Exoplanetary Atmospheres and Habitability

Observatoire de Nice

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N-rich prebiotic chemistry in the atmosphere of Titan

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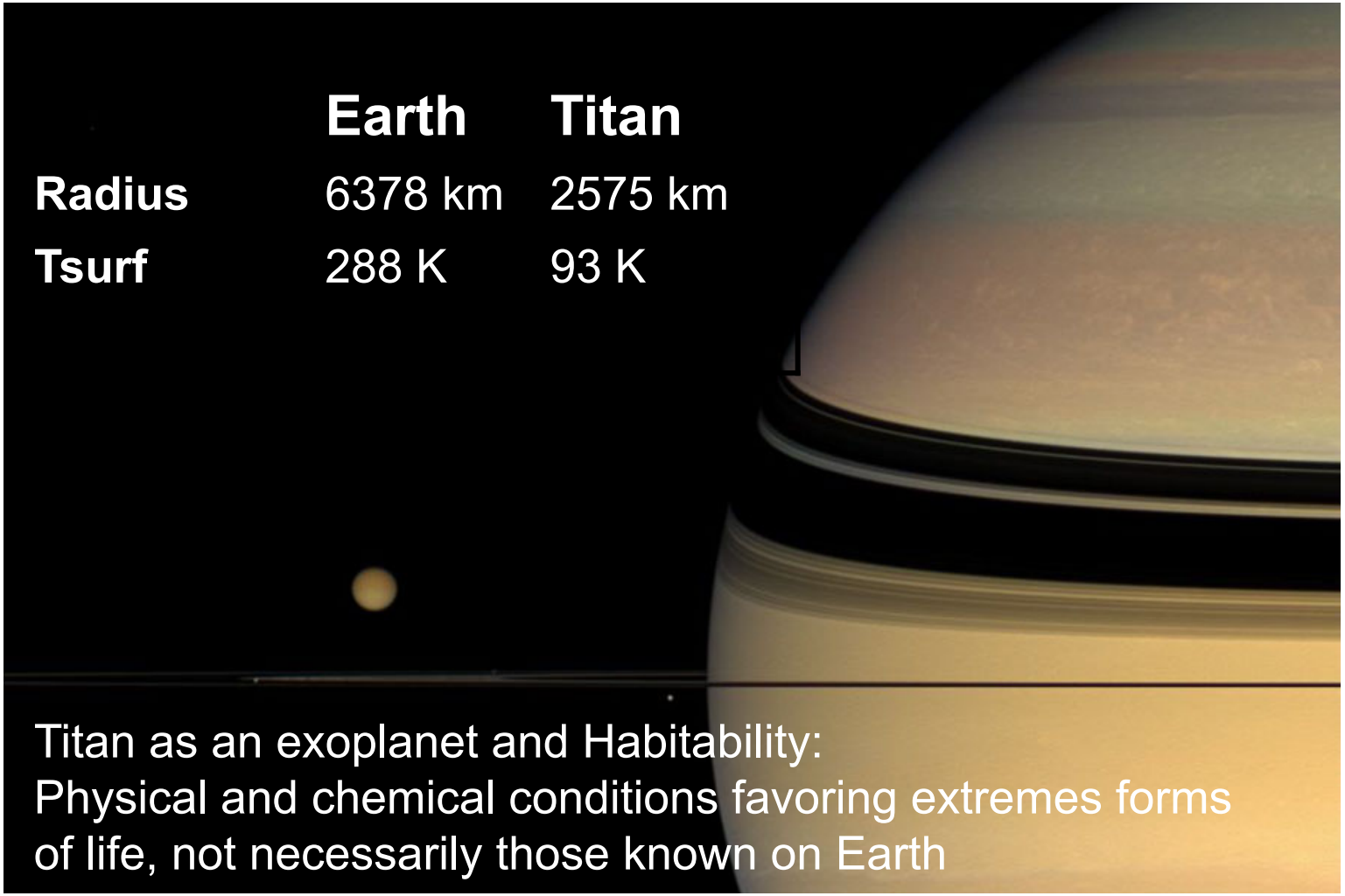
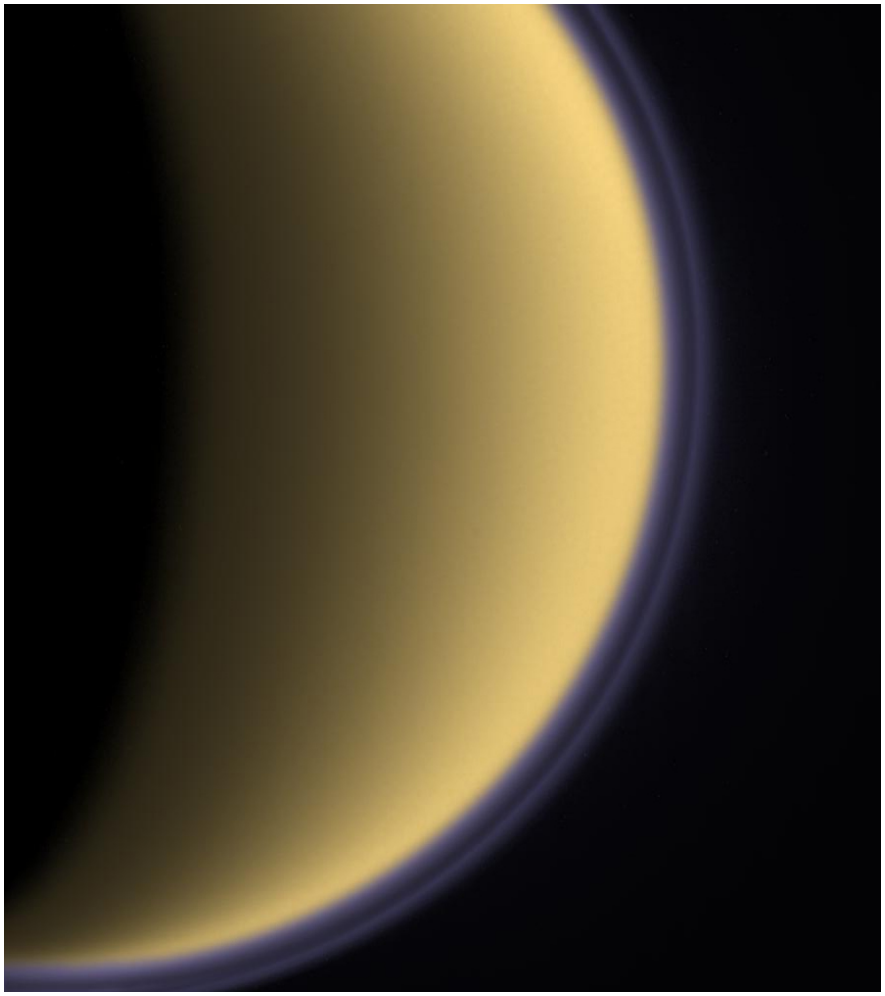
Why looking at Titan ?



	Earth	Titan
Radius	6378 km	2575 km
Tsurf	288 K	93 K

Titan as an exoplanet and Habitability:
Physical and chemical conditions favoring extremes forms of life, not necessarily those known on Earth

1- A dense atmosphere

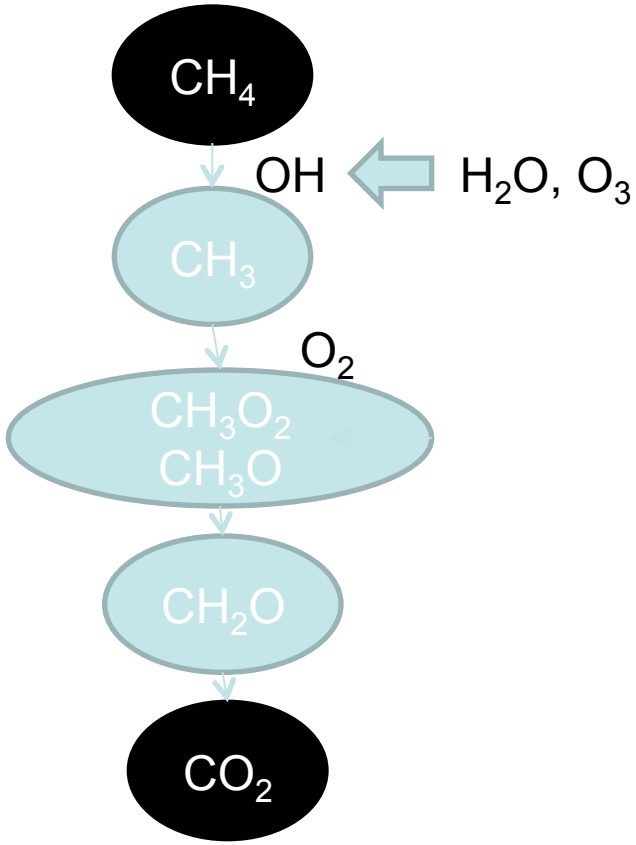


	Earth	Titan
Psurf	10^5 Pa	1.5×10^5 Pa
Atmospheric composition	N_2 78 %, **O_2 21 %**	N_2 98 %, **CH_4 2 %**

Protects the surface from harsh UV irradiations

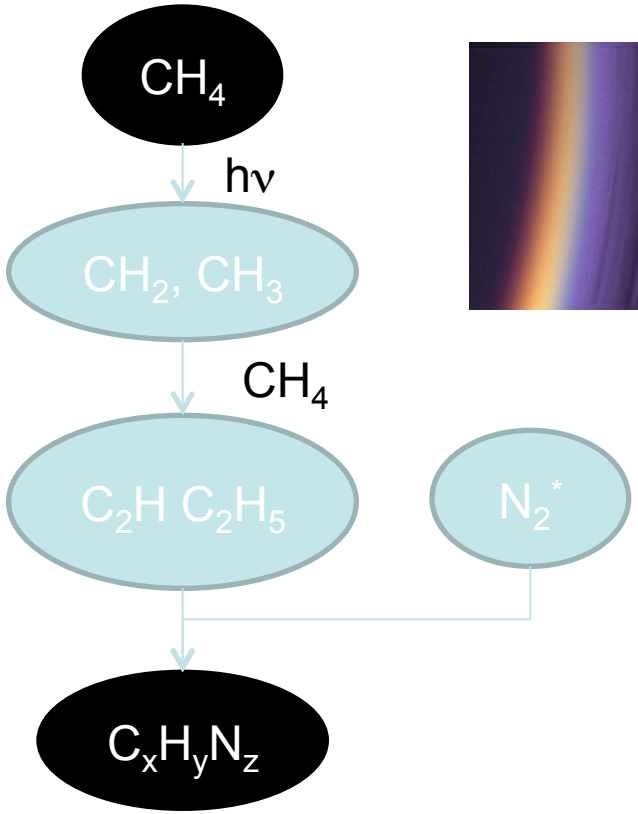
2- Organic molecules

Earth troposphere



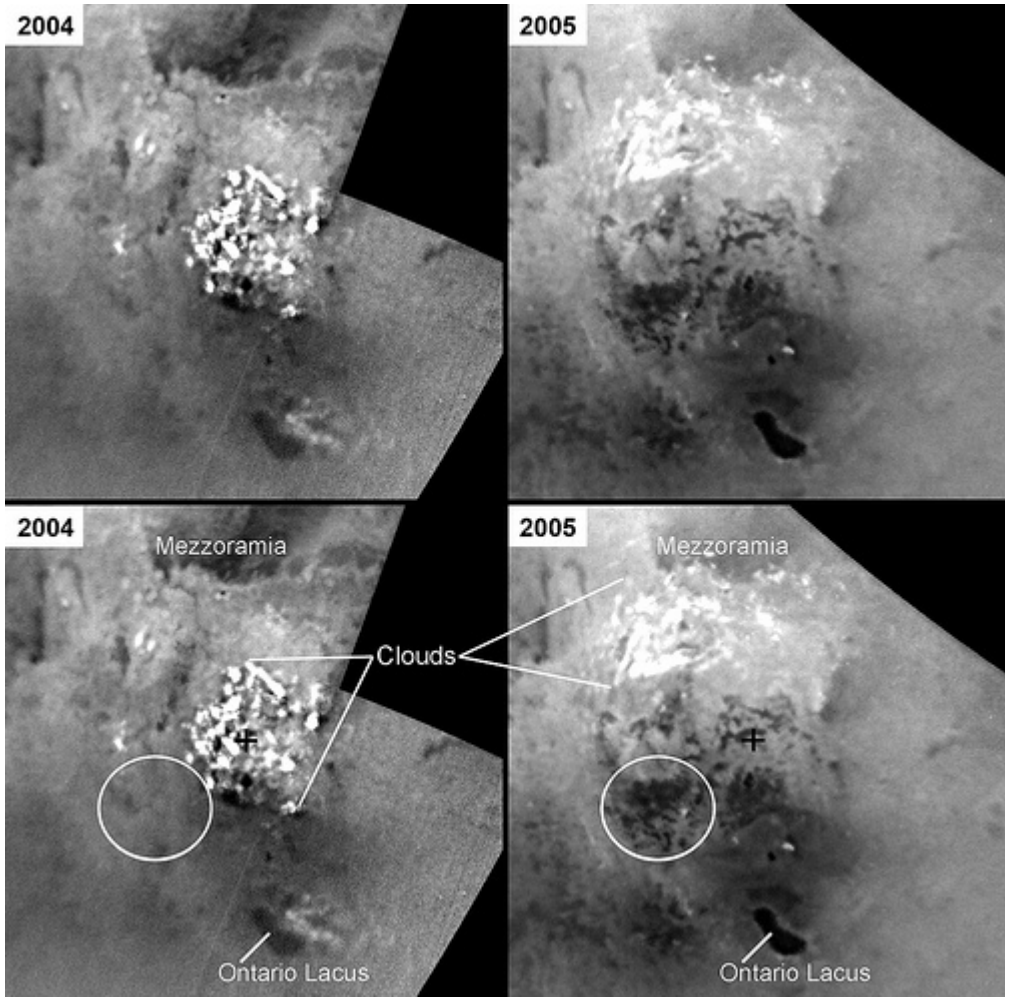
→ Oxydant lysis

Titan atmosphere

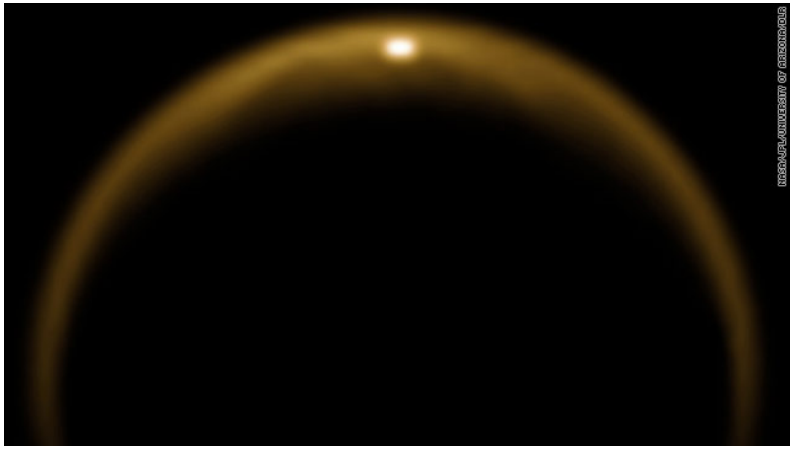


→ Organic growth

3- Liquid area



Storms and methane rain



Specular reflection on a North giant lake

(Copyright NASA)

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The Cassini-Huygens mission: 2004-2017

- Data for probing Titan's atmosphere

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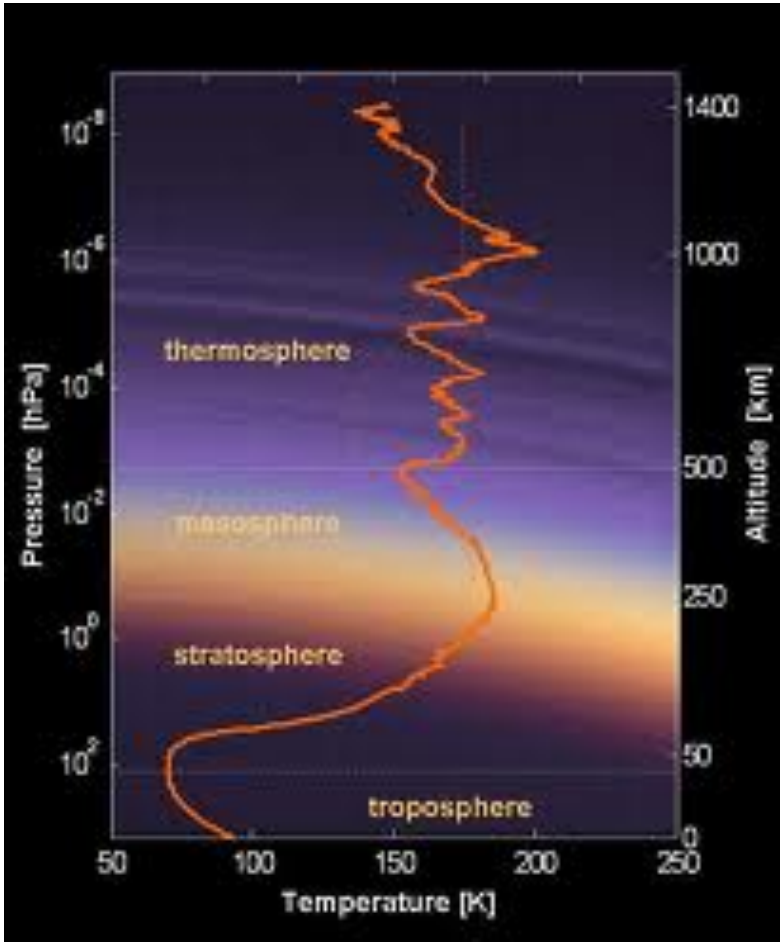

- Ionosphere:

In situ instruments / MS

neutrals, cations, anions, e-

- Stratosphere:

Remote sensor / IR

Neutrals, aerosols

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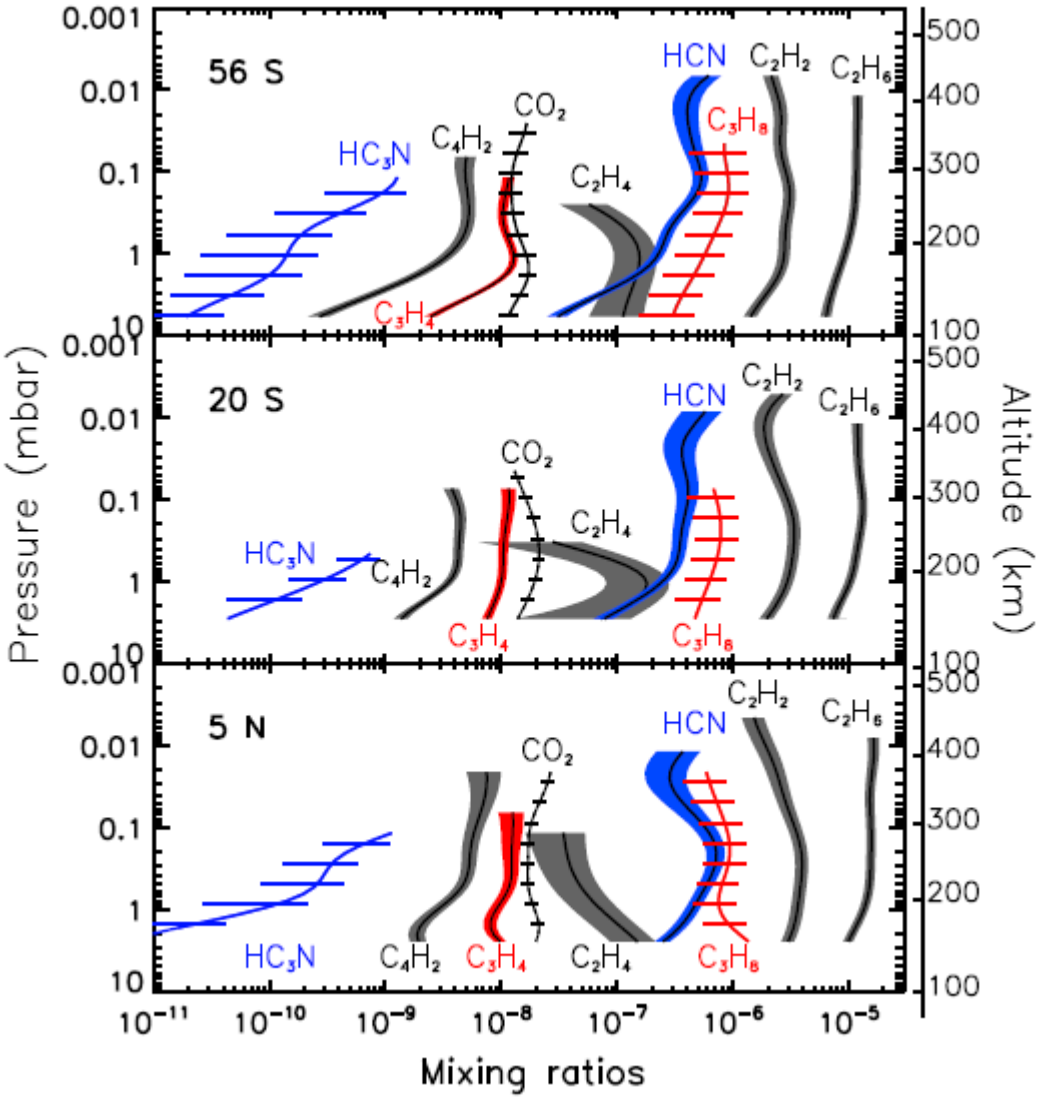
Stratosphere: IR spectroscopy



HCN: abundant molecule @ppm

Vinatier at al. 2007

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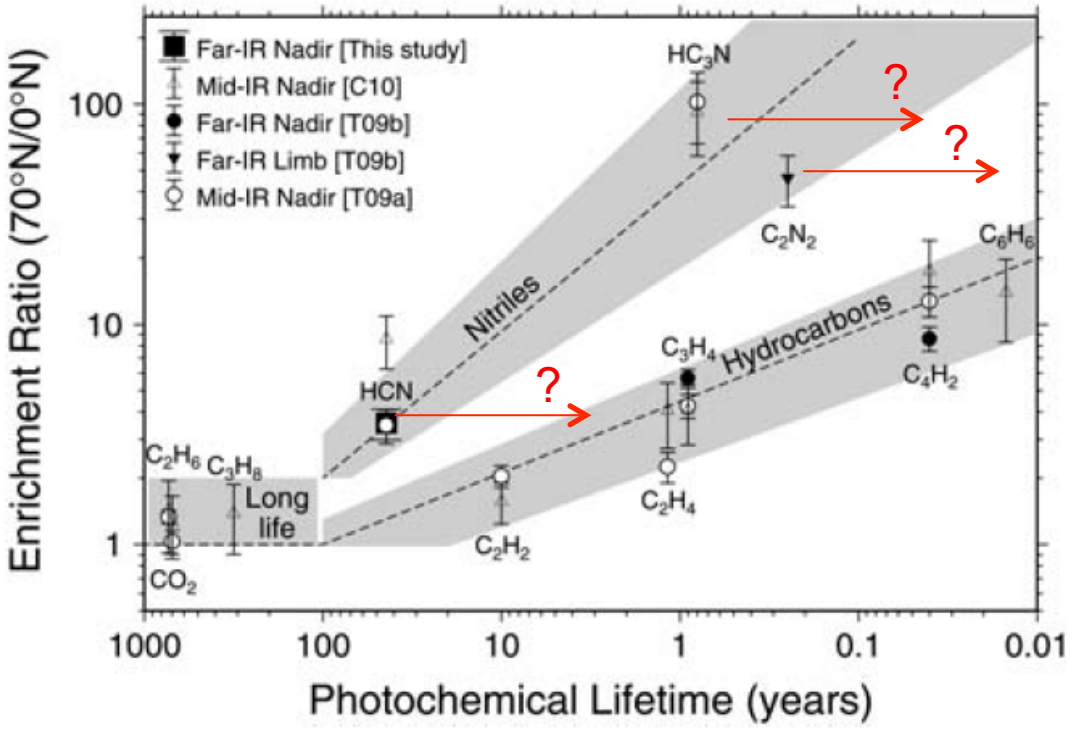
Stratosphere: IR spectroscopy

– Unsuspected reactivity of nitriles:
Missing consumption process

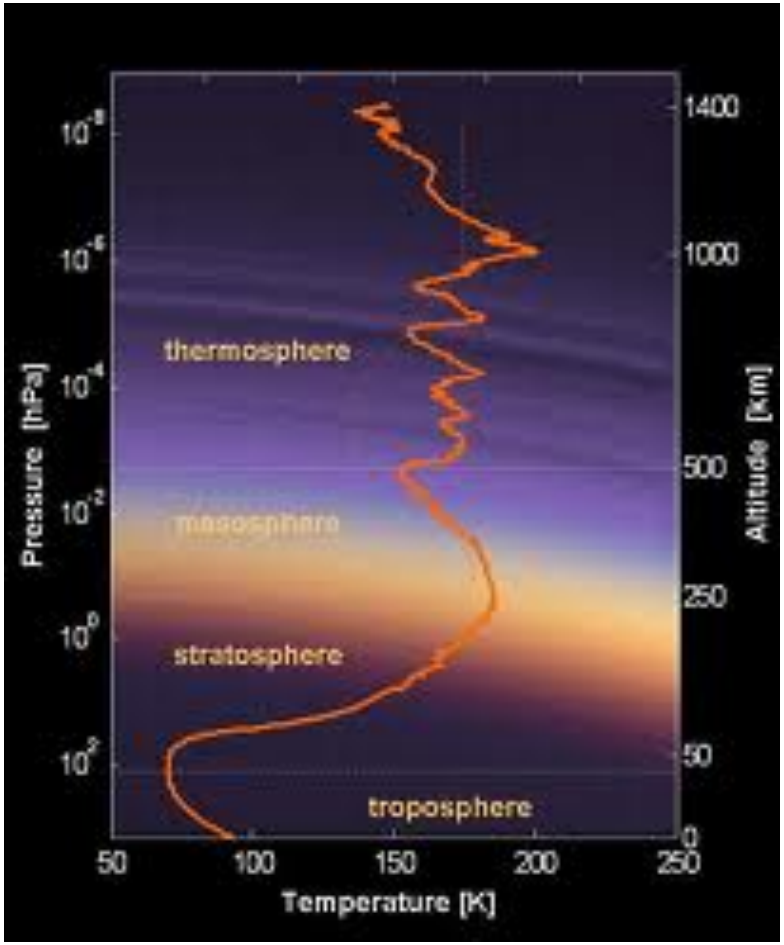


- Stronger polar enrichment of nitriles than hydrocarbons for a similar photochemical lifetime
- Steeper HCN profile observed than predicted

Teanby et al. 2010
Vinatier at al. 2007

The Cassini-Huygens mission: 2004-2017

- Data for probing Titan's atmosphere



- Ionosphere:

In situ instruments / MS

neutrals, cations, anions, e-

- Stratosphere:

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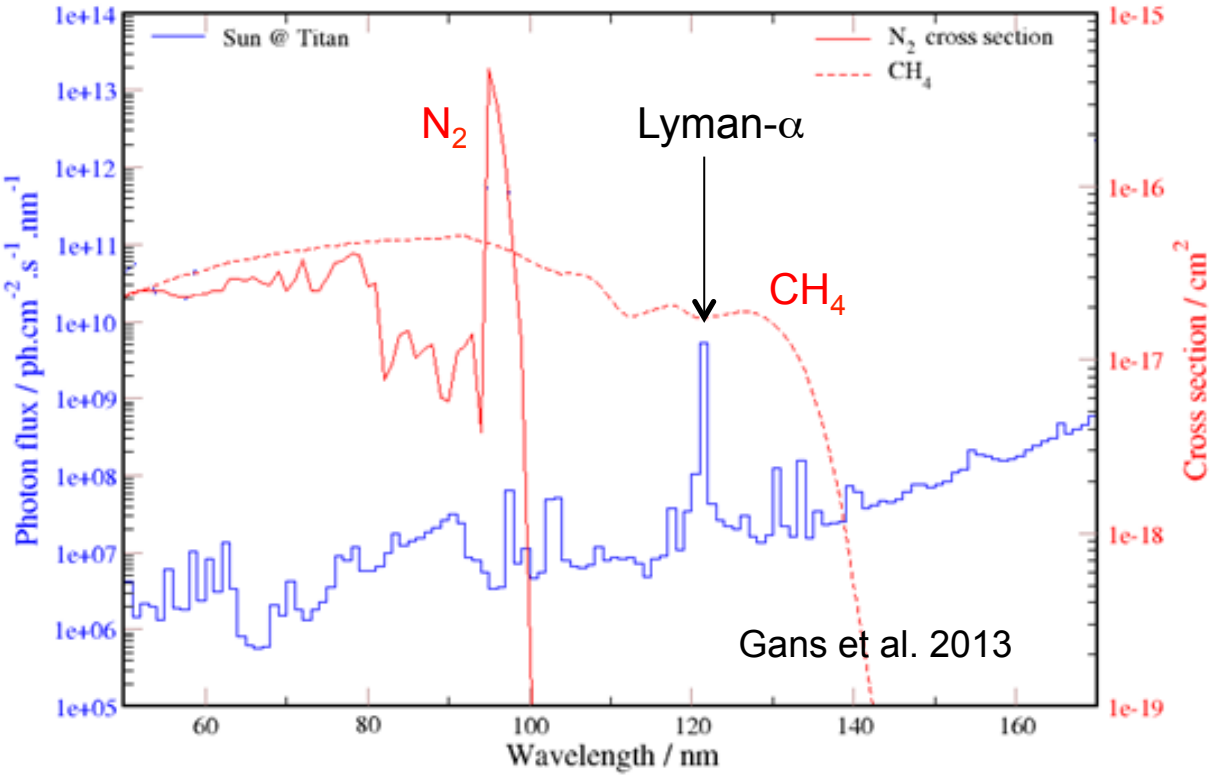
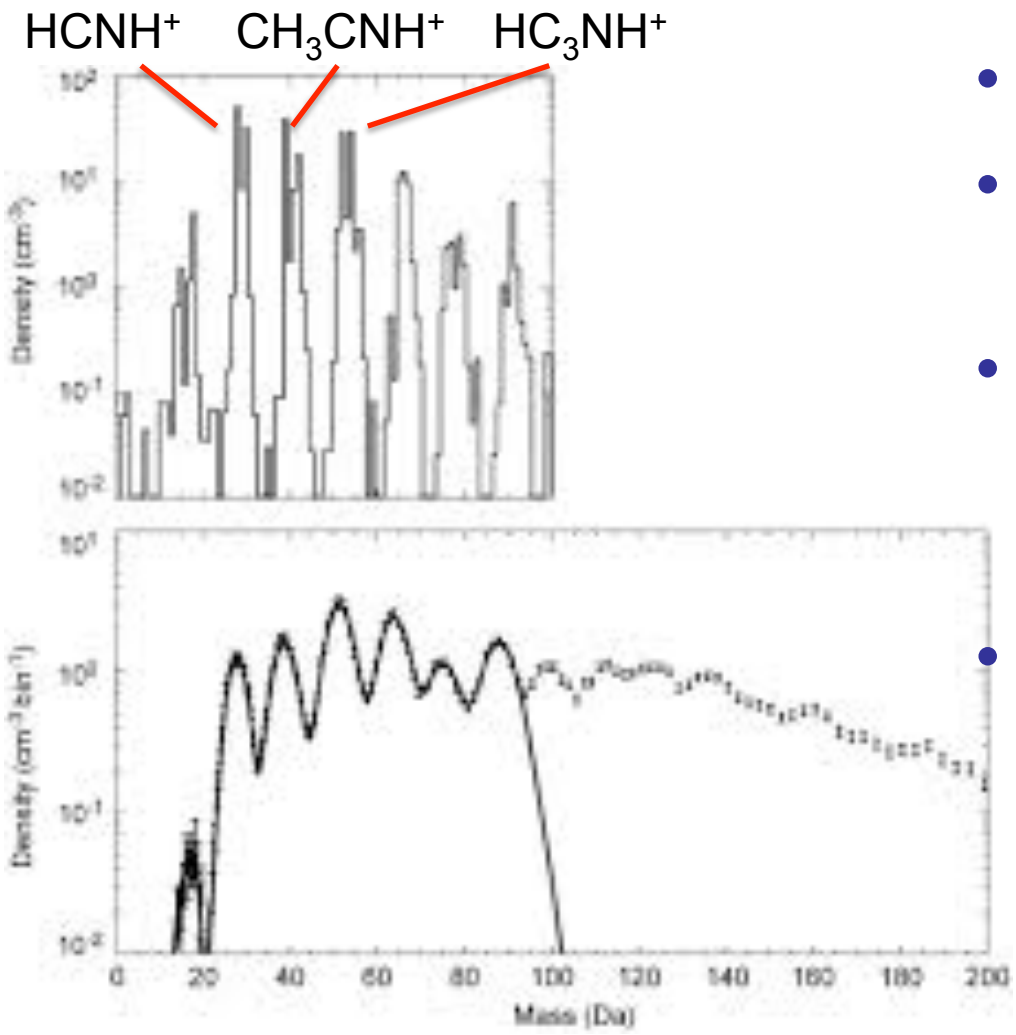
Ionosphere: chemical involvement of N_2

- Photodissociation and ionization of N_2
  - N_2*, $N(^4S)$, $N(^2D)$, N_2^+, N^+, N_2^{++}, N^{++}
  - Reactions with hydrocarbons: CH_4 – C_3H_8

Dutuit et al. 2013, APJ Sup ser.



Ionosphere: unexpected organic growth



- INMS: Neu & Ion$^+$
- CAPS-IBS : Ion$^+$

- « Ion chemistry » models hardly explain ion growth
- Highest abundances = N-containing ions

Waite et al 2007
Vuitton et al. 2008
Carrasco et al. 2007

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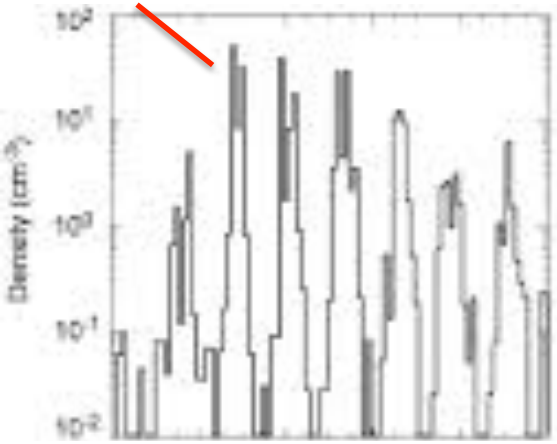
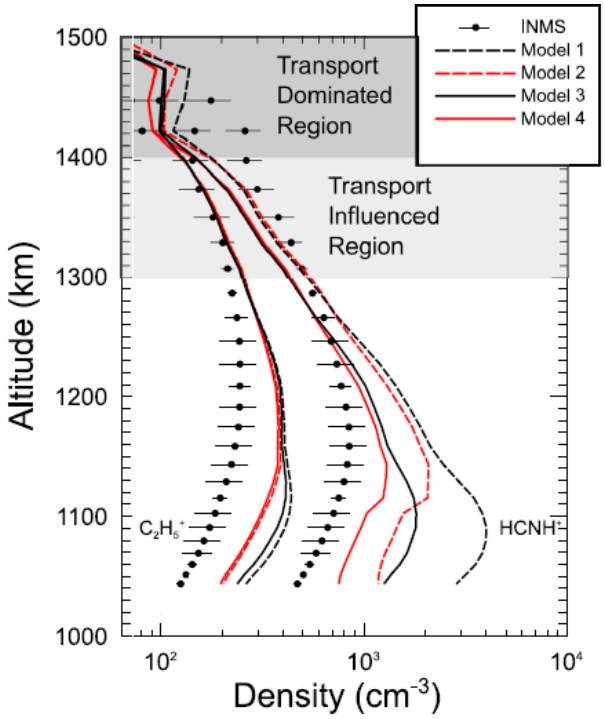
Ionosphere: main ion $HCNH^+$

$HCNH^+$



Westlake et al. 2012



→ Missing $HCNH^+$ consumption process

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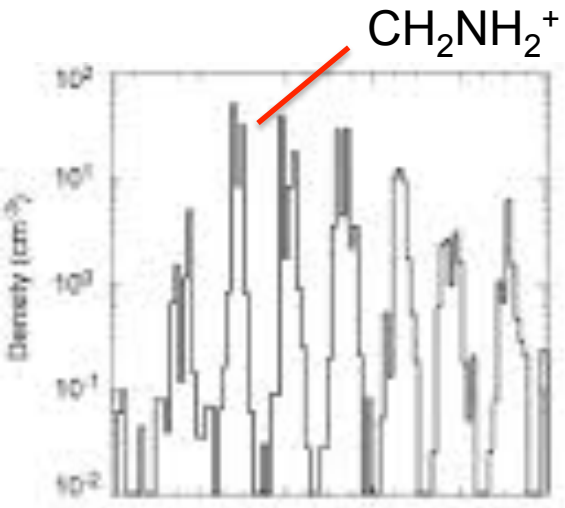
Ionosphere: protonated imines

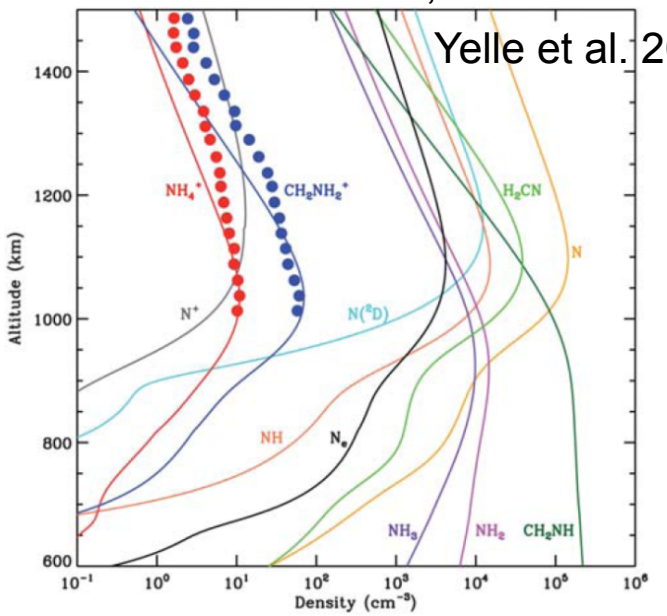


$N(^2D)+CH_4 \rightarrow CH_2=NH + H$

highly polymerizable

Balucani et al., 2009

Yelle et al. 2010



→key towards aerosols ?

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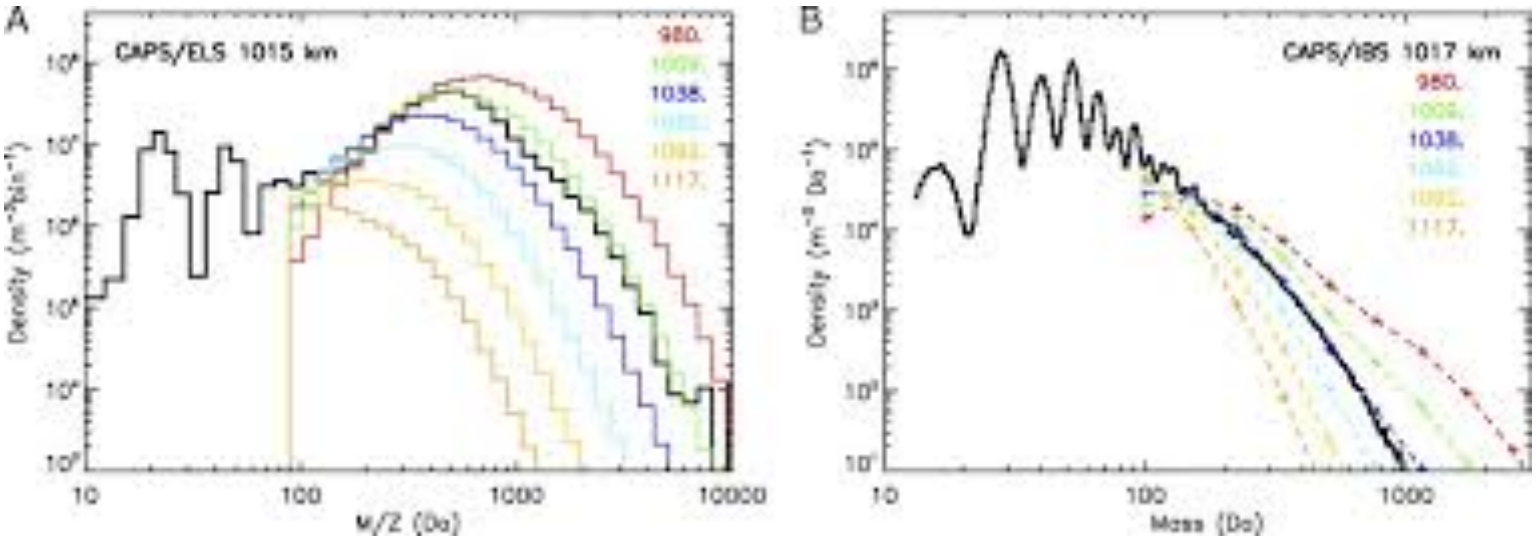
Ionosphere: where aerosol are initiated

- Mass transfer from positive ions to negatively charged particles
  - Correlation between CAPS IBS and CAPS ELS spectra



→ New microphysic models

Lavvas et al. 2013

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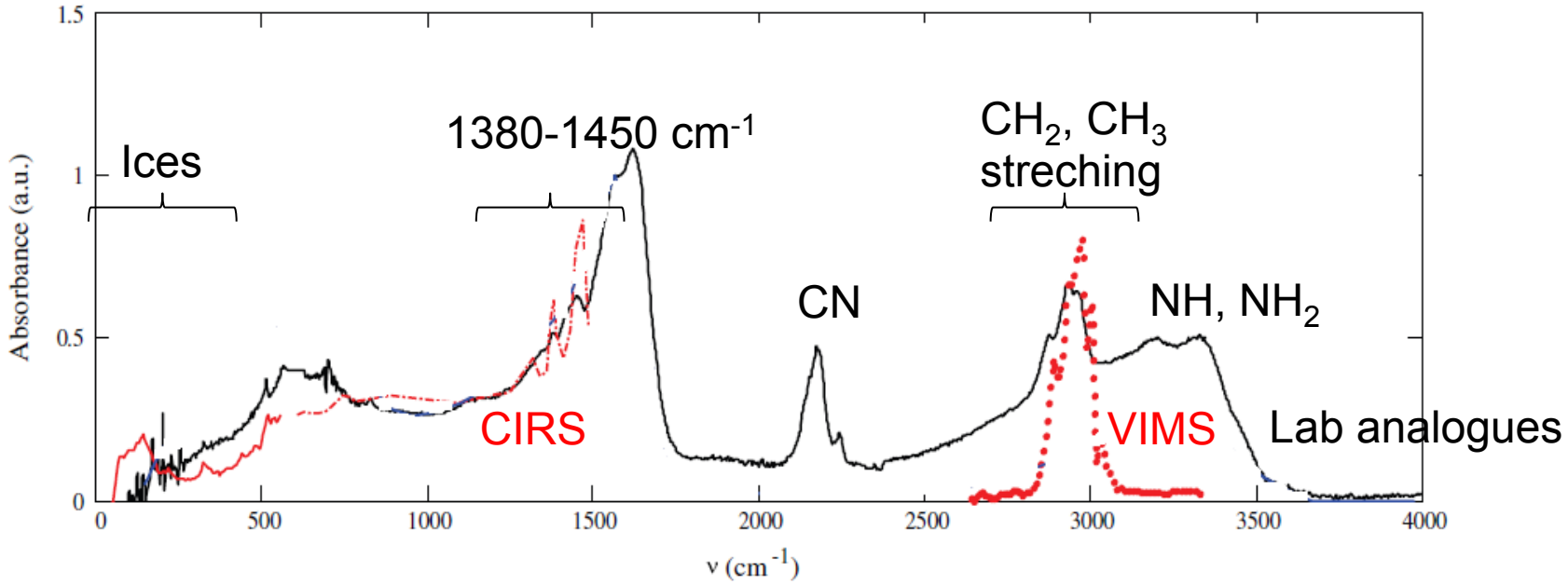
Stratosphere: IR spectroscopy

- Aerosols signature FIR-MIR



- Clear aliphatic signatures
- Ice coating
- N incorporation ?

Gautier et al. 2012

A future mission to Titan after Cassini ?

- What cannot be answered with the present instruments onboard Cassini
  - Identification of the large molecules in the atmosphere
    - N content ?
    - Nucleation precursors

→Mass resolution improvement in the upper atmosphere

→In situ analysis of the aerosols in the stratosphere

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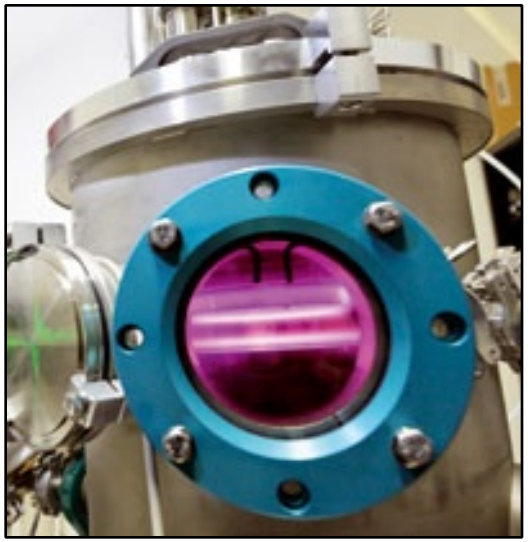
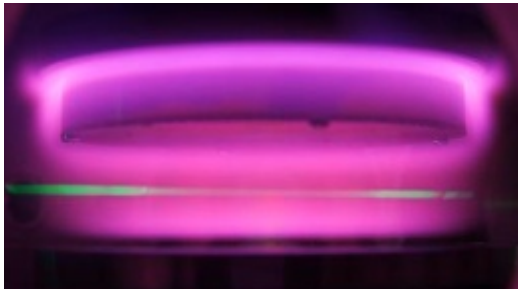
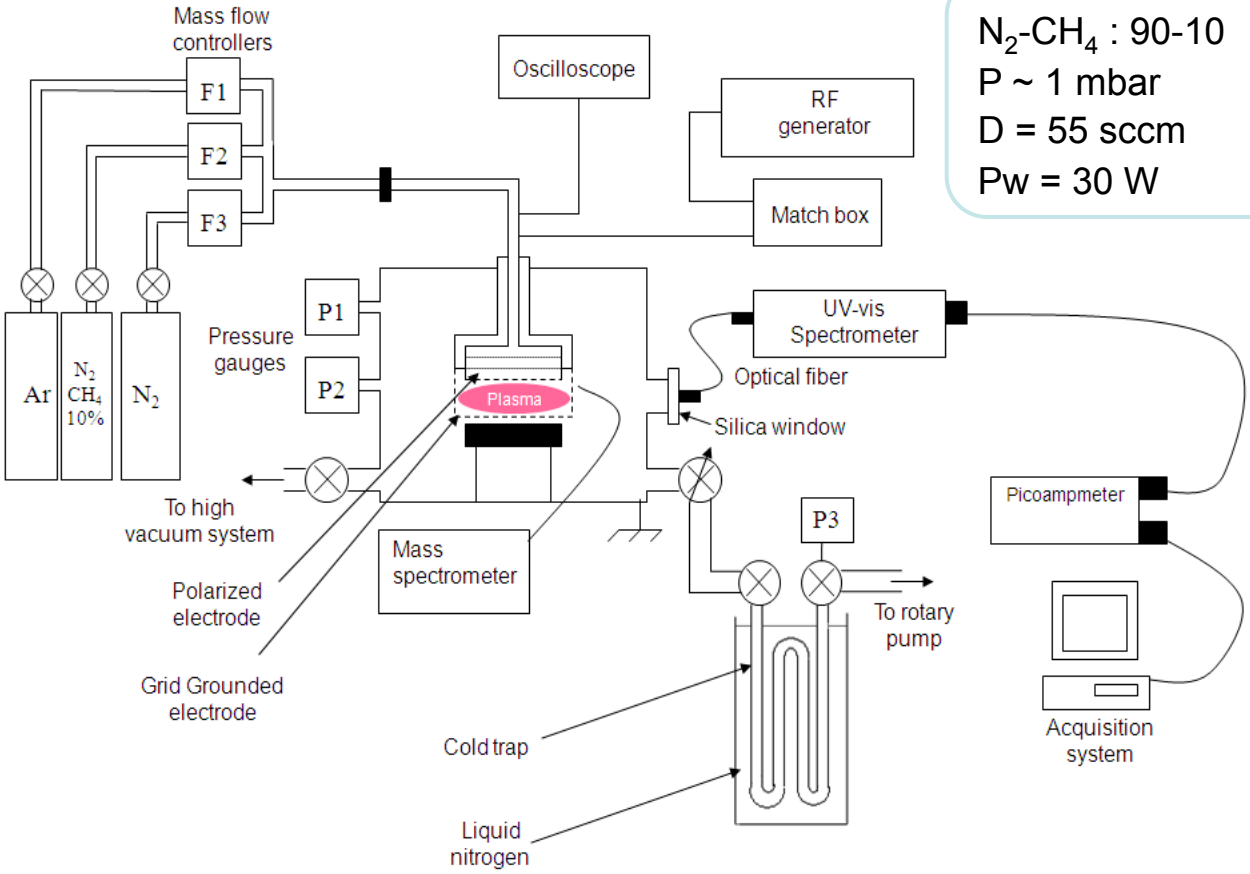
Meanwhile : experimental simulation

Plasma: dissociation and dissociative ionization of N_2 and CH_4 by electronic impact

PAMPRE



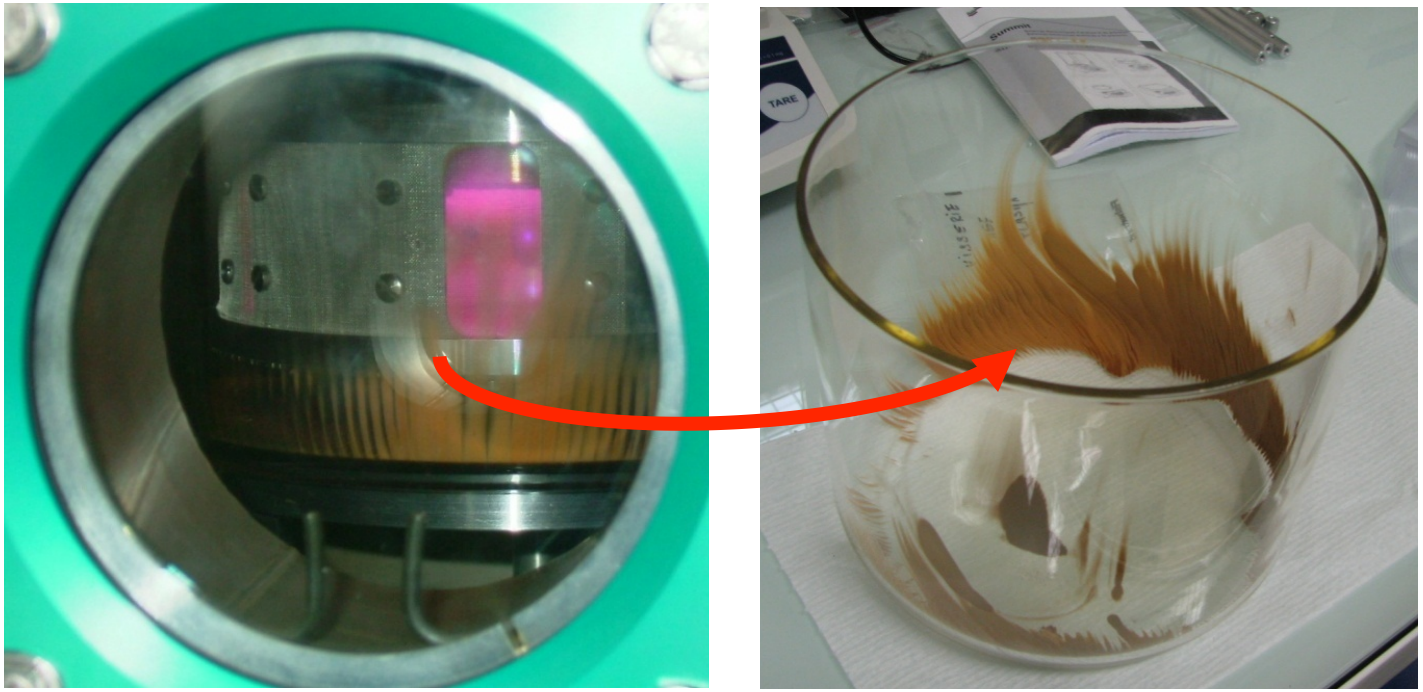




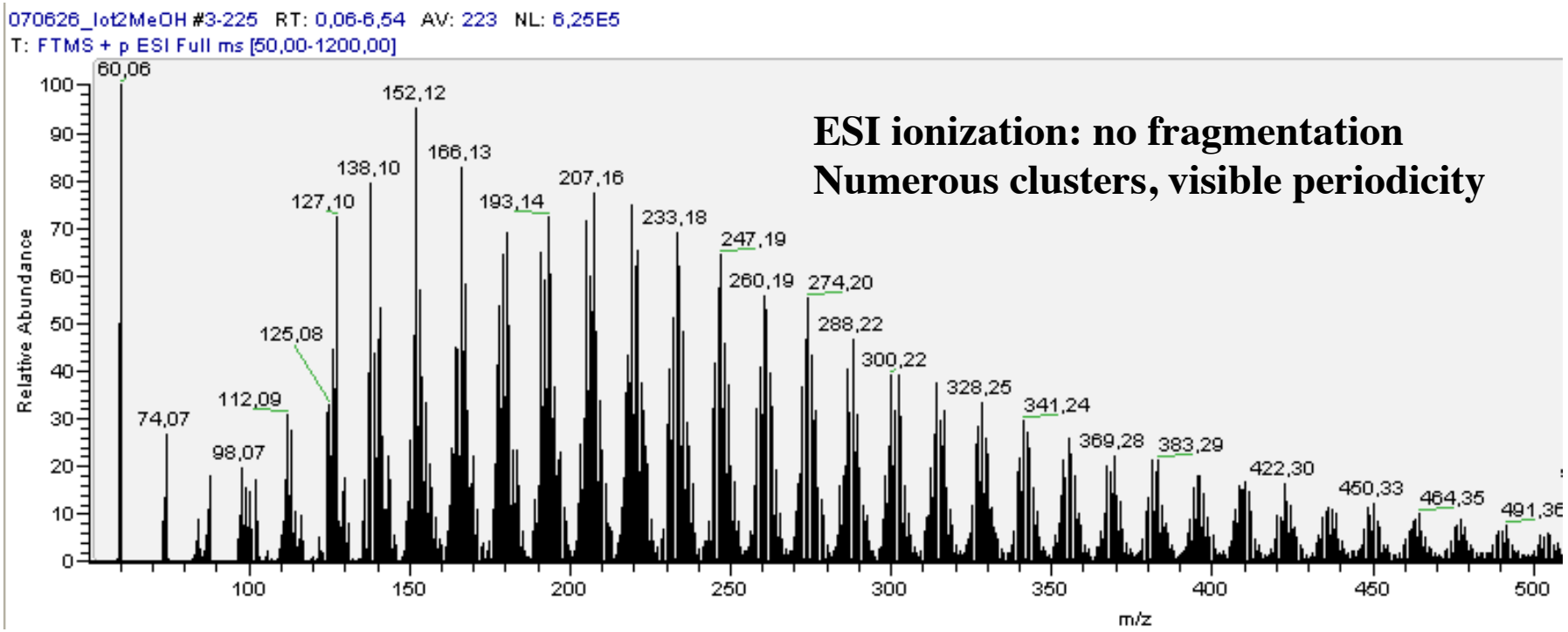
N_2-CH_4 : 90-10
P ~ 1 mbar
D = 55 sccm
Pw = 30 W

Aerosol collection and analysis

- 10 hrs ≈ 100 mg of Titan's organic aerosol analogues



High resolution mass spectrometry



Complex composition, but well structured spectra
→ polymeric structure

Pernot et al. Anal. Chem 2010.

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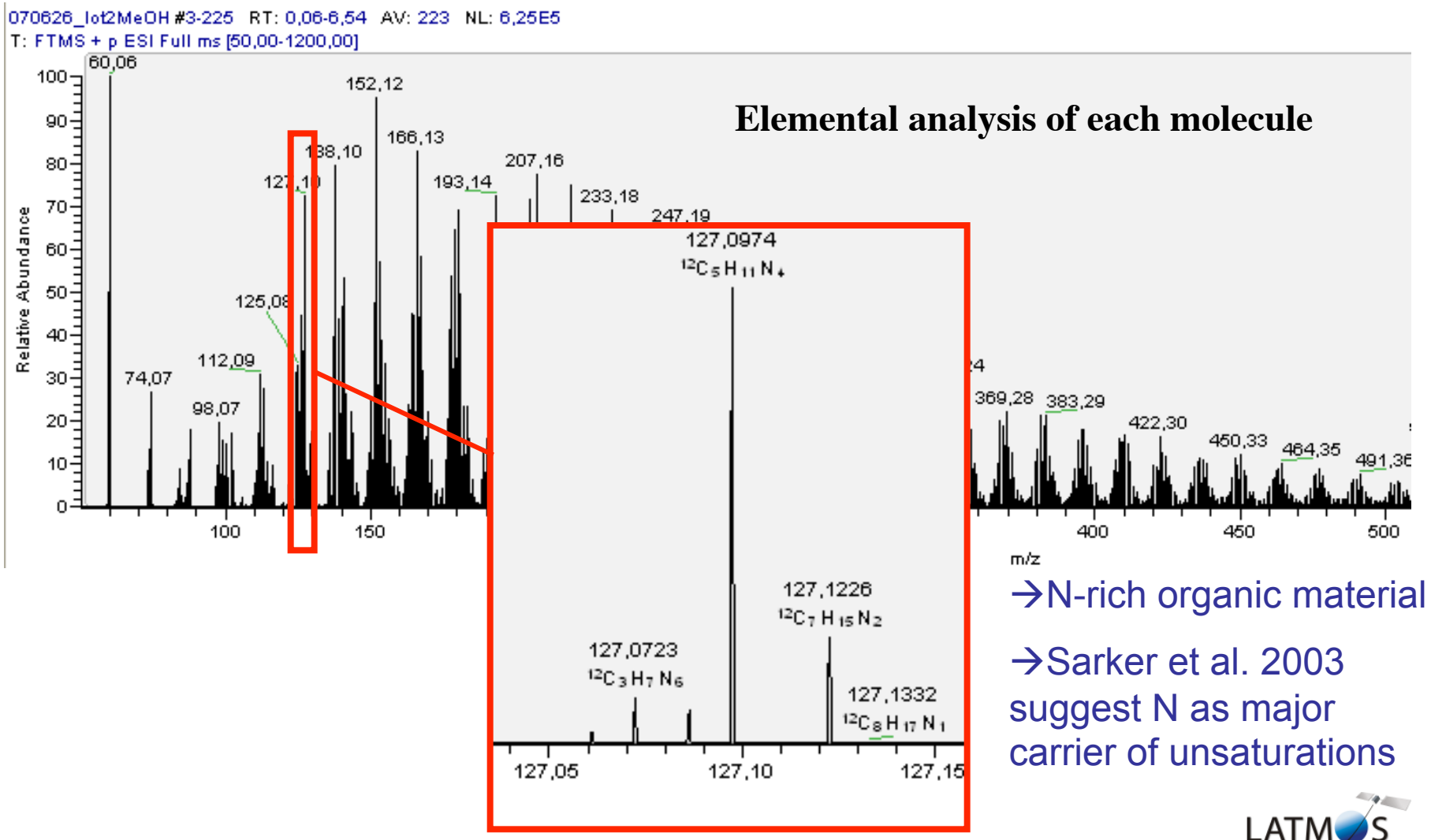
High resolution mass spectrometry



Elemental analysis of each molecule

→N-rich organic material

→Sarker et al. 2003 suggest N as major carrier of unsaturations

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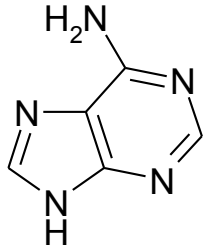
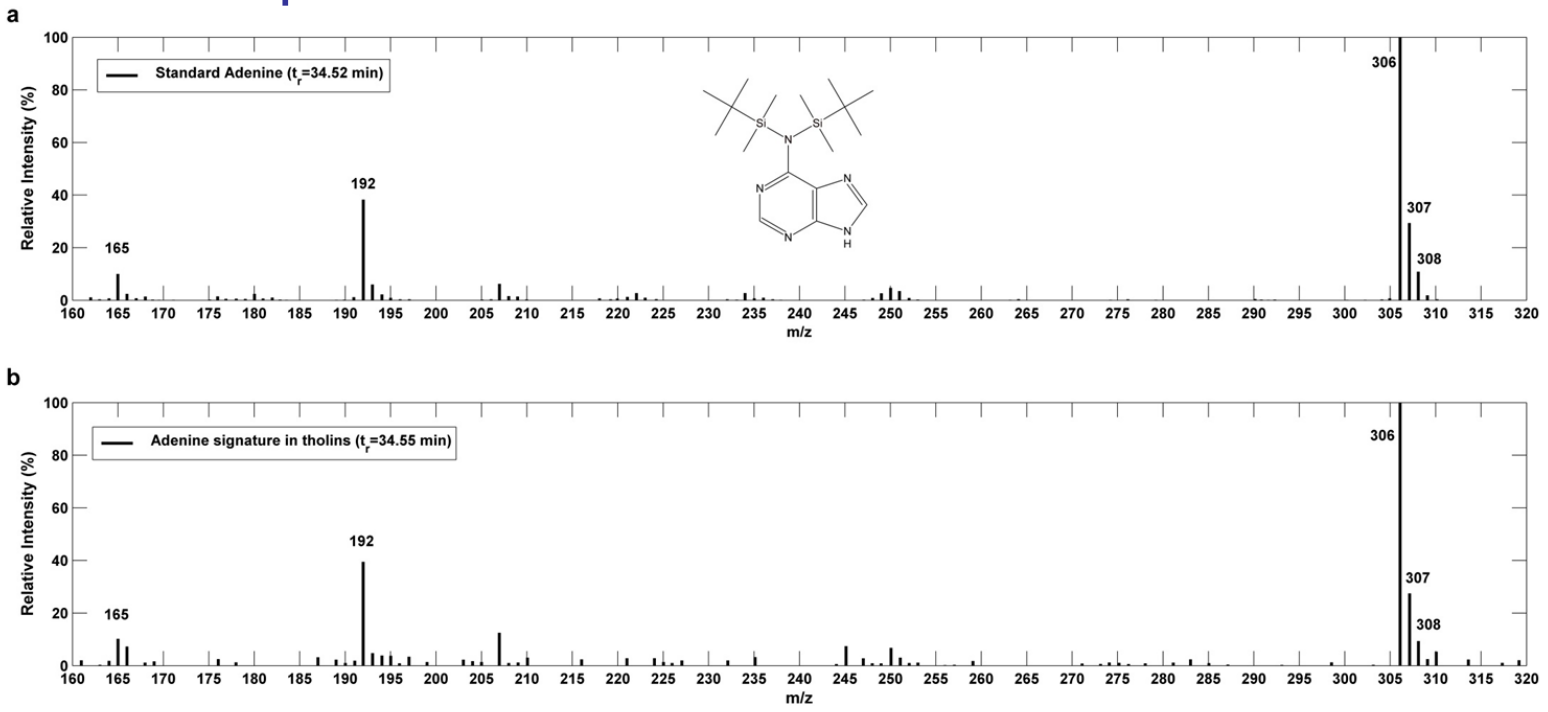
Molecular identification

- Nitrogen-rich prebiotic matterial
  - Derivatization + GC-MS analysis + comparison to a standard





Hörst et al. 2012

Nitrogen efficient for chemical growth

- Comparison of the aerosol productions with and without N_2

- CH_4 diluted either in N_2 or in He (90-10%)

	With N_2	**With He**
Aerosol production rate mg.hr^{-1}	6.1	1.0

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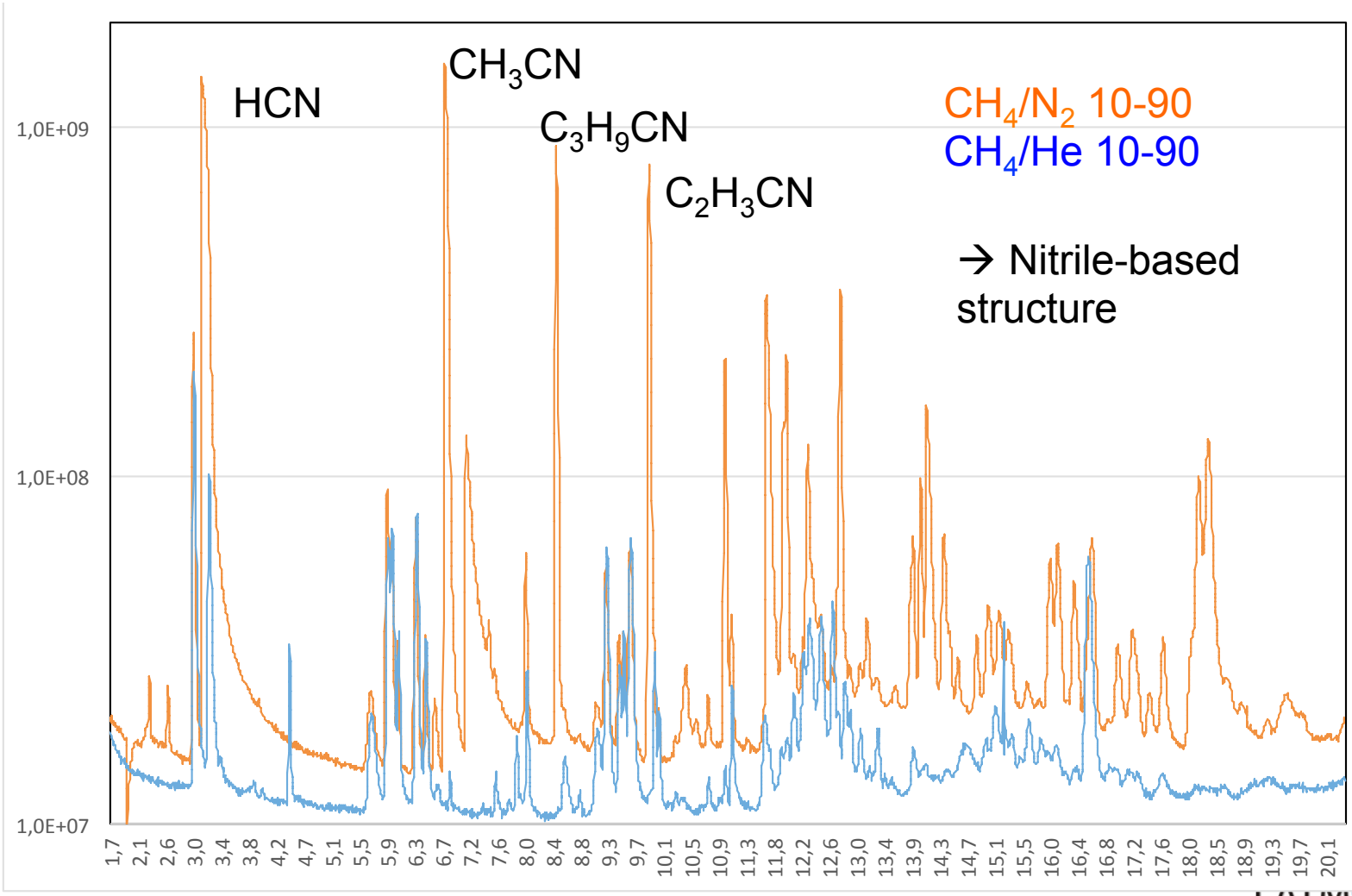
Pyr-GCMS analysis of analogues



Conclusion

- Titan is an accessible model of exoplanet with a high habitability interest
- Nitrogen is found to be essential for chemical growth
- The accessibility and the numerous Cassini data enabled to validate global experimental simulation to study upper atmospere system

→ Plasma experiments provide a pertinent and powerful tool to explore the reactivity of exoplanet upper atmospheres.