Exploration of the Saturn System by the Cassini Mission: Observations with the Cassini Infrared Spectrometer

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OUTLINE

- Introduction to the Cassini mission , and Cassini mission objectives
- Cassini spacecraft, instruments, launch, and orbit insertion
- Saturn, Rings, & Satellites , Titan
- Composite Infrared Spectrometer (CIRS)
- Infrared observations of Saturn and Titan

The Cassini Mission

The Cassini mission, named after of the 17th century Italian/French astronomer, Giovanni Domenico Cassini, is a joint NASA-ESA mission, launched on October 17, 1997 for exploration of the Saturn system.

- Successful insertion in Saturn's orbit for a four year orbital tour occurred on July 1, 2004.
- The French Huygens-Probe with six instruments, was programmed for a soft landing on Titan. Successful landing on Titan's surface occurred in January 2005.

The Cassini Mission General Objectives

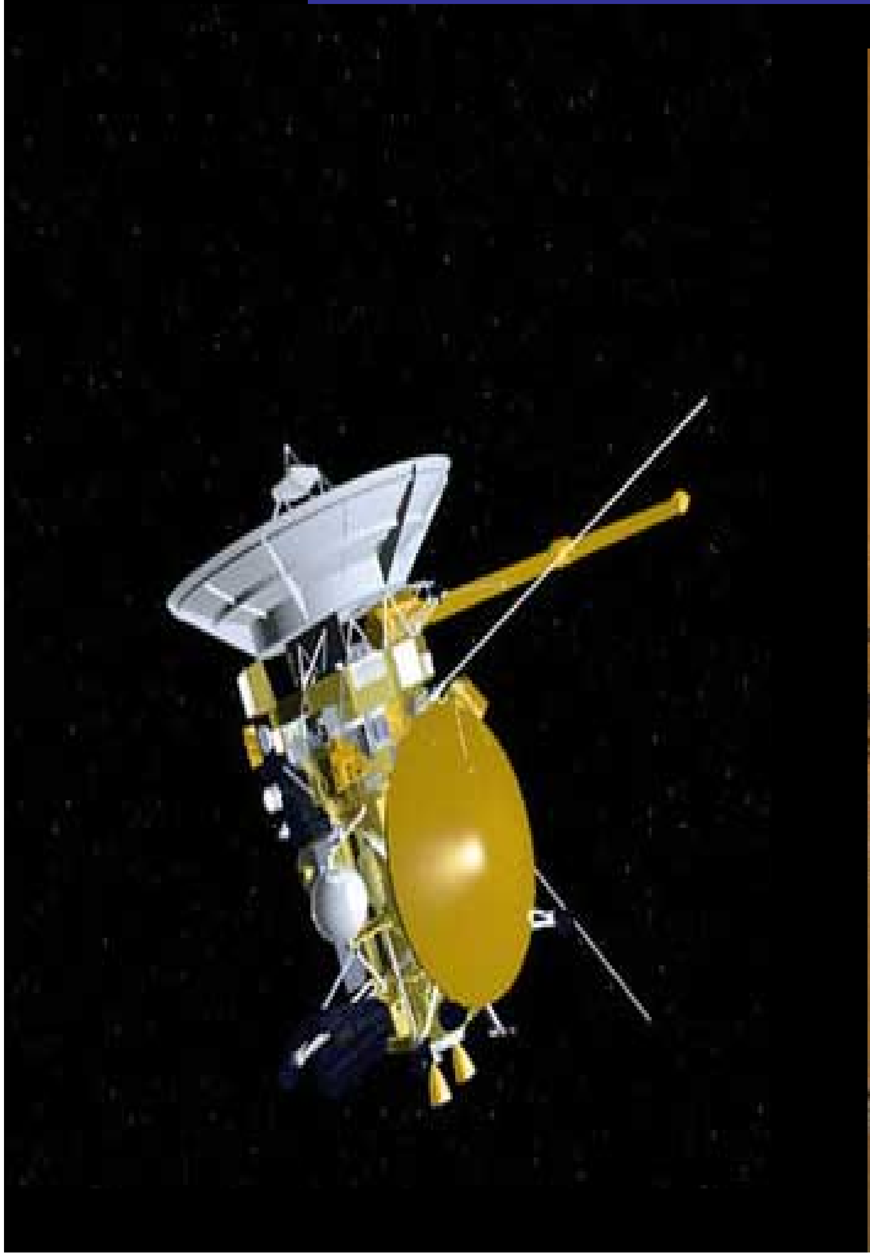
- **Exploration of the Saturn system for investigations of the origin, formation, & evolution of the solar system.**
- **The solar system is believed to be formed in a gravitationally collapsing giant interstellar cloud of gas and dust, or proto-solar nebula, with the proto-sun formed at the core and the planets in the surrounding disc.**

- **Two current models of formation are:**
- **(a) Core accretion model: agglomeration of dust grains into pebbles, to rocks, to planetesimals, and to the formation of planets in a gaseous disc.**
- **(b) Gravitational instability model where the planets are formed directly at various distances from the sun in a proto-stellar disc.**
- **None of the two models provide satisfactory explanation of the observations.**

The Cassini Mission Specific Objectives

- **Measure atmospheric thermal structure, gas abundances & isotopic ratios for Saturn system.**
- **Measure wind speeds and cloud structure.**
- **Obtain data for better understanding of the structure and formation of the interior.**
- **Investigations Saturn's rings and its satellites.**
- **Study Saturn's Magnetosphere & ionosphere, and interactions with the magnetic field.**

Cassini Spacecraft



Spacecraft Characteristics

- The Cassini spacecraft orbiter carries 12 instruments.
- The Huygens Probe contained 6 instruments.
- The spacecraft weights about 5000 kg, about the size of an empty school bus, and is 6.8 m (~ 22 ft) high.
- Three Radioisotope Thermoelectric Generators (RTGs) provide the electric power.
- Sequence commands received via 4-m diameter high gain antenna on the Orbiter's central computer.
- Attitude control maintained by a dedicated computer which continually propagates up to 50 vectors to a variety of objects (e.g., Sun, Earth, Saturn and its satellites). The computer commands the reaction wheels to point Cassini to he desired direction.
- Data stored on stored on 2 solid state recorders (SSRs) during the tour.

Spacecraft Characteristics (cont'd)

- **Power at Saturn: ~ 660 W**
- **Data Storage: 4 Gbits**
- **Pointing Accuracy: 2.0 mrad; Pointing stability 0.036 mrad (~ 5 sec)**
- **Number of Engineering Computers: 26**
- **Transmitter Power: 19 W (RF): Transmitter Freq : Xband**
- **Data rate at Saturn: 140 KB/s**
- **Main Engine Thrust: 445 N**

The Huygens Probe

- **The Probe was designed as a fully instrumented robotic laboratory designed to enter Titan's atmosphere using a heat shield and a series of parachutes.**
- **Scientific measurements made during descent, with 30 min at the surface of Titan.**

Cassini Orbiter Instruments

Optical and Microwave Remote Sensing Instruments

- **Composite Infrared Spectrometer (CIRS):** Temperature & composition of surfaces & atmospheres in the Saturn system.
- **Visual and Infrared Mapping Spectrometer (VIMS):** Spectral mapping to study composition & structure or surfaces, atmospheres, & rings.
- **Imaging Science Subsystems (ISS):** Multispectral imaging of Saturn, Titan, rings, & the icy satellites to observe their properties.
- **Ultraviolet Imaging Spectrograph (UVIS):** Spectra & low resolution imaging of atmospheres, & rings for structure, chemistry and composition.
- **Cassini Radar (RADAR):** Radar imaging, altimetry, & backscatter of Titan's surface.
- **Radio Science Subsystem (RSS):** Study of atmospheric & ring structure, gravity fields, & waves.

Cassini Orbiter Instruments

FIELDS, PARTICLES, AND WAVES INSTRUMENTS:

Cosmic Dust Analyzer (CDA): In-situ study of ice & dust grains in the Saturn system.

Ion and Neutral Mass Spectrometer (INMS): In-situ compositions of neutral & charged particles in the Saturn magnetosphere.

Cassini Plasma Spectrometer (CAPS): In-situ study of plasma within & near Saturn's magnetic field of atmospheres, & rings for structure, composition.

Radio & Plasma Wave Science (RPWS): Study of plasma waves, radio emissions, and dust in the Saturn system.

Dual Technique Magnetometer (MAG): Study of Saturn's magnetic field & interactions in the solar wind.

Magnetospheric Imaging Instrument (MIMI): Global magnetospheric imaging & in-situ measurements of Saturn's magnetosphere & solar wind interaction.

Huygens Probe Instruments

Probe Science Payload Instrumentation:

Huygens Atmospheric Structure Instrument (HASI)

A suite of sensors to measure the physical and electrical properties of Titan's atmosphere.

Doppler Wind Experiment (DWE)

Radio signals to deduce wind speeds on Titan

Descent Imager/Spectral Radiometer (DISR)

Imaging and spectral observations of Titan's surface and atmospheric hazes.

Aerosol Collector and Pyrolyser (ACP)

Chemical composition of Titan's aerosols. composition analysis.

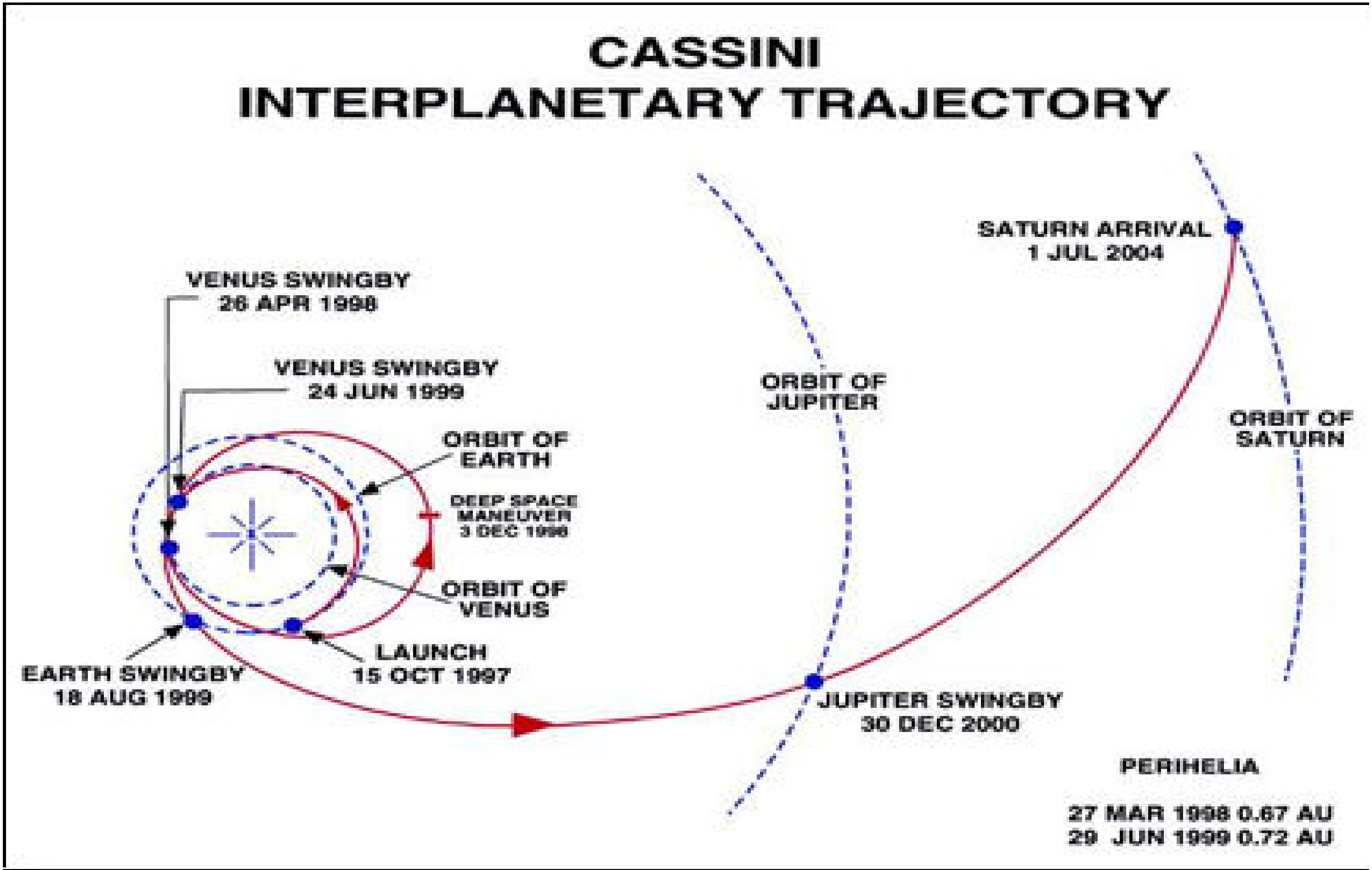
Surface-Science Package (SSP)

A number of sensors designed to determine the physical properties of Titan's surface.

Gas Chromatograph & Mass Spectrometer (GCMS)

The Cassini Launch on Oct. 17, 1997, Cape Canaveral

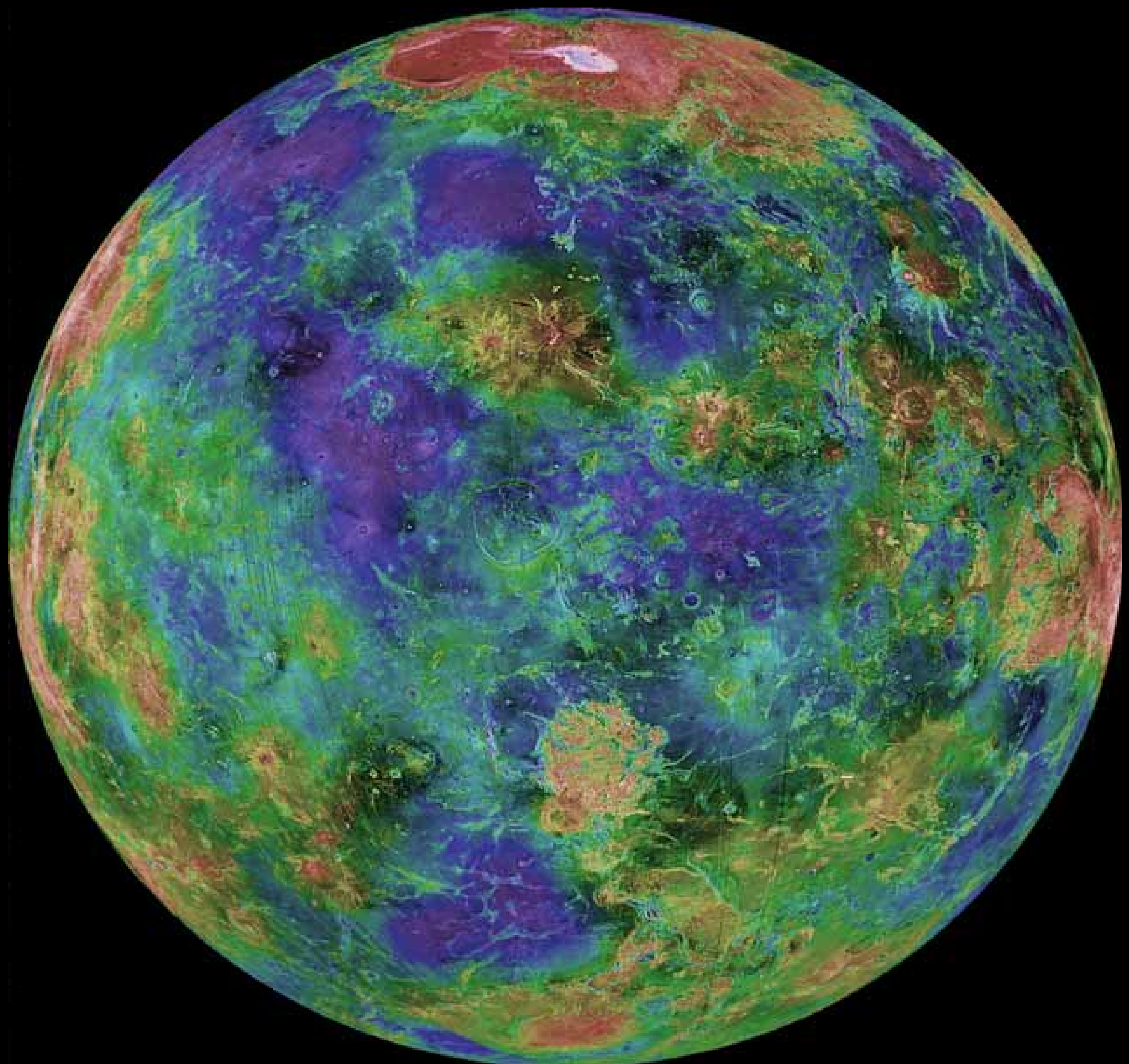
The Cassini Launch on Oct. 17, 1997, Cape Canaveral



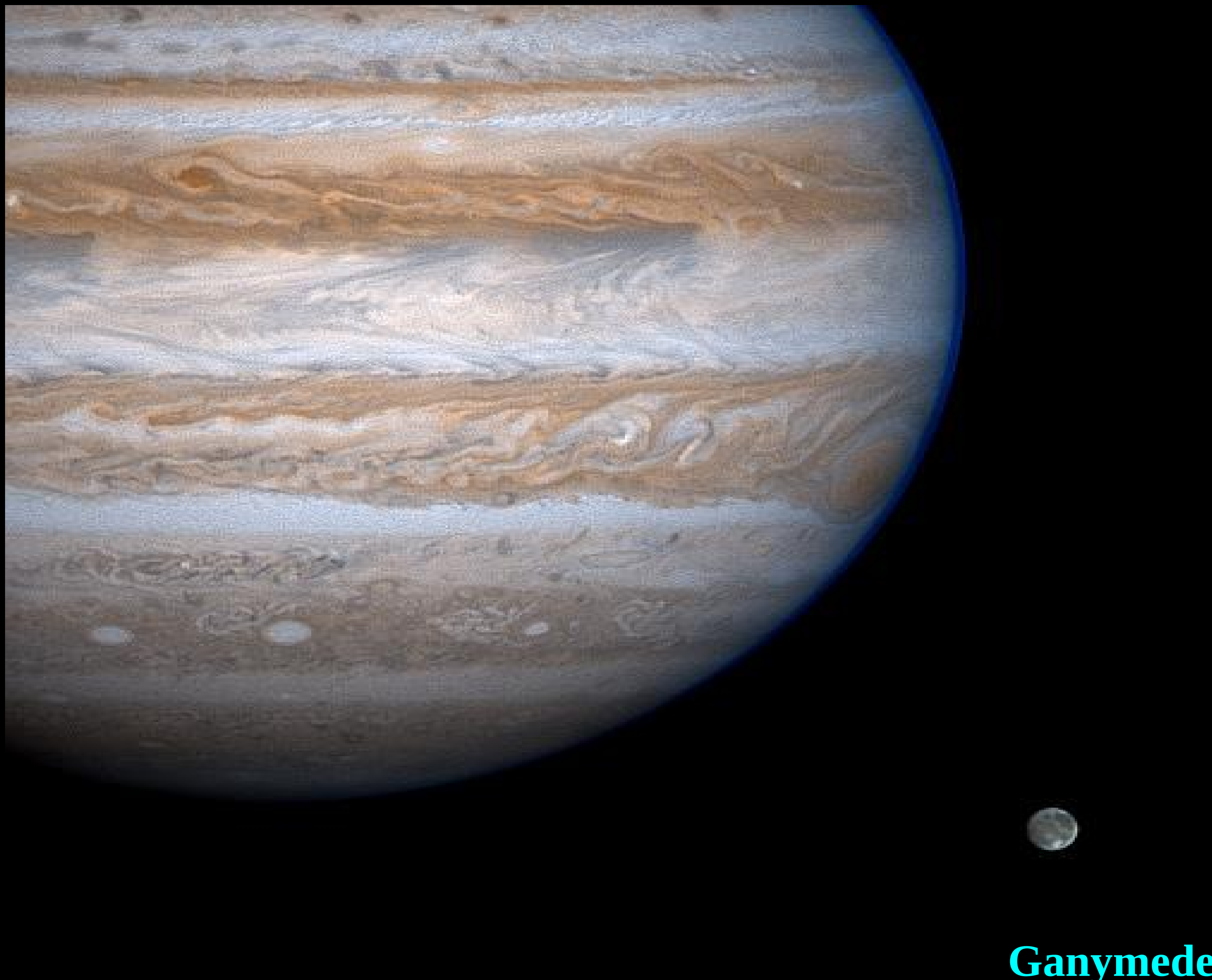
VVEJGA

Venus-Venus-Earth-
Jupiter: Gravity Assist

A View of VENUS obtained by Magellan



Jupiter image by Cassini during fly-by in Dec. 2000-Jan. 2001

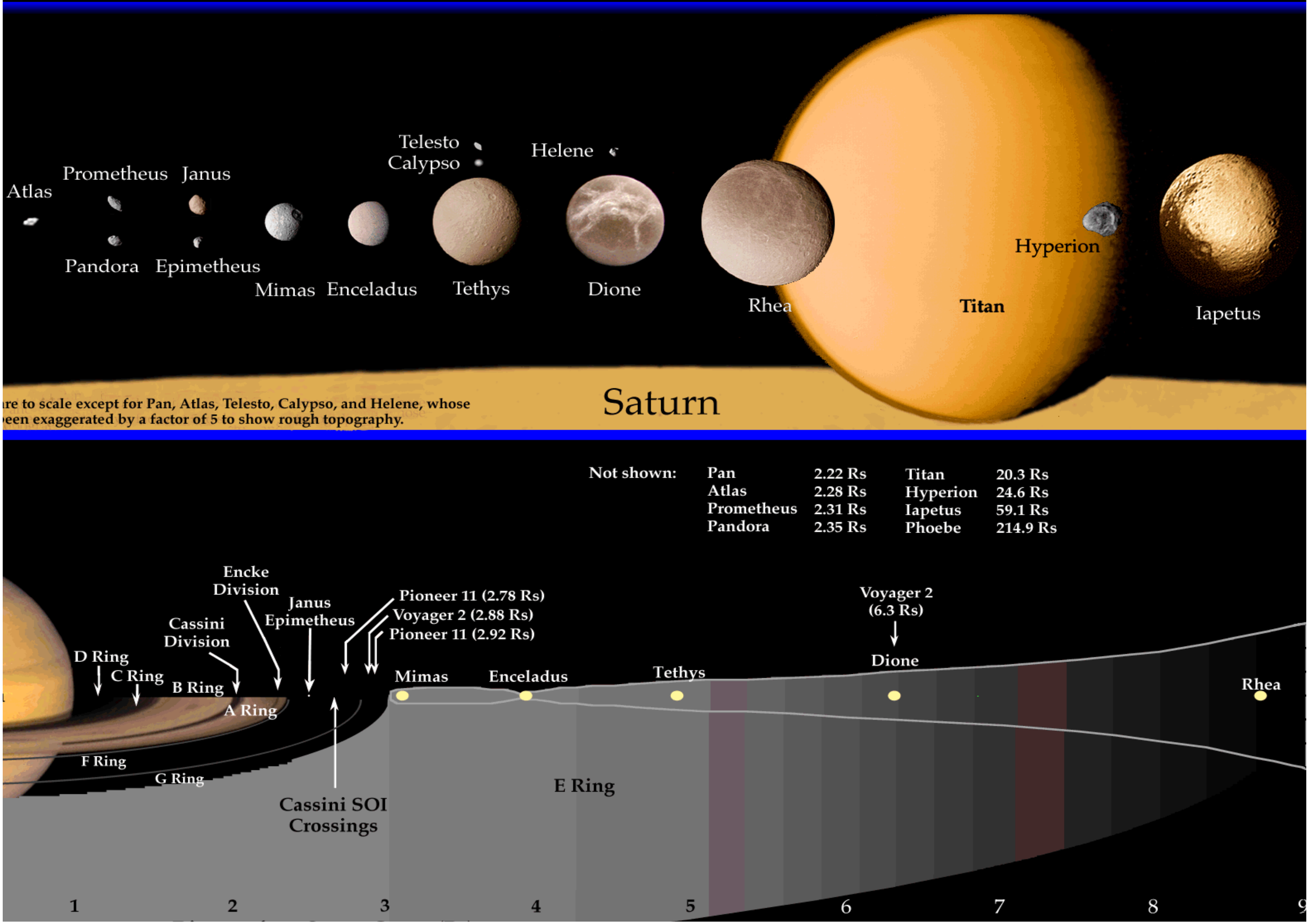


Cassini/Infrared Jupiter Observations

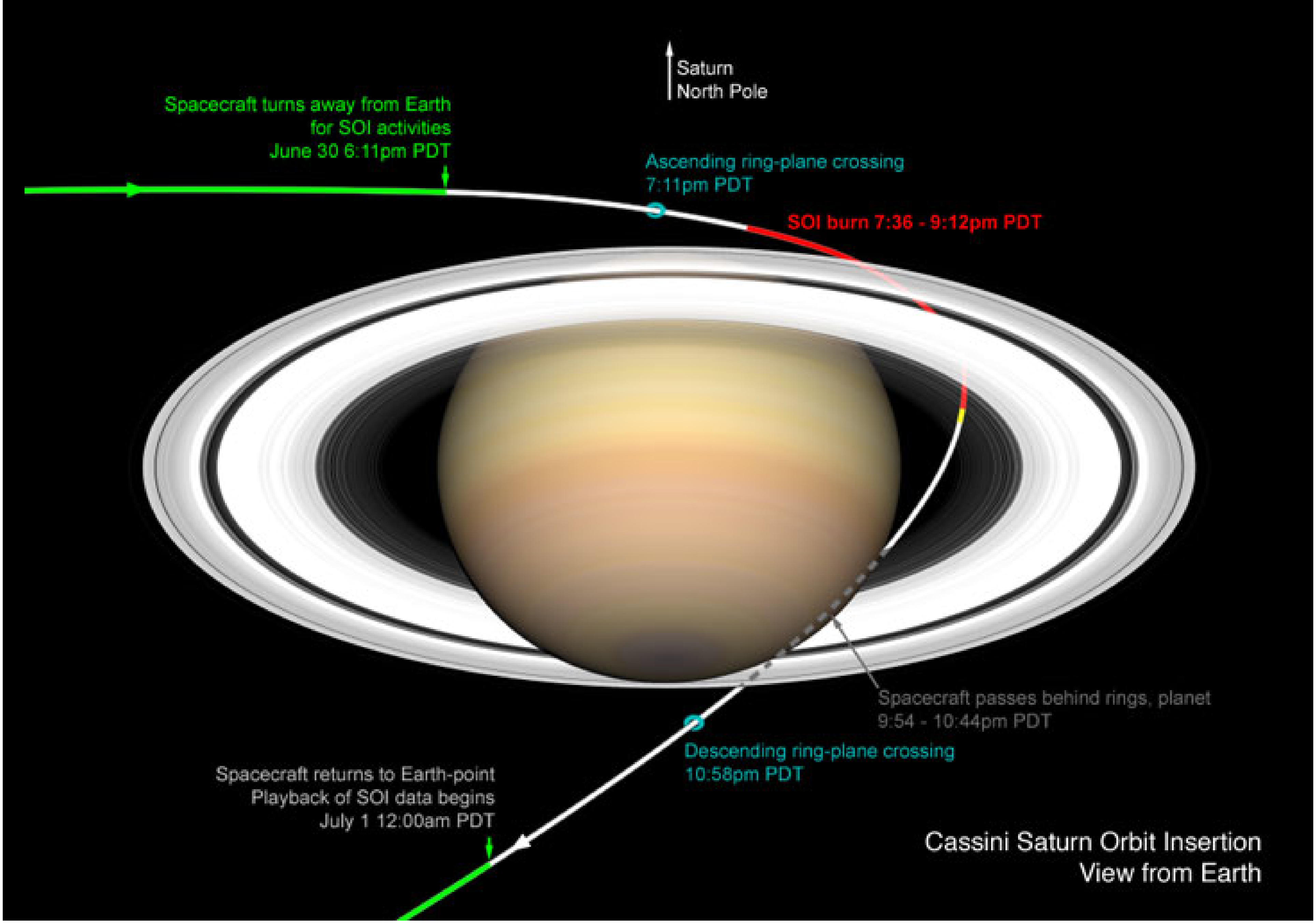
- **Global Temperature Maps**
  - **Observations of dynamical processes on Jupiter**

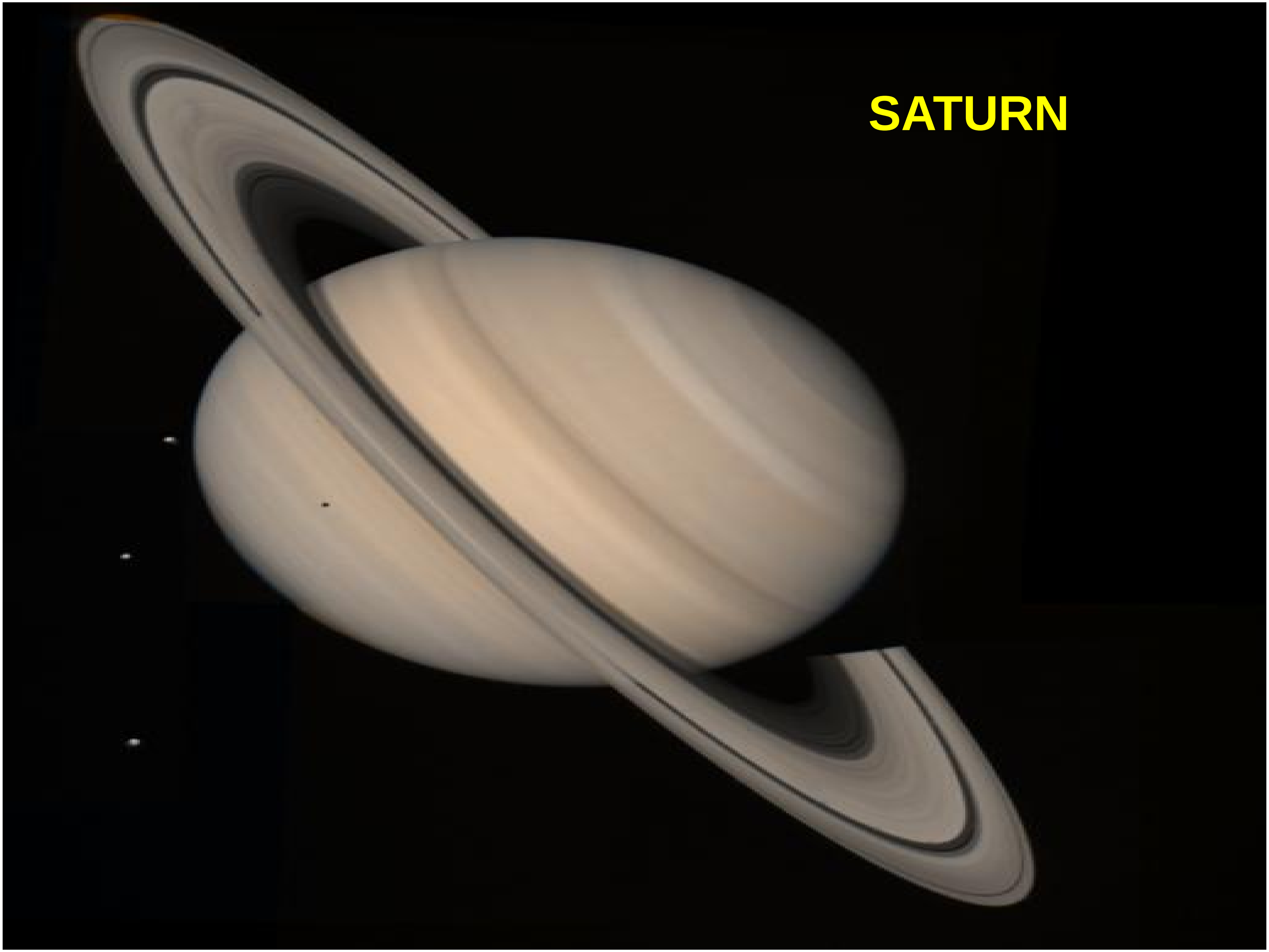
- **Global distribution of gas abundances**
  - $^{14}NH_3$, $^{15}NH_3$, PH_3, C_2H_6, C_2H_2
  - **Complex hydrocarbons**

Saturn's Satellites and Ring Structure

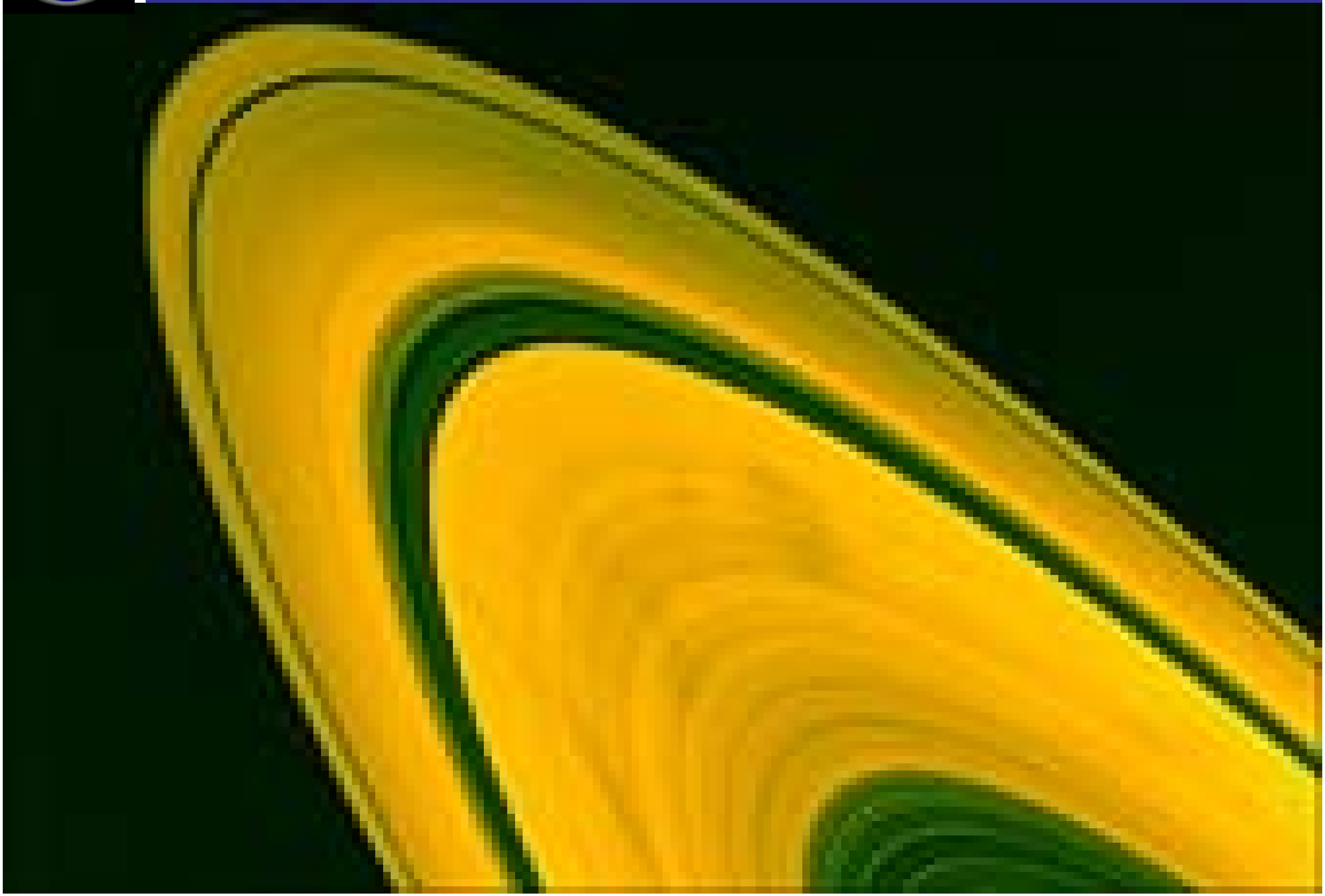


Saturn's Orbit Insertion




SATURN

Saturn's Rings



Some Physical Parameters of Saturn

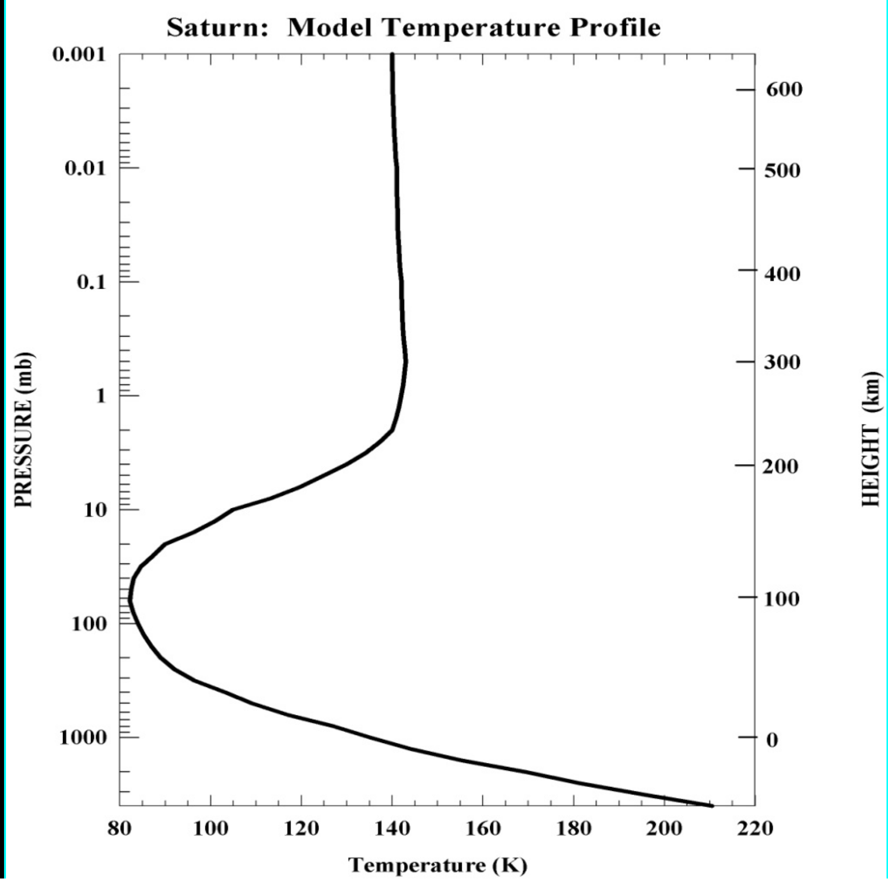
- **Mean Distance from Sun: 9.6 AU**

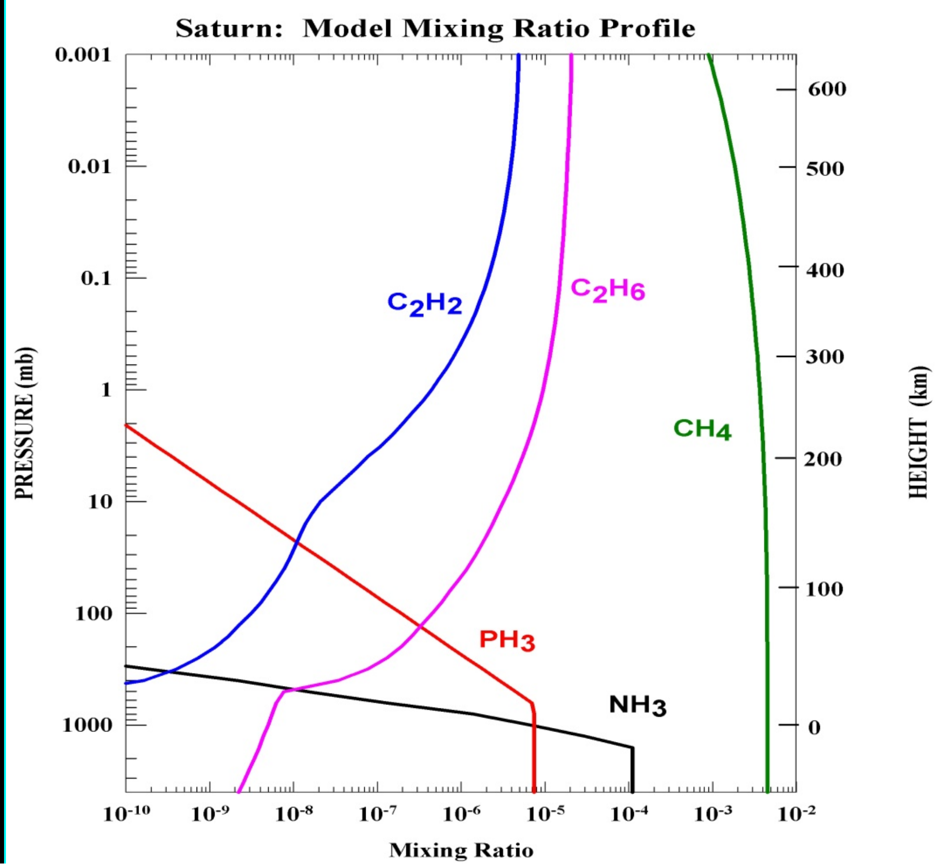
  1.4 billion km (~ 0.9 billion miles)
- **Diameter: 120,660 km (Equator)**

  107,629 km (Polar)
- **Mass (Earth = 1): 95.2**
- **Gravity (Earth = 1): 1.06**
- **Density (Earth = 5.52): 0.69 g/cm^3 (Water = 1.0)**
- **Orbital Period: 29.4 years**
- **Rotation Period: 10 h 40 m**
- **Orbital Inclination: 2.5°**

Saturn's Atmospheric Thermal Structure and Composition

- Temperature: 135 K at 1 bar; 82 K at tropopause (60 mbar)
- Composition: H_2 (~ 88%), He (~ 12%), CH_4, NH_3, PH_3, C_2H_2, C_2H_6, CO, CO_2, H2O, plus other trace gases.
- Cloud layers of: Water cloud at the bottom, Ammonia at the top, and NH_4SH in the middle troposphere, theorized.





Saturn's Rings

Name	Inner Radius (Rs)	Width (km)	Mass (kg)
D-Ring	1.1	7500	?
C-Ring (inner)	1.235	17,500	1×10^{18}
B-Ring	1.524-1.947	25,500	3×10^{19}
Cassini Division	1.985 (center)	4800	
A-Ring	2.023-2.267	14,600	6×10^{18}
F-Ring	2.3267	30-500	?
G-Ring	2.8	8000	1×10^{7} (?)
E-Ring	3.0 - 8.0	300,000	?

Ring Science Objectives

- Study the **shape and structure of the rings and the processes responsible for the ring structure** (gravitational, viscous, erosional, and electromagnetic).
- Map the **chemical makeup and the size distribution** of ring material.
- Investigate the **relationship between the rings and the moons of Saturn**, including moons contained within the ring system.
- Determine the **distribution of dust and meteoroids** in the vicinity of the rings.
- Study **interactions between the rings and Saturn's magnetosphere, ionosphere, and atmosphere.**

Saturn Science Objectives

- **Global mapping of atmospheric thermal structure, gas abundances, and isotopic ratios to provide observational constraints for the formation and evolution of Saturn and Titan.**
- **Measure wind speeds and directions across the planet.**
- **Observe long-term variations in the cloud features and processes.**
- **Collect data for better understanding of the interior of the planet.**
- **Study the day-to-night variations of Saturn's ionosphere and determine its degree of interaction with the magnetic field.**

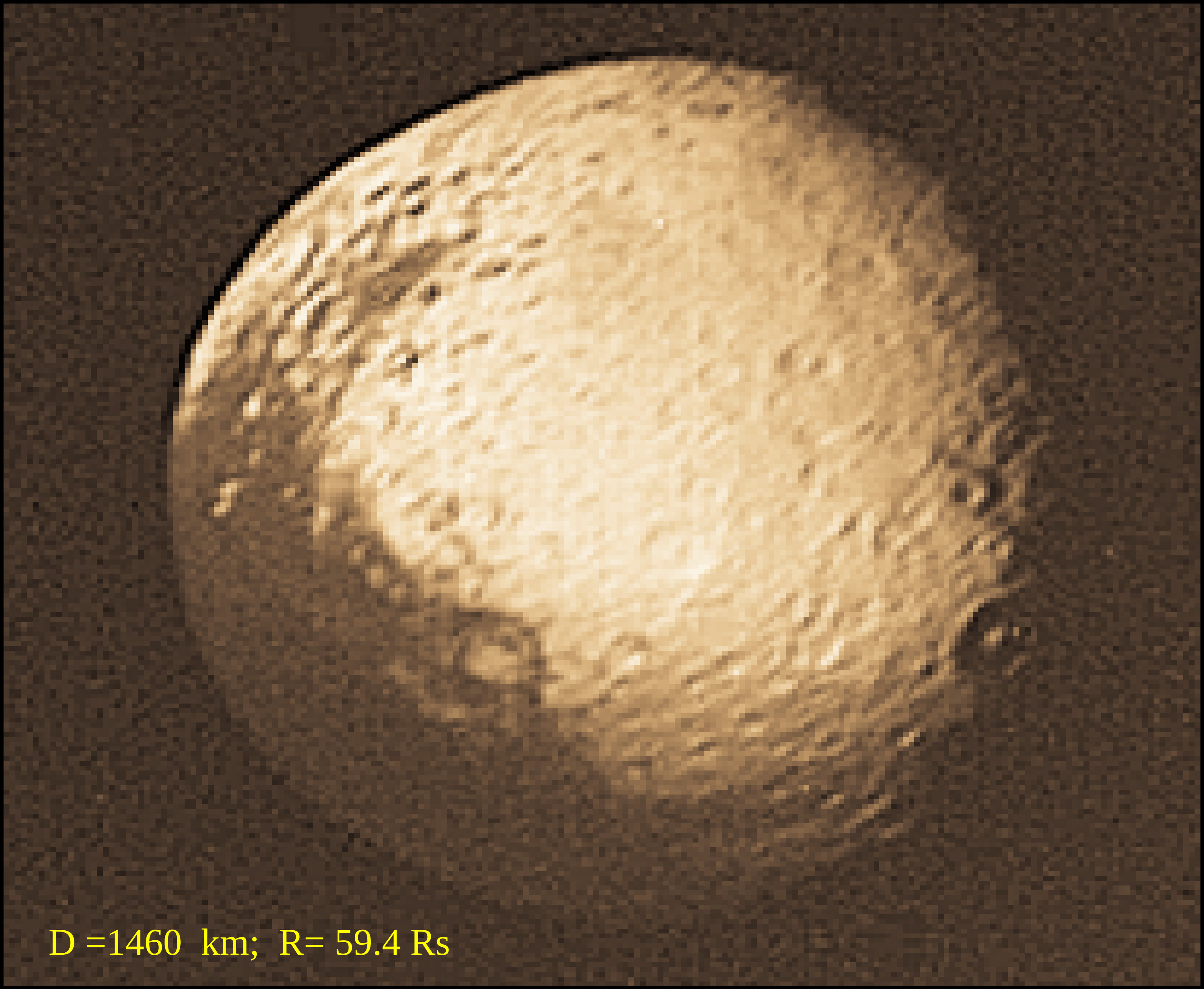
Satellites of Saturn

Name	Diameter (km)	Distance (R_s)	Discoverer	Date
Pan	20	2.2	Showalter	1980
Atlas	28	2.3	Terrile	1980
Prometheus	92	2.3	Collins	1980
Pandora	92	2.4	Collins	1980
Epimetheus	114	2.5	Walker	1980
Janus	178	2.5	Dollfus	1966
Mimas	392	3.1	Herschel	1789
Enceladus	520	4.0	Herschel	1789
Tethys	1060	4.9	Cassini	1684

Satellites of Saturn (cont'd)

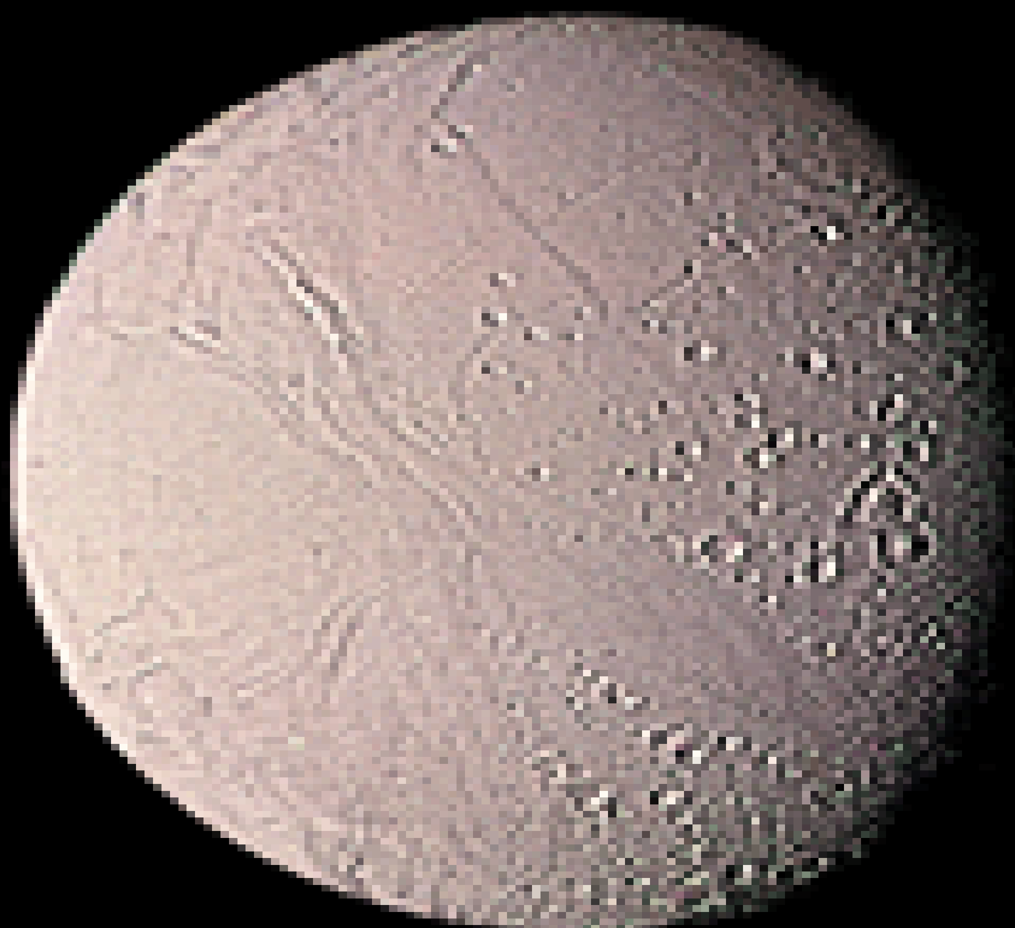
Name	Diameter (km)	Distance (R_s)	Discoverer	Date
Telesto	30	4.9	Reitsema	1980
Calypso	26	4.9	Pascu	1980
Dione	1120	6.3	Cassini	1684
Helene	32	6.3	Laques	1980
Rhea	1530	8.8	Cassini	1672
Titan	5146	20.4	Huygens	1655
Hyperion	286	24.7	Bond	1848
Iapetus	1460	59.4	Cassini	1671
Phoebe	220	216	Pickering	1898

Saturn’s Moon – IAPETUS



Saturn's Moon - Tethys

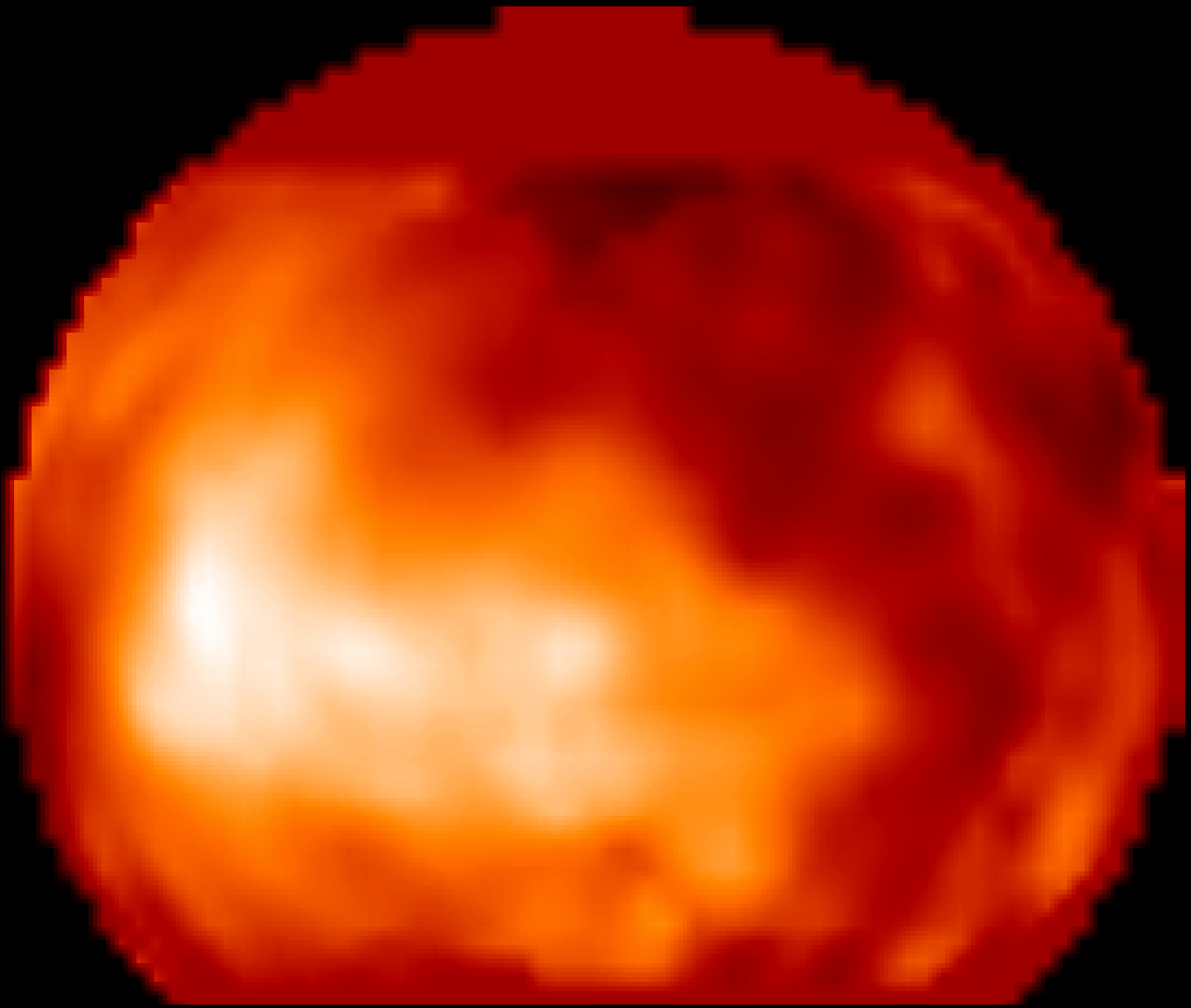
Saturn's Moon - ENCELADUS



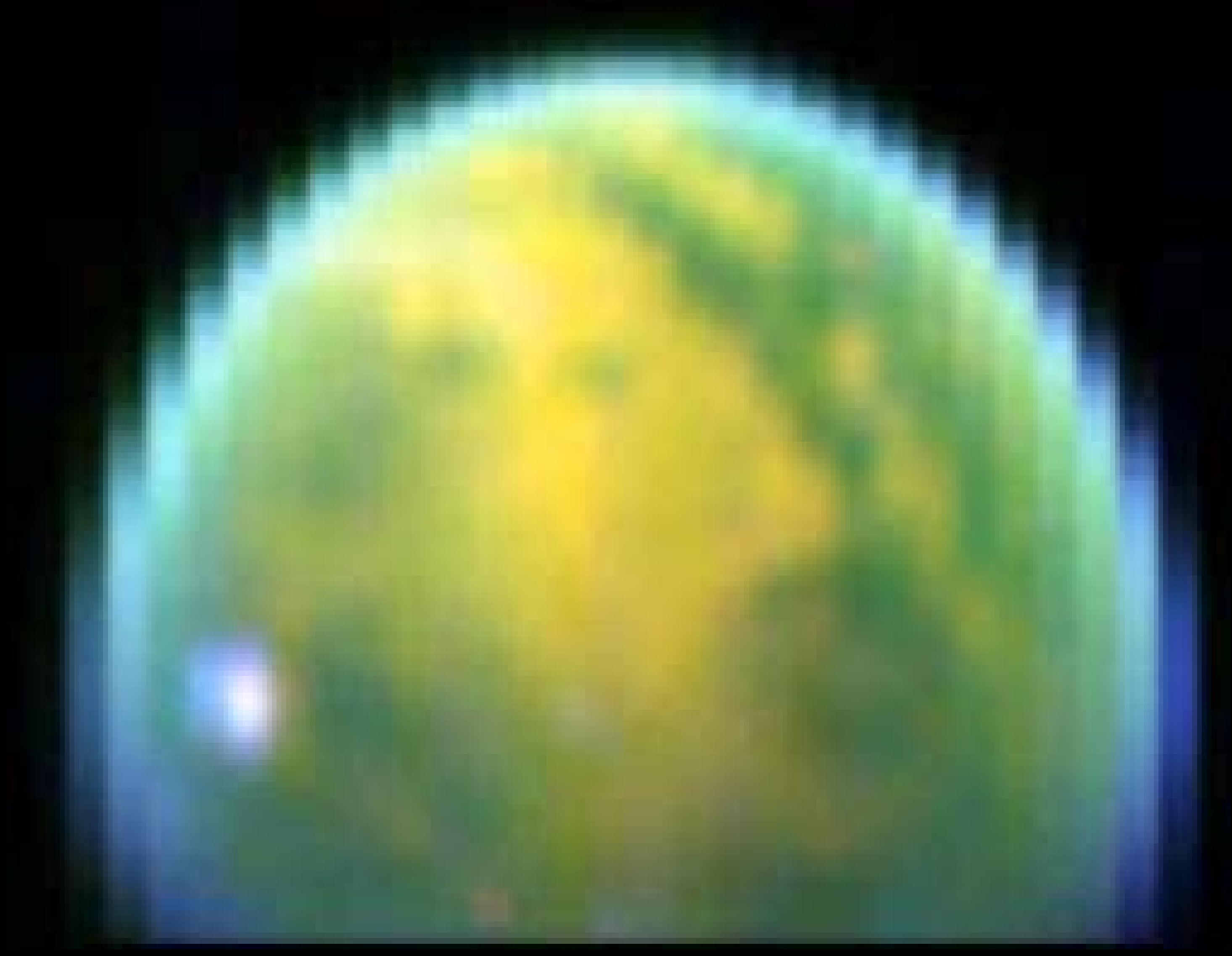
Objectives for the Icy Satellites

- **Determine the general characteristics and geological histories of the icy satellites.**
- **Determine the processes that change the surface and near-surface of the icy satellites, and determine the makeup and distribution of surface materials, especially the dark material.**
- **Provide observational constraints on the internal structure and makeup of the moons.**
- **Investigate interaction of the icy satellites with the magnetosphere and the ring system.**

Near IR image of Titan, with the dark and the bright reds representing the presence of pure water ice, simple hydrocarbons, respectively.

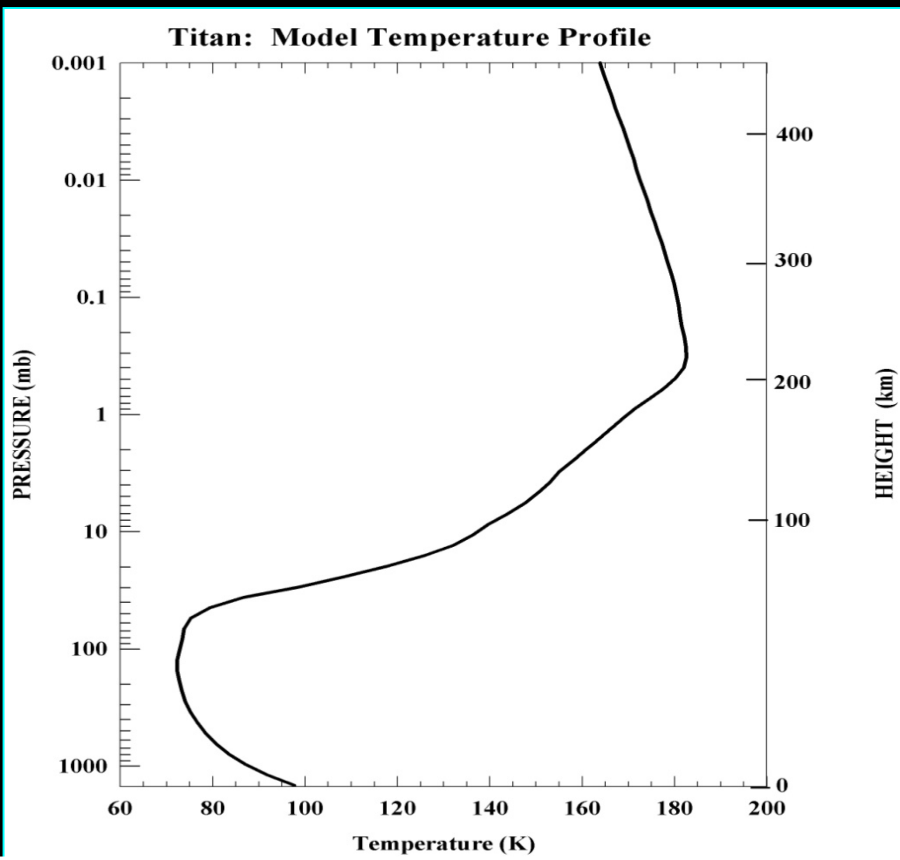


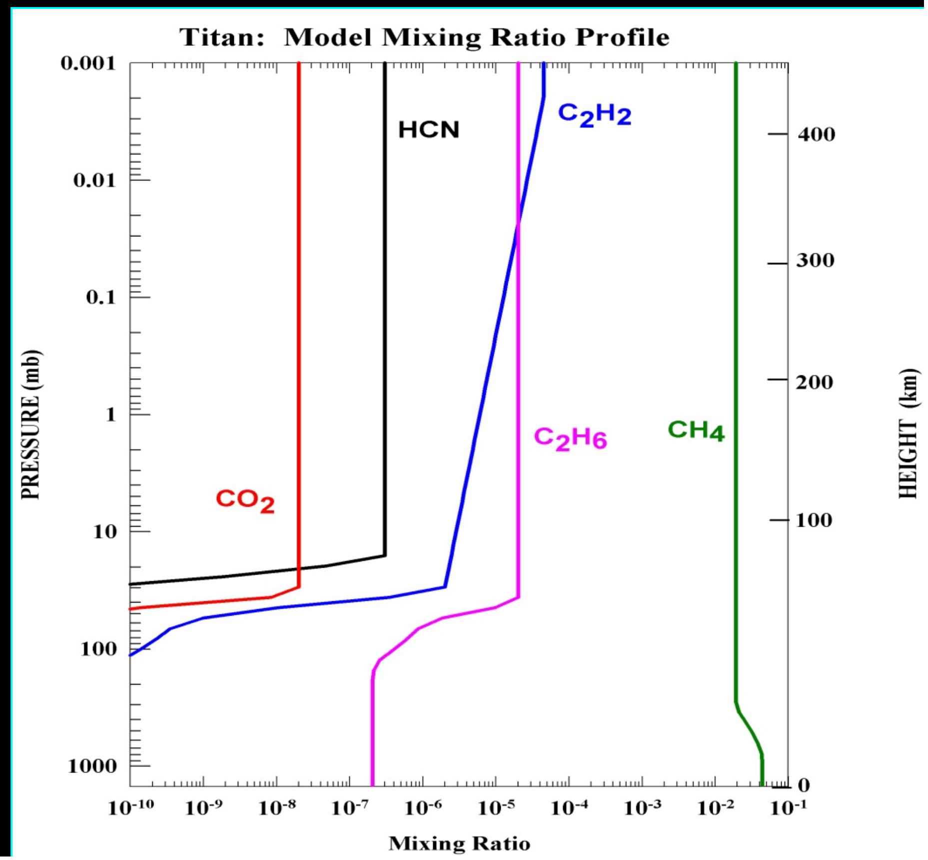
Near IR view of Titan by VIMS with the yellow, blue and white colors indicating presence of hydrocarbons, ice, and methane clouds, respectively.



Titan's Atmospheric Thermal Structure and Composition

- **Temperature: 92 K at surface (1.5 bar)**
  72 K at tropopause (150 mbar)
- **Gases: N_2 (~ 95%), H_2, Ar, CH_4, C_2H_2, C_2H_4, C_2H_6, C_3H_4, C_3H_8, C_4H_2, HCN, HC_3N, CO, CO_2, H_2O, complex hydrocarbons**
- **Haze, Clouds: CH_4 , Hydrocarbons**





Titan Science Objectives

- Global distribution of atmospheric gas abundances and isotopic ratios, Provide information for better understanding of the formation and evolution of Titan's atmosphere.
- Search for more complex organic molecules. Study photochemical models, the formation and composition of aerosols, and clouds.
- Measure winds and global temperatures and the seasonal effects.
- Determine whether the surface is liquid or solid, and determine the shape and composition of the surface.
- Collect data to determine the internal structure of Titan.
- Investigate the upper atmosphere and ionosphere of Titan and their roles as sources of neutral and ionized material in the magnetosphere of Saturn.

Cassini Infrared Observations with the Composite Infrared Spectrometer (CIRS)

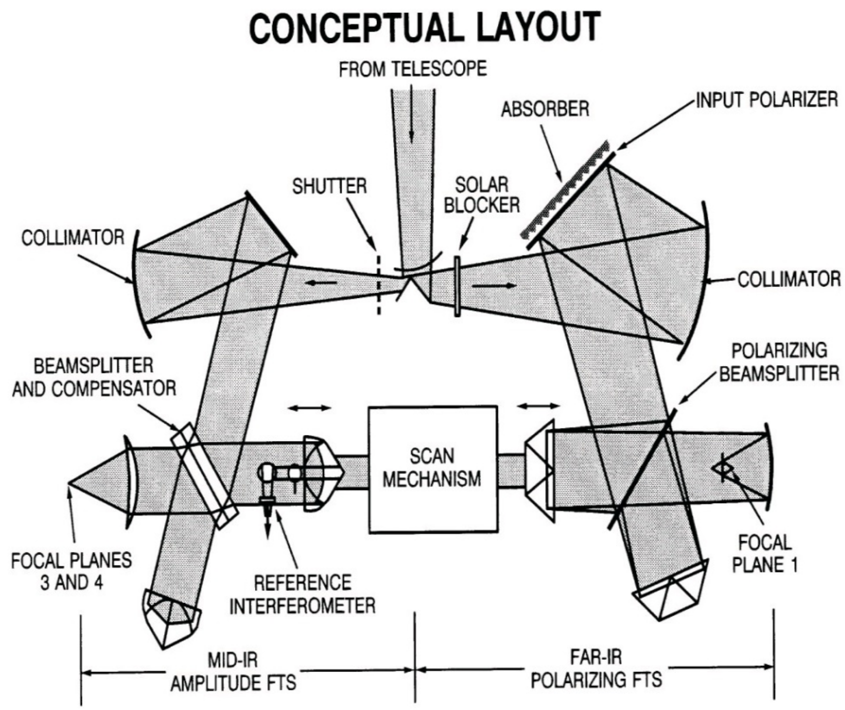


Fig. 35

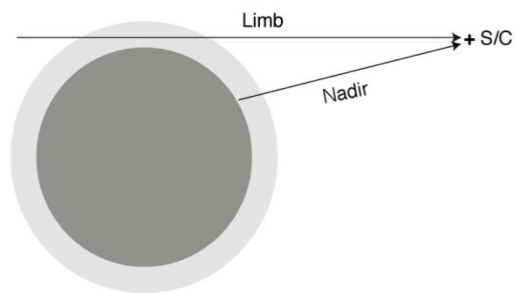


Fig. 2

CIRS Instrument Characteristics

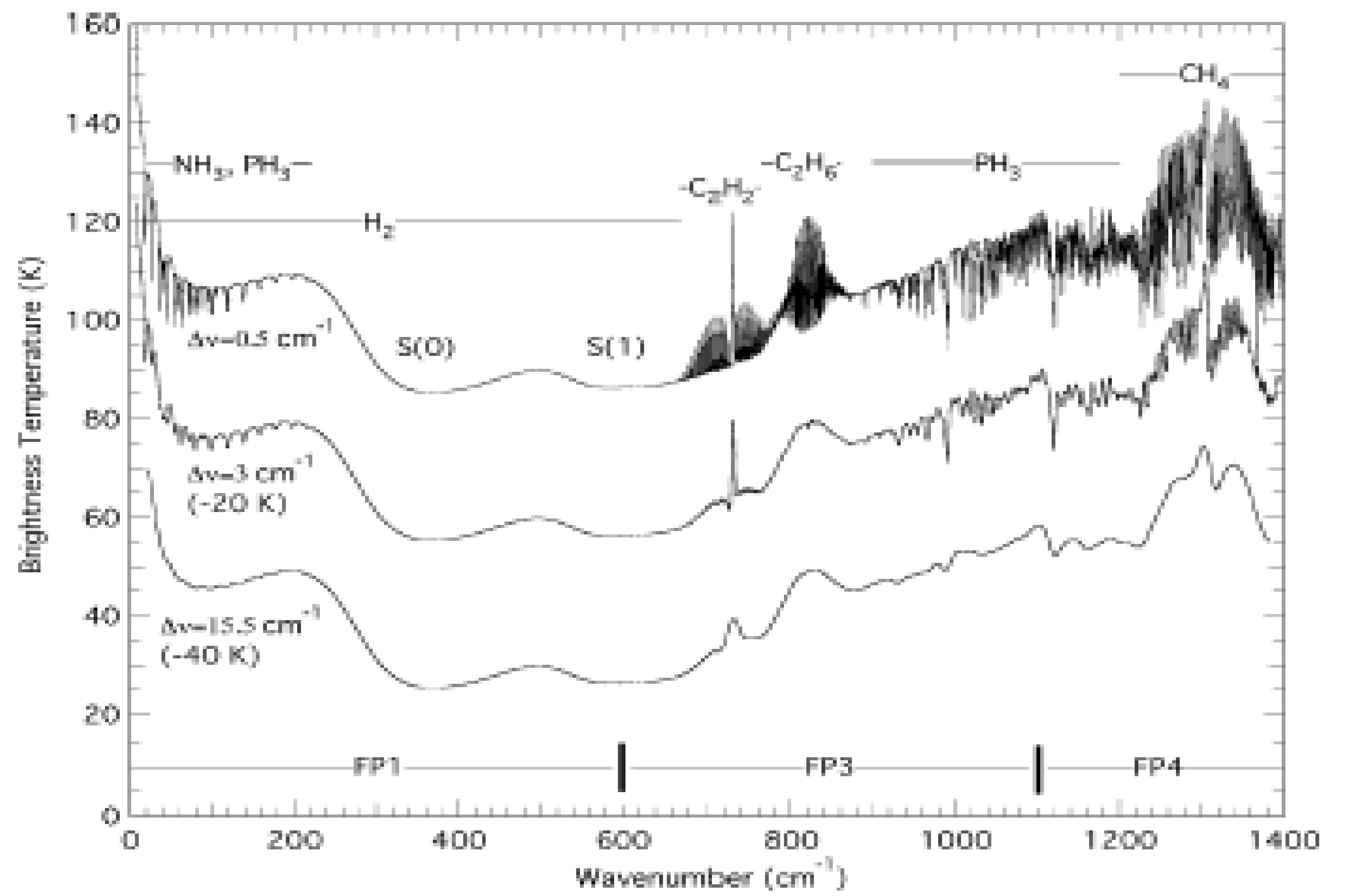
TABLE I

CIRS instrument characteristics.

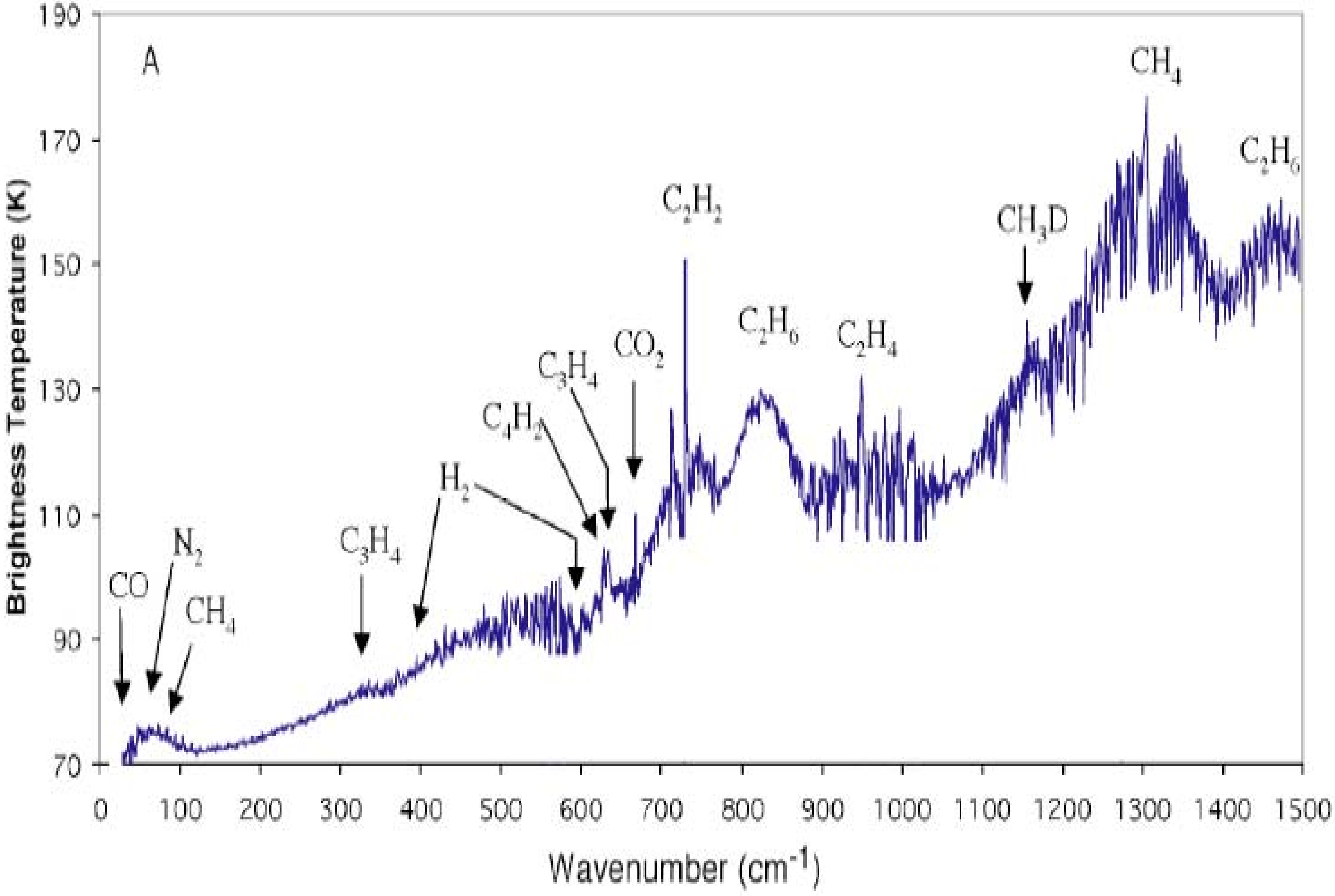
Telescope diameter (cm)	50.8		
Interferometers	Far-IR	Mid-IR	
Type	Polarizing	Michelson	
Spectral range (cm^{-1})	10—600	600–1400	
Spectral range (μm)	17—1000	7–17	
Spectral resolution (cm^{-1})	0.5–15.5	0.5–15.5	
Integration time (s)	2–50	2–50	
Focal planes	FP1	FP3	FP4
Spectral range (cm^{-1})	10—600	600–1100	1100–1400
Detectors	Thermopile	PC HgCdTe	PV HgCdTe
Pixels	2[a]	1×10	1×10
Pixel FOV (mrad)	3.9	0.273	0.273
Peak D^* ($cm\ Hz^{1/2}\ W^{-1}$)	4×10^9	2×10^{10}	5×10^{11}
Data telemetry rate (kbs)		2 and 4	
Instrument temperature (K)	170		
Focal planes 3 and 4 Temperature (K)	75—90		

[1]Single FOV, two polarizations.

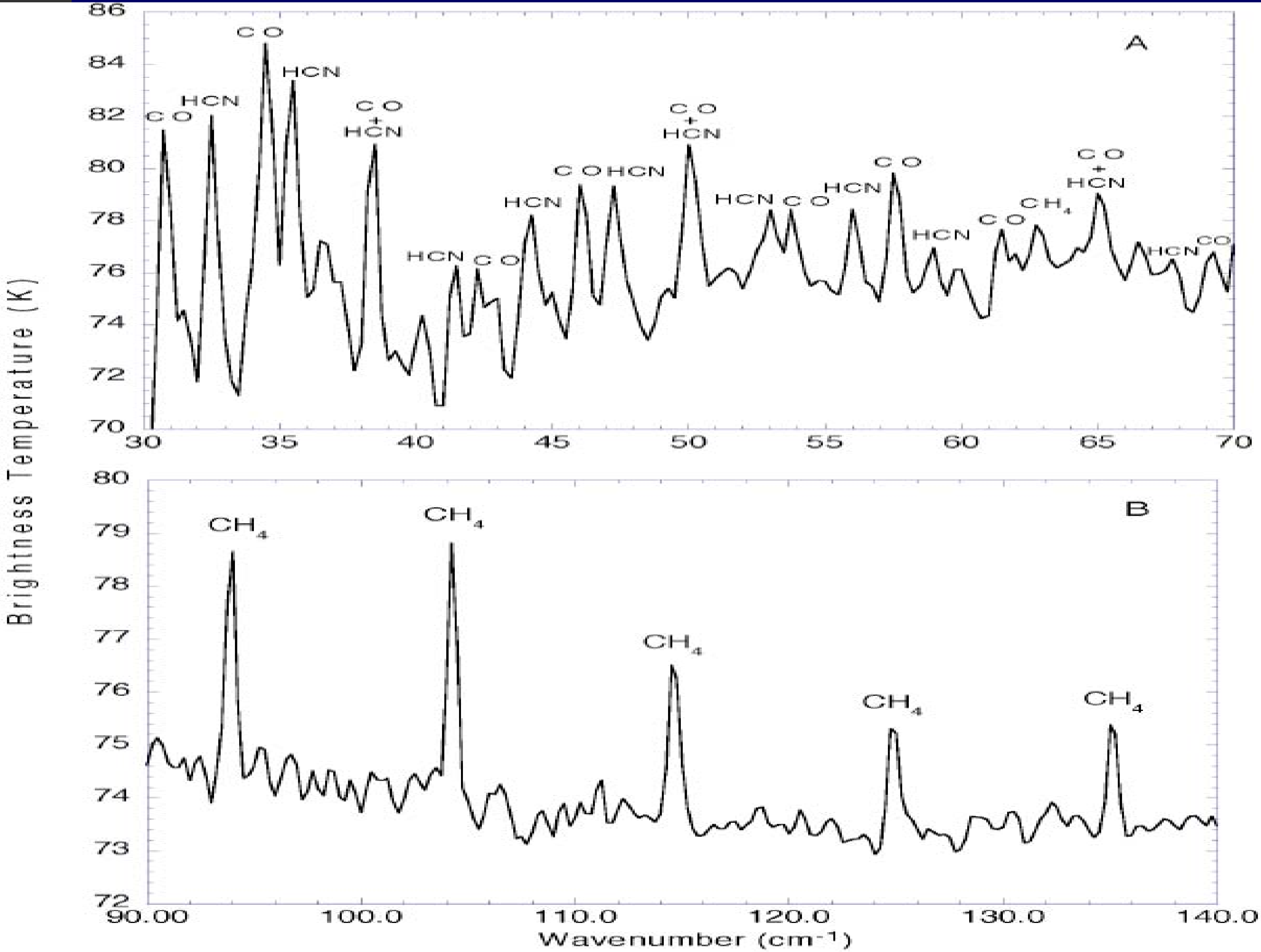
CIRS Infrared Spectrum of Saturn



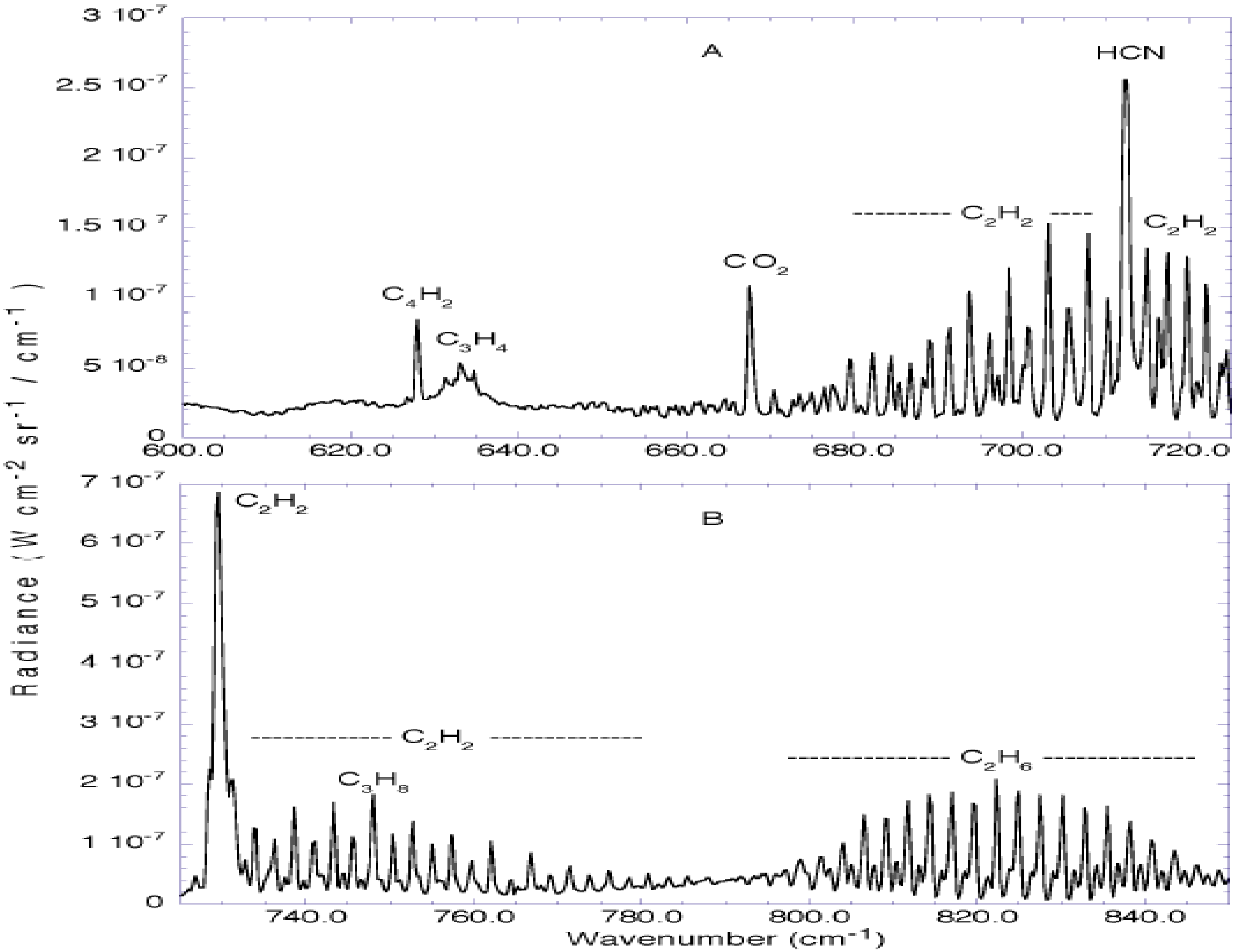
CIRS Infrared Spectrum Titan



FIR Spectrum of Titan



Titan's Composition Retrievals from Infrared Spectra



Analytical Techniques for Retrieval of Atmospher
Thermal Structure & Composition

- **Radiative Transfer Models (Forward solutions of the Radiative Transfer Equation (RTE)**
  - **Provide synthetic spectra for known values of : model atmosphe with known parameters (thermal structure, gas distributions, cl opacity etc.), instrument characteristics, and modes of observati**
- **Retrieval Programs (Inverse solutions of the RTE)**
  - **Calculate the atmospheric parameters (temperatures, gas distributions, isotopic ratios, cloud opacity, pointing directions, by comparison with the synthetic spectra and employing non-lin least- squares iterative techniques.**

Radiative Transfer Model

Observed radiance:

$$I_\nu(\theta) = \varepsilon_{\nu s}\tau_{\nu s}B_\nu(T_s) - \int_{ps}^{pt} B_\nu(T)\; C_\nu(\theta, p, T, n_i)\, d\ln p$$

Transmittance:

$$\tau_\nu = \exp\left[-\int \sum_i k_\nu^i(p,T)\, du_i \right]$$

$$du_i = n_i m_i ds$$

Contribution Functions:

$$C_\nu = B_\nu(T)\frac{\partial \tau_\nu}{\partial \ln p}$$

$$C_\nu = \frac{\partial B_\nu}{\partial T}\cdot\frac{\partial \tau_\nu}{\partial \ln p}$$

$$C_\nu = \frac{\partial \tau_\nu}{\partial \ln u_i}\cdot\frac{\partial B_\nu}{\partial \ln p}$$

Spectral Inversion Technique (contd.)

Relaxation Equations:

- **Assuming an initial guess model atmosphere, radiances are calculated for the selected frequencies and compared with the observed values.**

- **The atmospheric parameters (T, gas mixing ratios) are corrected at the peaks of the contributions functions (CFs) till the rms differences approach the noise level.**

- **The regions above and below the CFs are scaled appropriately**

$$I_i^n = I(q^n)$$

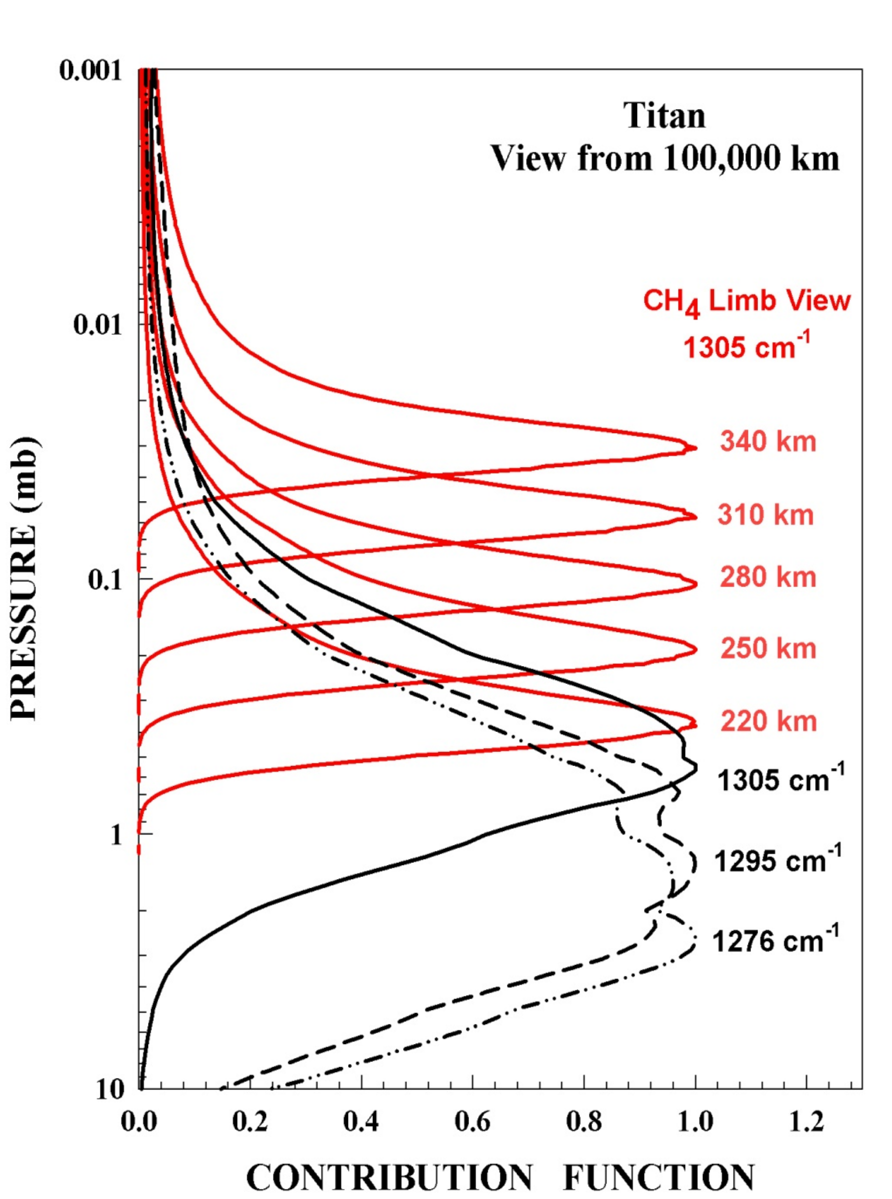
$$r_i^n = I_i^o - I_i^n$$

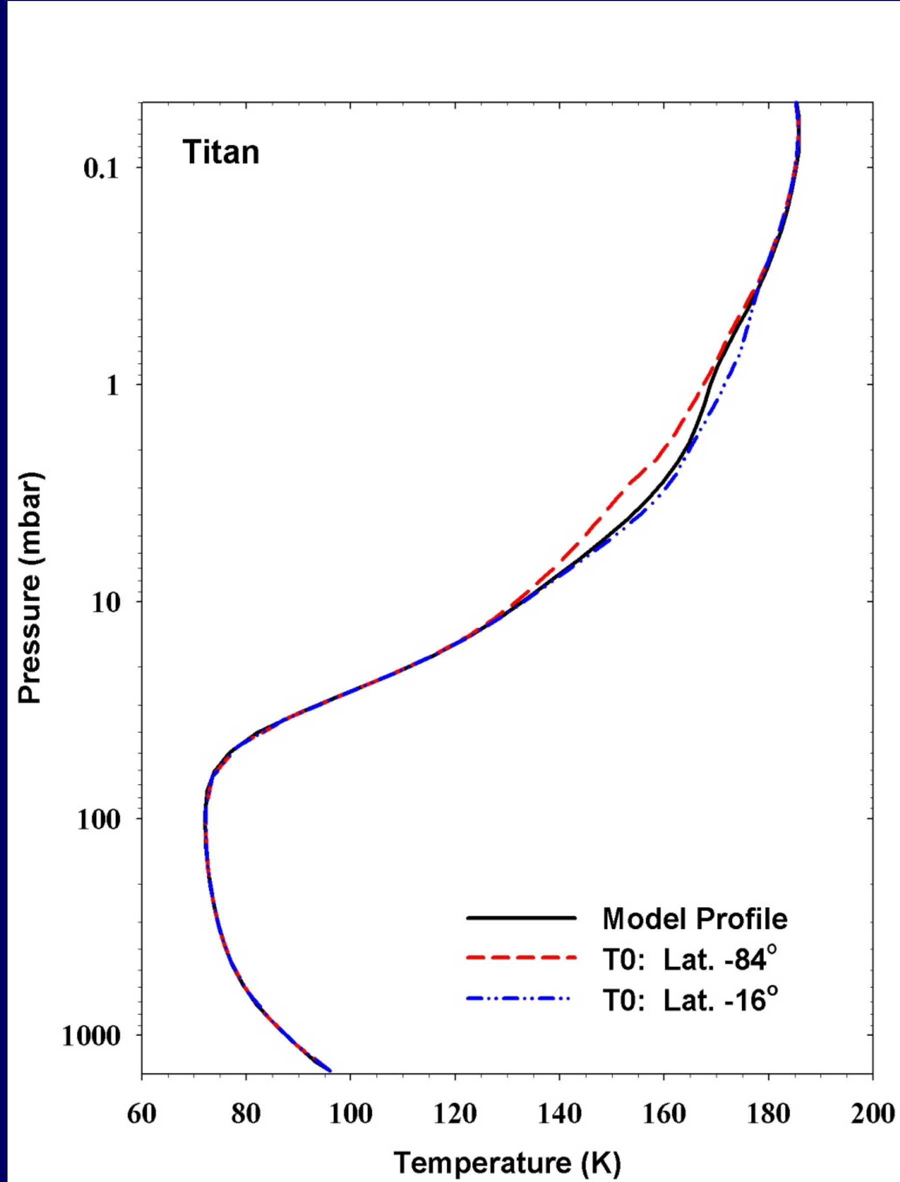
$$\sigma^n = \sqrt{\frac{1}{m}\sum_{i=1}^{m}(r_i^n)^2}$$

$$q^n = q^{n-1} + \frac{\sum_{i=1}^{m}\left(r_i^{n-1} a_i^{n-1}\right)}{\sum_{i=1}^{m}\left(a_i^{n-1}\right)^2}$$

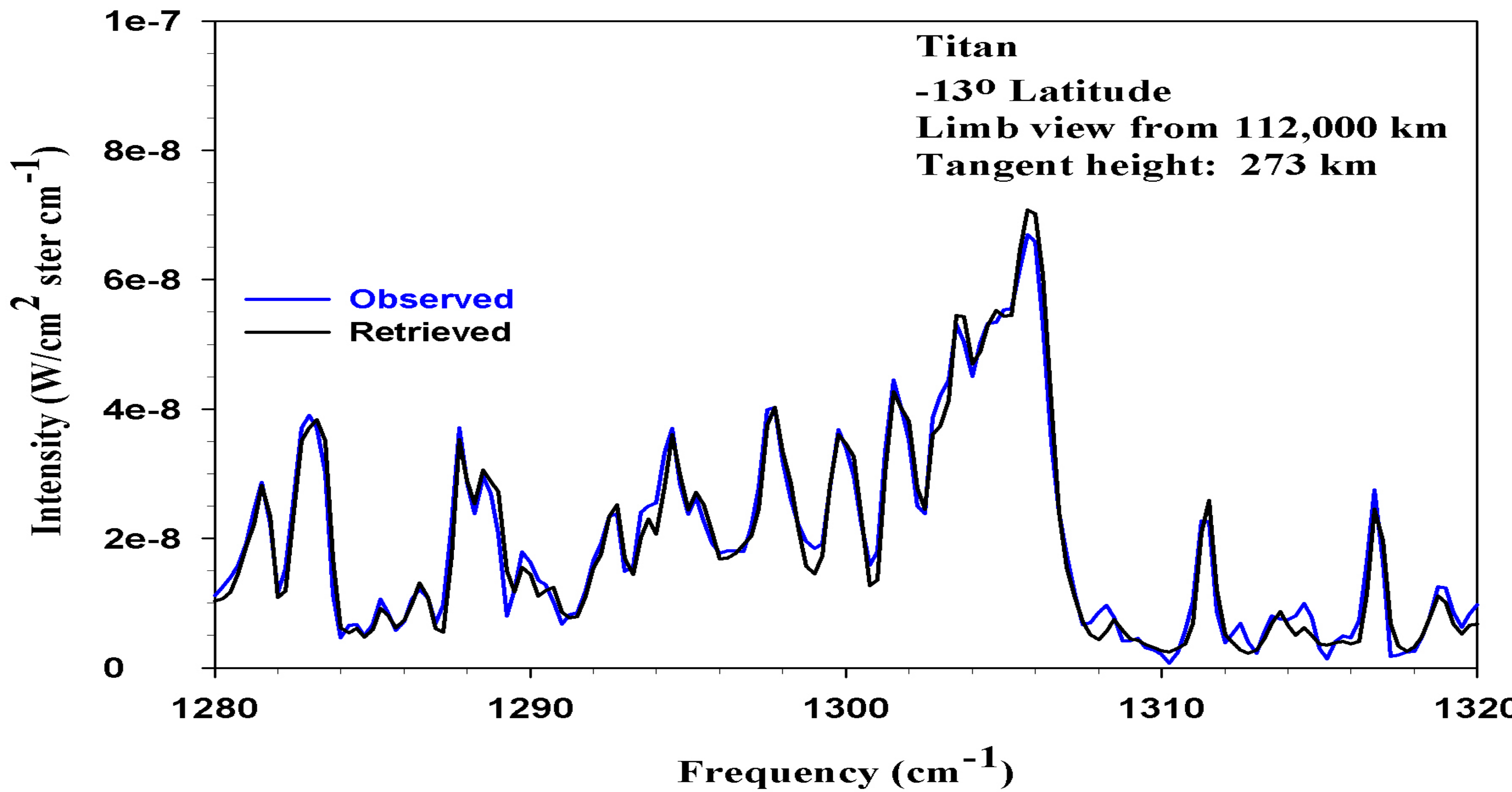
$$a_i^n = \left(\frac{\partial I\left(q;\nu_i\right)}{\partial q}\right)_{q=q^n}$$

Titan Temperature Retrieval





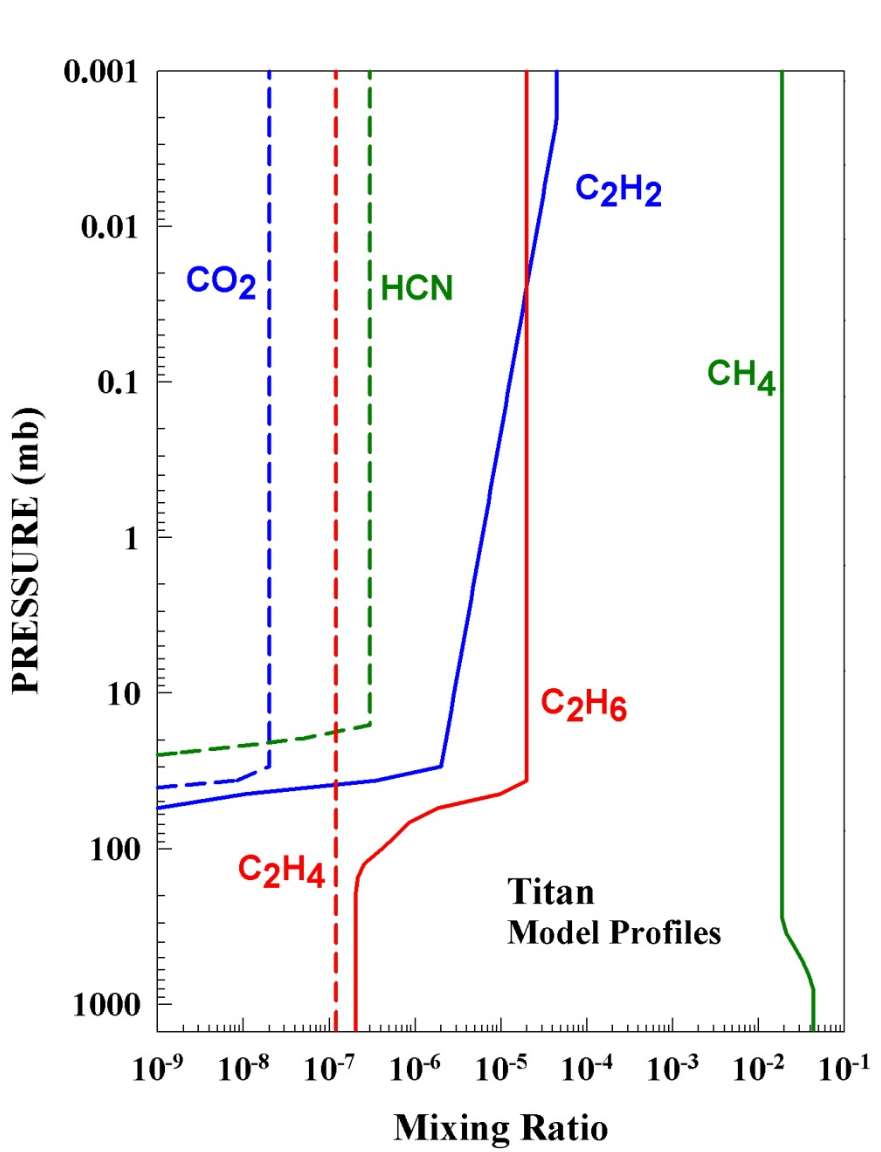
Titan Temperature Retrieval



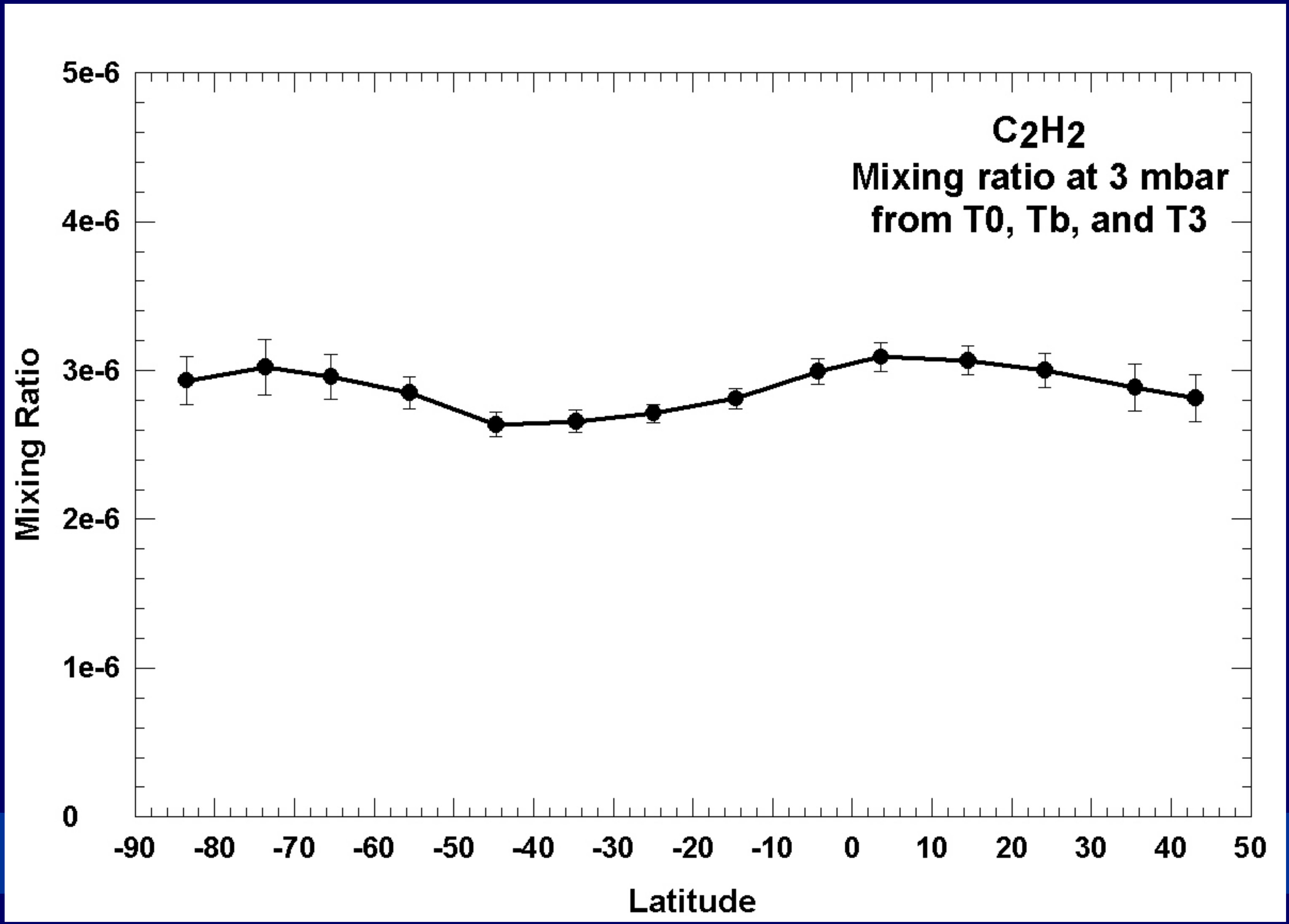
Combined limb and nadir temperature retrieval of Titan Tb observations at –13° latitude.

Titan Model Atmosphere

- **Composition:**
  - **N_2 ~ 95.6 - 98.1%**
  - **CH_4 ~ 4.4 - 1.6%**
  - **H_2 ~ 0.1%**
  - **C_2H_2, C_2H_4, C_2H_6, C_3H_4, C_3H_8, C_4H_2, C_6H_6**
  - **HCN, HC_3N**
  - **CO, CO_2, H_2O**

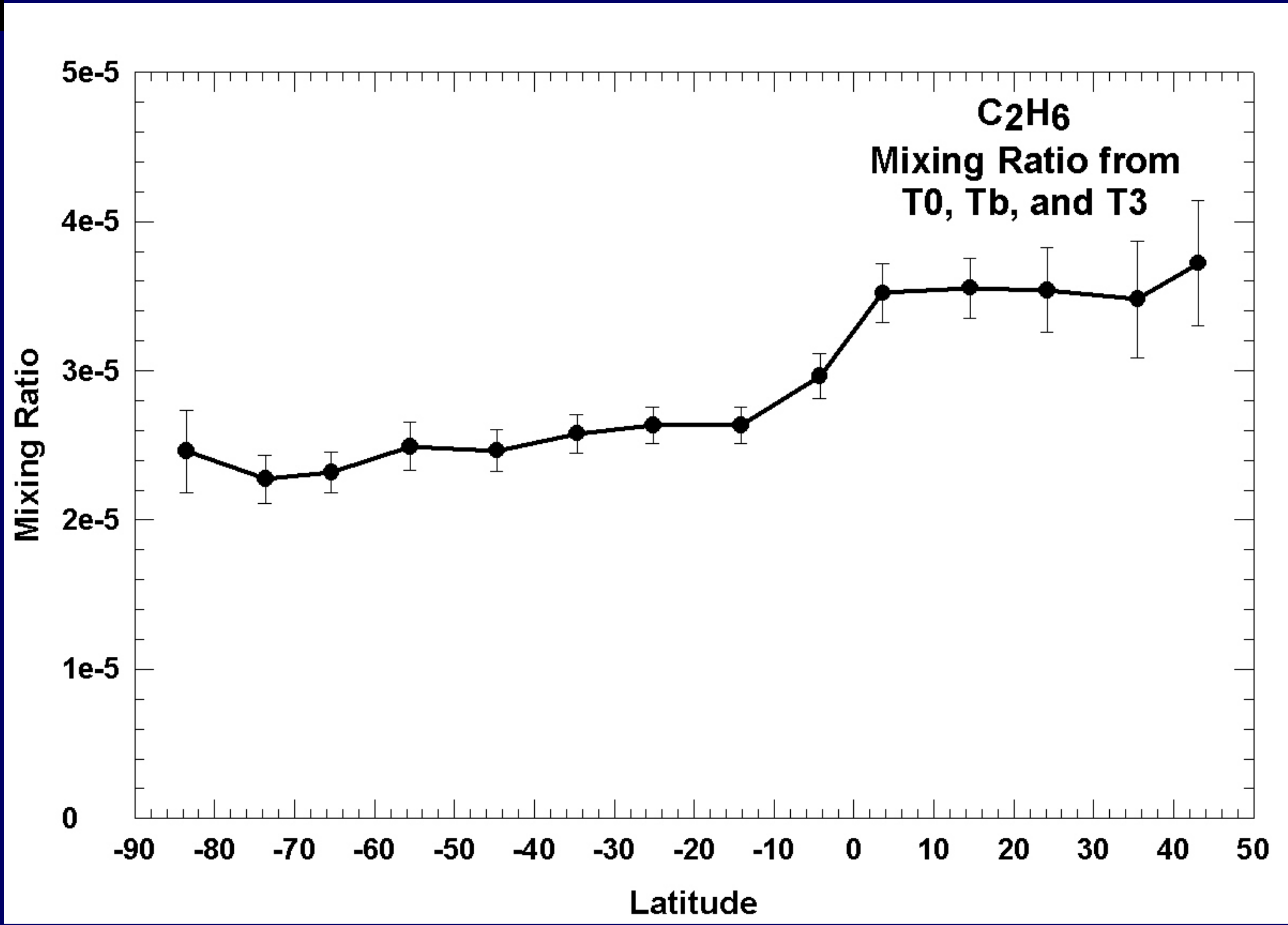


Titan Composition Retrieval: C2H2



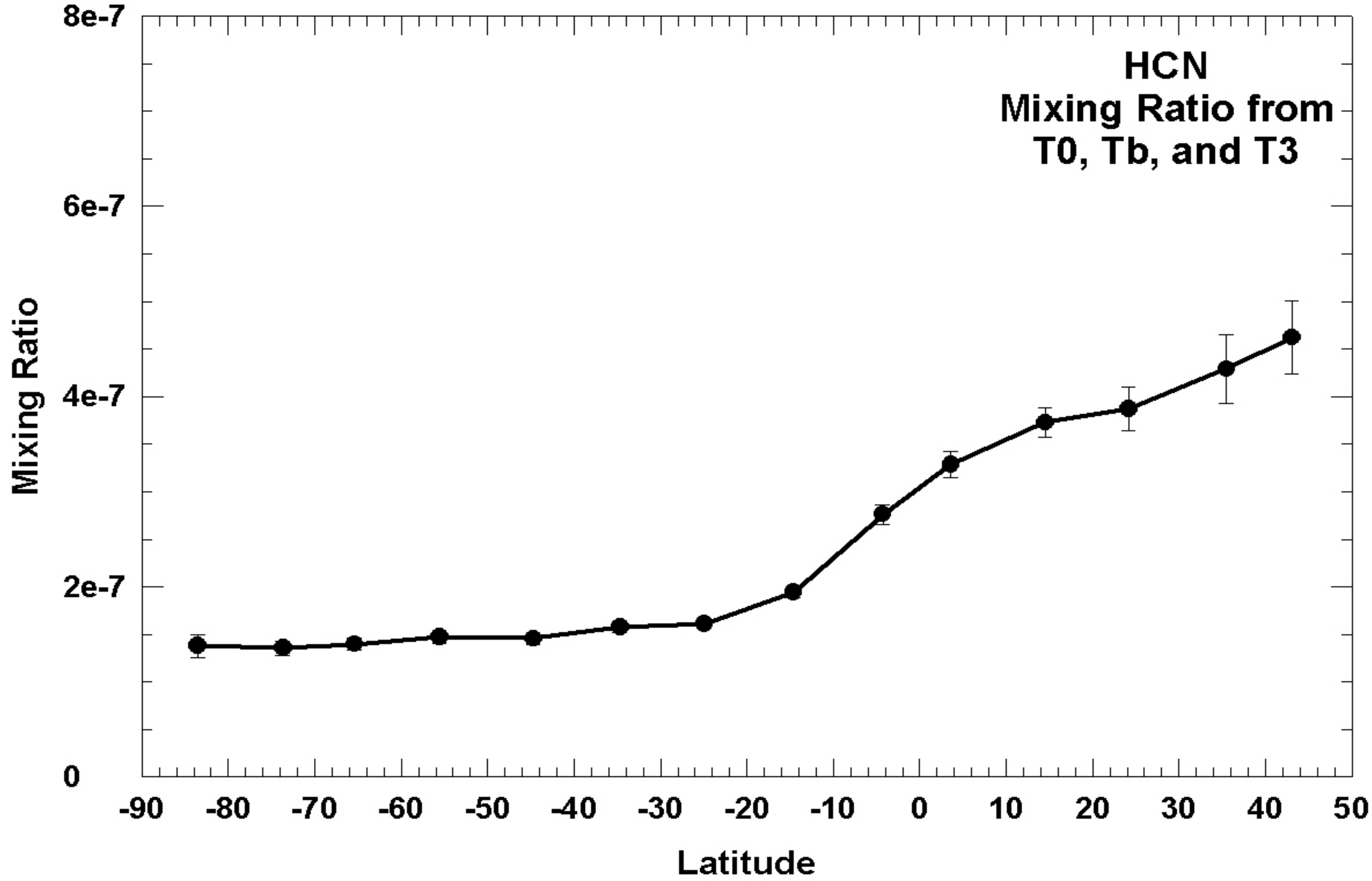
Mean C2H2 mixing ratio at 3 mbar in each latitude bin retrieved from T0, Tb, and T3 nadir observations.

Titan Composition Retrieval: C2H6



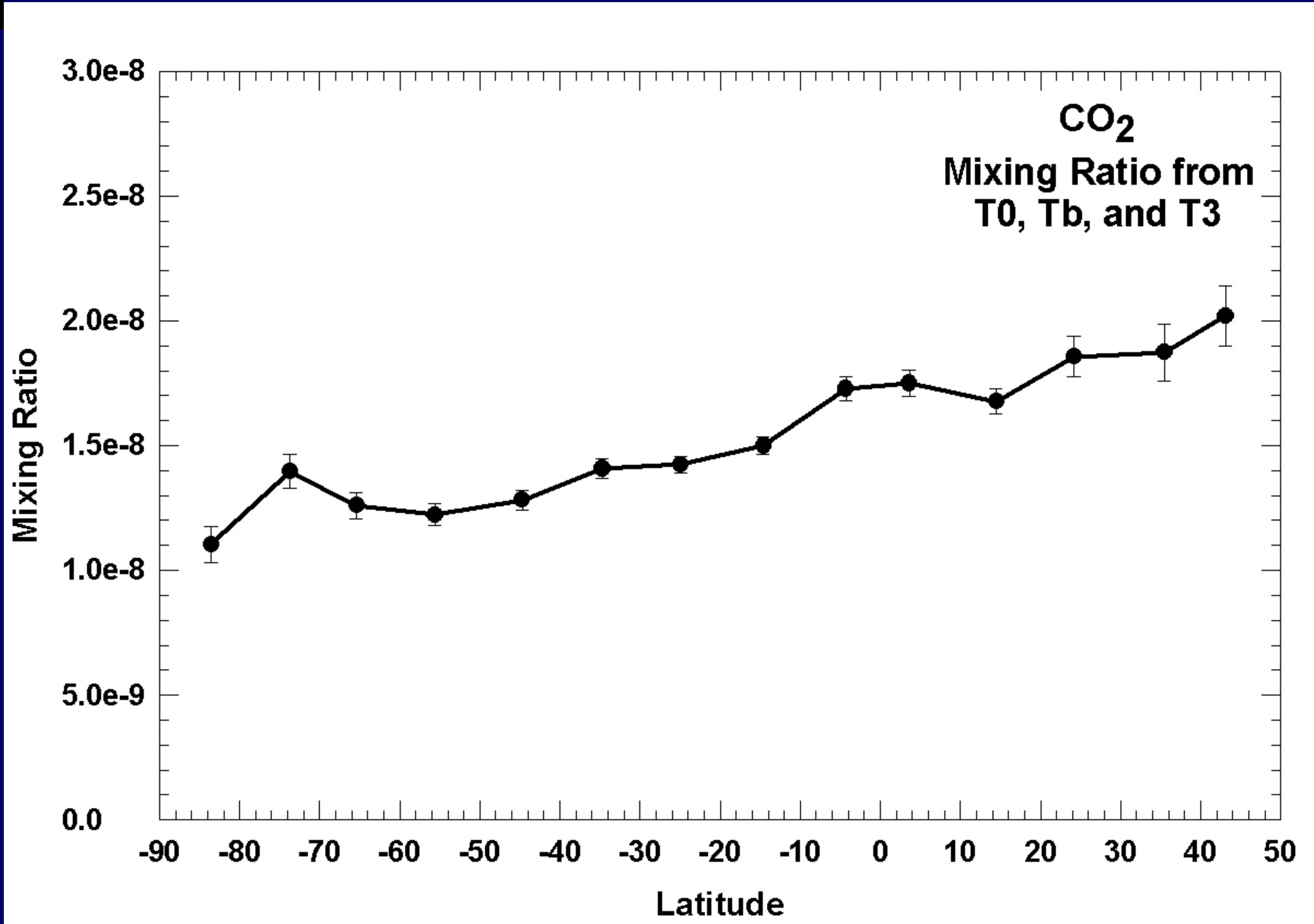
Mean C2H6 uniform mixing ratio in each latitude bin retrieved from T0, Tb, and T3 nadir observations. Run with HT04 data. Test run with GS03 data retrieves 1.6e-5 in southern hemisphere.

Titan Composition Retrieval: HCN



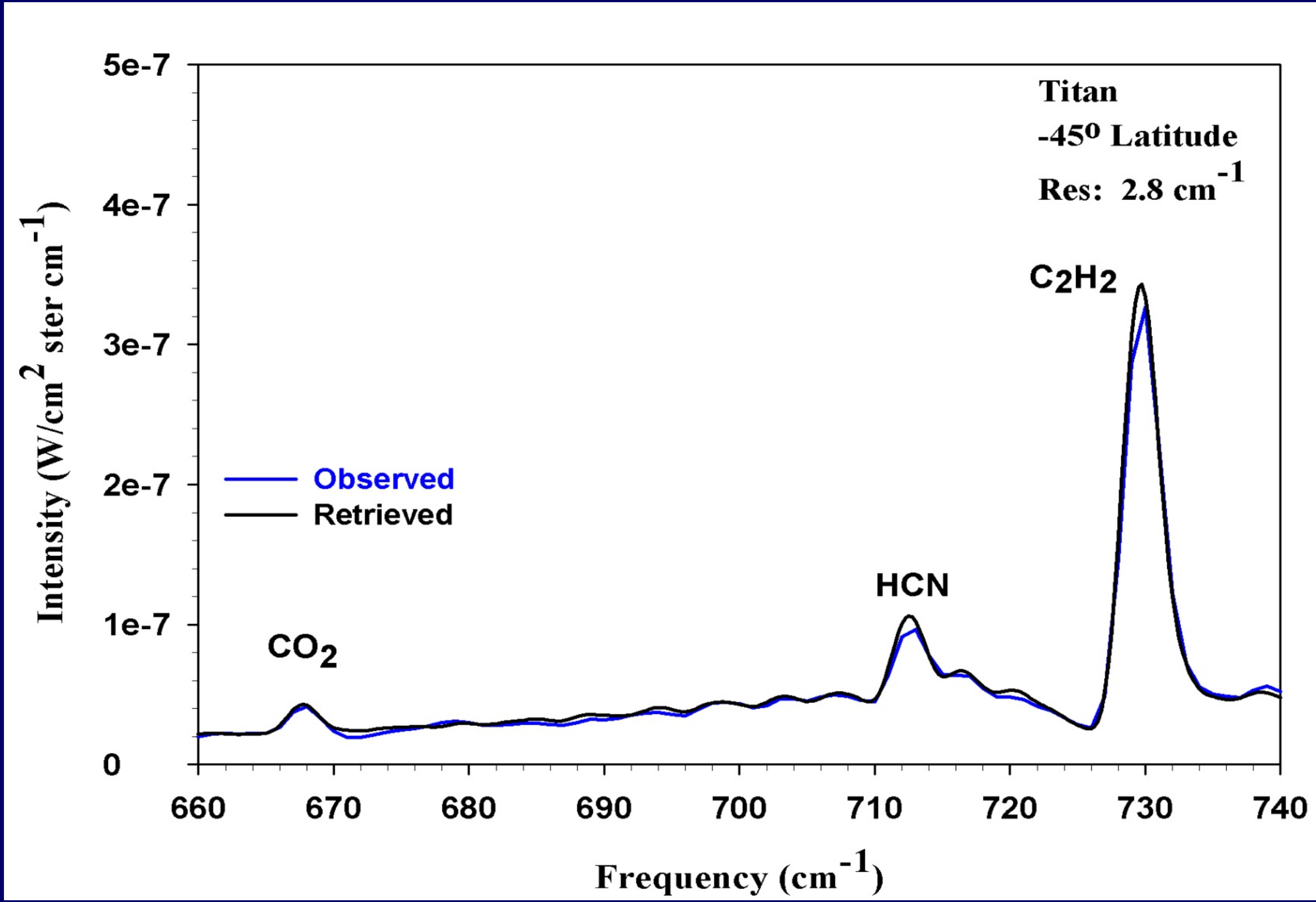
Mean HCN uniform mixing ratio in each latitude bin retrieved from T0, Tb, and T3 nadir observations.

Titan Composition Retrieval: CO2



Mean CO2 uniform mixing ratio in each latitude bin retrieved from T0, Tb, and T3 nadir observations.

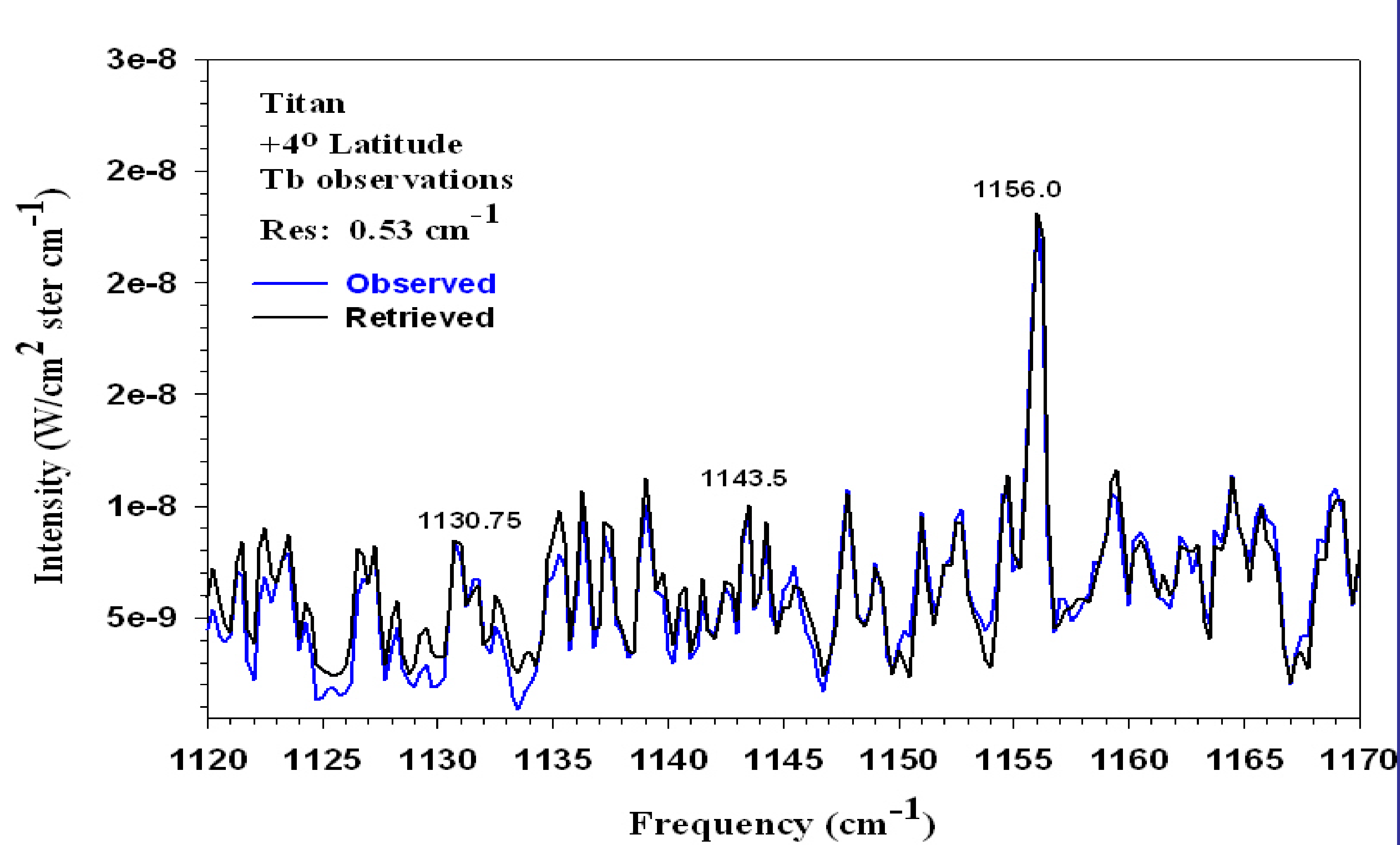
Titan Composition Retrieval: Comparison Spectra



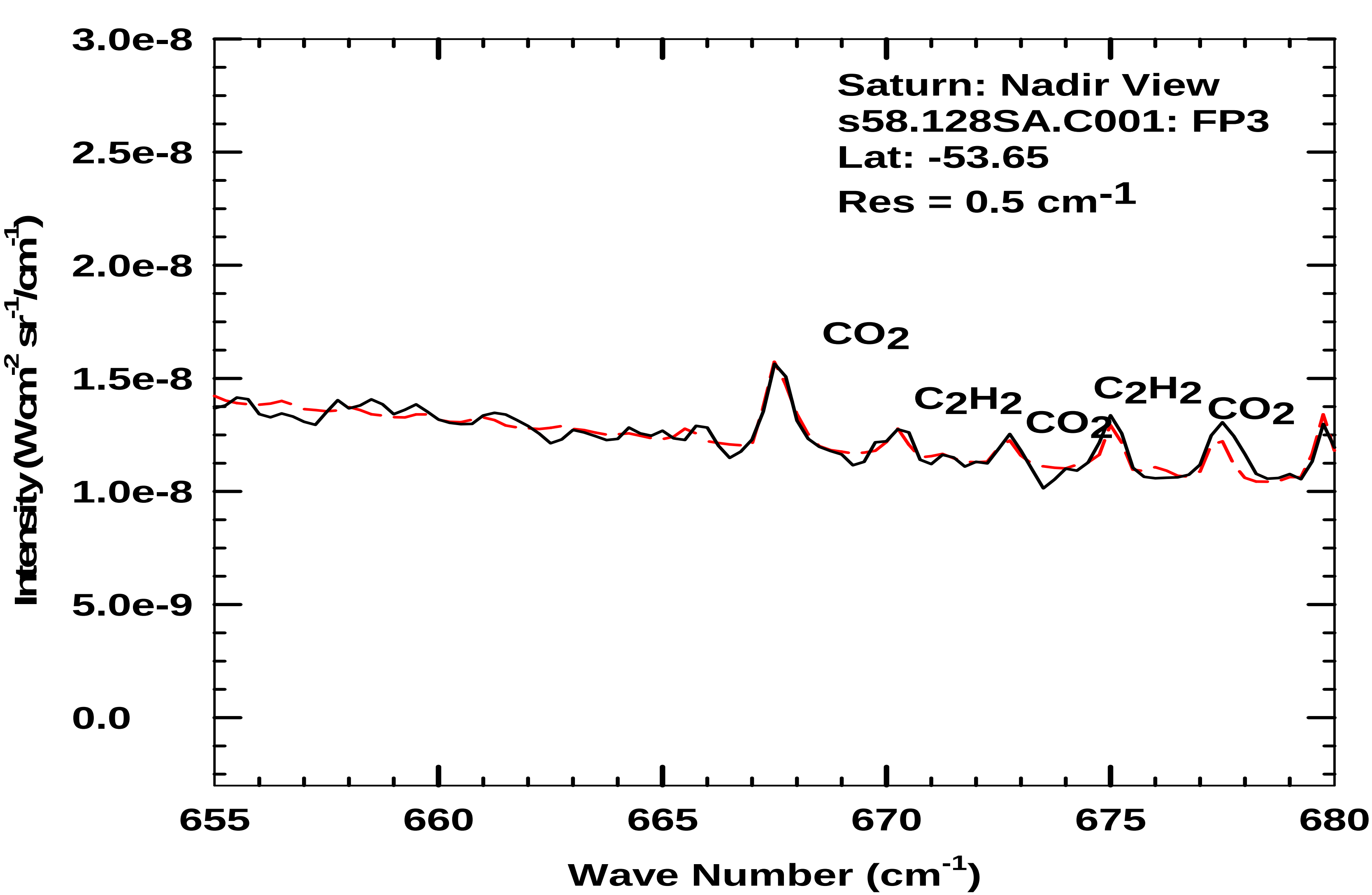
CH_3D Retrievals and D/H Ratio

- **Data: T0, Tb, T3 nadir observations at 0.5 cm^{-1} res, for 10° latitude bins centered at (T0: -60.6, -58.1); (Tb: -3.4, 4.3, 15.3); (T3: -23.0, -16.5)**
- **Spectral isolated CH_3D lines used: 1130.75, 1143.50, 1156.00 cm^{-1}**
- **Temperature profile retrieved from nadir observations at 2.8 cm^{-1} res. Provides good fit with the 0.5 cm^{-1} data in the 1300 cm^{-1} region.**
- **Continuum level is fitted with aerosol next to each frequency. The CH_3D abundance is retrieved to find the best fit of the three lines together.**
- **Retrieved CH_3D mean mixing ratio = 1.30×10^{-5}**
  - **CH_3D/CH_4 ratio = $(8.14 \pm 2.2)\times10^{-4}$**
  - **Mean D/H ratio = $(2.04 \pm 0.55)\times10^{-4}$**
- **Comparison with**
  - **Athena Coustenis: D/H: $(1.17^{+0.16}_{-0.21})\times10^{-4}$**
  - **Huygens D/H: $(2.3 \pm 0.5)\times10^{-4}$**

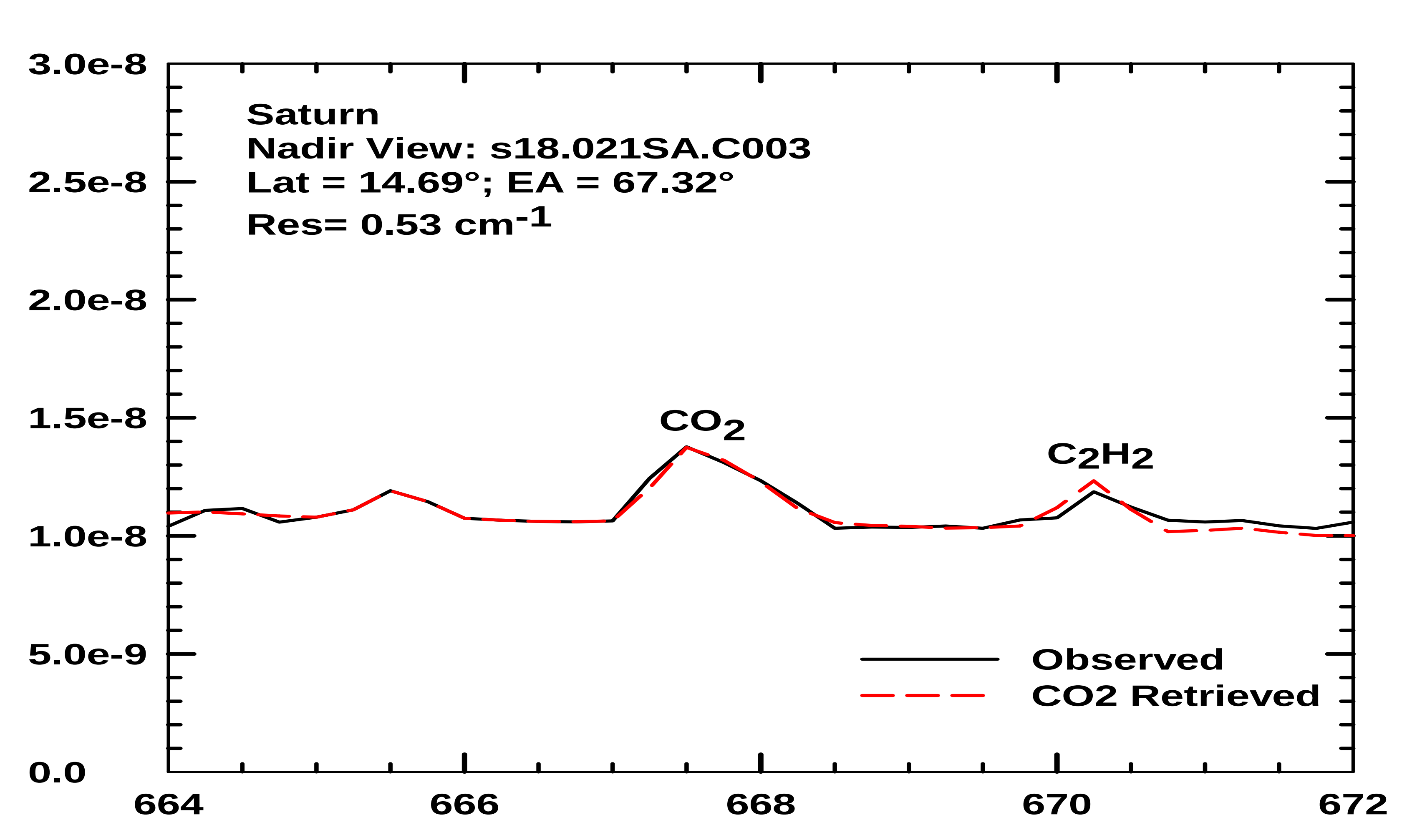
Titan Comparison Spectra : CH3D



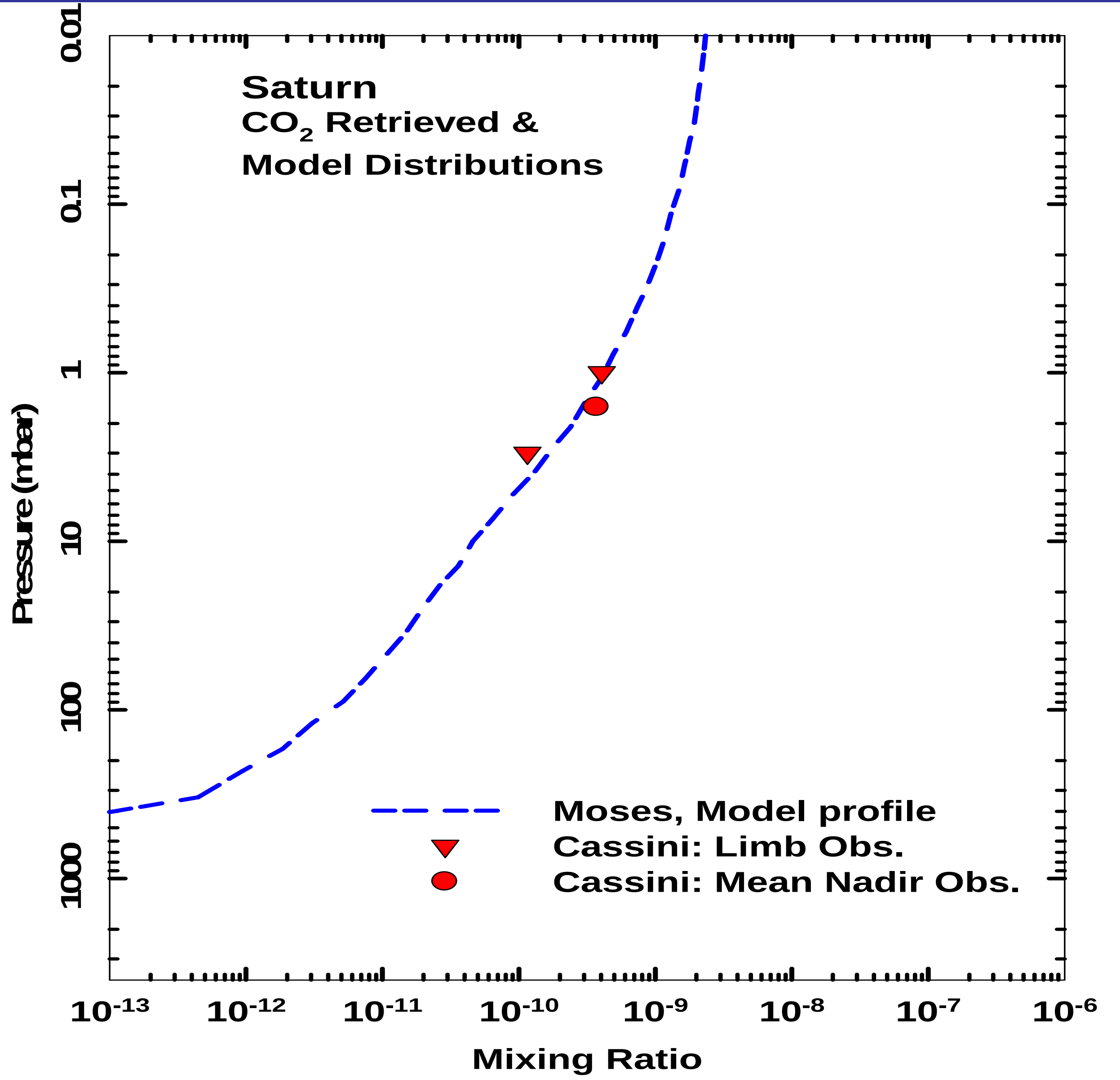
Saturn Infrared Spectra : CO2



Saturn IR Observed and Synthetic Spectra :



Retrieved Saturn CO2 Mixing Ratio Profile



Summary of Saturn's CO_2 mixing ratios retrieved from Cassini/CIRS Nadir observations

Parameter	Q_v (CO_2)	N (CO_2)
Mean Value of Atmos. Pressure @ 1 mb	4.74E-10	2.14E+14
Standard Deviation	1.52E-10	5.74E+13
Standard Deviation of Mean	5.10E-12	2.21E+12
Mean Value of Atmos. Pressure @ 10 mb	1.05E-10	6.30E+14
Standard Deviation	3.19E-11	1.56E+14
Standard Deviation of Mean	1.10E-12	5.77E+12

Thank You!