

# Cosmic Magnetic Fields

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**Abstract.** Most of the visible matter in the Universe is in a plasma state, or more specifically is composed of ionized or partially ionized gas permeated by magnetic fields. Thanks to recent advances on the theory and detection of cosmic magnetic fields there has been a worldwide growing interest in the study of their role on the formation of astrophysical sources and the structuring of the Universe. In this lecture, I will briefly review the importance of the cosmic magnetic fields both from a theoretical and from an observational perspective, particularly focusing on stellar and compact objects, the interstellar medium and star formation regions, and on galaxies, clusters of galaxies, and the primordial Universe.

**Keywords:** Magnetic fields in: stars, interstellar medium, jets and accretion disks, galaxies, clusters of galaxies, intracluster and intergalactic medium, and in the early universe.

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## INTRODUCTION

Few decades ago cosmic magnetic fields were generally regarded as unimportant. Only a few scientists, like Alfvén, Biermann, Chandrasekhar, and Parker, realized the potential role of the magnetism in the Universe. Since then, our view has changed considerably. We know now that most of the visible matter in the Universe is in a plasma state, or more specifically is composed of ionized or partially ionized gas permeated by magnetic fields. There seems to be now no doubts that magnetic fields play a crucial role in: star formation, solar and stellar activity, pulsars, accretion disks, formation and stability of jets, formation and propagation of cosmic rays, and stability of galactic disks. They are also probably crucial in: the interstellar medium (ISM) dynamical evolution, in molecular clouds, supernova remnants, proto-planetary disks, and planetary nebulae, but its importance is still not well understood in: stellar evolution, halos of galaxies, galaxy evolution, and structure formation in the early Universe (e.g., [1]). In this lecture, I will very *briefly* review the importance of the cosmic magnetic fields, particularly focusing on compact objects, the ISM and star formation regions, and on galaxies, clusters, and the early Universe. I will also briefly discuss the potential origin of the cosmic magnetic fields.

Before starting this review, let me consider the magnetic induction equation that describes the magnetic field evolution in a fluid:

$$\frac{\partial \mathbf{B}}{\partial t} = \nabla \times (\mathbf{v} \times \mathbf{B}) + \frac{1}{4\pi\sigma} \nabla^2 \mathbf{B} \quad (1)$$

Where  $\sigma$  is the electric conductivity. The first term of the RHS accounts for the flux freezing between the ionized gas and the magnetic field lines and the second one accounts for the magnetic diffusion. The comparison of the second term with the one of the LHS gives the diffusion time scale for the magnetic field configuration decay,  $t_{diff}(L) = 4\pi\sigma L^2$ , where  $L$  is the characteristic length scale of the spatial variation of  $\mathbf{B}$ . In most astrophysical systems and environments, the gas is a good conductor and since the typical length scales  $L$  are very large, one finds that  $t_{diff}(L)$  is generally much longer than the typical dynamical time scales of the systems. This implies that the first term on the RHS (the frozen-in term) generally dominates and the magnetic flux is conserved in most astrophysical plasmas, with the possible exception of magnetic boundary layers or surface discontinuities, like magnetic reconnection regions, where the condition above may be violated. Therefore, as a *golden rule* in Astrophysics, one may say that once magnetic fields are created in cosmic environments it is very difficult to get rid of them!

# Cosmic Magnetic Fields Lecture Notes In Physics

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**Cosmic Magnetic Fields** Richard Wielebinski, Rainer Beck, 2005-09-13 While magnetic fields permeate the universe on all scales the present book is dedicated to their investigation on the largest scales and affords a balanced account of both theoretical and observational aspects Written as a set of advanced lectures and tutorial reviews that lead up to the forefront of research this book offers both a modern source of reference for the experienced researchers as well as a high level introductory text for postgraduate students and nonspecialist researchers working in related areas **Astrophysical**

**Masers and Their Environments (IAU S242)** International Astronomical Union. Symposium, 2008-02-14 Astrophysical masers naturally occurring microwave and radio wave emissions provide an important tool to investigate astrophysical environments Several thousand maser sources have been observed in the interstellar medium and star formation regions in the expanding winds from evolved stars in the compressed shells of supernovae remnants in comets and in the centers of galaxies Masers are also useful for studying the structure and dynamics of our own galaxy while masers in other galaxies are now used for cosmological studies and studies of galactic nuclei This volume contains the latest research on the topic as presented at IAU Symposium 242 only the third international symposium on astrophysical masers Over 125 astronomers from 18 different countries gathered in Alice Spring Australia for discussions on maser research **Galaxies and their**

**Masks** David L. Block, Kenneth C. Freeman, Ivânio Puerari, 2010-11-12 Freeman Fellow of the Royal Society **Mapping the Galaxy and Nearby Galaxies** Keiichi Wada, Francoise Combes, 2007-12-20 Readers with any kind of an interest in astronomy will find this work fascinating detailing as it does the proceedings of the symposium of the same name held in Japan in 2006 The symposium focused on mapping the interstellar media and other components in galactic disks bulges halos and central regions of galaxies Thanks to recent progress in observations using radio interferometers and optical infrared telescopes in ground and space our knowledge on structures of our Galaxy and nearby galaxies has been growing for the last decade *Essays on Astronomical History and Heritage* Steven Gullberg, Peter Robertson, 2023-08-14 This multidisciplinary work celebrates Wayne Orchiston's career and accomplishments in historical and cultural astronomy on the occasion of his 80th birthday Over thirty of the world's leading scholars in astronomy astrophysics astronomical history and cultural astronomy have come together to honor Wayne across a wide range of research topics These themes include Astronomy and Society Emergence of Astrophysics History of Radio Astronomy Solar System Observatories and Instrumentation Ethnoastronomy and Archeoastronomy This exceptional collection of essays presents an overview of Wayne's prolific contributions to the field along with detailed accounts of the book's diverse themes It is a valuable and insightful volume for both researchers and others interested in the fields of historical astronomy and cultural astronomy Encyclopedia of

Geomagnetism and Paleomagnetism David Gubbins, Emilio Herrero-Bervera, 2007-07-19 Understanding the process underlying the origin of Earth magnetic field is one of the greatest challenges left to classical Physics Geomagnetism being

the oldest Earth science studies the Earth's magnetic field in its broadest sense. The magnetic record left in rocks is studied in Paleomagnetism. Both fields have applications pure and applied in navigation in the search for minerals and hydrocarbons in dating rock sequences and in unraveling past geologic movements such as plate motions; they have contributed to a better understanding of the Earth. Consisting of more than 300 articles written by ca. 200 leading experts, this authoritative reference encompasses the entire fields of Geomagnetism and Paleomagnetism in a single volume. It describes in fine detail at an assessable level the state of the current knowledge and provides an up-to-date synthesis of the most basic concepts. As such, it will be an indispensable working tool not only for geophysicists and geophysics students but also for geologists, physicists, atmospheric and environmental scientists, and engineers.

**Formation and Evolution of Galaxy Disks** José G. Funes, Enrico Maria Corsini, 2008. These are the proceedings of the international conference Formation and Evolution of Galaxy Disks organized by the Specola Vaticana, the Vatican Observatory. The meeting hosted 198 participants from 26 countries. The program consisted of 61 talks and about 130 poster papers. In 2000, the Vatican Observatory organized a conference on Galaxy Disks and Disk Galaxies, the proceedings of which were published in ASP Conference Series Vol. 230. Since that time, a great amount of work has been done in this very active field. October 2007 was deemed an appropriate time to hold another similar conference where outstanding senior and junior astronomers in this field could air new results. The conference was focused on the formation and evolution of galaxy disks and covered the following topics: 1. properties of nearby galaxy disks; 2. interstellar medium, star formation, and chemical evolution; 3. disk edges, outskirts, and environment; 4. accretion onto disks, interactions, and mergers; 5. secular evolution of disks and bar/spiral-driven evolution of galaxies; 6. evolution of disk structural properties; and 7. disk formation in a hierarchical universe. This book is of interest for researchers in extragalactic astronomy. It presents an overview of the relevant results and the progress made in the field in the last seven years. Publisher's website.

*Fractional Kinetics In Space: Anomalous Transport Models* Vladimir V. Uchaikin, Renat T. Sibatov, 2017-12-12. This book is first of its kind, describing a new direction in modeling processes taking place in interplanetary and interstellar space: magnetic fields, plasma, cosmic rays, etc. This method is based on a special mathematical analysis: fractional calculus. The reader will find in this book a clear physical explanation of the fractional approach and will become familiar with basic rules in this calculus and main results obtained in the frame of this approach. In spite of its profound subject, the book is not overloaded by mathematical details. It contains many illustrations, rich citations, and remains accessible to a wide circle of physicists. This book is addressed to graduate and postgraduate students, young and mature researchers specializing in applications of fractional calculus, astrophysics, solar/terrestrial science, and physics of cosmic rays.

*The Dynamic Universe: Realizing the Potential of Time Domain and Multimessenger Astrophysics* Rita Sambruna, Francesca M. Civano, 2025-10-31. The 2020 Astrophysics Decadal recommended Time Domain and Multi-Messenger Astrophysics as the top priority of the sustaining activities of the astrophysics portfolio. In order to highlight the most important science themes

NASA held the Time Domain and Multi Messenger Astrophysics NASA Workshop in 2022 convening scientists from across the US and the world to highlight the science that could be addressed in future missions This Research Topic is inspired by this workshop and the subsequent summary paper written by the workshop Science Organizing Committee and originally delivered to NASA HQ Broadly the themes that were addressed by the workshop are Non terminal Sources Jetted Transients Merger driven Transients and Explosive Transients The interdisciplinary nature of these topics makes this science highly significant to a range of fields including cosmology and fundamental physics The goal of this Research Topic is to provide a comprehensive review of the science of Time Domain and Multi Messenger Astrophysics We welcome contributions on topics concerning Time Domain and Multi Messenger Astrophysics particularly those related to or inspired by the Time Domain and Multi Messenger Astrophysics NASA Workshop 2022 We encourage papers that highlight the potential for the variable source to be a Multi Messenger source i e the likelihood of being detected in the future with Gravitational Wave detectors e g LVK LISA and or neutrinos We invite original research methods reviews and mini reviews hypothesis theory perspectives data reports brief research reports general commentaries and opinions

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