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CNO ISOTOPES IN ASTROPHYSICS

Edited by Jean Audouze

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PROCEEDINGS

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CNO ISOTOPES IN ASTROPHYSICS

PROCEEDINGS OF A SPECIAL IAU SESSION HELD ON AUGUST 30, 1976, IN GRENOBLE, FRANCE

Edited by

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A SERIES OF BOOKS ON THE RECENT DEVELOPMENTS
OF SPACE SCIENCE AND OF GENERAL GEOPHYSICS AND ASTROPHYSICS
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PREFACE

On behalf of the IAU Commission 48 "High Energy Astrophysics" a special session on "CNO Isotopes in Astrophysics" was held at the General Assembly of IAU in Grenoble on August 30, 1976. This topic was chosen since it has recently included many exciting developments in various domains of physics and astrophysics such as for instance meteoritical studies, radioastronomy measurements of the interstellar gas, new determinations of nuclear reactions cross-sections and fractionation processes. The papers of this volume are the written versions of the talks which were presented during this session and cover the most recent observations and theoretical developments regarding this fast-growing field.

Let me thank first Professor Martin Rees (Institute of Astronomy at Cambridge) the chairman of IAU Commission 48, who has sponsored this special session and made it possible. I am indebted to the authors of the papers for their contributions and all the work they have put in the excellent presentation of the material. I owe special thanks to Professor William A. Fowler (Kellogg Laboratory at Caltech) who has superbly chaired this session and made it very exciting and lively, to Professor Beatrice M. Tinsley (Yale University) who accepted the difficult task to conclude and summarize on such a burning and moving topic, and to Dr James Lequeux for his invaluable help in the edition of several contributions.

Finally, the edition of this book would not have been possible without the skilled and generous aid of Miss Jeannette Caro.

Let me express to all of them my gratitude.

<u>Orsay and Meudon</u>
<u>November 1976</u>

Jean Audouze

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PART I

INTRODUCTION

THE IMPORTANCE OF CNO ISOTOPES IN ASTROPHYSICS

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Carbon, nitrogen and oxygen are the most abundant nuclei after hydrogen and helium (fig. 1) in the observable universe. In fact CNO are elements which are more important than Fe for instance. Historically they have been more difficult to observe in stellar spectra but in spite of these difficulties which have been solved with the development of improved observation techniques and because of their large abundance, as it will be emphasized all throughout this book they play a major role in modern astrophysics. Their observation in the solar system (earth, meteorites, planets, comets, lunar rocks), the stellar spectra, the interstellar medium ... are more and more numerous and precise. More and more information regarding these elements can therefore be gathered and analyzed. This book and the session on which it is based attempt to summarize and to give some hints on all the data which are accumulated at the present on these elements focusing in particular on their isotopic composition. Study of isotopes is indeed most profitable in the sense that they are less affected than elements by chemical fractionation processes although such processes can be considered and be important (see e.g. Watson in this book).

The session organized on the topic of CNO isotopes in astrophysics has tried to give the latest developments on this question in three different directions. (i) The account of the latest abundance determinations in particular those which concern minute but very informative anomalies in the solar system (Clayton), observations of C,N,O abundances in old stars (Demarque, Carbon et al.), and of interstellar molecules. About forty different molecules have been discovered in the interstellar medium,the majority of which being organic : the large chemical activity of carbon explains the richness of the organic chemistry on which all the biology is based. (Wannier, Encrenaz, Wilson et al., Van den Bout et al., Shuter et al., Churchwell et al.). Some of these determinations have been discussed in terms of possible fractionation processes by several contributors such as Shuter and Churchwell but mainly by Watson. (ii) The formation processes i.e. the nucleosynthesis of such elements and isotopes have been recently

Jean Audouze (ed.), CNO Isotopes in Astrophysics, 3-11.

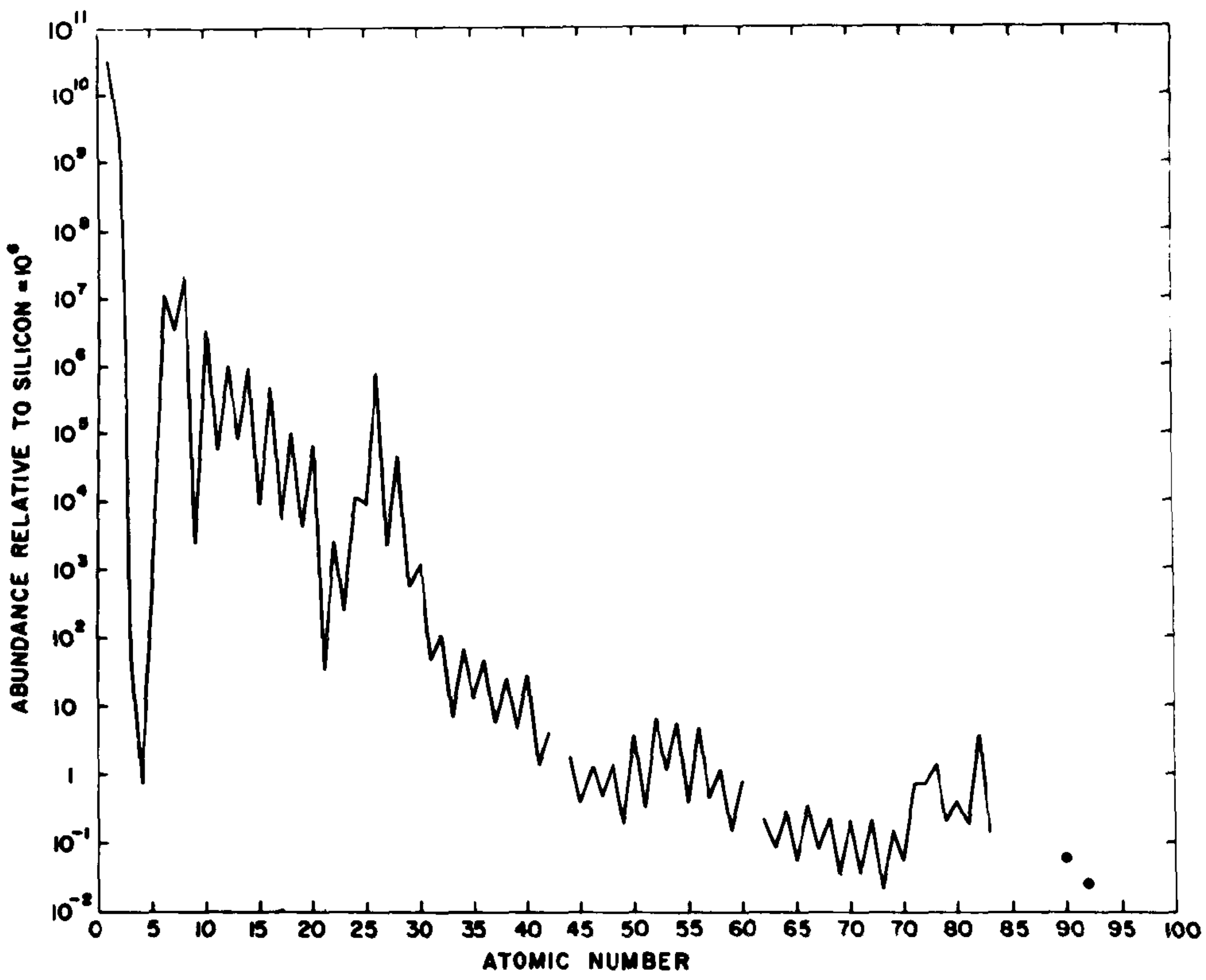

Figure 1 - Curve of the element abundances the atomic number (from Cameron 1973, co. the University of Texas Press)

investigated by various authors (see e.g. the review of Truran, but also the contributions of Caughlan and Starrfield et al). Although these investigations have been conducted since a rather long time (H. Bethe has earned the Physics Nobel prize mainly for his contribution to the understanding of the so called CNO cycle in 1938), new insights has been obtained in this domain especially due to the outcome of many nuclear physics experiments relevant to this problem and reported here by Rolfs. (iii) Finally the evolution of large astrophysical entities such as galaxies in particular our own Galaxy might be understood by using the element abundances and isotopic ratios as tracers of these evolution processes. In galaxies there is a continuous feed-back between the star formation processes, the ejection of matter during the stellar evolutionary phases and the content of the interstellar gas. Contributions of Dearborn and Audouze et al deal with this important by-product of the CNO isotope studies.

As it can be seen from this program this research includes many different subfields of astrophysics such as meteoretical studies, experimental and theoretical nuclear astrophysics, optical astronomy, radio astronomy ... The purpose of this introductory chapter is to

TABLE 1

Observed isotopic ratios of C, N, and O from Audouze et al., 1975, references are given in this paper - Co. Astronomy and Astrophysics.

Ratio	Interstellar medium				Solar system			
	Ratio	Location	Method	Authors	Ratio	Location	Method	Authors
$\frac{^{12}C^{18}O}{^{13}C^{16}O}$	0.080	14 clouds	CO	Wannier *et al.*, 1975	0.178	Earth		Wedepohl, 1969
	0.10 ± .01	Sgr B 2	H_2CO	Gardner *et al.*, 1971	0.20 ± .06	Sun	CO	Hall, 1973
$^{12}C/^{13}C$	36 ± 5	Sgr B 2	HC_3N	Gardner *et al.*, 1975				
	36 ± 8	Ori A	H_2CO 2 mm	Wannier *et al.*, 1975	89 ± 4	Earth		Wedepohl, 1969
	≃ 36	Ori B	$^{13}C^{18}O$	Lucas, 1975; Wannier *et al.*, 1975				
	≃ 37	Ori A	CS	Penzias *et al.*, 1972	89 ± 2	Meteorites		Boato, 1954
	22 − 45	Ori A	HCN	Wannier *et al.*, 1975	≃ 89	Moon		Epstein *et al.*, 1971
	> 20	Sgr B 2	H_2CO	Fomalont *et al.*, 1973	90 ± 15	Sun	CO	Hall *et al.*, 1972
	25 ± 5	Sgr A	H_2CO	Fomalont *et al.*, 1973	110 ± 35	Jupiter	CH_4	Fox *et al.*, 1972
	> 30	Sgr A	H_2CO	Whiteoak *et al.*, 1974	≃ 100	Venus	CO	Connes *et al.*, 1968
					≃ 100	Mars	CO	Kaplan *et al.*, 1969
	12 − 82	Various clouds	H_2CO	Zuckermann *et al.*, 1974; Evans *et al.*, 1975	70 − 135	3 Comets	C_2	Danks *et al.*, 1974
	> 80	local gas	H_2CO	Whiteoak *et al.*, 1972				
	42^{+29}_{-8} a)	ζ Oph	CH^+	Bortolot *et al.*, 1972				
	72^{+34}_{-15} a)	ζ Oph	CH^+	Vanden Bout, 1972				
	> 20 to > 77	6 stars	CH^+	Hobbs, 1973				
$^{16}O/^{18}O$	≃ 390	Sgr A	OH	Wilson *et al.*, 1972	500 ± 25	Earth		Wedepohl, 1969
	> 300	Sgr A	OH	Gardner *et al.*, 1970	500 ± 25	Meteorites		Taylor *et al.*, 1965
	> 200	Sgr B 2	OH	Gardner *et al.*, 1970	490 ± 25	Moon		Epstein *et al.*, 1971
	385	Ori B	$^{13}C^{18}O$	Wannier *et al.*, 1975	460 ± 150 b)	Sun	CO_2	Hall, 1973
					≃ 500	Venus	CO_2	Connes *et al.*, 1967
$^{17}O/^{18}O$	0.28 ± .08	Ori A	CO b)	Encrenaz *et al.*, 1973; Wannier *et al.*, 1975	0.183	Earth		Wedepohl, 1969
	0.25 ± .13	ρ Oph	CO b)	Encrenaz *et al.*, 1973	0.11 − 0.33 b)	Sun	CO_2	Hall, 1973
	≤ 0.2	Sgr A, B 2	OH	Zuckermann, 1973				
$\frac{^{12}C^{15}N}{^{13}C^{14}N}$	0.38 ± .12	Ori A	HCN	Wilson *et al.*, 1972	0.32	Earth		Wedepohl, 1969
	0.28 ± .06	Ori A	HCN	Wannier *et al.*, 1975				
	0.22	Ori A	HCN	Clark *et al.*, 1974				

a) Revised values, see text.
b) Indirect measurement. What is actually measured is $^{12}C^{18}O/^{13}C^{16}O$ and $^{12}C^{17}O/^{12}C^{18}O$ (or $^{12}C^{15}O/^{13}C^{16}O$).