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Monitoring of extragalactic water masers with the MPIfR 100-m telescope

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Abstract. We present single-dish monitoring of the 22 GHz water maser lines from the Seyfert 2 galaxies NGC 3079, M 51(NGC 5194), NGC 5793, and the radio galaxy NGC 315 with the Effelsberg 100-m radio telescope. During the monitoring period of 1995 – 2001, the H_2O masers flared in M 51 and NGC 5793, while maser emission from NGC 315 was not detected in 1996 and 2000. During 2000, we discovered new red-shifted velocity features in NGC 3079 and blue-shifted features in M 51. These velocity components are crucial to model the distribution of maser emission in each galaxy.

1. Background

VLBI observations reveal that water vapour maser emission (rest frequency; 22.23508 GHz) provides a unique tool to image the central parsecs of active galactic nuclei (AGN). From NGC 4258, we learned that the water maser line emission traces a Keplerian torus around a central super-massive object (e.g, Miyoshi et al. 1995). How typical is such a Keplerian torus in the circumnuclear region of an AGN? To deduce statistical properties, as many megamasers as possible have to be studied in detail. Previous single-dish surveys discovered more than 20 extragalactic water masers (e.g, Braatz et al. 1997), but single-dish-survey detection rates of new H_2O megamasers remain quite low, $\sim 3\%$. However, from the presently known sample of sources we can already learn more about intensity variations and velocity drifts. Therefore we are monitoring megamasers at Effelsberg.

2. Observations & Results

The observations were made in 1995 – 2001 with the MPIfR 100-m telescope. Until 1998, the telescope was equipped with a K-band maser receiver with a system temperature ($T_{\rm sys}$) of 75 K on a $T_{\rm A}^*$ scale. The maser receiver was replaced by a low-noise dual polarization HEMT receiver with $T_{\rm sys} \sim 50$ K after combining both polarizations.

NGC 3079 Extremely luminous (~ 500 $L_\odot$) H_2O emission is seen in the Seyfert 2 nucleus. Most of the known emission is blue-shifted w.r.t $V_{\rm sys} = 1116$ km s^{-1}. The red-shifted emission is quite faint and less well studied. We have monitored

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NGC 3079 since 1995 over 12 epochs covering $V_{LSR} = 500 - 1550$ km s^{-1}. From Fig 1 a main feature centered on $V_{LSR} = 959$ km s^{-1} shows significant flux variations possibly anti-correlated with that of the feature at $V_{LSR} = 1020$ km s^{-1}. From Fig 2a, we can see several features with $\Delta v \sim 1$ km s^{-1} between $V_{LSR} = 950 - 990$ km s^{-1}. VLBI velocity resolutions better than 1 km s^{-1} are probably needed to separate these components. On the VLBI/sub-parsec-scale image, the 959 km s^{-1} feature arises within 0.01 pc with the rest of the blue-shifted emission at $V_{LSR} = 933 - 1043$ km s^{-1} distributed along the disk over $\sim$ 1 pc (Trotter et al. 1998). However, the red-shifted emission was imaged only in two spots that are 0.8 – 1.2 pc south of the blue-shifted emission. To understand the overall maser distribution which can explain the nuclear kinematics, VLBI mapping of the red-shifted emission is crucial. Fig 2b shows a spectrum of red-shifted features that appeared after March 2000, with detections at $V_{LSR} = 1185$, 1220, and 1265 km s^{-1}. There is nearly continuous line emission between 1185 and 1365 km s^{-1} with a notable "shell-like" structure between 1220 and 1265 km s^{-1}. The total luminosity of those features is only $\sim 0.1\ L_{\odot}$. The velocity of each feature is symmetric to the blue-shifted features. The features at 1265 and 957 km s^{-1} almost symmetrically bracket $V_{sys} = 1116$ km s^{-1}, Doppler-shifted by $\sim$ 150 – 160 km s^{-1}. The emission at 1220 and 1020 km s^{-1} lies offset by +104 and –96 km s^{-1} to V_{sys} (the systemic velocity has an uncertainty of a few km s^{-1}). With these new detections, we find that the blue- and red-shifted emission symmetrically straddle V_{sys}, possibly suggesting the presence of water emission in an edge-on rotating circumnuclear torus.

M 51 (NGC 5194) In Fig 3, we present monitored H_2O maser spectra of the nearby face-on galaxy M 51. Observations were made from 1995, but regular monitoring began since early 2000. With its low isotropic luminosity ($\sim 1\ L_{\odot}$) the maser emission is classified as *kilomaser*. Throughout the monitoring the red-shifted features centered on $V_{LSR} = 560$ km s^{-1} have been visible. After Nov. 2000, we detected a blue-shifted feature at $V_{LSR} = 435$ km s^{-1}. Both features bracket asymmetrically V_{sys} ($V_{LSR} = 467$ km s^{-1}). A 22 GHz VLA-A observation on Jan 23, 2001 resulted in the detection of the red-shifted emission. According to our preliminary analysis, an unresolved maser spot < 5 pc is located some 5 pc north of the 8.4 GHz radio continuum nucleus (Kaiser, Baan, & Bradley 2001). The maser emission could arise from a thin disk with a Keplerian rotation curve as observed in NGC 4258 (Miyoshi et al. 1995). Alternatively, the maser might be associated with the continuum bipolar outflow: a jet maser as in NGC 1052 (Claussen et al. 1998), Mkn 348 (Peck et al. these proceedings), and NGC 1068 (Gallimore et al. 1996). The large velocity-shift ($\sim$ 100 km s^{-1}) of the red-shifted emission can also be explained in terms of an association with the giant molecular cloud red-shifted $\sim$ 90 km s^{-1} w.r.t V_{sys}, as observed in CO(1-0) (Aalto et al. 1999). Further high-resolution observations are needed to distinguish these possibilities.

NGC 5793 The galaxy hosts an edge-on Seyfert 2 nucleus and compact radio core in its center. Hagiwara et al. (1997) first discovered systemic and satellite maser emission that lies symmetrically on either side of V_{sys} ($V_{LSR} = 3442$ km s^{-1}). Because of sensitivity, only the blue-shifted emission centered on 3190 km s^{-1} could be imaged with VLBI. The obtained image reveals that the barely

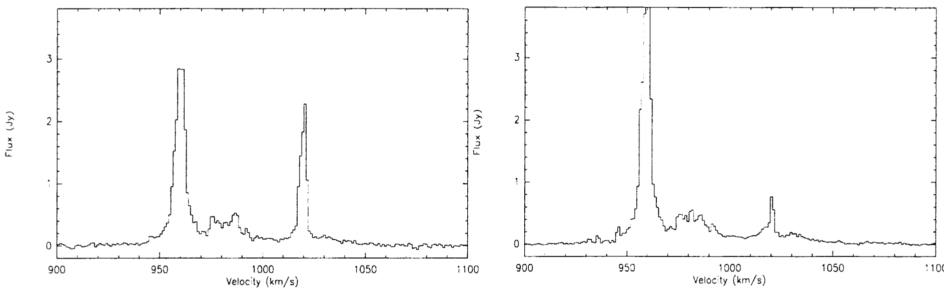

Figure 1. The blue-shifted velocity features of NGC 3079 observed in Mar.(left) and Dec. 2000 (right) (V_{sys} = 1116 km s^{-1}).

resolved maser emission has an extent of $\leq$ 1 mas, corresponding to 0.23 pc (D = 46 Mpc) and is located in the parsec-scale core-jet structure (Hagiwara et al. 2001). The systemic and red-shifted velocity features (V_{LSR} = 3370 – 3550 km s^{-1}) flared in early 2000, though the highly red-shifted narrow feature at 3677 km s^{-1} remained undetected since March 1996.

NGC 315 Broad H_2O maser emission was tentatively detected at Nobeyama in June 1996 towards the LINER nucleus of this radio elliptical galaxy. The emission seemed to be composed of systemic and high-velocity features red-shifted by 500 km s^{-1} w.r.t V_{sys} (V_{LSR} = 4843 km s^{-1}) (Nakai et al. 2001, in prep). Observations to confirm this marginal detection were conducted in Dec. 1996 searching for maser emission at V_{LSR} = 4460 – 5300 km s^{-1}, and resulted in non-detections at an rms noise of 20 - 70 mJy (channel spacing: $\Delta v \sim 0.7$ km s^{-1}). Observations made also in 2000 covered the velocity range V_{LSR} = 4500 – 5800 km s^{-1}. No maser emission was, however, detected at an rms noise of $\sim$ 5 mJy ($\Delta v \simeq 1$ km s^{-1}).

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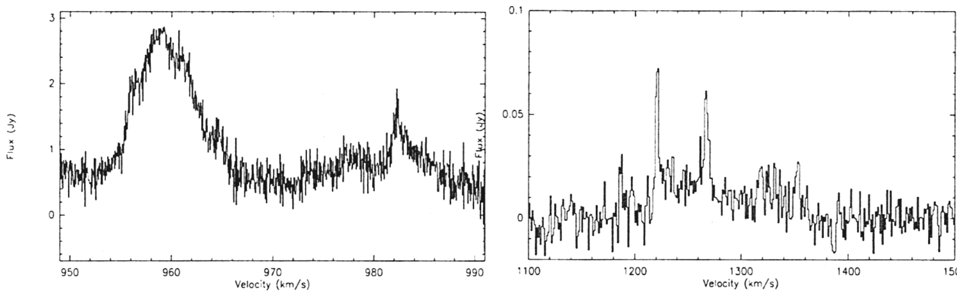

Figure 2. Details of the blue- and red-shifted emission in NGC 3079. a (*left*); Spectrum of the main feature with the highest velocity-resolution of 0.04 km s^{-1}, taken on August 2, 1998. b (*right*); The discovery spectrum of the red-shifted emission observed on December 21, 2000.

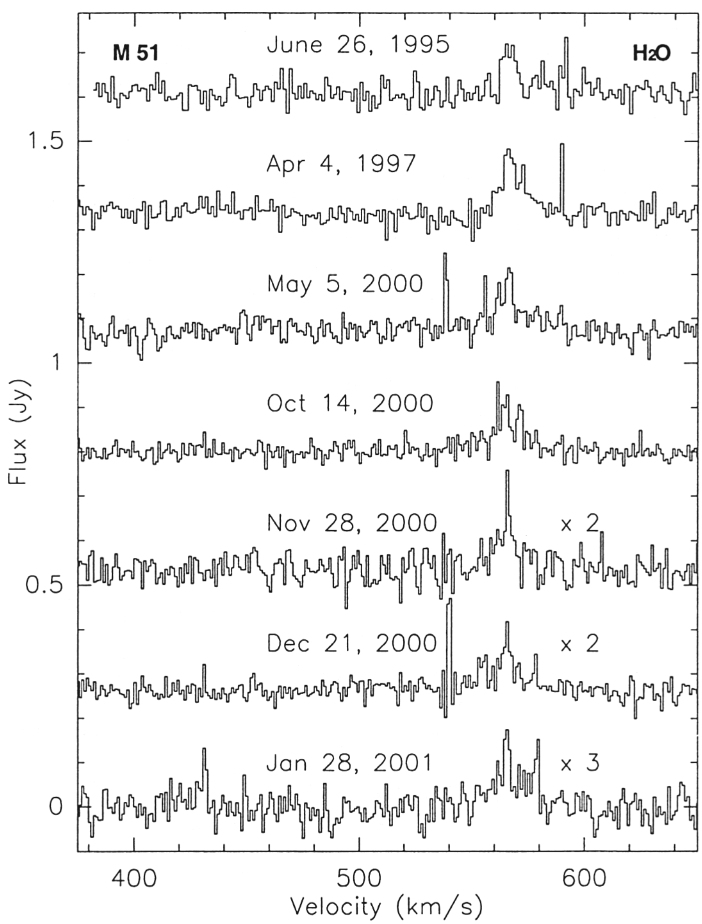

Figure 3. Monitored spectra of M 51 observed for seven epochs since 1995 (V_{sys} = 457 km s^{-1}). Note that amplitude scales after Nov. 2000 were multiplied by factors of 2 or 3.

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