WAS THE FORMATION OF A 20-KM-DIAMETER IMPACT CRATER ON THE MOON OBSERVED ON JUNE 18, 1178?

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As reported in medieval chronicles, on the evening of June 18, 1178, the upper horn of a new moon split, and from the division a flaming torch sprang up. We interpret this observation in terms of a large impact event which formed the 20-km-diameter crater, Giordano Bruno.

An interesting reference to an event which apparently occurred on the Moon on July 18, 1178 is given by Newton (1972, p. 690). ". . . the upper horn of the new moon seemed to split in two and a flame shot from it." A search for a more complete description of the event led to the following report written in the medieval chronicles by Gervase of Canterbury (Stubbs, 1879). The original Latin version is presented first; an English translation by Dr. Richmond Y. Hathorn, Classics Department, State University of New York at Stony Brook, follows.

> Hoc anno, die Dominica ante Nativitatem Sancti Johannis Baptistæ, post solis occasum, luna prima, signum apparuit mirabile, quinque vel eo amplius viris ex adverso sedentibus. Nam nova luna lucida erat, novitatis suæ more cornua protendens ad orientem; et ecce subito superius cornu in duo divisum est. Ex hujus divisionis medio prosilivit fax ardens, flammam, carbones et scintillas longius proiciens. Corpus interim lunæ quod inferius erat torquebatur quasi anxie, et, ut eorum verbis utar, qui hoc michi retulerunt et oculis viderunt propriis, ut percussus coluber luna palpitabat. Post hoc redíit in proprium statum. Hanc vicissitudinem duodecies et eo amplius repetiit, videlicet ut ignis tormenta varia sicut praelibatum est sustineret, iterumque in statum rediret priorem. Post has itaque vicissitudines, a cornu usque in cornu scilicet per longum seminigra facta est. Hæc michi qui hæc scribo retulerunt viri illi qui suis hoc viderunt oculis, fidem suam vel jusjurandum dare parati, quod in supradictis nichil addiderunt falsitatis.
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> In this year, on the Sunday before the Feast of St. John the Baptist, after sunset when the moon had first become visible a marvelous phenomenon was witnessed by some five or more men who were sitting there facing the moon. Now there was a bright new moon, and as usual in that phase its horns were tilted toward the east; and suddenly the upper horn split in two. From the midpoint of this division a flaming torch sprang up, spewing out, over a considerable distance, fire, hot coals, and sparks. Meanwhile the body of the moon which was below writhed, as it were,

> in anxiety, and, to put it in the words of those who reported it to me and saw it with their own eyes, the moon throbbed like a wounded snake. Afterwards it resumed its proper state. This phenomenon was repeated a dozen times or more, the flame assuming various twisting shapes at random and then returning to normal. Then after these transformations the moon from horn to horn, that is along its whole length, took on a blackish appearance. The present writer was given this report by men who saw it with their own eyes, and are prepared to stake their honor on an oath that they have made no addition or falsification in the above narrative.

The event reported in 1178 appears to be unique. Although a wide variety of short-duration events or transient lunar phenomena have been reported by observers of the Moon (Middlehurst *et al.*, 1968), to my knowledge no similar event of the magnitude and complexity observed has ever been described.

A variety of hypotheses may be advanced to explain the phenomena observed. The fact that five men were "prepared to stake their honor" leads me to believe that *something* was observed and that the report was not entirely the product of someone's imagination. The events described may have originated in the atmosphere of the Earth as a result of cloud layers or turbulence just above the western horizon or the entry of a meteroid along the line of sight to the Moon. I would prefer, however, to rely on the report which repeatedly refers to the Moon and never mentions clouds or the sky or anything not related to the Moon.

Such an event on the Moon must have had either an external (impact) or internal (volcanic) origin. From the report alone it may not be possible to explain the origin of the phenomena observed. However, with the report and our present understanding of the lunar surface and processes occurring in the Solar System, I would suggest the description is consistent with the occurrence of a very large impact on the lunar surface. "The upper horn (of a new Moon) split in two." A portion of the sunlit crescent visible at the earth was either obscured by the ejecta cone or cloud produced by the impact or darkened by the shadow of the ejecta. "A flaming torch sprang up, spewing out fire, hot coals, and sparks." Incandescent gases and solids or liquids were ejected. "The moon . . . writhed . . . and . . . throbbed like a wounded snake." Gases produced or released by the impact formed a temporary atmosphere which was in turbulent or non-uniform motion, thus causing the light from the moon to pass through variable amounts of material with variable indices of refraction.

Up to this point the phenomena described are reasonably consistent with what might be expected based on experience with laboratory impacts and study of large terrestrial impact craters (French and Short, 1968; Hörz, 1971). The remainder of the description is less easily interpreted, mainly because we are not familiar with the short-duration effects of a large impact

on a planetary body. This report by at least five men almost 800 years ago probably represents the best observational data on such effects that exist.

"Afterwards it (the crescent moon) resumed its proper state. This phenomenon was repeated a dozen times or more, the flame assuming various twisting shapes at random and then returning to normal." Evidently, "the flame" continued throughout the writhing process, which I attribute to the large-scale motion of gas clouds. Because the duration of a "flame" consisting of incandescent gases or other material among the ejecta should be short compared to the time scale for the motion of large gas clouds, some uncertainty exists regarding the interpretation of "the flame." Instead of consisting of incandescent material, the appearance of a "flame" could be produced by sunlight reflected from dust particles moving as ejecta from the crater or suspended by a temporary gas cloud above it.

"Then . . . the moon from horn to horn, that is along its whole length, took on a blackish appearance." This observation is consistent with the presence around the entire moon of a temporary atmosphere in which a sufficient amount of dust was suspended to block a significant amount of light reflected from the moon's surface.

The most decisive test of the validity of the report and the impact hypothesis explaining it would be the identification of a surface feature on the Moon which corresponds to the event reported. The occurrence of the event at the "midpoint" of the "upper horn" of a "new Moon" establishes its location at a latitude near 45° north and longitude near 90° east.

The size of the event may be estimated based on the fact that the observations were made by human eyes without optical aids. If it is assumed that the ratio of the linear dimension of an object to the distance from which the object is just visible to the unaided eye is about 10^{-4}, then the smallest shadow on, or ejecta cloud above, the Moon that could have been observed at the Earth would have had a linear dimension of about 40 km. Based on this I estimated that the ejecta cloud and the shadow actually observed would have had linear dimensions in excess of about 100 km; the diameter of the resulting crater would exceed 10 km; and the bright rays associated with such a recently formed crater would extend at least 100 km from the crater.

Does a crater corresponding to the medieval observations and our interpretations and estimates actually exist on the Moon? The answer is *yes*! The criteria we used in search of the actual crater formed only 800 years ago are that the crater must have a:

1. selenographic latitude between 30° and 60° N.
2. selenographic longitude between 75° and 105° E.
3. diameter greater than 10 km.
4. surrounding pattern of prominent bright rays.

Using Lunar Orbiter and Apollo mission photography, we found an impressive 20-km-diameter crater at a selenographic latitude of 36° N. and

longitude of 103° E. surrounded by very prominent bright rays extending for hundreds of km from the crater. We concluded that this crater is the one formed on June 18, 1178. The crater, Giordano Bruno, is shown in Figures 1 and 2.

Not only does Giordano Bruno satisfy the above-stated criteria, but there is independent evidence to suggest it was among the most recently formed large craters on the Moon. The crater is "the center of a ray system rivaling that of Tycho" (Whitaker, 1963), yet its rim diameter is only about one-fifth that of Tycho. The first photographs of Giordano Bruno, made in October 1959 during the Lunik III mission, showed a ray system so bright and impressive that the actual crater diameter was over-estimated by a factor of three (Lipskiy, 1963). Based on a survey of large bright-rayed craters on the Moon, I have not found a single crater with a larger ray-length-to-crater-diameter ratio than that for Giordano Bruno. These observations support the idea that this crater may have been the most recently formed large crater on the Moon.

The frequency of impacts on the Earth or Moon which form such large craters must be low because, apparently, no other similar events have been observed during recorded history. Furthermore, evidence for such craters occurs only rarely in the geologic record on the earth. From a study of impact craters on the Canadian Pre-Cambrian shield, Baldwin (1971) has found the expected recent average rate of formation of 20-km-diameter-and-larger craters on the whole moon is about 0.3 in 10^6 years. Thus, in any given 3000-year period (a rough estimate for all of recorded history), the chances are about one in a thousand that such an event would occur anywhere on the moon. The chance that a record of such an event would be preserved for us is still lower because only half of the moon can be seen, observations have not been made continuously, observations made may not have been recorded, and records may not have been preserved. In short, the probability of our having a recorded observation of a 20-km-diameter impact event is extremely small.

Several approaches may be taken to test further the correctness of the hypothesis given here. A search for independent observations of the same event may be made. The date of the possible impact, June 18, 1178, was recorded in the medieval chronicle. By analyzing the calculated positions of the Sun and Moon (Tuckerman, 1964), I found that the Moon was about 1.5 days past new Moon at the time of sunset on that date. Assuming the observation was made in the vicinity of Canterbury, England, I calculated that the Sun would have set at about 8:15 p.m. local Sun time and that the Moon would have set about 45 minutes later. Because local Canterbury Sun time differs from Greenwich local Sun time by about 4 minutes due to their different locations and 3 minutes, in the opposite sense, due to the difference between the actual and mean motion of the Sun (the equation of time), the time given above corresponds quite closely to Greenwich Mean Time (GWT). Thus, the event must have occurred between about 2015 and 2100 hours, GMT, on June 18, 1178. This date corresponds to the Julian calendar and is

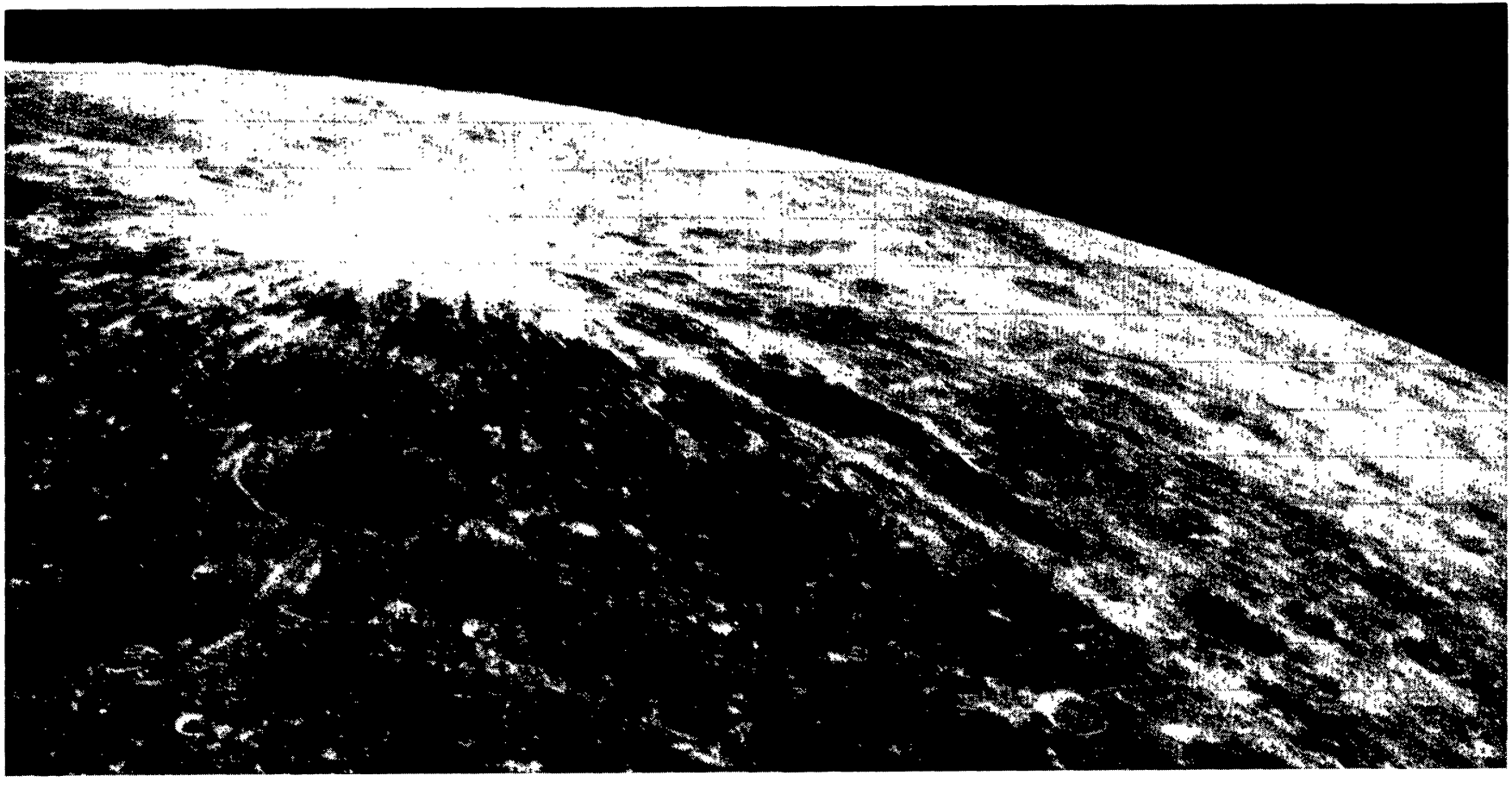

Fig. 1 A view of the bright ray system associated with the crater, Giordano Bruno, located at lunar latitude 36° N. and longitude 103° E. The viewing direction is north-northeast. The dark-floored crater below Giordano Bruno is Lomonosov, which is almost 100 km in diameter. The photograph, 8-12-2209, was made during the Apollo 8 mission and was provided by the National Space Science Data Center.

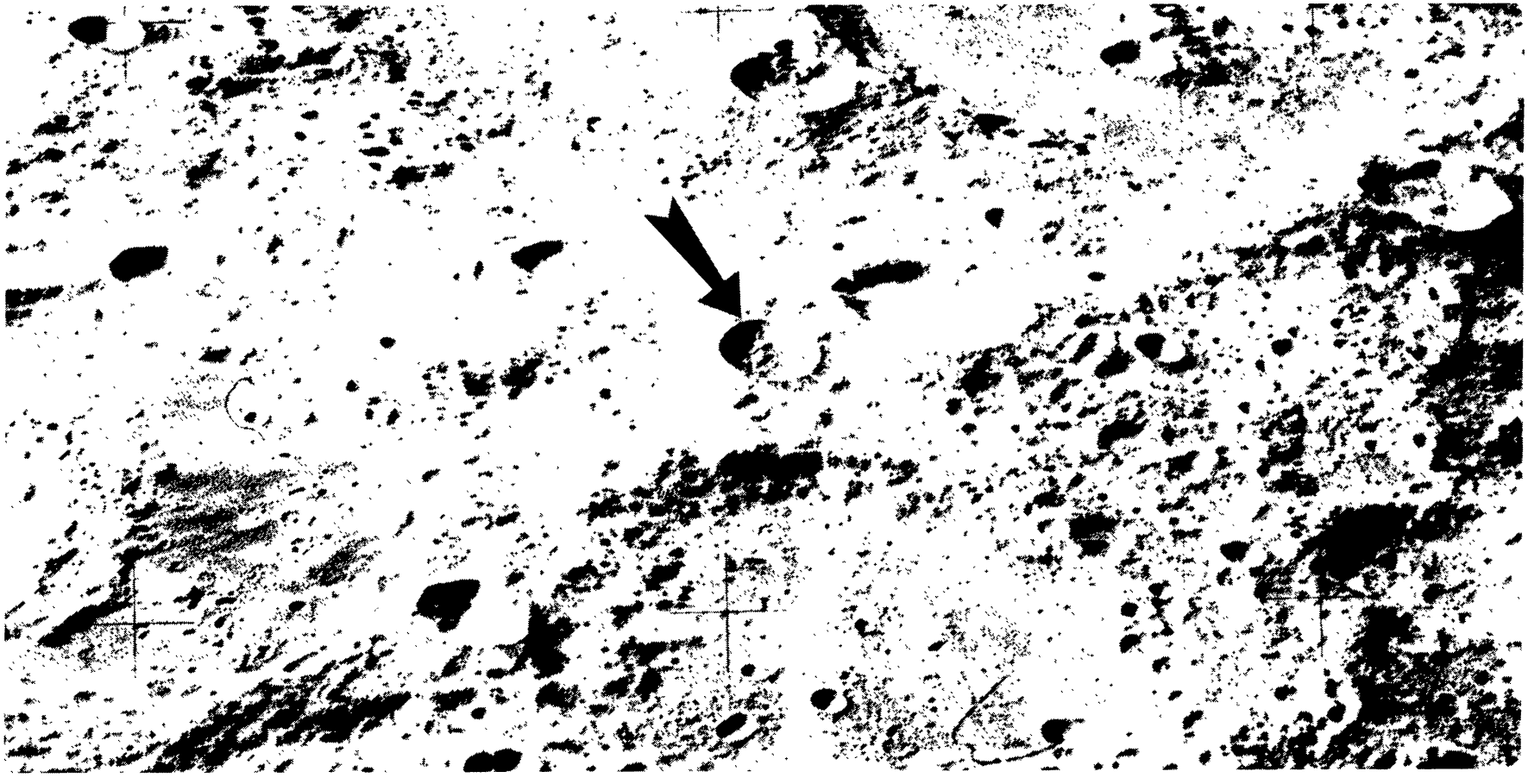

Fig. 2 A view looking northwest over the lunar landscape and showing Giordano Bruno, the 20-km-diameter impact crater indicated by the arrow. The impact forming the crater may have been observed on the Earth on the evening of June 18, 1178, by at least five men. The photograph is an enlargement of a portion of frame 3008 of the Apollo 16 metric camera photography and was provided courtesy of The Lunar Science Institute.

equivalent to June 28, 1178, if the present Gregorian calendar is used. If it is assumed that the observation was made in southern England and that it could not have been made at any location where the Sun was still above the horizon, the locations where observation of the event was possible can be identified. These locations lie along a line, corresponding approximately to the sunset terminator, which passed between Oslo, Norway and Stockholm, Sweden, through southern England and the northwest corners of France and Spain, west of the Canary Islands, and along the southeast coast of Brazil, at 2015 hours, GMT, on June 18, 1178.

Microwave sensors aboard a lunar polar orbiter spacecraft planned for launch within a few years may be able to detect higher temperatures inside the crater attributable to heat generated during the impact of the event. Based on a theoretical analysis of the cooling history of dikes, Jaeger (1957), has shown the internal temperature of an originally molten sheet reaches about one-half its initial value in centigrade degrees after a time of about 0.03 D^2 years, where D is the thickness of the sheet in meters. The melt sheet inside Giordano Bruno is expected to be on the order of 100 meters thick, based on observations of several terrestrial impact craters (Beals and Halliday, 1967; Robertson and Grieve, 1975). If an initial temperature of over 1200 °C is assumed, then a time of 300 years for the internal temperature of the melt sheet to decline to about 600 °C is obtained. Although the surface temperature inside the crater after 800 years is not easily predicted, some thermal anomaly due to residual heat from the impact may be expected.

Finally, if the crater, Giordano Bruno, was formed only 800 years ago, rock samples collected during some future lunar landing and return mission from the continuous ejecta blanket surround the crater would provide conclusive evidence to that effect. Rock surfaces excavated from depths greater than a few meters and exposed to space for only 800 years will have distinctive populations of micrometeorite impact craters and solar flare and cosmic ray particle tracks. Such surfaces would be valuable for the study of other solar system processes that occur on a time scale too large for effective study using satellite-borne experiments, such as the implantation of solar-wind particles and nuclear reactions produced by cosmic rays.

In summary, the phenomena reported by at least five men to Gervase of Canterbury are generally consistent with the occurrence of a large impact on the Moon. Although the probability of such an event occurring during recorded history is small, the existence of an exceptionally fresh bright-rayed crater at a location predicted based on the report alone leads me to conclude the formation of a 20-km-diameter impact crater was observed on June 18, 1178.

This work was supported by NASA Grant NSG-9013. The assistance and cooperation of M.A. Hager of the Lunar Science Institute, Houston, R.Y. Hathorn, Classics Department, M. O'Dowd, Department of Earth and Space Sciences, A.D. Hartung, archeoastronomy student and F.S. Johnson, Jr. are gratefully acknowledged.

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Manuscript received 4/12/76