NO. 183 DISCOURSE

Following Award of Kepler Gold Medal at A.A.A.S. Meeting,

Franklin Institute, Philadelphia

by Gerard P. Kuiper

December 28, 1971

Kepler's work caused a revolution in thought and science. It marked the transition in Planetary Astronomy from concepts held for 15 centuries,to the Newtonian and Laplacian period of universal law and order. Kepler's was the period of great discoveries of regularities, partial solutions, break-throughs, and of hopes of still greater things to come. He recognized the immense implications of his work and upon discovery of his third law, full of emotion, thanked God for having given him insights that had been withheld from humanity for 6,000 years.

Our modern times resemble more those of Kepler than those of Newton and Laplace. It is true that Einstein was a modern Newton; but most of the current work in scientific exploration deals with advances and new insights in one of the dozens of sub-disciplines in which Science has divided. Victor Starr has eloquently shown that Meteorology is in the Kepler era. Much the same can be said for Planetary Physics. It is a time full of excitement and often very hard work, in part directed by large and competent teams comprising numerous specialists and supported by major government programs. No doubt Kepler would be bewildered could he attend a planning session defining the mission profile for exploring life on Mars, the planet he loved so much; but he would be pleased to find that the spacecraft would (during the cruising modes) obey his laws of planetary motion.

This is a period of transition, turmoil, and frequent reassessment of priorities, in Science as in Society. Dr. Fred Singer suggested to me that I might review some of the more *continuing* trends in planetary research. Since it has been my privilege to work on the planets both in a university setting (Chicago, Texas) for one or two decades and during the Space Age, such comments may have a broader interest.

Astronomy before the Space Age had already gone through a period of rapid growth. The development of powerful telescopes on selected mountain sites around the turn of the century, plus the dramatic growth of Physics - atomic, molecular, nuclear - soon thereafter, combined to completely reset the priorities in Astronomy. Astrophysics absorbed all available manpower and research interests in most universities. Planetary research drew little attention, with the exception of traditional positional work at the Naval Observatories and studies in Celestial Mechanics which became more powerful and exciting after large computers were developed. The observation of the physical phenomena on the planets was mostly left to amateur astronomers in Britain, France, and elsewhere.

One might therefore wonder how a double-star astronomer, also involved with discoveries of white-dwarf stars, was deflected to planetary studies. The actual sequence was different. At the beginning of my career I was asked to review a book on the origin of the Solar System. The analytical part of this book impressed me greatly. The second, synthetic, part was entirely disappointing. After the review was written, I continued for many months to struggle with this problem and had to conclude that the state of Astronomy did not permit its solution. I was nevertheless fascinated by it, and had become aware of at least part of the extensive and difficult literature written in search for solutions. I then determined to find a closely-related problem, that with finite effort would probably lend itself to a solution. This, I thought, was the problem of the origin of double stars.

Some years later I felt that I had come to understand the problem of double-star origin, at least in outline; that it was identical to the general process of star formation, from slightly-turbulent prestellar clouds upon contraction, with conservation of angular momentum. It followed that the Solar System was no more than an "unsuccessful" double star with the companion mass spread out radially into a disk that in time developed the planets. The contraction process of a set of randomly-selected clouds would normally lead to a certain distribution function of semi-major axes for the new-born double stars - which appeared consistent with observation. The *mass partition* between the two components would be by random mass fractions of the total, a result I had derived empirically from a statistical study of double-star mass ratios. Thus, planetary systems clearly had to originate as the low-mass extremity of the almost universal process of double-star formation. Indeed, the median separation in double stars was just of the dimension of the system of the massive Jovian planets, around 10 A.U. A basis had thus been found for estimating the *frequency* of planetary systems in our galaxy.

Before this result was obtained it had been assumed by Chamberlin and Moulton, and later by Jeans and Jeffreys, that planetary systems must be extremely rare (about 1 in 10^{12} stars), being the result of stellar collisions. Thus Chamberlin, in his THE TWO SOLAR FAMILIES (1928), could write that the Earth was of "noble birth". I concluded that the frequency was at least 1 in 10^3 (the mass fraction of the planets). I announced this result on 4 September 1949 at a regular Sunday broadcast of the University of Chicago Roundtable. I still remember the skepticism of my astronomical colleagues; so strong was astronomical tradition. A year or two later I estimated the fraction to be at least 1 in 100 (the mass fraction of protoplanets).

Another item of personal history was my participation during World War II in the ALSOS Mission, the Overseas Branch of the Manhattan District. I learned about the great advances, made by both sides, in infrared detection and instrumentation. Upon returning to the University of Chicago I determined to use the lead-sulfide cell in a stellar spectrometer on the 82-inch telescope. This in 1947 led to the discovery of CO_2 on Mars, H_2O ice on the Rings of Saturn, following the earlier result of Titan as a satellite with a very substantial atmosphere. These and other reasons led me to the organization of a Conference on the Earth and Planets in 1947, at the 50th Anniversary of the Yerkes Observatory of the University of Chicago (such conferences became more frequent after 1957). The results were published in THE ATMOSPHERES OF THE EARTH AND PLANETS, the Second Revised Edition of which appeared in 1952. This was followed by two much larger editorial projects, the 4-Volume SOLAR SYSTEM series and the 9-Volume STARS AND STELLAR SYSTEM series, both published at the University of Chicago Press.

A third early item refers to the *small planets* in the Solar System, incidentally the source of the meteorites. In spite of enormous efforts, observational and computational, astronomers had no *statistics* that could assist in building further our concepts on the origin of the Solar System. In 1949 I started a 7-year program (the Yerkes-McDonald asteroid survey) providing reliable statistics down to magnitude 16.5; and in 1960 organized a second survey with the 48-inch Palomar Schmidt to extend this to 20.5 magnitude. In addition, a concentrated program of asteroid *light curves* was started, also in 1949, after 1960 continued by Dr. Gehrels. These light curves provided the first information on the periods of rotation of the asteroids, the orientation of their axes, and the approximate shapes of these bodies. Curiously, nearly all of them show to have marked deviations from sphericity, attributed in part to the collisional history that also produced the known meteorites. These three large asteroid programs have provided a much-needed basis for the understanding of the role of these hundreds of thousands of bodies in the larger framework. My associates, the van Houtens, have graciously taken the initiative with the I.A.U. for naming Asteroid 1776 in recognition of these efforts.

A very exciting era began with the organization of the National Aeronautics and Space Administration in 1958. Participation in the NASA programs became a dream to which any planetary astronomer would aspire. I had the privilege of being Principal Investigator on NASA's Ranger Program, 1960-1966, which led to the first close-range investigation of the moon, many surface studies, and the recognition of the NASA Space Program by naming the mare on which Ranger VII impacted, Mare Cognitum. This I proposed at the 1964 Hamburg meeting of the I.A.U. The 5-Volume Atlas of Ranger Photographs, comprising 1000 prints, 11" x 14", was produced under the personal direction of Mr. Ewen Whitaker and myself, in Tucson. Earlier our Lunar and Planetary Laboratory, started in 1960, had produced through a major Catalogue of 4500 coordinated base points and the ORTHOGRAPHIC ATLAS OF THE MOON, using the best available photography, the lunar coordinate system that is still in use on all lunar charts.

The Surveyor, Orbiter, and Apollo programs followed and supplied a storehouse of data about our satellite - and indirectly the Earth - that will take much more time to fully assess. It was naturally a personal satisfaction that our ideas developed through telescopic observation in the 1950's were in broad outline confirmed. I refer here to the nature of the maria, the craters, faults, graben, wrinkle ridges, etc.

Reference must be made to the parallel and in a sense competitive program developed in the U.S.S.R. The origins of the Russian program stemmed from the personal actions and inspirations of two great men, Tsiolkovsky in the 1890's, and Korolev beginning 1930 (not 1957!). The Great Designer, as Korolev was referred to anonymously till his death in January 1966, had unforeseen effects on world history and on the competition between two great nations. It is pleasant to contemplate that individual intellects can on occasion be so influential.

The modern developments in the Planetary Sciences have often paralleled those in Geophysics. Yet the astronomical setting remains. With the one exception - the recent lunar surface exploration and the collection of lunar samples - all studies of the planets from spacecraft have been made by astronomical methods, through imagery, spectroscopy, photometry, polarimetry, radio astronomy, and celestial mechanics. It is true that fly-bys make these methods much more effective, but the techniques of remote investigation remain.

I would like to conclude with a reference to some recent work on the planet Jupiter. It will illustrate the close interdependence of the Planetary Sciences and Geophysics, appropriate at this meeting of the A.A.A.S. At LPL we have made an effort to photograph Jupiter in color as well as through filters, into the infrared. Slide 1, taken in the heavy methane absorption band at λ8900Å, shows that, especially in 1970 and 1971, the North and South Tropical Zones, at 22° latitude N and S, are high in the atmosphere, with the famous Red Spot even higher. The identification is based on Slide 2, also showing the planet in red light. The Red Spot shows *anticyclonic rotation* and therefore flows outward on the top. Its visibility varies, with maximum visibility associated with the longest period of rotation around the planet's axis. Clearly, the Red Spot contains a *source of energy*, which must be the latent heat of condensation (H_2O, NH_3, + H_2S). A close study of the Red Spot, being published elsewhere, shows it to be a large cirrus anvil or shield over a 3,000 km diameter cumulus-type storm array, not unlike the Regions of Organized Cumulus Convection in the Earth's Tropical Convergence (Slides 3, 4). Typical terrestrial anvils of single cumulus towers are shown in Slide 5. The motion of the terrestrial "cloud clusters" or, better, "Regions of Organized Convection" within the Tropical Convergence are illustrated in Slide 6. The model of the Red Spot emerging is shown in Slide 7, both in plan view and vertical section. The detailed paper shows that the theory of Ooyama (1969) for terrestrial tropical cyclones accounts in a general way for the dimensions of the Red Spot (Slides 8, 9). The White Ovals (Slides 9, 11) are the next largest organized and persistent storm areas on

Jupiter, smaller because of the higher latitude (33° vs. 22°) and the stronger Coriolis force. Slide 12 shows a blue spot *inside* the Red Spot. Pre-mission planning may be done on the basis of reprojected photographs such as Slide 13, with rotation periods found at the various latitudes on the planet shown on Slide 14, readily interpretable except for the 20°-wide Equatorial Zone.

This summary is, of course, merely a glimpse of what may be expected in the decade of the 1970's, from the various missions planned by NASA and, presumably, the U.S.S.R.; supported by a vigorous ground-based program to keep track of - and interpret - the everchanging planetary atmospheres and cloud systems.

(The concluding remarks of the Discourse and my expressions of appreciation for the A.A.A.S. honor were made extemporaneously, and were not recorded or part of the prepared manuscript herewith reproduced. The slides here referred to are all found in *LPL COMMUNICATION NO. 173*).

Erratum: On p. 214, Fig. 18, No. 5 (Jupiter, blue) the UT is 07:00:43.

TABLE OF CONTENTS