

## **Lecture 11.**

### **Applications of passive remote sensing:**

#### **Remote sensing of planetary atmospheres - Examples**

1. General overview
2. Examples: Mars
3. Examples: Titan

#### **Recommended reading:**

NASA Planetary Science

<http://science.nasa.gov/planetary-science/>

Planetary Decadal Survey 2013-2022: The Future of Planetary Science

<http://solarsystem.nasa.gov/2013decadal/>

Mustard, J.F., et al. Hydrated silicate minerals on Mars observed by the Mars Reconnaissance Orbiter CRISM instrument. *Nature* 454, 305-309, doi:10.1038/nature07097, 2008.

Roe, H.G.:Titan's Methane Weather. *Annual Review of Earth and Planetary Sciences* Vol. 40: 355-382, 2012.

#### **1. General overview: NASA Planetary Science**

*Inner Solar System -*

Mercury, Venus, Earth and Mars.

*Outer Solar System -*

The giant planets of the outer solar system—Jupiter, Saturn, Uranus, and Neptune—and their rings and moons and the ice dwarfs (e.g., Pluto, Charon, Sedna).

*Small Bodies of the Solar System -*

Comets, asteroids and other small bodies

## **Planetary Science Data Centers**

*Planetary Data System (PDS) <http://pds.nasa.gov/>*

The PDS archives and distributes scientific data from NASA planetary missions, astronomical observations, and laboratory measurements. Its purpose is to ensure the long-term usability of NASA data and to stimulate advanced research. PDS is continually upgrading and updating its archives, to better serve the needs of its user communities.

*National Space Science Data Center (NSSDC) <http://nssdc.gsfc.nasa.gov/>*

The NSSDC communicates with active archives, and the active archives in turn communicate both with NSSDC and the scientists, educators and others who are end users of the data. In addition, numerous Project, Mission, and Principal Investigator (PI) web sites provide access to current data, some of which are not yet available through an active archive.

## **2. Examples: Mars**

***Major Accomplishments of Studies of Mars in the Past Decade (Planetary Decadal Survey):***

*Mars Global Surveyor, Odyssey, Mars Express, Mars Reconnaissance Orbiter*

Provided global mapping of surface composition, topography, remanent magnetism, atmospheric state, crustal structure.

*Odyssey*

Mapped the current distribution of near-surface ice and the morphologic effects of recent liquid water associated with near-surface ice deposits.

*Mars Exploration Rovers, Phoenix*

Confirmed the significance of water through mineralogic measurements of surface rocks and soils

*Mars Express, Odyssey, Mars Reconnaissance Orbiter, Mars Exploration Rovers*

Demonstrated the diversity of aqueous environments, with major differences in aqueous chemistry, conditions, and processes

Mars Global Surveyor, Odyssey, Mars Express, Mars Reconnaissance Orbiter and ground-based telescopes

Mapped the three-dimensional temperature, water vapor, and aerosol properties of the atmosphere through time; found possible evidence of the presence of methane

**Mars Reconnaissance Orbiter (MRO):** launched August 2005 - ongoing

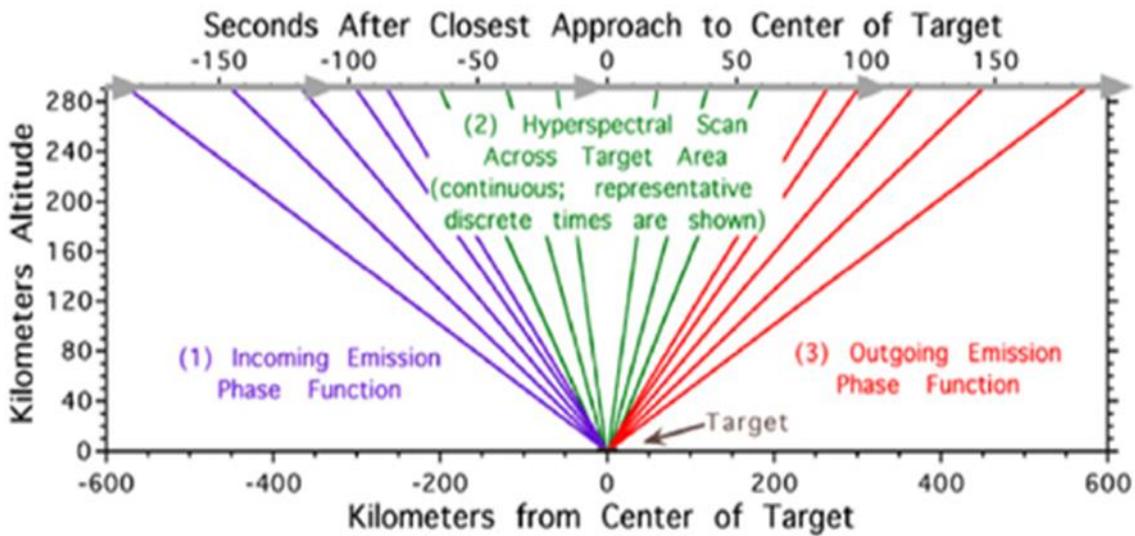
<http://mars.jpl.nasa.gov/mro/>

**CRISM (Compact Reconnaissance Imaging Spectrometer for Mars)** is a visible-infrared imaging spectrometer (from 0.362 to 3.92 microns) with a scanable field of view.

<http://crism.jhuapl.edu/index.php>

Key Performance Characteristics			
Aperture	100 mm (3.94 inches)	Focal length	441 mm (17.36 inches)
Field of view	2.12 degrees (37 milliradians)	Instantaneous FOV (pixel angular size)	0.0035 degree (61.5 microradians)
Spectral range	VNIR: 362-1053 nm IR: 1002-3920 nm	Spectral sampling	6.55 nm/channel
Swath width	9.4 to 11.9 km at 300 km altitude (5.8 to 7.4 miles at 186 miles altitude)	Spatial sampling	15.7 to 19.7 m/pixel; resolves 38-m spot at all wavelengths (51 to 64 feet/pixel; resolves 125-foot spot at all wavelengths)
Pointing	+/-60 degrees along the spacecraft ground track	Scan jitter	25 microradians from the aimpoint

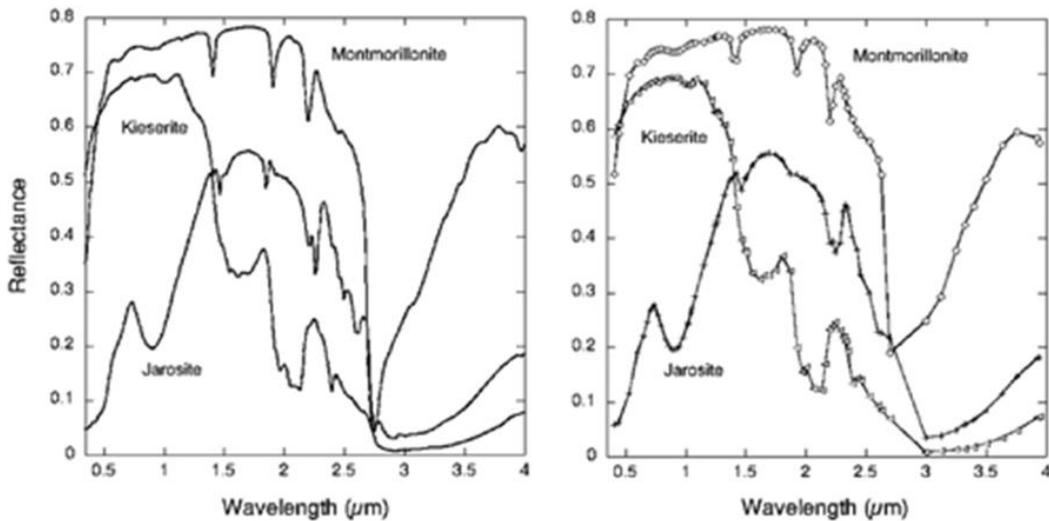
CRISM uses reflectance spectroscopy to determine mineralogical composition of Mars surface <http://crism.jhuapl.edu/instrument/seeSurface.php>



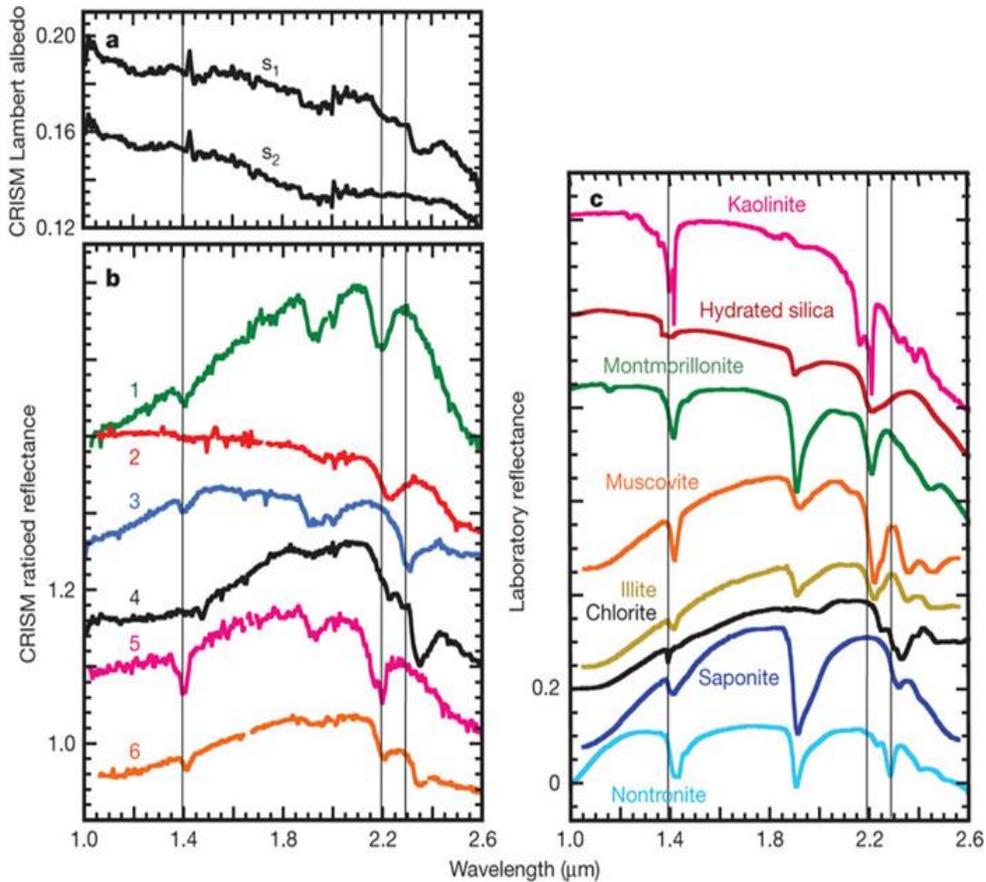
**Figure 11.1** CRISM superimposes a scan to cover a region approximately 10 km x 10 km at about 18 meters per pixel, covering the spectral range from 0.36-3.92 microns.

Hyperspectral mode: 554 wavelengths

Multispectral mode: 72 wavelengths



The CRISM Spectral Library is a collection of laboratory spectra of Mars-analog materials (2,260 spectral analyses of 1,134 Mars-analog samples) [http://pds-geosciences.wustl.edu/missions/mro/spectral\\_library.htm](http://pds-geosciences.wustl.edu/missions/mro/spectral_library.htm)



**Figure 11.2** CRISM and laboratory reflectance spectra showing hydrated silicate mineral diversity (From Mustard et al. 2008)

### **3. Examples: Titan**

*The Cassini-Huygens mission*: launched in 1997 and arrived in orbit around Saturn in mid-2004. Cassini will have completed ~125 Titan flybys by September 2017, when it will be crashed into Saturn. <http://saturn.jpl.nasa.gov/>

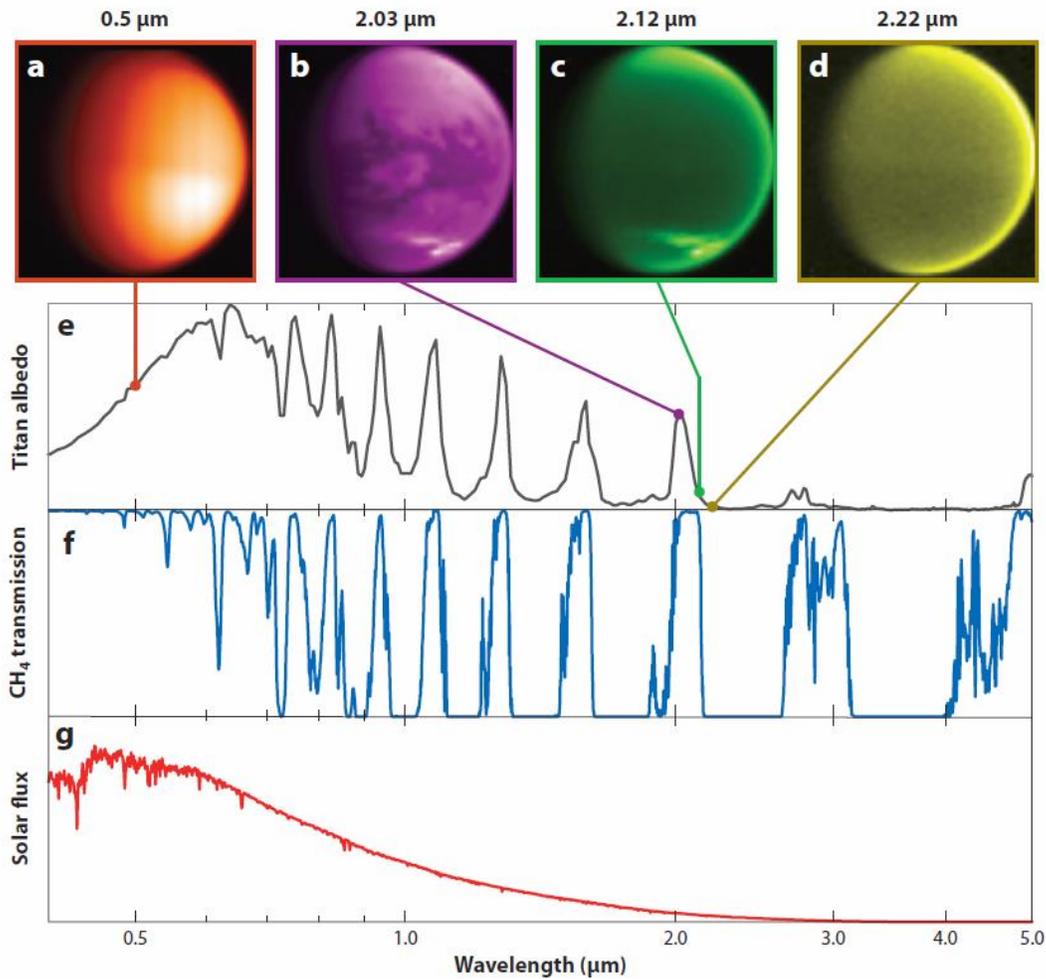
**Visible and Infrared Mapping Spectrometer (VIMS)** onboard the Cassini spacecraft has two cameras (a pair of imaging grating spectrometers): one is used to measure visible wavelengths, the other infrared. Combined, the two cameras provide information on the composition of moon surfaces, the rings, and the atmospheres of Saturn and Titan.

VIMS imaging grating spectrometers:

Visible Channel [VIMS-V] (0.35 to 1.07  $\mu\text{m}$  [96 channels]; 32x32 mrad field of view)

Infrared Channel [VIMS-IR] (0.85 to 5.1  $\mu\text{m}$  [256 channels]; 32x32 mrad field of view)

*Cassini Visual and Infrared Mapping Spectrometer (VIMS)*



**Figure 11.3** Albedo spectrum (e) and images (a–d) of Titan from the Cassini Visual and Infrared Mapping Spectrometer (VIMS) compared with a methane transmission spectrum (f) and the solar spectrum (g). Shortward of  $\sim 0.7\text{-}\mu\text{m}$  wavelength, absorption by haze and Rayleigh scattering dominate Titan’s spectrum. At these shorter wavelengths, only higher altitudes of the atmosphere are probed, and Titan appears relatively featureless (a). Longward of  $\sim 0.7\text{-}\mu\text{m}$  wavelength, methane absorption

dominates. In each of the “windows” between methane bands, Titan is bright, and surface features are visible (b). At wavelengths where methane is very absorbing, the images show only the relatively featureless high-altitude hazes (d). At wavelengths of intermediate degrees of methane absorption, surface features are obscured from view, but tropospheric clouds are revealed at high contrast (c) against the backdrop of the high-altitude haze. Although this example shows the  $\sim 2\text{-}\mu\text{m}$  window, this technique of separating tropospheric clouds from surface features and higher-altitude hazes can be used in each of the  $\sim 9$  methane windows. Through the fitting of radiative transfer models to spectra of individual clouds, accurate cloud-top altitudes can be assigned. VIMS images and Titan albedo spectrum were obtained from the NASA Planetary Data System Imaging Node. (From Roe 2012).

The clear windows between methane bands in the roughly  $1\text{--}2.5\text{-}\mu\text{m}$  wavelength range are suitable for lower atmosphere and surface observations.

**Titan:** conditions are near the triple point of methane, and phase transitions of methane play an important role (analogues to water in the Earth’s atmosphere). Pressure at the Titan’s surface is  $\sim 50\%$  greater than that of Earth.

The water vapor in Earth’s atmosphere condensed would form a layer just a few centimeters thick on average, with local variations of an order of magnitude. On Titan, the column of methane condensed from the atmosphere would be  $4\text{--}5$  m, and the variation from location to location is  $<20\%$ .

On Earth, the tropopause acts as a cold trap preventing water vapor from diffusing into the stratosphere. Titan’s tropopause is not cold enough to trap methane, and methane diffuses into the stratosphere. The abundance of methane in the stratosphere is the same as in the upper troposphere ( $1.4\%$ ). Photolysis of methane in Titan’s upper atmosphere is a significant and irreversible destruction mechanism, and the loss rate is governed by the availability of ultraviolet photons.