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MERLIN water maser observations of the Seyfert 2 galaxy Mrk 348

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Abstract. MERLIN images of Mrk 348 at 22 GHz show H_2O maser emission at 0.02 – 0.11 Jy, within ~ 0.8 pc of the nucleus. This is the first direct confirmation that molecular material exists close to the Seyfert 2 nucleus. Mrk 348 was observed one month after Falcke et al. (2000) first identified the maser in single-dish spectra. The peak maser flux density has increased about threefold. The masing region is $\lesssim 0.6$ pc in radius. The flux density of radio continuum emission from the core has been rising for about 2 years. The maser-core separation is barely resolved but at the 3σ significance level maser and continuum peaks are not coincident along the line of sight. The masers lie in the direction of the northern radio lobes and probably emanate from material shocked by a jet with velocity close to c although direct maser amplification of the core by masers tracing a Keplerian disc is not completely ruled out.

1. Introduction

Falcke et al. (2000) reported the discovery of a very luminous H_2O maser in Mrk 348 during a radio flare of the AGN. Mrk 348 is a well studied Seyfert 2 at a redshift of 0.015, with broad emission lines in polarized light. However its host is an S0 galaxy at an angle of inclination of only $\approx 16°$ with a dust lane crossing the nucleus. It has a high x-ray-absorbing column depth of $N_{\mathrm{H}} = 10^{27.1}$ m^{-2} towards the nucleus. These observations suggest the presence of an obscuring torus in Mrk 348, but no molecular or H I absorption has been detected so far. Mrk 348 has a bright and variable inverted-spectrum radio nucleus. Jets at position angles (p.a.) $\sim 170°$ and $\sim 30°$ were observed at 1.6 and 5 GHz (Neff & de Bruyn 1983; Unger et al. 1984). Halkides et al. (1997) first resolved the central part of Mrk 348, using the VLBA at 15 GHz, into two components separated by ~ 0.3 pc at p.a. $\sim 90°$ to the larger 1.4 GHz jet. Ulvestad et al. (1999) noted a rise in continuum flux from 120 to 570 mJy between 1997.10 and 1998.75. We have used MERLIN to image the maser and continuum flares with sub-pc relative positional accuracy, and to investigate their relationship and origins in the core or in a nascent jet. In this paper all velocities are given relative to the local standard of rest (V_{LSR}) in the radio convention. The systemic V_{LSR} of Mrk 348 is $4435 \leq V_{\mathrm{sys}} \leq 4480$ km s^{-1}. We adopt $H_0 = 75$ km s^{-1} Mpc^{-1}, so Mrk 348 is at a distance of ~ 60 Mpc, where 1 mas = 0.29 pc.

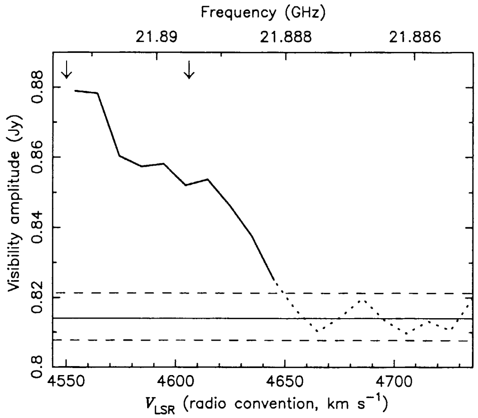

Figure 1. The total correlated flux density of Mrk 348 in each channel. The arrows mark the peaks observed by Falcke et al. (2000).

2. Observations and data reduction

We observed Mrk 348 on 2000 May 2 using MERLIN, which has a maximum baseline of 217 km, giving a beam size of 12 mas. In order to obtain images of Mrk 348 as rapidly as possible we observed for a single 17 hr run in the maximum 16 MHz bandwidth, which corresponds to a total velocity width of $\sim$ 200 km s^{-1} and only covers the red-shifted half of the line seen by Falcke et al. (2000). We observed at a fixed frequency of $\nu_0 = 21891.6$ MHz alternately with phase reference source J0057+3021 for 4 and 2 min respectively. 3C273 was used to set the flux scale and calibrate the bandpass. Standard data processing techniques were performed using AIPS. About 4.50 MHz of data at the low-frequency end of the bandpass were continuum-only and were used for self-calibration (applying the solutions to all data) and for continuum subtraction. Fig. 1 shows the maser+continuum (solid line) and continuum-only (dotted line) emission. The horizontal lines show the level of baseline we subtracted and the uncertainty.

The multi-channel Mrk 348 data were averaged over every 0.75 MHz to improve sensitivity. We produced three CLEAN data cubes: line-only, continuum-only and total emission, as well as a 4.25 MHz single-channel continuum map. We fitted 2D Gaussian components to emission above $3\sigma_{\mathrm{rms}}$ in each channel of every CLEAN map to determine the position and peak flux S_{p}. The continuum component S was resolved, giving a brightness temperature of 551 – 824$\times10^6$ K.

Peak	RA (J200)	Dec	σ_{pos} (mas)	S_{p} (mJy beam^{-1})	σ_{rms} (mJy beam^{-1})
S	$00^{\mathrm{h}}\,48^{\mathrm{m}}\,47^{\mathrm{s}}.14575$	$+31^\circ\,57'\,25''.1128$	0.2	744	6
N	$00^{\mathrm{h}}\,48^{\mathrm{m}}\,47^{\mathrm{s}}.14552$	$+31^\circ\,57'\,25''.1470$	0.4	239	6
M̄	$00^{\mathrm{h}}\,48^{\mathrm{m}}\,47^{\mathrm{s}}.14580$	$+31^\circ\,57'\,25''.1155$	0.7	24 – 107	8

Table 1. The positions and peak intensities S_{p} of the 22 GHz continuum and maser peaks in Mrk 348 N, S and M̄.

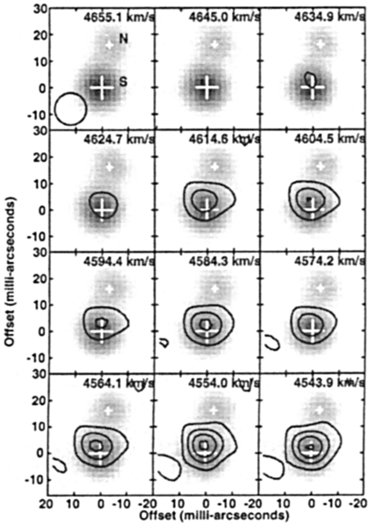

Figure 2. H_2O maser emission from Mrk 348 is shown by the contours, at (–1, 1, 2, 3, 4...)×20 mJy $beam^{-1}$. The grey scale shows continuum emission from 0 to 1 Jy $beam^{-1}$. The circular restoring beam of 12 mas FWHM is shown in the top left panel. The white crosses show the continuum peaks N and S, size proportional to the peak flux. The axes are labelled in mas offset from S. Each panel is labelled with the $V_{\rm LSR}$ (radio convention).

3. Discussion

These observations are the first direct detection of molecular material in the nuclear region of Mrk 348. The existence of H_2O implies shielding by a dusty medium with a column density $\gtrsim 10^{26} - 10^{27}$ m^{-2} and the conditions required for population inversion of the maser include a gas number densitity $\sim 10^{14} - 10^{16}$ m^{-3}, a fractional abundance of $H_2O \sim 10^{-5} - 10^{-4}$ and a temperature > 250 K. Conditions can be more tightly constrained depending on the association of the masers with a disc or a jet. We assume that the brightest 22-GHz continuum component S contains the core and 2-mas northern jet at position angle 15° found at 15 GHz. N is at a similar direction to the jet detected at 1.4 and 5 GHz at position angle 15° – 30°.

We consider three possible models for the relationship between the maser flare and the continuum flare: **(1)** The masers trace a small warped disc and the maser emission follows a Keplerian rotation law, and the masers directly amplify the continuum emission. **(2)** The masers are unsaturated and lie in a symmetric Keplerian nuclear disc. Perturbation of the disc creates spiral shocks which can preferentially excite maser emission on the red-shifted side of the disc and are also responsible for the continuum flare (Maoz & McKee 1998). **(3)** The radio continuum flare is associated with the ejection of material in the direction of the northern jet. The masers arise from the ISM where it is shocked by the jet. Our results show that model **(1)** is inconsistent with a Keplerian disc unless the masing material is infalling. Moreover the maser peak is consistently misaligned with S in every channel in Fig. 2. The 3σ position error boxes for $\bar{\mathsf{M}}$ and S (Table 1) are too close to rule out direct maser amplification of the continuum peak, but we consider other geometries are more probable. If the masers do lie in a disc our MERLIN results show the velocity gradient is ≤ 2 mas in 111 km s^{-1} corresponding to a radius $\lesssim 1.1$ pc. Even if the maser emission arises from only part of a disc orbiting the nucleus, such a disc would be elongated north-south, parallel to the radio jets. This is unlikely and so model **(2)** is also improbable.

$\bar{\mathsf{M}}$ is 0.8 ± 0.2 pc north of S. This is consistent with the $\lesssim 2$ yr time-lag between detection of the maser and continuum flares which (by the constraint of light-travel time) implies a separation of $\lesssim 0.6$ pc. Model **(3)**, in which the masers originate in a shock produced by the northern jet, is possibly due to the misalignment of the nuclear disc with respect to the host galaxy. If this material was ejected from the core when the continuum flare commenced $\lesssim 2$ years prior to the maser flare this implies speeds near c . The only previous detection of a relativistc Seyfert jet is in III Zw 2 (Brunthaler et al. 2000). However, Ulvestad et al. (1999) measured a jet speed of $\sim 0.07c$ for Mrk 348 on similar scales suggesting the jet power is rapidly dissipated once it reaches the shocked region. If the maser flare is not simply directly amplifying the radio continuum flare this indicates that there is some common excitation effect, possibly some sort of high level nuclear activity. If the masers are found along the radio jets, as is the case for NGC 1052 (Claussen et al. 1998), this mechanism for the correlation between the evolution of the maser flare and the radio flare is an important tool to study jet-ISM interactions.

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