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Non-linear interaction of a gravitational wave with a distribution of particles

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Abstract. The propagation of a gravitational wave in the non-empty interstellar space, in the presence of a uniform magnetic field, is investigated. It is found that the type of interaction of the wave with the interstellar plasma depends on the direction of propagation of the gravitational wave with respect to the magnetic field. In the oblique and parallel propagation cases the results are consistent with the already studied propagation in empty space (Kleidis et al. 1993). In the oblique case the interaction may be chaotic, leading to a diffusive acceleration of the plasma particles. In the parallel case the particles may be trapped in a resonance and accelerated to "infinite" energies. In the quasiparallel case, however (i.e. propagation at a small angle with respect to the magnetic field) a new type of interaction is possible, consisting of a combination of chaotic and resonant interactions.

Key words: acceleration of particles – gravitation – scattering – plasmas

1. Introduction

A possible detection of gravitational waves in the neighbourhood of Earth would probably be the ultimate verification of the theory of General Relativity. Unfortunately, this is not an easy thing to do. Even with markedly improved sensitivities, the efforts that have been made to detect gravitational waves gave no convincing evidence that they were actually being seen (Thorne 1987). This is due to the fact that not only their amplitude is very small (Smarr 1979), but it is highly possible that some kind of damping mechanism operates on them, as they travel through space (Esposito 1971a,b; Szekeres 1971; Macedo & Nelson 1983; Papadopoulos & Esposito 1985). In this sense, the study of the interaction of gravitational waves with the interstellar matter is of paramount importance in our effort to give theoretical estimates of the upper limit values of the waves' amplitude.

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Extensive work, based on modelling this interaction as a Hamiltonian dynamical system, has already been carried out, both in the linear regime (Macedo & Nelson 1990) as well as in the non-linear one (Varvoglis & Papadopoulos 1992, which hereafter is referred to as Paper I). In these papers it has been shown that, under certain conditions, a damping of the wave is possible. In a more recent paper (Kleidis et al. 1993, which hereafter is referred to as Paper II) the problem of the interaction between a charged particle, in the presence of a uniform magnetic field, and a gravitational wave of various polarizations and directions of propagation with respect to the magnetic field, has been studied. It was found that, in the oblique propagation case and for all types of polarization, diffusive acceleration of the particle, due to secular energy transfer from the wave, could lead to a damping. The most important results, however, came out from the parallel propagation case. Here, in the case of an exact resonance between the Larmor frequency of the particles and the frequency of the wave, a "phase lock" situation appears (e.g. see Menyuk et al. 1987). This may lead to an "infinite" acceleration of the particles and consequently to a considerable damping of the gravitational wave. Resonant acceleration might be of no physical importance, since the probability of an exact resonance is zero. This problem is expected to be waived out by the introduction of a distribution of particles, which leads to a dispersion relation for the gravitational wave (Grishchuk & Polnarev 1980).

In the present paper we consider the non linear interaction between charged particles, in the presence of a uniform and static, in time, magnetic field $\boldsymbol{B} = B_0\hat{e}_z$, with a gravitational wave, propagating in a non-empty space, which results in a non-trivial dispersion relation. The interstellar plasma is represented by a collisionless gas of particles, where by collisionless we simply mean that the mean time between successive collisions of the particles is much larger than the period of the gravitational wave. For the sake of simplicity we consider plane polarized gravitational waves only, since the corresponding results in the circular case turn out to be similar (Paper II).