Observing Application

Date:	
Proposal ID:	VLA/2017-00-028
PI:	T.K. Daisy Leung
Type:	Regular
Category:	
Total time:	5.5

This is a blank proposal created on Monday January 16, 2017

Abstract:

Authors:

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Related Proposals:

Joint:

Not a Joint Proposal.

Observing type(s):

Sources

Name	Position		Velocity		Group
RXJ1131	**Coordinate system**	Equatorial	**Convention**	Redshift	target - RXJ
	Equinox	J2000			
	Right Ascension	11:31:51.4	**Ref. frame**	LSRK	
		00:00:00.0			
	Declination	-12:31:59.1	**Velocity**	0.6541	
		00:00:00.0			
	Calibrator	No			

Sessions:

Name	Session time (hours)	Repeat	Separation	LST minimum	LST maximum	Elevation minimum
rxj	2.75	2	0 day	08:47:25	14:16:18	30

Session Constraints:

Name	Scheduling constraints	Comments
rxj		We split the total observing time of 5.5 hours into 2 sessions for more flexible scheduling.

Session Source/Resource Pairs:

Session name	Source	Resource	Time	Figure of merit
rxj	RXJ1131	RXJ	2.75 hour	

Present for observation: no Staff support: None Plan of dissertation: no

Technical Justification:

Combined telescopes:

N/A

Array configuration:

This is a detection experiment. Therefore, we do not require the line emission to be spatially resolved, as is the case here with the proposed B-array configuration paired with the L-band receiver. Using the B-array configuration will provide a higher fringe rate than the C- and/or D-array configurations, and thus will work to our advantage to mitigate effects of any RFIs that may be present within the line subband.

We expect emission of the OH line to be originating from <1 kpc near the quasar, whose quadruply lensed emission is confined along the Einstein ring of ~3.6" in diameter. Therefore, lensed emission of the OH line will be unresolved at the proposed resolution (~9.5").

The largest angular size is <1", as shown in the HST image (Fig. 1). Since the MRS is larger than this LAS, we do not expect any diffuse OH emission to be resolved out.

Scheduling restrictions:

1. Target is at RA~12h, which will be transiting
between 6am-3pm (Mountain time) during the B-array observing period. This indicates that it is a daytime source given the range of LST that our target is observable.

2. The object declination is -12 deg, therefore our sensitivity calculation assume medium elevation (25-50 deg).

3. N/A

4. N/A

5. N/A

Receivers requested:

The OH line at 1.667 GHz is redshifted to 1.0078 GHz (L-band) at the target redshift (z = 0.6541).

Samplers and correlator setup:

We will adopt a correlator setup of two 1 GHz IF pairs using the 8-bit samplers to maximize sensitivity and RFI overheads.

The OH line FWHM is assumed to be ~600 km/s, which is used to derived the required sensitivity.

Since this is a detection experiment, we do not require the line emission to be spectrally resolved. We will use 16 MHz per subband, providing a spectral resolution of 125 kHz (~35km/s) to identify RFIs in nearby channels. Since our science goals do not rely on cross-hands polarization, we will use dual polarization to increase the spectral resolution to identify potential unexpected RFIs.

The subband width of 16 MHz covers ~4600 km/s at the line frequency, and thus will be sufficient to cover the full OH line profile.

The OH line at rest frequency of 1.667 GHz is redshifted to 1.0078 GHz for our target at z=0.6541.

Mosaic requirements:

N/A

Sensitivity:

The total flux of the OH line is 330 mJy km/s over the line FWHM of ~600 km/s. We expect it to be spatially unresolved. Thus, to achieve a 5 sigma detection over the line FWHM, we require a sensitivity of ~110 µJy/beam over the line FWHM.

Integration time:

We used the VLA exposure calculator with the B array configuration, 600 km/s velocity bins, 110 uJy rms per bin at a frequency of 1.008 GHz, L-band receiver, 8-bit samplers, medium elevation, and autumn observing conditions. This yielded ~4.3 hours on-source and 5.5 hours total time including overheads.

Dump time:

Dump time: 3.0s
Data rate: xx MB/s
Total volume: xx GB/h
These are the standard values, and thus no problems are expected.

Imaging considerations:

Based on our existing continuum measurements at 5 GHz and assuming a spectral index of -0.7 between 1 GHz and 5 GHz, we expect an unresolved continuum emission of ~6.5 mJy at the proposed frequency. The spectral dynamical range between the continuum and the OH line in our science target is lower than the VLA standard SDR, thus simple wide-band imaging will suffice.

Polarimetric considerations:

N/A

RFI considerations:

We do not expect to see strong RFIs at the proposed line frequency based on the most recent VLA W8 monitor plots and the list of RFIs known at the VLA site.

Joint considerations:

N/A

Other:

N/A

Probing OH Megamaser in a Strongly-Lensed Gas-Rich Merger at $z\sim 0.65$

Current understanding of OH megamasers and galaxy evolution

Almost all (>95%) OH "megamaser" (OHMs) known to date are associated with (ultra)-luminous infrared galaxies (U)LIRGs ($L_{\rm IR} > 1\times10^{11}\,L_\odot$; see Lo 2005 for a review), which are undergoing extreme bursts of star formation triggered by mergers events (e.g., Sanders & Mirabel 1996; Hopkins et al. 2006). Theoretically, the intense IR radiation field and the large column of molecular gas found in (U)LIRGs/mergers are the required conditions for generating OHMs (Baan 1989). Thus, OHM is expected to arise naturally in all galaxy mergers.

The scaling relation of $L_{\rm OH}\propto L_{\rm FIR}^{1.2-2}$ (Baan 1989; Darling & Giovanelli 2002b, hereafter DG02) suggests that the number density of OHM is expected to increase towards $z\sim 3$, when (U)LIRGs /mergers are more common (e.g., Le Floc'h et al. 2005; Magnelli et al. 2009). OHM has therefore been proposed as one of the most promising avenue for tracing mergers beyond the nearby universe and for constraining the merger history independent of IR luminosity function (Briggs 1998, DG02). These model predictions indicate that we should be able to detect OHMs out to at least $z\sim 3$ with current facilities. Yet, the most distant OHM host galaxy known-to-date is at $z=0.265$, which was discovered over two decades ago (Baan et al. 1992). In addition, the null detections reported in the latest OHM studies (over half a decade ago) — by Ivison (2006) in a $z\sim 4$ galaxy and by Willett (2012) in a sample of (U)LIRGs at $z\lesssim 1.5$ (Fig. 1) — suggest a potential redshift evolution in the $L_{\rm OH}$-$L_{\rm FIR}$ relation, which may hint at a different OHM triggering mechanism at earlier epochs. Detecting OH line emission at $z\gtrsim 0.3$ is therefore crucial to enable a better understanding of OHM and to improve existing predictions for planning future OHM surveys with next generation facilities (e.g., FAST, APERTIF/WSRT, ASKAP; Zhang et al. 2014). Here we propose to observe OH 1667 MHz line emission in the gravitationally-lensed starbursting galaxy merger RXJ1131 at $z=0.65$ (Fig. 2) using the VLA's B-array configuration. In contrast to the Willett (2012) sample, which does include any active galactic nucleus (AGN) host galaxies, our target hosts an optically bright AGN, and thus offers an alternate view to high-z OHM hosts.

A well-suited target — a lensed gas-rich, starbursting merger at $z > 0.6$

High-resolution imaging and spectroscopy in optical wavelength shows that RXJ1131 is lensed by a foreground galaxy at $z\sim 0.3$ (Fig. 2; Sluse et al. 2003). By exploiting the effect of lensing magnification, our proposed detection experiment requires **an on-source time of ∼30 times less** than otherwise needed to reach the same sensitivity. The unique lensing configuration of RXJ1131 has led to extensive follow-up studies spanning X-ray to radio (Fig. 2; e.g., Claeskens et al. 2006; Sluse et al. 2007; Pooley et al. 2007; Reis et al. 2014; Leung et al. 2017), making it one of the well-studied galaxies at $z>0.5$ and the only source at $0.2<z<1$ with spatially resolved imaging of the molecular gas distribution (Leung et al. 2017). These data indicate a high apparent FIR luminosity of $L_{\rm FIR} > 4\times10^{12}\,L_\odot$, an intense star formation rate of SFR $\sim 120\ M_\odot$ yr^{-1} (lensing-corrected), evidence of recent starburst as traced by rest-frame UV observations, and the presence of a nearby companion and a large molecular gas reservoir of $M_{\rm gas}\gtrsim 10^{10} M_\odot$. Taking these properties altogether highly suggests that RXJ1131 is an excellent candidate to search for OHM. In addition, the redshift of RXJ1131 has been confirmed spectroscopically, allowing us to confirm that RFI is not a limiting factor in reaching the theoretical rms, which has been a major challenge in previous OHM surveys (e.g. Darling & Giovanelli 2002a; Willett 2012).

Science goals

The proposed observations will establish the first OHM detection in a *bona-fide* high-z merger, thereby building up our confidence in using OHM as a tracer of distant galaxy mergers and testing the long-envisaged hypothesis of using the number density of OHM to constrain the redshift evolution of merger rate. Such a high-z (non-)detection will also allow us to better constrain the L_{OH}-L_{FIR} scaling relation and its redshift evolution, and thus improve model predictions for designing future surveys to search for high-z OHMs with upcoming facilities. A null detection would indicate that a revision of the OHM number density-merger history hypothesis is critically needed before carrying out any future OHM surveys. In addition, regardless of whether the OHM is detected or not, the amount of data we have already acquired for this potential OHM host galaxy will allow us to compare its (host) galaxy properties (e.g., SFR or L_{FIR}, L_{IR}, L_{OH}, L_{radio}, molecular and dust content) against those of local OHM hosts to better understand the relationship between the maser emission and the environment of its (host) galaxy. A non-detection would therefore still be meaningful in advancing our knowledge.

With the aid of lensing and the wealth of existing multi-wavelength data probing a wide range of properties of this potential OHM host, RXJ1131 is an exceptional target for obtaining a better understanding of OHM in IR-luminous galaxies beyond the nearby universe. In the case of a detection, we will carry out follow-up observations with the VLBA to study the physical conditions of the nuclear molecular torus responsible for the OH line emission. The proposed investigation will therefore serve as an important benchmark for future studies of high-z OHM out to earlier epochs, when extremely IR-luminous sources are much more common.

References • Baan, W. A. 1989, ApJ, 338, 804 • Baan et al. 1992, ApJ, 396, L99 • Briggs, F. H. 1998, A&A, 336, 815 • Claeskens et al. 2006, A&A, 451, 865 • Darling et al. 2002a, AJ, 124, 100 • Darling et al. 2002b, ApJ, 572, 810 • Hopkins et al. 2006, ApJS, 163, 1 • Ivison, R. J. 2006, MNRAS, 370, 495 • Le Floc'h et al. 2005, ApJ, 632, 169 • Leung et al. 2017, ApJ, submitted • Lo, K. Y. 2005, ARA&A, 43, 625 • Magnelli et al. 2009, A&A, 496, 57 • Pooley et al. 2007, ApJ, 661, 19 • Reis et al. 2014, Nature, 507, 207 • Sanders et al. 1996, ARA&A, 34, 749 • Sluse et al. 2007, A&A, 468, 885 • Sluse et al. 2003, A&A, 406, L43 • Willett, K. 2011, PhD thesis • Willett, K. W. 2012, IAU Symposium, 287, 345 • Zhang et al. 2014, A&A, 570, A110

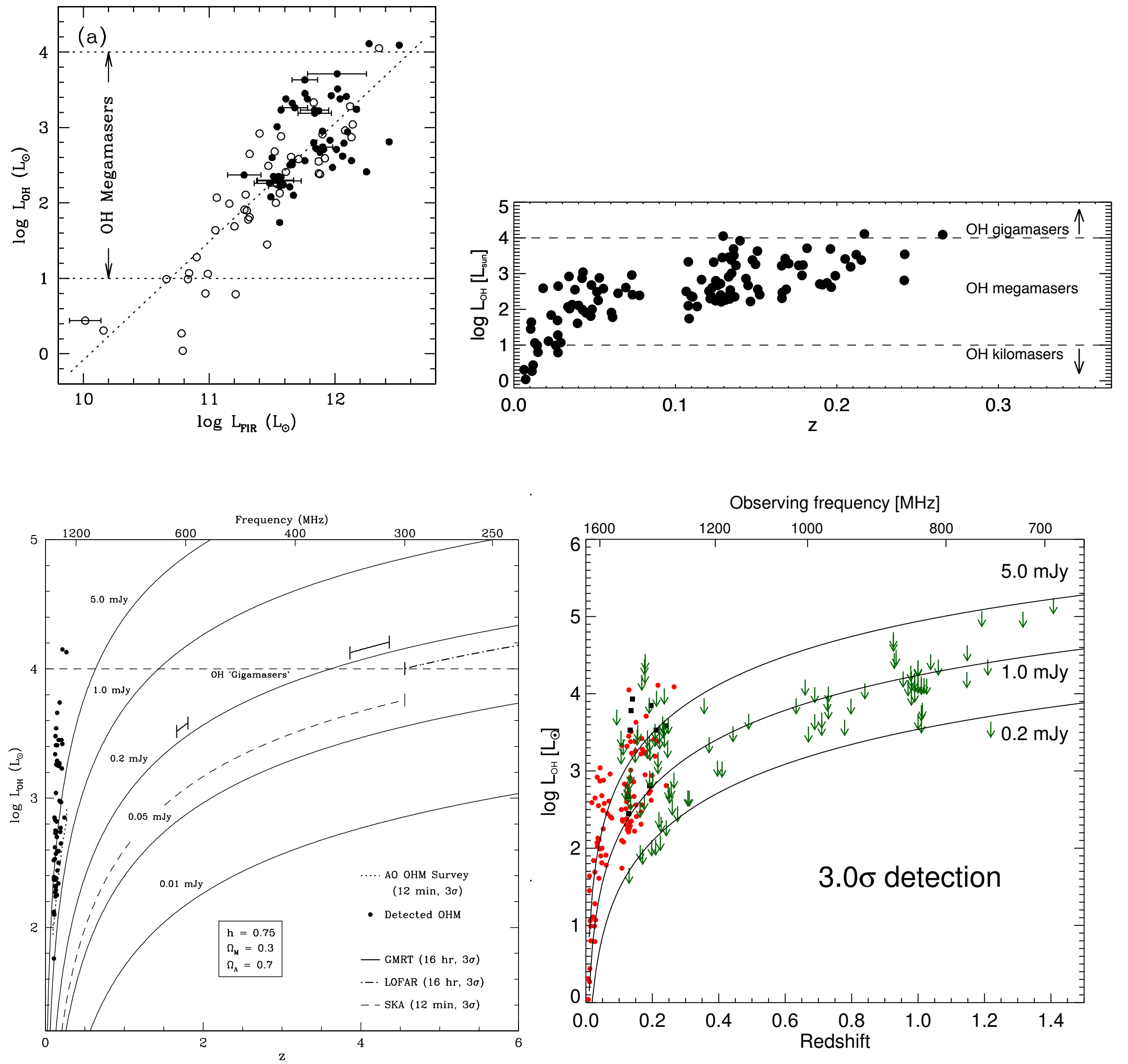

Figure 1: **Existing OHM measurements and predictions for future surveys.** *Top left*: The super-linear correlation between $L_{\rm OH}$ and $L_{\rm FIR}$ found in local studies suggests that OHM is a powerful tool for tracing distant mergers and thus constrain the cosmic merger history (DG02). *Top right*: Redshift distribution of all OHMs detected to date. The highest-z OHM at $z = 0.265$ was detected over two decades ago (Baan et al. 1992; Willett 2011). *Bottom left*: Detectability of OHMs at high redshift with (upcoming) facilities predicted based on existing OHM detections (dots; DG02). *Bottom right*: All OHMs detected to date (dots) and upper limits (green arrows) from the latest OHM survey (Willett 2012). Here we propose to observe OH 1667 MHz line emission in the gravitationally-lensed starbursting galaxy merger RXJ1131 at $z = 0.65$. In contrast to the Willett (2012) sample, which does include any active galactic nucleus (AGN) host galaxies, our target hosts an optically bright AGN, and thus offers an alternate view to high-z OHM hosts. The proposed observations will better constrain the $L_{\rm OH}$-$L_{\rm FIR}$ scaling relation and its redshift evolution, and thus improve model predictions for designing future surveys to search for high-z OHMs with upcoming facilities.

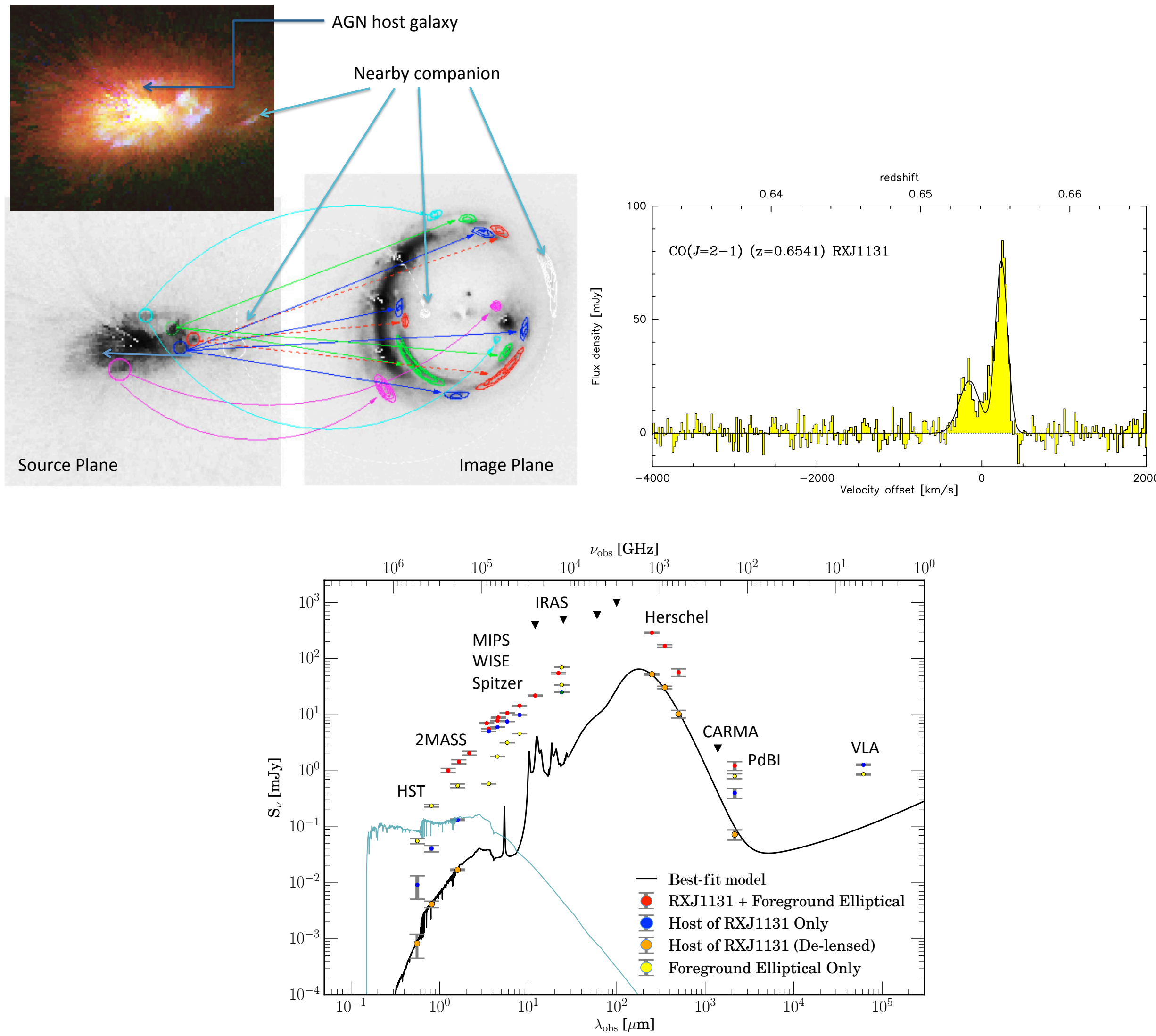

Figure 2: **Our target RXJ1131, a gas-rich, starbursting merger at $z > 0.6$ with a well-sampled spectral energy distribution (SED) spanning rest-frame UV to radio.** *Top left:* The rest-frame UV emission (tracing young star-formation) in this AGN host galaxy is lensed into an almost complete Einstein ring with a diameter of ∼3.6" in the image plane. Source-plane reconstruction illustrates the presence of a nearby companion (white component; Claeskens et al. 2006). *Top right:* Our recent study reports a large molecular gas reservoir of $M_{\rm gas} \gtrsim 10^{10} M_\odot$ in RXJ1131 and confirmed the presence of its companion, with a gas mass ratio of 7:1 (Leung et al. 2017). *Bottom:* Our best-fit model to the well-sampled SED indicates a high apparent FIR luminosity of $L_{\rm FIR} > 4\times10^{12}\, L_\odot$ and an intense star formation rate of SFR ∼ 120 $M_\odot$ yr^{-1} (lensing-corrected). These properties altogether indicates that RXJ1131 is likely hosting an OHM. The proposed observations together with the existing data acquired for our target will allow us to compare its (host) properties against those of local OHM hosts to better understand the physical environment for triggering OHM at an earlier epoch.

Array Configuration	B
Number of Antennas	25
Polarization Setup	Dual
Type of Image Weighting	Natural
Representative Frequency	1.0080 GHz
Receiver Band	L
Approximate Beam Size	9.533"
Digital Samplers	8 bit
Elevation	Medium (25°-50°)
Average Weather	Autumn
Calculation Type	Time
Time on Source	4h 20m 47s
Total Time	5h 28m 51s
Bandwidth (Frequency)	2.0174 MHz
Bandwidth (Velocity)	600.0000 km/s
RMS Noise (units/beam)	110.0000 μJy
RMS Brightness (temp)	1.4560 K
RMS H I Column Density	1.59253E+21

Produced by the NRAO EVLA Exposure Calculator v17A for semester 17A.