IN SITU MEASUREMENTS OF THE CHEMICAL AND ISOTOPIC COMPOSITION OF JUPITER WITH THE GALILEO PROBE MASS SPECTROMETER, AND PROSPECTS FOR THE OTHER GIANT PLANETS.

P. R. Mahaffy[1], S. K. Atreya[2], M. H. Wong[3], [1]NASA Goddard Space Flight Center (Emeritus), Paul.R.Mahaffy@nasa.gov. [2]Univsity of Michigan, [3]Univsity of California at Berkeley.

Introduction: The Galileo Probe entry into Jupiter's Atmosphere on December 7, 1995 provided the first insitu measurements of the deep atmosphere of a gas giant planet with the Galileo Probe Neutral Mass Spectrometer (GPMS) designed to study its structure and chemical and isotopic composition. Measurements of the elemental abundances of C, S, O, N and the noble gases relative to the dominant gas hydrogen as the probe descended into the atmosphere were intended to provide a basis for models of the formation of Jupiter and by extension to other gas giants. In addition to the Galileo Probe Mass Spectrometer [1], the Probe payload included: an atmospheric structure instrument; a helium-abundance interferometer; a nephelometer for cloud-particle characterization; a net-flux radiometer; and a lightning/radio-emission instrument.

The Galileo Probe Neutral Mass Spectrometer: Sampling of the Jovian atmosphere was through 2 inlets to maintain desired ion source pressures as the atmospheric pressure increased from ~0.5 bar to 22 bar during descent. Electron ionization of the sampled gas was with energies of 75 eV, 25 eV, and 15 eV. The analyzer was a quadrupole mass spectrometer with radius 5.0 mm and length 150 mm that sampled in unit or 1/8 Da scans in the mass range 2-150 Da (Fig. 1). Ion and getter pumps removed gas from the mass spectrometer volume and electronics were contained in a pressurized housing to isolate them from entry conditions. The instrument mass was 13.2 kg, the average power 13 W, and the data rate 13 bps. A comprehensive set of calibration experiments using the flight unit and a flight spare were essential for interpreting the data.

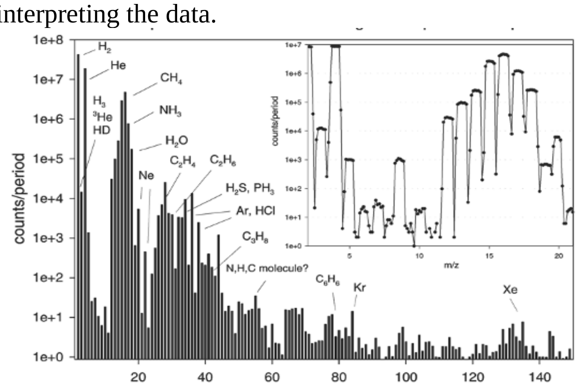

Fig. 1. *GPMS spectrum in the 17 to 18.5 bar region of Jupiter's atmosphere.*

Highlights of GPMS science: With measurements of vertical profiles from 0.5-21 bar of H_2, He, H_2O, H_2S, NH_3, Ne, and Ar as well as Kr and Xe (with enrichment measurements) the elemental ratios of H, C, N, O, S, [2] and the noble gases [3] were secured supporting the core accretion model of Jovian formation [4].

Condensable volatile mixing ratios (NH_3, H_2S, and H_2O) departed significantly from equilibrium values, influenced by local 5-µm hot spot meteorology and foreshadowing more widespread non-equilibrium distributions found by Juno (NH_3). The probe volatile measurements provide ground truth for challenging remote-sensing measurements of NH_3 and H_2O, while H_2S has only been measured by GPMS. The GPMS made the crucial primordial (Solar System) isotopic ratio measurements of D/H, $^3He/^4He$, $^{36}Ar/^{38}Ar$, and Kr and Xe isotopes. The depletion of Ne supported the previously predicted "rain" out of He and Ne.

Future Saturn and the Ice Giant Probe Missions: The recently released Decadal Study Report [5] described in-situ composition measurements at Saturn, Uranus, and Neptune as highly ranked "Strategic Research," needed to address priority science questions on the evolution of the protoplanetary disk, planetary accretion and formation, the structure and evolution of giant planets, and the interpretation of astronomical observations of exoplanets. Specific drivers for in-situ composition measurements at the ice giants are summarized in Atreya et al. [6]. The Galileo results—combined with the Juno discovery of deep horizontal/vertical variation in composition—support the synergistic value of in situ and microwave sounding.

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References: [1] Niemann H.B. (1992) Space Sci. Rev. 60, 111-142. [2] Wong M. H. et al. (2004) Icarus 171, 153-170. [3] Mahaffy et al. (2000) JGR Planets 105, 15061-15071. [4] Atreya S.K. et al. (2019) pp5-43 in *Saturn in the 21st Century*, Cambridge. [5] Nat. Acad. Sci., Eng., and Medicine (2022) https://doi.org/10.17226/26522. [6] Atreya et al. (2020) Space Sci. Rev. 216, 1, 1-31. [7] https://pds.nasa.gov