FIRST RESULTS FROM A 1.3 cm EXPANDED VERY LARGE ARRAY SURVEY OF MASSIVE PROTOSTELLAR OBJECTS: G35.03+0.35

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ABSTRACT

We have performed a 1.3 cm survey of 24 massive young stellar objects (MYSOs) using the Expanded Very Large Array. The sources in the sample exhibit a broad range of massive star formation signposts including infrared dark clouds (IRDCs), ultra-compact H ii (UC H ii) regions, and extended 4.5 μm emission in the form of extended green objects (EGOs). In this work, we present results for G35.03+0.35 which exhibits all of these phenomena. We simultaneously image the 1.3 cm NH_3 (1,1) through (6,6) inversion lines, four CH_3OH transitions, two H recombination lines, plus continuum at 0.05 pc resolution. We find three areas of thermal NH_3 emission, two within the EGO (designated as the NE and SW cores) and one toward an adjacent IRDC. The NE core contains a UC H ii region (CM1) and a candidate hyper-compact H ii region (CM2). A region of non-thermal, likely masing NH_3 (3,3) and (6,6) emission is coincident with an arc of 44 GHz CH_3OH masers. We also detect two new 25 GHz Class-I CH_3OH masers. A complementary Submillimeter Array 1.3 mm continuum image shows that the distribution of dust emission is similar to the lower-lying NH_3 lines, all peaking to the NW of CM2, indicating the likely presence of an additional MYSO in this protocluster. By modeling the NH_3 and 1.3 mm continuum data, we obtain gas temperatures of 20–220 K and masses of 20–130 M_☉. The diversity of continuum emission properties and gas temperatures suggests that objects in a range of evolutionary states exist concurrently in this protocluster.

Key words: ISM: individual objects (G35.03+0.35) – stars: formation – stars: massive – techniques: interferometric

1. INTRODUCTION

Massive star formation is a phenomenon of fundamental importance in astrophysics, yet it remains poorly understood. Massive protostars form in complex clusters and predominately at distances greater than a kiloparsec making them challenging to study (Zinnecker & Yorke 2007). Unfortunately, the tools used to study low-mass young stellar objects (primarily near-IR imaging) are largely inapplicable due to extreme dust obscuration even into the mid-IR. Radio and millimeter wavelengths penetrate the dust, and have revealed a wide variety of phenomena associated with massive young stellar objects (MYSOs): CH_3OH, H_2O, and OH masers, hyper-compact (HC) and ultra-compact (UC) H ii regions, recombination lines, infrared dark clouds (IRDCs), warm (>30 K) dust cores, massive outflows, extended 4.5 μm emission from shocks, and hot core line emission. However, these signposts have been compiled from a heterogeneous set of observations with varying angular resolution and sensitivity, making correlation analyses difficult.

In order to advance our understanding of MYSOs, we are using the Expanded Very Large Array (EVLA) to observe 24 MYSOs with ~10,000 AU resolution in the 1.3 cm continuum and a comprehensive set of diagnostic lines simultaneously. This resident shared risk observing project is among the first to utilize 16 spectral windows with high spectral resolution including: the NH_3 ladder from (1,1) to (6,6) (E_J = 23–540 K), four CH_3OH transitions that can show maser emission, two H recombination lines, and other potential hot core species, plus reasonable continuum sensitivity. The majority (22/24) of our sample originates from the Cyganowski et al. (2008) catalog of MYSO outflow candidates (extended green objects, EGOs, selected based on extended 4.5 μm emission). Many EGOs are located in IRDCs (for an overview of IRDCs see Rathborne et al. 2006), with a smaller subset associated with HC or UC H ii regions. To explore the range in the properties of MYSOs associated with extended 4.5 μm shock emission, the sample includes five EGOs with compact H ii regions, as well as two non-EGOs for comparison (an IRDC and a UC H ii region). In this Letter, we present the first results from the survey by describing the observations of one source in detail: G35.03+0.35 (hereafter G35.03). To show the location of dust emission with respect to the centimeter emission, we include complementary 1.3 mm Submillimeter Array (SMA) observations.

1.1. Background on G35.03+0.35

G35.03 is an EGO at a distance of ~3.4 kpc with a bipolar 4.5 μm morphology oriented NE–SW at a systemic velocity of ~53.1 km s⁻¹ based on H13CO⁺ (3–2) single dish data (Cyganowski et al. 2009). A saturated Spitzer MIPSGAL 24 μm source is located near the center of the two lobes and is coincident with five compact centimeter continuum sources called CM1...CM5 in order of decreasing flux (Cyganowski et al. 2011). CM1 has a flat centimeter spectral index (α ≈ −0.1, S_v ∝ ν°) consistent with optically thin free–free emission from a UC H ii region (also see Kurtz et al. 1994; Argon et al. 2000). In contrast, CM2 has a rising spectrum (α ≈ +0.7), suggesting it may be a HC H ii region or wind/jet source (Cyganowski et al. 2011). Coincident with CM2 are blueshifted Class-II 6.7 GHz CH_3OH masers (ΔV ~ 6–12 km s⁻¹; Cyganowski et al. 2009), blueshifted OH masers (ΔV ~ 3–14 km s⁻¹; Argon et al. 2000), and redshifted H_2O masers (ΔV ~ 13–17 km s⁻¹, Forster & Caswell 1999). Additionally, an arc-like structure of outflow-tracing Class-I 44 GHz CH_3OH masers is located toward the eastern side of the EGO (Cyganowski et al. 2009).
rest frequencies were obtained from http://splatalogue.net. The National Radio Astronomy Observatory is a facility of the National Science Foundation operated under agreement by the Associated Universities, Inc. 8 The Submillimeter Array (SMA) is a collaborative project between the Smithsonian Astrophysical Observatory and the Academia Sinica Institute of Astronomy & Astrophysics of Taiwan.

| Parameter | Value |
|-----------|-------|
| EVLA 1.3 cm (~24 GHz) AB1346 observations | |
| Observing date (duration) | 2010 Sep 7 (3 hr) |
| Configuration | D |
| Primary beam size | 2′ |
| Bandwidth | 16 × 8 MHz, single polarization |
| Baseband 0 subbands (MHz), lines | 23692.78, NH$_3$ (1,1) |
| | 23724.78, NH$_3$ (2,2) |
| | 23828.78, OH $^{2}$$Pi_{0,2}$ (5−$^5$) |
| | 23868.78, NH$_3$ (3,3) |
| | 24084.78, SO$_2$ (8$_2$,6−9$_1$,9) |
| | 24140.78, NH$_3$ (4,4) |
| | 24508.78, H$_6$3α |
| | 24532.78, NH$_3$ (5,5) |
| Baseband 1 subbands (MHz), lines | 24927.88, CH$_3$OH (3$_2$,−3$_1$,2) |
| | 24959.88, CH$_3$OH (5$_3$,3−5$_1$,4) |
| | 25033.88, NH$_3$D (4,1,4−4,0,4) |
| | 25055.88, NH$_3$ (6,6) |
| | 25295.88, CH$_3$OH (8$_2$,6−8$_1$,7) |
| | 25327.88, DC$_3$N (3−2) |
| | 25687.88, H$_6$3α |
| | 25979.88, CH$_3$OH (10$_2$,8−10$_1$,9) |
| Velocity resolution | 0.4 km s$^{-1}$ |
| Angular resolution | 3′′ × 3′′ (P.A. = −50°) |
| Spectral line rms noise | 3 mJy beam$^{-1}$ channel$^{-1}$ |
| Gain calibrator | J1815+0035 |
| Bandpass and flux calibrator | J1924−2914 (17.1 Jy assumed) |
| SMA 1.3 mm (~225 GHz) observations | |
| Observing date (duration) | 2008 Jun 24 (11 hr) |
| Configuration | Compact-north |
| Primary beam size | 52″ |
| Bandwidth | 2 × 2 GHz, single polarization |
| Velocity resolution | 1.1 km s$^{-1}$ |
| Angular resolution | 3′′ × 1′′ (P.A. = +70°) |
| Continuum rms noise | 3 mJy beam$^{-1}$ |
| Gain calibrators | J1733−130 and J1751+096 |
| Bandpass calibrator | J1724+035 |
| Flux calibrator | Uranus |

Notes.

a These are the rest-frame subband center frequencies; because the subbands were required to be on an 8 MHz grid, the lines are offset from the centers. Line rest frequencies were obtained from http://splatalogue.net.

b Briggs weight of 0.5.

c Due to its inadvertent proximity to a subband filter edge, the NH$_3$ (2,2) subband is a factor of two noisier than the others.

d 3C 286 observation failed, used bootstrapped flux density of J1924−2914 from previous track.

2. OBSERVATIONS

The NRAO EVLA observations are summarized in Table 1; see Perley et al. (2011) for additional details on the EVLA system. The EVLA data were calibrated and imaged in CASA. All images were restored with a synthesized beam of 3′′ × 3′′ (P.A. = −50°), corresponding to 12,600 × 10,000 AU at 3.4 kpc.

The SMA observations are also summarized in Table 1. The sidebands were centered at 220.1 and 230.1 GHz. The data were calibrated in MIRIAD, then exported to CASA for self-calibration and imaging. In this Letter we only consider the 1.3 mm continuum data estimated from line-free channels in the $uv$-plane. The SMA spectral line data will be described in a future publication.

3. RESULTS

As shown in Figure 1(a), we detect three major regions of NH$_3$ (1,1) emission: (1) the strongest emission is coincident with the central region of the bipolar 4.5 μm nebulousity, the five centimeter continuum sources described in Section 1.1, and 6.7 GHz CH$_3$OH masers; (2) a slightly weaker and more compact core coincident with the SW lobe of the bipolar 4.5 μm nebulousity; and (3) a weak but extended core coincident with the IRDC ∼30′′ SW of the EGO. Figures 1(b) and (c) show the intensity-weighted velocity field and velocity dispersion of the NH$_3$ (1,1) emission, respectively. The emission spans a velocity range of about 4 km s$^{-1}$, with a distinct NE–SW blue–red velocity gradient across the EGO. This velocity gradient is not clearly associated with an outflow, but instead seems to trace a shift in systemic velocity across the region. The mean systemic velocity toward the EGO and the “Dark” core to the SW is ∼54 km s$^{-1}$. In the vicinity of the “NE” core (and the centimeter sources), the velocity dispersion shows a marked increase from ∼0.6 km s$^{-1}$ to values as high as ∼1.9 km s$^{-1}$. There are also “fingers” of weak NH$_3$ emission evident around the periphery of the EGO—these fingers are not apparent in the integrated intensity map (Figure 1(a)) because as demonstrated in Figure 1(c) they have extremely narrow velocity dispersion (∼0.25 km s$^{-1}$).

Figure 2(a) shows a detailed comparison of the EVLA NH$_3$ (1,1) integrated intensity, SMA 1.3 mm continuum, and the Very Large Array (VLA) 3.6 cm continuum (Cyganowski et al. 2011; CM1 and CM2 are also detected in the line-free channels of the current EVLA data; albeit at lower angular resolution and sensitivity). Overall, there is strong agreement between the NH$_3$ and 1.3 mm continuum emission. The strongest 1.3 mm emission arises from the NE core, coincident with CM1 and CM2. Though it is difficult to quantify the free–free versus dust contributions at 1.3 mm due to the mismatch in the continuum resolution (and $uv$-coverage) between the SMA, VLA, and EVLA (not shown), it is clear that a significant fraction must be due to dust. The morphology of the NH$_3$ (1,1) and (2,2) emission (see Figure 2(b)), along with the 1.3 mm emission to the NW of CM2, suggests the presence of a third compact source in the NE core lacking in free–free emission. Millimeter continuum emission is also visible to the east–SE of the NE core that partially coincides with the arc of 44 GHz CH$_3$OH masers, and mimics the morphology of the NH$_3$ (1,1) integrated intensity. The SW NH$_3$ core also has a 1.3 mm counterpart. The “Dark” ammonia core was not detected by the SMA, probably due to the smaller primary beam of these data. Figure 2(c) gives a detailed comparison of the NH$_3$ (1,1), (3,3), and (6,6) integrated intensities. Significant (3,3) emission is detected toward both the NE and SW core regions, though the strongest emission is compact and located east of the EGO, toward the SE terminus of the 44 GHz maser arc. Interestingly,
this region shows only weak para-NH$_3$ emission suggesting a non-thermal origin for the (3,3) emission, though it appears to be connected to CM2 through a weaker ridge of warm thermal NH$_3$ emission. The (6,6) transition is also detected at the (3,3) peak, as well as toward the candidate HC H ii region CM2. We also detect strong, spatially unresolved emission in the CH$_3$OH 5$_2$–5$_1$ and 8$_2$–8$_1$ lines at two distinct positions (Figure 3). Using an upper limit to the fitted size of the emission ($1.5 \times 0.6\,\text{arcmin}$), their peak flux densities ($187 \pm 2\,\text{mJy beam}^{-1}$ and $39 \pm 2\,\text{mJy beam}^{-1}$) correspond to brightness temperatures ($T_b$) exceeding 400 and 85 K for the stronger and weaker source, respectively. These high $T_b$ compared to the energy levels above ground (57 and 105 K) strongly suggest that these transitions are masing (25 GHz CH$_3$OH masers have also been observed, for example, in IRAS16547–4247; Voronkov et al. 2006). Interestingly, the transition of peak maser intensity switches from $5_2$–$5_1$ for the stronger maser spot to $8_2$–$8_1$ for the weaker maser spot. The positions and peak velocities are (J2000) 18$^{h}$54$^m$01$^s$.043 ($\pm 0.002$ s), + 02$^\circ$01$'$16''/86 ($\pm 0.002$) at 52.8 km s$^{-1}$, and 18$^{h}$54$^m$00$^s$.562 ($\pm 0.002$ s), + 02$^\circ$01$'$17''.67 ($\pm 0.002$) at 55.2 km s$^{-1}$ for the strong and weak masers, respectively (see Figures 2(a)–(c)).

No emission greater than 5$\sigma$ was detected for the SO$_2$, DC$_2$N, HC$_2$N, and HC$_3$N transitions. The H63$\alpha$ and H64$\alpha$ recombination lines were detected toward the CM1 UC H ii region at a peak velocity of 55.9 km s$^{-1}$. Following the method of Garay et al. (1986), we use the line-to-continuum intensity ratio of 0.46, the fitted FWHM line width of 17.6 km s$^{-1}$, and the diameter of CM1 determined from the EVLA 1.3 cm continuum (1.3$''$) to derive an electron temperature of 7900 K and density of 1.3 $\times$ 10$^4$ cm$^{-3}$.

3.1. NH$_3$ Temperatures

Over the last few decades, considerable progress has been made in understanding the excitation of the NH$_3$ molecule under astrophysical conditions (see, e.g., Maret et al. 2009). For example in cold regions, analysis of the (1,1) and (2,2) transitions has evolved toward simultaneous least-squares fitting of the line profiles—freeing the analysis from previous failures wherever the intensity of (2,2) rivals (1,1) (e.g., Rosolowsky et al. 2008). However, this type of analysis typically assumes that the kinetic temperature is much less than the energy gap between levels (41.5 K) such that only the (1,1) and (2,2) rotational levels are populated. Due to these assumptions, this technique becomes less accurate above temperatures of about 30 K. Generic molecular modeling packages exist that can be used to model NH$_3$ emission from higher lying transitions using either radiative transfer with collisional excitation, or assuming local thermodynamic equilibrium (LTE). However, no package currently combines separateortho and para collision rates (with realistic collision partners) with the detailed hyperfine structure of NH$_3$ and a partition function that includes all relevant states that may be excited in warm gas (though we can expect this situation to improve in the near future).

For the current preliminary analysis we have pursued the following course: (1) in the colder regions of G35.03 we have simultaneously fit the full hyperfine structure of the (1,1) and (2,2) lines using a nonlinear, least-squares Gaussian fitting routine given a single common line-of-sight velocity, line width, excitation, and kinetic temperatures in IDL (Friesen et al. 2009); (2) in the warmer and coincidentally more kinematically complex regions, we have used the LTE method in the CASSIS$^9$ package to model all six observed NH$_3$ transitions, including multiple velocity components where necessary. To compare methods, we also fit the cooler regions with CASSIS. Figure 3(a) shows the results from technique (1), with gray areas indicating where this method’s assumptions are invalid. The fitted parameters for both techniques toward several representative positions are given in Table 2.

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$^9$ CASSIS has been developed by CESR-UPS/CNRS (http://cassis.cesr.fr).
As shown in Table 2, the temperatures in the kinematically simple Dark and SW core regions are in the 20–30 K range, with the latter being somewhat warmer on average. Both methods do a reasonable job here, with method (2) predicting about twice the total column density of (1), likely due to its more complete partition function. Toward the center of the NE core and along the 44 GHz maser arc, technique (1) breaks down for two reasons: (1) the gas is warm (\(\gtrsim 30\) K) throughout this region (or even non-thermal; Figure 3(b)) and (2) the lines become more kinematically complex with at least two distinct velocity components separated by about 1.7 km s\(^{-1}\), or in the case of CM2, what appears to be a significantly blueshifted hot (220 K) outflow component. Toward CM1, the redder velocity component shows temperatures as high as \(\sim 70\) K.

3.2. Dust Mass

The average column densities and masses of the NE and SW cores based on the methodology described in Brogan et al. (2009, in Equations (4) and (5)) using the 1.3 mm SMA data are shown in Table 2. The integrated 1.3 mm flux densities of the NE and SW cores are 831 and 170 mJy with estimated sizes of 11\(\prime\)0 and 6\(\prime\)8, respectively. For the NE core, we have subtracted 25 mJy to account for the 3.6 cm flux of CM1 and CM2 (see Figure 2) assuming they are entirely due to free–free emission and using the 1.3–3.6 cm spectral indices derived by Cyganowski et al. (2011). For the range of temperatures derived from the NH\(_3\) fits described in Section 3.1, the NE and SW cores have dust-based gas masses in the 50–132 \(M_\odot\) and 22–45 \(M_\odot\) range, respectively, and average column densities of \((3–7) \times 10^{22}\) cm\(^{-2}\). For comparison, Hill et al. (2005) report a SEST SIMBA 1.2 mm based mass for the whole G35.03 region of 390 \(M_\odot\), assuming a dust temperature of 20 K and a total size of 55\(\prime\) (includes the “Dark core” in addition to the NE and SW cores). The Bolocam Galactic Plane Survey (BGPS) catalog\(^{10}\) reports a 1.1 mm flux of 1380 and 3030 mJy for G35.03

\(^{10}\) BGPS: http://irsa.ipac.caltech.edu/data/BOLOCAM_GPS/
The millimeter continuum source NW of CM2 exhibits the 350 \text{M}_\odot emission toward the terminus of the 44 GHz CH$_3$OH maser within 40\,\arcsec. The Astrophysical Journal Letters

HC H\textsc{ii} similar regions (e.g., Hunter et al. 2006; Rodrón et al. 2008). A protocluster of massive stars like those identified in other regions (e.g., DR 21(OH), IRDC. Using complementary SMA 1.3 mm and VLA 3.6 cm continuum data, along with temperatures derived from the NH$_3$ (1,1) to (6,6) transitions, four CH$_3$OH transitions, two H recombination lines, and continuum. We find three major spot is located toward the SE edge of the CM1 UC H\textsc{ii} region. Class-I CH$_3$OH masers are thought to be excited by collisions in shocks, with the shock liberating methanol from dust grains and thus providing the necessary high column density. Sobolev et al. (2005) suggest that 25 GHz Class-I masers require densities of \sim10^5–10^7 \text{cm}^{-3} and temperatures of 75–100 K, hotter and denser than that required for 44 GHz Class-I masers. As demonstrated by Voronkov et al. (2006), detailed modeling of the ratio of brightness temperatures among the 25 GHz maser transitions can help to pinpoint the physical conditions. We hope to carry out such analysis for the ensemble of 25 GHz masers observed across our survey in the future.

5. SUMMARY

We present the first results from a 1.3 cm survey of MYSOs using the EVLA, focusing on the EGO source G35.03+0.35. The new EVLA correlator allows us to simultaneously observe the NH$_3$ (1,1) to (6,6) transitions, four CH$_3$OH transitions, two H recombination lines, and continuum. We find three major regions of dense NH$_3$ gas, two (the NE and SW cores) being coincident with the EGO and the third located in the adjacent IRDC. Using complementary SMA 1.3 mm and VLA 3.6 cm continuum data, along with temperatures derived from the NH$_3$ emission, we find warm gas temperatures in the range 20–220 K, core masses in the 20–130 \text{M}_\odot range, and average H$_2$ column densities of several \times10^{22} \text{cm}^{-2}. Together these data reveal a massive protocluster in an early stage of formation with members representing different phases of MYSO evolution concurrently. This work highlights the potential diagnostic

### Table 2

| Source        | Single Gaussian Two-level NH$_3$ Fits | Full Multitransition CASSIS NH$_3$ Fits | Estimates from 1.3 mm Continuum |
|---------------|--------------------------------------|----------------------------------------|---------------------------------|
|               | $V_{\text{LSR}}$ (km s$^{-1}$) | $\Delta V_{\text{WHM}}$ (km s$^{-1}$) | $T_{\text{e}}$ (K) | $N_{\text{NH}_3}$ ($\times10^{13}$ cm$^{-2}$) | $T_{\text{dust}}$ (K) | $M_{\text{gas}}$ (\text{M}_\odot) | $N_{\text{H}_2}$ ($\times10^{21}$ cm$^{-2}$) |
| NE core       | ... ... ... ... ... ... ... ... | ... ... ... ... ... ... ... ... | ... ... ... ... ... ... ... ... | ... ... ... ... ... ... ... ... | 70–30 | 50–132 | 3–7 |
| CM1-v1        | ... ... ... ... ... ... ... ... | 53.7 | 1.3 | 40 | 2.0 | ... ... ... ... ... ... ... ... | ... ... ... ... ... ... ... ... |
| CM1-v2        | ... ... ... ... ... ... ... ... | 55.4 | 1.3 | 70 | 3.2 | ... ... ... ... ... ... ... ... | ... ... ... ... ... ... ... ... |
| CM2-v1        | ... ... ... ... ... ... ... ... | 53.8 | 1.8 | 30 | 3.5 | ... ... ... ... ... ... ... ... | ... ... ... ... ... ... ... ... |
| CM2-v2        | ... ... ... ... ... ... ... ... | 50.0 | 3.0 | 35 | 2.0 | ... ... ... ... ... ... ... ... | ... ... ... ... ... ... ... ... |
| CM2-v3        | ... ... ... ... ... ... ... ... | 49.2 | 3.0 | 220 | 2.0 | ... ... ... ... ... ... ... ... | ... ... ... ... ... ... ... ... |
| NW CM2        | 53.3 | 2.8 | 41 | 2.1 | ... ... ... ... ... ... ... ... | ... ... ... ... ... ... ... ... |
| SW core       | 54.7 | 1.1 | 25 | 3.0 | ... ... ... ... ... ... ... ... | 35–20 | 22–45 | 3–6 |
| Dark core     | 53.9 | 1.0 | 20 | 1.2 | ... ... ... ... ... ... ... ... | ... ... ... ... ... ... ... ... |

Notes. a Positions for these fits are (J2000): CM1: 18h54m00.00+00.488, +02°01′19″; CM2: 18h54m00.650, +02°01′19″; NW CM2: 18h54m00.561, +02°01′17″; SW core: 18h54m00.164, +02°01′11″; Dark Core: 18h53m59.396, +02°01′01″.

within 40'' and 80'' apertures, respectively (Rosolowsky et al. 2010). Assuming $T_{\text{dust}} = 30$ K for $r < 20''$ and $T_{\text{dust}} = 20$ K for 20'' < $r < 40''$, we find a total mass for the region of 350 $M_\odot$ if we multiply by the BGPS “correction factor” of 1.5), in reasonable agreement with Hill et al. (2005) and our SMA results, accounting for both the smaller primary beam and spatial filtering of the interferometer.

4. DISCUSSION

4.1. Protocluster Nature of G35.03+0.35

Our high angular resolution observations reveal the presence of at least three MYSOs (possibly four if CM3 is included) within 20,000 AU of one another in the NE core (CM1, CM2, and NWCM2). This configuration suggests a trapezium-like protocluster of massive stars like those identified in other similar regions (e.g., Hunter et al. 2006; Rodón et al. 2008). Component CM1 is a modest UC H\textsc{ii} region associated with warm NH$_3$ and hosts two velocity components which may indicate further unresolved structure. CM2 appears to be an HC H\textsc{ii} region or wind/jet source exciting OH, H$_2$O, and Class-II CH$_3$OH masers, and a hot (220 K) blueshifted outflow. The millimeter continuum source NW of CM2 exhibits the peak dust emission, no centimeter continuum emission, but the broadest Gaussian (non-outflow) NH$_3$ profiles. Such diversity among the continuum properties and in the molecular gas temperatures toward these different objects is an increasingly familiar pattern seen in protoclusters (Zhang et al. 2007; Brogan et al. 2007). Similar to NGC6334I(N) (Brogan et al. 2009), the systemic velocities of these objects differ by up to 1.7 km s$^{-1}$, providing a measure of the cluster dynamics. However, detailed study of the kinematics requires higher angular resolution follow-up observations, in particular to spatially resolve the multiple velocity components toward the NE core objects.

4.2. New Masers in G35.03+0.35

As Figures 2(c) and 3(b) demonstrate, the (3,3) and (6,6) NH$_3$ emission toward the terminus of the 44 GHz CH$_3$OH maser arc shows significant departure from LTE. Unfortunately, our current angular resolution precludes the measurement of the high brightness temperatures required for absolute confirmation of maser emission. Walmsley & Ungerechts (1983) first predicted that the (3,3) transition could undergo weak population inversion for densities of $n \sim 10^4–10^5$ cm$^{-3}$ and temperatures of \sim50 K—physical conditions common in massive molecular outflows and similar to the conditions required to excite 44 GHz CH$_3$OH masers (Voronkov et al. 2005). We speculate that the non-thermal NH$_3$ emission traces a bow shock from an outflow originating from CM2. Indeed, (3,3) maser emission has been detected previously in several regions of massive star formation mostly associated with strong outflows (e.g., DR 21(OH), NGC 6334I, IRAS20126+4104, and G5.89–0.39; Mangum & Wootten 1994; Kraemer & Jackson 1995; Zhang et al. 1999; Hunter et al. 2008).

The stronger 25 GHz CH$_3$OH maser spot (Figure 3(c)) is coincident in position and velocity with one of the weaker 44 GHz Class-I masers from Cyganowski et al. (2009), and is within 1°3 of the strongest 44 GHz maser. The weaker 25 GHz maser spot is located toward the SE edge of the CM1 UC H\textsc{ii} region. Class-I CH$_3$OH masers are thought to be excited by collisions in shocks, with the shock liberating methanol from dust grains and thus providing the necessary high column density. Sobolev et al. (2005) suggest that 25 GHz Class-I masers require densities of \sim10^5–10^7 \text{cm}^{-3} and temperatures of 75–100 K, hotter and denser than that required for 44 GHz Class-I masers. As demonstrated by Voronkov et al. (2006), detailed modeling of the ratio of brightness temperatures among the 25 GHz maser transitions can help to pinpoint the physical conditions. We hope to carry out such analysis for the ensemble of 25 GHz masers observed across our survey in the future.

5. SUMMARY

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power that the full survey will provide toward understanding
the formation of massive stars and protoclusters.

Based on analysis using the CDMS, JPL, and Splatalogue
spectroscopic databases, NASA's Astrophysics Data System
Bibliographic Services, and the SIMBAD database.

REFERENCES

Argon, A. L., Reid, M. J., & Menten, K. M. 2000, ApJS, 129, 159
Brogan, C. L., Chandler, C. J., Hunter, T. R., Shirley, Y. L., & Sarma, A. P.
2007, ApJ, 660, L133
Brogan, C. L., Hunter, T. R., Cyganowski, C. J., et al. 2009, ApJ, 707, 1
Cyganowski, C. J., Brogan, C. L., Hunter, T. R., & Churchwell, E. 2009, ApJ,
702, 1615
Cyganowski, C. J., Brogan, C. L., Hunter, T. R., & Churchwell, E. 2011, ApJ,
submitted
Cyganowski, C. J., Whitney, B. A., Holden, E., et al. 2008, AJ, 136, 2391
Forster, J. R., & Caswell, J. L. 1999, A&AS, 137, 43
Friesen, R. K., Francesco, J., Shirley, Y. L., & Myers, P. C. 2009, ApJ, 697,
1457
Garay, G., Rodriguez, L. F., & van Gorkom, J. H. 1986, ApJ, 309, 553
Hill, T., Burton, M. G., Minier, V., et al. 2005, MNRAS, 363, 405
Hunter, T. R., Brogan, C. L., Indebetouw, R., & Cyganowski, C. J. 2008, ApJ,
680, 1271
Hunter, T. R., Brogan, C. L., Megeath, S. T., et al. 2006, ApJ, 649, 888
Kraemer, K. E., & Jackson, J. M. 1995, ApJ, 439, L9
Kurtz, S., Churchwell, E., & Wood, D. O. S. 1994, ApJS, 91, 659
Mangum, J. G., & Wootten, A. 1994, ApJ, 428, L33
Maret, S., Faure, A., Scifoni, E., & Wienenfeld, L. 2009, MNRAS, 399, 425
Perley, R. A., Chandler, C. J., Butler, B. J., & Wrobel, J. M. 2011, ApJ, 739, L1
Rathborne, J. M., Jackson, J. M., & Simon, R. 2006, ApJ, 641, 389
Rodríguez, I. A., Beuther, H., Megeath, S. T., & van der Tak, F. F. S. 2008, A&A,
490, 213
Rosolowsky, E., Dunham, M. K., Ginsburg, A., et al. 2010, ApJS, 188, 123
Rosolowsky, E. W., Pineda, J. E., Foster, J. B., et al. 2008, ApJS, 175, 509
Sobolev, A. M., Ostrovskii, A. B., Kirsanova, M. S., et al. 2005, in IAU Symp.
227, Massive Star Birth: A Crossroads of Astrophysics, ed. R. Cesaroni et al.
(Cambridge: Cambridge Univ. Press), 174
Voronkov, M. A.; Brooks, K. J., Sobolev, A. M., et al. 2006, MNRAS, 373,
411
Voronkov, M., Sobolev, A., Ellingsen, S., Ostrovskii, A., & Alakoz, A.
2005, Ap&SS, 295, 217
Walmsley, C. M., & Ungerechts, H. 1983, A&A, 122, 164
Zhang, Q., Hunter, T. R., Beuther, H., et al. 2007, ApJ, 658, 1152
Zhang, Q., Hunter, T. R., Sridharan, T. K., & Cesaroni, R. 1999, ApJ, 527, L117
Zinnecker, H., & Yorke, H. W. 2007, ARA&A, 45, 481