U-WISHeS and V-WiSHeS: Terahertz Heterodyne Flight Spectrometers under Development Targeting the Uranus and Venus Systems

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***Abstract*— New technology developments overcome critical limitations of heritage flight heterodyne spectrometers that sacrificed broadband spectral coverage for high spectral resolution at a fixed frequency and narrow frequency band. We are developing two flight instruments optimized for Uranus' stratosphere and Venus' middle atmosphere – the Uranus Wideband far-Infrared Spectrometer at Heterodyne reSolution and the Venus Wideband Submillimeter Heterodyne Spectrometer – that will revolutionize the present-day planetary flight spectrometers in that they achieve both high spectral resolution and broadband spectral coverage at terahertz frequencies in a low size, weight, and power configuration.**

I. SCIENCE RATIONALE

REMOTE sensing spectroscopy at high resolving power ($R\sim10^6$), is a powerful tool to investigate physical and chemical processes within environments throughout our solar system. Spectroscopy at heterodyne resolutions at long wavelengths in the submillimeter (sub-mm) and far-infrared (far-IR), enables retrieving temperature, dynamics, and chemical composition in atmospheres, including trace species that are more difficult to observe at shorter IR wavelengths, as well as cold surface temperatures of shadowed regions and small bodies in the outer solar system. The terahertz (THz) spectral region is optimal for remote sensing of thermal emission from cold objects, like those in the Uranus System, as well as from relatively cool regions, like Venus' atmosphere above its cloud tops, in which Venus' far-IR properties affect its climate system.

We present two flight instruments under development: the Venus Wideband Submillimeter Heterodyne Spectrometer (V-WiSHeS) and the Uranus Wideband far-Infrared Spectrometer at Heterodyne reSolution (U-WISHeS). The V-WiSHeS maturation effort is under NASA's Maturation of Instruments for Solar System Exploration (MatISSE) program and will achieve TRL 6 in September 2024. V-WiSHeS enables high sensitivity and high resolving power measurements of Venus' middle atmosphere to address key questions related to Venus' chemistry, dynamics, and thermal structure, and provides powerful diagnostics of trace gases that affect terrestrial planet climate systems. Similarly, U-WISHeS will measure the composition and temperatures in Uranus' cold stratosphere, as well as meridional circulation and the decay of zonal winds with height. High spectral resolution is essential to measure stratospheric zonal winds by Doppler shift, complementing cloud-tracking that probes deeper atmospheric levels, and contributes to constraining vertical temperature-pressure profiles. U-WISHeS will map surface temperature spatial variations on Uranus' moons by continuum emission and derive thermal inertia from day- and night-side temperature contrast.

II. TECHNOLOGY ADVANCEMENT

V-WiSHeS spans 64 GHz between 529 and 600 GHz, with 500 kHz spectral sampling ($R>10^6$), enabling measurements of H_2O, $H_2{}^{17}O$, $H_2{}^{18}O$, HDO, $CO^{18}O$, $CO^{17}O$, $^{13}CO^{18}O$, $^{13}CO^{17}O$, CO, ^{13}CO, $C^{18}O$, $O^{18}O$, O_3, $OO^{17}O$, $OO^{18}O$, H_2S, $H_2{}^{34}S$, $H_2{}^{33}S$, H_2SO_4, ClO, ^{37}ClO, H_2O_2, SO, SO_2, $^{34}SO_2$, OCS, $O^{13}CS$, $OC^{34}S$, $OC^{33}S$, NO, NO_2, and PH_3 in Venus' middle atmosphere. The high spectral resolution and broadband coverage directly results from advancements enabled in part by incorporating Application-Specific Integrated Circuit (ASIC) spectrometers into the receiver's back-end, critically needed for high-speed computation. We achieve wide spectral coverage with a time-multiplexed frequency-switching scheme using four 4-GHz ASIC spectrometers to achieve a 16-GHz instantaneous bandwidth, switched four times in frequency for a total coverage of 64-GHz.

U-WISHeS leverages the V-WiSHeS technology. It is a low TRL instrument spanning 300 GHz between 1.05 and 1.35 THz, with 2 MHz spectral resolution ($R>5x10^5$), enabling measurements of CH_4, CO, ^{13}CO, $C^{18}O$, H_2O, HDO, NH_3, H_2S, HCN, $H^{13}CN$, and $HC^{15}N$. Transitions of PH_3, HF, HCl, and HI reside in the U-WISHeS bandpass, opening a window to discovery science. We will summarize both the V-WiSHeS and U-WISHeS instrument architectures and their science.

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