THE OPPOSITION EFFECT OF THE MOON AS SEEN BY THE LUNAR RECONNAISSANCE ORBITER WIDE ANGLE CAMERA. B. Hapke[1], B. Denevi[2], H. Sato[3], M. Robinson[3]. ([1]Dept of Geology & Planetary Science, Univ. of Pittsburgh, Pittsburgh, PA 15260. [2]Applied Physics Lab., [3]Arizona State Univ.)

Introduction: The narrow surge in the intensity of sunlight scattered from the Moon near zero phase has been known since its discovery by Gehrels et al [1] in 1962. It has been studied extensively from the Earth and spacecraft (see Shkuratov et al [2] for a detailed review). We have analyzed data obtained in the vicinity of the zero phase point by the wide angle camera (WAC) on the LRO spacecraft to study the opposition effect (OE) at 7 wavelengths between 320 and 690 nm. Both the shadow hiding OE (SHOE) and coherent backscatter OE (CBOE) appear to have contributed to the OE. No dependence on wavelength was seen, contrary to theoretical predictions.

Observations: Three different types of observations were analyzed. (1) The light scattered from various points within a discrete region in a single image around the zero phase point located at 10.4°E, 3.0°S on 3 Oct. 2009 was measured as a function of the angles of incidence i, viewing e and phase g. (2) Light scattered from various points within a region 3° wide centered at 271.5°E, 0°N north of M. Orientale was measured in a large number of images taken at various times and phase angles. (3) Light scattered from a single pole-to-pole scan through the zero phase point located at 272.5°E, 3.0°S on 30 Sept. 2010 was measured. The angles were corrected for local slopes using a Lunar Orbiter Laser Altimeter shape model.

Analysis: The LRO WAC has been described in Robinson et al [3]. Observational data sets 2 and 3 were analyzed using a simplified version for the bidirectional reflectance r(i,e,g) in Hapke [4]

$$\text{IoF/LS} = [(\mu_0+\mu)/\mu_0]\pi r(i,e,g) = [w/4][p(g)+H(\mu_0)\,H(\mu)][1+B_0B(g)], \quad (1)$$

where $\mu_0 = cos i$, $\mu = cos e$,

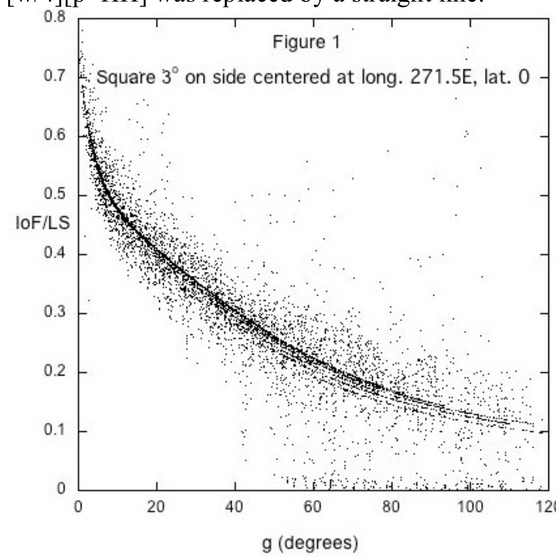
$$p(g) = \frac{1-\xi^2}{\left(1-2\xi\cos g+\xi^2\right)^{3/2}},$$

$$H(x) = (1+2x)/(1+2x\sqrt{1-w}),$$

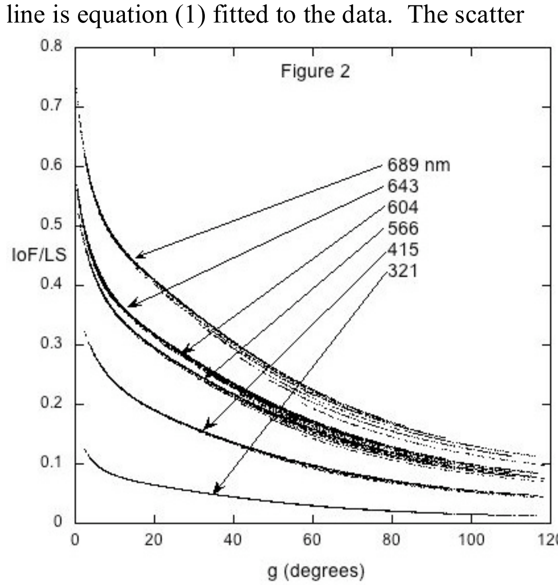
$$B(g) = \frac{1+\dfrac{1-\exp\left[-\tan(g/2)/h\right]}{\tan(g/2)/h}}{2\left[1+\tan(g/2)/h\right]^2}.$$

Eq. (1) contains 4 free parameters: w = single scattering albedo, ξ = mean value of $cosg$, B_0 = amplitude of the OE, h = OE angular width parameter. In eq. (1) we describe the OE is by an effective CBOE because studies of Apollo soil samples [5] show that the CBOE dominates the lunar OE.

For data set 1 the range of phase angles was insufficient to constrain w and ξ, so the factor [w/4][p+HH] was replaced by a straight line.



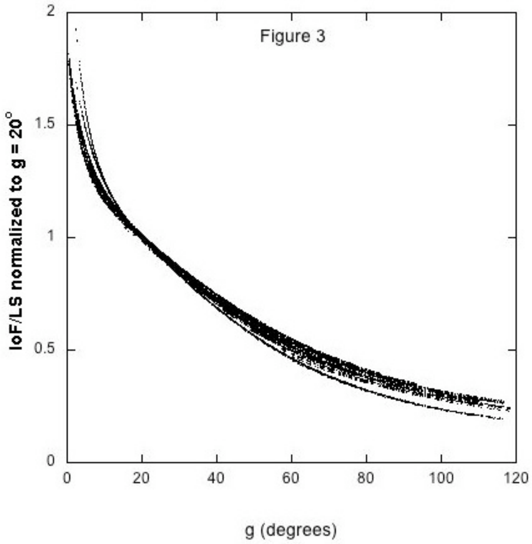
Results: Fig. 1 shows a typical result, in this case, the 689 nm filter from data set 2. The points are the data plotted as *IoF/LS* vs *g*, and the line is equation (1) fitted to the data. The scatter



of the points is caused by differing albedos.

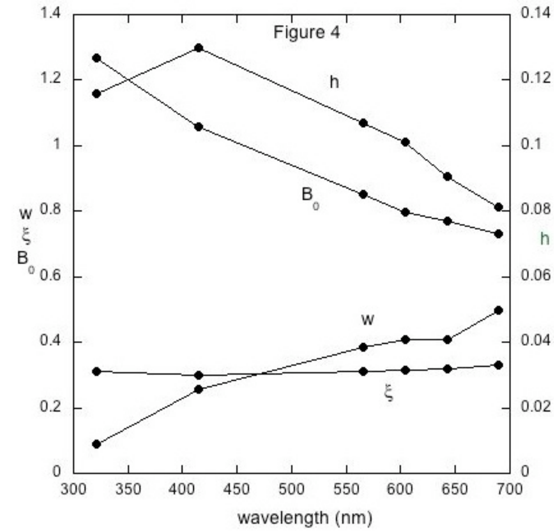
Fitted lines from all filters in data set 2 are shown in Figure 2. At large phase angles the lines divide into parallel mulltiples because of the influence of the multple scattering factor $H(\mu_0)H(\mu)$.

Figure 3 shows the same data in figure 2 normalized at g = 20°. It is apparent that there is little difference in the shapes of the curves for the various wavelengths, and in particular, in the angular widths of the OE.



Discussion: Figure 4 plots the values of the fitted parameters against wavelength. This figure shows that the single scattering albedo *w* increases with wavelength, consistent with the reddish spectrum of the Moon, and that the shape of the single particle phase function, determined by *ξ*, is virtually constant.

The amplitude B_0 of the OE decreases with wavelength and is > 1 at short wavelengths. This result shows that the SHOE contributes to the OE in addition to the CBOE, especially at short wavelengths where multiple scattering is small.



All theoretical models of the CBOE predict that the angular width should be proportional to the wavelength divided by the particle separation. However, a large number of laboratory studies (reviewed in [6]), including measurements on lunar samples, find little dependence on either property in media of touching particles larger than the wavelength. Also, the less well-calibrated cameras on Clementine hinted that the lunar OE may be independent of wavelength [2]. Some theorists remain skeptical of these results and have implied that there are errors in the measurements. The well-calibrated LROC *in situ* observations of the Moon now confirm the terrestrial laboratory studies: the width parameter h is virtually constant and may actually decrease slightly with wavelength. Evidently our present theoretical understanding of the CBOE is incomplete.

References: [1] Gehrels et al (1964). *Astron. J.* 69, 826. [2] Shkuratov et al (1999). *Icarus* 141,132. [3] Robinson et (2010). *Sp. Sci. Rev.* 150, 81. [4] Hapke (2002). *Icarus* 157,523. [5] Hapke et al (1993). *Science* 260, 509. [6] Hapke and Nelson (2010). *JQSRT* 111, 643.