2	**3**	**4**	**5**	**6**	**7 atoms**
H_2*,*	C_3*	c-C_3H	C_5*	C_5H	C_6H
AlF	C_2H	l-C_3H	C_4H	l-H_2C_4	CH_2CHCN
AlCl	C_2O	C_3N	C_4Si	C_2H_4	CH_3C_2H
C_2**	C_2S	C_3O	l-C_3H_2	CH_3CN	HC_5N
CH	CH_2	C_3S	c-C_3H_2	CH_3NC	$HCOCH_3$
*CH^+	HCN	C_2H_2*	CH_2CN	CH_3OH	NH_2CH_3
CN	HCO	CH_2D^+?	CH_4*	CH_3SH	c-C_2H_4O
CO	HCO^+	HCCN	HC_3N	HC_3NH^+	H_2CCHOH
CO^+	HCS^+	$HCNH^+$	HC_2NC	HC_2CHO	
CP	HOC^+	HNCO	HCOOH	NH_2CHO	
CSi	H_2O	HNCS	H_2CHN	C_5N	
HCl	H_2S	$HOCO^+$	H_2C_2O	l-HC_4H*	
KCl	HNC	H_2CO	H_2NCN		
HD*	*H_3^+,H_2D^+,HD_2^+				
	HN_2^+	NH_3, ND_3			

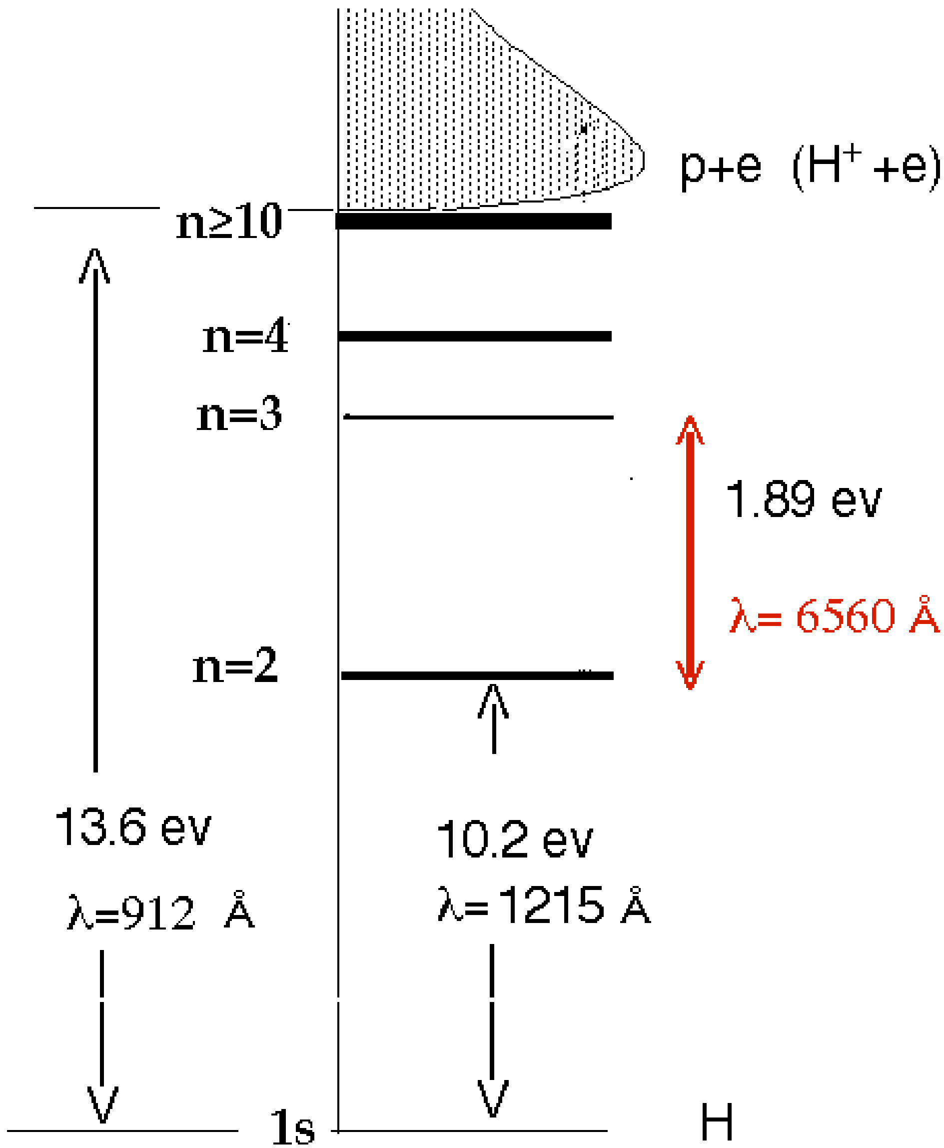
* Infrared **Optical l - linear c-cyclic

Big Molecules

8 atoms	9	10	11	12	13
CH_3C_3N	CH_3C_4H	CH_3C_5N ?	HC_9N	C_6H_6*?	$HC_{11}N$
$HCOOCH_3$	CH_3CH_2CN	$(CH_3)_2CO$			
CH_3COOH	$(CH_3)_2O$	$(CH_2OH)_2$?			
C_7H	CH_3CH_2OH	H_2NCH_2COOH Glycine??			
H_2C_6	HC_7N				
CH_2OHCHO?	C_8H				
l-HC_6H*					

Abundance of the Elements

	Cosmic	%[a]	%Earth Crust
H	$3.3x10^5$		0.22
He	$4.6x10^4$		$8x10^{-7}$
C	100	20.1	0.19
N	30.9	6.2	0.0025
O	235	47.4	46.6
F	0.01	0.002	0.095
Ne	91	18.3	$7x10^{-9}$
Na	0.6	0.12	2.8
Mg	10.6	2.1	2.1
Al	0.8	0.15	8.1
Si	9.9	2.4	27.1
Fe	8.9	2.2	5.0



p+e (H+ +e)
n≥10
n=4
n=3
n=2
1s
H
1.89 ev
λ= 6560 Å
13.6 ev
λ=912 Å
10.2 ev
λ= 1215 Å

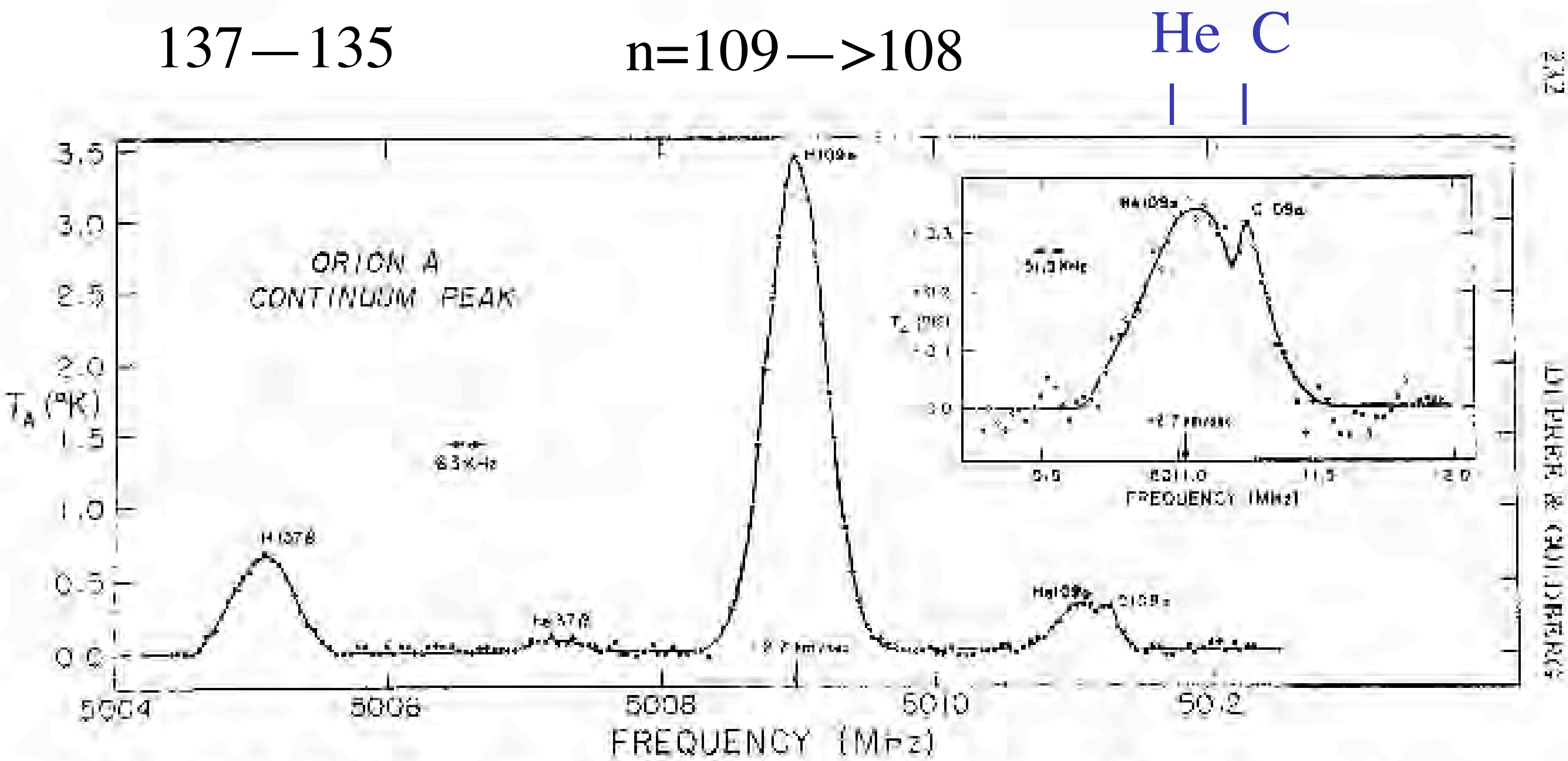
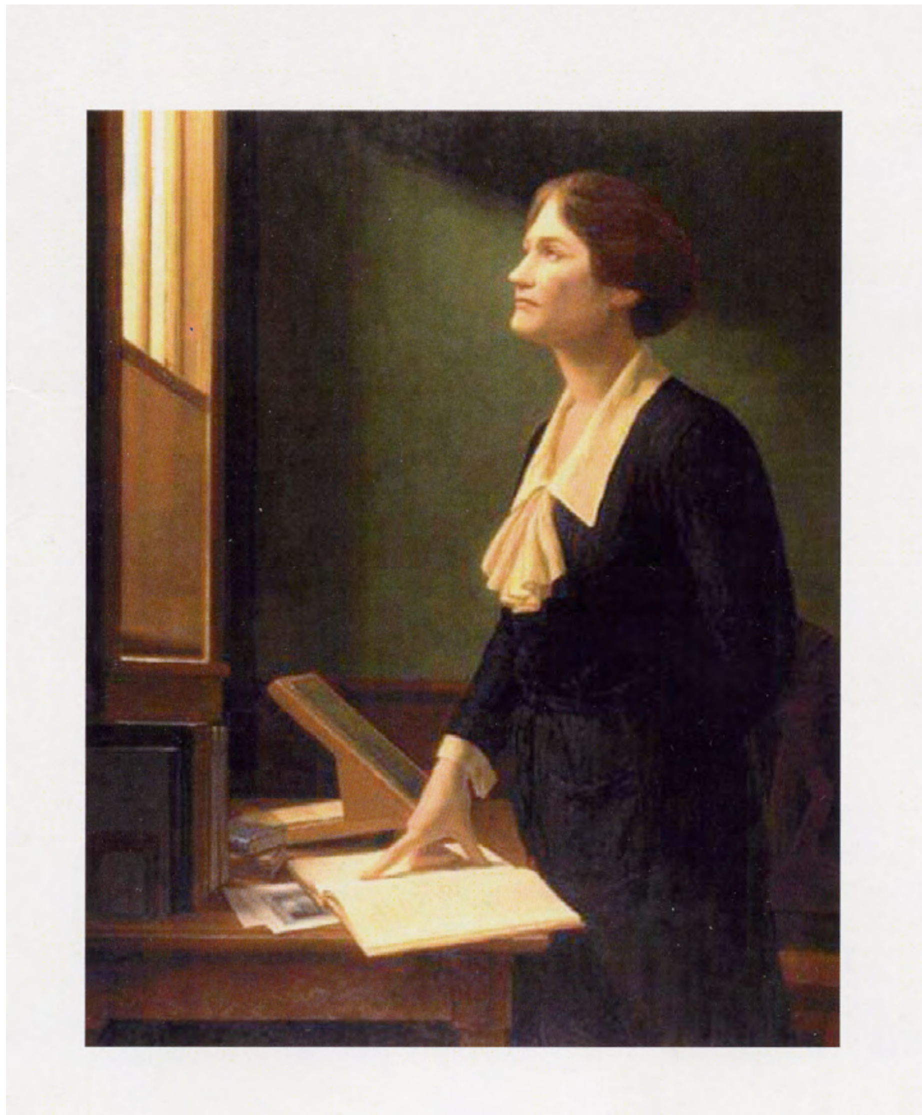
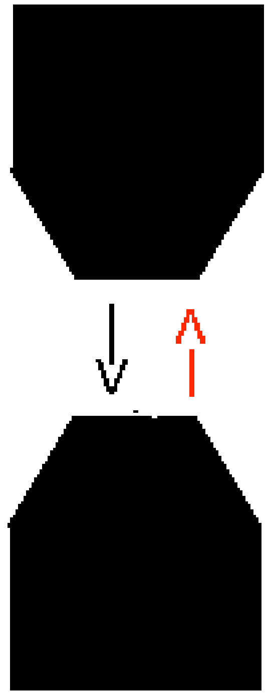


FIGURE 1. A broadband spectrogram showing recombination lines at the center of Orion A (M42). These observations were made with the 400-channel autocorrelator at the 140′ telescope of the NRAO in Green Bank, West Virginia by Churchwell & Mezger (1970). Five recombination lines are indicated: H 137β, He 137β, H 109α, He 109α, and the narrow anomalous line labeled C 109α. The bandwidth corresponds to 3.8 km sec^{-1} in the large figure, and 1.9 km sec^{-1} in the insert.

CECILIA PAYNE-GAPOSCHKIN: ASTRONOMER AND ASTROPHYSICIST 1900-1980 "THE MOST BRILLIANT Ph.D. THESIS EVER WRITTEN IN ASTRONOMY"



Ed Purcell

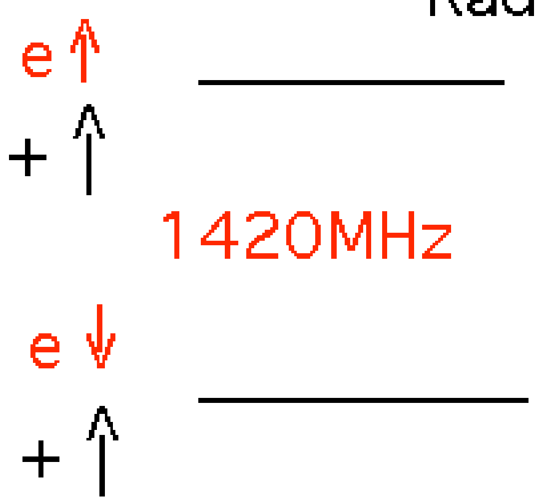


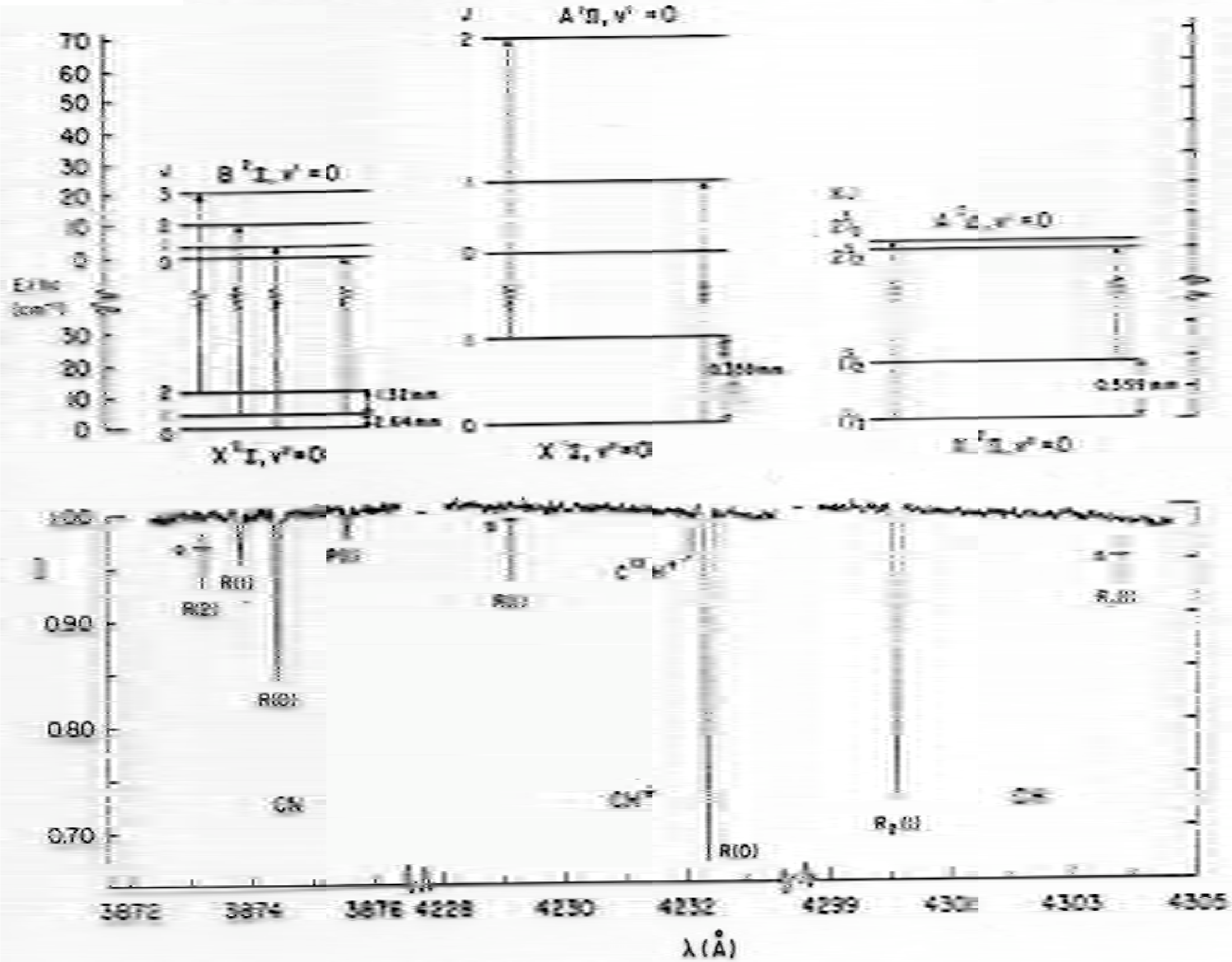
Nuclear Magnetic

Resonance

Radioastronomy

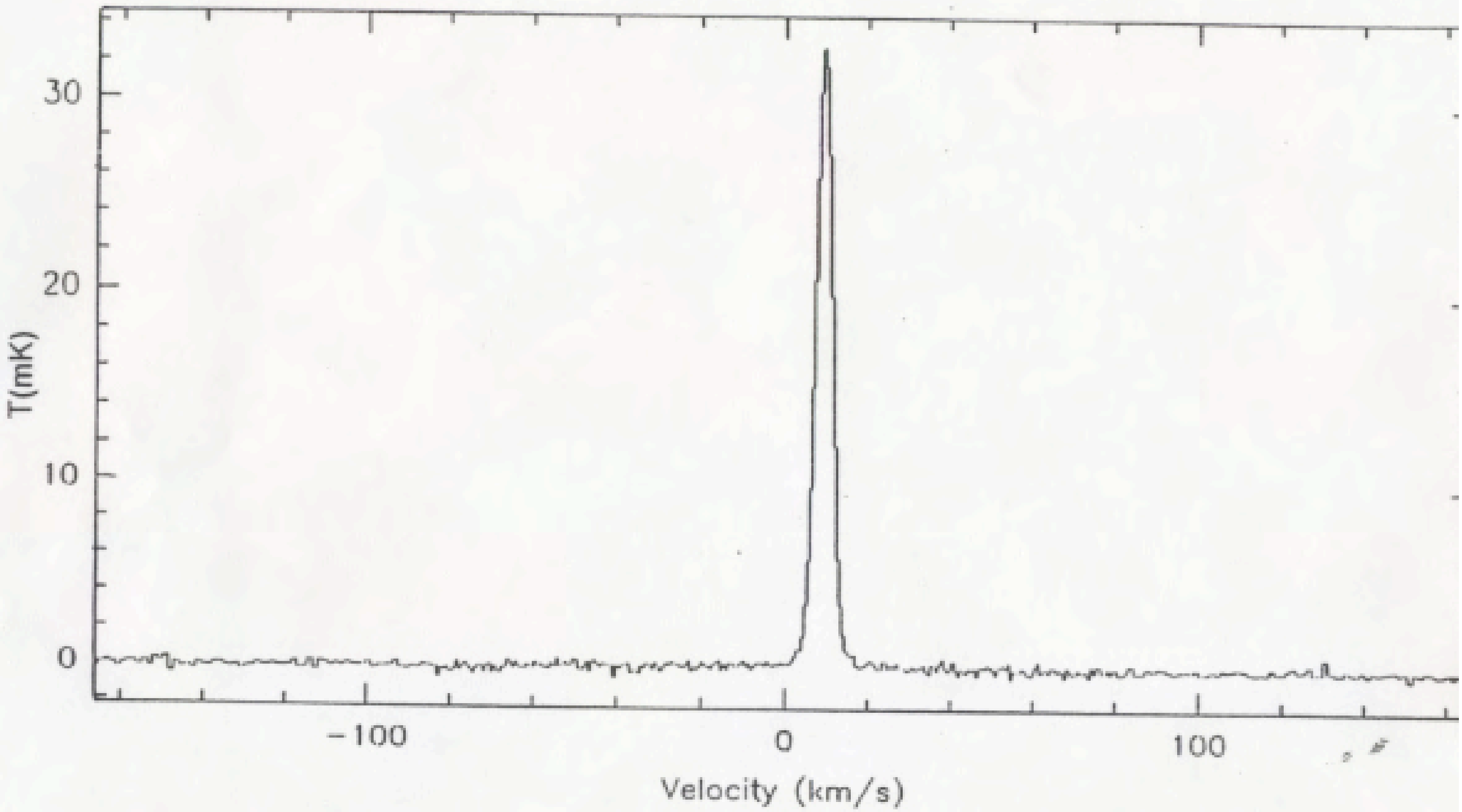
H atom





B ²Σ, v' = 0
A ²Δ, v' = 0
X ²Σ, v'' = 0
X ²Σ, v'' = 0
E/hc (cm⁻¹)
CN
CH⁺
CH
R(0)
R(1)
R(2)
P(1)
R₂(1)
λ (Å)

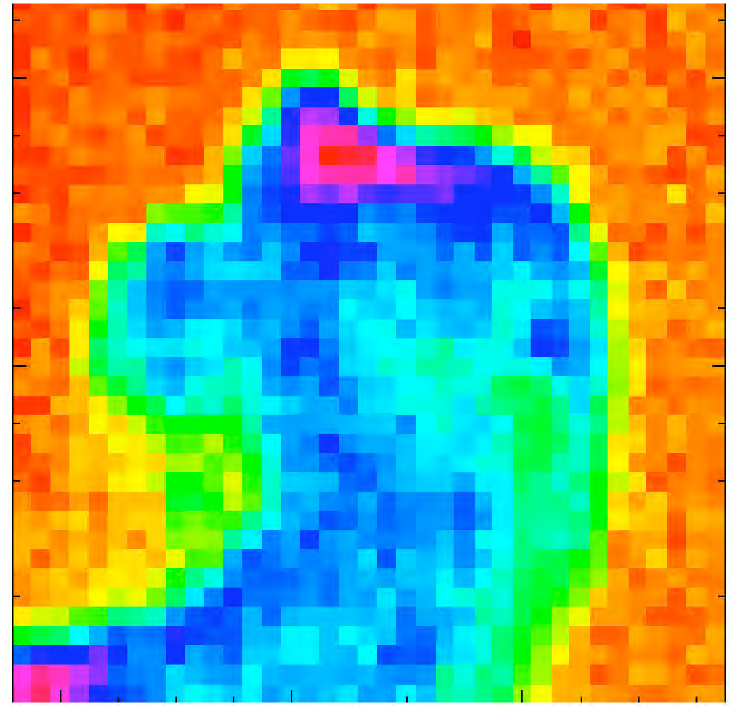
CO J=1—0 in Orion 115.3GHz

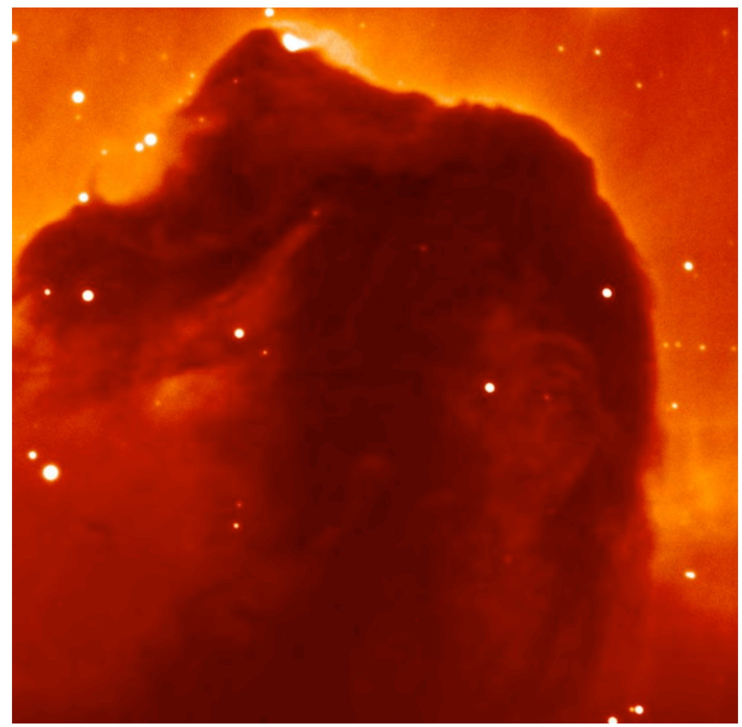


Galaxy • M104

Horsehead nebula in Orion

. Observed by microwave emission of carbon monoxide The green and yellow regions are of greater concentrations of carbon monoxide. Cal Tech





Chemical Equilibrium

$$CO + 3H_2 = CH_4 + H_2O$$

$$\Delta H^0 = -49.3 \text{ kcal}; \Delta G^0 = -45 \text{ kcal}$$

(20K)

$$K = [CH_4][H_2O]/[CO][H_2]^3 = 10^{490} \text{ cm}^6$$

Observation $[CO]/[H_2] = 10^{-4}$

$$[H_2O] \leq 10^{-4} [CO]$$

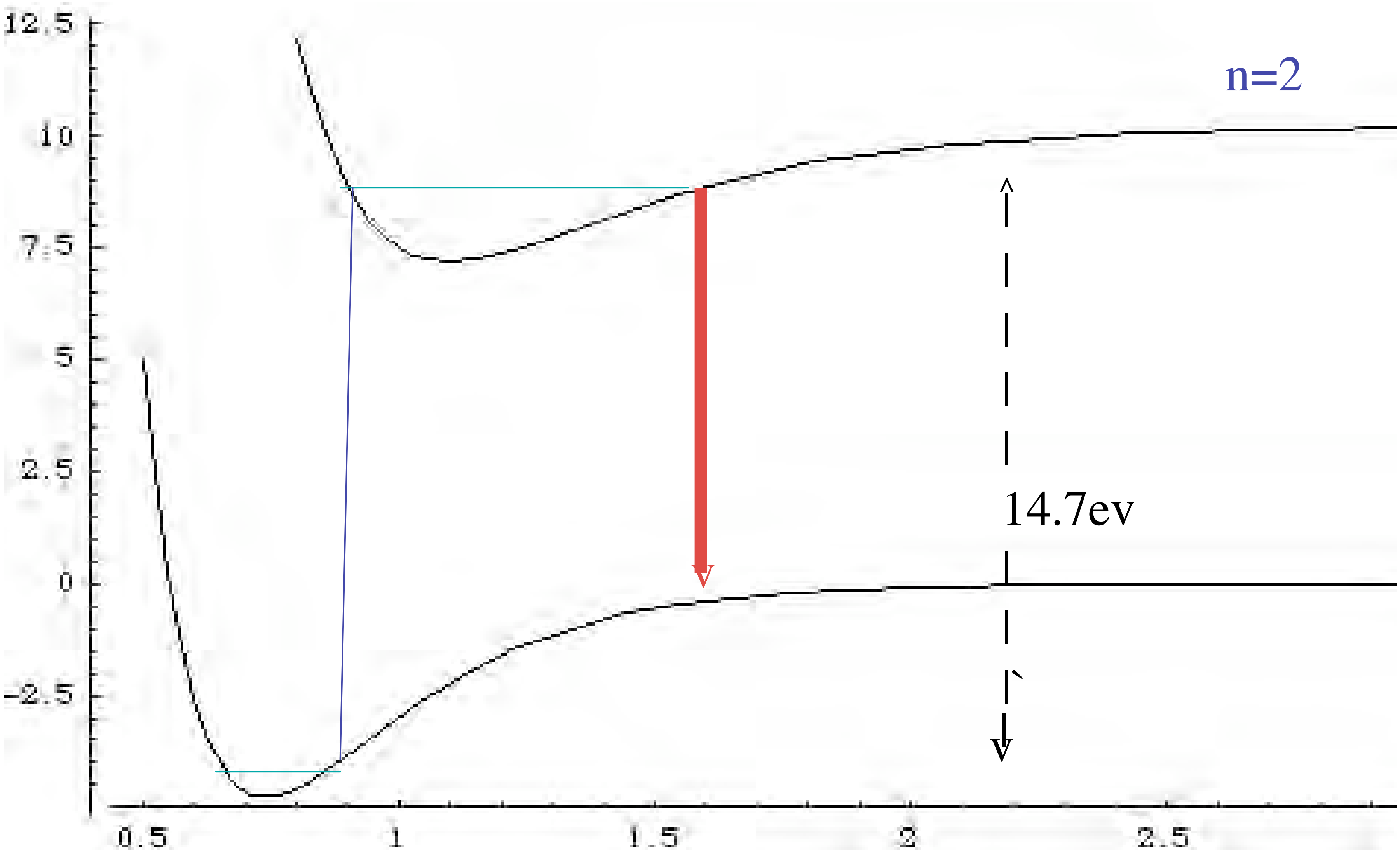
$$[CH_4] < 10^{-4} [CO]$$

Prediction/Observation $>10^{500}$

$[H]/[H_2]$ = ??

H + H = H_2 grain surface

H_2 + h□ = 2 H



Primary Ionization

H_2 + crp(≥100Mev)= H_2^+

He + crp(≥100Mev)= He^+

Secondary Reactions

$H_2^+ + H_2 = H_3^+ + H$ fast (10 min $[H_2]= 10^6$ cm^{-1}

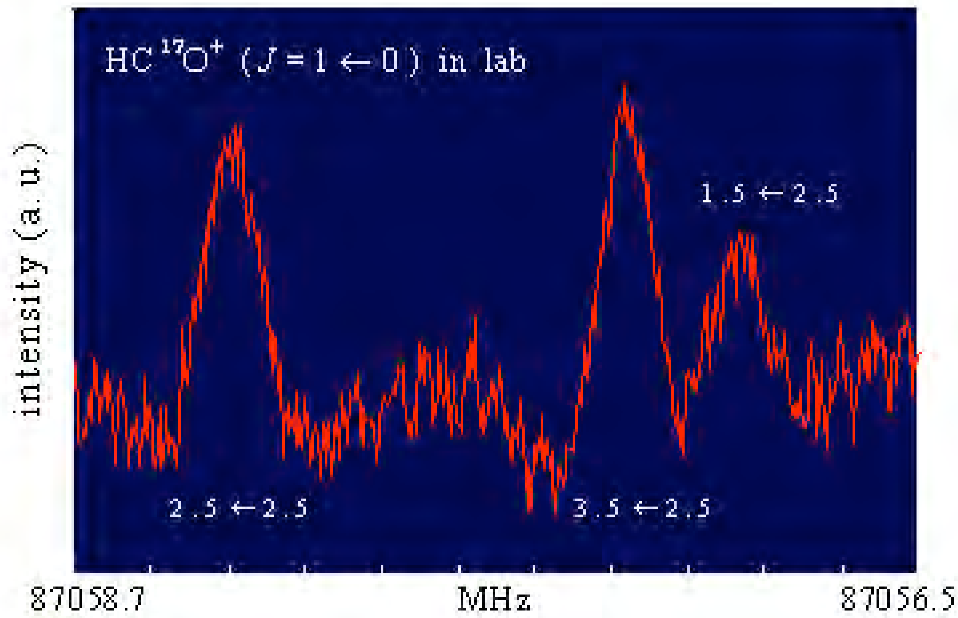
$He^+ + H_2 \neq HeH^+ + H$ very slow at low T

He + H^+ + H ”

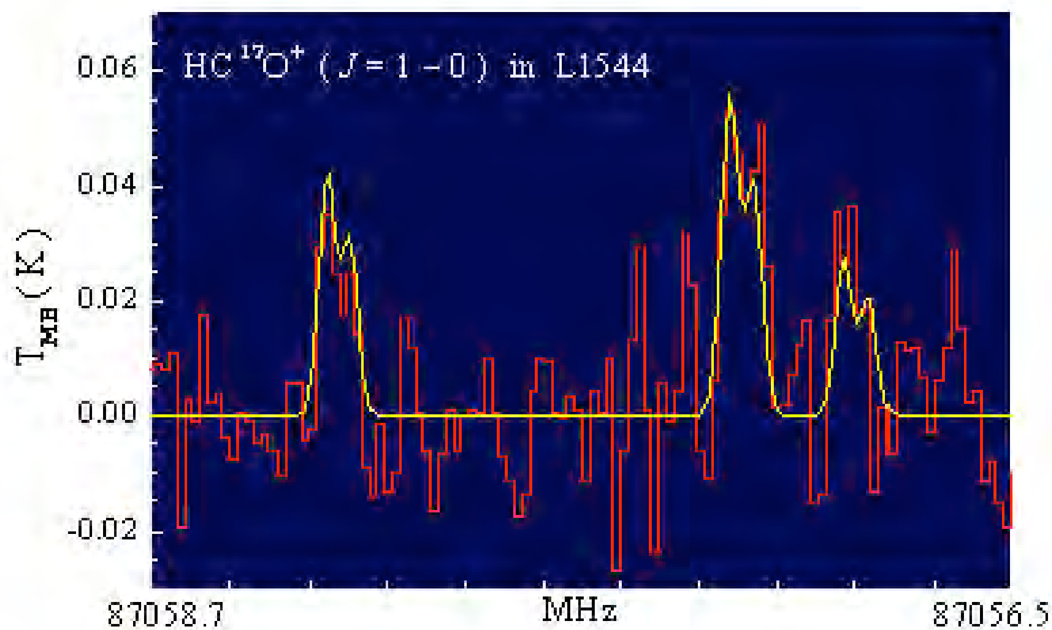
$H_3^+ + CO = HCO^+ + H_2$

$He^+ + CO = C^+ + O + He$

$[He] \approx 10^3 [CO]$

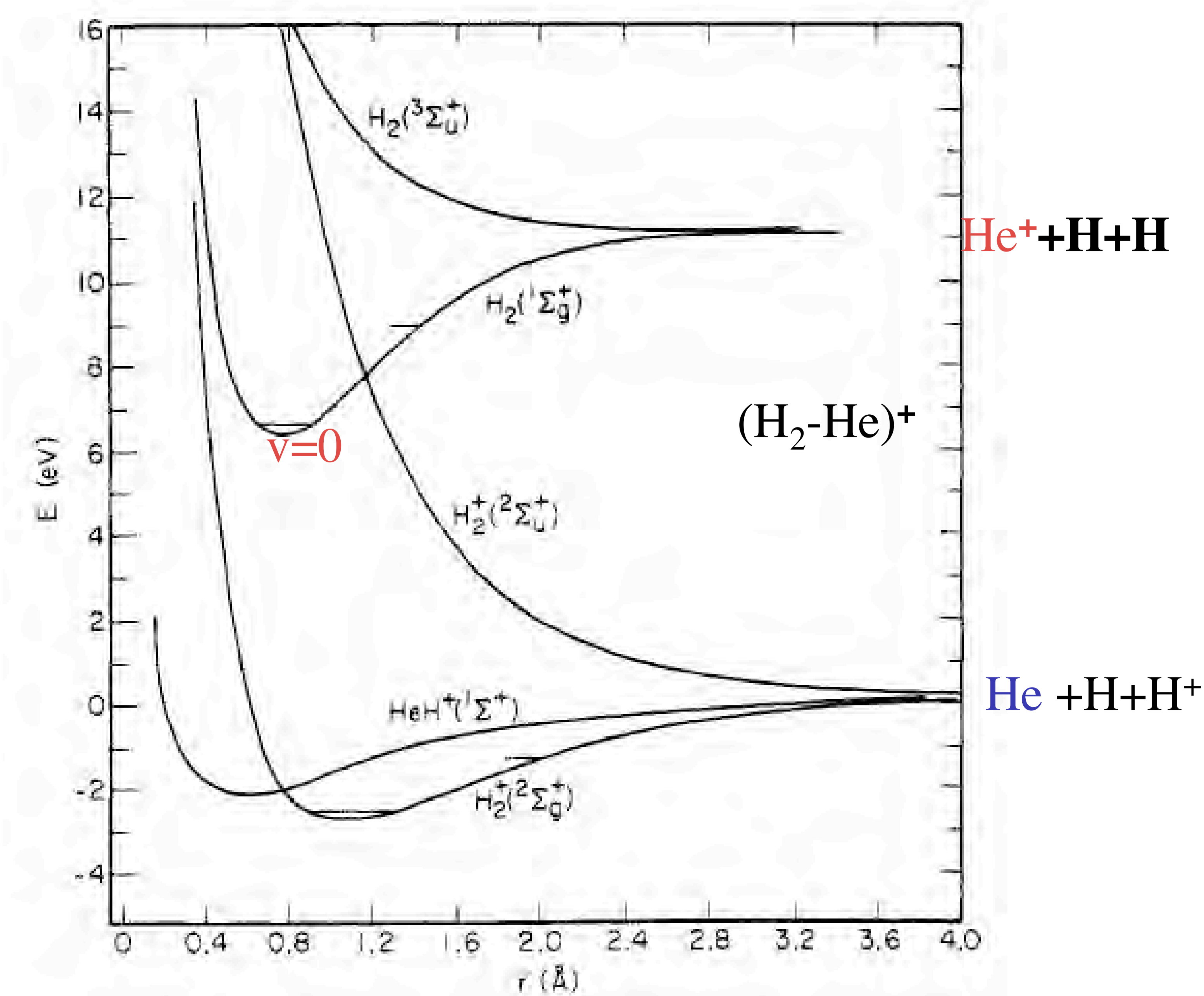


University of Bologna



$^{17}O/^{16}O$ = 0.00037

Bruce Mahan Accounts Chem. Research 1975



2	**3**	**4**	**5**	**6**	**7 atoms**
H_2*,*	C_3*	c-C_3H	C_5*	C_5H	C_6H
AlF	C_2H	l-C_3H	C_4H	l-H_2C_4	CH_2CHCN
AlCl	C_2O	C_3N	C_4Si	C_2H_4	CH_3C_2H
C_2**	C_2S	C_3O	l-C_3H_2	CH_3CN	HC_5N
CH	CH_2	C_3S	c-C_3H_2	CH_3NC	$HCOCH_3$
*CH^+	HCN	C_2H_2*	CH_2CN	CH_3OH	NH_2CH_3
CN	HCO	CH_2D^+?	CH_4*	CH_3SH	c-C_2H_4O
CO	HCO^+	HCCN	HC_3N	HC_3NH^+	H_2CCHOH
CO^+	HCS^+	$HCNH^+$	HC_2NC	HC_2CHO	
CP	HOC^+	HNCO	HCOOH	NH_2CHO	
CSi	H_2O	HNCS	H_2CHN	C_5N	
HCl	H_2S	$HOCO^+$	H_2C_2O	l-HC_4H*	
KCl	HNC	H_2CO	H_2NCN		
HD*	*H_3^+, H_2D^+, HD_2^+				
	HN_2^+	NH_3, ND_3			

* Infrared **Optical l - linear c-cyclic

Big Molecules

8 atoms	9	10	11	12	13 atms
CH_3C_3N	CH_3C_4H	CH_3C_5N ?	HC_9N	C_6H_6*(?)	$HC_{11}N$
$HCOOCH_3$	CH_3CH_2CN	$(CH_3)_2CO$			
CH_3COOH	$(CH_3)_2O$	$(CH_2OH)_2$?			
C_7H	CH_3CH_2OH	H_2NCH_2COOH Glycine??			
H_2C_6	HC_7N				
CH_2OHCHO?	C_8H				
l-HC_6H*					

http://www.ph1.uni-koeln.de/vorhersagen/

Hydrocarbon Synthesis

$C^+ + H_2 = CH_2^+ + h\nu$ (slow radiative association)

$C + H_3^+ = CH^+ + H_2$; $CH_2^+ + H$

$CH^+ + H_2 = CH_2^+ + H$

$CH_2^+ + H_2 = CH_3^+ + H$

$CH_3^+ + H_2 = CH_5^+ + h\nu$ (radiative association)

[$CH_5^+ + e = CH_4 + H$, $CH_3 + H_2$]

$CH_5^+ + CO = CH_4 + HCO^+$

$$CH_4 + C^+ = C_2H_2^+ + H_2$$

$$= C_2H_3^+ + H$$

$$C_2H_2^+ + e = C_2H + H$$

$$C_2H_3^+ + e = C_2H + H_2$$

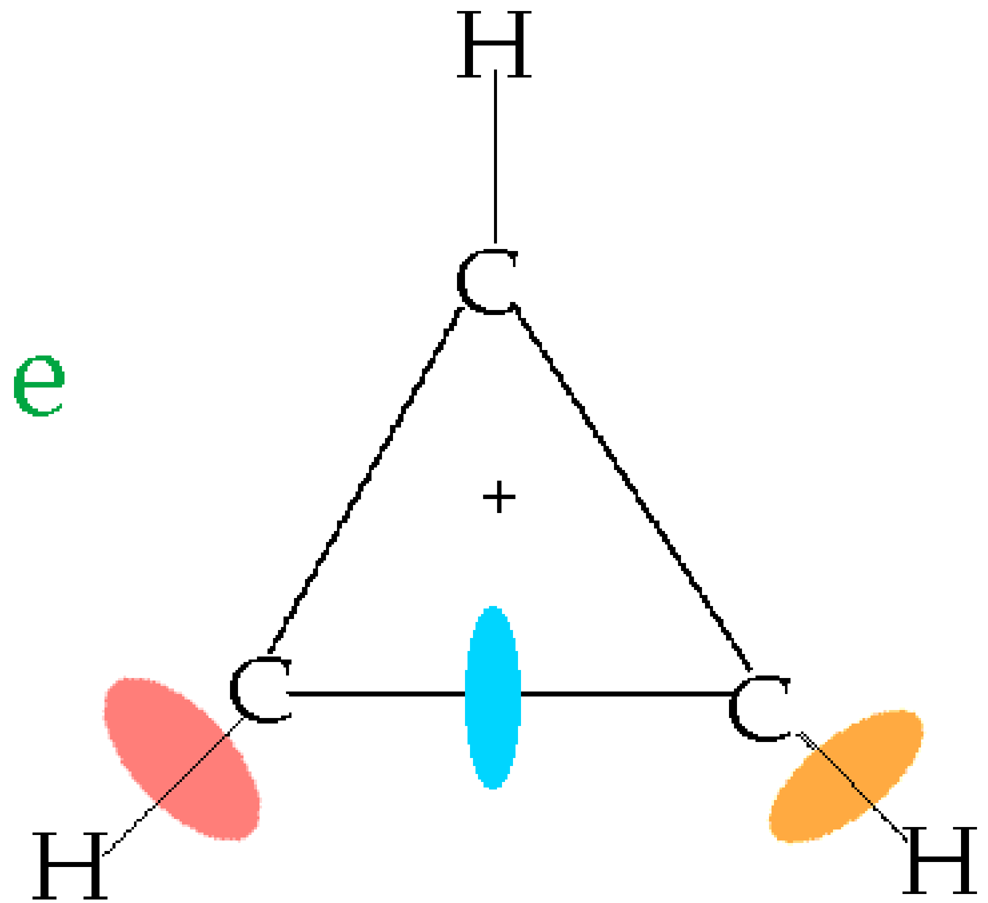
$$= C_2H_2 + H$$

$$C_2H_2 + C+ = C_3H^+ + H$$

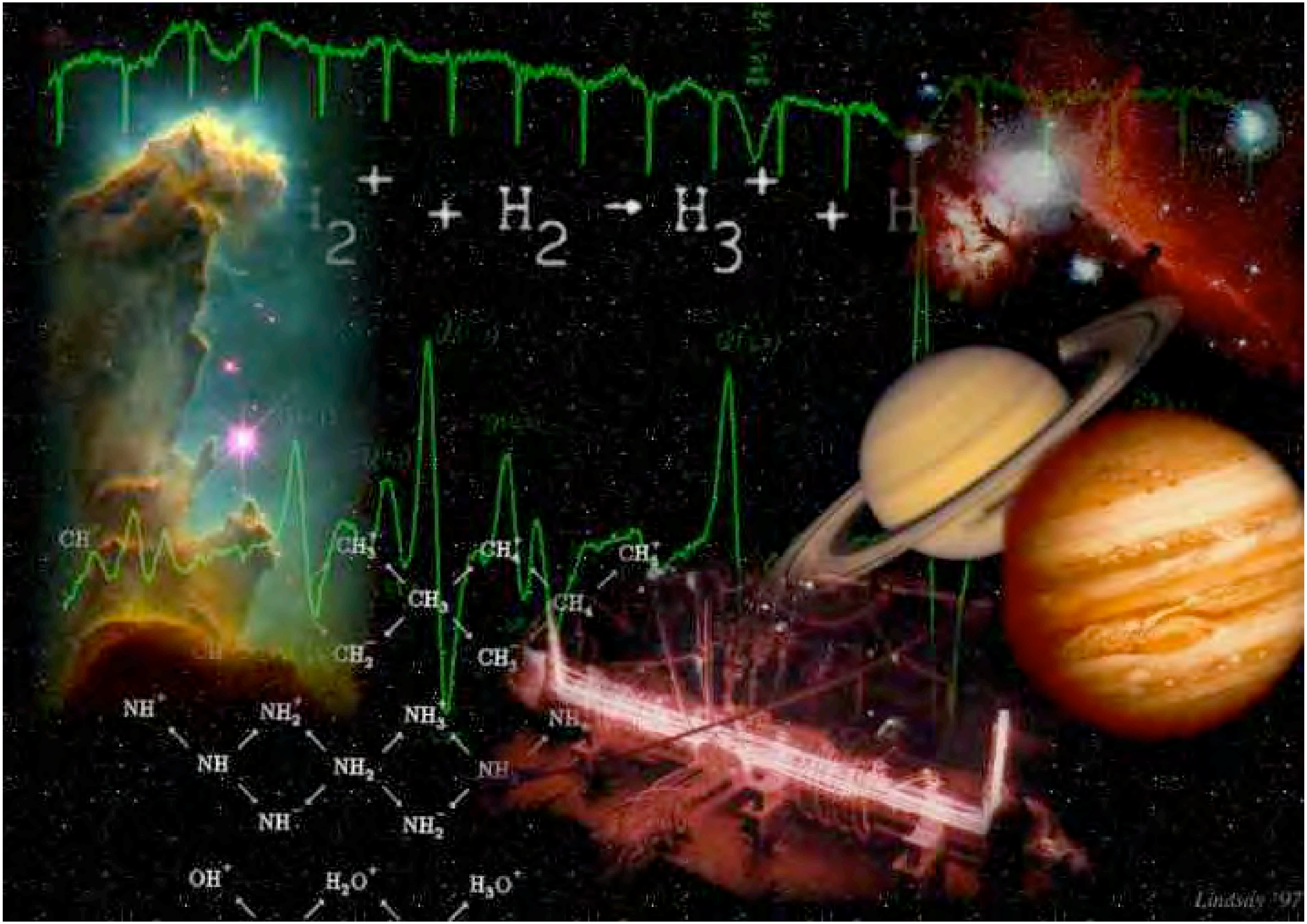
$$C_3H^+ + H_2 = C_3H_3^+ + h\nu$$

$$C_3H_3^+ + e = C_3H\ ,\ C_3H_2$$

linear&cyclic



H
e
C
+
C
C
H
H



+ H2 → H3+ + H
CH
CH3+
CH4+
CH5+
CH3
CH4
CH2
CH3-
NH+
NH2+
NH3+
NH
NH2
NH-
NH2-
OH+
H2O+
H3O+
Lindsay '97

Faraday Discuss., 1998, 109, 267–280

H_3^+ in dense and diffuse clouds

Benjamin J. McCall,[a]* Kenneth H. Hinkle,[b] Thomas R. Geballe[c] and Takeshi Oka[a]

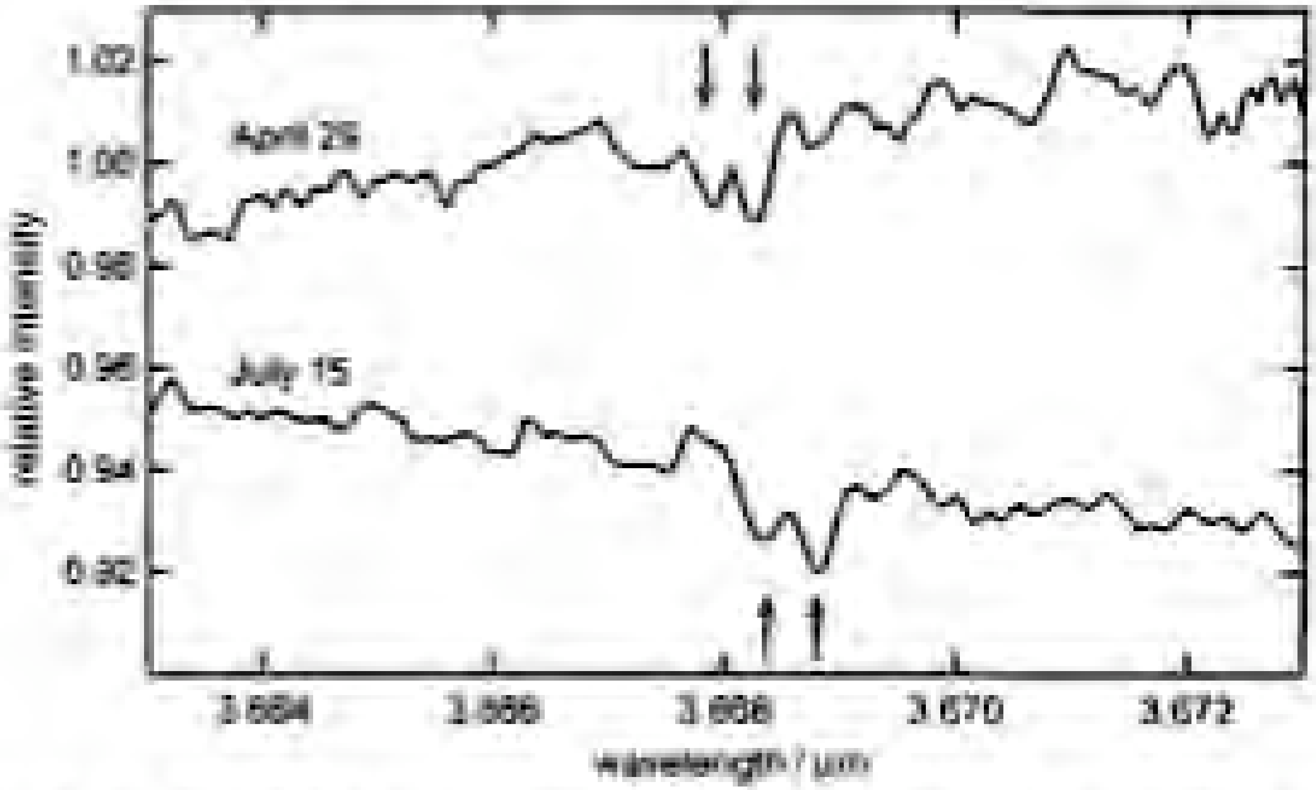


Fig. 4 Spectra of the R(1,0)–R(1,1)$^-$ doublet of H_3^+ obtained with the CGS4 spectrometer at UKIRT along the line of sight to GL2136. The upper trace was obtained on 29 April, 1996, while the lower trace was obtained on 15 July, 1996. The observed Doppler shift of the doublet (marked with arrows) between the two dates matches that expected from the Earth's orbital motion, providing convincing evidence that the doublet is genuine.

Very recently, there has been a report on the detection of glycine in Sgr B2(N-LMH), Orion KL, and W51 e1/e2:
Y.-J. Kuan, S. B. Charnley, H.-C. Huang, W.-L. Tseng, and Z. Kisiel,
Interstellar Glycine
Astrophys. J. **593**, 848–867 (2003).
This paper has caused quite a stir in the astronomical community, if one considers the following paper:
J. M. Hollis, J. A. Pedelty, L. E. Snyder, P. R. Jewell, F. J. Lovas, P. Palmer, and S.-Y. Liu,
A Sensitive Very Large Array Search for Small-Scale Glycine Emission toward OMC-1
Astrophys. J. **588**, 353–359 (2003).

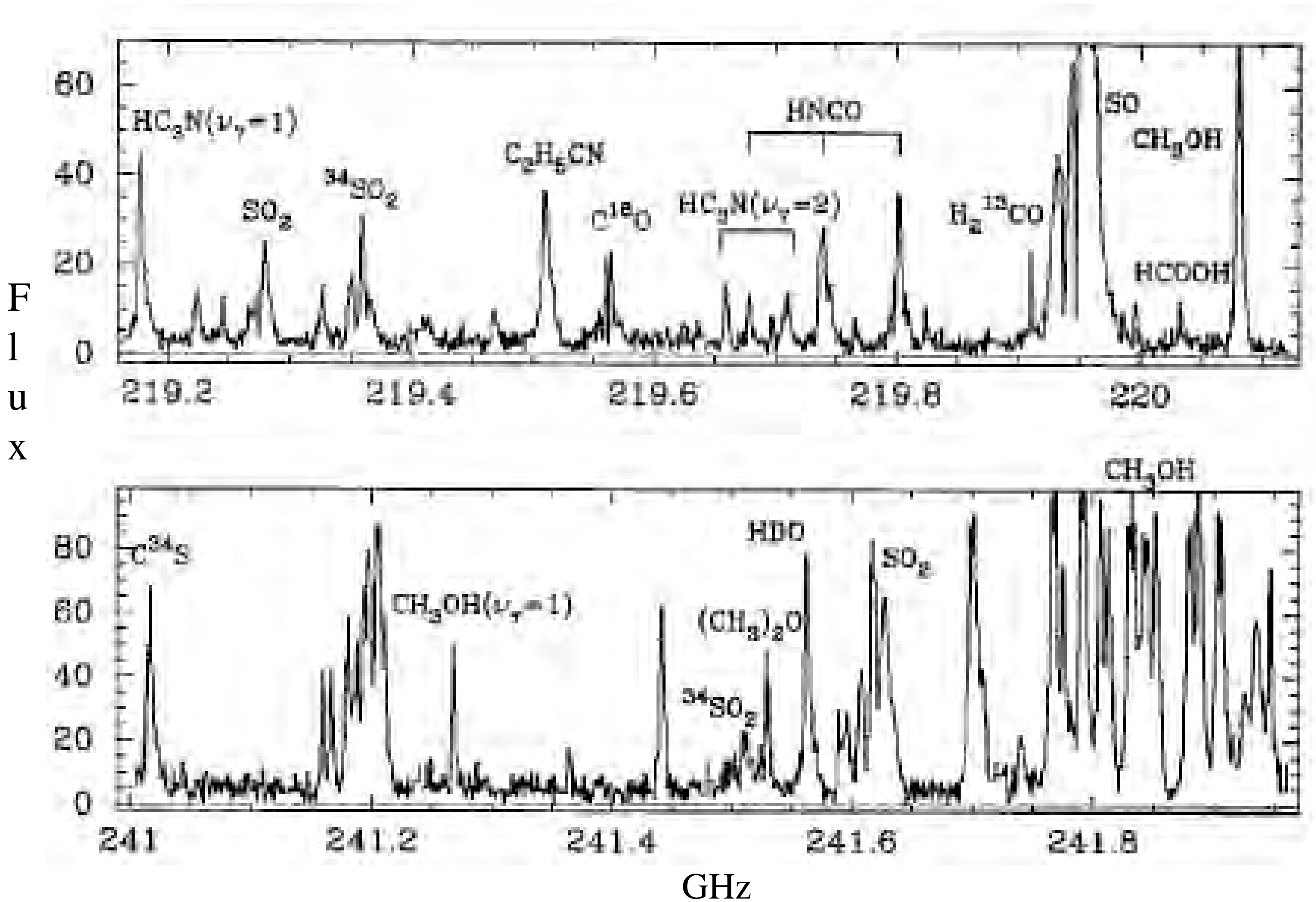
It should be noted that the number of supposedly positively identified transitions reported by Kuan *et al.* is fairly large. Therefore, the report may be considered quite convincing.
However, it was brought to our attention that there seem to be some inconsistencies in the intensities of the lines. In particular, some of the observed lines seem to be too weak by a substantial amount that seems to be incompatible with the derived abundances and rotational temperatures. This may cast doubt on the derived abundances and possibly even on the interstellar detection.
At the moment it appears as if the publication of these reported inconsistencies will not settle the dispute of the glycine detection.

The paper alluded to in the previous paragraph is about to appear:
L. E. Snyder, F. J. Lovas, J. M. Hollis, D. N. Friedel, P. R. Jewell, A. Remijan, V. V. Ilyushin, E. A. Alekseev, and S. F. Dyubko,
A Rigorous Attempt to Verify Interstellar Glycine
Astrophys. J. **619**, 914–930 (2005).

Overall, we would recommend the detection of glycine to be taken very cautiously.

MOLECULAR LINE SURVEY OF ORION KLEINMANN-LOW

GEOFFREY A. BLAKE,[1] L. G. MUNDY,[2] J. E. CARLSTROM,[3]
S. PADIN,[3] S. L. SCOTT,[4] N. Z. SCOVILLE,[3] AND D. P. WOODY[4]
Ap. J. **472**, L49 (1996)



Interesting Ions Observed

H_3^+ Protonating species √

Direct Test of Model

He^+ Enhances C^+ production

HCO^+ Major Ion, √

$HCNH^+$ Source of HNC,HCN √

$HOCO^+$\{CO_2 \}, HN_2^+\{N_2 \}√

\{$C_3H_3^+$\} Source C_3H_2,C_3H

H_3O^+ hot OH, H_2O √

H_2D^+, HD_2^+ Major √

Deuterating species

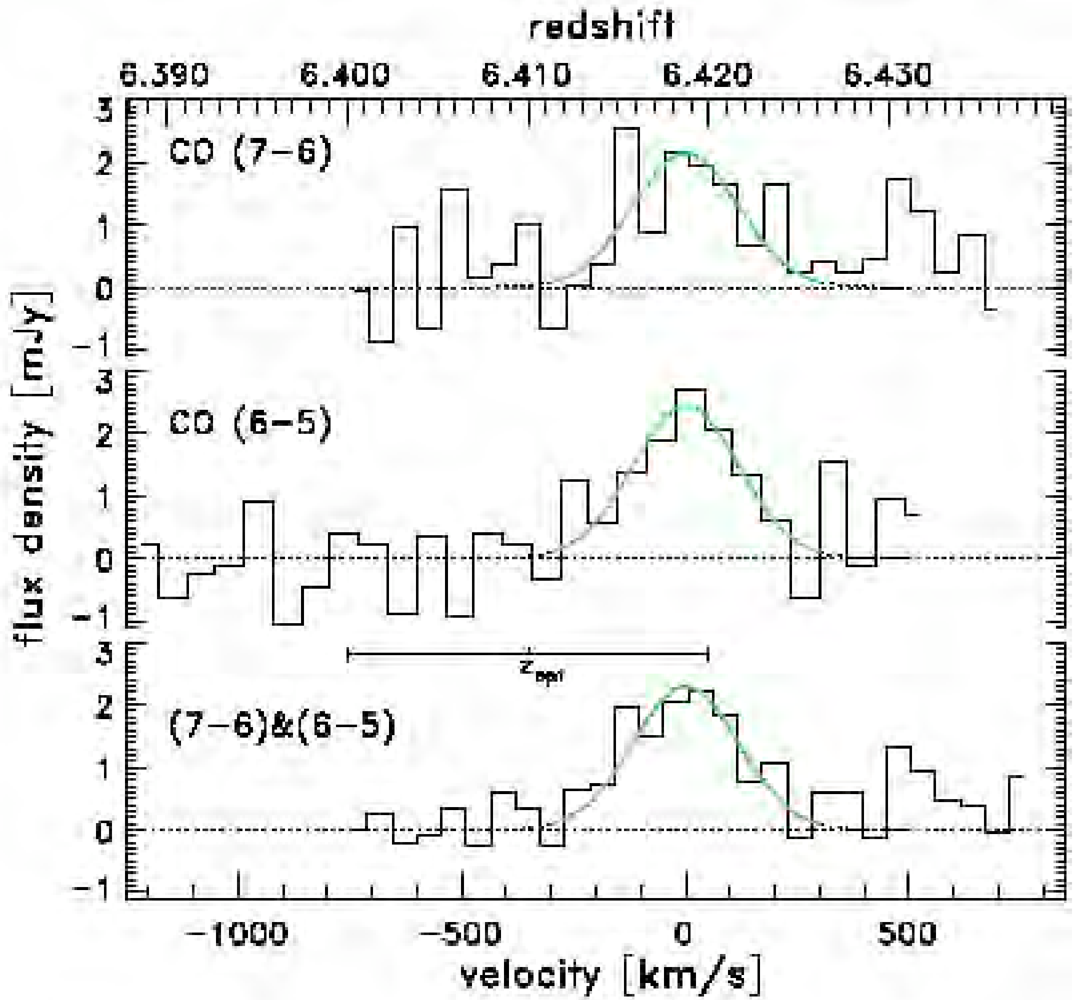
Molecules from Other Galaxies

CO	HCN	HNC	CH	CN
NH_3	**HCO^+**	N_2H^+	C_3H_2	
CH_3OH	C_2H	OCS	H_2CO	
OH	H_2O	SiO	SO	
HCCCN	HNCO	CH_3CCH	CH_3CN	

Phil Solomon

High-excitation CO in a quasar host galaxy at $z = 6.42$ *

F. Bertoldi[1], P. Cox[2], R. Neri[3], C.L. Carilli[4], F. Walter[4], A. Omont[5], A. Beelen[2], C. Henkel[1], X. Fan[6], Michael A. Strauss[7], K.M. Menten[1]



93.206GHz

Fig. 1. J1148+5251 spectra of CO (6→5), (7→6), ar

Interstellar van der Waals Molecules ??

Carrying Along the Third Body

HCO^+ The most abundant ion

$HCO^+ + H_2 = HCO^+\text{-}H_2 + h\nu$ $k = 10^{-18}$

$CO + HCO^+\text{-}H_2 = OC\text{-}HCO^+ + H_2$

$OC\text{-}HCO^+ + H = H_2CO^+ + CO$

$H_2CO^+ + H_2 = H_2COH^+ + H$

$H_2COH^+ + e^- = H_2CO + H$

A gas phase synthesis of Formaldehyde

DETECTION OF TRIPLY DEUTERATED AMMONIA IN THE BARNARD 1 CLOUD

D. C. Lis, E. Roueff, M. Gerin, T. G. Phillips, L. H. Coudert, F. F. S. van der Tak, and P. Schilke

$ND_3/NH_3 \approx 8 \times 10^{-4}$ Observed

$HD/H_2 = 10^{-5}$ Cosmic Abundance Ratio

The observed abundance ratios can be explained in the framework of gas-phase chemical models,

The Astrophysical Journal, **571**:L55–L58, 2002

LABORATORY SUBMILLIMETER-WAVE DETECTION OF D2H : A NEW PROBE INTO MULTIPLE DEUTERATION?

T. Hirao and T. Amano Received 2003 September 4; accepted 2003 September 17; published 2003 October 9 A pure rotational transition ( ) of D2H is measured 691.660440(19) GHz This accurately measured transition frequency should be of great use for astronomical identification of this ion.

DETECTION OF D2H IN THE DENSE INTERSTELLAR MEDIUM

C. Vastel and T. G. Phillips Downs, H. Yoshida, Received 2004 February 26; accepted 2004 March 23; published 2004 April 9 The 692 GHz para ground-state line of D2H toward the prestellar core 16293E. The derived D2H abundance is comparable to that of H 2D , as determined by observations of the 372 GHz line of ortho-H2D .

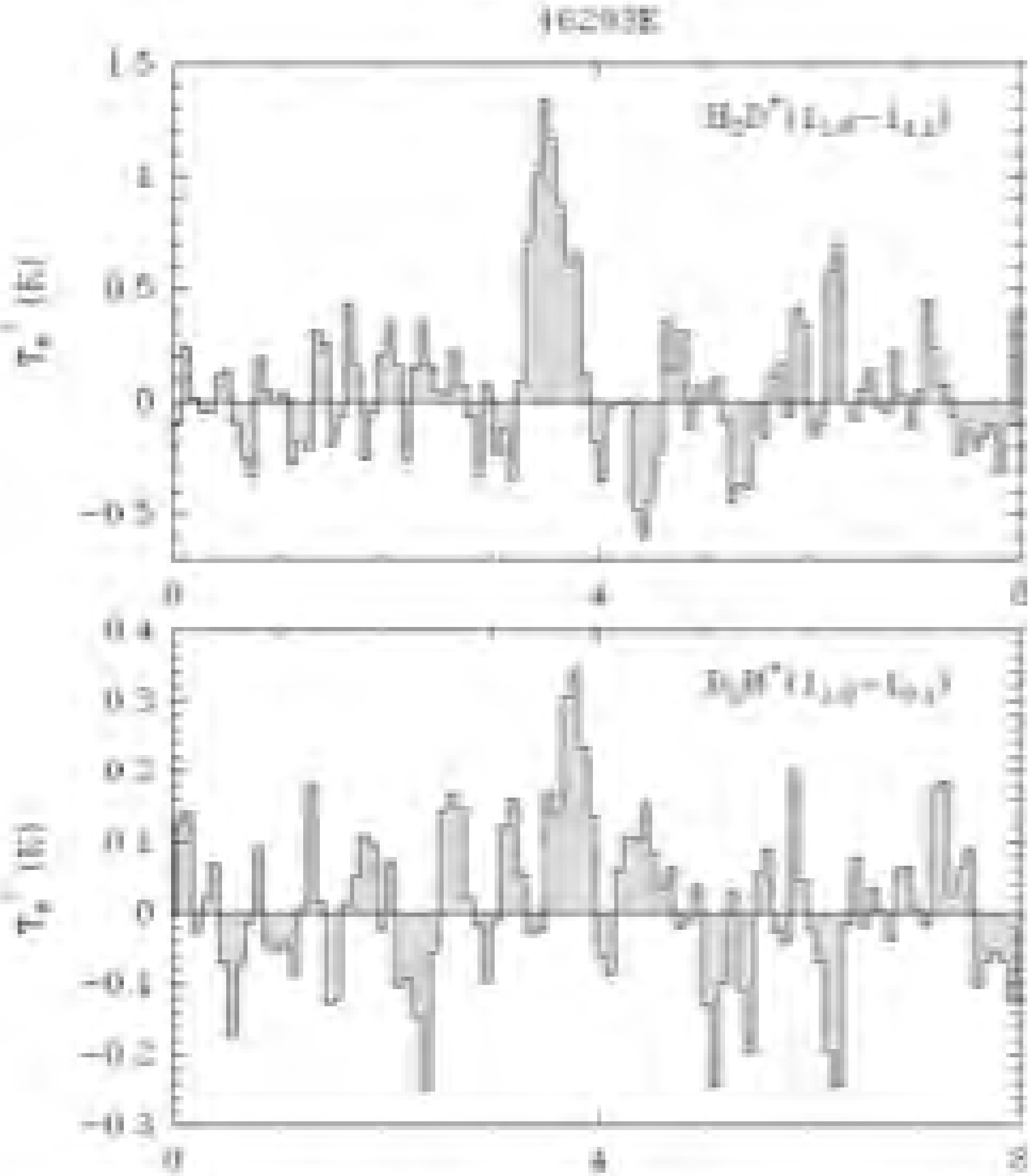


FIG. 3.—Spectra of the ortho-H_2D^+ 1_{10}–1_{11} and para-D_2H^+ 1_{10}–1_{01} transitions toward 16293E.

Abundance of the Elements

	Cosmic	%[a]
C	100	20.1
N	30.9	6.2
O	235	47.4
F	0.01	0.002
Ne	91	18.3
Na	0.6	0.12
Mg	10.6	2.1
Al	0.8	0.15
Si	9.9	2.4
Fe	8.9	2.2

Oxygen problem

H_2O /CO = 10^{-4}

SWAS Observation of Cold Molecular Clouds

O_2 unobserved O_2 /CO <10^{-3} SWAS , Odin

CO_2 nonpolar but observable as $HOCO^+$
Very low abundance.

Cosmic abundances		Oxygen in solid form	
C	100		
N	30.9		
O	235.6		
Na	0.6		
Mg	10.6	$MgCO_3 \cdot H_2O$	42
Al	0.8	Al_2O_3	1
Si	9.9	$Si(OH)_4$	40
S	5.1	$H_2SO_4 \cdot H_2O$	25
Fe	8.9	Fe_2O_3	13

	Orion	Orion		
Log N/[nH_2]	Ridge	Hot Core	TMC1	L183
T/K	40	200	10	10
H_2 cm^{-3}	10^6	^7	^4	^4
N[CO] cm^{-2}	8x10^18		8x10^17	7x10^17
Log[CO/H_2]	-4	-4	-4	-4
Log[SiO/H_2]	-9.3	-6.7	<-11.6	<-11.4
SO	-8.7		-8.3	-7.7
SO_2	-8.4		<-9	-8.5
CS	-8.4	<-9.5	-8.0	-9.1
H_2S	-8.7	-5.3	<-9.3	-8.5
HCN	-8.0	-6.0	(-8.0)	-8.4
HNC	-8.6	(-7.9)	-7.3	-8.2
HCO+	-8.5	<-9.5	-8.1	8.1
NH_3	-7.5	-6.2	-7.4	-6.9
H_2CO	-7.5	-7.6	-7.7	-7.7

C.M.Walmsley J.Chem.Soc.Faraday Trans. **89**,2113 (1993)


Orion KL
CISCO (H2 (v=1-0 S(1)) – Cont)

J. Phys. Chem. 1993, 97, 7351–7358

Physical Chemistry of the H_2SO_4/H_2O Binary System at Low Temperatures: Stratospheric Implications

Renyi Zhang, Paul J. Wooldridge, Jonathan P. D. Abbatt,† and Mario J. Molina*

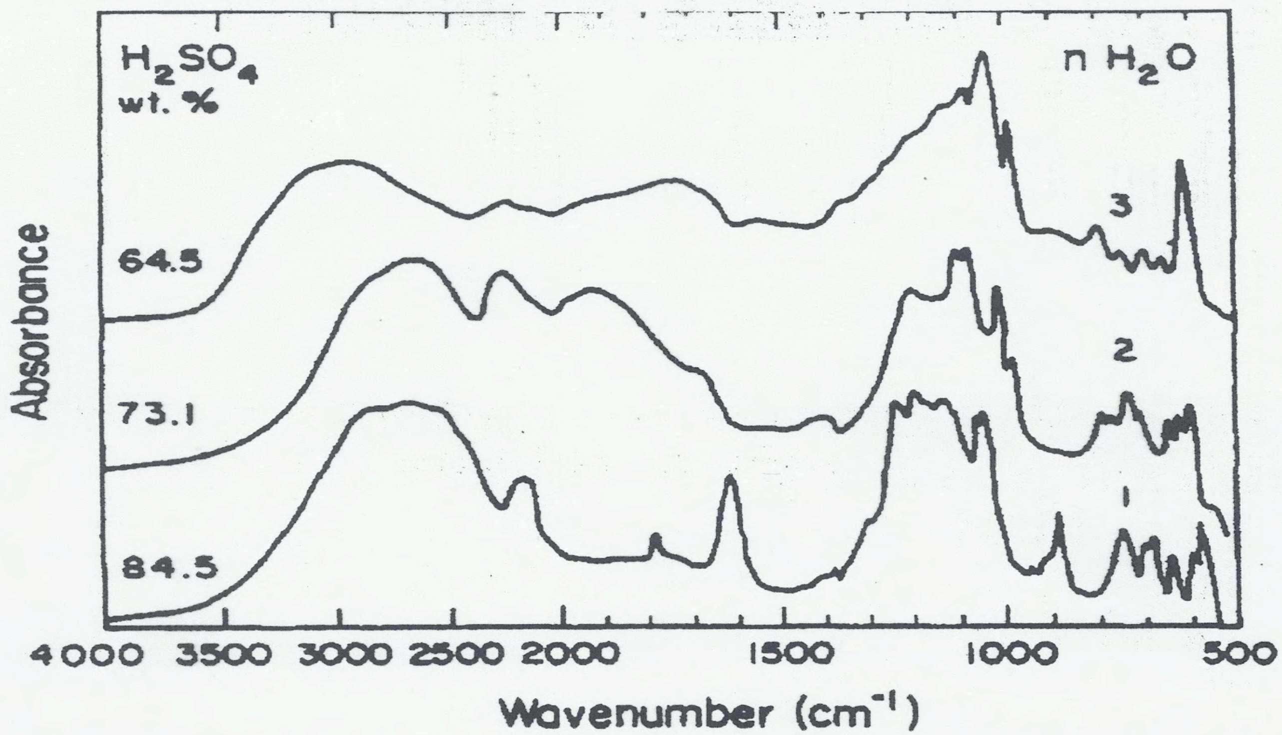


Figure 8. Spectra of crystalline hydrates $H_2SO_4{\cdot}nH_2O$. For $n = 1, 2,$ and 3 the spectra are presented at low temperatures (~140 K), showing sharper absorption bands.

Mon. Not. R. Astron. Soc. 341, 657–661 (2003)

Hydrated sulphuric acid in dense molecular clouds

Flavio Scappini,[1] Cesare Cecchi-Pestellini,[2]* Harvey Smith,[3]
William Klemperer[3] and Alexander Dalgarno[2]

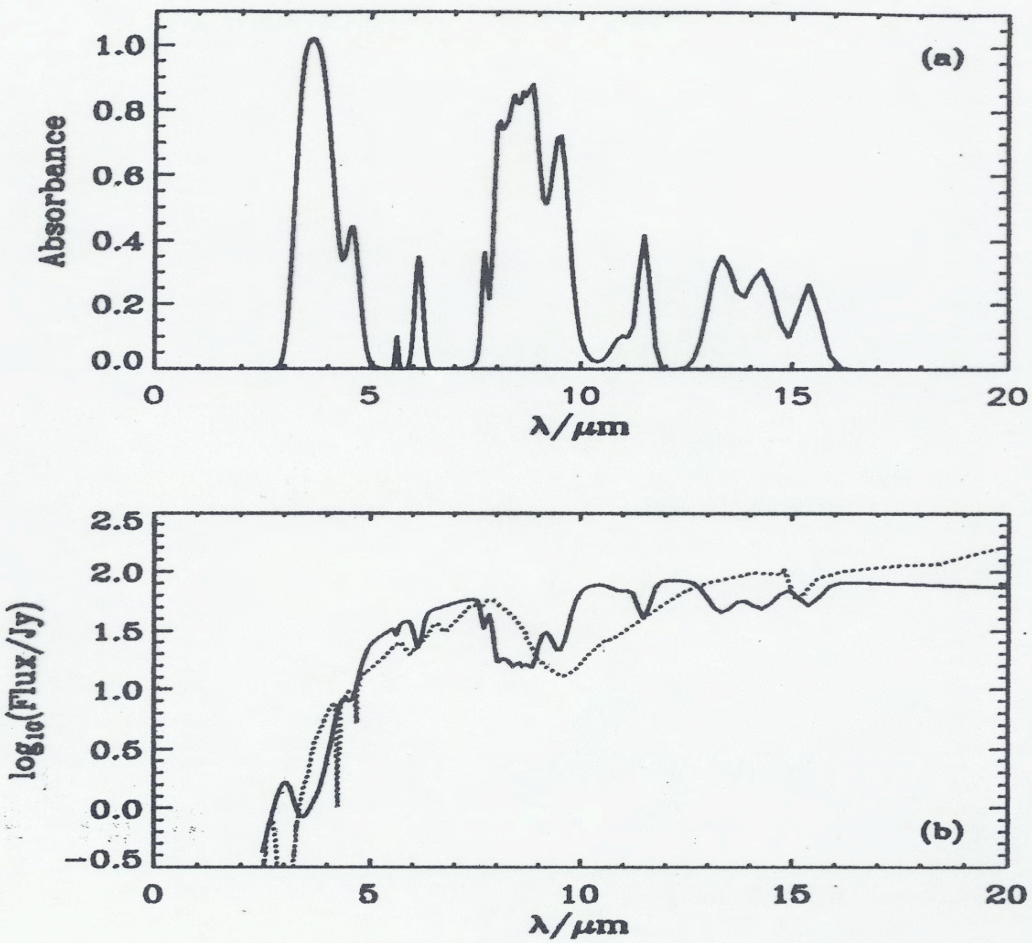


Figure 1. (a) Syinthesized laboratory spectrum of $H_2SO_4 \cdot H_2O$. The absorption coefficient is the sum of 18 gaussian components. (b) Synthesized interstellar spectrum of NGC 7538: IRS9 using the absorption coefficient from above. The flux (Jy) is that of a 700 K blackbody reduced by one power in frequency due to scattering. Dotted line represents a fit to the observational data of Whittet et al. (1996)

$HCO^+ + H_2 = H_2$-- HCO^+ 3.9kCal/m 1370cm^{-1}

Infrared Spectrum B_0= 14605.9(±11)MHz ∏ o-H_2

B_0= 14578.9(±16)MHz ∑ p-H_2

Bieske, Nizkorodov, Bennett,Maier J.Chem Phys. **102**, 5152 (1995)

$HCO^+ + CO = OC$- HCO^+ 14kcal/m 4900cm^{-1}

O—C----------H—C—O $\square_{CH} \approx$ 2700cm^{-1}

| 2.919Å |

O—C-------H-------C—O ΔE = 1100 cm^{-1}

B_e=1906 MHz

The UMIST Database for Astrochemistry 1999

Y.H. Le Teuff, T.J. Millar & A.J. Markwick

Astronomy & Astrophysics Supplement Series, 146, 157, 2000.

http://www.rate99.co.uk/

> 4000 Reaction Rates