# Final Technical Report for
# Cooperative Agreement NCC 2-953

National Aeronautics and Space Administration
Ames Research Center

## "Interacting Surfaces and Atmospheres in the Outer Solar System"

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The work reported here is an extension of ongoing efforts in data reduction and modeling of the spectral reflectances of several objects in the outer Solar System. In general terms, this requires an evaluation of the data obtained at the telescope, conversion of those data into geometric albedo units, and the combination of individual spectrum segments into a complete spectrum over the wavelength interval of interest. The modeling effort to produce a synthetic spectrum of a given Solar System object requires the complex refractive indices (the optical constants) of candidate surface materials, including ices, minerals, and organic solids. Those indices are primarily available only through contacts with other researchers, including colleagues at NASA Ames and at other institutions. Once obtained, the indices must be convolved with the telescopic data and then used in a computational model to produce the required synthetic spectrum for comparison with the data obtained at the telescope. In this way, we reach a convergence on the chemical composition and microstructural properties of the surfaces of objects in the outer Solar System.

Following is a brief description of the modeling efforts completed and which have been the primary focus of this work during the reported period of performance.

### Iapetus, the dark side.

Existing data from previous papers and new high resolution data were used to put together a spectrum ranging in wavelength between 0.3 and 3.9 um. Previously available data stopped at 2.5 um, short of a strong feature that was key in establishing the molecular components that model the spectrum.

After reproducing previously published results from Wilson et. al. (1995) that matched the spectrum in the 0.3-2.5 wavelength range, we proceeded with modeling the strong feature at 3um. The shape of this feature: skewed, broader at long wavelengths, but still rising steep, required an additional component to the simple $H_2O$ and amorphous molecular mixture that had been suggested by Wilson. The material available to us that together with $H_2O$ and an amorphous component best matched the feature was Triton Tholin. This is a compound which is produced in the laboratory by UV photolysis of a gaseous mixture. It produces a fairly sharp feature at 3um that, combined with the $H_2O$ 3um feature which would otherwise be too broad even for small grain sizes, results in a good fit of the observed spectrum. Amorphous carbon, the third component of our model, contributes to lowering the spectrum in the mid wavelength range that would otherwise be too high due to the Triton Tholin.

Triton Tholin is not necessarily the material that makes up the dark part of Iapetus, but it shares the same spectral signature with the actual molecule(s) in the wavelength range that is being studied.

Even when Iapetus is seen at eastern elongation, the time when the dark hemisphere is facing the Earth, a small contribution from the brighter part is still present. This contribution varies with time and has been estimated to contribute in the average about 10% of the total light coming from the leading hemisphere. To model this contribution we used a program which calculates mixtures from spatially separated components. If using the best fitting model of the dark side, only a few percent of bright water ice can be accommodated in the spatial mixture. The contribution rises to about 7% when, instead of $H_2O$ ice, we use the best model to the bright side of Iapetus as a component to the spatial mixture. The model that includes the spatial mixture does not reproduce the 3um feature shape to the same degree of accuracy as does the model to the plain dark side.

A paper describing this work is being produced and will be submitted to Icarus. The paper is entitled "

## The Composition of Centaur 5145 Pholus

The PI's contribution to this work was only at the final stage, but will continue under NCC 2–1119. She helped uncover the final missing component in the mixture which yields a good match to the observations. It turned out to be Olivine, a silicate mineral found in comets and in the interstellar dust, as well as on Earth. We concluded that Pholus is a primitive object not yet completely processed by solar heat. Its properties are those of a nucleus of a large comet that has never been active.

See attached reprint, TITLE, for the full story.

## Pluto $H_2O$ Test

When observed at maximum and at minimum light the spectrum of Pluto in the 1.4–2.5 um range shows a discrepancy of about 15% in albedo where the darker spectrum belongs to the maximum light.

The spectrum calculated by taking the difference of the two spectra at minimum and maximum light shows dips in correspondence of the 1.5 and 2um $H_2O$ features.

Modeling of the difference was complicated by a lack of constraints such as an albedo level and a clear 'continuum'. However, the clear presence of a $H_2O$ signature in the difference spectrum indicated that the darkening component could be added to the brighter spectrum, i.e., a spatial mixture could be appropriate.

We experimented mixing spatially $H_2O$ in different grain sizes with the brighter spectrum of Pluto: only the large grain sizes could fit the darker spectrum. We also experimented with relative abundances of $H_2O$: 10, 20, 30%. The final selection was: 18% $H_2O$ in 1200um grains mixed spatially with the spectrum of Pluto at minimum light. To select the best spatial mix we used a simple program that calculates the rms of the normalized difference of each point in the two spectra.

As a test we applied the spatial mix technique just described to $CH_4$ instead of $H_2O$. Again we tested different grain sizes and relative abundances. None of the attempts came close to a good fit.

## Charon

The surface composition of Pluto's satellite Charon appears to be distinctly different from that of the planet itself. While the 1.0-2.5um spectrum of Pluto shows spectroscopic evidence for solid $N_2$, $CH_4$, CO and $H_2O$ low resolution spectrophotometry (1.5-2.5um) of the Pluto-Charon system has shown that $H_2O$ ice, with characteristic signatures at 1.6, 2.0, and 2.4um, dominates the near infrared spectrum. With improved image quality now available from ground- and space-based telescopes it is possible to separate the spectra of Pluto and Charon at maximum elongation of the system, 0.9" as viewed from the Earth, despite the large difference in brightness of the two objects.

The best fit to the Charon spectrum is a "pure" $H_2O$ ice model consisting of two widely different grain sizes, 30um (35% of the mixture) and 600um (60%) together with a synthetic blue material (5%) to account for the blue slope of the continuum from optical to infrared wavelengths. The effect of the latter is very small across the 2um spectrum. The two widely different grain sizes are required to match the band depths and the interband continuum.

To test for the presence of CO and $CH_4$ in the spectrum of Charon we calculated model spectra with 10% and 30% CO in 50um H2O-ice grains, in a mixture with $H_2O$ ice in grain sizes of 30um and 600um plus the pseudo blue material, as described above. The model spectra are smoothed to the resolution of the binned spectrum of Charon. At the sensitivity of the present spectrum of Charon we can only set an upper limit of 30% CO. Furthermore we calculated four model spectra with abundances of 1, 5, 10, and 20% $CH_4$ in 50um grains, mixed in with $H_2O$ ice grains as previously described. Two bands coincide with marginally significant dips in the spectrum of Charon, but the other two, which are the strongest and weakest $CH_4$ band, are badly mismatched to the spectrum. We estimate an upper limit of 10% for the $CH_4$ abundance. However, these limits are 1–2 orders of magnitude higher than the concentrations of CO and $CH_4$ detected on Pluto and thus are not very constraining.

We also tested for the presence of $CO_2$ utilizing the three bands near 2.0um. This complex of bands lies entirely within the strong $H_2O$ absorption where the geometric albedo is at its lowest. As above, the model spectra included varying amounts of $CO_2$ in different grain sizes. Because of the low signal-to-noise ratio of the Charon spectrum the test is not very stringent; we estimate $CO_2/H_2O < 1$.

The existence of the shallow band of frozen $N_2$ at 2.15um on Triton and Pluto signifies that N2 is the dominant constituent of the surfaces of those objects. This band is not obviously present in our spectrum of Charon, but due to the low signal-to-noise ratio we can draw no conclusions regarding its abundance.

Better data are necessary to draw firmer conclusions on the surface composition of Charon.