METEOR STORM EVIDENCE AGAINST THE RECENT FORMATION OF LUNAR CRATER GIORDANO BRUNO. Paul Withers, Lunar and Planetary Laboratory, University of Arizona, Tucson, AZ 85721, USA (withers@lpl.arizona.edu).

Abstract: It has been suggested that the formation of 22 km diameter lunar crater Giordano Bruno was witnessed in June 1178 AD [1]. To date, this hypothesis has not been well tested. Such an impact on the Earth would be civilization threatening. Previous studies have shown that the formation of Giordano Bruno would lead to the arrival of 10 million tonnes of ejecta in the Earth s atmosphere in the following week [2]. I calculate that this would cause a week-long meteor storm potentially comparable to the peak of the 1966 Leonids storm. The lack of any known historical records of such a storm is evidence against the recent formation of Giordano Bruno.

Introduction: In 1976, Hartung suggested that the formation of the 22 km diameter lunar crater Giordano Bruno, located just beyond the north-eastern limb of the Moon at 36 ¡N, 103 ¡E and shown in Fig. 1, was witnessed and recorded around an hour after sunset on 18th June, 1178 AD in the Julian calendar [1], [3]. A dramatic passage in the medieval chronicles of Gervase of Canterbury speaks of the crescent Moon spewing out fire, hot coals, and sparks, a potentially plausible description of an impact on the Moon. Based on its extensive pattern of bright rays and uneroded morphology, Giordano Bruno is the youngest lunar crater of its size or larger [1]. Its position close to the north-eastern limb of the Moon is consistent with some details in the passage, and this and its youth led Hartung to suggest it as the impact site. Hartung s hypothesis has proven difficult to test over the years, as data from the region of the Moon surrounding Giordano Bruno is of low quality. In an attempt to explain unexpectedly large amplitudes of free libration of the Moon, a partial lunar laser ranging dataset was interpreted to be consistent with Hartung s hypothesis and was published on the front cover of Science [3]. A later analysis of a more complete dataset suggested that Hartung s hypothesis could not explain the large free librations and proposed turbulent core-mantle friction as their source [4].

Meteor Storm: The general fate of the ejecta from lunar impacts has been discussed in the literature — as has the specific case of Giordano Bruno ejecta, but the resultant meteor storm has not been described in the peer-reviewed literature. Gault and Schultz state that the Earth would have accreted 10^{13} grams of ejecta, travelling on direct trajectories with a characteristic entry speed of at least the Earth s escape velocity, in the week after the formation of Giordano Bruno [2]. Gault s work on the dynamics of lunar impact ejecta is consistent with currently authoritative work [5]. No statements are made about local day or night-time arrivals of the ejecta on the Earth, but, given the large range in initial speed and direction of the ejecta, it seems reasonable that at least a portion of the subsequent meteor storm would have been visible during night-time. This work calculates the properties of that meteor storm.

The size distribution of the ejecta is uncertain. Traditional power laws are applicable to the ejecta considered as a whole, not to the high speed portion of teh ejecta that escapes from the Moon. Crude constraints, from Vickery (1987) and Melosh and Vickery (1991), suggest that a characteristic radius of 0.1 - 10 cm is suitable for ejecta arriving at the Earth [6], [7]. According to Jenniskens et al, mass-velocity-magnitude relations for meteors are uncertain [8]. They use:

$$\log_{10} M\ (\mathrm{g}) = 6.06 - 0.62\ m_{vis} - 3.89 \log_{10} V_{¡}\ (\mathrm{km\ s^{-1}}) - 0.67 \log_{10} (\sin(hr))$$

with M the mass, hr the radiant altitude, $V_{¡}$ the apparent velocity and m_{vis} the visible magnitude of the meteor. Consider fragments with a characteristic radius of 1 cm and a typical silicate density of 2.5 g cm-3, giving a characteristic mass of 10 g. Taking hr as 45¡, $V_{¡}$ as 11.2 km s^{-1}, and M as 10 g results in a visible magnitude of 1.7 and total number of meteors of 10^{12}, where the total mass has been constrained by Gault and Schultz to be 10^{13} g. A uniform distribution over the surface of the Earth and the week-long interval corresponds to a rate of 10^3 meteors km^{-2} hr^{-1}. Taking the meteors to be visible at an altitude of 70 km or above, an observer viewing within 30¡ of zenith would see 5 x 10^4 meteors per hour. For comparison, the greatest meteor storm in living memory, the 1966 Leonids, had a zenith hourly rate of ~1.5 x 10^5 for 20 minutes over the western United States and typical background rates are a few per hour, with seasonal and diurnal variability of factors of a few. If the characteristic radius of the ejecta is allowed to vary between the extremes of 0.1 and 10 cm, the magnitudes and numbers of meteors changes correspondingly, as shown in Fig. 2. The predicted range of meteor fluxes and magnitudes is large, but is not a critical problem for visibility of the meteor storm. At one extreme, the meteor storm is composed of very many faint meteors, and at the other, of many bright meteors. For the smallest reasonable characteristic ejecta radius, a hourly rate of 10^8 and some allowance for variability about the characteristic radius may be invoked to ensure that some of the meteors are brighter than magnitude 6. For any reasonable characteristic ejecta radius, the meteor storm is exceptional. It is apparent that any reasonable size distribution between the two extremes of 0.1 and 10 cm will produce an exceptional meteor storm. A meteor storm as impressive as this and lasting for a week would have been considered apocalyptic by all medieval observers. Any historical source from this time that mentions any astronomical phenomena whatsoever would have recorded this event. Neither European, Arab, Chinese, Korean, nor Japanese sources record a storm at this time, though they do qualitatively describe many others. In such reports, large numbers of meteors are typically described as many or coun tless , and bright meteors as great stars or balls of fire. The qualitative nature of these descriptions makes estimates of hourly rates or magnitudes difficult, and hence quantitative comparison between the recorded storms of antiquity and the predicted Giordano Bruno storm is also difficult. There is room for debate on the precise size of the meteor storm created by the hypothesised formation of Giordano Bruno 800 years ago. However, as shown in Fig. 2, it seems clear that it would have been a magnificent spectacle, worthy of chroniclers attention, visible over much of the world. The lack of records of such a meteor storm is strong evidence against Hartung s hypothesis.

References: [1] Hartung. J. B. (1976) *Meteoritics,* **11**, 187-194. [2] Gault D. E. and Schultz P. H. (1991) *Meteoritics*, **26**, 336-337. [3] Calame O. and Mulholland J. D. (1978) *Science*, **199**, 875-877. [4] Yoder C. F. (1981) *Phil. Trans. R. Soc. Lond. A,* .**303**, 327-338. [5] Gladman *et al.* (1995) *Icarus*, **118**, 302-321. [6] Vickery A. (1987) *GRL*, **14**, 726-729. [7] Melosh H. J. and Vickery A. M. (1991) *Nature*, **350**, 494-497. [8] Jenniskens P. *et al.* (1998) In *Laboratory astrophysics and space research* (eds. Ehrenfreund, P. and Kochan H.), Kluwer

Figure 1 - Portion of Apollo 16 metric frame 3008 showing Giordano Bruno.

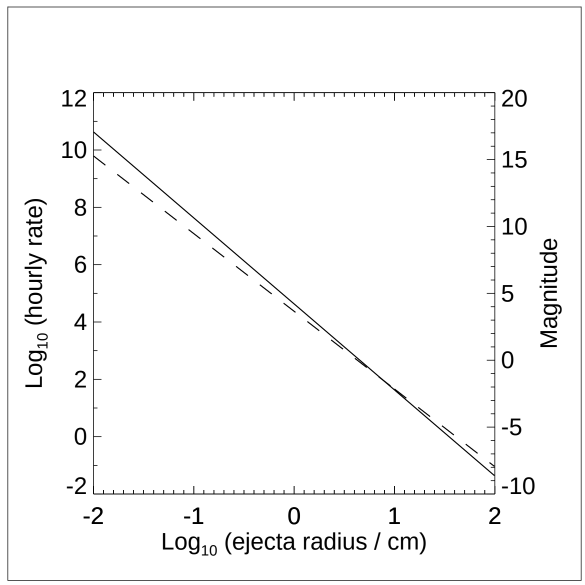

Figure 2 - Variation in hourly rate (solid line) and visible magnitude (dashed line) of meteor storm with characteristic ejecta radius. Reasonable values for characteristic ejecta radius are 0.1 — 10 cm, as discussed in the text.