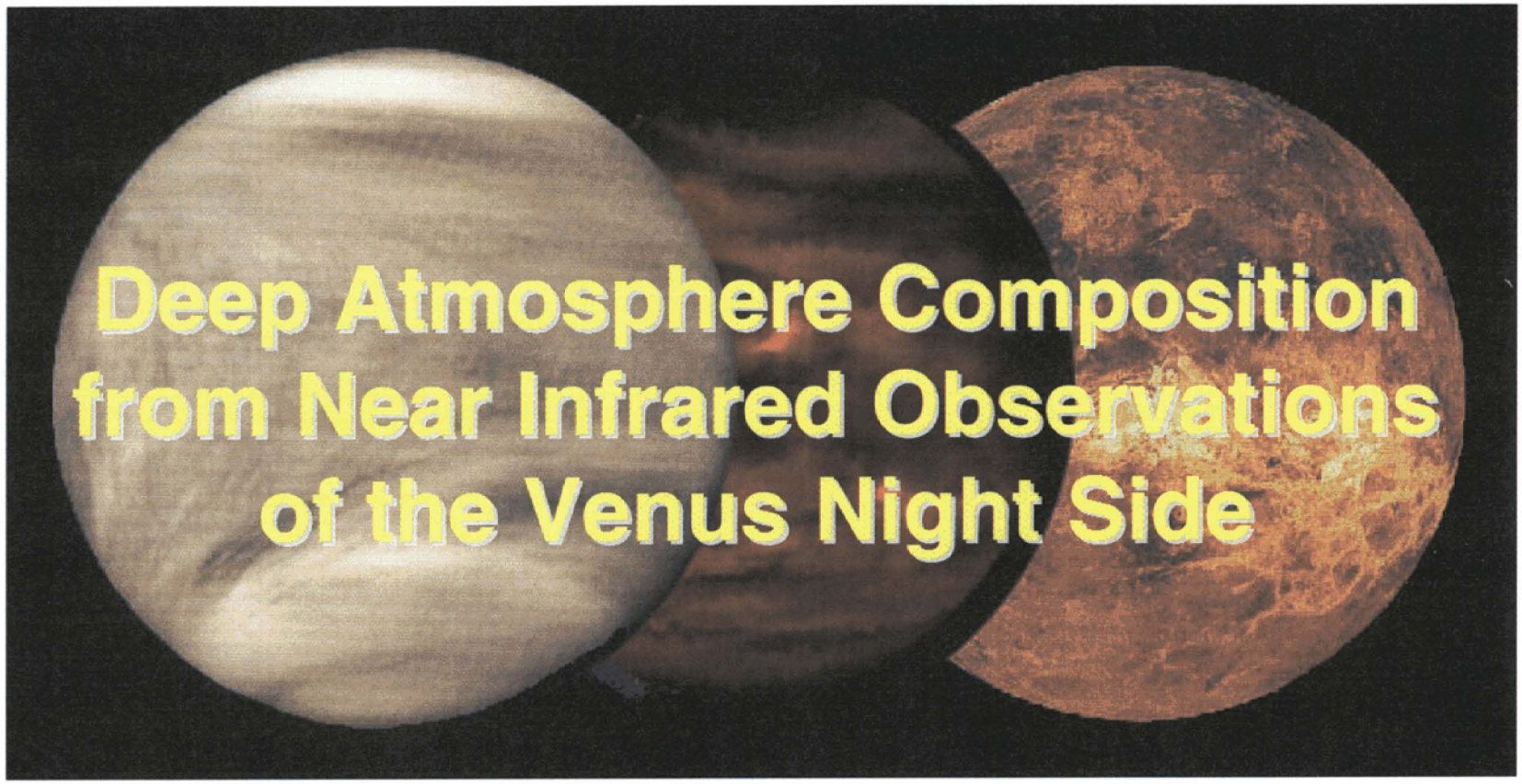

Deep Atmosphere Composition from Near Infrared Observations of the Venus Night Side

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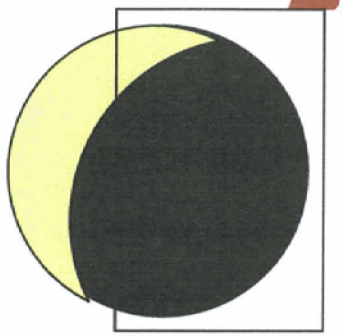
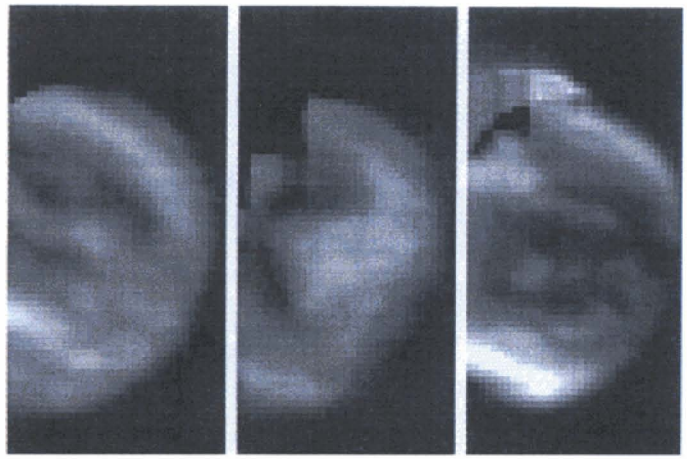
Existing Measurements

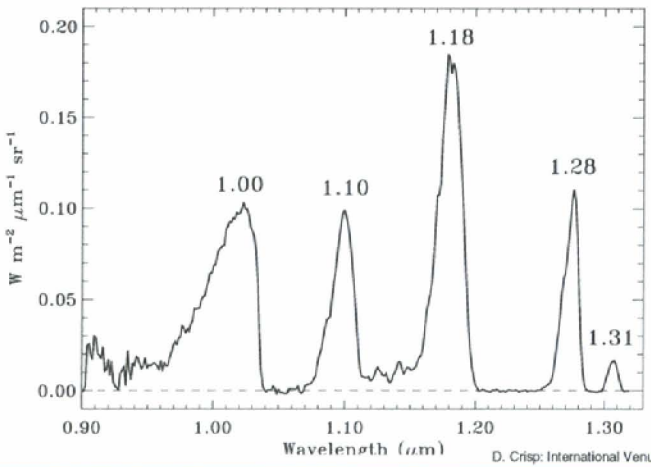
- Remote sensing observations provide valuable constraints on the composition of the atmosphere above the cloud tops
- The planet-wide sulfuric acid cloud deck largely precludes deep atmosphere observations at UV, visible, and far IR wavelengths
- Most information on the atmospheric structure, composition, and dynamics below the clouds has been provided by entry probes, but
  - They provide limited spatial and temporal coverage
  - Different probes have
    - had different measurement objectives, and used different instruments
    - Provided wildly differing answers some critical species
      - Water measurements by the Venera and Pioneer Venus (PV) probes span a range from 20 to 5000 ppm.
      - SO_2 measurements below the clouds indicate a decrease in its concentration with time, from 185 ppm in 1979 to as little as 30 to 40 ppm in the early 1980s.
    - If these variations are real they
      - indicate large spatial/temporal gradients in water vapor and other trace species
      - Suggest large chemical weathering rates for the surface
      - Provide on the vertical transport between the surface and cloud base.
    - Other predicted species were never detected
      - OCS, H_2S, SO_3, O_2

Near Infrared Observations of the Night Side



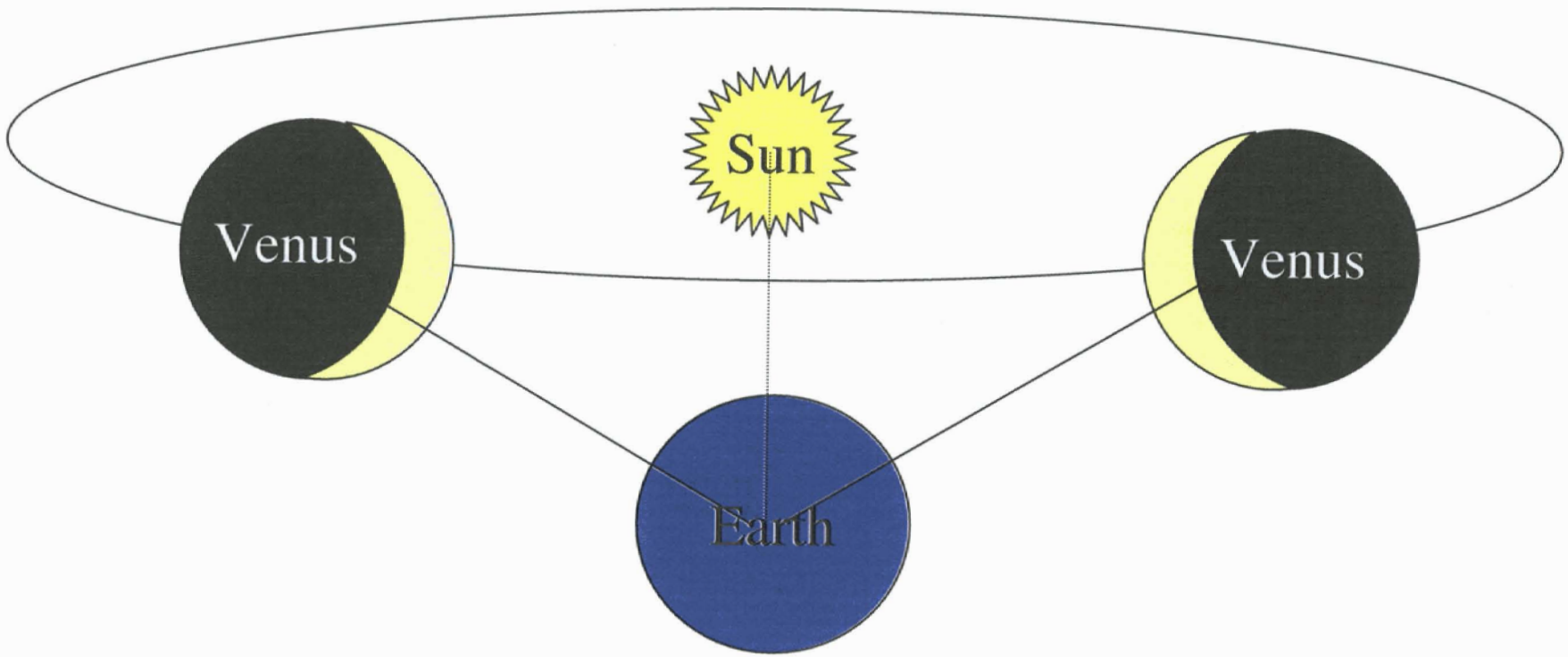
- Allen and Crawford (1984) discovered anomalous near-infrared (NIR) emission from the Venus night side in 1983
- This discovery has provided new opportunities to study the thermal structure, composition, and dynamics of the deep atmosphere and surface by remote sensing
- The emission is most intense in spectral windows between strong H_2O and CO_2 bands
  - Original windows:1.74, 2.3 μm
  - Discovered later
  - 1.0, 1.1, 1.18, 1.27, 1.32 μm
- Attributed to thermal emission from the surface and deep atmosphere, that escapes through the clouds



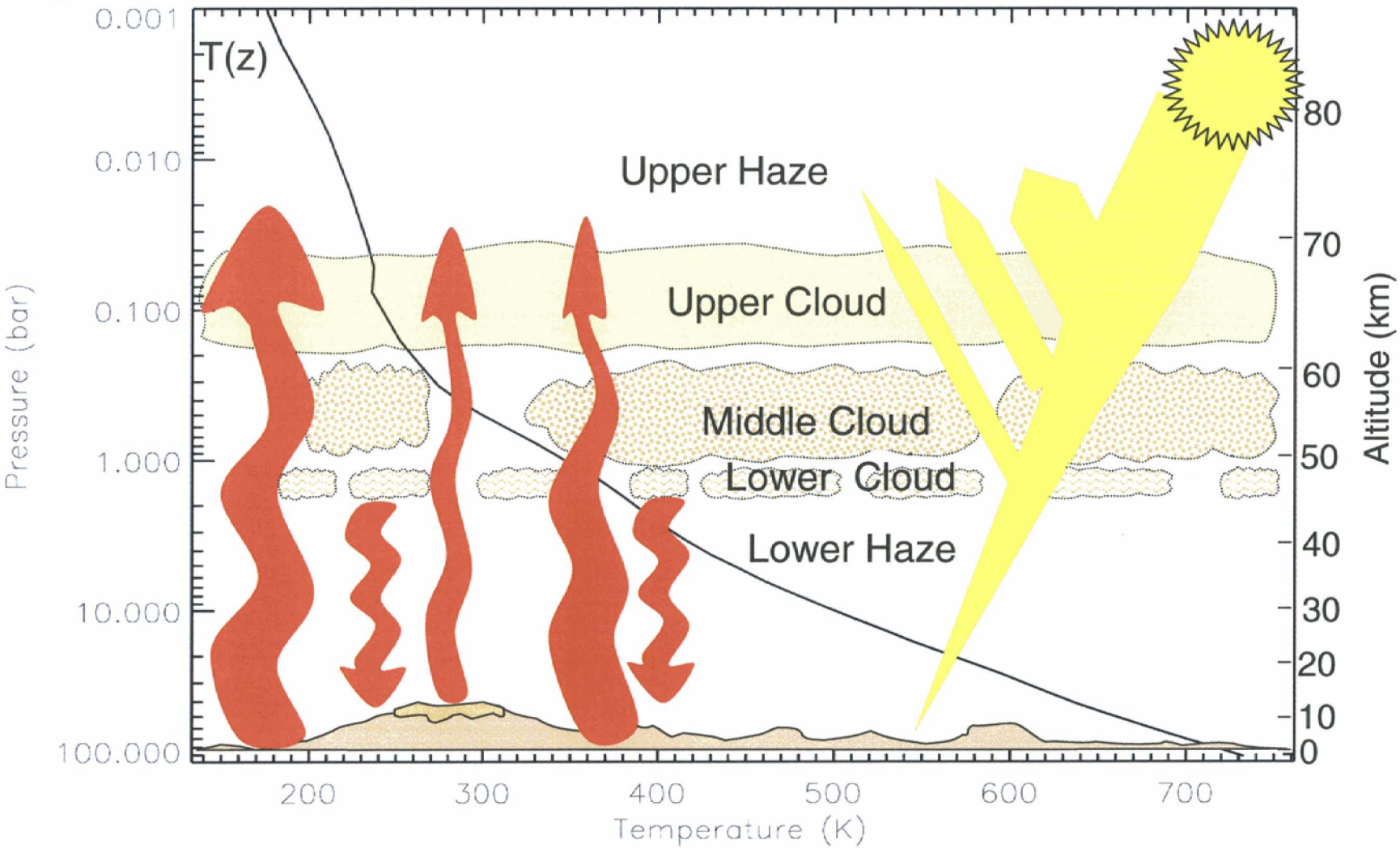


D. Crisp: International Venus Workshop

Viewing Geometry



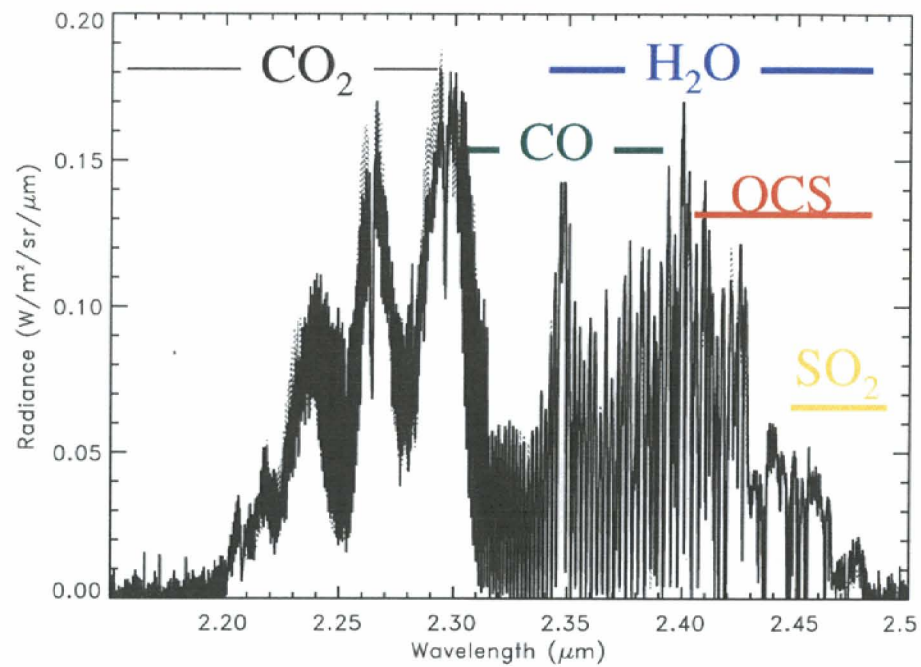
Origin of NIR Emission



Venus thermal structure and cloud distribution are shown along with the solar and thermal radiance fields. The upward thermal emission is most intense from low-elevation regions with minimum cloud opacity. The clouds both emit and reflect thermal radiation back to the surface.

Compositional Constraints from NIR Observations

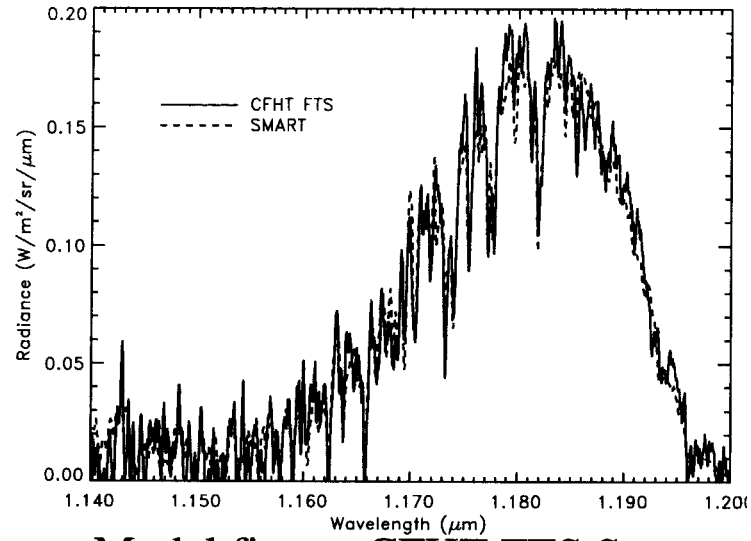
- Spectra of the NIR emission in the 1.74 and 2.3 μm windows indicate:
  - H_2O mixing ratios of 30 ppmv between ~25 km and the cloud base
  - D/H ratios 120 times greater than those on Earth
  - SO_2 mixing ratios of 130±40 ppm near the cloud base
  - The first detection of OCS, yielding mixing ratios that vary from 0.01 ppm at 50 km to 50 ppm at 25 km
  - CO mixing ratios varying from ~40 ppm at 45 km to ~10ppm at 25 km
  - HF and HCl uniformly mixed between ~25 km and the cloud base, with mixing ratios
    - HF: 0.001-0.005 ppm
    - HCl: 0.48 ±12 ppm
  - Spatial variation in cloud particle concentrations



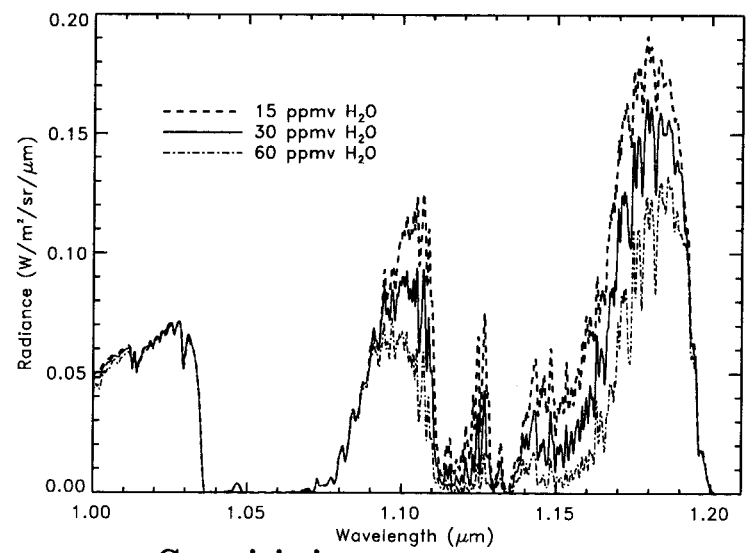
Model fit (dotted line) to a high resolution (0.23 cm^{-1}) spectrum of a bright region taken with the Canada-France- Hawaii Telescope (CFHT) Fourier Transform Spectrometer (FTS)

Compositional Constraints from NIR Observations (cont.)

- Spectra of the NIR windows between 1.0 and 1.3 μm reveal thermal emission that originates from the surface and lowest scale height
- Spatially resolved spectra of these windows provide constraints on the near-surface temperature gradients and water vapor abundance
  - Temperature lapse rates near the surface appear to be sub-adiabatic (on spatial scales of 250 to 500 km)
    - -8.0 K/km ≤dT/dz ≤ -7.5 K/km
  - There is no compelling evidence to support a decrease in the water vapor mixing ratio near the surface
    - Mixing ratios between 30 and 45 ppm produce the best fits

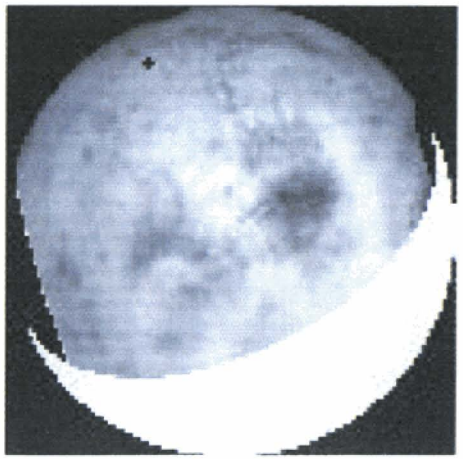


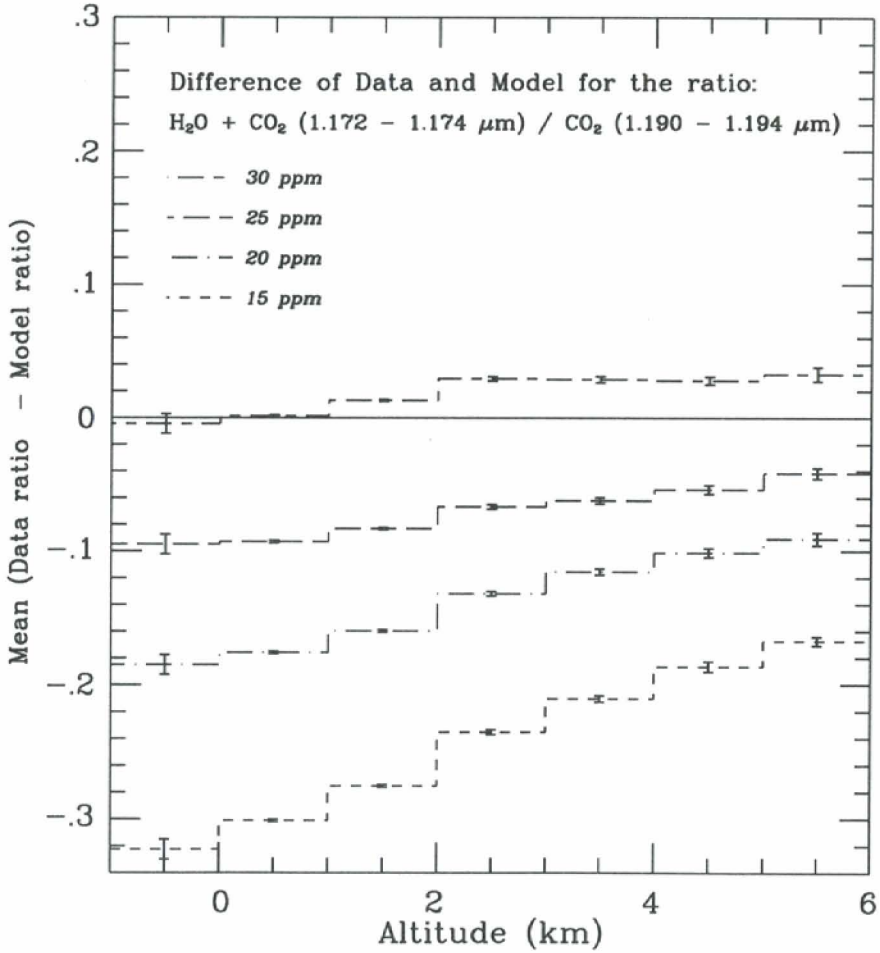
Model fit to a CFHT FTS Spectrum



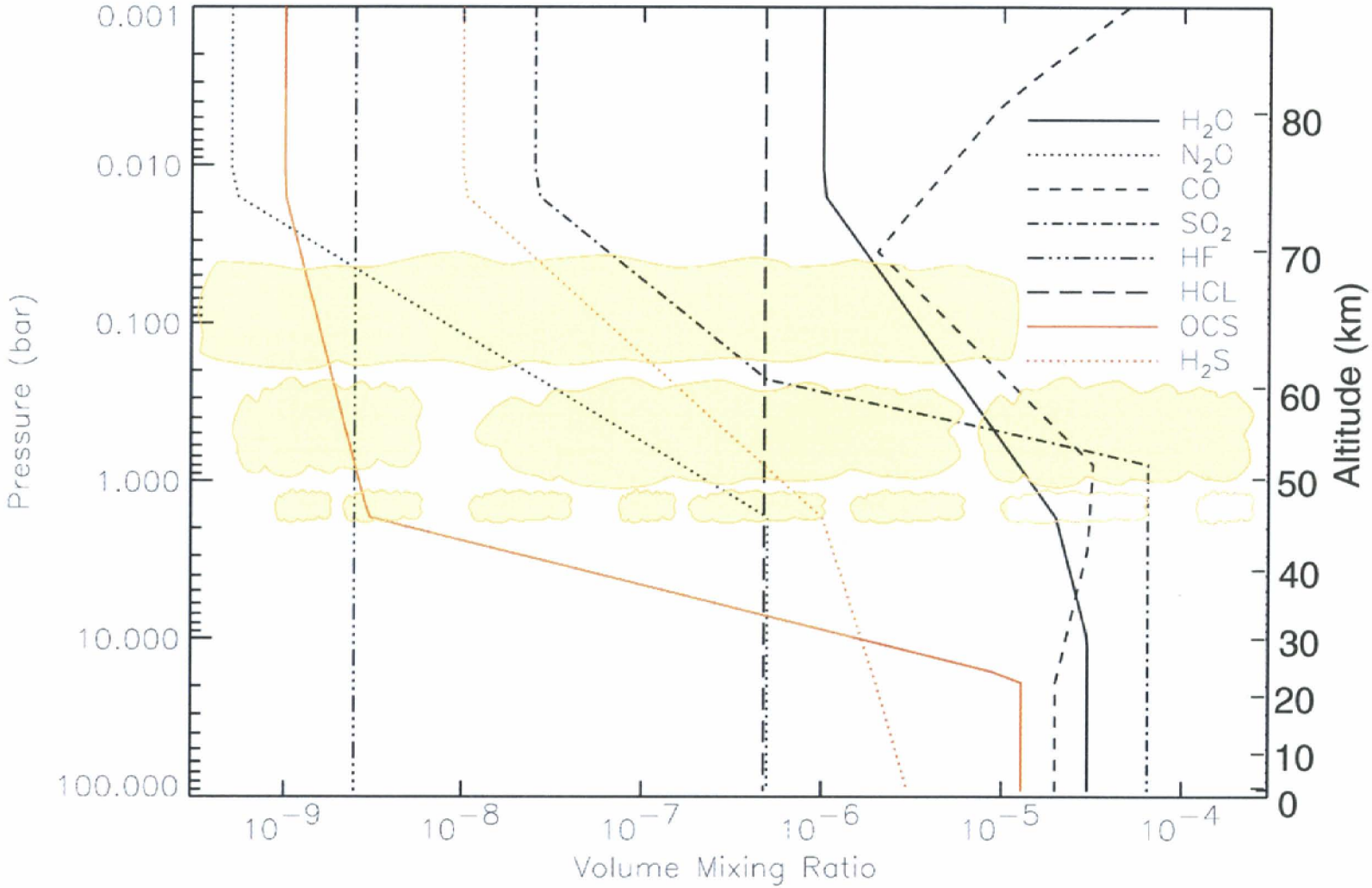
Sensitivity to water vapor

Spatial Variations in Topography Provide Opportunities to Learn About the Near-Surface Environment





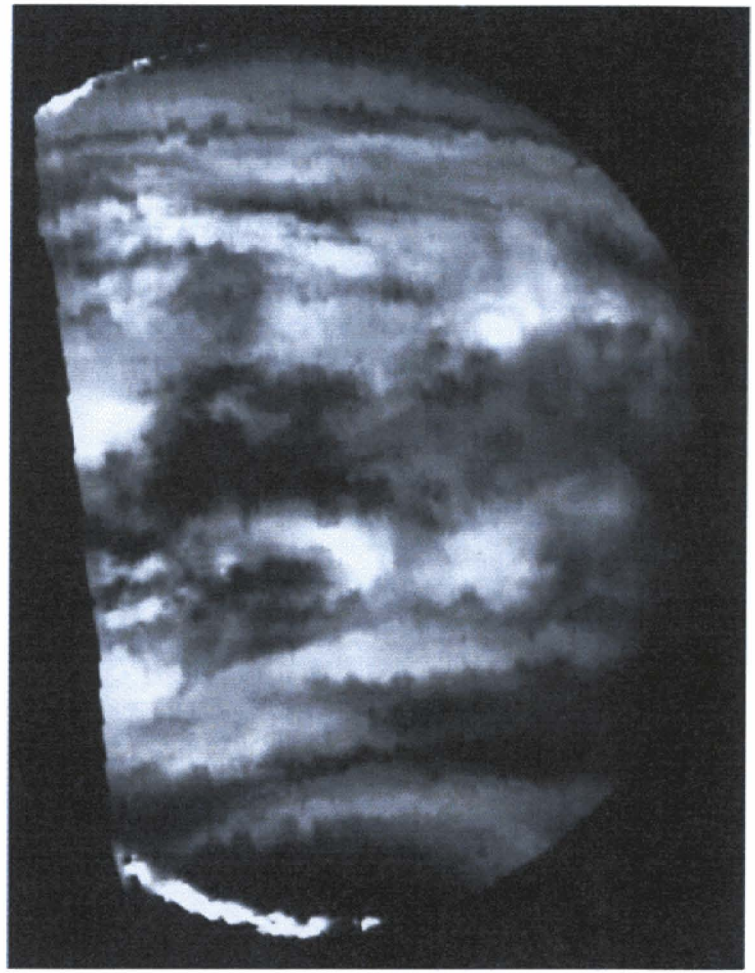
Trace Gas Distribution



Absorbing trace gas mixing ratio profiles are shown as a function of pressure and altitude. The principle absorbers at infrared wavelengths are CO_2, H_2O, SO_2, and CO. The Cloud and haze distribution is also shown.

Near Infrared Features

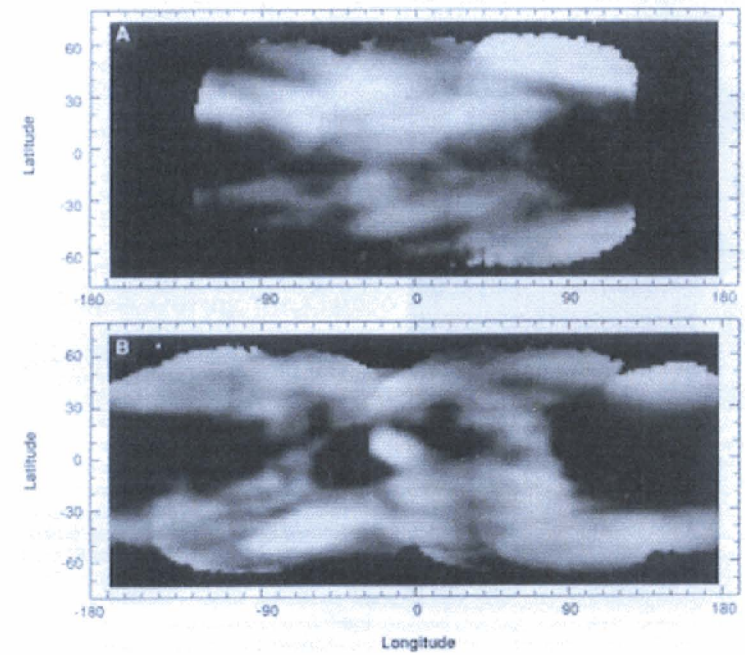
- The NIR feature contrasts are produced by spatial variations in the optical depths of the middle and lower clouds
- These features can be mapped to yield global maps of cloud densities
  - The upper cloud (58-70 km) is spatially uniform
  - The middle and lower clouds have large variations in their density
- These NIR features can also be tracked to infer winds in the middle and lower cloud decks.
  - Galileo NIMS experiment
  - Global, ground-based campaigns
    - Middle and lower cloud exhibit almost solid body rotation
    - Period of middle cloud is ~5.5 days
    - Period of lower cloud is ~7.4 days
  - Long-term measurements are of great value for tracking winds.

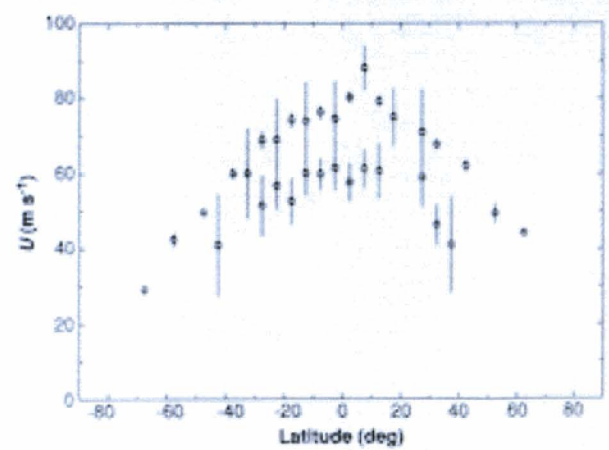


Galileo NIMS image of the Venus Night Side

Ground Based Feature Tracking

- Near IR features at wavelengths near 1.74 and 2.3 μm are produced primarily by horizontal variations in the opacity of the middle and lower clouds
- Tracking of cloud feature motions in time-resolved NIR images has provided the first global description of the winds within the cloud layer (Crisp et al. 1991)
  - Rotation period of middle cloud (50 – 55 km) is 5.5±0.15 days
  - Rotation period of lower cloud (47 – 49 km) is 7.4 ±1 days





Limitations of Existing NIR Measurements

- The Venus night side can only be observed from the ground during 1-2 month periods before or after inferior conjunction
  1. Not adequate for monitoring of time-variable phenomena
  2. Because the Venus rotation rate is roughly synchronized with its sydnodic period, the range of Venus longitudes visible from Earth is limited.
  3. Water vapor is currently the only gas whose concentrations can be constrained throughout the lower atmosphere
  4. SO_2, OCS, HF, and HCl can only be constrained above 25 km
     1. No strong bands in the most transparent spectral windows
  5. Other trace species (e.g. noble gases, isotopes) cannot be measured at these wavelengths.
  6. Additional information on the absorption by gases at high temperatures and pressures are needed to analyze the data.
- Issues 1-2 can be addressed by placing a spacecraft in orbit around Venus
- Issues 4 and 5 can best be addressed by entry probes