Cosmic MASERs: From Protostars to Blackholes
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Observations of water maser sources at Arcetri

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Abstract. We present the current activity of the Arcetri group in the field of water masers. This is mainly represented by observations with the Medicina radiotelescope, whose main outcome has been the compilation of the Arcetri Catalog and the study of time variability of selected sources. The Arcetri Catalog update reports the results of the observations carried out from January 1993 to April 2000 on a sample of 300 sources. The global properties of the complete Arcetri Catalog (including Comoretto et al. 1990, and Brand et al. 1994) are discussed. Of the 1013 sources, 937 have an IRAS counterpart within 1 arcmin from the nominal position of the maser. We establish a classification scheme based on the IRAS flux densities which allows to distinguish between water masers associated with star forming regions and late-type stars. The time variability study shows a large variety of behaviors. Generally more luminous sources present less variable emission and spectral components over a wider velocity range.

1. Introduction

It is well known that maser emission in the 6_{16}–5_{23} rotational transition of water at 22.2 GHz is a powerful tracer of the earliest and latest phases of star evolution.

The Arcetri group has routinely used the Medicina 32-m radio telescope to re-observe all the water masers north of declination -30°, reported in the literature, in order to compile a catalog of all known masers, which includes the (as yet) unpublished detections obtained with the Medicina antenna. The 1σ noise level of this telescope in good observing conditions for an observing time of 5 minutes on source has improved from 3 Jy in 1987 to 1 Jy at present.

We have collected observations for about 14 years for several tens of sources, and we have now analyzed the long term behavior of 14 selected masers in star forming regions, and ~ 10 associated with late-type stars.

2. The Arcetri Catalog update

The first Arcetri Catalog of H_2O maser sources was published in July 1990 (Comoretto et al. 1990). A revised version was given by Palagi et al. (1993), who also discussed the statistical properties of the sources. This first catalog provides the observational parameters for 500 masers with $\delta > -30°$ reported in the literature up to January 1989, and re-observed with the Medicina 32-m radio telescope. Of these sources, 199 were detected at Medicina: for these we listed the peak and integrated flux densities, the velocity interval over which emission has been observed and the velocity of the peak.

The basic motivation of the Arcetri Catalog is to provide a homogeneous and complete list of all H_2O maser *centers*, observable as separate sources with the $1\overset{'}{.}9$ HPBW of the 32-m Medicina telescope, and to present at least one spectrum for each detected maser or an upper limit to the peak flux density for those not detected by us.

Since 1989, a large number of new water masers have been reported in the literature or detected in our observing programs at Medicina. This development has prompted the compilation of a first update of the Catalog (Brand et al, 1994), and, recently, of a second update (Valdettaro et al., 2001a). The Catalog totals over 1000 sources (tab. 1), of which 423 have been detected at Medicina.

Catalog update	Sources		IRAS class.	
	Obs.	Detected	Star	SFR
Comoretto et al, 1990	500	199(40%)	219	183
Brand et al, 1994	213	141(66%)	40	152
Valdettaro et al, 2000	300	83(28%)	201	75
Total	1013	423(42%)	460	410

Table 1. Sources observed in the Arcetri Catalog. For each update the total number of sources and the detection rate at the Medicina telescope is listed. Sources have been classified, where possible, using the IRAS colors, as described in Valdettaro et al (2001a) and in this contribution.

An important piece of information, often not available in the literature, is whether the maser is associated with a star forming region or with a late-type star. Masers of the first type are beacons of star forming sites, often associated with the very first stages of protostar mass ejection, and allow one to explore the environment of deeply embedded sources. Knowledge of maser emission towards an infrared source pinpoints the direction in which more detailed searches for newly born stars should be made. Masers in late-type stars are observed to investigate the spatial and velocity structure of the circumstellar envelopes. Recently, they have been used to study stellar kinematic in the Galactic Center.

In order to optimize a classification based on the far-infrared fluxes, we have developed a classification scheme, described in Valdettaro et al. (2001a), that exploits all the information available in the colors of the associated IRAS point source. A maser is considered physically associated with an IRAS source

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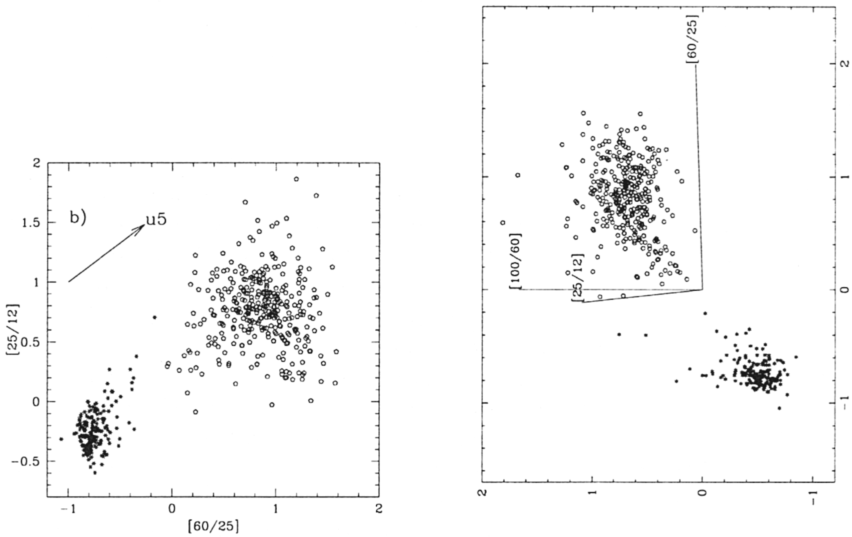

Figure 1. Colors of IRAS sources associated with stellar (star symbols) and SFR masers (circles). The four IRAS fluxes define a 3-dimensional color space, that is projected in figure 1a (left) to show the principal axis of the maser distribution. The color u_4, that maximizes the distance between the stellar and SFR maser subpopulations, is oriented along the arrow. If the 100 μm flux is not available, the color space is bidimensional (1b, right), and the two subpopulations can be discriminated using color combination u_5

if it lies at less than 1 arcmin from the nominal IRAS position. This is the case for 937 of the 1013 masers listed in the Catalog. Applying the principal component analysis to a mixed sample of known masers in young stellar objects and late-type stars, we verified that the IRAS colors of the two subpopulations are clearly separated, as can be seen in Fig. 1a.

Using the linear discriminant technique, we have thus derived a *color* (a linear combination of the logarithms of the IRAS fluxes), u_4, that maximizes the separation of the SFR and stellar maser populations. The physical meaning of this color is immediate: masers in star forming regions, deeply obscured, have a "red" infrared spectrum, while stellar masers are "blue". However many IRAS sources in our sample have an upper limit at 100 μm. Using only the remaining fluxes, a secondary discriminant, u_5, has been found (Fig. 1b), and has been used when u_4 cannot be computed.

Using these criteria it was possible to assign a classification to 870 of the 937 sources with IRAS counterpart. 460 were classified as late-type stars, and 410 as star forming regions. These numbers reflect the selection criteria used by the studies in the literature.

Sources in star forming regions appear strongly concentrated towards the galactic plane (rms latitude of 5°.2, against 23°.6 for stellar masers). This reflects the differences in both distance and galactic distribution of YSOs and stellar masers, and must be considered in planning unbiased searches for these sources.

3. Variability studies

Water masers are known to be highly variable, on timescales of a few weeks to a few hundred days. We have monitored a sample of 14 H_2O masers for about 13 years, with a sampling interval of 1-2 months. The sources are associated with young stellar objects with bolometric luminosities ranging from 20 to 2×10^6 $L_\odot$. This study is described in more detail in Valdettaro et al. 2001b.

Studies like this are important, since properties of masers derived from only a single or a few observations are not representative of the overall behavior. In particular, it is not rare to observe quiescent periods, lasting several years, in otherwise active masers (one example is given by L1455 IRS1). Some sources (notably S140) show many years of stable activity concentrated in a few clearly defined spectral components, followed by chaotic behavior, with components lasting less than one year appearing at random velocities.

We found a strong correlation between infrared and H_2O peak luminosities. More luminous infrared sources tend to produce less variable masers, with many components over a wider range of velocities. This does not seem to be a selection effect, since apparent luminosities in our sample are not too different. Velocity drifts of maser components are not uncommon, with drift rates of 0.1–0.3 km s^{-1} yr^{-1}.

Another study (Brand et al. 2001) analyzes the variability of the stellar maser in the Mira variable R Cas. Water maser emission is dominated by two strong lines. The integrated intensity of the maser is well fitted by the combination of an exponential decay, modulated by the stellar variability delayed by $\approx$ 115 days, and a *plateau*, also modulated with the stellar period.

References

Brand, J., Cesaroni, R., Caselli, P. et al. 1994, A&AS, **103**, 541

Brand, J. Baldacci, L., Engels, D. 2001, in IAU Symp. 206, Cosmic masers, V. Migenes and M.J. Reid eds., ASP Conference Series (this conference)

Comoretto, G., Palagi, F., Cesaroni, F., Felli, M., et al. 1990, A&AS, **84**, 179

Valdettaro, R., Palla, F., Brand, J. et al. 2001a, A&A, **368**, 845

Valdettaro, R., Palla, F., Brand, J. et al. 2001b, in IAU Symp. 206, Cosmic masers, V. Migenes and M. J. Reid eds., ASP Conference Series (this conference)