Astrophysical Masers and their Environments
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Submillimeter and millimeter masers

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Abstract. Despite theoretical predictions of the existence of many submillimeter masers, and some pioneering observational discoveries over the past few decades, these lines have remained relatively unstudied due to (i) challenges associated with observing at shorter wavelength; and, (ii) the lack of possibility of high ($< 14''$ at 345 GHz) angular resolution observations. With the advent of the SMA, the first submillimeter imaging array capable of sub-arcsecond resolution, APEX, and the promise of ALMA, opportunities are opening for performing new science with millimeter/submillmeter masers. In this talk, I will review recent work in the field - including extragalactic H_2O millimeter masers, hydrogen recombination masers, submillimeter masers in star-forming regions, and in the envelopes of evolved stars - and discuss prospects for the future.

Keywords. masers, submillimeter

1. Introduction

Submillimeter masers exist in a wide range of astronomical environments, and provide the possibility to probe physical conditions, source dynamics and magnetic fields on small angular scales. They occur in several molecular and atomic species, including H_2O, SiO, H (recombination), CH_3OH, HCN, and SiS, and can be very strong (e.g., 8000 Jy for the 325 GHz H_2O masers in W49N; Menten *et al.* 1990a). However, lack of angular resolution at submillimeter wavelengths has, until recently, been a serious obstacle to realizing the potential of the masers. Relating cm-wave maser emission observed on, say $0\farcs001$ scales, with that of the submillimeter maser emission on $>10''$ scales (at 345 GHz), has made it difficult to constrain and test the radiative transfer models that we will need to use in the Atacama Large Millimeter Array (ALMA) era to map out precise source temperature and density distributions.

The Submillimeter Array (SMA) on Mauna Kea, operating from 0.3 to 2 mm, is the first instrument capable of imaging in the submillimeter on sub-arcsecond scales ($0\farcs25$ at 345 GHz), and ALMA will further transform maser science opportunities (see review by Wootten in these proceedings). In this review, I will discuss results for masers at wavelengths shorter than 1.6 mm ($\nu > 180$ GHz), and future prospects for their observation using e.g., ALMA, the *Herschel* satellite, the Stratospheric Observatory for Infra-Red Astronomy (SOFIA) and submillimeter Very Long Baseline Interferometry (VLBI).

2. (Sub)millimeter H_2O masers

The H_2O masers detected to date, from rotational transitions within the vibrational ground state and within the ν_2=1 bending mode, are listed in Table 1 and are marked on the energy level diagram in Figure 1. The most studied lines are those at 183, 321 and 325 GHz, despite the relatively low atmospheric transmission at 183 and 325 GHz due to their low energies above ground state (Figure 2). These masers are believed to be collisionally-pumped by a subset of the conditions that pump 22 GHz masers, for the

Table 1. H_2O masers

Freq. (GHz)	Transition J_{k_a,k_c} - J_{k_a,k_c}	Vib. State	Species[1]	E_u/k (K)	CSE[2]	SFR[2]	EXG[2]	Primary Reference
22.235	6_{16} - 5_{23}	G	O	644	Y	Y	Y	Cheung *et al.* (1969)
96.261	4_{40} - 5_{33}	ν_2=1	P	3065	Y			Menten & Melnick (1989)
183.308	3_{13} - 2_{20}	G	P	205	Y	Y	Y	Waters *et al.* (1980)
232.687	5_{50} - 6_{43}	ν_2=1	O	3463	Y			Menten & Melnick (1989)
293.439	6_{61} - 7_{52}	ν_2=1	O	3935	Y			Menten *et al.* (2006)
321.226	10_{29} - 9_{36}	G	O	1862	Y	Y		Menten *et al.* (1990a)
325.153	5_{15} - 4_{22}	G	P	470	Y	Y		Menten *et al.* (1990b
[3]336.228	5_{23} - 6_{16}	ν_2=1	O	2956	Y			Feldman *et al.* (1993)
354.885	17_{412} - 16_{710}	G	O	5782	Y			Feldman *et al.* (1991)
380.194	4_{14} - 3_{21}	G	O	324		Y		Phillips *et al.* (1980)
437.347	7_{53} - 6_{60}	G	P	1525	Y			Melnick *et al.* (1993)
439.151	6_{43} - 5_{50}	G	O	1089	Y	Y		Melnick *et al.* (1993)
470.889	6_{42} - 5_{51}	G	P	1091	Y	Y		Melnick *et al.* (1993)
658.007	1_{10} - 1_{01}	ν_2=1	O	2361	Y			Menten & Young (1995)

[1] O=ortho-H_2O (parallel hydrogen atom nuclear spins) and P=para-H_2O (anti-parallel hydrogen nuclear spins). In thermal equilibrium, the two forms are present in an O/P ratio of 3:1.
[2] CSE=Circumstellar Envelope; SFR=Star Forming Region; EXG=Extragalactic
[3] Quasi-maser (Feldman *et al.* 1993), or thermal (Menten *et al.* 2006), emission toward VY CMa.

parameter space investigated by Neufeld & Melnick (1991, hereafter NM91) and by Yates, Field & Gray (1997, hereafter YFG97). However, Cernicharo *et al.* (1994, 1999, 2006a, 2006b) find that the 183 and 325 GHz transitions can also be inverted in significantly lower temperature and density regimes of $T_k \sim$ 40 K and n(H_2)=10^5-10^6 cm^{-3}. NM91 and YFG97 are in broad agreement, except that YFG97 find that the masers at 439 and 470 GHz are pumped by radiation from warm dust. Both NM91 and YFG97 make predictions for new H_2O masers (e.g., at 448, 1296, & 1322 GHz; also Deguchi 1977, Cooke & Elitzur 1985, Deguchi & Nguyen-Q-Rieu 1990, Humphreys *et al.* 2001), some of which could be observed using *Herschel*. NM91 and YFG97 do not include levels from the ν_2=1 vibrationally-excited state, see Deguchi (1977), Deguchi & Nguyen-Q-Rieu (1990) and Alcolea & Menten (1993) for ν_2=1 maser pumping models. Modelling of the ν_2=1 masers is severely hampered by lack of relevant collisional excitation rates.

2.1. *H_2O masers in evolved stars*

(Sub)millimeter masers at 183, 321 and 325 GHz are common in the circumstellar envelopes (CSEs) of evolved stars. 70% of the 22 GHz H_2O maser sources observed by Yates, Cohen & Hills (1995) also have H_2O maser emission at 321 and 325 GHz. Single-dish linewidths of 22 and 325 GHz masers have similar extents and peak flux densities, whereas 321 GHz maser line widths are narrower and weaker by a factor of a few (an exception is emission from R Aqr, a Mira variable in a symbiotic binary; Ivison *et al.* 1998). 321 GHz emission likely originates from a subset of the conditions that give rise to the 22 and 325 GHz emission, close to the central star. The 321 GHz line is generally more variable than the 22 and 325 GHz emission and variations in the 22, 321 and 325 GHz masers are not particularly well-correlated (in some cases they are completely anti-correlated; Yates *et al.* 1996). For 183 GHz H_2O masers, González-Alfonso *et al.* (1998) find that variability of the line profile and flux from one epoch to another is small in comparison with that of 22 GHz masers in a study of 23 evolved stars. As for 22 GHz H_2O masers, in stars of low mass-loss rates ($\dot{M}$) the 183 GHz emission peaks at a velocity similar to that of the star, whilst in stars with high $\dot{M}$ the emission peaks at velocities

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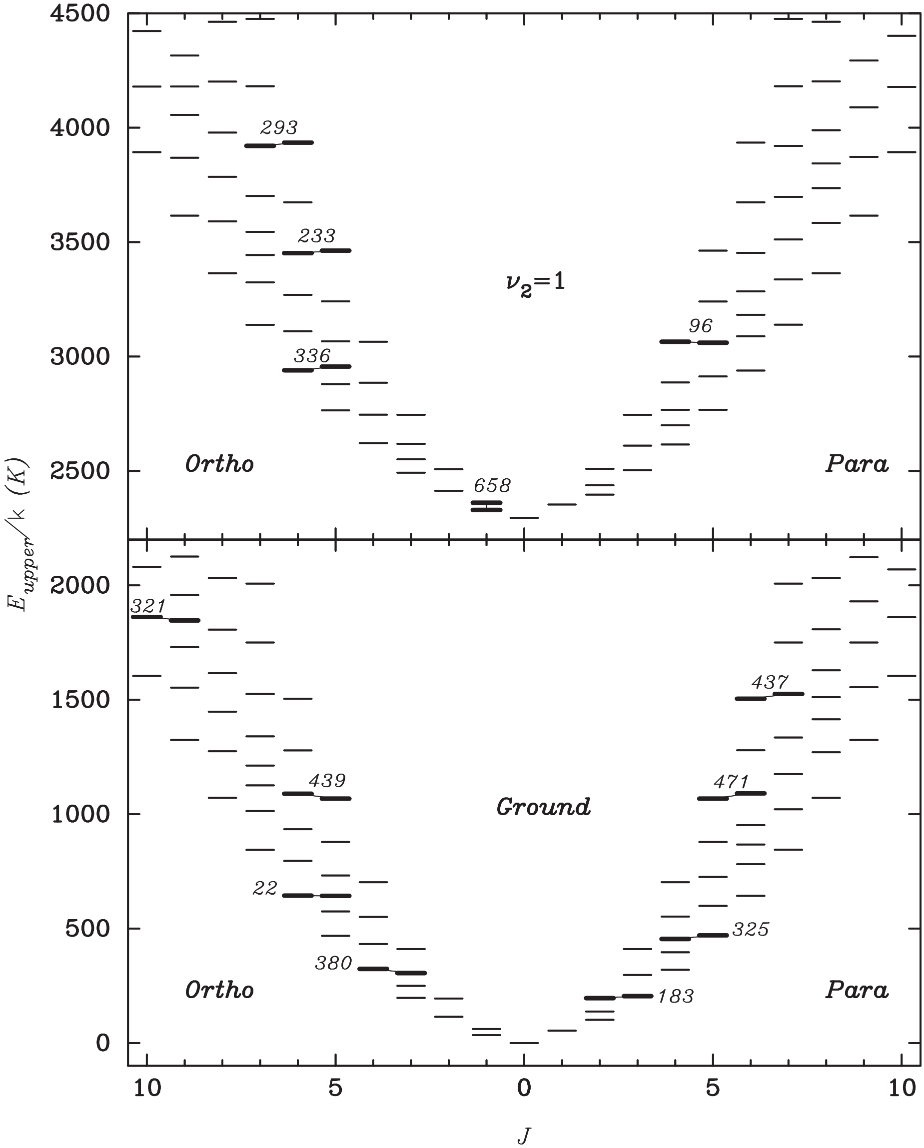

Figure 1. H_2O Energy Level Diagram. Rotational levels in the ground and vibrationally-excited ν_2 states are shown for energies between 0 to 2200 K, and 2200 to 4500 K respectively. Levels of maser transitions are plotted in bold, and labels are the transition frequencies in gigahertz. The maser at 355 GHz, at an energy of 5782 K above ground-state, is not shown on this plot. Ortho-H_2O plotted for values of the total molecular angular momentum J increasing to the left, para-H_2O to the right. Data are from the experimentally-derived energy levels of Tennyson *et al.* (2001), available on http://www.tampa.phys.ucl.ac.uk/ftp/astrodata/water/levels.

closer to the terminal velocity of the envelope (tangential vs. radial amplification as the envelope becomes denser at greater radii). Masers at 437, 439 and 471 GHz have all been detected in CSEs and the 437 GHz line has been found exclusively in this environment (Melnick *et al.* 1993; YFG97). Masers from the ν_2=1 state, at 96, 233, 293, (336) &

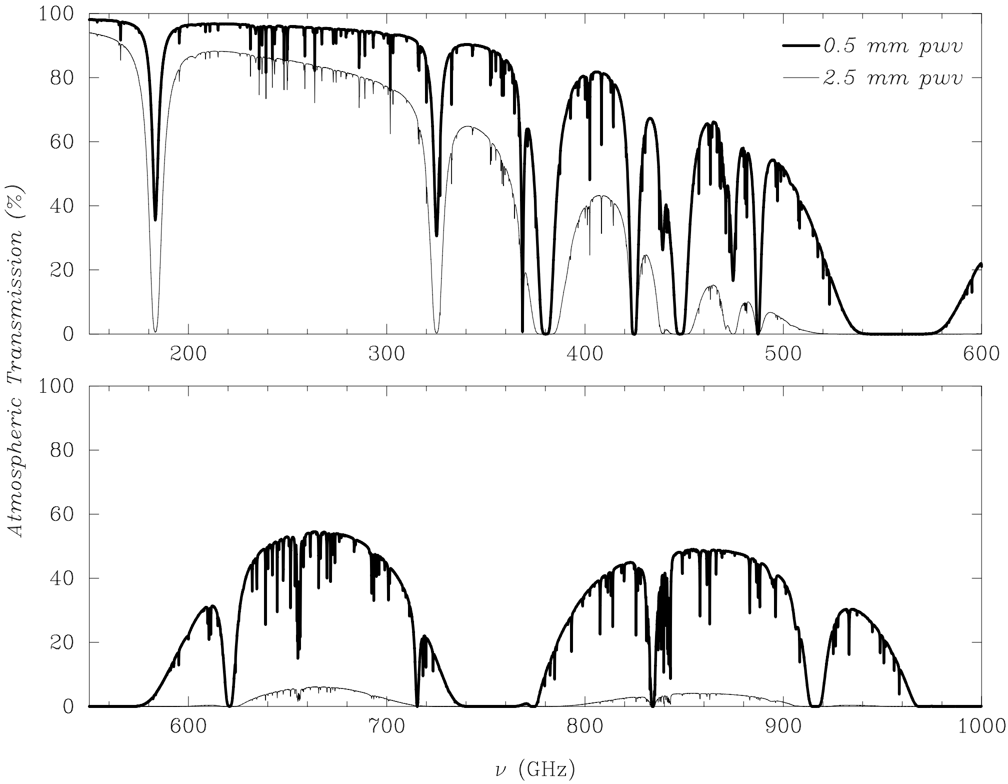

Figure 2. Zenith atmospheric transmission at Mauna Kea for column densities of 0.5 and 2.5 mm H_2O (τ_{225GHz}~0.04 and 0.13 respectively). Data are from the Caltech Submillimeter Observatory Atmospheric Transmission Interactive Plotter (http://www.submm.caltech.edu/cso/weather/atplot.shtml).

658 GHz, are only known to occur strongly from CSEs, although 658 GHz emission of undetermined nature is observed toward Orion-KL (Schilke *et al.* 2001). On the basis of excitation arguments, and similarity with SiO maser lineshapes in some cases, the ν_2=1 masers likely occur close (within a few R_*) to the central star. In recent Atacama Pathfinder Experiment (APEX) observations towards VY CMa, Menten *et al.* (2006) find weak maser emission from the 293 GHz line, a non-detection of emission at 297 GHz and thermal emission at 336 GHz. For a discussion of SMA observations of the 658 GHz masers, often particularly strong e.g., 3000 Jy toward VY CMa, see the review by Hunter in these proceedings.

2.2. *H_2O masers in star-forming regions*

Observations of the (sub)millimeter H_2O masers are summarized in Table 2. 183, 321, 325, 439 and 471 GHz masers have been observed towards high-mass star-forming regions, the 183 and 325 GHz lines have also been observed towards low-mass star-forming regions (HH7-11A, L1448IRS3, L1448-mm at 183 GHz; IRAS16293-2422 at 325 GHz). The velocity range covered by the 321 GHz maser is typically smaller than that observed at 22, 183, and 325 GHz. The 321 GHz emission is typically weakest of these four lines, and the 22 GHz is the strongest.

First arcsecond resolution observations of H_2O masers towards a star-forming region were performed at 325 GHz towards Orion-KL by Greenhill *et al.* (2007) using the compact configuration of the SMA, and followed up with a higher resolution (0.″65 circular),

Table 2. Some (Sub)millimeter H_2O observations towards star-forming regions

Freq. (GHz)	Sources	Telescope[1] (Beam)	Comments
183	Orion-KL	KAO (7$'$.5)	First 183 GHz detection (Waters *et al.* 1980)
	Orion-KL, Cep A, W49N, S252A, S158, HH7-11A, W3(H2O) NGC 7538S, RN013	IRAM 30-m (14$''$)	Established 183 GHz maser emission widespread (Cernicharo *et al.* 1990)
	Orion	IRAM 30-m	Spatially-extended emission; strong, narrow features at IRC2 (Cernicharo *et al.* 1994)
	W49N	IRAM 30-m	Spatially-extended; less time-variable than at 22 & 325 GHz (González-Alfonso *et al.* 1995)
	HH7-11A, L1448IRS3, L1448-mm	IRAM 30-m	183 GHz maser variability in low-mass star formation Cernicharo *et al.* (1996)
	Sgr B2	IRAM 30-m	Strong toward cores; moderate emission at Sgr B2 main condensations (Cernicharo *et al.* 2006a)
321	W3(OH), W49N, W51 IRS2 & Main	CSO (23$''$)	Strongest 22 GHz & 321 GHz features generally at similar velocities (Menten *et al.* 1990a)
	Cep A	SMA (0$''$.75)	22 & 321 GHz distributions perpendicular (cm & submm obs. ~1 mth apart) (Patel *et al.* 2007)
325	Orion-KL W49N, W51 Main IRAS 16293-2422	CSO (22$''$)	22 & 325 GHz cover similar velocity extents (Menten *et al.* 1990b)
	G34.3-0.2, W49N, Sgr B2	CSO	325, 439 & 470 GHz cover similar velocity extents (Melnick *et al.* 1993)
	Orion-KL	CSO	325 GHz emission much less extended than at 183 GHz (Cernicharo *et al.* 1999)
	Orion-KL	SMA (0$''$.65) Full Stokes	In high-mass protostar Source I outflow, 325 GHz emission more collimated than 22 GHz (cm & submm obs. ~5 yrs apart) (Greenhill *et al.* 2007)
439, 471	G34.3-0.2 W49N, Sgr B2	CSO (16$''$)	First detections: 325, 439 & 470 GHz cover similar velocity extents (Melnick *et al.* 1993)

[1] KAO = Kuiper Airborne Observatory; IRAM = Institut de Radioastronomie Millimétrique; CSO = Caltech Submillimeter Observatory; SMA = Submillimeter Array

full polarization epoch. In previous mapping of this region using the Caltech Submillimeter Observatory (CSO) with a 22$''$ beam, Cernicharo *et al.* (1999) concluded that the 325 GHz emission traces extended, low-density material of $n(H_2)\sim10^{5-6}$ cm^{-3}. However, Greenhill *et al.* (2007) find that it also arises from compact high-density clumps, much as the 22 GHz transition, although in the outflow of high-mass protostar Source I the 325 GHz emission appears more collimated. Line ratios of these H_2O transitions could therefore be valuable diagnostics for shocked material in protostellar outflows.

Using the SMA, Patel *et al.* (2007) imaged 321 GHz H_2O maser emission towards high-mass star-forming region Cepheus A with a resolution of 0$''$.75, in close time proximity to Very Large Array observations of the 22 GHz H_2O masers (43 days later). The majority of 321 GHz maser spots did not appear to be associated with those at 22 GHz, and the position angles of the roughly linear structures traced by the masers appeared perpendicular, perhaps tracing a jet and disk respectively. Patel *et al.* (2007) interpret the submillimeter masers in Cepheus A to be tracing significantly hotter regions (600-2000 K) than the centimeter masers, see the contribution by Patel in these proceedings for further details.

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2.3. *Extragalactic H_2O masers*

There have been two recent detections of extragalactic H_2O masers at 183 GHz. Humphreys *et al.* (2005) detected emission toward the well-known 22 GHz H_2O megamaser galaxy NGC 3079 using the SMA. At a distance of 14 Mpc, NGC 3079 harbors an active galactic nucleus (AGN), and additionally has some starburst indicators. Spatially and kinematically the 183 GHz emission is associated with the AGN, with emission peaking at the same position as that of 22 GHz emission imaged by Kondratko *et al.* (2005) using VLBI. At 22 GHz, the emission has a time-variable peak flux density in the range 3-12 Jy, whereas at 183 GHz, the H_2O maser emission had a peak flux density of $\sim$0.5 Jy. Humphreys *et al.* (2005) also make a tentative detection of the 439 GHz maser using the JCMT.

Cernicharo, Pardo & Weiss (2006) detected a megamaser at 183.310 GHz in Arp 220 using the IRAM 30 m, with a line width of $\sim$350 km s^{-1} and total luminosity of $\sim 2.5 \times 10^8$ K km s^{-1} pc^2. This is very interesting since no emission at 22 GHz has been detected from Arp 220 (an OH megamaser source). This fact puts constraints on the physical conditions of the central region of Arp 220, which are further strengthened by observations of HCN and HNC $J = 3-2$ and $J = 1-0$, suggesting densities of n(H_2)=10^5 cm^{-3}. Cernicharo, Pardo & Weiss (2006) propose a scenario with $\sim 10^6$ star-forming cores similar to those found in Sgr B2 in the central kiloparsec of Arp 220. The 183 GHz line is therefore an additional tool to explore the physical conditions in starburst and AGN sources, with the potential for high angular resolution observations using ALMA.

3. (Sub)millimeter SiO masers in evolved stars

(Sub)millimeter ^{28}SiO masers have been detected from the J =5-4 $\approx$ 215 GHz ($v = 1$ & 2, Clemens & Lane 1983; $v = 3$ tentative detection from VX Sgr, Jewell *et al.* 1987; $v =$ 3 & 4 from VY CMa, Cernicharo, Bujarrabal & Santaren 1993), $J = 6-5 \approx 258$ GHz (v =1, Jewell *et al.* 1987; v =2, VY CMa, Cernicharo, Bujarrabal & Santaren 1993), $J = 7-6 \approx 301$ GHz ($v = 1$ & 2, R Aqr, Gray *et al.* 1995), $J = 8-7 \approx 344$ GHz ($v = 1$, VY CMa, and tentative $v = 2$, Humphreys *et al.* 1997; $v = 2$, VY CMa, Gray, Humphreys & Yates 1999). The highly-rotationally excited masers are very rare from the $v = 3$ & 4 states (Pardo *et al.* 1998 and references therein) which lie at >5400 K above ground state. They are more common in the v =1 & 2 (Jewell *et al.* 1987; Cernicharo, Bujarrabal & Santaren 1993; Humphreys *et al.* 1997; Gray, Humphreys & Yates 1999) especially ing J =5-4 emission, but weaker than their lower frequency counterparts in the same vibrational states, and more time-variable. In a survey of 34 supergiant and long-period variable stars, Gray, Humphreys & Yates (1999) found that for Mira variables, emission from the high-frequency transitions is absent or weak from optical phase range $\phi \sim 0.4-0.7$ of the stellar pulsation cycle.

SiO maser emission at lower frequencies is well-known to display high degrees (tens of %) of linear polarisation e.g., $v = 1$ $J = 1-0$ (43 GHz) maser components can be $\sim$100% linearly polarized (e.g., Kemball & Diamond 1997). Using a partially-completed SMA, Shinnaga *et al.* (2004) imaged the $v = 1$, $J = 5-4$ SiO maser emission of supergiant VY CMa to investigate linear polarization properties at higher frequency. The majority of components showed significant degrees of linear polarization, with one at the 60% level, that Shinnaga *et al.* attribute to a radiative pumping process.

For the less abundant isotopomers ^{29}SiO and ^{30}SiO, Cernicharo & Bujarrabal (1992) detected maser emission from the $v = 0$ $J = 5-4$ transition for both species, the ^{29}SiO $v = 2$, $J = 6-5$ line, and the ^{30}SiO $v = 1$ $J = 6-5$ towards VY CMa. For ^{29}SiO,

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the $v = 3$ $J = 8-7$ at 335.9 GHz was detected toward TX Cam, R Leo and W Hya at optical stellar phases ϕ of 0.3, 0.15 and 0.25 respectively (González-Alfonso *et al.* 1996) and towards VY CMa (González-Alfonso *et al.* 1996; Menten *et al.* 2006 using APEX). Menten *et al.* (2006) also detected maser emission in the ^{30}SiO $v = 1$ $J = 8-7$ line towards VY CMa, whereas the ^{29}SiO $v = 0$ $J = 8-7$ transition appears thermal. Infrared line overlaps of the SiO isotopomers is believed to be important in the pump scheme of these masers (e.g., Herpin & Baudry 2000). For a detailed discussion of SiO masers in evolved stars, see the review by Bujarrabal in these proceedings.

4. (Sub)millimeter H recombination masers

Hydrogen recombination maser emission is known from two galactic peculiar stellar sources, MWC 349A (Martin-Pintado *et al.* 1989) and Eta Carinae (Cox *et al.* 1995). (Sub)-millimeter maser emission from MWC 349A has been detected from at least the H31α (210.5 GHz), H30α (231.9 GHz), H29α (256.302 GHz) (Martin-Pintado *et al.* 1989) from H26α (353.623 GHz; Thum *et al.* 1994a) and the H21α (662.405 GHz; 350 Jy; Thum *et al.* 1994b), H32β (366.6 GHz; Thum *et al.* 1995). Planesas, Martin-Pintado & Serabyn (1992) spatially resolved the double-peaked maser spectrum into two emitting regions, separated by $0\farcs065$, associated with the red and blue-shifted emission from a sub-arcsecond disk imaged in the near-infrared by Danchi, Tuthill & Monnier (2001). Weintroub *et al.* (2007) again detected H30α and H26α maser emission from the two regions using the SMA, but also found emission at positions between them with an accuracy of $0\farcs01$. The emission position-velocity diagram is consistent with that of an edge-on disk in approximate Keplerian rotation. However, Weintroub *et al.* (2007) argue that systematic deviation from Keplerian rotation may indicate the presence of spiral structure in the MWC 349A disk (see also these proceedings). From Zeeman observations of the H30α maser, Thum & Morris (1999) report a dynamically-important magnetic field associated with the corona of the circumstellar disk, possibly generated by a local disk dynamo. Pumping of the masers in MWC 349A has been explained by Strelnitski *et al.* (1996). Towards Eta Carinae, Cox *et al.* (1995) detected millimeter maser emission at H30α, H29α and H37β (240.021 GHz) (see also Abraham *et al.* (2002)).

Extragalactic H recombination maser emission from the H27α (316.416 GHz) transition has also been detected towards M82 (Seaquist *et al.* 1996). The emission is highly time-variable, and of peak flux density 1.5 Jy at the strongest epoch. We note that H recombination masers at lower frequency may also have been detected from starburst galaxies, see references in Seaquist *et al.* (1996), and that H recombination masers are predicted to probe the Epochs of Recombination and Reionisation (Spaans & Norman 1997).

5. (Sub)millimeter CH_3OH masers

In a survey of Galactic star-forming regions, Kalenskii, Slysh & Val'Tts (2002) detected maser emission from methanol 8_{-1} - 7_0 E at 229.8 GHz towards DR 21(OH) and DR 21 West, and toward two maser candidates, L 379IRS3 and NGC 6334I(N). The maser emission in DR21(OH) and DR 21 West indicates gas kinetic temperatures of $T_k \sim 50$ K and densities of $n(H_2) = 3 \times 10^4$ cm^{-3}. Towards 16 other sources, the emission detected from this line was thermal in nature. Sobolev *et al.* (2002) reported the detection of class II methanol emission at 216.9 GHz, and models by Cragg *et al.* (2005) predict the existence of many more (sub)millimeter Class II methanol masers.

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6. (Sub)millimeter HCN & SiS masers in carbon stars

(Sub)millimeter HCN maser emission has been detected from carbon-rich circumstellar envelopes. Using the Caltech Submillimeter Observatory (CSO), Schilke, Mehringer & Menten (2000) and Schilke & Menten (2003) detected the $J = 9 - 8$ maser of the $(04^0 0)$ vibrationally-excited state of HCN at a frequency of ≈804.751 GHz towards IRC+10216 (at two epochs of peak flux densities 1420 & 840 Jy) and CIT 6 (110 Jy). The lower level of the maser is at 4200 K above ground state, such that emission should originate from the innermost region of the CSEs (< 3.5 R_*). Schilke & Menten (2003) also detected the $(11^1 0)$-$(04^0 0)$, $J = 10 - 9$ maser at 890.761 GHz towards IRC+10216 (at four epochs with peak flux densities of 6120, 4430, 9230, 900 Jy), CIT 6 (1090 & 1150 Jy) and Y CVn (140 Jy). In surveys using the Heinrich-Hertz-Submillimeter Telescope, Bieging, Shaked & Gensheimer (2000) and Bieging (2001) discovered maser emission in the $J = 3 - 2$ (265.886 GHz) and 4−3 (354.505 GHz) transitions of the HCN $(01^{1c}0)$ vibrational bending mode toward five stars: R Scl, V384 Per, R Lep, Y CVn, and V Cyg (out of 12 observed). Submillimeter HCN masers at 964 and 968 GHz are also predicted by Schilke & Menten (2003), and could be detected using SOFIA.

SiS masers were first discovered by Henkel, Matthews & Morris (1983) from the $v = 0$, $J = 1 - 0$ transition at 18 GHz toward carbon-rich star IRC+10216. (Sub)millimeter SiS maser emission was also detected toward IRC+10216 from the $v = 0$, $J = 11 - 10$ (199.672 GHz), $J = 14 - 13$ (254.103 GHz) and $J = 15 - 14$ (272.243 GHz) transitions by Fonfría Expósito *et al.* (2006) using the IRAM 30-m. Line overlap is believed to be important in the pumping scheme of the highly-rotationally excited masers and they are thought to occupy ∼5 - 7 R_* in the CSE of IRC+10216. Future high-resolution observations of the HCN and SiS masers using ALMA will therefore yield new information on the dust formation zone of carbon stars.

7. Summary & future propects

Observations of submillimeter masers at high angular resolution provide new means of studying stellar evolution, star formation and AGN/starburst activity. Where different maser transitions trace the same gas, we will be able to place new constraints on radiative transfer models to determine small-scale source temperature and density distributions. Where maser lines trace different regions of sources, we will be able to map out more of source structures and dynamics than ever before. Submillimeter masers could be particularly important probes of regions in which longer wavelength maser emission is subject to obscuration e.g., due to free-free or synchrotron opacity.

The spatial resolution and sensitivity of ALMA will revolutionize submillimeter science. There have also been huge strides in submillimeter VLBI, with fringes obtained at 129, 147, and 230 GHz (see e.g., Krichbaum *et al.* (2007)) and with imaging of SiO $J = 3 - 2$ masers at 129 GHz in VY CMa and several AGB stars already achieved (Doeleman *et al.* 2005; Doeleman, private communication). Within the next decade, observations of submillimeter masers are likely to become very much more commonplace and, in conjunction with detailed modelling, will yield a wealth of new and exciting avenues of research.

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