Near-infrared & CARMA Observations of the Confirmed Massive Pre-ZAMS Object Mol 160 A

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Abstract

We present near-infrared images of Mol 160 (IRAS 23385+6053) that include a young stellar cluster, two HII regions, and a confirmed massive pre-ZAMS object, Mol 160 A. In addition to diffuse H_2 2.12 μm and 2.25 μm emission that we attribute to fluorescence from Photo-Dissociation Regions (PDRs) surrounding the HII regions, we identify ten H_2 2.12 μm Molecular Hydrogen Emission-Line Objects (MHOs) that have no detected 2.25 μm counterparts. A comparison of the H_2 2.12 μm fluxes with upper limits derived from the H_2 2.25 μm observations suggests that the MHOs are due to shocked gas, presumably associated with outflows in this region. Despite the high extinction towards Mol 160 A, we detect two MHOs with apparent separation of ~4″ in bipolar orientation about this object. We have also acquired CS, HCO+, and CH_3OH, and 3 mm continuum observations of Mol 160 A with CARMA. The MHOs are associated with Class I CH_3OH masers and high-velocity HCO+ outflow emission, although one MHO is offset ~ 0.75″ from the blueshifted CH_3OH and HCO+ peaks. We detect two MHOs at distances of ~46″ & ~49″ from Mol 160 A that are oriented along the axis of the large-scale CO outflow, which is distinctly different from the axis of the compact HCO+ outflow and CH_3OH masers.

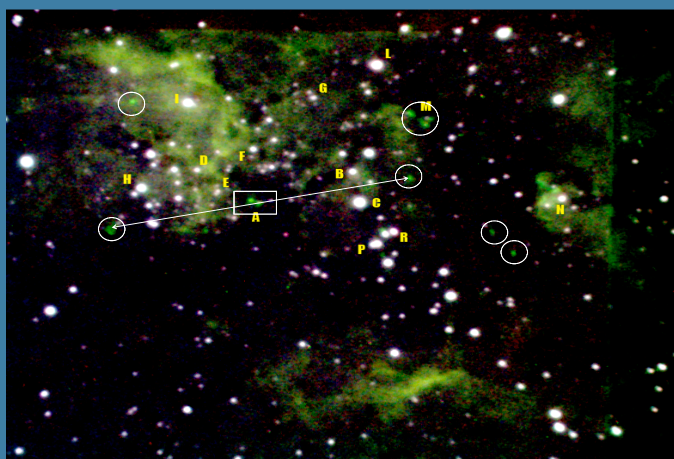

Figure 1a: Mol 160 region (IRAS 23385+6053): Combined H_2 2.12 μm (green), H_2-continuum 2.13 μm (blue), and H_2 2.25 μm (red) images. YSOs (letters) with 24 μm detections identified in Table 1 of Molinari et al. (2008) are indicated. The box indicates the pull-out in Fig. 1b of Mol 160 A, which is a confirmed massive protostar. Note the bright bipolar H_2 2.12 μm knots associated with this object and the complete lack of continuum emission. Other identified MHOs are circled. The double arrow links two MHOs that are aligned along the direction of the large-scale CO outflow identified by Zhang et al. (2005).

Observations

Apache Point Observatory: Near-infrared data were acquired using the NICFPS instrument on the ARC 3.5-m telescope at Apache Point, NM (Vincent et al. 2003). We recorded data in K_s (1000 sec), H_2 2.12 μm (2400 sec), H_2 2.25 μm (1800 sec), and in a narrow-band H_2-continuum filter centered on 2.13 μm (2400 sec). All images were reduced using standard techniques (sky subtraction, flat fielding, etc) in IRAF. Flux calibration was done by comparing stars in our Ks data to the same stars in the 2MASS point source catalog.

CARMA: 3 mm continuum, CH_3OH (95.169 GHz), HCO+ (89.189 GHz), and CS (97.981 GHz) spectral line observations were acquired simultaneously on March 23 & 24, 2010, with the interferometer in the C configuration with baselines ranging from 26-370 meters. The synthesized beam has a FWHM of 2.003″ X 1.683″. MWC349 and Uranus were used as flux calibrators, 3C84 and 1927+739 were used as passband calibrators, and 0102+584 was used for phase calibration. Total on-source integration time over multiple observations was 4.75 hours. Calibration and imaging were performed using the MIRIAD data reduction package (Sault et al. 1995).

Figure 1b: Mol 160 A - MHOs (greyscale)
CS & 3 mm continuum core peak (diamond)
Class I CH_3OH masers (x)
HCO+ outflow (blue & red contours)
(from 0.55 km s^{-1} resolution data)
Blue: -57.3945 to -54.1115 km s^{-1}
Red: -50.8285 to -47.5455 km s^{-1}

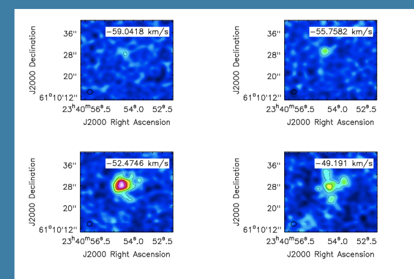

Figure 2: (generated using the CASA Viewer)
Channel maps of 3.28 km s^{-1} resolution CARMA HCO+ data.

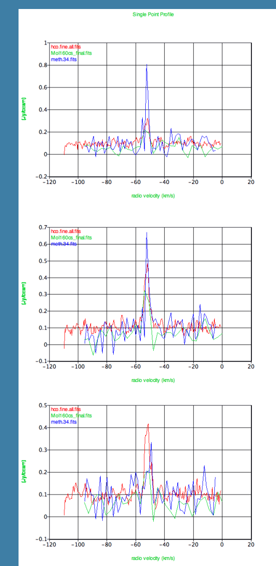

Figure 3: (from the CASA Viewer)
CARMA HCO+, CS, & CH_3OH spectra at:
blue-shifted outflow peak (upper);
continuum peak (middle);
and red-shifted outflow peak (lower)

Looking Toward Alma:

- Mol 160 A is ~ 10 X as distant as Orion BN/KL. The Mol 160 A core and bipolar MHOs span a distance comparable to the BN/KL H_2 "fingers". Future ALMA observations will distinguish massive bipolar outflows that appear to be scaled up versions of their lower-mass counterparts (e.g., Caratti o Garatti 2006, 2008) from explosive events such as BN/KL (Zapata et al. 2009). [Which type does(do) the Mol 160 A outflow(s) represent?]

- ALMA will (1) enable evaluation of which objects drive outflows and separate their energetics; (2) detect dust from lower-mass objects in the Mol 160 A core.

- Mol 160 A is an ideal Early Science single-pointing target (or small mosaic for Band 9).

- Mol 160 A has been observed over a range of frequencies and spatial scales, facilitating flux recovery and source structure (e.g., Fontani et al. 2004 JCMT & PdBI observations, and references therein).

Results-to-Date

- Mol 160 (IRAS 23385+6053) is part of a narrow-band near-infrared imaging survey we have conducted on regions containing candidate High Mass Protostellar Objects (HMPOs), which have been also associated with massive outflows identified in CO J=2→1 data (Wolf-Chase et al. 2011; Zhang et al. 2005).

- Mol 160 A is a confirmed massive pre-ZAMS object (Molinari et al. 2008). Though it is undetected at continuum wavelengths shorter than 24 μm, H_2 2.12 μm MHOs, with flux calibrated magnitudes of 19.5 & 19.7, lie within 4″ of Mol 160 A. Our H_2 2.12 μm detection within 4″ of 160 A is remarkable, given that N_{H2} estimates in the central 4″ are > ~ 10^{24} cm^{-2} (Molinari et al. 1998; Fontani et al. 2004). Lack of detection of the H_2 2.25 μm line strongly suggests the 2.12 μm emission is shock-produced. NIR spectroscopy is required to determine the actual extinctions toward the MHOs, and thereby the true H_2 luminosity.

- The association of the MHOs with Class I CH_3OH masers and a compact HCO+ outflow indicates the H_2 2.12 μm emission traces shocks in an outflow centered on Mol 160 A. This outflow lies along a different position angle from the large-scale CO outflow associated with this object (Zhang et al. 2005); however, we detect two other MHOs at distances of ~46″ & ~49″ from Mol 160 A that lie approximately along the axis of the CO outflow and are co-linear with Mol 160 A.

- The surface density of the Mol 160 A core (which encloses ~ 324 M_{sun} at 4″ - Fontani et al. 2004; Molinari et al. 1998) is ~4.9 – 9.6 g cm^{-2}, depending upon the adopted distance, which is consistent with theoretical models predicting the formation of at least one massive star (Krumholz et al. 2010).

- A list of positions of the ten MHOs (#2915 – #2924) we identified in Mol 160 can be found in the on-line MHO catalogue hosted by the Joint Astronomy Centre in Hawaii (Davis et al. 2010).

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