p8

Technical Report No. 32-664

The Lunar Reflectivity Model for Ranger Block III Analysis

D. Willingham

JET PROPULSION LABORATORY
CALIFORNIA INSTITUTE OF TECHNOLOGY
PASADENA, CALIFORNIA

November 2, 1964

Technical Report No. 32-664

The Lunar Reflectivity Model for Ranger Block III Analysis

D. Willingham

Carl Thiele, Chief
Applied Sciences Section

JET PROPULSION LABORATORY
CALIFORNIA INSTITUTE OF TECHNOLOGY
PASADENA, CALIFORNIA

November 2, 1964

Prepared Under Contract No. NAS 7-100
National Aeronautics & Space Administration

CONTENTS

FIGURES

ABSTRACT

The methods employed in deriving a revised lunar reflectivity model are described in detail, illustrated by plots showing the data scatter that was encountered. A discussion of the need for the revision to the photometric function developed in 1963 and a comparison of the "old" and "new" functions are also included.

I. INTRODUCTION

Early in the *Ranger* 3, 4, 5 series of spacecraft, it became apparent that a method for predicting lunar luminance values as a function of impact geometry was a necessity. It was recognized that development of a single luminance function for the entire lunar surface was a gross generalization; however, Van Diggelen (Ref. 1) and others had shown that nearly all lunar areas have a very similar relative luminance cycle, with nearly every area reaching maximum brightness at 0-deg phase. Van Diggelen further published a photometric function

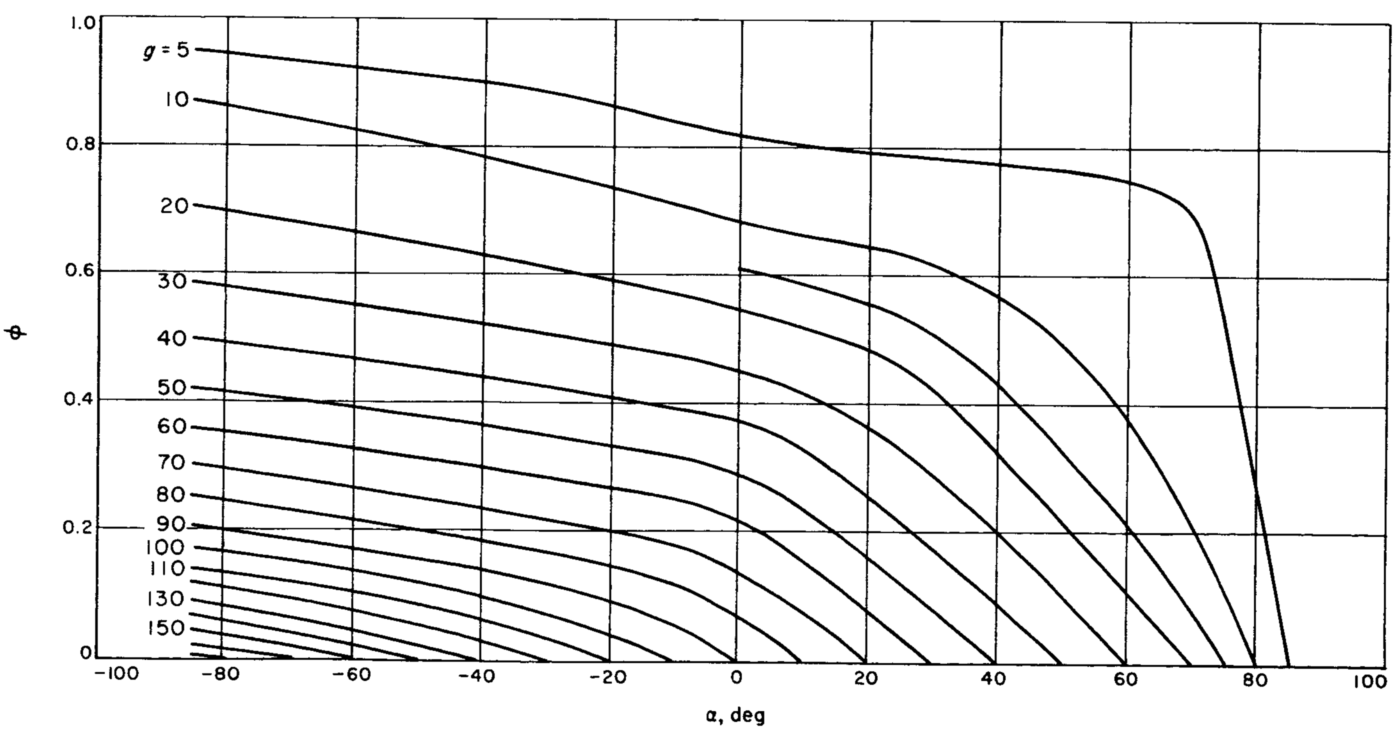

Fig. 1. Photometric function from Ref. 3 (ϕ vs. α)

of lunar crater floors. Additional data showed that the mare from all portions of the Moon were approximately the same in absolute reflectivity, with an average reflectivity of about 7% at phase angles of 3–4 deg and reflectivity extremes from 5 to 10% at these phase angles.

In Ref. 2, a lunar photometric function of the mare was developed using the luminance data of V. A. Fedorets, a Russian astronomer, whose work was performed in 1948–49 (Ref. 3). His data were obtained by reducing photographic plates of the Moon taken at various lunar phases. Since the data were on a nonspecified luminance scale, they had to be used in a relative manner.

The photometric function ϕ was derived by selecting mare areas and extrapolating a luminance curve fitting the data from each area to 0-deg phase. The data from each mare area were then normalized such that at 0-deg phase the luminance was 1.0. A number of mare areas were then grouped together (to obtain a range of emission angles) and a "best" fit of the data was made. The aforementioned extrapolation was generally over the range from 1.5 to 0-deg phase angle or 7 to 0-deg phase angle, depending upon the area involved.

With knowledge of the solar flux at the lunar surface and the full-Moon reflectivity $\rho_{0,0}$ (0-deg phase), one could then predict the brightness of the lunar surface as a function of incidence, emission, and phase angle. It was further shown that the normalized photometric function could be considered a function of two angles, the phase angle g and an auxiliary angle α, which was the projection of the emission angle into the plane containing the Sun and the observer (i.e., the phase plane). The above work was completed in early 1962 and resulted in Figs. 1 and 2.

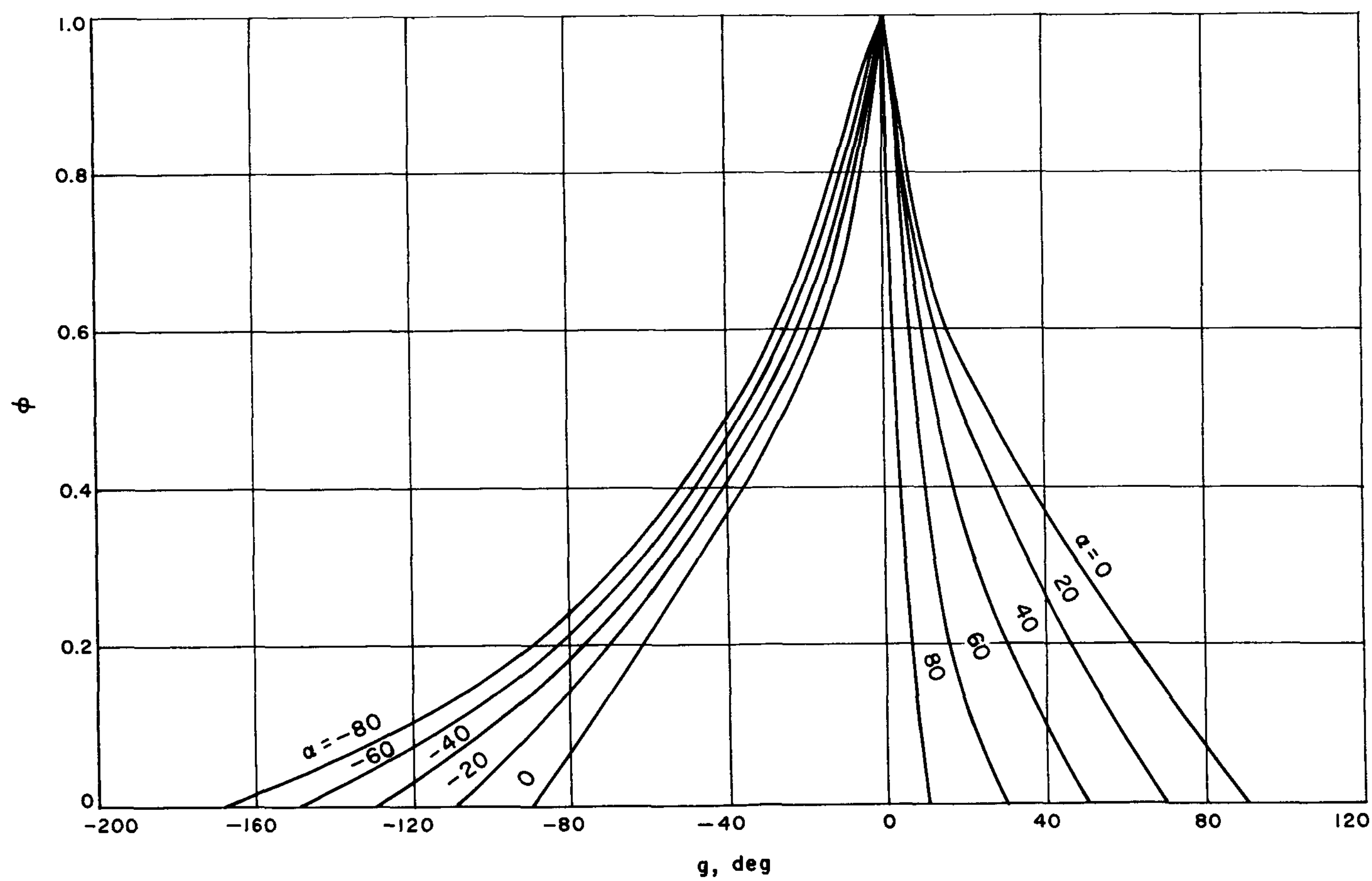

Fig. 2. Photometric function from Ref. 3 (ϕ vs. g)

II. DISCUSSION OF FEDORETS' DATA AND THE 1962 PHOTOMETRIC FUNCTION

Several lunar observational efforts have shown that Fedorets' data were not completely accurate, as for instance his conclusion that brighter lunar areas exhibit a phase lag before reaching their peak luminance. Various efforts have shown this conclusion not to be so. It is now believed that some error in photographic plate controls was present during this experimentation.

In addition, lunar photometric data have an extremely large slope between 0 and 5-deg phase angles, and extrapolation of these data is, to say the least, a questionable procedure.

With the aid of E. A. Whitaker (*Ranger* Experimenter)* the most reliable Fedorets data points were selected for reanalysis in May 1964. All but 45 areas including continents, craters, and mare were eliminated, and the data after full Moon (0-deg phase) were discarded from these 45 areas. Further restriction of the areas to mare and large crater floors narrowed the number to 22. Data from these 22 areas for phase angles of 1.5 and 7.1 deg are plotted in Fig. 3. The 7.1-deg data show much less scatter than the 1.5-deg data. Data scatter near full Moon has been noted in discussions with the California Institute of Technology Lunar Laboratory and further reflects on the inadvisability of extrapolating to 0-deg phase.

*Lunar and Planetary Laboratory, University of Tucson, Tucson, Arizona.

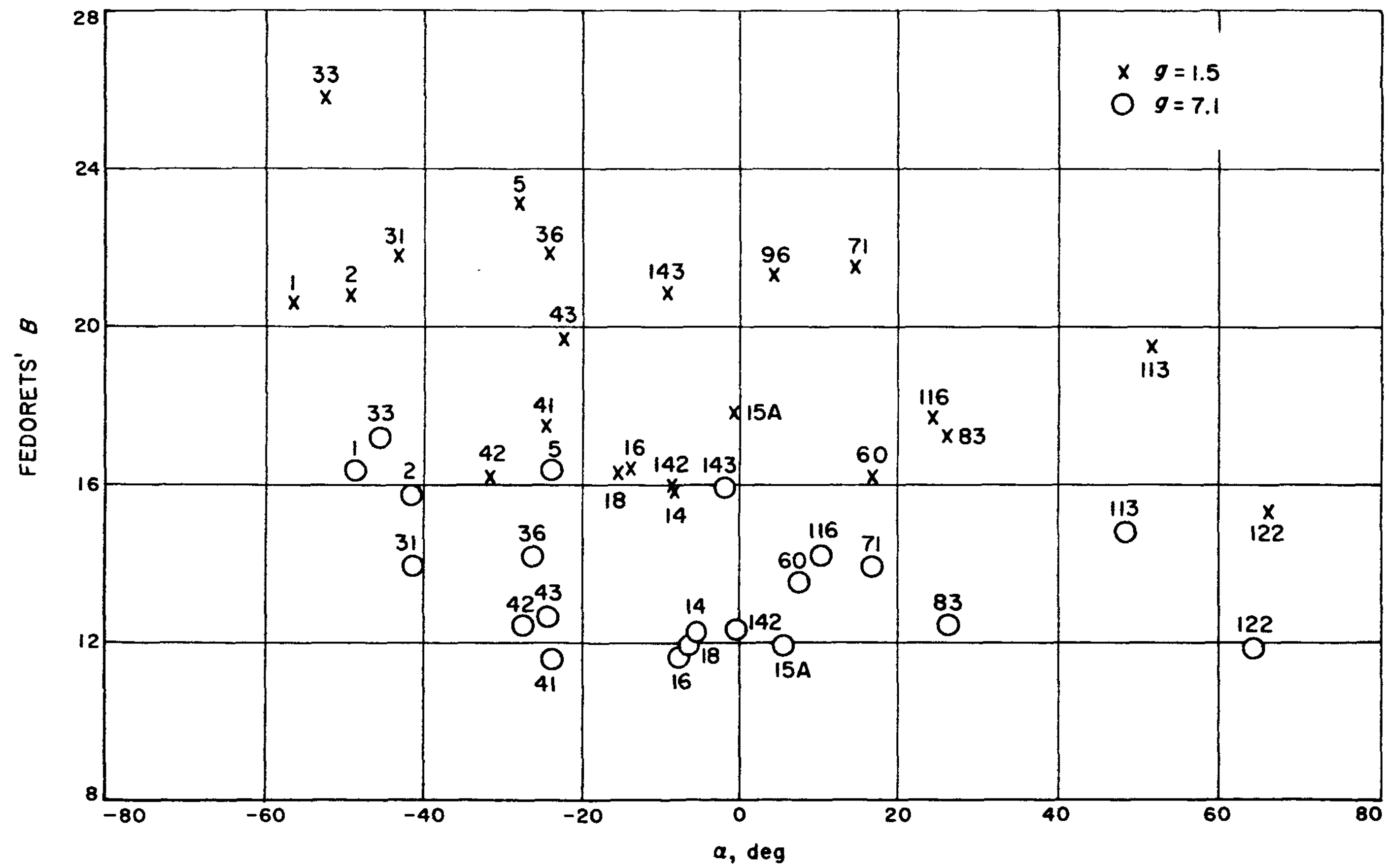

Fig. 3. Mare and crater floor data from Ref. 3 (no data adjustment)

III. OTHER PHOTOMETRIC DATA AND THE REVISED LUNAR REFLECTIVITY MODEL

It was felt necessary to study other data in view of the possible errors in Fedorets' work. The most complete work was that of a group of Russian astronomers lead by N. N. Sytinskaya and V. V. Sharanov in 1939 (Ref. 4). Furthermore, the data were obtained by direct lunar photoelectric observation, thus eliminating possible unknown photographic errors, and were in the form of a brightness factor ρ. That is, the data points were the

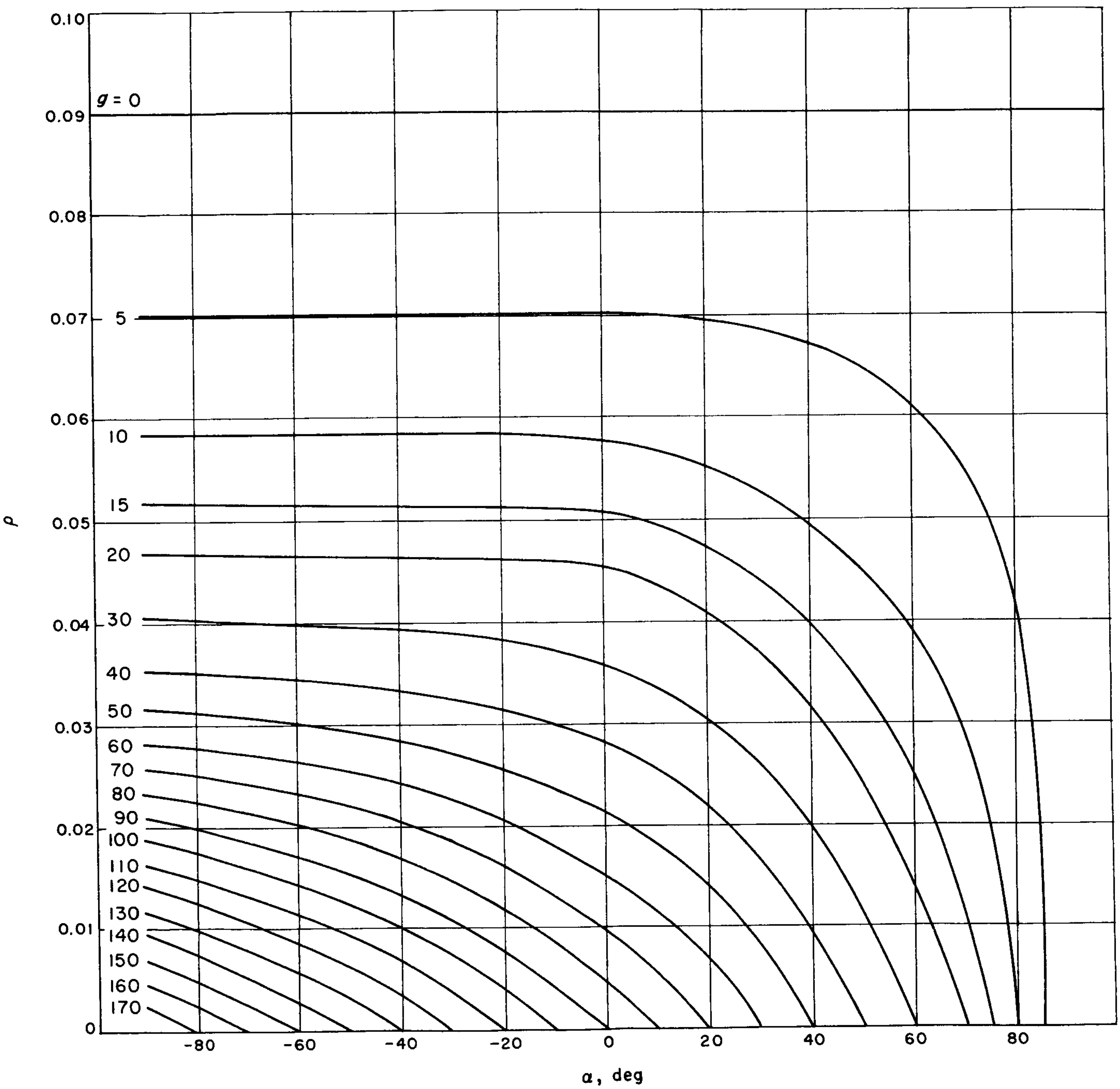

Fig. 4. Lunar reflectivity function from Ref. 4 (ρ vs. α)

ratio of the brightness of a surface area as viewed from a given direction to that of an absolutely white surface situated at the same point but normal to the incident rays of the Sun. Multiplication of this brightness factor by the solar illumination then gives the brightness of the surface.

Mare areas were selected from the multitude of areas observed and, after calculation of the auxiliary angle α, by use of the given incident, emission, and phase angles for each data point, the data were plotted. However, it became evident that errors were present in the given incident and emission angles so that recalculation of these values by use of ephemeris data was necessary.

It was further decided to plot the data without any form of normalization or adjustment. If the mare areas do have some common property, a correlation will be recognizable without data tampering; in addition, the data scatter will give some idea of the luminance extremes that may be encountered in mare areas.

Initial hand fits of the data were made by plotting constant phase vs. auxiliary angle for several phase values (see Fig. 1 for an example of this type of plot). Cross plots of these fits, as in Fig. 2, enabled a smoothing of the fitted curves to ensure functional consistency for all angles.

The resultant function is shown in Figs. 4 and 5. Since the revised function is not normalized and is a ratio of the luminance of the lunar surface to an ideal surface normal to the incident Sun rays, it already incorporates the full-Moon reflectivity. In order to avoid confusion, the revised function has been called the Lunar Reflectivity Model.

The above function is the one incorporated in the Flight Operations Programs for *Ranger 7*.

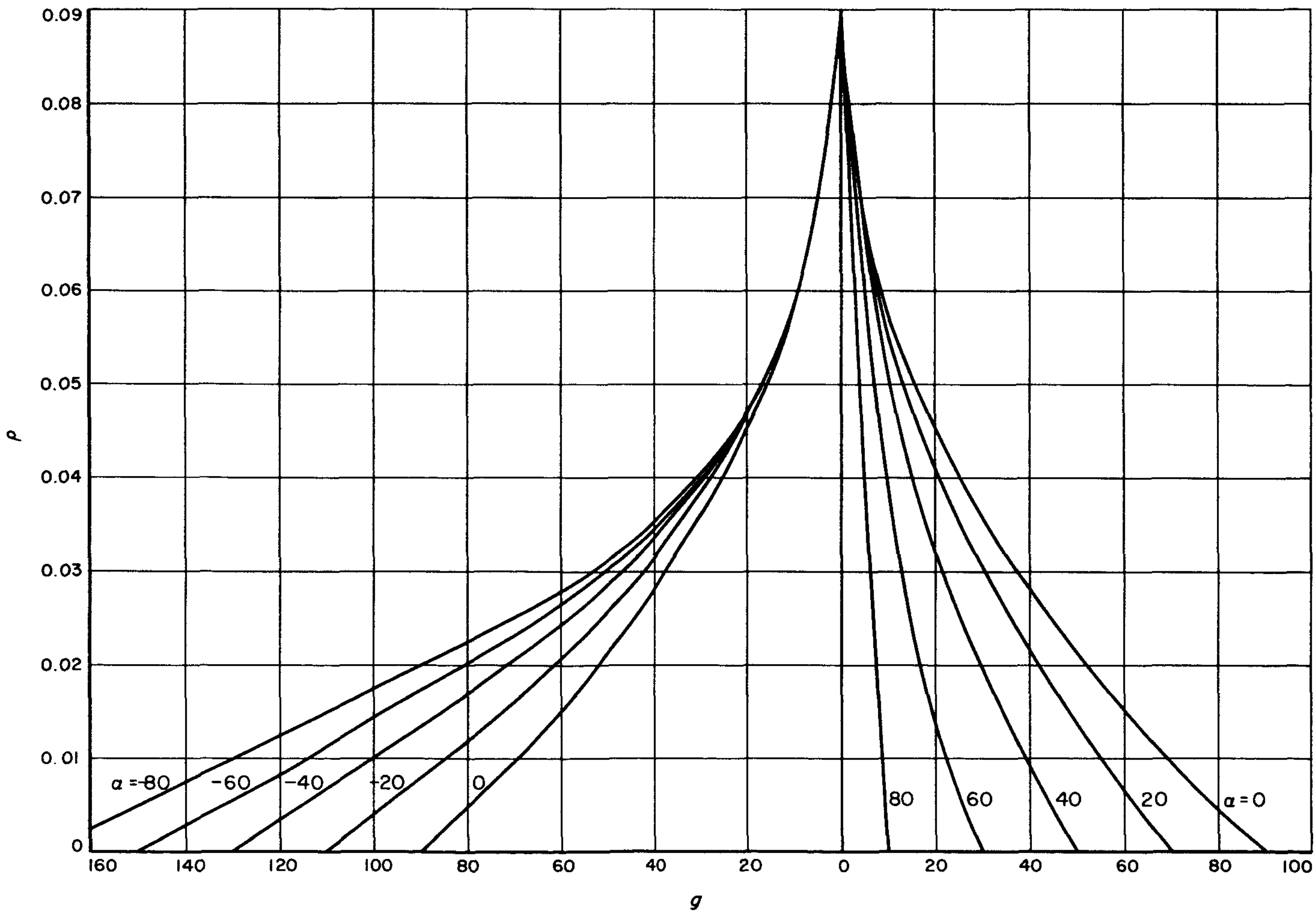

Fig. 5. Lunar reflectivity function from Ref. 4 (ρ vs. g)

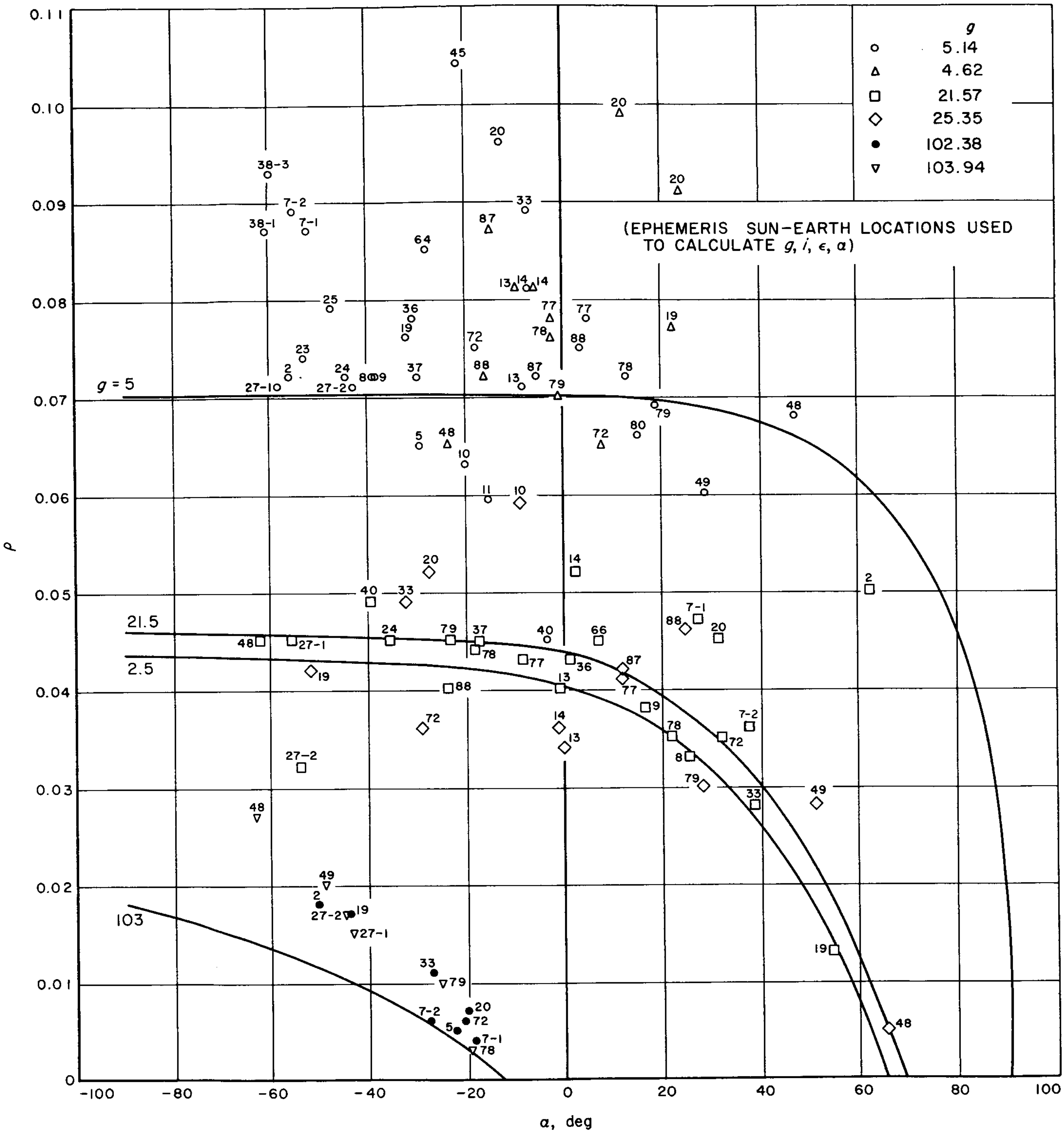

Fig. 6. Processed data from Ref. 4 (g = 5.14, 4.62, 21.57, 25.35, 102.38, 103.94)

Comparisons of the data scatter with the final function are shown in Figs. 6–9. The number above each data point is keyed to the observed area of the Moon in Ref. 4. Large data scatter is evident, and one will note that in some cases, the lines do not seem to fit the data well. This, of course, was necessitated by deriving a function which best fit all the data and was well behaved. In addition, the data for each phase angle represent a different night of observation, which adds to the scatter. In some cases, the data for a larger phase angle fall above the data for a smaller phase angle; examination of the overall data shows that such a property cannot be valid (for example,

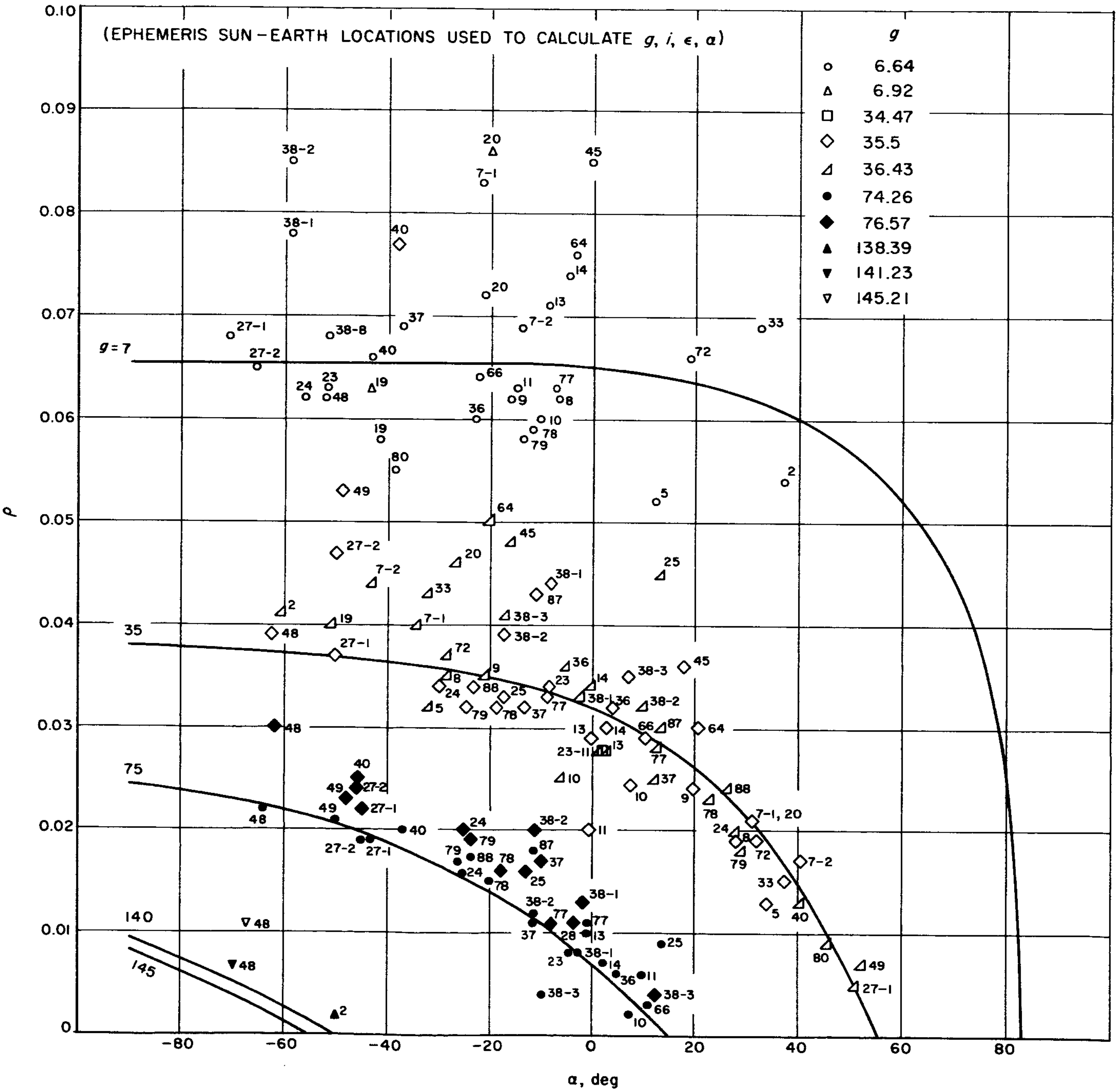

Fig. 7. Processed data from Ref. 4 (g = 6.64, 6.92, 34.47, 35.5, 36.43, 74.26, 76.57, 138.39, 141.23, 145.21)

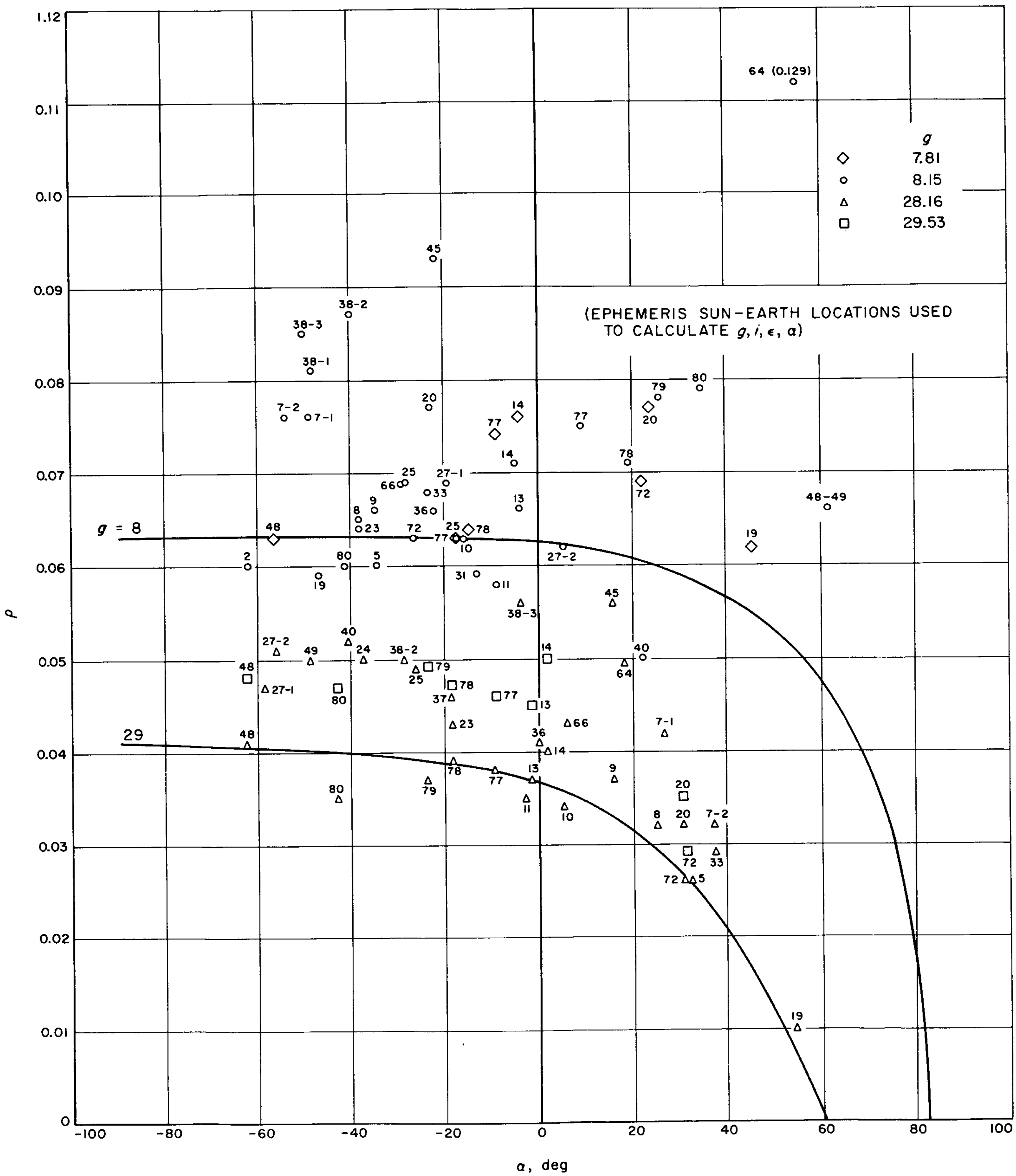

Fig. 8. Processed data from Ref. 4 (g = 7.81, 8.15, 28.16, 29.53)

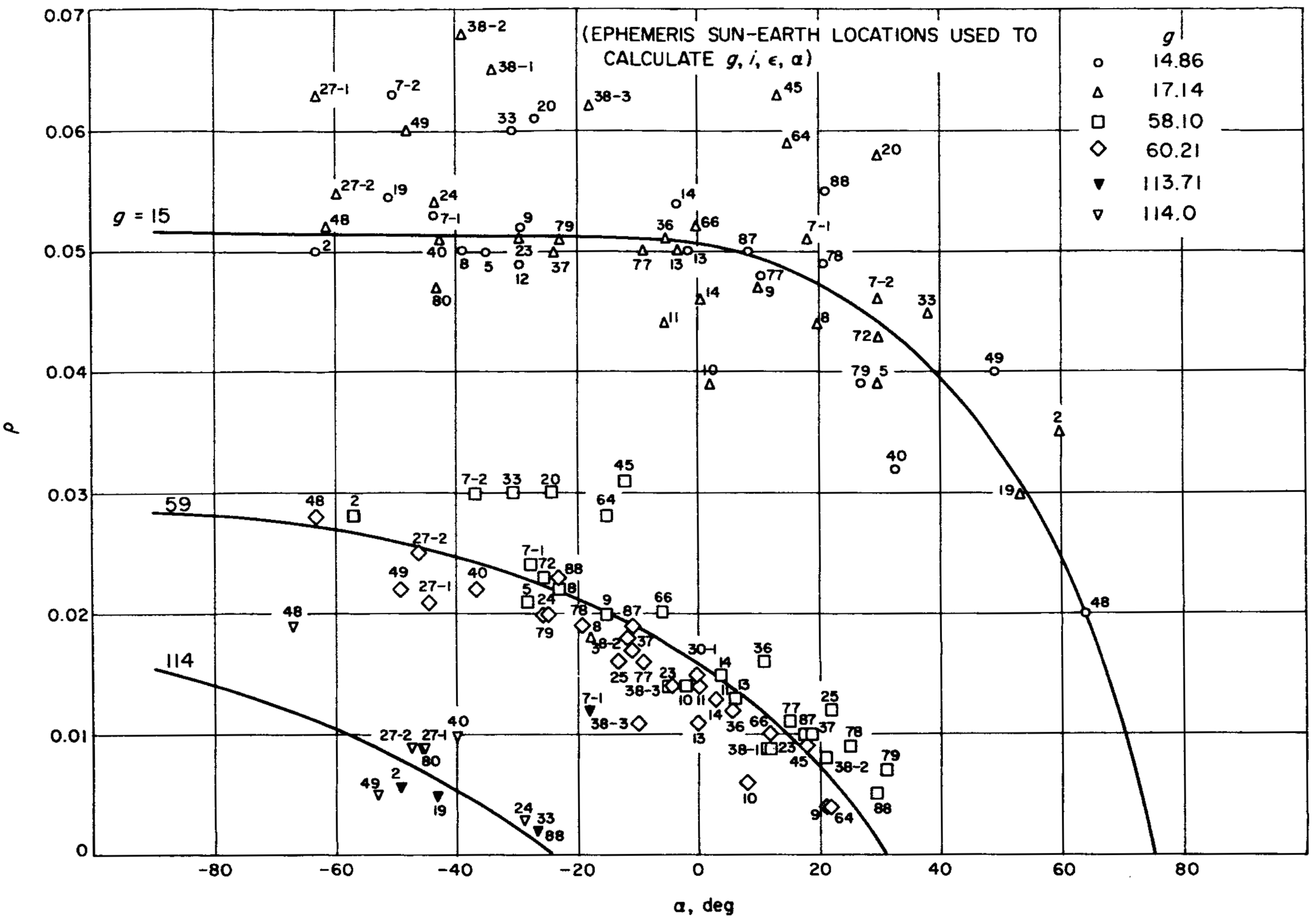

Fig. 9. Processed data from Ref. 4 (g = 14.86, 17.14, 58.10, 60.21, 113.71, 114.0)

g = 23.16 and 29.53 deg). One explanation of this phase overlap could be the fluorescence of the surface, a lunar property which is coming into acceptance.

The most important property of the function is the slope of the constant phase lines. It is felt that, in this respect, the revised function is much superior to the function of 1962. In Fig. 10, Fedorets' data from the selected mare and crater areas are plotted. Corresponding phase values are plotted from the revised Lunar Reflectivity Model after adjustment of the scale factor for a best fit of the Fedorets data at 7.1-deg phase. One will note that, in general, the slopes of the Fedorets data agree with the revised function.

By comparison, the near-terminator luminance values predicted from the revised Reflectivity Model are very nearly the same as those predicted by use of the old function. However, near full Moon, contrast values are much lower than before (from 15- to 0-deg phase).

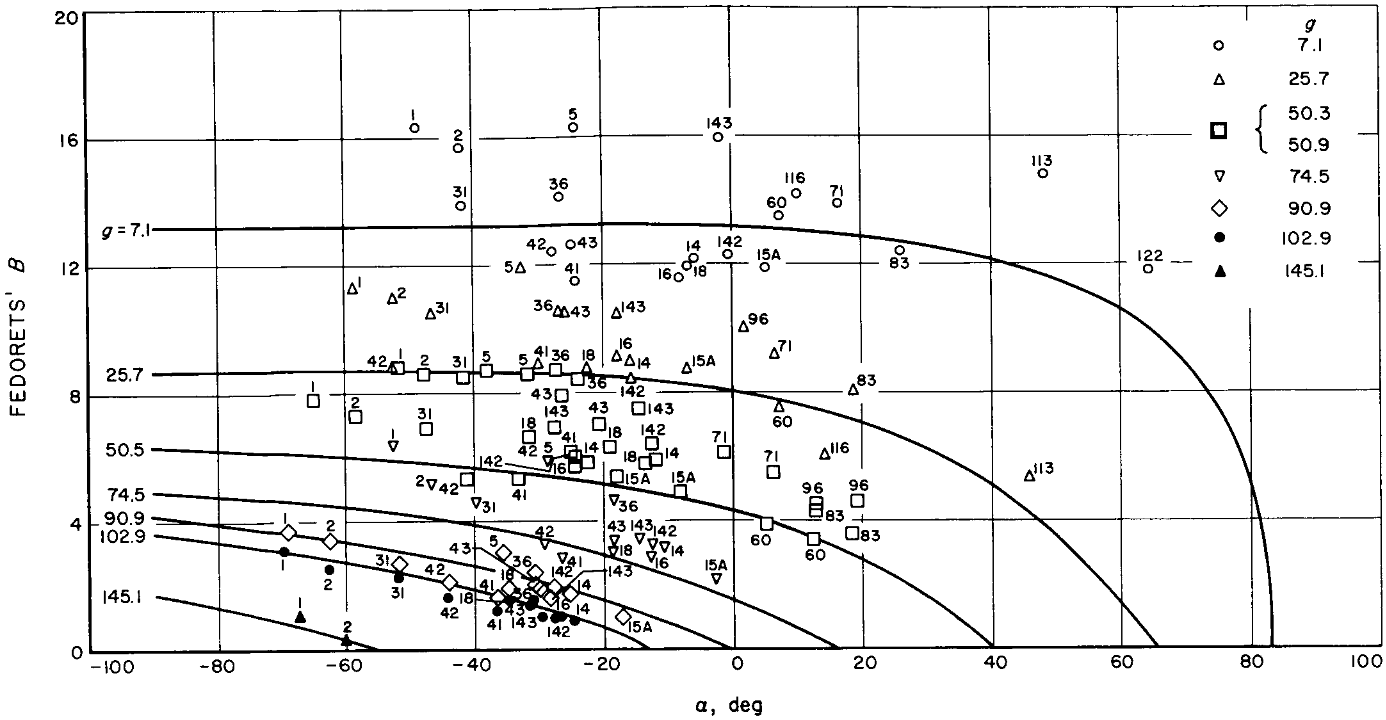

Fig. 10. Fedorets' mare and crater floors and reflectivity function from Ref. 4

REFERENCES

1. Van Diggelen, J., *Photometric Properties of Lunar Crater Floors,* Translation, Jet Propulsion Laboratory, Pasadena, California (no date).

2. Herriman, A., Washburn, H., and Willingham, D., *Ranger 3, 4, 5 Preflight Science Analysis and the Lunar Photometric Model,* Technical Report No. 32-384 (Revised), Jet Propulsion Laboratory, Pasadena, California, March 1963.

3. Fedorets, V. A., "Photographic Photometry of the Lunar Surface," *Reports of the Astronomical Observatory of the Charkow State University,* Vol. 2, 1952.

4. Sytinskaya, N. N., and Sharonov, V. V., *Study of the Reflecting Power of the Moon's Surface,* Translated by Space Technology Laboratories, Inc., Advanced Research Technical Information Center, STL-TR-61-5110-23, May 1961.