A lunar photometric function

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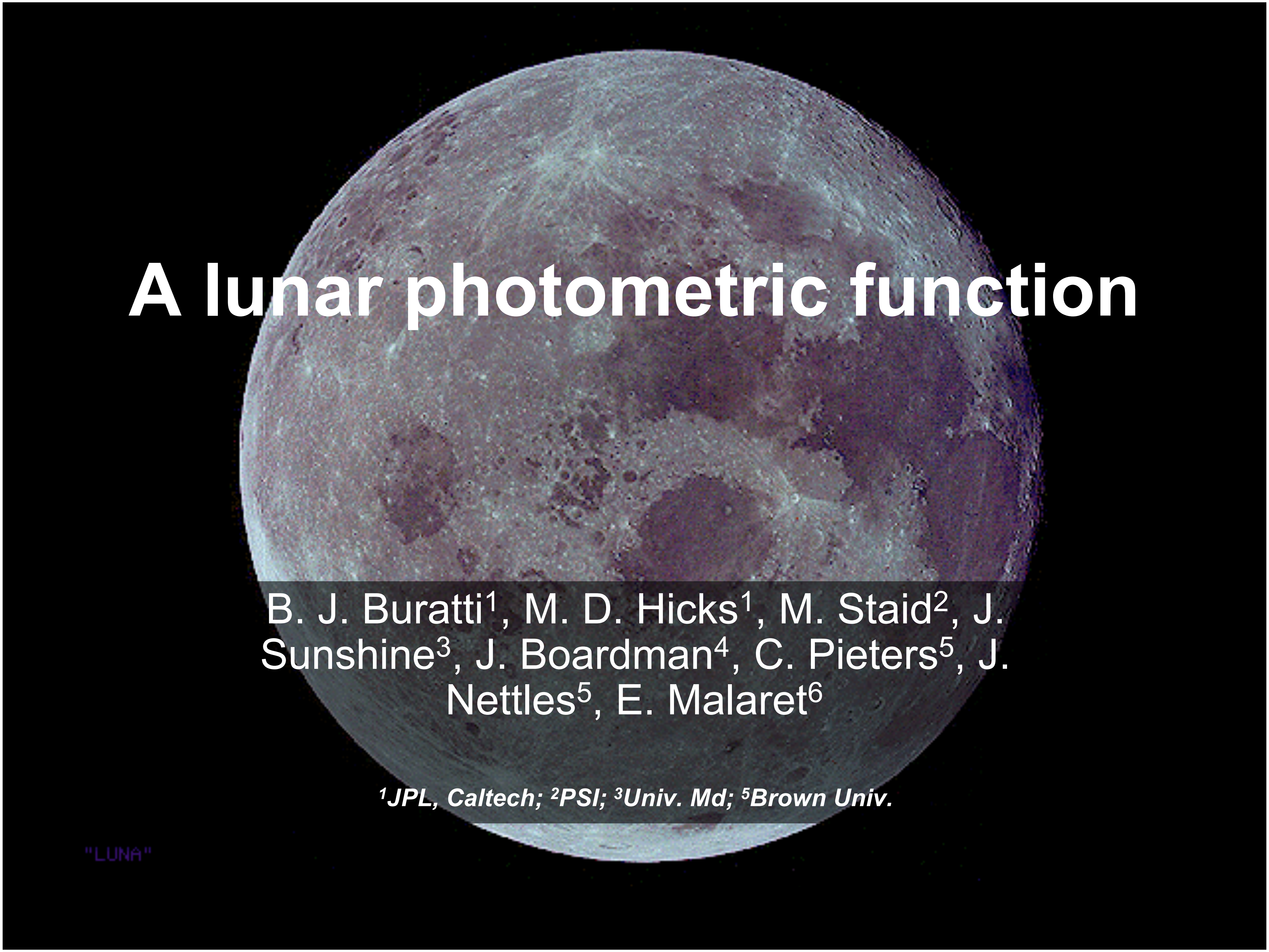


Background

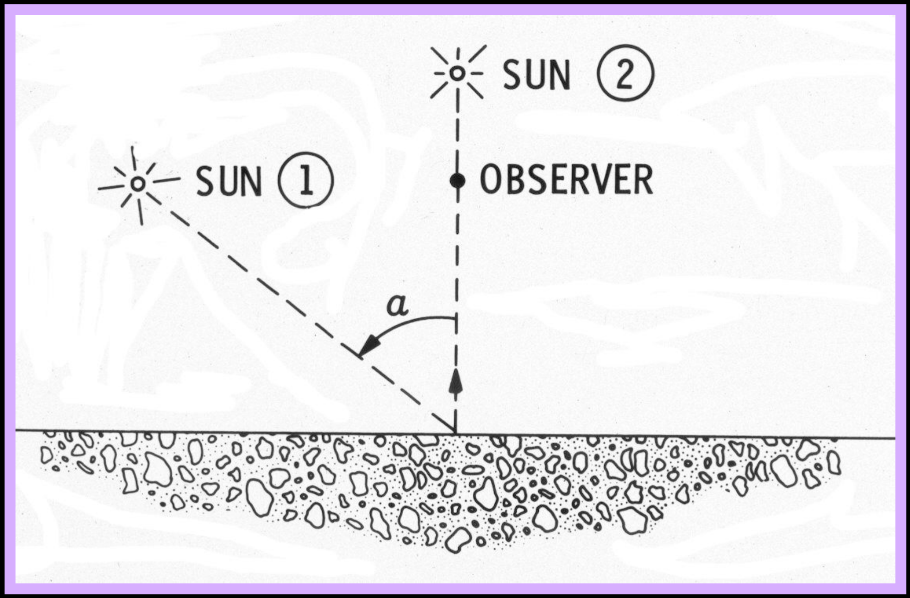
- **Most of the changes in intensity on a planetary surface are not intrinsic but rather due to variations in the radiance incidence, emission, and solar phase angle.**
- **The "job" of photometry is twofold: "Practical" and "scientific". The goal of practical photometry is to model these changes so that accurate instrument integration times can be calculated, and so data products of integrity can be produced.**
- **"Scientific" photometry aims to apply radiative transfer models to data to derive surface physical properties such as roughness, particle size, compaction state, and the single-scattering albedo.**

Changes in intensity on the Moon

The full moon exhibits no variations in I/F due to viewing geometry. At other phase angles, "limb darkening" and "limb brightening" occur. These changes follow the following function:

$$I/F = f(\alpha)\mu_o/(\mu_o + \mu)$$

where f(α) is the surface phase function and μ_o and μ are the cosines of the incident and emission angle. This function is a "Lommel-Seeliger" or lunar scattering law. F(α) describes changes in intensity on the surface due to phase angle alone; it contains the physical attributes of the surface (roughness, single particle phase function, etc.). μ_o and μ can be calculated from navigation routines

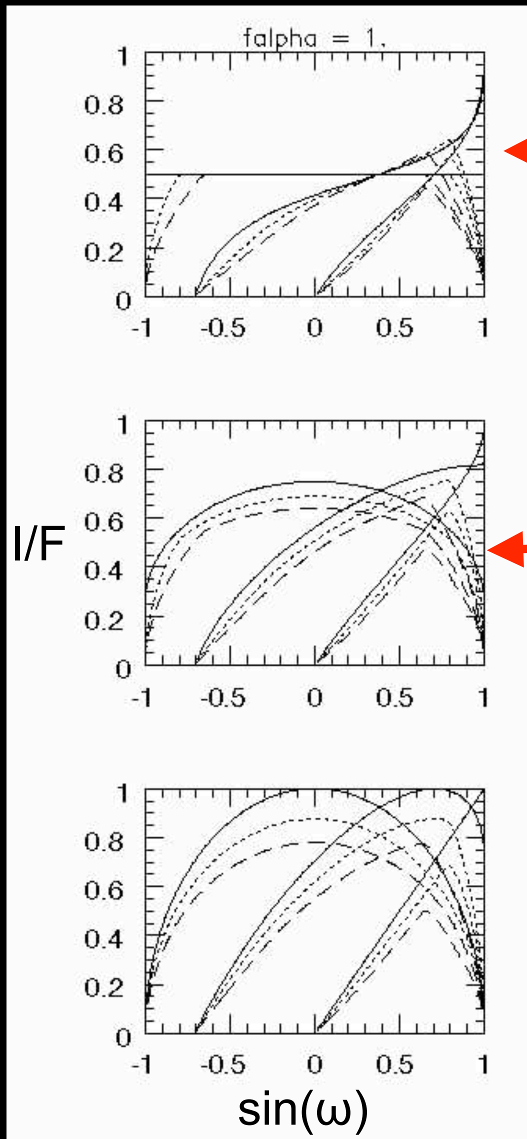


Examples of photometric models

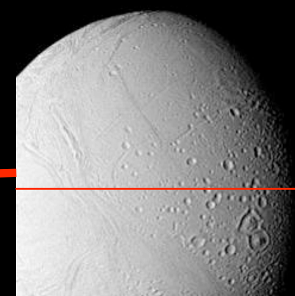
A lunar law

Lunar
+ Lambert

Lambert



The Moon



Enceladus

α = 0,45,90º

NO PLANETARY SURFACE IS LAMBERTIAN!!!!

Correct for limb-darkening, and normalize to reference phase angle:

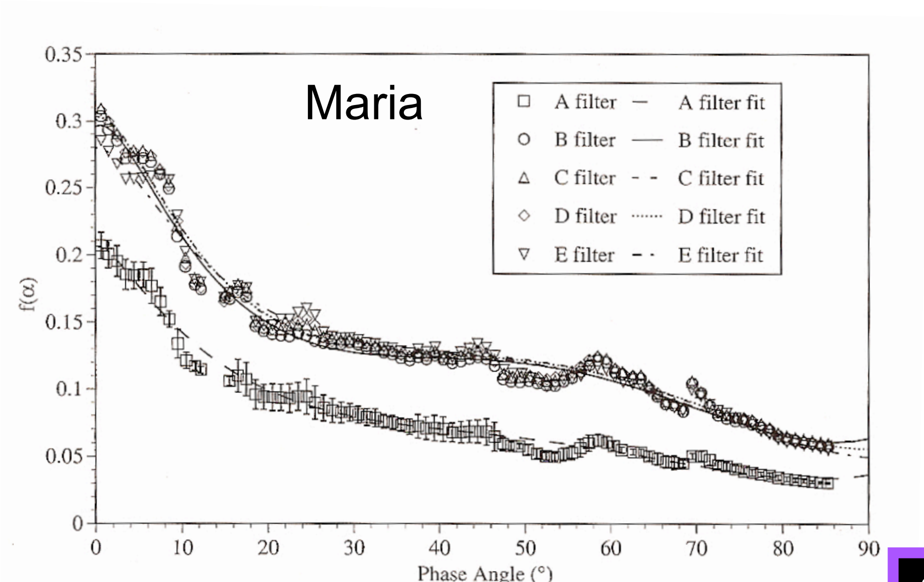
$$r_n = I/F(\mu_o + \mu)/\mu_o *f(\alpha)*0.5/f(0)$$

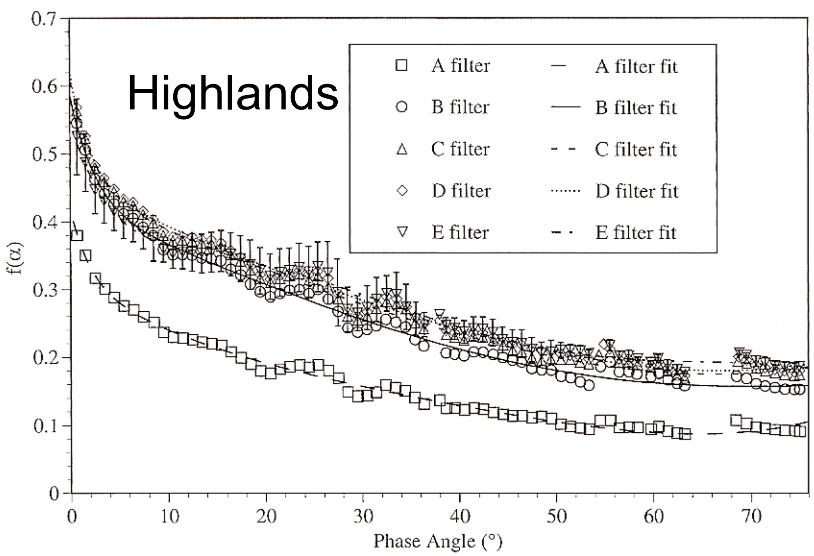
where r_n is the normal reflectance

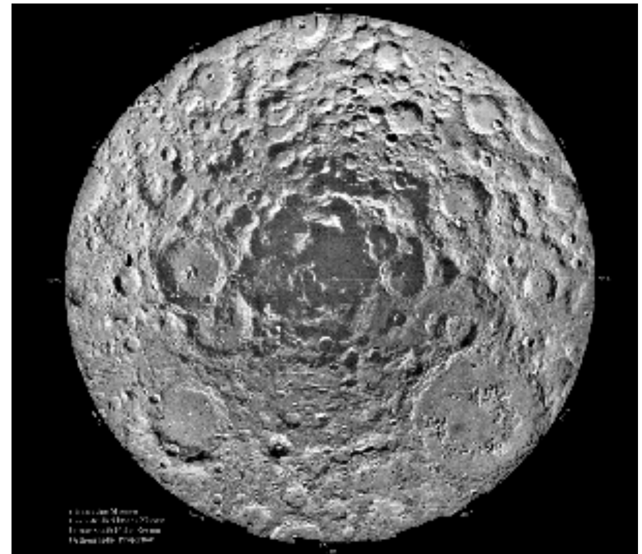
f(α), including f(0), can be derived empirically from a a number of data sets, including ROLO, Clementine, and now Chandrayaan-1 M3.

f(0)/2 = spectral geometric albedo

Example: Clementine best-fit f(α) functions for 0.415-1.0 µm







$$f(\alpha) = b_o e^{-b_1 \alpha} + a_o + a_1\alpha + a_2\alpha^2 + a_3\alpha^3 + a_4\alpha^4$$

Best Fit Parameters for the Empirical Photometric Function to the Maria and the Highlands

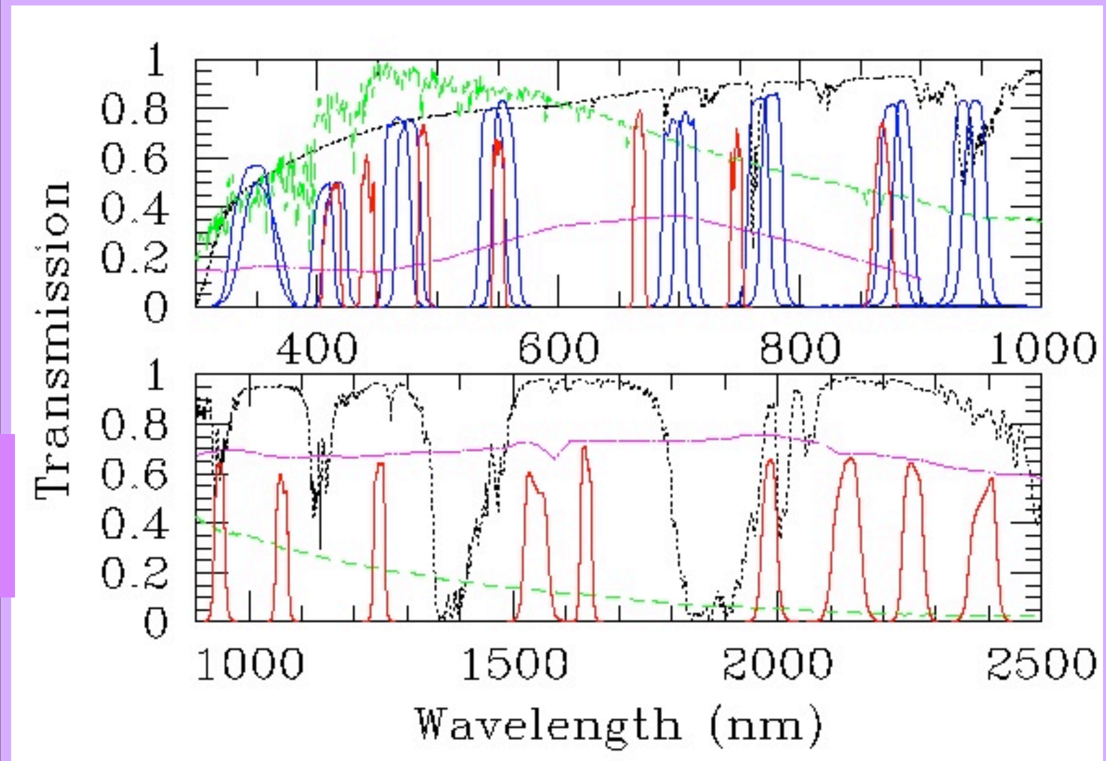
Filter	b_0	b_1	a_0	$a_1(\times10^{-3})$	$a_2(\times10^{-5})$	$a_3(\times10^{-7})$	$a_4(\times10^{-9})$
				Maria			
A	−0.0198	0.600	0.226	−11.08	30.82	−39.25	17.89
B	−0.0661	0.359	0.362	−20.01	61.78	−81.46	37.16
C	−0.0633	0.356	0.366	−19.76	60.27	−78.78	35.63
D	−0.0558	0.373	0.358	−18.73	55.84	−71.52	31.61
E	−0.0486	0.320	0.328	−15.23	44.10	−56.31	24.76
1 µm	−0.0557	0.350	0.351	−17.89	53.34	−68.79	30.63
				Highlands			
A	0.1053	0.541	0.316	−9.65	23.57	−37.46	24.18
B	0.1718	0.374	0.414	−4.48	−7.42	18.75	−9.26
C	0.1598	0.450	0.451	−6.72	3.81	−3.47	5.36
D	0.1589	0.498	0.461	−7.50	7.44	−9.37	8.42
E	0.3545	0.194	0.193	19.80	−89.65	136.01	−69.15
1 µm	0.1857	0.337	0.401	−1.18	−16.06	26.76	−11.13

Hillier et al., 1999

1.0-2.4 µm: The ROLO database

ROLO passbands

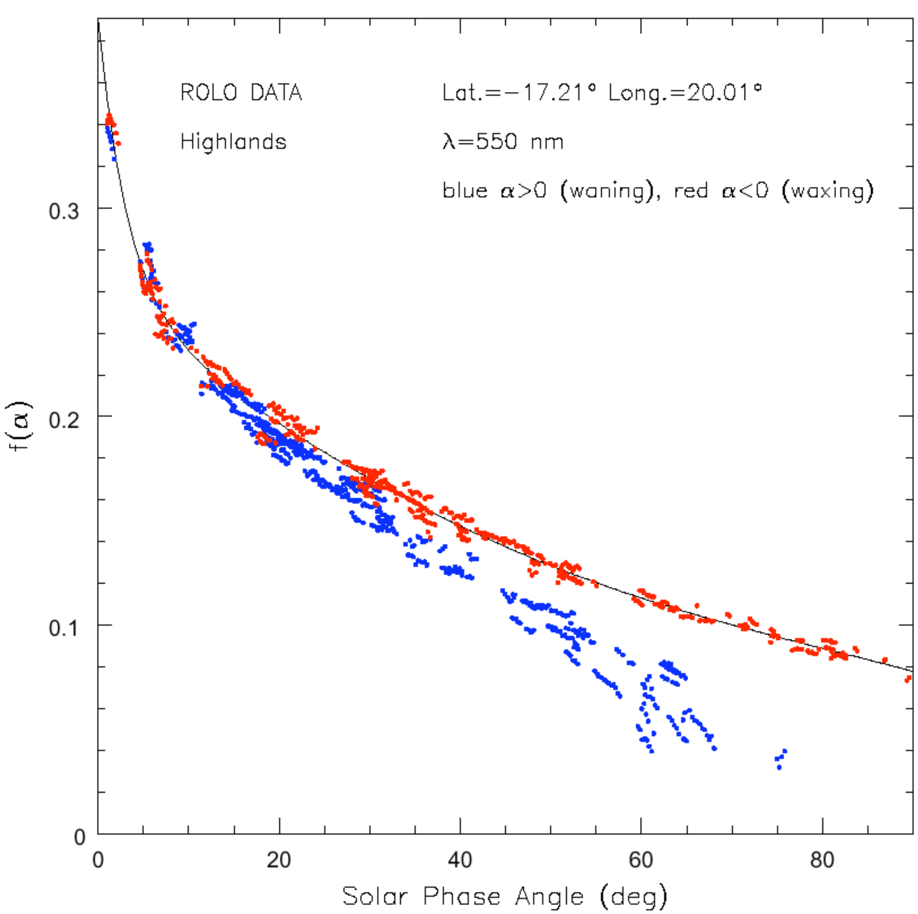
Phase angles covered 1.55-97º

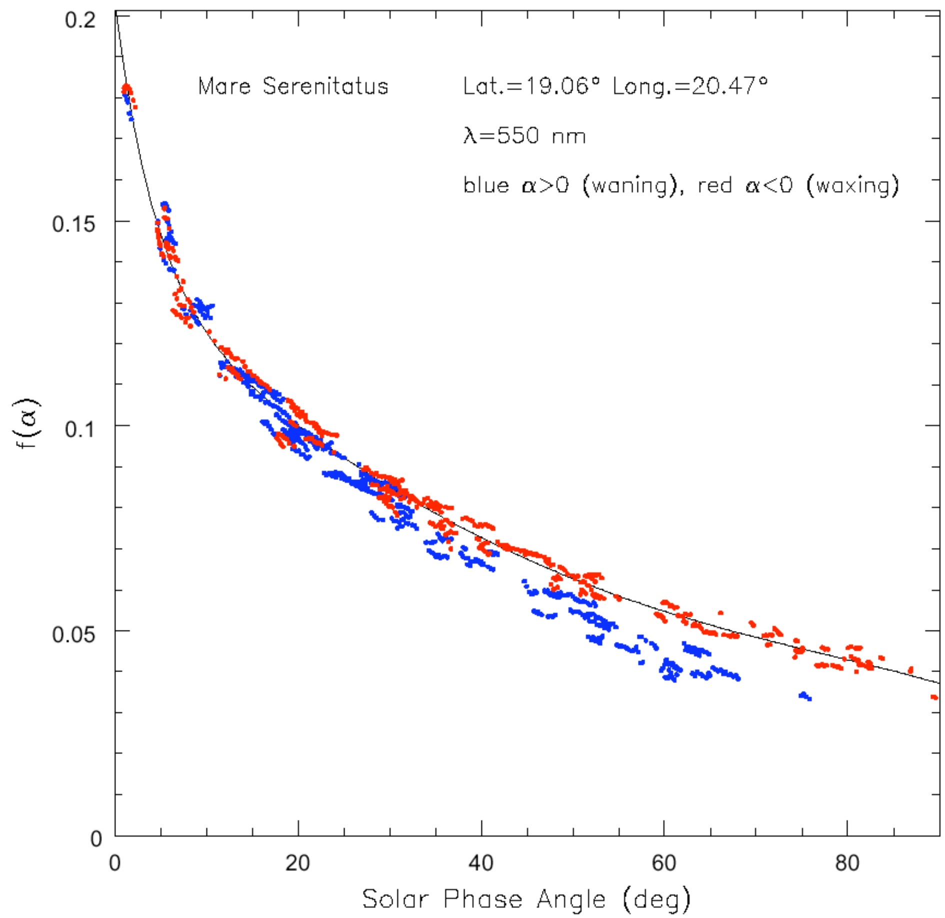


H. H. Keiffer and T.S. Stone (2005). The spectral irradiance of the Moon. *A. J.* 129, 2887-2901.

ROLO (Robotic Lunar Observer) is a dedicated telescope at USGS that has gathered and made available observations up to 2.4 µm. There is a "metadata" table for each observation that includes "sums of pixels in instrument units" plus the observation geometry. This is exactly what we need to extend the photometric model to longer wavelengths. Some data gathering, number crunching, and simple modeling is necessary to bring the data to the same state as the Clementine data, but it is all straightforward and "doable."

Examples of ROLO disk resolved solar phase function, $f_\lambda(\alpha)$





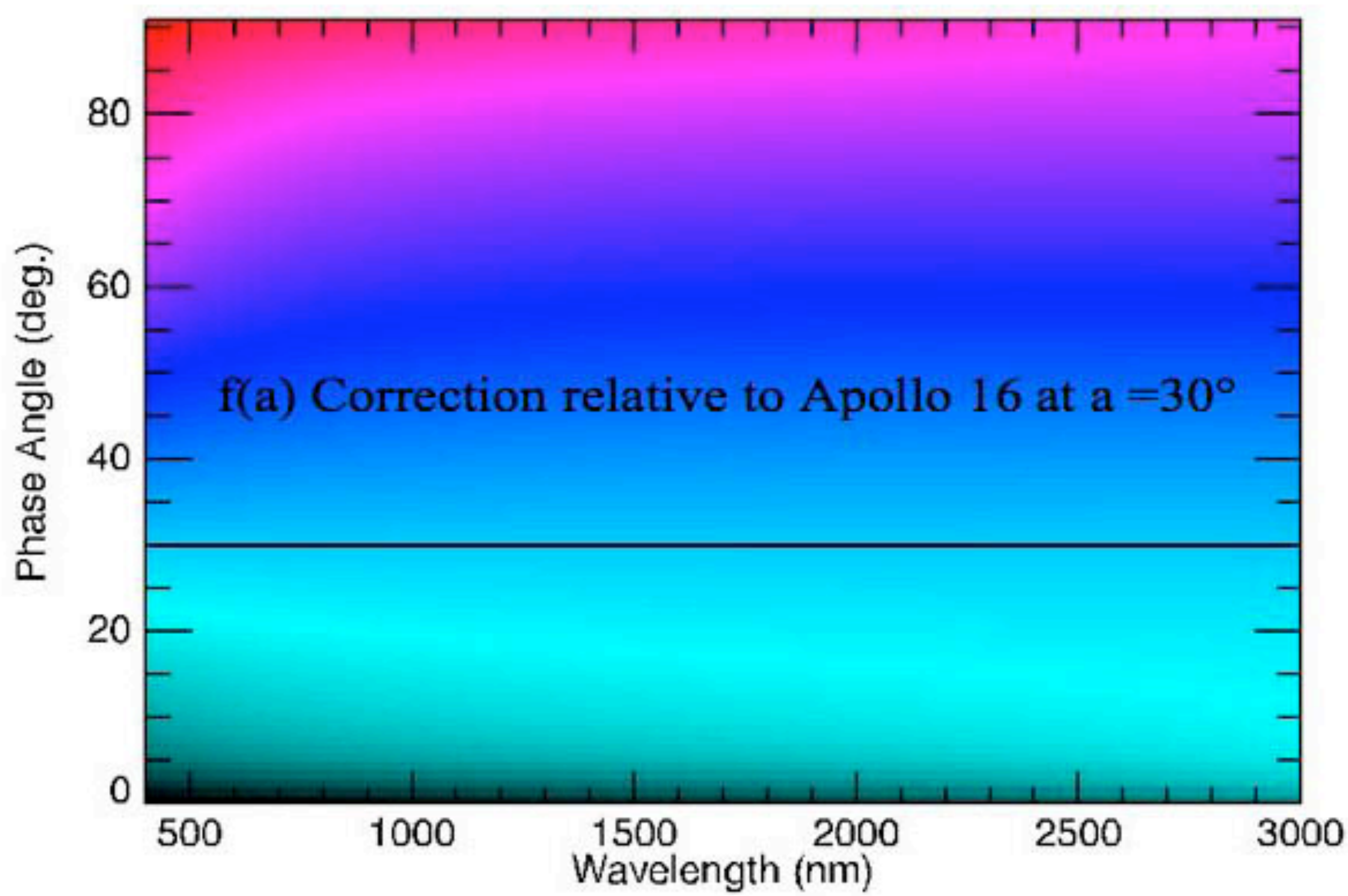
Waxing/Waning discrepancy: when the incident angle is large, rough features cast shadows and alter the local i,e angles from the perfect sphere we are assuming. The net effect is a decrease in the measured intensity for the waning phases. Fits have been made for both waxing and waning.

Fit of ROLO data to empirical equation

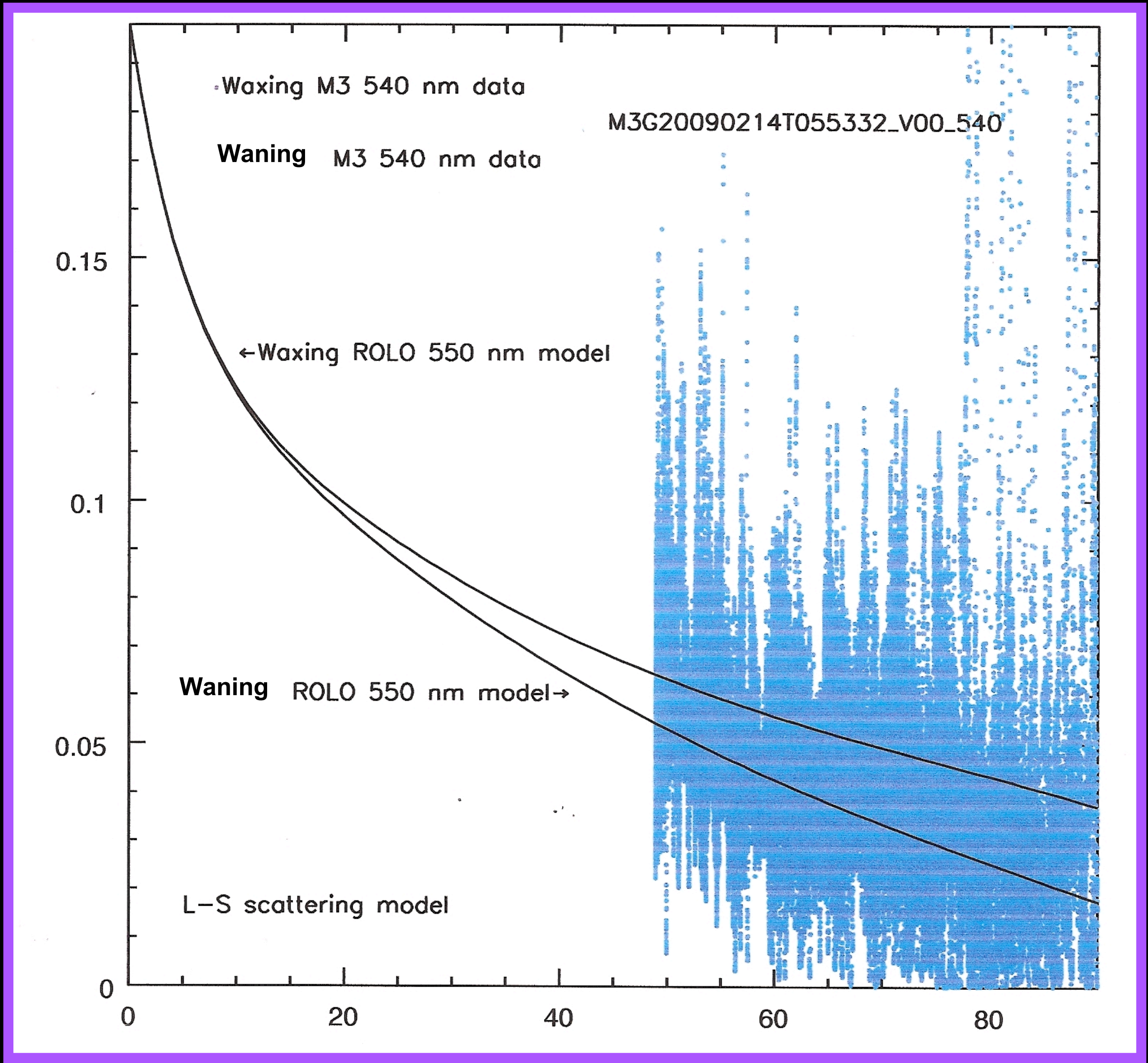
λ	channel	B_0	B_1	A_0	A_1	A_2	A_3	A_4
0347	V	0.1830	0.0359	0.0807	-0.1371	0.1016	-0.0092	-0.0213
0353	V	0.1670	0.0398	0.0786	-0.1141	0.0402	0.0577	-0.0478
0405	V	0.2000	0.0467	0.0995	-0.1625	0.1039	0.0191	-0.0400
0413	V	0.1900	0.0486	0.0994	-0.1631	0.1199	-0.0155	-0.0198
0415	V	0.1850	0.0490	0.0984	-0.1535	0.0919	0.0211	-0.0383
0442	V	0.2200	0.0503	0.1126	-0.2091	0.2176	-0.1114	0.0138
0467	V	0.1740	0.0580	0.1072	-0.1407	0.0239	0.1109	-0.0774
0476	V	0.1900	0.0544	0.1155	-0.1808	0.1167	0.0143	-0.0406
0488	V	0.2140	0.0554	0.1209	-0.2088	0.1845	-0.0581	-0.0126
0545	V	0.1820	0.0697	0.1242	-0.1299	-0.1056	0.3244	-0.1856
0550	V	0.2020	0.0653	0.1322	-0.1891	0.0786	0.0873	-0.0794
0555	V	0.1940	0.0668	0.1301	-0.1684	0.0123	0.1741	-0.1194
0667	V	0.2420	0.0751	0.1661	-0.2718	0.2389	-0.0828	-0.0119
0695	V	0.2060	0.0763	0.1615	-0.2146	0.0638	0.1344	-0.1070
0706	V	0.1950	0.0843	0.1573	-0.1654	-0.0769	0.2973	-0.1743
0747	V	0.2510	0.0754	0.1849	-0.3226	0.3544	-0.2184	0.0453
0766	V	0.2000	0.0777	0.1751	-0.2456	0.1532	0.0114	-0.0506
0777	V	0.2020	0.0812	0.1741	-0.2225	0.0618	0.1383	-0.1095
0868	V	0.2140	0.0863	0.1838	-0.2465	0.1148	0.0714	-0.0772
0875	V	0.2030	0.0866	0.1774	-0.2027	-0.0152	0.2359	-0.1511
0885	V	0.2100	0.0867	0.1797	-0.2168	0.0207	0.1958	-0.1349
0935	V	0.1830	0.0888	0.1741	-0.1579	-0.1557	0.4259	-0.2426
0944	V	0.1860	0.0831	0.1794	-0.1943	-0.0553	0.3151	-0.2009

λ	channel	B_0	B_1	A_0	A_1	A_2	A_3	A_4
0944	I	0.1700	0.1352	0.1467	0.1190	-1.0138	1.4590	-0.6728
1062	I	0.2230	0.1139	0.2078	-0.2390	0.0309	0.2173	-0.1646
1247	I	0.2510	0.1416	0.2411	-0.1913	-0.3161	0.7924	-0.4712
1543	I	0.2650	0.1381	0.3013	-0.3251	0.0771	0.2042	-0.1774
1638	I	0.2500	0.1459	0.3094	-0.2958	-0.0183	0.3414	-0.2584
1985	I	0.2060	0.1883	0.3024	0.0667	-1.1542	1.5768	-0.6852
2132	I	0.2650	0.1048	0.3928	-0.5994	0.9454	-1.3068	0.6721
2256	I	0.2830	0.1319	0.3925	-0.3849	0.0953	0.1415	-0.1275
2390	I	0.2590	0.1606	0.3909	-0.0659	-0.9753	1.3711	-0.5908

Solar phase correction, averaged and interpolated



M3 First Results



Summary

- A new lunar solar surface phase function has been derived from ROLO data
- This empirical function can be used to correct a wide range of lunar data for viewing geometry
- The function has been validated on M3 observations