

N87-17637

NON-SOLAR NOBLE GAS ABUNDANCES IN THE ATMOSPHERE OF JUPITER

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The presentation by Lunine and Stevenson is largely contained in a paper appearing in the *Astrophysical Journal Supplement* (1985; 58, 493-531). The abstract of the conference presentation along with the discussion following that presentation is reproduced here.

We assess the possibility that the ratios of noble gases in the atmosphere of Jupiter, which will be measured by the Galileo Probe, could test the hypothesis of massive early bombardment of the planet by outer solar system planetesimals. It has been suggested (Stevenson, 1982, Lunar Planet. Sci. Conf. Abstract XIII, p. 770) that the two-fold enhancement of carbon relative to solar in the atmosphere of Jupiter (Gautier et al., 1982, *Astrophys. J.* 257, 901-912) might be due to the accretion of several Earth masses of cometary material on the planet. This material could contain carbon as CH_4 or CO ices or as these gases enclathrated in water ice. Temperatures and pressures in the environment of the accreting Jupiter (Lewis, 1974, *Science* 186, 440-443) were probably not conducive to the formation of methane clathrate or solid methane; hence the initial supply of methane in the Jovian envelope would have been gaseous and presumably solar in abundance. Doubling the gaseous methane abundance implies dredging >2 Earth masses of CH_4 from the core, an unreasonable quantity if the core material did not originally contain CO or CH_4 clathrate. Alternatively, if the enhanced carbon were derived from clathrate-bearing planetesimal debris, the noble gas signatures would be distinctive, with the ratios of xenon/argon and krypton/argon enhanced, and neon/argon depleted, relative to solar values. Moreover, with the possible exception of Ne/Ar, these ratios will not be altered by chemical partitioning at high pressures in the planet (Stevenson, 1985, Lunar Planet. Sci. Conf. Abstract XVI). The noble gas abundance ratios as a function of total carbon enhancement in the Jovian atmosphere are presented based on the above model. Application is also made to the other giant planets which may have incorporated clathrate in their cores. Challenges to the model, such as the recently determined depletion of water in the atmosphere of Jupiter (Bjoraker, 1985, this conference), are also discussed. Measurements of noble gas abundance by the Galileo Probe may provide a test of this hypothesis against others which do not involve clathrate as the source of carbon.

DR. LANE: I had a question, Jon. Do you have some feeling for the altitude distribution in the half bar to three-or-four bar region for this enhancement?

DR. LUNINE: Well, as long as one is looking at the convective region, which is the region that you are talking about, one would expect the noble gases to be well-mixed, as would all gases that are not going to be condensed. In fact, noble gases should be uniformly distributed through the deep interior of Jupiter with the possible exception of neon. Some work done recently by Stevenson suggests that in fact neon may precipitate out in the deep interior. As far as these other gases go, the mixing ratios are sufficiently small that they are carried along in the well-mixed convective zone, so the mixing ratio should be uniform.

DR. POLLACK: I'd like to take issue with you, Jonathan. One of the basic points you made was that in the place where Jupiter formed, one would not expect carbon present in the condensed phase except as a clathrate. This is fine up until a certain point, but we know that there are meteorites which are very rich in carbon, and there is a strong suspicion that many of the asteroids in the outer asteroid belt are very rich in carbon. There is some evidence that the irregular satellites of Jupiter, which presumably were captured in its early history, are also very rich in carbon. All those things would raise some questions about the assumption you made.

DR. LUNINE: I agree that carbon may be present in a meteoritic component that could be incorporated in the core of Jupiter. However, the enhancement of carbon that one sees in the atmosphere, if it extends throughout the interior, is quite substantial and is in fact 10 percent or more of the total mass of the core. One would therefore have to contemplate dredging up, or introducing in some way into the atmosphere, an amount of carbon that is essentially equal to, or perhaps a fifth of the abundance of the rock. That's a lot of carbon, even for meteorites. But I agree in principle that that is one possible source.

DR. POLLACK: Two points are relevant. One, carbonaceous chondrites have carbon abundances that go anywhere from 1 to 20 percent, so in that sense you're not in an implausible range. Secondly, and perhaps more importantly, if you think in terms of plausible models of how the outer planets formed, namely, the core forms first and then captures the gas, core material comes in as a gas envelope builds up. It's hard to imagine an immaculate process which is going to produce a core first in its entirety, and then suddenly obtain all its gas.

DR. LUNINE: I agree that it won't be immaculate. Noble gases may be enhanced in that case as well. The other thing to think about is whether one gets a very strong D to H enhancement coming in as well in this regards.

DR. ROSSOW: We have time for two more questions.

DR. PODOLAK: I just want to add one more point to what Jim Pollack said. That is that experiments have been done by Bar-Nun in which he has deposited water ice at low temperatures and then allowed methane or CO or N₂ or any

other kind of gas you like to flow around it. He has also deposited them simultaneously. The results are that as long as the water ice is deposited at temperatures below 100 K, you can get large abundances of CO, N₂ or anything you like. It's not a clathrate.

DR. LUNINE: Right, it's adsorbed.

DR. PODOLAK: It's not adsorbed...well, there are several things that go on. If you deposit it at 15 K or 30 K and let it heat up slowly, you'll find that at 30 K you get a big burst of N₂ coming off. That's the adsorbed stuff. When you go to 140 K you get another burst, and that seems to be because the water is going from amorphous to crystalline and releasing some of the stuff that's occluded. Then when you let the water get to about 160 K, it starts sublimating and you then get another release. So there is a substantial amount of volatile gas that could be kept in the water, and you can put it in even at 100 K. So it could be that when you're building up stuff from material in Jupiter's zone--certainly in Saturn's zone, you can have a lot of volatile gases there.

DR. LUNINE: Yes, you also have to remember though that the ratio of carbon to the bulk species has to be on the order of 10-20 percent, otherwise you have to put an amount of water and rock in that is a ridiculously large mass.

DR. PODOLAK: That's no problem.

DR. LUNINE: That's satisfied for clathrate. It may be satisfied as well for certain adsorption processes which have a large adsorbing surface area. It's also satisfied for carbonaceous chondrites, as Jim Pollack correctly pointed out. But it does have to be a fairly large abundance of carbon. They have to be, in some sense dominated by carbon.

DR. PODOLAK: It is. It varies with conditions, but it can be much more than you get for clathrates, so that's not a problem at all. You can get 20 percent easily.

DR. HUBBARD: The other possible test of this model would be to compare the abundance of methane in the atmospheres of Jupiter and Saturn. The Jupiter hydrogen envelope is about 4 or 5 times as massive as the hydrogen envelope of Saturn. If one could predict the flux rate of these carbon-bearing planetesimals into both bodies, one could then compute the dilution factor. It seems to me that that's something that could be modeled and maybe should be checked.

DR. LUNINE: Well, the other thing is that when one gets out to Saturn and actually more so for Uranus, the core size is more comparable to the envelope size, and dredging may therefore be a more important process. Also, one may get clathrate formation in the ice out at that distance. So the carbon could be very much enriched in the core, and then whether it actually comes out or not depends on how efficient one regards the dredging process to be.