A SPITZER-MIPS SEARCH FOR DUST IN COMPACT HIGH-VELOCITY H\textsc{i} CLOUDS

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ABSTRACT

We employ three-band Spitzer-MIPS observations to search for cold dust emission in three neutral hydrogen compact high-velocity clouds (CHVCs) in the vicinity of the Milky Way. Far-infrared emission correlated with H\textsc{i} column density was previously reported in H\textsc{i} Complex C, indicating that this object contains dust heated by the Galactic radiation field at its distance of \(\sim 10\) kpc. Assuming published Spitzer, IRAS, and Planck, IR-H\textsc{i} correlations for Complex C, our Spitzer observations are of sufficient depth to directly detect 160 \(\mu\)m dust emission in the CHVCs if it is present at the same level as in Complex C, but no emission is detected in any of the targets. For one of the targets (CHVC289) which has well-localized H\textsc{i} clumps, we therefore conclude that it is fundamentally different from Complex C, with either a lower dust-to-gas ratio or a greater distance from the Galactic disk (and consequently cooler dust temperature). Firm conclusions cannot be drawn for the other two Spitzer-observed CHVCs since their small-scale H\textsc{i} structures are not sufficiently well known; nonetheless, no extended dust emission is apparent despite their relatively high H\textsc{i} column densities. The lack of dust emission in CHVC289 suggests that at least some compact high-velocity clouds objects may exhibit very low dust-to-gas ratios and/or greater Galactocentric distances than large HVC complexes.

Key words: Galaxy: evolution – Galaxy: structure – infrared: ISM – ISM: general

1. INTRODUCTION

Neutral hydrogen high-velocity clouds (H\textsc{i} HVCs) have been known to exist for nearly half a century (Muller et al. 1963), but their cosmological significance and role in the Milky Way and Local Group remain ambiguous. HVCs span a wide range of sizes on the sky: from enormous systems like Complex C, subtending an angular area of roughly \(90^\circ \times 20^\circ\) (Wakker \& van Woerden 1991), to subdegree-scale compact high-velocity clouds, some of which are unresolved even with large single-dish radio telescopes (Braun \& Burton 1999; Putman et al. 2002). As their name suggests, the radial velocities of HVCs relative to the local standard of rest \((|v_{\text{LSR}}| > 100\) km s\(^{-1}\)) are inconsistent with Galactic rotation, implying that they reside either in the extended Galactic halo or at extragalactic (Local Group) distances. HVCs appear to be a common feature around either in the extended Galactic halo or at extragalactic (Local Group) distances. HVCs appear to be a common feature around the Galaxy (Moore et al. 1999; Giovannelli et al. 2010). Oddly, unlike recently discovered, very low mass satellite galaxies which appear to harbor both stars and dark matter (e.g., Strigari et al. 2008) but little or no gas (Gruveich \& Putman 2009), searches for stellar populations associated with HVCs have only succeeded in placing upper limits (Willman et al. 2002; Siegel et al. 2005; Simon et al. 2006; Hopp et al. 2007). Similarly, aside from one case (Richter et al. 1999), HVCs appear to contain little or no molecular gas (Wakker et al. 1997; Akeson \& Blitz 1999; Combes \& Charmandaris 2000). The detection of associated ionized gas (up to O \textsc{ii}; Sembach et al. 2003; Shull et al. 2009), but not the very high ions tracing 10\(^6\) K gas (Williams et al. 2006), supports the notion that HVCs may be related to non-equilibrium cooling processes, either from the IGM or a Galactic fountain.

Thus, although the most extended HVCs appear to be located relatively near the Galaxy (Wakker et al. 2008; Lockman et al. 2008; Smoker et al. 2011), they may nonetheless be connected to extragalactic phenomena. Complex C, for example, lies at a distance of \(\sim 10\) kpc (Wakker et al. 2007; Thom et al. 2008) and exhibits a low but inhomogeneous metallicity (Gibson et al. 2001; Tripp et al. 2003; Collins et al. 2007) that may be indicative of a combination of infalling primordial gas and outflowing enriched material. While compact HVCs (CHVCs) were initially hypothesized to be faint Local Group denizens (Braun \& Burton 1999), evidence is mounting that most of them simply represent the smallest fragments of the “normal” HVC population. For instance, Maloney \& Putman (2003) concluded that, due to their large inferred masses and inconsistent velocity widths, CHVCs as a population are more likely to be associated with the Galactic halo than the Local Group; additionally, searches for similar clouds in nearby Local Group analogs indicate that CHVCs are probably clustered within 90 kpc of the Galaxy, and massive intragroup H\textsc{i} clouds are relatively rare (Pisano et al. 2004, 2007; Chynoweth et al. 2009). The lack of large H\textsc{i} clouds beyond 50 projected kpc from M31 (Westmeier et al. 2008) further suggests that most of the HVCs around our analogous spiral Galaxy do not lie far beyond the halo. Putman et al. (2011) recently found that at least 35% of CHVCs exhibit head-tail morphologies (suggesting interaction with a diffuse warm–hot Galactic halo medium; Williams et al. 2006, 2007; Bregman et al. 2009) and most of these lie near larger HVC...
complexes. In certain rare cases, though, CHVCs which are not associated with larger-scale H\textsc{i} structure may be candidates for low-luminosity dwarf galaxies.

The reported detection of dust in Complex C by Miville-Deschênes et al. (2005, hereafter M05) provides a novel way to test the connection between HVCs and CHVCs. If CHVCs are simply scaled-down versions of Complex C at similar distances, their dust emission properties should be similar. On the other hand, if certain CHVCs differ fundamentally from the non-compact HVCs (e.g., in their metallicities or Galactocentric distances), this would manifest itself through correspondingly different dust emission properties. M05 inferred the dust content of Complex C by cross-correlating the far-IR surface brightness in the Spitzer Extragalactic First-Look Survey with H\textsc{i} observations in the same field (Lockman & Condon 2005); however, a subsequent analysis by Peek et al. (2009) using more sensitive Arecibo H\textsc{i} measurements and IRC fluxes did not confirm the M05 detection in Complex C (but, interestingly, detected dust in HVC Complex M). New longer-wavelength data from the Planck satellite (Planck Collaboration 2011a) may have finally found dust in Complex C, albeit at the $\sim3\sigma$ level (Planck Collaboration 2011b, hereafter Planck11). In short, the prevalence of dust in HVCs is still essentially unknown, yet this information is crucial to our understanding of both HVCs themselves and their significance in the Milky Way and Local Group.

With much smaller sizes and often high peak H\textsc{i} column densities, CHVCs may allow the direct detection of dust emission; such detections (or strong upper limits thereupon) can therefore provide insight to the nature of these mysterious objects. Here we present a targeted Spitzer-MIPS search for dust emission in three CHVCs: one with high-resolution radio data revealing several dense arcminute-scale knots and two other high-column density CHVCs from the H\textsc{i} Parkes All-Sky Survey (HIPASS) catalog (Putman et al. 2002). This paper is organized as follows: in Section 2 we discuss the CHVC sample and the Spitzer observations; Section 3 describes the flux measurements from the Spitzer images, in Section 4 we discuss possible interpretations of the Spitzer observations (and caveats thereto), with the overall results briefly summarized in Section 5.

### 2. SAMPLE AND OBSERVATIONS

Due to its extremely compact, “clumpy” morphology as revealed by the high-resolution radio maps of BW04, and their conclusion that this is potentially a good candidate for a “missing” dark matter minihalo, we selected CHVC289 as our primary follow-up target. This object exhibits high peak H\textsc{i} column densities in all its five knots ($N_{\text{H}} > 10^{20}$ cm$^{-2}$) in the high-resolution maps, even though its properties appear unremarkable in single-dish observations (peak $N_{\text{H}} \sim 2.9 \times 10^{19}$ cm$^{-2}$ as observed with Effelsberg), having a relatively small total flux compared to other CHVCs due to its small size.

To complement this observation, we selected two other CHVCs from the HIPASS catalog of Putman et al. (2002): CHVC 319.1 $-$ 78.8 + 215 and CHVC 147.8 $-$ 82.4 $-$ 268 (hereafter referred to as CHVC319 and CHVC148, respectively). These were specifically chosen because of their very high peak column densities averaged over the Parkes beam ($N_{\text{H}} > 5 \times 10^{19}$ cm$^{-2}$), and compact sizes (semimajor axes less than 0.2 deg). In addition to the HIPASS column densities and sizes, higher-resolution observations of CHVC148 were obtained by Westmeier et al. (2005) on the 100 m Effelsberg single-dish telescope and by de Heij et al. (2002) on the Westerbork interferometer. Although the detailed (arcminute-scale) structures of these CHVCs are unknown due to the lack of high-resolution imaging comparable to that obtained by BW04 on CHVC289, their HIPASS column densities are over four times higher than that of CHVC289, making them good candidates for objects with high-column density H\textsc{i} knots that may harbor dust.

Although three of these CHVCs were observed in Cycle 3 with the Spitzer-MIPS 24-μm, 70-μm, and 160-μm channels (MIPS1, MIPS2, MIPS3, respectively; see Table 1 for a summary of the observations), and the data were processed using standard techniques given in the Spitzer Data Analysis Cookbook. Because of its extreme compactness and precisely constrained H\textsc{i} knot positions, CHVC289 was observed with a single MIPS large-field Astronomical Observation Template (AOT) in MIPS1 and MIPS3. Since half of the MIPS2 array is unusable, in this band we used two separate observations offset by 160′ to ensure complete coverage of the CHVC. These observations were designed to provide a full 5′ by 5′ image of the central portion of CHVC289 in all three bands, though due to an inoperative MIPS3 readout there are two narrow strips of missing data in the 160-μm image. The nominal integration time per pixel in channels 1, 2, and 3 are 648, 629, and 52 s, respectively.

The other two CHVC positions are only known to within a few arcminutes and their angular sizes are larger (albeit with significantly higher column densities than CHVC289); we thus instead obtained MIPS scan maps of the regions surrounding these two CHVCs, but to lower sensitivity since their high-column densities should correspond to stronger dust emission. The scan maps were designed to cover 24′ × 30′ regions with 1/4 array (80′) offsets to fill in the gaps caused by the bad MIPS3 detector pixels; this area is sufficient to fully cover CHVC148 and CHVC319 with at least two overscans in each band. Basic characteristics of these observations are also listed in Table 1.

### Table 1

| Target   | R.A. (J2000) | Decl. (J2000) | $t_{\text{exp},24}$ (s) | $t_{\text{exp},70}$ (s) | $t_{\text{exp},160}$ (s) | $\sigma_{24}^b$ (MJy sr$^{-1}$) | $\sigma_{70}^b$ (MJy sr$^{-1}$) | $\sigma_{160}^b$ (MJy sr$^{-1}$) | Notes                  |
|----------|--------------|--------------|--------------------------|--------------------------|---------------------------|--------------------------------|-----------------------------|---------------------------|------------------------|
| CHVC289  | 11 : 59 : 30 | $-28 : 34 : 32$ | 648                      | 629                      | 52                        | 0.073                          | 0.45                        | 1.1                       | single pointing         |
| CHVC148  | 01 : 05 : 06 | $-20 : 09 : 00$ | 168                      | 84                       | 17                        | 0.18                           | 0.39                        | 0.54                      | MIPS scan map           |
| CHVC319  | 00 : 35 : 42 | $-37 : 52 : 00$ | 168                      | 84                       | 17                        | 0.068                          | 0.35                        | 0.38                      | MIPS scan map           |

Notes:

- Exposure times are seconds per pixel as estimated from the Astronomical Observation Requests (AORs).
- Median pixel-to-pixel rms values in the regions covering each CHVC.

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6 http://ssc.spitzer.caltech.edu/dataanalysis/tools/cookbook/
3. MEASUREMENTS

3.1. Mid-IR Fluxes and Upper Limits

For CHVC289, we employ the known positions and sizes of the H I clumps measured by BW04 with the Australia Telescope Compact Array (ATCA), shown overplotted on the MIPS images in Figures 1 and 2. The central, highest-column density clump was resolved by ATCA with a diameter of 90". This is roughly 1.5–2 times larger than the MIPS 160 μm point-response function and therefore (provided the dust and H I densities are correlated) the mid-IR dust emission from this clump should similarly be resolved by all MIPS channels. The four less-dense clumps are unresolved by ATCA (with sizes less than 50''); unfortunately, these fall either partly or entirely on the bad-pixel gaps in the MIPS3 image, so we only consider the dense central clump here.

Since the emission is nominally extended rather than a point source, we measure the flux of the central CHVC289 clump in each of the MIPS images with a 90" diameter circular aperture (i.e., approximately equal to the H I size measured with ATCA). The uncertainty on the flux is determined with the "empty aperture method," where the same flux measurement is repeated for many randomly placed apertures on source-free regions of each image; the resulting dispersion in the flux measurements represents the uncertainty in the background levels, while the median provides an estimate of the background levels in the image. In none of the three MIPS bands is the flux in the CHVC289 cores significant; we therefore compute 2σ upper limits in all bands assuming the measured uncertainties.

The small-scale H I structures and positions of CHVC148 and CHVC319 are less well constrained: the estimated size of CHVC319 in the HIPASS catalog is given as 0'2 ± 0'1 (Putman et al. 2002), while CHVC148 has an FWHM of ∼20' (Westmeier et al. 2005). The uncertainty ellipses of these clouds take up a substantial fraction of the MIPS field; thus, the empty aperture method cannot be used to estimate flux uncertainties in these cases. Note that although de Heij et al. (2002) report a compact H I core in CHVC148, this comprises only 4% of the total H I flux from this CHVC with a peak column density of ∼10^{19} cm^{-2}, or roughly an order of magnitude less than the...
central concentration in CHVC289; any dust emission from this core is therefore likely to be negligible. The MIPS 160 μm images of both of these CHVC regions are shown in Figure 3, with the positions and beam sizes overplotted. No extended 160 μm emission is evident within the CHVC areas, but a number of point sources are visible, particularly with the positions and beam sizes overplotted.

Figure 3. Left panel: MIPS 160 μm scan maps of the region around CHVC148. The dashed circle shows the approximate position and beam size of the Westmeier et al. (2005) Effelsberg observation, while the narrow solid ellipse denotes the compact core reported by de Heij et al. (2002) containing 4% of the CHVC’s flux (note that this represents their synthesized Westerhok beam, not the actual size and shape of the core). While many compact sources fall within the CHVC region, all correspond to background galaxies. Right panel: same, but for CHVC319; here, the ellipse denotes the CHVC size and shape reported in the HIPASS catalog (Putman et al. 2002). No significant extended emission is apparent in either of these CHVCs.

The modified blackbody function employed by Planck11 scales as $\epsilon_\nu(\nu, T)$, where $\beta$ and $T$ are the free parameters and $B_\nu(T)$ is the standard Planck function.

3.2. The CHVC289 Mid-IR Spectral Energy Distribution

As noted in the previous section, we were only able to derive upper limits on the dust emission in CHVC289 in all three Spitzer bands. With previously measured correlation coefficients between H I column density and dust emission, we can predict the mid-IR surface brightnesses that the densest core of CHVC289 should exhibit if its dust properties are similar to HVC Complex C or intermediate-velocity clouds (IVC). Here we employ measurements made by two independent groups: M05 in the Spitzer Extragalactic First Look Survey and the “Draco” field analyzed by Planck11, both of which cover small parts of Complex C. These analyses claimed a significant correlation of mid-IR emission with H I in Complex C, assuming a simple proportionality ($I_\nu \sim \alpha_\nu N_{HI}$ in M05, $I_\nu \sim \epsilon_\nu N_{HI}$ in Planck11; both define the emissivities $\alpha_\nu$ and $\epsilon_\nu$ in units of MJy sr$^{-1}$ (10$^{20}$ cm$^{-2}$)$^{-1}$). Furthermore, in their fitting, both allowed for independent mid-IR emission from known local, IVC, and HVC H I velocity components. Planck11 only include one IVC component in their fits while M05 consider two; for clarity, in our comparison to M05, we only consider their “IVC1” and “HVC” components.

In Figure 4 we show these expected surface brightnesses for the central H I core of CHVC289, assuming the Brüns & Westmeier (2004) column density of 1.58 × 10$^{20}$ cm$^{-2}$. Estimates for the measured Planck11 IRAS and M05 IRAS/MIPS IR–H I correlations are shown as points. Additionally, we estimate modified blackbody spectra$^8$ based on the Planck 100, 350, 550, and 850 μm measurements in the Draco field (Planck11, Table 2). These curves are normalized to the IRAS 100 μm flux, and the IRAS 60 μm point is not included in the fit since dust emission at high frequencies is dominated by non-equilibrium processes.

We convert our mid-IR flux limits for the central CHVC289 core to surface brightness upper limits by assuming that the flux is distributed evenly over the 90′ measurement aperture. Since this is comparable to the size (FWHM) of the H I emission itself, in essence we are comparing the predicted and measured average surface brightnesses in the central CHVC289 core; due to the effects of beam smearing and the lack of a 160 μm detection, this is a reasonable approximation. These derived upper limits for all three bands are overplotted in Figure 4. Although the two bluer MIPS upper limits (24 μm and 70 μm) are more or less consistent with the predicted emission for Complex C-like dust, the 160 μm upper limit is a factor of ~4 below the prediction from M05, and a factor two below the Planck11 blackbody curve; the two redder MIPS bands strongly rule out IVC-like emission (and our 24 μm measurement appears inconsistent with the expected flux from...
M05). Unfortunately, without a detection in any of the bands, we are unable to place limits on the dust temperature in CHVC289.

4. DISCUSSION

4.1. Consistency between M05 and Planck11

As alluded to in Section 1, the presence of dust in HVC Complex C has been a somewhat contentious topic. In large part this stems from the presence of multiple Galactic components along the line of sight (including local interstellar medium, one or more intermediate-velocity components, and Complex C itself) which vary in column density, velocity, and even composition across the enormous area spanned by Complex C. Mid-IR emission, by contrast, lacks the detailed velocity information of H$_1$, so two-dimensional spatial correlations must take into account contributions from each distinct component, with each potentially exhibiting a different dust fraction and temperature. As a result, there can be substantial degeneracies between the various measured parameters, and properly accounting for uncertainties is paramount.

M05 first reported a significant detection of dust (with $\epsilon_{160} = 0.8 \pm 0.1$, nominally an 8$\sigma$ result in this band) over a $\sim 5$ deg$^2$ field, using a $\chi^2$ minimization technique; both calibration and statistical uncertainties were included. However, as pointed out by Peek et al. (2009), spatial variations in the dust-to-gas ratio of the “local” component (which by far dominates the IR emission) can introduce spurious signals for weaker components like the HVC. Since this possibility was not taken into account by M05, and since their analysis does not account for position-to-position statistical variations (like the empty aperture method we employ, or the “displacement map” technique described by Peek et al. 2009), it appears likely that M05’s uncertainties are underestimated (especially for the HVC component).

Given this, plus the fact that M05 and Planck11 analyzed different parts of Complex C, the discrepancies between some of the M05 and Planck11 data points in Figure 4 are not surprising. In particular, it is notable that the quoted errors on the 60 $\mu$m and 100 $\mu$m fluxes are comparable between Planck11 and M05, despite the factor $\sim 5$ larger angular area analyzed by Planck11. On the other hand, Planck11 do not include data at 24 $\mu$m, and at 160 $\mu$m we can only interpolate their modified blackbody fits. Due to their far wider spatial and spectral coverage, we take the Planck11 as the most reliable comparison to our data; however, for completeness we include comparisons to the M05 points as their Spitzer measurements are more analogous to ours. At worst, if the M05 160 $\mu$m point is taken as an upper limit, our data provide a nearly order-of-magnitude more stringent limit and also lie a factor $\sim 2$ below the expectation from Planck11.

4.2. Are CHVCs a Distinct, Dust-poor Population?

None of the CHVCs studied here show evidence for the presence of dust in our deep Spitzer-MIPS imaging, despite their relatively high-column-densities. CHVC289 in particular, with its strong central core resolved with ATCA, should have been confidently detected at the 4$\sigma$–8$\sigma$ level in the 160 $\mu$m band (and perhaps marginally at 70 $\mu$m) if its dust temperature and dust-to-gas ratio are similar to HVC Complex C. As shown in Figure 4, the 160 $\mu$m upper limit is incompatible with a similar origin, lying a factor of $\sim 2$ below the flux expected from the Planck11 measurements. Even more striking is the discrepancy in the two redder bands between CHVC289 and IVC1. IVCs are thought to reside closer to the Galactic disk, perhaps resulting from outflowing material due to star formation or other processes; however, the limits on CHVC289 are a factor of 2–10 below the IVC emission level predicted by either M05 or Planck11. The dust–gas correlation for IVC2 as reported by M05 is not shown in Figure 4, but lies in between Complex C and IVC1. The extreme compactness of CHVC289, along with its lack of detected IR emission, suggest that it represents a different type of system than either Complex C or the IVCs.

However, with the current data we cannot ascertain whether this difference is intrinsic to CHVC289, or simply due to a greater distance from the Galactic plane (hence weaker ambient radiation field and lower dust temperature/emissivity). The upper limit to CHVC289’s 160 $\mu$m surface brightness is a factor four below the expectations from M05, who estimate a dust temperature in Complex C of 10.7 K (though the uncertainties on this quantity are likely large, as well). Assuming blackbody emission, this discrepancy in flux is consistent with CHVC289 having a lower temperature, $< 9.2$ K, which in turn means (if the temperature difference depends entirely on Galactocentric distance and the dust heating scales as $\sim 1/R_G^2$) that CHVC289 could in principle be only marginally ($\geq 10\%$) farther away than Complex C’s average distance of 10 kpc (Wakker et al. 2007; Thom et al. 2008). An even smaller difference in distance could explain the discrepancy between CHVC289 and the better-constrained Planck11 measurements. Of course, this rough estimate assumes that these two clouds have identical dust properties aside from their temperatures; in reality, other variables are likely to be in play (e.g., dust
distribution and dust-to-gas ratio). A robust determination of the physical conditions in CHVC289 thus evades us, since the current data cannot directly constrain the dust temperature of this cloud.

Similarly, no mid-IR emission is seen in either of the other two systems presented here, CHVC148 and CHVC319. However, this result is weaker since the small-scale structures of these CHVCs are essentially unknown. These objects were initially chosen for MIPS follow-up due to their compact (single-dish) sizes and far higher peak column densities than CHVC289; given that ultracompact, high-density cores in CHVC289 were found under interferometric scrutiny by BW04, correspondingly higher-density (or more numerous) cores may also exist in CHVC148 and CHVC389. Nonetheless, neither obvious clumps nor diffuse haze in the mid-IR is visible within either of these systems. de Heij et al. (2002) did in fact find a “core” (albeit with much lower resolution than the BW04 observations) in CHVC148, but this core comprises only 4% of the total HVC flux. Higher-resolution H i observations of these systems would allow a more detailed comparison with the MIPS data; however, since no sources are seen in the mid-IR, these comparisons will likely produce only weak upper limits (as with CHVC289).

4.3. Caveats

This analysis partly hinges on a comparison of the mid-IR emission in the CHVCs to estimates of the dust content of Complex C, which is still uncertain even with the Planck11 data; the primary reason for this is the weakness of the Complex C dust emission and dominant foreground H i/dust components. Moreover, as M05 point out, despite the evidence that Complex C contains dust, no molecular gas has been detected thus far; either through H 2 absorption (Murphy et al. 2000; Richter et al. 2001) or 12CO emission (Dessauges-Zavadsky et al. 2007). Since dust and molecular gas elsewhere in the Galaxy are strongly correlated, this appears somewhat incongruous. M05 suggest that the dust in Complex C may instead be confined to cold, compact cores with the surrounding warmer gas comprising most of the H i; however, our observations strongly rule out such emission in CHVC289’s compact cores. On the other hand, this may further highlight that CHVC289 and Complex C are different in some elementary way besides their angular sizes.

Although the central clump of CHVC289 is resolved with ATCA, it is only marginally so: the inferred clump size is 90′′, compared to the 112′′ × 36′′ beam reported by Brüns & Westmeier (2004). The morphology of the clump could actually be more complex, consisting of several denser clumps spread over the 90′′ area. Since we assumed constant H i column density and dust emission over this area, the presence of such clumps could “hide” emission in higher (but still undetected) surface brightness regions, implying that our upper limits could in principle be too low. However, such effects are unlikely to account for the large (factor of 2 at 160 μm) discrepancy between the CHVC289 and Complex C emission properties, especially given the large H i column density measured over the same 90′′ area.

Since only upper limits in all three bands can be calculated for CHVC289, it is not possible to compare the shape of the putative dust spectral energy distribution (SED) with the other systems (Complex C and the IVCs). If CHVC289 has a substantially flatter dust SED (e.g., due to a different grain size distribution or higher temperature), this may also account for its lower 160 μm flux. On the other hand, such scenarios would be necessarily contrived (e.g., CHVC289 would need to be both hotter and very dust poor), and the overall conclusion would remain: it is a fundamentally different system than the ones studied by M05 and Planck11.

5. SUMMARY AND OUTLOOK

Using deep Spitzer-MIPS observations of three CHVCs, we have placed limits on the dust emission from these enigmatic objects, ruling out similar physical conditions in HVC Complex C and the most compact object in our sample (CHVC289). Notably, the 160 μm surface brightness limit falls a factor of two below that inferred via Planck measurements for dust in HVC Complex C and are even more discrepant with IVC measurements, indicating that CHVC289 is either farther away or exhibits a lower dust-to-gas ratio than these other two object categories. CHVC289 (and by extension other CHVCs) may therefore reside farther from the Galactic disk or exhibit more “primordial” compositions. Alternatively, if all (C)HVCs exhibit similar physical conditions and the M05/Planck11 dust detections in Complex C are spurious, our CHVC289 measurement places the most stringent upper limit on HVC dust yet. Unfortunately, since all we have are upper limits, the current data do not allow us to distinguish between these possibilities.

No extended dust emission is seen toward the other two CHVCs (CHVC148 and CHVC389) observed with MIPS; however, their small-scale H i distributions are poorly constrained. Since their total column densities are much higher than CHVC289 with comparable radii measured from single-dish observations, high-resolution H i maps of these two clouds might allow stronger constraints to be placed on their dust emission with the existing MIPS data. A robust study of the dust content over the full CHVC population (and comparison to large-scale HVCs) will require of a much larger sample than the three presented here. In particular, the Planck mission (Planck Collaboration 2011a), with its full-sky coverage, sensitivity to cold dust at submillimeter wavelengths, and angular resolution well matched to CHVC sizes, will prove integral to this aim.

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