A Spectral Tour of Planetary Atmospheres:
Venus, Earth, Mars, Giant Planets, Titan

Venus

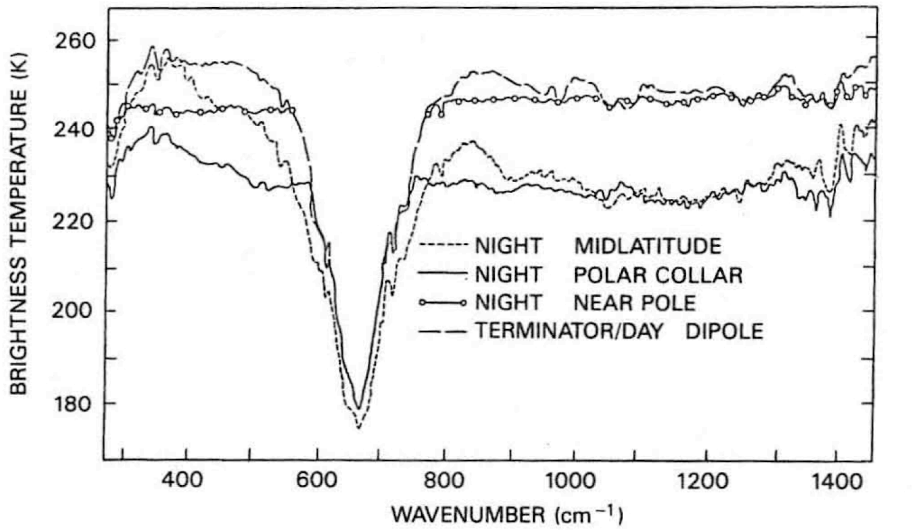

Fig. 1: Venus emission spectra from different latitudes recorded by Venera 15 (Spankuch etal.,1984).

Qu.): (1) What level are we looking at in the continuum? Can we see the surface of Venus?

Qu.) What processes are responsible for producing a broad feature at 667 cm^{-1} (15 microns)?

Qu.) What does this feature tell you about the change in temperature with height?

Other info: Liquid sulphuric acid has broad absorption near 900 cm^{-1} and SO_2 gas has a feature near 1360 cm^{-1}. A contrast in brightness temperature between a warm pole and colder polar collar may reflect cloud effects and also a real gradient that drives circumpolar winds.

Earth

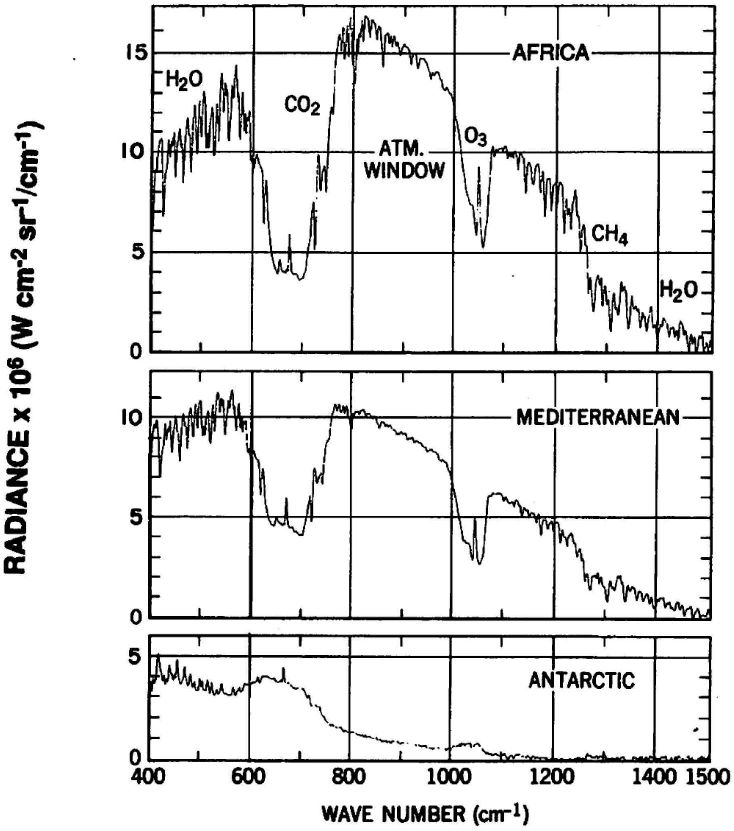

Fig 2: Typical terrestrial emission spectra of cloud-free areas recorded over Central Africa, the Mediterranean Sea, and the Antarctic from Nimbus 4(Hanel etal.,1972).

Qu.) What does the center of the 667 cm^{-1} CO_2 band tell you about the atmospheric structure?

Qu.) Why are the CO_2 and O_3 bands so different in Antarctica?

Qu.) You can hardly see the O_3 band in Antarctica, so what does this tell you about the temperature difference between the surface and stratosphere?

Note: the ubiquity of the H_2O absorptions below 500 cm^{-1} and above 1300 cm^{-1}. Note the difference in radiances between Africa (hottest) and the other places.

Mars: With a global dust storm experiment

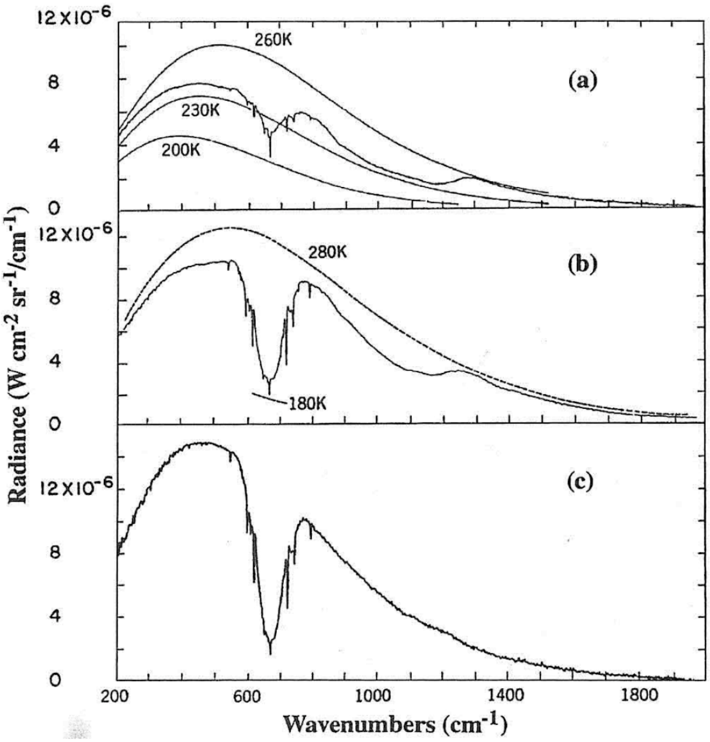

Fig. 3: Martian mid-latitude spectra recorded by Mariner 9 (a) during the dust storm of 1971, (b) towards the latter part of the storm, and (c) after the storm ended.

Qu.) How does the temperature of the atmosphere change with the suspended dust?

Qu.) How does the temperature of the surface change with suspended dust (and the temperature contrast with the atmosphere)?

Other info: there is a broad absorption feature at ~1100 cm^{-1} (9 micron), which is due to the suspended dust. In principle, this gives mineral composition information, but analysis is under-constrained since you also need to know the size distribution of the dust.

Jupiter

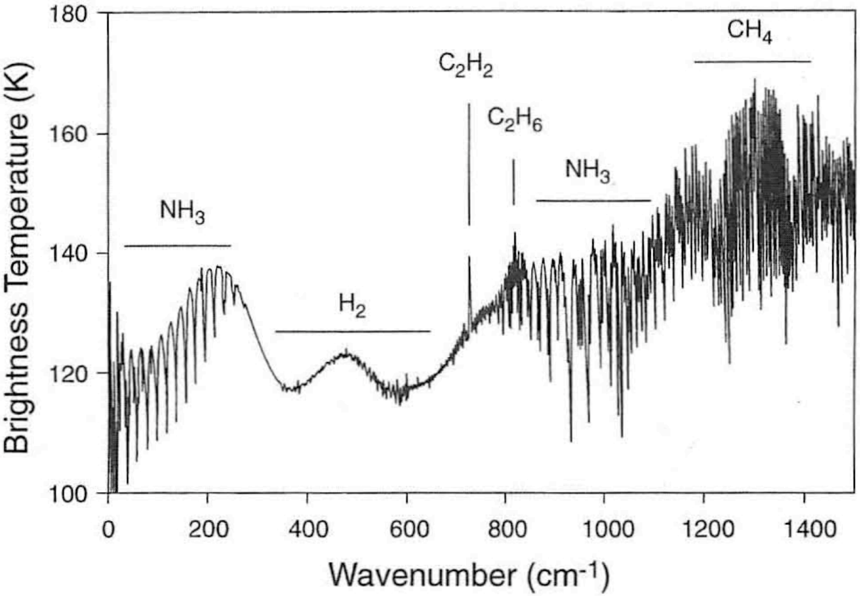

Fig. 4: Spectrum of Jupiter recorded by the Composite Infrared Spectrometer (CIRS) on Cassini.

Qu.) The giant planet spectra differ fundamentally from the terrestrial planets. Provide some examples of this in looking at Jupiter's spectrum.

Qu.) The CH_4 band centered at 1304 cm^{-1} (7.67 microns) is relatively warm. The band center is actually in emission. What does this tell you about the temperature structure of Jupiter?

Other info: How come there is absorption from the H_2 molecule?
Homonuclear molecules (H_2, O_2, N_2, etc.) have no permanent electric dipole moment and so no electric dipole transitions when electromagnetic waves pass by. Essentially all introductory textbooks will tell you that homonuclear molecules cannot have atmospheric absorption. These authors have not studied *planetary* atmospheres!

At high pressure and long path length, electric dipole absorption is observed. It happens because of collisions. Radiative transitions take place amongst rotational, vibrational and translational states of colliding pairs of molecules even though they are not allowed in isolated molecules. In fact, collision-induced absorption by molecular H_2 **dominates** the far IR spectrum of the giant planets, as seen above.

Other info: Note the regular pattern in the NH_3 absorptions below 200 cm^{-1} (>50 microns). This is a rotational absorption spectrum for ammonia.

Saturn (compared to Jupiter)

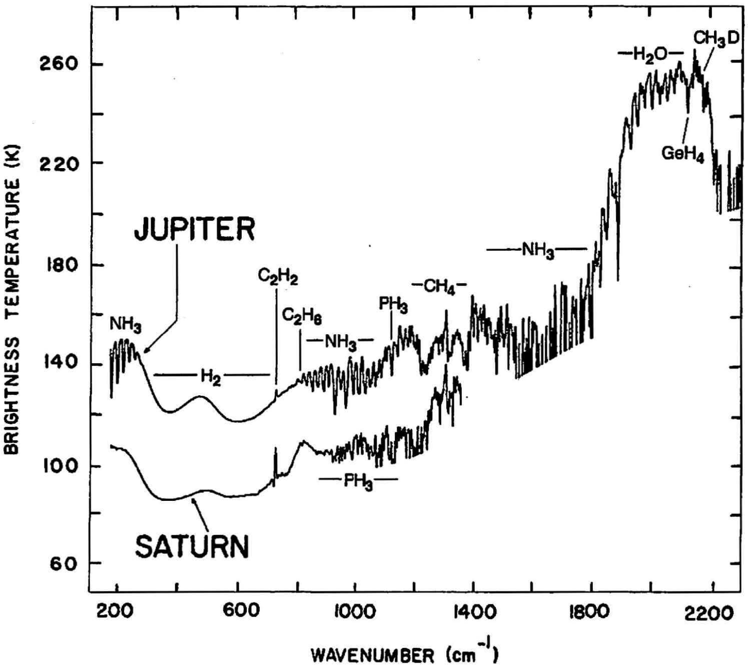

Fig. 5: Spectra of Jupiter and Saturn recorded with the IR interferometer of Voyager.

Qu.) What are some key differences and similarities between these spectra?

Qu.) Why do we see abundant NH_3 absorption in Jupiter's spectrum at 850-1000 cm-1 (11.8-10 microns) but not in Saturn's spectrum? Instead we see PH_3. (Hint: vapor pressure).

Qu.) Are there CH_4 clouds in the stratospheres of Jupiter or Saturn?

Uranus and Neptune

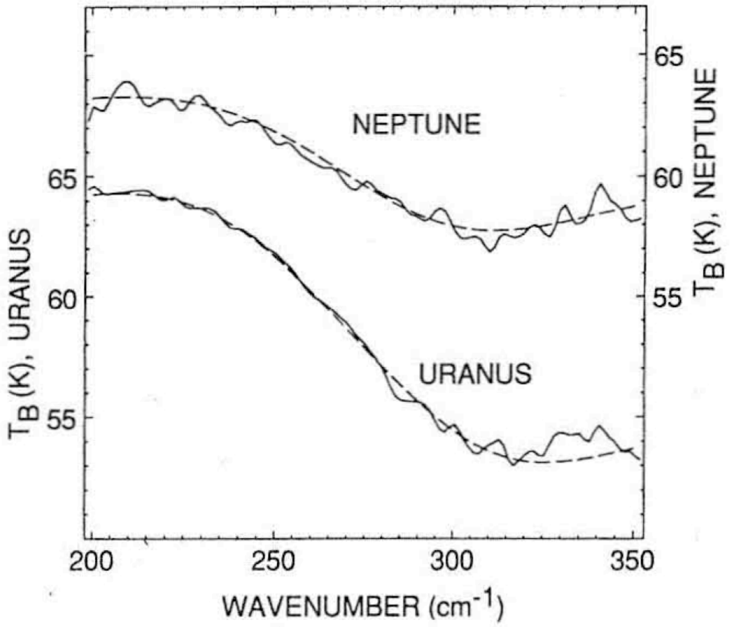

Fig. 6: Thermal emission spectra of Uranus and Neptune obtained with the Michelson interferometer (IRIS) carried on Voyager 2. The solid curves represent averages of 125 individual spectra from Uranus and 157 spectra from Neptune. For clarity the spectra have been offset from one another by 5K. The superposed broken curves are model spectra calculated using temperature profiles obtained by inversion of the measured spectra.

Qu.) These spectra cover only a small spectral range. What feature do they correspond with, if we look back at the spectra of Saturn and Jupiter?

Little can be deduced from visual inspection of these spectra. Inversion techniques allow something to be deduced about the temperature profile. But the more comprehensive temperature profile we had at the beginning of the course was derived from radio occultation measurements.

Titan

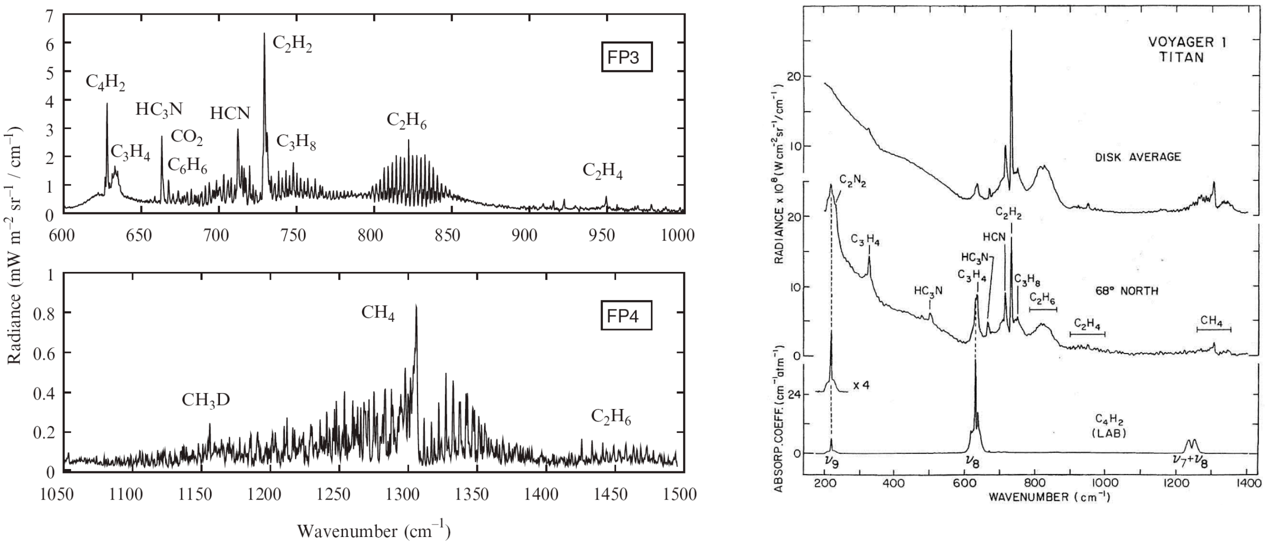

Fig. 6: *Left*: Average Cassini/CIRS limb spectra recorded at 100-200 km altitude and high northern latitudes, showing emission features from various hydrocarbons and nitriles (from Bezard, 2009). *Right*: Disk average and high latitude spectra of Titan recorded by Voyager l, plus a lab spectrum of diacetylene (C_4H_2) (Kunde et al.,1981).

Titan's spectrum is different from both the terrestrial and giant planets. We see a smooth continuum with a number of strong emission peaks. Features include: Ethane (C_2H_6), acetylene (C_2H_2), propane (C_3H_8), diacetylene (C_4H_2), hydrogen cyanide (HCN), cyanogens (C_2N_2), cyanoacetylene (HC_3N)

Qu.) We have emission features of various molecules. What does this suggest about the region of the atmosphere where these molecules are being formed and the process?

Qu.) We should not expect to see CO_2 on Titan but it is present. Where might it come from?