National Aeronautics and Space Administration

FY24 Strategic Initiatives Research and Technology Development (SRTD)

Gas and Aerosol Separator with Mass Spectrometer (GAMS)

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

Objectives:

GAMS (Fig 1) is the state-of-the-art aerosol mass spectrometer (AMS) instrument for long-duration planetary aerial missions with a projected mass of 12kg in 12L volume with a peak power of 50W. Competing commercial AMS from Aerodyne (>100kg and >300W) was deployed on the NASA P3-B, DC-8, and NSF C-130 aircraft [1] but cannot operate under variable outside pressures (0.1-0.8 bar in Venus cloud layer [2]).

The overall objective for GAMS is to perform in the range of harsh environmental conditions expected in the Venus clouds and demonstrate the performance needed to meet the Venus science objectives. Specific FY24 objectives are to demonstrate that:

Objective 1) prototype Differential Pumping System (DPS) removes N2 gas to < 1E-5 Torr inside vacuum chamber;

Objective 2) motorized gate valve has ultra-high vacuum compatibility;

Objective 3) measured mass spectrum of PH_3/H_2S gas mixture in CO_2 ballast separates PH_3 fragment ions from H_2S interferences.

Background:

The miniature Aerodynamic Aerosol Separator (minAAS), shown in Fig 1, is the front-end of any mass spectrometer (MS), and its purpose is to extract aerosols from various planetary atmospheres. It features the Input Control Microvalve (ICMV), an adaptive high-pressure (60 bar) piezo valve that enables studies of deep atmospheres of Ice Giants that were prohibitive in the past due to overwhelming amounts of gas to be ingested with aerosol particles [3]. minAAS maintains the optimal gas flow into MS despite changes in the outside pressure simply by adjusting the PV's gap size. Measuring the chemical composition of aerosols is challenging as they are only a minute fraction of the mass of the atmospheric gasses in which they are suspended. We matured minAAS to admit CO_2 gas containing sulfuric acid aerosols and then strip away the gas, leaving mostly the aerosols to enter MS vacuum chamber. The minASS uses IDS NanoJet flow cell technology to focus aerosols into narrow beams with mass concentrations as low as tens parts per billion (ppb).

Approach and Results:

This task involved the assembly and experimental work of the TRL4 test bed we used to accomplish the following FY24 milestones::

Milestone 1: Differential Pumping subsystem reaches 3E-8Torr in a MS vacuum chamber starting from the ambient pressure Patm=760 Torr, and holds 1.7E-6Torr over 42 hours with pumps powered off. Low gas background pressure inside the MS vacuum chamber facilitates the detection of vaporized aerosols with an estimated signal partial pressures of up to 5E-6 Torr..

Milestone 2: Demonstrated that motorized gate valve while being exposed to 200uℓ of 98% H_2SO_4 directly on the Viton seal (see Fig3) has measured leak rate <1E-10 Torr ℓ/s at Patm=760 Torr over 90 days. Excellent sealing properties of the gate valves enable isolation of the MS vacuum chamber while pumps are powered off or in between aerosol and gas measurement modes, thus making it possible that needed ultra-high vacuum conditions (<5E-8Torr) are established within 5 minutes after pumps are powered on.

Milestone 3: Demonstrated separation of PH_3 fragment ions from H_2S interferences (Fig.2) using the ground support electronics (Fig1c). With mass resolution better than 10mDa, the MS sensor is capable of separating fragment ions of similar masses [5].

Milestone 4: Proposal 24-MATISE24_2-0007 has been submitted to ROSES in which we describe the integration and maturation of the GAMS instrument. We incorporated in the proposal the SBIR Phase II deliveries from IDS (aerosol focusing subsystem) and Creare (miniature pumps and pump control electronics subsystems), both at TRL5, to improve the overall maturation procedures for the GAMS instrument.

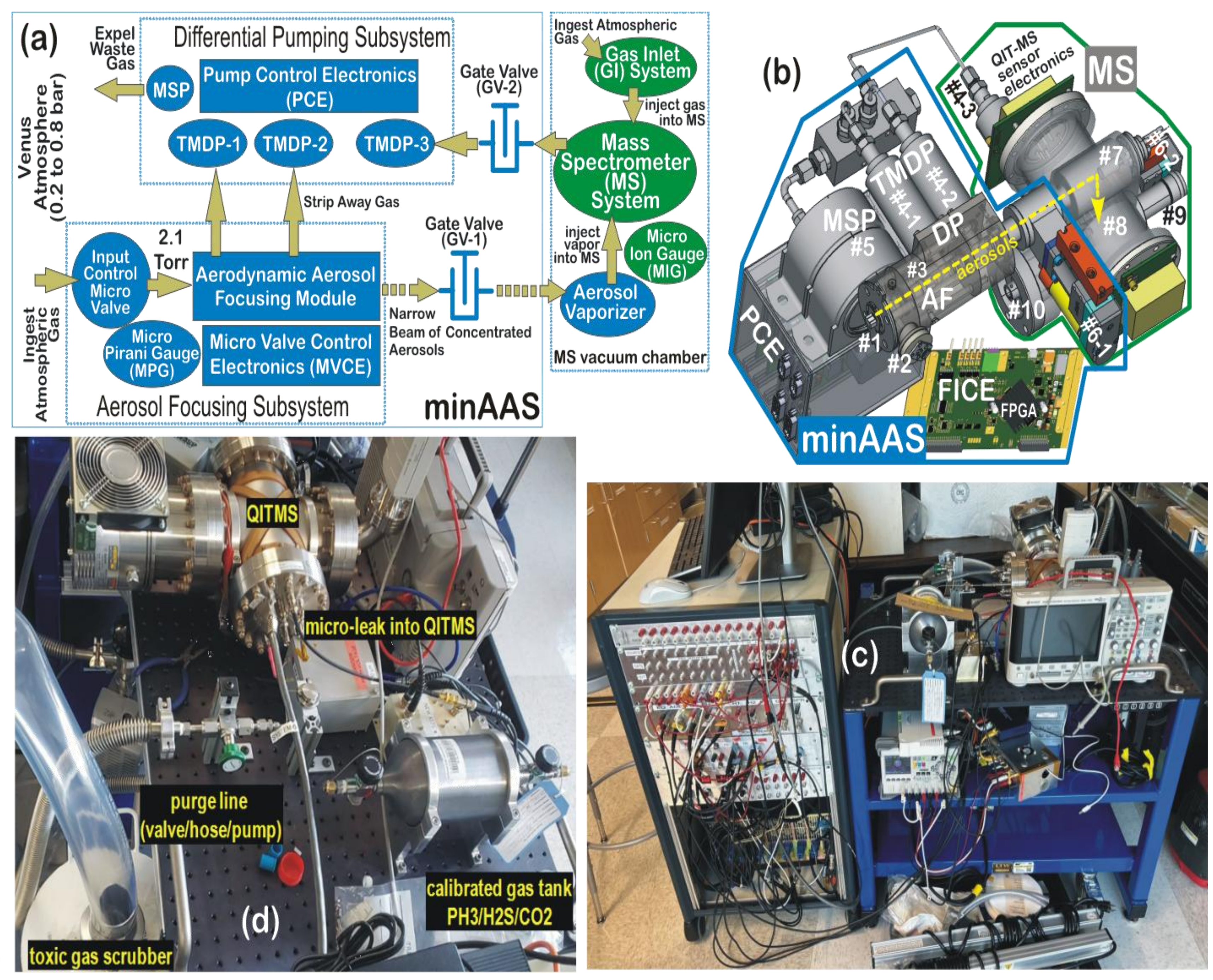

Figure 1. GAMS Instrument. (a) Functional diagram and (b) CAD model of the GAMS subsystems and components with the miniature Aerodynamic Aerosol Separator (minAAS) connected to the Mass Spectrometer (MS). The Aerosol Focusing (AF, #3) subsystem directs a beam of aerosols through the gate valve (GV,#6) to impinge on the aerosol vaporizer (#7). Input control microvalve (ICMV, #1) regulates flow at a pressure of P0=2.1 Torr (MPG, #2) into the AF. The Differential Pumping (DP) subsystem strips gas away from the aerosol beam using Creare Turbo Molecular Drag Pumps (TMDP, #4) and a Miniature Scroll Pump (MSP, #5). Vapor injection into the MS requires a low residual background (1E-9 Torr) maintained by the TMDP-3(#4-3). (c) Experimental setup and (d) Gas Inlet (GI) system used to measure the mass spectrum of PH_3/H_2S mixture in CO_2 ballast.

Significance/Benefits to JPL and NASA:

The GAMS instrument enables composition analyses of aerosols in various planetary atmospheres (featuring the JPL QIT-MS mass spectrometer) and for this purpose contains the minAAS system, as the aerosol frontend to any MS. In addition to applications to Venus exploration and a Uranus probe, other concepts include probes, landers, and aerial platforms for Mars and Titan or entry probes to Saturn and Neptune. The instrument could also be deployed on drones and small balloons to conduct investigations of the Earth's troposphere and stratosphere as an alternative to the much larger platforms required today.

Figure 3. Switch-operated motorized GV (vertical scale 90mm) exposed to 200ℓ of 98% H_2SO_4 directly on the Viton seal. The measured leak rate was <1E-10 Torr ℓ/s at Patm=760 Torr over 90 days.

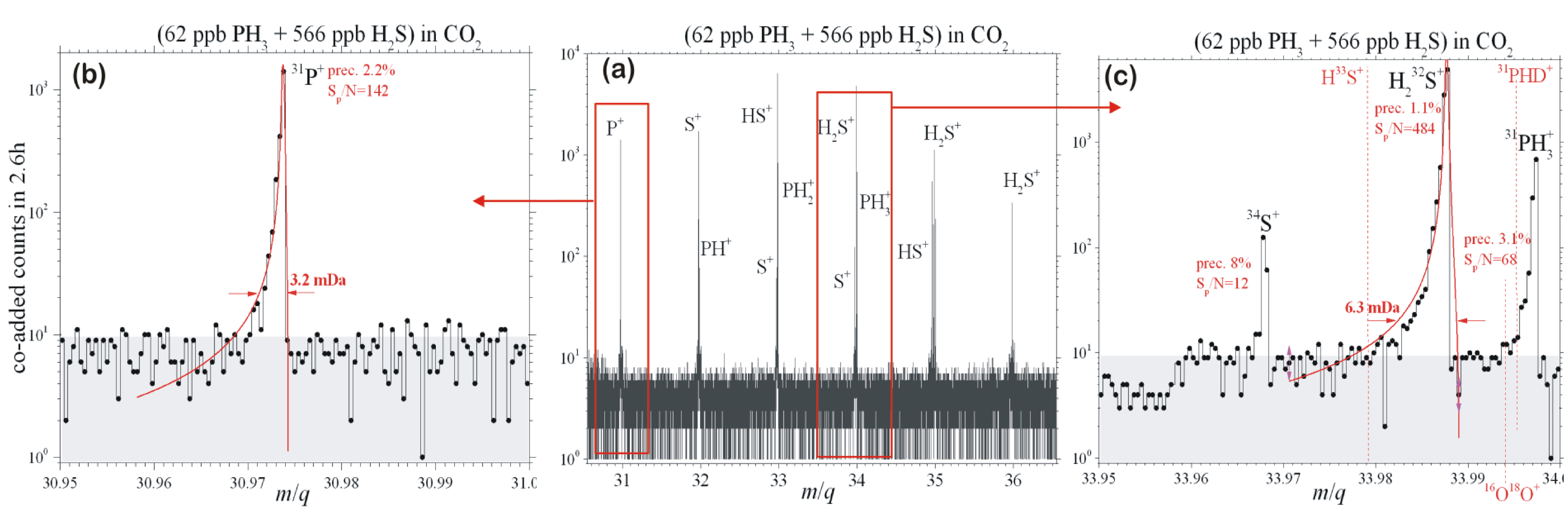

Figure 2. (a) Mass spectrum of PH_3/H_2S mixture in CO_2 ballast eluted through a capillary into the QIT-MS sensor (see Fig. 1d). (b) Fragment ion $^{31}P^+$ is isolated and can be used to detect the presence of PH_3, and (c) the parent fragment ion PH_3+ is sufficiently separated from the H_2S+ interference.

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[5] J. Simcic, D. Nikolić, et al.,"Quadrupole Ion Trap Mass Spectrometer for Ice Giant Atmospheres Exploration", Space Sci Rev 217, 13 (2021). doi:10.1007/s11214-020-00785-5

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