Cosmic MASERs: From Protostars to Blackholes
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H_2O maser emission from the Seyfert 2 Galaxy IC 2560: Evidence for a super-massive black hole and a probe for mass-accretion rate

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Abstract. Our observations of H_2O masers have detected some high-velocity features and a secular velocity drift of the systemic features in the Seyfert 2 Galaxy IC 2560. The high-velocity features were blue- and red-shifted from the systemic velocity of 220–420 km s^{-1} and 210–350 km s^{-1}, respectively. The velocity of the systemic features drifted at a secular rate of 2.62 km s^{-1} yr^{-1}. Assuming the existence of a compact rotating disk as in NGC 4258, IC 2560 possesses a nuclear disk with inner and outer radii of 0.07 pc and 0.26 pc, respectively, and a confined mass of $2.8 \times 10^6 M_\odot$ at the center, making the central density $> 2.1 \times 10^9 M_\odot$ pc^{-3}. Such a dense object cannot be a cluster of stars, and this strongly suggests that the central mass is a super-massive black hole. Since the 2–10 keV luminosity of IC 2560 is 1×10^{41} erg s^{-1}, the mass accretion rate of the suggested black hole must be $2 \times 10^{-5} M_\odot$ yr^{-1}.

1. Introduction

H_2O masers can be a powerful tool to study the structure and kinematics of molecular gas in active galactic nuclei (AGN). Because of its high brightness temperature, it is one of the few sources of line emission that can be observed using VLBI. By observing with VLBI, the distribution and motion of dense gas in the AGN can be detected on milliarcseconds (mas) scale and it is even possible to directly determine the distance to the galaxy and estimate the Hubble constant.

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Out of about 20 known megamasers, only the stronger ones can be observed with VLBI. Megamasers having peak flux density of ~ 0.3 Jy to several Jy have already been observed with VLBI techniques (e.g. NGC 4258, Miyoshi et al. 1995). We chose to study IC 2560, because although it has a relatively strong flux density of ~ 0.3 Jy, no VLBI observations have been done on this source.

The H_2O maser emission of IC 2560 was detected by Braatz et al. (1996), but only around the systemic velocity ($V_{\rm sys}$). IC 2560 is an SB(r)b galaxy (de Vaucouleurs et al. 1991) at α(J2000) = $10^{\rm h}16^{\rm m}18.71^{\rm s}$, δ(J2000) = $-33°33'49.74''$ (Ishihara et al. 2001). The systemic velocity of the galaxy, converted into the LSR frame and radio definition, is 2876 ± 20 km s^{-1} (Strauss et al. 1992). We adopted the distance to the galaxy to be 26 Mpc (Aaronson et al. 1989).

2. Nobeyama 45-m Observations and Results

The H_2O maser emission (rest frequency of 22.23508 GHz) from IC 2560 was observed using the 45-m telescope of the Nobeyama Radio Observatory (NRO) from 1996 January to 2000 June. The HPBW of the telescope was 74$''$, at 22 GHz, and the velocity resolution was 0.50 km s^{-1}. The observations covered the velocity range of $V_{\rm sys} \pm 1690$ km s^{-1}. Finally, the system noise temperature ranged between 170–300 K according to atmospheric conditions.

The averaged spectrum for all the observing period is shown in figure 1. In addition to the strong systemic features, we also detected the weaker high-velocity features. One group of features was blue-shifted from the $V_{\rm sys}$ by 220–420 km s^{-1}, and another group was red-shifted by 210–350 km s^{-1}. This is the first detection of these high-velocity features in this galaxy.

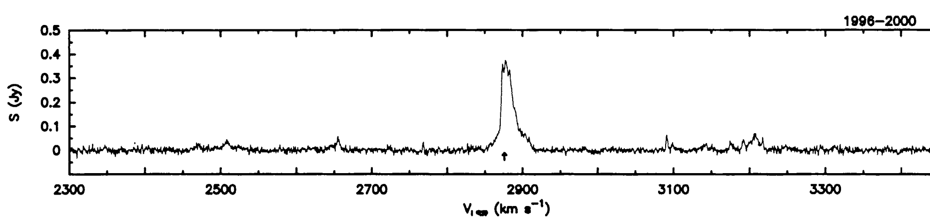

Figure 1. IC 2560 H_2O maser spectrum measured with NRO 45-m.

We also monitored the peak velocity of the strong features and detected a secular velocity drift. For the systemic features (figure 2a), a secular drift of 2.62 ± 0.09 km s^{-1} yr^{-1} was seen over the observing period of 4.4 yr. This is the third detection of this effect, after NGC 4258 (e.g. Nakai et al. 1995) and NGC 2639 (Wilson et al. 1995). For the red-shifted feature, there was no apparent change in velocity for 1.1 yrs (figure 2b), but a longer time monitoring is needed for confirmation.

3. The Nuclear Rotating Disk in IC 2560

From the single-dish observations, we know that: (1) the maser spectrum of IC 2560 shows systemic features plus the blue- and red-shifted features which

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are symmetric in velocity, and (2) the systemic features have a velocity drift which the high-velocity features do not have. Since these results are similar to NGC 4258 masers (e.g. Nakai et al. 1993; Miyoshi et al. 1995), it is likely that there is a nuclear rotating gas disk also in IC 2560 (figure 2c).

Assuming that we are viewing a circular rotating disk edge-on, the velocity drift of the systemic features comes from the acceleration of the rotating disk. Interpreting the maximum velocity offset of the high-velocity features (418 km s^{-1}) as the rotation velocity at the inner radius of the disk, the inner radius is given by r_{in} = 0.07 pc. If the disk is rotating in Keplerian motion, the outer radius is r_{out} = 0.26 pc. The mass confined within r_{in} is estimated to be $2.8 \times 10^6 M_\odot$, and the density must be at least $2.1 \times 10^9 M_\odot$ pc^{-3}. The nuclear disk in IC 2560 has the smallest r_{in} of the 5 megamasers showing evidence of nuclear disks. The confined mass is about an order of magnitude smaller, compared to the mass in NGC 4258, but the central density is relatively high among the megamasers with known disks.

4. Super-Massive Black Hole and Mass-Accretion Rate

If the nuclear mass of IC 2560 is a cluster of stars, the cluster lifetime will be restricted by either the stellar evaporation timescale or the collision timescale (Maoz 1998). For a cluster consisting of stars with a given mass, whichever is the shorter of these timescales will be the cluster lifetime. If this nuclear mass were a main-sequence-star cluster, its maximum lifetime would be 6×10^7 yr. This is much smaller than the age of the galaxy ($\sim 10^{10}$ yr), so observing such an object is not likely. The results were similar for white dwarfs, neutron stars, or brown dwarfs. The only thing that can be this massive, dense, and can still

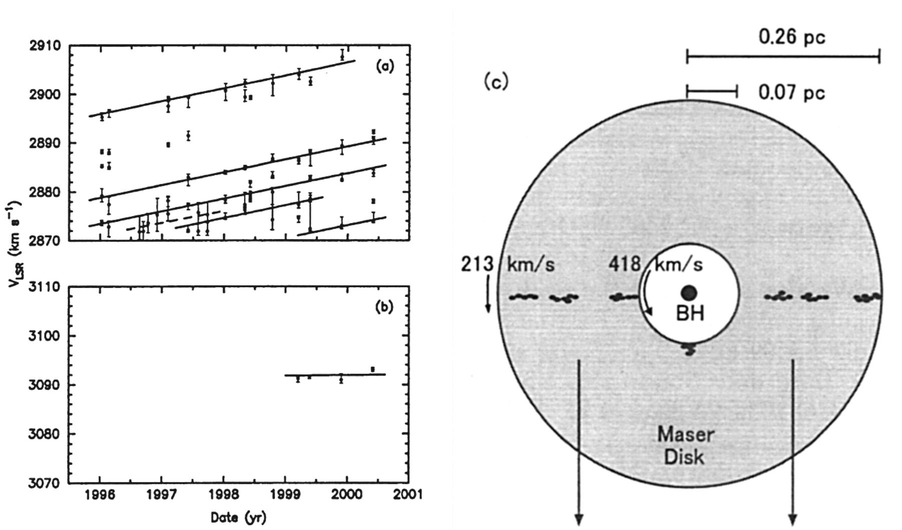

Figure 2. (a) The variation of the peak velocity of the systemic features at a rate of 2.62 km s^{-1}. (b) The variation of the peak velocity of the red-shifted feature. (c) The nuclear rotating disk.

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exist is a super-massive black hole, and the nuclear mass in IC 2560 seems to indicate that this one of them.

The mass-accretion rate onto this central black hole can be estimated using its X-ray luminosity. The X-ray emission of IC 2560 was observed by ASCA on 1996 December 19–20. By fitting the spectrum with a two-component model resulted in a 2–10 keV luminosity of 1×10^{41} erg s^{-1}. Using the standard accretion model and assuming that (1) a stable disk is formed outside 3 times the Schwartzschild radius, and (2) half the energy released until then turns into radiation, the mass-accretion rate must be $2 \times 10^{-5} M_{\odot}$ yr^{-1} in order to explain the X-ray emission. The mass-accretion rate for NGC 4258, calculated using the same method, is $8 \times 10^{-6} M_{\odot}$ yr^{-1}, so the accretion rates are similar for these two galaxies.

5. VLBA Observation

The H_2O maser of IC 2560 was observed by the VLBA, plus the phased VLA in 1998 January. At that time, the high-velocity features were not known, so the observation was only done in the velocity range of the systemic features. The synthesized beam size was 0.32 mas $\times$ 1.0 mas. The maser spots were distributed within 0.1 mas $\times$ 0.3 mas (0.01 pc $\times$ 0.04 pc at 26 Mpc). A velocity gradient of -0.85 km s^{-1} μas^{-1} (-6700 km s^{-1} pc^{-1} at 26 Mpc) was found in the right ascension direction, which is consistent with the nuclear rotating disk model.

Presently, another VLBA observation which includes the high-velocity features is planned to confirm the existence of a nuclear disk.

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