The Angular Size of the Moon and Other Planetary Satellites An Argument for Design

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Abstract

It previously has been argued that the circumstances of total solar eclipses for the earth-moon system are unique in the solar system and that this suggests design. This is reexamined using the latest data on the many satellites now known to exist in the solar system. This argument is shown to be stronger than ever. Some comments about the design argument in astronomy are made. It is suggested that discussion of the definition and application of the design argument be pursued.

Introduction

While the sun is about 400 times larger than the moon, the moon is also approximately 400 times closer to the earth, so that both objects extend nearly identical angular sizes of about ½ degree. This causes a total solar eclipse to be a very remarkable event, one of the most beautiful and awe-inspiring experiences in nature, as anyone who has seen one can attest. If the moon were slightly farther away or smaller (or the sun closer or larger in size), total solar eclipses would not be possible. If the situation were reversed, many of the startling features of a total solar eclipse, such a the diamond ring effect, Bailey's beads, and prominences near the sun's limb, would not be as readily visible. Total solar eclipses also would be more common, making them less thrilling phenomena that they are now.

As beautiful as total solar eclipses are, perhaps more importantly they offer an opportunity for scientific study of certain solar phenomenon that would be difficult or impossible to do otherwise. For instance, the sun's chromosphere is briefly visible at the instants when totality begins and ends. Almost all of the energy that we receive from the sun comes from the portion of the sun's atmosphere called the photosphere. The chromosphere is a thin, cooler, more rarefied region of the sun's atmosphere lying just above the photosphere. It's feeble light is usually overpowered by the photosphere, except when the photosphere is blocked during a total eclipse. Historically the chromosphere's emission spectrum has been studied when it is revealed as a flash spectrum that briefly appears around the onset and end of totality.

Lying above the chromosphere is the solar corona, which extends a few solar diameters into space. Only visible during totality, the pearly white corona is very rarefied, but is at a high temperature (between one and two million °K). How this high temperature is maintained has remained a mystery for some time, and some recent creationists have used its high temperature as evidence of its recent formation. Magnetic field lines are clearly visible in the corona, and the size and shape of the corona changes from sun spot minimum to sun spot maximum. So the observations of the corona during total solar eclipses provides clues to the complex magnetic interactions taking place in the sun.

One of the first confirmations of general relativity was the bending of star light by the sun's mass, which could be observed only during a total solar eclipse when the images of stars were visible near the sun's edge. Total (or near total) solar eclipses give us a unique opportunity to gauge the relative sizes of the sun and moon. This provides data in deciding the question of whether the sun is shrinking, another argument that is used for the sun's recent origin. Historical data on the locations of eclipses have allowed us to determine the rate at which the earth's rotation is slowing because of tidal braking. This too places an upper limit on the age of the earth-moon system.

For generations astronomers have traveled to exotic locations to observe total solar eclipses because total solar eclipses are such rare events. On average a total solar eclipse is visible from any location only once every few centuries. Therefore without planning it is unlikely that a typical person will ever view a total solar eclipse, let alone more than one. Whitcomb and DeYoung (1978, p. 132-136) and Mendillo and Hart (1974) have previously called attention to the interesting circumstance necessary for total solar eclipses as an argument for design in the earth-moon-sun system. More recently Englin and Howe concluded that the unique geometry of the earth-moon system that gives us total eclipses is no accident. No other moon in the solar system has such a close balance between the rarity and stark beauty of eclipses. Many have no eclipses at all. In the two decades since the work of Whitcomb and DeYoung the number of known satellites in the solar system has nearly doubled. At the same time the orbital parameters and measured sizes of most of the others have been greatly improved. Let us examine the latest values to determine how unique our moon is in this respect.

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Calculation of Ratios

Table I lists the 61 satellites known at the time of the writing of this article. It is possible that additional ones may be discovered or confirmed by the time that this goes to press, but, as it will be argued later, any of those would be unlikely to alter the conclusion given here. All data were taken from the 1997 *Astronomical Almanac*. The first two columns give the names of the satellites. The third column lists the angular size, in degrees, of the sun at the distance of the planet from the sun. The fourth column gives the angular size, in degrees, that each satellite has as seen from the planet about which the satellite orbits. The angular sizes were calculated using the average distance (semi-major axis) of each orbit (epoch February 1, 1997). For ease in comparison, it was decided to express each number as a simple decimal rather than in scientific notation. The precision of each number reflects the precision of the satellite parameters, with the uncertainty usually dominated by uncertainties in satellite diameters. Some of the satellites are known to be oblong rather than spherical in shape. In those cases the largest diameters were used.

Because the orbits of the planets and the major satellites are nearly circular, these calculated average angular diameters are a good starting approximation. If any satellites were discovered to have nearly the same angular diameter as the sun, then they could be further investigated as to the conditions of eclipse. The orbits of some of the smaller satellites are appreciably elliptical, and so these could be further investigated as well if it appears that eclipses could be possible near the extremes of the orbits.

The best way to evaluate the possibility, rarity, and beauty of a particular satellite's eclipses is to compare the sizes of the apparent solar and satellite diameters. For instance, the ratio of the moon's apparent diameter to that of the sun is 0.9719. This means that a typical centerline eclipse tends to be annular rather than total. An annular eclipse is one in which the moon is too small to completely cover the sun, so that a thin ring, or annulus, of the sun's photosphere remains visible at mid eclipse. This is particu-

Table I. Planets and their satellites with their relationships to the sun and to each other.

Planet	Satellite	Solar Diameter	Satellite Diameter
Earth I	Moon	0.5331	0.5181
Mars I	Phobos	0.3499	0.165
Mars II	Deimos	0.3499	0.037
Jupiter I	Io	0.1025	0.493
Jupiter II	Europa	0.1025	0.268
Jupiter III	Ganymede	0.1025	0.2818
Jupiter IV	Callisto	0.1025	0.1461
Jupiter V	Amalthea	0.1025	0.0855
Jupiter VI	Himalia	0.1025	0.00093
Jupiter VII	Elara	0.1025	0.00037
Jupiter VIII	Pasiphae	0.1025	0.00012
Jupiter IX	Sinope	0.1025	0.000087
Jupiter X	Lysithea	0.1025	0.00018
Jupiter XI	Carme	0.1025	0.00010
Jupiter XII	Ananke	0.1025	0.000081
Jupiter XIII	Leda	0.1025	0.00008
Jupiter XIV	Thebe	0.1025	0.028
Jupiter XV	Adrastea	0.1025	0.011
Jupiter XVI	Metis	0.1025	0.018
Saturn I	Mimas	0.05573	0.121
Saturn II	Enceladus	0.05573	0.120
Saturn III	Tethys	0.05573	0.206
Saturn IV	Dione	0.05573	0.170
Saturn V	Rhea	0.05573	0.166
Saturn VI	Titan	0.05573	0.2415
Saturn VII	Hyperion	0.05573	0.0159
Saturn VIII	Iapetus	0.05573	0.0235
Saturn IX	Phoebe	0.05573	0.000973
Saturn X	Janus	0.05573	0.083
Saturn XI	Epimetheus	0.05573	0.053
Saturn XII	Helene	0.05573	0.0055
Saturn XIII	Telesto	0.05573	0.0066
Saturn XIV	Calypso	0.05573	0.0066
Saturn XV	Atlas	0.05573	0.017
Saturn XVI	Prometheus	0.05573	0.058
Saturn XVII	Pandora	0.05573	0.044
Saturn XVIII	Pan	0.05573	0.0086
Uranus I	Ariel	0.02762	0.347
Uranus II	Umbriel	0.02762	0.252
Uranus III	Titania	0.02762	0.208
Uranus IV	Oberon	0.02762	0.150
Uranus V	Miranda	0.02762	0.213
Uranus VI	Cordelia	0.02762	0.030
Uranus VII	Ophelia	0.02762	0.032
Uranus VIII	Bianca	0.02762	0.041
Uranus IX	Cressida	0.02762	0.058
Uranus X	Desdemona	0.02762	0.049
Uranus XI	Juliet	0.02762	0.075
Uranus XII	Portia	0.02762	0.094
Uranus XIII	Rosalind	0.02762	0.044
Uranus XIV	Belinda	0.02762	0.050
Uranus XV	Puck	0.02762	0.10
Neptune I	Triton	0.01761	0.4370
Neptune II	Nereid	0.01761	0.00353
Neptune III	Naiad	0.01761	0.069
Neptune IV	Thalassa	0.01761	0.092
Neptune V	Despina	0.01761	0.16
Neptune VI	Galatea	0.01761	0.15
Neptune VII	Larissa	0.01761	0.162
Neptune VIII	Proteus	0.01761	0.212
Pluto I	Charon	0.01344	3.47

larly true when an eclipse occurs near the moon's apogee or the earth's perihelion. This also effects the duration of an eclipse. The longest totalities, about seven minutes, occur at noon in the tropics, with the earth at aphelion and the moon at perigee.

We can conclude that if the ratio of the angular diameter of a satellite to that of the sun is much less than one, then no total eclipse would be possible. On the other hand, a ratio much larger than one would cause eclipses to be very total and very frequent. As described above, both of these effects would tend to detract from the wonder of a total eclipse, though gross over totality would have the greater effect. Much of the beauty of a total solar eclipse derives from the appearance of the inner corona and the very colorful prominences, both of which are visible near the limb (edge) of the sun. Because of the near match in angular diameters of the moon and sun, these are visible all around the sun's limb. For a overly total eclipse, these would only be briefly visible near the points of second and third contact (defined below), the points where totality begins and ends.

Table II displays the ratios of the angular diameters (satellite/solar) for the 34 satellites for which the ratio exceeds 0.9. It can be assumed that the other 37 satellites fail to produce any total solar eclipses. As can be seen from the second table, the ratios show that most satellites that produce total eclipses produce ones that are overly total. The most extreme is Pluto's moon, which has a ratio of 258. The best candidates for total eclipses are Saturn XI(0.95), Saturn XVI(1.02), and Uranus VI (1.08)

Saturn XI and Saturn XVI are not spherical, but are elongated, and as stated above, the longest diameter was used to find the angular size. Most of the satellites of the solar system are believed to follow synchronous orbits, that is, they orbit the planets with one face toward the parent body at all times. This is caused by a tidal interaction, and is expected to be especially true of the small, elongated satellites. For a particular satellite this would result in the longest diameter pointing toward the planet, and so a smaller diameter would be the diameter needed to calculate the angular diameter of the moon. Therefore it is unlikely that total eclipses would occur for these two small moons. Using the largest satellite diameter, the angular diameter of the sun, and the satellite's orbital period, the duration of eclipse can be calculated. The duration of an eclipse can best be expressed in terms of the times of first, second, third, and fourth contacts. First contact is defined as the instant when the eclipsing body first begins to block the sun's disk, and is generally considered the beginning of the eclipse. Second contact is the instant when the sun's disk is completely blocked, and thus marks the onset of totality. Third contact is the end of totality, while fourth contact is the end of the eclipse. The time from second to third contacts is the duration of totality, and the length of the entire eclipse is the time difference between first and fourth contacts.

For Saturn XI the duration of eclipse is 19 seconds, while Saturn XVI has duration of 17 seconds. These durations are for the entire eclipses from first to fourth contacts, including the partial phases before and after any totality (or annularity). The length of totality is impossible to calculate with the current knowledge of the diameters of these two satellites, but it would likely be less than one second. Such eclipse would be almost unnoticeable, let alone enjoyable or useful for scientific study. An even worse situation prevails for Uranus VI, with a ratio of 1.08. It is not known if it is elongated, but given its small size, it probably is. Eclipse duration from first to fourth contact would be less than five seconds, causing any totality to be far less than a second.

Table II. Satellites with satellite/solar ratios exceeding 0.9.

Name	Ratio	Name	Ratio
Jupiter I	4.81	Jupiter II	2.61
Jupiter III	2.750	Jupiter IV	1.425
Saturn I	2.17	Saturn II	2.16
Saturn III	3.70	Saturn IV	3.05
Saturn V	2.98	Saturn VI	4.333
Saturn XI	0.95	Saturn XVI	1.03
Uranus I	12.6	Uranus II	9.13
Uranus III	7.52	Uranus IV	5.42
Uranus V	7.70	Uranus VI	1.08
Uranus VII	1.16	Uranus VIII	1.47
Uranus IX	2.1	Uranus X	1.8
Uranus XI	2.7	Uranus XII	3.4
Uranus XIII	1.6	Uranus XIV	1.8
Uranus XV	3.7	Neptune I	24.82
Neptune III	3.9	Neptune IV	5.2
Neptune V	9.2	Neptune VI	8.3
Neptune VII	9.20	Neptune VIII	12.1
Pluto I	258		

It is obvious that the smaller satellites of the solar system do not provide a good opportunity for total solar eclipses, because their small sizes and rapid motion combine to produce very short duration eclipses. It then becomes obvious that the only hope of producing awe-inspiring eclipses is to look to the larger satellites. Most of the larger moons produce very overly total eclipses, but the most promising one is Jupiter IV (Callisto) with a ratio of 1.425. Calculation shows that Callisto produces eclipses having first to fourth contact duration of 16.6 minutes, with totality lasting 2.9 minutes. At first look this appears to fulfill our requirements established for rare, beautiful events. But the over totality means that the inner corona and the prominences can only be glimpsed at narrow ranges near the points of second and third contact. The author personally noted that while watching the February 26, 1979 total solar eclipse in Arborg, Manitoba with two minutes, 50 seconds of totality, prominences were best visible on the east limb of the sun early in totality and on the west end late in totality. This was caused by the moon's proximity to perigee at the time, giving it a slightly larger apparent size, covering those features first on the west limb, and then on the east limb. The rapid motion of Callisto, combined with the more over total nature of its eclipses, would greatly shorten the length of time that these features would be visible.

This leads to a very subtle effect that is hiding in these calculations. Note that for the planets closer to the sun, total eclipses are quite rare, while for the more distant ones, they are quite common. For instance, only the four larger (Galilean) of the 16 satellites of Jupiter produce total eclipses, all the satellites of Uranus and all but one of Neptune do. This is because the angular diameter of the sun is progressively smaller as one gets farther from the sun. This has three effects. First, it lowers the requirement for totality. Second, it causes the eclipses to be very over total. Third, the decreasing angular diameter diminishes the visual effect of the eclipses. For instance, Jupiter being more than five times more distant from the sun causes the features of the corona and prominences to be more that five times smaller as seen from the earth. From Saturn and beyond it is doubtful that the appearance of the sun with its photosphere eclipsed would be that impressive or that the eclipses would be very noticeable.

Conclusion

The doubling of the number of planetary satellites in the past two decades has not undermined the prior conclusion of Whitcomb and DeYoung and Mendillo and Hart that the earth-moon system produces uniquely beautiful total eclipses. To the contrary, the calculations presented here demonstrate that their conclusion is more sound than ever. Additional consideration shows that overly total eclipses are not expected to be as spectacular as the ones produced by our moon. Furthermore the greatly diminished apparent size of the sun at the distances of the larger planets means that any total solar eclipse there would lack the visual effect as seen from the earth. The earth-moon system combines three aspects that enhances the beauty and wonder of total solar eclipses:

- A large angular size of the sun, which produces high visual resolution of features only seen during total solar eclipses
- Optimal duration of totality of up to seven minutes that allows for maximum enjoyment
- Frequency that makes total solar eclipses uncommonly rare, yet occur often enough to be enjoyed by many

For some time this author has been concerned with the design argument in astronomy. In discussing biological systems, the design argument can be very powerful. For instance, if gross properties of the earth, such as atmospheric composition or gravity were altered, life would be impossible. If the sun's size and temperature or the earth's orbit were different, life would again be endangered. The same can be said for atomic properties of matter, such as the many bonds that carbon can form, or the status of water as the universal solvent, or the unique property of water expanding upon freezing. In short, the design argument is a demonstration that nature must be as it is, or else life as we know could not exist. Even evolutionary scientists have recognized this fact and have coined the term the "anthropic principle" to describe it (Barrow and Tipler, 1986).

Creationists often attempt to extend this very powerful design argument to astronomical topics as discussed here. But the design argument for the earth-moon system presented here is a much weaker one than is usually presented for biological systems. If the earth-moon system were not unique, or if total solar eclipses did not occur, life would not be imperiled. In other words, while the earth-moon system may demonstrate the Creator's imagination and concern for our enjoyment, it must not be thus for our existence.

Just as Barrow and Tipler define weak and strong anthropic principles, perhaps creationists should adopt the terms weak and strong in discussing design arguments. Many of the astronomical design arguments, including the one discussed here, would be of the weak variety. Even more basic would be a definition of design and a methodology in consistently applying the design argument. At this time it appears that this definition and methodology do not exist, because most people assume that design is readily recognized. If this is the case, then two criticisms readily come to mind. First, many may see design where none actually exists. Second, a sort of circular reasoning may develop where people see design because they know that it must exist, while others of the different persuasion fail to see the evidence.

It is hoped that other creationists join in the discussion to define and refine the design argument.

References

The Astronomical Almanac for 1997. U. S. Government Printing Office. Washington, D.C.

Barrow, J. D. and F. J. Tipler. 1986. *The anthropic principle*. Oxford University Press. New York.

Englin, D. and G. F. Howe. 1985. An annular solar eclipse. *Creation Research Society Quarterly* 22: 7.

Mendillo, M. and R. Hart. 1974. Resonances. *Physics Today* 27(2): 73.

Whitcomb, J. C. and D. B. DeYoung. 1974. *The Moon, its creation, form, and significance*. BMH Books. Winona Lake, IN. pp. 132-136.

The religion that is married to science today will be a widow tomorrow. The sciences in their multiple theories and forms come and go. Biology in the year 2050 may be as different from the biology of today as the religion of today is from the religion of 1850. But the religion that is divorced from science today will leave no offspring tomorrow (p. vii).

Holmes, Rolston, III. 1987. *Science and Religion: A Critical Survey*. Random House, New York.