Astrophysical Masers:
Unlocking the Mysteries of the Universe
Proceedings IAU Symposium No. 336, 2017
A. Tarchi, M.J. Reid & P. Castangia, eds.

doi:10.1017/S1743921318000698

Exploring the Nature of MMB sources: A Search for Class I Methanol Masers and their Outflows

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Abstract. We present the initial results from a class I 44-GHz methanol maser follow-up survey, observed with the MOPRA telescope, towards 272 sources from the Methanol Multi-beam survey (MMB). Over half ($\sim$60%) of the 6.7 GHz class II MMB maser sources are associated with a class I 44-GHz methanol maser at a greater than 5σ detection level. We find that class II MMB masers sources with an associated class I methanol maser have stronger peak fluxes compared to regions without an associated class I maser. Furthermore, as part of the MOPRA follow-up observations we simultaneously observed SiO emission which is a known tracer of shocks and outflows in massive star forming regions. The presence of SiO emission, and potentially outflows, is found to be strongly associated with the detection of class I maser emission in these regions.

Keywords. masers, stars: formation

1. Introduction

Our lack of understanding of the formation and early evolution of massive stars, in part, reflects that there is not a well established evolutionary categorization in young high mass stars. Establishing such a classification requires large samples of massive young objects, to capture intrinsically rare or short-lived phases of evolution. One possible such probe are the methanol masers associated with young high mass sources. With this in mind, a 44-GHz class I Mopra follow-up survey was performed towards 272 MMB sources with the aim of exploring the environmental and evolutionary nature of regions harboring both class II and class I methanol masers compared with those associated with only class II methanol masers. In addition to the 44-GHz methanol maser, the Mopra survey also included the known shock/outflow tracer SiO (1-0). The observations were selected to sample different spiral arms of the Galaxy, plus all sources identified in the 3kpc arm Green *et al.* (2009).

2. Overview

The overarching goal of this work is to explore the environments and evolutionary nature of class II methanol masers in regions harboring class I methanol masers and if the properties differ to those regions with only class II masers.

Detection Statistics We observed 272 class II MMB maser sources, where approximately 60% have associated class I methanol maser emission at greater than 5σ. For those MMB sources with a known distance in Green & McClure (2011), we find there is no significant difference between the distances to sources with and without a class I methanol maser detection. Thus, for the majority of the non-detections the lack of a class I maser detection does not appear to be a result of distance alone. If we compare the MMB 6.7-GHz class II peak maser fluxes between sources with and without class I detected maser emission, we find that those regions with a class I maser association have higher peak class II fluxes than regions with no detected class I masers. Furthermore, a KS test between the class II peak flux returns a P-value of <0.001 between the class I detected and non-detected samples, suggesting those regions with both class I and class II masers have more luminous class II maser emission.

SiO Outflows. SiO emission is a known tracer of shocks from jets and outflows in massive star forming regions (e.g. Gibb *et al.* 2007, Klaassen *et al.* 2012, Leurini *et al.* 2014, Cunningham *et al.* 2016). With this in mind, we explore the association of SiO (1-0) emission and therefore outflows in these regions. Of the 272 regions observed ~30% have SiO emission detected above 4σ. Furthermore, of those sources with an SiO detection $> 80\%$ are associated with regions harboring class I methanol masers.

3. Implications

We have presented the preliminary results from a Mopra 44-GHz class I methanol maser follow-up survey towards 272 MMB 6.7-GHz class II methanol maser sources. We find ~60% of the class II sources have associated class I methanol maser emission at $>5\sigma$, where the distance to non-detected sources does not appear to be a limiting factor in the non-detections. In addition, we observed the shock/jet/outflow tracer SiO (1-0) towards these regions and detect emission towards ~30% of the sample, where $> 80\%$ of these detections are associated with the presence of class I maser emission. This highlights that the presence of SiO emission and potentially outflows is strongly associated with class I maser emission in these regions. Previous works by Breen *et al.* (2010) and Jordan *et al.* (2017), have indicated that more luminous 6.7-GHz methanol masers are generally associated with a later evolutionary phase of massive star formation than less luminous 6.7-GHz masers. Towards this sample, we find the class II peak fluxes are stronger in regions with an associated class I maser compared with regions without a class I maser detection, which may indicate that regions with both class I and class II masers are at a later stage of evolution than regions harboring only class II masers.

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