" 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"

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with support from the 'kvinnliga gästföreläsare' programme

department of physics at the university of strathclyde

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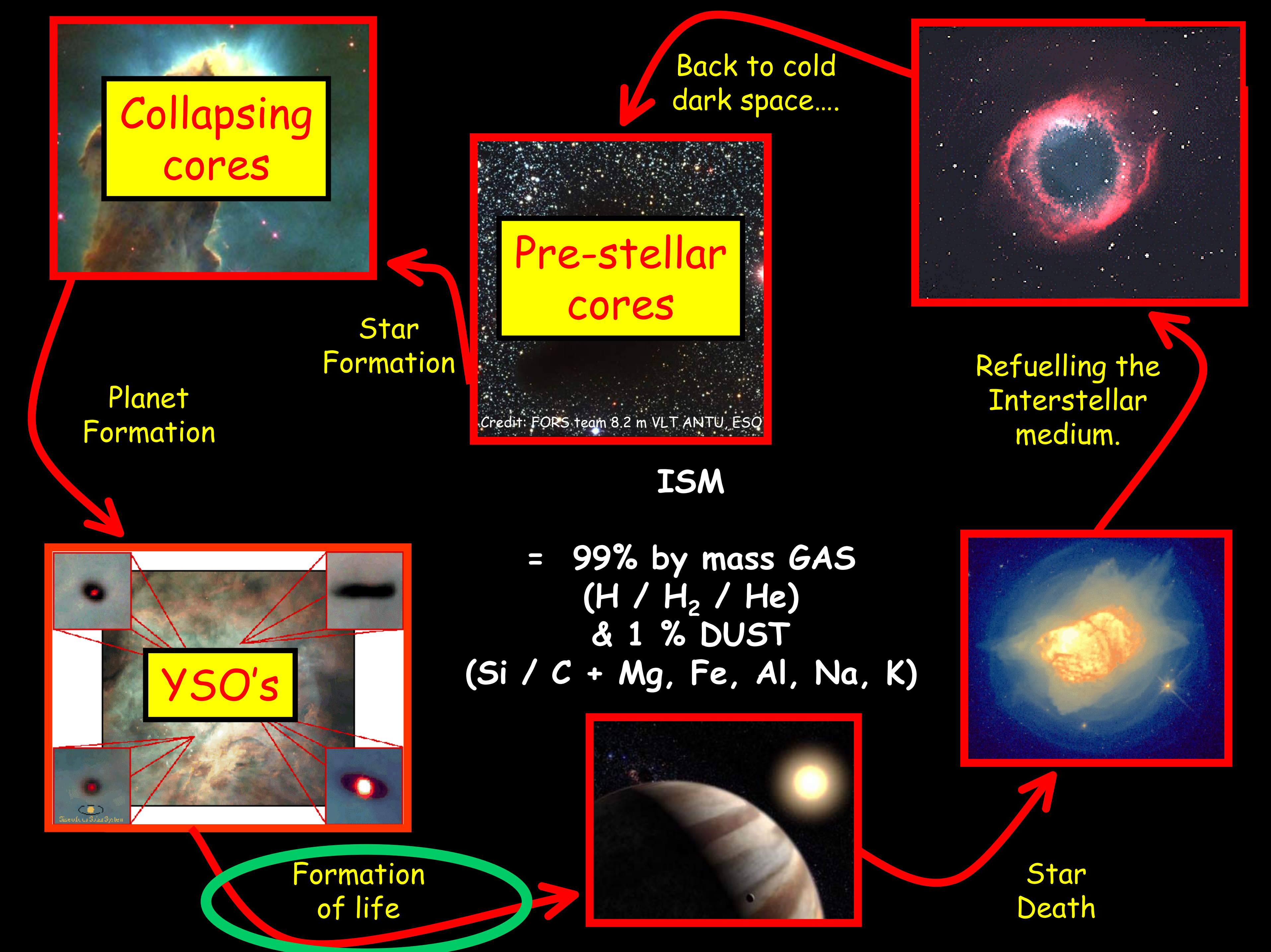
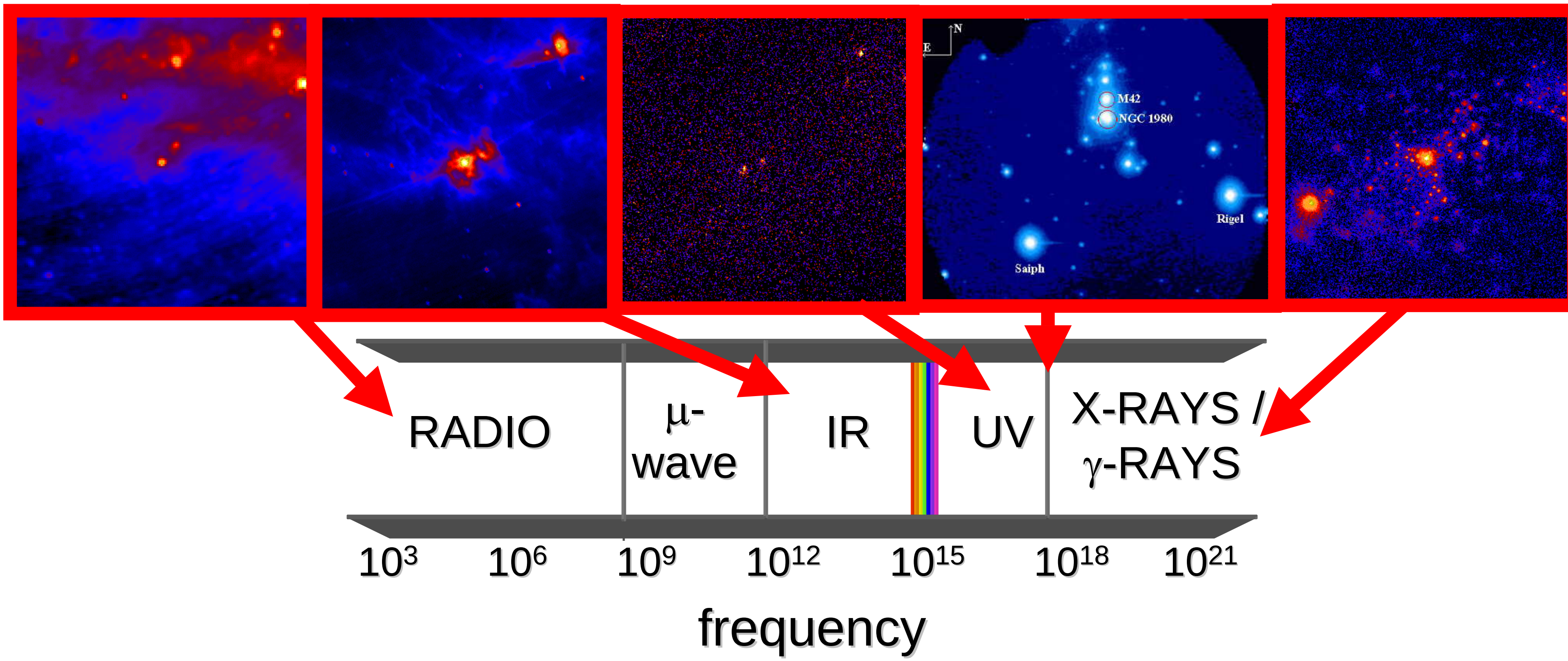
SUPA


Collapsing cores
Back to cold dark space....
Pre-stellar cores
Credit: FORS team 8.2 m VLT ANTU, ESO
Star Formation
Planet Formation
Refuelling the Interstellar medium.
ISM
= 99% by mass GAS
(H / H_2 / He)
& 1 % DUST
(Si / C + Mg, Fe, Al, Na, K)
YSO's
Formation of life
Star Death

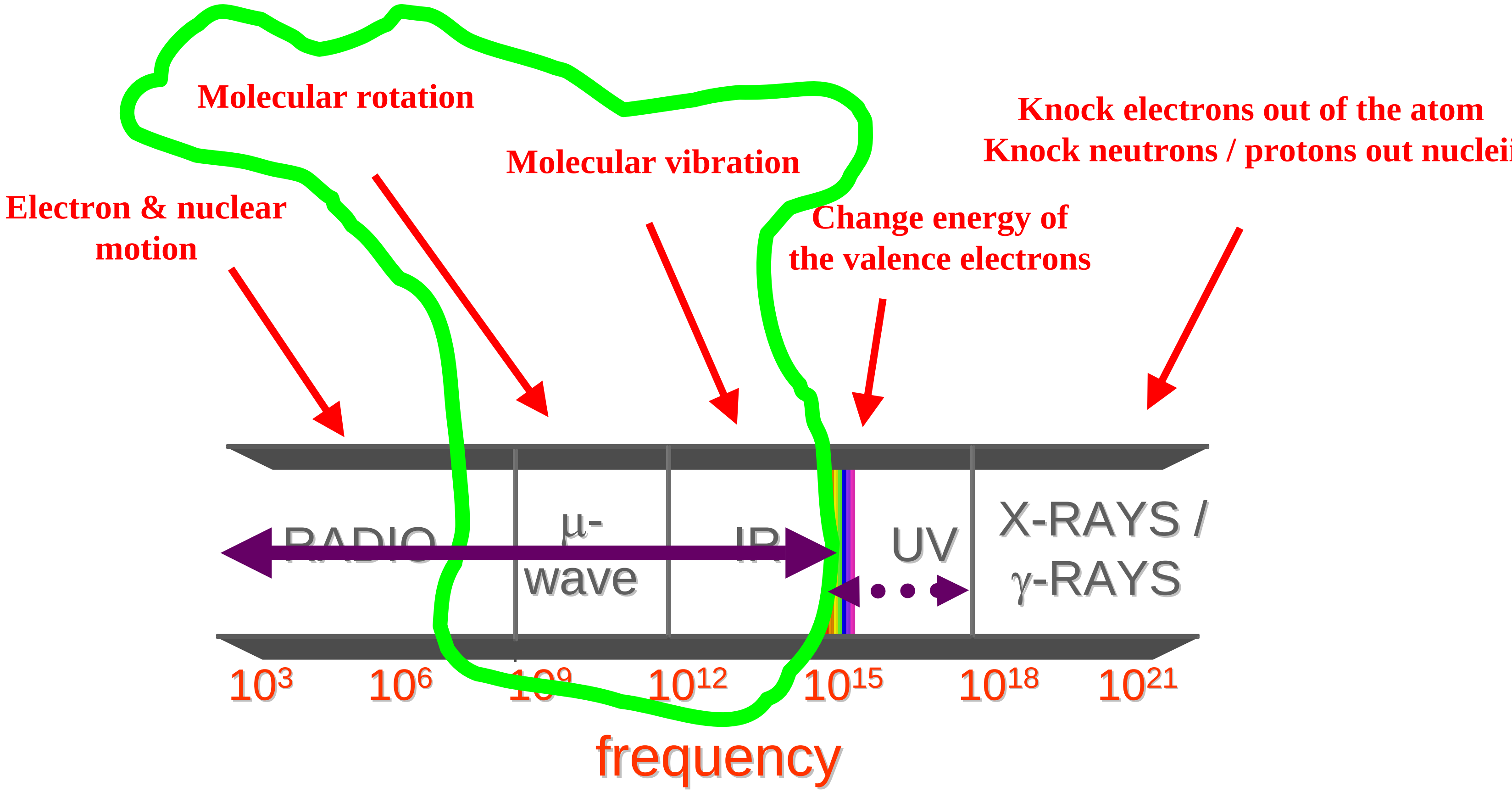
The Electromagnetic Spectrum



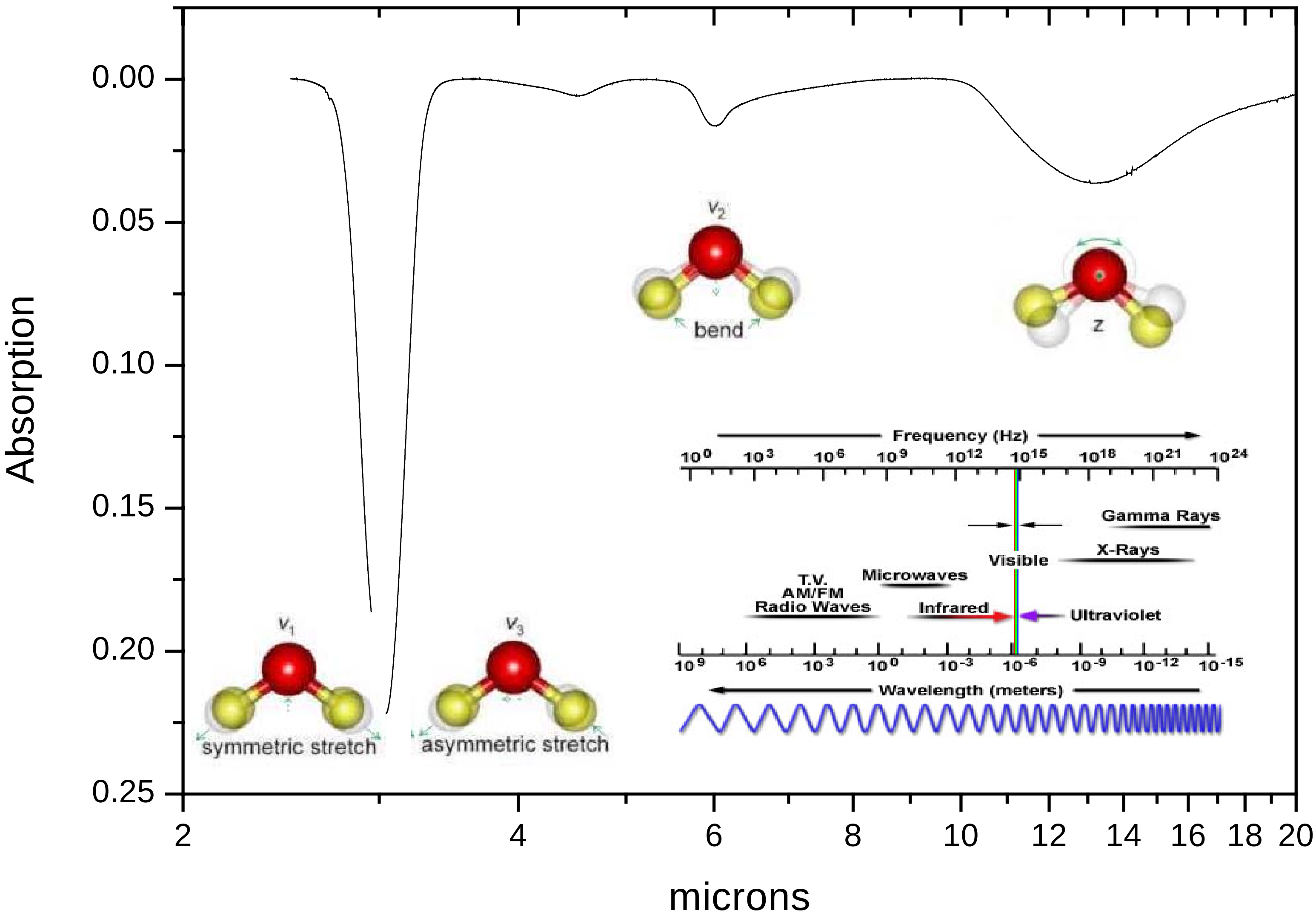
In each part of the electromagnetic spectrum we 'see' objects differently

Molecular Motion

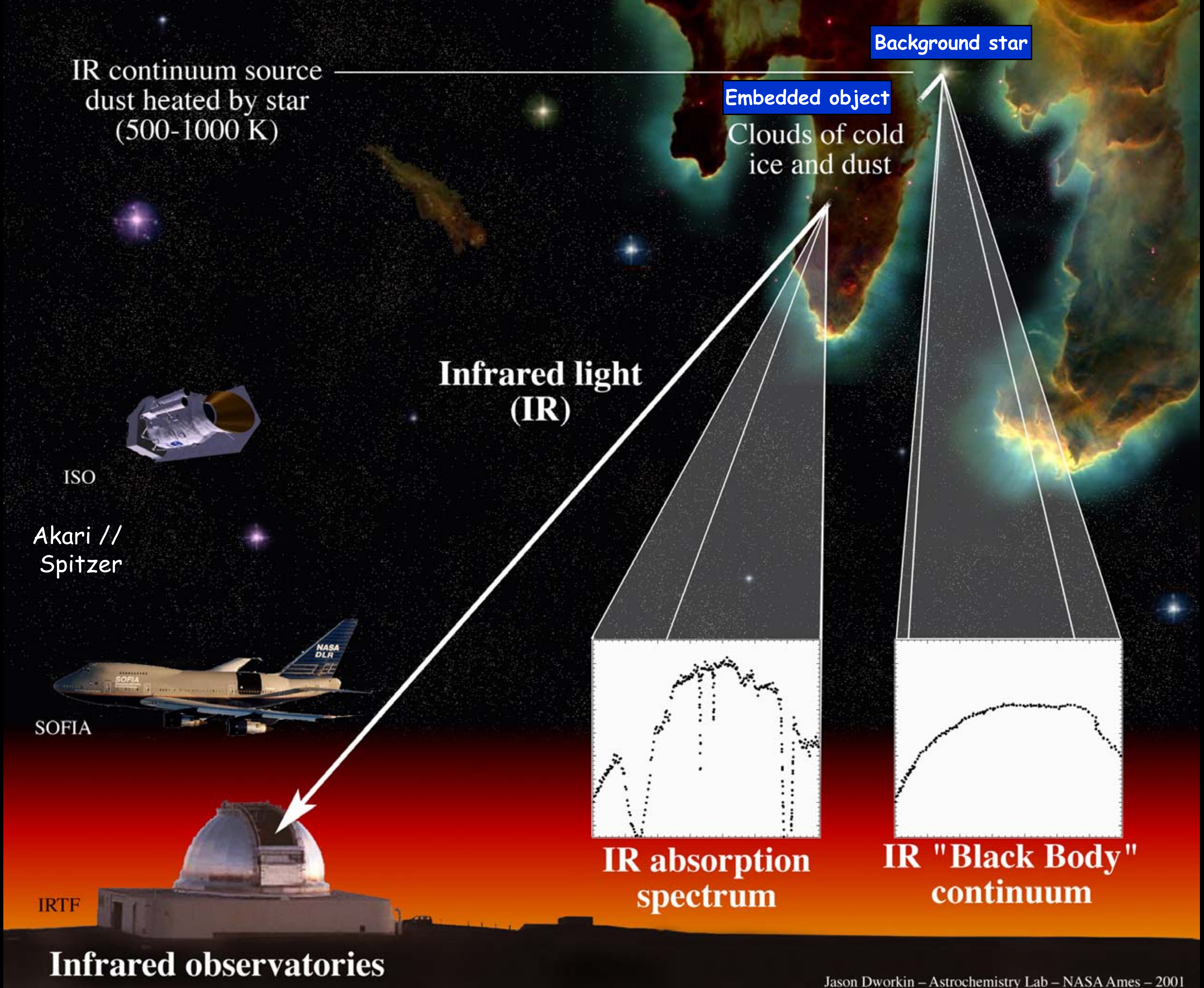
Study of how molecules absorb and emit EM radiation (like light) called SPECTROSCOPY



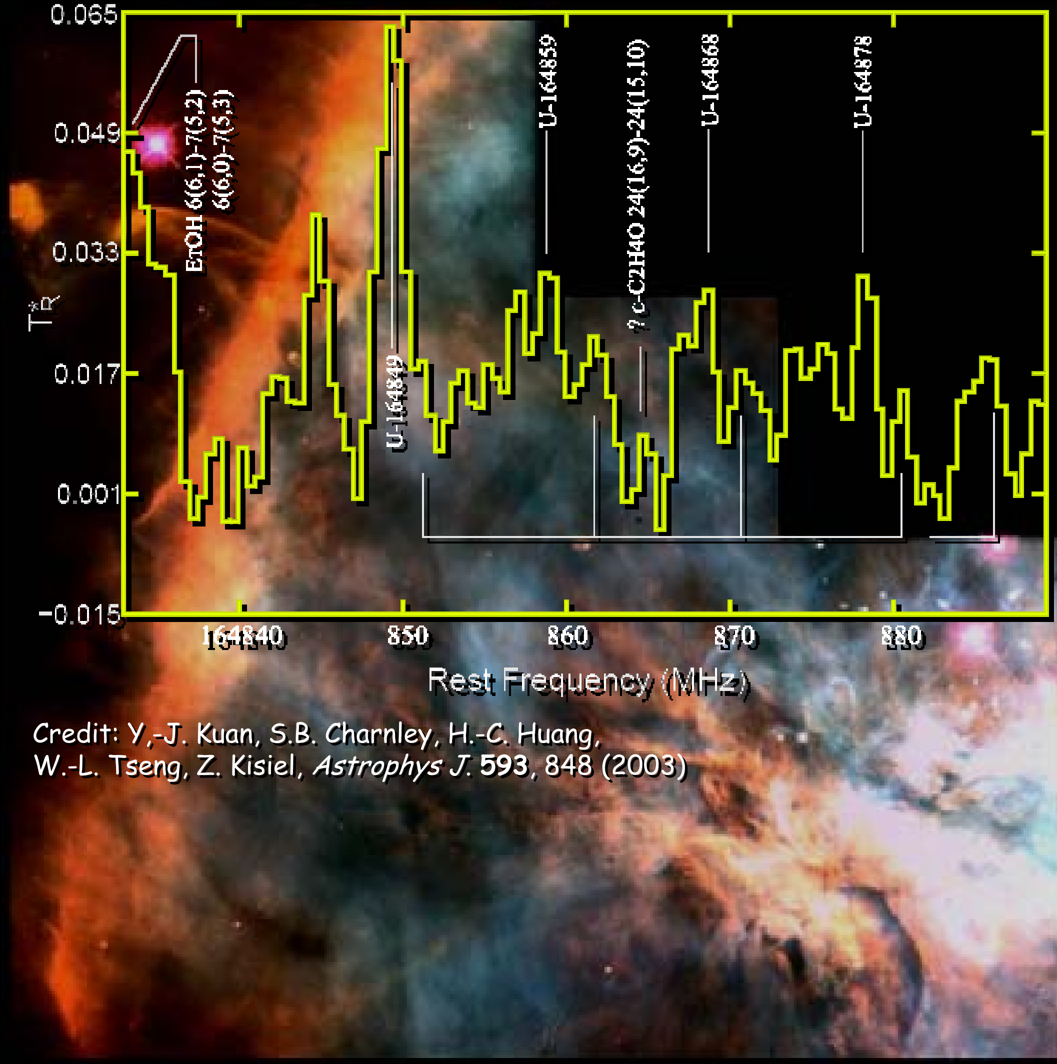
An INFRARED WATER SPECTRUM



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

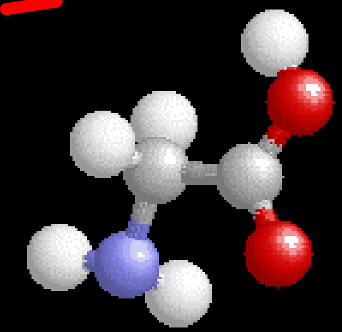


Complex molecules such as amino acids (the building blocks of life), have also been found in space



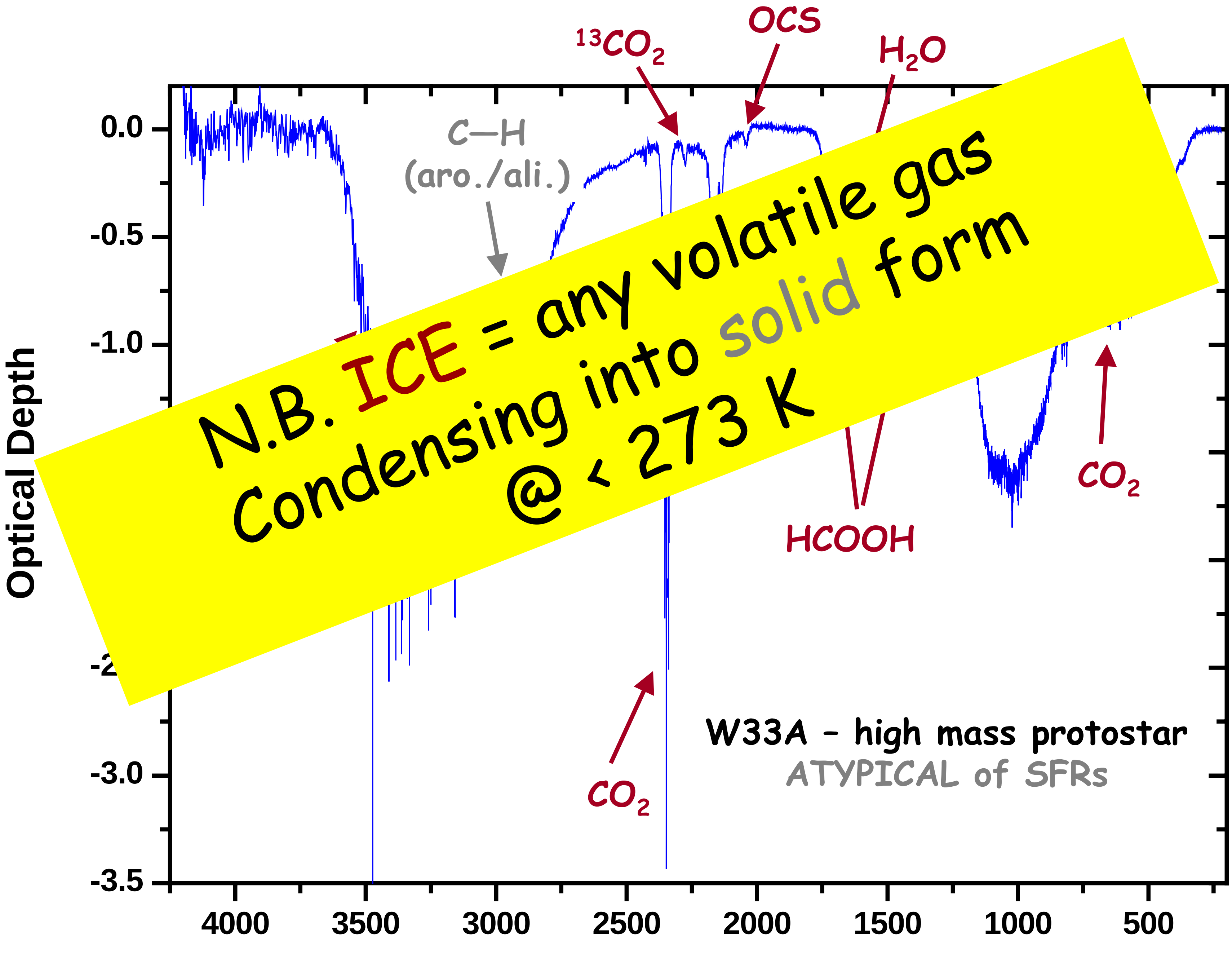
Credit: Y,-J. Kuan, S.B. Charnley, H.-C. Huang, W.-L. Tseng, Z. Kisiel, *Astrophys J.* **593**, 848 (2003)

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



glycine in Orion!

Radio = large molecules
Permanent dipoles



E.L. Gibb et al., ApJ 536, 347 (2000)

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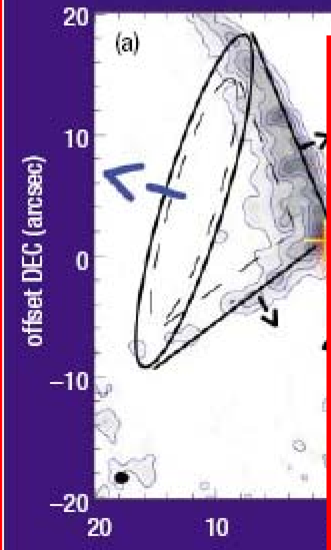
Astrobiologists ask…

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)

“m

…sents the COSMIC ABUNDANCE of each element



6: An overview of the outflow
(a) Integrated ^{12}CO J = 2→1 e
molecular outflow cones. The
0.9 Jy km s^{-1} per beam for th
and blue arrows denote red-
indicated by the short black a
(b) The central low-velocity C
contour and contour interval a
(approximately) 30° wide, as
thickness varies from 850 AU
continuum emission which tr
interval are 5 mJy per beam.
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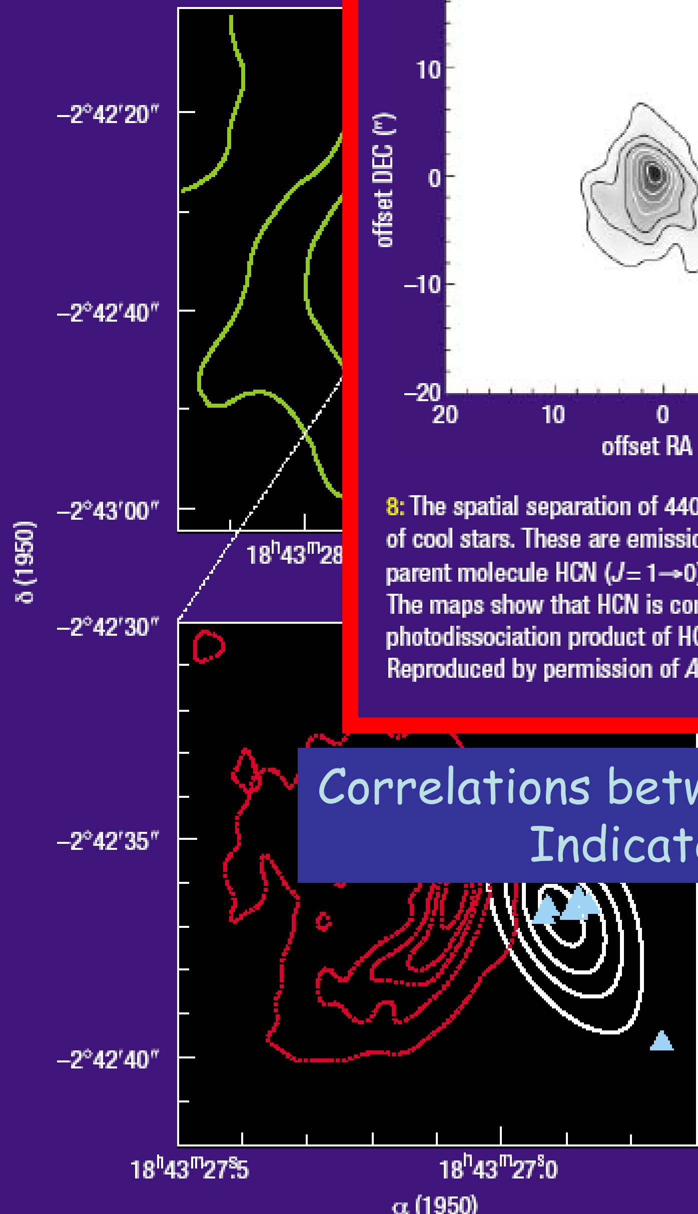
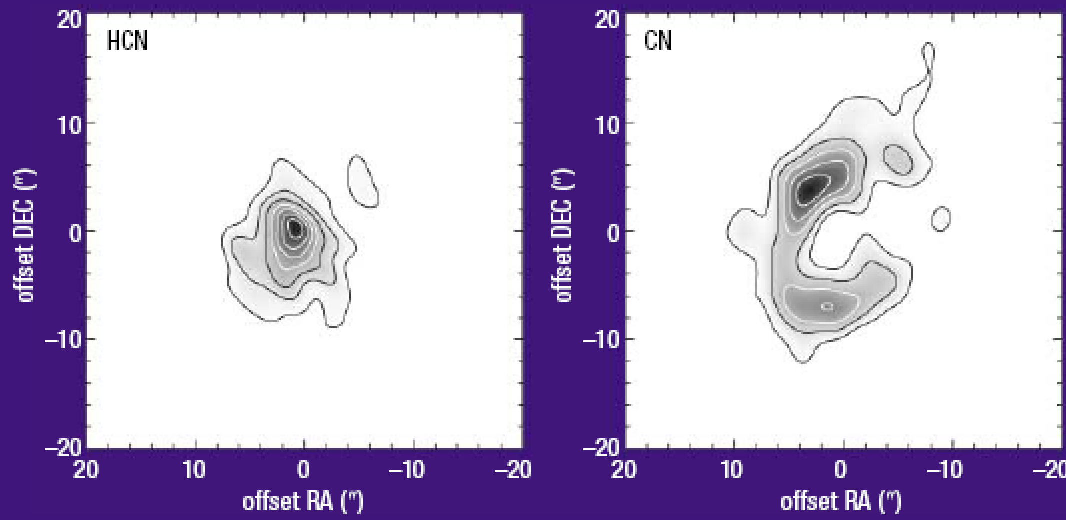


Kurtz, R Cesaroni, I
Russell, © 2000 The Arizona
Board of Regents.



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

OUTFLOWS
&
DYNAMICS

Gas Phase Abundance Plots
Tracer of Gas T / ρ //
physical processes

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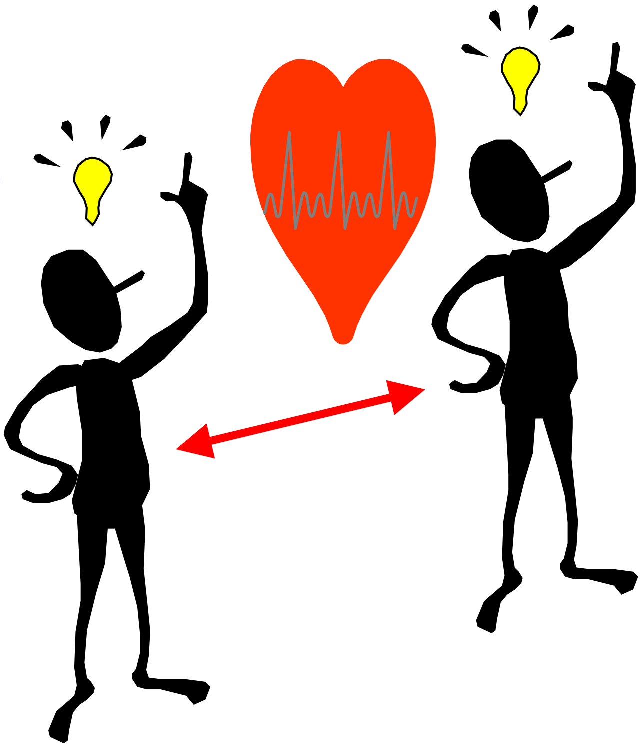
How does

CHEMISTRY

happen?

•**THERMODYMANICS**

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

Stockholm Astrobio seminar
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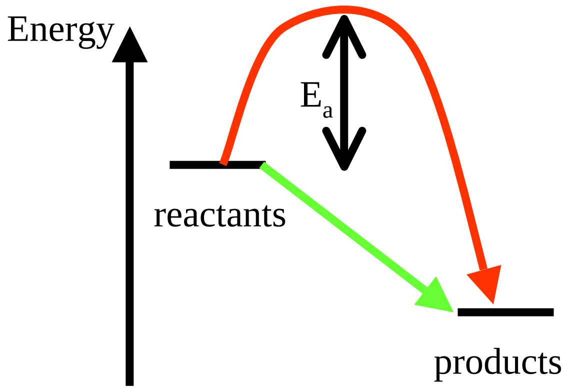
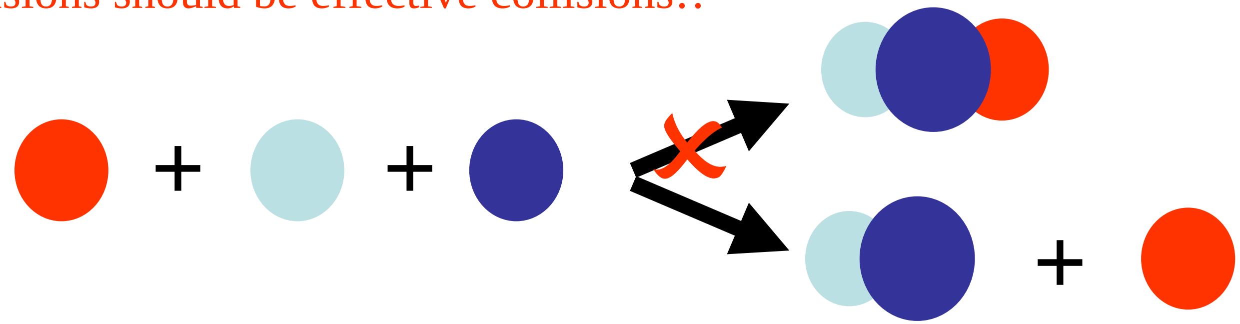
- T too low to overcome activation energy barrier



T = 10 - 200 K

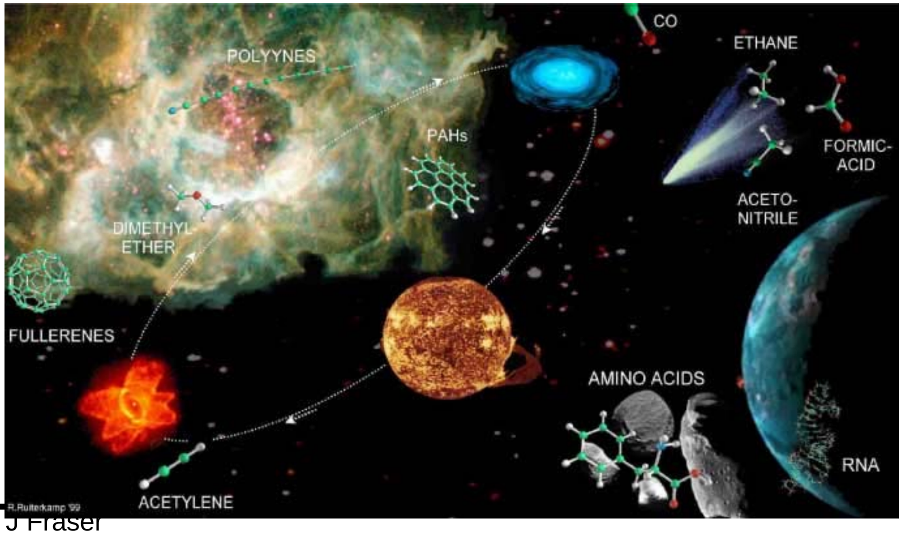
‘No barrier chemistry’

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



2	3	4	5	6	7	8	9+
$\boxed{H_2}$	C_3	$c\text{-}C_3H$	C_5	C_5H	C_6H	CH_3C_3N	CH_3C_4H
AlF	C_2H	$l\text{-}C_3H$	C_4H	$l\text{-}H_2C_4$	CH_2CHCN	$HCOOCH_3$	CH_3CH_2CN
AlCl	C_2O	C_3N	C_4Si	C_2H_4	CH_3C_2H	CH_3COOH	$(CH_3)_2O$
C_2	C_2S	C_3O	$l\text{-}C_3H_2$	CH_3CN	HC_5N	C_7H	$\boxed{CH_3CH_2OH}$
CH	CH_2	C_3S	$c\text{-}C_3H_2$	CH_3NC	$HCOCH_3$	CH_2OHCHO	HC_7N C_8H
CH^+	HCN	C_2H_2	CH_2CN	$\boxed{CH_3OH}$	NH_2CH_3		CH_3C_5N
CN	HCO	CH_2D^+	$\boxed{CH_4}$	CH_3SH	$c\text{-}C_2H_4O$		$(CH_3)_2CO$
CO	HCO^+	HCCN	HC_3N	HC_3NH^+	CH_2CHOH		NH_2CH_2COO
CO^+	HCS^+	$HCNH^+$	HC_2NC	HC_2CHO			H? HC_9N
CP	HOC^+	$\boxed{HNCO}$	HCOOH	NH_2CHO			$HC_{11}N$
CSi	$\boxed{H_2O}$	HNCS	H_2CHN	C_5N			
HCl	H_2S	$HOCO^+$	H_2C_2O				
KCl	HNC	H_2CO	H_2NCN				
NH	HNO	H_2CN	HNC_3				
NO	MgCN	H_2CS	SiH_4				
NS	MgNC	H_3O^+	H_2COH^+				
NaCl	N_2H^+	NH_3					
OH	N_2O	SiC_3					
PN	NaCN						
SO	OCS						
SO^+	SO_2						
SiN	$c\text{-}SiC_2$						
SiO	$\boxed{CO_2}$						

List of Detected Cosmic Molecules in Interstellar and Circumstellar Environments.



Fraser et. al. A&G, 43, no. 2, 2.10 (2002)

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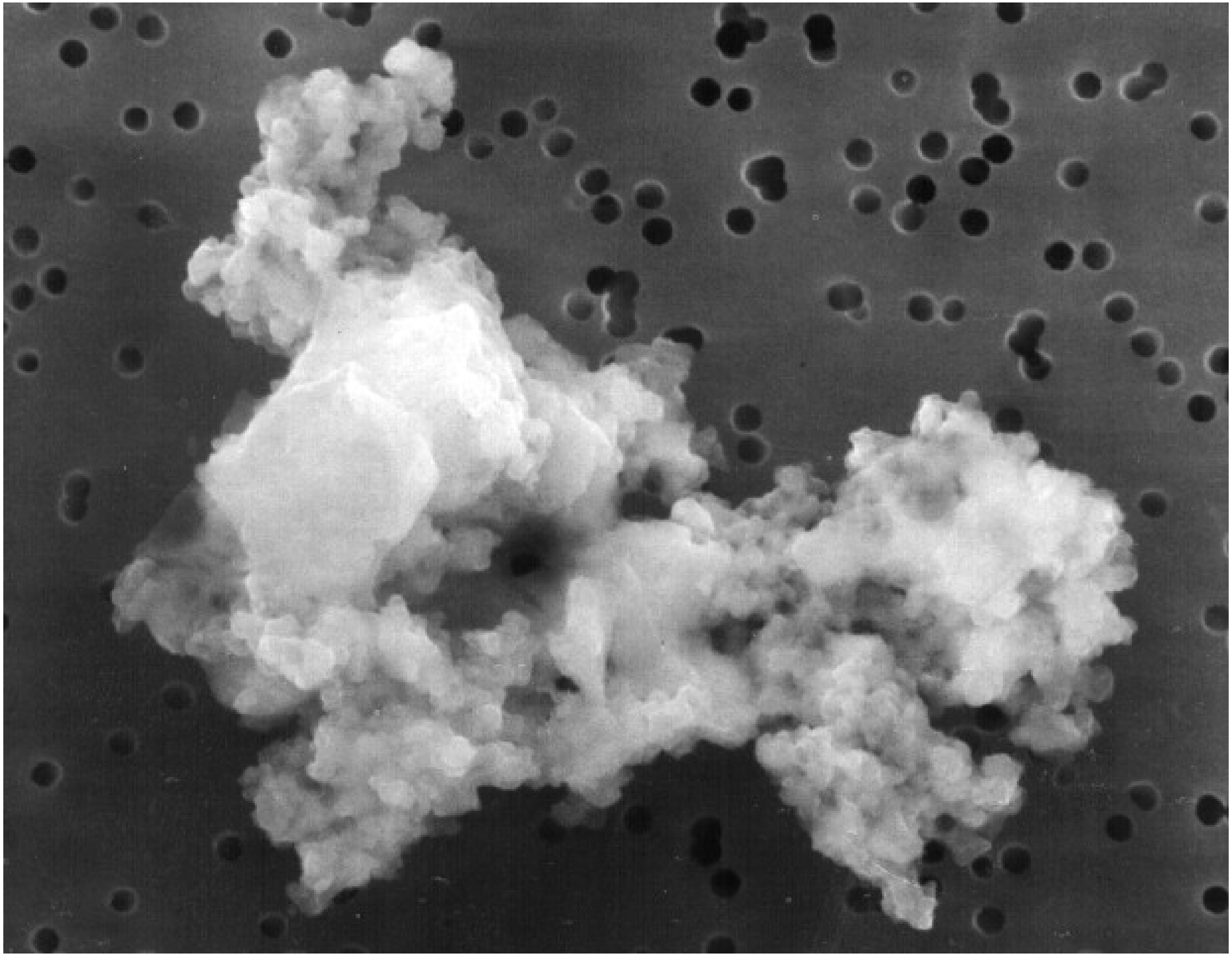
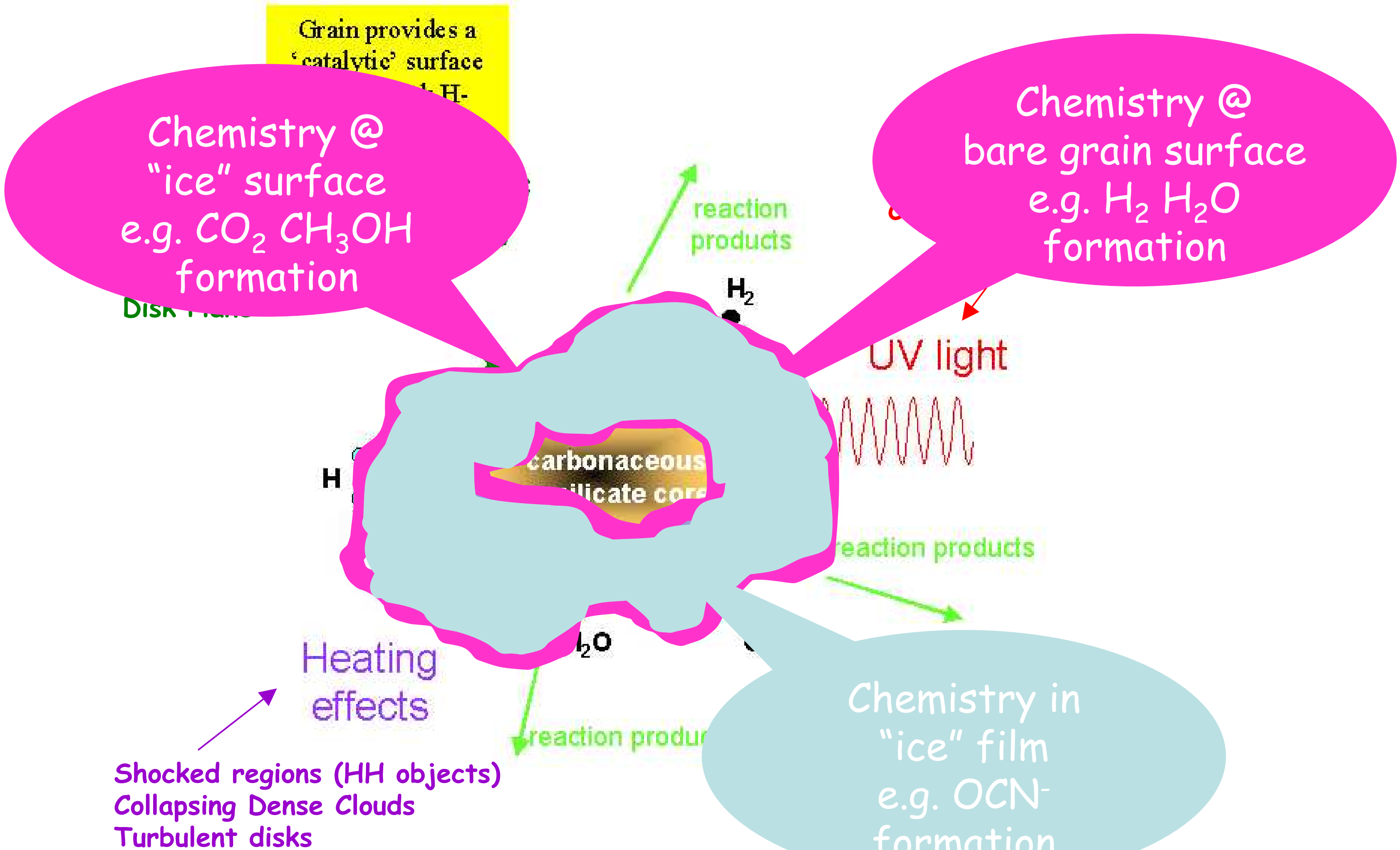


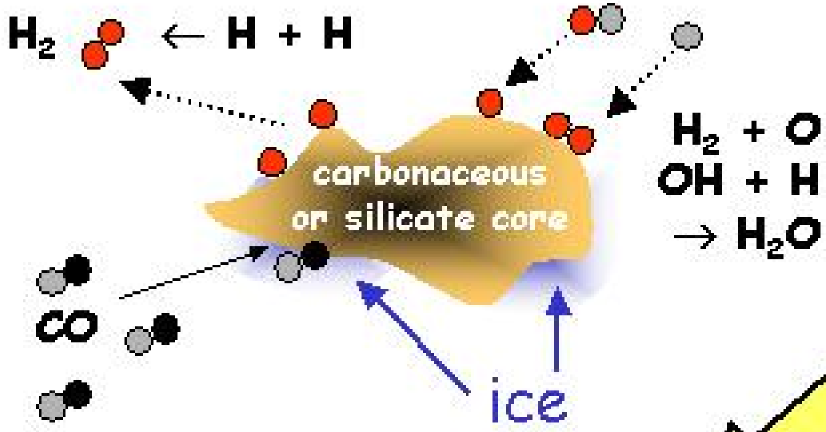
Solid-State Chemistry of Star-Forming Regions



Fraser, Collings & McCoustra,
Rev. Sci. Inst. 73, no.5, 2161 (2002)

Forming interstellar ice:

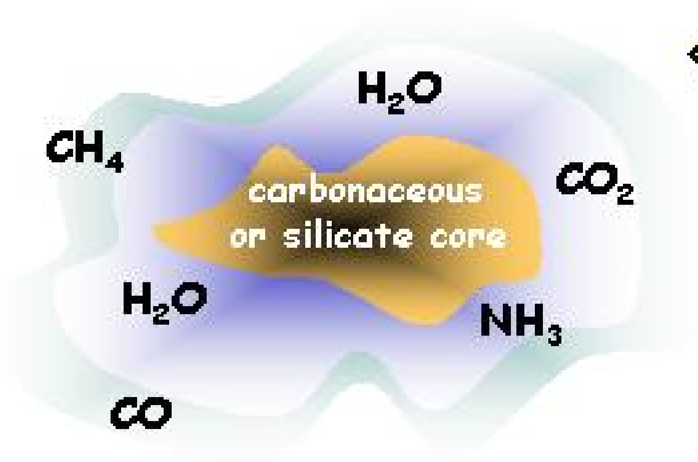
Atoms and molecules stick onto the cold dust, reacting to form H_2 and H_2O or freezing to form "solids".



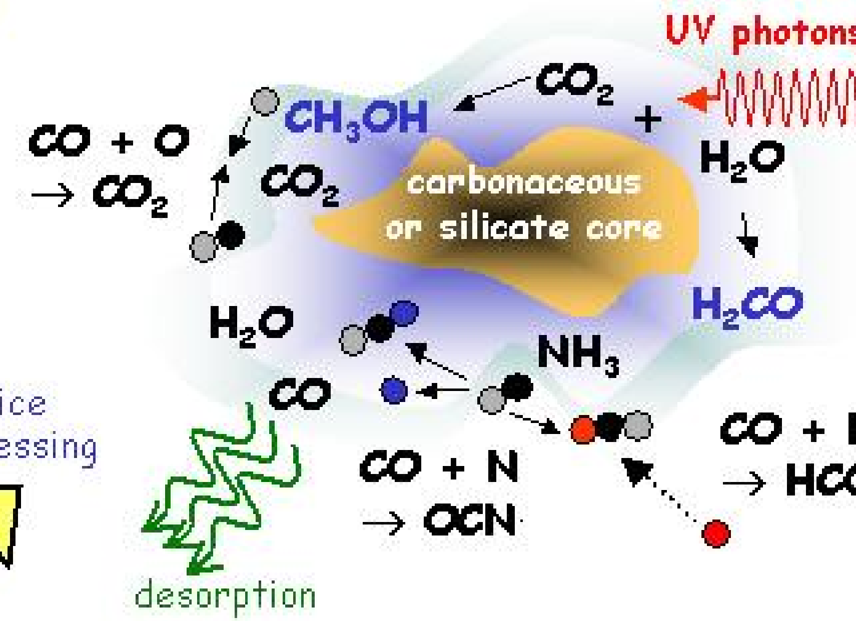
...after some time

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.



...ice processing



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

=

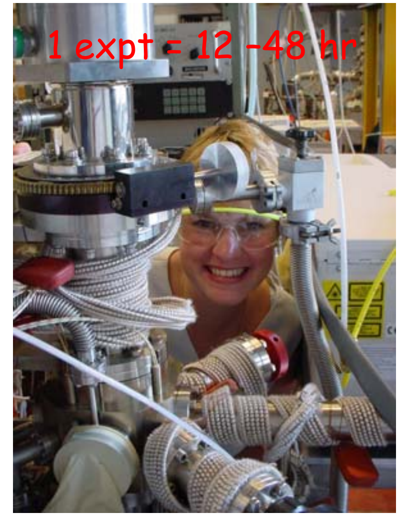
ICE & DUST

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 H_2 then CO)

T_{grain} = 10 – 300 K

T_{gas} = 10 – 1000 K

1 Lyman α / Lyman-Werner band UV photon per 10^6 years per grain

1 atom / molecule – grain collision per 10^4 years

1 X-Ray / CR 'direct hit' per 10^5 years

S
gas
D
CR

Surface Science

To date = flat surfaces

P < 10^{-10} mbar
(also dominated by H_2 then CO)

T_{grain} = 10 – 450 K

T_{gas} = 100 - 300 K

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

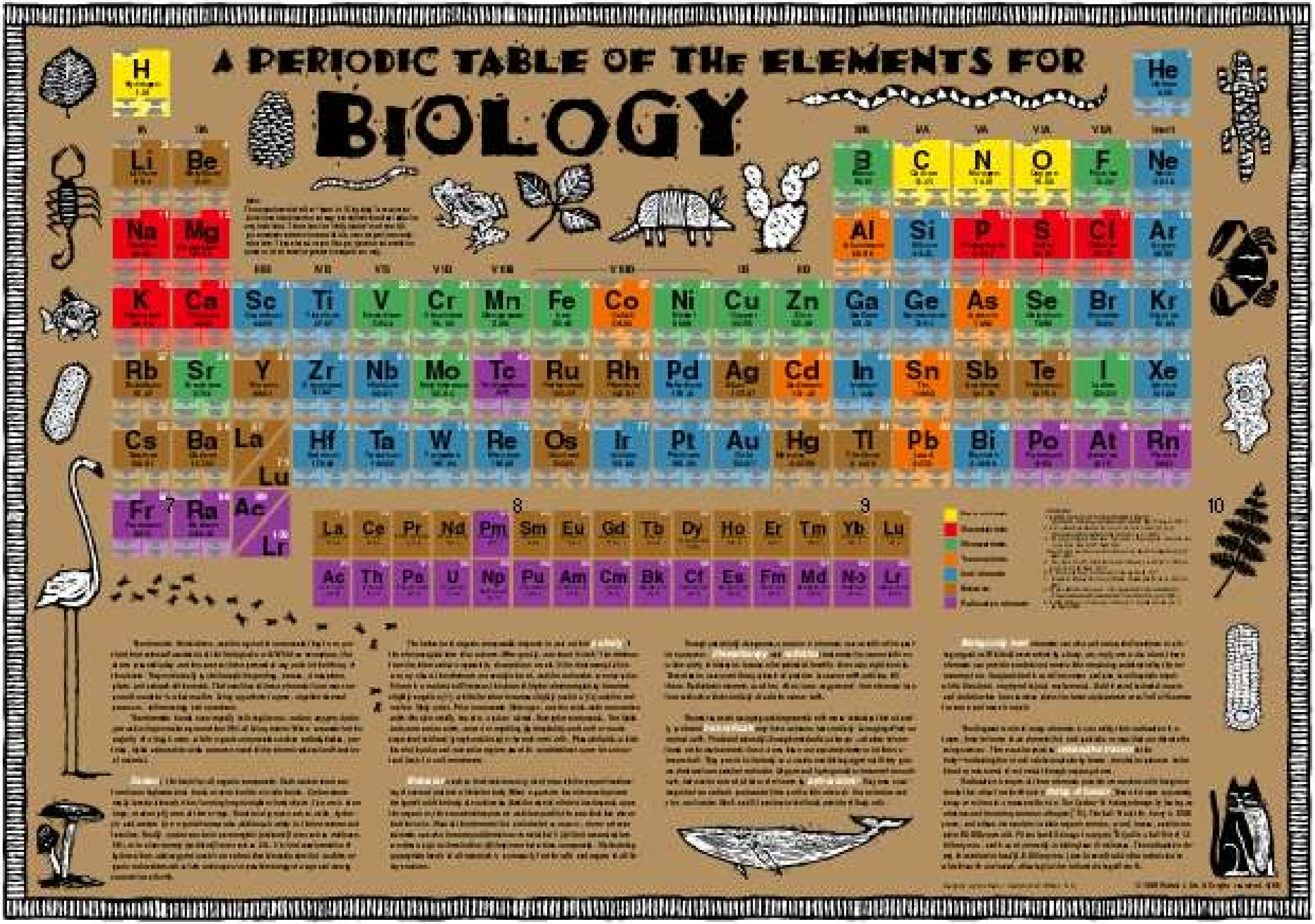
@ 1 L (Langmuir) dose = 10^{15} molec cm^{-2} s^{-1}

1 X-Ray / CR …. ✘

rob
J F
h.fraser@phys.strath.ac.uk

Fraser, Collings & McCoustra, Rev. Sci. Inst. 73, no.5, 2161 (2002); Fraser & Va... k, ASR, 33, 14 (2004)

From molecules to life…



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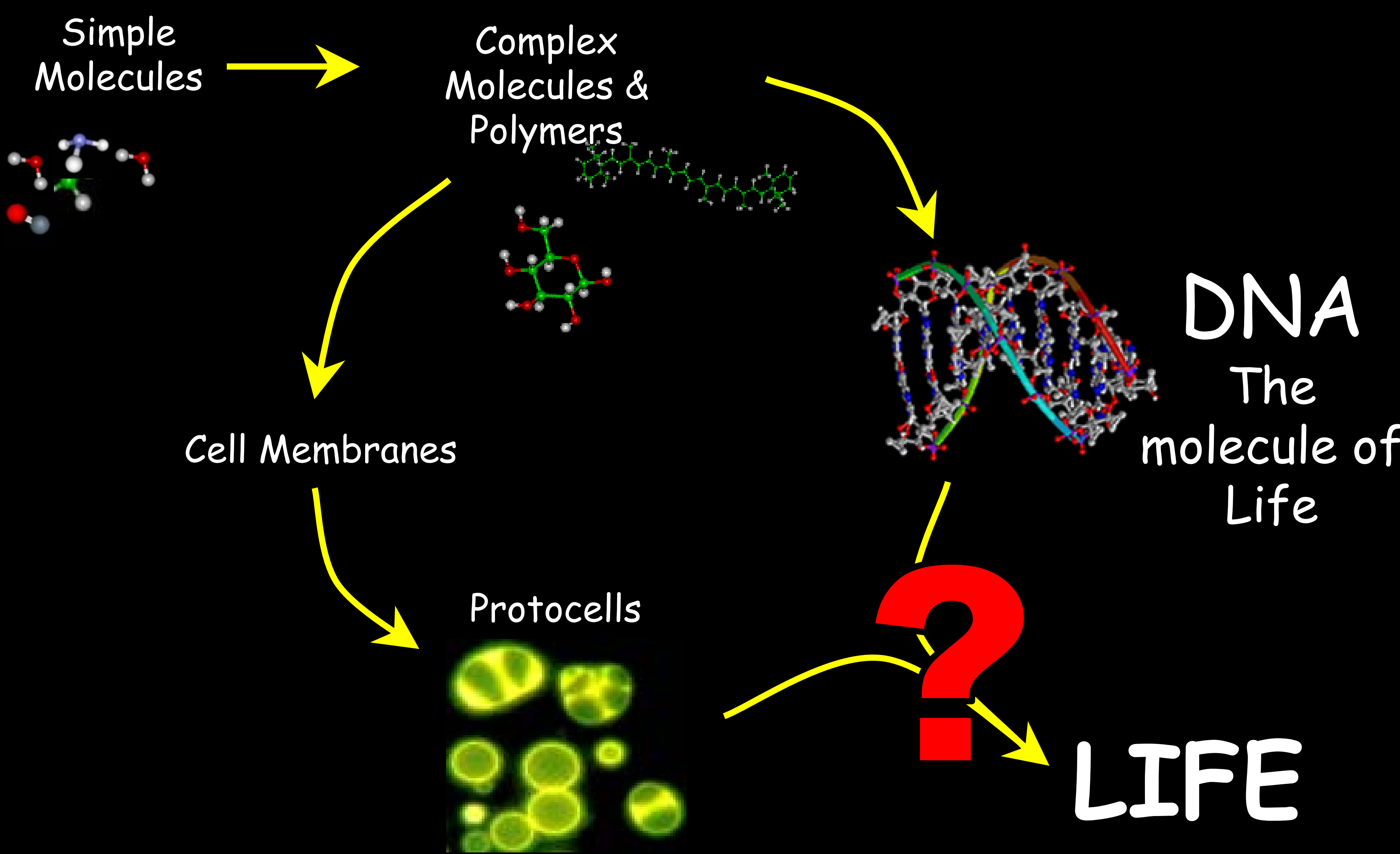
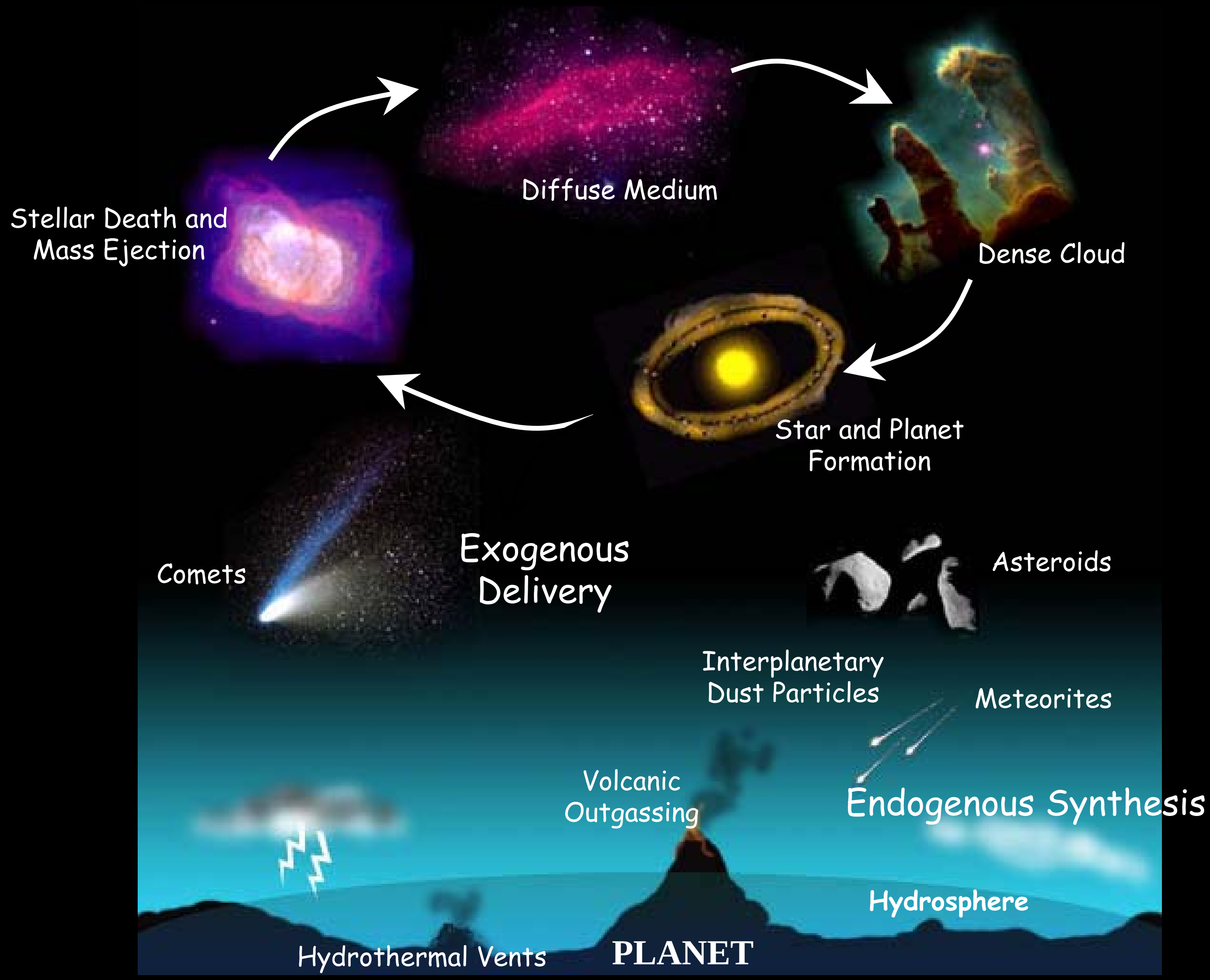
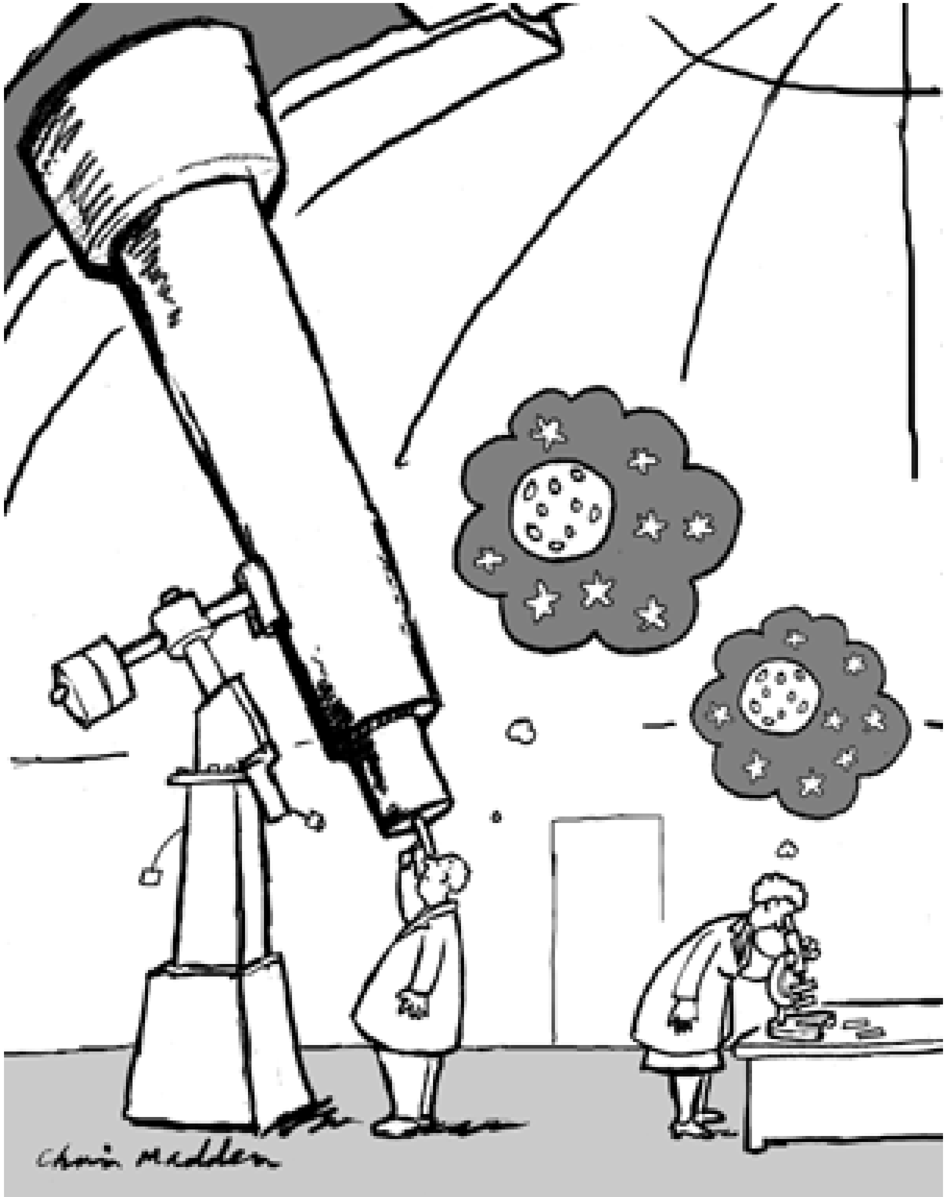
These complex molecules are important for forming the molecules of Life...



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




Chris Madden