The Flying InfraRed Spectrograph for Surface Thermal Emission (FIRSSTE)

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IPPW 12

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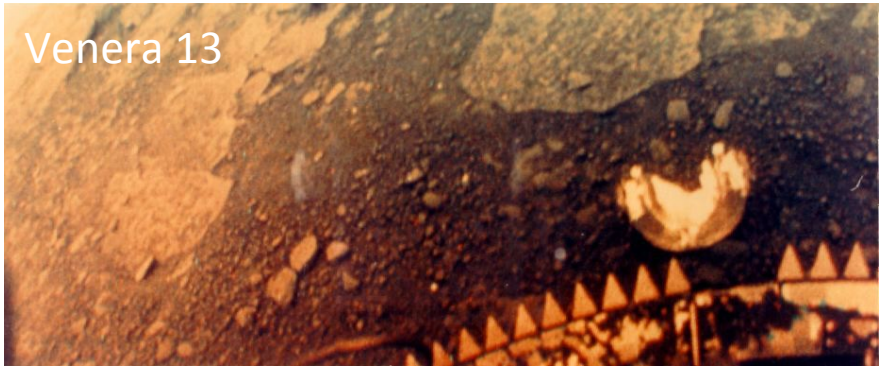
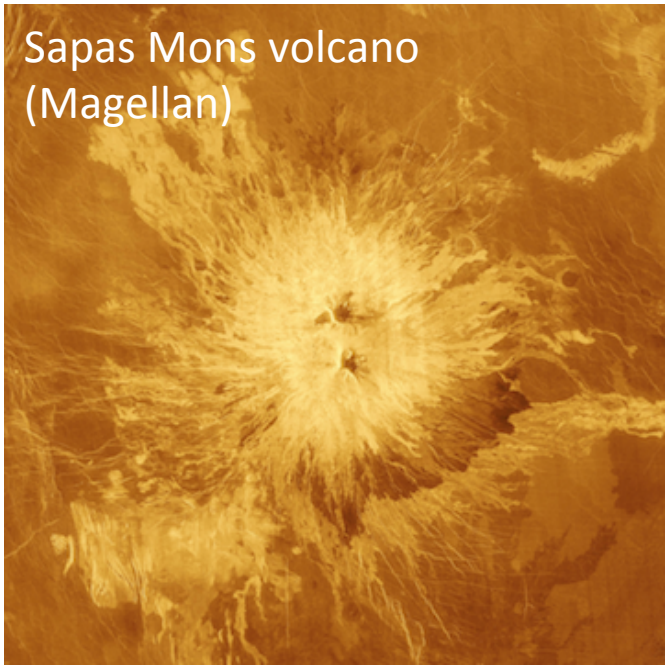
The Venus Surface

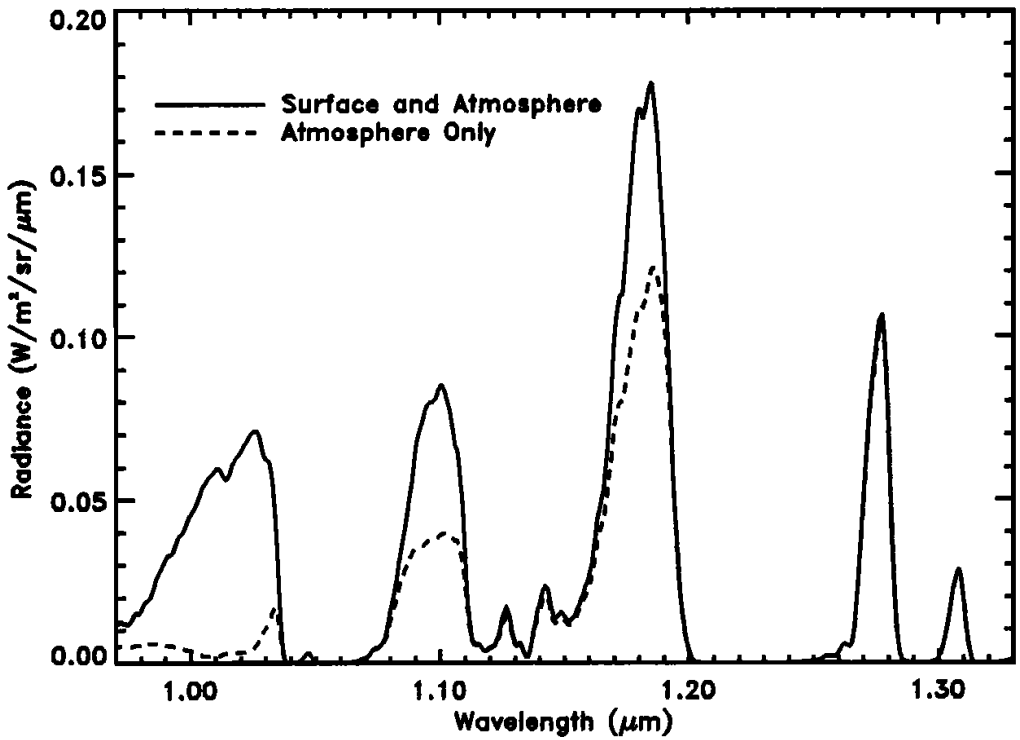
- The Venus surface is obscured by the thick atmosphere and clouds, making it difficult to study
- A few surface images from the Soviet Venera landers
- Surface topography was characterized by the Magellan spacecraft (1992-1994) using radar
- Few impact craters were found, indicating a geologically young surface
- Volcanic features dominate





Remote sensing of the surface

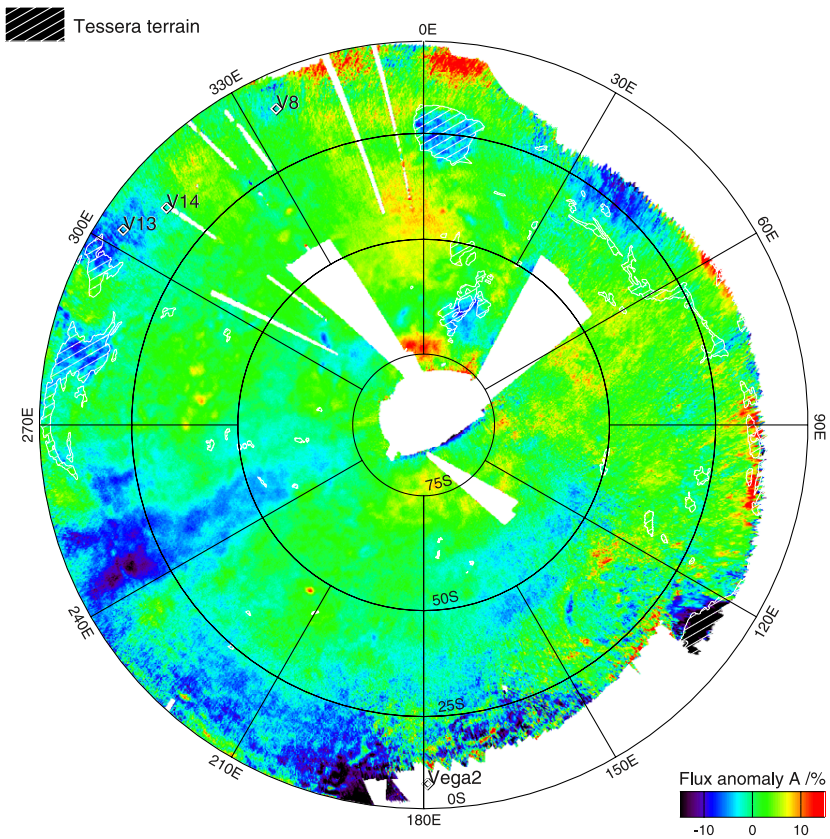
- Telescopic observations of the Venus nightside revealed narrow-band emissions
- Eventually determined to be thermal emission from the surface and lower atmosphere, absorbed and scattered by the clouds and upper atmosphere
- Emission is seen through atmospheric "windows"



Meadows and Crisp, 1993, JGR 101, E2

Venus Express VIRTIS observations

- VIRTIS-M was a near-infrared (1-5µm) imaging spectrometer on ESA's Venus Express (EOM Jan 2015)
- The nightside southern hemisphere was observed
- Correlations found associated with geologic boundaries
- Interpretation is compositional variation



Variation in derived temperature from expected, possibly due to compositional (emissivity) heterogeneity

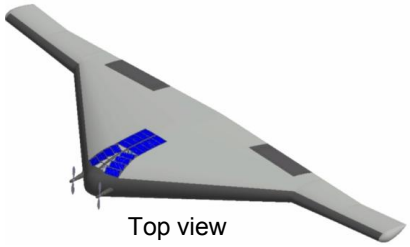
Mueller et al, JGR 113, 2008

FIRSSTE Objectives

- Determine composition by identifying unique mineral species
- Characterize compositional variations across geologic boundaries
- Locate areas of low chemical weathering
- Search for areas of current volcanic activity

Platform

- A balloon or airplane would serve as a convenient platform
  - Balloons successfully flown by the Soviet Union Vega mission in 1985
- At an altitude of 55 km, the environment is relatively benign (~0.5 atm CO2, ~30degC)



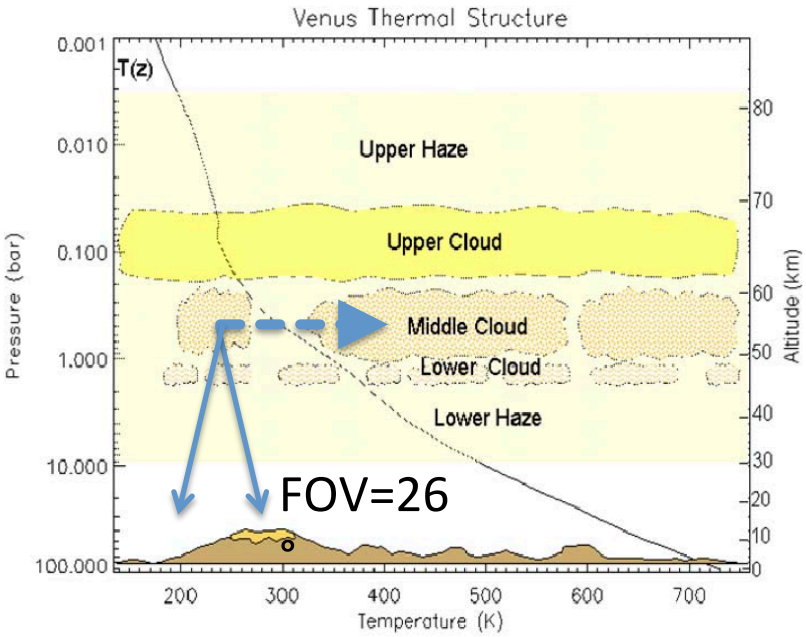


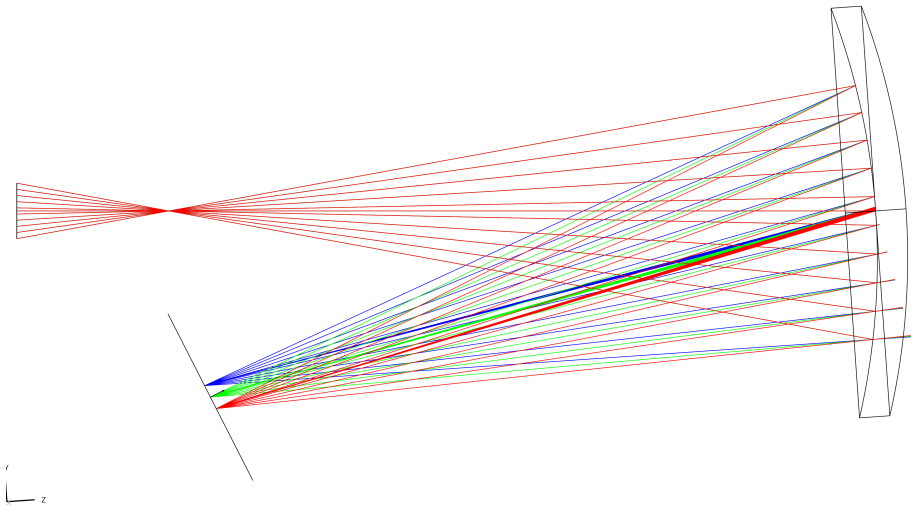
Image credits: Balloon by Tibor Balint, atm plot from 2009 Venus flagship mission study, VAMP airplane from Northrop Grumman

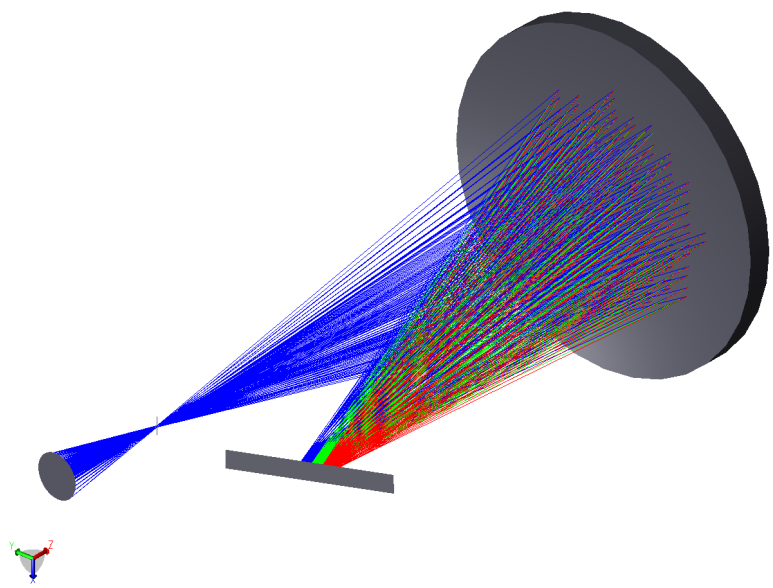
Instrument requirements and constraints

- Coverage of the 1.02 micron window, where 95% of the signal originates from the surface
- Coverage of multiple windows to facilitate cloud removal
- Low mass and low-power due to platform limitations
  - This precludes a near-infrared sensor with high cooling requirements.
- Multiple scattering limits the spatial resolution to 50 – 100 km

Optical Design

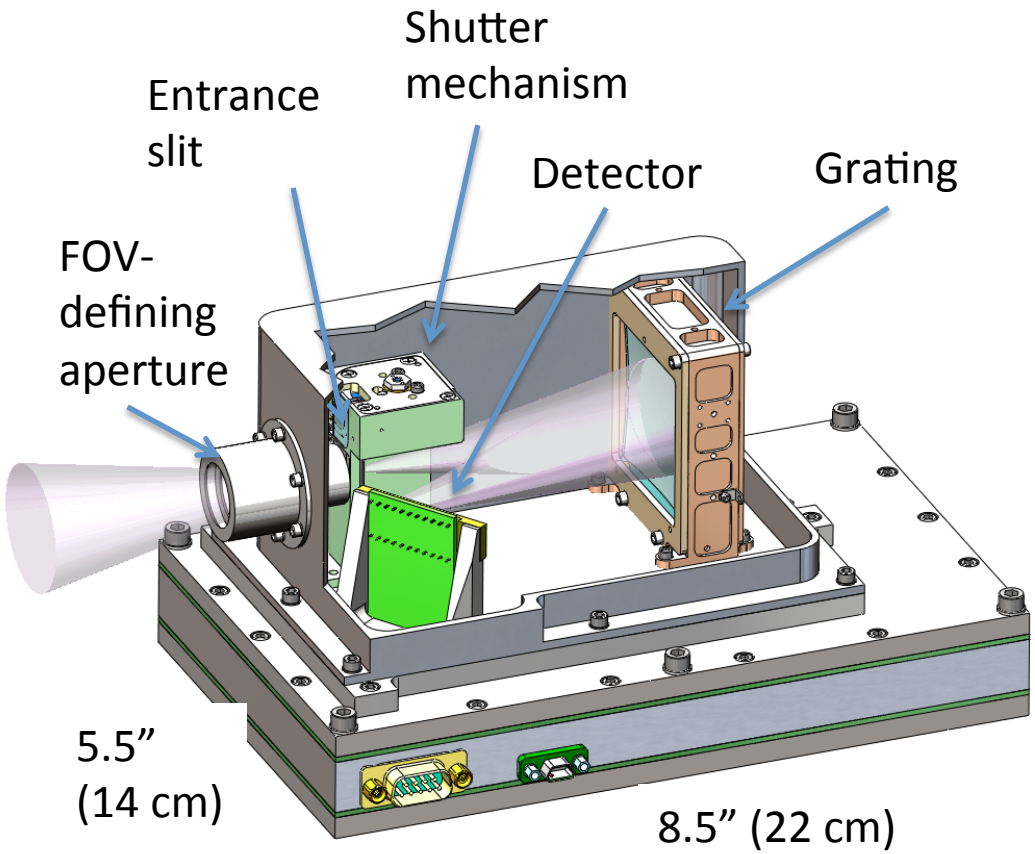
- Simple optical design: Rowland circle spectrograph with a single concave grating
- Point spectrograph: one spectrum per spatial sample
- No telescope required due to wide field-of-view (26deg)





Instrument Design

- Shutter mechanism for background measurement
- Sensor is a 1024x122 silicon CCD, with low noise and low dark current
- Stock holographic, flat-field grating
- Heritage from previous programs (MESSENGER, AIM, GOLD)



Instrument specifications and estimated resource requirements

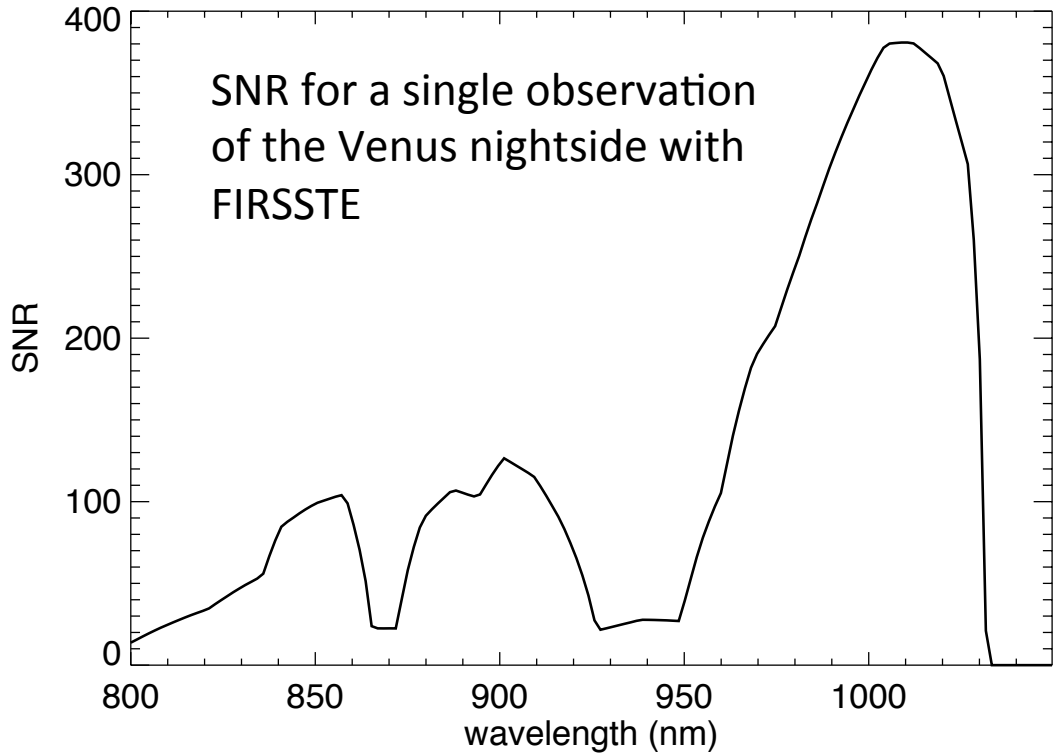
- Further design work expected to reduce mass
- Power cycling results in low consumption
- Times of minimal clouds can improve spatial resolution

FIRSSTE specifications and accommodation

Wavelength range	800 – 1050 nm
Spectral resolution	5 nm
Spectral sampling	1.6 nm
Field of view	26° (25 km from 55 km)
Estimated spatial resolution (with clouds)	50 – 100 km (with clouds), ~40 km (no clouds)
Mass	2 kg
Power	0.2 W average (3 W operating)
Volume	22×14×10 cm
Data production rate	~14 bits per second

Performance

- Compared to VEX VIRTIS-M, FIRSSTE provides:
  - up to ~2.5x improvement in spatial resolution
  - full spectral coverage across 1 µm feature
  - >100x larger SNR
  - no solar-scattered light



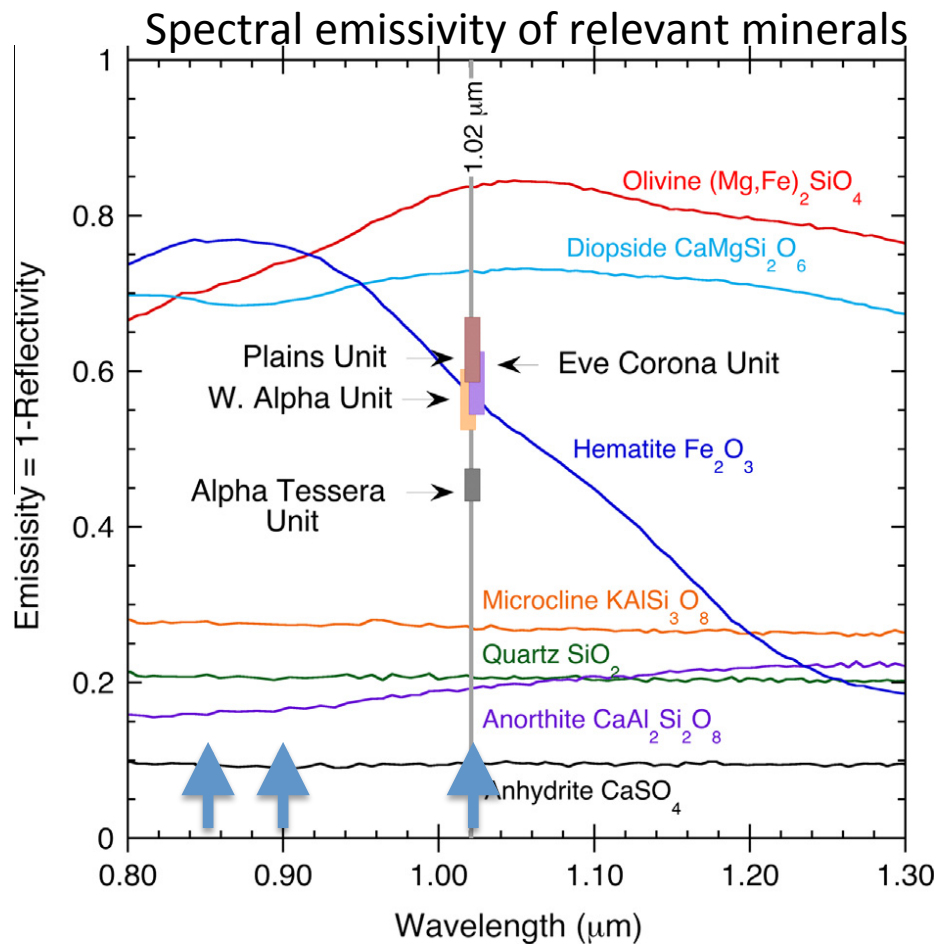
Details: one second integration time, brightness from Cassini VIMS, background subtracted, 10 rows of binning.

Data processing

- Surface temperature corrections
  - The surface exists in thermal equilibrium with the atmosphere
  - The surface temperature is altitude dependent due to the lapse rate
  - Like VIRTIS, this effect can be corrected using Magellan topographic data
- Clouds have a large optical depth
  - Variability causes a change in signal
  - Spectral dependence is gray (flat) and so changes seen in all transmission windows are due to clouds
  - Atmospheric models can be used to derive a measure of the absolute emissivity, but the uncertainty is likely high
  - Relative and spectral variations in emissivity will be well-determined

Mineral discrimination

- Limited atmospheric transmission windows preclude continuous spectroscopy
- However, multiple bands can separate many species of important petrologic significance
- For example, tesserae are topographic high areas hypothesized to be of felsic (low iron) composition in contrast to basaltic (high iron) lowlands.

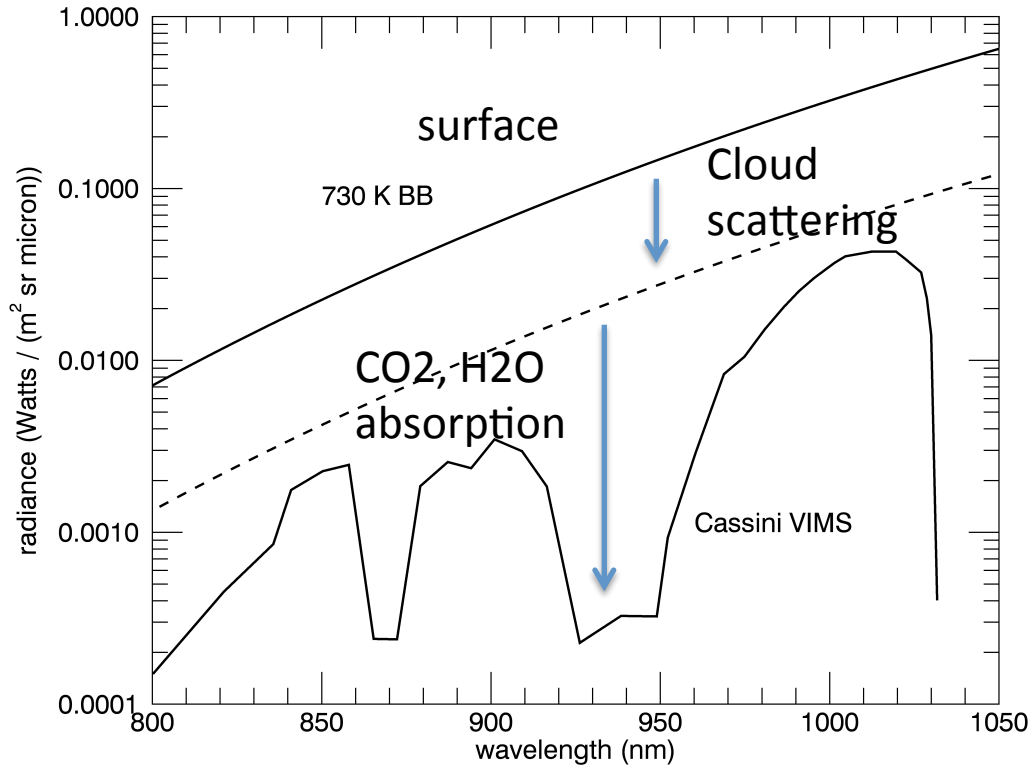


Gilmore et al, 2015, VIRTIS emissivity of Alpha Regio, Venus, with implications for tessera composition, Icarus 254, 350-361.

Summary

- FIRSSTE is a near-infrared point-spectrograph to measure the emissivity of the Venus surface
- As a compact, low-mass, low-power instrument, FIRSSTE is suitable for a balloon or airplane platform
- Objectives include: determination of composition through mineralogy, search for areas of low chemical weathering and possible active volcanism
- Capabilities significantly improve upon the VEX-VIRTIS observations

Backup

Effects of the atmosphere

- Thermal emission from the surface is scattered by the clouds and absorbed by CO2 and H2O.
- This leaves a few "windows" through which we can see the surface directly