10ο Συνέδριο της Ελληνικής
Αστρονομικής Εταιρείας (ΕΛ.ΑΣ.ΕΤ.)
5-8 September 2011

TEMPORAL VARIATIONS RELATED TO TITAN'S ATMOSPHERE AFTER ONE YEAR

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[4]Dept. of Astronomy, Univ. of Maryland, College Park;
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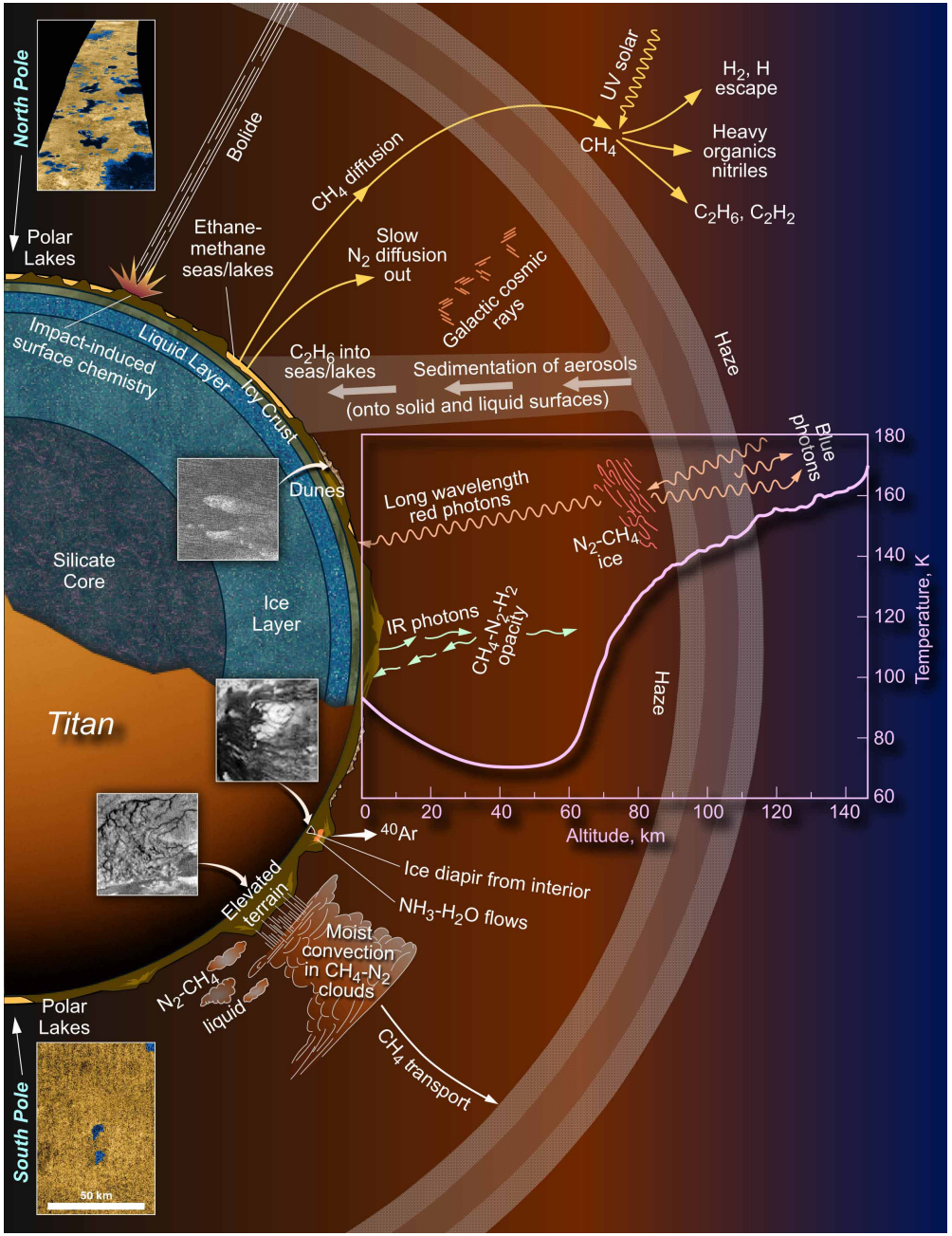
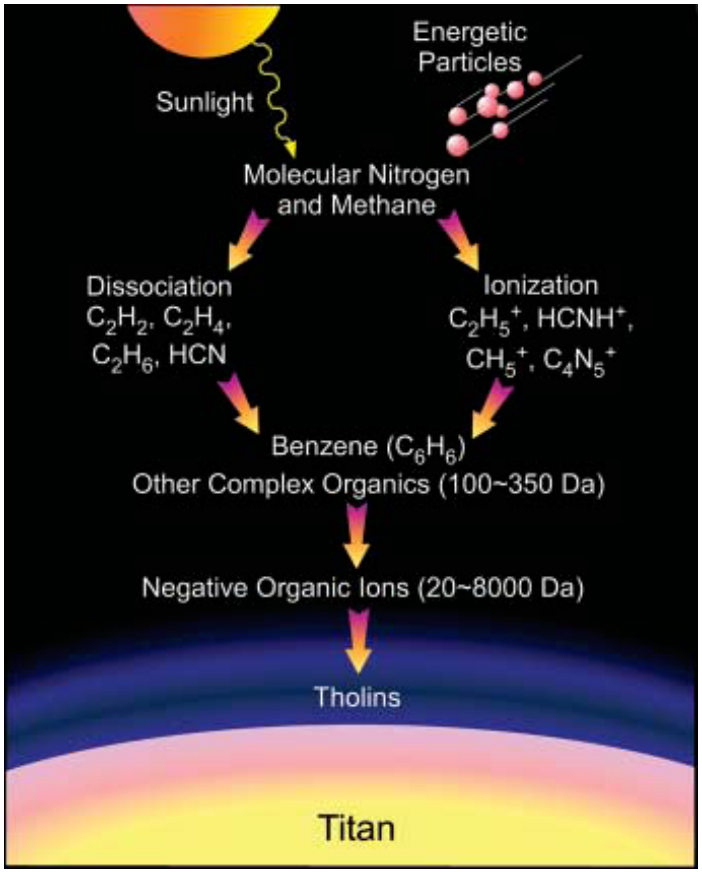
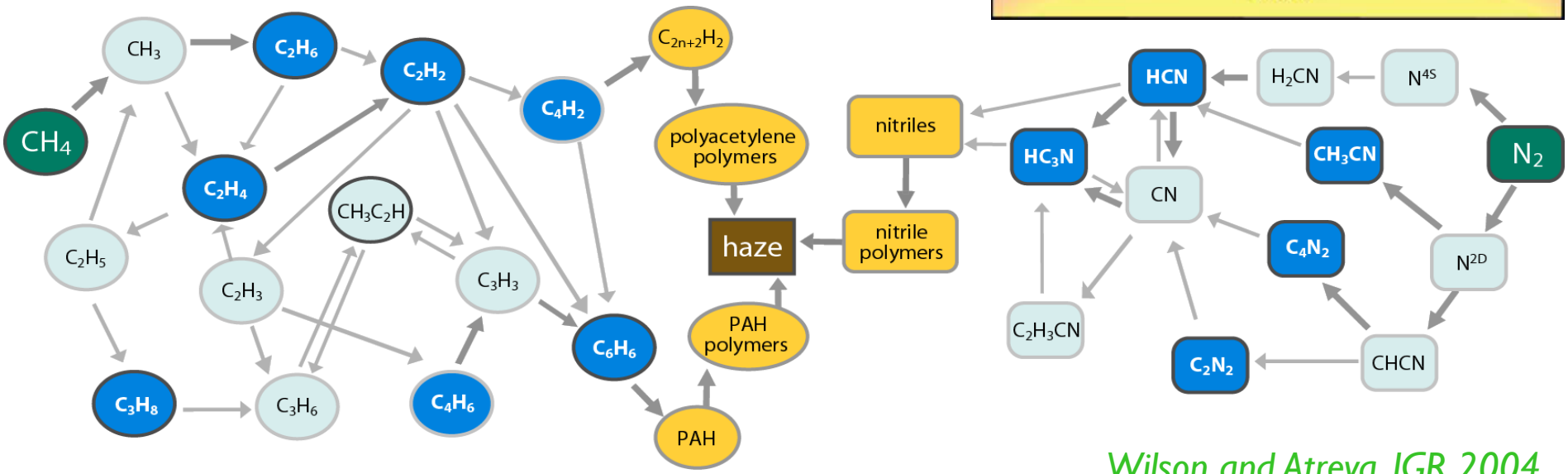
Titan: a world of high interest for planetology and astrobiology studies



Organic chemistry on Titan

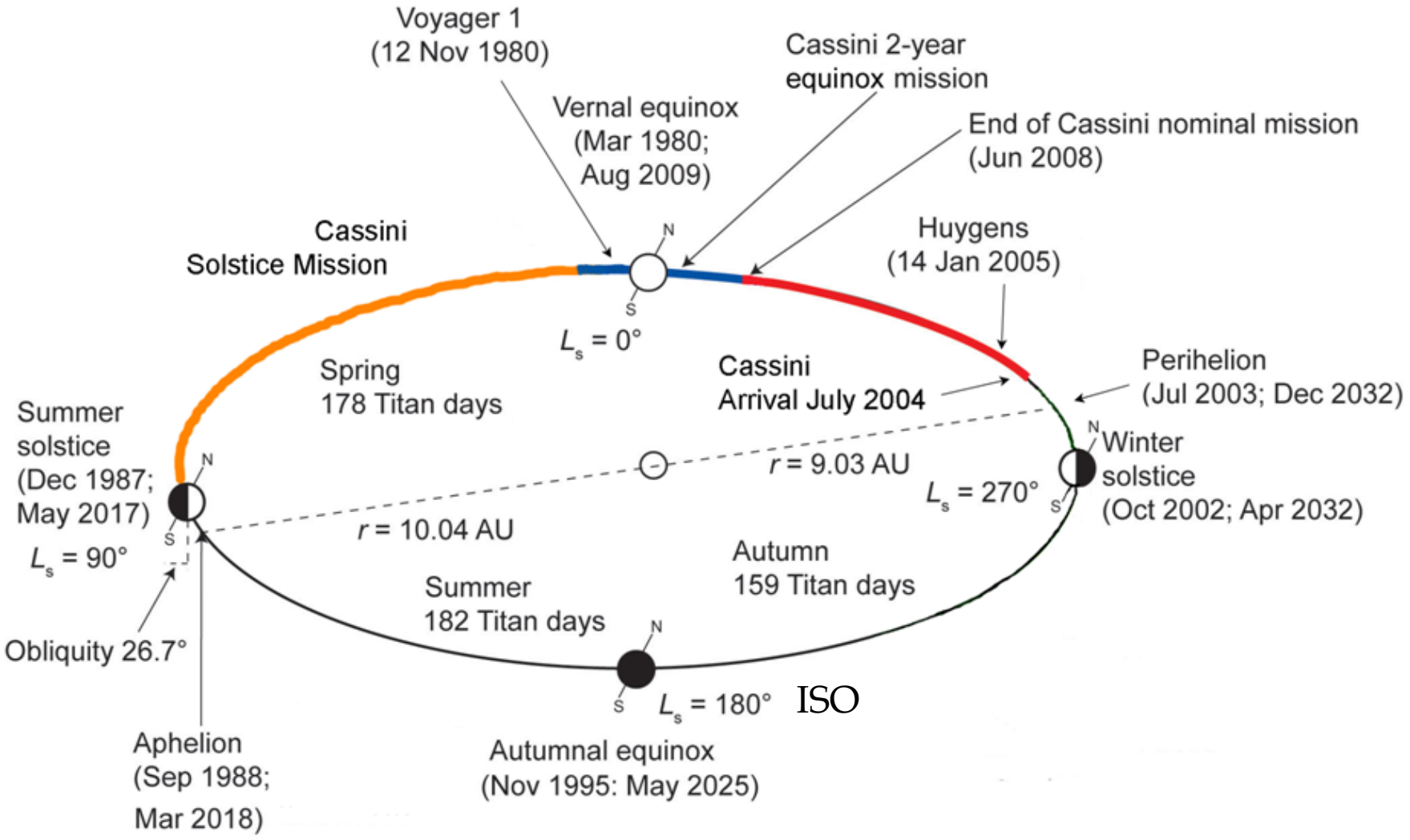


Cassini/INMS on Titan: Waite et al (2006)



Wilson and Atreya, JGR 2004

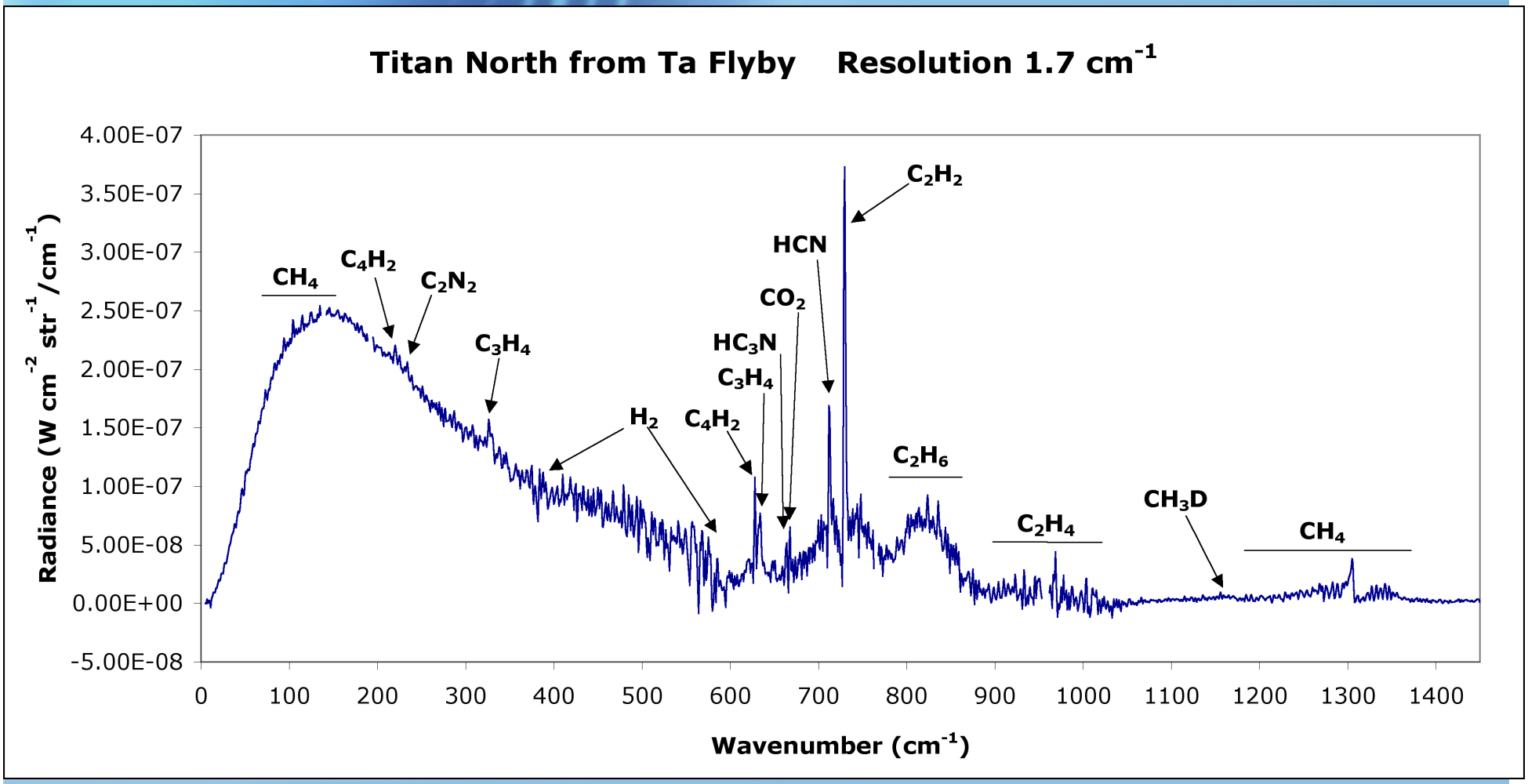
TEMPORAL COVERAGE



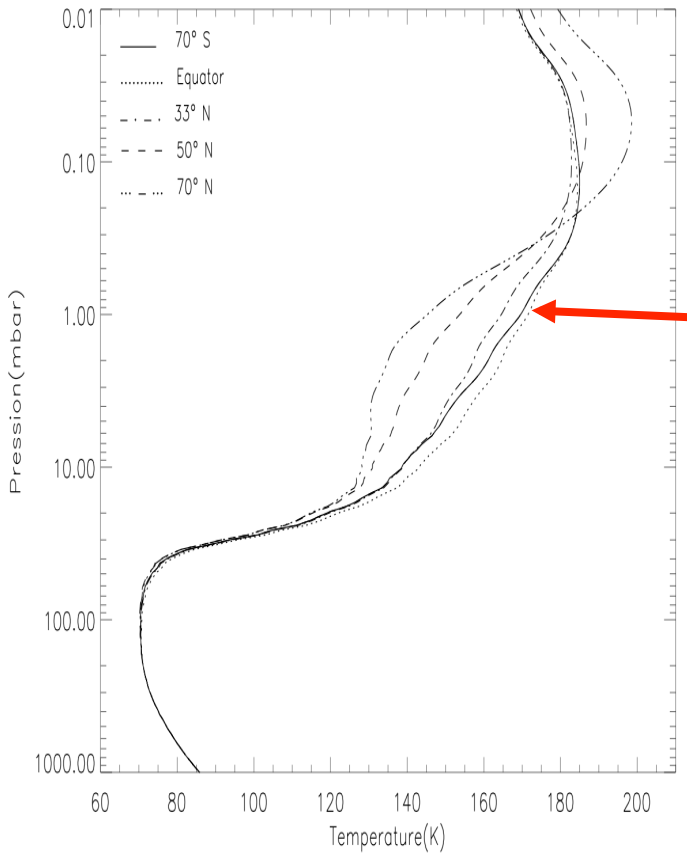
R. Lorenz

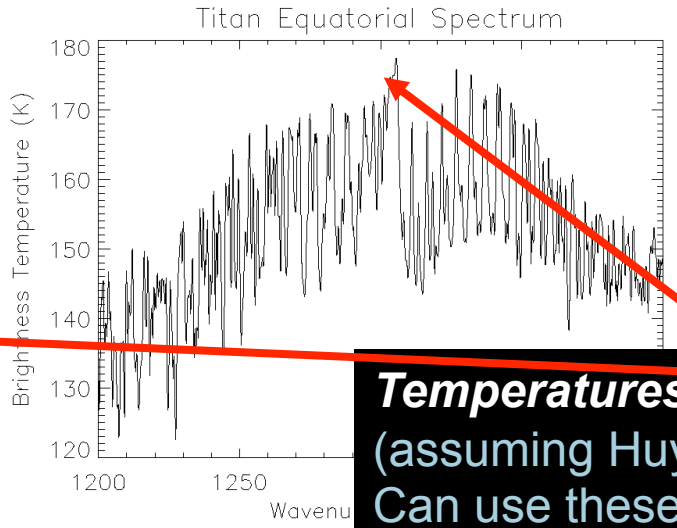
FIT TO THE DATA , T PROFILE, CHEMICAL COMPOSITION

Cassini-CIRS Ta at Titan



Spectral Modelling

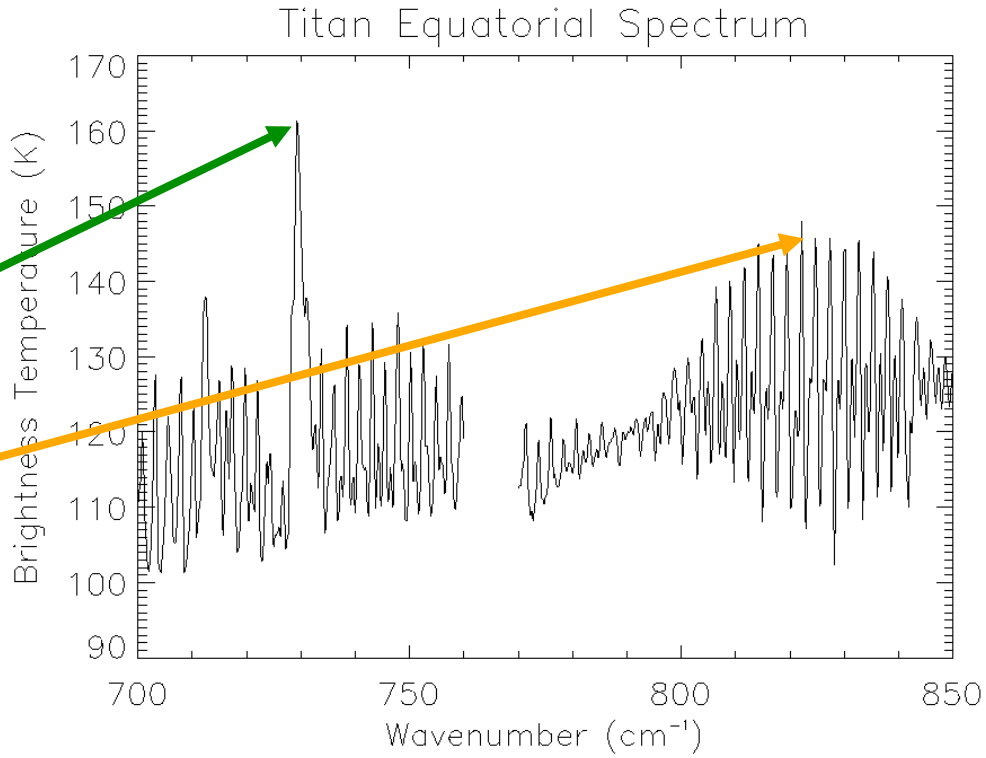




Temperatures from CH_4 ν_4 band (assuming Huygens VMR profile). Can use these to measure…

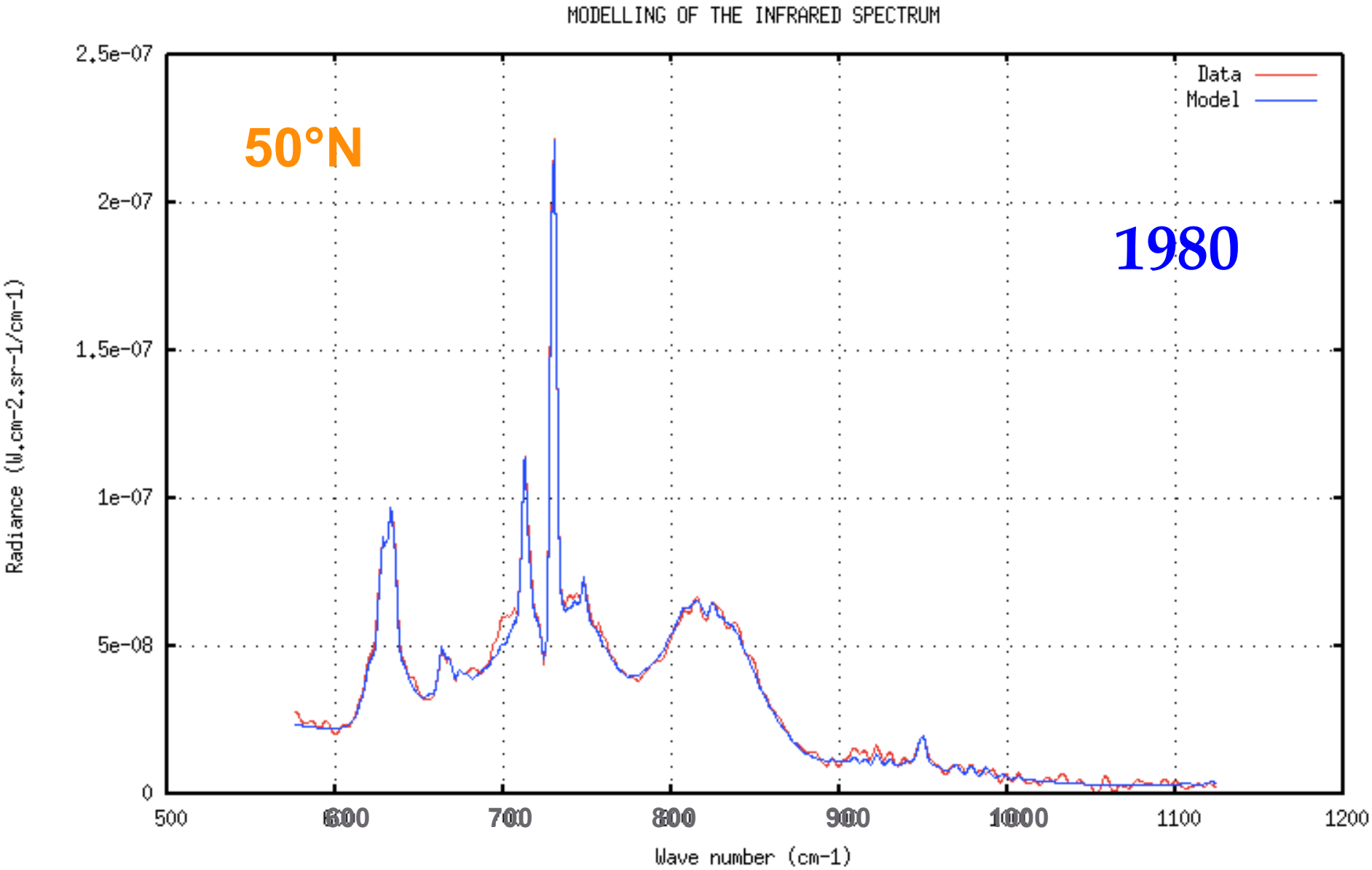
Abundances from emission bands of $^{13}CH_4$, C_2H_2, $^{13}C^{12}CH_2$, C_2H_6, $^{13}C^{12}CH_6$

- allows calculation of isotopic ratios.



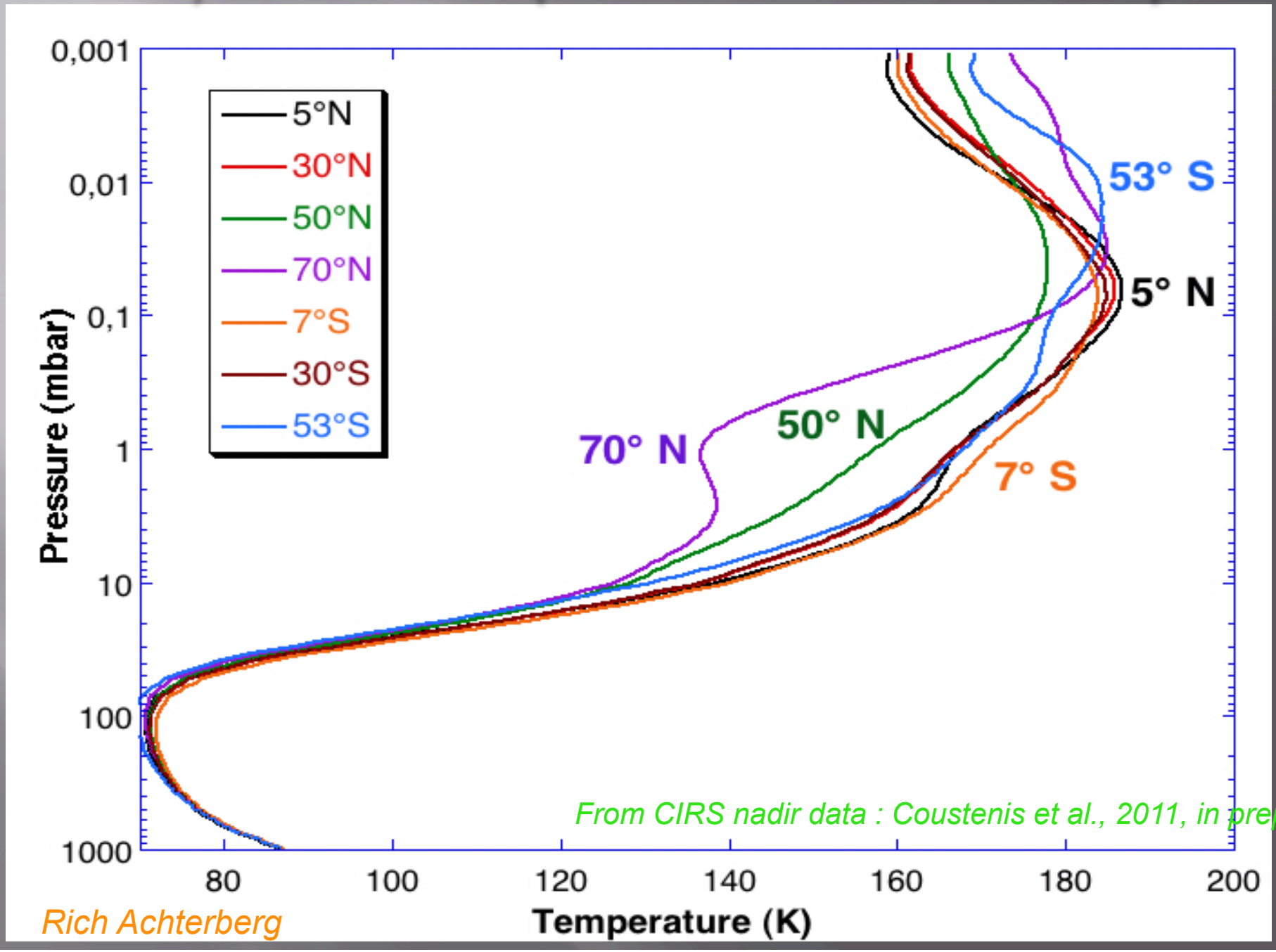
TEMPORAL VARIATIONS OF STRATOSPHERIC TEMPERATURES AND ABUNDANCES

Re-analysis of the V1/IRIS data



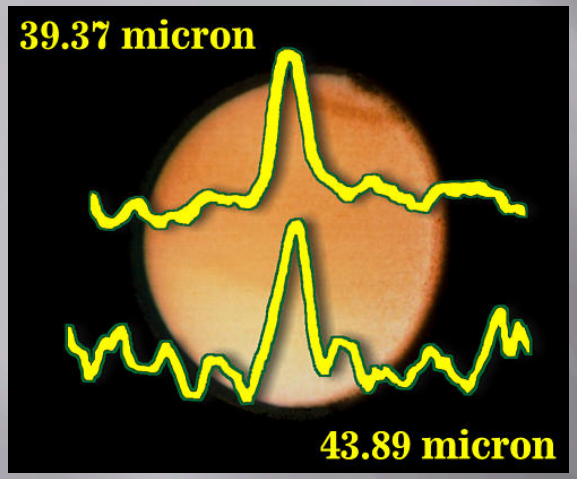
From V1/IRIS re-analysis :
Coustenis et al., 2011, in prep.

Re-analysis of the V1 profiles of Titan's stratosphere



Discoveries on Titan in 1997 by the Infrared Space Observatory (ISO)

A. Coustenis, A. Salama, B. Schulz, E. Lellouch, Th. Encrenaz, S. Ott, M. Kessler, Th. De Graauw, the ISO Titan Team

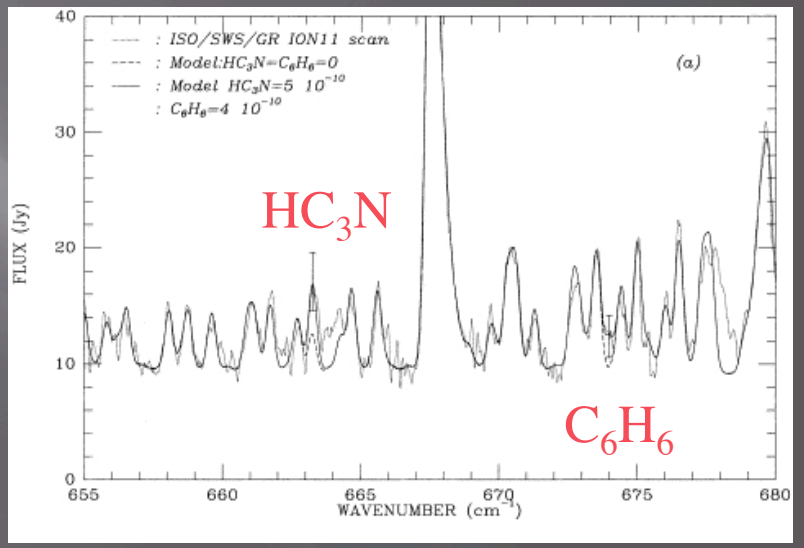


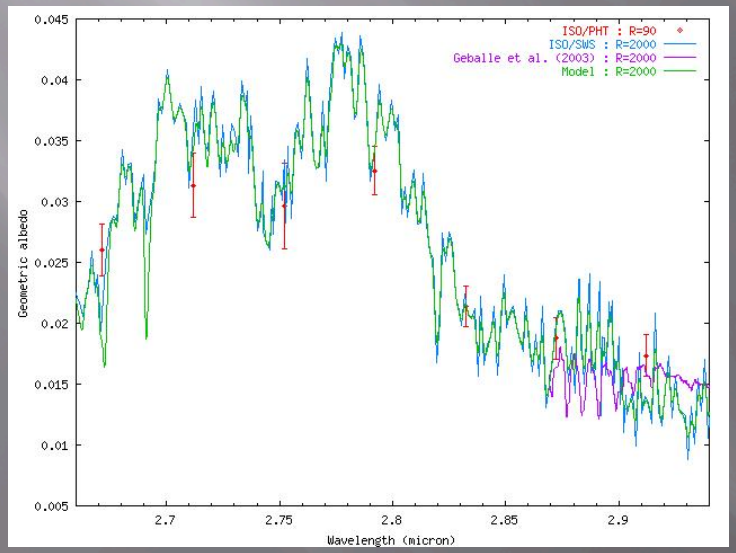
Water vapour

(Coustenis et al., 1998)

Benzene (C_6H_6)

(Coustenis et al., 2003)





First surface albedo spectrum in the 3 micron methane window

(Coustenis et al., 2004-2005)

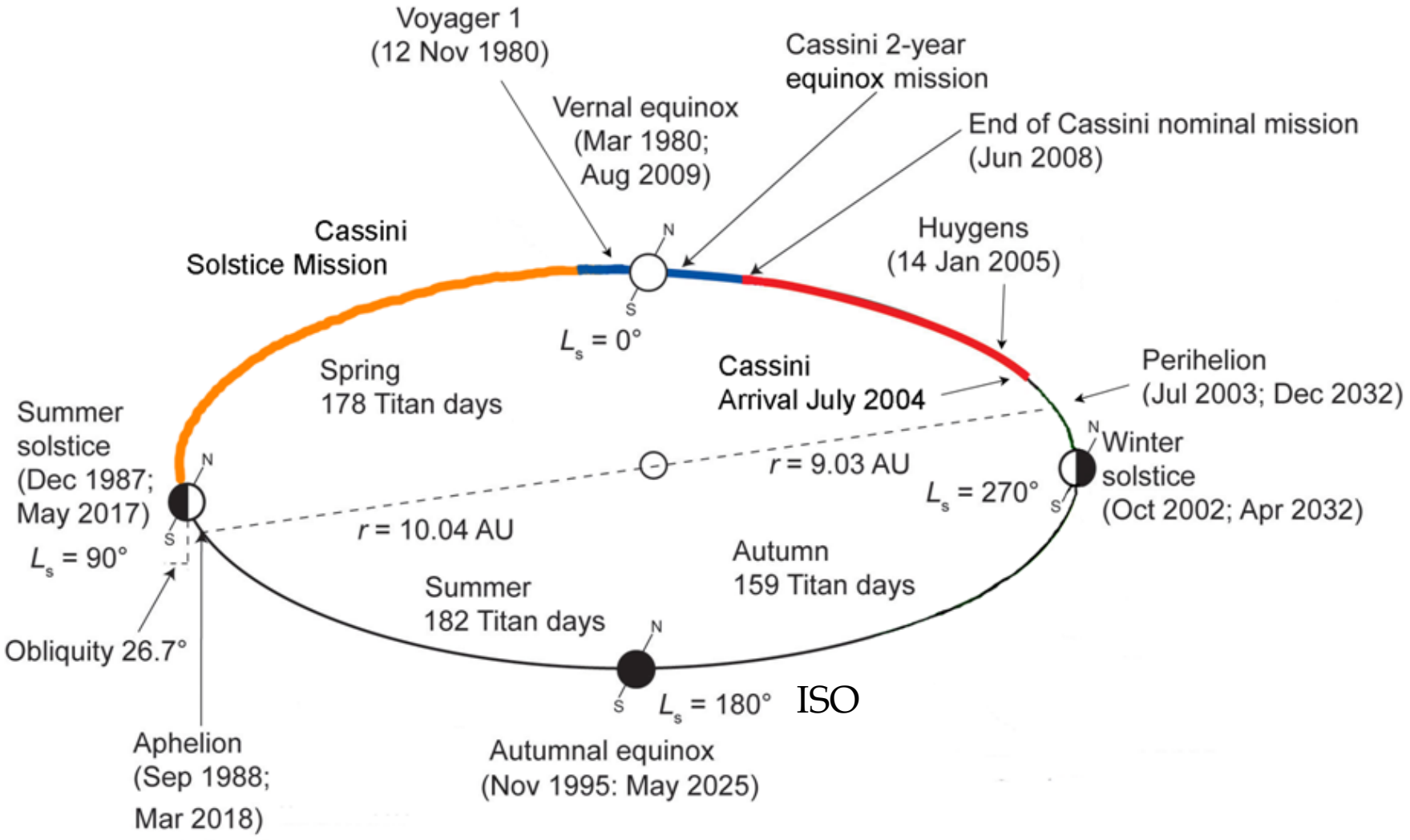
Ground-based data on Titan molecules

molecule	date	ls	abudance	altitude	latitude	instrument	reference
C2H2	10 January, 19 June, 27 December 1997	194, 200, 206	5,50E-06	stratosphere		iso	26
C2H4	24 september 1999, 18 october 2000, 22 february 2002	229, 243, 272	7,50E-06		south 60S	W.M. Keck I 10-meter telescope, Long Wavelength Spectrometer	15
	10 January, 19 June, 27 December 1997	194, 200, 206	1,20E-07	stratosphere		iso	26
C4H2	10 January, 19 June, 27 December 1997	194, 200, 206	2,00E-09	stratosphere		iso	26
C2H6	18 december 2003	286	3,00E-06	stratosphere	W 15N-40S	8.2-meter National Astronomical Observatory of Japan Subaru telescope on Mauna Kea, Hawaii	16
			9,00E-06		E 5N-50S		
			8,00E-06		w & E		
	august 1993	153 (152,98-153,93)	1,96E-05	stratosphere	center	IRTF	18
			5,80E-06		west		
	october 1995	179 (178,45-179,44)	1,17E-05		east		
			1,36E-05		west		
	september 1996	190 (189,64-190,65)	1,60E-05		east		
			5,20E-06		west		
	average	153-191	8,80E-06				
	10 January, 19 June, 27 December 1997	194, 200, 206	2,00E-05	stratosphere		iso	26
C3H8	13,14,20 december 2002		6,20E-07	90–250 km		texes/ IRTF	19
	10 January, 19 June, 27 December 1997	194, 200, 206	2,00E-07	stratosphere		iso	26
HCN	21,22,24 may 1995	174	3,50E-07	>200 km		IRAM 30-m telescope	25
	10 January, 19 June, 27 December 1997	194, 200, 206	3,00E-07	stratosphere		iso	26
	7-8 september 1986, 5-6 may 1987	76, 84	5,20E-06	300 km		IRAM 30-m telescope	24
	april 1996 - december 1999	185-232	4,00E-07	stratosphere		IRAM 30-m radio telescope at Pico Veleta	21
HC3N	15-17 may 1992	139	>1,0*10-7			IRAM 30-m radio telescope at Pico Veleta	30
	25-27 december 1992	146	>1,0*10-7			IRAM 30-m radio telescope at Pico Veleta	30
	april 1996 - december 1999	185-232	4,00E-08	stratosphere		IRAM 30-m radio telescope at Pico Veleta	21
	10 January, 19 June, 27 December 1997	194, 200, 206	5,00E-10	stratosphere		iso	26
C3H4	10 January, 19 June, 27 December 1997	194, 200, 206	1,20E-08	stratosphere		iso	26
CO2	10 January, 19 June, 27 December 1997	194, 200, 206	2,00E-08	stratosphere		iso	26
C6H6	10 January, 19 June, 27 December 1997	194, 200, 206	4,00E-10	stratosphere		iso	26

15	roe 2004 (icarus)
16	kostiuk 2005 (grl)
18	livengood 2002 (icarus)
19	roe 2003 (aj)
21	marten 2002 (icarus)
24	tanguy 1990 (icarus)
25	hidayat 1997 (icarus)
26	coustenis 2003
30	bezard 1992

AK

TEMPORAL COVERAGE



R. Lorenz

Temperature and chemical composition meridional variations in the stratosphere with Cassini/CIRS

Gas		Mole fraction		Comments-Ref.
Major components				
Nitrogen	N_2	0.97		Inferred indirectly
Methane	CH_4	$1.4\text{-}1.8\times10^{-2}$		Stratosphere (1,2)
		4.9×10^{-2}		Surface (2,3)
Monodeuterated methane	CH_3D	8×10^{-6}		(4)
Hydrogen	H_2	0.0011		(5)
Argon	^{36}Ar	2.8×10^{-7}		(2)
	^{40}Ar	4.32×10^{-5}		(2)
		Equator	*North Pole*	
Hydrocarbons				
Ethane	C_2H_6	1.3×10^{-5}	1.7×10^{-5}	(4)
Acetylene	C_2H_2	3.7×10^{-6}	4.0×10^{-6}	(4)
Monodeuterated acetylene	C_2HD	2×10^{-9}		
Propane	C_3H_8	6.0×10^{-7}	8.0×10^{-7}	(4)
Ethylene	C_2H_4	1.6×10^{-7}	1.1×10^{-7}	(4)
Methylacetylene	C_3H_4	6.4×10^{-9}	1.2×10^{-8}	(4)
Diacetylene	C_4H_2	1.3×10^{-9}	4.2×10^{-9}	(4)
Benzene	C_6H_6	3.0×10^{-10}	1.1×10^{-9}	(4)
Nitriles				
Hydrogen cyanide	HCN	1.3×10^{-7}	5.5×10^{-7}	(4,6)
Cyanoacetylene	HC_3N	3.0×10^{-10}	2.2×10^{-9}	(4)
Cyanogen	C_2N_2	5×10^{-10}	9×10^{-10}	(6)
Dicyanogen	C_4N_2			Solid form only (7)
Acetonitrile	CH_3CN	1.5×10^{-9}		(8)
Oxygen compounds				
Water vapor	H_2O	8×10^{-9}		(9) at 400 km
Carbon dioxide	CO_2	1.5×10^{-8}	1.9×10^{-8}	(4)
Carbon monoxide	CO	$(2\text{-}4)\times10^{-5}$		Troposphere (10,11)
		$(3\text{-}6)\times10^{-5}$		Stratosphere (1,12)
Isotopic ratios				
$^{13}C/^{14}C$		82.3±1		(2)
$^{14}N/^{15}N$ in HCN		67		(11)
In N_2		183±5		(2)
D/H in CH_3D		1.3×10^{-4}		(4)
in HD		2.3×10^{-4}		(2)
in C2HD		1.7×10^{-4}		(4)

1. Flasar *et al.* (2005) from Cassini/CIRS data
2. Niemann et al. 2005 from Huygens/GCMS data
3. Tomasko et al. (2005) from Huygens/DISR data
4. Coustenis et al. (2007) from Cassini/CIRS data
5. Samuelson *et al.* (1997a) from V1/IRIS data
6. Teanby et al. (2006) from Cassini/CIRS data
7. Samuelson *et al.* (1997b) from V1/IRIS data
8. Bézard *et al.* (1993) from disk-averaged ground-based heterodyne mm observations
9. Coustenis *et al.* (1998) from ISO/SWS data
10. Lellouch *et al.* (2003) from ground-based VLT data at 5 micron
11. Marten *et al.* (2002) from disk-averaged ground-based heterodyne mm observations
12. Gurwell and Muhleman (2000) from disk-averaged mm heterodyne data

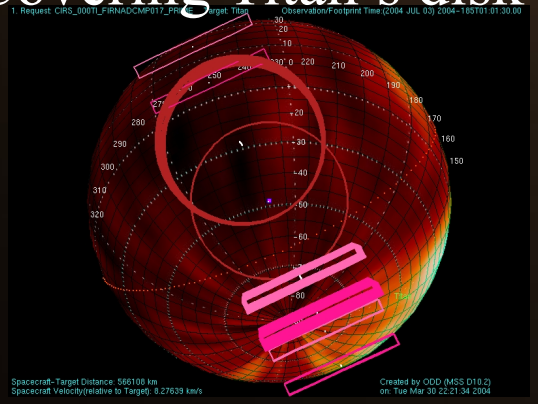
From Vuitton, Waite, et al. INMS

Ionospheric species detected by INMS	Neutral mole fractions
H_2	4×10^{-3}
CH_4	3×10^{-2}
C_2H_2	3×10^{-4}
C_2H_4	6×10^{-3}
C_2H_6	1×10^{-4}
C_4H_2	6×10^{-5}
HCN	2×10^{-4}
HC_3N	2×10^{-5}
CH_3CN	1×10^{-5}
C_2H_3CN	1×10^{-5}
C_2H_5CN	5×10^{-7}
NH_3	7×10^{-6}
CH_2NH	$<1\times10^{-5}$

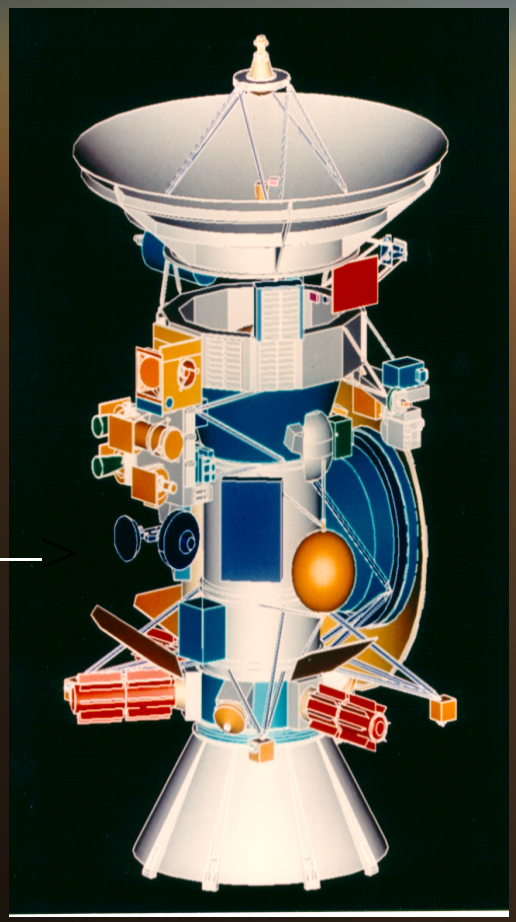
Coustenis & Taylor 2008 (WSP)

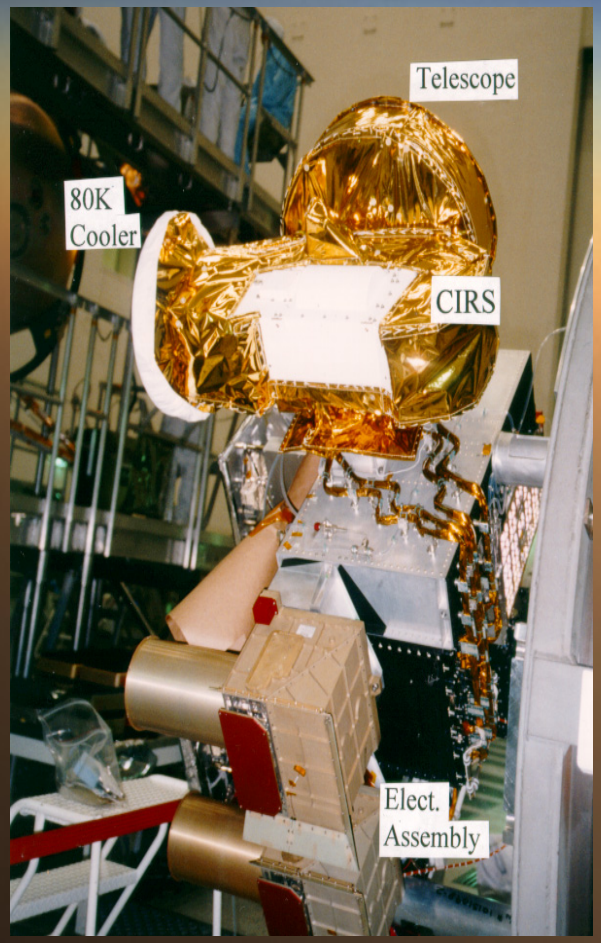
We have analyzed CIRS observations (nadir and limb) covering the thermal infrared region (10-1500 cm^{-1})

Since July 2, 2004 : TB-T62 flybys
FP3 and FP4 spectra
high resolution apodized (0.53 cm^{-1}) or medium resolution (2.5 cm^{-1})
Covering Titan's disk

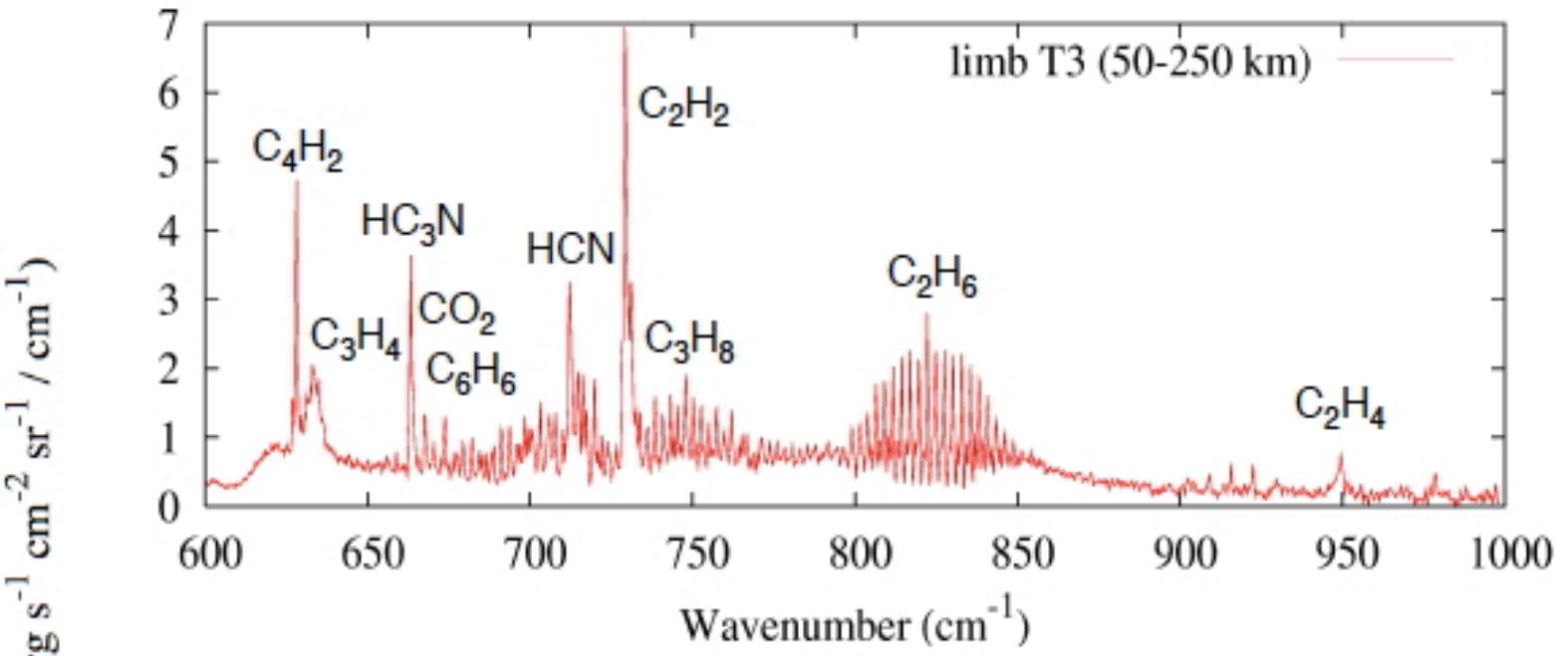


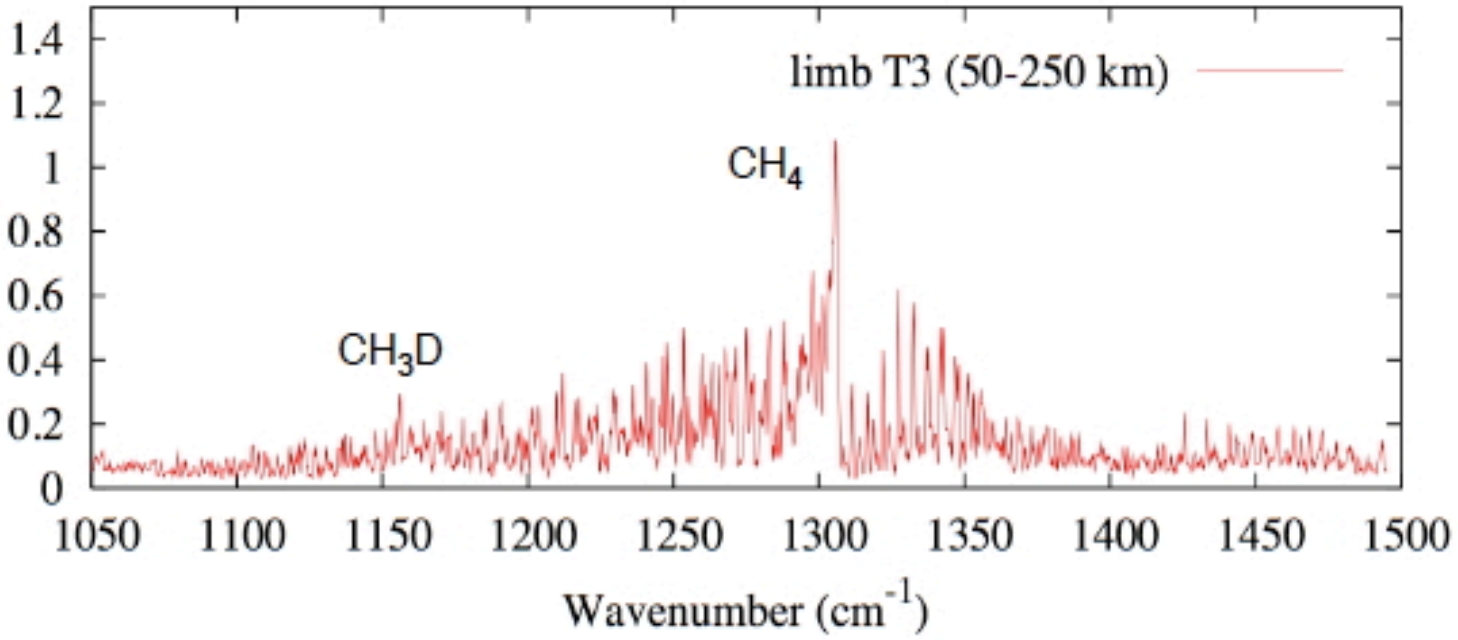
CIRS—>



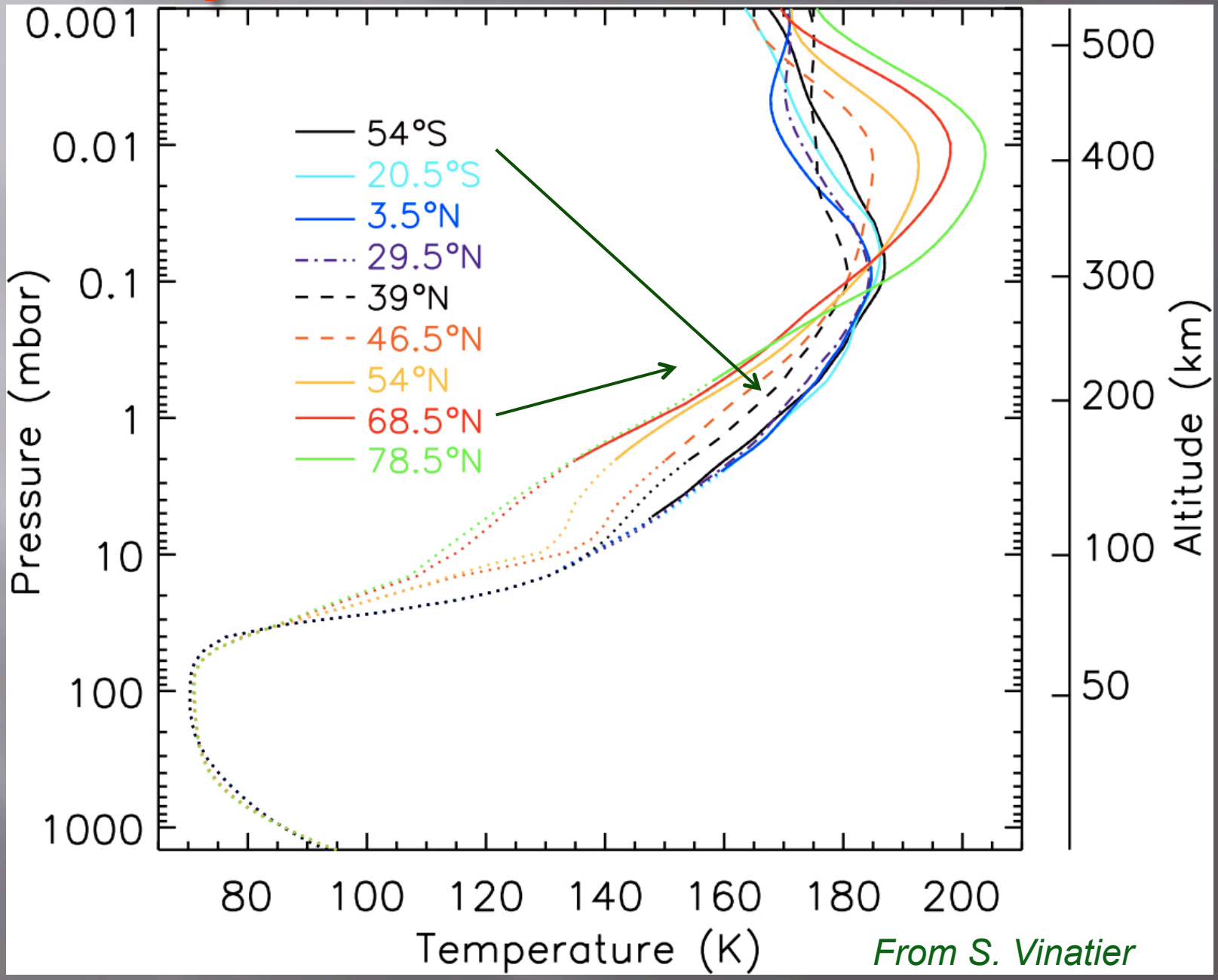


Titan

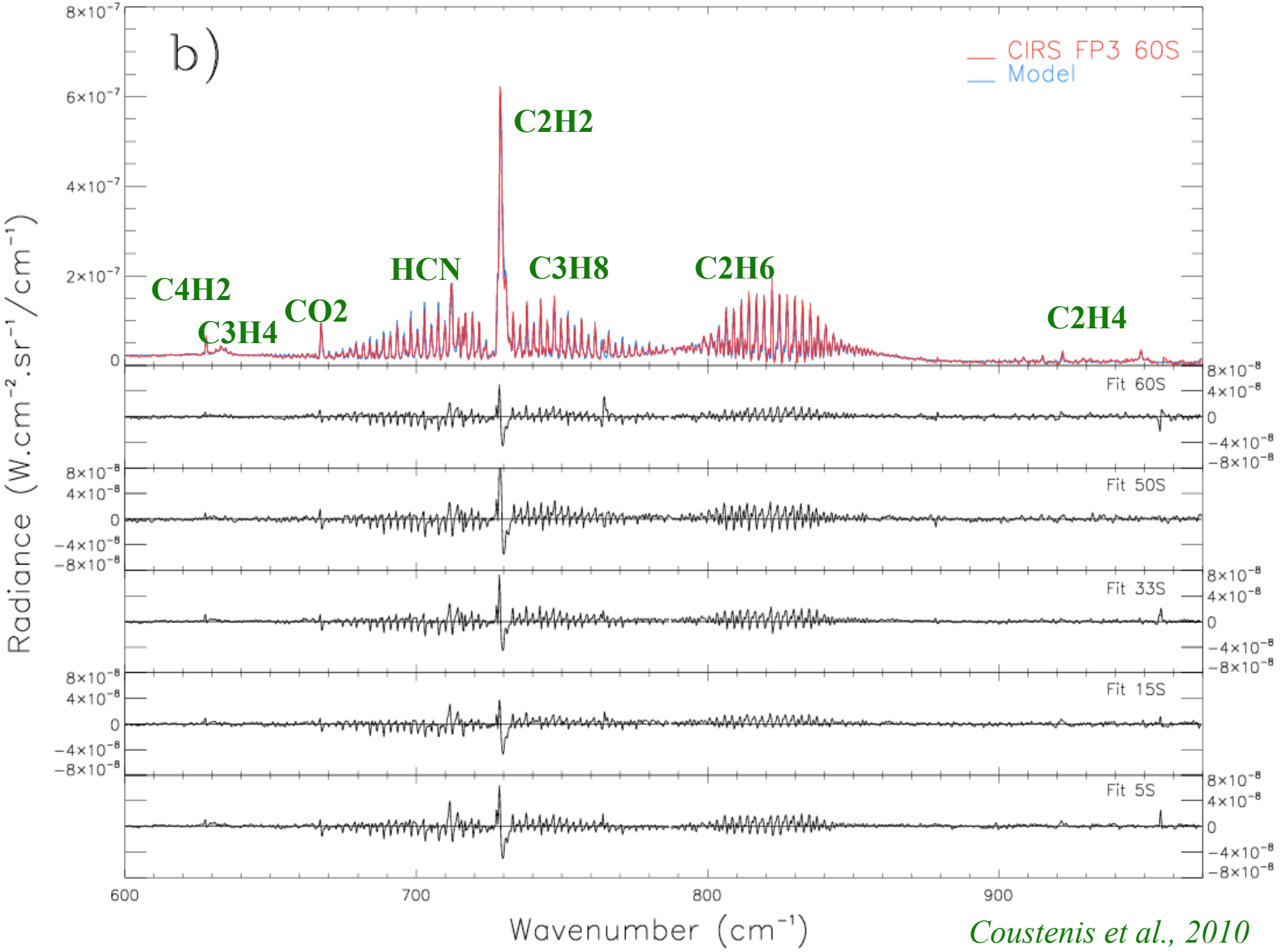

limb T3 (50-250 km)
C_4H_2
HC_3N
C_2H_2
HCN
C_2H_6
C_3H_4
CO_2
C_6H_6
C_3H_8
C_2H_4
Radiance (erg s^{-1} cm^{-2} sr^{-1} / cm^{-1})
Wavenumber (cm^{-1})
0
1
2
3
4
5
6
7
600
650
700
750
800
850
900
950
1000


limb T3 (50-250 km)
CH_4
CH_3D
Wavenumber (cm^{-1})
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1050
1100
1150
1200
1250
1300
1350
1400
1450
1500

T profiles from limb data

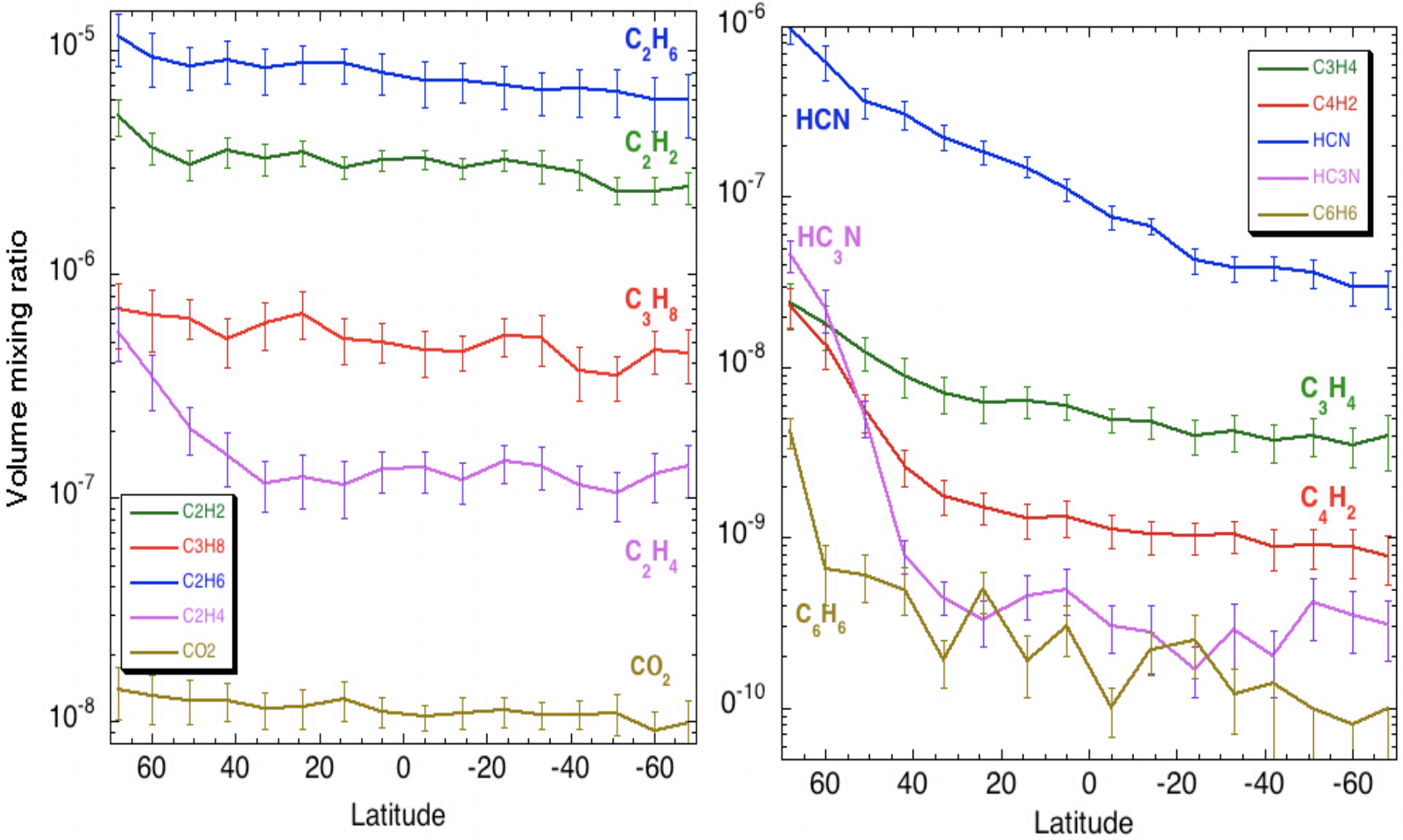


From S. Vinatier



Coustenis et al., 2010

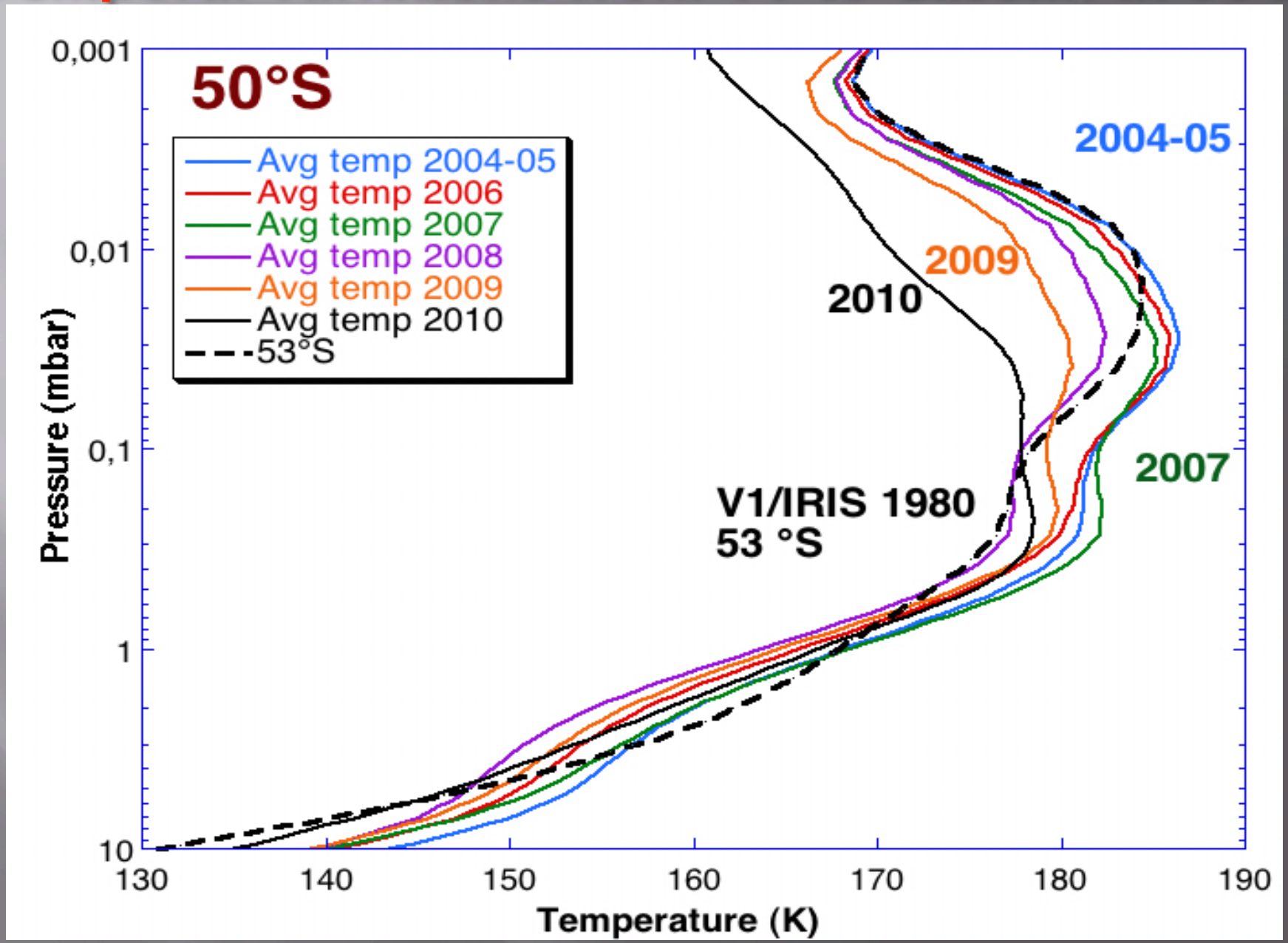
Meridional variations TB-T44 (mid 2008)



Strong increase in the North : HCN,HC3N,C3H4,C4H2,C2H4,C6H6
Small increase for: C2H2, C2H6

Coustenis et al. 2010

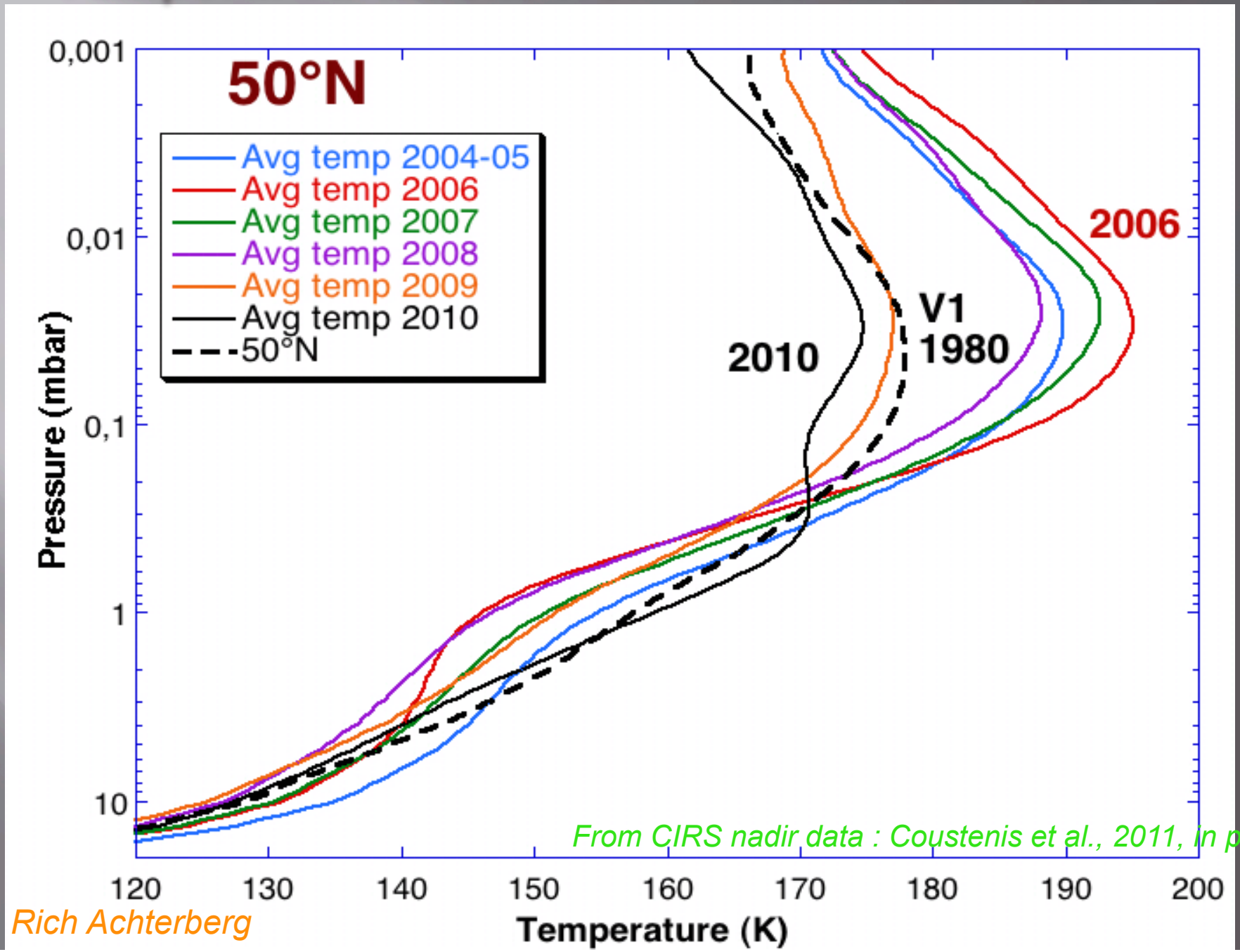
Temporal variations from V1 to Cassini at 50°S



From CIRS nadir data : Coustenis et al., 2011, in prep.

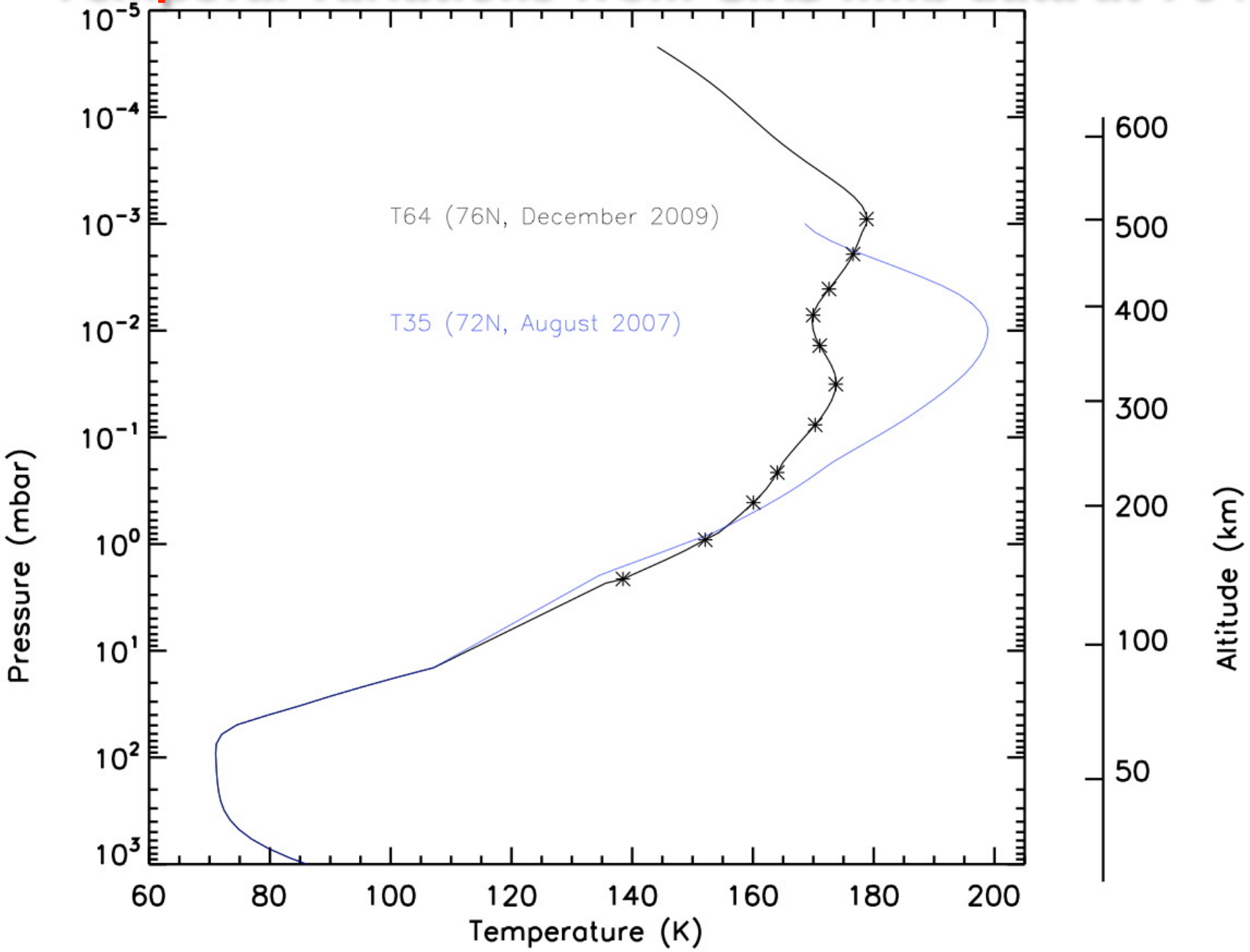
Rich Achterberg

Temporal variations from V1 to Cassini at 50°N



Rich Achterberg

Temporal variations from CIRS limb data at 70°N

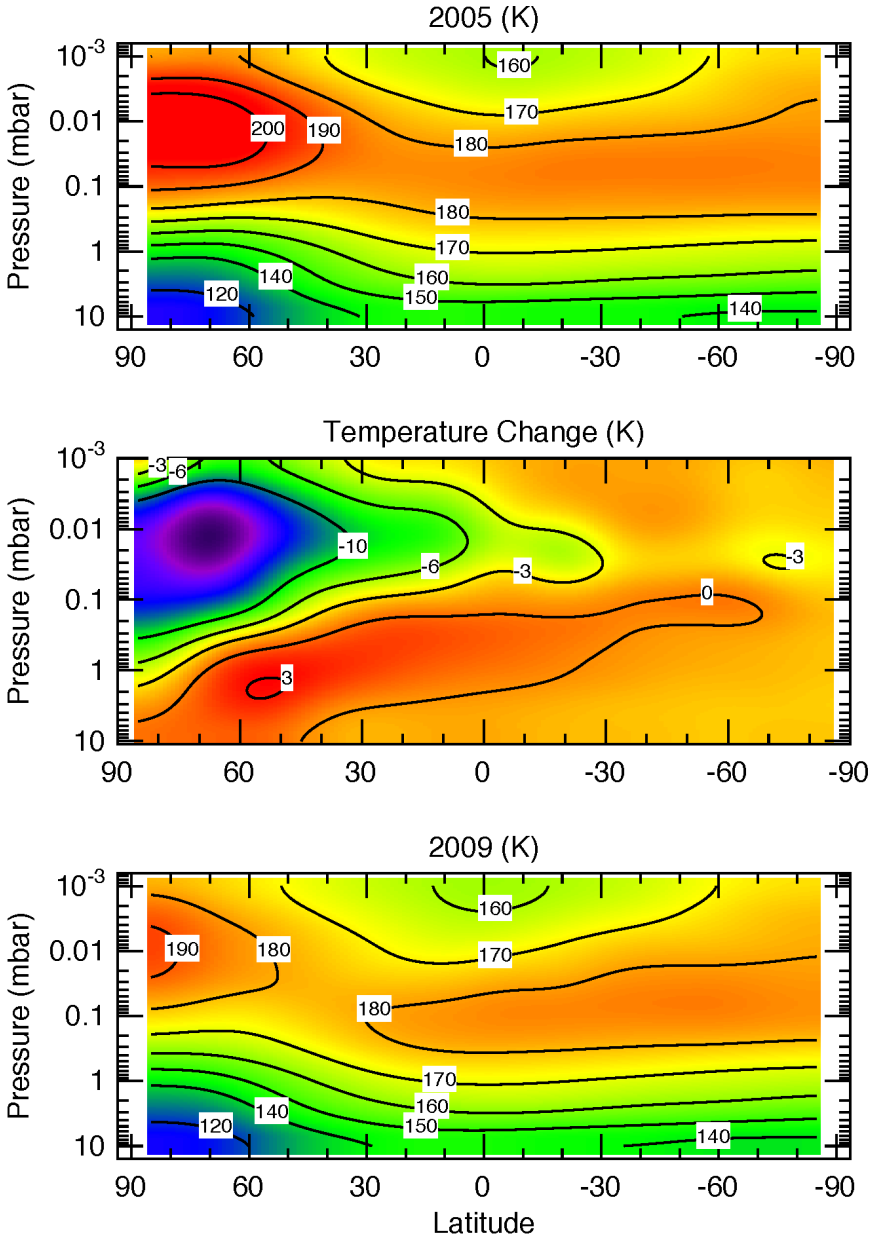


Sandrine Vinatier

From CIRS limb data : Coustenis et al., 2011, in prep.

Large scale changes in temperature from early and late in the Cassini mission, from both limb and nadir observations.

Achterberg et al., 2010

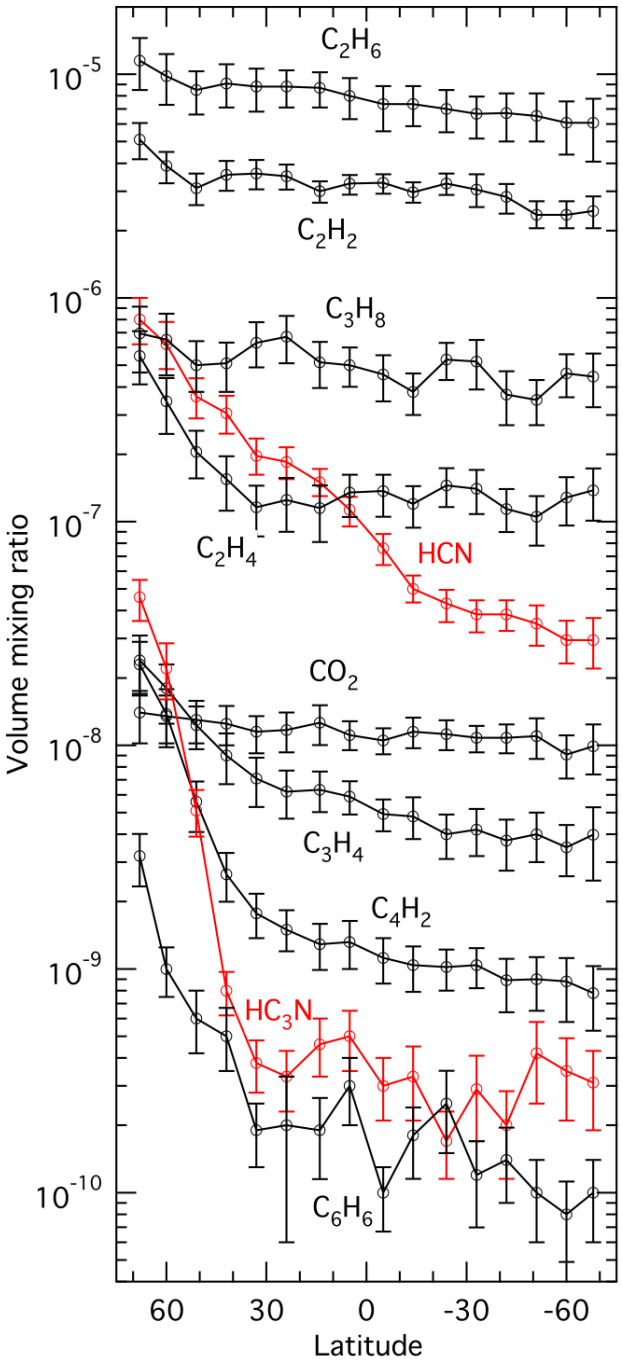


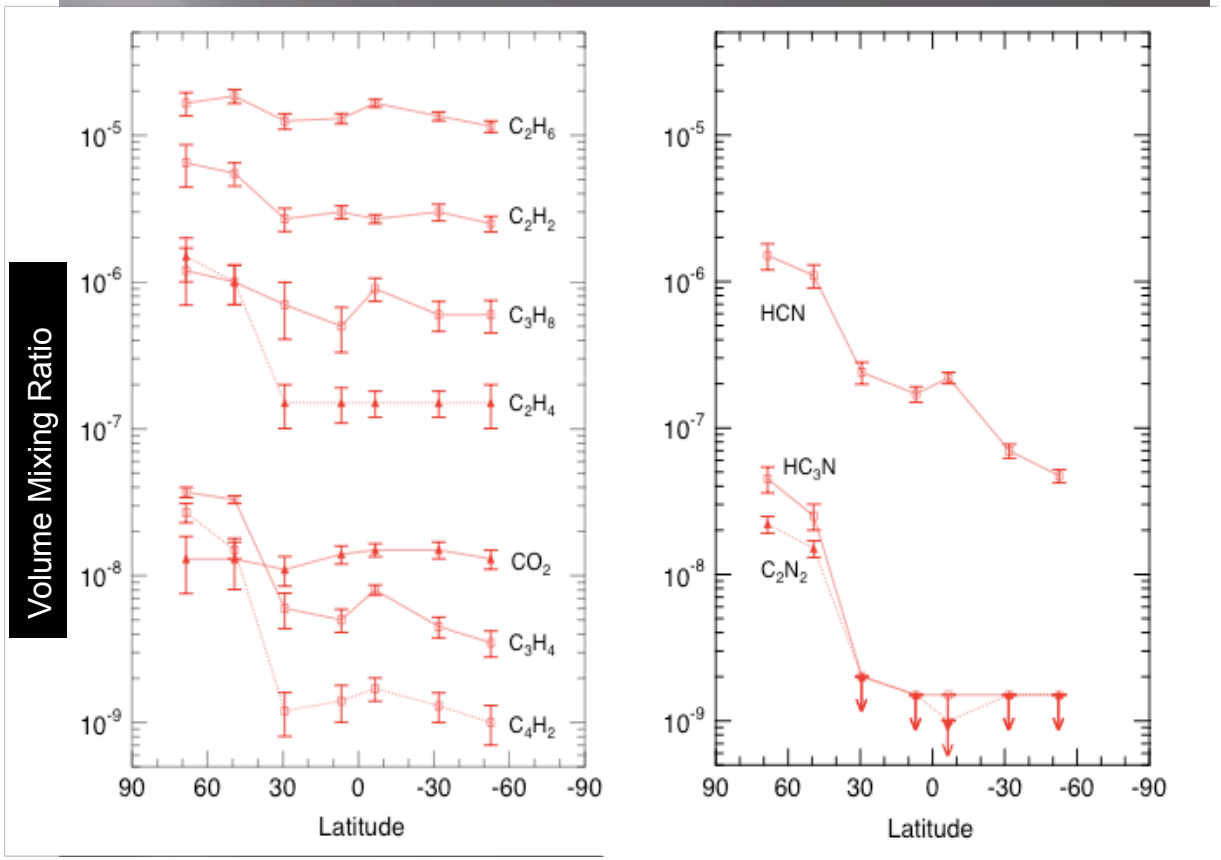
Titan

Cassini CIRS (2004-5):
Coustenis *et al.* (2007)
(N. winter)

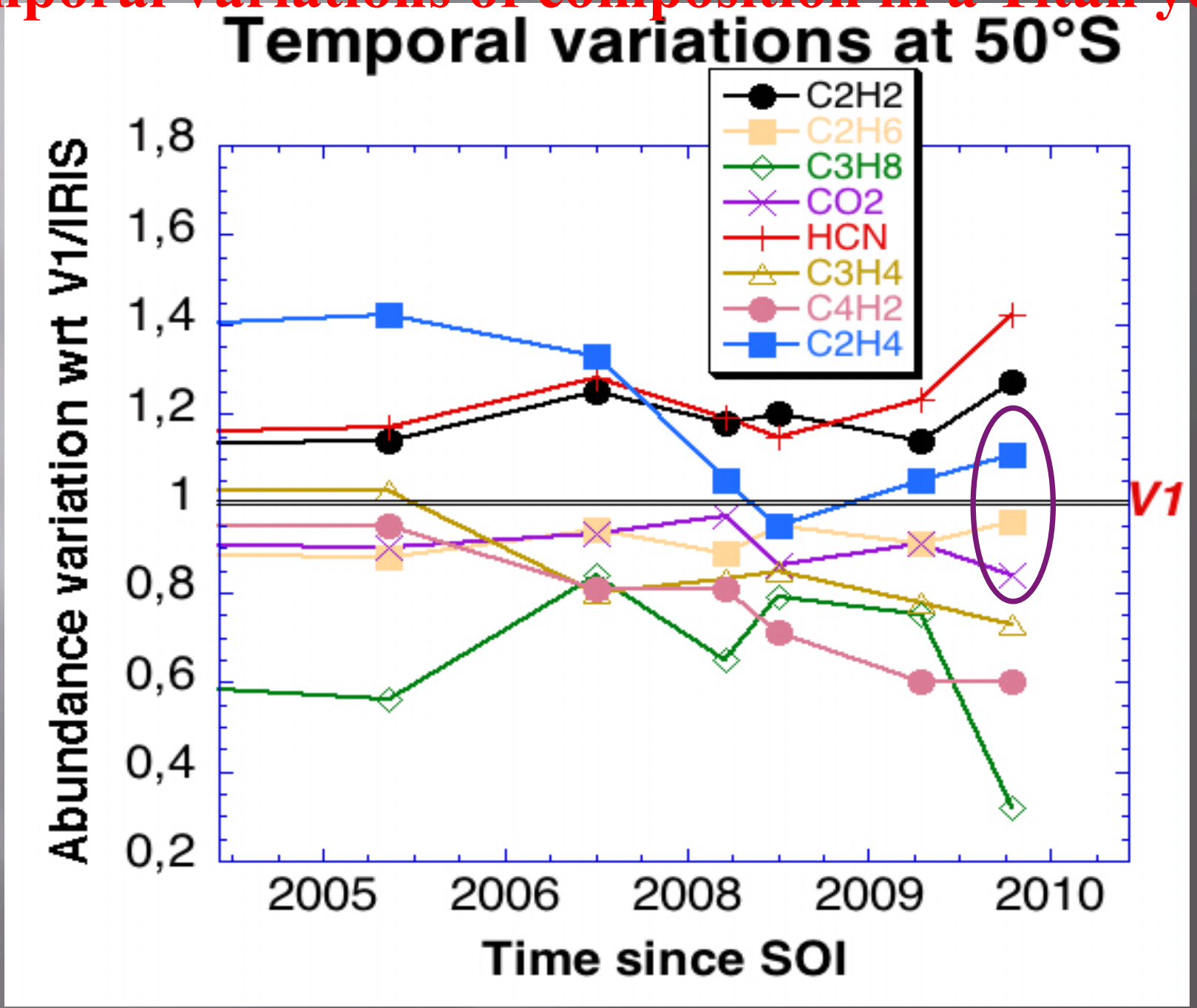
The enhancement at the North pole during Cassini is a factor of 1.5-5 smaller than at the time of the Voyager encounter

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

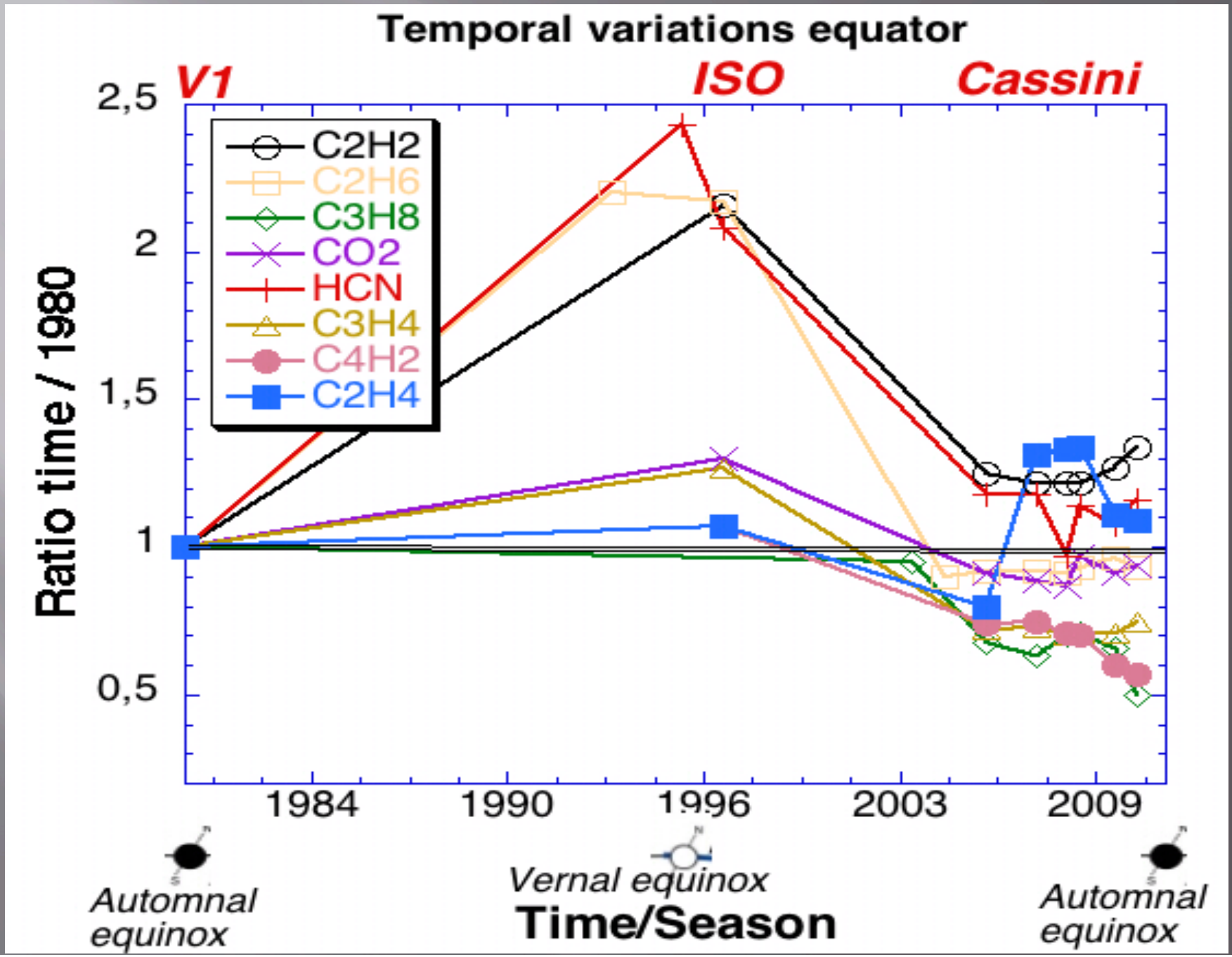




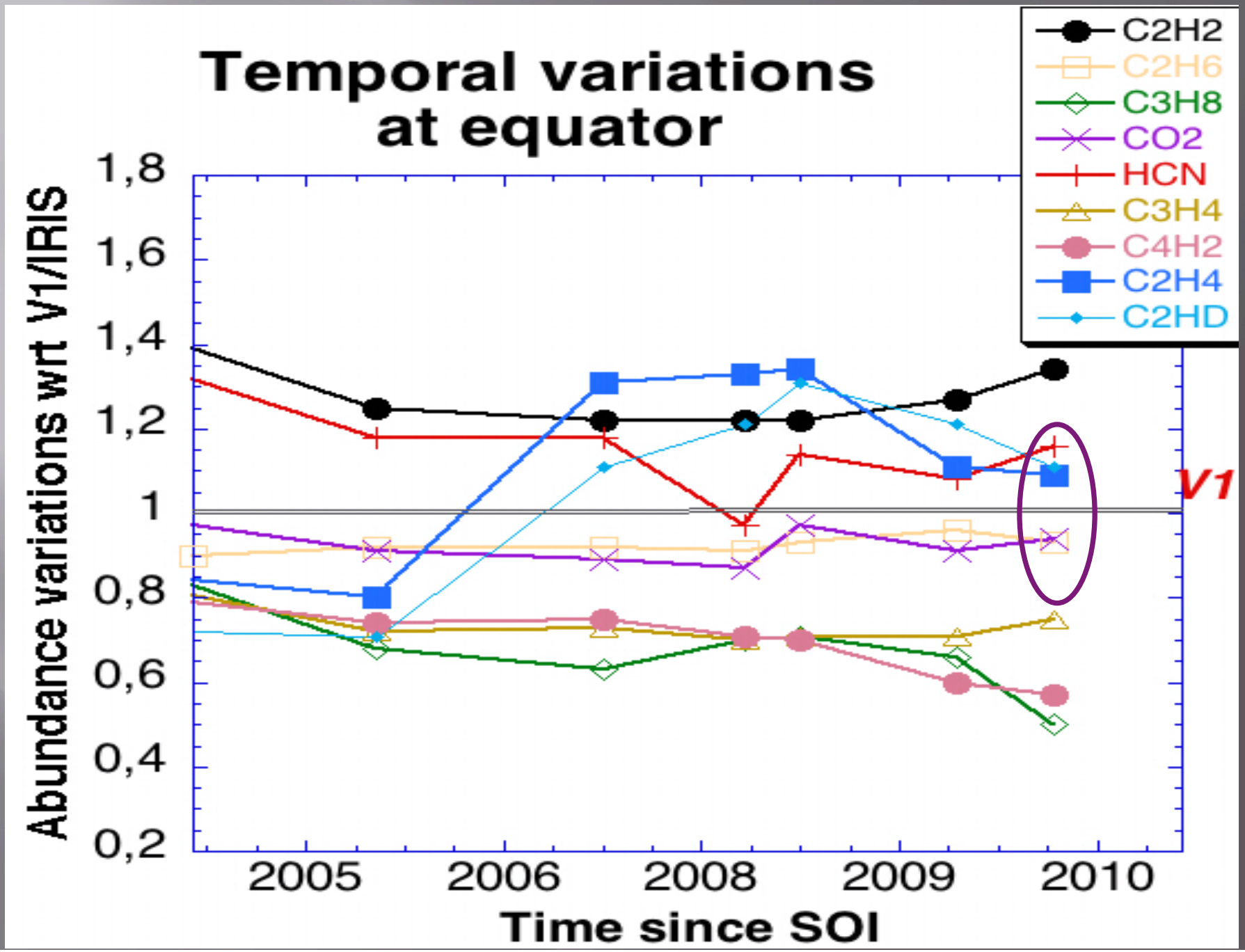
Temporal variations of composition in a Titan year



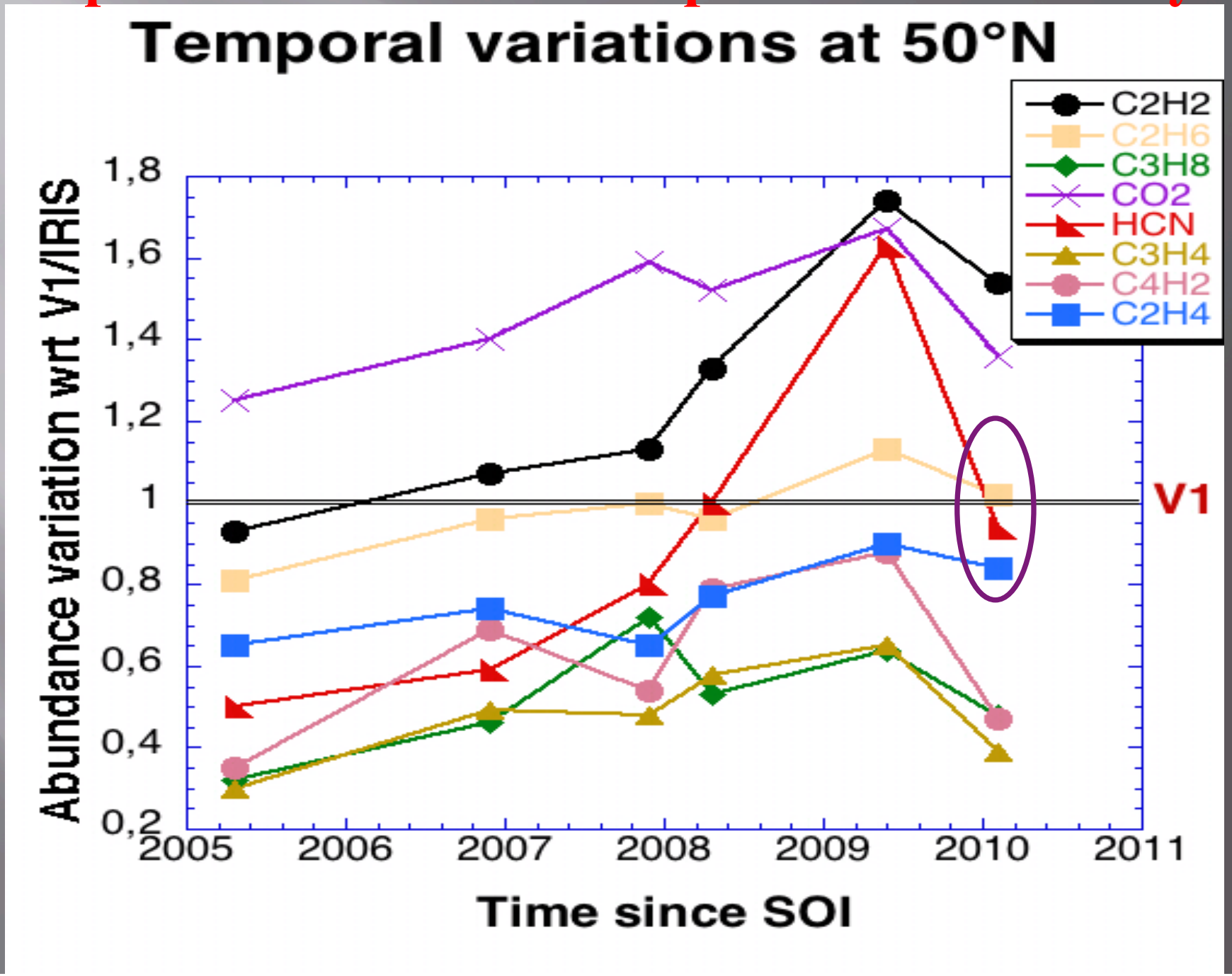
Temporal variations of composition in a Titan year



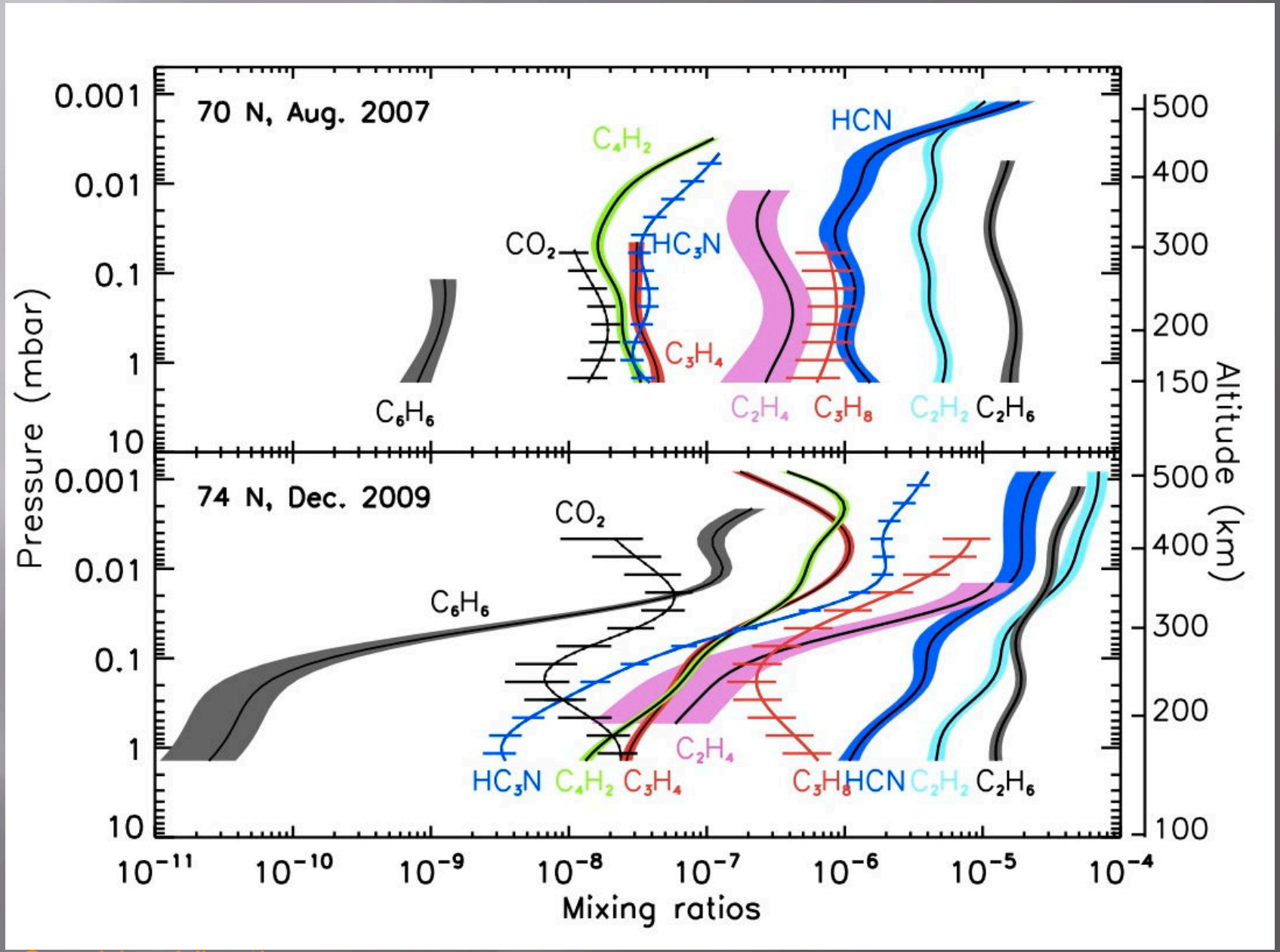
Temporal variations of composition in a Titan year



Temporal variations of composition in a Titan year



Temporal variations from limb data at 70°N



Sandrine Vinatier

Conclusions and future prospects for the Titan atmosphere

TITAN

ORGANICS THAT REMAIN TO BE SEEN

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

[a] Coustenis *et al.* (1993).
[b] Coustenis *et al.* (2003).
[c] Shindo *et al.* (2001a).
[d] Shindo *et al.* (2003).
[e] Shindo *et al.* (2001b).
[f] Nishio *et al.* (1995).
[g] Khlifi *et al.* (1999).
[h] Cerceau *et al.* (1985).
[i] Khlifi *et al.* (1997).
[j] Shindo (2002).
[k] Khlifi *et al.* (1996).
[l] Feature not yet observed. CH_3CN detected in millimeter Marten *et al.*, 2002).

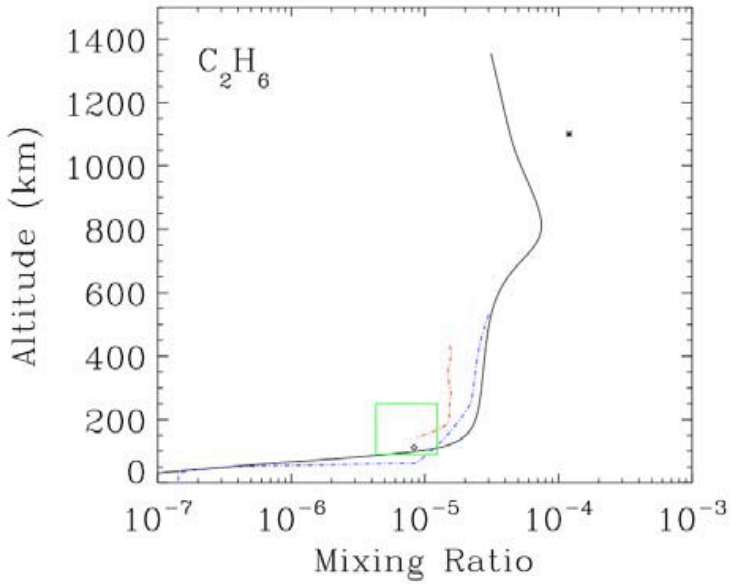
Flasar et al., 2004

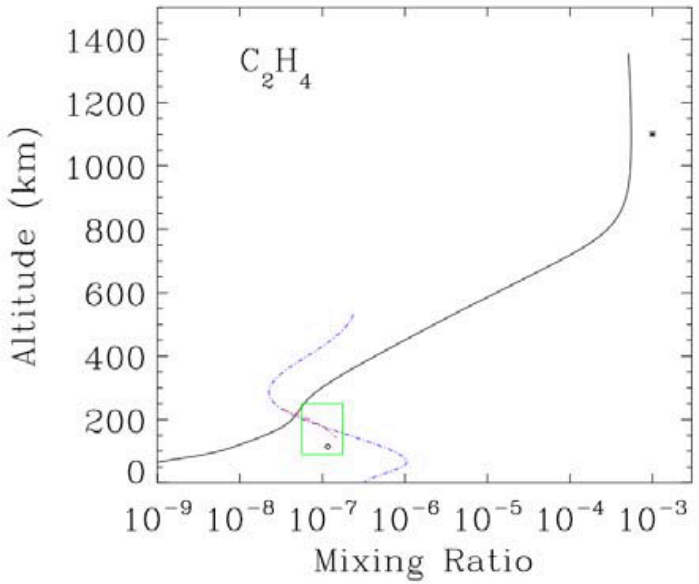
Prospects

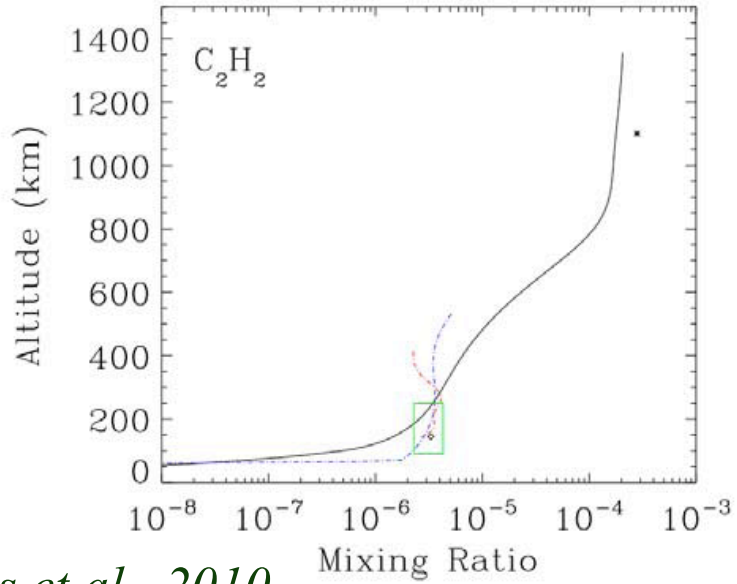
- Search for new species from large averages
- Quantify temporal variations of gases and condensates in Titan's atmosphere
  - At all other latitudes and medium resolution
  - Including other (ground-based, etc) data
  - Refine vertical distributions
- Set constraints on seasonal models by accurately determining the changes in the volatile content and the thermal structure as a function of altitude
- In good time … GO BACK!

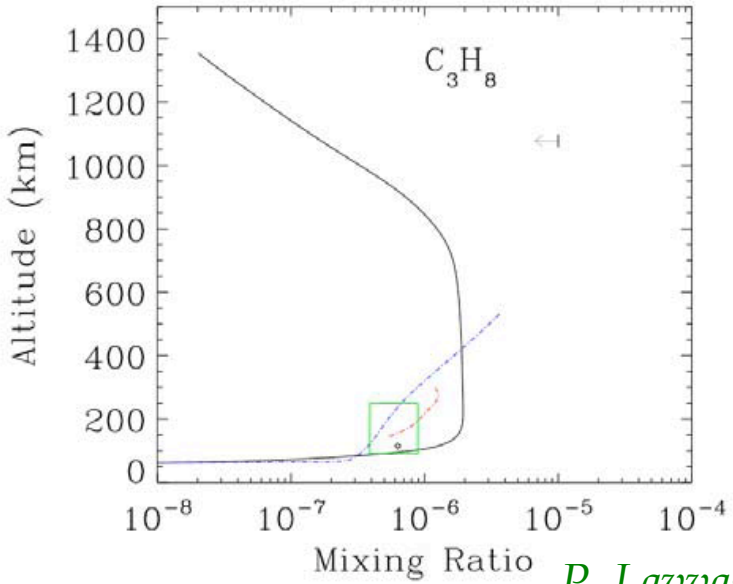
Modeling of vertical distributions throughout the atmosphere: bringing CIRS and INMS data together

Hydrocarbons (hi-res)



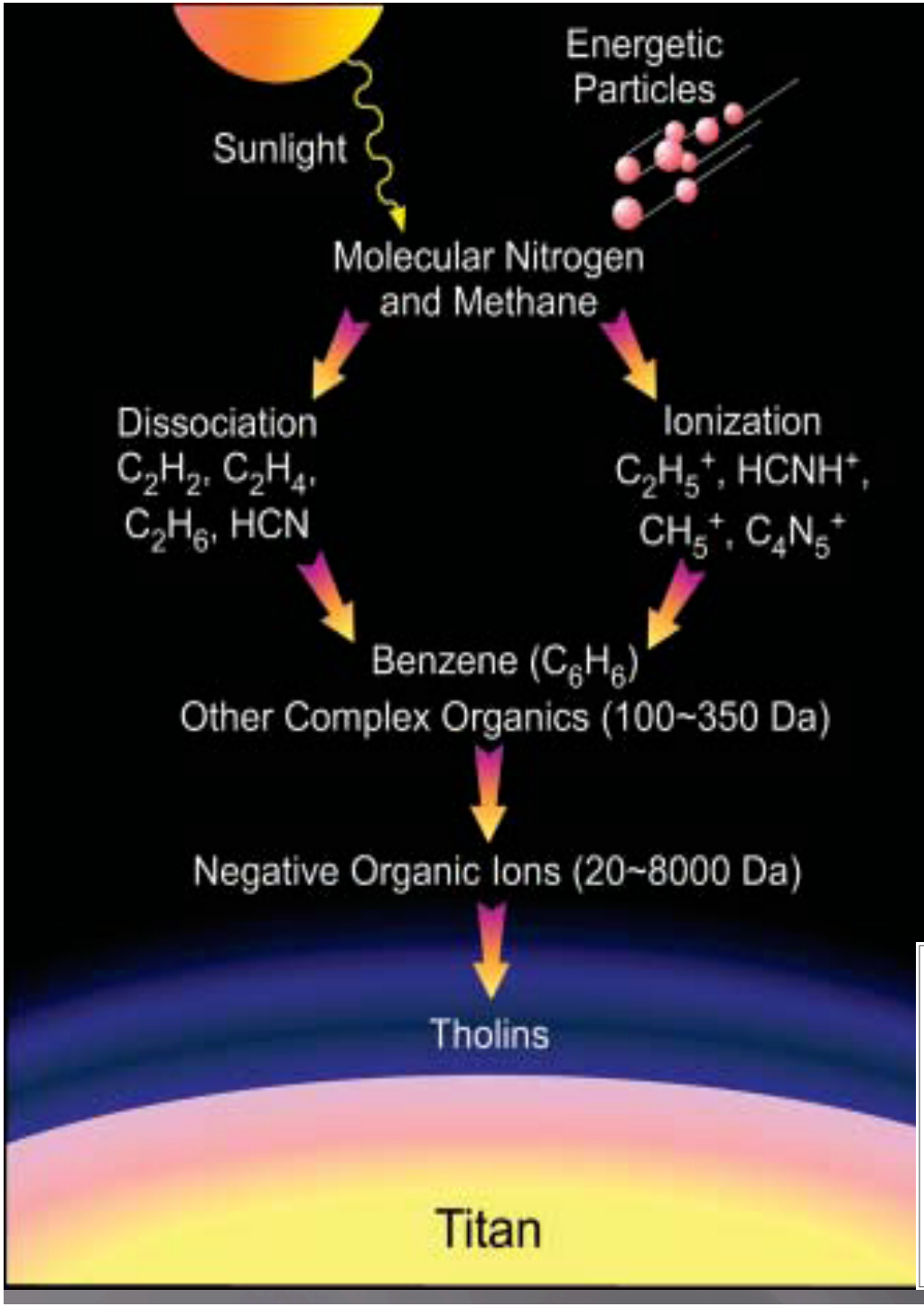




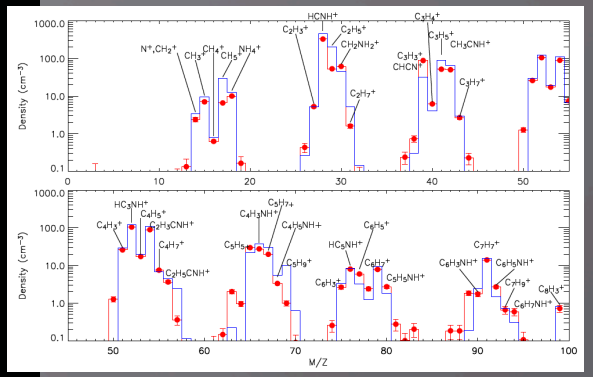


Coustenis et al., 2010

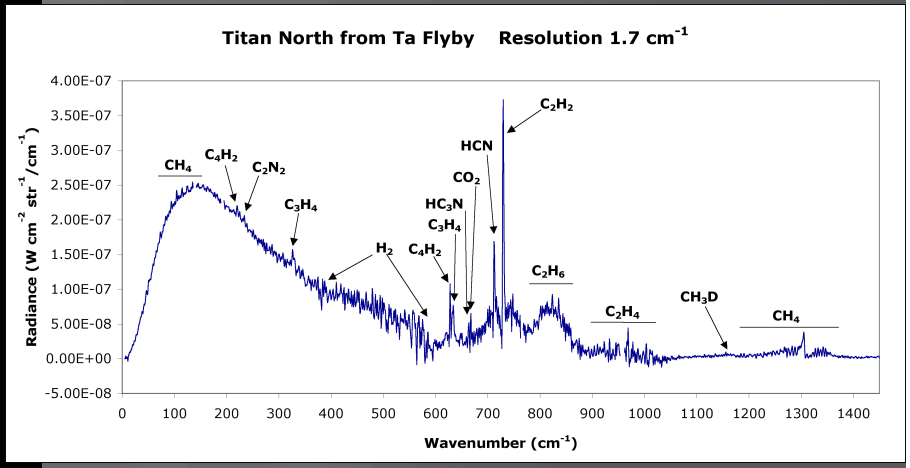
P. Lavvas



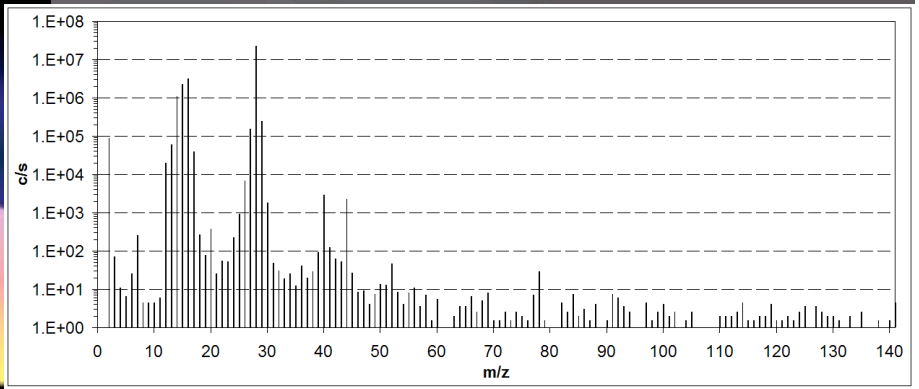
Cassini INMS



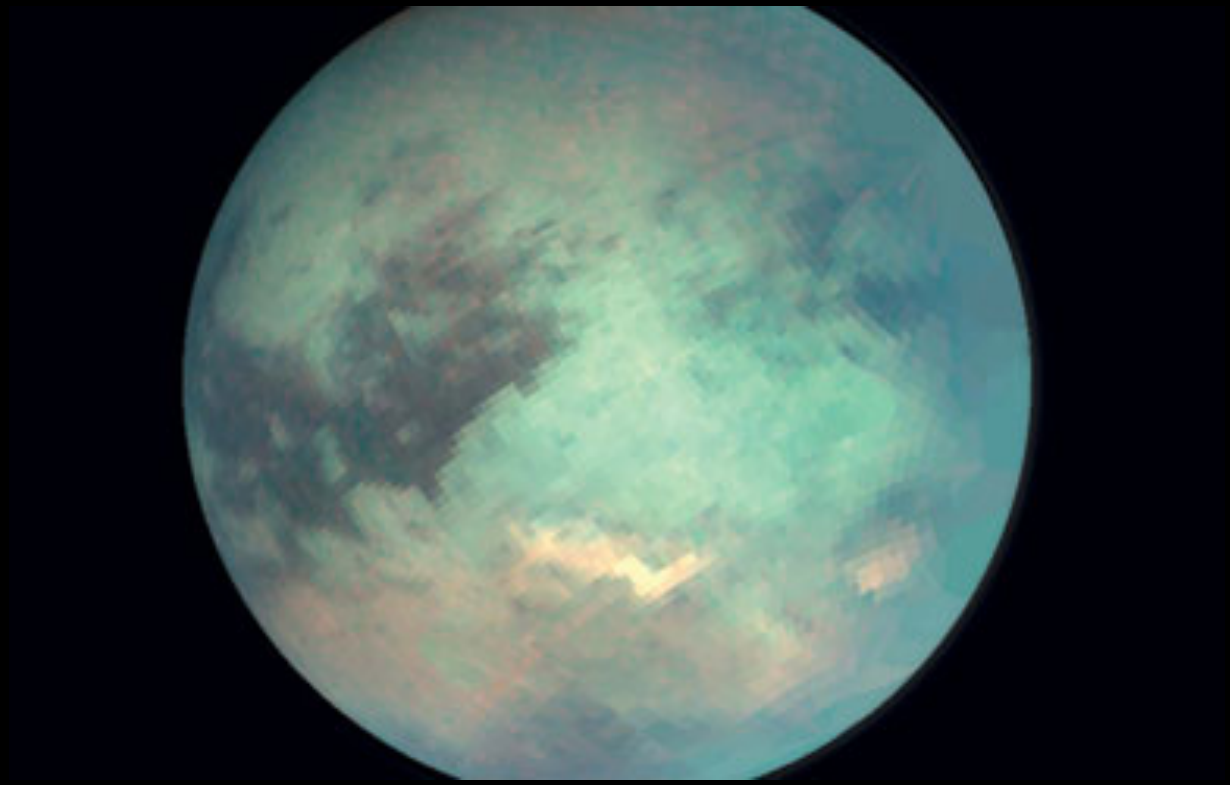
Cassini CIRS



Huygens GCMS



Variations of Titan's surface : morphotectonics, composition and variations



Titan: Properties

Mean distance from the Sun
10 AU

Temperature
95K

Gravity
1.352 m/s^2

TITAN ≈ 2/5 Earth's size

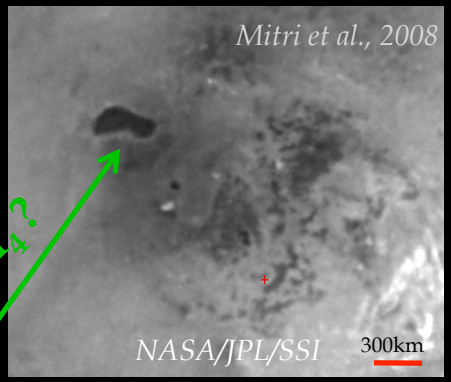
TITAN	Core	Mantle	Crust
2,576km	1,875km	610km	90km

Composition

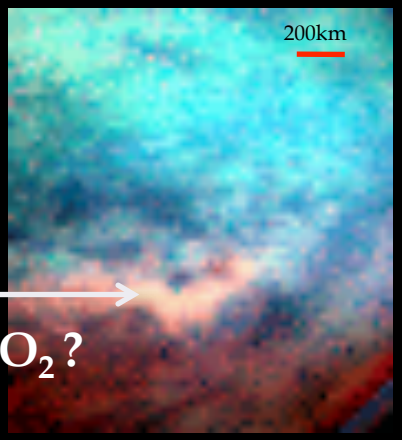
Atmosphere: 98.4% N_2
1.6% CH_4

Surface: H_2O ice?
CH_4?

NH_3?



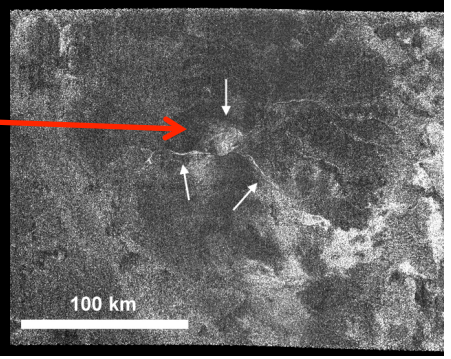
CH_4?



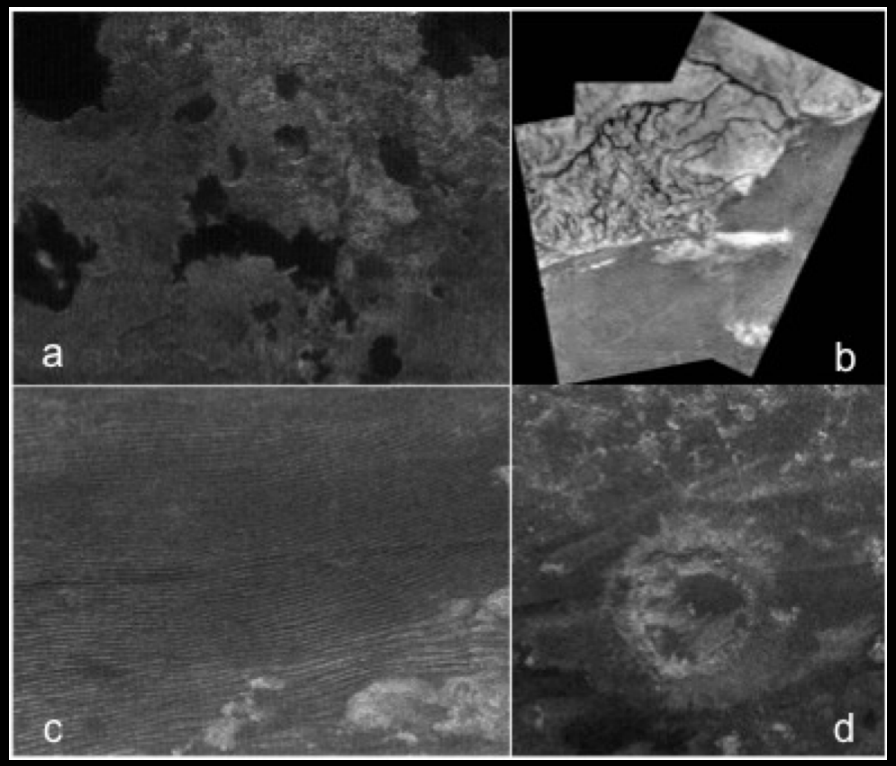
CO_2?

NH_3?

Solomonidou et al., 2010



Titan: Surface features

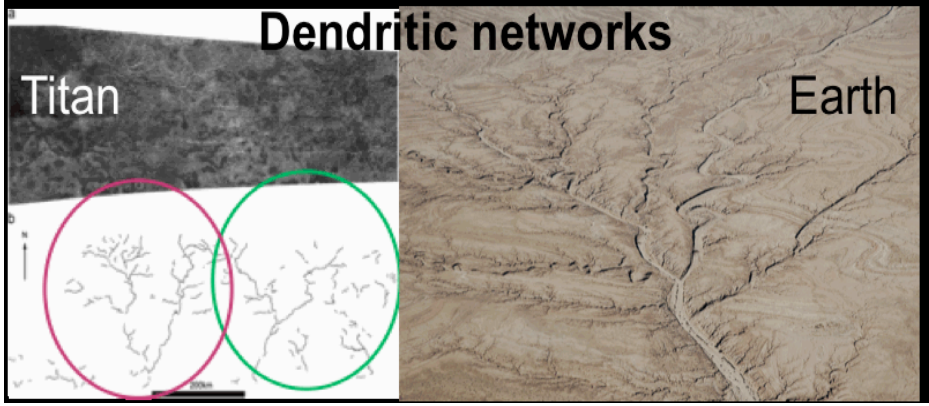


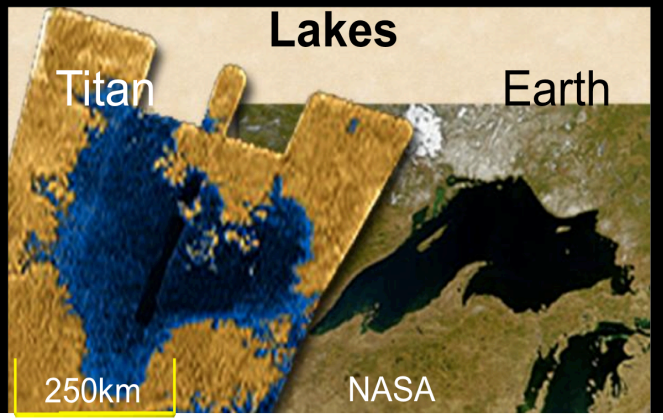
(a) Liquid lakes

(b) Drainage channels

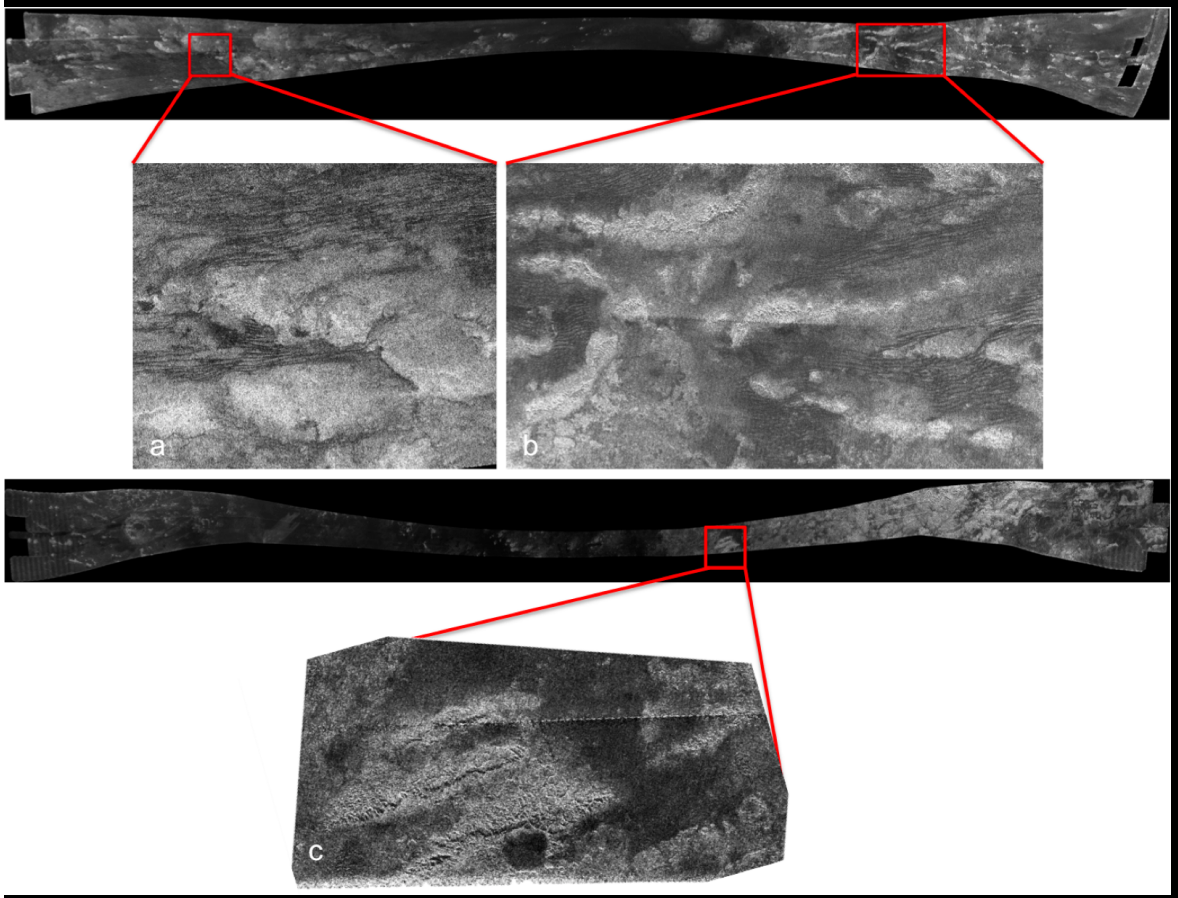
(c) Sand dunes

(d) Impact crater

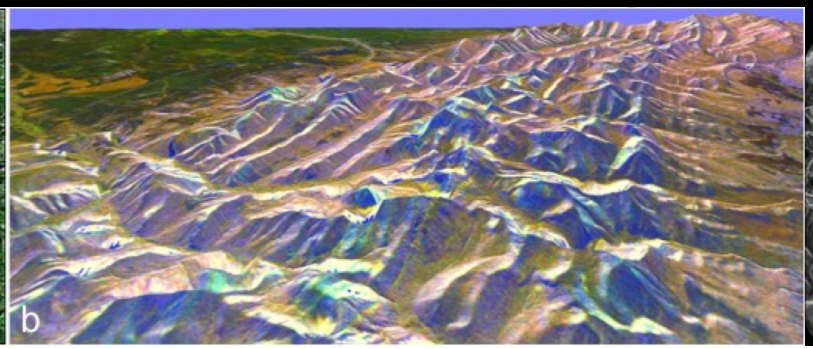


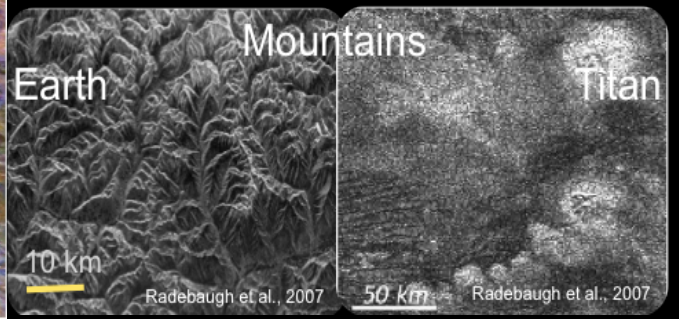


Titan: Morphotectonic features: Mountains-Ridges-Hills

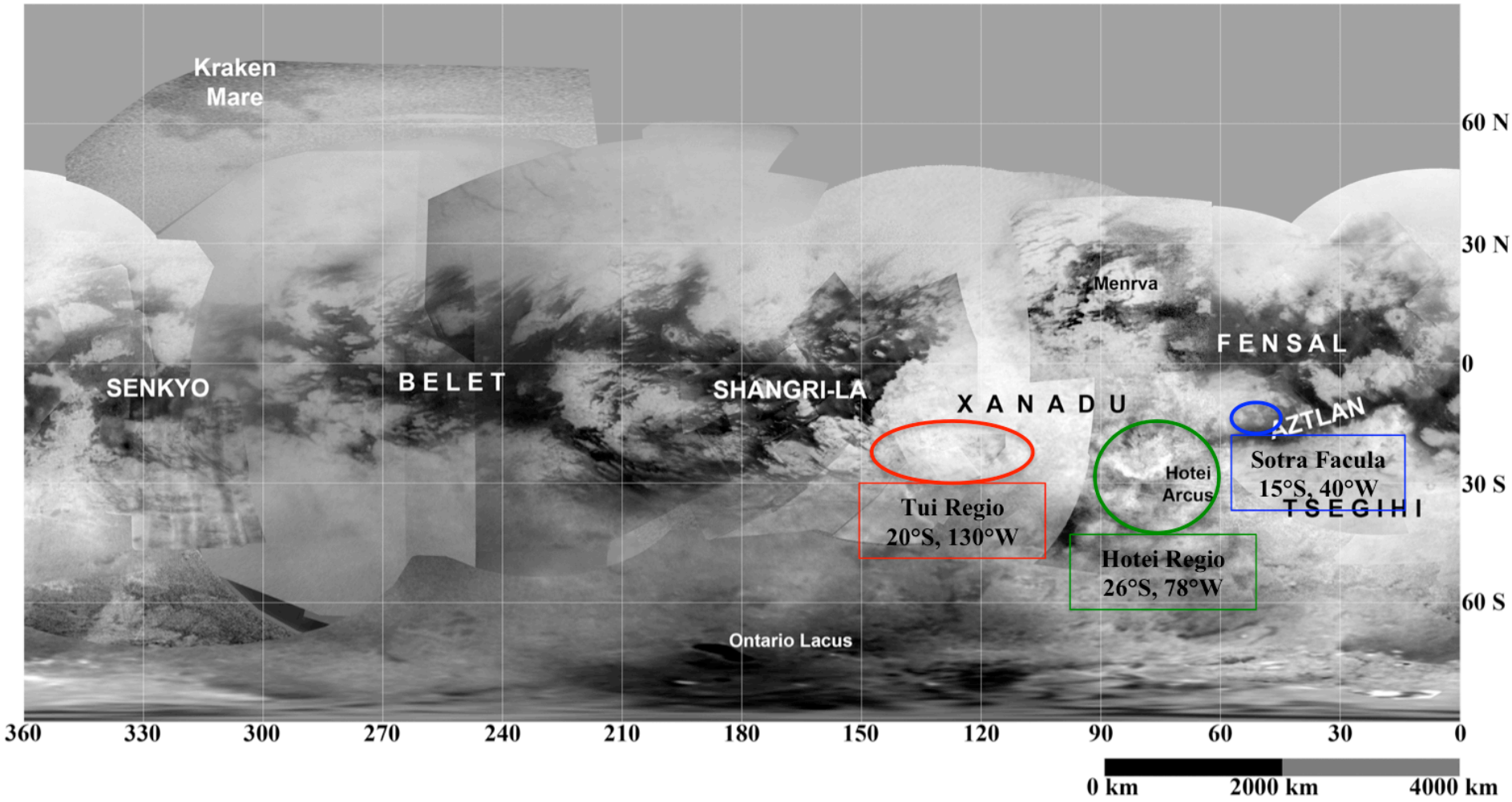


Mountainous regions: The elevated morphotectonic-like features on Titan, such as mountains, ridges, hills and ranges, indicate a formation preference around the equatorial zone of the moon.





Titan: Cryovolcanic candidates

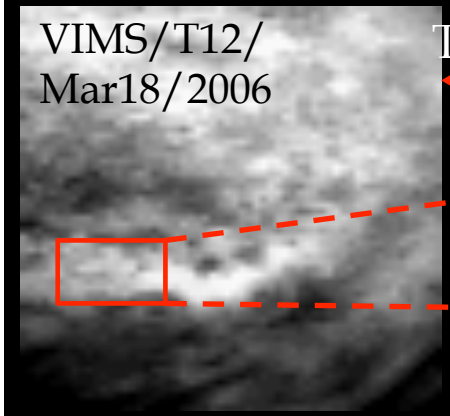


Tui Regio 20°S, 130°W

Hotei Regio 26°S, 78°W

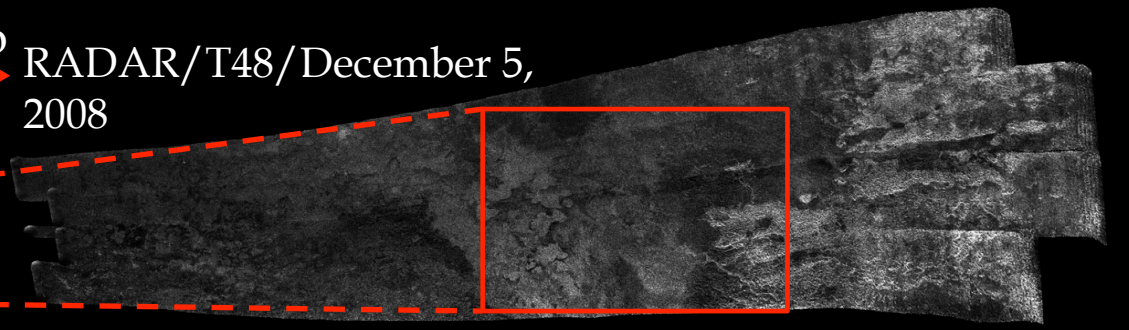
Sotra Facula 15°S, 40°W

Titan: Data: Tui Regio – Hotei Regio – Sotra Facula



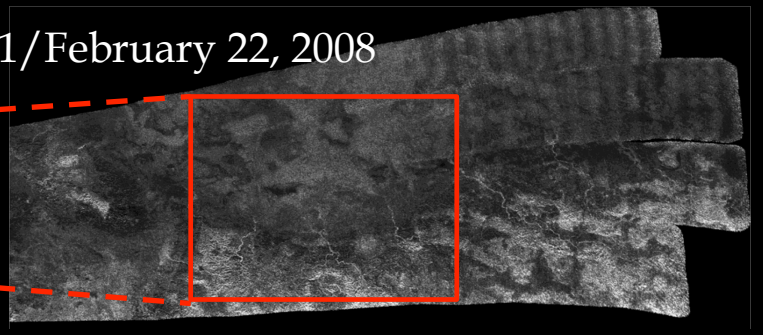
Tui Regio

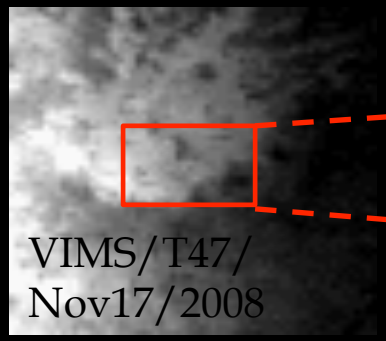
RADAR/T48/December 5, 2008



Incidence angle: 28 deg
Emission angle: 45 deg
Pixel scale: 17km/pixel

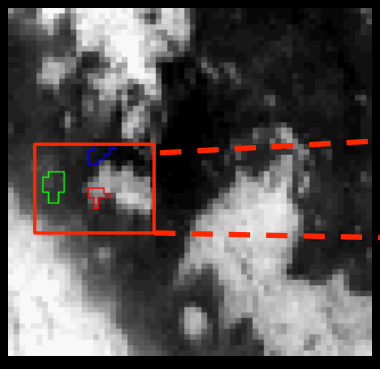
RADAR/T41/February 22, 2008



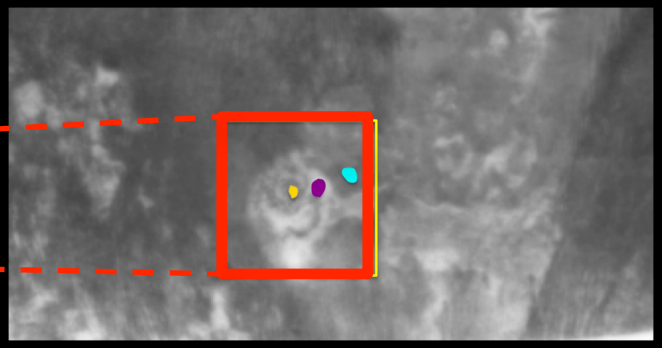


Hotei Regio

Incidence angle: 75 deg
Emission angle: 10 deg
Pixel scale: 13km/pixel

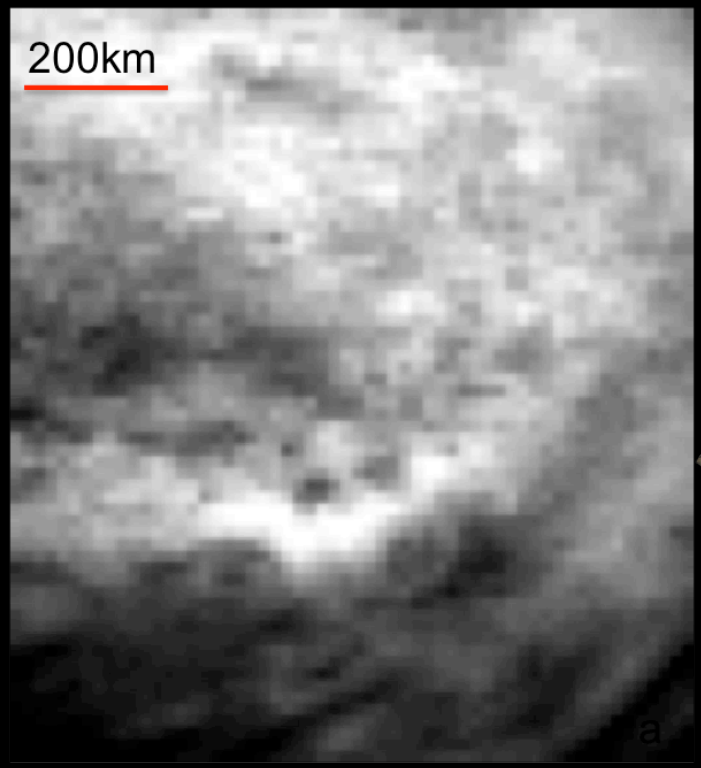


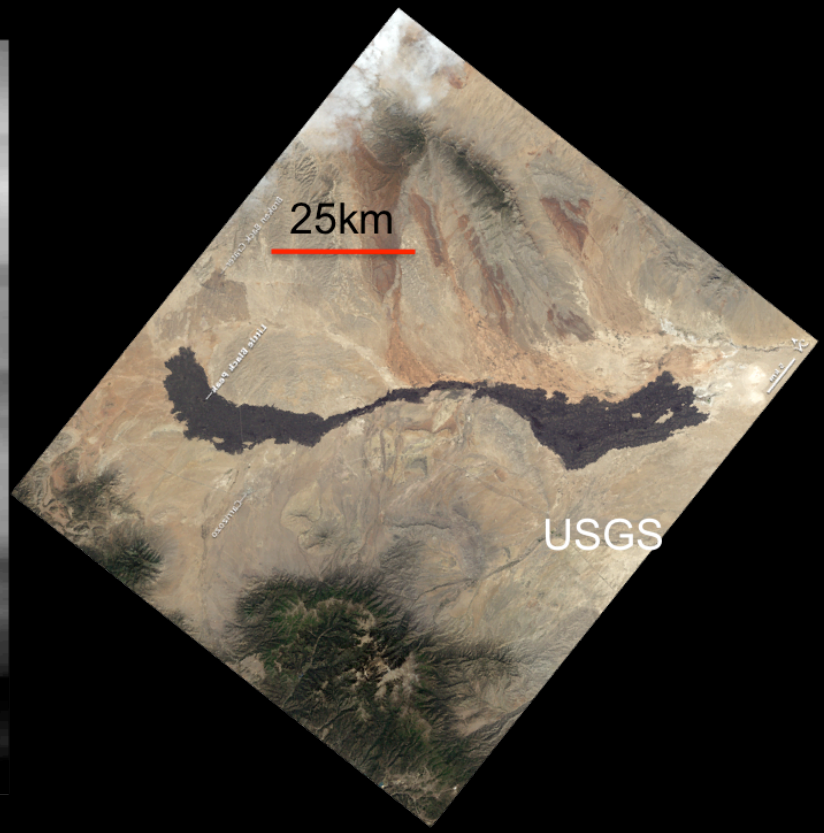
Sotra Facula



Titan: Terrestrial Analogues :

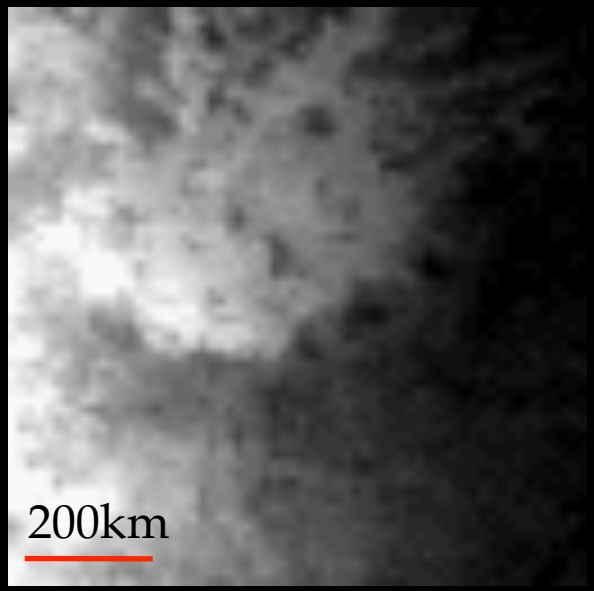
Tui Regio – Carrizozo lava flow

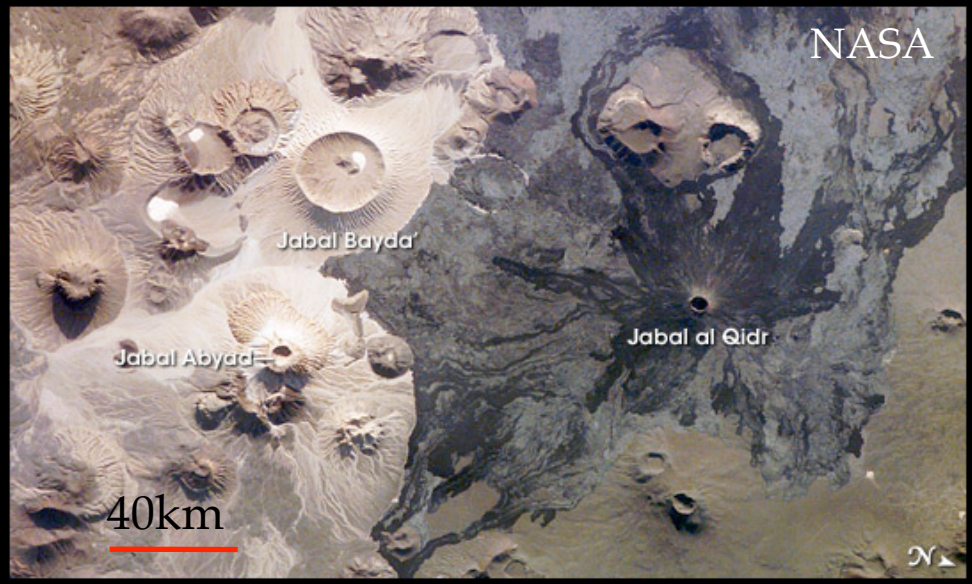


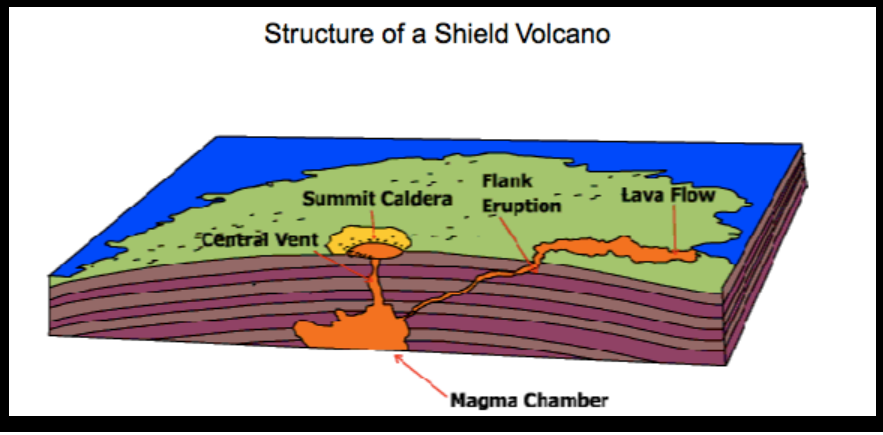


Titan: Terrestrial Analogues :

Hotei Regio – Harrat Khaybar







Shield Volcano?

SURFACE COMPOSITION

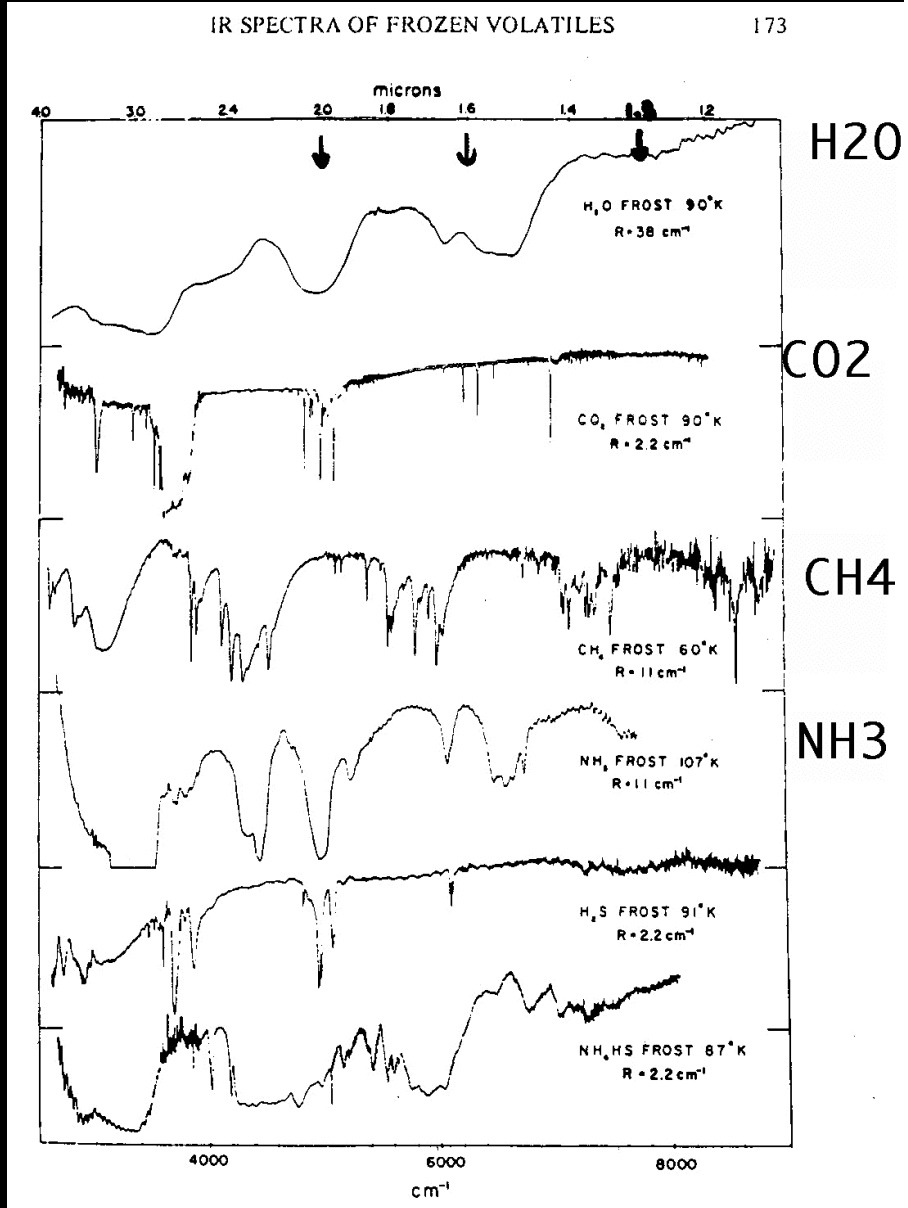
- **NEW RADIATIVE TRANSFER CODE TO ANALYZE SURFACE COMPOSITION FROM VIMS AND GD-BASED DATA**
  - **H_2O, CH_4, tholins, CO_2**

From comet impacts (Kress and McKay, 2004)

Recent deposits of CO_2 (Barnes et al., 2005)

Ground-based & VIMS spectroscopic evidence (Negrao et al., 2006; Griffith et al., 2003; Coustenis et al., 2006; McCord et al., 2006; 2008).

- HC_3N, C_6H_6, Higher order organics (Clark et al., 2009)



TITAN

Endogenic Processes

Volcanic modeling

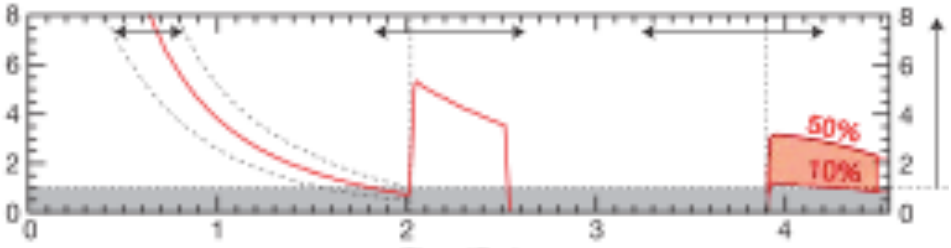
a

Time of core overturn and initial amount of CH_4

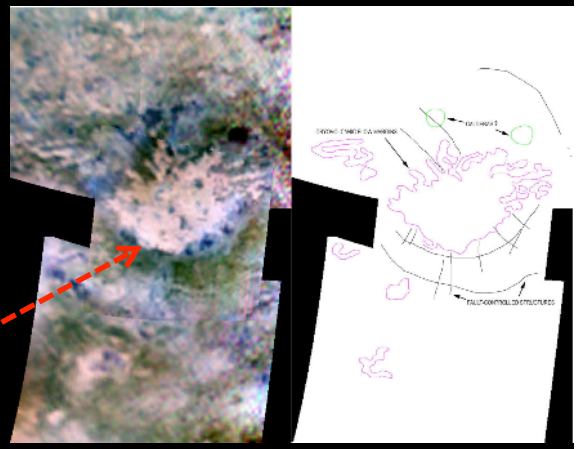
Onset time of convection in the silicate core

Onset time of convection in the outer icy layer

CH_4 release rate normalized by CH_4 loses rate



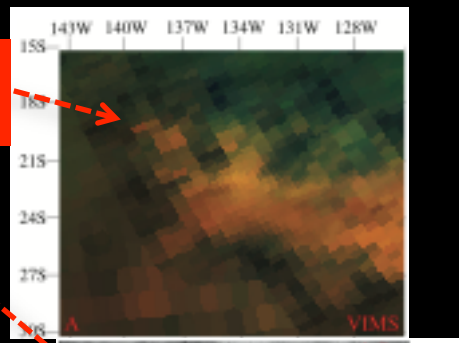
Outgassing rate required to keep CH_4 in Titan's atmosphere



b

Evolution of the outer layer

Deposits of major volcanic eruptions ?



c

Accretion

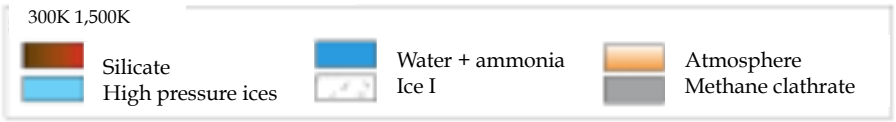
Core overturn

Core diffusive heating

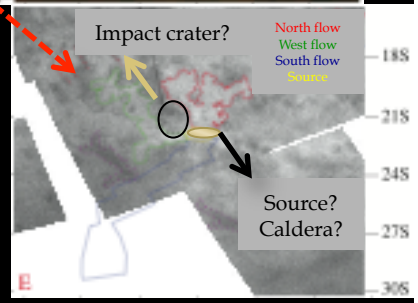
Onset of core convection

Crystallization of HP ice

Crystallization of HP and ice I



Convection in the outer layer



Tobie et al., 2006

Active Regions ?

Tui Regio, Hotei Regio and Sotra Facula are located in **the 15°S - 30°S latitude zone** ➔ Characteristic of active regions that overlay a zone of crustal weakness

Presence of flows ➔ Both possibly exhibit **volcanic structures**

Comparable sizes - **massive structures** ➔ Resembling terrestrial Super-volcanoes

Both display **higher 5-µm reflectivity** than any other region on Titan ➔ Component of which chemical composition distinct than in other regions ➔ Possible cryovolcanic deposit

Please see poster No S1-17 by Solomonidou et al.

Conclusions/perspectives for the surface

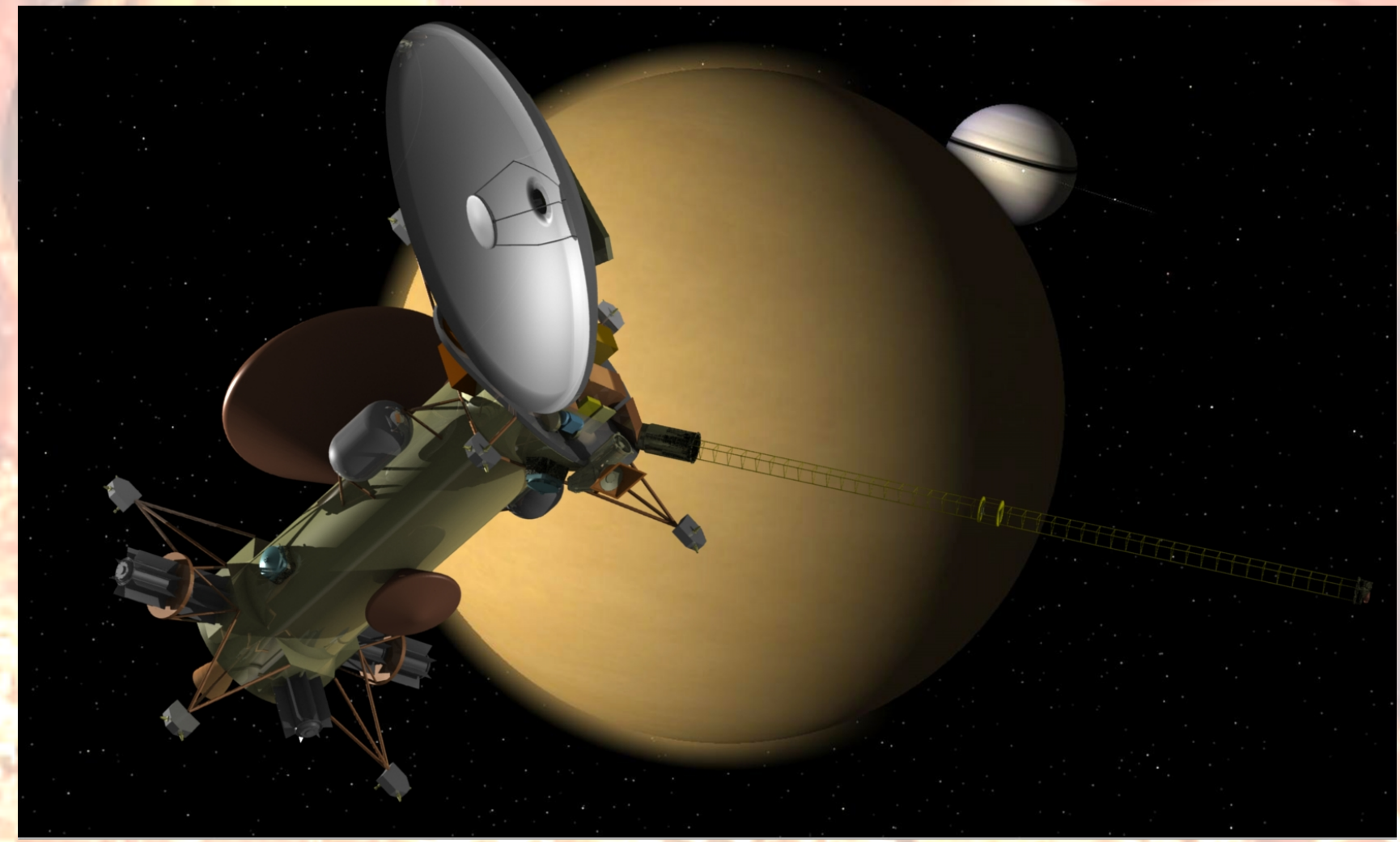
•Several Cassini-Huygens mission measurements suggest that some of the Saturnian satellites are geologically active and may support tectonic processes.

•Titan, in particular, possesses a complex and dynamic geology as witnessed by its varied surface modified by aeolian, fluvial, and possibly tectonic and endogenous cryovolcanic processes.

•The Synthetic Aperture Radar (SAR) instrument on oard Cassini spacecraft indicates the possibility for morphotectonic features on Titan's surface such as mountains, ridges, faults and canyons whose formation mechanisms are still unclear since later processes, may have re-shaped or partially covered them.

• Due to the limitations of Cassini-Huygens in the acquisition of *in situ* geo-tectonic measurements or samples and the lack of high spatial resolution imaging, we do not know with enough precision Titan's morphology and topography.

•Nevertheless, the hypothesis that contractional tectonism - followed by surface and/or atmospheric modifications - has formed the observed features is a probable one



For planning and discussion purposes only