Cosmic Masers: Proper Motion toward the Next-Generation Large Projects
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GASKAP-OH: A New Deep Survey of Ground-State OH Masers and Absorption in the Southern Sky

J. R. Dawson[1,2], **S. L. Breen**[3] **and the GASKAP-OH Team**

[1]School of Mathematical and Physical Sciences and Macquarie University Astrophysics and Space Technologies Research Centre, Macquarie University, NSW 2109, Australia.
email: joanne.dawson@mq.edu.au

[2]Australia Telescope National Facility, CSIRO Space & Astronomy, NSW 1710, Australia

[3]SKA Observatory, Jodrell Bank, Lower Withington, Macclesfield SK11 9FT, UK

Abstract. The Galactic ASKAP survey of OH (GASKAP-OH) is surveying the Milky Way Fourth Quadrant, the Galactic Centre, the Galactic Bulge and the Large Magellanic Cloud (LMC) in the 18-cm ground-state lines of the hydroxyl radical (OH), using Australia's Square Kilometre Array Pathfinder (ASKAP) telescope. With an expected per-channel rms sensitivity of 36 mJy/beam in its shallowest regions, and a velocity channel width of 0.1 $\mathrm{km\,s^{-1}}$, GASKAP-OH is expected to discover hundreds of new star-formation and evolved star OH masers, as well as extensive absorption from quasi-thermal OH throughout the Galactic Plane. We here summarise the science goals and technical specifications of the survey, and report initial detection results from test observations. GASKAP-OH is expected to run for several years and is an open collaboration. Data products will be made available to the wider community as soon as they are verified.

Keywords. masers, surveys, radio lines: ISM, radio lines: stars

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1. Introduction

The 18-cm hyperfine transitions of ground-state ($^2\Pi_{3/2}, J = 3/2$) OH are a versatile probe of a range of astrophysical phenomena – from star formation (e.g. Caswell 1998), to late-stage stellar evolution (e.g. Habing 1996), to molecular cloud evolution (e.g. Barriault et al. 2010) and stellar feedback (Wardle and Yusef-Zadeh 2002). The four transitions (two main lines at 1665.402 and 1667.359 MHz and two satellite lines at 1612.231 and 1720.530 MHz) all exhibit maser emission whose diverse pumping mechanisms and physical requirements set strong constraints on the astrophysical environments that produce them (Elitzur 1992). Even when not masing, the lines are often anomalously excited, and are observed extensively in absorption or weak emission from extended molecular gas (e.g. Dawson et al. 2022).

While a number of OH surveys have been conducted in the Southern Hemisphere, they either cover only relatively small portions of the Plane, are shallow with poor sensitivity, are low resolution, and/or cover only some of the 4 ground-state transitions (e.g. Sevenster et al. 1997; Caswell 1998; Qiao et al. 2018; Dawson et al. 2022). GASKAP-OH aims to address this deficit, by achieving uniform coverage of the Galactic Plane in the Fourth Quadrant, and carrying out multi-epoch observations of the Galactic Centre region, the Galactic Bulge, and the Large Magellanic Cloud (LMC) – all at high resolution and sensitivity.

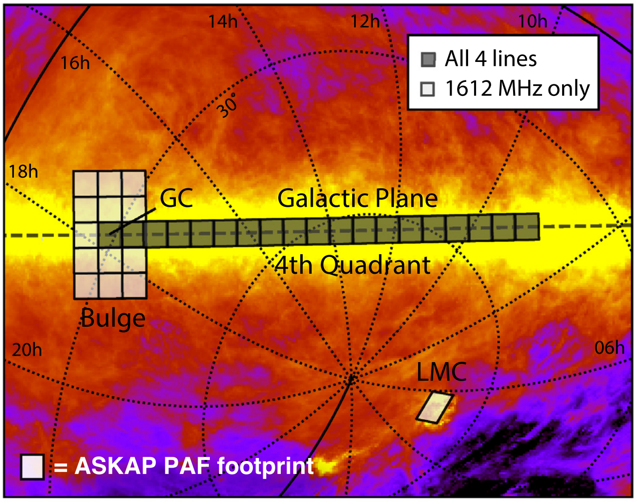

Figure 1. Planned GASKAP-OH survey coverage shown in equatorial coordinates, overlaid on an integrated HI column density map from the HI4PI survey (HI4PI Collaboration 2016). Each square corresponds to the size of a single ASKAP PAF footprint, approximately 5×5 degrees. The Galactic Plane coverage runs from $l = 290°$ to the Galactic Centre – the entirety of the Fourth Quadrant.

Table 1. GASKAP-OH planned survey specifications.

Region	Time/field (hrs)	No. fields	Epochs	Transitions (MHz)	Total time (hrs)	Target rms (mJy/beam)	Vel. chan. (km s^{-1})	HPBW arcsec
Galactic Plane	6	18	1	1612, 1665, 1667, 1720	342	36 (15)	0.1 (0.7)	10
Galactic Centre	18	1	6	1612, 1665, 1667, 1720	56	18 (7)	0.1 (0.7)	10
Galactic Bulge	6	13	3	1612	78	36 (15)	0.1 (0.7)	10
LMC	50	1	4	1612	50	8	0.2	10

2. Survey Specifications

GASKAP-OH is one of the nine approved Survey Science Projects (SSPs) to be carried out on the Australia Square Kilometre Array Pathfinder (ASKAP) telescope. ASKAP consists of 36 12m dishes situated in one of the most radio-quiet locations in the world – *Inyarrimanha Ilgari Bundara*, the CSRIO Murchison Radio-astronomy Observatory. Its Phased Array Feed (PAF) receivers allow it to observe a field of view of approximately 25 square degrees in a single pointing, and its backend permits a velocity resolution of up to $\sim 0.1\,\mathrm{km\,s^{-1}}$ (at the frequency of the OH lines) in a single 9 MHz band (see Hotan et al. 2021, for detailed system information). Figure 1 shows the GASKAP-OH survey region, and Table 1 shows the expected sensitivity and resolution in each of the survey subregions. The Galactic Centre, Galactic Bulge and LMC will be observed in multiple epochs to quantify maser variability and derive a more complete population of sources. In common with all ASKAP SSPs, GASKAP-OH data will be processed automatically by the observatory using the ASKAPsoft package, and released to the survey-team as a collection of datacubes, images and catalogues.

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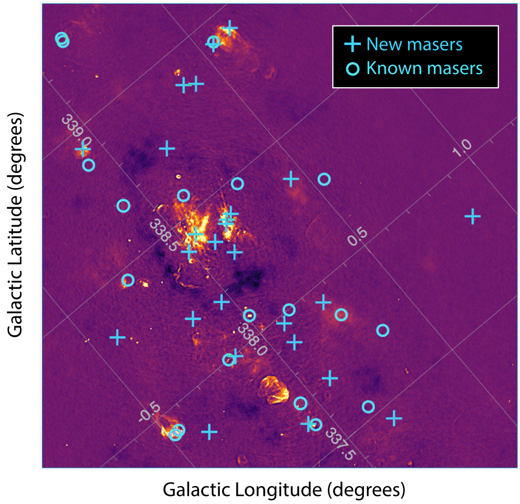

Figure 2. Newly-detected 1665 MHz masers in a portion of the G340 Test Field, overlaid on the 1665 MHz continuum image. Preliminary source-finding using SELAVY (Whiting and Humphreys 2012) recovered all 19 previously published sources in this region and detected 26 new ones, down to a 5σ detection limit of $\sim$100mJy.

3. Main Science Goals

Star Formation: GASKAP-OH will provide the deepest ever unbiased survey of star-formation OH masers in the Southern Hemisphere, revealing a currently invisible population. Main line OH masers are widely regarded as a signature of the later stages of high-mass star formation (Forster and Caswell 1989), however all four ground-state OH transitions may be seen (see e.g. Qiao et al. 2018), with uncommon combinations indicating the presence of unusual physical conditions. Combining GASKAP-OH with the wealth of complementary multi-wavelength maser and thermal line surveys available in the South (e.g. class II methanol and water lines from the Methanol Multibeam Survey and the H_2O Southern galactic Plane Survey, Green et al. 2009; Walsh et al. 2014) will allow us to piece together a cohesive picture of where OH masers fit in the maser evolutionary timeline (Breen et al. 2010), both in phase and duration. Zeeman splitting of the OH maser lines will also provide a large sample of in-situ measurements of the strength and direction of the magnetic field in star forming regions.

Evolved Stars: GASKAP-OH will provide the deepest ever unbiased sky survey of circumstellar envelopes (CSE) OH masers across the Galactic Plane, Galactic Centre, Bulge and the LMC. Evolved stars, especially in the AGB and post-AGB phase, play a major role in returning metal-rich stellar mass to the ISM. However, the total rate of mass return is poorly constrained, and the precise relationship between the mass-loss rate and luminosity (which depends sensitively on the dust fraction in the outflow) is still in unknown. OH masers (primarily at 1612 MHz) associated with circumstellar envelopes (CSEs) provide an excellent tool for addressing these questions, allowing us to derive the luminosity function of CSE OH maser sources, and directly measure the CSE wind speed. This is key to understanding wind driving, to determining the dust-to-gas ratio (Marshall et al. 2004; Goldman et al. 2017), and to determining the mass-loss rates of individual stars.

Molecular Cloud Evolution: The formation of dense molecular clouds from the diffuse atomic ISM sets fundamental boundaries on the star formation rate. GASKAP-OH, in combination with GASKAP-HI (e.g. Dempsey et al. 2022) will provide a statistical

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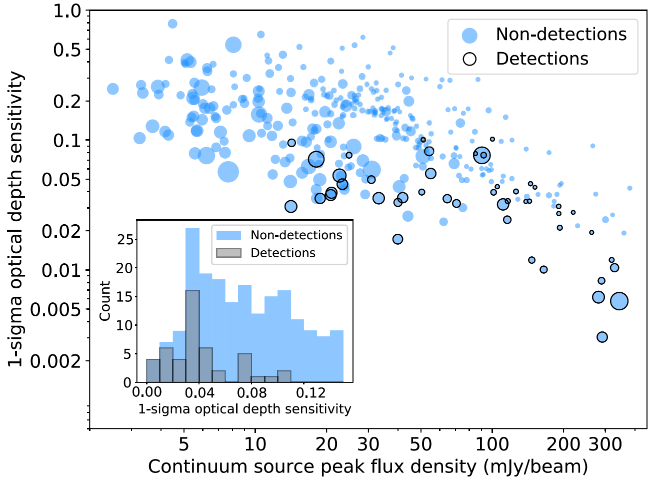

Figure 3. 1667 MHz absorption detection statistics for the G340 Test Field. The scatter plot shows the 1σ optical depth sensitivity (at a velocity resolution of $1\,\mathrm{km\,s^{-1}}$ and integrated over the entire continuum source) as a function of source peak brightness for SELAVY continuum "islands" output as part of the ASKAPSOFT processing workflow. The symbol size is proportional to the continuum island major axis. The inset panel shows optical depth sensitivity histograms for detected and non-detected continuum sightlines. 70 distinct velocity components are detected towards 47 continuum islands.

census of the atomic and molecular gas along hundreds of absorption sightlines throughout the Milky Way Disk, allowing us to probe the cold ISM pre- and post-transition to the molecular phase, and constrain the conditions required for the atomic-molecular phase transition. Modelling the non-LTE excitation of the quasi-thermal OH lines (e.g. Guibert et al. 1978) can constrain temperature, density and mass of both the molecular and atomic gas, and track how these vary with Galactic environment. Importantly, the OH lines are able to probe so-called 'dark' molecular gas – diffuse H_2 that is very poorly traced by common tracers such as CO (e.g. Li et al. 2018; Busch et al. 2021).

4. Preliminary Results & Detection Statistics

Figures 2 and 3 show preliminary detection results based on a single 8-hour integration centred on l=340°, b=0°, at a central frequency of 1666 MHz – covering both the main lines. These first test observations (the G340 Test Field) were carried out in September 2021. While the data is not of full publication-quality – in particular, the Doppler correction is not properly applied, resulting in velocity smearing across several channels – it was sufficient to verify the basic ASKAPsoft imaging parameters and explore initial detection rates. Even with compromised velocity resolution, we have more than doubled the known number of 1665 MHz OH masers in this part of the Galactic Plane (at a 5σ detection limit of $\sim$100 mJy) and detected around three 1667 MHz absorption sources per square degree – triple the detection rate of the only other comparable survey THOR (Rugel et al. 2018), in the North. We expect the main survey to achieve comparable or better (despite a marginally shorter integration time on the Galactic Plane fields), once velocity corrections are properly applied.

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