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Class I methanol masers in the Galactic center

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Abstract. We report on the detection of 36 and 44 GHz Class I methanol (CH_3OH) maser emission in the Sagittarius A (Sgr A) complex with the Karl G. Jansky Very Large Array (VLA). These VLA observations show that the Sgr A complex harbors at least three different maser tracers of shocked regions in the radio regime. The 44 GHz masers correlate with the positions and velocities of previously detected 36 GHz CH_3OH masers, but less with 1720 MHz OH masers. Our detections agree with theoretical predictions that the densities and temperatures conducive for 1720 MHz OH masers may also produce 36 and 44 GHz CH_3OH maser emission. However, many 44 GHz masers do not overlap with 36 GHz methanol masers, suggesting that 44 GHz masers also arise in regions too hot and too dense for 36 GHz masers to form. This agrees with the non-detection of 1720 MHz OH masers in the same area, which are thought to be excited under even cooler and less dense conditions. We speculate that the geometry of the 36 GHz masers outlines the current location of a shock front.

Bright maser lines are useful probes of physical conditions within molecular clouds. One example is the collisionally pumped 1720 MHz OH maser which is widely recognized as a tracer for shocked regions, observed both in SFRs and SNRs. In SNRs, Karl G. Jansky Very Large Array (VLA) observations have shown they originate in regions where the shocks collide with the interstellar medium (e.g. Claussen *et al.* 1997). Such OH masers are numerous in Sgr A East, thus probing the conditions of the interaction regions between the +50 and +20 $\mathrm{km\,s^{-1}}$ clouds and the SNR Sgr A East.

Dense gas structures in the Galactic center region are traced by ammonia and methanol thermal emission (e.g., Coil & Ho 2000, Szczepanski *et al.* 1989). Methanol abundances are high enough to produce maser emission. Like 1720 MHz OH masers, Class I methanol masers such as the 36 and 44 GHz transitions are excited through collisions. At least in SFRs, at higher densities and temperatures the Class I 44 GHz line will have optimized maser output, while the 36 GHz maser eventually becomes quenched (e.g., Pratap *et al.* 2008). Finding these methanol maser lines may therefore constrain the upper limit of the density in the shocked SNR regions.

1. Discussion

To date, four collisionally excited radio frequency maser tracers have been detected in the Sgr A complex; 1720 MHz OH, 36 and 44 GHz CH_3OH and 22 GHz H_2O. The 22 GHz water masers trace regions of higher density and temperature than are typical for the SNR/cloud interaction regions. The methanol and hydroxyl are excited under similar conditions, and here we discuss their relative positions and possible origins.

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Modeling of methanol masers suggests that the 36 GHz transition occurs under somewhat cooler and less dense conditions than the 44 GHz transition. The range of physical conditions do however overlap, and some spatial overlap could therefore be expected. Several 44 GHz masers show an almost perfect overlap in both position and velocity with 36 GHz masers. Here the densities and temperatures should be close to 10^5 cm^{-3} and 100 K to produce both methanol maser lines.

It is striking that the brightest 36 GHz masers are narrowly distributed along a line roughly from north to south, of which three coincide with 44 GHz masers in position and velocity (Sjouwerman, Pihlström & Fish 2010). This NNW-SSE division more or less coincides with the sharp gradient in low-frequency radio continuum emission of the Sgr A East SNR (Pedlar *et al.* 1989) and appears to be located in the sheath in the CS emission as mapped by Tsuboi, Miyazaki & Okumura (2009). The mean velocity of each transition is 46 $km\,s^{-1}$, implying that they arise in similar regions of the molecular cloud where the velocities still are less disturbed by the SNR shock. We generally do not find any 44 GHz (nor 36 GHz) masers westward of this line in our pointings. It is therefore tempting to speculate that the line delineates the arrival of the shock front, where enough material has been swept up to provide the density for the creation of methanol masers, but not yet enough energy has dissipated to dissociate all methanol or to disturb the velocity structure by means of a shock.

In the northeastern part of Sgr A East toward the core of the 50 $km\,s^{-1}$ cloud, there is a group of 44 GHz masers with a distinct positional offset from the 36 GHz masers. The narrower distribution of 36 GHz masers suggests that the conditions required to produce masers in this transition are not fulfilled further to the northeast. The position of the 36 GHz emission is consistent with being just in the SNR/cloud interaction region, while the 44 GHz masers may be found deeper inside the denser parts of the cloud where 36 GHz masers are quenched. These 44 GHz masers, which are typically found to be brighter than the 36 GHz masers, may originate near sites of massive star formation instead (e.g. Pratap *et al.* 2008).

As is the case with Class I methanol masers, 1720 MHz OH masers are used as tracers of shocked regions. The presence of 1720 MHz OH masers indicates the presence of C-shocks. Modeling of OH and CH_3OH shows that the three maser transitions discussed here require similar densities and temperatures. This agrees well with the detection of all three masers in Sgr A East. However, we observe a distinct offset in positions between the methanol and OH masers. In the northeast interaction region between the 50 $km\,s^{-1}$ cloud and Sgr A East the OH masers are found more to the southwest. In addition, the 1720 MHz OH masers have a slightly higher mean velocity of $\sim$57 $km\,s^{-1}$ versus $\sim$ 46 $km\,s^{-1}$ for the methanol. We do note however, that the 1720 MHz OH does overlap in the sky with the line of 36 GHz masers.

The association between 1720 MHz OH and 36 GHz methanol emission may be due to the processes that form these molecules. OH is created by dissociation of H_2O (and maybe also CH_3OH), and the propagation of a C-shock creates densities and temperatures suitable for 1720 MHz OH inversion. Thus, OH masers should preferentially be found in the SNR post-shock region. This agrees with the OH masers being co-located with radio continuum, outlining regions where electrons have been accelerated by the shock.

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