# FROM MARS TO JUPITER AND BEYOND: IN SITU ATMOSPHERIC STUDIES WITH SYNERGISTIC INSTRUMENT PAYLOADS.

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**Introduction:** Atmospheres are exciting but challenging targets for in situ studies. As with past missions, future in situ atmospheric measurements (from e.g., Saturn or ice giant probes) may be difficult to interpret due to variability over temporal, horizontal, and vertical dimensions. One approach to these challenges is to conduct studies using a distributed array of sensors, such as a multiprobes [1]. But at a single location, it is essential to employ a synergistic instrument payload capable of inferring the effects of variability on the measurements obtained. Simultaneous global/regional context data are also very important.

The in situ investigations of the martian and jovian atmospheres by the flagship-class Curiosity Rover and Galileo Probe provide important case studies for instrument complementarity. Very rarely are science questions addressed with a single instrument. I will discuss how data from multiple instruments in each payload combine to deliver the clearest picture of atmospheric dynamics, composition, evolution, chemistry, and physics.

**Instrumentation:** The Galileo Probe's payload was specifically designed to study the gas composition, atmospheric structure, aerosols, and radiative fluxes in Jupiter's atmosphere, with the mission and instrumentation described in [2]. Curiosity carries a meteorology package [3], as well as multiple instruments for sample analysis and remote sensing that also collect data constraining aerosols and atmospheric composition [4].

**Cloud physics and chemistry on Jupiter:** The nephelometer measured aerosol opacity and scattering properties [5], but determining the cloud composition required complementary information from the atmospheric structure instrument (ASI) [6], which gave the temperature/pressure conditions within aerosol layers needed to compare with compositional cloud models [7]. The Galileo Probe descended into a meteorologically anomalous "hot spot," as shown by highly important ground-based context observations [8]. Within these features, large-scale downwelling produces generally cloud-free conditions and depleted condensable gases [9], but the ASI detected stable regions [10] corresponding to downwardly-displaced cloud layers, an interpretation supported by mass spectral composition measurements [11].

The large-scale downwelling could be reconciled with the continued presence of clouds if small-scale turbulence was responsible for condensation [12], a scenario that could have been confirmed if the probe had carried an imaging experiment (and had the bandwidth to transmit the data). A Net-Flux Radiometer on board the probe at least provided enough photometric information to determine sky color (Fig. 1). Future probes with imagers would provide additional constraints on cloud types in the descent area. Probe imaging data from future missions would help interpret ground-based or orbital/flyby observations with coarser spatial resolution.

**Composition and origin of Jupiter's atmosphere:** Spatial variation at Jupiter prevented the Galileo Probe from measuring Jupiter's O/H ratio, leaving a strong science driver for the Microwave Radiometer on Juno [13]. The N/H ratio however was measured by the mass spectrometer [14], with confirmation by the probe radio signal attenuation [15,16] and now finally by ground-based thermal radio spectroscopy [17]. Other heavier elemental ratios like He/H and C/H were easily measured by the probe [18] because helium and methane are invariable in Jupiter's troposphere, but $CH_4$ may also be horizontally and vertically variable on the ice giants. An accurate measurement there will rely on knowledge of local meteorological conditions,

**Fig. 1.** Visualization of the Galileo Probe descent, just before ejection of the heat shield [19]. For this science-education planetarium movie, we determined the approximate sky color as a function of descent time using NFR data (pers. comm., L.A. Sromovsky).

as was the case for the Jupiter probe. Heavy element relative abundances are related to the composition of planetesimals that formed the planet, so measuring abundances of volatiles and noble gases on the ice giants will provide additional constraints on conditions in the proto-planetary disk.

**Martian chemical variability:** Instrumentation on the Curiosity rover has been used to study unexpected chemical variability in the martian atmosphere. Methane, a potential biomarker, had previously shown spatial and temporal variability [20]. Specialized instrumentation on Curiosity, the SAM/TLS [21], additionally found that even the low-level background of $CH_4$ was inexplicably variable [22]. This variability is now being correlated with variable environmental conditions, which are determined by data from the weather sensors (REMS) [4,23] as well as models of UV flux constrained by the MASTCAM imager [24]. Other molecules—$O_2$ and CO—have been observed to vary using both the SAM mass spectrometer and the ChemCam passive spectrometer [25,26]; CO variability is somewhat inconsistent between ground-based telescopes and orbiters [27,28]. Photochemical lifetimes of all these molecules are long compared to the length of the martian year, so the observed variability may be suggestive of new chemical processes. Explaining these processes will require synthesis of observations of dust, solar radiation, temperature, and humidity from the rover instrument suite.

**Conclusion:** Whether we have "been there" or not, important questions remain about the workings of planetary atmospheres, as well as their origins. Most of these questions cannot be answered by a single instrument; instead, synergistic payloads are needed to disentangle the effects of temporal and spatial variability.

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