DARK RAY AND DARK FLOOR CRATERS ON GANYMEDE; Paul M. Schenk and William B. McKinnon, Department of Earth and Planetary Sciences and McDonnell Center for the Space Sciences, Washington University, Saint Louis, MO 63130.

Dark ray and dark floor craters are rare and intriguing classes of craters on Ganymede. Poscolieri [1] originally identified eight dark ray craters, seven occurring on dark terrain and none larger than 40 km in diameter. He thus concluded that these craters reflect target composition and that dark terrain in particular consists of a rock-ice mixture to a depth of ~4-5 km. This latter conclusion was made despite that the size distribution of bright ray craters on dark terrain was not demonstrably different from that of the dark ray craters. The interspersed bright and dark ray craters also indicated that any subsurface horizontal stratigraphy was discontinuous. No crater locations were given [1]. Hartmann [2] quoted earlier results of [1] of a much more restricted range of dark-ray crater sizes, and argued for a distinct subsurface layer. This interpretation is no longer valid.

Conca identified forty-three "dark-ray" craters [3]. Selection effects were judged negligible for those twenty-one greater than 5 km in diameter, and these were equally divided among the bright and dark terrains that are roughly equally abundant on Ganymede. Conca's spatial distribution is strongly skewed towards the antapex of orbital motion, and increasing areal coverage of low-albedo deposits around dark ray craters and decreasing geometric albedo were said to correlate with decreasing distance from the antapex. These observations argued for a magnetospheric role in the creation and maintenance of dark ray deposits; their scarcity and lack of terrain correlation argued for a dominant role for projectile characteristics [3]. Correspondingly, Conca modeled the creation of dark rays as being due to differential sputtering of dirty-ice ejecta by Jovian magnetospheric ions. The contaminant was assumed to be in the form of small particles with volume percentages ranging between 10^{-5}-10^{-2}, and the rays were assumed to be initially bright (albedo = 0.35), decreasing to an albedo of 0.12. A plausible range in contaminant size and volume fraction was found to work, leading to the hypothesis that a rare velocity component of the projectile population could suffice as well as one of rare composition. Shoemaker et al. [4] further argue that insolation-driven sublimation as well as sputtering play a role in dark ray formation.

We have reexamined dark ray craters on Ganymede, and find that there are at least two distinct classes: dark ray craters and dark floor craters. Eleven identified dark ray craters have distinct low albedo ejecta patterns (the largest of which typically have brighter floors), range in size from 40 km in diameter down to the limit of resolution, and are all found on the trailing hemisphere, equally divided between dark and bright terrain. Most are found in the Tiamat Sulcus quadrangle between ±15° latitude. Three very large (up to 500 km long), overlapping, ancient (by virtue of their irregular appearance), dark ray systems are seen in this quadrangle. One source crater to the south is obscured by younger bright ejecta, one occurs in an unimaged area to the west, and one is probably associated with a dark circular region partially obscured by the young bright crater Tammuz. It would appear that, close to the antapex, dark ray craters are not at all rare. Assuming a lunar-like scattering law for dark rays gives photometric phase function values intermediate to those of Ganymede dark terrain and Callisto dark terrain [5]. Scaling the slope of the phase function to these values, and using the opposition surge for Ganymede dark terrain [5], we estimate minimum Voyager clear filter reflectances for dark rays of ~0.20. Dark floor craters, on the other hand, are characterized by extremely dark floors (~0.15 clear-filter reflectance, similar to that of Callisto dark terrain); some of these are surrounded by a narrow bright halo and occasionally have dark streamer-like deposits. These craters are evenly distributed over the surface of Ganymede. Fourteen have been identified, five of which are on dark terrain, seven on bright terrain, and two are uncertain. These craters are probably not of the same origin as dark ray craters. Helfenstein [6] has hypothesized that they are due to the formation of "devolatilized impact melt," presumably meaning a contaminant-enriched surface layer. More than eleven other dark "something" craters have been identified so far, but they have not been classified due to their small size. Most of these are less than 5 km across and occur on bright terrain, but their small size would make detection difficult on dark terrain. The dark terrain, though, has innumerable small dark regions of uncertain origin.

Voyager color measurements of dark ray and dark floor craters were made incorporating the calibration corrections of Buratti (in[7]). Orange/violet ratios for the three largest dark ray craters Antum, Mir and Kittu (at 4.7° N, 219.1° W; 3.4° S, 230.4° W; and 0.4° N, 334.2° W, respectively), and adjacent terrains are:

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	Dark rays		Dark terrains	Bright terrains	Phase angle
Antum	1.38 ±0.03	1.37 ±0.04	1.34 ±0.02	1.32 ±0.03	22° VGR 2
Mir	1.43 ±0.03	1.39 ±0.04	1.32 ±0.03	1.32 ±0.03	22° VGR 2
Kittu	0.94 ±0.07		1.11 ±0.05	1.12 ±0.06	52° VGR 1

Both Mir and Antum rays are "red" with respect to surrounding terrains. We note that the brighter floors of these craters are comparatively less "red", as are all bright rim and ray deposits on Ganymede [8]. Kittu dark rays are relatively less "red" relative to local terrains, and appear spectrally neutral. Voyager 1 colors are less "red" overall compared to Earth-based hemispherically-averaged Ganymede spectra [9], though, so Kittu rays are actually probably somewhat "red". But they are still significantly less "red", compared to surrounding terrains, than any other dark ray or dark floor crater. Of the smaller craters for which we have color measurements to date, five are "red", three are "neutral", and two are less "red" relative to local terrains. There does not appear to be any correlation of color with terrain type or apparent age. Although Voyager wavelengths extend only from 0.35 to 0.65 μm, the different Voyager colors for various dark rays and dark floors indicate that there may be different impacting projectile compositions, if this latter hypothesis is correct. Color differences of this type are not obviously expected if dark rays excavate from a uniform, dark subsurface horizon.

Earth-based spectra of Ganymede [9] and of abundant low-albedo outer solar system bodies [10-12], including C- and D-type asteroids and outer Jovian satellites, were convolved with the Voyager band passes for comparison. D-type asteroids, primarily the Trojan asteroids, are the reddest of these. None of the classes compared so far, including the D-types, are as "red" as the ground-based Ganymede spectra, and probably cannot account for the "red" dark-ray colors unless spectrally modified by the Jovian magnetosphere. This reddening is probably due to magnetospheric sulfur implantation and Fe^{+3} absorption [13]. The relatively neutral color of Kittu and several of the smaller craters argues against significant alteration of the dark component, however, at least to the extent of turning a Kittu-like ray into an Antum-like ray. The "flat" spectra of C-type asteroids and most of the outer Jovian satellites are compatible with the "neutral" or slightly "red" rays, and spectrally-modified D-type material may be compatible with the more "red" rays. Hartmann [14] has suggested that some comets may contain D-type dust. No reliable spectra of non-active comets are available, however, and D-dust enriched cometary impact, possibly with additional reddening, cannot be ruled out as a cause for "reddish" dark ray colors.

If dark-rays are due to projectile contamination, such craters might be expected on Callisto, the other heavily cratered Galilean satellite. The lowest estimated reflectances of Ganymede dark rays and floors are equal to or greater than that of Callisto dark terrain, however, so dark rays should be almost impossible to detect on Callisto. Numerous small dark splotches can be seen on Callisto, but their origin is unclear. We note that ray craters of any type are virtually absent in the Saturnian system.

Although it is not possible with Voyager data to uniquely identify source bodies for the formation of dark ray and dark floor craters, their distribution, size range, and limited Voyager color measurements suggest that these craters may record the influx of projectiles of differing compositions, and this material may be incorporated into the ray deposits. These craters are prime candidates for the higher spatial and spectral resolution observation planned for Galileo. Identification of projectile types would help in isolating projectile source regions and estimating bombardment rates in the Jovian system, and may also provide clues as to the source and composition of darkening agents on these predominantly icy worlds.

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