Measuring interstellar magnetic fields by radio synchrotron emission

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Abstract. Radio synchrotron emission, its polarization and its Faraday rotation are powerful tools to study the strength and structure of interstellar magnetic fields. The total intensity traces the strength and distribution of total magnetic fields. Total fields in gas-rich spiral arms and bars of nearby galaxies have strengths of 20–30 $\mu$Gauss, due to the amplification of turbulent fields, and are dynamically important. In the Milky Way, the total field strength is about 6 $\mu$G near the Sun and several 100 $\mu$G in filaments near the Galactic Center. – The polarized intensity measures ordered fields with a preferred orientation, which can be regular or anisotropic fields. Ordered fields with spiral structure exist in grand-design, barred, flocculent and even in irregular galaxies. The strongest ordered fields are found in interarm regions, sometimes forming “magnetic spiral arms” between the optical arms. Halo fields are X-shaped, probably due to outflows. – The Faraday rotation of the polarization vectors traces coherent regular fields which have a preferred direction. In some galaxies Faraday rotation reveals large-scale patterns which are signatures of dynamo fields. However, in most galaxies the field has a complicated structure and interacts with local gas flows. In the Milky Way, diffuse polarized radio emission and Faraday rotation of the polarized emission from pulsars and background sources show many small-scale and large-scale magnetic features, but the overall field structure in our Galaxy is still under debate.

Keywords. Techniques: polarimetric – ISM: magnetic fields – galaxies: magnetic fields – galaxies: spiral – radio continuum: galaxies

1. Introduction

Interstellar magnetic fields were discovered already in 1932 by Karl Guthe Jansky who first detected diffuse low-frequency radio emission from the Milky Way, but the explanation as synchrotron emission was given only in 1950 by Karl Otto Kiepenheuer. The sensitivity of radio observations has improved by several orders of magnitude in the past decades, and synchrotron emission was detected from the interstellar medium (ISM) in almost all star-forming galaxies, in galaxy halos and the intracluster medium, proving that a large fraction of the Universe is permeated by magnetic fields. However, in spite of our increasing knowledge on interstellar magnetic fields, many important questions are unanswered, especially their first occurrence in young galaxies, their amplification when galaxies evolved, and their effect on galaxy dynamics.

As magnetic fields need illumination by cosmic-ray electrons to become observable by synchrotron emission, which are generated in star-forming regions or intracluster shocks, we do not know yet whether magnetic fields also exist in radio-quiet elliptical or dwarf galaxies or in the general intergalactic medium (IGM). Progress can be expected from using Faraday rotation which does not need cosmic rays, only magnetic fields and thin ionized gas. One of the research areas of the forthcoming radio telescopes (LOFAR, ASKAP, SKA) will be the search for Faraday rotation in these objects against polarized background sources (Gaensler, this volume). The SKA will also be needed to detect magnetic fields in young galaxies (Beck & Gaensler 2004, Arshakian et al. 2008).