with both area and depth of the survey, and the number of cosmological parameters fitted simultaneously. Our fiducial models are based on the South Pole Telescope SZ survey. Assuming perfect knowledge on mass and redshift, we obtain that some estimators have non negligible biases. For example, the bias of σ_8 corresponds to 37% of its statistical error bar when it is fitted together with the cold dark matter density parameter Ω_c and the dark energy equation of state parameter w_0. Including mass and redshift uncertainties, decreases the relevance of the bias in comparison with the error bars. Considering a joint likelihood for cluster abundance and distance priors

from the cosmic microwave background, we obtain that, in most cases, the biases are negligible compared to the statistical error bars. Finally, we compute the error bars of Ω_c, σ_8, and w_0 using Fisher matrix and profile likelihood approaches, showing that they are compatible with the Monte Carlo ones. The results of this work validate the use of the current maximum likelihood methods for cluster abundance.

Anisotropic orientations of polarisations from quasars ligth: a new statistical method and analysis

Vincent Pelgrims & Jean-Rene Cudell

IFPA, AGO Dept., Université de Liège, Belgium

We recently built a new statistical method dedicated to the study of the dispersion of polarisation vector directions coming from sparse cosmic sources. We propose to review the content of the paper Pelgrims and Cudell, 2014 (arxiv:1402.4313); namely, we will present the basis of the new method and we will discuss the results of its application to the sample of quasar polarisation measurements in optical wavelength compiled in Hutsemékers et al., 2005 (A&A, 332, 410). Using the new method, we found that the probability that the large-scale alignments of polarisation vectors are due to chance is as low as 0.003%.

The European Extremely Large Telescope: Preparing a Revolution (in Cosmology and Fundamental Physics)

Carlos J. A. P. Martins

CAUP – Centro de Astrofísica da Universidade do Porto, Portugal

The E-ELT is the top priority of European ground-based astronomy, cf. Astronet and ESFRI. In this talk I will present a very brief summary of the status of the project, and then discuss its key science drivers in the area of cosmology and fundamental physics, including some detailed forecasts of its performance. Particular emphasis will be given to the synergies between the E-ELT and other facilities, specifically ALMA, Euclid, the SKA and planned intensity mapping experiments.

Machine Learning Classification of Transient Survey Images

Bruce A. Bassett[1,2,3], Lise du Buisson[1,2,3], Navin Sivanandam[1] &
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3. South African Astronomical Observatory, South Africa

4. University of the Western Cape, South Africa

We explore various machine learning feature extraction and classification algorithms for distinguishing between objects and artifacts in automatically detected transient survey images. SDSS difference images are used to compare the strength and weaknesses of various approaches. These include PCA and LDA for feature extractions and SVM, neural networks and nearest neighbors for classifiers. Results for different approaches are reported and discussed.

Towards a better understanding of galaxy clusters

Pedro Viana

CAUP – Centro de Astrofísica da Universidade do Porto, Portugal

Clusters of galaxies are the largest gravitationally collapsed structures in the Universe. The hierarchical growth of large-scale structure also ensures they are the rarest. Further, although not all important physical processes involved in the assembly of galaxy clusters are well known, they are relatively simple astrophysical objects. All of these characteristics make clusters of galaxies excellent probes of the growth of structure in the Universe and of its large-scale evolution.

Within the next few years, several surveys of the sky will detect many thousands of galaxy clusters. The largest catalogue is expected to result from the Euclid mission. However, the accuracy with which we will be able to distinguish, for example, competing hypothesis for the cause of the present accelerating expansion of the Universe, will be limited by our understanding of the galaxy cluster catalogue selection function, systematic errors and the uncertainty in the galaxy cluster mass determinations. The combination of Euclid data with that obtained through other galaxy cluster surveys, based on the detection of the galaxy cluster signal on the X-rays (XCS and eROSITA surveys) and due to the Sunyaev-Zeldovich effect in the mm/sub-mm (SPT and

Planck surveys), can help in this respect, by enabling the cross-calibration of both the selection functions of those surveys and the mass-observable relations, unearthing possible systematic errors in the process.

We are presently developing an integrated bayesian framework that will allow for the characterization of galaxy clusters using Euclid data jointly with data gathered on other wavelengths. For the moment, data from the XMM Cluster Survey (XCS), Sloan Digital Sky Survey (SDSS) and Planck is being used. Our immediate aim is to understand better the selection functions of these catalogues, estimate the joint posterior distribution function of the most relevant cluster properties, and characterize correlations between such properties.

Detecting Particle Dark Matter Signatures via Cross-Correlation of Gamma-Ray Anisotropies and Cosmic Shear

Stefano Camera
CENTRA, Instituto Superior Técnico, Universidade de Lisboa, Portugal

Both cosmic shear and cosmological gamma-ray emission stem from the presence of Dark Matter (DM) in the Universe: DM structures are responsible for the bending of light in the weak lensing regime and those same objects can emit gamma-rays, either because they host astrophysical sources (active galactic nuclei or star-forming galaxies) or directly by DM annihilation/decay (depending on the properties of the DM particle). Such gamma-rays should therefore exhibit strong correlation with the cosmic shear signal. Here, I present recent results on the cross-correlation angular power spectrum of cosmic shear and gamma-rays produced by the annihilation/decay of Weakly Interacting Massive Particle (WIMP) DM, as well as from astrophysical sources. I show that this observable provides novel information on the composition of the extra-galactic gamma-ray background, since the amplitude and shape of the cross-correlation signal strongly depends on which class of source is responsible for the gamma-ray emission. Furthermore, I also outline how to extract the maximum information by means of a tomographic approach - namely, we bin the signal in redshift slices (thanks to cosmic shear) and energy intervals (thanks to gamma-ray detection). By performing a Fisher matrix analysis of this method, I show that future data coming from the Fermi-LAT satellite and the Dark Energy Survey will enable us to put strict constraints on the particle properties of WIMP DM - and even to detect WIMP DM signatures.

The Planck Legacy Archive: data and tools to mine the Cosmic Microwave Background

Xavier Dupac[1], et al.
European Space Agency – ESAC

The ESA Planck space telescope has recently (March 2013) released its first major dataset. It includes Cosmic Microwave Background full-sky maps, Extragalactic sources and Galactic foreground emissions. Full-sky intensity maps are released at nine frequencies (30 GHz to 857 GHz) with unprecedented angular resolution (4' for the High-Frequency Instrument dust channels) and sensitivity. In this presentation, I will explain what is in the data and how to search and process them from the Planck Legacy Archive user interface. I will also present the broader context of the Planck archive and its current and future developments, emphasizing the next major data release to come in the fall 2014 and the associated improvements to appear in the Planck Legacy Archive.

A Close Examination of CMB Mirror-Parity after Planck

Assaf Ben-David[1] & Ely D. Kovetz[2]
1. The Niels Bohr Institute, Copenhagen, Denmark
2. The University of Texas at Austin, USA

Large scale symmetries in the CMB, breaking statistical isotropy, can provide insight into pre-inflationary physics as well as the topology of the Universe. Evidence for such a symmetry, large scale mirror-parity, has been previously claimed significant in data from both WMAP and Planck. In this talk, based on the recent work arXiv:1403.2104, I revisit these claims with a careful analysis of the latest data available. The data are analyzed using statistical estimators in both harmonic and pixel spaces. These estimators are compared using tests on simulations with and without mirror-parity, and after applying various Galactic masks. The dependence of the results on arbitrary choices of free parameters is also studied. While the data indeed show significant signs of odd mirror-parity, under some circumstances, the broad study shows that given the inherent biases and the dependence on the choice of Galactic mask and other parameters, the results should not be regarded significant, and are not in tension with ΛCDM.

Multi-property Statistics for Clusters of Galaxies

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Observable properties of the massive dark matter halos that host groups and clusters of galaxies appear to be log-normally distributed about power-law mean scaling relations in halo mass. Coupling this assumption with either quadratic or cubic approximations to the halo mass function in log space, we derive closed-form expressions for the space density of groups and clusters as a function of multiple observables, as well as forms for the low-order moments of properties of observable-selected samples. Using a Tinker mass function in a ΛCDM cosmology, we show that the cubic analytic model reproduces results obtained from direct, numerical convolution at the 10% level or better over nearly the full range of observables covered by current observations and for redshifts extending to $z = 1.5$. The model provides an efficient framework for estimating effects arising from selection and covariance among observable properties in survey samples. Applications to ongoing and future X-ray, SZ and optical surveys are presented.

Reconstructing light curves from imaging observations of Hard X-ray Modulation Telescope

HUO Zhuo-Xi

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The Hard X-ray Modulation Telescope (HXMT) is a Chinese space telescope mission. As the first dedicated astronomical space telescope of China, it is scheduled for launch in the first half of 2015. The telescope will perform an all-sky survey in hard X-ray band (1 – 250 keV), a series of deep imaging observations of small sky regions as well as pointed observations. It's expected that various X-ray objects (e.g., AGNs, binaries, transients) to be detected with imaging observations, namely, the all-sky survey and imaging observations, while light curves and energy spectra of these objects are investigated through pointed observations. In this talk we will discuss the feasibility of reconstructing light curves from HXMT imaging observation directly. A conceptual pipeline design is also presented. An initial estimate is achieved through multi-energy image reconstruction, including hardness of spectra and

a static image. From the image bright sources are detected and extracted. Then precise locations and time-varying fluxes are estimated through a Kalman filter approach. High-time-resolution light curves are reconstructed by time-domain demodulation. We hope it's possible to monitor time-varying objects such as GRB, AXP and SGR in hard X-ray band with HXMT imaging observations.

Modelling Galaxy Populations in the Era of Big Data

Steven Murray, Chris Power & Aaron Robotham

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The coming decade will witness a deluge of data from next generation galaxy surveys such as the Square Kilometre Array, Euclid, etc... How can we optimally and robustly analyse these data to maximise scientific returns from these surveys? In this talk I will discuss my recent work developing both the conceptual and software frameworks for carrying out such analyses and their application to the dark matter halo mass function (Murray, Power & Robotham 2013 a,b). I will summarise what we have learned about the halo mass function from the last 10 years of precision CMB data using my open-source HMFcalc framework, before discussing how this framework is being extended to model halo occupation statistics and fast approximate schemes for synthetic galaxy surveys.

The ALHAMBRA survey: evolution of galaxy clustering since z $\sim$ 1

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We study the clustering of galaxies as function of luminosity and redshift in the range $0.35 < z < 1.25$ using data from the Advanced Large Homogeneous Area Medium Band Redshift Astronomical (ALHAMBRA) survey. The ALHAMBRA data used in this work covers $2.38 deg^2$ in 7 independent fields, after applying a detauled angular selection mask, with accurate photometric redshifts, $\sigma_z < 0.014(1+z)$, down to $I_{AB} < 24$. Given the depth of the survey we select samples in B-band luminosity down to $L^{th} = 0.16L*$ at $z = 0.9$. We mesure the real-space clustering using the projected correlation function, accounting for photometric redshift uncertainties. In addition, for galaxies with $M_B^{th} < -18.6$, we perform the analysis of the clustering evolution with segregated populations using ALHAMBRA templates, separating the population in early and late type galaxies. The high quality of ALHAMBRA photometric redshifts and the high galaxy density of the covered fields, allow us to extend the projected correlation function down to very small scales ($0.03h^{-1}$ Mpc), below any other previous calculation. We study the effect of sample variance, and confirm earlier results that the COSMOS and ELAIS-N1 fields are dominated by the presence of large structures.

New Challenges in Cosmology Posed by the Sloan Digital Sky Survey Quasar Data

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According to the Hubble Law, under the assumption of the universe being homogeneous and isotropic, the galaxies appear to be receding with a velocity v proportional to their distance d from the observer: v = H0d , where H0 is called the Hubble constant. There are two luminosity functions i.e. absolute luminosity and apparent luminosity. Normally astronomers work with absolute magnitude M and apparent magnitude m, where $d \approx m - M$ is known as distance modulus and is related to the luminosity distance. Therefore, the relation between the distance modulus and logz is considered to test Hubble law. Efron and Petrosian studied the viability of various statistical tests for truncated data in connection with redshift survey of galaxies and quasars. From the plot of redshifts zi and log luminosities (=yi) for 210 quasars they found the data to be doubly truncated data. Roy et al studied the bivariate distribution of redshift and apparent magnitude observed in Sloan Digital Sky Survey(SDSS) for quasar redshift (2005) in which the data was truncated. However, the redshift data in SDSS quasar survey of 2007 was no longer truncated. Mukhopadhayay et al (2009) discussed a general framework to study data for redshift and apparent magnitude in quasar sample and found a nonlinearity of the fitting curve for Hubble like relation. Now the intriguing issue is, for SDSS quasar data (2005) we have truncated data structure whereas for the survey of 2007 the data is no longer truncated. This calls for development or use of completely different statistical methodology to study the data for the evolution of the same objects like quasars. These two different methodologies suggest different interpretation for a particular phenomenon in nature. This leads to the issue of validation of the data. More intriguing and challenging issue crops up as, given all of the data, what can be said about the laws of physics that have been operating over the universe?

The cosmic radio dipole and local density effects

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In our work we investigate the contribution that a local over-density or under-density can have on linear cosmic dipole estimations. We focus here on radio surveys, such as the NVSS, and forthcoming surveys such as those with LOFAR and the Square Kilometre Array. The NVSS has already been used to estimate the cosmic radio dipole; it was shown recently that this radio dipole amplitude is larger than expected from a purely kinematic effect, assuming the velocity measured by the dipole in the CMB. We show here that a significant contribution to this excess could come from a local void or similar structure.

A new model to predict weak lensing peak counts

Chieh-An Lin & Martin Kilbinger

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Peak statistics from weak gravitational lensing has been shown as a promising tool for cosmology. Weak lensing peaks probe the high density, non-linear regions of the large scale structure and encompass a wealth of information on cosmology and structure formation.

Here we propose a new approach to predict weak lensing peak counts, by generating fast simulations of halos without the use of time-consuming N-body simulations. Our method can model peak counts in any cosmology, for which the halo mass function is known. Predictions can be done for peaks obtained from the linearly filtered shear field, but also for non-linear estimators of the reconstructed convergence field.

We validate our method by comparing our fast lensing simulations of halos with N-body runs. We replace identified halos with analytical NFW profiles and show that the peak abundance remained unchanged for high signal-to-noise peaks ($\gtrsim 5$). Further, randomization of the halo positions does not change the peak counts, demonstrating that halo clustering has a minor impact on weak lensing peak statistics. In addition, we compare our method to the analytical peak abundance prediction model from Fan et al. (2010).

As a preliminary result, we show that some cosmological parameters, such as σ_8, can be constrained by the abundance. The optimal combinations of parameters sensitive to our approach is under studying.

Statistical Challenges in the Photometric Calibration for the 21st Century Cosmology: The J-PAS Case

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The success of many cosmological surveys in the near future is highly grounded on the quality of their photometry. The Javalambre-PAU Astrophysical Survey (J-PAS) will image more than $8500 deg^2$ of the Northern Sky Hemisphere in 54 narrow + 2 medium/broad optical bands plus Sloan u, g and r bands. The main goal of J-PAS is to provide the best constrains on the cosmological parameters before the arrival of projects like Euclid or LSST. To achieve this goal the uncertainty in photo-z cannot be larger than 0.3% for several millions of galaxies and this is highly dependent on the photometric accuracy.

The photometric calibration of J-PAS will imply the intensive use of huge amounts of data and the use of statistical tools is unavoidable. I will present some of the key steps in the photometric calibration of J-PAS that will demand a suitable statistical approach.

Foreground Removal on LOFAR-EoR Data: First Results

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The accurate and precise removal of 21-cm foregrounds from EoR data is essential to make the first detection of this epoch. With the current generation of radio interferometers edging ever closer to a detection I will discuss how non-parametric foreground removal methods such as FASTICA and GMCA can be utilised with great success on the incoming data and showcase some of the preliminary results.

The Epoch of Reionization with LOFAR: current results and predictions

Ajinkya Patil[1], Saleem Zaroubi[1] & the LOFAR Epoch of Reionization team
1. Kapteyn Astronomical Institute, Netherlands

The Epoch of Reionization (EoR) is the epoch in which most of the neutral hydrogen in the Universe was reionized by the radiation from the first stars and galaxies. Many projects are underway to detect the EoR signal, i.e. the cosmic redshifted 21-cm signal from neutral hydrogen, using low frequency radio telescopes. I will present the current results from the Low Frequency Array (LOFAR) EoR experiment. I will show the upper limit on the EoR signal in the redshift range 6 to 11 based on analysis of 200 hours of the observed data. I will also show that the LOFAR should be able to detect the variance and power spectrum of the signal with a 3 sigma confidence with 600 hours of integration. The variance and power spectrum statistics of the EoR signal can be used to constrain the evolution of the neutral hydrogen in the Universe.

Transformed Auto-correlation

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Echo signals probably exist in the light curves of some sorts of astronomical objects, such as supernovae, x-ray binaries and AGNs etc.. If the distance between central radiator and a reflecting object is fixed, then auto-correlation can be used to detect the reflected signal and estimate the distance thereafter. However, in common situation, the nearby reflecting objects are always moving, therefore, the lags between radiated and reflected signal are variable, which means no echo signals could be detected by auto-correlation. Here, we propose a transformed auto-correlation method in which a received light curve is transformed based on a priori model, then the adjusted light curve is cross-correlated to the original one. After transformation, a small part of reflected signal and its counterpart in radiated signal have a constant lag. These lags can be removed dynamically so that a long period of signal would has a peak at zero lag in a transformed auto-correlation curve. The priori model

is parameters dependent. By searching the maximum in a series of the peak values of transformed auto-correlation curves in the whole parametric space, the real values of the parameters can be determined.

Type Ia supernova cosmology with CMAGIC

Santiago González-Gaitán
Universidad de Chile, Chile

Type Ia supernovae (SNe Ia) have been successfully used as standardizable distance indicators for cosmology providing primary evidence for the accelerated expansion of the universe. Traditional SN Ia standardization methods use the known relations between lightcurve-shape and brightness, as well as color and brightness, to correct for peak luminosity and reduce the intrinsic luminosity scatter. We present here a method based on post-maximum color-magnitude relations (CMAGIC, Wang et al. 2003, Conley et al. 2006), which reveal a linear regime where the luminosity scatter is small and the effects of host extinction by dust are less important. We apply this technique to a mutli-redshift dataset from the literature and obtain first Hubble diagrams.

Probing cosmology with Intensity Mapping of high redshift emission lines

Marta Silva & Mario Santos
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The intensity mapping technique consists in measuring the overall intensity of an emission line, at a given redshift, from galaxies and from the IGM without attempting to resolve individual sources. This method was first thought for the 21 cm line but it can also be used for measuring the intensity of other lines. Since intensity mapping experiments can cover large volumes and are able to detect the emission from even the faintest sources, out of the reach of galaxy surveys, these experiments are particularly useful for probing the nonlinear underlying density field. In this study I show how intensity maps of high redshift emission lines trace density fluctuations and what are the signatures non linearities in the mass distribution or different cosmologies leave in the power spectra of different emission lines.

Unraveling general relationships into multidimensional datasets

Rafael S. de Souza

Korea Astronomy and Space Science Institute, Korea

I will present a set of tools for mining multidimensional datasets. In particular, an application to the Millennium-II Simulation dataset, where we automatically recover all groups of linear and non-linear associations within a set of 30 parameters from thousands of galaxies. Also, I will show alternative ways to visualize general correlations and how dimensionality reduction techniques and graph theory can help us to understand the temporal evolution of galaxy properties. Finally I will give a short introduction of the recently created working group of cosmostatistics within the international astrostatistics association.

Adaptive density estimator for galaxy surveys

Enn Saar

Tartu Observatoorium (Tartu Observatory), Estonia

Galaxy number or luminosity density serves as a basis for many structure classification algorithms. Several methods are used to estimate this density. Among them kernel methods have probably the best statistical properties and aillow also to estimate the local sample errors of the estimate. We introduce a kernel density estimator with an adaptive data-driven anisotropic kernel, describe its properties and demonstrate the wealth of additional information it gives us about the local properties of the galaxy distribution.

3D-Needlets on the unit ball

Claudio Durastanti[1], Yabebal Fantayé[1], Domenico Marinucci[1] & Isaac Pesenson[2]

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2. Temple University, Philadelphia, USA

In this talk, we will present a new frame of wavelets defined on the unit ball. These wavelets, named 3D-needlets, are built following, on one hand, the construction of band-limited localized frames on compact manifolds, developed by Geller and Pesenson [2010] (see also Pesenson, 2013), and, on the other hand, the characterization of (2-dimensional) needlets on the sphere, as described in Narcowich, Petrushev and Ward [2006a,2006b]. The coordinate system chosen on the ball is the combination of the set of spherical harmonics (for the spherical coordinates) and the set of properly modified trigonometric functions (for the radial coordinate): The 3D-needlets can be viewed as the convolution of a finite linear combination of elements of this coordinate system computed on a generic point and on a set of cubature points on the ball, balanced by a suitable weight function. This framework features some relevant properties, as for instance precisely quantifiable localization in both spatial and harmonic domains, and seems to fit naturally into the experimental set-up of astrophysical observations on large scale structure. The results are illustrated both by analitycal arguments and numerical evidence. Based on joint work with Yabebal Fantaye, Domenico Marinucci and Isaac Pesenson. - Geller, D., Pesenson, I. (2010) Band-Limited Localized Parseval Frames and Besov Spaces on Compact Homogeneous Manifolds, Submitted; - Pesenson, I. (2013). ϕ-Transform on Domains. Submitted; - Narcowich, F.J., Petrushev, P. and Ward, J.D. (2006a) Localized Tight Frames on Spheres, SIAM Journal of Mathematical Analysis Vol. 38, p. 574; - Narcowich, F.J., Petrushev, P. and Ward, J.D. (2006b) Decomposition of Besov and Triebel-Lizorkin Spaces on the Sphere, Journal of Functional Analysis, Vol. 238, 2, 530.

Application of Statistical Method on Automatic Detecting Solar Active Phenomena and Analyzing Their Correlation

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Not only observational data volume from space, but also data volume from ground are tend to very high produce rate in solar physics field. So there has been an increased need to automatically detect, extract solar features and events for now and further solar active warn and prediction and to help to stream-line the process in solar physics analysis. Many of these automation methods are closely related to the statistical methods. Author investigations the extensive literatures to clarify the function of statistical methods and their advantages in detecting automatically solar features and analyzing solar active phenomena correlation. This review summarizes the results of the study, the results will be helpful to promote further automation processing for us.

Back to Normal: Gaussianizing posterior distributions for arbitrary cosmological probes

Robert Schuhmann, Benjamin Joachimi & Hiranya Peiris

University College London, United Kingdom

We present a method to map multivariate non-gaussian posterior probability densities into gaussian ones via non-linear Box-Cox transformations, and generalizations thereof. This is analogous to the search for normal parameters in the CMB, but can in principle be applied to any probability density that is continuous and unimodal. The search for the optimally gaussianizing transformation amongst the Box-Cox family is performed via a maximum-likelihood formalism; the quality can be judged a posteriori: qualitatively via statistical tests of gaussianity, and more illustratively by how well the confidence regions are reproduced. The method permits an analytical reconstruction of the posterior from a sample, e.g. a Markov chain, and simplifies the subsequent combination with other experiments. Furthermore, it allows for the reporting of a non-gaussian posterior in a compact and efficient way. The expression for the non-gaussian posterior can be employed to find analytic formulae for the Bayesian evidence, and consequently be used for model comparison.

Generic inference of inflation models by local non-Gaussianity

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In this talk a generic inference method for inflation models from observational data by the usage of higher-order statistics of the curvature perturbation is presented. This method is based on the calculation of the posterior for the primordial, local non-Gaussianity parameters $f_{\rm NL}$ and $g_{\rm NL}$, which in general depend on specific parameters of inflation and reheating models, and enables to discriminate among the still viable inflation models. To keep analyticity as far as possible to dispense with numerically expensive sampling techniques a saddle-point approximation is introduced, whose precision is validated for a

numerical toy example. The mathematical formulation is done in a generic way so that the approach remains applicable to cosmic microwave background data as well as to large scale structure data. To demonstrate the efficiency of the higher-order statistics method I present numerical toy examples of two currently interesting inflation models. Reference: arXiv:1403.5067

Reconstruction of cosmic density fields from non-Poisson statistics

Metin Ata, Francisco-Shu Kitaura & Volker Müller
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We use Hamiltonian Monte Carlo solvers, (see e.g. Kitaura et al. 2010) to reconstruct the cosmic matter density fields from simulated halo distributions in real and redshift space. To describe deviations from Poisson expectations of counts in cells, we employ the negative binominal distribution and gravitational thermodynamics in the reconstruction and a lognormal prior function of the overdensity δ. Our aim is to evaluate the local non-linear bias in relation to the cosmic web characteristics.

Testing the Equivalence Principle with MICROSCOPE: the data analysis challenge

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The Weak Equivalence Principle (WEP), which states the equality of the inertial and the gravitational masses, is a corner stone of General Relativity (GR). While it has currently been tested down to a few 10e-13, most theories of modified gravity predict its violation at a level between 10e-18 and 10e-13. Those theories may explain the accelerated expansion of the Universe without requiring dark energy. They can be tested on cosmological scales by observing large scale structures, and on laboratory scales by looking for a WEP violation. MICROSCOPE ("Micro-Satellite à trainee Compensée pour l'Observation du Principe d'Equivalence", French for "Drag-free micro-satellite for the observation of the Equivalence Principle") is a funded mission of the French space agency that aims to test the WEP in space, down to a level 10e-15. It will therefore allow us to experimentally test theories beyond GR. However, we expect a possible WEP violation signal to be buried in the noise (hence, its analysis will be statistical) and plagued by systematics; moreover, we expect to lose some data. Although we can calibrate the measurement to control instrumental systematics, the data analysis will be hampered by missing data and therefore will require advanced statistical techniques. In this talk, I will first present Microscope, with an emphasis on its links with cosmology. Then I will present the challenges that we will face to analyze its data, as well as some solutions to the challenges we are working on.

Intuitive model for 21 cm power spectrum of the epoch of reionization

Sander Bus & Saleem Zaroubi
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The epoch of reionization (EoR) is a pivotal era in the history of the universe, where the first stars and galaxies ionize their surroundings. Several teams around the globe, among which the LOFAR EoR team we are part of, are working very hard on making a detection of the EoR using the redshifted 21cm line. The first detections of the EoR will be statistical in nature. The power spectrum is a statistic which is sensitive to astrophysical processes during the EoR. In this talk, we argue that the power spectrum can be fit by a simple model that intuitively encapsulates the physical properties of the power spectrum evolution. We discuss the properties of this fit and how it can be used to learn about astrophysics during the epoch of reionization.

Sparsity based high resolution density mapping from 3D weak lensing

François Lanusse[1], Adrienne Leonard[2] & Jean-Luc Starck[1]
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2. University College London, United Kingdom

From current and next generation weak lensing surveys with photometric redshift follow up it has recently become possible to map the matter density in 3D. However, the linear methods introduced to address this complex inverse problem were limited in resolution (both angular and along the line of sight) and only produced Signal to Noise maps.

We recently proposed a new non linear, sparsity based, weak gravitational lensing technique, coined GLIMPSE, allowing us to reconstruct the 3D matter density contrast (not SNR maps) from weak gravitational lensing with high resolution. Having access to the value of the density contrast allows us to put constraints on the masses of reconstructed structures.

Tested on a large set of simulated isolated dark matter halos, we show that GLIMPSE provides a good sensitivity to clusters of virial mass above a few 10^{13} solar masses/h for a Euclid-like space-based survey. In particular, our technique proves very efficient at probing the high-mass end of the mass function ($\geq 8 \times 10^{14}$ Msol/h) as we still expect to detect above 60% of clusters at redshift 0.75. Furthermore GLIMPSE provides an unbiased estimator of the redshift of detected clusters as well as a largely unbiased estimator for the mass which can be constrained to below 5% accuracy if the actual redshift is known.

Weak lensing with size and magnitude magnification

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Light from distant galaxies is continuously deflected by the gravitational field of intervening large-scale density inhomogeneities in the Universe on its way to Earth. This so-called weak gravitational lensing results in distortions in the projected images of galaxies on the sky, modifying their shapes (cosmic shear), sizes and magnitudes (through the convergence field) at the % level. The intrinsic shape, size or flux of an observed galaxy is not known a priori, so the lensing effect on individual sources is not accessible. However, if the intrinsic distribution of these properties is known, then a weak lensing analysis can be performed at the statistical level by observing a large number of galaxies and looking for a signal through deviations in the observed distribution.

Traditionally, the statistic of choice has been cosmic shear. However, since weak lensing has other effects (such as the magnification of sizes and magnitudes) one would ideally like to use all of the available information to elicit the full statistical power of a weak lensing survey. Furthermore, each of the weak lensing observables comes with its own set of observational and theoretical hurdles; systematic effects are rife in any weak lensing analysis and this is one of the major challenges in the field. This provides very strong motivation for developing a number of independent probes, each suffering from different systematic effects.

In this work we are concerned with how much additional information is available from analysing the sizes and magnitudes of individual sources (probing the convergence field), in addition to galaxy shapes (cosmic shear). This question neatly splits into two parts: Firstly, we explore how well we can (statistically) determine the convergence field from sizes and magnitudes, given their intrinsic distribution. We measure the joint distribution of galaxy sizes and magnitudes in CFHTLenS data and demonstrate that with this measured intrinsic size-magnitude distribution, we could expect to recover κ with an effective dispersion of ~ 0.7. Secondly, we show that in light of these results we expect magnification to have roughly half of the signal-to-noise for cosmological parameter inference compared to cosmic shear (neglecting systematics).

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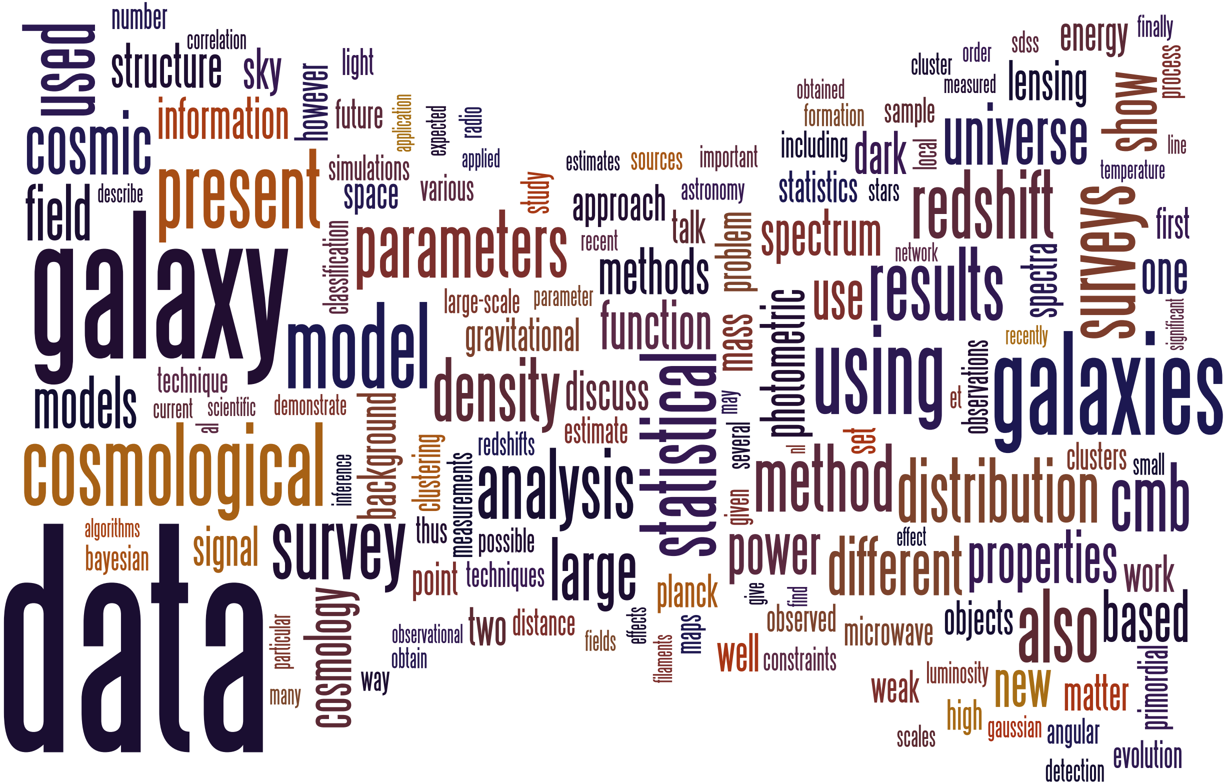
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