Planetary Science and Astrobiology

The planets, satellites, and other small bodies in the solar system, and protoplanetary disks in other planetary systems, will be important objects for study with the LMT. Aspects of these investigations are critical for astrobiology, setting the conditions under which life arose on Earth and for seeking similar conditions in the forming planetary systems around other stars.

Small Bodies

The solar system was born from the collapse of a portion of a dense interstellar cloud, which resulted in the Sun at the center of a flattened disk of gas and dust known as the solar nebula, with the dust containing frozen gases (ices), rocky material, and organic matter. Small bodies, called planetesimals by astronomers, formed as the dust accreted, creating objects relatively close to the Sun that contained little ice (such as the asteroids) and objects in the outer solar system that contained more ice (comets and Kuiper Belt Objects). The planetesimals were, in turn, the building blocks of the planets. Since the early record of events on planets like the Earth has been destroyed by the heat and pressure of geological processes which do not operate on small bodies, planetary scientists look to asteroids and comets to provide clues to the physics and chemistry of planetary formation. Since comets clearly have a higher icy content than other small bodies (it is the sublimation of these ices which produces the characteristic atmosphere and tail), they have been less heated and hence should preserve a clearer record of conditions and processes at that early epoch. Moreover, comets and those asteroid fragments known as carbonaceous chondrites have brought vast quantities of organic matter to the Earth, particularly early in its history, and comets are thought to be a significant source of terrestrial water. Whether and/or how these contributions may have played a role in the origin of life are active subjects of current research.

Asteroids, Centaurs and Kuiper Belt Objects

Observations of the continuum thermal emission from asteroids and other small bodies allow us to sample the temperatures and hence thermophysical properties of the material on and below the surfaces of these objects. In addition to the Main Belt asteroids whose orbits are between those of Mars and Jupiter, these bodies include the Near Earth Objects (NEOs), whose orbits approach or cross that of Earth; the Trojan asteroids at the Lagrangian points of Jupiter's orbit; the Centaurs, icy planetesimals with orbits between those of Jupiter and Neptune; and the Kuiper Belt Objects (KBOs), the relic planetesimals lying beyond Neptune. The high sensitivity of the LMT for such observations, resulting from its large collecting area and sensitive instruments such as SPEED, AzTEC, and later generations of bolometers, will exceed that of competitive telescopes by a wide margin at least until the final completion of ALMA in about 2012. The LMT can thus undertake the first mm-wave survey of small solar system bodies. Such a survey can produce the flux, spectral energy distribution, and light curves for a statistically significant sample of Near Earth Objects, Main Belt Asteroids, Trojans, Centaurs, and Kuiper Belt Objects. This data will provide valuable compositional information for the different asteroid classes and types, since the dielectric properties of rocky, metallic, and icy surfaces will be manifested in the fluxes and spectra.

Planetary and Satellite Atmospheres

Many molecular species have been observed at mm/sub-mm wavelengths in the atmospheres of planets and satellites, including CO, H_2O, HO_2 HCN, CS, HC_3N, CH_3CH, NaCl, SO, SO_2, and various isotopic variants. Spectroscopic observations of planetary and satellite atmospheres provide information on the composition, temperature, and in some cases the winds in these atmospheres. Mm-wavelength spectroscopy is particularly sensitive to gas at low pressures, making it a good probe of the upper atmospheres. In fact, the shape of spectral lines in this wavelength range can be used to determine the vertical structure of the temperature and composition in such regions and hence to gain insight into the physical and chemical processes occurring there. Moreover, upper atmospheric composition can be profoundly affected by winds, so that compositional measurements give indirect information on atmospheric circulation. In fact, wind systems may be directly measured in some cases from the Doppler shift of mm-wavelength spectral lines, taking advantage of the extremely high spectral resolution of heterodyne receivers.

Extrasolar Planets and Protoplanetary Disks

Now that planets have been detected around other solar-type stars, studying the properties of analogs of the solar nebula becomes a realistic possibility. What are probably protoplanetary disks, with radii of hundreds of AU, appear to be a common feature of young stars. Investigating the physics and chemistry of such disks remains a challenging problem, because of their small angular size, but observations with, e.g., the IRAM 30 m telescope have revealed the presence of molecules such as HCN, HNC, H_2CO, CN, C_2H, CS and HCO^+, as well as CO, in disks around stars in Taurus[11]. From the excitation of the observed lines, the H_2 density in the disk may be estimated, and disk masses and the extent of molecular freeze-out onto grains determined. Although directly measuring gradients in disk properties will require the resolution and collecting area of ALMA, the LMT can provide the initial studies of many systems that will produce information on the diversity and evolution of disk properties in nearby star-forming regions. Such results are clearly of basic importance to astrobiology, since any extraterrestrial life similar to that on Earth will be found on Earth-like planets.

In addition, LMT observations with AzTEC can provide an extensive survey of dust emission from disks around young stellar objects. Comparing dust masses with stellar ages will constrain the timescales over which dust accretes to form planets.

Astrobiology

Among the goals of astrobiology are understanding the evolution of organic compounds during the cosmic processes leading to the origin of life on Earth and, potentially, on other Earth-like planets. Stars and planetary systems form by the collapse of dense interstellar cloud cores, with an intermediate stage involving disks of gas and dust around the young stars. Some stages in this evolution can be directly observed when stellar nurseries are imaged, but other stages remain cloaked behind veils of dust which can, however, be penetrated by observations at mm wavelengths. To understand the origin of life, we must first develop a comprehensive understanding of the formation of our own planetary system, including the processes that were important on the early Earth. To understand the probability of finding life elsewhere, we must understand both the similarities and differences between the evolution of our own system and that of a typical star.

As has been pointed out earlier, the LMT will play a crucial role in various aspects of astrobiology. At the largest scales, investigations of galaxy formation in the early universe are important to questions of the time scale for the formation and distribution of the heavy chemical elements that are necessary for life as we know it. The study of galaxies and star formation in the local universe bears on the issue of whether the conditions that led to the origin of life on a planet around a typical star in the Milky Way are likely to be duplicated in other galaxies. Investigating star formation in our own Milky Way will shed light on the question of whether the Sun and planets formed as an isolated system or within a cluster of stars which would have subjected the primitive Earth to a much more energetic (and presumably biologically hazardous) environment. The organic chemistry of the interstellar medium is clearly relevant to issues concerning the origin of complex molecules in objects like comets and carbonaceous chondrites, as well as to the possible distribution of carbon-based life in the Galaxy.

Closer to "home," the relevance of solar system research with the LMT to astrobiology has been repeatedly emphasized in the current chapter. Comets provide a link between the surprisingly complex organic chemistry of the interstellar medium and the corresponding chemical complexity of bodies forming in the primeval solar nebula; comets and fragments of asteroids, particularly carbonaceous chondrites, brought water and organic matter to the early Earth; the nature of planetary and satellite atmospheres are clearly fundamental to the issue of whether life has, or could ever, emerge on those bodies; and the distribution and properties of protoplanetary disks around other stars provide key data on the possibility of life elsewhere in our Galaxy.

Radar Astronomy

Radar astronomy, in which a powerful radio signal is broadcast toward a target and the echo from that target is detected and analyzed, provides perhaps the only "experimental" technique in astronomy, in the sense that the properties of the transmitted signal are chosen by the astronomer. Because the strength of both the transmitted radar signal and of the reflected echo decrease as the inverse square of the distance, the observed echo strength depends on the inverse fourth power of the distance to the target. This strong dependence on distance limits the objects that can be studied by radar astronomy to those within the solar system. Moreover, "soft" targets such as the Sun and the giant planets reflect radar signals very weakly or hardly at all, and so are likewise not useful targets for study by this technique.

However, the terrestrial planets, planetary satellites, asteroids, and comets have all proved to be fruitful objects for study by radar astronomy. The radar echo contains information on the roughness of the surface (on scales of the same order as the radar wavelength) and on its electrical properties (e.g., the character of the echoes from the polar regions of Mercury and the Moon suggests that ice may be present, presumably in permanently shadowed craters). Because the echo may be analyzed in exquisite detail as a function of both frequency and travel time, the surface properties may be mapped at a resolution vastly higher than would be expected from the angular resolution of the radar telescope. In addition, because radar waves sample the surface at greater depths as longer wavelengths are used, the characteristics of the surface can in principle be studied as a function of depth. Because of the lack heretofore of high-powered transmitters at mm wavelengths, this part of the spectrum has not yet been used for planetary radar astronomy.

However, such transmitters for mm wavelengths are now becoming available. With such equipment, the LMT would open a new era in radar astronomy. It would be capable of probing the topmost part of the surfaces of terrestrial planets, satellites, and small bodies in the solar system. In addition, radar measurements of Near Earth Objects would provide distance and velocity data vastly more accurate than that available from optical images, a critical consideration for the protection of Earth from potentially impacting asteroids and comets. Although the LMT will not initially be instrumented for radar astronomy, such equipment will be obtained in the future. One possibility is to use the LMT as a radar transmitter with the radar echo being observed using ALMA, providing additional collecting area, angular resolution, and transmitting time (since the LMT would not need to cease transmitting in order to monitor the echo).