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# The Effect of Magnetic Field on Type I Planetary Migration: Angular Momentum Conservation

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Planetary migration is one of the most important topics in the theory of planetary system formation. Type I planetary migration is the radial motion of low mass protoplanets induced by the gravitational interaction with the circumstellar gas. A protoplanet generates density waves in the gas disk that carry angular momentum. A torque is exerted on the protoplanet as a back reaction, resulting in the radial motion of the protoplanet. There is also a torque exerted in the corotation region, but it may saturate unless there is some dissipation in the disk. Recent work by Tanaka et al. [1] indicates that when a protoplanet of an Earth mass is formed at 1AU, it falls towards the central star within a hundred thousands years, which is shorter than the observed timescale of protoplanetary disk gas dispersal. Therefore, protoplanets may fall onto the central star at the same time as they form.

Recently, Terquem [2] suggested that the presence of a toroidal magnetic field in the disk may slow down or reverse the inward planetary migration when the profile of the magnetic field satisfies a certain condition. Muto et al. [3] studied the effect of a poloidal magnetic field and showed that, when the magnetic field is strong enough, the rate of planetary migration may be slowed down. Therefore, magnetic field may play an important role in halting rapid inward migration.

In the presence of a magnetic field, the perturbation induced by the protoplanet is singular at the so-called magnetic resonances, which lie on both sides of the orbit. The point-like torque exerted on the protoplanet at these locations is responsible for the migration reversal. It is therefore important to understand how angular momentum is exhanged between the orbital motion of the planet and the rotation of the disk at these locations.

In this work we study the angular momentum flux conservation in a magnetized disk. We find there are two contributions that account for angular momentum exchange between the disk and the protoplanet. One is the angular momentum flux that is carried away to the disk edge, which is also present in an unmagnetized case. In addition to this, we show that there is a direct transport of angular momentum to the disk at the magnetic resonances, which is due to dissipative effects such as viscosity or friction. This transfer of angular momentum to the disk is similar to the transfer that occurs at the corotation resonance in a non magnetized disk. We then discuss the possibility of the saturation of the torque exterted at the magnetic resonances, and the effect on the migration rate.

[1] Tanaka, Takeuchi and Ward ApJ 565 1257 (2002)
[2] Terquem MNRAS 341 1157 (2003)
[3] Muto, Machida and Inutsuka ApJ submitted