CO Outflow Candidates toward the W3/4/5 Complex. II. Feedback from Candidate Outflows

Yingjie Li¹,², Ye Xu¹, Yan Sun¹, and Ji Yang¹

¹ Purple Mountain Observatory, Chinese Academy of Sciences, Nanjing 210023, People’s Republic of China; liyj@pmo.ac.cn, xuye@pmo.ac.cn
² University of Science and Technology of China, Hefei, Anhui 230026, People’s Republic of China

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Abstract

To date, few studies have focused on protostellar outflow feedback at scales larger than several parsecs. To address this paucity of research, we investigate the effects of feedback from CO outflow candidates on their parent clouds over ~110 deg² toward the W3/4/5 complex and its surroundings. Our search identified 265 ¹³CO clouds with radii being ~0.04–17.12 pc. We estimate the turbulent support and potential disruptive effect of the outflow activities through analyzing physical properties of outflow candidates and their host clouds in terms of turbulence and gravitational binding energy. We find that (1) clouds of larger size might be less affected by feedback; (2) the possible scale break is ≥4.7 pc for both turbulent support and potential disruptive effect; (3) if outflows couple to dense gas where stars are forming, for clouds in the Perseus arm, a scale ≤0.2–0.4 pc is sufficient for the energy and momentum injected by outflow activity to maintain turbulence, while for clouds in the Local arm, the scale is ≤0.1–0.2 pc; and (4) for clouds in the Perseus arm, a scale ≤0.3–1.0 pc is needed for outflow activity to potentially disperse material away from the natal clouds, while for clouds in the Local arm, the scale is ≤0.2–0.6 pc. The strength of outflow activity may affect the values in points 3 and 4. Finally, we find that outflow feedback probably possesses the power to alter the line width–size relation.

Unified Astronomy Thesaurus concepts: Interstellar clouds (834); Jets (870); Interstellar dynamics (839); Star formation (1569); Chaos (222)

Supporting material: figure set, machine-readable tables

1. Introduction

Protostellar outflows are an intrinsic process during the early stages of star formation. They can impact clustered star formation in two feedback scenarios (Bally 2016) that are related to eruptive star formation (e.g., rapid cloud dispersal following a burst of star formation; Elmegreen 2007; Hartmann & Burkert 2007) and slow, quasi-equilibrium star formation regulated by the replenishment of turbulence via feedback (Tan et al. 2006; Nakamura & Li 2007, 2014). As a protostar accretes mass from its host core, the subsequent outflow likely represents the first rung of the feedback ladder arising from ever more powerful momentum and energy injection mechanisms (such as ejection by wide-angle winds and soft-UV radiation from moderate-mass stars, or by ionizing radiation, stellar winds, and the explosions of massive stars; Frank et al. 2014; Bally 2016). Feedback from these mechanisms can impact the ecology of star-forming regions (Krumholz et al. 2011; Myers et al. 2014; Bally 2016). Overall, outflow feedback is related to two critical star formation issues: the relatively low efficiency of star formation and the driving source of turbulence in clouds (Elmegreen & Scalo 2004; McKee & Ostriker 2007; Frank et al. 2014).

Two perspectives are frequently explored to investigate the feedback of outflows: their turbulent support and potential disruptive effect. The first one compares the total outflow kinetic energy, luminosity, and conserved momentum with the corresponding properties of cloud turbulence (Frank et al. 2014). For instance, Graves et al. (2010) found that the total outflow kinetic energy is ~70% of the total turbulent energy in the Serpens cloud. Similar conclusions have also been drawn based on other regions such as NGC 2264C (Maury et al. 2009), ρ Ophiuchi (Nakamura et al. 2011a), Serpens South (Nakamura et al. 2011b), L1641-N (Nakamura et al. 2012), etc. A few studies have investigated areas containing several star-forming regions, e.g., six subregions in the Perseus cloud complex (Arce et al. 2010) and several nearby Gould Belt clouds (Drabek-Maunder et al. 2016). In these two studies, conclusions were drawn whereby the total outflow kinetic energy accounted for at least ~14% of the natal cloud’s turbulent energy. All of these studied regions were confined to distances ≤800 pc and cloud radii ≤2.0 pc. Moreover, in other studies, it was found that when the cloud’s radius is ≥9 pc, the outflow kinetic energy only makes up ≤1% of the host cloud’s turbulent energy (Li et al. 2015, 2018; Wang et al. 2017).

The potential for outflows to disrupt their parent clouds has been previously traced by comparing the total outflow kinetic energy and the cloud’s gravitational binding energy (e.g., $E_{\text{flow}}/E_{\text{grav}}$ or the quantity $\eta_{\text{out}} = 2 E_{\text{flow}}/E_{\text{grav}}$; see the definition in Nakamura & Li 2014). In filaments or isolated small clouds, outflows can blow out of their parent cores (Bally 2016). Nakamura & Li (2014) investigated $\eta_{\text{out}}$ toward eight nearby clumps (distances ≤415 pc and cloud radii ≤2 pc) and found 0.01 < $\eta_{\text{out}}$ < 0.10 except for one clump that had $\eta_{\text{out}}$ = 5, implying that outflows cannot disrupt most clumps. Similar conclusions have been drawn based on studies toward the Perseus molecular cloud complex (Arce et al. 2010) and several nearby Gould Belt clouds (Drabek-Maunder et al. 2016). It was also shown that $E_{\text{flow}}/E_{\text{grav}}$ decreases to <1% when the cloud radius is ≥9 pc (e.g., Li et al. 2015, 2018).

Theoretical studies have shown that outflows modify the environments in which stars form by injecting energy and momentum into their surroundings (Norman & Silk 1980; McKee 1989; Krumholz et al. 2014). Dynamic equilibrium between momentum input and turbulent dissipation is achieved
for a young cluster once star formation and its outflows have commenced (Frank et al. 2014). Numerical simulations have demonstrated that a cluster-forming clump can remain in quasi-equilibrium when subjected to turbulence driven by outflows (Li & Nakamura 2006). Jets and collimated outflows are more efficient in driving turbulence (Matzner 2007; Carroll et al. 2009; Cunningham et al. 2009; for more detail see the review by Krumholz et al. 2014). So far, though it has widely been believed that outflows are sources of energy and momentum input, a fundamental question, i.e., whether the momentum injected by protostellar outflows is enough to counteract turbulence decay in clouds (Frank et al. 2014), is still outstanding. A coexistent and unanswered question is how protostellar outflows limit the collapse rate or disrupt the parent clouds (e.g., Matzner 2007; Matzner & Juniper 2015; Bally 2016).

Whether there is a clear break of the scale of turbulence driven by outflow feedback is still an open question (Bally 2016). Almost all studies have been confined to scales below several parsecs except those by Li et al. (2015, 2018) in which the scales were investigated in these two studies. Fortunately, we are now able to systematically investigate the feedback of outflow activities for a much larger sample thanks to the study of the structures and physical properties of the molecular (12CO and its other two isotopic molecules) gas toward the W3/4/5 complex and its surroundings (Sun et al. 2020) and the related outflow survey (Li et al. 2019, hereafter, Paper I).

The remainder of the paper is organized as follows. In Section 2, we describe the data used in this work. In Section 3, we present the cloud detection process, the physical properties of the clouds, and the effect of feedback of the outflow activities on their parent clouds. In Section 4, we discuss the outflow feedback in terms of turbulent support and potential disruptive effects caused by the outflow activities and the potential effect of the outflow activities on the line width–size relation. Finally, we summarize our conclusions in Section 5.

2. Data

As stated in Paper I, the data used in our analysis cover \( \sim 110 \) deg\(^2\) \((129^\circ.755 \leq l \leq 140^\circ.25, \sim 5^\circ.25 \leq b \leq 5^\circ.25)\), which were obtained by the Milky Way Imaging Scroll Painting Project (MWISP; Su et al. 2019). The data of 13CO \((J = 1 \rightarrow 0)\) (115.271 GHz) and 12CO \((J = 1 \rightarrow 0)\) (110.201 GHz) were observed from 2011 to 2017 November using the Purple Mountain Observatory Delingha (PMODLH) 13.7 m telescope with the nine-beam superconducting array receiver (SSAR), which works in the sideband separation mode and employs a fast Fourier transform spectrometer (Zuo et al. 2011; Shan et al. 2012). The velocity resolution is \( \sim 0.16 \) km s\(^{-1}\) for 12CO and \( \sim 0.17 \) km s\(^{-1}\) for 13CO. The main-beam rms noise after main-beam efficiency correction at these velocity resolutions is \( \sim 0.45 \) K for 12CO and \( \sim 0.25 \) K for 13CO. The half-power beamwidth (HPBW) is \( \sim 49'' \) for 12CO and \( \sim 51'' \) for 13CO, and the data were gridded to 30'' pixels for both transitions.

3. Data Analysis and Results

3.1. Summary of Outflow Candidates

In this work, the outflow candidates in the Perseus arm, the Local arm, and interarm 1, as presented in Paper I, are considered. Those candidates were searched for based on the longitude–latitude–velocity \(^{12}\)CO data, where the cores were traced by three-dimensional \(^{13}\)CO data. The outflow candidate sample was finally obtained after searching for the 12CO velocity bulges based on the 13CO peak velocity distribution maps and conducting line diagnoses of each candidate (see more details in Paper I; Li et al. 2018). The proportion of bipolar outflow candidates is \( \sim 22\% \) (see Table 3 in Paper I). The median value of the dynamical timescale of outflow candidates, \( t_{\text{flow}} \), before correction for inclination is \( \sim 0.4 \) Myr, which is consistent with the estimated duration of the Class 0 and likely Class I phases of the evolution of young stellar objects (Evans et al. 2009; Bally 2016). Thus, these candidates were more likely driven by protostars. To further distinguish individual protostellar outflow candidates from high-velocity outflowing 12CO gas driven by stellar wind, new observations with improved spatial resolution are required.

The momentum, \( P_{\text{flow}} \), of an outflow candidate was calculated by multiplying the outflow candidate’s mass, \( M_{\text{flow}} \), by its velocity relative to the central cloud weighted by the main-beam brightness temperature of each channel in the line wing (outflow candidate’s velocity, \( \langle \Delta v_{\text{flow}} \rangle \)). For kinetic energy, \( E_{\text{flow}} \), of an outflow candidate, \( \langle \Delta v_{\text{flow}}^2 \rangle \) was replaced with \( \langle \Delta v_{\text{flow}} \rangle^2 \). The luminosity of an outflow candidate was \( L_{\text{flow}} = E_{\text{flow}}/\text{flow} \), with \( t_{\text{flow}} = L_{\text{flow}}/\Delta v_{\text{max}} \), where \( \Delta v_{\text{max}} \) and \( t_{\text{flow}} \) are the maximum velocity and the length of an outflow candidate, respectively (see more details in Paper I). We list the outflow candidates’ physical properties after corrections for optical depth, average inclination, and blending effect in Table 1.

3.2. Cloud Identification

Similar to Arce et al. (2010) and Li et al. (2015, 2018), the 13CO emission was used to evaluate the physical quantities of each cloud. 13CO clouds near/coversing the outflow candidates were identified with the following steps. First, the integrated intensity map of 13CO was mapped with the velocity range of integration being the full velocity range characterized by zero intensity of an outflow candidate. The boundary of a cloud was determined by pixels where the main-beam brightness temperatures were larger than 3 × rms in at least three successive channels.

Second, we searched for a cloud that covered the position of the outflow candidate. If we did not obtain such a cloud, we searched for a cloud where the boundary was <30'' away from the outflow candidate. For the latter case, if two or more clouds satisfied the criterion, we chose the nearest one.

Third, we searched for other outflow candidates that were covered by or close to the acquired cloud. We then adjusted the velocity range accordingly and mapped the intensity map over the adjusted velocity range. This step was repeated until the size of the 13CO cloud and the number of outflow candidates associated with the cloud reached their maximum values. This step provides the maximal velocity range of the 13CO cloud, because the full velocity range of 12CO outflow candidates is larger than that of the 13CO outflow or cloud, at least at current detection limits. Similar to Arce et al. (2010) and Li et al. (2015, 2018), we are not attempting to differentiate the ambient cloud and components of outflowing gas for the properties of clouds.

\(^{5}\) The distance to the boundary of the acquired cloud was <30''.
Finally, in order to try to diminish the impact of uncorrelated components, the velocity range of the $^{13}$CO cloud was further adjusted referring to the mean spectrum of the $^{13}$CO cloud. Following the above steps, the associations between the $^{13}$CO clouds and $^{12}$CO outflow candidates were obtained. We detected 265 such clouds, including 136 in the Perseus arm,$^4$ 124 in the Local arm,$^5$ and 5 in interarm 1 (correlated with five outflow candidates). The details of the correlations between the clouds and outflow candidates are cataloged in Table 1, and the integrated intensity maps and mean spectra of the clouds are mapped in Figure 1.

### 3.3. Physical Properties of Turbulent Support and Potential Disruptive Effect

The turbulent support and potential disruptive effect of outflow candidates are considered here to evaluate their feedback effect. Because the W3/4/5 complex in the Perseus arm is a massive star-forming region (Westerhout 1958; Heyer & Terebey 1998), the outflow candidates in Paper I are probably similar to those presented by Beuther et al. (2002) and

![Figure 1](image.png)

**Figure 1.** The integrated intensity map and spectrum for cloud 97. The color bar is in units of K km s$^{-1}$.

### Table 1

| Cloud Index | $l$ (deg) | $b$ (deg) | $V_{low}$ (km s$^{-1}$) | $V_{high}$ (km s$^{-1}$) | $M_{low}$ (M$_\odot$) | $P_{low}$ (M$_\odot$ km s$^{-1}$) | $E_{flow}$ (erg) | $L_{flow}$ (erg s$^{-1}$) | Outflow Index |
|-------------|-----------|-----------|-------------------------|-------------------------|----------------------|-------------------------|--------------|-----------------------|-------------|
| Perseus Arm |           |           |                         |                         |                      |                         |              |                       |              |
| 1           | 130.103   | −4.471    | −46.0                   | −37.0                   | 1.59                 | 5.12                    | 1.59E+44     | 1.14E+31               | 1, 2         |
| 2           | 130.380   | −0.784    | −38.0                   | −26.0                   | 27.41                | 126.20                  | 5.44E+45     | 2.10E+32               | 3, 5         |
| 3           | 130.392   | 1.638     | −47.0                   | −38.0                   | 0.14                 | 0.46                    | 1.46E+43     | 2.05E+30               | 4            |
| 4           | 130.578   | 1.953     | −49.0                   | −40.0                   | 5.14                 | 21.69                   | 8.68E+44     | 7.98E+31               | 6, 9         |
| 5           | 130.854   | −0.929    | −38.0                   | −29.0                   | 0.24                 | 0.97                    | 3.66E+43     | 3.80E+30               | 10           |

**Note.** Column (1): index for each molecular cloud. Columns (2)–(3): central position of each molecular cloud in Galactic coordinates (see Figure 1). Columns (4)–(5): integral interval used to calculate the cloud mass (see Section 3.3). Columns (6)–(9): total outflow mass, momentum, kinetic energy, and luminosity corresponding to each cloud. They are from Paper I, but here we newly apply the corrections for inclination angle, blending effect, and optical depth. All values in Columns (6)–(9) also have been multiplied by 1.36 to take into consideration the mean molecular weight (Brunt 2010) instead of the weight of only molecular H$_2$ given in Li et al. (2019). Column (10): outflow candidate indexes corresponding to each cloud.

(This table is available in its entirety in machine-readable form.)
Global Physical Properties of the Clouds

| Cloud Index | $M_{\text{cloud}}$ (M$_\odot$) | $R_{\text{cloud}}$ (pc) | $\Delta V_{\text{cloud}}$ (km s$^{-1}$) | $\Delta V_{\text{err}}$ (km s$^{-1}$) | $T_{\text{cloud}}$ (K) | $\tau_{\text{cloud}}$ | $E_{\text{turb}}$ (erg) | $P_{\text{turb}}$ (erg s$^{-1}$) | $t_{\text{ff}}$ (10$^6$ yr) | $t_{\text{diss}}$ (10$^6$ yr) | $L_{\text{turb}}$ (erg s$^{-1}$) | $v_{\text{esc}}$ (km s$^{-1}$) | $M_{\text{esc}}$ (M$_\odot$) | $E_{\text{grav}}$ (erg) |
|-------------|----------------|----------------|----------------|----------------|---------------|-------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|
| Perseus Arm |                |                |                |                |               |             |               |                |                |                |                |               |             |                |
| 1           | 299.5          | 1.96           | 2.0            | 0.05           | 8.4           | 0.3         | 6.2E+45       | 430.8          | 2.6            | 1.7            | 1.1E+32        | 1.1            | 4.5            | 3.9E+45       |
| 2           | 649.6          | 2.39           | 1.8            | 0.05           | 10.4          | 0.2         | 1.1E+46       | 845.8          | 2.4            | 3.2            | 1.1E+32        | 1.5            | 82.5           | 1.5E+46       |
| 3           | 46.5           | 1.08           | 1.2            | 0.05           | 6.2           | 0.5         | 3.4E+44       | 40.0           | 2.7            | 1.5            | 7.0E+30        | 0.6            | 0.8            | 1.7E+44       |
| 4           | 686.8          | 3.37           | 1.8            | 0.04           | 7.6           | 0.3         | 1.2E+46       | 921.2          | 3.9            | 1.7            | 2.3E+32        | 1.3            | 16.4           | 1.2E+46       |
| 5           | 163.3          | 0.42           | 2.9            | 0.14           | 10.0          | 0.2         | 7.6E+44       | 35.2           | 1.1            | 0.8            | 2.9E+31        | 0.6            | 1.7            | 5.5E+43       |
| ...         |                |                |                |                |               |             |               |                |                |                |                |                |                |                |                |

(This table is available in its entirety in machine-readable form.)

Given the absence of an accurate distance to each cloud, we do not present the errors of those physical parameters here, but the impact of uncertainty of distance will be discussed in detail in Sections 4.4 and 4.5.2.

3.3.2. Turbulent Support

The turbulent energy, $E_{\text{turb}}$, and momentum, $P_{\text{turb}}$, of a cloud are given approximately by

$$E_{\text{turb}} = 0.5M_{\text{cloud}}\sigma_{3d}^2$$

and

$$P_{\text{turb}} = M_{\text{cloud}}\sigma_{3d},$$

respectively, where $M_{\text{cloud}}$ and $\sigma_{3d}$ are its mass and three-dimensional velocity dispersion ($\sigma_{3d} = \sqrt{3\Delta V_{\text{cloud}}/2/2\ln 2}$, respectively. The turbulent dissipation rate (turbulent luminosity), $L_{\text{turb}}$, of a cloud can be calculated as

$$L_{\text{turb}} = \frac{E_{\text{turb}}}{t_{\text{diss}},}$$

where $t_{\text{diss}}$ is the turbulent dissipation timescale. The value of $t_{\text{diss}}$, which arises from the energy dissipation of uniformly driven magnetohydrodynamic turbulence, is approximately given by (see the numerical study in Mac Low 1999)

$$t_{\text{diss}} = \frac{3.9\kappa}{M_{\text{rms}}} t_{\text{ff}},$$

where $\kappa$ is the ratio of the driving wavelength (was approximately equal to the length of the outflow lobe of a continuous outflow; Nakamura & Li 2007; Cunningham et al. 2009) over the Jeans’s length of the cloud, $\lambda_J$, $t_{\text{ff}}$ is the freefall timescale of the cloud, and $M_{\text{rms}} = \sigma_{3d}/c_s$, where $c_s = (3kT_{\text{cloud}}/mH\mu)^{1/2}$ is the Mach number of the turbulence (Mac Low 1999), $k$ is Boltzmann’s constant, $mH$ is the mass of atomic hydrogen, and $\mu = 2.72$ is the mean molecular weight (Brunt 2010). For more details regarding the calculation of $L_{\text{turb}}$, see Li et al. (2018). The derived turbulent properties of each cloud are listed in Table 2.
Three indicators were provided to estimate the turbulent support of the outflow candidates, i.e., the ratios of the total kinetic energy, momentum, and luminosity (kinetic energy injection rate) of the outflow candidates to their respective cloud turbulence values (see Table 3). These three ratios are denoted by $E_{\text{flow}}/E_{\text{turb}}$, $P_{\text{flow}}/P_{\text{turb}}$, and $L_{\text{flow}}/L_{\text{turb}}$, respectively.

The driving wavelength and $t_{\text{diss}}$ from Equation (4) may be overestimated if we misinterpret a clustered outflow as a single one (see Paper I). Therefore, $L_{\text{turb}}$ might be underestimated from Equation (3) and $L_{\text{flow}}/L_{\text{turb}}$ might be overestimated. In addition, $t_{\text{diss}}$ and $L_{\text{turb}}$, as stated by Arce et al. (2010), can only be roughly estimated owing to the differences of outflow activity between numerical simulations and reality. Therefore, $L_{\text{flow}}/L_{\text{turb}}$ may be highly uncertain owing to the uncertainties in both $L_{\text{turb}}$ and the dynamical timescale of the outflow lobe candidates, which are related to $t_{\text{diss}}$ (see Paper I).

Approximately 18% (24/136) and 3% (4/136) of the clouds have values of $E_{\text{flow}}/E_{\text{turb}}$ and $P_{\text{flow}}/P_{\text{turb}}$, that are greater than unity in the Perseus arm. The proportions are $\sim$29% (36/124) and $\sim$6% (8/124) for the Local arm and 0% (0/5) and 0% (0/5) for interarm 1, respectively. These proportions indicate that, in a minority of clouds, outflow activity is enough to maintain turbulence. Note that we did not consider the proportion of $L_{\text{flow}}/L_{\text{turb}}$ because it might be highly uncertain.

### 3.3.3. Potential Disruptive Effect

Outflow candidates may potentially disrupt their parent clouds (Arce & Goodman 2002). One method to evaluate this effect is to compare the total kinetic energy of the outflow candidates to the cloud’s gravitational binding energy, $E_{\text{flow}}/E_{\text{grav}}$, or $\eta_{\text{out}} = 2E_{\text{flow}}/E_{\text{grav}}$. $E_{\text{grav}}$ can be written as

$$E_{\text{grav}} = \frac{GM_{\text{cloud}}^2}{R_{\text{cloud}}}.$$  

(5)

Another method to estimate the potential disruptive effect is to determine the ratio of the escape mass, $M_{\text{esc}}$, to the cloud mass, $M_{\text{cloud}}$, where $M_{\text{esc}}$ is defined, following Arce et al. (2010), as

$$M_{\text{esc}} = \frac{P_{\text{flow}}}{v_{\text{esc}}} = \frac{P_{\text{flow}}}{\sqrt{2GM_{\text{cloud}}/R_{\text{cloud}}}}.$$  

(6)

For this equation, $P_{\text{flow}}$ is cataloged in Table 1, and $v_{\text{esc}}$ is the cloud’s escape velocity. The ratio of $M_{\text{esc}}$ to the total mass of the outflow candidates in the cloud, $M_{\text{esc}}/M_{\text{flow}}$, can be used to estimate the impact of the outflow candidates on the environment in their immediate vicinity (e.g., Li et al. 2018). These quantities are listed in Table 2, and the ratios are listed in Table 3.

### 4. Discussion

In this work, 265 clouds with radii ranging from $\sim$0.04 to $\sim$17.12 pc were detected. This large sample enabled us to calculate the feedback properties of the outflow candidates as functions of the cloud radius. In the following, we further investigate the obtained fitted functions.

### 4.1. Correlations among Cloud Properties

Figure 2 shows that the two samples (one in the Perseus arm and the other in the Local arm) are different from each other in properties of $M_{\text{cloud}}$ and $R_{\text{cloud}}$ but similar in properties of $\Delta V_{\text{cloud}}$. The distances to the Perseus arm and the Local arm are significantly different, resulting in the different levels of beam dilution effect. A greater fraction of molecular gas is expected to be missed for the sample with a larger distance (such as the Perseus arm) and therefore to bias the derived properties of the clouds (e.g., sizes and masses of the clouds) and the relationships between different properties. To diminish the bias introduced by the different levels of beam dilution, we investigate the physical properties of clouds within individual spiral arms, e.g., we separately investigate the turbulent support of the outflow candidate of clouds in the Perseus arm and the Local arm.

Figure 3 shows $E_{\text{turb}}$ and $P_{\text{turb}}$ as functions of $R_{\text{cloud}}$. The power-law indices (PLIs) for the former one are 2.68 ± 0.25 and 2.64 ± 0.17 (with 95% confidence using a least-squares method; this method also applies to all fits below) for clouds in the Perseus arm and the Local arm, respectively, and the corresponding correlation coefficients (c.c.) are 0.89 and 0.94. For the latter one, the corresponding PLIs are 2.44 ± 0.17 and 2.43 ± 0.11, with c.c. of 0.93 and 0.97. The expected PLIs for $E_{\text{turb}} - R_{\text{cloud}}$ from Larson’s relations are 1.60 (with the assumption of $M_{\text{cloud}} \propto R_{\text{cloud}}^{1.1}$ and $\Delta V_{\text{cloud}} \propto R_{\text{cloud}}^{0.38}$; Larson 1981; Traficante et al. 2018) or 1.84 (with the assumption of $\Delta V_{\text{cloud}} \propto R_{\text{cloud}}^{0.5}$ determined from large-scale observations; Padoan & Nordlund 2002; McKee & Ostriker 2007; Traficante et al. 2018, see details about the line width–size relation in Section 4.5). The corresponding expected PLIs for $P_{\text{turb}} - R_{\text{cloud}}$ are 1.48 or 1.60.

### Table 3

| Cloud Index | $E_{\text{flow}}/E_{\text{turb}}$ | $P_{\text{flow}}/P_{\text{turb}}$ | $L_{\text{flow}}/L_{\text{turb}}$ | $E_{\text{flow}}/E_{\text{grav}}$ | $M_{\text{esc}}/M_{\text{cloud}}$ | $M_{\text{esc}}/M_{\text{flow}}$ |
|-------------|-------------------------------|---------------------------------|---------------------------------|---------------------------------|---------------------------------|---------------------------------|
| Perseus Arm |                               |                                 |                                 |                                 |                                 |                                 |
| 1           | 2.6E–02                       | 1.2E–02                         | 1.0E–01                         | 4.1E–02                         | 1.5E–02                         | 2.8                             |
| 2           | 5.0E–01                       | 1.5E–01                         | 2.0E+00                         | 3.6E–01                         | 1.3E–01                         | 3.0                             |
| 3           | 4.3E–02                       | 1.2E–02                         | 2.9E–01                         | 8.6E–02                         | 1.6E–02                         | 5.6                             |
| 4           | 7.1E–02                       | 2.4E–02                         | 3.5E–01                         | 7.2E–02                         | 2.4E–02                         | 3.2                             |
| 5           | 4.8E–02                       | 2.8E–02                         | 1.3E–01                         | 6.7E–01                         | 1.0E–01                         | 6.9                             |

(The 1st column is available in its entirety in machine-readable form.)
These facts indicate that, for clouds in the Local arm and the Perseus arm, $E_{\text{turb}}$ and $P_{\text{turb}}$ are correlated with $R_{\text{cloud}}$ (with c.c. $\geq 0.89$), and the measured PLIs deviate from (are larger than) those expected from Larson’s relations. It is interesting to investigate whether outflow activity plays a role in impacting cloud properties.

4.2. Turbulent Support

The ratios used to evaluate the turbulent support of the outflow candidates to their parent clouds are $E_{\text{flow}}/E_{\text{turb}}$, $P_{\text{flow}}/P_{\text{turb}}$, and $L_{\text{flow}}/L_{\text{turb}}$ (see Table 3). These three ratios are plotted as functions of cloud radius, $R_{\text{cloud}}$, in Figure 4. The samples in Li et al. (2018), labeled as “Gem OB1,” are also included to enlarge the sample to larger radii. Here the ratio $P_{\text{flow}}/P_{\text{turb}}$ was calculated using Equation (2) with data from Li et al. (2018).

Figure 4 shows that $L_{\text{flow}}/L_{\text{turb}}$ is much bigger than $E_{\text{flow}}/E_{\text{turb}}$; such a result has been reported by many other researchers (e.g., Arce et al. 2010; Li et al. 2015, 2018). This result may arise from an overestimation of the driving wavelength (see Sections 3.3.2). Further discussion regarding the three ratios as functions of $R_{\text{cloud}}$ is presented in detail below, which is followed by a summary.

4.2.1. Ratio of $E_{\text{flow}}/E_{\text{turb}}$ as a Function of $R_{\text{cloud}}$

The best-fitting power-law functions for the clouds in the Perseus arm, the Local arm, and the entire sample are given by

\[
\log(E_{\text{flow}}/E_{\text{turb}}) = (-1.58 \pm 0.28)\log R_{\text{cloud}} - 0.57 \pm 0.08, \quad \text{c.c.} = -0.70, \quad (7a)
\]

\[
\log(E_{\text{flow}}/E_{\text{turb}}) = (-2.11 \pm 0.18)\log R_{\text{cloud}} - 1.46 \pm 0.10, \quad \text{c.c.} = -0.91, \quad (7b)
\]

\[
\log(E_{\text{flow}}/E_{\text{turb}}) = (-1.37 \pm 0.17)\log R_{\text{cloud}} - 0.84 \pm 0.07, \quad \text{c.c.} = -0.71, \quad (7c)
\]

respectively. The PLIs and the scale factors (SFs) are cataloged in Table 4.

The critical radius (hereafter CRR) at which the fitted line of the ratio equals unity was used to describe $E_{\text{flow}}/E_{\text{turb}}$ as a function of $R_{\text{cloud}}$. From our results it can be concluded that the turbulence driven by the ejecta of the outflow activity is enough to maintain the turbulence at the scale below the CRR.
if the outflows can couple to the dense gas where stars are forming, and therefore limit the star formation rate in their host clouds. The CRRTE (cataloged in Table 4) is $0.43 \pm 0.16$ pc, $0.20 \pm 0.06$ pc, and $0.24 \pm 0.10$ pc with 95% confidence for the clouds in the Perseus arm, the Local arm, and the entire sample, respectively. These values are consistent with the results of Brunt et al. (2009) and Arce et al. (2010), which collectively suggest a turbulence driving scale of $\lesssim 0.4$ pc.

### 4.2.2. Ratio of $P_{\text{flow}}/P_{\text{turb}}$ as a Function of $R_{\text{cloud}}$

The best-fitting power-law functions for the clouds in the Perseus arm, the Local arm, and the entire sample are

$$\log(P_{\text{flow}}/P_{\text{turb}}) = (−1.54 \pm 0.24) \log R_{\text{cloud}} - 1.09 \pm 0.06, \text{ c.c.} = −0.74, \quad (8a)$$

$$\log(P_{\text{flow}}/P_{\text{turb}}) = (−1.98 \pm 0.15) \log R_{\text{cloud}} - 1.94 \pm 0.09, \text{ c.c.} = −0.92, \quad (8b)$$

$$\log(P_{\text{flow}}/P_{\text{turb}}) = (−1.28 \pm 0.16) \log R_{\text{cloud}} - 1.36 \pm 0.07, \text{ c.c.} = −0.72, \quad (8c)$$

respectively. CRRTM is smaller than CRRTE, where the former is $0.20 \pm 0.10$ pc, $0.11 \pm 0.04$ pc, and $0.09 \pm 0.06$ pc for the clouds in the Perseus arm, the Local arm, and the entire sample, respectively.

### 4.2.3. Ratio of $L_{\text{flow}}/L_{\text{turb}}$ as a Function of $R_{\text{cloud}}$

The best-fitting power-law functions for the clouds in the Perseus arm, the Local arm, and the entire sample are

$$\log(L_{\text{flow}}/L_{\text{turb}}) = (−1.51 \pm 0.31) \log R_{\text{cloud}} + 0.22 \pm 0.09, \text{ c.c.} = −0.65, \quad (9a)$$

$$\log(L_{\text{flow}}/L_{\text{turb}}) = (−2.24 \pm 0.22) \log R_{\text{cloud}} - 0.69 \pm 0.13, \text{ c.c.} = −0.88, \quad (9b)$$

$$\log(L_{\text{flow}}/L_{\text{turb}}) = (−1.39 \pm 0.16) \log R_{\text{cloud}} - 0.04 \pm 0.08, \text{ c.c.} = −0.72, \quad (9c)$$

respectively. CRRTL is much higher than CRRTE and CRRTM, which is $1.45 \pm 0.58$ pc, $0.49 \pm 0.16$ pc, and $0.94 \pm 0.26$ pc for the clouds in the Perseus arm, the Local arm, and the entire sample, respectively. However, we note that CRRTL is likely overestimated, and therefore these values are highly uncertain (see Sections 3.3.2).

### 4.2.4. Summaries of Turbulent Support

The three ratios defining turbulent support (i.e., $E_{\text{flow}}/E_{\text{turb}}$, $P_{\text{flow}}/P_{\text{turb}}$, and $L_{\text{flow}}/L_{\text{turb}}$) as functions of $R_{\text{cloud}}$ showed negative PLIs (see Table 4). The Local arm presented the steepest slope. One reason for this might be that the amount of outflow activities in the Local arm is less than those in other regions. For instance, the number of outflow candidates that were associated with each cloud in the Local arm was less than that in the Perseus arm (see Table 1 for details). Therefore, when $R_{\text{cloud}}$ increases, the quantities related to outflow activities (such as $E_{\text{flow}}$, $P_{\text{flow}}$, $L_{\text{flow}}$, and $M_{\text{flow}}$) increase more slowly in the Local arm than those in the Perseus arm, but the cloud’s properties (such as $E_{\text{turb}}$ and $P_{\text{turb}}$) increase at a similar rate in both arms (e.g., see Figure 3), resulting in a steeper slope in the Local arm.

CRRTE, CRRTM, and CRRTL showed different values (see Table 4). CRRTE and CRRTM were, respectively, $\sim 0.2$ and $\sim 0.4$ pc for clouds in the Perseus arm and $\sim 0.1$ and $\sim 0.2$ pc for those in the Local arm. The strength of outflow activities might influence the value of the critical radius, because the critical radius in the Perseus arm with stronger outflow activities was higher than that in the Local arm. CRRTL provided less useful physical information because $L_{\text{flow}}/L_{\text{turb}}$ is highly uncertain.

The spatial resolution of the telescope may have little effect on creating the differences in the CRRTE and the CRRTM, but the conclusion for CRRTL should be viewed with caution. Two possible reasons are presented as follows. First, the physical scale, whether the minimum deconvolution radius\(^9\) ($\sim 0.14$ and $\sim 0.04$ pc for clouds in the Perseus arm and the Local arm, respectively) or the half-width of the telescope resolution ($\sim 0.24$ and $\sim 0.07$ pc), is less than the CRRTE ($\sim 0.43$ and $\sim 0.20$ pc). Similarly, these two physical scales are less than the CRRTM ($\sim 0.11$ pc) for clouds in the Local arm. For clouds in the Perseus arm, CRRTM ($\sim 0.20$ pc) is larger than the minimum deconvolution radius but is slightly less than the half-width of the telescope resolution, and only one cloud has radius below CRRTM.

Second, lower spatial resolution would be more likely to result in multiple-component clouds (i.e., large clouds that contain some small ones). The effect of multiple components is

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8 On average, $\sim 2.1$ outflow candidates were associated with a single cloud in the Perseus arm, and $\sim 1.3$ in the Local arm.

9 The minimum deconvolution radius is equal to the minimum cloud radius (see Section 3.3.1), with the area of a cloud corresponding to 3 pixels (i.e., the minimum number of pixels is 2 in the direction of both $l$ and $b$).

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Figure 4. (a) $E_{\text{flow}}/E_{\text{turb}}$ vs. $R_{\text{cloud}}$ (b) $P_{\text{flow}}/P_{\text{turb}}$ vs. $R_{\text{cloud}}$ (c) $L_{\text{flow}}/L_{\text{turb}}$ vs. $R_{\text{cloud}}$. The data used to fit the relationships are located on the left side of the vertical line (totaling 134 clouds for the sample of the Perseus arm) for panels (a) and (b).
Table 4
Effect of Beam Dilution, the Uncertainty of Distance, and Multiple Components on CRR

| Sample        | $E_{\text{tot}}/E_{\text{thr}}$ | $P_{\text{tot}}/P_{\text{thr}}$ | $L_{\text{tot}}/L_{\text{thr}}$ | $E_{\text{tot}}/E_{\text{thr}}$ | $M_{\text{tot}}/M_{\text{thr}}$ |
|---------------|---------------------------------|---------------------------------|---------------------------------|---------------------------------|---------------------------------|
| PLI SF CRR (pc) | PLI SF CRR (pc) | PLI SF CRR (pc) | PLI SF CRR (pc) | PLI SF CRR (pc) |
| Without Regard to Effects (All the Physical Values Are with 95% Confidence) |
| Perseus arm  | $-1.58 \pm 0.28$ | $-0.57 \pm 0.080.43 \pm 0.16$ | $-1.54 \pm 0.24$ | $-1.09 \pm 0.060.20 \pm 0.10$ | $-1.51 \pm 0.31$ | $0.22 \pm 0.091.54 \pm 0.58$ | $-2.37 \pm 0.28$ | $-0.30 \pm 0.071.01 \pm 0.14$ | $-1.93 \pm 0.24$ | $-0.96 \pm 0.070.32 \pm 0.10$ | $-0.45 \pm 0.060.68 \pm 0.02$ |
| Local arm    | $-2.11 \pm 0.18$ | $-1.46 \pm 0.100.20 \pm 0.06$ | $-1.98 \pm 0.15$ | $-1.94 \pm 0.090.11 \pm 0.04$ | $-2.24 \pm 0.22$ | $-0.69 \pm 0.130.49 \pm 0.16$ | $-2.91 \pm 0.18$ | $-1.04 \pm 0.100.56 \pm 0.10$ | $-2.37 \pm 0.16$ | $-1.73 \pm 0.090.19 \pm 0.06$ | $-0.52 \pm 0.060.73 \pm 0.03$ |
| Entire sample | $-1.37 \pm 0.17$ | $-0.84 \pm 0.070.24 \pm 0.10$ | $-1.28 \pm 0.16$ | $-1.36 \pm 0.070.09 \pm 0.06$ | $-1.39 \pm 0.16$ | $-0.04 \pm 0.080.94 \pm 0.26$ | $-2.26 \pm 0.16$ | $-0.52 \pm 0.070.80 \pm 0.12$ | $-1.73 \pm 0.15$ | $-1.20 \pm 0.060.20 \pm 0.06$ | $-0.49 \pm 0.030.72 \pm 0.02$ |
| Perseus      | $-1.36 \pm 0.17$ | $-0.84 \pm 0.080.25 \pm 0.10$ | $-1.28 \pm 0.16$ | $-1.36 \pm 0.070.09 \pm 0.06$ | $-1.41 \pm 0.19$ | $-0.04 \pm 0.090.95 \pm 0.28$ | $-2.25 \pm 0.16$ | $-0.52 \pm 0.070.80 \pm 0.12$ | $-1.72 \pm 0.15$ | $-1.19 \pm 0.070.20 \pm 0.06$ | $-0.53 \pm 0.040.70 \pm 0.02$ |
| Effect of Beam Dilution (Set the Distance to the Perseus Arm to be 600 pc. All the Physical Values Are with 95% Confidence) |
| Perseus arm  | $-1.58 \pm 0.28$ | $-0.57 \pm 0.080.43 \pm 0.18$ | $-1.54 \pm 0.24$ | $-1.88 \pm 0.140.06 \pm 0.06$ | $-1.51 \pm 0.31$ | $-0.55 \pm 0.180.44 \pm 0.30$ | $-2.37 \pm 0.28$ | $-1.09 \pm 0.160.51 \pm 0.18$ | $-1.93 \pm 0.24$ | $-1.69 \pm 0.140.14 \pm 0.08$ | $-0.45 \pm 0.060.71 \pm 0.03$ |
| Local arm    | $-2.11 \pm 0.18$ | $-1.46 \pm 0.100.20 \pm 0.06$ | $-1.98 \pm 0.15$ | $-1.94 \pm 0.090.11 \pm 0.04$ | $-2.24 \pm 0.22$ | $-0.69 \pm 0.130.49 \pm 0.16$ | $-2.91 \pm 0.18$ | $-1.04 \pm 0.100.56 \pm 0.10$ | $-2.37 \pm 0.16$ | $-1.73 \pm 0.090.19 \pm 0.06$ | $-0.52 \pm 0.060.73 \pm 0.03$ |
| Perseus      | $-1.39 \pm 0.16$ | $-1.45 \pm 0.090.17 \pm 0.06$ | $-1.79 \pm 0.14$ | $-1.94 \pm 0.080.08 \pm 0.04$ | $-1.92 \pm 0.19$ | $-0.66 \pm 0.110.45 \pm 0.14$ | $-2.68 \pm 0.16$ | $-1.05 \pm 0.090.53 \pm 0.10$ | $-2.19 \pm 0.14$ | $-1.74 \pm 0.080.16 \pm 0.04$ | $-0.48 \pm 0.040.72 \pm 0.03$ |
| Effect of the Uncertainty of Distance (“Average Value” ± “Standard Deviation” of 1000 Tests) |
| Perseus arm  | $-1.53 \pm 0.04$ | $-0.57 \pm 0.010.42 \pm 0.02$ | $-1.49 \pm 0.03$ | $-1.09 \pm 0.010.19 \pm 0.02$ | $-1.61 \pm 0.04$ | $-0.21 \pm 0.010.74 \pm 0.02$ | $-2.32 \pm 0.03$ | $-0.30 \pm 0.011.00 \pm 0.02$ | $-1.88 \pm 0.03$ | $-0.96 \pm 0.010.31 \pm 0.02$ | $-0.46 \pm 0.010.68 \pm 0.00$ |
| Local arm    | $-1.85 \pm 0.09$ | $-1.38 \pm 0.040.18 \pm 0.04$ | $-1.73 \pm 0.08$ | $-1.87 \pm 0.040.08 \pm 0.02$ | $-1.96 \pm 0.10$ | $-0.61 \pm 0.040.49 \pm 0.06$ | $-2.67 \pm 0.08$ | $-0.97 \pm 0.040.56 \pm 0.04$ | $-2.14 \pm 0.09$ | $-1.66 \pm 0.040.17 \pm 0.02$ | $-0.52 \pm 0.010.73 \pm 0.00$ |
| Effect of Multiple Components (“Average Value” ± “Standard Deviation” of 3000 Tests) |
| Perseus arm  | $-1.50 \pm 0.05$ | $-0.55 \pm 0.010.43 \pm 0.02$ | $-1.46 \pm 0.04$ | $-1.07 \pm 0.010.19 \pm 0.01$ | $-1.39 \pm 0.05$ | $-0.25 \pm 0.010.66 \pm 0.02$ | $-2.24 \pm 0.06$ | $-0.27 \pm 0.011.03 \pm 0.02$ | $-1.84 \pm 0.05$ | $-0.94 \pm 0.010.31 \pm 0.02$ | $-0.44 \pm 0.010.67 \pm 0.00$ |
| Local arm    | $-2.07 \pm 0.03$ | $-1.41 \pm 0.010.21 \pm 0.02$ | $-1.93 \pm 0.02$ | $-1.90 \pm 0.010.10 \pm 0.01$ | $-2.19 \pm 0.03$ | $-0.63 \pm 0.020.52 \pm 0.02$ | $-2.85 \pm 0.04$ | $-0.97 \pm 0.020.58 \pm 0.02$ | $-2.33 \pm 0.03$ | $-1.69 \pm 0.010.19 \pm 0.01$ | $-0.52 \pm 0.010.73 \pm 0.00$ |

Note. 0.00 represents <0.005.
Figure 5. (a) $E_{\text{flow}}/E_{\text{grav}}$ vs. $R_{\text{cloud}}$, (b) $M_{\text{esc}}/M_{\text{cloud}}$ vs. $R_{\text{cloud}}$, and (c) $M_{\text{esc}}/M_{\text{flow}}$ vs. $R_{\text{cloud}}$. The data used to fit the relationships are located on the left side of the vertical line (totaling 134 clouds for the sample of the Perseus arm) for panels (a) and (b).

4.3. Potential Disruptive Effect

As stated in Section 3.3.3, the quantities used to estimate the potential disruptive effect of the outflow candidates include $E_{\text{flow}}/E_{\text{grav}}$, $M_{\text{esc}}/M_{\text{cloud}}$, and $M_{\text{esc}}/M_{\text{flow}}$. Figure 5 shows these three ratios as functions of $R_{\text{cloud}}$, where the ratios in the study of Li et al. (2018), labeled as “Gem OB1,” are also included. We comment on each ratio in detail and provide a summary in the following subsection.

4.3.1. Ratio of $E_{\text{flow}}/E_{\text{grav}}$ as a Function of $R_{\text{cloud}}$

The best-fitting power-law functions for the clouds in the Perseus arm, the Local arm, and the entire sample are

$$
\log(E_{\text{flow}}/E_{\text{grav}}) = (-2.37 \pm 0.28) \log R_{\text{cloud}} - 0.30 \pm 0.07, \ c.c. = -0.83,
$$

$$
\log(E_{\text{flow}}/E_{\text{grav}}) = (-2.91 \pm 0.18) \log R_{\text{cloud}} - 1.04 \pm 0.10, \ c.c. = -0.95,
$$

$$
\log(E_{\text{flow}}/E_{\text{grav}}) = (-2.26 \pm 0.16) \log R_{\text{cloud}} - 0.52 \pm 0.07, \ c.c. = -0.87,
$$

respectively.

Similar to $E_{\text{flow}}/E_{\text{turb}}$, we also defined the CRR (i.e., the cloud radius where the ratio of the fitted line equaled 0.5, i.e., $\eta_{\text{out}} = 1$) for $E_{\text{flow}}/E_{\text{grav}}$ (denoted as CRR$_{\text{GE}}$). CRR$_{\text{GE}}$ (see the expression in Section 4.2.1) is 1.01 ± 0.14 pc, 0.56 ± 0.10 pc, and 0.80 ± 0.12 pc for the clouds in the Perseus arm, the Local arm, and the entire sample, respectively.

4.3.2. Ratio of $M_{\text{esc}}/M_{\text{cloud}}$ as a Function of $R_{\text{cloud}}$

The best-fitting power-law functions for the clouds in the Perseus arm, the Local arm, and the entire sample are

$$
\log(M_{\text{esc}}/M_{\text{cloud}}) = (-1.93 \pm 0.24) \log R_{\text{cloud}} - 0.96 \pm 0.07, \ c.c. = -0.81,
$$

$$
\log(M_{\text{esc}}/M_{\text{cloud}}) = (-2.37 \pm 0.16) \log R_{\text{cloud}} - 1.73 \pm 0.09, \ c.c. = -0.94,
$$

$$
\log(M_{\text{esc}}/M_{\text{cloud}}) = (-1.73 \pm 0.15) \log R_{\text{cloud}} - 1.20 \pm 0.06, \ c.c. = -0.82,
$$

respectively.

CRR$_{\text{MC}}$ (the cloud radius where the $M_{\text{esc}}/M_{\text{cloud}}$ of the fitted line equals unity: see the expression in Section 4.2.1) is 0.32 ± 0.10 pc, 0.19 ± 0.06 pc, and 0.20 ± 0.06 pc for the clouds in the Perseus arm, the Local arm, and the entire sample, respectively. They are close to the values in the case of $E_{\text{flow}}/E_{\text{turb}}$ (i.e., CRR$_{\text{TE}}$).

The ratio $M_{\text{esc}}/M_{\text{cloud}}$ exceeds unity in environments with specific mass-to-flux ratios (e.g., see Figure 8 in Offner & Chaban 2017). In addition, magnetic fields might provide more effective coupling between outflows and molecular clouds (De Colle & Raga 2005; Frank et al. 2014, and references therein). Constraining the properties of the magnetic fields in these regions is therefore of great interest in the future.

4.3.3. Ratio of $M_{\text{esc}}/M_{\text{flow}}$ as a Function of $R_{\text{cloud}}$

The best-fitting results for the clouds in the Perseus arm, the Local arm, and the entire sample are

$$
\log(M_{\text{esc}}/M_{\text{flow}}) = (-0.45 \pm 0.06) \log R_{\text{cloud}} + 0.68 \pm 0.02, \ c.c. = -0.82,
$$

$$
\log(M_{\text{esc}}/M_{\text{flow}}) = (-0.52 \pm 0.06) \log R_{\text{cloud}} + 0.73 \pm 0.03, \ c.c. = -0.86,
$$

$$
\log(M_{\text{esc}}/M_{\text{flow}}) = (-0.49 \pm 0.03) \log R_{\text{cloud}} + 0.72 \pm 0.02, \ c.c. = -0.88,
$$

respectively.

$M_{\text{esc}}/M_{\text{flow}}$ ranges from ~1.6 to ~34, indicating that the outflow activities have the potential to entrain and accelerate...
ambient gas up to 10 times their own mass. Such powerful processes could destroy the gas in the immediate vicinity of the outflow candidates.

The negative slopes in Equation (12) indicate that outflows in smaller clouds were more effective in dispersing gas than those in larger clouds. This suggests that some physical mechanisms probably cancel out the action of entraining or accelerating the ambient gas surrounding the protostars via outflows in larger clouds.

4.3.4. Summaries of Potential Disruptive Effect

Three ratios related to the potential disruptive effect (i.e., $E_{\text{flow}}/E_{\text{turb}}$, $M_{\text{esc}}/M_{\text{cloud}}$, and $M_{\text{esc}}/M_{\text{flow}}$) as functions of $R_{\text{cloud}}$ showed negative PLIs (see Table 4). The Local arm showed the steepest slopes for the first two ratios. Similar to the explanation for the cases of turbulent support (see Section 4.2.4), one reason is probably that the amount of outflow activities in the Local arm is less than those in other regions. $M_{\text{esc}}/M_{\text{flow}}$ against $R_{\text{cloud}}$ showed a similar slope for the Perseus arm, the Local arm, and the entire sample. The negative value of this slope implies that some physical mechanisms may enable the ambient gas surrounding the protostars to resist dispersal by outflows in larger clouds.

CRRGE and CRRMC showed different values, where CRRGE is $\sim 1.0$ and $\sim 0.6$ pc, respectively, for clouds in the Perseus arm and the Local arm, and the corresponding values of CRRMC are $\sim 0.3$ and $\sim 0.2$ pc. CRRMC is similar to the CRRs found for turbulent support in Section 4.2.4 (i.e., $\sim 0.1$–0.4 pc). In addition, similar to the discussion of turbulent support (see Section 4.2.4), the strength of the outflow activity might also influence the value of these characteristic radii above, and the spatial resolution of the telescope may have little effect on creating the differences in the CRRGE and the CRRMC.

4.4. Uncertainties of Turbulent Support and Potential Disruptive Effect

4.4.1. Effects of Beam Dilution and the Uncertainty of Distance

To estimate the effect of beam dilution, we set the distance to the Perseus arm to be the same as that to the Local arm (i.e., 600 pc). The corresponding results are plotted in Figure 6 and cataloged in Table 4. The result shows that both PLI and CRR for the sample of Perseus + Local after changing distance are consistent with those for the clouds in the Local arm and are different from the sample of Perseus + Local before changing distance. This indicates that the effect of beam dilution is probably coupled with the effect of distance.
To test the effect of the uncertainty of distance, we have constructed simulated cloud samples, where the distance is randomly generated according to the probability density function that obeys a normal distribution. The parameters of the generated distance are as follows: (1) for the Perseus arm, the expected value is 1950 pc, the standard deviation is ~213 pc, and the range of values is (1450, 2450) pc; (2) for the Local arm, the corresponding values are 600 pc, ~170 pc, and (200, 1000) pc, respectively (see Sun et al. 2020). The results after 1000 tests are plotted in Figure 7 and cataloged in Table 4. The PLIs and CRRs are roughly consistent with the results after 1000 tests are plotted in Figure 7 and cataloged in Table 4. The PLIs and CRRs are roughly consistent with the results after 1000 tests are plotted in Figure 7 and cataloged in Table 4.

Sections 3.3.2 and 4.2.3. This indicates that the uncertainties of distance and beam dilution, which are probably coupled together (see discussion above), have little effect on the conclusions of Sections 4.2.4 and 4.3.4.

4.4.2. Effect of Multiple Components

To test the effect of multiple components, we have artificially merged some clouds to be one cloud. Similar to the proportion of the clouds with multiple velocity components, the proportions of clouds with multiple components (i.e., the cloud that merges two or more old clouds) are set to be ~19% and ~17%, resulting in the total numbers of clouds in the new sample being 119 and 111, respectively, for clouds in the Perseus arm and the Local arm. For clouds in the Perseus arm, a set of random numbers with the sum of 134 or 136 (see Figure 6 or Footnote 11) and the number of elements of 119 are created to determine which clouds should be merged to be one. For clouds in the Local arm, the corresponding value of the sum and the number of elements are 124 and 111, respectively. The radius of the new cloud is set to be the maximum value of the following terms: the sum of the radius of old clouds multiplied by a random number ranging from zero to one (determine the overlaps of the old clouds), and the maximum radius of old clouds. Other physical parameters are revised accordingly.

A total of 3000 tests are needed to stabilize the result (see Figure 8 and Table 4). Similar to the effect of beam dilution and the uncertainty of distance, the results show that multiple components have little effect on the conclusions of Sections 4.2.4 and 4.3.4.

Throughout what has been done in Sections 4.2–4.4, differences of both PLIs and CRRs between the samples in the Perseus arm and the Local arm roughly remain unchanged for four ratios (i.e., $E_{\text{flow}}/E_{\text{turb}}$, $P_{\text{flow}}/P_{\text{turb}}$, $E_{\text{flow}}/E_{\text{grav}}$, and $M_{\text{esc}}/M_{\text{cloud}}$; see Table 4). This indicates that these differences probably resulted from the environment of the cloud, such as outflow activity discussed in Sections 4.2.4 and 4.3.4 or other star-forming activities.

4.5. Line Width–Size Relation

4.5.1. Feedback of Outflow Activity

The line width, $\Delta V_{\text{cloud}}$, as a function of cloud radius, $R_{\text{cloud}}$, is shown in Figure 9. The best-fitting line width–size relations for the clouds in the Perseus arm and the Local arm are

$$
\log(\Delta V_{\text{cloud}}) = (0.24 \pm 0.08)\log R_{\text{cloud}} + 0.17 \pm 0.02, \text{ c.c. } = 0.46,
$$

(13a)

$$
\log(\Delta V_{\text{cloud}}) = (0.21 \pm 0.07)\log R_{\text{cloud}} + 0.18 \pm 0.04, \text{ c.c. } = 0.48,
$$

(13b)

respectively. These two slopes are much shallower than the slope of 0.38 found by Larson (1981) and 0.5 determined from large-scale observations (Padoan & Nordlund 2002; McKee & Ostriker 2007; Traficante et al. 2018). However, they are similar to the results from high-mass star-forming regions (e.g., 0.21 ± 0.03, Caselli & Myers 1995; 0.3, Shirley et al. 2003). It is interesting to see whether outflow activity could play a role in some way.

To confirm the possibility of outflow feedback on the slopes reported in Equation (13), we compared $\Delta V_{\text{cloud}}$ with the line width, $\Delta V_0$, which was used to attempt to subtract the contribution of the momentum injected by the outflow activity to the cloud turbulence. The $\Delta V_0$ was measured by

$$
\Delta V_0 = \Delta V_{\text{cloud}}(1 - P_{\text{flow}}/P_{\text{turb}}) = \frac{2\sqrt{2\ln 2} P_{\text{turb}}}{\sqrt{3} M_{\text{cloud}}} (1 - P_{\text{flow}}/P_{\text{turb}}),
$$

where $P_{\text{flow}}/P_{\text{turb}}$ (see Table 3) as a function of $R_{\text{cloud}}$ (see Table 2) is plotted in Figure 4(b). The fitted line width–size relations of $\Delta V_0$ against $R_{\text{cloud}}$ for the clouds in the Perseus arm and the Local arm are

$$
\log(\Delta V_0) = (0.39 \pm 0.10)\log R_{\text{cloud}} + 0.11 \pm 0.03, \text{ c.c. } = 0.58,
$$

(15a)

$$
\log(\Delta V_0) = (0.59 \pm 0.13)\log R_{\text{cloud}} + 0.20 \pm 0.07, \text{ c.c. } = 0.64,
$$

(15b)

respectively. Relative to the case of $\Delta V_{\text{cloud}}$, the slopes in Equations (15) are steeper and closer to the slope found from large-scale observations (i.e., 0.5; see above). This fact supports the idea that feedback from outflow activity may potentially sculpt the line width–size relation.

Going further, the slope reported in Equation 15(a) is shallower than the slope found for the large-scale observations mentioned above, likely indicating that additional feedback from star formation activities plays a role in further altering the line width–size relation. For instance, such additional feedback might be radiative feedback (Myers et al. 2013) or could originate from turbulence regenerated through gravitational collapse (e.g., Field et al. 2008; Klessen & Hennebelle 2010; Robertson & Goldreich 2012).

4.5.2. Uncertainty of Distance and Effect of Multiple Components

As discussed in Section 4.4, the effect of beam dilution is probably coupled with the effect of distance. In the constructed simulated cloud samples (the number of clouds is 136 and 124 for clouds in the Perseus arm and the Local arm, respectively), the distance is the same as that in Section 4.4. For a single cloud, the line width is generated

12 There are two reasons for considering the momentum here: momentum is a conserved quantity, and the number of excluded samples with $\Delta V_0 \leq 0$ is small (see Figure 4(b)). Values of $\Delta V_0 \leq 0$ indicate that outflow candidates can eject momentum that is no less than the turbulent momentum of the cloud.
Figure 7. Effect of the uncertainty of distance for (a)–(f) the Perseus arm and (g)–(l) the Local arm.
Figure 8. Effect of multiple components on (a)–(f) the Perseus arm and (g)–(l) the Local arm.
according to the similar probability density function with the expected value, standard deviation, and number of elements being $\Delta V_{\text{cloud}}, \Delta V_{\text{err}}$, and 1000 (which is enough to stabilize the result), respectively. In each test (totaling 1000), we take one of the generated line widths for a single cloud. The result shows that the slope is $0.24 \pm 0.01$ and $0.19 \pm 0.01$ (“the average value” $\pm$ “the standard deviation” of the fits of 1000 tests) for clouds in the Perseus arm and the Local arm, respectively (see Figure 10).

Similar to the treatment of the effect of multiple components in Section 4.4.2 for the case of $L_{\text{flow}}/L_{\text{turb}}$ or $M_{\text{esc}}/M_{\text{flow}}$, clouds are merged to construct new samples. In this process, the line width of a new cloud is the average value of the corresponding old clouds weighted by the mass. The result shows that the slope is $0.24 \pm 0.01$ and $0.21 \pm 0.01$ for clouds in the Perseus arm and the Local arm, respectively (see Figure 11).

From the above results, beam dilution, uncertainty of distance, and multiple components have little effect on the slope reported in Equation (13). This implies that the slope does change after the contribution of the momentum injected by the outflow activity to the cloud turbulence being subtracted, indicating that outflow feedback has the potential to alter the line width–size relation.

Based on the discussion above, especially the comparison of the properties of $V_{\text{cloud}}$ and $V_0$, the feedback from outflow activity may potentially affect the line width–size relation, so that the slope becomes shallower. This scenario may also apply to the cases presented by Caselli & Myers (1995) and Shirley et al. (2003),
where other types of feedback related to star-forming activities may also have played a role.

5. Summary and Conclusions
A large-scale survey of $^{13}$CO clouds that were associated with outflow candidates was conducted toward the W3/4/5 complex and its surroundings ($\sim$110 deg$^2$, within the Galactic coordinates of $129^\circ.75 \leq l \leq 140^\circ.25$ and $-5^\circ.25 \leq b \leq 5^\circ.25$). A total of 265 clouds were identified, with radii ranging from $\sim$0.04 to $\sim$17.12 pc. Our main conclusions are as follows:

1. The outflow activity was enough to maintain the turbulence in a minority of clouds if the outflows can couple to the dense gas where stars are forming, but in some cases it could potentially disrupt the entire cloud. It is likely that the scale break is $\gtrsim 4.7$ pc for both turbulence support and potential disruptive effect.

2. Larger clouds might possess stronger ability to resist feedback from outflow activities than small ones, because negative PLIs were obtained when fitting $M_{\text{esc}}/M_{\text{flow}}$ as a function of $R_{\text{cloud}}$.

3. The feedback of outflow activity has the potential to shape the line width–size relation, causing the profile to become shallower, because steeper power-law profiles were found when the contribution of momentum injected by outflow activity to the cloud turbulence was subtracted.

4. For turbulent support, three ratios (i.e., $E_{\text{flow}}/P_{\text{urb}}$, $P_{\text{flow}}/P_{\text{urb}}$, and $L_{\text{flow}}/L_{\text{urb}}$) as functions of $R_{\text{cloud}}$ all represented negative PLIs. From the analyses of the first two ratios, the CRRs were probably $\sim$0.2–0.4 pc and $\sim$0.1–0.2 pc for clouds in the Perseus arm and the Local arm, respectively, as derived from the nodes of the best-fitting power-law profiles and the ratios of unity. Outflow activity or other star-forming activities may affect the value of CRR.

5. For the potential disruptive effect, the power-law profiles of two ratios ($f_{\text{flow}} = 2E_{\text{flow}}/E_{\text{grav}}$ and $M_{\text{esc}}/M_{\text{cloud}}$) as functions of $R_{\text{cloud}}$ had negative indices. The nodes of the best-fitting power-law profiles and the ratios of unity indicate that the possible CRRGE is $\sim$1.0 and $\sim$0.6 pc, respectively, for clouds in the Perseus arm and the Local arm, and the corresponding values of CRRMC are $\sim$0.3 and $\sim$0.2 pc. Similar to the case of turbulent support, outflow activity or other star-forming activities may affect the value of CRR.

Note that all results of this work are based on the short segments of the Perseus arm, the Local arm, and interarm 1 only over an interval of 11° in Galactic longitude. Therefore, the conclusions reached here might not necessarily apply to the regions across the Perseus arm, the Local arm, and interarms in the entire Milky Way.

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Facility: PMO 13.7 m.

ORCID iDs
Ye Xu https://orcid.org/0000-0001-5602-3306
Yan Sun https://orcid.org/0000-0002-3904-1622
Ji Yang https://orcid.org/0000-0001-7768-7320

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