졸업논문청구논문

Orion A Cloud의 쌍극 방출류의 성질

Properties of Bipolar Outflows of the Orion A Cloud

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Properties of Bipolar Outflows of the Orion A Cloud

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A thesis submitted to the Gyeonggi Science High School in partial fulfillment of the requirements for the graduation. The study was conducted in accordance with Code of Research Ethics.*

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Approved by
Teacher Park, Kie Hyun
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Orion A Cloud의 쌍극 방출류의 성질

이 선 재

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Properties of Bipolar Outflows of the Orion A Cloud

Abstract

Stars are born when matter from interstellar molecular clouds fall to the center to increase the mass of the protostar. Bipolar outflows are formed to remove the excess angular momentum of falling matter. Intensities of outflows are known to be in a close relationship with their bolometric luminosity and evolutionary stages. In this study, data from Institute for Radio Astronomy in the Millimeter Range (IRAM) 30 m Telescope and Taeduk Radio Astronomy Observatory (TRAO) were used. IRAM data were used to map ^{12}CO J = 2 - 1 over Orion A molecular cloud. TRAO data were used to map ^{13}CO J = 1 - 0 over the same region. Outflows were observed and measured by drawing contour maps and line profiles of red/blue shifted components. The correlation between a protostar's luminosity and outflow momentum flux have been confirmed. Also, outflows could be detected better if the energy level of the emission line is higher.

Orion A Cloud의 쌍극 방출류의 성질

초 록

별은 성간분자운의 물질이 중심으로 떨어져 원시성의 질량을 증가시켜야만 탄생된다. 이 과정에서 중심으로 떨어지는 물질의 각운동량을 제거하기 위해 방출류가 발생한다. 여기서 방출류의 세기는 원시성의 진화 단계와 광도와 관련이 있다고 알려져 있다. 이를 새로 관측된 데이터를 사용하여 기존의 연구를 검증해 보려고 한다. 이 연구에서는 Institute for Radio Astronomy in the Millimeter Range (IRAM) 30 m 망원경으로 관측한 ^{12}CO J = 2 - 1 관측 자료와 대덕 전파 망원경(Taeduk Radio Astronomy Observatory, TRAO)으로 관측한 ^{13}CO J = 1 - 0 천이 선 자료를 이용하였다. 두 자료 모두 Orion A Cloud 영역을 담고 있다. 빠른 속도를 가진 적색/청색편이된 성분의 contour map을 그려 방출류를 관찰하고 방출류의 세기를 구하였다. 방출류의 세기와 원시성의 광도가 대체적으로 비례한다는 것을 알 수 있었다. 그리고 천이 선의 에너지 준위가 높을수록 방출류를 더 잘 검출할 수 있음을 확인할 수 있었다.

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I. 서론

페로브스카이트는 태양 전지에서 빛을 흡수해서 움직이는 전하를 만드는 역할을 한다. 태양 전지가 1970년대 재생 가능 에너지의 일부로써 주목을 받은 이후 지속적인 투자를 받아왔으며 2030년이 되기 전에 광전지로 만드는 전기의 양이 전체 전력의 3분의 1이나 될 것이라는 예측도 있다 [?]. 페로브스카이트 재료(이 논문에서 페로브스카이트라고 한다)는 ABX_3의 결정 구조를 가진 물질로, 여기서 A, B는 양이온, X는 음이온이다. 쇼클리-퀴서 한계(Shockley-Quiesser limit) 이론에 의하면, 하나의 p-n 접합에서 1.34eV의 전위차가 걸릴 때 가장 큰 효율인 33.7많은 연구자들과 과학자들은 이러한 장점을 가진 페로브스카이트의 제작 비용, 시간을 줄이고 에너지 전환 효율성을 높이기 위해 활발히 연구하고 있다. 처음으로 페로브 스카이트를 이용하여 빛을 이용한 발전을 한 사람은 Miyasaka였다. 그는 2006년에 처음으로 CH3NH3PbBr3를 이용한 전지로 2.2최근에는 PDMS(폴리디메틸실록산)를 이용해 단결정 할라이드(hallide) 페로브스카이트를 만드는 새로운 방법이 발견되었다. PDMS는 용액이 웨이퍼에 코팅된 후 압력으로 이을 누르는 데 사용된다. PDMS 스탬핑 없이 AFM(Atomic force microscopy)으로 측정한 거칠기는 79.1 ± 43.3nm이었지만 PDMS 스탬핑은 거칠기를 7.1 ± 4.6nm 로 감소시켰다 [?]. 또한, 이 방법은 용액에서 석출하는 방법(Czochralski 방법) 같은 기존의 방법보다 많은 시간을 절약했다. PDMS 스탬프를 적용한 연구에서, 할로겐화 페로브스카이트 필름에 약 130nm 크기의 패턴을 성공적으로 인쇄했다 [?]. 이러한 패턴은 1차원 및 2차원 분산 피드백(DFB) 구조에서 표면 반사율을 감소시켜 효율성을 향상시키기 위해 사용될 수 있다. 앞선 논문들에서는 PDMS 스탬핑 방식으로 페로브스카이트를 만들긴 했지만 이에 대한 의문을 제기하진 않았다. 새롭게 발견된 방법으로 만들어진 페로브스카이트가 기존의 방법으로 만들어진 페로브스카이트와 같은 특성을 가지고 있다는 것을 증명해야 한다. 이 논문에서는 이를 증명하기 위해 XRD 무늬와 TRPL 분석을 이용하였다. XRD(X-Ray Diffraction)은 결정성 물질에 X선을 쏘아 나타나는 고유

무늬로 물질을 구분하는 것이다. 측정기의 각도를 바꿔가며 도달하는 X선의 세기를 측정하여 무늬를 알아낸다. TRPL(Time-Resolved Photoluminescence)은 전하 운반자의 시간에 따른 변화를 관찰할 수 있는 장치이다. PL(Photoluminescence)은 물질에 에너지를 가해서 들뜬 상태를 만든 후 물질에서 방출되는 빛을 파장별로 검출하는 방식이다. TRPL은 PL spectra의 시간에 따른 변화를 확인하는 방식으로, 광발광 수명(photoluminescent lifetime)으로 물질을 식별하거나 LED의 효율을 측정되는 데에 쓰인다. 물질마다 TRPL 데이터의 모양이 다른데, 이는 광발광 수명이 물질의 특성이기 때문이다. CsPbBr3의 경우에는 PL의 시간에 따른 변화가 exciton과 biexciton의 재결합에 의해 일어나는데, 각각의 수명은 1170±10ps와 510±5ps이다 [**?**]. 이렇게 본 논문은 XRD와 TRPL 분석 방법을 이용하여 PDMS 스탬핑을 이용한 새로운 방법이 페로브스카이트를 합성할 수 있다는 것을 제시한다.

II. Obervations and Data Reduction

II.1 Observation Region

The Orion region consists of two giant molecular clouds, the Orion A and B clouds. This study covers the Orion A Cloud. The Orion A Cloud covers about $29\,\mathrm{deg}^2$ of the sky and its distance is about $450\,\mathrm{pc}$ [**?**]. The total mass is estimated to be about $10^5\,M_\odot$. It contains several hot molecular cores, such as the BN-KL nebula. It is known that the Orion Cloud was formed by the collision and fragmentation of two giant molecular clouds about 60 million years ago. The effects of the collision can be seen in the present. There is a big velocity gradient along the declination axis. The north side of the Orion A Cloud (OMC 2) shows about $12\,\mathrm{km\,s^{-1}}$ but the south end (L1641) it is about $5\,\mathrm{km\,s^{-1}}$ [**?**].

II.2 Observation Data

The ^{12}CO (J = 2 - 1, 230.538 GHz) data was observed with the IRAM 30 m telescope in Granada, Spain, in 2013. The spatial beamwidth was $11''$, and the spectral resolution was $0.4\,\mathrm{km\,s^{-1}}$. The noise level was 0.2 K. It only covers the north region of the Orion A cloud [**?**].

The ^{12}CO (J = 1 - 0, 115.271 GHz) data was observed with the NRO 45m telescope in Nobeyama, Japan.

The ^{13}CO (J = 1 - 0, 110.201 GHz) and the C^{18}O (J = 1 - 0, 109.782 GHz) data were observed with the 13.7 m telescope at Taeduk Radio Astronomy Observatory (TRAO) in 2017. The spatial beamwidth was $45''$, and the spectral resolution was $0.05\,\mathrm{km\,s^{-1}}$. The noise level was 0.4 K. ^{13}CO and C^{18}O lines are optically thin lines which can trace most of the matter on the line of sight, contrasting to ^{12}CO lines which are so optically opaque that it can only trace the outermost part of the molecular core. In this study, I used TRAO data to determine the

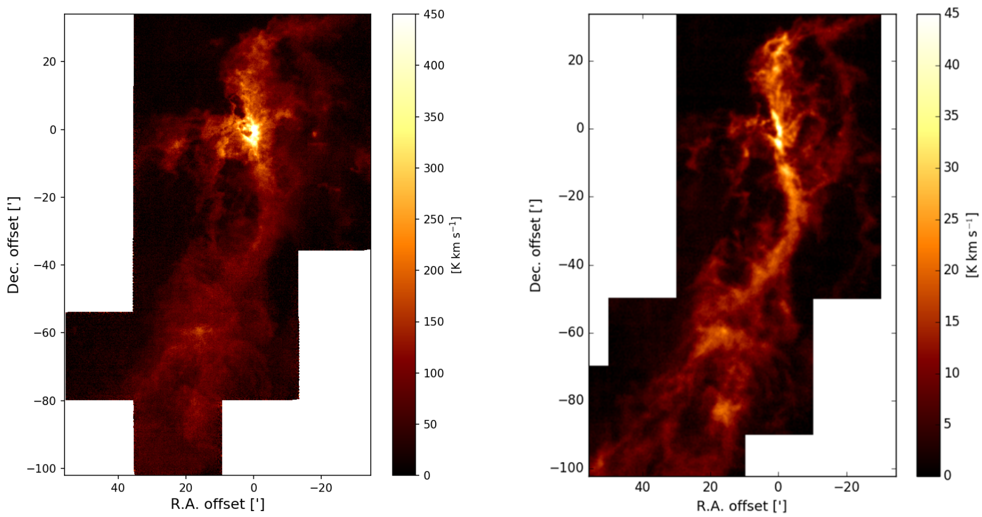

Figure 1. Orion A ^{12}CO (J = 2 - 1) integrated intensity map (left) ^{13}CO (J = 1 - 0) integrated intensity map (right).

protostar's velocity and linewidth which are the kinematic properties of the envelope. Then, I traced the outflow jets using ^{12}CO data.

Figure 1 shows the data from IRAM and TRAO. The intensity of the ^{12}CO data is approximately 10 times stronger than the ^{13}CO data.

II.3 Identification of Outflows

Data obtained by observing radio waves were summed over the line of sight, which tells us the distribution of matter with a relative radial velocity to the observer. The envelope around the protostar is static or is contracting slowly towards the protostar itself, but the outflow jets have large velocity components from each pole. If the inclination of the outflows are not zero, it would appear like the jets are moving closer to or further from the observer. In this study, ^{13}CO and C^{18}O lines were used to get the velocity distribution of the protostar. By using Gaussian fitting to the velocity distribution, I calculated the protostar's central velocity(v_{cen}) and the full width at half maximum (FWHM).

Because the emission lines of ^{12}CO are optically thicker than other lines, it is appropriate to trace the outflows with ^{12}CO lines. The intervals of the red/blue lobes were obtained by using the central velocity and the FWHM calculated previously. I drew contour maps to find out if bipolar outflows existed with the protostar at the center. To check if the red/blue lobes that were found are outflows from the same protostar I checked the ^{12}CO, ^{13}CO, C^{18}O lines from the red peak, blue peak, and the center points. For each outflow confirmed, I calculated the momentum force and the column density of each point.

The column density can be calculated with the following expression:

$$\begin{aligned} N_{H_2} =& \frac{8\pi\nu^3}{c^3}\frac{1}{(2J_l+3)A} \\ &\times \frac{Z(T_{ex})}{\exp(-E_l/kT_{ex})[1-\exp(h\nu/kT_{ex})]} \\ &\times \frac{\int T_B dV}{J(T_{ex})-J(T_{bg})} \end{aligned} \tag{1}$$

$$J(T) = \frac{h\nu/k}{\exp(h\nu/kT)-1} \tag{2}$$

In equation (1), ν is the corresponding frequency of the emission line, c is the speed of light, J_l is the rotational quantum number of the lower energy level, A is the Einstein A coefficient, Z is the partition function, E_l is the rotational energy of the lower energy level, k is the Boltzmann's constant, T_{ex} is the excitation temperature of the transitions, $\int T_B dV$ is the integrated intensity measured, and T_{bg} is the background radiation temperature. I assumed a local thermal equilibrium(LTE) excitation at an outflow temperature of 50 K [**?**]. The mass within one beam can be calculated as the following:

$$M_B = \frac{\pi}{4} D^2 \theta_B^2 X[\mathrm{CO}] N_{\mathrm{H_2}} m_{\mathrm{H_2}} \tag{3}$$

D is the distance to the objects, θ_B is the beam size, and m_{H_2} is the mass of one hydrogen molecule. $X[\mathrm{CO}]$ is the abundance ratio of CO to H_2. In this paper, $D = 450\,\mathrm{pc}$ and $X[\mathrm{CO}] = 10^{-4}$ was used [**?**].

II.4 Calculating Momentum Flux

The momentum flux within one beam is calculated with the following:

$$\dot{P} = \frac{dP}{dt} = \sum_v \frac{M_B(v)(v/\cos i)}{D\theta_B/(v \tan i)} \tag{4}$$

v is the velocity offset from v_{cen}, $M_B(v)$ is the mass within one beam, and i is the inclination within one beam [**?**]. Then the momentum flux from individual beams were summed in annuli.

$$F_{\mathrm{CO}} = \sum_{annulus} \frac{2\pi\theta_r}{N_{pix}\theta_B} \dot{P} \tag{5}$$

N_{pix} is the number of pixels in an annulus. θ_r is the distance between each pixel and the outflow center. θ_B is the beam size [**?**, **?**].

III. Results

III.1 Outflow Identification

Table 1. Protostars with observed outflows.

Name	Coordinates RA	Coordinates Dec	$\mathbf{L_{bol}}$ [$\mathbf{L_\odot}$]	$\mathbf{T_{bol}}$ [**K**]
FIR2	05:35:24.3	-05:08:33.3	5.68	100.6
FIR3	05:35:27.5	-05:09:32.5	360.86	71.5
FIR6b	05:35:23.4	-05:12:03.2	21.93	54.1
MMS2	05:35:18.3	-05:00:34.8	20.11	186.3
MMS5	05:35:22.4	-05:01:14.1	15.81	42.4
MMS9	05:35:26.0	-05:05:42.4	8.91	38.1

Table 1 shows the protostars with bipolar outflows observed. The names of the protostars are from the 1.3mm continuum observations by Chini et al. [**?**] and Nielbock et al. [**?**] L_{bol} and T_{bol} were calculated from the Spitzer and Herschel surveys [**?**, **?**].

III.1.1 ^{12}CO J = 2 - 1 Observations

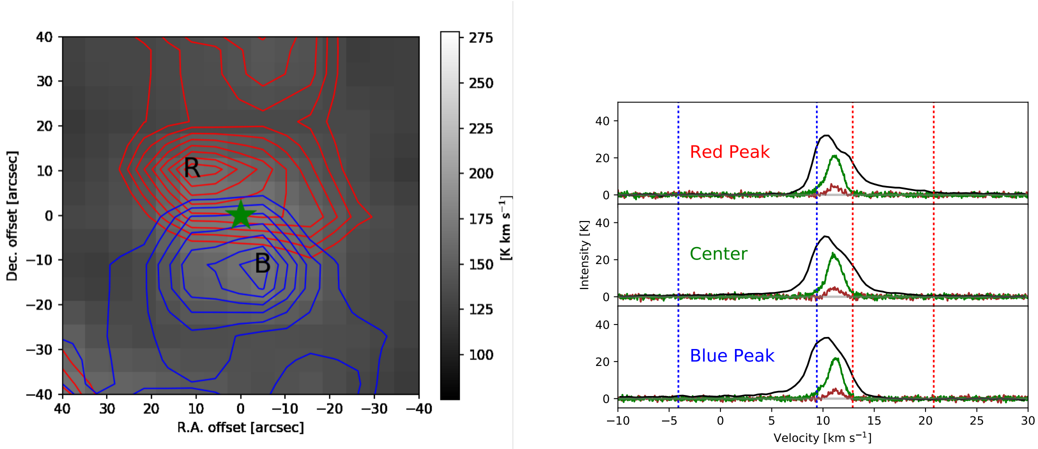

Figure 2. The ^{12}CO J = 2 - 1 intensity contour map (left) and the line profile (right) of FIR2.

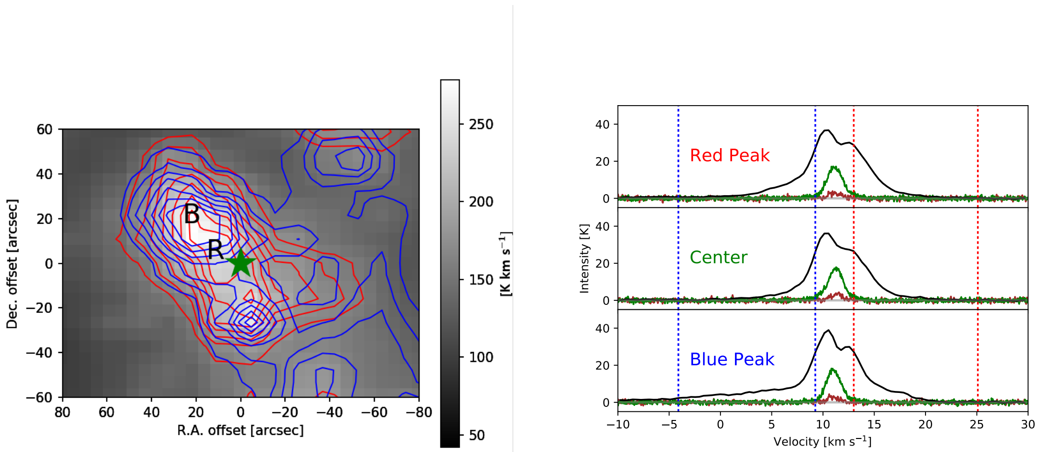

Figure 3. The contour map and the line profile of FIR3.

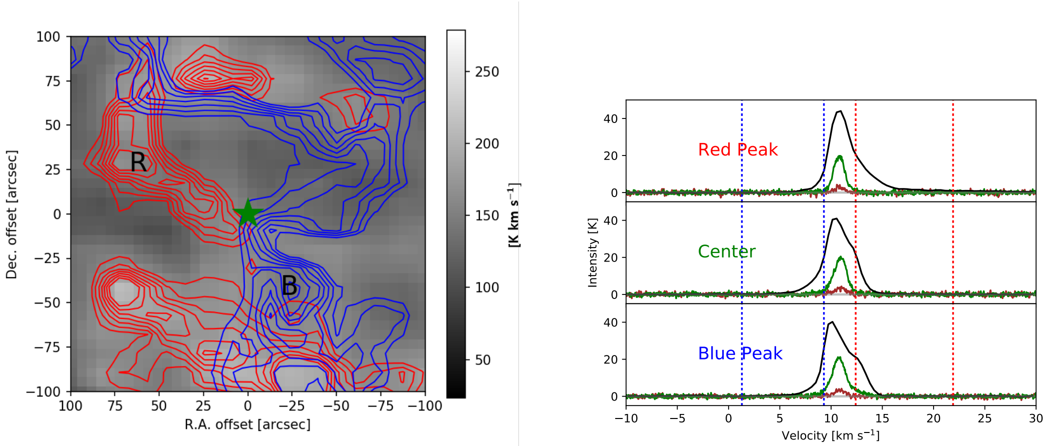

Figure 4. The contour map and the line profile of FIR6b.

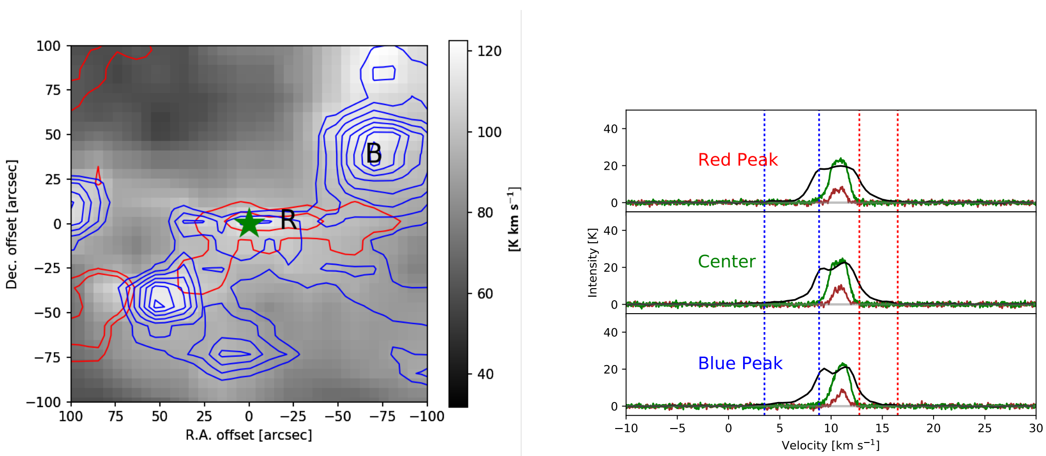

Figure 5. The contour map and the line profile of MMS2.

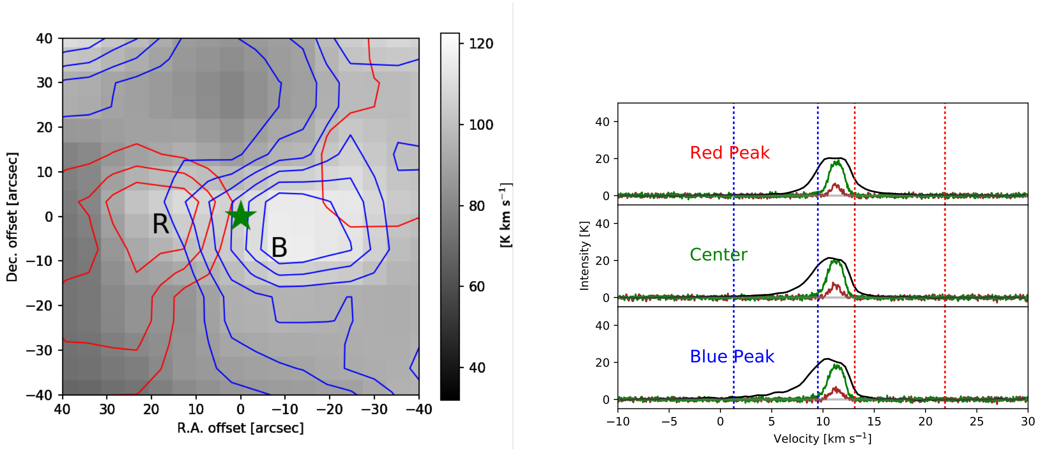

Figure 6. The contour map and the line profile of MMS5.

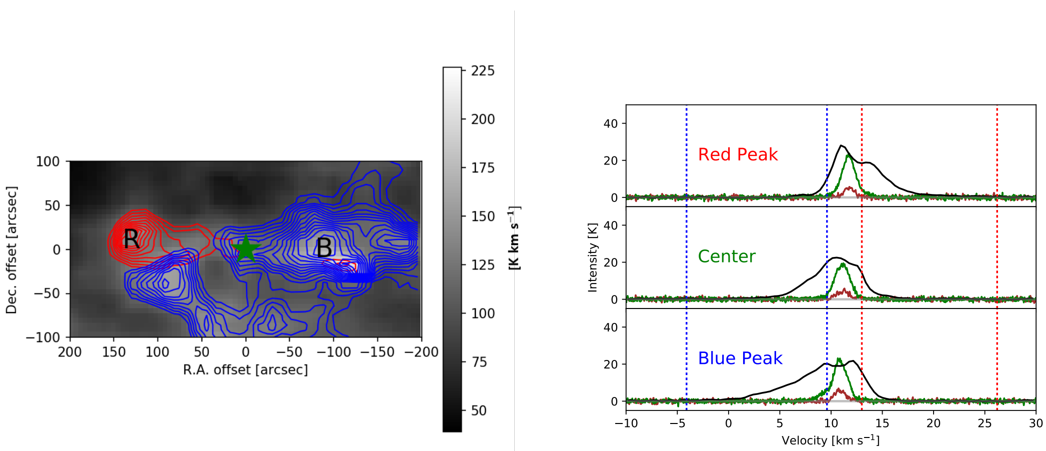

Figure 7. The contour map and the line profile of MMS9.

The ^{12}CO J = 2 - 1 intensity for each point were calculated by using equations (1) and (3). The line profile shows the intensities of ^{12}CO J = 2 - 1 (black), ^{13}CO J = 1 - 0 (green), and C^{18}O J = 1 - 0 (brown) for each point.

FIR2 – There is a strong bipolar outflow elongated along the N-S direction as shown in Figure 2. The size is about 30 arcsec, which is smaller than other outflows detected. Red and blue contour intervals are 10σ starting from 60σ and 10σ starting from 100σ respectively.

FIR3 – A strong bipolar outflow can be seen along NE-SW direction, with red and blue lobes overlapping each other as shown in Figure 3. This tells us that the outflow axis is almost parallel to the line of sight. Red and blue contour intervals are 20σ starting from 40σ and 20σ starting from 60σ respectively.

FIR6b – The contour is not so clear because of other IR sources nearby as shown in Figure 4. The outflow is along the NW-SE direction. Red and blue contour intervals are 10σ starting from 45σ and 10σ starting from 110σ respectively.

MMS2 – The contour is in a tricky situation, because both red and blue lobes are on the east side of the protostar as shown in Figure 5. The outflow structure on the SW side is the outflow from another protostar, MMS5. It is possible that the outflow structure changed shape because of the turbulence from other protostars. Red and blue contour intervals are 10σ starting from 30σ and 10σ starting from 60σ respectively.

MMS5 – There is an outflow structure along the E-W direction as shown in Figure 6. This outflow is much smaller than other bipolar outflows. Red and blue contour intervals are 10σ starting from 20σ and 10σ starting from 40σ respectively.

MMS9 – There is a strong outflow along the E-W direction as shown in Figure 7. We can see a smaller red lobe near the center of the blue lobe. Red and blue contour intervals are 10σ starting from 50σ and 10σ starting from 60σ respectively.

III.1.2 ^{12}CO J = 1 - 0 Observations

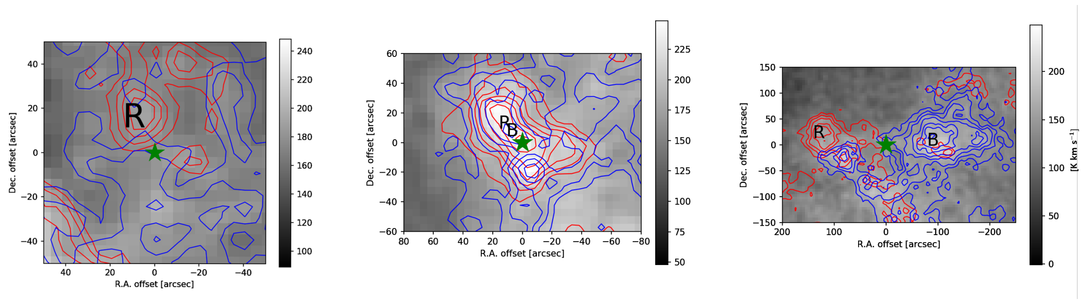

Figure 8. The ^{12}CO J = 1 - 0 intensity contour map of FIR2 (left), FIR3 (middle), and MMS9 (right).

FIR2 – The red lobe is clear on the NW side of the protostar, but the blue lobe is not as clear as shown in Figure 8.

FIR3 – The outflows are in a similar shape as the J = 2 - 1 observations as shown in Figure 8. The lobe centers are slightly near the protostar.

MMS9 – The outflows are also in a similar shape as the J = 2 - 1 observations as shown in Figure 8. We can also see that there is a small red lobe near the center of the blue lobe.

III.2 Momentum Flux

Table 2. CO outflow parameters.

Name	J = 2 - 1			J = 1 - 0		
	$\mathbf{F_R}$	$\mathbf{F_B}$	$\mathbf{F_{CO}}$	$\mathbf{F_R}$	$\mathbf{F_B}$	$\mathbf{F_{CO}}$
	($M_\odot$ km s^{-1}yr^{-1})					
FIR2	1.14E-05	3.28E-05	4.42E-05	4.78E-06	-	4.78E-06
FIR3	4.77E-04	7.43E-04	1.22E-03	1.86E-04	3.02E-04	4.88E-04
FIR6b	1.13E-05	1.18E-05	2.31E-05	-	-	-
MMS2	1.14E-05	4.50E-05	5.64E-05	-	-	-
MMS5	5.80E-06	1.55E-05	2.13E-05	-	-	-
MMS9	3.67E-06	1.09E-05	1.46E-05	1.45E-06	6.02E-06	7.47E-06

Table 2 shows the parameters of the outflows detected. F_R and F_B stands for the outflow forces for the red lobe and the blue lobe respectively. F_{CO} is calculated by adding the two forces, which shows the momentum flux of the protostar. We can see that more outflows were detected by using J = 2 - 1 data, and the momentum flux is 2-3 times higher.

III.3 Momentum flux vs. Bolometric luminosity

Figure 9 shows the relation between the bolometric luminosity and the momentum flux of the outflows from previous studies and this work [?, ?, ?, ?, ?, ?]. Since the momentum flux of the same protostar is known to vary somewhat depending on the calculation methods [?], the relation between the bolometric luminosity and the momentum flux is difficult to express with an exact formula and only the degree of tendency can be analyzed.

Orion A Cloud is a region where stars with medium mass are formed. The fact that the momentum flux of the outflow is proportional to the bolometric luminosity can be confirmed.

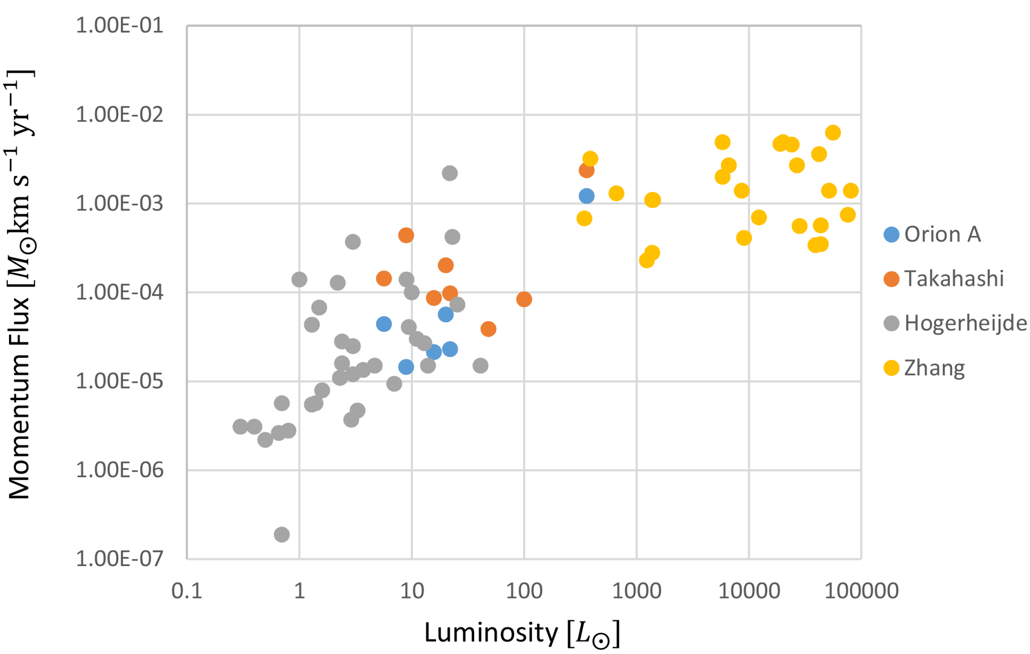

Figure 9. CO outflow momentum flux vs. L_{bol}

III.4 Momentum flux by emission line energy level

Figure 10 compares momentum flux calculated by three different emission lines of the same protostar. The ^{12}CO J = 3 - 2 observation was made by Takahashi et al [**?**]. We can see that it is possible to detect more outflows by using a higher energy emission line of ^{12}CO. Using data with smaller beamwidth also enhances detecting outflows.

The reason that higher energy lines can detect more outflows can be explained as the following: The excitation temperature is higher for emission lines with higher energy. Outflows drag out matter from the protostar's envelope, which has higher temperature than its surroundings. Lines with higher energy are emitted, which has an effect that makes column density higher than usual.

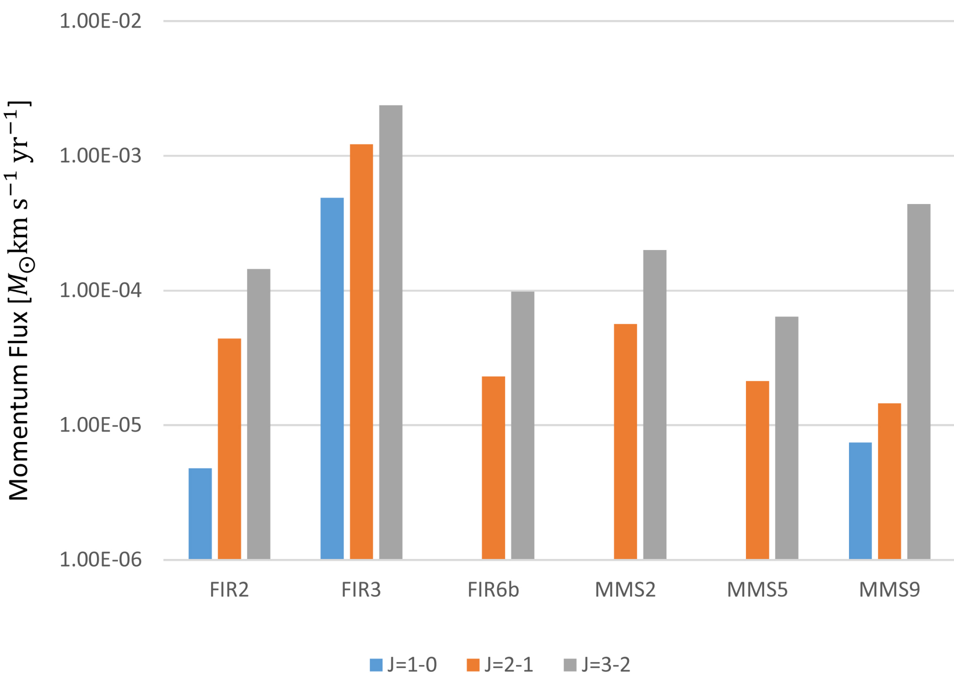

Figure 10. Momentum flux difference by emission line energy.

IV. Conclusion

The main results of this study are as follows:

1. 6 bipolar outflows were detected from the Orion A Cloud. All outflows were detected by J = 2 - 1 data and 3 outflows were detected by J = 1 - 0 data.
2. The well-known correlation between the momentum flux and the bolometric luminosity can be confirmed.
3. It is possible to detect more outflows by using a higher energy emission line of ^{12}CO. Using data with smaller beamwidth also enhances detecting outflows. The reason that higher energy lines can detect more outflows can be explained as the following. The excitation temperature is higher for emission lines with higher energy. Outflows drag out matter from the protostar's envelope, which has higher temperature than its surroundings. Lines with higher energy are emitted, which has an effect that makes column density higher than usual.

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