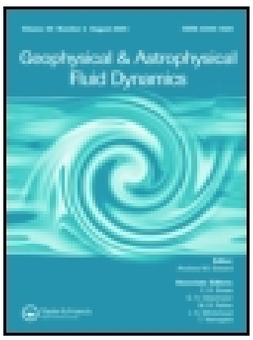

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Astrophysical magnetic fields: from galaxies to the early universe

Astrophysical magnetic fields: from galaxies to the early universe, by Anvar Shukurov and Kandaswamy Subramanian, Cambridge University Press, Cambridge, UK, 2022, Part of Cambridge Astrophysics, 650 pp., £165.00 (hardback), ISBN 9780521861052

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BOOK REVIEW

Astrophysical magnetic fields: from galaxies to the early universe, by Anvar Shukurov and Kandaswamy Subramanian, Cambridge University Press, Cambridge, UK, 2022, Part of Cambridge Astrophysics, 650 pp., £165.00 (hardback), ISBN 9780521861052

This book promises to be the new bible in the field of galactic magnetism. Until now, the main reference on this topic was the more slender book by Ruzmaikin, Sokoloff, and Shukurov of 1988 with the title "Magnetic fields of galaxies". With altogether 650 pages, the new book by Shukurov and Subramanian covers a much broader range of topics, including also magnetic fields of the early universe. Still, for my taste, the title, "Astrophysical magnetic fields" promises more than what is actually covered, given that the entire regime of low magnetic Prandtl numbers is not addressed. This would have included solar and stellar magnetism, planetary dynamos, and perhaps even laboratory liquid sodium dynamos, which provide the only experimental evidence we have for dynamo action. As the authors noted themselves, except for just the dynamo problem alone, the physical processes involved in those denser bodies are in many ways completely different, which motives their choice. Accretion disk dynamos map the borderline between large and small magnetic Prandtl numbers, and crucial aspects of those are being discussed in the book. An example is the possibility of an opposite sign of the α effect in accretion disks. Also, to be fair, the book does come with a subtitle "From galaxies to the early universe", but this easily remains unnoticed until one found out for oneself. I would not be surprised if the choice of the grander title was actually on the encouragement of the publisher rather than the idea of the authors.

Clearly, the book by Shukurov and Subramanian is the most comprehensive treatise of magnetic fields on the scale of galaxies and beyond that we have today. It is obviously not meant for teaching purposes, as it covers much more than what would usually be presented – even in an advanced course on the subject. It also does not contain any exercises, which would have invited instructors to consider the book for their courses. Thus, the book addresses mostly researchers, including graduate students, who are working in the field and need to read up on the many details that can indeed be found in the book. Also, as the authors suggest, the detailed derivations presented in many places of the book could easily be converted into problems or even projects for the students.

For readers with automatic library access through the university, the electronic version can easily be downloaded from the publisher's website as separate files for the different chapters. It is therefore just as easily accessible as other research papers. The printed version is rather heavy, which is mostly because of the high-quality paper, allowing the reproduction of high-quality gray-scale images. Unfortunately, also the electronic version only contains gray-scale images. Colour reproductions would have been nicer, and should have been the default given that many of the original figures were actually in colour, but it would not have been crucial for any of them. Nevertheless, studying the content of the book from the printed version is certainly worth the price. It can therefore also be a nice present for your colleague.

The book starts with an introduction to magnetohydrodynamics (MHD), covering relevant topics such as magnetic helicity, the two-fluid approximation, applications to waves and instabilities, as well as turbulence. Interestingly, when introducing turbulence on seven out of the first sixty pages, the inverse cascade could have been mentioned, but it is not even listed in the index, although the difference between forward and inverse cascades is clearly demonstrated in a later section on decaying MHD turbulence in the early universe. While much of this is still subject of ongoing research, there are also more specialised books on that subject, for example,

the one by Biskamp, which is also from Cambridge University Press, and it is indeed referenced in that chapter.

The book has a fairly comprehensive coverage of observational signatures of magnetic fields, including the discussion of synchrotron and dust emission, linear polarisation, as well as radio and optical observing techniques. It also discusses the utilisation of depolarisation to infer tomographic information of galactic magnetic fields. The book then continues with dynamo theory, presenting also results from various simulations as well as some analytic approaches. For my taste, however, one could have been more critical regarding our current understanding of the important role of magnetic helicity fluxes that are critical for the large-scale dynamo to work in the regime of very large magnetic Reynolds numbers. Future research still needs to address the question of why the formation of large-scale magnetic fields often becomes less promising as the simulations become more realistic and better resolved.

The authors then turn to the physics of galaxies and the interstellar medium, highlighting also interesting historical details, for example, the earlier use of the term galactic coronae relative to the now more commonly used term of galactic halos. Cosmic rays are being mentioned in various places in the book. Whether they might also play a crucial role in the formation of larger-scale magnetic fields, as has often been proposed, remains still an open question.

The authors then present results for the calculation of mean-field dynamos models, including nonlinear mean-field theory invoking magnetic buoyancy, magnetic helicity fluxes, and other effects. They then also compare with observations and discuss both spiral and elliptical galaxies, and consider the hydrostatic adjustment of galaxies as the dynamo evolves.

The final 100 pages of the book are devoted to galaxy clusters and the early universe. Both involve aspects of decaying MHD turbulence. They also discuss various magnetogenesis mechanisms such as inflationary and cosmological phase transition-generated magnetic fields. This part culminates in a discussion of the observed cosmic microwave background radiation and the physics of the universe past recombination.

One of the authors' ambitions is to present observations in a way that is understandable to theoreticians. The detailed discussions on the observations of synchrotron and dust emission as well as the presentation of the cosmic microwave background radiation are examples that demonstrate that this has indeed been a success. However, I would imagine that some of these aspects could easily be extended in future editions of the book. The more the authors will work with their own book, the more they will perhaps also see the need for an appendix with frequently recurring mathematical techniques, formulae, and tables. As with many other books, this one does contain a wealth of interesting historical information. It is usually scattered over several places. While it is easy to come up with additional suggestions that would make the book even more extensive, it might be possible to simply rearrange some of that information in tabular form, which would make it easier to find and to absorb.

The book has no outlook or conclusions and turns directly to the 63 pages of references and the 15 index pages. This underlines the authors focus on detail, with less emphasis on the broader picture or on speculations about the future. Global simulations of galaxy formation and the interaction with the circumgalactic medium are briefly discussed and are probably aspects that will gain much more importance in the years to come.

In summary, I can say that I thoroughly enjoyed reading this monograph, which contains a tremendous amount of information with mathematical derivations, discussions, and pictures. I hope that many scientists will be exposed to this monumental work and will use it for their research.

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