Detection of CH in the Pipe Nebula

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Abstract

The Interstellar Medium (ISM) is the vast expanse of material that exists between stars. **Comprised of gas and dust,** the **ISM** contains **large aggregations known as nebulae.** One such example, **the Pipe Nebula, classified as a dark nebula** due to its high density, **gives rise to molecular clouds** within its confines. Interestingly, despite its density, the **Pipe Nebula is not birthing many stars in these cores,** and it is also known for having a strong magnetic field. As part of a **larger pilot survey of the galactic plane,** we **observed the Pipe Nebula for Methylidyne (CH),** a **common tracer of molecular gas.** Among the molecules present within these clouds is CH, whose hyperfine ground **state transition emits three spectral lines around 3.3 GHz.** We present the **preliminary results for the detection of CH in the Pipe Nebula** and examine the consequences of these results.

Figure 1. Pipe Nebula image processed by ESO/beletsky [1]

Motivation

Methylidyne (CH) is a **common tracer of molecular gas** that exists in a wide range of density regimes. As such, **it can trace molecular hydrogen (H_2) more effectively than the conventional Carbon Monoxide (CO) in regions of low density.** In the case of Pipe Nebula, CH supplies an additional piece of information about the abundance of molecular gas, its dynamics, and its environment.

Research Questions

- As Pipe Nebula appears to be a highly converted molecular cloud, **what are the relative abundances of CH, CO, and H_2?**
- What do the **properties of the CH 3.3 GHz emission lines** tell us about the **kinematics** of the molecular cloud?
- What do the **relative intensities of the CH lines** tell us about the **environment of the cloud**?

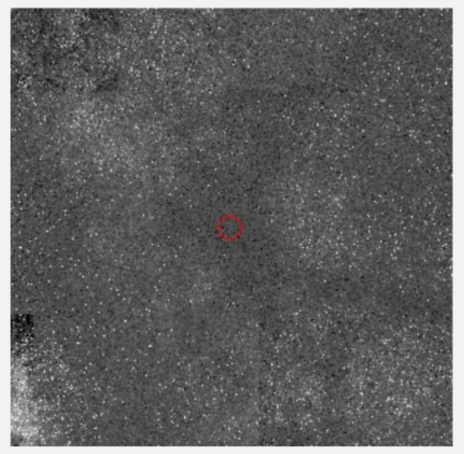

Figure 2. Observation radius of 12 meter radio telescope beam

Results, Conclusion, and Analysis

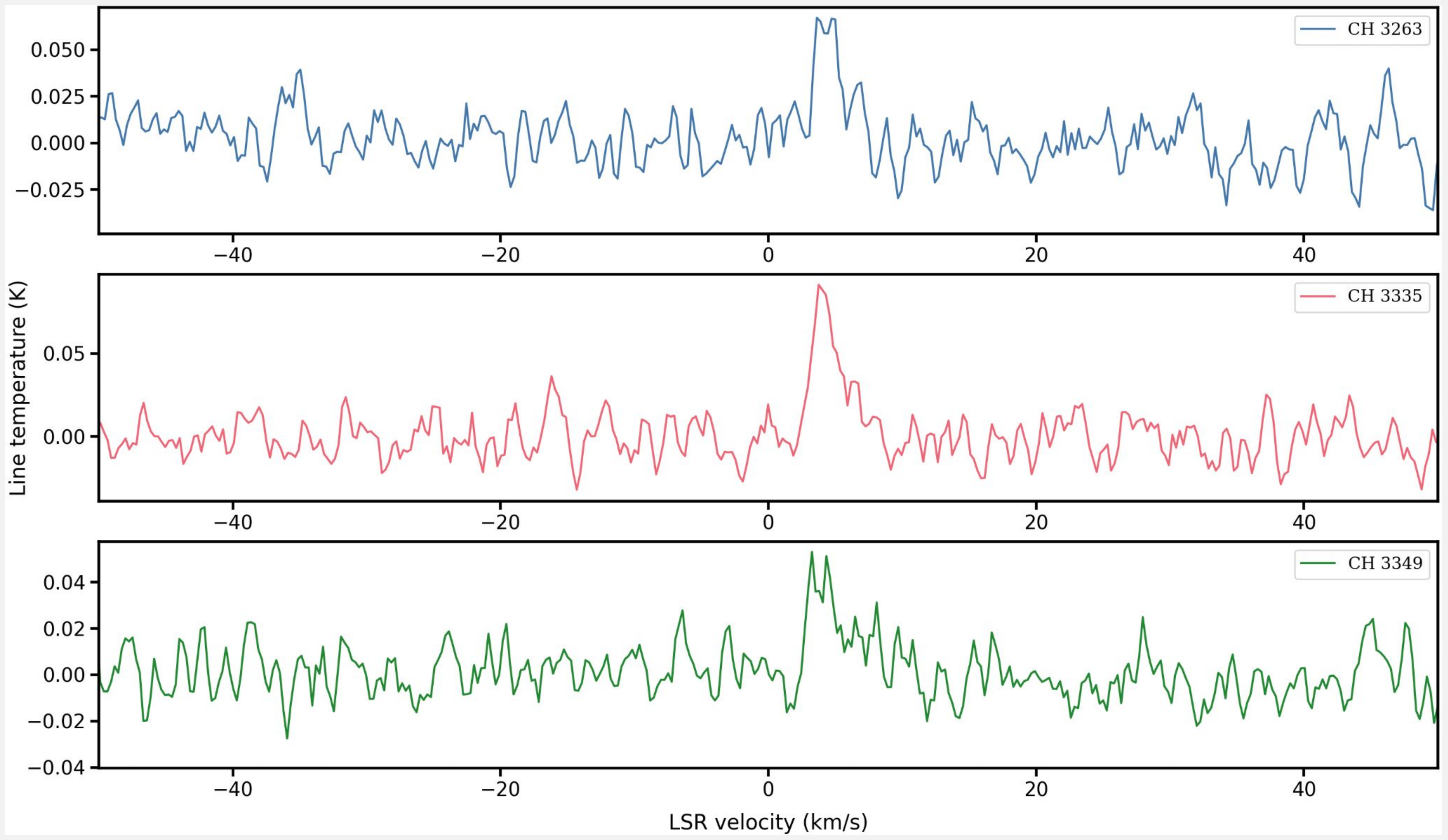

Figure 3. Preliminary results for the Pipe Nebula

Mock	Species observed	Line Rest Frequency (MHz)	Centered frequency (MHz)
1	CH	3263.79500	3257.7
2	CH	3335.48100	3329.3
3	CH	3349.19400	3340.0
4	H_2CO	3225.42300	3219.3
5	H – RRL (methanimine)	3248.49770 (3248.707154)	3242.2
6	H – RRL	3324.9875	3320.8

Table 1. Mock Sub-spectrometer, Species (elements or molecules) observed, the line rest frequency for each transition, and center frequency for each sub-spectrometer.

- Using the **cryogenically cooled 12-m radio telescope at the Arecibo Observatory site,** we **detected CH in the Pipe Nebula.**
- **Detections** were observed for all three transition states
- **The (main) 3.335 GHz transition is prominent** in addition to the satellite line
- The spectrometer was also configured for one H_2CO transition and two hydrogen Radio Recombination Lines, but none were detected, consistent with the lack of star formation in Pipe Nebula

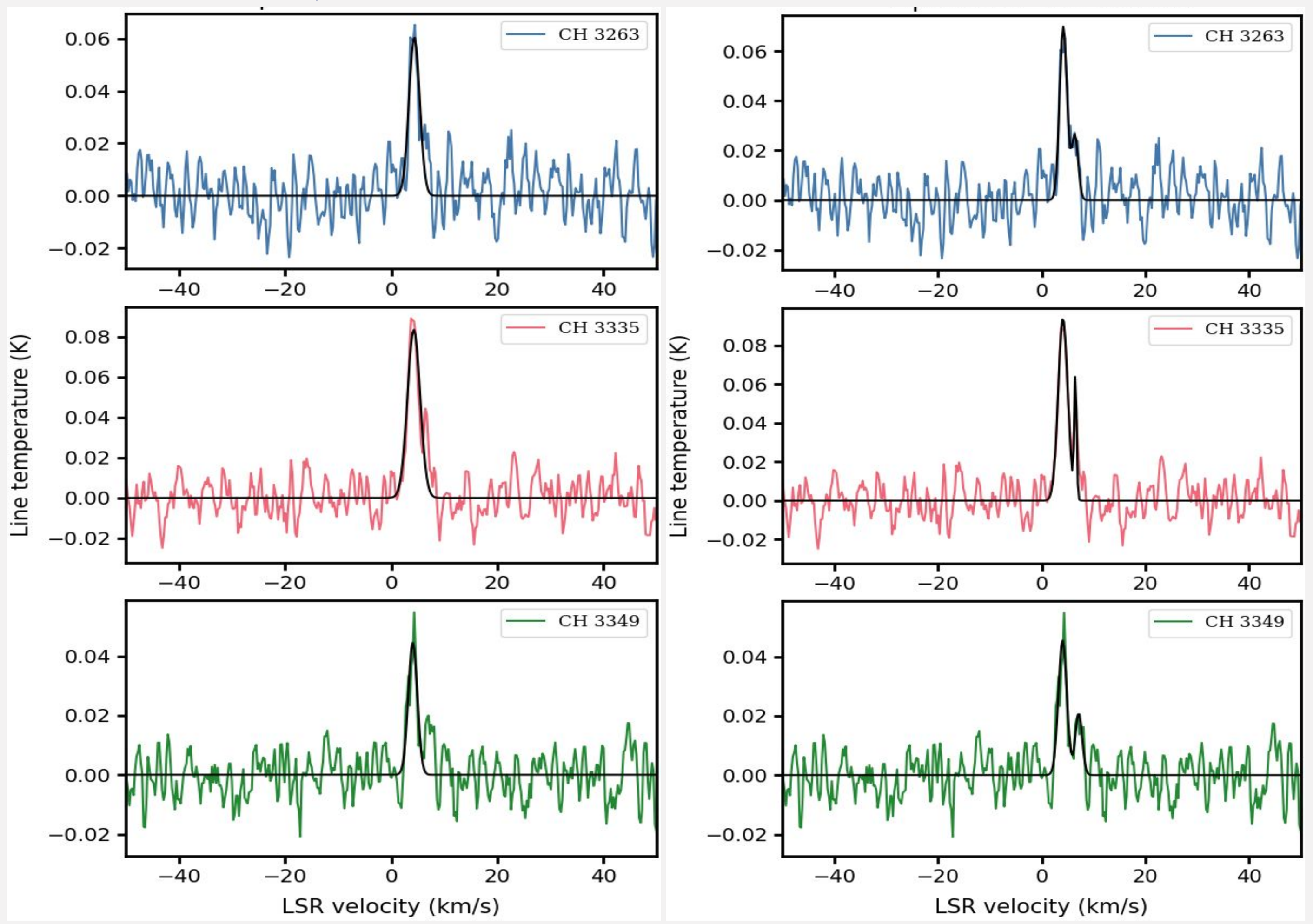

Figure 4.Gaussian models give the radial velocity and other characteristics of the CH lines. Experimentation with single vs. double gaussian fits indicates there might be two velocity components.

Table 2. Gaussian Parameters

Single Gaussian

Mock 1
Amplitude (err) Center(err) FWHM (err)
0.060(0.007), 4.36(0.15), 2.39(0.36)

Mock 2
Amplitude (err) Center(err) FWHM (err)
0.083(0.006), 4.26(0.11), 2.82(0.25)

Mock 3
Amplitude (err) Center(err) FWHM (err)
0.044(0.007), 4.07(0.15), 2.00(0.36)

Double Gaussian

Mock 1
Amplitude (err) Center(err) FWHM (err)
0.069(0.009), 4.19(0.13), 1.68(0.34)
0.025(0.009), 6.43(0.34), 1.47(0.83)

Mock 2
Amplitude (err) Center(err) FWHM (err)
0.093(0.007), 4.12(0.08), 2.17(0.20)
0.063(0.014), 6.53(0.06), 0.53(0.14)

Mock 3
Amplitude (err) Center(err) FWHM (err)
0.045(0.007), 4.05(0.15), 1.90(0.36)
0.020(0.007), 7.16(0.29), 1.56(0.71)

Methodology

All the data was processed using a data reduction pipeline using IDL and Python scripts.

- **Combine the ON/OFF** (or position-switched) pairs and calibrate the data from raw voltages into antenna temperature.
- **Inspect the data for Radio Frequency Interference** and average all salvageable scans.
- **Doppler correct the spectra** for different observing dates, and average all dates together to produce a final spectrum.
- **Baseline and gaussian fit** the spectrum to obtain line parameters.

Interpretation

This is the **first detection of all three CH lines in the Pipe Nebula.** The line ratios are **close to the expected LTE ratio but may indicate a slight overpopulation of the 3.263 GHz** level. The CH lines are consistent with the CO lines in the literature, and in our result. This gives us confidence in the CH detections. Moving forward, these results will **shed light on the relative abundances of species within the cloud and overall dynamics of the gas.**

Observation

All observations were made by the **upgraded 12-meter radio telescope** at the **Arecibo Observatory (AO).** The observations were obtained using an **ON-OFF method**, where we point the telescope at the source for a given time and then point it away from the source. each sub -spectrometer has 25 MHz bandwidth, 8192 channels, and, hence, a resolution of 3 kHz.

Future Work

We are **presently engaged in the process of data interpretation,** aiming to **compare the molecular hydrogen column density derived from CH observations with that obtained from CO**. Our current focus involves **analyzing CO data cubes sourced** from a large-scale survey, to **produce CO spectral lines for Pipe**. Additionally, we are conducting **extensive literature research to augment our understanding and contextualize our findings.** This project is ongoing, and we are committed to employing a comprehensive approach to achieve meaningful insights into the distribution and dynamics of interstellar gas.

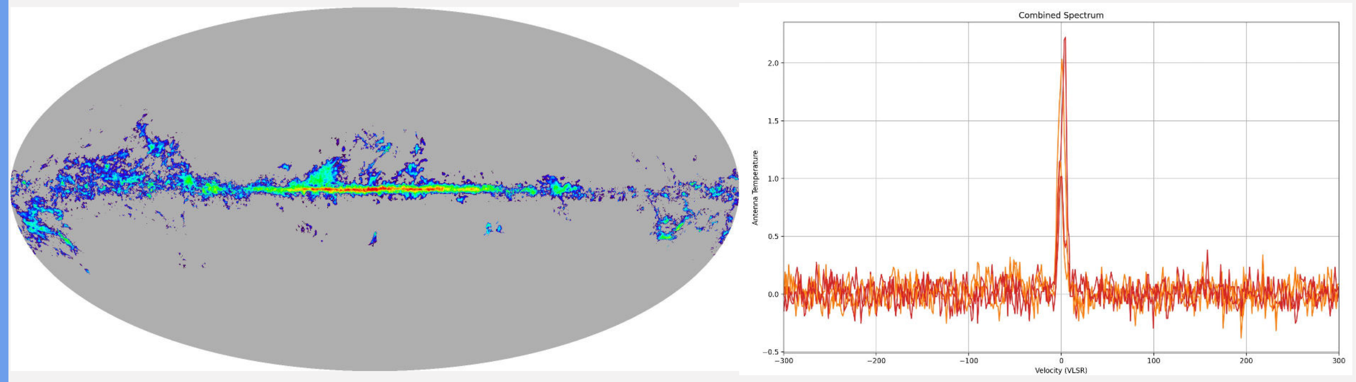

Figure 5. CO(J=1-0) map of the galactic plane[2] and CO spectral line for Pipe.

References

[1] Information@eso.org. "The Pipe Nebula." *Www.Eso.Org*, www.eso.org/public/- images/yb/. Accessed 28 Feb. 2024.

[2] Dame et al. 2001, *ApJ*, 547,792

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