SPITZER AND NEAR-INFRARED OBSERVATIONS OF A NEW BIPOLAR PROTOSTELLAR OUTFLOW IN THE ROSETTE MOLECULAR CLOUD

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ABSTRACT

We present and discuss Spitzer and near-infrared H2 observations of a new bipolar protostellar outflow in the Rosette Molecular Cloud. The outflow is seen in all four InfraRed Array Camera (IRAC) bands and partially as diffuse emission in the MIPS 24 μm band. An embedded MIPS 24 μm source bisects the outflow and appears to be the driving source. This source is coincident with a dark patch seen in absorption in the 8 μm IRAC image. Spitzer IRAC color analysis of the shocked emission was performed from which thermal and column density maps of the outflow were constructed. Narrowband near-infrared (NIR) images of the flow reveal H2 emission features coincident with the high temperature regions of the outflow. This outflow has now been given the designation MHO 1321 due to the detection of NIR H2 features. We use these data and maps to probe the physical conditions and structure of the flow.

Key words: ISM: individual objects (MHO 1321) – ISM: jets and outflows – methods: data analysis

Online-only material: color figure

1. INTRODUCTION

Outflows and jets from young stellar objects (YSOs) accompany the early stages of star formation. Outflows can manifest themselves as jets and knots of shocked material visible at optical and near-infrared wavelengths and also molecular emission observable at longer wavelengths. The outflowing material plays a role in removing the excess angular momentum from the YSOs, allowing them to evolve into stars. Outflows are able to trace the history of mass loss and accretion of their driving sources. Studying the structure and properties of these flows may provide clues to understanding the connection between jets and the associated wide angle molecular flows (Reipurth & Bally 2001). Additionally, this outflowing material interacts with its surroundings and may affect its environment, possibly regulating further star formation and cluster evolution. The energy and momentum inputted by outflows may disrupt the surrounding ambient gas, contribute to the turbulence in the cloud, and affect chemical processes (Bally 2007). Ybarra & Lada (2009) developed a technique to study the thermal structure of shocked H2 gas using color analysis of observations from the Spitzer InfraRed Array Camera (IRAC). Given the vast amount of Spitzer data available, this technique can be used to survey large regions and simultaneously find and analyze shocked emission. The IRAC color analysis enables the construction of temperature maps of the shocked gas which may in turn be used to probe the interaction of outflow with its surroundings. These maps may also be used to compare the properties of outflow with those of simulations allowing a better understanding of the physics involved and estimating the energy and momentum inputted by outflows into their environment.

The Rosette Molecular Cloud (RMC) is a star-forming region located at a distance of 1.6 kpc. Near-infrared imaging studies have revealed nine embedded clusters across the cloud (Phelps & Lada 1997; Román-Zúñiga et al. 2008). Outflow activity in the cloud has been revealed through the [S ii] narrowband imaging survey of Ybarra & Phelps (2004) and the 12CO survey of Dent et al. (2009). In an analysis of the Spitzer IRAC images of the RMC, we have discovered a structure with the morphology of a bipolar outflow that is visible in the images from all four IRAC bands. This structure can be seen in the images published by Poulton et al. (2008) although it is not discussed in their paper.

In this study, we analyze the outflow using near infrared (NIR) narrow band imaging of the flow to confirm the presence of shocked gas inferred from analysis of the IRAC images. We improve the IRAC color analysis of Ybarra & Lada (2009) and use it to create temperature and column density maps of the outflow. Using both the NIR and IRAC data, we probe the physical conditions and structure of the outflow.

2. OBSERVATIONS AND DATA REDUCTION

2.1. Spitzer IRAC and MIPS Data Reduction

We used MIPS 24 μm and IRAC 3.6–8.0 μm data from program 3391 (PI: Bonnel) available in the Spitzer archive. The IRAC frames were processed using the Spitzer Science Center (SSC) IRAC Pipeline v14.0, and mosaics were created from the basic calibrated data (BCD) frames using a custom IDL program (see Gutermuth et al. 2008 for details). The MIPS frames were processed using the MIPS Data Analysis Tool (Gordon et al. 2005).

2.2. Near-infrared H2 Observations and Data Reduction

Near-infrared, narrowband observations of the outflow were obtained with the Infrared Side Port-Imager (ISPI) on the Blanco 4 m telescope at the Cerro Tololo Inter-American Observatory.
Figure 1. Spitzer IRAC images of the outflow. The origin is set at (α, δ)(J2000) = (06h35m25s, +03° 56′ 21″).

Figure 2. Near-infrared images of the outflow: (a) H$_2$ 1–0 S(1) 2.122 μm line, (b) $K$ cont, (c) continuum subtracted H$_2$ 1–0 S(1) 2.122 μm, and (d) continuum subtracted H$_2$ 1–0 S(2) 2.034 μm. The horizontal scale is in arcminutes and the vertical scale is in arcseconds. The origin is set at (α, δ)(J2000) = (06h35m25s, +03° 56′ 21″).

(CTIO). ISPI employs a 2048 × 2048 HgCdTe Hawaii-2 array with a 10.25 × 10.25 arcmin field of view and a plate scale of ∼0′′.305 pixel$^{-1}$. The outflow was imaged using the H$_2$ 1–0 S(2) 2.034 μm filter ($\lambda_c = 2.0336$ μm, $\Delta\lambda/\lambda = 0.007$), H$_2$ 1–0 S(1) 2.122 μm filter ($\lambda_c = 2.1262$ μm, $\Delta\lambda/\lambda = 0.01$), and $K$ cont filter centered at 2.1462 μm. The telescope was dithered with a 20 point dither pattern with a integration time of 60 s at each dither position. The images were taken on the nights of 2008 December 17 and 19 with total integration time of 40 minutes in each filter.

The raw images were flat fielded, corrected for bad pixels, and linearized using the task osiris from the CTIO Infrared Reduction Package. For each image, a sky frame was created by median combining the dithered images closest in time to the image. The IRAF tasks mctpeak and mcsimage, which are part of the IRAF Mosaic Data Reduction Package, mcsred, were used to correct the images for geometric distortions. The high order polynomial distortion terms were calculated with mctpeak using the Two Micron All Sky Survey (2MASS) Point Source Catalog as the reference catalog and the distortion correction was applied with mcsimage. The corrected images were aligned and then combined to form the final science images.

3. RESULTS AND ANALYSIS

Figure 1 shows the outflow in all four IRAC bands. The outflow appears as patchy regions of diffuse emission with an overall structure that is elongated and collimated in the E–W direction. Figure 2 shows the narrowband near-infrared emission images of the outflow. The NIR H$_2$ knots coincide with the diffuse emission seen in the IRAC images. The NIR H$_2$ images confirm the presence of shocked gas and the interpretation that this structure is an outflow. The eastern end appears to truncate at a bow shock. Slightly west of the bow shock, the H$_2$ images reveal a small-scale chaotic structure followed by a more linear chain of knots. The western end of the outflow appears slightly deflected northward followed by a bright knot (g) and then a complex structure of smaller knots.

The NIR images were flux calibrated to the 2MASS $K_s$ band by determining the magnitude difference between the 2MASS $K_s$-band catalog values and the ISPI image magnitudes for
Table 1

| Knot | R.A. (J2000) | Decl. (J2000) | H$_2$ 1–0 S(2) | H$_2$ 1–0 S(1) |
|------|--------------|---------------|----------------|----------------|
| a    | 06:35:20.08  | +03:56:37.9   | 4.1 ± 2.0      | 7.6 ± 2.2      |
| b    | 06:35:21.64  | +03:56:28.8   | 2.2 ± 1.4      | 8.9 ± 2.2      |
| c    | 06:35:21.82  | +03:56:32.3   | 3.9 ± 1.9      | 12.5 ± 2.4     |
| d    | 06:35:21.85  | +03:56:27.6   | 4.2 ± 1.8      | 15.6 ± 2.8     |
| e    | 06:35:22.19  | +03:56:29.5   | 2.2 ± 1.7      | 10.1 ± 2.4     |
| f    | 06:35:22.70  | +03:56:33.2   | 2.0 ± 1.6      | 4.9 ± 2.1      |
| g    | 06:35:22.90  | +03:56:28.7   | 15.5 ± 3.8     | 52.4 ± 5.8     |
| h    | 06:35:23.21  | +03:56:17.3   | 1.2 ± 1.5      | 3.3 ± 1.8      |
| i    | 06:35:23.77  | +03:56:24.1   | 1.8 ± 1.6      | 5.2 ± 1.9      |
| j    | 06:35:24.33  | +03:56:21.6   | 4.7 ± 2.2      | 20.8 ± 3.4     |
| k    | 06:35:24.61  | +03:56:20.7   | 2.5 ± 1.6      | 10.4 ± 2.4     |
| l    | 06:35:25.26  | +03:56:21.4   | 2.4 ± 1.6      | 8.3 ± 2.1      |
| m    | 06:35:25.46  | +03:56:21.6   | 1.5 ± 1.3      | 4.3 ± 1.8      |
| n    | 06:35:26.13  | +03:56:20.9   | 2.0 ± 1.7      | 8.6 ± 2.5      |
| o    | 06:35:26.57  | +03:56:23.5   | 1.4 ± 1.4      | 3.3 ± 1.6      |
| p    | 06:35:27.90  | +03:56:18.3   | 3.1 ± 1.9      | 11.8 ± 2.6     |
| q    | 06:35:28.56  | +03:56:25.7   | 3.0 ± 2.0      | 10.8 ± 2.6     |
| r    | 06:35:29.02  | +03:56:14.2   | 12.8 ± 3.4     | 42.3 ± 5.0     |
| s    | 06:35:29.18  | +03:56:18.6   | 2.1 ± 1.6      | 6.9 ± 2.0      |
| t    | 06:35:31.16  | +03:56:15.8   | 1.6 ± 1.5      | 4.3 ± 1.8      |
| u    | 06:35:33.64  | +03:56:16.6   | 3.0 ± 1.7      | 11.3 ± 2.6     |
| v    | 06:35:33.85  | +03:56:18.9   | 2.8 ± 1.9      | 7.9 ± 2.1      |
| w    | 06:35:34.04  | +03:56:20.5   | 2.0 ± 1.5      | 5.1 ± 2.0      |

Notes: Flux is in units of 10^{-18} W m^{-2}. Aperture radius used is 7 pixels. Flux uncertainty includes calibration uncertainty.

...stars in common. The zero point flux in each NIR image after calibration is then the filter bandwidth multiplied by the 2MASS Ks-band zero point flux density. This results in a relation between the counts s^{-1} in each filter image and the flux in W cm^{-2}. The narrow band continuum $K_c$ images were scaled and subsequently subtracted from the H$_2$ line images. Figures 2(c) and (d) show the continuum subtracted H$_2$ 1–0 S(1) 2.122 μm and H$_2$ 1–0 S(2) 2.034 μm line images. The quality of the subtraction is good although there are some subtraction residuals from the brightest stars present in the subtracted images due to differences in wavelength and point-spread function (PSF) combined with changing atmospheric conditions.

Based on the observation, this outflow has been given the designation MHO 1321 in the Catalogue of Molecular Hydrogen Emission-Line Objects (MHOs) in outflows from young stars\(^6\) (Davis et al. 2010). The fluxes of the individual H$_2$ knots comprising this outflow were determined using a circular aperture on the continuum subtracted images. Table 1 lists the NIR fluxes of the H$_2$ emission knots. The flux uncertainty is composed of the rms background, poisson noise, and uncertainty from the flux calibration.

3.1. IRAC Color Space of Shocked Gas

In order to study the structure of the shocked gas, we applied the IRAC color analysis method developed by Ybarra & Lada (2009). We improved the color analysis method by including the effects of CO $v = 1–0$ band emission in the total emission of the shocked gas. The distribution of the population of pure rotational levels of CO due to collisional excitation with H$_2$, H, and He was calculated using the rate coefficients of Draine & Robege (1984). We employed the method of González-Alfonso et al. (2002) to calculate the relative rotational population for the CO $v = 1$ vibrational level. The Einstein A-values for the CO $v = 1–0$ rovibrational transitions were obtained using the oscillator strengths of Hure & Roueff (1993). In our calculations, we set $n_H = n(H)+2n(H_2)$, $n(He)/n(He) = 0.1$, and $n(CO)/n(H) = 7 \times 10^{-5}$. The fraction of atomic to molecular hydrogen was estimated by considering the rate of collisional dissociation by H atoms, $R_d = 1.0 \times 10^{-10} \exp(-52000/T) \text{cm}^3 \text{s}^{-1}$ (Le Bourlot et al. 2002) and the rate of formation on grains, $R_f = 3.8 \times 10^{-17} T^{-1.5} \text{cm}^3 \text{s}^{-1}$, derived from Hollenbach & McKee (1979) with the cooling rates for H$_2$ and H$_2$O (Le Bourlot et al. 1999, 2002).

Figure 3 shows the location of shocked gas in IRAC [3.6]–[4.5] versus [4.5]–[5.8] color space for maximum shock temperature of $T_{\text{max}} = 6 \times 10^3$ K for gas temperatures $T = 1500–5000$ K and densities $n_H = 10^5–10^7 \text{cm}^{-3}$. The square brackets refer to IRAC magnitudes. The post-shock fraction of atomic hydrogen was found to be $n(H)/n_H \sim (1–4) \times 10^{-3}$ which is consistent with simulations of non-dissociative C-shocks (Wilgenbus et al. 2000). In the simulations by Wilgenbus et al. (2000), it was found that the atomic fraction is relatively constant over a wide range of maximum temperatures. Therefore, we will assume our color space to be representative of non-dissociative C-shocks in general. The location of the shocked emission in IRAC color space depends on the gas density, fraction of atomic hydrogen, and the kinetic temperature of the gas. The [4.5]–[5.8] color is strongly dependent on temperature, while the [3.6]–[4.5] color has a strong dependence on the atomic hydrogen density. At high densities, the dependence on density decreases as the H$_2$ gas moves toward local thermal equilibrium (LTE). The slope of the reddening vector is similar to the approximate slope of the constant temperature lines. Thus, temperature maps of high extinction regions remain accurate even if the extinction cannot be accounted for. However, unless extinction can be corrected for, accurate density information may not be attainable.

We fit an analytic form to the relationship between color and temperature for the non-dissociative case:

$$T_3 = 4.19 - 0.97(3.6-[4.5]) - 2.11(4.5-[5.8]) + 0.59(3.6-[4.5])^2 + 0.50(4.5-[5.8])^2,$$

where $T_3 = T/10^3$ in the color space defined by $2.0 < [3.6]-[4.5] > -0.21([4.5]-[5.8]) + 1.5$ and $-0.2 < [4.5]-[5.8] < 2.0$. The difference between the analytic fit and...
the calculated temperature–color relation over the defined range is less than 10%. Additionally, one can use the flux in the 3.6 μm image to estimate the column density of the shocked H₂. Using our calculations, we fit the following analytic form to the relationship between column density, IRAC 3.6 μm flux density, and temperature:

$$\log(N_{H_2}/F_{3.6}) = 23.11 - 3.40T_3 + 0.742T_3^2 - 0.0589T_3^3 - 0.071n_6 + 0.012n_6T_3,$$

where $N_{H_2}$ is the column density of shocked H₂ in cm⁻², $F_{3.6}$ is the IRAC 3.6 μm band flux density in units of MJy sr⁻¹, and $n_6 = n_1/10^6$ for $1.5 < T_3 < 5.0$ and $2 < n_6 < 10$.

In order to investigate the color space of dissociative J-type shocks, we simulated the gas properties of a dissociative shock by setting the maximum temperature of the gas to $T_{max} = 1 \times 10^4$ K. Our calculations show significant dissociation of H₂ with increasing density. Figure 4 shows the IRAC color space for dissociatively shocked gas. As the molecular hydrogen gets dissociated, emission from the CO ν = 1–0 band begins to dominate the 4.5 μm IRAC channel.

The relationships between temperature, density, and color are different for the case of the non-dissociative shock and the case of the dissociative shock. There is some degeneracy at the low density and low dissociation region of color space for the dissociative shock and at the high density non-dissociative shock region. These two models meet in a region of color space, the low density and low dissociation region of color space for the dissociative shock and at the high density non-dissociative shock region. Figure 4 shows the IRAC color–color plot indicating the region occupied by dissociatively shocked gas composed of H₂ and CO.

In a recent study, Micelotta et al. (2010) show that strong shocks can destroy PAHs or severely denature them.

### 3.2. IRAC Color Analysis of MHO 1321

The IRAC 8 μm image of the outflow region reveals patches of absorption against the diffuse background (Figure 1). Of particular interest is a dark patch seen in absorption that bisects the outflow. We created an extinction map from the 8 μm data using a small-scale median filter assuming a uniform background. We applied this extinction map to the images of the outflow region using the mid-infrared reddening law (KP, v5.0) of Chapman et al. (2009). However, this is not able to account for the total extinction in the line of sight toward the outflow. Nonetheless, the temperature–color relation is insensitive to extinction for non-dissociative shocks. We estimate the background using a ring median filter and subsequently remove this background from the IRAC 3.6 μm, 4.5 μm, and 5.8 μm images. A ring median filter is a median filter from which only the pixels within an annulus are used in calculating the median (Secker 1995). The scale of this filter needs to be larger than the scale of the shocked emission otherwise the background will be overestimated, yet small enough to account for the large-scale background fluctuations. The images were shifted and registered with each other and then IRAC colors at each pixel location were determined. Figure 5 shows the pixel density in IRAC color space for the knots of the outflow. Due to the lack of pixels whose colors are in or near the CO dominated region and our criteria above for non-dissociative shocks, we conclude that this shock is mostly non-dissociative and we can therefore estimate the thermal structure based on color analysis. We compared the colors to those of non-dissociative shocked gas with the cutoff $[4.5]–[5.8] \leq 1.5$. A thermal map was created by estimating the gas temperature based on the location of the pixels in color space. Figure 6 shows the thermal map of the outflow.

We find that most of the NIR H₂ knots are spatially coincident with the high temperature regions of the flow. However, knots a and ν do not have a corresponding IRAC derived temperature. The NIR images reveal stars in the line of sight for these knots which add to the emission and prevent IRAC color analysis from deriving temperatures. Seven of the knots have estimated temperatures greater or equal to $3 \times 10^3$ K. By combining the NIR and temperature data, it is possible to estimate the extinction.
toward the brightest knots. For this we used the extinction cross sections of Weingartner & Draine (2001). The median extinction to the knots is $A_v = 27$. The knots j and k in the vicinity of the dark clump have higher extinction compared to the rest of the knots. We use the median extinction value to deredden the 3.6 μm flux and use it to create a column density map with our column-density–temperature relation. Figure 7 shows the column density map of shocked H$_2$ in the flow. We find that there is also a correspondence between the NIR H$_2$ knots and regions of higher column density. Using the established distance to the RMC of 1.6 kpc and the column density map, we calculate the total mass of the shocked H$_2$ ($T > 2000$ K) in the outflow to be $3.5 \times 10^{30}$ g ($\sim 2 \times 10^{-3} M_\odot$). Table 2 shows the estimated temperature and column density of the identified H$_2$ knots.

### 3.3. Outflow Source

The source of the outflow is not seen in the NIR nor in the IRAC images. However, inspection of the MIPS 24 μm image reveals a source ($\alpha, \delta$)(J2000) = (06$^h$35$^m$25$^s$, +03$^\circ$56$^\prime$21$^\prime\prime$) bisecting the outflow (Figure 8). Moreover, this source is spatially coincident with a dark patch seen in the 8 μm image. This patch is elongated nearly perpendicular to the outflow and the northwest part of it has the morphology of an outflow cavity. The dark patch is seen in the contours that indicate mass surface densities obtained through extinction mapping of the 8 μm imaging data by the method of Butler & Tan (2009). The contour levels correspond to mass surface densities of $\Sigma = (2.5, 4.0, 5.0, 6.0) \times 10^{-3}$ g cm$^{-2}$. This small cloud may be a remnant of the core from which the protostar formed.

The morphology of the northern end of the cloud appears as a bipolar outflow cavity with an opening angle $\theta \sim 30^\circ$–$40^\circ$. H$_2$ 1–0 S(1) surface brightness contours are overlaid on the MIPS 24 μm image that bisect the MIPS source and a coincident with the cavity of the dark cloud. This source is also detected in the MIPS 70 μm and MIPS 160 μm imaging data. However, we are unable to estimate the flux in the MIPS 70 μm band image due to incomplete coverage and possible contamination from the adjacent knot (j) which may have emission from dust and the 63 μm [O I] line (Reipurth & Bally 2001). Similarly, the MIPS 160 μm band image may include emission from the knot in addition to the source. This source is not detected at shorter wavelengths and thus can be classified as a Class 0 protostar. We propose this newly discovered protostar to be the source of the outflow. Additionally, using the column density map, we find that the mass of the shocked H$_2$ to the east ($1.8 \times 10^{30}$ g)
of this source is almost equal to the mass west of the source
\(1.7 \times 10^{30} \text{ g}\).

Faint extended 24 \(\mu m\) emission is also detected at the locations of the brightest H\(_2\) knots (g and j). This may arise from fine-structure [Fe\textsc{ii}] lines within the MIPS 24 \(\mu m\) band (Velusamy et al. 2007). This is consistent with our IRAC color analysis of these knots that reveal them to be high temperature regions \(T \geq 3.2 \times 10^3 \text{ K}\). This consistency between the IRAC color analysis and the MIPS 24 \(\mu m\) emission validates our usage of the color space for non-dissociative shocks.

4. DISCUSSION

4.1. Structure of the Outflow

The long axis of the flow extends to 3.3. With a distance of 1.6 kpc to the RMC, the flow would have a projected total length of 1.5 pc. The east lobe extends 2.3 from the MIPS source to the bow shock, while the west lobe extends only 1.6. Assuming a projected outflow velocity of 100 km s\(^{-1}\), using the east lobe we estimate the age of the outflow to be 10\(^8\) yr. This age is consistent with the typical age of a Class 0 source and thus this outflow may provide an accretion record of the protostar (Reipurth & Bally 2001). We can estimate the mass flux of the outflow as \(M \sim M(\text{H}_2) v_r l_t\), where \(v_r\) is the projected outflow velocity and \(l_t\) is the projected outflow length. Assuming the typical value of \(v_r = 100 \text{ km s}^{-1}\) and using the values for the H\(_2\) mass and length of the east lobe, we estimate a mass flux of \(M \sim 10^{-7} M_{\odot} \text{ yr}^{-1}\). This value is consistent with those obtained from other outflows using spectroscopic data (Podio et al. 2006).

The NIR H\(_2\) data reveal the higher temperature regions of the outflow seen in the IRAC images. The IRAC images also show the cooler regions of the flow as the IRAC bands contain pure rotational H\(_2\) lines in addition to \(v = 1-0\) and \(v = 2-1\) rovibrational lines.

The flow is spatially coincident with two lobes of high velocity CO gas observed by Dent et al. (2009). Similar to many HH flows which extend further than their CO counterpart, we find the eastern half to extend beyond the eastern CO lobe. The eastern end of the H\(_2\) flow ends in a large bow shock, while the western end reveals a structure resembling either a broken up bow shock or multiple smaller bow shocks. Although the outflow is linear on large scales, the IRAC and H\(_2\) data reveal a region in the eastern lobe before the bow shock with a more chaotic structure. This deviation from a linear progression of knots may be due to a possible interaction with another outflow. The CO observations of Dent et al. (2009) reveal another flow in the NE–SW direction originating from the embedded cluster PL07 (Phelps & Lada 1997) that points toward this region. A collision between the two flows may explain the morphology and high temperature of knot r. The distribution of knots may also be due to variations in time over thus an indication of jet precession.

4.2. Deflection of the Outflow

The western end of the outflow appears slightly bent northern. The outflow is deflected by an angle \(\theta_d = 20^\circ\) where it appears to graze the densest region within the dark patch. The deflection angle remains small and appears to decrease slightly beyond the interaction region. This is consistent with the simulations by Baek et al. (2009) of outflows colliding with dense cloud cores where the impact parameter is large. The deflection of the outflow may explain why the western end of the outflow is shorter than the eastern end as the outflow velocity is expected to decrease after the collision (Raga & Canto 1995). This is consistent with the IRAC color analysis that reveals high temperature shocked gas (knot j) to the east of the collision.

If the outflow is composed of episodic ejection of material, there may be collision between clumps of material moving through the flow due to the velocity change (Raga & Canto 2003). As these successive clumps collide, they may give rise to the high temperature and high column density region (g) found slightly west of the deflection. This interaction may also explain why the western lobe lacks the bow shock structure seen in the eastern end.

5. CONCLUSIONS

We present the discovery of a new bipolar outflow and in the RMC and use NIR narrowband and Spitzer imaging data to study the flow. We show that IRAC color analysis can be used to interpret the interaction of an outflow with its surrounding environment. Using our calculations of the IRAC space of non-dissociative shocked gas, we fit analytic forms to the color–temperature and column-density–temperature relationships. We verify that IRAC color analysis can reveal regions of shocked gas and find that the NIR H\(_2\) knots correspond to regions of high temperature and/or column density determined through color analysis. We discover a Class 0 object in the MIPS imaging data that bisects the outflow and propose this to be the outflow source. We find diffuse MIPS 24 \(\mu m\) emission, most likely from [Fe\textsc{ii}] lines, to be coincident with regions of high temperature, thus confirming the validity of using the non-dissociative shock IRAC color space. The NIR line ratios combined with the temperature estimates allow for the determination of extinction along the line of sight which is used to create a column density map of the shocked H\(_2\) gas. We deduce that the asymmetry in the outflow is due to interactions with the dense material to the west of the outflow source causing deflection and possibly deceleration of the outflowing material.
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