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ORIGINAL ARTICLE

Interstellar turbulent magnetic field generation by plasma instabilities

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Abstract The maximum magnetic field strength generated by Weibel-type plasma instabilities is estimated for typical conditions in the interstellar medium. The relevant kinetic dispersion relations are evaluated by conducting a parameter study both for Maxwellian and for suprathermal particle distributions showing that micro Gauss magnetic fields can be generated. It is shown that, depending on the streaming velocity and the plasma temperatures, either the longitudinal or a transverse instability will be dominant. In the presence of an ambient magnetic field, the filamentation instability is typically suppressed while the two-stream and the classic Weibel instability are retained.

Keywords Plasmas · Magnetic field · Interstellar medium · Instabilities · Counterstream

1 Introduction

Galactic magnetic fields are ubiquitous (see Beck et al. 1996, for an overview). Even in galaxies at high redshifts, magnetic fields have been found (Bernet et al. 2008). The correlation between far-infrared radiation of massive stars and radio emission produced by synchrotron radiation of energetic particles in the surrounding magnetic fields (Murphy 2009). Such implies a connection between the formation of massive stars and galactic magnetic fields.

The generally accepted model for the generation of galactic magnetic fields is found in the dynamo process (Beck et al. 1996; Brandenburg and Subramanian 2005; Kulsrud 2010), which, however, requires a seed magnetic field (Schlickeiser 2005; Schober et al. 2012). Among other processes (e.g., Ryu et al. 2012; Durrer and Neronov 2013), seed fields can be generated by plasma instabilities for example in the neighborhood of massive stars that ionize the surrounding interstellar medium (Schlickeiser 2012). A special class of such instabilities generates modes that purely grow in time and do not propagate—the so-called "aperiodic" modes (Weibel 1959; Tautz and Lerche 2012a). The fact that such modes can be emitted spontaneously even in unmagnetized plasmas (Yoon 2007; Tautz and Schlickeiser 2007; Yoon and Schlickeiser 2012; Lazar et al. 2012) again underscores the validity of the process. On smaller scales, magnetic fields play an important role in the formation of molecular clouds (Inoue and Inutsuka 2012), star formation, and thermally unstable interstellar flows (Mantare and Cole 2012). Furthermore, aperiodic modes are essential for particle acceleration at cosmic shocks (e.g., Reville et al. 2008; Niemiec et al. 2010). In general, the coupling of matter and magnetic fields is confirmed by the typical scaling $B \propto \sqrt{n}$ for relatively high particle densities (Heiles and Crutcher 2005).

Because of the typically low plasma densities, the relevant processes have to be described using kinetic plasma theory (see, e.g., Davidson 1983; Schlickeiser 2002; Tautz 2012, for an introduction), which has a long tradition. Much of the progress in cataloging waves in plasmas, both non-relativistically as well as relativistically, has ably been summarized by Clemmow and Dougherty (1969) and, with astrophysical applications much to the fore, by Schlickeiser (2002), where copious references to the many advances in understanding such waves are to be found. Typically, concentration is focused on simplified geometries, for example modes propagating parallel or perpendicular with respect to a given symmetry axis such as a streaming direction or an

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