**AN EMPIRICAL PHOTOMETRIC CORRECTION FOR EUROPA.** P. E. Geissler[1], L. Keszthelyi[1], and L. A. Weller[1], [1]Astrogeology Science Center, U.S. Geological Survey, 2255 N. Gemini Drive, Flagstaff AZ 86001 (pgeissler@usgs.gov; laz@usgs.gov, lweller@usgs.gov)

**Introduction:** Photometric corrections are necessary to construct image-based maps of planetary surfaces from images captured under different illumination and viewing geometries and from images captured using different filters. The U.S. Geological Survey has software applications for making photometric corrections in the Integrated Software for Imagers and Spectrometers (ISIS), but few tools for deciding on an appropriate photometric model and the correct parameters to be applied. Here, we take a data-driven approach to deriving an empirical photometric correction for Europa using ISIS and Python.

**Approach:** We began investigating the photometric behavior of Europa with a data set of 702 Voyager and Galileo images of Europa with resolutions better than 32 km/pixel, all those that could be calibrated and geometrically controlled so that illumination and viewing angles could be determined using USGS ISIS software.

Step 1. We ran the ISIS program ***phocube*** to calculate the latitude, longitude, incidence angle ($i$), emission angle ($e$), phase angle ($g$), pixel resolution, sub-spacecraft ground azimuth, sub-solar ground azimuth, and local time for each pixel in each image. This first step produced new ISIS image cubes with backplanes for each of the photometric parameters.

Step 2. Here we extracted spatially resolved statistics from those new cubes. To sample those data, we used the ISIS command ***crop*** to extract small sub-images (3x3 pixels) from each cube at regular intervals (25x25 pixels) to obtain more than 615,000 data points. We then ran the ISIS program ***stats*** on each sub-image to obtain a text file with the average of each plane listed. These text files were named with a string concatenation of the original file name, the pixel location, and the filter name so they could be tracked to a specific set of pixels.

Step 3. Next, we compiled these individual files into a single comma-separated flat file. Here we replaced the string 'N/A' with the string '-999' to denote invalid data (from points that were not on Europa, for example).

Step 4. We next sorted the flat file by filter and removed invalid points with '-999' in any field and removed points with incidence angles greater than 90 degrees (i.e., beyond the terminator).

Step 5. We were then ready to plot these data as I/F (DN) vs. photometric parameters. We created 3D histograms of these data, initially viewing all these data together in a single heat-map display. We made four such plots: I/F vs. $g$ (phase angle); I/F vs. cos($i$); I/F vs. cos($e$); and I/F vs. the cos($i$)/(cos($i$) + cos($e$)). We used Python's ***NumPy*** for reading our data file and ***Pyplot*** for creating the heat-maps.

We quickly noticed the linear relationship between I/F and cos($i$) in Figure 1 and decided to investigate the Lambertian photometric model further.

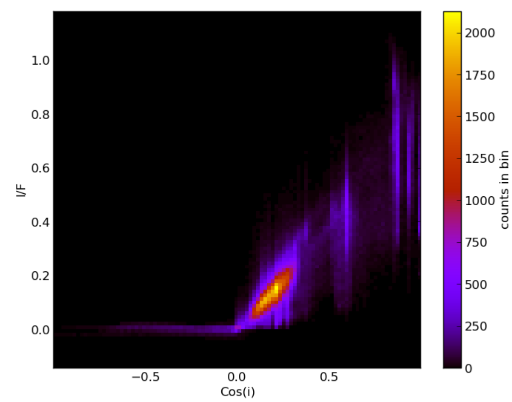


**Figure 1. Histogram of calibrated reflectance I/F vs. cosine of incidence angle (*i*).**

Step 6. We fit a curve to these data sorted by instrument and filter to measure Europa's photometric behavior as a function of wavelength. We required our straight line fits to go through the origin and we solved for the slope only. We used ***curve_fit*** from Python's ***SciPy*** for this task.

In a simple Lambertian photometric model, the reflectance is the product of the cosine of the incidence angle and the albedo. The fits that we calculated gave us a measure of Europa's albedo as a function of wavelength, averaged over all illumination and viewing angles.

Table 1 reveals that Europa is strongly colored, stained by sulfur from its smoking neighbor, Io [e.g., 1].

Finally, we separated observations by phase angle to detect differences in Europa's color as a function of phase. We found that Europa is brighter and redder at low phase angles (for example, $g$ < 30°) than at high phase angles ($g$ > 90°). Moreover, there is more scatter in the fits at low phase angles than at high phase angles. This suggests that non-Lambertian photometric behavior is more common at low phase angles.

**Application:** We tested our photometric correction by applying it to each of our Europa images, dividing by the cosine of the incidence angle and the derived albedo averaged over phase angles. These corrected images were used to construct a global mosaic in the exact same manner as a similar mosaic constructed of uncorrected images.

Figure 2 shows the improvement obtained by applying our simple photometric correction. Individual images in the mosaic, taken under different conditions, are better matched to one another.

**Next Steps:** Having established a dependence of albedo on phase angle, we would next like to work on a simple parametrization of albedo vs. phase, and the functional form of a photometric correction that incorporates both incidence and phase angles and allows albedo to be a function of phase.

**Reference**: [1] McEwen, A. (1986) *JGR*, *91*, 8077-8097.

**Table 1: Spectral reflectance of a Lambertian Europa**

| FILTER NAME | CENTER WAVELENGTH IN NM (SPACECRAFT) | SLOPE | STANDARD DEVIATION OF SLOPE |
|---|---|---|---|
| UV | 325 (V) | 0.256 | 0.002 |
| VIOLET ALL | | 0.467 | 0.002 |
| VIOLET GALILEO | 404 | 0.473 | 0.002 |
| VIOLET VOYAGER | 400 | 0.431 | 0.003 |
| BLUE | 480 (V) | 0.551 | 0.004 |
| GREEN ALL | | 0.662 | 0.002 |
| GREEN GALILEO | 559 | 0.656 | 0.002 |
| GREEN VOYAGER | 585 | 0.816 | 0.010 |
| CLEAR ALL | | 0.730 | 0.000 |
| CLEAR GALILEO | 611 | 0.736 | 0.000 |
| CLEAR VOYAGER | 460 | 0.443 | 0.002 |
| ORANGE | 615 (V) | 0.625 | 0.004 |
| RED | 671 (G) | 0.605 | 0.005 |
| 756 NM | 756 (G) | 0.646 | 0.002 |
| 889 NM | 889 (G) | 0.808 | 0.004 |
| 968 NM | 968 (G) | 0.723 | 0.002 |

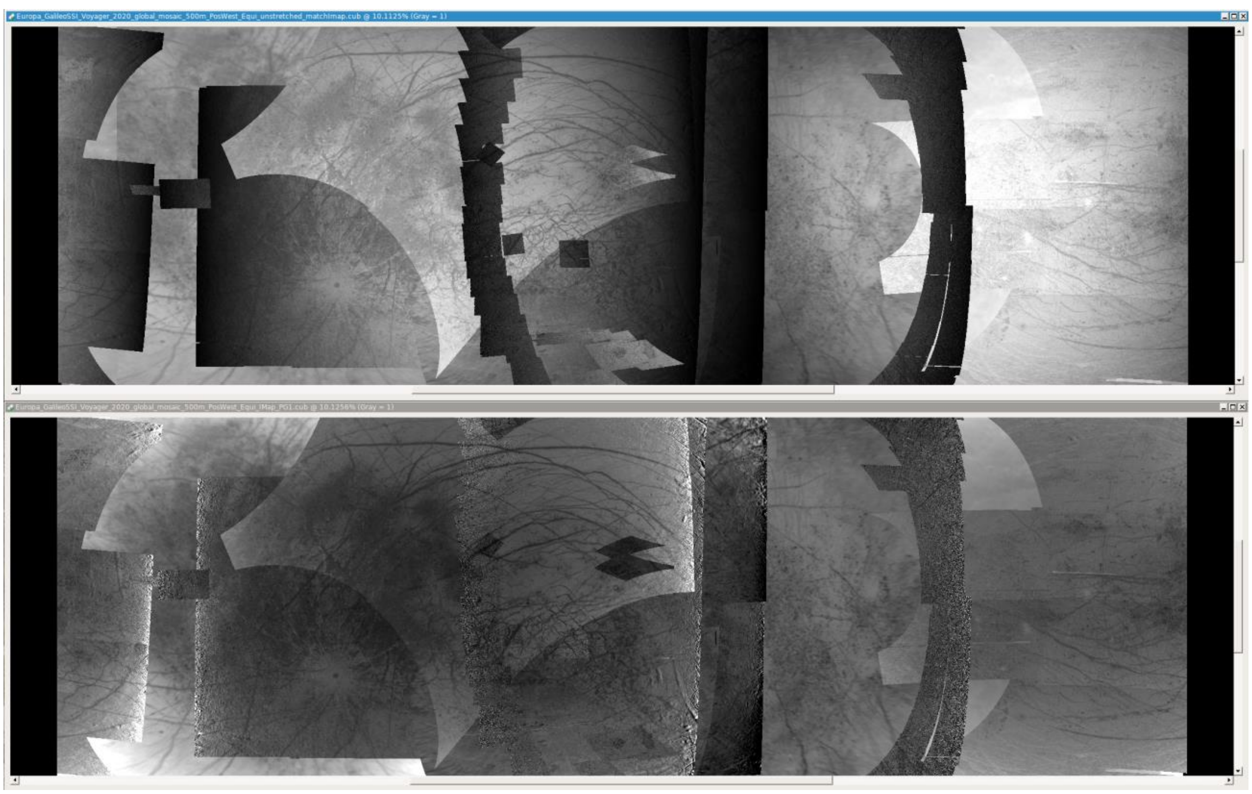

**Figure 2: Comparison of uncorrected global mosaic (top) with empirical correction**