Hyperspectral remote sensing
.. Theory and Application

Planetary Remote sensing
Wavelengths and sensors
Sun and Moon
Planets” Mercury …Mars …. Pluto
Hyperspectral remote sensing ('Image spectroscopy')

**Multispectral** systems contain ~4–15 bands ~70–400 nm wide
**Hyperspectral**: 100–200+ bands 0.38 – 2.5 μm 5–10 nm each
Bands are contiguous and high spectral resolution
Some airborne hyperspectral systems

<table>
<thead>
<tr>
<th>Sensor</th>
<th>Wavelength (nm)</th>
<th>Band width (nm)</th>
<th># bands</th>
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<tbody>
<tr>
<td>AVIRIS</td>
<td>400-2500</td>
<td>10</td>
<td>224</td>
</tr>
<tr>
<td>TRWIS III</td>
<td>367-2328</td>
<td>6</td>
<td>335</td>
</tr>
<tr>
<td>HYDICE</td>
<td>400-2400</td>
<td>10</td>
<td>210</td>
</tr>
<tr>
<td>CASI (1500)</td>
<td>400- 900</td>
<td>1.8</td>
<td>288</td>
</tr>
<tr>
<td>OKSI AVS</td>
<td>400-1000</td>
<td>10</td>
<td>61</td>
</tr>
<tr>
<td>ESSI Probe-1</td>
<td>400-2450</td>
<td>15</td>
<td>128</td>
</tr>
</tbody>
</table>
Spectral signatures: Landsat TM v hyperspectral

Above: Spectral comparison between hyperspectral and broad-band data.

http://www.ccrs.nrcan.gc.ca/hyperspectral/isst_e.php
Quantifying structural physical habitat attributes using LIDAR and hyperspectral imagery

![LiDAR DEM](image1.png)

**Saltcedar**

**Perennial pepperweed**

**Russian knapweed**

**Scotch thistle**

**Hoary cress**

**Leafy spurge**

IR image and 10 class  →  ISODATA classification
SOME APPLICATIONS:

- wetland and coastal vegetation
- mineral composition
- agricultural crops
- forest structure
- soil types

ITRES is the longest-established commercial hyperspectral company in the world.

We offer high-performance airborne hyperspectral, thermal, and ultraviolet imaging mappers, including models for UAV and ground use.

We are airborne hyperspectral and thermal:
- Sensors
- Surveys
- Warranty and Service
SOME APPLICATIONS:

- wetland and coastal vegetation
- mineral composition
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Satellite borne hyperspectral systems

**Hyperion**: launched on Earth Observing 1 (EO-1), Dec 2000; 50km behind Landsat7.
Venice by CHRIS
(Compact High Resolution Imaging Spectrometer)
on PROBA (2001)

CHRIS provides 19 bands in the VNIR range (400 - 1050 nm) at 17 m. Each nominal image forms a square of 13 km x 13 km.

CHRIS can be reconfigured to provide 63 spectral bands at a spatial resolution of 34 m and can provide up to 150 channels.

Launch:
http://www.esa.int/SPECIALS/Proba/index.html
The Niau atoll, in the central South Pacific Ocean, acquired on 6 October 2005 with the Compact High Resolution Imaging Spectrometer (CHRIS).

Gallery: [http://earth.esa.int/cgi-bin/satimsql.pl?search=&sat=12](http://earth.esa.int/cgi-bin/satimsql.pl?search=&sat=12)
2021: Spaceborne Hyperspectral Applicative Land and Ocean Mission (SHALOM)

... is a joint mission by the Israeli Space Agency and the Italian Space Agency to develop two commercial hyperspectral satellites
Remote sensing of the planets

A vast literature and methodology exists in optical and radar astronomy that parallels and often exceeds our methods used in remote sensing.
Wide-field Infrared Survey Explorer (WISE) since Nov 20, 2009

Looking out into space

Detectors at 3.4, 4.6, 12 and 22 microns, chilled to 10 Kelvin

Hubble telescope
UV-> NIR

## Methods and wavelengths used on planetary missions

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<th>INFORMATION</th>
<th>INTERPRETATION</th>
<th>MISSION</th>
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<td>Gamma-Ray Spectroscopy</td>
<td>Gamma rays</td>
<td>Gamma spectrum</td>
<td>K, U, Th Abundances</td>
<td>Apollo 15, 16: Venera</td>
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<tr>
<td>X-ray Fluorescence spectrometry</td>
<td>X-rays</td>
<td>Characteristic Wavelengths</td>
<td>Surface mineral/chemical comp.</td>
<td>Apollo; Viking Landers</td>
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<tr>
<td>Ultraviolet Spectrometry</td>
<td>UV</td>
<td>Spectrum of Reflected sunlight</td>
<td>Atmospheric Composition: H, He, CO₂</td>
<td>Mariner; Pioneer; voyager</td>
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<tr>
<td>Photometry</td>
<td>UV, Visible</td>
<td>Albedo</td>
<td>Nature of Surface; Composition</td>
<td>Earth Telescopes; Pioneer</td>
</tr>
<tr>
<td>Multispectral Imagers</td>
<td>UV, Visible, IR</td>
<td>Spectral and Spatial</td>
<td>Surface Features; Composition</td>
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<tr>
<td>Reflectance Spectrometers</td>
<td>Visible, IR</td>
<td>Spectral intensities of reflected solar radiation</td>
<td>Surface Chemistry; mineralogy; processes</td>
<td>Telescopes; Apollo</td>
</tr>
<tr>
<td>Laser Altimeter</td>
<td>Visible</td>
<td>Time delay between emitted and reflected pulses</td>
<td>Surface Relief</td>
<td>Apollo 15, 16, 17</td>
</tr>
<tr>
<td>Polarimeter</td>
<td>Visible</td>
<td>Surface Polarization</td>
<td>Surface Texture; Composition</td>
<td>Pioneer; Voyager</td>
</tr>
</tbody>
</table>


<table>
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<th>Waveband</th>
<th>Analysis</th>
<th>Mission</th>
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<td>Infrared Radiometer</td>
<td>Infrared</td>
<td>Thermal radiant intensities</td>
<td>Apollo; Mariner; Viking; Voyager</td>
</tr>
<tr>
<td>(includes scanners)</td>
<td></td>
<td>atmospheric temperatures; compos.</td>
<td></td>
</tr>
<tr>
<td>Microwave Radiometer</td>
<td>Microwave</td>
<td>Passive microwave emission</td>
<td>Mariner; Pioneer; Venus</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Atmosphere/Surface temperatures; structure</td>
<td></td>
</tr>
<tr>
<td>Bistatic Radar</td>
<td>Microwave</td>
<td>Surface reflection profiles</td>
<td>Apollo 14, 15, 16; Viking</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Surface Heights; roughness</td>
<td></td>
</tr>
<tr>
<td>Imaging Radar</td>
<td>Microwave</td>
<td>Reflections from swath</td>
<td>Magellan; Earth systems</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Topography and roughness</td>
<td></td>
</tr>
<tr>
<td>Lunar Sounder</td>
<td>Radar</td>
<td>Multifrequency Doppler Shifts</td>
<td>Apollo 17</td>
</tr>
<tr>
<td>S-Band Transponder</td>
<td>Radio</td>
<td>Doppler shift single frequency</td>
<td>Apollo</td>
</tr>
<tr>
<td>Radio Occultation</td>
<td>Radio</td>
<td>Gravity data</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Frequency and intensity change</td>
<td>Atmospheric density and pressure</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>Flybys and Orbiters</td>
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</tbody>
</table>

Types of Remote Sensing Missions

- **Fly-bys**
  - Mariner Missions, Mercury and Venus
  - New Horizons 2007, Jupiter and Pluto

- **Orbiters**
  - LandSat, Earth
  - Mars Reconnaissance Orbiter

- **Landers / Rovers**
  - Surveyor Lunar Lander, 1966
  - Mars Rovers, 2003
SOHO the Solar & Heliospheric Observatory is a project of international collaboration between ESA and NASA to study the Sun from its core to the outer corona and the solar wind.

Nov 18, 2009: 195 nm 304 nm (also 171 and 284)

Launched 1995, cost €1 billion; Sensor: Extreme ultraviolet Imaging Telescope (EIT)
**SOHO**, the Solar & Heliospheric Observatory

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Latest images - Nov 19, 2014:

- 195 nm
- 304 nm (also 171 and 284)

Launched 1995, cost €1 billion; Sensor: Extreme ultraviolet Imaging Telescope (EIT)
After Apollo (1972), the Moon was not revisited until an unmanned spacecraft, Clementine orbited it to conduct mapping studies February 19 - April 21, 1994, using UV/Visible, Near IR, and High Resolution Cameras, Lidar
specialized products include detailed maps of lunar topography and the distribution of several chemical elements, such as iron (Fe) and titanium (Ti), determined by analyzing reflectance variations at 0.75 μm and 0.95 μm, where these elements absorb radiation.
In mid-April 2000, the Terra spacecraft was turned upside down and pointed at the Moon. This ASTER image was acquired at that time, showing band 3 visible in black and white.
Recent Lunar missions

Right: China: Chang'e-1 (2007)
Chang'e-3 (2013) soft landed on moon

Below: Japan – Kayuga
Launched 2007, impacted on lunar surface 2009 (near South Pole)
Imaging links: Sun 23, Mercury 281, Venus 149, Earth 1205 (?), Mars 6327, Jupiter 817, Saturn 2291, Uranus 55, Neptune 80, Pluto 7
Mercury Messenger: Mercury Surface, Space Environment, Geochemistry, and Ranging

Mercury Dual Imaging System (MDIS) and Mercury Laser Altimeter (MLA)
Venus
From Magellan
-first imaging device launched from Shuttle 1989
Planet is Cloud covered
Radar 100m

Composite colours based on elevations
DSCOVR: Deep Space Climate Observatory - 2015
1 million miles away – ~10km resolution

Proposed by Al Gore, 1998 to study earth and solar wind
The first satellite orbiting in deep space ..... 'Goresat'
1. EPIC: Earth Polychromatic Imaging Camera, 10 bands

<table>
<thead>
<tr>
<th>Wavelength (nm)</th>
<th>Full Width (nm)</th>
<th>Primary Application</th>
</tr>
</thead>
<tbody>
<tr>
<td>317.5 ± 0.1</td>
<td>1 ± 0.2</td>
<td>Ozone, SO₂</td>
</tr>
<tr>
<td>325 ± 0.1</td>
<td>2 ± 0.2</td>
<td>Ozone</td>
</tr>
<tr>
<td>340 ± 0.3</td>
<td>3 ± 0.6</td>
<td>Ozone, Aerosols</td>
</tr>
<tr>
<td>388 ± 0.3</td>
<td>3 ± 0.6</td>
<td>Aerosols, Clouds</td>
</tr>
<tr>
<td>443 ± 1</td>
<td>3 ± 0.6</td>
<td>Aerosols, Clouds</td>
</tr>
<tr>
<td>551 ± 1</td>
<td>3 ± 0.6</td>
<td>Aerosols</td>
</tr>
<tr>
<td>680 ± 0.2</td>
<td>3 ± 0.6</td>
<td>Aerosols, Vegetation</td>
</tr>
<tr>
<td>687.75 ± 0.2</td>
<td>0.8 ± 0.2</td>
<td>Aerosols, Vegetation, Clouds</td>
</tr>
<tr>
<td>764 ± 0.2</td>
<td>1 ± 0.2</td>
<td>Cloud Height</td>
</tr>
<tr>
<td>779.5 ± 0.3</td>
<td>2 ± 0.4</td>
<td>Clouds, Vegetation</td>
</tr>
</tbody>
</table>

2. Radiometer to measure radiance UV-TIR, - monitor earth temperature
Dark side of the Moon crossing Earth from DSCOVR satellite

daily images from EPIC

http://epic.gsfc.nasa.gov/
Mars Global Surveyor (1996) Instruments

- MOLA - Mars Orbiter Laser Altimeter
- MOC - Mars Orbiter Camera
- TES - Thermal Emissions
DEM resolution in \( z = 30 \text{cm} \) (N. Pole to S. Pole transect)

https://www.google.ca/mars/
Suspected rock glacier, Mars Orbiter Camera JPL/NASA

Resolution = 1m

• MOC has produced over 250,000 images to date
Welcome to Hyperspectral Thermal Emission Spectrometer website

The Hyperspectral Thermal Emission Spectrometer (HyTES) is an airborne imaging spectrometer with 256 spectral channels between 7.5 and 12 micrometers in the thermal infrared part of the electromagnetic spectrum and 512 pixels cross-track. HyTES is being developed to support the Hyperspectral Infrared Imager (HypIIRI) mission. HypIIRI includes two instruments mounted on a satellite in Low Earth Orbit. There is an imaging spectrometer measuring from the visible to short wave infrared (VSWIR) and a multispectral thermal infrared (TIR) imager. The VSWIR and TIR instruments will both have a spatial resolution of 60 m at nadir. HyTES will provide the HypIIRI Group data at much higher spatial and spectral resolutions to help determine the optimum band positions for the HypIIRI-TIR instrument as well as provide precursor datasets for Earth Science research in the TIR.

HyTES completed its first flights in July 2012.
Thermal Emission Spectrometer
6 to 50 (μm),
143 bands

Onboard Mars Global Surveyor

1996-2006
Mars Express (ESA, 2003): High Resolution Stereo Camera
Resolution 2–10m

The “hourglass” feature
HRSC, ESA
Mars Express: High Resolution Stereo Camera

Nicholson Crater
HRSC, ESA 2005
Onboard:

- HiRISE - High Resolution Imaging Science Experiment (Visible and infrared wavelengths)

- CRISM - Compact Reconnaissance Imaging Spectrometer for Mars

- CTX - Context Imager Takes low resolution overview images for geological context
MRO HIGH RESOLUTION IMAGING SCIENCE EXPERIMENT (HIRISE) - 1 foot (0.3m)
three bands, 400–600 nm (blue-green), 550–850 nm (red) 800–1,000 nm (near infrared)

Compact Reconnaissance Imaging Spectrometer for Mars (CRISM) on NASA's Mars Reconnaissance Orbiter (2005)

CRISM covers wavelengths from 0.362 to 3.92 microns (362 to 3920 nm) at 6.55 nanometers/channel, to identify a broad range of minerals on the Martian surface.

False colour infrared: Red = dust, blue = water ice

Green = polyhydrated sulphate,
This is a special camera on the Mars Odyssey spacecraft (2001). Its main tasks are mapping rock mineralogies and detecting heat, which yields information on the Martian surface.

**THEMIS is a multi-wavelength camera**

**5 visual bands:**
0.425 microns, 0.540 microns, 0.654 microns, 0.749 microns, 0.860 microns

**10 infrared bands:**
6.78 microns (used twice), 7.93 microns, 8.56 microns, 9.35 microns, 10.21 microns, 11.04 microns, 11.79 microns, 12.57 microns, 14.88 microns

**Resolution:**
visual images, 59 feet (18 meters) per pixel
infrared images, 328 feet (100 meters) per pixel

[http://themis.asu.edu/gallery](http://themis.asu.edu/gallery)
The Grandest Canyon of all isn't on Earth, it's on the planet Mars - Valles Marineris, or Mariner Valley.

http://themis.asu.edu/valles_video
http://themis.asu.edu/maps
Mars Exploration Rover Missions 2004

http://mars.nasa.gov/mars3d/
http://pds.jpl.nasa.gov/planets/
The 8 Planets
A Multimedia Tour of the Solar System:
one star, eight planets, and more
by Bill Arnett

http://www.nineplanets.org/
Pluto and Charon (pre-2015)
New Horizons 2015, launched 2006

Snow clad mountains on Pluto

Landslides on Charon
New Horizons Mission 2015
Launched 2006

Alice Ultraviolet sensor and Ralph
Enceladus, Moon of Saturn, by Cassini Orbiter, 2005
Meteor and Comet Impact Hazards: North American Impact Craters
Data from Observer's Handbook 2004, Royal Astronomical Society of Canada

Pingualuit Crater, Northern Quebec
http://earthobservatory.nasa.gov/IO/ view.php?id=8472
Sudden impact: Google unearths rare meteorite crater - Australia

Dr Arthur Hickman and the meteorite impact crater he discovered on Google Earth.