Observing Venus with NASA's Terrestrial Balloon Program

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1. The Basic Idea

NASA regularly flies balloon missions to altitudes of 33 - 38 km. These telescopes have two major advantages over ground-based observations of Venus: turbulence-free imaging in UV and visible wavelengths and nearly complete access across the 0.2 - 5 μm spectrum.

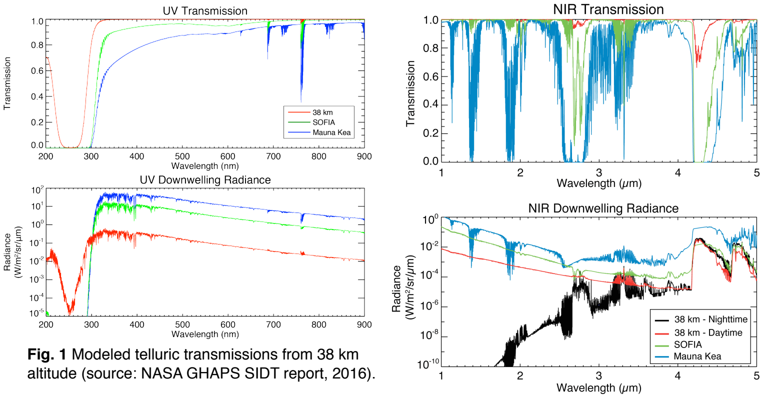

Fig. 1 Modeled telluric transmissions from 38 km altitude (source: NASA GHAPS SIDT report, 2016).

Given expected flight durations of 100 days, a balloon mission is well-suited to study Venus in the ±50 day windows surrounding Venus's inferior conjunctions. The Venus Reference Mission (*VRM,* §4) would take infrared images and spectra (0.8 to 2.55 μm) with spatial resolutions of 0.18″ at 1.74 μm. Venus subtends 35″ - 62″ in the 100-day window around inferior conjunction: this angular resolution translates to 75 km - 43 km resolutions on Venus. The VRM would take cloud-top images (usually obtained near 0.3 μm) at 26 km - 14 km resolutions.

2. Science Drivers

Many of the "big questions" on Venus (described in the VEXAG Goals, Objectives and Investigations <https://www.lpi.usra.edu/vexag/>) can be addressed from a stratospheric telescope.

VEXAG Objective	How the VRM Achieves it
Did Venus have temperate conditions and liquid water...	Imaging of Venus in six IR windows from 0.8 - 1.31 μm can distinguish mafic vs. felsic minerals and constrain plate tectonics.
What processes drive the global atmospheric dynamics of Venus?	- Nightside cloud tracking (1.74, 2.3 μm) - Dayside cloud tracking (0.283, 0.365 μm) - Trace gas maps below the cloud base - Stellar occultations characterize the SS-AS transition from 90 - 150 km
What processes determine... atmospheric composition and global and local radiative balance?	- Make maps of trace gases (e.g., CO, H_2O, OCS, SO, SO_2, HCl, HF) via absorptions in CO_2 windows (e.g., 2.25 - 2.55 μm) - Estimate cloud optical depths from the nightside radiances at 1.31, 1.74, 2.3 μm - Constrain vertical upwelling from SO/SO_2 ratio (and photochemical breakdown rates)

3. NASA's Balloon Program

(From <https://www.csbf.nasa.gov/balloons.html>):

- *Zero-pressure balloons* (ZPBs) can lift payloads of up to 3600 kg to altitudes of 36 - 42 km. ZPBs have open vents and do not sustain a pressure gradient with respect to the ambient air. ZPB payloads must drop ballast at night unless they are in a continuous sunlight area (e.g., Antarctica in Dec - Feb).
- *Super-pressure balloons* (SPBs) are sealed and maintain internal positive pressure. They can lift payloads of ~2000 kg to altitudes of 33 - 34 km. Unlike ZPBs, they can maintain altitude through many day/night cycles without dropping ballast or venting helium. NASA launches large SPBs from Wanaka, NZ, a latitude intended to avoid flight paths over large cities. Flights lasting 100 days are expected, providing 1000 hrs of dark time.
- SPBs float at 8 Torr, above 99.3% of the atmosphere. ZPBs float at 3 Torr, above 99.7% of the atmosphere.
- *Pointing stabilization* is a critical part of achieving sharp images. Several payloads have stabilized telescopes at the ~1″ level (WASP, SuperBIT, BOPPS). Fine steering mirrors can correct smaller-scale image motion to achieve sub-arcsecond stability.
- *Scattered light* is about 100x less at float relative to the surface (at a given wavelength) but still significant in UV/visible.

Fig. 2. A 2+ ton scientific payload hangs on a mobile crane (left side), just before launch in Antarctica. The flight train (including the parachute) is laid out on the ice. The balloon canopy (right side) expands to a volume that is larger than a cubic football field at float altitude (33 - 38 km). (https://www.csbf.nasa.gov)

4. A Venus Reference Mission (VRM)

Requirements	Rationale & Implications for VRM Design
Track cloud top (dayside) and middle cloud deck (night) motions at 0.5 m/s level	Necessary to resolve meridional motion (expected to be ~1 m/s). Nightside requires 75-km spatial resolution over a 4-hr span, which in turn requires a 2-m aperture at 1.74 μm. The GHAPS study suggests *separate* UV (1-m warm) and IR (2-m cold) telescopes.
Characterize cloud properties and map trace gas distributions	Dayside (above cloud tops) and nightside (surface to ~50 km) spectral observations are key to understanding cloud formation chemistry, mechanisms controlling airglow and coupled dynamical and chemical trace gas processes below the cloud base. Requires *R*=2000 at 200-240 nm and at 2.2-2.55 μm. *Consider a framing camera with a tunable filter* in IR wavelengths with 1 nm-wide bandpass.
Look for wave phenomena in Venus's atmosphere	- Mission durations spanning several periods - LIR camera to see thermal waves near cloud tops. 300 km resolution is sufficient (10 μm observations from a 2-m aperture).