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Magnetic Cosmos - To B or not to B

Ulrich v. Kusserow, Olbers-Society Bremen

Today, cosmic magnetic fields can be detected almost everywhere in the Universe. They affect essential structure forming and development processes in galactic, stellar and planetary systems. A variety of processes, mediated by them, is therefore subject of current astrophysical research. There is a great fascination emanating from these processes, not only for scientists and amateur astronomers, but also for the public audience. For example the ejection of high-energy solar clouds of matter, special activities in elongated comet tails or the dynamic development of colorful auroras belong to the magnetically controlled phenomena, in which many people are interested in and deeply inspired in the age of modern media.

Magnetic fields belong to the "radical elements" in the Universe. High-energy processes like eruptions or the acceleration of cosmic matter observed in different star and galaxy systems can be significantly effected by them. On the other hand, they support the structure formation processes almost everywhere in the cosmos. Without magnetic fields the formation of stars and planets could not happen or at least would proceed significantly different. Without the protection of magnetic fields the highly developed life on Earth could not have emerged. Magnetic processes determine the space weather in our Solar System, thereby also influencing the climate not only on our planet.

It was not until about a century, that the diverse and partly particularly strong influence of cosmic magnetic fields on the processes in the different celestial objects had been appreciated with a really steadily increasing tendency. How strong is their influence respectively in detail?

Where does the magnetic flux density, which is abbreviated and designated with the letter B, really play an important and existential role for the different celestial objects? In a modification of the famous Shakespeare quotation therefore arises again and again the question "To B or not to B". Hoch much and in which way are magnetic fields important in the Universe or not?

How did the relatively weak magnetic fields in the early universe actually originate ? How can you explain the formation of the extremely strong fields in the neutron stars, which are designated as "magnetars"? Why do solar or planetary magnetic fields reverse their polarity in a periodic respectively chaotic way? How do magnetic fields manage the transportation, focusing and acceleration of matter? Which are the physical processes that can convert magnetic energy into kinetic energy or radiant energy? How do cosmic magnetic fields cause the wave propagation, the heating of the matter, the dynamic processes in shock fronts after-eruptions or collisions with different objects in the sky?

Based on colorful images and video sequences, the widespread existence of magnetic fields in the Universe will be proved and illustrated in this lecture. Using animations, results of model calculations and numerical simulations, but also on the basis of results of analogue „cosmic“ laboratory experiments, the effect of the different magnetic processes will be clearly explained . For example, it will be shown how magnetic fields can be produced by cosmic dynamo processes, how magnetic energy can be released and converted to other forms of energy by the action of the so-called magnetic reconnection. It will be explained how the creation of galaxies, stars and planets is effectively and magnetically supported by the necessary removal of angular momentum. The influence of magnetic fields in a variety of high-energy cosmic processes is described.

Content of the lecture

The talk will start with some remarks concerning historical and didactical aspects. How did the exploration of the magnetic forces start, how can human beeings discover the real existence of the magnetic fields? And how can you get an easy impression of what magnetic field lines are, how they act?

In the **first part** of this lecture the obvious evidence for the existence of such fields will be demonstrated, suitable methods for measuring magnetic fields will be presented. The great importance of magnetic processes in the current astrophysical research but as well for the people's lives will be clarified. The matter in the Universe resides in the so-called plasma state almost everywhere. Our Solar System affords astrophysicists "on site" relatively good opportunities for research on fundamental magnetic processes in the ionized and charged turbulent matter.

In the **second part** of the lecture the particular properties of the plasma will therefore presented first . Dynamo processes for generating cosmic magnetic fields, magnetic reconnection and acceleration processes for the release of stored magnetic energies for the heating as well as the acceleration of charged matter will be explained. The typical structures and developments of solar and planetary magnetic fields , the influence of heliospherical magnetic fields on the space weather will be introduced.

Cosmic magnetic fields play a central role in the many different stages of development of stars with different masses, especially during star formation processes and in high-energy processes at the end of their life. In the beginning of the **third part** of the talk the magnetic factors of influence in the early stages of stellar evolution in the molecular clouds and in the protostellar disk-jet structures will be discussed. The subsequent"magnetic" evolution of stars and stellar systems with different masses will be described . The special importance of magnetic processes in compact objects like white dwarfs , neutron stars and stellar-mass black

holes in binary systems and during supernova explosions and gamma-ray bursts will be highlighted.

Today cosmic magnetic fields can be detected in a variety of different types of galaxies als well as in the interior and in the vicinity of galaxy clusters. Obviously, they existed already in the early stages of the cosmological evolution of the universe in different process sequencies. In the **fourth part** of the paper, first the typical properties and magnetic field structures of the different galaxies, for example the Milky Way, spiral, elliptical, irregular and active galaxies will be described. Then the early primordial magnetic field and the emergence process of seed fields, produced in the young galaxies in a so-called Biermann-Battery, will be visualized. They later enable the production of stronger galactic fields by dynamo processes. Finally the outflow of magnetically collimated jets from the center of active galactic nuclei and dynamic processes in star birth galaxies will be explained, possible cosmological influences of magnetic field discussed.

Astrophysicists usually gain new insights regarding the evolution of important magnetic processes by the analysis of observational data, based on theoretical modeling and numerical experiments using powerful computers. More than in former times successful analog laboratory experiments are performed today, which imitate remote and complex cosmic processes "on the spot ". In the **fifth part** of the lecture the different possibilities to gain knowledge will be demonstrated by means of impressive examples. New and planned solar telescopes, satellites, radio and space telescopes will be presented which can promote the research on cosmic magnetic fields everywhere in the Universe in the future more effectively than before. Results of numerical experiments shall demonstrate how strongly our understanding of many impressive processes in the Universe has increased. A lot of outstanding laboratory experiments will be shown in the end. But despite the particular fascination for the great importance and influence of the magnetic fields in the Universe we should bear in mind, that there always are as well frontiers for our human intellectual insights.

Contents

More Information about the lecture can be obtained by:

Ulrich v. Kusserow
Besselstraße 32-34
D 28203 Bremen
Germany
Tel.: + 49 421-75160
E-mail: uvkusserow@t-online.de
Internet: http://uvkusserow.magix.net/website/, http://kosmischemagnetfelder.wordpress.com/

Dipl. - Phys. Ulrich v. Kusserow, Olbers-Society Bremen

After studying Astrophysics (thesis on "Stationary Spherical αω-Dynamos and the Earth's Magnetic Field") Ulrich v. Kusserow taught as a college teacher of mathematics and physics. For many years he was chairman of the Bremer Olbers Society. He is a member of the Astronomical Society (AG), the German Physical Society (DPG) and the Vereinigung der Sternfreunde (VdS) . For several years he has worked on "Learning about Cosmic Magnetic Fields" at the Institute of Physics Education at the University of Potsdam. He currently serves practical experiments at the University of Bremen for solar physics, writes articles and lectures, including at events for teacher training, with a focus on didactic aspects of modern astrophysics on the areas of solar and cosmic magnetic fields, space physics, evolution of planets, stars and galaxies as well as environmental and climate problems. In Bremen, he assists the PALAZZI publishing company in the preparation of the yearly, in collaboration with the magazine "Bild der Wissenschaft", published "Startime" calendar. In October 2013, a book of the speaker with the title „Magnetischer Kosmos - To B or not to B“ has been released by the Springer Publishing House.

Supplementary material for the lecture and the book is available on the Internet in German under

http://uvkusserow.magix.net/website#Vortr%C3%A4ge
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