A SUPERMASSIVE OBJECT IN THE NUCLEUS OF NGC 4258?

L. J. GREENHILL, D. R. JIANG, J. M. MORAN AND M. J. REID
Harvard-Smithsonian Center for Astrophysics
60 Garden St, Cambridge, MA 02138 USA

K.-Y. LO
Department of Astronomy, University of Illinois
1002 W. Green St, Urbana, IL 61801 USA

M. J. CLAUSSEN
National Radio Astronomy Observatory
P. O. Box O, Socorro, NM 87801 USA

C. HENKEL AND T. L. WILSON
Max-Planck-Institut für Radioastronomie
Auf dem Hugel 69, D-53121 Bonn, Germany

R. BECKER
GKSS Forschungszentrum, Institut für Physik
Max-Planck-Strasse, D-21502 Geesthacht, Germany

AND

J. G. A. WOUTERLOOT
I. Physikalisches Institut
Universität zu Köln, Zülpicher Str. 77, D-50937 Köln, Germany

Abstract.
    VLBI images of the H_2O megamaser in NGC 4258 and a time series of spectra taken over several years combine to make a compelling case that there is a compact molecular disk associated with a supermassive object in the nucleus of this galaxy. The images of the maser in the velocity range near the systemic velocity show a highly elongated structure with a major axis of about 0.009 pc, along which the gradient in line-of-sight velocity is essentially a constant of 7970 ± 40 km s^{-1} pc^{-1}. The observed acceleration of these spectral features by about 6–11 km s^{-1} yr^{-1}, the presence of high-velocity maser satellite emission, and the VLBI results suggest emission

from a disk of diameter 0.2 pc, rotating with a velocity of ~ 800 km s^{-1}, bound by a mass of 1.5×10^7 M$_\odot$ and density of $\gtrsim 3.6 \times 10^9$ M$_\odot$ pc^{-3}.

1. Introduction

The H$_2$O maser in NGC 4258, with an apparent luminosity > 50 $L_\odot$ on the assumption of isotropic emission of radiation, is among 13 known extragalactic H$_2$O "megamasers". Subarcsecond astrometry shows that at least three are associated with galactic nuclei and that the maser emission arises at projected distances of less than a few parsecs from the compact radio continuum sources (Claussen & Lo 1986). There is no accepted mechanism that explains the extraordinary apparent luminosity of these megamaser sources. They either mark individual sites of star formation, as in our galaxy, or sites of energetic interactions between outflows (e.g., jets) or intense high-energy radiation fields (e.g. X-ray) and ambient material (Elitzur 1992, Neufeld et al. 1994).

The megamaser in NGC 4258 is a potentially important diagnostic tool for understanding the galaxy's active nucleus, which contains a radio jet and a twisted optical jet (Cecil et al. 1992) whose orientation is almost north–south within the innermost 1 kpc of the nucleus (Cecil et al. 1995). We assume a distance of 7 Mpc for the galaxy (cf. Courtès et al. 1993).

Recently, Nakai et al. (1993) discovered high-velocity maser emission symmetrically offset from the systemic velocity by about ± 800 km s^{-1}, with the redshifted emission arising within 0″05 (1.7 pc) of the emission at the systemic velocity of the galaxy. In addition, many of the low-velocity maser features appear to drift in concert by about 6–11 km s^{-1} yr^{-1} (Haschick et al. 1994, Greenhill et al. 1995a). Features fade away at the high velocity end of the systemic velocity group and new ones appear at the low velocity end such that the mean velocity of the group remains nearly constant and close to the systemic velocity of the galaxy.

2. Evidence for a Disk

We observed the megamaser with a 4 station VLB array. Preliminary reduction of the data was presented by Claussen et al. (1988). Synthesis imaging shows that the spectral features are spatially unresolved and distributed along a line in the sky, subtending about 260 μas in angle (0.009 pc) at a position angle of $83° \pm 2°$ (Figure 1). The distribution of the maser emission exhibits a linear gradient of position with line-of-sight velocity of 3.70 ± 0.02 μas km^{-1}s or 7970 ± 40 km s^{-1} pc^{-1} along the major axis (Figure 2). The elongation and velocity gradient suggests the maser emission lies in

a rotating disk that is viewed edge-on. In the model, maser emission traces only a small arc along the near side of the disk, where it amplifies continuum emission from the massive central source. The high-velocity emission arises at the edges of the disk where the line of sight is tangent to it (Watson & Wallin 1994, Greenhill et al. 1995b).

The radius of the disk, extrapolated from the gradient, is $\sim$ 0.1 pc, where the rotational velocity of the disk at this radius is about 800 km s^{-1}. The anticipated drift in the velocities of the low-velocity spectral features (V^2/R) is about 7 km s^{-1} yr^{-1}. This is close to the observed values of $6-11$ km s^{-1} yr^{-1} (Haschick et al. 1994 and Greenhill et al. 1995a), and is inversely proportional to the assumed distance to the galaxy. Of equal importance, the drift of the high-velocity features is $\lesssim$ 1 km s^{-1}yr^{-1}, as expected for the disk model (Greenhill et al. 1995a). It is unlikely that the acceleration of spectral features is an artifact of relative intensity variations among blended lines. The binding mass for this system is 1.4×10^7 M$_\odot$, and the mass of the gas in the disk is $\lesssim 10^6$ M$_\odot$, precludes solid-body rotation. The tight correlation of position and velocity suggests that the maser emission is confined to a thin annulus, of faction radial thickness $\lesssim$ 0.2. This width together with a 50 μas upper limit on the north-south extent of the emission limits the inclination of the disk to $\lesssim$ 5°. A revised distance of 5.4 ± 1.0 Mpc can be computed based on the geometry of this disk model.

The diameter of the molecular ring is smaller than that often predicted for active nuclei (Antonucci 1993, and references therein). However, Gwinn et al. (1993) may also have evidence, from H$_2$O maser emission, for a disk of similar dimension in the Seyfert NGC 1068. The strongest confirmation of the disk model for NGC 4258 will be the VLBI measurements of the relative positions and proper motions of the low and high-velocity emission. A motion of 800 km s^{-1} (25 μas yr^{-1}) could be observed in $\sim$ 1 yr.

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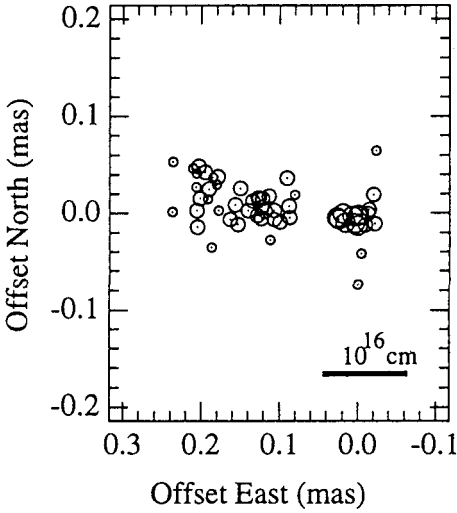Watson, W. D. & Wallin, B. K. 1994, ApJ, 432, L35

Figure 1. - Distribution of megamaser emission from VLBI observations with resolution ~0.1 mas. Each circle represents emission over 1.3 km/s. The areas are proportional to the peak flux densities.
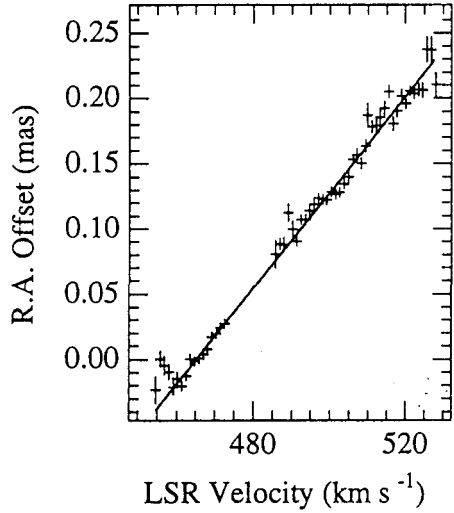
Figure 2. - Position-velocity gradient in the megamaser emission. The fitted line has a slope of 3.67 μas/km/s.
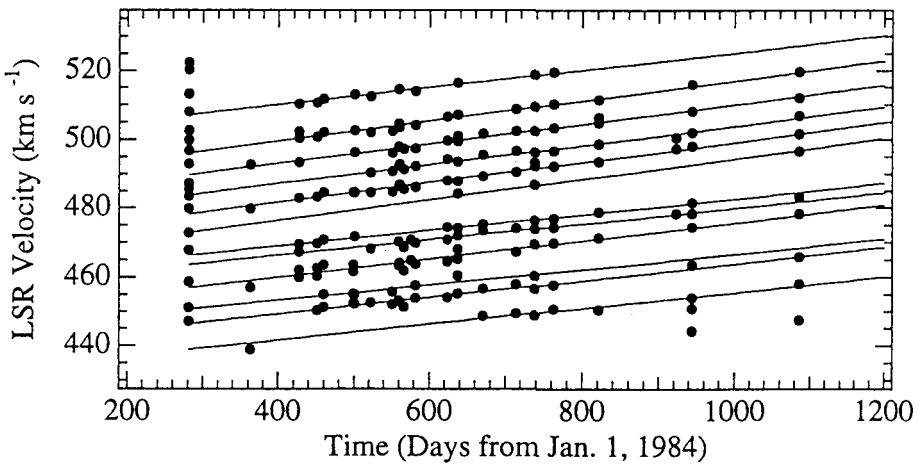

Figure 3. Velocities of 12 maser features followed through 20 epochs over 2 years. The average drift is 9.5 km/s/yr.