

Vignettes in Gravitation and Cosmology

This page intentionally left blank

Vignettes in Gravitation and Cosmology

Editors

L. Sriramkumar

Harish-Chandra Research Institute, India

T. R. Seshadri

University of Delhi, India

 **World Scientific**

NEW JERSEY • LONDON • SINGAPORE • BEIJING • SHANGHAI • HONG KONG • TAIPEI • CHENNAI

Published by

World Scientific Publishing Co. Pte. Ltd.

5 Toh Tuck Link, Singapore 596224

USA office: 27 Warren Street, Suite 401-402, Hackensack, NJ 07601

UK office: 57 Shelton Street, Covent Garden, London WC2H 9HE

British Library Cataloguing-in-Publication Data

A catalogue record for this book is available from the British Library.

VIGNETTES IN GRAVITATION AND COSMOLOGY

Copyright © 2012 by World Scientific Publishing Co. Pte. Ltd.

All rights reserved. This book, or parts thereof, may not be reproduced in any form or by any means, electronic or mechanical, including photocopying, recording or any information storage and retrieval system now known or to be invented, without written permission from the Publisher.

For photocopying of material in this volume, please pay a copying fee through the Copyright Clearance Center, Inc., 222 Rosewood Drive, Danvers, MA 01923, USA. In this case permission to photocopy is not required from the publisher.

ISBN-13 978-981-4322-06-5

ISBN-10 981-4322-06-7

Printed in Singapore.

Preface

This book is a unique collection of articles, written by former students and collaborators of T. Padmanabhan, on different aspects of gravitation and cosmology.

Padmanabhan, or Paddy, as he is affectionately known, constantly inspires us with his passion for physics, his intense enthusiasm for research, and his continued earnestness to work harder than any of his students. He has always been easily accessible to us and has played a significant role in shaping our outlook on physics and research. We hope that this collection of articles serves as a small token of our appreciation for the positive influence he has had on all of us. (At the end of the collection, we have listed the publications of all the contributors to this volume with Padmanabhan.)

Gravitation and cosmology are presently very active fields of research. The articles in this collection are focussed on topics that are of contemporary research interest, and they have been aimed at the level of graduate students. We believe that the articles will bridge the gaps that can exist between the discussions in the textbooks and the research level articles available on these topics.

We would like to thank all the contributors to this volume for their constant encouragement and support. We would also like to express our sincere gratitude to World Scientific, in particular, to Lakshmi Narayanan and her team, for guidance, support and infinite patience.

Editors: L. Sriramkumar and T. R. Seshadri

This page intentionally left blank

Contents

<i>Preface</i>	v
1. Non-linear gravitational clustering in an expanding universe	1
<i>Jasjeet Singh Bagla</i>	
1.1 Introduction	1
1.2 Gravitational clustering	2
1.2.1 Linear approximation	3
1.2.2 Quasi-linear approximations	4
1.3 In search of universalities	6
1.3.1 Mode coupling: Effect of small scale perturbations	8
1.3.2 Mode coupling: Effect of large scale perturbations	11
1.4 Conclusions	12
References	13
2. Dark ages and cosmic reionization	15
<i>Tirthankar Roy Choudhury</i>	
2.1 Introduction	16
2.2 Theoretical formalism	18
2.2.1 Cosmological radiation transfer	19
2.2.2 Post-reionization epoch	20
2.2.3 Pre-overlap epoch	25
2.2.4 Reionization of the inhomogeneous IGM	27
2.3 Modelling of reionization	30
2.3.1 Reionization sources	30
2.3.2 Illustration of a semi-analytical model	35

2.4	Current status and future	37
2.4.1	Simulations	37
2.4.2	Various observational probes	38
2.5	Concluding remarks	43
	References	43
3.	Probing fundamental constant evolution with redshifted spectral lines	51
	<i>Nissim Kanekar</i>	
3.1	Introduction	51
3.2	Redshifted spectral lines: Background	54
3.3	Optical techniques	55
3.3.1	The alkali doublet method	55
3.3.2	The many-multiplet method	56
3.3.3	Molecular hydrogen lines	60
3.4	“Radio” techniques	60
3.4.1	Radio-optical comparisons	61
3.4.2	Radio comparisons	62
3.4.3	Ammonia inversion transitions	63
3.5	“Conjugate” Satellite OH lines	64
3.6	Results from the different techniques	65
3.7	Future studies	67
3.8	Summary	69
3.9	Acknowledgments	70
	References	70
4.	Averaging the inhomogeneous universe	77
	<i>Aseem Paranjape</i>	
4.1	Introduction	78
4.2	History of the averaging problem	80
4.2.1	Noonan’s averaging scheme	81
4.2.2	Futamase’s scheme	82
4.2.3	Boersma’s scheme	82
4.2.4	Kasai’s scheme	83
4.2.5	Conventional wisdom and controversy	83
4.3	Buchert’s spatial averaging of scalars	86
4.4	Zalaletdinov’s Macroscopic Gravity (MG)	88

4.4.1	A spatial averaging limit	92
4.5	Backreaction in cosmological perturbation theory	95
4.5.1	Lessons from linear theory	98
4.5.2	The nonlinear regime	101
4.5.3	Calculations in an exact model	103
4.6	Conclusions	104
4.6.1	The “Special Observer” assumption	105
References	106
5.	Signals of cosmic magnetic fields from the cosmic microwave background radiation	115
	<i>T. R. Seshadri</i>	
5.1	Introduction	115
5.2	Origin of CMBR	116
5.2.1	Homogeneous universe	117
5.3	Origin of CMBR and the homogeneity of the universe	119
5.4	Finer features of the CMBR: A brief introduction	122
5.4.1	Temperature anisotropy	123
5.5	Origin of temperature anisotropy in the CMBR	125
5.6	Characterizing the nature of CMBR polarization anisotropy	126
5.7	Origin of CMBR polarization anisotropy	129
5.8	Cosmic magnetic fields	131
5.9	Polarization in CMBR due to magnetic fields	132
5.10	Non-Gaussianity from magnetic fields	137
References	143
6.	Quantum corrections to Bekenstein-Hawking entropy	147
	<i>S. Shankaranarayanan</i>	
6.1	Paddy	148
6.2	Prologue	148
6.3	Entropy and the choice of system states	149
6.3.1	Thought experiment by von Neumann	150
6.4	An intriguing feature of black hole entropy	153
6.5	Quantum corrections	155
6.6	Quantum entanglement	157
6.6.1	Relevance of entanglement for black hole entropy	157

6.6.2	Rapid review of entanglement	158
6.7	Entanglement entropy: Assumptions and setup	160
6.8	Entanglement entropy: Microcanonical	162
6.9	Entanglement entropy: Canonical	167
6.10	Conclusions and discussion	168
6.11	Acknowledgments	169
6.12	Appendix	170
	References	172
7.	Quantum measurement and quantum gravity: many worlds or collapse of the wave function?	177
	<i>T. P. Singh</i>	
7.1	The quantum measurement problem	178
7.1.1	First explanation: The many-worlds interpretation	178
7.1.2	Second explanation: Collapse of the wave-function	179
7.1.3	Goal of the present paper	180
7.2	A toy model for non-linear quantum mechanics and collapse of the wave-function	182
7.2.1	Introduction	182
7.2.2	The toy model	184
7.2.3	The Doebner-Goldin equation	186
7.3	Quantum gravity suggests that quantum mechanics is non- linear	186
7.3.1	Outline of the approach	186
7.3.2	Why quantum mechanics without classical space- time?	186
7.3.3	A reformulation based on noncommutative differential geometry	189
7.3.4	Quantum Minkowski spacetime	190
7.3.5	Including self-gravity	192
7.3.6	A non-linear Schrödinger equation	193
7.3.7	Explaining quantum measurement	194
7.3.8	Ideas for an experimental test of the model	197
7.4	Other models for collapse of the wave-function	198
7.4.1	Models that do not involve gravity	199
7.4.2	Models that involve gravity	200
7.5	Discussion	201
	References	203

8. On the generation and evolution of perturbations during inflation and reheating 207

L. Sriramkumar

8.1 Inflation and reheating 207

8.2 Inflating the universe 210

 8.2.1 Drawing the modes back inside the Hubble radius 210

 8.2.2 Propelling accelerated expansion with scalar fields 212

 8.2.3 Slow roll inflation 213

 8.2.4 Solutions in the slow roll approximation 215

8.3 Gauge invariant, linear, perturbation theory 216

 8.3.1 Scalar perturbations 217

 8.3.2 Vector perturbations 223

 8.3.3 Tensor perturbations 224

8.4 Generation of perturbations during inflation 225

 8.4.1 Equation of motion for the curvature perturbation 226

 8.4.2 Quantization of the perturbations and the definition of the power spectra 227

 8.4.3 The scalar and tensor spectra in slow roll inflation 229

8.5 Reheating the universe 232

 8.5.1 Behavior of the scalar field at the end of inflation 233

 8.5.2 Transferring the energy from the inflation to radiation 235

8.6 Evolution of perturbations during reheating 238

 8.6.1 Equations governing the evolution of perturbations 239

 8.6.2 Effects of reheating on the perturbations 242

8.7 Non-trivial post-inflationary dynamics: Modulated reheating and the curvaton scenarios 243

 8.7.1 Modulated or the inhomogeneous reheating scenario 243

 8.7.2 The curvaton scenario 244

8.8 Summary and discussion 245

References 246

9. Patterns in neural processing 251

Sunu Engineer

9.1 Introduction 251

9.2 The brain—the neuron 252

9.3	The model	257
9.4	Evolution of the neural system	260
9.5	Conclusions	261
	References	261
	Articles co-authored by the contributors with T. Padmanabhan	263
	<i>Index</i>	269