A LUNAR EARTH OBSERVATORY. Patrick Hamill, Physics Department, San Jose State University, San Jose, CA, 95192, USA. (hamill@wind.sjsu.edu)

Introduction: A robotic Earth observatory on the surface of the Moon will greatly enhance the science payback of proposed lunar exploration. The observatory would consist of a telescope and a number of standard instruments that would allow us to make scientifically valuable measurements of the atmosphere of Earth over a long period of time. Here we describe (in general terms) the observatory, the scientific value of the proposed measurements, a brief discussion of commercial aspects, a comment on the lunar dust problem, and finally, a suggested roadmap towards realizing the observatory.

Why the Moon? A telescope placed at any location on the near side of the Moon can observe the entire disk of Earth. No satellite in low Earth orbit can do this. A satellite in geosynchronous orbit observes one third of the total area, but is limited to the same view at all times. A satellite at the unstable Lagrange point between Earth and Sun (L1) only sees the sunlit side of Earth and cannot be permanent because of the need for continuous orbital corrections. L1 is about a million miles from Earth. The Earth-Moon distance is somewhat less than one fourth of this value.

From the Moon, over the course of a day, as the Earth rotates, all sublunar points are visible. During the course of a month, the entire Earth is visible, including the two polar regions. Over the course of a year, the view of Earth varies in an interesting way as the Sun illuminates the Earth from different angles, consistent with the 23.5 degree tilt of the axis.

As seen from the Moon, Earth exhibits phases, from "new Earth" through "full Earth" to "waning Earth" until it presents its dark side to the Moon. An interesting feature of the observations of Earth's night side will be the quantification of artificial illumination related to population growth and industrialization. The orbit of the Moon is inclined to the Earth's equator by about 5 degrees, allowing one to observe both poles during a 14 day period. For example, in late spring, an observatory on the Moon would be looking "up" at the Antarctic region during "new" Earth; at "full Earth" it would be over the equator, and as the Earth wanes, the observatory would be looking "down" on the Arctic region.

The varying views of Earth, the visibility of the entire disk, the relatively rapid rotation of Earth and the stability of the lunar surface make the Moon an ideal location for long-term monitoring of the Earth.

The Observatory: As envisaged at present, the observatory would consist of a telescope, a diffraction grating with an associated CCD array, a CCD camera, a radiometer, and the associated telemetry. The telescope would scan the disk of the Earth and the light from different points on the Earth would be sent through a diffraction grating onto the CCD array. This allows one to determine the column amounts of various atmospheric gases, such as ozone, CO_2, SO_2, NO_2, as well as aerosols. A telescope of diameter 0.25 meters would give a theoretical resolution of about 1km X 1km on the Earth's surface. The Ozone Measurement Instrument [1] (OMI on AURA) has a nadir pixel of 13km X 24km and it scans the entire Earth once per day. If the Lunar telescope had a resolution of 100km X 100km, and the CCD array were integrated over 1 sec, the entire disk of Earth, could be scanned in about 3.5 hours.

When the opportunity arises, the telescope would be used to track the image of a bright star as it is occulted by Earth. [2] Such scans are best carried out as the star descends onto the dark limb of Earth to avoid "earthshine" and to obtain maximum contrast. From the vantage point of a satellite in a 500 km orbit, a star descends through the atmosphere at a speed of about 8 km/sec. From the vantage point of the Moon, a star descends at about 1 km/sec, that is, eight times slower. Thus if stellar occultation is possible from artificial satellites (the GOMOS instrument on ENVISAT [3], for example), it will be even easier from the surface of the Moon. Note that a star is always a point source, so scanning is not required, as in most solar occultation measurements. (One cannot carry out solar occultation from the Moon because it only occurs during "Earth eclipses.")

Stellar occultation will allow us to determine profiles of extinction from aerosol particles, and the altitude dependence of concentrations of gas species such as O_3, CO_2, etc. Profiles of stratospheric particle extinctions are of particular value following energetic volcanic eruptions that inject large amounts of SO_2 into the stratosphere. Profiles of O_3 allow one to determine the vertical structure of the ozone hole. Stellar occultation is a particularly valuable technique for studying the formation and structure of polar stratospheric clouds.

The fact that the entire disk of the Earth is visible from the Moon make it an excellent location to measure the radiation balance of the Earth. Consequently, a component of the observatory would be an ERBE/CERES type of radiometer to measure short and longwave radiation. [4] The goal would be to monitor, on a continuous basis, the global energy balance, planetary brightness, regional forcings and the net radiative effect of clouds. [5] The fact that during the course of a month Earth presents both day and night faces to the Moon allows one to determine emitted and reflected radiation under a variety of solar illuminations.

Infrared measurements usually require cooling instruments with cryogens, but on the lunar surface extremely low temperatures are obtainable by simply shading the instrument during the day. Furthermore, the side of the Moon facing Earth is dark for half of the month, so a cycling between extreme cold and extreme heat allows us to consider the possibility of some sort of heat engine operating in (perhaps) a Stirling cycle to power various components. (The temperature of the lunar surface ranges from 120K at night to 390K during the day.)

As mentioned above, the surface of the Moon is a highly stable platform, so the observatory should be built to operate for a very long time (decades rather than years). This is reasonable when one considers that many satellite observing systems have lasted much longer than their expected lifetimes. (For example, the SAM II system lasted 15 years before it was turned off due to orbit degradation. The instrument was still operational.) Therefore, the instrumentation of the observatory should be standard and well developed rather than innovative.

Commercialization: Some of the light received from the Earth would be fed into a CCD camera to generate a visible picture of Earth to be transmitted frequently (perhaps once per hour) to a ground station and disseminated to weather stations on a world-wide basis. These pictures would be beautiful as well as useful, helping meteorologists to track weather patterns. They could also serve as an early warning of volcanic plumes and desert storms. Images of Earth from the Moon on an internet site such as Google Earth would have an enormous psychological impact, since people could look at (essentially) real-time high-resolution pictures of Earth. It would also be an excellent form of “outreach” from NASA to the general public.

Lunar Dust: An oft-cited problem with the lunar surface is lunar dust. This dust is formed from micrometeorite collisions and is highly abrasive. However, the problem may have been over-rated. The retroreflectors placed by NASA astronauts and Soviet robotic rovers on the lunar surface some forty years ago are still operational, so optical surfaces are not necessarily degraded by the dust. [6] Therefore, it seems probable that dust is not a serious problem for a stationary object (such as the proposed observatory).

Roadmap: A roadmap for making the Lunar Earth Observatory a reality would begin with a feasibility study (1-2 years), the design of the observatory and instrument (1 year), construction of the observatory (2 years), and finally launch, emplacement and operation. The heritage of the Observatory is Triana, the SAGE satellites, TOMS/OMI and ERBE/CERES. We suggest the work be the combined responsibility of the Earth Science and the Space Science Divisions of NASA Ames Research Center.

[1] Levelt, P. F. *et al.* (2006) *IEEE Trans. Geosci. Remote Sens. 44*, 1093-1101. [2] Yee, J-H. *et al.* (2002) *JGR, 107,* doi 10.1029/2001JD000794. [3] Wielicki, B. A. *et al.* (1996) *Bull. Am. Met. Soc., 77,* 853-868. [4] Meijer, Y. J. *et al.* (2004) *JGR, 109,* doi 10.1029/2004JD004834. [5] Ramanathan, V. (1987) *JGR, 92,* 4075-4095. [6] Lowman, P. D. (2006) *Phys. Today, 59,* 50-54.