Gravitational interaction between a planet and an optically thin protoplanetary disk

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We investigate gravitational interaction between a planet and an optically thin protoplanetary disk, taking account of radiative transfer. A planet excites two density waves on both sides of the planet orbit due to Lindblad resonances. The outer density wave exerts a negative torque on the planet while the inner density wave exerts a positive torque. The sum of the two torque gives the net torque on the planet. As a first step, we examine one of the torques (one-side torque) in the present study. In most previous studies of density waves, the isothermal equation of state has been assumed. In this study, solving the energy equation in the linear calculation, we examine the effect of energy transfer on the wave excitation. In protoplanetary disks, the energy is transfered is by radiation and the radiative transfer is governed by dust opacity. At the stage of planet formation, the dust opacity is expected to be sufficiently low because of dust growth and planetesimal formation. Thus we assume an optically thin gaseous disk. The efficiency of radiative transfer increases with the amount of dust in optically thin disks. We consider the amount of dust as a parameter and calculate the one-side torque on a planet. Due to radiative transfer, the values of the one-side torque is deviated only by about 10% from the isothermal case. However, it is also found that the gas in the Hill sphere of the planet has a large contribution on the one-side torque. This large contribution in the Hill sphere may change the net torque sufficiently.