THE UNSYMMETRICAL BOMBARDMENT OF CALLISTO

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Callisto, the outermost of the four Galilean satellites of Jupiter, differs from the other three in several respects : it has the lowest density (1.6 ± 10%) and by far the lowest albedo. The average surface albedo of Callisto of 17% ressembles the lunar surface (Io : 63%, Europa : 64%, Ganymède : 43%). The high albedo of Europa and Ganymède, and the spectroscopic measurements, indicate a frosty surface; the ice bands are absent on Callisto, whose spectra shows mainly features associated with silicates and water of hydration (Pollack et al. 1977, Morrison and Cruikshank 1974).

Models in agreement with the density, for the internal structure of Callisto, consist of a silicaceous rock core of about half its radius, surrounded by liquid water, with a thin outer crust of ice ($\simeq$ 100km) and rock debris (Lewis 1971).

Telescopic observations of the surface features (Lyot 1953, Dollfus et al. 1974) show that each of the Galilean satellites has always the same face turned towards Jupiter; there is therefore a leading and a following hemisphere in its orbital motion, and all four satellites show distinct brightness differences between these hemispheres.

Polarization measurements by Dollfus (1971), Veverka (1971) and Gradie (1974) were interpreted by Dollfus (1975) by comparison with terrestrial lunar and artificial samples. They proved that the surface of Callisto is of rocky nature, with no significant amount of observable frost. It was advocated that the outer crust of ice has silicate fragments embedded in it, and that surface evaporation of ice left blocks piled up at the surface in a chaotic terrain (Dollfus 1975, Dollfus et al. 1975,1976). Furthermore, polarization measurements have shown very different characters on the leading and following faces of Callisto in its orbit round Jupiter. The leading hemisphere has the polarization variation with phase angle V given in curve B on the figure enclosed, which characterize the texture of a fluffy layer of fines of the lunar type, as expected for silicaceous surfaces subjected to regolithization by impacts. But the opposite hemisphere (curve A) has the structure of fragmented solid rocks, with no significant amounts of dust or fines.

This unexpected effect is supported by the variation of total brightness with solar phase angle, which shows, for the leading hemisphere, a sharp increase toward zero phase angle, as for the Moon; this "spike effect" is characteristic of a surface which is deeply pitted, or which has a complex vertical grain structure like the lunar regolith. The significantly lower value for Callisto's following hemisphere suggests that it is less complex in structure.

The fact that the whole following hemisphere of Callisto is not regolithized requires that this surface is protected against meteoroid bombardment. We cannot exclude entirely the presence of a small amount of regolith on the trailing side, but the impact rate has to be too low to give a distinctive signature for polarimetry. The unsymmetrical bombardment observed needs an explanation :

Recent computations by Hartmann (1977) show that the crater production rates, based on the present distribution of interplanetary small bodies, are at least by two orders of magnitude lower in the vicinity of Jupiter than on terrestrial planets. We have to assume : (1) that the flux of meteoroids at Callisto surface has been significantly enhanced on the leading hemisphere; and (2) that most of the ejected material stays on the same hemisphere after impact.

(1) There is in fact a possibility of impact enhancement on the leading hemisphere if the velocity of meteoroids at Callisto's orbit is small in comparison with the orbital velocity of Callisto, which is 8.1 Km/sec. We compute that, for a meteoroid approach velocity of 4 Km/sec., an impact rate 20 times greater on the leading hemisphere is expected (see Banderman and Singer 1973). A possible source of such bodies may have been planetesimals left over, after building Jupiter's satellite system, in highly elliptical orbit with pericenter close to Jupiter. In an earlier paper (Dollfus 1975), it was stated that the anisotropy in bombardment could be the result of collision with bodies generated by collisions in the asteroid belt, or from short period comets; however the relatively high velocity of these bodies at Callisto's orbit would induce too small an enhancement on the leading hemisphere ($\simeq 3$) to explain the observed anisotropy.

(2) Computations based on laboratory experiments (Gault et al. 1963, Stöfler et al. 1975) and observation of ejecta at the Moon's surface, show that the range of ejected material after a high-velocity impact is relatively small compared to the dimension of the satellite, and consequently most of the ejecta stay on the impacted hemisphere. This should be the more so for Callisto, if its surface consists of a kind of permafrost with a low mobility, which reduces the ejecta range.

A possible explanation of the different characteristics of the surfaces of Ganymede and Europa resides in the fact that these satellites have a thinner icy crust which would probably be more easily broken by the impact of large bodies, followed by an extrusion of liquid water or outgassing of water vapour and an obliteration of the crust of silicaceous material.

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To summarise the formation of the observed regolith on the surface of the leading hemisphere of Callisto, and its absence of the trailing side, could be explained by the unsymmetrical effects of an early bombardment by local planetisimals in orbit round Jupiter; the difference in the thickness of the icy crust could explain the different characteristics of Europa and Ganymede.

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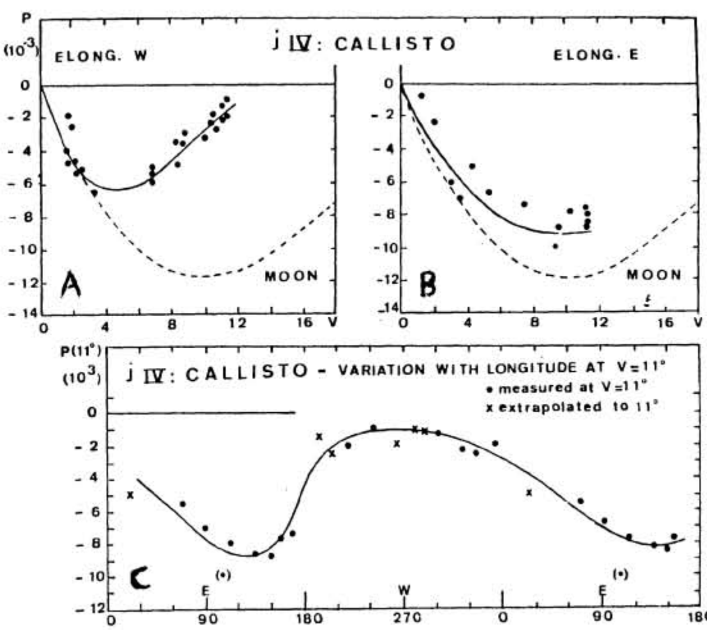

A : Polarization as a function of phase angle V, for Callisto's trailing hemisphere.

B : Same for the leading hemisphere.

C : Variation of P (at phase angle 11°) as a function of the longitude of Callisto in orbit. At 90°, the leading hemisphere is observed; at 270° the following hemisphere is observed.