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CARBON ISOTOPE RATIO IN COMETS AND INTERSTELLAR MATTER

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The $^{12}C/^{13}C$ isotope ratio in the interstellar medium and in stellar atmospheres is discussed and compared to the value found in the solar system and especially in comets. The cometary value (≥ 100) tends to be slightly above the terrestrial value (89) and is definitively higher than that for interstellar molecular clouds (about 30 to 50). This result implies that comets are not of interstellar origin.

INTRODUCTION

The ratio of stable isotopes in comets is obviously one of significant sources of information which may shed some more light on the primeval conditions in the solar nebulae. The comparison of isotope ratio in cometary volatile material and in the interstellar matter should be one of the first necessary steps in such an attempt. The only suitable isotopes for such study are ^{12}C and ^{13}C, which could be detected in molecular compounds in comets as well as in the interstellar clouds.

During the evolution of the Galaxy the cosmic abundance of the ^{13}C have been constantly enhanced predominantly by CNO cycle in the stellar interiors where, in equilibrium, the ratio ($^{12}C/^{13}C$) is about 4 (*i.e.*, about 5% of terrestrial value), or by some other processes which can be for instance heavy neutron irradiation of ^{12}C in the circumstellar or interstellar gas and solids during the early stage of stellar evolution or supernova outburst. The second process would produce ^{13}C by reaction $^{12}C(n,\gamma)^{13}C$ but must be considered only as marginal due to limited life time of neutron and because the hydrogen is a strong absorbing medium for the neutron flux. Assuming that comets are relicts of the most remote part of the primordial nebulae and if ^{13}C is enriched by chemical evolution of Galaxy (*i.e.*, predominantly by mass loss from stars), then the cometary ratio of ($^{12}C/^{13}C$) should be higher by a factor 3 than those observed in molecular interstellar clouds.

CARBON ISOTOPE RATIO IN COMETS

The determination of the ratio of two stable carbon isotopes in comets is usually based on the analysis of spectra in the visible region and using the intensity of $^{12}C\,^{13}C$(1-0) band head at 475.4 nm compared with intensities of $^{12}C\,^{12}C$(2-0) band head at 438.2 nm or with triplets of $^{12}C\,^{12}C$(1-0) at λλ473.0

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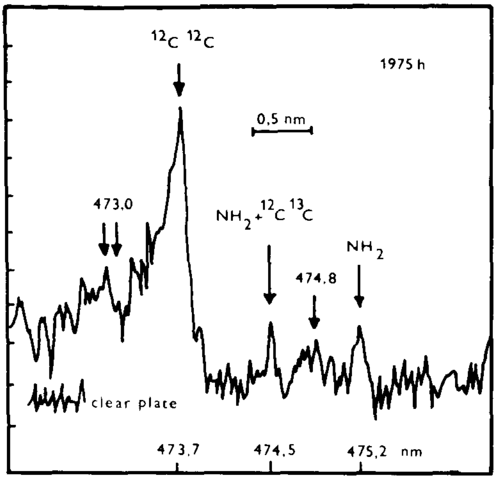

and 473.1 nm. This method was described and applied by Stawikowski and Greenstein (1964) for determination of ($^{12}C/^{13}C$) of Comet Ikeya 1963 I and later by Owen (1973) for Comet Tago-Sato-Kozaka 1969 IX, Kikuchi and Okazaki (1975), for Comet Kohoutek 1973 XII and by Vanysek (1976) for Comet 1975h.

Danks *et al.* (1974) derived the carbon isotope ratio of Comet 1973 XII using the photoelectric scanning of ^{12}C ^{12}C and ^{12}C ^{13}C(1-0) bands and blending ammonia bands with spectral resolution of 0.5 A and 0.16 A respectively. The results of all these observations are summarized in Table I.

TABLE I

AVERAGE ISOTOPE RATIO OF $^{12}C/^{13}C$

Object	$^{12}C/^{13}C$	Reference
Earth, Meteorites, Moon	89	Allen (1963)
Venus, Mars, Jupiter	100	Allen (1963)
Sun	90	Allen (1963)
COMETS:		
Ikeya 1963 I	70 ± 15	Stawikowski & Greenstein (1964)
Tago-Sato-Kosaka 1969 IX	100 ± 20	Owen (1973)
Kohoutek 1973 XII	115 (+30, -20)	Danks *et al.* (1974)
	135 (+65, -45)	
Kobayashi-Berger-Milon 1975h	110 (+20, -30)	Vanysek (1976)
Interstellar Matter	30 - 50	Winnewisser (1976)

The most serious disadvantage of the study of isotope ratio from the shifted band C_2(1-0), is the blending by emission of four lines of NH_2 at

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474.5 nm. Stawikowski and Greenstein noted the NH_2 blending, but the effect in the shifted isotope bands are obviously underestimated in their results. Some reasonable account of the NH_2 contribution was given by Owen (1973). But most precise analysis of this problem was discussed in above mentioned paper by Danks *et al.* (1974).

The intensity ratio of unblended and blended band at λ434.5 nm is ≤ 0.4 and perhaps the most reliable value would be about 0.2. Some effect of two stronger and two fainter absorption Fe I and Cr I lines in the solar spectrum in the fluorescence mechanism of NH_2 must be taken in account, particularly in the two NH_2 lines which lies in "red" wing of the $^{12}C\ ^{13}C$(1-0) band head.

The strength of NH_2 emission generally varies substantially from comet to comet and the reliable intensity value of ammonia lines at λλ474.5 nm could be estimated only by assumption of constant ratio of intensities of these and nearly NH_2 lines at λλ475.2 nm. Although the accuracy of the determination of carbon isotopic ratio in comets is low, the tendency to values ($^{12}C/^{13}C$) ≥ 100 is obviously evident in all until known cases. Because of blending of the carbon isotope band by NH_2 lines, it seems to be very likely that the value of ($^{12}C/^{13}C$) in comets is considerably higher than those found for the molecular interstellar clouds. This is perhaps one of the most important observational evidences of the growing abundance of ^{13}C in course of the chemical evolution of our Galaxy.

INTERSTELLAR CARBON ISOTOPE RATIO

In the optical region the $^{12}C/^{13}C$ ratio has been studied using the λ = 423.2 nm interstellar absorption lines of $^{12}CH^+$ and $^{13}CH^+$ (Bortolot and Thaddeus 1969, Vanden Bout 1972) towards the star Zeta Oph. The ratios determined by both groups (*i.e.*, ($^{12}C/^{13}C$) = 82 (+55, -15) and 75 (+15, -15) respectively) essentially agree with the terrestrial ratio. But the $^{13}CH^+$ line exceedingly weak and the estimation of the contribution of the underlying continuum to the equivalent widths is difficult. Audouze *et al.* (1975) have attempted to interpret the above mentioned results using the high resolution $^{12}CH^+$ profile of Hobbs (1973). They find the ($^{12}C/^{13}C$) ratios to be 44 (+29, -8) and 72 (+24, -15) respectively. On the other hand the $^{12}C/^{13}C$ ratio inferred from absorption lines in UV region of ^{12}CO and ^{13}CO towards the same stars (Smith and Stecher 1971) is 105 and close to the terrestrial value. Again the uncertainties in the equivalent widths of the ^{13}CO lines are large and the optical observations have not yet reached the sufficient accuracy. One further point should be mentioned:

The interstellar lines of $^{12}CH^+$ and ^{13}CH are governed predominantly in the low density interstellar matter over large distances but the molecular clouds measured by radio-astronomical methods are mostly dense, massive and extremely young objects where the abundance of ^{13}C would be substantially enhanced by mass losses from red giant and by supernova outbursts. The interstellar isotopic ratio ($^{12}C/^{13}C$) has been shown to be considerably lower than the solar system value indeed. According to compilation of data by Audouze *et al.* (1975), the interstellar ratio of the carbon isotopes ranging from 10 to 60. The determination of isotopic ratio by measurement in microwave spectral regions poses some specific problems concerning the optical depth of the measured lines.

The molecular carbon compounds as CO, HCN, H_2CO, CS and HC_3N belong to common species of interstellar clouds observed at radio wavelengths. However, for the determination of the abundance ratio ($^{12}C/^{13}C$) the optical depth of some isotopic species, namely carbon monoxide, is high and lead to uncertain values because of line saturation. The most typical and well known case is the intensity ratio of ($^{12}C^{16}O/^{13}C^{16}O$) in the direction of Sgr A varying strongly with the line profile. This phenomenon due rather to the variation of optical depth than to the intrinsic differences in ($^{12}C/^{13}C$) ratio. For the carbon

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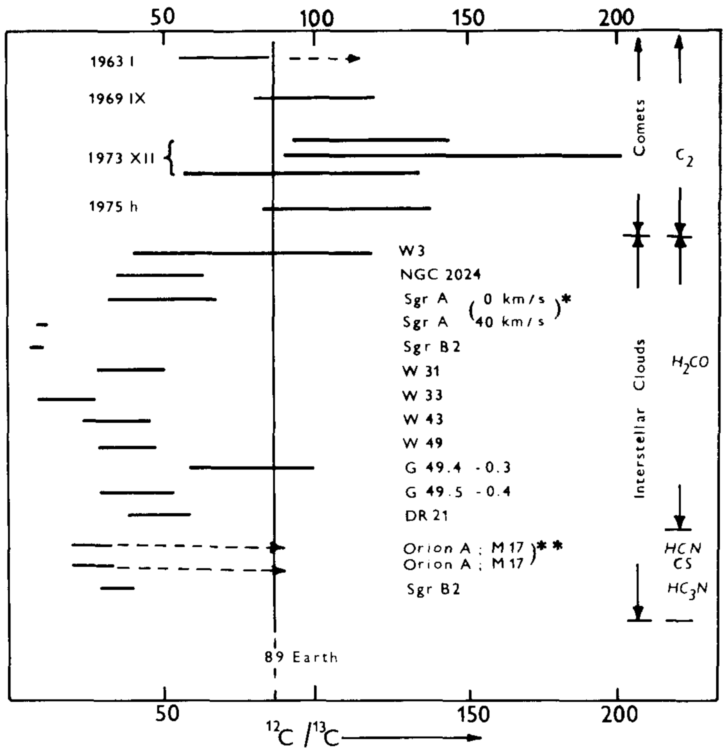
ISOTOPE RATIO



isotope studies, there are more suitable lines with low optical depth of relatively abundant species like formaldehyde H_2CO, hydrogen cyanide HCN, cyanoacetylene H_3CN and carbon monosulfide CS and for which the saturation problem is avoided.

In earlier studies of interstellar carbon isotope ratio, derived from the formaldehyde absorption lines in the direction of Sgr B2, Whiteoak and Gardner (1972) found the $(^{12}C/^{13}C) = 13$. Extremely low value of isotope ratio are probably due to clumplike structure of dense clouds with high variation of the optical depth and - consequently - with considerable variation of the line saturation. In the other words, the real values of $(^{12}C/^{13}C)$ in the interstellar dense clouds may be somewhat underestimated.

Nevertheless, the real abundance ratio of carbon isotopes is close to 40 *i.e.*, considerable lower, than the terrestrial ratio, as was shown in the data compilation made by Bertojo *et al.* (1974), Winnewisser (1976) in a review about the radio measurements of interstellar molecular lines, postulates as the most probable range for $(^{12}C/^{13}C)$ a ratio 30 to 50.

CONCLUSIONS

Differences between value of $(^{12}C/^{13}C)$ found in comets and interstellar clouds are beyond any doubt quite evident. If cometary material preserves the isotopic abundances identical with abundances in the primitive solar nebula and in the interstellar matter of young galaxy (*i.e.*, 4.5 x 10^9 years ago), then the above comparison of $(^{12}C/^{13}C)$ radio leads to the following implications.

a) Suggestions concerning the interstellar origin of comets (*i.e.*, in the contemporaneous interstellar dense clouds) are incorrect.

b) The isotope ratio of ($^{12}C/^{13}C$) decreases during 4.5×10^9 years by a factor 2.5 which is roughly in agreement with present hypothesis of chemical evolution of our Galaxy.

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DISCUSSION

ARNOLD: You seem to propose that C^{13} will be increased in the inner solar system by the reaction $C^{12}(n,\gamma)C^{13}$. Yet the cross-section for this reaction is very small. Any neutrons which come from the sun will surely react with ^1H, ^{14}N, or other nuclei rather than ^{12}C. There is no obvious way to make this nuclear reaction occur to an appreciable extent.

VANÝSEK: The ^{13}C must, of course, have been formed essentially by the CNO cycle in the stellar interiors; however, the differences *in the ratio $^{12}C/^{13}C$ in the solar nebula come from the process $^{12}C(n,\gamma)^{13}C$, which is effective* only *in the innermost region (due to the concurrence reactions). If the comets were formed in the periphery of the solar system, then the ratio $^{12}C/^{13}C$ in the cometary volatile material should be higher than in the Earth, Moon, etc.*

ANDERS: I am rather pleased with your conclusion that the cometary ratio HCN/CH_3CN is near 1. I do not have our 1974 paper with me, but if I remember correctly, we found a ratio near 3 in Fischer-Tropsch reactions (catalytic reactions of CO, NH_3, and H_2).

VANÝSEK: I am referring here to this ratio following a private communication by W. Huebner. I believe that the ratio of HCN/CH_3CN is close to 1 *and may be 0.1 or 10 but not > 100.*

DONN: CH_3CN was observed in an excited state with an unknown excitation mechanism. In such a case no abundance determinations are possible.

HUEBNER: The ratio of CH_3CN/HCN is based on our ground state observations of CH_3CN. We find the ratio $\lesssim$ 3 (See Astron. J., *Aug. 1976).*