A&A 394, L23–L26 (2002)
DOI: 10.1051/0004-6361:20021297

Astronomy & Astrophysics

Letter to the Editor

Discovery of water vapor megamaser emission from Mrk 1419 (NGC 2960): An analogue of NGC 4258?

C. Henkel[1], J. A. Braatz[2], L. J. Greenhill[3], and A. S. Wilson[4]

1 Max-Planck-Institut für Radioastronomie, Auf dem Hügel 69, 53121 Bonn, Germany
2 National Radio Astronomy Observatory, PO Box 2, Green Bank, WV 24944, USA
3 Harvard–Smithsonian Center for Astrophysics, 60 Garden St., Cambridge MA 02138, USA
4 Department of Astronomy, Univ. of Maryland, College Park, MD 20742, USA

Received 30 July 2002 / Accepted 6 September 2002

Abstract. Water vapor emission at 22 GHz is reported from the nucleus of the LINER galaxy Mrk 1419 (NGC 2960). Single-dish spectra of the maser source show properties that are similar to those seen in NGC 4258, namely (1) a cluster of systemic ($V \sim V_{\rm sys}$) H_2O features, (2) two additional H_2O clusters, one red- and one blue-shifted with respect to $V_{\rm sys}$, (3) a likely acceleration of the systemic features ($dV/dt = 2.8 \pm 0.5$ km s^{-1} yr^{-1}), and (4) no detectable velocity drifts ($<$1 km s^{-1} yr^{-1}) in the red- and blue-shifted features. Interpreting the data in terms of the paradigm established for NGC 4258, i.e. assuming the presence of an edge-on Keplerian circumnuclear annulus with the systemic emission arising from the near side of its inner edge, the following parameters are derived: $V_{\rm rot}$ = 330–600 km s^{-1}, $R \sim 0.13$–0.43 pc, binding mass $M \sim 10^7\ M_\odot$, and mass density inside the disk $\rho \sim 10^9\ M_\odot$ pc^{-3}. With the galaxy being approximately ten times farther away than NGC 4258, a comparison of linear and angular scales (the latter via Very Long Baseline Interferometry) may provide an accurate geometric distance to Mrk 1419 that could be used to calibrate the cosmic distance scale.

Key words. galaxies: active – galaxies: individual: Mrk 1419 (NGC 2960, UGC 05159) – galaxies: ISM – galaxies: nuclei – masers – radio lines: galaxies

1. Introduction

Water vapor masers provide the only emission lines from the accretion disks of active galactic nuclei (AGN) that can be spatially mapped. Our ability to image these objects comes about through the very high brightness provided by the maser process and the fortuitous location of a line at 1.3 cm (22 GHz), at which wavelength we are able to image with submilliarcsecond resolution. Very Long Baseline Interferometry (VLBI) images showed that, in the LINER galaxy NGC 4258, the water vapor megamaser arises in a thin, edge-on warped gaseous annulus between galactocentric radii of 0.16–0.28 pc (Greenhill et al. 1995b; Miyoshi et al. 1995; Herrnstein et al. 1999). Maser emission is observed both near systemic velocity, arising from clouds at the near side of the disk, and from "satellite lines" with velocities $\sim\pm900$ km s^{-1} w.r.t. systemic (Nakai et al. 1993), arising from gas at the tangent points with rotational velocities directed towards and away from Earth. The satellite lines show an accurately Keplerian rotation curve implying a central mass of $3.9 \times 10^7\ M_\odot$. The recessional velocities of the near systemic features are observed to be increasing at a rate of $\sim$9 km s^{-1} yr^{-1} (Haschick et al. 1994; Greenhill et al. 1995a; Nakai et al. 1995). This increase in velocity is caused by the centripetal acceleration of clumps of gas in the annulus as they move across our line of sight to the central core (e.g. Greenhill et al. 1994; Watson & Wallin 1994).

In this paper we report the detection of a luminous H_2O megamaser in the Sa LINER galaxy Mrk 1419 (NGC 2960, UGC 05159), that appears to be quite similar to the maser in NGC 4258.

2. Observations

We observed Mrk 1419 in the $6_{16}-5_{23}$ transition of H_2O (rest frequency: 22.23508 GHz) with the 100-m telescope of the MPIfR at Effelsberg[1] on January 28 and 30, March 12, May 7, December 15, 16, and 31, 2001, and on March 5, 2002. The beam width was 40″. The observations were made with a two channel K-band receiver in a dual beam switching mode with a beam throw of 2′ and a switching frequency of $\sim$1 Hz. System temperatures, including atmospheric contributions, were $\sim$100 K (Jan., Mar., Dec. 2001) and $\sim$150 K (May 2001, Mar. 2002) on a main beam brightness

Send offprint requests to: C. Henkel,
e-mail: chenkel@mpifr-bonn.mpg.de

1 The 100-m telescope at Effelsberg is operated by the Max-Planck-Institut für Radioastronomie (MPIfR) on behalf of the Max-Planck-Gesellschaft (MPG).

Article published by EDP Sciences and available at http://www.aanda.org or http://dx.doi.org/10.1051/0004-6361:20021297

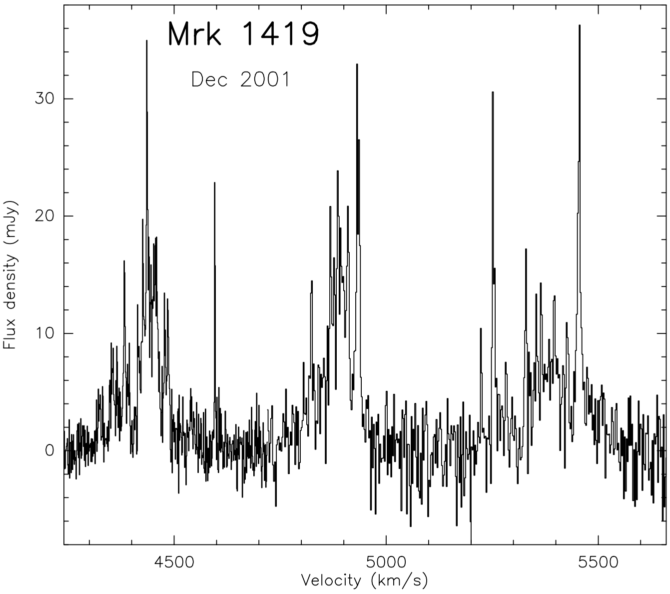

Fig. 1. Averaged 22 GHz H_2O spectrum of Mrk 1419 (α_{2000} = $9^h40^m36\overset{s}{.}5$, δ_{2000} = 3°34′38″) including data taken on Dec. 15, 16, and 31. The velocity scale is with respect to the Local Standard of Rest (LSR) and uses the optical convention that is equivalent to cz (V_{sys} = 4932 km s^{-1}; Braatz et al. 1997). Channel spacings are 2.18 km s^{-1} for the systemic and red-shifted and 1.09 km s^{-1} for the blue-shifted features.

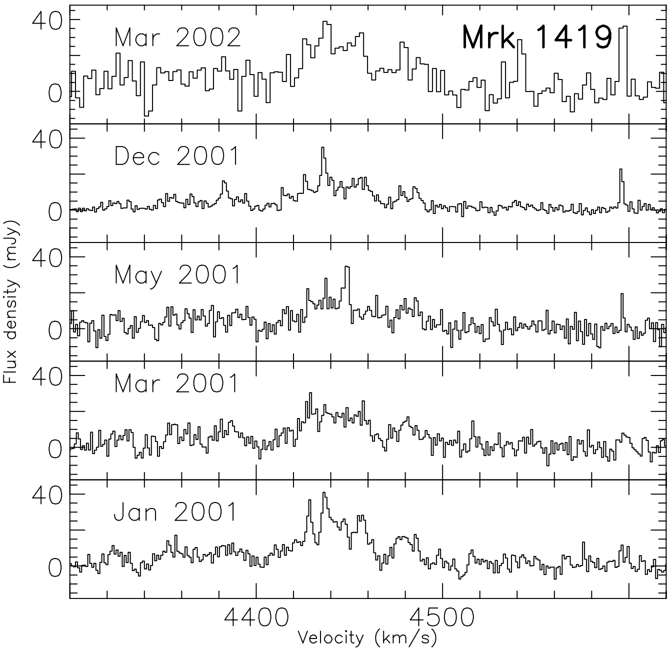

Fig. 2. Blue-shifted H_2O features of Mrk 1419. Channel spacings are 2.18 km s^{-1} for the upper panel and 1.09 km s^{-1} for the lower panels.

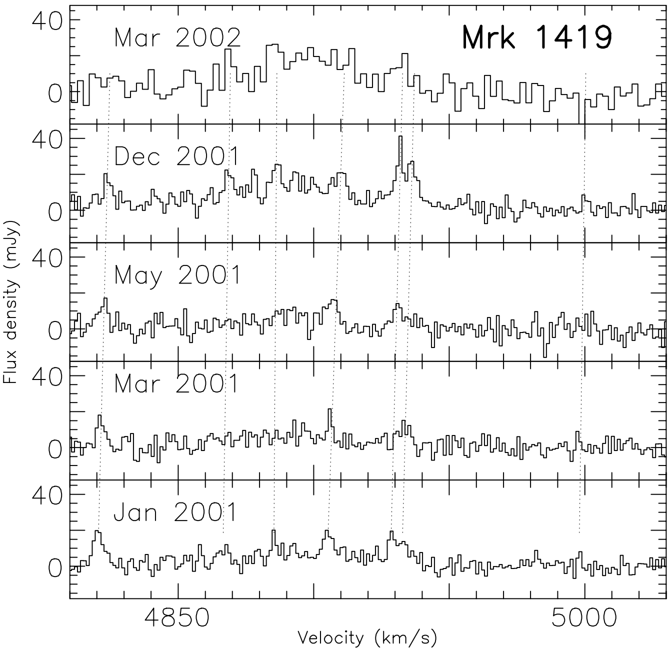

Fig. 3. Near systemic H_2O features of Mrk 1419. Dotted lines connect features detected both in Jan. and Dec. 2001 (for Gaussian fits, see Table 1). Channel spacings are 2.18 for the upper panel and 1.09 km s^{-1} for the lower panels.

temperature scale. An autocorrelator provided eight 40 MHz wide bands with 512 channels each, overlapped to produce a total bandwidth coverage of ≳100 MHz with dual polarization. Flux calibration was obtained by measuring 3C 286 (2.5 Jy). Gain variations of the telescope as a function of elevation were taken into account and the accuracy of the calibration should be better than ±25%. The pointing accuracy deduced from measurements of 0851+202, 0906+01, 3C 218 and 1127–14 was better than 10″.

3. Results

Figure 1 shows a characteristic 22 GHz H_2O spectrum of Mrk1419, displaying the velocity interval from 4240 to 5660 km s^{-1}. There are three groups of maser features: The blue-shifted components are found between 4320 and 4600 km s^{-1}, the red-shifted ones between 5200 and 5550 km s^{-1}, and the systemic ones between 4820 and 5000 km s^{-1}. Systemic line intensities are consistent with the upper limit provided by Braatz et al. (1996). The two gaps devoid of line emission have widths of 200–220 km s^{-1}. Figures 2–4 show 22 GHz H_2O spectra from all five epochs with an enlarged velocity scale. Data obtained within a month do not show significant differences and were averaged. Integrated fluxes of our most sensitive spectra, those taken during January and December 2001, are about 1.8 and 1.25 (blue-shifted), 0.75 and 1.55 (systemic) and 1.2 and 1.6 Jy km s^{-1} (red-shifted), respectively, implying total (isotropic) 22 GHz H_2O luminosities of ~350 and ~425 $L_\odot$ at these times (assumed distance: D = 65 Mpc). Not accounting for (possibly small) beaming angles, Mrk 1419 is thus one of the more luminous known H_2O megamasers. Some individual components show strong variability. The feature at ~5250 km s^{-1} varies in intensity by a factor ≳5; the ~5352.5 km s^{-1} component (Fig. 4) was only detected in January 2001.

On January 28, 2001, we searched for maser emission in a wide velocity range, from 3430 to 6500 km s^{-1}. No significant very blue or red feature was detected at noise levels of 7–10 mJy and channel spacings of 1.09 km s^{-1}.

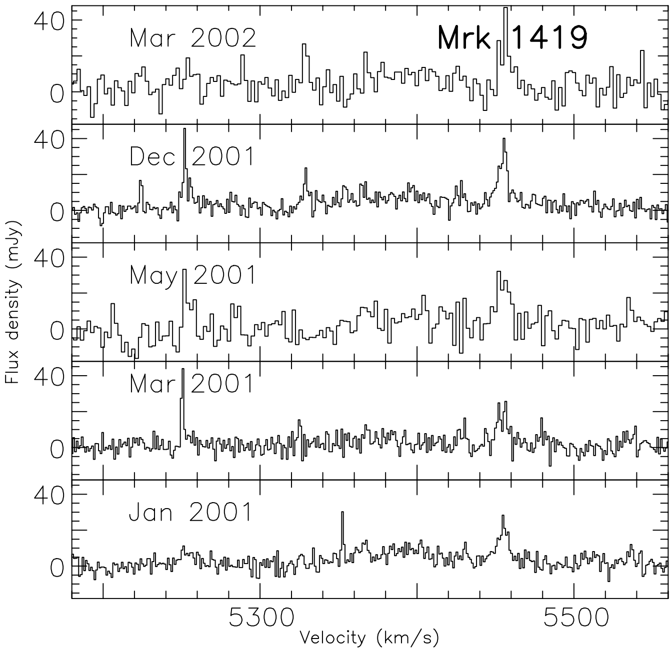

Fig. 4. Red-shifted H_2O features of Mrk 1419. Channel spacings are 2.18 for the May 2001 and March 2002 spectra and 1.09 $km\,s^{-1}$ for the other profiles.

Table 1. H_2O in Mrk 1419: radial velocities of systemic (left) and non-systemic (right) components detected both in January and December 2001.

Epoch			
2001.08	2001.97	2001.08	2001.97
4820.6 ± 0.3	4823.9 ± 0.3	4437.0 ± 0.2	4436.2 ± 0.2
4866.6 ± 0.8	4868.6 ± 0.5	4456.6 ± 0.5	4456.6 ± 0.7
4885.3 ± 0.3	4886.2 ± 0.4	4597.4 ± 0.6	4596.1 ± 0.1
4905.3 ± 0.3	4910.0 ± 0.5	–	–
4928.6 ± 0.3	4931.9 ± 0.1	–	–
4932.8 ± 0.9	4936.3 ± 0.3	5253.1 ± 1.1	5252.1 ± 0.1
4998.0 ± 0.2	5001.1 ± 0.4	5455.0 ± 0.4	5454.9 ± 0.3

4. Discussion

A comparison of Mrk 1419 with the best studied H_2O megamaser source, NGC 4258, shows a striking similarity: in both galaxies, there are systemic features as well as red-, and blue-shifted groups of H_2O components that symmetrically bracket V_{sys}. Furthermore, accounting for a ratio of ∼10 in recessional velocity and distance, the systemic features (a few Jy towards NGC 4258, a few 10 mJy towards Mrk 1419) show similar luminosities. An interpretation in terms of the NGC 4258-paradigm (H_2O emission from a Keplerian circumnuclear disk; see Sect. 1) is therefore suggestive. Detection of acceleration of the systemic features, caused by centripetal acceleration at the front or back side of the putative edge-on disk, and the absence of such a drift in the non-systemic features from the tangentially seen parts of the disk would provide independent evidence and would go a long way towards confirming an analogous model to that already established for NGC 4258.

Figure 5 shows radial velocities for blue, systemic, and red features (as shown in Figs. 2–4, respectively) as a function of time. Our most sensitive spectra are from Jan. and Dec. 2001. Connecting systemic features observed during both epochs (dotted lines in Fig. 5, central panel) a positive drift is detected in each of a total of seven components. This is also shown in Fig. 3, where dotted lines connect the line peaks obtained from Gaussian fits. Velocities and standard deviations of these components are given in Table 1. Fits to the data lead to an acceleration of 2.8 ± 0.5 $km\,s^{-1}\,yr^{-1}$, the error being the standard deviation of the mean. Assuming a normal error distribution, the likelihood of an acceleration <1.0 $km\,s^{-1}\,yr^{-1}$ is $\sim 10^{-4}$. For all seven components the measured acceleration is larger than the sum of the related standard deviations (the scatter can be explained by groups of individual maser features with varying intensities (e.g. Genzel & Downes 1977)). The corresponding drift for the red- and blue-shifted components (-0.6 ± 0.3 $km\,s^{-1}$) is not significant and the likelihood for an overall acceleration within $|\dot{V}_{drift}| < 1$ $km\,s^{-1}\,yr^{-1}$ is ∼90%.

Having demonstrated that the systemic features likely show a secular acceleration, while the red- and blue-shifted components lack a similar drift, it makes sense to assume that the maser emission in Mrk 1419 arises from an almost edge-on circumnuclear annulus like that in NGC 4258. Assuming similar morphologies for NGC 4258 and Mrk 1419, no interferometric data are needed to estimate the size of the disk and the mass enclosed (for equations, see e.g. Ishihara et al. 2001). Assuming that the systemic emission arises (as in NGC 4258) from the near side of the inner edge of the annulus, where Keplerian velocities are highest, the difference in velocity between systemic and red- and blue-shifted features (see Figs. 2–4) gives $V_{rot,in} = 600 \pm 20$ $km\,s^{-1}$. $V_{rot,in}$, the velocity drift mentioned above, and an assumed inclination of 90° then yield a radius $R_{in} = 0.13 \pm 0.03$ pc for the inner edge of the disk ($R \propto V_{rot}^2$, so the disk would be smaller if the systemic features do not arise from the inner edge but farther out). For the outer edge with $V_{rot,out} \sim 330 \pm 20$ $km\,s^{-1}$ (Figs. 2–4), we then find $R_{out} = (V_{rot,in}/V_{rot,out})^2 \times R_{in} \sim 0.43 \pm 0.08$ pc. The full angular extent of the disk should thus not greatly exceed 2 mas (D = 65 Mpc). Still assuming that the systemic features arise from the inner edge, the binding mass and the mass density encircled by the disk become $1.1 \pm 0.3 \times 10^7$ $M_\odot$ and $1.2 \pm 0.4 \times 10^9$ $M_\odot\,pc^{-3}$, respectively.

5. Concluding remarks

All four galaxies with (putative) circumnuclear H_2O disks and reported velocity drift of the systemic emission (NGC 4258, Mrk 1419, NGC 2639, Wilson et al. 1995; and IC 2560, Ishihara et al. 2001) show galactic stellar disks seen at intermediate inclination. The (presumably) edge-on nuclear disks are therefore substantially inclined relative to the plane of the parent galaxies as has also been inferred for Seyfert galaxies from the orientation of their nuclear radio continuum ejecta (e.g. Ulvestad & Wilson 1984). None of the sources shows negative acceleration, a characteristic of emission from the far side of the disk. Although there may be no masers there, symmetry arguments suggest that instead, absorption in the vicinity of the central engine blocks our view toward the back side of the circumnuclear disk. That red, blue, and systemic features

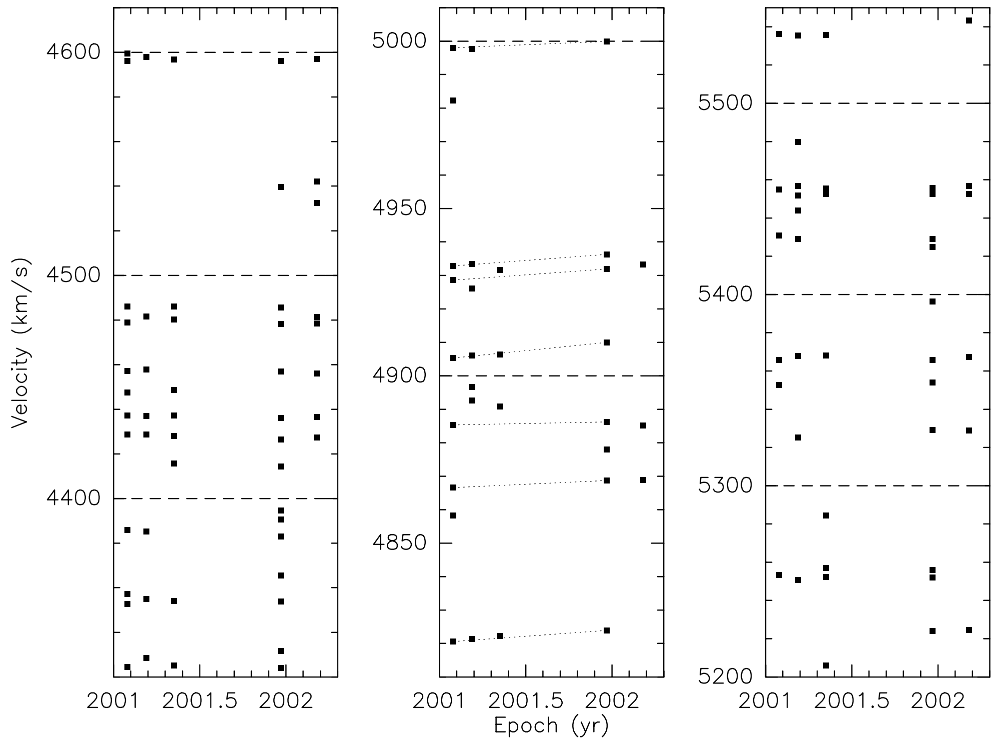

Fig. 5. Velocities of individual H_2O features obtained from Gaussian fits with standard deviations of 0.1–1.8 km s^{-1}. From left to right the blue-shifted, systemic, and red-shifted components of Mrk 1419 are shown as a function of time. Dotted lines (central panel) connect systemic features detected in both Jan. and Dec. 2001 (see Sect. 4).

have similar intensities is unique to Mrk 1419, but it is not yet possible to judge why the source is different. Mrk 1419 should become an important target for a direct determination of the geometric distance of a galaxy approximately ten times as distant as NGC 4258 (for NGC 4258, see Herrnstein et al. 1999; Maoz et al. 1999). A measurement of the distance requires detailed mapping of the structure of the disk via VLBI. *If* a simple disk model can be established, the resulting distance could then be used to check calibration of more common optical or near infrared distance indicators, thus helping to establish the cosmic distance scale reliant at least in part on geometric arguments.

Acknowledgements. This research was supported by the National Science Foundation through grant AST 9527289 to the University of Maryland.

References

Braatz, J. A., Wilson, A. S., & Henkel, C. 1996, ApJS, 106, 51
Braatz, J. A., Wilson, A. S., & Henkel, C. 1997, ApJS, 110, 321
Genzel, R., & Downes, D. 1977, A&AS, 30, 145
Greenhill, L. J., Jiang, D. R., Moran, J. M., et al. 1994, Highlights in Astronomy 10, ed. I. Appenzeller (Dordrecht, Kluwer), 531
Greenhill, L. J., Henkel, C., Becker, R., Wilson, T. L., & Wouterloot, J. G. A. 1995a, A&A, 304, 21
Greenhill, L. J., Jiang, D. R., Moran, J. M., et al. 1995b, ApJ, 440, 619
Haschick, A. D., Baan, W. A., & Peng, E. W. 1994, ApJ, 437, L35
Herrnstein, J. R., Moran, J. M., Greenhill, L. J., et al. 1999, Nature, 400, 539
Ishihara, Y., Nakai, N., Iyomoto, N., et al. 2001, PASJ, 53, 215
Maoz, E., Newman, J. A., Ferrarese, L., et al. 1999, Nature, 401, 351
Miyoshi, M., Moran, J. M., Herrnstein, J. R., et al. 1995, Nature, 373, 127
Nakai, N., Inoue, M., & Miyoshi, M. 1993, Nature, 361, 45
Nakai, N., Inoue, M., Miyazawa, K., Miyoshi, M., & Hall, P. 1995, PASJ, 47, 771
Ulvestad, J. S., & Wilson, A. S. 1984, ApJ, 285, 439
Watson, W. D., & Wallin, B. K. 1994, ApJ, 432, L35
Wilson, A. S., Braatz, J. A., & Henkel, C. 1995, ApJ, 455, L127