10 May 1974, Volume 184, Number 4137 **SCIENCE**

Isotopic Abundances and Their Variations within the Galaxy

M. Bertojo, M. F. Chui, C. H. Townes

The relative abundances of isotopic species in parts of the Galaxy outside the solar system represent an important record of the past, and one which is becoming increasingly available through measurement of molecular spectra in interstellar clouds and in stellar atmospheres. Information on isotopic abundances in interstellar material from microwave molecular spectra, along with a small amount of information from other spectral regions, is assembled and analyzed here to obtain as clear a view of these abundances as is presently practical.

It has been known for some time that the $^{12}C/^{13}C$ abundance ratio differs substantially in many stars from that found on the earth, and more recently a striking similarity between interstellar isotopic abundances and terrestrial values has been established in most regions of the Galaxy, although the precision of many of the measurements has been rather poor. Nevertheless, it is shown here that, in at least two large interstellar clouds, isotopic ratios deviate markedly from terrestrial ones. The available data are presented in a series of tables. Table 1 represents present results for the $^{12}C/^{13}C$ abundance ratio in interstellar material from the spectra of a variety of molecules. Table 2 is a similar table for the abundance ratios of sulfur isotopes, but the data are much more limited and imprecise. Table 3 represents other information on the abundance ratios of the common isotopes to the rarer ones of a particular element. Table 4 is a collection of determinations of the hybrid ratio $(^{16}O/^{18}O)/(^{12}C/^{13}C)$, obtained from the molecular abundance ratio $(^{13}C^{16}O)/(^{12}C^{18}O)$. Since ^{12}C and ^{16}O are very close to 100 percent abundant, the molecular ratio is essentially the ratio of the fractional abundance of ^{13}C to that of ^{18}O. Table 5 contains all other available hybrid ratios of abundances, giving information on the fractional abundances of ^{2}H, ^{15}N, ^{33}S, and ^{34}S. In most cases, these hybrid ratios represent measurements which are independent of those in the earlier tables. Table 6 is a summary of probable abundance ratios in a particular cloud, the cloud with a velocity of + 62 kilometers per second near the star Sagittarius (Sgr) B2, near the galactic center.

In Tables 1 through 6, the symbol $\geq$ is used when a value is the ratio of measured intensities of the lines due to the common and the rare molecular species, and the value represents a lower limit because the opacity for the molecular line of the more abundant species may be large, and in some cases is known to be large. In cases where the sign $>$ is used alone, the ratio represents the upper limit for the intensity of the molecular line of the rare species, which has been searched for but not yet detected. Errors listed for a particular ratio are thought to represent reasonable upper limits to the possible variation of this ratio. However, because of the nature of the data and the uncertainties, it is usually not possible to provide clear-cut statistical limits. Values and uncertainties in some particular cases are discussed either in the tables or in the text.

The $^{12}C/^{13}C$ Abundance Ratio

The $^{12}C/^{13}C$ abundance ratios in interstellar materials listed in Table 1 are all derived from microwave spectra of molecules, except those for the star Zeta Ophiuchi. The latter come from visible and ultraviolet absorption spectra of molecules between the earth and the star.

A number of ratios in Table 1 agree with the terrestrial ratio, which is 89, within experimental uncertainties. Those which are lower limits are consistent with such a ratio. There are two outstanding exceptions—the + 62 km/sec cloud in Sgr B2 and the + 42 km/sec cloud in Sgr A, where the $^{12}C/^{13}C$ ratio is substantially less than that on the earth and the errors cannot reasonably be large enough to bring these values close to the terrestrial one. Some additional confirmation of the $^{12}C/^{13}C$ abundances in Sgr B2 and Sgr A is obtained from the measured values of $^{16}O/^{18}O$ and of $(^{16}O/^{18}O)/(^{12}C/^{13}C)$, which will be discussed below.

It is striking that clouds of other velocities in the Sgr B2 and Sgr A directions show much higher values for the $^{12}C/^{13}C$ abundance ratio, and ones which are generally consistent with the terrestrial value of 89. Clearly, these clouds at other velocities must be separate and distinct and are perhaps even quite distant from those with peculiar isotopic ratios. The Sgr B2 components at − 41.1 and + 3.7 km/sec can be attributed to the arm of the Galaxy at 3 kiloparsecs from the sun and to local material, respectively. The components at − 104.9 and + 15.8 km/sec appear to be some of those, along with the one at + 62 km/sec, which Scoville (*1*) has at-

---

Dr. Townes is University Professor of Physics at the University of California, Berkeley 94720. M. F. Chui is a graduate student in the physics department at Berkeley. M. Bertojo is a student visitor from École Normale Supérieure de Jeunes Filles, Paris.

Table 1. Carbon-12/carbon-13 abundance ratios in various sources; the terrestrial value is 89.

Cloud	Abundance ratio in					Reference
	H_2CO	CO	CS	HCN	CH^+	
Sgr B2						
+ 62.0 km/sec	14 ± 5	>3	≧9			(*4*) (*14, 18*) (*19*)
− 104.9 km/sec	>37					(*20*)
− 76.6 km/sec	≧20					(*20*)
− 41.1 km/sec	≧68					(*20*)
+ 3.7 km/sec	≧34					(*20*)
+ 15.8 km/sec	≧24					(*20*)
Sgr A						
+ 42.0 km/sec	18^{+10}_{-5}	≧7		≧ 5		(*6*) (*14, 18*) (*21*)
− 4.0 km/sec	≧70					(*6*)
Orion A			≧32	≧14		(*19*) (*16*)
W51	55 ± 15		>26			(*20*) (*19*)
W51, 4′N	73 ± 10					(*20*)
IRC+10216		≧8		≧ 2.6		(*22*) (*23*)
IRC+30219 (CIT6)		>1		> 3.2		(*23*) (*23*)
Zeta Ophiuchi		105^{+100}_{-50}			75^{+25}_{-15}	(*24*) (*25*)
DR21	35 ± 15					(*20*)
NGC2024	>67					(*20*)
W3	>71					(*20*)
W33N	81 ± 40					(*20*)
W33N(OH)	>22					(*26*)
W43	41 ± 12					(*20*)
W49	>16					(*26*)
Cassiopeia A						
+ 38 km/sec	≧44					(*27*)
+ 46 km/sec	≧42					(*27*)
NGC2264	≧32					(*27*)
L134	≧31					(*27*)
L134N	37 ± 7					(*27*)
Taurus, dark cloud	64 ± 12					(*27*)
Orion, dark cloud	≧27.8					(*27*)
L1630		1.5–9.0				(*28*)

tributed to an exploding shell around the galactic nucleus. However, since their isotopic abundances differ substantially from that of the + 62 km/sec cloud, they cannot very well be assigned to a common exploding source.

The source IRC+10216 represents another exceptional case, but it is not strictly an interstellar cloud. Rather, it is a large shell of gas which has recently been expelled from an old star, and where the gases involved probably represent essentially the material of the stellar atmosphere (*2*). Low ^{12}C/^{13}C abundance ratios are frequently found in the atmospheres of red giants or carbon stars.

In addition to the two large molecular clouds, Sgr B2 and Sgr A, where the ^{12}C/^{13}C ratio is markedly different from the terrestrial value of 89, there are a number of cases where this ratio appears to be about one-half the terrestrial value (*3*), although because of the possible uncertainties these cases are not very conclusive. There are no measured clouds where a value greater than 89 is indicated. Thus, an overall view of all sources other than the + 62 km/sec cloud in Sgr B2 and the + 42 km/sec cloud in Sgr A gives a somewhat uncertain indication that the ^{12}C/^{13}C ratio in interstellar materials is frequently about one-half the terrestrial value.

It must be kept in mind that a comparison of the measured lines of two isotopic molecular species in an interstellar region cannot by itself give a firm determination of the relative isotopic abundance. Errors can be expected from saturation effects, differences in excitation between the two isotopic species, or differential concentrations of the isotopes in a particular molecular species. Saturation effects are probably the most troublesome. Usually, these are taken into account by observing the resulting differences in line shapes between isotopes of different abundances, the more abundant species being expected to have a somewhat wider and less sharply peaked line if it is saturated. However, it is possible to imagine conditions which would be quite misleading. As an illustration of such a case, consider the possible occurrence of many small clouds of various velocities within an antenna beam, with each cloud having a small velocity dispersion and the same large optical depth, so that the strengths of isotopic lines have a misleadingly small fixed ratio. The resulting isotopic lines would thus appear to be unsaturated, but the derived isotopic abundance ratio would be nearer unity than the true value. Such an accidental uniformity of optical density in many small clouds is unlikely, but cannot be ruled out without additional information about the cloud—information which is usually not adequately available. Still other special conditions may be imagined which would produce errors in the determination of isotopic abundances. Nevertheless, by comparing line shapes for two isotopes and, still better, the behavior of more than one line and more than one molecule, one can be reasonably sure that saturation or other special effects are not grossly misleading.

Table 2. Abundance ratios of sulfur isotopes. These are ratios of antenna temperatures given in (*16*).

Cloud	Measured value of ratio
^{32}S/^{34}S, terrestrial value 22.5	
Sgr B2, + 62 km/sec	≧ 4.7
Sgr A, + 20 km/sec	> 8.7
Orion A	> 20.0
DR21(OH)	≧ 5.3
NGC7538(OH)	> 4.2
W3(OH)	> 11.0
W51	≧ 9.8
IRC + 10216	> 17.0
^{34}S/^{33}S, terrestrial value 5.5	
Sgr B2, + 62 km/sec	2.3 ± 2.0
Orion A	> 3.0
W51	> 3.0

In the case of the + 62 km/sec component of Sgr B2, Gardner *et al.* (*4*) have examined rather thoroughly and with good signal-to-noise ratios the shapes of the lines due to the $1_{10} \leftarrow 1_{11}$ absorption of $H_2{}^{12}C^{16}O$, $H_2{}^{13}C^{16}O$, and $H_2{}^{12}C^{18}O$. These lines have very similar shapes, the most notable difference being that the $H_2{}^{12}C^{16}O$ line is broader by a few percent than those due to the two rare isotopes, indicating a moderate amount of saturation. Fomalont and Weliachew (*5*) have examined the spatial distribution of formaldehyde opacity in this cloud with a microwave interferometer, and concluded that the ^{12}C/^{13}C ratio is ≥ 20. The ratio of the peak intensities of the $H_2{}^{12}C^{16}O$ and $H_2{}^{13}C^{16}O$ lines measured by Gardner *et al.* (*4*) is 8.4, which can be taken as a minimum value of the isotopic abundance ratio ^{12}C/^{13}C. Their analysis of the optical depths of the two lines leads to the ratio 15. Additional simple checks can be made by comparing the ratio of intensities in the wings of the lines, where saturation effects can be expected to be less im-

Table 3. Other primary ratios of single atomic species.

Cloud	Molecule	Measured value of ratio	Comment	Reference
$^{16}O/^{18}O$, terrestrial value 489				
Sgr B2, +62 km/sec	OH	250 ± 80	Weighted average of ratios for $F = 2 \rightarrow 2$ and $F = 1 \rightarrow 1$ hyperfine components.	(*29*)
Sgr B2, −90 km/sec	OH	>1000	$F = 2 \rightarrow 2$. This component is absent in the ^{18}OH spectrum, possibly because of instrumental effects or differential pumping.	(*29*)
Sgr B2, −90 km/sec	OH	300 ± 100	$F = 1 \rightarrow 1$.	(*29*)
Sgr A, +42 km/sec	OH	350 ± 75	$F = 2 \rightarrow 2$. Average of results in (*13*) and (*29*).	(*13, 29*)
Sgr A, −130 km/sec	OH	>500	$F = 2 \rightarrow 2$. This component is absent in the ^{18}OH spectrum in (*29*).	(*29*)
Sgr A, −130 km/sec	OH	160 ± 120	$F = 1 \rightarrow 1$. Average of results in (*13*) and (*29*).	(*13, 29*)
IRC+10216	CO	>1000		(*30*)
$^{16}O/^{17}O$, terrestrial value 2675				
IRC+10216	CO	400 ± 200		(*30*)
Orion A	CO	≧350	Ratio of intensities for $C^{16}O$ (*31*) and $C^{17}O$ (*32*) lines, considered a lower limit because of $C^{16}O$ saturation.	(*31, 32*)
$^{18}O/^{17}O$, terrestrial value 5.45				
IRC+10216	CO	<0.2		(*30*)
Orion A	CO	3.6 ± 1.5		(*32*)
Rho Ophiuchi	CO	4.0 ± 2.0		(*32*)
$^{14}N/^{15}N$, terrestrial value 273				
Sgr B2, +49 km/sec	NH_3	≧70		(*33*)

portant (unless, of course, one assumes special conditions such as the dense multicloud model mentioned above). At the two half-power points of the $H_2{}^{12}C^{16}O$ line, the intensity ratio for the two isotopes is about 11, and at the two quarter-power points approximately 15. Thus, in the wings of the line the ratio increases somewhat, as would be expected for a modestly saturated $H_2{}^{12}C^{16}O$ line, and is consistent with the value 14 ± 5 given in Table 1. It seems extremely unlikely that the actual value could be near 89. The $^{12}C/^{13}C$ ratios from CO and CS molecular lines in the + 62 km/sec component of Sgr B2 are consistent with that from H_2CO, but not as conclusive.

Formaldehyde in the + 42 km/sec component of Sgr A has been similarly studied by Whiteoak and Gardner (*6*). The line breadth of the $1_{10} \leftarrow 1_{11}$ transition of $H_2{}^{12}C^{16}O$ is about 20 percent larger than that of $H_2{}^{13}C^{16}O$. The ratio of peak intensities is 12, and of integrated intensities 18. The ratio of intensities at the two half-power points is about 23. Ratios further in the wings cannot be accurately obtained because of signal-to-noise problems and the interference of a second velocity component at − 4 km/sec. Fomalont and Weliachew (*5*) derived the ratio 25 ± 5 from interferometric measurements. For the − 4 km/sec component, the $H_2{}^{13}C^{16}O$ line is not detected, so that a much larger $^{12}C/^{13}C$ ratio is obtained, $\geq$ 70. Lines of CO and HCN in the + 42 km/sec component of Sgr A give values of the $^{12}C/^{13}C$ ratio consistent with the value 18^{+10}_{-5} obtained from H_2CO, but not definitive in themselves. Thus, the $^{12}C/^{13}C$ ratio in Sgr A is somewhat less well determined than in Sgr B2, but it also seems to differ substantially from the terrestrial ratio.

If mechanisms dependent on isotopic concentration or differential excitation between two isotopic species are important in Sgr B2 or Sgr A, they would need to be ineffective in many other clouds, such as that in Orion A, where approximately terrestrial abundance ratios occur. This makes most such mechanisms empirically unlikely. However, the possibility needs to be examined. One source of differences in excitation is saturation and consequent trapping of resonant radiation. This can be tested and allowed for in much the same way as other saturation effects. Any other substantial difference in excitation of two molecular species would also need to involve a resonant radiative process; collisions and blackbody radiation cannot by themselves be expected to produce such differences.

For the $1_{10} \leftarrow 1_{11}$ transition of H_2CO, three mechanisms have been proposed for producing anomalous absorption. One depends on a variation from a blackbody curve in the intensity of the isotropic radiation in the millimeter region (*7*), and it could vary in such a way that the $H_2{}^{13}CO$ transition would appear stronger than that of $H_2{}^{12}CO$. Such a mechanism seems to have been ruled out by the discovery of anomalous absorption in the $2_{11} \leftarrow 2_{12}$ transition in dark clouds (*8*). Furthermore, if it occurred, the effect should be universal for all clouds, although more pronounced in the less dense clouds than in denser ones such as Sgr B2 or Sgr A. Another suggested mechanism involves excitation of resonant H_2CO vibrational radiation in shock waves and its reabsorption (*9*). This, too, seems to have been ruled out by the detection of anomalous $1_{10} \leftarrow 1_{11}$ absorption in $H_2{}^{13}CO$ with a relative intensity about equal to the

Table 4. Hybrid ratios $^{13}C^{16}O/^{12}C^{18}O$; the terrestrial value is 5.5.

Cloud	Molecule	Measured value of ratio	Comment	Reference
Sgr B2, +62 km/sec	H_2CO	10.0 ± 1.0		(*4*)
	CO	6 – 10	Lowest value at line center, suggesting saturation.	(*18*)
Sgr A, +42 km/sec	CO	7.7 ± 1.5	Average of 8.5 from (*15*) and 7.0 from (*34*).	(*18, 34*)
Orion A	CO	5.1 ± 2.5	These values are averages of the peak and integrated intensity ratios.	(*18*)
W3(OH)	CO	8.2 ± 1.5		(*18*)
W51	CO	4.4 ± 1.0		(*18*)
DR21	CO	4.2 ± 1.5		(*18*)
DR21(OH)	CO	4.7 ± 2.0		(*18*)
NGC2024	CO	8.7 ± 2.0		(*18*)
NGC2264	CO	6.4 ± 2.5		(*18*)

Table 5. Hybrid ratios other than $^{13}C/^{18}O$.

Ratio	Terrestrial value	Cloud	Molecule	Transition	Measured value of ratio	Reference
$^{13}C/^{15}N$	3.11	Orion A	HCN	$J = 2 \rightarrow 1$	2.6 ± 0.8	(*35*)
		IRC+10216	HCN	$J = 1 \rightarrow 0$	> 6.0	(*36*)
$^{13}C/^{34}S$	0.26	Sgr B2, + 62 km/sec	CS	$J = 1 \rightarrow 0$	0.53 ± 0.16	(*19*)
		Orion A	CS	$J = 2 \rightarrow 1$	0.35 ± 0.12	(*19*)
		W51	CS	$J = 1 \rightarrow 0$	< 0.3	(*19*)
$^{13}C/^{33}S$	1.48	Sgr B2, + 62 km/sec	CS	$J = 1 \rightarrow 0$	1.23 ± 0.6	(*19*)
		Orion A	CS	$J = 2 \rightarrow 1$	> 1.0	(*19*)
$^{2}H/^{15}N$	~ 0.041	Orion A	HCN	$J = 2 \rightarrow 1$	1.58 ± 0.5*	(*37*)
$^{2}H/^{13}C$	0.0135	Orion A	HCN	$J = 2 \rightarrow 1$	0.71 ± 0.2*	(*37*)
			HCN	$J = 1 \rightarrow 0$	0.34 ± 0.2*†	(*21, 37, 38*)

* These are apparent ratios, which were given under the mistaken assumption that ^{2}H is not concentrated in HCN. † For $J = 1 \rightarrow 0$, Wilson *et al.* (*37*) give $^{2}HCN/^{1}H^{13}CN = 0.55$, using the intensity of $^{1}H^{13}CN$ given in (*21*) as 0.4°K. However, a recent recalibration (*38*) gives this intensity as 0.7°K, which leads to the ratio listed here.

relative isotopic abundance (*8*). This mechanism should, in any case, make the $H_2{}^{13}CO$ absorption weaker than expected from its relative abundance rather than stronger, as needed to explain the relatively increased strength of $H_2{}^{13}CO$ lines in Sgr B2 and Sgr A. The third proposed mechanism, based on collisional excitation of $H_2{}^{13}CO$ (*10*), seems to be reasonably well established, and a calculation based on this mechanism gives a difference in its effect on the strength of the two isotopes of about 2 percent, quite small as is expected from any collisional process.

It is well established that there is a large concentration of ^{2}H in HCN, compared with atomic or molecular hydrogen, and it is therefore natural to inquire whether something similar might occur in the case of ^{13}C. One popular explanation of this has been associated with zero-point vibrational energies (*11*). The difference in zero-point vibrational energy between $^{1}H^{2}H$ and $^{1}H_2$ is 281 cm^{-1}, and that between ^{2}HCN and ^{1}HCN is approximately 598 cm^{-1}, giving an energy difference of 317 cm^{-1} in favor of the heavier molecule. The difference in zero-point vibrational energy between ^{12}CO and ^{13}CO is 24 cm^{-1}, and that between $H_2{}^{12}CO$ and $H_2{}^{13}CO$ is estimated to be 34 cm^{-1}, giving an energy difference of about 10 cm^{-1} in favor of the heavier molecule. For the carbon isotopes, a variety of molecules would produce similar or somewhat smaller variations in energy. The isotope ^{2}H is concentrated in HCN by a factor of about 40, which, if associated with a Boltzmann factor due to the molecular energy difference and a particular temperature, would correspond to a ^{13}C enrichment by a factor of only 1.10.

Watson (*12*) has suggested a mechanism for concentrating ^{2}H in HCN which seems more likely correct than the earlier suggestion of a Boltzmann factor associated with differences in zero-point vibrational energies. His mechanism depends on the difference between the optical depths of $^{1}H_2$ and $^{1}H^{2}H$ in an interstellar cloud, which allows ultraviolet stellar light to photodissociate a much larger fraction of $^{1}H^{2}H$ than of $^{1}H_2$, and thus forces the ^{2}H into certain other molecules such as HCN. This mechanism also depends on having the largest reservoir of H in the form of hydrogen atoms and molecules. Such a mechanism seems inapplicable to the effective concentration of ^{13}C in H_2CO.

It is possible to imagine mechanisms which, in principle, can give a substantial concentration of ^{13}C in various molecules or a difference in excitation between isotopic molecules which could make the $^{12}C/^{13}C$ abundance ratios determined from molecular spectra misleading. The concentration of ^{2}H in HCN provides such an example. However, the mechanisms proposed in that case would not produce any large concentration of ^{13}C, and detailed examination of reasonable excitation mechanisms does not produce any large difference of the appropriate type between isotopic species of H_2CO, so that misleading effects large enough to allow the Sgr B2 or Sgr A sources to have terrestrial $^{12}C/^{13}C$ abundance ratios seem very unlikely.

Table 6. Comparison between probable isotopic abundance ratios in Sgr B2 and terrestrial values. (The probable values are consistent with all available information. However, the precision with which each is known is not high, as indicated by the errors given in Tables 1 through 5.)

Isotopic ratio	Measured value	
	Earth	Sgr B2
$^{12}C/^{13}C$	89	16
$^{16}O/^{18}O$	489	180
$^{14}N/^{15}N$	273	$\geq$ 70
$^{32}S/^{34}S$	23	8
$^{32}S/^{33}S$	127	20

Isotopic Abundance Ratios for Oxygen, Nitrogen, and Sulfur

It has been noted (*13*) that the $^{16}O/^{18}O$ ratio in interstellar clouds obtained from OH spectra is not very different from the terrestrial one, as shown in Table 3. However, in the + 62 km/sec cloud in Sgr B2 and the + 42 km/sec cloud in Sgr A a ratio appreciably less than that on the earth is, in fact, indicated. The source IRC+10216, noted above as having an unusual $^{12}C/^{13}C$ ratio, also appears to have a nonterrestrial $^{16}O/^{18}O$ abundance ratio, but in contrast to the two interstellar clouds, the ^{18}O is underabundant in this case. Tables 2 and 3 show a somewhat similar pattern for other isotopic ratios, except for $^{14}N/^{15}N$, which does not appear to be different from the terrestrial value in Sgr B2 on the basis of the very imprecise information available at present. Oxygen-17 is clearly overabundant in IRC+10216, and ^{33}S appears to be overabundant in Sgr B2 (+ 62 km/sec). An overabundance of ^{34}S is indicated in Sgr B2 and DR21(OH); this could well be due simply to saturation effects, except that Table 4, discussed below, gives additional evidence for the overabundance of ^{34}S in Sgr B2.

The ratios of ratios, such as $(^{16}O/^{18}O)/(^{12}C/^{13}C)$ which gives the hybrid ratio $^{13}C/^{18}O$, provide some independent and confirming information on the primary ratios of isotopic abundances for a single chemical element discussed above. It has been noted (*14*) that the ratio $^{13}C/^{18}O$ is generally close to the terrestrial value, as shown by Table 4. However, for Sgr B2 (+ 62 km/sec) and Sgr A (+ 42 km/sec) this ratio again deviates substantially from the terrestrial value, being high by about a factor of 2. Within experimental uncertainties this is in agreement with the observations from OH spectra that $^{16}O/^{18}O$ is about a factor of 2 smaller than terrestrial values and $^{12}C/^{13}C$ is approximately four times smaller. Deviation of this hybrid ratio of two rare isotopes from the terrestrial value of 5.5 is a useful assurance that the low values of $^{12}C/^{13}C$ are not simply due to saturation of the ^{12}C molecular lines in these two anomalous clouds. Table 4 also indicates that NGC2024 and W3(OH) may have anomalous isotopic ratios, as do Sgr B2 (+62 km/sec) and Sgr A (+42 km/sec). Unfortunately, there are no adequately accurate direct measurements of the $^{12}C/^{13}C$ ratio for NGC2024 and W3(OH).

The hybrid ratios of Table 5 also confirm that Sgr B2 (+62 km/sec) has an extra abundance of ^{34}S and ^{33}S. On the other hand, isotopic abundances in Orion A appear to be similar to terrestrial ones. Table 1 gives no precise information on the $^{12}C/^{13}C$ ratio for Orion A, except that is is substantially larger than in Sgr B2 and Sgr A. The argument of Snyder and Buhl (*15*), based on relative intensities of hyperfine components, that HCN lines in Orion A are unsaturated seems unconvincing in view of anomalies widely observed in the intensities of HCN hyperfine components (*16*). The $^{18}O/^{17}O$ ratio from Table 3 appears near the terrestrial value, and so do the hybrid ratios $^{13}C/^{15}N$, $^{13}C/^{34}S$, and $^{13}C/^{33}S$ from Table 5, indicating that the isotopic constitution of Orion A is probably very similar to that of the solar system. The hybrid ratios involving ^{2}H are all artificially large because of the concentration of ^{2}H in HCN.

Summary Discussion

Experimental evidence presently available indicates that isotopic abundances for the interstellar clouds Sgr B2 (+62 km/sec) and Sgr A (+42 km/sec) as well as for the circumstellar cloud IRC+10216 are substantially different from those on the earth for several elements. Table 6 compares the most likely set of values for isotopic abundances in Sgr B2 with terrestrial ones. In addition, there is some evidence (see Table 4) that W3(OH) and NGC2024 have exceptional isotopic abundances. Most interstellar clouds have relative isotopic abundances which are not very different from those on the earth, except that the relative abundance of ^{13}C may be as much as about twice that in the solar system.

It is natural to attribute an abnormally small abundance ratio $^{12}C/^{13}C$ to abnormally rapid nuclear processing in stars where matter is dense. For the large clouds Sgr B2 and Sgr A near the galactic center, it is also easy to justify such an increased rate of nucleosynthesis. An abundance ratio $^{12}C/^{13}C$ about half the terrestrial value in most interstellar regions can be attributed to normal nucleosynthesis which has taken place since formation of the solar system. It fits, for example, Wollman's calculation (*17*) of time changes in average composition of the Galaxy. However, it is not yet clear how the material with peculiar abundances has remained unmixed with other galactic material over the necessary period of time, and what processes would give the particular pattern of abundances of other isotopes, some of which are not described by previously discussed mechanisms. High local activity and differentiation of material near the galactic center is somewhat more easily justified in terms of the usual description of galactic behavior than it is in other parts of the Galaxy. If the W3(OH) and NGC2024 regions also show a low $^{12}C/^{13}C$ ratio, a result which is at present less sure than for Sgr B2 and Sgr A, their variations from the average composition indicate a more special peculiarity. More and better clues to galactic and stellar evolution will be provided as observational determinations of isotopic abundances accumulate and become more refined.

References and Notes

1. N. J. Scoville, *Astrophys. J.* **175**, L127 (1972).
2. T. R. Geballe, E. R. Wollman, D. M. Rank, *ibid.* **183**, 499 (1973).
3. B. Zuckerman, in *Molecules in the Galactic Environment*, M. A. Gordon and L. E. Snyder, Eds. (Wiley, New York, 1973), p. 216.
4. F. F. Gardner, J. C. Ribes, B. F. C. Cooper, *Astrophys. Lett.* **9**, 181 (1971).
5. E. B. Fomalont and L. Weliachew, *Astrophys. J.* **181**, 781 (1973).
6. J. B. Whiteoak and F. F. Gardner, *Astrophys. Lett.* **11**, 15 (1972).
7. P. Thaddeus, *Annu. Rev. Astron. Astrophys.* **10**, 305 (1972).
8. N. J. Evans II, thesis, University of California, Berkeley (1973).
9. M. M. Litvak, *Astrophys. J.* **160**, L133 (1970).
10. C. H. Townes and A. C. Cheung, *ibid.* **157**, L103 (1969).
11. P. M. Solomon and N. J. Woolf, *ibid.* **180**, L89 (1973).
12. W. D. Watson, *ibid.* **181**, L129 (1973).
13. W. J. Wilson and A. H. Barrett, *Astrophys. Lett.* **6**, 231 (1970).
14. A. A. Penzias, K. B. Jefferts, R. W. Wilson, *Astrophys. J.* **165**, 229 (1971).
15. L. E. Snyder and D. Buhl, *ibid.* **185**, L79 (1973).
16. M. Morris, P. Palmer, B. E. Turner, B. Zuckerman, in preparation.
17. E. R. Wollman, *Astrophys. J.* **184**, 773 (1973).
18. A. A. Penzias, K. B. Jefferts, R. W. Wilson, H. S. Liszt, P. M. Solomon, *ibid.* **178**, L35 (1972).
19. B. E. Turner, B. Zuckerman, P. Palmer, M. Morris, *ibid.* **186**, 123 (1973).
20. B. Zuckerman, D. Buhl, P. Palmer, L. E. Snyder, *ibid.*, in press.
21. L. E. Snyder and D. Buhl, *ibid.* **163**, L47 (1971).
22. R. W. Wilson, P. M. Solomon, A. A. Penzias, K. B. Jefferts, *ibid.* **169**, L35 (1971).
23. W. J. Wilson, P. R. Schwartz, E. E. Epstein, *ibid.* **183**, 871 (1973).
24. A. M. Smith and T. P. Stecher, *ibid.* **164**, L43 (1971).
25. P. A. Vanden Bout, *ibid.* **176**, L127 (1972).
26. B. Zuckerman, P. Palmer, L. E. Snyder, D. Buhl, *ibid.* **157**, L167 (1969).
27. N. J. Evans, II, G. Morris, T. Sato, B. Zuckerman, in preparation.
28. K. D. Tucker, M. L. Kutner, P. Thaddeus, *Astrophys. J.* **186**, L13 (1973).
29. F. F. Gardner, R. X. McGee, M. W. Sinclair, *Astrophys. Lett.* **5**, 67 (1970).
30. D. M. Rank, T. R. Geballe, E. R. Wollman, *Astrophys. J.*, in press.
31. T. G. Phillips, K. B. Jefferts, P. G. Wannier, *ibid.* **186**, L19 (1973).
32. P. J. Encrenaz, P G. Wannier, K. B. Jefferts, A. A. Penzias, R. W. Wilson, *ibid.*, p. **L55**.
33. B. Zuckerman, M. Morris, B. E. Turner, P. Palmer, *ibid.* **169**, L105 (1971).
34. P. M. Solomon, N. Z. Scoville, K. B. Jefferts, A. A. Penzias, R. W. Wilson, *ibid.* **178**, 125 (1972).
35. R. W. Wilson, A. A. Penzias, K. B. Jefferts, P. Thaddeus, M. L. Kutner, *ibid.* **176**, L77 (1972).
36. M. Morris, B. Zuckerman, P. Palmer, B. E. Turner, *ibid.* **170**, L109 (1971).
37. R. W. Wilson, A. A. Penzias, K. B. Jefferts, P. M. Solomon, *ibid.* **179**, L107 (1973).
38. L. E. Snyder, private communication.

39. We thank Drs. N. J. Evans, L. E. Snyder, R. W. Wilson, and B Zuckerman for a number of useful discussions, and for making available information before publication. This work was supported in part by ONR contract N 00014-69-A-0200-1003 and by NSF grant GP30424X.