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I – The Planets and the Satellite Titan

The planets as they currently present themselves to us are classified into two categories more or less following their distance from the Sun and their composition.

The more distant are the outer planets: Jupiter, Saturn, Uranus, Neptune and Pluto. They are situated further out from the region of the Solar System in which we find most of those small, solid bodies which we call asteroids. Due to their very large sizes, Jupiter, Saturn, Uranus and Neptune are called giant planets. These planets do not have a solid surface. Due to their considerable masses, these are the only planets in which the atmosphere has changed little since the formation of the Solar System. We know that at least two of these planets are surrounded by a region of intense magnetic fields. The giant planets possess many satellites. Amongst these, Titan is the largest and possibly the only one to possess an important atmosphere. Pluto is considered apart from them because it appears to have more features in common with a satellite of an outer planet than with another of those planets.

On the other side of the asteroid belt and on both sides of Earth, we find the terrestrial planets. They are so called because their sizes and natures are comparable to that of Earth. They are Mercury, Venus and Mars. These are rocky planets that have probably lost their primitive atmosphere; the present atmosphere of these planets will be of secondary origin, essentially produced by degassing.

Planetary research that has been done at the Paris Observatory is composed of, firstly, theoretical studies of the formation of the planets and, secondly, studies of the planets themselves. In the second part, the main focus of research is on the composition and vertical structure of the atmospheres of the giant planets and Titan and on the magnetic environment of the giant planets. The only work on the terrestrial planets Mercury, Venus and Mars are studies of their surfaces and their atmospheric hazes or clouds by polarimetric measurements. Researchs on the terrestrial magnetic environment and interplanetary space are also conducted at the Observatory by several teams but, as indicated in the introduction, this theme is not tackled in the present report.

IA – The Formation of the Solar System

It is now readily conceded that the planets were formed from collisions between planetesimals of an initial size on the order of a km. The first phase of the formation of the planets appears, for the moment, well understood: from the end of the contraction of the protosun, the gas of the primordial nebula cooled and grains of a few cm in diameter formed; local instabilities then caused the agglomeration of grains into planetesimals. By contrast, a physical theory that explains the transition from planetesimals to planets in their actual size finds difficulties that are currently unresolved. The models developed until now lead to the formation of many small planets of a size comparable to or smaller than that of the Moon and not to the formation of nine “large planets”. A. Brahic is interested in the problem of the agglomeration of plantesimals into the planets and has in particular studied these past years the simultaneous role of collisions and of near-misses (changes in orbits of two bodies that pass near each other) in the accretion of the planets.

IB – The Atmospheres of the Giant Planets

This theme of research is, for many years, the domain of research granted to two groups of the Paris Observatory: that of D. Gautier and that of M. Combes.

The giant planets were formed far from the Sun, in a cold and rarefied environment, they are less dense and of much larger size, from 20 to 100 times the volume of Earth. They do not have solid surfaces. They are primarily composed of hydrogen and a lesser proportion of helium. Three of these planets radiate more energy than they receive from the Sun.

The giant planets having evolved little since their formation, their study presents an especial interest in that observations which they allow to be made are indications on the composition of the protosolar nebula at the time of formation of the Solar System, that is 4.5 billion years ago. One such study contributes to a much more general astrophysical programme which is the study of the chemical evolution of the galaxy. The comparison between various planets and by extension the Sun supplies, in addition, constraints on the true evolution of the planets. The study of the atmospheres of the giant planets also permits knowledge of other characteristics of those planets: clouds, photochemical processes, meteorology, the importance of convection, thermal structure …

Not one probe has penetrated into the atmosphere of a giant planet, the only knowledge that we now have comes from remote sensing. Due to the fact that these atmospheres are very dense, only their upper part is accessible to direct analysis by this type of measurement.

As the interiors and atmospheres of these planets are composed of the same original material, that is to say of hydrogen and helium, although in different physical states (gaseous in the atmospheres, liquid or metallic in the interiors) the study of the composition of the atmospheres allows access to the bulk composition of these planets.

The principal methods used by the two groups of the Observatory that primarily study the atmospheres of the giant planets are, firstly, remote spectroscopy (from Earth or from a spacecraft) that allows the determination of the vertical structure and the composition of the planetary tropospheres and stratospheres, and at the same time obtains information on a certain number of physical and chemical processes and, secondly, observations of occultations of stars by the planets. This second method permits measurements of the temperature profile to very high altitudes and, in certain cases, the mean molecular weight of the atmosphere. A third group, that of A. Dollfus, uses remote polarimetry measurements to obtain information on the atmospheric hazes.

The work carried out by these teams has to date used measurements made using ground-based telescopes, French and foreign, using satellites (the International Ultraviolet Explorer satellite), using the American Voyager spacecraft (D. Gautier is co-investigator on the infrared interferometer experiment IRIS – Infrared Radiometer Interferometer and Spectrometer). The data so far received cover all the electromagnetic spectrum from the ultraviolet to the radio range with the exception of the sub-mm range, as yet very little explored. The greatest importance is given to the studies in the infrared range in the region where the planets, being cold stars, emit above all in this wavelength range. A large part of the work now accomplished by the groups of M. Combes and D. Gautier concern the preparation and utilisation of new ground-based infrared radiometers, of instruments for the Franco-Germano-Spanish Institute of mm-wave Radioastronomy (IRAM), of the European Infrared Space Observatory Satellite (ISO) satellite, of the American Galileo spacecraft (T. Encrenaz is co-investigator on the Near-Infrared

Mapping Spectrometer (NIMS) experiment) in the same way as the Voyager 2 spacecraft during its missions to Uranus and Neptune. It is necessary to emphasise that certain indispensable measurements for the study of giant planets by spectroscopy are made on site, at Meudon, with a laboratory Fourier Transform interferometer, which is a cooled box of multiple reflections (see thematic report “Physics and Astrophysics”) in which are placed the analysed gases. Close collaborations are formed by the groups concerned with other laboratories in France and abroad. In particular, as far as work on atmospheric modeling is concerned, close relationships have been established with the Laboratory for Dynamic Meteorology of the Ecole Polytechnique and the Laboratory for Atmospheric Optics of the University of Lille. The relationships with molecular spectroscopists are very numerous, whether in France or abroad (Universities of Paris XI, of Dijon, of Beancon, of Lille, of Marseille; Herzberg Institute in Ottawa, Canada; Kitt Peak Observatory, USA; National Bureau of Standards, USA …).

Thus, important results have been obtained by the groups of the Paris Observatory concerning the elemental and isotopic composition of the planets, the thermal structure of their atmospheres, the localisation, nature and opacity of the clouds, the photochemistry, the meteorology, the importance of convection, the presence and localisation of intense energetic sources – auroral phenomena – in the planetary stratospheres … These results supply extremely precious indications of a part of the origin and evolution of the Solar System and on the internal structure of the giant planets and, from elsewhere on the nature and the importance of the photochemical processes that are dominant in the atmospheres of these planets. Here we point out only some of these results.