Cosmic MASERs: From Protostars to Blackholes
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Testing extragalactic H_2O masers against the thin disk model: the present and the future

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Abstract. Water maser emission is detected towards the nuclei of 22 galaxies, all of them showing some sign of nuclear activity. Except for a couple of cases, maser features have been found only within 150 km s^{-1} of the systemic galaxy recession velocity but are often offset from systemic within that window. Spectral features in maser-detected galaxies are monitored regularly and these observations show that velocity drifts like those seen in the systemic masers of NGC 4258 are rare. Hence the conclusion that either masers in other galaxies are generally located farther from the central black hole than in NGC 4258, that the black holes in those galaxies are less massive than the one in NGC 4258, or that the masers' acceleration is in the plane of the sky (as in the case of maser gas at the projected extremities of an edge-on disk). Assuming the disk model holds, the last of these options leads to the possibility that, despite the relative faintness of high velocity maser features in the case of NGC 4258, the brightest maser emission originates from the projected edges of the disk, in general. A selection effect would have caused a bias, then, in previous surveys whereby masers in larger, more slowly rotating disks are favorably detected. New wide-bandwidth capabilities at the 100-m Effelsberg telescope and the emergence of the GBT will help to overcome any such bias and provide new examples of maser sources.

1. Introduction

The majority of surveys for H_2O masers towards galactic nuclei have utilized a single tuning of the spectrometer backend near the systemic velocity of the galaxy. Typical bandwidths have ranged from 40 MHz to 64 MHz, giving a total useful velocity coverage of 500 – 800 km s^{-1} at the frequency of the water maser line, 22.23508 GHz. These surveys have covered roughly a thousand unique galaxies and have yielded 22 detections. A catalog of survey results is available at http://www.gb.nrao.edu/~jbraatz/H2O-list.html.

The most spectacular of the masers is that in NGC 4258, which has components near the systemic velocity and others offset by $\pm$ 1000 km s^{-1}. Regular monitoring of its maser spectrum shows that systemic components drift redward in velocity at a rate of about 9 km s^{-1} yr^{-1} while the high velocity components show only negligible velocity drifts (Bragg et al., 2000). According to the thin, edge-on disk model revealed by VLBI observations (Miyoshi et al., 1995), the velocity drifts are understood to result from the centripetal acceleration of the

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masing gas. Those components along the extreme edges of the projected disk are accelerated in the plane of the sky and so the drifts are negligible there.

2. Maser Monitoring

Twelve extragalactic maser sources have been observed periodically to search for changes in their spectral profile. Complete results of these observations are presented by Braatz et al. (2001). Only one maser source from those monitored - NGC 2639 - has a velocity drift analogous to that in NGC 4258, although slower drifts in NGC 1068 (Baan & Haschick 1996) and IC 2560 (Ishihara et al., 2001) are reported by others. In the rest of the monitored sources, maser components tend to remain at a fixed velocity with upper limits < 1 km s^{-1} yr^{-1}, and in many cases (e.g. Mrk 1210, IC 1481, NGC 1386, Mrk 1, NGC 4945, NGC 5506) at least some of the maser components are offset from the systemic velocity by up to 150 km s^{-1}.

Figure 1 shows a sample of the maser monitoring data, that for IC 1481, which has been monitored for nearly 6 years. The lines shown in the figure are redshifted from the systemic velocity, 6122 km s^{-1} (LSR), and show no discernible velocity drift over the monitoring period. It is noteworthy, too, that no maser features are detected near the systemic velocity. Sand, Braatz and Greenhill (1999) observed the maser and continuum sources in this galaxy with the VLA and reported the tentative detection of an offset between the positions of the peak continuum and peak maser equal to 14 ± 4 mas (5 pc at the distance of IC 1481). One might suppose that the maser lines detected here are from the projected edge of a disk, albeit a slowly rotating one. In analogy with NGC 4258 where the mas-scale continuum points to the nucleus and the high velocity features point to the projected edge of the disk, one can speculate that the separation corresponds to the radius of the maser disk in IC 1481. With the radius and rotation velocity (~ 120 km s^{-1}) known, the black hole mass can be calculated at 1.7×10^7 $M_\odot$. This measurement is extremely speculative but it does demonstrate a powerful technique for probing black hole masses which might prove important as more sensitive observations become available.

3. New Maser Searches

The maser in NGC 4258 allows for detailed studies of the inner parsec of its AGN due to the kinematically clean disk there. It seems, though, that NGC 4258 is not typical among the group of 22 known extragalactic masers both in its clean disk structure revealed by VLBI imaging and in the characteristics of its spectrum. The brightest features of NGC 4258, for example, are right on the systemic velocity while high velocity lines are much fainter. In other galaxies, the brightest features have modest offsets from the systemic velocities, but no additional high velocity lines are detected. That the maser components remain at fixed velocity over time suggests that those modestly offset masers may be analogous to the high velocity features in NGC 4258. It is likely, then, that maser surveys have been biased due to the limited search windows available during a single tuning for those searches. That is, previous surveys favor detecting masers whose high velocity features are within a few hundred km s^{-1} of the systemic

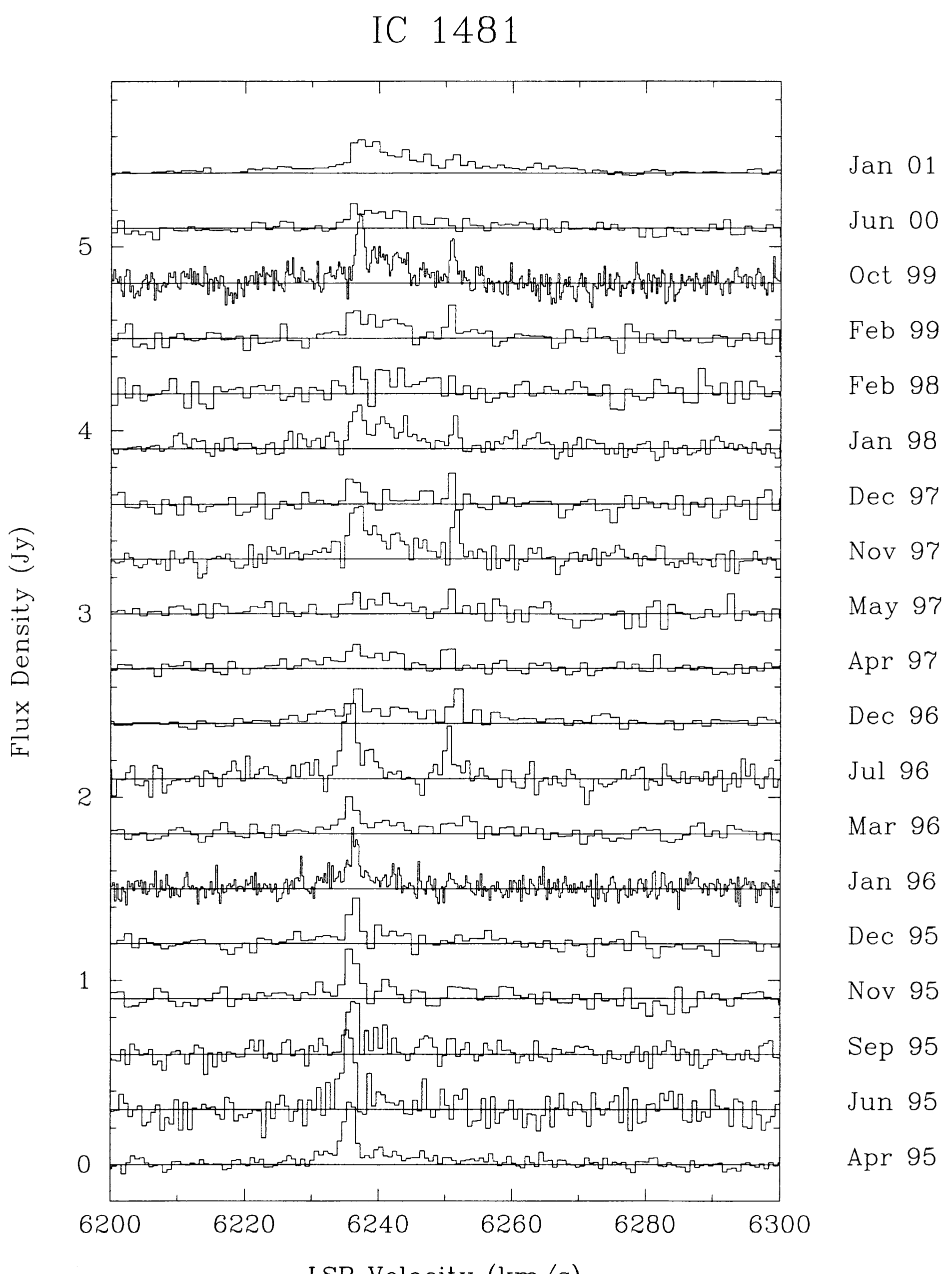

Figure 1. A sample of the spectral monitoring of H_2O masers. This plot shows nearly 6 years of observations of IC 1481.

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velocity. Since it is the high velocity features in NGC 4258 which are most valuable in tracing the nuclear disk, it is possible that we are missing very interesting sources (those with clean nuclear disks) because of this bias.

A new spectrometer at the MPIfR 100-m telescope in Effelsberg offers several wide bandwidth modes (e.g. 8 × 80 MHz with 4.2 km s^{-1} channel spacing or 8 × 40 MHz with 1.1 km s^{-1} channel spacing) which facilitate overcoming this bias, and an early survey with this instrument has been successful in detecting a new extragalactic source with a triply-peaked maser profile strongly suggesting a disk structure (Braatz et al., 2001).

4. The Green Bank Telescope

The NRAO Green Bank Telescope (GBT) is a new 100-m, fully steerable antenna with an unblocked aperture, active surface, and laser metrology system. It will operate (nominally) from 300 MHz to 100 GHz, with the lower frequencies coming on line first. K-band observing is expected for the winter of 2001–2002. With the K-band aperture efficiency anticipated at 60% and using a low-noise receiver (T_{sys} = 40K), the GBT will have outstanding sensitivity. The backend for spectral line work is a versatile spectrometer which includes an 800 MHz bandwidth mode covered by 16K channels.

Previous maser surveys indicate that new maser discoveries will rely on improvements in sensitivity and velocity coverage. The GBT capably addresses both of these issues, and should prove to be a valuable telescope for future water maser work.

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