How can we explain all these steps of haze/cloud formation and evolution?

Titan after Cassini-Huygens, 2025, Elsevier

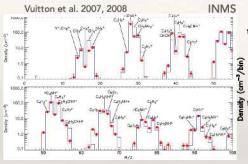
Chapter 7 - Titan's atmospheric structure, composition, haze, and dynamics (Vuitton et al. 2025)

Haze formation

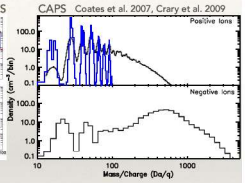
Microphysics of photochemical haze formation & evolution

Formation

Vuitton et al. 2007, 2008 INMS

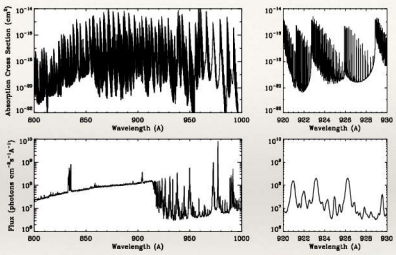


CAPS Coates et al. 2007, Crary et al. 2009



Gas to particle transition in the ionosphere

N_2 Photons

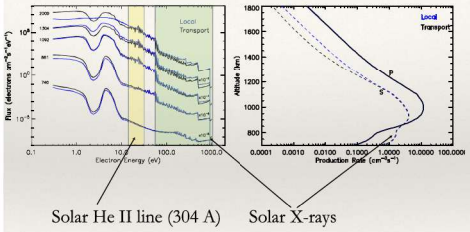


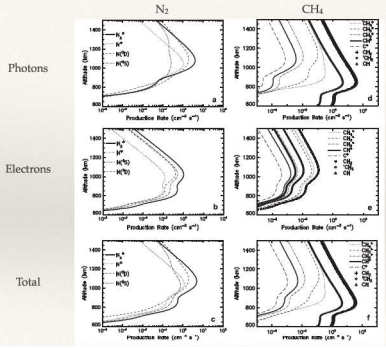
(Walter, Cosby and Helm, 1993)

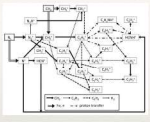
$1021\ \text{Å} > \lambda > 891\ \text{Å} : N(^2D) + N(^4S)$

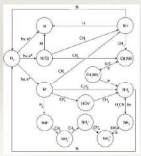
$891\ \text{Å} > \lambda > 854\ \text{Å} : N(^2P) + N(^4S)$

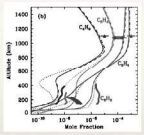
$\lambda < 854\ \text{Å} : N(^2D) + N(^2D)$

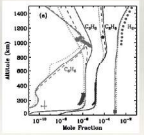












Models

Strobel et al. 1978
Yung et al. 1984
Toublanc et al. 1995
Lara et al. 1996
Lebonnois et al. 2001
Wilson & Atreya 2004
Vuitton et al. 2007/8
Horst et al. 2008
Lavvas et al. 2008a,b
Krasnopolsky 2009/12
Yelle et al. 2010
Lavvas et al. 2011
Mandt et al. 2012
Vuitton et al. 2012
Vuitton et al. 2014
Loison et al. 2015
Vuitton et al. 2019
Loison et al. 2019

100s - 1000s of reactions

Immense efforts from experimental & theoretical investigations

MOLECULAR GROWTH

Photochemical products

Positive ions

electrons

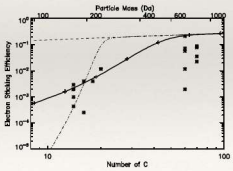
Macromolecules from ion chemistry

MOLECULAR GROWTH

Macromolecules Photochemical products

MOLECULAR GROWTH

Macromolecules electrons attach on macromolecules



MOLECULAR GROWTH

Macromolecules Charged macromolecules attract positive ions

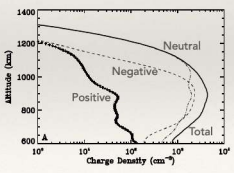
MOLECULAR GROWTH

Macromolecules Recombination leads to mass transfer to macromolecules

MOLECULAR GROWTH

Macromolecules Recombination leads to mass transfer to macromolecules

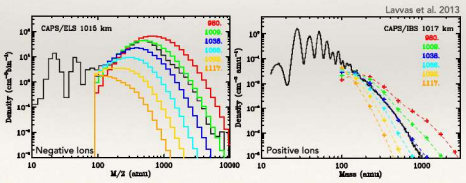
Charge balance based on collisions with ion/electrons & photoelectric effect



MOLECULAR GROWTH

Macromolecules Recombination leads to mass transfer to macromolecules

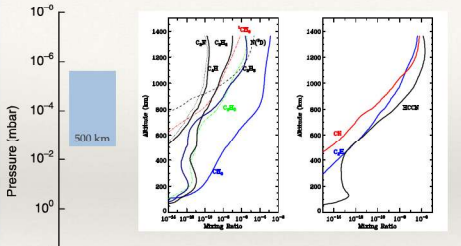
Lavvas et al. 2013



So, ion chemistry is starting the haze formation!

What provides further mass on the particles, though?

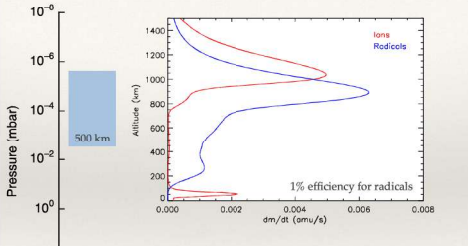
Heterogeneous neutral chemistry



Need constraints on heterogeneous reaction efficiency of different species

H on tholins: Sekine et al. 2008a,b

Haze lifetime on Titan: Heterogeneous neutral chemistry



Need constraints on heterogeneous reaction efficiency of different species

H on tholins: Sekine et al. 2008a,b

Adsorption
Desorption
Chemisorption
Ageing

CH3 CH3:H	10^{-4} 10^{-2}	von Keudell et al. 2002	Exp
C2	~1	Neyts et al. 2006	MD
C2H	0.80	Hopf et al. 2000	Exp
C2H3	0.35	Hopf et al. 2000	Exp
C2H5	0.001	Hopf et al. 2000	Exp
C3	~0.5	Neyts et al. 2006	MD
l-C3H	0.1-0.3	Neyts et al. 2006	MD
c-C3H	0.97	Neyts et al. 2006	MD

Extended literature in studies on C:H films and molecular dynamic studies.