GALACTIC CARBON MONOXIDE ISOTOPE RATIOS

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1. Introduction

For twenty-five years, almost since the first detection of CO, isotopic abundance ratios of molecules in interstellar clouds (ISC) have been measured by radio techniques. These observations have been used to: 1) determine Galactic chemical evolution (nucleosynthesis, star formation rate, injection and mixing of gas in the interstellar medium); 2) interpret physical conditions in ISCs; and, 3) test models of interstellar chemistry. The carbon isotopic species are important because 12 and 13 carbon trace primary and secondary nucleosynthesis, respectively, and carbon molecules are pervasive in ISCs. To appreciate the difficulty of these measurements, keep in mind that we are looking for small differences by usual astronomical standards, about a factor of two across the Galaxy and 25 percent locally.

2. Observations of Carbon Isotopic Ratios

Across the Galaxy carbon isotopic ratios have been measured in the radio, mainly with CO and H_2CO, and locally (< 1 kpc) also measured in the optical with CH^+ and CN. CO is pervasive and easily observed in emission, however the most abundant isotopes have large optical depths. The earliest efforts relied on $^{13}C^{16}O$ and $^{12}C^{18}O$ but unfortunately even $^{13}C^{16}O$ is optically thick in the line center. Wannier et al. (1976) circumvented this problem by using the line wings where $\tau < 1$. With dramatic improvements in receiver technology, recent measurements have been able to make use of $^{12}C^{18}O$ and the very weak $^{13}C^{18}O$. Formaldehyde is observed in absorption towards strong continuum sources in its ^{12}C and ^{13}C isotopes. To use these probes one must address line transfer, chemical fractionation, line of sight

origins of the signals, including the uncertain effects of clumpiness on the trapping correction.

The optical absorption studies are generally limited to sources within 1 kpc (towards very bright nearby sources) and require high velocity resolution to separate the isotopic lines. The determination of ratios is complicated by baseline subtraction and line fitting (cf. Vladilo and Centurion 1991). Isotopic enhancement is probably not important for CH^+ formation towards these sources because of the high temperatures in the CH^+ regions, but may be a factor for CN and CO.

To analyze the carbon isotopic ratio across the Galaxy, Langer & Penzias (1990) studied nine interstellar clouds observed in the rare and doubly rare isotopes of carbon monoxide, $^{12}C^{18}O$ and $^{13}C^{18}O$. These low abundance species minimize radiative trapping, and observations towards dense shielded cores reduce isotopic chemical and photodissociation enhancements. They found a systematic gradient in the $^{12}C/^{13}C$ ratio across the Galaxy from 30 in the inner part at 5 kpc to 70 at 12 kpc, similar to the trend derived from formaldehyde observations (Henkel, Wilson, & Beiging 1982). However, the formaldehyde ratios are generally higher across the disk and show more scatter than the CO measurements (see Figure 1 in Langer 1992). CO and formaldehyde both yield a Galactic Center value about 24.

Because there are many techniques and species available for measuring the ratio in the solar neighborhood, accurate determinations in this region are important for fixing the local value. Langer & Penzias (1990) derived an average value $^{12}C/^{13}C= 57\pm3$ locally, although individual sources ranged from 49 to 67. To improve the local solar neighborhood value they later studied three sources not associated with HII regions: B5, B335, and L134N (L183); and, observed another position in Orion far from the HII region near K-L (Langer & Penzias 1993). In these 4 sources the ratio ranges from 58 to 71 with a weighted average of 61 ± 2. This value is considerably smaller than the formaldehyde result of 80 ± 7, and the terrestrial value of 89. Orion is the most extensively studied source. From $^{13}C^{18}O$ Langer & Penzias found 79 ± 7 in KL and 67 ± 3 a few arcmin away. Using the optically thin line wings of far-IR emission from excited $^{12}C^{16}O$ and $^{13}C^{16}O$, Genzel et al. (1988) derived a ratio of 85 ± 20. In the near-IR bands of CO Scoville et al. (1983) found 96 ± 5, while the ratio way out in the line wings of J=1-0 emission yield 74 ± 9.

The most reliable optical determinations of the carbon isotope ratio probably come from CH^+. Those from CN may be affected by fractionation (Langer 1992). Stahl et al. (1989), Crane et al. (1991), and Stahl & Wilson (1992) find a value about 67 ± 2 from CH^+. The best values derived from the CH^+ absorption measurements are of the nearby cloud Zeta Oph, 71 ± 3 (Stahl & Wilson 1992), 67 ± 2 (Crane et al. 1991), and 67 ± 3 (Centu-

Figure 1. Carbon isotopic ratios in the local solar neighborhood using different probes. $^{13}C^{18}O$ is used for B5, B335, L183, Orion A (-2.5,-14), Orion A (0.5,2.5) from Langer & Penzias; CH^+ used for Zeta Oph where the letters SW, CHL, and CV refer to Stahl & Wilson, Crane et al., and Centurion & Vladilo, respectively; the other Orion A data uses the Far-IR (FIR), Near-IR (NIR), and CO line wings (wings) as referenced in the text.

rion & Vladilo 1991). These radio and the optical data in the local solar neighborhood are summarized in Figure 1. The carbon ratio ranges from 57 to 96 with a weighted mean value of 67.3±1.5.

This work was performed at the Jet Propulsion Laboratory, California Institute of Technology, under contract to the National Aeronautics and Space Administration.

3. References

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