THIRD ARIZONA CONFERENCE ON PLANETARY ATMOSPHERES

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The Outer Planets: Some Early History

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Many ideas fundamental to understanding the nature of planets are so readily grasped in terms of every-day experience in the terrestrial environment that they appear quite early in the patristic literature of science. An example is the *Cosmotheoros* of Huygens (1698), who could speak with authority of the planets, since he had unravelled the mystery of Saturn's rings and discovered its brightest satellite. The *Cosmotheoros* contains both quaint speculation about the inhabitants of planets and sound reasoning in regard to the physical conditions on these bodies. Some passages from a contemporary English translation make a fitting introduction to the theme of this conference.

> . . . "And, First, 'tis more than probable that the Bodies of the planets are solid like that of our Earth, and that they don't want what we call Gravity, that Virtue, which like a Loadstone attracts whatsoever is near to the Body to its Center. And that they have such a Quality, their very Figure is a proof; for their Roundness proceeds from an equal pressure of all their Parts to the same Center" . . .

Huygens goes on to discuss at length the presumable differences in the bodily organization of the terrestrial animals and the planetary populations, and notes that the discovery of the American continent has failed to enrich the naturalists' collections with any species of excessively weird shape. Speaking of organisms he says:

> . . . "'Tis more than probable that all the difference there is between us and them, springs from the greater or less distance and influence from that Fountain of Heat and Life the Sun; which will cause a difference not so much in their Form and Shape, as in their Matter and Contexture.
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> "And as for the Matter whereof the Planets and Animals there consist, tho' it is impossible ever to come to the knowledge of its Nature, yet this we may venture to assert (there being scarce any doubt of it) that their Growth and Nourishment proceeds from some liquid principle . . .
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> "But since 'tis certain that the Earth and Jupiter have their Water and Clouds, there is no reason why the other Planets should be without them. I can't say that they are exactly of the same nature with our Water; but that they should be liquid their use requires, as their beauty does that they should be clear. For this Water of ours, in Jupiter and Saturn, would be frozen up instantly by reason of the vast distance of the Sun. Every Planet therefore must have its Waters of such a temper, as to be proportion'd to its heat: Jupiter's and Saturn's must be of such a nature as not to be liable to Frost; and Venus's and Mercury's of such a nature, as not to be to easily evaporated by the Sun. But in all of them, for a continual supply of Moisture whatever Water is drawn up by the Heat of the Sun into Vapors, must necessarily return back again thither.
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> . . . "The Air I confess may be much thicker and heavier than ours, and so, without disadvantage to its Transparency, be fitter for volatile Animals. There may be too many sorts of Fluids ranged over one another in rows as it were. The Sea perhaps may have

such a fluid lying on it, which tho' ten times lighter than Water, may be a hundred times heavier than Air; whose utmost Extent may not be so large as to cover the higher places of their Earth" . . .

More interesting than the teleological musing about well-tempered waters are, perhaps, the final suggestions just quoted. They foreshadow the realization that a subadiabatic atmosphere at supercritical temperatures might solidify under its own weight, and the surmise on thermodynamic grounds that in the deep atmospheres of the Jovian planets immiscibility of fluid phases could profoundly affect the dynamical regime. The subject of fluid-fluid equilibria has not been assimilated into textbooks of chemical physics and engineering, and even standard works on high-pressure phenomena give it no more than brief mention. Therefore, I am pleased that an expert, Col. Street, has consented to reviewing before this conference problems of phase equilibria that are potentially relevant to studies of the major planets. Incidentally, Lavoisier, the father of quantitative chemistry, had already remarked that if the earth were removed to very cold regions of space, such as those of Jupiter and Saturn, its atmosphere, or at least a portion its of aeriform constituents, would revert to the state of liquid (*Oeuvres*, II, 805).

A record of the state of physical astronomy just before the dawn of astrophysics has been left to us by Alexander von Humboldt, whose prime concerns were the stark facts of nature, the residue of scientific scrutiny that has defied subsumption under general laws. Humboldt insisted on the disparity between the terrestrial and major planets, especially the wide difference in mean density. Stressing the parallel difference in concentration of mass toward the center, as revealed by the respective oblateness of figure, he hinted at the undeniable, if obscure, cosmochemical meaning of this dichotomy. It would appear that Humboldt regarded these reflections as original. For he refrained from ascribing them to some predecessor, although the voluminous historical notes appended to the *Cosmos* meticulously document the evolution of ideas culminating in his conception of the physical universe. I am not aware of any references to Humbolt's views in subsequent historical accounts. According to his testimony, astronomers at that time pictured Jupiter and Saturn as having solid surfaces under broken cloud layers. It may well have been the increasing atmospheric activity since the middle of the last century, and a growing awareness of energetic constraints, which led to the long controversy as to whether or not these planets are miniature suns. As late as 1934, Sir Harold Jeffreys informed me in a letter as follows: "Some astronomers here are still disinclined to believe that Jupiter and Saturn are not red-hot."

The opposition of Jeffreys (1923, 1924) to the traditional view, i.e., that these planets are very hot even near the surface, derived from his conviction that radiative loss of heat during 10^9 years, or more, must have sufficed for solidification on any reasonable hypothesis concerning their original temperatures, so that heat would only slowly be conducted out. His conclusion that the surfaces are probably at nearly the temperatures maintained by insolation was confirmed immediately by the temperatures Menzel (1923) extracted from the radiometric measurements of Coblentz and Lampland. A refined analysis of the marked concentration of mass toward the centers of Jupiter and Saturn enabled Jeffreys to fix upper limits to the surface densities, namely 0.90 and 0.31 gm cm^{-3}, respectively. The actual densities throughout substantial fractions of the volume must be less than these assigned limits and can be matched only by those of the lightest liquids and solids. Apparently, Jeffreys hesitated to take this fact at its face value, though he mentions hydrogen, helium, methane and ammonia as presumptive constituents. Independently, Fessenkoff (1924) advanced similar, though less articulate, considerations. Jeffreys' tentative model for the giant planets was a conservative one; namely, a rocky core surrounded by a layer of ice under cover of a gaseous envelope of inappreciable density. With the densities of the core and the two (spherical) shells prescribed, the radius of the core and the depth of the gaseous envelope are the unknowns to be determined from the astronomical values of mean density and moment of inertia of the configuration. Characteristically, this procedure was a replica of the method by which the geophysicist Wiechert (1897) for the first time had computed the average density and the radius of the earth's core from the mass and moment of inertia of the earth as a whole and an estimated density of the mantle. The depth of the atmospheres on Jeffreys' model turned out to be 8% of the radius of Jupiter and 23% of that of Saturn, a result hardly consistent with the supposition of an inappreciable contribution to the total mass. In a review of the chemical differentiation inside the earth, Tammann (1931) made passing reference to the constitution of the Jovian planets. Their low mean densities were taken as proof of the existence of extremely deep atmospheres, to which Tamman, more realistically, ascribed a hypothetical density of 0.5 gm cm^{-3}. Moreover, the low mean densities of some of Jupiter's satellites suggested to Tammann that they might consist primarily of liquefied gases. There is no evidence that Tammann was familiar with the earlier comments by Jeffreys (1923) to the same effect. All in all, Jeffreys papers were a landmark. In a final commentary (Jeffreys, 1938) he urged study of the internal heat transfer. No definitive results have been obtained even now, because physical theory does not supply reliable predictions of the conductivity. Of these problems I shall have something to say later during the conference.

To sum up, Jeffreys' work brought to a close the era of speculation without proper attention to the relevant doctrines of geophysics and geochemistry. On the astronomical side, the paucity of precise observational data is strikingly illustrated by the total of 15 pages which the 1929 edition of the *Handbuch der Astrophysik* alloted to physical characteristics of the major planets, and a small fraction of this space sufficed to cover spectroscopic and photometric data. In 1937 the distinguished Director of the Poulkovo Observatory stated emphatically: "Planetary astrophysics offers a very wide and a still unexplored field both for observational and theoretical work. In fact, except for some fragmentary information afforded by recent spectroscopic and radiometric investigations as well as by purely qualitative visual observations of planetary surfaces, we know practically nothing about physical properties of planets" (Gerasimovic, 1937). Gerasimovic deplored that no attempt had been made to apply well-ripened methods of theoretical astrophysics to the world of planets, derived an approximate solution for the limb darkening of Jupiter and Saturn from transfer theory (with a two-parameter scattering diagram), and tried to interpret observations by Barabascheff and Semejkin. His was a pioneering effort worth recalling.

Enough has been said to contrast the dormant stage of planetary physics with its period of early flowering well within the memory of the older members of this conference. Approaching maturity, the study of planetary physics has taken firm roots in the soil of Arizona, both at the Lunar and Planetary Laboratory of the University and at the Kitt Peak National Observatory.

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[1] In English, with a Russian abstract. The journal is now called *Astronomicheskiĭ Zhurnal*, but was then called *Russkiĭ Astronomicheskiĭ Zhurnal*.

[2] No. 127, i.e., Vol. XV, No 4., pp. 1–32, are in English; pp. 33–35 are the Russian abstract. The publication is called *Izvestiia Glavnoĭ Astronomicheskoĭ Observatorii v Pulkove* or *Bulletin de l'Observatoire Central à Poulkovo* (both languages printed on cover).

[3] The beginning *page* numer is 221; there are *no* volume numbers given for these, only the years. Full title is *Nachrichten von der Königl. Gesellschaft der Wissenschaften zu Göttingen, Mathematisch-physikalisch Klasse.* There is another part of the same journal, with parallel page numbering, dealing with historical matters.