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J. H. Knapen, J. E. Beckman, I. Shlosman, and T. J. Mahoney

VLBA Observations and Effelsberg Monitoring of a Flaring Water Maser in Mrk 348

A. B. Peck, H. Falcke, C. Henkel, K. M. Menten

Max-Planck-Institut für Radioastronomie, Auf dem Hügel 69, D-53121 Bonn, Germany

Abstract. We report on single-dish monitoring as well as extremely high angular resolution observations of the flaring H_2O maser in the Seyfert 2 galaxy Mrk 348. The H_2O line is redshifted by $\sim$130 km s^{-1} with respect to the systemic velocity, is very broad, with a FWHM of 130 km s^{-1}, and has no detectable high velocity components within 1500 km s^{-1} on either side of the strong line. Monitoring observations made with the Effelsberg 100m telescope show that the maser varies significantly on timescales as short as one day. VLBA observations indicate that the maser emission arises entirely from a region less than 0.25 pc in extent, located toward a continuum component thought to be associated with the receding jet.

1. Introduction

Mrk 348 (NGC 262) is a Seyfert 2 galaxy at a redshift of 0.01503 (Huchra *et al.* 1999). The galaxy is classified as an S0 with a low inclination, and exhibits a large H I halo which may have been produced by an interaction with the companion galaxy NGC 266 (e.g. Simkin *et al.* 1987). VLBA images (Ulvestad *et al.* 1999) reveal a small-scale double continuum source, the axis of which is aligned with the optical ([OIII], Capetti *et al.* 1996) emission. Astrometry indicates that the optical and VLBI cores are nearly coincident. Ground-based observations (Simpson *et al.* 1996) show evidence of a dust lane crossing the nucleus and an ionization cone. Attempts to detect the expected obscuring torus at radio wavelengths (e.g. H I, Gallimore *et al* 1999; CO, Taniguchi *et al.* 1990; free-free absorption, Barvainis & Lonsdale 1998) have not been successful.

The compact radio source in Mrk 348 is unique among Seyferts in that it is very bright and extremely variable. The observations presented here were made during a local minimum, when the total continuum flux density at 22 GHz was $\sim$0.6 Jy.

2. Observations

The initial detection of the flaring maser in Mrk 348 using the Effelsberg 100m telescope took place in 2000 March (see Fig. 1, 2nd profile). Re-analysis of previous data on this source (shown in the top profile, Fig. 1) indicates that the maser was also present but only marginally detectable in late 1997. The H_2O

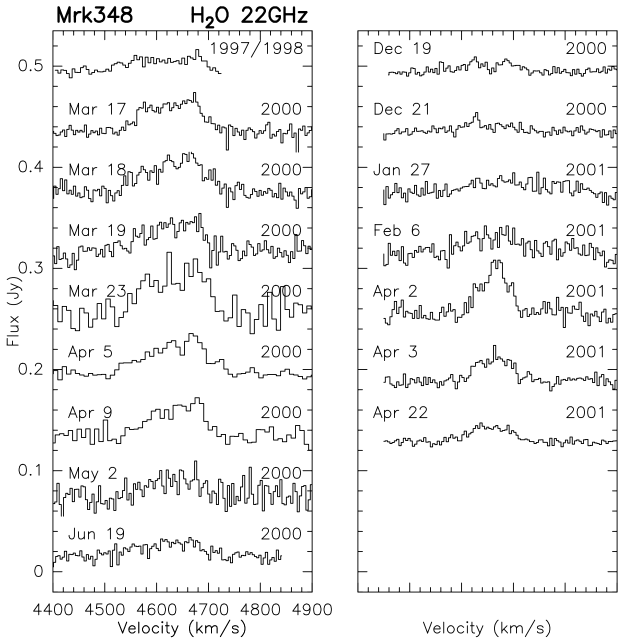

Figure 1. Single dish profiles from Effelsberg 100m telescope. The peak flux in the line was ∼40 mJy on April 9, but decreased to 18 mJy by June 19. In April 2001, the line peak again increased to 50 mJy, but the FWHM decreased to ∼65 km s^{-1}. This latest flare lasted only a few days.

maser line in Mrk 348 is extremely broad, with a FWHM of ∼130 km s^{-1}, though in many of the monitoring epochs the emission appears to consist of 2 lines which can be fit by Gaussian functions with FWHM of ∼60 km s^{-1} and ∼100 km s^{-1} respectively, separated by ∼70 km s^{-1}. There are no detectable high velocity components within 1500 km s^{-1} on either side of the strong emission line.

Monitoring through June 2000 showed that the maser again decreased to its original level within 2 months. The June profile (bottom profile, Fig. 1) indicates a peak flux of ∼18 mJy. This is consistent with the VLBA results shown in Fig. 2, taken on June 10, 2000. The monitoring observations indicated that the line was too broad (FWZP>250 km s^{-1}) to fit in a single 16 MHz VLBA IF, so 2 IFs of 16 MHz each were used, overlapped by 5 MHz. Following calibration, the overlapping channels were removed and the 2 IFs were added together to yield a single cube of 174 channels covering 23 MHz. Line profiles of the resulting cube are shown in Fig. 2, superimposed on a continuum map made from 20 line-free channels. The maser emission is clearly seen to lie along the line of sight to the jet, rather than the core which is thought to lie nearer the bright component of the continuum source. No maser emission is seen toward any other region of the radio source, only toward the jet, and here the maser emission is unresolved at our angular resolution of 0.42×0.76 mas. This corresponds to a linear size of less than 0.25 pc (assuming H_0=75 km $s^{-1}$$Mpc^{-1}$). The Gaussian fit to the line shown in the first profile has an amplitude of 16±2 mJy and an integrated flux of 2.4±0.3 Jy/beam/km s^{-1}, indicating that all of the flux measured in the Effelsberg 19 June observation has been recovered. The FWHM

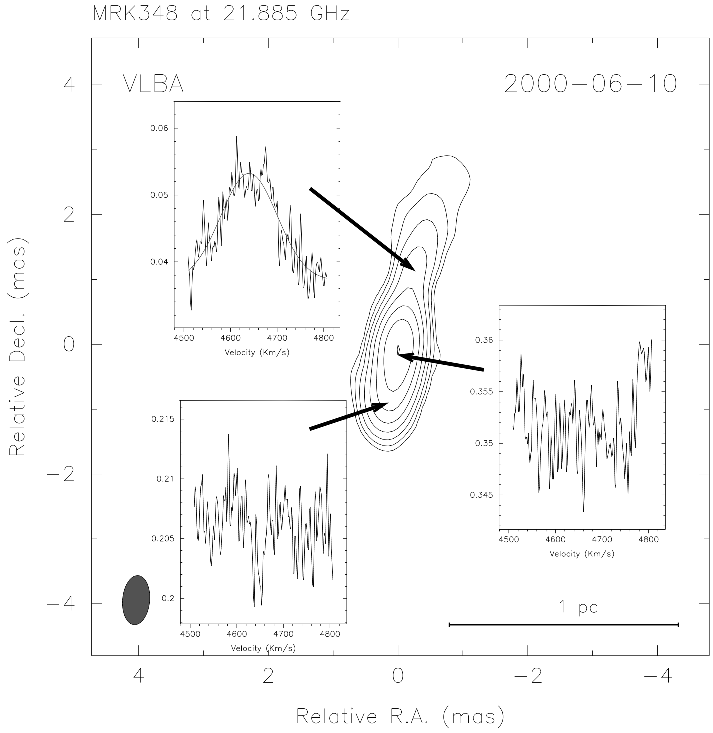

Figure 2. Line profiles from VLBI data. The continuum map is naturally weighted. The lowest contour is 3 mJy and the peak is 352 mJy. The RMS noise in the continuum map is <1 mJy/beam, and in the line profiles is ∼4 mJy/beam/channel.

is 142±9 km s^{-1} centered on V_{LSR}=4640±2 km s^{-1}, consistent with the single-dish measurements and redshifted by 131 km s^{-1} with respect to the systemic velocity. This redshift might indicate that it is the receding jet that impacts the molecular cloud, and that the masing gas is being entrained. A tentative 2 component fit to the H_2O profile yields a narrower line at 4683 km s^{-1} with FWHM ∼60 km s^{-1} and amplitude ∼8 mJy, and a broader line at 4620 km s^{-1} with FWHM ∼100 km s^{-1} and amplitude ∼12 mJy, again consistent with our single-dish measurements.

Resumption of the monitoring program at Effelsberg in December 2001 showed little change in the line flux, then in February another flare appears to have begun. The observations made in early April 2001 (see Fig. 1) show that the FWHM in the line decreased to 65 km s^{-1}, and the centroid increased from 4642 km s^{-1} to ∼4665 km s^{-1}. Thus it seems likely that only one of the two line components was flaring. Following this peak on 2 April, the line again began to decrease in flux. We are continuing our single-dish monitoring program at the Effelsberg telescope, and will attempt to observe with the VLBA during the next maser flare.

3. Conclusions

During early 2000, the H_2O emission toward Mrk 348 showed a dramatic intensity increase which coincided with a significant increase in the flux of the nuclear radio continuum source. The unusual line profile leads us to suspect that this source, and possibly NGC 1052, might belong to a class of megamaser galaxies in which the amplified emission is the result of an interaction between the radio jet and an encroaching molecular cloud, rather than occurring in a circumnuclear disk. Analysis of our recent VLBA observations indicates that the emission does indeed arise along the line of sight to the jet in Mrk 348 (see Fig. 2), confirming this prediction. The very high linewidth occurring on such small spatial scales indicates that the H_2O emission arises from a shocked region at the interface between the energetic jet material and the molecular gas in the cloud where the jet is boring through. This hypothesis is supported by the spectral evolution of the continuum source (Brunthaler, priv. comm.), which showed an inverted radio spectrum with a peak at 22 GHz, later shifting to lower frequencies. By analogy to IIIZw2 (Brunthaler *et al.* 2000) this would indicate the formation and evolution of very compact hotspots propagating through a dense medium. In this scenario, the recent high frequency radio continuum flare and the apparent northward movement of the brightest continuum component are attributable to the impact between the jet and the molecular cloud. This is consistent with recent VLBA continuum monitoring observations that show that the continuum source does not appear to be expanding (Ulvestad, *priv.comm.*), as one would expect from a hotspot or working surface. Rather the jet component toward which the maser appears might be associated with a stationary shock. The very close temporal correlation between the flaring activity in the maser emission and the continuum flare further suggest that the masing region and the continuum hotspot are nearly coincident and may be different manifestations of the same dynamical events.

References

Barvainis, R. & Lonsdale, C. 1998, AJ, 115, 885

Brunthaler, A., Falcke, H., Bower, G. C., Aller, M. F., Aller, H. D.,Teräsranta, H., Lobanov, A. P., Krichbaum, T. P. & Patnaik, A. R. 2000, A&A, 357, L45

Capetti, A., Axon, D. J., Macchetto, F., Sparks, W. B. & Boksenberg, A. 1996, ApJ, 469, 554

Falcke, H. Henkel, C., Peck, A. B., Hagiwara, Y., Prieto, M. A. & Gallimore, J. F. 2000, A&A, 358, L17

Gallimore, J. F., Baum, S. A., O'Dea C. P., Pedlar, A. & Brinks, E. 1999, ApJ, 524, 684

Huchra, J. P., Vogeley, M. S. & Geller, M. J. 1999, ApJS, 121, 287

Simkin, S. M, Su, H.-J., van Gorkom, J. & Hibbard, J. 1987, Science, 235, 1367

Simpson, C., Mulchaey, J. S., Wilson, A. S., Ward, M. J. & Alonso-Herrero, A. 1996, ApJ, 457, L19

Taniguchi, Y., Kameya, O., Nakai, N. & Kawara, N. 1990, ApJ, 358, 132

Ulvestad, J. S., Wrobel, J. M., Roy, A. L., Wilson, A. S., Falcke, H & Krichbaum, T. P. 1999, ApJ, 517, L81