Formaldehyde in the Far Outer Galaxy

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Abstract

We present results from an initial survey of the 2_{12}-1_{11} transition of formaldehyde (H_2CO) in the Far Outer Galaxy (galactocentric distances > 16 kpc). Formaldehyde is a key prebiotic molecule. Determining the outermost extent of its distribution can set an outer limit to the Galaxy's "Habitable Zone", the region where conditions for the formation of life are most favorable. We surveyed 65 molecular clouds in the outer Galaxy ranging from 8.5 to 23.5 kpc in galactocentric radius (R_G). Formaldehyde emission at 140.8 GHz was detected in 27 of the clouds with $R_G > 16$ kpc (detection rate $\sim$ 66%), including 7 clouds at $R_G > 20$ kpc (detection rate $\sim$ 64%). Formaldehyde is readily found in the Far Outer Galaxy - even beyond the edge of the old stellar disk. The widespread distribution of H_2CO in the Far Outer Galaxy is a first step in determining how favorable this large region of the Galaxy is towards the formation of life.

1 Introduction

In order to determine what regions of the Galaxy are most favorable for the formation of life, one must establish the galactic distribution of biologically important organic molecules in molecular clouds. Because all stars and their protoplanetary disks form from molecular clouds, the presence of organic molecules in the clouds can seed newly-formed planetary systems with the compounds necessary for the production of amino acids and, eventually, proteins - absolutely key ingredients for the development of life. Determining the large-scale distribution of biologically important molecules is thus a necessary condition for defining a "Habitable Zone" in the Galaxy.

Of the hydrocarbon molecules that have been identified in the ISM, formaldehyde (H_2CO) is one of the most important prebiotic precursor molecules. Miller (1953) demonstrated that reactions between H_2CO and other simple organic molecules can produce amino acids. For example, Glycine can be formed from a reaction of H_2CO with NH_3 and HCN. The role of H_2CO in amino acid synthesis has been widely investigated in a number of early Earth scenarios (Sakurai & Yanagawa 1984; Chadha & Choughuley 1984; Hennet et al. 1992).

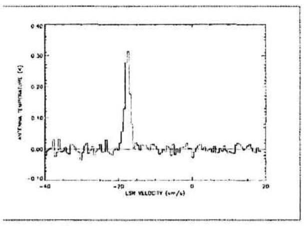
In light of the above considerations, the presence of H_2CO on the early Earth is considered critical for the formation of life. Atmospheric models of the early Earth address the conditions under which H_2CO could have formed, further emphasizing the biological importance of the molecule (Kasting 1993); and even a study investigating the role of cometary delivery of organics to early Earth termed H_2CO a "key prebiotic molecule" (Chyba et al. 1990).

2 Molecular Clouds in the Outer Galaxy

It is likely that organically important molecules like H_2CO share the same general distribution as CO: a strong concentration at the Galactic Center; a sharp decrease to about 3 kpc followed by a rapid increase peaking at the so-called "Molecular Ring" at about 6 kpc; and a rapid drop off to about 12 kpc. Beyond 12 kpc, the molecular clouds tend to be smaller and isolated (Brand & Wouterloot 1996; Digel, de Geus, & Thaddeus 1994) and surveys have primarily focused on CO. In the Far Outer Galaxy ($R_G > 16$ kpc) we have little or no information about the distribution and abundance of *any* prebiotic molecules.

The molecular Outer Galaxy begins immediately beyond the Solar Circle ($\sim$ 8 kpc) and continues to more than 20 kpc from the Galactic Center. Digel, de Geus, & Thaddeus (1994) report the detection of about a dozen molecular clouds at distances of 18 - 28 kpc from the Galactic Center; these objects establish the outer limit of molecular gas in the Galaxy. Closer in, between 10 and 18 kpc from the Galactic Center, there are several hundred large molecular clouds (see Brand & Wouterloot 1996 for a review).

Few (1979) observed 39 lines of sight along the Galactic plane between longitudes 8° and 60° in the 4.8 GHz transition of H_2CO using the Jodrell Bank telescope. Unfortunately, his data extend only to $R_G \sim 13$ kpc, with no information about H_2CO in the Outer Galaxy. In their series of papers on molecular clouds in the Far Outer Galaxy, Brand and Wouterloot have extensively studied CO, its isotopes, H_2O, and OH, but not H_2CO. We thus began a program to study the distribution of H_2CO in the Outer Galaxy with the aim of determining how the abundance of this species varies with galactocentric radius. When completed, this project will have laid the groundwork for determining the outer boundary of the Galaxy's Habitable Zone.



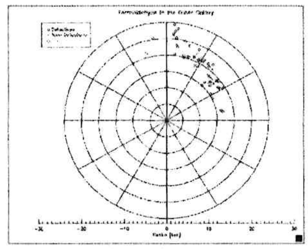
The H_2CO 140.8 GHz spectrum for WB 670. This cloud is at $R_G \sim 23.5$ kpc (however, see caveat in §4).

3 Observations

We observed the 2_{12}-1_{11} transition of H_2CO at 140.8 GHz with the Arizona Radio Observatory (ARO) 12-meter millimeter-wave telescope on Kitt Peak, AZ during May and November 2005. The spatial resolution of the ARO 12-meter radiotelescope at 140.8 GHz is 44 arcseconds. In order to maximize velocity coverage, all the observations were made in position-switched mode with the off-position chosen to be 1 degree east or west of the source in azimuth. The 100 and 250 kHz filterbanks were chosen to provide velocity coverages of 27 and 68 km s^{-1}m, respectively, and velocity resolutions of 0.21 and 0.53 km s^{-1}. Because many of the lines of sight had CO emission at 2 or even 3 different velocities (see Wouterloot & Brand 1989), we centered the filterbanks at the LSR velocity of the molecular cloud with the greatest galactocentric distance. In almost all cases, the other velocity components, easily detected in the CO(1-0) line, were not detected in the 140.8 GHz H_2CO line. This most likely implies that the line of sight traversed lower density regions in the nearer clouds. Typical rms noise values per channel ranged from 10 to 30 mK. The stronger lines were integrated for shorter periods of time because this initial phase of the project emphasizes primarily detecting and identifying which molecular clouds in the Outer Galaxy are good subjects for multitransition H_2CO studies. The 140.8 GHz spectrum for WB 670, at a galactocentric distance of $\sim$ 23.5 kpc, is shown above.

4 The Distribution of Formaldehyde in the Outer Galaxy

We observed a total of 65 clouds from the catalogs of Digel et al. (1994), Wouterloot & Brand (1989), and Bronfman, Nyman, & May (1996) chosen to give both latitude and galactocentric coverage. The objects range in R_G from 8.5 - 23.5 kpc and in ℓ from 61.7° - 239.3°. We detected H_2CO in 45 of the 65 clouds observed. The distances to the clouds are derived from kinematic assumptions using $R_\odot = 8.5$ kpc and $v_\odot = 220$ km s^{-1}. For the Far Outer Galaxy ($R_G > 16$ kpc), we detected 27 out of 41 clouds, and in the extreme Outer Galaxy, $R_G > 20$ kpc, far beyond the stellar disk, we detected 7 out of 11 objects. The figure above shows the distribution of our observations using the kinematic assumptions. However, kinematic distances are notoriously unreliable - especially within 15° of the Galactic anticenter. For instance, in their 1994 survey of molecular gas in the extreme Outer Galaxy, Digel et al. list Cloud 2 at $R_G =$ 28 kpc based on kinematic considerations. Smartt et al. (1996) identify the star exciting the HII region associated with the cloud and revise the cloud's R_G to 15 - 19 kpc. With this caveat, our most distant detection is WB 670 at 23.5 kpc.



Distribution of our H_2CO observations. Detections are denoted by black diamonds and non-detections by red x's. Concentric circles mark R_G in increments of 4 kpc. The location of the Sun is denoted by the green square.

The results of this initial study show that H_2CO is readily detected in the Outer Galaxy, even at $R_G > 20$ kpc. However, in order to really discern the distribution of this biologically important molecule, the abundance must be determined and compared to that of H_2CO at the Solar Circle and in the Inner Galaxy. A multi-transition study of H_2CO in our detected clouds must be undertaken to answer this question fully.

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6 References

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