Combined Array for Research in Millimeter-wave Astronomy

Proposal Number

Unsubmitted

Observing Proposal Cover Sheet

General Proposal Information

Title	Date	TOO/Time Critical
Mapping the Molecular Envelope of the Hypergiant NML Cyg	2010-08-29	—

Scientific Category	1cm Project	3mm Project	1mm Project	Level of Help Required
Chemistry / Interstellar Medium	—	—	X	Consultation

Authors List

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Advisor must send a supporting letter if Thesis is checked. See Instructions.

Abstract

NML Cyg is a massive oxygen-rich, hypergiant star with an estimated mass and mass-loss rate of $\sim$50 $M_\odot$ and 2×10^{-4} $M_\odot$ yr^{-1}, respectively. This powerful OH/IR source is at an estimated distance of $\sim$1.7 kpc and is associated with Cyg OB2, a region located in the X-ray emitting Cygnus X superbubble approximately $\sim$100 pc toward the northeast from NML Cyg. The circumstellar envelope of NML Cyg shows overwhelming evidence of asymmetric ejections with a possible photodissociation front. It is not fully understood to what effect the association with this Cyg OB2 region has on the circumstellar envelope of NML Cyg or the chemistry within. To better understand the chemistry, kinematics, and morphology of this star, we propose to map the molecular emission of NML Cyg in ^{12}CO, ^{13}CO, SO_2, SO, and H_2O. These species were particularly chosen because of their previous detection using single dish techniques and intriguing velocity profiles in VY CMa, a similar massive oxygen-rich supergiant star. In mapping these five species, we will be able to determine the distribution of the each molecule in the circumstellar shell of this star and start piecing together the questions: Are all oxygen-rich, massive stars similar, how do they compare, and what effect does NML Cyg's association with the Cyg OB2 region cause on the circumstellar envelope?

Source Information

#	Source	RA	DEC	Freq	A[1]	B[1]	C	D	E	SL	# Fields	Species	Imag/SNR	Flex.HA
1	NML Cyg	20:46	+40:07	220.39868	0	0	0	0	15	0	7	12CO/13CO, SO2, SO, H2O	Imaging	—

Total Hours: 15.0

Special Requirements

None

Status of Prior CARMA Observations

None

Scientific Justification

NML Cygnus (hereafter, NML Cyg) is a massive oxygen-rich, hypergiant star with an estimated mass and mass-loss rate of $\sim$50 $M_{\odot}$ and 2×10^{-4} $M_{\odot}$ yr^{-1}, respectively (Zubko et al. *ApJ*, 610, 427, 2004). This powerful OH/IR source is at an estimated distance of $\sim$1.7 kpc and is associated with the Cyg OB2 region. The Cyg OB2 region is located in the X-ray emitting Cygnus X superbubble approximately $\sim$100 pc toward the northeast from NML Cyg (See Figure 1) (Knodlseder, *Astron.Astrophys.*, 360, 539 2000; Schuster et al., *ApJ*, 131, 603, 2006; Schuster et al., *ApJ*, 699, 1423, 2009). As has been observed for years, the mass-loss occurring from NML Cyg is highly intriguing. Its circumstellar envelope shows overwhelming evidence of asymmetric ejections with a possible photodissociation front as a result of the star's proximity to the Cyg OB2 region (Schuster et al. 2006, 2009). As the mass-loss of a star governs the evolution and structure of the surrounding envelope, it is crucial that we continuously pursue a more complete understanding of this complex and poorly known process (Muller et al., *ApJ*, 656, 1109, 2007).

Extensive work has been done observing the MASER emission of NML Cyg, including SiO, OH, and H_2O (Benson and Mutel, *ApJ*, 223, 119, 1979; Richards et al., *Mon.Not.R.Astron.Soc.*, 282,665, 1996; Diamond and Norris, *Mon.Not.R.Astron.Soc.*, 207, 611, 1984; Zubko et al. 2004). The results of these studies indicate emission along a northwest/southeast axis with a position angle between 132-150 degrees. It has been suggested that the emission is being protected by the stars envelope from the Cyg OB2 radiation, resulting in the one-sided distribution observed (Schuster et al. 2006, 2009).

Yet, in contrast to the conclusions determined from the maser studies, Harbing and colleagues (*Astron.Astrophys.*, 108, 412, 1982) reported observations of ionized hydrogen near NML Cyg (Figure 2). These unexpected observations were then modeled by Morris and Juna (*ApJ*, 267, 179, 1983) who proposed that the molecular material of the circumstellar shell is being photodissociated close to the star due to the ionizing radiation from the Cyg OB2 association. Thus, adequate shielding within the cirumstellar shell is NOT sufficient, resulting in these unexpected observations of ionized hydrogen. Further details of the morphology of NML Cyg are also revealed through high resolution HST images (Figure 1) (Shuster et al. 2006). An asymmetric, almost winged shell is observed. The symmetry axis is facing towards the Cyg OB2 association and the line of symmetry of NML Cyg runs in a west-northwest/east-southeast direction, very similar to the observed MASER emission. Comparing Figures 1 and 2, it is seen that the observed circumstellar material is closer to NML Cyg than the surrounding HII emission. Based on the HST data (Figure 1), Schuster and coworkers (2006, 2009) concluded that the shape of the envelope is a result of the molecular outflow interacting with the flux from the Cyg OB2 association. They refer to this as the "inverse photodissociation region"(Schuster et al. 2006, 2009).

However, it is still not known to what extent the Cyg OB2 region is interacting with the molecular content within the circumstellar envelope of NML Cyg. Also, how close is the molecular material being photodissociated to the star as suggested by Morris and Juna (1983)? In 2009, using the Arizona Radio Observatory Submillimeter Telescope and 12 m Telescope, Milam and coworkers (*ApJ*, 690, 837, 2009) reported observations of the J=1-0 and 2-1 transition of ^{12}CO and the J=1-0 transition of ^{13}CO (see Figure 3). Observations of ^{12}CO were used to determine a molecular source size of $\sim$28″using a radiative transfer model (Ziurys et al. *ApJ*, 695, 1604, 2009).

However, the model assumes a spherically expanding envelope, which is clearly not the case for NML Cyg. Based on these detections and initial approximation of the molecular emission, we continue our investigation with CARMA by mapping both ^{12}CO and ^{13}CO in this source at high spatial resolution to obtain a better understanding of the extent and morphology of molecular emission in the circumstellar envelope of NML Cyg.

Taking this investigation a few steps further, we also propose to map SO, SO_2, and vibrationally excited H_2O. Observations of VY CMa, another massive supergiant star with a comparable mass-loss rate to NML Cyg, show radically different velocity profiles between CO, SO_2 and other species (Figure 4) (Ziurys et al., *Nature*, 227, 1094, 2007). Furthermore, single dish mapping conducted of the surrounding circumstellar environment of VY CMa in both CO and SO show two kinematic components: a slowly expanding shell in the north-south direction and a higher velocity component moving to the east and west (Muller et al. 2007). Mapping these five molecules in the circumstellar envelope of NML Cyg will undoubtably provide valuable information concerning the structure of this massive star. In addition, we will be able to trace the chemistry of the surrounding envelope and start piecing together the questions: Are all oxygen-rich, massive stars similar, how do they compare, and what effect does NML Cyg's association with the Cyg OB2 region cause on the circumstellar envelope?

Technical Justification

To map the molecular content in NML Cyg, we propose to use CARMA in its E configuration. The main goal of this proposal is to map both the ^{12}CO and ^{13}CO isotopologues in the J=2-1 transition at 230.538 GHz and 220.398 GHz, respectively. From Milam and coworkers (2009) (Figure 3), we know the expected line widths of both isotopologues of CO are ∼50 km/s. For ^{13}CO we will use the BW500, allowing for 5.3 km/s channel resolution and we will observe ^{12}CO using BW125 with a channel resolution of 0.39 km/s. This will allow us to resolve possible velocity structure present in the spectral line profile of ^{12}CO. By taking advantage of the new correlator settings, we are also able to simitaneously observe three additional molecular lines to provide further information about this star: the $J(K_a,K_c)$=11(1,11)-10(0,10) transition of SO_2 at 221.96520 GHz and the N=6-5, J=5-4 transition of SO at 219.94943 GHz, both in LSB, and the v_2=1, 5(5,0)-6(4,3) transition of water at 232.68670 GHz in USB. Observing these addition lines will provide valuable information concerning the kinematics and morphology of the circumstellar envelope and insight as to how the CYG OB2 association is effecting the chemistry within the shell.

In addition, from Ziurys et al. (2009), we know the approximate extent of ^{12}CO emission in NML Cyg is ∼28″. Therefore, we propose to conduct a 7 point mosaic on this source. Using the CARMA RMS calculator, centered at 220 GHz for a 7 point mosaic, we should achieve a synthesized beam of 5.09″×4.21″, a mosaic coverage of 31″ and an RMS noise level of ∼21 mK in 10 hours of on source integration time at 5.3 km/s channel resolution. We expect the weakest emission from ^{13}CO and thus this low RMS is necessary to achieve the desired SNR based on the single dish observations (Figure 3). Under these same conditions, at 0.39 km/s channel resolution, 10 hours of on source integration time will give an rms of ∼75 mK, more than adequate to observe ^{12}CO in this source. Thus, we request 15 hours of total telescope time or two full tracks on NML Cyg, allowing for overhead, to successfully the complete 7 point mosaic observations.

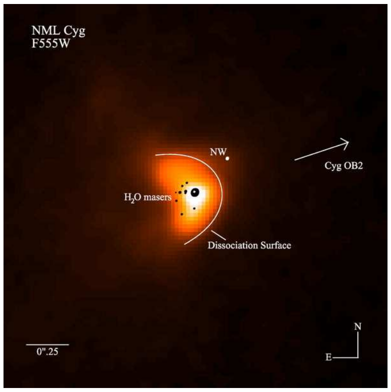

Fig. 1.— HST/WFPC2 F555W image of the circumstellar envelope of NML Cyg (Image from Schuster et al. 2006). The large black dot marks the star position.

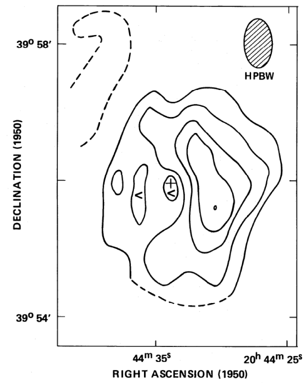

Fig. 2.— 21 cm continuum map observed by Habing et al. (1982) (Image from Morris and Juna 1983). The cross hairs mark the central star position

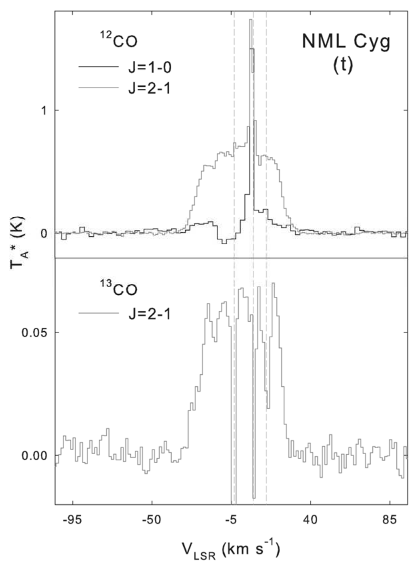

Fig. 3.— Observations of the J=2-1 and J=1-0 transiton of ^{12}CO and the J=2-1 transition of ^{13}CO towards NML Cyg (Image from Milam et al. 2009)

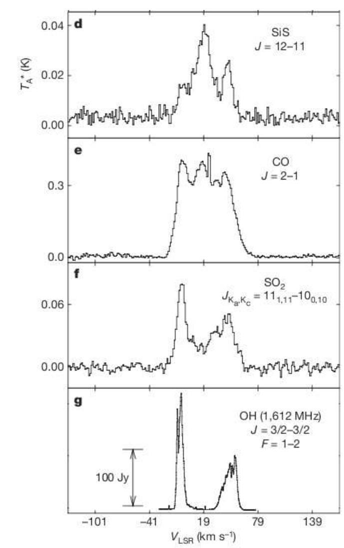

Fig. 4.— Molecular spectra from VY CMa demonstrating the asymmetric shapes of each molecular line observed (Image from Ziurys et al., 2007)