OPTICAL AND NEAR-INFRARED SHOCKS IN THE L988 CLOUD COMPLEX

J. Walawender¹, B. Reipurth², and J. Bally³

¹ Subaru Telescope, National Astronomical Observatory of Japan, Hilo, HI 96720, USA; joshw@naoj.org
² Institute for Astronomy, University of Hawai‘i at Manoa, Hilo, HI 96720, USA
³ Center for Astrophysics and Space Astronomy, University of Colorado, Boulder, CO 80309, USA

Received 2013 April 3; accepted 2013 July 1; published 2013 August 15

ABSTRACT

We have searched the Lynds 988 dark cloud complex for optical (Hα and [S II]) and near-IR (H2 2.12 μm) shocks from protostellar outflows. We find 20 new Herbig–Haro objects and 6 new H2 shocks (MHO objects), 3 of which are cross detections. Using the morphology in the optical and near-IR, we connect several of these shocks into at least five distinct outflow systems and identify their source protostars from catalogs of infrared sources. Two outflows in the cloud, from IRAS 21014+5001 and IRAS 21007+4951, are in excess of 1 pc in length. The IRAS 21007+4951 outflow has carved a large cavity in the cloud through which background stars can be seen. Also, we have found an optical shock which is the counterflow to the previously discovered “northwest outflow” from LkHα 324SE.

Key words: Herbig-Haro objects – ISM: individual objects (Lynds 988) – ISM: jets and outflows – stars: formation

1. INTRODUCTION

Star formation is a dynamic process whereby newborn stars interact with their parent cloud. High velocity outflows from accreting stars collide with parent molecular material generating shocks (known as Herbig–Haro (HH) objects when detected optically), opening cavities (Quillen et al. 2005), and driving turbulence (Miesch & Bally 1994; Bally et al. 1999; Arce & Goodman 2002; Walawender et al. 2005). Shocks from outflows heat, dissociate, and ionize the gas. They also inject kinetic energy and momentum into the cloud which may affect the rate of gravitational collapse of cores within these clouds (e.g., Leorat et al. 1990). Outflows may play a fundamental role in the evolution of star forming molecular clouds, turbulence generation, and cloud destruction. In this paper, we have searched the Lynds 982, 984, and 988 dark cloud complex (hereafter L988; see Figure 1) for shocks from protostellar outflows using tracers in both optical (Hα and [S II]) and near-IR (H2) tracers.

L988 lies in Cygnus near the Cygnus OB7 association which is among the nearest of the Cygnus OB associations at roughly 740–800 pc. L988 is part of a larger cloud complex known as Kh 141 (Chavtasi 1960), or TG 541 (Dobashi et al. 2005), and is sometimes called The Northern Coalsack. The two regions of highest extinction within the Kh 141 complex are L988 and L1003 (see Reipurth & Schneider 2008, Figure 28), both of which are active regions of star formation.

Distance estimates for the L988 complex range between 500 and 780 pc. Chavarria (1981) estimated the distance at 700 pc based on photometry of several stars in the region. Later, Chavarria & de Lara (1981) estimated a distance of 780 pc. Shevchenko et al. (1991) found a distance of 550 pc based on extinction estimates. Alves et al. (1998) studied extinction around the nearby L977 cloud and found a distance of 500 pc. For calculations in this paper, we assume an intermediate distance of 600 pc.

The first outflow study in the region was a millimeter CO line survey by Clark (1986) who found four molecular outflows around IRAS sources which he designated a, c, e, and f. Subsequently the flow surrounding IRAS 21007+4951 (Clark source a) was imaged by Hodapp (1994) in the near-IR (K′) and by Staude & Elsasser (1993) in r. Staude & Elsasser (1993) found four HH objects which were not assigned catalog numbers. These HH objects correspond to our HH 1050 knots B, C, E, and F (see Section 3).

Felli et al. (1992) searched for H2O masers around young stars and found a maser associated with Clark source a. Their search did not detect masers coincident with Clark sources e or f.

Herbig & Dahm (2006) examined the LkHα 324 region in L988 using broadband optical and near-IR imaging and optical spectroscopy and discovered a small cluster of YSOs surrounding LkHα 324. They found the age of the cluster surrounding LkHα 324 to be 0.6–1.7 Myr depending upon the evolutionary model used in the analysis. Herbig & Dahm (2006) also examined the LkHα 324SE star (IRAS 21014+5001, Clark source c) in detail using Keck HIRES spectroscopy. They found features which they designate the “northwest outflow” (later designated HH 899) which is composed of several condensations prominent in [S II] and [O I] lines. In a 7” long slit oriented at P.A. = 129°/309°, they found three [S II] condensations to the northwest at velocities of −160 to −185 km s−1 relative to the −18 km s−1 rest velocity of the star. No red-shifted counterparts to the “northwest outflow” knots were detected.

Allen et al. (2008) examined the cluster surrounding Clark source e with the Spitzer Space Telescope and cataloged young stars in the region.

2. OBSERVATIONS

Near-infrared data for this project were obtained on the nights of 2006 July 11–13 on the United Kingdom Infrared Telescope (UKIRT) using the Wide Field InfraRed Camera (WFICAM; Casali et al. 2001), which is composed of four Rockwell Hawaii-II 2048 × 2048 pixel arrays separated by 94% of the size of an individual chip. The instantaneous field of view is 0.21 deg2, however, to obtain a contiguous field of view, four pointings of the telescope must be used to fill in the space between arrays. A four pointing “tile” covers approximately 0.8 deg2. In the J, H, and K filters, we obtained a total integration time of 6 minutes over the L988 tile. In the H2 filter, we obtained

THE ASTRONOMICAL JOURNAL, 146:66 (11pp), 2013 September
© 2013. The American Astronomical Society. All rights reserved. Printed in the U.S.A.
72 minutes of integration time. WFCAM data were pipeline processed by the Cambridge Astronomical Survey Unit. The 16 resulting image stacks were then mosaiced together using the Image Reduction and Analysis Facility (IRAF)\(^4\) to form the full field of view of the tile.

Visible wavelength narrowband images were obtained on the night of 2006 May 28 on the Subaru Telescope using the Suprime-Cam instrument (Miyazaki et al. 2002). Suprime-Cam is a wide field prime focus camera comprised of ten 2048 \(\times\) 4096 pixel CCDs. The instantaneous field of view is approximately 34’ \(\times\) 27’. Images were taken in the H\(\alpha\) and [S\(\text{ii}\)] filters, each with a total exposure time of 50 minutes.

Subaru data were processed using IRAF’s mscred package. Images were overscanned, trimmed, bias subtracted, and then flat fielded (using both dome and twilight flats) by the ccdproc task. Images were intensity matched using mscimatch and stacked using mscstack based on world coordinate system fits generated by mscamatch.

Visible wavelength Sloan Digital Sky Survey (SDSS) \(i'\) images were obtained on the night of 2010 August 25 on the University of Hawaii 88 inch Telescope using the Wide Field Grism Spectrograph 2 (WFGS2; Uehara et al. 2004) instrument in imaging mode. WFGS2 uses the Tek2k CCD camera with 2048 \(\times\) 2048 pixels. With the WFGS2 focal reducer, the field of view is approximately 11 arcmin on a side. SDSS \(i'\) images were only obtained for the field centered on the IRAS 21007+4951 reflection nebula. A total of 35 minutes of integration time was obtained. Reductions, alignment, and stacking were performed using the ccdproc package in IRAF.

\(^4\) IRAF is distributed by the National Optical Astronomy Observatory, which is operated by the Association of Universities for Research in Astronomy, Inc., under cooperative agreement with the National Science Foundation.
Table 1

| HH Designation | MHO Designation | R.A. (J2000.0) | decl. (J2000.0) |
|----------------|-----------------|----------------|----------------|
| HH 1044        | ...             | 21:01:08.0     | 50:18:39       |
| HH 1045 A      | MHO 958         | 21:02:33.5     | 50:03:13       |
| HH 1046        | MHO 958         | 21:02:32.1     | 50:03:11       |
| HH 1047 A      | MHO 958         | 21:02:28.4     | 50:03:17       |
| HH 1048 A      | MHO 958         | 21:02:27.0     | 50:03:03       |
| HH 1049        | MHO 958         | 21:02:12.4     | 50:02:35       |
| HH 1050 A      | MHO 958         | 21:02:11.3     | 50:02:08       |
| HH 1051 A      | MHO 958         | 21:02:09.5     | 50:02:55       |
| HH 1052 A      | MHO 956         | 21:02:38.8     | 50:13:09       |
| HH 1053        | MHO 956         | 21:02:32.2     | 50:13:15       |
| HH 1054        | MHO 957         | 21:02:09.5     | 50:03:32       |
| HH 1055 A      | MHO 958         | 21:02:11.8     | 50:06:19       |
| HH 1056 A      | MHO 958         | 21:03:14.6     | 50:06:01       |
| HH 1057        | MHO 958         | 21:03:13.4     | 50:06:01       |
| HH 1058        | MHO 958         | 21:03:12.3     | 50:05:35       |
| HH 1059 A      | MHO 958         | 21:03:07.9     | 50:05:30       |
| HH 1060        | MHO 956         | 21:03:14.9     | 50:15:49       |
| HH 1061 A      | MHO 958         | 21:04:00.7     | 50:13:55       |
| HH 1062 A      | MHO 958         | 21:04:05.0     | 50:13:18       |
| HH 1063 A      | MHO 958         | 21:04:06.7     | 50:13:10       |
| HH 1064 A      | MHO 958         | 21:04:08.5     | 50:12:52       |
| HH 1065 A      | MHO 958         | 21:04:24.9     | 50:13:57       |
| HH 1066 A      | MHO 958         | 21:04:34.5     | 50:13:28       |
| HH 1067 A      | MHO 958         | 21:04:34.9     | 50:13:15       |
| HH 1068 A      | MHO 958         | 21:04:27.4     | 50:08:12       |
| HH 1069 A      | MHO 958         | 21:04:27.8     | 50:07:51       |

Table 2

The Astronomical Journal, 146:66 (11pp), 2013 September

Walawender, Reipurth, & Bally

The Astronomical Journal, 146:66 (11pp), 2013 September

Walawender, Reipurth, & Bally
and $116^{\circ}$ respectively. We also note that these shocks lie roughly along a line defined by the HH 1057 and 1056 shocks that passes through the reflection nebula. HH 1062 may be a shock in a larger flow and is perhaps not driven by the nearby IRAS 21028+5001.

**HH 1058.** This is a faint, H$_\alpha$ only shock (Figures 3 and 5) which appears to be a jet emerging from an optically visible star along P.A.$\sim125^\circ/305^\circ$. The star was detected by both Two Micron All Sky Survey (2MASS) and WISE (WISE J210339.46+501552.9) and those magnitudes are listed in Table 2. Using those fluxes, we fit the SED using the models of Robitaille et al. (2007; see Figure 16(c)). The best fit models show that this is a low mass young star ($\sim0.25\; M_\odot$) with a relatively low disk accretion rate ($\sim10^{-11}\; M_\odot\; yr^{-1}$).

---

**Table 2.** Photometry of Sources in L988

| Source                  | 2MASS          | WISE            | IRAS           |
|------------------------|----------------|-----------------|----------------|
|                        | J (mag) | H (mag) | K (mag) | 3.4 $\mu$m (mag) | 4.6 $\mu$m (mag) | 12 $\mu$m (mag) | 22 $\mu$m (mag) | 12 $\mu$m (Jy) | 25 $\mu$m (Jy) | 60 $\mu$m (Jy) | 100 $\mu$m (Jy) |
| LKHa 324SE$^a$         | 10.56   | 8.27   | 6.46   | 3.94     | 2.20     | 0.33     | -1.337   | 23.9     | 33.7     | 87     | 199     |
| IRAS 21028+5001$^b$    | 10.26   | 9.16   | 8.31   | 7.10     | 6.46     | 4.33     | 2.43     | 0.81     | 1.1      | 2.76   | 199    |
| IRAS 21010+5000e        |          |         |        |          |          |          |          |          |          | 0.54   | 0.25   |
| WISE J210240.13+501236.5| ...     | ...    | ...    | 12.48    | 10.69    | 7.78     | 2.38     | ...      | ...      | ...    | ...    |
| IRAS 21014+5001$^c$    | 10.10   | 9.95   | 9.86   | 9.57     | 9.32     | 4.34     | 2.08     | 1.12     | 1.71     | 11.8   | 39.8   |
| WISE J210240.13+501236.5| ...     | ...    | ...    | 12.48    | 10.69    | 7.78     | 2.38     | ...      | ...      | ...    | ...    |
| IRAS 21010+5000$^e$    | <16.98  | 14.42  | 12.17  | 11.39    | 9.11     | 6.09     | 2.53     | <0.36    | 0.81     | <1.8   | <47.0  |
| WISE J21024.15+501013.0$^f$ | 14.54   | 13.63  | 13.05  | 11.69    | 10.71    | 8.62     | 7.29     | ...      | ...      | ...    | ...    |
| IRAS 21010+5000$^e$    |          |         |        |          |          |          |          |          |          | 0.54   | 0.25   |
| WISE J21024.13+501236.5| ...     | ...    | ...    | 12.48    | 10.69    | 7.78     | 2.38     | ...      | ...      | ...    | ...    |
| 2MASS 21024889+5010351  | 16.32   | 13.42  | 13.94  | ...      | ...      | ...      | ...      | ...      | ...      | ...    | ...    |
| IRAS 21010+5000$^e$    |          |         |        |          |          |          |          |          |          | 0.54   | 0.25   |
| IRAS 21010+5000$^e$    |          |         |        |          |          |          |          |          |          | 0.54   | 0.25   |

Notes:

$^a$ Clark source e, IRAS 21023+5002, WISE J210358.18+501343.9, see Figure 16(a).

$^b$ WISE J210428.01+501348.5, see Figure 16(b).

$^c$ See Figure 16(c).

$^d$ Clark source w, WISE J210303.24+501312.4, see Figure 16(d).

$^e$ IRAS 210324.41+501227.8, see Figure 16(e).

$^f$ Clark source f, see Figure 16(f).

$^g$ Western star; see Figure 16(g).

$^h$ Eastern star; see Figure 16(h).

$^i$ Clark source a. This IRAS source may be a blend of the two sources listed above it (WISE J210222.70+500308.3 and WISE J210223.85+500306.8).

---

**Figure 3.** H$_\alpha$ image of the LkHa 324 region (IRAS 21023+5002; Clark source e) region which includes the shock HH 1056–1059 and 1061–1062 shocks.
HH 1053, 1049, 1046, 1060, and 1063. The HH 1053, 1049 (Figure 6), and 1046 shocks (Figure 7) appear to all be the western components of a single flow powered by IRAS 21014+5001 (aka Clark source c), it is possible that HH 1049 or 1046 are from another source, but the alignment of these three shocks with IRAS 21014+5001 appears convincing.

The corresponding counterflow to the southeast emerges into a low extinction region of the cloud and is composed of the HH 1060 and 1063 shocks (Figure 8). If this is all one flow which emerges from that source, then the length of the flow is 26.5 which corresponds to a length of 4.6 pc at an assumed distance of 600 pc.

Clark designated IRAS 21014+5001 as a molecular outflow source based upon finding a patch of blue-shifted gas west of the source (see Clark 1986, Figure 1). This patch of blue-shifted
CO does not correspond to our HH 1053, 1049, 1046 outflow. The blue-shifted CO is centered south of the axis defined by our HH objects. Though the northernmost contour in Clark (1986, Figure 1) comes close to our flow axis near HH 1049, the bulk of the blue-shifted CO is closer to our HH 1052 (see below). The IRAS 21014+5001 source was detected by WISE, the fluxes are listed in Table 2 and the model SED is shown in Figure 16(d).

MHO 955. There is a star visible in the J, H, and K images (and faintly in Hα and [S ii]) 1.2 east–southeast of IRAS 21014+5001 near the axis defined by the HH 1053, 1049, 1046, 1060, 1063 outflow which is coincident with a 0.2 long H2 filament (MHO 955) pointing northeast from the star, at first glance it appears that it is emanating from the star. That star was determined to be a Class I protostar by Allen et al. (2008), however, it lies along the axis of the HH 1053, 1049, 1046 flow from IRAS 21014+5001 and so may alternatively be a shock in the embedded counterflow which happens to be coincident with a star along our line of sight.

HH 1044. This is a [S ii] bright knot (Figure 9) which lies at the northwest corner of the Subaru image. There appears to be a faint Hα filament extending due north from it, but this may also be an illuminated cloud edge. IRAS 20595+5009 lies 2.5 north of the shock, outside of the field of view of our Hα and [S ii] images.

HH 1052. The A and B knots of this object (Figure 6) are a pair of faint Hα and [S ii] filaments. The B component has an H2 counterpart (MHO 956). There is a faint V-shaped reflection nebula visible in the H and K images 0.3 southeast of the knots. The reflection nebula opens toward both of the knots. At the apex of the reflection nebula is a candidate for the source star. While it is not detected in our J, H, or K images, it is detected by WISE (WISE J210240.13+501236.5; Table 2). In addition, there is another candidate source star visible in our near-IR images which lies 19′ to the southeast. It is coincident with IRAS 21010+5000 and is detected in the WISE catalog (WISE J210242.41+501227.8; Table 2; Figure 16(e)).

The blue-shifted CO which was discovered by Clark (1986) is coincident with the HH 1052 shock system. Clark associated this with IRAS 21014+5001, however we associate that source with the HH 1053, 1049, 1046 flow.

HH 1047. This shock system appears to be a curved, C-shaped outflow (see Figure 10). The C-shaped curve suggests that the source is moving to the southeast (Bally & Reipurth 2001).

In our near-IR images, several stars (many with corresponding WISE detections) lie on or near the arc of the flow and would be source candidates. Of these, three stand out as being directly along the arc of the flow (WISE J210214.15+501013.0, WISE J210218.93+501102.3, and WISE J210217.70+501046.5).
This star is a likely candidate for the outflow source as the ori-
and lies about 1 arcmin north of the $H_2$ shock. Its reflection
Robitaille et al. (2007) built based upon the
visible only in our near-IR images. We examined the models of
The first of these is optically visible while the other two are
magnitudes of each of these and have selected the optically vis-
images) appears to open southward. This source has a brighter
cloud edge which is visible in the $H_2$ images, nor are there faint stars at those locations in any of
The reflection nebula surrounding the HH 1050 outflow
There are two stars embedded in the reflection nebula.
western star, is visible at all wavelengths, and is brighter
of HH 1051, or the southern half of a less collimated component
There is also a bright, compact $H_2$, $H_\alpha$, and $[S\,\text{ii}]$ knot (HH 1050 F/MHO 958) 4° west of the
Further to the southwest are faint shocks (see Figure 13)
which is may be part of this flow, however they overlap with the
western lobe of the HH 1050 flow described below.

**HH 1050 and 1045.** The western of the two stars in the region
appears to drive a long outflow (HH 1050; see Figure 13) in the east–west direction. This outflow is much more extended
than the HH 1051 outflow and lies along a nearly east–west
direction. The B and C knots are bright in both $H_\alpha$ and $[S\,\text{ii}]$ and both have $H_2$ counterparts (MHO 958). Knots D and
K nots A–E of this shock system (Figure 12) are the eastern
component of the flow. The furthest is knot A which lies 1.6
west of the source. The B and C knots are bright in both $H_\alpha$ and $[S\,\text{ii}]$ and both have $H_2$ counterparts (MHO 958). Knots D and
appears to connect many of the shocks in this region, we favor
the expectation that all of the knots (F–P) are part of the HH
The northern half of this cavity, past knots L, and K, emerges into a low extinction region in which background stars can be seen. The southern half of the cavity is a higher extinction region.
Figure 12. [S\textsubscript{ii}] image of the area around the HH 1048, 1050, and 1051 shock systems. The positions of the eastern and western stars described in the text are indicated with arrows and the circles mark the positions of HH objects.

Figure 13. H\textalpha{} image of the western half of the HH 1050 shock system. The positions of the eastern and western stars described in the text are indicated with arrows and the circles mark the positions of HH objects. The error ellipse for the position of IRAS 21007+4951 is indicated in white.

The Clark (1986) outflow map shows red- and blue-shifted lobes which correspond to our HH 1050 outflow. The eastern half of the flow (knots A–E) correspond to red-shifted CO and the western half (knots F–P) correspond to blue-shifted CO.

HH 1048. Knot A of HH 1048 is a small, compact blob of emission just emerging from a star which lies at the apex of a C-shaped reflection nebula (Figure 12) and which is coincident with WISE J210226.45+500203.4 (Table 2). Knot B of HH 1048 is an H\textalpha{} and [S\textsubscript{ii}] filament which lies in the middle of that C-shaped reflection nebula.

HH 1048 knot C is a compact, H\textalpha{} only bow which lies near the eastern end of the reflection nebula, about 0.5 from the star. HH 1048 D is a compact, nearly starlike knot of H\textalpha{} and [S\textsubscript{ii}] emission. HH 1048 knot E is another filament which lies...
roughly 1′ east of the star and slightly north of the line defined by the knot B filament, it may trace the northern edge of the outflow cavity. The $J$, $H$, and $K$ images also show one arc of the reflection nebula extending roughly 15′ northeast of the source star.

The Clark (1986) outflow map shows a blob of blue-shifted CO which is connected to the blue-shifted lobe of his source $a$. While Clark did not discuss this as a separate outflow, it is perfectly coincident in position with our HH 1048 knots A and B and appears to match the outline of the associated reflection nebula in size.

**HH 1055.** This shock system is a cluster of faint, [S II] bright, low surface brightness shock filaments (Figure 15) embedded in some patchy dust filaments along the eastern edge of the cloud. They lie near to the axis defined by the HH 1051 and 1050 outflows from the IRAS 21007+4951 source, however a positive association with those outflows is not possible based on the present data.

### 4. DISCUSSION

The L988 region contains significant outflow activity as revealed by our surveys for optical and near-IR shock tracers. The region contains nearly two dozen independent shock systems (20 HH objects and 3 MHO objects unaffiliated with HH objects), however we can only confidently identify the driving protostar for five outflows (LkHα 324SE, IRAS 21014+5001, WISE J210214.15+501013.0, WISE J210222.70+500308.3, and WISE J210223.85+500306.8).

Two outflows we have identified (from IRAS 21014+5001 and the IRAS 21007+4951/WISE J210222.70+500308.3/WISE J210223.85+500306.8 shock complex) each exceed 1 pc in length with the IRAS 21014+5001 flow being 4.6 pc long. Both of these large scale outflows originate from sources which are in the highest extinction regions of the cloud. We find several HH objects and one H$_2$ shock complex near the well studied cluster surrounding LkHα 324 (IRAS 21023+5002, Clark source $e$).

While much of the outflow activity in the L988 cloud is widely distributed over a region ∼30′ (∼4–7 pc) in diameter, a group of at least three sources which drive overlapping outflows is clustered around the IRAS 21007+4951 source and its associated reflection nebula, located in the center of the L988 cloud.

A notable feature of this study is that outflow activity is detected primarily at visible wavelengths (Hα and [S II]) while our near-IR images (H$_2$) show relatively little shock activity and most of what is detected in the near-IR is coincident with Hα or [S II] shocks. This is likely due, at least in part, to the combination of the near-IR data being taken on a smaller telescope (3.8 m as opposed to 8.2 m) and under much worse seeing conditions (∼1′$''$ FWHM for the H$_2$ images compared to 0.65–0′$''$70 for the Hα and [S II]). We suspect that further study of this region at near-IR wavelengths will reveal additional details.

We thank an anonymous referee for helpful comments.

J.W. was supported by the NSF through grants AST-0507784 and AST-0407005. J.W. and B.R. acknowledge support from the National Aeronautics and Space Administration through the NASA Astrobiology Institute under Cooperative Agreement No. NNA09DA77A issued through the Office of Space Science. This work is based in part on data collected at the Subaru telescope, which is operated by the National Astronomical Observatory of Japan (NAOJ). We are grateful to Nobunari Kashikawa for permission to use his [S II] filter for the SuPrimeCam instrument on the Subaru Telescope. This publication makes use of data obtained on the United Kingdom Infrared Telescope (UKIRT) which is operated by the Joint Astronomy Centre on behalf of the Science and Technology Facilities Council of the U.K. This publication makes use of data products from the 2MASS, which is a joint project of the University of Massachusetts and the Infrared Processing and Analysis Center/California Institute of Technology, funded by the National Aeronautics and Space Administration and the National Science Foundation. This publication makes use of data products from the Wide-field Infrared Survey Explorer, which is a joint project of the University of California, Los Angeles, and the Jet Propulsion Laboratory/California Institute of Technology, funded by the National Aeronautics and Space Administration. This research has made use of the VizieR catalog access tool, CDS, Strasbourg, France. MHO catalog is hosted by Liverpool John Moores University.

We also thank the University of Hawaii Time Allocation Committee for allocating the nights during which these objects.
Figure 16. Spectral energy distributions based on 2MASS, WISE, and IRAS catalog data fit with models by Robitaille et al. (2007).
observations were made. The authors wish to recognize and acknowledge the very significant cultural role and reverence that the summit of Mauna Kea has always had within the indigenous Hawaiian community. We are most fortunate to have the opportunity to conduct observations from this sacred mountain.

Facilities: Subaru (Suprime-Cam), UKIRT (WFCAM), UH:2.2m (Tek2k), WISE

REFERENCES

Allen, T. S., Pipher, J. L., Gutermuth, R. A., et al. 2008, ApJ, 675, 491  
Alves, J., Lada, C. J., Lada, E. A., Kenyon, S. J., & Phelps, R. 1998, ApJ, 506, 292  
Arce, H. G., & Goodman, A. A. 2002, ApJ, 575, 911  
Bally, J., & Reipurth, B. 2001, ApJ, 546, 299  
Bally, J., Reipurth, B., Lada, C. J., & Billawala, Y. 1999, AJ, 117, 410  
Casali, M., Lunney, D., Henry, D., et al. 2001, in ASP Conf. Ser. 232, The New Era of Wide Field Astronomy, ed. R. Clowes, A. Adamson, & G. Bromage (San Francisco, CA: ASP), 357  
Chavarría, C. 1981, A&A, 101, 105  
Chavarría, C., & de Lara, E. 1981, RMxAA, 6, 159  
Chavtasi, D. S. 1960, Atlas of Galactic Dark Nebulae (Abastumani: Astrophysical Observatory)  
Clark, F. O. 1986, A&A, 164, L19  
Davis, C. J., Gell, R., Khanzadzayan, T., Smith, M. D., & Jenness, T. 2010, A&A, 511, 24  
Dobashi, K., Uehara, H., Kandori, R., et al. 2005, PASJ, 57, 1  
Felli, M., Palagi, F., & Tofani, G. 1992, A&A, 255, 293  
Herbig, G. H., & Dahm, S. E. 2006, AJ, 131, 1530  
Hodapp, K.-W. 1994, ApJS, 94, 615  
Leorat, J., Passot, T., & Pouquet, A. 1990, MNRAS, 243, 293  
Miesch, M. S., & Bally, J. 1994, ApJ, 429, 645  
Miyazaki, S., Komiyama, Y., Sekiguchi, M., et al. 2002, PASJ, 54, 833  
Mundt, R., & Eisloffel, J. 1998, AJ, 116, 860  
Quillen, A. C., Thorndike, S. L., Cunningham, A., et al. 2005, ApJ, 632, 941  
Reipurth, B., & Schneider, N. 2008, Handbook of Star Forming Regions I: The Northern Sky, I (ASP Monograph Publications, Vol. 4; San Francisco, CA: ASP), 36  
Robitaille, T. P., Whitney, B. A., Indebetouw, R., & Wood, K. 2007, ApJS, 169, 328  
Shevchenko, V., Yakubov, S. D., Ambaryan, V. V., & Garibdzhanyan, A. T. 1991, SvA, 35, 135  
Staude, H. J., & Elsasser, H. 1993, A&ARv, 5, 165  
Uehara, M., Nagashima, C., Sugitani, K., et al. 2004, Proc. SPIE, 5492, 661  
Walawender, J., Bally, J., & Reipurth, B. 2005, AJ, 129, 2308