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One-Armed Oscillations of Accretion Disks in AGN: Application to the Warped Maser Disk of NGC 4258

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Abstract. We present a numerical example of a warping mode in the maser disk of NGC 4258. We find that the characteristics of the mode agree with the observed position and velocity distribution of the maser sources.

1. The Warped Maser Disk of NGC 4258

The high-velocity water maser sources at the center of NGC 4258 provide compelling evidence for the presence of a central supermassive black hole of a mass of $3.6 \times 10^7\, M_\odot$ (Miyoshi et al. 1995; Nakai et al. 1995). Curiously, the position and velocity distribution of these maser sources are fitted well with a warped Keplerian disk model in which the inner and outer radii of the emitting region are 0.12 pc and 0.26 pc, respectively (Miyoshi et al. 1995; Nakai et al. 1995). The maser disk is so thin that the upper limit of the disk thickness is 3×10^{-4} pc (Moran et al. 1995).

Such a disk can be perturbed by global one-armed ($m = 1$) oscillations (e.g., Kato 1983). The purpose of this paper is to examine the characteristics of one-armed warping modes supposed to be present in the maser disk of NGC 4258.

2. Characteristics of Warping Modes in the Maser Disk of NGC 4258

As an unperturbed equilibrium disk, we take a non-self-gravitating, axisymmetric disk rotating around a black hole. To simulate the weak general relativistic effect, we use the pseudo-Newtonian potential (Paczyński & Wiita 1980). We assume that the gas obeys a polytropic relation with an index of 5/3, adopt a simple toy model for the density distribution shown by contours in Fig. 1(b), and consider a linear adiabatic perturbation. As the boundary conditions for the resulting second-order partial differential equation for the perturbation, we require that the Lagrangian enthalpy perturbation vanishes at the disk surface, and that the Eulerian enthalpy perturbation is antisymmetric with respect to z.

In Fig. 1, we present a typical example of a fundamental warping mode: (a) the (r, ϕ) distribution of the vertically-averaged perturbed quantities and (b) the (r, z) distribution of perturbed quantities. The period of the mode is $\sim 10^8$ yr.

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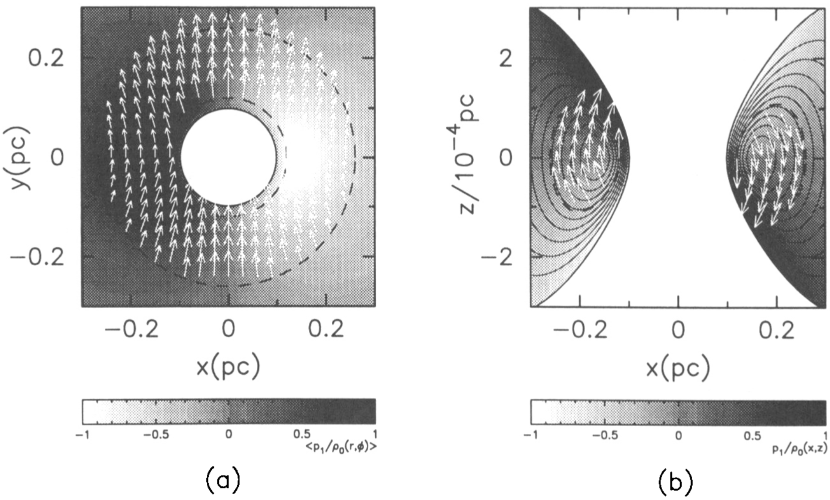

Figure 1. Structure of the fundamental warping mode: (a) the (r, ϕ) distribution of the perturbed quantities averaged vertically over the half-thickness of the disk and (b) the (r, z) distribution of the perturbed quantities. A gray-scale representation denotes the distribution of the enthalpy perturbation. Arrows superposed on the gray-scale plot are the perturbed velocity vectors in the maser-emitting region (surrounded by dashed lines). Note that the enthalpy perturbation and the azimuthal component of velocity perturbation vary as $\cos(\psi - \phi)$, while the poloidal components of velocity perturbation vary as $\sin(\psi - \phi)$, where ψ is the phase of the perturbation. Contours in Fig. 1b, which show the unperturbed density distribution, are separated by 0.1.

From Fig. 1, we notice that the structure of the fundamental warping mode is in agreement with the observed spatial distribution of the maser spots of NGC 4258. Moreover, we find that the velocity vector associated with the warping mode is roughly parallel to the z-axis, especially near the equatorial plane. This feature is also consistent with the observed nearly Keplerian velocity distribution of maser spots of NGC 4258.

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