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"Galileo Probe Mass Spectrometer"

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During the past year, the Principal Investigator's research carried out under this contract has focused on an analysis of the implications of Galileo Probe Mass Spectrometer (GPMS) results for the origin of Jupiter's atmosphere and the origin of the ice and other possible volatiles on the Galilean satellites.

The first step in this work was a team effort to establish the characteristics of the two principal atmospheric constituents, hydrogen and helium. Thanks to extensive calibration work by Dr. P. Mahaffy at Goddard, we have been able to determine that D/H = (2.7 +/-0.7) x10e-5 and 3He/4He = (1.7 +/-0.2) x 10e-4. The D/H value tells us that the hydrogen in Jupiter's atmosphere was safely sequestered for 4.5BY, while the hydrogen in the Local Interstellar Medium (LISM) was gradually losing deuterium as a result of stellar evolution, so that today, D/H = (1.7 +/-0.2) X 10e-5 in the LISM (Linsky 1996).

The helium isotopes agree within the associated errors with measurements of this ratio in the erroneously designated "planetary component" of noble gases found in meteorites (Geiss 1993), viz., 3He/4He = 1.5 +/- 0.3 x 10e-4. This is the value of the helium isotopes at the time the solar system was formed. Inside the sun, the original deuterium was quickly consumed to make 3He, which now adds to the primordial 3He in the solar wind. Thus one can in principle derive the original value of D/H in solar system hydrogen from the following simple equation:

D/H = 4He/H {[3He/4He]sw - [3He/4He]p}

where p refers to the primordial value, i.e. the value that was in the helium in the original cloud that formed the solar system, and sw refers to the ratio now found in the solar wind. Using the solar wind value of 3He/4He = (4.4 +/- O.4) x 10 e-4 and 4He/H = 0.1, we find D/H = 2.7 x 10 e-4, in excellent agreement with the value of D/H determined directly in Jupiter's hydrogen (Mahaffy et al. 1998).

With this fundamental context established, we can move on to the determination of local meteorological conditions at the probe entry site. The great depletion of H2O and H2S along the entry trajectory has been demonstrated to result from the action of a local downdraft (Owen 1996, Atreya 1996). The essential clue to this interpretation was provided by the behavior of H2S. There is no sink for H2S in the atmosphere except the formation of NH4SH clouds. Yet neither H2S nor the expected clouds were found in the upper part of the trajectory. In the 10 bar region, however, H2S was detected and its abundance was observed to increase with depth. In the last segment of the trajectory, at pressures approaching 20 bars, the H2S abundance reached a plateau corresponding to an enrichment of sulfur on Jupiter by a factor of ~3 x the solar value. This behavior is exactly what one would expect for a massive downdraft of cold, "dry" air that ultimately mixes with the surrounding atmosphere. Knowing the conditions of observation, it is possible to proceed to a proper interpretation of the results.

Using data from the end of the trajectory, it is apparent that both sulfur and carbon are enriched in the Jovian atmosphere by approximately the same amount: ~3 x solar. I.e., C/S =

solar, but both C/H and S/H are 3 x solar. This fact alone strongly implicates icy planetesimals as the vehicle for heavy element enrichment on Jupiter, by some combination of outgassing from the core and dissolution of infalling planetesimals. Even carbonaceous chondrites, the most carbon-rich meteorites we know, have C/S = 0.1 solar. Only comets exhibit a solar ratio of these elements (Owen et al. 1997).

At the same time, we can rule out the clathrate hydrates as the specific structures in the ice that would carry these volatiles. This can be done on the basis of the noble gas abundances. Although these abundances are not yet fully analyzed, we can already say that Xe/Ar < 5x solar, and this limit is sufficient to show that these gases are not carried by clathrate hydrates. Lunine and Stevenson (1985) investigated clathrate formation in detail and showed that the ratio Xe/Ar in Jupiter's atmosphere must be a strong function of the enrichment of carbon, as CO and/or CH4 will compete for space in the clathrate cages. With C/H established as ~3 x solar on Jupiter, we can use the Lunine and Stevenson analysis to predict Xe/Ar > 9 x solar, regardless of whether CO or CH4 is dominant. It therefore appears that trapping in amorphous ice as suggested by Owen and Bar-Nun (1995) is the primary mechanism for volatile sequestration in the ice.

There remains the problem of nitrogen. This element should have been predominantly in the form N2 in the solar nebula. Therefore, we don't expect it to be trapped in ice that formed at the temperatures that prevailed at Jupiter's distance from the sun, an expectation that is borne out by the depletion of N in comets (Owen and Bar-Nun 1995). The GPMS could not measure NH3 or N2, but NH3 was found to exhibit the same behavior as H2S by Folkner and Woo (1997), who analyzed the probe carrier signal. If this analysis is correct, it means that N is also enriched by a factor of about 3, and something other than local planetesimals must have brought it to Jupiter. The icy planetesimals that formed the planet's core and later dissolved in its atmosphere must have been dominated by objects that formed at temperatures of ~35 K or less, e.g., Kuiper belt comets or icy grains coming directly from the interstellar cloud from which the solar system formed (Niemann et al. 1998).

The next year's research will allow us to test this possibility by determining the nobel gas abundances more precisely. The same low temperature ice that is required to bring in the N2 would also carry Ar, Kr, and Xe in solar proportions relative to N (Owen and Bar-Nun 1995). We will also pursue the isotope ratios of Xe and Kr, to see if we can distinguish between solar and terrestrial patterns. The third major effort will be a systematic search for trace constituents in Jupiter's atmosphere.

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