## V61 WHERE THE PLANE OF THE LUNAR ORBIT MEETS THE SURFACE OF THE EARTH

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### 1. INTRODUCTION

Does Earth have a ring system? If so, does it influence climate?

### 1.1 *Historical Background*

Ring systems have been detected around seven planets and dwarf planets, most recently at the dwarf planet Quaoar by Morgado et al. (2023). Not only gas giants but also rocky dwarf planets, are now known to be ringed. Yet no rings have been identified at any of the four inner planets, including Earth.

One possibility is that rings are not found because there are none. The Sun is near, the dynamical environment is more complex; possibly it cannot sustain particles in orbit around the inner planets.

But there is another possibility. O'Keefe (1991) pointed out that the nominally ring-less Earth is rounder than the planets known to be ringed (and subsequent discoveries have sustained this generalization, see Table 1). O'Keefe noted that rings at the rounder planets may simply be unspectacular and harder to find. He recalled Maxwell's (1859) discussion of the rings of Saturn. Let us quote that: "Laplace has also shown (Liv. v. Chap. III.), that on account of the oblateness of the figure of Saturn, the planes of the rings will follow that of Saturn's equator through every change of its position due to the disturbing action of other heavenly bodies." That is to say, it is the oblateness of a planet, specifically, that flattens equatorial rings. High contrast makes rings easier to find as departures from background.

Table 1:
More and more rings … but never at roundest planets….

| Jupiter | Saturn | Uranus | Neptune | Haumea | Chariklo | Quaoar |
|---|---|---|---|---|---|---|
| Gas giant 1979 – Voyager | Gas giant 1610 – Galileo | Gas giant 1977 - | Gas giant 1989 – Voyager 2 | Minor planet - 2017 | Centaur 2013 - | Dwarf planet - 2023 |
| In this case oblateness defined as R(equatorial) – R(polar) / R(equatorial) | | | | | | |
| 0.065 | 0.108 | 0.03 | 0.02 | A triaxial ellipsoid | About 0.3 | 0.12 |
| **But not at Mercury** | **Not at Venus** | **Not at Earth** | **Not at Mars** | Maybe just a detection problem? It is the oblateness of a planet that flattens the equatorial rings… | | |
| 0.0 | 0.0 | 0.0034 | 0.005 | | | |

Source: Royal Museums Greenwich. https://www.rmg.co.uk/stories/topics/solar-system-data

Several anomalies have given investigators positive reasons to think Earth rings may exist.

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#### 1.1.1 *George Jones and the Zodiacal Light*

First to suggest Earth is ringed was George Jones (1856), an observer of the well-known zodiacal light (Figure 1)

***Figure 1.*** Photo by Y. Beletsky. Zodiacal Light Seen from Paranal, 19 November 2009. Source: European Southern Observatory (ESO). https://commons.wikimedia.org/wiki/File:Zodiacal_Light_Seen_from_Paranal.jpg

Jones argued from several years of shipboard observations that the appearance of the zodiacal light was more consistent with illumination of a circumterrestrial dust ring than with illumination of a circumsolar dust ring as Cassini (1730) had suggested. Jones observed that the zodiacal light was tilted with respect to the ecliptic; that the appearance of the zodiacal light changed considerably as the ship moved in latitude, suggesting that the illuminated structure was nearby; and that there existed a "Moon zodiacal light" which occurred at the rise of the full Moon. As to that last consideration, it is inexplicable that the position of the Moon should be significant in this way, if the zodiacal light is due to illumination of a circumsolar dust ring. To reconcile these considerations, Jones proposed that the zodiacal light is due to a circumterrestrial dust ring, near but not on the plane of the ecliptic.

Jones's proposal was not adopted. This author has not found a published critique contemporary with his work, but suggests the likely issue was Jones's lack of an account for the source of the dust or an explanation of why it would tend to collect in orbits near the ecliptic. The date of Jones's publication is significant: Maxwell (1859) presented his paper on the rings of Saturn in 1856 and won a prize for it in the same year as Jones's publication. But Maxwell's paper showed why dust would tend to collect in the equatorial plane.

These difficulties with Jones's proposal were mitigated by the discovery of the Phoebe ring of Saturn by Verbiscer et al. (2009). Saturn's Phoebe ring is a tenuous, low-contrast dust ring in the plane of Saturn's moon Phoebe – importantly, it is not in the equatorial plane of Saturn.

If an Earth analogy to the Phoebe ring were to be imagined, that would be a ring in the plane of the Moon's orbit, a plane tilted about five degrees from the ecliptic. It would correspond to Jones's proposal of a dust ring "near the plane of the ecliptic."

### 1.1.2 *John O'Keefe and Tektites*

After Jones, the next investigator to propose an Earth ring was O'Keefe (1980), who proposed an Earth ring in Earth's equatorial plane, a ring alternating between epochs of depletion and of replenishment. Shading of Earth by such a dust structure would account for the winter-predominant Ice Age climate anomaly. The cycles of replenishment and depletion would account for the intermittent character of the Ice Ages. O'Keefe also proposed a ring structure to account for the Cretaceous climate boundary (1985).

There are other accounts of the origin of climate boundaries; however, O'Keefe's proposal also addressed a further anomaly, the properties of a type of rock called tektite, which has a composition very similar to desert sand and yet the form of a glass so dry and fine that no terrestrial process has been observed to produce a similar glass. This was a preoccupying question of the 20th century.

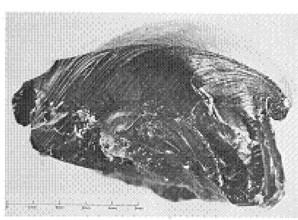


***Figure 2.*** Javanite tektite. Plate 10 from Tektites and Their Origin (O'Keefe 1976)

O'Keefe proposed that tektite glass was refined in lunar volcanoes and that the tektites found on Earth are ejecta from a dozen or so lunar explosive events (1976).

In the course of a long scientific debate at the mid-20th-century, summarized by O'Keefe (1976), Harold Urey highlighted a difficulty with O'Keefe's proposal: most ejecta from lunar events would miss Earth because Earth subtends a small angle at the Moon. It follows that a significant mass of lunar ejecta not intercepted by Earth would have to exist also, all falling to Earth eventually. Yet tektite dating does not record any such gradual deposit; all tektites seem to have traversed the atmosphere on one of a score or so discrete dates.

O'Keefe proposed in turn that the material which missed Earth and circulated in the Earth-Moon environment would have been crushed to smaller particles by spinup in sunlight followed by rotational bursting, a process studied by Paddack (1969), an effect now known as the YORP effect. Thus the greater mass of lunar ejecta would arrive at Earth without the form of tektite rocks, though with the same composition.

As a corollary of this discussion of lunar ejecta reaching Earth, O'Keefe predicted that Earth intermittently possesses an equatorial ring, comprised of crushed tektite material (O'Keefe 1980, 1985 and following work). That is, this would be a ring comprised of material of the composition of desert sand. This satisfies the requirement, since Earth's geology includes enough of that material to permit the tektite field be a small fraction.

O'Keefe's proposal drew attention but was not accepted. O'Keefe's proposal requires recent lunar volcanism, while at that time there was a consensus the Moon has been dead for billions of years. Thus, O'Keefe's proposal appeared impossible. Today, however, that difficulty is mitigated by evidence that the Moon may not be dead (e.g., Stopar et al., 2017; Siegler et al., 2023, *inter alia*).

## 2. A TWO-RING SYSTEM

The ring proposals of Jones and O'Keefe taken together comprise a logical system: Jones's proposal (revised to specify a ring in the plane of the lunar orbit) interpreted as an accretion disk mediating transfer of mass from Moon to Earth, O'Keefe's proposal a secondary structure evolving per Maxwell's account of planetary ring systems. See Figure 3 for a summary visualization of this proposal.

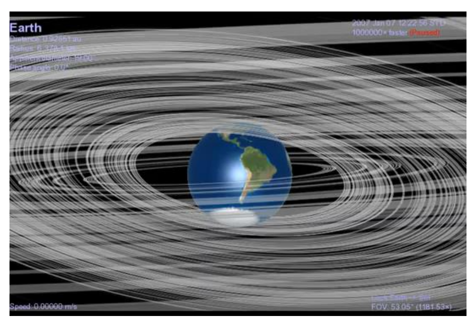



***Figure 3.*** Visualization of Earth with an equatorial ring and a ring in the plane of the lunar orbit. Made in Celestia (https://github.com/CelestiaProject/Celestia). An animated video is posted at https://youtu.be/OmzyyTBcRFQ .

### 2.1 *Sky Illumination*

The test of sky illumination does not help us very much in evaluating the reasonableness of the two-ring proposal. The sky illumination due to Jones's ring would appear as all or some part of the zodiacal light, for which other explanations are available. The sky illumination due to reflection from an equatorial ring would comprise an illuminated arc from the celestial equator down to the horizon, dimmed by the shadow of the ringed Earth itself which would transit at midnight (Hancock, 2013). This latter illumination would be like urban light pollution in some respects; thus, it is difficult to say whether it is observed.

### 2.2 *Dimming of Solar Radiation*

By contrast, testing solar radiation is dimmed by Earth rings may enable evaluation of the two-ring hypothesis. After all, the most recent planetary ring discovery at Quaoar by Morgado et al., (*op cit.*) was established by identifying the dimming of distant stars by Quaoar's rings lying in the line of sight between the distant stars and Earth. The same idea could be used for Earth rings. If there is a ring system, then stellar radiation should be dimmed when the dust rings lie in the line of sight. Dimming of the distant stars is observed near the ecliptic, but it is attributed to the zodiacal light. However, solar radiation should also be dimmed when the configuration of Earth and rings places dust in the line of sight Earth to Sun. There should be a cyclic discrepancy between ground-based observations of solar radiation, versus models of solar radiation, and it should be about the same magnitude as the extinction of distant stars attributed to the zodiacal light.

There exists a dataset well-suited for this test, the archive of solar radiation observations accumulated from 2009 to the present by the Citizen Weather Observer Program Solar Radiation Data Archive (http://wxqa.com/lum_search.htm). Contributions come from thousands of stations, globally distributed, recording a wide range of climates, in all seasons and times of day, at many elevations, using all kinds of observing programs with a variety of sensor technologies and software. (See technical reports Hancock and Chadwick 2015, 2020, 2021).

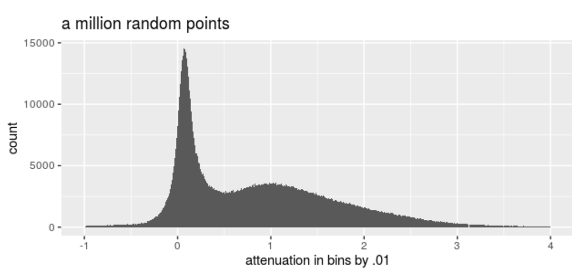



***Figure 4.*** Histogram of optical depth (a comparison between observed and modeled values) for a million random points from the CWOP archive. The figure is from Hancock and Chadwick (2021).

A first-look analysis presented by Hancock and Chadwick (2022) shows there are systematic discrepancies from the model (see Figure 4), and suggests these could be due to dust in the line of sight Earth to Sun as expected for a ring. That presentation proposed how to analyze this data for consistency with ring shading (Hancock and Chadwick 2016, Hancock and Chadwick 2022).

## 3. SIGNIFICANCE FOR WEATHER AND CLIMATE

A ring system could influence weather and climate.

### 3.1 *Shading of Earth*

As noted above, O'Keefe (1980, 1985) pointed out that a ring system with long term optical depth variations could drive the alternation of climate epochs, the Ice Ages and the Cretaceous in particular. This was further discussed by Fawcett and Boslough (2002).

### 3.2 *Ring Dust In the Atmosphere*

Given the instability of orbits in the Earth-Moon environment, dust in orbit would tend to fall to the Earth's surface. Weather effects would follow from a deposit of such particles: charged by the photoelectric effect in space and conveying both anomalous momentum and also potential energy relative to the Earth's surface. Weather effects could reasonably include lightning, wind, and sandstorms. Such dust could nucleate (or suppress) rainfall. Large particles would plummet and burn, causing heat bursts in the atmosphere or even launching wildfires at the surface. Particles too small to plummet could import the cold of space. Health would be affected especially by PM2.5 (cf. Haikerwal et al., 2015, among many others).

Effects due to particle infall would be stratified by the Earth's magnetic field (Spilker, pers. comm.) acting on a range of charge to mass ratios over varying time-in-space. Particle infall would also be stratified by the relative importance of solar radiation pressure and gravity, on particles of varying mass.

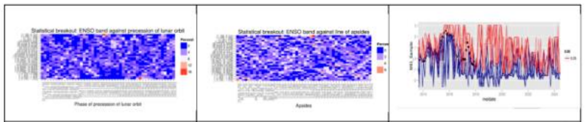
On all these considerations, the simplest ring structure could drive global patterns of lightning, wind, rainfall, wildfires, sandstorms, and heating and cooling at the surface.

## 4. DETECTING WEATHER EFFECTS OF SPACE DUST

To measure the likelihood that infalling space dust affects weather, it would be helpful to have a statistical study relating the footprint of expected dust infall, to weather events.

### 4.1 *ENSO*

Figure 5 associates the multivariate ENSO index (MEI) to the plane of the lunar orbit.



| | | |
|---|---|---|
| Figures are from Hancock and Chadwick, 2018.<br><br>(a) Statistical breakout of MEI v.1 1950 to 2017 against phase of the precession of lunar nodes. | (b) Statistical breakout of MEI v.1 1950 to 2017 against rotation of the line of apsides of the lunar orbit | (c) Forecast of MEI v.1 against time, computed in 2017 for dates up to spring 2024, a Bayesian forecast based on astronomical data. MEI is to fall on the boundary between red and blue. |

***Figure 5.*** Statistical association between elements of the lunar orbit and MEI (https://psl.noaa.gov/enso/mei/ )

Figures 5a and 5b bin the values of elements of the lunar orbit against ENSO. Figure 5c prepares a Bayesian forecast using lunar ephemerides. This figure was prepared in 2017 and projects ENSO to spring 2024.

The forecast presented as Figure 5(c) was made by preparing a Bayesian forecast model of MEI using lunar orbital elements and the last ENSO value (persistence). Since the previous value of MEI is not available in the future, this model was then run twice, one run assuming the previous ENSO value was very high, and another run assuming it was very low. These two model runs are represented in Figure 5c respectively as a red projection and a blue one. This approach which I informally describe as the Moriarty approach tends to drag forecasts that are weakly determined by the astronomical data, to the top and bottom of the frame. Where the red and blue forecasts meet in the middle, the forecast is clearly not dependent on persistence. Such values comprise the forecasts of MEI v.1.

The forecast in Figure 5c has not been formally validated because MEI v.1 has not been computed since 2018, so a rigorous validation is out of reach. However, it is noteworthy that the projection of MEI v.1 had some skill as a projection of MEI v.2. (For values of MEI v.2 see https://psl.noaa.gov/enso/mei/). Namely, the projection in Figure 5c correctly forecast a long La Nina beginning in 2020, and a rise to positive ENSO values in late 2023. We may test it further by observing it predicted a drop in spring 2024.

### 4.2 *Rainfall*

The next step in testing and making use of the hypothesis of a ring system that drives weather, , appears to be a statistical study to associate the ring hypothesis to shorter-term weather effects, such as rainfall. Considering that weather effects due to a ring in the plane of the equator would occur in phase with the solar year, and be captured by climatology, it seems more opportune to focus on expected effects from a ring *in the plane of the lunar orbit.* Such effects would drive cycles not commensurate with the solar year (Hancock, 2012).

## 5. PROJECTION OF LUNAR ORBIT

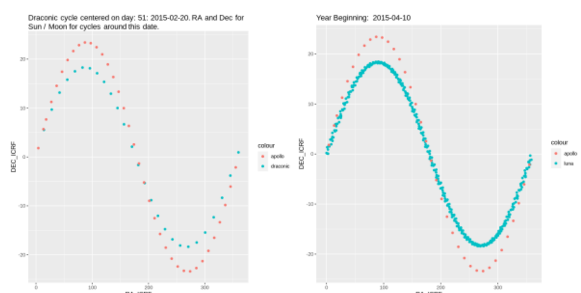
The above considerations provide the rationale for the work presented here: a database of the projected position of the lunar orbit to the surface of the Earth.

### 5.1 *Database in netCDF format*

Such a database has been prepared and is available in the universally accessible format of a netCDF database. The database comprises calculations once/3 hours, for the period January 2015 through December 2034. Access is provided, as well as code and documented, at Hancock (2024a,b).

### 5.2 *Preparation of the Database*

The database was prepared as follows. For each day under consideration, from mid-January 2015 to mid-December 2034, an instantaneous estimate was made of the plane of the lunar orbit in celestial coordinates. The position of the Moon was downloaded from ephemerides provided by JPL Horizons (https://ssd.jpl.nasa.gov/horizons/), for the 13 previous days, the day under study, and the 13 following. In 27 days the Moon orbits the Earth; thus these 27 positions sample the instantaneous position of plane of the lunar orbit. The estimate would not be a good one if this plane changed quickly over a 27-day time period in these coordinates, but it does not. See Figure 6b for one year of change.



(a) (b)

***Figure 6.*** (a) The position of the Sun in celestial coordinates is sampled over one year in orange. The position of the Moon in celestial coordinates is sampled for a month centered on 2-20-2015, an arbitrary date. Right ascension is on the X axis, declination on Y. (b) Same, except that the sky position of the Moon samples an entire year.

The analysis now is simply to project those positions to the surface of Earth and smoothly resample. Celestial declination was projected as terrestrial latitude. As for right ascension, the solution was as follows.

At each of the eight timepoints per day, local sidereal time was collected (from Horizons, cited above) for 36 positions on the equator (zero longitude, ten degrees E, and so on). These 36 tuples provide an instantaneous linear association between terrestrial longitude and local sidereal time. Local sidereal time is equal (up to a unit change) to the right ascension then transiting. From that association, the right ascension values from the lunar orbit can be interpolated as terrestrial longitudes.

The code to do this, with the methods used to smooth singularities, resample, and convert results to netCDF, are available for inspection and replication of results, at Hancock 2024a.

### 5.3 *Resolution and Animation of the Database*

The database is low resolution (see Figure 7) only because the author could find no suitable data type under the CF Conventions (https://cfconventions.org) for compact representation of a great circle that moves from one time point to the next. Lack of such a data type required that each time point be represented as an almost-empty grid from 30N to 30S, merely to depict a trajectory that has a nonzero value at only one latitude per value of longitude. Therefore the author chose low resolution to keep the files small. The approach provided could just as well be used to prepare a high-resolution database. The author would be grateful to know if a compact representation does exist under the CF Conventions.

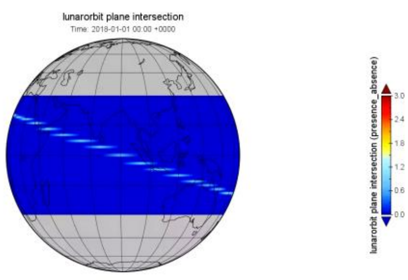



***Figure 7.*** Projection of the lunar orbit to the surface of the Earth at one timepoint in one hemisphere. For an animation of this point of view for the year 2018 see Hancock (2024b) in References. The figure was made in Panoply (https://www.giss.nasa.gov/tools/panoply/).

Of note, the north-south extent of this great circle varies significantly. See Figure 8.

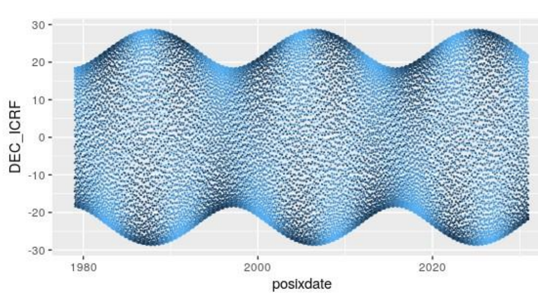



***Figure 8.*** The declination of the Moon (latitude of the projection of that sky position to Earth) from 1979 to 2034. The color range black to blue indicates the angular rate of the Moon's travel across the sky.

### 5.4 *Footprint of Lunar Orbit vs Rainfall*

The database can be conveniently compared to 3-hourly meteorological databases such as Multi-Source Weighted-Ensemble Precipitation (MSWEP) (Beck et al., 2019). See Figure 9 for an example overlay of the projected lunar orbit, with MSWEP.

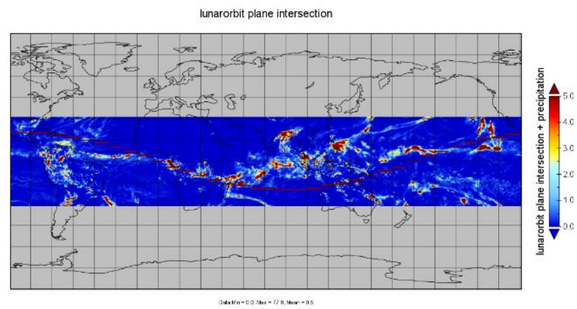



***Figure 9.*** The plane of the lunar orbit (red) on 1 January 2018 06:00 UTC, plus the precipitation estimates from three-hourly Multi-Source Weighted-Ensemble Precipitation (MSWEP) data from the corresponding timepoint. The variable plotted (in Panoply) is the sum of rainfall plus a presence/absence variable.

### 5.5 *Rainfall*

An example hypothesis that this database could conveniently test, is that "Space dust is a limiting input for rainfall." Figure 10 details the steadiness of total rainfall.

For example, one might propose that drought and flood are only rearrangements of that steady total, and that the Earth-Moon configuration provides the key to those rearrangements, and in this way droughts could be forecast. With the database offered herein, machine learning could study that question efficiently.

A few aspects of this exogenous driver may be useful for anyone attempting the question. First, particles in orbit would be stabler orbiting the Earth-Moon barycenter (EMB), and in such an orbit, would tend to encounter Earth on the side opposite the Moon. This point seems aligned to traditional forecasting in Malawi (James, 2016).

Second, the relative velocity of dust particles with respect to atmosphere and surface will be seasonal, will depend on latitude, and could reverse.

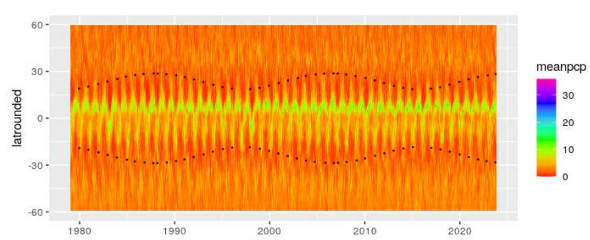



***Figure 10a.*** Total rainfall (MSWEP) by day and by latitude 2079 to 2023. Black dots are N-S extent of the projected plane of the lunar orbit.

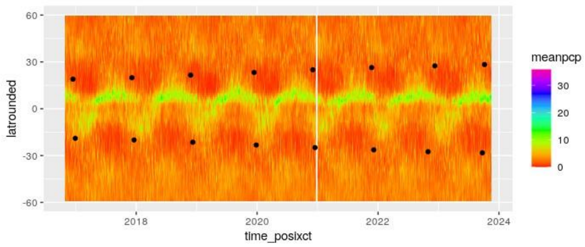



***Figure 10b.*** Total rainfall (MSWEP) by day and by latitude 2017 to 2023. Black dots are N-S extent of the projected plane of the lunar orbit.

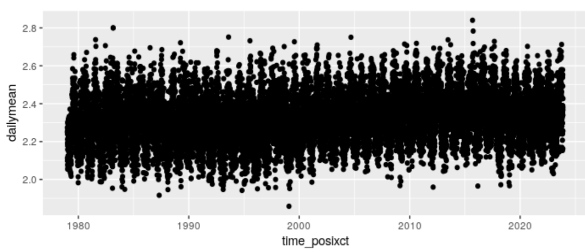



***Figure 10c.*** Total rainfall (MSWEP) by day 2079 to 2023.

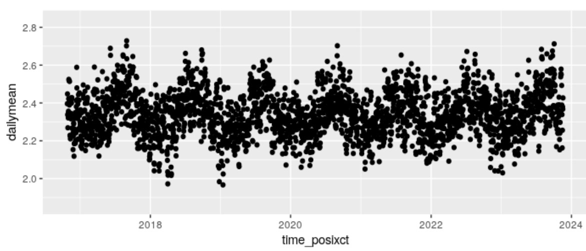



***Figure 10d.*** Total rainfall (MSWEP) by day 2017 to 2023.

## 6. CONCLUSION

A database of the projection of the lunar orbit to the surface of the Earth has been presented in netCDF format. It is hoped this will facilitate machine learning studies to associate weather events with characteristics of dust that may fall through the atmosphere from a ring in the plane of the lunar orbit.

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James, doorman, Southern Sun, Malawi, circa 2016. The author regrets the lack of further reference. In the context of a discussion of traditional weather forecasting, James remarked that rainfall is unlikely when the moon is well above the horizon. This remark led the author to consider that dust in orbit around the EMB might be favored for infall on the side of Earth opposite the EMB, nucleating rainfall where the Moon is down and potentially accounting for traditional forecasting.

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