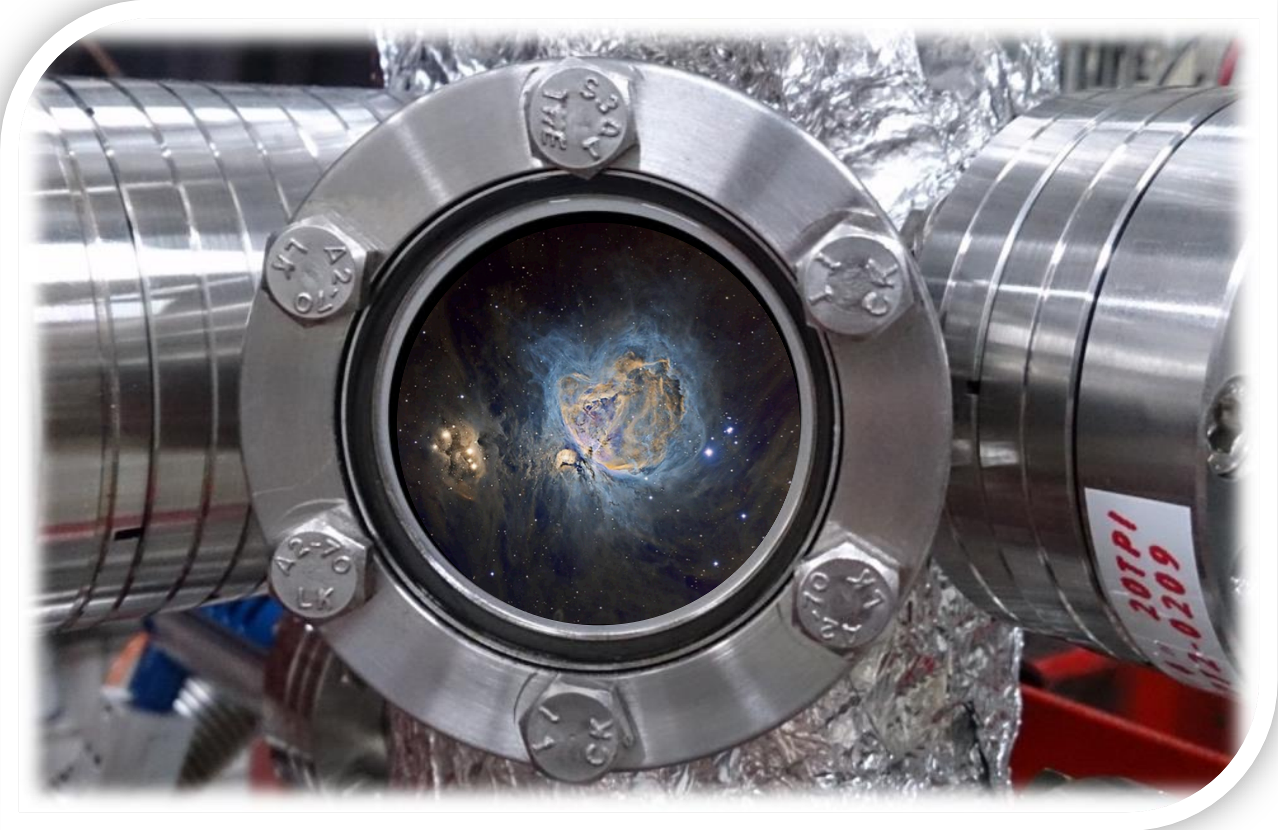
在實驗室裡遇見彗星



陳 俞 融

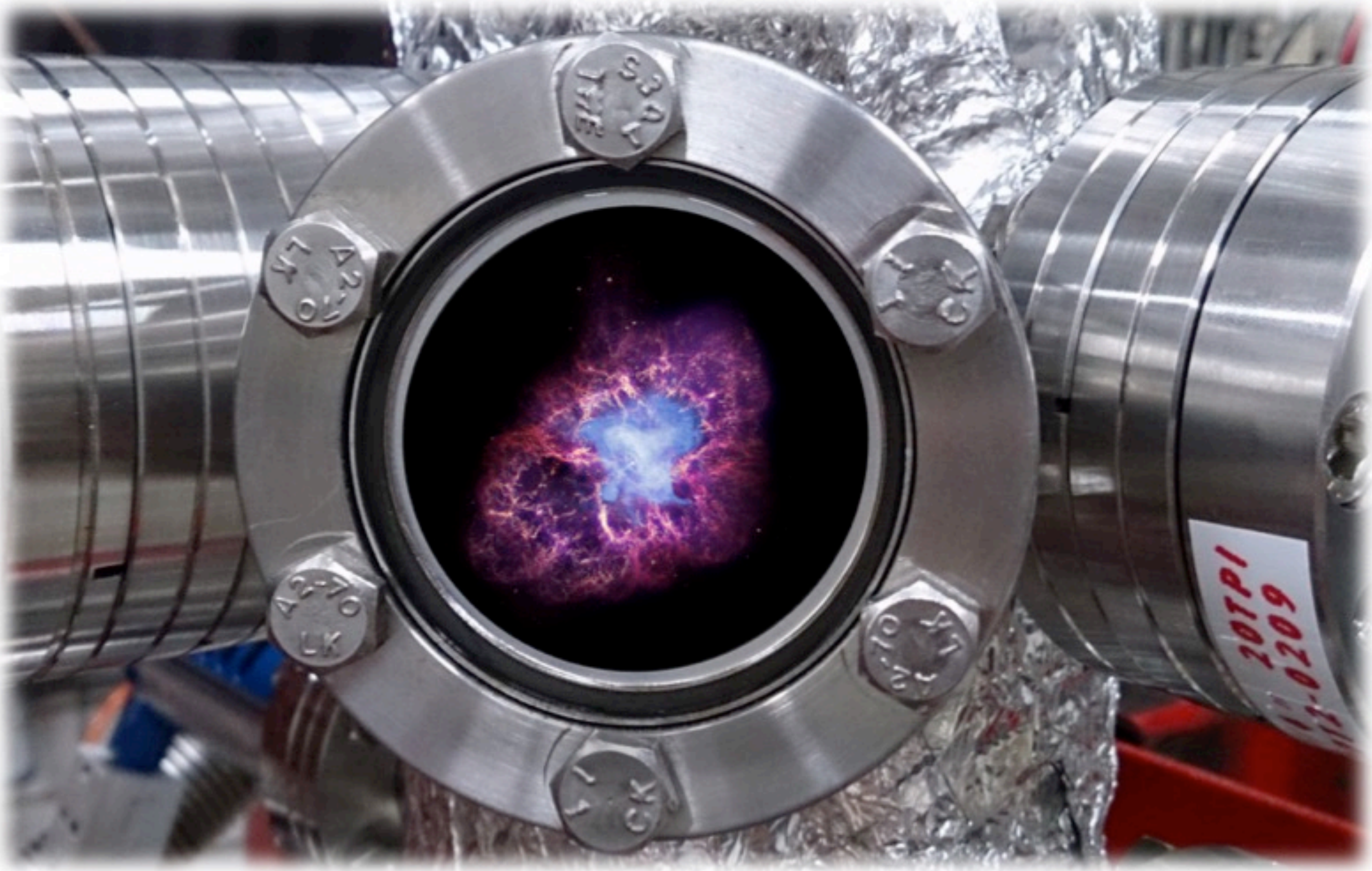
國立中央大學物理系

光子作用與光譜分析實驗室

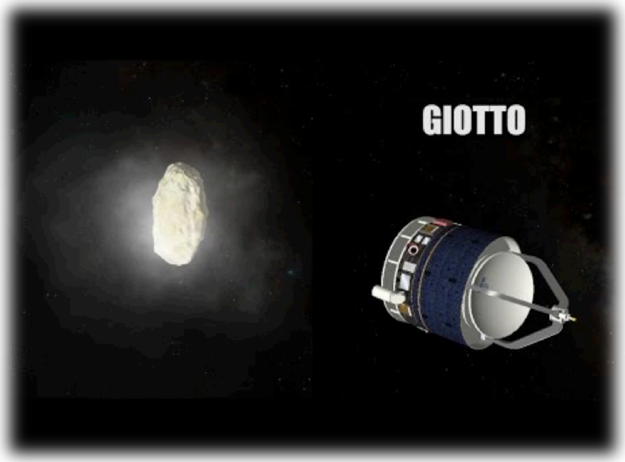
國立中央大學

National Central University

什麼是實驗室天文學？

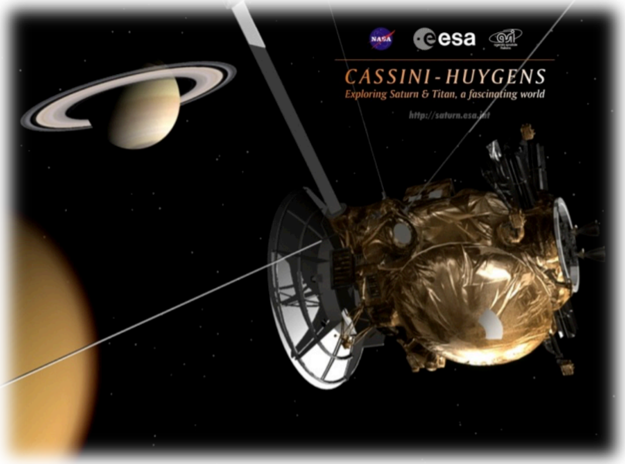

S3A
Y
A2-70
LK
A2-70
LK
CK
Y
A2-70
CK
20TPI
0209

為什麼要有實驗室天文學？



1986 ESA
Giotto mission
Comet Halley

2005 NASA
Deep Impact
9P/Tempel 1

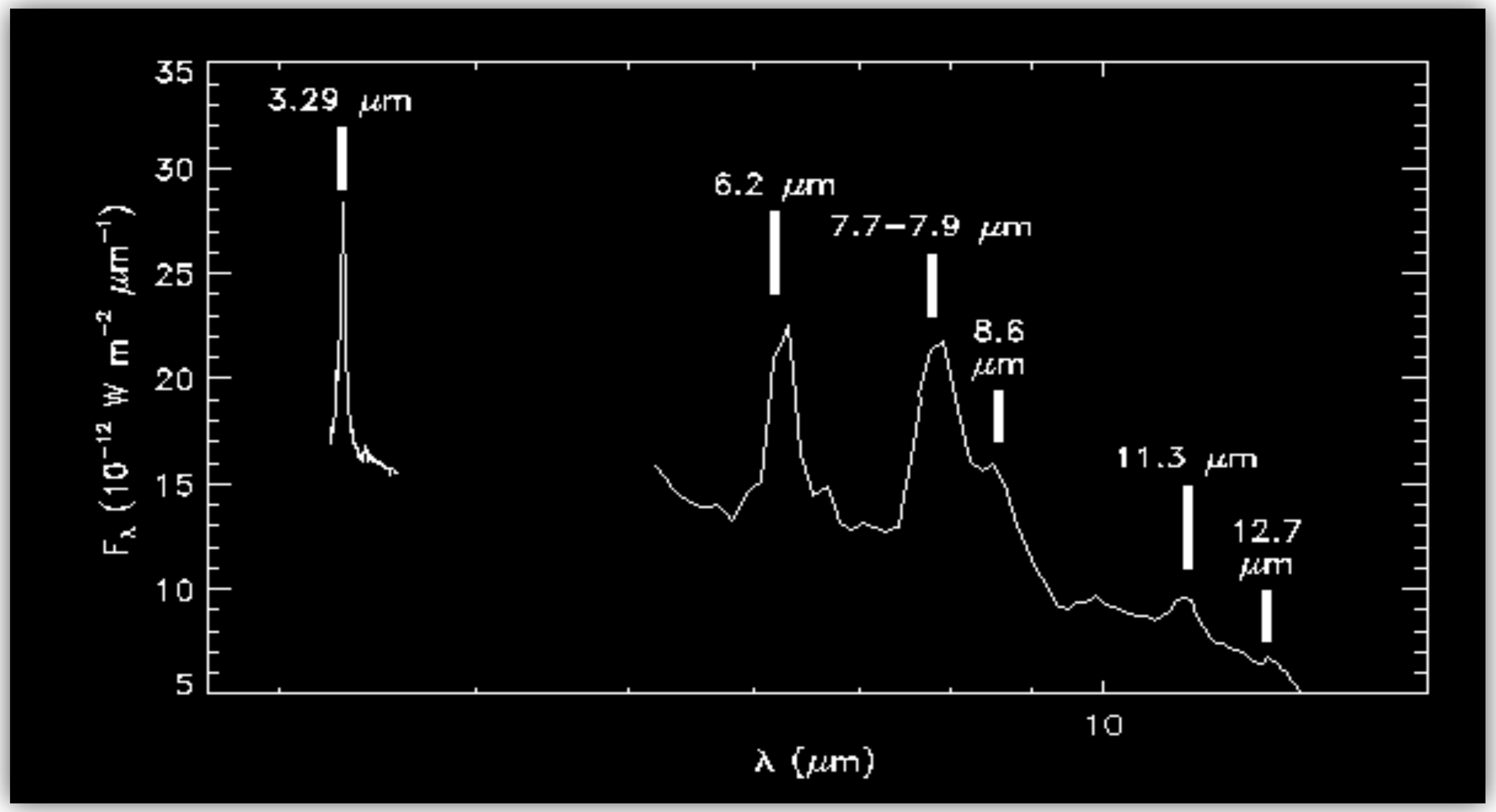


1997 ESA/NASA/ISA
Cassini mission
Saturn

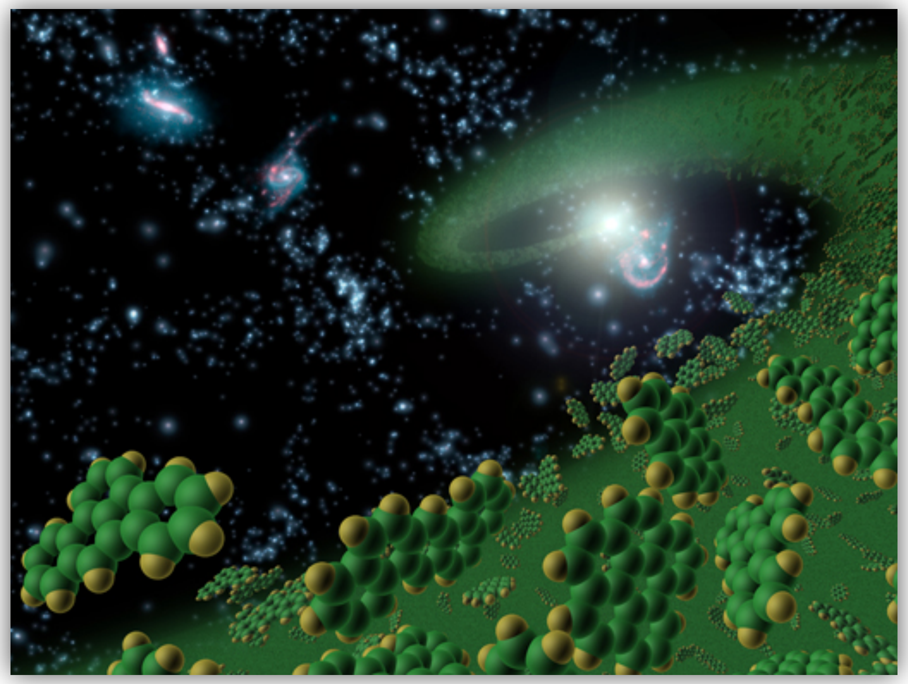
2004 ESA
Rosetta mission
Churyumov–Gerasimenko

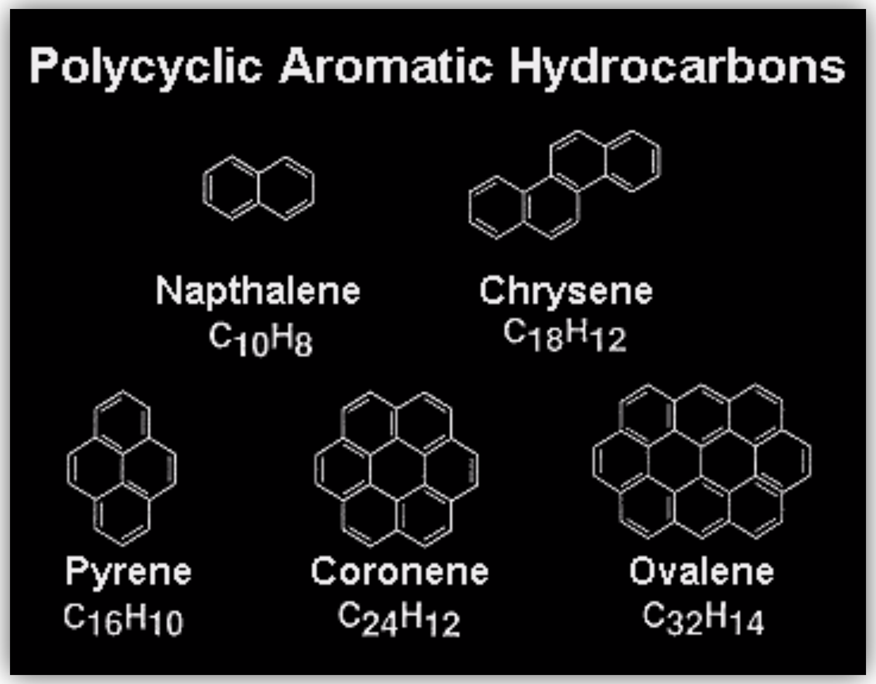
2013 ALMA
Star and planet formation

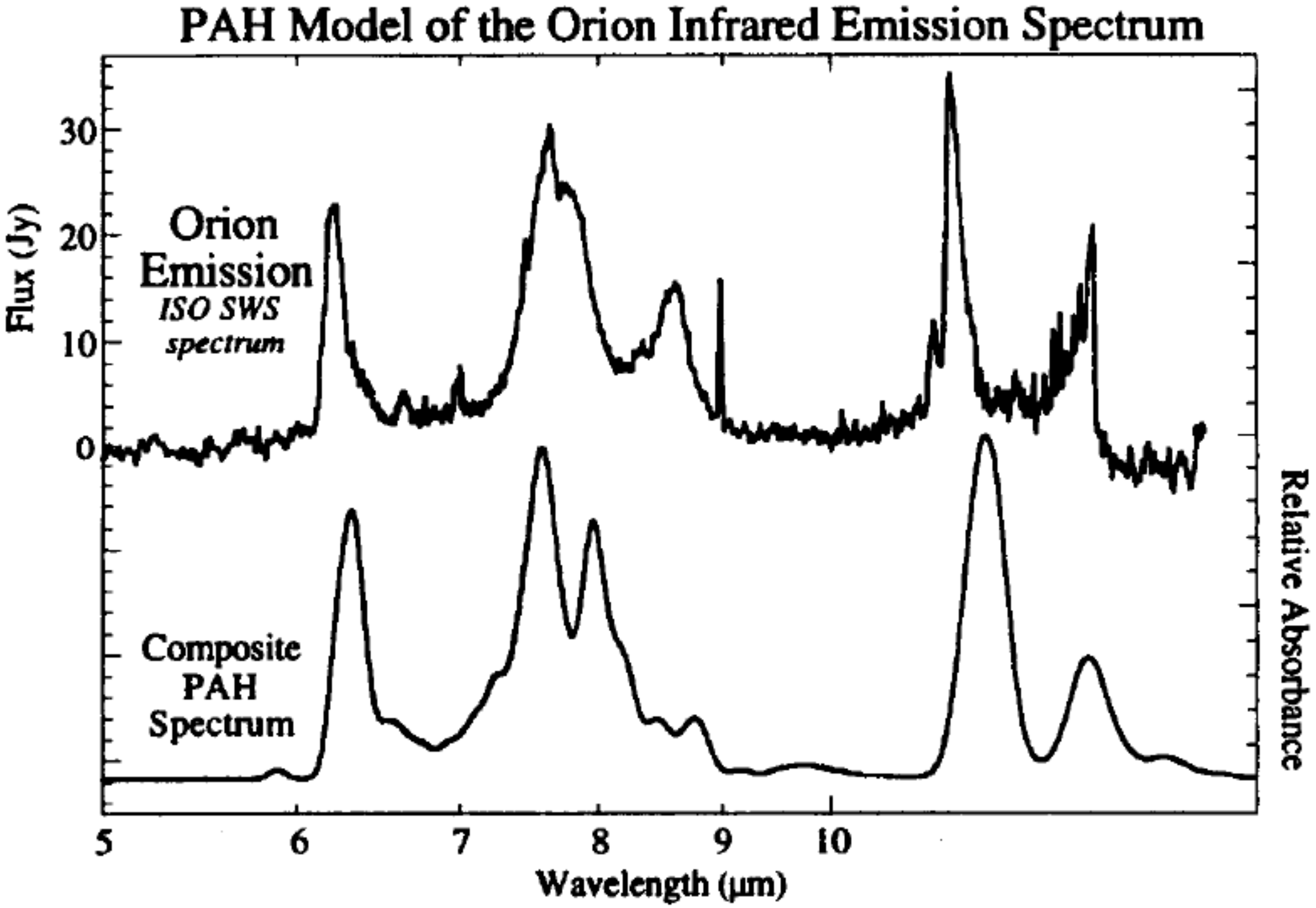
Unidentified Infrared Bands



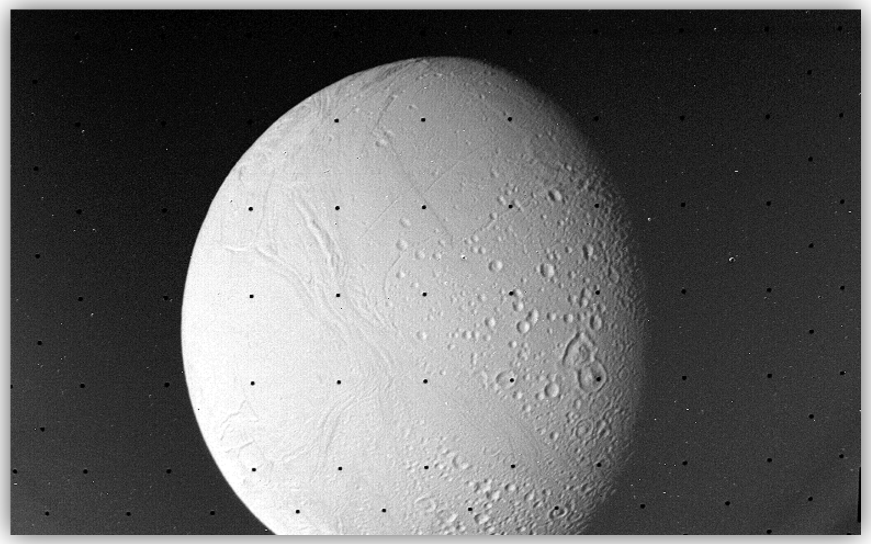
PAHs are among the most commonly proposed candidates for UIB



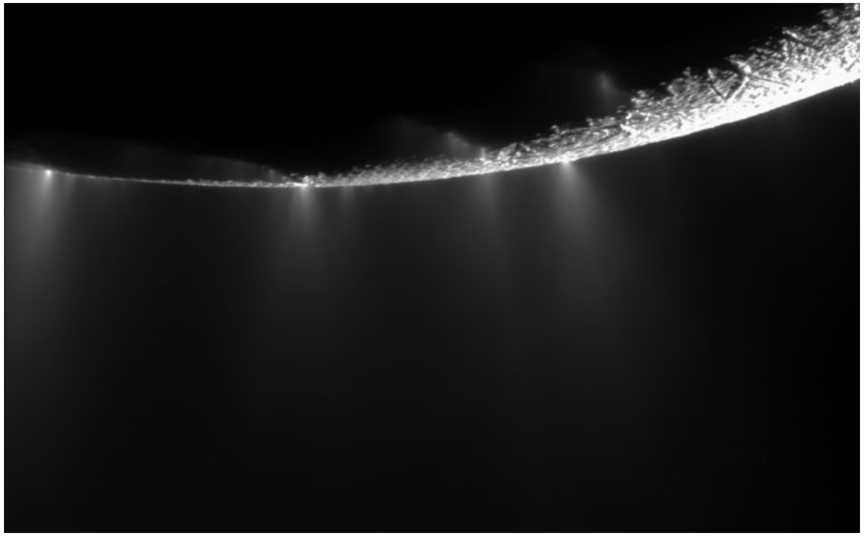




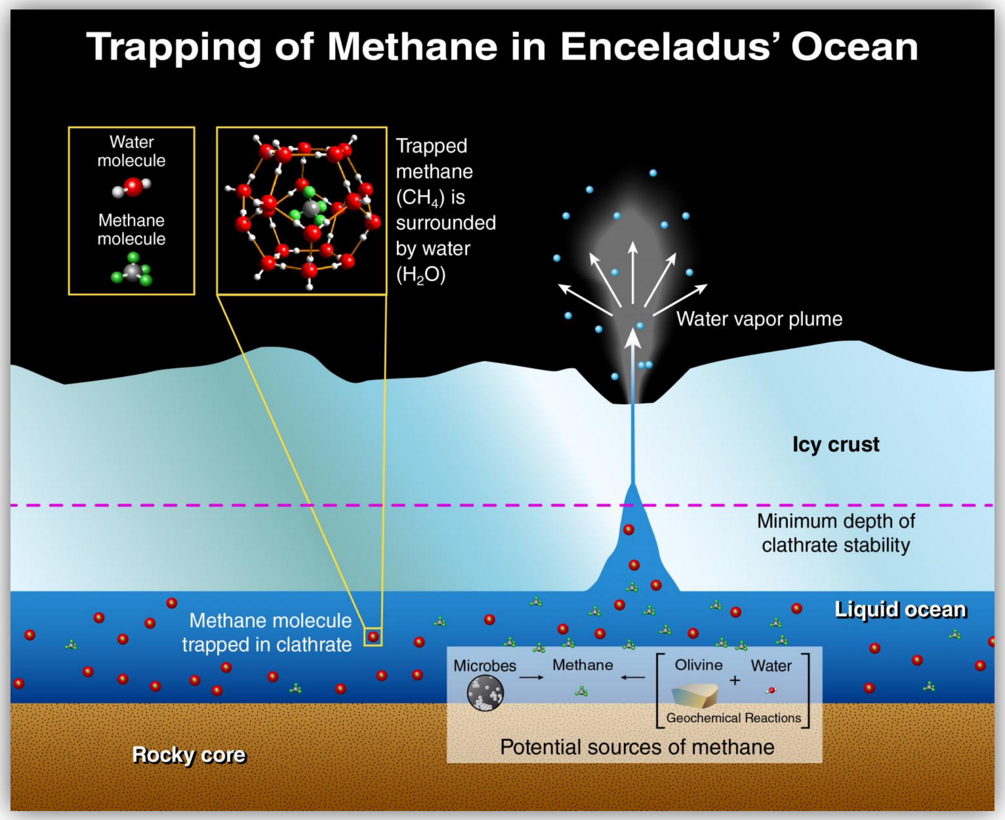
Hudgins & Allamandola 2002, NASA LAW



Voyager 2 image of Enceladus (1981)



Cassini, Enceladus plumes (2005)



Models for Interstellar Chemistry

Gas-Gas reaction

Processes are ion-molecule, neutral-neutral, charge exchange, radiative association, radiative recombination, dissociative recombination, CRP and FUV ionization and dissociation…etc.

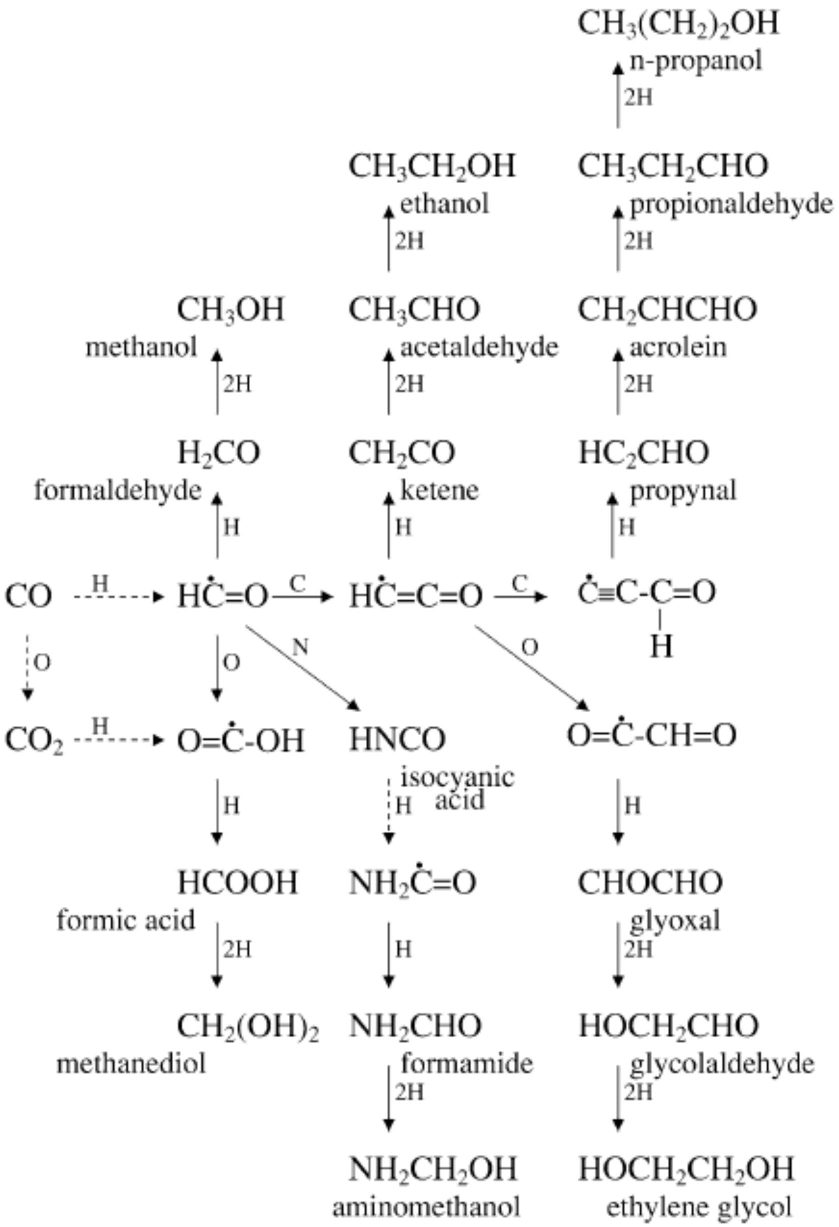
Gas-Surface reaction

Assumes molecules/atoms tunneling through potential wells of the surface sites and reaction barriers.

Gas-Surface Chemistry

Atom Addition Reactions

proposed by Tielens and Hagen (1982)



Models for Interstellar Chemistry

Gas-Gas reaction

Processes are ion-molecule, neutral-neutral, charge exchange, radiative association, radiative recombination, dissociative recombination, CRP and FUV ionization and dissociation…etc.

Gas-Surface reaction

Assumes molecules/atoms tunneling through potential wells of the surface sites and reaction barriers.

Grain Surface reaction

Includes *accretion* of neutral molecules onto the surfaces of amorphous silicate grains, *energetic sources irradiation* induced molecule-radical, radical-radical, atom-radical, atom-molecule, ion-radical, ion-atom, ion-molecule interaction/recombination, as well as thermal, CRP-driven and UV-desorption.

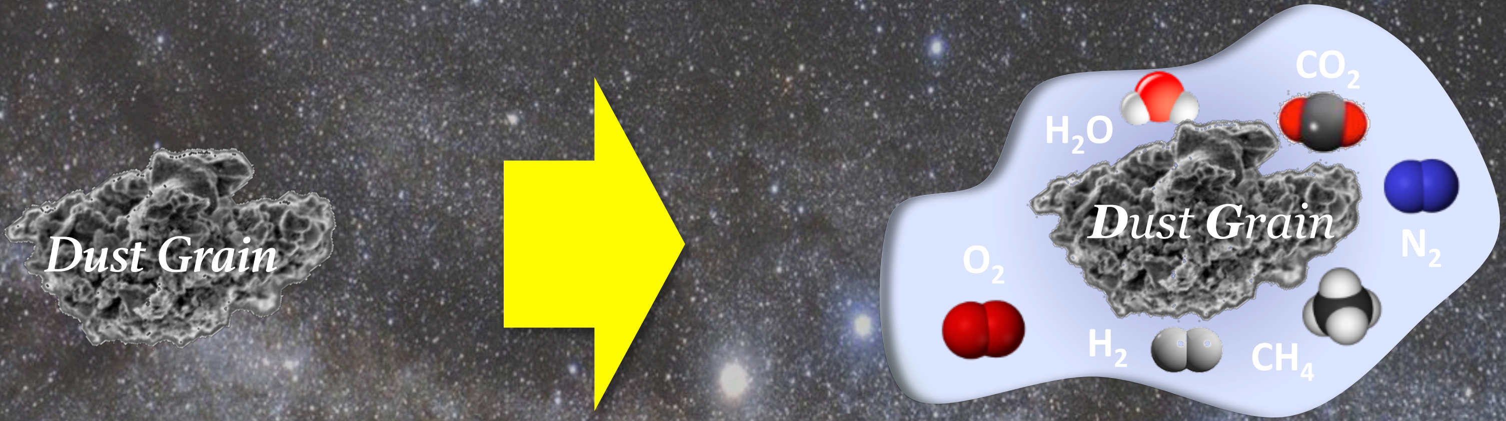
Grain Surface Chemistry

Energetic Sources Irradiation

Interstellar Medium (ISM)

99% is gas, 1% is dust

Interstellar Ice



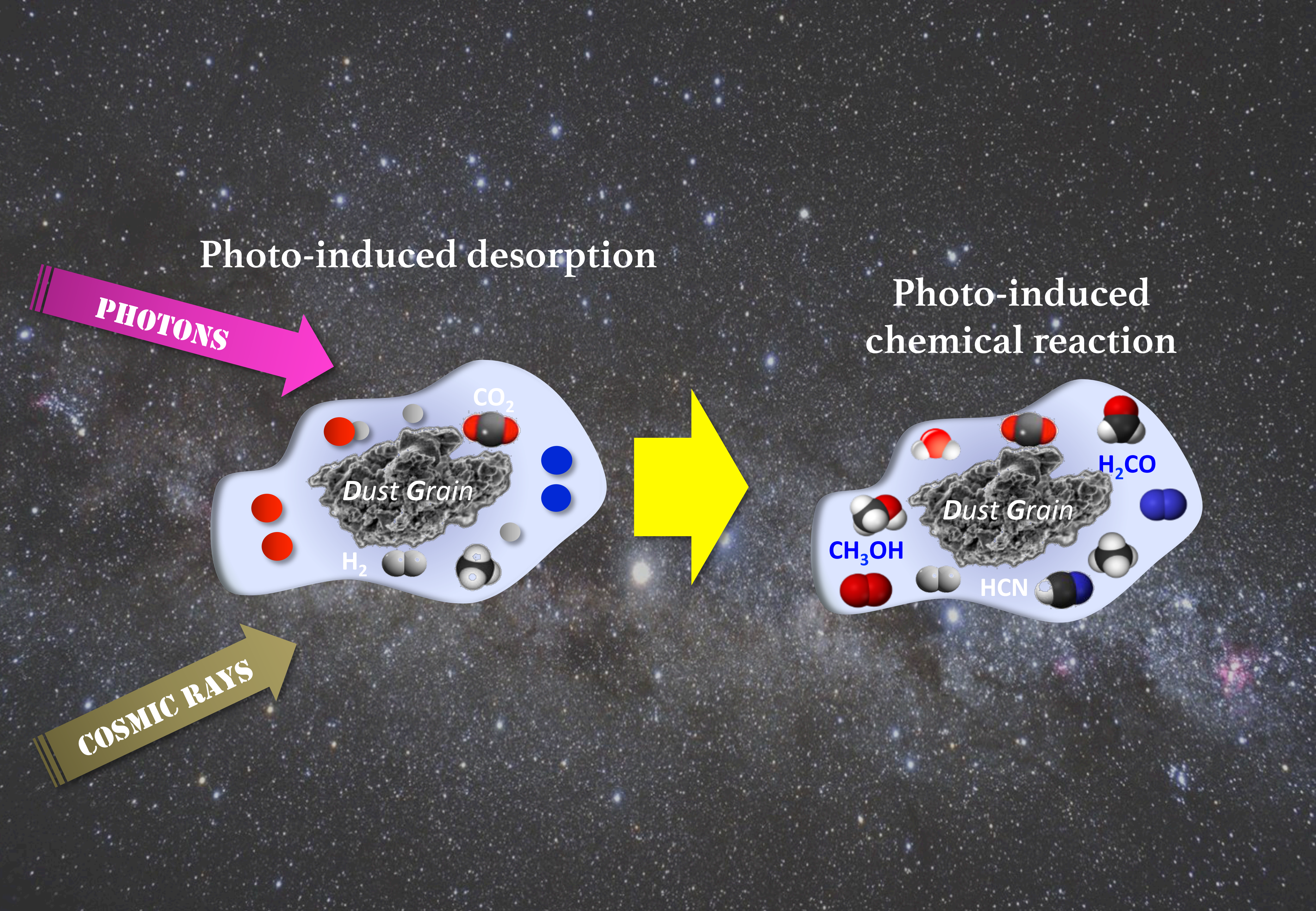
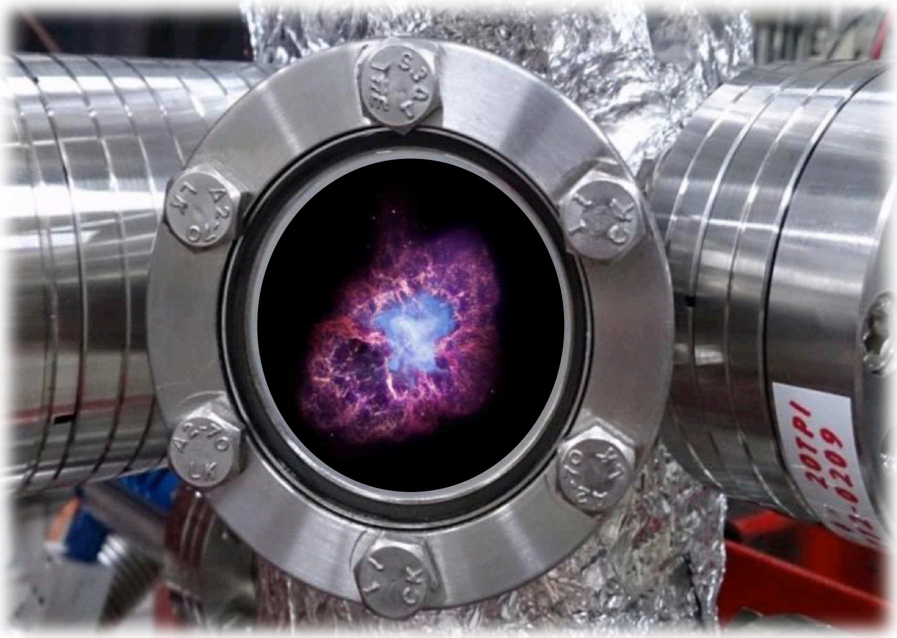


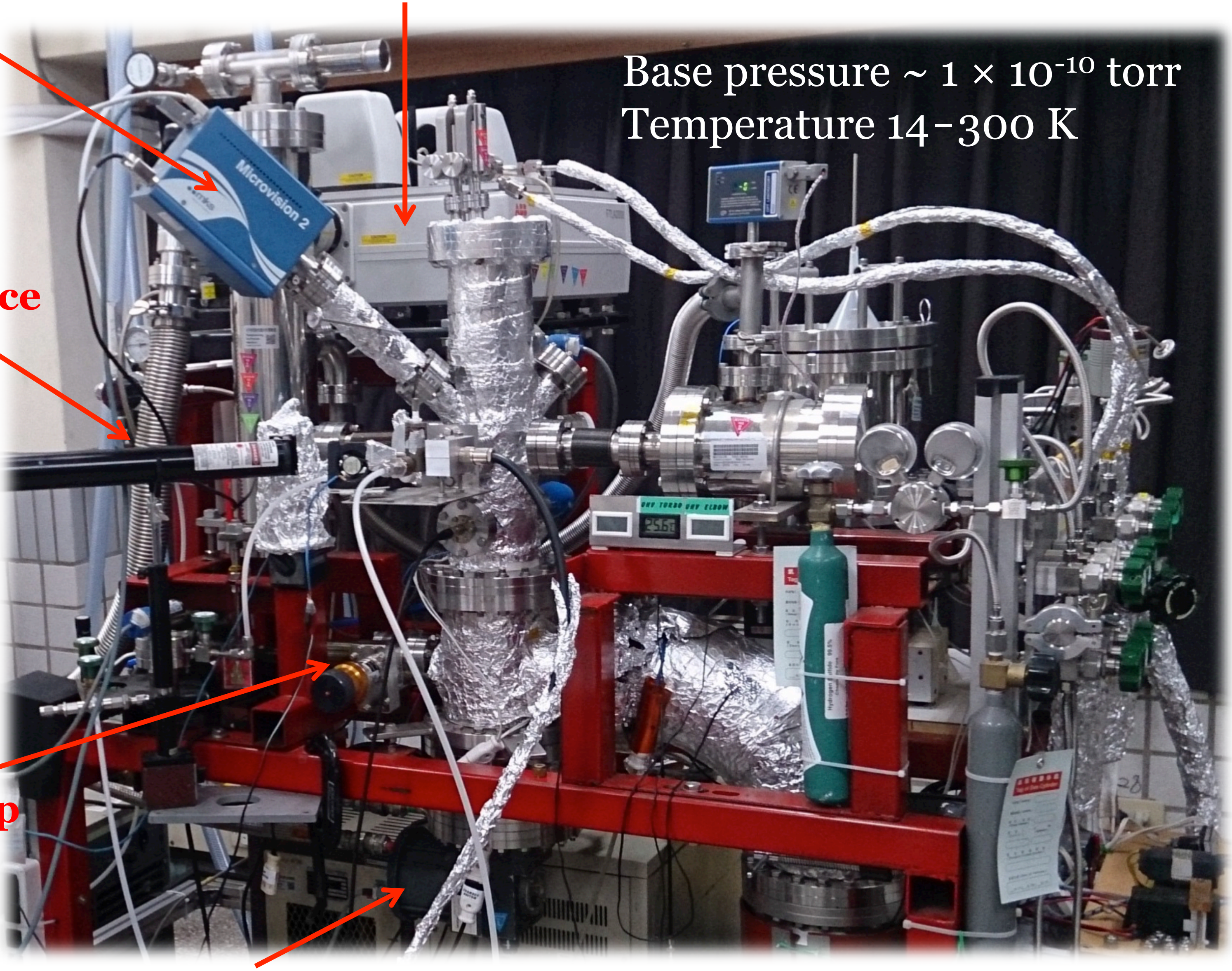
Photo-induced desorption

Photo-induced chemical reaction

How to Approach Interstellar Environment ?



- Ultra High Vacuum
- Extreme Low Temperature
- Energy Source



Transmission FTIR

QMS

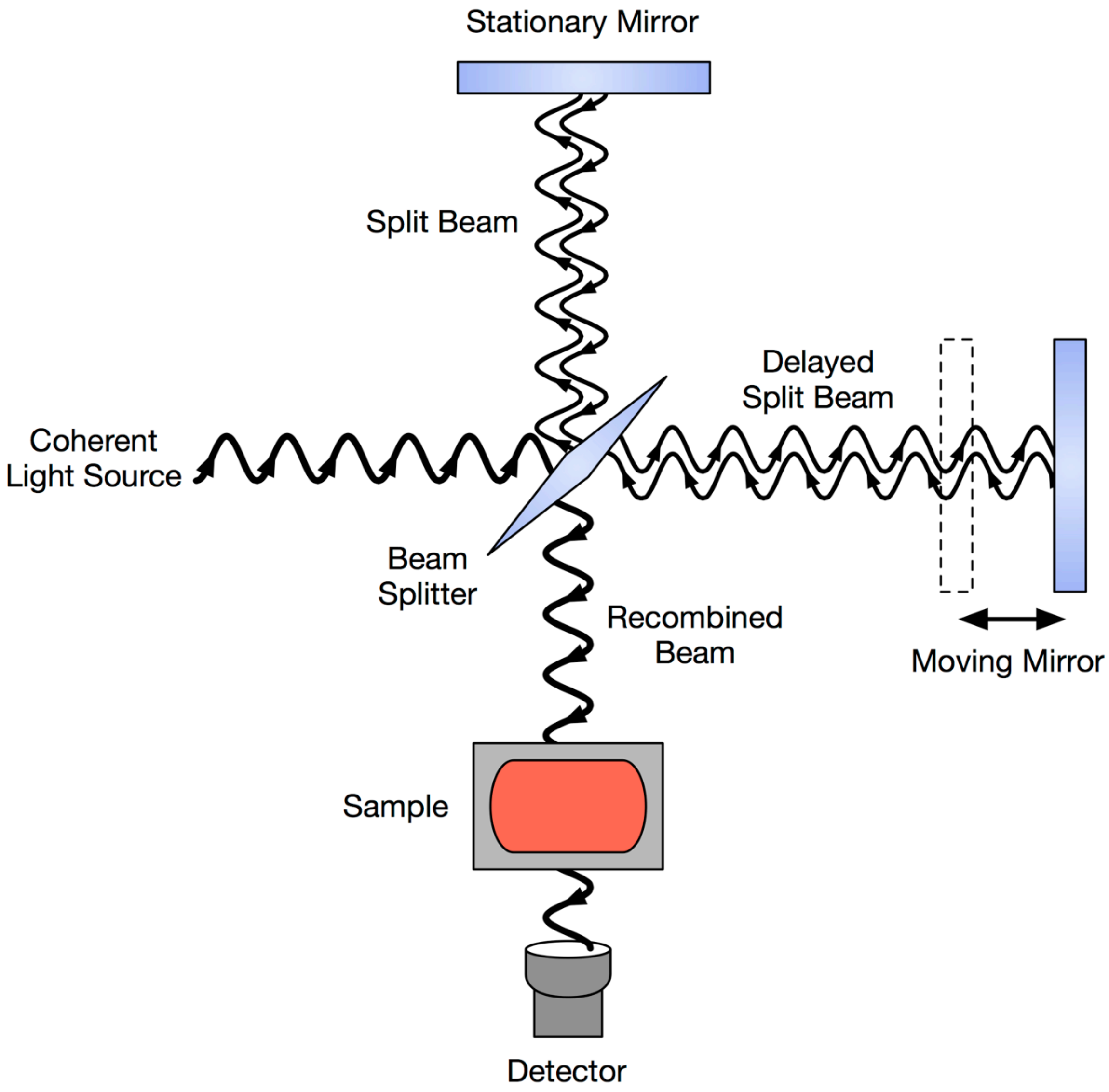
Laser Interference System

Getter Pump

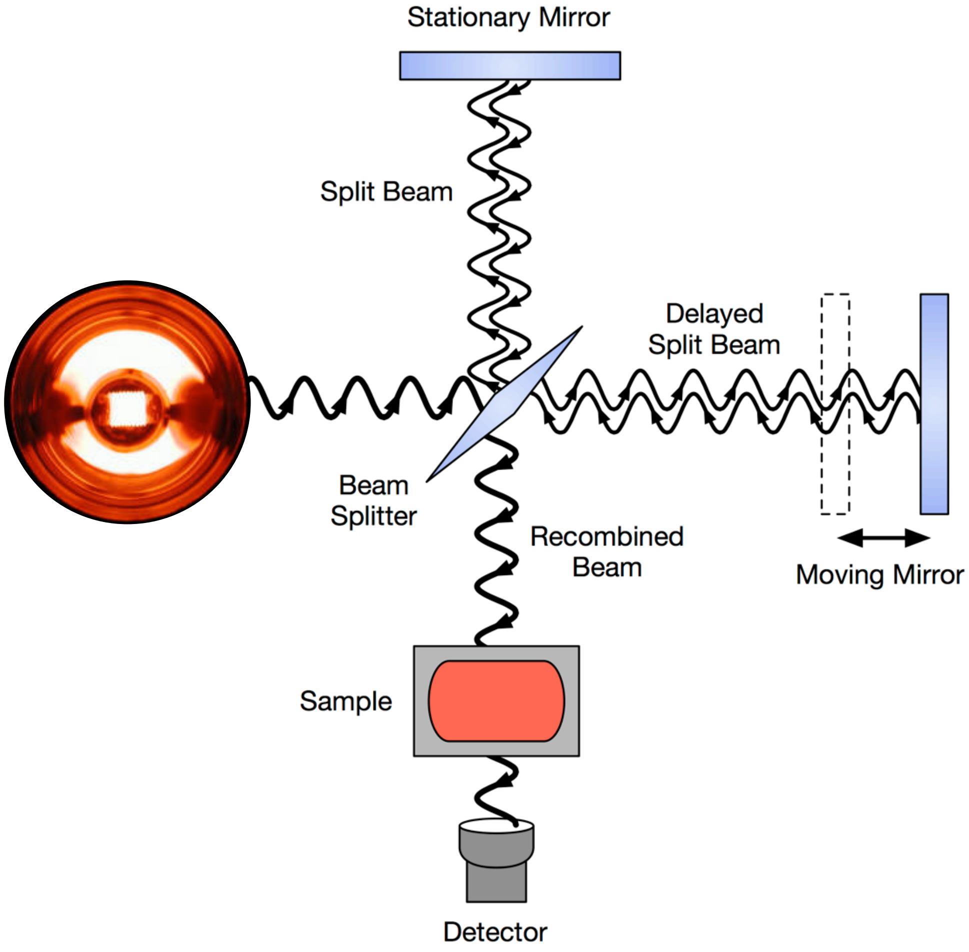
He Closed-Cycle Cryostat

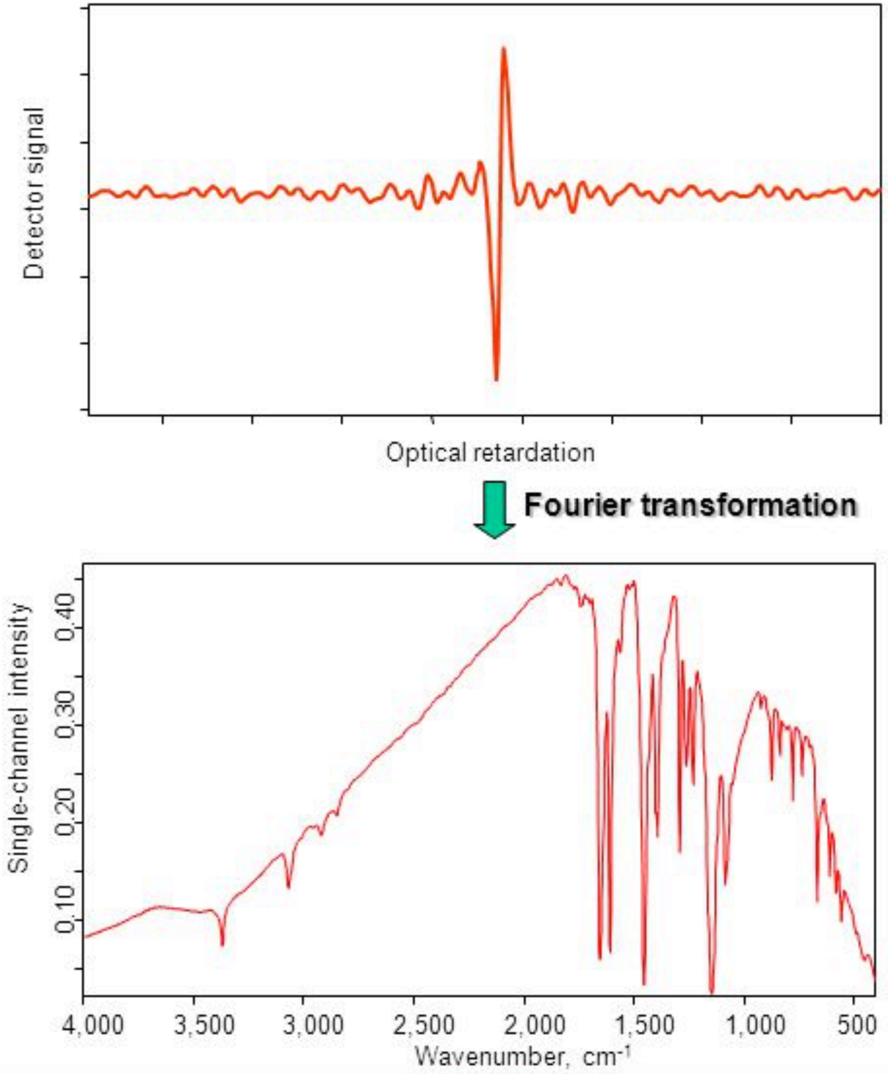
Base pressure ~ 1 × 10^{-10} torr
Temperature 14–300 K

Fourier Transform Infrared Spectrometry

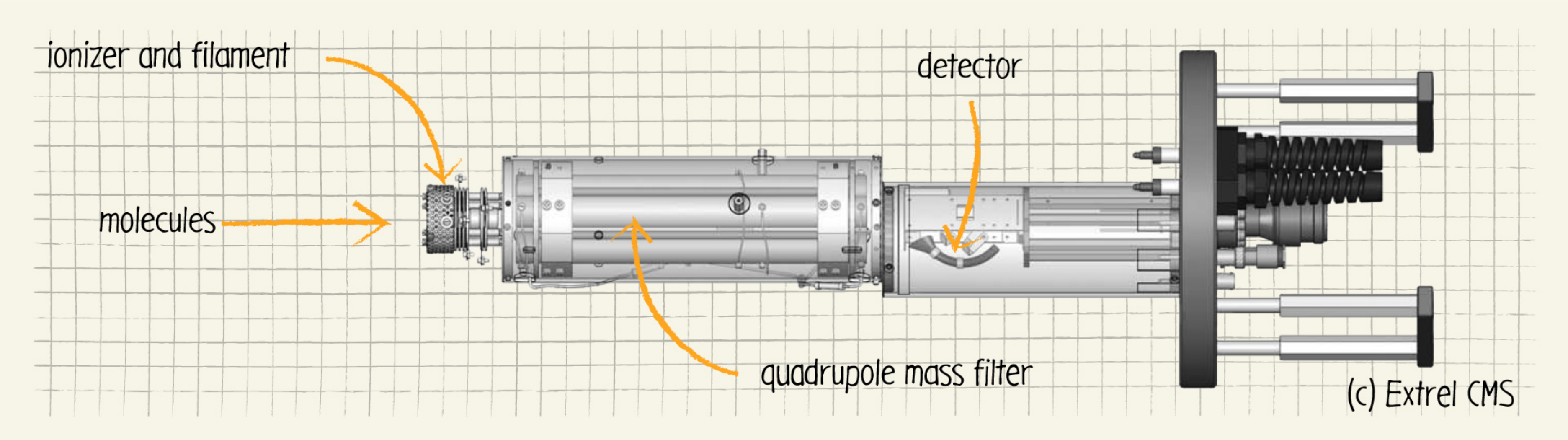


Fourier Transform Infrared Spectrometry

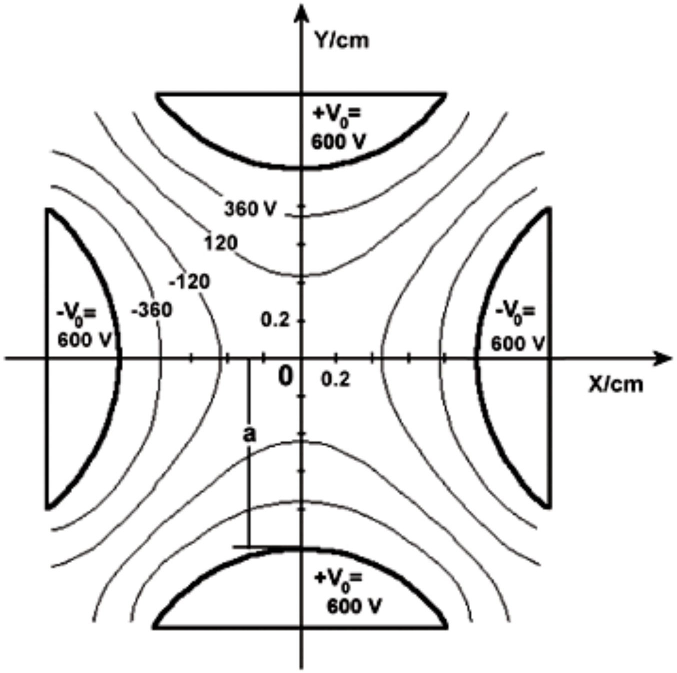


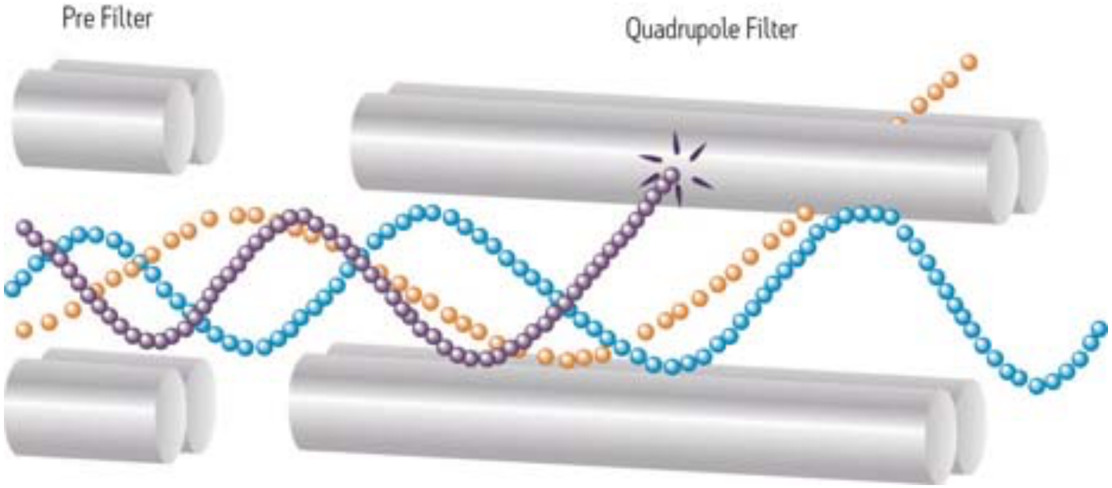


Quadrupole Mass Spectrometer

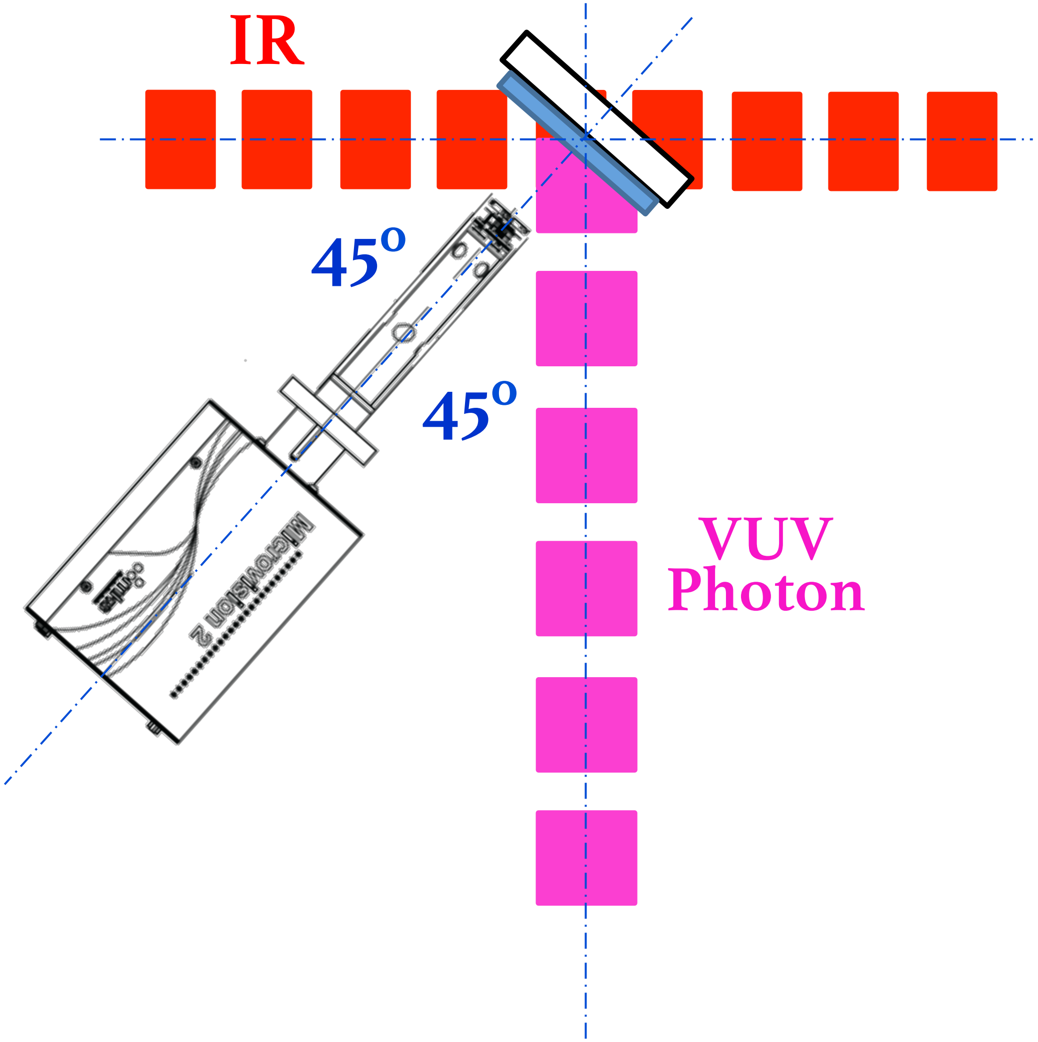


Quadrupole Mass Spectrometer

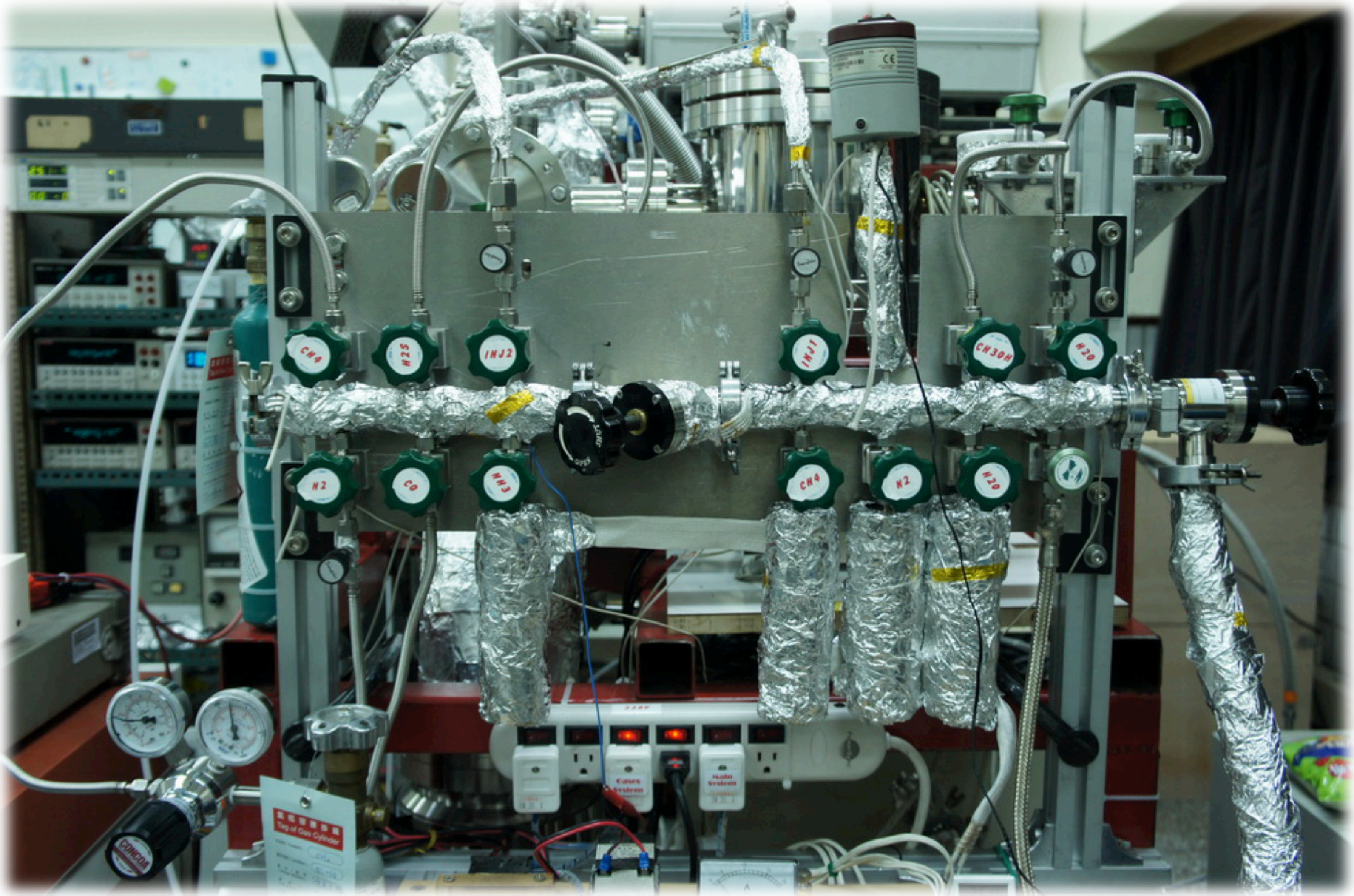


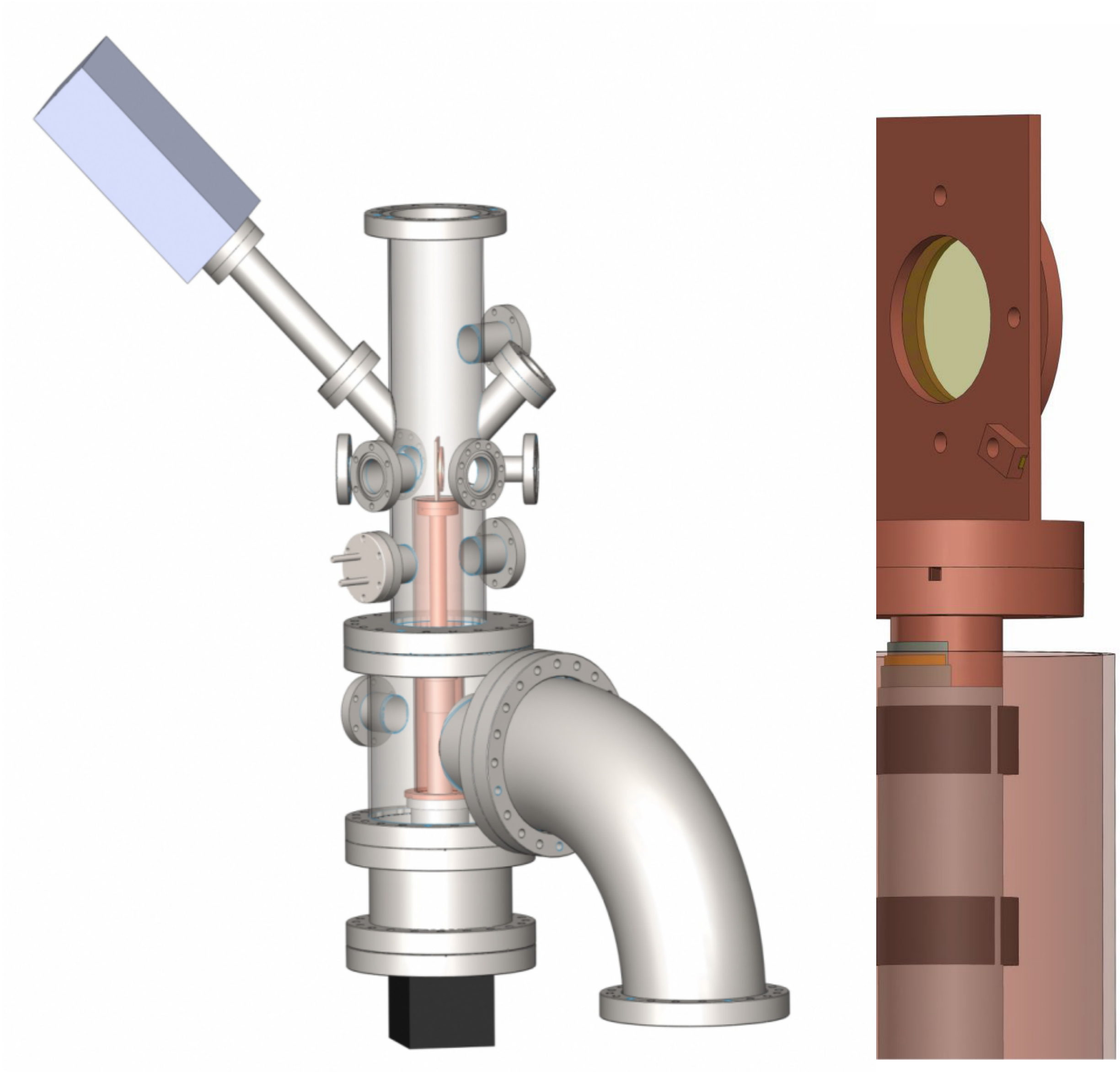


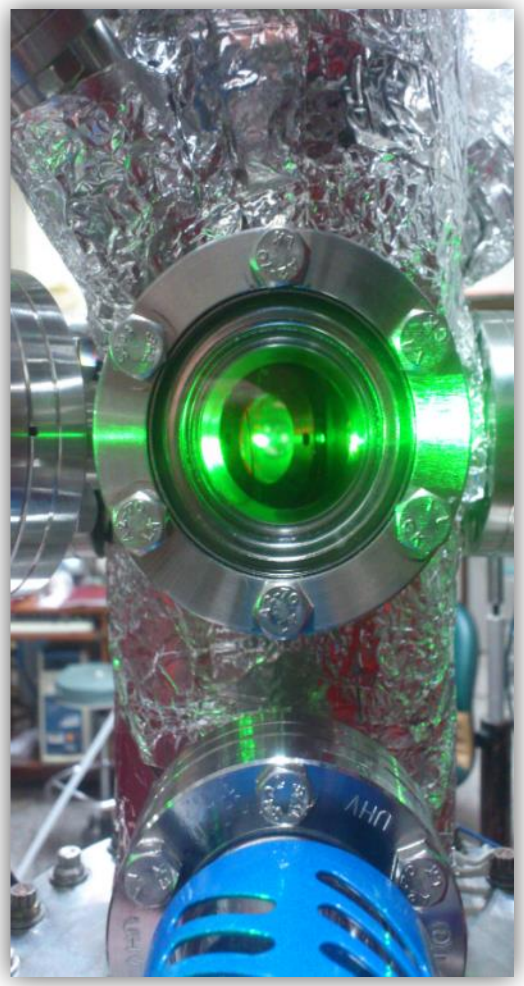
Transmission-FTIR + Quadrupole Mass Spectrometer

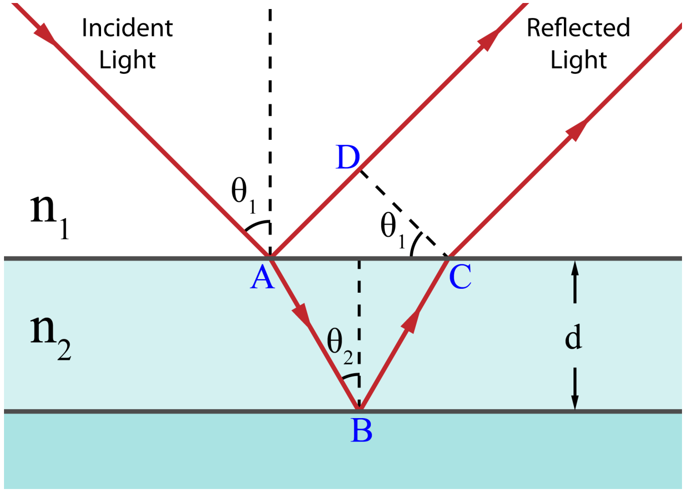


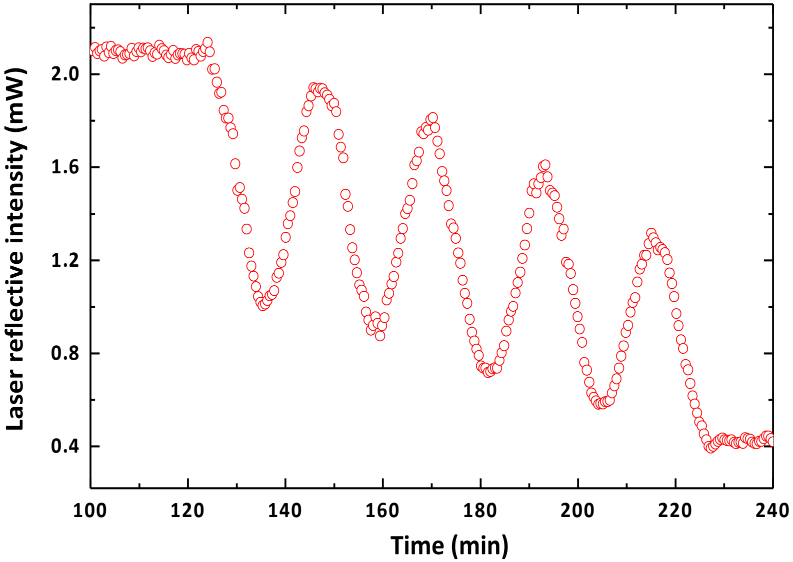
Premixing Gas-line System







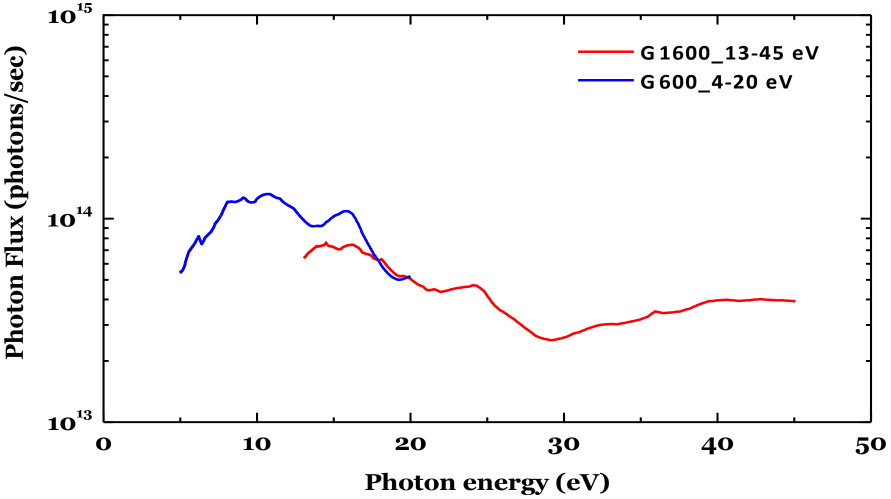

Incident Light
Reflected Light
n_1
n_2
θ_1
θ_1
θ_2
D
A
C
B
d

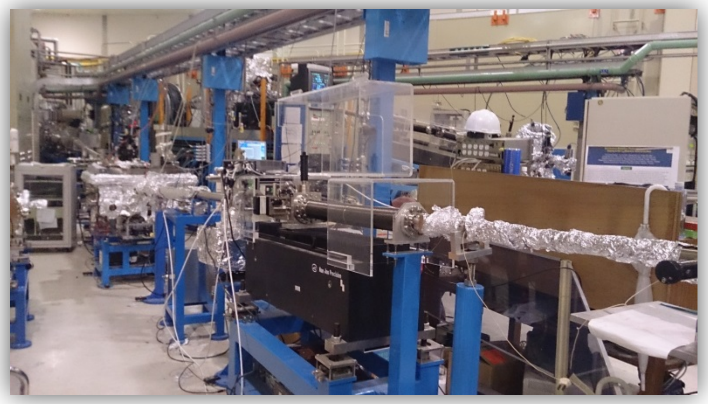

Laser reflective intensity (mW)
2.0
1.6
1.2
0.8
0.4
100
120
140
160
180
200
220
240
Time (min)

Light sources

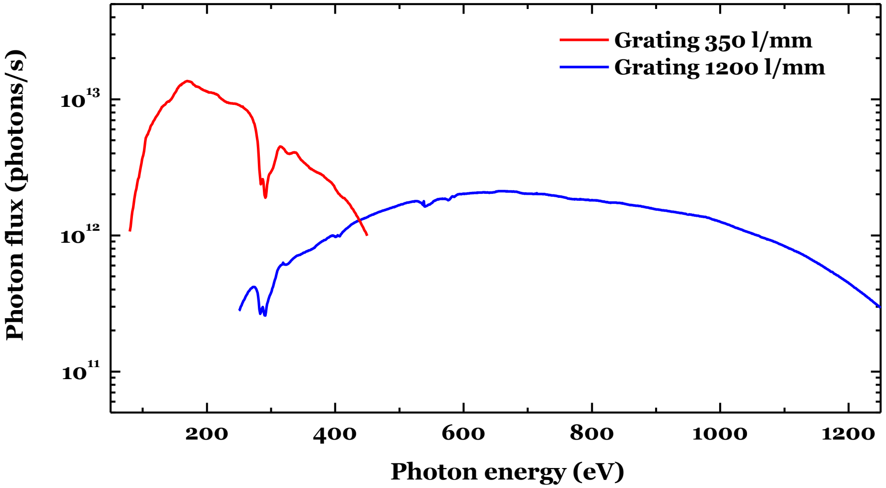
National Synchrotron Radiation Research Center, Taiwan

BL03A (4–45 eV)

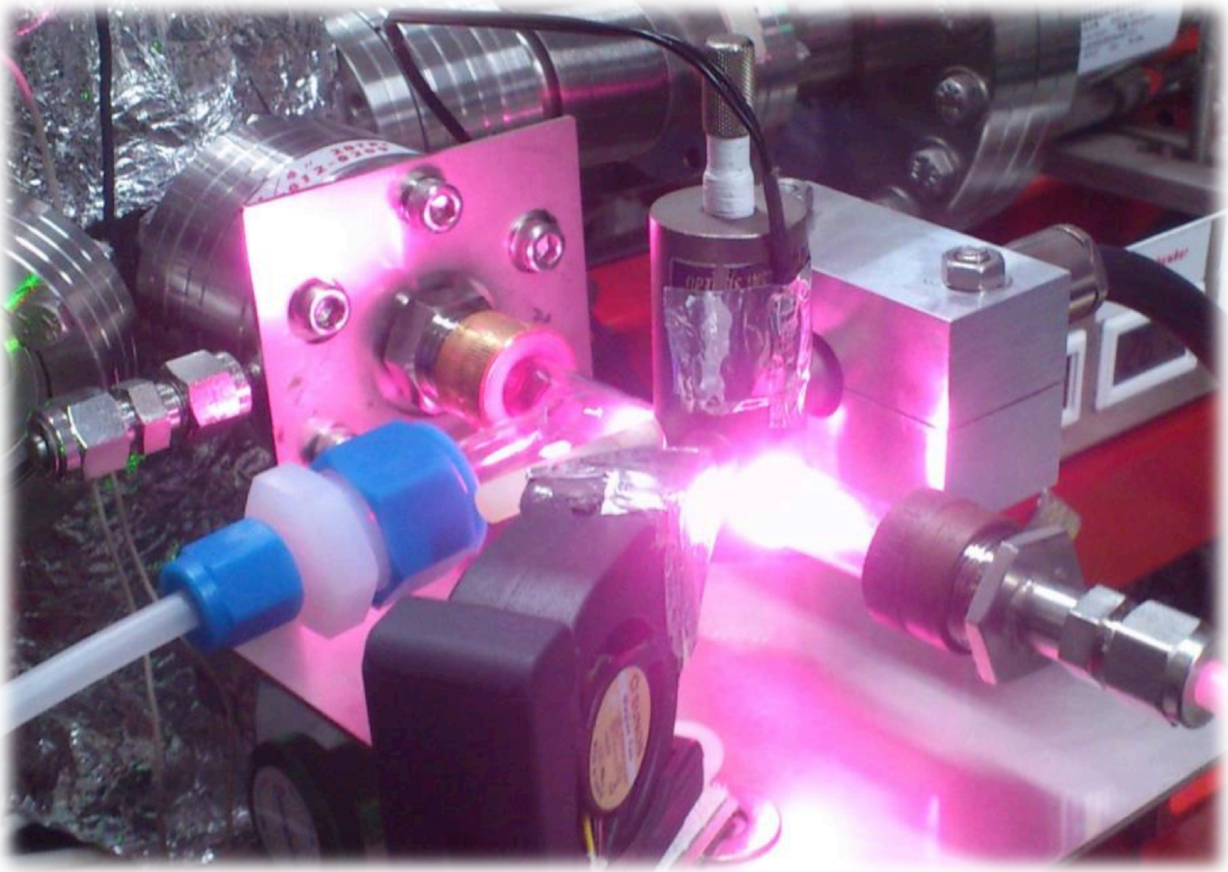




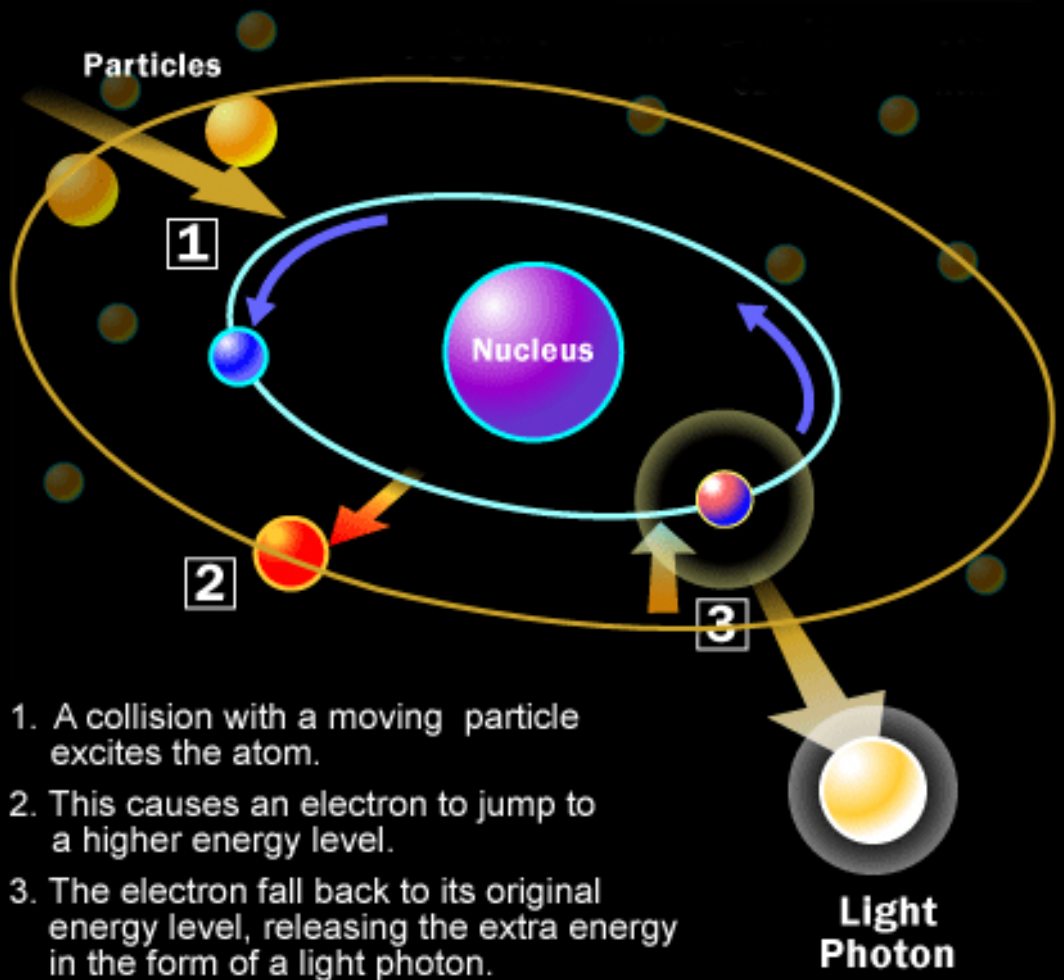
BL08B (80–1200 eV)



Microwave-Discharge Gas-flow Lamp

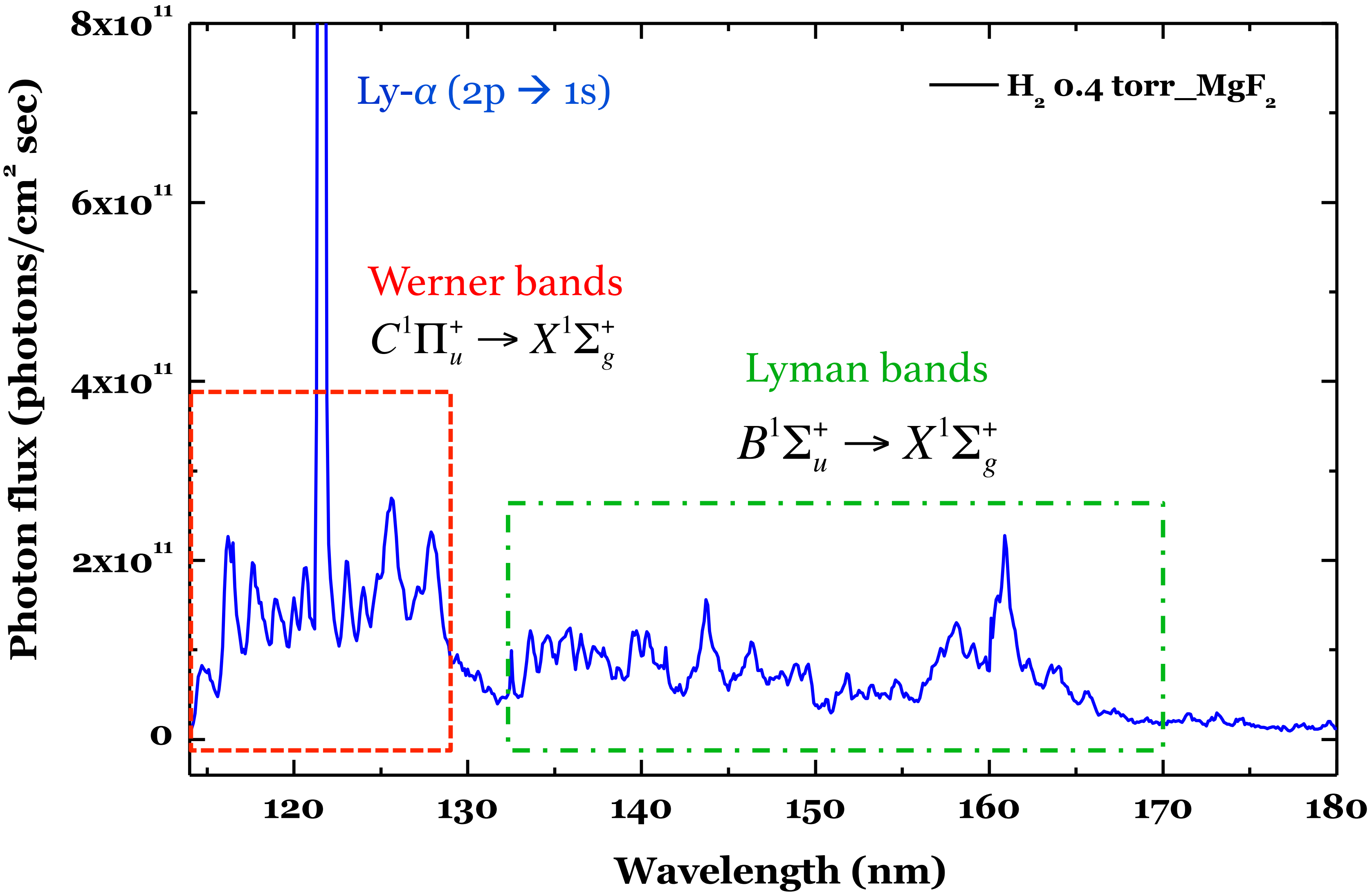


HOW ATOMS EMIT LIGHT



1. A collision with a moving particle excites the atom.
2. This causes an electron to jump to a higher energy level.
3. The electron fall back to its original energy level, releasing the extra energy in the form of a light photon.

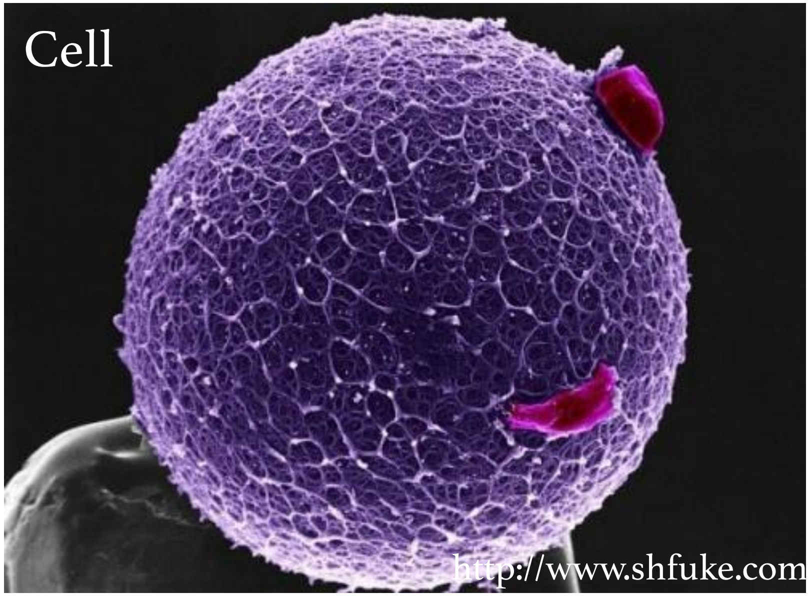
VUV Spectrum of Microwave-Discharge H_2-flow Lamp



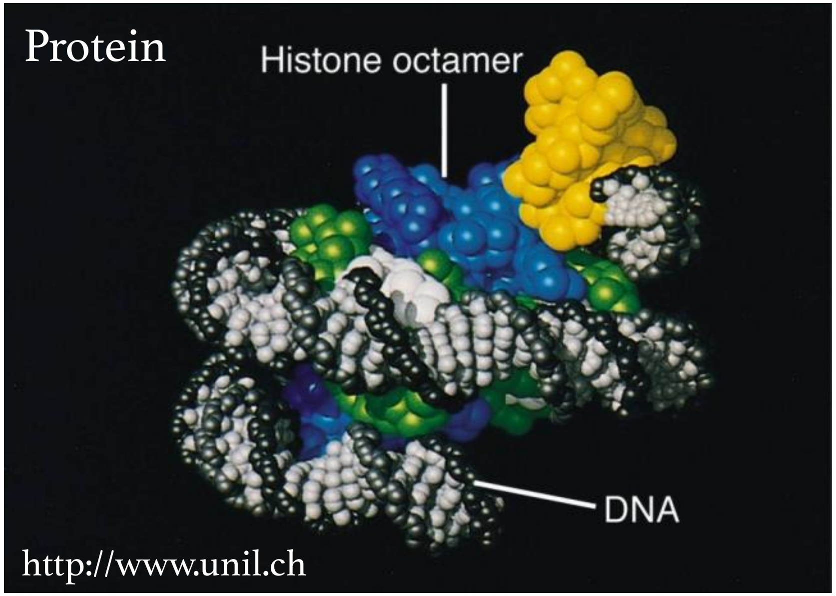
光子作用與光譜分析實驗室
http://pps.phy.ncu.edu.tw

Grain Surface
Photo-induced Chemistry

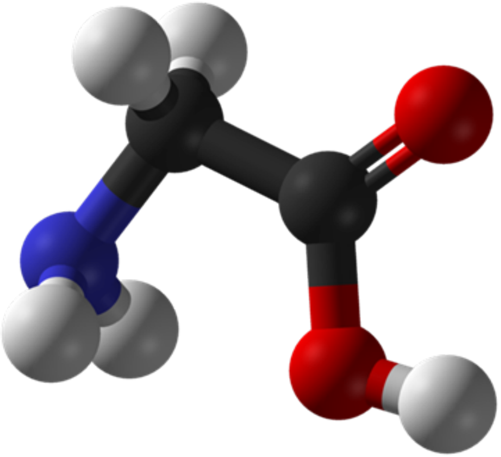
The Origin of Prebiotic Molecules on Primitive Earth

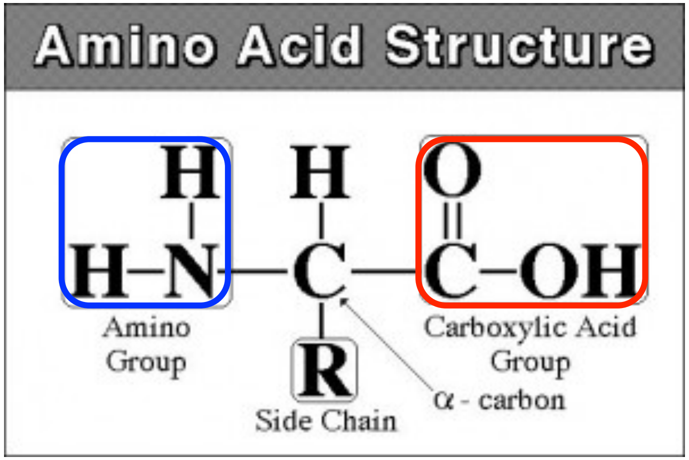


http://www.shfuke.com



http://www.unil.ch

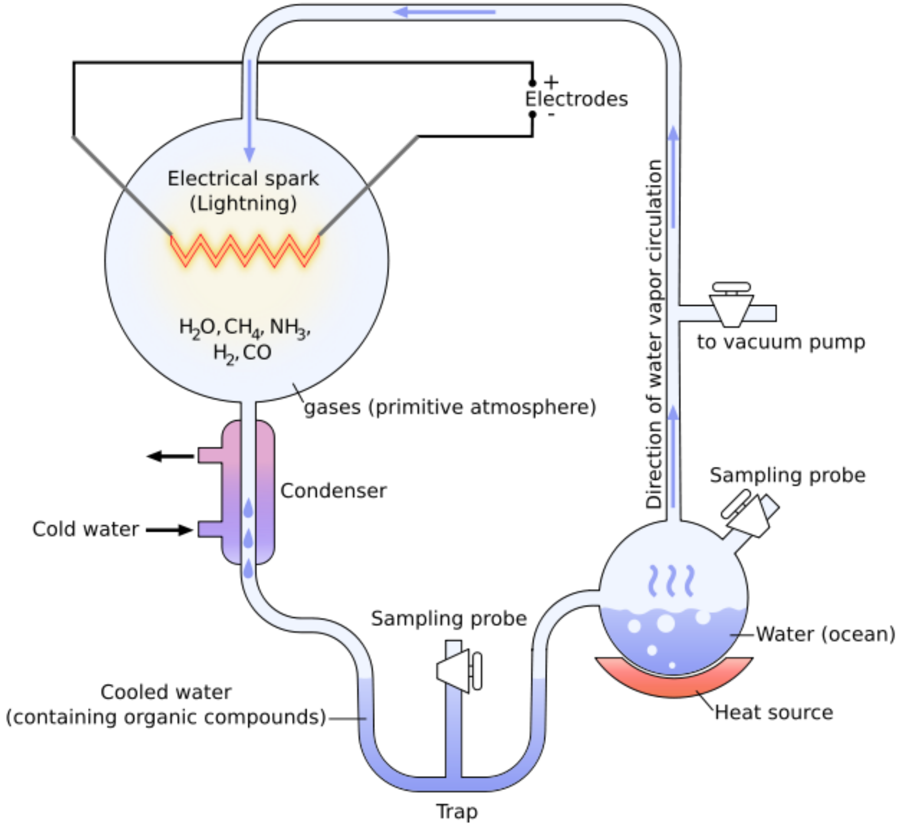




The Origin of Life on Earth


Miller-Urey exp. (1952)

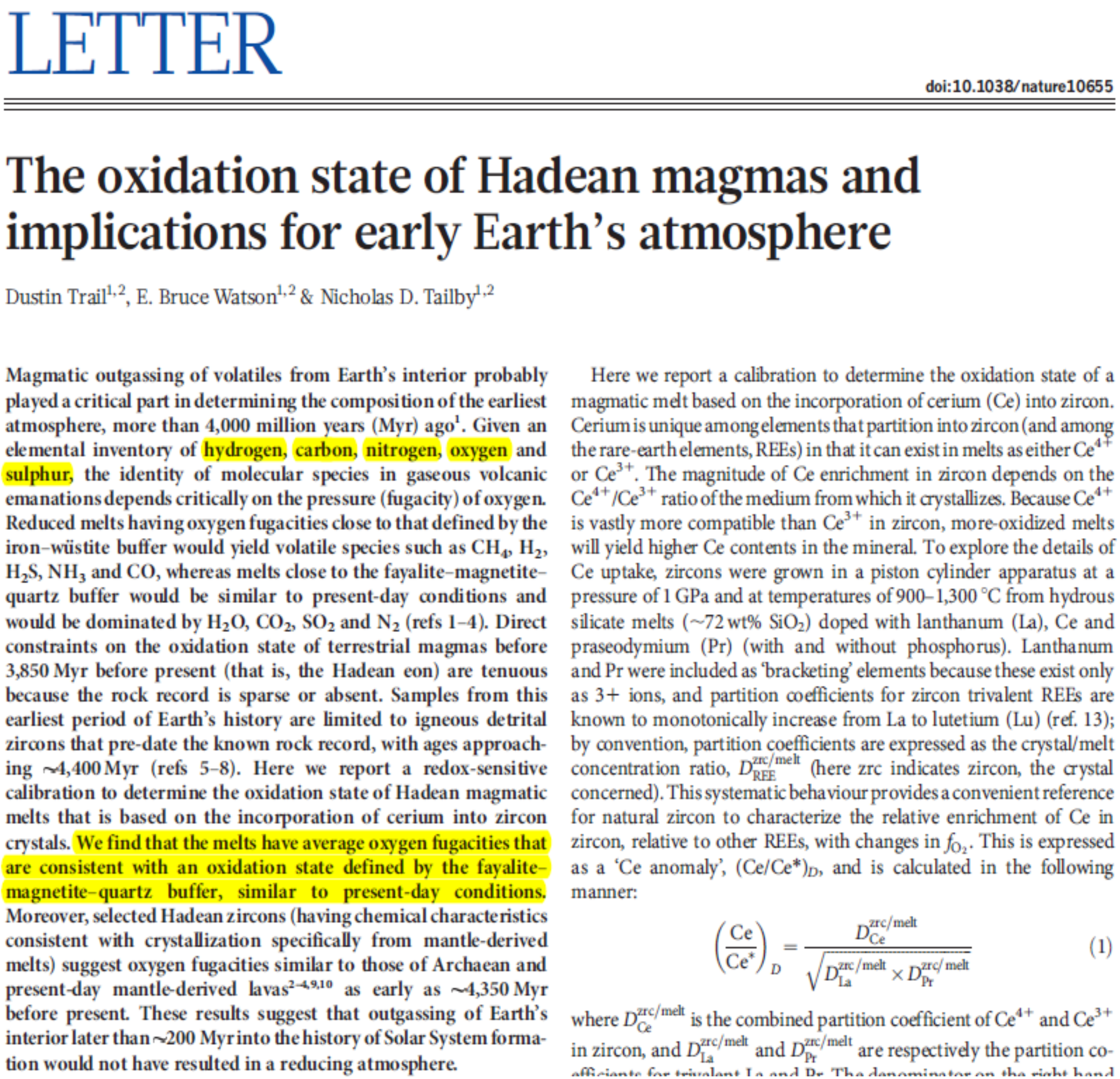
2 % C → amino acids



Argument

There is an absence of oxygen and nitrogen which are the main elemental constituents of our present environment

Production CN-bearing molecules is difficult in an oxidating atmosphere



LETTER

doi:10.1038/nature10655

The oxidation state of Hadean magmas and implications for early Earth's atmosphere

Dustin Trail[1,2], E. Bruce Watson[1,2] & Nicholas D. Tailby[1,2]

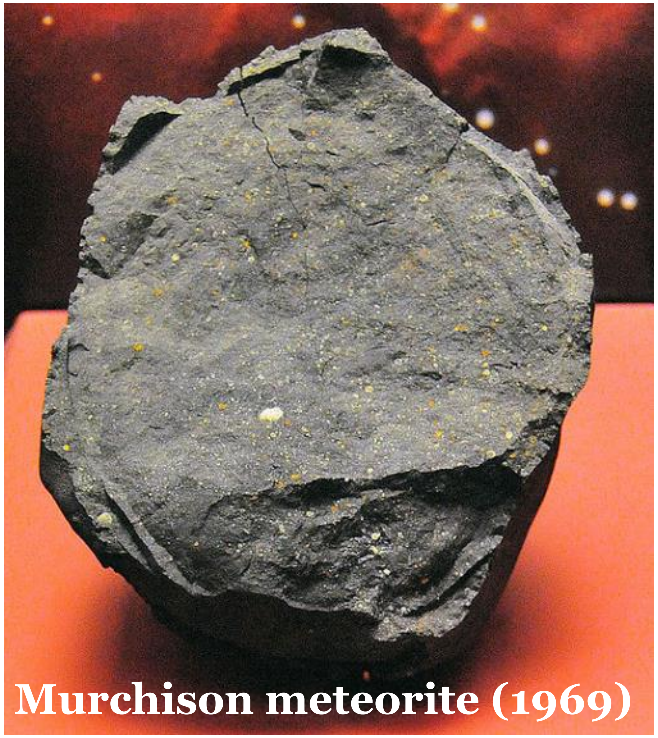
Magmatic outgassing of volatiles from Earth's interior probably played a critical part in determining the composition of the earliest atmosphere, more than 4,000 million years (Myr) ago[1]. Given an elemental inventory of hydrogen, carbon, nitrogen, oxygen and sulphur, the identity of molecular species in gaseous volcanic emanations depends critically on the pressure (fugacity) of oxygen. Reduced melts having oxygen fugacities close to that defined by the iron–wüstite buffer would yield volatile species such as CH_4, H_2, H_2S, NH_3 and CO, whereas melts close to the fayalite–magnetite–quartz buffer would be similar to present-day conditions and would be dominated by H_2O, CO_2, SO_2 and N_2 (refs 1–4). Direct constraints on the oxidation state of terrestrial magmas before 3,850 Myr before present (that is, the Hadean eon) are tenuous because the rock record is sparse or absent. Samples from this earliest period of Earth's history are limited to igneous detrital zircons that pre-date the known rock record, with ages approaching ~4,400 Myr (refs 5–8). Here we report a redox-sensitive calibration to determine the oxidation state of Hadean magmatic melts that is based on the incorporation of cerium into zircon crystals. We find that the melts have average oxygen fugacities that are consistent with an oxidation state defined by the fayalite–magnetite–quartz buffer, similar to present-day conditions. Moreover, selected Hadean zircons (having chemical characteristics consistent with crystallization specifically from mantle-derived melts) suggest oxygen fugacities similar to those of Archaean and present-day mantle-derived lavas[2–4,9,10] as early as ~4,350 Myr before present. These results suggest that outgassing of Earth's interior later than ~200 Myr into the history of Solar System formation would not have resulted in a reducing atmosphere.

Here we report a calibration to determine the oxidation state of a magmatic melt based on the incorporation of cerium (Ce) into zircon. Cerium is unique among elements that partition into zircon (and among the rare-earth elements, REEs) in that it can exist in melts as either Ce^{4+} or Ce^{3+}. The magnitude of Ce enrichment in zircon depends on the Ce^{4+}/Ce^{3+} ratio of the medium from which it crystallizes. Because Ce^{4+} is vastly more compatible than Ce^{3+} in zircon, more-oxidized melts will yield higher Ce contents in the mineral. To explore the details of Ce uptake, zircons were grown in a piston cylinder apparatus at a pressure of 1 GPa and at temperatures of 900–1,300 °C from hydrous silicate melts (~72 wt% SiO_2) doped with lanthanum (La), Ce and praseodymium (Pr) (with and without phosphorus). Lanthanum and Pr were included as 'bracketing' elements because these exist only as 3+ ions, and partition coefficients for zircon trivalent REEs are known to monotonically increase from La to lutetium (Lu) (ref. 13); by convention, partition coefficients are expressed as the crystal/melt concentration ratio, $D_{REE}^{zrc/melt}$ (here zrc indicates zircon, the crystal concerned). This systematic behaviour provides a convenient reference for natural zircon to characterize the relative enrichment of Ce in zircon, relative to other REEs, with changes in f_{O_2}. This is expressed as a 'Ce anomaly', $(Ce/Ce^*)_D$, and is calculated in the following manner:

$$\left(\frac{Ce}{Ce^*}\right)_D = \frac{D_{Ce}^{zrc/melt}}{\sqrt{D_{La}^{zrc/melt} \times D_{Pr}^{zrc/melt}}} \qquad (1)$$

where $D_{Ce}^{zrc/melt}$ is the combined partition coefficient of Ce^{4+} and Ce^{3+} in zircon, and $D_{La}^{zrc/melt}$ and $D_{Pr}^{zrc/melt}$ are respectively the partition co-

Trail *et al.* 2011, Nature **480**, 79

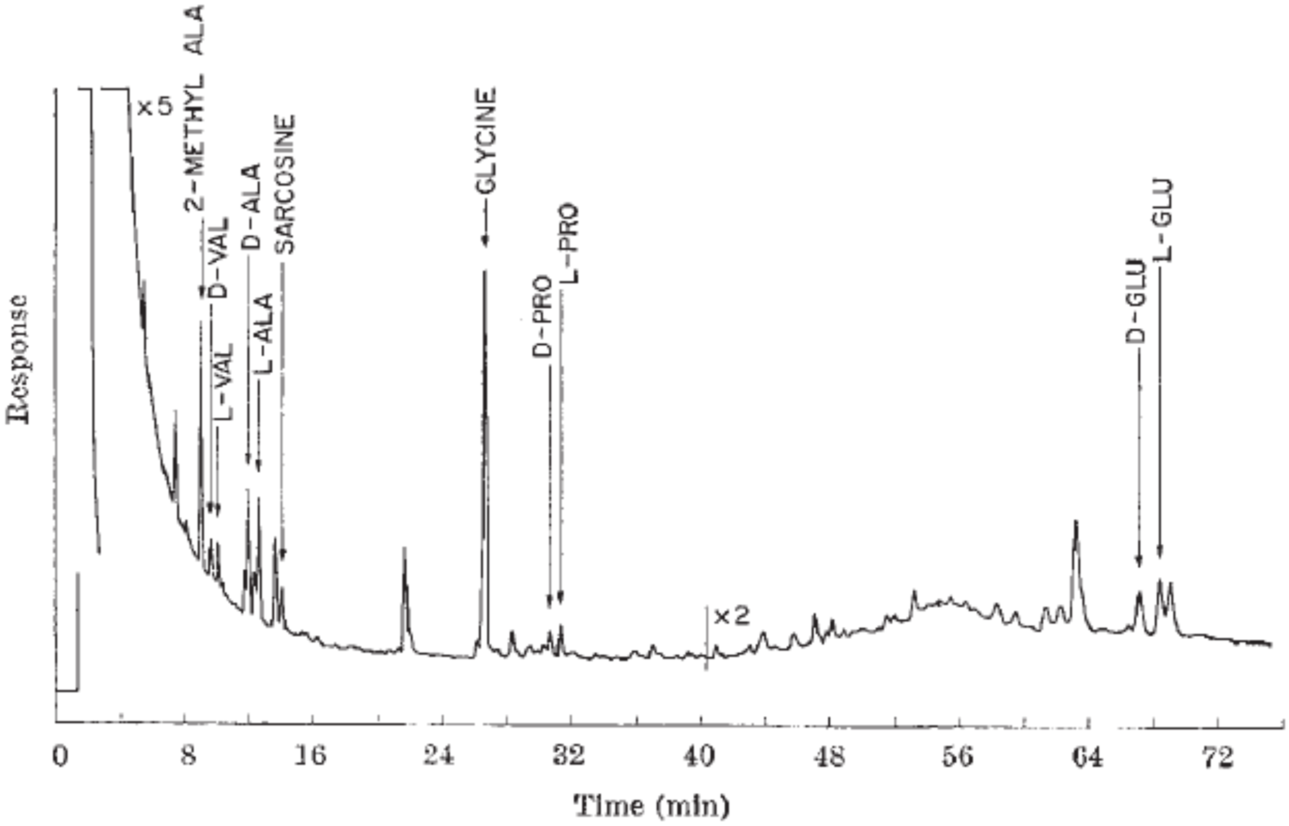


Murchison meteorite (1969)

High-performance liquid chromatography

Gas chromatography–mass spectrometry

Over *15* amino acids have been identified



Kvenvolden *et al.* 1970, Nature, **228**, 923

Contamination ?

Isotope Fractionation

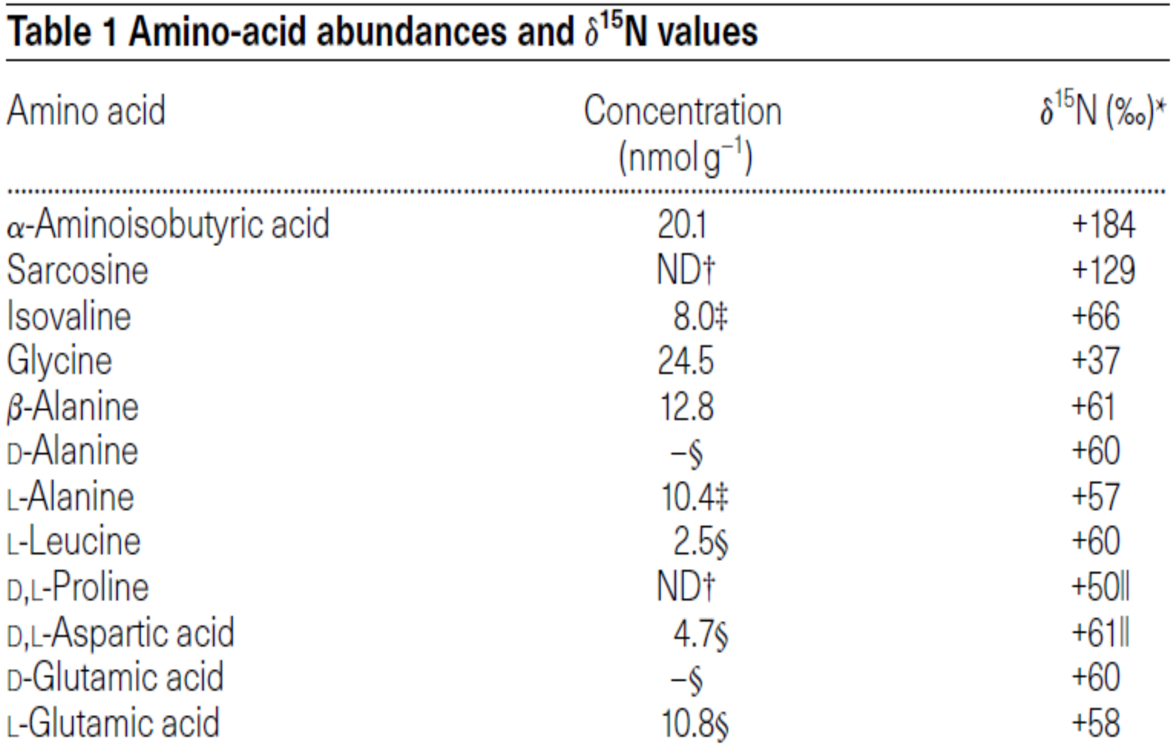


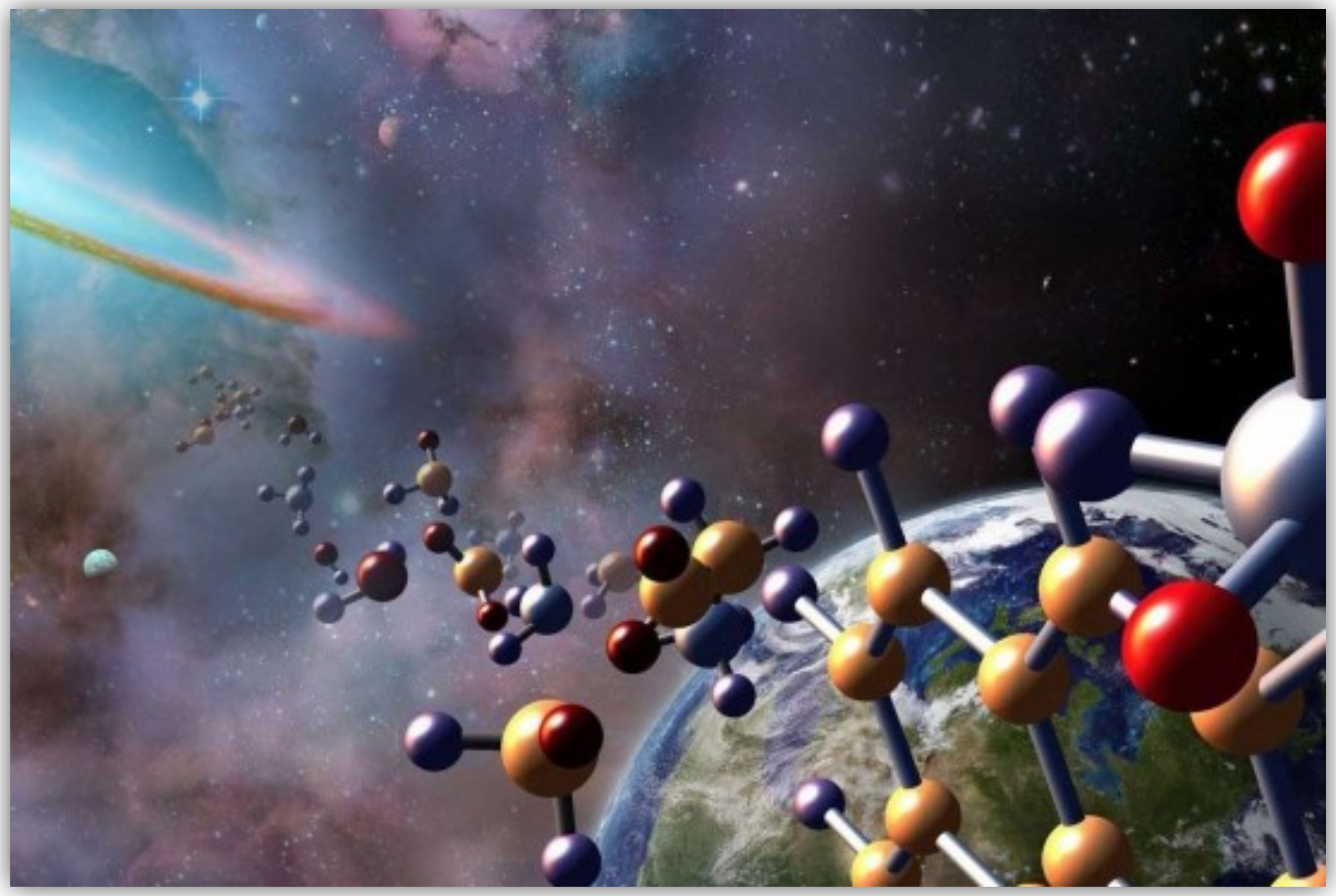
Table 1 Amino-acid abundances and δ^{15}N values

Amino acid	Concentration (nmol g^{-1})	δ^{15}N (‰)*
α-Aminoisobutyric acid	20.1	+184
Sarcosine	ND†	+129
Isovaline	8.0‡	+66
Glycine	24.5	+37
β-Alanine	12.8	+61
D-Alanine	–§	+60
L-Alanine	10.4‡	+57
L-Leucine	2.5§	+60
D,L-Proline	ND†	+50‖
D,L-Aspartic acid	4.7§	+61‖
D-Glutamic acid	–§	+60
L-Glutamic acid	10.8§	+58

$$\delta^{15}\mathrm{N}(‰) = [(^{15}\mathrm{N}/^{14}\mathrm{N})_{\mathrm{sample}}/(^{15}\mathrm{N}/^{14}\mathrm{N})_{\mathrm{standard}} - 1] \times 10^3$$

Engel *et al.* 1997, Nature **389**, 265

A possible scenario of the origin of life

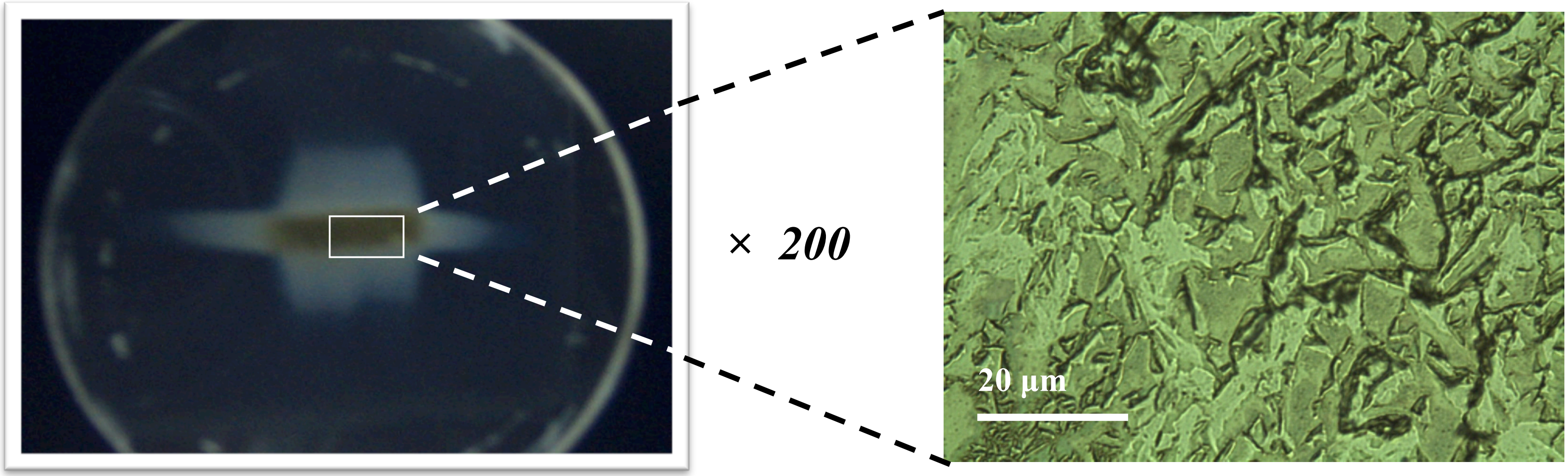


What can we do for the hypothesis
Origin of Life Came From Outer Space?

Species	Comet Hale-Bopp [a]	NGC 7538 IRS 9 [b]	W33A [b]
H_2O	100	100	100
CO	20	16	9
CO_2	6	22	14
NH_3	0.6	13	15
CH_3OH	2	5	22
H_2CO	1	4	1.7-7
HCOOH	0.05	3	0.4-2
CH_4	1	2	2
C_2H_2	0.5	...	...
C_2H_6	0.5	...	...
OCN^-	0.37	1	3
OCS,XCS	0.7	...	0.3
SO_2	0.15	...	...

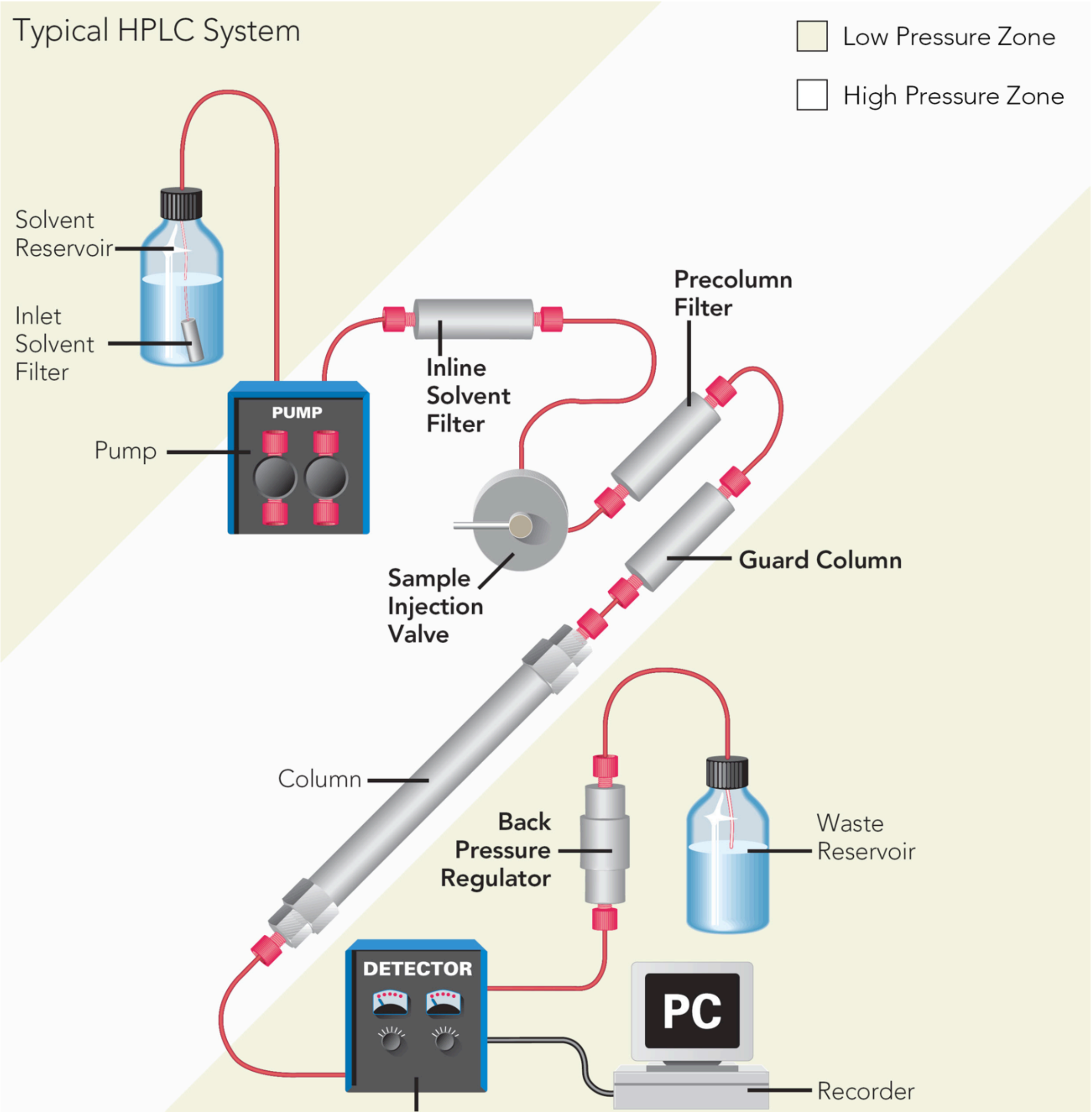
a. Crovisier et al. 1998, Faraday Discussion, 109, 437
b. Gibb et al. 2000, ApJ, 536, 347

Residue of H_2O+CO_2+NH_3 ice mixture

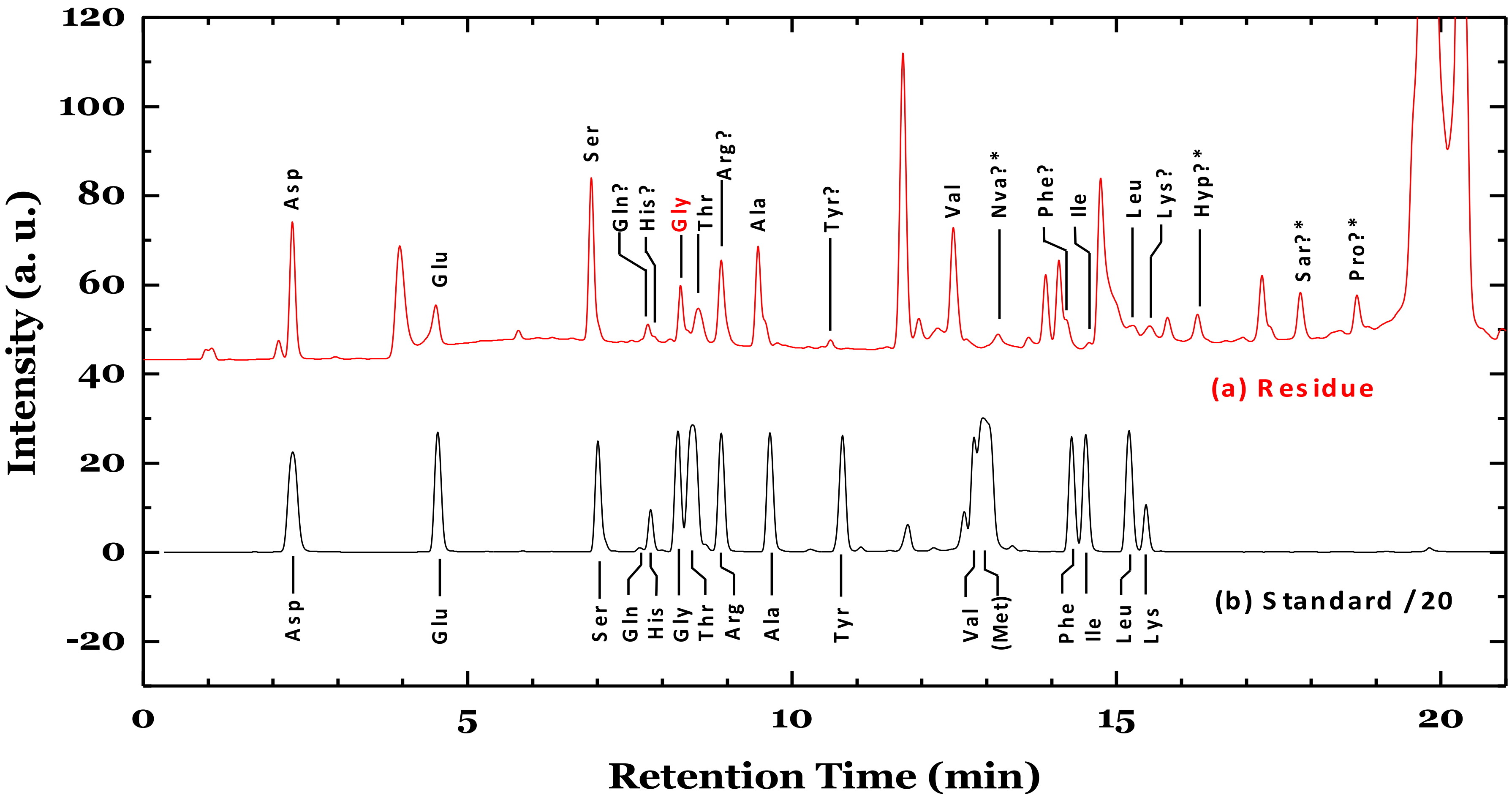


After broad band VUV/EUV irradiation (4-20 eV) and warmed up (15-300 K)

High-performance liquid chromatography



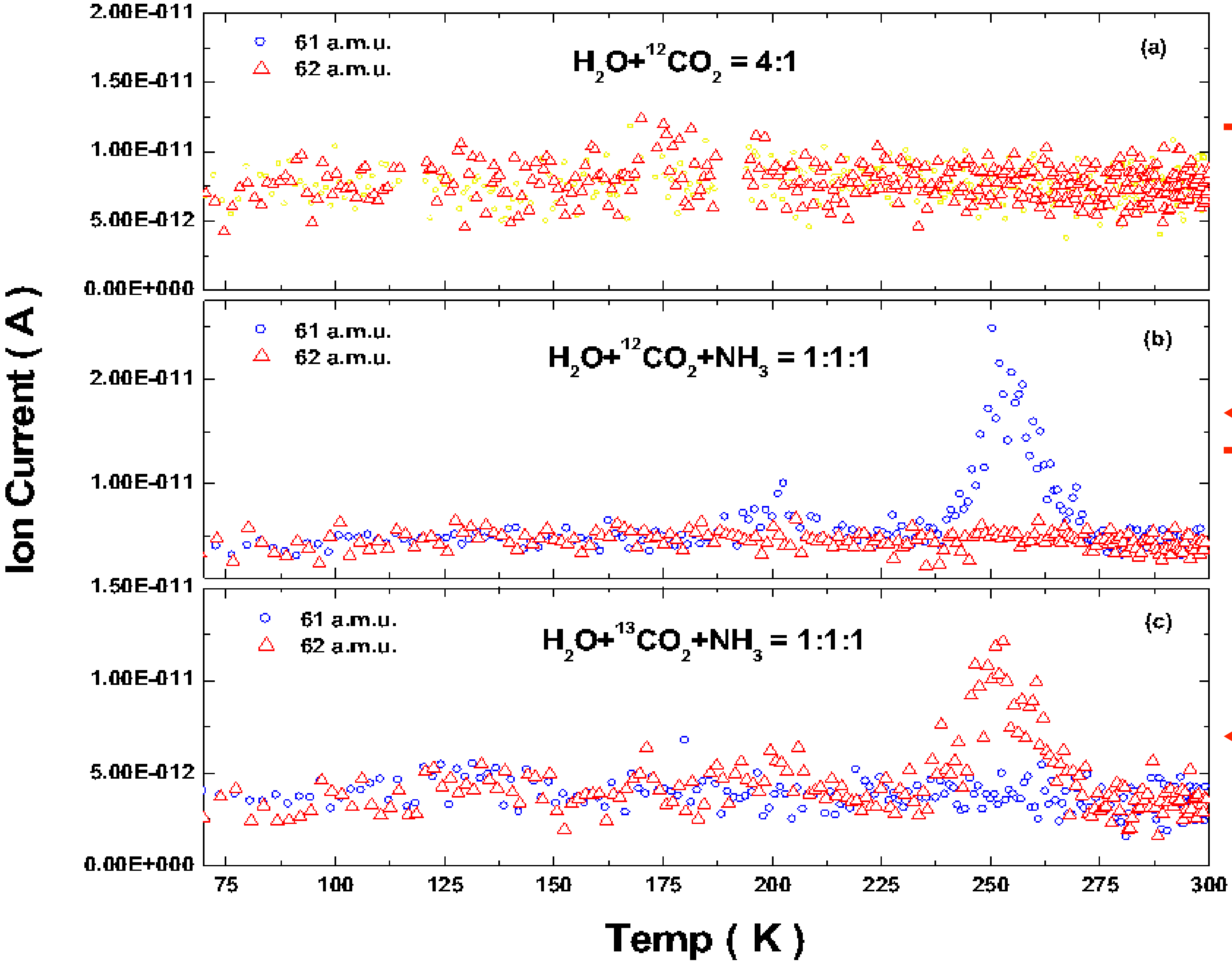
> *9* *amino acids have been identified*



Nuevo et al. 2007, Adv. Space Res., 40, 1628

It seems that amino acids are not difficult to be produced !

But the problems is How amino acids be produced ?



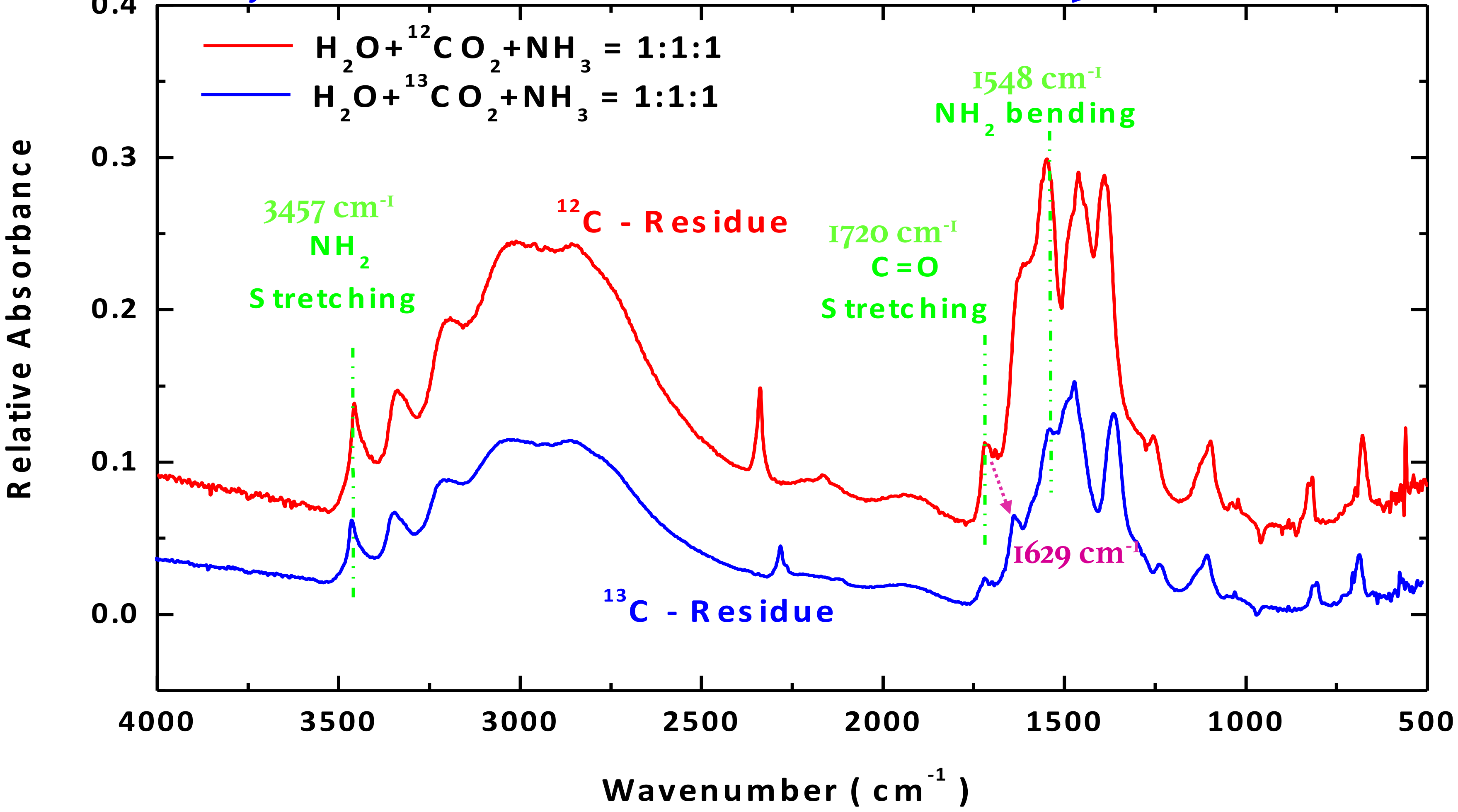
Contained

N

Contained only

One C

After UV/EUV irradiation, ice mixture warmed up to 250K



Chen *et al*. 2007, A&A, **464**, 253-257.

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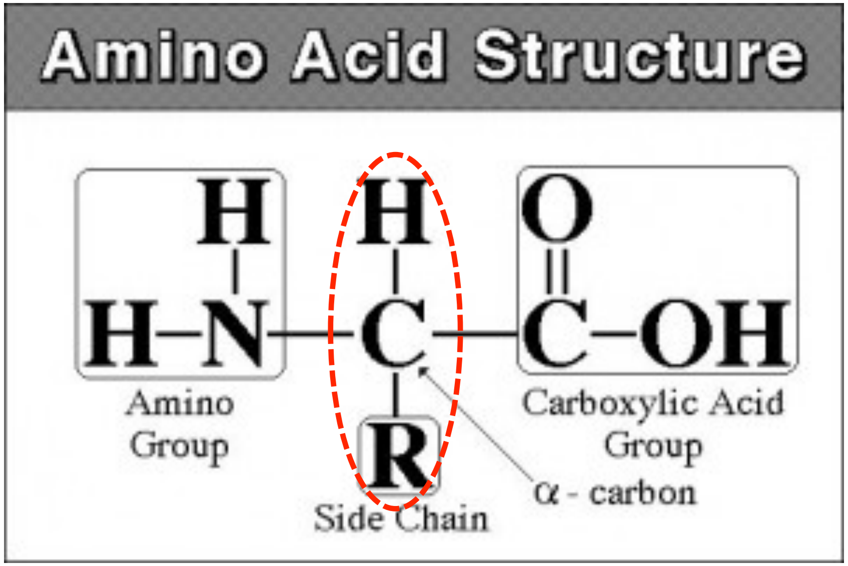
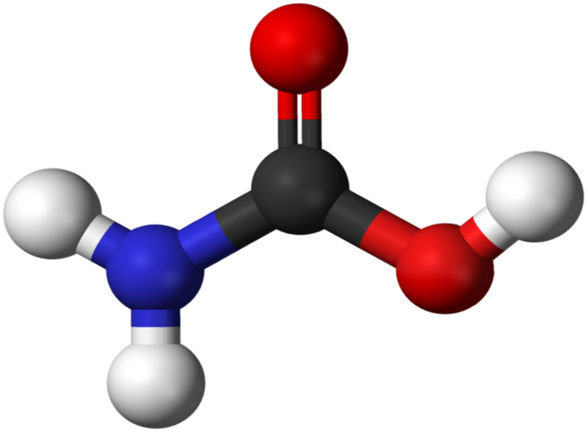
A Molecule called *carbamic acid*



m/z = 61

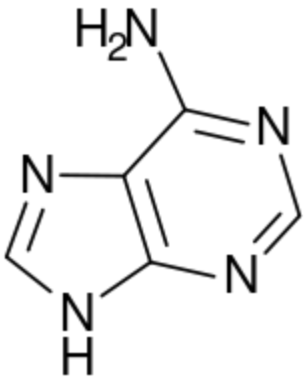


It is technically the *simplest amino acid*

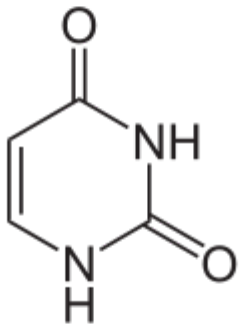
Besides amino acids, *Uracil* was also discovered in Murchison meteorite

Murchison meteorite (1969)

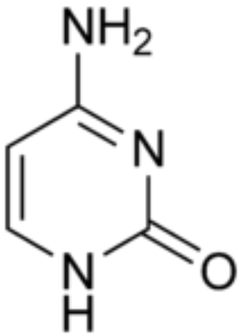
Ribonucleic acid (RNA) 核糖核酸



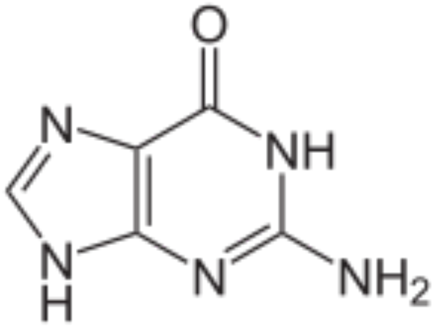
Adenine
腺嘌呤



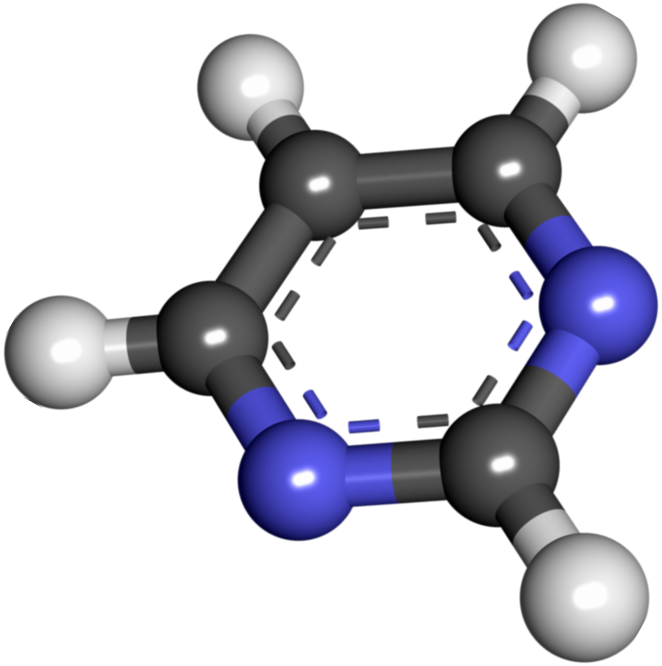
Uracil
尿嘧啶



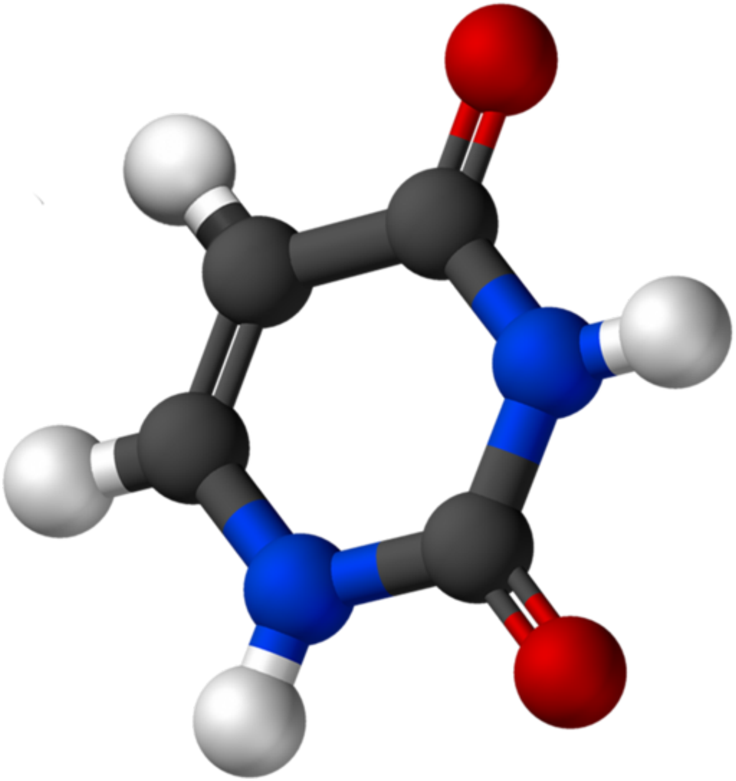
Cytosine
胞嘧啶



Guanine
鳥嘌呤



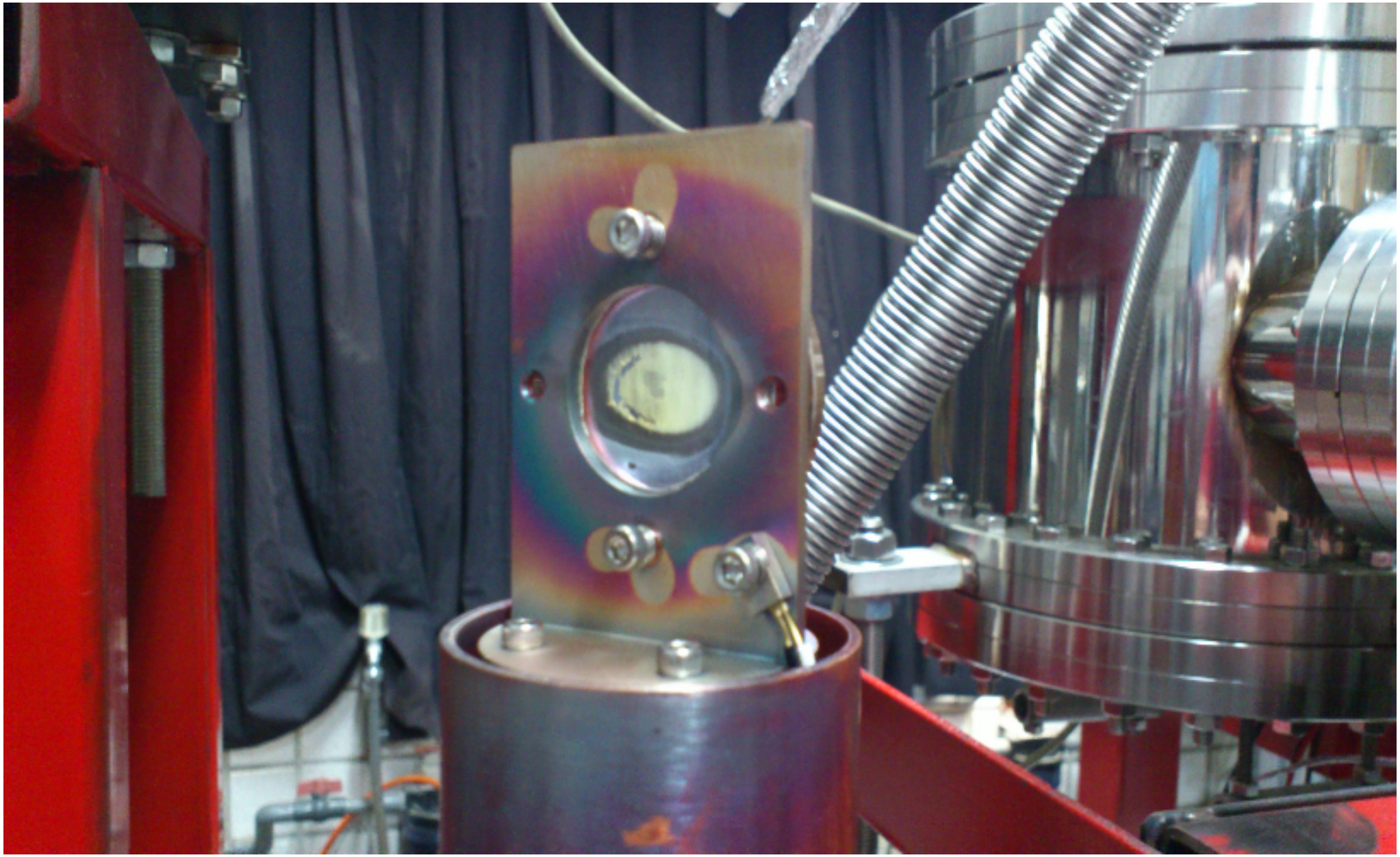
Pyrimidine
嘧啶



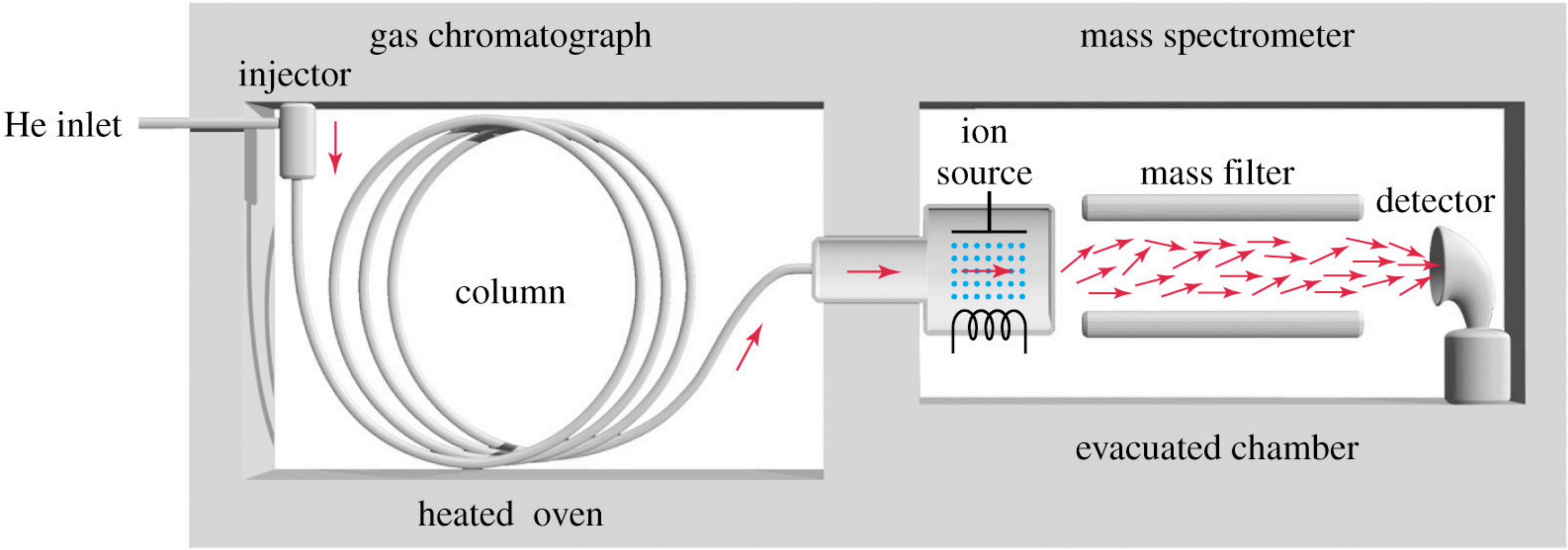
Uracil
尿嘧啶

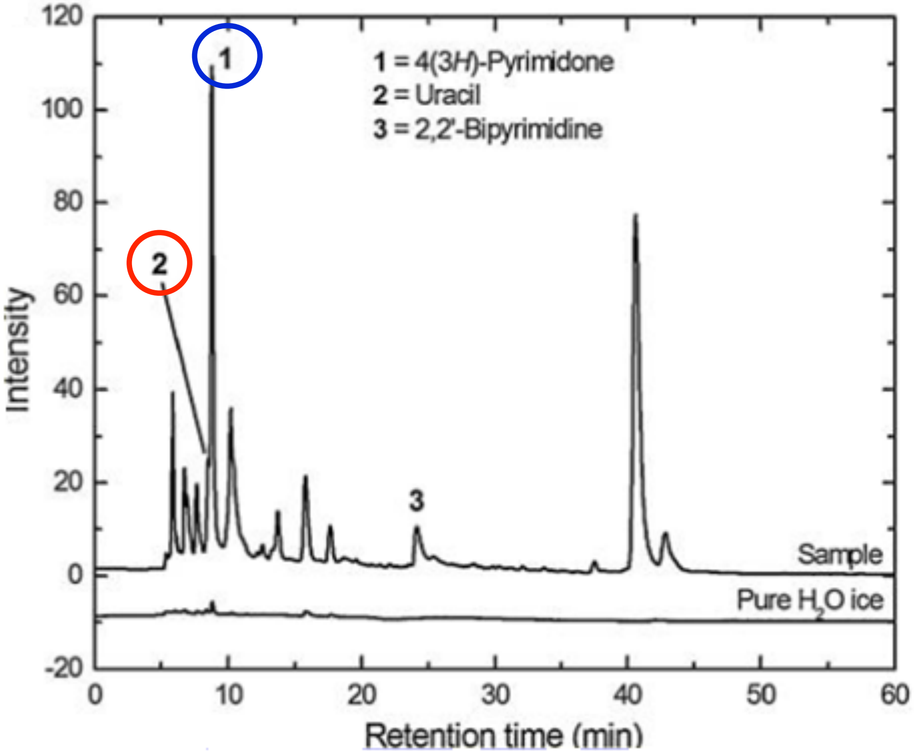
$H_2O:C_4H_4N_2 = 20:1$

Irradiation and deposition simultaneously for 24 hr

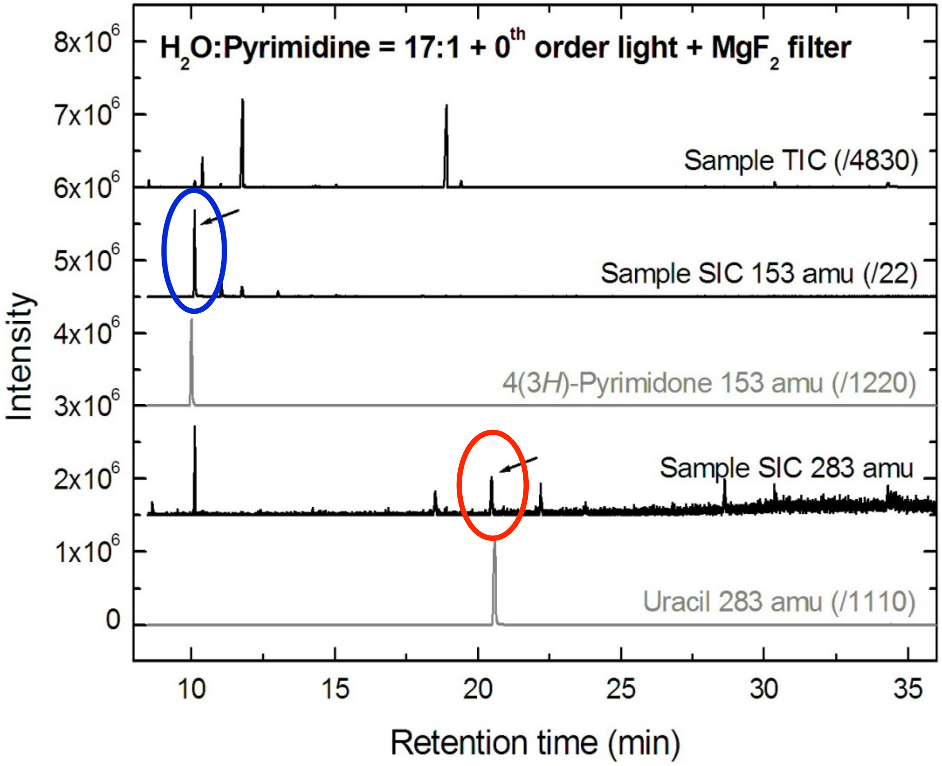


High-Performance Liquid Chromatography

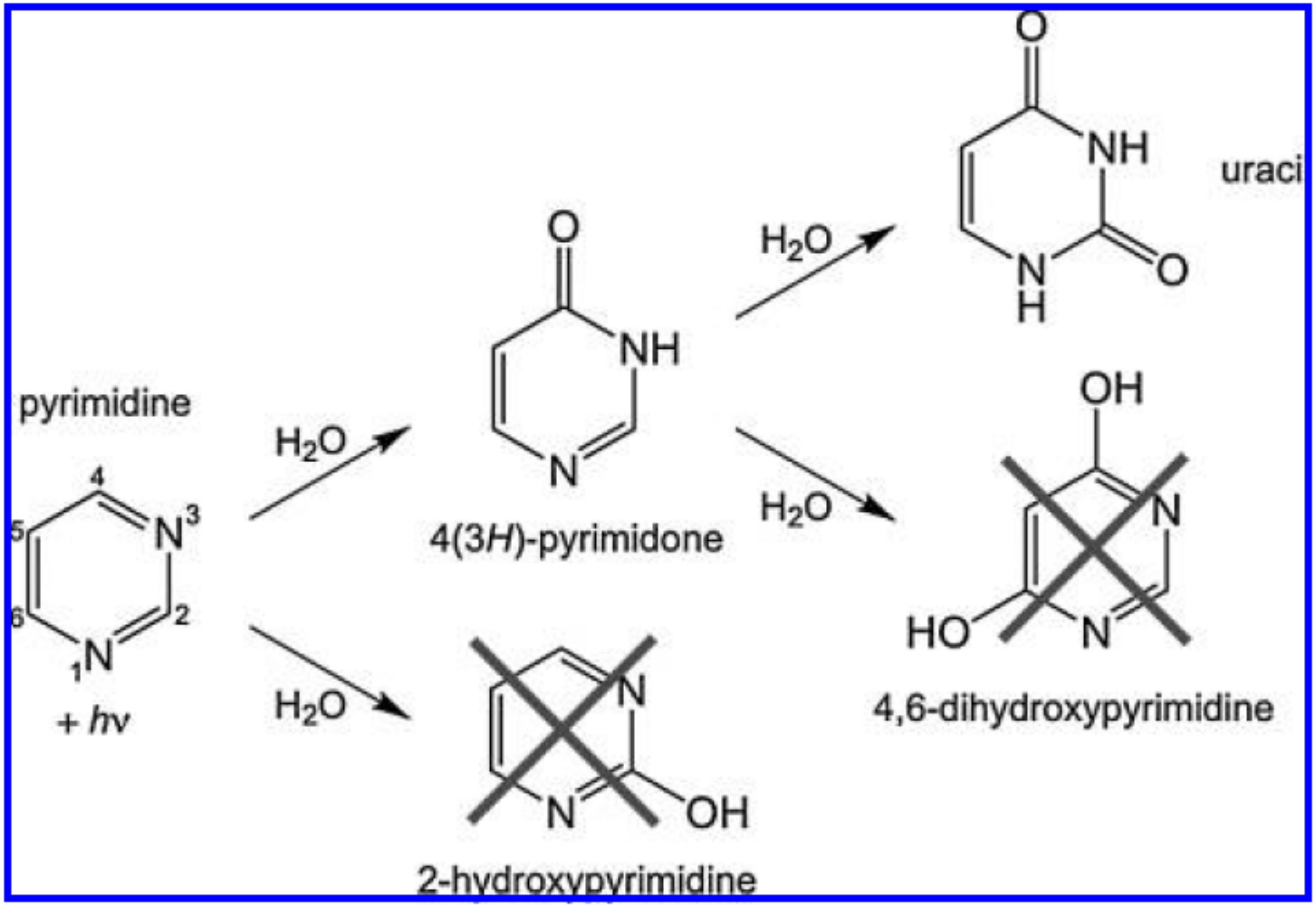



1 = 4(3*H*)-Pyrimidone
2 = Uracil
3 = 2,2'-Bipyrimidine
1
2
3
Sample
Pure H_2O ice
Intensity
120
100
80
60
40
20
0
-20
0
10
20
30
40
50
60
Retention time (min)

HPLC


H_2O:Pyrimidine = 17:1 + 0^{th} order light + MgF_2 filter
Sample TIC (/4830)
Sample SIC 153 amu (/22)
4(3*H*)-Pyrimidone 153 amu (/1220)
Sample SIC 283 amu
Uracil 283 amu (/1110)
Intensity
$8x10^6$
$7x10^6$
$6x10^6$
$5x10^6$
$4x10^6$
$3x10^6$
$2x10^6$
$1x10^6$
0
10
15
20
25
30
35
Retention time (min)

GC-MS



Nuevo *et al.* 2010, JCP, 133, 104303

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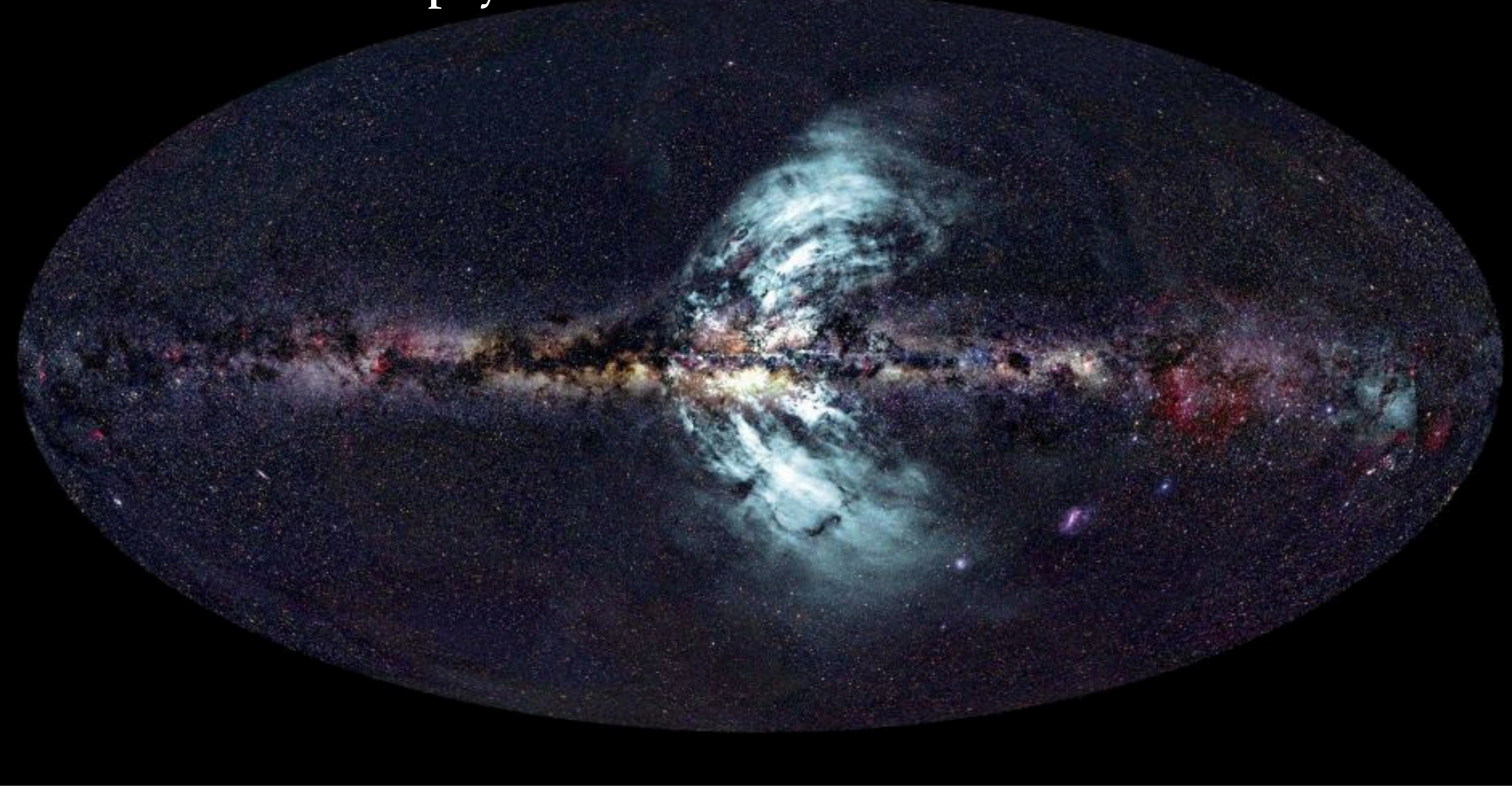
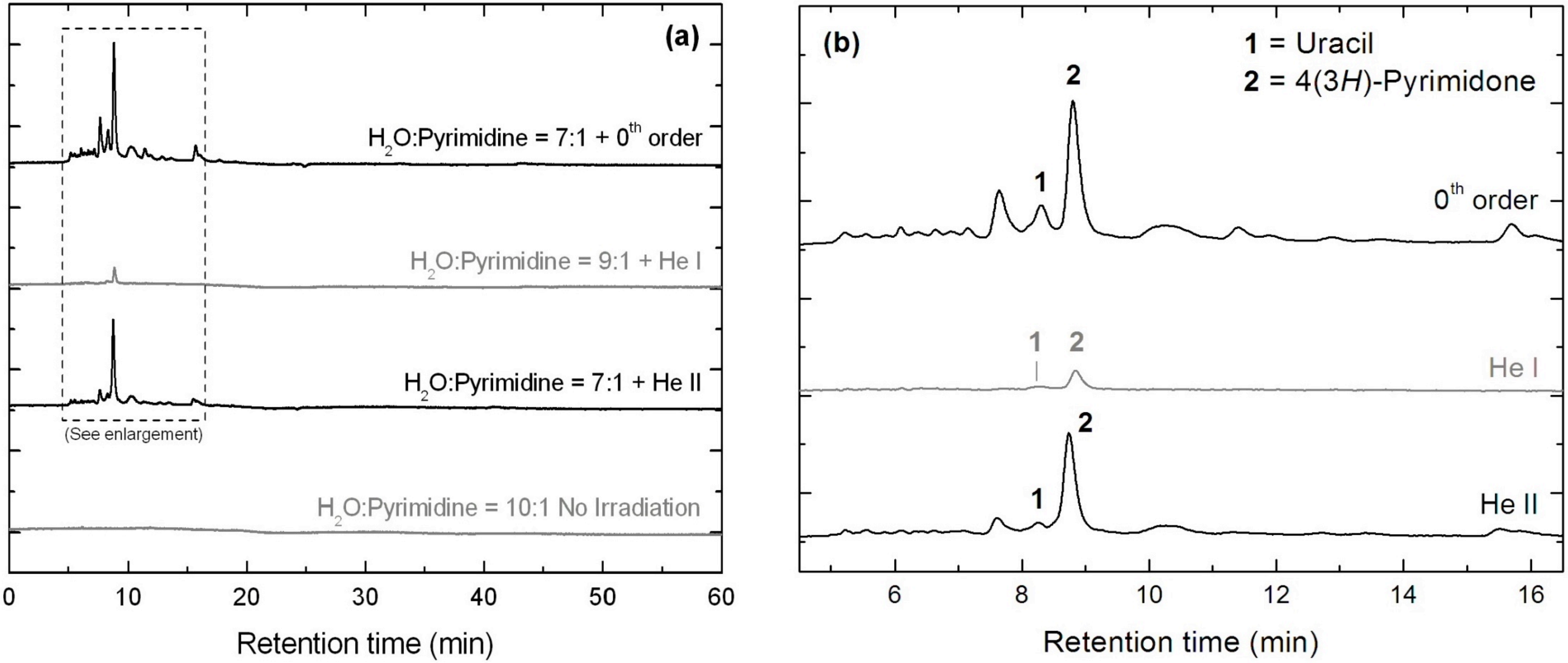
Various astrophysical environments have various UV fields



Sample	4(3H)-Pyrimidone /Uracil
0^{th} Order Beam **(4-45 eV)**	4.4
He I Line **(21.23 eV)**	**254**
He II Line **(40.78 eV)**	36.5
H_2 Lamp **(7.3-10.9 eV)**	13.9



Nuevo et al. 2014, Astrobiology, 14, 119

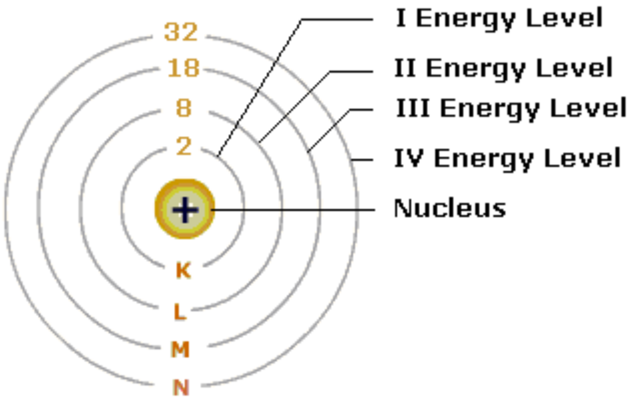
Soft X-ray Irradiation

X-ray irradiation study (200 – 1200 eV)

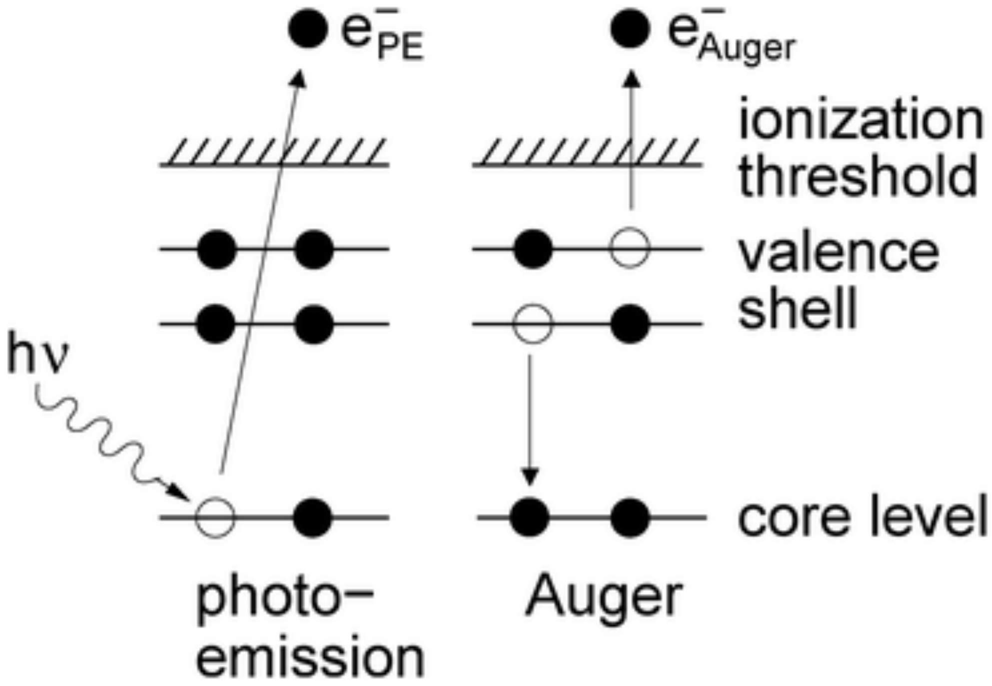
Young solar type stars emit X-rays at a level 3-4 orders of magnitude higher than the present-day Sun.

Feigelson et al. 2003, *ApJ*, **84**, 911
Favata et al. 2005, *ApJS*, **160**, 469

- **Break bond**
- **Eject electron from inner shell**



Photoelectron & Auger electron



Eject electron from inner shell

High energy electrons

Degrade energies in multiple ionization events

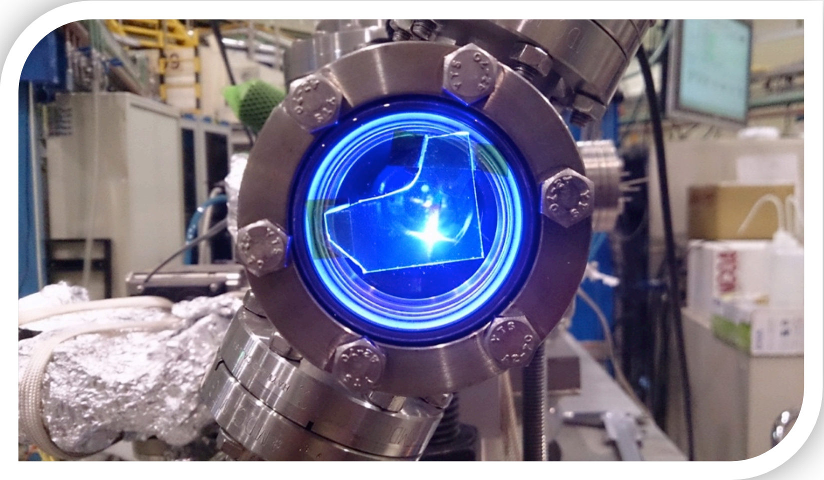
Low energy electrons

Dissociative electron attachment (DEA)

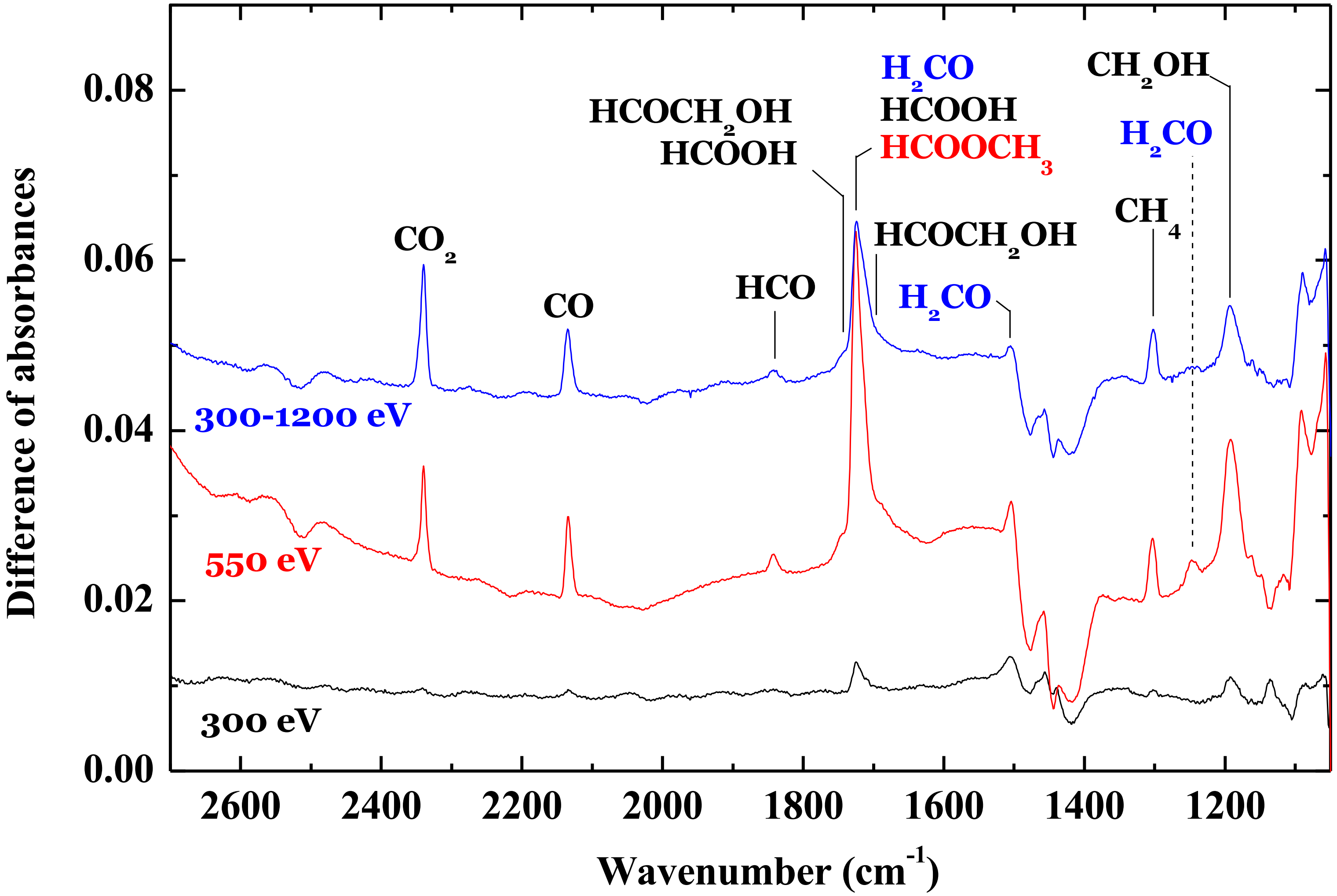
$$e + A \rightarrow A^-$$

$$e + AB \rightarrow A^- + B$$

$$e + AB \rightarrow A^- + B^+ + e$$

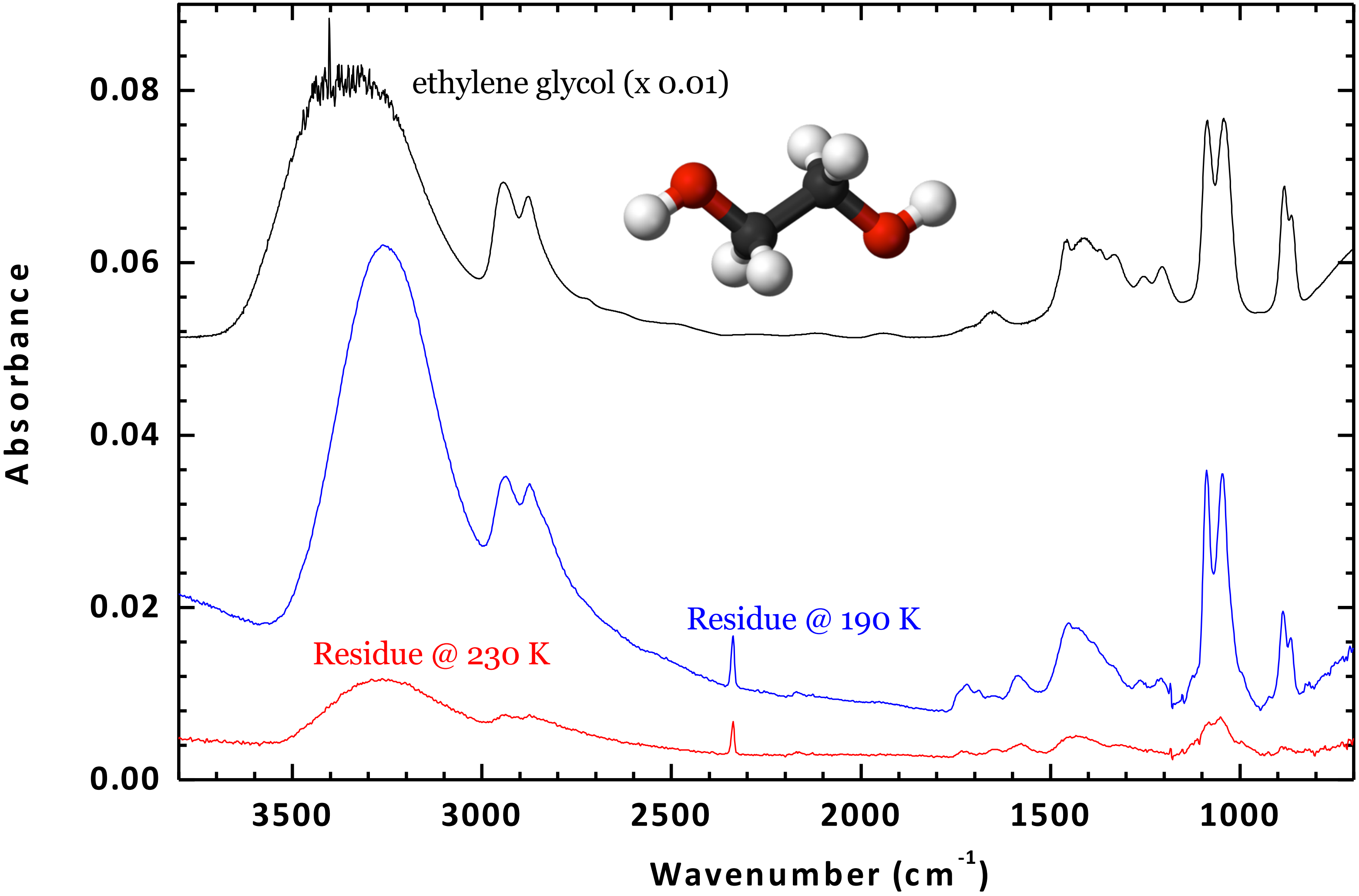


Pure CH_3OH ice @ 14 K



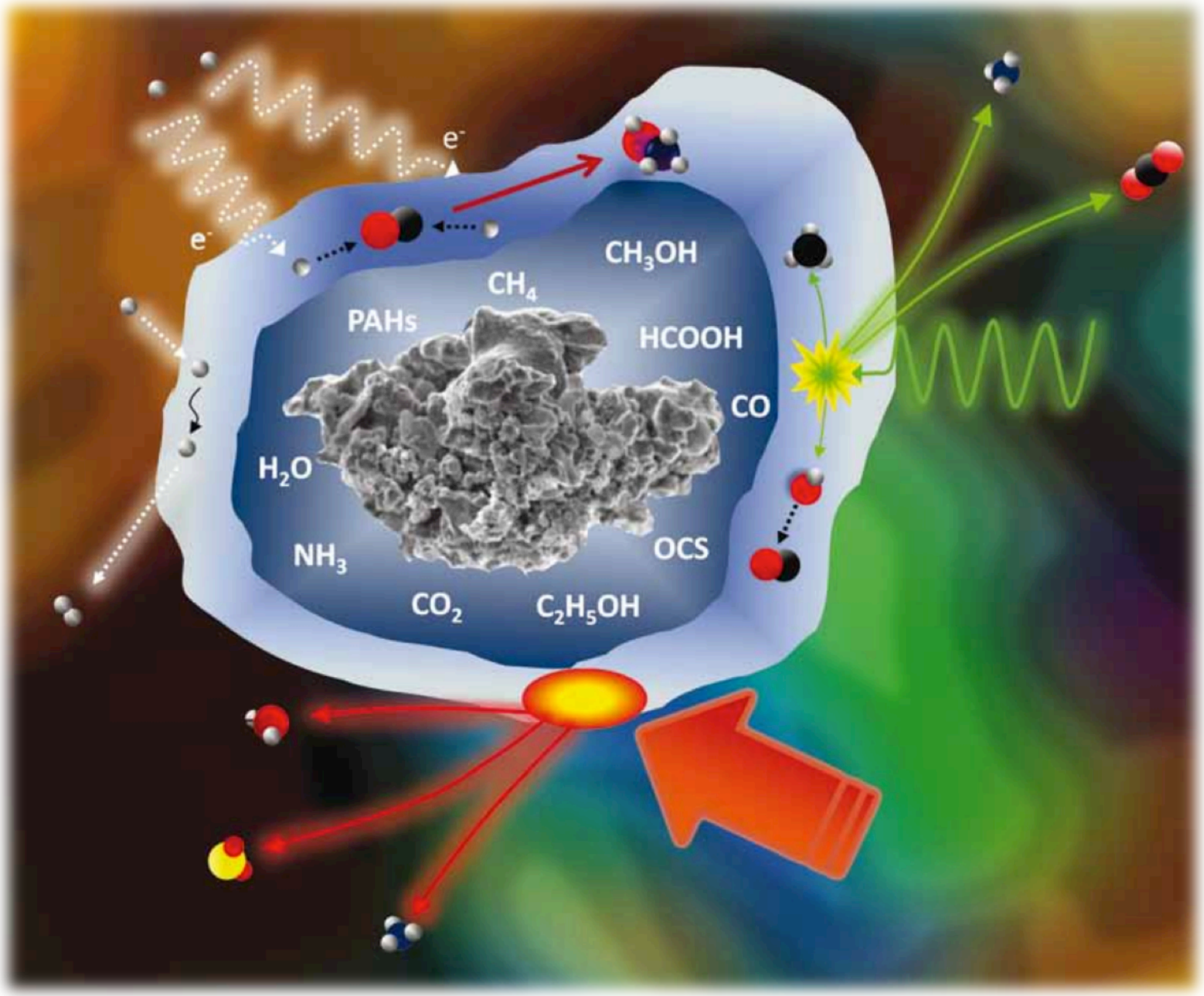
Chen et al. 2013, ApJ, 778, 162

X-rays irradiation of pure CH_3OH ice

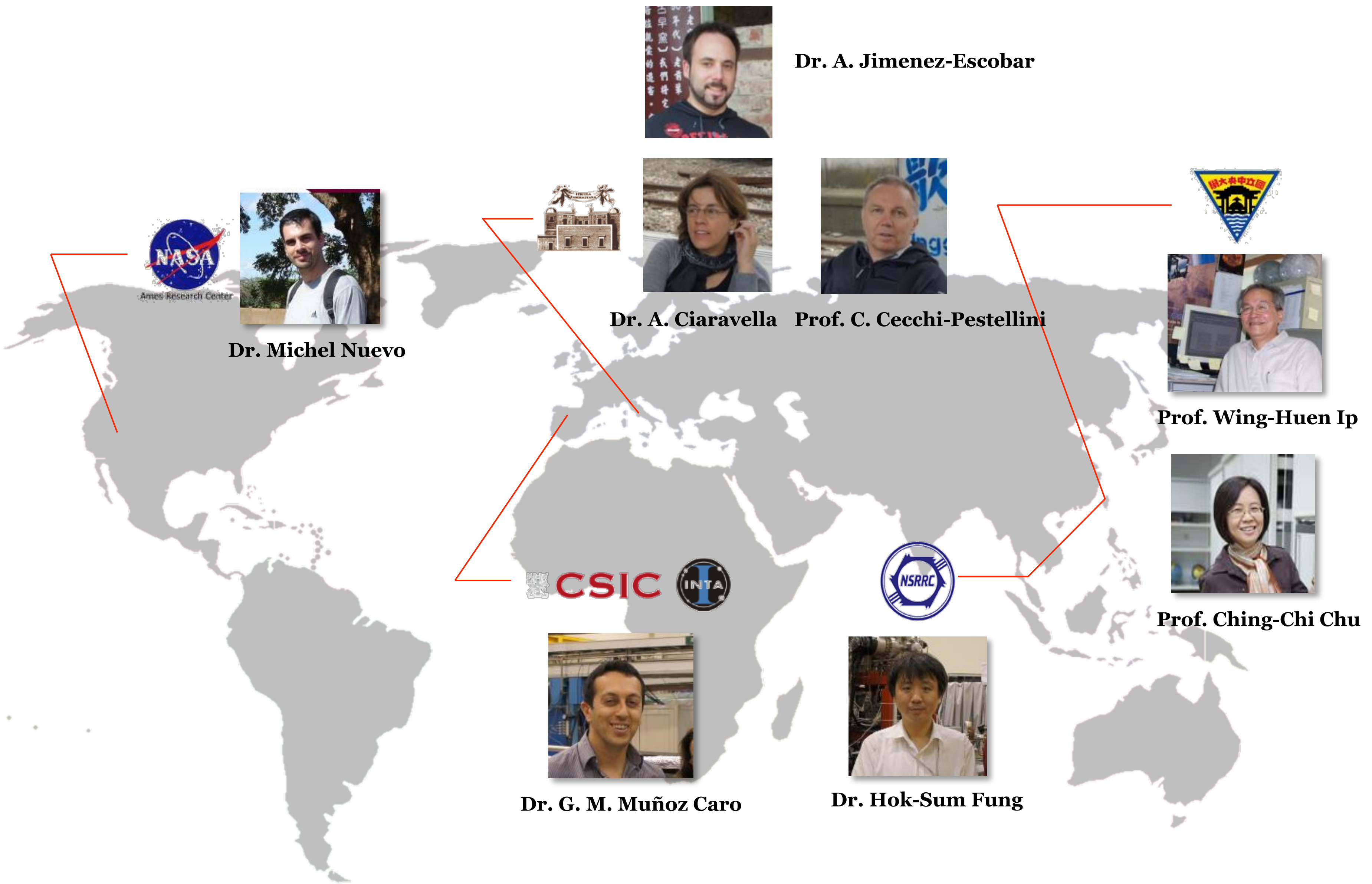


Chen et al. 2013, ApJ, 778, 162

Summary



Cited: PCCP, 12, 5929 (2010)



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Thank you for your attention