Curriculum Vitae et Studiorum

PERSONAL DATA

MATTEO BILLI

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Date of birth 11th July 1992| **Citizenship** Italian

ACADEMIC STUDIES

PUBLIC COMPETITIONS WON

- Ph.D. student position at the Stockholm University Physics Department with the Prof. Katherine Freese and the Dr. Jon Gudmundsson. I have refused the position for personal and family reasons.
- Ph.D. student position in Astrophysics at the University of Bologna.

THIRD CYCLE DEGREE	:	**Ph.D. IN ASTROPHYSICS**
• Date (from – to)	:	1 November 2018 – in progress (expected end: 31 January 2022)
• Name of School	:	**Università di Bologna**
• Institute providing educational and training	:	INAF-OAS Bologna
• Supervisor	:	**Dr. Alessandro Gruppuso**
• Co-supervisor	:	**Prof. Lauro Moscardini**
• Title	:	**Polarised CMB anisotropies: the search of new Physics**
• Main research topic	:	The goal of this Ph.D. thesis is to test fundamental physics through the Cosmic Microwave Background (CMB) polarised observations, in particular focusing on the Cosmic Birefringence effect and CMB anomalies..
• Research period abroad	:	15 September– 15 December 2019. Visiting student at Stockholm University, Stockholm. Research collaboration with Dr. Jon Gudmundsson and his group.
SECOND CYCLE DEGREE	:	**LAUREA MAGISTRALE IN ASTROPHYSICS AND COSMOLOGY**
• Date (from – to)	:	2015 - 2018
• Name of School	:	**Università di Bologna**
•Class	:	LM-58 Scienze dell'Universo
•Learning activities completed(90 CFU)	:	see **Attached1:** Second cycle career
•Final grade	:	**110/110 e Lode**
•Thesis (31 CFU)	:	**Supervisor: Prof. Lauro Moscardini.** **Co-supervisors: Dr. Alessandro Gruppuso, Prof. Nazzareno Mandolesi.** **Title:** Joint temperature and polarisation analyses of the lack-of-power anomaly in the CMB anisotropy pattern. **Abstract:** I employed several statistical estimators to evaluate the lack of power observed at large angular scales in the CMB anisotropy pattern as measured by the Planck satellite. Methodologically I followed a frequentist approach and included in the analysis both temperature and polarisation maps. To perform this task I have generated Monte Carlo simulations from the ΛCDM model, which, consistently with the 2015 Planck low-ell data set (available in the PLA https://www.cosmos.esa.int/web/planck/pla), do include realistic effects from the residual instrumental noise (correlated in the polarisation), beams and sky fraction. Specific estimators based on the CMB angular power spectra, were then built, tested and used on each simulated realisation and on Planck data through a code written in Python. The comparison between simulations and Planck data, was evaluated in terms of percentage of consistency. Forecasts of the proposed estimators improvement with respect to future (as the JAXA satellite LiteBIRD) or ideal CMB observations are provided as well. (https://amslaurea.unibo.it/16205/)

FIRST CYCLE DEGREE	:	**LAUREA TRIENNALE IN PHYSICS**
• Date (from – to)	:	2011 - 2015
• Name of School	:	**Università di Bologna**
•Class	:	L-30 Scienze e tecnologie fisiche
•Learning activities completed	:	see **Attached2:** First cycle career
•Final Grade	:	**105/110**
• Thesis (6CFU)	:	**Supervisor: Prof. Lauro Moscardini** **Title:** Vincoli cosmologici da Supernovae ad alto redshift **Abstract:** In this project I have constrained the cosmological parameters $\Omega_{0\Lambda}$ and Ω_{0m} through SNe Ia observations. The purpose was to reproduce the results obtained by two independent research teams in the 1998: the Supernovae Cosmology Project (SCP), lead by Saul Perlmutter, and the High-z Supernovae Search Team (Hz SN), created by Brian P. Schmidt. These research teams, through the observations of the luminosity distance and the redshift of a sample of SNe Ia in distant galaxies (with about z=0.2-0.9), were able to detect for the first time a non-null cosmological constant in the ΛCDM model, responsible for driving the accelerated expasion of the universe today. This result was worth a Nobel prize awarded in 2011 to Perlmutter, Riess and Schmidt. Furthermore I have considered an extended sample, known as SCP Union 2.1, with 580 SNe Ia, publicly released in 2011 by the SCP (see http://supernova.lbl.gov/union/). Using a chi-square statistic method, which I have implemented in a C++ code, I was then able to constrain the Ω_{0m} and $\Omega_{0\Lambda}$ in two different cases: fixing a flat geometry of the universe, and letting the geometry to vary. The outcome of this analysis was fully compatible with what is known in the literature (http://amslaurea.unibo.it/9551/).

HIGHSCHOOL DEGREE		
• Date (from – to)	:	2006-2011
• Name of School	:	Liceo Scientifico E. Fermi, Bologna
• Educational qualification	:	Diploma Scientifico
• Final grade	:	84/100

SCHOOLS, COURSES AND TALKS

SEMINARS AND TALKS

- 6 September 2021 – **Presented** talk at 11th Young Researcher Meeting 2021. Title: **"New estimators for anisotropic birefringence from CMB observations**".
- 13 April 2021 – **Presented** seminar at the Astrophysics Talk organized by INAF OAS Bologna. Title: **"New estimators for anisotropic birefringence from CMB observations**".

PH.D. COURSES

- 5-14 May 2021 – Attending the online Ph.D. course on: " **Writing, talking and presenting Science**", organized by Department of Physics and Astronomy of the University of Bologna for the Ph.D. students in Astrophysics.
- Sept-Dec 2020 – Attending the online Ph.D. course (16 hours) on: "**Introduction to theoretical cosmology with examples of data analysis**" held by Dr. Alessandro Gruppuso, organized by Department of Physics and Earth Science of the University of Ferrara for the Ph.D. students.
- 17-22 September 2020 – Attending the online Ph.D. course on: " **Gaia: Great advances in Astrophysics**", organized by Department of Physics and Astronomy of the University of Bologna for the Ph.D. students in Astrophysics.
- June 2019 – Attended the Ph.D. course " **Statistics for Astrophysics**" held by Prof. Ben Metcalf, organized by Department of Physics and Astronomy of the University of Bologna for the Ph.D. students in Astrophysics .

PH.D. SCHOOLS

- April 2021 – Attended the CMB Data School: **"ACT Data School".**
- February 2021 – Attended the SIGRAV International School 2021: "**Gravity of Compact Astrophysical Objects and Gravitational Waves**".
- February 2020 – Attended the SIGRAV International School 2020 : "**General Relativity and beyond. Astrophysics, Cosmology and Gravitational Waves"**, Vietri sul Mare, Salerno.
- March 2019 – Attended the 2019 GGI Postgraduate School: "**Theoretical Aspects of Astroparticle Physics, Cosmology and Gravitation"**, Galilelo Galileo Institute (GGI), Arcetri(FI), Italy.
- December 2018 – Attended the 12th Tonale Winter School in Cosmology 2018: "**Theory for Observers & Observations for Theorists**", Passo del Tonale, Italy.

OTHER COURSES

- September – November 2021 – **'CLA Academics: Academic English Skills (AcES)'**. Provided by 'CENTRO LINGUISTICO DI ATENEO – CLA'.
- February - May 2020 – Attended the Course 90569 (48 hours, 6CFU) - "**High performance computing for astrophysics and cosmology**", held by prof. Marco Baldi, in the Master's Degree in 'Astrofisica e Cosmologia' of the University of Bologna
- November 2017 – Attended the course on Python (12 hours): "**Learning with Python"**, organized by Department of Physics and Astronomy of the University of Bologna.

MAIN SCIENTIFIC AND DIDACTIC INTERESTS

I am very keen on computational cosmology and data analysis since I realized the strong connection between fundamental physics and observational cosmology. I have learned that to test cosmological models it is mandatory to master codes and have a good knowledge of statistical methods. During my Master and Ph.D. thesis, I acquired excellent skills on different programming languages and in statistical treatment of large amounts of data.

My research activity has mainly focused on testing fundamental physics through the Cosmic Microwave Background (CMB) polarisation observations, both from a theoretical and observational point of view. I have worked on CMB anomalies, defining a new joint estimator for the lack of power at large scale aiming at capturing information from both temperature and polarisation CMB maps. At the present, I am studying the cosmological birefringence effect, which traces parity violating extensions of the standard electromagnetism, under the supervision of Dr Alessandro Gruppuso and in collaboration with the Cosmology group of the University of Ferrara led by Prof Paolo Natoli. At the end of the 2019 I have been visiting the CMB group of Dr Jon Gudmundsson at Stockholm University where I have studied the interplay between non-idealities coming from the half-wave plates (HWP), a polarisation modulator, and the beams for forthcoming CMB missions.

Additionally, I am very charmed by the didactic aspect of the mathematics, physics and astrophysics. I was didactic tutor for the course 'LABORATORY OF DIDACTICS OF PHYSICS' in the Master's Degree in Physics at the University of Bologna, for the academic year 2020-2021 and I will be it again in 2021-2022. In June 2021 I was the tutor for the 2021 summer stage at University of Ferrara: 'Stage estivi a UNIFE: laboratori e seminari per studenti di scuola secondaria superiore'. At the moment, I am the didactic tutor of the course 'MATHEMATICAL ANALYSIS 1, in the Bachelor's Degree in Astronomy at the University of Bologna.

In 2018 I also collaborated with *'SOFOS Divulgazione delle Scienze, Bologna, Italy'* in projects of popularisation of Science.

INFORMATICS COMPETENCIES

Key skills include:

Languages: Python, C++, Cython, R and FORTRAN
Data Reduction Software: HEALPix, AIPS, IRAF, XSPEC
Writing Software: LaTeX, Microsoft Office
Operating systems: Linux, Mac Os and Windows

My experience in coding began with my Bachelor's thesis, where I wrote a code in C++ that implemented a chi-square statistic method in order to constrain the cosmological parameters Ω0Λ and Ω0m through SNe Ia observations.

During my master's degree I attended the specific course "Astrophysics Laboratory" which provided lessons, tutorials, and hands-on training on reduction, analysis and interpretation of data from ground-based and space-based facilities across a wide range of wavelengths, from radio (low and high frequency) to optical and X-rays/Gamma-rays, using the specific softwares IRAF, AIPS and XSPEC.

During my Master's and my Ph.D. theses my research activity has been dedicated to develop code in Python language in order to analyse CMB datasets, using packages for astrophysics and cosmology such as NumPy, SciPy, healpy, Astropy. In particular I have employed statistical estimators for evaluating cosmological birefingence effect and the lack of power observed at large angular scales in the CMB anisotropy pattern as measured by the Planck satellite. In collaboration with Dr. Jon Gudmundsson and his group at the Stockholm University, we extended the capabilities of the publicly available beamconv (https://github.com/AdriJD/beamconv) code. This new version of the code can be used to to modellise non-idealities coming from half-wave plates (HWP) in forthcoming CMB missions taking into account for the first time both HWP non-idealities and realistic full-sky beam convolution. Currently I am studying Cython, R and FORTRAN to enhance my knowledge.

I have broaden my knowledge on high performance computing (HPC) attending from Febraury to May 2020 the course “High performance computing for astrophysics and cosmology” (48 hours), held by prof. Marco Baldi, at the Master’s Degree in ‘Astrofisica e Cosmologia’ of the University of Bologna. I learned the basic concepts of algorithm parallelisation, the methods to test the computational efficiency of a parallel algorithm and to assess its performance in terms of scaling, work load, and memory consumption.
At present, I am parallelising the serial version of codes that implement statistical estimators for evaluating the anisotropic birefringence effects. These new versions will be performed on the MARCONI cluster (https://www.hpc.cineca.it/hardware/marconi) at CINECA (https://www.hpc.cineca.it/) through the ASI / INAF INFN Convention ('INF21_indark' project).

SCIENTIFIC PUBLICATIONS

[1] **M. Billi**, A. Gruppuso, N. Mandolesi, L. Moscardini, P. Natoli.
“Polarisation as a tracer of CMB anomalies: Planck results and future forecasts”.
Physics of the Dark Universe, Volume 26, December 2019, 100327,
doi:10.1016/j.dark.2019.100327, [arXiv:1901.04762 [astro-ph.CO]]

[2] A. Duivenvoorden, A. Adler, **M. Billi**, N. Dachlythra, J. Gudmundsson.
“Probing frequency-dependent half-wave plate systematics for CMB experiments with full-sky beam convolution simulations“.
Monthly Notices of the Royal Astronomical Society, Volume 502, Issue 3, April 2021, Pages 4526–4539, doi:10.1093/mnras/stab317, [arXiv:2012.10437 [astro-ph.CO]]

[3] **M. Billi**, M. Bortolami, A. Gruppuso, P. Natoli, L. Pagano.
“New estimators for anisotropic birefringence from CMB observations: the formalism and the application to Planck 2018 data.”
In preparation.

[4] M. Bortolami, **M. Billi**, A. Gruppuso, P. Natoli, L. Pagano.
“Constraints on anisotropic birefringence and its cross-correlation with CMB”.
In preparation.

TEACHING EXPERIENCE

- Didactic tutor for the course 'LABORATORY OF DIDACTICS OF PHYSICS, Module 1', 2020-21 in the Master's Degree in Physics at the University of Bologna.
- Didactic tutor for the 2021 summer stage at University of Ferrara: ‘Stage estivi a UNIFE: laboratori e seminari per studenti di scuola secondaria superiore’.
- Didactic tutor for the course 'LABORATORY OF DIDACTICS OF PHYSICS, Module 3', 2021-22 in the Master's Degree in Physics at the University of Bologna.
- Didactic tutor for the course 'MATHEMATICAL ANALYSIS 1, Module 1’, 2021-22 in the Bachelor's Degree in Astronomy at the University of Bologna.

WORKSHOPS AND CONFERENCES

- 8 March-12 March 2021 – Attended the virtual meeting: “CMB-S4 spring 2021 collaboration meeting”.
- 18-20 November 2020 – Attended the virtual conference: “BeyondPlanck release conference”
- May-July 2020 – Attended the Virtual seminars series on multimessenger astronomy; organized by the CRC “Neutrinos and Dark Matter in Astro and Particle Physics” .
- 22-26 June 2020 – Attended the online ESO Conference: H0 "Assessing Uncertainties in Hubble’s Constant Across the Universe".
- 30 March-2 April 2020 – Attended the virtual meeting: “CMB-S4 spring 2020 collaboration meeting”.
- 28 January 2020 – Attended the seminar at University of Ferrara: “Precision cosmology with CMB lensing, delensing and cross-correlation with galaxy surveys”.
- 13 December 2019 – Attended the conference at University of Stockholm: “My life in

physical Cosmology", held by Nobel Prize in Physics 2019, P. James Peebles.

- 21 November 2019 – Attended the conference at University of Stockholm: "New ideas for Dark Matter", held by Lisa Randal.
- 11 June 2019 – Attended the Workshop at University of Ferrara: "The Hubble constant day".

LANGUAGES

MOTHER LANGUAGE : Italian
OTHER LANGUAGE : English (B1 level)

REFERENCES

1. **Dr. Alessandro Gruppuso:** PhD supervisor, Master's thesis co-supervisor
   Researcher at INAF-OAS Bologna, Istituto Nazionale di Astrofisica - Osservatorio di Astrofisica e Scienza dello Spazio di Bologna (via P.Gobetti 101,40129 Bologna, Italy),
   phone: (+39) 051 6398783 (office)
   e-mail: alessandro.gruppuso@inaf.it

2. **Prof. Nazzareno Mandolesi:** Master's thesis co-supervisor
   University of Ferrara, Department of Physics and Earth Science (Via Saragat 1, 44122 Ferrara, Italy),
   phone: (+39) 3371474687
   email: mndnzr@unife.it

3. **Prof. Lauro Moscardini:** PhD co-supervisor, Master's thesis supervisor, Bachelor's thesis supervisor.
   University of Bologna, Department of Physics and Astronomy (via Gobetti 93/2, 40129 Bologna, Italy),
   phone: (+39) 051-20 95726 (office)
   email: lauro.moscardini@unibo.it

ATTACHED

Attached1: Second cycle career
Attached2: First cycle career

The ECTS scale is not used in the Italian graduating system which instead is based only on marks expressed from 0 to 30. The conversion from the Italian grade to the ECTS Scale is provided as well (see attached files). The ECTS grades are computed directly by the University under specific request by means of four different conversion tables: one for the exams of the bachelor's degree, one for the final bachelor's grade, one for the exams of the master's degree and the last one for the final master's grade. For this reason, I would be appropriate to take into account the Italian grades and not the ECTS.

Bologna, 21st October 2021

Matteo Billi