Rencontres de Blois 2006
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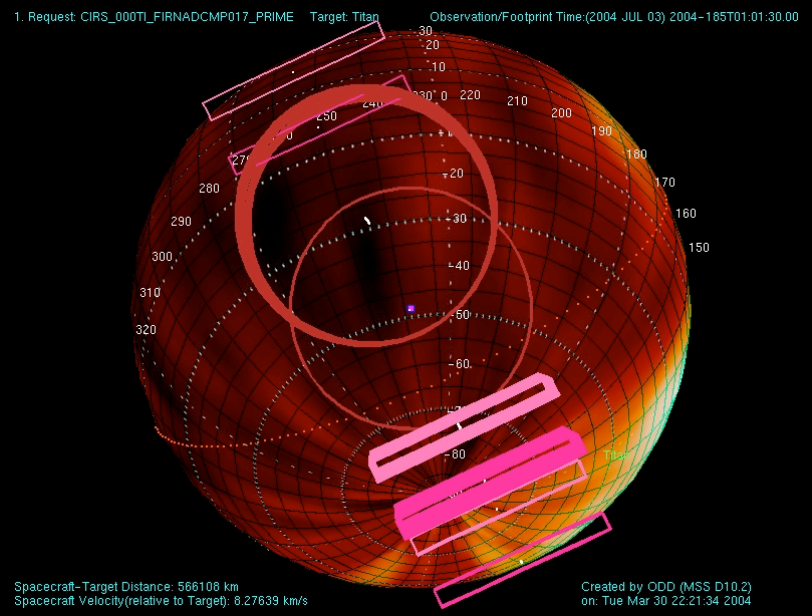
28/5-3/6 2006

Stratospheric composition of Titan from Cassini/CIRS observations

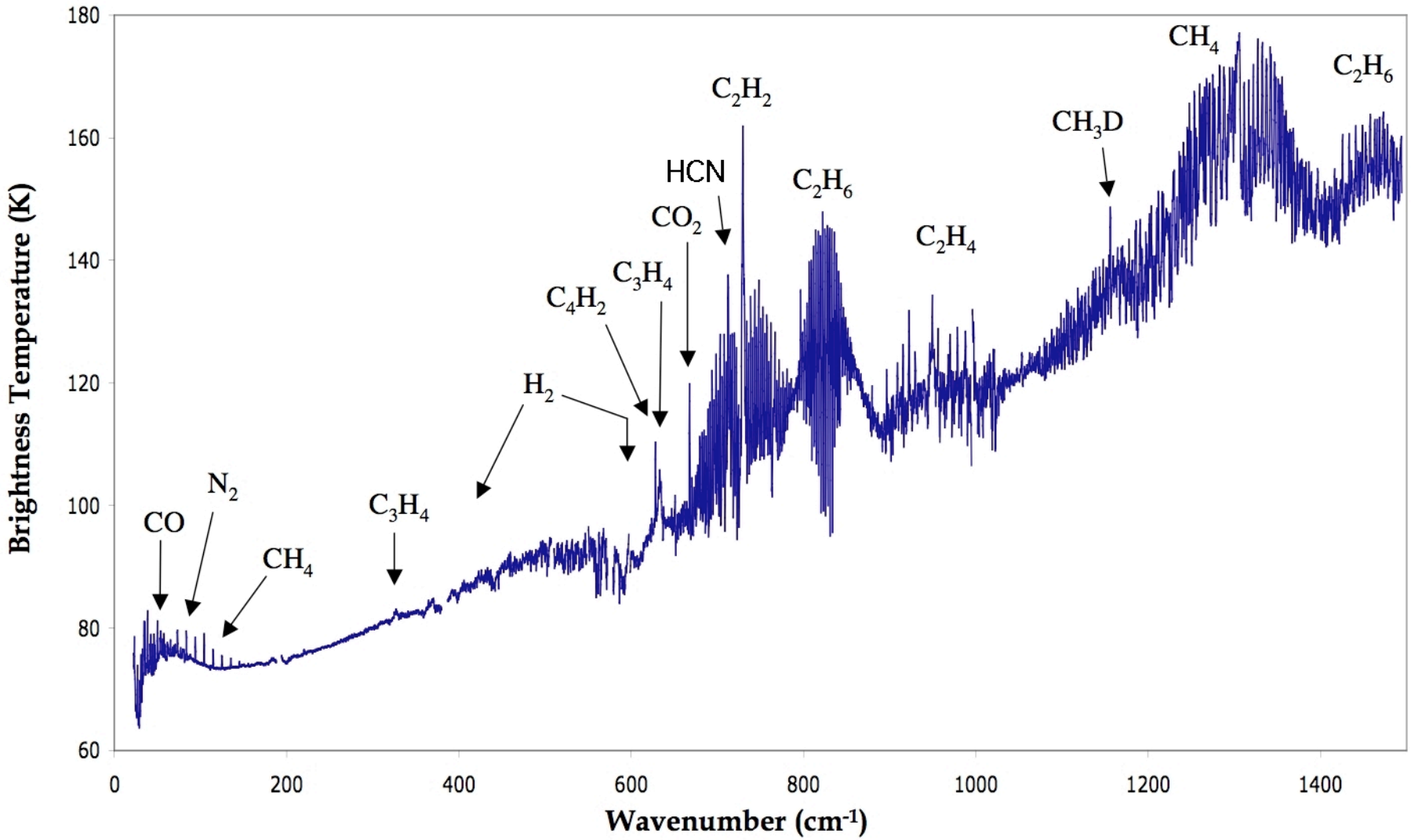
Athena Coustenis
For the CIRS Team

CIRS at Titan

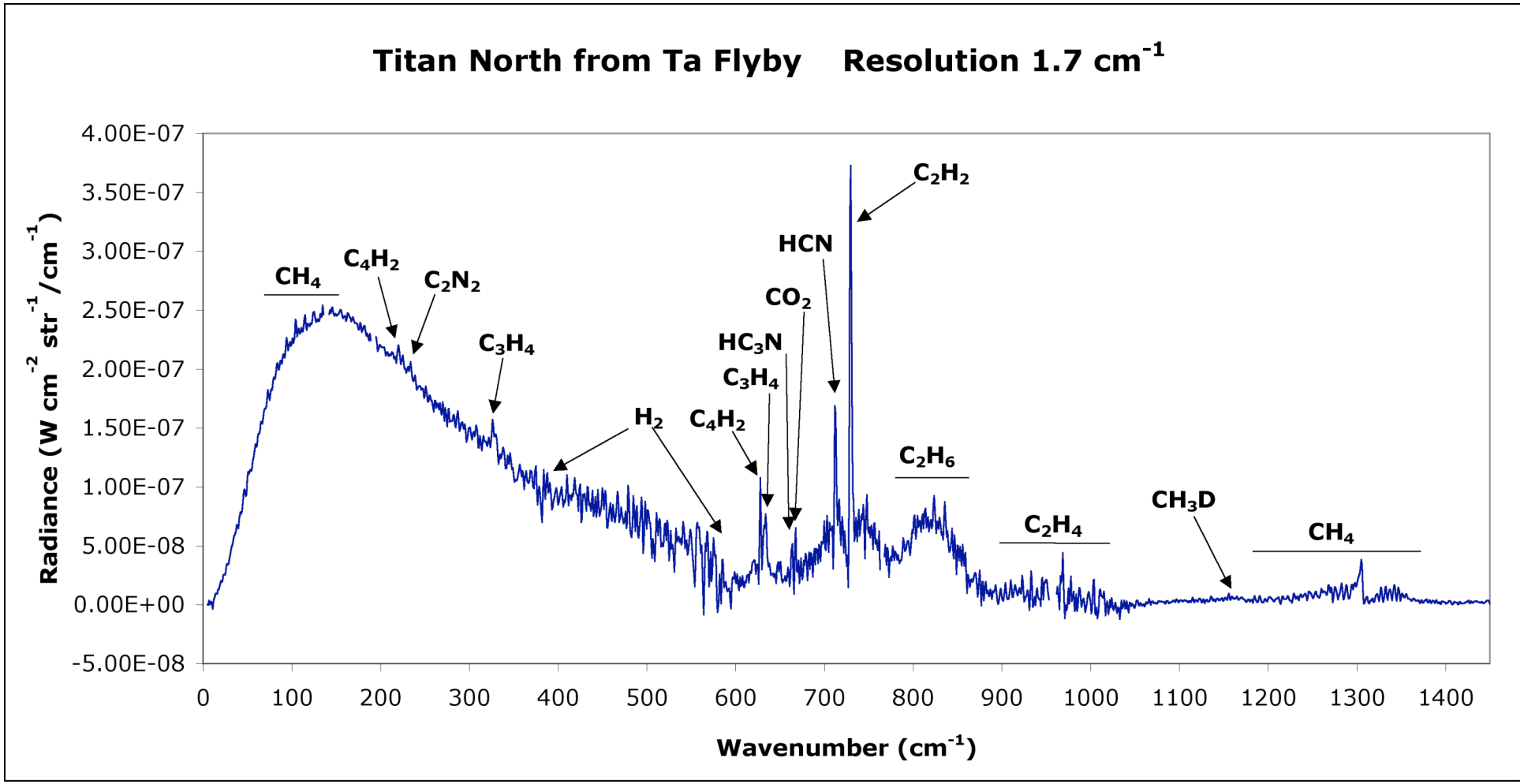


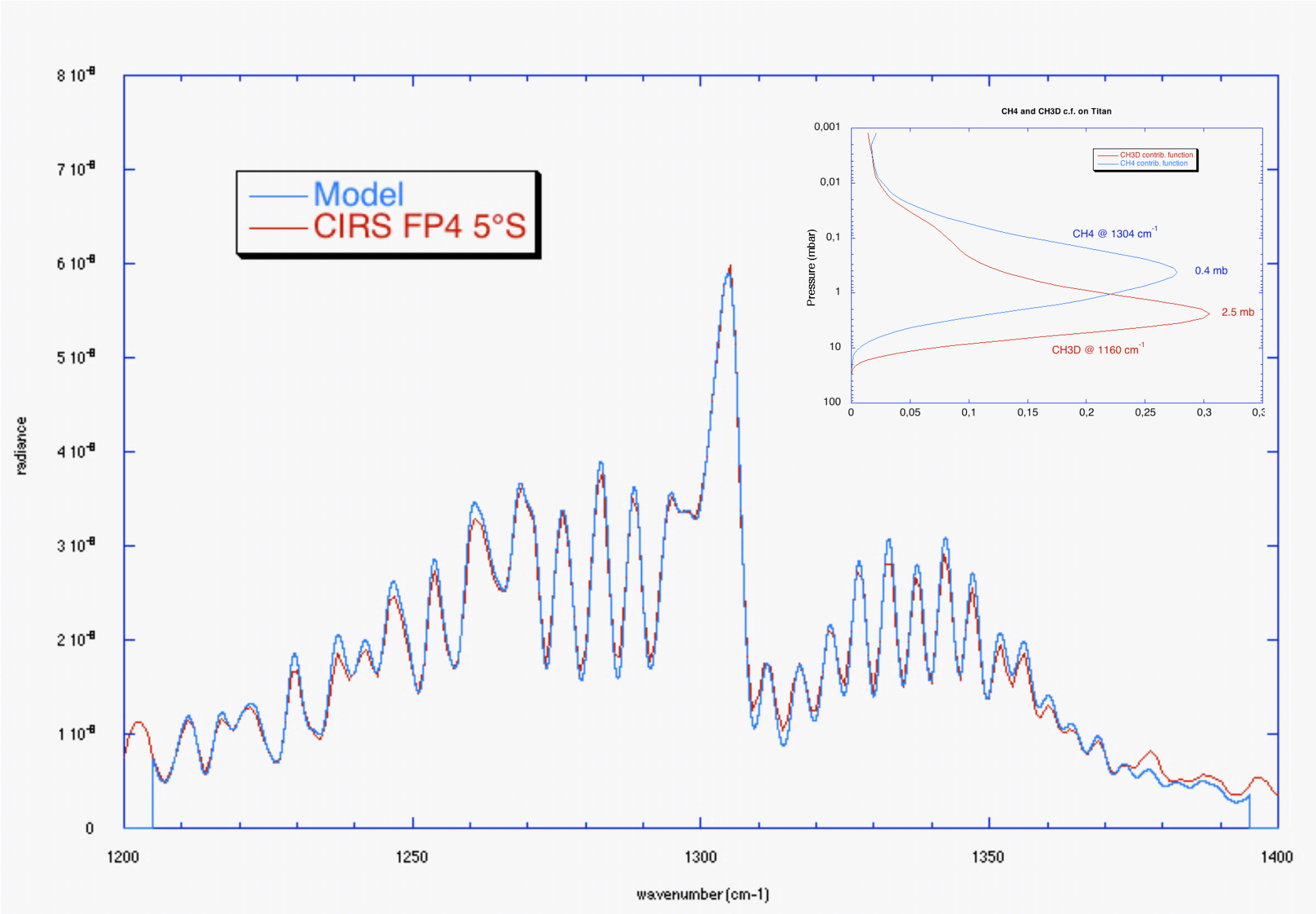
T0 Composition Integrations

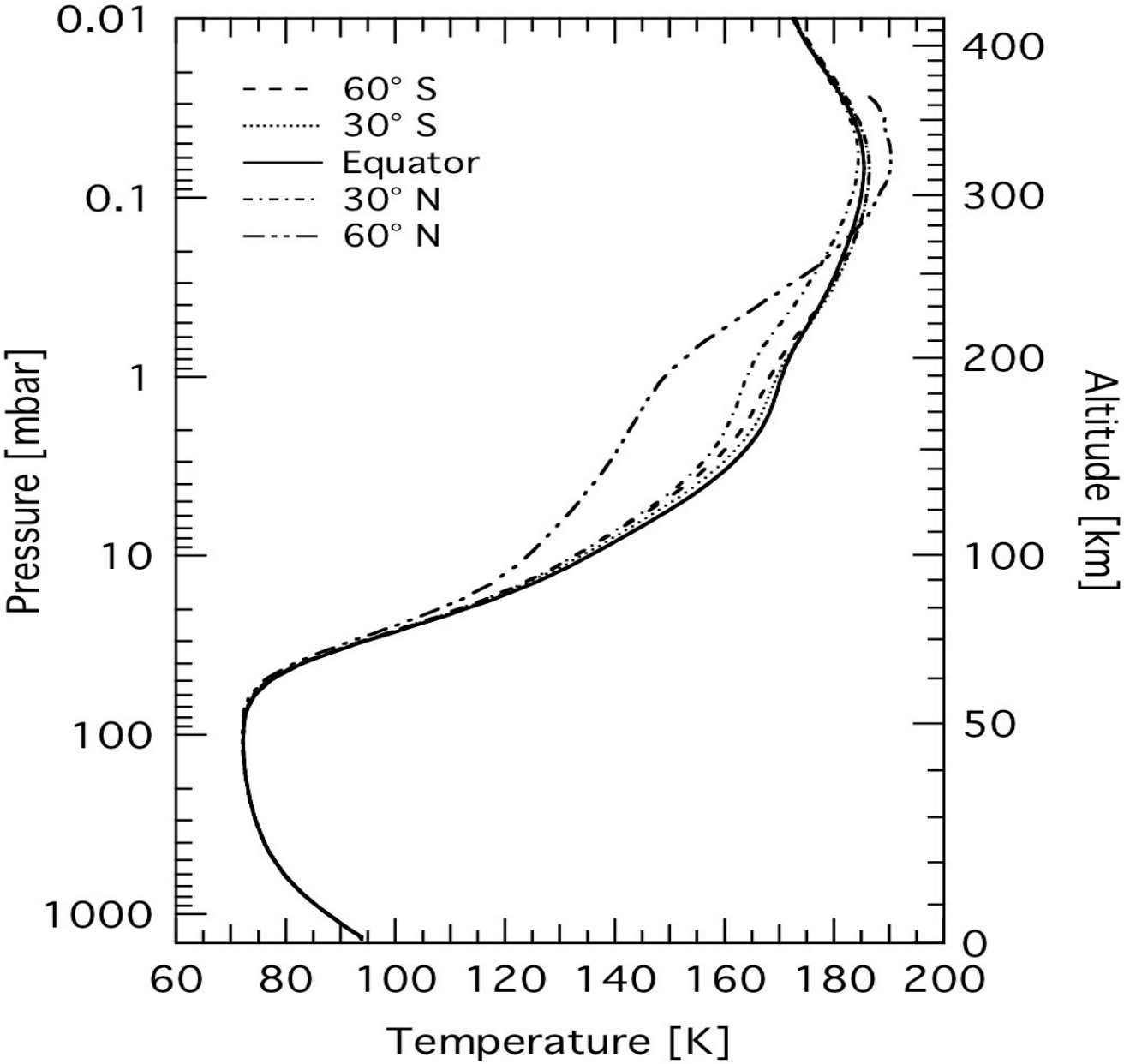
Since July 2, 2004 : T0-T10 flybys
FP1, FP3 and FP4 spectra
high resolution apodized (0.53 cm^{-1}) or medium resolution (2.5 cm^{-1})
Covering Titan's disk

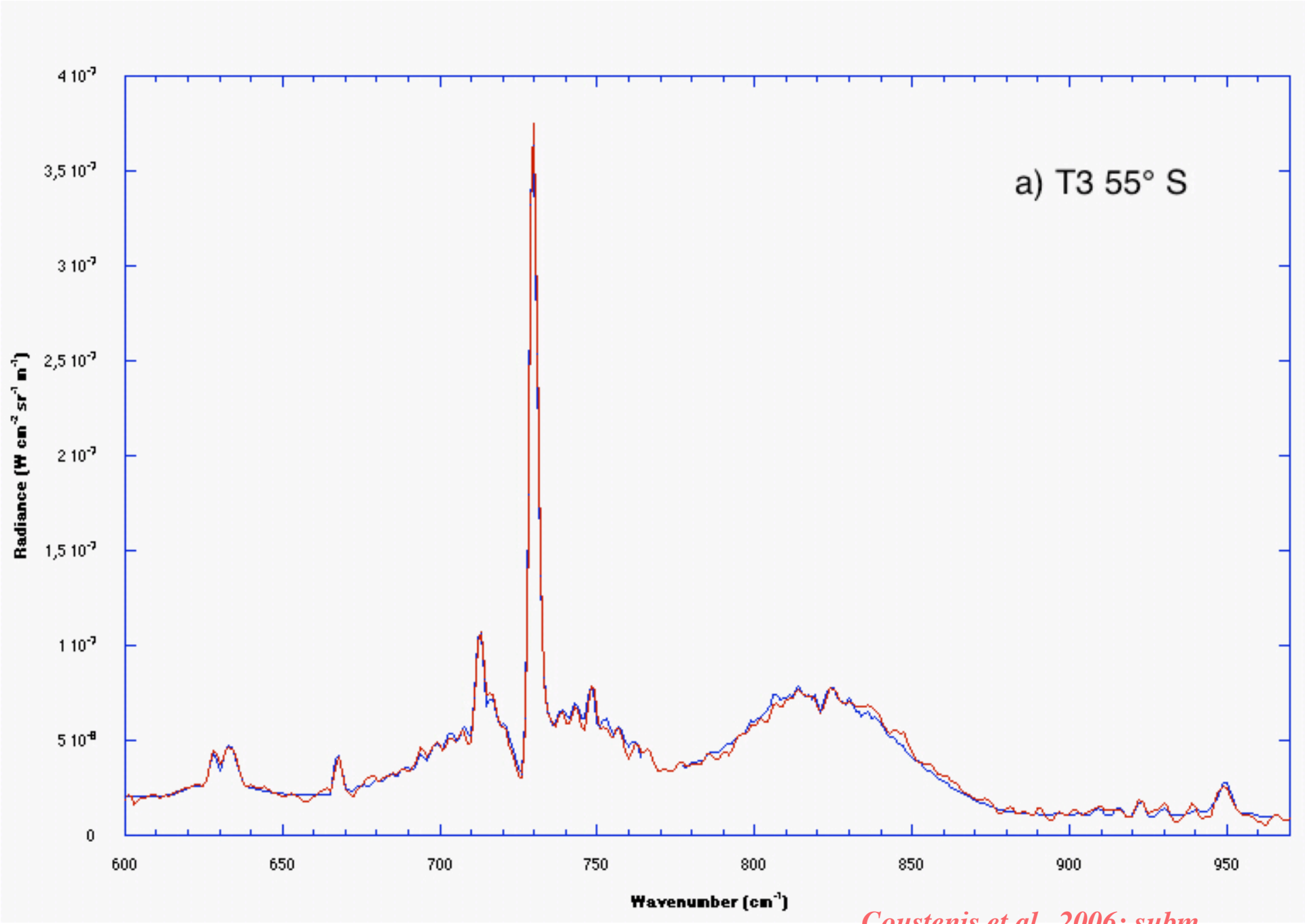

Brightness Temperature (K)
Wavenumber (cm-1)
180
160
140
120
100
80
60
0
200
400
600
800
1000
1200
1400
CO
N2
CH4
C3H4
H2
C4H2
C3H4
CO2
HCN
C2H2
C2H6
C2H4
CH3D
CH4
C2H6

Cassini-CIRS Ta at Titan

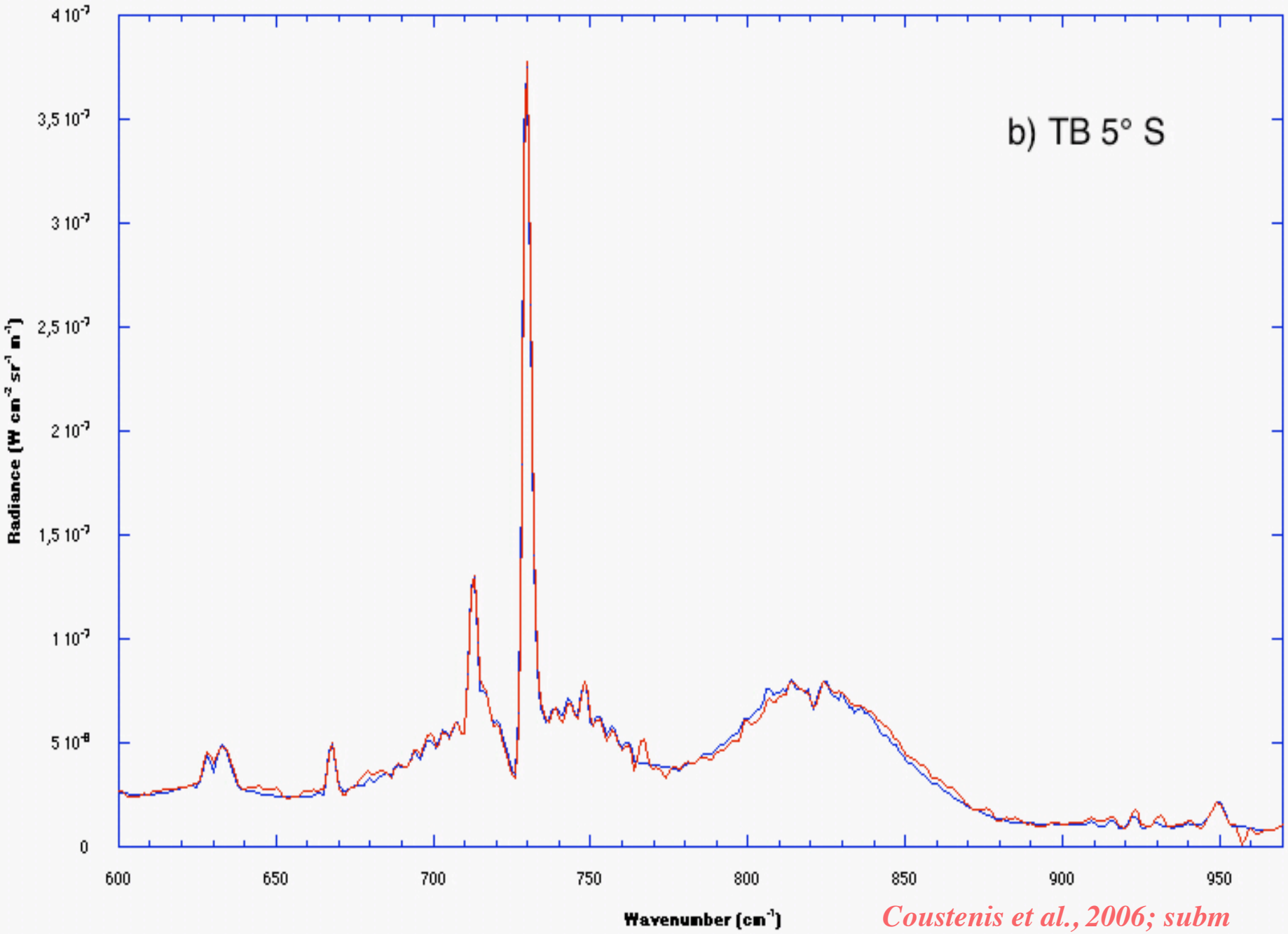



Model
CIRS FP4 5°S
radiance
wavenumber (cm-1)
CH4 and CH3D c.f. on Titan
CH3D contrib. function
CH4 contrib. function
Pressure (mbar)
CH4 @ 1304 cm-1
0.4 mb
2.5 mb
CH3D @ 1160 cm-1

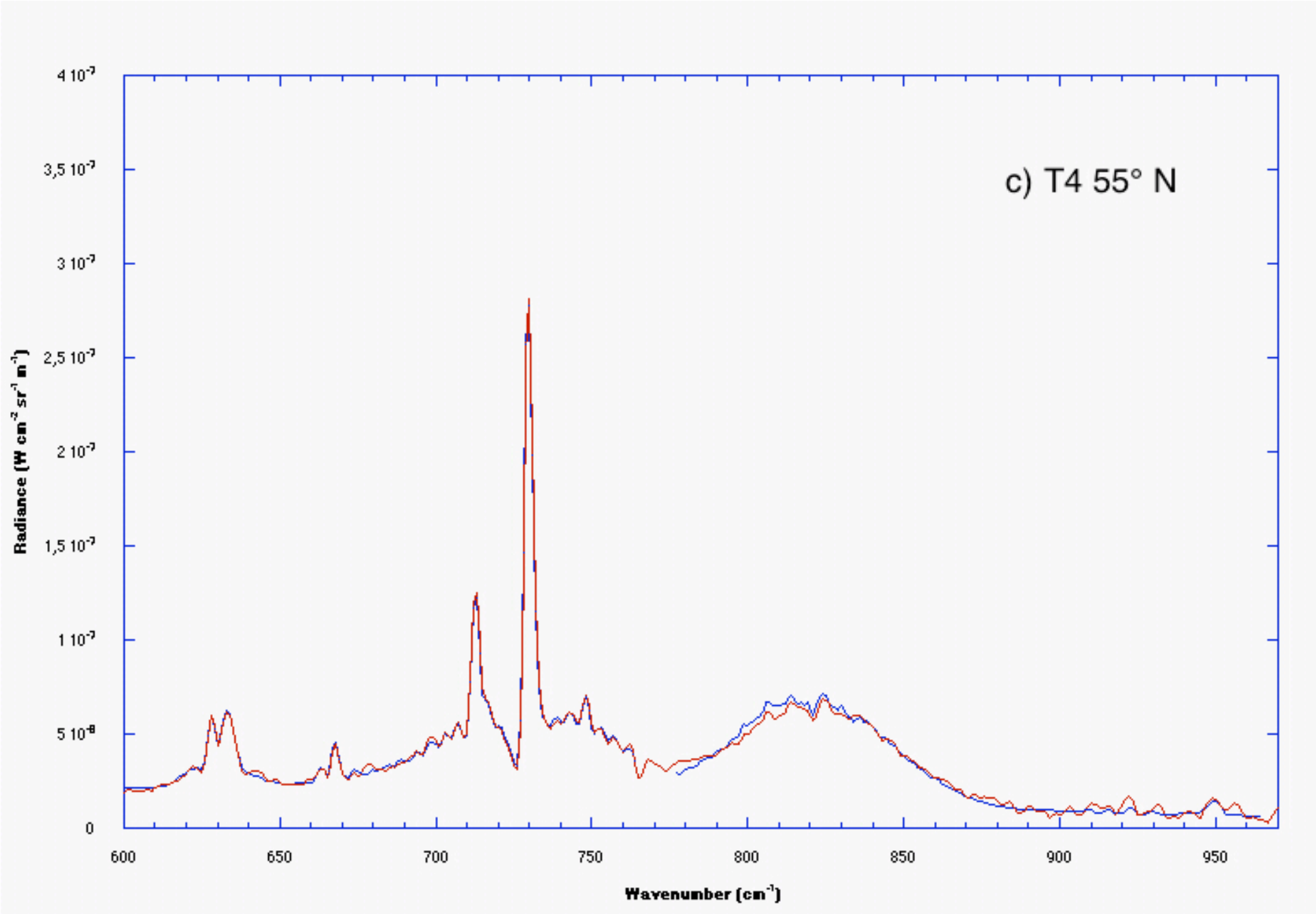

60° S
30° S
Equator
30° N
60° N
Pressure [mbar]
0.01
0.1
1
10
100
1000
Altitude [km]
400
300
200
100
50
0
60
80
100
120
140
160
180
200
Temperature [K]



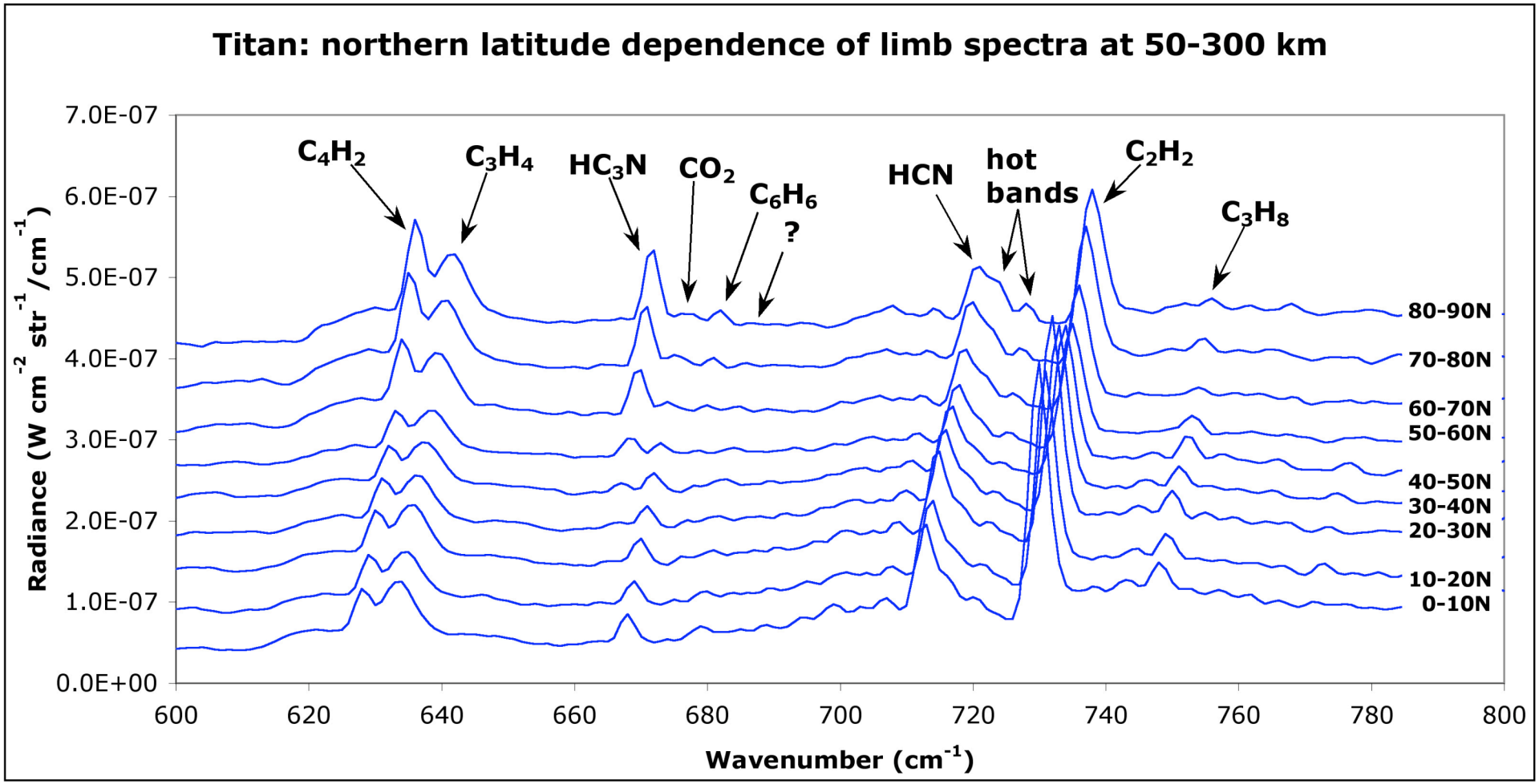
Coustenis et al., 2006; subm



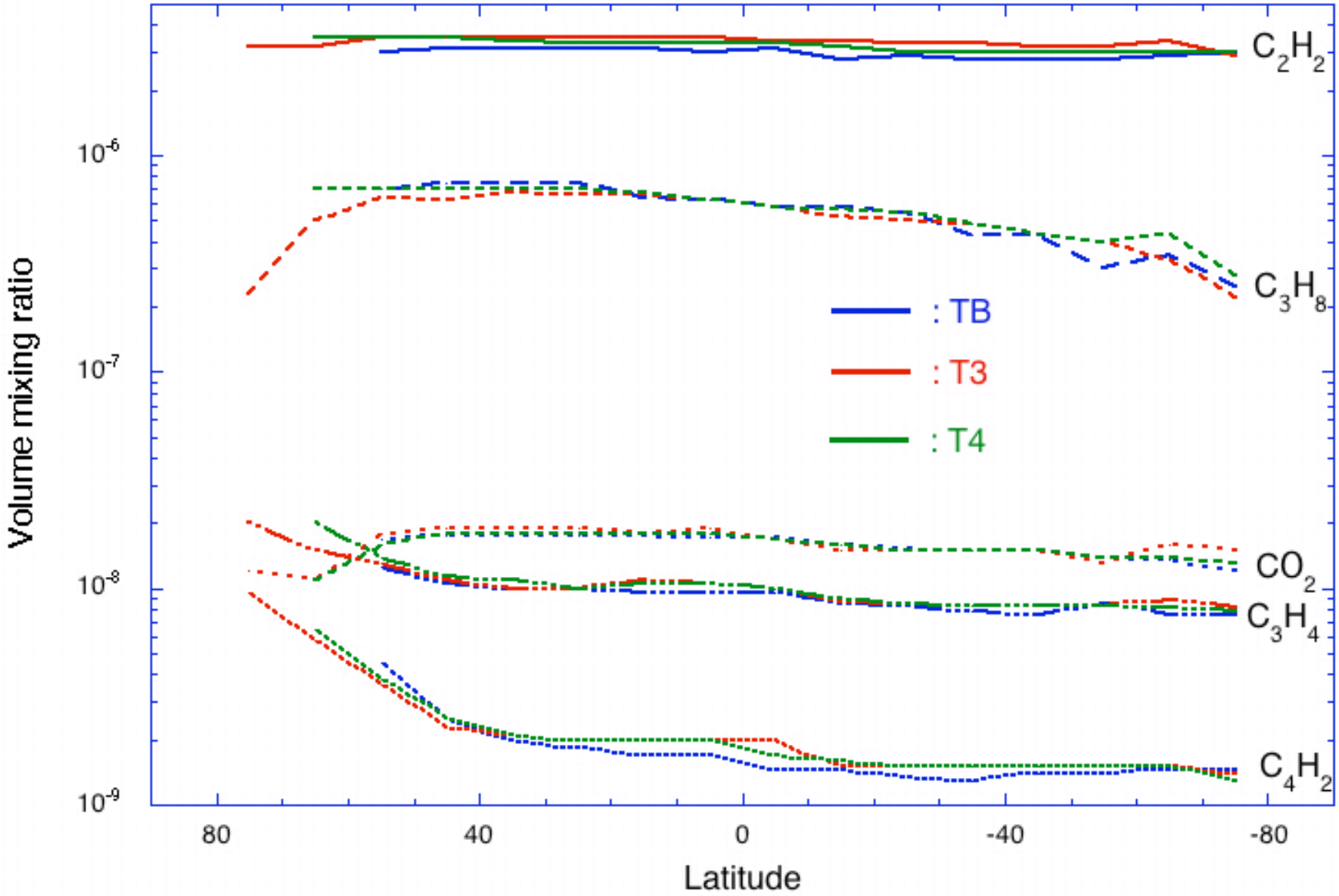
Coustenis et al., 2006; subm



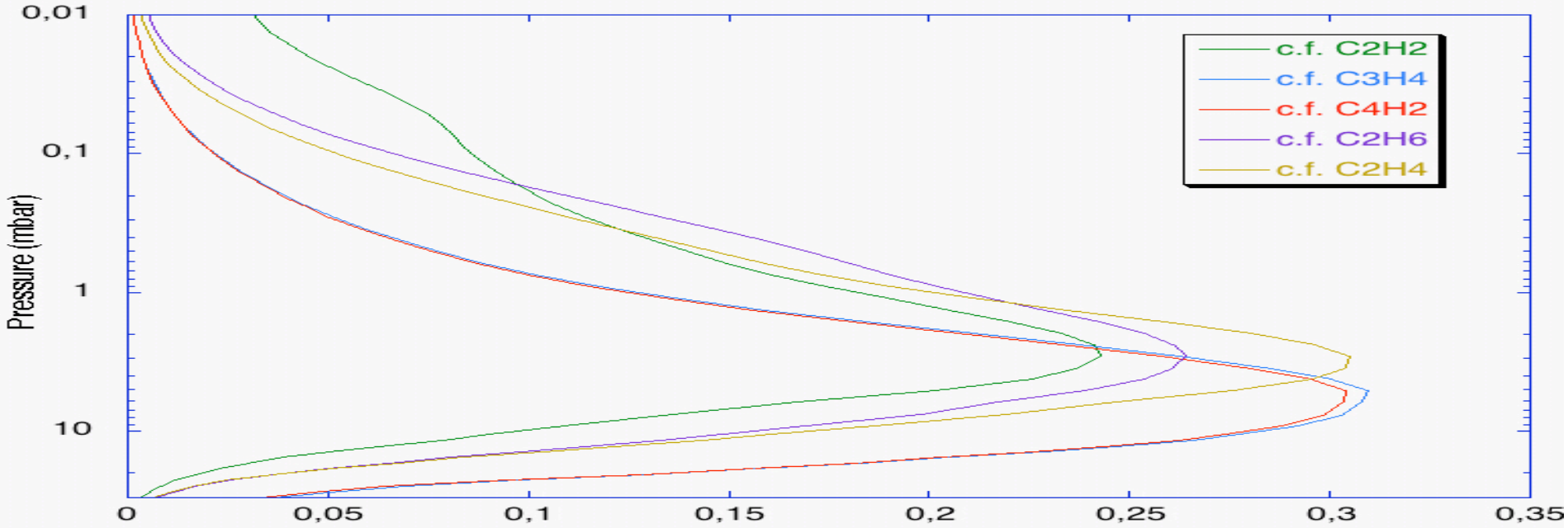
Coustenis et al., 2006; subm

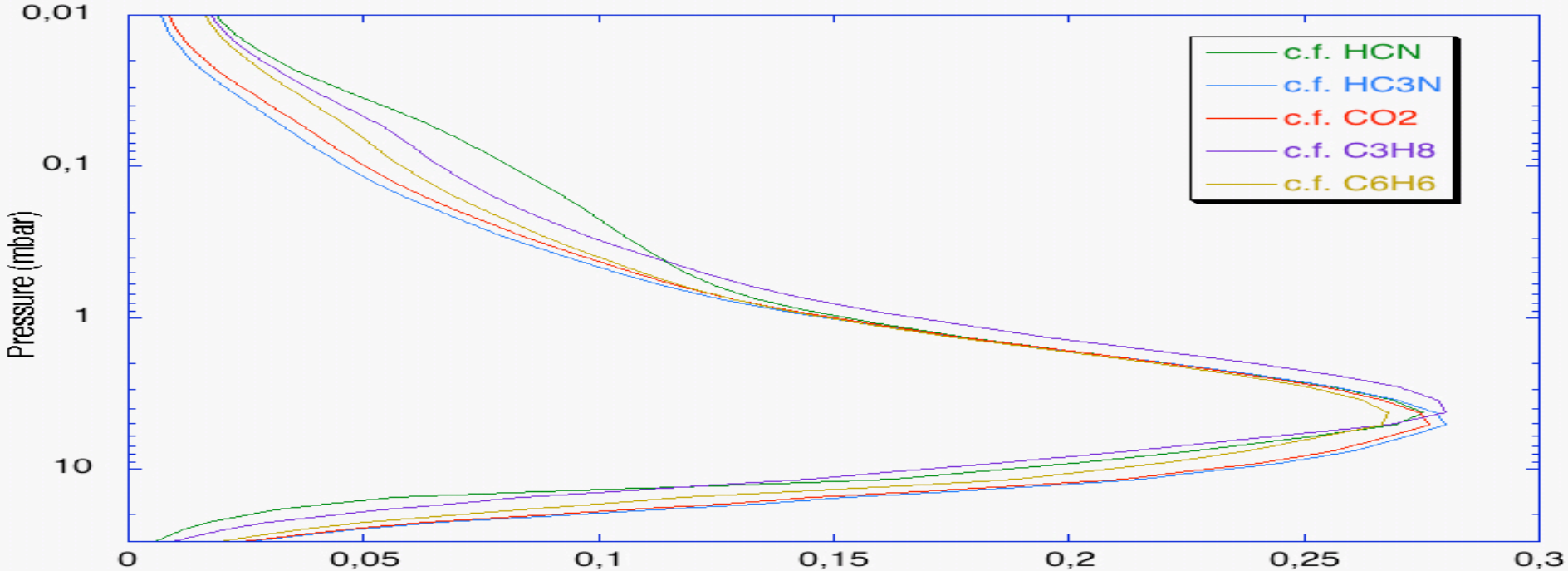


T3 latitude dependence : *abrupt change around 60°*
C4H2 increases faster than C3H4
HC3N and C6H6 appear, CO2 and C3H8 drop
at higher lat than 60°N, HCN and C2H2 drop slightly

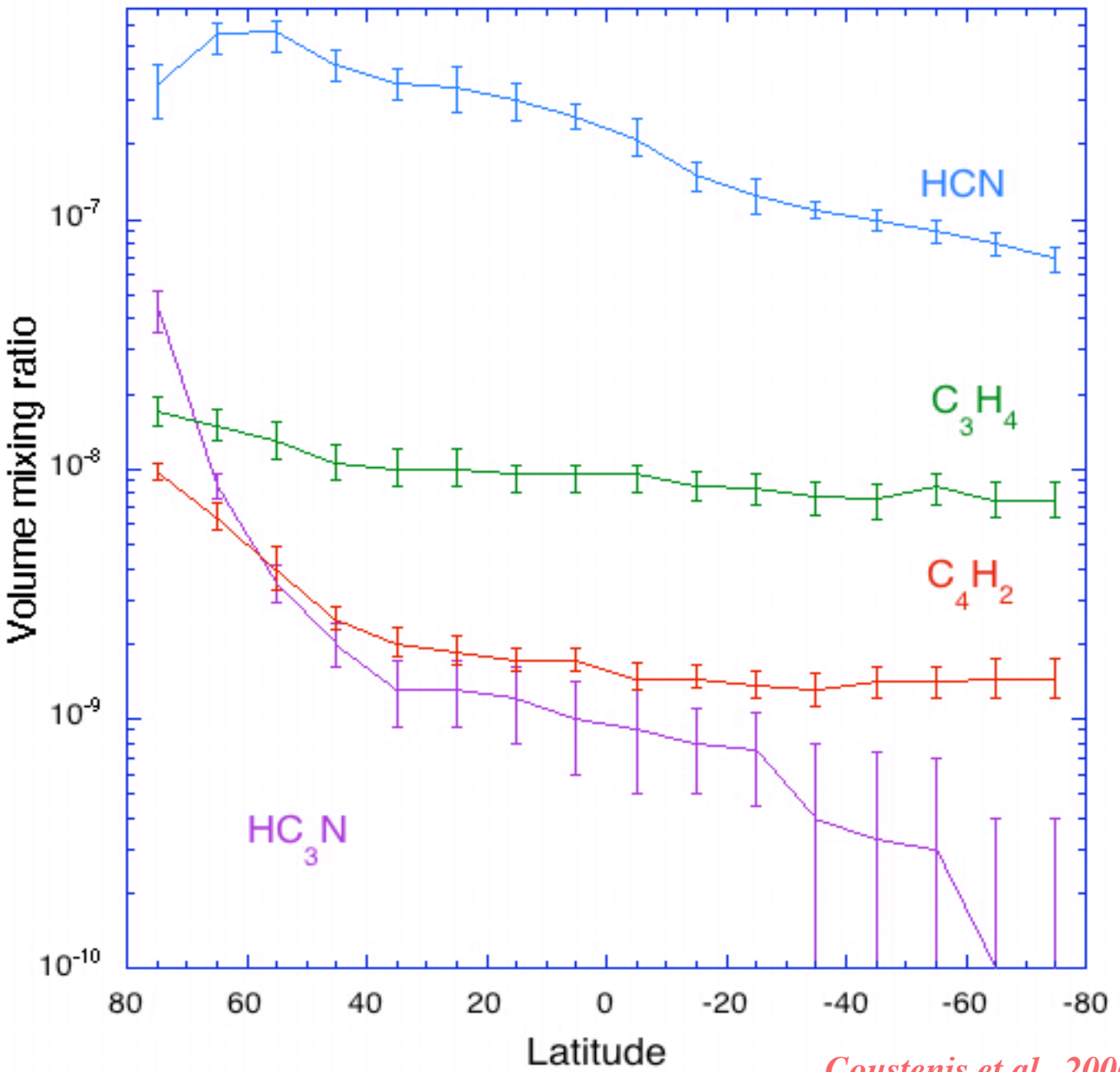


Coustenis et al., 2006; subm


0,01
0,1
1
10
Pressure (mbar)
0
0,05
0,1
0,15
0,2
0,25
0,3
0,35
c.f. C2H2
c.f. C3H4
c.f. C4H2
c.f. C2H6
c.f. C2H4

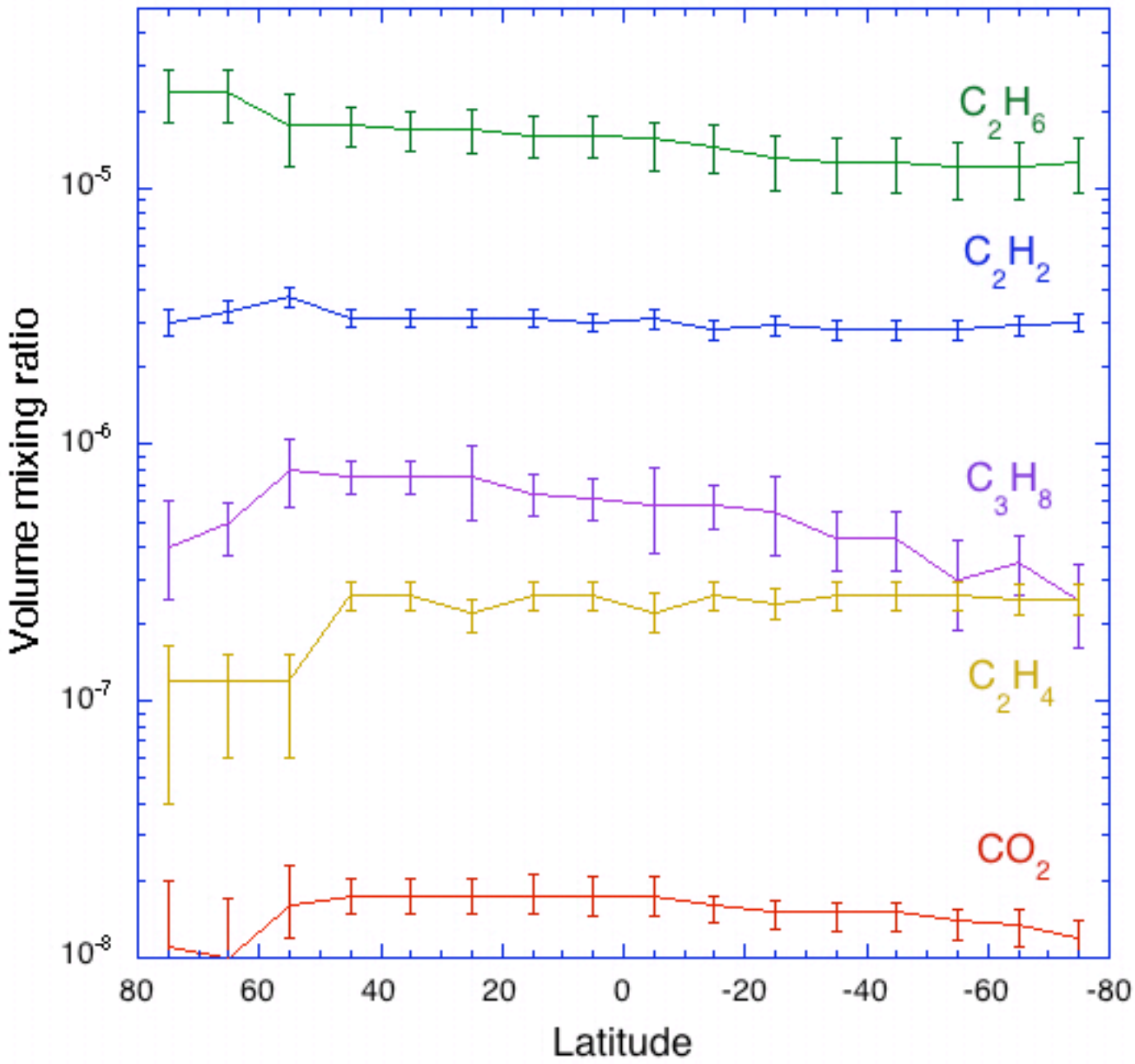

0,01
0,1
1
10
Pressure (mbar)
0
0,05
0,1
0,15
0,2
0,25
0,3
c.f. HCN
c.f. HC3N
c.f. CO2
c.f. C3H8
c.f. C6H6

Meridional variations of Titan's minor constituents

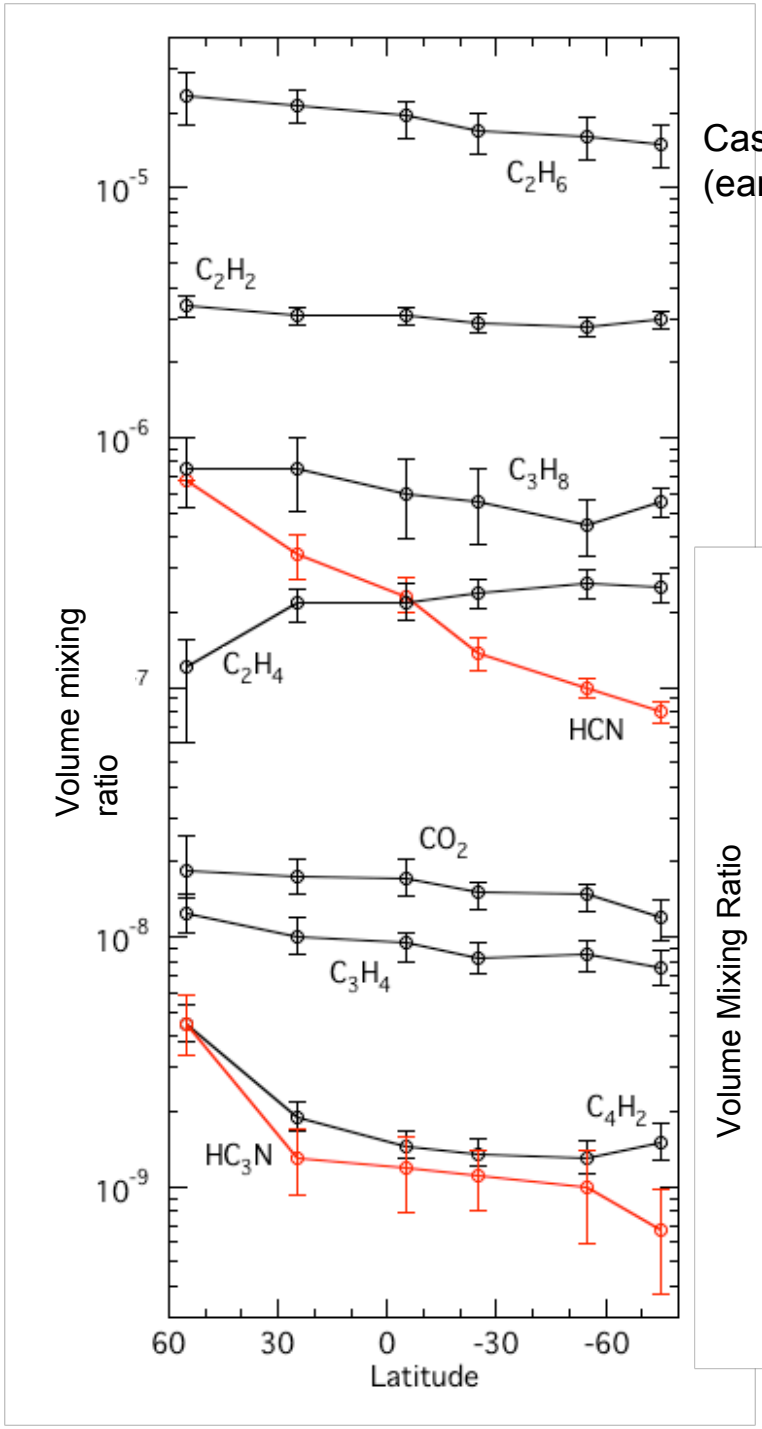


Coustenis et al., 2006; subm

Meridional variations of Titan's minor constituents

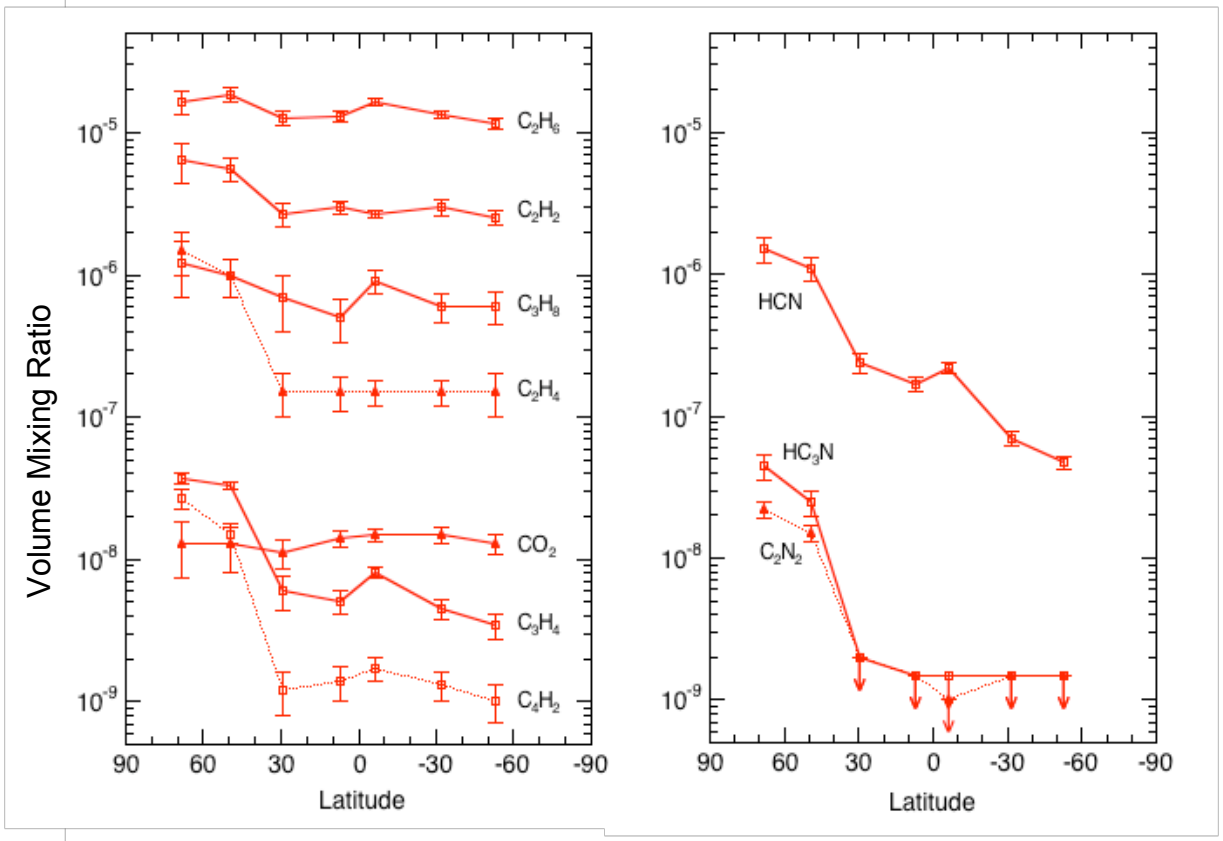


Coustenis et al., 2006; subm

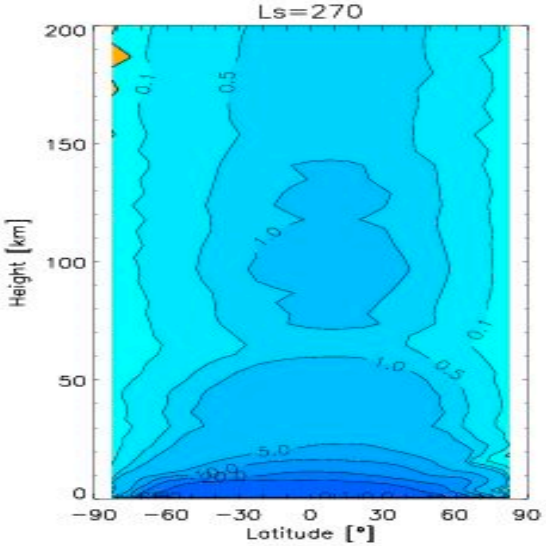


Cassini CIRS (2004)
(early N. winter)

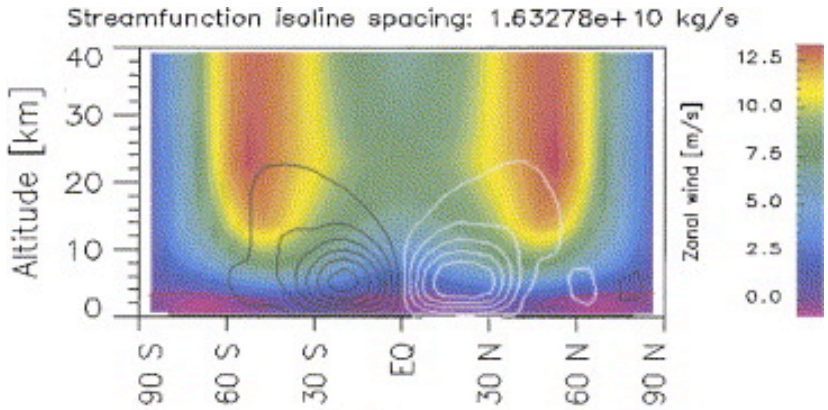
Voyager IRIS (1980):
Coustenis & Bézard (1995)
(early N. spring)



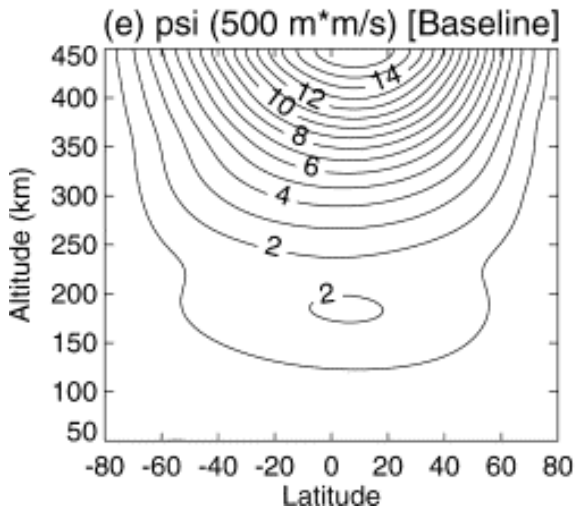
Hadley circulation in Titan GCMs



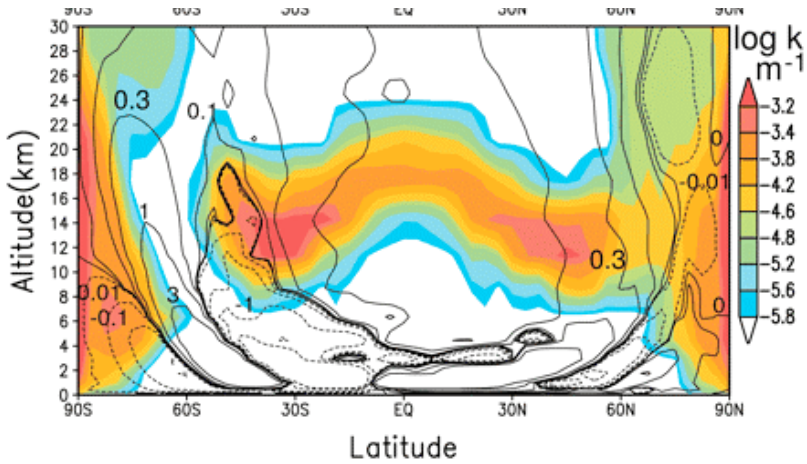
Tokano and Neubauer (2005)



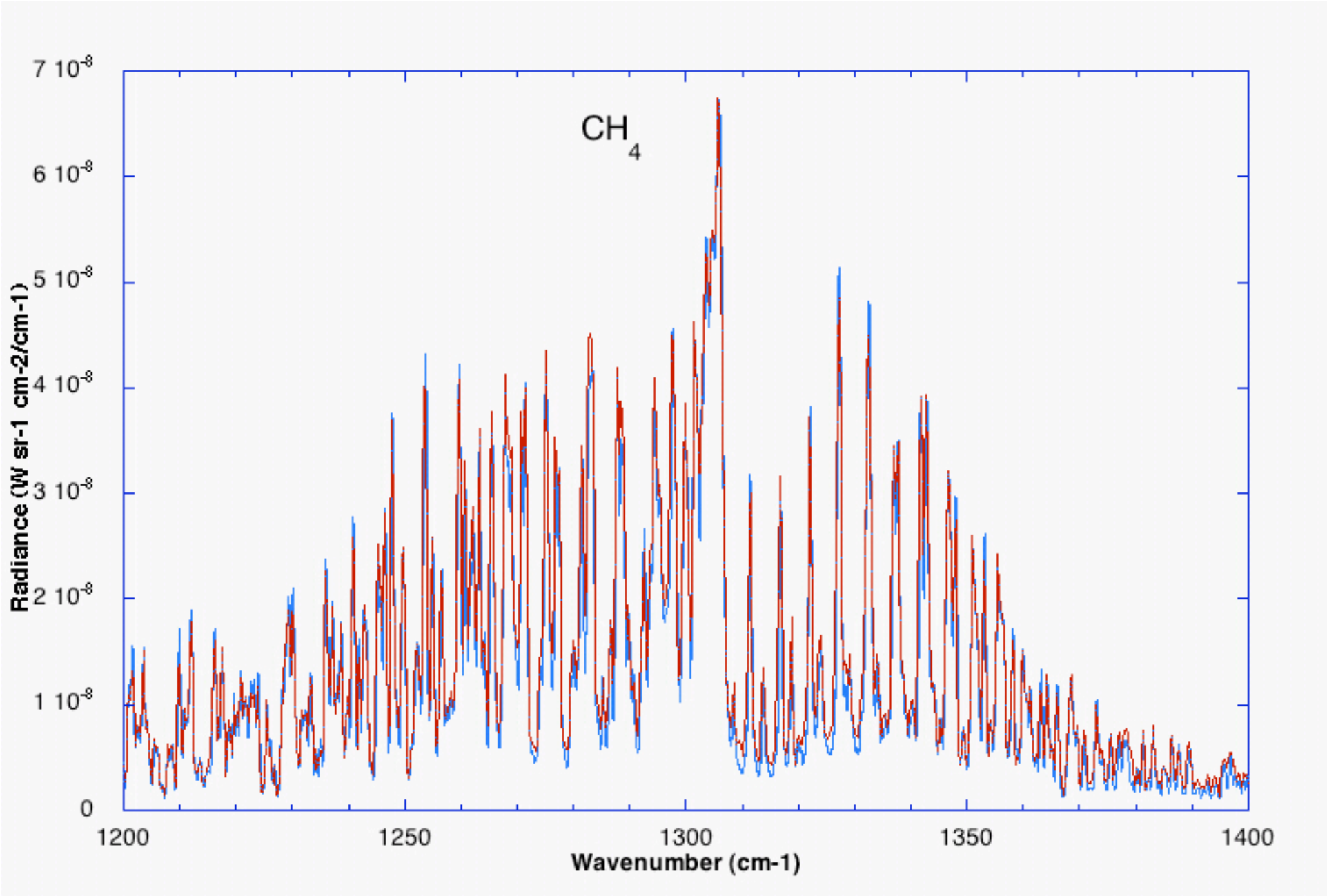
Grieger et al. (2004)

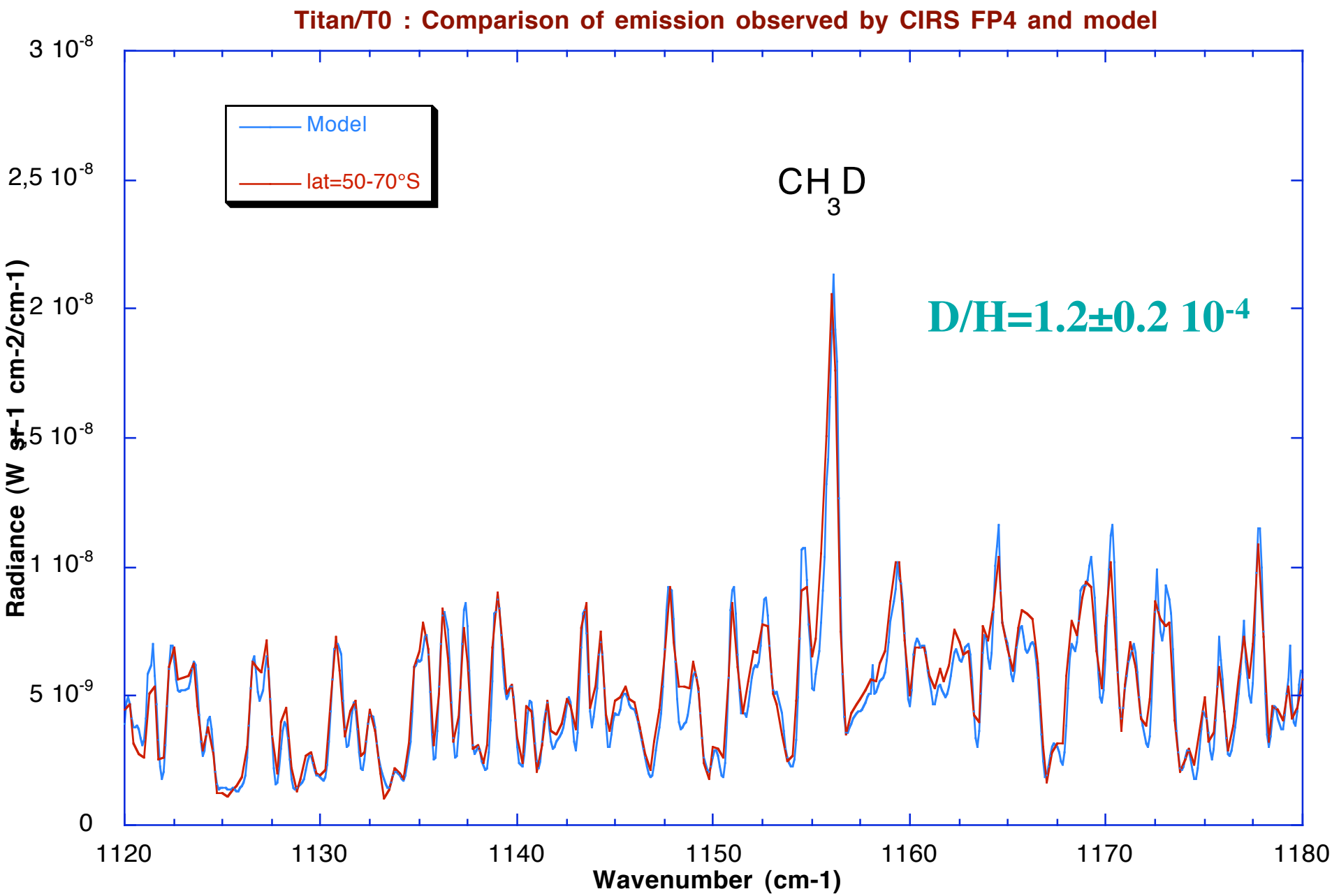


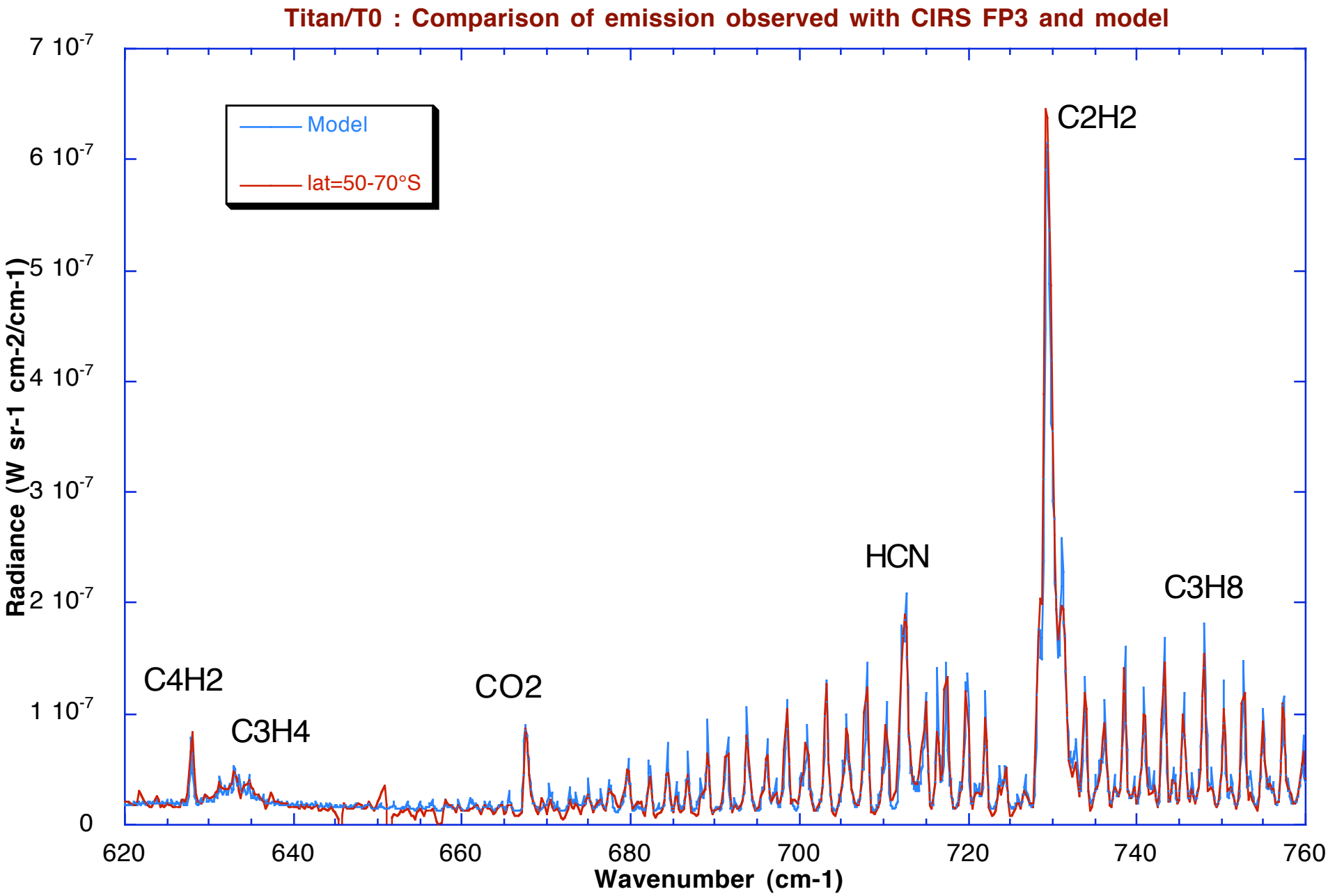
Zhu and Strobel (2005)

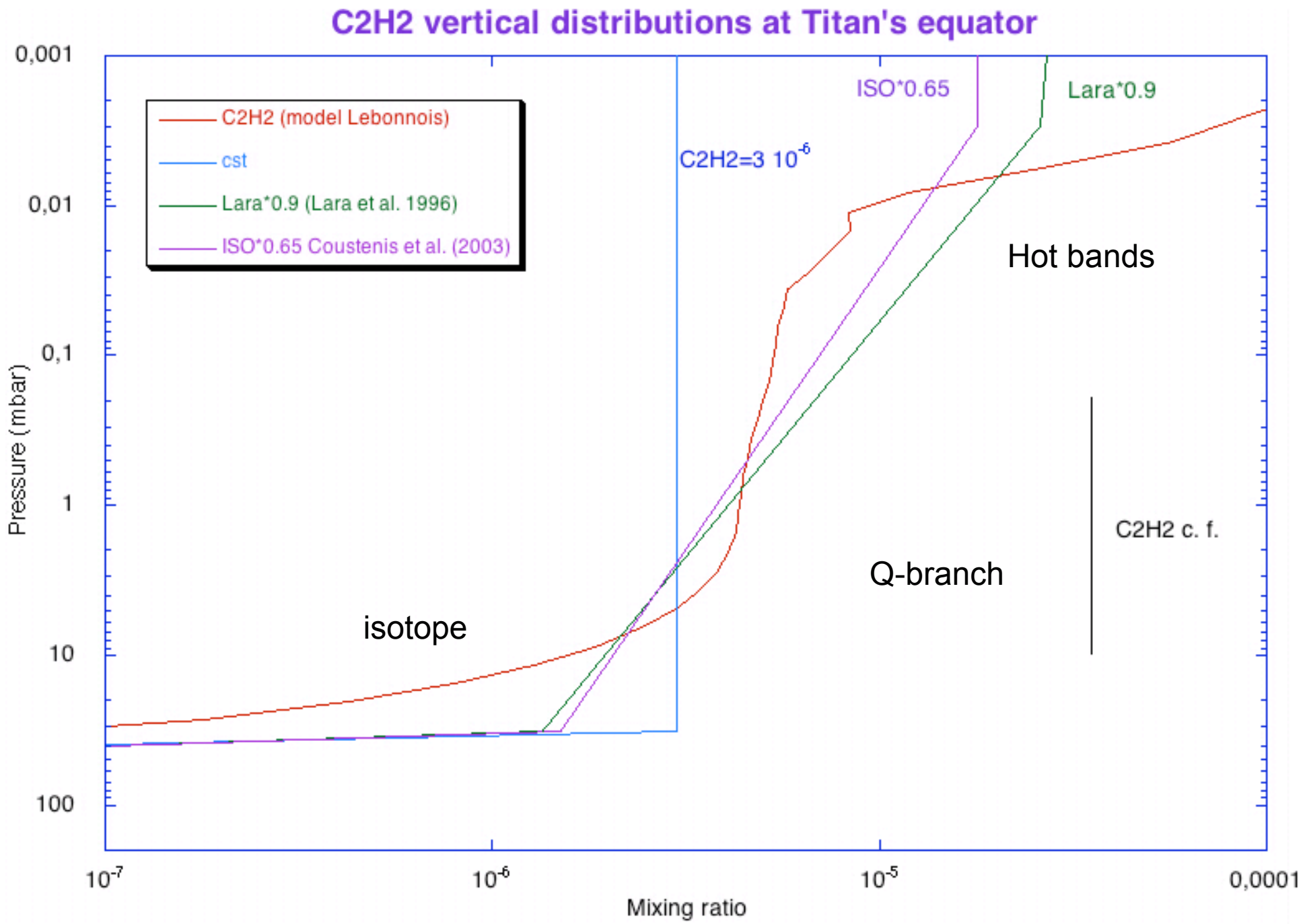


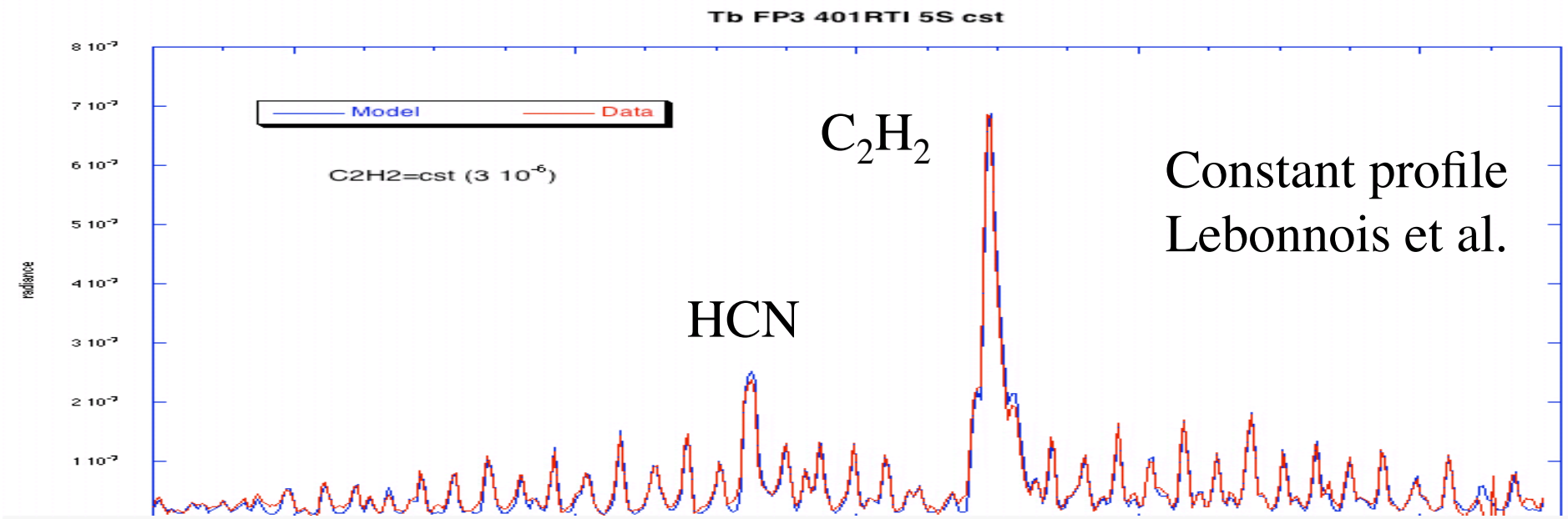
Rannou et al. (2006)

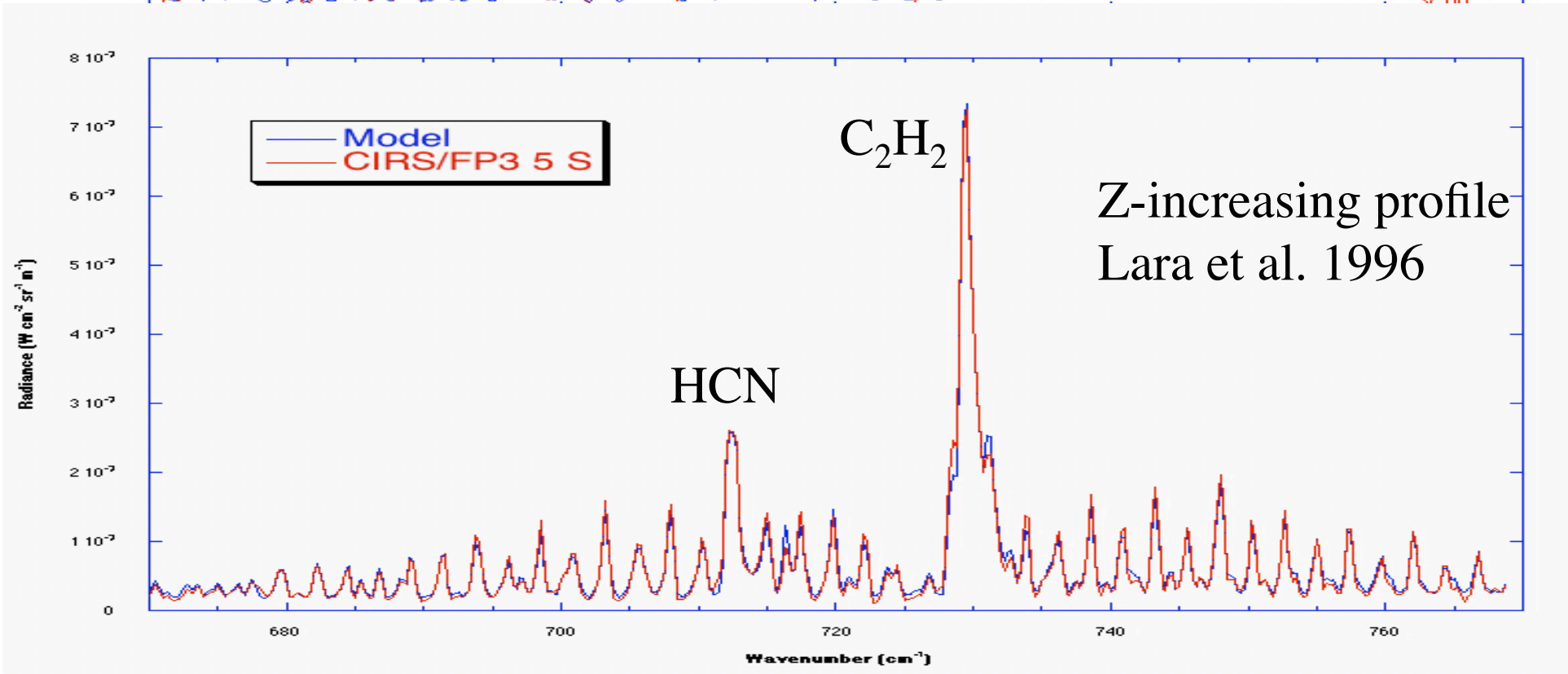

CH4
Radiance (W sr-1 cm-2/cm-1)
7 10-8
6 10-8
5 10-8
4 10-8
3 10-8
2 10-8
1 10-8
0
1200
1250
1300
1350
1400
Wavenumber (cm-1)

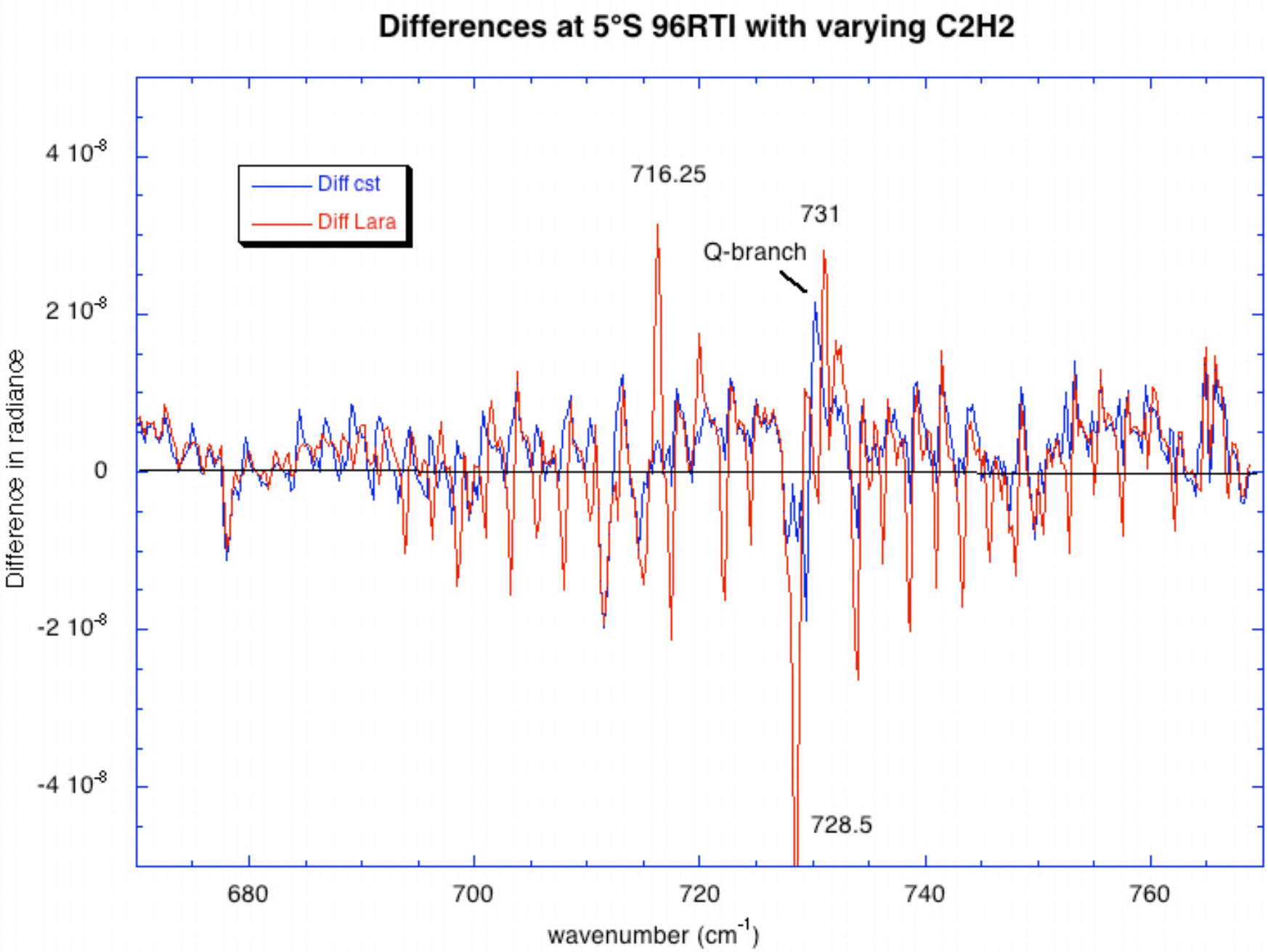

Titan/T0 : Comparison of emission observed by CIRS FP4 and model
Model
lat=50-70°S
CH3D
D/H=1.2±0.2 10-4
Radiance (W sr-1 cm-2/cm-1)
Wavenumber (cm-1)
3 10-8
2,5 10-8
2 10-8
1,5 10-8
1 10-8
5 10-9
0
1120
1130
1140
1150
1160
1170
1180

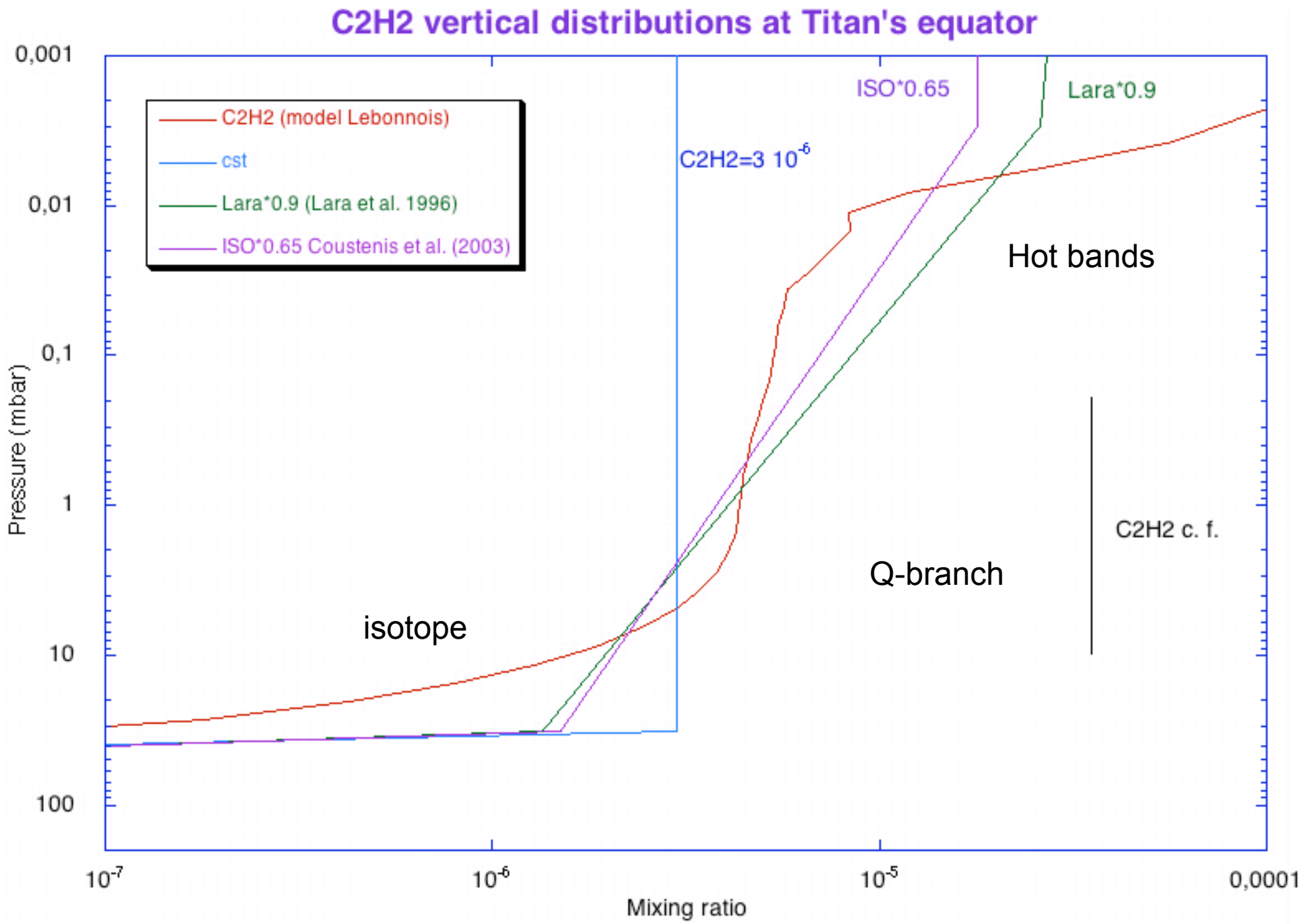

Titan/T0 : Comparison of emission observed with CIRS FP3 and model
Model
lat=50-70°S
C2H2
HCN
C3H8
C4H2
C3H4
CO2
Radiance (W sr-1 cm-2/cm-1)
Wavenumber (cm-1)
7 10-7
6 10-7
5 10-7
4 10-7
3 10-7
2 10-7
1 10-7
0
620
640
660
680
700
720
740
760

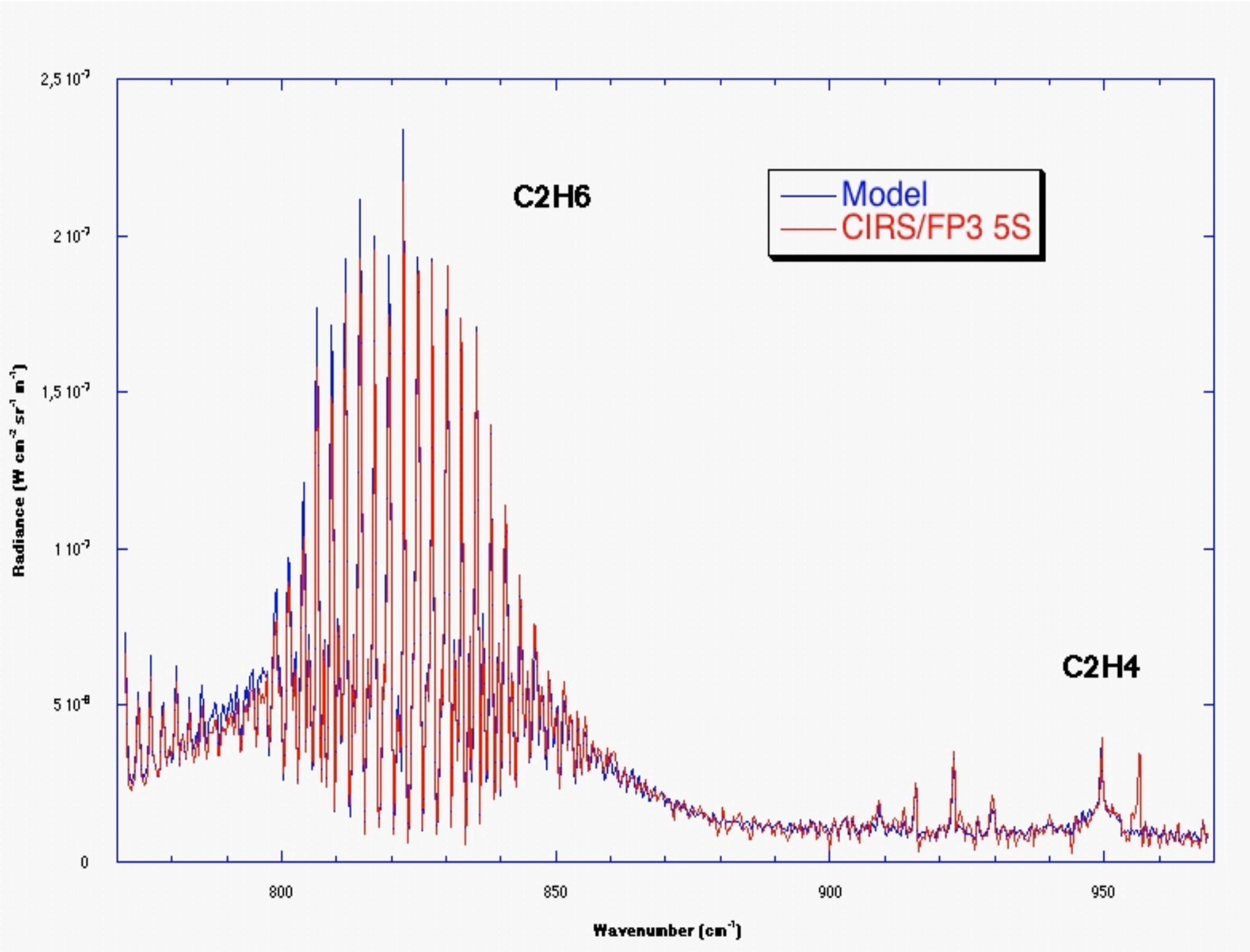

C2H2 vertical distributions at Titan's equator
C2H2 (model Lebonnois)
cst
Lara*0.9 (Lara et al. 1996)
ISO*0.65 Coustenis et al. (2003)
ISO*0.65
Lara*0.9
C2H2=3 10-6
Hot bands
Q-branch
isotope
C2H2 c. f.
Pressure (mbar)
0,001
0,01
0,1
1
10
100
10-7
10-6
10-5
0,0001
Mixing ratio


Tb FP3 401RTI 5S cst
Model
Data
C2H2=cst (3 10^-6)
radiance
C2H2
HCN
Constant profile
Lebonnois et al.

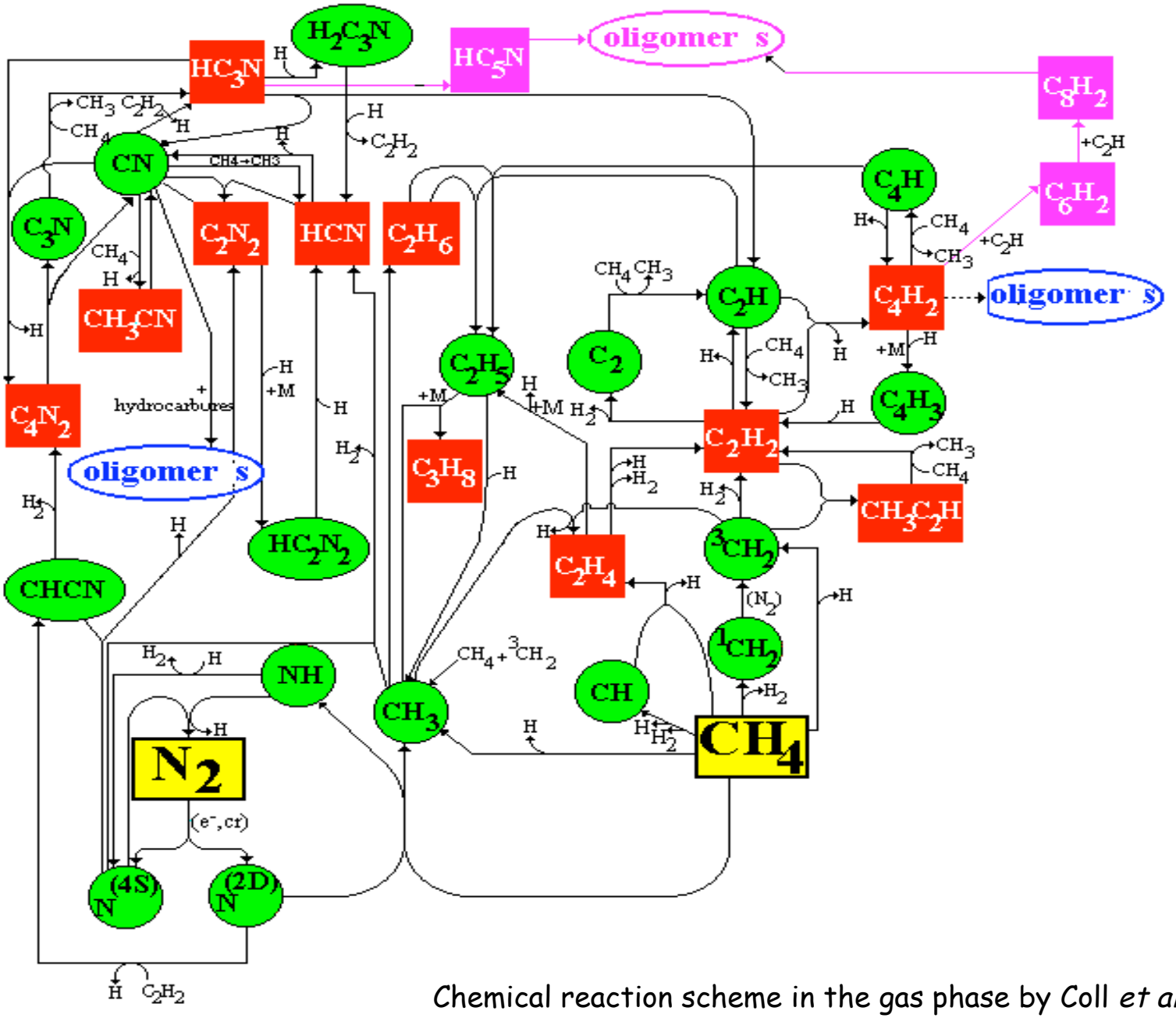

Model
CIRS/FP3 5 S
Radiance (W cm^-2 sr^-1 m^-1)
Wavenumber (cm^-1)
680
700
720
740
760
C2H2
HCN
Z-increasing profile
Lara et al. 1996


Differences at 5°S 96RTI with varying C2H2
Diff cst
Diff Lara
716.25
731
Q-branch
728.5
4 10-8
2 10-8
0
-2 10-8
-4 10-8
Difference in radiance
680
700
720
740
760
wavenumber (cm-1)


C2H2 vertical distributions at Titan's equator
C2H2 (model Lebonnois)
cst
Lara*0.9 (Lara et al. 1996)
ISO*0.65 Coustenis et al. (2003)
ISO*0.65
Lara*0.9
C2H2=3 10-6
Hot bands
Q-branch
isotope
C2H2 c. f.
Pressure (mbar)
0,001
0,01
0,1
1
10
100
10-7
10-6
10-5
0,0001
Mixing ratio


C2H6
C2H4
Model
CIRS/FP3 5S
Radiance (W cm-2 sr-1 m-1)
Wavenumber (cm-1)
2,5 10-7
2 10-7
1,5 10-7
1 10-7
5 10-8
0
800
850
900
950

Photochemical models



Chemical reaction scheme in the gas phase by Coll *et al.*, 1995

Benzene and HC_3N on Titan

Context:

- Benzene has been discovered in the stratospheres of the giant planets Jupiter and Saturn with ISO (Bézard et al., 2002) but not in Uranus and Neptune. Nothing appeared in the V1/IRIS data at 674 cm^{-1} at the resolution of 4.3 cm^{-1}.
- Benzene was expected in Titan's atmosphere with a formation dominated by propargyl recombination through (Wilson et al., 2002) :

$$2(CH_4 + h\nu \rightarrow {}^1CH_2 + H_2)$$
$$2(C_2H_2 + {}^1CH_2 \rightarrow C_3H_3 + H)$$
$$\underline{C_3H_3 + C_3H_3 \rightarrow [n\text{-}]\ C_6H_6}$$
$$2C_2H_2 + CH_4 \rightarrow C_6H_6 + 2H + H_2$$

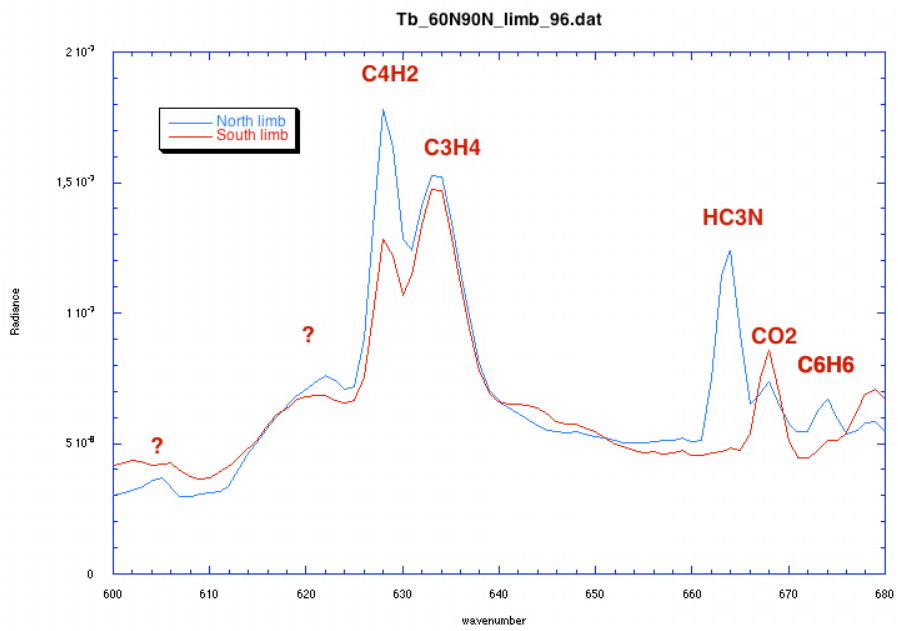
ISO saw the C_6H_6 emission feature at 674 cm^{-1} where the ν_4 band occurs. The abundance derived was **4±3 10^{-10}** at the 9-mbar region **(Coustenis et al., 2003)**. ISO also observed HC_3N in emission at mid-latitudes at 663 cm^{-1} (5±3 10^{-10} at 9-mbar).

CIRS finds **C_6H_6**

1.4±0.5 10^{-9} at 60° N

and < 5 10^{-10} elsewhere.

HC_3N varies from some 10^{-10} up to **5 10^{-9}** at 60°N



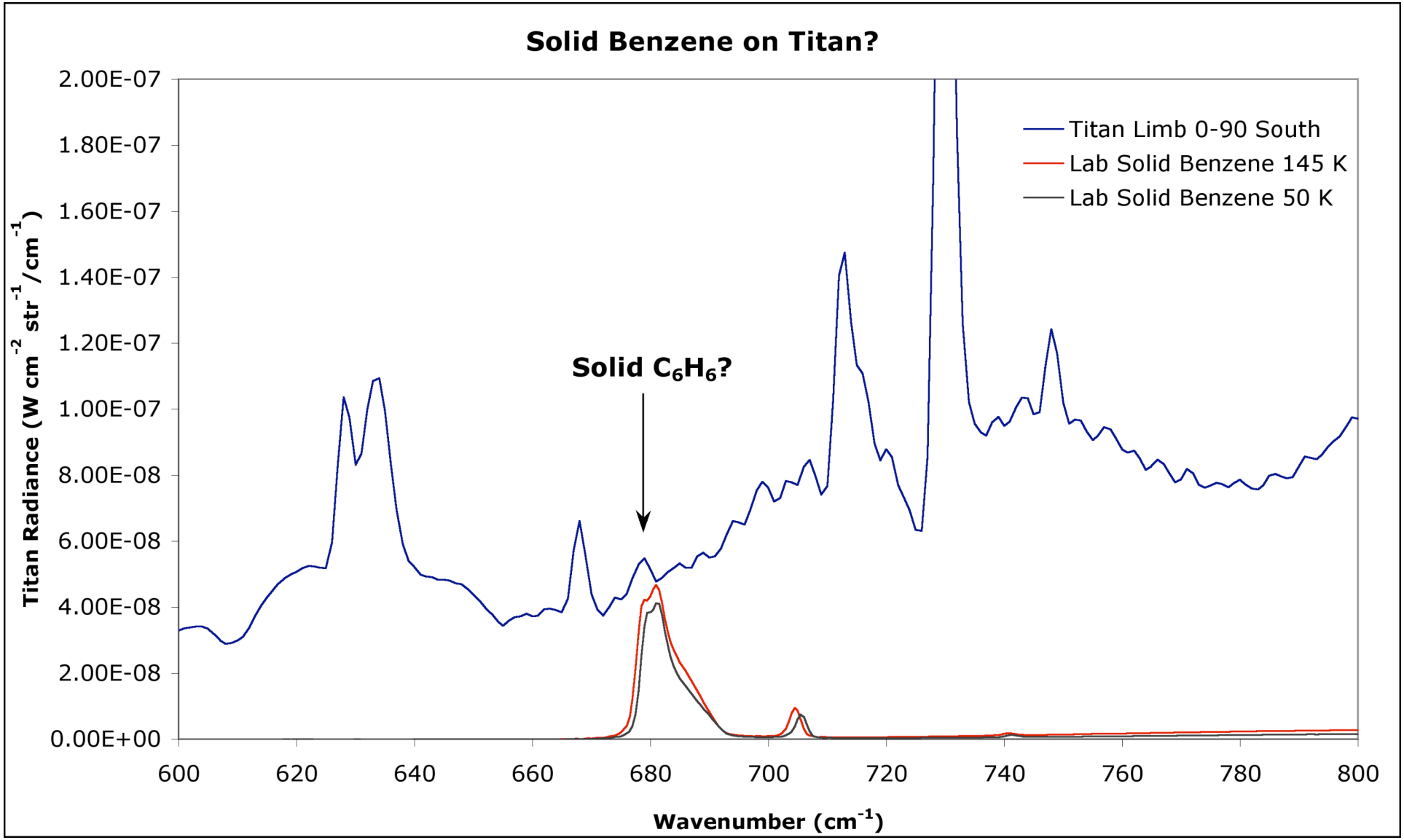

Solid Benzene on Titan?
Titan Limb 0-90 South
Lab Solid Benzene 145 K
Lab Solid Benzene 50 K
Solid C_6H_6?
Titan Radiance (W cm^{-2} str^{-1}/cm^{-1})
2.00E-07
1.80E-07
1.60E-07
1.40E-07
1.20E-07
1.00E-07
8.00E-08
6.00E-08
4.00E-08
2.00E-08
0.00E+00
600
620
640
660
680
700
720
740
760
780
800
Wavenumber (cm^{-1})

Table 1. Some organics, as yet unobserved on Titan in the thermal IR, but potentially observable with CIRS and their deduced upper limits in Titan's atmosphere from previous observations

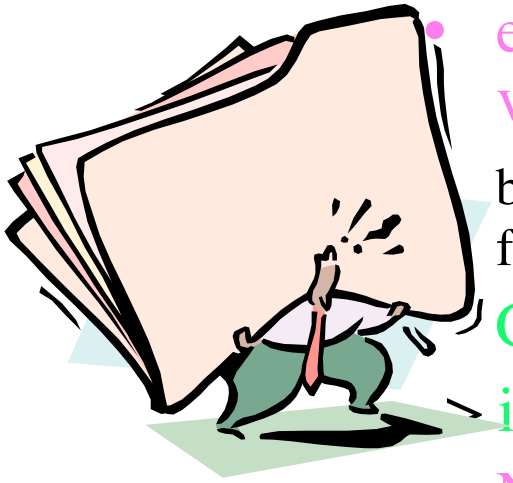
Studied Compounds	***Strongest signatures***		***Upper limit of mean mixing ratio in Titan's stratosphere***	
	Frequency (cm^{-})	*Band strength at 300 K (cm^{-2} atm^{-1})*	*using Voyager IRIS spectra*	*using ISO disk-average data*
Hydrocarbons				
CH_2CCH_2	356 845	65 407	5×10^{-9} *(a)*	2×10^{-9} *(b)*
C_4H_4	629	288	7×10^{-10} *(c)*	
C_6H_2	622	428	4.4×10^{-10} *(d)*	
C_8H_2	621.5	496	4×10^{-10} *(e)*	
Nitriles				
CH_3CN	362†	4.4		
CH_2CHCN	230 954	10 100	8.4×10^{-8} *(g)*	$< 5\times10^{-10}$ *(b)*
CH_3CH_2CN	207 1075	15 37	2.5×10^{-7} *(a)*	$< 1\times10^{-10}$ *(b)*
$CH_3CH_2CH_2CN$	728/742	3.5	5×10^{-7} *(a)*	
$(CH_3)_2CHCN$	538	3.3	2×10^{-7} *(a)*	
Δ CN	726 818	19 34	1.5×10^{-7} *(a)*	
CH_3CCCN	338 499	100 91	1.0×10^{-8} *(a)*	
$CH_3CHCHCN$	728	230	2.5×10^{-7} *(a)*	$< 5\times10^{-10}$ *(b)*
CH_2CHCH_2CN	557 942	64 110	4×10^{-8} *(h)*	$< 5\times10^{-10}$ *(b)*
$CH_2C(CH_3)CN$	535 928	33 130	7.5×10^{-8} *(h)*	$< 5\times10^{-10}$ *(b)*
C_4N_2	614	34.4	5.6×10^{-9} *(i)*	
NCCHCHCN (trans)	947	178	1×10^{-8} *(j)*	
Other N organics				
CH_3NC	526	8.8	1.3×10^{-9} *(k)*	
CH_2N_2	419	144	5.0×10^{-9} *(k)*	
CH_3N_3	250	9	5.4×10^{-9} *(k)*	

† Feature not yet observed. CH_3CN detected in millimeter observations (l), with a derived mole fraction 1.5×10^{-9} at 1 mbar.

From Flasar et al., 2004

Cassini/CIRS :what to do next

Work in progress:



- evolution of the N-S asymmetry and meridional variations

be fun to see if we find similar results as Voyager in 4 years from now (will be almost a full Titan year since 1980)

GET MORE DATA AT HIGH LATITUDES

-> interpretation: dynamics, seasonal effects, GCM

- New atmospheric species : benzene, allene, higher hydrocarbons (C6H2…) and nitriles (HC5N…)

-> Highest degree of chemical complexity

- Isotopes : D/H, 14N/15N, 12C/13C

-> Titan's formation and evolution

- Vertical profiles for species with intense lines
- (C2H2, C2H6, etc…)

->photochemical models