Special Issus: 1st Scientific International Conference, College of Science, Al-Nahrain University, 21-22/11/2017, Part I, pp.69-71

ALMA Study of the Lensed Galaxy SDP.81

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Abstract

In this paper we present high resolution data from Atacama Large Millimeter /sub-millimeter Array (ALMA) of CO (5-4) and CO (8-7) rotational transitions toward the gravitational lensed galaxy (SDP.81). We calculate the molecular gas mass in the clumpy region which is around 1.5×10^{9} $M_{\odot}$. We overly the CO(8- 7) and CO(5- 4) intensity distributions to calculate the brightness temperature ratio R_{85} at various region. The CO line ratio was in the range between 0.39 and 0.75 with an average value about 0.48. This line ratio suggests that most sub-millimeter galaxies, SMGs, include a significant proportion of extended, moderate-density, cool gas. [DOI: 10.22401/ANJS.00.1.09]

Keywords: Galaxies, High redshift, ALMA, SDP.81.

1. Introduction

Gravitational lensing is an important astrophysical tool to understand the formation and evolution of distant galaxies. At sub-millimeter wavelength, the investigation of redshifted molecular lines in gravitationally lensed sources provides a valuable diagnostic tracer of their interstellar medium, structure and dynamics [1-4]. H-ATLAS J090311.6+ 003906 (also known as SDP.81) is a gravitationally lensed sub-millimeter galaxy (SMG) at redshift z=3.042 that was discovered in Herschel Astrophysical Terahertz Large Area Survey [5, 6].

Obtaining the desired high-resolution imaging in the sub-millimeter become available using ALMA. The aim of this manuscript is to use the high-resolution ALMA imaging of the lensed source to study the physical properties of its molecular gas. The structure of this manuscript is composed from the following sections: Section 2 describe the radio instrument. Section 3.1 describe the data and initial results. In section 3.2 we calculate the brightness temperature ratio. Lastly, the summary and conclusions were listed in section 4.

2. Radio Instruments

ALMA is the largest astronomical project to date. It is composed of a large array of 12 m antennas, with baselines of up to 16 km. The antennas are movable within the surrounding regions. In addition to the 12 m array, ALMA is also equipped with the Atacama Compact Array (ACA), which is composed of twelve 7 m antennas and four 12 m antennas. The ACA array is often fixed and used for observing large-scale structures that are not clearly imaged by the 12 m array. Extra extended arrays can offer higher spatial resolutions, whereas more compact arrays can offer the best sensitivity for extended objects.

3. Results and Discussion

3.1 Molecular Gas Mass

SDP.81 was observed with ALMA science verification SV data band 4 on 2014 October 21. The band 4 receivers were tuned to cover CO J = 5 – 4 transition (rest frequency = 576.267 GHz; SDP.81's redshift = 3.042). The observational characteristics are shown in Table (1). The data were manipulated using the Common Astronomy Software Application (CASA). We have used the publically available SV CO (J = 5 – 4) data as a tracer for molecular gas mass. The CO(J = 5 – 4) integrated intensity and velocity field maps are shown in Fig.(1).

Table (1)
ALMA Observational Characteristics.

Characteristic	*Value*
Galaxy	H-ATLAS J090311.6+003906 (SDP.81)
Observing date	2014 October 21
Field center: R.A.(J_{2000}) Dec.(J_{2000})	$09^h\ 03^m\ 11.610^s$ $+00^o\ 39'\ 06.700''$
Rest frequency	576.267 GHz
Velocity resolution	21 km s^{-1}
Restoring beam	(major, minor, P.A.) 0.15″, 0.12″, 57.26

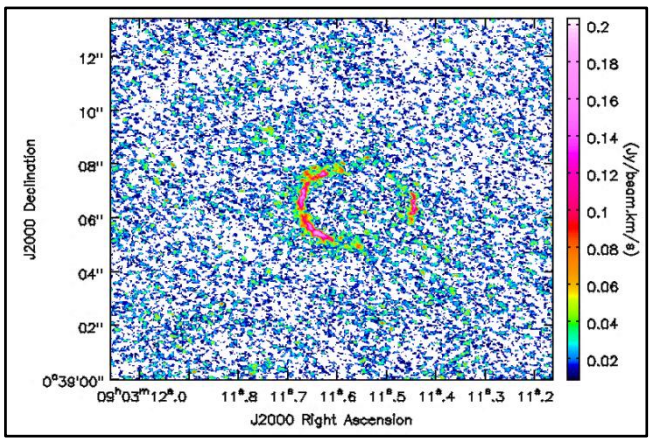

Fig.(1) ALMA CO(J=5–4) integrated intensity image of SDP.81.

We calculate the molecular gas mass using the following formula [7]:

$$\left(\frac{M_{H_2}}{M_\odot}\right) = \alpha_{CO} L'_{CO} \quad \text{.....(1)}$$

where α_{CO} is CO-to-H_2 gas mass conversion factor which is equal to 0.8 M_O (K km $s^{-1}pc^2)^{-1}$ [8], L'_{CO} is CO luminosity which was calculated from the following equation:

$$L'_{CO} = 3.25 \times 10^7 S_{CO}\Delta v \nu_{obs}^{-2} D_L^2 (1+z)^{-3} \quad \text{.....(2)}$$

where $S_{CO}\Delta v$ is the intensity of ^{12}CO(J=5-4) in Jy km s^{-1}, D_L is the luminosity distance in Mpc and $\nu_{obs}^{-2}$is the observed frequency in GHz. We adopted CO line ratio R_{51} = 0.3, [9]. The total molecular gas mass M(H_2) within the area of clumpy molecular gas $\Delta x \times \Delta y$ = 4″×4″ is equal to 1.5×10^9 $M_\odot$.

3.2 CO Line Ratio

In Fig.(2) we overlay ALMA integrated intensity maps of the CO(J=8–7) line emission (raster image) and CO (J=5-4) line emission (contour image) for the galaxy SDP.81. We can see from this figure the overall distribution of both CO (8-7) and CO (5-4) are very similar. We divided the clumpy molecular gas into 8 regions (1→8) in the same way as [10, 11, 12]. The size of each region is 0.5″×0.5″. The CO(8-7)/CO(5-4) brightness temperature ratios, R_{85}, are calculated for each region and listed in Table (2). There is no clear ratio difference between these 8 regions which have a range of brightness temperature ratio between 0.39-0.75. The average value in these regions about 0.48. This value was consistent with previous work. The values of the line ratios propose that most sub-millimeter galaxies, SMG, include a significant proportion of extended, moderate-density, cool gas, [13].

Table (2)
The CO(8–7)/CO(5–4) Line Ratios in Different Areas.

Region	R.A.(J_{2000})	Dec.(J_{2000})	R_{85}
1	09:03:11.640	+00:39:07.648	0.52
2	09:03:11.668	+00:39:07.070	0.39
3	09:03:11.673	+00:39:06.507	0.43
4	09:03:11.665	+00:39:05.957	0.36
5	09:03:11.649	+00:39:05.394	0.45
6	09:03:11.612	+00:39:05.302	0.49
7	09:03:11.446	+00:39:06.767	0.75
8	09:03:11.442	+00:39:06.225	0.45

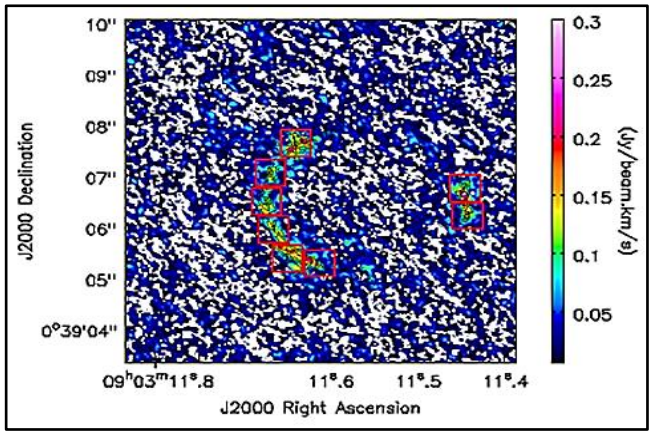

Fig. (2) ALMA integrated intensity map of the CO(J=5-4) line emission (contour image) overlaid on CO(J=8-7) line emission (raster image) for the galaxy SDP.81. We also plot 8

boxes (1→8) that are used to calculate the line ratios.

4. Summary and Conclusions

We used a very high resolution data of ALMA observation of the ^{12}CO(J=8−7) and ^{12}CO(J=5−4) line emissions as a molecular gas indicator in the clumpy region of the gravitational lensed galaxy H-ATLAS J090311.6+003906 (SDP.81) at redshift z = 3.042. Both the ^{12}CO(J=8−7) and ^{12}CO(J=5−4) line show similar distribution in the integrated intensity maps. We find the molecular gas mass from ^{12}CO(J=5−4) equal to 1.5×10^{9} $M_{\odot}$. We also find the brightness temperature ratio R_{85} at different regions. The CO line ratio varies between 0.39 and 0.75 with an average value of 0.48. This value of line ratio suggests that most of the SMGs have a considerable amount of extended, moderate-density, cool gas.

Acknowledgments

This paper makes use of the following ALMA data: ADS/JAO.ALMA #2011.0. 000016.SV. ALMA is a partnership of ESO (representing its member states), NSF (USA) and NINS (Japan), together with NRC (Canada) and NSC and ASIAA (Taiwan), and KASI (Republic of Korea), in cooperation with the Republic of Chile. The Joint ALMA Observatory is operated by ESO, AUI/NRAO and NAOJ.

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