Titan Haze*

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*This presentation is associated with a book chapter of the same title. Co-authors are Panayotis Lavvas, Carrie Anderson, and Hiroshi Imanaka

Topics

- Relevant Observations
  - Vertical Distribution
  - Optical Properties
  - Physical Properties
  - Composition
- Microphysical Models
- Laboratory Studies
- Evolution of the detached haze and what it can tell us about dynamics and microphysics

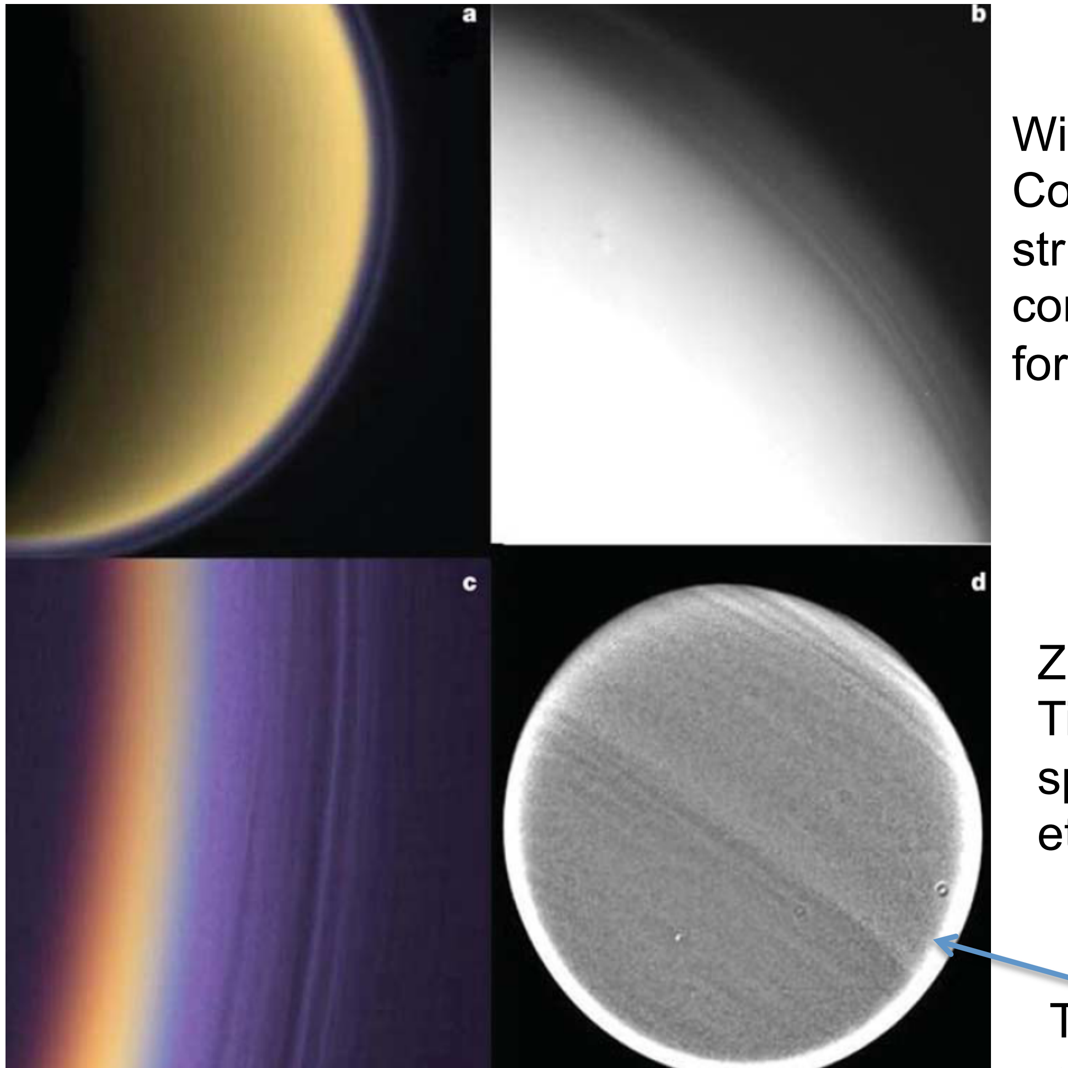
Strong ties to other Titan science

- For Dynamics:
  - Radiative heating and cooling by haze
  - Provides clues to seasonal behavior
  - Constrains and plays a role in General Circulation Models and may be important for super-rotation
- For Chemistry
  - A sink for photochemistry starting from the gas phase
  - A source of organics on the surface
- Profoundly affects surface visibility below 5 μm

Components of Titan's Haze

Main and detached haze. Hemispheric contrast and altitude variations with different seasonal phase lags

Fine structure



Winter polar vortex. Complicated structure and condensate formation.

Zonal structure. Tilted from Titan spin axis (Roman et al., 2009)

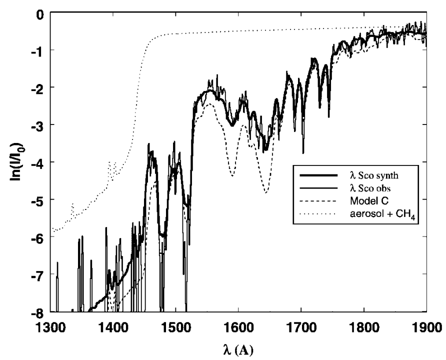
Tropical haze band de Kok et al. 2010

Porco et al. *Nature* **434** 159, 2005

Vertical Distribution

Occultation Results: UV (UVIS)

L200 LIANG, YUNG, & SHEMANSKY Vol. 661



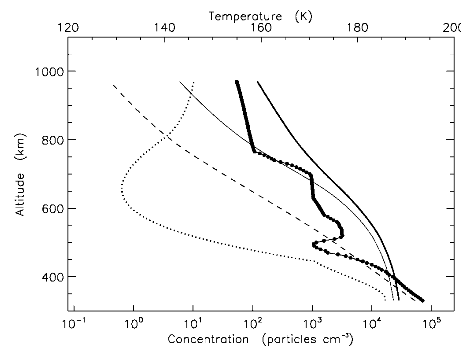


FIG. 2.—Aerosol density (*filled circles*) derived from the UVIS λ Sco oc-

Latitude 36° S
December 13, 2004

Liang et al., Astrophysical Journal, 661: L199–L202, 2007

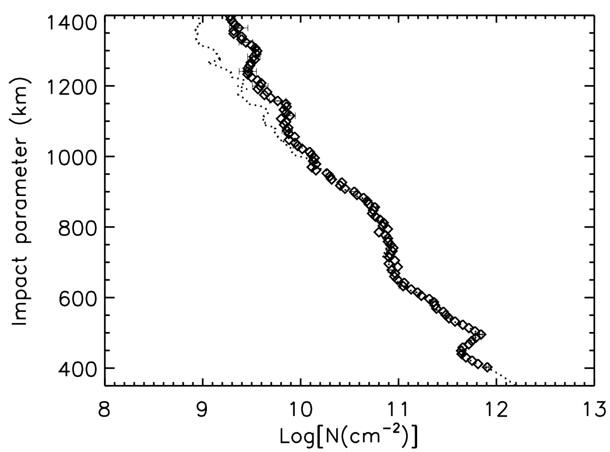
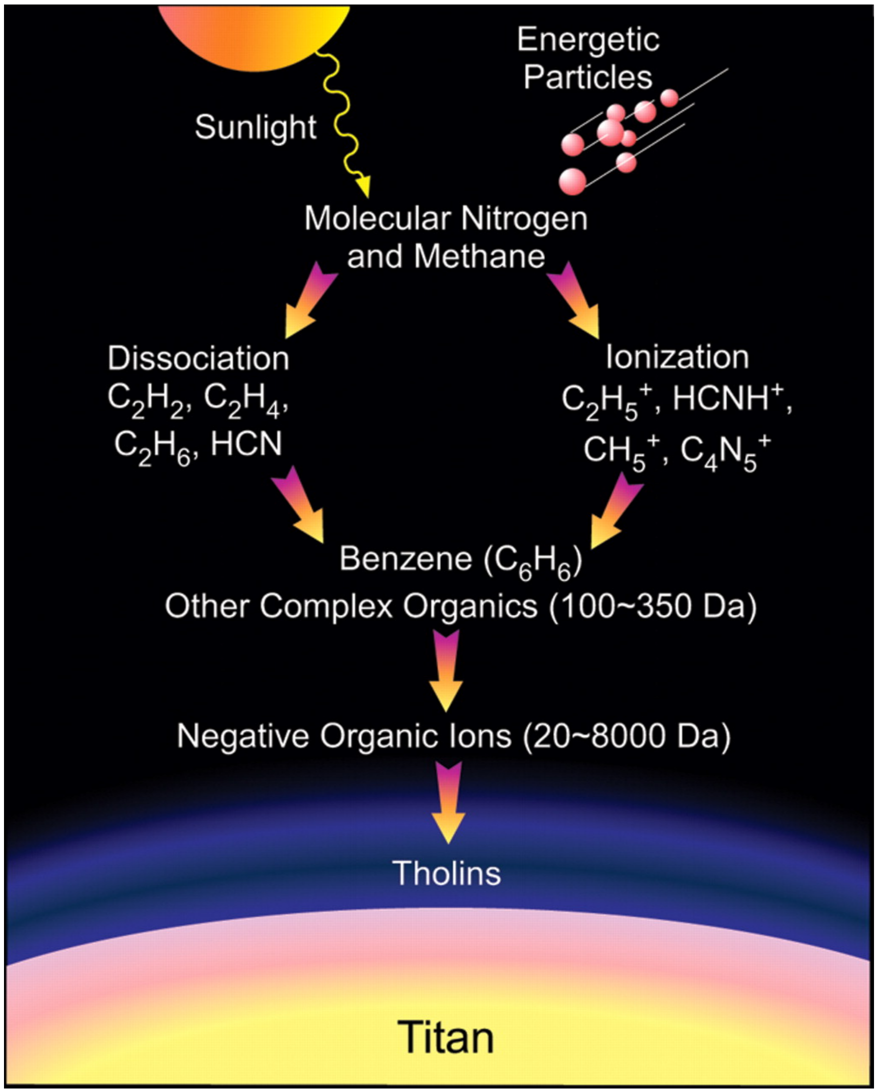


FIG. 7.— Column density profile of spherical tholins with a radius of r_a = 12.5 nm retrieved from synthetic T41 I data. The input column density profile is shown by the dotted lines.

Koskinen et al. 2011
Latitude 6° S
February 23, 2008

These imply <u>unbelievable</u> radiative heating rates – Roger Yelle will elaborate.

From CH_4 and N_2 to aerosols



What goes up (methane, nitrogen) comes back down as more complex organics, nitriles, and 'tholin' haze

Figure from Waite, JH Jr., et al.(2007) The process of tholin formation in Titan's upper atmosphere. *Science* **316**:870–875

Occultation Results: Near – IR (VIMS)

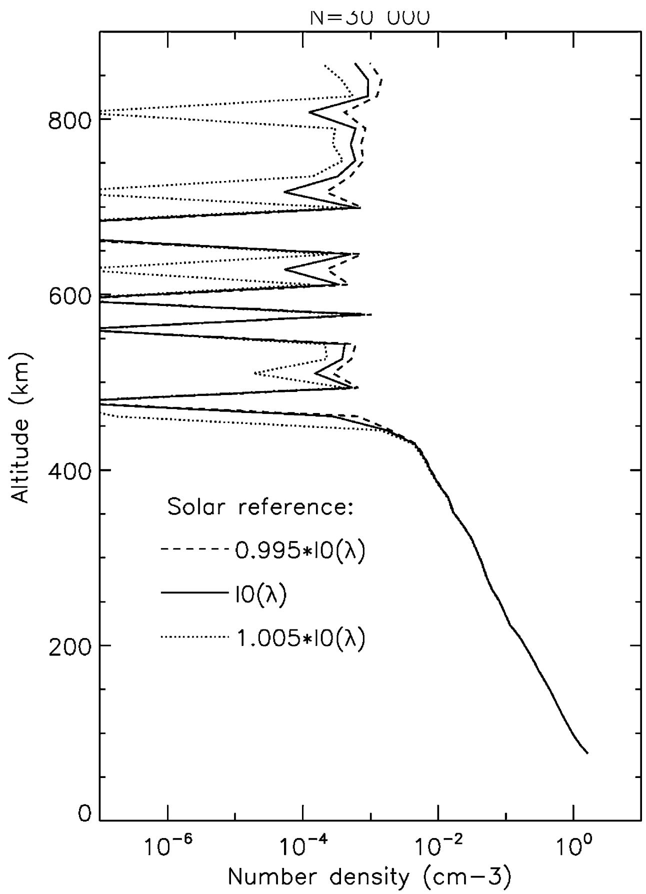


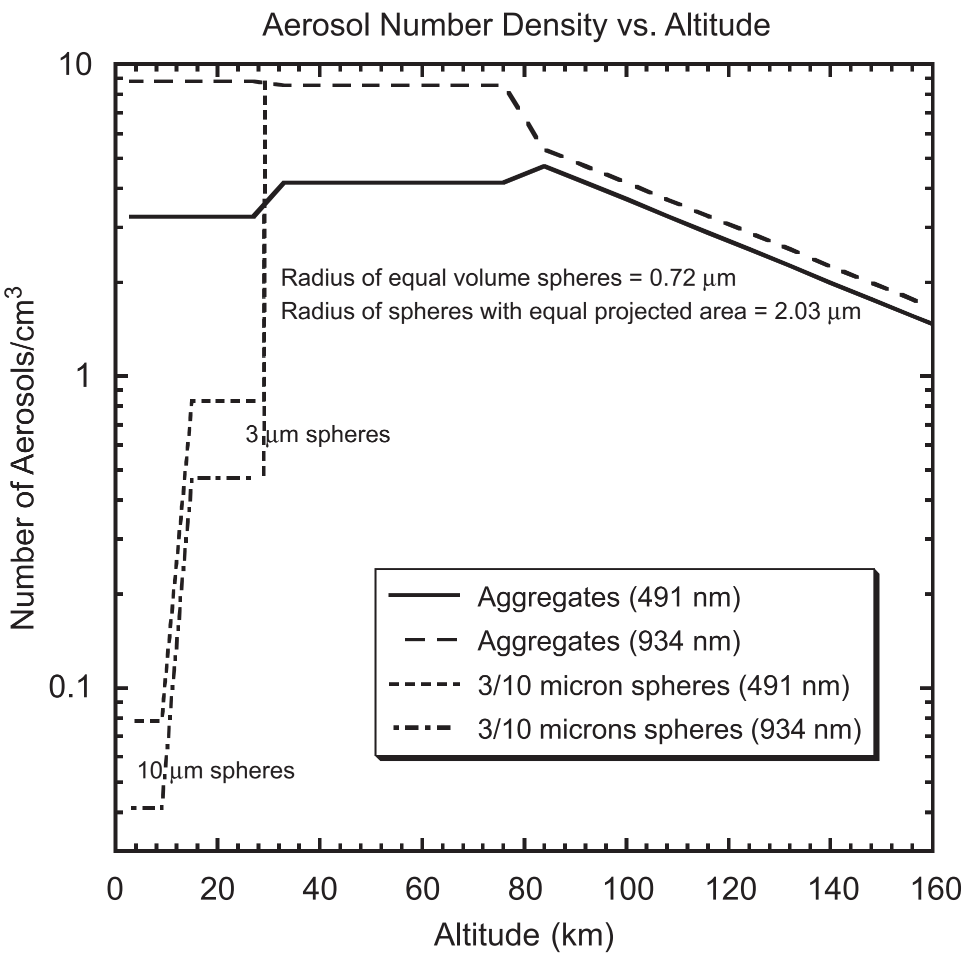
Fig. 14. Number density profile for aggregate of 30,000 spheres. The three profile were calculated using three values of the reference solar spectrum: $I_0(\lambda)$ (straight line), $0.995 \times I_0(\lambda)$ (dashed line), $1.005 \times I_0(\lambda)$ (dotted line).

Bellucci et al., *Icarus* **201** 198–216, 2009

Latitude 71° S
January 15th, 2006

Fall–off with scale height 60 km below 500 km altitude

Vertical Profiles from the Descent Imager and Spectral Radiometer



Tomasko et al.,
Planetary and Space Science
56 (2008) 669–707

Latitude -10
January 15, 2005

Optical Properties

The Haze is Highly Polarizing

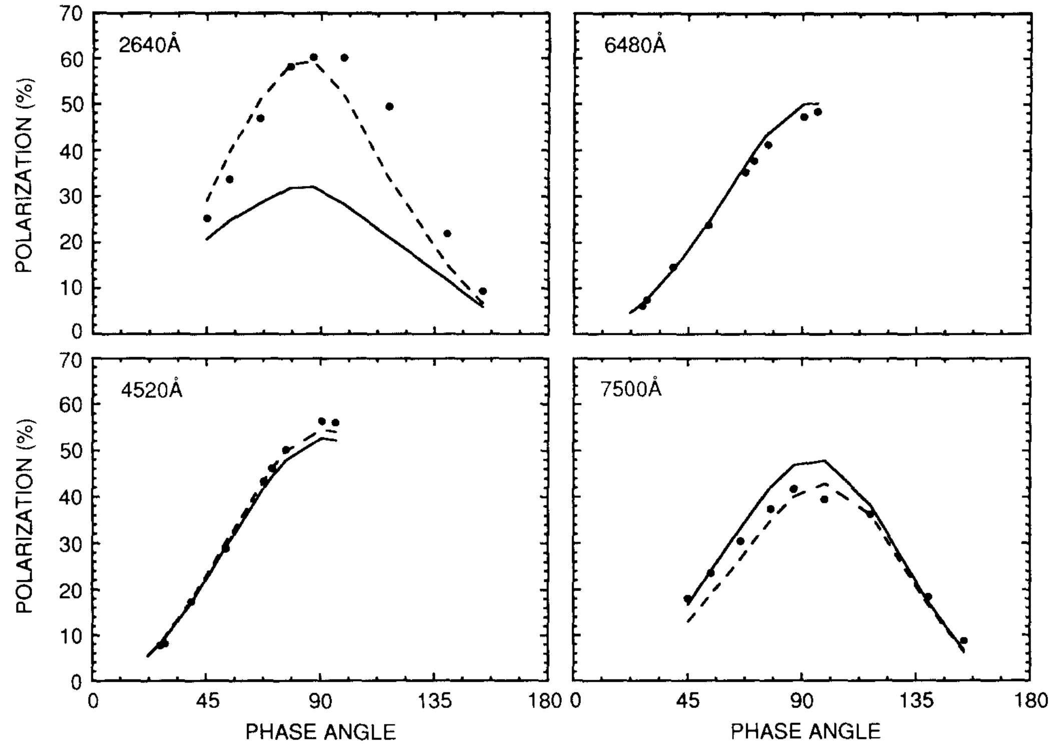
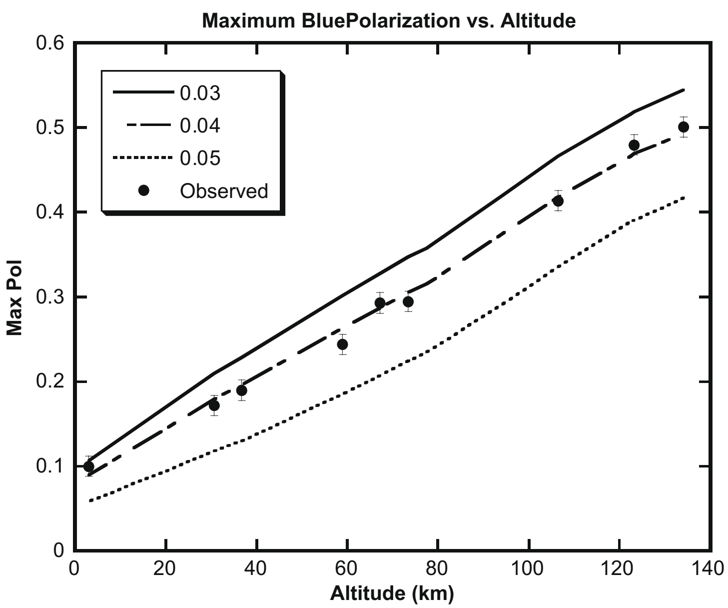
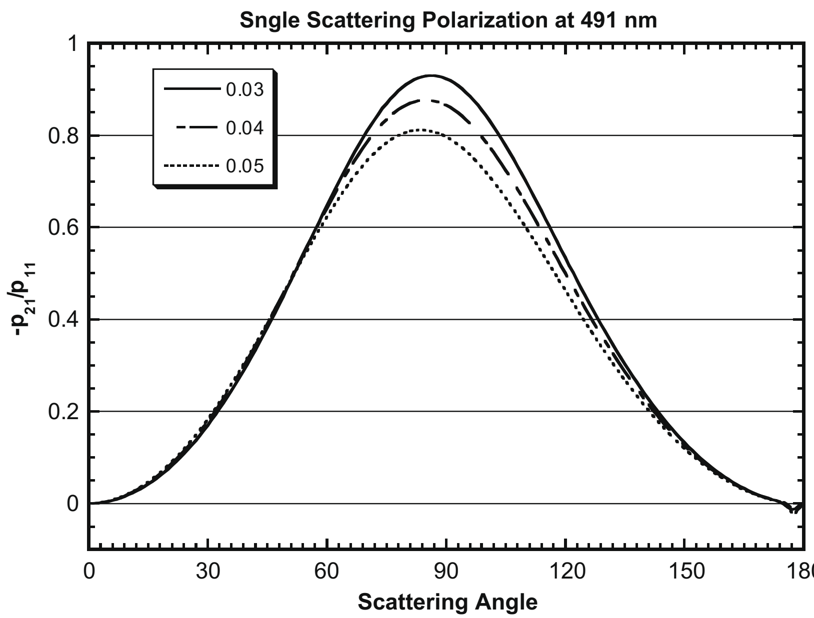


FIG. 3. Pioneer 11 and Voyager 2 polarization measurements of Titan compared with predictions for a plane-parallel, semi-infinite atmosphere of type II particles having monomers with radius 0.06 μm. In order to fit Titan's geometric albedo the imaginary index of refraction of these particles is 0.21, 0.085, 0.023, and 0.013 at wavelengths 2640, 4520, 6480, and 7500 Å (continuous curves). The real index is close to 1.7 (based on laboratory work of Khare *et al.*, 1984). The models shown by the dashed curve at the two shortest wavelengths incorporate a second size mode of 0.03-μm-radius spheres (17% of the phase function is contributed by these particles in the UV, 4% in the blue). The dotted curve at 7500 Å shows the depolarizing influence of the surface when the atmosphere becomes less optically thick (optical depth 0.5) at 7500 Å. Error bars are no larger than the size of the dots.

From West and Smith, *Icarus* **90**, 330-333 (1991)

Blue Polarization from DISR





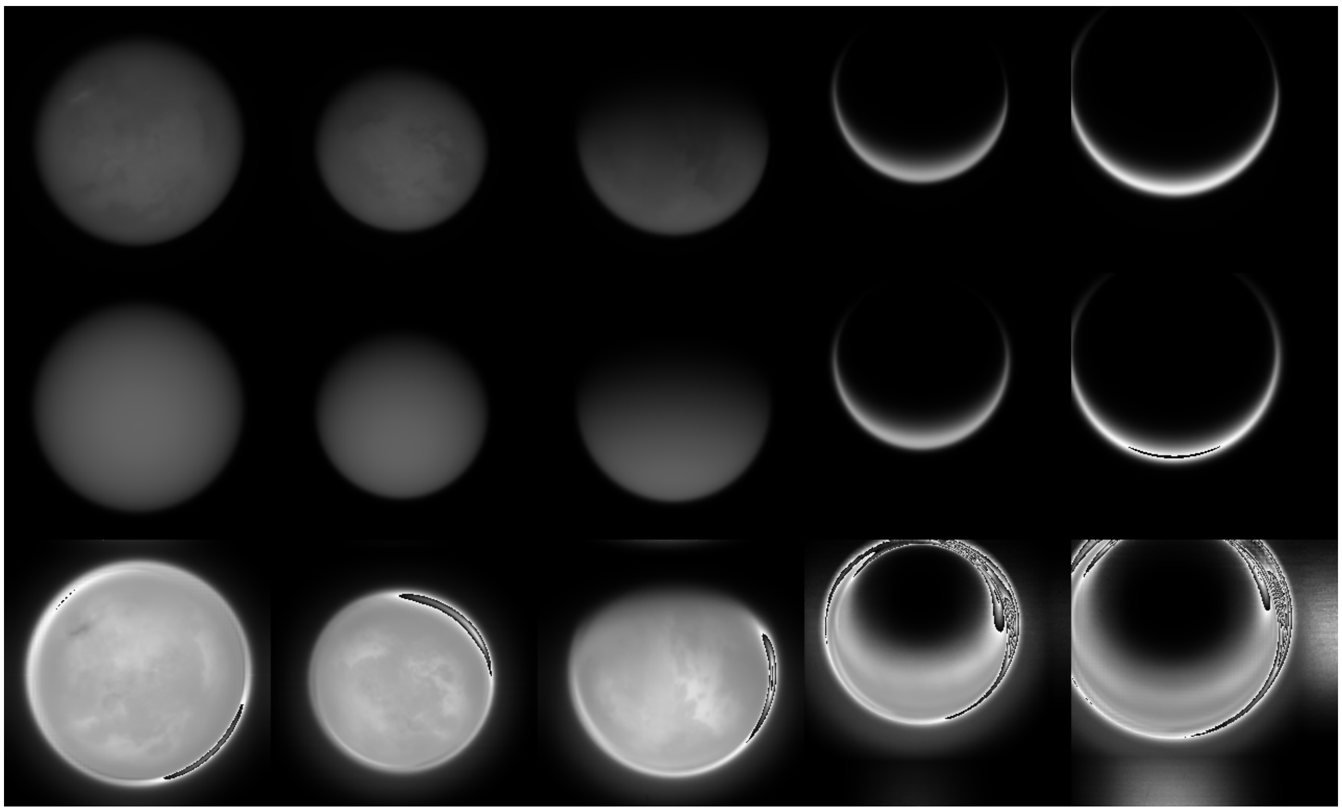
Tomasko et al., *Icarus* **204**, 2009, 271-283

Titan Reflectivity at 938 nm

Strong Forward Scattering is Apparent

Phase Angle (180 – scattering angle)

10 24 60 137 147

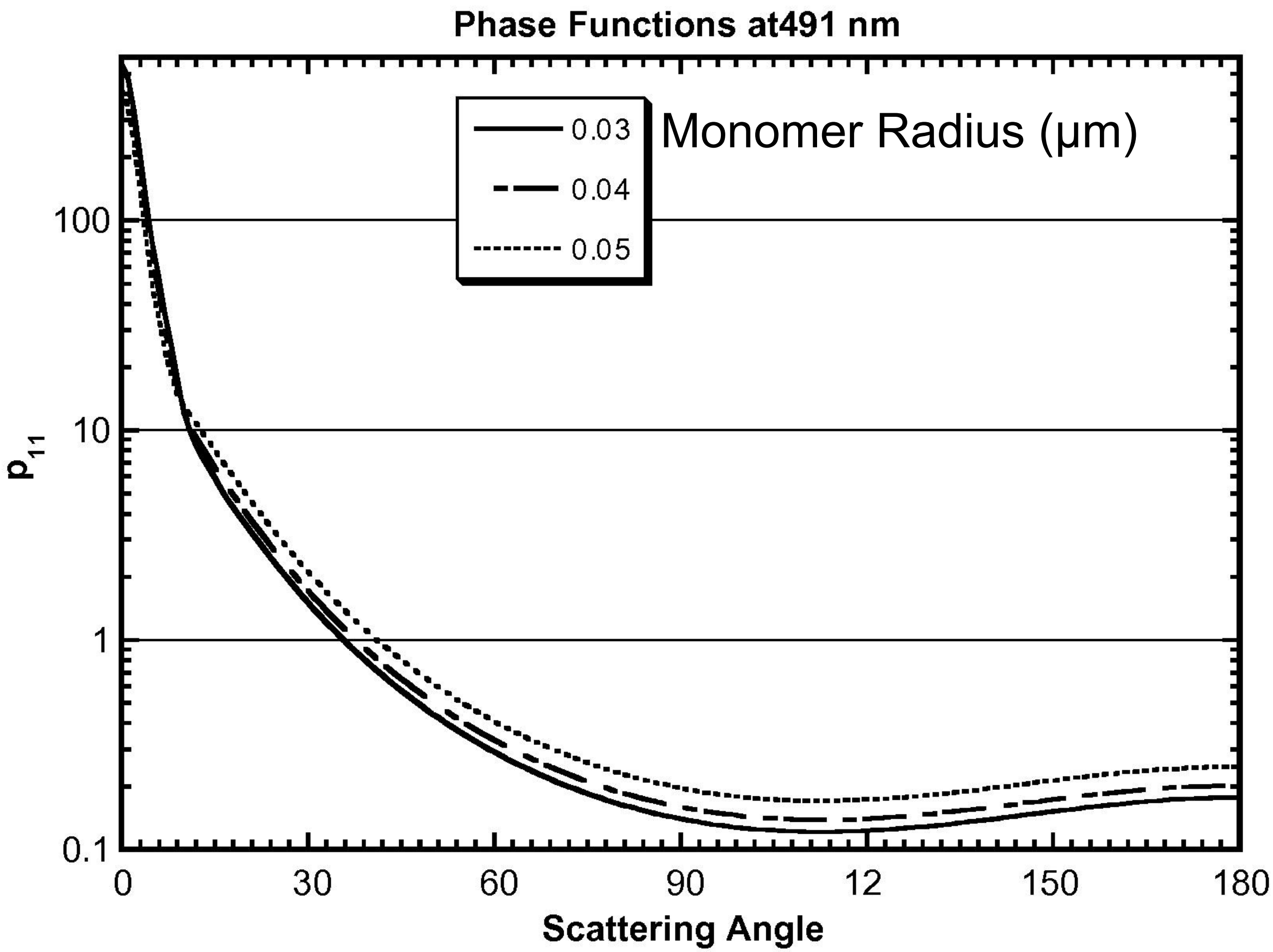


Data from ISS

Model:
Spherical Shell
Radiative Transfer

Ratio

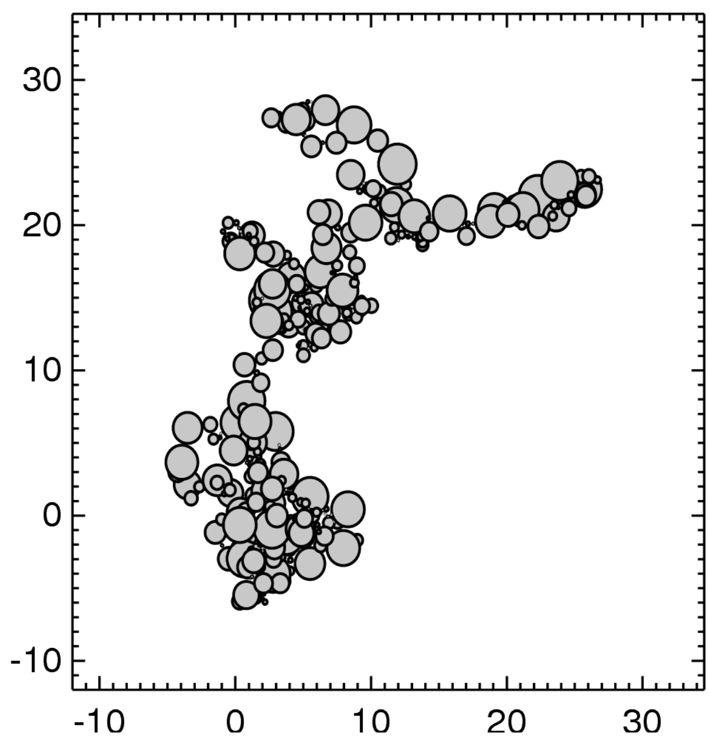
Phase Function, Blue Channel from DISR

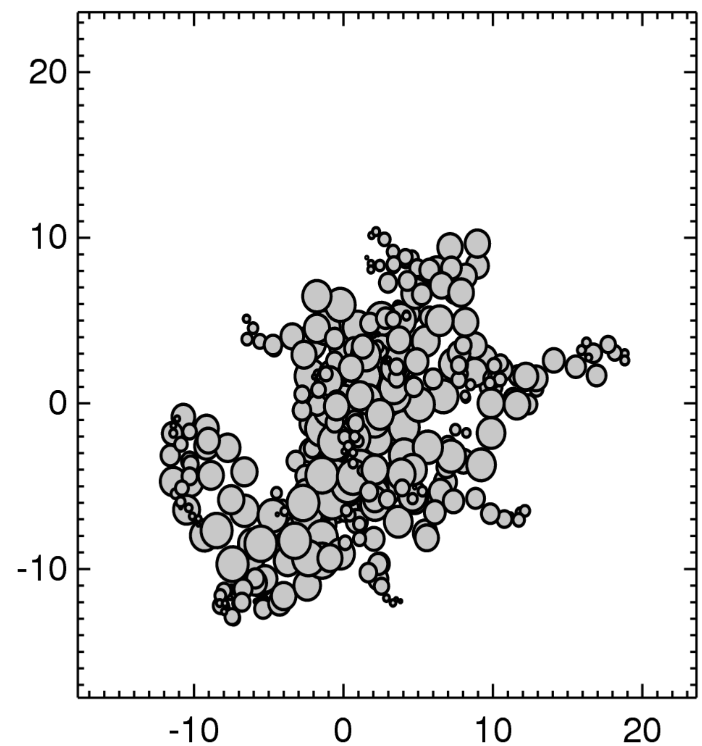


from Tomasko et al. 2009

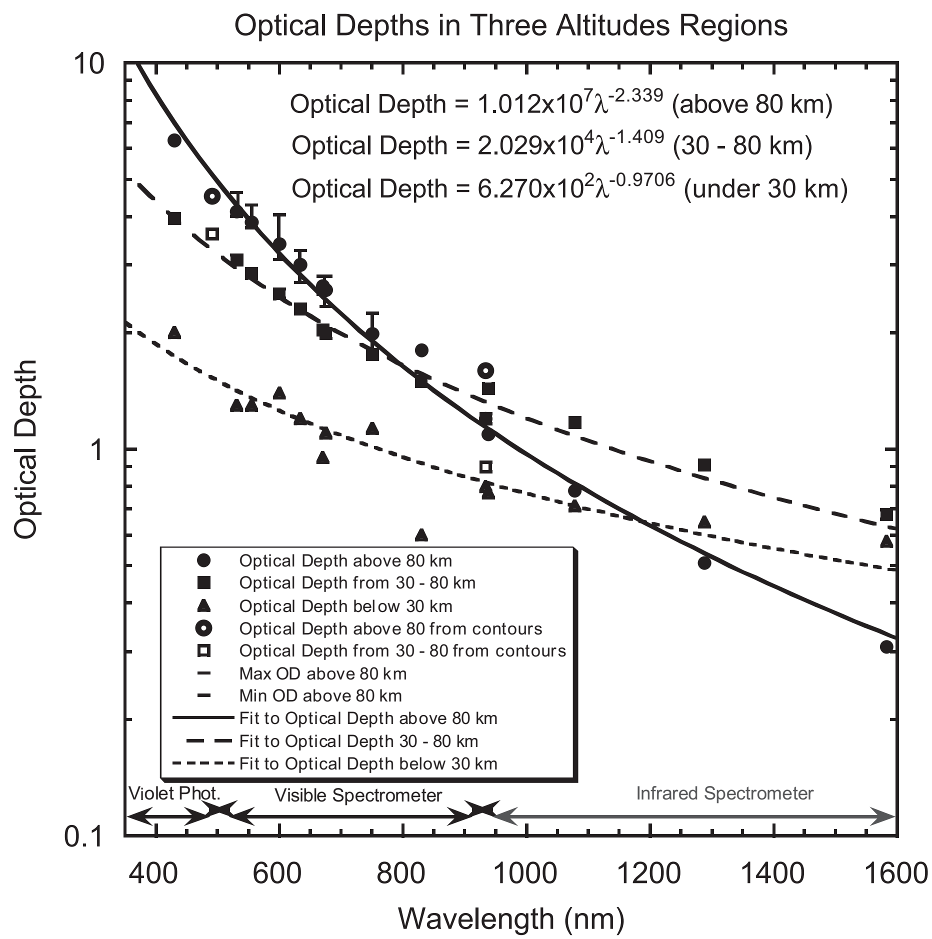
Aggregate Structures can be both Highly Polarizing and Strongly Forward Scattering

However, Compact Structures are not Highly Polarizing





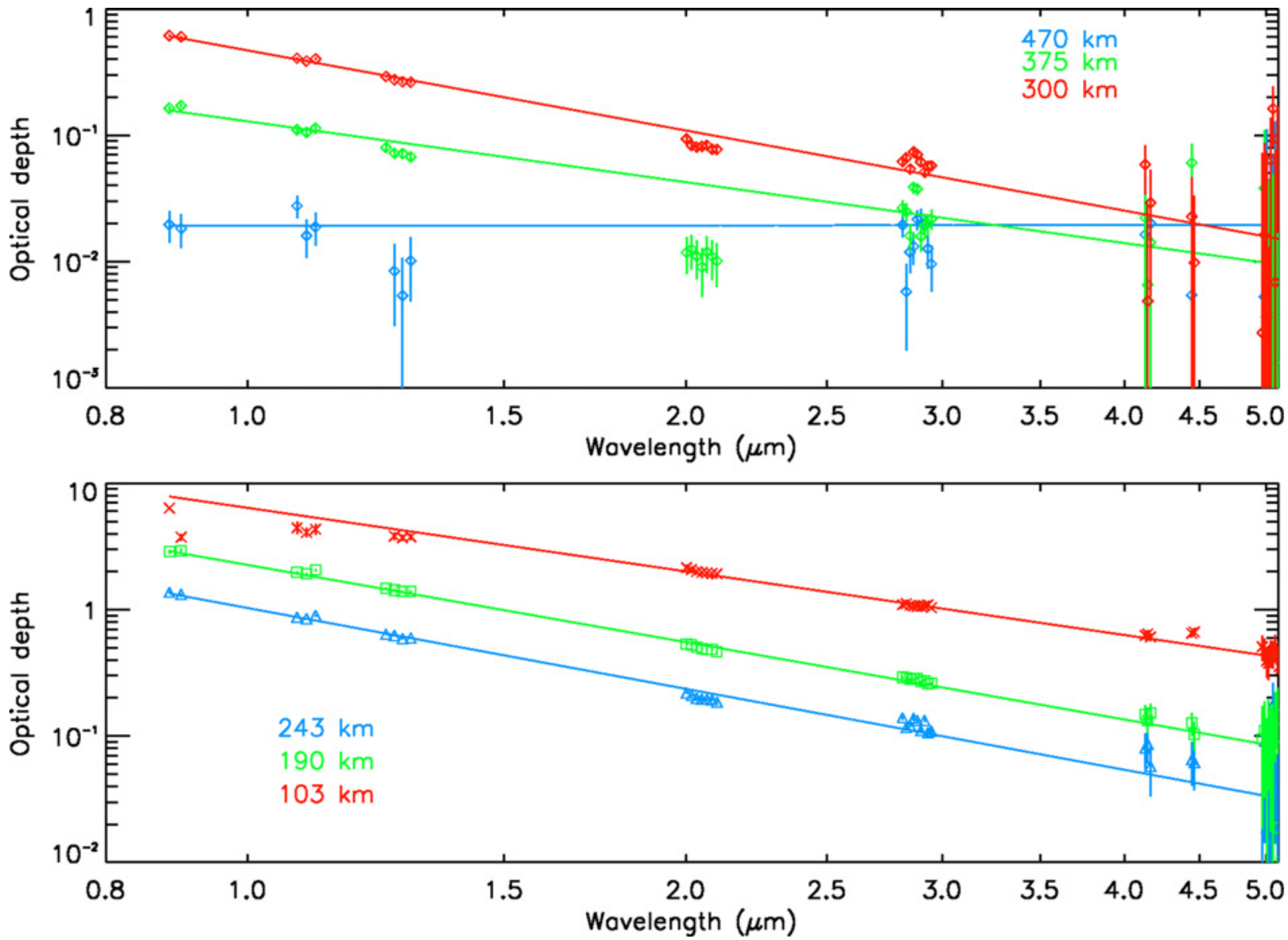
Optical Depth from DISR



Tomasko et al., 2008

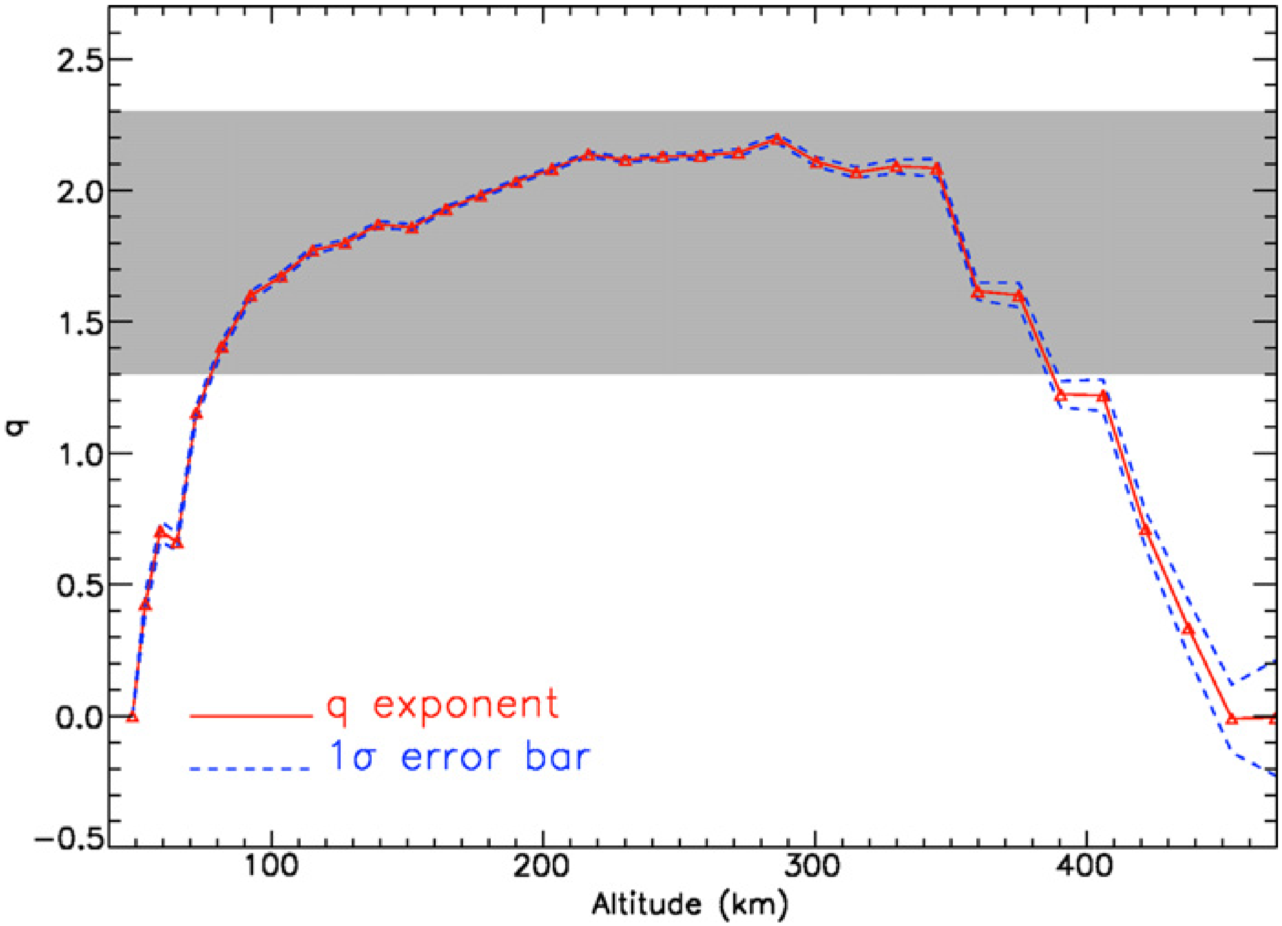
Optical Depth from VIMS Solar Occ

A. Bellucci et al. / Icarus 201 (2009) 198–216



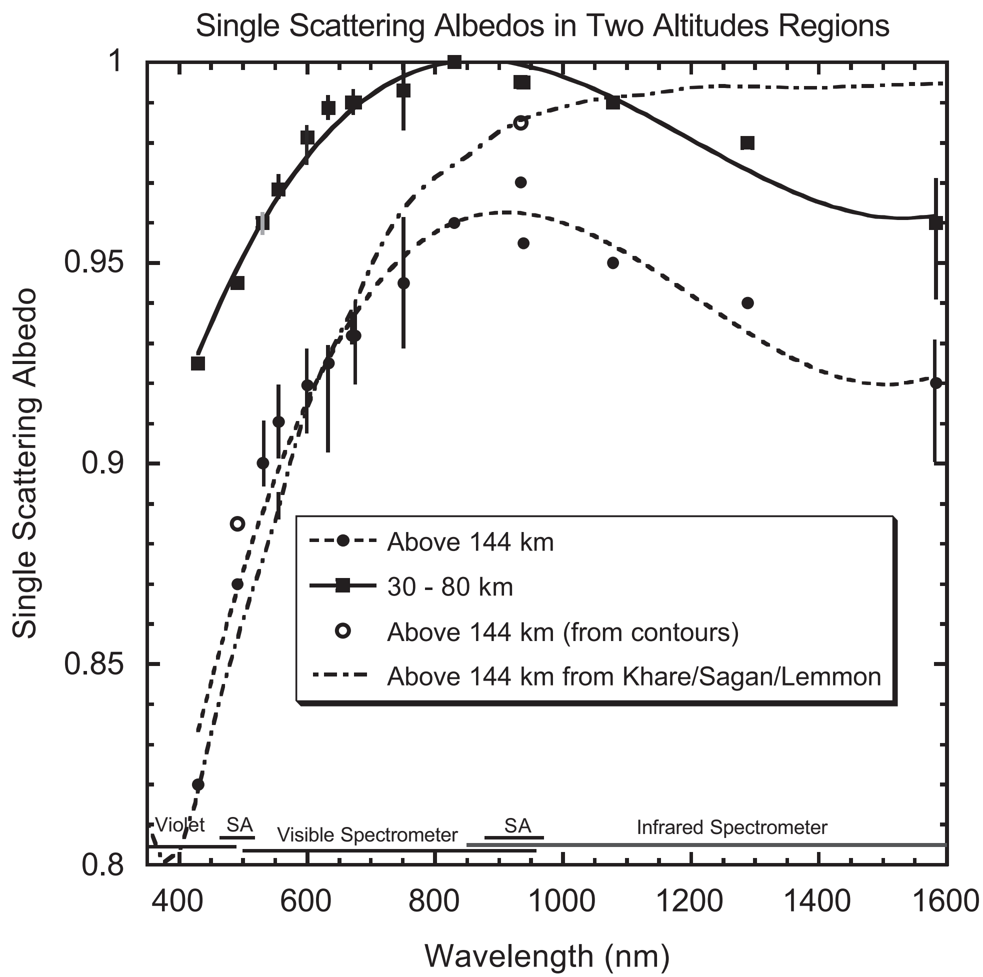
Spectral Slope

18 *A. Bellucci et al. / Icarus*



Shaded region from
Sicardy et al., 2006,
J. Geophys. Res.
111, E11S91

Particle Single-Scatter Albedo

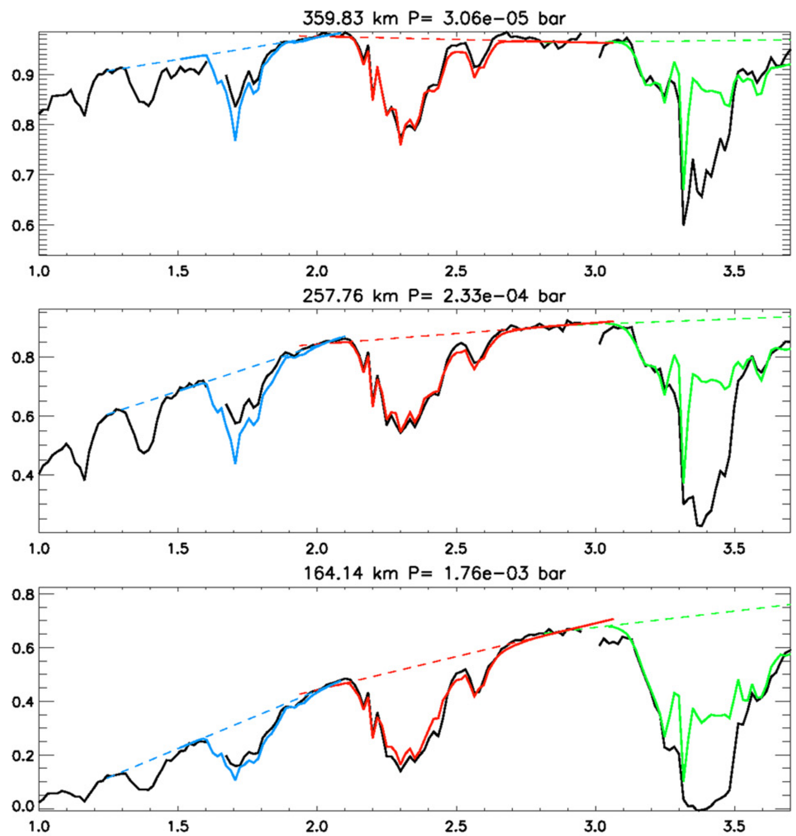


Constraints on Composition

- Broad spectral characteristics: Strong absorption at blue/UV wavelengths, little absorption in the red, increasing absorption in the near-IR, less absorption below 30 km
- C-H absorption feature seen in VIMS solar occultation (Bellucci et al., 2009)
- Spectral features in the thermal-IR, especially in the winter polar vortex – Carrie Anderson will discuss this

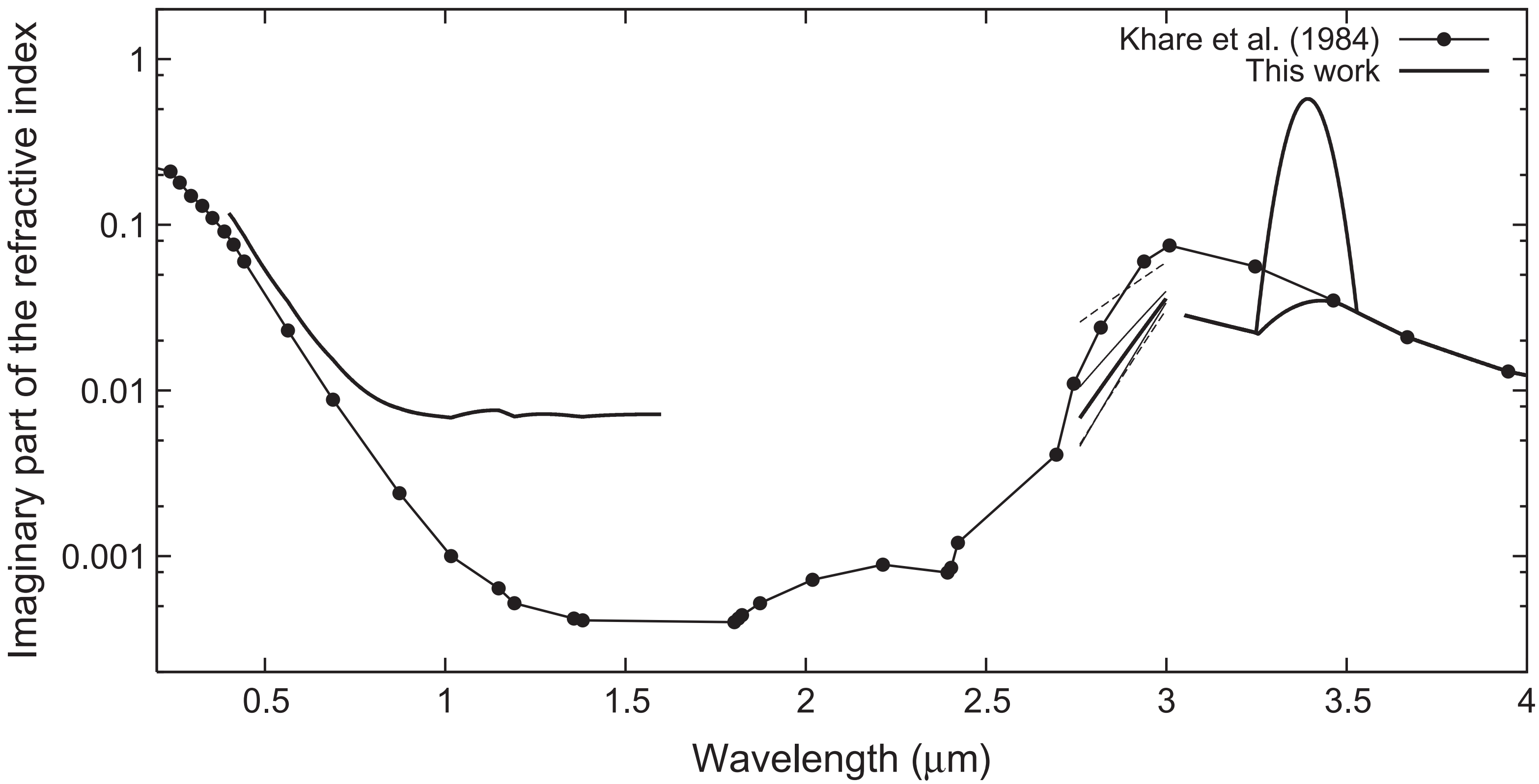
Feature at 3.3 μm

A. Bellucci et al. / Icarus 201 (2009) 198–216



"Under 480 km, the 3.3 μm CH_4 band is mixed with a large and deep additional absorption. It corresponds to the C–H stretching mode of aliphatic hydrocarbon chains attached to large organic molecules." Bellucci et al., 2009

Refractive Index from Rannou et al. analysis of the VIMS Solar Occ



Rannou et al., *Icarus* **208** (2010) 850–867

Haze Microphysical Models

- Models try to account for
  - Gas -> Particle conversion
  - Growth from vapor
  - Sticking and electric charge
  - Size evolution
  - Aggregation
  - Sedimentation and (for 2-Dimensional models) advection

Models with Aggregation

- Cabane M, Chassefiere E, Israel G (1992) Formation and growth of photochemical aerosols in Titan's atmosphere*.* *Icarus* **96**, 176–189
- Cabane M, Rannou P, Chassefiere E, Israel G (1993) Fractal aggregates in Titan's atmosphere*. Planet Space Sci* **41**, 257–26
- Rannou P, Cabane M, Chassefiere E, Botet R, McKay CP, Courtin R (1995) Titan's geometric albedo: role of the fractal structure of the aerosols*. Icarus* **118**, 355–372
- Rannou, P., F. Hourdin, and C. P. McKay (2002), A wind origin for Titan's haze structure, *Nature*, **418**, 853–85
  - Haze advected upward from the main haze layer forms the detached haze
- Lavvas, P., R. V. Yelle, and V. Vuitton (2009), The detached haze layer in Titan's mesosphere, *Icarus*, **201**, 626–633
  - The detached haze is a signature of the aggregation process
- Rodin AV, Keller HU, Skorov YuV, Doose L, Tomasko MG (2009) Microphysical processes in Titan haze inferred from DISR/Huygens data. *In preparation*
  - Monomer size depends on charging, not a function of altitude
- Some pros and cons will be presented below regarding the detached haze

Laboratory Simulations

- Haze formation is a complex set of processes, both chemical and physical, and depend on altitude
- Laboratory simulations may reveal their nature
- Issues include the relative importance of C-H versus N-H-C bonds, functional groups (polyacetylenes, PAHs, HCN-related compounds, etc.), rates of formation, size and shapes of solid products, refractive index, solubility,…

A Classic Laboratory Example

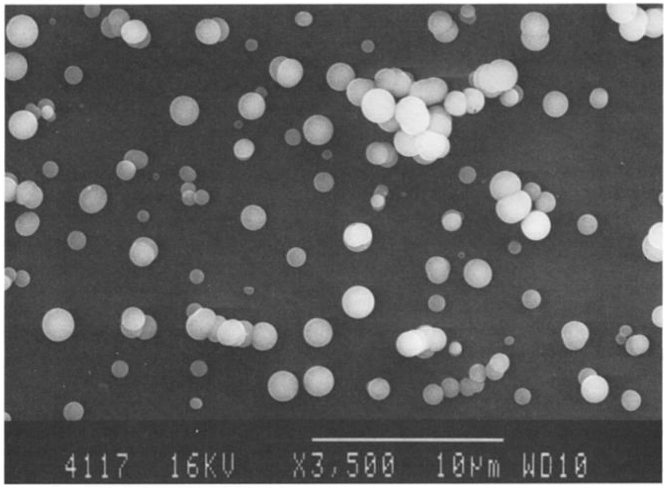
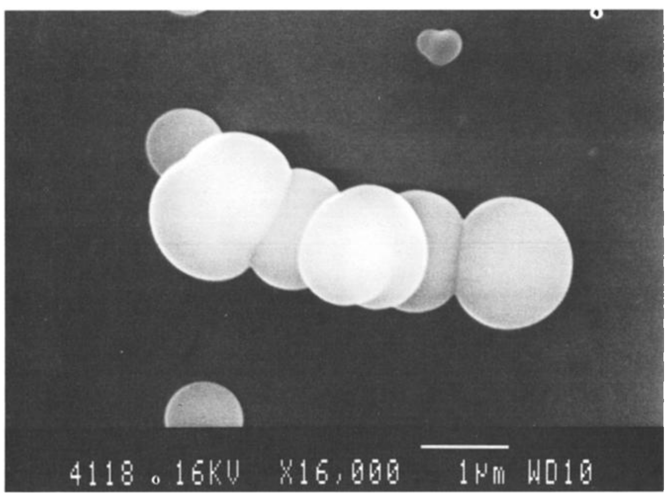


Fig. 1a



From Bar Nun et al., (1988) Shape and Optical Properties of Aerosols Formed by Photolysis of Acetylene, Ethylene, and Hydrogen Cyanide, *J. Geophys. Res*., **93,** 8383-8387

This work provided impetus for my investigation of the optical properties of aggregate particles which led to

West, R.A., and Smith, P.H., (1991) Evidence for aggregate particles in the atmospheres of Titan and Jupiter. *Icarus* **90**, 330–333

Lab Parameters vs. Titan

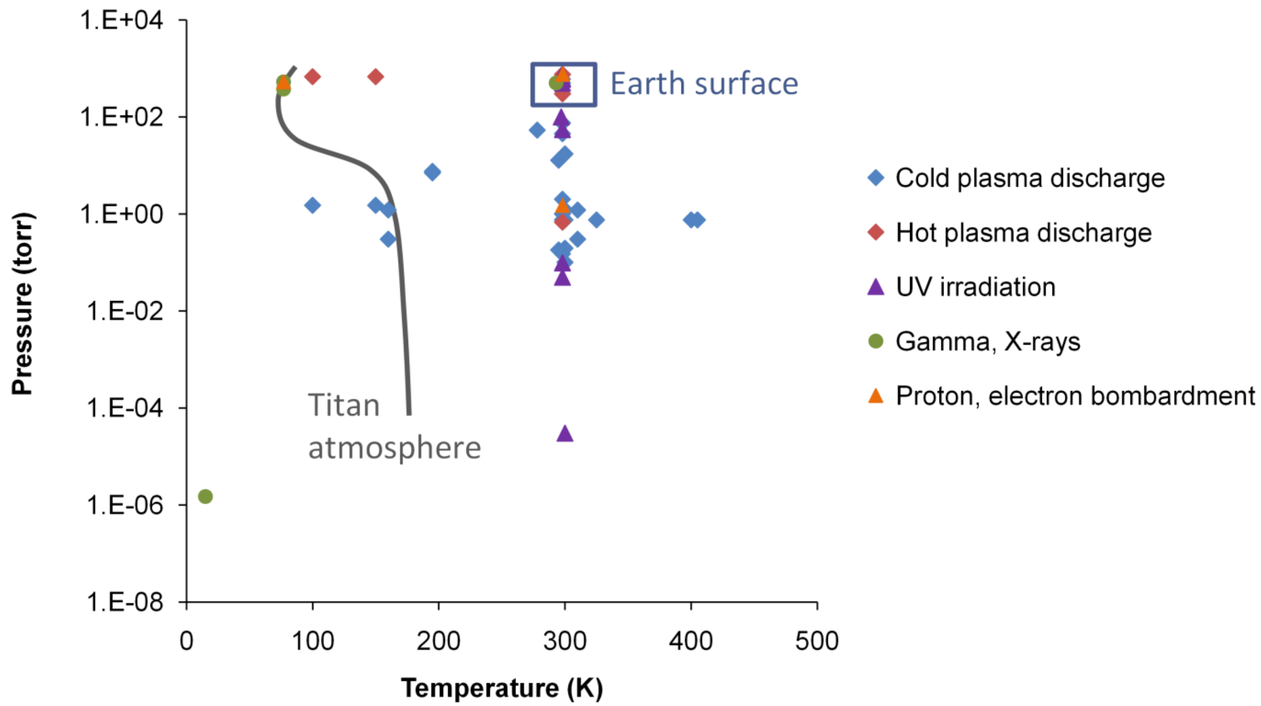


Fig 7 Plot of the temperature and pressure parameters for various tholin generation methods. Note that few methods fall along the profile of Titan's atmosphere.

Source:

Titan Tholins: Simulating Titan Organic Chemistry in the Post Cassini-Huygens Era, submitted to *Chemical Reviews*

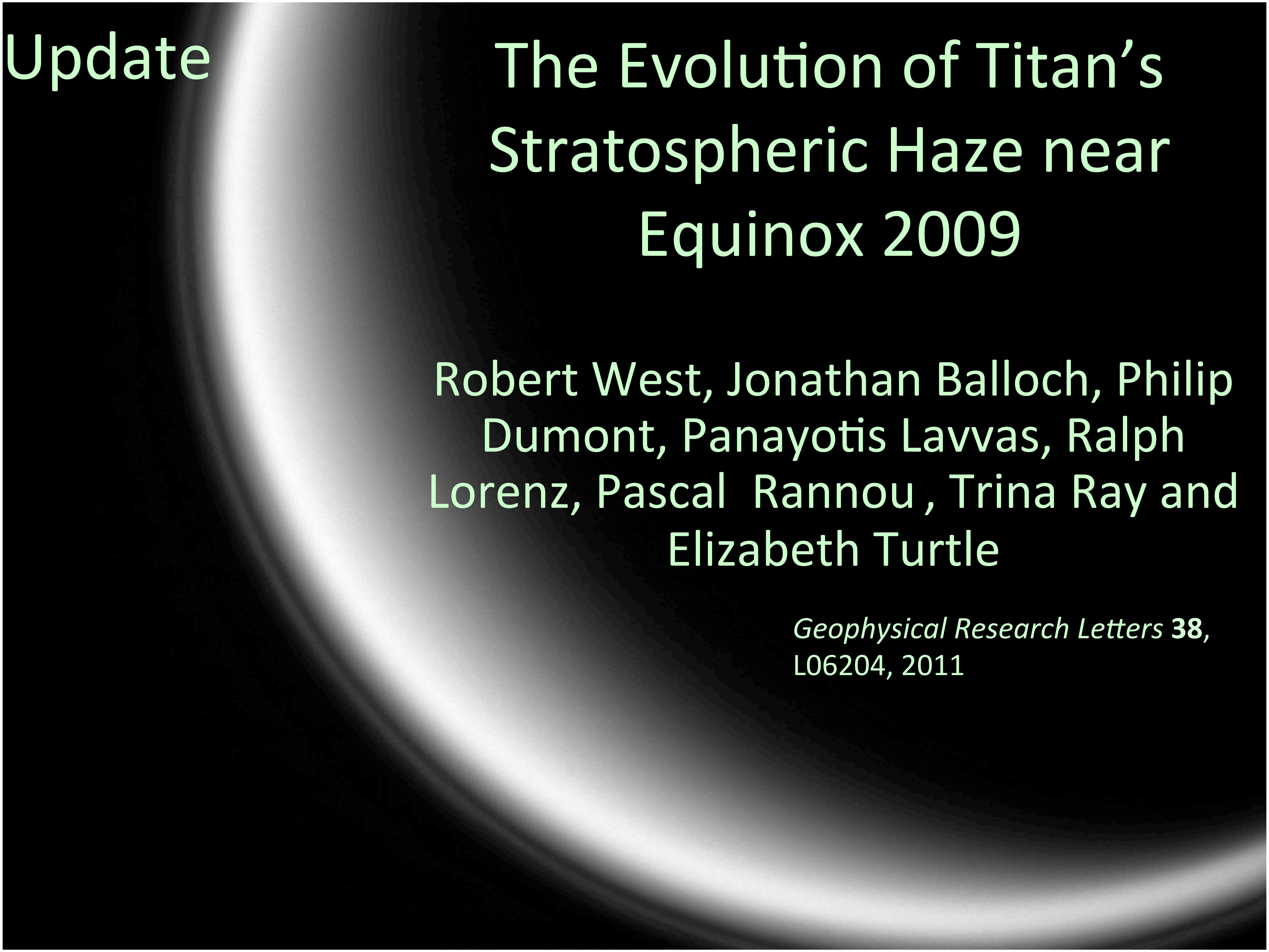
Morgan L. Cable, Sarah M. Hörst, Robert Hodyss, Patricia M. Beauchamp, Mark A. Smith and Peter A. Willis

Update

The Evolution of Titan's Stratospheric Haze near Equinox 2009

Robert West, Jonathan Balloch, Philip Dumont, Panayotis Lavvas, Ralph Lorenz, Pascal Rannou, Trina Ray and Elizabeth Turtle

Geophysical Research Letters **38**, L06204, 2011



Voyager 2 Epoch (1981)

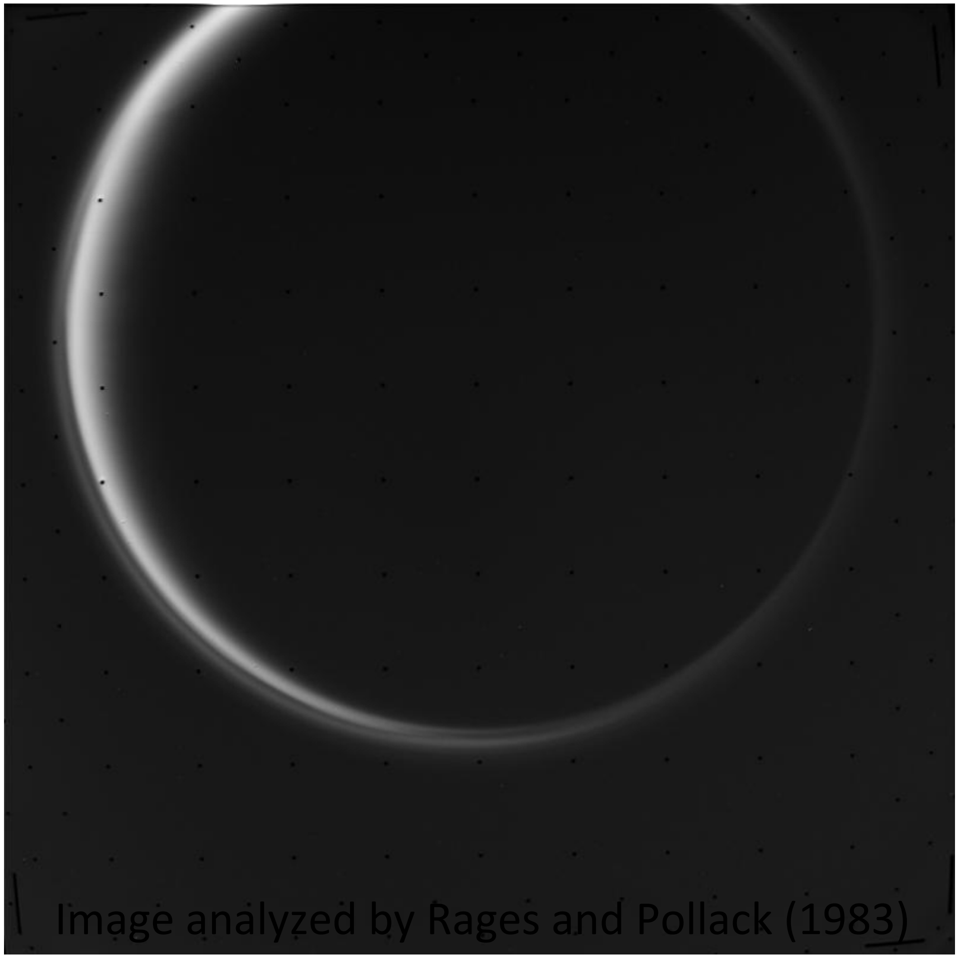
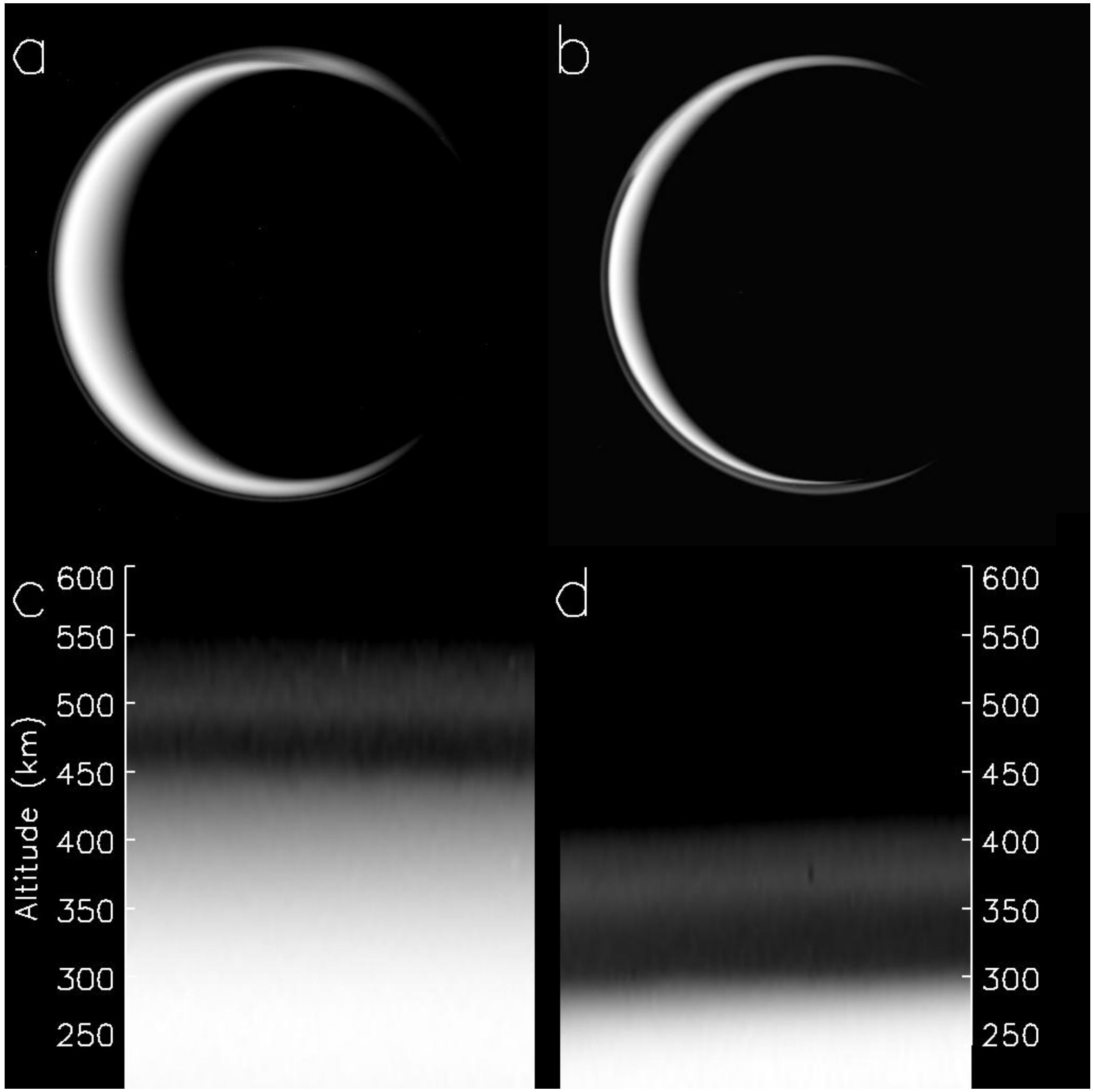
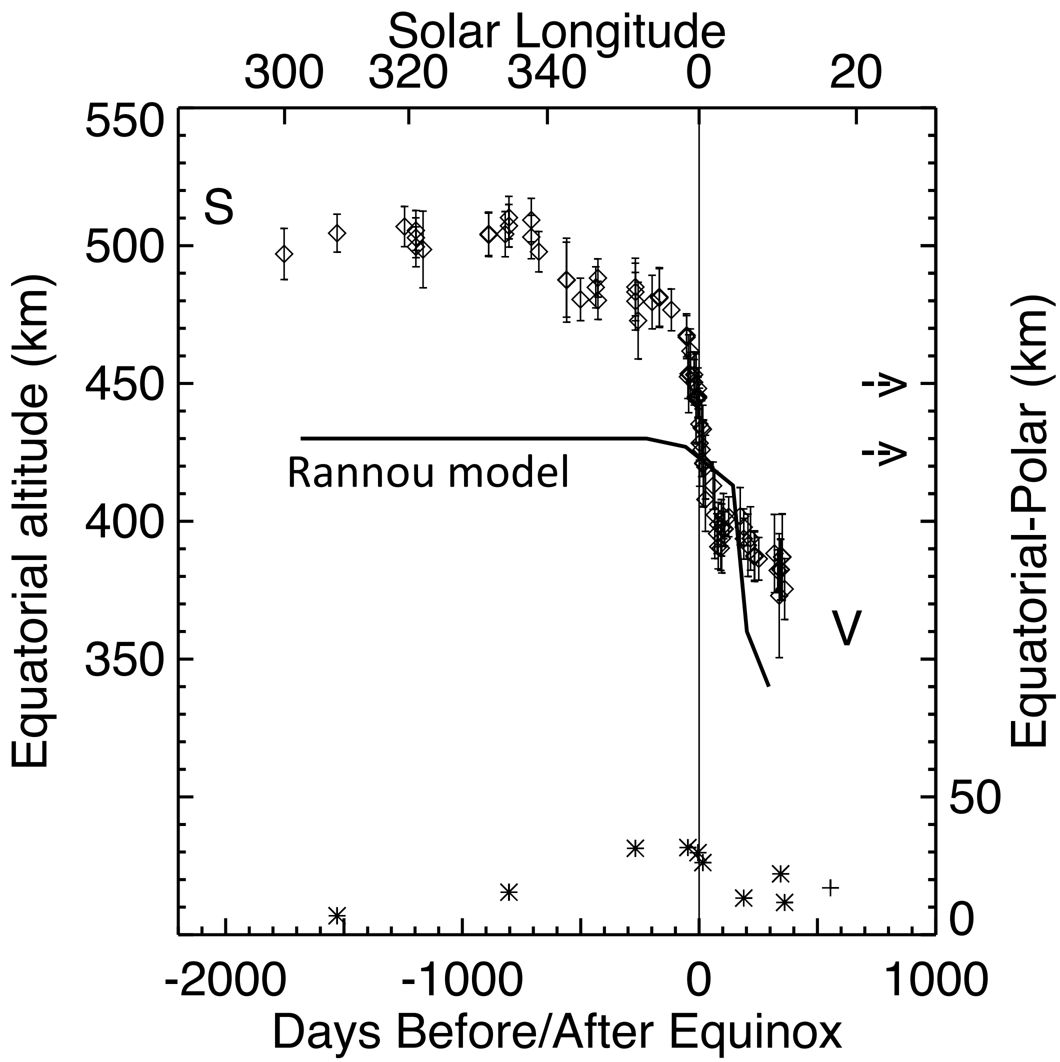


Image analyzed by Rages and Pollack (1983)

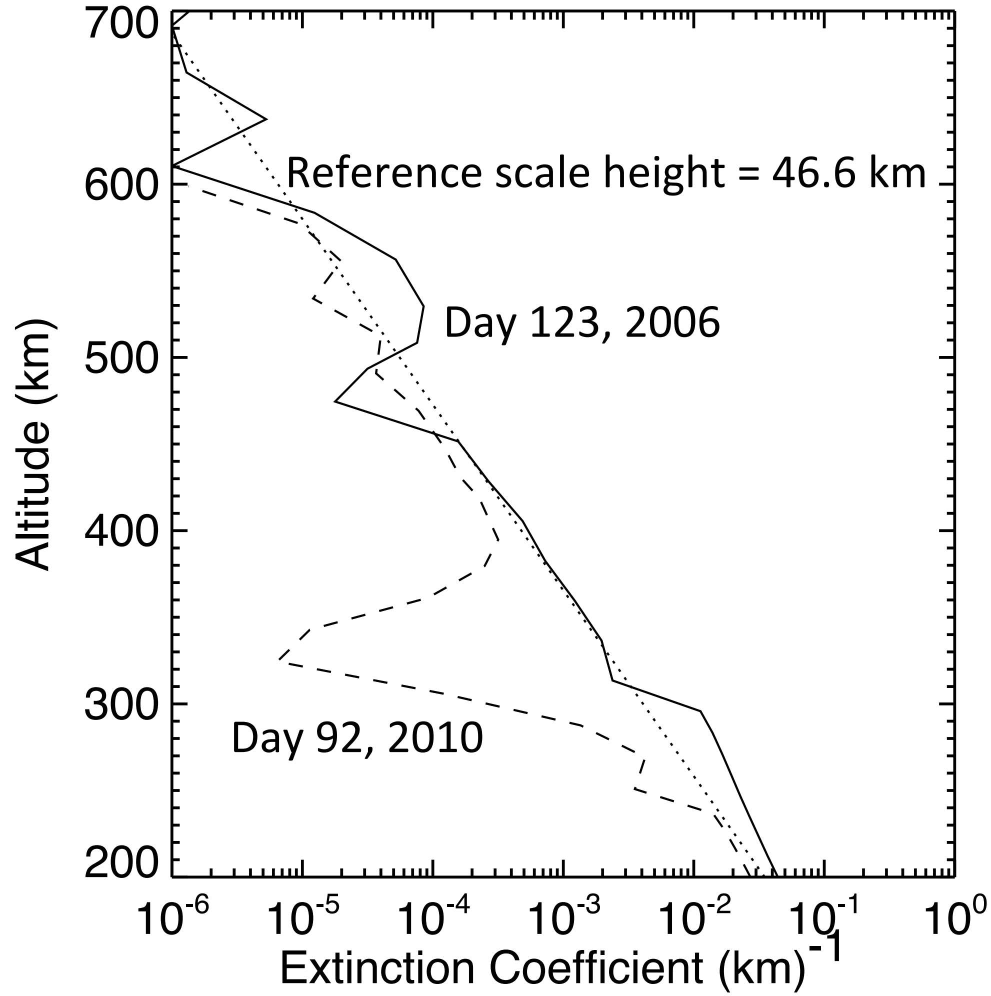


Day 123, 2006 Day 92, 2010

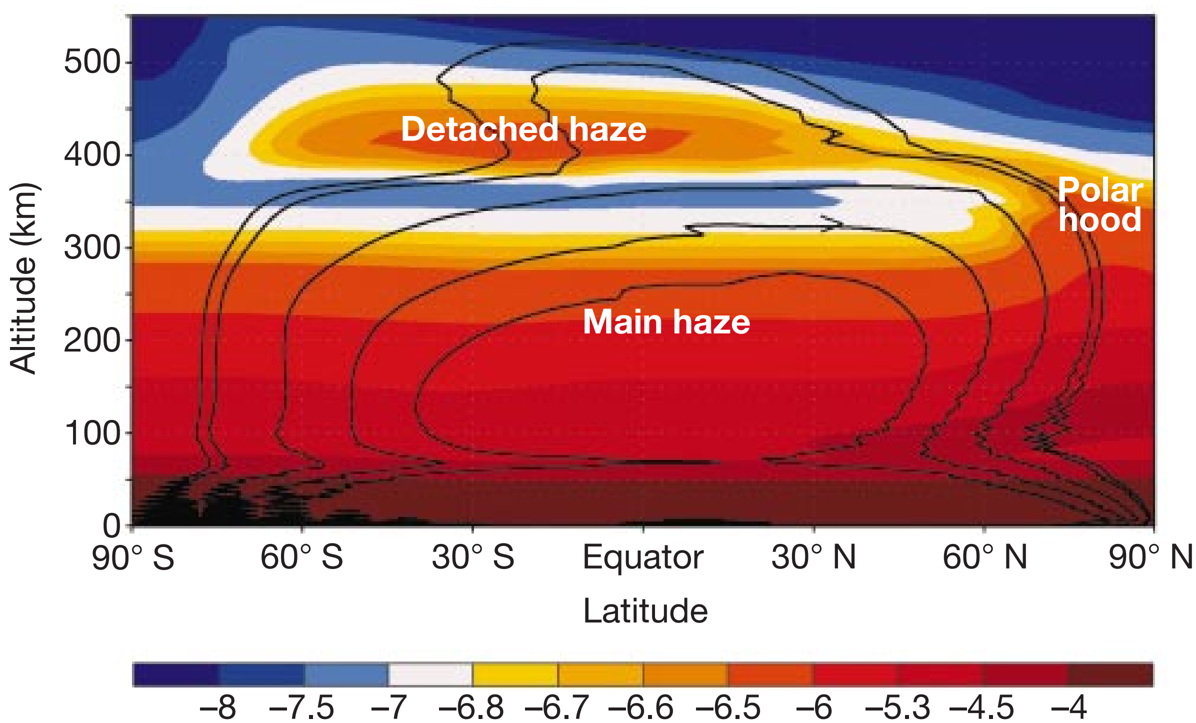
Altitude of the detached haze



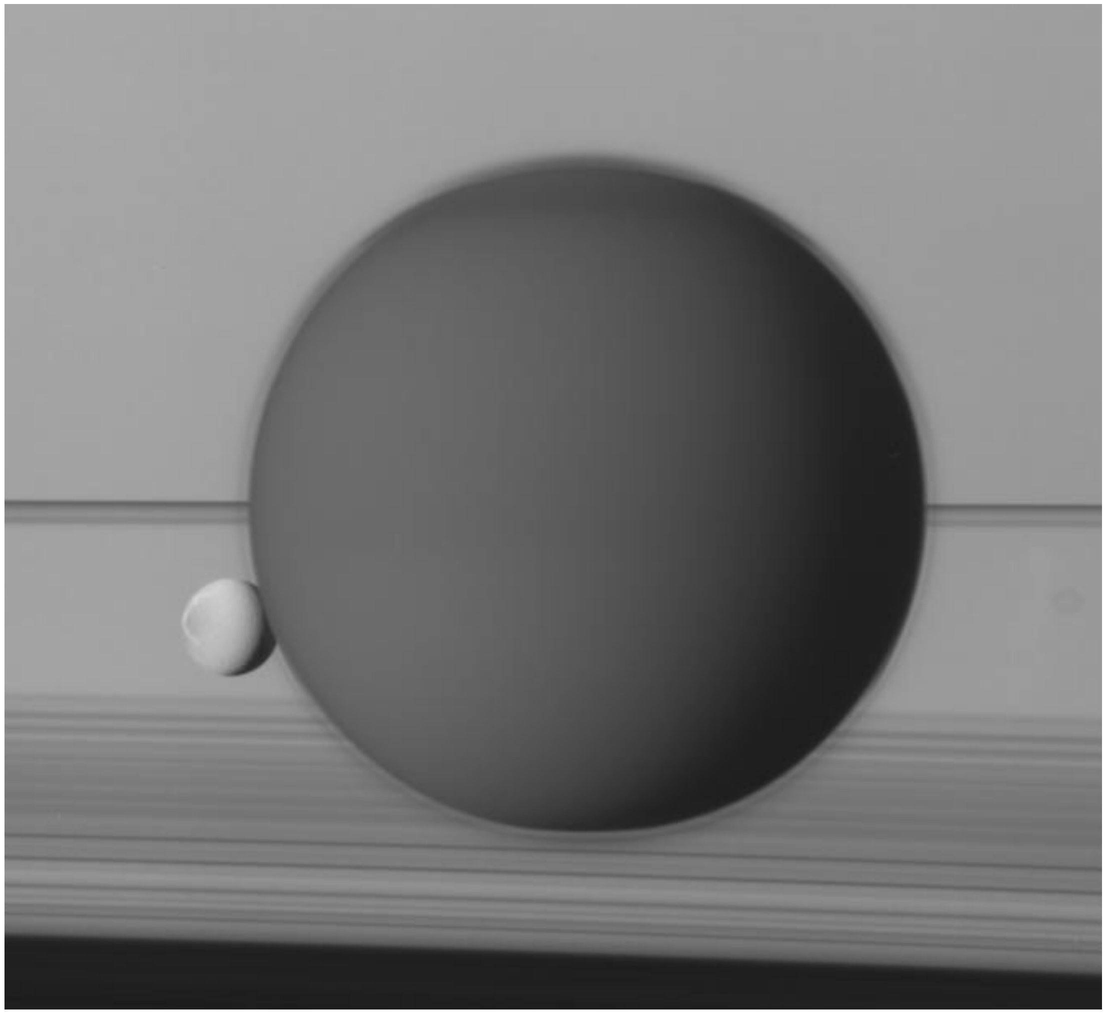
Haze Profiles 2006 and 2010



Model of Rannou et al. (2002)



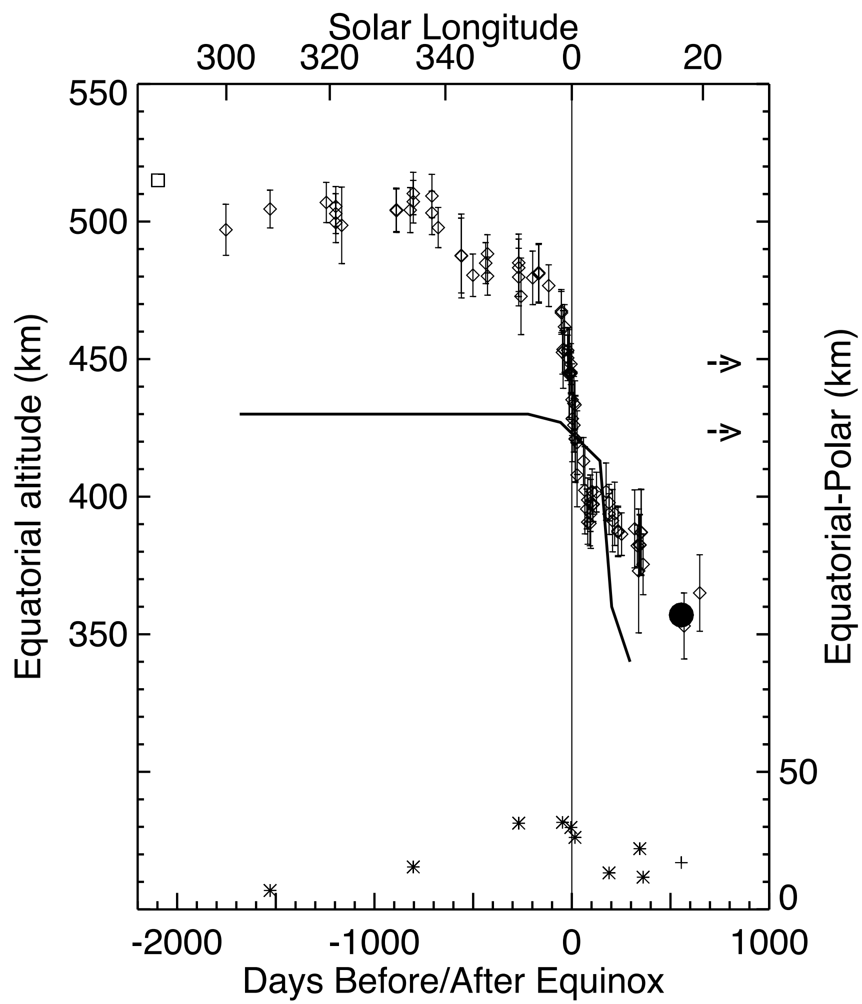
Most Recent Image
2011 DOY 141



Items of Note
Titan detached haze at L_S near 20°

- The detached haze is visible as a continuous entity everywhere south of the north polar vortex with a small (~13 km) difference in equator-pole altitude.

Previous and New Measurements



Detached Haze Evolution: Conclusions

- The detached haze has undergone a large-amplitude seasonal variation in altitude and has returned to the altitude where it was observed in Voyager images taken almost 30 years (one Saturn year) earlier.
- The collapse of Titan's detached haze is most likely a feature of the breakdown of a global meridional cell in the high stratosphere at equinox as solar heating becomes symmetric. This feature was predicted by the Rannou et al. (2002) circulation/haze model.
- The detached haze, a scientific curiosity for almost 30 years, has become an incisive test for Titan circulation and haze microphysical models.
  - There are problems with the Rannou et al. model which calls for the dissolution of the detached haze simultaneous with its drop in altitude, so far not seen.
  - The microphysical model of Lavvas et al. (2009) does not predict altitude change but better accounts for the nearly constant altitude of the detached haze as a function of latitude. It must be coupled with a dynamical process to account for the observed seasonal behavior.