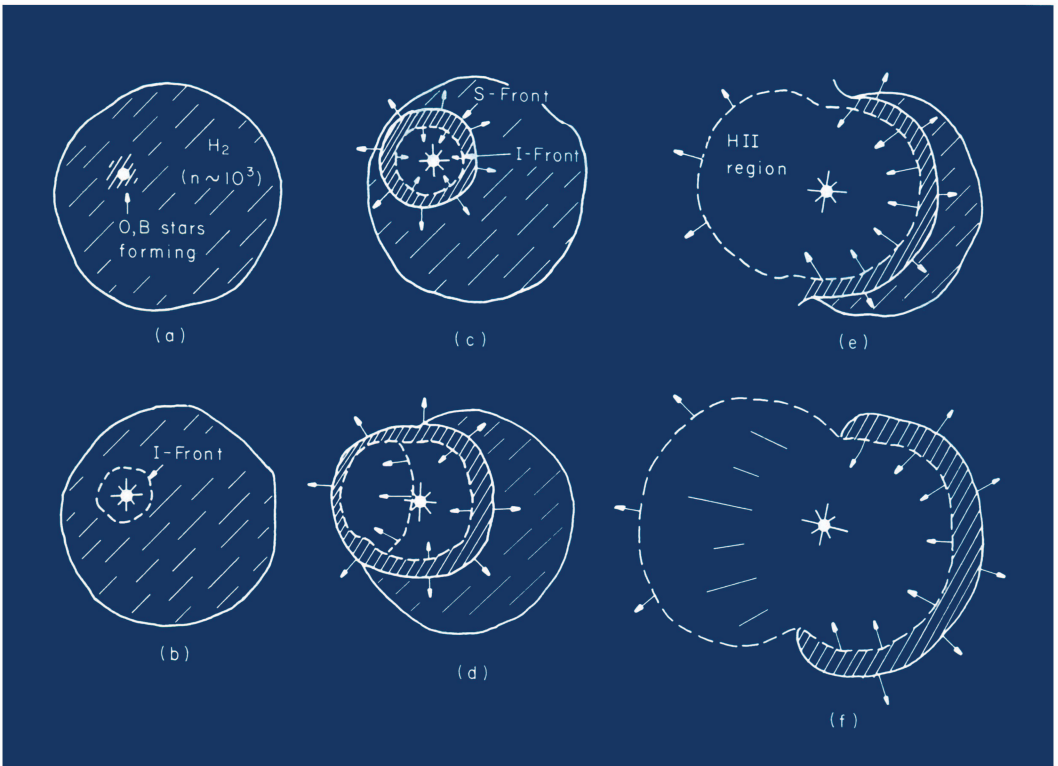


# INTERSTELLAR MOLECULES

Edited by BRYAN H. ANDREW



INTERNATIONAL ASTRONOMICAL UNION

D. REIDEL PUBLISHING COMPANY / DORDRECHT : HOLLAND

BOSTON : U.S.A. / LONDON : ENGLAND



# INTERSTELLAR MOLECULES

SYMPOSIUM No. 87

The study of interstellar molecules has become the most exciting and rapidly developing field in astronomy, attracting laboratory, theoretical, and observational scientists from many disciplines. In recent years astronomers have realised the importance of the role played by interstellar molecular clouds in the evolution of the galaxy and the birth and death of stars. An understanding of the behaviour of these clouds and of the physics and chemistry of their constituent molecular species is fundamental to an understanding of the galaxy itself. This book represents a unique and up-to-date compendium of knowledge in the field. It illustrates well both the successes and failures of current understanding; comprehensive review articles develop the background into which can be fitted the many reports of important new research. The book will be an invaluable asset for many years for all those with an interest in interstellar molecules.

D. REIDEL PUBLISHING COMPANY  
DORDRECHT : HOLLAND / BOSTON : U.S.A.  
LONDON : ENGLAND

# INTERSTELLAR MOLECULES

INTERNATIONAL ASTRONOMICAL UNION  
UNION ASTRONOMIQUE INTERNATIONALE

SYMPOSIUM No. 87  
HELD AT MONT TREMBLANT, QUÉBEC, CANADA  
AUGUST 6 – 10, 1979

# INTERSTELLAR MOLECULES

EDITED BY

B. H. ANDREW

*Herzberg Institute of Astrophysics,  
National Research Council of Canada,  
Ottawa, Canada*



D. REIDEL PUBLISHING COMPANY

DORDRECHT : HOLLAND / BOSTON : U.S.A. / LONDON : ENGLAND



Library of Congress Cataloging in Publication Data  
Main entry under title:

**CIP**

Interstellar molecules.

(Symposium – International Astronomical Union ; no. 87)

Sponsored by Commission 14, 34, and 40 of IAU

Includes indexes.

I. Interstellar matter—Congresses. I. Andrew, Bryan H.  
II. International Astronomical Union. Commission 14. III. International  
Astronomical Union. Commission 34. IV. International Astronomical Union.  
Commission 40. V. Series: International Astronomical Union. Symposium ;  
no. 87.

QB790.I58 523.1'12 80-20663

ISBN 90-277-1160-7

ISBN 90-277-1161-5 (pbk.)

---

*Published on behalf of  
the International Astronomical Union  
by  
D. Reidel Publishing Company, P. O. Box 17, 3300 AA Dordrecht, Holland*

*All Rights Reserved  
Copyright © 1980 by the International Astronomical Union*

*Sold and distributed in the U.S.A. and Canada  
by Kluwer Boston Inc.,  
190 Old Derby Street, Hingham, MA 02043, U.S.A.*

*In all other countries, sold and distributed  
by Kluwer Academic Publishers Group,  
P. O. Box 322, 3300 AH Dordrecht, Holland*

*D. Reidel Publishing Company is a member of the Kluwer Group.*

*No part of the material protected by this copyright notice may be reproduced or utilized  
in any form or by any means, electronic or mechanical, including photocopying, recording  
or by any informational storage and retrieval system, without written permission from  
the publisher*

*Printed in The Netherlands*

TABLE OF CONTENTS

Preface		xvii
The Organising Committees		xxi
List of Participants		xxiii
Conference Photograph		xxxii
Program of Events at IAU Symposium No. 87		xxxvii
Physical and Dynamical Conditions in Interstellar Clouds	N.J. Evans II	1
Detection of Submillimeter Lines of CO (0.65 mm) and H <sub>2</sub> O (0.79 mm)	T.G. Phillips J. Kwan P.J. Huggins	21
New Detections of Spectral Lines in the Frequency Range 260-285 GHz	N. Erickson J.H. Davis N.J. Evans II R.B. Loren L. Mundy W.L. Peters III M. Scholtes P.A. Vanden Bout	25
Further Observational Studies of the High Velocity Molecular Source ("Plateau") in Orion	T.B.H. Kuiper E.N. Rodriguez Kuiper B. Zuckerman	31
High Velocity Gas in the Orion Nebula	N.Z. Scoville	33
High Spatial Resolution Studies of H <sup>13</sup> CN, H <sup>12</sup> CN and HCO <sup>+</sup> J=1-0 Emissions in Orion A	O.E.H. Rydbeck Å. Hjalmarson G. Rydbeck J. Elldér A. Sume S. Lidholm	39

Lunar Occultation Observations of Millimeter CO Emission in S255	F.P. Schloerb N.Z. Scoville	41
Radio-Frequency Observations of Interstellar CH <sub>4</sub> and HC <sub>5</sub> N	K. Fox D.E. Jennings	43
On the Identification of Mm-Wavelength U-Lines	B.E. Turner	45
Long Chain Carbon Molecules in the Interstellar Medium	L.W. Avery	47
Long Carbon Chain Molecules in the Laboratory and in Space	G. Winnewisser F. Toelle H. Ungerechts C.M. Walmsley	59
The Relative Distribution of Ammonia and Cyanobutadiyne Emission in Heiles 2 Dust Cloud	L.T. Little G.H. Macdonald P.W. Riley D.N. Matheson	67
Observations of HC <sub>5</sub> N (J=12-11 and 13-12) and HC <sub>7</sub> N (J=28-27), including a Detection of B335	Å. Hjalmarson P. Friberg	69
Spectra of the 1 <sub>0</sub> -0 <sub>1</sub> Transition of Sulfur Monoxide in Interstellar Clouds	O.E.H. Rydbeck Å. Hjalmarson G. Rydbeck J. Elldér E. Kollberg W.M. Irvine	71
CN Observations in Taurus Dark Cloudlets	E. Churchwell	77
C <sub>2</sub> H and HC <sub>3</sub> N in Interstellar Clouds	A. Wootten G.P. Bozyan D.B. Garrett R.B. Loren R.L. Snell P. Vanden Bout	81
Detection of New Ammonia Sources	G.H. Macdonald A.T. Brown L.T. Little D.N. Matheson M. Felli	83
Ammonia Observations of the Molecular Clouds near S68, S140 and OMC2	L.T. Little A.T. Brown G.H. Macdonald P.W. Riley D.N. Matheson	85

TABLE OF CONTENTS

vii

Ammonia Observations of the Molecular Cloud near S106	L.T. Little G.H. Macdonald P.W. Riley D.N. Matheson	89
The Core of a Quiescent Cloud, L183	C.M. Walmsley H. Ungerechts G. Winnewisser	91
Observations of NH <sub>3</sub> toward DR21	T. Pauls T.L. Wilson	93
High Resolution 4.8 GHz Mapping of H <sub>2</sub> CO using the Westerbork Synthesis Radio Telescope	J.R. Forster W.M. Goss T. de Jong C.A. Norman H.J. Habing H.R. Dickel	95
Surveys of the 4.8 GHz Formaldehyde Absorption Line in Dark Clouds in M17 and NGC 2024	Y.K. Minn	99
Cloud-to-Cloud Variations in H <sub>2</sub> CO-to-H <sub>2</sub> Ratios	W.A. Sherwood	101
Formaldehyde in L1551, L134 and the Galactic Centre	Aa. Sandqvist C. Bernes	103
Observations of the 3.4-mm HCO <sup>+</sup> Line toward the Galactic Centre	Y. Fukui N. Kaifu M. Morimoto T. Miyaji	109
CO and OH in the Galactic Center Region	J. Inatani N. Ukita N. Kaifu S. Kodaira K. Ishii	111
In Search of $\approx$ 5K Galactic Molecular Gas	R.H. Rubin N.J. Evans II B. Zuckerman	113
CO (J=2-1) Observations of Several Galactic HII Regions	T. de Graauw S. Lidholm B. Fitton F.P. Israel A. Sargent T.B.H. Kuiper H. Nieuwenhuyzen	115



Molecular Cloud Densities from Observations of Carbon Monosulfide	R.A. Linke P.F. Goldsmith	117
CO Observations in the Southern Hemisphere	A.R. Gillespie	123
CO (J=2-1) Observations of the Carina Nebula and G 333.6-0.2 and a Search for CO in LMC and SMC	T. de Graauw S. Lidholm B. Fitton F.P. Israel J. Beckman H. Nieuwenhuyzen J. Vermue	125
Population Inversion and Suprathermal Excitation in Carbon Monoxide	J. Köppen W.H. Kegel	127
1.0 mm Continuum Observations of Cool Southern Clouds	D.Y. Gezari L. Cheung M.G. Hauser J.A. Frogel	129
The Extinction Efficiency of Dust Grains at 1 Mm	W.A. Sherwood E.M. Arnold G.V. Schultz	133
Comparison of Submillimeter and CO Brightness in Orion and Mon R2	D. Cudaback L. Anderson D. Lynch J. Smith	135
The Evolution of Giant Molecular Clouds	C. Norman J. Silk	137
The Disruption of the Molecular Cloud Associated with the North America and Pelican Nebulae	J. Bally	151
The Structure and Evolution of the W3 Molecular Cloud	H.R. Dickel	157
Atomic Hydrogen in and around the Giant Molecular Cloud near W3 and W4	T. Hasegawa F. Sato Y. Fukui	159
High Rate of Destruction of Molecular Clouds by Hot Stars	M. Heydari-Malayeri M.C. Lortet L. Deharveng	163
The Interaction of T-Tauri Stars with Molecular Clouds	J. Silk C. Norman	165

Observations of the J=1-0 and J=2-1 Lines of $^{12}\text{CO}$ in L1551: Evidence for Anisotropic Mass Loss	R.L. Snell R.B. Loren R.L. Plambeck	173
Ammonia Observations of Dark Clouds containing Herbig-Haro Objects	P.T.P. Ho A.H. Barrett	175
Hydrostatic Models of Molecular Clouds	T. de Jong A. Dalgarno W. Boland	177
Contagious B Star Formation in the Rho Ophiuchi Dark Cloud	E. Falgarone	183
A Nearby Example of a Giant Molecular Cloud	J.W. Barrett R.L. deZafra D.B. Sanders P.M. Solomon	185
Cold HI Gas in the Region of the Giant Molecular Cloud near M17	F. Sato Y. Fukui T. Hasegawa	187
Search for CO in Atomic Hydrogen Clouds	I. Kazès J. Crovisier	189
Optical and Theoretical Studies of Giant Clouds in Spiral Galaxies	B.G. Elmegreen D.M. Elmegreen	191
Molecular Clouds in Orion and Monoceros	M. Morris J. Montani P. Thaddeus	197
Columbia CO Survey: Molecular Clouds and Spiral Structure	R.S. Cohen T.M. Dame P. Thaddeus	205
Molecular Fan of 360-pc Radius in the Galactic Center Region	Y. Fukui	209
The Galactic Rotation Curve to $R = 18$ kpc	L. Blitz M. Fich A.A. Stark	213
The Hydrogen Molecule as a Collision Partner	T. Oka	221
Recent Laboratory Work on Molecules of Possible Importance for Interstellar Studies	G. Herzberg	231

Far Infrared Laser Magnetic Resonance Spectroscopy	K.M. Evenson R.J. Saykally	239
Optical Observations of Interstellar Molecules	T.P. Snow Jr.	247
Observations of Interstellar Molecules with the International Ultraviolet Explorer	J.H. Black	257
Interstellar Line Spectra of a Dense Cloud: The VI Cygni Association	S.P. Souza B.L. Lutz	261
Rotational Fine Structure Lines of Interstellar C <sub>2</sub> toward $\zeta$ Persei	F.H. Chaffee Jr. B.L. Lutz J.H. Black P.A. Vanden Bout R.L. Snell	263
Laboratory Measurements of Oscillator Strengths of Ultraviolet Molecular Lines of HCl and H <sub>2</sub> O and Column Densities of These Molecules in the Zeta Ophiuchi Cloud	P.L. Smith K. Yoshino W.H. Parkinson	269
Chlorine Chemistry in Diffuse Interstellar Clouds	J.H. Black P.L. Smith	271
Molecular Formation in Hot Diffuse Clouds	A. Dalgarno	273
Formation of Simple Molecules by C <sup>+</sup> Reactions on Oxide Grains in Diffuse Clouds	W.W. Duley	281
The Photodissociation of Interstellar CH <sup>+</sup>	K. Kirby	283
Charge Exchange and Fine Structure Excitation in O-H <sup>+</sup> Collisions	G. Chabaud J.M. Launay B. Lévy P. Millié E. Roueff F. Tran Minh	287
Molecular Synthesis in Interstellar Clouds: the Radiative Association Reaction H+OH $\rightarrow$ H <sub>2</sub> O+h $\nu$	D. Field N.G. Adams D. Smith	289
Experimental Measurements of Ion-Molecule Reactions	F.C. Fehsenfeld	291

## TABLE OF CONTENTS

xi

Interstellar Sulfur Chemistry	S.S. Prasad W.T. Huntress Jr.	297
An ICR Study of Ion-Molecule Reactions in the C <sub>2</sub> H <sub>2</sub> /HCN System	M.J. McEwan V.G. Anicich W.T. Huntress Jr.	299
An ICR Study of an Association Reaction at Low Pressure	M.J. McEwan V.G. Anicich W.T. Huntress Jr. P.R. Kemperer M.T. Bowers	305
Laboratory Studies of Interstellar Carbon/ Nitrogen Ion Chemistry	H.I. Schiff G.I. Mackay G.D. Vlachos D.K. Bohme	307
Gas Phase Synthesis of Amino-, Cyano- and Nitroso-Compounds in Interstellar Clouds	N.G. Adams D. Smith	311
The Formation of Complex Interstellar Molecules by Radiative Association	E. Herbst	317
The Formation of Interstellar Molecules via Radiative Association Reactions	D. Smith N.G. Adams	323
On the Formation of Interstellar Linear Molecules	A. Sakata	325
Laboratory and Modeling Studies of Chemistry in Dense Molecular Clouds	W.T. Huntress Jr. S.S. Prasad G.F. Mitchell	331
Molecular Evolution in Dense Clouds	H. Suzuki	337
The Determination of Electron Abundances in Interstellar Clouds	A. Wootten R. Snell A.E. Glassgold	339
Molecule Formation in Cool, Dense Interstellar Clouds	W.D. Watson	341
Laboratory and Theoretical Results on Interstellar Molecule Production by Grains in Molecular Clouds	J.M. Greenberg L.J. Allamandola W. Hagen C.E.P. van de Bult F. Baas	355
Interstellar Molecules on Dust Mantles	N. Nakagawa	365

The Formation of Hydrocarbons and Iron-Hydrides on Cold Interstellar Grains - Experimental Studies	A. Bar-Nun M. Litman M. Pasternak M.L. Rappaport	367
The Chemical Identification of Grain Mantles by Infrared Spectroscopy	L.J. Allamandola J.M. Greenberg C.A. Norman W. Hagen	373
Infrared Molecular Absorption Features	S.P. Willner R.C. Puetter R.W. Russell B.T. Soifer	381
Reproduction of the Interstellar Ice Band by Grain Mantle Analogs	W. Hagen A.G.G.M. Tielens J.M. Greenberg	387
Correlations between the $\lambda 2200$ Feature, the Diffuse $\lambda 4430$ Band and $E_{B-V}$	A.C. Danks	389
Correlations for Interstellar Molecules and Diffuse Bands	W.B. Somerville	395
Measurements of Isotopic Abundances in Interstellar Clouds	A.A. Penzias	397
Isotopic Abundance Ratios from Microwave Observations of Formaldehyde	T.L. Wilson C. Henkel C.M. Walmsley T. Pauls	405
Isotope Ratios in Interstellar Formaldehyde	M.L. Kutner D.E. Machnik K.D. Tucker W. Massano	409
The $^{12}\text{C}/^{13}\text{C}$ Ratio in Interstellar Dark Clouds	W.H. McCutcheon R.L. Dickman W.L.H. Shuter R.S. Roger	411
CO Abundance and Isotopic Fractionation in Dark Clouds	P.F. Goldsmith W.D. Langer E.R. Carlson R.W. Wilson	417
CO Isotope Line Shapes in Dark Clouds	P.C. Myers R.B. Buxton P.T.P. Ho	421

Isotopic Fractionation in Interstellar Carbon-bearing Molecules Unrelated to Carbon Monoxide	V. Vanýsek	423
Interpretation of Isotopic Abundances in Interstellar Clouds	M. Guélin J. Lequeux	427
Detection of Deuterated Formaldehyde in Interstellar Clouds	W.D. Langer M.A. Frerking R.A. Linke R.W. Wilson	439
Theoretical Considerations of Shock Wave Behavior	D. Hollenbach	445
Observations of Shock Waves in Interstellar Clouds	S. Beckwith	455
Observations of the V=0 S(2) Line of Molecular Hydrogen at 12.28 $\mu\text{m}$ in the Orion Molecular Cloud	T.R. Geballe S.C. Beck J.H. Lacy	465
Spectra of the 2.12 $\mu\text{m}$ Quadrupole Line of H <sub>2</sub> in the Orion Molecular Cloud	D. Nadeau G. Neugebauer T.R. Geballe	469
Molecule Formation in the Seyfert Galaxy NGC 1068	W.J. Carlson C.B. Foltz	471
Molecular Clouds near Supernova Remnants	V.I. Slysh T.L. Wilson T. Pauls C. Henkel	473
Behavior and Significance of Circumstellar Clouds	B. Zuckerman	479
Observations of Circumstellar Clouds	P.G. Wannier R.O. Redman T.G. Phillips R.B. Leighton G.R. Knapp P.J. Huggins	487
Radio Detection of Ammonia in IRC+10216	M.B. Bell S. Kwok P.A. Feldman	495
Molecular Abundances in IRC+10216	E.M. McCabe R.C. Smith R.E.S. Clegg	497

Infrared Heterodyne Spectroscopy of Circumstellar Molecules	A.L. Betz R.A. McLaren	503
Spectroscopic Studies of IRC+10216 and Similar Objects	S.T. Ridgway D.N.B. Hall	509
Infrared Spectroscopy of Molecules in Circumstellar Material	D.N.B. Hall	515
Observational Characteristics of Masers Associated with Stars	L.E. Snyder	525
VLBI Observations of the V=1 and V=2 SiO Masers in W Hydra and VX Sagittarius	A.P. Lane P.T.P. Ho C.R. Predmore J.M. Moran R. Genzel S.S. Hansen M.J. Reid	535
Vibrationally Excited Silicon Monoxide Masers	D. Buhl F.O. Clark G. Chin D. Glenar T. Kostiuik M.J. Mumma F.J. Lovas	537
Time Variation of SiO Maser Emissions	N. Ukita N. Kaifu	539
Time Variability of the Orion A, R Leo and $\alpha$ Ceti SiO ( $v=1$ , $J=2-1$ ) Masers	$\text{\AA}$ . Hjalmarson H. Olofsson	541
Polarized Emission in the Broad SiO Feature from R Leo	F.O. Clark D.R. Johnson T.H. Troland C.E. Heiles	543
SiO Emission from the Orion Nebula	B. Baud J. Bieging R. Plambeck D. Thornton W.J. Welch M. Wright	545
The OH Circumstellar Maser in Late-Type Stars	Nguyen-Q-Rieu V. Bujarrabal J. Guibert A. Omont	549

Interpretation of Circumstellar Masers	P. Goldreich	551
Pumping Mechanisms of OH Masers	A. Omont J. Guibert S. Guilloteau V. Bujarrabal Nguyen-Q-Rieu	559
Observations of Masers in Regions of Star Formation	D. Downes R. Genzel	565
Absolute Positions of OH Masers Associated with HII Regions	R.S. Booth R.P. Norris	579
The Pumping of Interstellar OH Main Line Masers: an Efficient Mechanism	R. Lucas	581
$\Lambda$ -Doublet Population Inversion in Collisions of OH, OD, CH, CD and NH <sup>+</sup>	R.N. Dixon D. Field	583
Collisional Inversion of the Populations of $\Lambda$ -Doublets in CH and OH: a Critical Study	D.R. Flower	589
Pumping of Strong H <sub>2</sub> O Cosmic Masers	V.S. Strel'nitsky	591
Time Variations of Interstellar Water Masers in HII Regions	G.J. White G.H. Macdonald	593
Further Observations of the H <sub>2</sub> O Emission from NGC 4945	J.R.D. Lépine P. Marques dos Santos	599
The Interpretation of High Velocity H <sub>2</sub> O Masers	V.V. Burdyuzha	603
Far-Ultraviolet Objective Spectrographic Surveys for Mapping of Interstellar H <sub>2</sub> , H, and CO	G.R. Carruthers	611
Future Possibilities for Ultraviolet Observations of Interstellar Molecules	G.R. Carruthers	613
Maser Amplifiers	E. Kollberg	615
Wideband Spectrometers for Millimetre Wavelengths	B.J. Robinson	619
Acousto-Optic Radiospectrometers for Mm-Wave Spectroscopy	Y. Chikada N. Ukita J. Inatani N. Kaifu S. Kodaira	625



Future Spectral Line Research with the VLA	K.J. Johnston	627
New Experimental Possibilities and Future Prospects for 1-5 $\mu\text{m}$ Infrared Spectroscopy of Interstellar Molecules	D.N.B. Hall	631
A 10 Micron Heterodyne Receiver for Ultra High Resolution Astronomical Spectroscopy	D. Buhl G. Chin J. Faris T. Kostiuik M.J. Mumma D. Zipoy	633
New Experimental Possibilities and the Future at Far IR Wavelengths	C.H. Townes	637
Detection of Interstellar BS in the Cirrus Dark Cloud of the Numbbum Association I' - An Intuitive Model and Its Subsequent Observation	J.J. Charfman	645
Author Index		649
Index of Astronomical Objects		655
Molecules Index		665
Subject Index		675