

## STUDIES OF OUTER PLANET SATELLITES, MERCURY, AND URANUS

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### *Ring Geometry on Ganymede and Callisto*

Arguments have been made, based on geometry, for both an impact and an internal origin for the ancient, partially preserved furrow system of Ganymede. Zuber and Parmentier (1984) concluded that furrows were not concentric, but could be impact related if multiringed structures on icy satellites are initially noncircular. We examine the geometry of the Valhalla ring structure on Callisto in order to assess the circularity of an unmodified ring system. Despite prominent local meandering, the only gross deviations from concentricity in the Valhalla system are found in the outer north-east quadrant of the system. Here, a number of ring segments intersect small circles about the center at angles up to  $30^\circ$ . The Ganymede furrow system was remapped to make use of improvements in coordinate control. The least-squares center of curvature (determined using natural weighting) for all furrows in Marius and Galileo Regio is  $-20.7^\circ, 179.2^\circ$ . Furrows in Marius and Galileo Regio are reasonably concentric, and are much more circular than previously estimated and probably once covered at least an entire hemisphere of Ganymede. Thus we find furrow geometry is consistent with an impact origin (Schenk and McKinnon, 1986, 1987). Deviations of some furrows from concentricity about the center of curvature, on the scale of those found at Valhalla, do exist. As in the case of Valhalla these variations are principally confined to outer regions of the structure, and are interpreted as inherent properties of multiringed structures on icy satellites. The cause(s) of this may be in the ring formation mechanism itself, but are more likely due to variations in preexisting lithospheric mechanical properties. The perceived present nonalignment of the assumed originally concentric furrows has been used to argue for large-scale lateral motion of dark terrain blocks in Ganymede's crust, presumably in association with bright terrain formation. The overall alignment of furrows as well as the inherent scatter in centers of curvature for subregions of Galileo and Marius Regio do not support this hypothesis.

### *Primitive Material on Ganymede and Callisto*

The surfaces of the two outermost Galilean satellites may record the influx of carbonaceous and "ultracarbonaceous" material in the Jupiter region (McKinnon and Schenk, 1986). Major albedo units on both satellites are spectrally red as determined by Voyager (excepting the brightest craters on Ganymede), and increasing redness is correlated with decreasing albedo and increasing crater density (age). Present optical, infrared, and microwave data indicate very ice-rich optical surfaces and regoliths, globally averaged, for both bodies. Together, these argue for the presence of an exogenic, dark, reddish, contaminant. Regionally, the darkest and reddest units on Ganymede are dark-ray craters, although they are not as dark as Iapetus dark material or even as dark as Callisto dark terrain. In some cases they are no more red than nearby dark terrain, and one large dark-ray crater, Kittu, is actually spectrally neutral (in the visible). If the rays are areal mixtures of ice-free and ice-rich materials, then the non-ice portion may in most cases be analogous to D-type "ultracarbonaceous" material, and in the case of Kittu, "ordinary" C-type material. The best model for formation of dark rays involves the creation of a lag deposit in the ejecta of projectiles of rare low velocity or composition or both (Conca, 1981). We infer the compositional class to be (mostly) either D-class asteroids or comets (possibly silicate-enriched). We cannot rule out the impact of C asteroids coupled with spectral modification by the Jovian magnetosphere, but Kittu makes this hypothesis less likely. Terrain contamination by the integrated effects of dispersed D asteroid ejecta and infalling D-type meteoritic dust is also plausible, if accumulation preceded crater retention in the heavily cratered terrains. D-type objects are also the most likely ones available in the Jovian region; C types may have only dominated Jupiter-crossing objects during dispersal of the main asteroid belt by Jupiter,

apparently near the time the protojovian nebula itself dispersed if the flat spectra of the "captured" outer Jovian satellites are to be explained. "Himalia-dust" alone cannot account for the contamination of the surfaces of Ganymede and Callisto without spectral alteration. Work on this topic is continuing.

#### *Tectonics of Caloris Basin, Mercury*

Caloris is in many ways a unique basin compared with its lunar counterparts (McKinnon, 1986a). As a multiringed basin. Although youthful and vast, most of its multiringed elements are obscured. Ring segments immediately outside the Caloris Montes lie at diameter ratios smaller than 1.4. If the ridge systems and concentric arches of the basin floor indicate buried rings, their spacings are consistent with the inter-ring distances outside the basin rim and indicate an upper limit to the thickness of the impact-defined lithosphere of ~120 km. As a volcanic center. The smooth plains fill, presumably volcanic, is extraordinarily deep if it is required to completely bury ring topography; alternatively, the mercurian lithosphere may not be as buoyant as that of the moon. Later lunar basin volcanism usually occurs near the basin periphery; at Caloris this apparently corresponds to the emplacement of the smooth plains in an annulus surrounding the basin. That this annulus may be nearly complete is supported by radar and earth-based visual observations. All these volcanic manifestations provide a model for intercrater plains formation. The only lunar analogue to this volcanic style might be the Oceanus Procellarum basalts, if they are viewed as a partial annulus surrounding the Imbrium basin. As a mascon. Topographic depression and ridge formation imply that the basin floor subsided under a load, but the predominantly concentric orientation of the ridges is not consistent with a central mascon (radial ridges are predicted) unless basement ring structure controls tectonic orientation or the scale of the load is larger than Caloris itself. The latter may be consistent with a broad withdrawal of magma to form the smooth plains, as advocated by Dzurisin (1978). The final tectonic episode appears to be uplift and extension of the basin floor, and thus any present mascon is likely to be associated with the exterior smooth plains. The effects of such a ring load were investigated (McKinnon, 1979) using the thick-plate theory of Melosh, in which shell curvature is parameterized. The main characteristics of the predicted tectonic pattern are normal faulting within the basin and thrust faulting beneath the ring load, both in agreement with observation. The dominant concentric trend of the basin normal faults is consistent with the ring load hypothesis provided the elastic lithosphere of Mercury was  $\lesssim 125$  km thick at the time of faulting. Although this solution is approximate due to the great scale of the structure compared to Mercury's radius, it suggests that central concentric normal faults are characteristic of annular loading in the long-wavelength limit. (The dominant long-wavelength component of the annular load is second order, and thus equivalent to the tidal despinning problem. Concentric normal faults within the basin are predicted in this case.) Simple updoming within the basin would produce normal faults of predominantly radial orientation. A lower limit to the elastic lithosphere thickness (~75 km) is set by requiring sufficient deviatoric stress to initiate faulting for reasonable load magnitudes (consistent with photogeological observation, radar subsidence profiles, and limits to the contribution to  $J_2$ ).

#### *Microwave Interferometry of the Deep Atmosphere of Uranus*

A less-appreciated feature of the Uranian microwave spectrum is its apparent flatness at wavelengths longward of ~6 cm. From the suite of measurements made by various workers during 1978-1979 (the Uranus spectrum can be time-variable), averaged brightness temperatures at 6, 13, and ~20 cm can be estimated as  $251 \pm 5$ ,  $255 \pm 18$ , and  $265 \pm 45$  K. The last figure includes a strenuous attempt to measure the 21-cm brightness temperature with the Owens Valley three-element interferometer. Eighty hours of integration over five days yielded a value of  $240 \pm 63$  K (McKinnon et al., 1981). More recent higher-precision VLA measurements by Jaffe et al. (1984) and de Pater (Gulkis and de Pater, 1984) give brightness temperatures ranging between ~225-235 K at 6 cm and ~240 at 21 cm, suggesting that the averages above were biased upward or that the decimeter flux has fallen in recent years. In either case there is no evidence that the spectrum is steeply rising with

wavelength, and it may well be flat. We originally considered three explanations: a subadiabatic region, a high surface, and a rapid increase in microwave absorption below some level. The first two were rejected on physical grounds. I examine the last by calculating theoretical brightness temperatures by standard methods, incorporating the Voyager 2 radio occultation profile as the upper boundary condition (McKinnon, 1986b). One class of model atmosphere has only molecular hydrogen and water vapor as opacity sources. (This may actually occur if a super-massive water cloud [ $>$ several 100 x solar abundance] traps essentially all the available ammonia deep in the cloud.) As long as the water abundance is greater than a few times solar, then the calculated spectrum is rather flat, ranging between  $\sim 270$  and  $\sim 290$  K as the wavelength varies from 6 to 21 cm. Although this spectrum is too warm to fit the decimeter data, emission from a water-cloud deck may account for the 270 K warm regions seen in 6-cm VLA maps. The decimeter brightness spectrum requires that the water abundance of the deep atmosphere not be so great that a sensible amount of ammonia vapor is not distributed between the base of the water-ice cloud and the top of the probable  $\text{NH}_4\text{SH}$  cloud. Including ammonia in the brightness temperature modeling, using abundance profiles calculated by S.K. Atreya (in the manner of Atreya and Romani [1985]) and Fegley and Prinn (1985), shows that disk-averaged brightness temperatures in the 6-21 cm range are well fit by a deep atmosphere with abundances of water and ammonia of  $\sim 20$  x solar. In this sense, ammonia has been detected on Uranus. Any global abundance determination is suspect, however, because the disk-resolved VLA maps show strong latitudinal variation in ammonia abundance. Perhaps the polar regions, which are ammonia-free at the wavelengths discussed here, are more representative of the deep atmosphere, thus implying a much greater enhancement in water and ammonia ( $>$ several 100 x solar) at deep levels. The detectable ammonia in the Uranian atmosphere at equatorial and mid-latitudes may be due to convective lofting.

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