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/S1743921317010201

Methanol Masers in the Andromeda Galaxy

Ylva M. Pihlström[1,2] and Loránt O. Sjouwerman[2]

[1]Department of Physics and Astronomy, University of New Mexico,
MSC07 4220, Albuquerque, NM 87111, USA
email: ylva@unm.edu

[2]National Radio Astronomy Observatory,
P.O. Box O, 1003 Lopezville Road Socorro, NM 87801, USA
email: lsjouwer@nrao.edu

Abstract. Is M31 going to collide with the Milky Way, or spiral around it? Determining the gravitational potential in the Local Group has been a challenge since it requires 3D space velocities and orbits of the members, and most objects have only had line-of-sight velocities measured. Compared to the less massive group members, the transverse velocity of M31 is of great interest, as after the Milky Way, M31 is the most dominant constituent and dynamic force in the Local Group. Proper motion studies of M31 are preferentially done using masers, as continuum sources are much weaker, and are enabled through the high angular resolution provided by VLBI in the radio regime. The challenges of achieving high astrometric accuracy at high VLBI frequencies (> 20 GHz) makes observations at lower frequencies attractive, as long as sufficient angular resolution is obtained. In particular, we have discovered 6.7 GHz methanol masers in M31 using the VLA, and here we will address their feasibility as VLBI proper motion targets using a set of global VLBI observations.

Keywords. masers, techniques: high angular resolution, galaxies: individual (M31), (galaxies:) Local Group, radio lines: galaxies

---

1. Introduction

One main observational task in cosmology is to determine the distribution of dark matter in galaxies and galaxy groups. Locally, this is measured by estimating the masses of the individual components of the Local Group. Determining the gravitational potential in the Local Group has been a challenge since it requires full three-dimensional velocities of the objects. Except for close Local Group components with optically measured proper motions (the LMC, the SMC, the Canis Major dwarf galaxy and other components closer than ∼150 kpc; e.g., Kallivayalil *et al.* 2009; Piatek *et al.* 2008; Vieira *et al.* 2010 and references therein), only line-of-sight velocities have been available. This situation is improving after, for example, Brunthaler *et al.* (2005; 2007) successfully measured proper motions of both M33 and IC10 using VLBI observations of H_2O masers. Other methods to determine the gravitational potential have applied statistical approaches (e.g., van der Marel & Guhathakurta 2008), but trigonometric measurements would put more stringent limits on the potential.

A major uncertainty in the mass distribution of the Local Group still lies in the undetermined transverse velocity of M31. With the Milky Way, M31 is the most dominant constituent and dynamic force in the Local Group (together with M31's satellite M33). Obtaining the transverse velocity of M31 would resolve the largest unknown in the modeling (e.g., Peebles *et al.* 2001; Loeb et al. 2005; Cox & Loeb 2008). With the high angular resolution provided by VLBI in the radio regime, proper motion studies of masers with M31 should be feasible, similar to what has been done for M33 (Brunthaler *et al.* 2007).

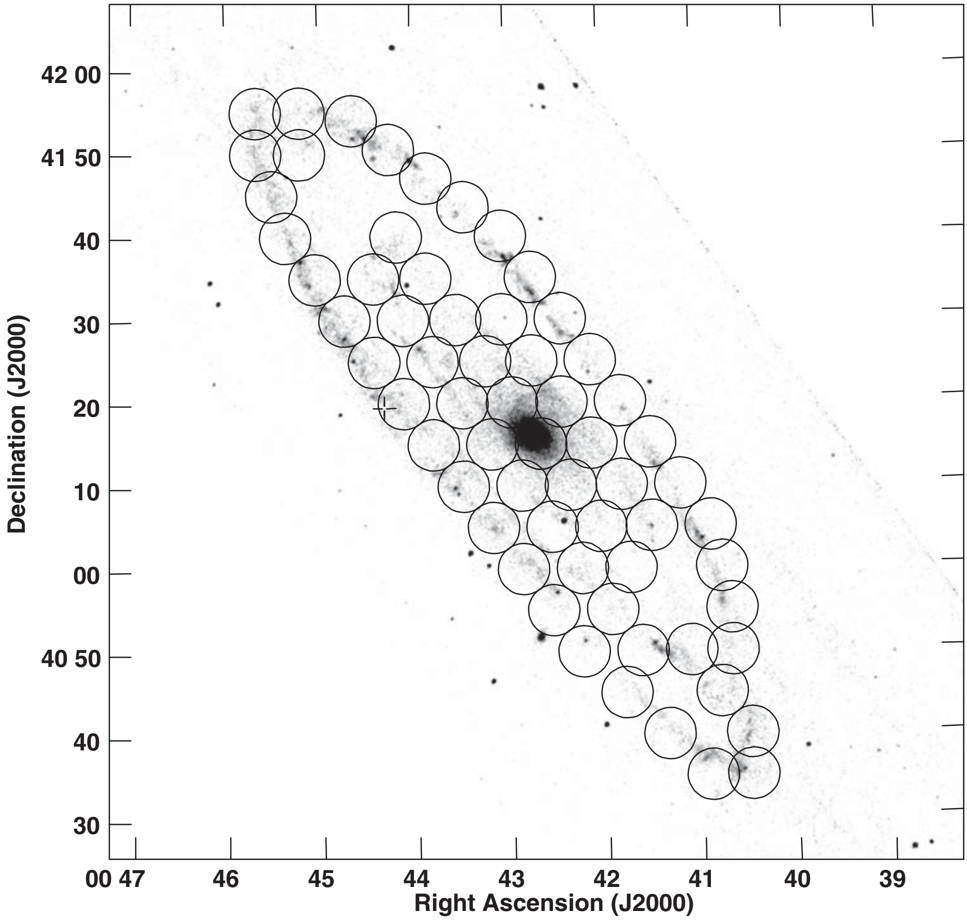

Figure 1. VLA 6.7 GHz pointings overlaid onto an MSX 8μm infrared image of M31. The size of the circles represents the primary beam of the VLA pointings. The cross marker placed in the eastern row of circles denotes the position of the methanol maser seen in Fig. 2.

High frequency masers like the 22 GHz H_2O transition are optimally suited for proper motion studies due to the high angular resolution that can be achieved. However, with the small primary beam it has been difficult to find masers in M31 since the galaxy subtends a large angle on the sky ($40' \times 150'$ in the infrared). Targeted M31 maser searches were therefore aimed to find H_2O masers near HII regions with Hα, radio continuum emission, or CO emission, without any detections until very recently (Darling 2011; Huchtmeier, Eckart & Zensus 1988; Imai *et al.* 2001). Although 22 GHz masers are preferred for proper motion studies, other maser transitions may be an alternative when no H_2O masers are available. We have discovered Class II 6.7 GHz methanol masers in M31 (Sjouwerman *et al.* 2010), and here we are using global VLBI data to investigate their feasibility as VLBI proper motion targets in M31 and in other galaxies that may lack sufficiently bright H_2O maser detections.

2. Detection of Methanol Masers in M31

We have performed a systematic survey for 6.7 GHz methanol masers in M31. Selected regions of M31 were observed with the VLA during 2009 until the VLA shut down in

https://doi.org/10.1017/S1743921317010201 Published online by Cambridge University Press

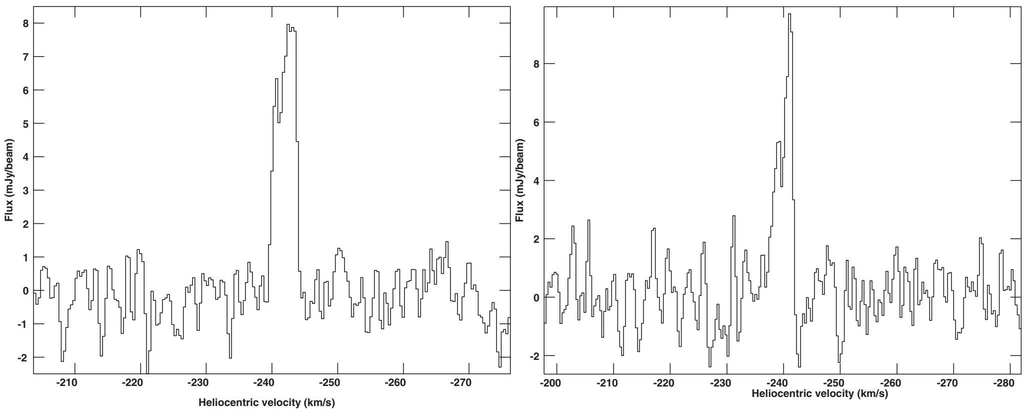

Figure 2. Spectra of one of the Class II 6.7 GHz methanol masers observed in M31, displaying a more or less constant flux density over a period of three years. The spectrum on the left was observed in 2010, and the one on the right in 2013, both using the upgraded VLA.

mid-January 2010. Several tentative detections at the 5-7σ level have been made. One of these candidates was selected for a follow-up study using the upgraded VLA in July 2010, confirming that the feature was real (see Sjouwerman *et al.* 2010). Later on, additional pointings covering most of the M31 angular extent was performed with the upgraded VLA system (the complete set of pointing positions is shown in Fig. 1). In September 2013, we did another observation with the VLA confirming the maser is still present, and this showed the maser is stable, with the same flux density as in 2010 (Fig. 2). The maser peak flux density of about 8 mJy/beam compares to masers on the high-end tail of the Class II 6.7 GHz methanol maser distribution in the Milky Way (Goldsmith, Pandian & Deshpande 2008). The brightest Galactic methanol maser with a very accurate distance measurement is W3(OH): $\sim$3700 Jy at 2.0 kpc (Pestalozzi, Minier & Booth 2005; Hachisuka *et al.* 2006). At this distance, the M31 detection would measure $\sim$1300 Jy, while the brightest maser in the LMC would be $\sim$3000 Jy (e.g., Beasley *et al.* 1996). Thus, it is plausible that M31 may host even brighter methanol masers than the initial detection (Sjouwerman et al. 2010). However, given the lower star formation rate of M31 compared to the Milky Way, it is equally plausible that all of the brightest methanol masers have been detected in the VLA observations.

3. Follow up VLBI Observations

To test the feasibility of the detected Class II methanol masers as Very Long Baseline Interferometry (VLBI) targets, observations using a global array consisting of the European VLBI Network (EVN), the Very Long Baseline Array (VLBA), and the phased Very Long Array (VLA) was performed. The data were taken over four consecutive days, with in total 24 hours of observing time. To obtain an accurate source position, phase referencing using a nearby calibrator within $< 1.5^\circ$ was applied. The cycle time was three minutes.

A preliminary analysis of the data does not confidently detect the maser feature. Given the previously measured VLA flux density, we are confident that an unresolved maser should be detectable with the achieved VLBI sensitivity. During the VLBI observations, the phased VLA also collects a pseudo-continuum data set for the individual VLA baselines. Using this VLA-only data set, despite a much coarser spectral resolution, it could

https://doi.org/10.1017/S1743921317010201 Published online by Cambridge University Press

be confirmed that the maser was still present, although it may have reduced somewhat in its brightness.

The difficulty of confidently detecting the maser may be due to the emission distribution, implying that it may be resolved on the scales of the VLBI baselines. However, if the M31 6.7 GHz methanol maser emission would be contained within a similar spatial distribution as the methanol masers in Galactic star forming regions, the emission should be unresolved. Galactic star forming regions are often accompanied by other signs of star formation, including H_2O maser emission, Hα emission, and HII region signatures. Toward the location of the methanol maser there are no other typical signs of star formation confirmed, which could indicate a different maser formation environment in M31. However, the velocity width, luminosity, and more or less invariable peak flux density is consistent with other Class II methanol masers associated with Galactic star forming regions.

Additional work on the data to confirm whether the 6.7 GHz maser feature is indeed non-detected will be performed, including more rigorous radio frequency interference removal and combining all the four days of observations.

Acknowledgements

The European VLBI Network is a joint facility of independent European, African, Asian, and North American radio astronomy institutes. The National Radio Astronomy Observatory is a facility of the National Science Foundation operated under cooperative agreement by Associated Universities, Inc.

References

Beasley, A. J., Ellingsen, S. P., Claussen, M. J., & Wilcots, E. 1996, *ApJ* 459, 600
Brunthaler, A., Reid, M. J., Falcke, H., Henkel, C., & Menten, K. M. 2007, *A&A* 462, 101
Brunthaler, A., Reid, M. J., Falcke, H., Greenhill, L. J., & Henkel, C. 2005, *Science* 307, 1440
Cox, T. J. & Loeb, A. 2008, *MNRAS* 386, 461
Darling, J. 2011, *ApJ*Letters 732, L2
Goldsmith, P. F., Pandian, J. D., & Deshpande, A. A. 2008, *ApJ* 680, 1132
Hachisuka, K., Brunthaler, A., Menten, K. M., Reid, M. J., Imai, H., Hagiwara, Y., Miyoshi, M., Horiuchi, S., & Sasao, T. 2006, *ApJ* 645, 337
Huchtmeier, W. K., Eckart, A., & Zenzus, A. J. 1988, *A&A* 200, 26
Imai, H., Ishihara, Y., Kameya, O., & Nakai, N. 2001, *PASJ* 53, 489
Kallivayalil, N., Besla, G., Sanderson, R., & Alcock, C. 2009, *ApJ* 700, 924
Loeb, A., Reid, M. J., Brunthaler, A., & Falcke, H. 2005, *ApJ* 633, 894
van der Marel, R. P. & Guhathakurta, P. 2008, *ApJ* 678, 187
Peebles, P. J. E., Phelps, S. D., Shaya, E. J., & Tully, R. B. 2001, *ApJ* 557, 495
Pestalozzi, M. R., Minier, V., & Booth, R. S. 2005, *A&A* 432, 737
Piatek, S., Pryor C. & Olszewski, E. W. 2008, *AJ* 135, 1024
Sjouwerman, L. O., Murray, C. E., Pihlström, Y. M., Fish, V. L., & Araya, E. 2010, *ApJ*Letters 724, L158
Vieira, K., Girard, T. M., van Altena, W. F., Zacharias, N., Casetti-Dinescu, D. I., Korchagin, V. I., Platais, I., Monet, D. G., Lopez, C. E., Herrera, D., & Castillo, D. J. 2010, *AJ* 140, 1934