VSRT Memo # 065
21 September 2009

On the Feasibility of a Low-cost Methanol Radio Telescope

Vincent L. Fish & Alan E. E. Rogers

Abstract

This memo explores the feasibility of detecting and monitoring 12 GHz methanol masers using a low-cost system consisting of a MOSAIC-style LNBF and spectrometer system on a larger dish.

1 Introduction

The 12.178597 GHz transition of methanol (CH_3OH) is one of the most astrophysically important molecular lines in the radio spectrum. This transition ($2_0 \rightarrow 3_{-1}\,E$) is categorized as a "Class II" line, meaning that its population is inverted in the presence of a strong radiation field. In massive star forming regions (SFRs), this line is often seen to produce very bright masers (several hundred or even 1000 Jy).

The SRT and MOSAIC projects have been very successful in producing low-cost radio antennas to observe H I in the Galaxy (SRT) and the 11.072 GHz line of ozone in the atmosphere (MOSAIC). This memo explores the feasibility of building on these successes to produce a low-cost instrument to monitor 12 GHz methanol masers.

2 Requirements

At its highest level, a low-cost methanol telescope requires simply a large enough pointable dish for reasonable sensitivity and an LNBF/spectrometer system that can tune to the 12 GHz line of methanol. Additionally, the spectrometer should have sufficient bandwidth to cover the Doppler-shifted velocity range of methanol in a typical massive SFR with the frequency resolution to resolve typical maser lines.

At an initial glance, it would appear that an easy solution for a pointable dish would be to mount a Ku-band LNBF at the prime focus on an existing SRT. The FWHM beam size at $\lambda = 2.46$ cm of a 7-foot diameter SRT is approximately 0.8°. Unfortunately, the drive motors on the SRT are not capable of sub-degree pointing accuracy. Thus, the SRT as currently shipped by CassiCorp is not a suitable platform to observe at 12 GHz, although it is possible that modifications could be made to the SRT to provide the requisite pointing accuracy.

Alternatively, a Ku-band antenna can be purchased from numerous satellite television dealers, and motors are commercially available as well. A 1 m diameter offset dish with good aperture efficiency (claims of over 70%) can be purchased for under $150, and dishes as large as 2.4 m or even 10 ft can be obtained for several hundred to just over a thousand dollars. (If a mesh dish is used, special care should be taken to ensure that the mesh is fine enough that aperture efficiency is not compromised too badly.)

As a starting point for the LNBF and frequency chain, we consider the setup described in VSRT Memo #029 for the MOSAIC ozone spectrometer system. The Invacom SNH-031 LNBF described therein covers two frequency ranges: 10.7 – 11.7 GHz with a local oscillator (LO) frequency of 9.75 GHz (used by the MOSAIC project to mix a sky frequency of 11.072 GHz down to 1322 MHz) and 11.7 – 12.75 GHz witn an LO of 10.6 GHz (which could be used to mix the methanol 12.178 GHz signal down to 1578 MHz). Other choices of filter and second LO frequency would be required, but it does not appear that there are any fundamental restrictions that would prevent using a MOSAIC-style system at 12 GHz.

As described in VSRT Memo #031, the ADC operates at 20 Msamples s^{-1}, sufficient for 10 MHz of bandwidth, although only 2.5 MHz of bandwidth is used for MOSAIC. The MOSAIC spectrometer produces channelizes into 256 spectral channels (although the data have usually been averaged down to 64 channels). For the methanol rest frequency, 2.5 MHz divided into 256 channels corresponds to a velocity coverage of 62 $\mathrm{km\,s^{-1}}$ with a channel spacing of 0.24 $\mathrm{km\,s^{-1}}$. The latter is comparable to a typical 12 GHz methanol maser line width, and the velocity coverage is more than adequate for observing SFRs. The bandwidth could be further halved if necessary to allow frequency switching, as is presently used in the MOSAIC system.

3 Noise Calculation

A typical system temperature for the MOSAIC systems is approximately 100 K. This comes from the sum of the contributions from the LNA ($\sim$ 20 K), the atmosphere at 8° elevation ($\sim$ 35 K), spillover from the feed ($\sim$ 40 K), and the cosmic microwave background (2.7 K) (see VSRT Memo #045). In typical weather, a methanol maser telescope should have a much smaller contribution from the atmosphere, since most of the observations would occur at higher elevation (lower airmass). The contribution from spillover will depend on the particular dish selected and may also be significantly smaller than the value assumed for the MOSAIC system. Nevertheless, we will pessimistically assume a system temperature of 100 K for a small methanol telescope.

To calculate the gain of the telescope, we will assume a 1.2 m diameter dish with an aperture efficiency of 70%. The effective area is then 0.79 m^2. The telescope gain is the effective area divided by twice Boltzmann's constant, or 2.9×10^{-4} $\mathrm{K\,Jy^{-1}}$. That is, a 1000 Jy source is equivalent to a temperature of 0.29 K.

The rms noise of observations utilizing bandwidth B in time t is

$$\sigma = \frac{\alpha T_{\mathrm{sys}}}{\sqrt{Bt}},$$

where $\alpha > 1$ takes into account other system inefficiencies (e.g., sampling quantization). We will assume $\alpha = 1.5$, slightly greater than the $\sqrt{2}$ that comes from the folded noise contribution from frequency switching. The bandwidth of a single spectral channel is 9.77 kHz. In a 10 min observation, $\sigma = 62$ mK. That is, a 1000 Jy source could be detected with a signal-to-noise ratio (SNR) of 4.6 in 10 minutes, corresponding to an rms noise per channel of 220 Jy. In 6 hours, the same source could be detected with an SNR of 28, corresponding to an rms noise per channel of 36 Jy.

For comparison, Batrla et al. (1987) detect integrated fluxes of 1297, 1147, and 198 $\mathrm{Jy\,km\,s^{-1}}$ toward W3(OH), NGC 6334 F, and NGC 7538, respectively. Koo et al. (1988), reporting on individual maser components, find a 1010 Jy ($\Delta v = 0.36$ km s^{-1}) and 886 Jy (0.37 km s^{-1}) maser in NGC 6334 F, a 900 Jy maser in W3(OH), a 302 Jy maser (0.29 km s^{-1}) in Cep A, and a 230 Jy maser (0.82 km s^{-1}) in NGC 7538). With the exception of NGC 6334 F, which at less than -35° declination will be low to the horizon from mid-northern latitudes, all the rest of these sources transit very high in the sky in the United States. In practice, detection SNRs will be higher than values quoted for a single frequency channel because some maser lines are wider.

There are opportunities to increase the sensitivity by a factor of several from the figures calculated here. For instance, increasing the dish size from 1.2 m to 2.4 m increases the collecting area (and thus the gain) by a factor of 4, resulting in an increase in the SNR by a factor of 4 as well. High-elevation observations in good weather with an antenna suitably chosen to reduce spillover would likely decrease the system temperature by several tens of percent from the assumed value of 100 K, which would also increase the calculated SNR proportionally.

4 Applications

There are opportunities for educational value in a small methanol telescope system. A methanol system attached to a large dish may also have scientific potential for monitoring bright 12 GHz maser sources. Some methanol masers display little variability while others are seen to change flux density by over a factor of 2 (Moscadelli & Catarzi 1996). Additionally, a low-cost methanol radio telescope may be of interest to radio astronomy hobbyists.

References

Batrla, W., Matthews, H. E., Menten, K. M., & Walmsley, C. M. 1987, Nature, 326, 49
Koo, B.-C., Williams, D. R. W., Helies, C., & Backer, D. C. 1988, ApJ, 326, 931
Moscadelli, L., & Catarzi, M. 1996, A&AS, 116, 211