Search for Prebiotically Important Complex Organic Molecules Using ALMA

Ya-Wen Yo (游雅雯)
Department of Physics, NTNU
Supervisor: Prof. Yi-Jehng Kuan (管一政)

Abstract

Based on the knowledge learned from our previous searches of prebiotically important complex organic molecules with the SMA (Submillimeter Array), we searched for interstellar pyrimidine in the Orion KL massive star-forming region at 212 GHz using the high angular-resolution ALMA (Atacama Large Millimeter/Submillimeter Array). Our study is one of the first steps to detect essential biomolecules in space beyond the terrestrial atmosphere.

Introduction

Pyrimidine (c-$C_4H_4N_2$), an aromatic heterocyclic organic compound, is a prebiotically important complex organic molecule (COM); its derivatives are the three nucleobases, cytosine, thymine and uracil, of nucleic acids. Why do we want to detect prebiotically important interstellar complex organic molecules? There are many hypotheses which try to explain where life came from originally and what the original compositions of life were. One of the hypotheses suggested some important organic compositions of primitive life were delivered by comets to the Earth. If prebiotically important COMs were discovered in star-forming regions, we may infer the existence of these COMs in the Solar Nebula which plays a key role in the origin of life on the early Earth.

Orion KL is the most widely studied hot molecular core (HMC) of the well-known Orion giant molecular cloud (OMC-1). Lying at a distance of ~450 pc from Earth, Orion KL is one of the nearest massive star-forming regions with high luminosity (~10^5 $L_\odot$). Hot Core and Compact Ridge are the major continuum sources observed in Orion KL. Many molecular lines from simple molecules such as SO and CS and from organic molecules such as H_2CO and CH_3OH were detected in Orion KL. Previous studies showed that N-bearing molecular species is more abundant toward the Hot Core, and O-bearing molecules are richer toward the Compact Ridge.

Pyrimidine has been searched for over four decades without success (Simon & Simon 1973; Kuan et al. 2003). It is difficult to detect extremely weak spectral lines of complex organic molecules such as pyrimidine, probably due to their relatively low fractional abundances and exceedingly numerous transitions available. Using the powerful ALMA (Atacama Large Millimeter/ submillimeter Array) with arcsecond resolution (the synthesized *clean* beam is of 1.13″ × 0.88″) and high spectral sensitivity (an *rms* noise of 3–5 mJy $beam^{-1}$), we were now able to observe the spectral emission of pyrimidine toward Orion KL hot molecular core fortunately. Our ALMA results are helpful to understand chemical and dynamic evolution details of star formation.

Observations

We used the Common Astronomy Software Applications package (CASA) to image and analyze our Cycle-0 data. Table 1 lists information of our ALMA observations. Figure 1 shows the UV-coverage of our data

Table 1. Summary of our ALMA observations toward Orion KL at 212 GHz.

Parameter	Information
Date of observations	21-NOV-2012
Total integration time (sec)	3120
Observed time	From 03:57 to 04:49 on Nov 21, 2012 (UTC)
Phase tracking center (J2000)	$\alpha = 05^h35^m14^s.35$ $\delta = -5^\circ22'35''$
Number of antennas	25
Diameter of each antenna (m)	12
Number of Baseline	300
Band ID	Band 6
Spectral windows ID	0
Number of channels	3840
Frequency of the first channel (MHz)	213218.44
Total Band Width (GHz)	1.875
Spectral Resolution in velocity ($km \cdot s^{-1} \cdot ch^{-1}$)	0.687
Spectral Resolution in frequency ($kHz \cdot ch^{-1}$)	488
Weighting	Natural
Restoring Beam Size	1.13″×0.88″
Rms noise level (mJy $beam^{-1}$)	3–5

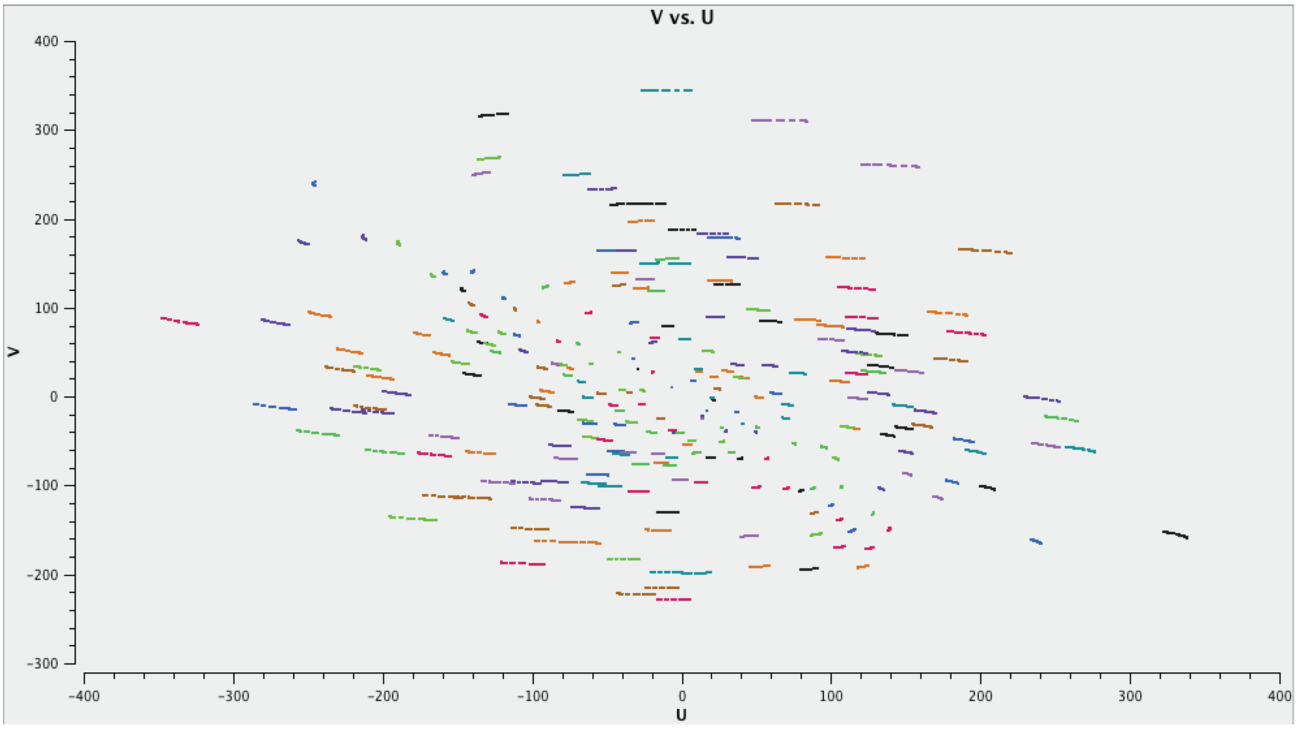


Figure 1. The UV-coverage of our pyrimidine observations with 25 antennas at 212 GHz toward Orion KL on 2012 November 21 from 03:57:06.3 to 04:49:06.2 UTC. Different baselines are shown in different colors.

Preliminary Results and Discussions

Because Orion KL is chemically rich, the observed spectrum in each spectral window (SPW) is full of low-intensity spectral weeds (aka line forest). Thus it is difficult to define line-free channels in each SPW for continuum subtraction. To make a continuum map in the SPW where pyrimidine lines are expected, ~100 line-free channels out of 3,840 channels in the baseband (BB) were selected. Two continuum sources, the Hot Core and Compact Ridge, are clearly detected in Orion KL (Figure 2). Orion Hot Core is known to have a hot physical environment at ~300 K with an H_2 number density of around 10^6 cm^{-3}, the Compact Ridge, on the other hand, is in a colder environment at a temperature of ~100 K.

From previous studies, it has been also shown that N-bearing molecules tend to be more abundant toward the Hot Core in the north, yet O-bearing molecules are concentrated to the south toward the Compact Ridge. The chemical differentiation seen in Orion KL between N-bearing and O-bearing molecular species is probably due to mantle evaporation occurred earlier in Hot Core than in Compact Ridge (Rodgers et al. 2001). Pyrimidine is an N-bearing molecule, so it also appears richer toward the Hot Core than in Compact Ridge. **Figure 3** shows the channel maps of the tentatively detected pyrimidine. If confirmed, our results will be crucial to astrobiology study.

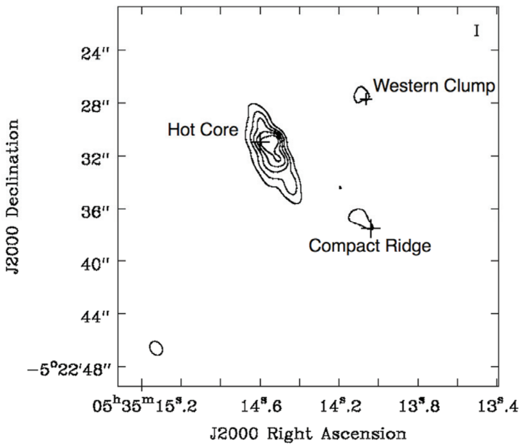
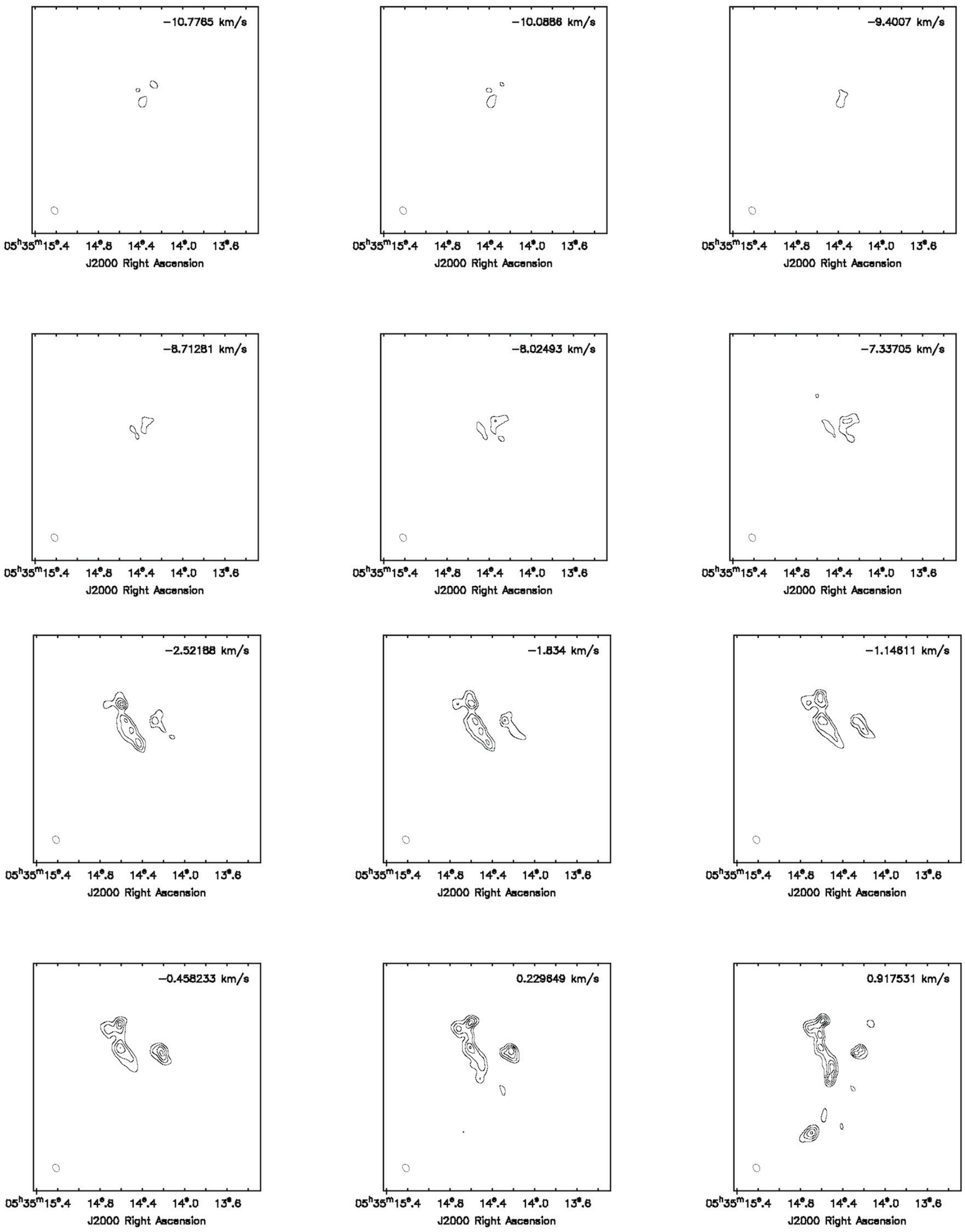


Figure 2. 212-GHz continuum map of Orion KL. The ellipse shown in the bottom-left corner is the synthesized *clean* beam. Crosses mark the three continuum sources: Hot Core, Compact Ridge, and Western Clump. The *rms* noise level of the continuum image is of 3 mJy beam^{-1}. Contour levels are at 100, 200, 300, 400, 500, and 600 mJy beam^{-1}.



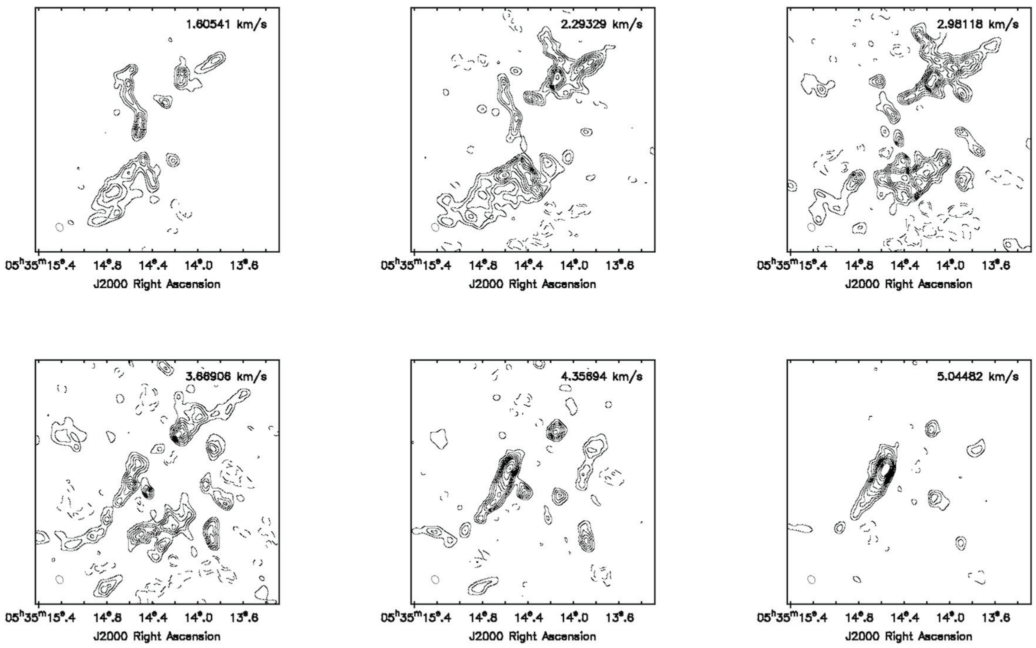


Figure 3. Pyrimidine channel maps at 212,807 MHz. The ellipse shown in the bottom-left corner is the synthesized *clean* beam. Negative contours at -150, -90 Jy beam^{-1} are shown in dash lines; solid lines indicate positive contours at 90, 150, 210, 270, 330, 390, 450, 570, 690 and 810 mJy beam^{-1}, with an *rms* = 2.5 mJy beam^{-1}. Pyrimidine transitions $J = 34_{1,34} - 33_{0,33}$ and $J = 34_{0,34} - 33_{1,33}$ are at 212,807.832 MHz. Interloping strong and extended $H_2{}^{13}CO$ emission is also shown.

References

Y.-J. Kuan et al. 2003, MNRAS, 345:650-656

S. D. Rodgers et al. 2001, ApJ, 546:324-329