A comparative study of high-mass cluster forming clumps^{★,★★}

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ABSTRACT

Aims. We have searched for star formation activity (mainly infall and outflow signatures) in a sample of high-mass molecular clumps ($M > 100 M_{\odot}$) in different evolutionary stages and with a wide range of surface densities, with the aim of looking for evolutionary trends and testing observationally recent theoretical models which predict the need for a minimum surface density to form high-mass stars.

Methods. Our sample has been selected from single-dish 1.2 mm continuum surveys and is composed of 48 massive molecular clumps, of which 29 are IR-loud and 19 are IR-dark. Each of these has been mapped in the $\text{HCO}^+(1-0)$, $\text{HCN}(1-0)$ and $\text{C}^{18}\text{O}(2-1)$ transitions with the IRAM-30 m telescope on Pico Veleta (Spain). We derive basic parameters (mass, momentum, kinetic energy) for the clumps and their associated outflows and examine the $\text{HCO}^+(1-0)$ line profiles for evidence of infall or expansion.

Results. Molecular outflows have been detected in 75% of our targets from the presence of high-velocity wings in the $\text{HCO}^+(1-0)$ spectra. These are equally frequent and massive (between ~ 1 and $\sim 100 M_{\odot}$) in IR-dark and IR-loud clumps, implying similar levels of star formation activity in both kinds of objects. A surface density threshold at $\Sigma = 0.3 \text{ g cm}^{-2}$ has been found above which the outflow detection rate increases significantly and the outflows are on average more massive. The infall detection rate in our sample is low, but significantly higher in the IR-dark sub-sample. Our clump mass estimates using the mm dust emission and $\text{C}^{18}\text{O}(2-1)$ are sensitive to the temperature, but assuming a value of 15 K for the IR-dark sub-sample, we find evidence that C^{18}O is depleted by a factor ~ 4.5 . The $\text{HCO}^+(1-0)$ to $\text{HCN}(1-0)$ integrated intensity ratios measured reveal a greater dispersion about the mean value in the IR-dark sub-sample than in the IR-loud by a factor of about 5. We find that a considerable number of IR-dark sources are self-absorbed in $\text{HCN}(1-0)$ suggesting that radiative transport effects in the ground state transitions have an important influence on the integrated intensity ratio.

Conclusions. Our results indicate that, in terms of outflow frequency and energetics, both IR-dark and IR-loud molecular clumps present equivalent signatures of star formation activity, and that the formation of high-mass stars requires sufficiently high clump surface densities. The higher infall detection rate measured for the IR-dark subsample suggests that these objects could be associated with the onset of star formation.

Key words. stars: formation – ISM: clouds – ISM: jets and outflows – ISM: molecules

1. Introduction

High-mass stars have a deep impact on their environment, shaping the physical and chemical properties of the interstellar medium. Despite the key role they play in the evolution of galaxies, their formation mechanism is still poorly understood. O-B stars reach the zero-age main sequence still in the accretion phase, and the radiation pressure they exert is expected to overcome the gravitational infall of material, thus preventing the stars from accumulating masses greater than $\sim 8 M_{\odot}$ (Palla & Stahler 1993). Several models have been proposed to explain the formation of high-mass stars. These include accretion driven formation through massive disks (e.g. Krumholz et al. 2009; McKee & Tan 2003; Yorke & Sonnhalter 2002; Keto et al. 2002), competitive accretion in dense clusters (Bonnell et al. 2004), and merging of low-mass protostars (Bonnell & Bate 2002).

From an observational point of view, the rareness of O-B stars and therefore the higher distances, their fast evolution towards the Zero-Age Main Sequence (ZAMS), and the high

dust extinction involved complicate the study of high-mass star formation. Moreover, massive stars form in molecular clumps together with clusters of low-mass stars, causing considerable confusion in the observations. In spite of this, a number of deeply embedded massive disk/outflow systems (see Cesaroni et al. 2007) have been identified, lending support to the accretion models. However, the statistics is very poor and it is not clear whether this is the general mechanism to form high-mass stars. Furthermore, a detailed picture of the different evolutionary phases of massive star formation is still lacking.

In the last years, several (sub)millimetre continuum and line surveys have been conducted towards high-mass star forming regions (SFRs; e.g. Beuther et al. 2002a; Bronfman et al. 1996). The targets of these surveys have been mostly molecular clumps selected on the basis of their infrared (IR) spectral energy distributions and/or maser emission, and are known to harbour one or more massive young stellar objects (YSOs) which are already formed. These objects will be referred to as *IR-loud clumps* hereafter. Nevertheless, to understand the formation of massive stars, it is also necessary to study the earliest phases of this process. These have been suggested to take place within IR-dark clouds (IRDCs; Rathborne et al. 2006), which are detected in absorption against the bright, diffuse mid-IR Galactic background (Perault et al. 1996; Egan et al. 1998). A limited number of surveys

[★] Based on observations carried out with the IRAM 30-m telescope at Pico Veleta (Granada, Spain). IRAM is supported by INSU/CNRS (France), MPG (Germany), and IGN (Spain).

^{★★} Appendices A and B are only available in electronic form at <http://www.aanda.org>

Table 1. Details of the 1.2 mm surveys from which our source sample has been selected.

Author	Instrument-Telescope	# sources	Dec	HPBW (")	T_D ? ^a	M ? ^a
Beuther et al. (2002a)	MAMBO – IRAM-30 m	69	$>-20^\circ$	11	Y	Y ^b
Faúndez et al. (2004)	SIMBA – SEST-15 m	146	$<9^\circ$	24	Y	Y
Hill et al. (2005)	SIMBA – SEST-15 m	404	$<24^\circ$	24	20 K ^c	Y
Rathborne et al. (2006)	MAMBO – IRAM-30 m	190	$(-16^\circ, +18^\circ)$	11	15 K ^c	Y

Notes. ^(a) Y: quantities provided by the authors; N: quantities not provided by the authors; ^(b) masses recomputed according to the authors' Erratum (Beuther et al. 2005) and assuming a dust opacity of $1 \text{ cm}^2 \text{ g}^{-1}$ (Ossenkopf & Henning 1994); ^(c) dust temperature adopted by the authors to compute clump masses.

towards these regions in the (sub)millimetre continuum (Carey et al. 2000; Rathborne et al. 2006) and in several line transitions (Carey et al. 1998; Simon et al. 2006) have measured high densities ($n > 10^5 \text{ cm}^{-3}$) and very low temperatures ($T < 20 \text{ K}$). They have sizes of several parsecs and typically contain a number of smaller condensations ($\sim 0.5 \text{ pc}$) detected as dust emission peaks at mm wavelengths within the more diffuse and extended IRDC (Rathborne et al. 2006). Following the nomenclature proposed by Bergin & Tafalla (2007), we will refer to these condensations as *IR-dark clumps*. IRDCs are considered potential cluster and high-mass SFRs (see Menten et al. 2005, for a review), and are therefore excellent candidates for studying the initial conditions of massive star formation.

In this context, we have conducted a survey with the IRAM-30 m telescope towards a sample of parsec-sized high-mass molecular clumps which include IR-dark as well as IR-loud clumps. The aim is to search for signatures of star formation activity, mainly in the form of outflow and infall, in order to obtain a comparative picture of the evolutionary stages of both kinds of objects. An additional motivation for this survey has been the claim by Krumholz & McKee (2008) that only clumps with surface densities greater than $\sim 0.7 \text{ g cm}^{-2}$ can form stars more massive than $10 M_\odot$. Our sample contains sources with surface densities ranging from ~ 0.1 to $\sim 10 \text{ g cm}^{-2}$, and this allows us to check Krumholz & McKee's prediction observationally.

In Sect. 2 we describe our sample and molecular line observations; maps and spectra are presented in Sect. 3; clump masses, outflow and infall parameters are derived in Sect. 4; in Sect. 5 we discuss our results; and finally, Sect. 6 summarises the main conclusions of this survey.

2. The sample and observations

2.1. The sample

The observed sample has been selected from several single-dish surveys at 1.2 mm and is composed of 49 high-mass molecular clumps, of which 18 are IR-dark clumps selected from the survey of Rathborne et al. (2006), and 31 are IR-loud clumps, selected from the surveys of Beuther et al. (2002a), Faúndez et al. (2004) and Hill et al. (2005). Table 1 summarises the main characteristics of these surveys.

For each source, we have computed the surface density, Σ , from the clump mass, M , distance, d , and deconvolved angular diameter, θ :

$$\Sigma = \frac{4M}{\pi(\theta d)^2} \quad (1)$$

in accordance with the definition of Σ given by Krumholz & McKee (2008).

The selection criteria applied by us are the following:

- declination higher than -15° , to be observable with the IRAM-30 m telescope;
- mass larger than $100 M_\odot$, to exclude low-mass star forming regions;
- distance smaller than 4 kpc, to obtain clump angular diameters greater than the IRAM-30 m beam at 3 mm, assuming typical diameters of $\sim 1 \text{ pc}$ ($\sim 25''$).

The sample sources, their observed centre coordinates, distance, observed systemic velocity, mass and surface density are listed in Table 2. The sources labelled *extra* do not fulfill all the selection criteria but were added to our original sample during the observations at Pico Veleta due to the allocation of extra observing time in an LST range not suitable for the majority of our targets. The source 18151–1208_2, selected from the Beuther et al. sample and initially believed to belong to the IR-loud subsample, was classified as IR-dark by Sridharan et al. (2005) and has therefore moved into this category. We stress here that the term *IR-dark* adopted by the authors we refer to is based on MSX observations, and that some sources in the IR-dark subsample may be detected at mid-IR wavelengths with more sensitive telescopes such as Spitzer. We are aware that at least some of our IR-dark sources are mid-IR emitters: G34.43+0.2M1 has a bolometric luminosity of $2 \times 10^4 L_\odot$ (Rathborne et al. 2008), and so does G24.60+0.1M2 (Rathborne et al. 2007). However we keep our classification as it is, noting that this category of molecular clumps will perhaps need further sub-classifications as our knowledge on them improves.

Figure 1 presents a plot of surface density, Σ , against clump mass, M , for all the sources in our sample. IR-loud and IR-dark masses are plotted in different panels. For both types of objects we find points above and below the Σ threshold given by Krumholz & McKee (2008), although the majority lie below this threshold. It is worth noting, however, that our Σ values represent an average across the whole clump, which may in reality contain smaller, denser cores.

Ignoring the *extra* sources, three sources belonging to the sample of Beuther et al. (2002a) have masses below $100 M_\odot$. The reason is that the mass of the clumps reported in such paper were derived using an dust opacity of $\sim 0.2 \text{ cm}^2 \text{ g}^{-1}$ (see the authors' erratum: Beuther et al. 2005). Therefore, we have re-calculated the masses from the continuum emission at 1.2 mm using a dust opacity of $1 \text{ cm}^2 \text{ g}^{-1}$ (Ossenkopf & Henning 1994), which is that adopted in Rathborne et al. (2006), Faúndez et al. (2004) and Hill et al. (2005), in order to homogenise the whole sample. This has produced, for the sources selected from Beuther et al. (2002a), masses smaller than the original ones by a factor ~ 5 .

Table 2. Observed sample.

Source	α (J2000)	δ (J2000)	d (kpc)	V_{LSR} (km s ⁻¹)	M ($M_{\odot}$)	Σ (g cm ⁻²)	Survey	Sub-sample
05358+3543	05:39:12.20	+35:45:52.0	1.8	-18	127	0.84	Beuther	IR-loud
G213.61-12.6	06:07:47.90	-06:22:57.0	2.1	+12	1800	0.78	Hill	IR-loud
G189.78+0.34	06:08:34.50	+20:38:51.0	1.8	+6	150	0.40	Hill	IR-loud
G192.58-0.04	06:12:52.90	+18:00:35.0	2.6	+8	500	0.47	Hill	IR-loud
G192.60-0.05	06:12:54.00	+17:59:23.0	2.6	+8	460	0.63	Hill	IR-loud
G192.59-0.04	06:12:54.00	+17:59:47.0	2.6	+8	310	1.60	Hill	IR-loud
18151-1208_2	18:17:50.50	-12:07:55.0	3.0	+33	475	0.90	Beuther	IR-dark
18151-1208_3	18:17:52.30	-12:06:56.0	3.0	+33	53	0.08	Beuther	IR-loud
18151-1208_1	18:17:58.00	-12:07:27.0	3.0	+33	211	0.63	Beuther	IR-loud
G18.15-0.28	18:25:01.30	-13:15:35.0	2.6	+55	280	0.13	Hill	IR-loud
G18.18-0.30	18:25:07.30	-13:14:23.0	2.6	+55	110	0.22	Hill	IR-loud
18223-1243	18:25:10.87	-12:42:26.8	3.7	+45	980	0.13	Faúndez	IR-loud
18228-1312	18:25:42.35	-13:10:18.1	3.0	+33	740	0.16	Faúndez	IR-loud
G19.27+0.1M2	18:25:52.60	-12:04:48.0	2.4	+26	114	0.18	Rathborne	IR-dark
G19.27+0.1M1	18:25:58.50	-12:03:59.0	2.4	+26	113	0.33	Rathborne	IR-dark
18236-1205	18:26:25.41	-12:03:51.4	2.5	+26	780	0.22	Faúndez	IR-loud
18264-1152	18:29:14.40	-11:50:21.3	3.5	+44	1100	0.36	Faúndez	IR-loud
G23.60+0.0M1	18:34:11.60	-08:19:06.0	3.9	+54	365	1.01	Rathborne	IR-dark
18316-0602	18:34:20.46	-05:59:30.4	3.1	+41	1000	0.29	Faúndez	IR-loud
G23.60+0.0M2	18:34:21.10	-08:18:07.0	3.9	+54	233	0.74	Rathborne	IR-dark
18317-0513	18:34:25.94	-05:10:48.6	3.2	+42	770	0.17	Faúndez	IR-loud
G24.08+0.0M2	18:34:51.10	-07:45:32.0	3.8	+54	201	0.11	Rathborne	IR-dark
G24.33+0.1M1	18:35:07.90	-07:35:04.0	3.8	+53	1759	14.44	Rathborne	IR-dark
G24.33+0.1M4	18:35:19.40	-07:37:17.0	3.8	+53	446	0.16	Rathborne	IR-dark
G24.33+0.1M2	18:35:34.50	-07:37:28.0	3.8	+53	123	0.20	Rathborne	IR-dark
G24.60+0.1M2	18:35:35.70	-07:18:09.0	3.7	+52	483	0.73	Rathborne	IR-dark
G24.60+0.1M1	18:35:40.20	-07:18:37.0	3.7	+52	192	0.82	Rathborne	IR-dark
G25.04-0.2M1	18:38:10.20	-07:02:34.0	3.4	+47	276	0.42	Rathborne	IR-dark
G25.04-0.2M4	18:38:13.70	-07:03:12.0	3.4	+47	307	0.15	Rathborne	IR-dark
G25.04-0.2M2	18:38:17.70	-07:02:51.0	3.4	+47	104	0.16	Rathborne	IR-dark
G28.28-0.35	18:44:14.20	-04:17:59.0	2.8	+48	650	0.23	Hill	IR-loud
18507+0121	18:53:18.00	+01:25:00.6	3.7	+57	2000	0.20	Faúndez	IR-loud
G34.43+0.2M1	18:53:18.00	+01:25:24.0	3.7	+57	1187	8.75	Rathborne	IR-dark
G34.43+0.2M3	18:53:20.40	+01:28:23.0	3.7	+57	301	0.55	Rathborne	IR-dark
G34.24+0.13	18:53:21.70	+01:13:37.0	3.5	+55	140	0.14	Hill	IR-loud
18517+0437	18:54:14.30	+04:41:40.0	2.9	+44	504	0.80	Beuther	IR-loud
G34.77-0.6M2	18:56:50.30	+01:23:16.0	2.9	+44	188	0.11	Rathborne	IR-dark
G35.39-0.3M4	18:57:06.70	+02:08:23.0	2.9	+45	108	0.14	Rathborne	IR-dark
G38.95-0.5M1	19:04:07.40	+05:08:48.0	2.7	+42	117	0.25	Rathborne	IR-dark
19035+0641	19:06:01.60	+06:46:43.0	2.2	+32	185	0.43	Beuther	IR-loud
19095+0930	19:11:54.02	+09:35:52.0	3.3	+44	500	0.20	Faúndez	IR-loud
20216+4107	20:23:23.60	+41:17:38.0	1.7	-2	31	0.23	Beuther	IR-loud, extra
20332+4124	20:34:59.90	+41:34:49.0	3.9	-2	286	0.27	Beuther	IR-loud
22134+5834	22:15:09.30	+58:49:06.0	2.6	-18	83	0.09	Beuther	IR-loud
22570+5912_2	22:59:02.80	+59:27:36.0	5.1	-47	131	0.10	Beuther	IR-loud, extra
22570+5912_1	22:59:05.90	+59:28:19.0	5.1	-47	305	0.14	Beuther	IR-loud, extra
23033+5951	23:05:25.50	+60:08:06.0	3.5	-53	250	0.64	Beuther	IR-loud
23139+5939	23:16:08.70	+59:55:18.0	4.8	-45	404	0.62	Beuther	IR-loud, extra
23151+5912	23:17:21.00	+59:28:49.0	5.7	-54	282	0.41	Beuther	IR-loud, extra

2.2. Observations and data reduction

The IRAM-30 m telescope near Pico Veleta (Granada, Spain) was used on August 4–8, 2008 to map our sample in the HCO⁺(1–0), HCN(1–0), and C¹⁸O(2–1) lines. The rest frequency, and the typical system temperature, T_{sys} , and 1σ rms of the spectra are listed in Table 3.

For each source, single pointing observations in wobbler mode were made before proceeding with the On-The-Fly (OTF) mapping, in order to check the presence of the HCO⁺(1–0) and/or HCN(1–0) emission lines. Such spectra were obtained with a wobbler throw of 120'' and an integration time of 4 min. The OTF maps have sizes of $1' \times 1'$ and were obtained with

the single beam A100, B100, A230 and B230 receivers. All the lines were covered at both low and high spectral resolution using a 1 MHz filterbank with 1024 channels and an autocorrelator (VESPA). The former was split into 4 sections of 256 channels, used separately with each of the four receivers. The angular resolution of the images is 29'' for the HCO⁺(1–0) and HCN(1–0) lines, and 12'' for C¹⁸O(2–1). The OTF dump time was 2 s, and the sampling interval 4''. Most of the maps were scanned twice, once along the RA and once along the Dec, to avoid scanning effects on the resulting images.

The data were reduced using the programs CLASS and GREG of the GILDAS software package developed by the IRAM and the Observatoire de Grenoble. The spectra have been

Fig. 1. Surface density, Σ , against clump mass, M , of the observed sample. Blue filled circles represent the *extra* sources selected from the sample of Beuther et al. (2002a). The dot-dashed vertical line marks the mass lower limit adopted when selecting the original sample (note that some of the points lie to the left of this line; see text for details). The dot-dashed horizontal line marks the Σ threshold given by Krumholz & McKee (2008).

Table 3. Observed lines.

Line	Frequency (GHz)	T_{sys} (K)	1σ rms ^a (K)
HCO ⁺ (1–0)	89.188516	144	0.48
HCN(1–0)	88.632176	166	0.55
C ¹⁸ O(2–1)	219.560328	749	3.5

Notes. ^(a) Average 1σ rms of a single spectrum after smoothing is to a resolution of 0.5 km s^{-1} .

smoothed to a resolution of 0.5 km s^{-1} to improve the signal to noise ratio.

2.2.1. Emission at the OFF position

Six sources suffer from emission at the OFF position in the OTF spectra. As a result, these spectra present an artificial “dip” or absorption feature which can affect the numbers obtained in the calculations. When possible, this effect has been corrected or at least minimised by fitting a negative Gaussian to the spectra at positions in the map where the real emission was below 3σ , and subtracting such a Gaussian from each spectrum in the OTF map. This method has not produced a good result in any case for the HCN(1–0) line, where 3 Gaussians are needed, and thus the correction has not been applied to this line. Table 4 lists the sources displaying emission at the OFF position, the line wing affected (*B* for blue, *R* for red), the number of scans affected (1 or 2), and the lines for which it was possible to apply a correction. Note that for G24.33+0.1M2 and G35.39–0.3M4, only one of the two OTF scans are affected by emission at the OFF position because the problem was spotted in time during the observations, and the coordinates of the OFF position were changed before the beginning of the second OTF scan.

Figure 2 illustrates the problem and the solution. It shows the average HCO⁺(1–0) spectrum of 05358+3543 before applying

Table 4. Sources affected by emission at OFF position.

Source	Wing	Scans	Corrected lines
05358+3543	B	2/2	HCO ⁺ , C ¹⁸ O
18223–1243	B (far)	2/2	none
G24.33+0.1M1	B	2/2	none
G24.33+0.1M4	B	1/1	HCO ⁺
G24.33+0.1M2	B	1/2	none; use good scan
G35.39–0.3M4	R	1/2	none; use good scan

Fig. 2. Example of emission at OFF for the HCO⁺(1–0) spectrum in 05358+3543. *Black*: spectrum without correction; the line displays an artificial absorption at -20 km s^{-1} . *Green*: the same spectrum after having applied the Gaussian correction (see text).

any correction (black). The line is absorbed at $\sim -20 \text{ km s}^{-1}$ due to the presence of emission at the OFF position. In green the corrected average spectrum is shown, and the absorption feature has disappeared.

2.2.2. Wrong systemic velocity

There are five IR-dark sources for which the systemic velocity differs considerably ($\sim 50 \text{ km s}^{-1}$) from that reported in Rathborne et al. (2006, based on ¹³CO(1–0) data). This can be seen by comparing the value of V_{LSR} in Table 2 (centre velocity used for the observations) to that given in Table A.2 (velocity obtained from a Gaussian fit to the line, see below). Unfortunately, for two of these sources, namely G24.33+0.1M4 and G24.60+0.1M2, the C¹⁸O(2–1) line falls outside the velocity limits of the VESPA unit used in the observations. Therefore, in these two cases, the 1 MHz resolution C¹⁸O(2–1) spectra have been used to obtain maps and derive the parameters presented in this paper.

3. Maps and spectra

3.1. Clump maps and spectra

The three lines were detected in wobbler mode with signal to noise ratios greater than 5 towards all of our targets. OTF line integrated maps are presented in Fig. B.1, where the (0, 0) position corresponds to the coordinates listed in Table 2 (i.e. the 1.2 mm dust emission peak). The 1σ rms value, first contour level, and contour step of each map are listed in Table A.1. Note

that in some cases, especially in IR-dark sources where the emission is weaker, the $\text{C}^{18}\text{O}(2-1)$ clump is poorly defined and the map is noisy. This is to be expected, since the observations were conducted during summer and their quality is very susceptible to the atmospheric conditions at this wavelength (1.2 mm). There are two sources, namely G25.04–0.2M4 and 22570+5912_2, for which the $\text{C}^{18}\text{O}(2-1)$ maps are not presented because, due to their high noise, they display no clear emission of the clump. Therefore, these will not be considered in the calculations derived from the $\text{C}^{18}\text{O}(2-1)$ emission, although their respective map 1σ rms values are shown in Table A.1 The $\text{HCO}^+(1-0)$ and $\text{HCN}(1-0)$ integrated maps have lower angular resolution, but are less noisy and the distribution of the emission is fairly clear for the whole sample.

The dashed contour in each map of Fig. B.1 marks the half power level of the integrated emission. The black solid contour denotes an arbitrarily defined *clump region* which has been used to obtain average spectra and, in the case of $\text{C}^{18}\text{O}(2-1)$, to derive clump masses (see below): in many cases this corresponds to the half power contour (dashed), but it may vary between the 40% and the 80% level depending on the intensity and morphology of the source. In some cases where the $\text{C}^{18}\text{O}(2-1)$ emission is weak and patchy, the corresponding $\text{HCO}^+(1-0)$ or $\text{HCN}(1-0)$ *clump region* contour has been assigned to them, as indicated in the figure caption.

In general, for the IR-loud sub-sample, the sizes and shapes of the IR-loud $\text{HCO}^+(1-0)$ and $\text{HCN}(1-0)$ clumps are very similar, and the peak positions of the $\text{HCO}^+(1-0)$, $\text{HCN}(1-0)$ and $\text{C}^{18}\text{O}(2-1)$ maps are the same within $\sim 10''$, with few exceptions such as G28.28–0.35 and 20332+4124. The same cannot be said for the IR-dark sub-sample, where it is more common to find that the clump sizes, shapes, and/or positions are different in the $\text{HCO}^+(1-0)$ and $\text{HCN}(1-0)$ maps (e.g. G19.27M1 and M2), and the $\text{C}^{18}\text{O}(2-1)$ emission may trace a different region with respect to $\text{HCO}^+(1-0)$ and $\text{HCN}(1-0)$ (e.g. G24.08M2, G24.60M1). This will be discussed in more detail in Sect. 5.

We have found some sources for which the peak of the emission is offset with respect to the centre of the map (and thus the 1.2 mm dust emission peak position) by more than $\sim 20''$. In particular, three cases, each of which shows two clearly separated components in the integrated maps (Fig. B.1), need to be mentioned here:

1. The maps of G192.59–0.04 contain two components: the northern one coincides in coordinates with G192.58–0.04, and the southern one with G192.60–0.05. Therefore this source does not have $\text{HCO}^+(1-0)$, $\text{HCN}(1-0)$ or $\text{C}^{18}\text{O}(2-1)$ counterparts, and will not be considered hereafter.
2. 18507+0121 corresponds to the southern component; the northern one is actually the IR-dark clump G34.43+0.2M1.
3. 22570+5912_2 corresponds to the south-western component; the north-eastern clump corresponds to 22570+5912_1.

In the last two and in other less extreme cases the whole clump does not fit into the $1' \times 1'$ map, and this loss of emission leads to lower limit mass estimates and other inaccuracies in the calculations. We will stress this point where appropriate throughout this paper.

Figure B.2 presents the $\text{HCO}^+(1-0)$, $\text{HCN}(1-0)$ and $\text{C}^{18}\text{O}(2-1)$ spectra for all the clumps. Each of these has been obtained by averaging the line emission over the clump region (black contour in Fig. B.1). The $\text{C}^{18}\text{O}(2-1)$ spectra of the two sources mentioned above for which no C^{18}O map is shown in Fig. B.1 are also presented in Fig. B.2 because, although the

Table 5. New distances computed for eight IR-dark clumps.

Source	d_{old} (kpc)	V_{LSR} (km s $^{-1}$)	d_{near} (kpc)	d_{far} (kpc)
G23.60+0.0M1	3.9	+106.0	6.2	9.3
G24.33+0.1M1	3.8	+112.9	6.7	8.8
G24.33+0.1M4	3.8	+114.0	6.7	8.8
G24.33+0.1M2	3.8	+117.7	7.0	8.5
G24.60+0.1M2	3.7	+114.6	6.8	8.6
G25.04–0.2M1	3.4	+63.6	4.3	11.1
G25.04–0.2M4	3.4	+62.9	4.3	11.1
G25.04–0.2M2	3.4	+63.3	4.3	11.1

maps are useless to define the shape and emission distribution of the clump, the $\text{C}^{18}\text{O}(2-1)$ integrated emission averaged over the whole map results in a visible line from which the systemic velocity of the clump can be measured. We note that the $\text{HCN}(1-0)$ line has three hyperfine (HF) components, with an expected proportion between the central, red and blue component intensities of 5:3:1, respectively (Townes & Schawlow 1955), although this is not necessarily what one sees in real spectra, due to optical depth and/or non-LTE effects (Kwan & Scoville 1975).

Many of the $\text{HCO}^+(1-0)$ and $\text{HCN}(1-0)$ spectra display self-absorbed profiles and thus the optically thinner $\text{C}^{18}\text{O}(2-1)$ line has been used to define the systemic velocity of the clumps. Table A.2 presents the results from the Gaussian fit to the $\text{C}^{18}\text{O}(2-1)$ spectrum at the peak coordinates of each integrated map. Analogous Gaussian fits have been performed to the $\text{HCO}^+(1-0)$ spectra, masking the self-absorption and high-velocity wings when present. The values are listed in Table A.3. Note that the peak coordinates in the $\text{C}^{18}\text{O}(2-1)$ and the $\text{HCO}^+(1-0)$ integrated maps of a given source may not coincide with each other exactly. In these cases the line parameters in Tables A.2 and A.3 correspond to slightly different positions in the maps. For those sources where the $\text{C}^{18}\text{O}(2-1)$ emission is too weak or without $\text{C}^{18}\text{O}(2-1)$ map in Fig. B.1, the Gaussian fit has been made at the $\text{HCO}^+(1-0)$ peak coordinates for both the $\text{C}^{18}\text{O}(2-1)$ and the $\text{HCO}^+(1-0)$ lines, as specified in the table. In general, the peak velocity agrees within 1 km s $^{-1}$ between the $\text{HCO}^+(1-0)$ and the $\text{C}^{18}\text{O}(2-1)$ lines.

As mentioned in Sect. 2.2.2, five IR-dark sources have velocities which differ considerably (by ~ 50 km s $^{-1}$) from the ones reported by Rathborne et al. (2006) and used during the observations. For these, and for other three IR-dark clumps for which the discrepancy is ~ 15 km s $^{-1}$, a new kinematic distance has been recalculated using the Galaxy rotation curve of Brand (1986), which assumes a solar Galactocentric distance of 8.5 kpc. The resulting near and far distances (d_{near} and d_{far} , respectively) are listed in Table 5, together with the old distance, d_{old} . Note that the new distances are all greater than 4 kpc and therefore fall outside our distance selection criterium. For the purposes of this paper, we will adopt d_{near} , because IR-dark clumps are absorption features against the mid-IR Galactic background emission and therefore it is likely that they are located at the near distance. This change in distance implies different masses from the ones presented in Table 2, and will be taken into account in the calculations and figures in the remainder of this paper. By contrast, the surface density, Σ , remains unchanged, so in practice the affected points in Fig. 1 shift horizontally towards the right.

3.2. Outflow maps

The presence of molecular outflows has been assessed by searching for high-velocity wings in the $\text{HCO}^+(1-0)$ spectrum that

results from averaging all the spectra within the clump region (Fig. B.2). It is worth noting that the use of HCO^+ implies we are tracing the outflow in the near vicinity (the envelope) of the source driving it. With other molecules such as the more commonly used CO, one is more sensitive to the outer, lower density, high-velocity outflowing material (see Sect. 5.2.3).

Without distinguishing here between IR-dark and IR-loud sources, or between high and low clump surface density, we have identified a total of 19 sources with clear high-velocity $\text{HCO}^+(1-0)$ wings (extending up to $\sim 10 \text{ km s}^{-1}$ or more with respect to the line peak velocity) indicative of outflows. Out of the remaining 29 sources, 17 are also considered to be driving molecular outflows because, although the $\text{HCO}^+(1-0)$ wings are not as extended, the blue- and red-shifted lobes are spatially separated. This is compatible with a bipolar outflow oriented almost perpendicular to the line-of-sight (l.o.s.).

Adding all up, an outflow detection rate of 75% is obtained for our sample. Outflow maps are presented in Fig. B.3. In these maps, the blue and red wing emission of the $\text{HCO}^+(1-0)$ line (solid and dashed contours, respectively) are superimposed on either the $\text{C}^{18}\text{O}(2-1)$ integrated emission or the $\text{HCO}^+(1-0)$ integrated emission when the former is too noisy (grey scale). In a few cases, despite the presence of extended $\text{HCO}^+(1-0)$ wings, there is no clear outflow bipolarity in the maps (e.g. 23139+5939). This could be explained by an outflow directed close to the l.o.s., or by confusion due to the superposition of many outflows.

4. Properties derived from the $\text{C}^{18}\text{O}(2-1)$ and $\text{HCO}^+(1-0)$ lines

4.1. Clump mass estimates

From the emission integrated under the $\text{C}^{18}\text{O}(2-1)$ line we have estimated the molecular mass contained within the clump region of each $\text{C}^{18}\text{O}(2-1)$ map presented in Fig. B.1 (M_{clump} , Table A.4, Col. 5). A C^{18}O abundance dependent on the Galactocentric distance, R_{gal} , has been assumed (Wilson & Rood 1994):

$$\frac{[\text{C}^{16}\text{O}]}{[\text{C}^{18}\text{O}]} = 58.8 R_{\text{gal}} + 37.1. \quad (2)$$

We have adopted $[\text{CO}]/[\text{H}_2] = 10^{-4}$, and an excitation temperature, T_{ex} , equal to the dust temperature, T_{dust} , given in the four papers from which our sample was originally selected (Table A.4, Col. 4). Additionally, Col. 6 of Table A.4 lists a range of masses derived for T_{ex} between 15 and 60 K. We note that the resulting mass rises by about a factor two from 15 to 60 K, which shows that this temperature range translates into an uncertainty of a factor ~ 2 on the mass. An additional 20% uncertainty on the mass estimates is due to the calibration error on the $\text{C}^{18}\text{O}(2-1)$ line. Since we have no means to determine the optical depth of the $\text{C}^{18}\text{O}(2-1)$ line, the calculations assume optically thin conditions and therefore M_{clump} should be considered a lower limit.

An estimate of the virial mass, M_{vir} , of each of these clumps, has been obtained from the $\text{C}^{18}\text{O}(2-1)$ line *FWHM* (Table A.2), and from the angular diameter of the C^{18}O clump, D (Table A.4), using Eq. (3) of MacLaren et al. (1988), assuming uniform density across the clump. Given the variety of morphologies displayed by our sample sources, the major source of uncertainty in the derivation of this quantity is the clump size. We estimate an average uncertainty of 50% on the clump sizes, and this same error applies to the virial mass determination. The resulting values are also listed in Table A.4. For comparison, this table

presents also the mass of the clumps derived from the dust emission at 1.2 mm. For the eight sources listed in Table 5, this has been modified to account for the new distance.

The issue of clump masses will be covered in more detail in Sect. 5.1.

4.2. Derivation of outflow parameters

A comparison between the optically thick $\text{HCO}^+(1-0)$ line and the optically thinner $\text{C}^{18}\text{O}(2-1)$ is helpful, not only to define the clump systemic velocity and to discriminate between self-absorption and multiple components in the former, but also to define the HCO^+ line wings. For each source with an outflow detection, the low-velocity limits have generally been defined where the $\text{C}^{18}\text{O}(2-1)$ line intensity falls below 2σ . In a few cases where also the $\text{C}^{18}\text{O}(2-1)$ line displays non-Gaussian extended wings, the beginning of these on the spectra of Fig. B.2 has been chosen as low-velocity limits. The high-velocity limits have been chosen where the $\text{HCO}^+(1-0)$ line intensity falls below 2σ . The outflow velocity ranges thus defined (ΔV_{blue} and ΔV_{red} , respectively) are presented in Table A.5 and have been used both to obtain the outflow maps in Fig. B.3 and to compute the outflow parameters.

Table A.5 also lists, for the blue and red emission, the outflow velocities, $V_{\text{out,b}}$ and $V_{\text{out,r}}$, and the deconvolved lobe sizes, r_b and r_r . By outflow velocity we mean the difference between the high-velocity limit of the outflow velocity range ΔV , and the systemic velocity, V_{LSR} , of the $\text{C}^{18}\text{O}(2-1)$ clump (Table A.2). Typical values of this quantity are $\sim 10 \text{ km s}^{-1}$, although higher values have also been found. The most extreme case is 18316–0602, with blue and red wings that extend beyond 20 km s^{-1} .

Following the procedure described in López-Sepulcre et al. (2009; Eqs. (4)–(6)), the outflow mass, momentum and energy of the outflow (M_{out} , p_{out} and E_{out} , respectively) have been derived from the emission integrated under ΔV_{blue} and ΔV_{red} , and spatially integrated over the area defined by the 5σ contour level of the corresponding outflow lobe. Note that in many cases the maps are not large enough to cover all such area. As a result, part of the outflow emission is lost, but in no case is this loss significant because the blue and red lobe half power contours are always within the limits of the map. Therefore, the effect on the numbers derived is negligible. In the calculations, we have adopted a HCO^+ abundance relative to H_2 of 5×10^{-9} (Irvine et al. 1987) and $T_{\text{ex}} = 10 \text{ K}$ (the numbers increase by a factor 1.5 and 2 for $T_{\text{ex}} = 20$ and 30 K , respectively), and the emission in the line wings has been assumed optically thin. We derive a median outflow mass and energy of $10 M_{\odot}$ and $0.21 \times 10^{46} \text{ erg}$, respectively.

A kinematic timescale has been estimated for each outflow lobe from $t_{\text{kin}} = r/V_{\text{out}}$, where r is the deconvolved projected spatial size of the lobe, and V_{out} is the outflow velocity defined above. The average of the numbers obtained for the blue and red lobes produces the kinematic timescale presented in Table A.6, typically a few 10^4 yr . For G24.33+0.1M1 only the red wing emission has been considered to derive t_{kin} because the blue wing is blended with an absorption feature due to the emission at the OFF position, as pointed out in Sect. 2.2.1. and Tables A.5 and A.6. We note that, as a consequence, the outflow parameters derived for this source are lower limits.

Finally, the outflow parameters $\dot{M}_{\text{out}} = M_{\text{out}}/t_{\text{kin}}$ (mass loss rate), $F_{\text{out}} = p_{\text{out}}/t_{\text{kin}}$ (mechanical force), and $L_{\text{mec}} = E_{\text{out}}/t_{\text{kin}}$ (mechanical luminosity) have been determined.

Table 6. Factors to multiply by the projected outflow-related parameters, as a function of outflow inclination, i .

i	Velocity	Size	t_{kin}	p	E	$\dot{M}$	F_{out}	L_{mec}
10	1.02	5.8	5.7	1.02	1.03	0.18	0.18	0.18
20	1.06	2.9	2.7	1.06	1.13	0.36	0.39	0.41
30	1.15	2.0	1.73	1.15	1.33	0.58	0.67	0.77
45	1.41	1.41	1.00	1.41	2.0	1.00	1.41	2.0
60	2.0	1.15	0.58	2.0	4.0	1.73	3.5	6.9
70	2.9	1.06	0.36	2.9	8.5	2.7	8.0	23.5
80	5.8	1.02	0.18	5.8	33.2	5.7	32.7	188

All the outflow parameters derived as described here are listed in Table A.6. With the exception of the outflow mass, M_{out} , these are subject to an uncertainty due to the lack of knowledge of the outflow axis inclination with respect to the l.o.s., i . For an inclination of 45° the outflow parameters do not change much: t_{kin} and $\dot{M}$, for instance, remain the same, while E and L_{mec} increase by a factor 2. Quantities which depend strongly on the outflow velocity, such as E and L_{mec} , are most affected by the inclination: for $i > 60^\circ$ these increase by about an order of magnitude or more. Table 6 lists the factors by which each parameter must be multiplied to correct for several inclinations. Clearly this is, together with the HCO^+ abundance, one of the major sources of uncertainty in the determination of outflow parameters.

4.3. Identification of infall candidates: the asymmetry parameter δV

The profiles of optically thick lines arising from regions undergoing infall have stronger blue-shifted emission than red-shifted emission, provided the excitation temperature decreases outwards from the centre of the region (e.g. Anglada et al. 1987; Zhou 1992). In order to analyse quantitatively the presence of infall in our sample sources, we have used the nondimensional asymmetry parameter δV , defined by Mardones et al. (1997) as the velocity difference between the peaks of an optically thick and an optically thin line, in units of the $FWHM$ of the optically thin line:

$$\delta V = \frac{V_{\text{thick}} - V_{\text{thin}}}{\Delta V_{\text{thin}}}. \quad (3)$$

Our optically thin and thick lines are $\text{C}^{18}\text{O}(2-1)$ and $\text{HCO}^+(1-0)$, respectively. To compute this quantity, we have first fitted a Gaussian to the $\text{C}^{18}\text{O}(2-1)$ line at the peak coordinates of the $\text{HCO}^+(1-0)$ integrated map (Col. 2 of Table A.7) to obtain $V_{\text{C}^{18}\text{O}}$ and $\Delta V_{\text{C}^{18}\text{O}}$. When these coordinates are within a radius of $15''$ from the centre of the map (i.e., approximately the extension of the $\text{HCO}^+(1-0)$ beam), the wobbler spectrum, centred at $(0'', 0'')$, has been used instead of the OTF spectrum because the noise is considerably lower in the former. V_{HCO^+} has also been obtained from a Gaussian fit to the line at the same position, but in this case the situation is more complicated, because in many cases the $\text{HCO}^+(1-0)$ line is self-absorbed, giving rise to line profiles which are not well-represented by a single Gaussian. In such cases two or even three Gaussian fits have been necessary, of which the highest-peaked V_{HCO^+} has been chosen. When the line profile presented two equally high peaks (within 2σ), the mean of their respective velocities has been used. In other cases, masking part of the spectrum has been necessary to produce acceptable fits, i.e., reasonably good values

for V_{HCO^+} . The values of δV , as well as the associated errors are presented in Table A.7.

By definition, negative values of δV correspond to blue asymmetric $\text{HCO}^+(1-0)$ line profiles and therefore potential infall candidates. Positive values of δV correspond to red asymmetric profiles, which could be interpreted as expansion. We have considered the line asymmetry to be significant only when $|\delta V| > 3\sigma = 0.15$, where $\sigma = 0.05$ is the typical error we derive for the asymmetry parameter δV . Therefore, we define as *infall candidates* those sources for which $\delta V < -0.15$, labelled *B* in Table A.7. On the other hand, sources with $\delta V > +0.15$ display a significantly red asymmetry and are labelled *R* in Table A.7.

5. Discussion

5.1. Clump masses

Figure 3 presents a plot of virial mass, M_{vir} , against clump mass derived from the emission under the $\text{C}^{18}\text{O}(2-1)$ line, M_{clump} (see Sect. 4.1), with IR-dark and IR-loud sources (filled circles) plotted in different panels. The error bars on the bottom right corner of each panel represent the uncertainties of the quantities plotted according to what is described in Sect. 4.1. For comparison, also the high-mass molecular clumps studied by Hofner et al. (2000) in the C^{17}O molecule are plotted with the IR-loud sources (crosses) in this figure. While most of the sources of the Hofner et al. sample have larger clump masses than virial masses, the opposite holds for the majority of our IR-loud sources. This feature is even more pronounced for the IR-dark sub-sample. Indeed, we find that the virial masses are greater than the clump masses by an average factor of 4.7 for the IR-dark clumps, and only 2.2 for the IR-loud.

As described in Sect. 4.1, our clump masses, M_{clump} , have been derived from the emission under the $\text{C}^{18}\text{O}(2-1)$ line assuming it is optically thin. If this is not the case, our masses have been underestimated. For example, accounting for an optical depth of 1.9 in the $\text{C}^{18}\text{O}(2-1)$ line of the IR-loud clumps would result in a horizontal shift of all the IR-loud points towards the $M_{\text{vir}} = M_{\text{clump}}$ line and thus to a situation in which the clumps are virialised. By contrast, one would need an optical depth of ~ 4.8 to virialise the IR-dark subsample. This would indicate that the $\text{C}^{18}\text{O}(2-1)$ emission is optically thicker for the IR-dark clumps than for the IR-loud, by a factor of ~ 2.5 . However, there is no particular reason to expect higher optical depths in IR-dark clumps, especially in a sample like ours, where both IR-dark and IR-loud sources cover the same range of column densities.

Figure 4 shows the mass derived from the dust continuum emission at 1.2 mm, M_{dust} , plotted against M_{clump} . In spite of the large scattering, it is clear that the points representing IR-loud sources cluster around the $M_{\text{dust}} = M_{\text{clump}}$ line, while almost all the points representing IR-dark clumps lie above and to the left of this line, i.e., the region where $M_{\text{dust}} > M_{\text{clump}}$.

We will now explore three possibilities that may explain this result. The first one is an overestimate of the clump mass and size obtained from the mm continuum as opposed to that obtained from the $\text{C}^{18}\text{O}(2-1)$ emission. A higher sensitivity in the continuum at 1.2 mm may allow detection of more extended emission and therefore larger sizes and masses. However, once more, this should have the same effect in both the IR-loud and IR-dark subsamples, while we find a systematic difference between the two: M_{clump} is smaller than M_{dust} only for the IR-dark clumps. Furthermore, we find that the “dust” sizes are similar to the “ C^{18}O ” sizes for our whole sample, independently of the presence of IR emission. This can also be inferred from Fig. 5,

Fig. 3. Virial mass, M_{vir} , against clump mass derived from the emission under the $\text{C}^{18}\text{O}(2-1)$ line, M_{clump} , for IR-dark (*top*) and IR-loud sources (*bottom*, filled circles). The error bars are depicted on the bottom right corner of each panel. Crosses represent the high-mass molecular clumps studied by Hofner et al. (2000). The dashed line marks the positions on the plot where M_{vir} equals M_{clump} .

where, to get rid of any effect due to the different sizes measured in the two tracers, we have plotted the surface density derived from the dust emission at 1.2 mm, Σ_{dust} (the same as Σ in Fig. 1), as a function of the surface density derived from the $\text{C}^{18}\text{O}(2-1)$ emission, Σ_{clump} . The same behaviour found in Fig. 4 is present in this plot: Σ_{dust} is systematically greater than Σ_{clump} only for IR-dark sources. Therefore, this result cannot be explained by mm continuum clumps having larger measured sizes than C^{18}O clumps.

A second and more plausible explanation is a lower C^{18}O abundance in IR-dark clumps. From the ratio between the column densities obtained from the $\text{C}^{18}\text{O}(2-1)$ and the dust continuum emission at 1.2 mm, we measure a median depletion factor of 4.5 for our IR-dark subsample. This agrees with what reported by Fontani et al. (2006), who found CO was depleted in their sample of IR-dark clumps by a median factor of ~ 3 . They argue that the low temperatures present in IR-dark clumps may cause CO to be trapped in H_2O ice on dust grains, leading to lower CO abundances. The fact that we have assumed the same C^{18}O abundance for both IR-loud and IR-dark clumps, without taking into account that this molecule may be depleted in the latter, may lead to underestimated IR-dark clump masses. A C^{18}O underabundance also explains why the C^{18}O emission

Fig. 4. Clump mass derived from the continuum emission at 1.2 mm, M_{dust} , against clump mass derived from the emission under the $\text{C}^{18}\text{O}(2-1)$ line, M_{clump} , for IR-dark (*top*) and IR-loud sources (*bottom*). The error bars corresponding to the uncertainty on the clump mass estimates are depicted on the bottom right corner of each panel. The dashed line marks the positions on the plot where M_{dust} equals M_{clump} .

is weaker and the C^{18}O clumps do not show a clear morphology in many of our IR-dark clumps.

There is a third important factor that needs to be examined, and this is temperature. We have assumed a low excitation temperature ($T_{\text{ex}} = 15$ K) for all the IR-dark clumps when computing M_{clump} , which is also the dust temperature adopted by Rathborne et al. (2006) to derive the clump masses from the continuum emission at 1.2 mm. It is likely that this temperature has been underestimated at least in some cases, which results in an overestimated M_{dust} and an underestimated M_{clump} .

As an example, let us consider one of the most massive IR-dark clumps in our sample: G34.43+0.2M1. Rathborne et al. (2008) estimate a dust temperature of 34 K for this source. Table 7 lists the values of M_{dust} and M_{clump} of G34.43M1 for temperatures of 15 and 34 K. When using 34 K instead of 15 K, M_{dust} becomes smaller by a factor ~ 2 , and M_{clump} increases by 25%, approximately. Although at 34 K M_{dust} still exceeds M_{clump} by a factor ~ 5 , the discrepancy is not as large as at 15 K. This example demonstrates how the choice of temperature can affect the calculation of clump masses, and that in the case of our IR-dark clumps, an underestimate of T_{ex} and T_{dust} may in part explain the appearance of Fig. 4, at least for some of the sources (e.g. G34.43M1, G24.60M2).

In conclusion, we believe that the behaviour of the IR-dark sub-sample in Fig. 3 is not real, but results from either an

Fig. 5. Surface density derived from the continuum emission at 1.2 mm, Σ_{dust} , against surface density derived from the emission under the $\text{C}^{18}\text{O}(2-1)$ line, Σ_{clump} , for IR-dark (*top*) and IR-loud sources (*bottom*). The error bars corresponding to the uncertainty on Σ_{clump} are depicted on the bottom right corner of each panel. The dashed line marks the positions on the plot where Σ_{dust} equals Σ_{clump} .

Table 7. M_{dust} and M_{clump} derived for G24.33+0.1M1 for two different temperatures.

T (K)	M_{dust} ($M_{\odot}$)	M_{clump} ($M_{\odot}$)
15	1187	73
34	524	91

overestimate in the C^{18}O abundance when computing M_{clump} , or an underestimate in the excitation and dust temperatures adopted (or a combination of both). While the choice of temperature affects both M_{dust} and M_{clump} , only M_{clump} is affected by the uncertainties on the C^{18}O abundance. Therefore, we conclude that the clump mass computed from the 1.2 mm continuum emission, M_{dust} , is more reliable than the one obtained from the $\text{C}^{18}\text{O}(2-1)$ emission, M_{clump} , and we will thus make use of the former in Sects. 5.2 and 5.3.

Indeed, if we plot M_{vir} , against M_{dust} instead of M_{clump} (Fig. 6), we obtain similar trends for both IR-dark and IR-loud clumps. In this case M_{vir} and M_{dust} are comparable for our sources, and thus our clumps are on average virialised. An interesting feature of this figure, if one considers both IR-loud and IR-dark sources, including those of Hofner et al., is that M_{dust} generally exceeds the virial mass for $M_{\text{dust}} \gtrsim 1000 M_{\odot}$, while this is not so evident for smaller masses. This suggests that the

Fig. 6. Virial mass, M_{vir} , against clump mass derived from the dust continuum emission at 1.2 mm, M_{dust} , for IR-dark (*top*) and IR-loud sources (*bottom*, black circles). The error bars corresponding to the uncertainty on the virial mass estimates are depicted on the bottom right corner of each panel. Crosses represent the high-mass molecular clumps studied by Hofner et al. (2000). The dashed line marks the positions on the plot where M_{vir} equals M_{dust} .

most massive molecular clumps are more unstable under gravitational collapse than the lowest mass clumps, unless the former are magnetically supported. According to Eq. (8) of Fontani et al. (2002; see also McKee et al. 1993), magnetic fields of 1 or a few mG are sufficient to stabilise the most massive clumps ($M_{\text{dust}} \geq 1000 M_{\odot}$). However, bear in mind that Hofner et al. used the less abundant C^{17}O molecule, and it is therefore likely that they were tracing a more internal region of the clump undergoing collapse. The same consideration applies also to Fig. 3.

5.2. Molecular outflows

5.2.1. Outflow detection rate

As mentioned in Sect. 3.2, a total outflow detection rate of 75% has been measured in our sample. If we distinguish between IR-dark and IR-loud clumps, very similar detection rates are found, of 79% and 73%, respectively.

In Fig. 7 we show a plot of surface density against mass, $\Sigma(M_{\text{dust}})$, in which outflow detections are represented by filled circles, and non-detections by open circles. IR-dark and IR-loud clumps are plotted in two different panels, as in Fig. 1. We remind the reader that, unlike Fig. 1, the eight IR-dark sources listed in Table 5 are plotted here with the corrected

Fig. 7. Molecular outflow detections for the IR-dark (*top*) and IR-loud (*bottom*) sub-samples. Plot of surface density, Σ , against dust mass, M_{dust} . Filled circles represent outflow detections, whereas open circles represent sources with no outflow signatures. The dashed and dotted lines at $\Sigma = 0.3$ and 0.7 g cm^{-2} mark, respectively, the threshold given by Krumholz & McKee (2008) and our empirical outflow threshold (see text for details).

mass values according to the new distances. This plot illustrates the high outflow detection rate measured for both IR-dark and IR-loud sources, a finding which indicates that star formation takes place actively in both kinds of objects. The most remarkable result is that we can define an empirical outflow threshold at $\Sigma = 0.3 \text{ g cm}^{-2}$ under which the outflow detection rate falls considerably, both for IR-dark and IR-loud sources. Indeed, the detection rate for both sub-samples is of 100% above $\Sigma = 0.3 \text{ g cm}^{-2}$, and 56% below it. This threshold is marked with a dashed line in Fig. 7 under the dotted line at $\Sigma = 0.7 \text{ g cm}^{-2}$, which defines the theoretical prediction made by Krumholz & McKee (2008).

The histogram in Fig. 8 also evidences the increase of the outflow detection rate with surface density, starting from only a 30% for sources with $\Sigma \sim 0.1 \text{ g cm}^{-2}$, and growing rapidly towards saturation at 100% for the highest Σ values. This implies that sufficiently high surface densities are required for active star formation to occur. For the sample under study, $\Sigma = 0.3 \text{ g cm}^{-2}$ is found to be high enough for this. This value is smaller than the theoretical $\Sigma = 0.7 \text{ g cm}^{-2}$ required for high-mass star formation according to Krumholz & McKee (2008). However, parsec-sized molecular clumps like the ones in our sample are not likely to be homogeneous, but may contain a number of smaller fragments, not resolved by our single-dish observations, which may be massive and dense enough to satisfy Krumholz & McKee's prediction. Moreover, one must evaluate the outflow masses to find out whether the driving sources are indeed high-mass YSOs (see below). In short, our empirical $\Sigma = 0.3 \text{ g cm}^{-2}$ threshold supports Krumholz & McKee's idea and gives a measure of the minimum surface density that a molecular clump needs to undergo effective star or cluster formation.

5.2.2. Outflow parameters against clump mass and surface density

To investigate how the outflow parameters vary with clump mass, we have plotted the outflow mass, M_{out} , momentum, p_{out} ,

Fig. 8. Molecular outflow detection rate as a function of surface density for the whole sample.

and kinetic energy, E_{out} against clump mass, M_{dust} (Fig. 9). Our sample sources are represented by circles, open if they are IR-loud, and filled if they are IR-dark. Different colours have been used to mark different ranges of surface densities: $\Sigma < 0.3 \text{ g cm}^{-2}$ (black), Σ between 0.3 and 0.7 g cm^{-2} (green) and $\Sigma > 0.7 \text{ g cm}^{-2}$ (blue). For comparison, the sample sources from the outflow surveys conducted by López-Sepulcre et al. (2009; black crosses) and Beuther et al. (2002b; red crosses) are also plotted. For the latter, only the sources with no distance ambiguity, and which do not overlap our sample are represented. For consistency with these two surveys, $T_{\text{ex}} = 30 \text{ K}$ has been assumed to calculate the outflow parameters, and therefore the corresponding outflow parameter values presented in Table A.6, obtained for $T_{\text{ex}} = 10 \text{ K}$, have been multiplied by a factor 2 (see Sect. 4.2). The error bars on the top-left corners of the p_{out} and E_{out} plots correspond to a correction for an arbitrary inclination of 60° (see Table 6).

A general look at the $M_{\text{out}} - M_{\text{dust}}$ plot reveals that our detected molecular outflows are massive, with masses ranging between a few and $\sim 100 M_{\odot}$, similar to the ones detected by Beuther et al. (2002b). This suggests that the sources powering them are also massive, although high-resolution imaging is needed to confirm this and to test for possible multiplicity of the outflows. The behaviour of the points indicate that more massive clumps drive more massive outflows. This trend is also evidenced by the dotted line, which represents our least squares fit to all the points plotted: $M_{\text{out}} = 0.4 M_{\text{dust}}^{0.7}$. The dashed line, on the other hand, corresponds to the relation $M_{\text{out}} = 0.3 M_{\text{dust}}^{0.8}$, which is the best fit to the Beuther et al. data, and represents also a fair fit to both our data and those from López-Sepulcre et al. (2009). The good correlation between outflow mass and clump mass is a remarkable finding, and the fact that it holds for several orders of magnitude suggests that the character of star formation, in this case in the form of outflows, remains unchanged within a wide range of clump masses, including the most massive ones. This result is also reflected in Fig. 10, where to avoid distance dependency, we have plotted $M_{\text{out}}/M_{\text{dust}}$ against M_{dust} . It is worth noting in this plot the upper limit of $M_{\text{out}}/M_{\text{dust}} \sim 0.2$,

Fig. 9. Outflow mass (*bottom*), total outflow momentum (*middle*) and outflow kinetic energy (*top*) against mass of the clump derived from the dust emission. Filled circles represent IR-dark sources, while open circles represent IR-loud sources. Different colours are used to mark sources with $\Sigma < 0.3 \text{ g cm}^{-2}$ (black), Σ between 0.3 and 0.7 g cm^{-2} (green) and $\Sigma > 0.7 \text{ g cm}^{-2}$ (blue). Black crosses correspond to the sources studied by López-Sepulcre et al. (2009), and red crosses to those of Beuther et al. (2002b) which do not overlap our present sample. The vertical bars drawn in the boxes of the middle and top panels indicate, respectively, the variation of p_{out} and E_{kin} for an inclination of the outflow axis of 60° with respect to the l.o.s. The dotted line in the *bottom panel* represents our best fit to all the points plotted, whereas the dashed line the best fit obtained by Beuther et al. (2002b) for their data.

an indicator that up to about 20% of the clump mass can be affected by molecular outflows. This suggests that outflow feedback can be important in the process of high-mass star/cluster formation, which supports the theoretical results obtained by Wang et al. (2010).

Fig. 10. Ratio between outflow mass and clump mass, $M_{\text{out}}/M_{\text{dust}}$ plotted against clump mass, M_{dust} . Filled circles represent IR-dark sources, while open circles represent IR-loud sources. Different colours are used to mark sources with $\Sigma < 0.3 \text{ g cm}^{-2}$ (black), Σ between 0.3 and 0.7 g cm^{-2} (green) and $\Sigma > 0.7 \text{ g cm}^{-2}$ (blue). Black crosses correspond to the sources in the survey of López-Sepulcre et al. (2009), and red crosses to those of Beuther et al. (2002b) which do not overlap our present sample.

If we focus only on our sources in Fig. 9, we find that IR-dark and IR-loud clumps contain equally massive outflows, with no apparent segregation between the two types of objects. Furthermore, no clear difference in outflow mass can be seen among the three different surface density ranges. Overall, this plot suggests that our outflow-bearing sources may be treated as a homogeneous sample in which the outflow mass increases with the mass of the clump, and neither the surface density nor the membership of the IR-dark or IR-loud subsample influence strongly the mass of the molecular outflows. Similar trends are found in the $p_{\text{out}} - M_{\text{dust}}$ and $E_{\text{out}} - M_{\text{dust}}$ plots.

For completeness, also the outflow parameters $\dot{M}_{\text{out}}$, F_{out} , and L_{mec} , plotted against the mass of the clump are shown in Fig. 11. The same symbology as in Fig. 9 applies here. The error bars correspond to a correction for an outflow inclination varying from 30° (lower error bar) to 60° (upper error bar). The behaviour of the points is very similar to that in Fig. 11.

In order to examine in more detail the role of the surface density on the outflow parameters, we present in Fig. 12 a plot of outflow mass, M_{out} , as a function of surface density, Σ . As expected from Figs. 9 and 11, the points are very scattered and they do not show a trend as clear as the one found for $M_{\text{out}} - M_{\text{dust}}$. However, for almost all the sources with $\Sigma > 0.3 \text{ g cm}^{-2}$, the outflow masses are $\geq 10 M_\odot$, whereas below 0.3 g cm^{-2} the presence of lower mass outflows is more common (about 30%). Therefore, while low surface density clumps may drive outflows with a wide range of masses, from ~ 1 to $\sim 100 M_\odot$, high surface density clumps favour only the most massive outflows in this range. Again, no distinction is found between IR-dark and IR-loud sources, and thus we can conclude that IR-loud and IR-dark clumps are very similar in terms of outflow frequency, mass and energetics.

Fig. 11. Outflow mass loss rate (*bottom*), mechanical force of the outflow (*middle*) and mechanical luminosity of the outflow (*top*) against mass of the clump derived from the dust emission. Filled circles represent IR-dark sources, while open circles represent IR-loud sources. Different colours are used to mark sources with $\Sigma < 0.3 \text{ g cm}^{-2}$ (black), Σ between 0.3 and 0.7 g cm^{-2} (green) and $\Sigma > 0.7 \text{ g cm}^{-2}$ (blue). Black crosses correspond to the sources studied by López-Sepulcre et al. (2009), and red crosses to those of Beuther et al. (2002b) which do not overlap our present sample. The vertical bars drawn in the boxes of each panel indicate, from bottom to top, the variation of $\dot{M}_{\text{out}}$, F_{out} and L_{mec} for an inclination of the outflow axis ranging between 30° (lower limit) and 60° (upper limit) with respect to the l.o.s.

5.2.3. Comparison with a CO survey

The present survey has made use of the $\text{HCO}^+(1-0)$ line to derive outflow parameters, instead of the more commonly used CO molecule. This section is aimed at comparing our outflow parameters to those derived from the CO(2–1) line by

Fig. 12. Outflow mass against surface density of the clump. IR-dark sources are represented by filled circles, and IR-loud by open circles. The two vertical dashed lines mark the theoretical ($\Sigma = 0.7 \text{ g cm}^{-2}$) and empirical ($\Sigma = 0.3 \text{ g cm}^{-2}$) surface density thresholds.

Beuther et al. (2002b) for eight IR-loud clumps that are common to both studies. Table 8 lists the sources as well as their respective M_{out} , p_{out} , and E_{out} derived by us and by Beuther et al. We note that the values presented have been computed for $T_{\text{ex}} = 30 \text{ K}$, which is the excitation temperature assumed by Beuther et al. (2002b).

On average, the outflow mass, momentum, and kinetic energy obtained by Beuther et al. are greater than the ones derived by us by a factor 1.5, 5, and 17, respectively. In other words, the discrepancy is larger the more the parameter depends on the velocity. This finding is illustrated in Fig. 13, which presents a comparative plot for each of the three outflow parameters under analysis. The outflow masses are similar for the two surveys, although Beuther et al. report slightly higher values. This may be caused in part by the fact that we, unlike Beuther et al., have assumed optically thin conditions and thus obtain lower limit values to the outflow mass. An overestimate of the assumed HCO^+ abundance by a factor 1.5 is another possible explanation for the discrepancy. The greater differences found for the outflow momentum and kinetic energy are most likely explained by the more extended wings of the CO(2–1) line with respect to the $\text{HCO}^+(1-0)$ line. p_{out} and especially E_{out} are more sensitive to the higher velocity channels of the line wings, and so it is expected that a line with broader wings will produce higher values of moment and kinetic energy of the outflow.

In summary, while we obtain similar outflow masses, the less extended outflow wings of the $\text{HCO}^+(1-0)$ line produces underestimated outflow momenta and kinetic energies. Even though this effect can be noticed in the upper panel of Fig. 9, where the points representing our sources appear to “sink” slightly with respect to the points corresponding to the other two surveys, the overall trend of the plot remains unchanged, and so do the conclusions drawn in the previous sections.

Table 8. Comparison of outflow mass, momentum and kinetic energy between this study and that of Beuther et al. (2002b).

Source	M_{beu} ($M_{\odot}$)	M_{our} ($M_{\odot}$)	p_{beu} ($M_{\odot} \text{ km s}^{-1}$)	p_{our} ($M_{\odot} \text{ km s}^{-1}$)	E_{beu} (10^{46} erg)	E_{our} (10^{46} erg)
05358+3543	21	10	288	68	4.0	0.45
18151-1208_1	12	29	106	81	0.9	0.27
19035+0641	3	2	28	15	0.3	0.11
20216+4107	6	4	43	17	0.3	0.07
22134+5834	17	5	242	17	3.4	0.06
23033+5951	32	44	566	214	10.0	1.18
23139+5939	57	29	662	176	7.7	1.22
23151+5912	21	20	597	86	18.0	0.42

Fig. 13. Comparison between our derived outflow mass, M_{out} , moment, p_{out} , and kinetic energy E_{out} (horizontal axis) and the same quantities derived from the CO(2–1) emission by Beuther et al. (2002b; vertical axis) for eight common IR-loud clumps. The dashed lines mark the positions where the respective outflow parameters have the same values for both surveys.

5.3. Infall

According to the definition of *infall candidate* given in Sect. 4.3, the infall detection rate in our sample is low: 13% for IR-loud clumps, and 32% for IR-dark clumps. Unlike the outflow detections, there seems to be no correlation at all between the detection of infall and the surface density, Σ , of the clump. All the infall candidates except one (G34.77–0.6M2), present also molecular outflows. The low infall detection rate measured is illustrated in Fig. 14, where we present a plot of surface density against clump mass, Σ vs. M_{dust} , in which sources with a significantly blue asymmetric HCO⁺(1–0) line (i.e., infall candidates) are represented as blue circles, and sources with significant red asymmetry are represented as red circles. We find that blue asymmetries are less abundant than red asymmetries, which implies that either clear large-scale infall signatures are difficult to detect, or this phase has a relatively short time scale.

The low percentage of infall candidates we obtain may be understood if one imagines an evolutionary picture starting with a prestellar infalling clump that subsequently forms a cluster of YSOs, leading to the appearance of winds and outflows which can gradually become more dominant at large scales and cause the velocity field of the region to become more chaotic with time. As a result, the optically thick molecular lines such as HCO⁺(1–0) are less likely to display a clear infall profile as star formation activity inside the clump evolves.

Despite the low overall infall detection rate, this is significantly higher in the IR-dark subsample, which suggests,

according to the picture mentioned above, that these are more likely to be associated with the onset of star formation and may thus represent an early evolutionary stage of star formation with respect to IR-loud clumps.

A parameter which provides a quantitative idea of whether a sample is dominated by blue or red asymmetries is the blue excess, E , defined by Mardones et al. (1997) as:

$$E = \frac{N_{\text{blue}} - N_{\text{red}}}{N_{\text{tot}}} \quad (4)$$

where N_{blue} and N_{red} are, respectively, the number of blue and red asymmetry cases within the sample, and N_{tot} is the total number of sources observed. This definition implies that any sample dominated by blue asymmetries, or in other words infall candidates, yields a positive value of E . We obtain $E_{\text{dark}} = -0.16 \pm 0.16$ and $E_{\text{loud}} = -0.27 \pm 0.11$ for the IR-dark and IR-loud subsamples, respectively, which indicates that red asymmetries dominate (marginally, in the case of the IR-dark sub-sample), as Fig. 14 already makes clear. This result contrasts with other surveys such as those conducted by Fuller et al. (2005) and Wu & Evans (2003), who also studied infall in a sample of high-mass SFRs and obtained positive blue excesses. The former derived $E = 0.15 \pm 0.07$ from the HCO⁺(1–0) line, and the latter obtained $E = 0.21 \pm 0.12$ using the HCN(3–2) line, where the statistical errors have been computed by us. This finding led the authors to the conclusion that their samples have a significant contribution from infalling regions.

Fig. 14. $\text{HCO}^+(1-0)$ line asymmetries for the IR-dark (*top*) and IR-loud (*bottom*) sub-samples. Plot of surface density, Σ , against dust mass, M_{dust} . Open circles correspond to sources with no significant asymmetry in the $\text{HCO}^+(1-0)$ line (see text). Red and blue circles correspond to red and blue $\text{HCO}^+(1-0)$ line asymmetries, respectively, the latter representing infall candidates. The dot-dashed lines at $\Sigma = 0.3$ and 0.7 g cm^{-2} mark, respectively, the threshold given by Krumholz & McKee (2008) and our empirical outflow threshold (see text for details).

5.3.1. Comparison with another survey

To try to understand the disagreement between our E values and those obtained by the above cited authors, we have made a comparative analysis of the derived δV for nine of our IR-loud sources which also belong to the sample studied by Fuller et al. (2005). The sources and their respective δV values are listed in Table 9. In addition, Fig. 15 presents a comparative plot of each pair of δV values, where the limits of the significant blue and red asymmetry regions have been marked at $|\delta V| = 0.15$ with dot-dashed lines. We have assumed a typical error of 0.05 on δV for the sources of Fuller et al., as reported by the authors. We find there is good agreement between our numbers and those derived by Fuller et al., in the sense that, within the errors, all the points fall inside one of the three quadrants intersected by the equality line (dashed), and therefore have the same type of line asymmetry. This analysis leads to the conclusion that, at least for the IR-loud sub-sample, our δV values are as reliable as those obtained in similar surveys. Consequently, our low percentage of infall candidates among IR-loud clumps is to be regarded as valid as the high percentages reported in other surveys.

5.3.2. Asymmetry parameter distribution

As expected from Fig. 14, the histogram in Fig. 16 reveals a higher population of red asymmetric sources with respect to the one with blue asymmetries. For the IR-loud clumps, there is a central peak of sources without significant asymmetry, a feature reported also by Fuller et al. (2005). However, this central peak is not present for the IR-dark sub-sample, which in addition displays more scattering and reaches more extreme values of δV . It is not straightforward to interpret this interesting result only from our observations. A more complete analysis of infall would require knowledge of the excitation temperature gradient present

Table 9. Comparison between our δV and the one derived by Fuller et al. (2005) from $\text{HCO}^+(1-0)$.

Source	δV_{fuller}	δV_{our}
05358+3543	+0.23	+0.23
18151-1208_1	+0.02	+0.19
18223-1243	-0.31	-0.19
18264-1152	+0.10	-0.06
19035+0641	-0.11	-0.07
20216+4107	+0.03	-0.03
22134+5834	+0.66	+0.48
23033+5951	-0.07	-0.04
23139+5939	-0.27	-0.10

Fig. 15. Comparison of the asymmetry parameter, δV , derived from the $\text{HCO}^+(1-0)$ line between the present survey and that of Fuller et al. (2005). The dashed line marks the region where $\delta V(\text{Fuller}) = \delta V(\text{present work})$, and the horizontal and vertical dot-dashed lines are drawn at $|\delta V| = 0.15$, which represents the limit above which the asymmetry is significant. The vertical errors equal 0.05 for all the sources (see text).

within the clumps. This finding highlights the complexity and diversity present among IR-dark clumps, and encourages further investigation of this kind of objects.

5.3.3. Infall rates

For the sources identified as *infall candidates*, we provide a rough estimate of the infall rate, $\dot{M}_{\text{inf}}$, using the following equation:

$$\dot{M}_{\text{inf}} = 4\pi R^2 V_{\text{inf}} \rho \quad (5)$$

where $V_{\text{inf}} = V_{\text{HCO}^+} - V_{\text{C}^{18}\text{O}}$ is an estimate of the infall velocity, $\rho = M/(4/3\pi R^3)$ is the average clump volume density, and R is the radius of the clump. We have used R and M derived from the dust continuum emission at 1.2 mm. The values obtained are listed in Table A.7 and range between 10^{-3} and $10^{-1} M_{\odot} \text{ yr}^{-1}$. We note that the high values derived are comparable to those reported by Fontani et al. (2002). However, our values should be considered upper limits as the method used implicitly assumes that most of the clump mass is infalling at velocity V_{inf} whereas the region responsible for HCO^+ self-absorption is likely only a

Table 10. Infall and accretion rates, and ratio between the two quantities.

Source	Subsample	t_{kin} (10^4 yr)	p_{out}^a ($M_{\odot} \text{ km s}^{-1}$)	$\dot{M}_{\text{jet}}$ ($10^{-5} M_{\odot} \text{ yr}^{-1}$)	$\dot{M}_{\text{acc}}$ ($10^{-5} M_{\odot} \text{ yr}^{-1}$)	$\dot{M}_{\text{inf}}$ ($10^{-3} M_{\odot} \text{ yr}^{-1}$)	$\dot{M}_{\text{inf}}/\dot{M}_{\text{acc}}$
G213.61–12.6	IR-loud	4.22	59.0	0.20	0.60	4.7	780
18223–1243	IR-loud	5.09	134	0.37	1.1	2.3	210
18236–1205	IR-loud	1.81	47.7	0.38	1.1	6.9	630
18316–0602	IR-loud	2.75	579	3.0	9.0	6.9	77
G23.60+0.0M2	IR-dark	4.42	47.7	0.15	0.46	13.3	2900
G24.33+0.1M1	IR-dark	7.25	248	0.49	1.5	125	8300
G25.04–0.2M1	IR-dark	11.2	87.4	0.11	0.33	5.9	1800
G25.04–0.2M4	IR-dark	9.6	50.5	0.075	0.23	4.9	2100
G34.77–0.6M2 ^b	IR-dark	—	—	—	—	—	—
G38.95–0.5M1	IR-dark	4.67	47.5	0.15	0.44	1.8	410

Notes. ^(a) Outflow momentum corrected for an inclination of 45° ; ^(b) no outflow detection for this source.

Fig. 16. Histograms of the asymmetry parameter δV for IR-loud (white) and IR-dark (green) clumps. The blue and red dashed vertical lines mark the lower limit of the regions of significant blue and red asymmetry, respectively.

low density outer layer. Rough estimates suggest that this could cause us to overestimate the clump infall rate by as much as 1–2 orders of magnitude. Accurate estimates require observations of the ^{13}C substituted isotopologues as well as excited state transitions of HCO^+ .

An approach to estimate the mass accretion rate, $\dot{M}_{\text{acc}}$, towards the protostars is described in Beuther et al. (2002b) and López-Sepulcre et al. (2009). We can derive this quantity for the *infall candidates* from the outflow mass loss rates, $\dot{M}_{\text{out}}$. Considering the molecular outflows to be momentum driven, the following equation holds:

$$p_{\text{out}} = p_{\text{jet}} = \dot{M}_{\text{jet}} V_{\text{jet}} t_{\text{kin}} \quad (6)$$

where V_{jet} is the jet velocity and we assume that the kinematic timescale of the jet is the same as that of the molecular outflow (see Table A.6). After correcting our values of p_{out} (Table A.6) for a mean outflow inclination of 45° , and adopting a typical jet velocity of 700 km s^{-1} (e.g. Martí et al. 1998), we can calculate the mass loss rate of the jet, $\dot{M}_{\text{jet}}$. If we assume that $\dot{M}_{\text{jet}}$ is about one third of $\dot{M}_{\text{acc}}$ (Tomisaka 1998), we obtain values of about $10^{-5} M_{\odot} \text{ yr}^{-1}$ (see Table 10).

A comparison between the infall rates derived from Eq. (5) and the accretion rates calculated from Eq. (6) reveals differences of between 2 and 4 orders of magnitude, as can be seen in the last column of Table 10. As we have mentioned above, our infall rates are overestimates, but the discrepancies between $\dot{M}_{\text{inf}}$ and $\dot{M}_{\text{acc}}$ are huge. Nevertheless, it is likely that the former represents the infalling material onto the whole protocluster, while the latter corresponds to the material being accreted towards individual protostars and therefore yields much smaller values. If this is the case, it is worth noting in Table 10 that the ratio $\dot{M}_{\text{inf}}/\dot{M}_{\text{acc}}$ is on average higher for the IR-dark sources by about an order of magnitude. Even though the number of sources analysed here is very small and therefore the statistics is poor, this result is interesting. According to Tomisaka (1998), while the accretion rate remains constant during the accretion phase, the outflow rate increases with time until it reaches about one third of the accretion rate (which is what we have assumed in the determination of $\dot{M}_{\text{acc}}$). In this scenario, the greater $\dot{M}_{\text{inf}}/\dot{M}_{\text{acc}}$ ratios obtained for the IR-dark clumps support the idea that these objects are in an earlier evolutionary phase in which, while the whole clump is actively undergoing infall, the outflows formed within it are still young and have not attained their maximum outflow mass loss rate yet.

5.4. Velocity gradients

In half of our sample we detect $\text{C}^{18}\text{O}(2-1)$ velocity gradients. The corresponding velocity maps are shown in Fig. B.4. It is not easy to tell whether these velocity gradients are due to rotation, multiple components or outflowing motions, but a comparison between the orientation of the velocity gradient and that of the outflow axis (when present) might give a hint. There are four cases in which the velocity gradient is roughly perpendicular to the outflow axis: 18236–1205, 18316–0602, G34.43+0.2M1, and 19095+0930. For these sources, the interpretation of a rotating envelope perpendicular to the bipolar outflow is plausible. In other cases, such as G23.60+0.0M1, the velocity gradient is parallel to the outflow axis and therefore it likely traces the outflowing gas. However, we have estimated a “dynamical mass” for all the sources with a velocity gradient, assuming they are rotating structures, from the following equation:

$$M_{\text{dyn}} = \frac{V_{\text{rot}}^2 R}{G} \quad (7)$$

where V_{rot} is the rotation velocity, R is half the extension of the velocity gradient, and G the universal gravitational constant. This equation assumes equilibrium between centrifugal

Table 11. Specific angular momentum of 4 sources at two different scales.

Source	M_{dust} ($M_{\odot}$)	r^a (pc)	l^b (km s^{-1} pc)	r_{ini}^c (pc)	l_{ini}^d (km s^{-1} pc)
18236–1205	780	0.17	0.08	15	7
18316–0602	1000	0.23	0.14	17	9
G34.43+0.2M1	301	0.22	0.07	11	4
19095+0930	500	0.23	0.15	13	6

Notes. ^(a) Radius of the rotating clump: half the extension of the $\text{C}^{18}\text{O}(2-1)$ velocity gradient; ^(b) specific angular momentum of the clump; ^(c) radius of the initial clump (assuming $n_{\text{H}_2} \sim 1 \text{ cm}^{-3}$); ^(d) estimated specific angular momentum of the initial clump.

and gravitational forces, and since V_{rot} is not corrected for inclination it provides only a lower limit to the actual dynamical mass. Both V_{rot} and M_{dyn} are presented in Table A.4. Our values are small compared to the other clump mass estimates, which is consistent with the result derived by López-Sepulcre et al. (2009), and leads to the conclusion that at present rotation is not dynamically relevant in the clumps of our sample.

Assuming the velocity gradient present in the four sources above is due to rotational motions, we can study the conservation of the specific angular momentum, l , on them. Using V_{rot} in Table A.4, and the radius, r of each clump presented in Table 11, we derive the values of l reported in Col. 4 of the same table, which range between 0.07 and 0.15 km s^{-1} pc. These values can be compared with the initial specific angular momentum of the parental clumps, l_{ini} . Under the assumption that the initial clump angular momentum is due to the Galactic differential rotation, i.e. for an angular velocity $\omega \sim 10^{-15} \text{ s}^{-1}$ (Clemens 1985), and that the molecular clumps were formed from larger spheres of gas at a density of 1 cm^{-3} (typical of the interstellar medium), we derive, for each of the four sources, the initial clump radius, r_{ini} , and initial specific angular momentum, l_{ini} , listed in Table 11. The latter are on the order of a few km s^{-1} pc, between one and two orders of magnitude higher than the (sub)parsec scale values. This indicates that there is a loss of specific angular momentum when going from large scales (i.e. ~ 10 pc) to scales of about 1 pc or less, a result which was already found by López-Sepulcre et al. (2009) for G10.62–0.38, and which supports magnetic braking as a mechanism that removes angular momentum from the clump during its collapse (e.g. Mouschovias & Morton 1985; Galli et al. 2006). A more complete analysis of the conservation of l , such as the one carried out by Ohashi et al. (1999, see their Fig. 2) for a sample of low-mass protostars, requires further measurements at smaller scales.

5.5. $\text{HCO}^+(1-0)$ versus $\text{HCN}(1-0)$

HCN and HCO^+ are commonly used as tracers of the dense gas from which “bursts” of star formation emanate both in the Galactic and extragalactic contexts (Wu et al. 2005; Gao & Solomon 2004). They have the advantage relative to CO that their dipole moments are high and hence that even their 3 mm transitions trace gas of density above $\sim 10^4 \text{ cm}^{-3}$. On the other hand, they both are “minor species” in that they in general trace a small fraction of C, N, O and hence their abundances tend to be more sensitive to the quirks of chemistry (CO in contrast takes up essentially all gas phase C). One test of the stability of their abundances is to examine the variability of the $[\text{HCO}^+]/[\text{HCN}]$ ratio or, more practically, of the intensity ratio of their 3 mm transitions and in this section, we consider the dispersion in our observed values of this ratio.

It should be noted while doing this that, as we shall see, abundance ratio variations are *not* the only factor causing variations in $R = I(\text{HCO}^+(1-0))/I(\text{HCN}(1-0))$, where I is the velocity integrated intensity of the line specified in brackets. Radiative transport as well perhaps as temperature variations may also be important and these must be considered. One should also realise that there are notable chemical differences between HCN and HCO^+ . Most obviously, the HCO^+ abundance is linked via ion-molecule reactions to that of CO as well as to the general ionization equilibrium. HCN on the other hand is linked to the hydrocarbon chemistry as well as to the amount of nitrogen in the gas phase. Thus elemental depletion onto dust grains (as presumably in IR-dark clumps) can have a considerable effect on the abundance of species like HCN and one can expect abundance variations linked to grain temperature (see the recent discussion of Hily-Blant et al. 2010, for example).

With this in mind, we have computed R for each of our sample sources from the velocity-integrated emission under the $\text{HCO}^+(1-0)$ and $\text{HCN}(1-0)$ lines at the same offset coordinates used for the calculation of δV (Col. 2 in Table A.7). The resulting values and their errors are listed in Table A.8.

When plotting this quantity as a function of clump mass or surface density for IR-dark and IR-loud sources separately (Fig. 17), the difference between the two types of objects is evident: even though there is no clear correlation between R and M_{dust} or Σ for either of the two sub-samples, the points corresponding to the IR-dark clumps are more spread, spanning a larger range, and the average ratio is higher. The mean ratios and standard deviations for the IR-dark and IR-loud subsamples are, respectively, 1.3 ± 1.0 and 0.74 ± 0.21 . Thus there is much more dispersion in the IR-dark than in the IR-loud sub-sample.

As can be seen from the histograms in Fig. 18, the emission of both the $\text{HCO}^+(1-0)$ and $\text{HCN}(1-0)$ lines is generally weaker among the IR-dark clumps, which is not so unexpected taking into account that they are colder. However, the $\text{HCN}(1-0)$ emission has been found to be particularly weak relative to the $\text{HCO}^+(1-0)$ emission in many IR-dark sources, as evidenced by some maps and spectra in Figs. B.1 and B.2.

Considering the IR-loud sub-sample, R covers a range of values between 0.3 and 1.1. There are two IR-dark clumps (G19.27+0.1M2 and G23.60+0.0M2) that fall below this range. These are actually the weakest $\text{HCO}^+(1-0)$ emitters in the whole sample, but not the weakest $\text{HCN}(1-0)$ emitters, and hence the low R values. On the other hand, eight IR-dark sources lie above $R = 1.1$. Examining the spectra and maps of these sources, one notes that (a) there are a few cases (examples are G19.27+0.1M1 and G25.04–0.2M4) where there is an offset of more than $10''$ between the HCN and HCO^+ peaks and (b) there are some spectra where there appears to be severe self-absorption of the blue wing of the HCN line. Examples of the latter are the four IR-dark

Fig. 17. Ratio of $\text{HCO}^+(1-0)$ to $\text{HCN}(1-0)$ line emission against clump mass (*left*) and against surface density (*right*).

Fig. 18. Histogram of the $\text{HCO}^+(1-0)$ (*left*) and $\text{HCN}(1-0)$ (*right*) velocity-integrated line emission.

sources G24.33+0.1M4, G24.60+0.1M2, G25.04–0.2M1, and G25.04–0.2M2 and we compare in Fig. 19 the HCO^+ and HCN spectra. While the hyperfine splitting of HCN renders the interpretation difficult, the evidence suggests strong self absorption in HCN due presumably to a foreground low density layer with relatively large HCN abundance. This as well as the offsets between map peaks suggests to us the presence of abundance gradients with density and we conclude that it would be very helpful to obtain maps in higher J transitions of these species to compare with the present results. It would certainly also be useful to obtain observations of the ^{13}C isotopomers of HCN and HCO^+ .

In conclusion, the diversity of R values measured for the IR-dark clumps contrasts with the relative uniformity of R found in the IR-loud subsample. We suspect that this reflects abundance gradients within IR-dark clumps possibly linked to freeze out of heavy elements upon grain surfaces at low dust temperatures. We note in this context that some IRDCs are known to have a “nitrogen-rich” chemistry with strong ammonia and

N_2H^+ emission (Wang et al. 2008; Pillai et al. 2006; Fontani et al. 2006). In local clouds, this is linked to freeze out of CO at high densities and low temperatures and it seems reasonable to assume that an analogous process operates in IR-dark clumps. IR-loud sources probably have larger grain temperatures at which CO and other volatile species evaporate.

Finally, our findings have also relevance for the extragalactic community, who make use of the HCN molecule to estimate the amount of dense molecular gas and correlate it to the star formation rate in galaxies (see Wu et al. 2005, for a Galactic and extragalactic analysis on the matter). It is interesting that our mean value for the $\text{HCO}^+(1-0)$ to $\text{HCN}(1-0)$ ratio of 0.74 for the IR-loud sub-sample is not greatly different than that (a median of 0.86) found by Krips et al. (2008) for a sample of AGN and starburst galaxies (though with a variation from 0.48 to 1.5). As remarked above concerning the IR-dark sub-sample, a thorough study of the HCO^+/HCN abundance ratio in our sample would be interesting in its own right as well as producing useful insight into the mechanisms operating in extragalactic starbursts.

Fig. 19. HCN(1–0) spectrum (black) superimposed on the HCO⁺(1–0) spectrum (green) of the IR-dark sources G24.33+0.1M4, G24.60+0.1M2, G25.04–0.2M1, and G25.04–0.2M2. The dashed vertical line marks the peak velocity of the C¹⁸O(2–1) spectrum. We note that the velocity in the case of the HCN(1–0) line has been calculated with respect to the main hyperfine component. The three purple vertical lines mark the positions of the HCN(1–0) satellite components.

6. Summary

We mapped in HCO⁺(1–0), HCN(1–0), and C¹⁸O(2–1) a sample of 19 IR-dark and 30 IR-loud high-mass molecular clumps with the IRAM-30 m telescope near Pico Veleta (Spain), to search for star formation activity signatures, such as infalling motions and molecular outflows, and try to look for evolutionary trends and constraints on the formation of massive stars.

Our main conclusions are the following:

1. An estimate of the clump masses has been derived from the emission under the C¹⁸O(2–1) line. For the IR-loud clumps, these agree with the masses derived from the dust continuum emission at 1.2 mm. By contrast, the C¹⁸O-derived masses of the IR-dark clumps are systematically smaller than the continuum-derived masses, due to either underestimated excitation temperatures, and/or CO depletion in these regions. Considering the latter, we obtain a median CO depletion factor of 4.5 for our IR-dark sub-sample. Taking this into account, we find the clump masses are comparable to the virial masses in the whole sample, and that M_{clump} becomes greater than M_{vir} for the most massive objects, indicating they may be unstable under gravitational collapse. We estimate that a magnetic field of a few mG is sufficient to support these clumps against collapse.
2. From the presence of high-velocity HCO⁺(1–0) wings, we have detected molecular outflows in 75% of our sample sources. For these, the outflow parameters have been derived, finding they are high-mass outflows (i.e., between a few and $\sim 100 M_{\odot}$) and thus likely to be driven by massive YSOs. We find molecular outflows are as common, massive and energetic among IR-dark sources as they are among IR-loud sources, indicating both kinds of objects are equally active in the formation of stars and clusters. In addition, our data

allows us to set an empirical outflow threshold surface density at $\Sigma = 0.3 \text{ g cm}^{-2}$ below which the detection rate falls considerably, and the outflows are less massive and energetic on average. This lends support to the theoretical prediction made by Krumholz & McKee (2008), who establish a minimum clump surface density for high-mass star formation to occur. A good correlation is found between outflow parameters and clump mass, with more massive and energetic outflows corresponding to more massive molecular clumps. Our results also indicate that up to a 20% of the clump mass can be affected by molecular outflows, and therefore outflow feedback may be an important factor in the process of high-mass star/cluster formation.

3. The presence of infall has been assessed by looking for blue-shifted asymmetries in the HCO⁺(1–0) line profiles. With this method, infall detection rates of 13% for the IR-loud, and 32% for the IR-dark clumps have been measured. The higher number of infall candidates in the IR-dark sub-sample suggests these objects are more likely associated with the accretion phase and thus may represent the onset of star or cluster formation. A more detailed study of the kinematics and temperature distribution within the molecular clumps in our sample is necessary to interpret correctly the HCO⁺(1–0) line profiles.
4. About half of our sample sources present C¹⁸O(2–1) velocity gradients. In four cases these are perpendicular to the outflow axis, and could therefore represent a rotating envelope around the bipolar outflow. The low dynamical masses implied by the velocity gradients measured suggest that rotation is not dynamically relevant in our sample. We also conclude from our estimates of specific angular momentum in these clumps that this quantity is at least an order of magnitude lower than that expected on the basis of differential galactic rotation and hence that magnetic braking has led to angular momentum loss.
5. On average, the HCO⁺(1–0) to HCN(1–0) line ratio is greater and presents much more scattering in the IR-dark sub-sample. Inspection of the clump morphologies in the integrated maps indicates that these two molecules may trace different regions of the IR-dark clumps. This, together with the discovery of a number of IR-dark sources which display highly self-absorbed HCN(1–0) line profiles, suggests that the ground state lines are sensitive to foreground material at low density, and points to abundance gradients with density.

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References

- Anglada, G., Rodríguez, L. F., Canto, J., et al. 1987, A&A, 186, 280
 Bergin, E. A., & Tafalla, M. 2007, ARA&A, 45, 339
 Beuther, H., Schilke, P., Menten, K. M., et al. 2002a, ApJ, 566, 945
 Beuther, H., Schilke, P., Sridharan, T. K., et al. 2002b, A&A, 383, 892
 Beuther, H., Schilke, P., Menten, K. M., et al. 2005, ApJ, 633, 535
 Bonnell, I. A., & Bate, M. R. 2002, MNRAS, 336, 659
 Bonnell, I. A., Vine, S. G., & Bate, M. R. 2004, MNRAS, 349, 735
 Brand, J. 1986, Ph.D. Thesis, Leiden University
 Bronfman, L., Nyman, L. Å., & May, J. 1996, A&AS, 115, 81
 Carey, S. J., Clark, F. O., Egan, M. P., et al. 1998, ApJ, 508, 721

- Carey, S. J., Feldman, P. A., Redman, R. O., et al. 2000, *ApJ*, 543, L157
- Cesaroni, R., Galli, D., Lodato, L., Walmsley, C. M., & Zhang, Q. 2007, *PPV* (Tucson: Univ. Arizona Press), 197
- Clemens, D. P. 1985, *ApJ*, 295, 422
- Egan, M. P., Shipman, R. F., Price, S. D., et al. 1998, *ApJ*, 494, 199
- Faúndez, S., Bronfman, L., Garay, G., et al. 2004, *A&A*, 426, 97
- Fontani, F., Cesaroni, R., Caselli, P., & Olmi, L. 2002, *A&A*, 389, 603
- Fontani, F., Caselli, P., Crapsi, A., et al. 2006, *A&A*, 460, 709
- Fuller, G. A., Williams, S. J., & Sridharan, T. K. 2005, *A&A*, 442, 949
- Galli, D., Lizano, S., Shu, F. H., & Allen, A. 2006, *ApJ*, 647, 374
- Gao, Y., & Solomon, M. 2004, *ApJ*, 606, 271
- Hill, T., Burton, M. G., Minier, V., et al. 2005, *MNRAS*, 363, 405
- Hily-Blant, P., Walmsley, C. M., Pineau des Forêts, G., & Flower, D. 2010, *A&A*, 513, A41
- Hofner, P., Wyrowski, F., Walmsley, C. M., & Churchwell, E. 2000, *ApJ*, 536, 393
- Keto, E. 2002, *ApJ*, 580, 980
- Krips, M., Neri, R., García-Burillo, S., et al. 2008, *ApJ*, 677, 262
- Krumholz, M. R., & McKee, C. F. 2008, *Nature*, 451, 1082
- Krumholz, M. R., Klein, R. I., McKee, C. F., et al. 2009, *Science* 323, 754
- Kwan, J., & Scoville, N. 1975, *ApJ*, 195, L85
- Irvine, W. M., Goldsmith, P. F., & Hjalmarson, Å. 1987, *ASSL*, 134, 561
- Liszt, H., Lucas, R., & Black, J. H. 2004, *A&A*, 428, 117
- López-Sepulcre, A., Codella, C., Cesaroni, R., et al. 2009, *A&A*, 499, 811
- MacLaren, I., Richardson, K. M., & Wolfendale, A. W. 1988, *ApJ*, 333, 821
- Mardones, D., Myers, P. C., Tafalla, M., et al. 1997, *ApJ*, 489, 719
- Martí, J., Rodríguez, L. F., & Reipurth, B. 1998, *ApJ*, 502, 337
- McKee, C. F., & Tan, J. C. 2003, *ApJ*, 585, 850
- McKee, C. F., Zweibel, E. G., Goodman, A. A., & Heiles, C. 1993, in *Protostars and Planets III*, ed. E. H. Levy, & J. I. Lunine, 327
- Menten, K. M., Pillai, T., & Wyrowski, F. 2005, in *Massive Star Birth: A crossroads of Astrophysics*, ed. R. Cesaroni, M. Felli, E. Churchwell, & C. M. Walmsley (Cambridge: Cambridge Univ. Press), *Proc. IAU*, 227, 23
- Mouschovias, T. C., & Morton, S. A. 1985, *ApJ*, 298, 190
- Ohashi, N. 1999, in *Star Formation*, ed. T. Nakamoto, *NRO*, 129
- Ossenkopf, V., & Henning, Th. 1994, *A&A*, 291, 943
- Palla, F., & Stahler, S. 1993, *ApJ*, 418, 414
- Pérault, M., Omont, A., Simon, G., et al. 1996, *A&A*, 315, L165
- Pillai, T., Wyrowski, F., Carey, S. J., & Menten, K. M. 2006, *A&A*, 450, 569
- Rathborne, J. M., Jackson, J. M., & Simon, R. 2006, *ApJ*, 641, 389
- Rathborne, J. M., Simon, R., & Jackson, J. M. 2007, *ApJ*, 662, 1082
- Rathborne, J. M., Jackson, J. M., Zhang, Q., & Simon, R. 2008, *ApJ*, 689, 1141
- Simon, R., Rathborne, J. M., Shah, R. Y., et al. 2006, *ApJ*, 653, 1325
- Sridharan, T. K., Beuther, H., Saito, M., et al. 2005, *ApJ*, 634, L57
- Tomisaka, K. 1998, *ApJ*, 502, L163
- Townes, C. H., & Schawlow, A. L. 1955, *Microwave Spectroscopy* (New York: McGraw-Hill)
- Wilson, T. L., & Rood, R. T. 1994, *ARA&A*, 32, 191
- Wang, Y., Zhang, Q., Pillai, T., et al. 2008, *ApJ*, 672, L33
- Wang, P., Li, Z. Y., Abel, T., & Nakamura, F. 2010, *ApJ*, 709, 27
- Wu, J., & Evans II, N. J. 2003, *ApJ*, 592, L79
- Wu, J., Evans II, N. J., Gao, Y., et al. 2005, *ApJ*, 635, L173
- Yorke, H. W., & Sonnhalter, C. 2002, *ApJ*, 569, 846
- Zhou, S. 1992, *ApJ*, 394, 204

Appendix A: Tables

Table A.1. 1σ rms values, first contour, and contour step of the clump maps in Fig. B.1 (grey scale).

Source	HCO ⁺ (1–0)			HCN(1–0)			C ¹⁸ O(2–1)		
	1σ rms (K)	1st contour	Step	1σ rms (K)	1st contour	Step	1σ rms (K)	1st contour	Step
05358+3543	0.020	20 σ	20 σ	0.020	20 σ	20 σ	0.12	5 σ	5 σ
G213.61–12.6	0.015	20 σ	6 σ	0.015	20 σ	10 σ	0.12	5 σ	5 σ
G189.78+0.34	0.020	20 σ	20 σ	0.020	20 σ	15 σ	0.16	5 σ	5 σ
G192.58–0.04	0.020	20 σ	20 σ	0.020	20 σ	20 σ	0.47	5 σ	1 σ
G192.60–0.05	0.020	20 σ	15 σ	0.020	20 σ	20 σ	0.14	5 σ	5 σ
18151–1208_2	0.020	20 σ	20 σ	0.010	20 σ	20 σ	0.12	5 σ	1 σ
18151–1208_3	0.020	20 σ	20 σ	0.010	20 σ	20 σ	0.12	5 σ	2 σ
18151–1208_1	0.020	20 σ	20 σ	0.015	20 σ	20 σ	0.12	5 σ	2 σ
G18.15–0.28	0.010	20 σ	20 σ	0.010	20 σ	20 σ	0.12	5 σ	5 σ
G18.18–0.30	0.010	20 σ	20 σ	0.010	20 σ	10 σ	0.27	5 σ	5 σ
18223–1243	0.010	20 σ	20 σ	0.010	20 σ	20 σ	0.16	5 σ	5 σ
18228–1312	0.010	20 σ	10 σ	0.025	10 σ	5 σ	0.10	5 σ	5 σ
G19.27+0.1M2	0.010	10 σ	5 σ	0.010	10 σ	5 σ	0.11	5 σ	3 σ
G19.27+0.1M1	0.020	10 σ	5 σ	0.010	10 σ	5 σ	0.18	5 σ	2 σ
18236–1205	0.010	20 σ	5 σ	0.020	20 σ	5 σ	0.16	5 σ	5 σ
18264–1152	0.010	20 σ	40 σ	0.030	20 σ	10 σ	0.18	5 σ	1 σ
G23.60+0.0M1	0.010	20 σ	20 σ	0.020	20 σ	5 σ	0.37	5 σ	3 σ
18316–0602	0.010	20 σ	10 σ	0.010	20 σ	10 σ	0.10	5 σ	5 σ
G23.60+0.0M2	0.020	10 σ	2 σ	0.020	10 σ	4 σ	0.19	5 σ	2 σ
18317–0513	0.010	20 σ	30 σ	0.020	20 σ	10 σ	0.14	5 σ	5 σ
G24.08+0.0M2	0.020	10 σ	5 σ	0.020	5 σ	5 σ	0.33	3 σ	1 σ
G24.33+0.1M1	0.020	10 σ	5 σ	0.020	5 σ	3 σ	0.13	5 σ	5 σ
G24.33+0.1M4	0.020	5 σ	3 σ	0.020	5 σ	3 σ	0.08	5 σ	3 σ
G24.33+0.1M2	0.020	5 σ	4 σ	0.015	10 σ	3 σ	0.13	5 σ	2 σ
G24.60+0.1M2	0.025	10 σ	5 σ	0.020	5 σ	5 σ	0.44	3 σ	1 σ
G24.60+0.1M1	0.010	20 σ	10 σ	0.015	5 σ	5 σ	0.14	5 σ	2 σ
G25.04–0.2M1	0.015	10 σ	10 σ	0.015	5 σ	3 σ	0.21	5 σ	2 σ
G25.04–0.2M4	0.020	10 σ	3 σ	0.020	5 σ	2 σ	0.56	—*	—*
G25.04–0.2M2	0.015	10 σ	5 σ	0.010	5 σ	3 σ	0.20	3 σ	2 σ
G28.28–0.35	0.020	10 σ	5 σ	0.015	10 σ	5 σ	0.14	5 σ	5 σ
18507+0121	0.010	20 σ	10 σ	0.020	20 σ	5 σ	0.40	3 σ	1 σ
G34.43+0.2M1	0.010	20 σ	10 σ	0.020	20 σ	5 σ	0.42	3 σ	1 σ
G34.43+0.2M3	0.020	20 σ	10 σ	0.010	20 σ	10 σ	0.39	—*	—*
G34.24+0.13	0.010	20 σ	20 σ	0.010	20 σ	10 σ	0.11	5 σ	5 σ
18517+0437	0.030	20 σ	20 σ	0.020	20 σ	10 σ	0.31	5 σ	2 σ
G34.77–0.6M2	0.015	10 σ	3 σ	0.030	5 σ	3 σ	0.12	5 σ	3 σ
G35.39–0.3M4	0.015	20 σ	10 σ	0.020	10 σ	5 σ	0.15	5 σ	1 σ
G38.95–0.5M1	0.015	20 σ	10 σ	0.020	10 σ	5 σ	0.14	5 σ	4 σ
19035+0641	0.010	20 σ	10 σ	0.020	20 σ	5 σ	0.09	5 σ	3 σ
19095+0930	0.020	20 σ	10 σ	0.010	20 σ	20 σ	0.09	5 σ	5 σ
20216+4107	0.010	20 σ	20 σ	0.015	20 σ	10 σ	0.09	5 σ	1 σ
20332+4124	0.020	20 σ	10 σ	0.020	10 σ	5 σ	0.09	5 σ	3 σ
22134+5834	0.010	20 σ	10 σ	0.020	10 σ	5 σ	0.09	5 σ	3 σ
22570+5912_2	0.020	20 σ	10 σ	0.015	20 σ	5 σ	0.09	5 σ	1 σ
22570+5912_1	0.020	20 σ	10 σ	0.020	10 σ	5 σ	0.21	5 σ	2 σ
23033+5951	0.020	20 σ	20 σ	0.020	20 σ	10 σ	0.20	5 σ	3 σ
23139+5939	0.015	20 σ	20 σ	0.010	20 σ	20 σ	0.14	5 σ	3 σ
23151+5912	0.020	10 σ	5 σ	0.010	20 σ	10 σ	0.18	5 σ	3 σ

Notes. (*) No C¹⁸O(2–1) map shown in Fig. B.1 (see text).

Table A.2. Gaussian fit to C¹⁸O(2–1) spectra at peak coordinates*.

Source	V_{LSR} (km s ⁻¹)	$FWHM$ (km s ⁻¹)	T_{MB} (K)	$\int T_{\text{MB}} dV$ (K km s ⁻¹)
05358+3543	-16.7 (0.2)	4.2 (0.5)	2.9 (0.5)	13.0 (1.3)
G213.61-12.6	10.0 (0.1)	2.7 (0.2)	7.6 (0.6)	21.6 (1.1)
G189.78+0.34	9.0 (0.1)	3.0 (0.1)	6.9 (0.4)	22.1 (0.9)
G192.58-0.04	9.1 (0.1)	2.9 (0.3)	8.8 (0.7)	27.0 (0.5)
G192.60-0.05	7.4 (0.1)	3.3 (0.2)	7.4 (0.6)	25.9 (1.1)
18151-1208_2 ^b	30.0 (0.4)	3.5 (1.0)	3.3 (1.3)	12.5 (2.8)
18151-1208_3	30.4 (0.1)	1.4 (0.1)	10.5 (0.2)	15.1 (1.2)
18151-1208_1	33.6 (0.2)	3.3 (0.4)	9.8 (1.5)	34.4 (3.4)
G18.15-0.28	55.2 (0.1)	3.2 (0.1)	13.4 (0.7)	46.3 (1.3)
G18.18-0.30	50.1 (0.1)	3.0 (0.2)	10.0 (0.9)	31.7 (1.6)
18223-1243	45.0 (0.1)	3.0 (0.1)	13.0 (0.9)	40.8 (1.7)
18228-1312	33.1 (0.1)	4.2 (0.2)	8.5 (0.6)	37.5 (1.4)
G19.27+0.1M2	26.8 (0.1)	2.3 (0.3)	3.7 (0.6)	9.1 (0.9)
G19.27+0.1M1 ^a	26.3 (0.2)	1.7 (0.3)	2.8 (0.8)	5.2 (1.1)
18236-1205	26.3 (0.1)	3.3 (0.1)	9.2 (0.5)	32.6 (1.0)
18264-1152	43.8 (0.1)	3.1 (0.4)	7.7 (1.1)	25.8 (2.5)
G23.60+0.0M1	106.0 (0.1)	3.7 (0.3)	6.6 (0.5)	25.5 (1.5)
18316-0602	42.6 (0.1)	4.8 (0.2)	8.0 (0.6)	41.3 (1.5)
G23.60+0.0M2	53.5 (0.1)	2.9 (0.3)	4.3 (0.6)	13.2 (1.1)
18317-0513	41.7 (0.1)	2.3 (0.1)	9.9 (0.6)	24.8 (1.0)
G24.08+0.0M2	51.9 (0.3)	1.9 (0.5)	3.2 (1.2)	6.4 (1.7)
G24.33+0.1M1	112.9 (0.1)	3.5 (0.3)	5.1 (0.7)	19.1 (1.4)
G24.33+0.1M4 ^c	114.0 (0.3)	5.5 (0.7)	2.6 (0.3)	15.3 (1.8)
G24.33+0.1M2	117.7 (0.2)	3.8 (0.4)	3.3 (0.6)	13.2 (1.2)
G24.60+0.1M2 ^c	114.6 (0.2)	3.7 (0.6)	4.1 (0.5)	16.1 (2.2)
G24.60+0.1M1	53.6 (0.1)	2.8 (0.3)	3.6 (0.4)	10.6 (1.0)
G25.04-0.2M1	63.6 (0.1)	2.2 (0.2)	6.3 (0.4)	14.8 (0.9)
G25.04-0.2M4 ^{a,b}	62.9 (0.4)	2.5 (1.0)	2.7 (1.5)	7.1 (2.5)
G25.04-0.2M2	63.3 (0.1)	2.5 (0.3)	2.9 (0.4)	7.7 (0.8)
G28.28-0.35	48.2 (0.1)	3.6 (0.1)	7.6 (0.5)	29.0 (1.0)
18507+0121	58.0 (0.2)	6.0 (0.5)	6.9 (1.4)	43.4 (3.4)
G34.43+0.2M1	58.0 (0.3)	4.8 (0.8)	4.5 (1.2)	23.3 (2.8)
G34.43+0.2M3	58.5 (0.2)	2.3 (0.6)	4.1 (0.5)	10.1 (2.1)
G34.24+0.13	56.9 (0.1)	2.6 (0.1)	14.0 (0.5)	38.4 (0.8)
18517+0437	44.1 (0.1)	2.7 (0.3)	10.4 (1.6)	29.4 (2.7)
G34.77-0.6M2 ^{b,d}	43.2 (0.7)	6.2 (1.4)	1.0 (0.5)	6.4 (1.3)
G35.39-0.3M4 ^b	45.1 (0.2)	1.3 (0.3)	1.6 (0.2)	2.2 (0.6)
G38.95-0.5M1	42.2 (0.1)	3.1 (0.2)	5.7 (0.4)	19.0 (0.8)
19035+0641	32.8 (0.2)	5.7 (0.5)	3.0 (0.4)	18.0 (1.1)
19095+0930	43.9 (0.1)	5.8 (0.2)	8.8 (0.5)	54.7 (1.4)
20216+4107	-1.4 (0.1)	1.5 (0.2)	7.0 (0.5)	11.2 (1.0)
20332+4124	-2.6 (0.1)	3.0 (0.3)	6.9 (0.8)	21.9 (1.6)
22134+5834	-18.3 (0.1)	2.3 (0.1)	7.2 (0.6)	17.3 (0.9)
22570+5912_2 ^{a,b}	-48.5 (0.7)	3.2 (1.7)	1.9 (0.8)	6.4 (2.1)
22570+5912_1	-45.7 (0.1)	2.5 (0.3)	4.7 (0.6)	12.6 (1.0)
23033+5951	-53.6 (0.1)	3.1 (0.2)	6.4 (0.7)	20.9 (1.4)
23139+5939	-44.1 (0.1)	3.7 (0.2)	4.7 (0.5)	18.8 (1.0)
23151+5912	-54.6 (0.1)	3.2 (0.3)	5.5 (0.6)	18.6 (1.2)

Notes. (*) The errors are indicated in brackets; (^a) fit to spectrum at HCO⁺(1–0) peak coordinates; (^b) weak line and/or noisy spectrum: bad fit; (^c) C¹⁸O line outside VESPA unit limits: 1 MHz spectrum used; (^d) fit to spectrum at offset coordinates (−13.3'', −9.0'') (see HCO⁺(1–0) and HCN(1–0) integrated maps in Fig. B.1).

Table A.3. Gaussian fit to HCO⁺(1–0) spectra at peak coordinates* .

Source	V_{LSR} (km s ⁻¹)	$FWHM$ (km s ⁻¹)	T_{MB} (K)	$\int T_{\text{MB}} dV$ (K km s ⁻¹)
05358+3543 ^a	-16.0 (0.1)	3.7 (0.1)	11.2 (0.6)	44.1 (0.5)
G213.61-12.6	9.2 (0.1)	1.9 (0.1)	8.8 (0.5)	18.0 (0.4)
G189.78+0.34	9.2 (0.1)	3.8 (0.1)	8.4 (0.4)	34.0 (0.3)
G192.58-0.04	8.9 (0.1)	3.2 (0.1)	10.4 (0.3)	35.5 (0.6)
G192.60-0.05	7.8 (0.1)	4.2 (0.1)	7.1 (0.2)	31.7 (0.5)
18151-1208_2	30.0 (0.1)	3.6 (0.1)	10.2 (0.2)	38.9 (0.5)
18151-1208_3	30.7 (0.1)	2.2 (0.1)	6.5 (0.2)	15.0 (0.4)
18151-1208_1	33.2 (0.1)	2.8 (0.1)	12.6 (0.3)	37.9 (0.5)
G18.15-0.28	55.6 (0.1)	4.9 (0.1)	4.5 (0.5)	23.7 (0.4)
G18.18-0.30	49.5 (0.1)	5.1 (0.2)	3.9 (0.2)	20.9 (0.6)
18223-1243 ^a	45.4 (0.1)	4.4 (0.2)	4.5 (0.2)	20.9 (0.7)
18228-1312 ^a	32.9 (0.1)	4.8 (0.1)	9.2 (0.3)	46.6 (0.9)
G19.27+0.1M2 ^b	25.1 (0.7)	9.9 (1.7)	0.4 (0.2)	4.4 (0.6)
G19.27+0.1M1	29.4 (0.2)	4.6 (0.6)	0.8 (0.2)	4.0 (0.4)
18236-1205 ^{a,b}	26.6 (0.4)	13.2 (1.1)	1.3 (0.2)	17.7 (1.2)
18264-1152	43.6 (0.1)	4.6 (0.1)	13.0 (0.6)	63.9 (0.1)
G23.60+0.0M1 ^a	106.9 (0.1)	5.2 (0.1)	4.4 (0.1)	24.4 (0.5)
18316-0602 ^a	43.3 (0.1)	10.2 (0.2)	4.6 (0.3)	49.7 (0.8)
G23.60+0.0M2 ^{a,b}	54.0 (0.6)	8.7 (1.1)	0.9 (0.2)	8.1 (1.1)
18317-0513	41.9 (0.0)	2.2 (0.0)	9.4 (0.2)	21.5 (0.3)
G24.08+0.0M2	51.9 (0.1)	2.6 (0.3)	2.1 (0.4)	5.9 (0.5)
G24.33+0.1M1	112.0 (0.1)	4.2 (0.4)	1.4 (0.1)	6.3 (0.4)
G24.33+0.1M4	118.2 (0.2)	3.5 (0.6)	0.9 (0.2)	3.4 (0.5)
G24.33+0.1M2 ^a	117.9 (0.2)	6.9 (0.7)	1.7 (0.2)	12.4 (1.6)
G24.60+0.1M2	114.9 (0.2)	4.5 (0.4)	1.7 (0.3)	8.3 (0.6)
G24.60+0.1M1 ^a	52.9 (0.1)	5.0 (0.1)	5.2 (0.2)	27.7 (1.3)
G25.04-0.2M1 ^a	63.7 (0.1)	4.6 (0.2)	3.7 (0.2)	18.4 (0.9)
G25.04-0.2M4 ^a	63.6 (0.1)	4.1 (0.4)	3.2 (0.3)	14.1 (1.4)
G25.04-0.2M2 ^a	63.8 (0.1)	4.6 (0.3)	2.6 (0.2)	12.6 (0.7)
G28.28-0.35 ^a	48.4 (0.2)	7.4 (0.5)	1.8 (0.2)	14.5 (0.9)
18507+0121 ^a	59.6 (0.2)	8.2 (0.4)	3.2 (0.3)	27.9 (1.8)
G34.43+0.2M1 ^a	59.0 (0.2)	6.1 (0.3)	3.6 (0.3)	23.4 (1.2)
G34.43+0.2M3	60.7 (0.1)	4.0 (0.2)	4.6 (0.3)	19.5 (0.6)
G34.24+0.13 ^a	56.6 (0.1)	2.5 (0.1)	5.6 (0.2)	14.8 (0.5)
18517+0437	43.9 (0.1)	3.6 (0.1)	12.3 (0.3)	46.8 (0.6)
G34.77-0.6M2 ^c	44.1 (0.1)	2.7 (0.3)	10.4 (1.6)	29.4 (2.7)
G35.39-0.3M4	42.9 (0.1)	2.1 (0.2)	2.7 (0.1)	6.1 (0.5)
G38.95-0.5M1 ^a	42.3 (0.1)	3.6 (0.1)	4.9 (0.3)	18.7 (0.7)
19035+0641	32.4 (0.1)	3.6 (0.1)	3.4 (0.3)	12.9 (0.4)
19095+0930 ^a	44.0 (0.1)	6.9 (0.1)	6.0 (0.4)	44.1 (0.7)
20216+4107	-1.6 (0.0)	2.4 (0.1)	5.9 (0.2)	15.1 (0.3)
20332+4124	-3.1 (0.1)	3.1 (0.1)	3.4 (0.1)	11.2 (0.4)
22134+5834 ^a	-18.2 (0.1)	3.3 (0.2)	2.9 (0.2)	10.1 (0.4)
22570+5912_2	-48.2 (0.0)	2.5 (0.1)	4.5 (0.2)	12.2 (0.4)
22570+5912_1	-45.6 (0.0)	2.8 (0.1)	3.9 (0.2)	11.5 (0.3)
23033+5951	-53.2 (0.0)	4.3 (0.1)	9.0 (0.2)	40.9 (0.5)
23139+5939	-44.6 (0.1)	5.0 (0.1)	4.6 (0.3)	24.0 (0.5)
23151+5912	-54.6 (0.1)	3.9 (0.3)	1.4 (0.1)	5.9 (0.4)

Notes. ^(*) The errors are indicated in brackets; ^(a) self-absorption masked (see text); ^(b) bad fit due to noisy spectrum or considerable self-absorption; ^(c) fit to spectrum at offset coordinates (-13.3'', -9.0'') arcsec (see HCO⁺(1–0) and HCN(1–0) integrated maps in Fig. B.1).

Table A.4. Deconvolved C¹⁸O(2–1) clump diameter, Galactocentric distance and various mass estimates.

Source	D (pc)	R_{gal} (kpc)	T_{dust} (K)	$M_{\text{clump}}(T_{\text{dust}})$ ($M_{\odot}$)	$M_{\text{clump}}(T = 15\text{--}60\text{ K})$ ($M_{\odot}$)	M_{vir} ($M_{\odot}$)	M_{dust} ($M_{\odot}$)	V_{rot} (km s ^{−1})	M_{rot} ($M_{\odot}$)
05358+3543 ^a	0.44	10.3	47	129	86–153	815	127	—	—
G213.61–12.6	0.45	10.3	20	196	192–345	344	1800	—	—
G189.78+0.34	0.24	10.3	20	55	53–96	227	150	—	—
G192.58–0.04	0.26	11.1	20	94	92–164	230	500	—	—
G192.60–0.05	0.31	11.1	20	138	135–241	354	460	—	—
18151–1208_2 ^a	0.63	5.7	18.5 ^d	173	172–306	810	475	—	—
18151–1208_3	0.52	5.7	47	129	86–153	107	53	0.49	14
18151–1208_1	0.52	5.7	47	250	165–297	595	211	0.56 ^e	15 ^e
G18.15–0.28	0.42	6.1	20	236	231–414	452	280	1.05 ^c	44 ^c
G18.18–0.30	0.34	6.1	20	125	123–219	321	110	0.27	2.2
18223–1243	0.45	5.1	21	202	197–350	425	980	—	—
18228–1312	0.64	5.7	34	542	438–779	1185	740	0.51 ^c	15 ^c
G19.27+0.1M2 ^a	0.44	6.3	15	50	50–90	244	114	—	—
G19.27+0.1M1 ^a	0.35	6.3	15	20	20–35	106	113	—	—
18236–1205	0.36	6.2	26	135	124–220	412	780	0.49	9.4
18264–1152	0.43	3.5	27	121	108–194	434	1100	0.45 ^e	14 ^e
G23.60+0.0M1	0.76	3.8	15	305	305–545	690	580	0.40	12.4
18316–0602	0.44	5.9	30	250	216–383	1064	1000	0.62	25
G23.60+0.0M2	0.53	5.2	15	73	73–130	468	233	—	—
18317–0513	0.43	5.8	31	153	130–230	239	770	0.45	9.6
G24.08+0.0M2 ^a	0.42	5.3	15	21	21–38	159	201	—	—
G24.33+0.1M1	0.57	3.7	15	132	132–235	412	5470	—	—
G24.33+0.1M4	0.65	3.7	15	145	145–257	1175	1390	—	—
G24.33+0.1M2 ^a	0.65	3.6	15	85	85–151	515	417	—	—
G24.60+0.1M2 ^a	0.80	3.7	15	115	115–206	618	1630	0.30 ^e	9.2 ^e
G24.60+0.1M1	0.79	5.4	15	133	133–237	650	192	0.47	20
G25.04–0.2M1	0.93	5.0	15	305	305–543	376	441	0.29 ^e	5.2 ^e
G25.04–0.2M4 ^b	— ^b	5.6	15	— ^b	— ^b	341	491	—	—
G25.04–0.2M2 ^a	0.91	5.0	15	111	111–198	472	166	—	—
G28.28–0.35	0.69	6.2	20	330	324–578	939	650	0.83 ^c	41 ^c
18507+0121	0.64	3.7	28	390	345–614	2419	2000	0.62	19
G34.43+0.2M1 ^a	0.42	5.8	15	73	73–131	1016	1187	0.33	5.5
G34.43+0.2M3 ^a	0.26	5.8	15	73	73–131	144	301	—	—
G34.24+0.13	0.75	5.9	20	737	725–1290	532	140	—	—
18517+0437	0.61	6.4	38	346	262–468	467	504	0.70 ^e	35 ^e
G34.77–0.6M2 ^a	0.70	6.3	15	87	87–155	2825	188	—	—
G35.39–0.3M4 ^a	0.78	6.4	15	95	95–169	138	108	—	—
G38.95–0.5M1	0.69	6.6	15	223	223–398	696	117	—	—
19035+0641	0.24	7.0	51	49	32–55	819	185	0.41 ^e	4.5 ^e
19095+0930	0.33	6.5	34	240	193–345	1166	500	0.67	22
20216+4107	0.30	8.3	46	57	40–69	71	31	0.35	4.0
20332+4124	0.86	8.8	56	789	465–829	813	286	0.83	52
22134+5834	0.46	9.5	61	228	126–226	255	83	—	—
22570+5911_2 ^b	— ^b	11.3	54	— ^b	— ^b	957	131	—	—
22570+5912_1	0.86	11.3	54	646	289–696	564	305	0.42	18
23033+5951	0.59	10.2	52	410	254–454	595	250	—	—
23139+5939	0.65	11.2	41	418	304–459	934	404	0.30	4.9
23151+5912	0.54	11.8	68	574	291–523	581	282	0.34	5.3

Notes. ^(a) Bad quality C¹⁸O maps: M_{clump} and D estimates not reliable; ^(b) C¹⁸O(2–1) map not shown in Fig. B.1: no C¹⁸O(2–1) quantities derived (see text); ^(c) C¹⁸O velocity gradient likely due to multiple components; ^(d) dust temperature from Sridharan et al. (2005); ^(e) C¹⁸O velocity gradient roughly aligned with outflow axis: it may be tracing the outflow.

Table A.5. Outflow detection, velocity range of the HCO⁺(1–0) wings and lobe sizes.

Source	Outflow? (Y/N)	ΔV_{blue} (km s ⁻¹)	ΔV_{red} (km s ⁻¹)	V_{out_b} (km s ⁻¹)	V_{out_r} (km s ⁻¹)	r_b (pc)	r_r (pc)
05358+3543	Y	[-30, -21]	[-13, -6]	13.3	10.7	0.31	0.33
G213.61-12.6	Y	[+0.5, +7.5]	[+13.5, +20]	9.5	10.0	0.42	0.42
G189.78+0.34	Y	[+0.5, +6.5]	[+11.5, +18]	8.5	9.0	0.24	0.19
G192.58-0.04	Y	[+3, +7]	[+11, +13.5]	6.0	4.5	0.36	0.30
G192.60-0.05	Y	[-3, +5]	[+10.5, +16.5]	10.4	9.1	0.46	0.44
18151-1208_2	Y	[+23.5, +27.5]	[+32.5, +37]	6.5	7.0	0.34	0.42
18151-1208_3	N	—	—	—	—	—	—
18151-1208_1	Y	[+28.5, +31]	[+35, +42]	5.2	8.3	0.51	0.44
G18.15-0.28	N	—	—	—	—	—	—
G18.18-0.30	Y	[+42.5, +47]	[+52.5, +57]	7.6	6.9	0.40	0.40
18223-1243	Y	[+37, +43]	[+48, +57]	8.0	12.0	0.50	0.50
18228-1312	Y	[+23.5, +29.5]	[+36.5, +40]	9.5	7.0	0.40	0.40
G19.27+0.1M2	Y	[+21, +24.5]	[+29.5, +34]	5.8	7.2	0.24	0.34
G19.27+0.1M1	Y ^a	[+19, +23.5]	[+30.5, +33.5]	7.3	7.2	0.36	0.18
18236-1205	Y	[+12, +20]	[+34.5, +41]	14.3	14.7	0.25	0.29
18264-1152	Y	[+29.5, +41]	[+47, +56.5]	14.3	12.7	0.45	0.44
G23.60+0.0M1	Y	[+94.5, +103]	[+110, +116.5]	11.7	10.3	0.83	0.70
18316-0602	Y	[+20.5, +37.5]	[+49, +69]	22.0	26.5	0.68	0.68
G23.60+0.0M2	Y	[+41.5, +49]	[+58, +60.5]	12.0	7.0	0.54	0.32
18317-0513	N	—	—	—	—	—	—
G24.08+0.0M2 ^b	Y	[+47.5, +50.5]	[+53.5, +59.5]	7.1	9.4	0.41	0.41
G24.33+0.1M1	Y	[+107, +110.5] ^c	[+114, +125]	5.9 ^c	12.1	0.90	0.90
G24.33+0.1M4	N	—	—	—	—	—	—
G24.33+0.1M2	N	—	—	—	—	—	—
G24.60+0.1M2	Y	[+112.5, +113]	[+116.5, +120.5]	2.0	6.0	0.99	0.79
G24.60+0.1M1	Y	[+45.5, +49.5]	[+57.5, +64.5]	8.1	10.9	0.50	0.45
G25.04-0.2M1	Y	[+58, +61]	[+66, +72.5]	5.5	9.0	0.78	0.78
G25.04-0.2M4	Y	[+59.5, +61]	[+66, +70]	3.4	7.1	0.46	0.46
G25.04-0.2M2	Y	[+59, +61.5]	[+66, +72]	4.3	8.7	0.57	0.57
G28.28-0.35	N	—	—	—	—	—	—
18507+0121	Y	[+44.5, +54.5]	[+62, +72.5]	13.5	14.5	0.64	0.64
G34.43+0.2M1	Y	[+45, +54.5]	[+62.5, +77]	13.0	19.0	0.55	0.55
G34.43+0.2M3	Y	[+50, +57]	[+63, +72]	8.5	13.5	0.64	0.61
G34.24+0.13	N	—	—	—	—	—	—
18517+0437	Y	[+38.5, +41.5]	[+46.5, +49.5]	5.6	5.4	0.46	0.34
G34.77-0.6M2	N	—	—	—	—	—	—
G35.39-0.3M4	N	—	—	—	—	—	—
G38.95-0.5M1	Y	[+31.5, +39.5]	[+44.5, +50.5]	10.7	8.3	0.45	0.45
19035+0641	Y	[+22, +27]	[+38, +42.5]	10.8	9.7	0.22	0.26
19095+0930	Y	[+32.5, +38.5]	[+49, +53.5]	11.4	9.6	0.39	0.47
20216+4107	Y	[-9.5, -3.5]	[+0.5, +3.5]	8.1	4.9	0.28	0.37
20332+4124	N	—	—	—	—	—	—
22134+5834	Y	[-23.5, -20.5]	[-16, -12]	5.2	6.3	0.49	0.37
22570+5911_2	N	—	—	—	—	—	—
22570+5912_1	N	—	—	—	—	—	—
23033+5951	Y	[-64, -56]	[-50, -44]	10.4	9.6	0.63	0.63
23139+5939	Y	[-57.5, -47.5]	[-41, -33.5]	13.4	10.6	0.58	0.58
23151+5912	Y	[-63, -57]	[-52, -48]	8.4	6.6	0.74	0.74

Notes. ^(a) Outflow map not very clear: probably contains more than one outflow; ^(b) bipolar outflow in the E-W direction $\sim 20''$ south from the centre of the map; ^(c) emission at OFF position affects blue wing: blue velocity range truncated at 107 km s⁻¹.

Table A.6. Total outflow energetics and kinematics.

Source	$\dot{M}_{\text{out}}$ ($M_{\odot}$)	p_{out} ($M_{\odot} \text{ km s}^{-1}$)	E_{out} (10^{46} erg)	t_{kin} (10^4 yr)	$\dot{M}_{\text{out}}$ ($10^{-4} M_{\odot} \text{ yr}^{-1}$)	F_{out} ($10^{-4} M_{\odot} \text{ km s}^{-1} \text{ yr}^{-1}$)	L_{mec} ($L_{\odot}$)
05358+3543	5.1	33.8	0.244	2.65	1.99	13.39	0.828
G213.61–12.6	8.6	41.7	0.225	4.22	2.04	9.94	0.455
G189.78+0.34	4.8	19.0	0.086	2.39	1.99	0.83	0.304
G192.58–0.04	10.3	28.5	0.086	6.17	1.71	4.76	0.124
G192.60–0.05	9.0	40.9	0.217	4.51	2.01	1.24	0.407
18151–1208_2	9.2	31.3	0.112	5.51	1.66	5.59	0.172
18151–1208_1	14.7	40.4	0.135	7.32	2.35	6.21	0.179
G18.18–0.30	11.8	46.7	0.197	5.38	2.19	8.69	0.310
18223–1243	19.5	94.5	0.556	5.09	4.20	21.11	1.083
18228–1312	11.5	52.9	0.253	4.85	2.44	11.39	0.469
G19.27+0.1M2	2.4	9.1	0.036	4.38	0.55	2.07	0.069
G19.27+0.1M1	1.2	6.1	0.032	2.91	0.43	2.21	0.097
18236–1205	3.3	33.7	0.344	1.81	1.85	18.70	1.615
18264–1152	35.7	188.8	1.190	3.21	11.17	59.06	3.160
G23.60+0.0M1	39.4	226.3	1.456	6.78	5.79	33.26	1.808
18316–0602	38.0	409.2	5.098	2.75	13.79	150.42	16.008
G23.60+0.0M2	4.8	33.7	0.257	4.42	1.07	7.59	0.490
G24.08+0.0M2	5.4	18.6	0.079	5.77	1.04	3.66	0.131
G24.33+0.1M1 ^a	43.7	175.7	0.976	7.25	6.04	24.22	1.145
G24.60+0.1M2	15.2	41.0	0.121	30.70	0.98	2.76	0.076
G24.60+0.1M1	7.2	41.7	0.252	5.04	1.56	9.11	0.476
G25.04–0.2M1	16.8	61.8	0.254	11.20	1.66	6.28	0.228
G25.04–0.2M4	10.3	35.7	0.140	9.60	1.28	4.90	0.172
G25.04–0.2M2	14.8	49.2	0.190	9.70	1.81	6.55	0.228
18507+0121	15.3	104.3	0.801	4.49	3.45	23.53	1.525
G34.43+0.2M1	17.0	134.3	1.236	3.47	5.63	44.99	3.540
G34.43+0.2M3	11.5	74.6	0.540	5.91	2.35	15.66	0.973
18517+0437	10.1	32.2	0.106	7.09	1.44	4.55	0.126
G38.95–0.5M1	8.0	33.6	0.166	4.67	1.75	7.45	0.310
19035+0641	1.0	7.6	0.054	2.34	0.47	3.38	0.203
19095+0930	5.0	35.3	0.248	4.08	1.26	8.90	0.535
20216+4107	2.1	8.3	0.033	5.44	0.51	1.79	0.060
22134+5834	2.6	8.6	0.030	7.45	0.34	1.17	0.037
23033+5951	21.8	106.8	0.588	6.16	3.55	17.32	0.807
23139+5939	14.7	87.8	0.610	4.79	3.19	19.25	1.145
23151+5912	10.1	43.2	0.208	9.85	1.05	4.55	0.188

Notes. ^(a) Emission at OFF position affects blue wing: blue velocity range truncated at 107 km s^{-1} ; only red wing considered in t_{kin} .

Table A.7. Spectral line velocities, line asymmetry, and infall rate.

Source	Offset (", ")	V_{HCO^+} (km s ⁻¹)	$V_{\text{C}^{18}\text{O}}$ (km s ⁻¹)	$\Delta V_{\text{C}^{18}\text{O}}$ (km s ⁻¹)	δV	Asymmetry (B/R)	$\dot{M}_{\text{inf}}$ (10 ⁻³ $M_{\odot}$ km s ⁻¹)
05358+3543	(0.0, 0.0)	-15.4 (0.5)	-16.1 (0.1)	3.1 (0.1)	+0.23 (0.17)	R	4.7
G213.61-12.6	(+4.1, +27.5)	9.2 (0.1)	9.5 (0.1)	2.1 (0.2)	-0.16 (0.05)	B	
G189.78+0.34	(+17.1, +16.0)	9.2 (0.1)	9.0 (0.1)	2.4 (0.1)	+0.09 (0.03)	—	
G192.58-0.04	(0.0, 0.0)	8.9 (0.1)	9.1 (0.1)	2.2 (0.1)	-0.07 (0.01)	—	
G192.60-0.05	(0.0, 0.0)	7.9 (0.1)	7.4 (0.1)	3.4 (0.1)	+0.15 (0.01)	—	
18151-1208_2	(0.0, 0.0)	29.8 (0.1)	29.4 (0.1)	3.8 (0.3)	+0.13 (0.03)	—	
18151-1208_3	(0.0, 0.0)	30.7 (0.1)	30.5 (0.1)	1.5 (0.1)	+0.11 (0.02)	—	
18151-1208_1	(0.0, 0.0)	33.2 (0.1)	32.8 (0.1)	2.0 (0.2)	+0.19 (0.04)	R	
G18.15-0.28	(+16.0, +4.5)	56.9 (0.1)	55.2 (0.1)	3.3 (0.1)	+0.53 (0.03)	R	
G18.18-0.30	(0.0, 0.0)	49.7 (0.1)	50.0 (0.1)	3.4 (0.1)	-0.10 (0.03)	—	
18223-1243	(0.0, 0.0)	44.2 (0.1)	44.8 (0.1)	2.8 (0.1)	-0.19 (0.01)	B	2.3
18228-1312	(0.0, 0.0)	34.3 (0.1)	33.5 (0.1)	4.6 (0.2)	+0.16 (0.02)	R	
G19.27+0.1M2	(0.0, 0.0)	29.3 (0.2)	26.6 (0.1)	2.3 (0.1)	+1.19 (0.12)	R	
G19.27+0.1M1	(0.0, -18.2)	29.3 (0.3)	26.3 (0.2)	1.7 (0.3)	+1.67 (0.38)	R	
18236-1205	(0.0, 0.0)	25.2 (0.1)	26.5 (0.1)	3.1 (0.1)	-0.45 (0.02)	B	6.9
18264-1152	(0.0, 0.0)	43.7 (0.1)	43.9 (0.1)	2.9 (0.1)	-0.06 (0.01)	—	
G23.60+0.0M1	(0.0, 0.0)	108.3 (0.1)	106.3 (0.1)	3.4 (0.1)	+0.59 (0.02)	R	
18316-0602	(0.0, 0.0)	40.8 (0.5)	41.9 (0.1)	5.1 (0.2)	-0.21 (0.11)	B	6.9
G23.60+0.0M2	(0.0, 0.0)	50.9 (0.2)	53.6 (0.1)	2.5 (0.1)	-1.08 (0.11)	B	
18317-0513	(0.0, 0.0)	41.8 (0.1)	41.7 (0.1)	2.0 (0.1)	+0.05 (0.01)	—	13.3
G24.08+0.0M2	(0.0, 0.0)	51.8 (0.1)	51.8 (0.1)	1.2 (0.3)	+0.03 (0.12)	—	
G24.33+0.1M1	(0.0, 0.0)	111.8 (0.1)	113.0 (0.1)	3.7 (0.2)	-0.32 (0.04)	B	125
G24.33+0.1M4	(-11.9, -8.0)	118.2 (0.3)	114.6 (0.4)	3.7 (0.9)	+0.97 (0.27)	R	
G24.33+0.1M2	(+16.0, +30.0)	118.1 (0.1)	117.9 (0.3)	3.8 (0.6)	+0.04 (0.08)	—	
G24.60+0.1M2	(0.0, 0.0)	114.7 (0.1)	114.9 (0.1)	3.3 (0.3)	-0.06 (0.04)	—	
G24.60+0.1M1	(0.0, 0.0)	54.6 (0.1)	53.0 (0.1)	2.4 (0.3)	+0.66 (0.09)	R	5.9
G25.04-0.2M1	(0.0, 0.0)	62.3 (0.1)	63.4 (0.1)	2.6 (0.1)	-0.44 (0.03)	B	
G25.04-0.2M4	(0.0, 0.0)	61.9 (0.1)	63.5 (0.1)	2.6 (0.2)	-0.58 (0.06)	B	4.9
G25.04-0.2M2	(0.0, 0.0)	65.7 (0.1)	63.7 (0.1)	2.6 (0.3)	+0.77 (0.11)	R	
G28.28-0.35	(+16.0, +6.1)	51.2 (0.1)	47.3 (0.1)	2.9 (0.3)	+1.34 (0.14)	R	3.1
18507+0121	(+12.0, -17.0)	62.1 (0.1)	57.4 (0.2)	6.7 (0.7)	+0.69 (0.08)	R	
G34.43+0.2M1	(0.0, 0.0)	60.0 (0.1)	57.6 (0.1)	3.5 (0.1)	+0.66 (0.03)	R	
G34.43+0.2M3	(0.0, 0.0)	60.5 (0.1)	58.7 (0.1)	2.6 (0.3)	+0.69 (0.08)	R	
G34.24+0.13	(0.0, 0.0)	57.3 (0.1)	56.7 (0.1)	2.6 (0.1)	+0.22 (0.01)	R	1.8
18517+0437	(0.0, 0.0)	43.9 (0.1)	44.0 (0.1)	2.9 (0.1)	-0.03 (0.01)	—	
G34.77-0.6M2	(-12.0, -7.9)	40.0 (0.1)	43.2 (0.7)	6.2 (1.4)	-0.51 (0.16)	B	
G35.39-0.3M4	(+17.3, 0.0)	43.8 (0.1)	42.6 (0.6)	6.6 (1.5)	+0.18 (0.11)	R	
G38.95-0.5M1	(0.0, 0.0)	40.7 (0.1)	42.2 (0.1)	2.1 (0.2)	-0.71 (0.07)	B	1.8
19035+0641	(0.0, 0.0)	32.5 (0.1)	32.8 (0.1)	4.3 (0.3)	-0.07 (0.03)	—	
19095+0930	(0.0, 0.0)	45.5 (0.1)	43.7 (0.1)	5.8 (0.1)	+0.31 (0.02)	R	
20216+4107	(0.0, 0.0)	-1.7 (0.1)	-1.6 (0.1)	1.8 (0.1)	-0.03 (0.01)	—	
20332+4124	(0.0, 0.0)	-3.0 (0.1)	-2.8 (0.1)	2.6 (0.1)	-0.09 (0.01)	—	
22134+5834	(0.0, 0.0)	-17.1 (0.1)	-18.2 (0.1)	2.4 (0.1)	+0.48 (0.02)	R	
22570+5912_2	(-28.0, -6.1)	-48.2 (0.1)	-48.5 (0.7)	3.2 (1.7)	+0.08 (0.23)	R	
22570+5912_1	(0.0, 0.0)	-45.5 (0.1)	-45.9 (0.1)	2.2 (0.1)	+0.16 (0.02)	R	
23033+5951	(0.0, 0.0)	-53.3 (0.1)	-53.2 (0.1)	2.7 (0.1)	-0.04 (0.01)	—	
23139+5939	(+12.0, +8.4)	-44.6 (0.1)	-44.4 (0.1)	2.8 (0.2)	-0.10 (0.04)	—	
23151+5912	(0.0, 0.0)	-54.3 (0.1)	-54.7 (0.1)	2.3 (0.1)	+0.16 (0.02)	R	

Table A.8. HCO⁺(1–0) to HCN(1–0) line ratios* .

Source	Area HCO ⁺ (1–0) (K km s ^{−1})	Area HCN(1–0) (K km s ^{−1})	Ratio
05358+3543	46.6 (0.1)	42.4 (0.2)	1.10 (0.005)
G213.61–12.6	21.9 (0.5)	41.9 (0.7)	0.52 (0.016)
G189.78+0.34	36.3 (0.5)	45.8 (0.7)	0.79 (0.017)
G192.58–0.04	31.6 (0.1)	55.8 (0.1)	0.57 (0.002)
G192.60–0.05	28.5 (0.1)	73.2 (0.1)	0.39 (0.001)
18151–1208_2	38.5 (0.1)	56.8 (0.2)	0.68 (0.003)
18151–1208_3	14.2 (0.1)	20.6 (0.1)	0.69 (0.006)
18151–1208_1	35.1 (0.1)	47.8 (0.2)	0.73 (0.004)
G18.15–0.28	23.0 (0.5)	35.1 (0.8)	0.65 (0.020)
G18.18–0.30	17.0 (0.2)	21.8 (0.3)	0.78 (0.015)
18223–1243	16.5 (0.2)	27.7 (0.3)	0.59 (0.010)
18228–1312	26.2 (0.2)	31.9 (0.3)	0.82 (0.010)
G19.27+0.1M2	2.1 (0.1)	7.4 (0.2)	0.29 (0.017)
G19.27+0.1M1	2.9 (0.3)	4.9 (1.0)	0.59 (0.140)
18236–1205	9.6 (0.2)	12.1 (0.3)	0.80 (0.028)
18264–1152	65.4 (0.1)	80.6 (0.2)	0.81 (0.002)
G23.60+0.0M1	21.1 (0.1)	34.4 (0.2)	0.61 (0.004)
18316–0602	40.6 (0.3)	62.5 (0.4)	0.65 (0.006)
G23.60+0.0M2	2.6 (0.1)	14.8 (0.2)	0.18 (0.005)
18317–0513	22.2 (0.3)	33.5 (0.6)	0.66 (0.016)
G24.08+0.0M2	3.9 (0.1)	3.7 (0.2)	1.06 (0.053)
G24.33+0.1M1	4.3 (0.1)	1.0 (0.1)	4.3 (0.484)
G24.33+0.1M4	3.9 (0.4)	3.7 (0.5)	1.05 (0.186)
G24.33+0.1M2	9.8 (0.5)	7.3 (0.7)	1.35 (0.148)
G24.60+0.1M2	6.6 (0.1)	3.2 (0.1)	2.06 (0.082)
G24.60+0.1M1	11.3 (0.2)	13.9 (0.2)	0.81 (0.019)
G25.04–0.2M1	10.6 (0.1)	5.6 (0.2)	1.90 (0.080)
G25.04–0.2M4	6.1 (0.1)	1.9 (0.2)	3.15 (0.298)
G25.04–0.2M2	7.4 (0.2)	3.3 (0.2)	2.23 (0.161)
G28.28–0.35	9.7 (0.5)	19.1 (0.9)	0.51 (0.037)
18507+0121	15.7 (0.6)	32.5 (1.3)	0.48 (0.027)
G34.43+0.2M1	17.2 (0.1)	51.1 (0.2)	0.34 (0.003)
G34.43+0.2M3	18.9 (0.1)	37.8 (0.2)	0.50 (0.004)
G34.24+0.13	9.8 (0.1)	19.7 (0.2)	0.50 (0.008)
18517+0437	45.6 (0.2)	48.6 (0.2)	0.94 (0.005)
G34.77–0.6M2	4.2 (0.4)	2.2 (0.6)	1.92 (0.535)
G35.39–0.3M4	11.6 (0.4)	9.0 (0.6)	1.29 (0.099)
G38.95–0.5M1	9.7 (0.2)	11.5 (0.2)	0.85 (0.022)
19035+0641	16.1 (0.2)	18.4 (0.2)	0.88 (0.017)
19095+0930	39.1 (0.2)	40.1 (0.3)	0.98 (0.009)
20216+4107	15.5 (0.1)	15.1 (0.1)	1.02 (0.010)
20332+4124	9.2 (0.1)	10.2 (0.1)	0.90 (0.014)
22134+5834	8.6 (0.1)	14.4 (0.2)	0.60 (0.008)
22570+5912_2	13.3 (0.4)	12.0 (0.7)	1.11 (0.075)
22570+5912_1	10.8 (0.1)	11.7 (0.1)	0.92 (0.011)
23033+5951	40.7 (0.1)	36.7 (0.1)	1.11 (0.005)
23139+5939	24.6 (0.5)	28.3 (0.7)	0.87 (0.028)
23151+5912	5.6 (0.1)	15.5 (0.1)	0.36 (0.005)

Notes. (*) The errors are indicated in brackets.

Appendix B: Figures

Fig. B.1. Contour maps of the molecular clumps. IR-dark and IR-loud sources are labelled *IRD* and *IRL*, respectively. Black dashed lines represent the half power contours and black solid lines the *clump regions* (see text), defined as follows. *Left panels:* $\text{HCO}^+(1-0)$ emission. Clump regions: 50% (G189), 60% (05358, G192.58), 70% (G192.60), and 80% (G213) power contours. *Central panels:* $\text{HCN}(1-0)$ emission. Clump regions: 50% (G189), 60% (05358, G192.58), and 70% (G213, G192.60) power contours. *Right panels:* $\text{C}^{18}\text{O}(2-1)$ emission. Clump regions: 60% (G189, G192.58), 70% (G213, G192.60), and $\text{HCO}^+(1-0)$ 60% (05358) power contours.

Fig. B.1. continued. We note that G192.59 has not been detected by our observations: the two components seen in the maps represent G192.58 (northern) and G192.60 (southern). *Left panels:* $\text{HCO}^+(1-0)$ emission. Clump regions (black solid contours): 50% (18151_2), 60% (18151_1), and 70% (18151_3, G18.15) power contours; in the cases of 18151_3, and G18.15 it has been manually cut to include only the central component. *Central panels:* $\text{HCN}(1-0)$ emission. Clump regions: 60% (18151_2, 18151_1) and 70% (18151_3, G18.15) power contours; in the cases of 18151_3 it has been manually cut to include only the central component. *Right panels:* $\text{C}^{18}\text{O}(2-1)$ emission. Clump regions: 50% (18151_3, 18151_1, G18.15) and $\text{HCO}^+(1-0)$ 50% (18151_2) power contours; in the cases of 18151_3 and G18.15 it has been manually cut to include only the central component.

Fig. B.1. continued. *Left panels:* HCO⁺(1-0) emission. Clump regions (black solid contours): 60% (18223, 18228, G19.27M1), 70% (G18.18), and HCN(1-0) 60% (G19.27M2) power contours. *Central panels:* HCN(1-0) emission. Clump regions: 60% (18223, G19.27M2, G19.27M1), 70% (18228), and 80% (G18.18) power contours. *Right panels:* C¹⁸O(2-1) emission. Clump regions: 50% (18223), 70% (G18.18, 18228), and HCN(1-0) 60% (G19.27M2, G19.27M1) power contours.

Fig. B.1. continued. *Left panels:* $\text{HCO}^+(1-0)$ emission. Clump regions (black solid contours): 50% (18264), 60% (G23.60M1, 18316, G23.60M2), and 70% (18236) power contours. *Central panels:* $\text{HCN}(1-0)$ emission. Clump regions 60% power contours. *Right panels:* $\text{C}^{18}\text{O}(2-1)$ emission. Clump regions: 50% (G23.60M2), 60% (18264, 18316), 70% (18236), and 80% (G23.60M2) power contours.

Fig. B.1. continued. *Left panels:* $\text{HCO}^+(1-0)$ emission. Clump regions (black solid contours): 50% (18317), 60% (G24.08M2, G24.33M1, G24.33M4) and 80% (G24.33M2) power contours. *Central panels:* $\text{HCN}(1-0)$ emission. Clump regions: 50% (18317, G24.08M2, G24.33M1), 60% (G24.33M1), and 80% (G24.33M2) power contours. *Right panels:* $\text{C}^{18}\text{O}(2-1)$ emission. Clump regions: 50% (G24.08M2), 60% (18317, G24.33M1), 70% (G24.33M2), and 80% (G24.33M4) power contours.

Fig. B.1. continued. *Left panels:* $\text{HCO}^+(1-0)$ emission. Clump regions (black solid contours): 50% (G24.60M2) and 70% (G24.60M1, G25.04M1, G25.04M4, G25.04M2) power contours. *Central panels:* $\text{HCN}(1-0)$ emission. Clump regions: 50% (G24.60M2, G24.60M1), 60% (G25.04M1, G25.04M4), and 70% (G25.04M2) power contours. *Right panels:* $\text{C}^{18}\text{O}(2-1)$ emission. Clump regions: 50% (G24.60M2), 60% (G24.60M1), 70% (G25.04M1), $\text{HCO}^+(1-0)$ 70%, and $\text{HCN}(1-0)$ 60% (G25.04M4) power contours.

Fig. B.1. continued. *Left panels:* $\text{HCO}^+(1-0)$ emission. Clump regions (black solid contours): 40% (G34.43M3), 60% (18507), and 70% (G28.28, G34.43M1, G34.24) power contours; in the case of 18507 it has been manually cut to include only the southern component. *Central panels:* $\text{HCN}(1-0)$ emission. Clump regions: 50% (18507, G34.43M3), 60% (G34.43M1), and 70% (G28.28, G34.24) power contours; in the case of 18507 it has been manually cut to include only the southern component. *Right panels:* $\text{C}^{18}\text{O}(2-1)$ emission. Clump regions: 40% (G34.43M1), 50% (G28.28, 18507), 80% (G34.24), and $\text{HCO}^+(1-0)$ 40% (G34.43M3) power contours.

Fig. B.1. continued. *Left panels:* $\text{HCO}^+(1-0)$ emission. Clump regions (black solid contours): 50% (18517, G34.77M2, 19035) and 60% (G35.39M4, G38.95M1) power contours. *Central panels:* $\text{HCN}(1-0)$ emission. Clump regions: 50% (G35.39M4, 19035), 60% (18517, G34.77M2), and 70% (G38.95M1) power contours. *Right panels:* $\text{C}^{18}\text{O}(2-1)$ emission. Clump regions: 50% (18517, G38.95M1, 19035), $\text{HCO}^+(1-0)$ 60% (G35.39M4), and $\text{HCN}(1-0)$ 60% (G34.77M2) power contours.

Fig. B.1. continued. *Left panels:* $\text{HCO}^+(1-0)$ emission. Clump regions (black solid contours): the 50% (19095, 20216, 22570_2) and 60% (20332, 22134) power contours. *Central panels:* $\text{HCN}(1-0)$ emission. Clump regions: 50% power contours. *Right panels:* $\text{C}^{18}\text{O}(2-1)$ emission. Clump regions: 50% (19095, 20332, 22134), 60% (20216), and $\text{HCO}^+(1-0)$ 50% (22570_2) power contours.

Fig. B.1. continued. *Left panels:* $\text{HCO}^+(1-0)$ emission. Clump regions (black solid contours): 40% (23151) and 50% (22570_1, 23033, 23139) power contours. *Central panels:* $\text{HCN}(1-0)$ emission. Clump regions: 50% power contours. *Right panels:* $\text{C}^{18}\text{O}(2-1)$ emission. Clump regions: 50% (23033, 23139, 23151) and 60% (22570_1) power contours.

Fig. B.2. Average spectra. For each source, the peak velocity from the Gaussian fit to the $\text{C}^{18}\text{O}(2-1)$ line at the peak coordinates (see Table A.2) is marked with a dashed vertical line. The purple vertical solid lines mark the positions of the $\text{HCN}(1-0)$ hyperfine components. IR-dark and IR-loud sources are labelled *IRD* and *IRL*, respectively.

Fig. B.2. continued.

Fig. B.2. continued.

Fig. B.2. continued. G24.33+0.1M1: Note the blue-shifted absorption due to emission at the OFF position (see text and Table 4). G24.33+0.1M4: The $\text{C}^{18}\text{O}(2-1)$ line falls outside the limits of the VESPA unit and therefore the spectra obtained with the 1 MHz backend have been used instead (spectral resolution: 1.4 km s^{-1}).

Fig. B.2. continued. G24.60+0.1M2: The $\text{C}^{18}\text{O}(2-1)$ line falls outside the limits of the VESPA unit and therefore the spectra obtained with the 1 MHz backend have been used instead (spectral resolution: 1.4 km s^{-1}).

Fig. B.2. continued.

Fig. B.2. continued.

Fig. B.2. continued.

Fig. B.3. Outflow maps. IR-dark and IR-loud sources are labelled *IRD* and *IRL*, respectively. Blue-shifted (solid contours) and red-shifted (dashed contours) $\text{HCO}^+(1-0)$ integrated wing emission, with contours starting from 5σ (G19.27M1, G24.33M1), 8σ (G24.08M2), 10σ (G189, G192.58, G192.60, 18228, G19.27M2, 18236, G23.60M2, G24.60M2), 15σ (05358, G192.59, 18223), 20σ (G213, 18151_2, 18151_1, G18.18, 18264, G23.60M1), and 40σ (18316), and increasing by steps of 1σ (G23.60M1), 2σ (G189, G192.58, G192.59, G19.27M2, G19.27M1, 18236, G24.08M2, G24.33M1, G24.60M2), 3σ (G213, G192.60, 18151_1, G18.18, G23.60M1), 4σ (05358, 18151_2, 18223, 18228), 5σ (18264), and 10σ (18316). The rms values of the blue emission maps are 0.010 (G23.60M1, 18316, G23.60M2), 0.015 (05358, G213, 18223, G19.27M1, 18236), 0.020 (G192.60, G192.59, 18151_2, G18.18, 18228, G19.27M2, 18264, G24.08M2, G24.33M1), 0.030 (G189, G192.58, 18151_1), and 0.040 (G24.60M2) K. The rms values of the red emission maps are 0.010 (18223, G23.60M1, 18316), 0.015 (05358, G19.27M2, 18236), 0.020 (G213, G192.60, G192.59, 18151_2, 18151_1, G18.18, 18228, G19.27M1, 18264, G23.60M2, G24.08M2, G24.33M1, G24.60M2), 0.030 (G189), and 0.040 (G192.58) K. The grey scale corresponds to the $\text{C}^{18}\text{O}(2-1)$ line-integrated emission except in the cases of 05358, 18151_2, G19.27M1, G24.08M2, and G24.60M2, for which the $\text{HCO}^+(1-0)$ line-integrated emission is depicted instead. The contour levels are the same as in Fig. B.2.

Fig. B.3. continued. Blue-shifted (solid contours) and red-shifted (dashed contours) $\text{HCO}^+(1-0)$ integrated wing emission, with contours starting from 8σ (G25.04M4, 19035), 10σ (G24.60M1, G25.04M1, G25.04M2, 18507, G34.43M3, 19095, 22134, 23139, 23151), 15σ (G34.43M1, G38.95M1, 20216), and 20σ (18517, 23033), and increasing by steps of 1σ (G25.04M4, 19035), 2σ (G25.04M2, G34.43M3, G38.95M1, 22134, 23151), 3σ (G24.60M1, G25.04M1, G34.43M1, 19095, 20216, 23139), and 5σ (18507, 18517, 23033). The rms values of the blue emission maps are 0.010 (18507, G34.43M1, 23151), 0.015 (G34.43M3, G38.95M1, 20216, 23033, 23139), 0.020 (G24.60M1, G25.04M1, 18517, 19035, 19095, 22134), 0.030 (G25.04M2), and 0.050 (G25.04M4) K. The rms values of the red emission maps are 0.010 (G24.60M1, 18507, G34.43M1, 23151), 0.015 (G25.04M1, G34.43M3, G38.95M1, 20216, 22134, 23033), 0.020 (G25.04M2, 18517, 19035, 19095, 23139), and 0.040 (G25.04M4) K. The grey scale corresponds to the $\text{C}^{18}\text{O}(2-1)$ line-integrated emission except in the cases of G24.60M1, G25.04M4, G25.04M2, and G34.43M3, for which the $\text{HCO}^+(1-0)$ line-integrated emission is depicted instead. The contour levels are the same as in Fig. B.2.

Fig. B.4. $\text{C}^{18}\text{O}(2-1)$ velocity maps. The arrows indicate the orientation of the bipolar outflow, where present (solid for the blue lobe, dashed for the red lobe). IR-dark and IR-loud sources are labelled *IRD* and *IRL*, respectively. Sources with no outflow detection are labelled “NO”, and sources with an outflow detection but no clear orientation are labelled “ORI”.

Fig. B.4. continued.

Fig. B.4. continued.