MOONSHINE VERSUS EARTHSHINE: PHYSICS MAKES A DIFFERENCE. T. L. Wilson[1], [1]NASA, Johnson Space Center, Houston, Texas 77058 USA.

Introduction: The scattering of astronomical light by the Earth-Moon system is a subject of much importance, ranging from surface properties of the Moon [1] and the backscatter albedo of the Earth's atmosphere [2, 3] to the solar radiation constant and issues of global warming. Moonshine is the term for sunlight reflected by the Moon and illuminating portions of the Earth. Earthshine is the reciprocal, being that portion of sunlight reflected by the Earth and illuminating the Moon. The latter is the basis for astronomical scattering studies of the dark portion of a crescent Moon as well as for measuring attributes of the Earth's atmospheric albedo. By symmetry, the two terms are interchanged under reciprocity for an Earth-based optical observer O (Figure 1).
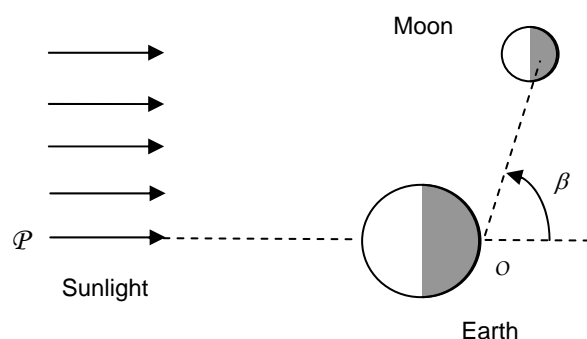

Figure 1. Scattering geometry of sunlight in the Earth-Moon system.

However, for a Moon-based observer the reciprocity fails (a broken symmetry). The reason is that the Moon has no appreciable atmosphere and is directly bombarded by a charged particle flux of cosmic rays (CRs) and solar wind material, while the Earth's surface is not. The consequence is that the lunar surface has a small CR albedo which is absent from the Earth's surface (althouth it is present at the top of Earth's atmosphere as a neutron albedo [4], a property since corroborated by AMS [5]). Therefore, a lunar-based observer standing in the dark of the Moon does not see Earthshine, but rather Earthshine plus CR albedo. On the far side of the Moon where there is no Earthshine, the same observer still sees CR albedo. The effect is a local one not noticed by remote sensing from Earth or spacecraft, although transient optical events on the Moon have been discussed for centuries [6-10].

A thermal albedo also exists as part of the photon radiation emitted by the Earth or Moon in Figure 1, and is one method for arriving at a planetary temperature at thermal equilibrium. Nevertheless, it is infrared and does not contribute to the optical luminescence of the Moon, whereas Earthshine and CR albedo do.

Cosmic-Ray Albedo of the Moon: The broad discipline involved is particle astronomy, introduced in [11] as a subdiscipline of particle physics. One definition of albedo (although not the only one) is all backward scattering events. For the case of the Moon the subject is complex, and the hadronic chemistry of the lunar regolith has been discussed elsewhere [11, 12].
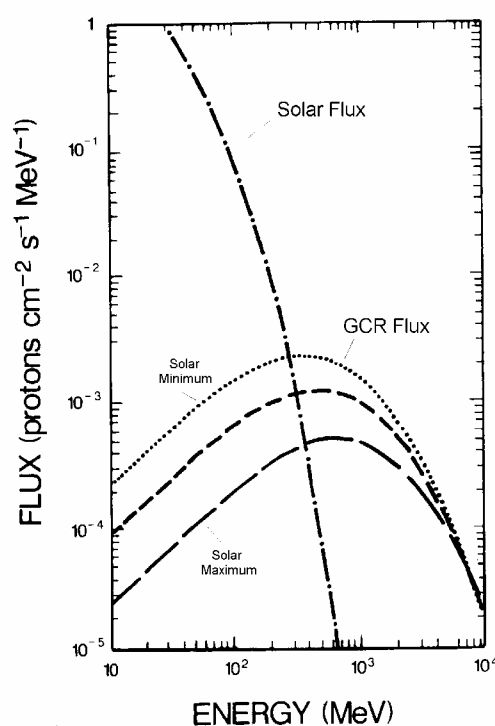

Figure 2. Galactic cosmic-ray and solar flux (proton component only) on the Moon.

The bathing of the lunar surface by the Galactic CRs (GCRs) and solar flux (Figure 2) has been studied in the past [13-15] to address forward-scattering production of nuclides that alter surface chemistry in the regolith. Therefore, the solar flux in Figure 2 was av-

eraged over the last few million years when in actuality it is a transient phenomenon subject to the frequency of solar flares localized against the celestial sphere. The CRs and GCRs, on the other hand, are ever-present, being isotropic in space and only modulated in intensity by solar activity in time.

Since albedos are due to backward scattering out of the regolith, this secondary radiation seems contrary to intuition. It is akin to glory and coherent backscatter in geometrical optics, having been largely ignored and rarely measured in a lunar context. Only through the advent of modern-day Monte Carlos (MCs) have recent investigations been made [16-17].

Albedo physics for the radiation influx in Figure 2 involves numerous particle species from neutrons to neutrinos [16-17], although only the photon albedo contributes to the luminescence of the Moon. The CR influx produces energetic collisions that are explosive in nature giving rise to many products. There are heavy nuclear cascades in forward scattering as well as particles in the backward scattering direction (Figure 3). This secondary backward-scattering component includes exicted neutrons known as evaporation neutrons that literally boil off the lunar surface to form the neutron albedo there (viewed in the surface rest frame). Such a neutron albedo is not produced by the surface of the Earth because the latter has an atmosphere that turns off the CR influx and a magnetic dipole that creates a magnetosphere for regulating the solar wind influx.
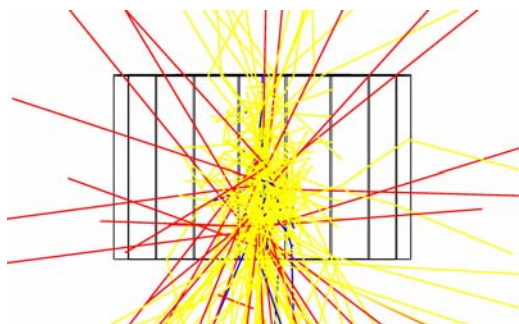

Figure 3. CR albedo (upward moving trajectories) produced by MC simulation of [7] with a 100 GeV CR proton impacting (top to bottom) lunar regolith [16].

The solar phase angle β in Figure 1 is the angle between the line of sight vector of observer O (in this case to the Moon) and the line of sight from the Sun (the Poynting vector $\mathcal{P}$). When the Sun is in opposition (sunlight coming over the shoulder of the observer O who is usually on the dark side of the Earth), $\beta \sim 0^o$ and interesting physics begins to happen. In the presence of water on Earth, glories, rainbows, fogbows,

and heiligenschein are observed. In the absence of water in space, pronounced effects still appear as coherent backscatter [18], shadow-hiding, and gegenschein (glory-enhanced backscatter from interplanetary dust). Glory is understood (though not fully explained) through Mie and Debye scattering theory. Coherent backscatter and shadow-hiding are observed when the full Moon is at opposition.

The Moon as a Calorimeter: The suggestion to use the entire Moon as a detector for neutrinos and gravitational radiation was made in [19], later expanded upon in [20]. In a related application, the Earth's entire atmosphere was already being considered as a CR detector for Fly's Eye [21], and there exists a proposal [22] to use it as a neutrino detector.

Conclusion: It is proposed here that the entire Moon can serve as a calorimeter for observing the CR albedo predicted in this abstract (Figure 3), and its associated optical flashes. An instrumented optical array on the lunar surface or in lunar orbit should serve quite well as a means for collecting data from such a large-scale calorimeter. Free of Earthshine, the far dark side of the Moon would be particularly suited for these observations. Optical flashes as transient phenomena are also produced by meteor [10] and debris impacts, and those would have to be distinguished from CR albedo.

References: [1] Heiken G. H., Vaniman D. T., and French B. M. (1991) *Lunar Sourcebook*, Ch. 3 (Cambridge, NY). [2] Qiu J. et al. (2004) *JGR, 108, No. D22,* 4709. [3] Pallé E. et al. (2004) *JGR, 108, No. D22,* 4710. [4] Hess W. N. and Killeen J. (1966) *JGR, 71,* 2799. [5] Battiston R. (2002) *Intl. J. Mod. Phys., A17,* 1589. [6] Flamm E. J. and Lingenfelter R. E. (1965) *Nature, 205,* 1301. [7] Schutten J. and Van Dujk Th. (1966) *Nature, 211,* 470. [8] Kozyrev N. A. (1963) *Nature, 198,* 979. [9] Hershel F. W. (1787) *Scienctific Papers of Sir William Hershel, 1,* 38 (London). [10] Cudnik B. M. et al. (2002) *LPSXXXIII,* 1329. [11] Wilson T. L. (1990) in *Astrophysics from the Moon*, Mumma M. J. and Smith H. J. eds., AIP Conf. Proc. *207* (AIP, NY), 608. [12] Wilson T. L. (1992) *LPSCXXIII,* 1521. [13] Reedy R. C. (1987) *JGR, 92, No. B4,* E697. [14] Reedy R. C. and Arnold J. R. (1972) *JGR, 77,* 537. [15] Lingenfelter R. E. et al. (1972) *Earth Plan. Sci. Lett., 16,* 355. [16] Wilson T. L. et al. (2003) *LPSXXXIV,* 1392. [17] Andersen V. et al. (2004) *LPSXXXV,* 1870. [18] Hapke B. et al. (1993) *Science, 260,* 509. [19] Wilson T. L. (1990) in *Physics and Astrophysics from a Lunar Base*, Potter A. E. and Wilson T. L. eds., AIP Conf. Proc. *202* (AIP, NY) 53. [20] Learned J. G., in Ref. 18, 119. [21] Bird D. J. et al. (1995) *Ap. J., 441,* 144. [22] Linsley J. (1985) *Proc. 19th ICRC (La Jolla), 3,* 438.