National Aeronautics and Space Administration

Venus Aerosol Separator with Mass Spectrometer (VAMS)

Principal Investigator: Dragan Nikolic (389); Co-Investigators: Stojan Madzunkov (389), Jurij Simcic (389)

Program: FY22 R&TD Strategic Initiative

Strategic Focus Area: Technologies for Venus Cloud Environments /Venus In-Situ Aerosol Measurement Technologies - Strategic Initiative Leader: James A Cutts

Objectives:

VAMS, shown in Fig 1b, has no competing state-of-the-art aerosol mass spectrometer (AMS) instrument for long-duration planetary aerial missions. Large commercial AMS (>100kg and >300W) from Aerodyne has been flown on the NASA P3-B, DC-8, and NSF C-130 aircraft [4] and cannot handle variable outside pressures (0.1-0.8 bar in Venus cloud layer [5]). Overall, VAMS has a projected mass of 10.5kg in 12L volume with a nominal power of 59W.

FY22 Objective: Mature the Advanced Aerosol Inlet (AAI) and mass spectrometer (MS) components to TRL 4 to operate with H_2SO_4 aerosols and vapors. This entails:

1) ruggedize the piezo valve (PV) against clogging under severe aerosol loads while maintaining steady gas flow despite changing external pressures [5];
2) refurbish and test miniature Creare pumps for use in the Differential Pumping (DP) subsystem;
3) motorize Gate Valves (GV) and test their vacuum sealing under 98% concentrated H_2SO_4 exposure;
4) design, fit check, and fabricate custom 3D printed vacuum chamber for MS;
5) design, test, and expose the ceramic vaporizer (V) to 300°C temperatures and H_2SO_4 loads;
6) expose MS sensor's electron gun filament to high 98% H_2SO_4 loads while operating at 2000-2500K temperatures.

Background: The AAI as the front-end to any MS, see Fig.1, enables composition analyses of aerosols in various planetary atmospheres. It features an adaptive high-pressure piezo valve (PV) [7] that opens up chemical composition studies of deep atmospheres previously deemed prohibitive due to overwhelming amounts of gas separated from the aerosol particles [7,8]. More importantly, the AAI continues to operate despite changes in the outside pressure, simply by adjusting the PV's gap size. Measuring the composition of aerosols is challenging because aerosols generally represent only a minute fraction of the mass of the atmospheric gases in which they are embedded. We are developing the AAI that admits atmospheric gas containing aerosols and then strips away the gas leaving only the aerosols to enter the mass spectrometer (MS), which analyzes the chemistry of aerosol particles. The AAI uses NanoJet flow cell technology capable of admitting gas over a pressure range of 1 mbar to 100 bar and separating aerosols with mass concentrations as low as 10 parts per billion (ppb).

Approach and Results: Using the combination of modeling, experimental tests, and localized applications of 100x larger loads of 98% H2SO4 than the expected exposures in Venus clouds, we were able to mature to TRL 4 the following VAMS components (see Fig. 1c): MEMS Piezo Valve (PV,#1), MicroPirani Gauge (MPG,#2), two miniature Creare turbomolecular drag pumps (TMDP,#4) and one miniature scroll pump (MSP, #5) to be used in Differential Pumping (DP) subsystem, two Gate Valves (GV,#6), ceramic vaporizer (V,#7), custom 3D printed vacuum chamber (#8), MicroIon Gauge (MIG, #9), and Getter Pump (#10). We submitted the FY23 MatISSE proposal to complement TRL5 maturation of the FICE subsystem (JPL), development of space flight motorized GV (Honeybee Robotics), and conduct TVac/environmental TRL6 maturation of the integrated VAMS instrument.

In this task, we accomplished the following FY22 milestones:

Milestone M1: a) Custom-made vaporizer is delivered to JPL; b) Digitally-controlled in a lab to 300°C; Figure 2a-g shows the main results where we tested vaporizer at 1200°C without compromising the ultrahigh vacuum in MS chamber.

Milestone M2: a) Piezo valve simulated; b) Piezo valve redesigned; Figure 2h-k illustrates the fabricated PV and its performance modeling and successful flow control using the micro-valve electronics development board - a component of the FICE breadboard.

Milestone M3: a) 3D-printed Ti vacuum chamber designed; b) fabricated, and c) holds UHV at 300°C vaporizer. Figure 3a illustrates a high-fidelity prototype of the chamber finalized at the JPL machine shop.

Milestone M4: QIT-MS sensor, vaporizer, ion/getter pump integrated into the 3D-printed vacuum chamber; Figure 3b shows VAMS components being fit checked, and interfaced to the low-fidelity prototype of the vacuum chamber. Vacuum levels achieved were between 4-8E-9 Torr with vaporizer at 1200°C.

Milestone M5: QIT-MS sensor remains operational after vaporizing 90 $\mu\ell$ of liquid sulfuric acid (equivalent to twice the total aerosol loads expected in a 100-day Venus mission). The electron gun was not damaged by direct exposure to large amounts of 98% H_2SO_4 drops, and its tantalum emitter was successfully operated in a vacuum at 2500K. Figure 4a-b shows the QIT-MS sensor and the thermionic emitter, the sensor's component most sensitive to H2SO4. All other components of the QIT-MS sensor are less susceptible to H_2SO_4 exposures. Figure 4c shows the part of the simulated spectrum near the 32Da mass channel and required operating voltages to separate interfering fragment ions.

Milestone M6: 6a) Demonstrate Venus relevant number density measurements of aerosols; 6b) Demonstrate no clogging of piezo valve with 25,000 particles/sec; Figure 4d shows the size distribution of ethylene glycol aerosols compared to the ambient air. Figure 4f demonstrates that PV operates nominally even at these large aerosol loads. Number densities are similar to those expected for H_2SO_4 droplets in Venus clouds. In Figure 4e, we show aerosol mist at number densities 358 times higher than what is expected in Venus clouds.

Significance/Benefits to JPL and NASA: The investigation of aerosols in planetary atmospheres is now widely recognized as an important objective for the 2022 Planetary Science and Astrobiology Decadal Survey (PSADS) [1], which declared that "Aerosols (dust, hazes, and clouds) are key features of many planetary atmospheres and affect the atmospheric absorption and scattering of solar radiation. Aerosol transport, microphysics, and radiative processes [6] are often coupled via complex feedbacks, yet few measurements related to such processes exist for atmospheres other than Earth's". To rectify this situation, PSADS identified several high-priority investigations that could only be achieved with in situ measurements of the chemistry of aerosols. These are Strategic Research for Q6.6, Q7.3, and Q10.5. In addition to applications to Venus exploration, other concepts include probes, landers, and aerial platforms for Mars and Titan or entry probes to Saturn, Uranus, and Neptune. The concept is also applicable to balloons in Earth's stratosphere. To date, NASA does not have an instrument capable of extracting molecular information from planetary aerosol samples. The proposed instrument technology is sensitive, quantitative, and can measure aerosol distributions during atmospheric descent or on landed spacecraft.

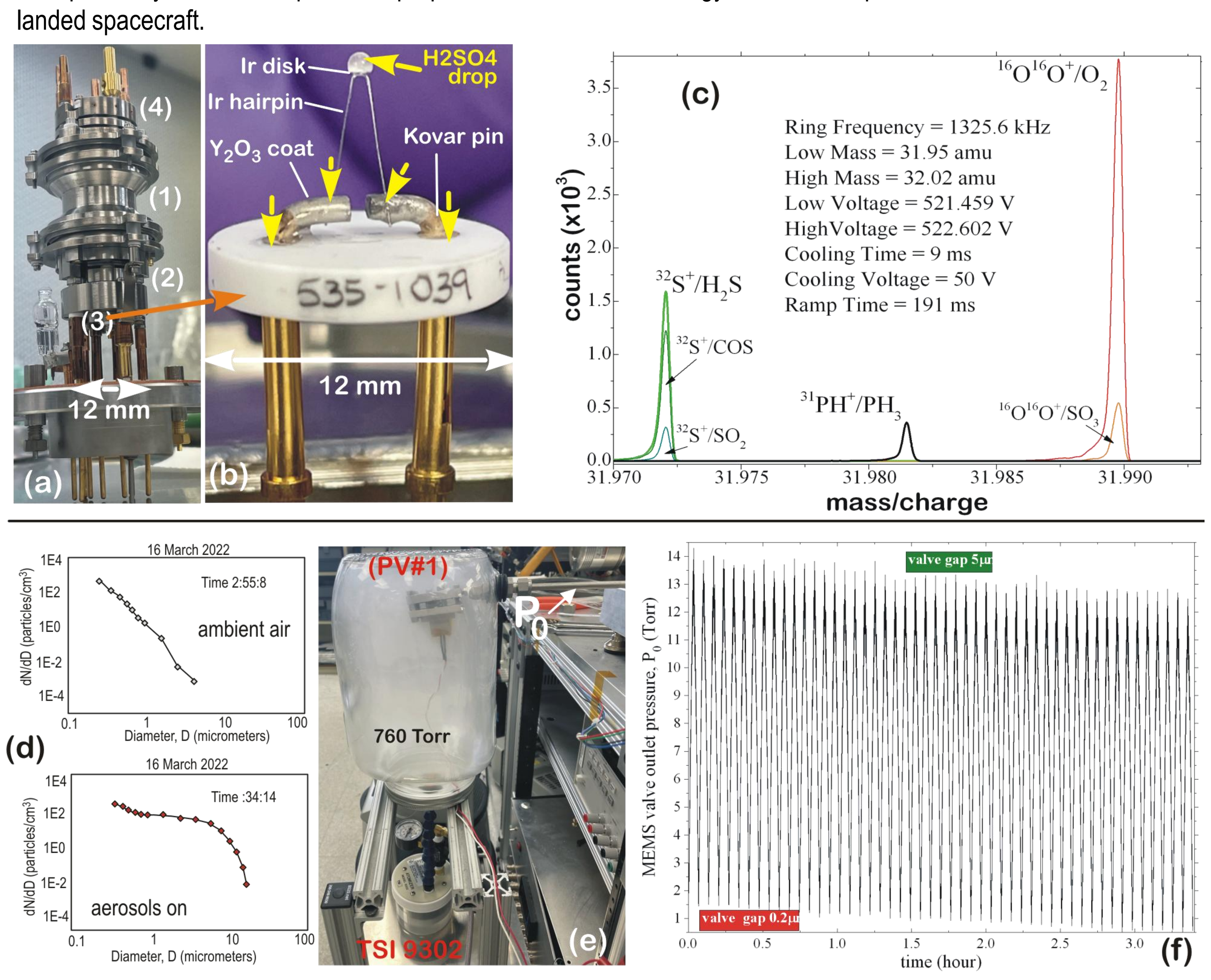

Figure 4. *Milestone M5* accomplishments: QIT-MS sensor; (a) key parts: (1) ion trap, (2) electron gun assembly with Ir filament (3), (4) ion detector; (b) Yttria-coated Ir filament: Ir hairpin electrical contacts are spot welded to Kovar pins embedded into the standard ceramic AEI base; arrows point to locations where 0.5 uL drops of 98% H2SO4 were applied (each drop is 100x the load during a 4-month mission); Ir filament remained functional after six weeks of continued acid exposure followed by 12hrs of operations in vacuum at 2,000K; (c): QIT-MS performance model of the resolved spectrum at 32 amu containing PH_3 and H_2S daughter fragments.

Milestone M6 accomplishments: (d) using a micro syringe pump, we aerosolized 10uL/min of ethylene glycol resulting in size/number density distribution of aerosols as in Venus clouds; (e) using TSI 9302 aerosols generator, we captured ethylene glycol aerosols in a glass jar at number densities ~1E7 particles / cm3 and sampled the mist through the 5um stroke PV, without clogging; (f) in 50 cycles of opening and closing the PV while ingesting 232,897 particles / second over 3 hours, we saw no evidence of blocking.

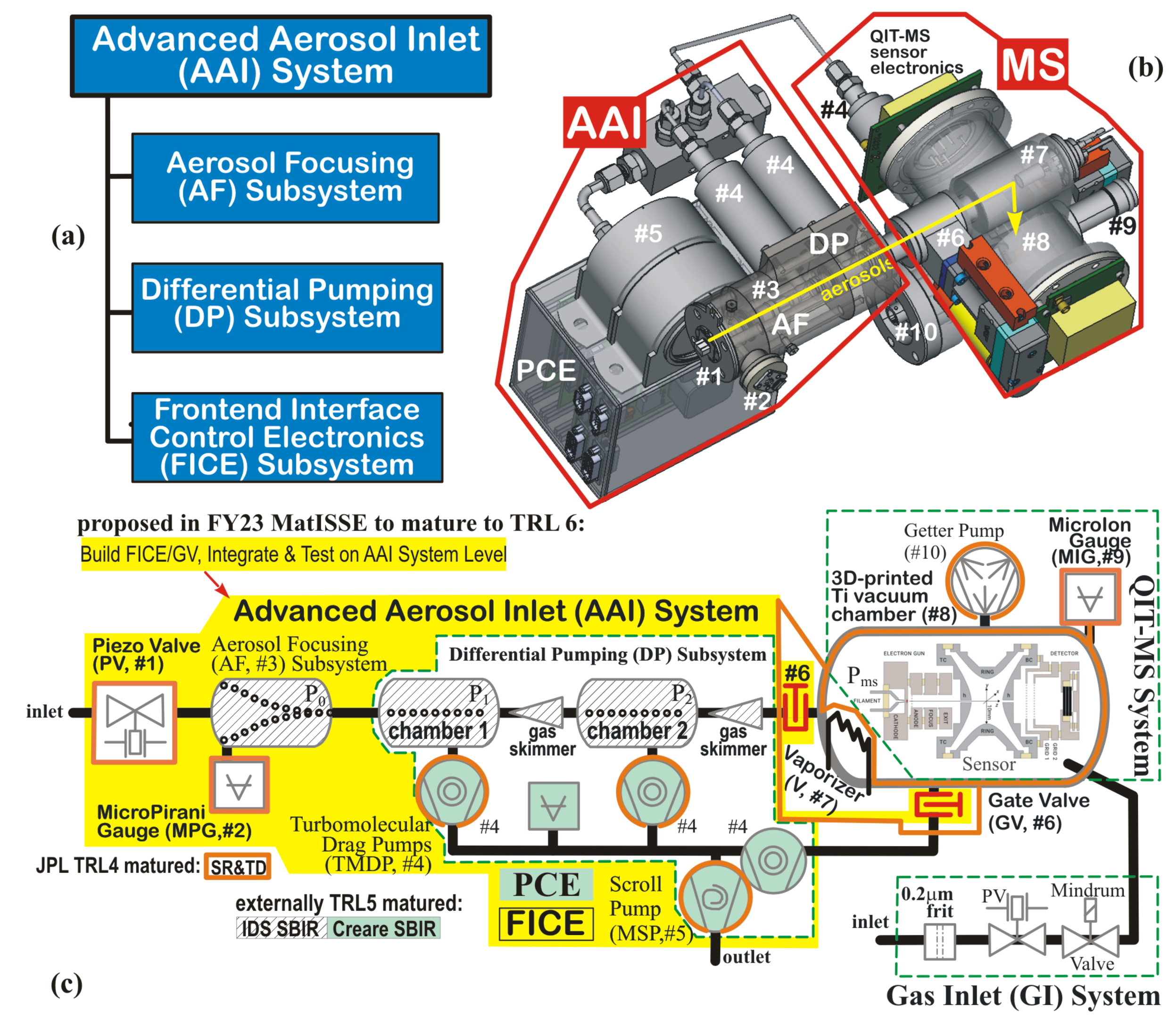

Figure 1. Schematic of the VAMS instrument with the Advanced Aerosol Inlet (AAI) connected to the Mass Spectrometer (MS). The AAI admits atmospheric gas with aerosols through the Piezo Valve (PV, #1) using the pressure gradient monitored by the MicroPirani Gauge (MPG, #2). The AF accepts and focuses aerosols into the 40 um wide beam, and DP strips away the gas using gas skimmers, two Creare turbo (#4), and a scroll (#5) pump. Pumps are operated by the Pump Control Electronics (PCE) designed to accommodate the FICE breadboard. Gate Valve (#6) admits the aerosol beam into MS vacuum chamber (#8). The vaporizer (V, #7) controls the temperature at which the admitted aerosols are being vaporized and analyzed by MS for their composition. At Venus cloud conditions, the mass concentration of vaporized aerosols yields at most 1E-7 Torr, which is the optimal vacuum level for the QIT-MS analysis. Vacuum pressure is monitored by the MicroIon Gauge (MIG, #9) and sustained by the getter (#10) and the third Creare (#4) pump.

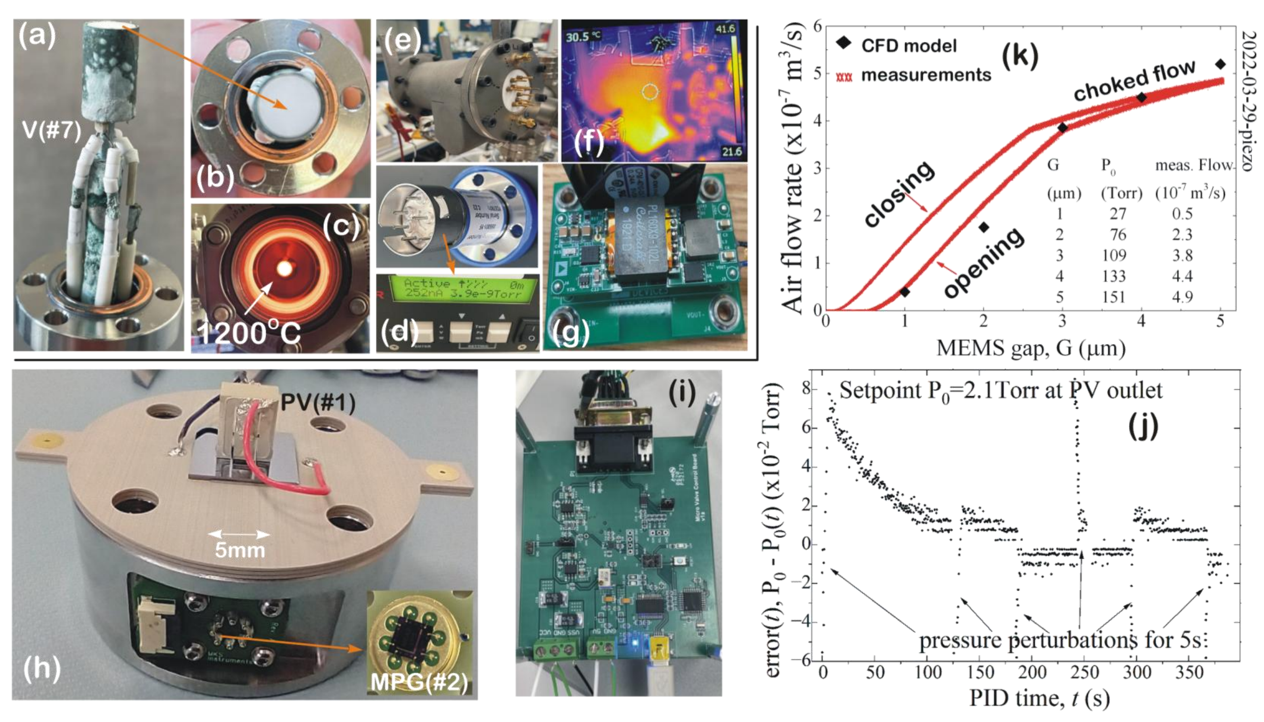

Figure 2. *Milestone M1* accomplishments: (a) Vaporizer (V,#7) electrical contacts remain functional after extreme 98% H2SO4 exposure while its ceramic heater surface (b) stays clean and acid-free; (c) when vaporizer at 1200°C and under vacuum (d) in the vacuum chamber (e), localized heat transfer is 20°C (f) above the ambient temperature; (g) the vaporizer driver board is tested as a separate component of the FICE subsystem. *Milestone M2* accomplishments: (h) new MEMS Piezo Valve (PV,#1) design has been fabricated and integrated with the MicroPirani Gauge (MPG,#2) that monitors PV's outlet pressure P_0 via micro-controller board (i); control of P_0 using MPG feedback (j) shows 1% stability and fast recovery during sudden inlet pressure changes; (k) model of the gas flow through 5μm stroke PV agrees with measurements.

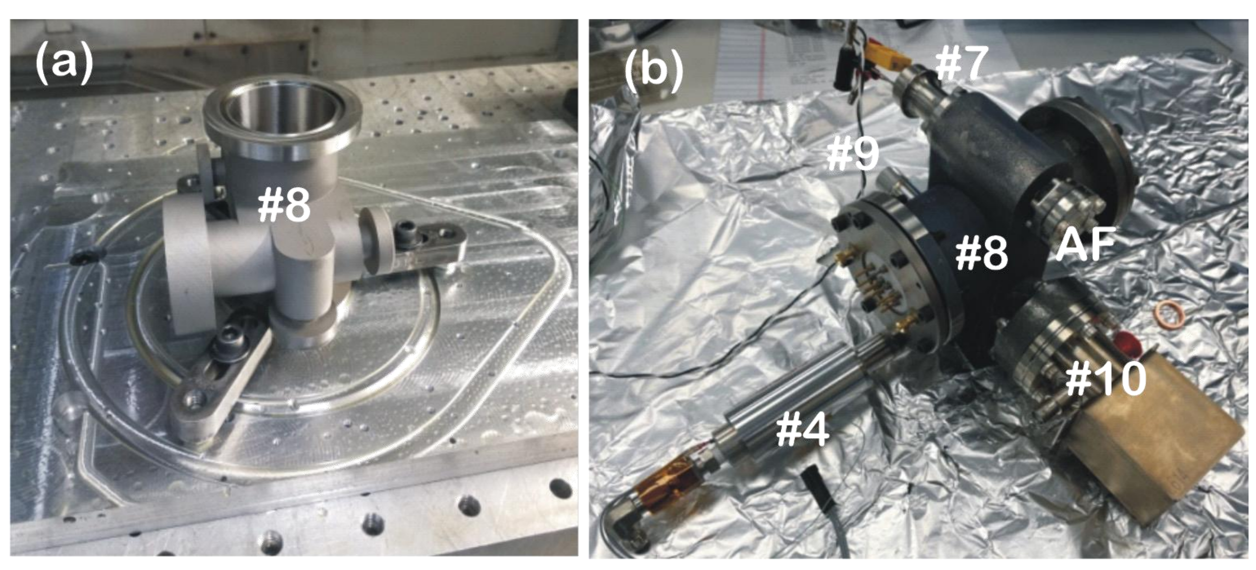

Figure 3. *Milestone M3* accomplishments: (a) high-fidelity 3D printed vacuum chamber (#8) is in its final machining stage. Milestone M4 is accomplished using (b) low-fidelity 3D printed chamber (#8), with successful fit check of Creare (TMDP,#4) pump, the custom vaporizer (V,#7), the MicroIon Gauge (MIG,#9), the ion/getter pump (#10) and interface to attach the Aerosol Focusing (AF,#3) subsystem to be delivered by IDS to JPL in October 2023 for the FY23 integrated tests at Caltech Venus Cloud Simulator

REFERENCES

[1] The National Academies of Sciences, Engineering, and Medicine, https://www.nationalacademies.org/ourwork/planetary-science-and-astrobiology-decadal-survey-2023-2032; **[2]** S.M. Madzunkov, D. Nikolić, et al., *Data analysis and isotopic ratios measured onboard the Spacecraft Atmosphere Monitor, International Journal of Mass Spectrometry 477, 116847 (2022).* **[3]** VEXAG Goals, Objectives, and Investigations, https://www.lpi.usra.edu/ vexag/ reports/ VEXAG_Venus_GOI_Current.pdf; **[4]** K. G. Moore II, et al., *A comparison of similar aerosol measurements made on the NASA P3-B, DC-8, and NSF C-130 aircraft during TRACE-P and ACE-Asia, Journal of Geophysical Research 109, D15s15 (2004).* **[5]** K.H. Baines, D. Nikolic, et al., *Investigation of Venus Cloud Aerosol and Gas Composition including Potential Biogenic Materials via an Aerosol-Sampling Instrument Package, Astrobiology 21(10), 1316-1323 (2021).* **[6]** O. Boucher, et al., Ch. 7 - *Clouds and Aerosols, in book: Climate Change: The Physical Science Basis. Contribution of Working Group I to the 5th Assessment Report of* the Intergovernmental Panel on Climate Change, 571-892 (2013). **[7]** J. Simcic, D. Nikolić, et al., *Quadrupole Ion Trap Mass Spectrometer for ice giant atmospheres exploration, EGU General Assembly 2020, Online, 4–8 May 2020,* EGU2020-2024, https://doi.org/10.5194/egusphere-egu2020-2024 (2020); Space Science Reviews vol: In Situ Exploration of the Ice Giants (2020). **[8]** Y. Chen, et al., *Response of the Aerodyne Aerosol Mass Spectrometer to Inorganic Sulfates and Organosulfur Compounds: Applications in Field and Laboratory Measurements, Environ. Sci. Technol*. 53(9), 5176-5186 (2019).

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Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

www.nasa.gov

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K. Baines, J. Cutts, D. Nikolić, et al., *An In-Situ Instrument Package for Direct Measurements of Both Gases and Aerosols in Venus and Other Planetary Atmospheres*, International Planetary Probe Workshop (2022); https://www.openconf.org/ippw2022/modules/request.php?module=oc_program&action=summary.php&id=56

PI/Task Mgr. Contact Information:

Email: Dragan.Nikolic@jpl.nasa.gov