

" There's life Jim....but we
don't KNOW it (yet): a
journey through the chemically
controlled cosmos from star
birth to the formation of life"

30th May 2007, Stockholm Observatory
with support from the 'kvinnliga gästföreläsare' programme



Collapsing
cores

Star
Formation



Pre-stellar
cores

Credit: FORS team 8.2 m VLT ANTU, ESO

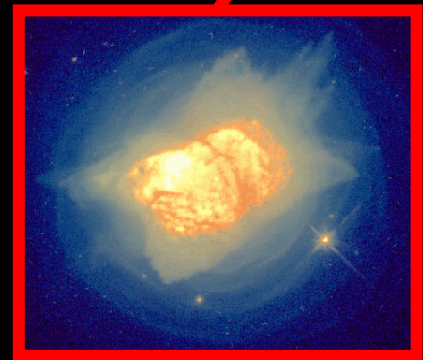
ISM

= 99% by mass GAS
(H / H₂ / He)
& 1 % DUST
(Si / C + Mg, Fe, Al, Na, K)

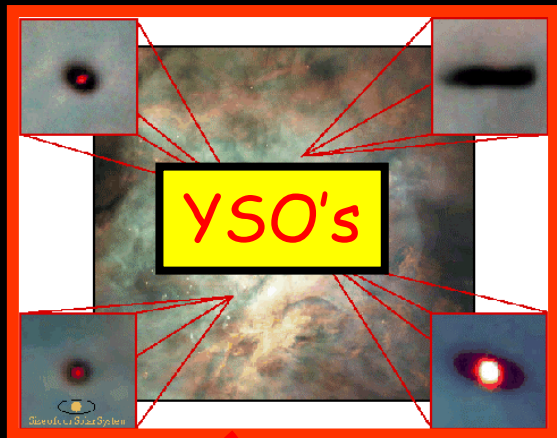


Back to cold
dark space....

Refuelling the
Interstellar
medium.



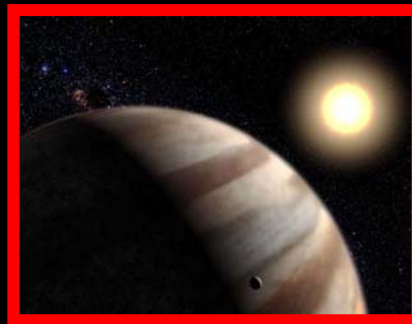
Star
Death



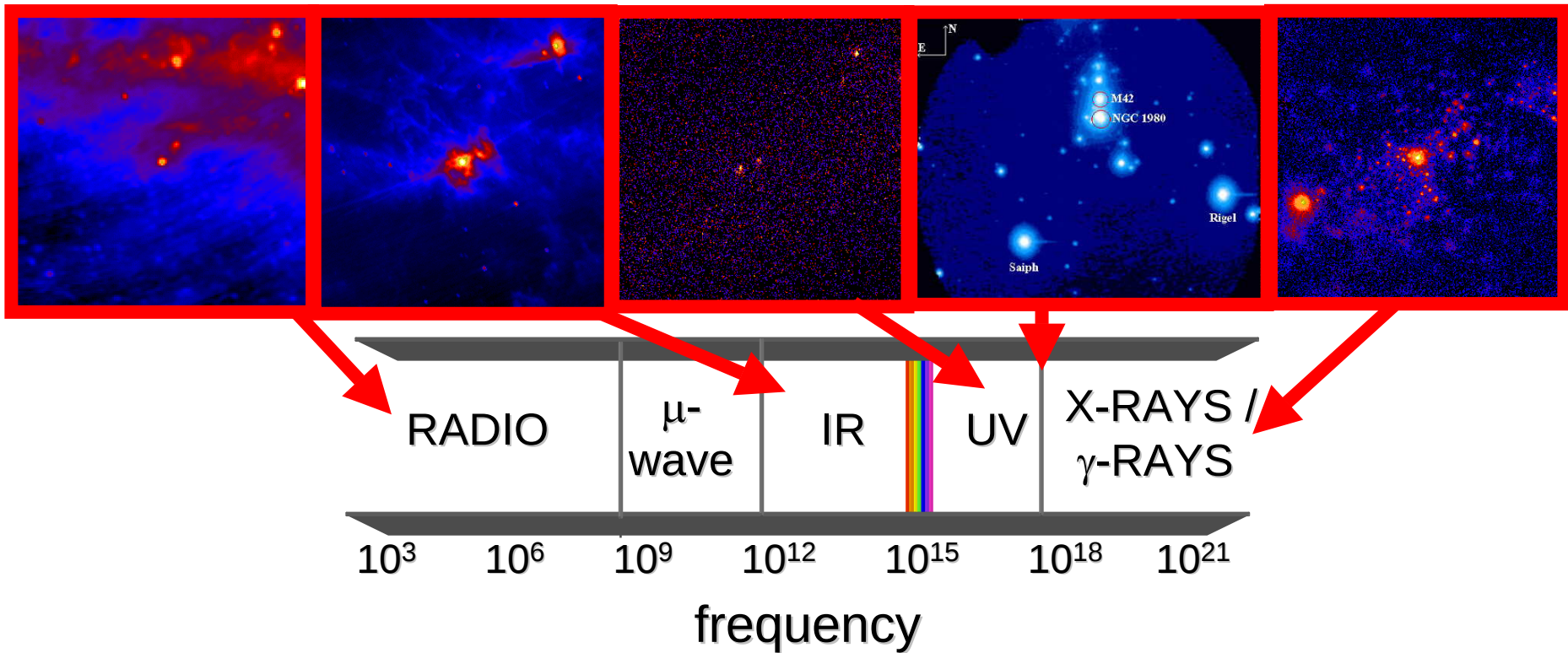
YSO's

Planet
Formation

Formation
of life



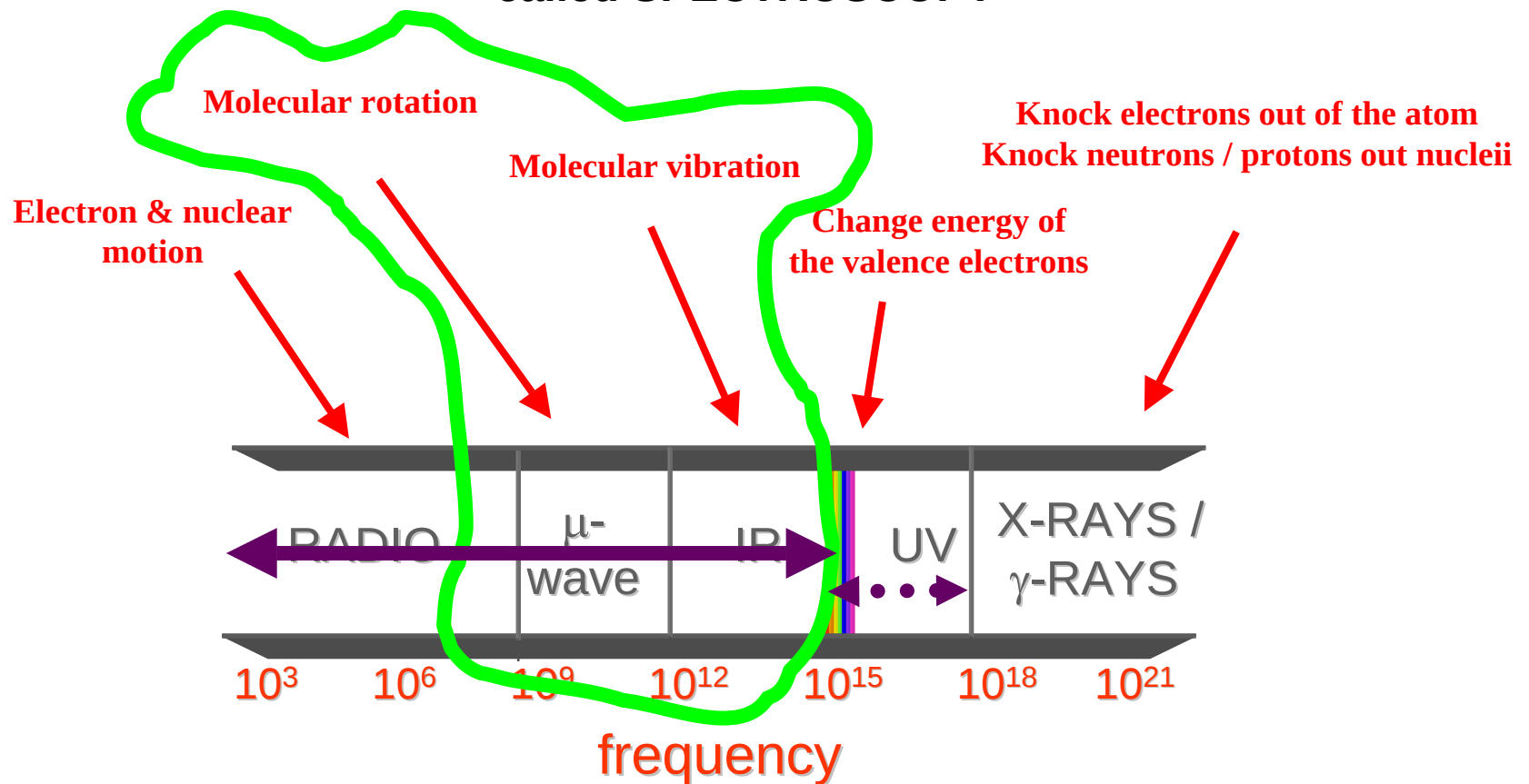
The Electromagnetic Spectrum



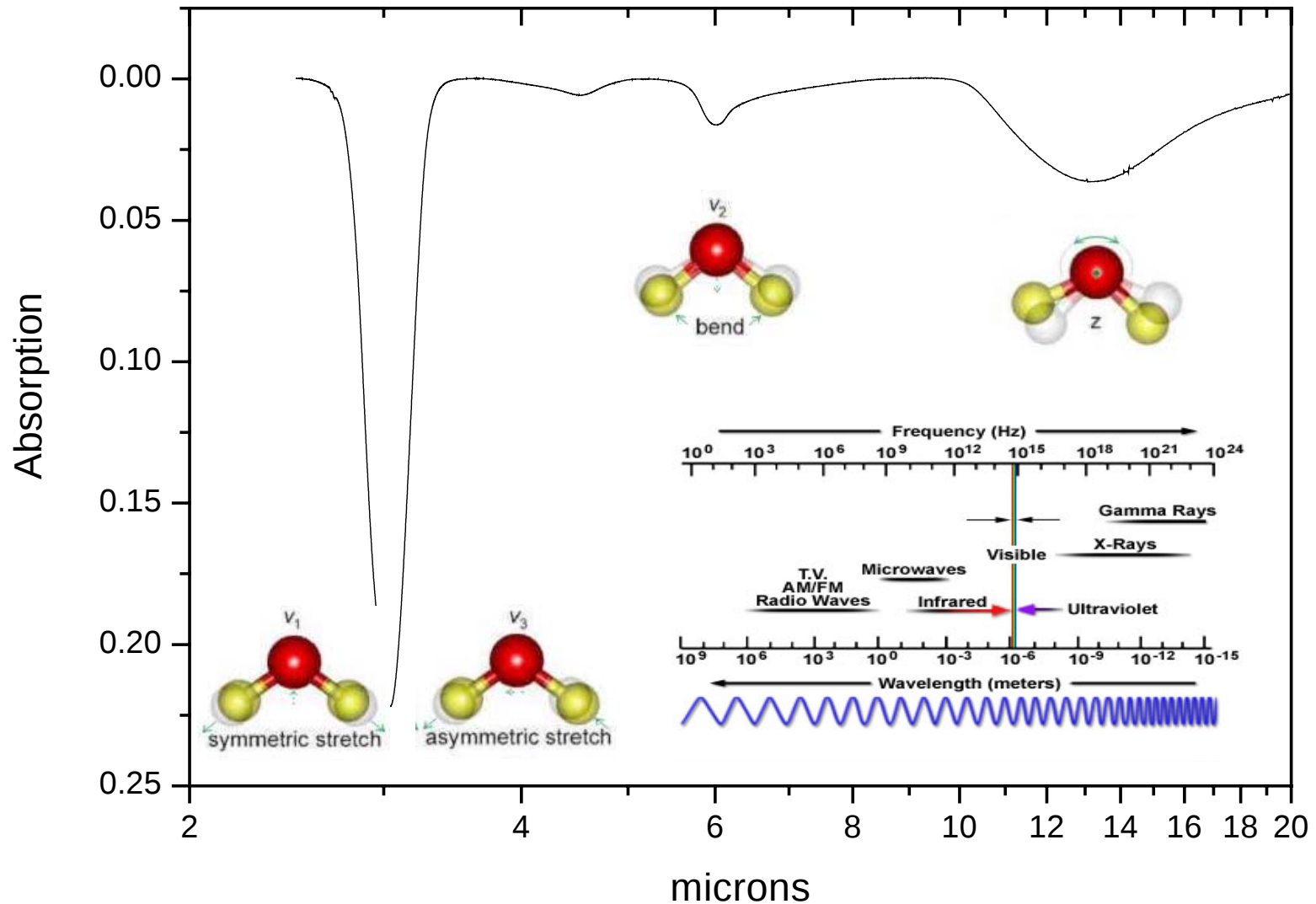
**In each part of the electromagnetic spectrum
we 'see' objects differently**

Molecular Motion

Study of how molecules absorb and emit EM radiation (like light)
called SPECTROSCOPY



An INFRARED WATER SPECTRUM



IR observations of a molecular cloud with cold (10 K) dust

IR continuum source
dust heated by star
(500-1000 K)

Background star

Embedded object

Clouds of cold
ice and dust

Infrared light
(IR)

ISO

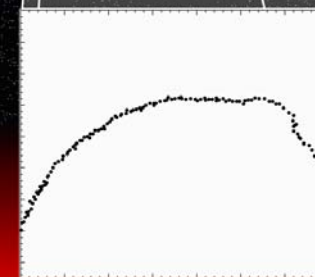
Akari //
Spitzer

SOFIA

IRTF



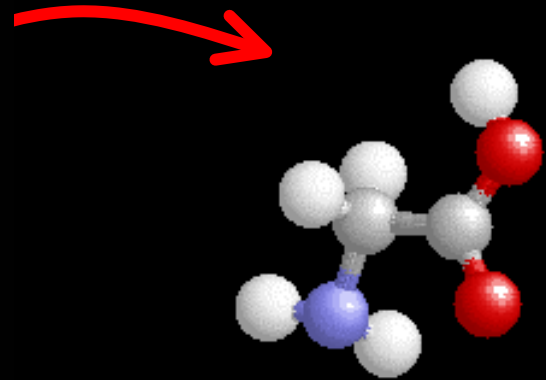
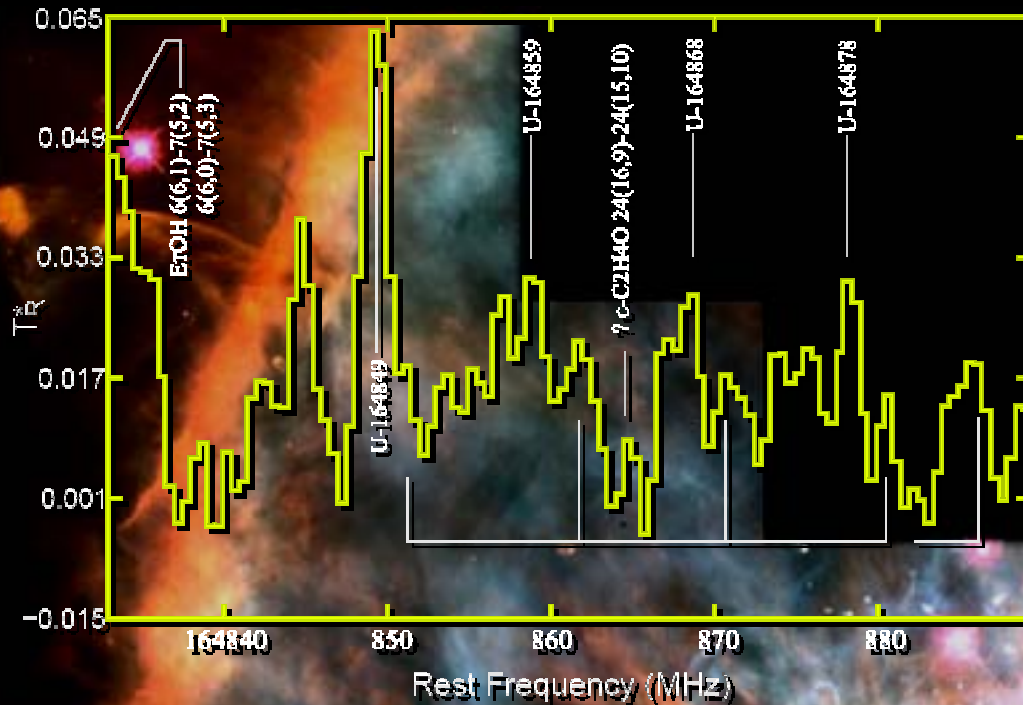
IR absorption
spectrum



IR "Black Body"
continuum

Infrared observatories

Complex molecules such as amino acids (the building blocks of life), have also been found in space

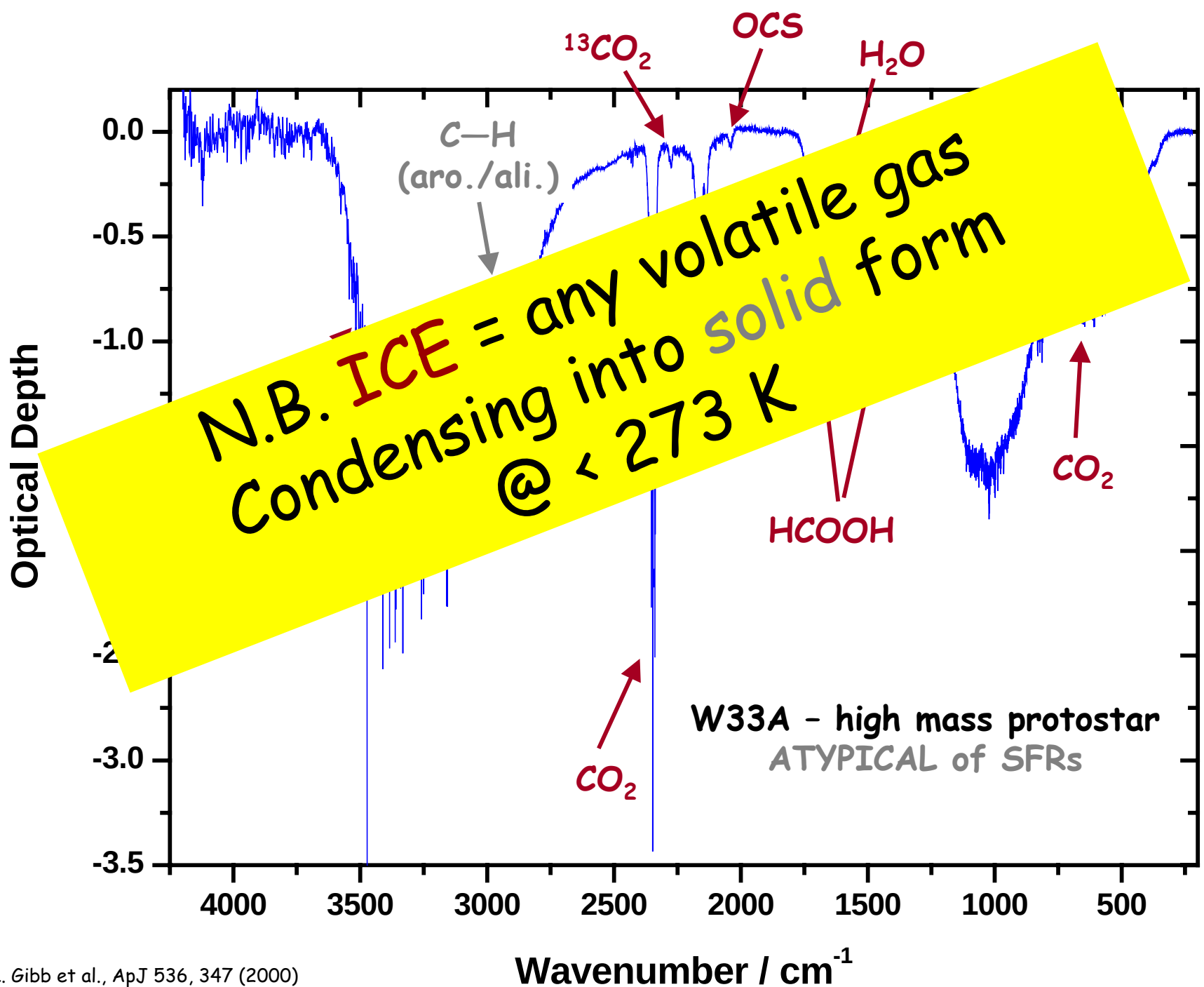


glycine
in Orion!

Radio = large molecules
Permanent dipoles

Credit: Y.-J. Kuan, S.B. Charnley, H.-C. Huang,
W.-L. Tseng, Z. Kisiel, *Astrophys J.* **593**, 848 (2003)

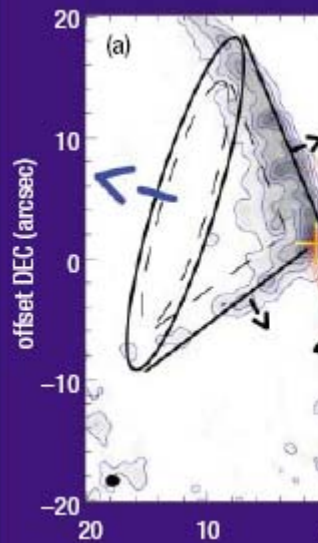
Credit: C.R. O'Dell/Rice University, NASA.



Astrobiologists ask...

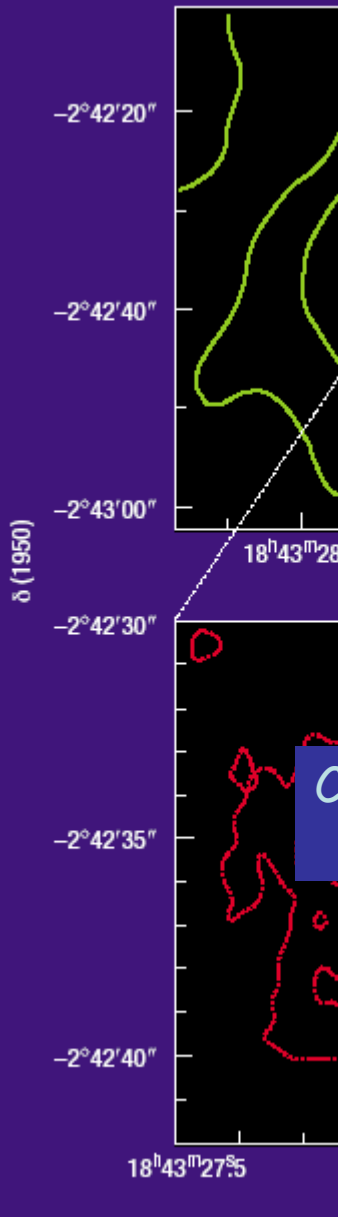
Whether there is life elsewhere in
our universe...

(by concentrating (right now) on
finding suitable habitable zones,
exoplanets, prebiotic molecules &
using solar system as lab)



6: An overview of the outflow
(a) Integrated ^{12}CO $J=2\rightarrow 1$ emission map showing molecular outflow cones. The beam size is 0.9 Jy km s^{-1} per beam for the ^{12}CO emission. The blue and black arrows denote red- and blue-shifted emission, respectively, indicated by the short black arrows.
(b) The central low-velocity CO emission map showing the central low-velocity CO emission contour and contour interval of 30 mJy per beam , as the thickness varies from 850 AU to 1000 AU. The continuum emission which traces the central star has a contour interval of 5 mJy per beam. Reproduced by permission from Cambridge University Press and Cambridge Magazines Ltd.

OUTFLOWS & DYNAMICS



8: The spatial separation of 440 pc between parent and daughter molecules in circumstellar envelopes of cool stars. These are emission maps of the circumstellar envelope around the C-star CIT6 for the parent molecule HCN ($J=1\rightarrow 0$) on the left, and the daughter molecule CN ($N=1\rightarrow 0$) on the right. The maps show that HCN is concentrated in the photosphere of the central star, whereas CN (the photodissociation product of HCN) is concentrated in a shell around the star. Reproduced by permission of A&A from Lindqvist *et al.* 2000.

Correlations between parent & daughter molecules Indicator of chemical reactions

Russell, © 2000 The Arizona Board of Regents.

Gas Phase Abundance Plots
Tracer of Gas $T / \rho //$
physical processes

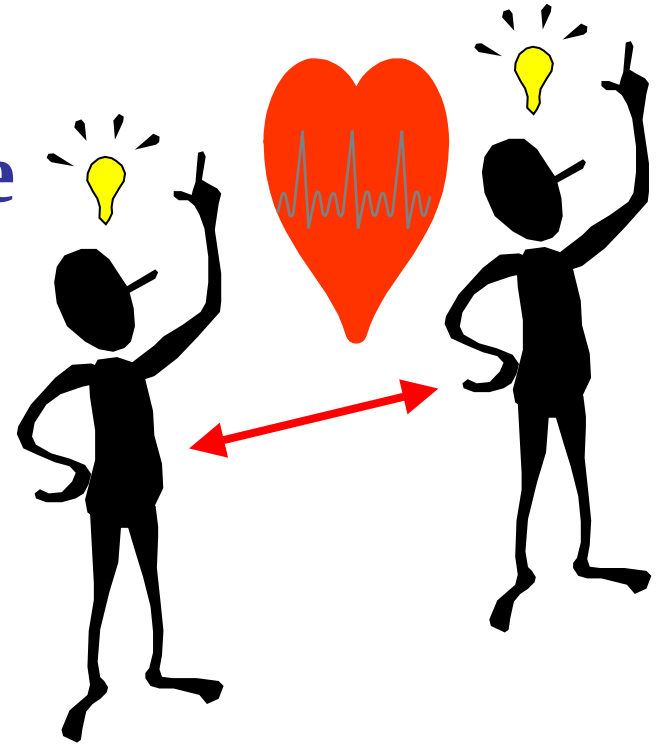
How does
CHEMISTRY
happen?

•THERMODYNAMICS

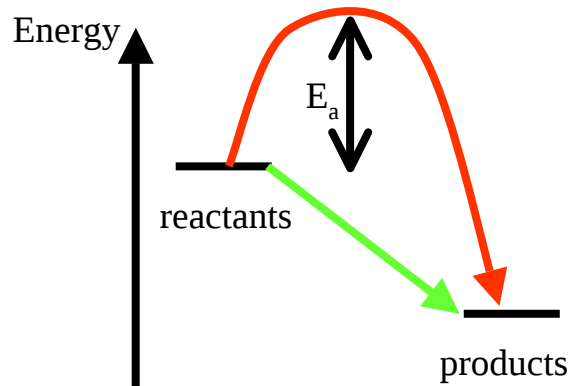
we need enough energy for the reactants to form products

•KINETICS

We have many millions of years in space but we need the reactions to occur within the lifetime of the astronomical object



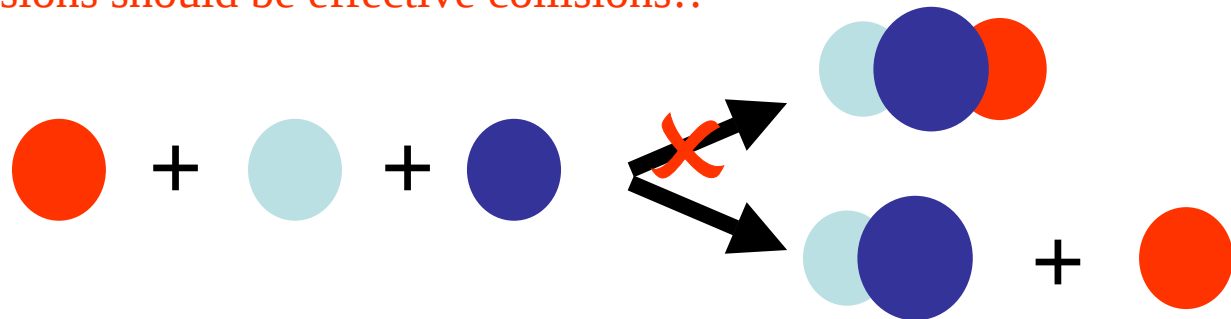
- T too low to overcome activation energy barrier



$T = 10 - 200 \text{ K}$

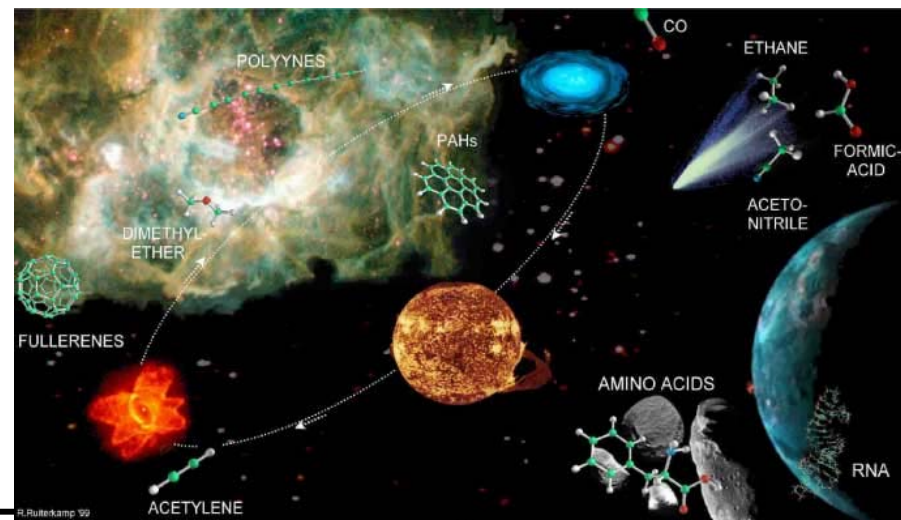
‘No barrier chemistry’

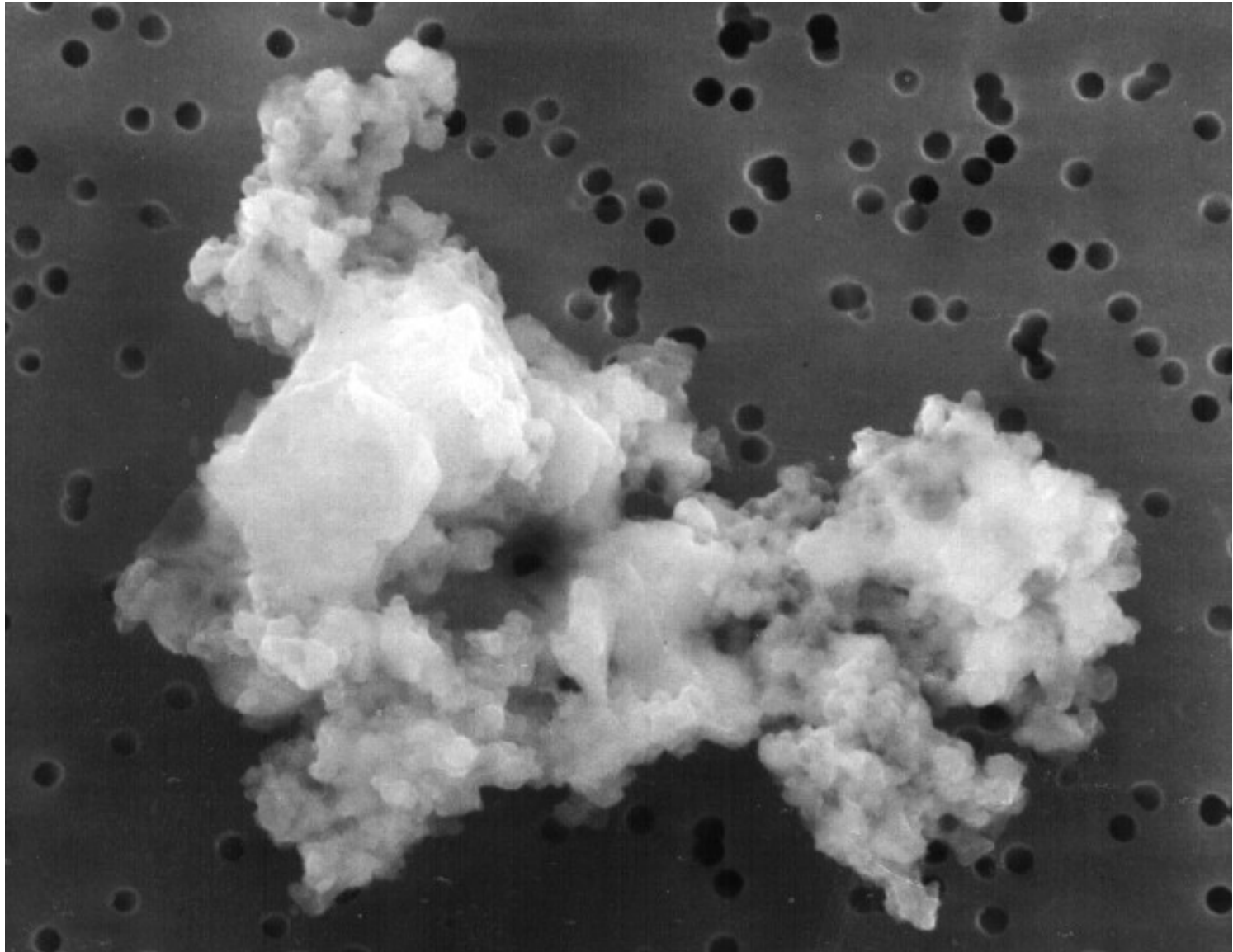
- Molecular density so low that 3 body collisions are rare ($10^{6 \text{ (max)}}$ vs. $10^{21} \text{ molecules cm}^{-3}$)
 - ‘all’ collisions should be effective collisions!!



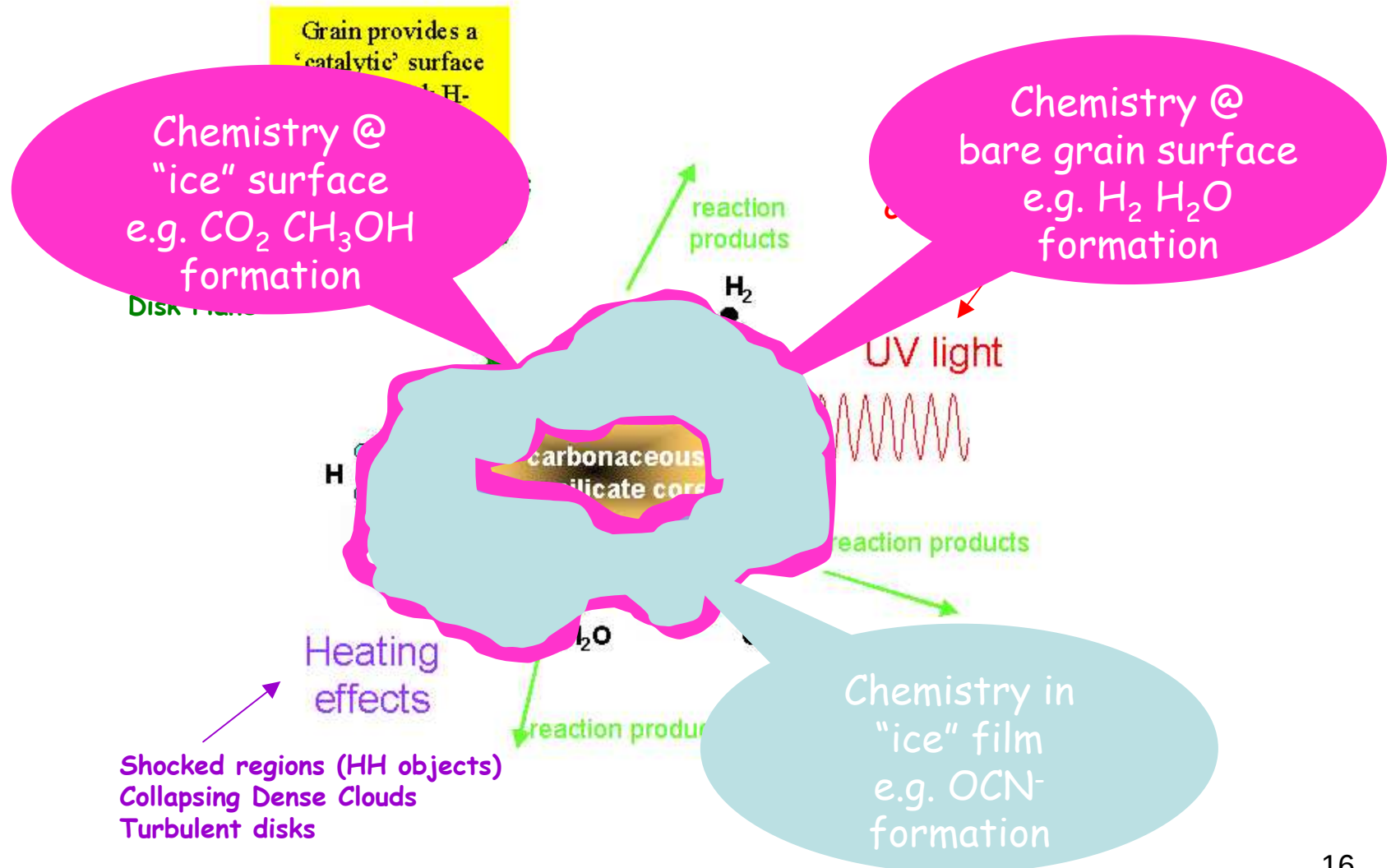
2	3	4	5	6	7	8	9+
H ₂	C ₃	c-C ₃ H	C ₅	C ₅ H	C ₆ H	CH ₃ C ₃ N	CH ₃ C ₄ H
AlF	C ₂ H	I-C ₃ H	C ₄ H	I-H ₂ C ₄	CH ₂ CHCN	HCOOCH ₃	CH ₃ CH ₂ CN
AlCl	C ₂ O	C ₃ N	C ₄ Si	C ₂ H ₄	CH ₃ C ₂ H	CH ₃ COOH	(CH ₃) ₂ O
C ₂	C ₂ S	C ₃ O	I-C ₃ H ₂	CH ₃ CN	HC ₅ N	C ₇ H	CH ₃ CH ₂ OH
CH	CH ₂	C ₃ S	c-C ₃ H ₂	CH ₃ NC	HCOCH ₃	CH ₂ OHCHO	HC ₇ N C ₈ H
CH ⁺	HCN	C ₂ H ₂	CH ₂ CN	CH ₃ OH	NH ₂ CH ₃		CH ₃ C ₅ N
CN	HCO	CH ₂ D ⁺	CH ₄	CH ₃ SH	c-C ₂ H ₄ O		(CH ₃) ₂ CO
CO	HCO ⁺	HCCN	HC ₃ N	HC ₃ NH ⁺	CH ₂ CHOH		NH ₂ CH ₂ COO
CO ⁺	HCS ⁺	HCNH ⁺	HC ₂ NC	HC ₂ CHO			H? HC ₉ N
CP	HOC ⁺	HNCO	HCOOH	NH ₂ CHO			HC ₁₁ N
CSi	H ₂ O	HNCS	H ₂ CHN	C ₅ N			
HCl	H ₂ S	HOCO ⁺	H ₂ C ₂ O				
KCl	HNC	H ₂ CO	H ₂ NCN				
NH	HNO	H ₂ CN	HNC ₃				
NO	MgCN	H ₂ CS	SiH ₄				
NS	MgNC	H ₃ O ⁺	H ₂ COH ⁺				
NaCl	N ₂ H ⁺	NH ₃					
OH	N ₂ O	SiC ₃					
PN	NaCN						
SO	OCS						
SO ⁺	SO ₂						
SiN	c-SiC ₂						
SiO	CO ₂						

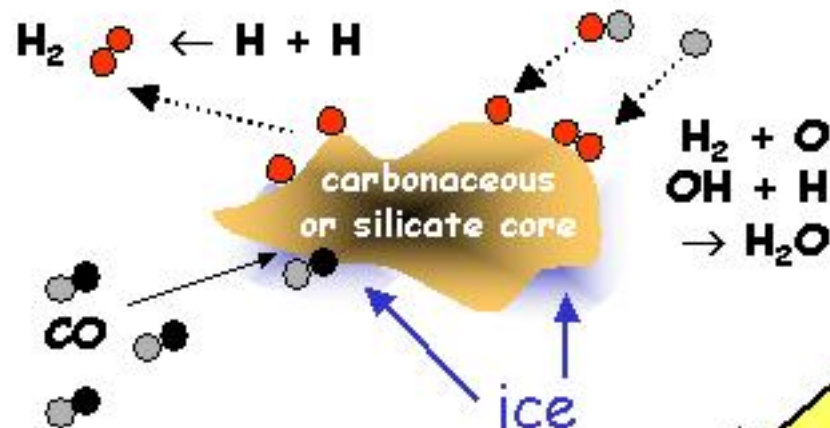
List of Detected Cosmic Molecules in Interstellar and Circumstellar Environments.





Solid-State Chemistry of Star-Forming Regions





Forming interstellar ice:

Atoms and molecules stick onto the cold dust, reacting to form H_2 and H_2O or freezing to form "solids".

An ICY GRAIN of INTERSTELLAR DUST:

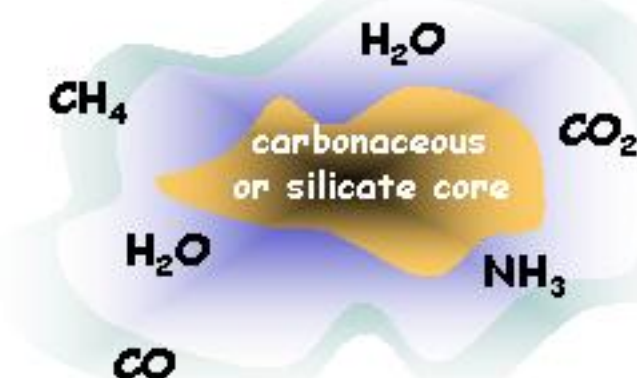
A 'crust' of ice entirely covers the dust. Dominated by H_2O , the ice contains many different chemicals - the least volatile molecules in the top layers.

...after some time



Processing interstellar ice:

Atoms and molecules react at the ice surface to form new, more complex molecules. UV photons and electrons from cosmic rays also "kick start" chemical reactions in the ice. When the ice is heated, many molecules are desorbed.



Key to
large molecule
formation
=
ICE & DUST

Surface Science

Surface Science paints a picture of gas-grain interactions on an atomic level

How might surface reactions lead to complex molecules?

Solid-State Astrochemistry



Astronomy

small grains

$P < 10^{-10} - 10^{-15}$ mbar
(dominated by H₂ then CO)

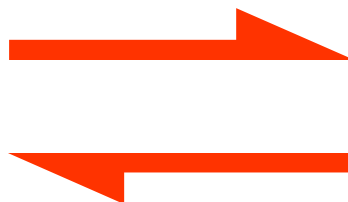
$T_{\text{grain}} = 10 - 300$ K

$T_{\text{gas}} = 10 - 1000$ K

1 Lyman α / Lyman-Werner band UV photon
per 10⁶ years per grain

1 atom / molecule - grain collision per 10⁴ years

1 X-Ray / CR 'direct hit' per 10⁵ years



Surface Science

To date = flat surfaces

$P < 10^{-10}$ mbar
(also dominated by H₂ then CO)

$T_{\text{grain}} = 10 - 450$ K

$T_{\text{gas}} = 100 - 300$ K

1 Lyman α / Lyman-Werner band UV photon
per molecule per second!! (≈ 5 sec $\cong$ ISM)

@ 1 L (Langmuir) dose = 10¹⁵ molec cm⁻² s⁻¹

1 X-Ray / CR ✗

S
gas

D

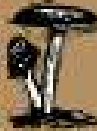
CR

robi

J F

Fraser & V

From molecules to life...



A PERIODIC TABLE OF THE ELEMENTS FOR BIOLOGY



H
Hydrogen
1.01

He
Helium
4.00

Li
Lithium
6.94

Be
Beryllium
9.01

Ne
Neon
20.18

Na
Sodium
22.99

Mg
Magnesium
24.31

Ar
Argon
39.95

K
Potassium
39.10

Ca
Calcium
40.08

Sc
Scandium
44.96

Ti
Titanium
47.88

V
Vanadium
50.94

Cr
Chromium
52.00

Mn
Manganese
54.94

Fe
Iron
55.85

Co
Cobalt
58.93

Ni
Nickel
58.69

Cu
Copper
63.55

Zn
Zinc
65.38

Ga
Gallium
69.72

Ge
Germanium
72.64

As
Arsenic
74.92

Se
Selenium
78.96

Br
Bromine
79.90

Kr
Krypton
83.80

Rb
Rubidium
85.47

Sr
Strontium
87.62

Y
Yttrium
88.91

Zr
Zirconium
91.22

Nb
Niobium
92.91

Mo
Molybdenum
95.94

Tc
Technetium
98.91

Ru
Ruthenium
101.07

Rh
Rhodium
102.91

Pd
Palladium
106.37

Ag
Silver
107.87

Cd
Cadmium
112.41

In
Indium
114.82

Sn
Tin
118.71

Sb
Antimony
121.76

Te
Tellurium
127.60

I
Iodine
126.91

Xe
Xenon
131.29

Cs
Cesium
132.91

Ba
Barium
137.33

La
Lanthanum
138.91

Hf
Hafnium
178.49

Ta
Tantalum
180.95

W
Tungsten
183.84

Re
Rhenium
186.21

Os
Osmium
190.23

Ir
Iridium
192.22

Pt
Platinum
195.08

Au
Gold
196.97

Hg
Mercury
200.59

Tl
Thallium
204.38

Pb
Lead
207.2

Bi
Bismuth
208.98

Po
Polonium
209

At
Astatine
210

Rn
Radon
222

Fr
Francium
223

Ra
Radium
226

Ac
Actinium
227

La
Lanthanum
138.91

Ce
Cerium
140.12

Pr
Praseodymium
140.91

Nd
Neodymium
144.24

Pm
Promethium
145

Sm
Samarium
150.36

Eu
Europium
151.96

Gd
Gadolinium
157.25

Tb
Terbium
158.93

Dy
Dysprosium
162.50

Ho
Holmium
164.93

Er
Erbium
167.26

Tm
Thulium
168.93

Yb
Ytterbium
173.05

Lu
Lutetium
174.97

Ac
Actinium
227

Th
Thorium
232.04

Pa
Protactinium
231.04

U
Uranium
238.03

Np
Neptunium
237.05

Pu
Plutonium
244

Am
Americium
243

Cm
Curium
247

Bk
Berkelium
247

Cf
Californium
251

Es
Einsteinium
252

Fm
Fermium
257

Md
Mendelevium
258

No
Nobelium
259

Lr
Lawrencium
262

- Legend:**
- Yellow: Non-metals
 - Red: Halogens
 - Green: Chalcogens
 - Blue: Nitrogen
 - Orange: Oxygen
 - Purple: Noble gases
 - Black: Radioactive elements
- Notes:**
1. Elements with atomic numbers greater than 118 are not shown.
 2. Elements with atomic numbers greater than 118 are not shown.
 3. Elements with atomic numbers greater than 118 are not shown.
 4. Elements with atomic numbers greater than 118 are not shown.
 5. Elements with atomic numbers greater than 118 are not shown.
 6. Elements with atomic numbers greater than 118 are not shown.
 7. Elements with atomic numbers greater than 118 are not shown.
 8. Elements with atomic numbers greater than 118 are not shown.
 9. Elements with atomic numbers greater than 118 are not shown.
 10. Elements with atomic numbers greater than 118 are not shown.

Hydrogen is the most abundant element in the universe. It is a colorless, odorless gas that is highly flammable. It is used in the production of ammonia and methanol. It is also used in the hydrogenation of oils and in the production of hydrogen gas.

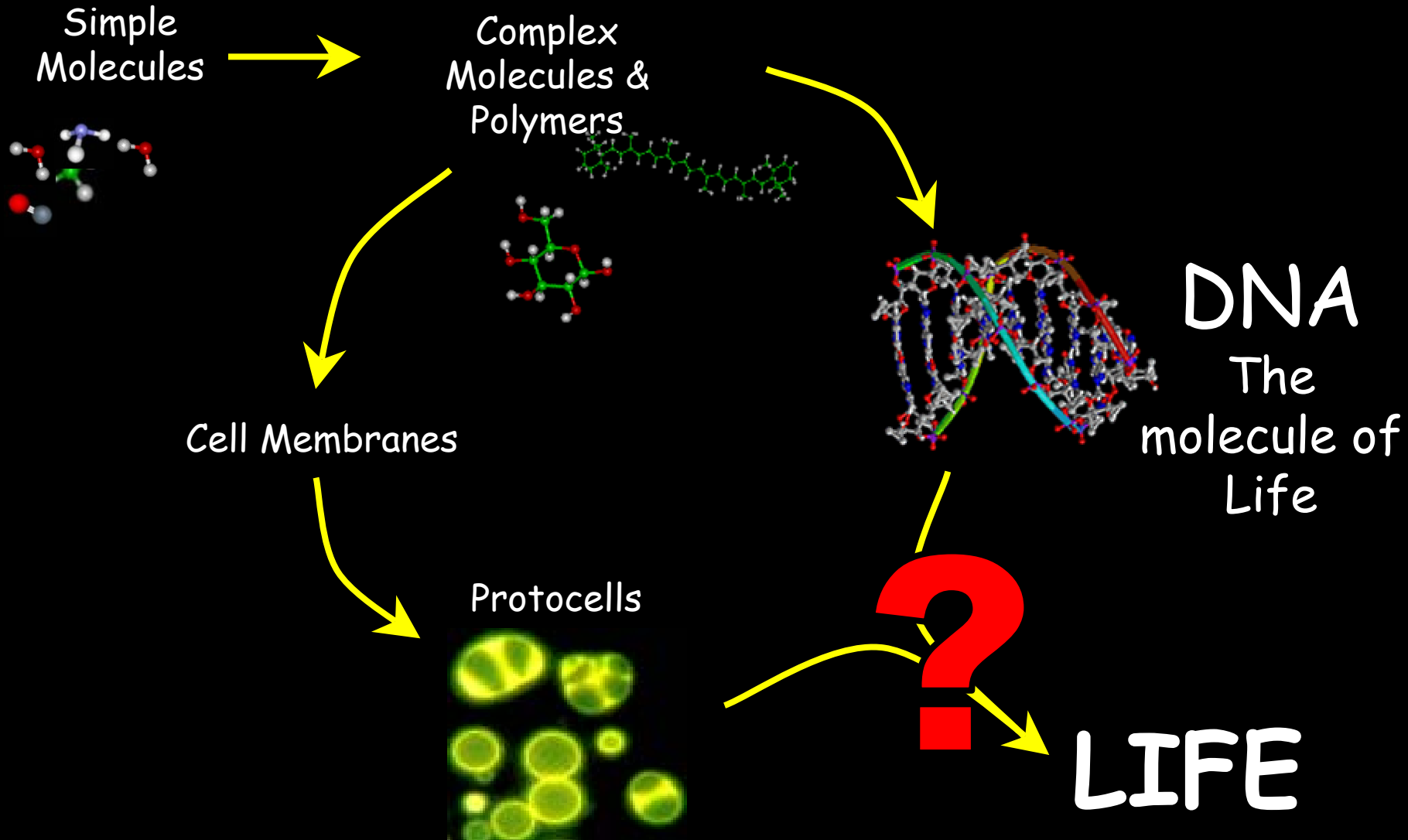
Carbon is the fourth most abundant element in the universe. It is a solid, black, crystalline material that is highly stable. It is used in the production of graphite and diamond. It is also used in the production of carbon fiber and in the production of carbon black.

Oxygen is the second most abundant element in the universe. It is a colorless, odorless gas that is highly flammable. It is used in the production of steel and in the production of oxygen gas. It is also used in the production of oxygenated fuels and in the production of oxygenated liquids.

Nitrogen is the fifth most abundant element in the universe. It is a colorless, odorless gas that is highly flammable. It is used in the production of ammonia and in the production of nitrogen gas. It is also used in the production of nitrogenated fuels and in the production of nitrogenated liquids.



These complex molecules are important for forming the molecules of Life...



So, do we make the building blocks of life in space...
and then transport them to planets?

