Astrobiology of Titan

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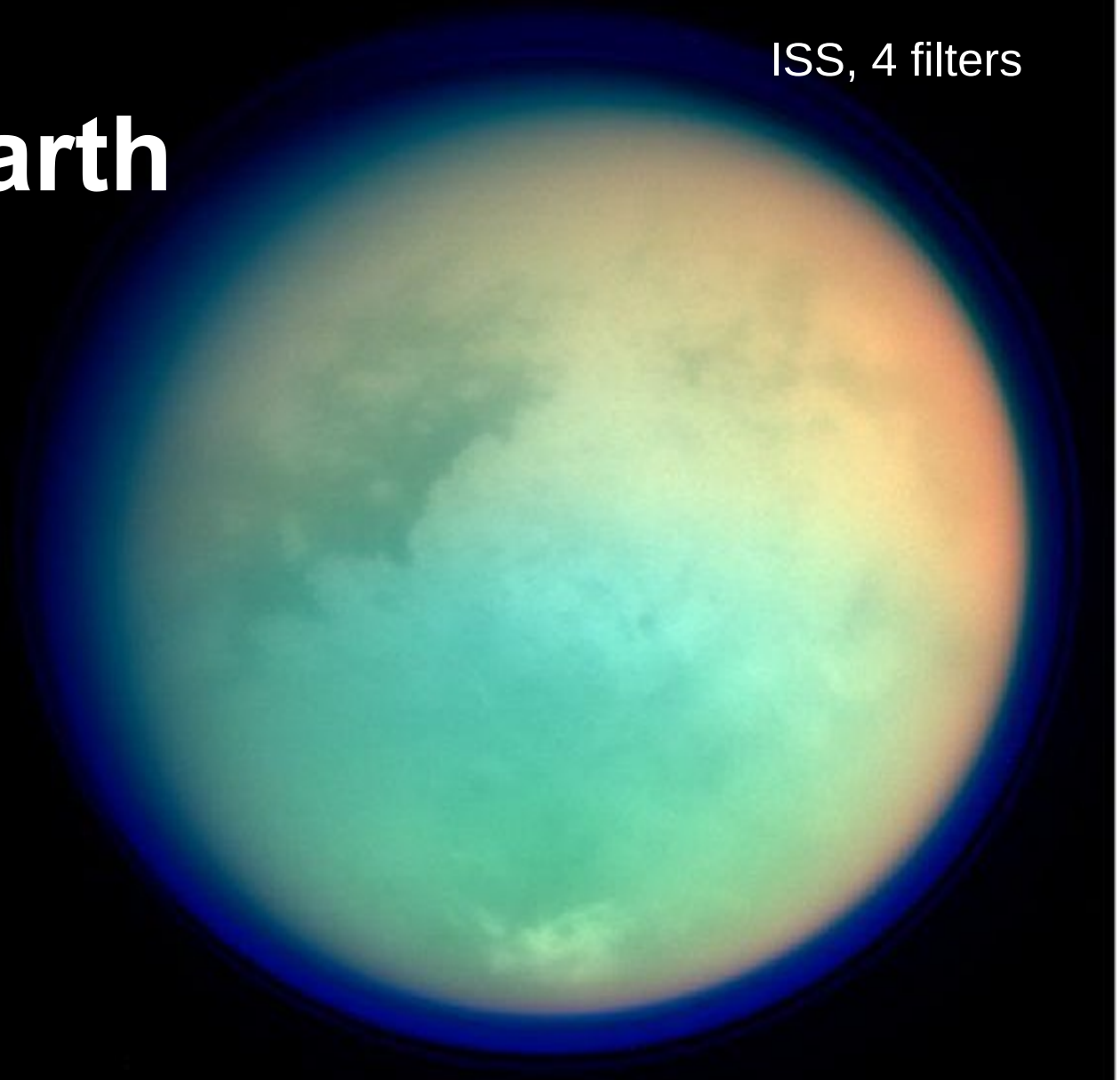
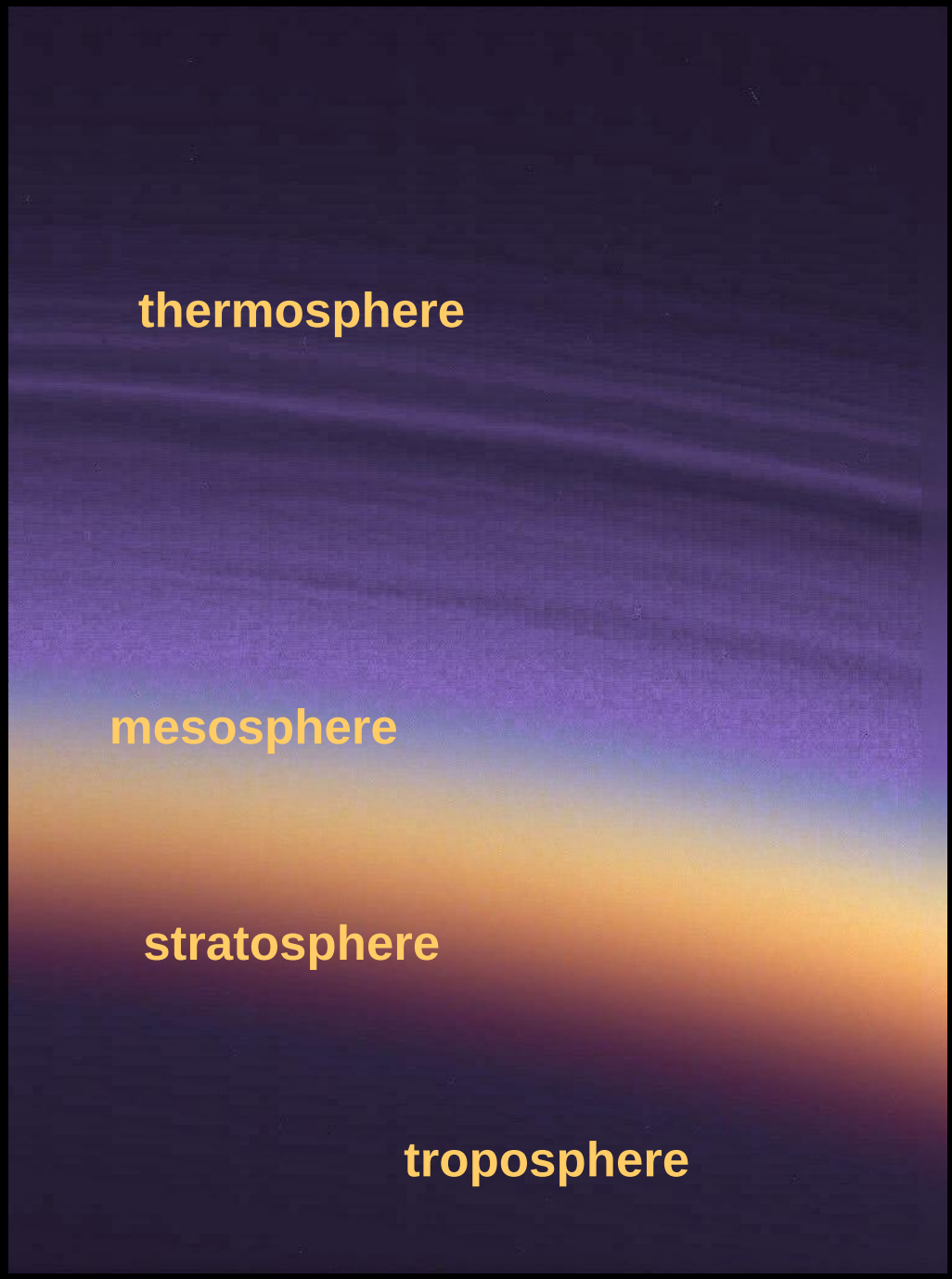
1. Titan ⇔ Earth



ISS, 4 filters

A dense atmosphere mainly made of N_2, with a vertical structure analog to that of the Earth

HASI temperature profile



Pressure [hPa]

Altitude [km]

Temperature [K]

Credit: ESA / ASI / UPD / OU / FMI

Greenhouse Effects & atmospheric dynamics

	Earth	*Titan*
Greenhouse gases		
Condensable	H_2O	CH_4
Non-condensable	CO_2	H_2
Antigreenhouse		
	Aerosols & clouds	Aerosol hazes
Polar vortex	Ozone layer	South pole atmospheric chemistry

Presence of ^{40}Ar (Cassini-INMS & Huygens-GC-MS)

~4,3x10^{-5} (GC-MS)

$\Rightarrow$ secondary atmosphere by degassing (^{40}K => ^{40}Ar)

Very small amount of primordial gases

^{36}Ar : 2.8 x 10^{-7} (GC-MS)

other noble gases : Kr and Xe : below 10^{-8} (GC-MS)

$\Rightarrow$ Atmosphere initially made of NH_3

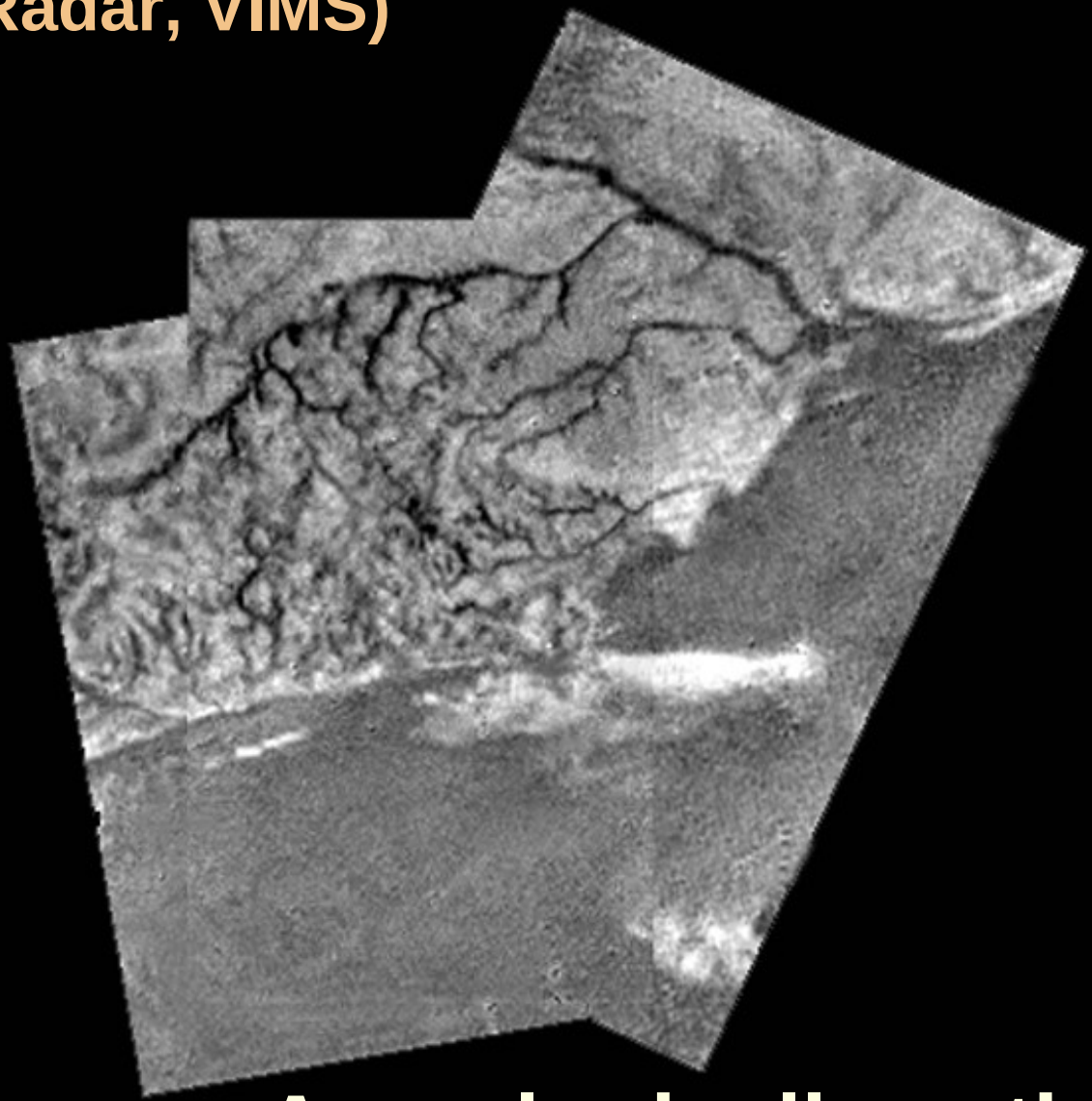
$^{14}N/^{15}N$ from GC-MS = 183 : < than primordial N

$\Rightarrow$ loss of several times the present atmosphere

$\Rightarrow$ large organic deposit on the surface

Other similarities

volcanic, sedimentological & meteorological origins of several surface features (Huygens DISR; Cassini ISS Radar, VIMS)



=> A geologically active planet !!

Science 13 May 2005:
Vol. 308. no. 5724, pp. 1014 - 1017

A Hydrogen-Rich Early Earth Atmosphere

Feng Tian,[1,2*] Owen B. Toon,[2,3] Alexander A. Pavlov,[2] H. De Sterck[4]

We show that the escape of hydrogen from early Earth's atmosphere likely occurred at rates slower by two orders of magnitude than previously thought. The balance between slow hydrogen escape and volcanic outgassing could have maintained ***a hydrogen mixing ratio of more than 30%.*** The production of prebiotic organic compounds in such an atmosphere would have been more efficient than either exogenous delivery or synthesis in hydrothermal systems.

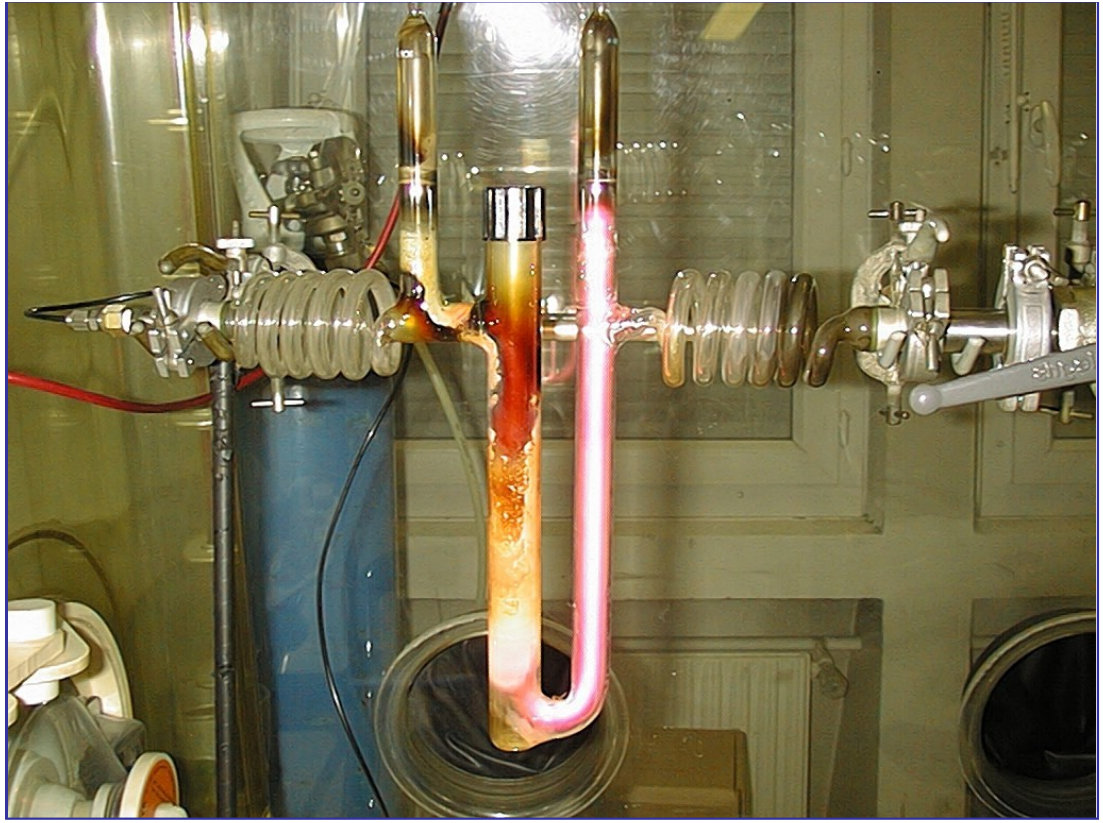
=> Atmospheric organic syntheses may have played an important role in prebiotic chemistry on the early Earth

2. Titan’s Organic Chemistry

Gas Mixture	ORGANIC PRODUCTS Electrical Discharges	 UV light
CH4 + NH3 + H2O (+ H2)	• RH (sat & unsat) • HCN & other RCN (sat) • RCO2H • H2CO, other aldehydes • Ketones & alcohols) *Solids* ==> Amino-acids, N- heterocycles	• RH (mainly sat) • HCN & other N-organics RCN (sat) if N/C <1 RNH2 if N/C >1 • H2CO, other aldehydes • Ketones & alcohols) *Solids* ==> Amino-acids
CH4 + N2 + H2O	• RH (sat & unsat) • HCN, other RCN (sat & unsat) : HC3N & C2N2 • O-organics including H2CO, other aldehydes, ketones & alcohols *Solids* ==> Amino-acids, N- heterocycles	• RH (sat & unsat) • O-organics including H2CO & other aldehydes at very low yield *Solids* ==> Carboxilic acids

SOLID PHASE :

THOLINS

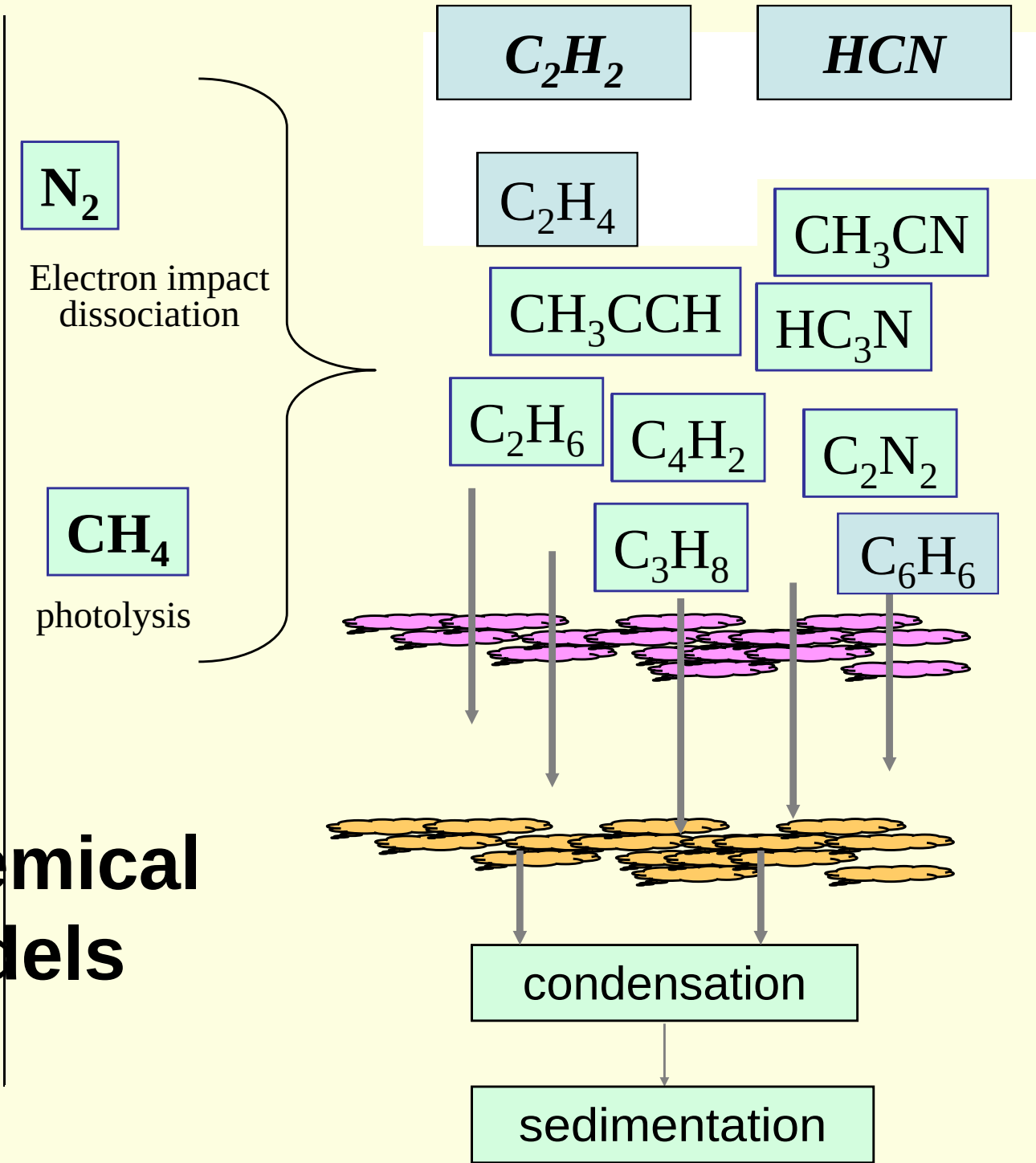


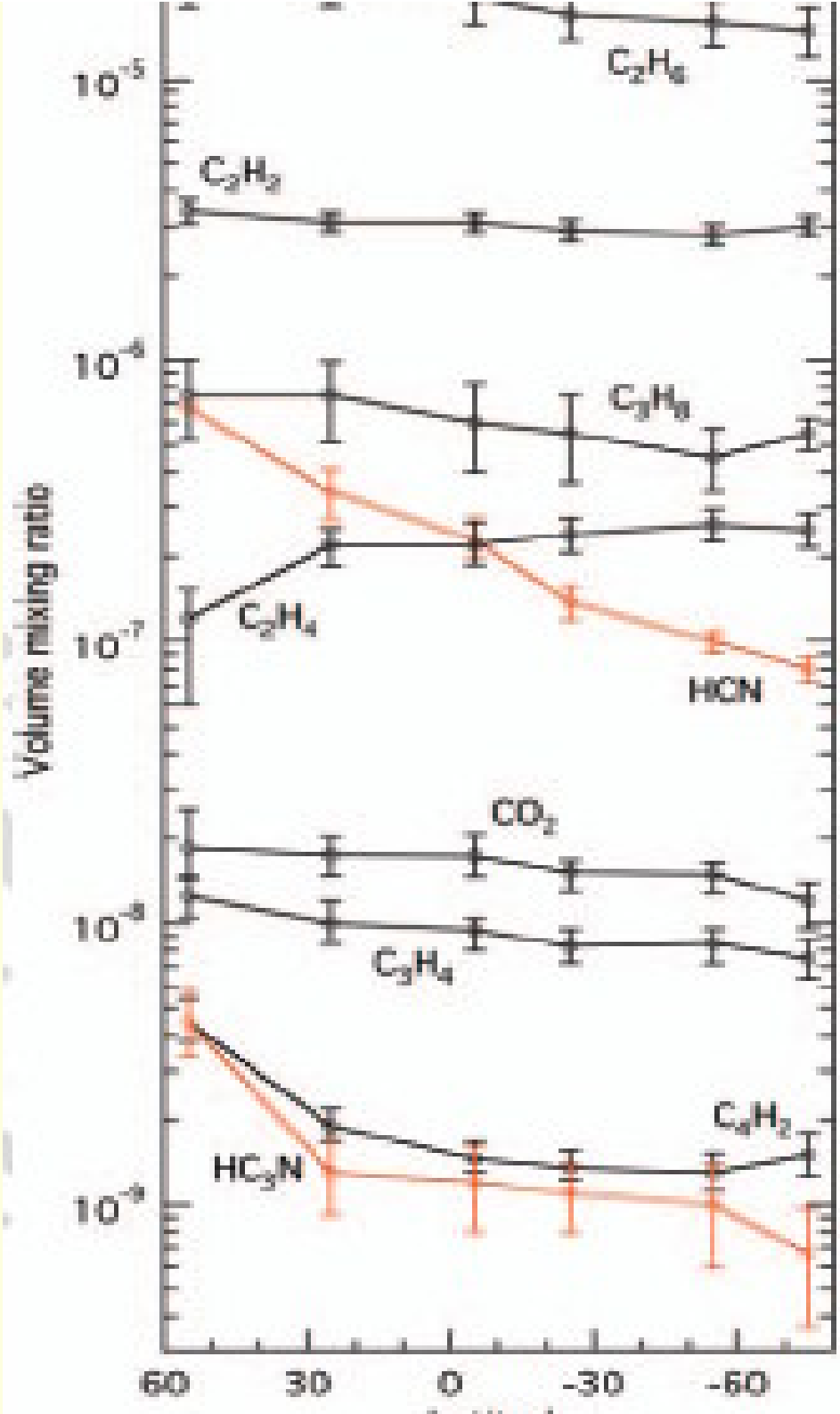
- **Tholins (Carl Sagan, *Nature*, 1979) names the solid organic product obtained after irradiation of gas mixtures of cosmically abundant molecules by energy sources of astrophysical importance**

- **Titan's tholins obtained after irradiation of N2-CH4 gas mixtures = laboratory analogues of Titan's aerosols**

Compounds	Stratosphere Mixing Ratio (E=Equ.; N=North Pole)		Production in Simulation Experiments
Main constituents			
Nitrogen N2	0.98 – 0.95		
Methane CH4	0.02 - 0.05		
Hydrocarbons			
Ethane C2H6	1.3 x 10-5	E	Maj.
Acetylene C2H2	2.2 x 10-6	E	Maj.
Propane C3H8	7.0 x 10-7	E	++
Ethylene C2H4	9.0 x 10-8	E	++
Propyne C3H4	1.7 x 10-8	N	+
Diacetylene C4H2	2.2 x 10-8	N	+
Benzene C6H6	few 10-9		+
N-Organics			
Hydrogen cyanide HCN	6.0 x 10-7	N	Maj.
Cyanoacetylene HC3N	7.0 x 10-8	N	++
Cyanogen C2N2	4.5 x 10-9	N	+
Acetonitrile CH3CN	few 10-9		++
Dicyanoacetylene C4N2	Solid Phase	N	+
O-Compounds			
Carbon monoxide CO	2.0 x 10-5		
Carbon dioxide CO2	1.4 x 10-8	E	
Water H2O	few 10-9		

Chemical Models

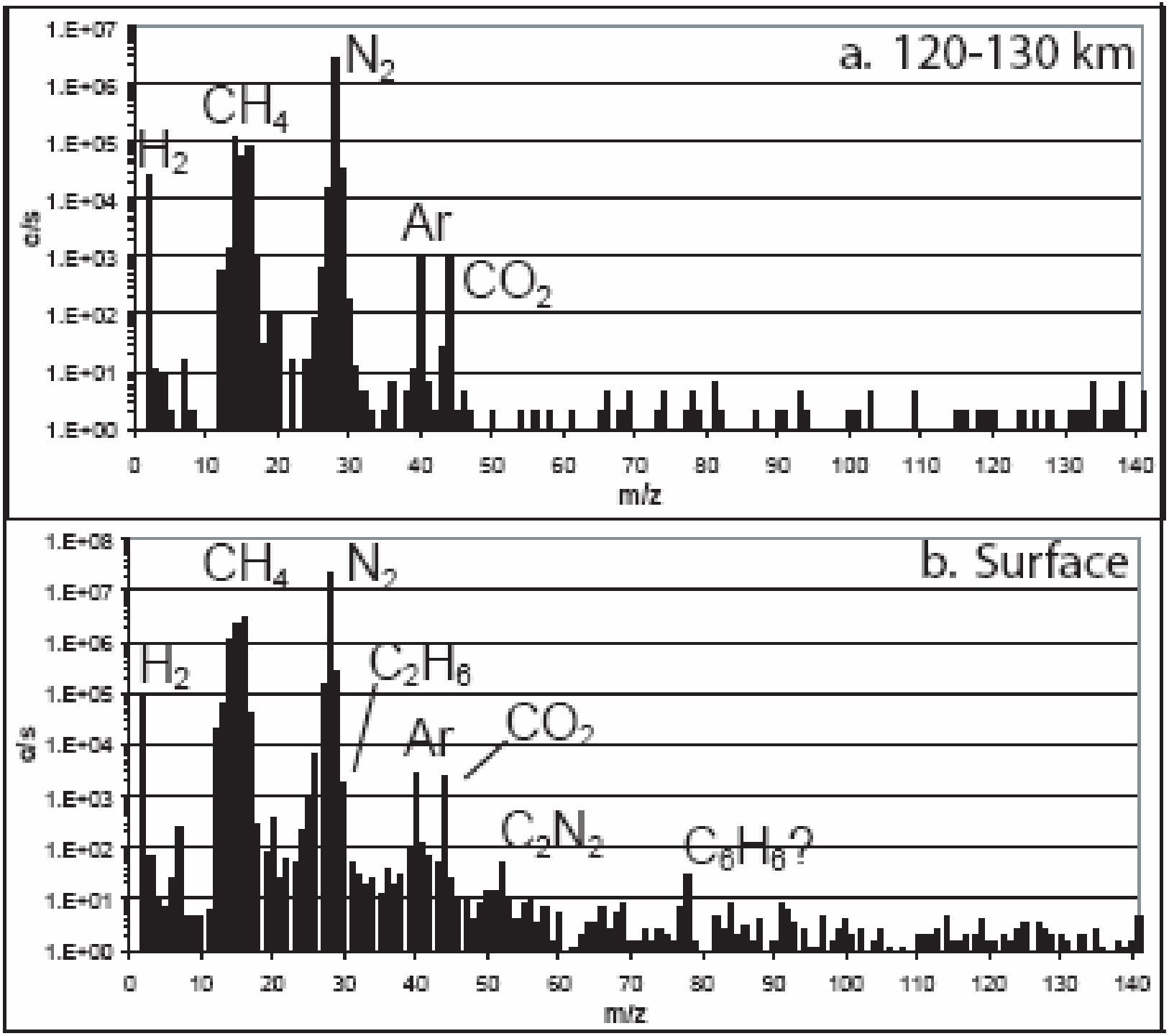




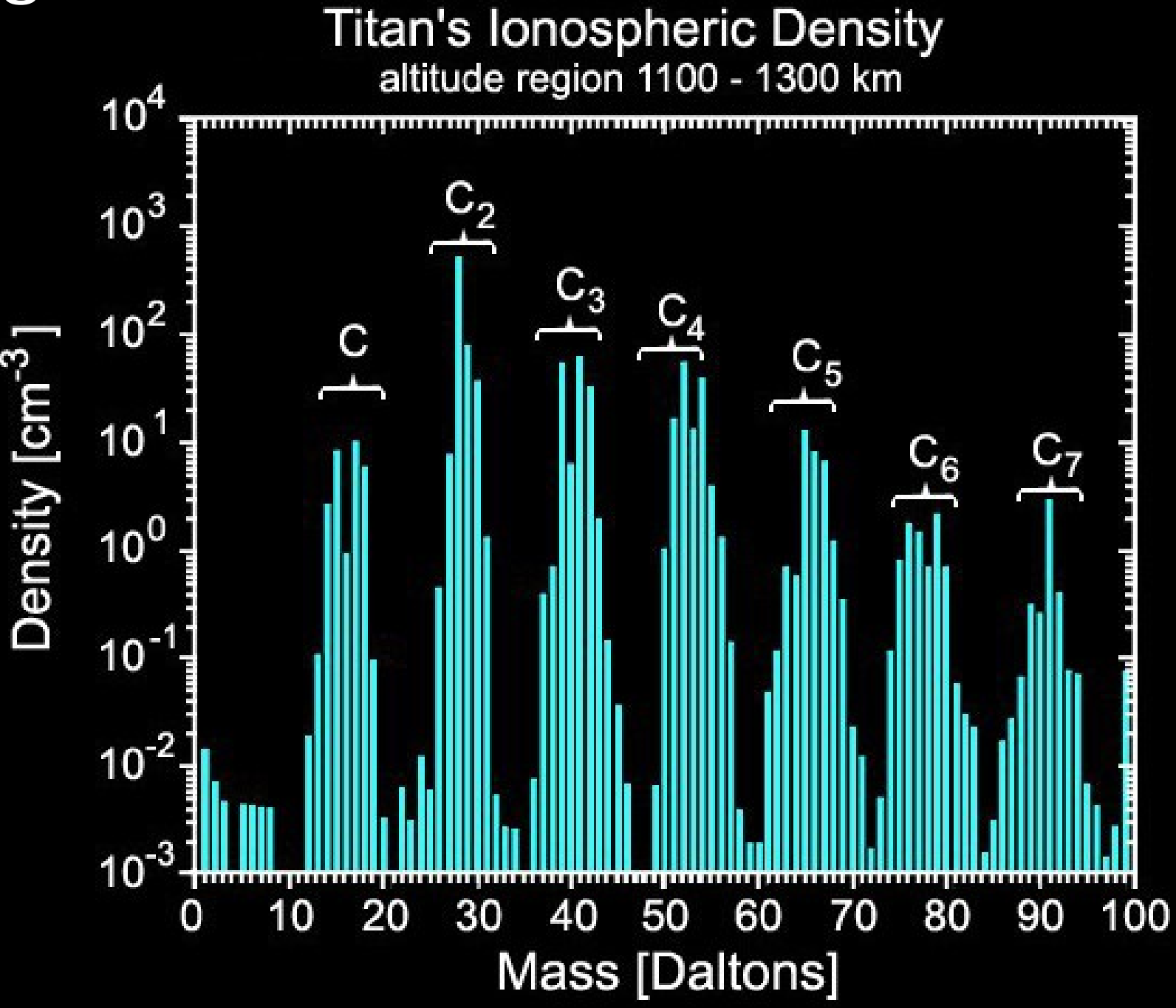
CIRS data

Flasar et al, *Science* **308**,975 (2005)

Huygens GC-MS data



INMS

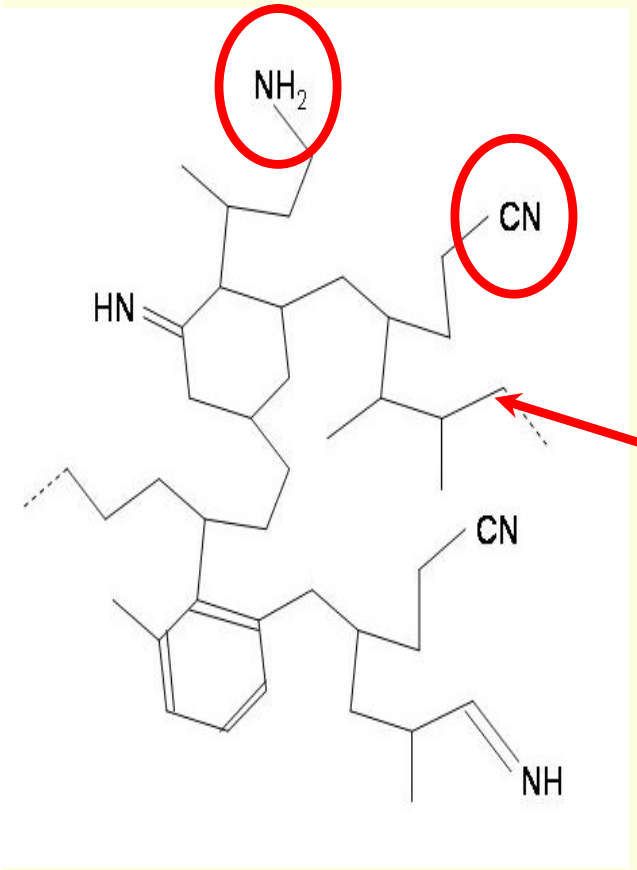

Titan's Ionospheric Density
altitude region 1100 - 1300 km
Density [cm-3]
Mass [Daltons]
C
C2
C3
C4
C5
C6
C7
10^4
10^3
10^2
10^1
10^0
10^-1
10^-2
10^-3
0
10
20
30
40
50
60
70
80
90
100

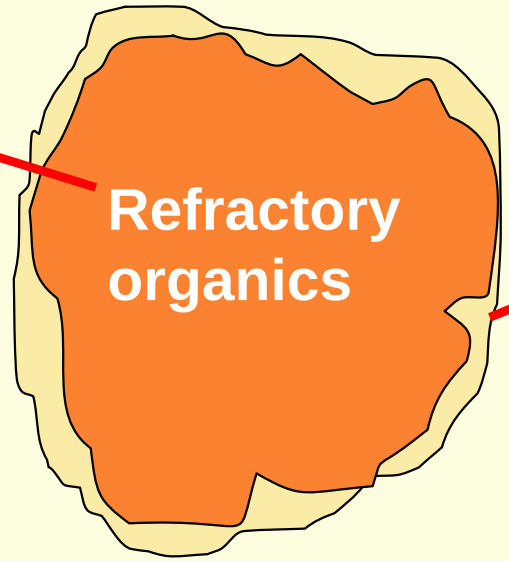
Huygens-ACP/GC-MS first data : chemical composition of the aerosols

- **Aerosols are composed of :**
  - **an organic refractory part,**
  - **made of carbon, hydrogen and nitrogen atoms.**

- **Their pyrolysis at 600°C produces HCN and NH_3: fingerprints of the chemical structure of the aerosol organic solid core.**

- Core molecular structure may include:
- -CN, -NH_2, -NH- and -N< and /or -C=N-



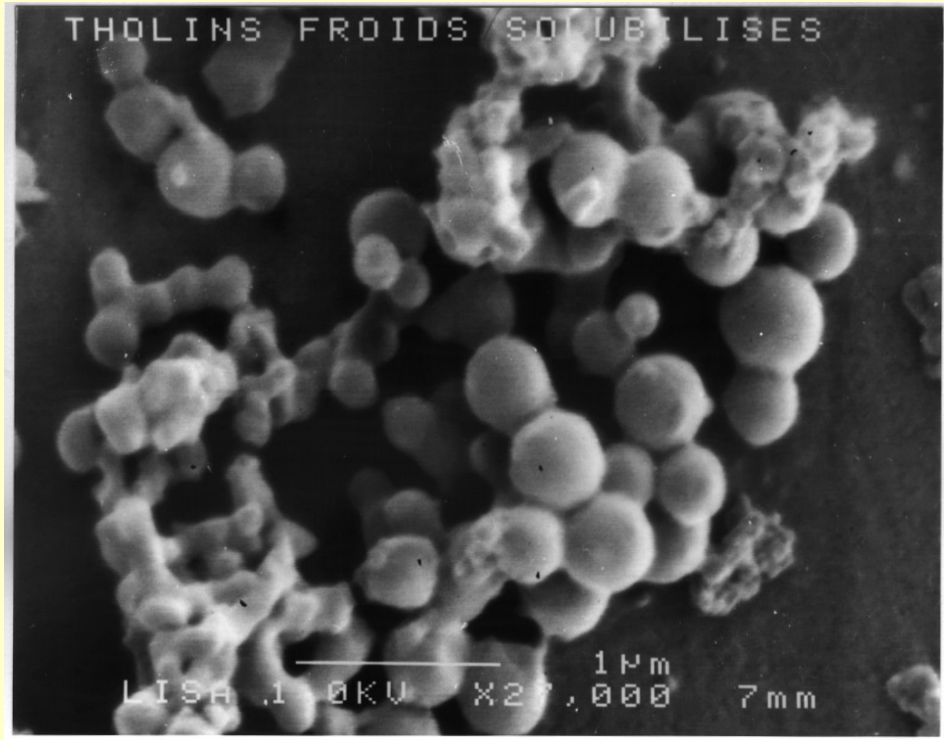


Small part of condensates

- => important photochemical sink for atmospheric N and C
- => end-product of a complex organic chemistry
- => supports the tholins model

SOLID PHASE : THOLINS

- **Optical properties: refractive indices**
- **C/H (0.6 – 1.1) & C/N (~0.7 – ~3)**
- **IR and UV spectra + pyrolysis-GC-MS**
  - **aliphatic & benzenic groups**
  - **CN & NC groups**
  - **NH_2 & C=NH groups**
- **Morphology**



Low T tholins, Coll *et al*., ASR, 2001

- **Organic macromolecular material of largely irregular structure**

- **Gel filtration chromatography of the water soluble fraction :**

  => molecular mass of ~ 500 to 1000 Daltons

- **Direct analysis by chemical derivatization techniques before and after hydrolysis:**

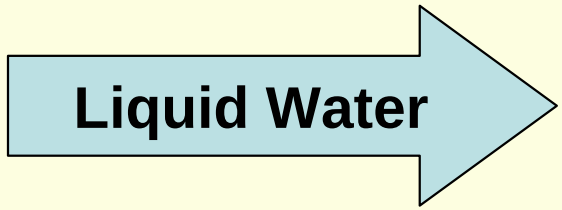
  => amino-acid or their precursors

- **And even :**

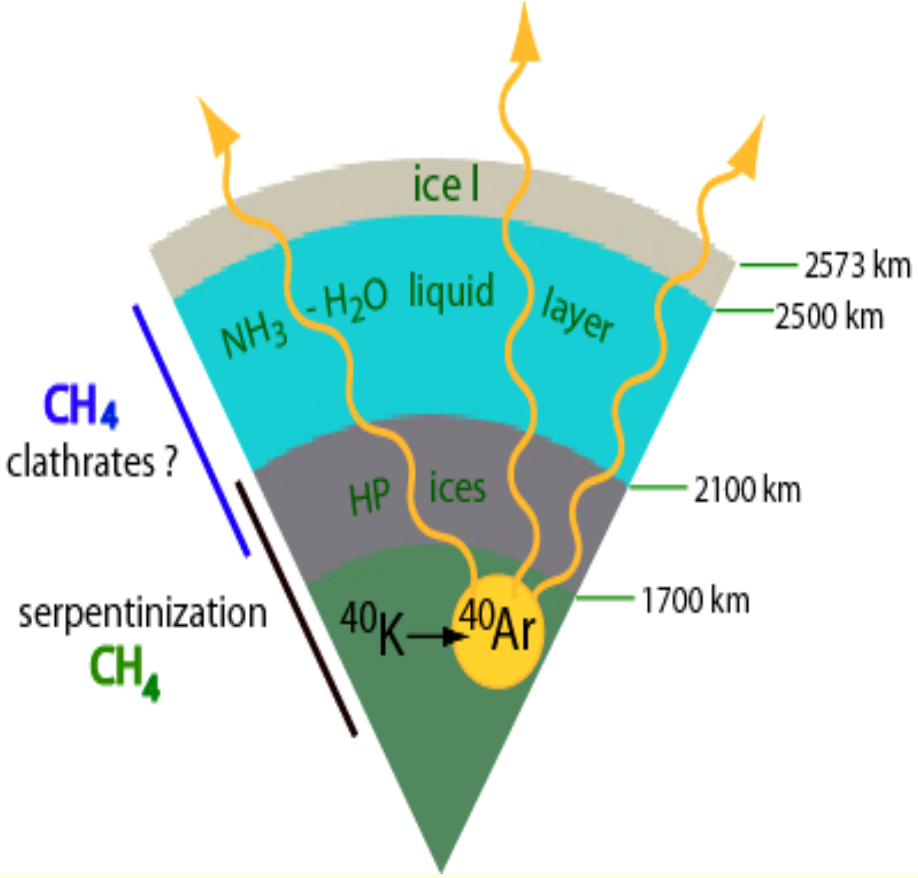
  => nutritious properties (for terrestrial bacteria …)

- **No noticeable isotopic C fractionation from starting methane**

- **Complex organic chemistry in the atmosphere – and mainly in the aerosols**
- **Presence of organics playing a key role in terrestrial prebiotic chemistry (HCN, HC3N, …. and their oligomers)**

Organic chemistry  **Life**

3. Life on Titan ?



Possible presence of a H_2O-NH_3 internal ocean

chondritic matter => prebiotic compounds

An efficient prebiotic reactor:

- **Low temperature** reduces the rate constants of chemical reactions, but may increase the concentration of species by **eutectic effect** => increases the rate of the reaction

- **High pressure** conditions may induce chemical condensation reactions

- **Hydrothermal vents**, if present, can increase chemical complexity

Life in Titan's ocean ?

Fortes (Icarus, 2000) no insurmountable obstacle in this environment:

- **possible temperature: ~ 260 + possible occurrence of cryovolvanic hotspots at ~ 300 K**

- **pressure: ~ 5 kbar at depth of 200 km**
  => not incompatible with life

- **pH: 15 % wt NH_3 => pH ~11.5**
  Some bacteria can grow on Earth at pH 12

- **energy: *with radiogenic heat flow ~ 5×10^{11} W**
  *** biomass density could be 1g /m2 (not so low….)**

What kind of life? Prokaryotic and anaerobic?
Terrestrial archaebacteria good examples of what can be expected

Methanogenic archaebacteria:

heterotrophic: organics + H_2 → CH_4 + *organic products*

autotrophic: CO_2 + H_2 or Fe° => CH_4 + *organic products*

**** organic products* = *methanol, methylamine, formate,..***

**** with a ^{12}C enrichment : => $^{12}C/^{13}C$ ~ 91 – 94***

(reference ~89)

In Titan low atmosphere:

*** GCMS data => $^{12}C/^{13}C = 82$**

*** suggests a non biological origin for CH_4**

(PRELIMINARY) CONCLUSION & PROSPECTIVE

Origin and cycle of CH_4 : a key question

- **Illustrates the whole complexity of the Titan's system**

- **CH_4 sources ? Clathrates ? Serpentinisation ? ..**
  => Mars and … Earth inputs ….

- **CH_4 reservoir replenishing the atmosphere since the beginning ? Episodically ?**
  => a sub surface CH_4 reservoir ?

- **The main product of CH_4 photolysis is C_2H_6: should form (surface ?) liquid reservoirs, not yet detected**

- **Complexity of the organic chemistry ?**

LISA - P. Coll, E. Hebrard, M.-J. Nguyen, R. Sternberg

Service Aéronomie - M. Cabane, G. Israel, C. Szopa

LPG - J.-M. Bernard, E. Quirico, B. Schmitt

NASA-GSFC - H. Niemann

With my astrobiolocal thanks For your attention