GANYMEDE CRATERS: RELATIONSHIPS BETWEEN SPECTRAL PROPERTIES AND CRATER RETENTION AGE. K. Stephan[1], R. Jaumann[1], R. Wagner[1], C. A. Hibbitts[2], G. B. Hansen[2], [1] German Aerospace Center (DLR), Rutherfordstr.2, 12489 Berlin, Germany, [2] Department of Earth and Space Science, University of Washington, Seattle, Washington, USA (Katrin.Stephan@dlr.de).

Introduction: Both bright and dark craters occur on Jupiter's satellite Ganymede. The Near Infrared Mapping Spectrometer (NIMS) onboard the Galileo spacecraft performed spectroscopic measurements of Ganymede in the spectral range of 0.7 to 5.2 microns [1]. Observations of Ganymede's craters acquired at sufficiently high spatial resolution coordinated with Galileo SSI (Solid State Imaging) observations and additionally with medium- and low-resolution SSI and Voyager observations were used for investigating relationships between the spectral properties, morphology and relative retention age of Ganymede's impact crater material, and of substrate material.

Data: The analysis was conducted on NIMS high-resolution observations which cover the areas around the craters Amon, Mir, Antum, Tammuz, Melkart, Harakthes and Osiris located on Ganymede's leading hemisphere and the craters Kittu, Hershef, Ta-urt, Shu and Tashmetum on the trailing side.

Based on the high-resolution Galileo SSI images, the stratigraphic position of Kittu, Melkart and Harakthes, and their relative and absolute ages have been determined by measuring the superimposed crater frequencies on their continuous ejecta blankets and crater floors. If no high-resolution images were available, the superimposed crater frequency and the relative age of the specific crater was estimated using a method described by Wagner et al. (1999) [2]. Currently, two conflicting impact cratering chronology models to estimate absolute cratering model ages exist: Model I by Neukum et al., 1998 [3], and Model II by Zahnle et al., 1998 [4].

Results: Bright ray craters like Osiris and dark ray craters Kittu, Mir and Antum were found to be formed fairly recently [5,6,7]. The dark ray material of **Kittu** (0.5°lat, 334.5°lon), **Antum** (5°lat, 219°lon) and **Mir** (3.5°lat, 230.2°lon) shows the highest concentration of non-ice component(s) found so far on the surface of Ganymede. Kittu's cratering model age could be defined at a maximum of 800 Myr (Model I) and 20 Myr (Model II) respectively, the youngest crater age determined in this analysis. The young age of Kittu could account for the color variations in Voyager images described by Schenk & McKinnon [6], if there are processes that support "reddening" of surface material with time. NIMS spectra provide no obvious spectral differences between the dark ejecta of Kittu and the other dark ray craters (Fig. 1). If the color difference of Kittu were caused by different impactor composition, it must be a material which is spectrally similar to the material of the other craters within the spectral range provided by NIMS, but not within the Voyager [6] and SSI spectral range.

The largest bright ray crater **Osiris** (-39°lat, 161°lon) exhibits spectra of almost pure water ice (Fig. 2). A strong reflectance peak at 3.6 microns only observed in the spectra of Osiris and Harakthes is consistent with a composition of water ice with a relatively fine-grained particle size (<50 microns) [8,9].

The large bright craters on Ganymede's leading hemisphere like Osiris appear to be relatively younger than the bright ray craters **Hershef** (-47°lat, 269°lon), **Ta-urt** (28°lat, 304°lon) and **Tashmetum** (39.5°lat, 264,5°lon) on the trailing side (Fig. 2), according to Shoemaker et al. [5]. However, the reflectance spectra of Hershef, Ta-urt and Tashmetum exhibit a very low reflectance longward of 3 microns which indicate a larger particle size of water ice than in the case of Osiris, and is probably caused by sputtering dominant on Ganymede's trailing hemisphere [10,11]. Large-grained ice tends to be darker longward of 0.5 microns than the more fine-grained water ice of Osiris. This difference could be more influenced by the location/environment on Ganymede than by the evolution of properties over time. We assume that these craters could also be formed fairly recently.

In the case of crater **Tammuz** (13,5°, 230,5°), the slope of the reflectance spectrum from 1-3 microns is indicative of a significant proportion of very large-grained ice and appears to be the steepest of the craters studied here. It is still not clear whether the bright and dark rays are the results of one or two different impact events, or whether the diversity originates from target or impact contamination. In fact, the relatively high concentration of water ice in the crater material suggests a relatively younger age of Tammuz than Melkart and Amon, whose spectra indicate a high concentration of non-ice contaminant(s). The age of Tammuz may be similar to that of the large bright ray craters on Ganymede's trailing side. The crater retention age of Tammuz could not be measured. Higher resolution images are necessary to address this question.

Craters deposits with spectra exhibiting mixtures of water ice and non-ice contaminant(s), like the bright craters **Melkart** (-10°lat, 186°lon) and **Amon** (-33.5°lat, 220.8°lon), are supposed to be of intermediate

age. An upper limit of crater retention age of 3.8 Gyr using Model I and 550 Myr using Model II was measured for Melkart, which supports this assumption.

Similar spectral properties of the crater floors of Harakthes (36° lat, 100°lon) and Osiris cannot be interpreted as indicators of similar age. In the case of Harakthes, re-depositing of water ice as fine-grained frost on colder areas of Ganymede's surface, such as at the poles [11], is supposed to be responsible for the high concentration of fine-grained water ice on the crater floor. Furthermore, the lack of well-defined ray deposits indicates that Harakthes has had more time to reach an equilibrium state and appears to be distinctly older than the other craters, especially Osiris. An upper limit of crater retention age at 4 Gyr for Model I and 1.4 Gyr for Model II were measured for Harakthes, the oldest crater on Ganymede discussed here.

In the case of Ganymede's bright ray craters, no significant spectral differences occur between crater material and the corresponding ejecta, except for a slight increase of the particle size and a decreasing amount of water ice in the ejecta with increasing distance from the crater. On the other hand, we find no consistent relation between the spectral properties of the ejecta and the crater material of the dark ray craters Antum, Kittu and Mir. The crater materials contain distinctly more water ice than the ray material, but also show distinct non-ice features, mainly CO2 at 4.25 microns and a significant positive slope beyond 3 microns [12,13,14].

In the case of the dark ray craters, only Kittu is located within the bright grooved terrain, whereas Antum and Mir are situated within the old dark cratered terrain. However, the crater material and the ray material show no remarkable spectral variations in spite of their apparently different substrate [15].

In general, spectra of craters and ray material, except for Melkart are predominately independent of the underlying substrate. The variations in the case of Melkart could be caused by fading of crater and ray material with time as a result of water ice deposition on Ganymede's polar caps, as mentioned above, which probably includes selective ablation of ice from low latitudes [16].

The amount of water ice in bright impact craters and the amount of non-ice contaminant(s) within the ejecta of observed dark ray craters is assumed to be indicative of relative age. The combination of both spectral and imaging data is a powerful method for linking composition and color variations of different surface features on Ganymede, may permit the spectral detection and identification of non-ice contaminant(s), and improve the understanding and degree of compositional modification of the surface material by external and internal processes as a function of time.

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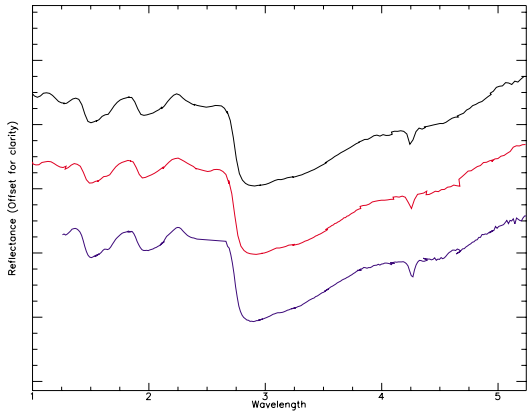

Figure 1. Continuum removed reflectance spectra of ray materials of Ganymede's dark ray crater Antum (black), Mir (red) and Kittu (blue).

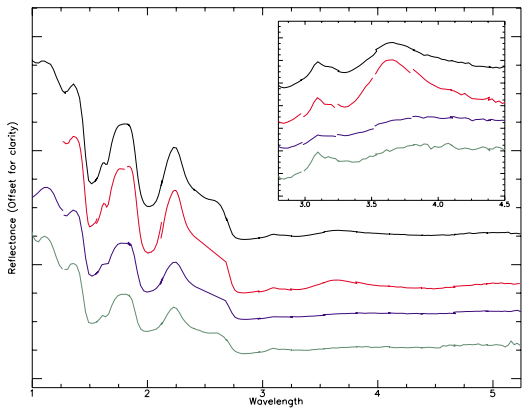

Figure 2. Reflectance spectra of the crater materials of Osiris (black), Harakthes (red), Tashmetum (blue) and Tammuz (green).