N_2 IN TITAN'S ATMOSPHERE

[OR WHEN HIGH-RESOLUTION IS NEEDED]

PANAYOTIS LAVVAS

GROUPE DE SPECTROSCOPIE MOLÉCULAIRE & ATMOSPHÉRIQUE

UNIVERSITÉ DE REIMS

CNRS

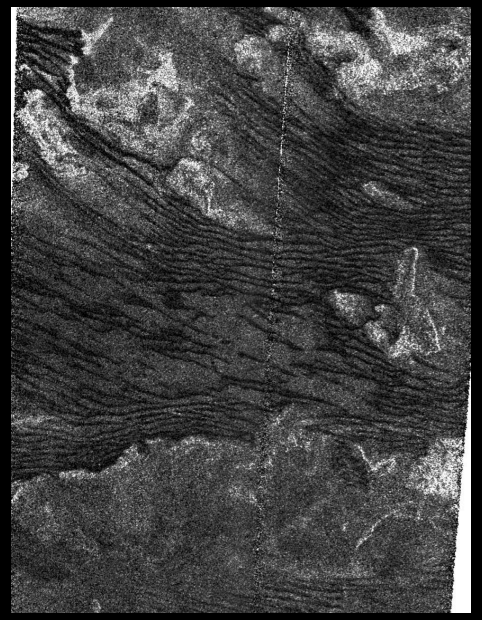
PHOTODISSOCIATION IN ASTROCHEMISTRY - LEIDEN FEB-2015

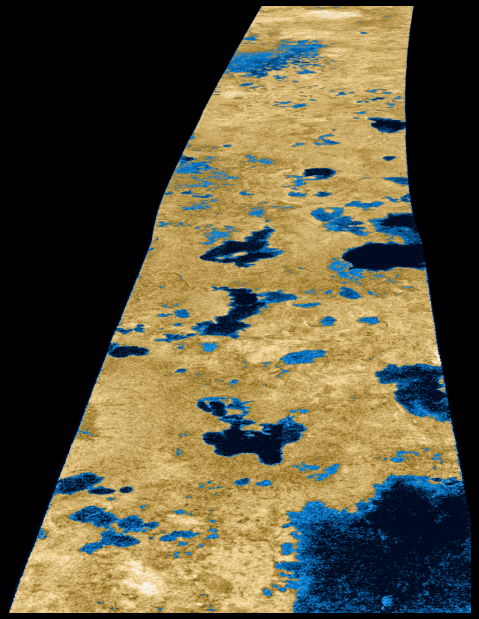
TITAN

Christiaan Huygens
1629-1695

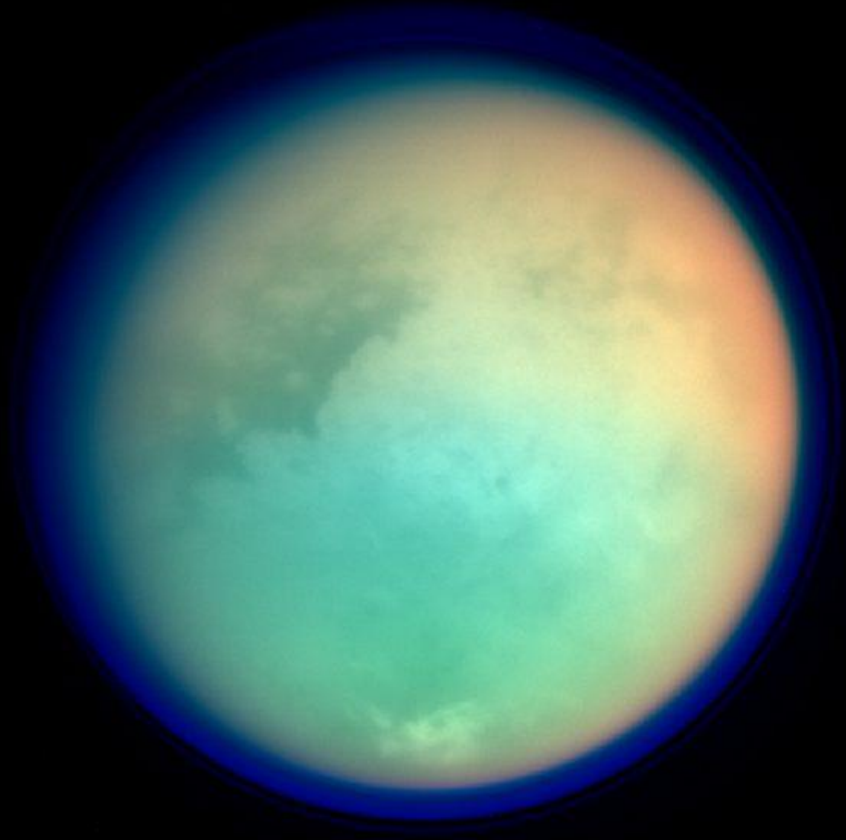
N_2~98%
CH_4~2%

Dune Fields

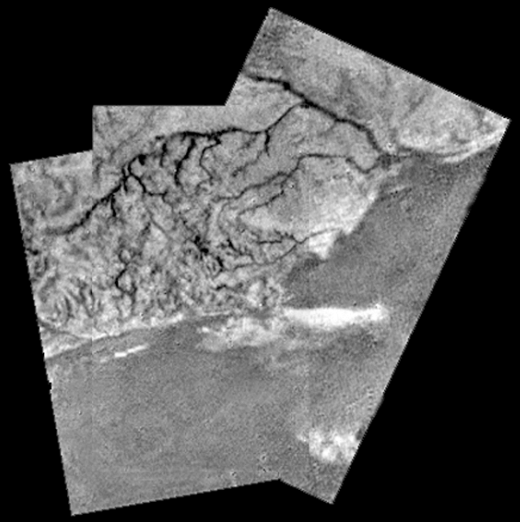




Lakes & Seas

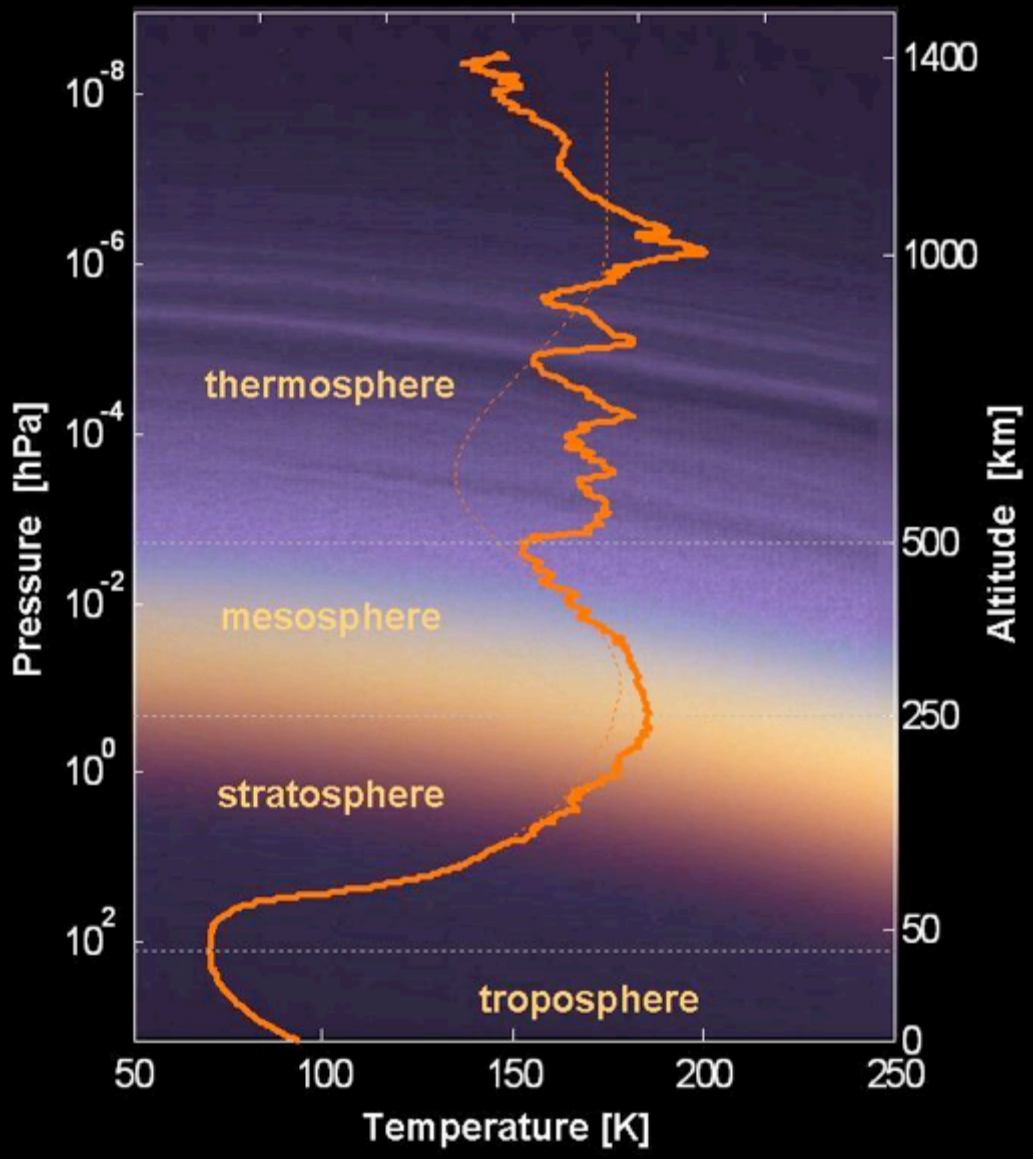


Cassini
Composite from IR (red-green)
and UV (blue) wavelengths
2005

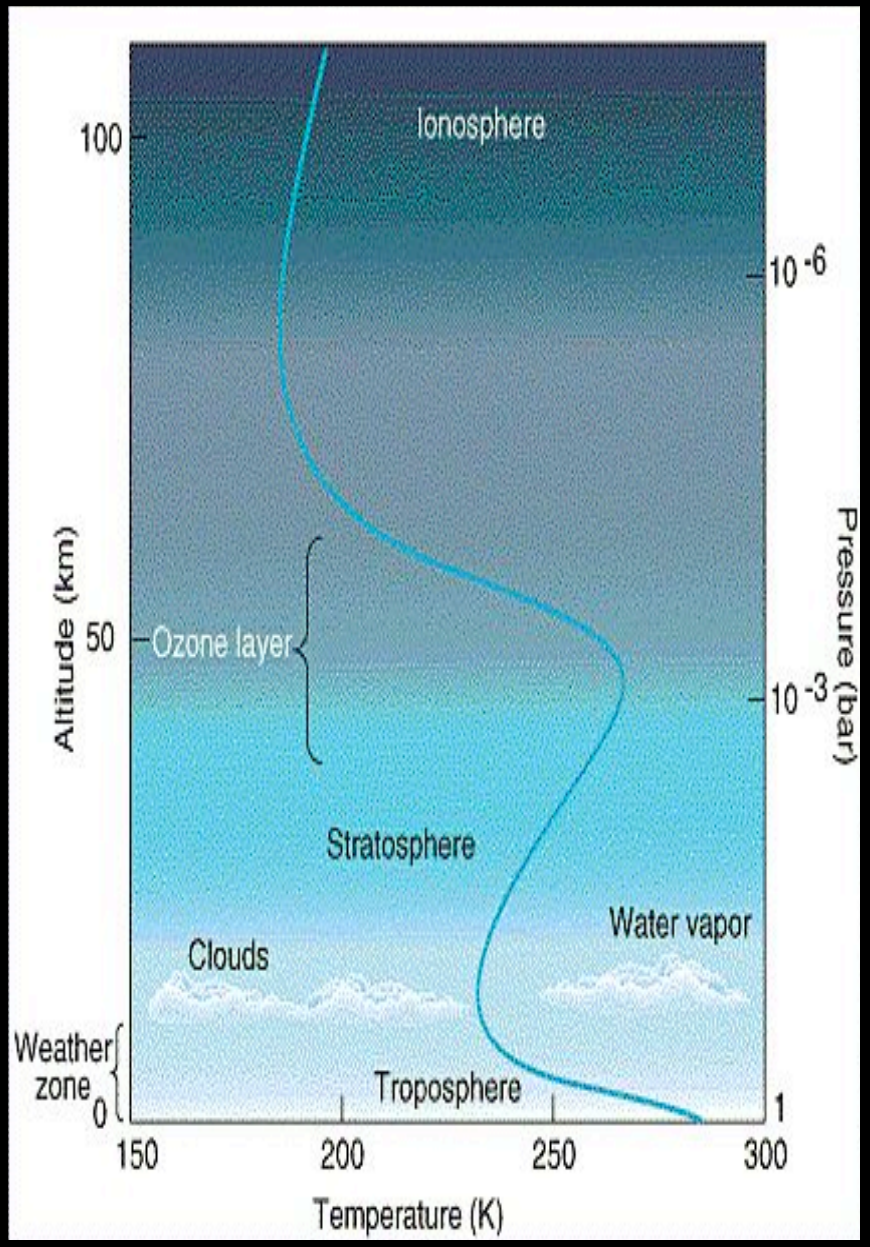


River Channels

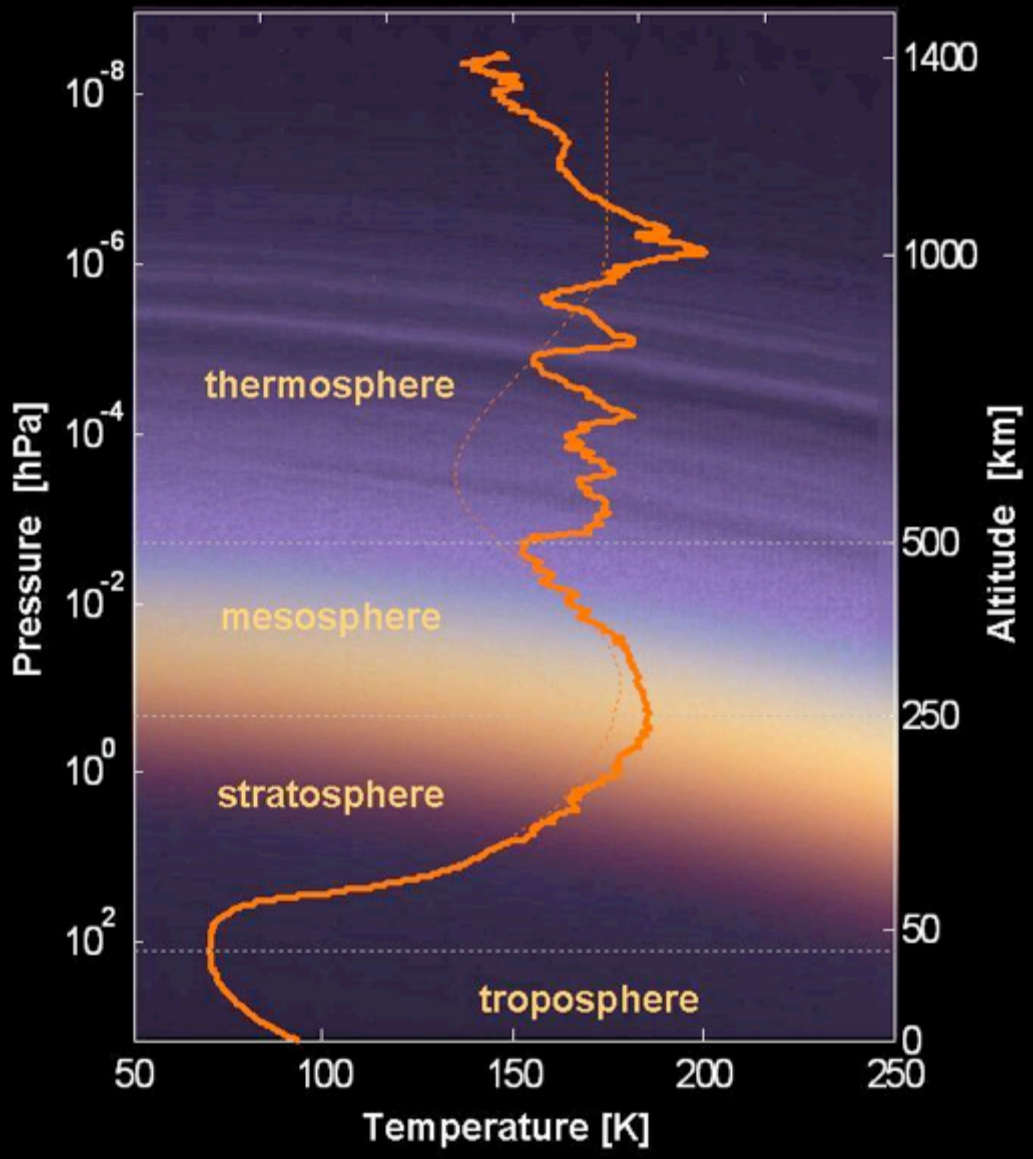
Titan


thermosphere
mesosphere
stratosphere
troposphere
Pressure [hPa]
Altitude [km]
Temperature [K]
10^-8
10^-6
10^-4
10^-2
10^0
10^2
1400
1000
500
250
50
0
50
100
150
200
250

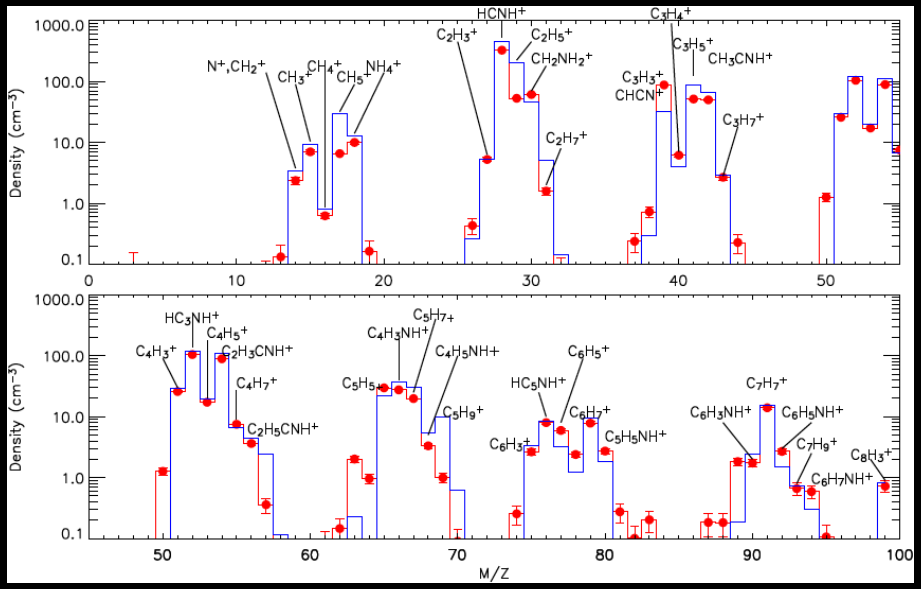
Earth


Ionosphere
Ozone layer
Stratosphere
Water vapor
Clouds
Weather zone
Troposphere
Altitude (km)
Pressure (bar)
Temperature (K)
100
50
0
10^-6
10^-3
1
150
200
250
300

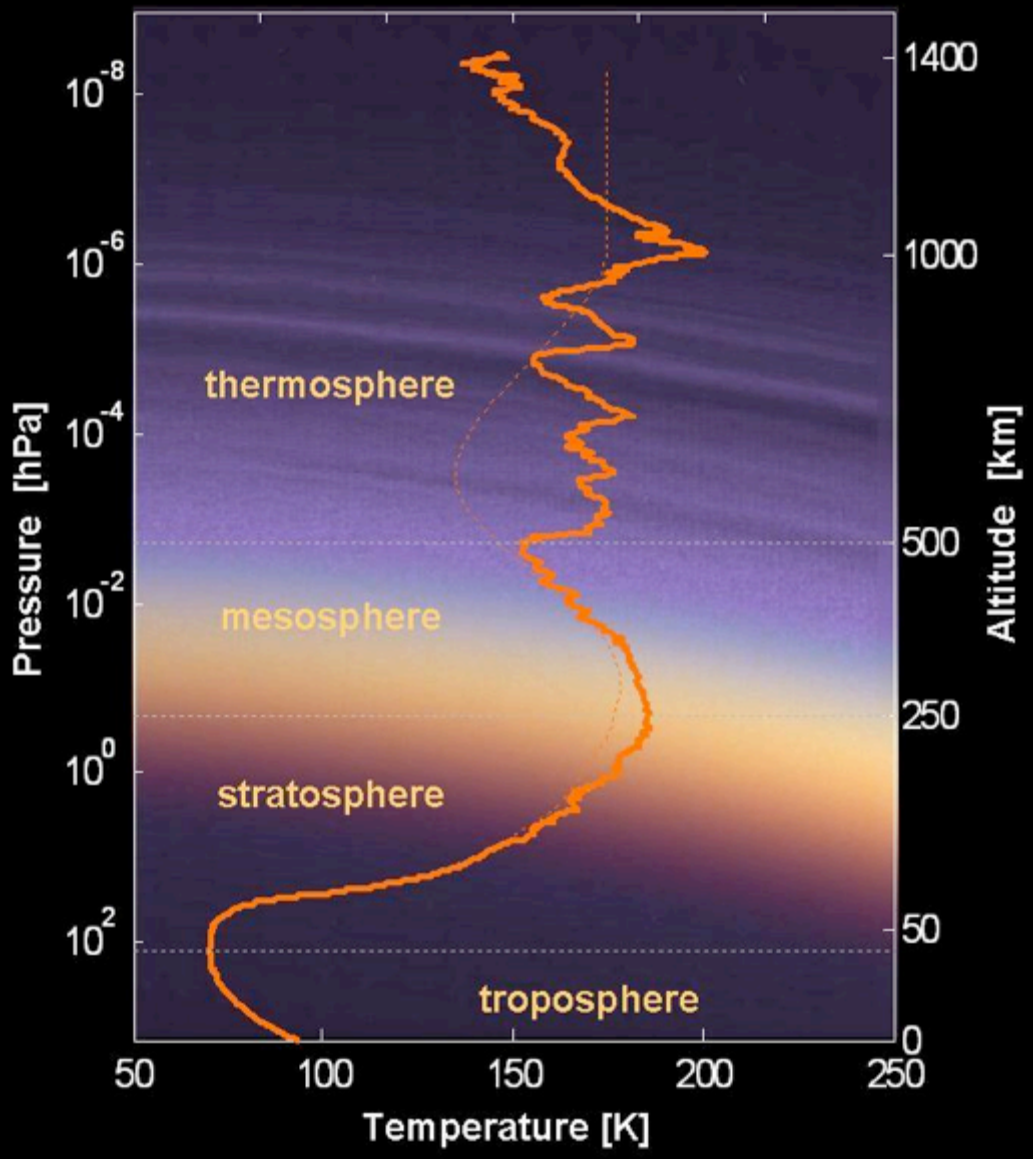
Titan



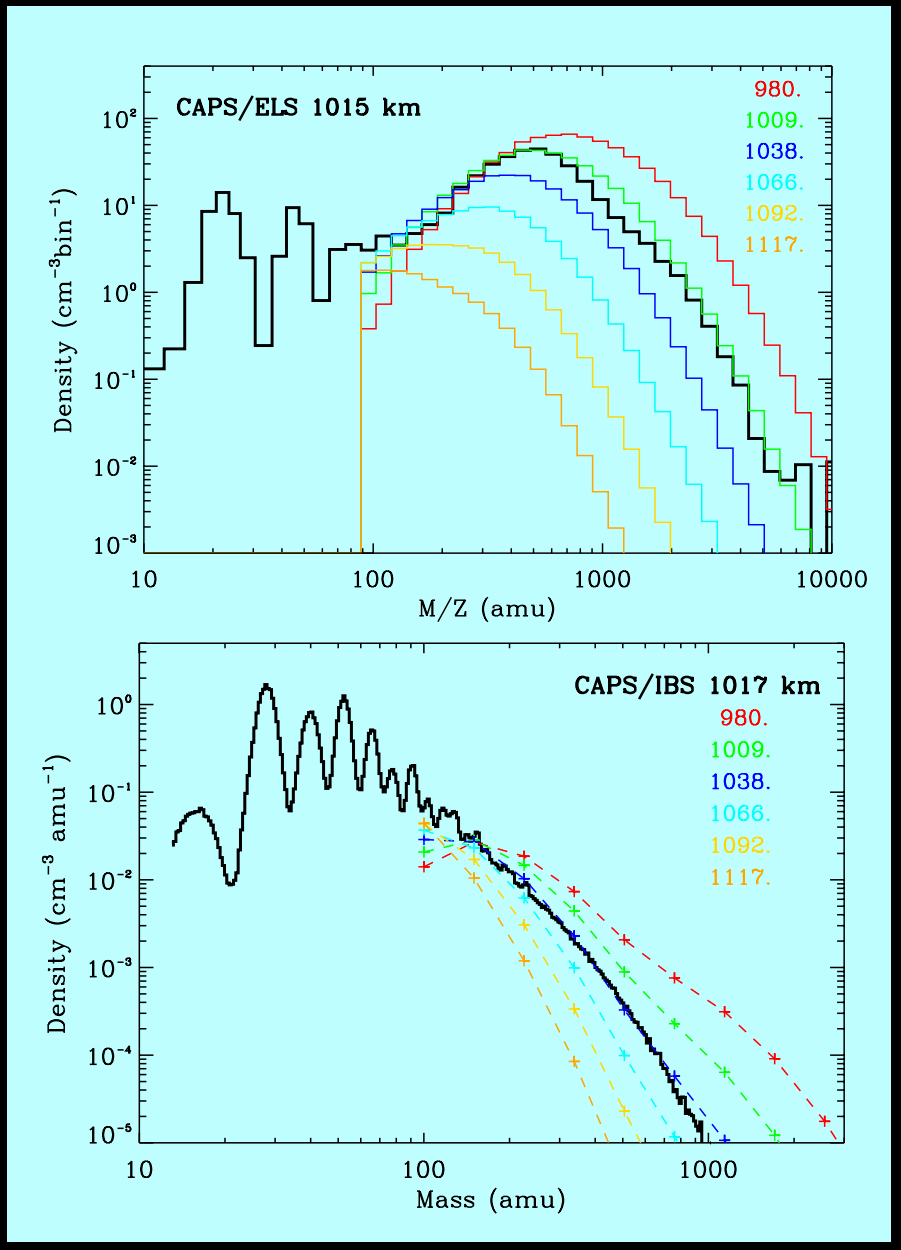
Vuitton et al. 2007



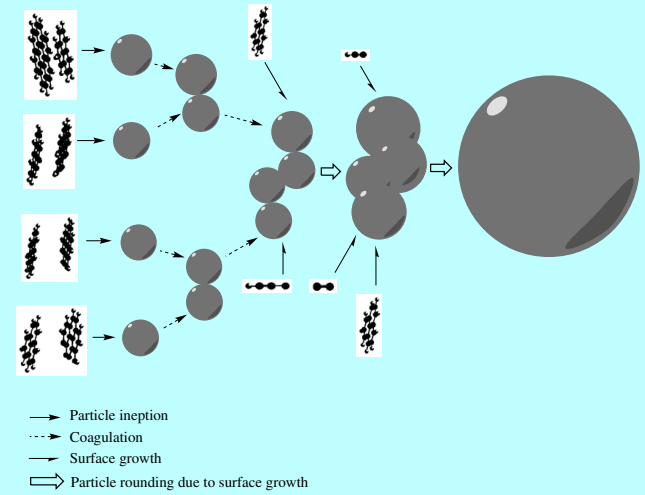
Titan

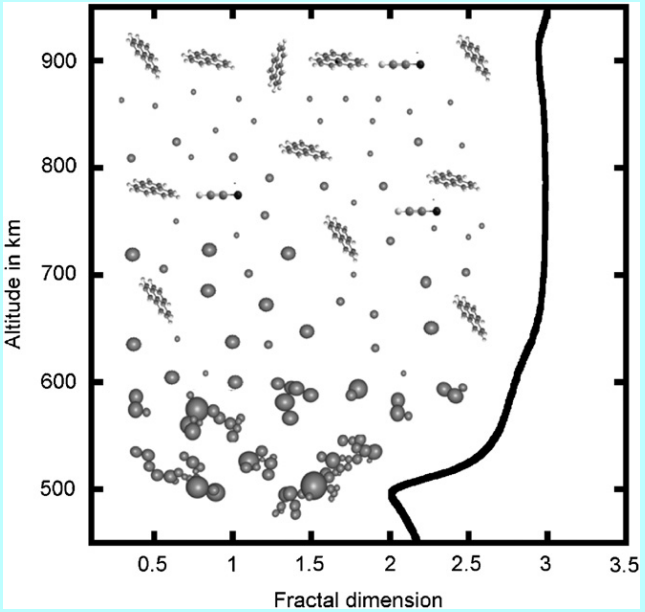


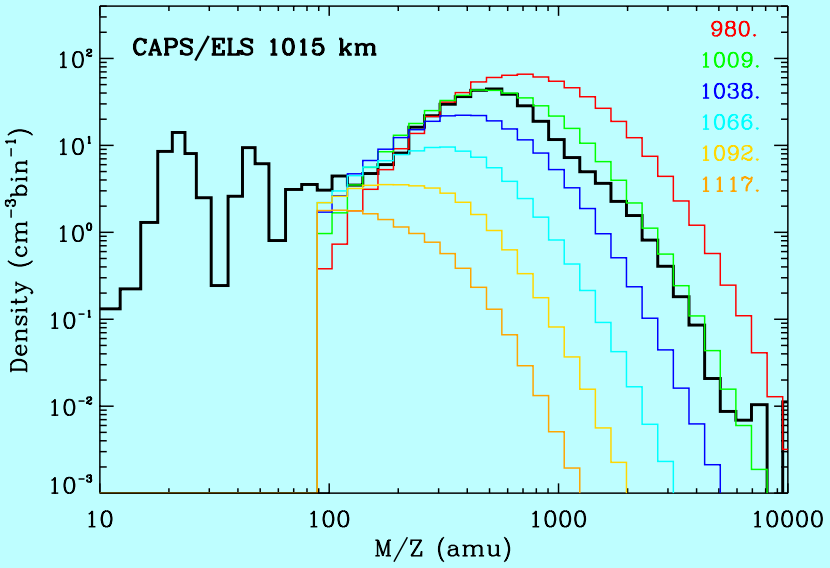
Lavvas et al. 2013

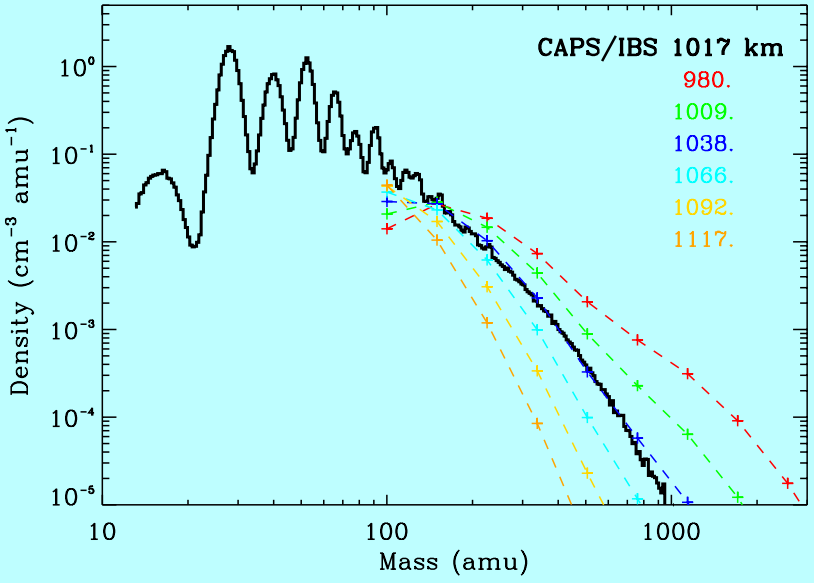


Lavvas et al. 2013









All this chemical complexity starts
from the photodissociation of N_2 & CH_4

High detail spacecraft observations

Need for detailed studies

Energy Sources

SUN

Photons

$N_2 + hv \rightarrow N(^4S) + N(^2D)$

$N_2 + hv \rightarrow N_2^+ + e^-$

$E_e = E_{hv} - I$

photoelectrons

Supra-thermal Electrons

$N_2 + e^- \rightarrow N_2^+ + e^- + e^-$

Secondary electrons

SATURN

Magnetospheric Electrons

Variation of EUV emissions and electron temperature between night and day side suggest that their contribution is smaller than that of photons

[Ajello et al. 2007, 2008; Agren et al. 2009, Cui et al., 2009, Cravens et al. 2009, Galand et al., 2010, Lavvas et al., 2011a]

IPM

Cosmic Rays

Meteoroids

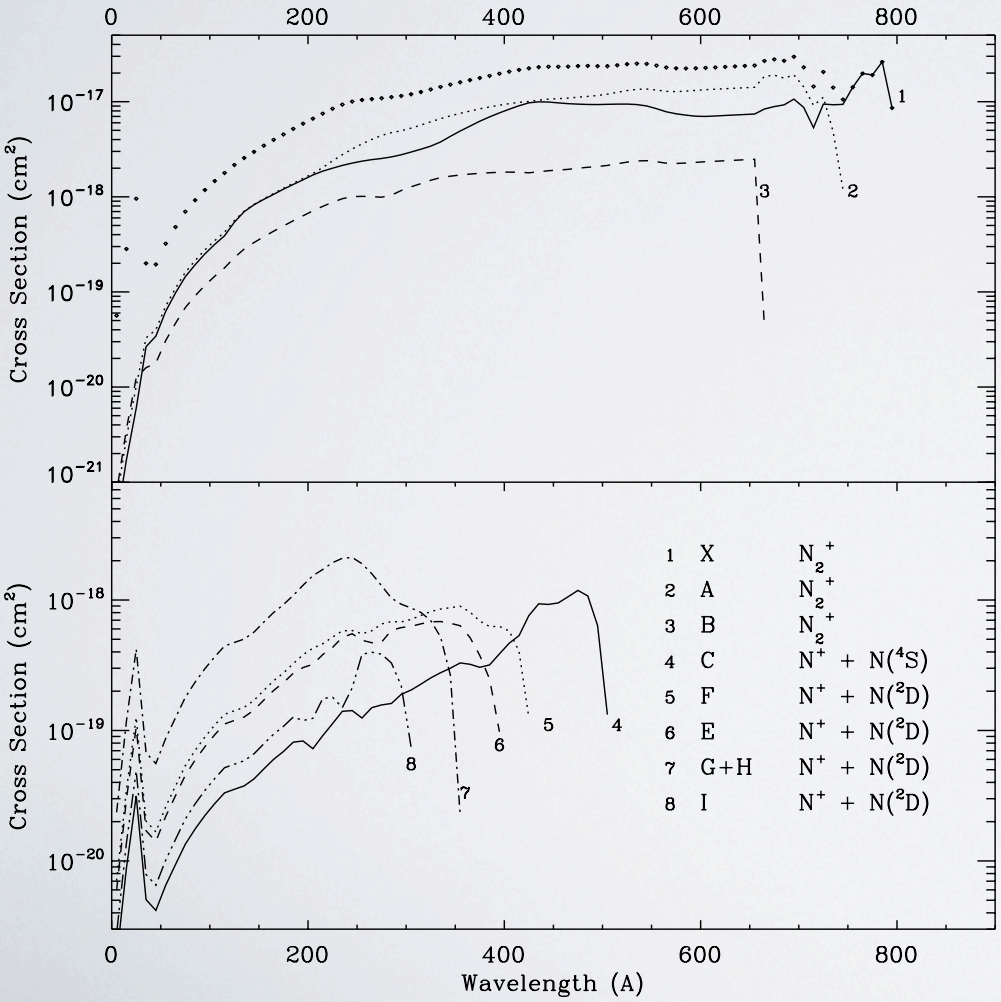
Photons

$N_2 + h\nu \rightarrow N + N$ 796.8 A<λ<1000 A

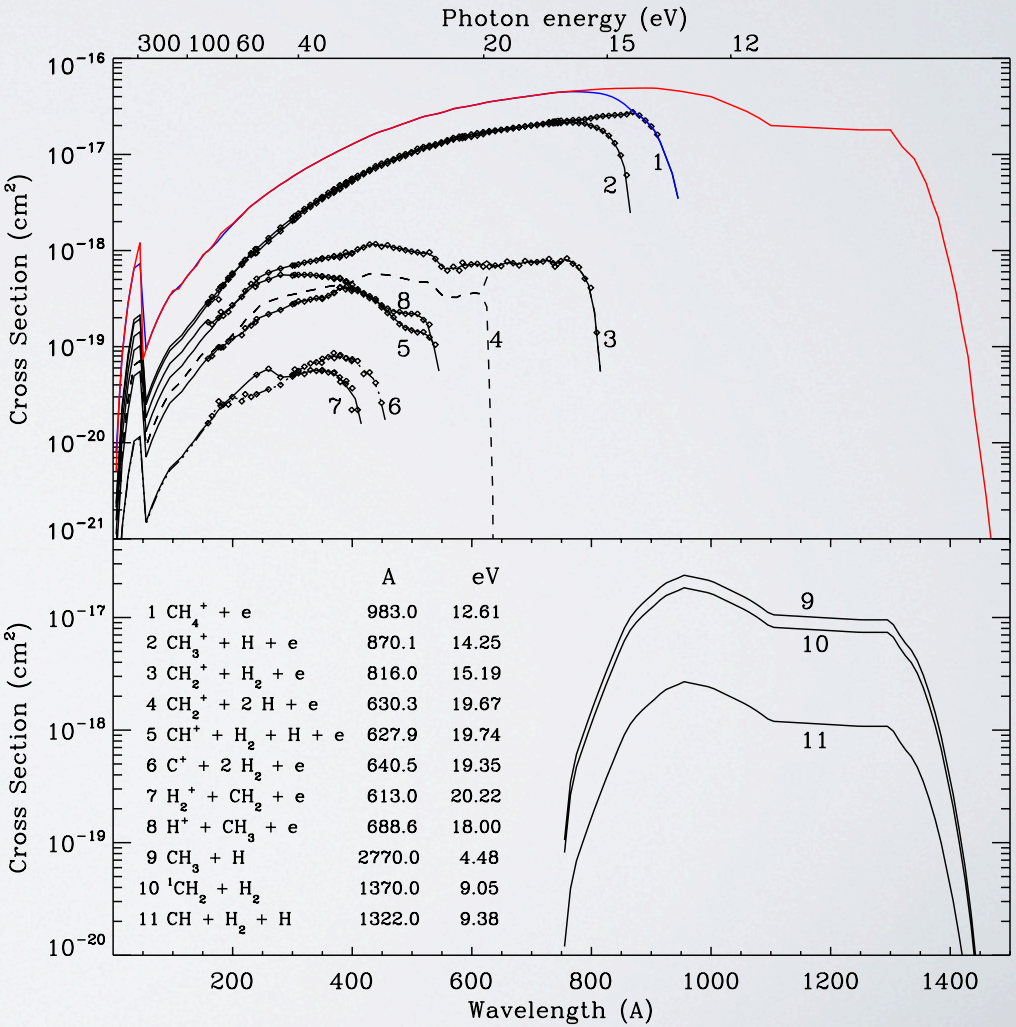
$N_2 + h\nu \rightarrow N_2^+ + e^-$ λ<796.8 A

$N_2 + h\nu \rightarrow N^+ + N + e^-$ λ<510 A

N_2



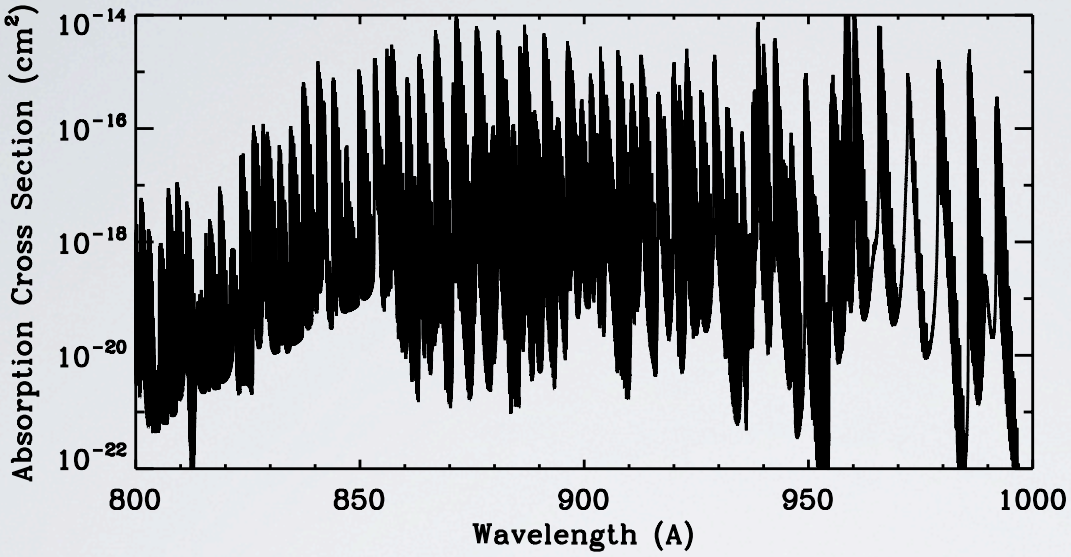
CH_4

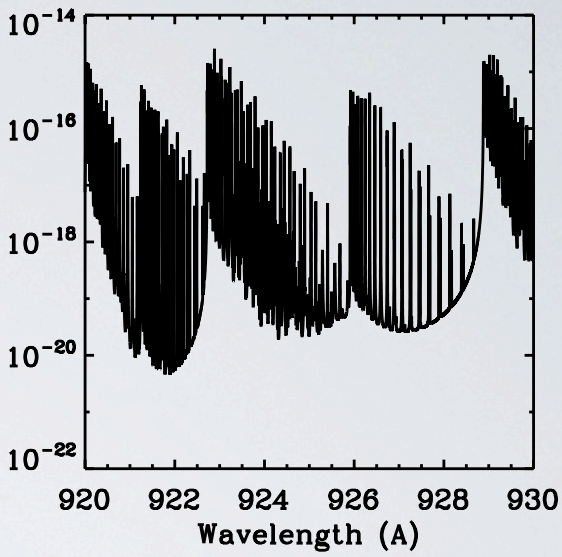


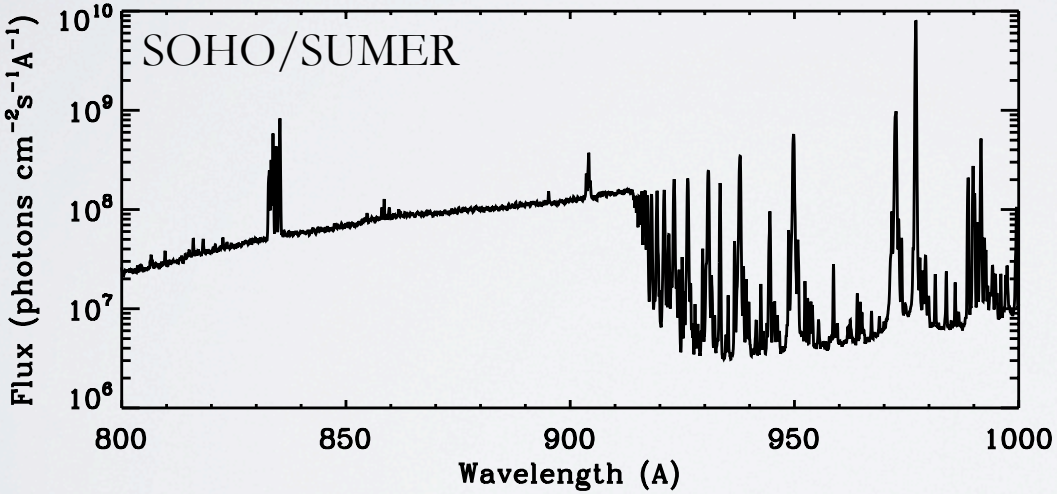
N_2

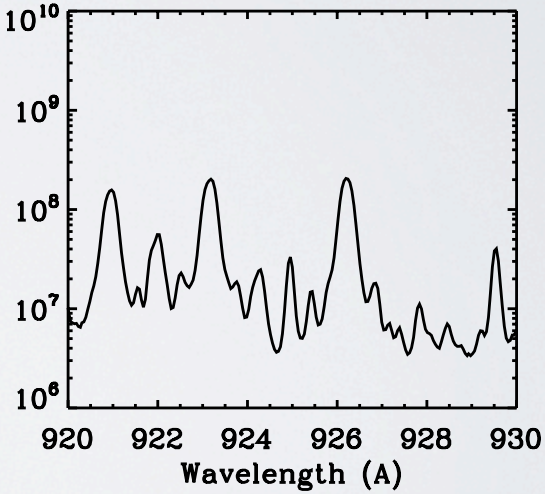
Lewis et al. 2005
Heays et al. 2014

Neutral Dissociation









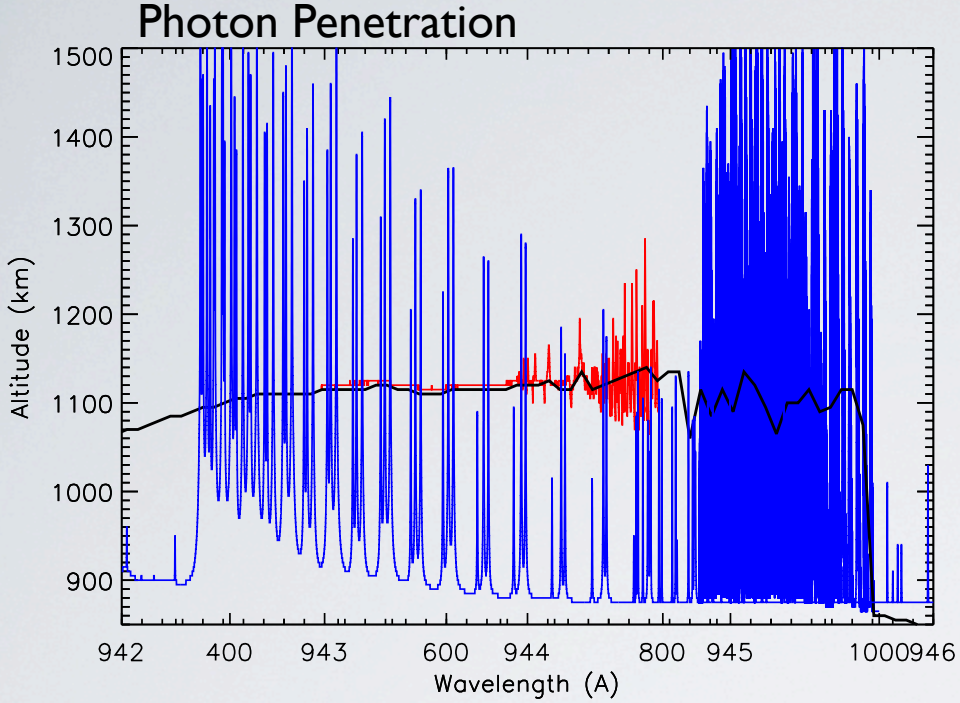
(Walter, Cosby and Helm, 1993)

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

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

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

Calculations in spherical geometry

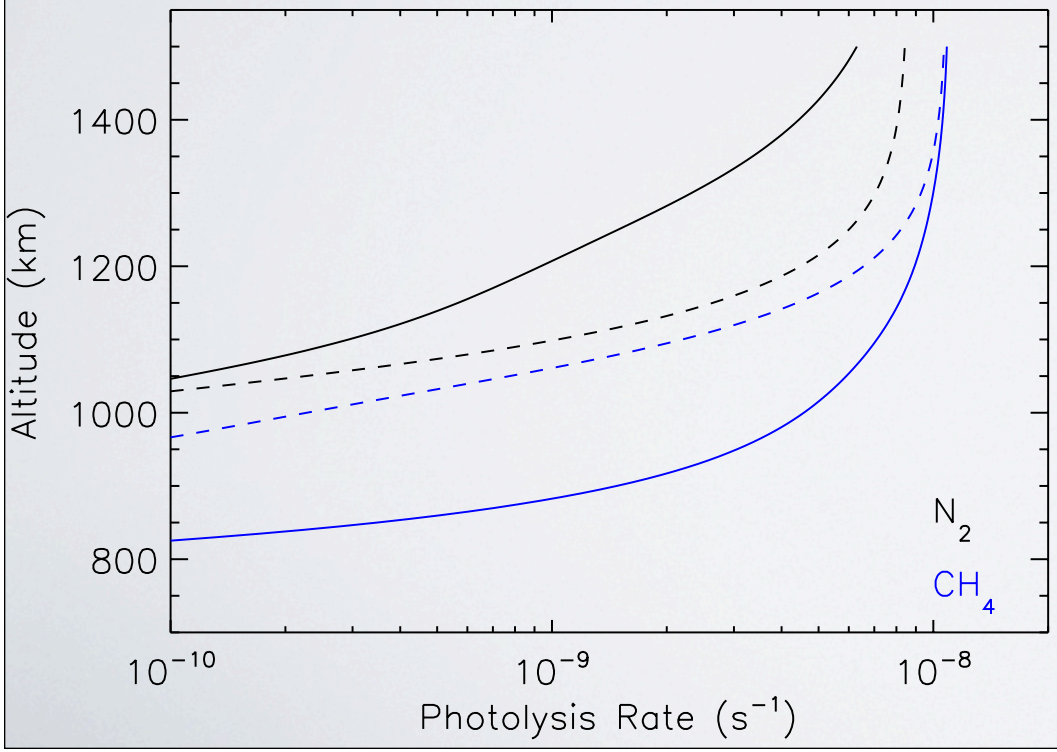


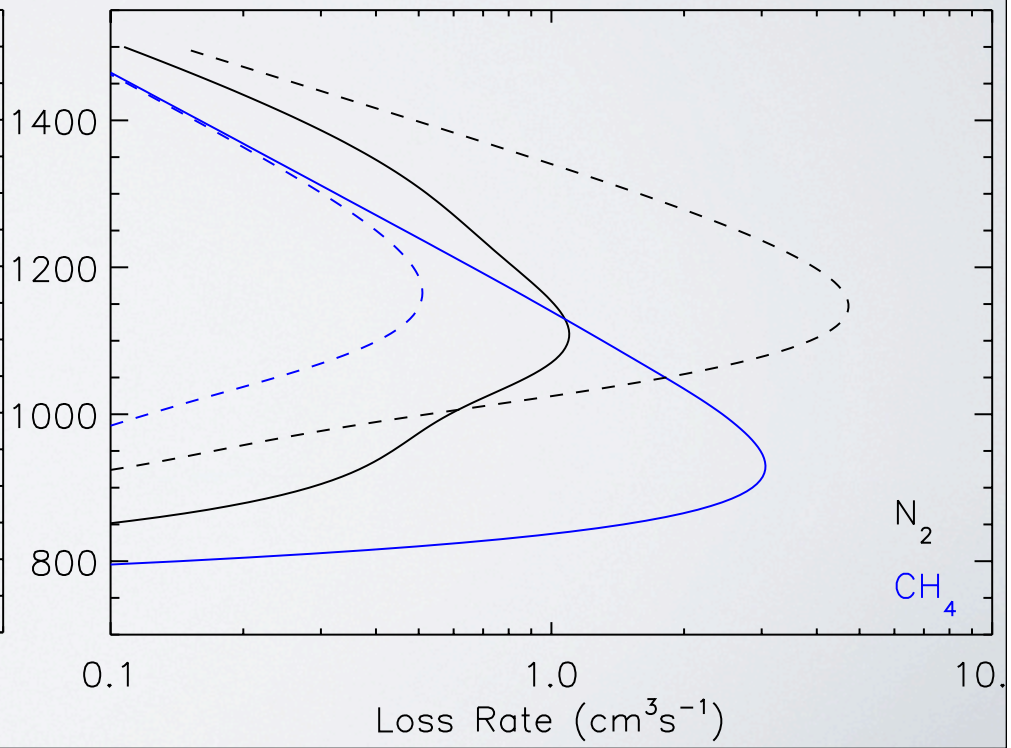
Why is high resolution important ?

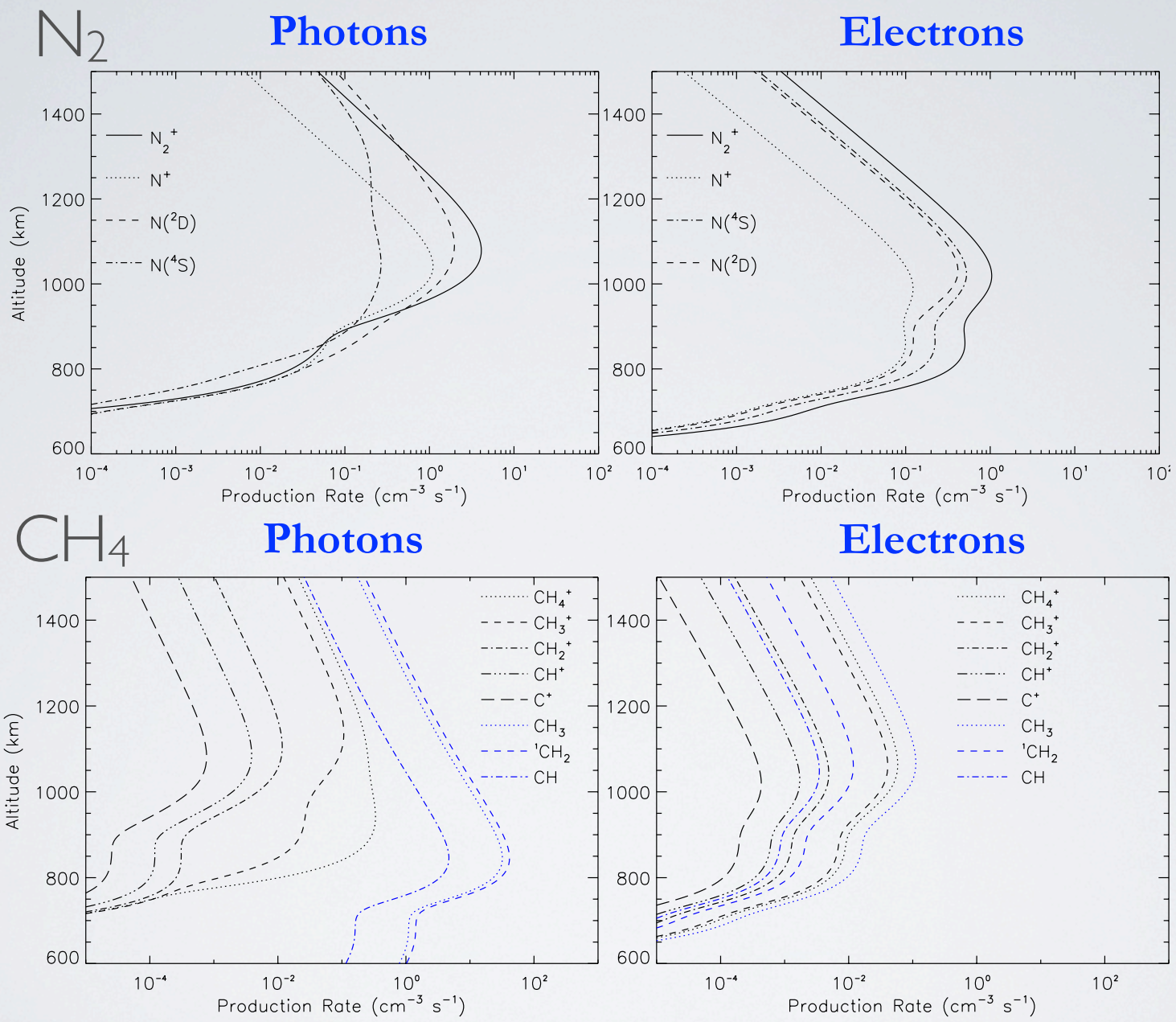
Photons penetrate deeper at wavelengths between N_2 bands and are absorbed by CH_4

——— High resolution

---------- Low resolution

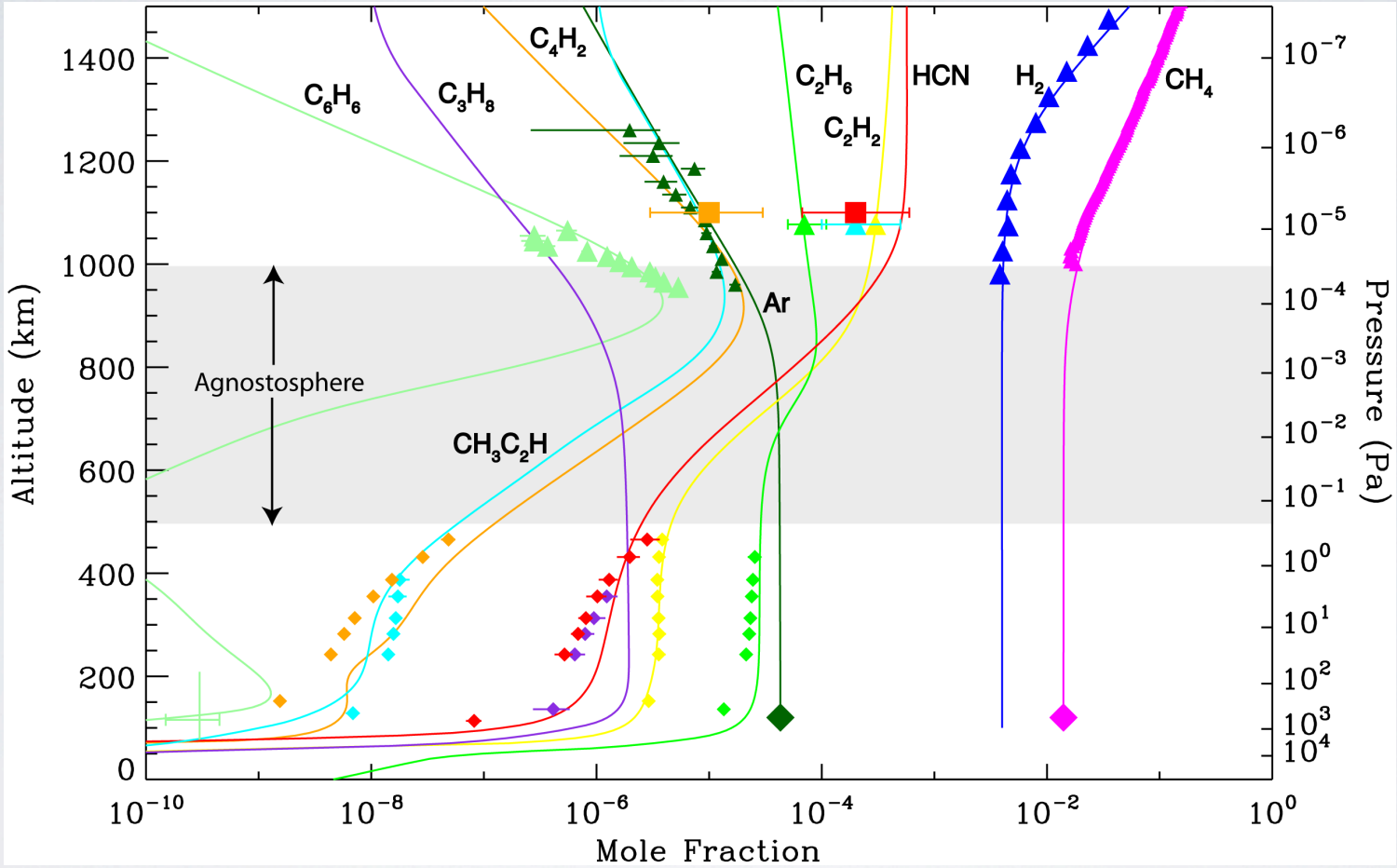






for more details see Lavvas et al. 2011

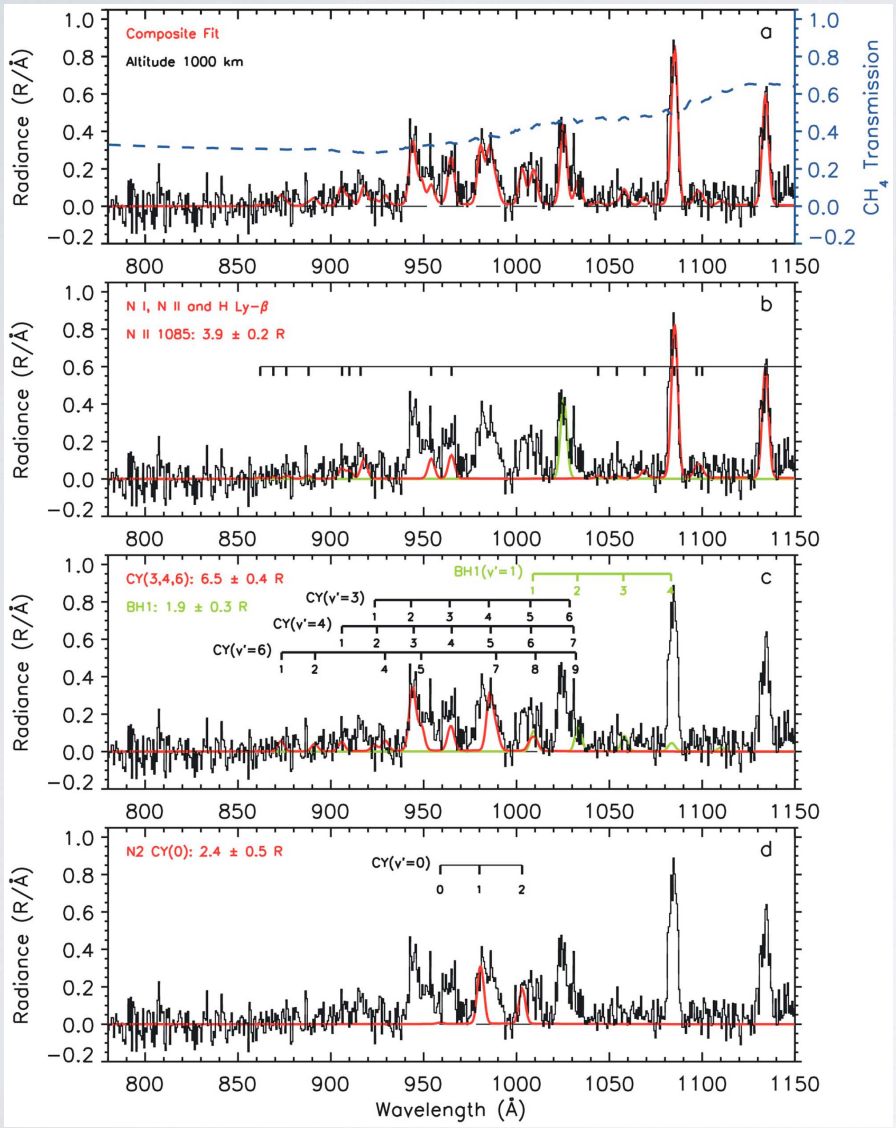
Further down the chemical pathways...

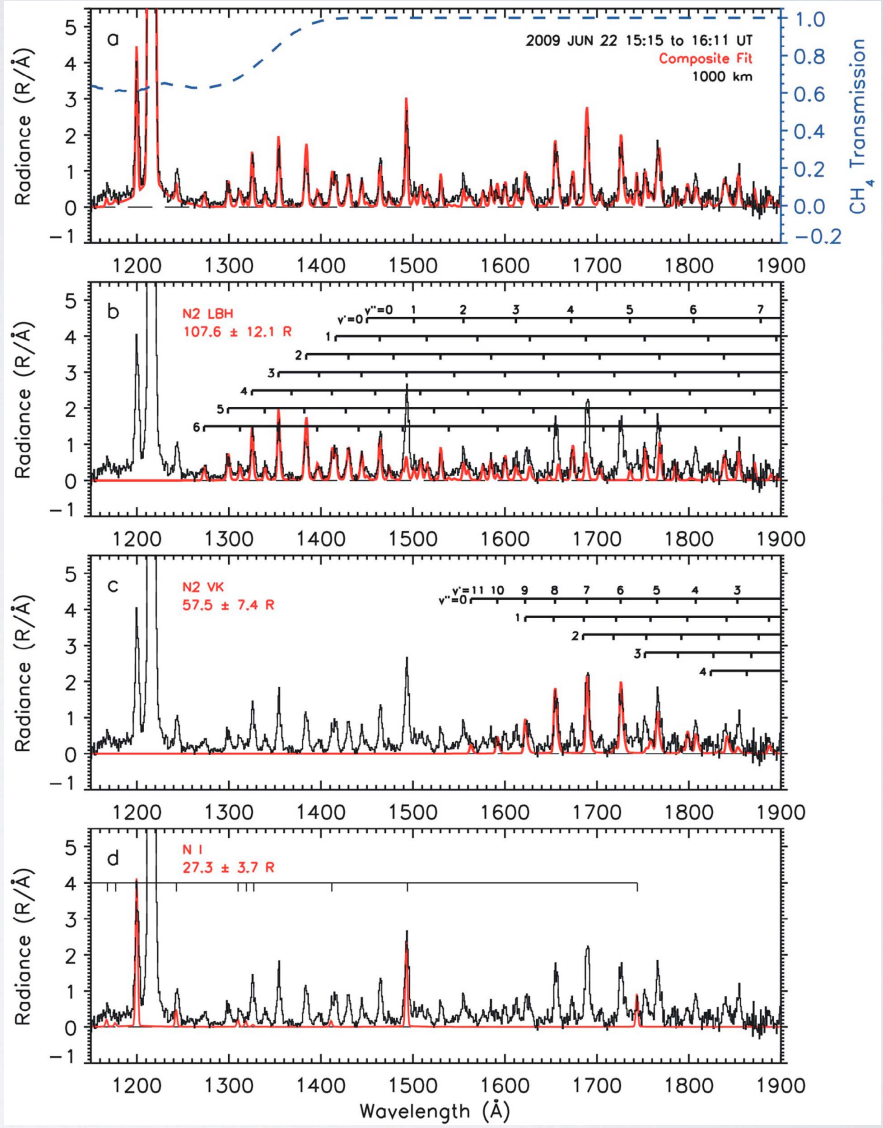


Vuitton et al. 2007/8
Lavvas et al. 2008a,b
Horst et al. 2008
Yelle et al. 2010

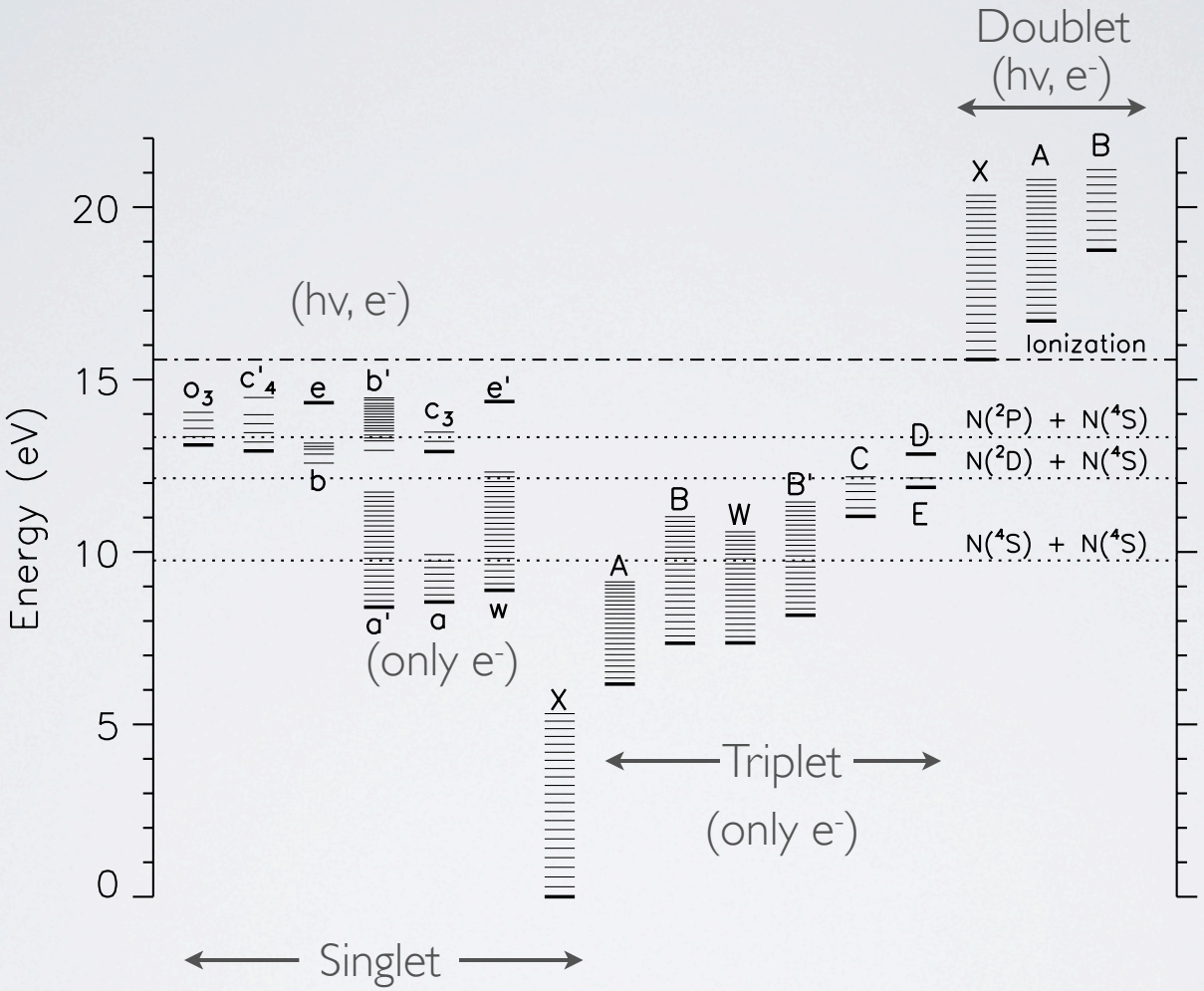
Airglow

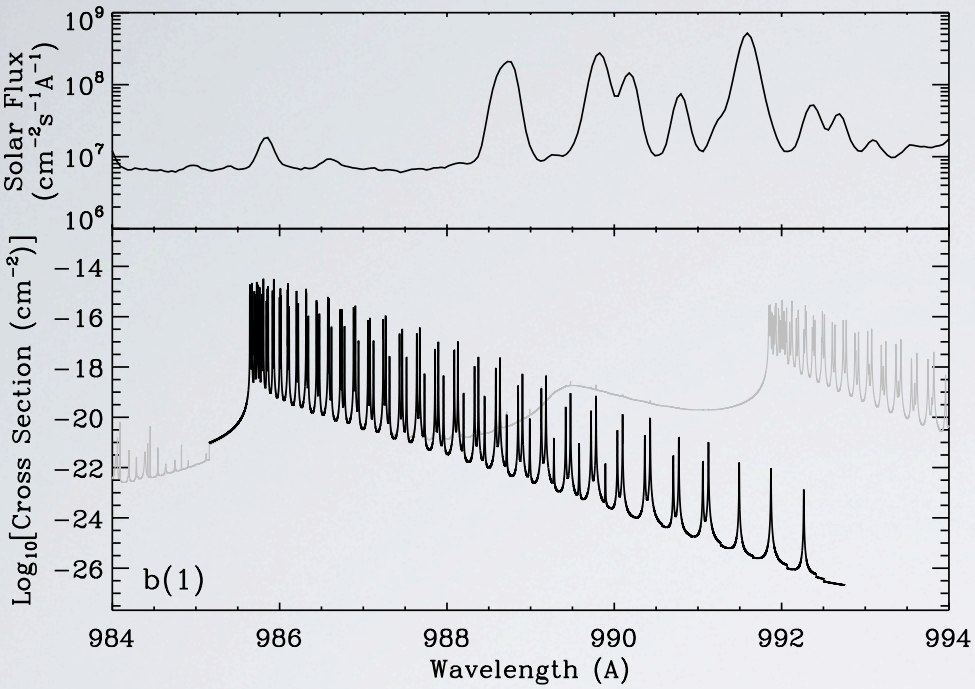
Cassini UVIS

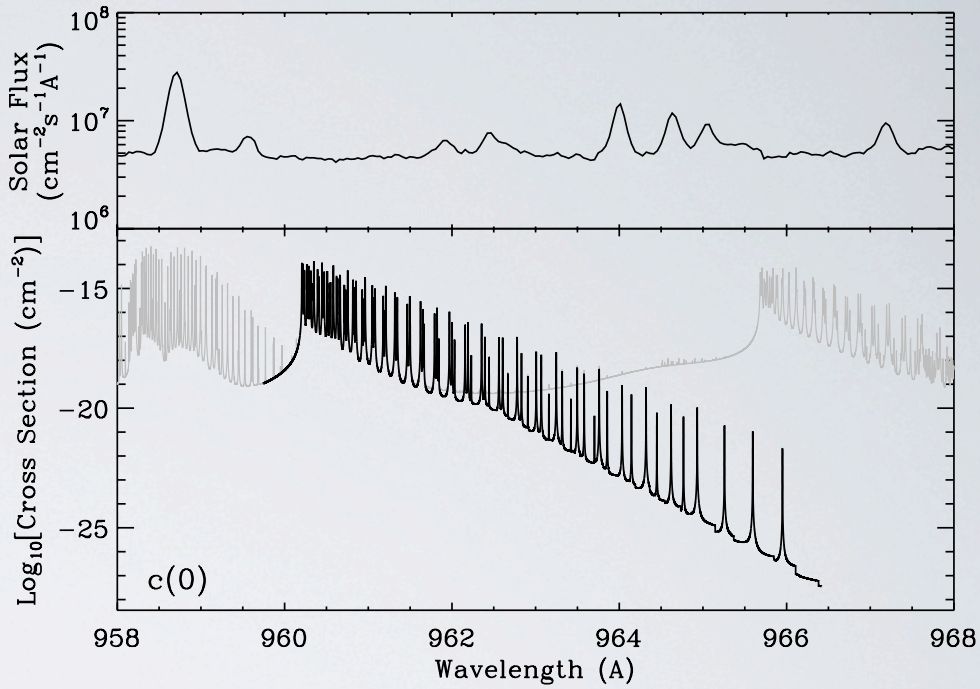


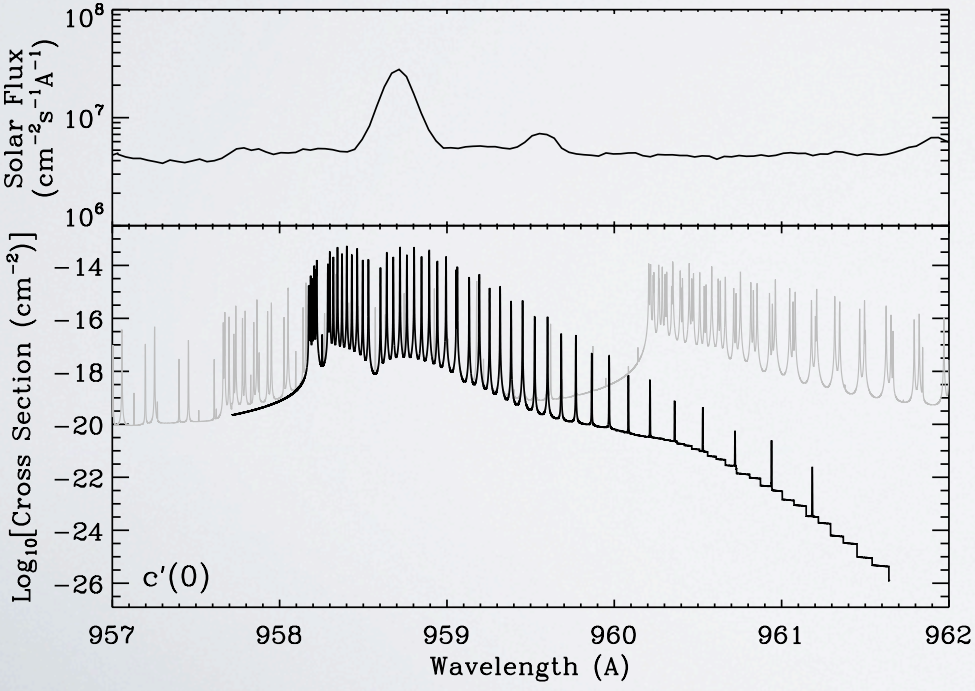


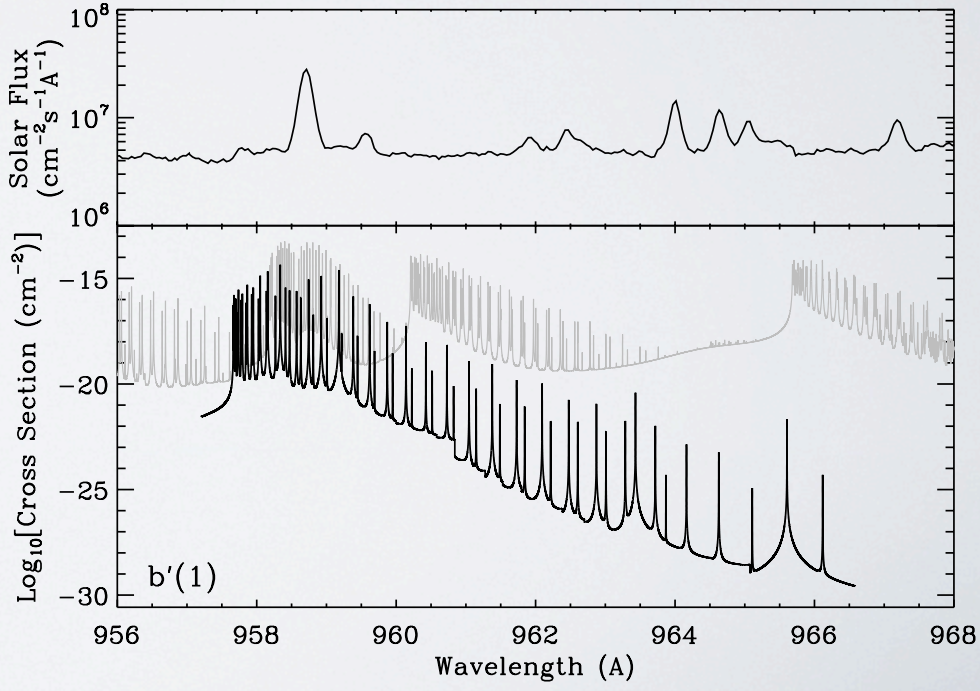
Stevens et al. 2011

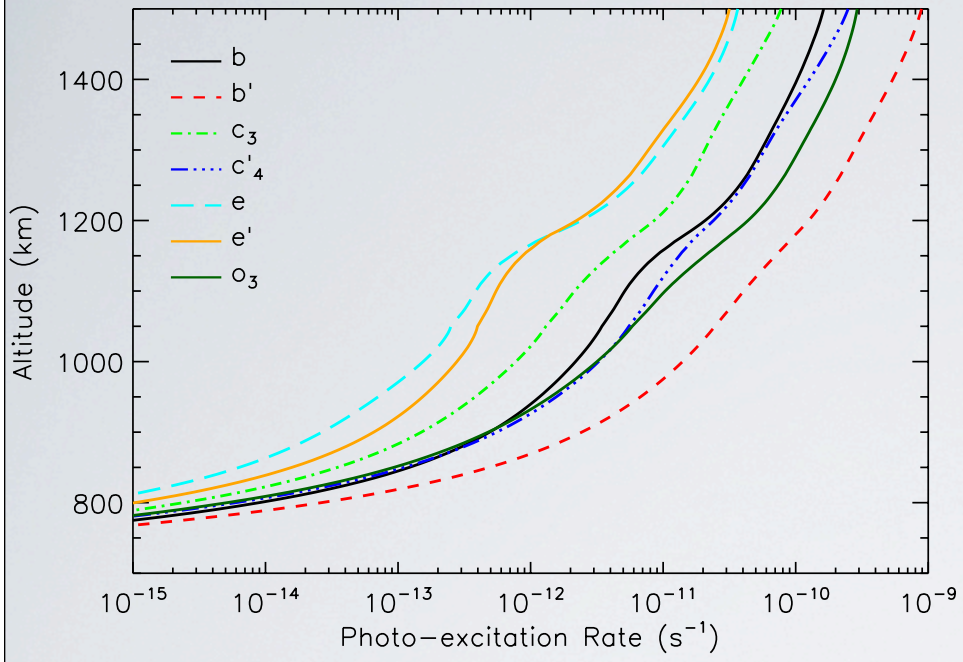

Doublet
(hv, e⁻)
X
A
B
Ionization
(hv, e⁻)
20
15
10
5
0
Energy (eV)
o3
c'4
e
b'
c3
e'
b
a'
a
w
X
A
B
W
B'
C
D
E
N(²P) + N(⁴S)
N(²D) + N(⁴S)
N(⁴S) + N(⁴S)
(only e⁻)
Triplet
(only e⁻)
Singlet

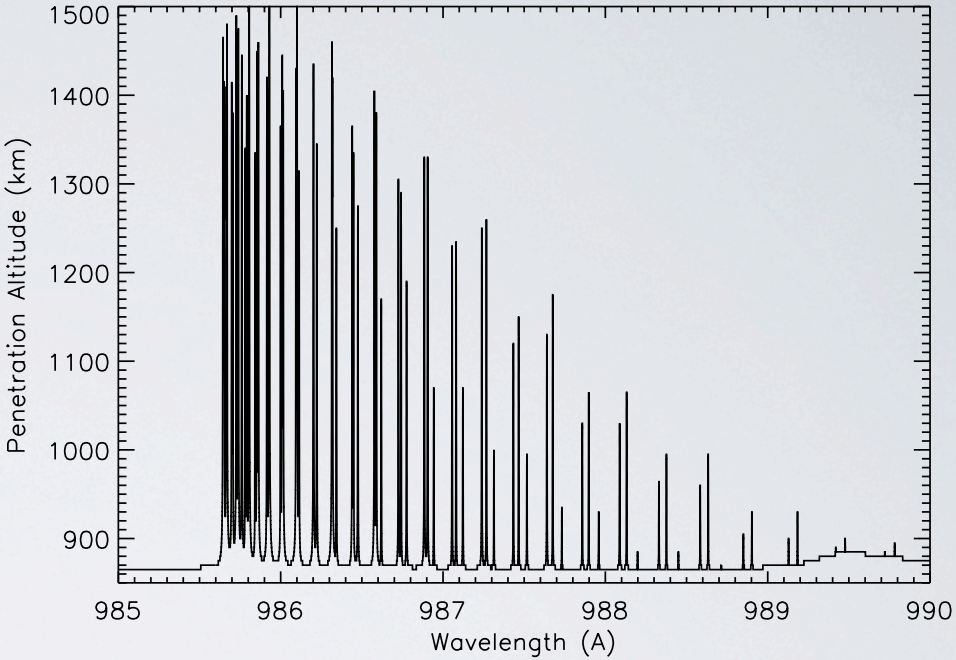

Solar Flux (cm^{-2}s^{-1}A^{-1})
10^9
10^8
10^7
10^6
Log$_{10}$[Cross Section (cm^{-2})]
−14
−16
−18
−20
−22
−24
−26
b(1)
984
986
988
990
992
994
Wavelength (A)

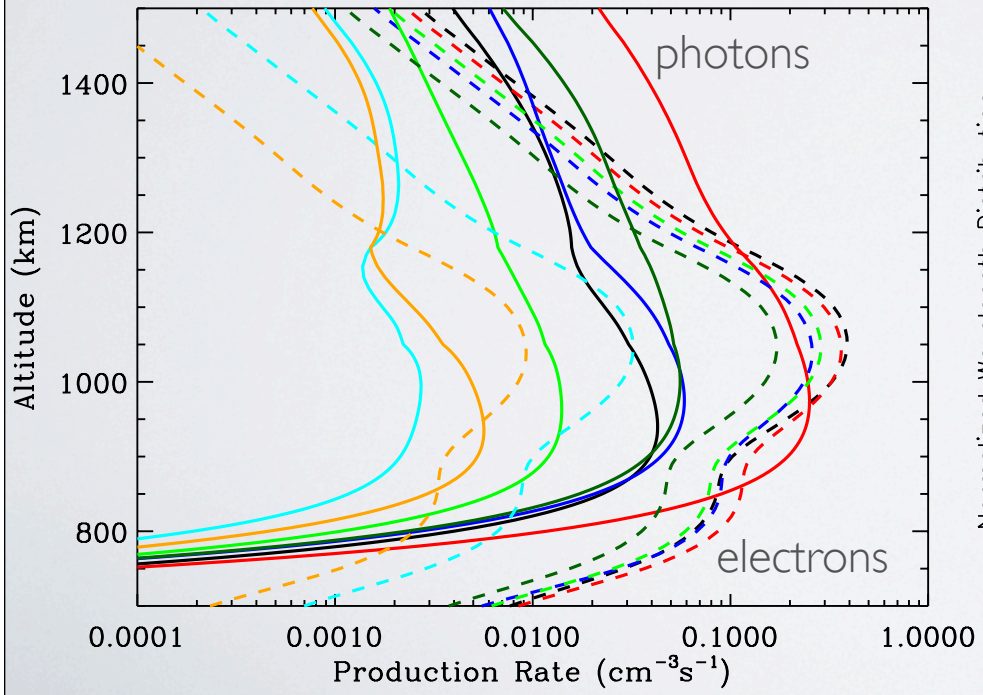

Solar Flux (cm^{-2}s^{-1}A^{-1})
10^8
10^7
10^6
Log$_{10}$[Cross Section (cm^{-2})]
−15
−20
−25
c(0)
958
960
962
964
966
968
Wavelength (A)

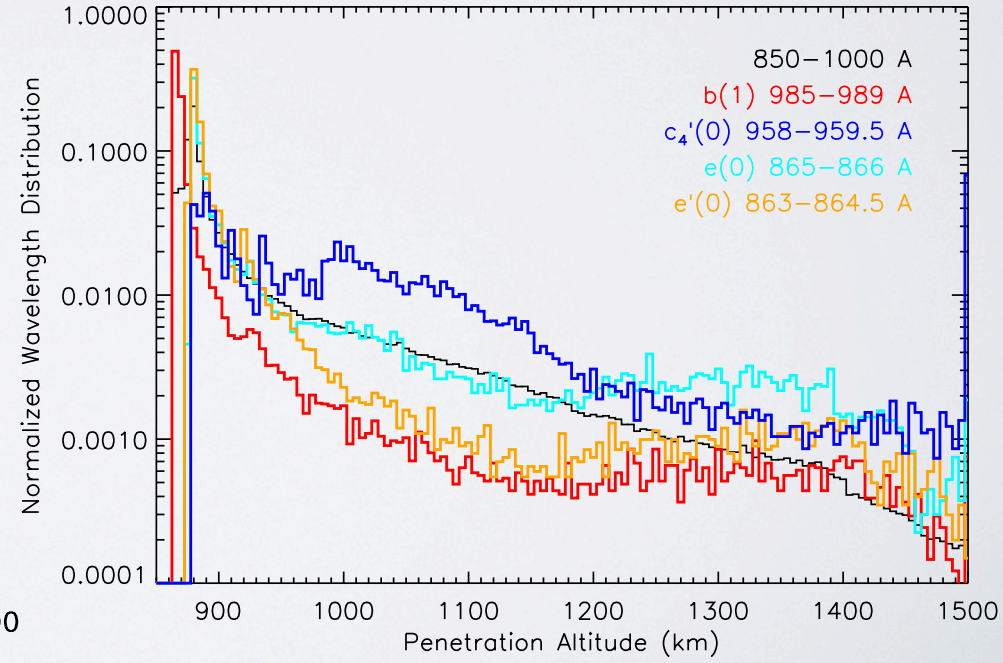

Solar Flux (cm^{-2}s^{-1}A^{-1})
10^8
10^7
10^6
Log$_{10}$[Cross Section (cm^{-2})]
−14
−16
−18
−20
−22
−24
−26
c′(0)
957
958
959
960
961
962
Wavelength (A)


Solar Flux (cm^{-2}s^{-1}A^{-1})
10^8
10^7
10^6
Log$_{10}$[Cross Section (cm^{-2})]
−15
−20
−25
−30
b′(1)
956
958
960
962
964
966
968
Wavelength (A)


b
b'
c3
c'4
e
e'
o3
Altitude (km)
1400
1200
1000
800
10−15
10−14
10−13
10−12
10−11
10−10
10−9
Photo−excitation Rate (s−1)


Penetration Altitude (km)
1500
1400
1300
1200
1100
1000
900
985
986
987
988
989
990
Wavelength (A)

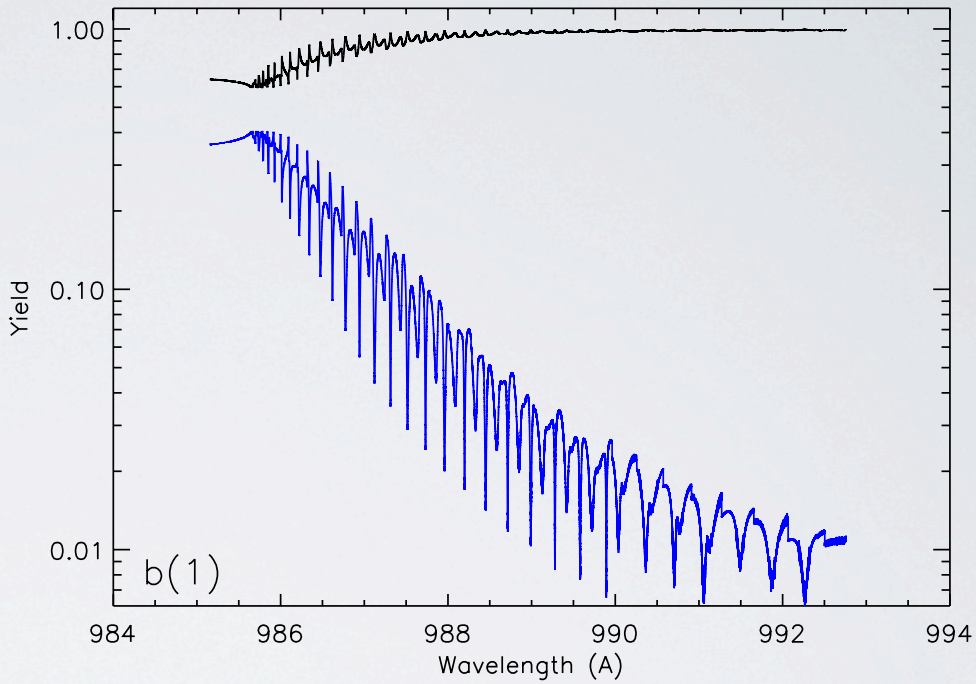

photons
electrons
Altitude (km)
1400
1200
1000
800
0.0001
0.0010
0.0100
0.1000
1.0000
Production Rate (cm−3s−1)


850−1000 A
b(1) 985−989 A
c4'(0) 958−959.5 A
e(0) 865−866 A
e'(0) 863−864.5 A
Normalized Wavelength Distribution
1.0000
0.1000
0.0100
0.0010
0.0001
900
1000
1100
1200
1300
1400
1500
Penetration Altitude (km)

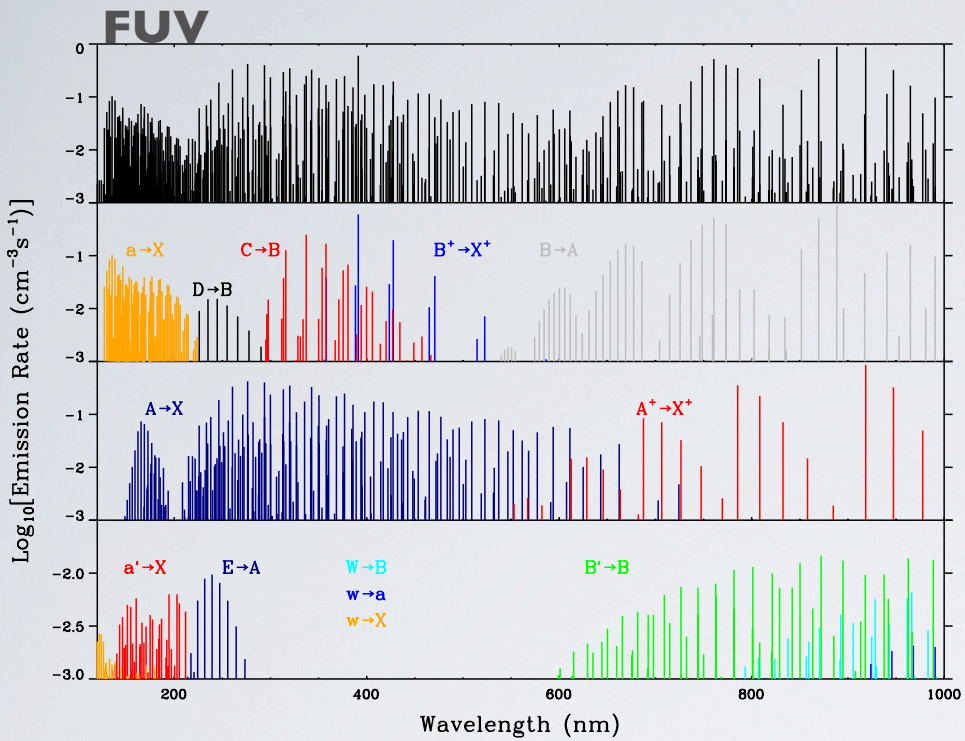
Pre-dissociation Yields

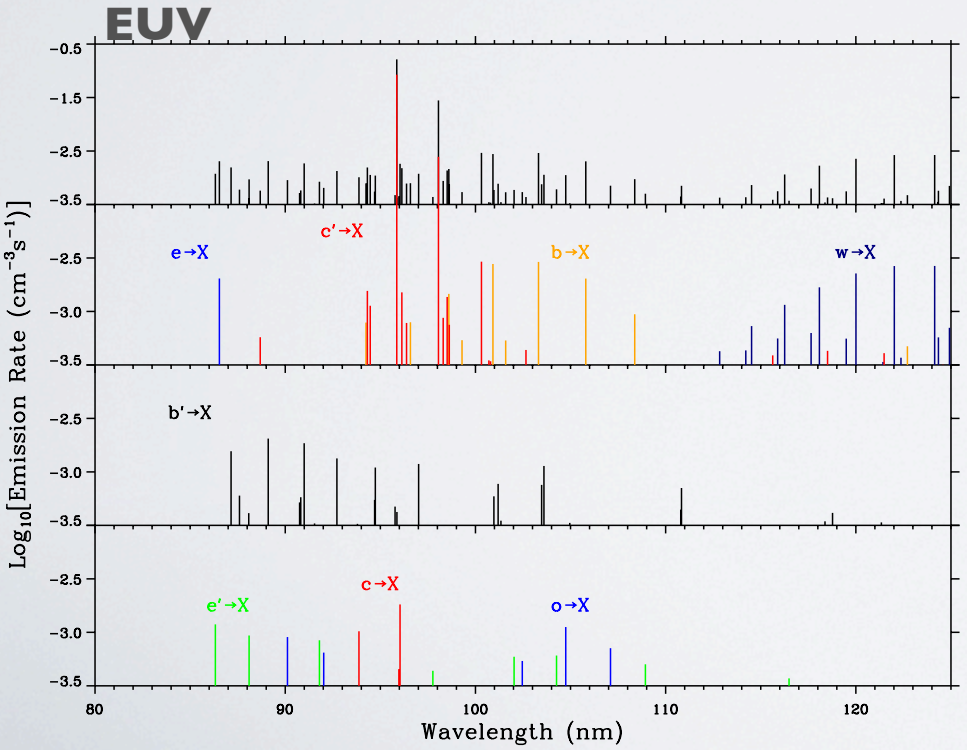
Table 1: Average dissociation yields for singlet states. States in boldface characters have pre-dissociation yields less that 95%.

	$< f_{dis} >$		
State	100K	150K	200K
b(1)	0.634	0.657	0.678
b(4)	0.994	0.994	0.994
b(5)	0.979	0.974	0.968
b(6)	0.957	0.958	0.959
b(7)	0.969	0.972	0.974
b′(1)	0.453	0.444	0.440
b′(4)	0.903	0.920	0.926
b′(5)	0.683	0.683	0.684
b′(6)	0.938	0.938	0.938
b′(7)	0.485	0.531	0.579
b′(8)	0.930	0.930	0.930
b′(9)	0.730	0.751	0.768
b′(10)	0.965	0.965	0.966
b′(11)	0.946	0.946	0.946
b′(12)	0.834	0.827	0.819
b′(13)	0.971	0.971	0.971
b′(14)	0.981	0.980	0.980
b′(15)	0.978	0.978	0.978
b′(16)	0.949	0.950	0.951
b′(17)	0.988	0.987	0.986
b′(18)	0.975	0.975	0.975
b′(19)	0.975	0.976	0.977
c(0)	0.980	0.979	0.978
c(1)	0.976	0.980	0.983
c(2)	0.985	0.985	0.985
c_4'(0)	0.109	0.133	0.155
c_4'(1)	0.689	0.694	0.699
c_4'(2)	0.800	0.797	0.795
c_4'(3)	0.826	0.826	0.827
c_4'(4)	0.752	0.779	0.798
c_4'(6)	0.922	0.924	0.928
e(0)	0.925	0.927	0.928
e′(0)	0.491	0.494	0.524
o(0)	0.951	0.959	0.962
o(1)	0.989	0.990	0.990
o(2)	0.991	0.991	0.991
o(3)	0.990	0.990	0.990
o(4)	0.712	0.716	0.717

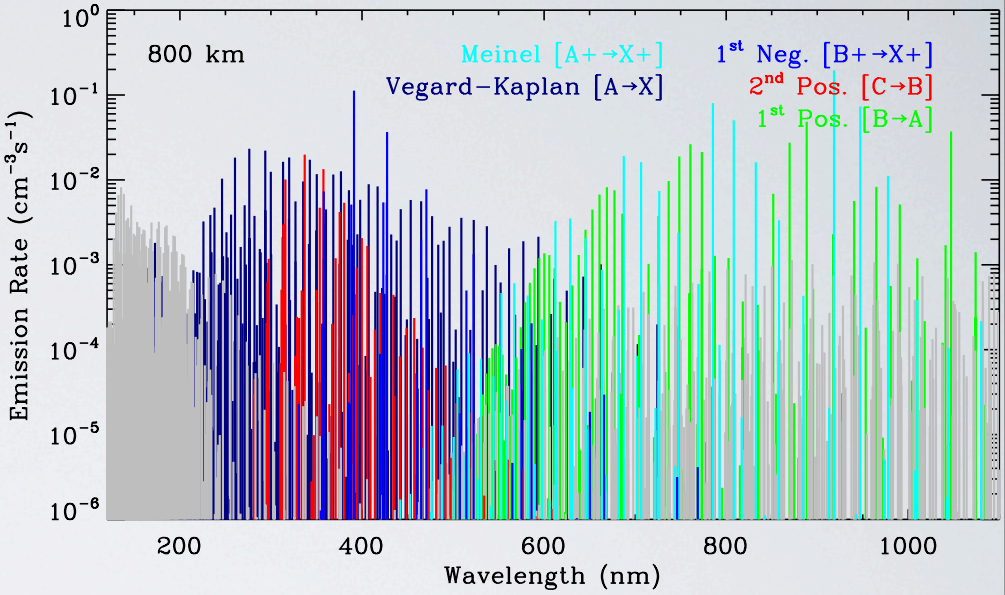


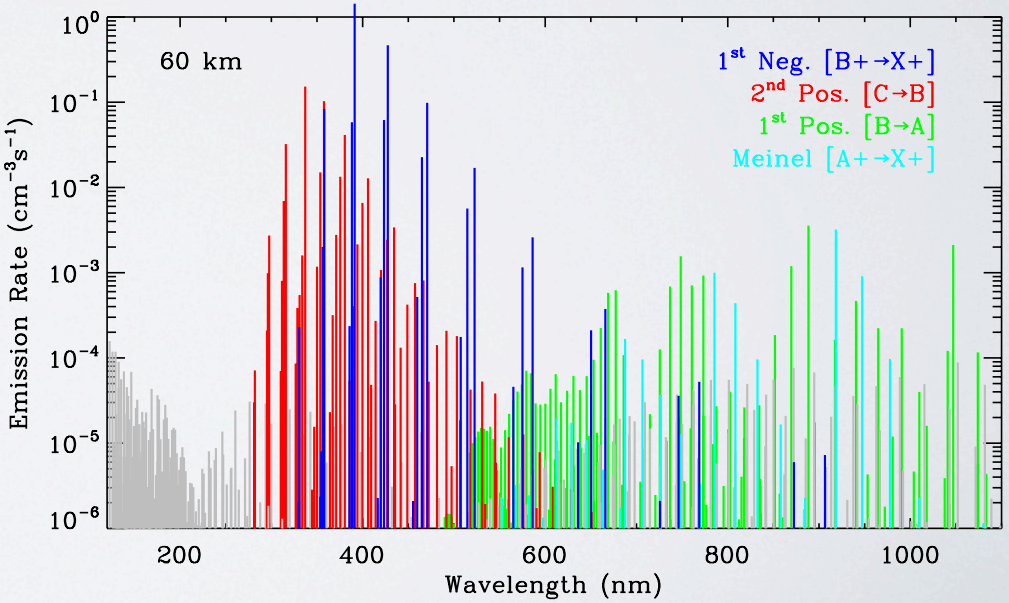
$$< f_{dis} >= \frac{\int \sigma_\lambda f_{dis,\lambda}}{\int \sigma_\lambda}$$



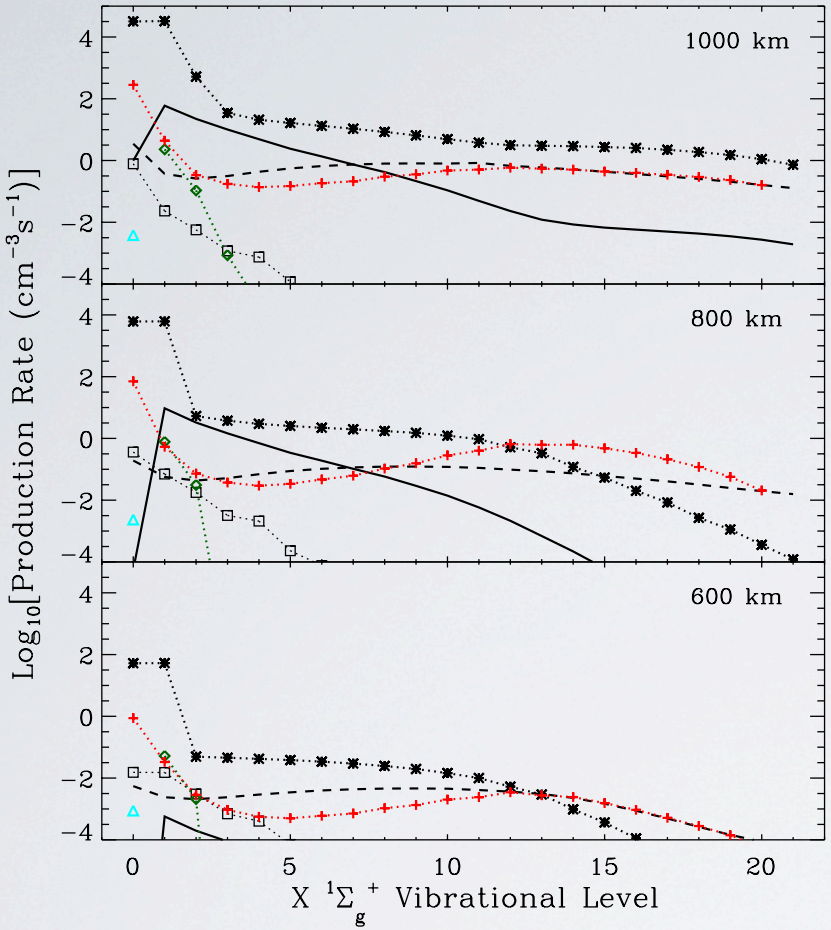


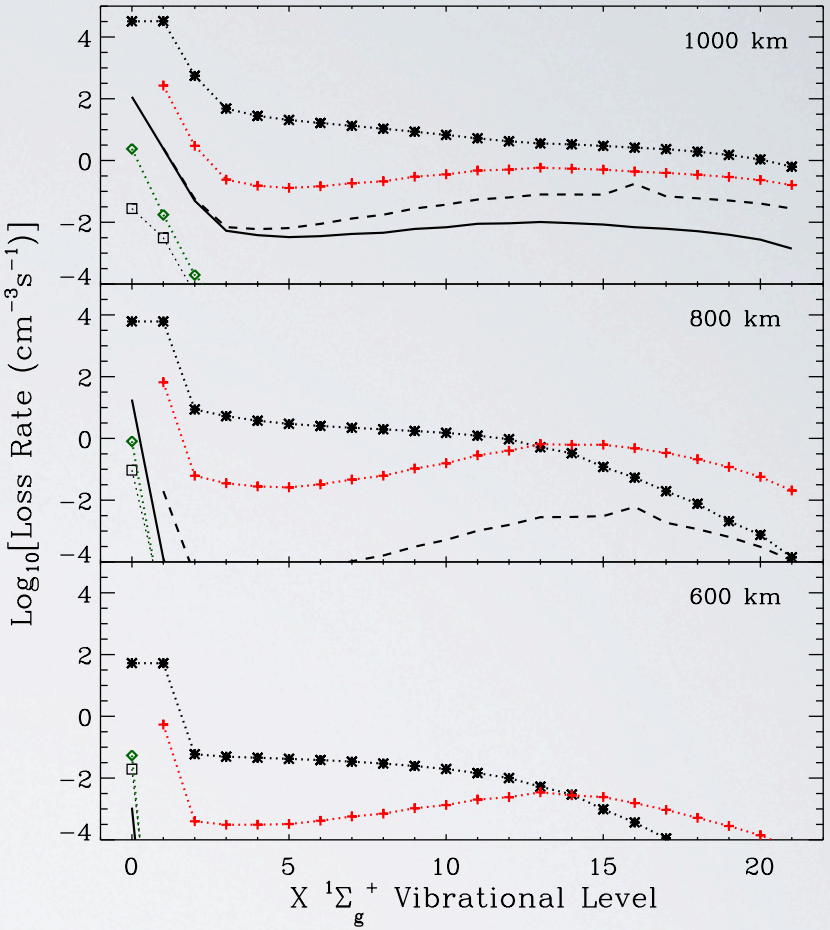
Lavvas et al. 2014





The N_2 Ground State





VV energy transfer *

Electrons ——

Photons - - - - - -

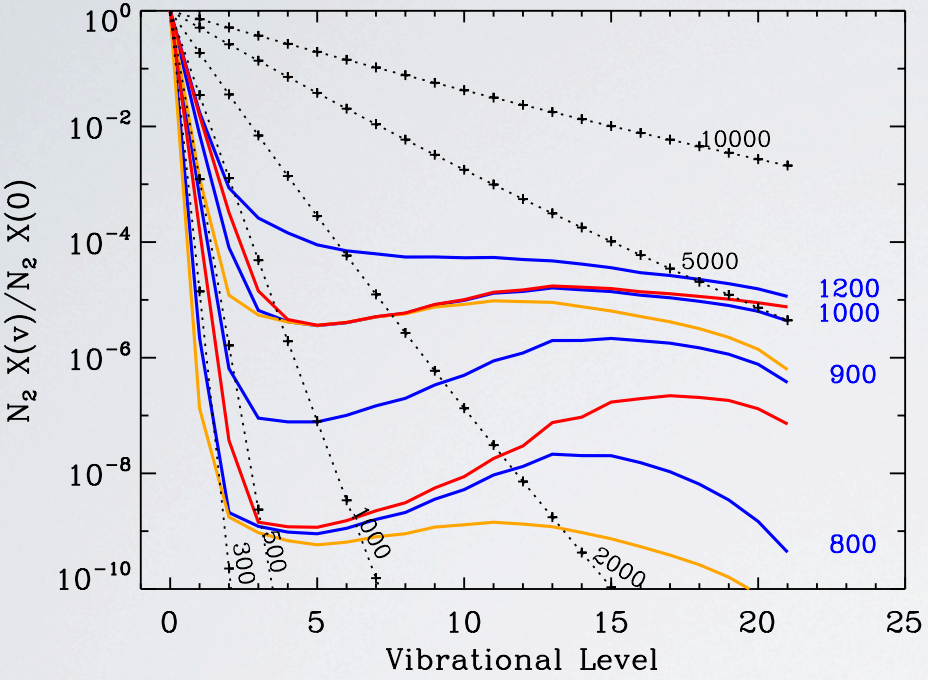
Methane +

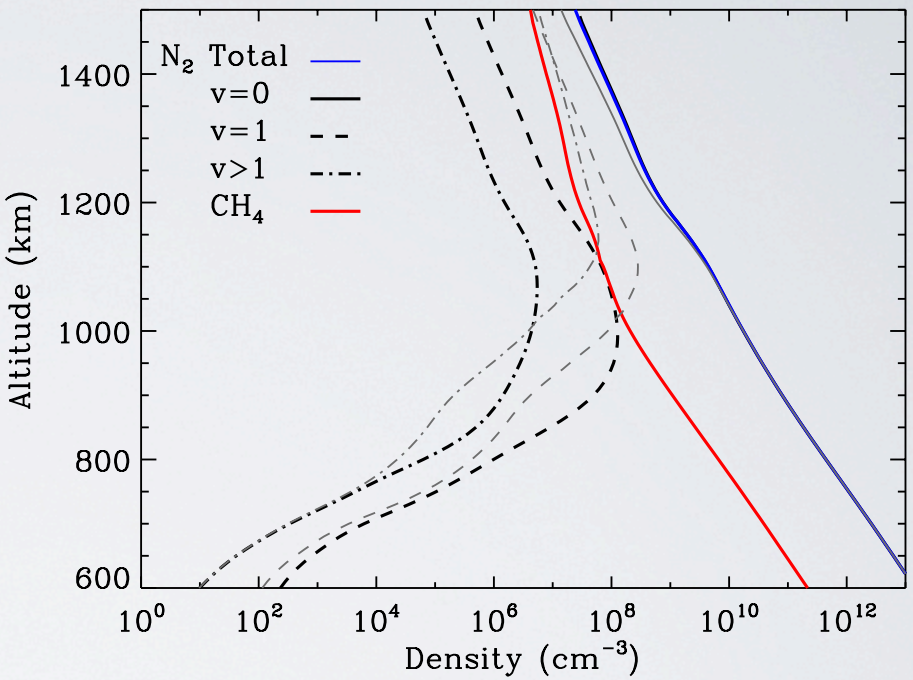
Collisions □

VV with ions ◇

El.Quenching △

Ground State



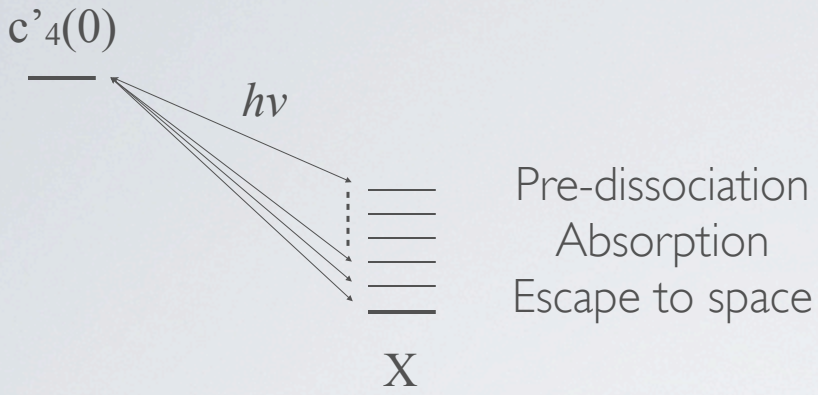


$k_{CH4} = 10^{-15}\ cm^3 s^{-1}$

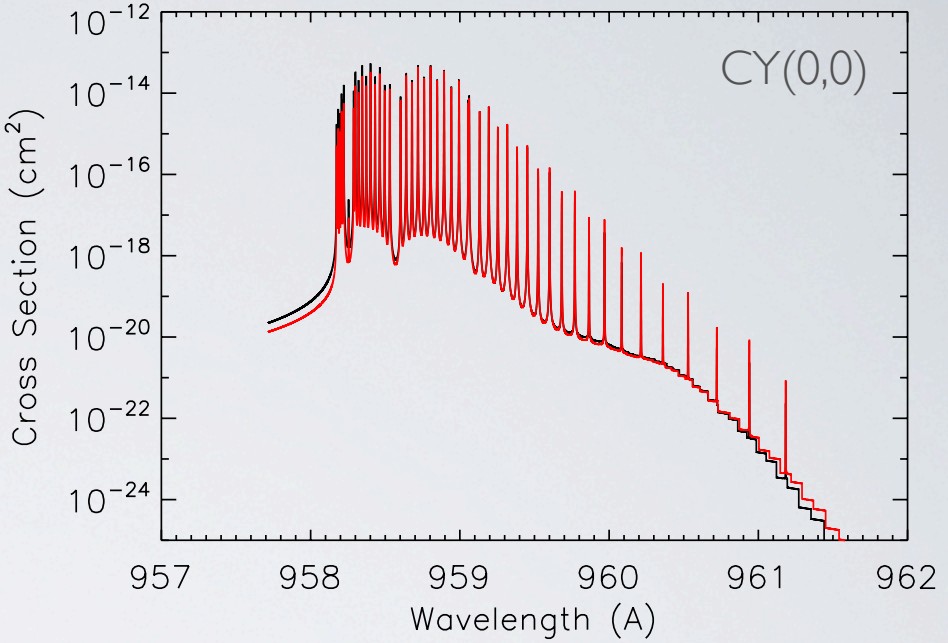
$k_{CH4} = 10^{-14}\ cm^3 s^{-1}$

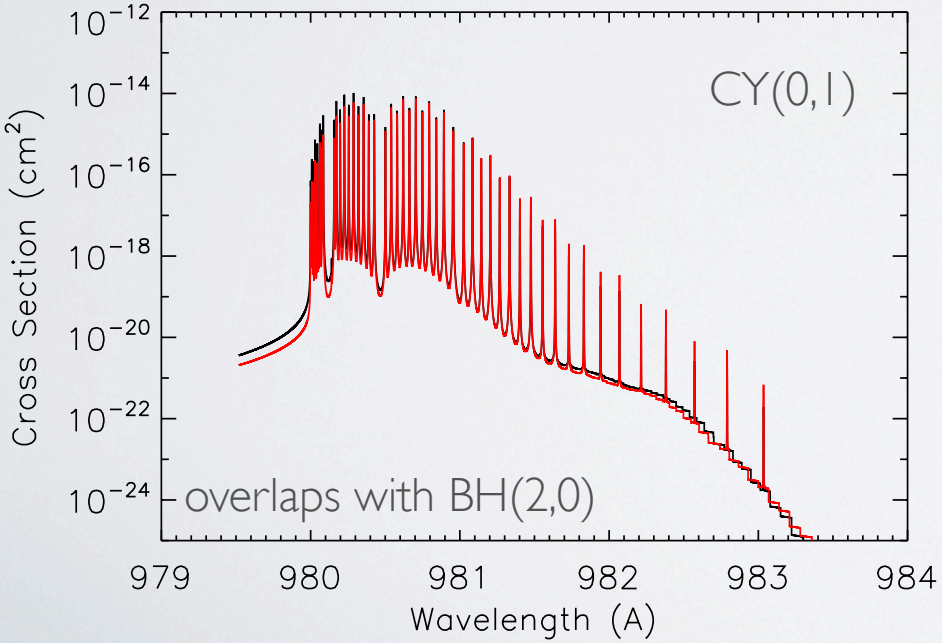
$k_{CH4} = 10^{-13}\ cm^3 s^{-1}$

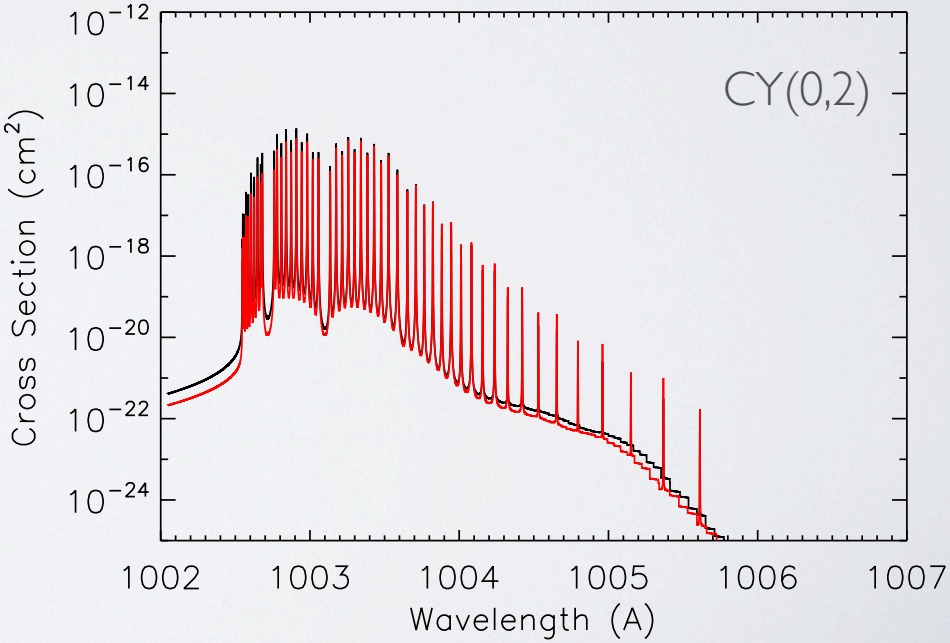
$N_2(v) + CH_4 > N_2(v-1) + CH_4^*$



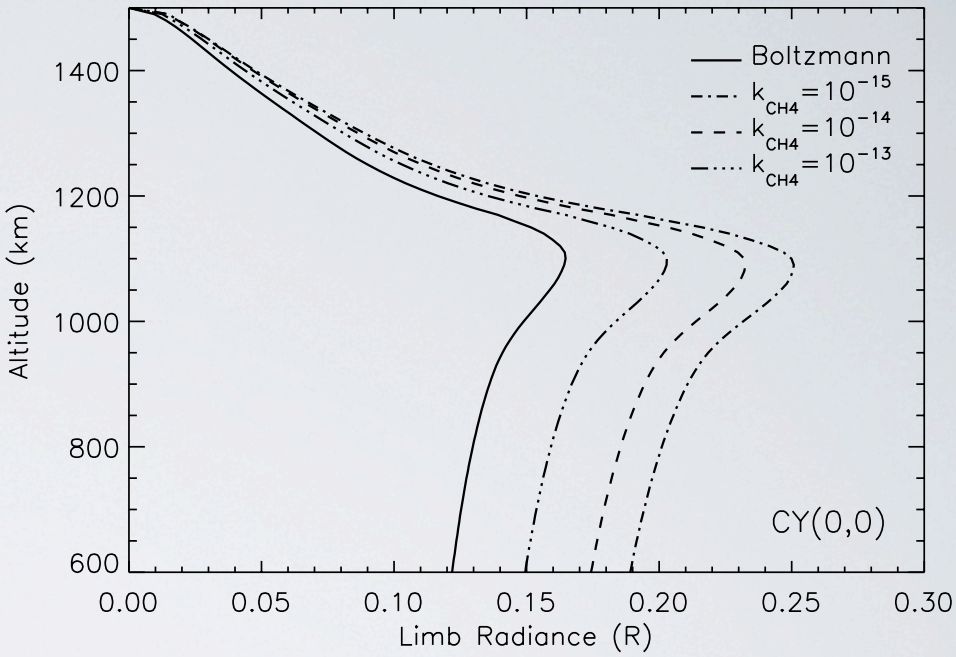
Pre-dissociation
Absorption
Escape to space

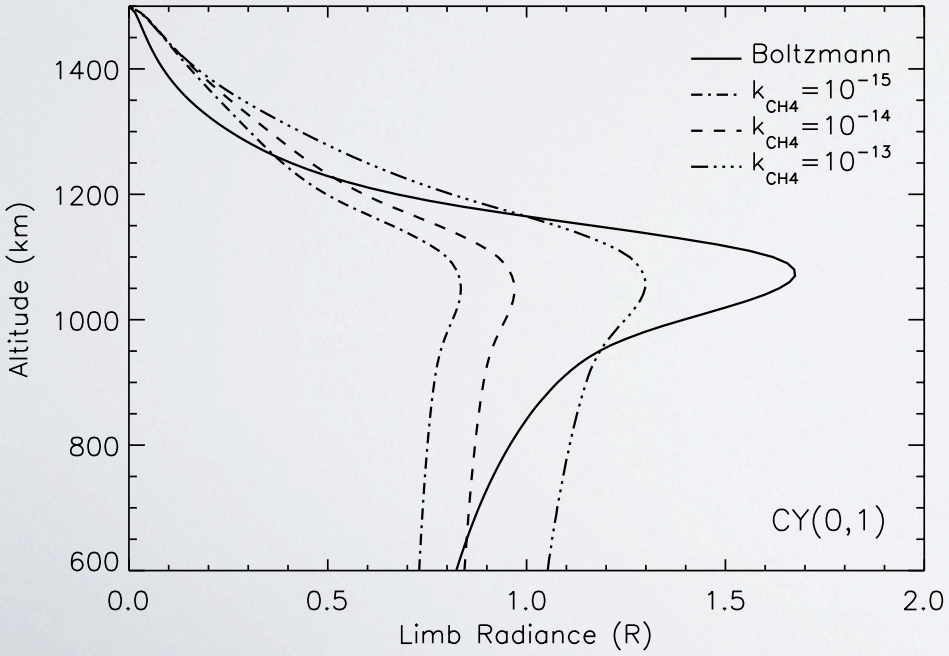


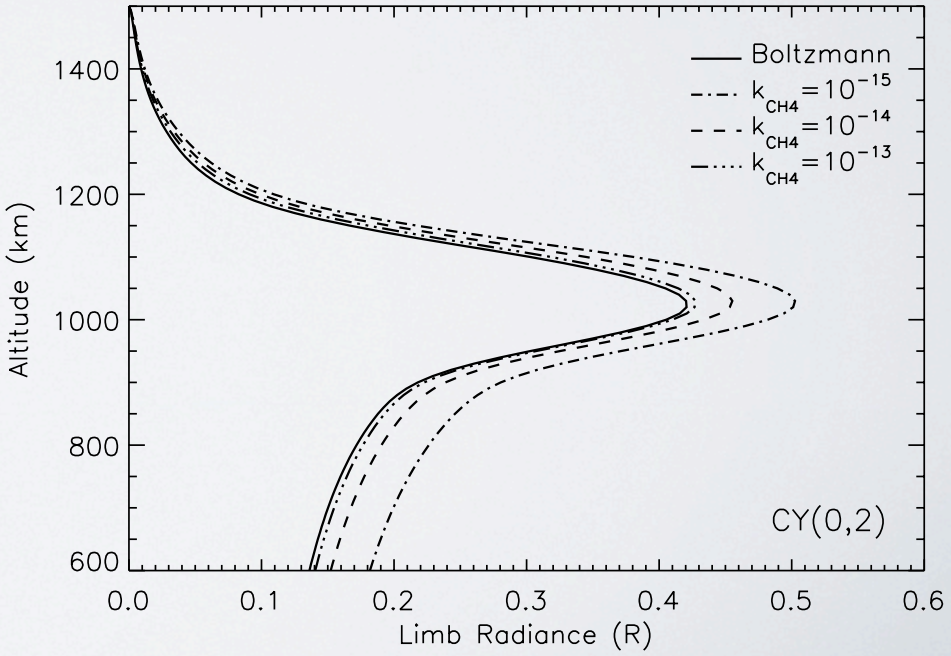




The N_2 hot population reduces the CY(0,1) emission and modifies the peak emission altitudes





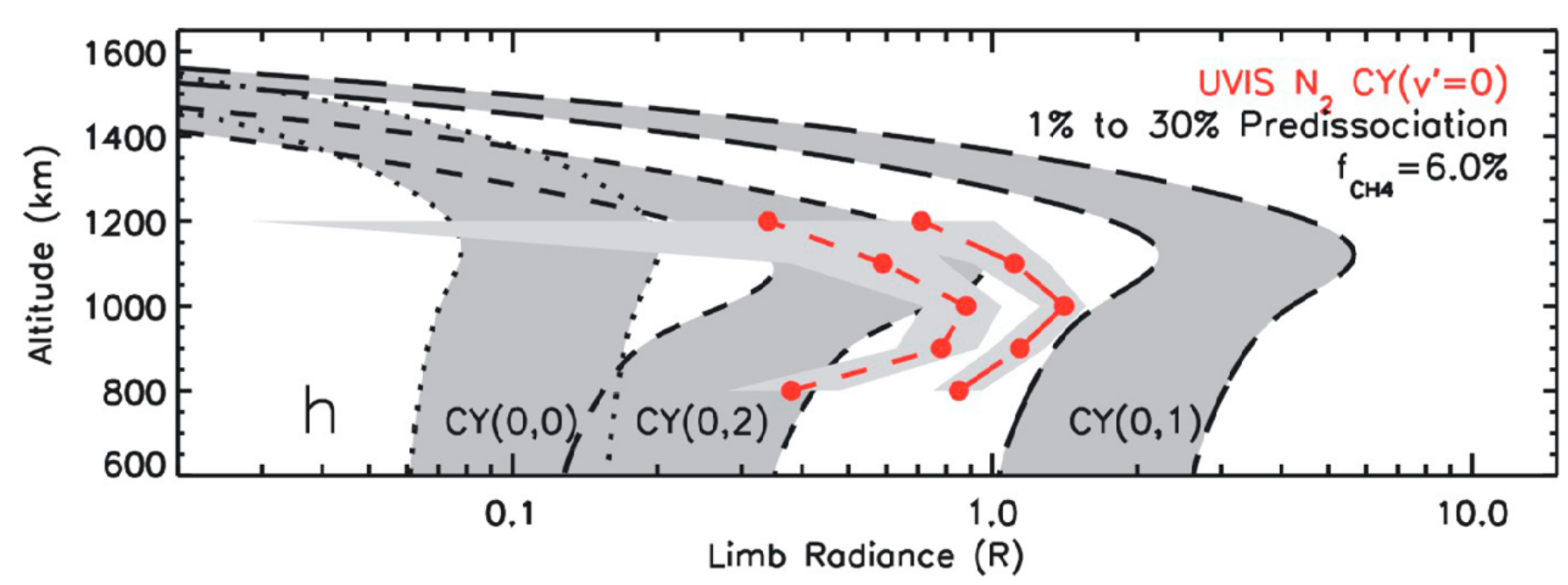


Is this variation consistent with observations?

Stevens et al. 2011

Table 1. Comparison of Modeled and Observed Titan Limb Airglow Radiances

	Observed Peak (R)[a]	Modeled Peak (R)[b]	Model / Observed	Observed Peak (km)	Modeled Peak (km)	Model – Observed (km)
N_2 LBH[c]	136.0 ± 12.5	143.9	1.1	900 ± 55	933	33
N_2 VK[d]	67.8 ± 7.4	52.0	0.8	900 ± 55	928	28
N I[e]	31.8 ± 4.8	47.4	1.5	900 ± 55	956	56
N II 1085 Å	4.1 ± 0.2	4.5	1.1	900 ± 55	996	96
BH I(1)	2.0 ± 0.3	1.6	0.8	900 ± 55	1009	109
CY(3,4,6)	6.5 ± 0.4	1.4	0.2	1000 ± 55	1014	14
CY(0,1)	1.4 ± 0.2	4.2 ± 1.9[f]	3.0	1000 ± 55	1120	120
CY(0,2)	0.9 ± 0.2	0.7 ± 0.3[f]	0.8	1000 ± 55	1080	80

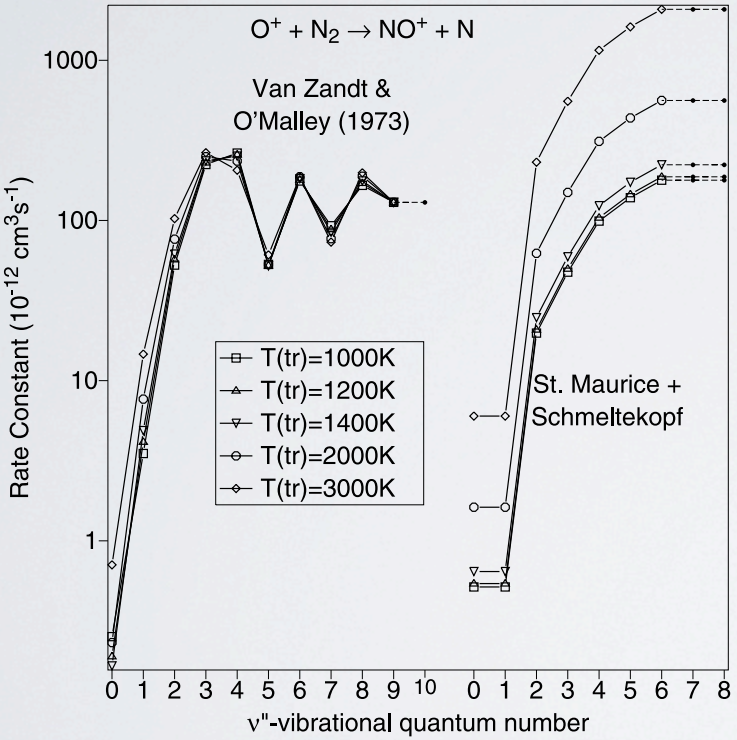


EFFECTS ON THE ATMOSPHERE

Ionosphere

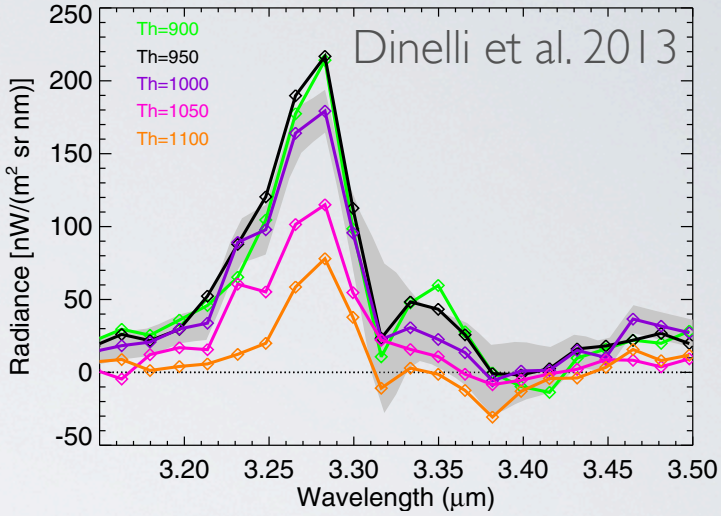
From the Earth's F region

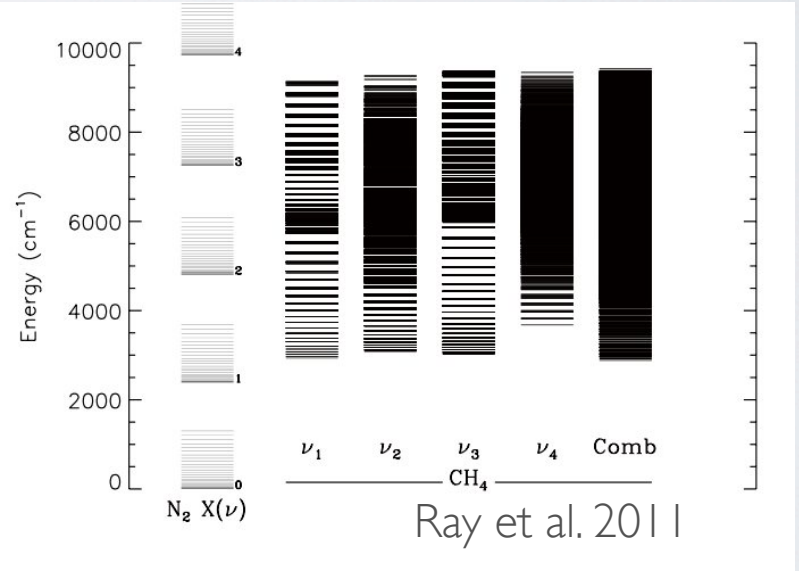
Campbell et al. 2006



$$O^+ + N_2\,X(v) \longrightarrow NO^+ + N$$

CH_4 V_3 Emission





$N_2(v) + CH_4 > N_2(v-1) + CH_4^*$

$CH_4^* > CH_4 + hv$

Which RV states are excited?

Conclusions

High resolution N_2 cross sections have major implications for Titan's photochemistry

The high quality observational constraints from Cassini/Huygens mission necessitate the detailed description of the complex processes taking place in Titan's atmosphere.