ON SUB-KEPLERIAN VELOCITY DISTRIBUTION OF THE MEGAMASER SOURCE IN NGC 1068

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NGC 1068 is considered to be the archetypal galaxy, harboring an active galactic nucleus heavily obscured by a dense molecular torus. In the nucleus of NGC 1068 lies a megamaser source which enables us to probe the structure and the velocity field of the innermost part of the torus. Recently, Greenhill et al. (1996) observed the water maser emission in NGC 1068 with the VLBA and obtained images with sub-milliarcsecond angular resolution. Their best fit rotation curve for the redshifted maser emission was sub-Keplerian; the line-of-sight velocity of the maser source decreased as $r^{-0.31}$ for $0.57\,\mathrm{pc} < r < 0.92\,\mathrm{pc}$.

In this paper, we examined the effect of global oscillation modes on the kinematics of the maser emission region of NGC 1068. For this purpose, we used a simplified disk model and solved the resulting eigenvalue problem in the three dimensions. We found that there exist global eccentric (z-symmetric $m = 1$) modes as well as warping (z-antisymmetric $m = 1$) modes in the masing disk of NGC 1068. Figure 1 shows the three-dimensional structure of the fundamental eccentric mode.

The global eccentric mode can explain the observed sub-Keplerian velocity distribution of the maser source of NGC 1068. Figure 2 shows the position-velocity diagram calculated under the assumption that the masing disk is perturbed by the fundamental eccentric mode. As shown in Figure 2, the eccentric mode flattens the velocity gradient of the redshifted emission and shifts the systemic velocity blueward by $\sim 70\mathrm{km\,s^{-1}}$. Our model predicts that future VLBA observation of the blueshifted maser emission of NGC 1068 will reveal that its line-of-sight velocity distribution is steeper than the Keplerian distribution.

References

Greenhill, L.J., et al. 1996, ApJ 472, L21.

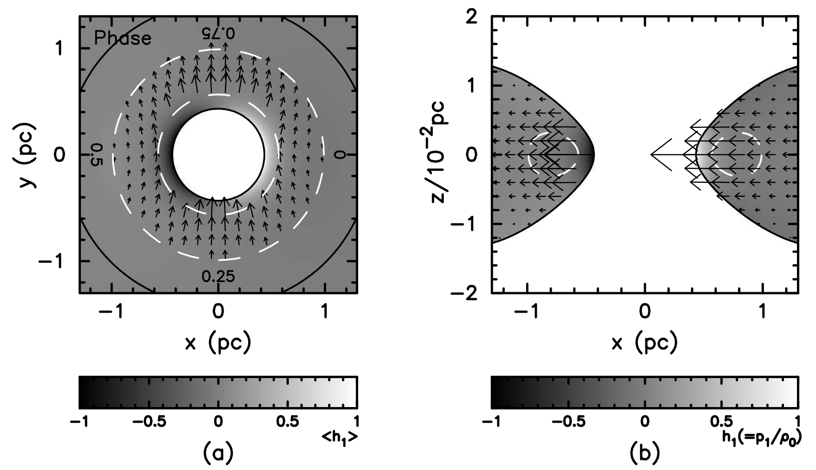

Figure 1. Fundamental eccentric mode in the masing disk of NGC 1068. (a) The (r, ϕ)-distribution of the vertically-averaged perturbations. At phase 0, the observer is in the x-direction. (b) The (r, z)-distribution of the perturbations. A gray-scale representation denotes the enthalpy perturbation h_1. Arrows superposed on the gray-scale plot are the perturbed velocity vectors in the maser emission region (surrounded by dashed lines).

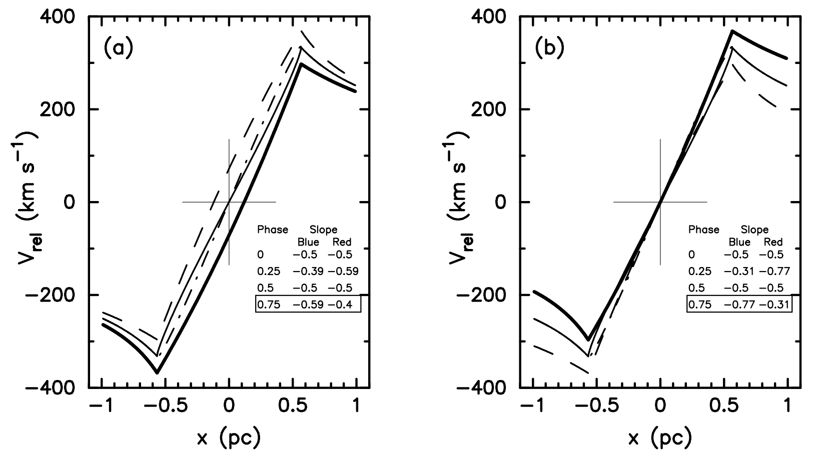

Figure 2. Position-velocity diagrams for the disk perturbed by the fundamental eccentric mode. In panel (a), the relative velocity is measured with respect to the systemic velocity, whereas in panel (b) it is measured with respect to the line-of-sight velocity of the systemic component at $x = 0$. Maser source is assumed to lie along the x-axis and along the inner radius of the maser emission region. The mass of the central black hole is $1.5 \times 10^7\, M_\odot$ and the inclination angle of the disk is 80°. The amplitude of the mode is normalized so that the maximum value of the velocity perturbation is 60% of the local Keplerian velocity. In the bottom-right part of each panel, the slope of $V_{\rm rel}$ distribution at each phase is given. Note that at phase 0.75 (thick solid line) the model reproduces the observed sub-Keplerian distribution. A thin solid line denotes the PV diagram at phase 0. The cross indicates the origin of the diagram.