Venus: Observe it while it's hot!

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Introduction:

Venus' global-scale cloud and haze layers are composed of complexes of sulfuric acid (H_2SO_4) and water. Because the clouds play a critical role in Venus' energy balance and long-term climate evolution, accurate definition of their formation process is a high priority in Venus atmospheric studies. On a basic level it is understood that the H_2SO_4 clouds and haze form via the combination of SO_3 and H_2O, and SO_3 forms via oxidation of SO_2. Thus, sulfur-bearing and sulfur-oxidized species, such as SO_2, SO, S, OCS, H_2SO_4, are key traces of Venus' H_2SO_4 cloud/haze formation process. However, the specific pathways (which may be chemical, microphysical and/or dynamical) that balance the budget of sulfur (and oxidized sulfur) in Venus' atmosphere are ill-defined [1-3], as are the mechanisms that sustain the density of the clouds. As result, Venus' climate evolution is ill-defined, and understanding Venus' sulfur-budget is highlighted as an important Venus exploration target.

New Observation Opportunities:

The recent success of the Venus Orbit Insertion (VOI) maneuvers implemented by JAXA's *Akatsuki* spacecraft has opened up another opportunity to obtain sustained and coordinated observations of Venus' atmosphere that can be used to investigate the progression of Venus' sulfur-cycle and the formation of the H_2SO_4 clouds and haze. The primary objective of the *Akatsuki* mission is to understand Venus' atmospheric dynamics, cloud chemistry and cloud physics by observing key characteristics of Venus' atmosphere from above and below the 47-70 km cloud layer on both the day and night side. Acquisition of coordinated HST and *Akatsuki* observations of Venus' sulfur-oxide species can be used to complete *Akatsuki*'s observing objectives and as well as the atmospheric observation priorities established by VEXAG and other International Venus Exploration Organizations [4,5].

In particular, we are proposing to obtain HST spectral and imaging observations of Venus' dayside atmosphere in the 200-600 nm wavelength region. The HST images can provide high (20±2 km) spatial resolution mapping of Venus' dayside SO_2 gas absorption signature below 240 nm, the 200-400 nm cloud top brightness/ contrast, and the distribution of the unknown UV absorber as a function of local time at each latitude. The HST spectra can provide at high (50±10 km) spatial resolution, which is comparable to the expected UVI image spatial resolution at *Akatsuki* apoapsis, detailed latitude and local time detections of i) the SO_2 and SO gas absorption signatures at wavelengths < 240 nm, at high (0.27 nm) spectral resolution ii) the long-wavelength (280-330 nm) SO_2 absorption signature at high (0.27 nm) spectral resolution, and iii) the 340-400 nm spectral signature of the unknown UV absorber at medium (0.54 nm) spectral resolution. The spectral data will also provide a means to validate/accurately complete radiometric calibration of the *Akatsuki* UVI images that will be obtained at 283±6.5 and 365±7.5 nm.

The two nearest observing windows during which coordinated HST-Akatsuki observation may be obtained occur in 2017. In the first observing window, which extends through January 2017 to the first week of February 2017, Venus' p.m. quadrant is observable from the Earth. HST spectral observations obtained at this time can provide the ***first*** simultaneous measurement SO_2 and SO densities ***on Venus' p.m. quadrant*** as a function of both local time and latitude resolution without any temporal confusion. With proper planning 365 nm *Akatsuki* UVI images of Venus' partially illuminated disk can be taken near-simultaneously (within 1.5 hours) of HST/STIS *and* from the same vantage point as HST. Analysis of the 365 nm limb brightness will map the variation in the haze properties as a function of latitude along the sunlit limb, i.e. at a local Venus time of ~ noon. *This is a critical empirical constraint needed for developing models that attempt to replicate Venus' a.m. to p.m. H_2SO_4 gas and aerosol distribution asymmetries, and can ONLY be derived from observations that are centered in latitude on Venus' equator and centered in longitude on either the a.m. or p.m. terminator longitude.*

In the second observing window, which extends from mid-May 2017 to late June-2017, Venus' a.m. quadrant is observable from the Earth. Detailed spectral observation of Venus' a.m. quadrant were obtained by HST during the Venus Express mission. Photochemical and dynamical modeling [1, 6] indicates that the 70-80 km SO_2 abundance is dependent on the influx of SO_2 (or an influx of species that control the SO_2 abundance) from lower altitudes. Thus, it is currently unclear whether:

i) the species responsible for balancing out the loss and production SO_x at 70 and 80 km are directly upwelled from lower altitudes, and if so from how low in the atmosphere, and through what process?

--or--

ii) fluctuations in the upward flux of SO_2 itself are the primary mechanism that determine the SO_2 density?

--or--

iii) the 70 to 80 km behavior is intimately linked to physical/chemical/microphysical processes occurring in the 60 to 70 km altitude region, and if so by what species/and or processes?

To segregate the import of these processes detailed empirically constrained models of the SO_2 profile over multiple altitudes at multiple times of day are needed. This need *is* the primary motivator for *new* spatially and temporally coincident pole-to-pole observations of Venus' a.m. quadrant during the Akatsuki mission when UVI images sensitive to the altitude region just below the region sampled by the short (λ < 240 nm) wavelength HST imaging and spectral observations. Additionally, in the absence of in-situ measurements, it is a high priority to obtain these observations coordinated with other ground based platforms over a range of wavelengths that have sensitivity to the lower altitude regions adjacent and below the 70-80 km cloud top region.

In each of the possible HST observing epochs details of the haze properties can be derived from analysis of limb brightness signatures captured in the 365 nm *Akatuski* images. These details can also be fed into Mie scattering models to define the impact of the aerosols on the photon (=radiation) budget as function of altitude at each local time observed. The combination of the HST derived SO_2 and SO gas observations with the radiation budget results can be fed into photochemical and microphysical models and used to investigate the impact of H_2SO_4 formation on Venus' overall sulfur budget. This has the potential to improve our overall understanding of the cloud formation process which in turn impacts modeling of Venus' long term climate evolution.

Summary:

The successful insertion of *Akatsuki* into Venus orbit on December 7, 2015 has opened up a new epoch of continuous Venus observation. This in turn provides a new opportunity to obtain coordinated observations that can capitalize, in concert, on the unique capabilities of the *Akatsuki* suite of instruments as well as other ground and space-based observing platforms, enhancing and expanding the science return of each observation.

References: [1] Jessup, et al. (2015) *Icarus*, **258**, 309-336. [2] Vandaele et al. (2016), *Space Sci. Revs*., submitted. [3] Sandor et al. (2010), *Icarus*, **208,** 49-60. [4] VEXAG *Goals, Objectives and Investigations for Venus Exploration,* 2014. [5] Jessup et al., 2015, 13th *VEXAG meeting, Washington, D.C.*. [6] Marcq et al., 2013, *Nature GeoSci* **6**, 25-28.