The Organic Aerosols of Titan's Atmosphere

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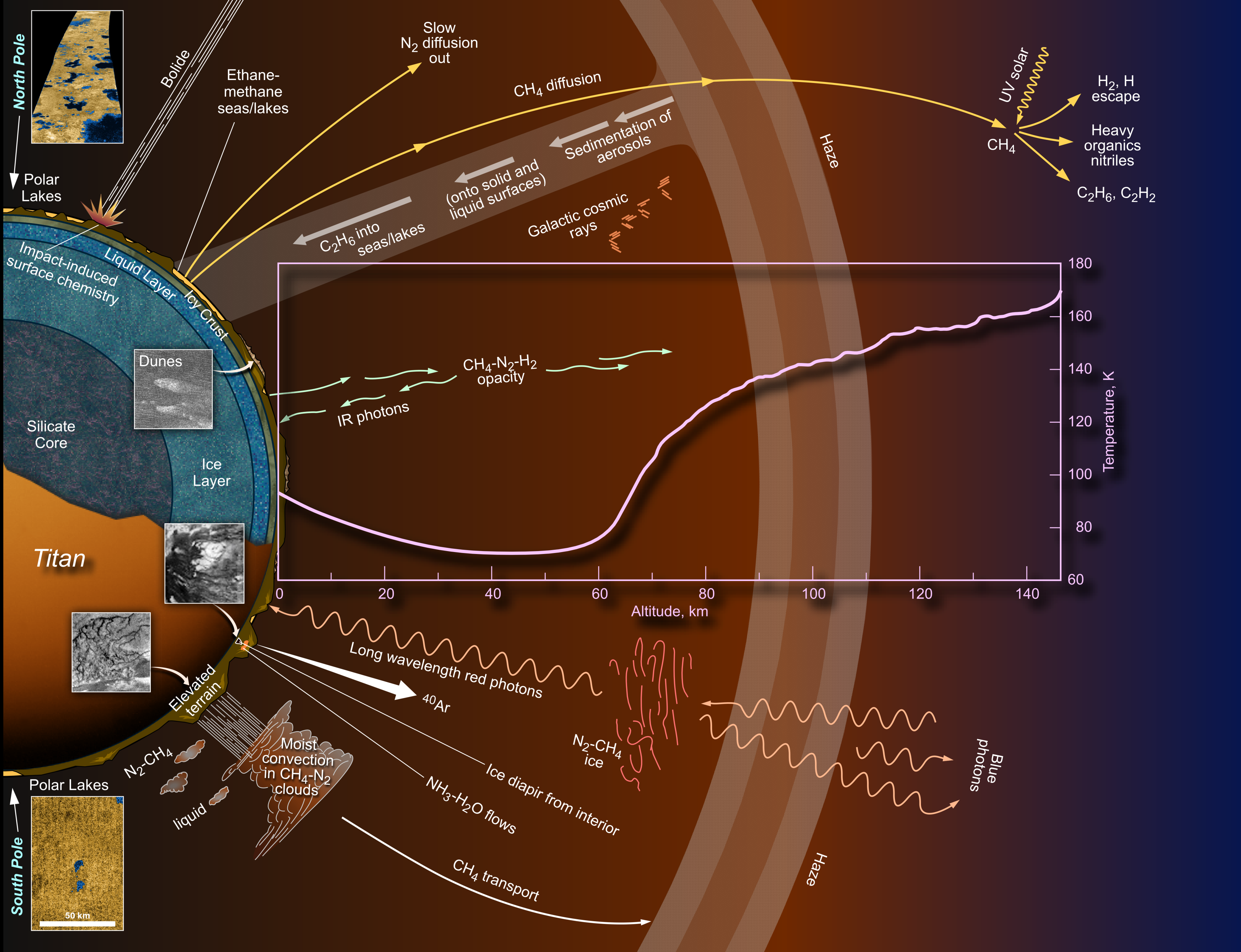
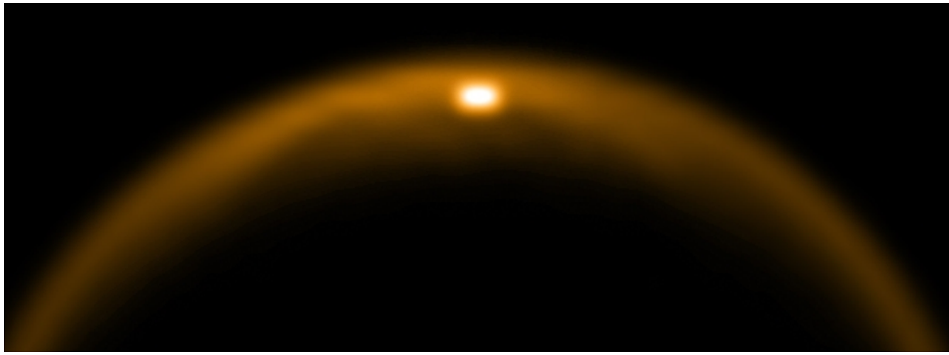
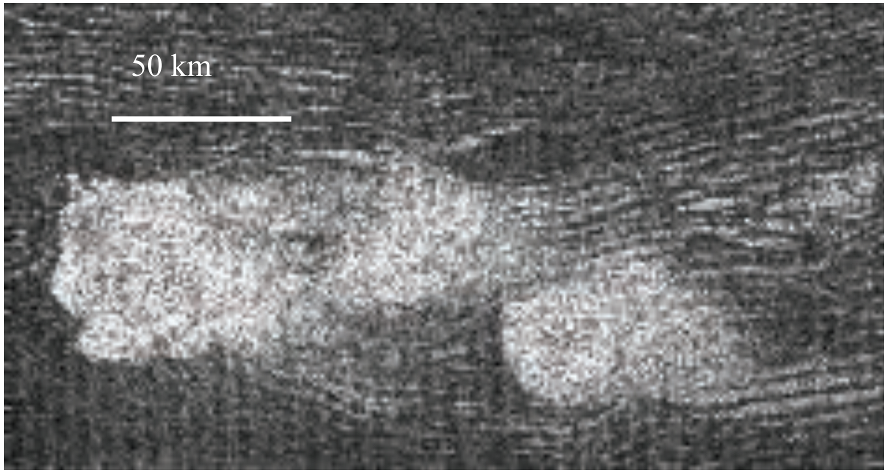


North Pole
Polar Lakes
Bolide
Ethane-methane seas/lakes
Slow N_2 diffusion out
CH_4 diffusion
UV solar
H_2, H escape
CH_4
Heavy organics nitriles
C_2H_6, C_2H_2
Sedimentation of aerosols
(onto solid and liquid surfaces)
C_2H_6 into seas/lakes
Galactic cosmic rays
Haze
Impact-induced surface chemistry
Liquid Layer
Icy Crust
Dunes
CH_4-N_2-H_2 opacity
IR photons
Silicate Core
Ice Layer
Titan
180
160
140
120
100
80
60
Temperature, K
0
20
40
60
80
100
120
140
Altitude, km
Long wavelength red photons
^{40}Ar
Elevated terrain
N_2-CH_4 ice
Blue photons
N_2-CH_4
liquid
Moist convection in CH_4-N_2 clouds
Ice diapir from interior
NH_3-H_2O flows
CH_4 transport
Haze
Polar Lakes
South Pole
50 km

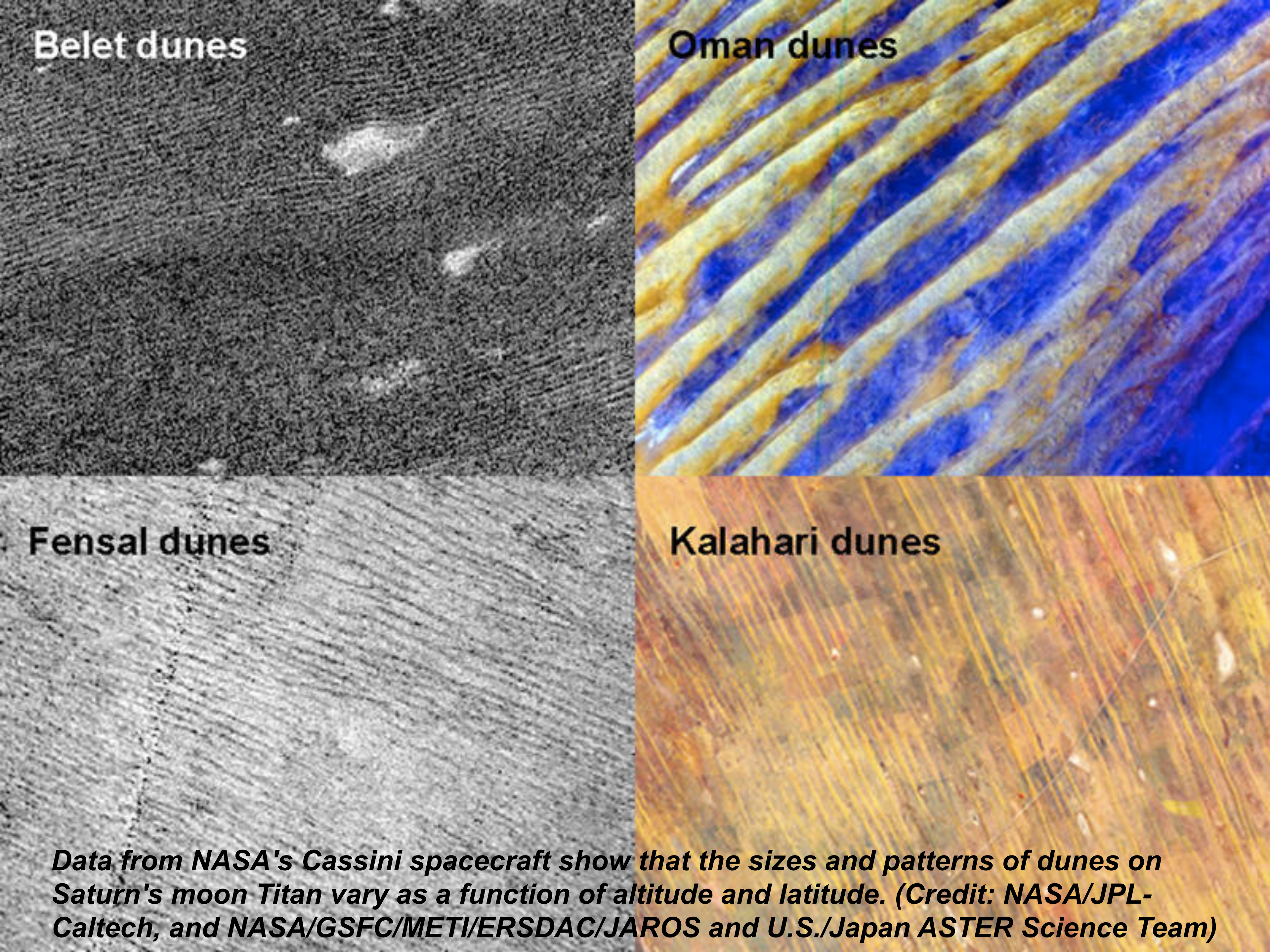
Motivation

- The formation of organic particles in Titan's atmosphere is one of the outstanding question in astrobiology.
- Are these organic particles those that form the dune fields? Are additional processes involved in the formation of the organic 'sand'?
- What is the size of this carbon reservoir? How does it compare with other carbon reservoirs? What is the downward flux? What is the timescale of formation of the haze? How does it compare with the age of the dunes?

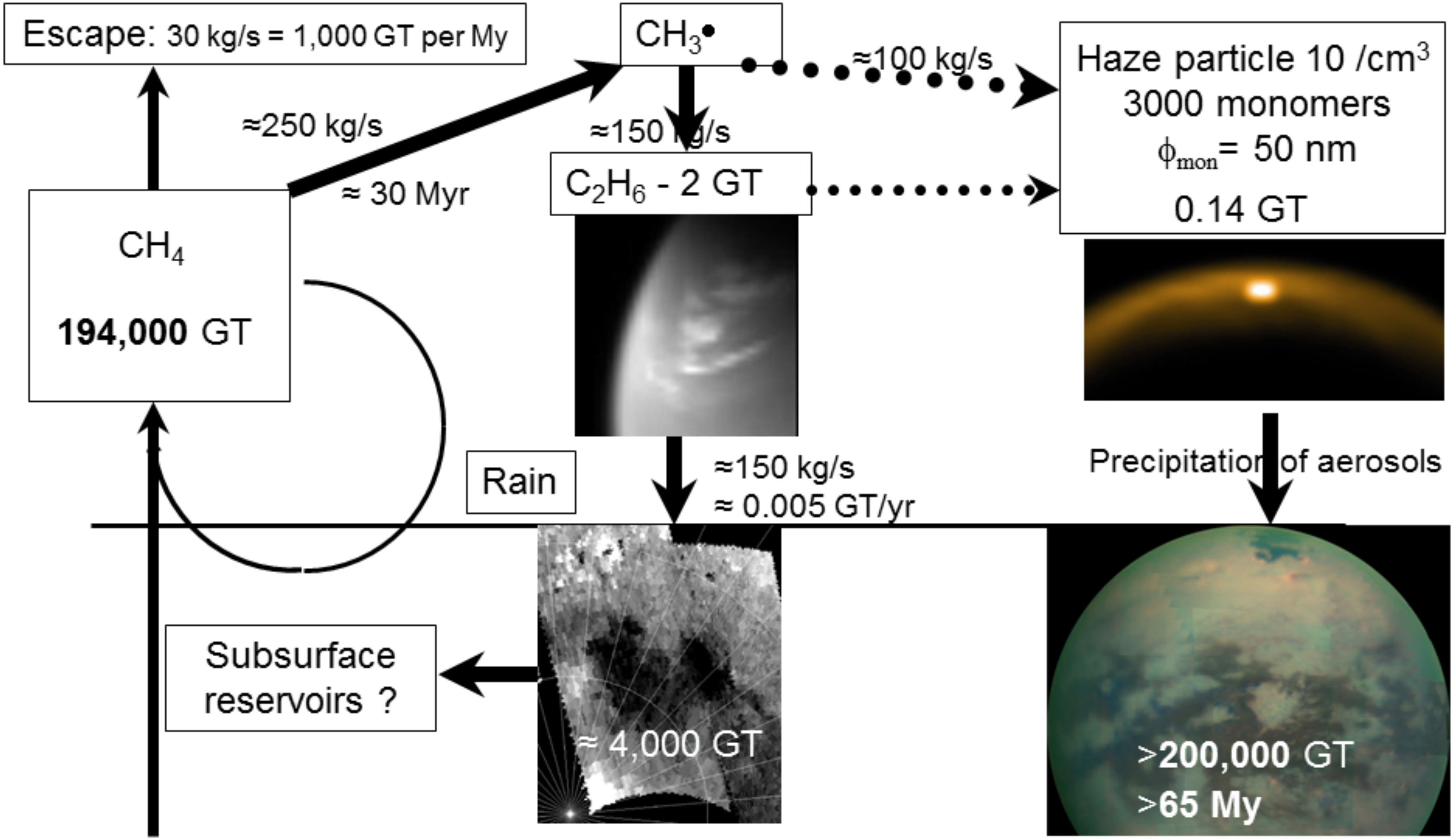




How can future probes to Titan determine the chemical composition and the structural properties of these organic particles?



Data from NASA's Cassini spacecraft show that the sizes and patterns of dunes on Saturn's moon Titan vary as a function of altitude and latitude. (Credit: NASA/JPL-Caltech, and NASA/GSFC/METI/ERSDAC/JAROS and U.S./Japan ASTER Science Team)



When? 500 My (isotopic ratios, density of impact craters, Titan's shape)
Where and how ? One catastrophic event or several large events (impact craters, cryovolcanism)

Cassini-Huygens observations

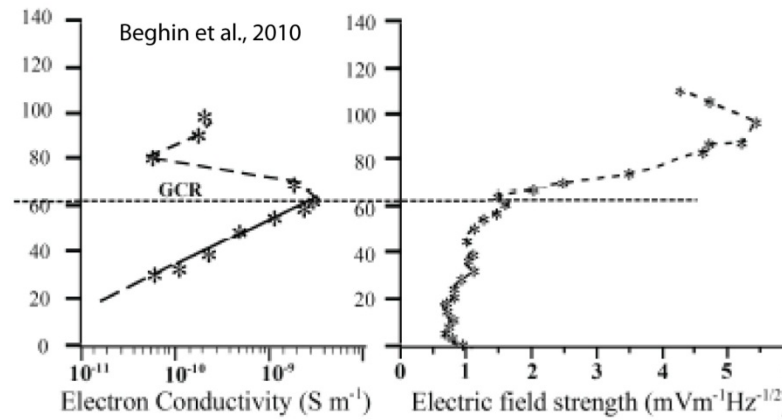
Several instruments provide information on the organic haze :

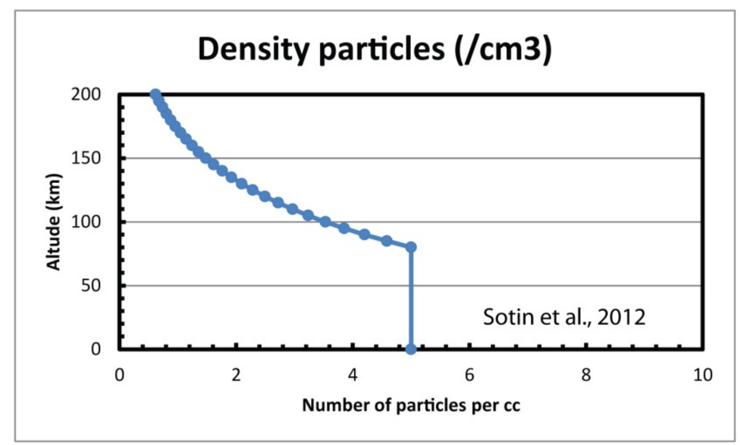
- Instruments such as CAPS and INMS have been able to probe the upper atmosphere (920 km to 1200 km) of Titan's atmosphere. CAPS demonstrated that heavy molecules exist at these altitudes (Coates et al., 2007).
- Other like UVIS, ISS, and VIMS provide information on the haze at lower altitudes thanks to solar occultations.
- Huygens provided information in the lower 200 km.
- Models (e.g. Rannou et al., 2010) suggest that the haze opacity **increases by a factor of 3** from the South Pole to the equator, and then **decreases by a factor of 2** between 30°N and the North Pole (see next slide).
- The reference density varies in the literature from 5 to 90 cm^{-3}.

Here we focus on the analysis of the VIMS solar occultations to derive properties of the aerosols. (side application is to infer the opacity in order to retrieve the surface reflectance and its variations).

Types of aerosols

Type of aerosols/ particles	Location	Size	density
haze	Global – peak density is around 80 – 100 km depending on models.	0.2 to several μms – made of 3000 monomers that may form at very high altitude (1000 km)	30 cm^{-3} at 90 km and strong decrease below Griffith et al. (2006). Peak value of 5 cm^{-3} in Tomasko et al. (2008)
Ethane clouds	North pole in winter. Above 50°–permanent– 40 to 60 km altitude	1 to 3 μms	Column abundance of 60,000 cm^{-2} = 60 cm^{-3} if cloud is 10 m thick.
Methane clouds	Southern mid-latitudes in winter – episodic – 10 km altitude	Larger than 10 μms (Toon et al., 1988)	





The aerosol density of 5 cm-3 in the first 80 km comes from Tomasko et al. (2008) Scale height of 57.5 km (Bellucci et al., 2009)

Aerosols at the poles

General atmospheric circulation is characterized by downwellings at the winter pole with the formation of a polar hood made of haze particles and a large cloud system (upper right panel).

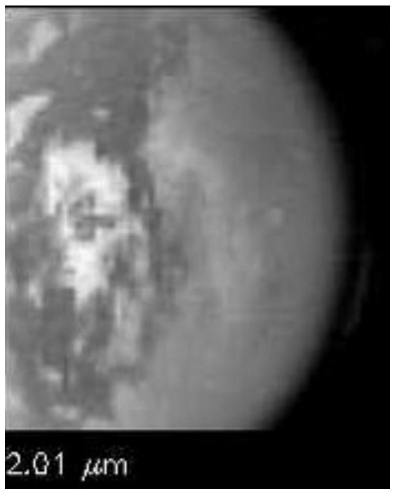
Mar. 26, 2008

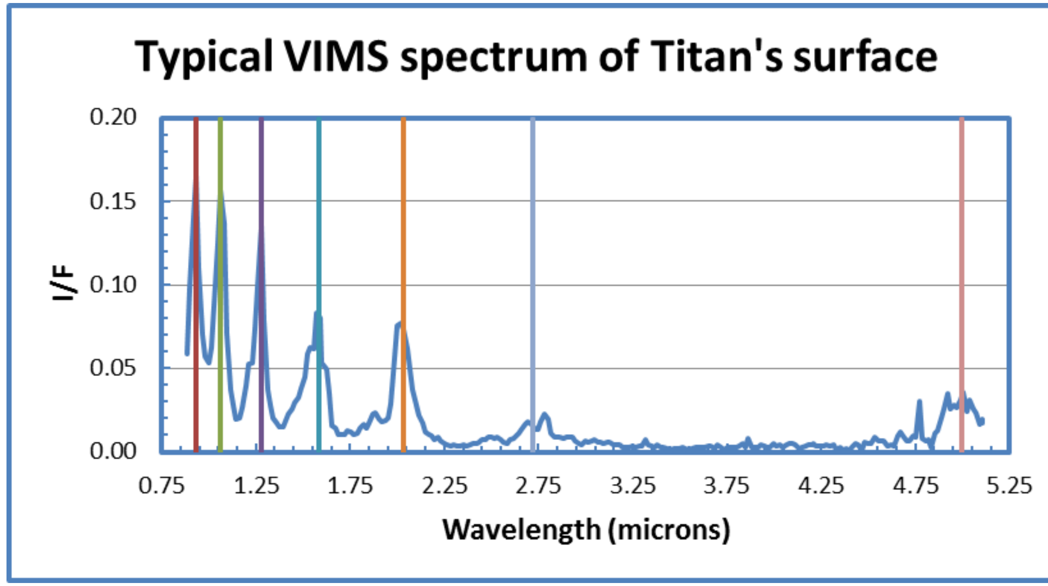
May 12, 2008

After equinox (August 2009), as Titan's summer starts, Global Circulation Models predicted the formation of a South polar hood. ISS and VIMS observations during T83 and T84 in May and June 2012 confirm this prediction. The red arrows show the location of a dense haze layer over the South Pole. This layer forms due to the down-welling circulation that brings high altitude particles over the South Pole.

The VIMS observations

VIMS can see Titan's surface in 7 atmospheric windows. In these atmospheric windows, the transmission is limited by the haze opacity. Observations at these wavelengths for different viewing geometry provide information on the characteristics of the haze. Solar Occultations probe different altitudes.





$$I(\lambda,\phi) = F(\lambda).\cos(i).R_S(\lambda).\exp(-\tau_{atm}) + I_{scattered}(\lambda,\phi)$$

$$\tau_{atm} = \int_{D_{inc}}^{0} \sigma_{Scat}(\lambda) n(z) dl + \int_{0}^{D_{emi}} \sigma_{Scat}(\lambda) n(z) dl \qquad n(z) = n_{ref}.\exp\left(-\frac{z - Z_{ref}}{H_{haze}}\right)$$

The VIMS observations

Several instruments provide information:

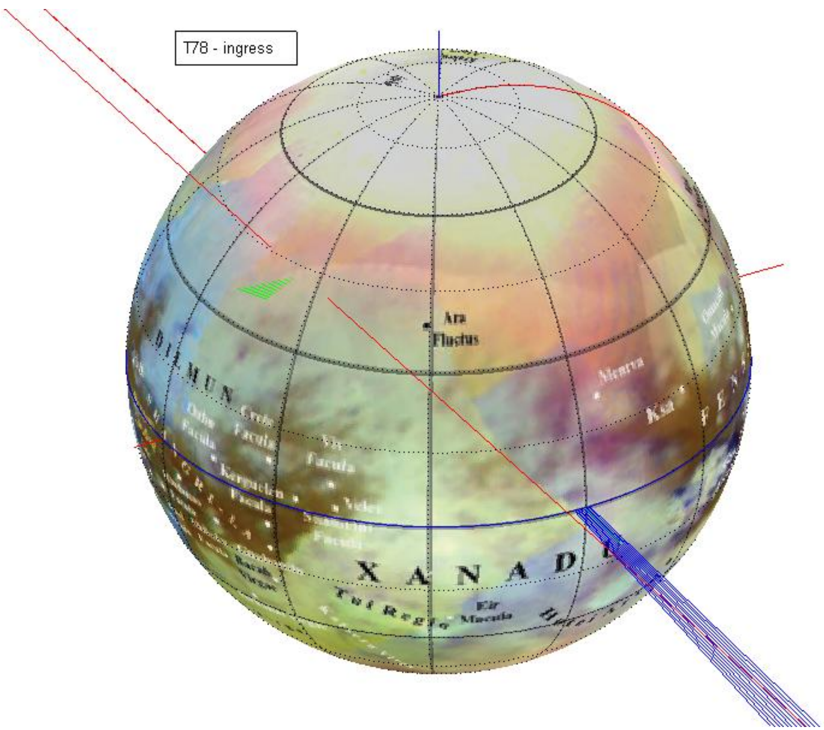
- Rannou et al. (2010) suggest that the haze opacity **increases by a factor of 3** from the South Pole to the equator, and then **decreases by a factor of 2** between 30°N and the North Pole. The reference density varies in the literature from 5 to 90 cm^{-3}. Use the solar occultations to constrain the density of aerosols.

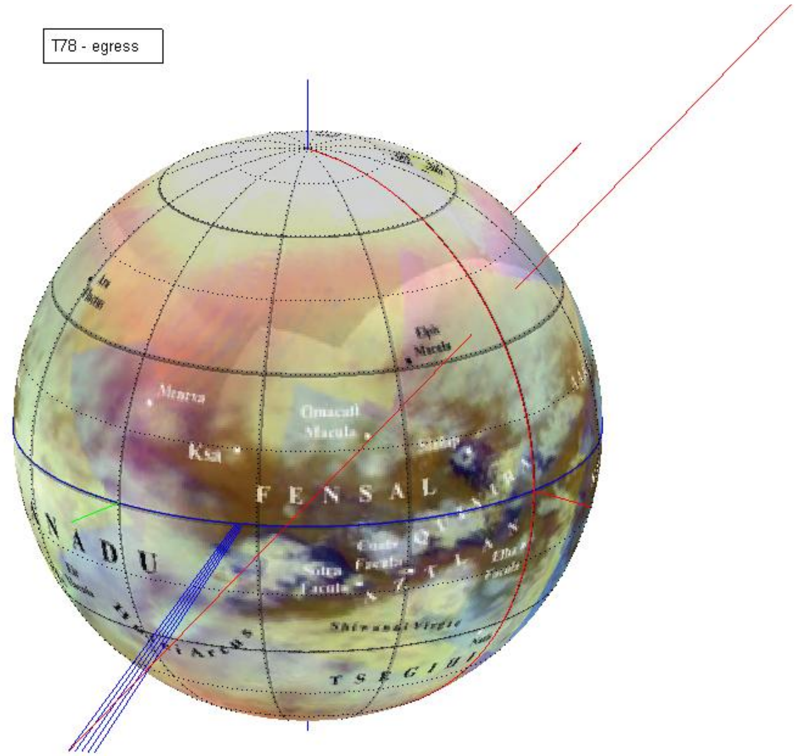
- Correction for determining the reflectance of the surface – correction depends on latitude and time

$$I(\lambda,\phi) = F(\lambda).\cos(i).R_S(\lambda).\exp(-\tau_{atm}) + I_{scattered}(\lambda,\phi)$$

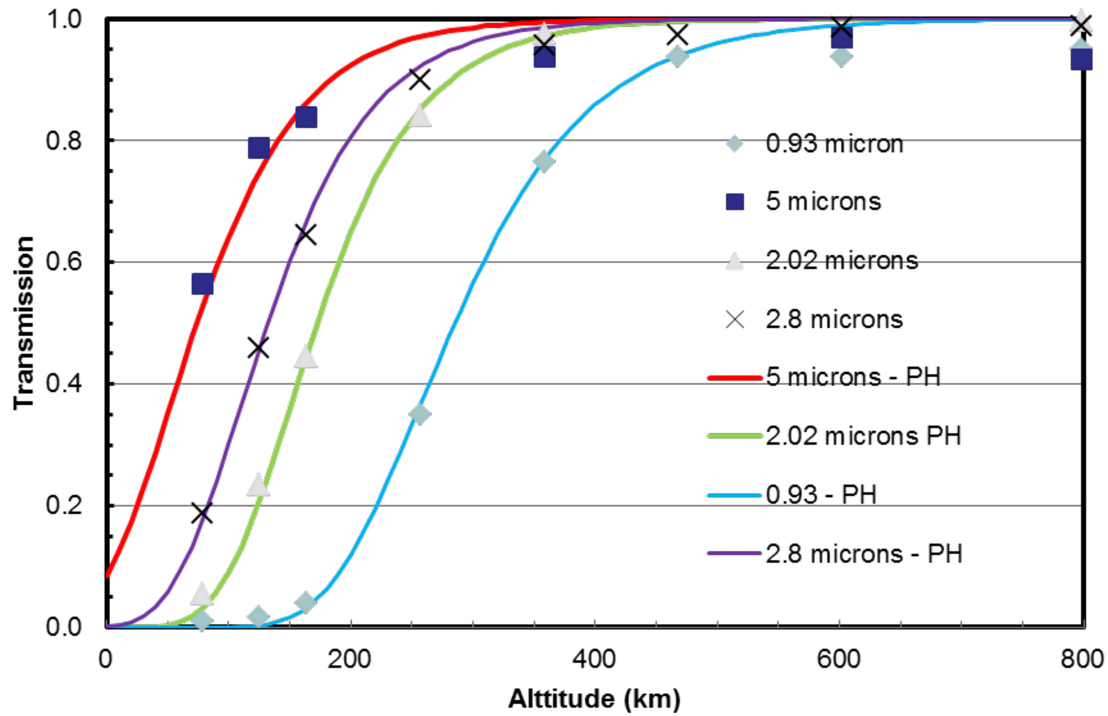
$$\tau_{atm} = \int_{D_{inc}}^{0} \sigma_{Scat}(\lambda) n(z) dl + \int_{0}^{D_{emi}} \sigma_{Scat}(\lambda) n(z) dl \qquad n(z) = n_{ref}.\exp\left(-\frac{z - Z_{ref}}{H_{haze}}\right)$$

Analysis of solar occultations
S70-Rev153-T78 – 29 November 2011
2011-255T02:50:06 @ 5821 km altitude





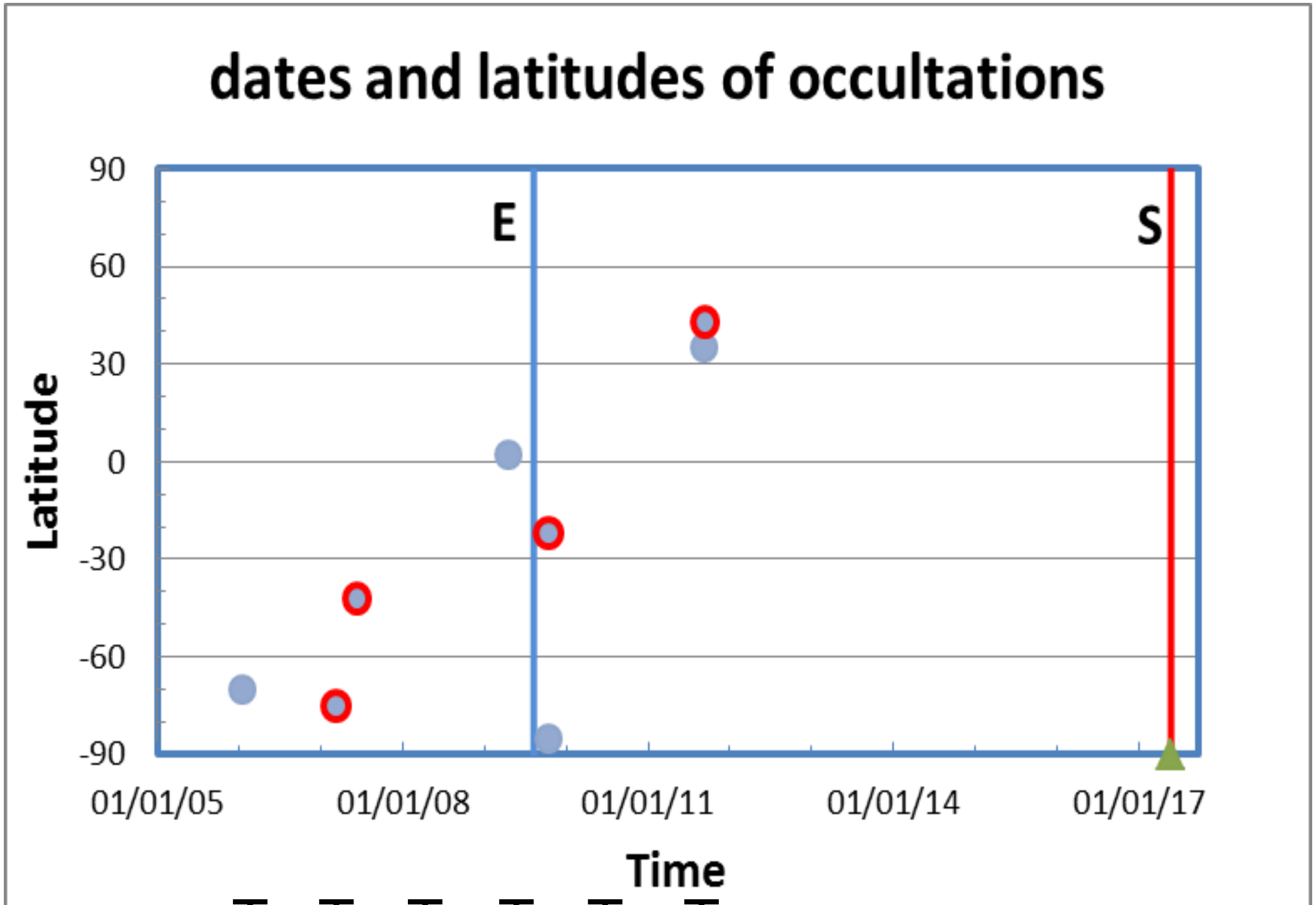
Transmission during T10 solar occ



$$\tau = n_{ref}\sigma_{scat}(\lambda)H_{haze}\exp\left(\frac{Z_{ref}}{H_{haze}}\right)\exp\left(-\frac{z_0}{H_{haze}}\right)\sqrt{2\pi\left(\frac{R}{H_{haze}}+\frac{z_0}{H_{haze}}\right)}$$

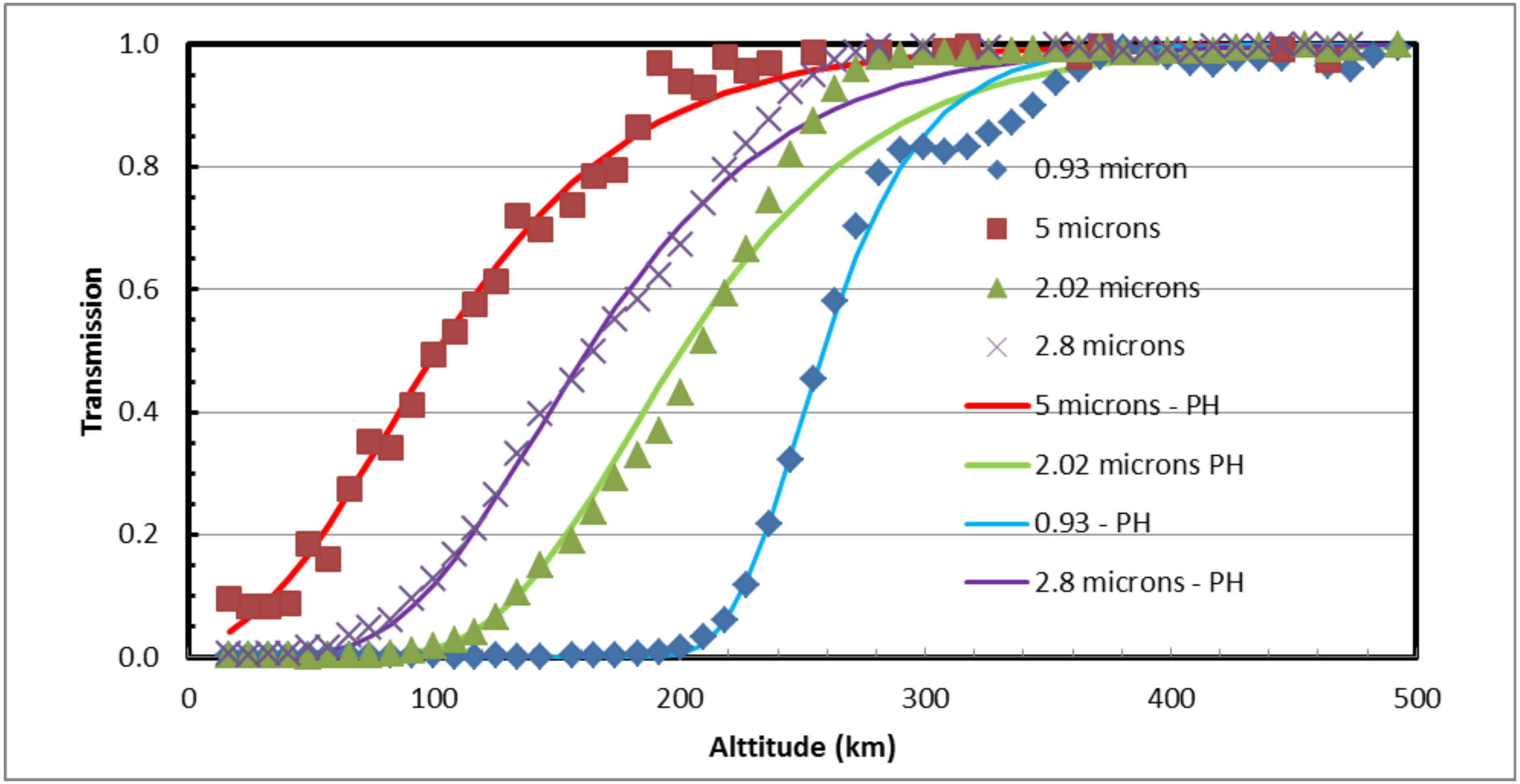
Transmission curves in different atmospheric windows and fit with a transmission curve assuming constant scattering cross-section and an exponential law for the density of haze particles (scale height on the order of 60 km). These results are identical to those published by Bellucci et al (2009).

List of occultation observations



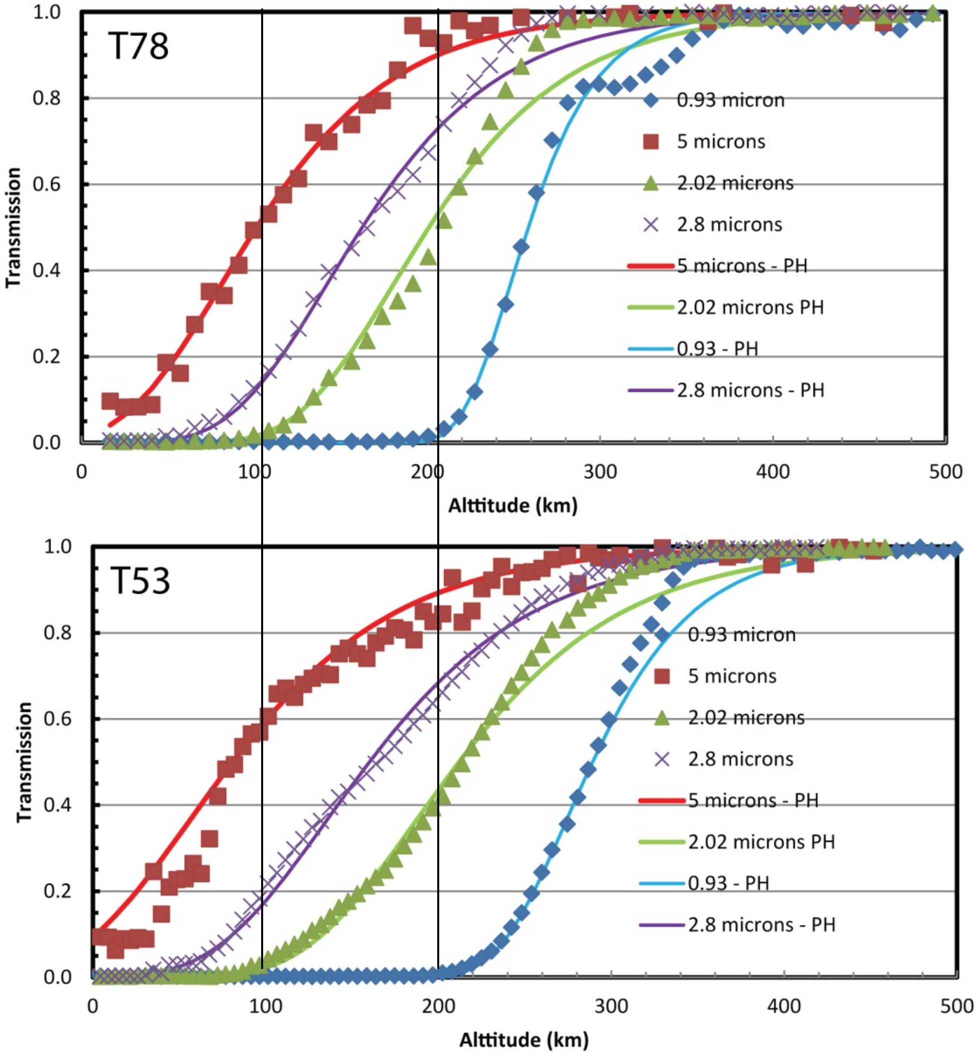
T10 T26 T32 T53 T62 T78

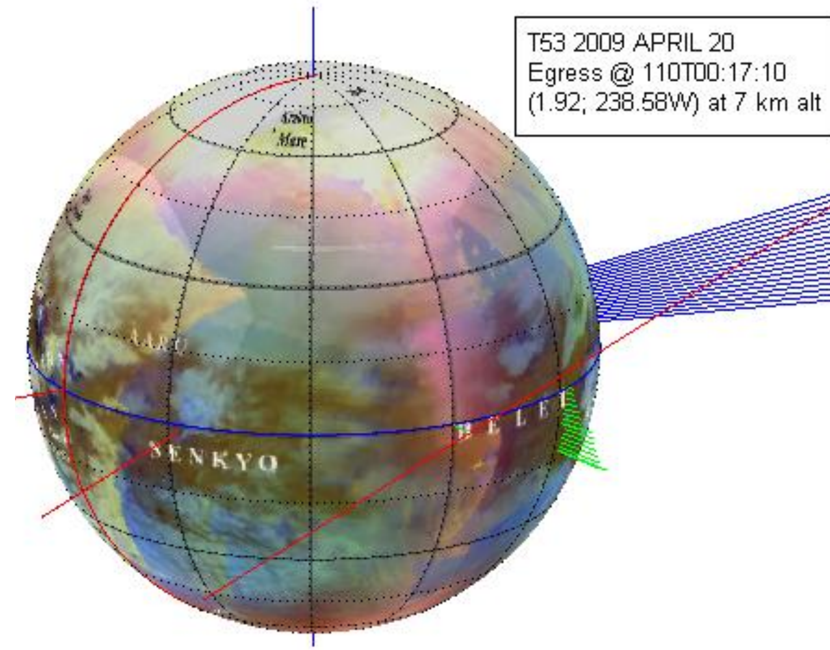
Transmission during T78 ingress solar occ



$$\tau = n_{ref}\sigma_{scat}(\lambda)H_{haze}\exp\left(\frac{Z_{ref}}{H_{haze}}\right)\exp\left(-\frac{z_0}{H_{haze}}\right)\sqrt{2\pi\left(\frac{R}{H_{haze}}+\frac{z_0}{H_{haze}}\right)}$$

T78 and T53


T78
T53
Transmission
Alttitude (km)
Altitude (km)
0.93 micron
5 microns
2.02 microns
2.8 microns
5 microns - PH
2.02 microns PH
0.93 - PH
2.8 microns - PH


T53 2009 APRIL 20
Egress @ 110T00:17:10
(1.92; 238.58W) at 7 km alt
SENKYO

Work still in progress

Questions to be addressed:

- Two different kinds of haze revealed by different scale heights
- Density of the haze varies with latitude and time
- Values of haze opacity in the different atmospheric windows should yield information on the characteristics of the haze

				0.933			2.018			2.799			5 micron band		
Flyby #	lat	long W	day	H0	tau0	exp(-tau)	H0	tau0	exp(-tau)	H0	tau0	exp(-tau)	H0	tau0	exp(-tau)
T10 ingress															
T10 egress	-70	305	1/15/2006	75.0	2.00	5.80	57.50	0.8	38.6	57.5	0.40	62.10	57.5	0.15	83.9
T26 ingress	-75	4	3/10/2007												
T32 ingress	-42	96	6/13/2007												
T53 egress	2	238	4/20/2009	40.0	45.00	0.00	65.00	1.1	48.8	65.0	0.50	72.20	65.0	0.15	90.7
T62 ingress	-22	235	10/12/2009												
T62 egress	-85	51	10/12/2009												
T78 ingress	43	156	9/12/2011												
T78 egress	35	175	9/12/2011	28	280	0	55	1.5	17.9	55	0.75	42.3	55	0.25	75.1

Conclusions

The Cassini-Huygens mission has shed light on Titan’s atmospheric organic factory. The data provide information on:

- the density of aerosols in Titan’s atmosphere
- the size of aerosol particles

Future missions will build upon the discoveries of the Cassini-Huygens mission by determining the composition and the structure of these aerosols.

- Only probes can perform such analysis.

The density of the organic aerosols being small, a probe should

- collect aerosols at different altitudes in different containers for future analysis once the probe has landed,
- do in-situ analysis for threshold science to be acquired before hazardous landing