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The Starburst-AGN Connection: 3-D Structure of the Massive Gas Disk around the Nucleus

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Abstract. The structure of obscuring matter in the environment of active galactic nuclei with associated nuclear starbursts is investigated using 3-D hydrodynamical simulations, in which the multi-phase inhomogeneous interstellar matter and its interaction with the supernovae are consistently followed. A globally stable, torus-like, but highly inhomogeneous and turbulent structure is found. To achieve the high column densities as suggested by observations of some Seyfert 2 galaxies with nuclear starbursts, the viewing angle should be larger than about 70° from the pole-on for a $10^8 M_\odot$ massive black hole. We propose that nuclear starbursts and the mass of the black hole that determines the geometry of the obscuring torus.

Optically thick obscuring molecular tori have been postulated to explain various properties of active galactic nuclei (AGN), especially the two major categories of the AGN, namely type 1 and type 2. However, the true structure and the formation and maintenance mechanism of the torus has not yet been understood either theoretically or observationally.

A number of observations have suggested that, in some Seyfert 2 galaxies, a nuclear starburst is associated with the obscuring material whose scale is $R < 100$ pc (Levenson et al. 2001). These observations imply that the classic picture of the unified mode for AGNs, in which the diversity of the Seyfert galaxies is explained only by the geometrical effect of the thick torus, may not be applicable to some fraction of the Sy2s.

Recently we presented high-resolution, 3-D hydrodynamical modeling of the interstellar medium in the central hundred pc region in galaxies, taking into account self-gravity of the gas, radiative cooling from 10 K to 10^8 K, and energy feedback from supernovae (Wada & Norman 2001; Wada 2001). In this paper, we apply this numerical method to the gas dynamics around the central massive black hole, and verify the starburst-AGN connection in Seyfert galaxies.

We solve the hydrodynamical equations numerically in 3-D to simulate the evolution of a rotating ISM around a super massive black hole (SMBH). We use the AUSM (Advection Upstream Splitting Method) for the hydrodynamical scheme, and $256^2 \times 128$ Cartesian grid points covering a $64^2 \times 32$ pc^3 region around the galactic center are used. The initial condition is an axisymmetric and rotationally supported thin disk with a uniform density profile (total gas

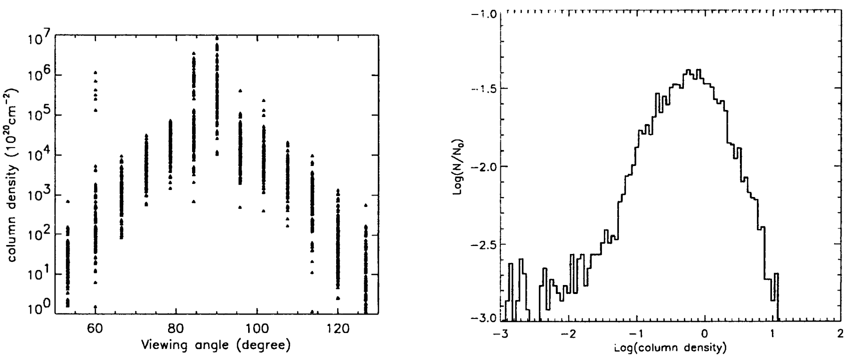

Figure 1. (left) Column density vs. viewing angle. The column density toward the nucleus is calculated for the density distribution of the result of a 3-D simulation. (right) Distribution function of the normalized column density

mass of $M_g = 5 \times 10^7 M_\odot$). SN explosions are assumed to occur at random positions in the disk. The energy of 10^{51} ergs is instantaneously injected into a single cell as thermal energy.

We find that the disk around the SMBH in a quasi-steady state has a torus-like structure, which looks like a 'concave lens'. The internal density structure is very inhomogeneous and filamentary. The local ($<$ several pc) inhomogeneous structure is time-dependent, but the global torus-like morphology does not significantly change during several rotational period.

In Fig. 1 (left), we plot line-of-sight column density of the gas as a function of the viewing angle (90° is edge-on). The column density is higher in edge-on view. To achieve $N > 10^{24}$ cm^{-2}, which is suggested in observations of Sy2s with nuclear starbursts, the viewing angle should be larger than $\sim 70°$ in this model. It should be noted, however, that the column density is very sensitive to the line-of-sight, and it has large (about two orders of magnitude) fluctuations for the same viewing angle. The column density distribution for each position angle has a Log-Normal distribution with a factor of 100 dispersion around the average (Fig. 1(right)). This is caused by the inhomogeneous internal structure of the torus. The volume density has a Log-Normal distribution function, which implies that the system is caused by a strong non-linear evolution (Wada 2001). A factor of 100 change in the average column density corresponds to about $\pm 20°$ in the viewing angle.

References

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