E. PHOTO-ELECTRIC OBSERVATIONS OF STELLAR OCCULTATIONS

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THE VALUE OF PHOTOELECTRIC OCCULTATION TIMINGS IN LUNAR MOTION STUDIES

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Abstract. The two most important advantages of photoelectric timings of occultations over visual timings are accuracy and freedom from systematic error. The observational error is so small compared with uncertainties in the lunar ephemeris, star positions, limb corrections, and such, that the value of the observations will continue to increase as time goes on and the other error sources are eliminated.

A recent result made possible largely by the availability of photoelectric timings over the last 20 yr is a new value for the secular acceleration of the Moon, with corresponding consequences for the Ephemeris Time scale.

An important current application for simultaneous photoelectric and visual observations is the determination of 'personal equation' for the visual observers. Experiments so far indicate the visual observers require a minimum of 0.1 sec to detect that an event has occurred, plus additional time to react to it; hence, typical personal equations are around 0.4 sec.

The value of occultation timings in lunar motion studies has been known for some time. Occultations offer several advantages over other competitive optical methods for observing the Moon, such as transit circles or dual-rate Moon cameras. Major advantages are the small mean error achievable in a single observation, and freedom from instrumental errors. But above all else must be mentioned the independence of occultation timings from any particular coordinate system, since only the time of the event is measured. Although the coordinates of the occulted star enter the reduction process, they are not part of the observation itself. Hence, the value of the observations continues to increase with passing time, as better star positions and lunar theories become available.

In addition to refinement of orbital elements for the Moon, the occultations provide information about the positions of the occulted stars, and the fundamental reference system on the celestial sphere. Equinox, equator, and obliquity corrections may be obtained with great precision and relative freedom from systematic error (e.g. Duncombe and Van Flandern, 1970). In the case of certain grazing occultations, relative displacements between the star and the Moon's limb may be measured with a precision of a few thousandths of an arc second, making them useful for the measurement of the relative displacements of geodetic datums on the Earth (Dunham, 1970). These latter two applications provide an immediate answer to the question, 'Will lunar laser observations make occultation observations obsolete'? After a sufficiently long period of time, the laser results may determine the Moon's orbital elements with greater precision; but they measure nothing about the stars or the fundamental reference system, and are sensitive to the geodetic coordinates of only a limited number of observing locations.

The determination of Ephemeris Time (ET) is another important application of lunar observations aided by occultations. ET is a uniform gravitational time scale,

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which is in principle independent of Atomic Time, although measurable at any epoch only to about 10^{-2} sec. Recently, studies of occultations back to 1627 (Martin, 1969), when combined with modern occultation data, have shown the need for major revisions of the Ephemeris Time scale (Van Flandern, 1970).

The special advantages offered by photoelectric timings of occultations for lunar motions are accuracy and freedom from systematic error. The accuracy of timings by this method is so great compared with uncertainties in the lunar ephemeris, star positions, limb corrections, and such, that for present purposes the observations may be regarded as 'perfect'.

An important current application for simultaneous photoelectric and visual observations is the determination of 'personal equation' to calibrate the observations of the visual observers. Preliminary results (Sinzi and Suzuki, 1967) indicate a surprisingly large value for the mean personal equation of visual observers, which seems to imply that perhaps 0.1 sec or so is required for an observer to detect that an event has occurred, plus an additional few tenths to react to it. Personal equation seems to be a function of magnitude and seeing, and becomes rapidly larger (even greater than one second) as the object approaches threshold visibility, as illustrated by Sinzi and Suzuki.

A good distribution of the observations around the lunar orbit is very important for some purposes. In addition, there is no *a priori* reason to believe that personal equation for the visual observers has the same behavior for reappearances as for disappearances. For both of these reasons, the primary need for photoelectric data in lunar motion studies at the moment is for reappearance observations. Admittedly, these are enormously more difficult to observe than disappearances. Differential refraction and instrument flexure must be estimated accurately over a period of perhaps an hour or more, for the star to reappear within the tiny diaphragm. However, the scientific value of these observations is great enough to merit additional investment in observational techniques for achieving success in observing reappearances photoelectrically.

In summary, then, timings of photoelectric observations of occultations are of great interest and importance in lunar motion studies, both now and for the foreseeable future. They supply the extended precision needed to keep optical observations competitive with laser and spacecraft data, and supply additional information about the fundamental reference system.

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